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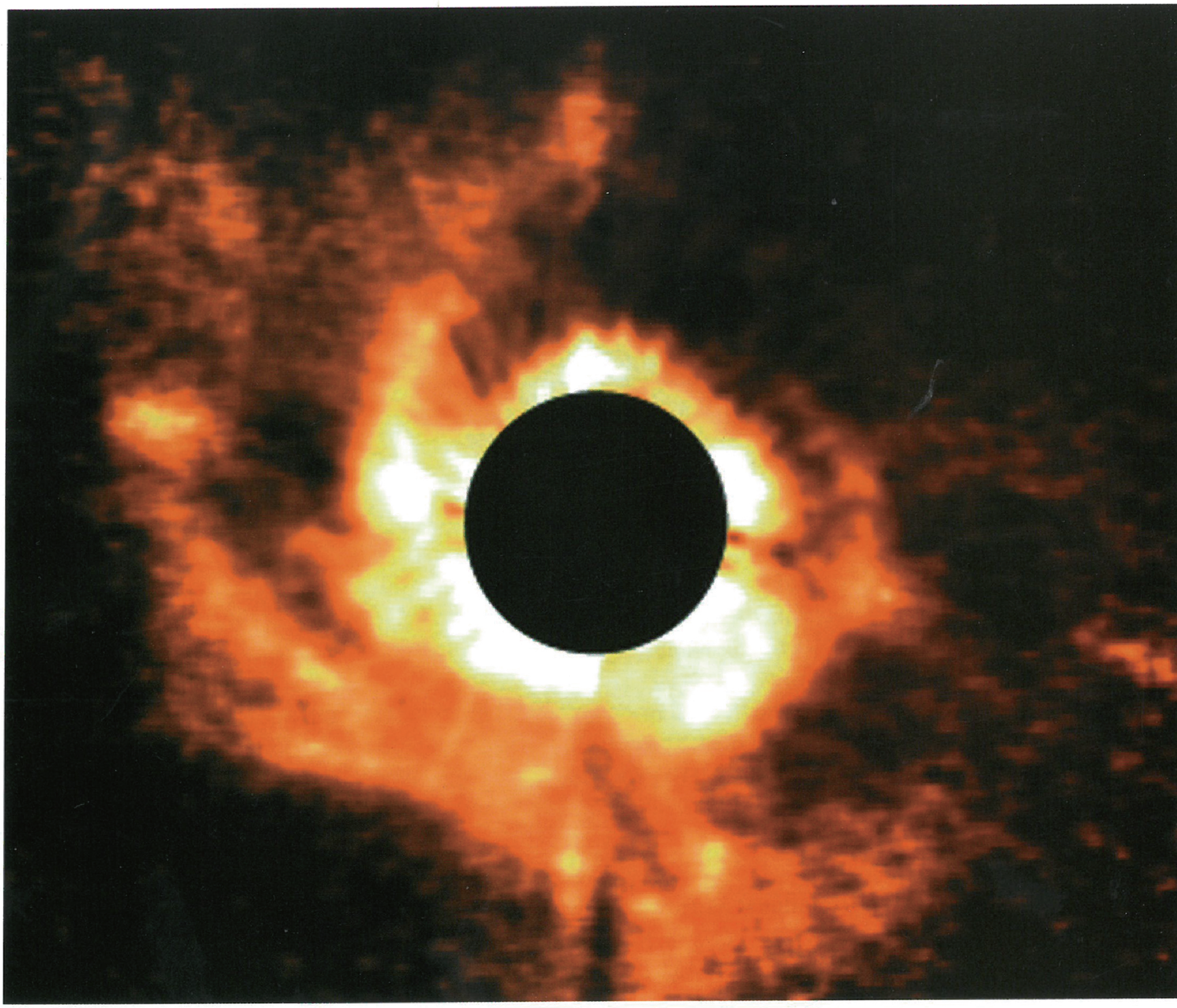

Volume 7 Fiscal 2004

NAOJ

Explanation of the cover photograph: Near-Infrared Image of the Protoplanetary Disk Surrounding AB Aurigae. Infrared light (wavelength 1.6 μm) from the central star is reflecting off the dust in the protoplanetary disks. The central star is hidden by a coronagraphic mask, and is not visible in this image. The fact that the lower left portion of the disk appears brighter suggests that this side of the disk is tilted toward us.

Postscript

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PREFACE

We present a report of annual achievement of NAOJ through the FY 2004.

The FY 2004 was a special and memorable year for NAOJ in many ways. Firstly NAOJ started the construction of Atakama Large Mm- and submm-wave Array (ALMA) under the three-party cooperation with European countries (ESO) and North American consortium. The developments of high precision antennas, mm- and submm-wave receivers of Atakama Compact Array (ACA) and other contributions by Japan for ALMA have started and been going quite well. The construction of ALMA atop Atakama Plateau, Chile, continues until 2011. By that time NAOJ prepares the Japanese ALMA Research Center in the NAOJ headquarters at Mitaka as an active center of East Asian mm- and submm-wave astronomy.

Secondly 2004 was the first year of NAOJ as a member of a newly established inter-university research agency “National Institute of Natural Sciences (NINS)”. NINS is composed of five inter-university research institutes; NAOJ, National Institute for Fusion Science, Institute for Molecular Science, National Institute for Basic Biology and National Institute for Physiological Science which are core institutes in each field of science in Japan, and aims to create new sciences by mutual cooperation as well as the powerful promotion of science in each field.

Thirdly from 2004 we NAOJ started new operational system based on a set of various projects. Seven NAOJ observatories and stations under operation like Nobeyama Radio Observatory and Subaru Telescope are re-defined as “C-Project” with clear mission and limited life. ALMA, Solar-B and gravitational detectors which are in construction phase are defined as “B-Project”. “A-Project” is defined for promising and possible future project to be developed and 3 projects (Space VLBI, JASMINE and MIRA) were designated as A-Projects. Other four new A-projects (4D2U, Exo-Solar Planets Search, HOP, and ELT) were examined by review committee and were established in 2005.

The re-organization of all national universities and inter-university research institutes (including NAOJ) to “agencies” from national organizations was carried out as one of the process of setting Japanese finances in order and naturally brought some difficulty and risks as well as some extent of freedom to the universities and research institutes. The future of Japanese science and technology highly depends on the outcome of this re-organization. Such outcome will not be visible within short term especially in the field of science. Therefore we need deep thinking and innovative works toward bright future of Japanese science under this new system.

Re-organization of NAOJ itself to the new internal operation system was, on the other hand, a self reform aiming at more effective and conscious style of research in astronomy. We feel that our new system is generally going well, growing better awareness of mission by project members and clearer plans by project managements. The new employment system gave NAOJ another benefit which made it possible for us to get skilled staff especially in the field of engineering. The Post Doc system which had been relatively complicated before was also made simple and clear. We still have, however, some unnecessary restraints as remnants of the former system and some portions still need to be improved. We are starting discussion of after-two-year’s review of the effects and outcome of our new operation system toward 2006.

The NAOJ also achieved superior scientific and development activities in many fields of astronomy through this fluctuating year 2004. In addition to the ALMA developments mentioned above, we enjoyed a number of exciting observational results from the 8.2m Subaru telescope in Hawaii. The VERA system with four 20m antennas under operation over the Japan Islands is approaching the final goal of extremely high angular resolution to achieve the triangulation measurements of distance to maser stars through the Milky Way galaxy.

As a new instrument the 10m submm-wave telescope ASTE has started the cutting-edge observations of molecular clouds and star forming regions on the 4,800m altitude ALMA site. The space Solar telescope SOLAR-B and the Lunar exploration mission SELENE are in the final phase of developments under the cooperation with JAXA. All of those scientific and engineering activities including Hawaii, Nobeyama, Okayama, Mizusawa, Norikura and other projects and three centers are summarized in this report.

Norio Kaifu
Director General.of NAOJ

I Scientific Highlights

(April 2004-March 2005)

New Method of Measuring Phase Characteristics of Antenna Using Doppler Frequency Measurement Technique

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The irregularities in phase characteristics of an antenna on a spin satellite, such as the relay satellite and the VLBI satellite of SELENE, create erroneous Doppler frequency measurements. Precise measurements of antenna phase characteristics are thus required. We developed a new technique to measure phase characteristics of antennas [1], that is different from the conventional range methods. The antenna being tested is rotated at a rate of $f_{\rm sp}$ and its phase characteristics are calculated from the harmonic components of $f_{\rm sp}$ during time variations in the Doppler frequency of radio waves emitted from the rotating antenna, rather than by comparing phase delays as used in conventional techniques. The accuracy of measuring phase characteristics is mainly influenced by the instability of frequency, system noise, and ground echo signals. We thus used a precise oscillator (H-Maser), and only used the harmonic components of $f_{\rm sp}$ to calculate the phase characteristics, which reduced the influence of system noise. In addition, a parabolic antenna was used as the receiving antenna, which reduced the influence of ground echo signals, and obviated the need for an anechoic chamber used in conventional techniques.

We applied the proposed method to the patch antenna loaded on the relay satellite of SELENE. The patch antenna was placed on a platform, and rotated clockwise at a rate of $f_{\rm sp}$=0.105 Hz around the axis through its geometrical center. A right-handed circularly polarized wave with a frequency in the S-band was transmitted, and received by the main beam of the parabolic antenna.

Fig. 1(a) plots an example of the spectra for time variations in the Doppler frequency. The spectra for the harmonics of $mf_{\rm sp}$, m=1,2...7, were detected, which were caused by irregularities in the phase characteristics of the patch antenna. Fig. 1(b) plots time variations in the harmonics of $mf_{\rm sp}$, which were detected with eight digital band pass filters. The center frequencies of these filters were set to $m \times 0.105$ Hz, where m=1,2...8. As we can see, the profiles during every period $T_{\rm p}$ =9.5 s were similar. Fig. 1(c) plots phase characteristics obtained by integrating the time variations in the harmonics of $f_{\rm sp}$. As we can see in the figure, although they varied over a range of about ± 1 degrees, the profiles of phase variations during every period were very similar. Fig. 1(d) plots the averaging phase characteristics $\Phi(\theta)$ with respect to azimuth angle θ, which were calculated from Fig. 1(c).

We also obtained the three-dimensional phase characteristics of the antenna from the phase characteristics obtained with different elevation angles ψ (Fig. 2). Here, the z-axis shows elevation angle ψ and the x-y plane shows variations in azimuth angle θ. As we can see from Fig. 2, the phase characteristics of the antenna were very irregular. The range of variation in phase characteristics was about ± 3 degrees for 0°$< \psi <$20°, and about ± 8 degrees for 20°$< \psi <$90°. The reasons for this may be because when ψ is small, radio waves emitted from the entire patch antenna are received almost simultaneously, and phase variations in radio waves are averaged. When ψ is large, only radio waves emitted from the patch edges facing the receiving antenna are received, and the phases of radio waves vary for different edges.

The three-dimensional phase characteristics of the antenna were obtained with a root-mean-square error of about 0.5 degrees, which demonstrates the efficacy of the method.

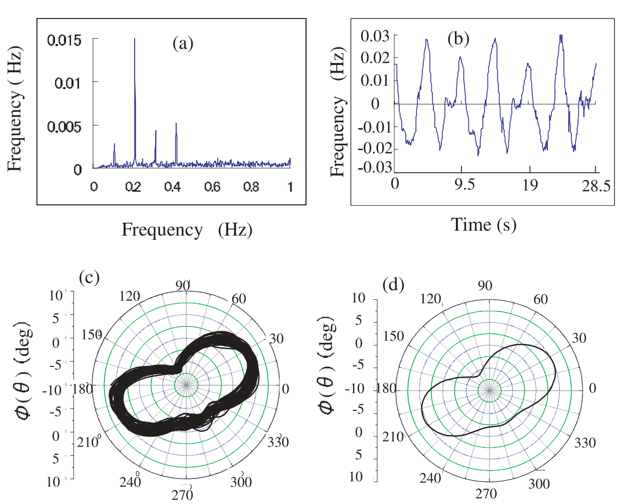

Figure1: (a) Spectrum for time variation in Doppler frequency. (b) time variation in the harmonics of $f_{\rm sp}$, (c) phase characteristics obtained by integrating the time variations shown in (b), (d) averaging phase characteristics.

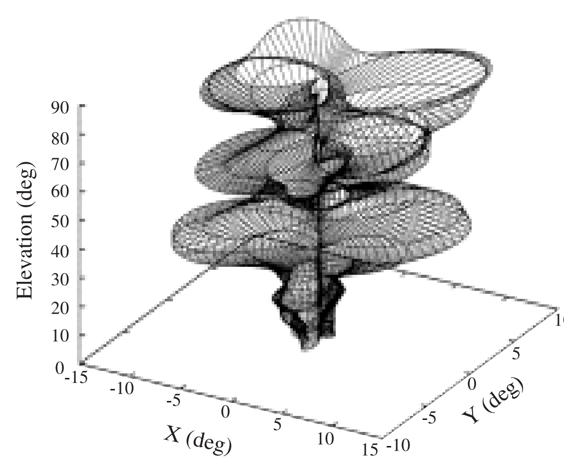

Figure2: Three-dimensional phase characteristics of patch antenna.

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Internal Structure and Librations of the Moon

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The idea is to detect fine variations in its rotation caused by a complex stratigraphy of lunar interior, using the high-precision astronomical observations of the lunar rotation in the forthcoming mission SELENE. An occurrence of additional oscillations in the polar motion of the Moon is one of manifestations of heterogeneous of a lunar body on its Eulerian (free) rotation (Fig. 1)[1] .

The first estimations of the lunar Free Core Nutation (FCN) period for a two-layer Moon (rigid mantle/solid core) have given the value about 140 - 190 years in inertial frame. There are reasons to view the Moon as a three-layer body: solid mantle/fluid outer / solid inner core. As result, new modes in free rotation appear. The fluid core does not share the rotation of the solid mantle: it can only weakly mimic the precession mantle motion. The resulting few cm/sec velocity difference at the core-mantle boundary causes a torque and dissipation energy [2].

For a planet with a solid inner core and a liquid outer core, there are four rotational normal modes. This numbers is reduced to two for a planet without inner core, and to one for a planet without liquid core [3]. For a planetary model with three homogeneous ellipsoidal layers the Hamiltonian analytical method for the calculation of the rotation variations gives magnitudes of these normal mode frequencies: they depend on a presence and on dimension of the inner core within the outer core, of their dynamical flattening. All types of modes are result of non-coincidence of rotation axes of mantle, outer and inner core (Fig. 2).

The Chandler Wobble (CW), which is a motion of the rotation axis of the Moon around its dynamical figure axis of the Moon around its body. It is the only global rotational mode for completely solid planet. For the Moon it has a long period 74.6 year in a frame tied to the Moon and is prograde (i.e. in the direction of lunar rotation). This mode was detected from LLR observation as 3"×8" elliptical component in the oscillation (Williams, 2001).

The Free Core Nutation (FCN), which represents a differential rotation of the liquid core relative to the rotation of the mantle. This mode does exist only if a core is liquid. It has a quasi-diurnal period in a frame connect to the Moon and is retrograde. The lunar FCN would have a long period in space of about 144 year, if dynamical figure of a core is similar to that of the mantle or about 186 year for core with ellipticity 4×10^{-4} .

The Free Inner Core Nutation (FICN), which represents a differential rotation of the inner core with respect to the outer layers of the Moon. The mode does exist only if the lunar two-layer core contains outer liquid and inner solid portions. It has a quasi-diurnal period in a frame connect to the Moon and is prograde. As preliminary estimation show, the lunar FICN would have a very long period in space is in the range of 500-600 years for the core's radius 350 km.

The Inner Core Wobble (ICW), which represents a differential rotation of the figure axis of the lunar core with respect to the rotation axis of the Moon and is due to the equatorial bulge of the inner core, having an excess of density with respect to the liquid core. This mode does exist only if there is an ellipsoidal solid inner core within a liquid core in the Moon. It has a long period greater than 100 years for the core's radius 350 km in a frame tied to the Moon and is prograde.

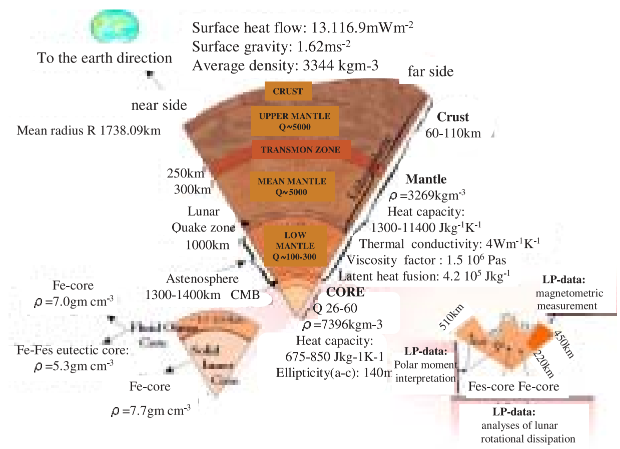

Figure1: Lunar interior as the result of different kind of observations and of theoretical modeling.

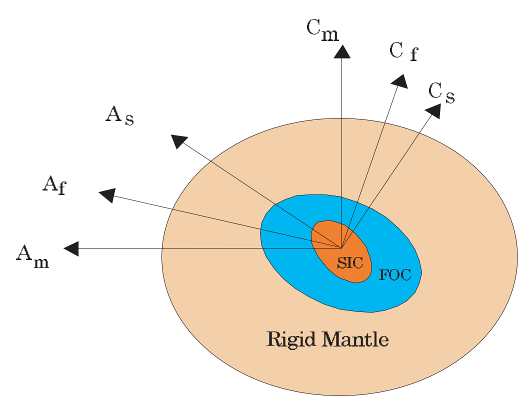

Figure2: The cross-section of the Moon along the rotational axis, A and C are momenta of inertia for mantle and core. FOC; Fluid outer core, SIC; Solid inner core.

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Down-sizing in Galaxy Formation at $z \sim 1$

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The SXDS team

It is known that the galaxy properties depend on mass or luminosity as well. Using the SDSS data, [1] and [2] have shown an interesting break mass at $3\times10^{10} M_\odot$ above which the dominant population is red passively evolving galaxies, while below that mass the contribution of blue active galaxies becomes dominant. Morphological mix of galaxies is also known to be strongly luminosity (or stellar mass) dependent [3]. It is therefore indicative that the formation of massive galaxies and less massive galaxies are quite different, in the sense that massive and/or early-type galaxies form early in the Universe, while dwarf and/or late-type galaxies form later on average or are still forming stars at present day. Such mass dependent star formation history is referred to as "down-sizing" [4].

Given the down-sizing seen in the local Universe, at high redshifts, we expect to go beyond the formation epoch of small galaxies or towards the early stage of their formation, as well as to approach the formation epoch of more massive galaxies. To test this hypothesis, we investigate the galaxy colours at $z \sim 1$ as a function of luminosity (or stellar mass) by utilizing the unique Suprime-Cam imaging data-set ($BRi'z'$) on the Subaru/XMM-Newton Deep Survey (SXDS). These data are both sufficiently deep (z'_{AB}=25, 6-10σ) and wide (1.2 deg^2), which enable us for the first time to investigate the photometric properties of statistical sample of galaxies at $z \sim 1$ down to $\sim M^*$+3 with respect to the passive evolution. We first identify five $z \sim 1$ high density regions by applying colour cuts at $1.7<R-z'<2.0$ and $0.8<i'-z'<1.1$, which correspond to the colours of passively evolving galaxies at $z \sim 1$. We then combine these five regions (amounting to 141 arcmin^2 in total) and subtract off the low density regions at $z \sim 1$ sampled from the same data-set and scaled to the same area. We do this subtraction on the colour-magnitude diagram [5] and isolate the $z \sim 1$ galaxies in a statistical sense. This method should work since both high and low density regions at $z \sim 1$ are expected to have the same amount of foreground/background contaminations.

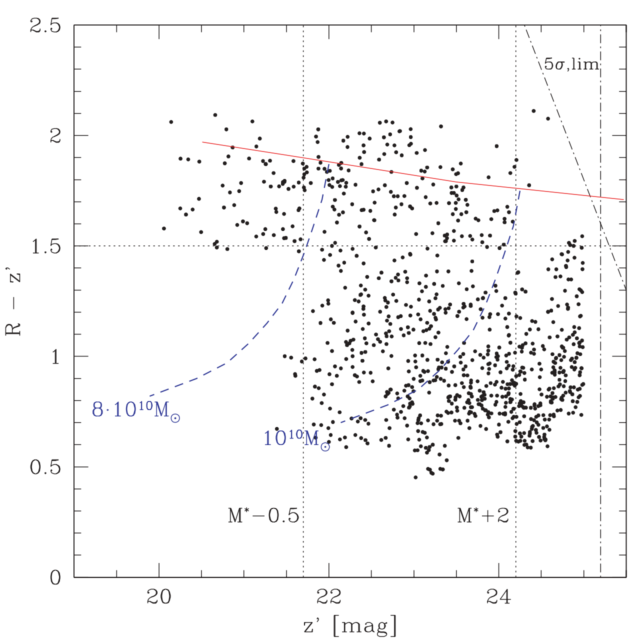

Figure1: Field-corrected colour-magnitude diagram for the $z \sim 1$ galaxies in high density regions in SXDS [6]. The solid line shows the expected location of colour-magnitude sequence at $z \sim 1$ assuming a passive evolution with $z_{\rm form}$=5 [7]. A deficit of blue galaxies at the bright/massive end, and a deficit of red galaxies at the faint/less-massive end, are both clearly identified. The stellar masses are scaled using the Kennicutt's IMF [8].

The field-corrected colour-magnitude diagram thus constructed for $z \sim 1$ galaxies in high density regions is shown in Fig. 1. The most striking feature in the galaxy distribution on this diagram is that the galaxies are separated into two distinct populations, 'bright+red' and 'faint+blue'. More precisely, we show a deficit of red and faint galaxies below M^*+2 or $10^{10} M_\odot$ in stellar mass and a lack of blue massive galaxies above $M^*-0.5$ or $8\times10^{10} M_\odot$ in stellar mass. The down-sizing in star formation is therefore also seen at high redshift, where star formation in massive galaxies takes place early in the Universe and is already truncated by $z \sim 1$, while almost all of small galaxies are still forming stars at $z \sim 1$ [6], [9], [10]. It is puzzling that the galaxy formation takes place in "down-sizing" fashion as *apparently* opposed to the currently favoured "bottom-up" scenario. It is required to accerelate the formation of massive galaxies (both star formation and mass assembly), and at the same time to delay the formation of small galaxies. Some critical physical mechanisms in galaxy formation may be still missing in the current models. It is interesting to see whether the break luminosity or mass get brighter with increasing redshift by going even higher redshifts with future wide-field NIR observations.

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Fe-bearing crystalline olivine around Vega-like star: material proof for planetesimals?

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We report Subaru/COMICS spectroscopic observations of Vega-like stars to investigate dust composition around Vega-like stars [1].

Vega-like stars are the main-sequence stars with circumstellar dust emission. We obtained the 8-13 μm spectrum of the Vega-like star HD145263, and found evidence for the crystalline silicate grains (Fig. 1). This is the second example of crystalline silicate grains around Vega-like stars after β Pictoris.

Detailed analysis of the silicate feature of HD145263 indicates that Fe-bearing cyrstalline olivine grains ($[Fe, Mg]_2SiO_4$) can be present around Vega-like star HD145263, which are not present in the protoplanetary disks around T Tauri stars and Herbig Ae/Be stars (see Fig. 1 and Fig. 2). Crystalline silicate in the protoplanetary disks is supposed to be Mg-rich olivine and pyroxene. Why can Fe-bering crystalline olivine grains be present around Vega-like stars?

In fact, Fe-bearing crystalline olivine is ubiquitous in the meteorites. Meteorites are supposed as a fragment of much larger parent-body (similar to planetesimals) and have records of various processes happened at the early phase of the solar system formation. From the studies of meteorites, Fe-bearing crystalline olivine is probably formed through alteration in the planetesimals, not from condensation of gas [3]. Therefore, if planetesimals are present around Vega-like stars and formation of dust through planetesimal collision occurs, Fe-bearing crystalline olivine grains can be present around Vega-like stars.

Originally, presence of planetesimals around Vega-like stars is suggested through discussion of grain survival timescale [4]. Thus presence of Fe-bearing olivine grains probably originated from planetesimals is consistent with the planetesimal hypothesis for the origin of dust around Vega-like star and can be a material proof for the presence of planetesimals.

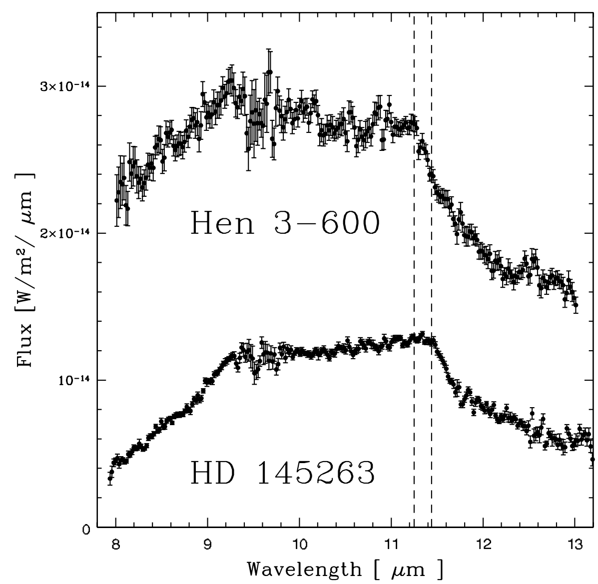

Figure1: 8-13 μm spectra of Vega-like star HD145263 and T Tauri star Hen3-600A. The longer wavelength "shoulder" of the silicate feature of the Hen 3-600A exhibits at 11.24 μm, while that of the HD145263 shows 11.44 μm. The presence of Fe-bearing crystalline olivine can account for this wavelength shift (see also Fig.2).

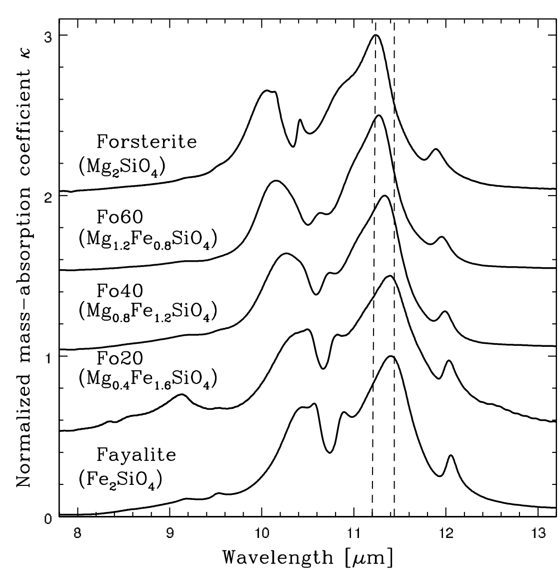

Figure2: Absorption spectra of olivine grains measured at laboratory [2]. The feature peak wavelength shifts to longer wavelength as Fe-content of olivine increases (from the top spectrum to the bottom one).

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Flare Ribbon Expansion and Energy Release Rate

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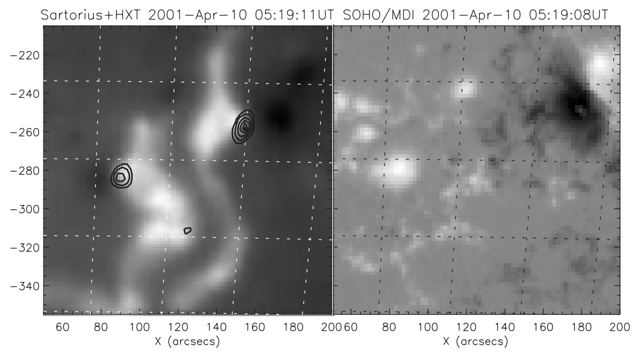

Figure1: Left: An Hα image taken with *Sartorius*. The overlaid HXR contour image was obtained by *Yohkoh*/HXT. Right: A photospheric longitudinal magnetogram obtained by *SOHO*/MDI. The white and black colors show the positive and negative magnetic polarities, respectively.

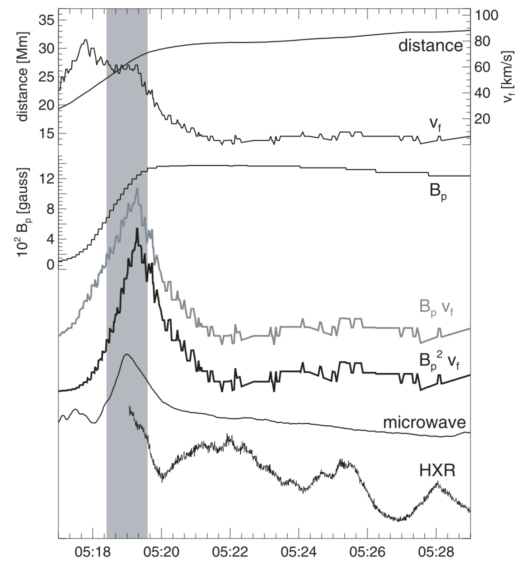

Figure2: Temporal variations of the physical parameters. From top to bottom: distance between the outer edge of the ribbon and the magnetic neutral line; separation speed of the ribbon; photospheric magnetic field strength at the outer edge of the ribbon; reconnection rate; Poynting flux; microwave correlation plot obtained with NoRH; hard X-ray count rate measured with the *Yohkoh*/HXT. The enhancements of the estimated reconnection rates and the Poynting fluxes, which are accompanied by the HXR bursts, are seen.

We have examined the relation between the evolution of the Hα flare ribbons and the released magnetic energy in a solar flare which occurred on 2001 April 10. See [1] for more details. Where and when does the energy release occur in a solar flare? In addition, how much energy is released? They are very important questions to answer in order to understand the trigger mechanisms of solar flares. The magnetic reconnection model has suggested that magnetic field lines successively reconnect in the corona, and can explain several well-known features of solar flares such as the growth of flare loops and the formation of the Hα two-ribbon structures at their footpoints. The Hα flare ribbons are caused by the precipitation of nonthermal particles and the effect of thermal conduction. As the magnetic field lines reconnect, newly reconnected field lines have their footpoints further out than those that have already reconnected. Therefore, the apparent separation motion of the flare ribbons is seen (Fig. 1).

Based on the reconnection models, the energy release rate can be expressed in terms of the coronal magnetic field strength and the inflow velocity into the reconnection region [2]. However, it is very difficult to measure the coronal magnetic field strength and the inflow velocity directly. Consequently, an indirect method is needed to evaluate the energy release rate quantitatively by using observable values.

We examined the relation between the expanding motions of the Hα flare ribbons and the magnetic energy released during a flare. We estimated the released magnetic energy by using the magnetic field strengths at the photospheric level and the separation speed of the flare ribbons, instead of direct coronal values. We used the Hα data obtained with *Sartorius* Telescope at Kwasan Observatory, Kyoto University, and the magnetogram taken with MDI[1] onbord *SOHO* satellite. Then, we compared the variation of the released energy with the temporal and spatial fluctuations in the nonthermal radiation observed in hard X-rays and microwaves (Fig. 2). Hard X-ray and microwave data were taken with *Yohkoh*/HXT[2] and Nobeyama Radioheliograph, respectively. Hard X-ray and microwave bursts appear when strong energy releases occur, and the sites of the radiation sources indicate where the energy is released. The HXR and the nonthermal microwave intensities are thought to be well correlated with the energy release rate. The estimated energy release rate well reconstructed the light curves of the nonthermal emissions. We also found that the estimated energy release rates in the Hα kernels associated with the hard X-ray sources are locally large enough to explain the difference between the spatial distribution of the Hα kernels and the hard X-ray sources.

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[1]Michelson Doppler Imager
[2]Hard X-ray Telecsope

Downflow Motions Associated with Impulsive Nonthermal Emissions

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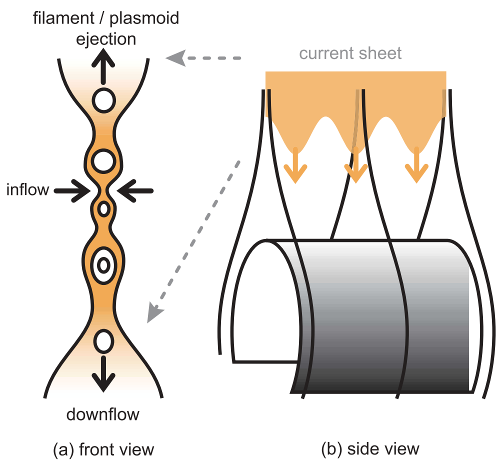

Figure1: Model of the downflows and plasmoid ejections. (a) Many plasmoids are created inside current sheet (gray region). (b) The current sheet is modified due to some instabilities.

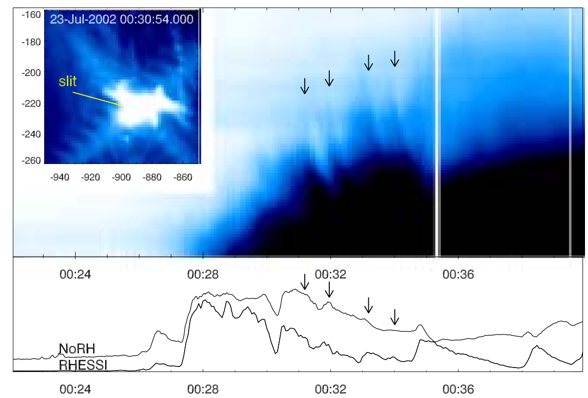

Figure2: *Top left*: an EUV image of the flare obtained with *TRACE*. The *yellow* line illustrates the position of the slit. *Top right*: time-sequenced EUV (195 Å) images obtained with *TRACE* along the slit line. The horizontal axis is time, and the vertical axis is the space along the slits. *Bottom*: microwave (17 GHz) and HXR (50 - 100 keV) light curves obtained with NoRH and RHESSI, respectively.

We examined in detail downflow motions above flare loops observed in the 2002 July 23 flare [1]. The finding of supra-arcade downflow motions (downflows) is one of the most important results achieved with *Yohkoh*/SXT[1]. These dark features move sunward from the high corona with speeds of about 200 km/s [2]. A few temperature analyses performed on the downflows suggest that they are "moving voids" which consist of such low density and high temperature plasma. These voids are pushed downward because of magnetic reconnection which occurred at higher altitudes, and therefore, they are thought to be new observational and morphological evidence of magnetic reconnection. However, there still remain many problems on downflows. So far, almost all the downflows have been observed in long duration event flares, and many of them were observed after the peak times of SXR light curves. If downflows are really related to magnetic reconnection, they are expected to be observed even in the impulsive phase, when magnetic reconnection occurs vigorously. We have examined in detail the evolution of a big two-ribbon flare which occurred on 2002 July 23 near the south-east solar limb. The extreme-ultraviolet (195Å) images were obtained with *TRACE*[2] satellite. They show dark downflow features above the post-flare loops. By using the *TRACE* images, with spatial resolution higher than with *Yohkoh*/SXT, we found that the downflows are seen not only in the decay phase, but also in the impulsive and main phases. Therefore, we concluded that the downflow phenomenon is not specific in the decay phase of a flare as had been thought.

[1] Soft X-Ray Telescope
[2] *Transition Region And Coronal Explorer*

Moreover, the hard X-ray and the microwave data of the flare were also obtained with *RHESSI*[3] satellite and Nobeyama Radioheliograph, respectively, which allowed us to examine the relationship between downflows and nonthermal emissions which implies strong energy release. We found that the times when the downflow motions start to be seen correspond to those when bursts of nonthermal emissions in hard X-rays and microwave are emitted. This result implies that the downflow motions occurred when strong magnetic energy was released, and suggests that they are correlated with reconnection outflows. Thus, we have been able to add a new piece of observational evidence to the model that downflows are reconnection outflow.

As another piece of observational evidence of reconnection outflows, the X-ray plasmoid ejections have been studied. The observations revealed a close relationship between plasmoid ejections and HXR emissions. From these results, we suppose that both the downflows and the plasmoid ejections are reconnection outflows (Fig. 1). Plasmoids are generated in the current sheet, and are ejected as downward (downflows) and upward (X-ray plasmoid ejections), when strong energy releases occur. Therefore, the correlations between plasmoid ejections, or downflow, and HXR bursts represent a plasmoid-induced, nonsteady reconnection [3].

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[3] *Reuven Ramaty High Energy Solar Spectroscopic Imager*

Global Structures of Optically Thin Black Hole Accretion Flows Obtained from Direct Magnetohydrodynamic Simulations

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MATSUMOTO, Ryoji (Chiba Univ.)

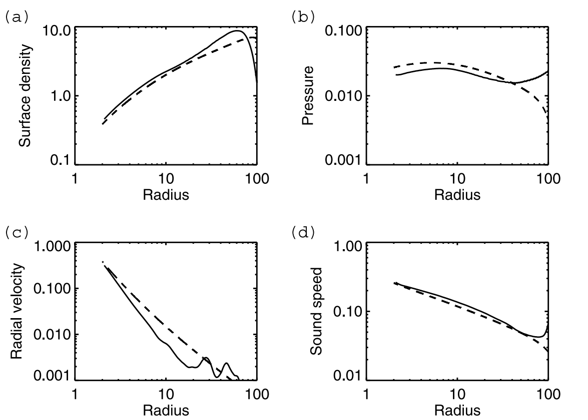

Figure1: Comparison between the radial structures obtained by 3D global MHD simulations (solid curves) and global steady transonic solution of non-radiative black hole accretion flow (dashed curves). The surface density (a) and integrated pressure (b) were computed by integrating the quantities in the range $0 < z < (0.4\varpi + 6)$. The radial velocity (c) and sound speed (d) were averaged in $0 < z < 1$.

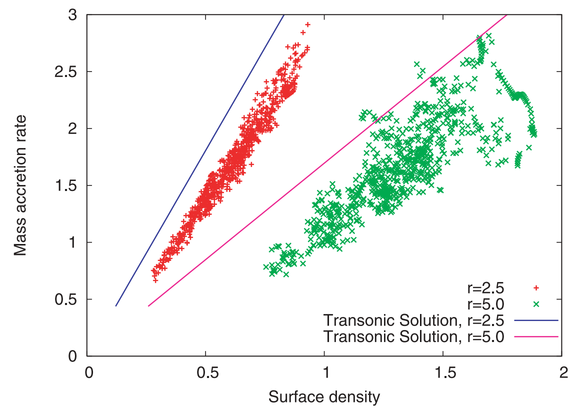

Figure2: Correlation between the surface density and the mass-accretion rate obtained by global MHD simulations. The red and green symbols denote the quantities at various times at $\varpi = 2.5$ and 5, respectively. The blue and pink line shows the transonic solution at $\varpi = 2.5$ and 5, respectively.

We compare the global structures of optically thin radiatively inefficient accretion flows obtained by global 3D magnetohydrodynamics (MHD) simulations with steady, one-dimensional global transonic solutions of black hole accretion flows assuming α-viscosity [1].

Optically thin advection dominated accretion flows (ADAFs) onto a balck hole have been studied extensively to explain the broad spectrum and activities in the low/hard state of galactic black hole candidates and in low-luminosity AGNs. In the conventional theory of accretion disks, the basic equations are derived by assuming stationarity and axisymmetry and assuming constant α-viscosity. This phenomenological approach was useful to construct disk models without knowing the exact mechanism of the angular momentum transport. However, we now know that the angular momentum of the disk is efficiently transported by Maxwell stress created by the MHD turbulence driven by magneto-rotational instability (MRI). Thus we carried out global 3D MHD suimulations of optically thin black hole accretion flows and compared the numerical results with global steady transonic solutions of optically thin one-temperature ADAFs.

The initial state of our numerical simulation is an equilibrium model of an axisymmetric MHD torus threaded by weak toroidal magnetic fields. As MRI grows, the torus deforms itself into an accretion disk. Fig. 1 compares the radial structure of the accretion flow obtained by 3D MHD simulations with the one-temperature steady transonic solution of nonradiative accretion flows. The latter solution is obtained by taking into account the radial dependence of α because simulation results indicate that the Maxwell stress depends on the radius, especially near to the centeral black hole and is approximated by $\alpha \sim \exp\left[1/(2\varpi)\right] - 0.99$.

Figs. 1a, 1b, 1c, and 1d show the radial profile of the surface density, vertically integrated pressure, averaged radial velocity, and averaged sound velocity in the azimuthal direction and in time, respectively. In order to avoid any contamination of coronal plasma, the radial velocity and sound speed were averaged only near to the equatorial plane. The solid curves show the simulation results, and the dashed curves show the steady transonic ADAF solution. The steady transonic solution approximately coincides with the simulation results.

In Fig. 2, we plot the correlation of mass accretion rate and surface density obtained from direct global simulations. The symbols show the mass accretion rate and surface density. When the mass accretion rate increases with time, the surface density becomes larger. The solid curves show the correlation expected from a steady transonic solution. The relation at $\varpi = 2.5$ coincides with the transonic solution, because at this radius almost all the mass (about 99.8%) is accreting toward the central black hole. However, at $\varpi = 5.0$, the coincidence is less clear because the radial oscillation of the disk is overlaid.

In conclusion, the global structure of the optically thin black hole aaccretion flows obtained by direct 3D global MHD simulations agrees fairly well with global steady transonic solutions of conventional radiatively inefficient accretion disks unlike the self-similar ADAF solutions which are often claimed to disagree with 3D global MHD simulation results.

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Nuclear starbursts in Seyfert 1 and 2 galaxies

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Seyfert galaxies are the most numerous class of Active Galactic Nuclei (AGNs) in the local universe, and their nuclear luminosities are believed to be powered by central mass-accreting supermassive black holes. There are two types of Seyfert galaxies, type-1 (which show broad optical emission lines) and type-2 (which do not), but the current AGN unification paradigm predicts that both types are intrinsically the same, but the central engines of type-2 are merely obscured by torus-shaped dust and molecular gas (the so-called dusty torus).

Since the dusty torus is rich in molecular gas, it is a plausible site for starbursts to occur. Such *nuclear* starbursts have been detected in type-2 Seyferts, but their detection rate in type-1 Seyferts has been surprisingly lower than type-2 Seyferts. One possible reason for this difference is the intrinsic difficulty in finding nuclear starburst signatures in type-1, because of the dilution by strong AGN emission. However, it is possible that nuclear starbursts can inflate the torus due to an energy input, and thereby a galaxy with such an inflated torus tends to be observed as a type-2. This modified unification paradigm predicts that nuclear starbursts are intrinsically stronger in type-2 than in type-1.

Infrared 3-4 μm slit spectroscopy is a powerful means to distinguish between these two scenarios. First, the 3.3 μm polycyclic aromatic hydrocarbon (PAH) emission feature is detected only in starbursts and not in AGNs, making its luminosity a good measure of starburst activity. Second, the 3.3 μm PAH emission from starbursts is intrinsically so strong that the signatures of even weak starbursts are detectable in normal (S/N $\sim$ 20) spectra. Third, dust extinction is much lower than at shorter wavelengths, and so the absolute magnitudes of starbursts are reasonably quantifiable from the *observed* 3.3 μm PAH luminosities.

We have obtained infrared 3-4 μm slit spectra of 23 type-1 Seyferts in the CfA and 12 μm samples (Fig. 1), and compared them with those of 32 type-2 in the same samples, previously obtained by ourselves [1]. We found the following main conclusions. (1) There is no systematic difference in nuclear starburst luminosities, relative to AGN powers, between type-1 and -2 Seyferts (Fig. 2). (2) The luminosities of nuclear starburts and AGNs positively correlate in both type-1 and -2 Seyferts, suggesting the physical connections between these kinds of activity [2].

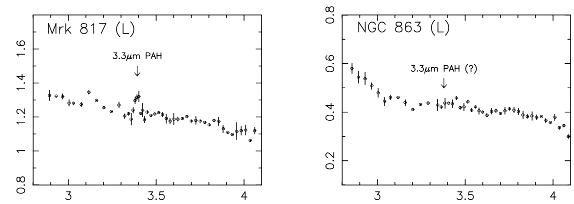

Figure1: Examples of infrared 3-4 μm spectra of Seyfert 1 nuclei. The abscissa is observed wavelength in μm, and the ordinate is F_λ in 10^{-15} W m^{-2} μm^{-1}. The left source shows a clear 3.3 μm PAH emission feature, while the PAH emission feature is not detected in the right source.

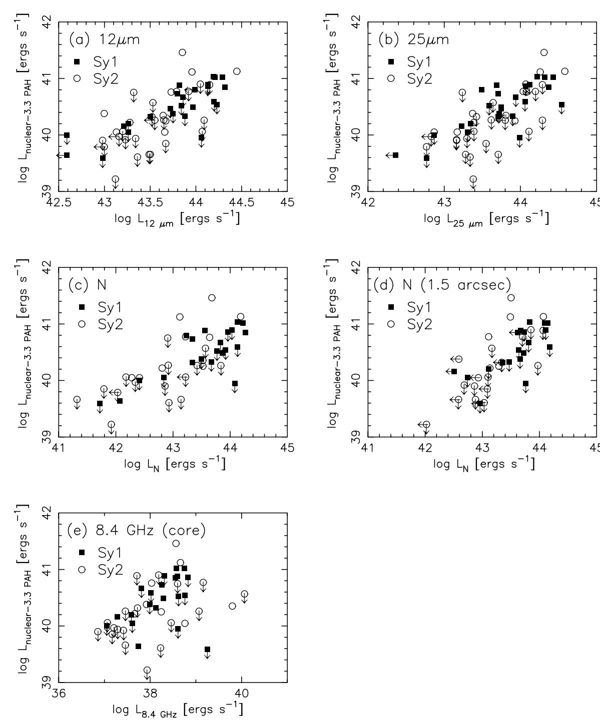

Figure2: The ordinate is the 3.3 μm PAH emission luminosities measured in our slit spectra and reflects the absolute magnitudes of nuclear starbursts. The abscissa is some luminosities that are thought to trace AGN powers. (a) *IRAS* 12 μm luminosities. (b) *IRAS* 25 μm luminosities. (c) Nuclear N-band (λ =10.5 μm) luminosities (<10 arcsec). (d) Nuclear N-band luminosities (1.5 arcsec). (e) Core radio luminosity at 8.4 GHz. In all the plots, there in no systematic difference in the distribution of Seyfert 1 and 2 galaxies, and statistical correlations are found between the luminosities in the abscissa and ordinate.

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A buried AGN in the infrared luminous galaxy NGC 4418

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Infrared luminous galaxies radiate very large luminosities ($L > 10^{11} L_{\odot}$) as infrared dust emission, and thus possess powerful energy sources hidden behind dust. To understand these galaxies, it is essential to distinguish whether the primary energy sources are starbursts or active galactic nuclei (AGNs).

If powerful AGNs are present and obscured by dust in a *torus* geometry, such AGNs are detectable through optical spectroscopy. However, since the nuclear regions of infrared luminous galaxies are very dusty, putative AGNs in these galaxies may be obscured by dust along all sightlines. Such **buried AGNs** are elusive, but its evaluation is fundamental to understanding the true nature of these galaxies.

To find such buried AGNs, observations at wavelengths of low dust extinction are clearly necessary. We thus performed near-infrared spectroscopy and millimeter interferometric observations of NGC 4418 [1], an infrared luminous galaxy which has been suspected to contain a buried AGN.

Our near-infrared K-band ($\lambda = 2$ μm) spectrum reveals strong emission lines of hydrogen molecule (Fig. 1). Their line ratios are indicative of a thermal origin. Millimeter interferometric observations using the Nobeyama Millimeter Array detected HCN (J=1–0) and HCO^+ (J=1–0) emission lines (Fig. 2, upper). By combining these data with CO (J=1–0) data in the literature, we found that NGC 4418 shows line ratios typical of AGNs with no detectable starburst activity (Fig. 2, lower). If an AGN, a strong X-ray emitter, is present deeply buried in dust and molecular gas, strong thermal emission lines of hydrogen molecule are expected, through X-ray heating. Furthermore, around a buried AGN, X-ray dissociation regions [2] should develop, which is predicted to produce a large HCN(J=1–0) to HCO^+(J=1–0) line ratio. Our results not only support the presence a powerful buried AGN in NGC 4418, but also clearly demonstrates that our method is effective in finding elusive buried AGNs. We are extending this successful approach to other infrared luminous galaxies.

References

[1] Imanishi, M., *et al.*: 2004, *AJ*, **128**, 2037.
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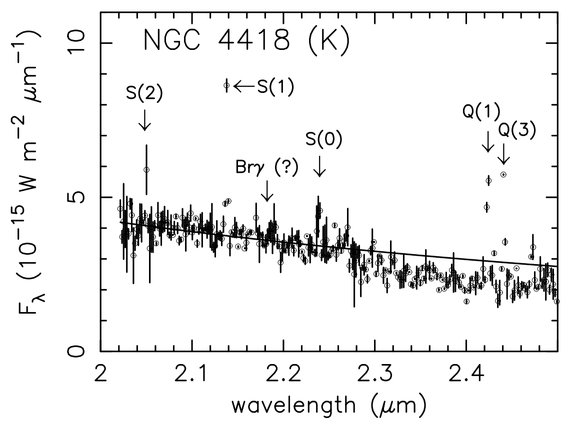

Figure1: Near infrared K-band spectrum of NGC 4418. Strong emission lines of hydrogen molecule (H_2) are seen. The equivalent width of H_2 1–0 S(1) line is the second largest observed to date in an external galaxy.

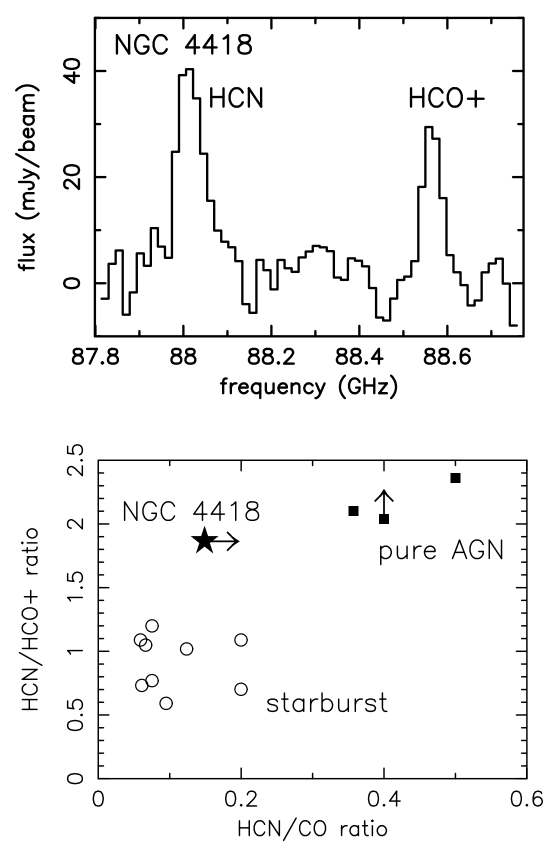

Figure2: Upper: Millimeter spectrum of NGC 4418 core obtained with the Nobeyama Millimeter Array. Lower: Line ratios in brightness temperature. NGC 4418 shows line ratios typical of an AGN-powered galaxy.

Discovery of a Young Brown Dwarf Companion around DH Tau

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SDPS team

NAOJ, collaborating with Kobe and Tokyo universities as well as other groups, is currently conducting a systematic survey of young stars in and around the Taurus molecular cloud to seek for circumstellar disks and/or young low-mass companions. Here we present the detection of a young brown dwarf companion, DH Tau B, associated with the classical T Tauri star DH Tau [1]. Near-infrared coronagraphic observations with CIAO on the Subaru Telescope have revealed DH Tau B with H$\sim$15 mag located $2''.3$ (330 AU) away from the primary, DH Tau A (Fig. 1). Comparing its position with a Hubble Space Telescope archive image, we confirmed that DH Tau A and B share a common proper motion, suggesting that they are physically associated with each other. The near-infrared color of DH Tau B is consistent with those of young stellar objects. The near-infrared spectra of DH Tau B (Fig. 2) show deep water absorption bands, a strong K absorption line, and a moderate Na absorption line. We derived its effective temperature and surface gravity of $T_{\rm eff}$ = 2700-2800 K and $\log g$ = 4.0 ± 4.5, respectively, by comparing the observed spectra with synthesized spectra of low-mass objects [2]. The location of DH Tau B on the H-R diagram gives its mass of 40 ± 10 Jupiter masses.

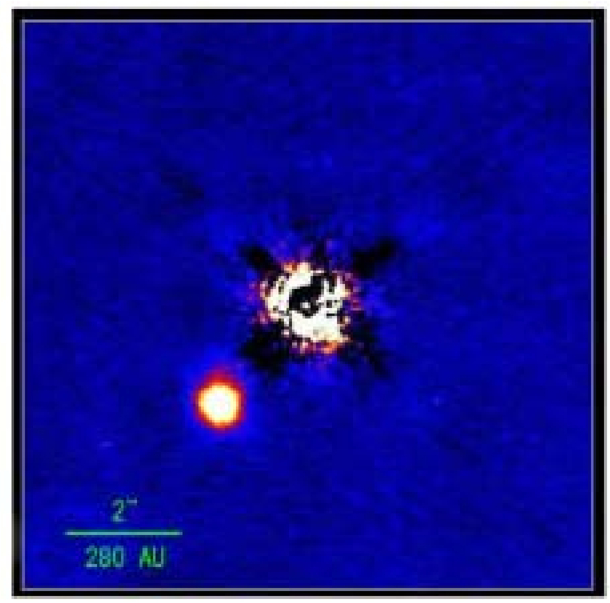

Figure1: CIAO 2.2 micron coronagraph image of DH Tau and its young brown dwarf companion. The field of view is 10″×10″.

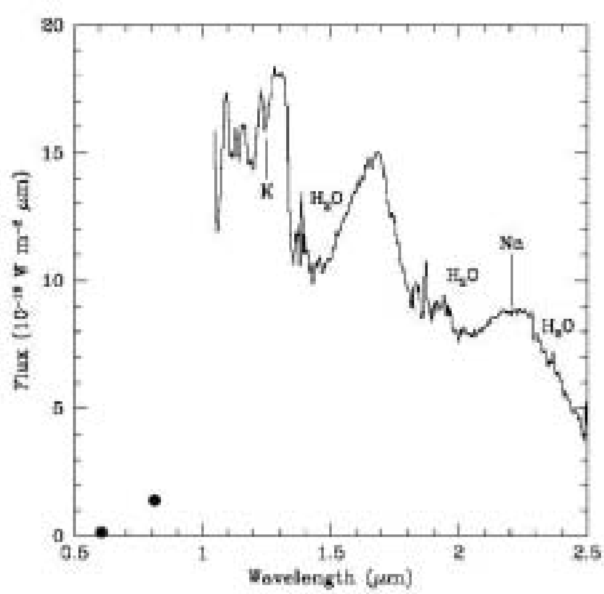

Figure2: Near-infrared spectra of DH Tau B. Optical broadband fluxes were measured from the HST archive data.

References

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High Resolution Near-Infrared Imaging Polarimetry of HL Tau

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Near infrared coronagraph instrument CIAO for the Subaru telescope is equipped with polarimetric capability [1]. We present high-quality near-infrared imaging polarimetry of HL Tau at 0.4-0.6 arcsec resolution, obtained with Subaru/CIAO and UKIRT/IRCAM [2]. HL Tau is a transitional object from a protostar to a T Tauri star [3]. Three-dimensional Monte Carlo modelling with aligned oblate grains is used to probe the structure of the circumstellar envelope and the magnetic field, as well as the dust properties. At the J band, the source shows a centrosymmetric pattern dominated by scattered light (Fig. 1). In the H and K bands, the central source becomes visible and its polarization appears to be dominated by dichroic extinction, with a position angle inclined by $\approx 40°$ to the disk axis (Fig. 2). The polarization pattern of the environs on scales up to 200 AU is consistent with the same dichroic extinction signature superimposed on the centrosymmetric scattering pattern. These data can be modelled with a magnetic field which is twisted on scales from tens to hundreds of AU [4], or alternatively by a field which is globally misaligned with the disk axis.

References

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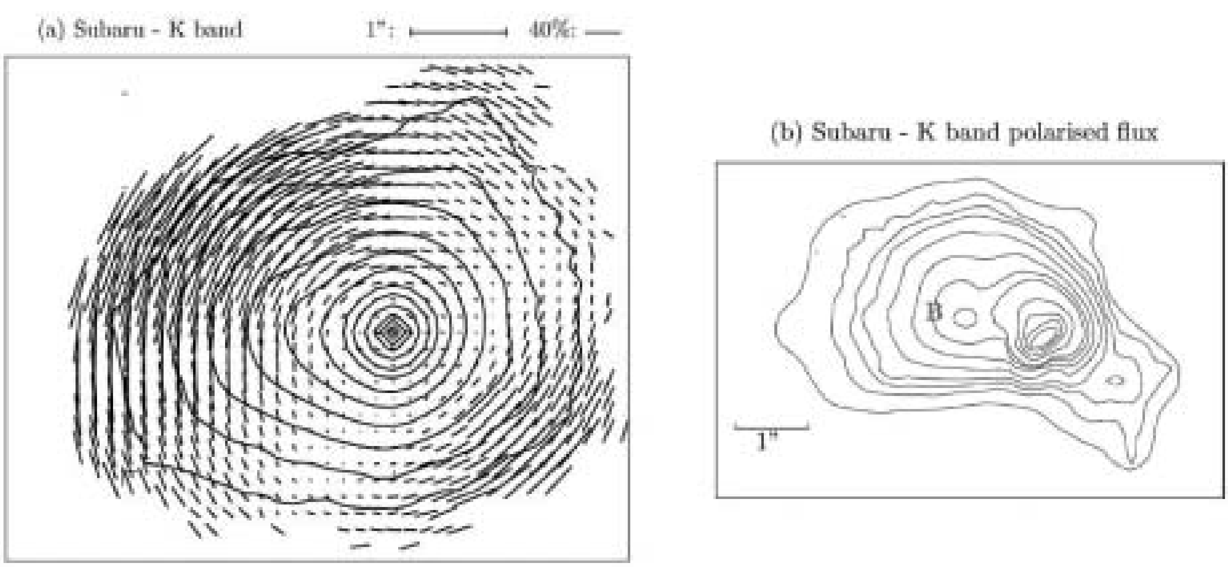

Figure1: (a) CIAO 2.2 micron surface brightness contour and polarization map, and (b) its polarized intensity contour. Contour levels are normalized to unity at the peak. The spatial scale and polarization degree scale are also shown.

Flared Disks and Silicate Emission in Young Brown Dwarfs

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It has been suggested that there are numerous candidates of young brown dwarfs and even planetary mass objects (aka, sub-brown dwarfs) in nearby star forming regions [1]. How are such very low-mass objects borne? Are they formed just like solar-mass stars (like T Tauri stars)? Are they originally companion objects which are somehow separated and mass accretion is terminated? Or are they formed in protoplanetary disks around more massive stars? Given the much lower mass and intrinsic luminosity of brown dwarfs relative to T Tauri stars, the preceding discoveries raise intriguing questions about how the detailed properties of brown dwarf disks compare to those of T Tauri disks. Observations in the mid-infrared, where optically thick disk emission dominates over the substellar photosphere, can provide important constraints on the disk models [2], [3]. We present mid-infrared photometry of three very young brown dwarfs located in the rho Ophiuchi star-forming region–GY 5, GY 11, and GY 310–obtained with the Subaru 8.2 m telescope [4]. All three sources were detected at 8.6 and 11.7 μm, confirming the presence of significant mid-infrared excess arising from optically thick dusty disks. The spectral energy distributions of both GY 310 and GY 11 exhibit strong evidence of flared disks; flat disks can be ruled out for these two brown dwarfs (Fig. 1). The data for GY 5 show large scatter and are marginally consistent with both flared and flat configurations. Inner holes a few substellar radii in size are indicated in all three cases (and especially in GY 11), in agreement with magnetospheric accretion models. Finally, our 9.7 μm flux for GY 310 implies silicate emission from small grains on the disk surface. Our results demonstrate that disks around young substellar objects are analogous to those girdling classical T Tauri stars and that they exhibit a similar range of disk geometries and dust properties.

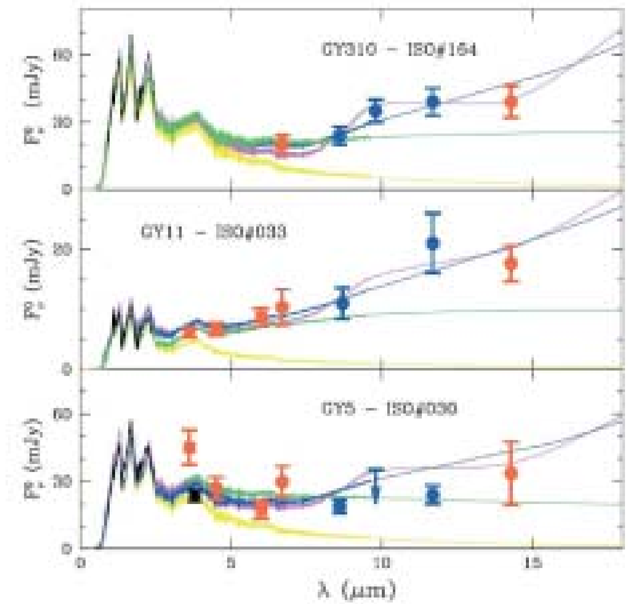

Figure1: Observed fluxes and model predictions for GY 310, GY11, and GY 5 (from top to bottom). The blue circles are from this work, and the red circles and the black curve from previous space observations. The magenta curve shows the prediction of a flared disk model with small grains. The blue curve shows the prediction of a flared disk model with large grains, and the green curve is the SED of a flat blackbody disk. The photospheric flux for the adopted substellar parameters is in yellow.

References

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SIRIUS Observations of Massive Star Forming Regions: W3 Main and NGC 7538

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SIRIUS is a simultaneous JHKs camera developed jointly by Nagoya University, NAOJ, and other institutions, and serves as an excellent tool for studies of star formation. Here we report near-infrared (JHKs-band simultaneous) observations of two massive star forming regions (SFRs), W3 Main and NGC 7538 (Fig. 1). A number of new YSO candidates are found and infrared nebulae associated with YSOs are detected; some show intricate color variations and morphology. A several hundreds of low-mass YSOs are formed with the formation of massive YSOs. Based on NIR-color classification, we found that each group of these YSOs shows clearly separate spatial distributions; Class I-like protostars distribute toward the dense cloud regions and Class II-like YSOs around or in optical (diffuse) HII regions [1], [2]. The distribution in NGC 7538 is most likely to be a signature of sequential star formation process. Other publications from SIRIUS in this school year include [3], [4], [5], [6], [7].

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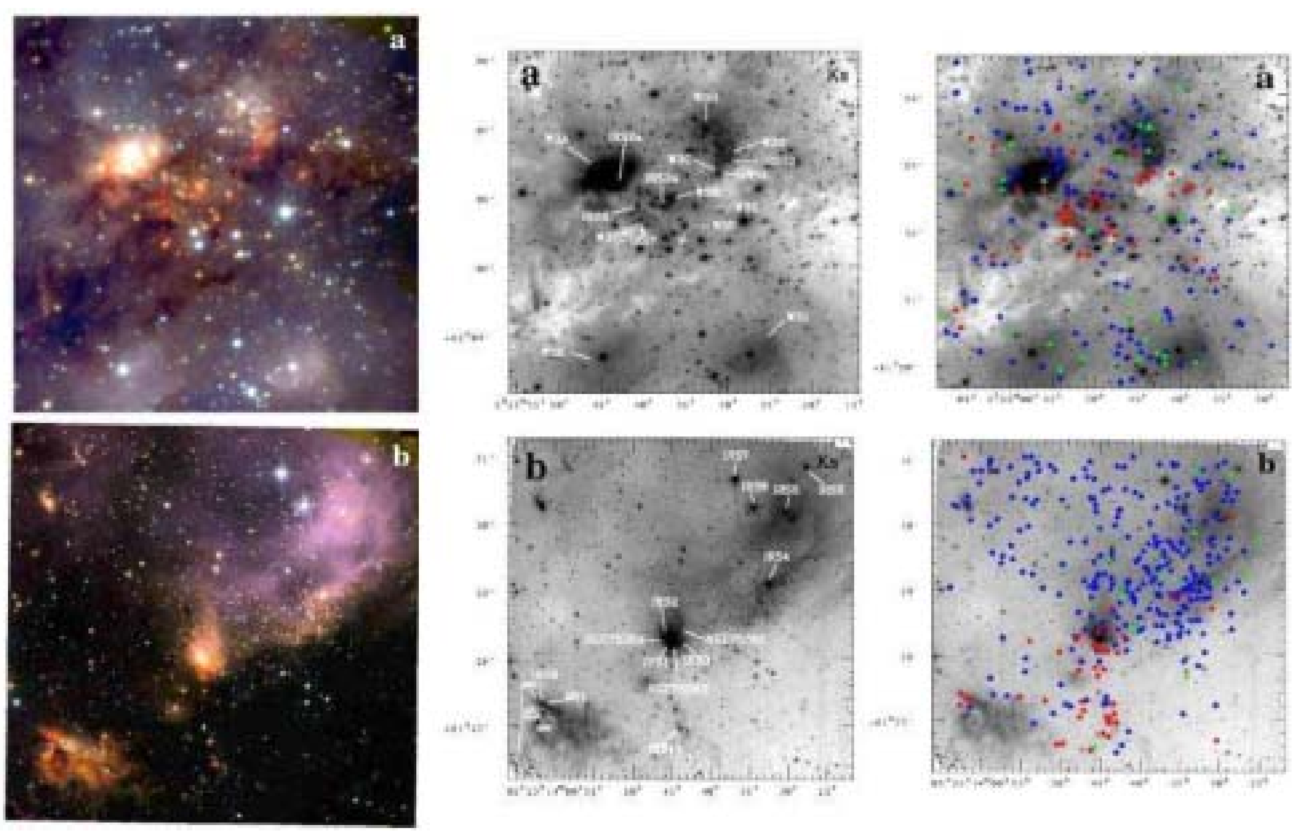

Figure1: <Left> SIRIUS JHKs composite images of W3 Main (top) and NGC 758 (bottom). <Middle> Identifications of main IR sources with radio sources, HII regions, compact HII regions, ultra-compact HII regions, and massive YSOs. <left> Spatial distribution of YSO candidates. Blue corresponds to Class II sources, green Class I sources, and red embedded res sources (H-Ks>2). Note that their spatial distributions are distinct.

Solar Polarimetry in the Hα line with a Ferroelectric Liquid Crystal Polarimeter

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The solar polarimetry with chromospheric absorption lines such as the Hα line is the key to understand
– the magnetic field in the chromosphere, which is close to the corona where the solar active phenomena actually take place,
– the high-energy particles which are accelerated in flares and penetrate into the chromosphere.
However, the chromospheric lines show weak polarization only, and therefore, their detection has been difficult.

The most significant source of errors in the polarization measurements is the cross-talk caused by the seeing effect. However, this can be reduced with high-speed polarization modulation. Therefore, we developed a polarimeter consisting of ferroelectric liquid crystals (FLC) and a high-speed CCD camera, of which the frame-rate is 500–1000 frame s^{-1}[1]. This polarimeter realized high-speed polarization modulation, and improved the sensitivity of the polarization measurements much. Now the crosstalk due to the seeing effect is negligible. Fig. 1 shows the FLC polarimeter. We installed it into the Solar Flare Telescope at Mitaka to observe the polarization in the Hα line.

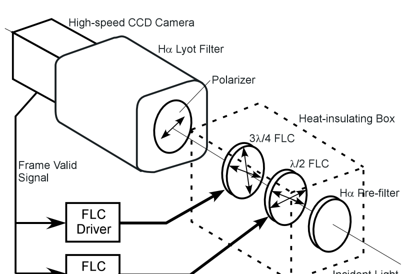

Figure1: The ferroelectric liquid crystal polarimeter for the Solar Flare Telescope.

With this polarimeter, we can measure the polarization of the fast varying phenomena such as impulsive flares with the sensitivity of the order of 0.1 %. In the case of the measurement of the polarization due to the Zeeman effect, which changes slowly, the integration realizes the sensitivity of 10^{-4}, with which we can derive the vector magnetic fields in the chromohsphere. Fig. 2 shows an example of the results of the measurement of the chromospheric magnetic field. In this figure, region NOAA 0596, which appeared in 2004 April, is shown. Fig. 2(c) shows a full-Stokes map, which corresponds to the vector magnetic map of the chromosphere. We studied the Stokes V/I data of this region, and obtained the following results [2].

– The Stokes V/I weakening is observed persistently in the sunspot umbra, though the polarization weakening (or reversal) in umbrae has so far been considered as a transient phenomenon. Our result suggests that the Stokes V/I weakening is caused by the atmospheric structure of the umbral chromosphere. This is one of the keys to understand the atmospheric structure above sunspots.
– The Stokes signals at the different wavelength offsets from the Hα center correspond to the magnetic fields of the different atmospheric layers. The photospheric magnetic field data have been used to study the solar magnetic field, but they are considered to show only two-dimensional magnetic information at a specific height. However, chromospheric magnetic field data (and the combination with the photospheric magnetic field data) have a potential to show the three-dimensional structure of the solar magnetic field.

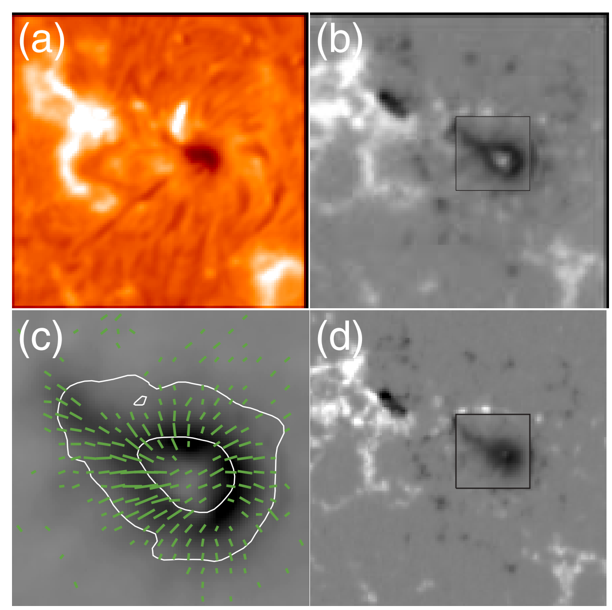

Figure2: Images of region NOAA 0596 on 2004 April 22. (a–c) Hα image, Stokes V/I map, and a close-up full-Stokes map of the sunspot, where the linear polarization signals are shown with sticks, respectively. All images were taken by the Solar Flare Telescope. (d) Photospheric magnetogram taken with the MDI of the *SOHO*. The squares in panels (b) and (d) shows the area displayed with the different scales to avoid saturation.

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Derivation of DEM Distribution using Yohkoh/SXT

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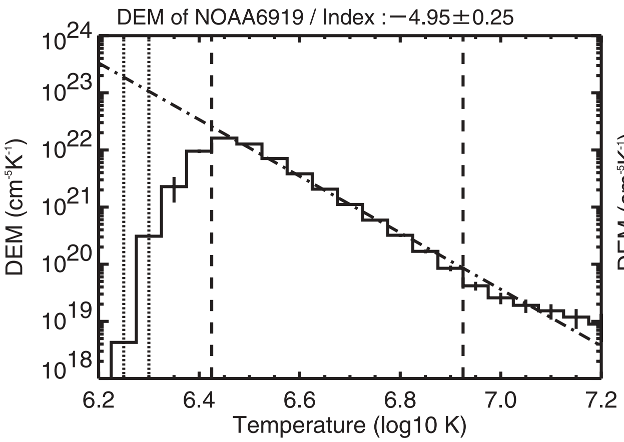

Figure1: The DEM Distribution of the central part of NOAA 6919. Dash-dot line shows the result of fitting and dashed line shows the temperature range for the fitting.

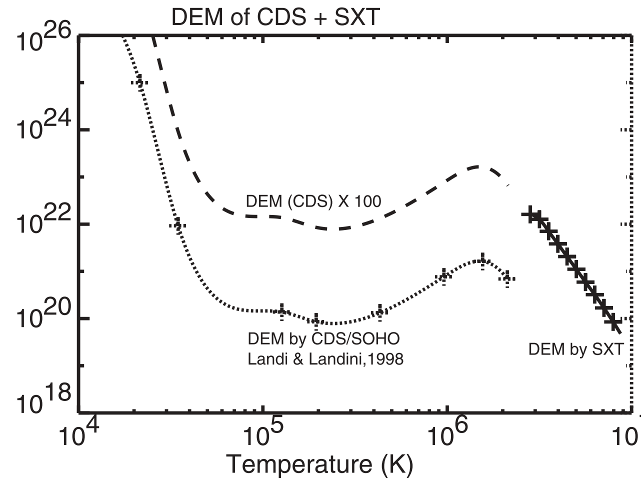

Figure2: The DEM distributions obtained from *SOHO*/CDS and SXT. Dotted line indicates the DEM distribution of an active region observed with *SOHO*/CDS on 9 April, 1996 (Landi & Landini 1996). Dashed line show 100 × DEM distribution from CDS. Solid line shows the DEM distribution of NOAA 6919 obtained from YOHKOH/SXT data.

The Sun has many mysteries. Among them, why the solar corona is heated to be so high in temperature is a long standing question, and understanding of the coronal heating mechanism is one of the most difficult problems to be tackled, partly because we do not know yet thermal structures of the solar corona precisely. Using soft X-ray images, like those taken by Yohkoh/Soft X-Ray Telescope (SXT)[1], we often derive single temperatures of the corona by a filter-ratio technique, simply neglecting multi-thermal structures of the solar corona, namely, its Differential Emission Measure (DEM) distributions.

Usually, we estimate the DEM distributions from EUV emission lines observed with EUV spectrometer (e.g. [2]), but it is difficult to derive the DEM distribution at higher temperature range (>2 MK), since the emissivities of these EUV lines become weak at these temperatures. On the other hand, soft X-ray lines (∼ 15Å) are emitted at high temperature, but we do not have the instruments that observe the soft X-ray spectra and resolve these X-ray lines. Strong et al.[3] show the possibility of deriving the DEM distributions between 2 MK and 20 MK from X-ray images observed with Yohkoh/SXT using Withbroe-Sylwester method [4], [5]. In this paper, we derive the DEM distributions from the SXT images of NOAA 6919 by Withbroe-Sylwester method.

Yohkoh/SXT observed NOAA 6919 using 5 X-ray filters from 05:10 UT to 06:06 UT on 18 November, 1992. The period corresponds to the day time during a spacecraft revolution. The spatial and time resolutions of the data are 5 arcsec and about 10 second, respectively. No apparent activity took place around the center of the active region during the period. We integrated for total of 344 seconds, and for the area of 150 arcsec × 150 arcsec. Hence, X-ray photon noises are rather negligibly smaller than the uncertainties in the ionization balance models.

Figure 1 is the result of the calculation. We derive the DEM distribution from 2 MK to 10 MK. The DEM distribution shows a power-law like distribution and the distribution from 2.8 MK to 8.9 MK fits the power-law function with an index of -4.95 ± 0.25.

In order to compare our result with other results of DEM analysis, we show the DEM distribution obtained from SXT and that of *SOHO*/CDS data (Fig. 2). The DEM distribution from *SOHO*/CDS data is obtained by Landi & Landini (1998) using the Arcetri method [6]. Discontinuity in active region DEMs might partly come from the inaccuracies of the absolute calibrations of the both instruments and the difference of abundance and ionization balance models. Furthermore, some observations show humps in the DEM distribution at temperatures of several MK [7], [8]. Therefore, it is not absolutely necessary to shift upwards the DEM obtained by *SOHO*/CDS, by two orders of magnitude, to have a continuously declining distribution above 2 MK.

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The Subaru Deep Field: The Optical Imaging Data

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Deeper and wider-field observations are required to understand the universe from a longer baseline of time and space. A large galaxy survey is a simple and essential method in today's astronomy for this purpose. However, an unprecedentedly large galaxy survey is made possible only with the combination of some distinctive resources, such as a large telescope, a unique and efficient instrument based on advanced technologies, and a large amount of telescope time created by the cooperation of many people who appreciate the value of the survey. In particular, such extremely deep and wide galaxy surveys to collect a statistically robust number of high-z galaxies beyond $z\!=\!3$ are definitely needed. The previous high-z galaxy surveys are sometimes not wide enough to overcome the effect of cosmic variance in deriving the universal nature of these high-z populations, or sometimes not deep enough to catch a faint signal from these distant populations.

The Subaru Deep Field (SDF) project is a program of Subaru Observatory to carry out a deep galaxy survey over a blank field as large as $34' \times 27'$. The program consists of very deep multi-band optical imaging, near-infrared imaging for smaller portions of the field, and follow-up optical spectroscopy. The major scientific goals of the project are to construct large samples of Lyman-break galaxies at $z \simeq 4-5$ and Lyman alpha emitters at $z \simeq 5.7$ and 6.6, and to make detailed studies of these very high-redshift galaxy populations. In this paper, we describe the optical imaging observations and data reduction, presenting mosaicked images and object catalogs in seven bandpasses [1]. The optical imaging was made through five broad-band filters, B, V, R, i', z', and two narrow-band filters, NB816 ($\lambda_c = 8150$Å) and NB921 ($\lambda_c = 9196$Å) with almost 10 hour integrations for each band. The limiting magnitudes measured at 3σ on a $2''$ aperture are $B\!=\!28.45$, $V\!=\!27.74$, $R = 27.80$, $i' = 27.43$, $z' = 26.62$, NB816 $= 26.63$, and NB921$=26.54$ in the AB system (Fig. 1).

The object catalog constructed for each of the seven bands contains more than 10^5 objects. The galaxy number counts corrected for detection incompleteness and star-count contributions are found to be consistent with previous results in the literature (Fig. 2). The initial discovery of two Lyman alpha emitters at $z\!=\!6.6$ on the SDF was reported [2]. Mosaicked images and catalogs of all the bands have been made open to the public on Oct. 1, 2004 on the SDF project website at http://soaps.naoj.org/sdf/.

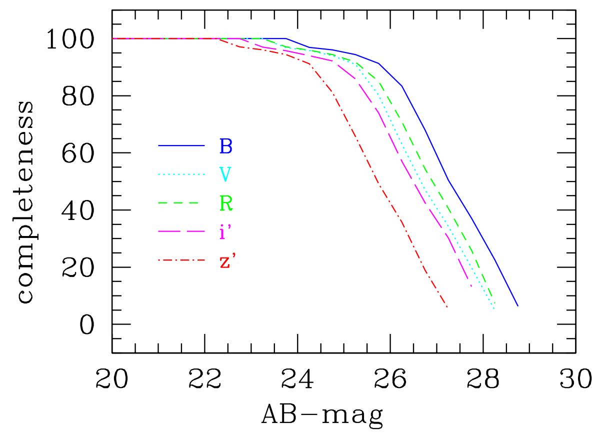

Figure1: Completess estimate for our final SDF sample as a function of the magnitudes.

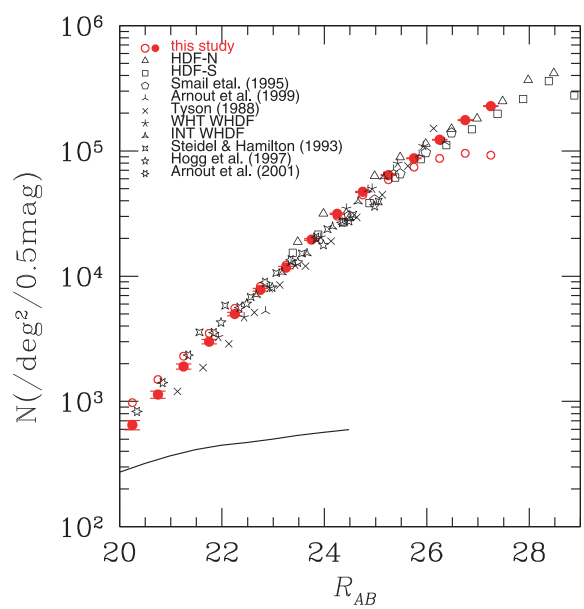

Figure2: Galaxy number counts in the R-band. The open (red) circles show the raw number counts from the SDF catalog, filled (red) circles show the galaxy number counts corrected with completeness and subtracted star counts, and other symbols from the literature. The solid line shows the predicted star counts of [3]. The error bars shown in the SDF counts are based on the simple Poisson errors. We have derived the number counts of galaxies for all the five broad bands.

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Near infrared imaging observations of the N159/N160 complex in the LMC : Large clusters of Herbig Ae/Be stars and sequential cluster formation

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The Large Magellanic Cloud (LMC) is one of the ideal targets for cluster formation studies, because it harbors large young clusters such as 30 Doradus, and dynamical environments like highly turbulent interstellar medium (e.g., [1]) and super-shells (e.g., [2]).

We carried out deep near-infrared imaging observations of the N159/N160 complex star forming region in the Large Magellanic Cloud (LMC). We observed an area of $\sim$ 380 arcmin^2 ($\sim$ 80,000 pc^2 at the distance of the LMC) in the J, H, and Ks bands. The observations are deep enough to detect down to $\sim$ 3 $M_\odot$ Herbig Ae/Be stars in the LMC.

We discovered a total of 338 and 464 candidates of Herbig Ae/Be and OB stars, respectively, based on the near-infrared colors and magnitudes. The Herbig Ae/Be star candidates constitute 10 clusters, while the OB star candidates 13. We discovered an embedded Herbig Ae/Be cluster in the N159E giant molecular cloud (GMC), N159-Y4, and a Herbig Ae/Be cluster at a north-east tip of the N159S GMC, N159S-Y1 (Fig. 1). Together with neighboring two H II regions, the Herbig Ae/Be cluster N159S-Y1 indicates a hint of the beginning of sequential cluster formation in N159S. Spatial distributions of the Herbig Ae/Be and OB clusters, in conjunction with previously known optical clusters and embedded massive stars, indicate (1) sequential cluster formation within each of the N159 and N160 star forming regions, and (2) large scale sequential cluster formation over the entire observed region from N160 to N159S [4]. Possible triggers for the large scale sequential cluster formation are a supergiant shell SGS19 and an expanding superbubble. Some Herbig Ae/Be clusters in the N159/N160 complex are significantly larger in spatial scale than pre-main sequence clusters of similar age in the Galaxy. Highly turbulent gas motion in the LMC is probably responsible for forming the large young clusters.

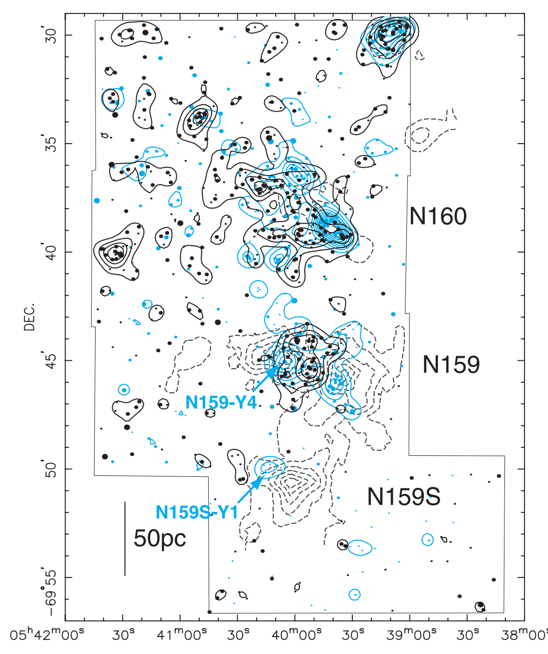

Figure1: Blue and black points denote the Herbig Ae/Be and OB star candidates, respectively. The solid contours show surface number density of the stars. The lowest level and the interval are 1 star/(10pc)^2. Dashed contours show ^{12}CO(1-0) integrated map [3].

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JASMINE Simulator

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We explain simulation tools in the JASMINE project [1] (JASMINE simulator). The JASMINE project stands at the stage where its basic design will be determined in a few years. Then it is very important to simulate the data stream generated by astrometric fileds at JASMINE in order to support investigations of error budgets, sampling strategy, data compression, data analysis, scientific performances, etc. We find that new software technologies, such as Object Oriented (OO)[2] methodologies and Unified Modeling Language (UML) are ideal tools for the simulation system of JASMINE (JASMINE simulator).

The simulation system should include all objects in JASMINE such as observation techniques, models of instruments and bus design, orbit, data transfer, data analysis etc. in order to resolve all issues which can be expected beforehand and make it easy to cope with some unexpected problems which might occur during the mission of JASMINE. Furthermore many researchers in various fields including engineering of the bus system should participate in developing the simulator. Then the simulator include many objects and furthermore flexibility and interaction is needed to cope with the objects. On the other hand, calibrations must be protected from unintentional modification for each model of the objects. Then we conclude that the OO methodologies are ideal for demands described above in the simulator. High maintainability and reusability of the OO approarch is very useful in making the simulator system. At the present time, the framework of the JASMINE simulator is completed. These new software technologies are used also in other space astrometry projects, GAIA and SIM, and are recognized to be important in other big science missions.

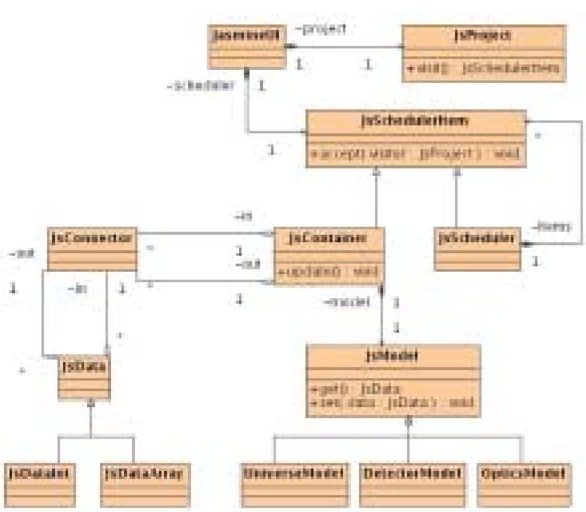

Figure1: UML diagram for JASMINE Simulator Framework.

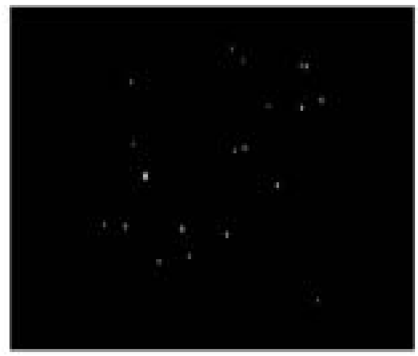

Figure2: Simulated image observed by JASMINE.

Programming of such a large software project starts from abstraction of components. For example,

Galaxy model Sources of lights

Optical system The component which require light as input and provide light as output.

Detector The component which convert light to electric signals.

Data Processor The component which convert electric signals to numeric data.

By this abstraction, JASMINE may be considered as a set of components which get information from other component, processing (including diffraction etc.), and provide information to other component.

Schematic UML diagram of our proto type simulator is shown in Fig. 1 In our implementation of proto type simulator, each components, such as optical systems or detectors are inherited from an abstract class "model". A class "container" which manages dependnecy graph has the class "model". The structure ensures extendability of modules. Simulated image by JASMINE observation is also shown in Fig. 2.

We are now starting collaboration with satellite system group in Univ. of Tokyo and JAXA and constructing individual components.

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Radio Observations of the Afterglow of GRB 030329

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In the fireball model, afterglows of gamma-ray bursts are described by synchrotron radiation from a relativistic blast wave. Radio observations of the afterglow of gamma-ray bursts at millimeter wavelengths are very important, since they can trace the time evolution of the synchrotron spectrum directly, and make it possible to derive physical parameters of gamma-ray bursts.

GRB 030329 is one of the closest events. Its redshift is $z = 0.168$. The afterglow of GRB 030329 was so bright that light curves at various frequencies, from X-ray to radio, have been obtained. Furthermore, a connection between the GRB and a supernova was confirmed.

We conducted radio observations of the afterglow of GRB 030329 at 23.5 GHz, 43 GHz, and 90 GHz with the Nobeyama 45-m telescope. The light curves show a steep decline after a constant phase (Fig. 1). The difference in the start time of the decline can be seen. Namely, the decay started earlier at the higher frequency. The time evolution of the spectrum shows a decay of the peak frequency and the peak flux. These results are qualitatively consistent with the fireball model. We compared the radio data with three models (ISM model, wind model, and jet model). Among the three models, the wind model and the jet model are relatively consistent with the observed data.

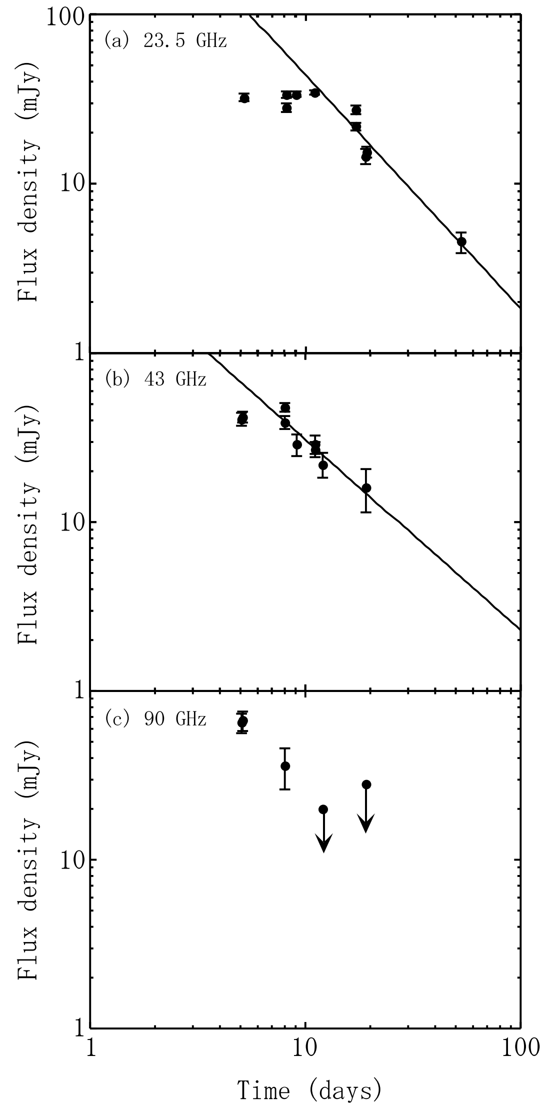

Figure1: Light curves of the radio afterglow at (a) 23.5 GHz, (b) 43 GHz, and (c) 90 GHz. The upper limits are 3 σ. The solid lines are the results of a power-law fitting of the decline of the light curves [F(23.5 GHz) $\propto t^{-1.38}$, F(43 GHz) $\propto t^{-1.13}$].

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Stellar Mass dependence of Color Evolution of Galaxies in the HDF-N

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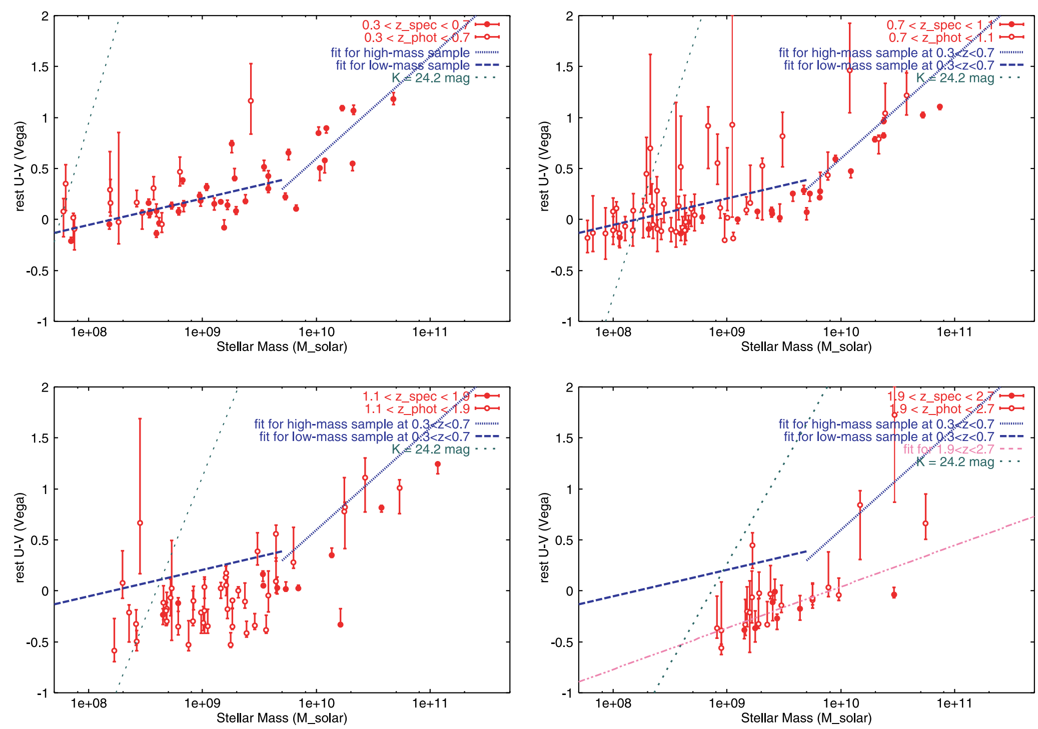

Figure1: Rest $U-V$ color distribution of galaxies in the Hubble Deep Field North as a function of stellar mass. dashed line and dotted line show the fitting results for low-mass ($M_* < 5\times10^9 M_\odot$) and high-mass ($M_* > 5\times10^9 M_\odot$) sample at $0.3 < z < 0.7$.

Using the very deep Subaru/CISCO imaging data and HST archival data, we investigated the relation between the stellar mass and rest-frame color of distant galaxies [1]. Here we report these results briefly.

For the Hubble Deep Field North field, there are very deep HST WFPC2/NICMOS *U, B, V, I, J, H*-band data. In order to study the evolution of the stellar mass and rest $U-V$ color of field galaxies back to $z\sim3$ and to low mass limit ($\sim 10^8 - 10^9 M_\odot$), we performed the very deep (10 hour exposure) K-band imaging with Subaru/CISCO in this field.

In Fig. 1, we show the rest $U-V$ color distribution of galaxies as a function of stellar mass for each redshift range. From the figure, it is seen that at $z<2$, the higher-mass galaxies tend to have the redder $U-V$ color at $M_* > 5\times10^9 M_\odot$, while most galaxies show blue color and there is only weak (or no) correlation between stellar mass and $U-V$ color at lower-mass region (dashed line and dotted line in Fig. 1). These results about the stellar mass dependence of color distribution are consistent with the results for galaxies in the present universe derived from the large surveys such as SDSS [2].

Further, we estimated the degree of evolution of the $U-V$ color distribution as a function of stellar mass, and found that the rest-frame $U-V$ color distribution of low-mass galaxies becomes gradually bluer with redshift, while the relation between the stellar mass and rest $U-V$ color of galaxies with $M_* > 5\times10^9 M_\odot$ does not seem to change significantly.

The blue $U-V$ color of the low-mass galaxies indicates that active star formation occurs in these galaxies and that their average stellar age is relatively young. Since most of the galaxies with $M_* < 5\times10^9 M_\odot$ have such blue $U-V$ colors at any redshift between $z\sim0.3$ and $z\sim2.7$, these galaxies have a relatively long characteristic timescale of star formation (or recurrent star formation activities with short duty cycle timescale such that these galaxies keep blue color). Their bluer color of galaxies at higher redshifts indicates that their average stellar age is younger. We found that the color prediction from the simple constant star formation rate model with formation redshift of 4 can reproduce the rest $U-V$ color distribution of low-mass galaxies at each redshift relatively well [1].

From these results, we guess that the low-mass galaxies continue to form stars at relatively constant rate since relatively early epoch ($z\sim4$ or so), while the galaxies with high stellar mass have been suppressed their star formation activities at early evolutionary stage and their average stellar age became higher.

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Okayama Astrophysical Observatory Project: Toward Clarifying the Origin of the Abundance Peculiarities in Planet-Harboring Stars

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The project "Spectroscopic Study of Planet-Harboring and Related Stars (PI: Y. Takeda)" was carried out in 2000–2003 at Okayama Astrophysical Observatory by using the new HIgh-Dispersion Echelle Spectrograph (HIDES), with aims of confirming the existence of abundance peculiarity (e.g., metal-rich tendency) reported for planet-harboring stars and clarifying its origin.

In carrying out this project, we paid special attention to (1) observing a sufficient number of non-planet-harboring stars to be used as standard stars, and (2) realizing the high-precision determination of relative abundances, in view of the fact that delicate abundance differences are involved with this problem. We eventually obtained high-dispersion specra of 160 stars (including ~ 30 planet-harboring stars) in three specral regions of green–yellow, red, and near-IR. These data were made open to the public at the ftp site [1] of the Astronomical Data Center, NAOJ, in order to provide anyone an opportunity to use our data as reference standards [2]. In addition, the atmospheric parameters ($T_{\rm eff}$, $\log g$, $v_{\rm t}$, [Fe/H]) of these 160 program stars were spectroscopically determined by using the equivalent widths of Fe I and Fe II lines, and discussed in detail in comparison with the published values in the literature [3].

Based on these data, several studies related to the photospheric abundances of planet-host stars were carried out with successful results described as follows:

— It was confirmed that stars with planets tend to be metal-rich (though not a few exceptions exist) compared to those without planets [3].

— A detailed investigation on the photospheric lithium abundances revealed that a difference is observed between planet-harboring and non-planet-harboring stars only in the narrow $T_{\rm eff}$ region of 5800–5900 K, in the sense that Li tends to be deficient in the former compared to the latter. This implies that some mechanism of reducing the photospheric Li, which is related to the existence of planets, may have acted in this narrow "transition" region where the Li abundance shows a large dispersion and thus may be sensitive to any external effect [4].

— We carried out an extensive abundance study on the representative volatile elements, C, N, and O, and found that the abundance ratios of these elements with respect to Fe (the representative of refractory metals) are essentially indiscernible between planet-host stars and non-planet-host stars. This conclusion may lend support to the "primordial" interpretation (i.e., planet-harboring stars tend to form more easily from comparatively metal-rich gas), rather than the hypothesis of "acquired"characteristics due to the mixing of solid planetesimals (self-enrichment), as the explanation for the origin of their metal-rich tendency [5].

— With the help of a newly developed efficient method for establishing the differential parameters between two similar stars with very high accuracies, the differences between the two components (A and B) of 16 Cyg were studied in detail, where B is known to harbor a planet while A is not. It was then found that the [Fe/H] values in these two components are essentially the same to a precision of within 0.01 dex. This conclusion contradicts the recent report of the USA group, who claimed the detection of a small but significant difference of 0.03 dex in favor of the "acquired" hypothesis (see above)[6].

After the completion of the project mentioned above, another new OAO project "Search for Extrasolar Planets around G-giant Stars (PI: B. Sato)" started since 2004, which aims at detecting planets by monitoring radial-velocities of evolved G-giant stars with an ultimate purpose of studying the planet-formation mechanism around intermediate-mass stars [7]. This project has already yielded a successful result of detecting a new planet-harboring G-giant HD 104985. Since it will become an important task in the near future to discuss the abundance characteristics of planet-harboring G-giants, we carried out an extensive abundance study on 57 G-giants (the first sample of the monitoring targets), and found the following results [8].

(i) The abundances of C, O, Na show appreciable signs of anomaly presumably caused by mixing of the dredged-up H-burning products, and thus are not adequate for discussing the primordial compositions.

(ii) The abundance of Fe tends to be slightly subsolar on the average. Since this tendency is typically seen for stars which were A-type main-sequence stars in the past, there is a possibility that these stars might have been metal-poor λ Boo stars while a part of their abundance anomaly still retained without being completely erased.

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CCD Centroiding Experiment for JASMINE (Japan Astrometry Satellite Mission) and ILOM (In-situ Lunar Orientation Measurement)

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INTRODUCTION

JASMINE and ILOM are space missions which are in progress at the National Astronomical Observatory of Japan. JASMINE will measure trigonometric parallaxes, positions and proper motions of stars with the precision of 10 microarcsec in order to obtain more accurate data than we have ever had. ILOM will also measure the positions of stars in order to obtain the lunar physical libration and the free librations directly from the lunar surface. Both projects use a common astrometric technique to obtain precise positions of stars. In order to accomplish this aim, we must determine the accurate center of star images on the detector. In order to determine the centers of stars, an image of the point source must be focused onto the CCD array with a spread of a few pixels. The distribution of photons (photoelectrons) over a set of pixels enables us to estimate positions of stars with accuracy of sub-pixel. We modify the algorithm to estimate the real positions of stars from the photon weighted mean, which is originally developed by the FAME (Full-Sky Astrometric Mapping Explorer) group. Then we experiment whether we obtain the sub-pixel accuracy of positions of stars by using our algorithm [1].

ALGORITHM

In order to estimate the precise distance of two point sources in image frames to sub-pixel accuracy, the following algorithm is proposed. Here, we show the algorithm used in this experiment. Before the analysis, each image frame is bias subtracted and flat fielded.

First of all, we pick up two stars to measure the distance. Next we seek the pixel in which a number of photons is maximum in each star. Then we pick up a square subset of 5×5 pixels around the peak pixel of each star image. Accordingly, the number of photons is the maximum values at the center of pixels in both two stars. Only the pixel values of the two subsets are used to measure the distance of the two stars. We calculate the photon weighted mean of each star.

The photon weighted means (x_c, y_c) are different from the real positions (x_a, y_a). Here, we assume that the difference between the photon weighted mean and the real position is proportional to the deviation of the photon weighted mean from the center of the pixel.

$$x_a - x_c = kx_c, \quad (1)$$

where k is a coefficient for the correction of the position of a star.

We calculate parameters, k, by using the least square method. Then we obtain the real position x_a from the estimated parameter, k.

RESULTS

We have taken twenty image frames by sliding the CCD array. The interval of sliding is 1μm, that is, twenty steps correspond to 1 pixel. From these twenty image frames, we estimate the distance of two stars, star1 and star2, using the algorithm shown above. An image of the point spread function (PSF) of a star is focused onto the CCD array with a spread of about three pixels using our equipment. According to the results from the experiment, the variance of the estimated distances of two stars is about 1/300 pixel, that is, the error of the estimation is 1/300 pixel for one measurement, which is almost ideal one given by the Poisson noise of photons.

We also investigate accuracy of estimation with a different size of PSF, using a different lens system. An image size of the PSF is about 1 pixels. In this case also, the accuracy of estimation is about 1/300 pixel.

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VLBI Observations of Narrow Bandwidth Signals from the Spacecraft

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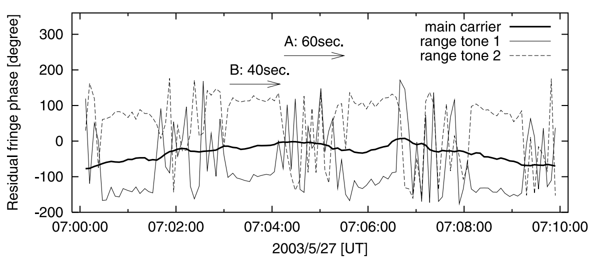

Figure1: The residual fringe phases of the main carrier wave and two range tones for USUDA-KASHIMA baseline.

Gravity measurement of the Moon is one of the methods to know the internal structure, and gravity field has been investigated by Doppler measurement. However, the gravity field of the rim of the Moon was not clearly investigated like the near side because the Doppler measurement is only sensitive to the direction of the line of sight (LOS). In contrast, VLBI measurement is sensitive to the direction perpendicular to LOS. So, we apply VLBI (very long baseline interferometry) technique in VRAD (the differential VLBI Radio sources) mission of Japanese lunar exploration project SELENE (SELenological and ENgineering Explorer) in addition to a conventional 2-way Doppler and newly applied 4-way Doppler measurement. In association with this plan, we have developed a narrow bandwidth sampling and recording system for VLBI and a correlation software and conducted VLBI observation of Japanese explorer Nozomi to confirm the performance and capability of these system and software. The VLBI stations involved in this observation were USUDA, KASHIMA, and MIZUSAWA. In ranging mode, Nozomi transmitted a main carrier wave and two range tones with frequencies of 515kHz apart from that of the main carrier. So we record these three signals for group delay analysis.

As a result of software correlation, the residual fringe phases (RFP) of the main carrier wave in each baseline were continuously obtained at every 1.3 seconds as shown in Fig.1. In contrast, the RFP of two range tones were obtained only for the USUDA-KASHIMA baseline because their SNR were far less than that of the main carrier wave. The SNR of range tones were also decreased when the ambiguity tones were added to the downlink signal, and the RFP were not obtained during this period (A in Fig. 1). Therefore the group delay analysis could only be carried out during the period B in Fig. 1.

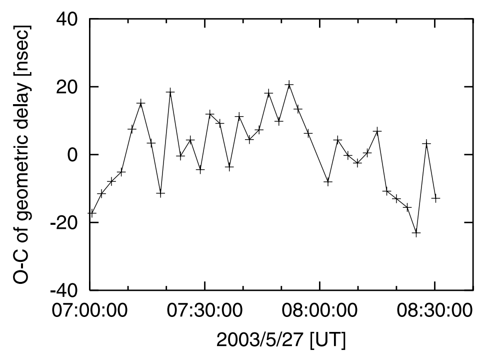

Figure2: The difference between the geometric delays in this VLBI observation and those calculated from the orbital motion estimated from the range and Doppler measurements.

Figure 2 shows the difference between the geometric delays derived by the group delay analysis and the geometric delays determined by the range and Doppler measurements. The RMS of them is 13 nsec. This result is in consistency with the error expected from the SNR of the range tone, which is 19 for 40 seconds integration in average. From this results, it could be expected that if the SNR of the range tones are as large as the main carrier wave and the frequency intervals are 20MHz, the accuracy of the position of Nozomi would be improved to be less than 1.4 km. This accuracy would satisfy the requirement of the orbit determination of the spacecraft (s/c).

We suppose the feasibility of the VRAD from the result of Nozomi considering the C/N of each observation. In VRAD, three carrier waves in S-band and one in X-band will be received to obtain the precise phase delay. In order to obtain the phase delay without the cycle ambiguity, the phase error of the RFP are required to be less than 4.3 degrees. From the result of this observation, the requirement of VRAD would be achieved by integrating the RFP for 12 seconds. This result indicates that the position of the s/c around the Moon will be determined within an error of 20cm.

These result reveal a capability of precise three-dimensional positioning of an s/c and give us a new possibility for next deep space mission.

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Determination of the Equation of State of the Universe Using ~ 0.1 Hz Gravitational Wave Detectors

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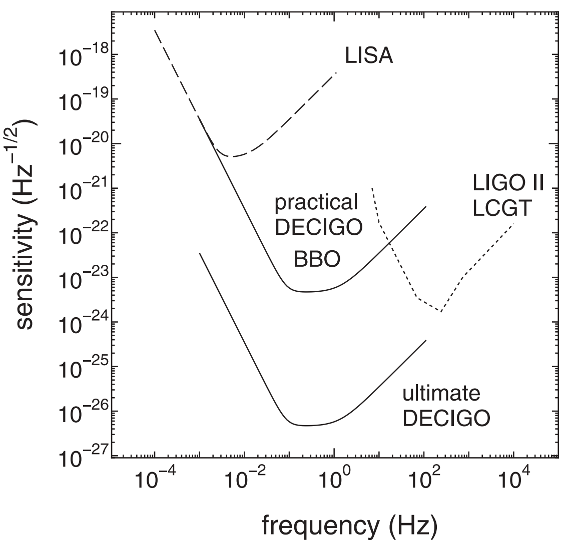

Figure1: Sensitivity of DECIGO/BBO.

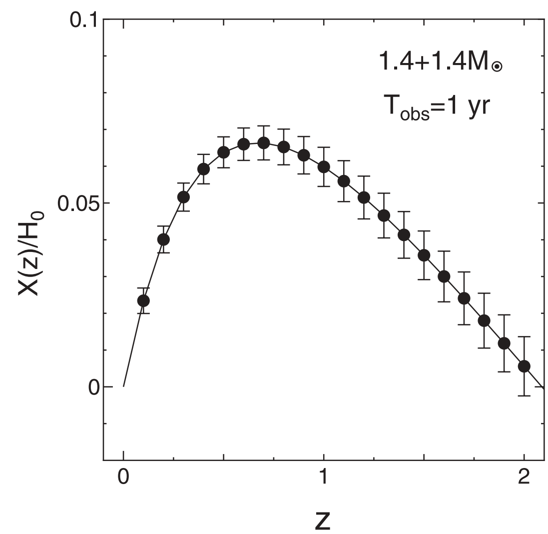

Figure2: The acceleration parameter $X(z)$ as a function of the redshift. The solid curve represents the case of ΛCDM cosmology ($H_0 = 75$ km/sec/Mpc, $\Omega_m = 1 - \Omega_\Lambda = 0.3$). The filled circles and the error bars indicate the mean values of $X(z)$ and the estimation errors (1σ) for NS/NS binaries ($M_1 = M_2 = 1.4M_\odot$) in bins of width $\Delta z = 0.1$ bins.

Laser interferometers have begun to search for astrophysical gravitational wave sources over a broad frequency band. For the higher frequency band $10 - 10^3$ Hz, ground-based interferometers such as LIGO, TAMA are currently in operation. For the lower frequency band $10^{-4} - 10^{-1}$ Hz, the space-based interferometer LISA (the Laser Interferometer Space Antenna) should be launched around 2014. To fill the frequency gap for the range $10^{-2} - 10$ Hz between the frequency of the ground-based detectors and LISA, a space-based decihertz laser interferometer is planned to be constructed sometime around 2020. This detector is called the DECIGO (DECihertz Interferometer Gravitational wave Observatory) by the Japanese group [1] and the BBO (Big Bang Observer) in the NASA SEU 2003 Roadmap “Beyond Einstein.”

The major scientific objectives of the decihertz antenna are as follows: (i) To observe the primordial gravitational wave background. (ii) To detect $\sim 10^5$ chirp signals of coalescing binary neutron stars and stellar mass black holes per year. By analyzing the signals from these binaries at cosmological distances, it may be possible to determine the expansion rate of the universe and the equation of state for dark energy [1]. (iii) To observe the merger of intermediate mass black holes $(10^2 - 10^5 M_\odot)$, which would be helpful to understand the formation and growth history of supermassive black holes. In this report, we discuss the second objective, i.e. the determination of the expansion rate of the universe using a decihertz gravitational wave detector [2].

We plot the sensitivity of the practical DECIGO and BBO in Fig. 1. We also plot that of LIGO II (or LCGT). The sensitivity of the ultimate DECIGO is 1000 times better than that of the practical DECIGO ($h \sim 10^{-27}$ at $f = 0.1$ Hz), which is determined by the quantum limit sensitivity [1]. Here, we use the sensitivity curve of the ultimate DECIGO. We consider NS/NS binaries ($M_1 = M_2 = 1.4M_\odot$) at a redshift z as the gravitational wave sources. We assume a 1 yr observation before the coalescence.

The acceleration parameter $X(z)$ is defined by [1]

$$X(z) = \frac{1}{2}\left[H_0 - \frac{H(z)}{1+z}\right], \tag{2}$$

where $H(z)$ is the Hubble parameter at z. We compute the estimation error for $X(z)$ for $z = 0-2$. Fig. 2 displays the acceleration parameter $X(z)$ as a function of z. The solid curve represents the case of ΛCDM cosmology ($H_0 = 75$ km/sec/Mpc, $\Omega_m = 1 - \Omega_\Lambda = 0.3$). The filled circles and the error bars indicate the mean values of $X(z)$ and the estimation errors (1σ) for bins of width $\Delta z = 0.1$. Thus, the cosmic acceleration rate for $z = 0-2$ would be directly determined by a 1 yr observation with the ultimate DECIGO. We also found that a ten year operation of the ultimate DECIGO could determine the cosmic equation of state with 0.06% accuracies, while a one year operation could do so with 3% accuracies.

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Effects of Dust in the Photosphere on the Spectral Classification and Effective Temperature of Brown Dwarfs

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We report the results of near-infrared spectroscopy of brown dwarfs using Subaru [1], and their interpretation [2].

[1]. We have obtained near-infrared spectra of L dwarfs, L-T transition objects, and T dwarfs using the Subaru telescope. The resulting spectra are examined in detail to study their dependence on spectral types. One question is where the methane feature appears: we suggest that it appears at L8 and marginally at L6.5. We have obtained bolometric luminosities of the objects with known parallaxes in our sample, first by integrating the spectra between 0.85 and 2.5 μm, and second by the K-band bolometric correction. The bolometric luminosities obtained by both methods agree well, and this implies that the K-band bolometric correction, which is obtained using the Unified Cloudy Models (UCMs)[2], can be applied to obtain the bolometric luminosities and effective temperatures of the L and T dwarfs with known parallaxes in the literature. The relation between the effective temperature and spectral type derived from the K-band bolometric correction shows monotonic behavior throughout the L-T sequence. However we also noticed that the effective temperature does not change much between L6 and T5 (Fig.1). This indicates that the brown dwarf spectra are not characterized by a single parameter, effective temperature.

[2]. We report an attempt to interpret the spectra of L and T dwarfs with the use of the UCM. For this purpose, we extend the grid of the UCMs to cases of log g = 4.5 and 5.5. The dust column density relative to the gas column density in the observable photosphere is larger at higher gravities, and molecular line intensity is generally smaller at higher gravities. The overall spectral energy distribution (SEDs) are $f_J < f_H < f_K$ in middle and late L dwarfs, $f_J < f_H > f_K$ in early T dwarfs (L-T transition objects), and finally, $f_J > f_H > f_K$ in middle and late T dwarfs, where f_J, f_H and f_K are the peak fluxes at $J, H,$ and K bands, respectively in f_ν units. This tendency is the opposite of what is expected for the temperature effect, but it can be accounted for as the effect of thin dust clouds formed deep in the photosphere together with the effect of the gaseous opacities, including H_2 (collision induced absorption), H_2O, CH_4, and K I. Although the UCMs are semiempirical models based on a simple assumption that thin dust clouds form in the region of $T_{cr} \le T \le T_{cond}$ ($T \approx 1800$K is only an empirical parameter, while $T_{cond} \approx 2000$K is fixed by the thermodynamic data), the major observations, including the overall SEDs and the strengths of the major spectral features, are consistently accounted for throughout L and T dwarfs. In view of the formidable complexities of the cloud formation, we hope that our UCM can be of some use as a guide for future modeling of ultracool dwarfs and for interpretation of observed data of L and T dwarfs.

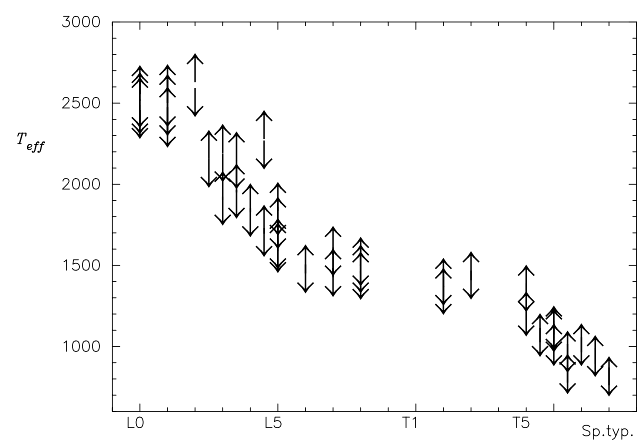

Figure1: Relation between spectral type and effective temperature. There exists a region between L6 and T5, where the effective temperature does not change much despite the drastic change of spectra. This implies that the effective temperature alone is not enough as an atmospheric parameter to specify the spectral type [1]. In order to interpret this behavior, the critical temperature, T_{cr}, which specifies the thickness of the dust layer in the photosphere, needs to be introduced [2].

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Search for 17μm H_2 Pure Rotational Emission from Circumstellar Disks

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We report spectroscopic observations of a pure rotational emission of molecular hydrogen carried out by the Subaru mid-infrared camera and spectrometer COMICS [1].

Studies of circumstellar disks around young stellar objects are important for the understanding of the formation of stars and planets. The presence of giant gaseous planets, which were recently found in some planet surveys, requires a substantial amount of gas in the disk to remain until their cores become massive enough to retain the atmosphere. The survival time of the gaseous component is one of the key issues for the planet formation.

Pure rotational line emission of H_2 at 17.035 μm is radiated from warm gas at $T > 150$ K. Since such warm gas is located at radii of $<$ a few AU from the central star, the H_2 pure rotational line emission is a good tracer of the warm gas in the inner region of the disk and an appropriate tool to focus on the gaseous component in the inner disk region where gaseous planets are formed. However, fluxes of the pure rotational line emissions are generally very weak because of prohibition of the dipole transition.

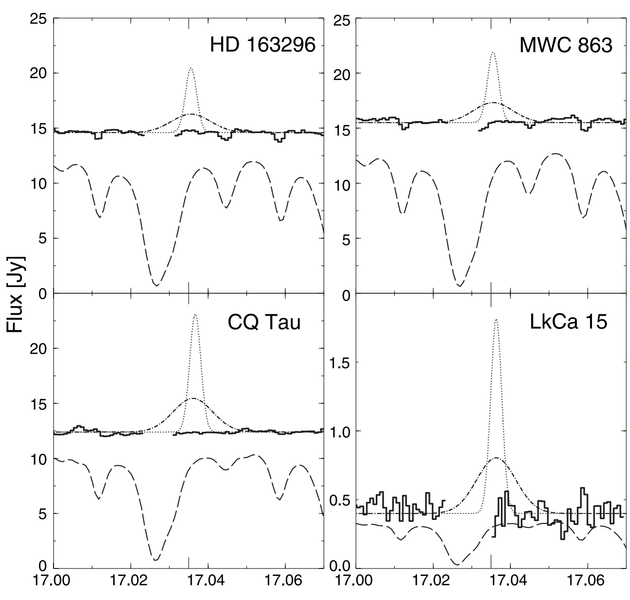

Figure1: (*solid lines*) COMICS spectra of four young stars around the H_2 $S(1)$ line at 17.035μm. (*dotted lines*) Line profiles obtained by the COMICS with a velocity resolution of 60 km s^{-1}, when the widths of the emission lines from the objects are sufficiently narrower than the resolution. Integrated fluxes of these line profiles correspond to those of the H_2 $S(1)$ line emissions detected by the *ISO* [2].

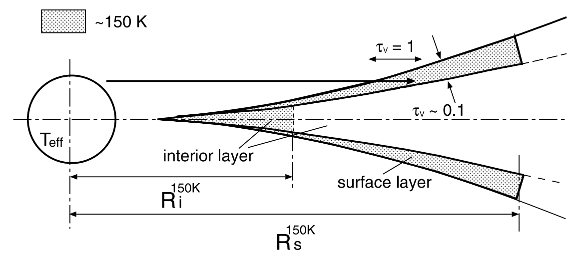

Figure2: Schematic view of the flared passive disk model [3]. The warm region in the surface layer is extended to radii larger than that of the interior layer.

Detection of the pure rotational emissions toward the directions of 11 young stellar objects with the *Infrared Space Observatory* (*ISO*) was reported by [2]. However, the beam size of the *ISO* is much larger than the disk sizes of their targets. Thus, the fluxes measured by the *ISO* could contain the emission from extended components around the young stars.

We carried out spectroscopy observations for the $S(1)$ emission of molecular hydrogen toward disks around young stars, HD 163296, MWC 863, CQ Tau, and LkCa 15, for which the ISO observations detected the $S(1)$ emission. The spectra were obtained with the COMICS with the spectral resolution of $\Delta v \sim 60$ km s^{-1} on the Subaru telescope.

The $S(1)$ emissions of the molecular hydrogen were not detected toward any stars of the present targets (Fig. 1). The present beam size corresponds to a disk radius of 30 to 45 AU at the distances to the objects. If the $S(1)$ emission detected by the *ISO* was arising from the disk region, we should have certainly obtained line profiles in the present higher sensitivity observations. Thus, it can be concluded that the H_2 $S(1)$ emissions detected by the *ISO* do not come from the region within the typical disk sizes for all the objects observed in the present study and are not directly related to the disk mass.

The upper limits of the disk masses estimated from the present observations are significantly lower than the warm molecular hydrogen mass predicted by the passive disk model of [3] (Fig. 2), suggesting that the optically-thick emission from dust dominates in the radiation from the disks in the mid-infrared wavelength.

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Detection of a deep 3-μm absorption feature in the spectrum of Amalthea (JV)

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In addition to the Galilean moons, Jupiter has two other types of satellites: four small inner moons orbiting Jupiter within the orbit of Io, the inner most Galilean satellite, and at least fifty five small outer moons outside the orbit of Callisto, the outer most Galilean satellite. All the outer satellites have orbits that reveal that they must have been captured by Jupiter during or after the formation of the planet.

The origin of the four small inner moons remain a mystery, however. They have orbits compatible with the hypothesis that they formed in orbit around Jupiter like the Galilean moons. On the other hand, their small irregular shapes and their comparatively low reflectivity and low densities resemble asteroids and suggest that they were captured by Jupiter's gravitational pull just like the outer moons.

We had obtained the first infrared spectrum of two of Jupiter's small inner moons, Amalthea and Thebe [1]. To obtain a spectrum over a wide range of infrared wavelengths, we used two instruments on two telescopes. For high resolution spectroscopy at wavelengths longer than 3 μm, the Infrared Camera and Spectrograph on the Subaru telescope was used. For shorter wavelengths, we used SpeX on the NASA IRTF, which has broad wavelength coverage.

A deep, broad absorption feature is seen at 3 μm in the spectrum for the trailing side of Amalthea (Fig. 1). The depth of this absorption feature is 65 $\pm$ 13 % of the continuum level at 2.5 μm. This 3-μm absorption feature is an important diagnostic of the composition of Amalthea's surface. The absorption band near 3 μm indicates the hydroxyl (O–H) stretch fundamental or the first overtone of the water (H_2O) stretch modes. The most likely location of this water is within water containing hydrous minerals. Such minerals typically form in low temperature environments.

According to current formation models of the jovian satellites [2], temperatures of the circumjovian nebula at the present location of Amalthea exceeded 800 K. This model temperature is too high to form hydrous minerals. Therefore our results suggest that Amalthea either formed in a cooler region of the circumjovian nebula at a larger distance than its present orbit, or that it is a product of early capture from a heliocentric (asteroidal) orbit.

A possible scenario is that Amalthea, and possibly Thebe and two other inner satellites Metis (JXVI) and Adrastea (JXV), were satellite embryos that formed near Callisto and then migrated into inner region. Because the temperature of the circumjovian subnebula near Callisto was cold for hydration, accretion or tidal heating may have occurred on Amalthea.

Another possibility is that Amalthea is a captured planetesimal. Most of the asteroids with heliocentric distances near Jupiter are D-types. Thus, it is likely that planetesimals with the same origins as D-type asteroids were captured into the early jovian system, and spiraled inward under gas drag. Amalthea and the other three satellites can be the remnants of these planetesimals.

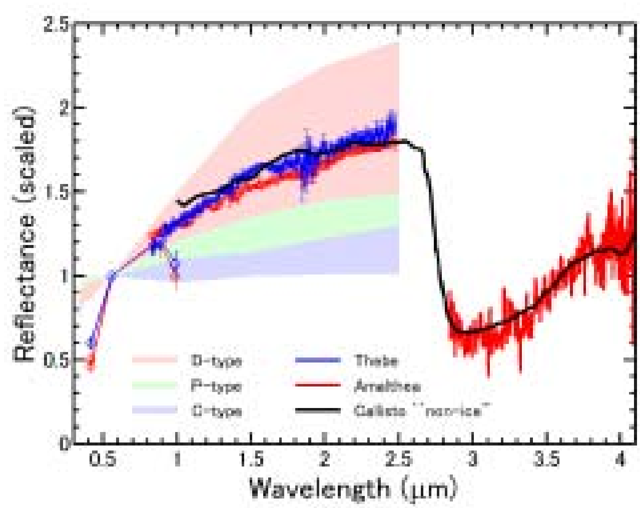

Figure1: A Comparison of the Reflectivity of Amalthea, Thebe, Callisto and Asteroids. Amalthea (red line) and Thebe (blue line) have reflective spectra similar to those seen in regionsof Callisto where there is little water ice (black line). The dip in the spectrum around 3 μm indicates the presence of water containing minerals. The spectrum at wavelengths shorter than 2.5 μm is similar to "D-type" asteroids (pink region), a type of asteroid common in the vicinity of Jupiter's orbit around the Sun.

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Near-Infrared Unidentified-Line Morphology of the Planetary Nebula NGC 7027

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In the near-IR K window, there remain some emission lines to be unidentified. The two strong unidentified lines near 2.199 and 2.287 μm (hereafter UIR1 and UIR2, respectively) were first detected in NGC 7027 [1], [2], and have since been seen in other Planetary Nebulae (PNe). However, they had not been identified for more than two decades. Both UIR1 and UIR2 fall near the wavelengths of vibrationally excited H_2 lines. These spectral coincidences prevent us from identifying of them. Also, unfortunately, the lines may have been mistaken for these “high-v” H_2 lines, which are important indicators of fluorescent excitation.

Here, we present spatial information about UIR1 and UIR2 of NGC 7027 [3], which will bring us new information about the nature of their origins. The spectroscopic data of NGC 7027 were obtained using Super-OASIS, mounted on the 188 cm telescope at Okayama Astrophysical Observatory.

Fig. 1 shows the spatial distributions of emission lines, along the east-west direction across the central position of NGC 7027. The distributions of the ionized gas are very similar to that of the continuum emission, whereas, that of H_2 differs from that of any other lines, because the H_2 line is emitted from the periphery of the ionized region. From the figure, one can easily recognize that UIR1 and UIR2 originate in ionized elements.

The UIR1- and UIR2-emission regions are larger than that of HeII, implying that the ionization potentials of the carriers of UIR1 and UIR2 are lower than that of HeII. In the figure, the sizes of the UIR1- and UIR2-emission regions appear to be larger than that of Brγ, especially at the west side of the western peak. It means simply that the ionization potentials of their carriers are lower than that of Brγ.

However, a similar appearance is seen in HeI 2^1P–2^1S, though its ionization potential is higher than that of Brγ. Beyond a critical density, the triplet 2^3S (metastable) HeI level is preferentially collisionally excited, and as a result, the strength of a 2^1P–2^1S transition is enhanced [4]. We assume that electron-density is high at the edge in the ionized region, which results in the HeI 2^1P–2^1S flux enhanced at the edge of the nebula.

We examined the flux-ratio distributions of HeI, UIR1, and UIR2, relative to Brγ, as an index of collisional excitation (see [3] for more details). The ratios of UIR1 and UIR2 to Brγ are found to be somewhat high at the edge of the ionized region. Therefore, we speculate that the flux-enhancements of UIR1 and UIR2 (and the “expansion” of their emission regions) are caused by contamination of collisional excitation, not by lower ionization potentials of their carriers.

We conclude that the ionization potentials of the carriers of UIR1 and UIR2 are lower than that of HeII, and comparable to or slightly higher than that of Brγ. We also note that their carriers are excited by collisions in part, particularly at the edge of the ionized region. Our conclusions support the recent proposals for the identifications of them [5], [6]. Further theoretical studies would be helpful to see how much collisions contribute to their excitation mechanisms. They will provide useful information to identify UIR1 and UIR2.

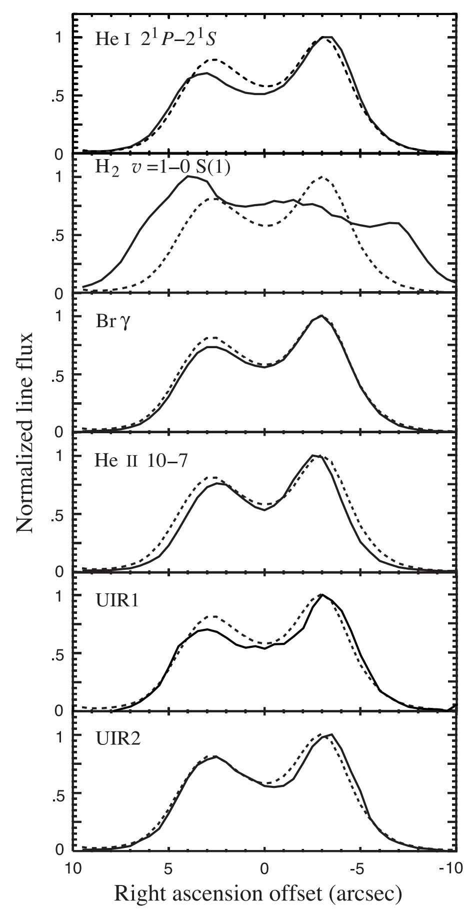

Figure1: Spatial distributions of selected emission lines, along the east-west direction over the central position of NGC 7027. The dashed lines in each panel show the distribution of the 2.16-μm continuum emission.

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A Subaru Search for Lyα Blobs in and around the Proto-Cluster Region at Redshift z=3.1

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Lyα blobs (LABs) are physically extended Lyα nebulae larger than $\sim$100 kpc without strong radio sources. The physical origins of LABs may be (i) photo-ionization by massive stars, or by active galactic nuclei, or (ii) cooling radiation from gravitationally heated gas, or (iii) shock heating by starburst driven galactic superwind. Although LABs are expected to be useful to examine the important physical processes of galaxy formation, there have been only a few LABs discovered in proto-cluster regions at high redshift.

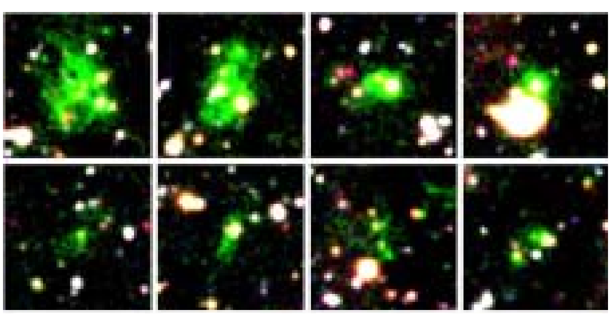

Figure1: Color images of LABs. Green shows Lyα emission line. Each panel is $25''$ square (190kpc at z=3.1 in physical scale) with the candidate centered. The two left-upper images show the previously known giant LABs.

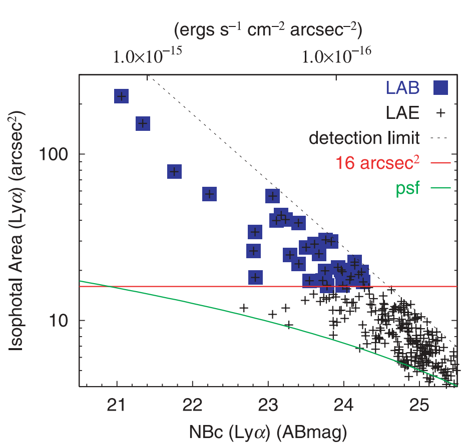

Figure2: Distribution of isophotal area and magnitude on the continuum subtracted NB image for emitter candidates. We selected the objects with the isophotal area larger than 16 arcsec^2 (red line) as candidates of LABs (blue squares). The green line shows the expected value for point sources. The dotted line shows detection limit.

We searched new LABs in and around the proto-cluster region at redshift $z = 3.1$ in the SSA22 field [1]. We took panoramic ($31' \times 23'$) and deep narrow-band (*NB*497; 4977Å/77Å) imaging of the proto-cluster using the prime-focus camera on the Subaru telescope. We identified 35 robust candidate LABs, which are larger than 16 arcsec^2 in isophotal area and brighter than 0.7×10^{-16} ergs s^{-1} cm^{-2}, including the two previously known giant LABs (see Fig. 1 and Fig. 2).

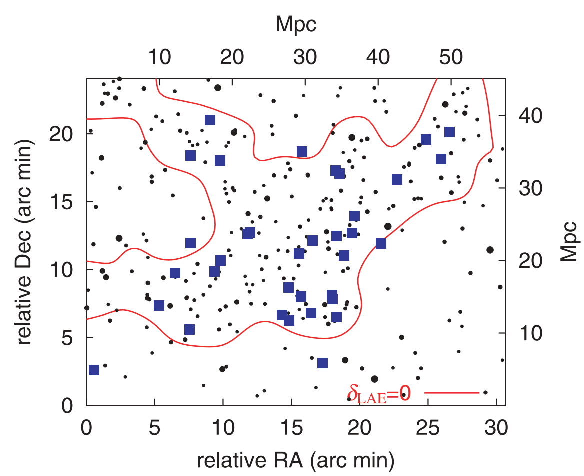

Figure3: Sky map of Lyα blobs (LABs, blue squares) and relatively compact Lyα emitters (LAEs, black points). Red line shows average local surface density of LAEs.

It was shown that the two previously known giant LABs are the most luminous and the largest ones in our survey volume of 1.3×10^5 Mpc^3. We revealed the internal structures of the two giant LABs and discovered some bubble-like features, which suggest that intensive starburst and galactic superwind phenomena occurred in these objects in the past (see Fig. 1). These 35 LABs show a continuous distribution of isophotal area and emission line flux (see Fig. 2). The 90% of these LABs are located inside the high surface density region of relatively compact Lyα emitters (see Fig. 3). Our results suggest that LABs larger than several tens kpc may be common phenomena in dense environment at high redshift [2].

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Spiral Structure in the Disk around AB Aur

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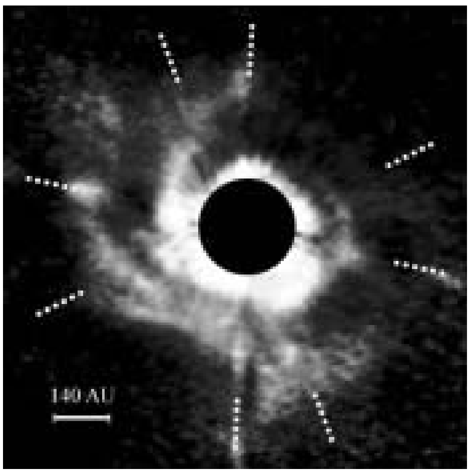

Figure1: H-band image of the circumstellar structure after the PSF subtraction. The surface brightness is multiplied by the distance squared from the center for display so that the fainter outskirts can be viewed with a high contrast. Directions where the spider patterns affect the image are indicated by dashed lines. The inner area of $1''.7$ diameter ($r < 120$ AU, *filled black circle*) is photometrically unusable and is masked. North is up and east is to the left.

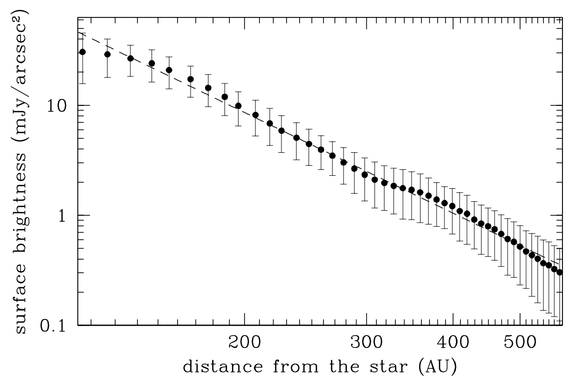

Figure2: Azimuthally averaged radial profile of the surface brightness (*filled circles*) after the assumed inclination of $i = 30°$ was corrected. *Dashed line* indicates a power-law fit with an index of -3.0 to the brightness over the radial range between 120 and 580 AU. [1]

We report the detection of a spiral structure in the protoplanetary disk around AB Aur [1].

Investigation of protoplanetary disks has primary importance to understand the formation of planetary systems. In order to constrain the formation mechanism, it is indispensable to study the spatial structure of a disk, since it reflects the physical environment where planets are formed. However, we have little knowledge about the real disk morphology because of the observational difficulty. High-spatial-resolution and high-contrast are required for obtaining the image of a small disk structure in the vicinity of a central bright star. The number of resolved disks is therefore quite limited at present.

AB Aur ($d = 144^{+23}_{-17}$ pc; A0 Ve, [2]) is one of the best-studied Herbig Ae/Be stars, with a mass of 2.4±0.2 $M_\odot$ and an age of 4±1 Myr. The circumstellar structure around AB Aur consists of two components; a compact rotating disk of 450 AU radius observed in CO [3] and an extended ($>$ 1000 AU) envelope detected in the optical [4]. The *HST* optical observations revealed the inner part of the circumstellar material with a spiral band structure [4], although the spiral pattern was not very clear possibly because the scattering emission from the more extended material mingles with it.

The H-band (1.65 μm) observations of AB Aur were carried out in 2004 January, using the stellar coronagraphic camera CIAO on the Subaru Telescope. The AO was utilized, giving the spatial resolution of $0''.1$. We occulted AB Aur with a mask whose diameter was $0''.6$. In order to detect the faint structure buried in the bright halo of the central star, we observed the reference star without any circumstellar material, then subtracted the image of the reference star from that of AB Aur.

The obtained image shows extended emission seen from the edge of the occulting mask ($r \sim 60$ AU) out to the radius of 580 AU ($= 4''.0$). The radial power-law dependence is $r^{-3.0\pm0.1}$, which is steeper than that of r^{-2} for the optical nebulosity. The steeper slope in the NIR suggests that the detected light originates mainly from the disk itself without significantly contaminated by the scattering emission in the envelope.

Of particular interest is a double spiral structure detected at r =200–450 AU. We identified four major spiral arms, which are trailing if the brighter, southeastern part of the disk is the near side. Since the companion stars have not been found around AB Aur, the spiral structure could be formed via gravitational instability. The Toomre's Q parameter can be around 2 at the disk outer edge, within the large uncertainty of dust opacity etc. The weak instability, maintained for millions of years by continuous mass supply from the envelope, might explain the presence of the spiral structure at the relatively late phase of the pre-main-sequence period.

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Reverberation Radius of the Central Dust Hole in NGC 5548

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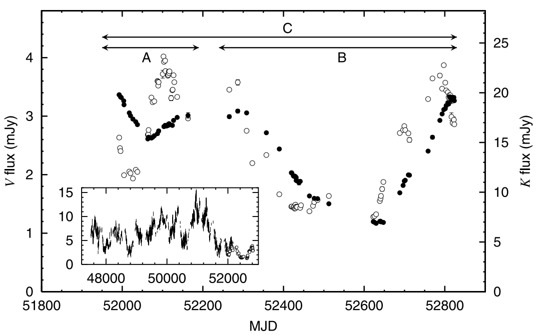

Figure1: Our V (open circles) and K (filled circles) light curves of NGC 5548 nucleus from 2001 March to 2003 July. The lag time between V and K variations was calculated for the data taken during each of the periods A, B, and C. *Inset:* Our V light curve (open circles) of NGC 5548 nucleus, together with the optical continuum (λ5100Å) data for 13 years by International AGN Watch consortium (vertical lines).

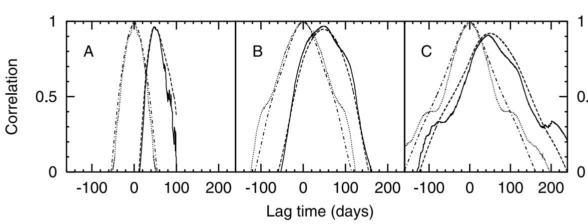

Figure2: The CCFs between observed V and K light curves and the ACFs of observed V light curves for each of the monitoring periods A, B, and C. Solid lines and long-dashed lines show CCFs calculated by two different methods based on linear interpolation scheme. Dot-dashed lines and short-dashed lines show ACFs.

We report the first measurement of lag time between the V and K light curves for NGC 5548 [1].

NGC 5548, which is a bright, nearby ($z = 0.017$) Seyfert 1 galaxy, has been a target of intensive spectroscopic monitoring observations at ultraviolet and optical wavelengths for the purpose of reverberation mapping of the broad emission-line region. We carried out most intensive multicolor monitoring observations in the optical and near-infrared wave-bands for this object using the multicolor imaging photometer mounted on the MAGNUM telescope [2]. During a monitoring period from 2001 March to 2003 July, the $V(0.55\mu\text{m})$ and $K(2.2\mu\text{m})$ fluxes separately reached a minimum state twice. A delayed response of light variations in the K band to those in the V band is seen in Fig. 1.

The lag time between the V and K light curves is evaluated by calculating their cross-correlation functions (CCFs). Fig. 2 shows the CCFs for two separate periods, each containing one clear minimum state, such as (A) 2001 March - 2001 September and (B) 2001 December - 2003 July, and also for our entire monitoring period of (C) 2001 March - 2003 July. Generally, a time shift τ_{peak} which gives a peak value of the CCF is taken for the lag time. To estimate the uncertainty of the lag time, Monte Carlo simulations were performed to generate a large number of artificial V and K light curves. The CCFs for any pairs of such light curves were calculated to give the frequency distribution of τ_{peak} from which a range of lag time is derived. In the simulation, we introduced a new technique of simulating the light curves to fill in the sampling gaps between the observations. The measured lag time is $\Delta t = 48^{+3}_{-2}$ days in the first minimum state (period A), $\Delta t = 47^{+5}_{-6}$ days in the second minimum state (period B), and $42 - 53$ days for the whole monitoring period of C.

The absolute V-magnitude of the nucleus during the monitoring period is estimated as $M_V = -18.35$ to -19.60, using the known redshift and the apparent magnitude observed in the monitoring period. This estimate of M_V against Δt is located close to the correlation line of $L \propto (\Delta t)^2$ shown in lag-time measurement of other objects in the literature together with our early result for NGC 4151 [3]. Such a correlation is derived from a theory of dust reverberation, in which the ultraviolet and optical radiation from the central energy source of NGC 5548 is absorbed by the surrounding dust to be reprocessed to the near-infrared thermal radiation at a temperature corresponding to the sublimation temperature of the dust. Furthermore, the lag time for hot dust is compared directly with those for the broad emission lines of lower ionization reported to date for NGC 5548, which the lag time for such dust reverberation is found to be longer, indicating that the inner radius of the dust torus corresponds to an outer edge of the broad emission-line region in NGC 5548.

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Gravitational Waves from Coalescing Supermassive Black Hole Binaries in a Hierarchical Galaxy Formation Model

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We investigate the expected gravitational wave emission from coalescing supermassive black hole (SMBH) binaries in the mass range of $10^6 - 10^9 M_\odot$ resulting from mergers of their host galaxies. When their host galaxies merge, SMBHs sink toward the center of the new merged galaxy and form a SMBH binary subsequently. Then, it will evolve to the gravitational wave emitting regime and begin inspiraling, eventually coalesces with a gravitational wave burst. An ensemble of gravitational waves from a number of inspiraling SMBH binaries can be observed as a gravitational wave background radiation (GWBR). Future space interferometers such as the *Laser Interferometer Space Antenna* (*LISA*) might detect GWBR and gravitational wave bursts.

In order to estimate the amplitude of the expected GWBR owing to inspiraling SMBH binaries and bursts rates owing to the SMBH binary coalescence events, we employ a semi-analytic model in which the SMBH formation model is incorporated into the galaxy formation model based on the hierarchical clustering scenario [1], [2]. In our model, it is assumed that a SMBH is fueled by accretion of cold gas during a major merger of host galaxies and that SMBHs coalesce simultaneously when host galaxies merge. Fig. 1 shows the black hole mass functions in our model. The predicted mass function is quite consistent with the observation.

We plot the spectrum of GWBR from binaries in different redshift intervals (Fig. 2(a)) and in different total mass intervals (Fig. 2(b)). The GWBR spectrum for $f \leq 1\mu$Hz has a characteristic strain $h_c(f) \sim 10^{-16}(f/1\mu\mathrm{Hz})^{-2/3}$. From these figures, we have found that the GWBR mainly comes from inspiraling SMBH binaries with total mass $M_{\rm tot} \geq 10^8 M_\odot$ at $0 < z < 1$. Therefore, the GWBR can be used as a probe of inspiraling SMBH binaries at low redshift. Fig. 3 shows that the expected region for signal of gravitational wave bursts and the instrumental noise threshold for *LISA*. We have also found that *LISA* might detect intense bursts of gravitational waves owing to the SMBH coalescence events at a rate $0.1 \sim 1.0\,\mathrm{yr}^{-1}$ and that the main contribution to the rate comes from SMBH binary coalescence events at high redshift $z \geq 2$. Comparing these predictions with observations in future, we can put a stringent constraint on SMBH formation and evolution models.

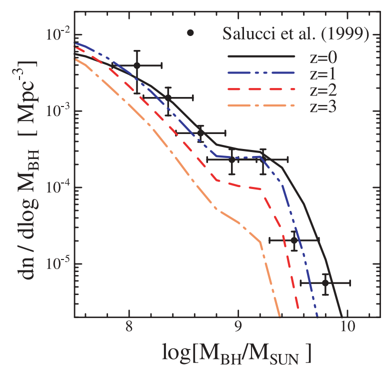

Figure1: Black hole mass function of the model at a series of redshifts [2]. The symbols with errorbars are the observed black hole mass function at $z = 0$ [3].

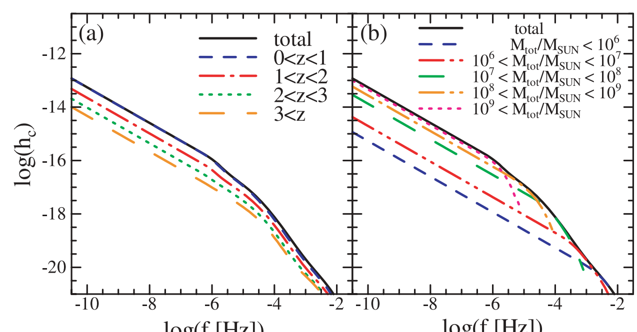

Figure2: Spectrum of gravitational wave background radiation, $h_c(f)$, from SMBH binaries in different redshift intervals (a) and in different total mass intervals (b) [2].

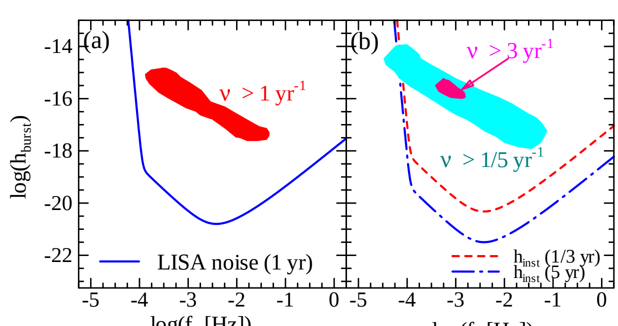

Figure3: Expected signals of gravitational wave bursts from SMBH coalescence [2]. The solid, dot-dashed and the short dashed curves indicate the instrumental noise threshold for 1 year, 5 year and $1/3$ year of *LISA* observations, respectively.

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The origin of light neutron-capture elements in very metal-poor stars

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It is known that the elements heavier than iron are synthesized by neutron-capture processes. However, there still remains unsolved problems on the rapid process (r-process), which is responsible for about half of neutron-capture elements in the solar system. In order to know the nature of the r-process, an effective method is to investigate the abundances of metal-poor stars, because it is believed that the heavy elements of metal-poor stars were supplied only by a few supernavae, and the nucleosynthesis yields from individual processes, including r-process, can be directly estimated from their abundance patterns. We performed high resolution spectroscopy covering light neutron-capture elements (e.g., Sr[$Z = 38$]) to heavy neutron-capture elements (e.g., Eu[$Z = 63$]), and further actinide (Th[$Z = 90$]), for metal-poor stars, and determined their abundances [1].

We have obtained spectra with resolving power of $R =$ 50,000 for 22 objects with the Subaru High Dispersion Spectrograph (HDS). Our abundance analysis confirmed that the abundance patterns of the elements with the atomic number from 56 to 70 are similar in metal-poor stars in our sample, and those are in agreement with the abundance pattern of the solar system r-process component. This result means not only that these heavy elements are synthesized by the r-process, but also that the abundance pattern produced by the r-process is universal.

However, the abundance ratios of the light neutron-capture elements ($38 \leq Z \leq 46$) relative to the heavier ones ($56 \leq Z \leq 70$) exhibit a large dispersion. We here adopt Sr ($Z = 38$) and Ba ($Z = 56$) as representatives of light and heavy neutron-capture elements. Fig. 1 shows the abundance ratios as a function of metallicity. There is a large dispersion close to 2 dex in the abundance ratios at [Fe/H] = –3.

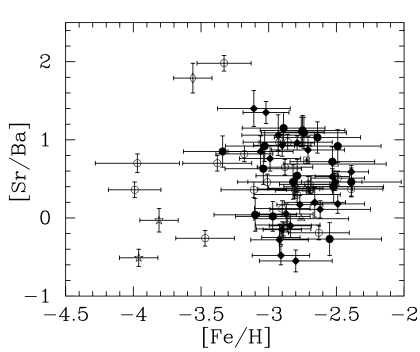

Figure1: [Sr/Ba] as a function of [Fe/H] from previous studies (open circles) and present work (filled circles).

Since our sample shown in Fig. 1 is extremely metal-poor stars, the chemical composition is expected to reflect a small number of nucleosynthesis process. Therefore we show the correlation between Sr and Ba abundances in Fig. 2, ignoring their metallicity dependence. This figure shows that (1) there is no Sr-poor star with high Ba abundance, and (2) the dispersion of Sr abundance is remarkable in Ba-poor stars. This trend can be explained by hypothesizing following two nucleosynthesis process. One is the process which produces Sr and Ba in similar proportions. The elements of heavier than Ba would be synthesized by this process in the early Galaxy (this process is sometimes called as main r-process which is well known so far). The other is the process producing Sr without Ba.

Fig. 2 suggests that the main r-process yields Sr and Ba with the abundance ratio close to unity. Concerning the latter process, recent observational and theoretical studies have suggested its existence. Our observations clearly revealed the nature of this process. This process differs from s-process and main r-process which were known so far, and should be an important source of the light neutron-capture elements in the universe.

In order to understand the nature of this nucleosynthesis process in detail, we quite recently investigated the correlation using the Y, Zr, La, and Eu which can be measured more accurately than Sr and Ba [2]. We are also performing more detailed abundance analysis for a few selected stars that represent this process. These observations will give an important indicator for modeling of this process.

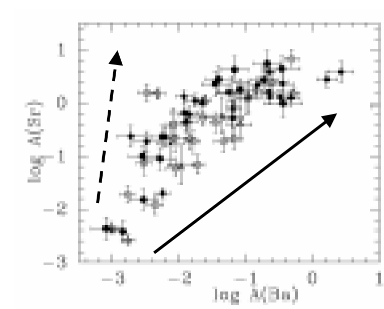

Figure2: Correlation between abundances of Sr and Ba for objects with [Fe/H] $\leq$ -2.5 from same sample in Fig. 1. Solid arrow shows the enrichment of Sr and Ba (main r-process), dashed arrow shows enrichment of Sr (weak r-process).

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The mm-Wave Detection of a Radio Source following the 27 December 2004 Giant Flare from SGR 1806–20

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On 27 December 2004, a giant flare was detected from SGR (Soft Gamma-Ray Repeater) 1806–20 [1], [2]. Soft gamma-ray repeaters (SGRs) are the remarkable transients on γ-ray, which are neutron stars with intense ($\leq 10^{15}$ G) magnetic fields ('magnetars'), and these objects cause giant flares rarely. Four objects were known in all sky until now. SGR 0526–66 and SGR 1900+14 caused an enormous flare in 1979 and 1998, respectively. The present flare was the strongest case in the history of γ-ray observation and saturated almost all γ-ray detectors of astronomical satellites. It is a phenomenon as rare as once for ten years.

On 3 January 2005, a radio counterpart of SGR 1806–20 was identified with the Very Large Array (VLA) at 1.4, 4.9, and 8.5 GHz and reported. The spectrum from these data can be modeled by a power law. Then we promptly observed SGR 1806–20 using the Nobeyama Millimeter Array (NMA) in order to detect the radio counterpart at mm-wavelength and search a spectral break on the radio spectrum. Fig. 1 (left panel) shows the intensity map toward SGR 1806–20 at 102 GHz at 4 January 2005. The delay from VLA to NMA observation is $\sim$8 hours. There is a compact peak with 16.3 ± 5.6 mJy at the map center. This is the first and unique detection of the radio counterpart at mm-wavelength with confidence level of about 3σ. The radio spectrum from 0.2 GHz to 100 GHz on 4 January 2005 was obtained by combination of observations with NMA, VLA, and GMRT (Fig. 2). The radio spectrum can be modeled by a single power law. The best fit spectral index is about -0.6. There is no spectral break on the spectrum.

Continuing observation is necessary in order to monitor the light curve at mm-wavelength of this radio afterglow. However, we could not observe it by bad weather and tight schedule. The follow-up observations were performed at 12 and 13 January. Fig. 1 (right panel) also shows the result. There is no significant peak in the map. The 1σ upper limit is about 3 mJy. The counterpart at 102 GHz was already fade out. We probably confirm a claim from cm-wavelength observations that the radio afterglow fades more rapidly at higher frequency. The result with NMA was published as a part of an international monitoring program in Nature [3].

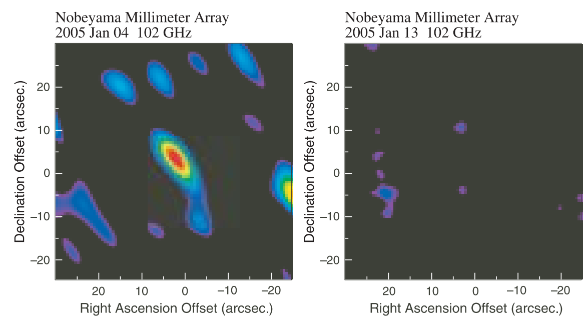

Figure1: Radio map at 102 GHz of SGR 1806–20 with NMA. The epoch of the left panel is 4 January 2005, that of right panel is 13 January 2005.

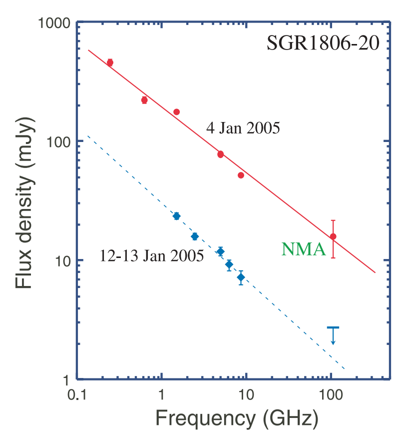

Figure2: Radio spectrum of SGR 1806–20 (reconstructed from Cameron et al. 2005 [3]). Red circles show results on 4 January 2005 with GMRT, VLA, and NMA. Blue diamonds show results on 13 January 2005 with ATCA and NMA. The blue horizontal bar at 102 GHz indicates 1σ upper limit by NMA.

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Results of Gravitational Wave Search with TAMA300 detector

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Since 1999, the Japanese laser interferometric gravitational-wave (GW) detector TAMA300 has performed observations nine times until April of 2005. As a result, 3086 hours of data have been accumulated totally. The detector sensitivity and its stability have been also improved gradually during the observation periods. In this article, we report the current status of several GW signal searches in the TAMA300 data.

Chirp Signals from Neutron Star Binaries

We performed a coincidence analysis to search for inspiraling compact binaries with the LISM detector [1]. LISM is an interferometer originally developed at the Mitaka campus, and then was moved to the Kamioka mine in Gifu prefecture, Japan. The data used for the coincidence analysis is 275 hours long. Both TAMA300 and LISM data were analyzed by matched filtering and candidate events were obtained. If there is a true gravitational wave signal, it should appear in both data with consistent waveforms characterized by masses of stars, amplitude of the signal and the coalescence time. We introduced a set of coincidence conditions of the parameters, and searched for coincident events. This procedure reduces the number of fake events considerably, by a factor of $\sim 10^4$ compared with the number of fake events in the single detector analysis. After imposing the coincidence conditions, we found that the number of selected events is consistent with the number of accidental coincidences produced purely by noise. Thus, we found no evidence of gravitational wave signals. However, we obtained an upper limit of 0.046 events/hour (C.L.=90%) for the galactic event rate within 1 kpc from the Earth.

Burst Signals from Supernova Explosion

Data-analysis targeting burst signals from stellar-core collapse events were also performed [2]. For the analysis, we used an excess-power filter for the extraction of gravitational wave candidates, because precise waveforms are not available. We developed two methods for the reduction of fake events caused by nonstationary noises of the detector. As a result, fake events were reduced by a factor of about 1000 in the best cases. We set an upper limit of 5.0 $\times 10^3$ events/sec on the burst gravitational wave event rate in our Galaxy with a confidence level of 90%.

Ring-Down Signals from Black-Hole Quasi-Normal Mode Oscillation

Gravitational radiation from a slightly distorted black hole with ringdown waveform is well understood in general relativity as a quasi-normal mode oscillation. It provides a probe for direct observation of black holes and determination of their physical parameters, masses and angular momenta (Kerr parameters). For ringdown searches, matched filtering technique is useful. We studied on the matched filtering analysis in realistic gravitational wave searches using observational data [3]. To investigate them, we have performed the matched filtering analysis for artificial ringdown signals which are generated with Monte-Carlo technique and injected into the TAMA300 observational data. With the TAMA300 sensitivity, we found that the detection probability for Galactic ringdown events is about 50% for black holes of masses greater than $20M_\odot$ with SNR > 10. The resolutions for black hole masses and the Kerr parameters are evaluated as a few % and 40%, respectively. They can be improved up to $<$ 0.9% and $<$ 24% for events of SNR > 10 by using fine-meshed template bank in the hierarchical search strategy.

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Intra-day Variation of Sagittarius A* at mm-Wavelengths

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We report our detection of intraday variation of Sagittarius A* at 140 GHz in the 2000 Mar flare using the Nobeyama Millimeter Array (NMA) of the Nobeyama Radio Observatory [1].

Sagittarius A* (Sgr A*) is the compact radio source located at dynamical center of the Galaxy, and is a supermassive black hole with $\sim 4 \times 10^6\ M_\odot$. After its discovery, Sgr A* was observed at many wavelengths, and, however, its emission mechanisms are not yet fully understood. Because this source is embedded in thick thermal material, it is practically difficult to observe its fine structure. The time variability observation is a powerful tool to probe the structure and the emission mechanism, if the variability is intrinsic. Sgr A* time variability at mm-wavelength was reported the first significant flux variation at 80 GHz in 1990 [2], and we have detected a flare in Mar 1998 using NMA [3], [4].

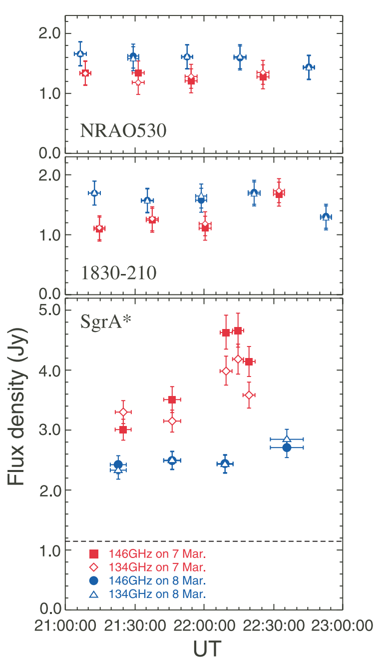

Figure1: Light curves of the Sgr A* flare and the calibrators (NRAO 530, 1830-210) at 140 GHz band on 7 (*red*) & 8 (*blue*) Mar 2000 with NMA [6]. The Sgr A* flux density at 146 GHz (*red filled squares in bottom panel*) increased from 3.5 to 4.7 Jy from 21:45 to 22:15 UT on 7 Mar. The horizontal dashed line is the mean flux density at 140 GHz.

We have performed the monitoring observations of the flux density of Sgr A* from 1996 to 2005 using NMA. The monitoring observations of Sgr A* have been carried out at shot mm-wavelengths (100 and 140 GHz) bands over one to several months on each observable season. We have detected several flares [3], [4], [5]. In particular, we found intraday variation of Sgr A* in the 2000 Mar flare [6] . We detected the about 30% increase in 30 minutes at 140 GHz on 7 Mar 2000 (Fig. 1), and the twofold increase timescale of the flare is estimated to be ~ 1.5 hr. This intraday variation at mm-wavelengths has a similar increase timescale as those in the X-ray and infrared flares (X-ray flare [6], infrared flare [7]) but has smaller amplitude. This short timescale variability suggests that the physical size of emitting region of the flare is compact at or below about 12 AU ($\approx 150\ R_{\rm s}$; Rchwarzschild radius assuming a black hole mass of $4 \times 10^6\ M_\odot$). Our result is consistent with the intraday variation detected at 3-mm using the OVRO mm-interferometer in May 2002 [8]. There is asymmetry in the light curve as the half decay timescale is much longer than the flare increase timescale. A light curve with rapid increase and slow decay obtained by our observations is similar to that often observed in outburst phenomena with ejections, for example, flares on the Sun, the 1972 outburst of Cyg X-3, *etc*.

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Asymmetric Surface Brightness Distribution of Altair Observed with the Navy Prototype Optical Interferometer

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The star Altair (A7IV-V) is known to be a rapid rotator with $v \sin i$ ~200km/s. Because the apparent disk diameter of the star is ~3mas, it is difficult to resolve the star with a single telescope. However, recent development of optical and infrared interferometers have made it possible to see its shape directly. In 2001, van Belle et al.[1] reported the star is distorted because of rapid rotation based on the data obtained with the PTI (Palomar Testbed Interferometer).We observed the star with the NPOI (Navy Prototype Optical Interferometer) and found that the star is not only elongated but also asymmetrically brightened. Altair is the first main sequence star for which direct measurement of the asymmetry of surface brightness distribution have been reported.

Characteristics of our observation are high resolution with the longest baseline of 64m and the measurement of closure phases, which is a sensitive indicator of the asummetry of the brightness distribution of the source. simultaneous observation using three telescopes. A part of measured observables of Altair and Vega for comparison is shown in Fig. 1. While the observables of Vega are well fitted with the limb darkening model with the diameter of 3.22mas, those of Altair are discrepant with the limb darkening model with the diameter of 3.32mas.

The discrepancy indicates that a small bright region is located on the stellar surface. Thus we made a simple model with a bright spot on a limb darkened ellipse and fitted with the observables. As a result, this model (blue lines in Fig. 1) explained the data better than the limb darkening model. The surface brightness distribution of the model with the best fitted parameters is shown in Fig. 2.

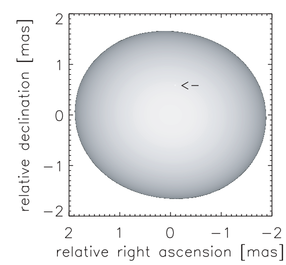

Figure1: A model with a spot on a limb darkened ellipse with the major axis of 3.29mas and the minor axis of 2.77mas.

Because of the rapid rotation of the star, the spot mentioned above indicates existence of a bright pole of a gravity darkened star. We intend to determine the physical parameters of the rotating star with Roche model.

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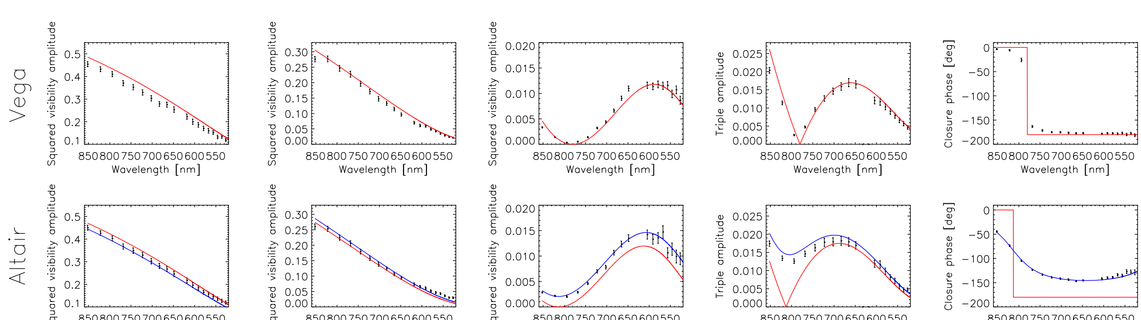

Figure2: Measured observables of Vega (upper) and Altair (lower) obtained in 2001 May 25.; From left to right, squared visibility amplitudes of baseline of 29m, 37m, 64m, triple amplitudes, and closure phase. Measured observables of Vega is well fitted with the limb darkening model with the diameter of 3.22mas (red lines). However, the triple amplitudes around the first zero and closure phaseof Altair are discrepant with the limb darkening model with the diameter of 3.32mas.A spot on a limb darkened ellipse model (blue lines) reproduce the data better.

The Qualification Model of ALMA Band 8 Cartridge Receiver

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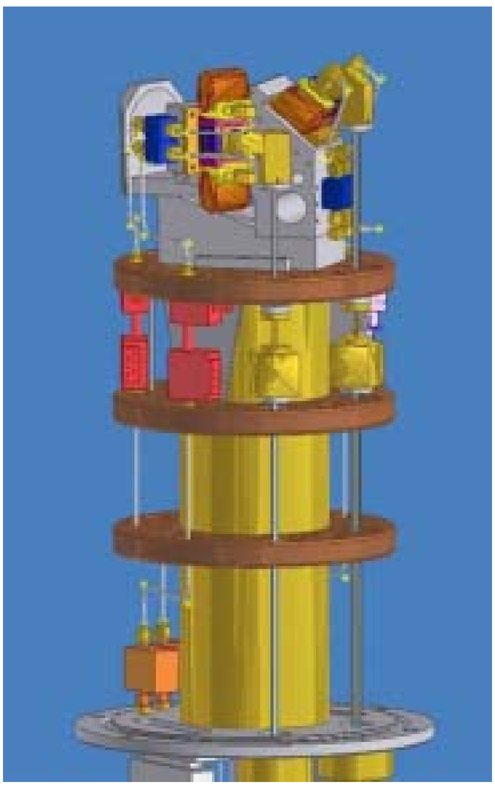

Figure1: Design of ALMA band 8 cartridge Qualification Model (QM).

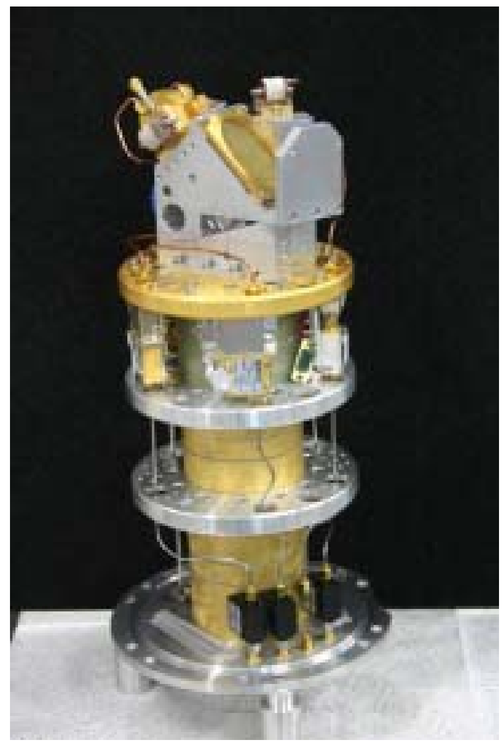

Figure2: A photo of ALMA band 8 cartridge Qualification Model.

We report design and development of the qualification model of ALMA band 8 cartridge receiver.

The ALMA band 8 cartridge receives frequency from 385 GHz to 500 GHz, which is 26 % bandwidth to the center frequency of 442.5 GHz. The development and production of the band 8 Cartridges is one portion of the Japanese contribution to ALMA. We have developed the qualification model of ALMA band 8 cartridge as shown in Figures.

It receives linear dual polarization simultaneously by using a wire grid as a polarization splitter. It employs sideband separating mixers with a waveguide quadrature hybrid [1], which is a scaled model of ALMA band 4 cartridge. The SIS mixers for the band 8 have very low noise as low as 3 times quantum noise limit [2].

The receiver optics adopts a single mirror to couple the feed horn in front of the mixer and the sub-reflector [3]. The merit of single mirror to two mirrors is relatively easy to align optical components of horns, mirrors and a wire grid [4]. The optical parameters were chosen as independent at both the feed horn and the sub-reflector in the frequencies of between 385 and 500 GHz. The receiver optics is inclined 1.2 degree toward the subreflector. The optics block was carefully designed mechanically to realize the optical parameters. The optics block and mirrors were measured mechanically with a coordinated measuring machine, Mitsutoyo LEGEX910 of the Advanced Technology Center of NAOJ, and consistent with designed values within typically 20 μm.

It has been designed and developed on a column-type cartridge structure, which has been described by Yokogawa et al. [5]. Similar cartridge for 800 GHz band has been developed and demonstrated on the Atacama Submillimeter Telescope Experiment by Sugimoto *et al.* [4].

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Cartridge-Type 800 GHz Receiver for the ASTE

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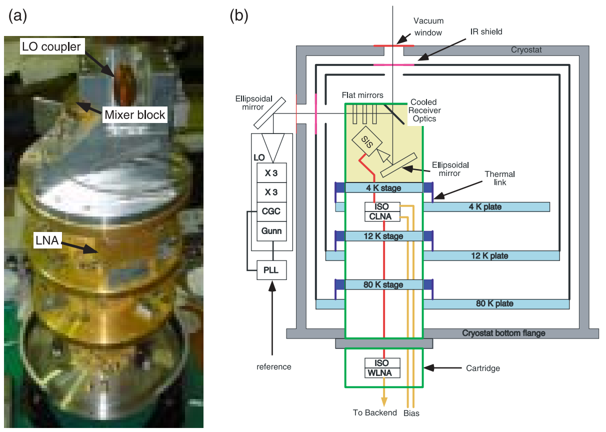

Figure1: (a) Photograph of the 800 GHz cartridge-type receiver. (b) Diagram of the cartridge-type receiver. A 3-stage Gifford McMahon cryocooler is not shown in this diagram for simplicity.

We have developed a cartridge-type 800 GHz receiver for the ASTE telescope in Atacama, Chile [1].

The receiver has been assembled with a cooled receiver optics, a Nb-based SIS mixer, a local oscillator (LO) optics, and IF components in a 170 mm diameter column-type cartridge as shown in Fig. 1. The cooled optics is composed of a single ellipsoidal mirror to couple between the feed horn and the subreflector of the antenna, and an LO coupler with 10% efficiency.

Cartridge-test cryostats that can cool one cartridge-type receiver have been developed to evaluate the receivers in laboratories [2]. Most performances of this receiver were measured using this cryostat. Owing to its cartridge and cryostat structure [3], [4], [5], the mechanical vibrations of the GM cryocooler are significantly reduced, and therefore the receiver is highly stable on the telescope. The receiver noise temperature, using a Nb-based SIS mixer and a $4-8$ GHz HEMT amplifier, was attained to 1300 K in DSB at an LO frequency of 815 GHz.

Three cartridge-type receivers including the 800 GHz receiver were integrated into the ASTE cryostat at the Mitaka campus of the National Astronomical Observatory of Japan (NAOJ). We verified the conditions of evacuation, the cooling properties, the electronic properties, and mechanical interference of the three receivers. Finally, we confirmed that their performance is almost the same as that measured with the cartridge-test cryostat. After integration, the system was shipped to the ASTE site.

Total power measurements scanning across the Moon were performed to estimate the beam pattern of the telescope. The measured beam pattern was fitted with three Gaussian components. The half-power beam width (HPBW) of the main beam was determined to be $11''.8 \pm 3''.5$. This value is consistent with the diffraction limit ($1.2 \cdot \lambda/D \sim 9''.2$) of a 10 m antenna at 806 GHz. 2nd and 3rd Gaussian components have amplitudes of -4 and -8 dB, respectively. The observed error beams is consistent with a simulated error beam. It was calculated using the surface error which is predicted by the Finite Element Method (FEM). After the observations in 2003, a surface adjustment was carried out considering the gravitational deformation between the holography elevation of $5.7°$ and the rigging elevation of $55°$. The beam pattern measurement at observing elevations of 30–80° is expected to be better than those reported in the present paper.

The system noise temperature, $T_{\rm sys}$, was typically 4000–8000 K in DSB at an LO frequency of 812 GHz during operations, which depended on the atmospheric opacity. The typical zenith opacity at an LO frequency of 812 GHz was ~ 1. A spectrum of the CO $J = 7{-}6$ line (806.6518 GHz) toward Orion KL was successfully detected (Fig. 2).

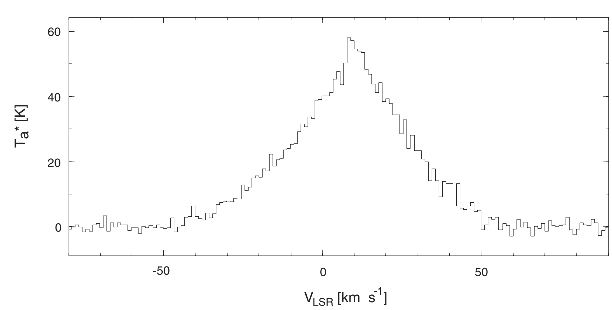

Figure2: CO $J = 7{-}6$ (806 GHz) spectrum around Orion KL. The integration times are 20 s. $T_{\rm a}^*$ was scaled under the assumption of a sideband ratio of 1.

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Photometric Observations of a Young Family Asteroid (832) Karin

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The Karin family was born only 5.8 million years ago [1]. Most asteroid families are very old (~ 2 Gyr), and they have undergone significant collisional and dynamical evolution since their formation that likely masks the properties of the original collisions. But the remarkably young Karin family asteroids possibly preserve some signatures of the original collisional event that formed the family. The Karin family would offer us several significant opportunities for asteroid research, such as the potential detection of tumbling motion of each family member, distributions of rotation period, and shape of newly-created asteroid fragments. Another important point is about space weathering. Generally, the reflectance spectra of S-type asteroids become redder with increasing of its surface age. However the time scale of the space weathering has not been known yet. Since the Karin family is a S-type cluster, it is very suitable observing target for getting information about space weathered surface of young asteroid. Based on these motivations, we have begun a program to observe the Karin family members since November 2002. Here we report our photometric observations of (832) Karin, which is the largest member of the Karin family [2].

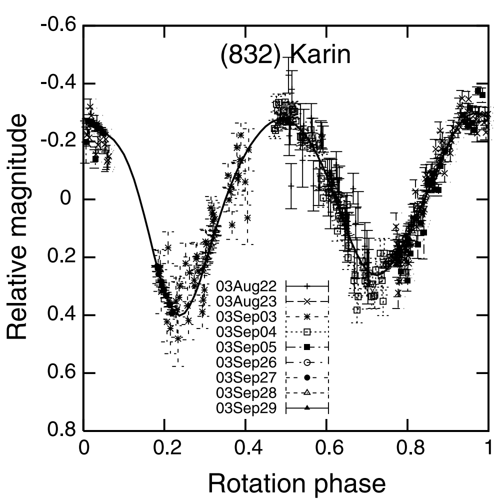

Figure1: Lightcurve of (832) Karin. The rotation period is found to be 18.35 ± 0.02 hr.

We observed (832) Karin from 2003 July to September. We used the 1.8-m telescope at Vatican observatory, Arizona, USA for our multicolor (B, V , R, and I-bands) observation and the 40 cm telescope belonging to the Fukuoka University of Education for our lightcurve observation. Fig. 1 shows the lightcurve of (832) Karin. Its rotational synodic period was determined to be 18.35 ± 0.02 hr. From color observations, we found an interesting surface color variation of this asteroid (see Fig. 2(a) and (b)). We infer that the color variation is due to the difference between the fresh surface, excavated by the family-forming disruption, and the weathered surface, originated from a parent body exposed to space radiation and particle bombardment over a long period. The existence of the color variations is supported by a near-infrared spectroscopy of this asteroid [3]. They exploited the CISCO at the 8.2-m Subaru Telescope on Mauna Kea, Hawaii. They found that there are two different spectra on its surface, one is similar to the spectra of ordinary S-type asteroids, another one matches well with the spectra of ordinary chondrites, possibly coming from the fresh inside of parent bodies. This trend is quite similar to what we have obtained in our observations (Fig. 2(b)).

We will keep observing the Karin family asteroids. They will give us important and unique information about asteroid disruption event.

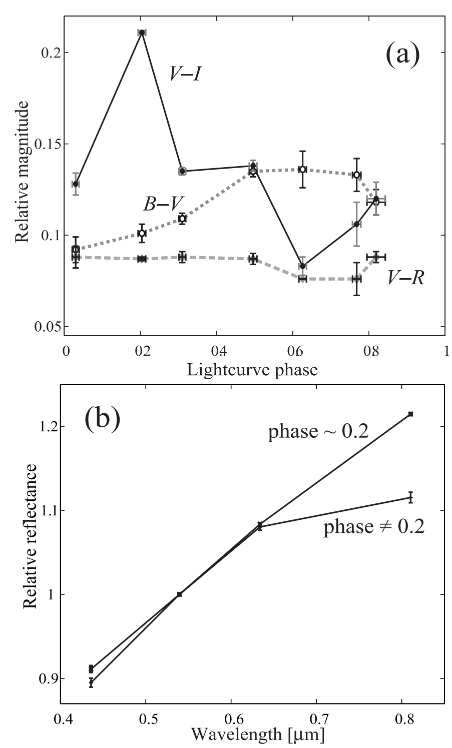

Figure2: (a) Color variation on (832) Karin's surface. (b) Relative reflectance spectra for the different hemispheres of Karin. Both relative reflectances were normalized at the *V*-band.

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Evaluation of ALMA 12-m Prototype Antenna

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The National Astronomical Observatory of Japan (NAOJ) has conducted the evaluation activities on the 12-m prototype antenna for Atacama Large Millimeter Submillimeter Arrays (ALMA) in astronomical observations with evaluation equipments in order to check whether the antenna meets the required performance under the operating conditions. The antenna was designed, manufactured, and delivered to the VLA site of the National Radio Astronomy Observatory (NRAO) in Socorro, New Mexico, US in 2002. After the assembly on site and the adjustment, the performance testing had been repeatedly conducted for about 6 months under as various operating conditions as possible in 2003 [1], [2].

Since measurements to confirm its performance are very challenging, the American, European, and Japanese teams have collaborated in establishing the evaluation method and the measurement technology as well as development of the evaluation equipment for several years. They are the computer control system for tracking celestial sources and for evaluation equipment, the radio holography receiver system for the surface accuracy measurement [3], the evaluation receiver system operating at the 1- and 3-mm bands, the optical telescope for measuring the pointing and tracking accuracy [4], the temperature monitor system for estimating thermal deformation of each part of the antenna and the accelerometer system which measures minute vibration of the antenna.

In the evaluation activities, the NAOJ used evaluation equipments such as an optical pointing telescope system and a submillimeter receiver system newly developed and integrated. The results of the evaluation have confirmed that the prototype antenna satisfied the major technical specifications including the surface accuracy of 25 μm rms, the offset pointing and tracking accuracy of 0.6 arcsec rms, and the fast motion capability with a step of 1.5 degrees on the sky within 1.5 seconds of time. The path length error (< 20 μm rms) has not been measured. Previous successful developments of high precision aluminum reflector panels and a high precision angle encoder greatly contributed to fulfill the required performance. On the other hand, we have not obtained the target values in some items including the temperature control in the receiver cabin, which are less important compared with the main technical specifications mentioned above. They shall be reflected in the design of the production antennas in the future.

The evaluation activities of the 12-m prototype antenna has demonstrated that the large millimeter and submillimeter antenna is technically highly feasible and it has also enabled us to establish evaluation methods and measuring techniques for the high precision antenna. In addition, we have gained the valuable technical expertise for the future operation of the antennas in Chile.

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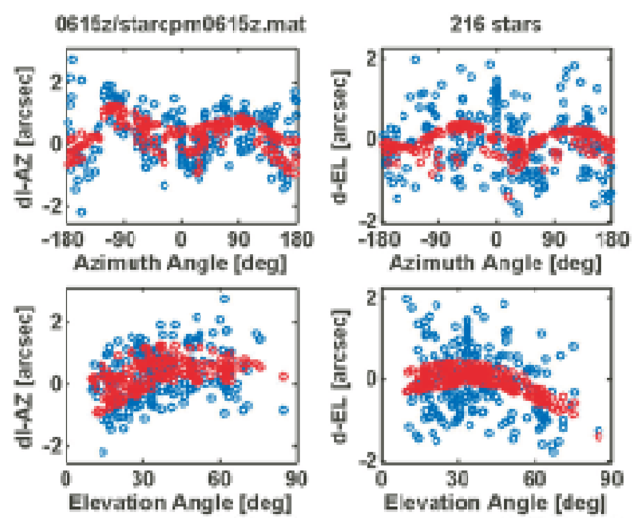

Figure1: Optical pointing measurement of absolute pointing accuracy, blue dots are measurement, red denotes fitting results, The measured azimuth and elevation pointing error was 0.85 and 0.80 arcsec and the total absolute pointing error was 1.17 arcsec rms.

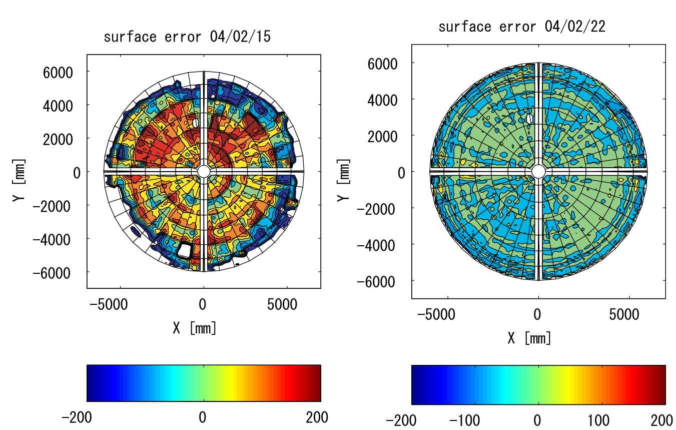

Figure2: Surface Accuracy of the 12-m antenna by Radio Holography, left:before adjustment 122 μm rms, right:after adjustment 20 μm rms.

Detection of New Molecules in a Bright Leonid Fireball

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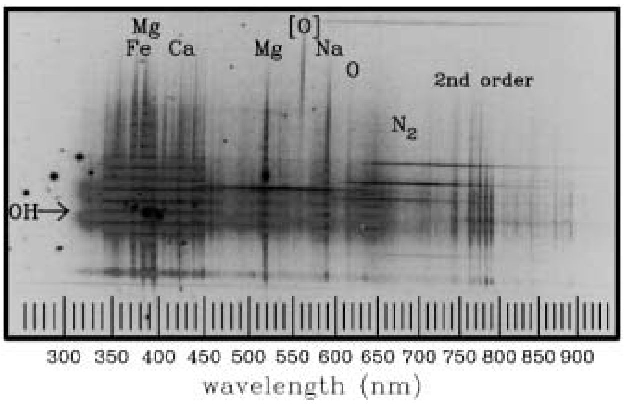

Figure1: First and second order spectrum of 2001 Leonid fireball. This image (with a field of view of 23°× 13°) is composed of 15 consecutive frames during a total duration of 0.5 s. The meteor moved from top to bottom and the dispersion direction is from left to right. A maximum brightness of – 4 visual magnitude at the standard range of 100 km was derived, which corresponded to a photometric meteoroid mass of ~1.8 g and a diameter of ~15 mm by assuming a density of 1.0 g cm^{-3}

An ultraviolet-visible spectrum between 300 and 450 nm of a cometary meteoroid that originated from 55P/Tempel-Tuttle was investigated, and its new molecules, induced by atmospheric interaction, were discovered [1].

Spectroscopic observations of meteors reveal not only the chemical composition of the cometary meteoroids but also the emission processes of hypervelocity impacts in the atmosphere(11.2 − 72.8 km s^{-1}); these processes are difficult to reproduce in laboratory experiments at present. Of particular interest is the question as to whether or not meteoroids could have delivered organics and water to the early Earth until now. To determine whether large cometary grains contain mineral water or trapped water in any forms, it is necessary to confirm the presence of OH $A^2\Sigma^+ \rightarrow X^2\Pi$ emission around a wavelength of 310 nm.

During the 2001 Leonid meteor shower over Japan, The spectroscopy was carried out using an intensified high-definition TV camera with a slitless reflection grating and original developed UV lenses (f=30 mm, F/1.2). In Fig. 1, we show a clear spectrum of a Leonid meteor fireball, which was obtained at 18:58:20 UT on 2001 November 18. Assuming the local thermal equilibrium (LTE), the atomic synthetic spectrum was computed by adjusting five parameters: temperature T and the column densities of four atoms (Fe, Mg, Ca, and Na). After the comparison between observed and synthetic spectra, we found that these atomic lines could not help us identify some unknown bands around 350, 330 and 310 nm. The 350 nm excess was particularly strong. As a result, the best account for two excess bands was found to be the "first negative B–X" band of the molecular nitrogen ion N_2^+(1–).

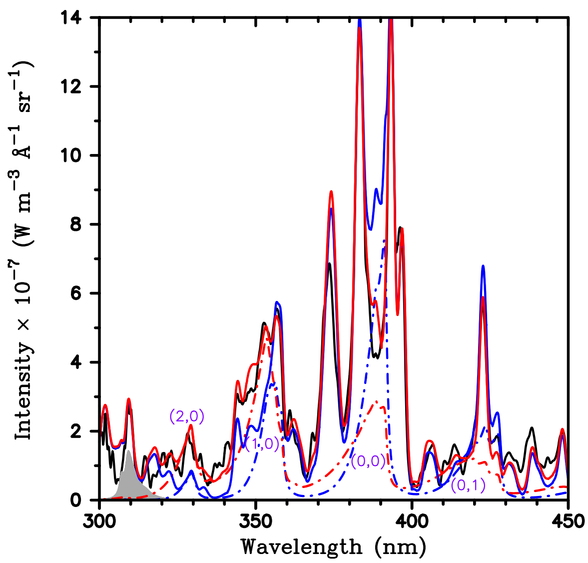

Figure2: Observed spectrum ($blackline$) compared with synthetic spectrum considering atoms and molecules of N_2^+(1–) with a temperature of 10,000 K ($redline$) and 4400 K ($blueline$). The dash-dotted lines indicate N_2^+(1–) at the appropriate temperature. The gray area near 310 nm shows OH A–X bands. The origin of OH band will be needed for future confirmation.

Fig. 2 shows the model spectrum of N_2^+(1–) with four bands heads (329.3, 353.4, 391.4, and 427.8 nm) caused by different vibrational states of (v', v") = (2, 0), (1, 0), (0, 0), and (0, 1), respectively. The model spectrum is wonderfully in complete agreement with the observational spectrum in the UV range from 320 to 360 nm.

In general, meteor spectra consist of two components at different temperatures [2]. A typical temperature of the "main (warm) component," is $T \sim$ 4500 K. The "second (hot) component" is excited at $T \sim$ 10000 K and consists of a few ionized elements such as Ca II and Mg II. A best-fit calculation mixed with atoms and molecules confirmed the first discovery of N_2^+ $B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$ bands in the UV meteor spectrum. The N_2^+ temperature was estimated to be 10000 K with a low number density of 1.55 × 10^5 cm^{-3}. Such unexpectedly strong ultraviolet emission, in particular for N_2^+ (1, 0) at 353.4 nm, is supposed to be formed through the wide dimensions of high-temperature regions caused by a large meteoroid. Spectroscopic observations of reentry capsules, such as $Stardust$ (cometary dust sample return in 2006 January), and $Hayabusa$ (asteroidal material sample return in 2007 June), will provide us with good opportunities for confirming the discovered N_2^+.

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Progress and Status of the Development of the Band 4 Cartridge Reciever

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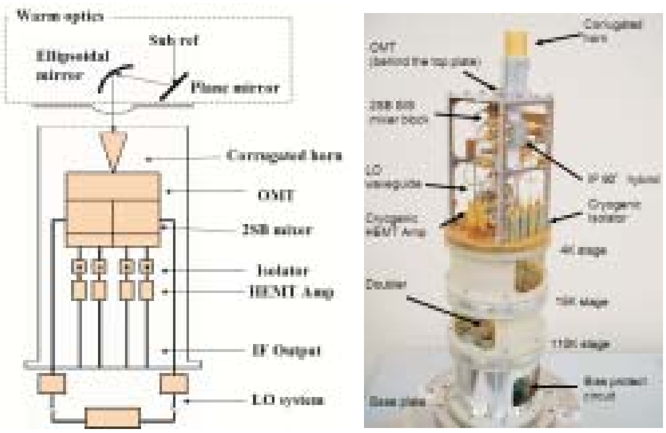

Figure1: Conceptual diagram of Band4 cartridge (left) and Band 4 prototype cartridge (right).

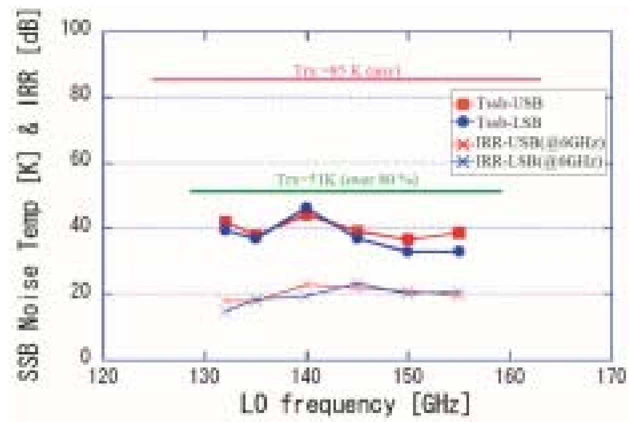

Figure2: SSB noise temperature of ALMA band 4 2SB mixer with averaging over the IF band of 4–8 GHz.

We have been developing the ALMA Band 4 cartridge receiver. The Atacama Large Millimeter/submillimeter Array (ALMA) is an international collaboration between Europe, North America and Japan to build a synthesis radio telescope that will operate at millimeter and submillimeter wavelengths. ALMA will be located on the Chajnantor plain of the Chilean Andes in the District of San Pedro de Atacama, 5,000 meters above sea level. The ALMA receiver system will cover all the available atmospheric frequency windows between 30 GHz and 950 GHz. The range shall be covered in 10 bands with HFET or SIS devices. The receiver should be modular so that one easy to install self-contained receiver should cover that one particular frequency band. These self-contained receivers are known as "cartridges." The development and production of the Band 4 cartridge receivers is one portion of the Japanese in-kind contribution to ALMA.

ALMA Band 4 will operate in the 125–163 GHz frequency band, which is 26 % bandwidth to the center frequency of 144 GHz. A conceptual diagram of the cartridge and a photograph of the Band 4 prototype cartridge are shown in Fig. 1. The beam coming from the telescope is incident on a flat mirror, which reflects the beam out to an elliptical mirror and then the beam is focused down into the cryostat onto the horn. It is a dual polarization receiver, which uses an orthomode transducer (OMT) as a polarization splitter. The cartridge consists of three stages (at operating temperatures 4, 15, and 110 K) and the base-plate (which acts as a vacuum seal) at 300 K, with GFRP 10 spacers between them. The 110 K stage has the LO doublers mounted on it and heat sinks for the LO waveguide, coax cables and wiring. The 15 K stage has only heat sinks for the LO waveguide, coax cables and wiring attached. The 4 K stage has the Corrugated horn, OMT, 2SB SIS mixers, Cryogenic Isolators, Cryogenic HEMT Amplifiers (CLNAs), IF hybrids and heat sinks for the LO waveguide, coax cable and wiring attached.

To meet the technical specification of the ALMA Band 4 receiver, Band 4 team has developed corrugated horn, OMT, 2SB SIS mixer, etc.

The corrugated horn was fabricated by NC machining suited for the series production. The measured beam patterns are consistent with the simulation down to a level of -30 dB relative to the center. The peak of cross polarization is lower than -30 dB relative to the peak of the co-polar power, which is good.

The OMT has been designed and prototyped for Band 4 based on the double ridged waveguide-based design. Tests of the prototype OMT exhibit a return loss better than 18 dB and an insertion loss of less than - 0.5 dB across the full 125 – 163 GHz band in both polarizations. This performance is excellent for a critical component in the Band 4 cartridge design.

The overall receiver noise temperatures of the 2SB mixer with OMT (Horizontal Port) averaged over the IF band of 4–8 GHz are plotted in Fig. 2. Image rejection ratio (IRR) was measured at IF = 6 GHz. The noise temperatures were corrected for the contribution of the image sideband at IF center frequency 6 GHz. The noise performance includes the contribution of the vacuum window, feed horn, OMT, and IF amplifier chain. The measured single-sideband (SSB) receiver noise temperatures are less than 45 K and the image rejection ratios are better than 10 dB in the LO frequency range of 133–155 GHz. This result is promising that the Band 4 cartridge will meet the noise temperature specification.

The First Build-up of the Solar-B Flight Models

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SHIMOJO, Masumi, SUEMATSU, Yoshinori, TAMURA, Tomonori, TSUNETA, Saku
NOGUCHI, Motokazu, NAKAGIRI, Masao, MIYASHITA, Masakuni, WATANABE, Tetsuya
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Figure1: Telescope apertures of the flight model Solar-B spacecraft. The Optical Telescope Assembly is at the center and its Focal Plane Package is on the left. X-ray Telescope and EUV Imaging Spectrometer on the bottom and top are covered with black baggings for protection from external contamination.

Figure2: Micro-vibration test configuration to measure a response of the Optical Telescope Assembly for moving components in the spacecraft that act as sources of disturbance.

All flight models (FM) of Solar-B, the sun observing spacecraft, gathered in a clean room of Institute of Space and Astronautical Sicnce of Japan Aerospace Exploration Agency (ISAS/JAXA) in 2004 for the first integration and spacecraft-level testing. The Solar-B Project Office of the National Astronomical Observatory of Japan (NAOJ) largely contributes to the system design and spacecraft-level testing of all telescopes, developments of the Optical Telescope Assembly in the Solar Optical Telescope (SOT) and X-ray CCD camera of the X-ray Telescope (XRT), and the spacecraft-level contamination control. From foreign partners (US NASA and UK PPARC) the Focal Plane Package of SOT, XRT, and EUV Imaging Spectrometer were delivered there. The primary purpose of the test was to check the specification and performance of the Solar-B FM through the electrical and mechanical interface checks during the course of assembly and after the final assembly. In addition, the SOT imaging performance was investigated under a disturbed environment in which the moving components in the spacecraft are steadily operating. Over a half-year period of time the interface specification and performance of all telescopes ([1], [2], and [3]) were checked in detail by the Solar-B Project Office of NAOJ together with ISAS/JAXA and foreign partners.

The integration and testing of FM started in June and the integrated spacecraft appeared at the beginning of Oct (Fig. 1). After the performance test of each subsystem was successfully finished by the end of Nov, a test to evaluate the effect of external disturbance to the diffraction-limited imaging performance of SOT was carried out (Fig. 2). From this test it was confirmed that the degradation of the SOT imaging performance does not occur under the steady disturbance from moving components in the spacecraft attitude control system and mechanical components in telescopes. Although sensitive CCD cameras as detectors are exposed to a severe noise environment from the spacecraft itself, it was also confirmed that the performace of Solar-B detectors in telescopes is maintained under various spacecraft operational modes.

All testings were finished successfully, with only minor problems uncovered, at the beginning of Dec. The spacecraft was de-integrated and each component was returned to each institute or a contractor in charge. All components are going to gather again in June 2005 after fixing problems and finishing the environmental testing such as mechanical and thermal vacuum tests. The Solar-B spacecraft is going to be launched in summer 2006 from the Uchinoura Space Center of JAXA in Kagoshima.

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Discovery of evidence of the nucleosynthesis process by photodisintegration reactions in supernova explosions

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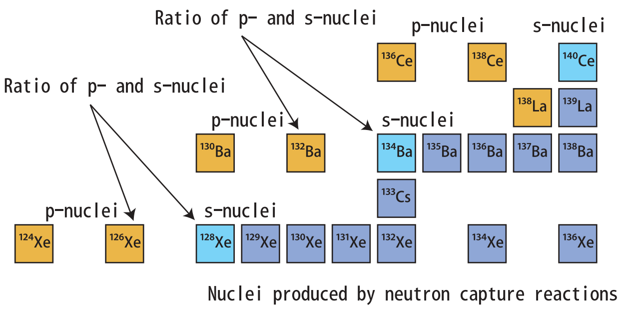

Figure1: A partial nuclear chart. X-axis is the proton number and Y-axis is the neutron number. The p-nuclei are located in the proton-rich side.

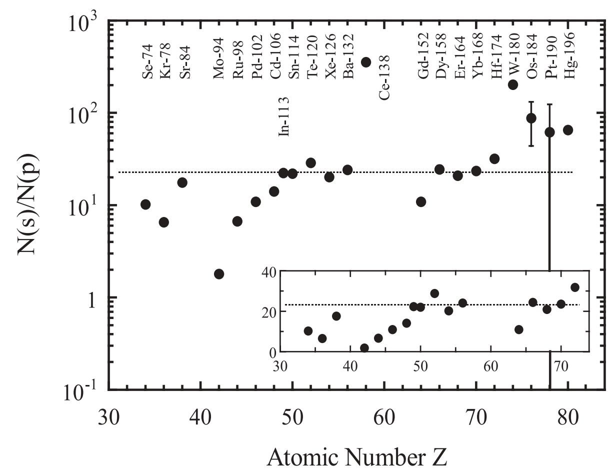

Figure2: The ratio of the s- and p-nuclei. X-axis is the atomic number. The ratios are almost constant with the wide range.

At the formation of the Galaxy, only the light elements such as H, He existed, while heavy elements were dominantly produced by nuclear reaction processes in stars. The solar system abundance is a record of these nucleosynthesis processes. About 99% of heavy elements are considered to be synthesized by two neutron-capture reaction chains, r- and s-processes. Two abundance peaks near the neutron magic number correspond to the r- and s-processes.

There are 35 p-nuclei that cannot be synthesized by the neutron-capture reactions. The p-nuclei are located in the proton-rich side in the nuclear chart and their isotope ratios are small (typically 0.1 $\sim$ 1 %) as shown in Fig. 1. The problem of the origin of the p-nuclei has been pointed out about 50 years ago and many nucleosynthesis processes have been proposed to explain the origin of the p-nuclei. They are nucleosynthesis by Cosmic-rays [1], X-ray bursts of Type I in neutron stars [2], photodisintegration reactions in supernova (SN) explosions (p-process)[3], neutrino-induced reactions in SNe [4], He detonations in C/O white dwarfs [5]. In order to investigate the origin of the p-nuclei, we study the solar system abundance.

There are 20 pairs of a p-nucleus and a pure s-nucleus that is two neutron heavier than the p-nucleus (see Fig. 1). The pure s-nucleus is dominantly produced by the s-process and is shielded against the β-decay after the r-process. ^{126}Xe has a p-nucleus and ^{128}Xe has a pure s-nucleus in Fig. 1. Taking the abundance ratios between the s- and p-nuclei, N(s)/N(p), we find an empirical scaling law that the abundance ratios, N(s)/N(p), are almost constant for a wide range of the atomic number except some deviations (see Fig. 2)[6]. The deviations can be explained by the contamination of the s- and r-processes. We would like to stress that this scaling has not been known.

The scaling indicates that the p-nuclei were synthesized from the s-nuclei by nuclear reactions such as (γ,n) reactions. This is evidence that the most probable origin of the p-nuclei is the p-process in SN explosions, because the nuclear reactions in the other processes change the proton number of the seed nuclei as well as the neutron number.

We carry out nucleosynthesis calculations based on a typical core-collapse SN model. The calculated ratios are almost constant for a wide range, although the average values is lower than the observed ratios. These resutls are consistent with the observed scaling in the solar system. We therefore conclude that the scaling is evidence of the p-process nucleosynthesis in SNe. This discovery is also important for the study of the stellar environment where the nuclei are synthesized, and of the galactic chemical evolutions.

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Start of regular geodetic VLBI observations within VERA network

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We succeeded first geodetic VLBI observations within the VERA network in October 2004 using S/X band receivers and 1Gbps recording system. Also, we started regular geodetic VLBI observations twice a month within the network from December 2004.

Since December 2001, Mizusawa Station joined domestic VLBI observations named JADE, which were coordinated by the Geographical Survey Institute (GSI), almost once a month. These observations have been carried out to tie the VERA network with the International Terrestrial Reference Frame (ITRF) via Tsukuba Station of GSI. In these observations, so-called K4 backend system was used which was based on tape recording system of 128Mbps. From March 2005, we introduced new disk recording system named K5/VSSP.

In the geodetic VLBI observations, we observed total 400 objects in 24 hours. We started the operation of Array Operation Center (AOC) in Mizusawa from October 2004. From the AOC, we can control VERA four stations and reduce the operation loads at the sites.

As for the analysis software, we can obtain the station coordinates, clock parameters and so on within one day after the correlation process was done at the Mitaka Correlation Center in NAOJ. In Fig. 1, the tentative analysis result of the observation on December 17, 2004, is shown. The baseline solutions might be change about a few mm when the constraint conditions such as nutation parameters were changed in the analysis.

The VERA project aims at measuring proper motions and annual parallax of radio sources in the Galaxy by using relative VLBI observation technique. To realize the main target of the project, the accuracy of the coordinates in VERA network should be in the order of 10^{-9} of baseline length, that is 1mm–2mm. The expected accuracy of the geodetic observation on one time is 2mm in the horizontal position and 8mm in the vertical one (see Fig. 2). Thus the regular geodetic observations are necessary to obtain required accuracy in the network coordinates.

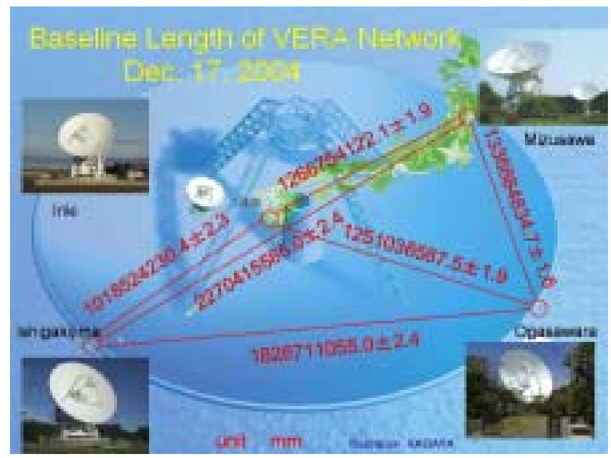

Figure1: Tentative baseline lengths of the VERA network obtained from the observations on December 17, 2004. The baseline lengths vary momentarily because of the plate motions which exceed 60mm per year at the maximum.

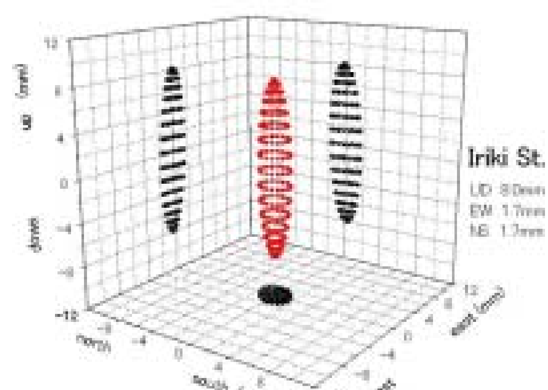

Figure2: A sample of error circle at the Iriki Station. The error of vertical position is larger then that of horizontal one, because the resolution among vertical position, clock parameter and atmospheric delay are poor in the parameter estimations.

Hemispheric Sign Rule of Magnetic Helicity on the Sun

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The activity cycle of the sun seen, e.g. in the eleven-year periodicity of sunspot numbers, has been the topic of intensive research for many years. However, its driving mechanism is still not fully understood and is regarded as the most fundamental problem in solar-stellar physics. In this respect, attention has been paid recently on the twist of solar magnetic fields, because it provides new information on how the magnetic fields are generated in the solar interior.

It has long been known that the whirl patterns around sunspots show hemispheric preferences, either clockwise or counter-clockwise. A more recent finding with the soft X-ray telescope of *Yohkoh* is that coronal loops also show hemispheric segregation in twists (either S or inverted S patterns). These properties can be interpreted as due to twisted magnetic tubes in the sun, which are left-handed in the northern hemisphere and right-handed in the southern hemisphere (Fig. 1).

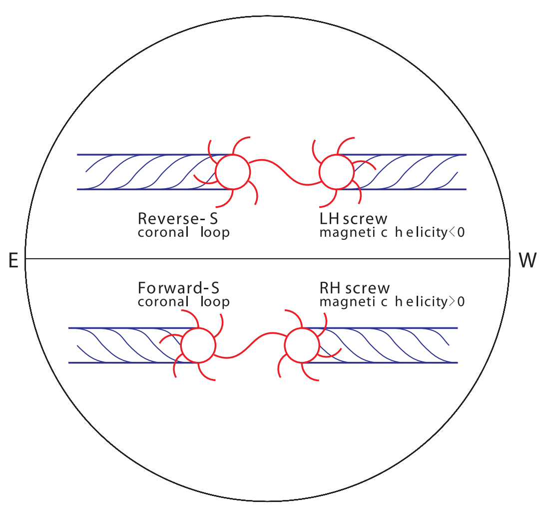

Figure1: A schematic picture showing the twist of magnetic fields in the interior of the sun, at the surface, and in the corona.

The twist of magnetic fields is quantitatively represented by 'magnetic helicity'; positive helicity means right-handed helical fields. From observations of the magnetic fields on the solar surface with the instrument called a vector magnetograph, we can derive the magnetic helicity by spatially averaging the quantity $\boldsymbol{B}\cdot(\nabla\times\boldsymbol{B})/B^2$.

Figure 2 shows the latitude distribution of magnetic helicity derived from 230 active regions observed in the period of 1992–2001, with the Solar Flare Telescope at Mitaka [1]. The slope is negative, namely the helicity is positive (negative) in the southern (northern) hemisphere. This property, known as the hemispheric sign property, was discovered by the teams at University of Hawaii and at Beijing Observatory. Our analysis not only confirmed their results, but also added more confidence to it by carefully scrutinizing the accuracy in the data and analysis methods. The large dispersion in the data points seen in this figure is not due to observational errors but is a real effect due to turbulence which the magnetic tubes rising through the convection zone have experienced.

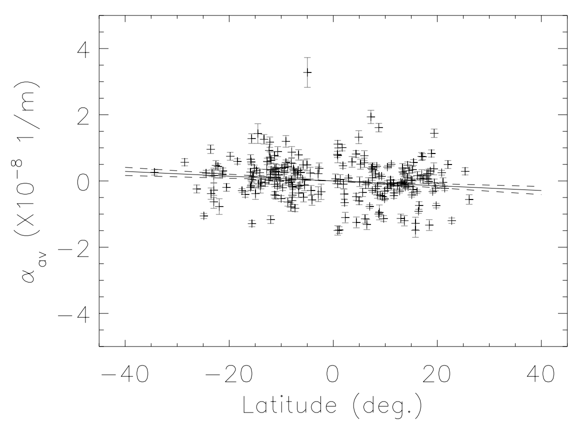

Figure2: The latitude distribution of magnetic helicity $\alpha_{\rm av}$ derived for 230 active regions. The solid line is the least-square regression line, and two dotted lines show the error bounds in the slope.

We are investigating the time variability in the magnetic helicity. It is already known that the hemispheric sign rule does not change from one eleven-year cycle to the next. There is, however, some indication of variability as a function of the phase in the activity cycle.

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Some Coronal Loops have Cooler Loop-Tops

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The mechanism which brings the solar corona into a temperature of 1–2 million degrees is still unknown and is regarded as one of the most fundamental problems in astrophysics.

The temperature distribution along a coronal loop may indicate important information on whether the heating is concentrated at some portion of the loop or is more or less uniformly distributed. Generally the heat conduction along the length of the loop (namely along the field lines) is efficient and tends to make the temperature gradually decrease toward the footpoint that is anchored to the cool solar surface. On the other hand if the heating is localized at the foot portion of the loop, the temperature at the top of the loop may be less hotter, or even cooler, than the footpoint regions. So far the observations in EUV and X-rays show that the loops show the highest temperature at their tops.

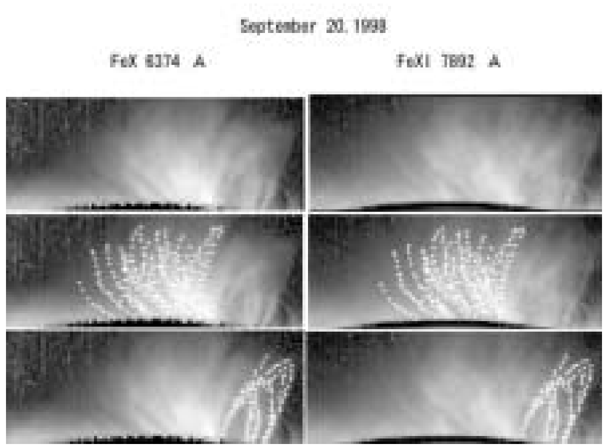

Figure1: Coronal loops observed with a 25cm-aperture coronagraph at Norikura Solar Observatory. The spectral lines used to obtain these maps are [Fe XI] 7892 Å and [Fe X] 6374 Å. The loops marked with + in the middle row showed a normal behavior of increasing temperature with height. The loops marked with + in the bottom row showed, on the contrary, a temperature decreasing with height.

We have been conducting systematic studies of the solar corona by using the coronagraph and the spectrograph at Norikura Solar Observatory. We found a rare case in which the coronal loop showed a temperature distribution decreasing with height [1]. Figure 1 shows the observed coronal region. These maps were made by observing the [Fe XI] 7892 Å line emitted from a 1.3 MK plasma and the [Fe X] 6374 Å line emitted from a 1.0 MK plasma. Many loops in the central part of the figure showed a normal behavior, namely the temperature increasing with height. However, the loops on the right-hand portion of the figure showed a peculiar behavior (Fig. 2). There the widths of the two lines and the intensity ratio (Fe XI/Fe X) of the two lines decreased with height. The decrease in the line widths alone might be interpreted as the decrease in the turbulent line broadening (unresolved motions). However, because the line intensity ratio also decreases with height, the observations are most consistently explained if the temperature in these loops decreases with height.

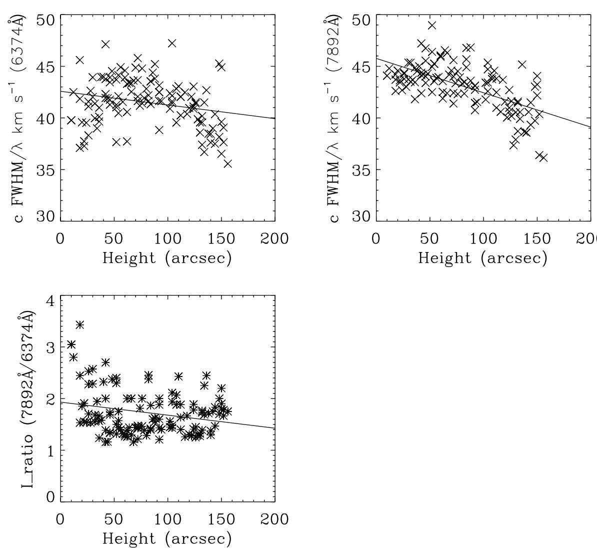

Figure2: The height variations of spectral line widths and line intensity ratio (Fe XI/Fe X). All of the three quantities are seen to decrease with height, which is possible only if the temperature decreases toward the top of these loops.

Our previous studies show that the distribution of temperatures in coronal loops is complicated. Generally a single temperature cannot explain the observations, and one is forced to introduce multi-temperature components along the line of sight. In the present example, however, the data used were from two ions (Fe X and Fe XI) which are close in the ionization equilibrium temperatures. Therefore, we can assume that we were looking at a plasma with an identical temperature, and the data really show the temperature which decreases toward the top of the loop.

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A CME onset observed with Norikura NOGIS coronagraph

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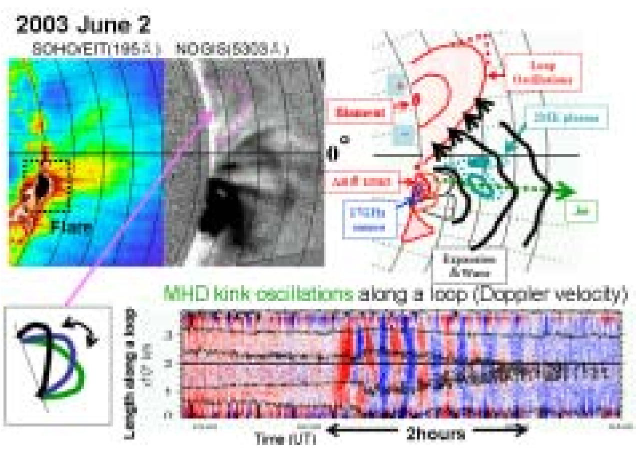

Figure1: Coronal disturbances on 2003 June 2.

We present the first detection of a coronal mass ejection (CME) in the coronal green-line emission (Fe XIV, 2MK) by the two-dimensional Doppler coronagraph NOGIS (Norikura Green-line Imaging System) at the Norikura Solar Observatory.

CME is a huge expansion of magnetically trapped coronal plasmas that is usually associated with a local explosion on the solar surface, such as flares and filament eruptions. Birth places, shapes and expansion process of CMEs reflect global structure of the coronal magnetic fields. Observations of CME onsets can, therefore, provide valuable information on coronal fields and surrounding plasmas that are changing as a result of magnetic energy release. While kinetic features of CMEs have been studied with whight-light coronagraphs [1], spectroscopic observations are essential for diagnosis of CME plasmas [2]. NOGIS is a unique imaging system that can provide both intensity and Doppler velocity images of 2MK plasma from the coronal green-line emission λ5303 Å of Fe XIV [3]. NOGIS has a field of view of 2000 $\times$ 2000 pixels in a full frame mode and a spatial resolution of 1$''$.84 in a partial frame mode. The line-of-sight velocity of up to $\pm$25km/s can be detected with an accuracy of 0.6 km/s. Since 1997, NOGIS has observed many flares and coronal waves. Here we introduce a CME onset on 2003 June 2 that was continuously observed with NOGIS in relatively good seeing conditions [4].

Figure 1 top panels show the event configuration around the west limb. From left to right, a *SOHO*/EIT 195Å (Fe XII; 1.6MK) image, NOGIS intensity image (where the solar disk is occulted), and a sketch that summarizes the evolution of the event. The grid shows 5° (dotted line) and 0.1 R_s intervals (solid line). Solar North is up, and west is to the right. Across the solar equator (thick horizontal line), there were two magnetic flux systems lying along the limb: a flare-productive active region, NOAA #10365, and a bundle of face-on coronal loops overarching a quiescent filament. The magnetic polarity of footpoints near the equator is opposite in each flux system, which suggests a possible magnetic link between the two systems. An early precursor of the event is a density enhancement of 2 MK plasma in between the two systems. Following a filament eruption from AR 10365 that was observed by *TRACE* spacecraft in the 195Å passband (1.6 MK), NOGIS observed a blue-shifted bubble and a red-shifted coronal wave that almost simultaneously expanded from the boundary of AR 10365 and the overlying dense region. The wave propagated toward the face-on loop system and triggered a damping oscillation in Doppler shifts among the adjacent loops within the system (Fig. 1 bottom). The blue-shifted bubble propagated both inward and upward. The inward motion triggered an M6.5 flare in AR 10365 while the upward motion evolved into a partial halo CME that had an angular extent covering the latitudinal range of the two flux systems. Different from typical CME disturbances that evolve within a single flux system with a bipolar arcade on its center, our event proceeded via interaction, which was presumably magnetic reconnection, between separatrices of the two flux systems.

As a future work, we are planning to combine NOGIS with spaceborn EUV imaging spectrometers, *SOHO*/CDS and Solar-B/EIS to have a temperature diagnosis of CME plasmas and coronal waves.

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Completion of Solar-B/Optical Telescope Flight Model

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Integration and optical test of Optical Telescope Assembly (OTA) flight model of SOLAR-B Solar Optical Telescope (SOT) is completed in a clean room of NAOJ. The aim of SOT is to provide data to investigate the physical coupling between the photosphere and the corona to ultimately understand the mechanism of coronal dynamics and heating with the coordinated observations with X-Ray Telescope and EUV Imaging Spectrometer onboard SOLAR-B. With SOT we will be able to continuously observe solar atmospheric structures, especially solar magnetic structures, with a diffraction-limited spatial resolution of 0.2 to 0.3 arcsec and a polarization accuracy better than 10^{-3}; these performances are difficult to realize with ground-based instruments.

The SOT consists of two separate optical structures: the Optical Telescope Assembly (OTA) designed and manufactured in Japan and the Focal Plane Package (FPP) by NASA, USA. The main structure of OTA is an aplanatic (coma aberration free) Gregorian telescope of a 50 cm effective aperture. The OTA is equipped with newly designed optical components such as a heat dump and a secondary field stop aluminum mirror with high reflectivity silver coating and a temperature low-sensitive apochromatic collimataing lens unit with a UV/IR cut coating on the first surface. These components are indispensable to keep OTA in moderate temperature and optical thermal deformation small. The SOT has an active image stabilization system consisting of correlation tracker (in FPP), tip-tilt mirror and its controller against satellite pointing jitter. A bench test demonstrated the performance of 0.002 arcsec stabilization with a cross over frequency of 14 Hz.

We had already demonstrated in the summer of 2004 that the initially assembled OTA has the diffraction limited performance in all observable wavelengths (388 – 668 nm). Since then, the OTA experienced system-level mechanical and electrical interface test, final installation of thermal equipments, and an acoustic test. The OTA also passed the opto-thermal and thermal cycling test in which it was exposed in the lowest temperature on-orbit for 24 hours; the temperature of telescope envelope, primary and secondary mirror went down to –45 degC, –15 degC, and –33 degC, respectively. Then, we confirmed that the the optical performance of OTA has not changed through these activities, keeping the diffraction-limited performance the same as a year before. In addition to the optical tests, the top- and side-door deployment were successfully demonstrated after the acoustic test. These doors protect inside of OTA from contamination on the ground and during lift-off and take a role of cold-traps of molecular contaminants on orbit before their deployments.

After completion in the end of June, 2005, the OTA moved to ISAS/JAXA for system-level final performance test before launch. The SOLAR-B is sheduled to be put on a solar synchronous polar orbit of altitude about 630 km in the summer of 2006.

Figure1: SOLAR-B Optical Telescope prior to top- and side-door installation in NAOJ clean room.

Figure2: Top door deployment test of SOLAR-B Optical Telescope in NAOJ clean room.

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Generalized Horseshoes in the Standard Mapping

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The 2-fold horseshoe map introduced by Smale [1] shows the essence of chaos in the sense that the maximal invariant set contained in the initial square exhibits sensitive dependence on initial conditions and transitivity. If a system contains this horseshoe map as a subsystem, we can conclude that the system is chaotic and the lower bound for topological entropy $h_{\rm top}$ is equal to $\ln 2$. Embedded 2-fold horseshoes are found in many systems such as the Hénon map [2] and the Duffing systems [3]. In general, if we find an embedded m-fold horseshoe for $m \geq 3$ in the system, we can say that the lower bound for topological entropy is $\ln m$. Such horseshoes are called the generalized horseshoes. McRobie–Thompson [4] analyzed the structure of the idealized 3-fold (or ternary) horseshoe expected to exist in a periodically driven damped oscillator system. Gaspard [5] systematically analyzed classical hard-disk scatterers and proved the existence of 2-fold and 3-fold horseshoes, respectively for the three-disk and four-disk scatterers provided that all disks can be seen from each other.

The purpose of this paper [6] is to show how to construct $(2n+1)$-fold horseshoes in the standard mapping T for every $n \geq 1$.

$$y_{n+1} = y_n + a \sin x_n, \quad (1)$$

$$x_{n+1} = x_n + y_{n+1} \pmod{2\pi} \quad (2)$$

where $a > 0$. The saddles are represented by $P_{0,0} = (0,0)$ and $P_{1,0} = (2\pi, 0)$.

Using the structure of the stable and unstable manifolds of $P_{0,0}$ and $P_{1,0}$, the existence of the three–fold horseshoe at $a \geq 3\pi$ is proved (see Fig.1). This result can be extended to the following theorem. The detailed proof is included in [6].

Theorem 1. In the standard mapping, for any $n \geq 1$, a $(4n-1)$-fold horseshoe Ω_{4n-1} exists for $a \geq (8n-5)\pi$ and a $(4n+1)$-fold horseshoe Ω_{4n+1} exists for $a \geq (8n-1)\pi$.

From Theorem 1, for example, at $a = 11\pi$, the coexistence of three different horseshoes Ω_3, Ω_5 and Ω_7 is derived. Then, the following relation holds.

$$\Omega_3 \subset \Omega_5 \subset \Omega_7. \quad (3)$$

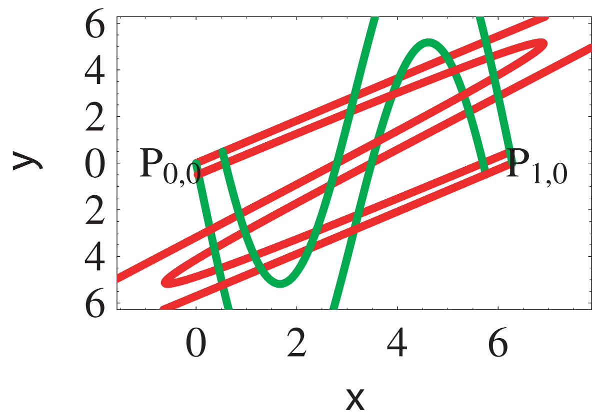

Figure1: Three–fold horseshoe at $a = 3\pi$.

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Metallic abundances of the 2002 Leonid meteor deduced from visible - ultraviolet spectra

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Spectroscopy of a large scale activity of the 2002 Leonid meteor shower and a small scale activity of the 2004 June Boötid meteor shower have been reported [1], [2].

Generally, meteor showers are originates from comets' dust and they enter the Earth's atmosphere with their high velocity. This results in the meteors reserving the import energy into the atmosphere; thus the excitation plasma flash from the ablated meteoroids, can be appropriate to discuss the origin of solar system and its evolution process. Composition of Comet dust is revealed to be almost same value of solar abundance by past Comet research. We have been focusing on spectroscopic observations of the meteor showers in the visible–ultraviolet region, where many lines of metallic atoms are expected, and carried out spectroscopy on the airborne mission (Fig. 1). Metallic abundances of meteors are slightly different from solar abundances and volatility feature of some element is clearly shown by high-time resolved observation during its ablation process. Large scale meteoroids may show different composition from that of comet dust with small scale. This may caused by the difference of their preserved area in comet. Otherwise, dust particles may be affected by a solar heating during their orbital revolution as dust trail. It is a considerable result for formating non-condritic dust composition. This may cause a possible enhancement of affection on thermal history for pristine objects.

Meteor science will be a new method for exploring primitive objects.

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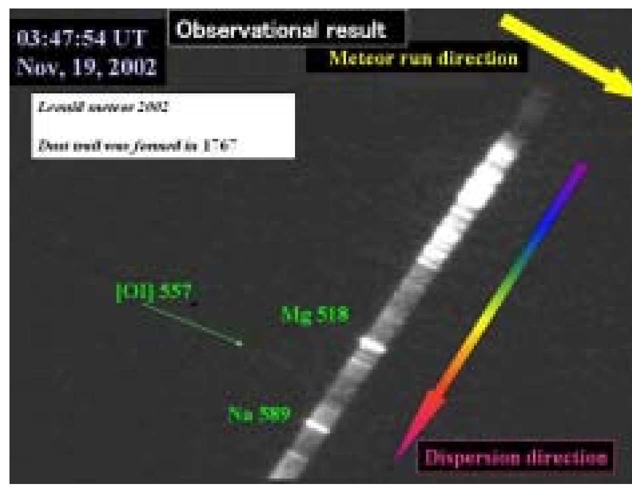

Figure1: The 2002 Leonid spectrum. Observed on airborne mission.

II Publications, Presentations

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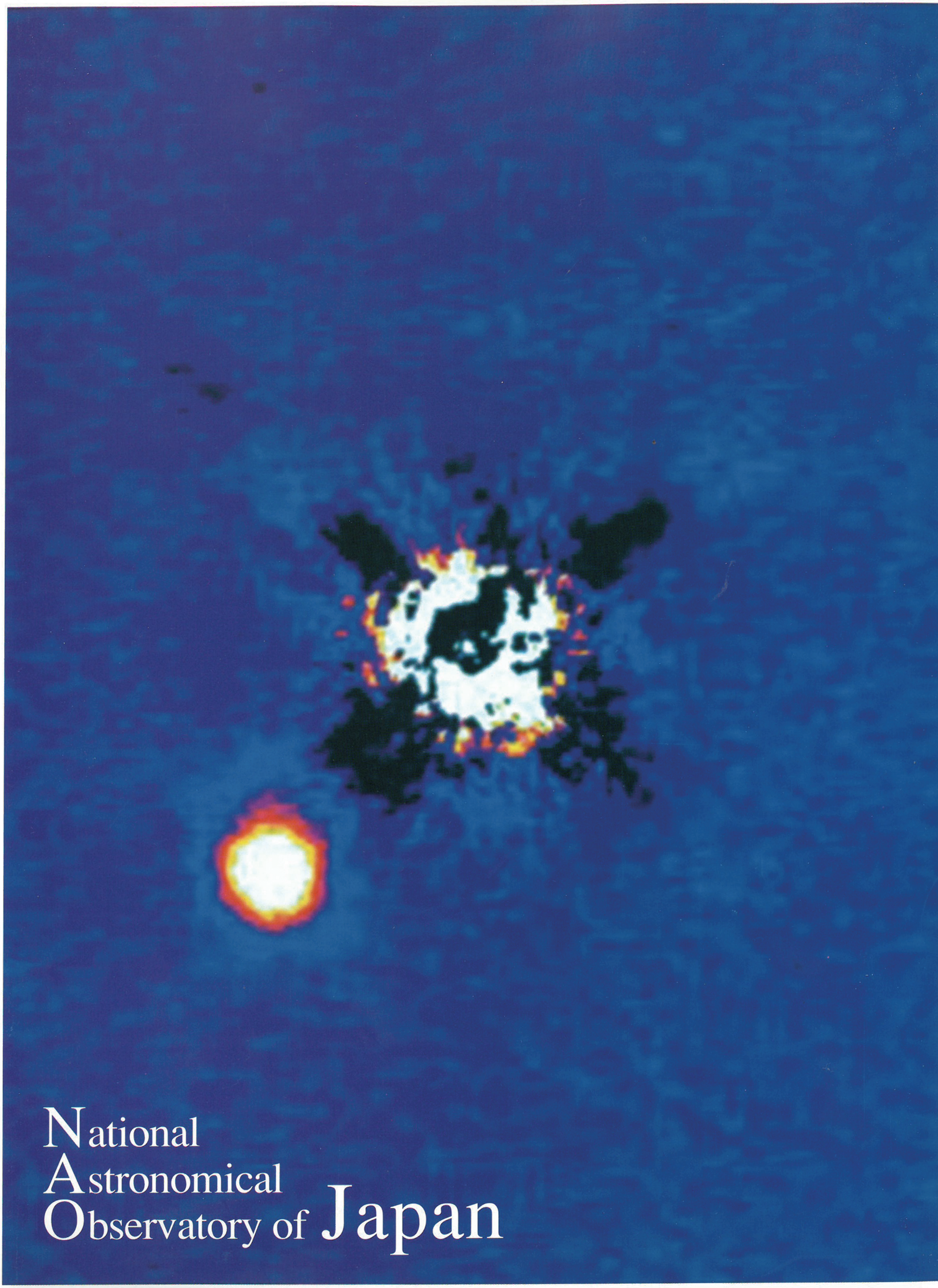
Explanation of the back cover photograph: An image of DH Tau's companion at 2.2 μm. DH Tau itself is obscured by a coronagraphic mask. The field of view is 10 by 10 arcseconds with North to the top and East to the left. The green scale bar in the image corresponds to 2 arcseconds (″), or 280 astronomical units (AU) at the distance of DH Tau (460 light years).



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