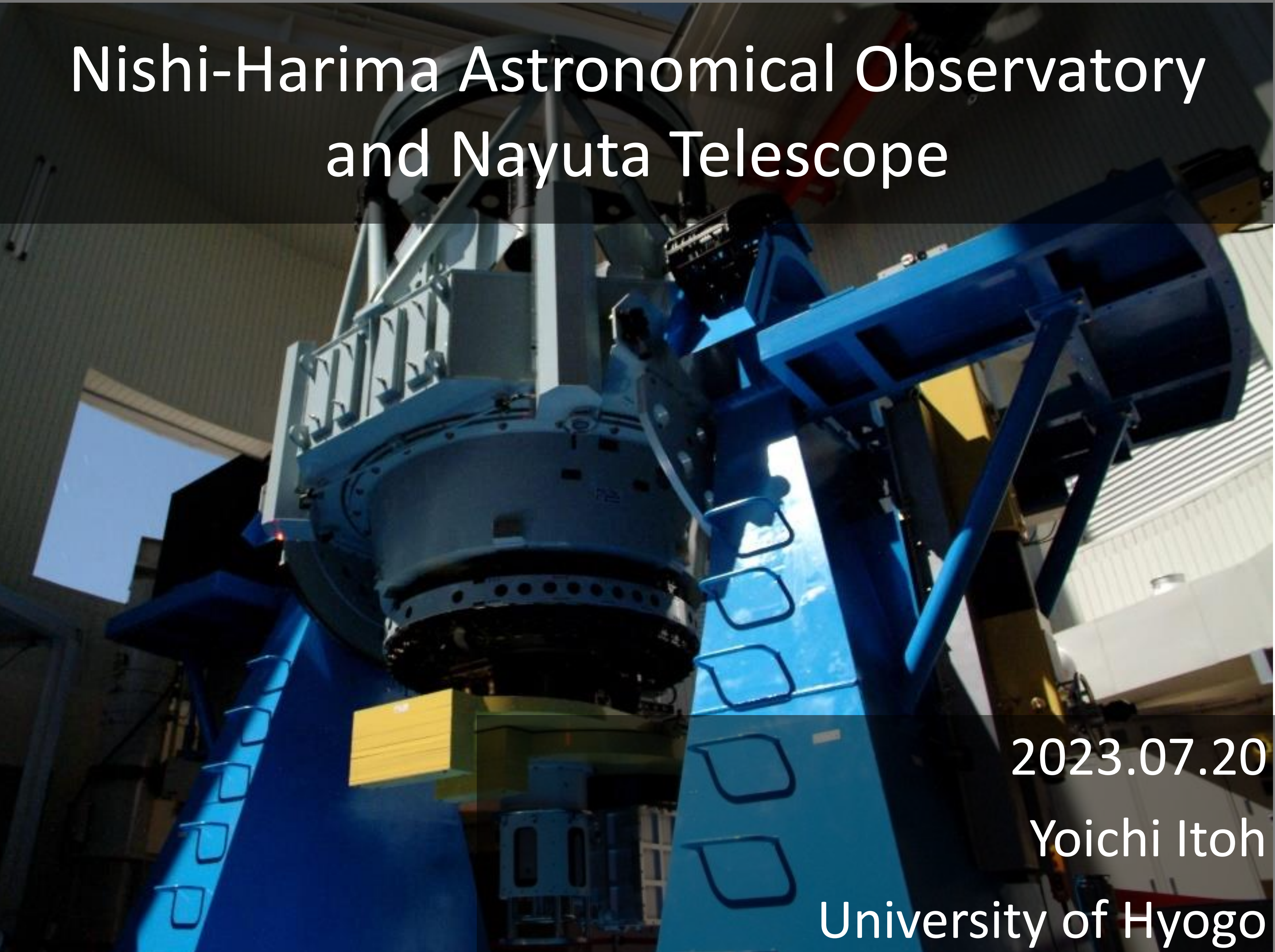
Nishi-Harima Astronomical Observatory and Nayuta Telescope

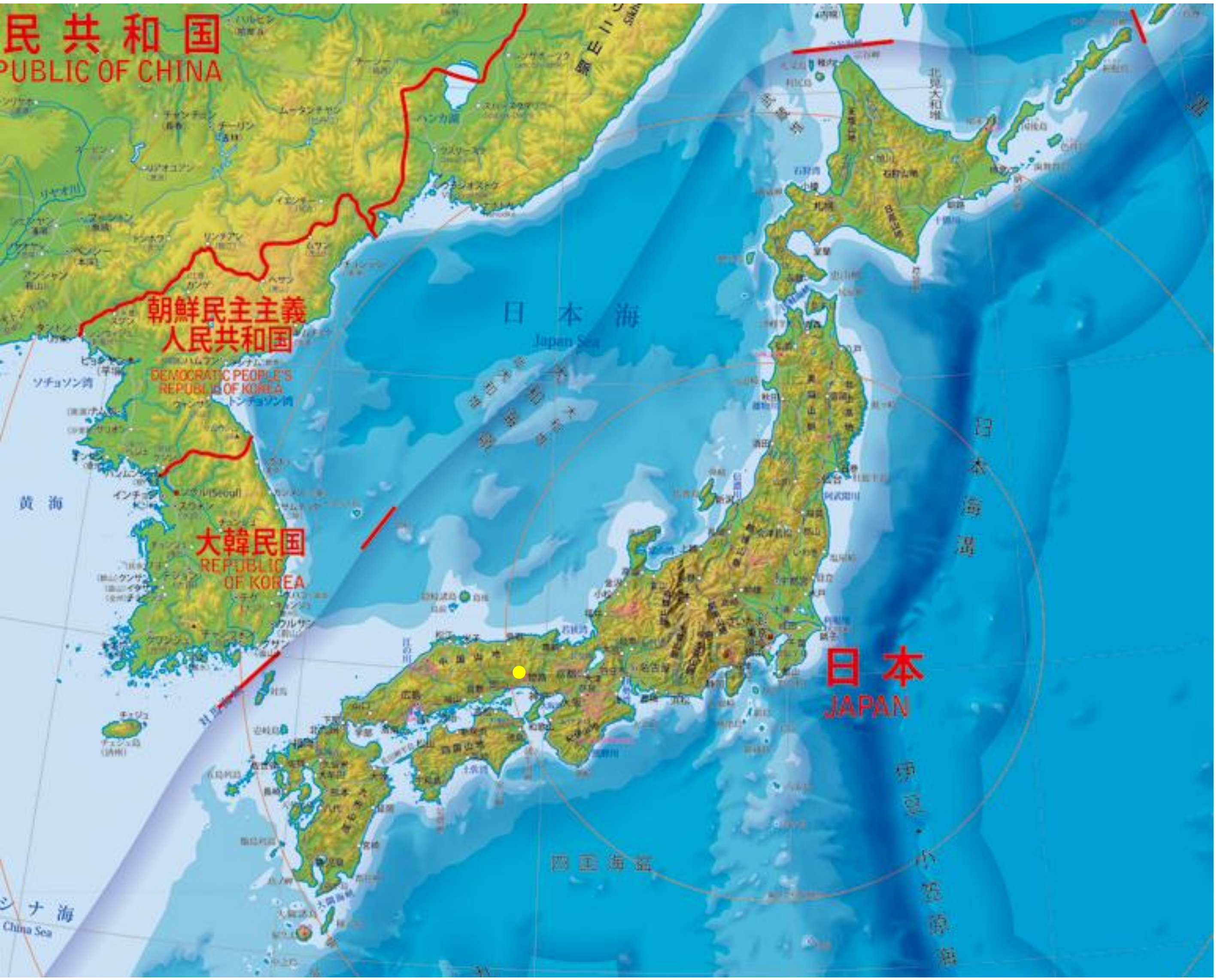


2023.07.20

Yoichi Itoh

University of Hyogo

1. Nishi-Harima Astronomical Observatory



- Hyogo pref.
- Since 1990

1. Nishi-Harima Astronomical Observatory

Elevation

430 m

3 staffs

1 technician

7 PDs

9 students

2. Nayuta Telescope

- 2m optical telescope
- Japan’s 2nd largest telescope
- Built in 2004 by Mitsubishi
- Alt-azimuth
- 3 foci

2. Observations

- 358 nights per year
- 21:00 --- morning
- Open-use program
  - 50 nights for 15 groups
  - Open even for foreigners (Taiwan, Korea, Turkey)
- Cooperative observations with other universities

- Gravitational wave
- Spectroscopic monitoring
- Gamma-ray burst

2. Instruments

- Optical medium-resolution spectrograph
- Wide field grism spectrograph
- Near-infrared 3 color camera
- Optical polarization camera

3. 60cm Telescope

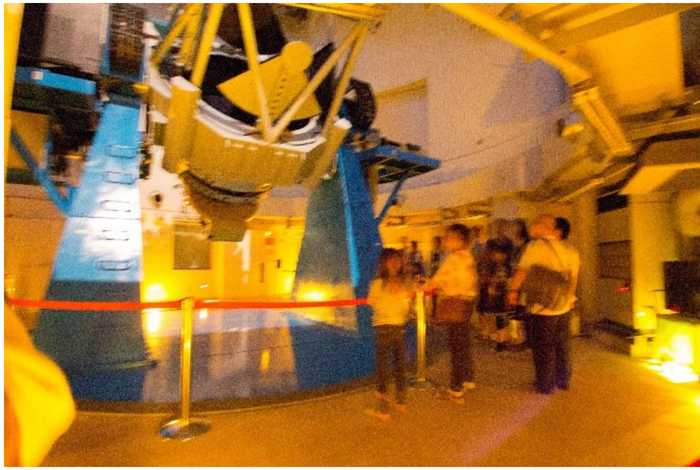
- 60cm optical telescope
- Built in 1990 by Nishimura
- Equatorial
- 1 focus
- CCD camera

4. Education for high-school students

- 40 high-schools used our astronomy program.
  - Daytime observation of bright stars and the Sun
  - Lectures
  - Observation with 60cm telescope

5. Outrearch activities

- Star gazing tour with Nayuta telescope
  - 19:30-21:00
  - 330 days / year
  - 12,000 people attended last year



- Lodges
  - 6 two bed rooms
  - 6 large rooms (20 person / room)

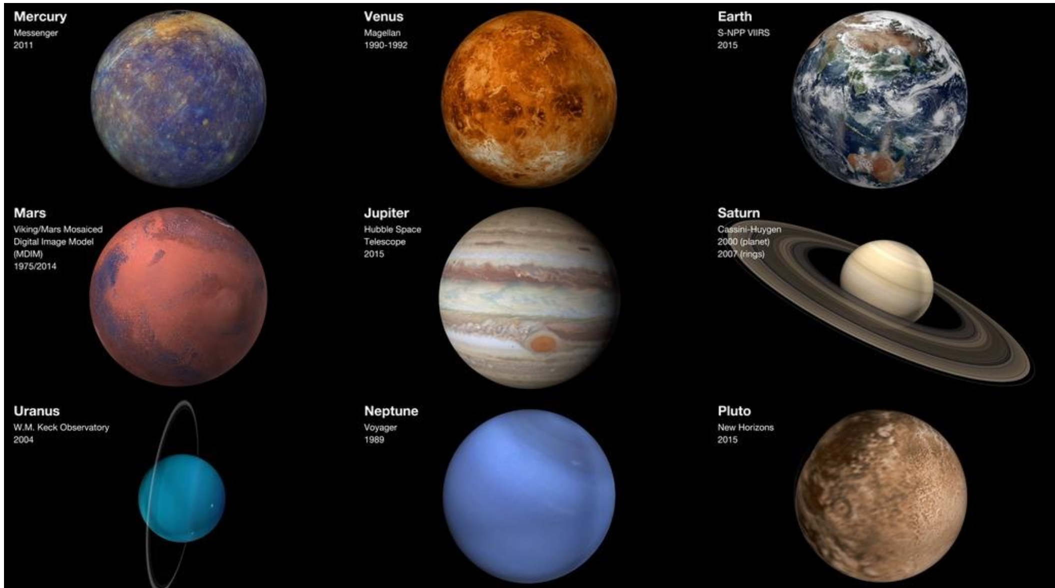
- Meteor day (Aug. 12)
  - 3,000 attendee

7. Extrasolar Planets

Yoichi Itoh
University of Hyogo
兵庫県立大学　西はりま天文台
センター長　伊藤洋一

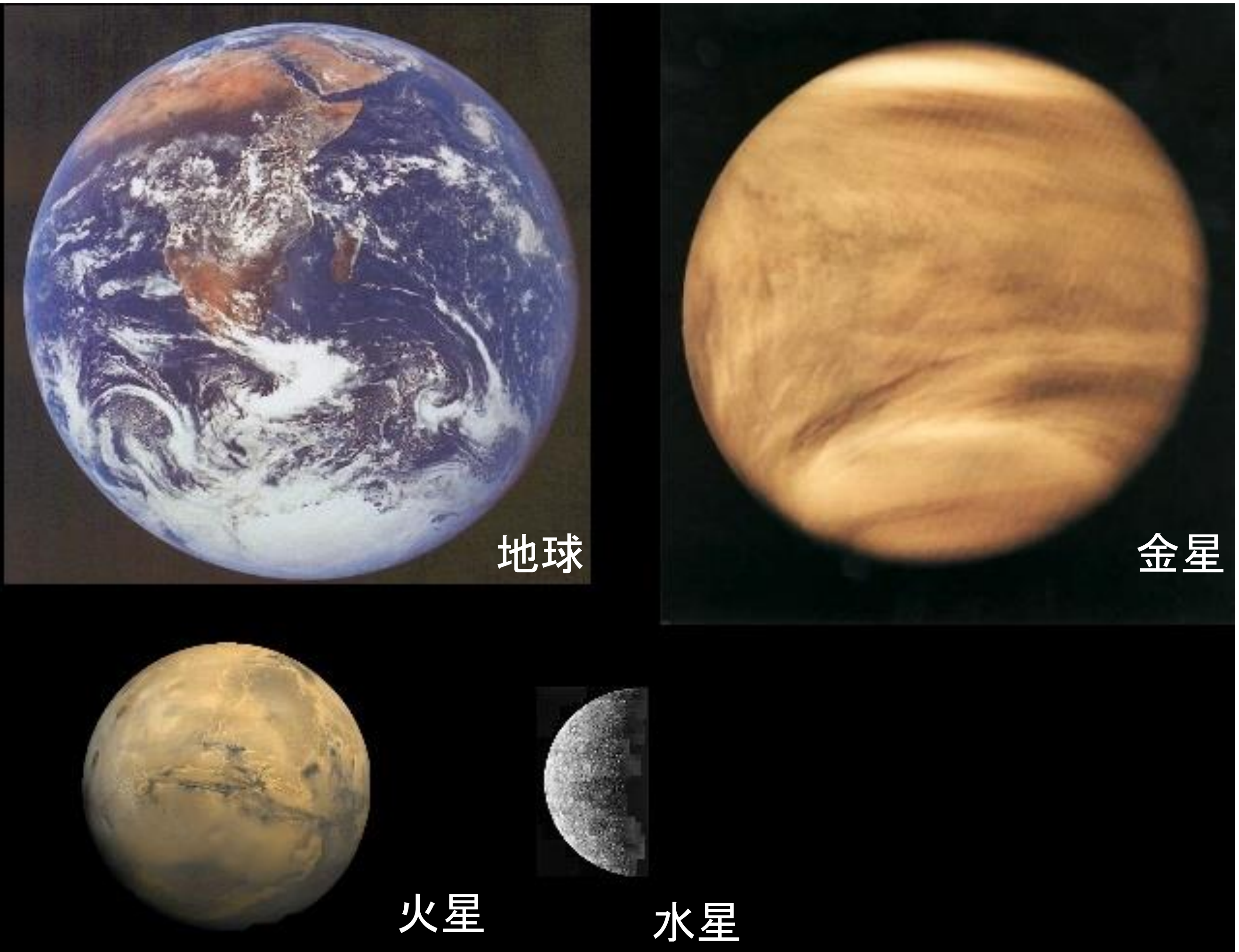
Discovery of planets in the Solar system

- Geocentric theory (Earth-centered)
- Heliocentric theory (Sun-centered)
- 1781   Uranus
- 1846   Neptune
- 1930   Pluto (now downgraded to sub-planet)



Earth-like planets

Rocky, small planets

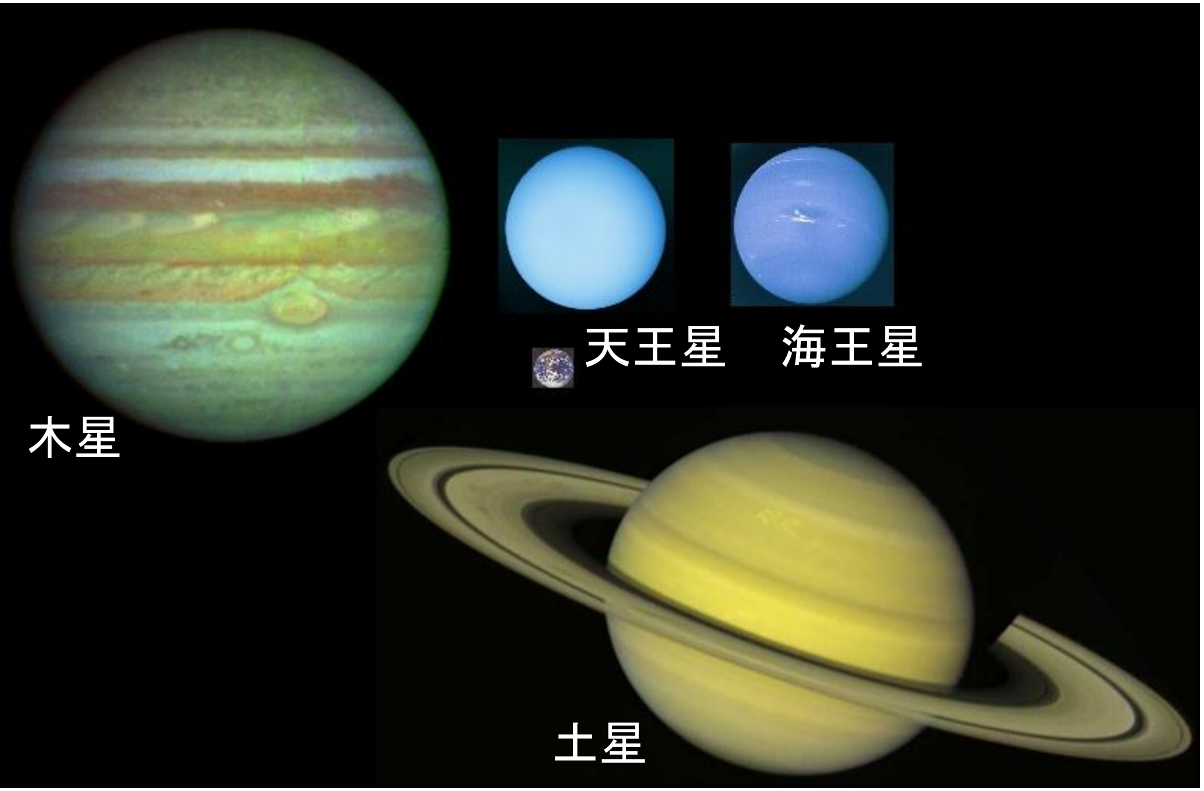


- Mercury
- Venus
- Earth
- Mars

Earth is only 1/300 of Jupiter in mass

Jupiter-like planets

Gas giants. Solid core and thick atmosphere



- Jupiter
- Saturn
- Uranus
- Neptune

Jupiter is only 1/1000 of Sun in mass

How old is the Sun？

- 5 million years
- 5 billion years
- 5 trillion years

How old is the Sun ?

- Age of the Sun ＝ oldest age of meteorites

  Decay time of Uranium 238 is (to lead)

  The oldest meteorite and the Sun were born during the same time ?

  No, maybe. The sun was formed (slight) before the meteorites were formed.

How many planetary system have been found to date?

- 1
- 5,000
- 5,000,000

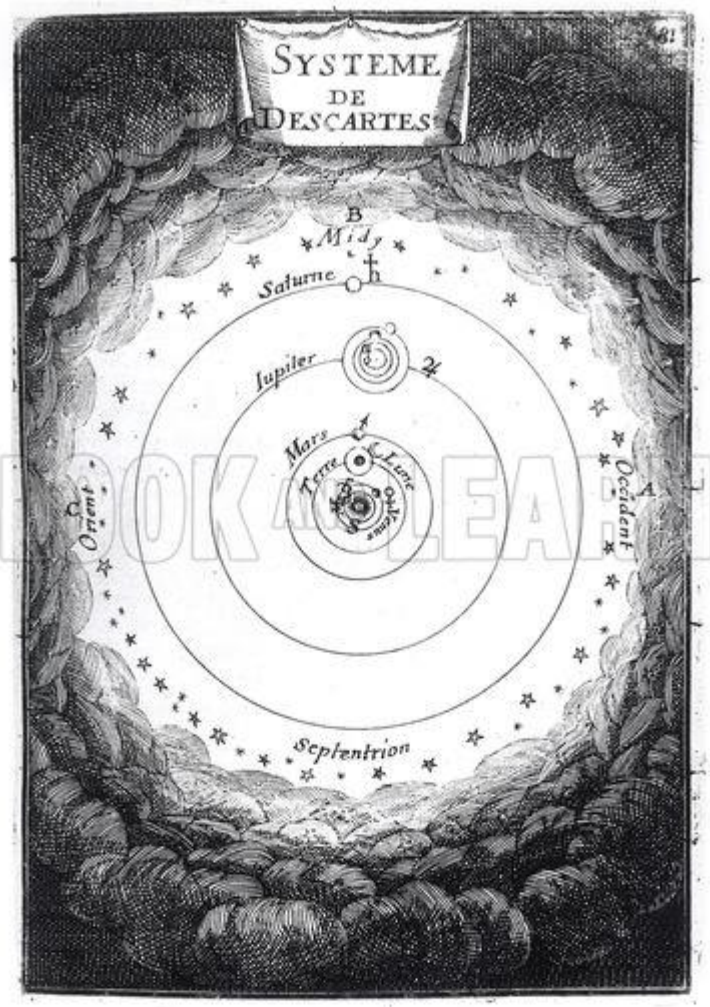
How to form the solar system

1. Nebula model　Descartes (1644)　Kant(1755)　Laplace(1796)

「Principles of Philosophy」

The Universe was filled with vortices of swirling particles.

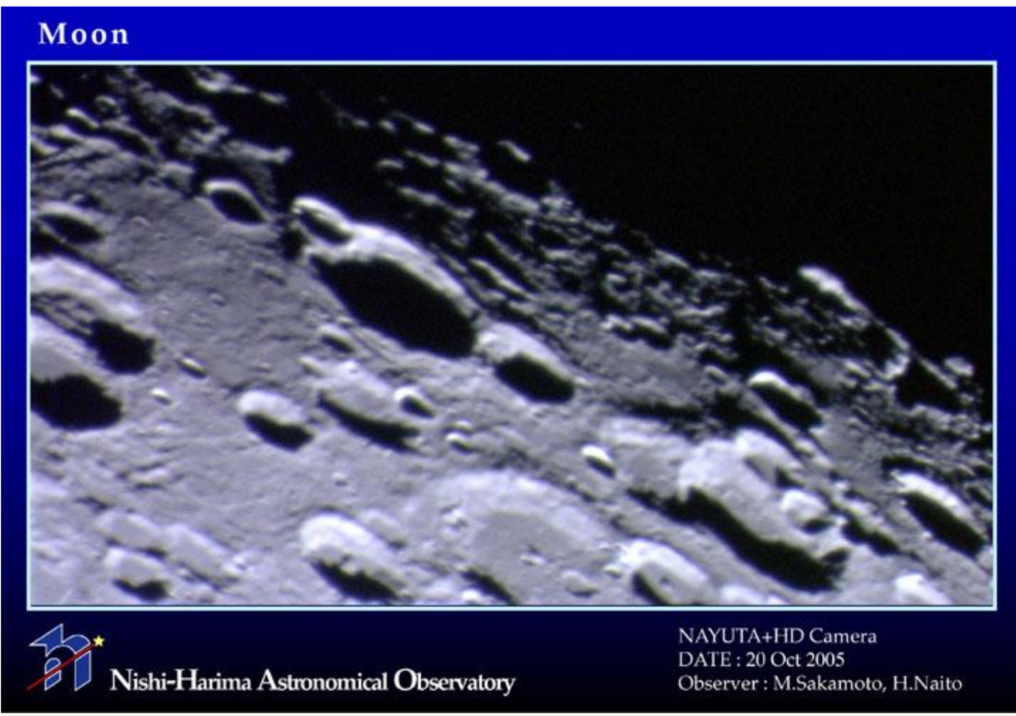
The Sun and planets had condensed from a particularly large vortex



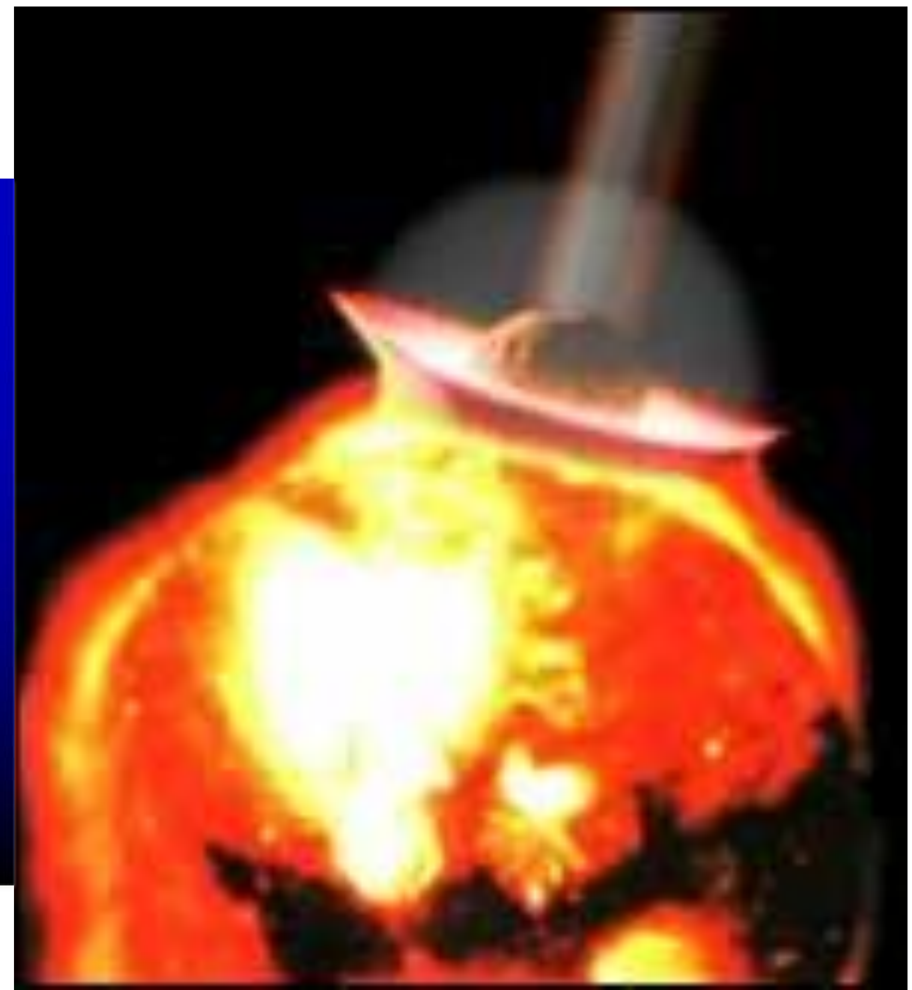
How to form the solar system

2. collision model Leclerc (1745)

Planets were formed by collision of the Sun and comets.



Lunar craters



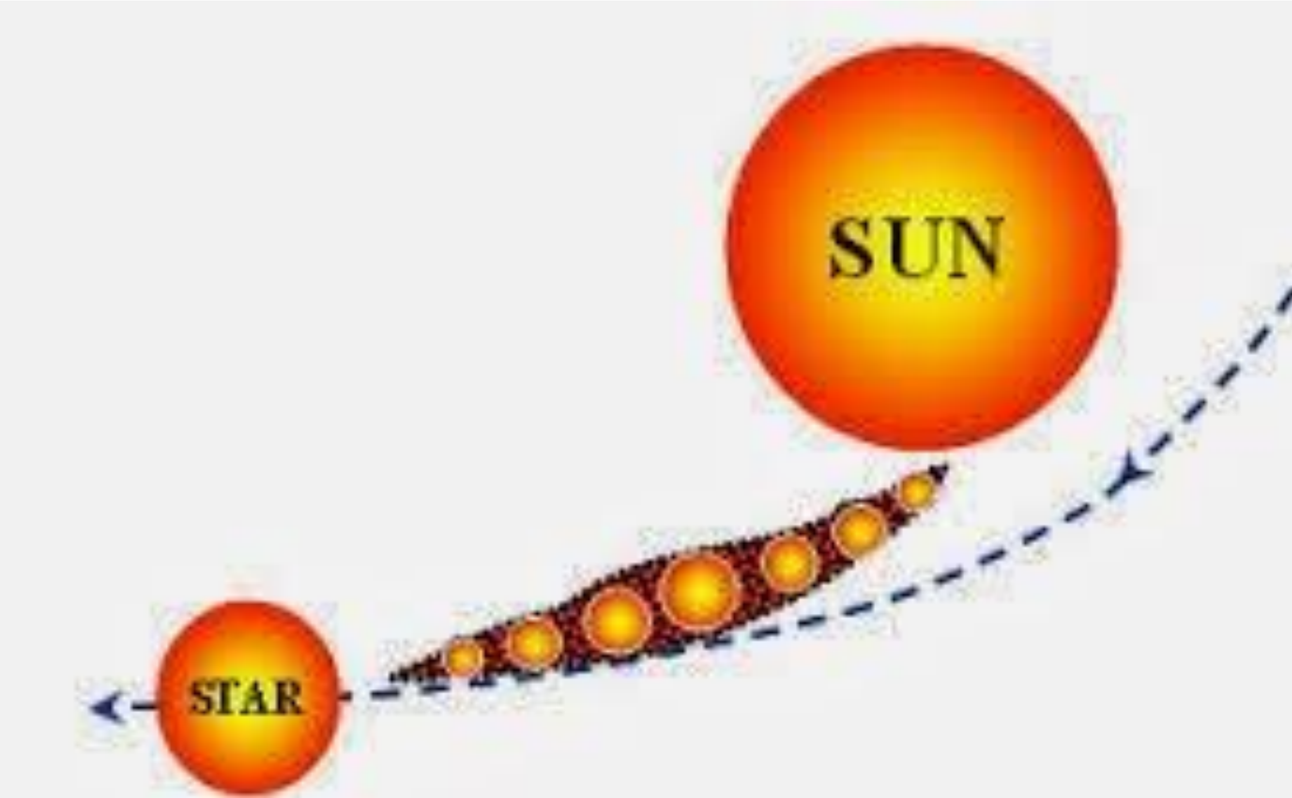
How to form the solar system

3. tidal force model Jeans (1917)

Rapid rotation of the proto-sun.

Or, close encounter.

Tearing the Sun into planets.



How to form the solar system

Which model do you believe ?

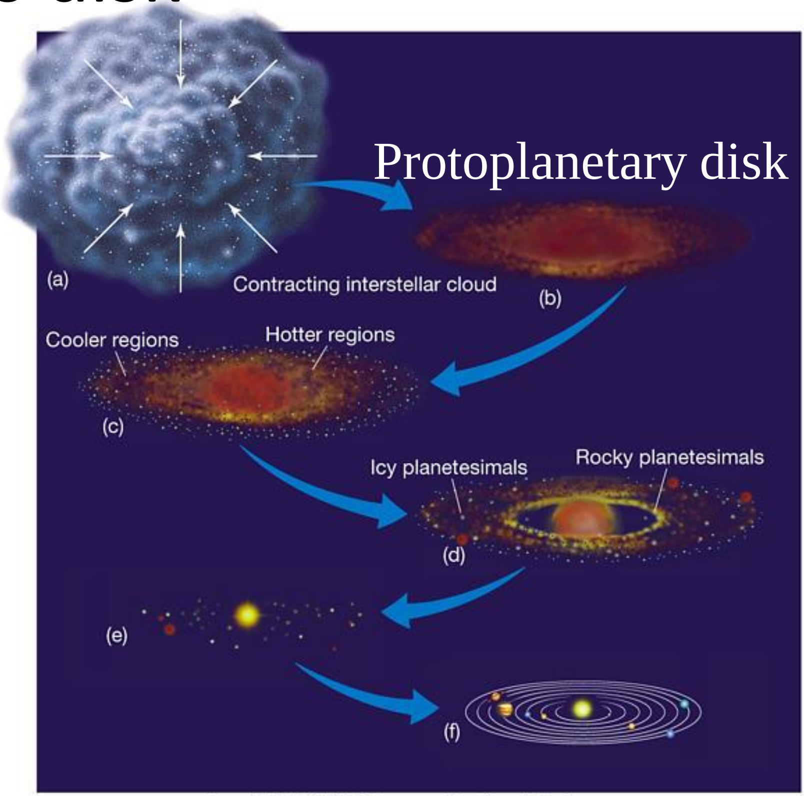
1. Nebula model
2. Collision model
3. Tidal force model

How to form the solar system

How to form the solar system

A. Core accretion model Hayashi (1980s)

- Collapse of molecular cloud
- Formation of protosun and gas disk
  (disk mass is 1/1000 of the Sun)
- Dusts coagulated in the disk
- Proto-planets formed



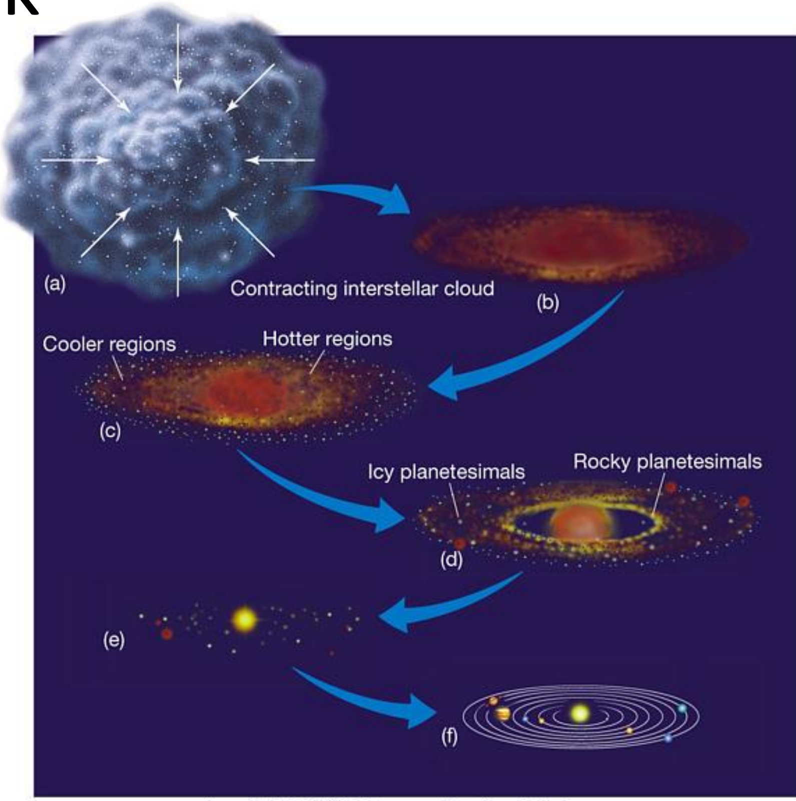
How to form the solar system

B. Gravitational instability model Cameron (1980s)

- Collapse of molecular cloud
- Formation of protosun and disk

  (disk mass is 1/10 of the Sun)

- Protoplanets formed by fragmentation of disk



How to form the solar system

Which model is correct？

A. Core accretion model

B. Gravitational instability model

How to form the solar system

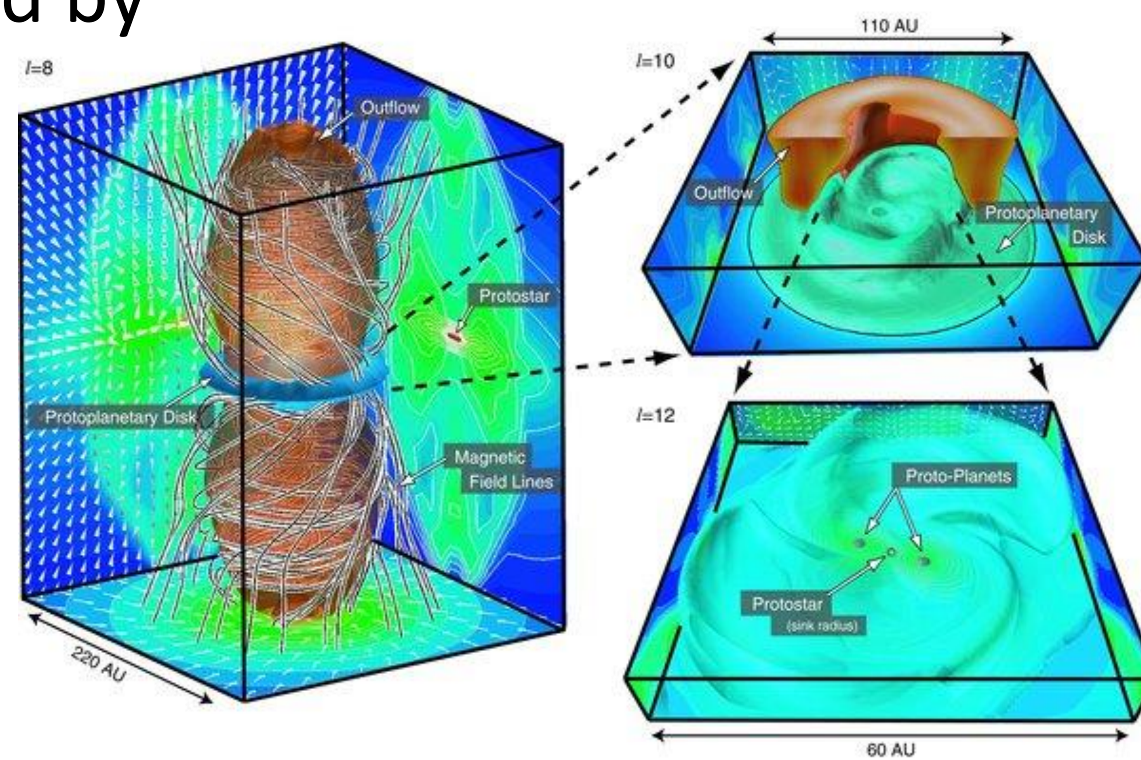
How to form the solar system

C. Hybrid model Inutsuka (2010)

- Collapse of molecular cloud
- Formation of protosun and gas disk

  (disk mass is 1/1000 and stellar mass is 1/100 of the Sun)

- Protoplanets formed by disk fragmentation

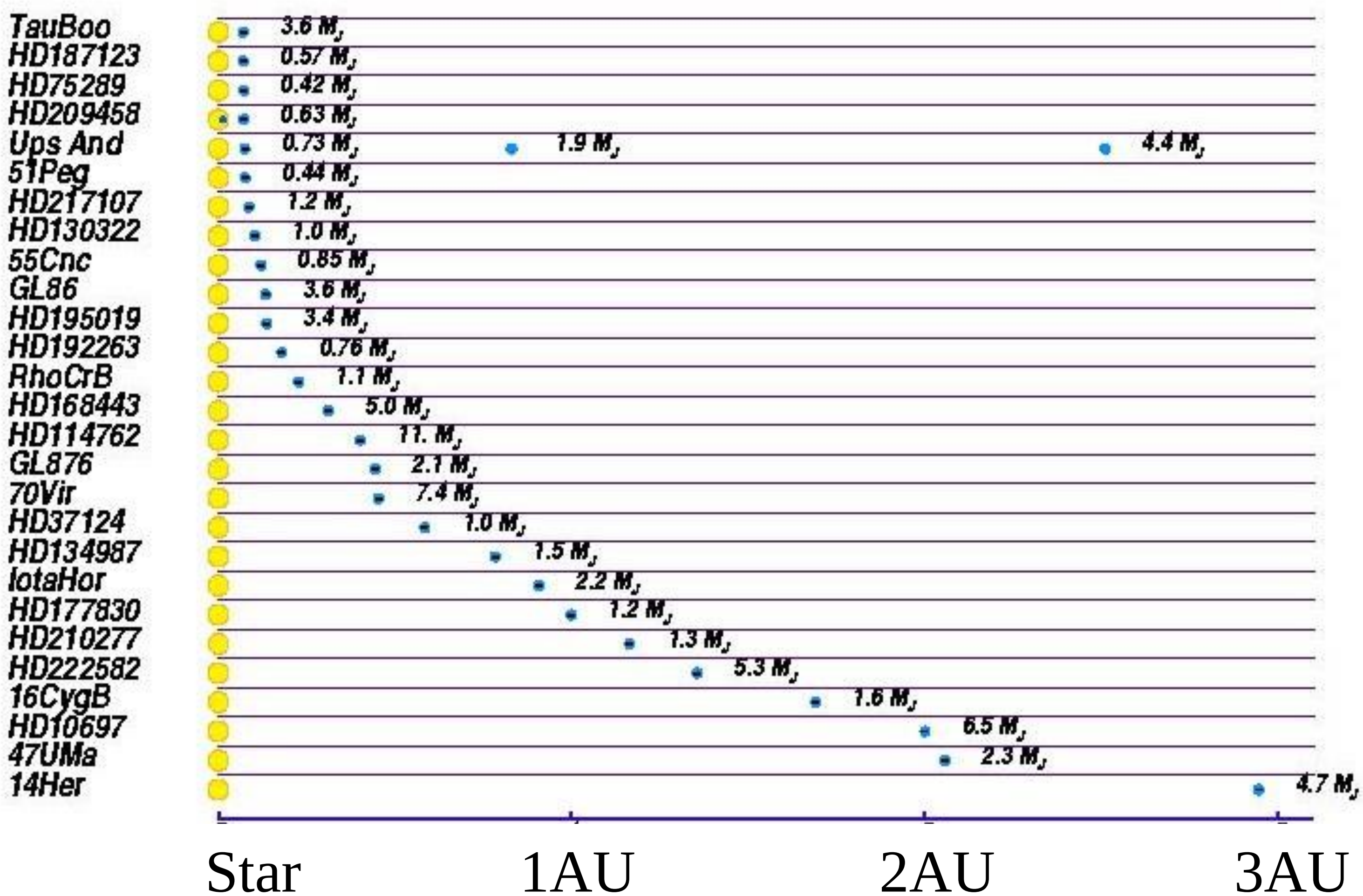


- Protosun grows

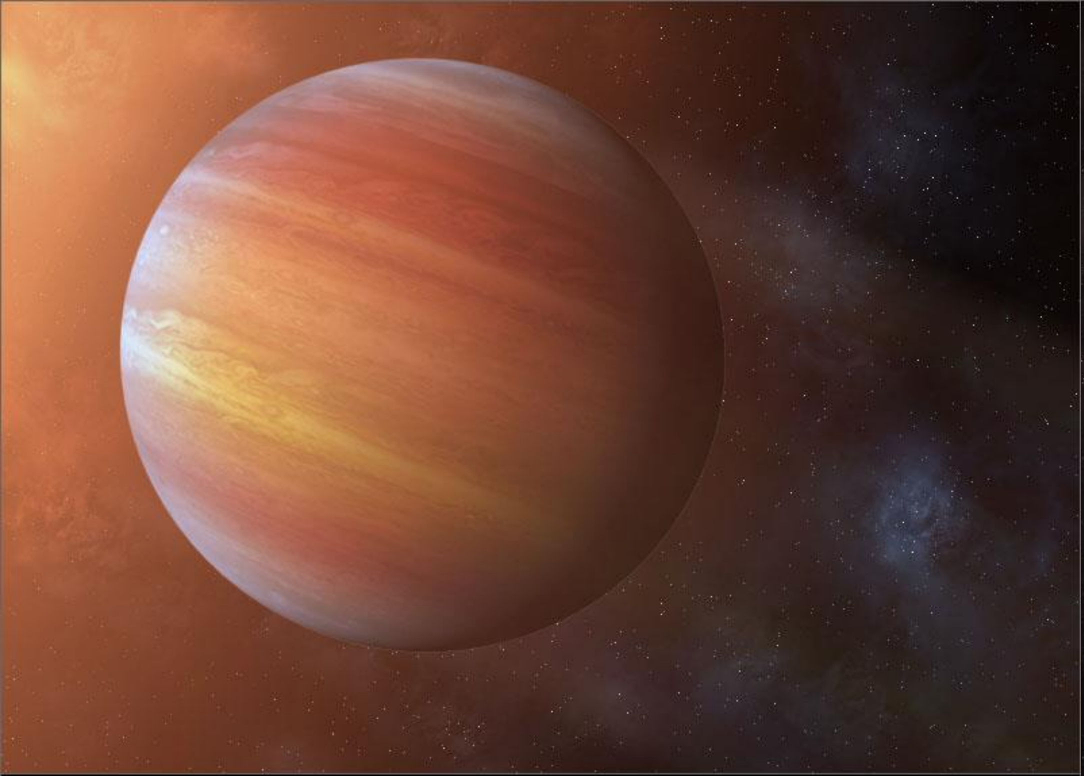
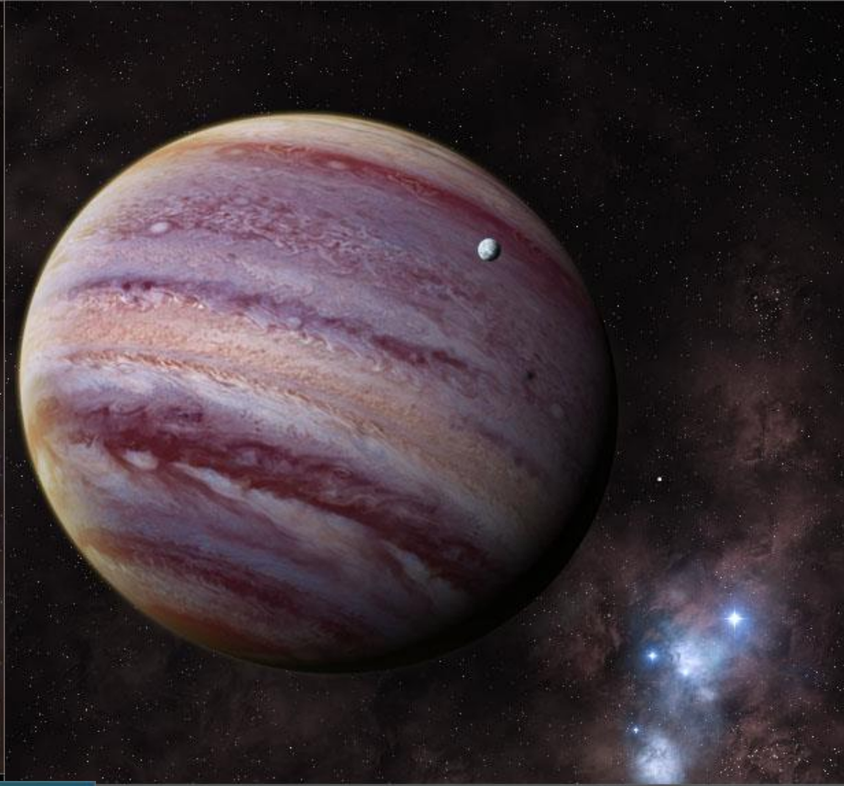
  (Solar mass)

- Dust coagulation
- Proto-Earth born

Extra-solar planets



- First discovery in 1995, about 5,000 planets have been found.
- Jupiter-like planets are located at very close to the central star.

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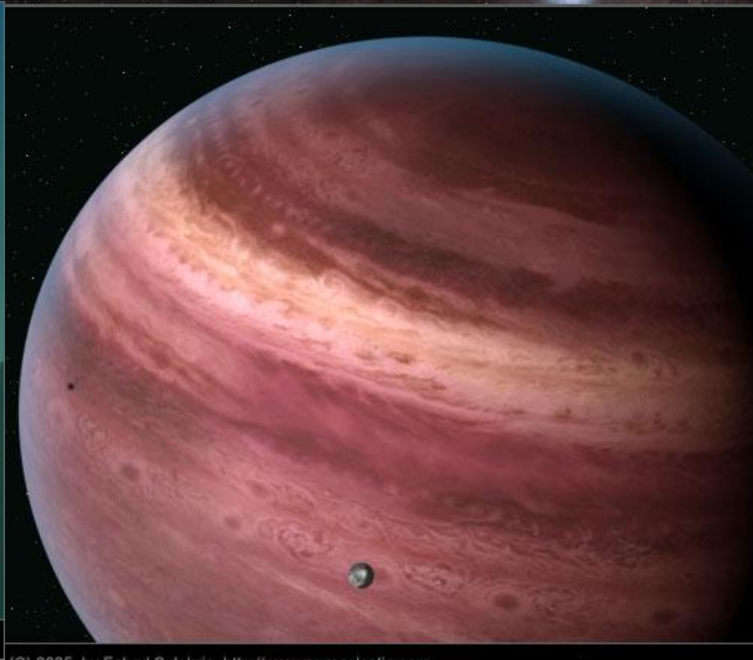
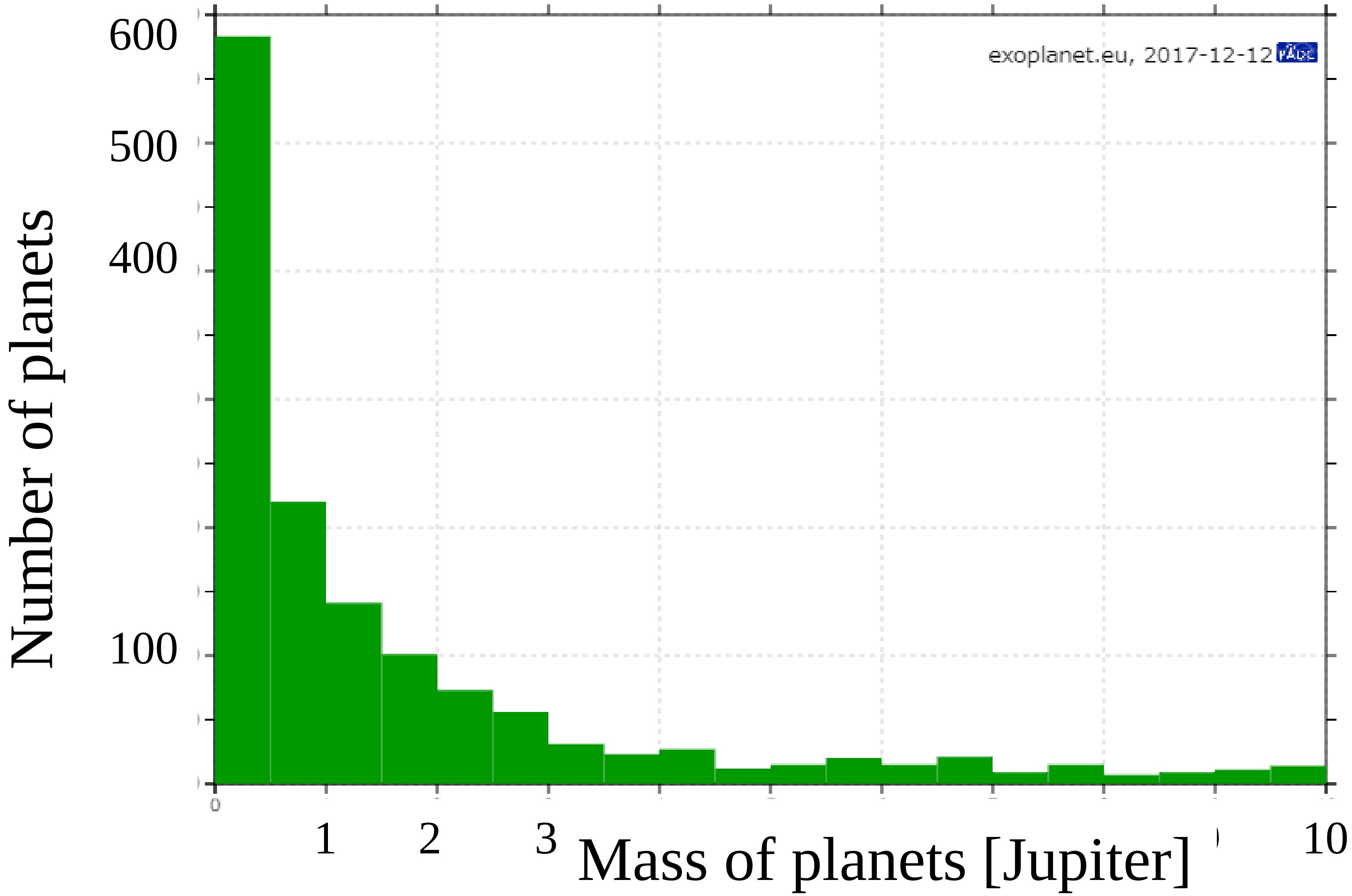


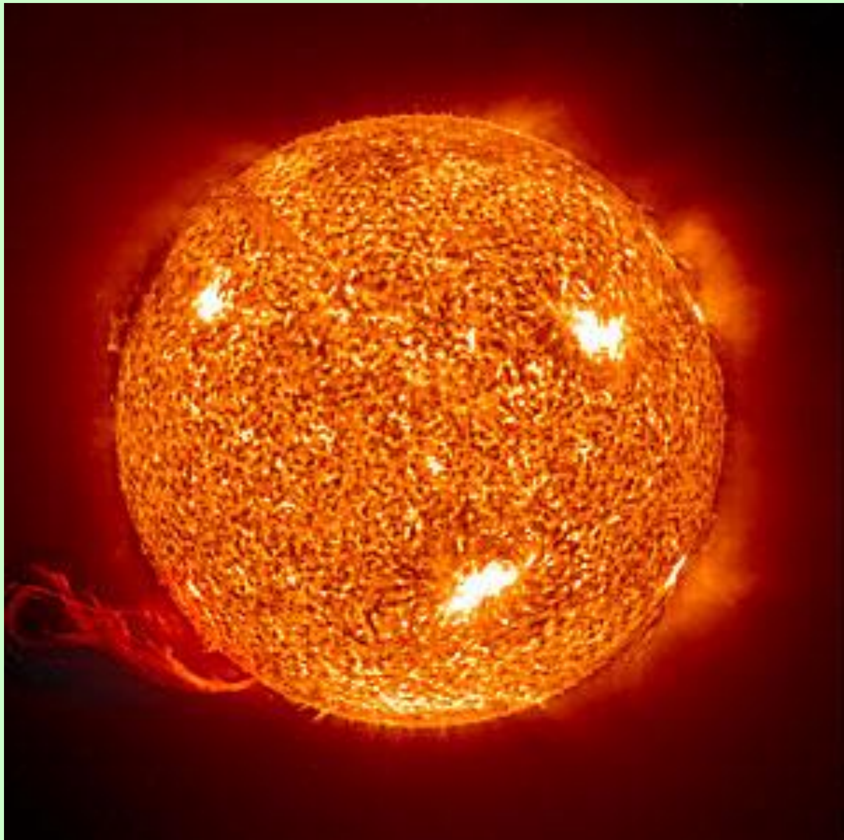
Characteristics of exoplanets --- mass



- Many planets are more massive than Jupiter.
- Many less massive planets are expected, but not yet discovered.

Calculate the mass of the Sun.
Answer in unit of kg.

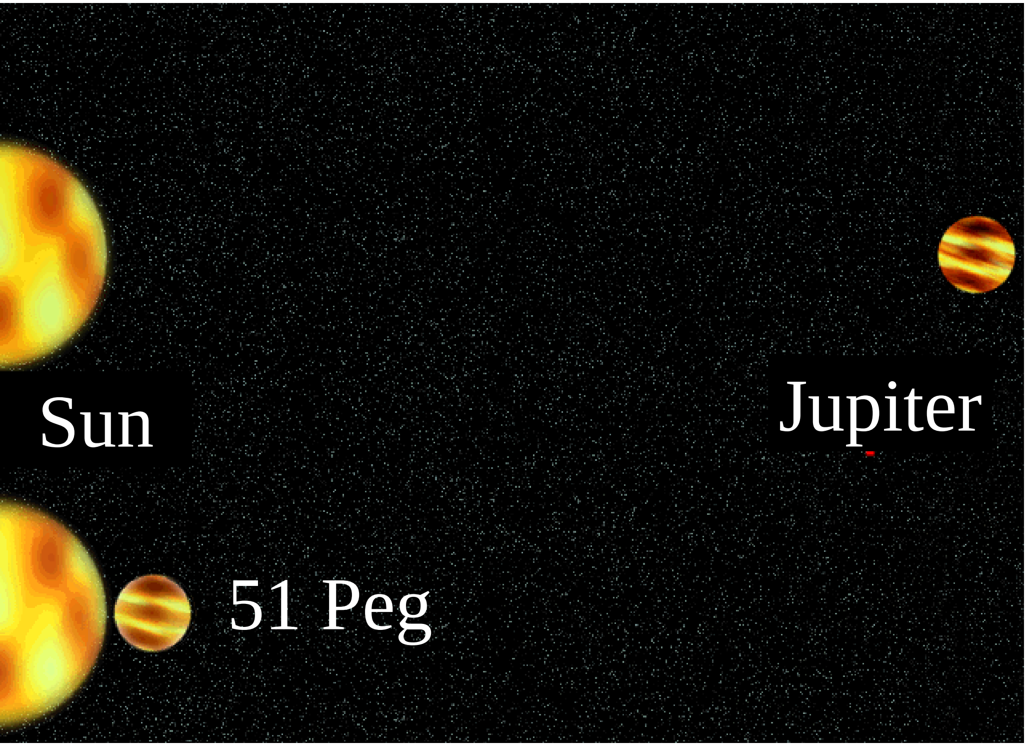
The Sun is spherical
Average density is $1 g/cm^3$
Radius is $7x10^8 m$



Calculate the mass of Jupiter.
Answer in unit of kg.

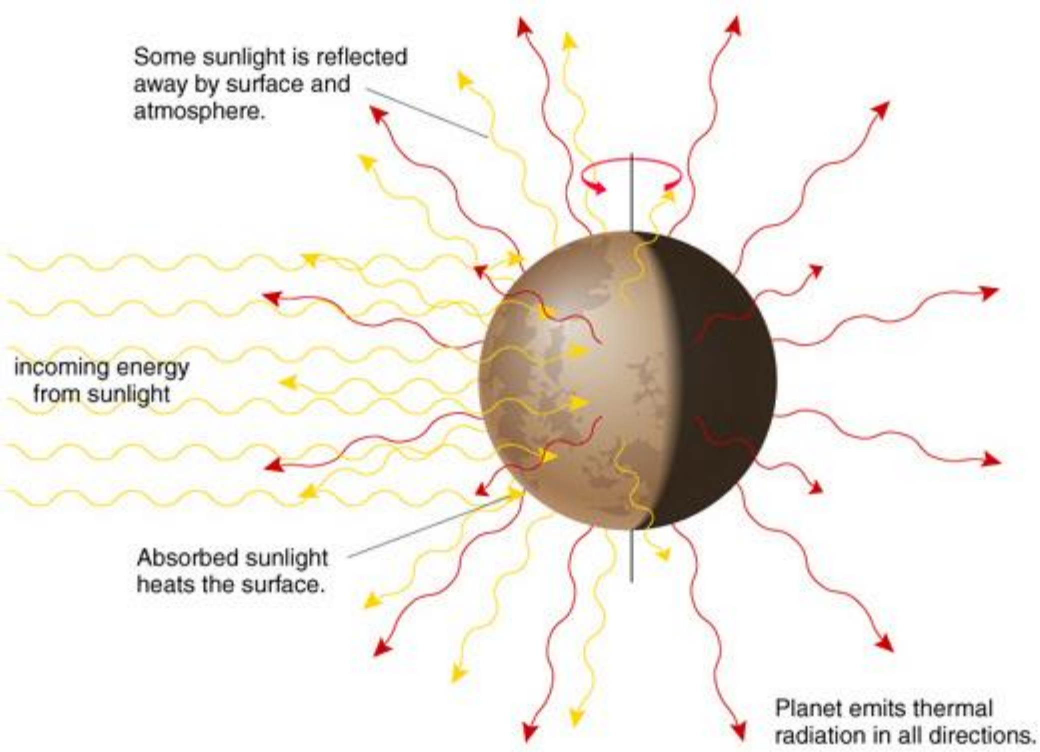
Radius of Jupiter is 1/10 of that of the Sun.
Average density of Jupiter is the same of that of the Sun
(similar interior structure)

Characteristics of exoplanets --- orbital radius



- Atmosphere evaporates, if the planet is very close to the star.
- Such a planet has a tail like a comet.

Equilibrium temperature



Temperature of a star: Ts, radius of a star: Rs, distance between a star and an object: d, Temp. of an object: To, radius of an object: Ro

Consider temperature of a spherical object around a star

Flux from a star is

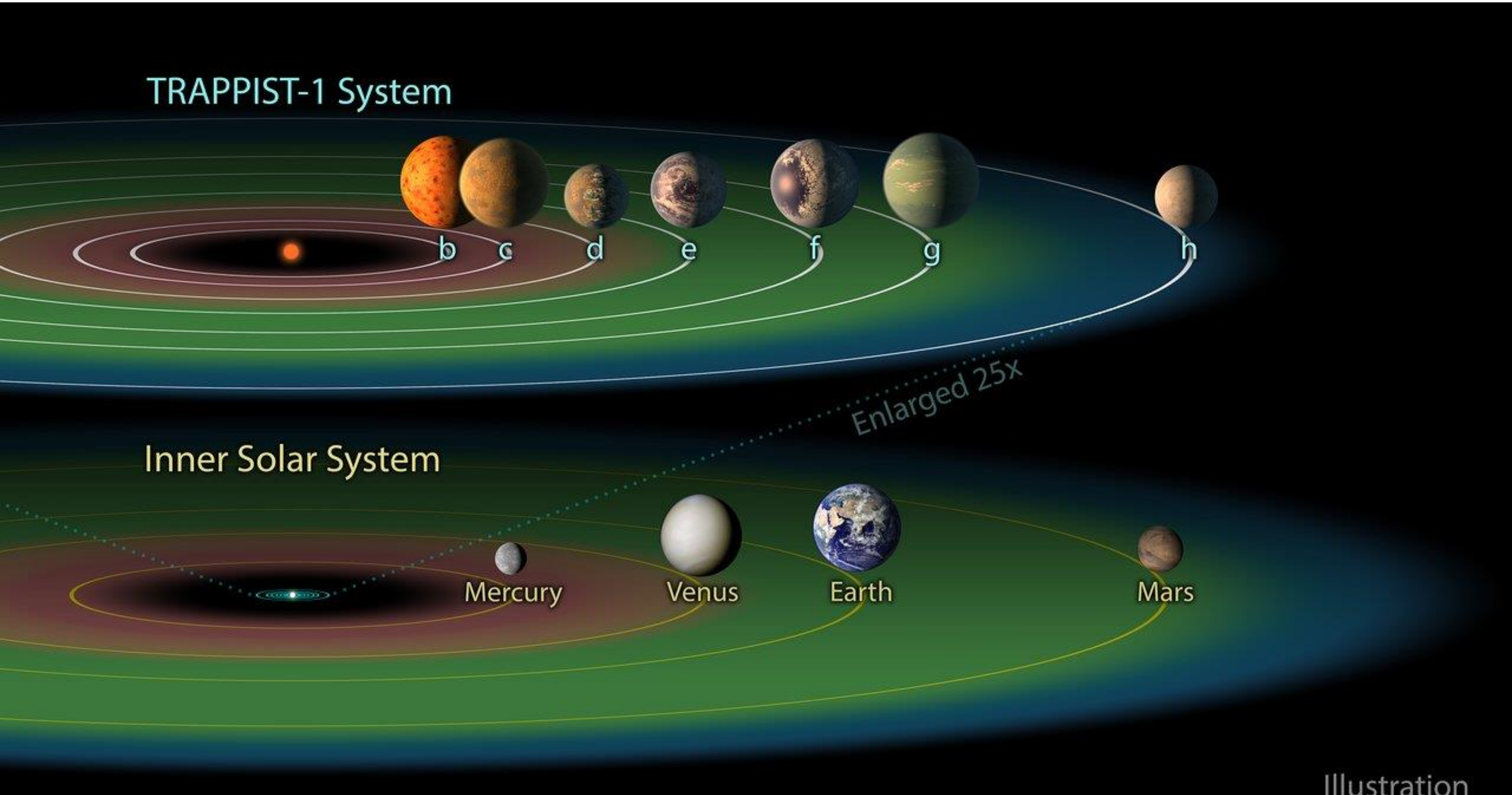
Emission from a blackbody object

Calculate the equilibrium temperature at 1 AU from the Sun

- 1 AU = 1.5 x 10^8 km
- 1Rsun = 7.0x10^5km
- Tsun = 5800K

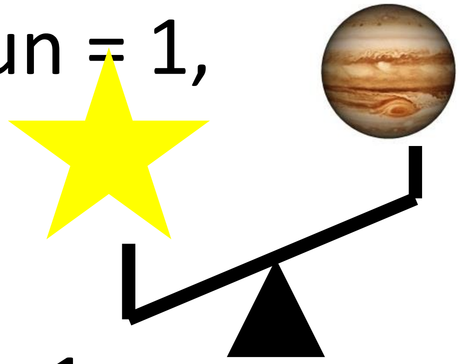
Habitable zone

- life＝life like those on the Earth
- Liquid water is important 273K～373K)



Hard to see exoplanets

- less massive..............If mass of the Sun = 1,
  - Earth=1/300,000
  - Jupiter=1/1,000

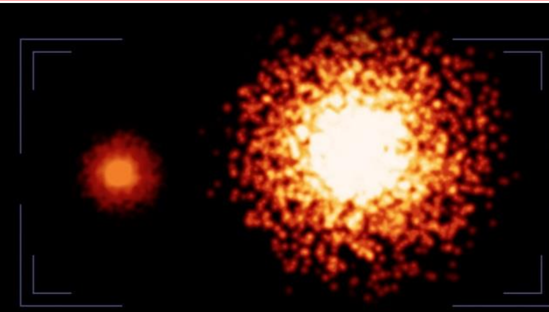


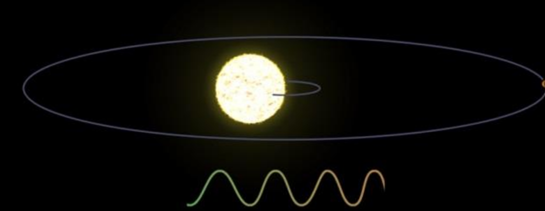
- faint.............If luminosity of the Sun = 1,
  - Earth= 1/50 billion (25 mag. difference)
  - Jupiter= 1/2 billion

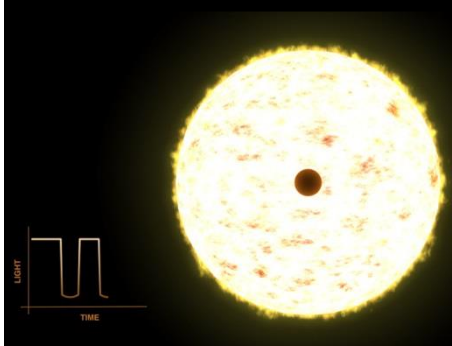
- very close to the star........If we see it from 10pc away, the separations is
  - Earth=0.1arcsec（1arcsec=1/3600 degree）
  - Jupiter=0.5arcsec

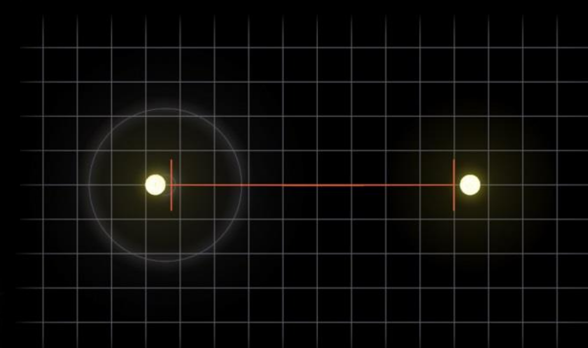
Detection methods of exoplanets

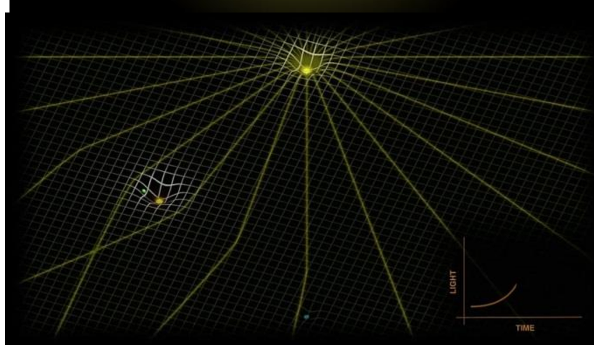
- Direct imaging
- Doppler effect
- Proper motion
- Transit
- Gravitational lens
- Coronagraph
- Polarization











Let’s see exoplanets

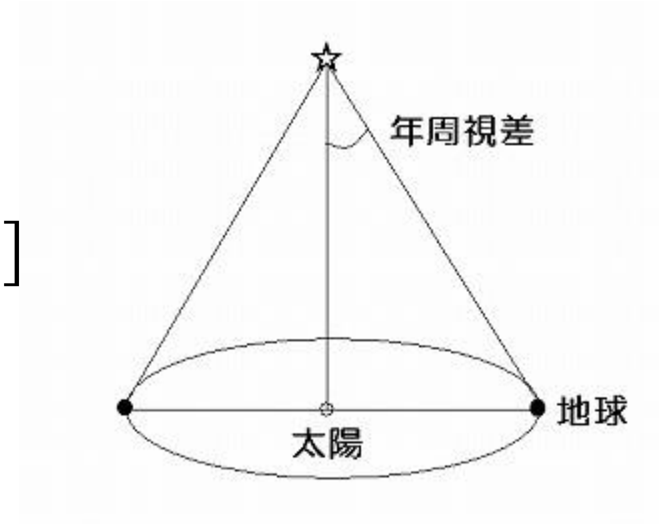
- parallax
  - Position of a star changes by season due to orbital motion of the Earth
  - Distance between the Sun and the Earth=1 AU

    1AU(Astronomical Unit)=1.5×10^8 km

An object located at α[parsec、pc]

away from the Sun = Parallax is 1/α[“]

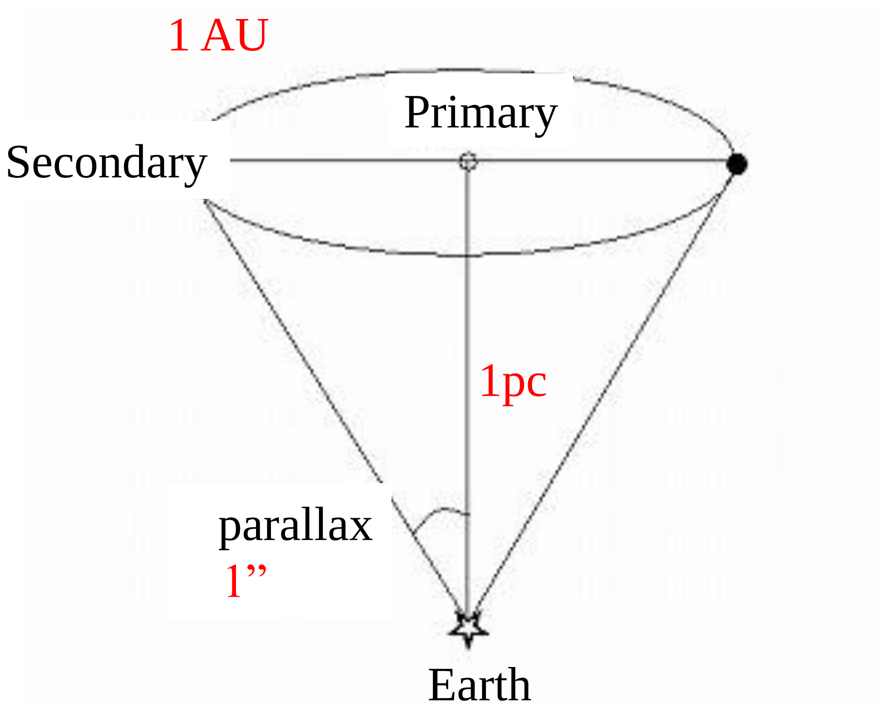
1pc = 3.26 light year



Let’s see exoplanets

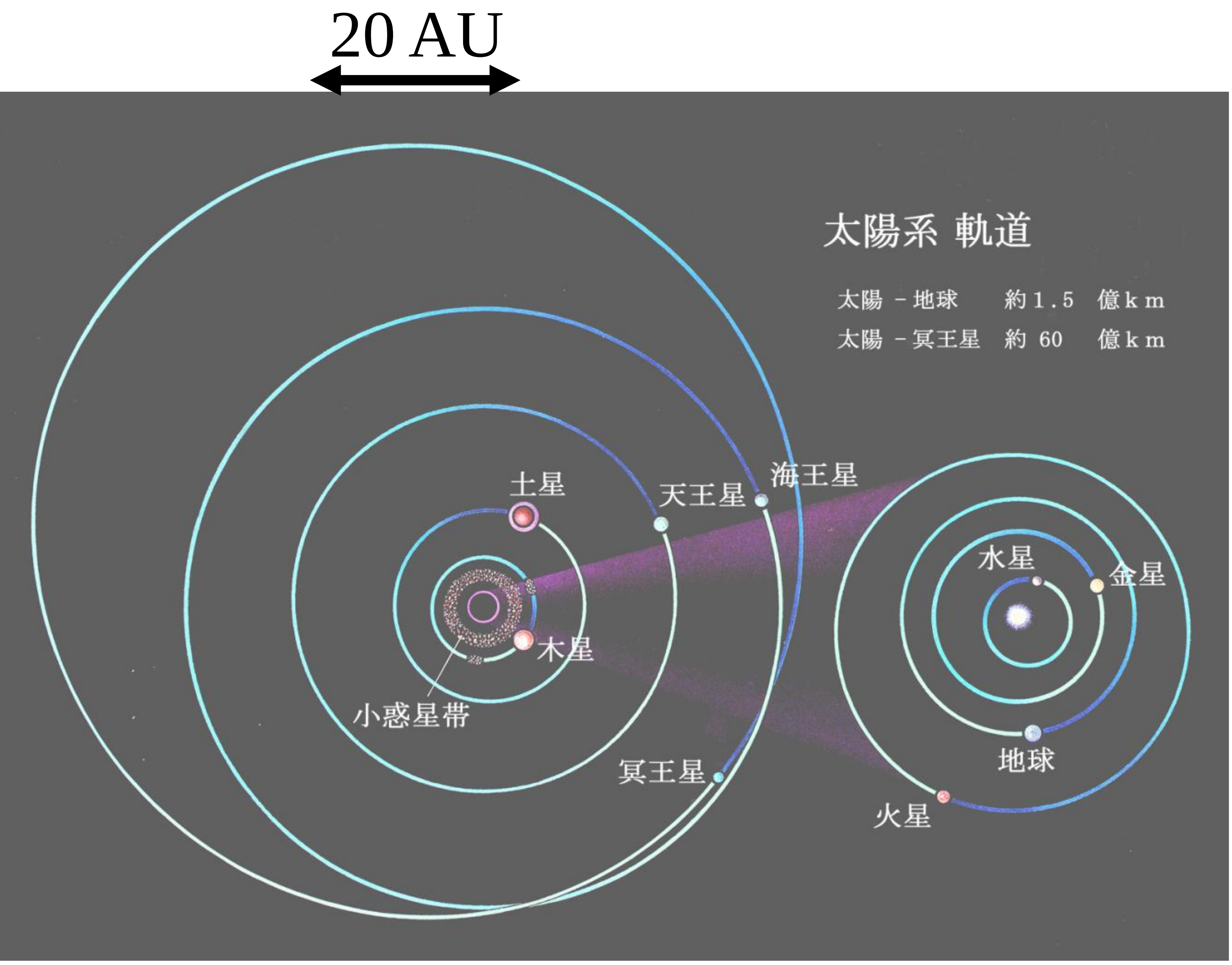
1 parsec (3.26 light year) =

1 arcsec corresponds 1 AU distance



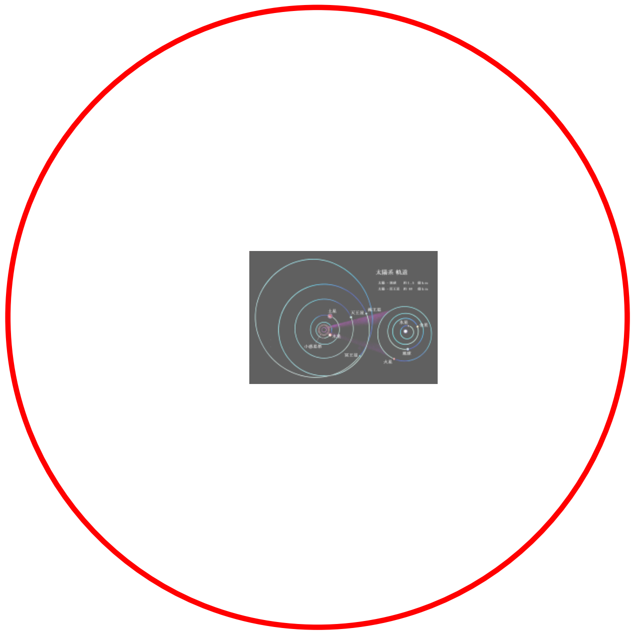
Taurus molecular cloud is located at 140 pc away from the Earth and is known as the nearest birth place of stars. Consider a binary star with the apparent separation of 1 arcsecond in Taurus molecular cloud. Calculate “real” separation of the binary. Answer in the unit of AU.

Let’s see exoplanets



Let's see exoplanets

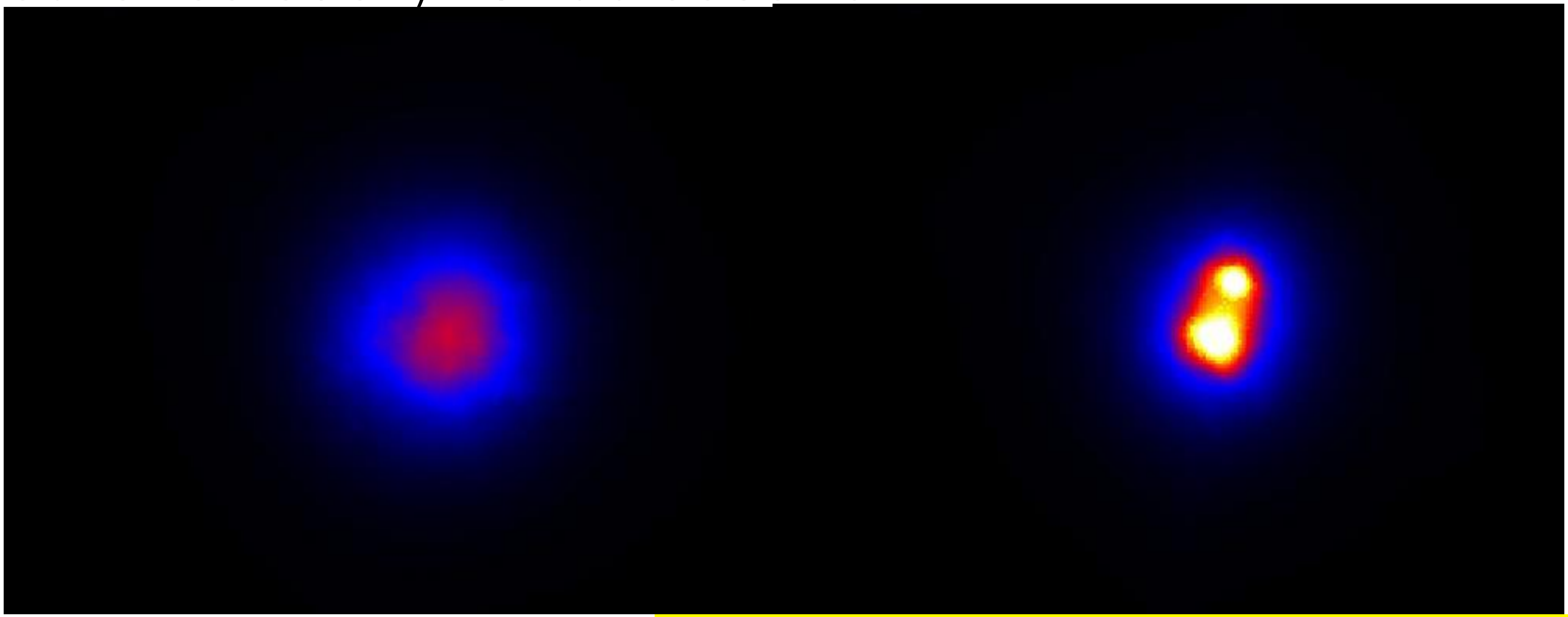
Observe the solar system from 140 pc away



Typical seeing size at Nishi-Harima Observatory is 2"
We can't see detailed structure due to stellar twinkle

Adaptive optics

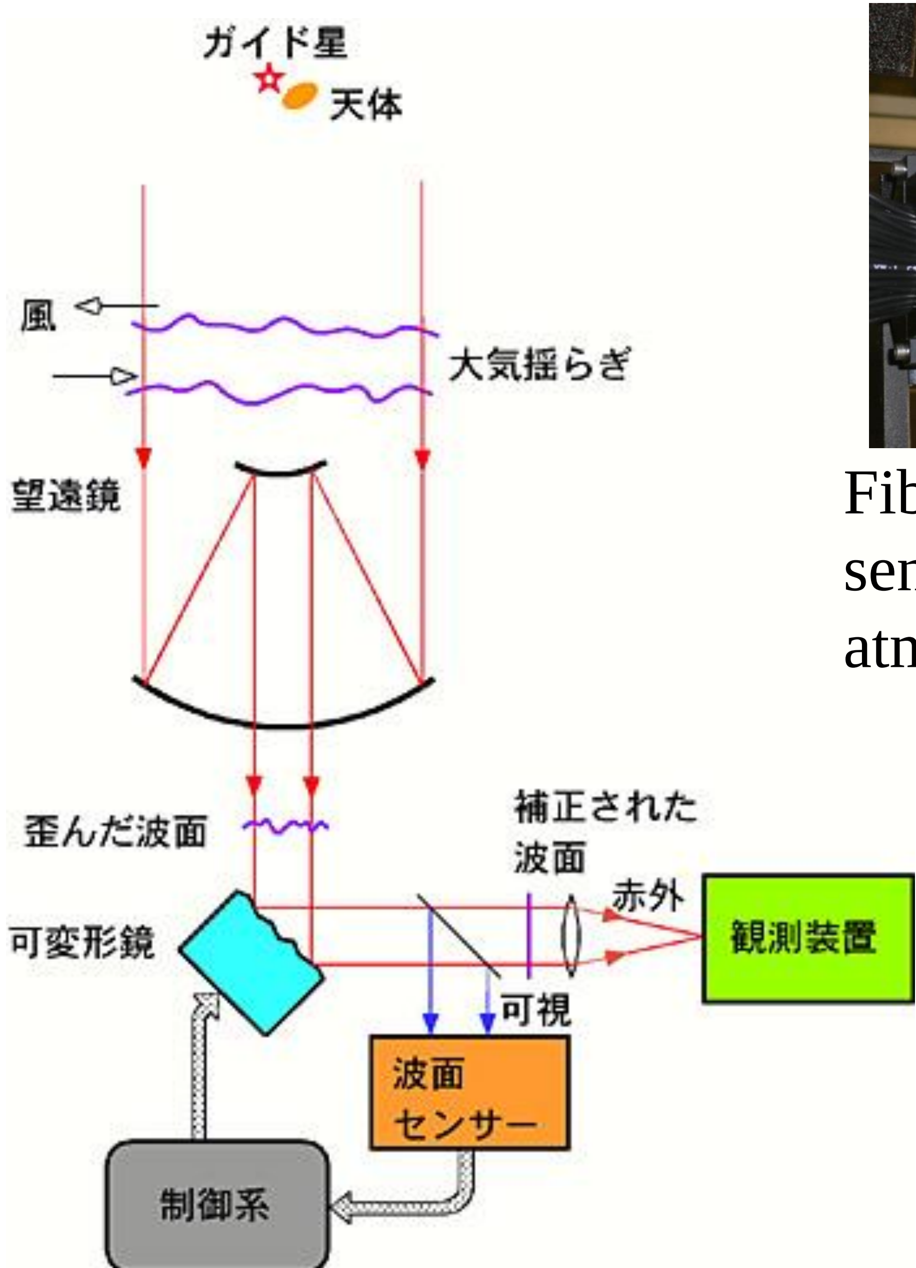
Exoplanets located very close to star
→get sharp image by compensating atmospheric turbulence every 1/100 second

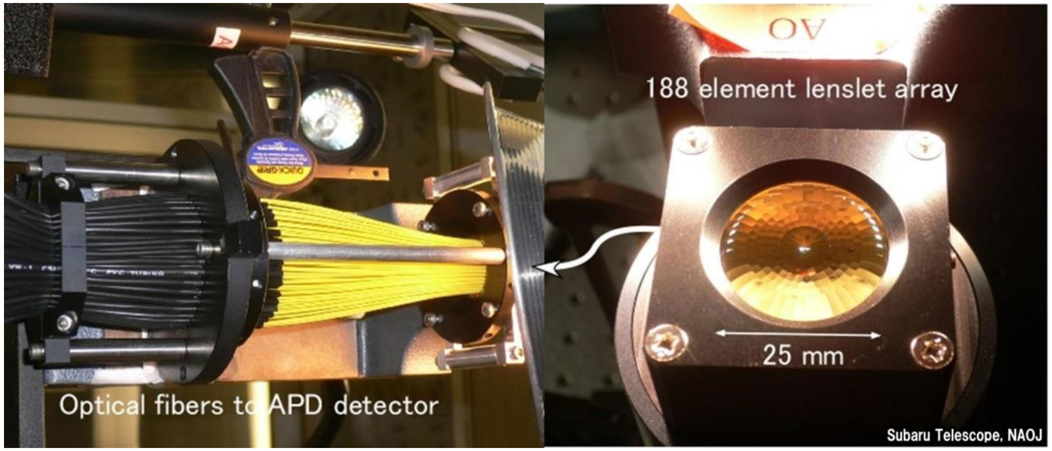


no AO
Seeing is 0.65”
looks like a single star

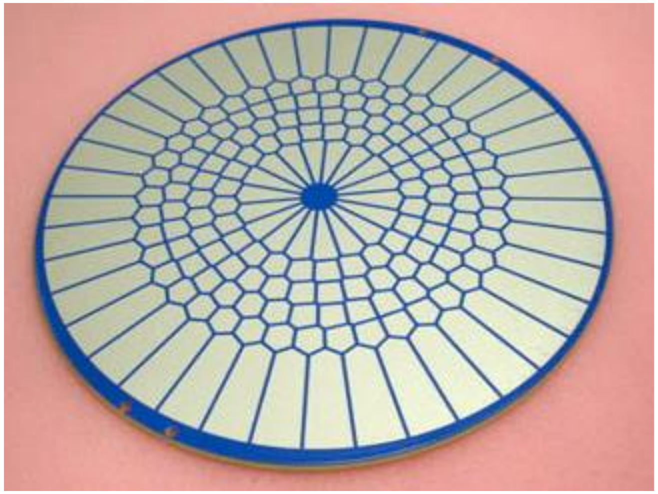
with AO
PSF is 0.10”
resolve 0.25” separated binary

Adaptive optics



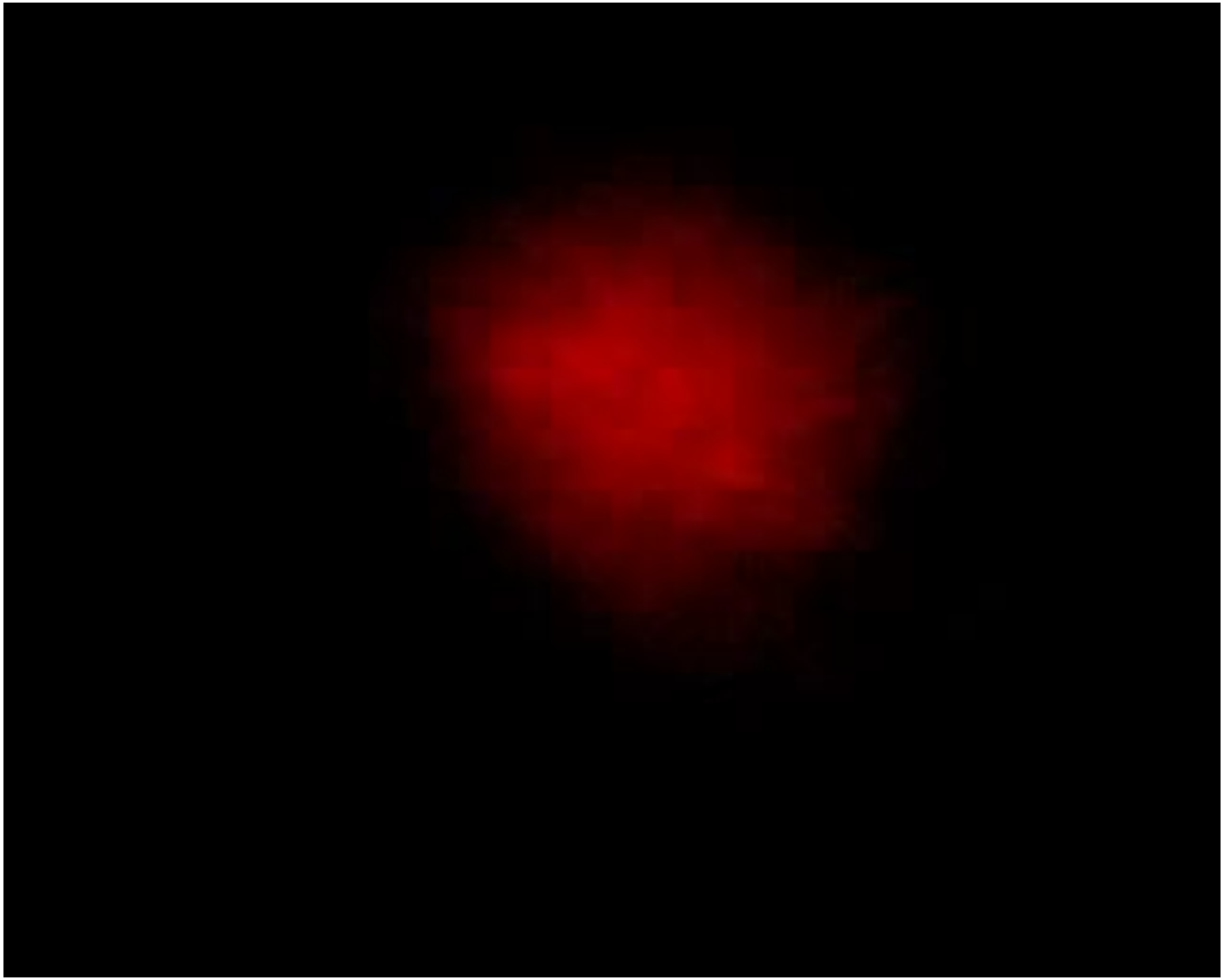


Fiber feeds stellar light to wavefront sensor. Measure wavefront disturbed by atmosphere 2000 times every second

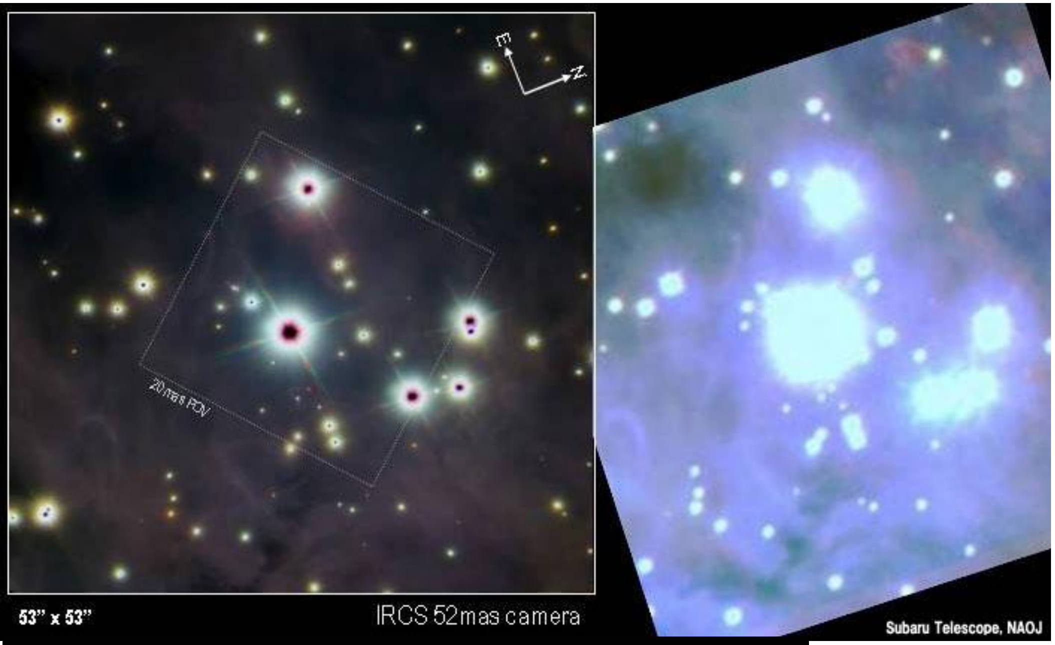


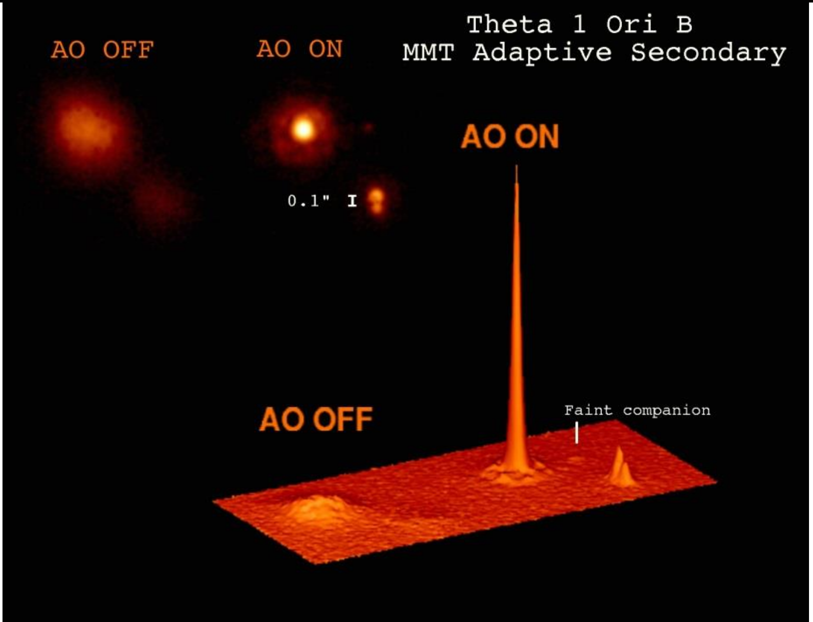
188 element deformable mirror

Adaptive optics



Adaptive optics





FWHM of PSF
no AO : 0.6 arcsec
with AO : 0.1 arcsec

Peak count increases by AO
→ detect fainter objects

Direct imaging

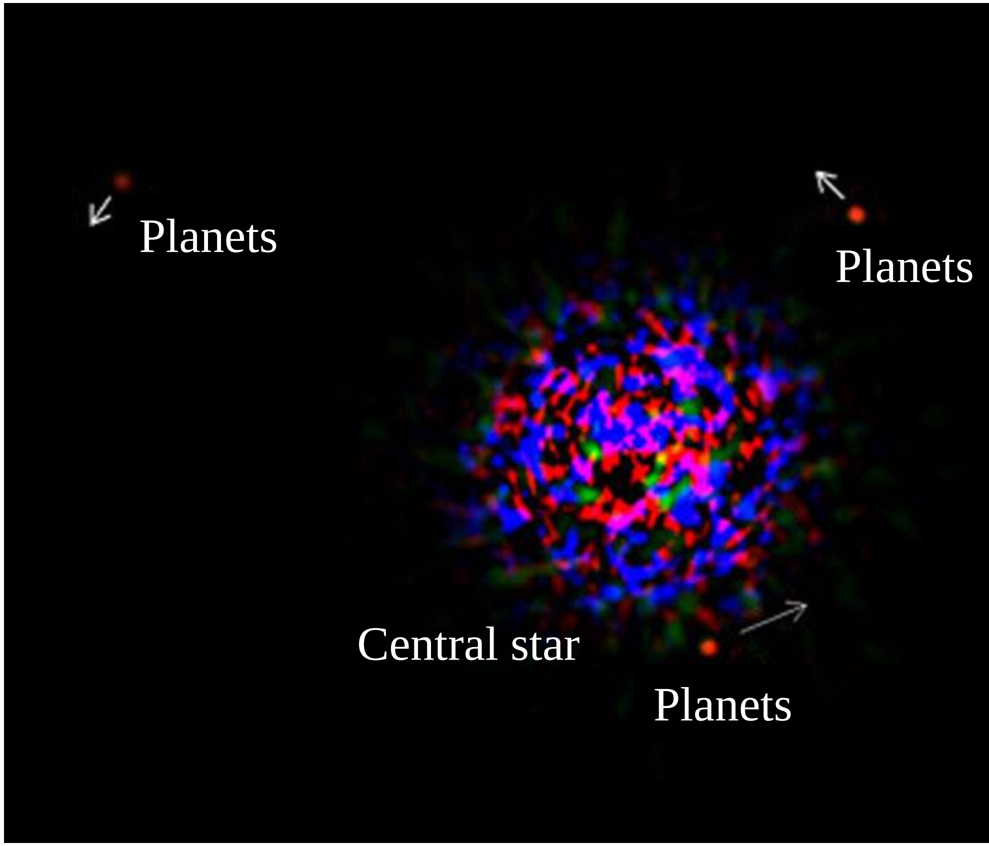
- Exoplanets are
  - faint
  - located very close to the bright star.

→Search for nearby stars.

HR 8799

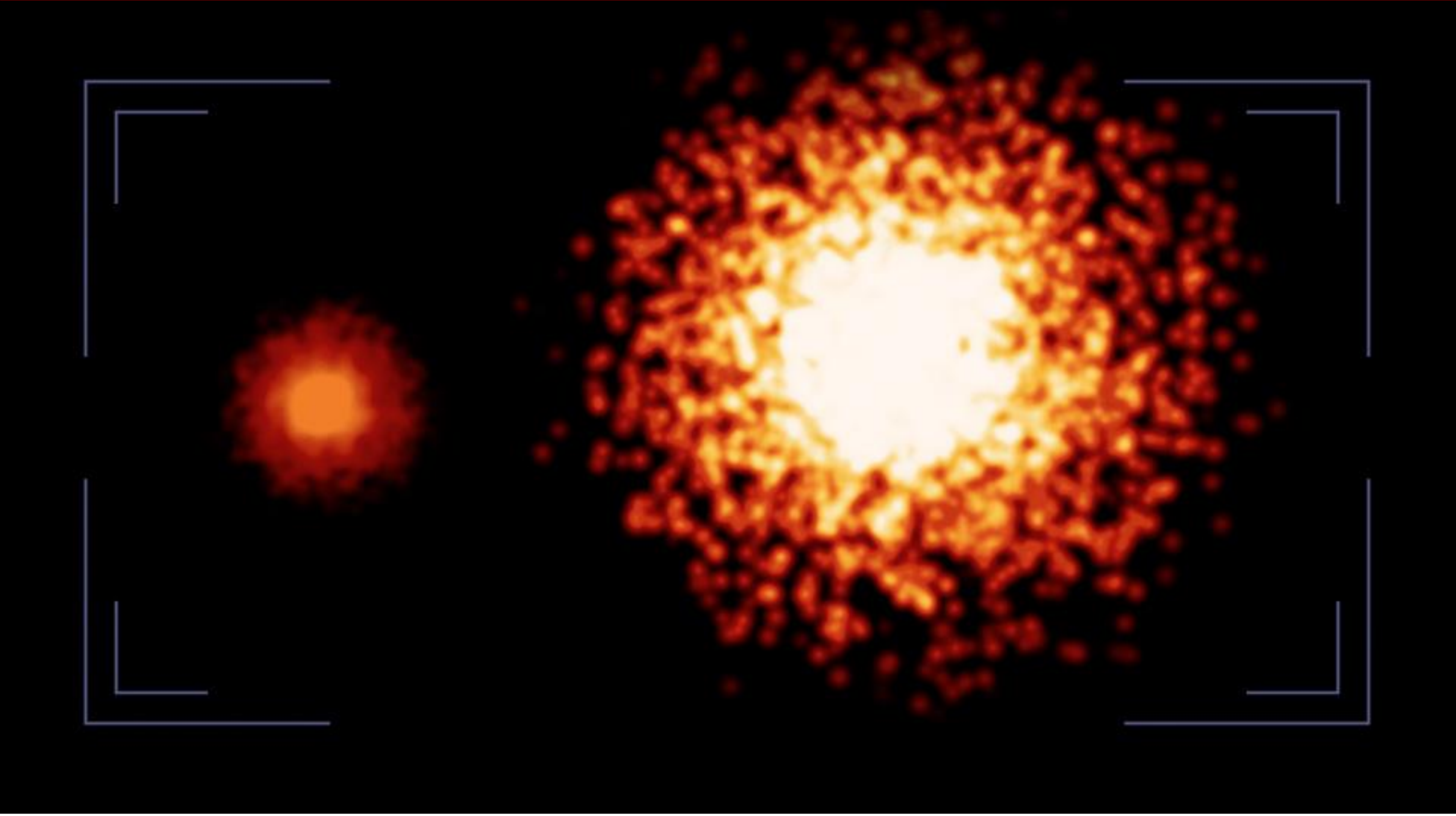
Planets detected?

→ Age of the central star is uncertain. They may be brown dwarfs if old.



Direct imaging of exoplanets are very difficult.

Direct imaging



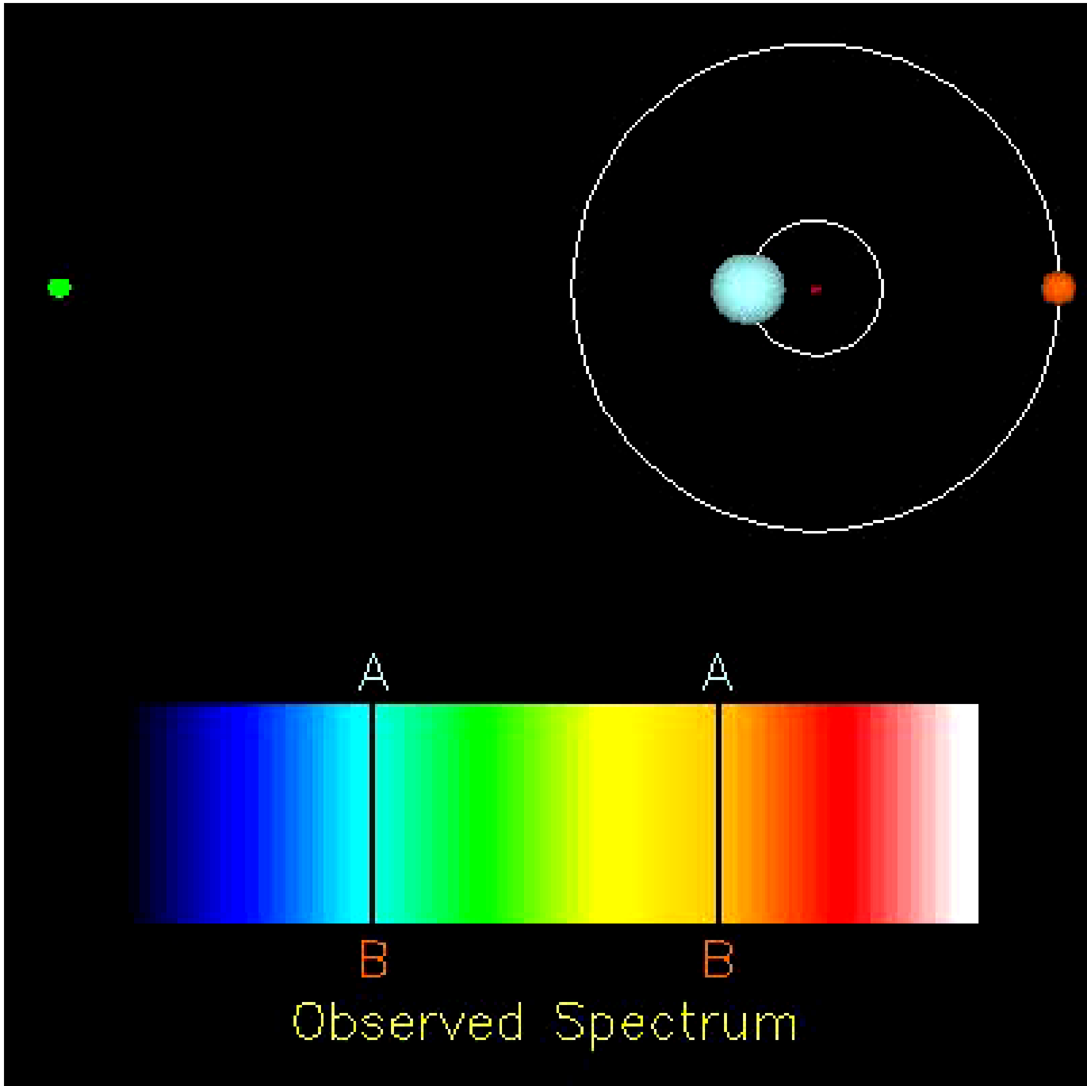
Doppler effect

- Ambulance approaching ＝ High tone（high freq.）
- Ambulance leaving ＝ Low tone(low freq.）

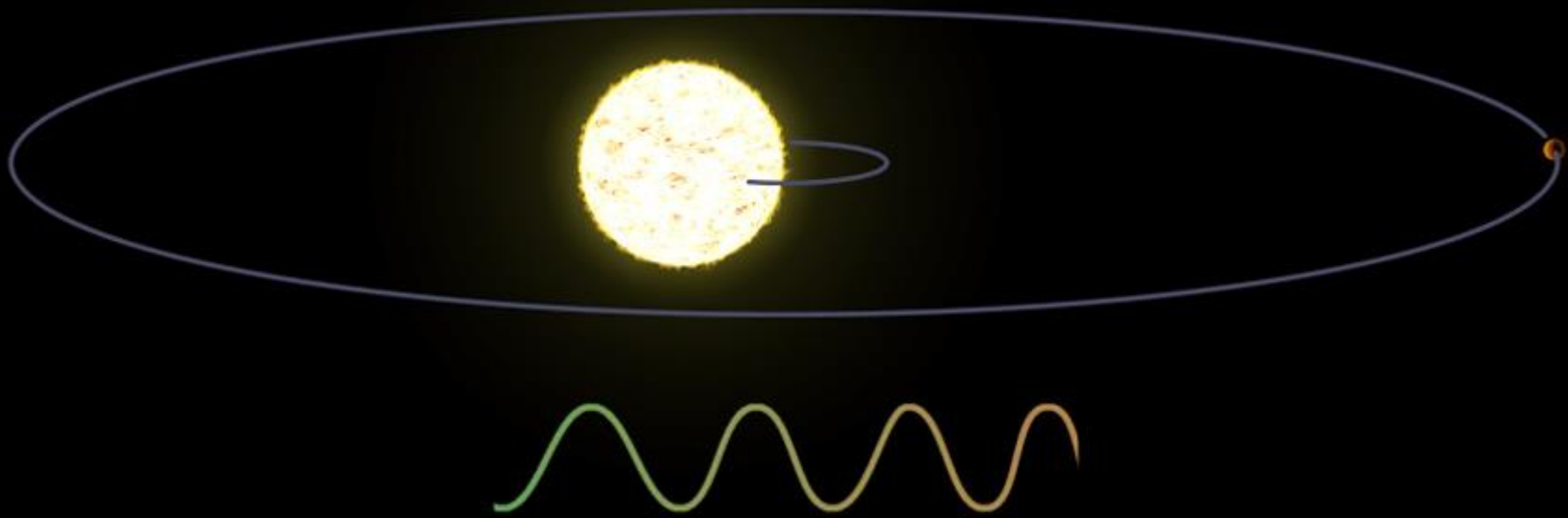
- Star approaching ＝ blue light（high freq.）
- Star leaving ＝ red light(low freq.）

Doppler effect of a star

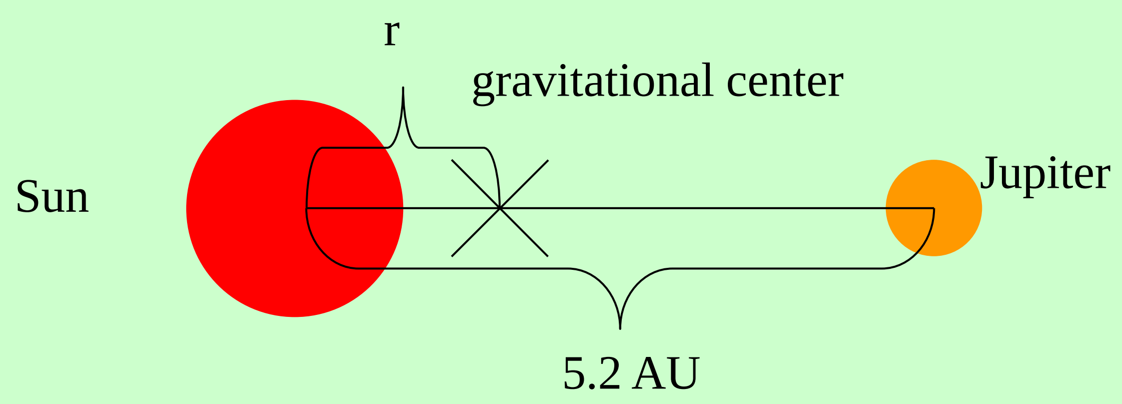
- If a planet orbits a star, the star moves opposite direction to the planet (the Sun is moving).
- Absorption lines move to blue or red, due to Doppler effect.



Doppler effect of a star



- Suppose two body system consisting of the Sun and Jupiter. Calculate the distance between the gravitational center of the system and the center of the Sun. Answer in unit of AU.

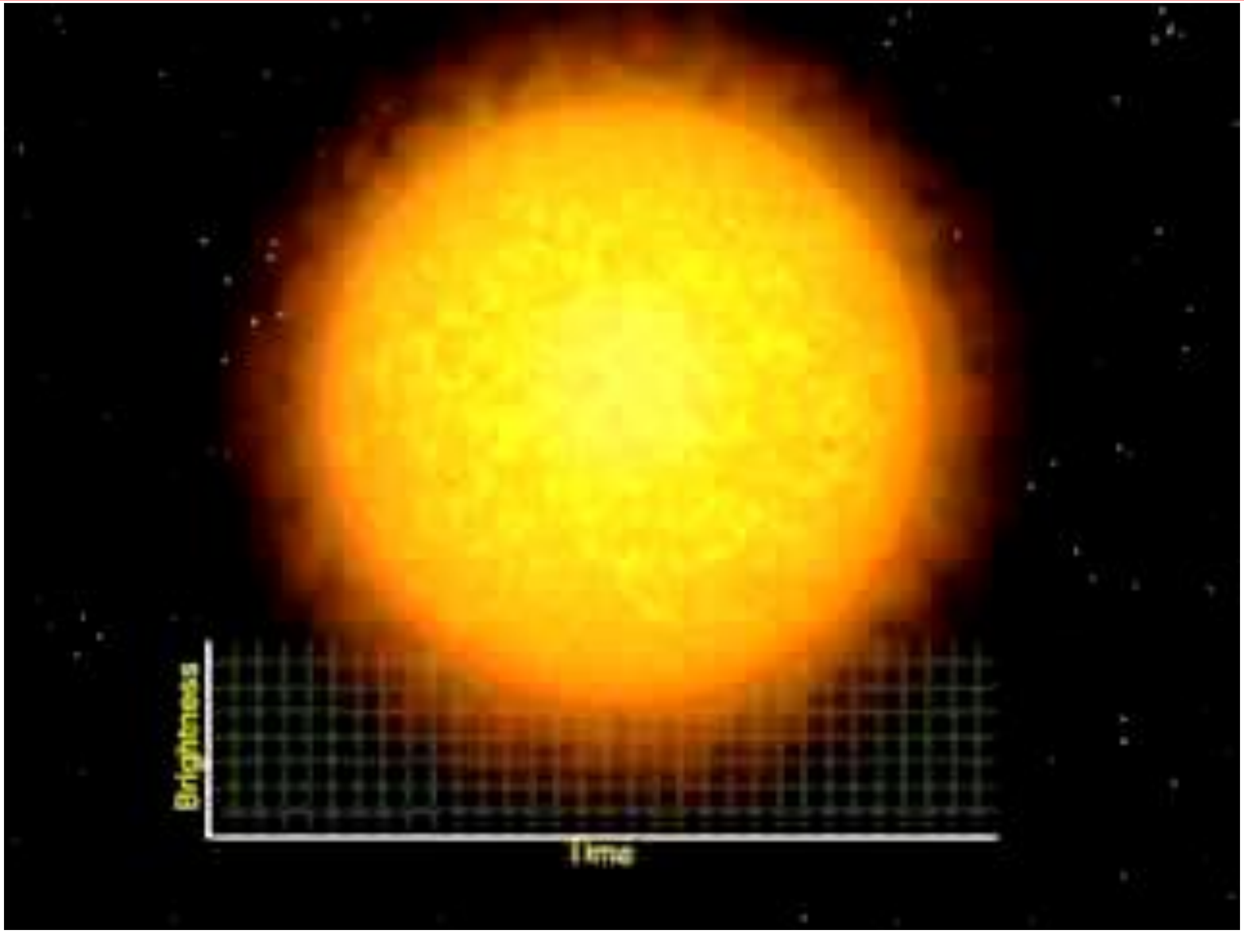


- The Sun orbit the gravitational center. Calculate the speed of the orbital motion of the Sun. Answer in unit of m/s.

- Suppose an absorption line at 500 nm in the solar spectrum. Calculate wavelength shift of the line due to orbital motion of the Sun induced by the orbital motion of Jupiter. Answer in unit of nm.

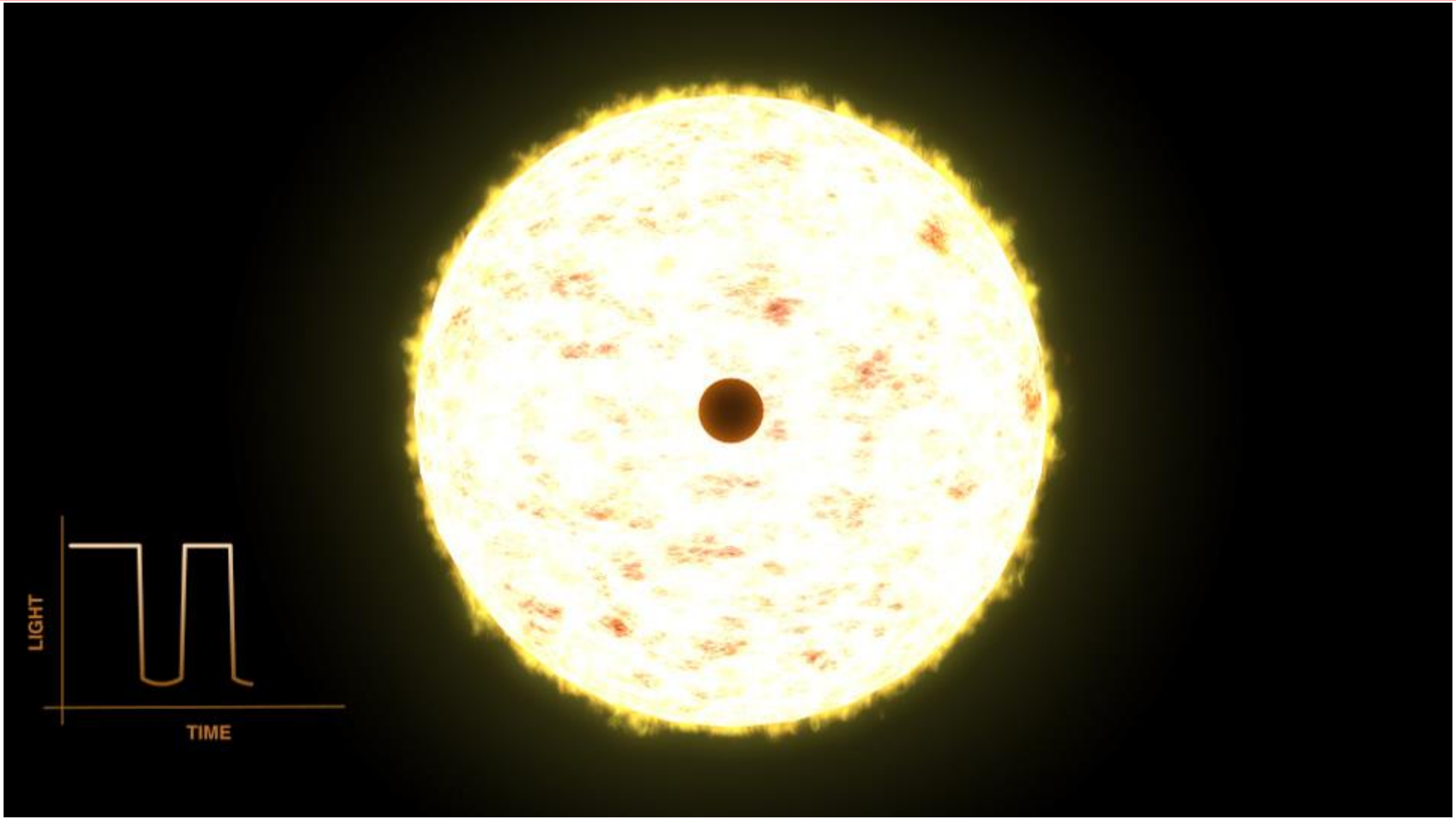
- Suppose the following planetary systems. Calculate wavelength shift of an absorption line at 500 nm in the stellar spectrum. Answer in unit of nm.
  - 1 solar mass star as the central star
    - 1 Jupiter mass planet located at the Sun – Earth distance from the central star.
    - 1 Jupiter mass planet located at the Sun – Mercury distance from the central star.
  - 1 Jupiter mass planet located at the Sun – Jupiter distance from the central star.
    - 10 solar mass star as the central star
    - 1/10 solar mass star as the central star

Transit



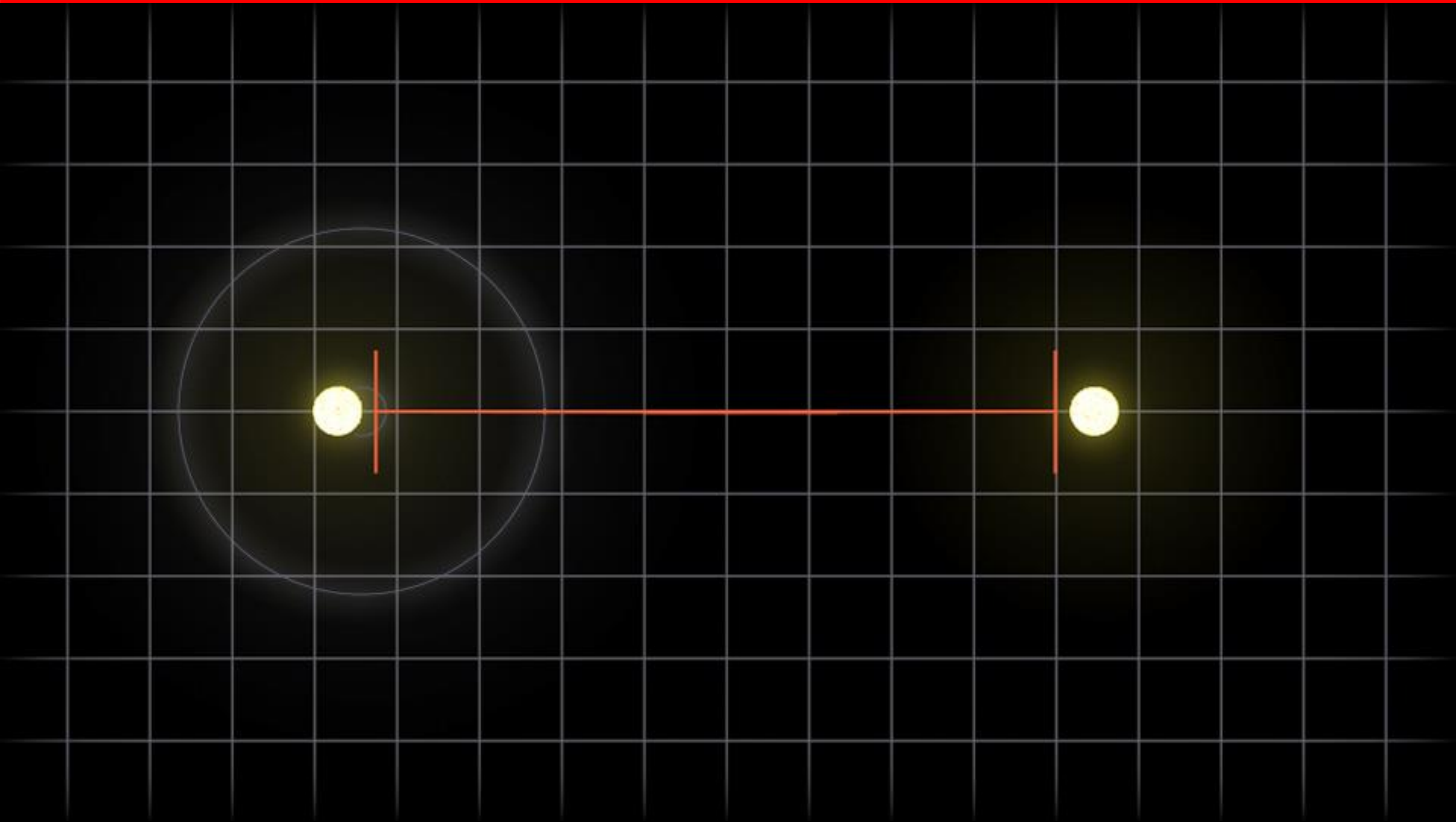
- A planet passes in front of a star.
- Decrease of brightness = (planet radius/stellar radius)^2
- We have to be aligned with the orbital plane of the planet.

Transit

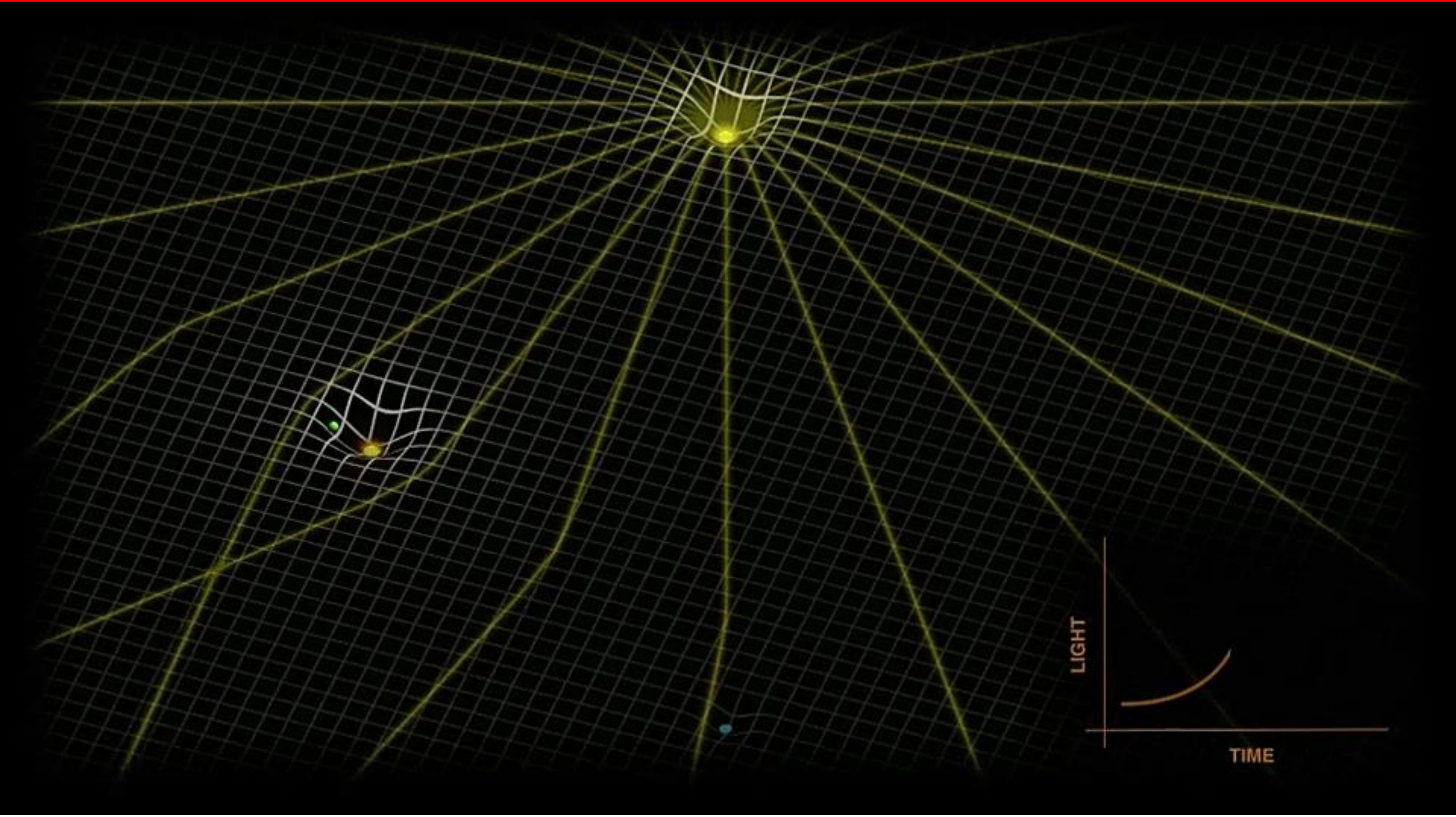


- A planet passes in front of a star.
- Decrease of brightness = (planet radius/stellar radius)^2
- We have to be aligned with the orbital plane of the planet.

Proper motion



Gravitational lens



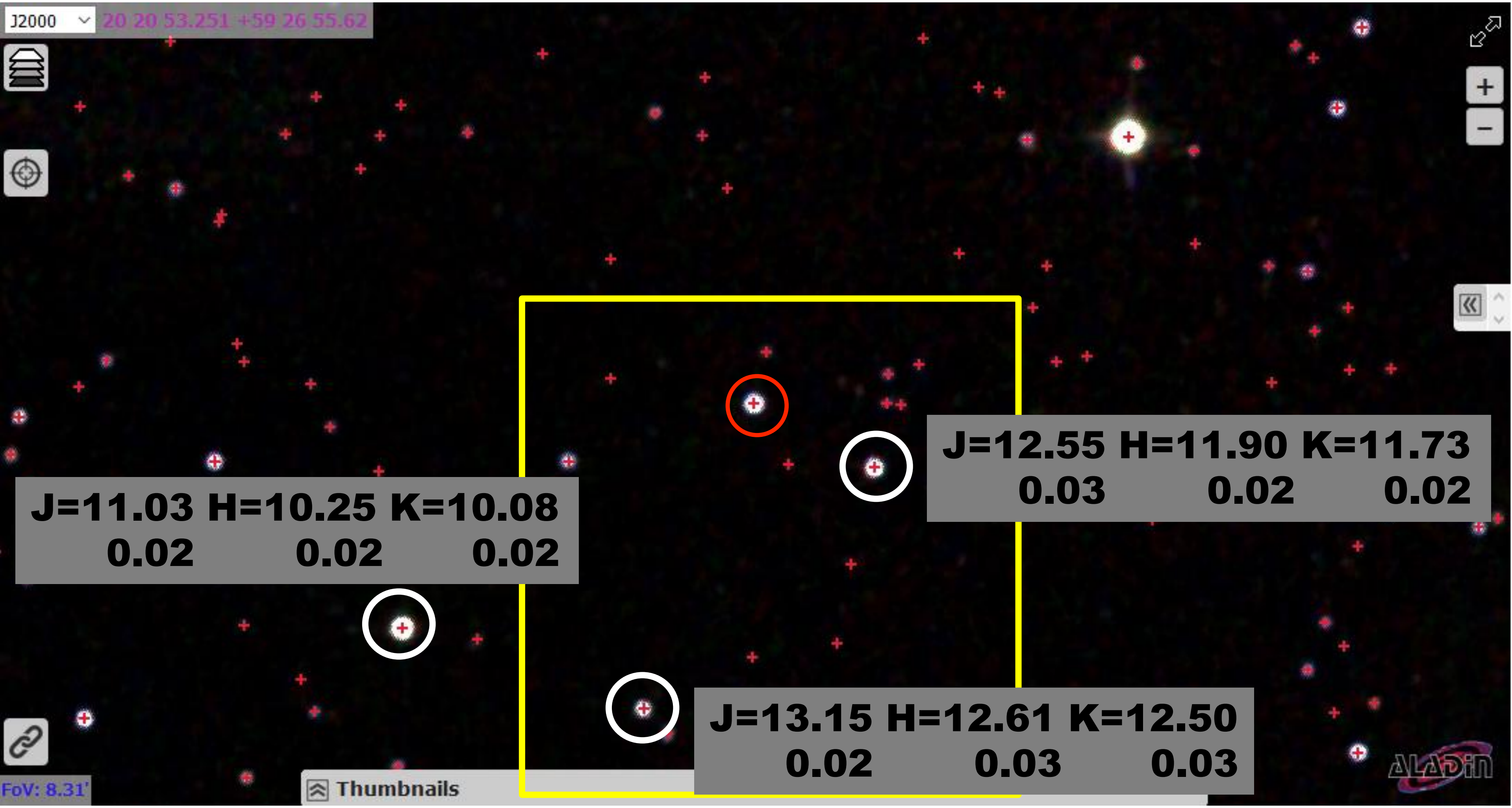
Data : Exoplanet

- Date of observation: Aug. 1, 2018
- Telescope: Nayuta telescope at the Nishi-Harima Astronomical observatory
- Instrument: Near-Infrared Camera (NIC)
- Filter: J, H, Ks band
- Exposure times: 30 sec
- Target TrES 5 b
  - Brightness (of the host star TrES 5): 12.11mag (J)
  - Predicted transit time (JST): 23:34 - 25:26
  - Transit depth: xx %

※JST = UT + 9 h

Let's detect a drop of brightness due to a transit of the planet.

Finding Chart



Finding Chart (up-side down)