

NAOJ Future Planning Symposium 2024, Dec. 3-6

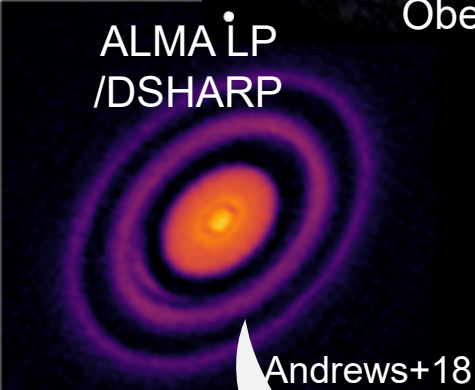
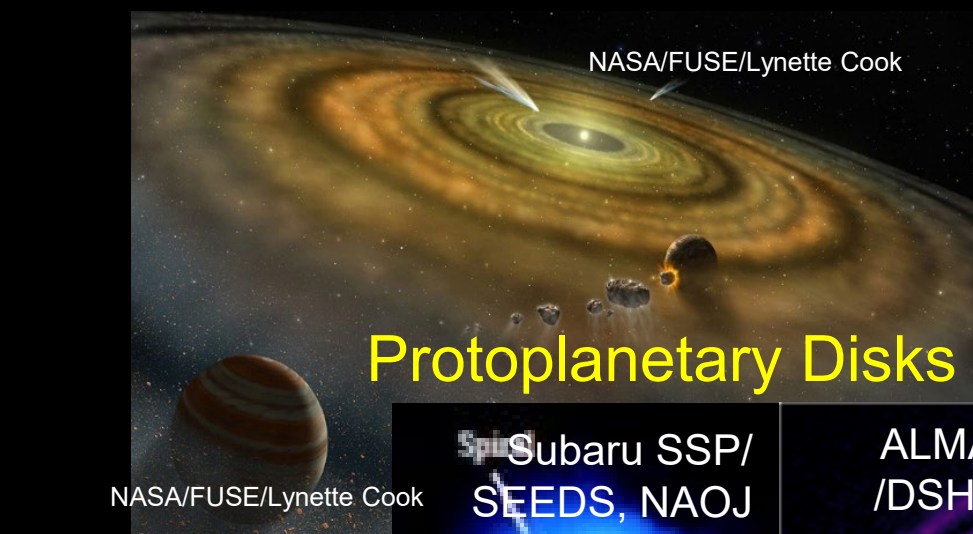
Revealing the Evolution from Star and Planet Forming Regions to Planetary Systems with Radio and Infrared Observations x Theory



Hideko Nomura (Division of Science, NAOJ)

A. Kataoka, K. Iwasaki, M. Fukagawa, C. Yasui, J. Hashimoto, F. Nakamura, N. Harada, S. Takahashi, K. Taniguchi, K. Tokuda (NAOJ), Y. Aikawa (U. Tokyo), E. Akiyama (Niigata Tech.), Y. Oya (Kyoto U.), S. Okuzumi (Science Tokyo), N. Sakai (RIKEN), H. Sano (Gifu U.), Shimonishi (Niigata U.), S. Takakuwa (Kagoshima U.), R. Tazaki (U. Tokyo), K. Tachihara (Nagoya U.), K. Tanaka (Science Tokyo), T. Tsukagoshi (Ashikaga U.), K. Tomida (Tohoku U.), S. Notsu (U. Tokyo), K. Furuya (RIKEN), M. Honda (Okayama U. Science), M. Machida (Kyushu U.), T. Muto (Kogakuin U.), M. Momose (Ibaraki U.)

From Protoplanetary Disks to Planetary Systems



Science Goals

Planet formation processes?

Material evolution?

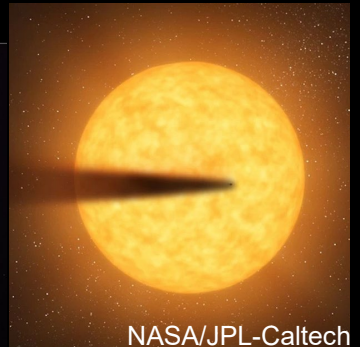
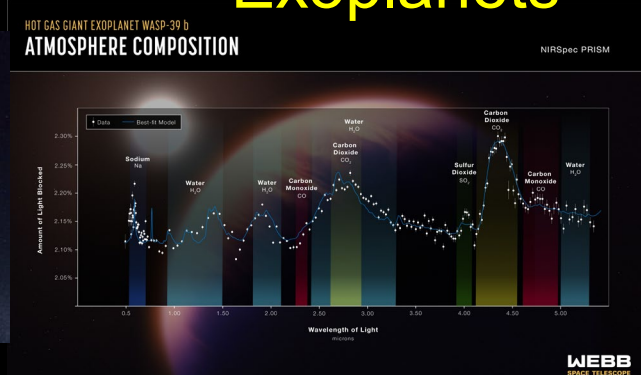
Origin of diversity?



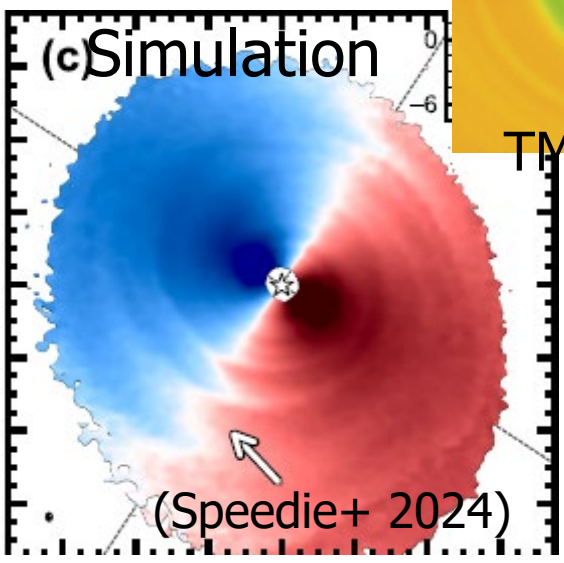
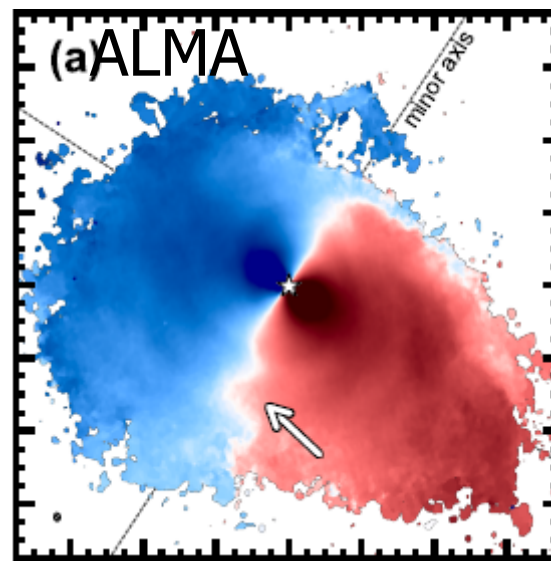
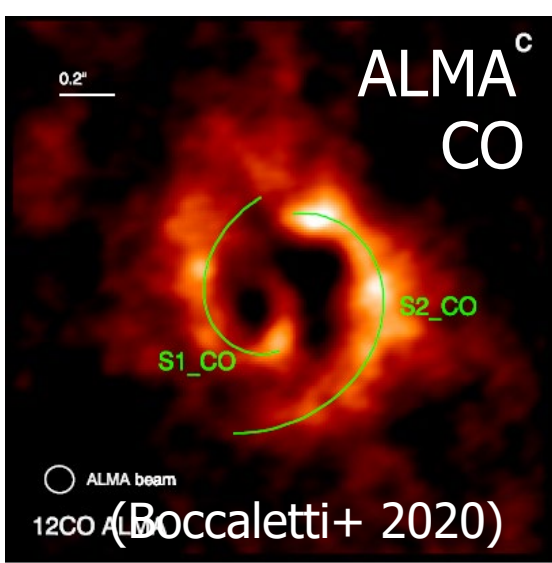
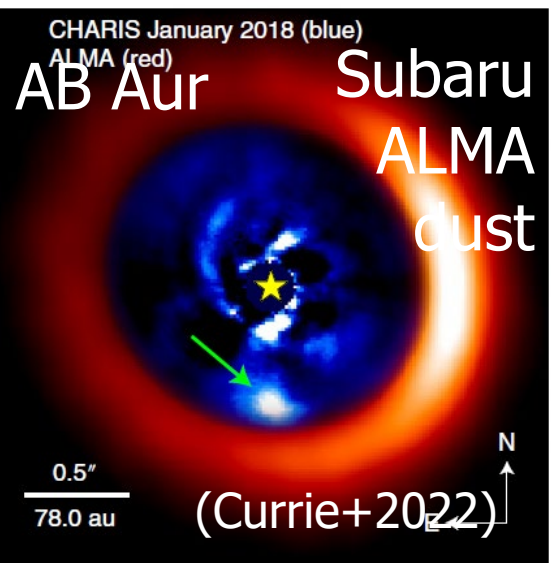
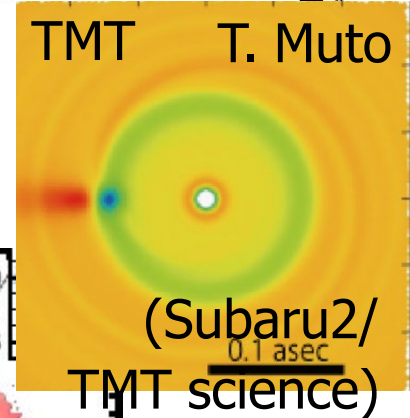
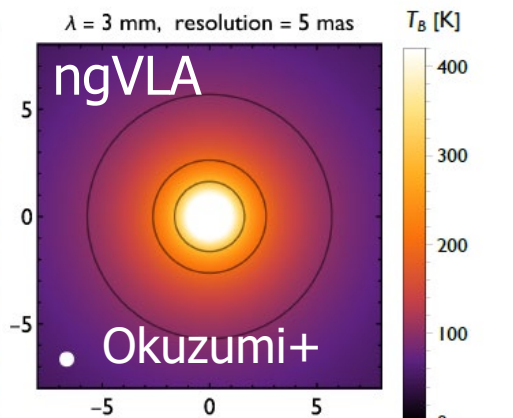
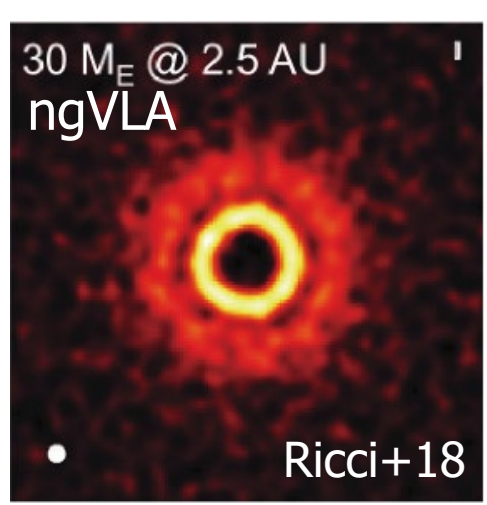
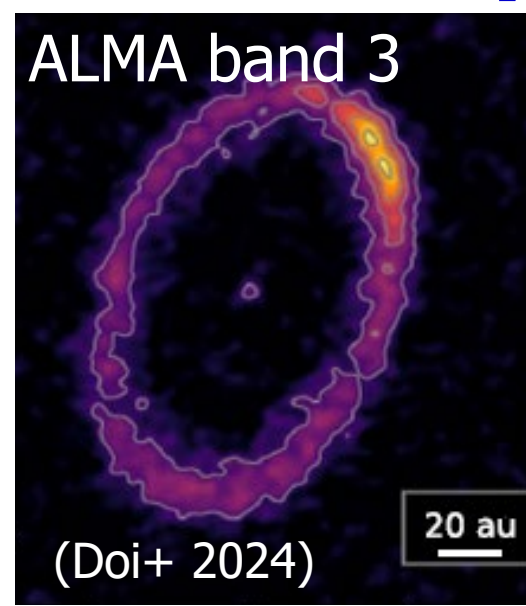
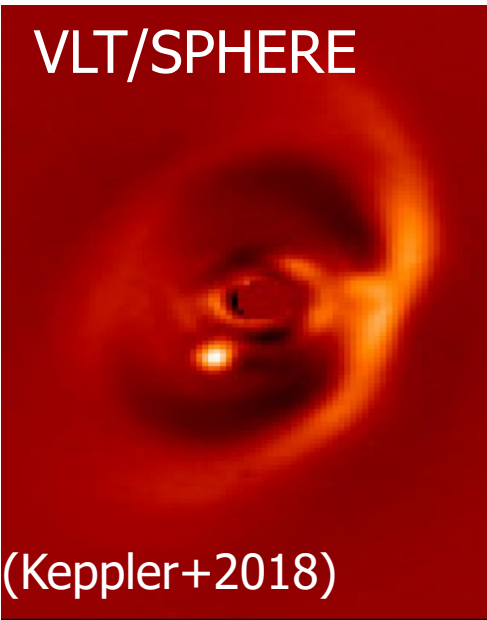
Solar System



Exoplanets



PDS 70 Formation of Planets/CPDs in PPDs

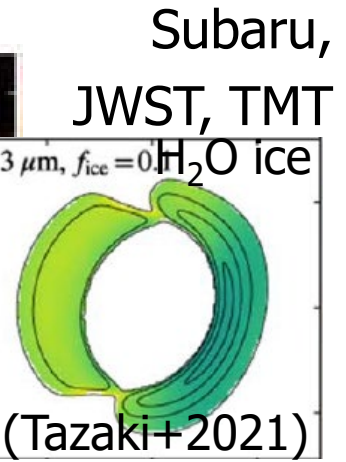
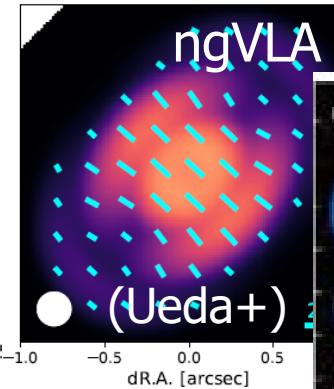
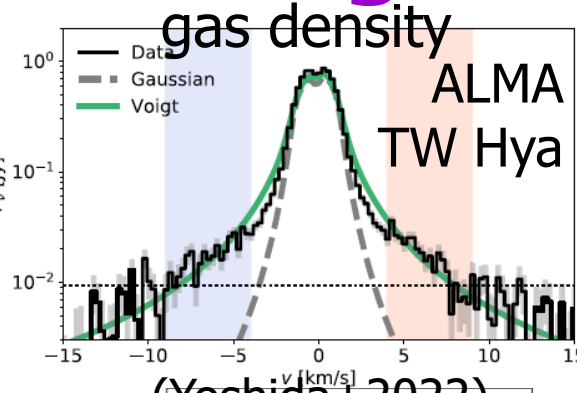
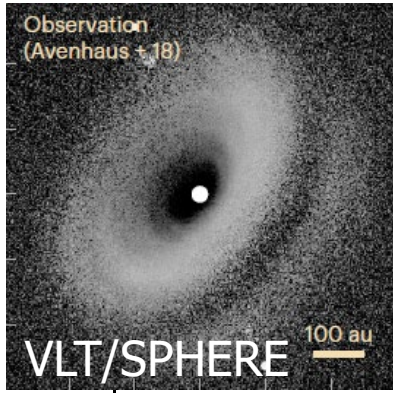


Planet formation in PPDs → ~au scale by ngVLA

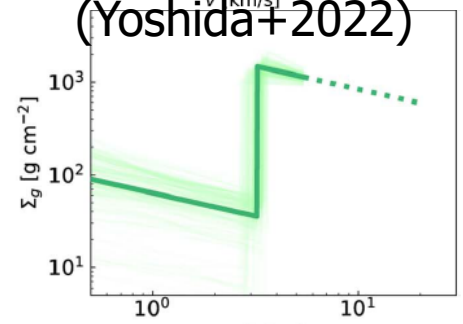
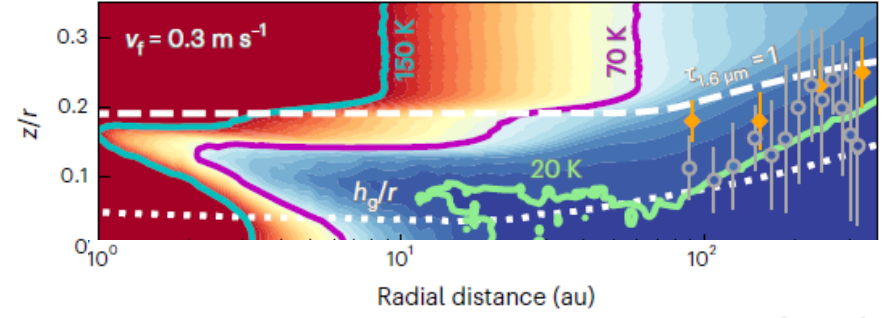
Dust, Gas & COMs: Building Blocks of Planets & Life

IM Lup
(Ueda+2024)

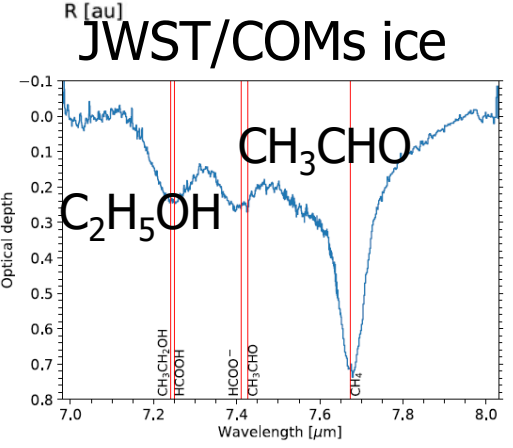
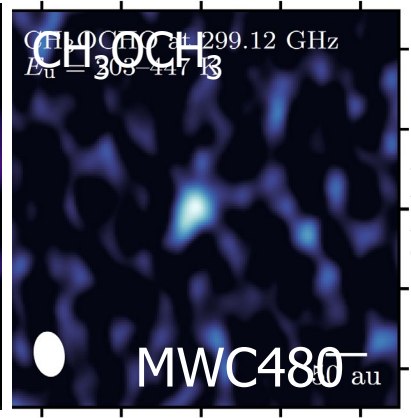
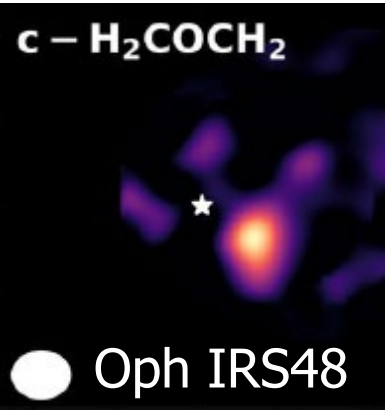
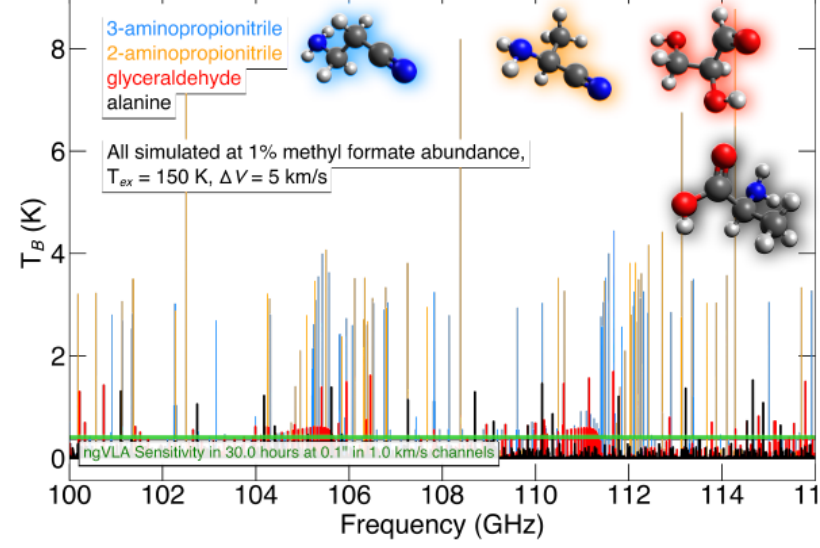
ALMA



- dust polarization



ngVLA (Wilner+ 2024)



(Booth+ 2021, 2024a,b, Brunken+2022, Yamato+2024, YangYL+2022)

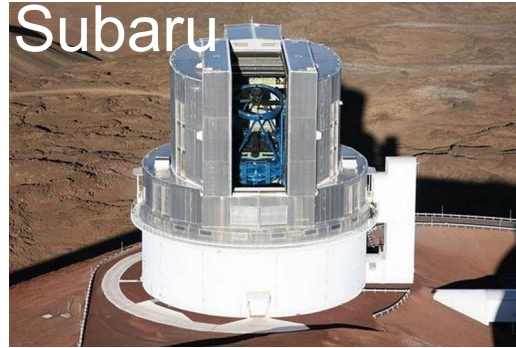
Dust properties in the inner disks & more complex mol. by ngVLA

Project Organization, Why NAOJ ?

Multi-wavelength Observations x Simulations 'Hub' for star- and planet-formation science in Japan and beyond



ALMA



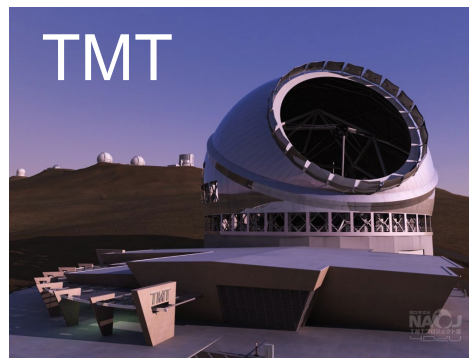
Subaru



ngVLA



CfCA



TMT

Shimonishi (Niigata U.)
Akiyama (Niigata Tech.)
Tomida (Tohoku U.)
Tsukagoshi (Ashikaga U.)
Honda (Okayama U. Sci.)
Oya (Kyoto U.)
Sano (Gifu U.)
Momose (Ibaraki U.)
Machida (Kyusyu U.)
Tachihara (Nagoya U.)
Okuzumi, Tanaka, K. (Science Tokyo)
Sakai, Furuya (RIKEN)
Muto (Kogakuin U.)
Takakuwa (Kagoshima U.)
Aikawa, Tazaki, Notsu (U. of Tokyo)



NAOJ: Nomura, Kataoka, Iwasaki, Fukagawa, Yasui, Hashimoto, Nakamura F., Harada, Takahashi, S., Taniguchi, K., Tokuda

Originality and international competitiveness:

- **Strong points:** - collaboration with planet formation theory group
- collaboration with numerical simulations, multiwavelength observations
- **Weak points:** large program requiring manpower → strategy to increase manpower, including education of postdocs & students, is needed

Current status:

- interactions through workshops and scientific collaborations
- joint postdocs/project assistant professors/assistant professors will contribute to collaborations and stable organization of workshops/schools to construct 'Hub' for star- and planet-formation science

Science investigations until 2033:

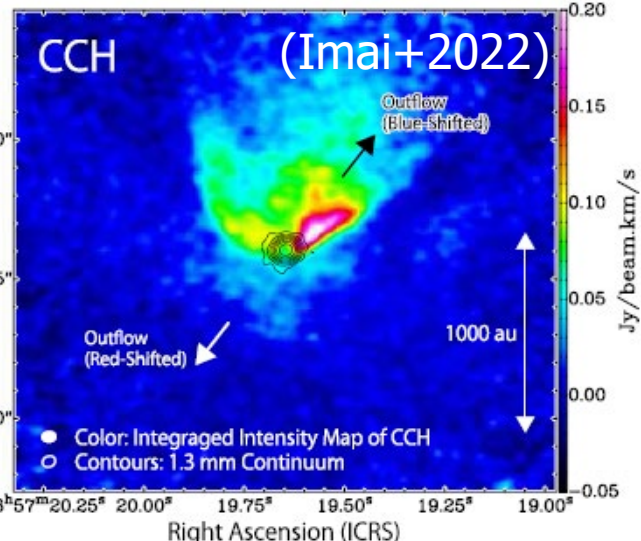
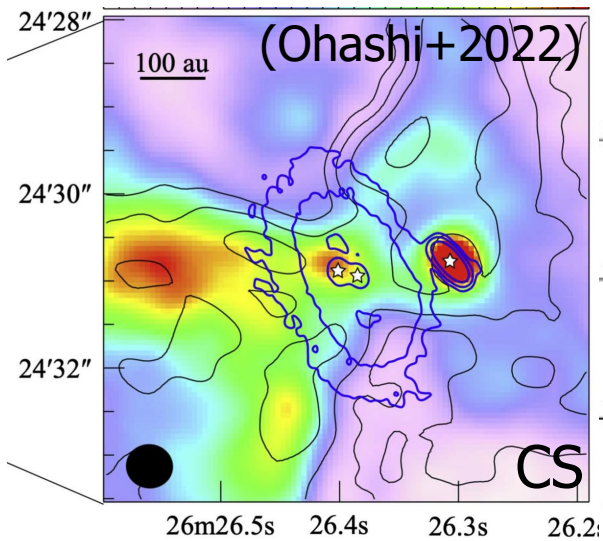
Intensive research project to prepare for & conduct obs. with ALMA/WSU (synthetic obs. of molecular lines, dust emissions, etc.)

Cost assessments, budget line and status:

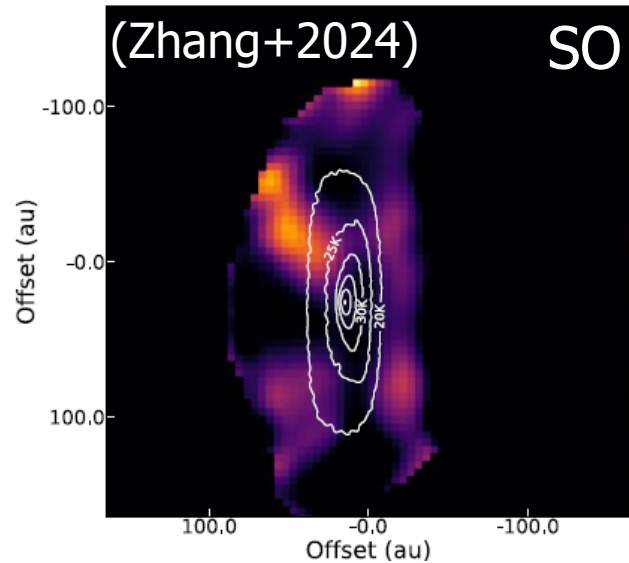
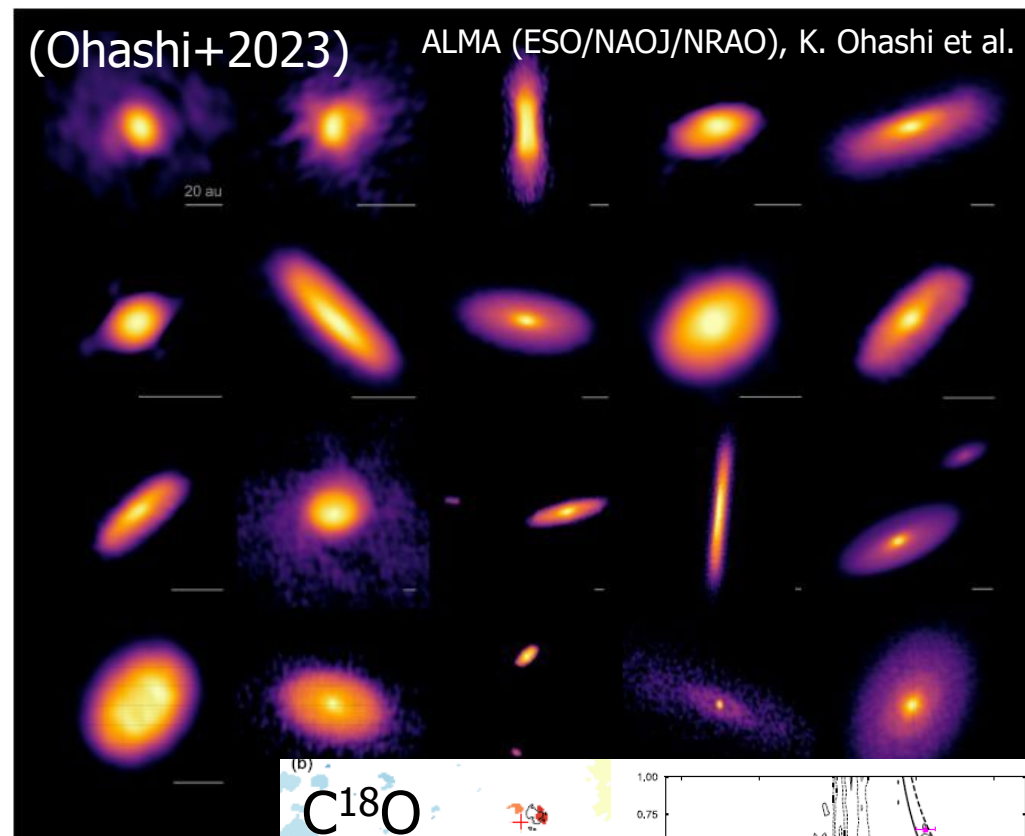
~ 20 M yen / year for 3-4 joint postdocs/project assistant professors, depending on candidates (KAKENHI + NAOJ budget for sustainable operation)

Formation of Planet-Forming Disks

ALMA LP/FAUST (PI: S. Yamamoto)

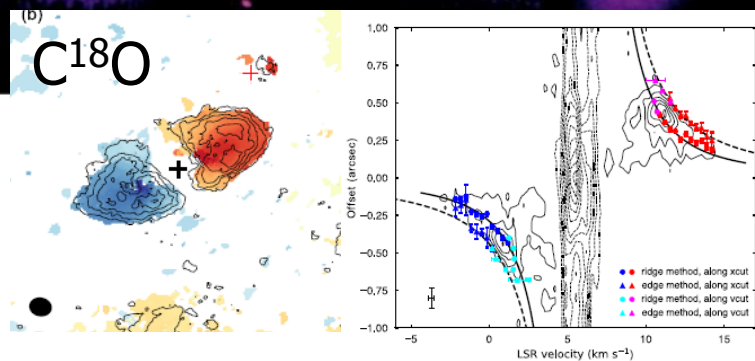


ALMA LP/eDisk (PI: N. Ohashi)



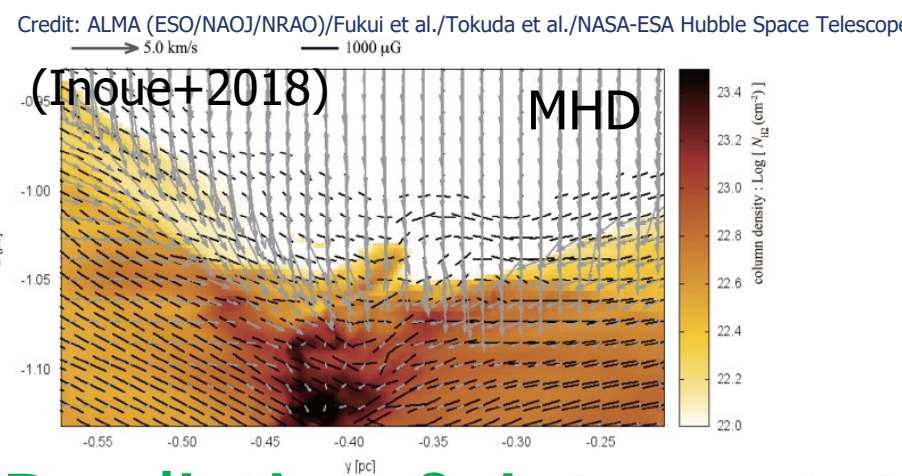
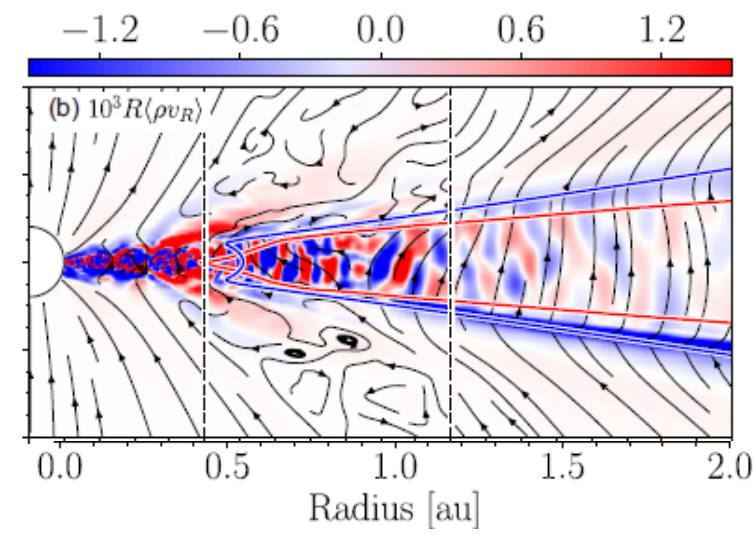
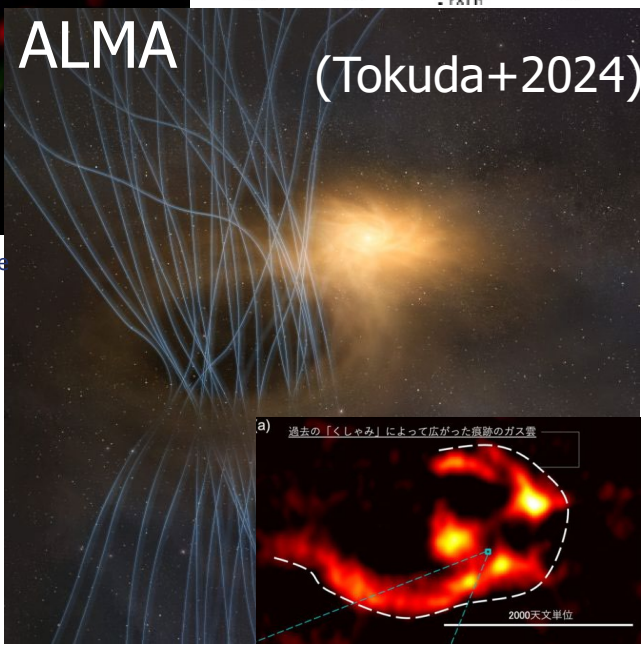
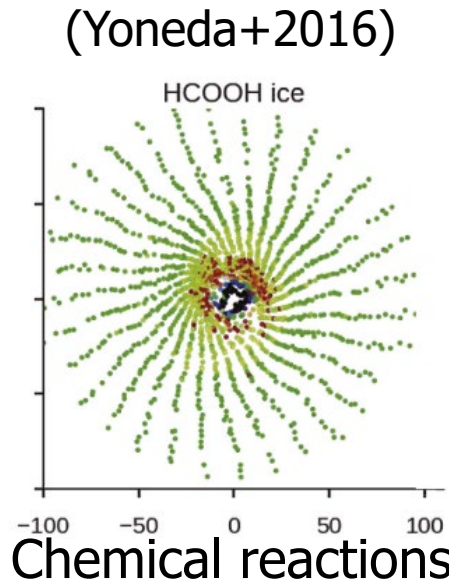
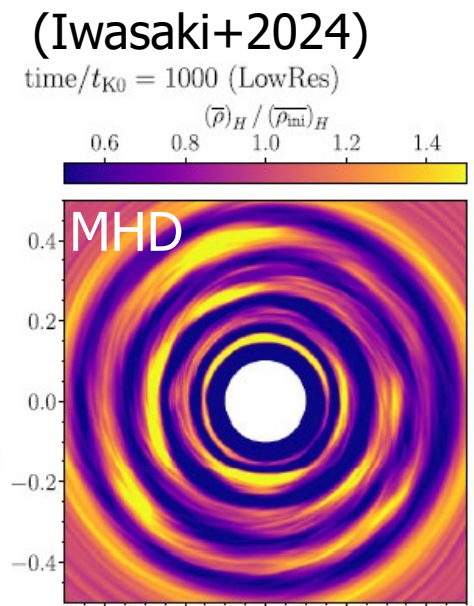
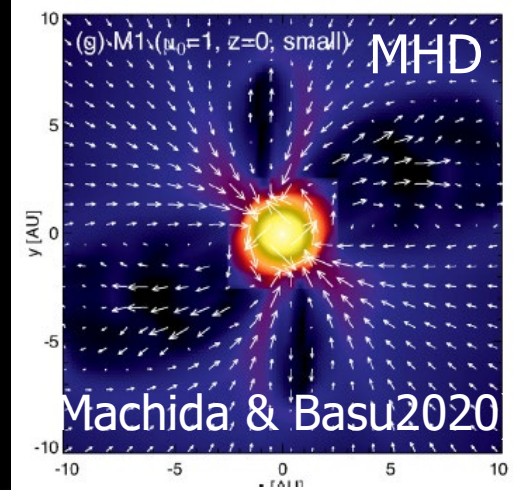
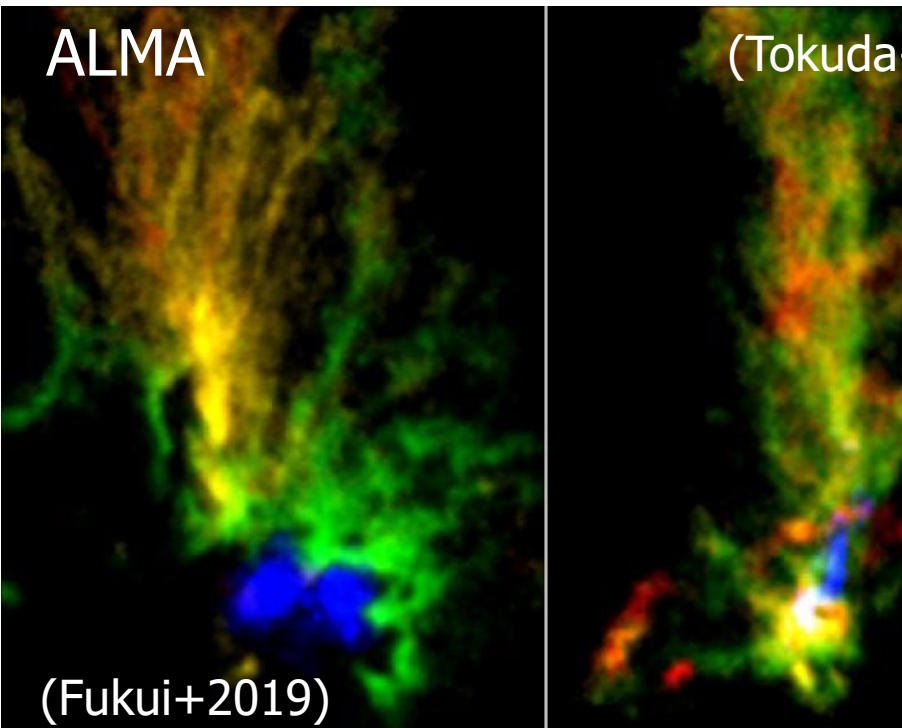
(Notsu+, in prep.)

→ ngVLA



Chemical & physical properties of formation of planet-forming disks

Observations x Dynamical Simulations



ALMA (ESO/NAOJ/NRAO), K. Tokuda et al.

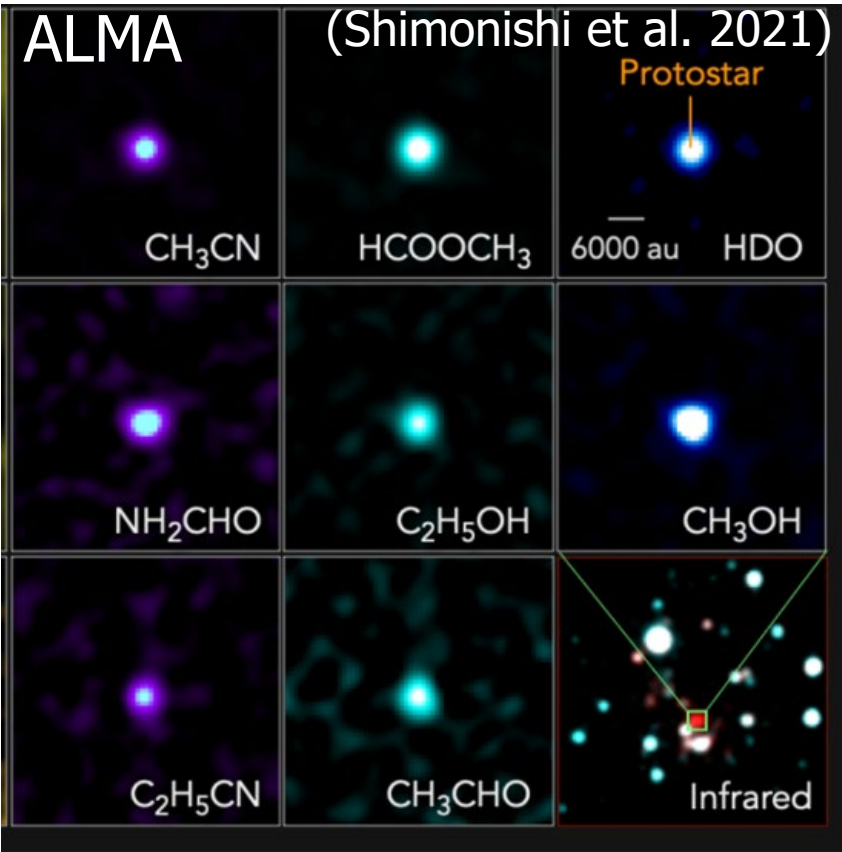
Prediction & interpretation of observations by theory/simulations

Environmental Effects : Origin of Diversity

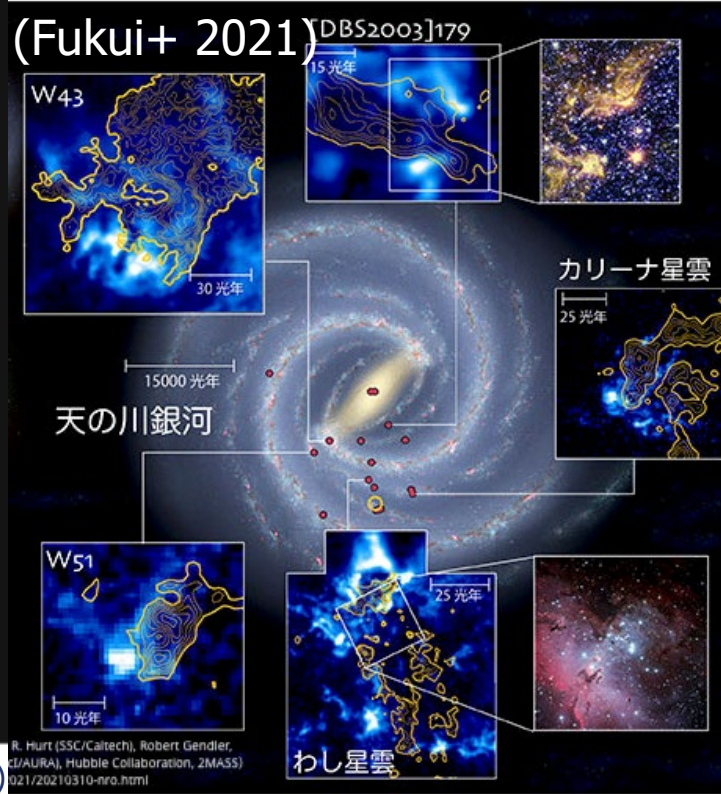
Effects of low-metallicity, cosmic-rays, X-rays, UV radiation (starbursts, AGNs), turbulence, magnetic fields, etc. ?

Effects of history of Milky Way Galaxy ?

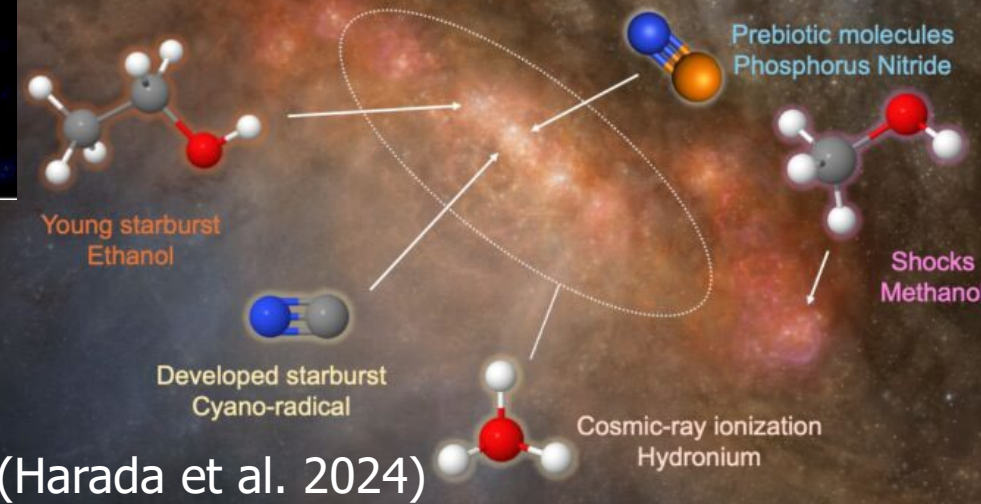
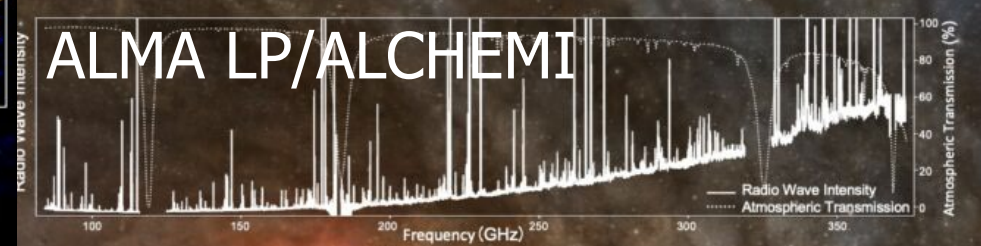
ALMA (ESO/NAOJ/NRAO), N. Harada et al.



ALMA (ESO/NAOJ/NRAO), T. Shimonishi (Niigata University)



Nagoya University, NAOJ, NASA, JPL-Caltech, R. Hurt (SSC/Caltech), Robert Gendler, Subaru Telescope, ESA, The Hubble Heritage Team (STScI/AURA), Hubble Collaboration, 2MASS



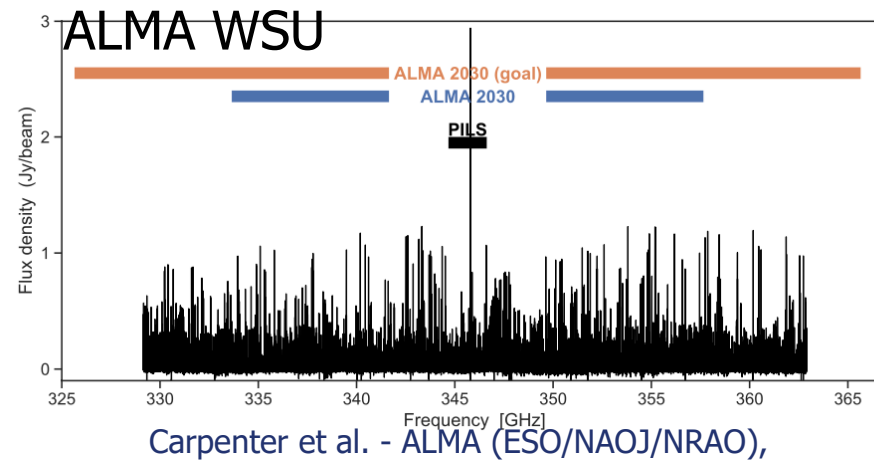
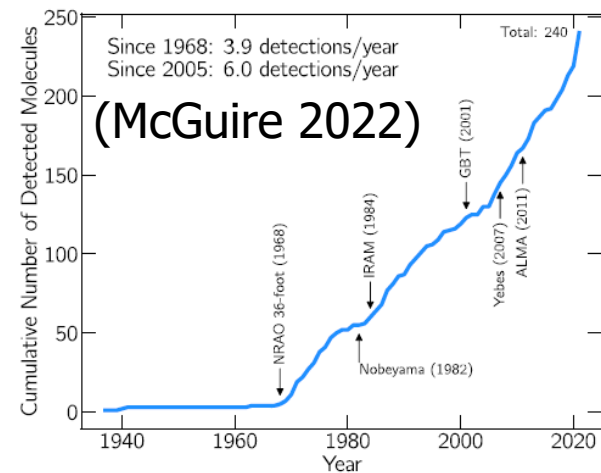
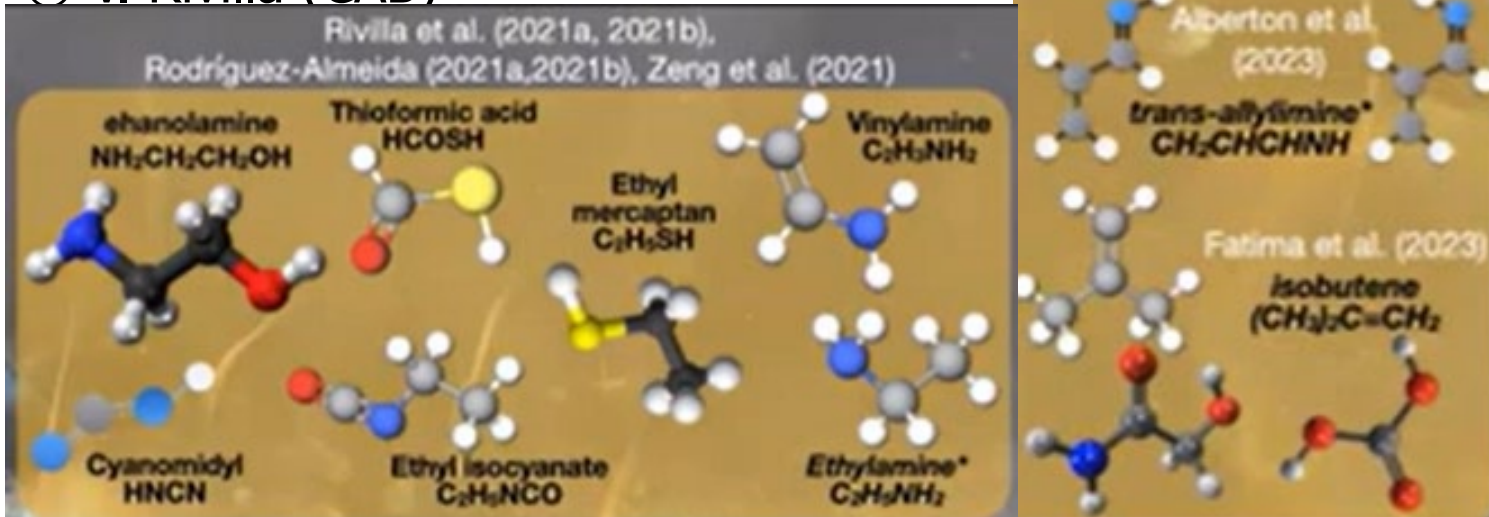
(Harada et al. 2024)

Survey of star-forming regions in MW and nearby galaxies
 → ALMA, ngVLA, LST/AtLAST

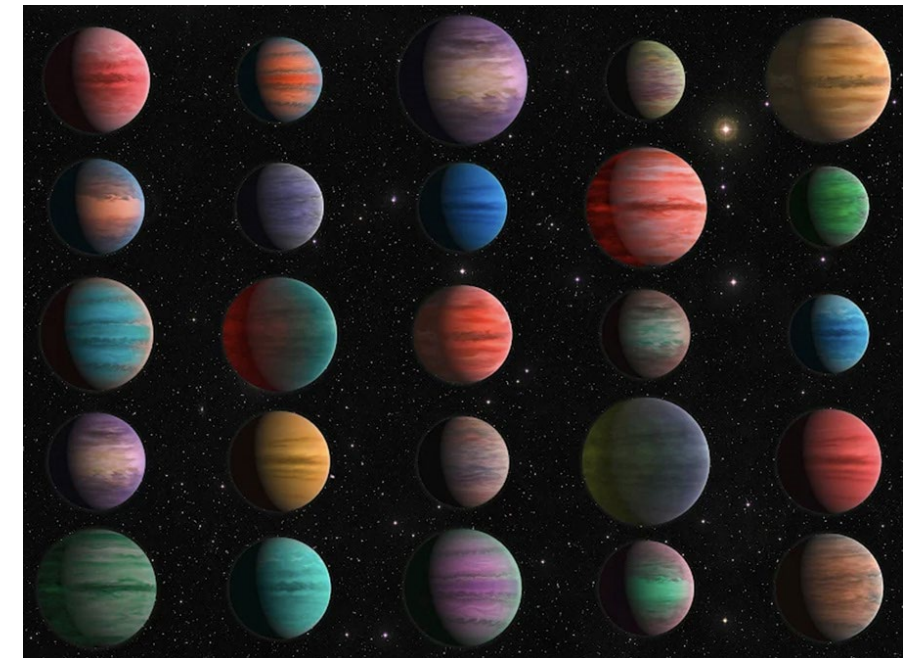
Habitable Worlds: Prebiotic Mol. & Exoplanets

© V. Rivilla (CAB)

From planet-forming disks
to planetary systems
→ habitability of
exoplanetary systems
Synergy with Roman, Ariel,
TMT,



ALMA WSU: boosts line survey efficiency
→ more prebiotic molecules will be found
⇔ Solar system materials



ESA/Hubble, N. Bartmann

Summary

- Formation of planetary systems, material evolutions, and their diversity
- Understanding planet formation in disks @ \sim au scale, properties of dust, gas, and organic molecules in the inner disks by ngVLA
- Improved sensitivity observations & line survey by ALMA/WSU
- Synergy with infrared observations (Subaru, JWST, TMT, GREX-PLUS, PRIMA) and theory/simulations (CfCA) is essential
- Understanding diversity of planetary systems:
 - chemical and physical properties of formation of planet-forming disks
 - environmental effects, such as, metallicity, cosmic-rays, X-rays, UV radiation, turbulence, magnetic fields, etc., including history of MW
- Synergy with solar system & exoplanetary sciences \rightarrow origin of habitability
- Construct 'hub' among NAOJ projects, and connection of science between NAOJ and other institutes (domestic and international)