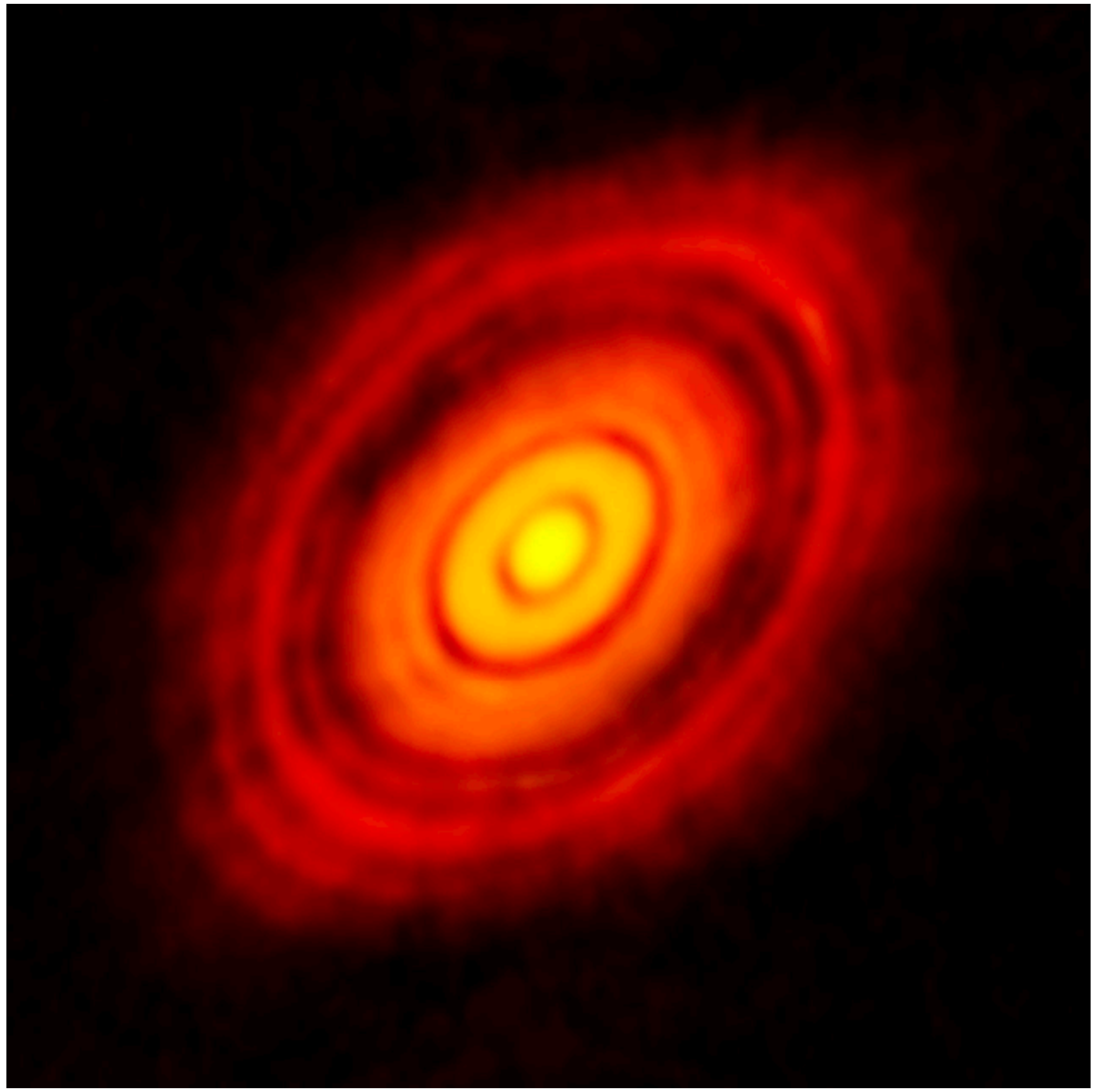
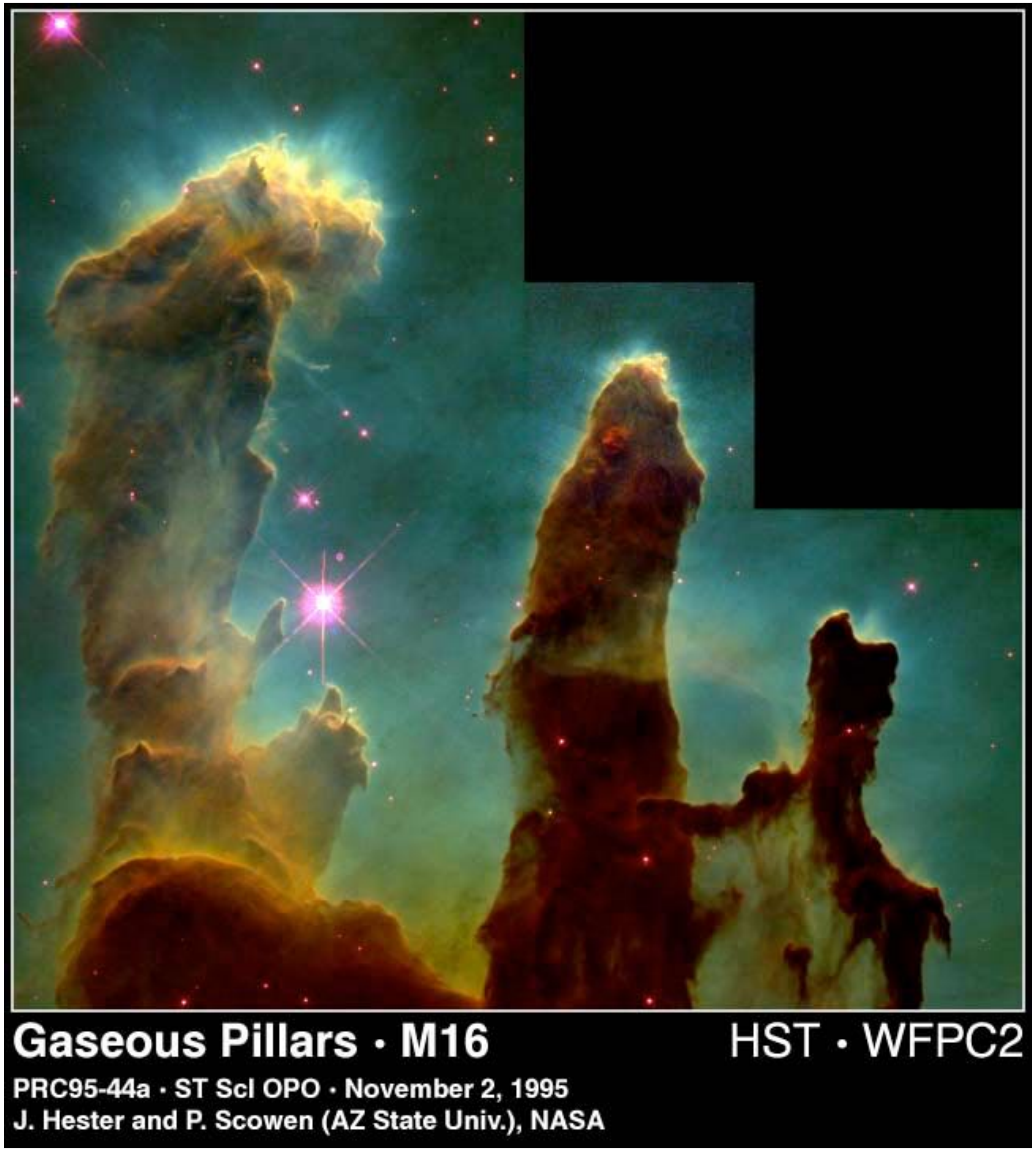
Chapter 5: Formation of Stars and Planets

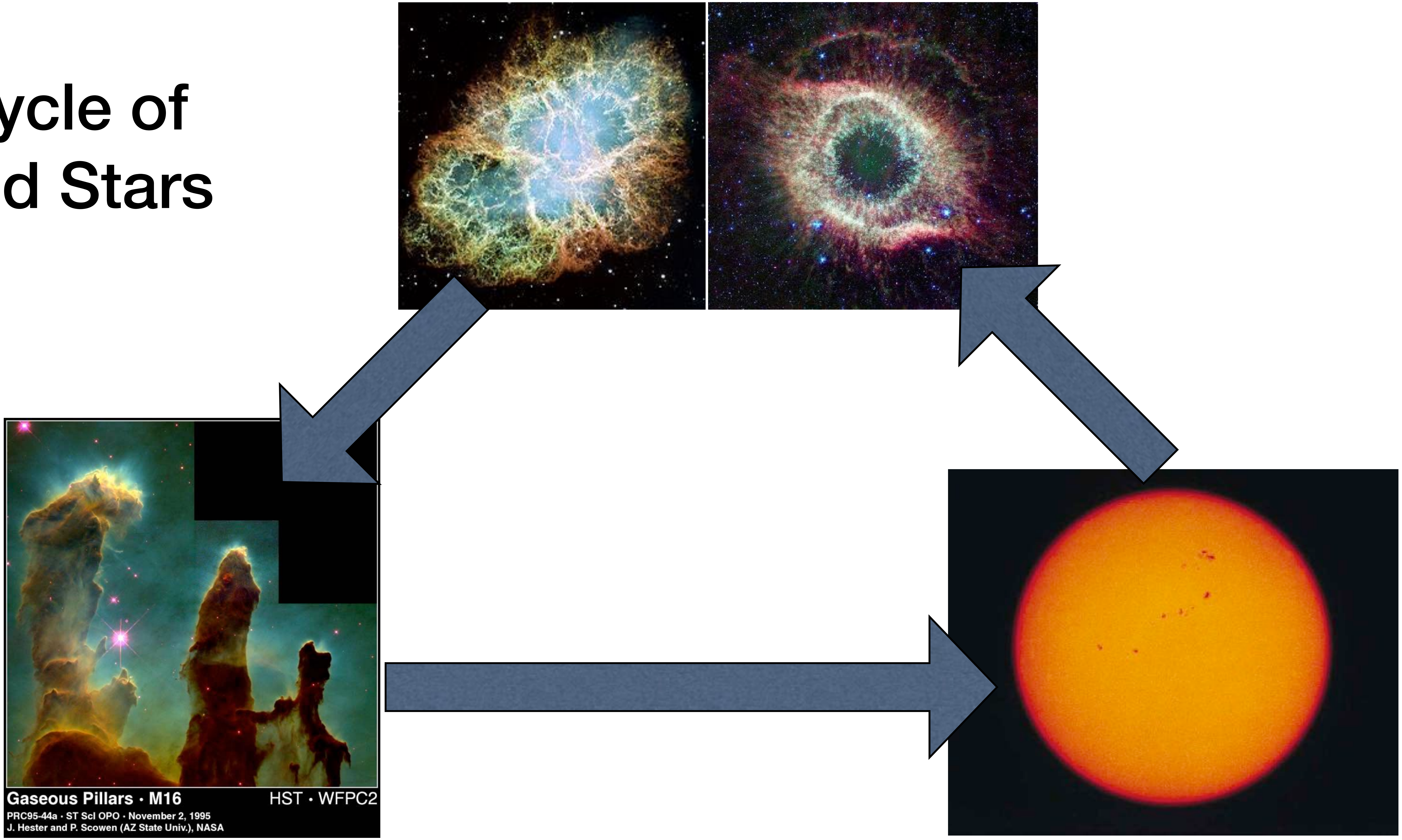


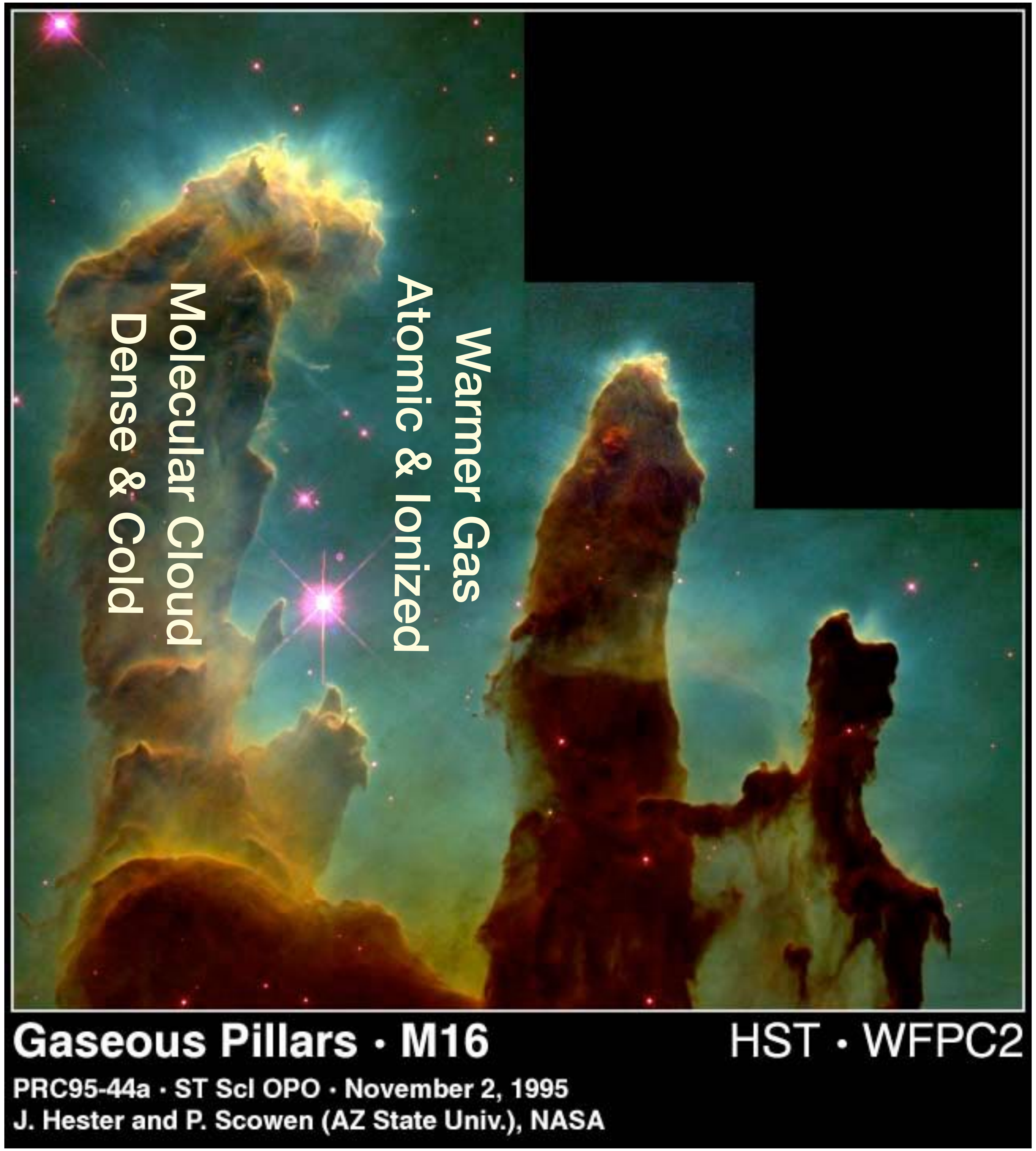


Stars form from the “interstellar medium”: gas in between stars

“Pillars of Creation”

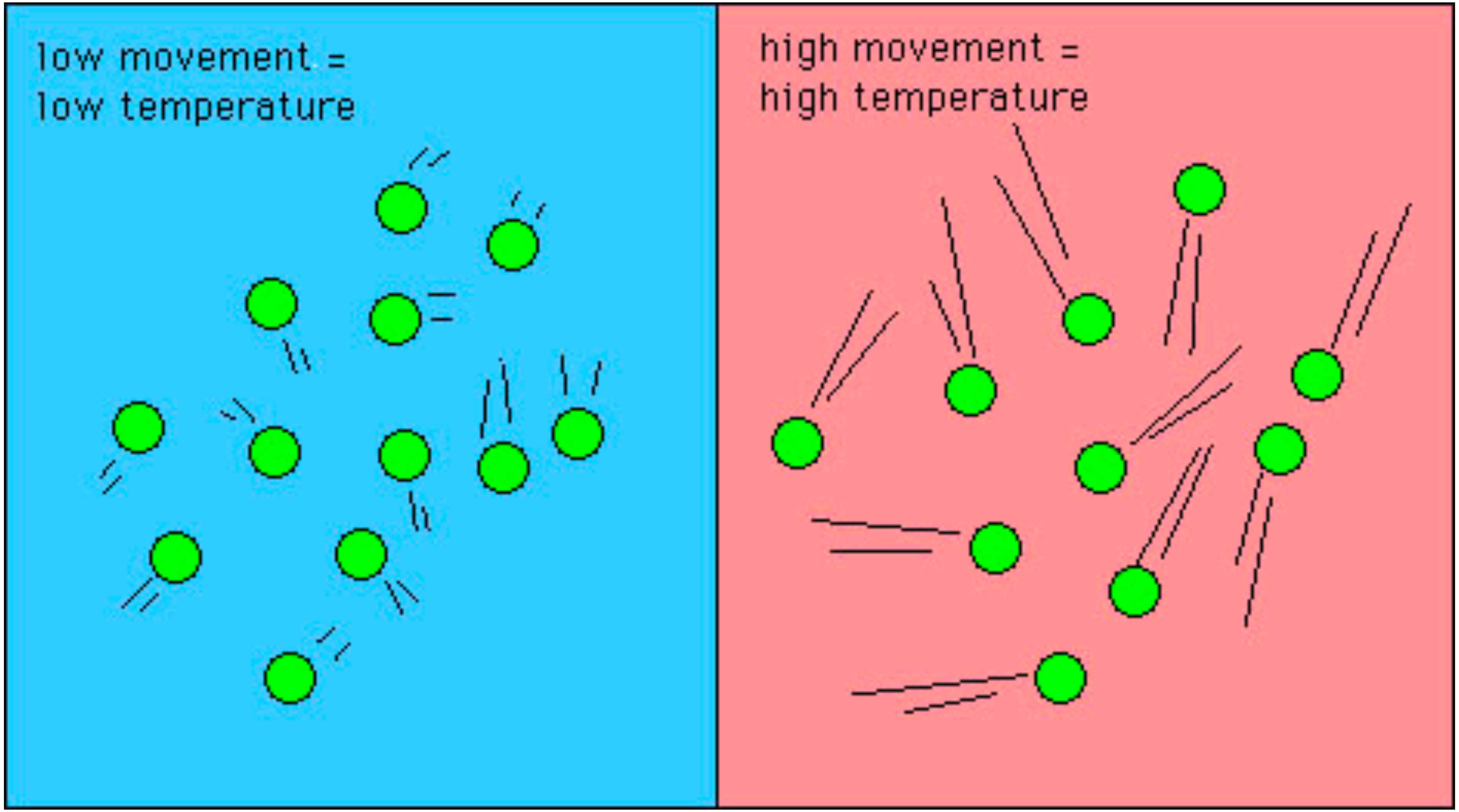
Life Cycle of Gas and Stars

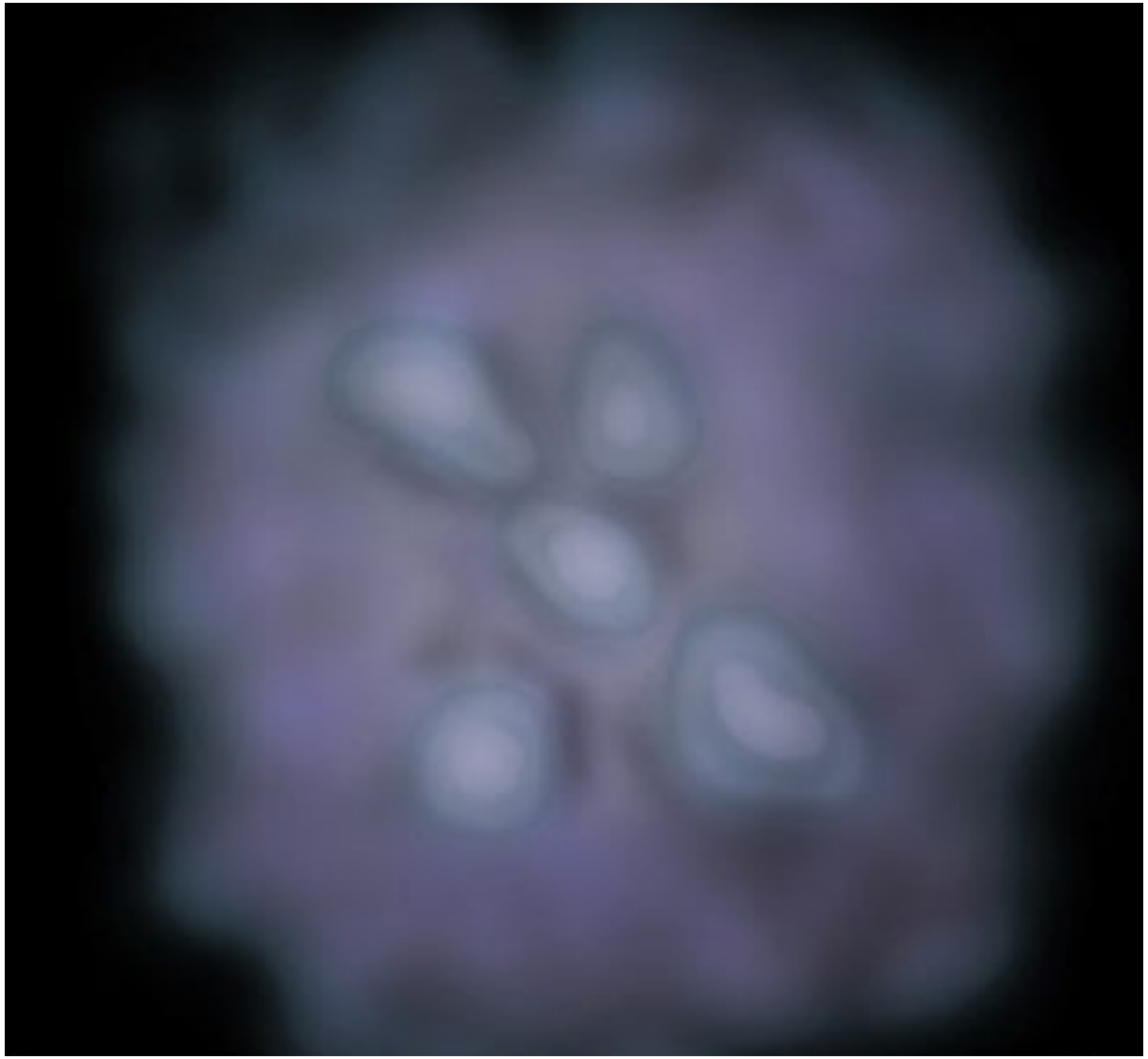




Which region is hotter and which is colder?

What is temperature?





If an interstellar cloud contracts to become a star, it is due to which force?

A) electromagnetic
B) nuclear
C) gravitational
D) all of the above

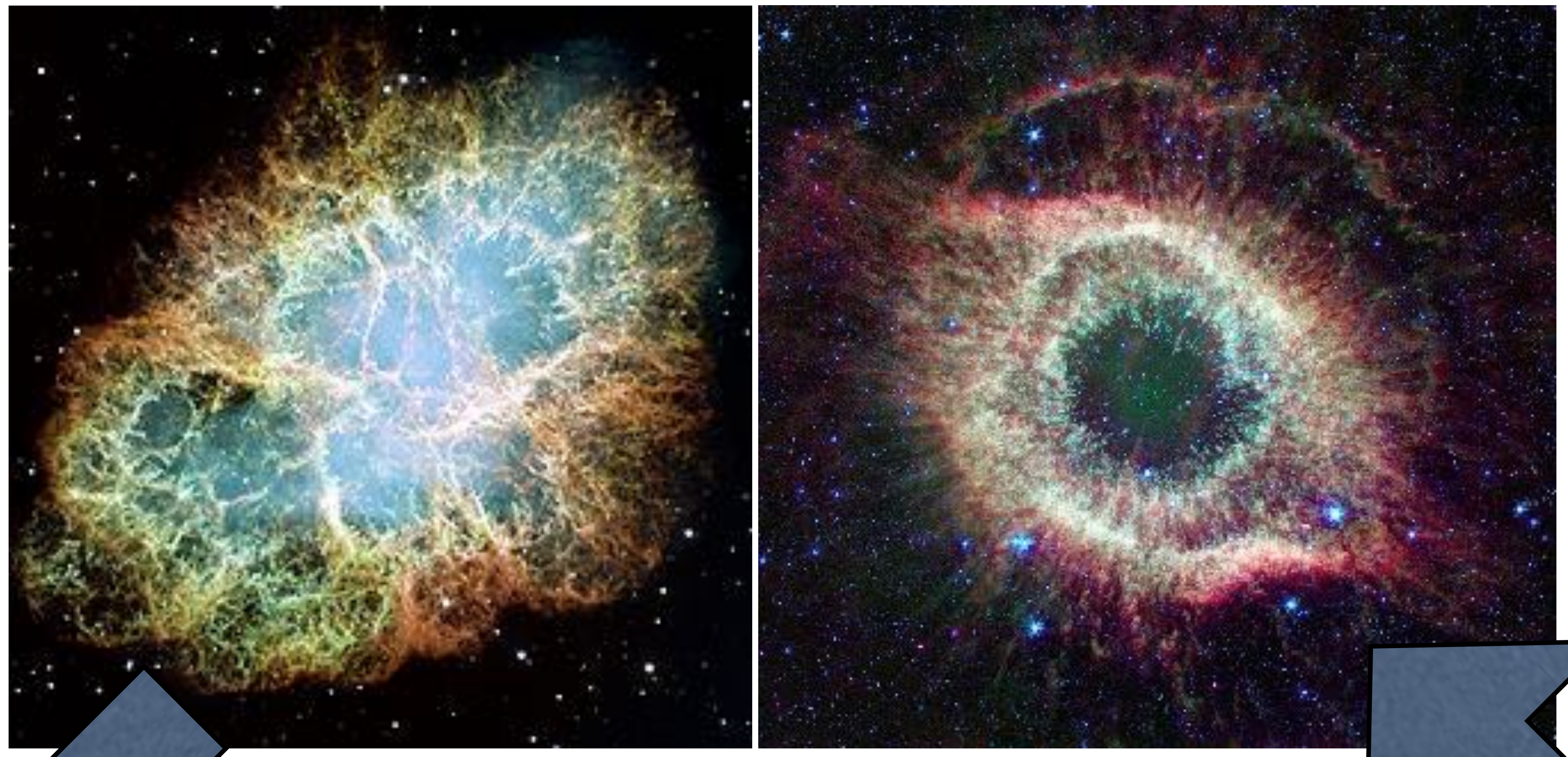
Ch. 5: Formation of Stars/Planets

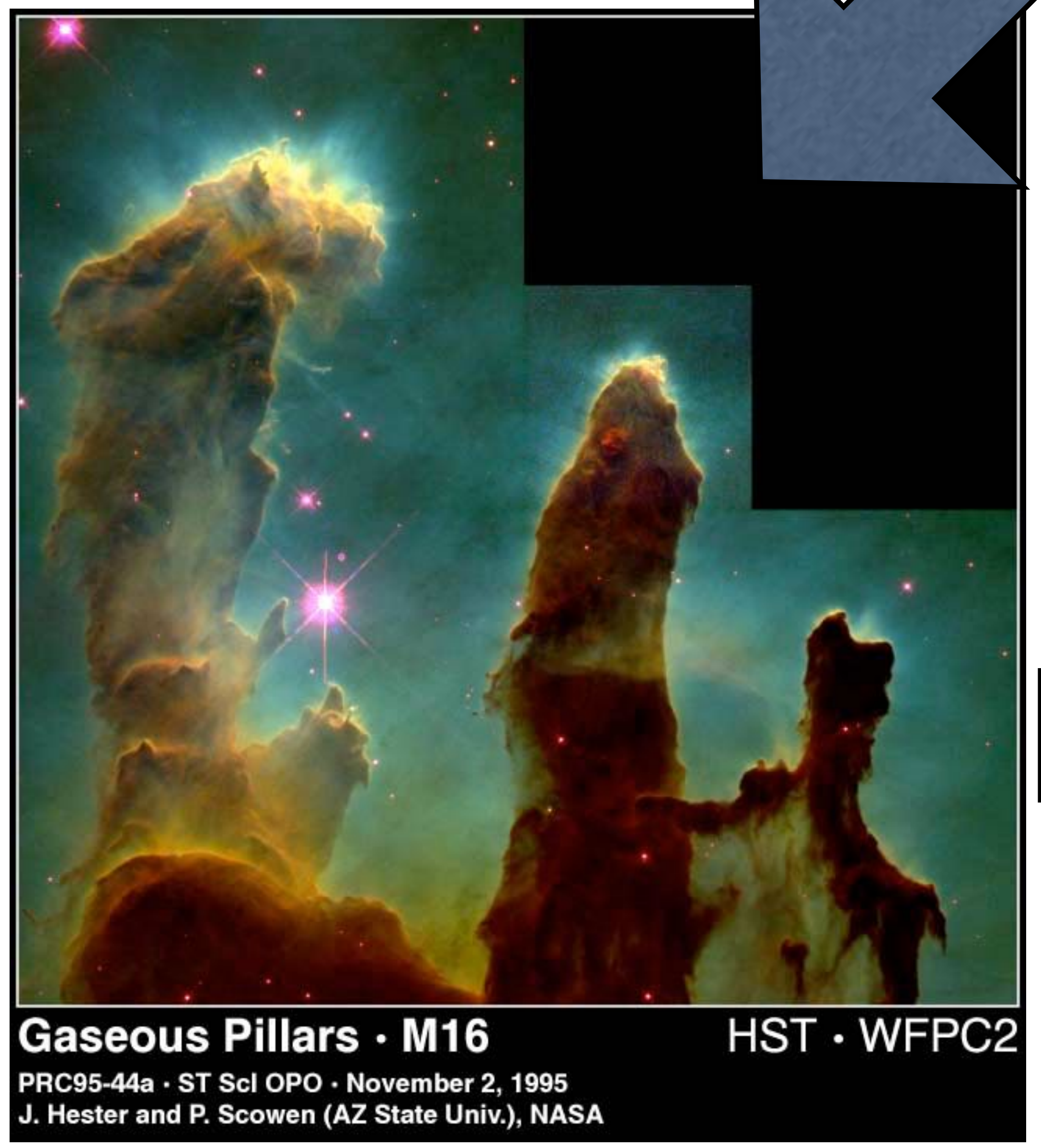
HW2 due NOW!

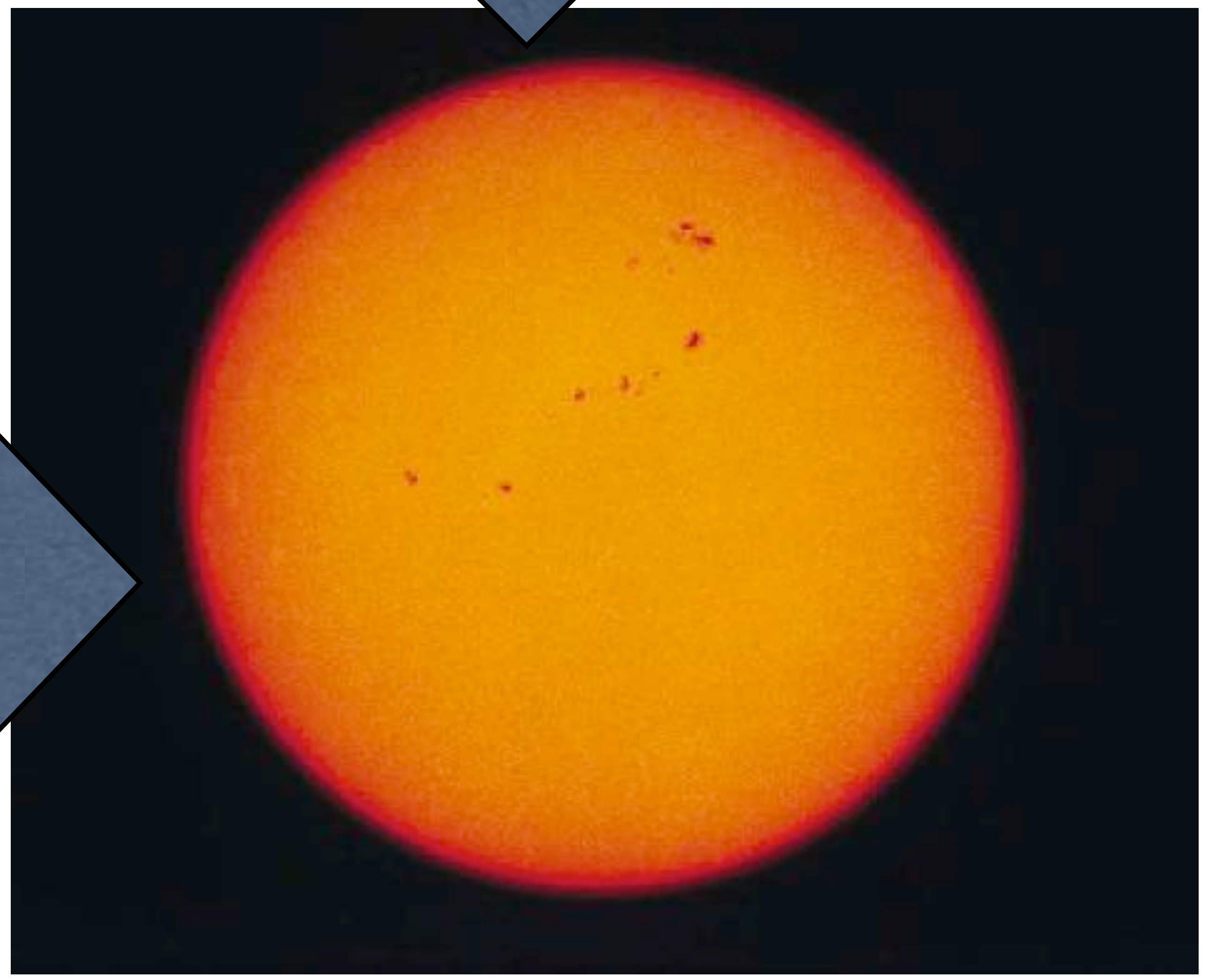
Midterm 1 on Sept. 28th
will cover Chapters 1-5 and lecture material

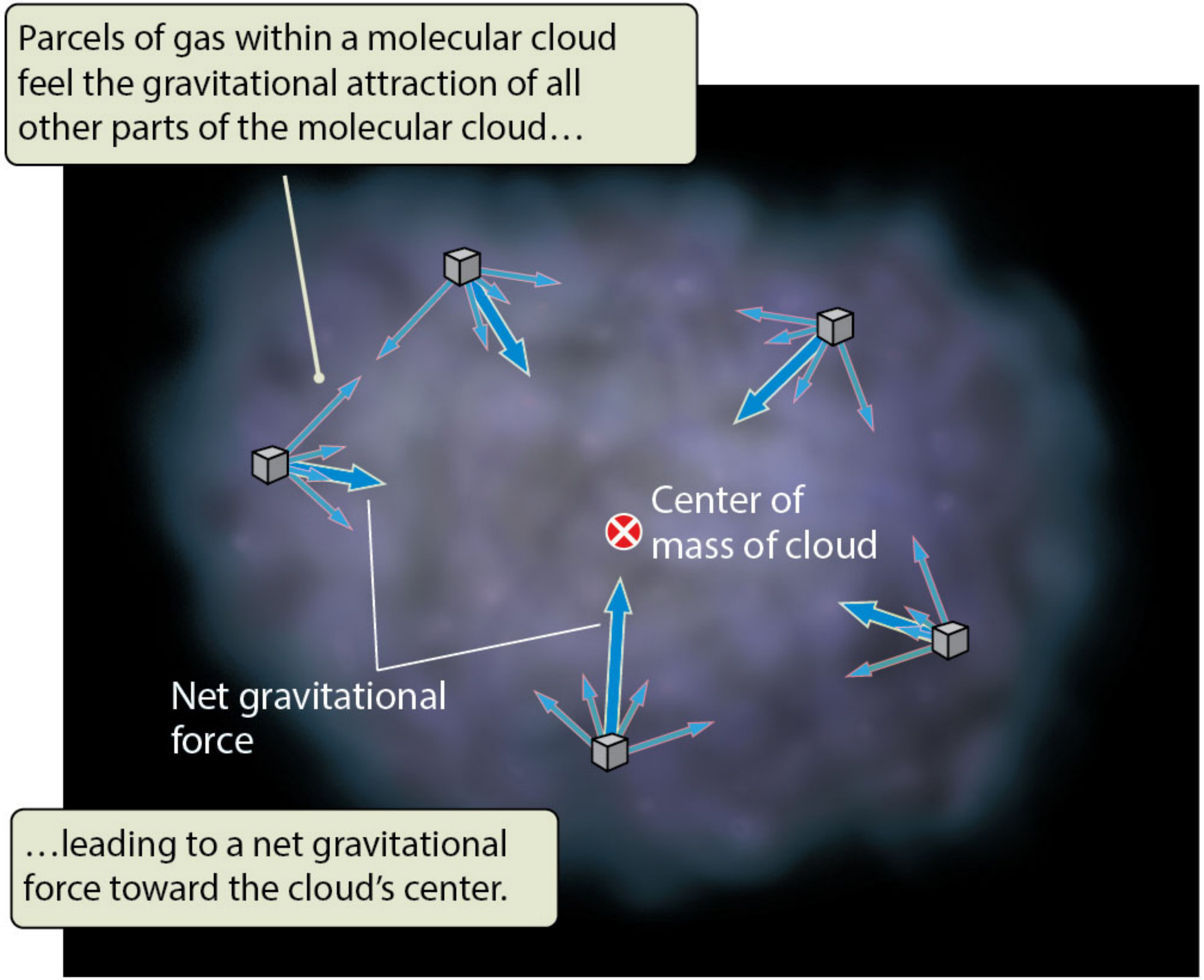
Moon Phases available up front if you haven't gotten yours yet

Life Cycle of Gas and Stars









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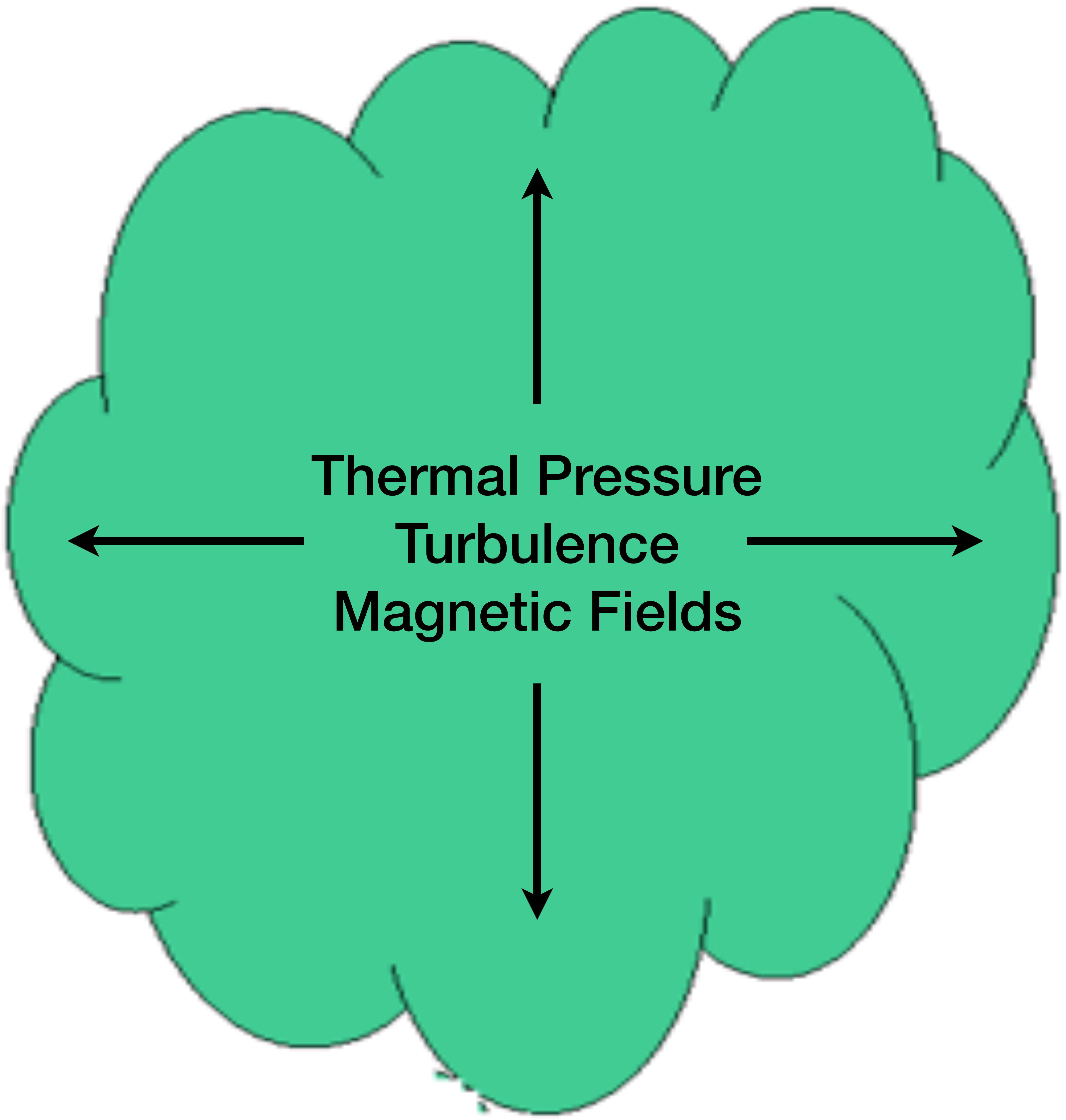
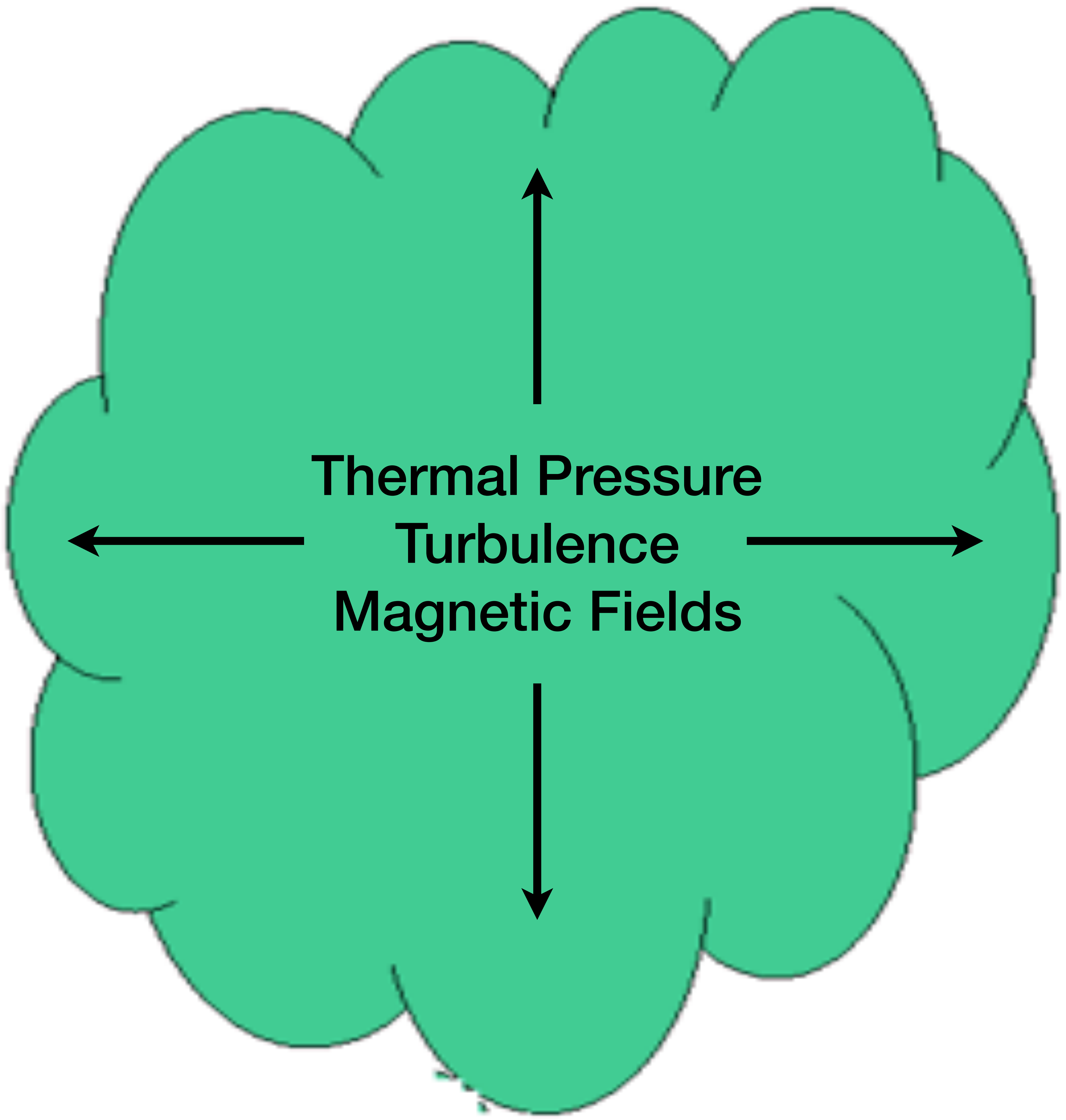


Gravity has to overcome other forces in the cloud that want to keep it from collapsing



Gravity has to overcome other forces in the cloud that want to keep it from collapsing

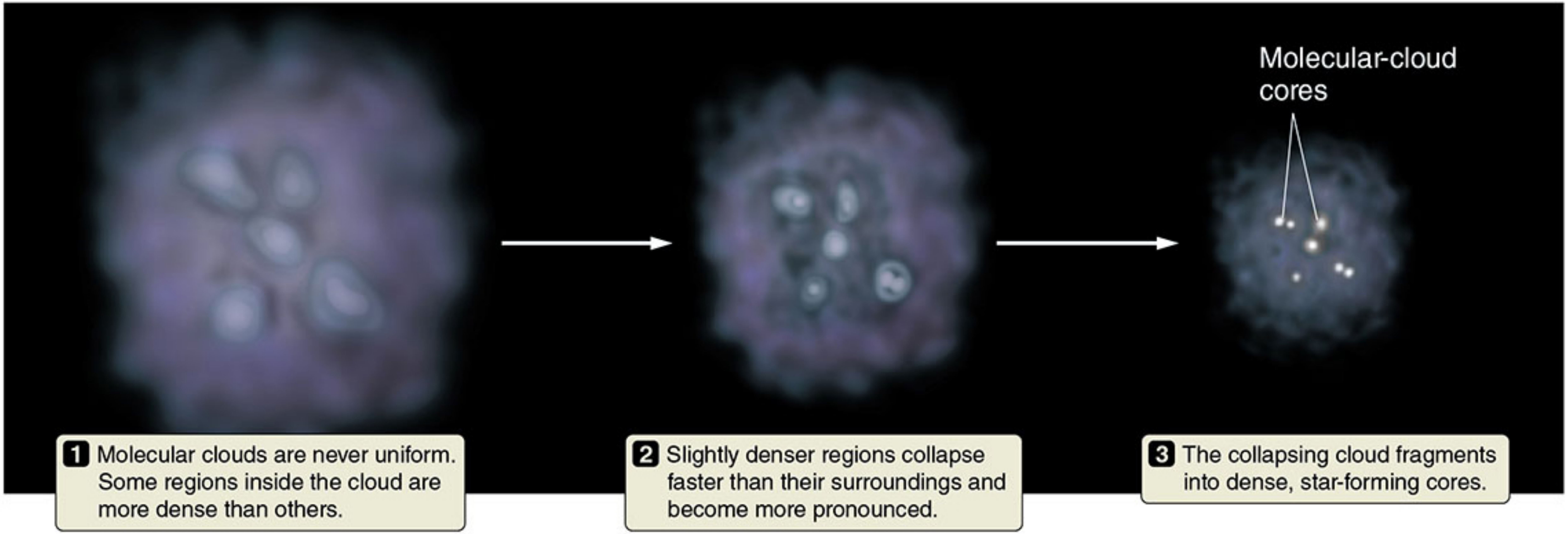
Easier for gravity to do this if the mass of the cloud is:

A) Doesn't Matter

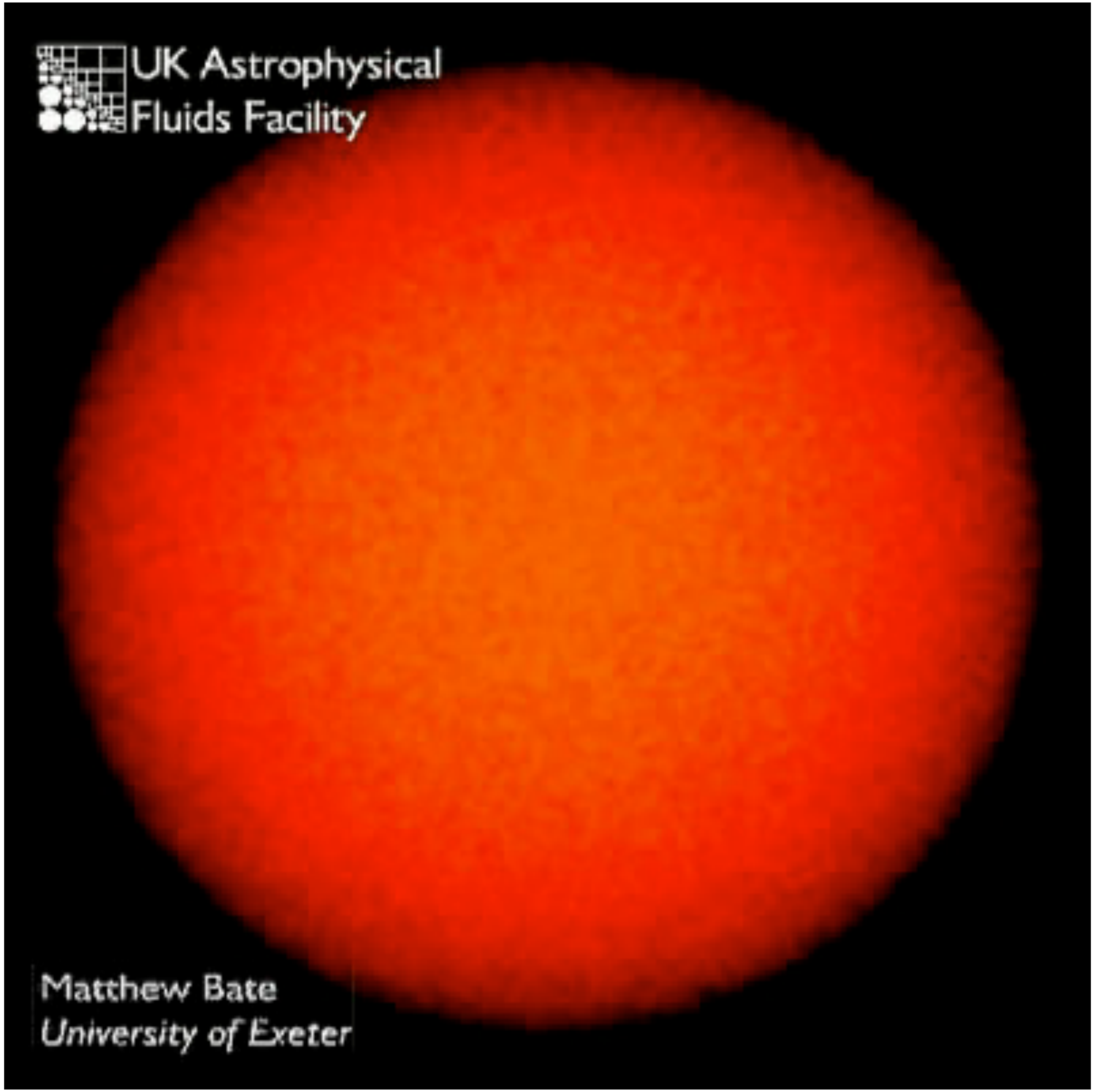
B) Large

C) Small

Cloud doesn't collapse uniformly

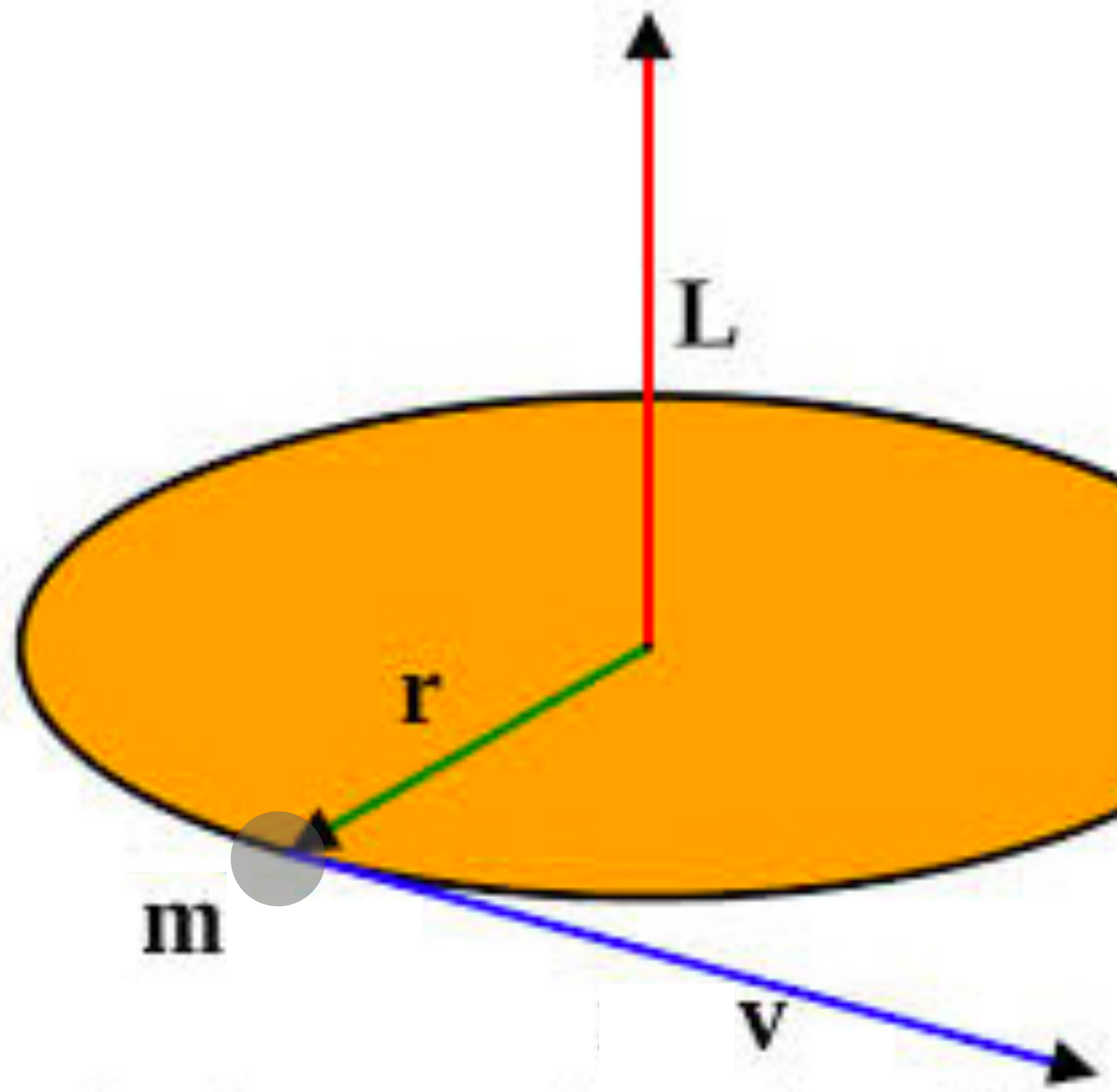


Simulation of the collapse of gas cloud, fragmenting, forming protoplanetary disks and low mass stars



Conservation of “Angular Momentum”

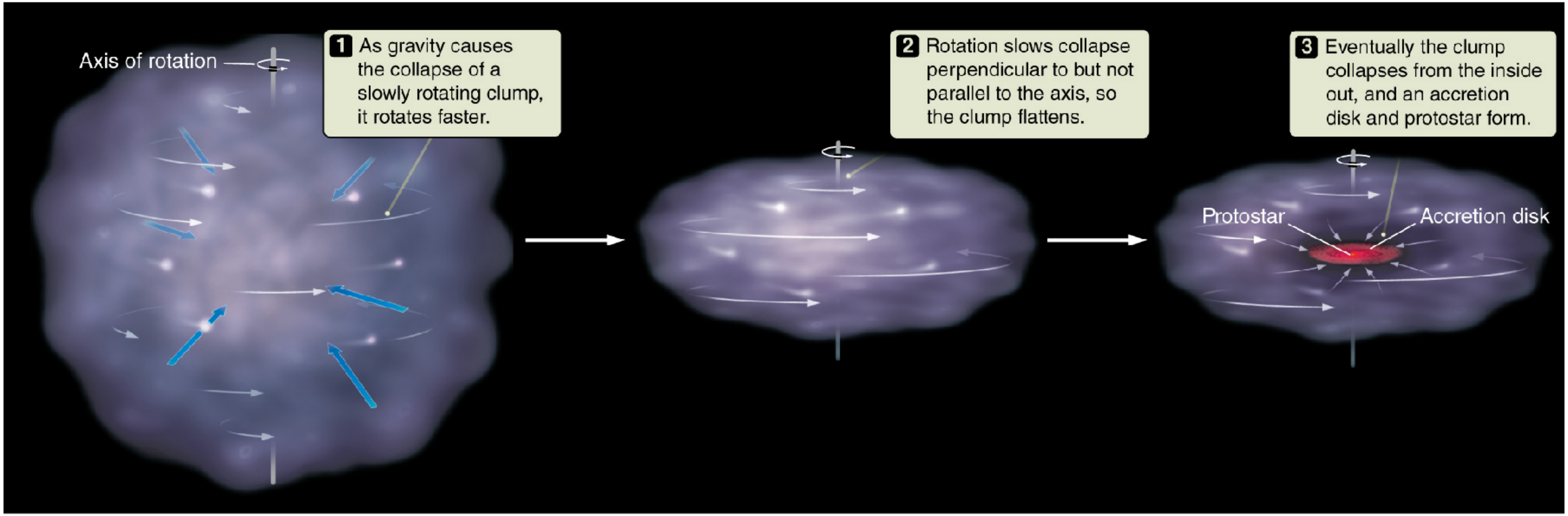
Angular Momentum



Angular momentum of a particle

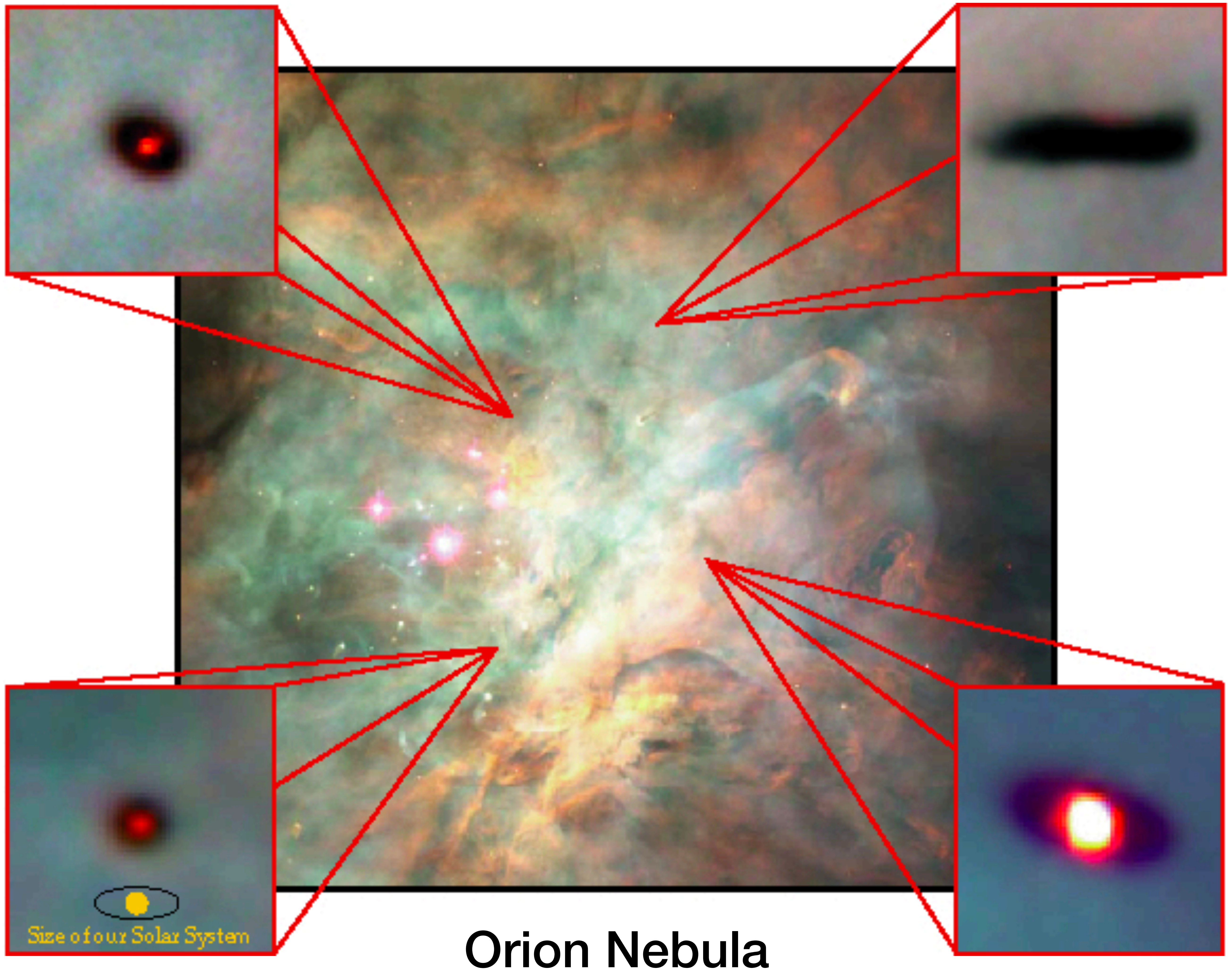
- $L = m\,v\,r$
- L is angular momentum
- m is mass
- v is velocity
- r is radius

Any small net spin of the collapsing cloud is amplified as it becomes smaller

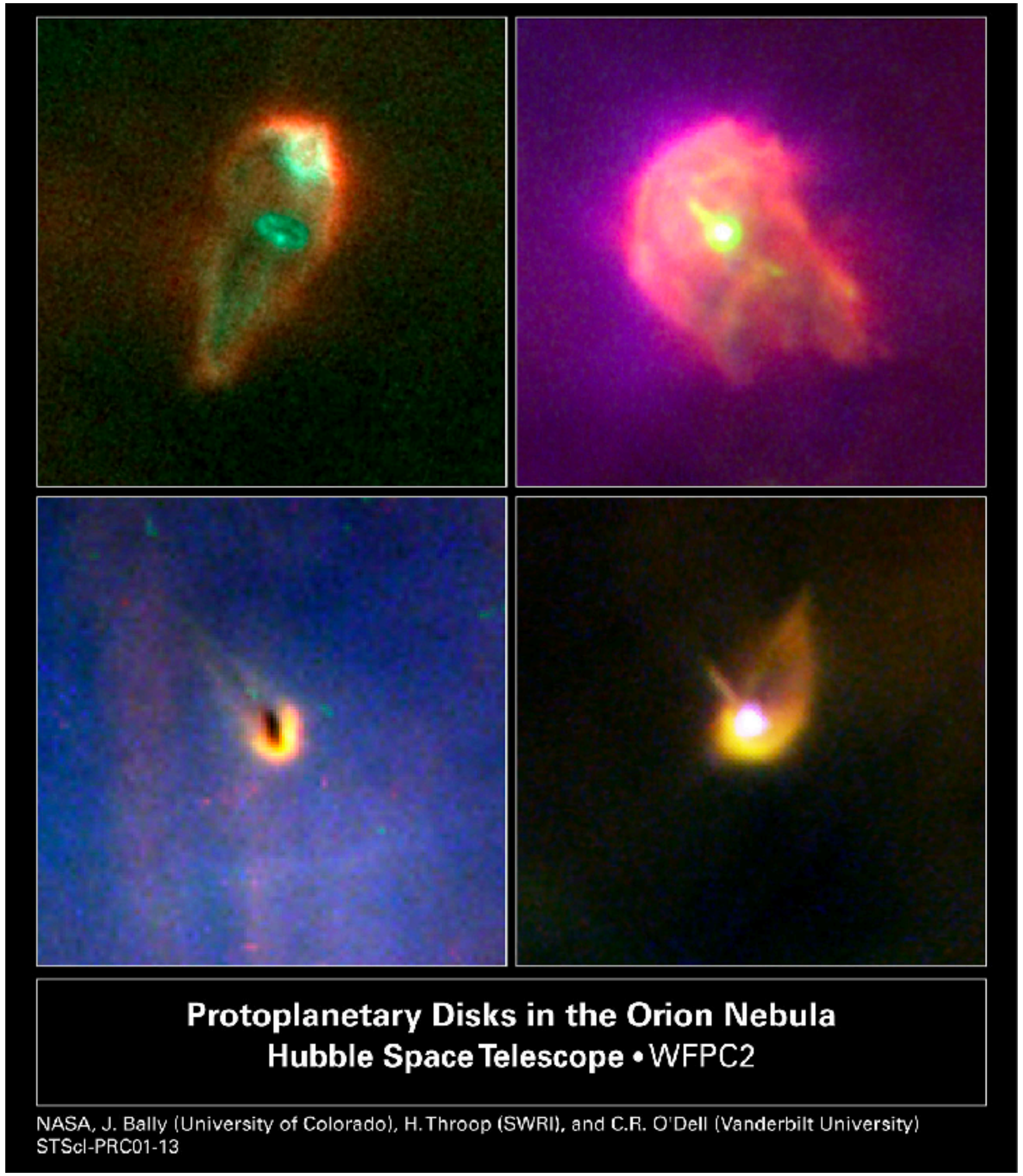


Protoplanetary Disk

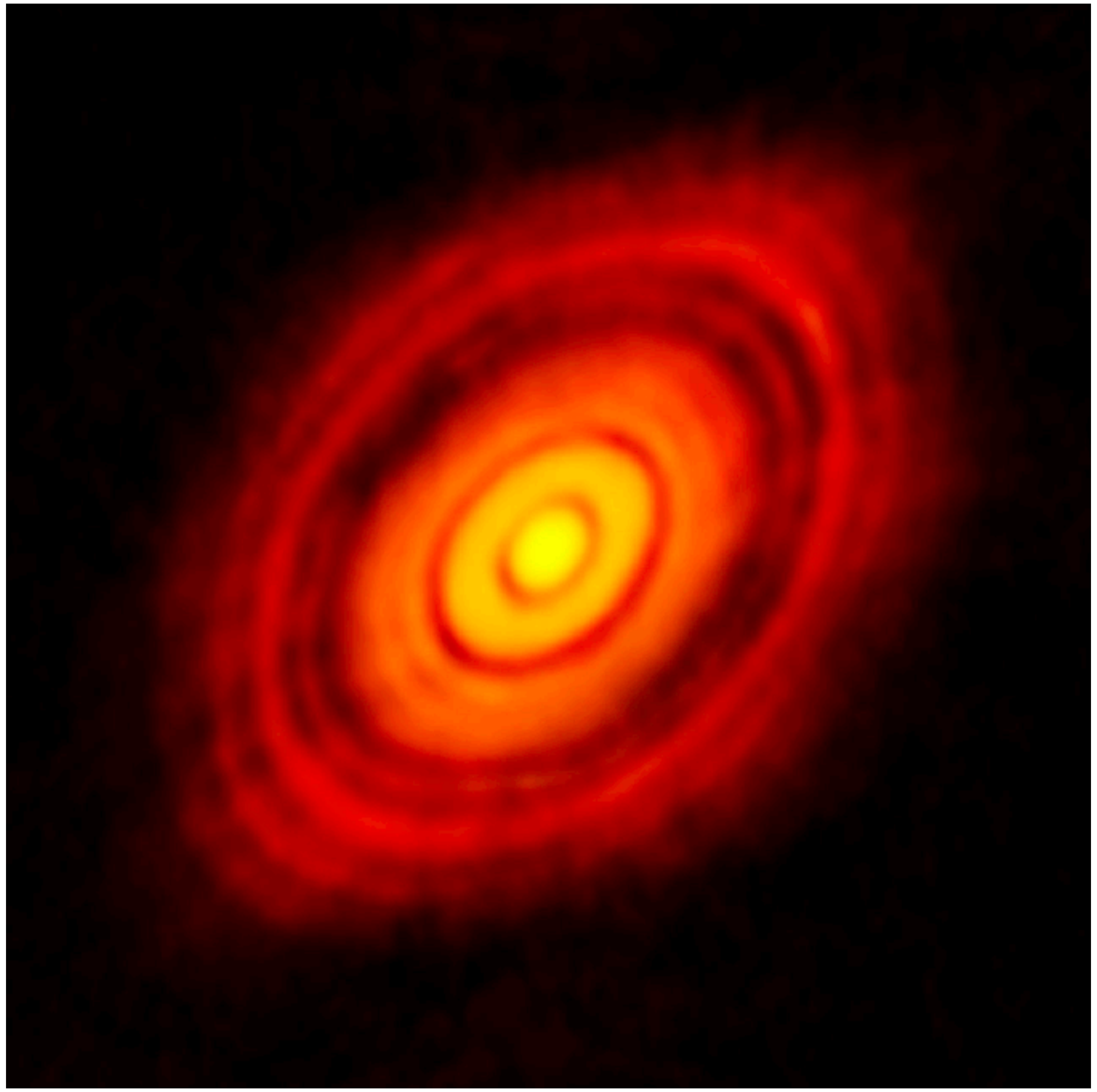
Observations of Disks



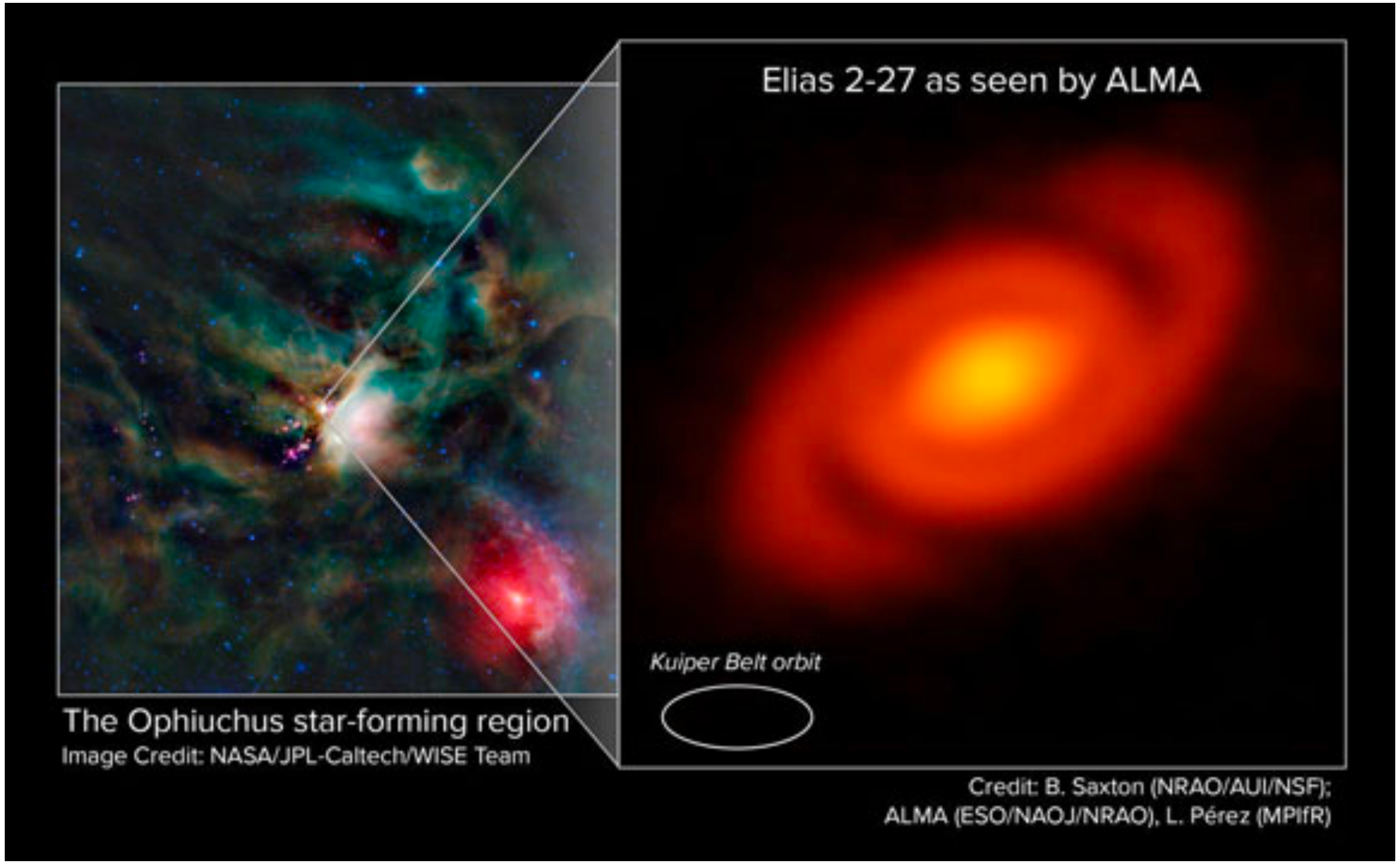
Orion Nebula
old Hubble Telescope data (visual)



Observations of Disks



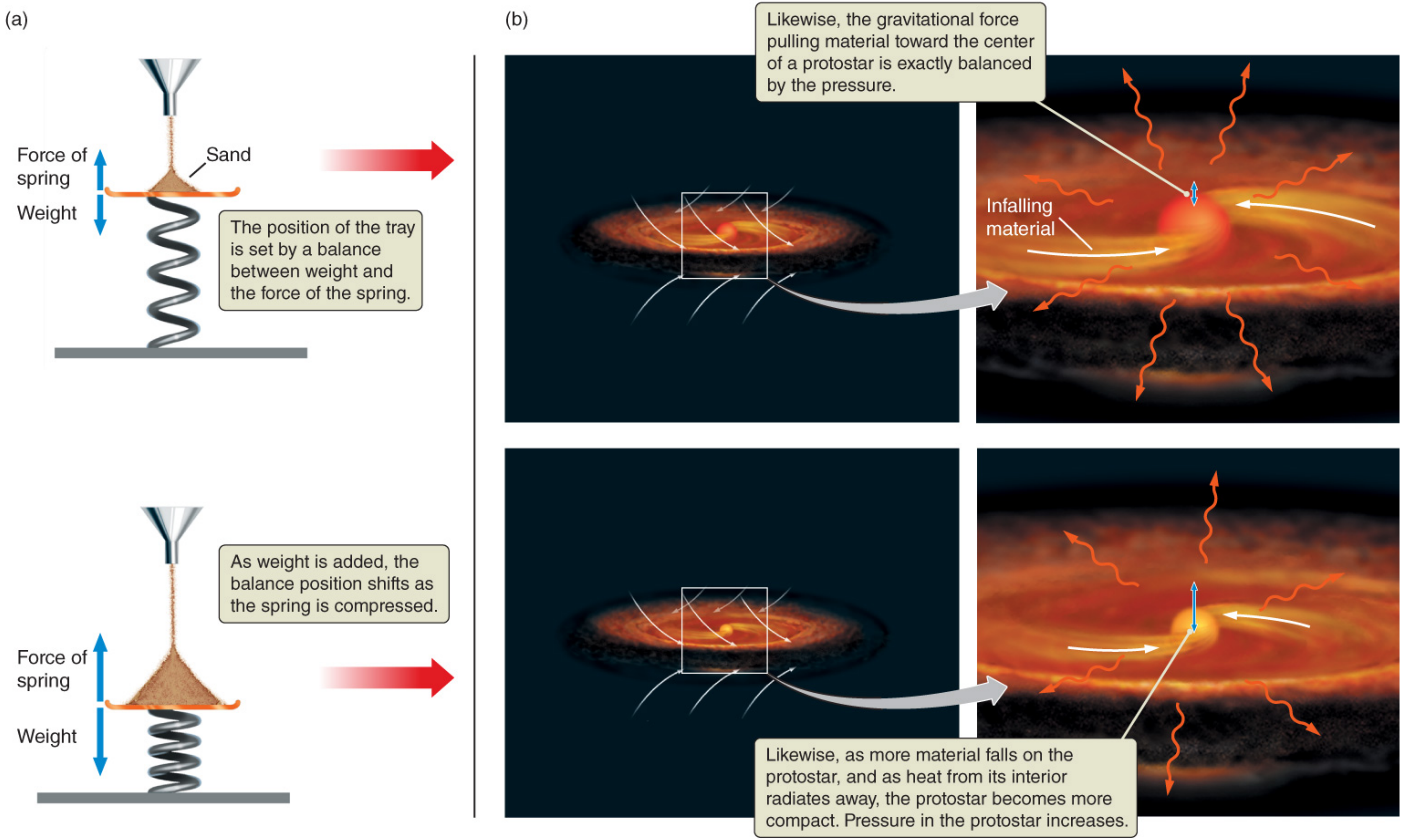
HL Tauri
ALMA (radio)

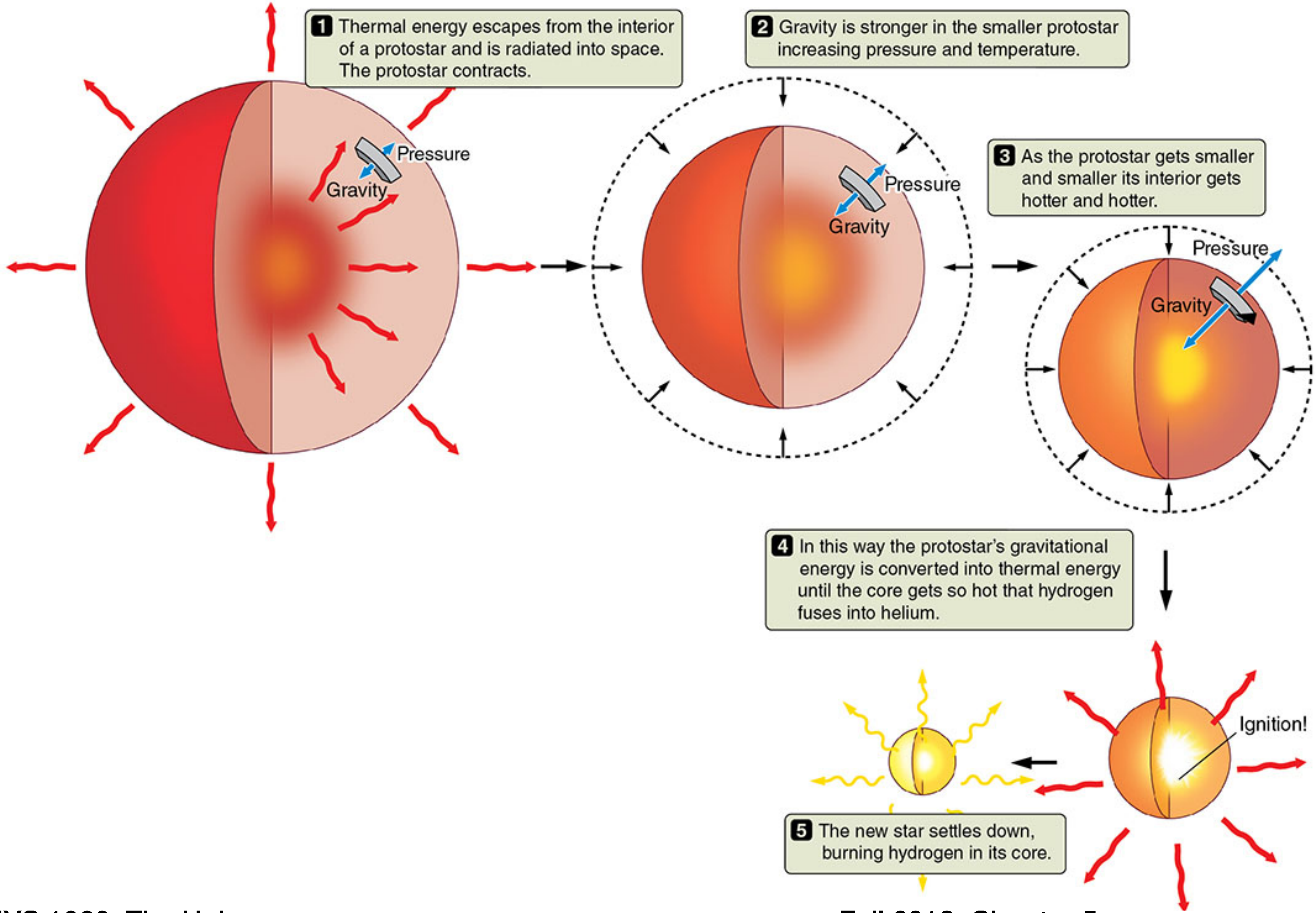


WISE (infrared) ALMA (radio)

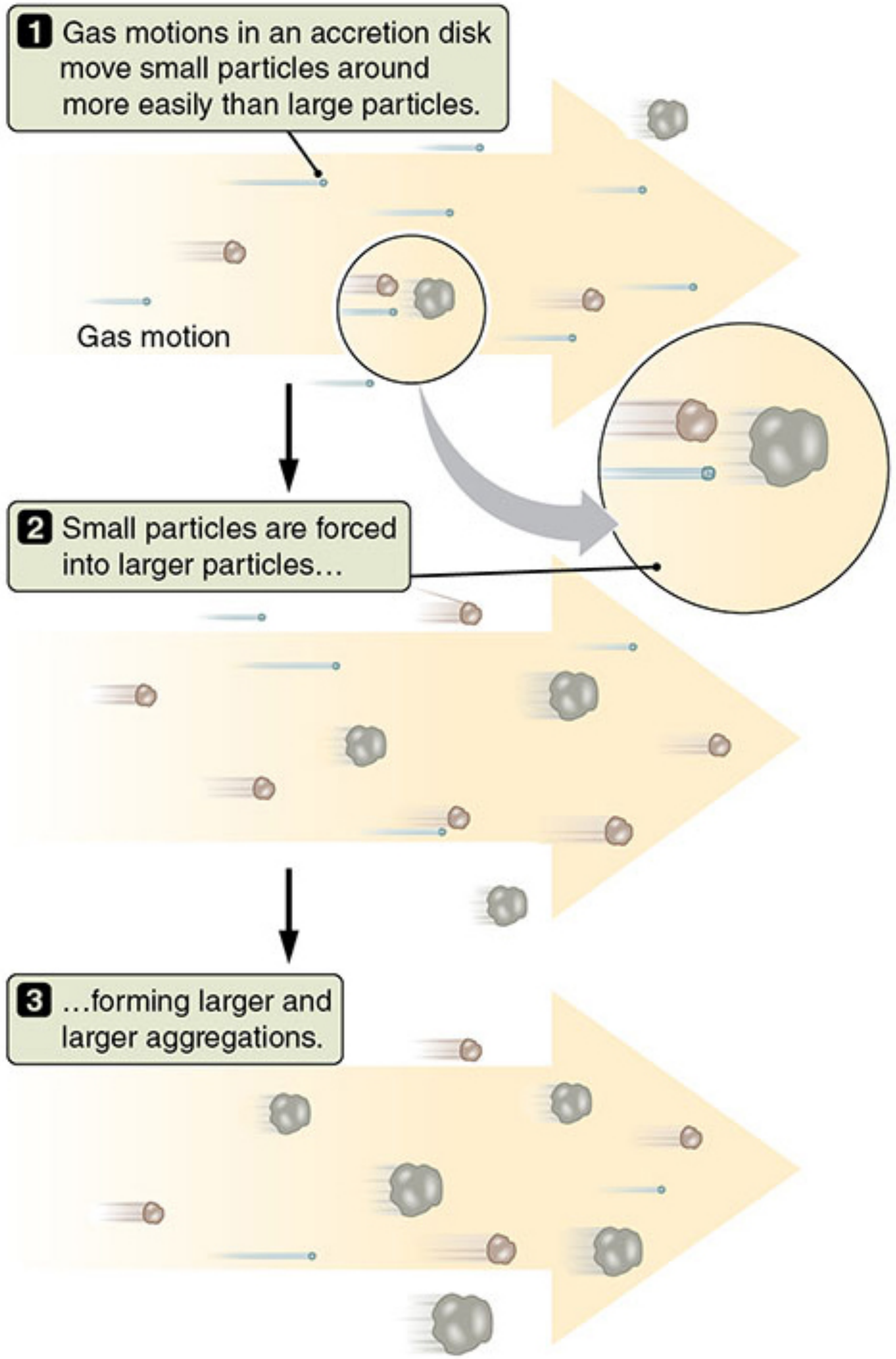
Computer Simulations of Protoplanetary Disks

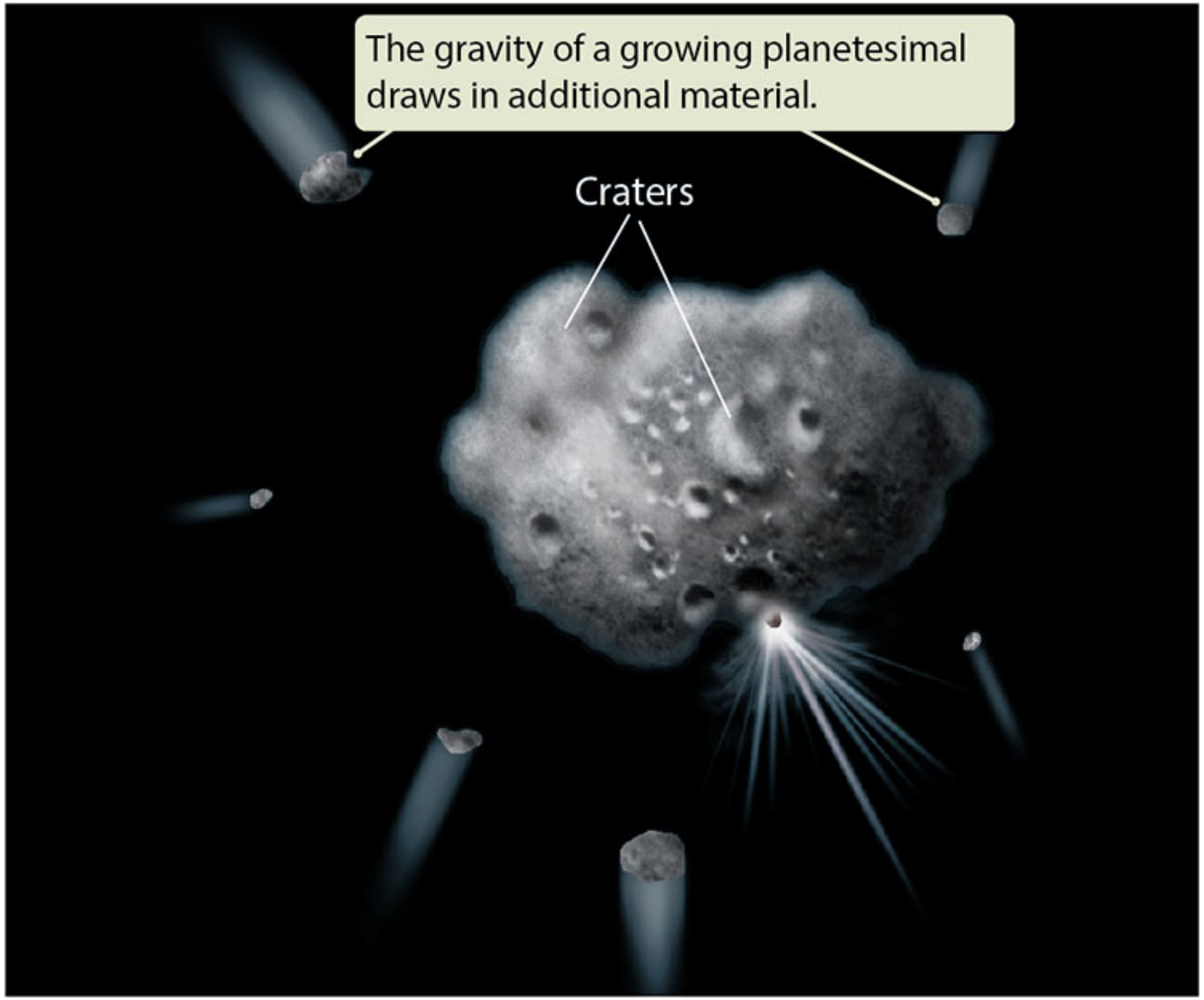
https://www.youtube.com/watch?v=yXq1i3HIumA&feature=youtu.be


(a)
Force of spring
Sand
Weight
The position of the tray is set by a balance between weight and the force of the spring.
As weight is added, the balance position shifts as the spring is compressed.
Force of spring
Weight
(b)
Likewise, the gravitational force pulling material toward the center of a protostar is exactly balanced by the pressure.
Infalling material
Likewise, as more material falls on the protostar, and as heat from its interior radiates away, the protostar becomes more compact. Pressure in the protostar increases.



1 Thermal energy escapes from the interior of a protostar and is radiated into space. The protostar contracts.
Pressure
Gravity
2 Gravity is stronger in the smaller protostar increasing pressure and temperature.
Pressure
Gravity
3 As the protostar gets smaller and smaller its interior gets hotter and hotter.
Pressure
Gravity
4 In this way the protostar's gravitational energy is converted into thermal energy until the core gets so hot that hydrogen fuses into helium.
Ignition!
5 The new star settles down, burning hydrogen in its core.


1 Gas motions in an accretion disk move small particles around more easily than large particles.
Gas motion
2 Small particles are forced into larger particles…
3 …forming larger and larger aggregations.


The gravity of a growing planetesimal draws in additional material.
Craters

Ch. 5: Formation of Stars/Planets

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HW1 solutions are online

Last name: beginning of alphabet to your left

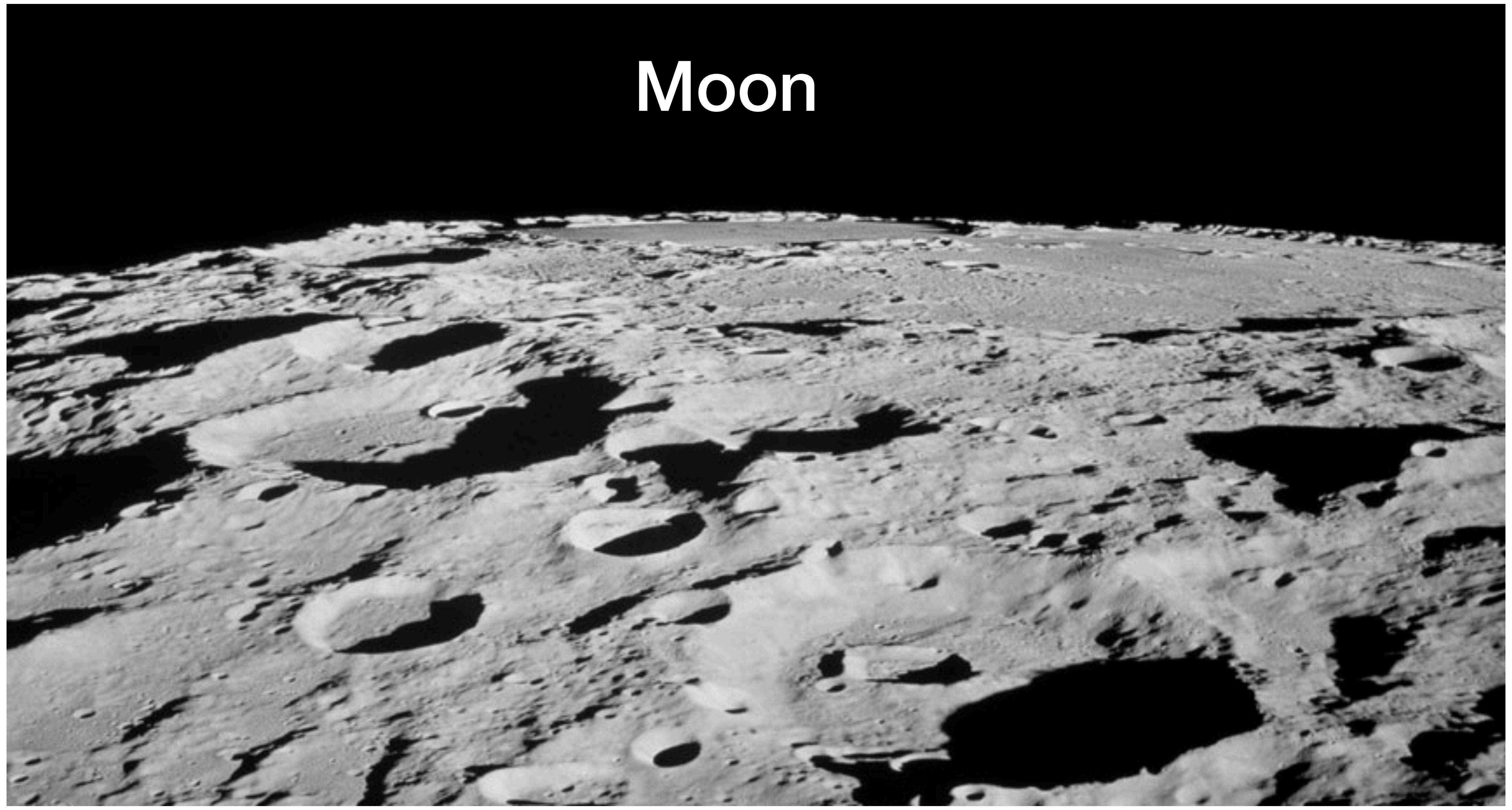
HW1 available up front

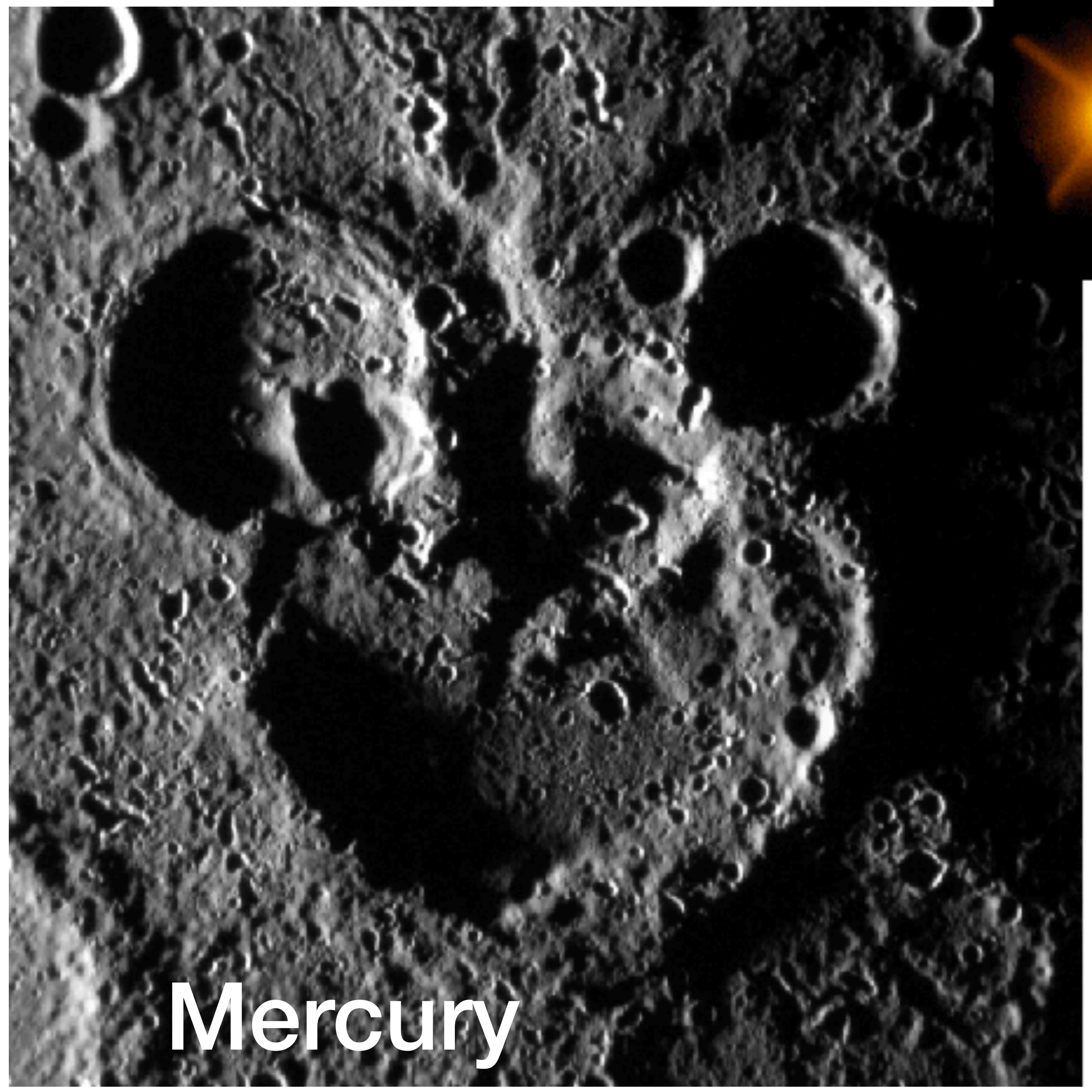
Last name: end of alphabet to your right

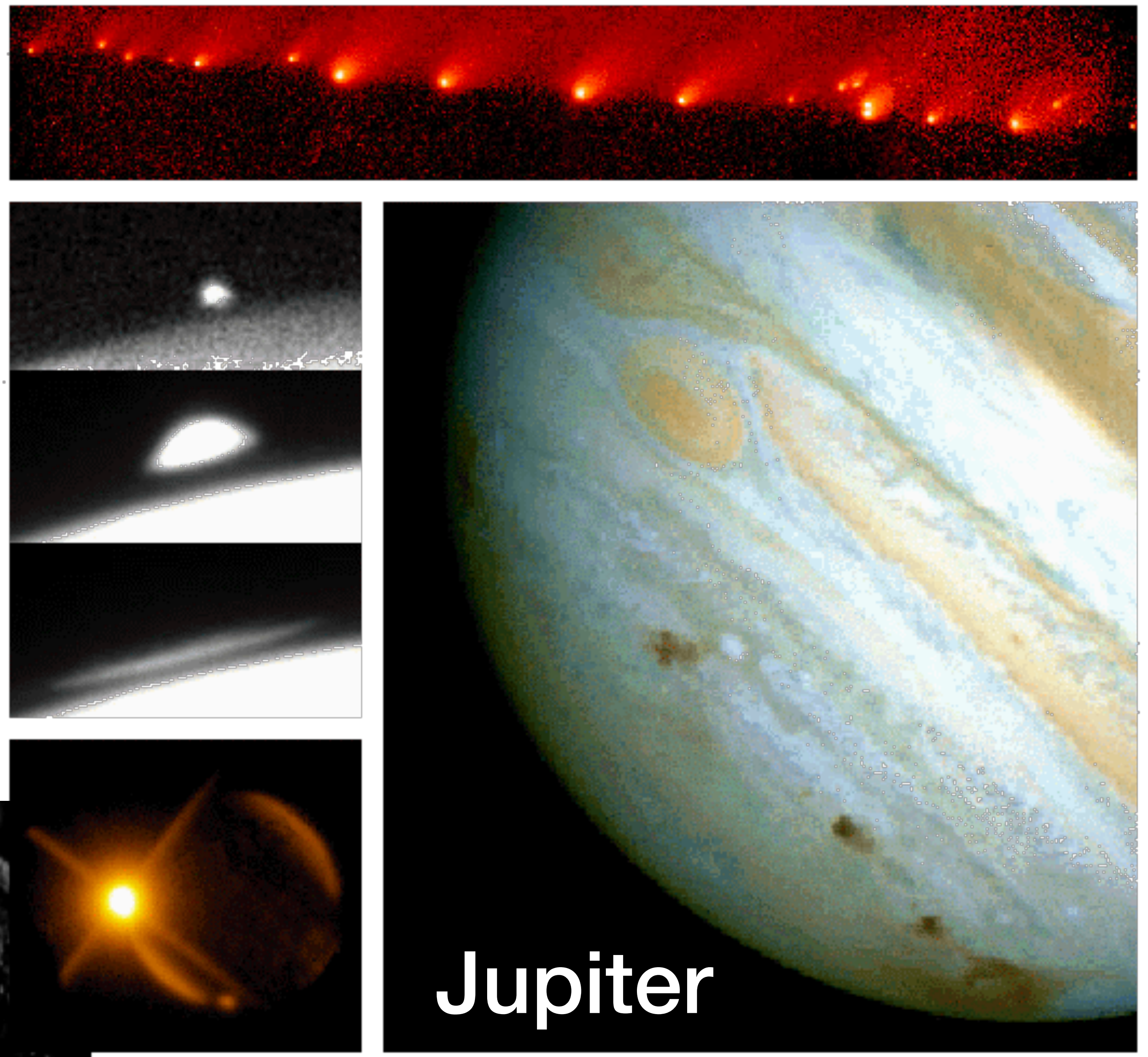
Are your grades in Canvas correct???

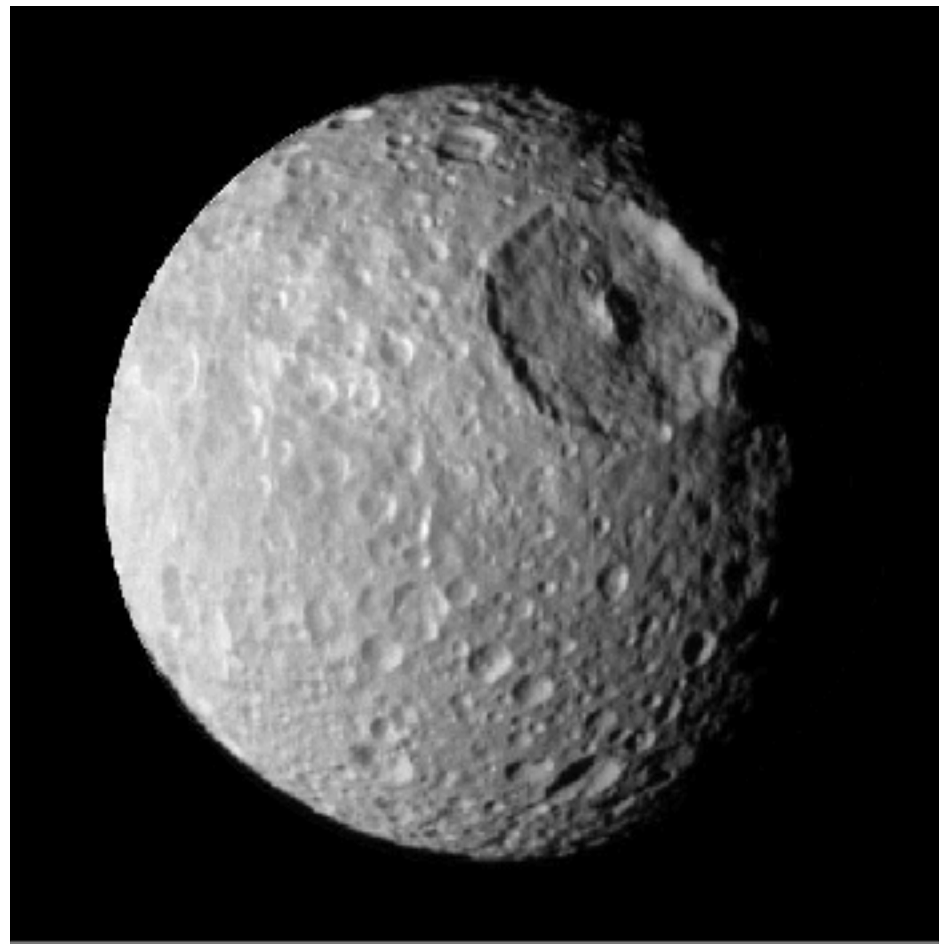
Evidence of impacts are everywhere!

Earth
(Meteor Crater)



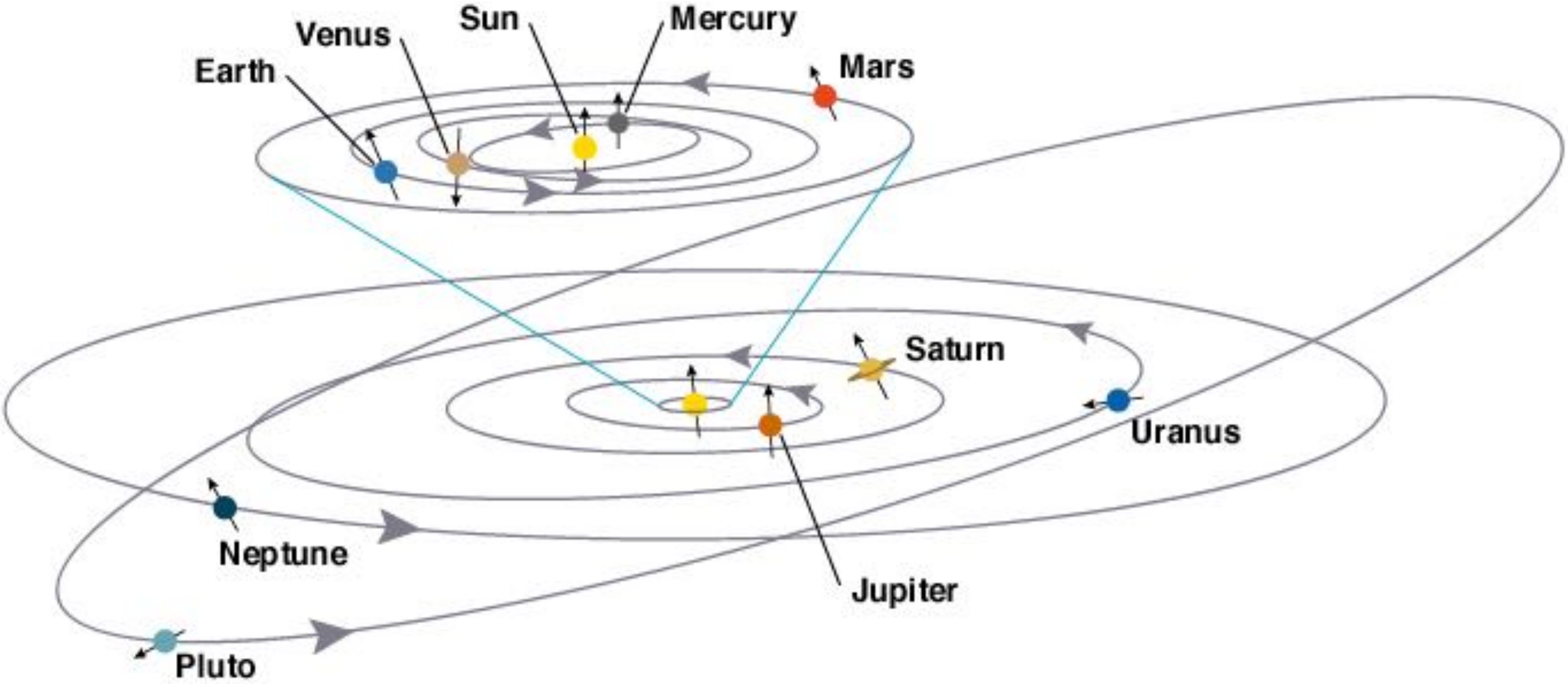


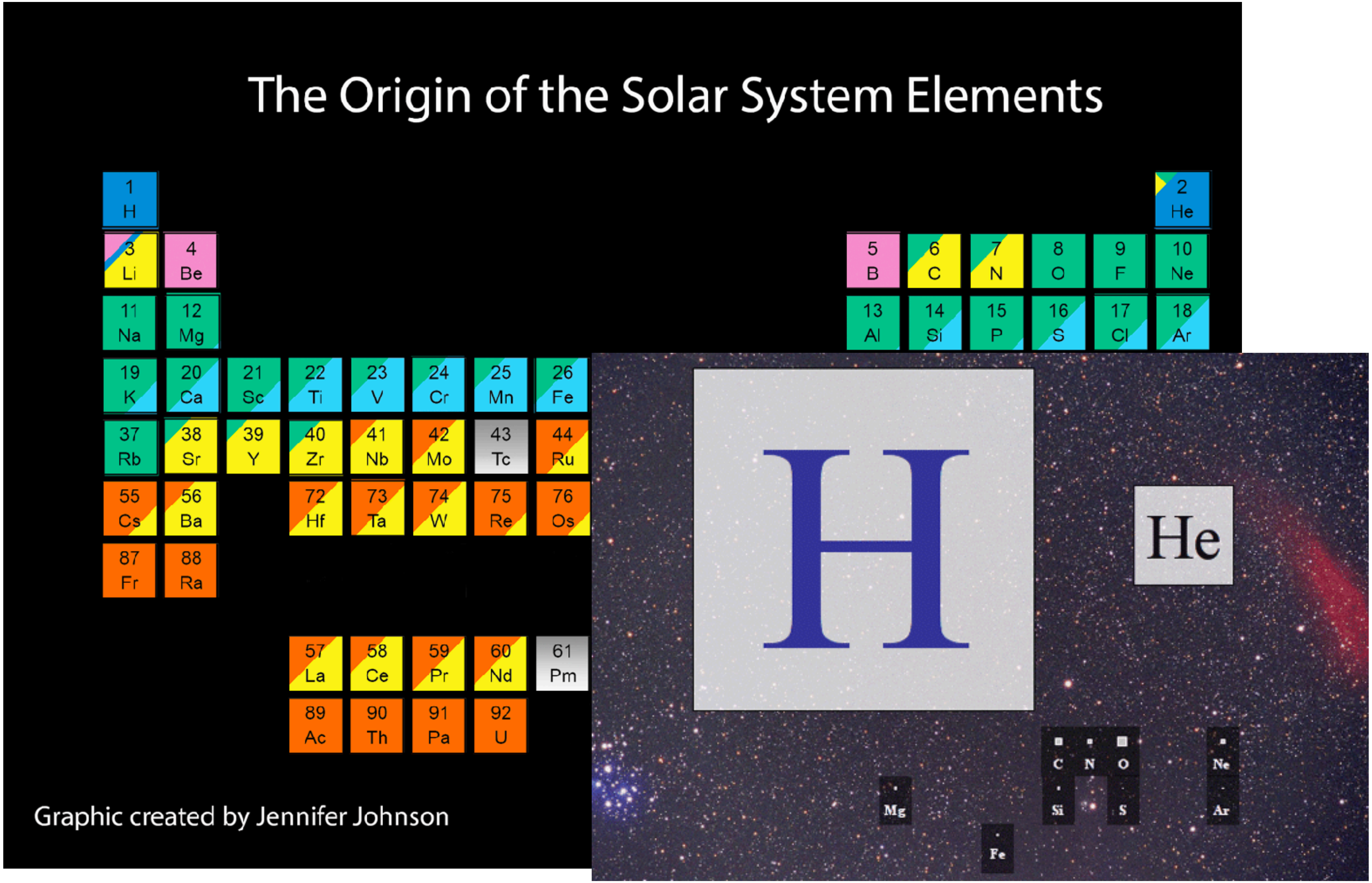


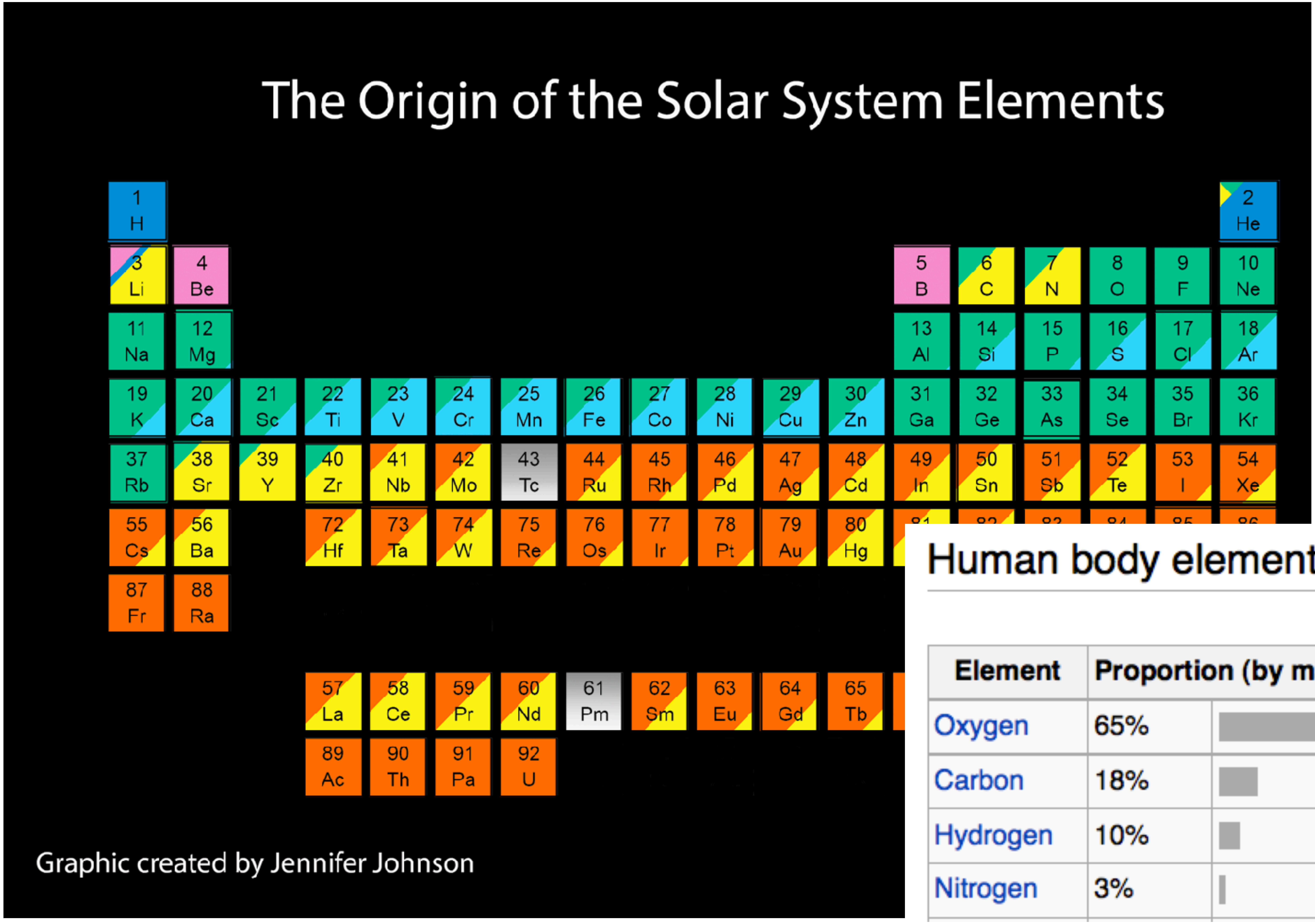


Mimas (Saturn)

What evidence do we have that our solar system formed from an accretion disk?




The Origin of the Solar System Elements
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
55 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
87 Fr
88 Ra
57 La
58 Ce
59 Pr
60 Nd
61 Pm
89 Ac
90 Th
91 Pa
92 U
Graphic created by Jennifer Johnson
H
He
C
N
O
Ne
Mg
Si
S
Ar
Fe



Human body elemental abundance

Element	Proportion (by mass)	
Oxygen	65%	
Carbon	18%	
Hydrogen	10%	
Nitrogen	3%	

Almost correct observation in Sci Fi

https://www.youtube.com/watch?v=LAIqp0_a0tE

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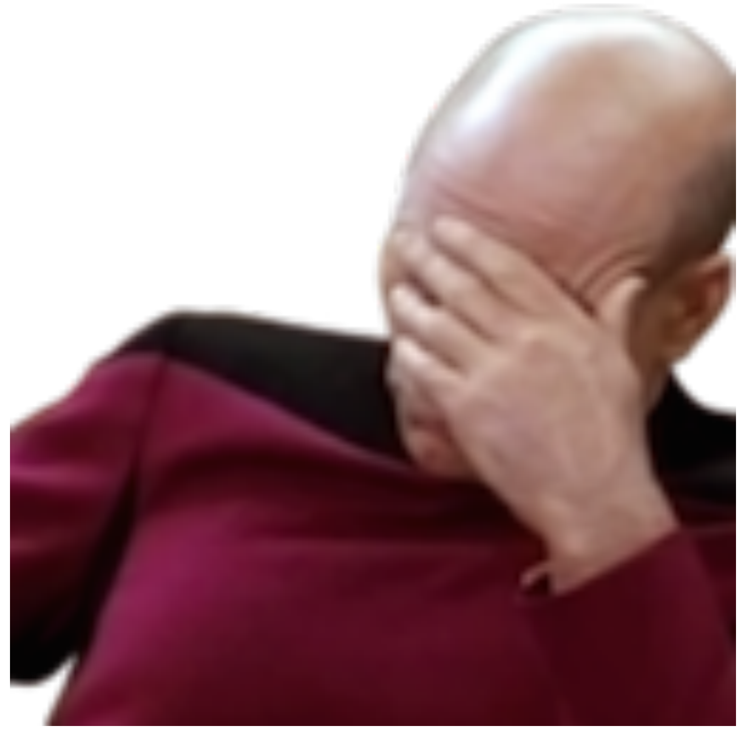
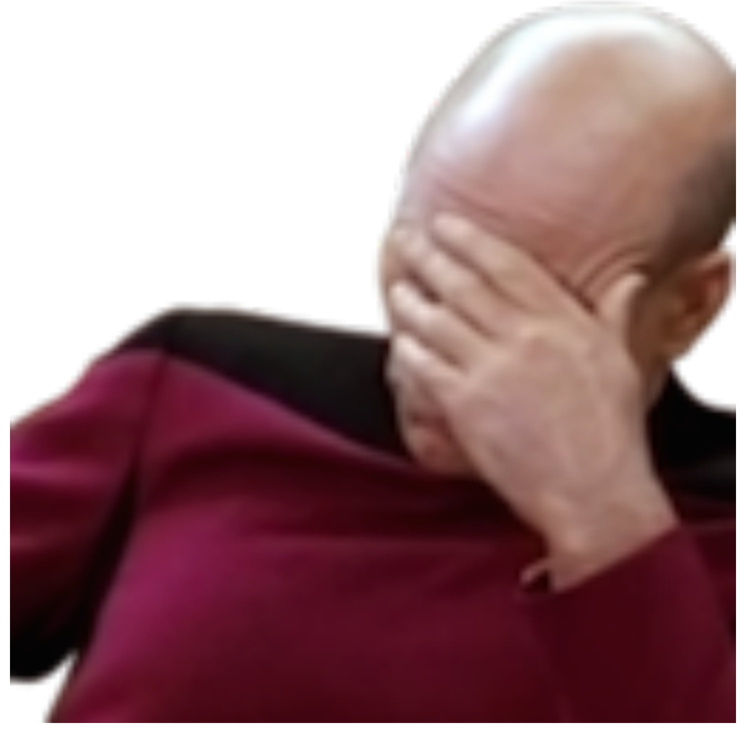
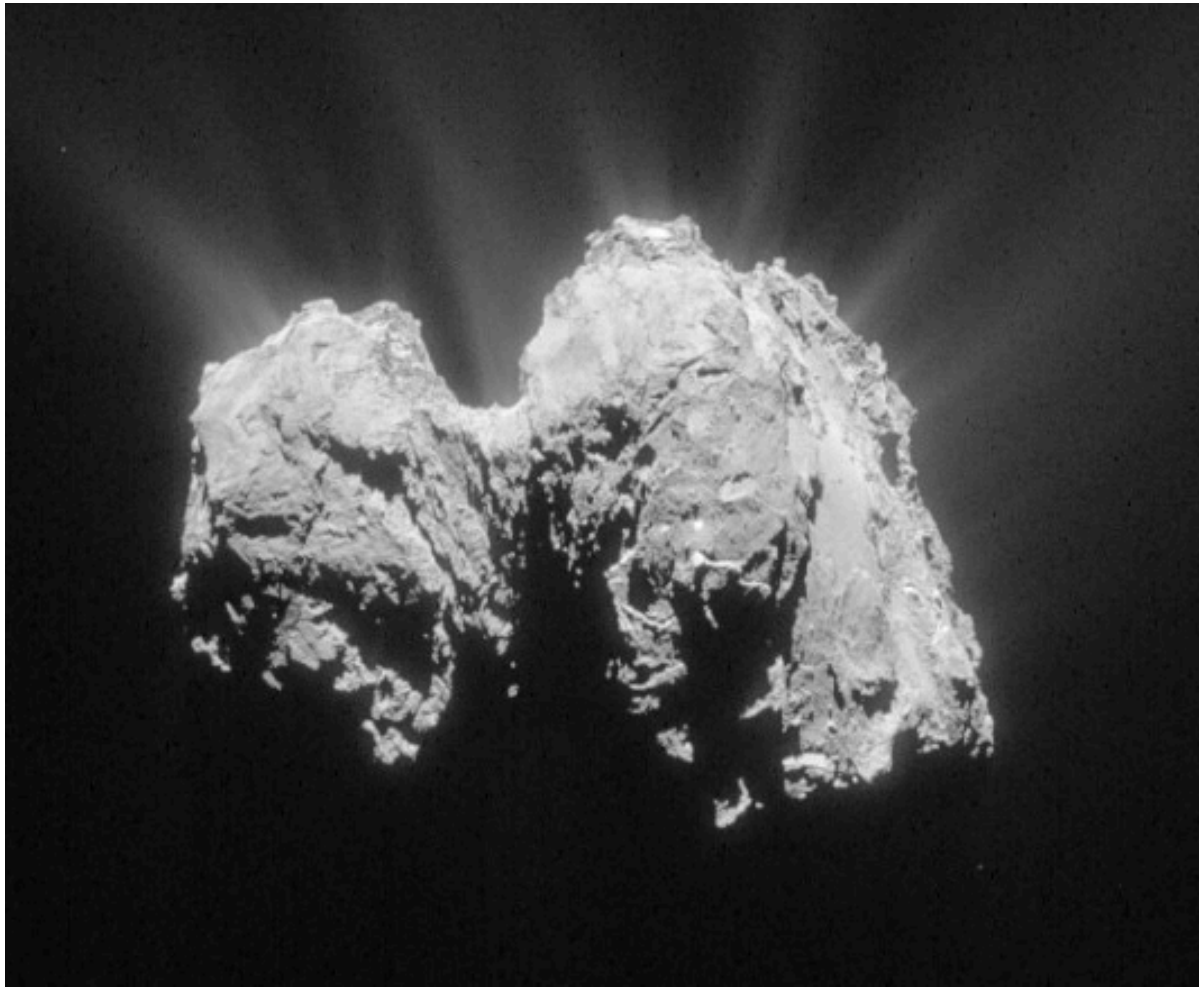


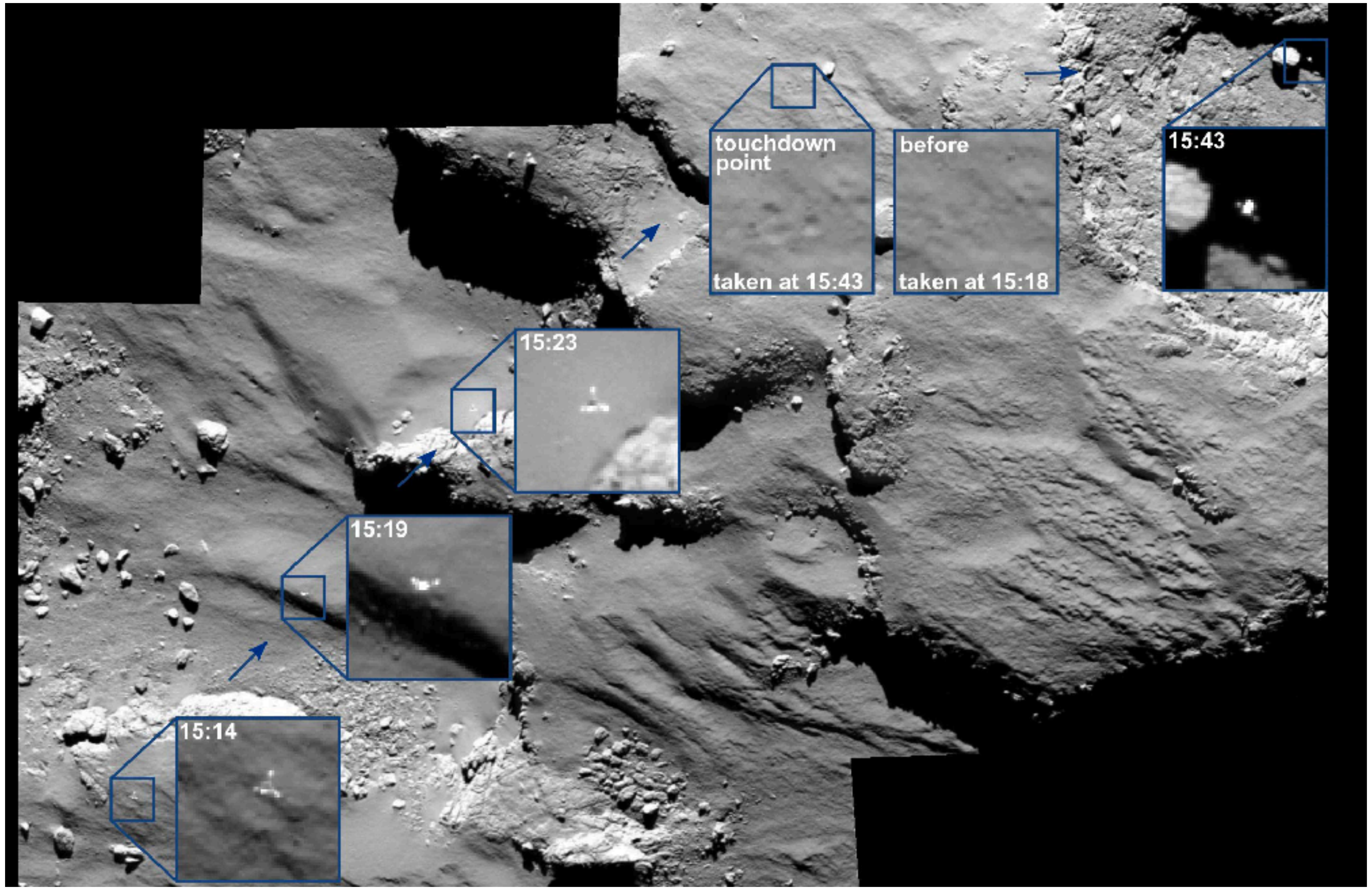


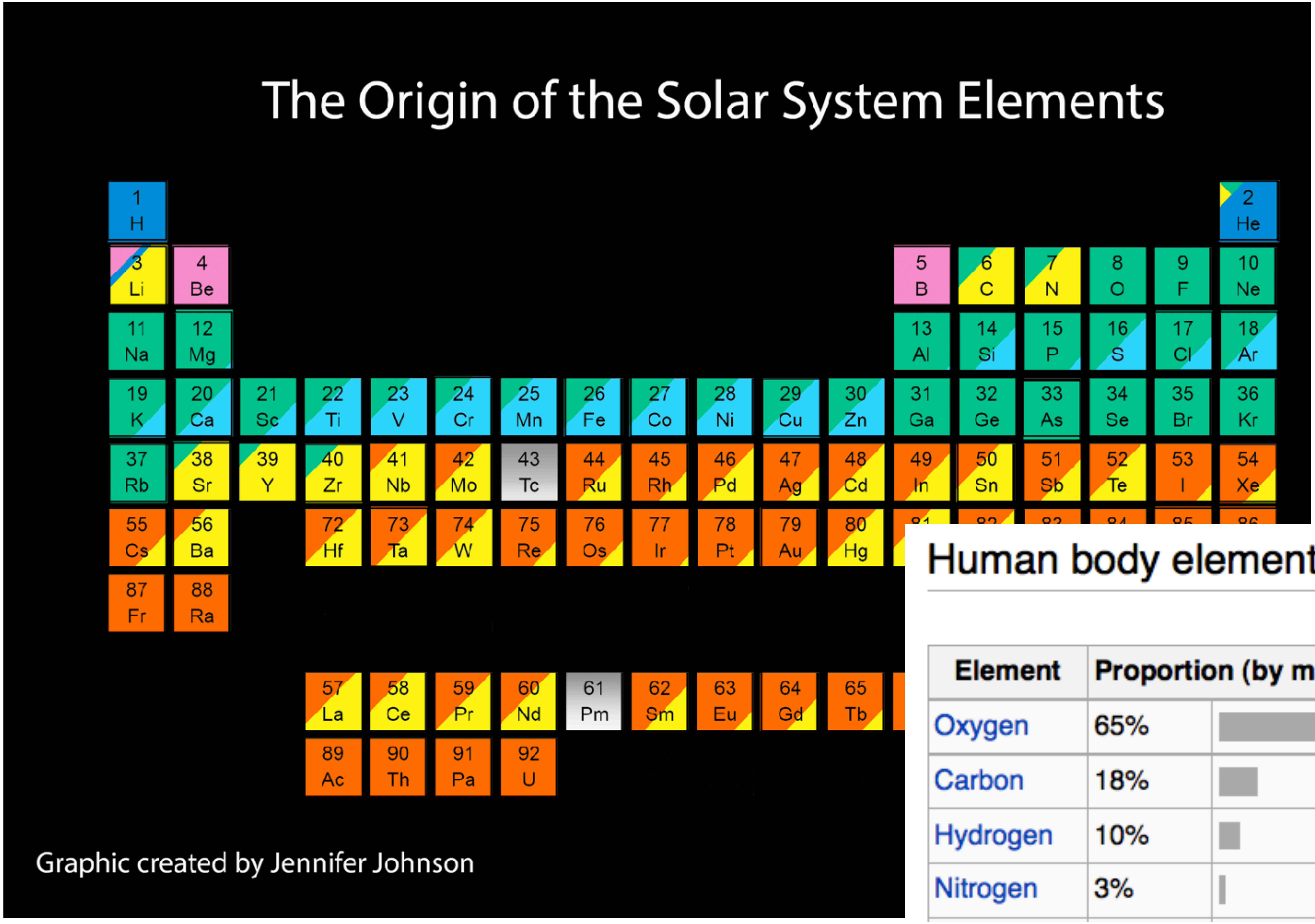
High Budget ESA PR

https://www.youtube.com/watch?v=32vlOgN_3QQ

Rosetta Mission and Philae Lander







Human body elemental abundance

Element	Proportion (by mass)	
Oxygen	65%	
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Nitrogen	3%	

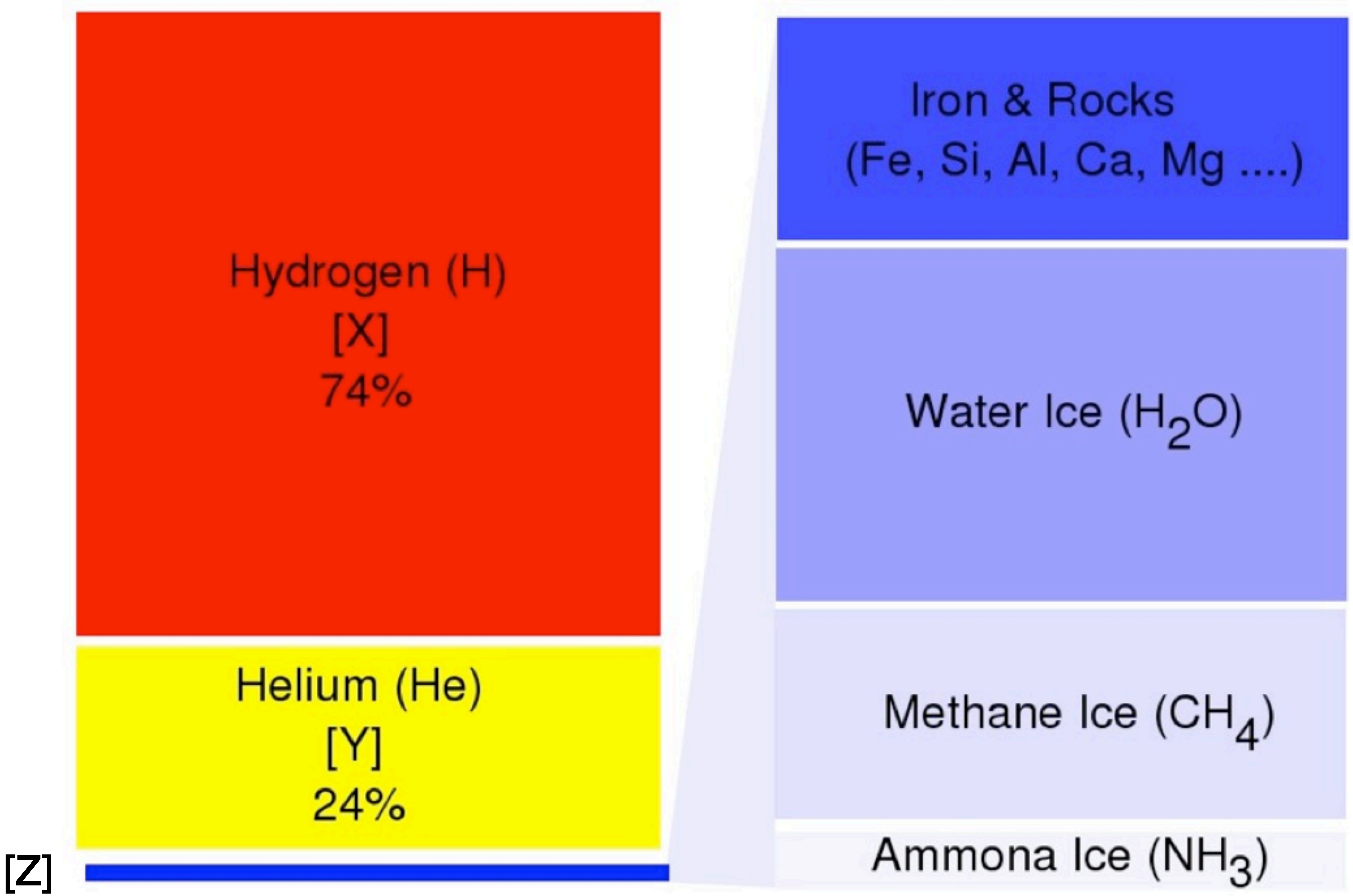
Mass Distribution in the Solar System

Sun
99.85%

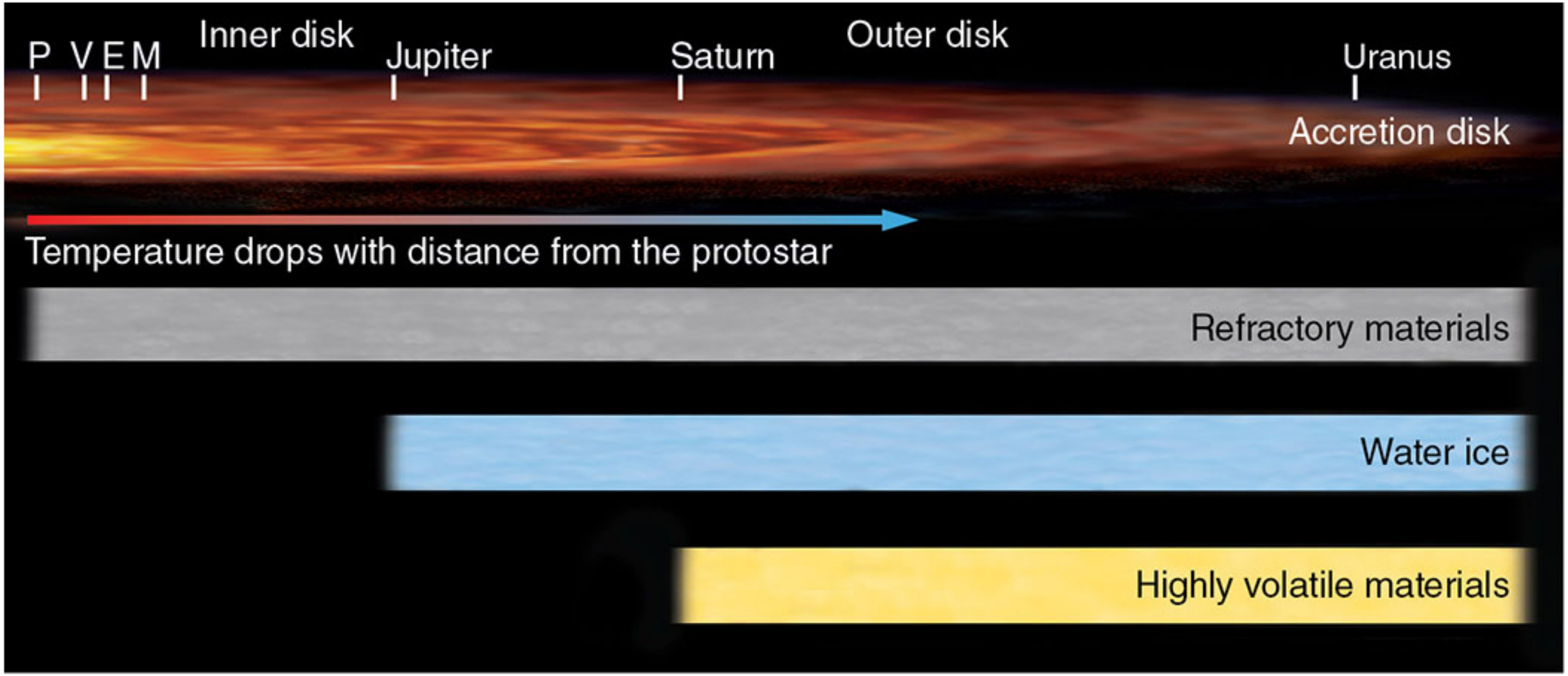
Outer Planets
0.134%

Terrestrial Planets
0.001%

What is the solar system made of?



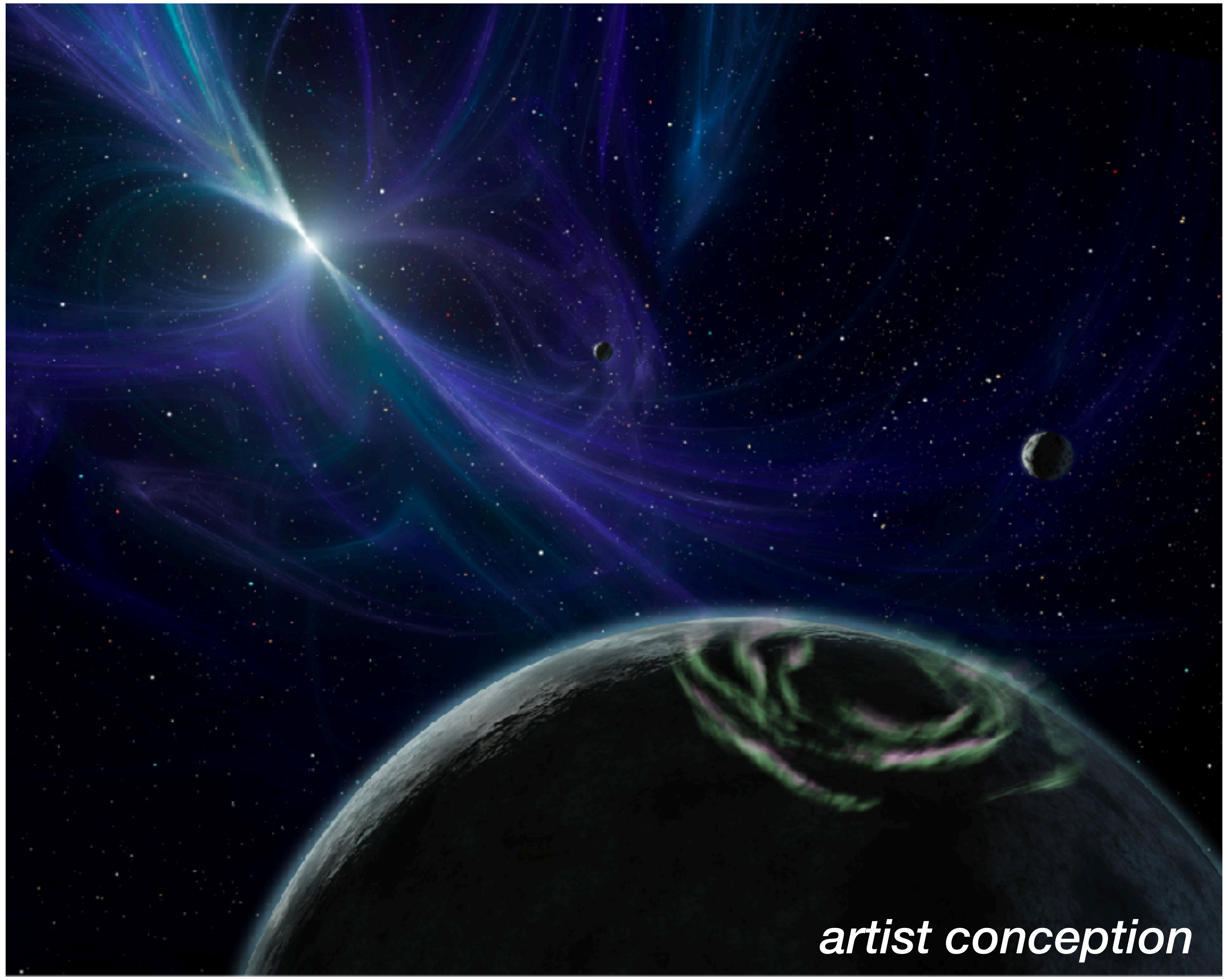
Inner versus outer planets



Exoplanets

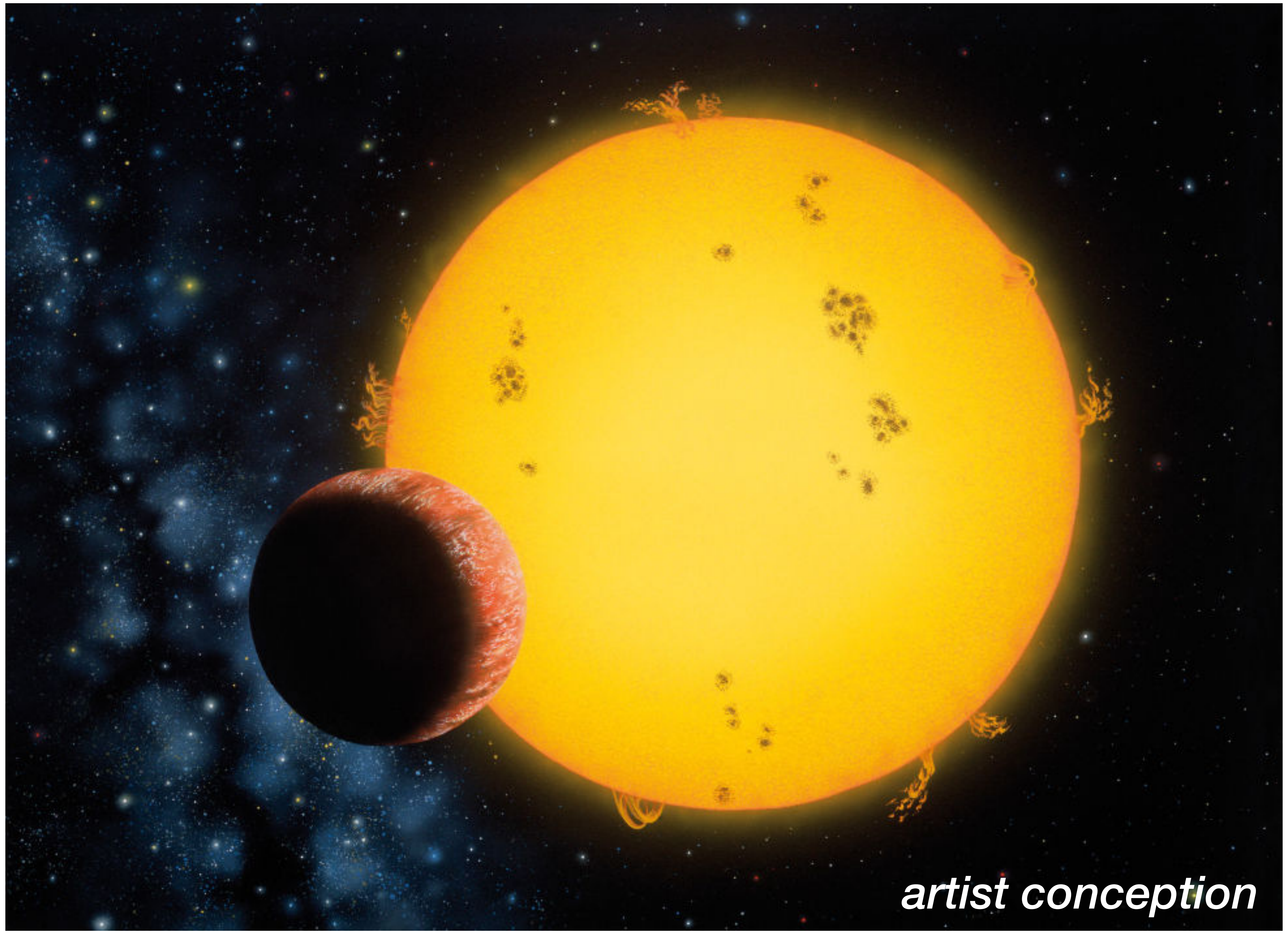
First planets discovered outside the solar system

Pulsar PSR B1257+12



1992 - 3 confirmed planets

Sun-like star: 51 Pegasi b



1995 - a “hot Jupiter”

How to find planets

- Detect them directly

Direct Imaging

- Image the planet
- Detect its atmosphere in a spectrum

- Detect their influence on their star

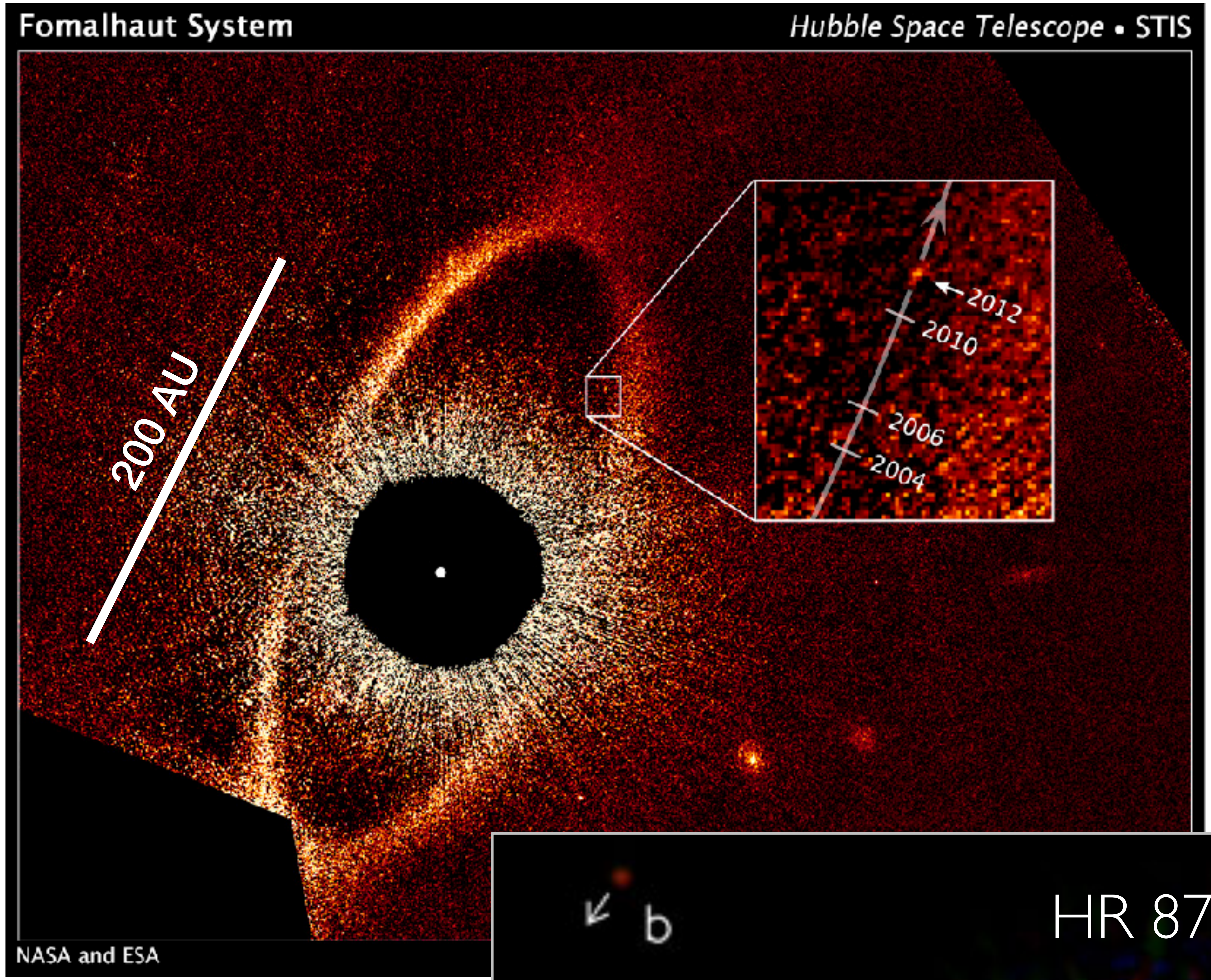
Transit Method

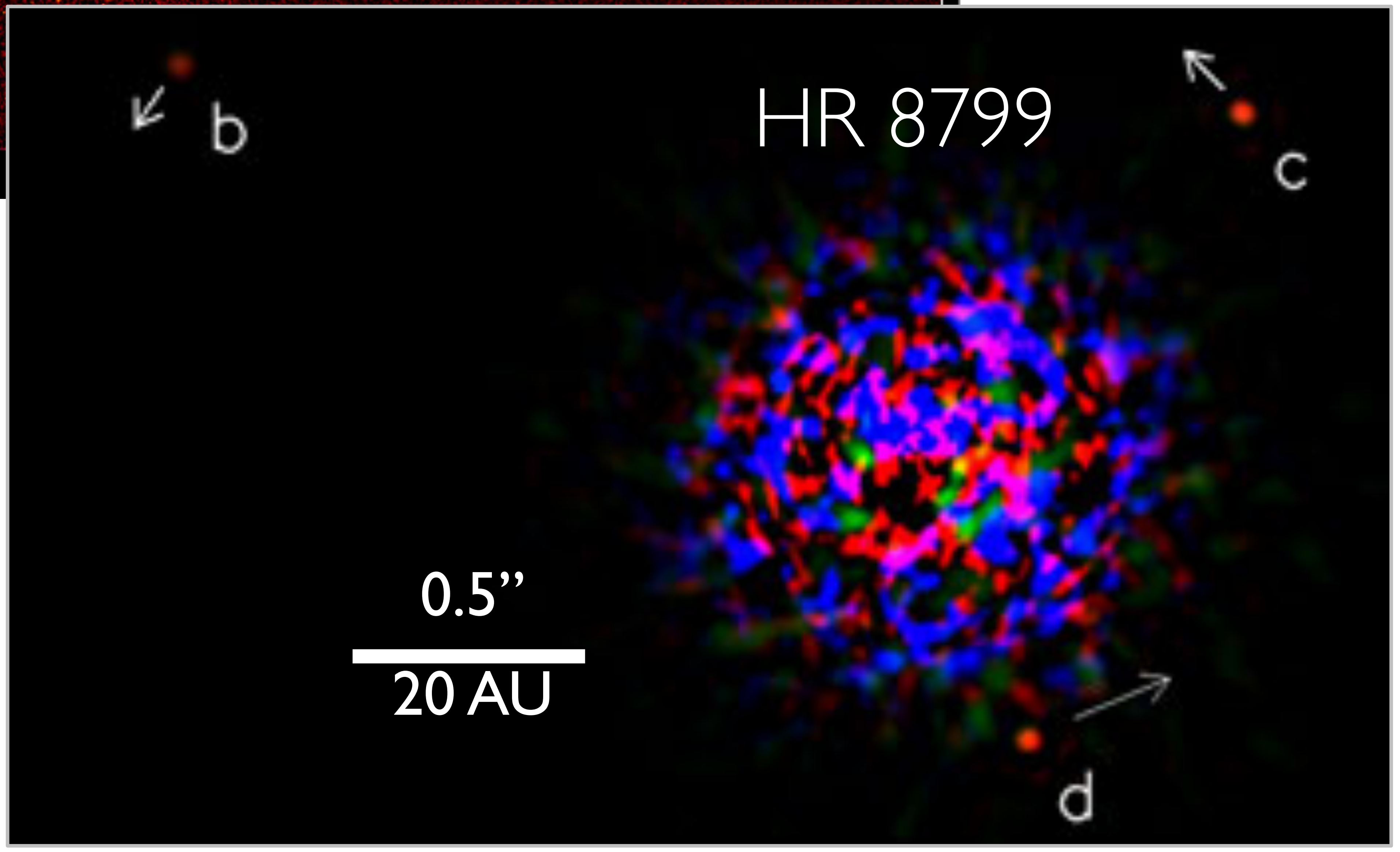
- Measure light blocked from the star when the planet eclipses it
- Measure the star's motion due to the planet's gravity

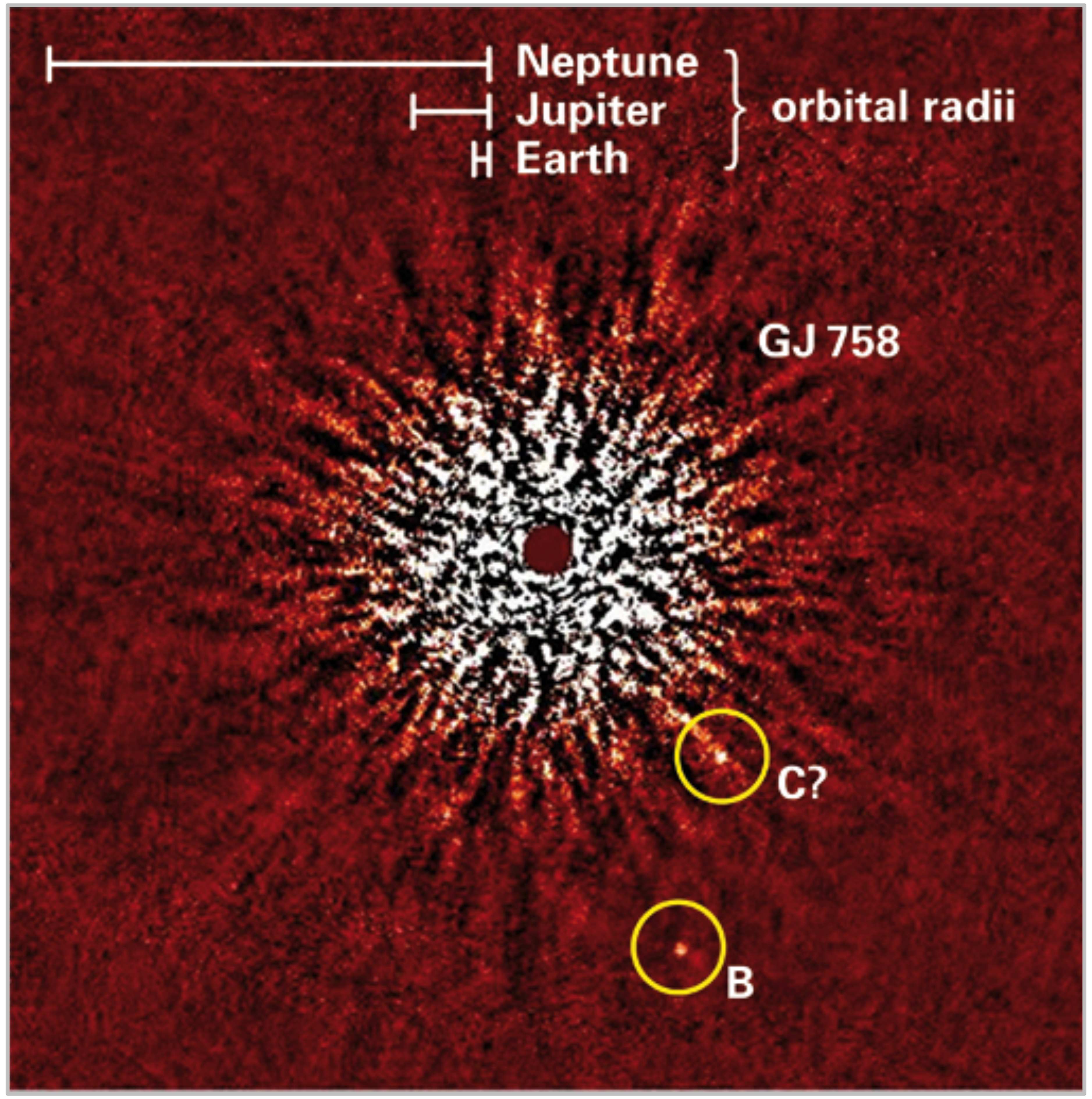
Radial Velocity Method

Direct Imaging

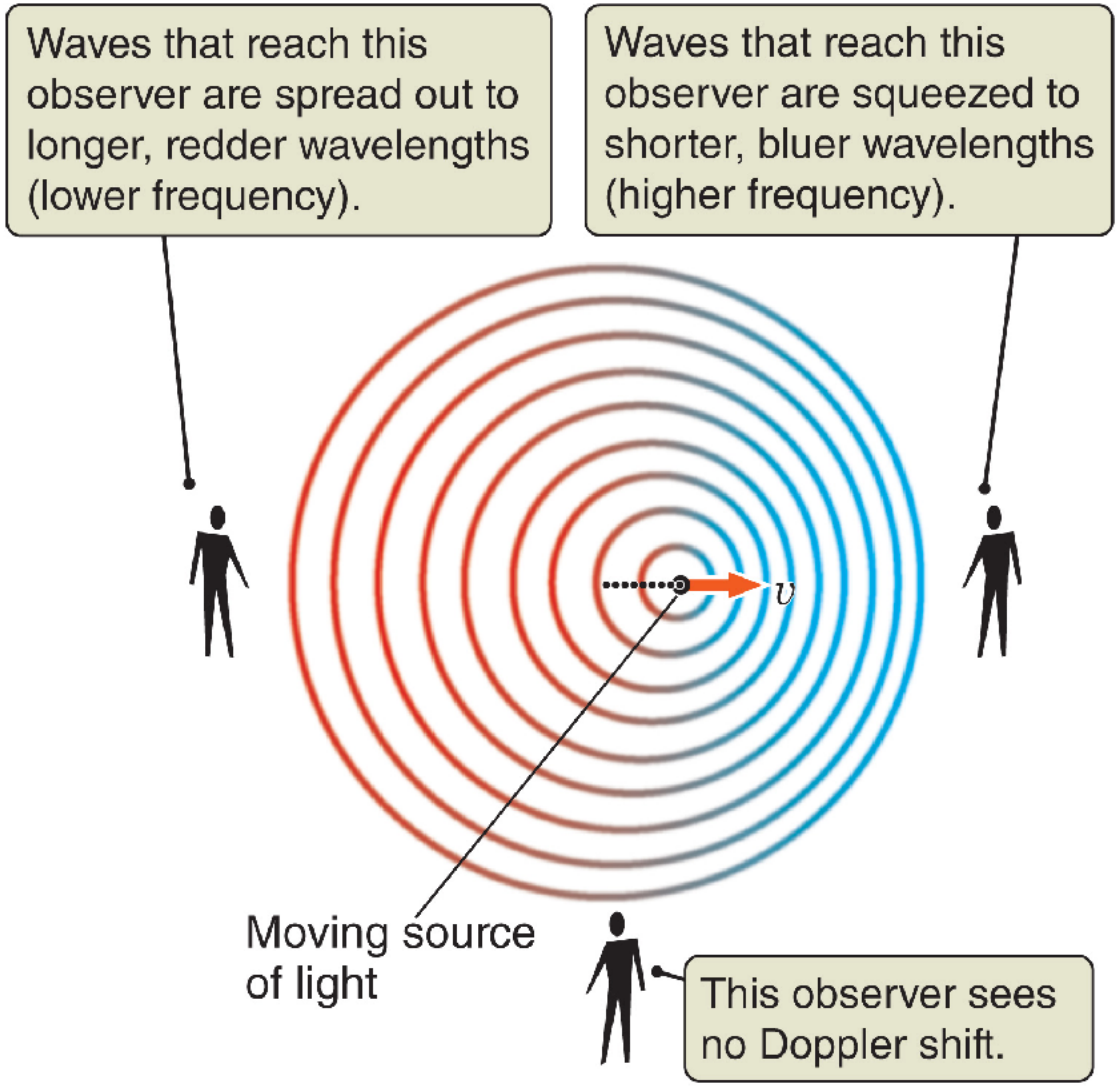
Planet millions of times fainter
Need to mask the starlight



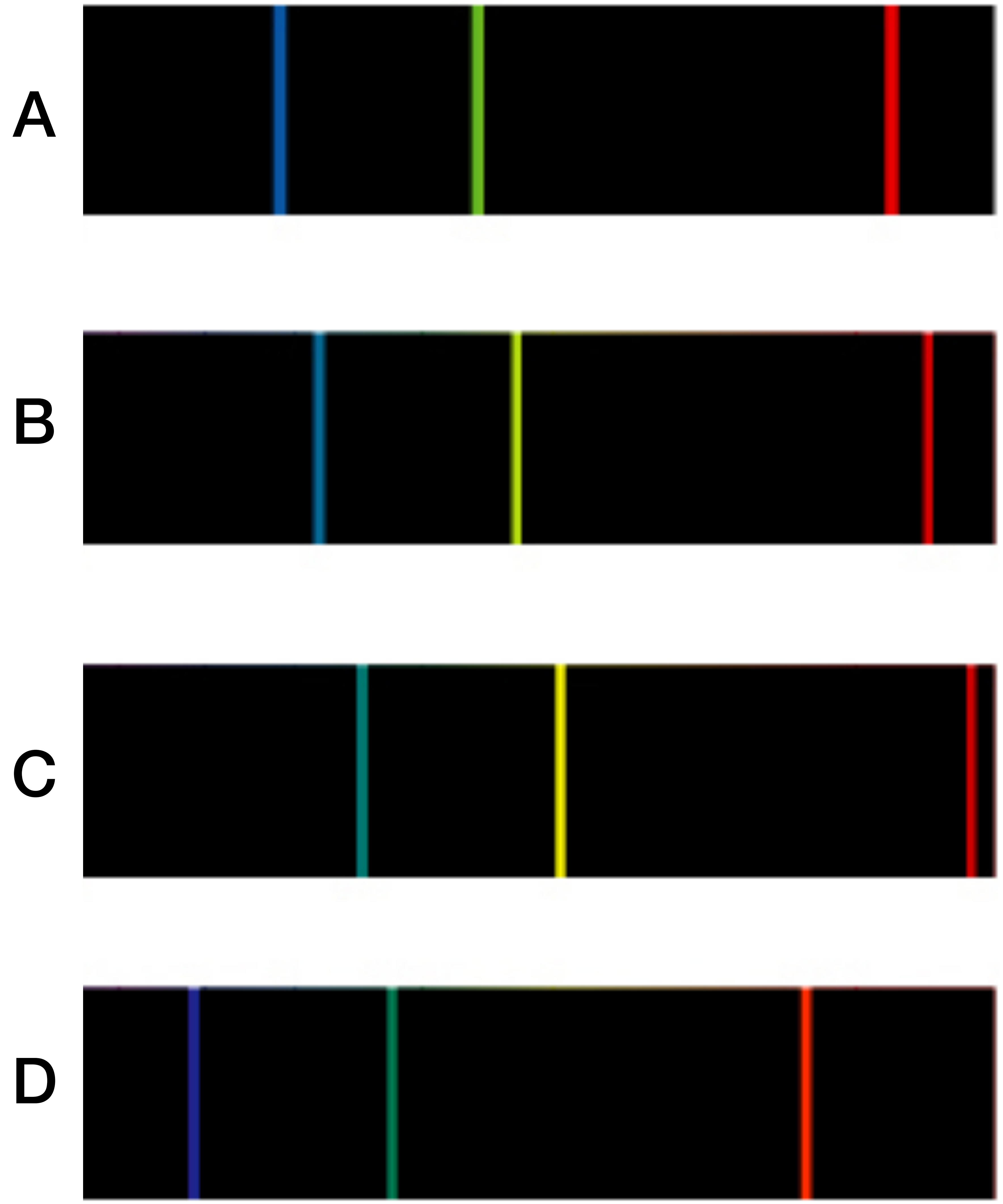




Radial Velocity Method



Doppler Shift of Light



$$\frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}} = \frac{v}{c}$$

Which spectrum is moving away from us the fastest?

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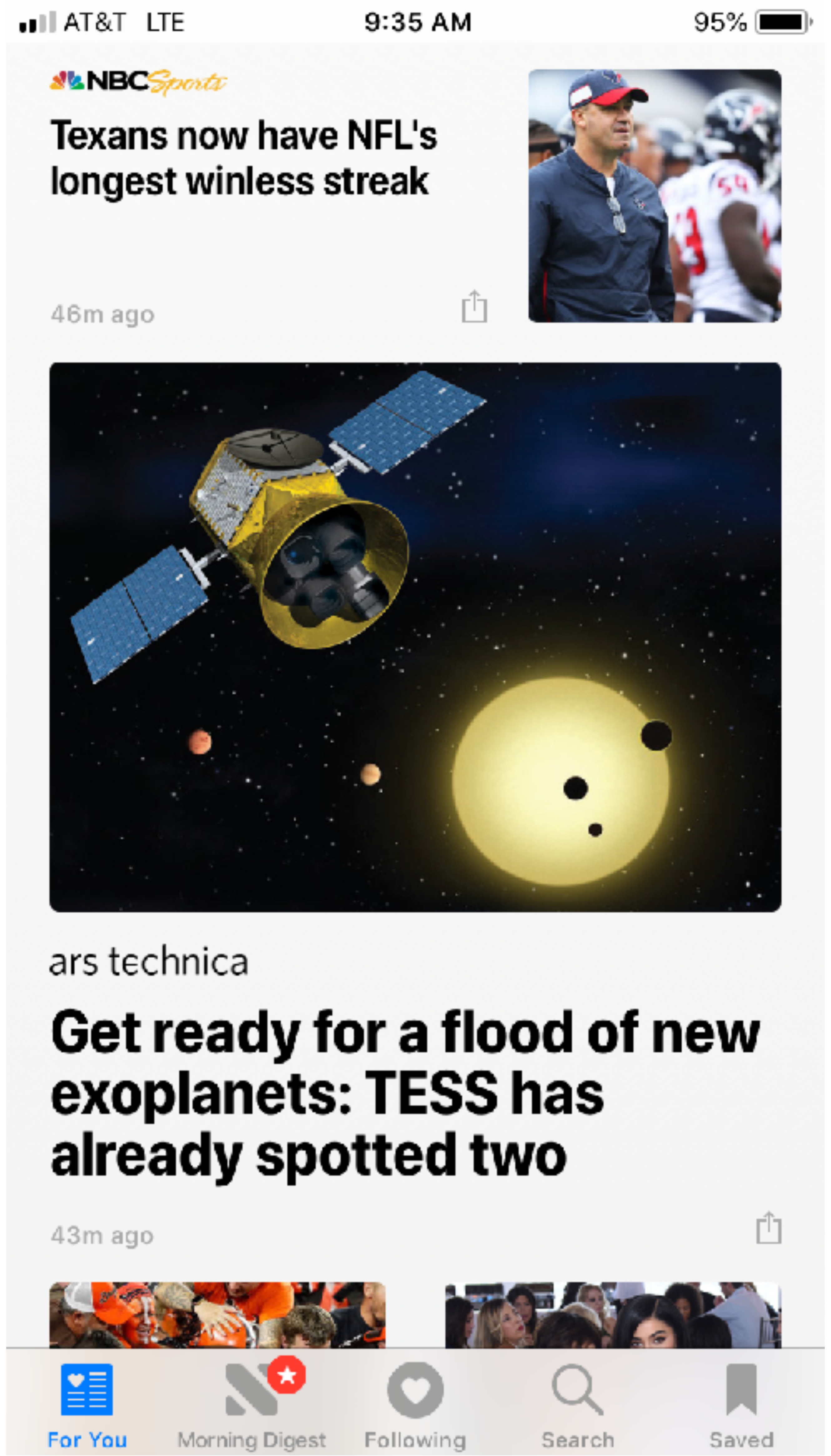
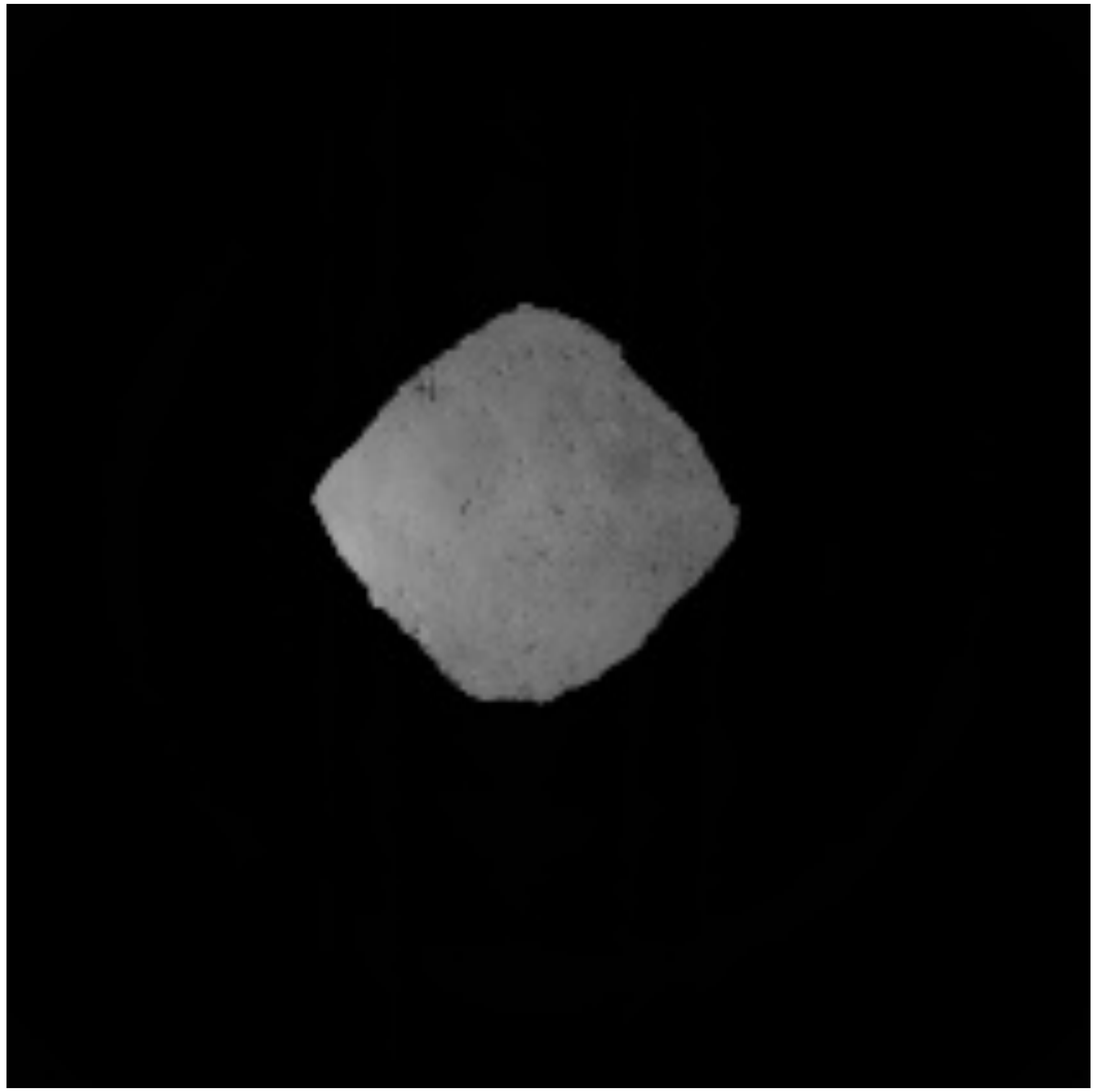
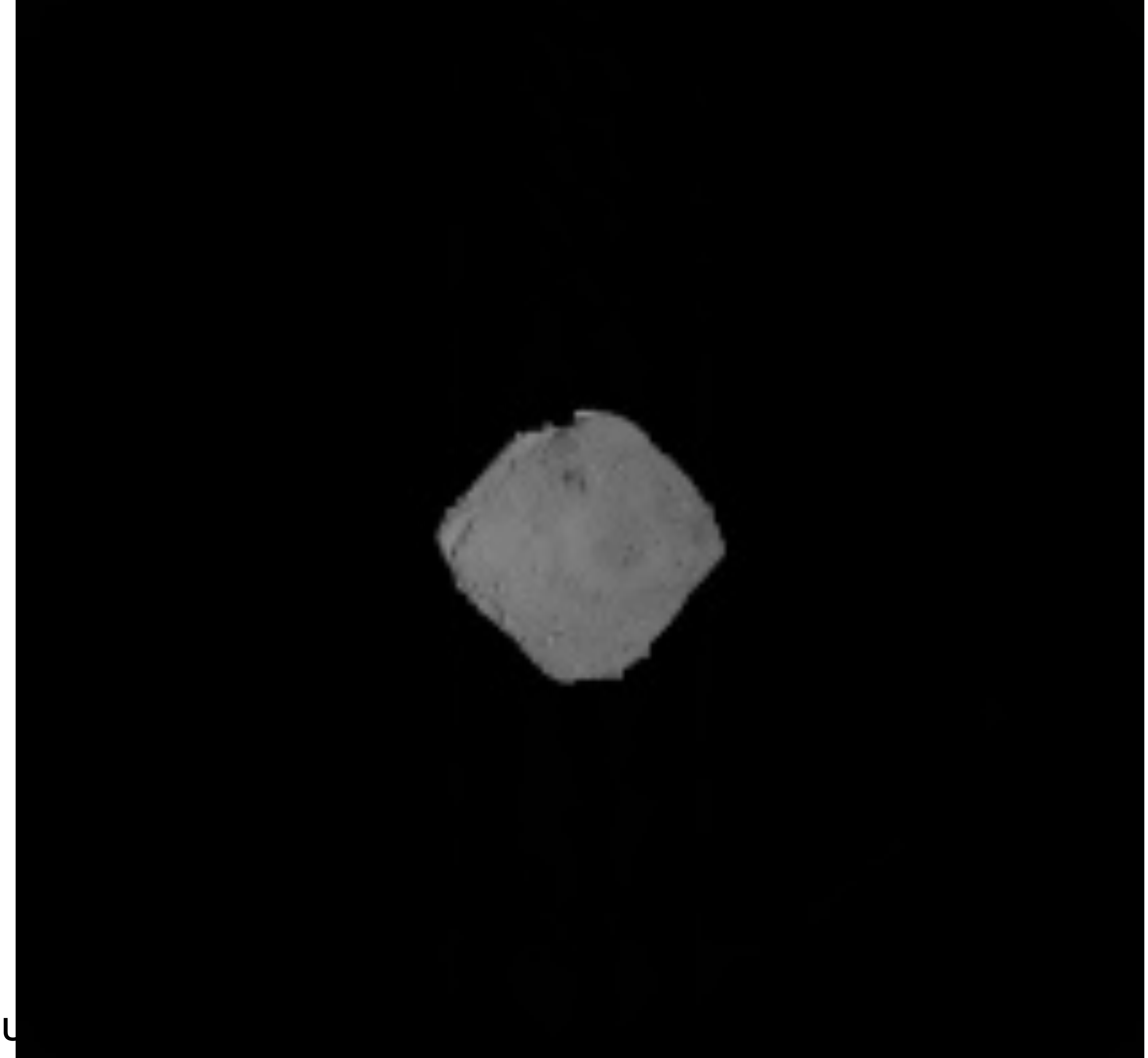
Are your grades in Canvas correct???

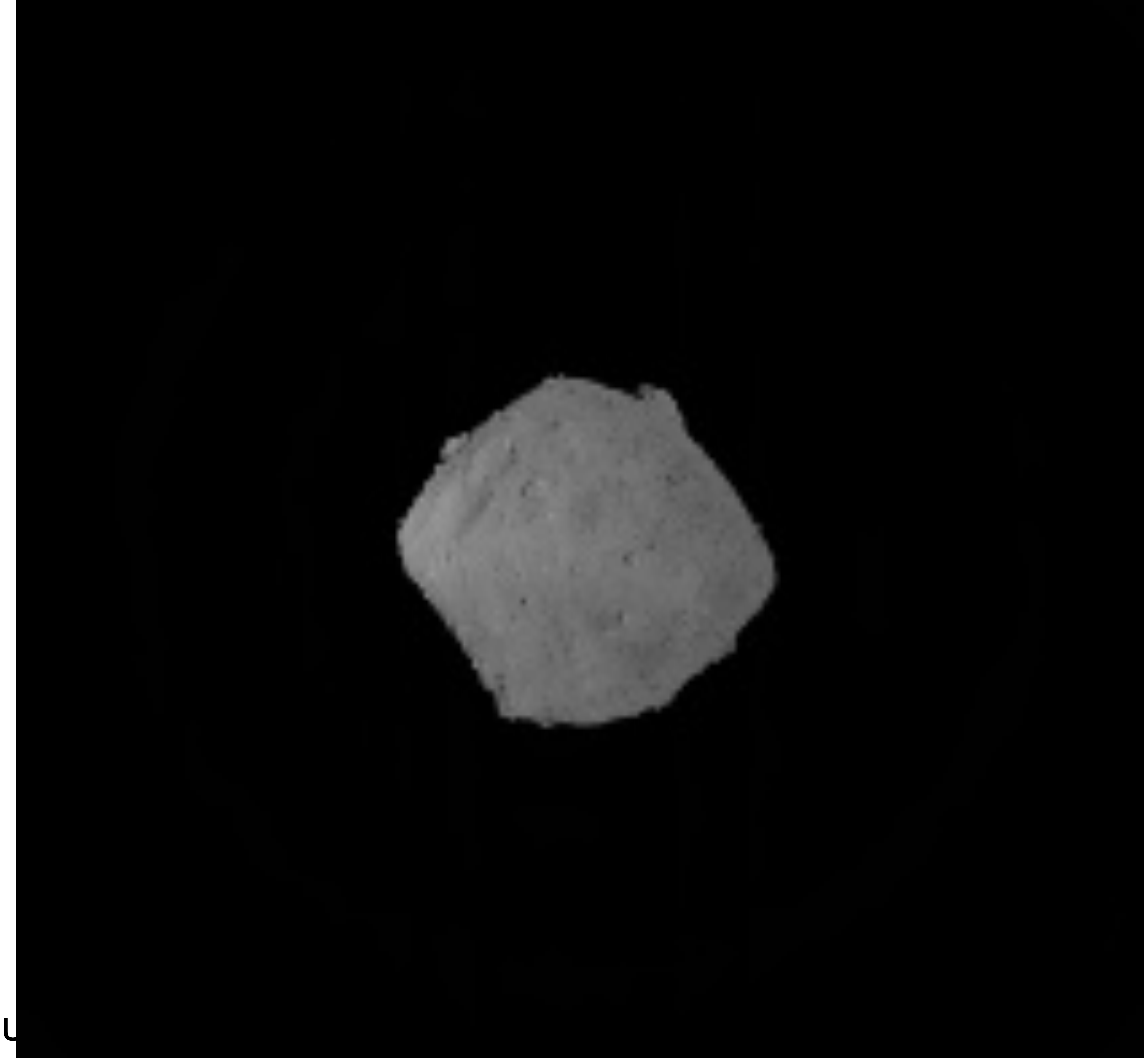
Astronomy in the News!

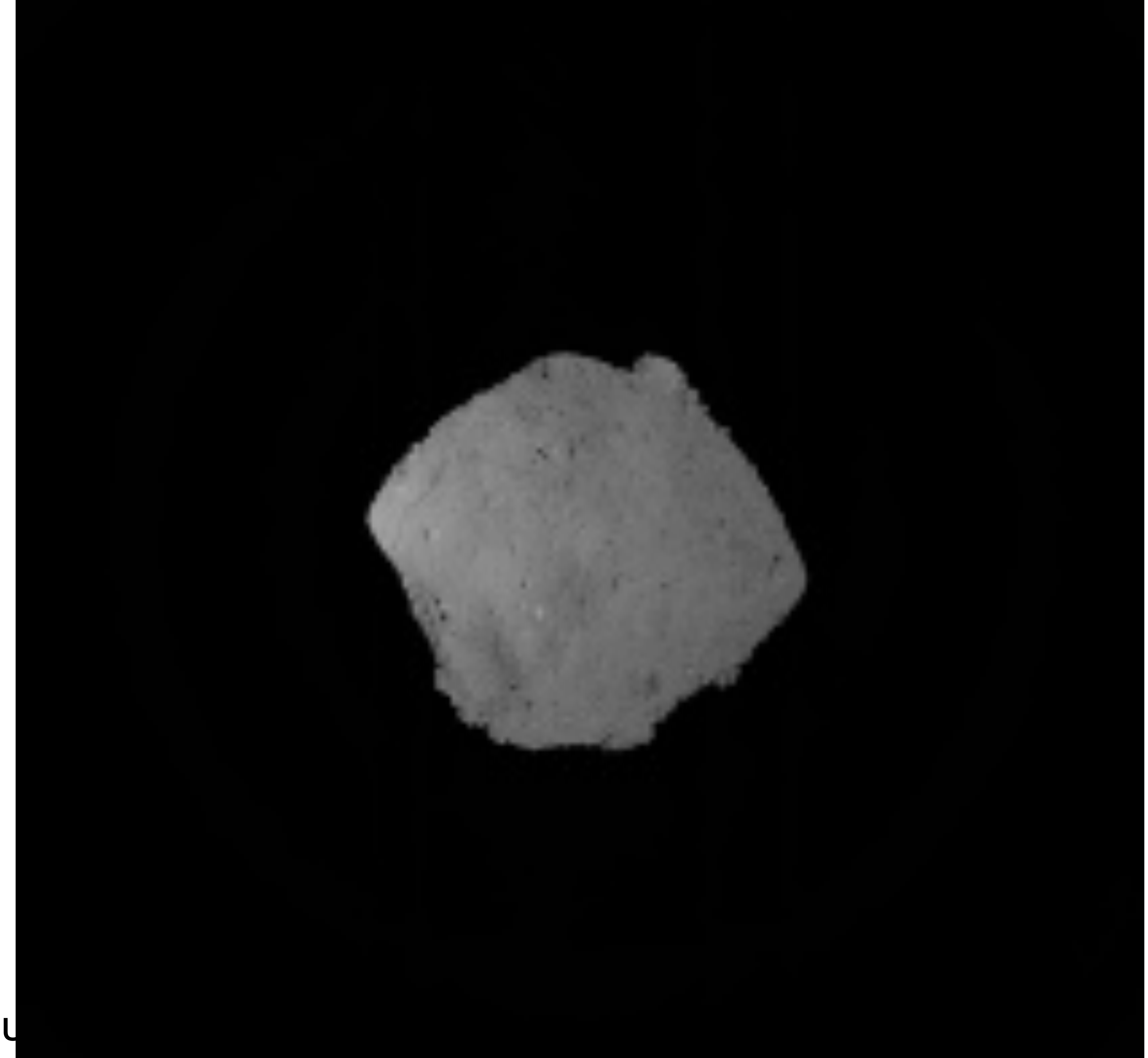


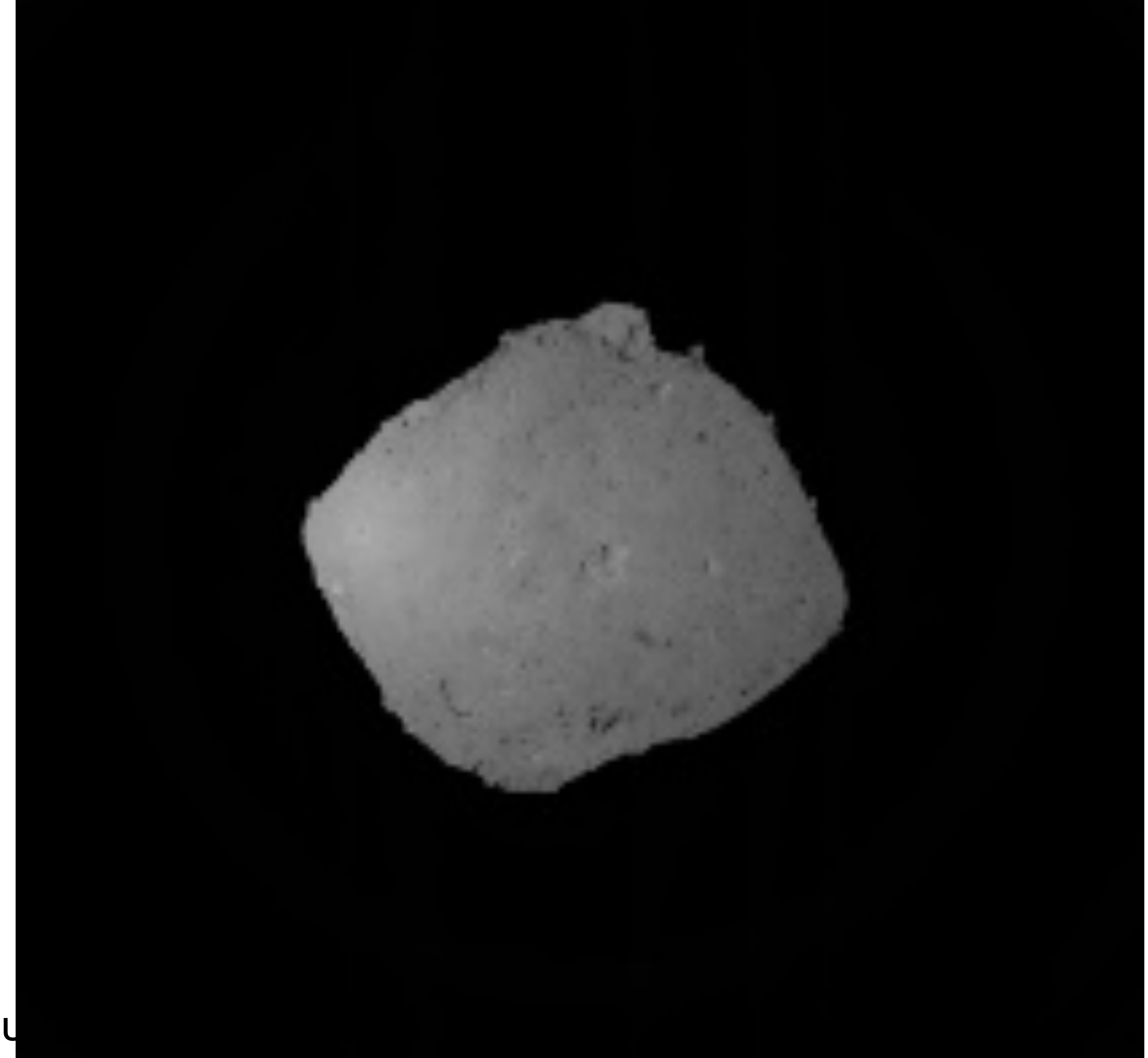
Japanese satellite Hayabusa 2 visits asteroid Ryugu!

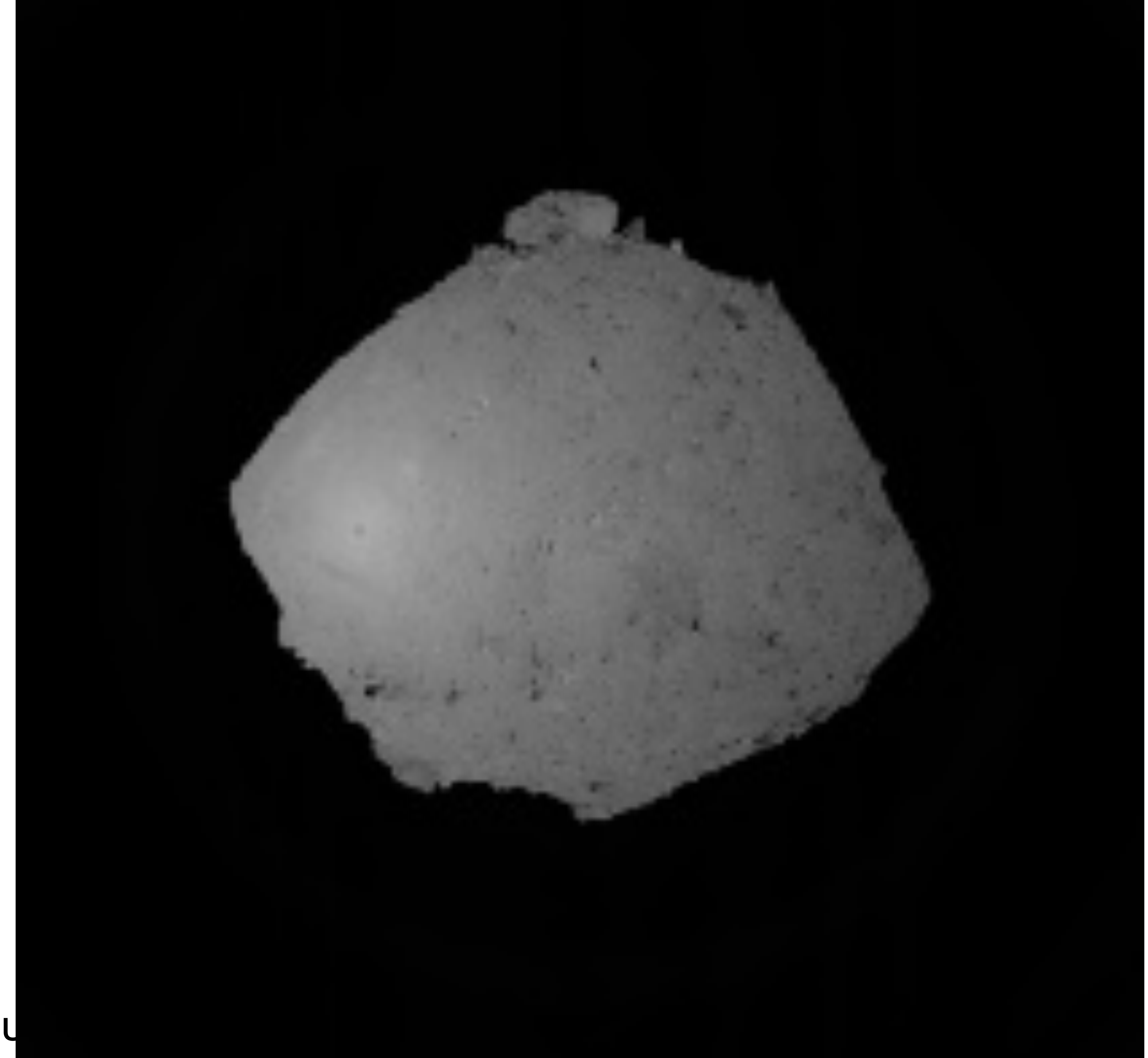


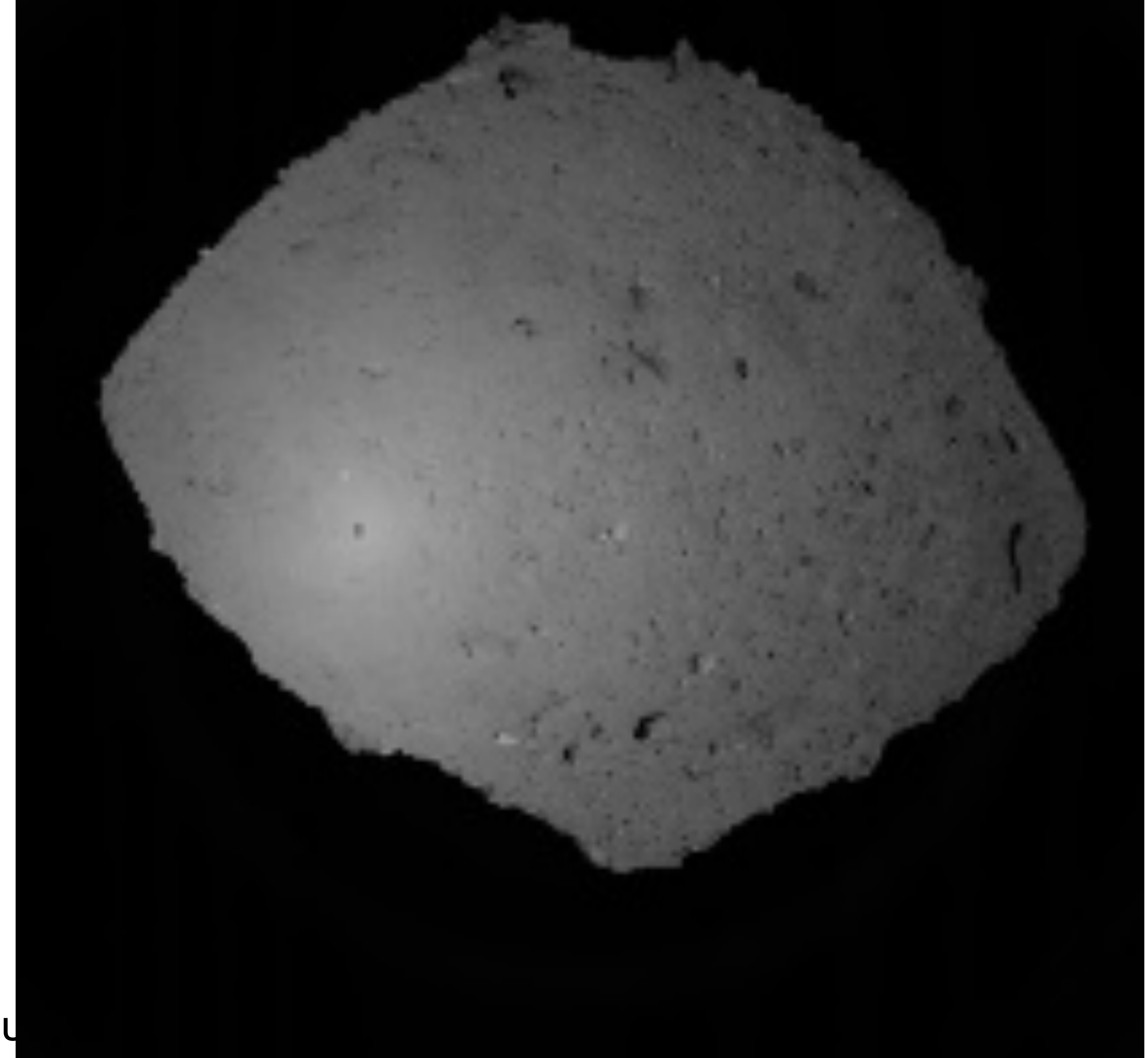




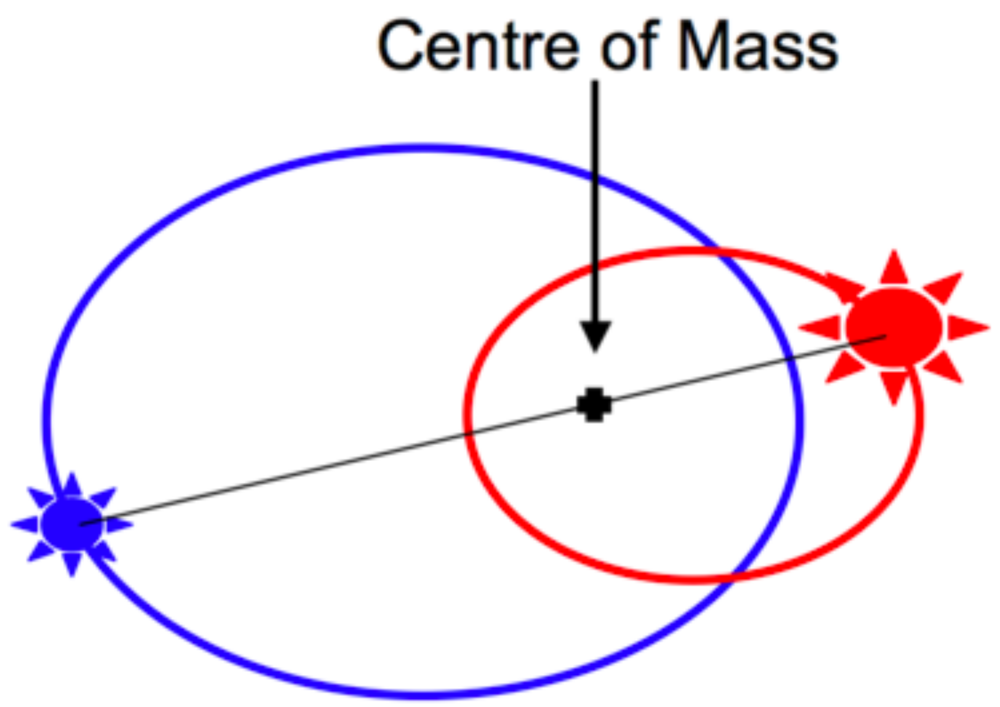


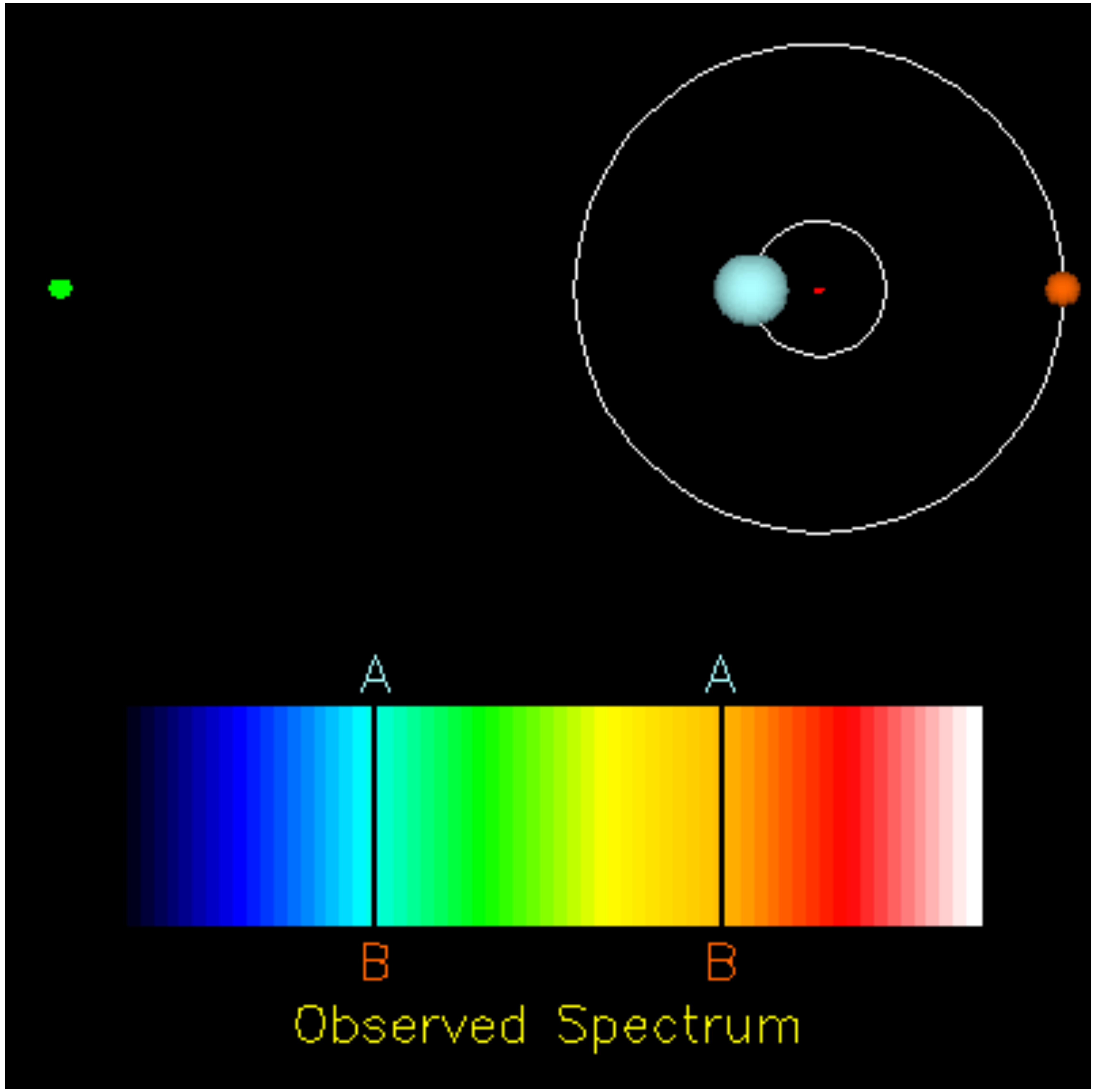


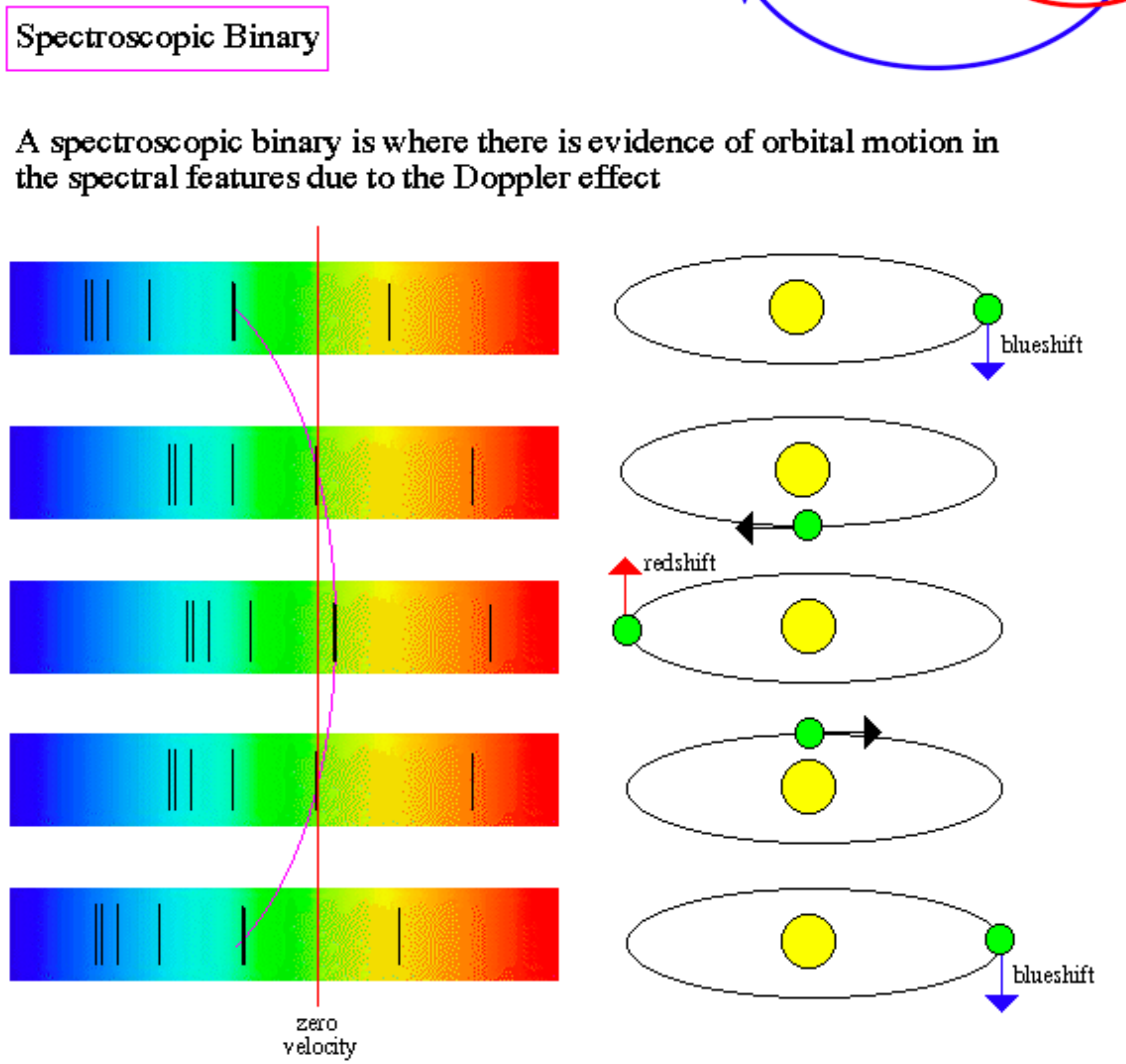




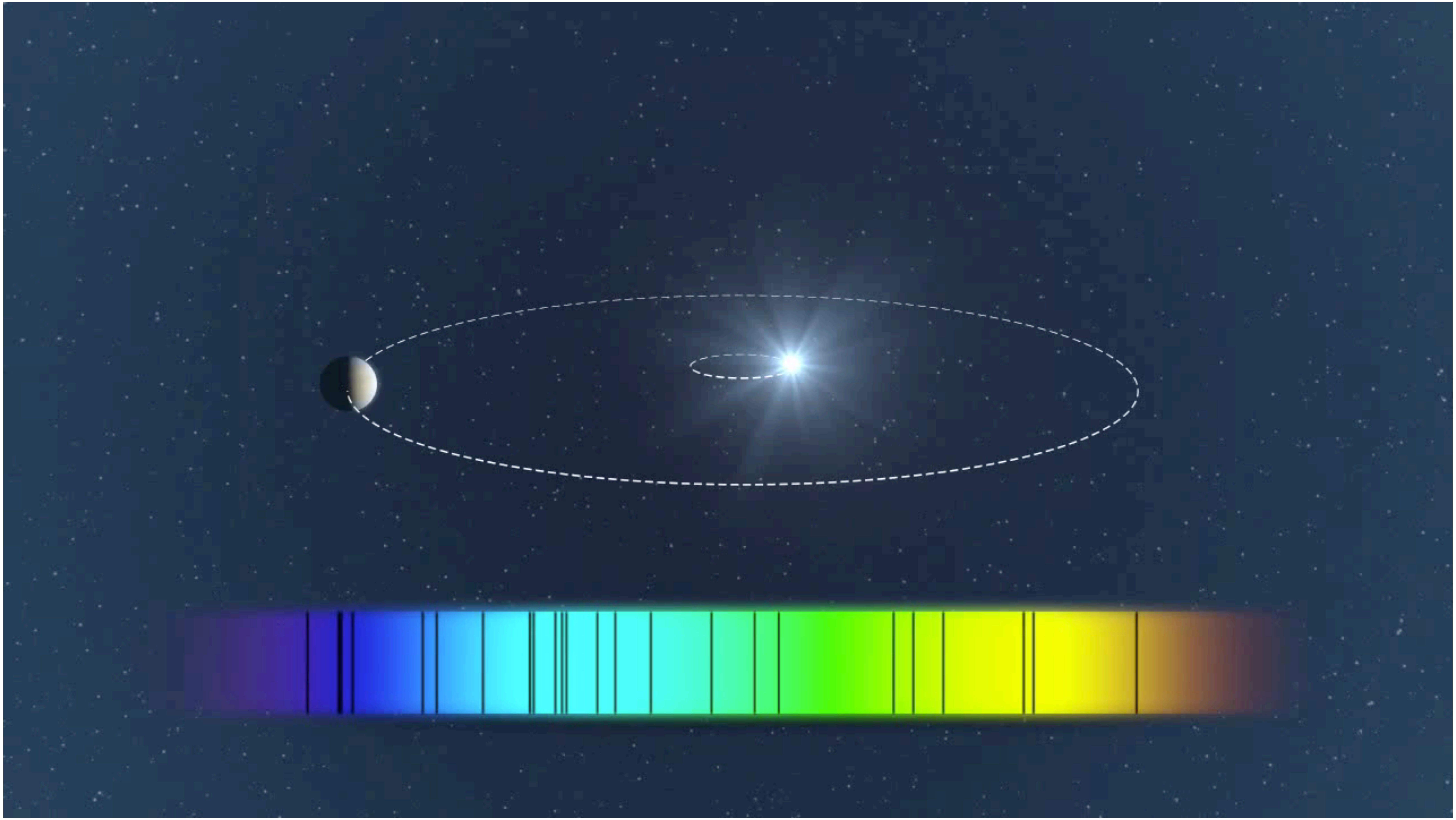
Binary Stars

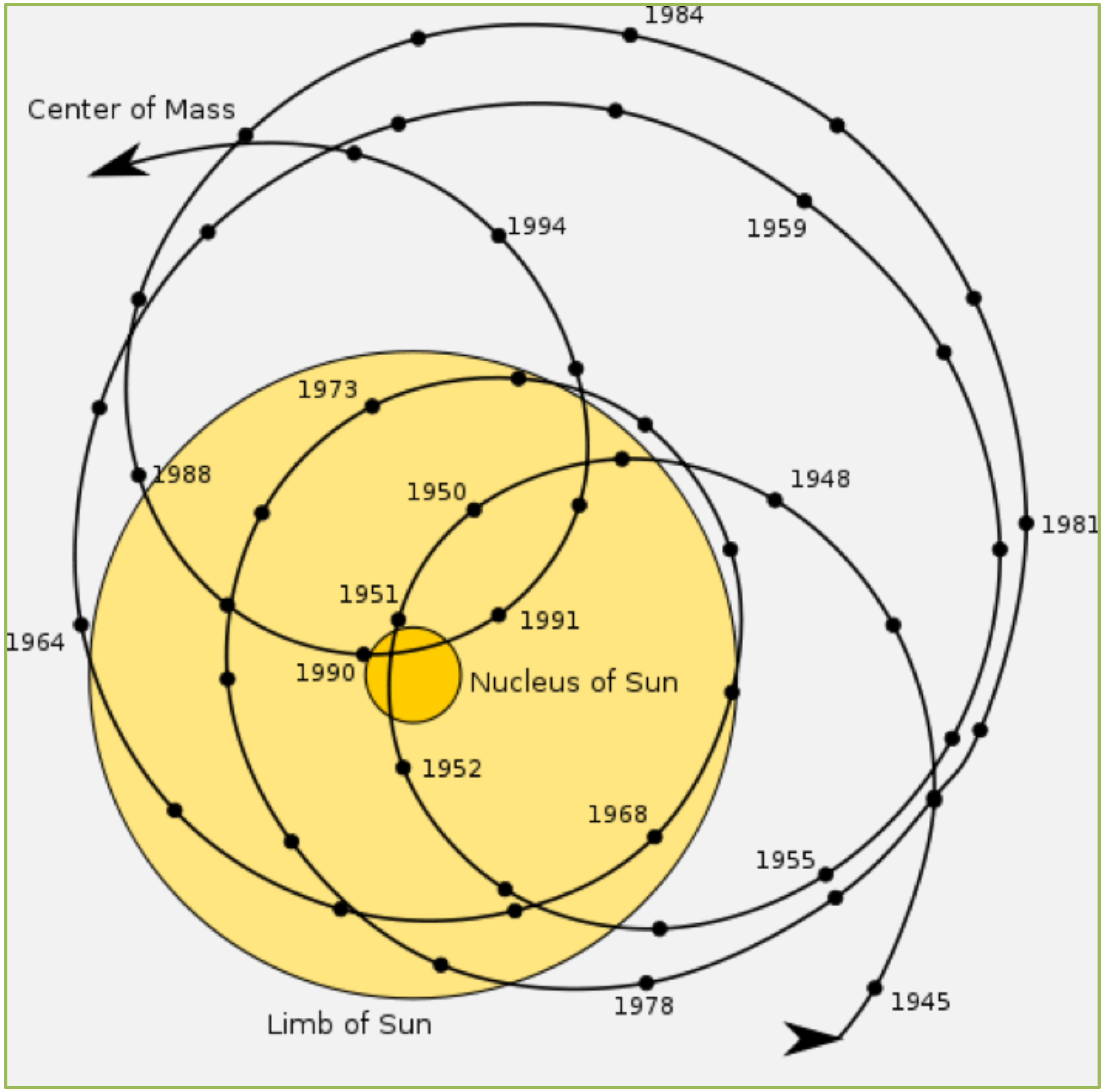






Can't see the planet, but can see the star



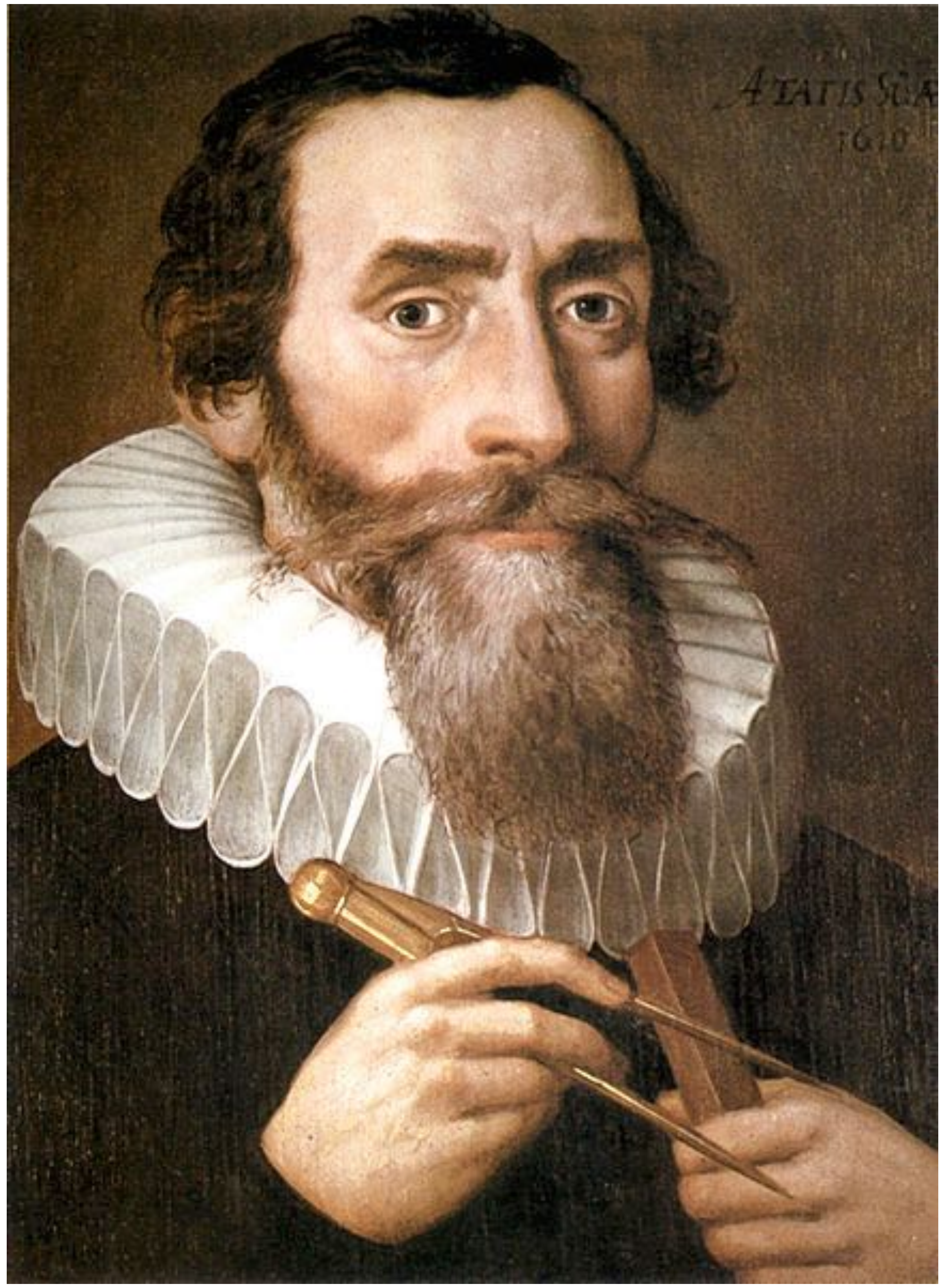


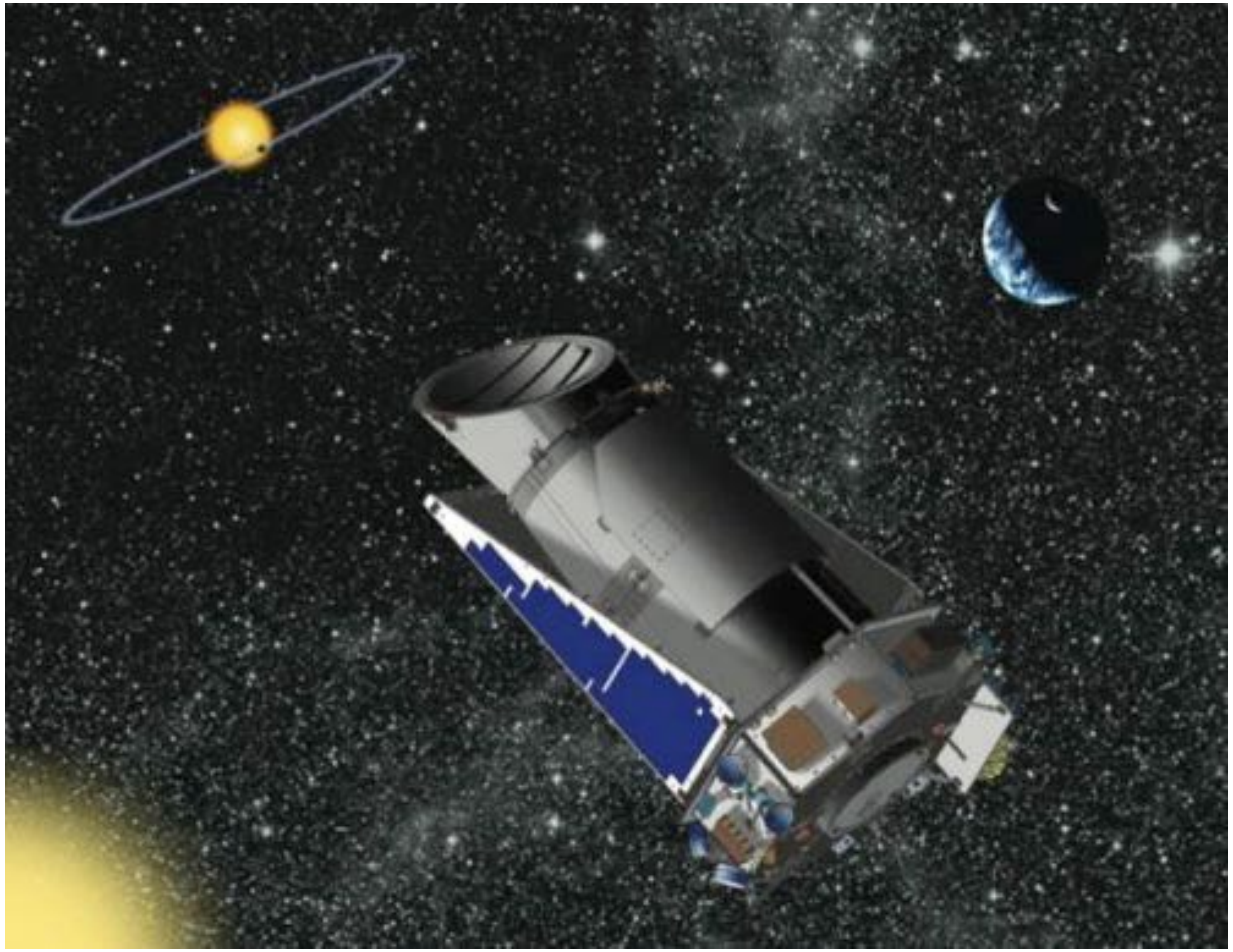
Motion of the Sun relative to its center of mass could be detectable by (more advanced than us) aliens

Transit Method

Starlight is blocked by the planet, reducing the amount of light detected from the star

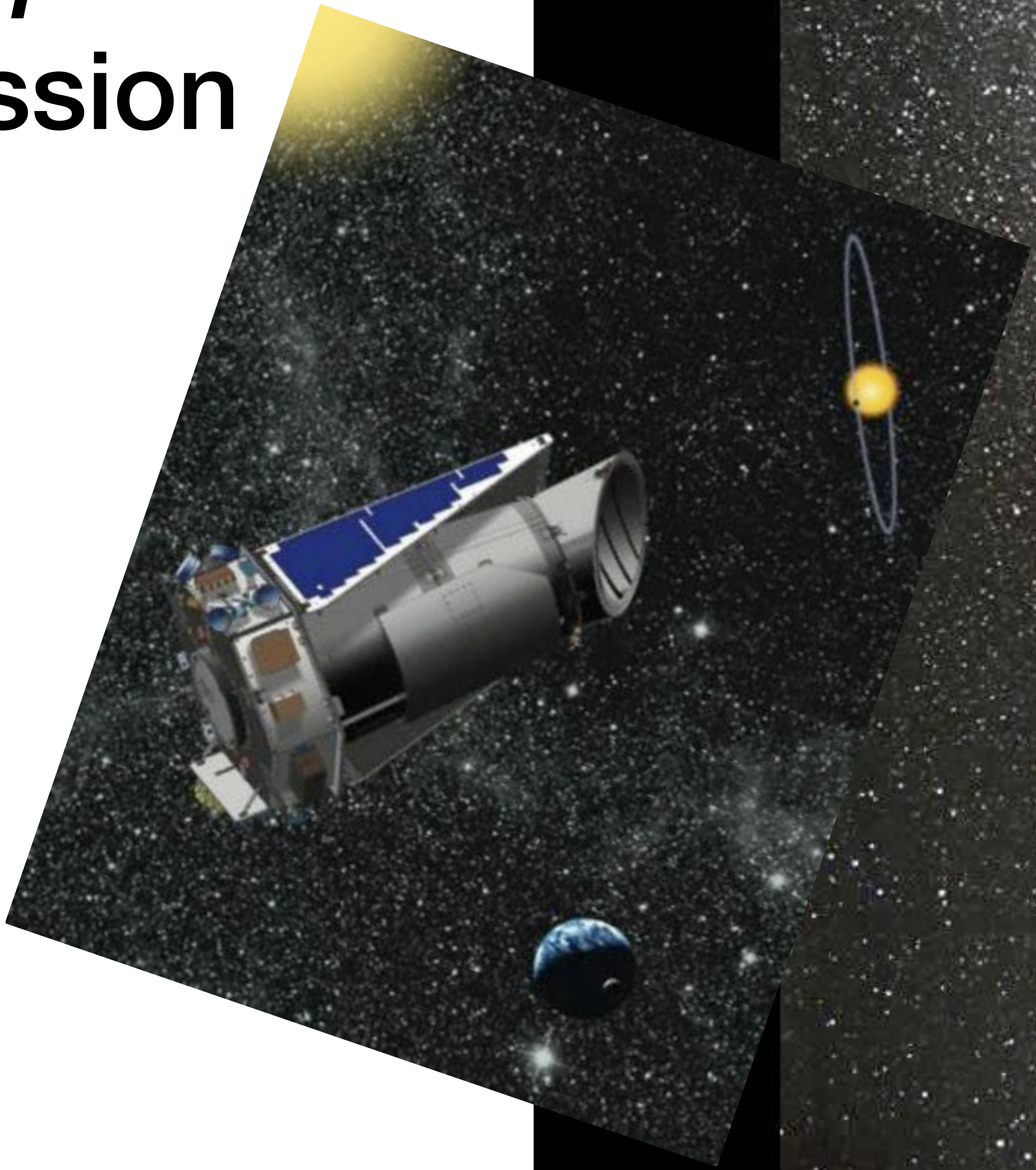
A quick review of orbits…

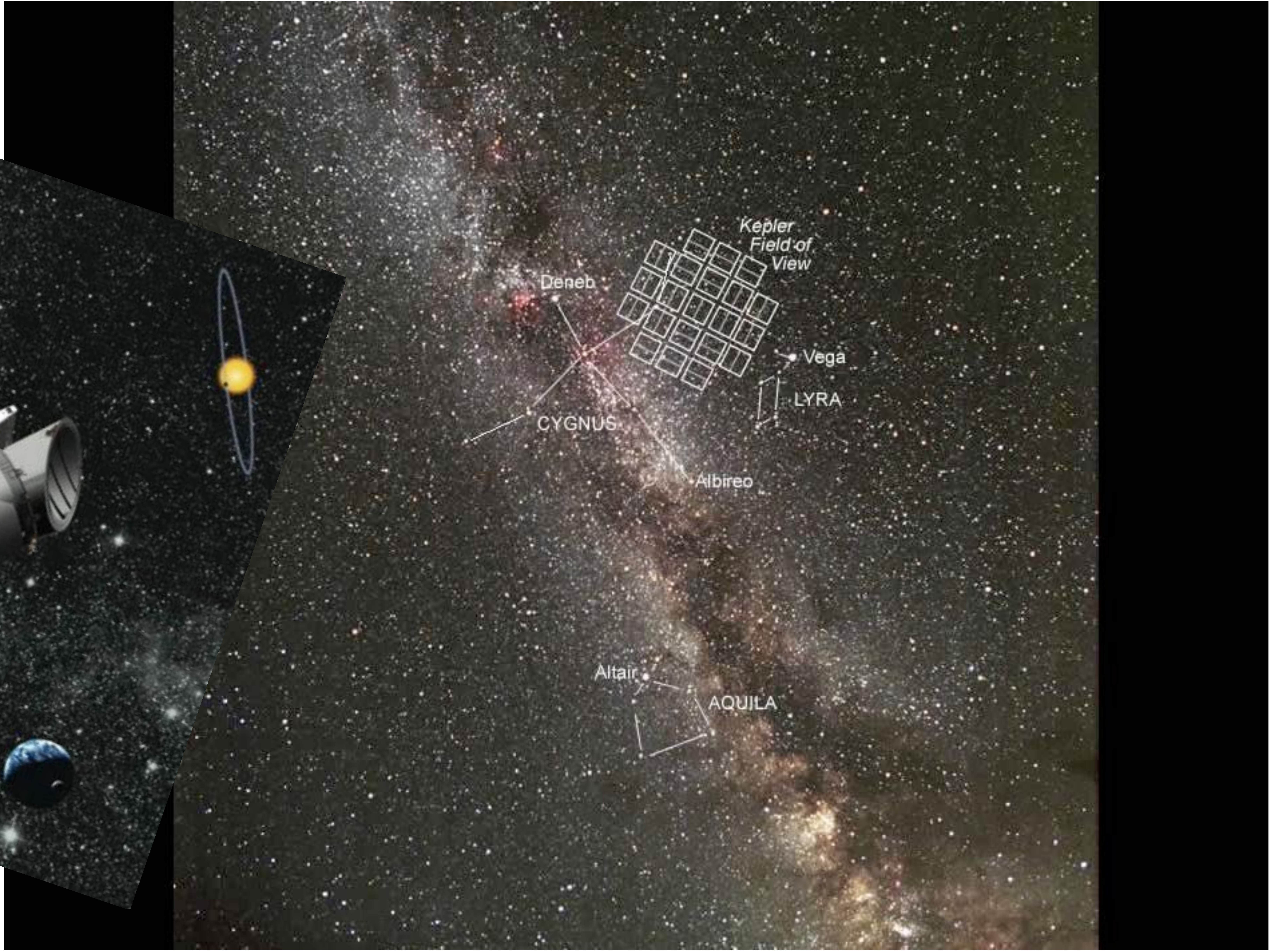




Kepler & *Kepler*

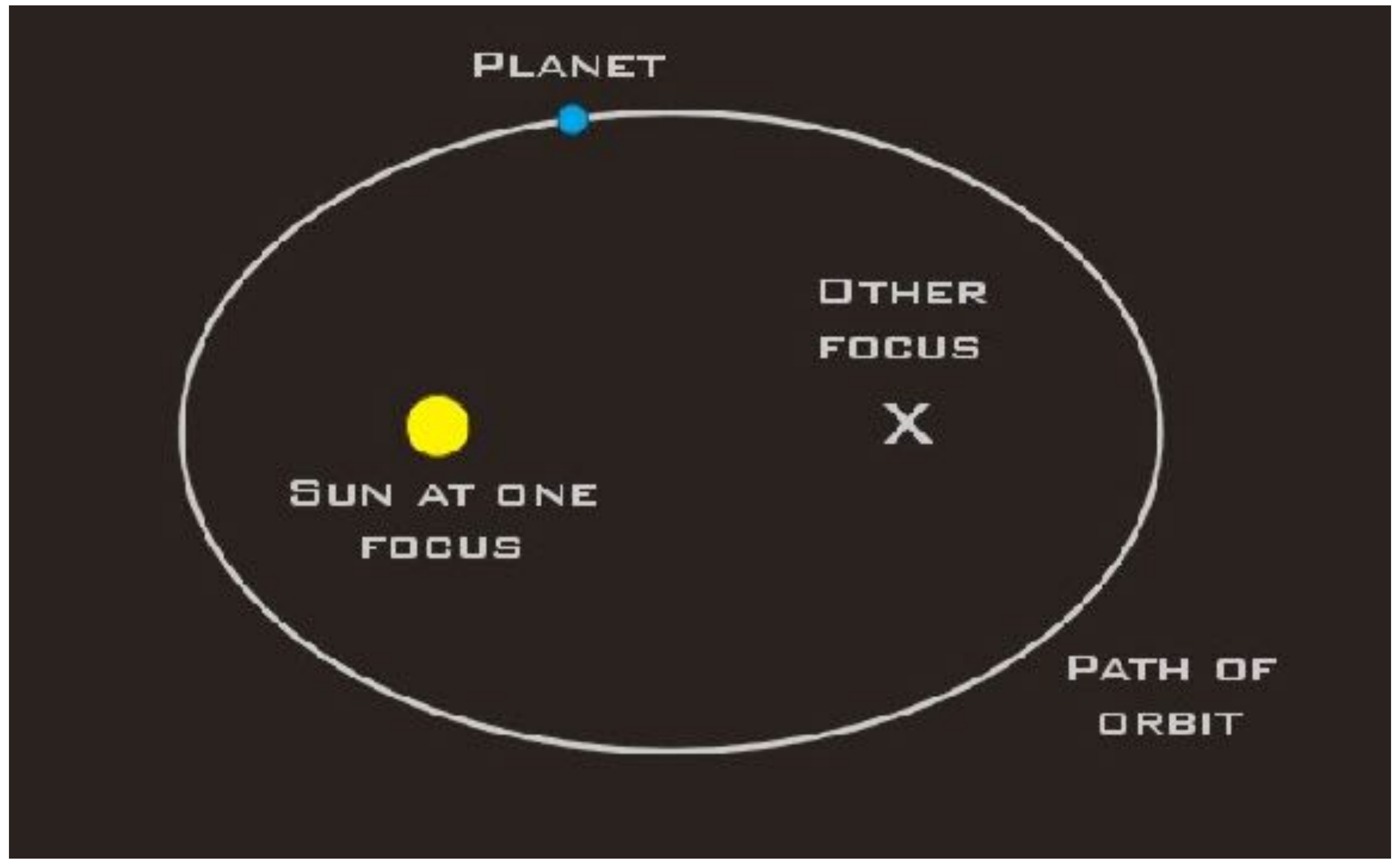
Kepler Mission



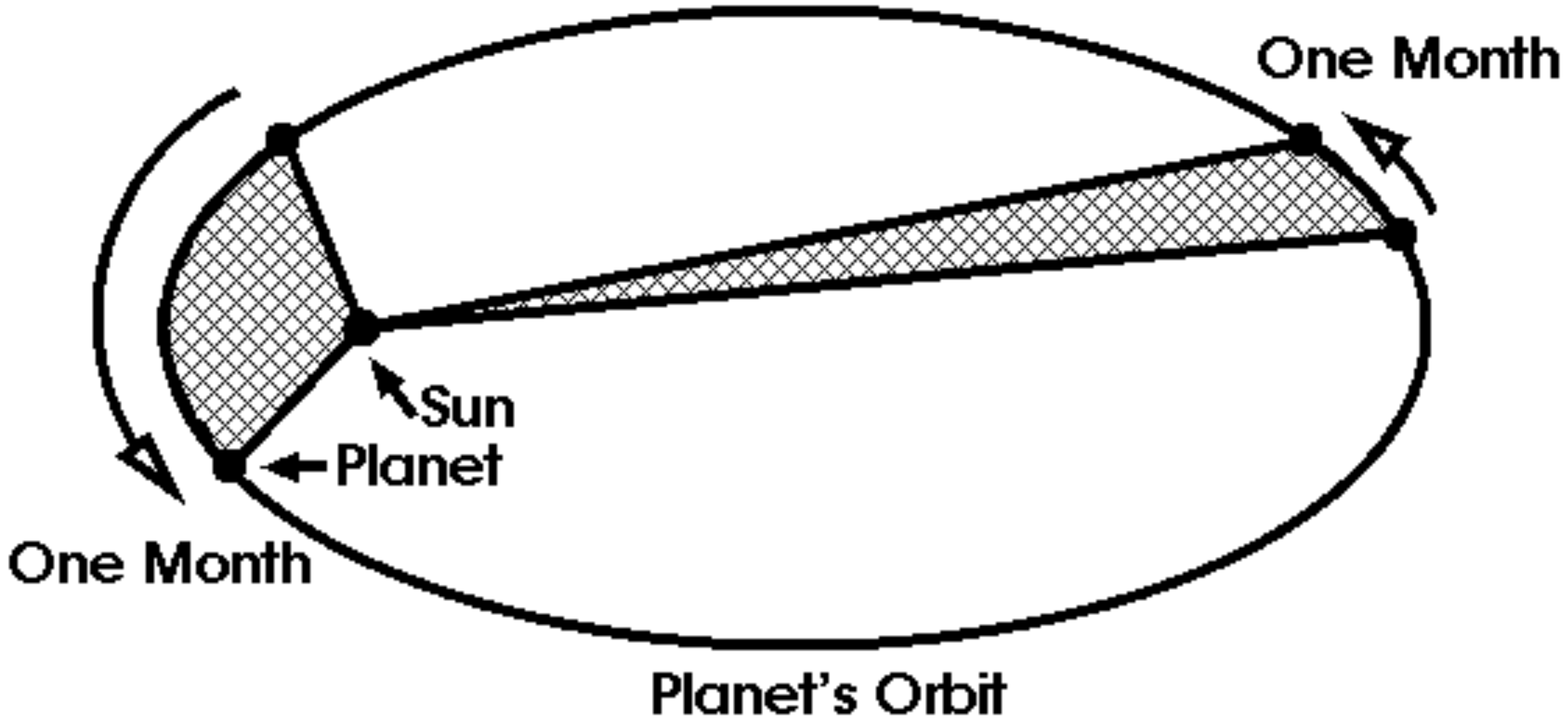


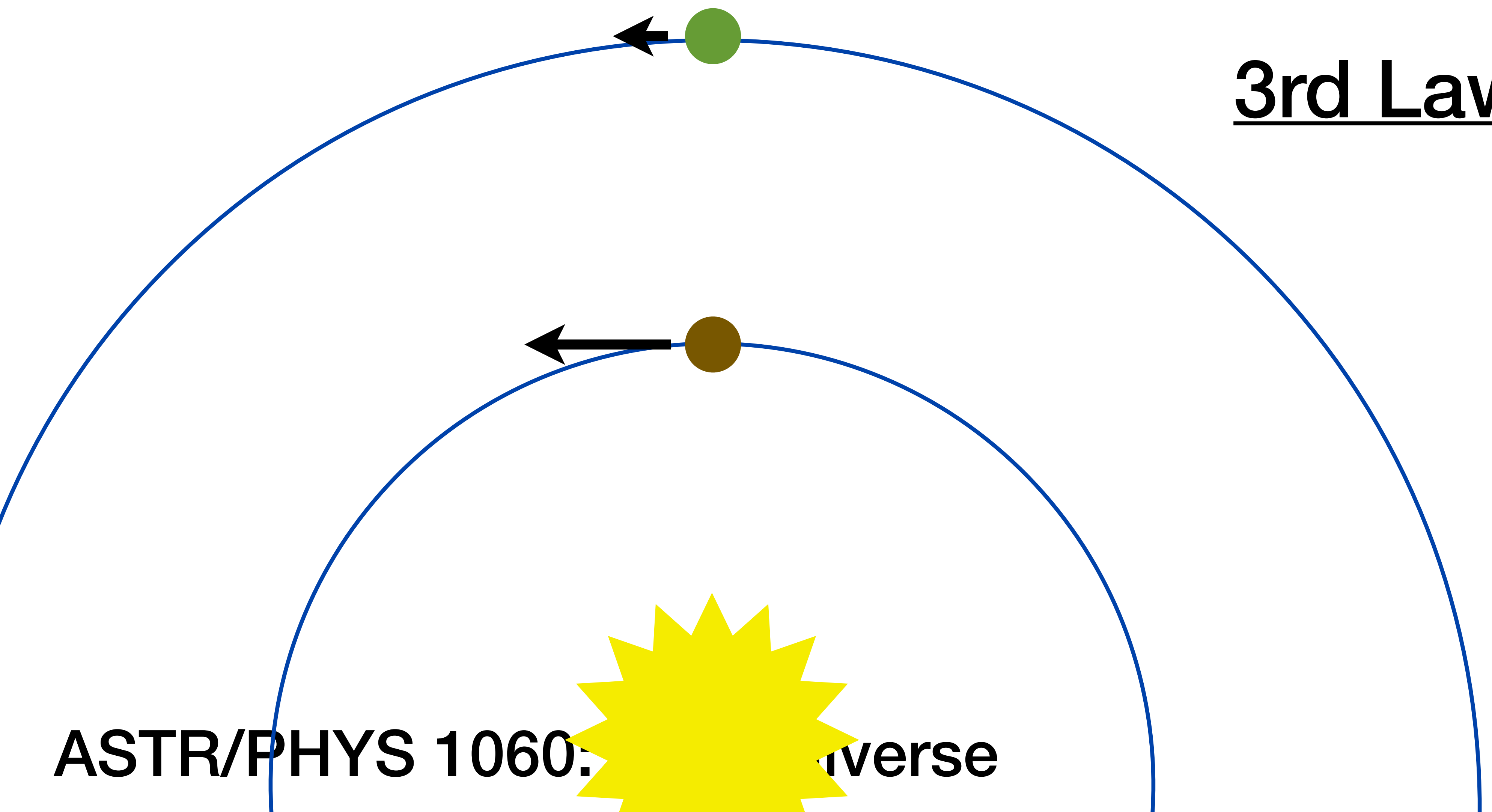
Kepler's 3 Laws

<u>1st Law</u>: Orbits are elliptical



<u>2nd Law</u>: equal areas in equal times





<u>3rd Law</u>: period depends on distance

$$(\text{Period of Planet [in years]})^2$$

$$=$$

$$(\text{Average Distance of Planet from Star [in AU]})^3$$

Ch. 5: Formation of Stars/Planets

Midterm 1 on Sept. 28th
will cover Chapters 1-5 and lecture material

Transit Activity due @10:55am
(feel free to discuss your answers with your group
or turn in up front anytime beforehand)

Are your grades in Canvas correct???

Office Hours

Mon 12-1pm	Zane
Tues 1:30-3pm	me
Tues 5-6pm	Randall
Wed 3-4pm	Randall
Thurs 11:45a-12:45pm	Zane
Fri 12-1pm	me

me: INSCC 320
Zane/Randall: JFB 325

1) Draw a planet orbiting a star - what orientation is required to produce planetary transits? How common do you think that orientation is?

2) What can you learn about the physical properties of the planets from transits based on the data you took (hint: there is more than one thing)?

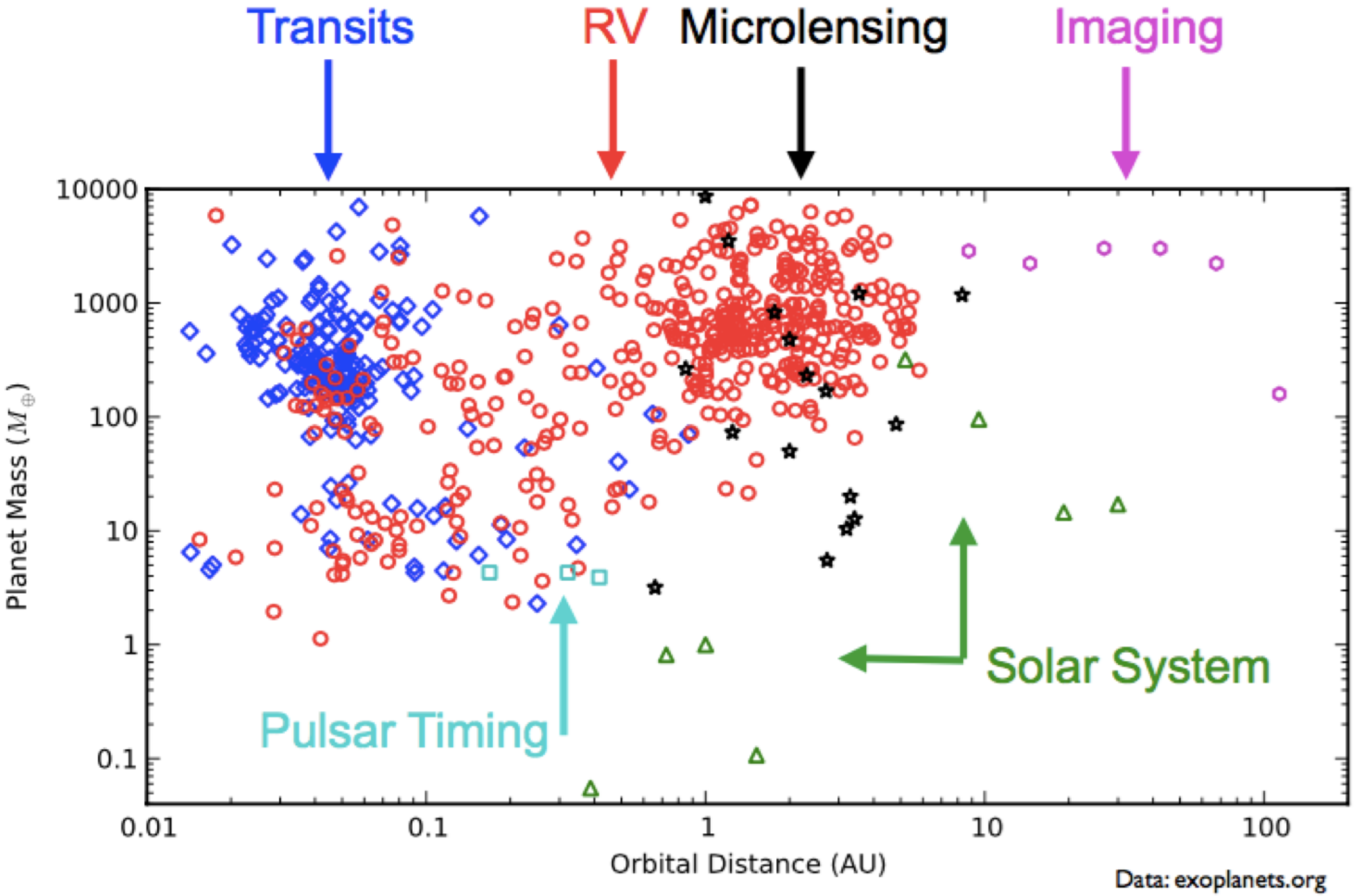
3) What is the difference between the planets around Star A and Star C (be as quantitative as possible)?

4) What is the difference between the planets around Star C and Star D?

5) How can you explain the results from star B (there are a variety of reasons that we may not see a signal)?

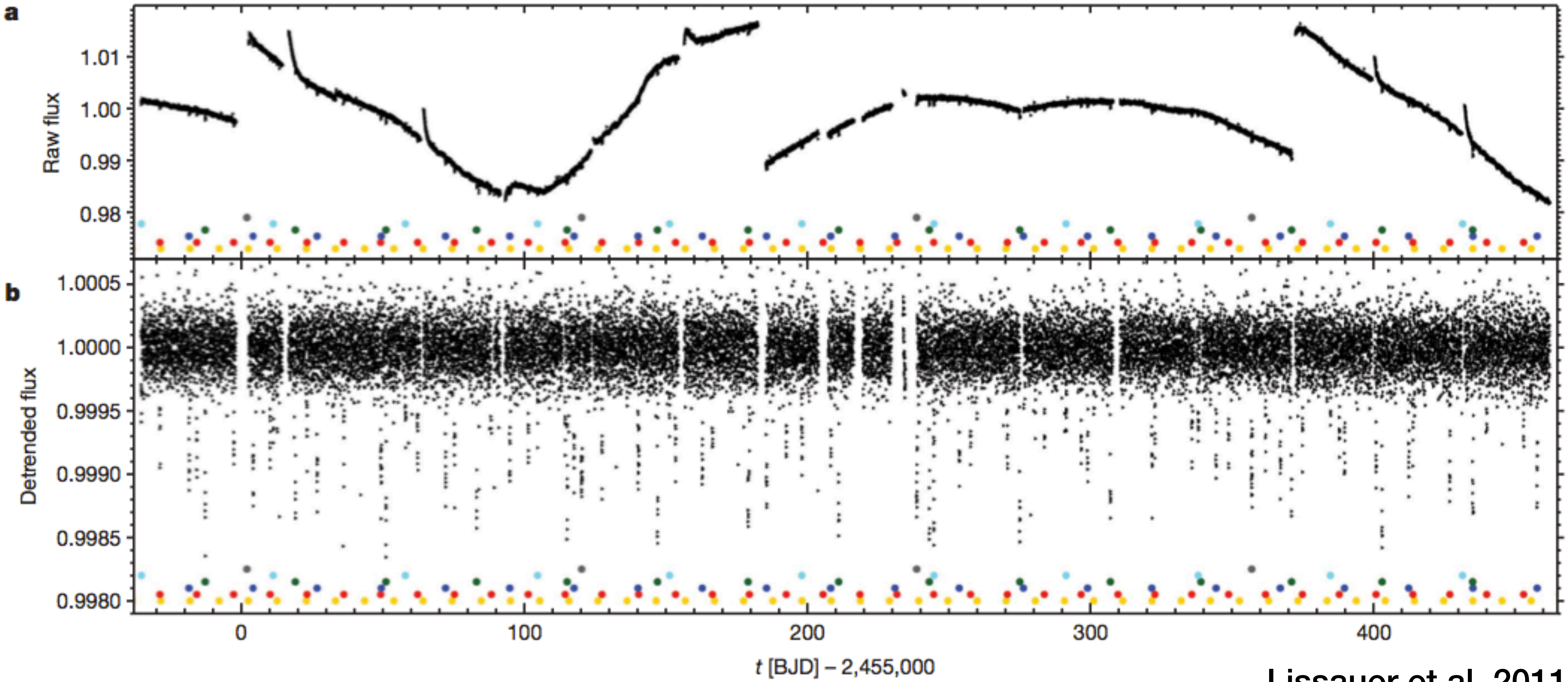
6) The Earth’s radius is about 100 times smaller than the sun? How sensitive would our light meter have to be to detect its transit?

How long would you have to observe to find an earth-like planet around another star?



Transits
RV
Microlensing
Imaging
10000
1000
100
10
1
0.1
Planet Mass ($M_\oplus$)
0.01
0.1
1
10
100
Orbital Distance (AU)
Pulsar Timing
Solar System
Data: exoplanets.org

Kepler-11 System (6 planets)

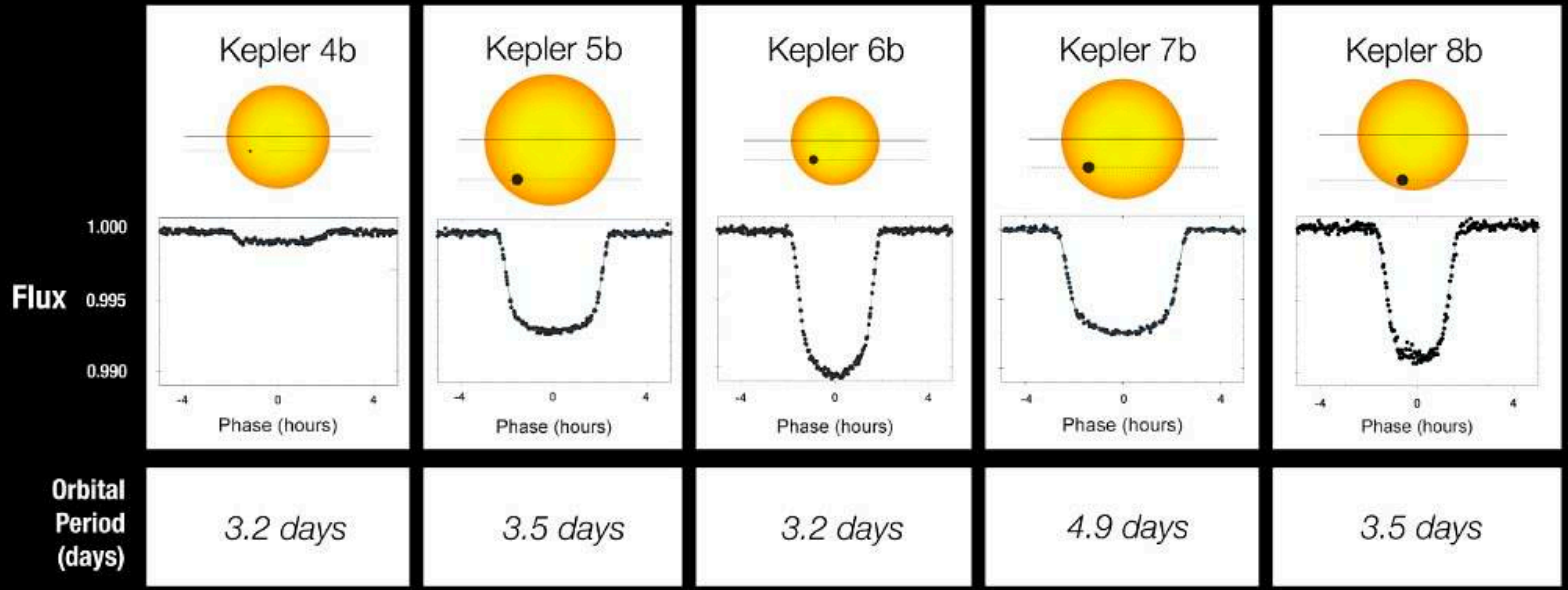


Lissauer et al. 2011

Kepler Planetary Systems

https://youtu.be/_DnDeBa0KFc

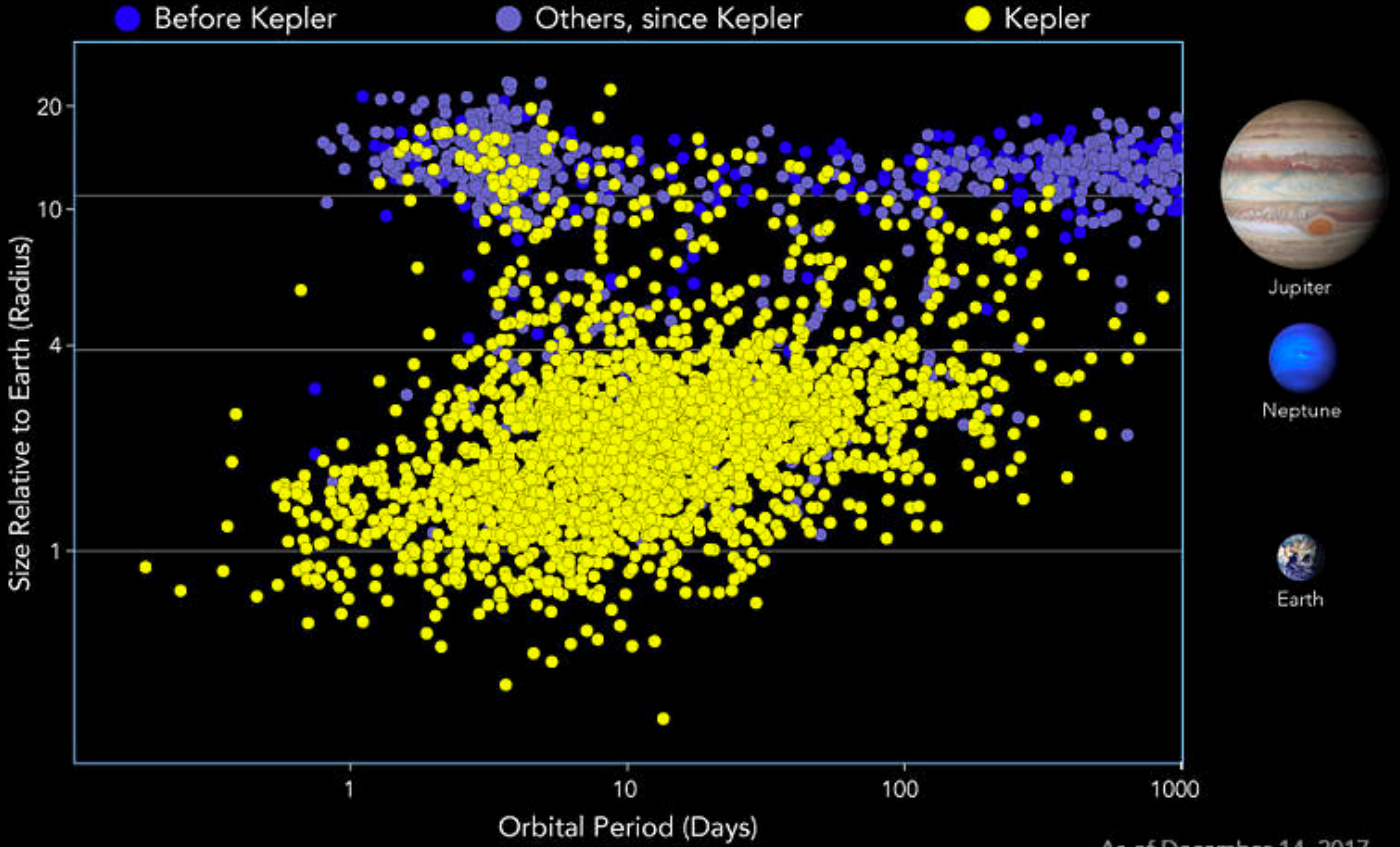
Transit Light Curves



Exoplanet Discoveries

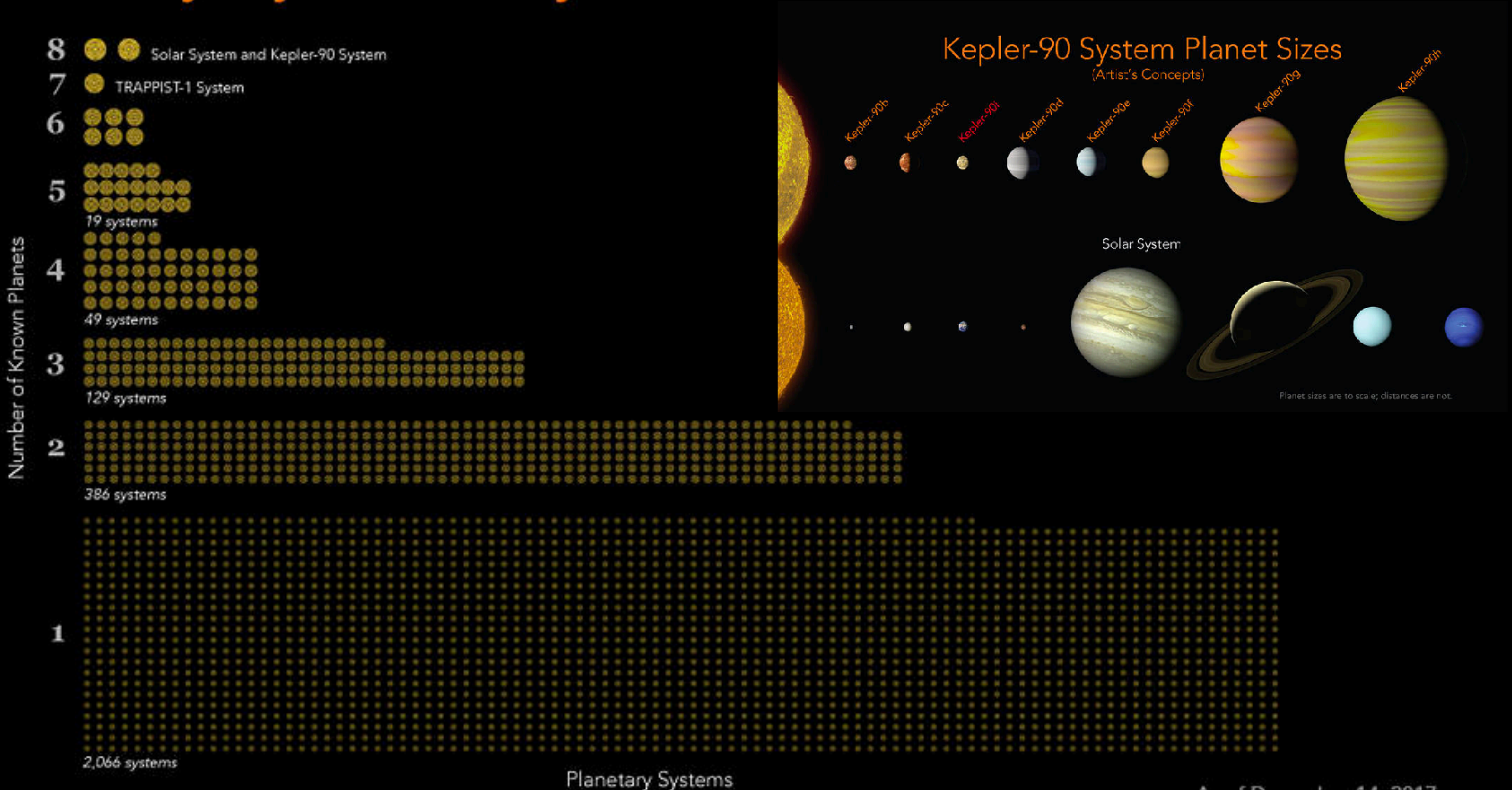
Total confirmed exoplanets = 3,567

Total Kepler = 2,525



As of December 14, 2017

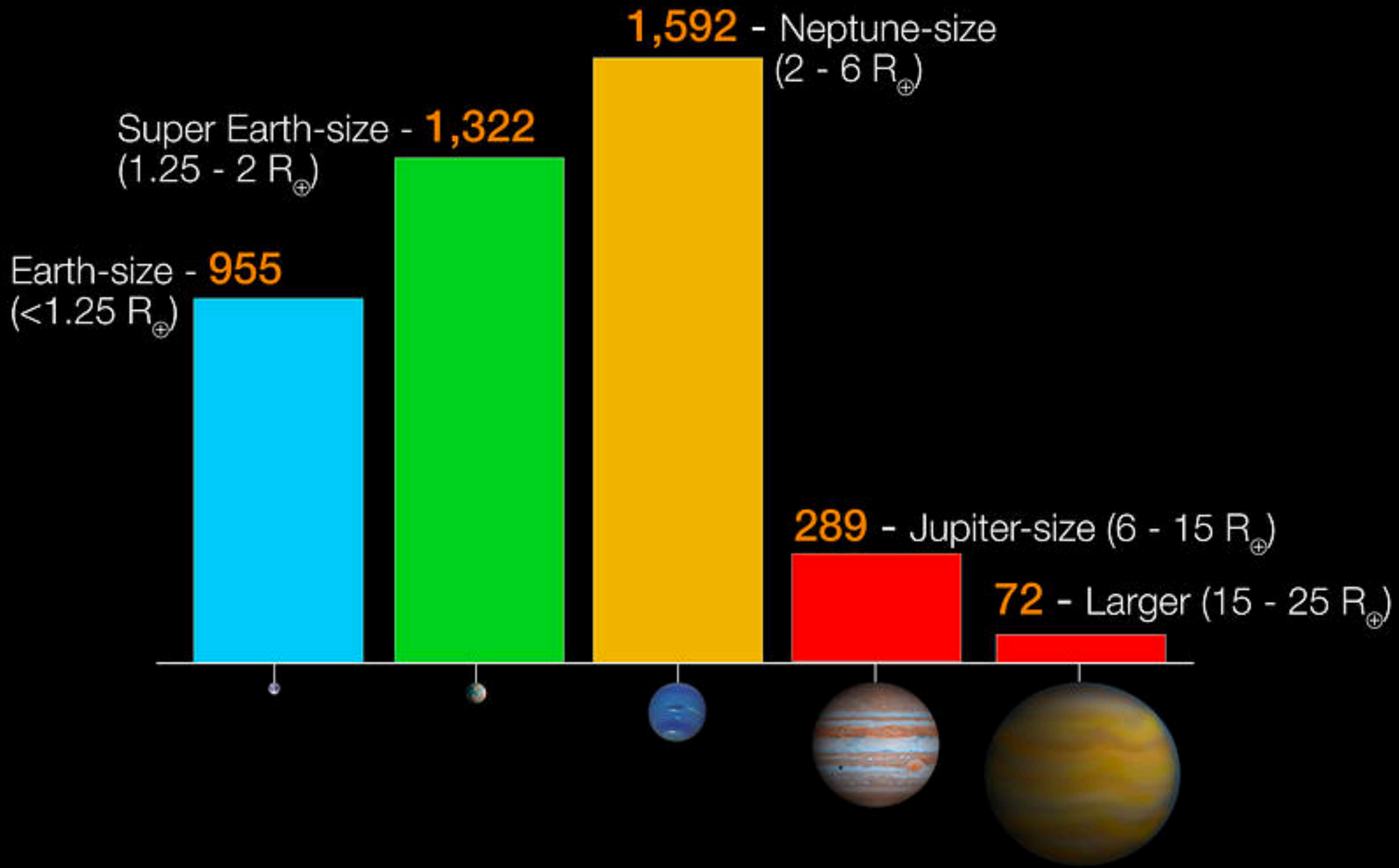
Planetary Systems by Number of Known Planets



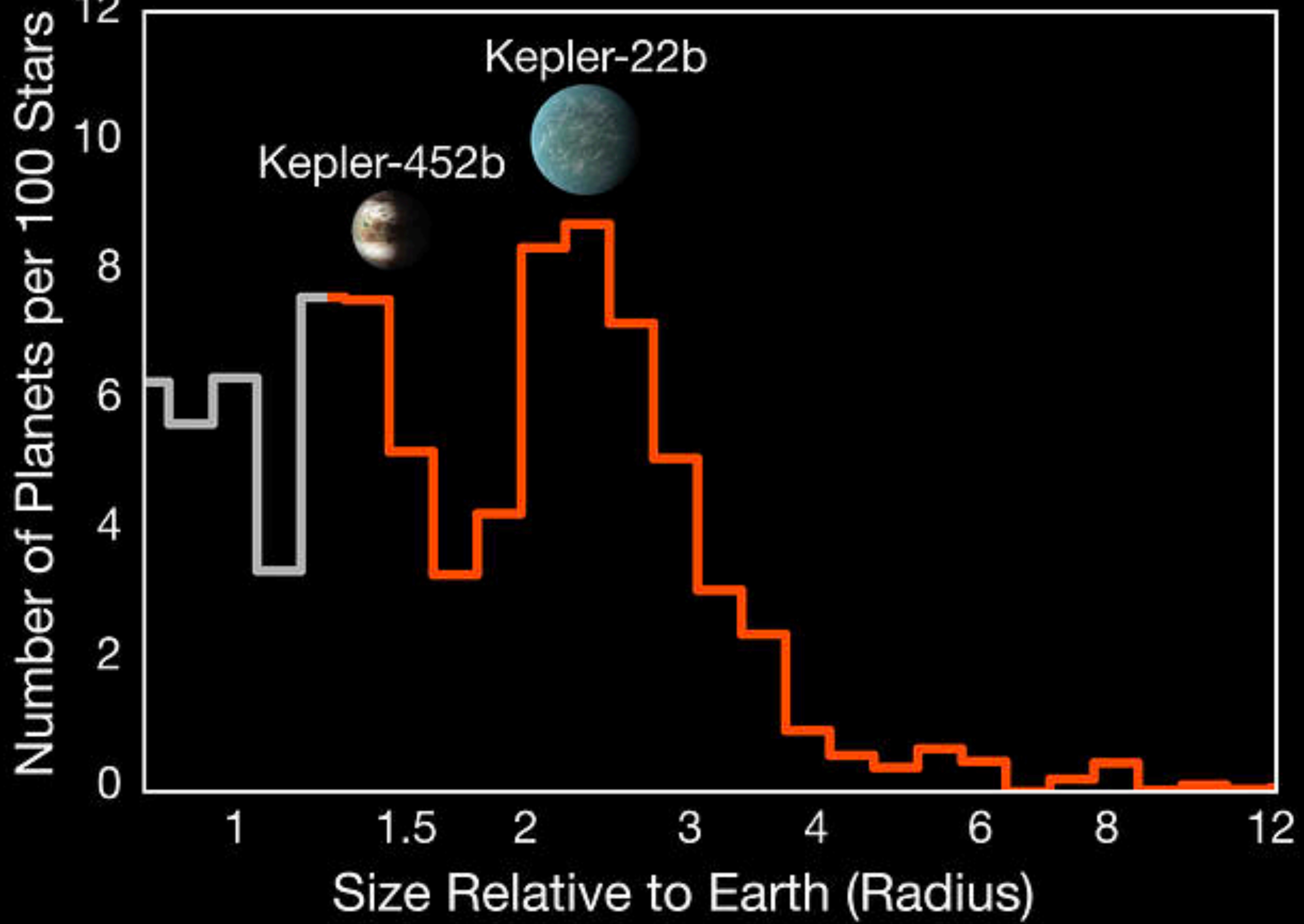
As of December 14, 2017

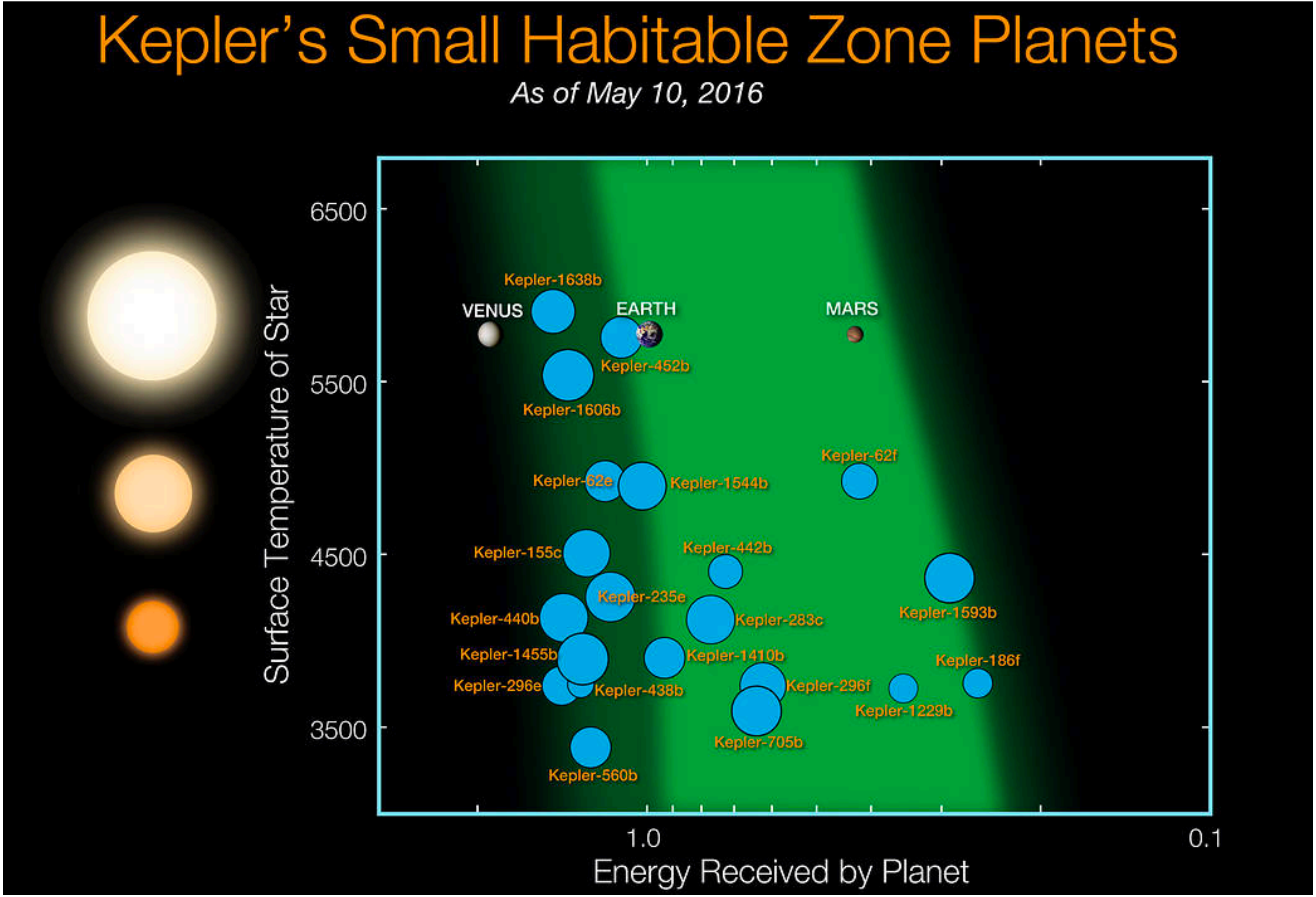
Sizes of Kepler Planet Candidates

As of July 23, 2015



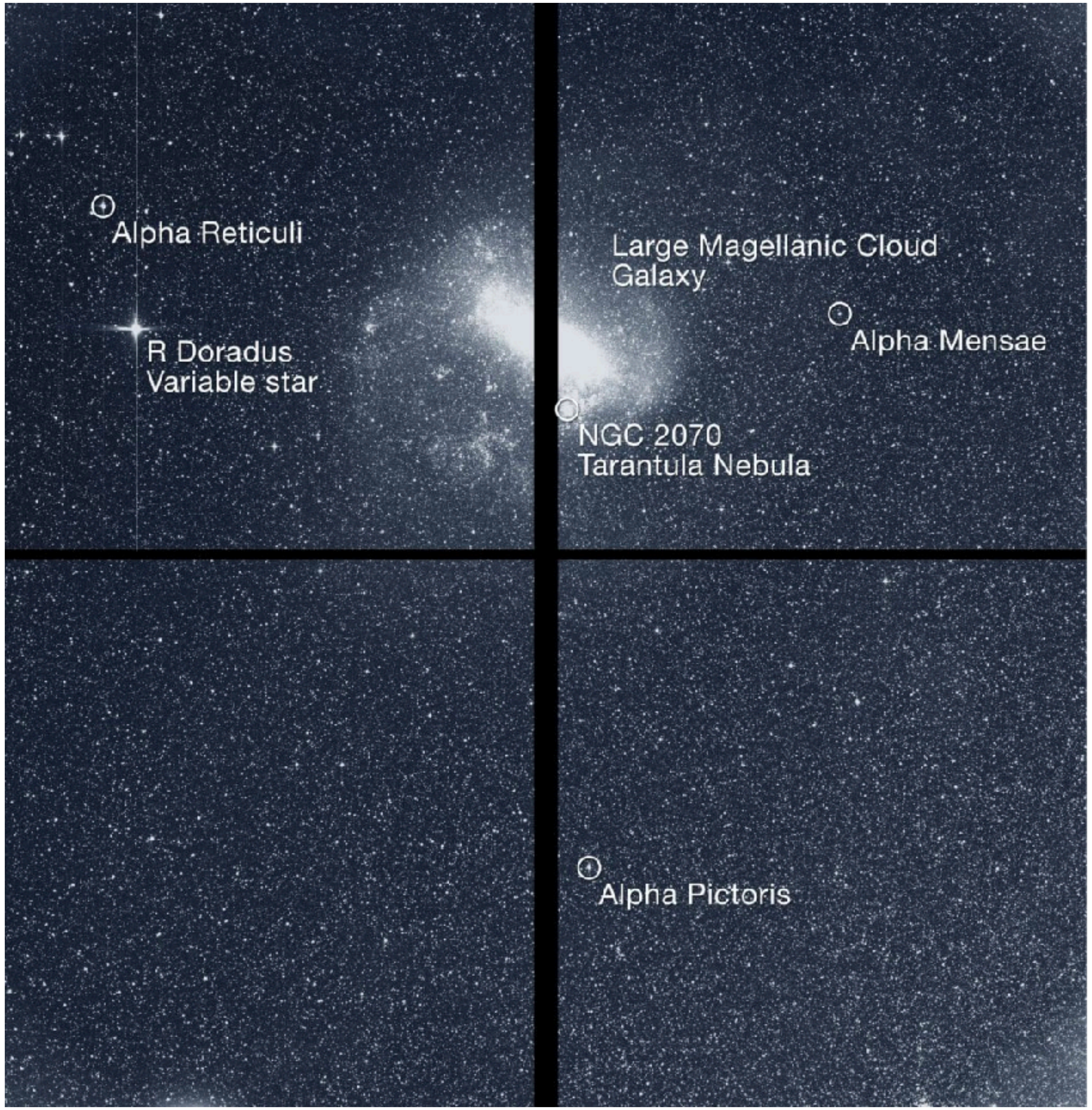
Small Planets Come in Two Sizes





Kepler's Small Habitable Zone Planets
As of May 10, 2016
Surface Temperature of Star
6500
5500
4500
3500
Energy Received by Planet
1.0
0.1
VENUS
EARTH
MARS
Kepler-1638b
Kepler-452b
Kepler-1606b
Kepler-62f
Kepler-62e
Kepler-1544b
Kepler-155c
Kepler-442b
Kepler-235e
Kepler-440b
Kepler-283c
Kepler-1593b
Kepler-1455b
Kepler-1410b
Kepler-186f
Kepler-296e
Kepler-438b
Kepler-296f
Kepler-1229b
Kepler-705b
Kepler-560b

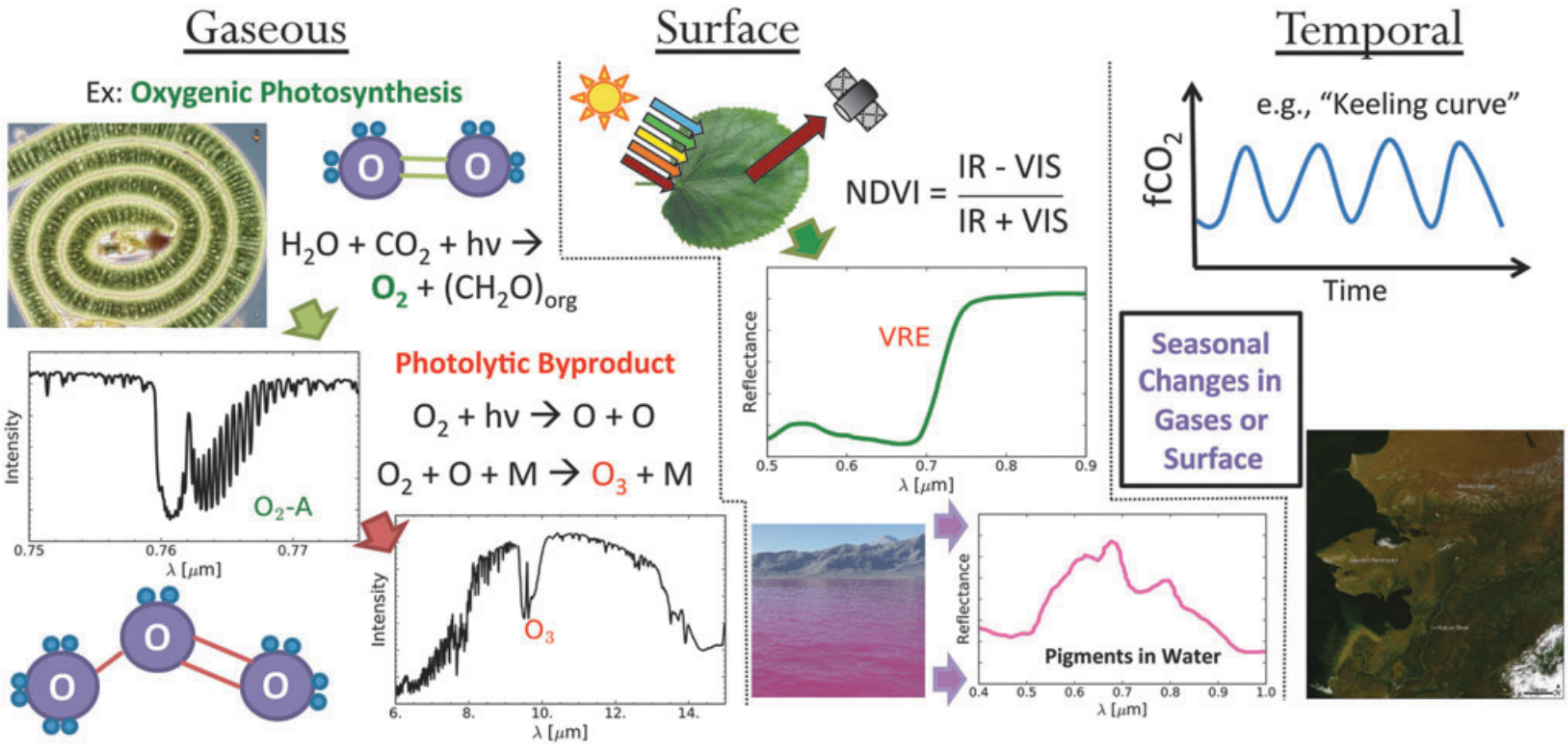
What's Next: TESS



"First Light" image taken by TESS, released last week - already found 2 new planets!

TESS will monitor the brightest stars in the sky for transits, finding planets around the stars nearest to us

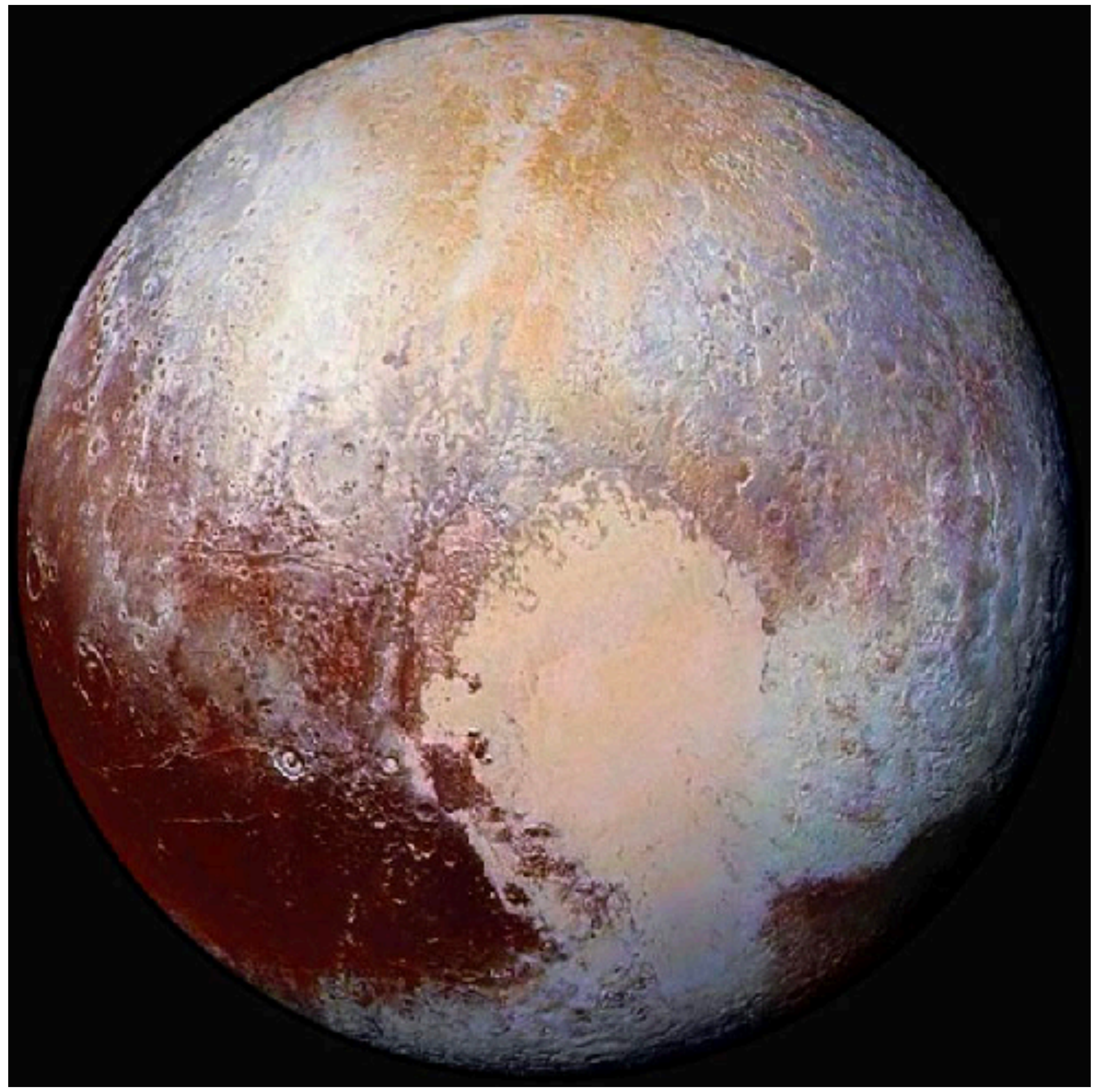
Biosignatures of Life in an Exoplanet Atmosphere



What do you think about the possibility of detecting biosignatures on an Earth-like planet orbiting another star?

Why Pluto is not a planet

- It is in orbit around the Sun.
- It has sufficient mass to assume hydrostatic equilibrium (a nearly round shape).
- It has "cleared the neighborhood" around its orbit.



Pluto

Charon

Paper recently out about this 3rd criteria not used <u>historically</u>