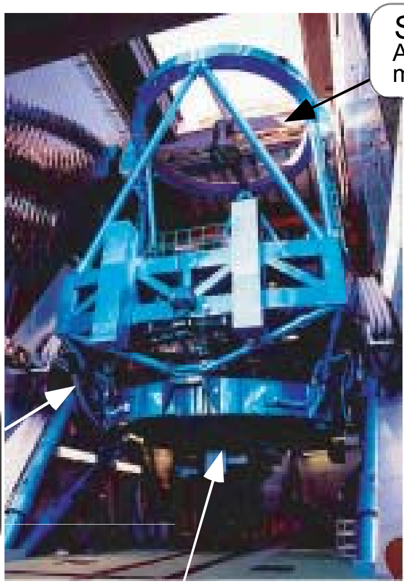
# Facts underlying the ultrahigh accuracy of the Subaru Telescope

The Subaru Telescope is a large-scale optical/infrared telescope located near the summit of Maunakea (4200 m elevation) on Hawai`i Island, where exceptional observational conditions are available. It features the large monolithic primary mirror, with an impressive 8.2 m effective aperture. In addition to the size of its light-collecting mirror, with its numerous cutting-edge technological innovations used to achieve revolutionary observation performance. These innovations include active optics to maintain a high-precision mirror surface, a dome for suppressing air turbulence, original observational instruments prepared for each of the four foci, and a system to automatically switch those observational instruments for efficient use.

Assembling a paper model of this telescope is an opportunity to understand its cutting-edge structure more deeply and think about the secrets behind its ultra-high precision.



**Spider:**
A thin shape to minimize blocking

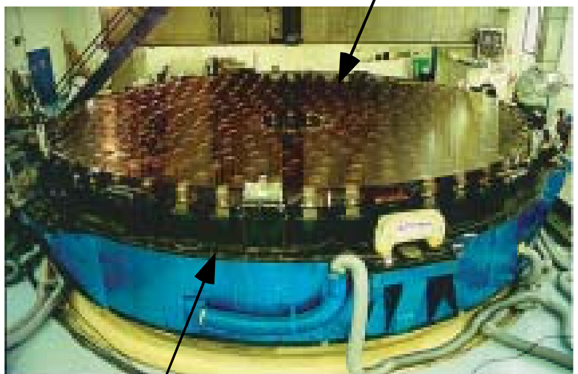
**Serrurier truss:**
The strength of the frame is designed so that the relative positions of the primary mirror and secondary mirror remain unchanged as the structure bends.

**Wavefront adaptive optics system:**
Stops the twinkling of the stars in the infrared domain.

## The Subaru Telescope's main specifications

Primary mirror diameter : 8.2 m (focal length: 15 m)
Weight : 555 metric tons (total rotating portion)
Polishing accuracy : 0.012 μm
Tracking accuracy : 0.1 arcsec (1/36,000 of a degree) or less
Best angular resolution achieved : 0.2 arcsec (without adaptive optics)
Maximum slewing speed : 0.5 degree/s
Mount : Alt-azimuth

**Thin-meniscus mirror:**
Made of ultralow-thermal-expansion (ULE) glass, this mirror took 3 years to manufacture. Another 4 years were spent for high-precision polishing and then an aluminum evaporation coating was applied.



**Active support mechanism:**
The primary mirror surface shape is controlled in real time with high precision by 261 actuators.

**Cylindrical dome:**
Designed using numerical simulations and water flow experiments so that it shuts out external air turbulence while efficiently removing internal heat.

Designed by Seiichi Sakamoto (NAOJ)

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Tools and materials to prepare:

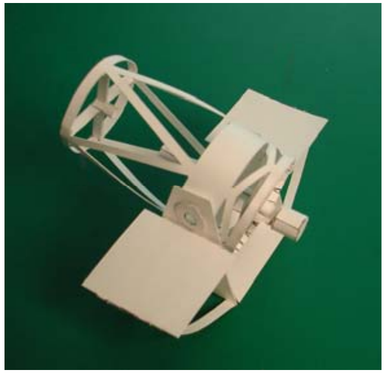
Model sheets (×2), these instruction sheets, box cutter or scissors, ruler, aluminum foil, glue (wood glue works well), thick paper (recommended but not required)

Preparation:

・Paste the two model cutout sheets onto Kent paper or similar thick paper.
・Paste aluminum tape on the back of the primary mirror and secondary mirror.
・ Cut along the bold lines, including the holes marked with an “X.”
 * Time required: Two hours or more

Crafting instructions

1. Cut out the Cassegrain instrument rotator and primary mirror cell. Cut the notches into the Cassegrain instrument rotator, roll it into a cylinder, and glue it together. Insert the end with tabs into the primary mirror cell hole and glue the two pieces together. At this point, the longer section should stick out from the back side of the cell.



2. Cut out the primary mirror and baffle from the model cutout sheet. Cut out the holes in the baffle and insert the baffle into the hole of the primary mirror in the same manner as the instrument rotator in Step 1, and glue them together.

3. Glue the products of Step 1 and Step 2 together so that the tabs on the rotating mechanism and baffle face each other.

4. Cut out the body tube and altitude axes (inner and outer). Glue the altitude axis (outer) to the outside of the body tube. Next, from the inside of the body tube guide the tabs on the altitude axes (inner) through the holes of the body tube and fold them open. Glue the tabs on the primary mirror cell to the bottom of the body tube. At this point, make sure the holes in the body tube and the holes in the baffle line up.

5. Cut out the spiders, mountain-fold them, and join them together at their centers.

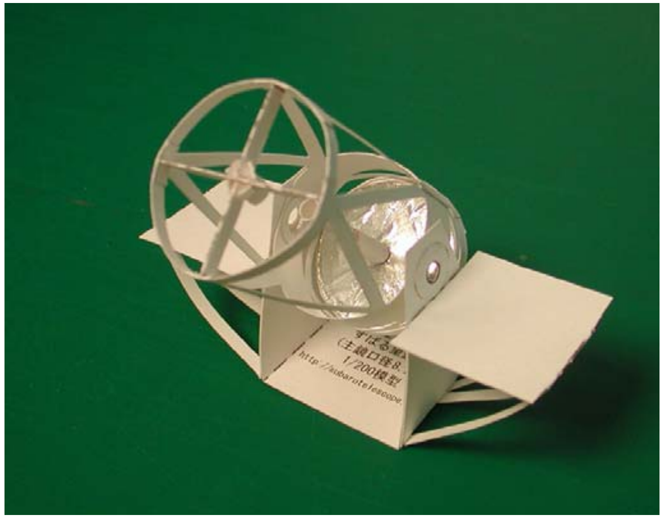
6. Cut out the secondary mirror and the secondary mirror support. Curl the support into a cylinder, and then glue the shorter tabs to the secondary mirror. <Secondary mirror unit>

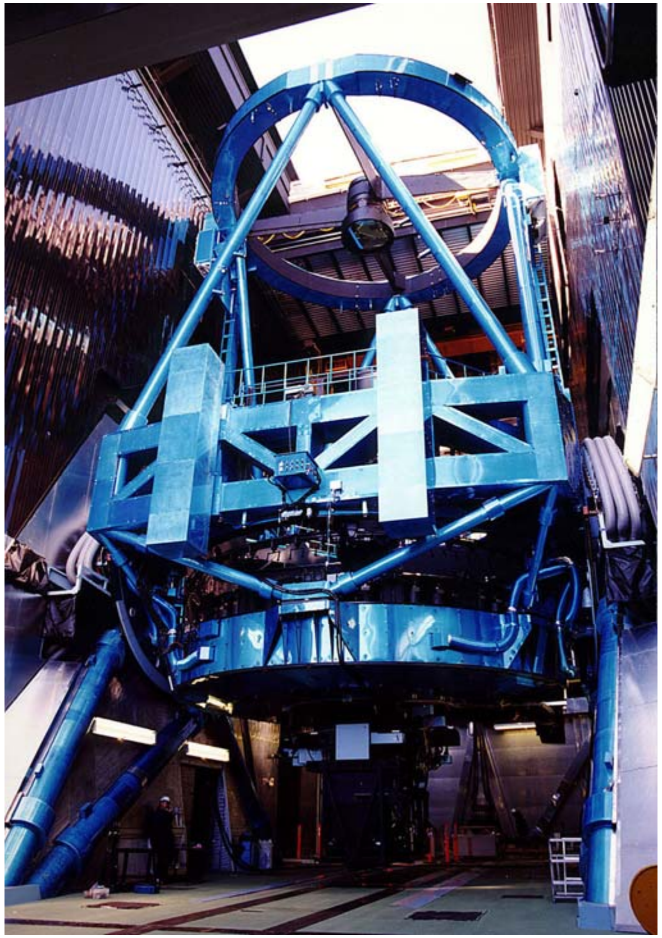
7. Cut out the mount, Nasmyth platforms, and altitude axis (outer covers). Assemble the Nasmyth platforms first. Pass the tabs of each of the altitude axes (inner) of the assembly made in Step 4 through the holes in the mount; fold the tabs down outwards from the hole and then glue the altitude axis (outer covers) in place covering them. This will join the telescope main body and the mount together.

8. Cut out the parts for the Cassegrain instrument. Curl the side wall into a cylinder and glue it.Glue the part without a hole to the larger tabs, and the part with the hole to the smaller tabs, respectively. Push the assembled Cassegrain instrument into the lower part of the Cassegrain instrument rotator.

9. Cut out the Suprime-Cam piece, curl it into a cylinder, and glue it. This unit is interchangeable with the secondary mirror unit depending on your taste.

Finishied!





The actual Subaru Telescope

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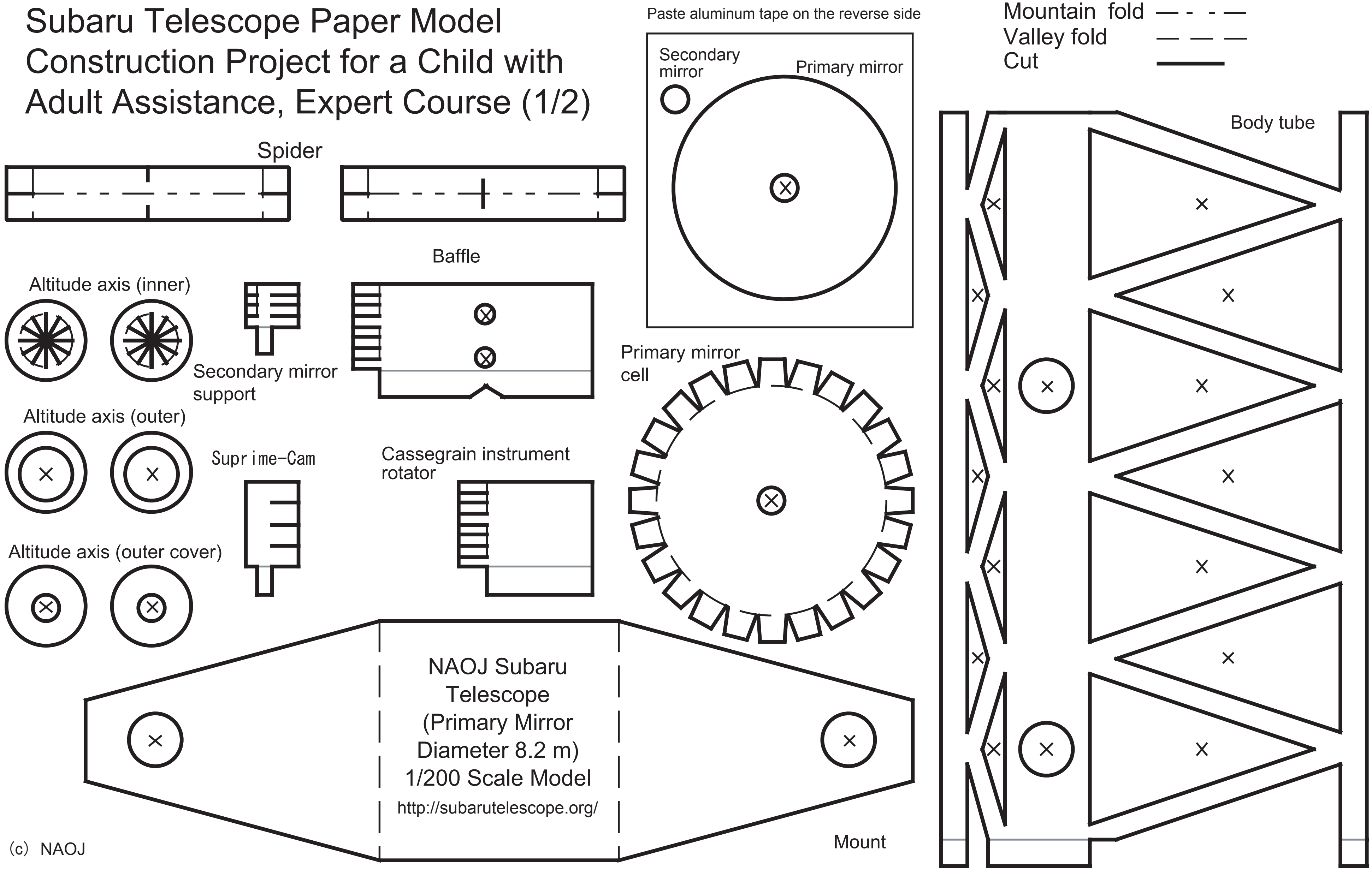
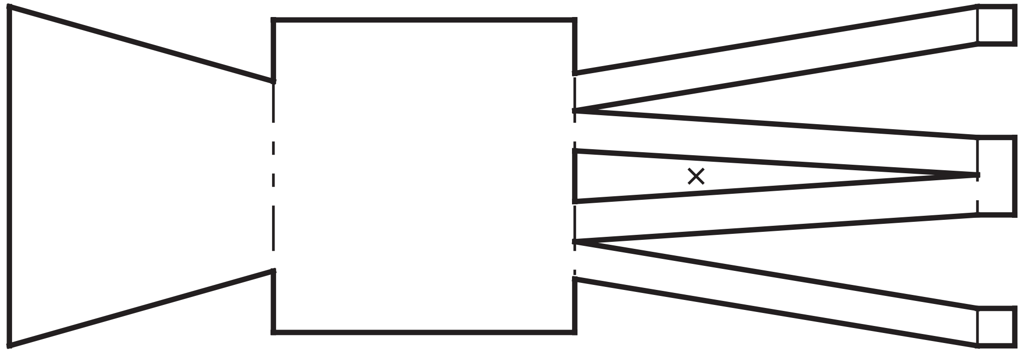
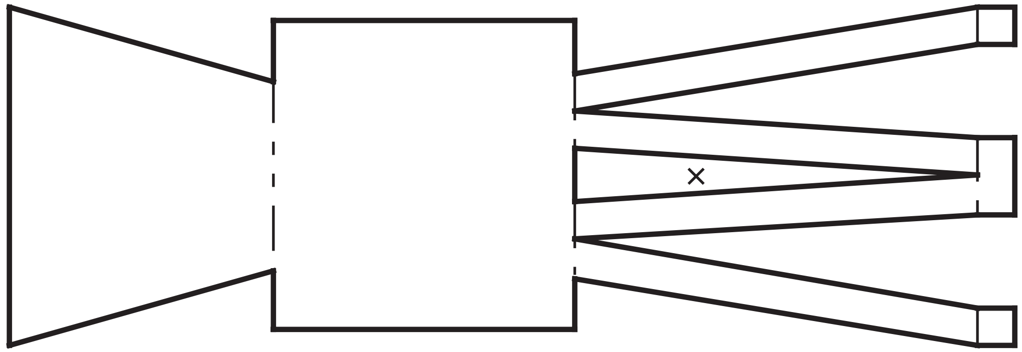


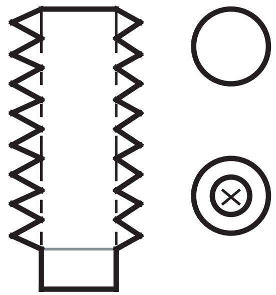
# Subaru Telescope Paper Model Construction Project for a Child with Adult Assistance, Expert Course (2/2)



Nasmyth platform



Cassegrain instrument



2cm = 4m

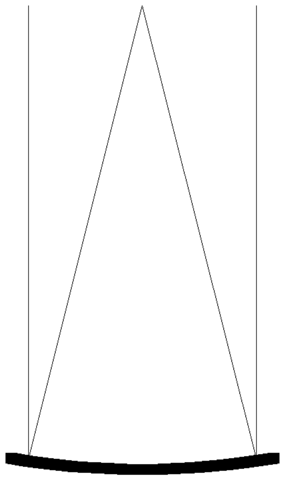
# Telescope Fun Facts
# About the types of foci

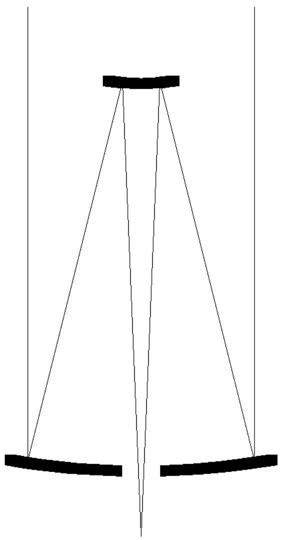
Reflector telescopes have various types of foci. The following sections introduce each focus type and their special features using the Subaru Telescope as an examples:

## 1.Prime focus

This is the point at which parallel rays that enter the (parabolic) primary mirror at normal incidence produce an image. It is characterized by its wide field of view.

At the Subaru Telescope, a wide-field camera called “Suprime-Cam (Subaru Prime Focus Camera)” can be attached at the prime focus. There are not many large-aperture telescopes that are designed to accept an instrument at the prime focus, so the Subaru Telescope is well known for this feature.





## 2. Cassegrain focus

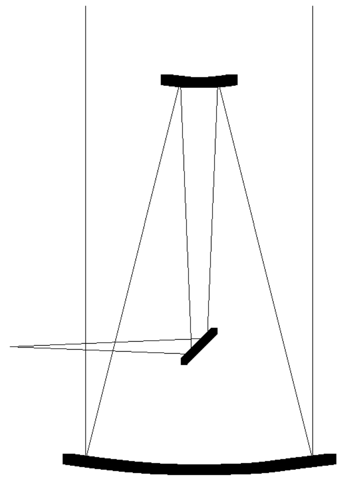
A (hyperbolic) secondary mirror is placed right in front of the prime focus, focusing the image of the target down through the hole in the center part of the primary mirror, to a location where a fairly complex instrument can be attached.

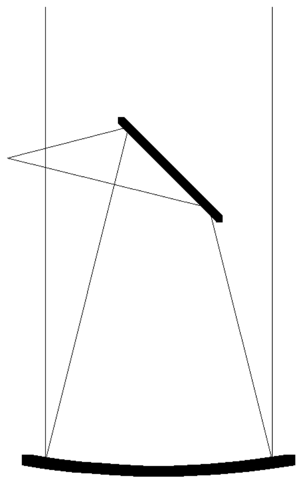
For the Subaru Telescope, the following instruments can be attached among others: Cooled Mid-Infrared Camera and Spectrometer (COMICS), Multi-Object Infrared Camera and Spectrograph (MOIRCS), and the Faint Object Camera and Spectrograph (FOCAS).

## 3. Nasmyth focus

A diagonal mirror is placed in front of the Cassegrain focus, and the optical axis is aligned with the altitude axis or declination axis to form an image of the target. Since the instrument position does not change at this focus, even large, heavy instruments can be installed.

The Subaru Telescope features two Nasmyth foci, one equipped with the High Dispersion Spectrograph (HDS) and the other with the Infrared Camera and Spectrograph (IRSC), High Contract Instrument for the Subaru Next Generation Adaptive Optics (HiCIAO) and Adaptive Optics (AO).





## 4. Newtonian focus

This is a variant of the prime focus. A diagonal mirror is placed right in front of the prime focus, to focus the target image to a point to the side of the body tube. The structure is simple and can be made inexpensively, which is why this focus is often used for amateur telescopes. However the drawbacks are that the secondary mirror is a little bigger and asymmetrical instruments are attached near the tip of the body tube, which make the telescope prone to losing balance.

The Okayama Astrophysical Observatory 1.88-m Reflector Telescope can mount instruments at this focus, but the Subaru Telescope does not include this feature.

## 5. Other foci

The Coude focus is based on the Cassegrain focus, using multiple diagonal mirrors to the direct light. It has the benefit that the focus position is not affected by the telescope position at all. Also, there are many variants such as the Gregorian focus, which places a concave secondary mirror right behind the prime focus and focuses the target image through a hole in the center part of the primary mirror.