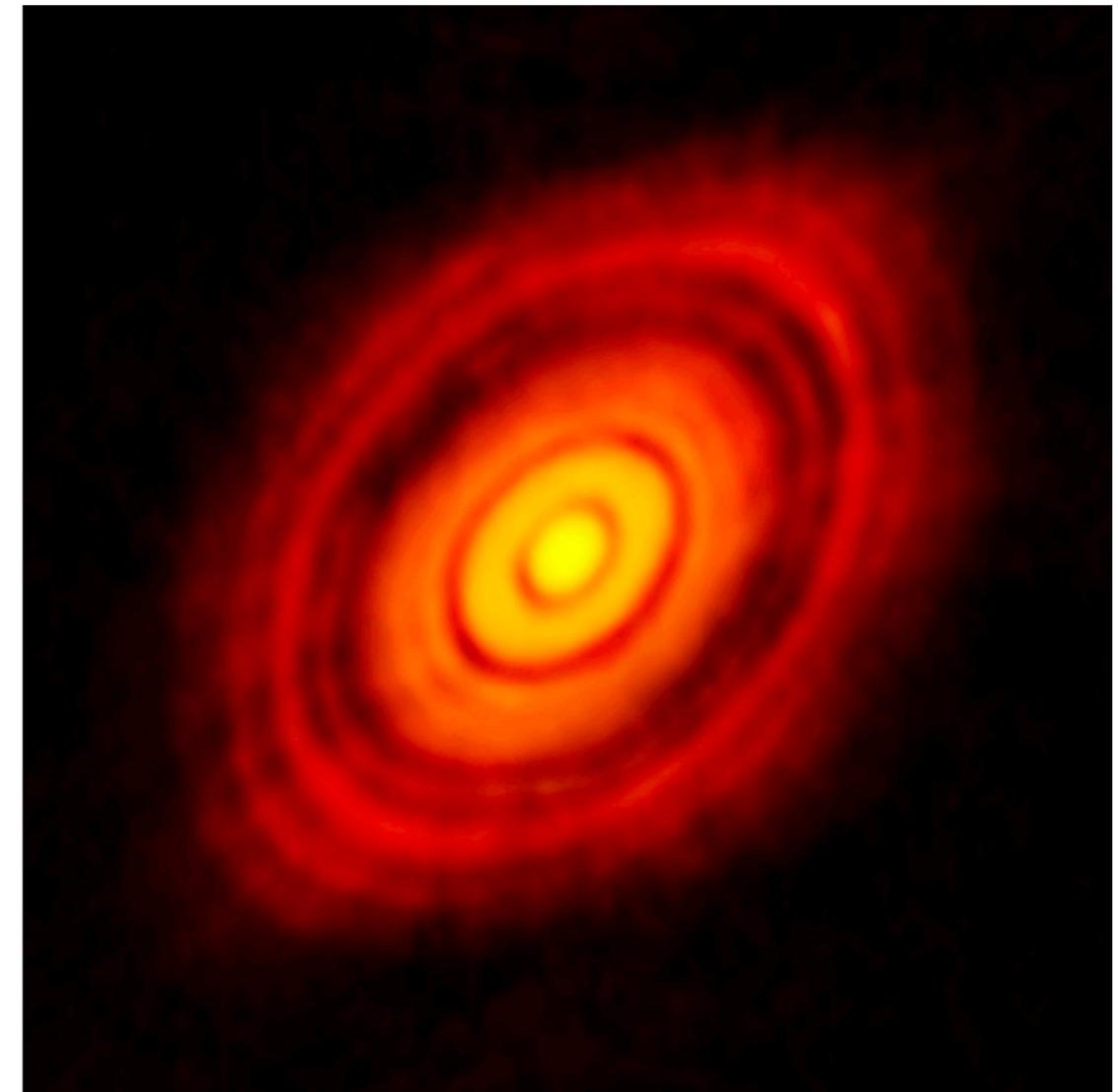
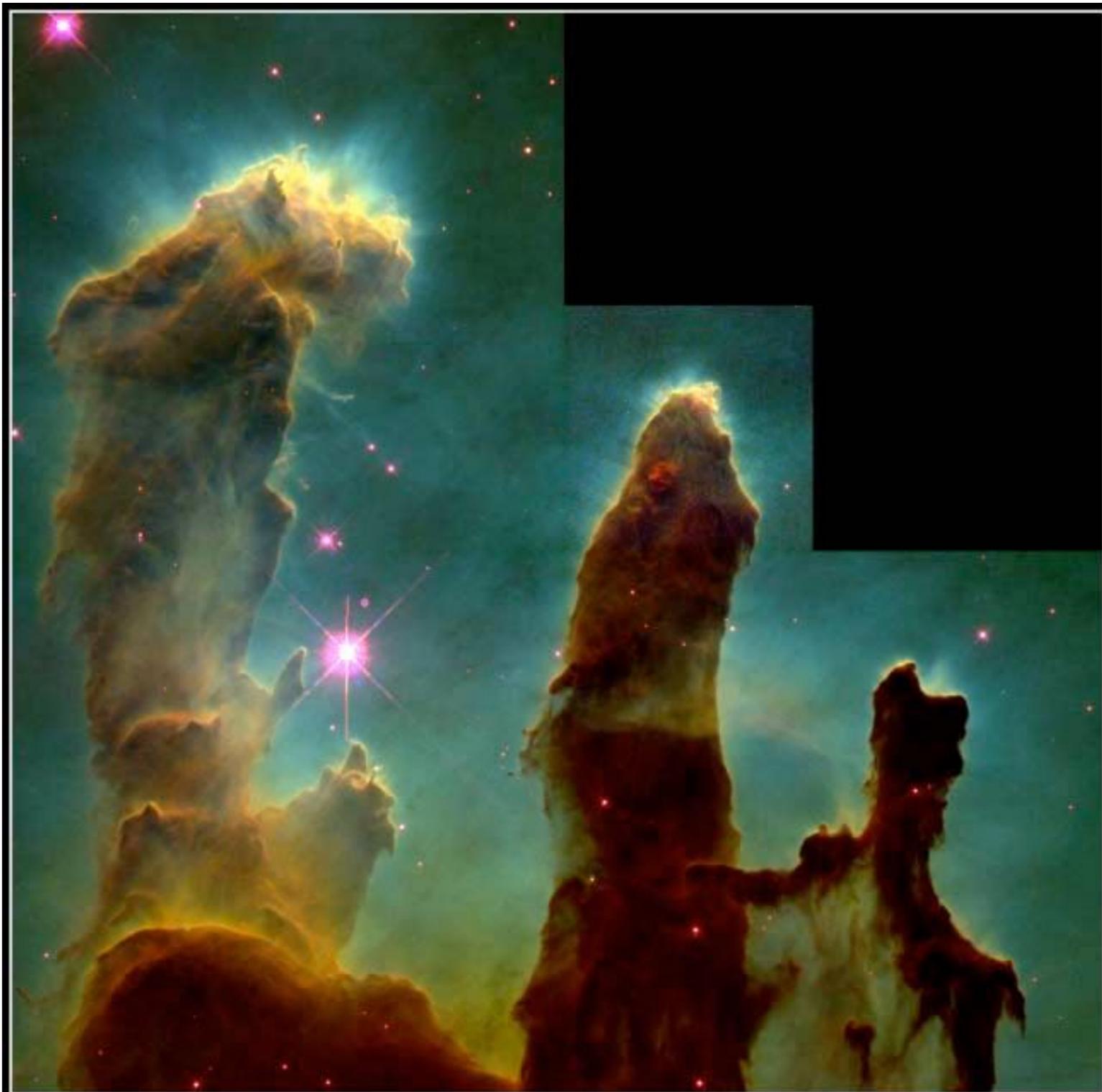


# ASTR/PHYS 1060: The Universe

## Chapter 5: Formation of Stars and Planets

Midterm 1 on Sept. 19th (a week from today!)  
will cover Chapters 1-5 and lecture material





**Gaseous Pillars • M16**

**HST • WFPC2**

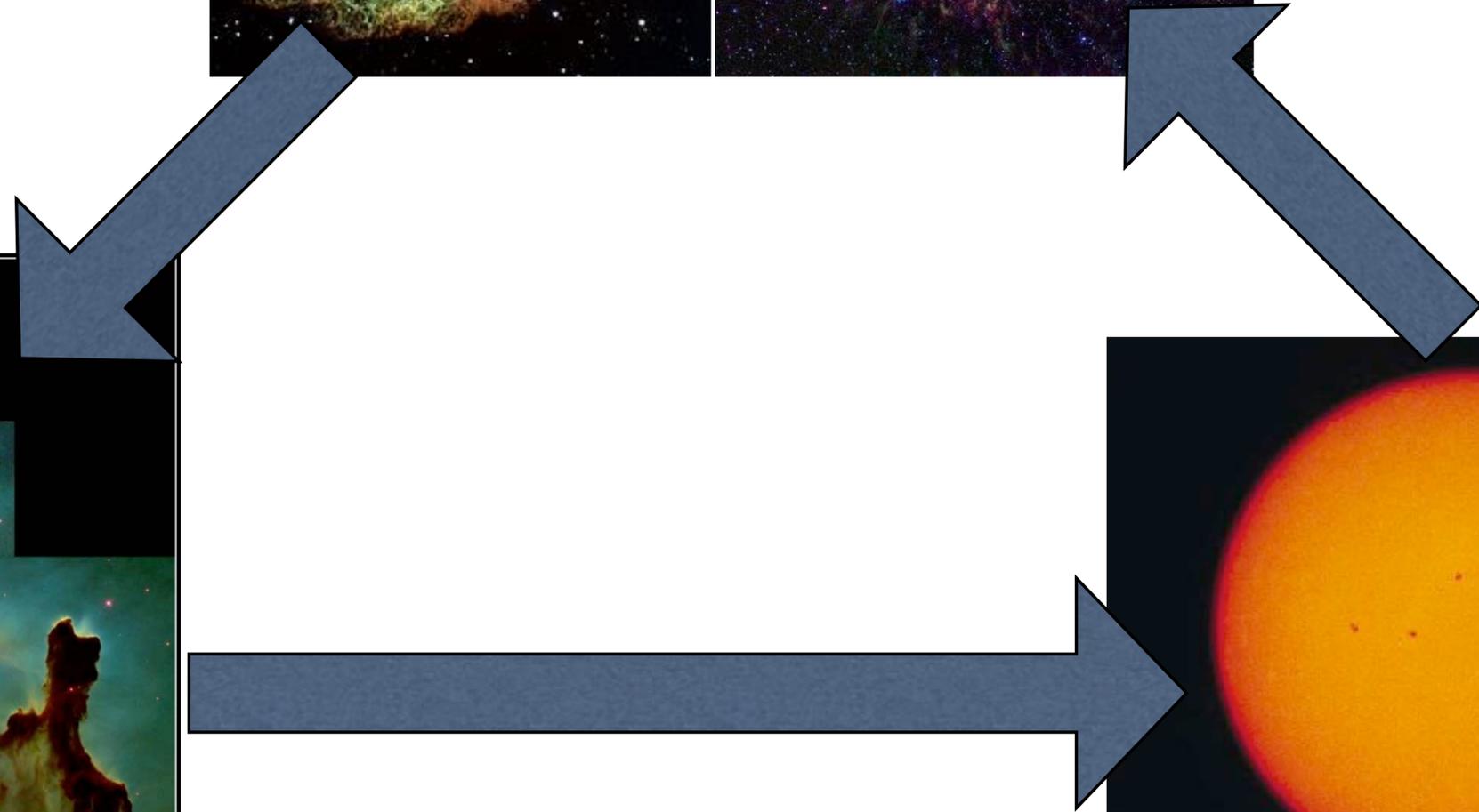
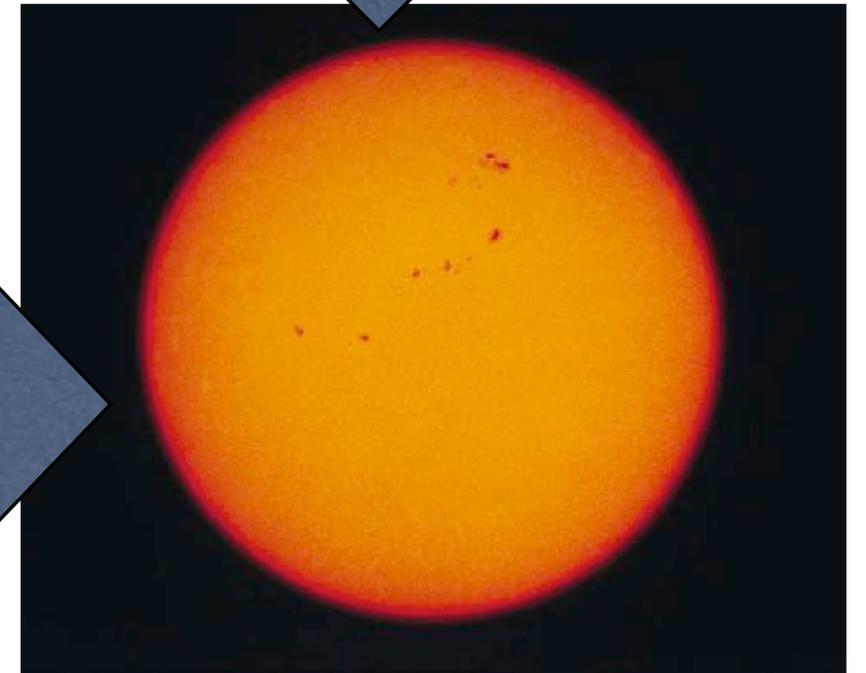
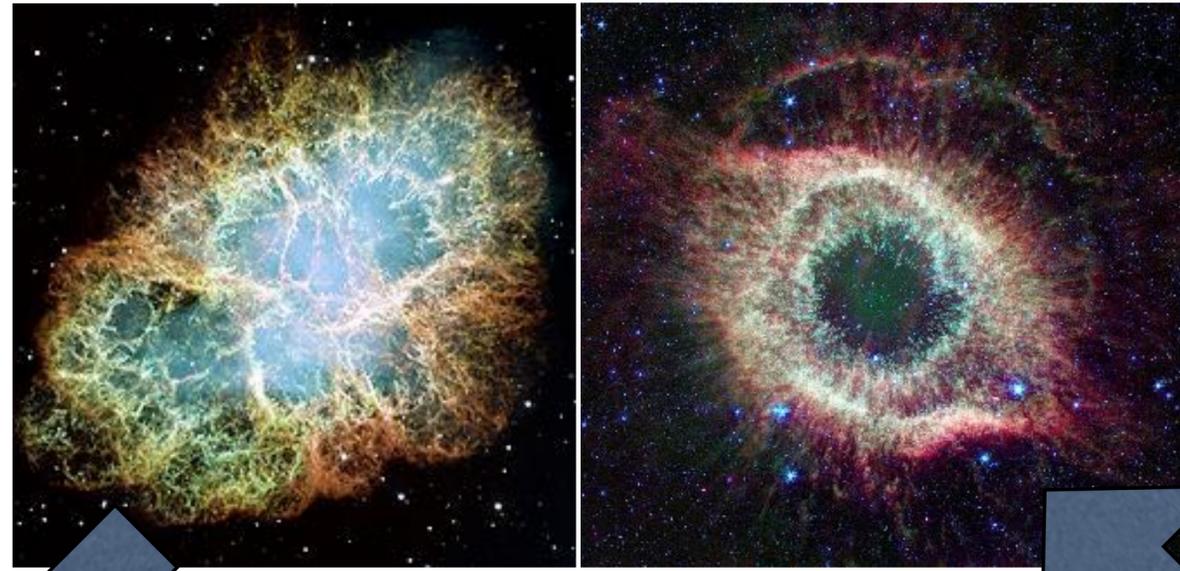
PRC95-44a • ST Sci OPO • November 2, 1995

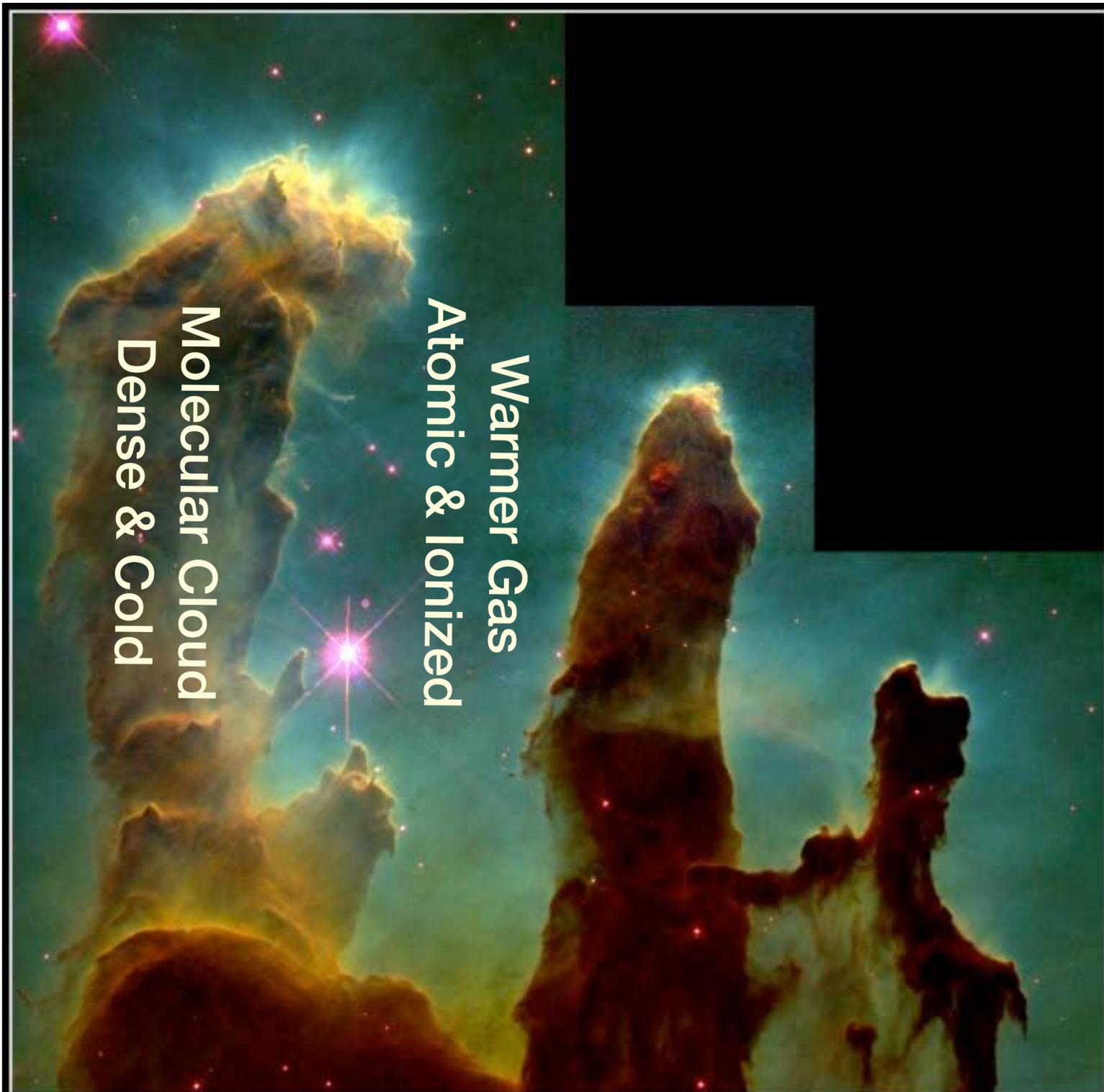
J. Hester and P. Scowen (AZ State Univ.), NASA

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

“Pillars of Creation”

# Life Cycle of Gas and Stars

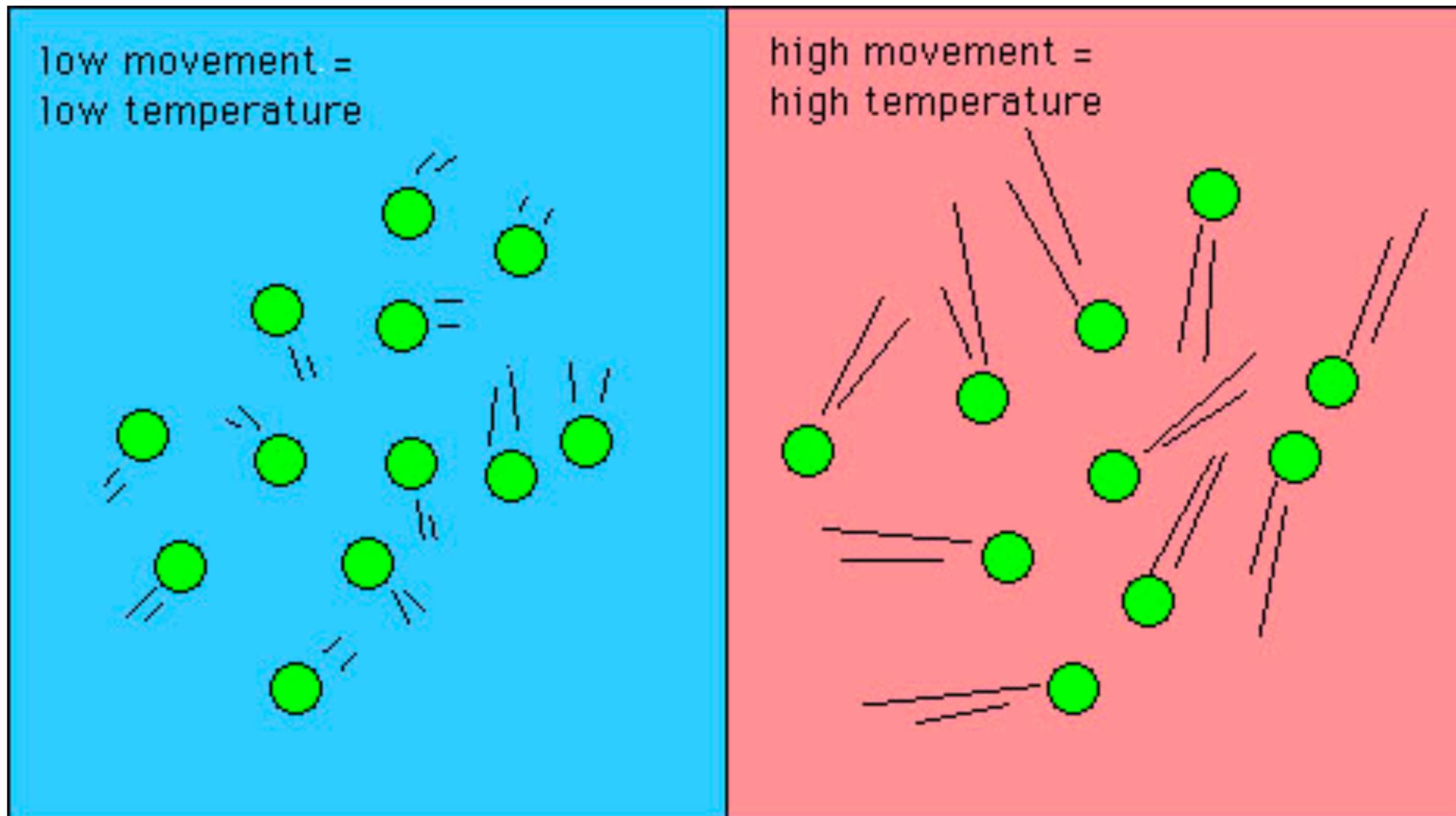


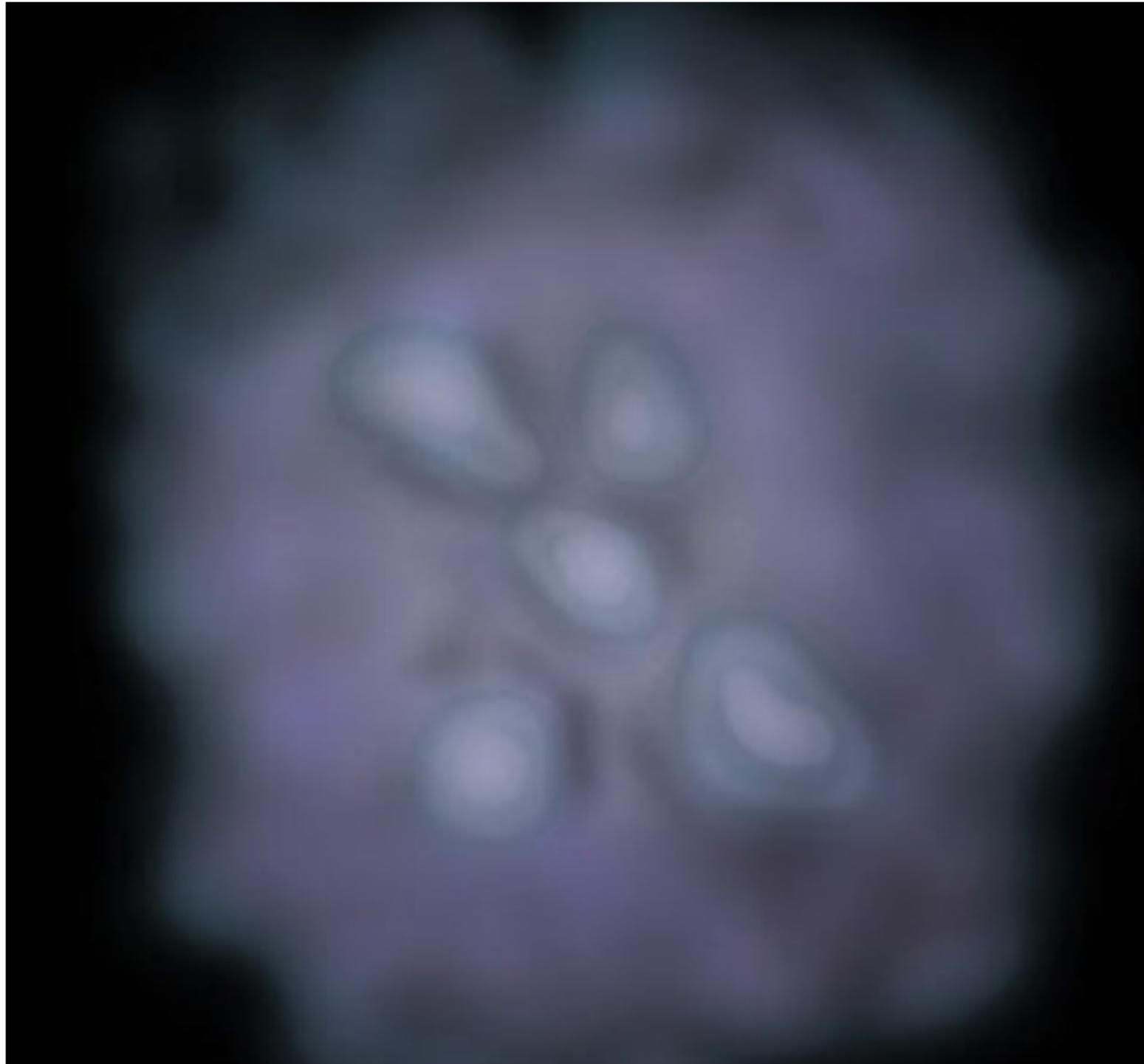


**Gaseous Pillars · M16** HST · WFPC2  
PRC95-44a · ST ScI OPO · November 2, 1995  
J. Hester and P. Scowen (AZ State Univ.), NASA

**Which region is hotter  
and which is colder?**

# What is temperature?

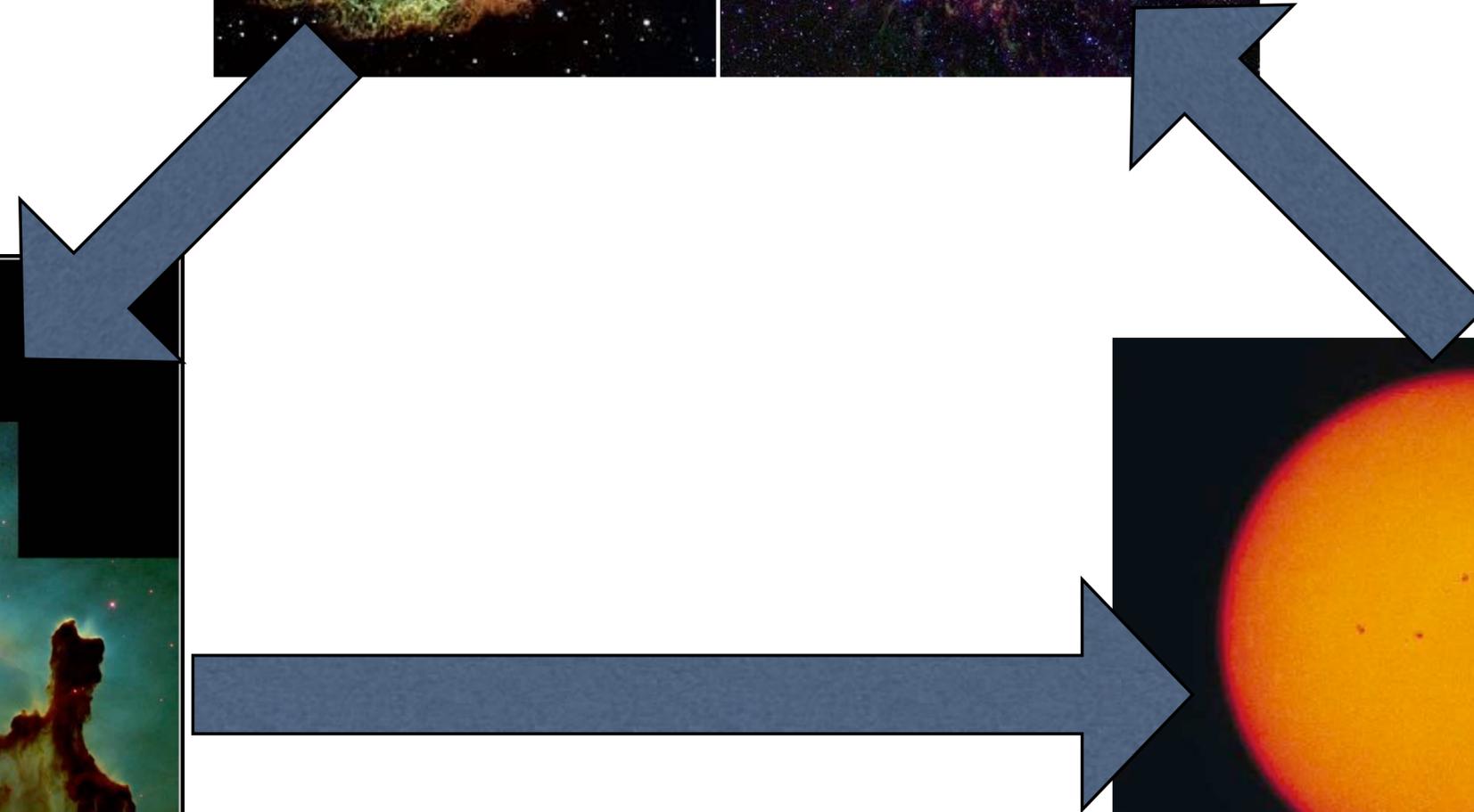
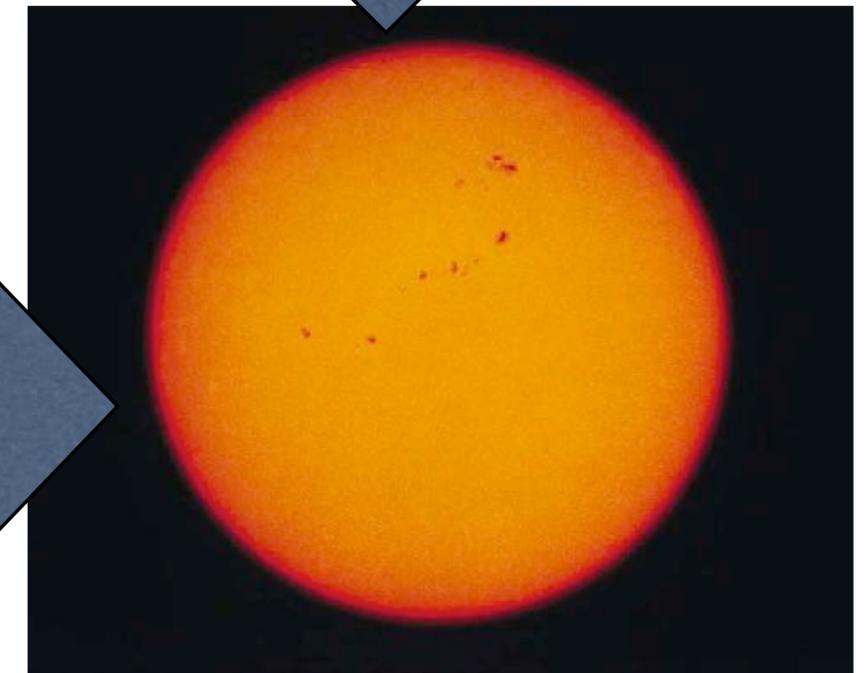
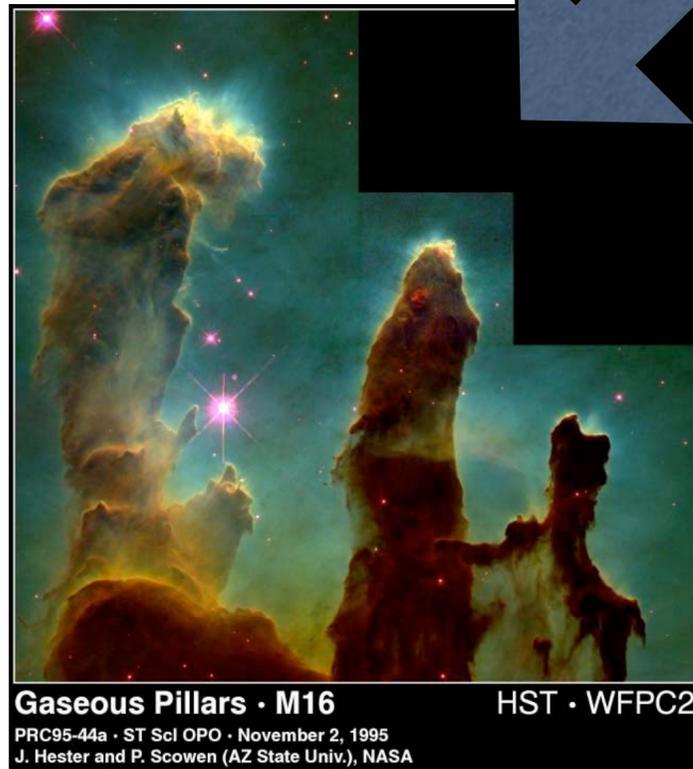
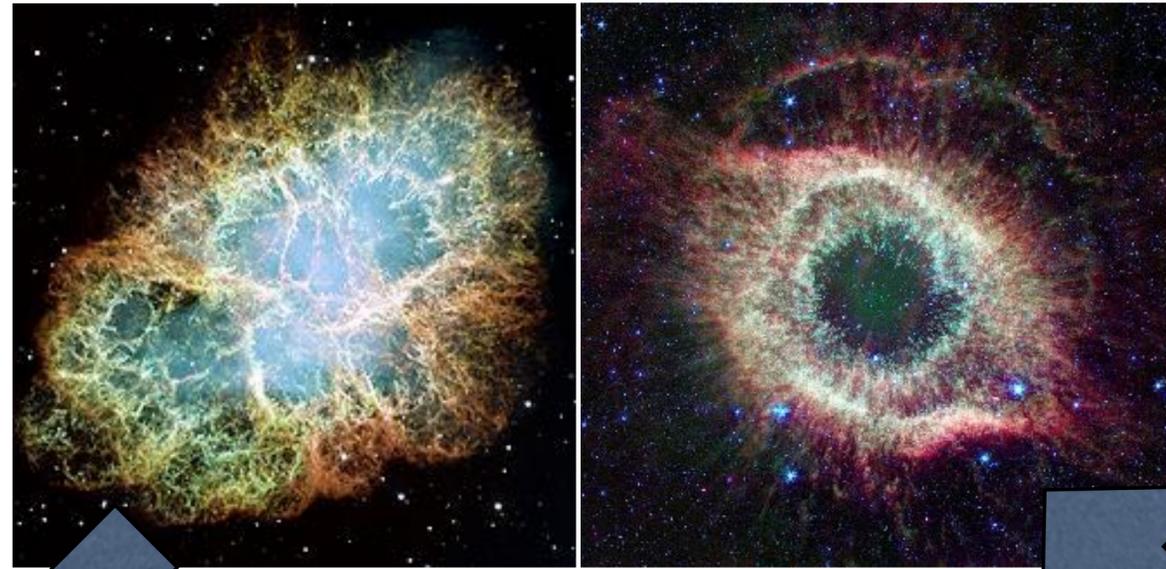




**If an interstellar cloud contracts to become a star, it is due to which force?**

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

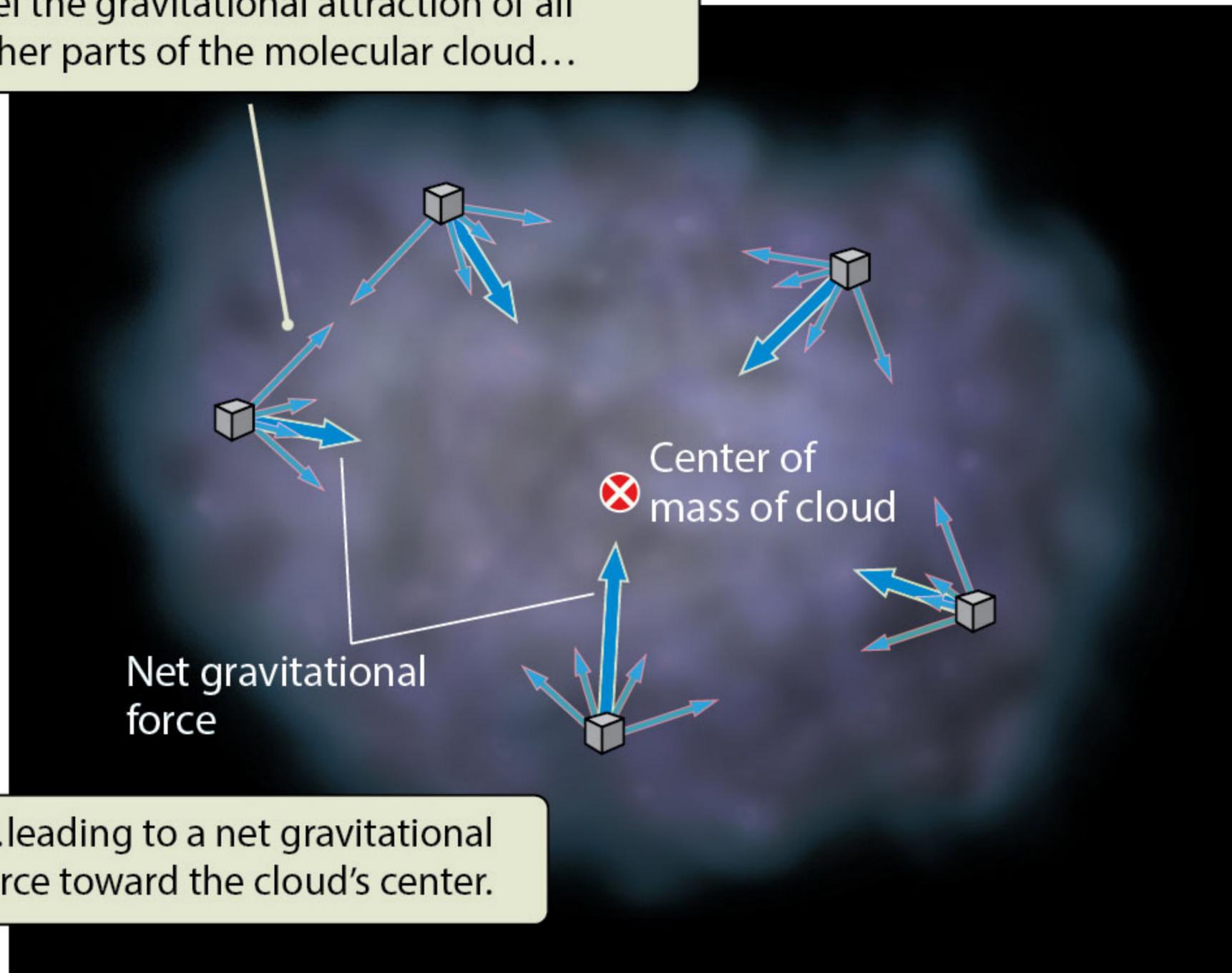
# Life Cycle of Gas and Stars



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

- A) electromagnetic**
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- C) gravitational**
- D) all of the above**

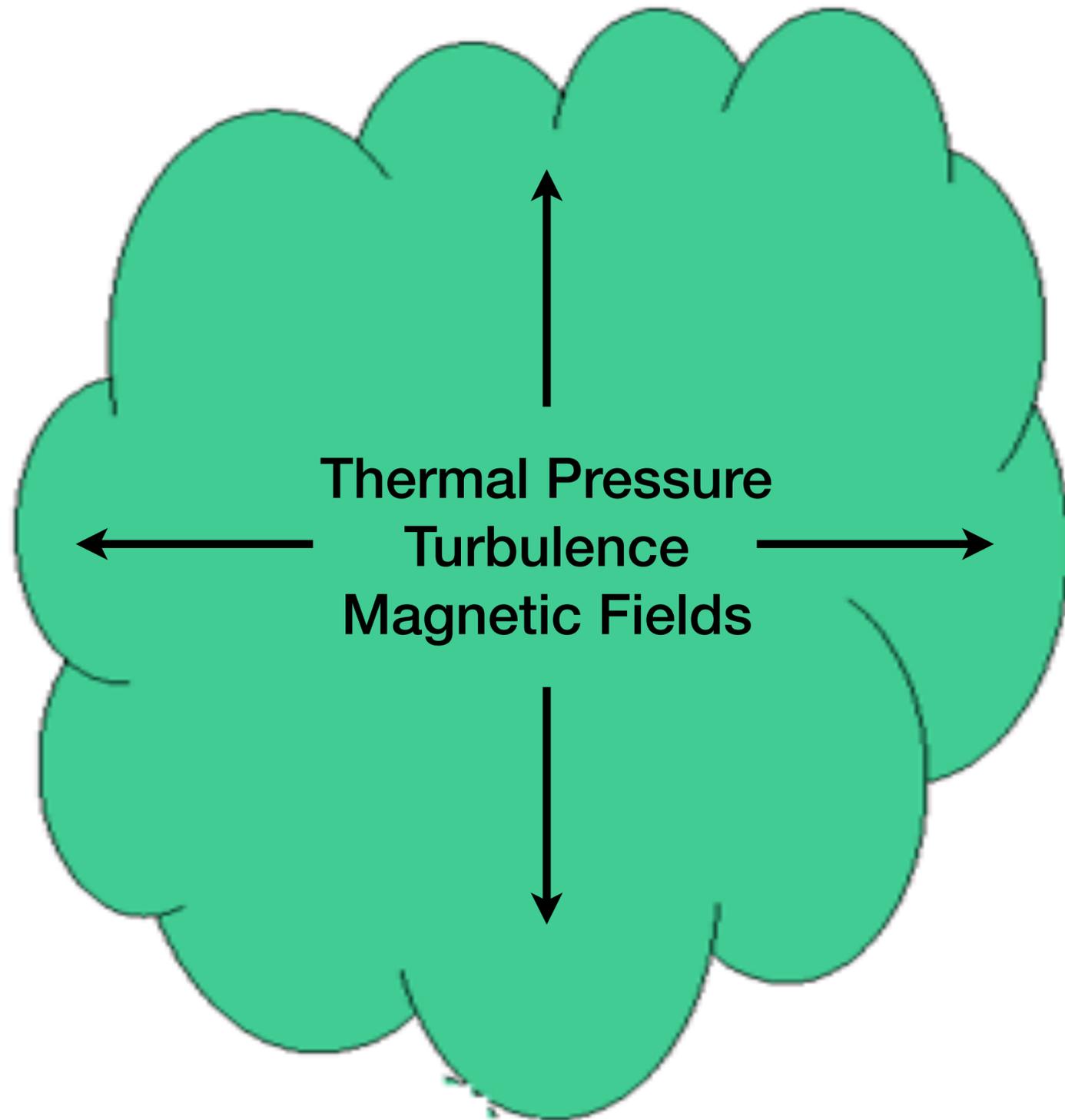
Parcels of gas within a molecular cloud feel the gravitational attraction of all other parts of the molecular cloud...



...leading to a net gravitational force toward the cloud's center.



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



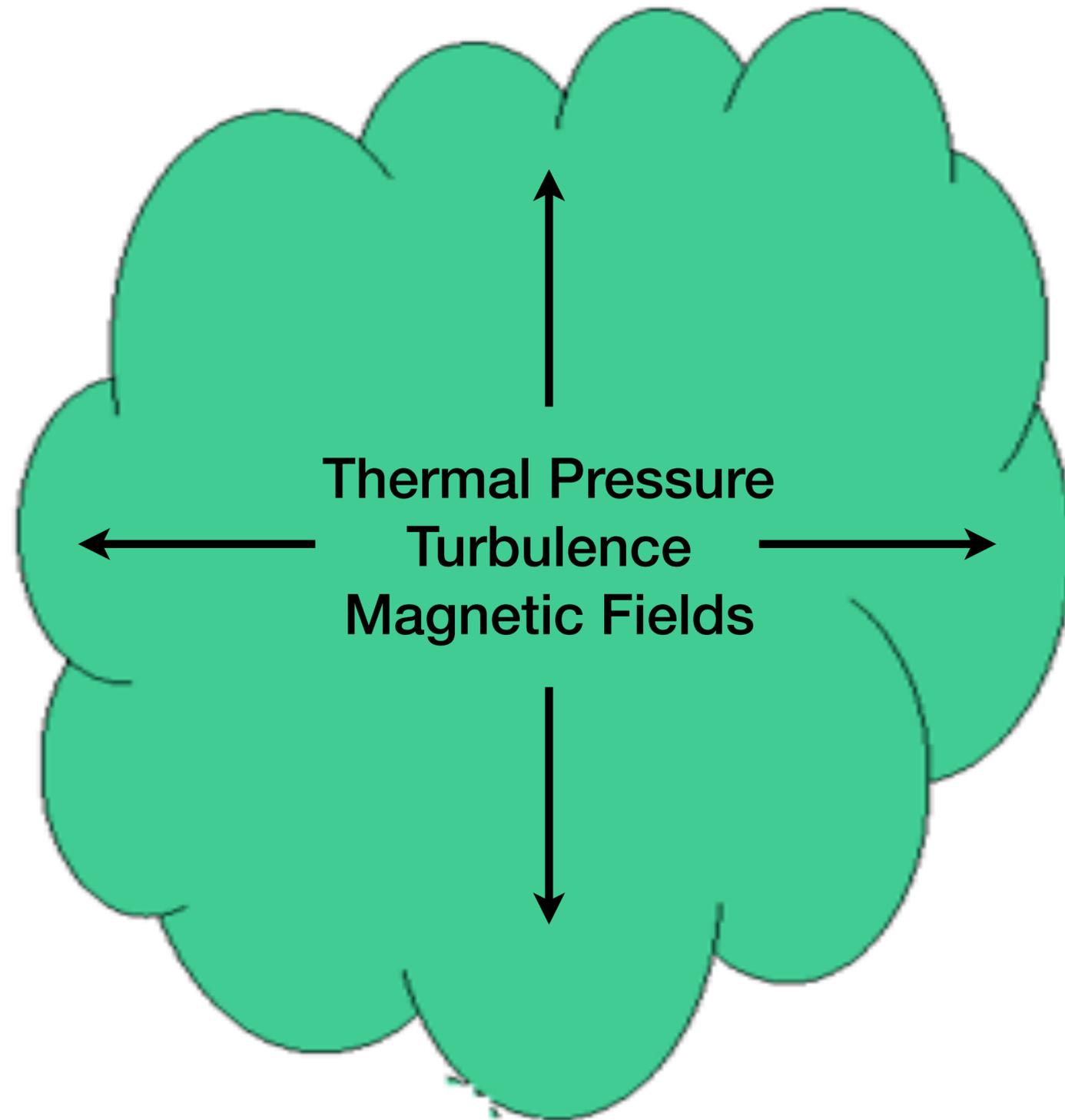
**Gravity has to overcome other forces in the cloud that want to keep it from collapsing**

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

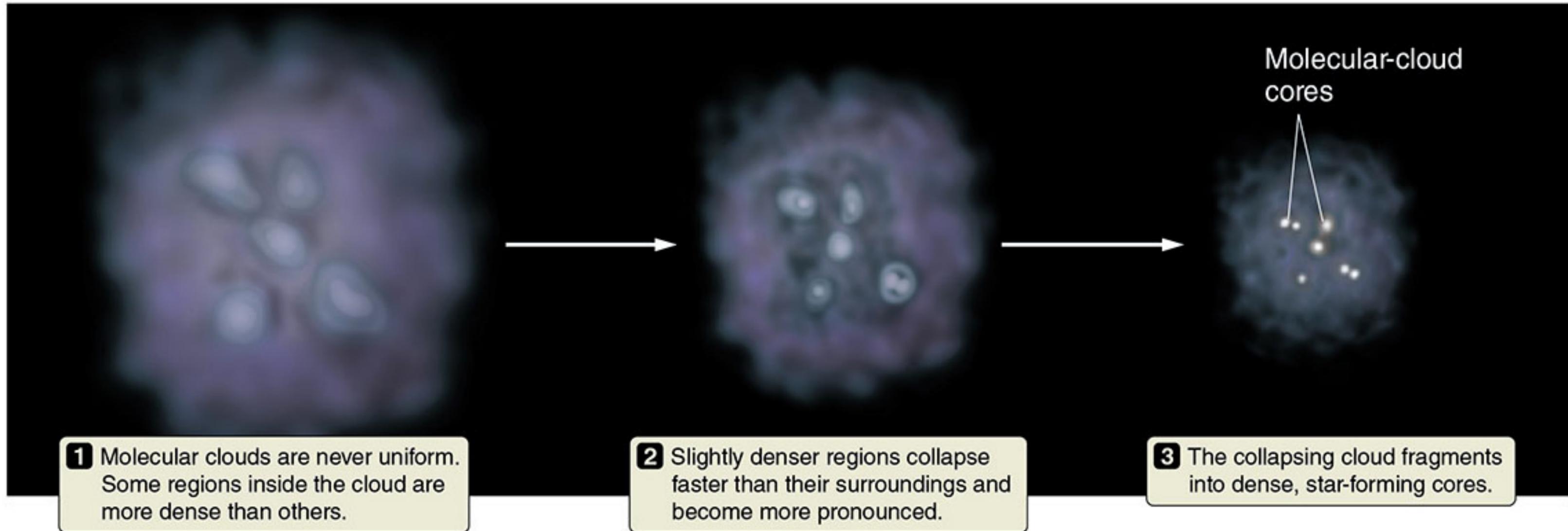
**A) Doesn't Matter**

**B) Large**

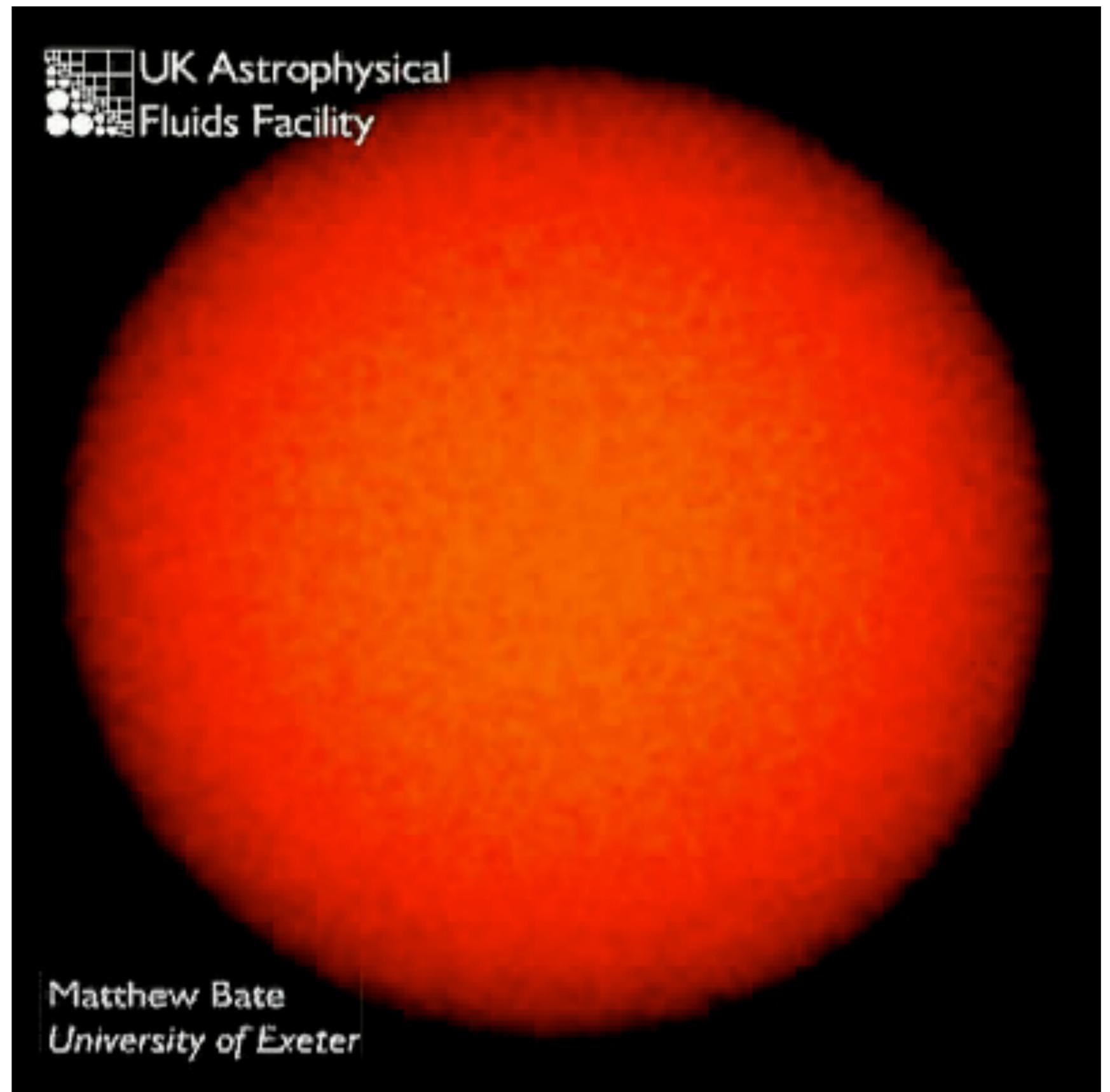
**C) Small**



# Cloud doesn't collapse uniformly

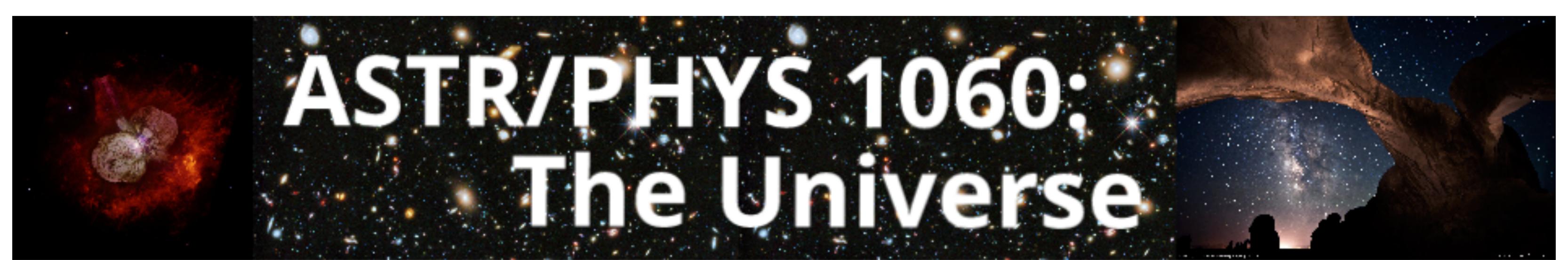


Simulation of the collapse of  
gas cloud, fragmenting,  
forming protoplanetary disks  
and low mass stars



UK Astrophysical  
Fluids Facility

Matthew Bate  
*University of Exeter*



# ASTR/PHYS 1060: The Universe

## Ch. 5: Formation of Stars/Planets

Midterm 1 on Sept. 19th (this Thursday)  
will cover Chapters 1-5 and lecture material  
HW up front!

I will try to provide a study guide today (link sent out via Canvas)

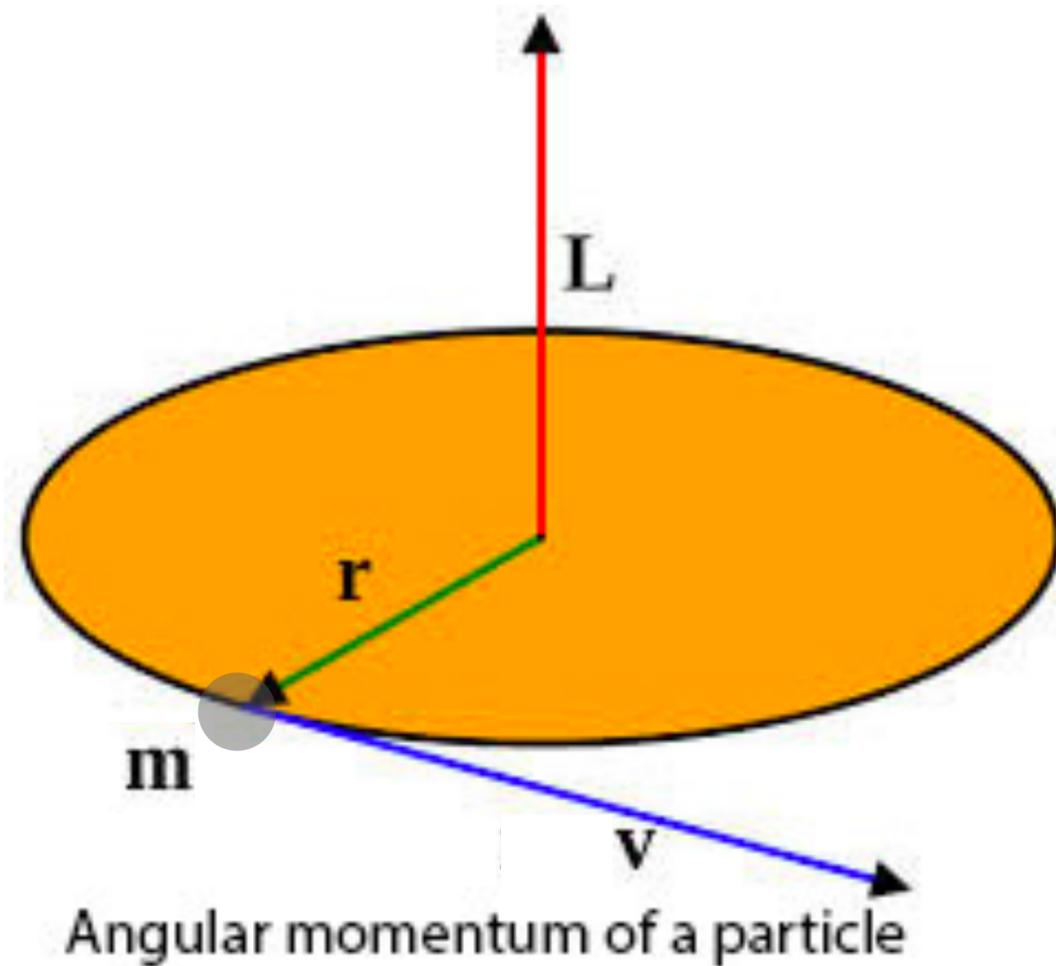
Mirna will host a review session  
Also, her office hours: Tues 11am-1pm & Wed 3-4pm

Are your grades in Canvas correct???

# Conservation of “Angular Momentum”

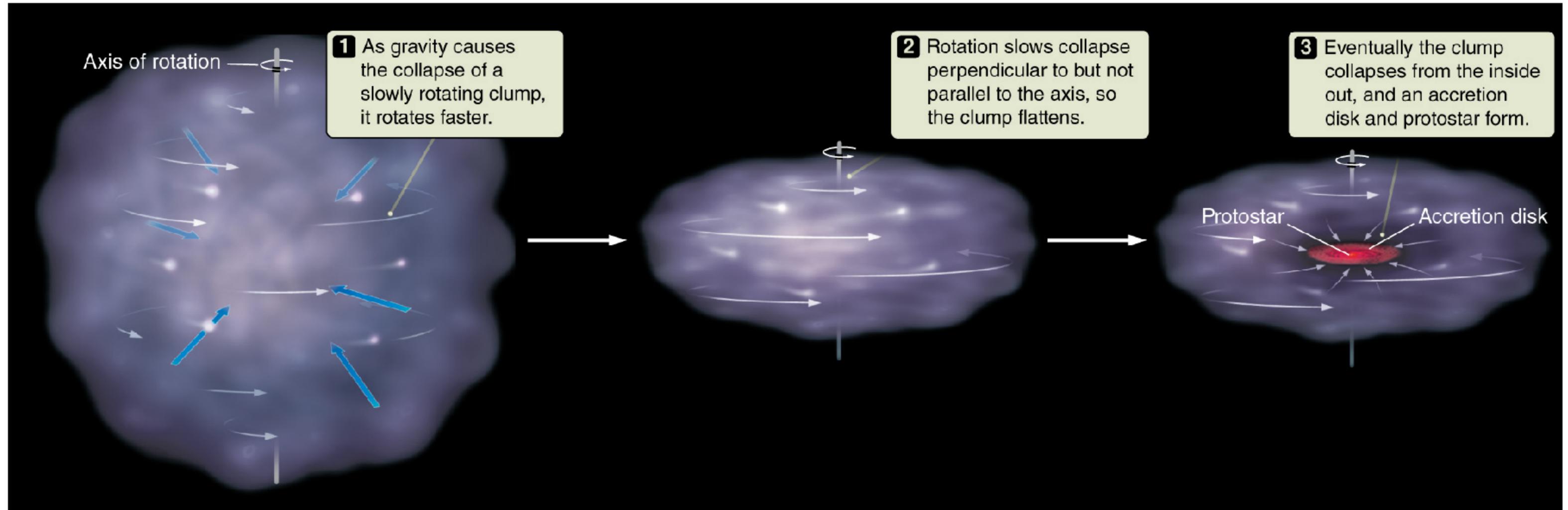


# Angular Momentum



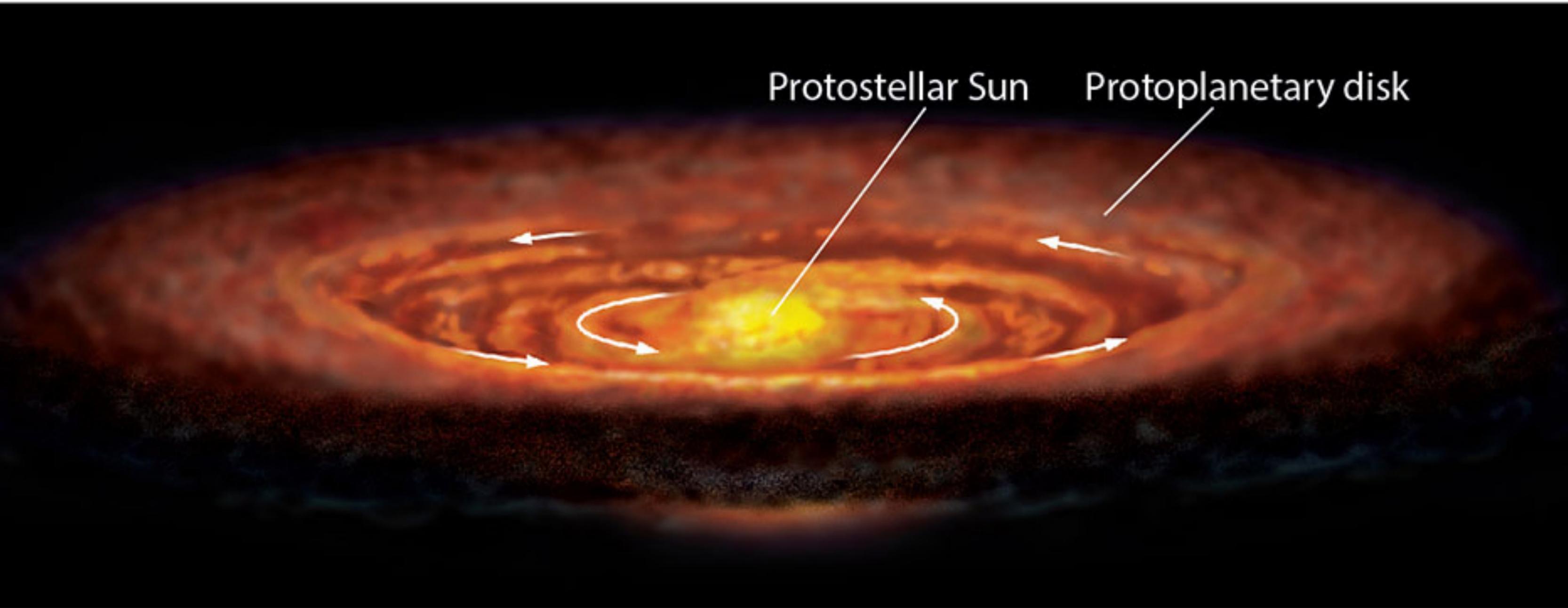
- $L = m v r$
- $L$  is angular momentum
- $m$  is mass
- $v$  is velocity
- $r$  is radius

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

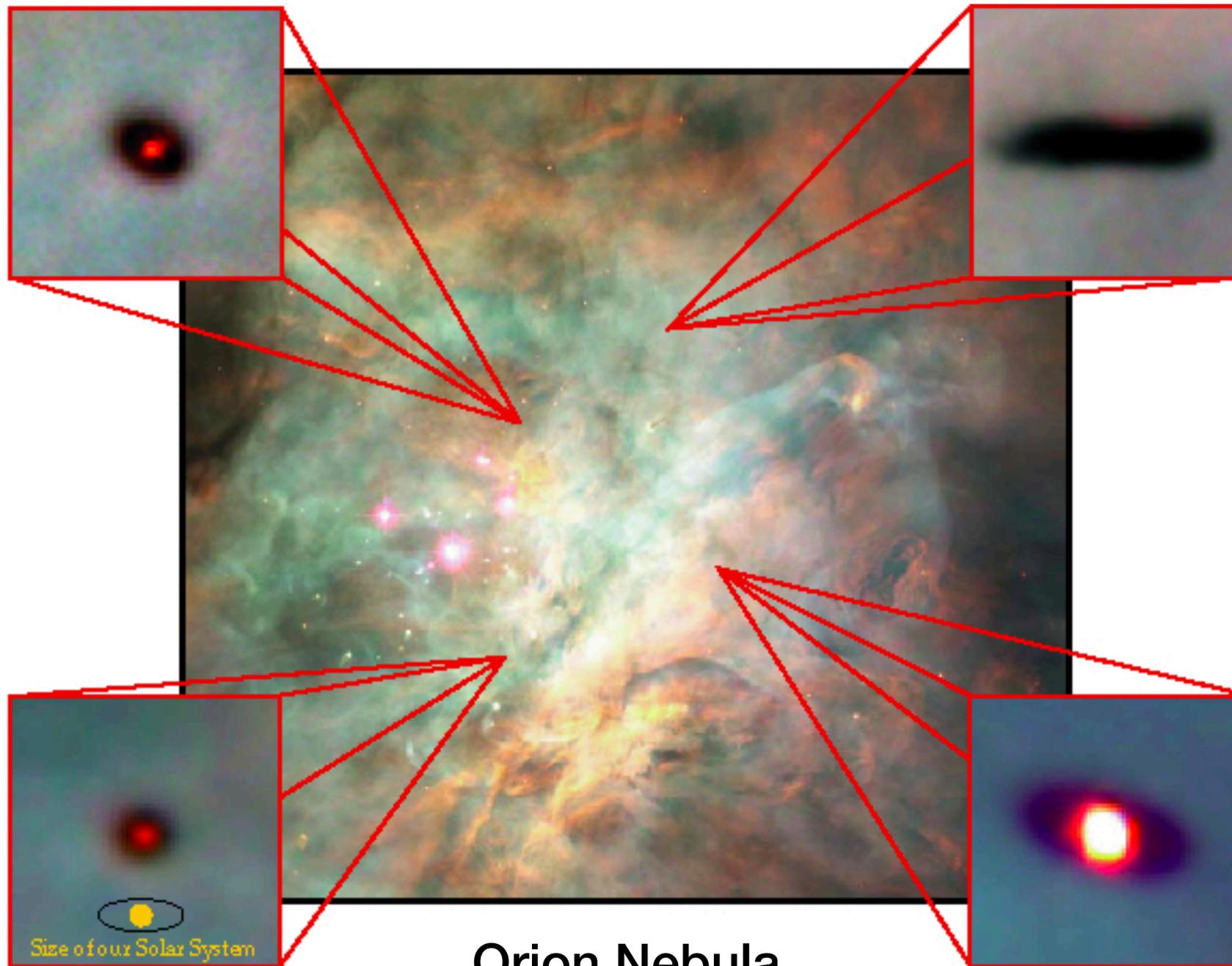




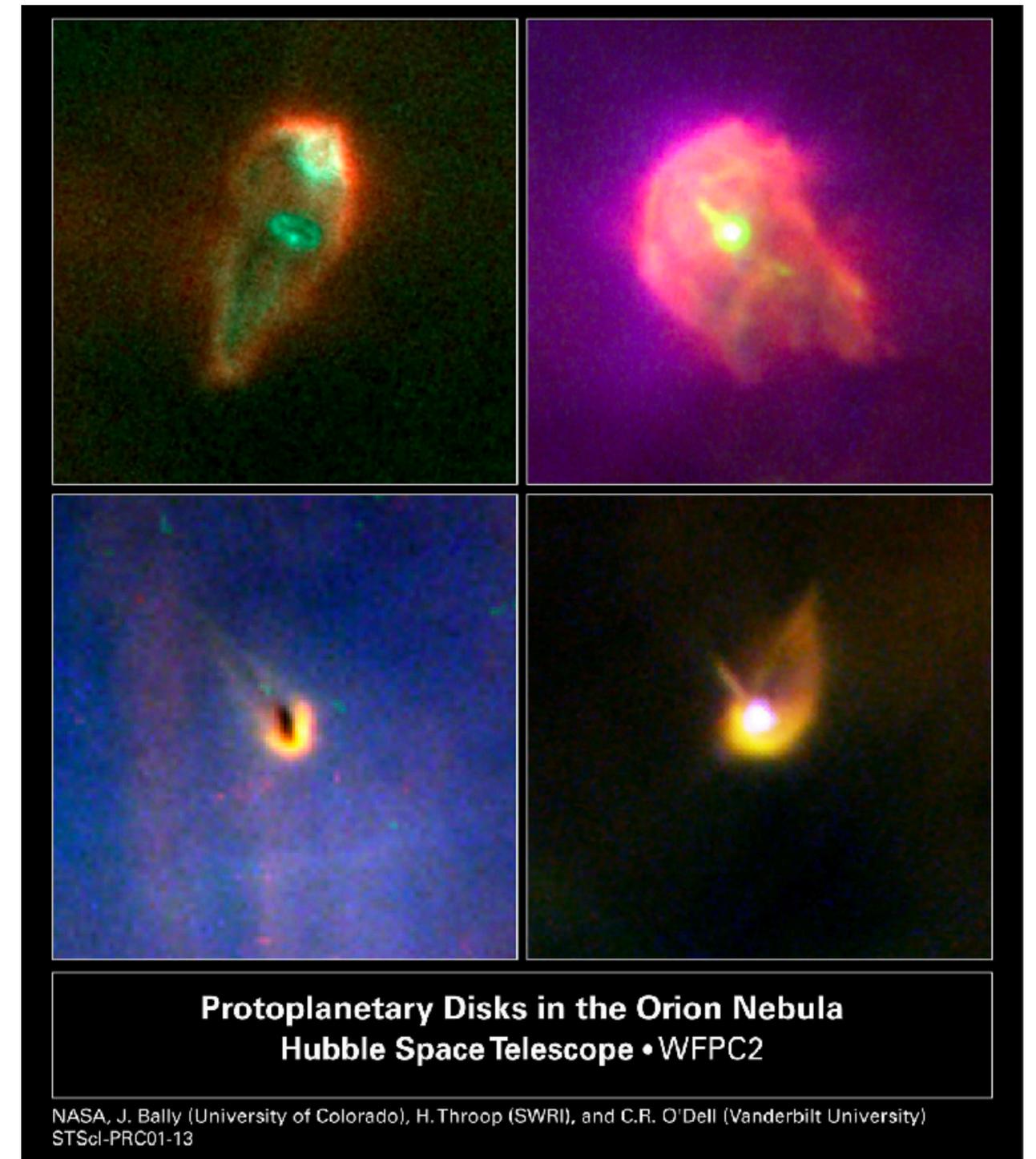
# Protoplanetary Disk



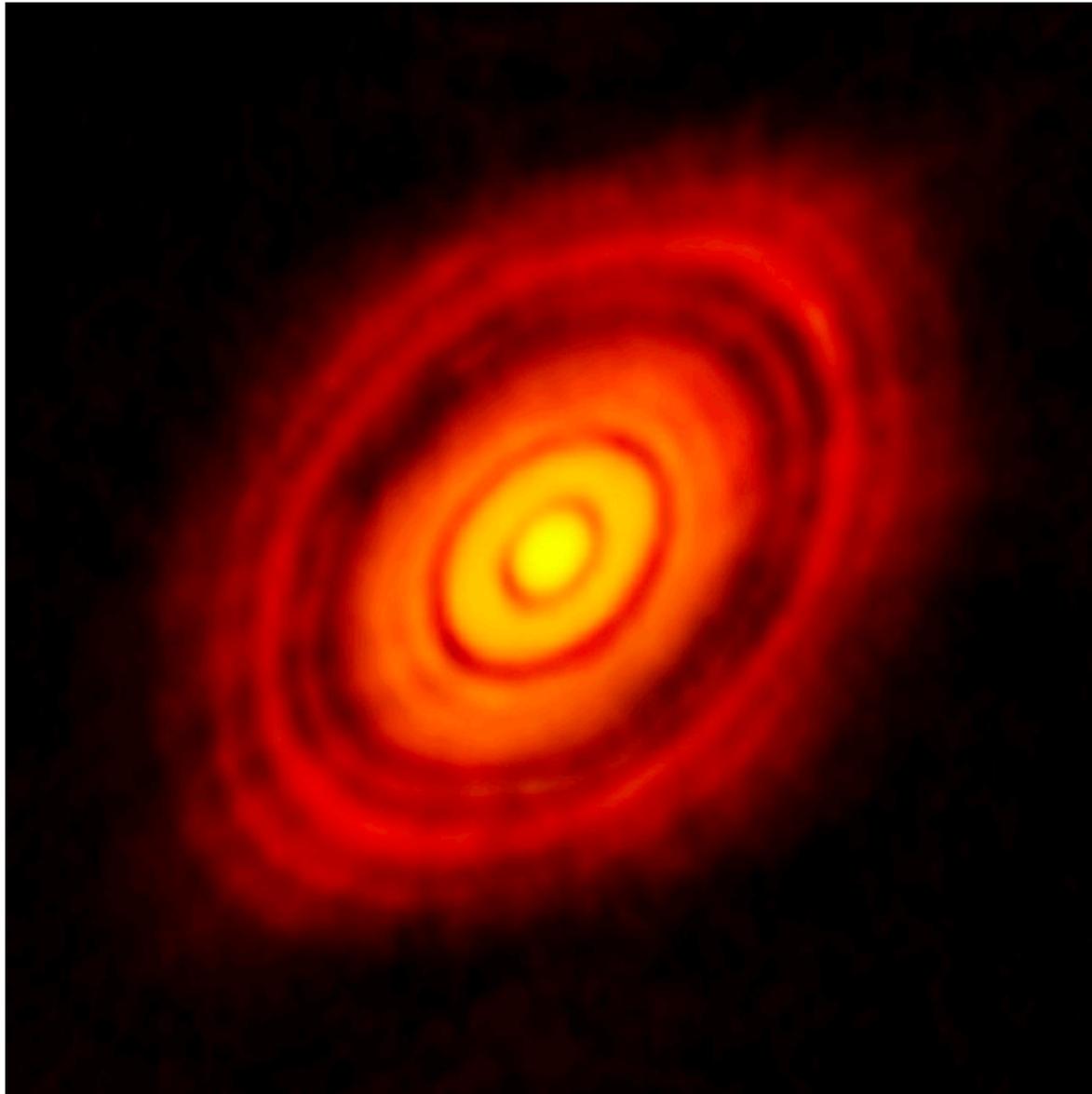
# Observations of Disks



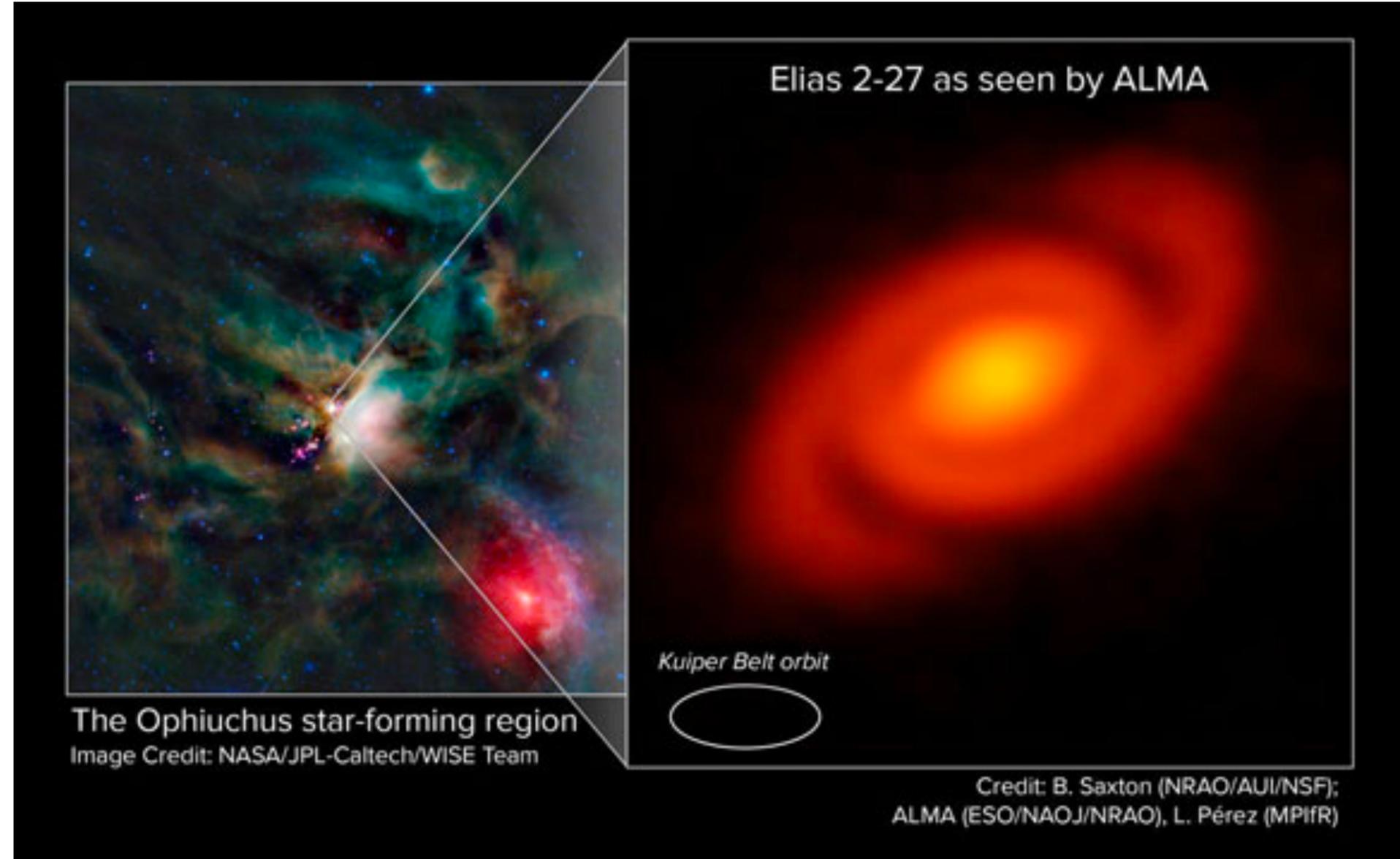
Orion Nebula  
old Hubble Telescope data (visual)



# Observations of Disks



HL Tauri  
ALMA (radio)

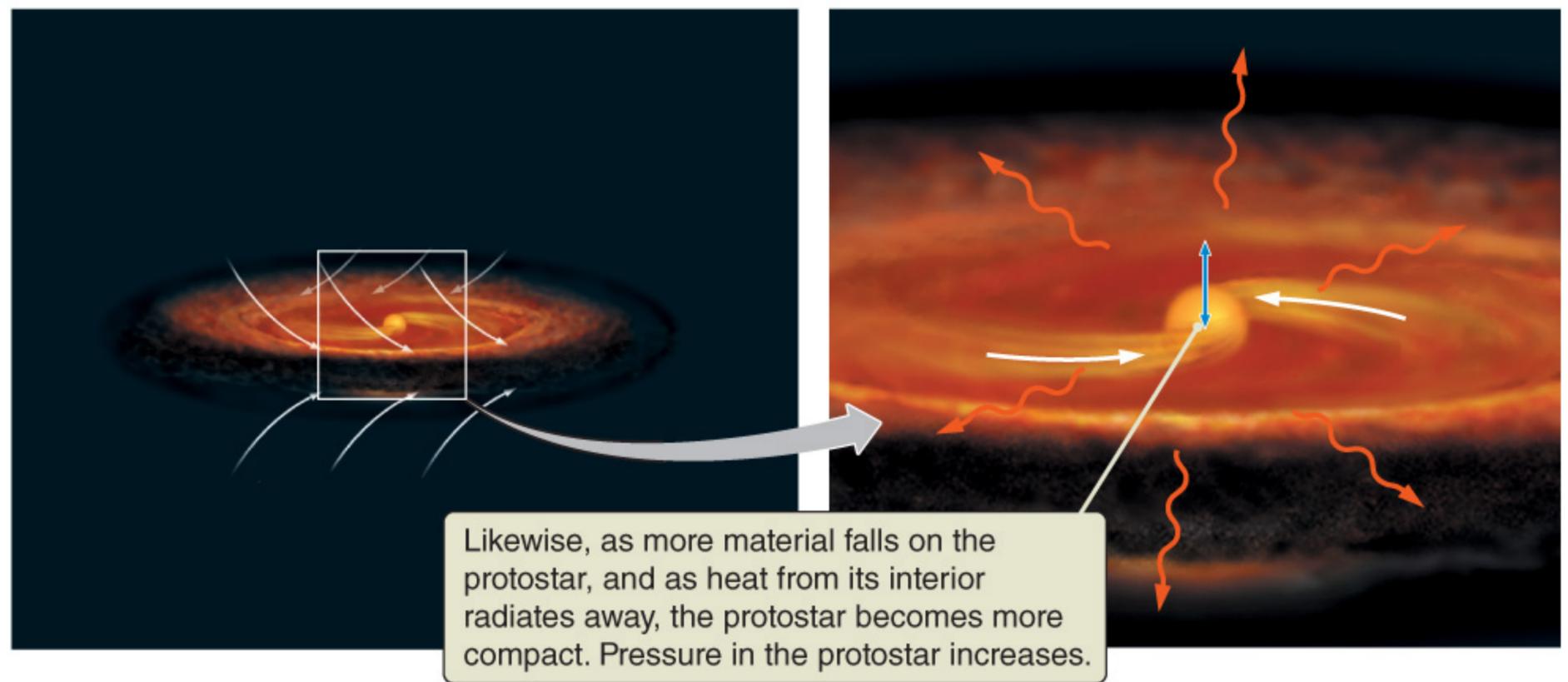
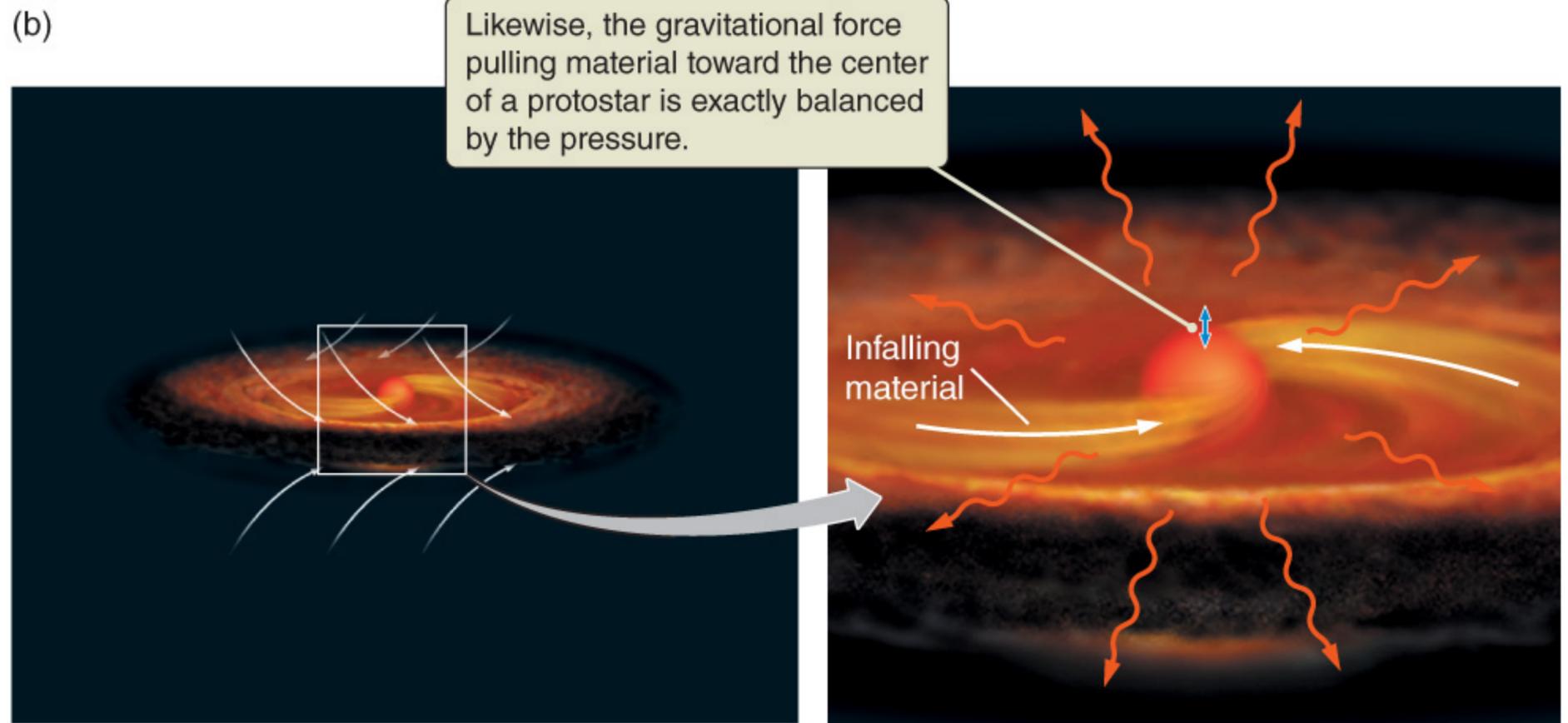
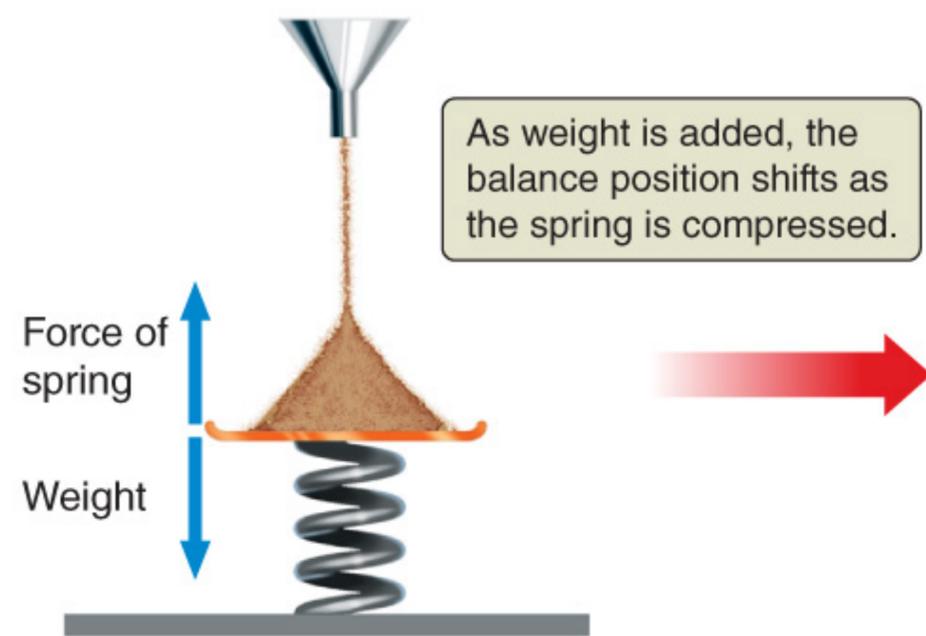
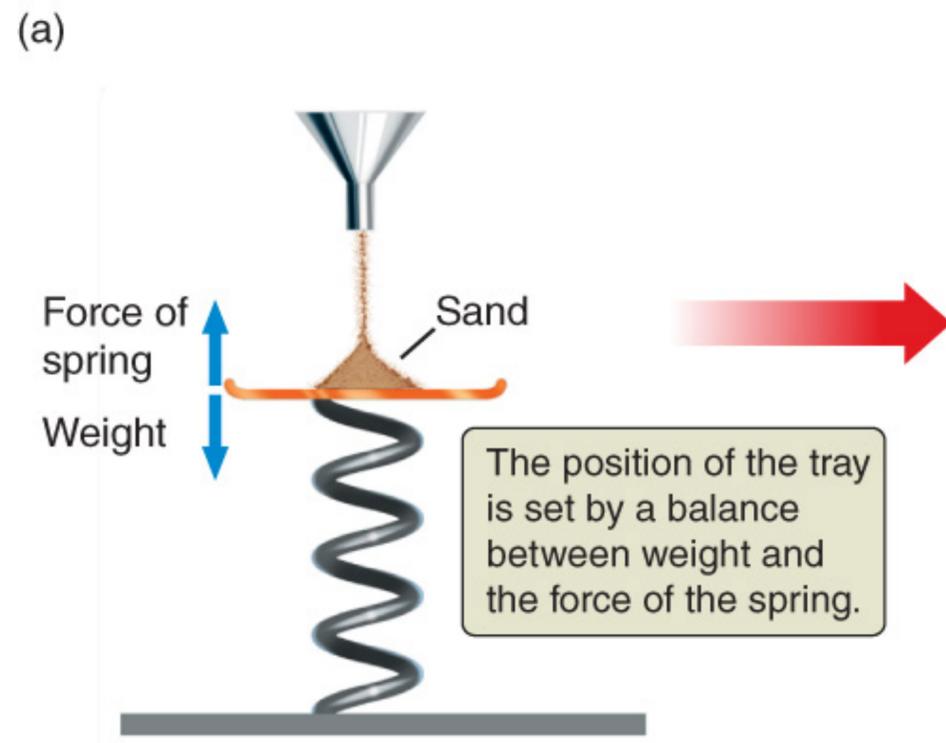


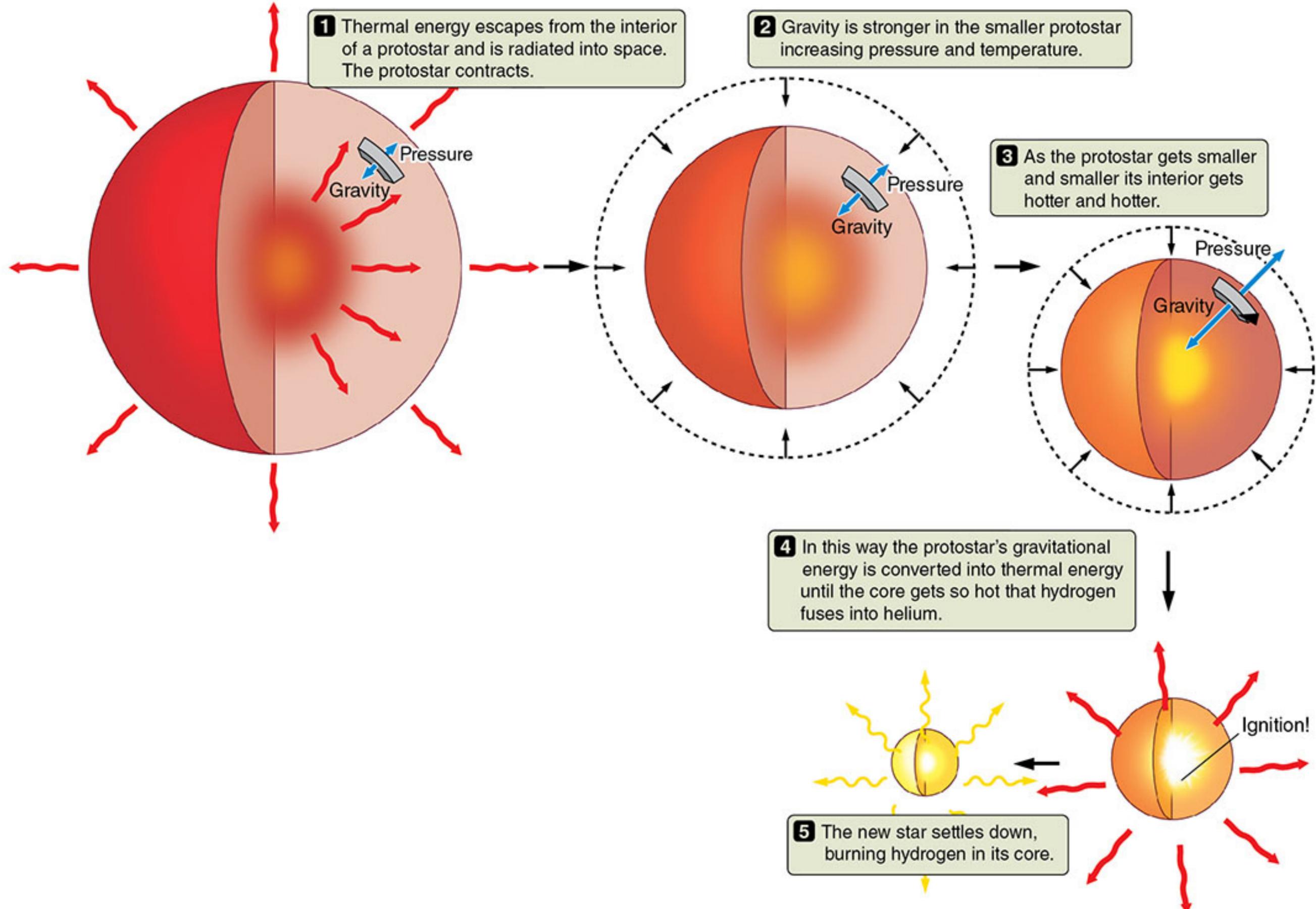
WISE (infrared)

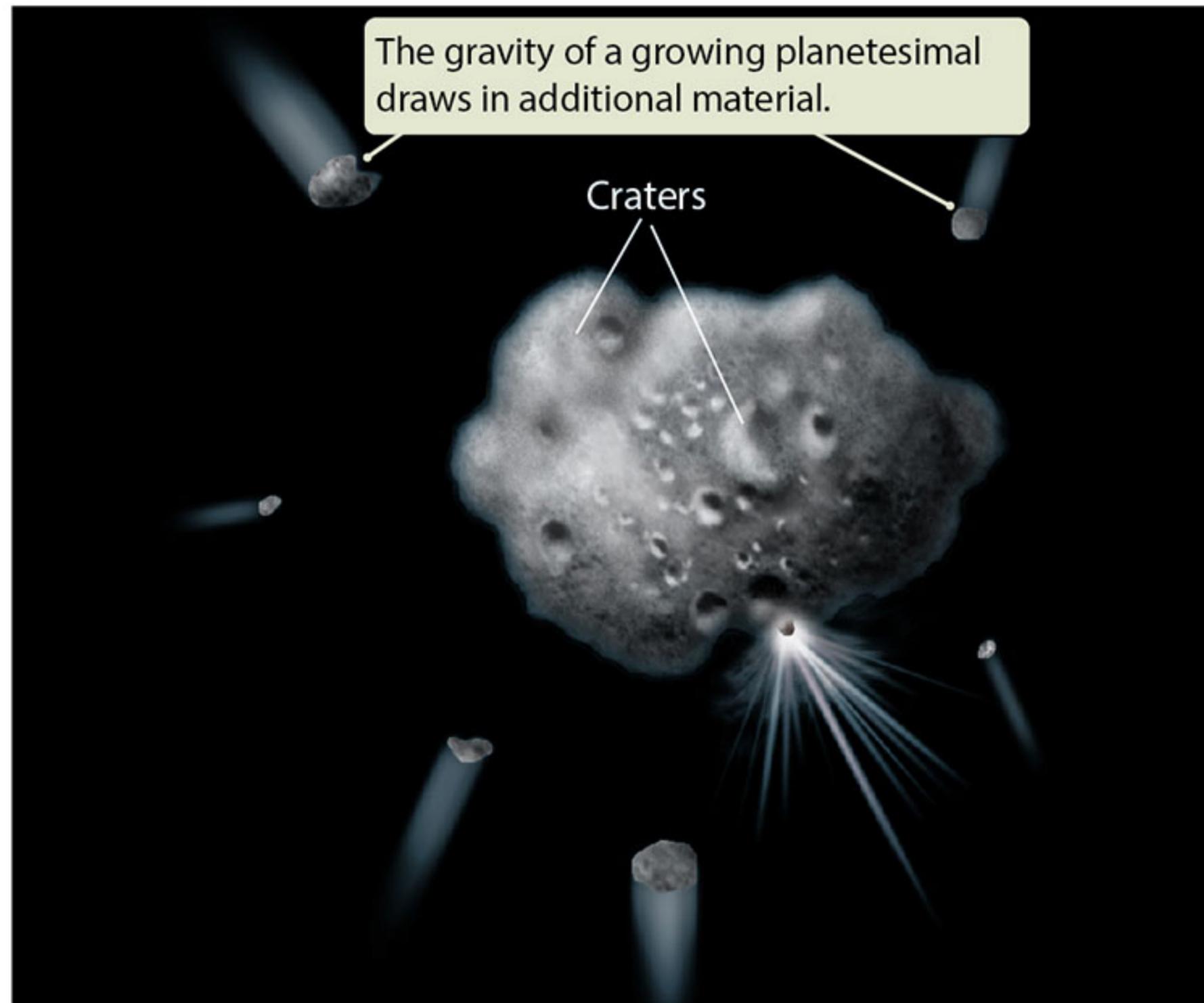
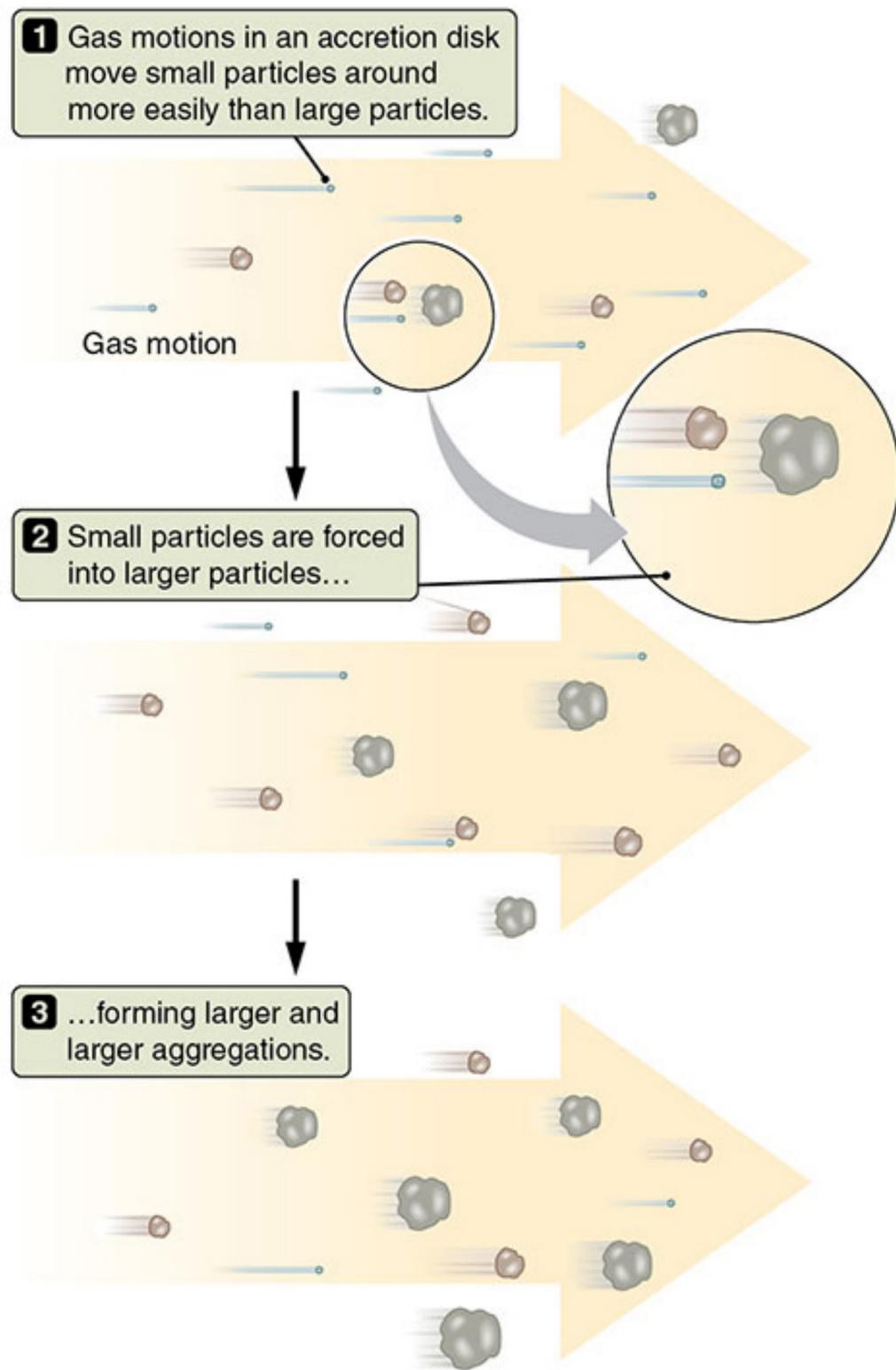
ALMA (radio)

# Computer Simulations of Protoplanetary Disks

<https://www.youtube.com/watch?v=yXq1i3HlumA&feature=youtu.be>

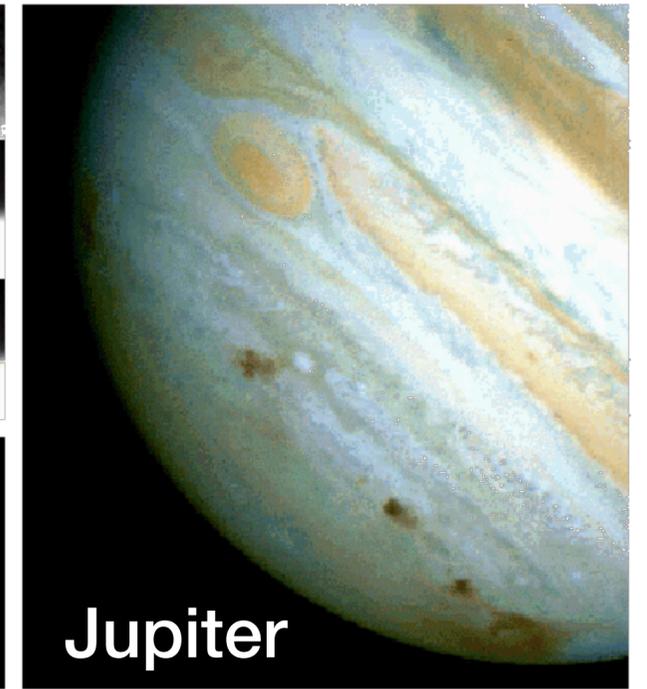
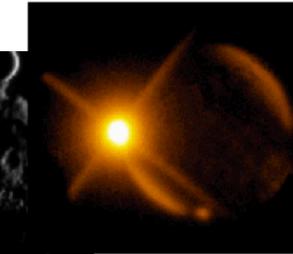
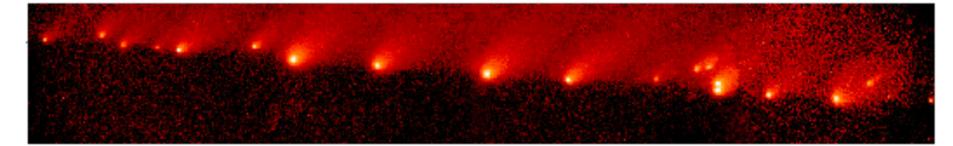




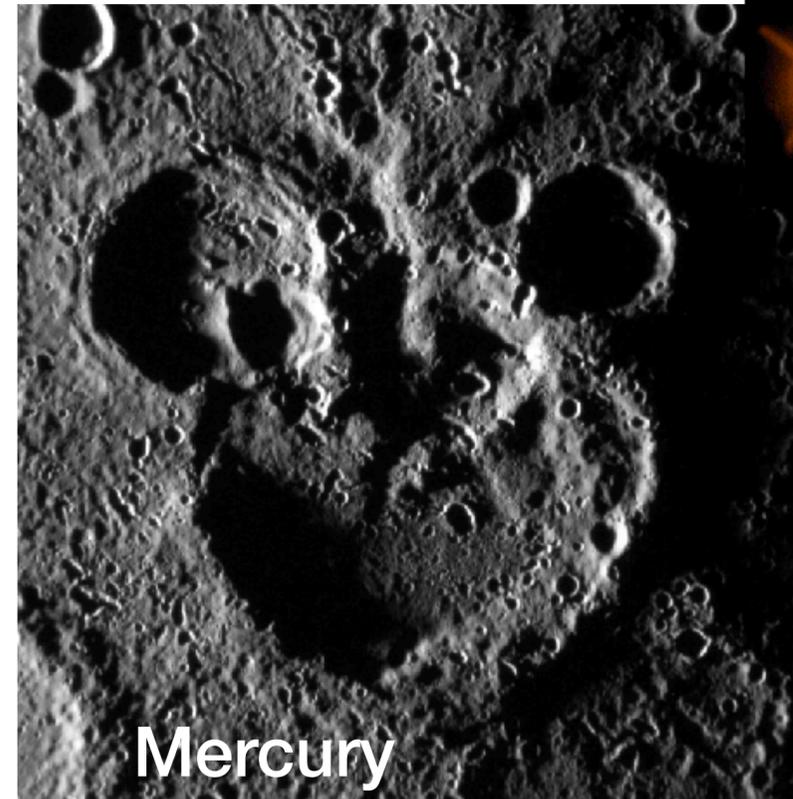
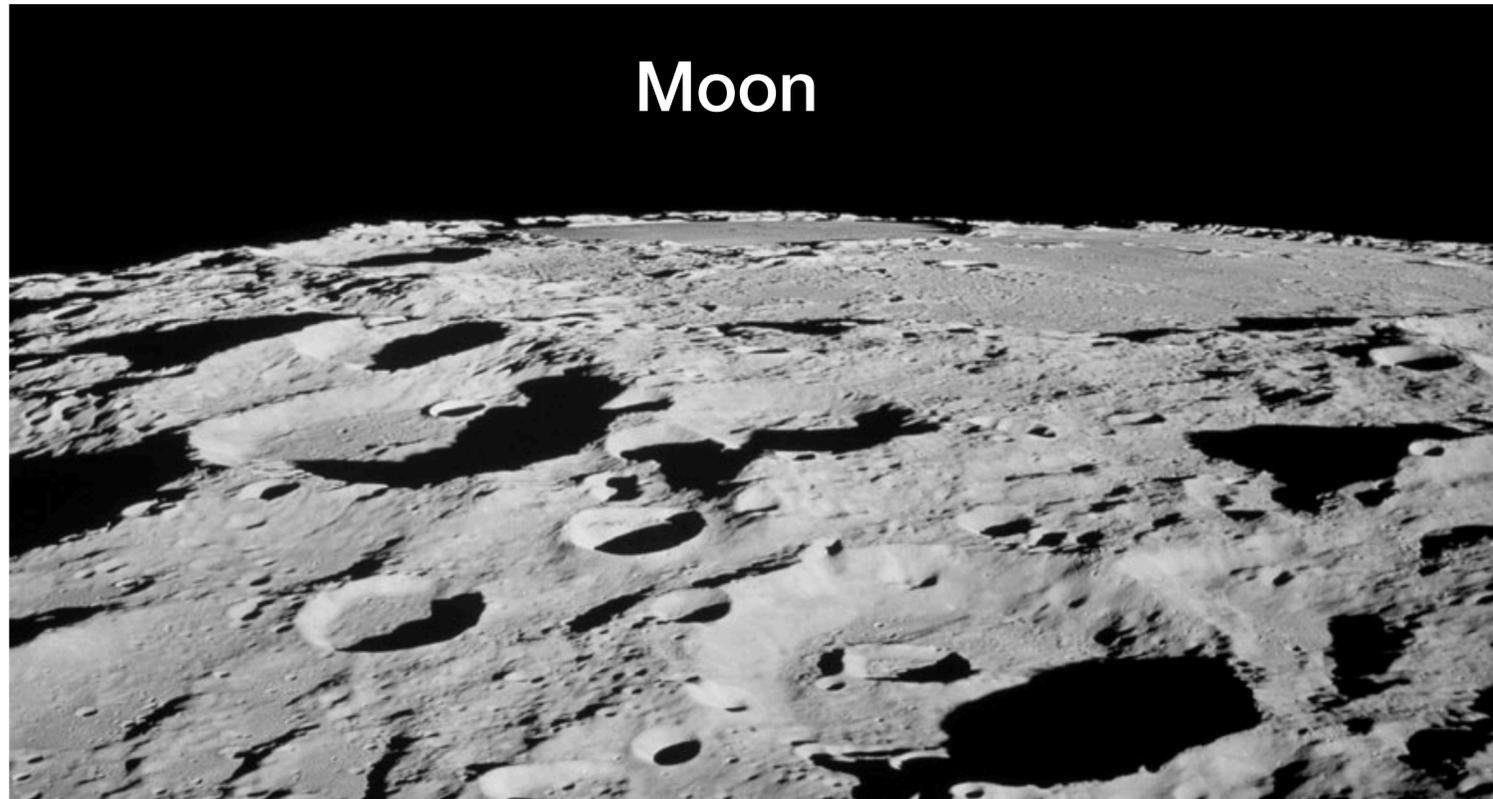


# Evidence of impacts are everywhere!

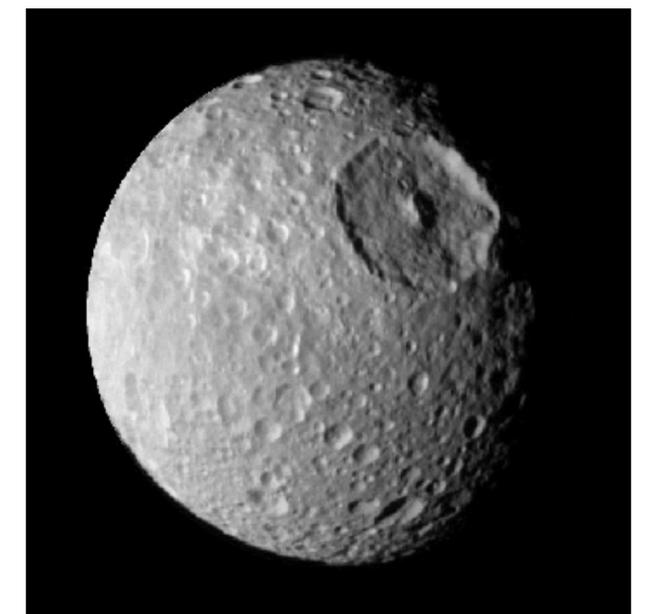
Earth  
(Meteor Crater)



Moon



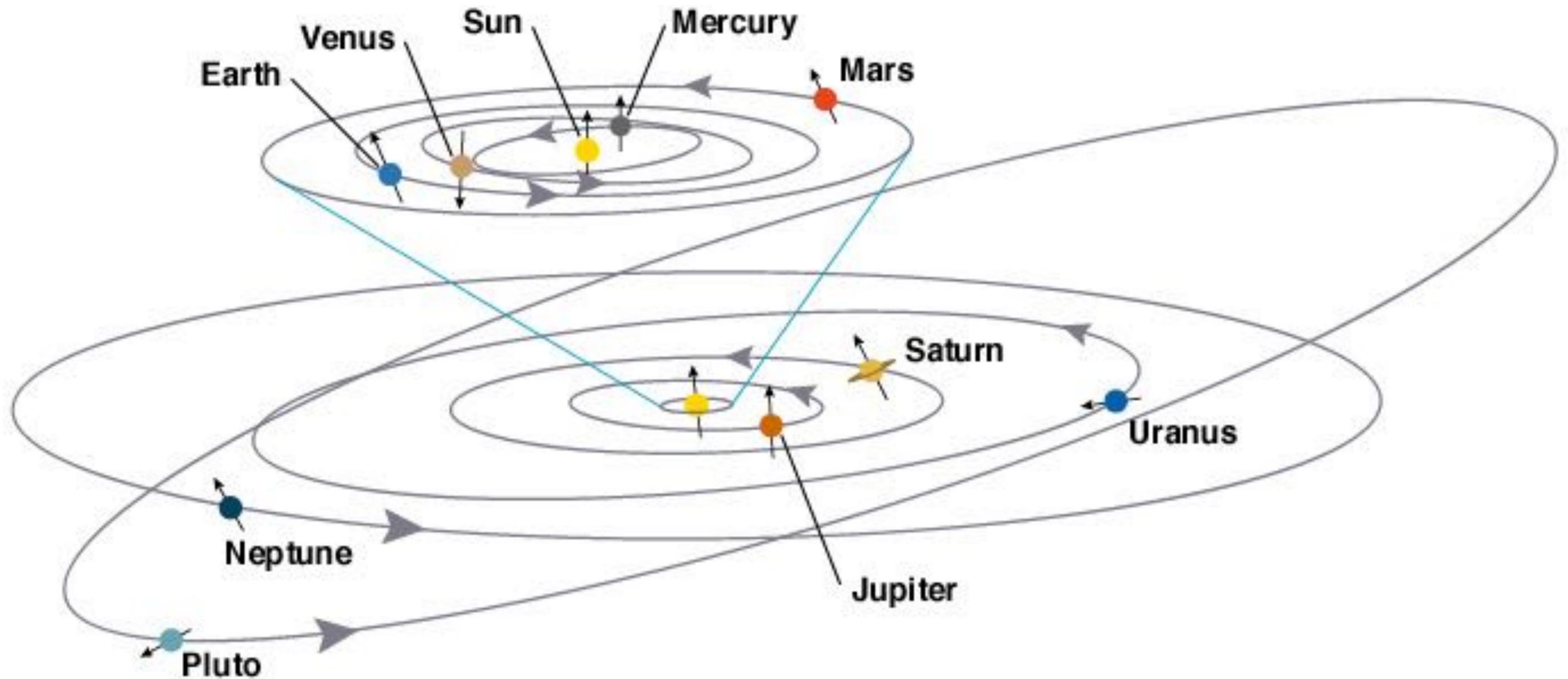
Mercury



Mimas (Saturn)



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

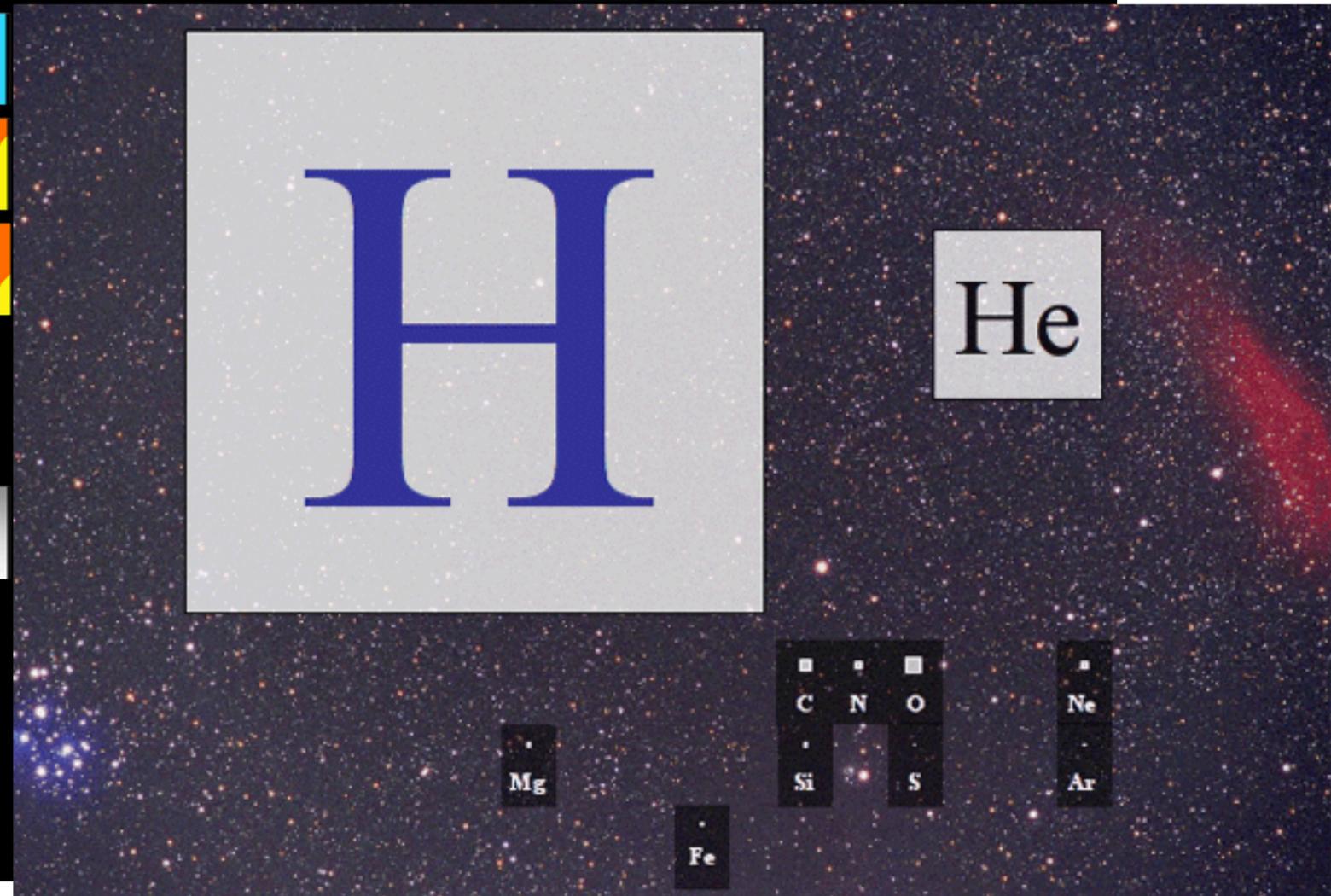


Copyright © Addison Wesley

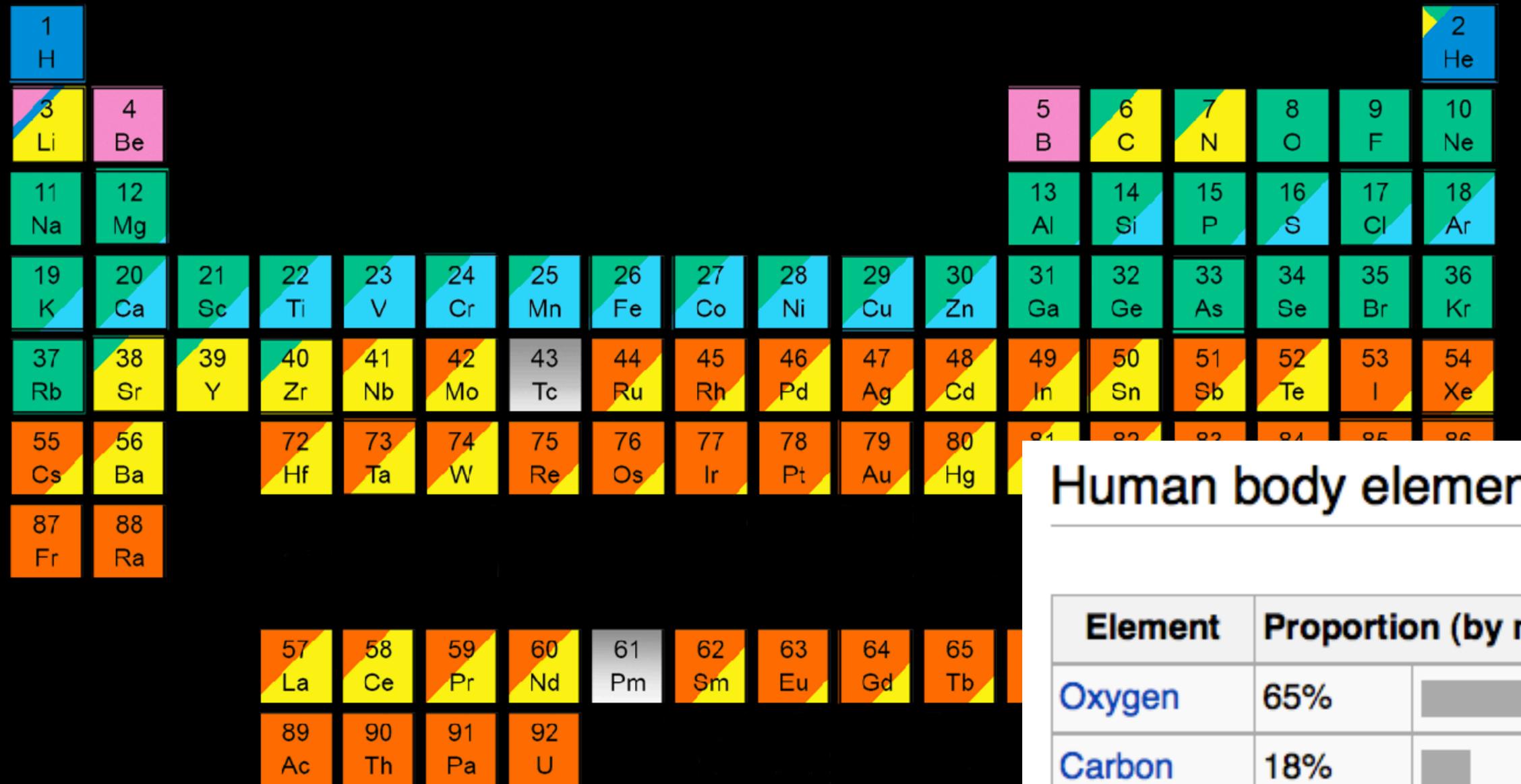
# The Origin of the Solar System Elements

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



# The Origin of the Solar System Elements



## Human body elemental abundance

Element	Proportion (by mass)	
Oxygen	65%	<div style="width: 65%; background-color: gray;"></div>
Carbon	18%	<div style="width: 18%; background-color: gray;"></div>
Hydrogen	10%	<div style="width: 10%; background-color: gray;"></div>
Nitrogen	3%	<div style="width: 3%; background-color: gray;"></div>

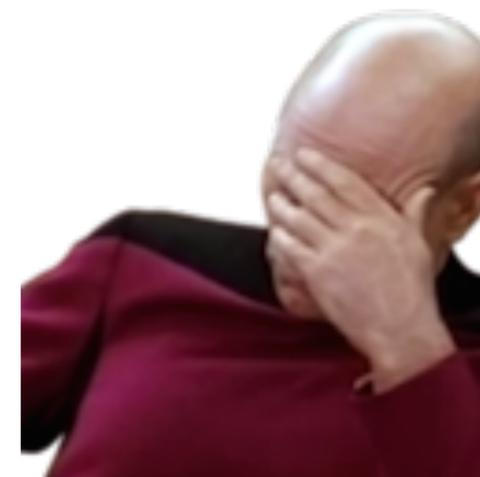
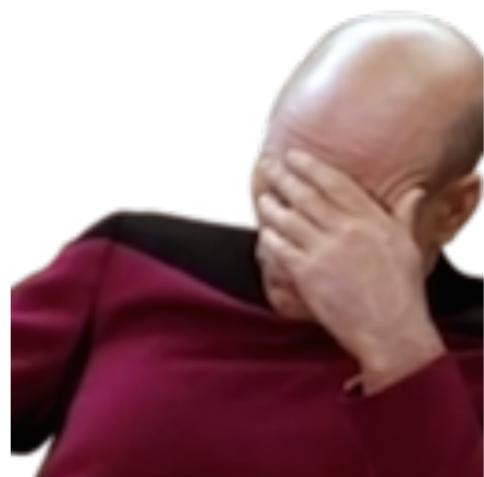
Graphic created by Jennifer Johnson

# Almost correct observation in Sci Fi

[https://www.youtube.com/watch?v=LAlqp0\\_a0tE](https://www.youtube.com/watch?v=LAlqp0_a0tE)

# Almost correct observation in Sci Fi

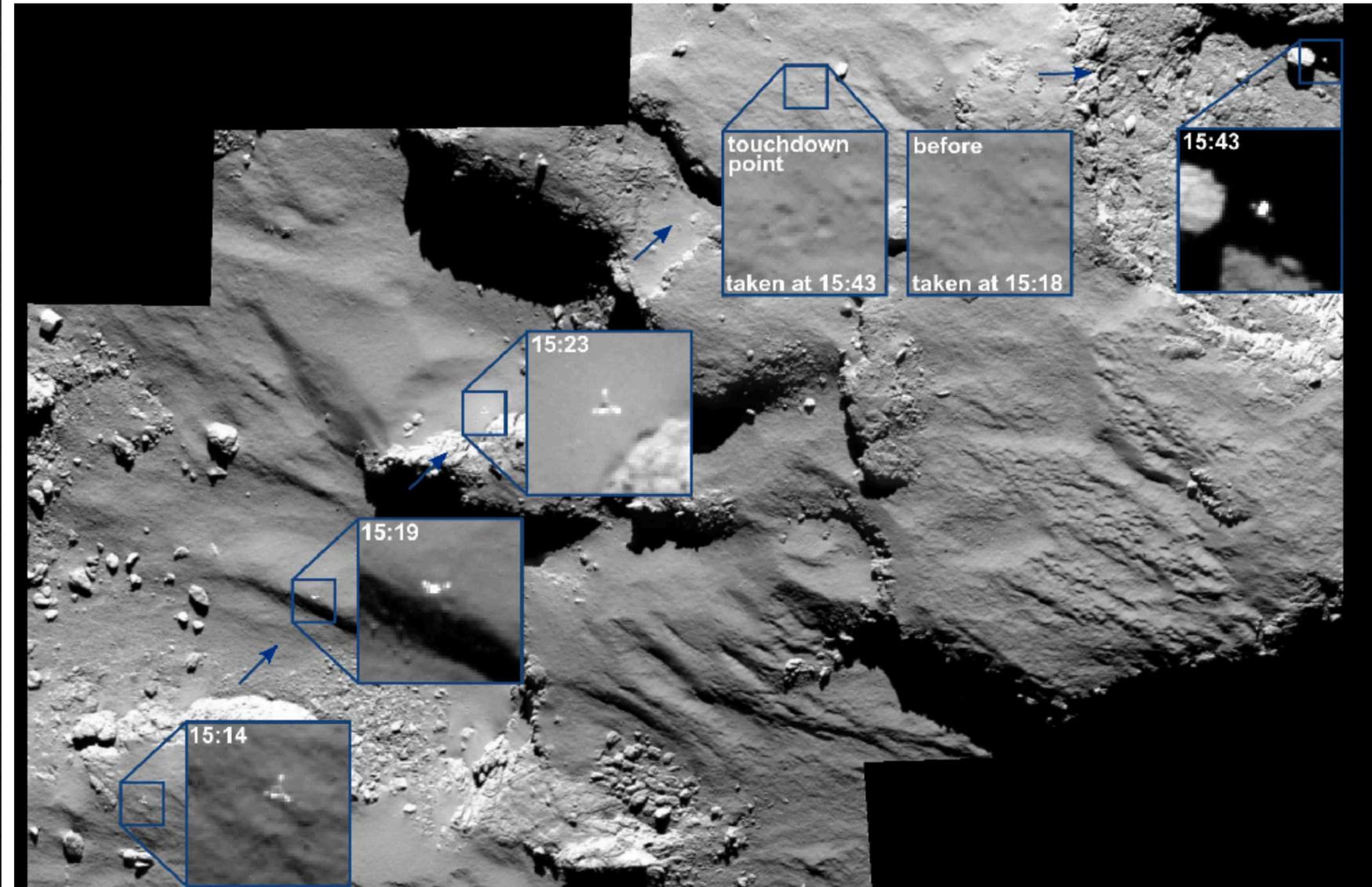
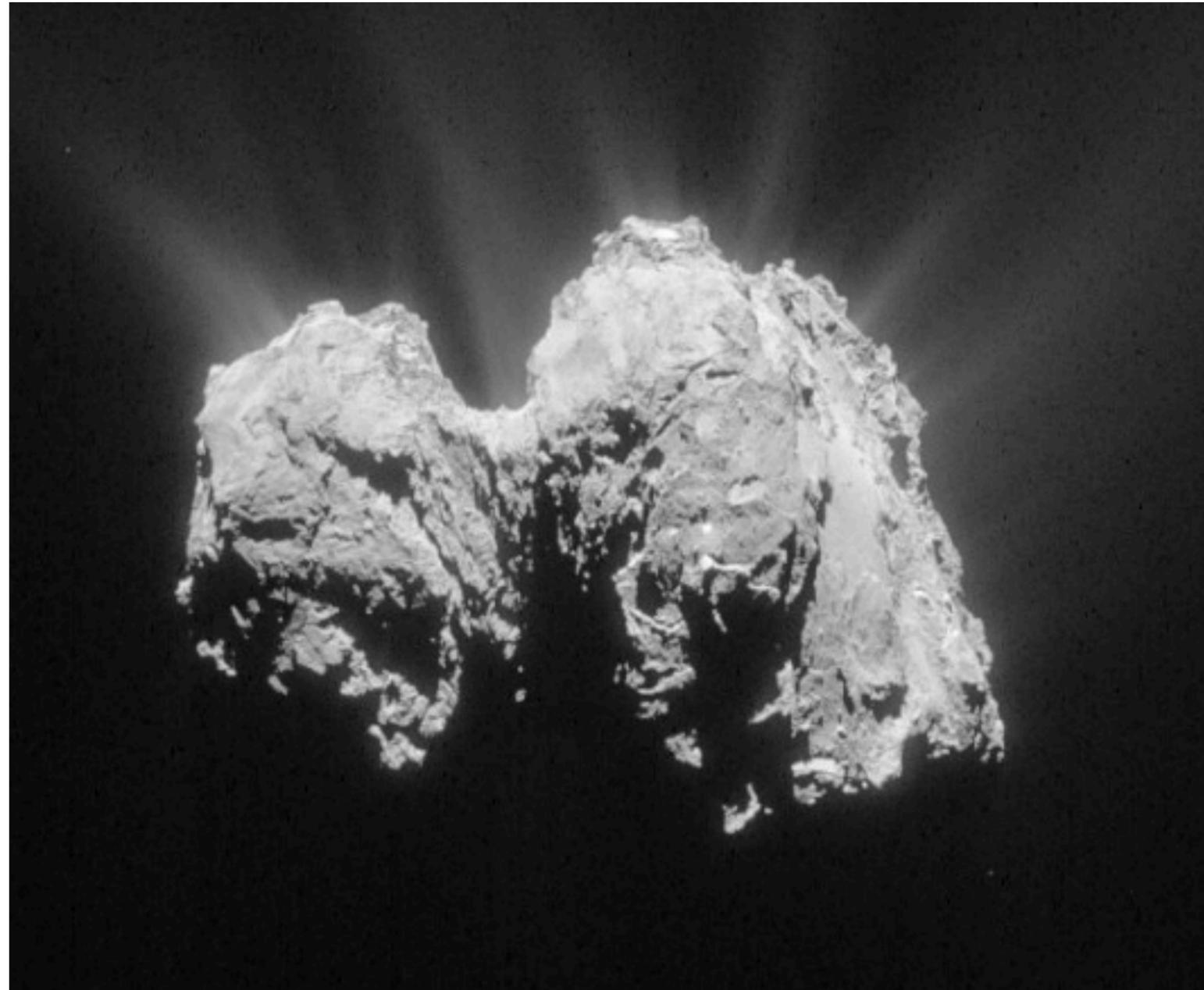
[https://www.youtube.com/watch?v=LAlqp0\\_a0tE](https://www.youtube.com/watch?v=LAlqp0_a0tE)



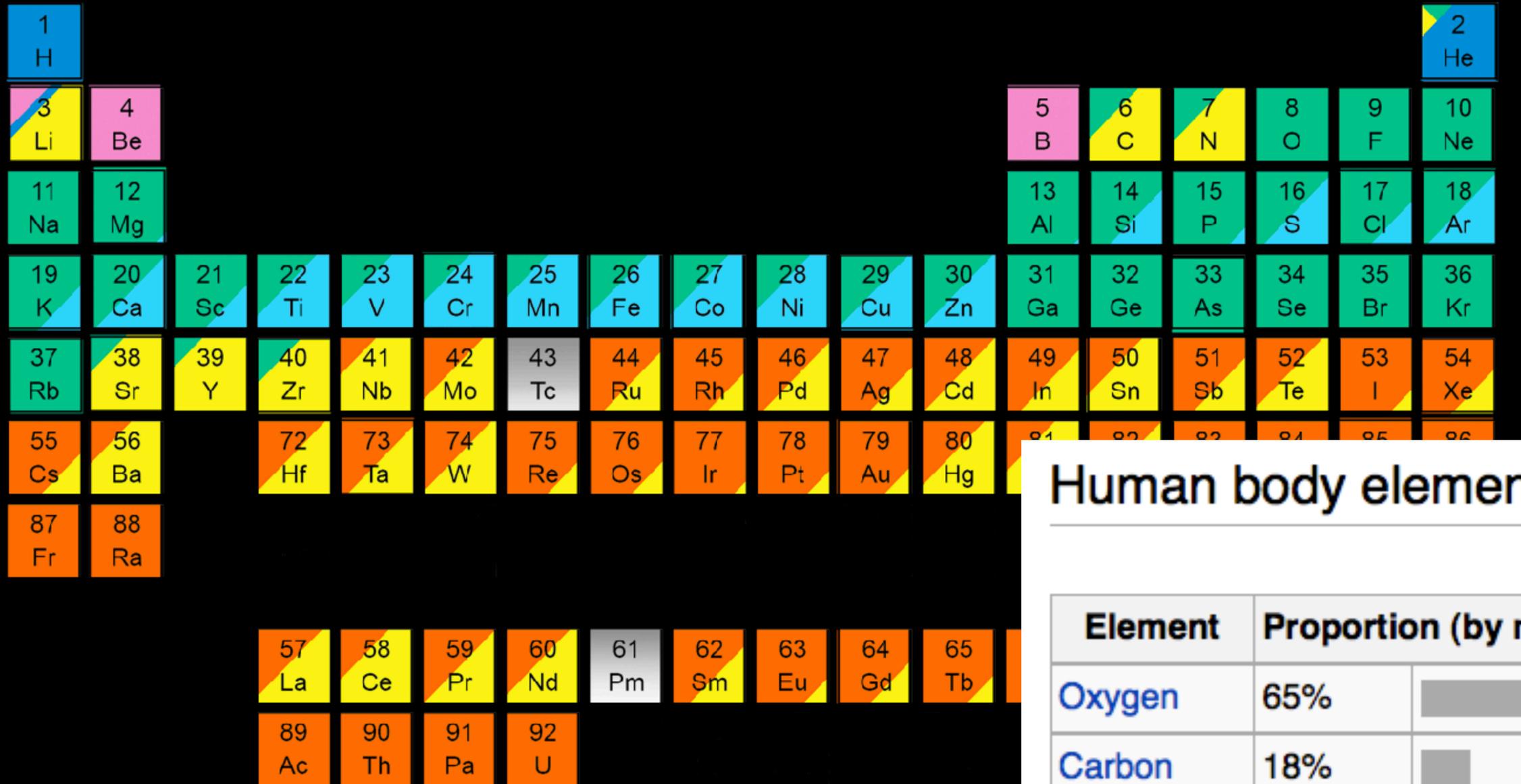
# High Budget ESA PR

[https://www.youtube.com/watch?v=32vIOgN\\_3QQ](https://www.youtube.com/watch?v=32vIOgN_3QQ)

# Rosetta Mission and Philae Lander



# The Origin of the Solar System Elements



## Human body elemental abundance

Element	Proportion (by mass)	
Oxygen	65%	<div style="width: 65%; background-color: gray;"></div>
Carbon	18%	<div style="width: 18%; background-color: gray;"></div>
Hydrogen	10%	<div style="width: 10%; background-color: gray;"></div>
Nitrogen	3%	<div style="width: 3%; background-color: gray;"></div>

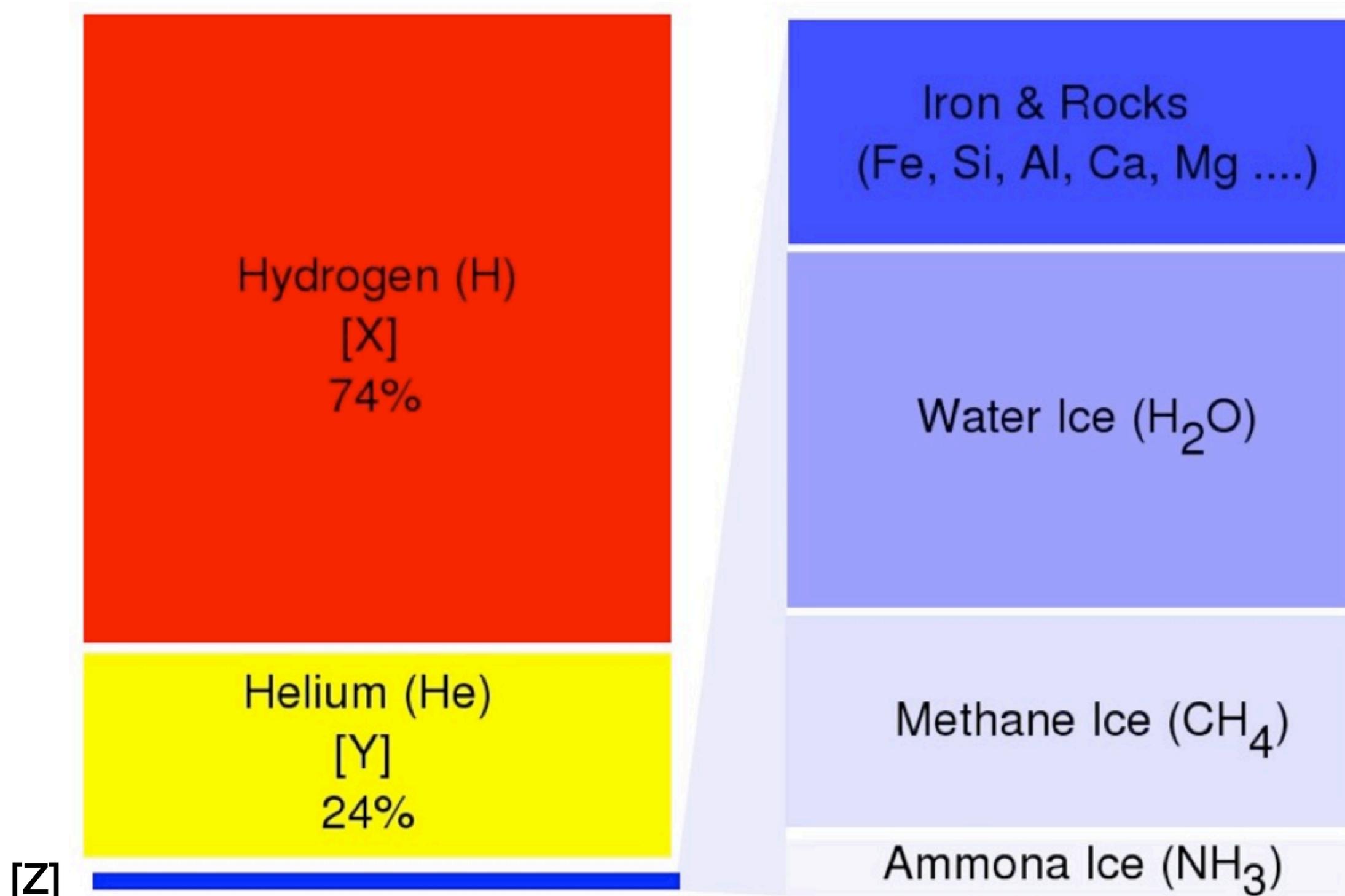
Graphic created by Jennifer Johnson



# Mass Distribution in the Solar System



# What is the solar system made of?

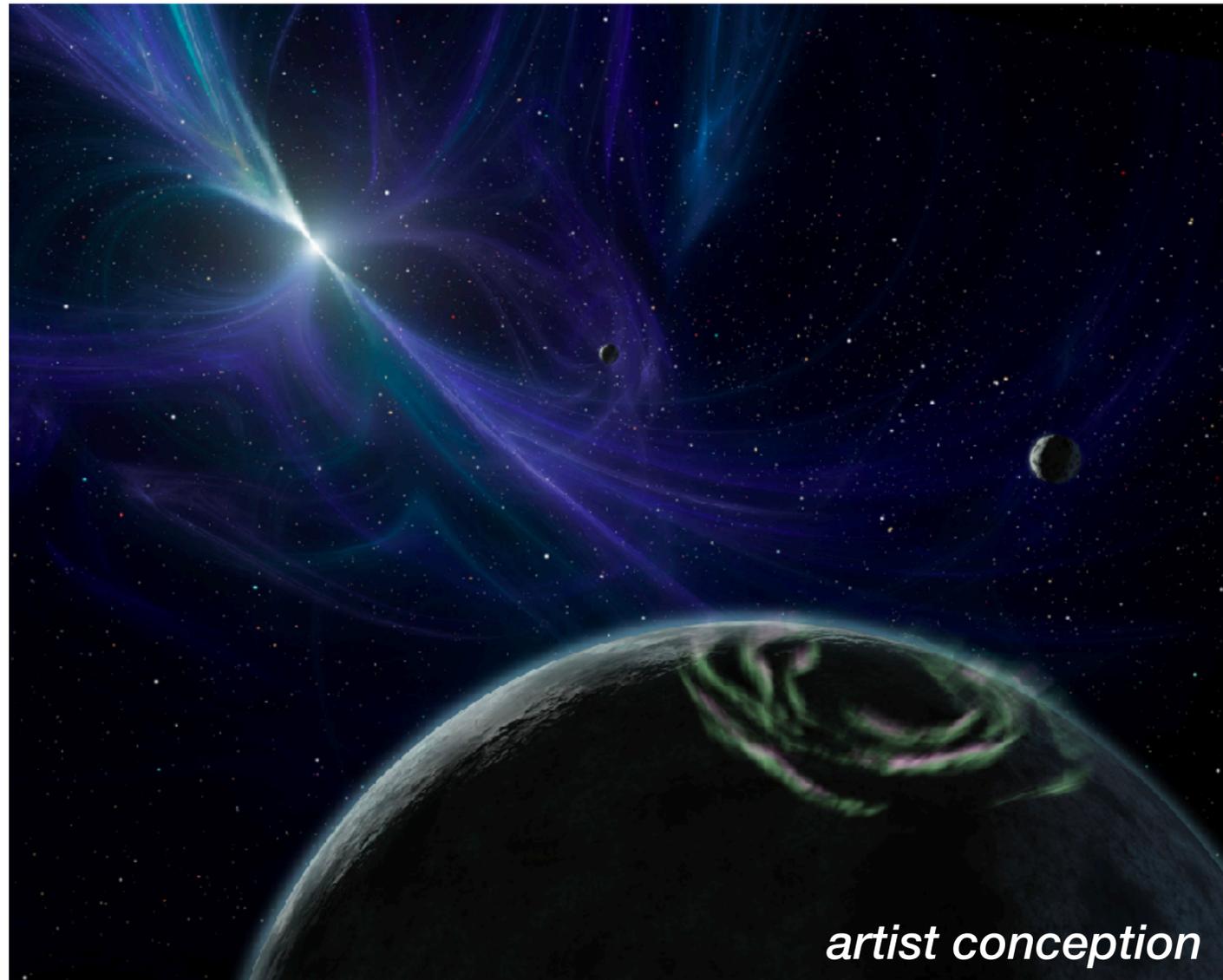


# Exoplanets



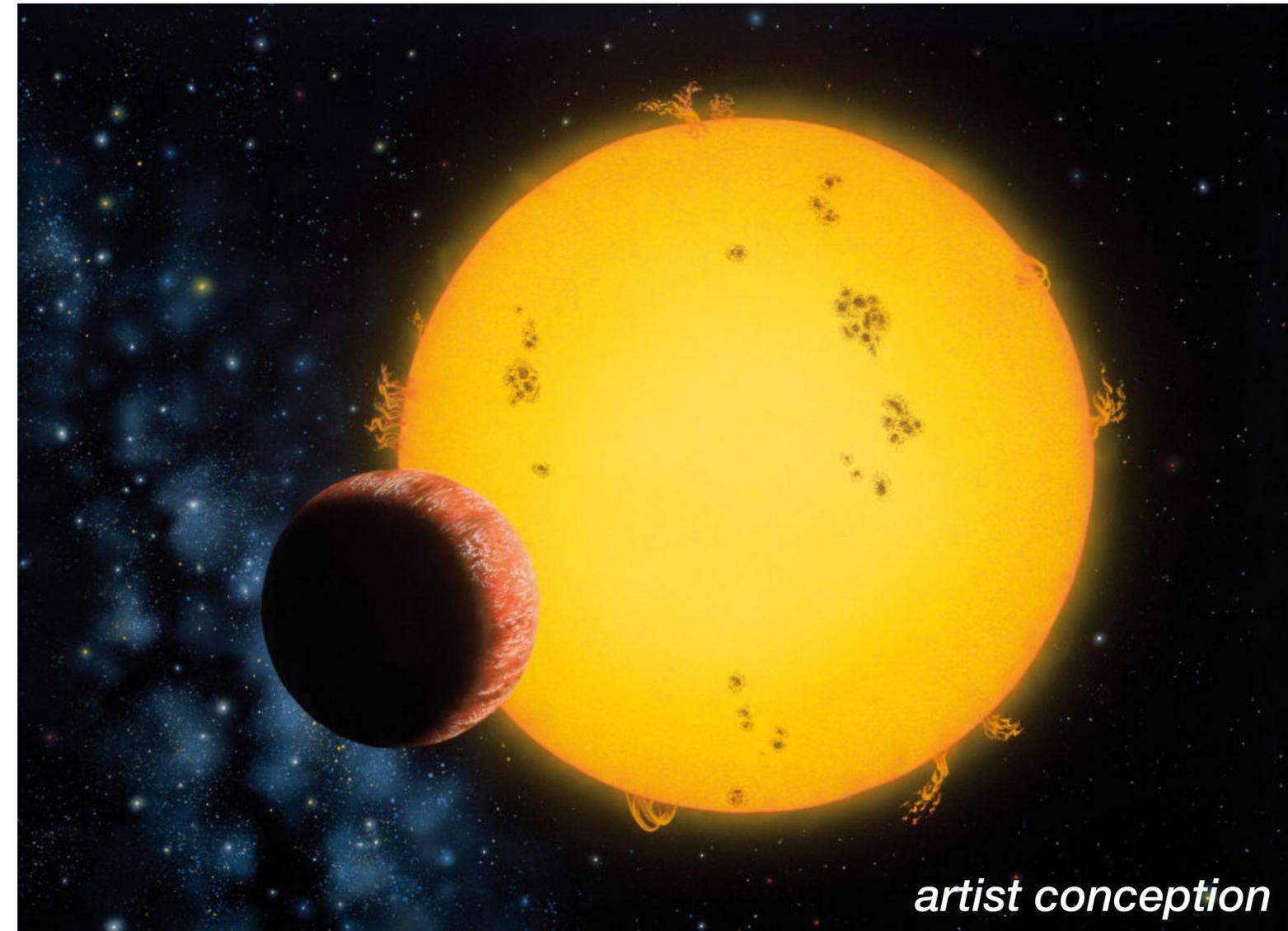
# First planets discovered outside the solar system

Pulsar PSR B1257+12

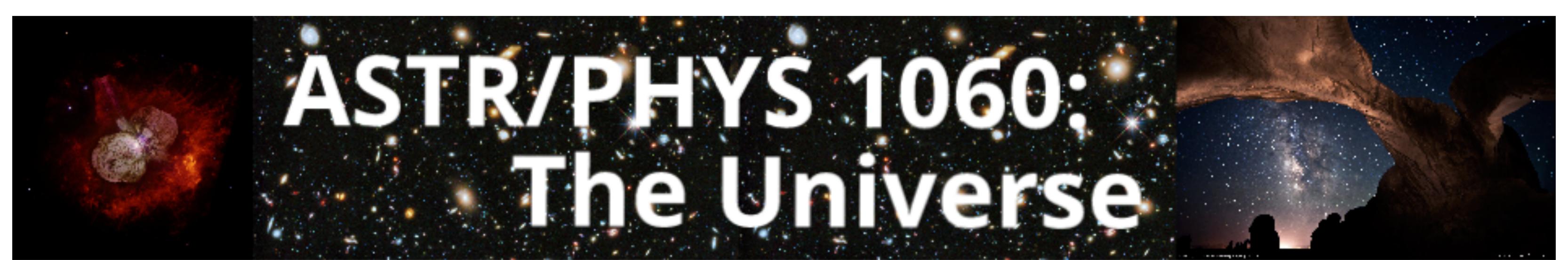


1992 - 3 confirmed planets

Sun-like star: 51 Pegasi b



1995 - a "hot Jupiter"



# ASTR/PHYS 1060: The Universe

## Ch. 5: Formation of Stars/Planets

Midterm 1 today (in 30min)

Chapter 10 Reading Quiz due on Tuesday, Sept. 24th

Have your Transit Activity handy — will discuss shortly

Are your grades in Canvas correct???

# How to find planets

- Detect them directly

- Detect their influence on their star

## Direct Imaging



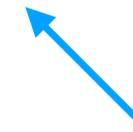
- Image the planet
- Detect its atmosphere in a spectrum

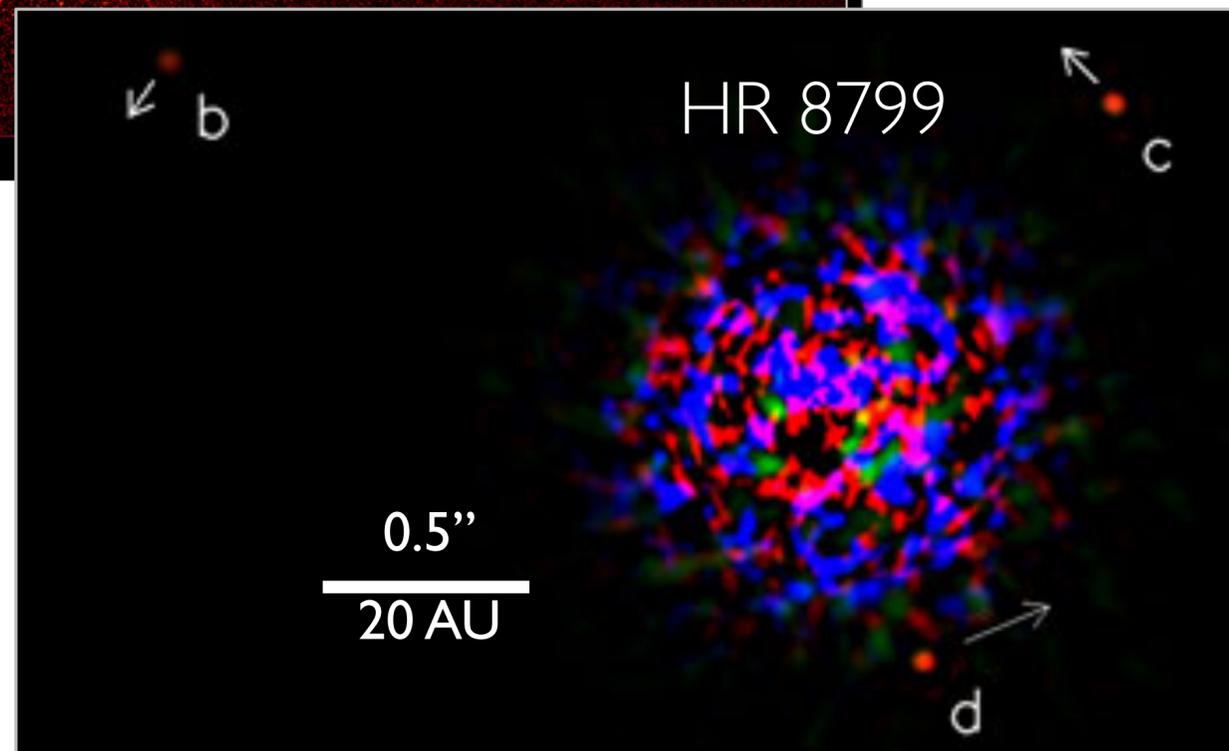
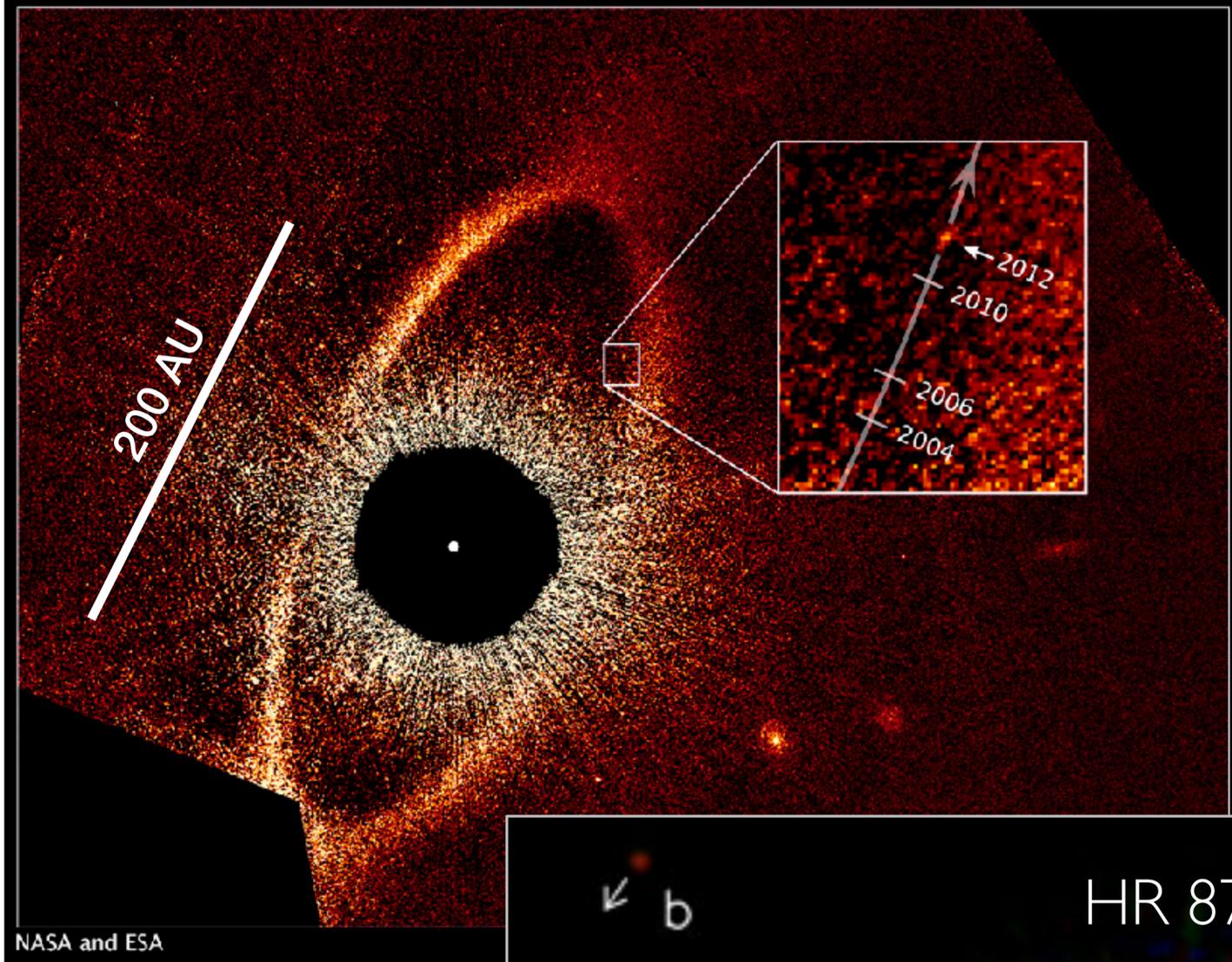
## Transit Method



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

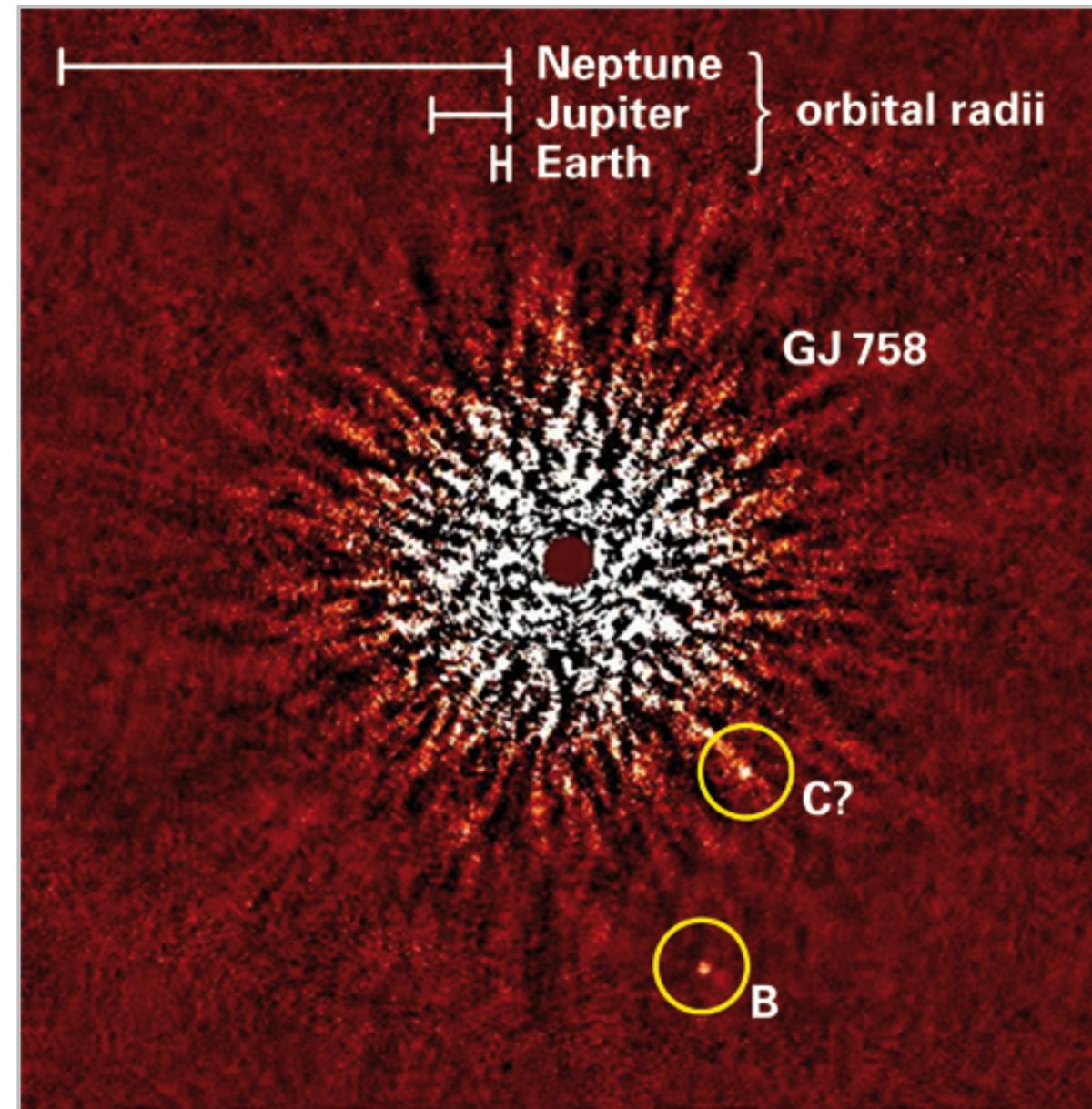
## Radial Velocity Method



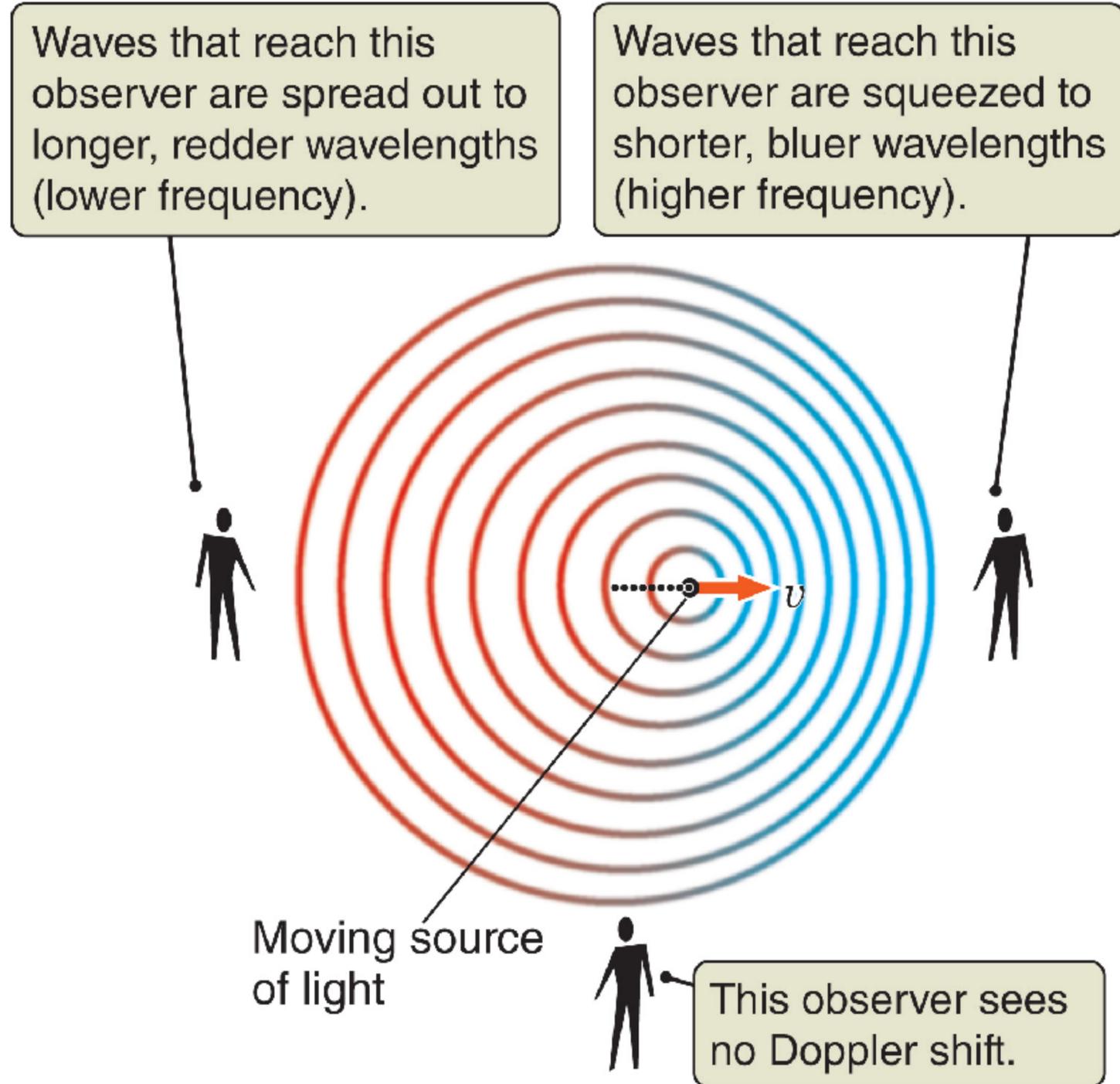


# Direct Imaging

Planet millions of times fainter  
Need to mask the starlight

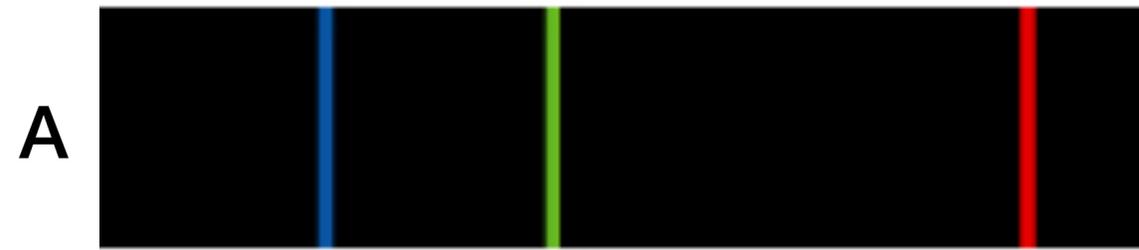


# Radial Velocity Method





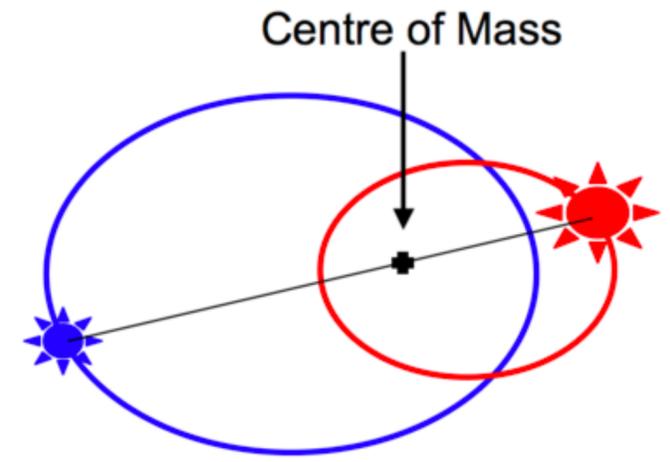
# Doppler Shift of Light



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

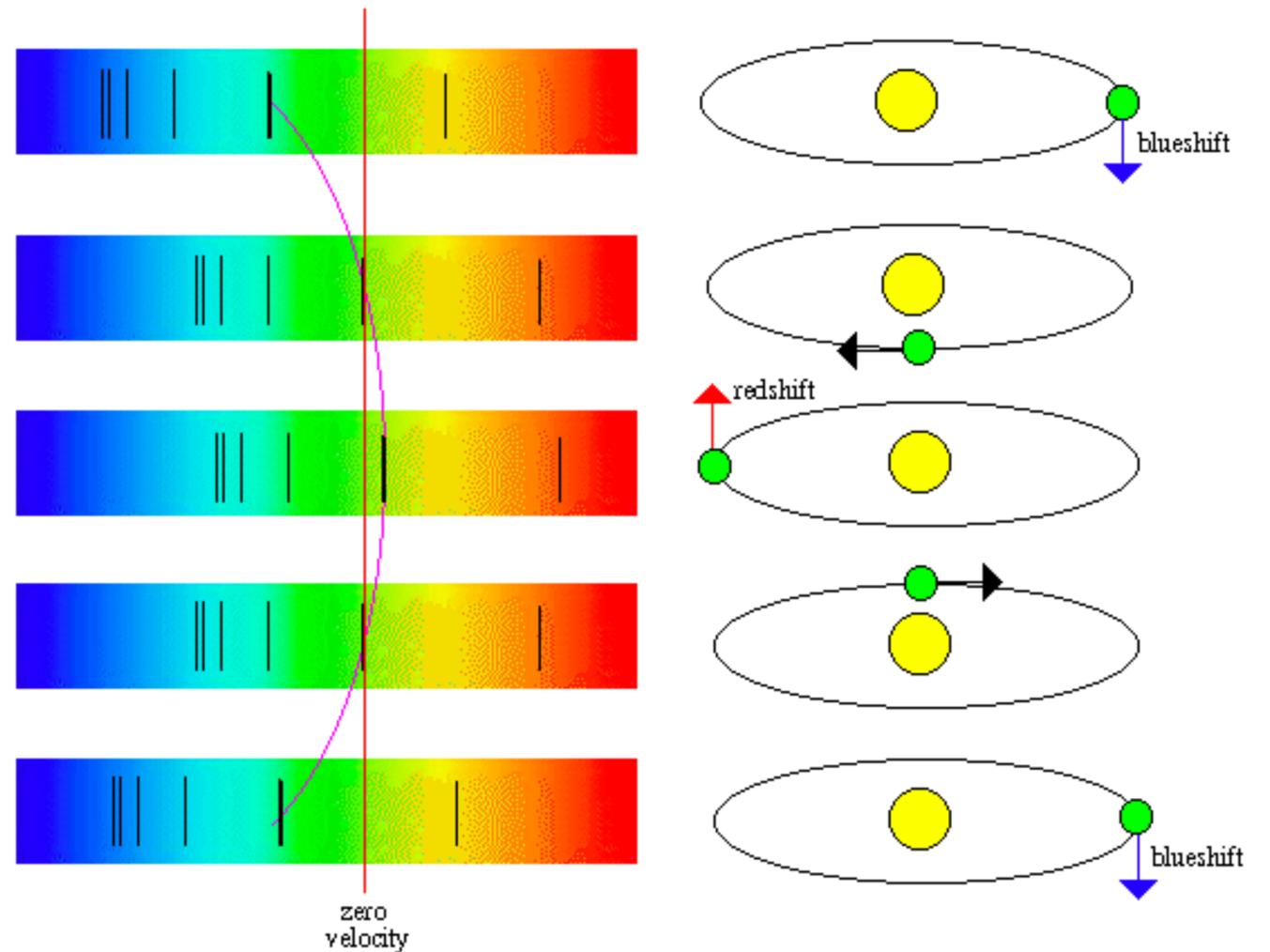
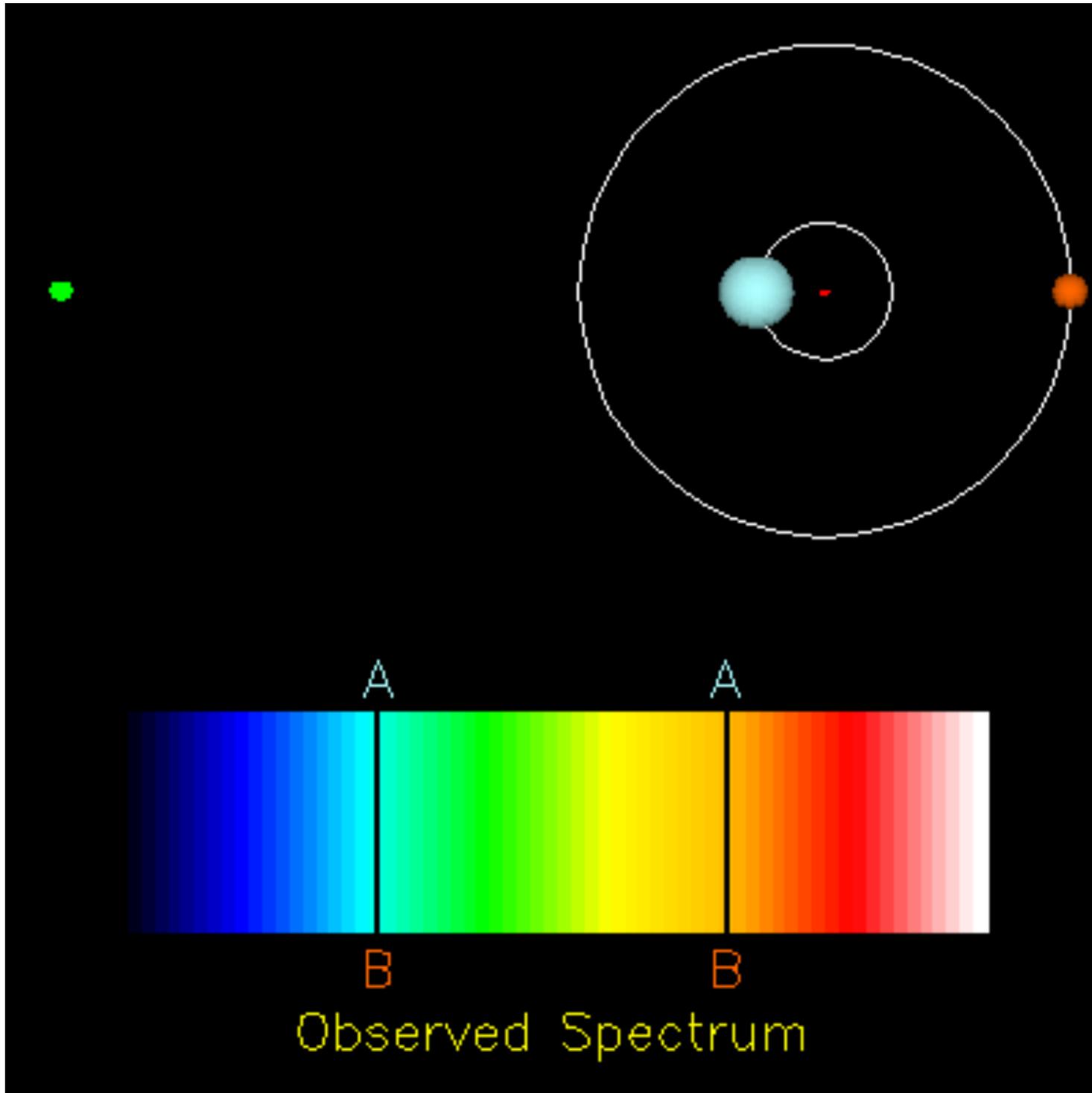
Which spectrum is moving away from us the fastest?

# Binary Stars

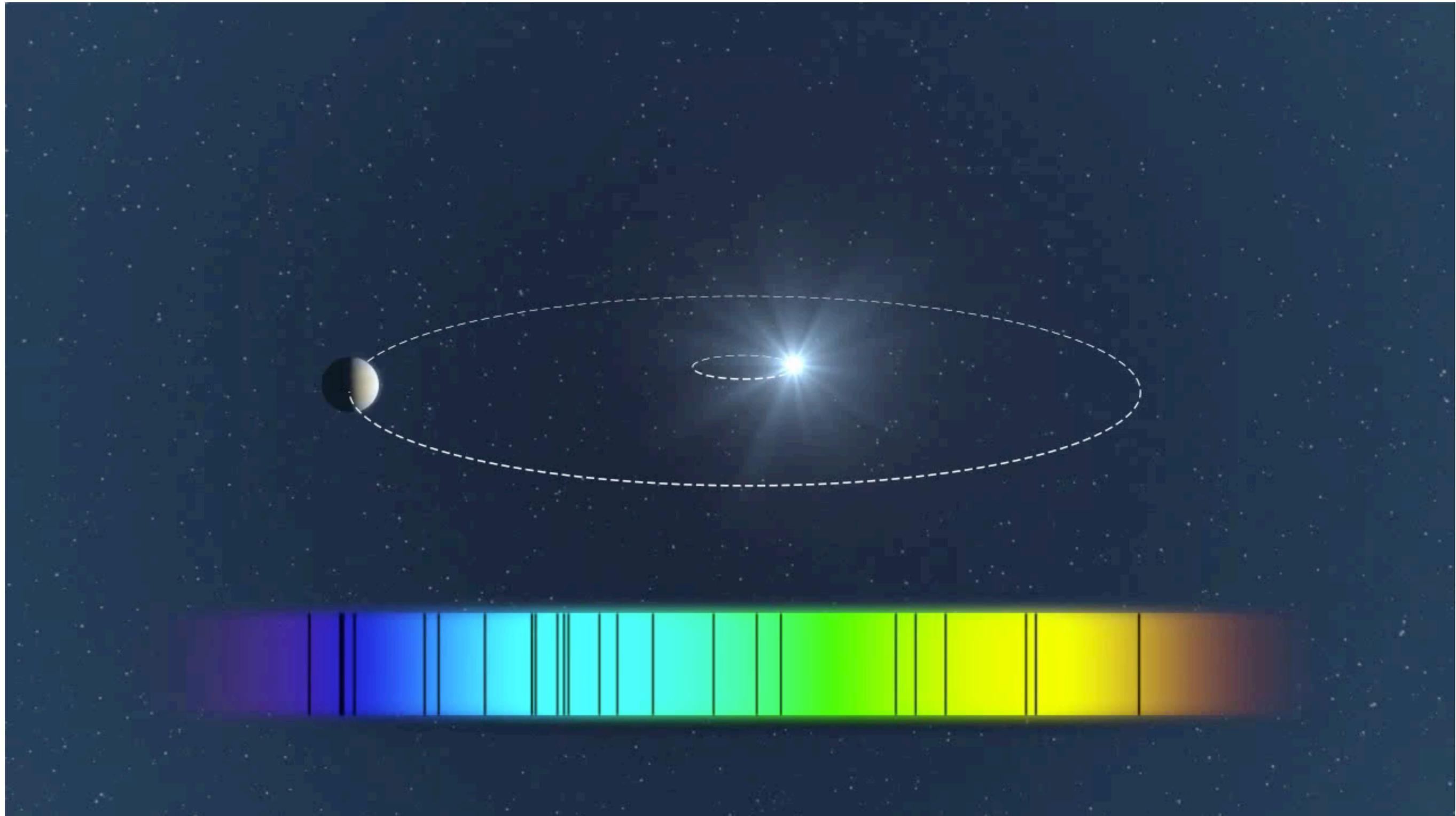


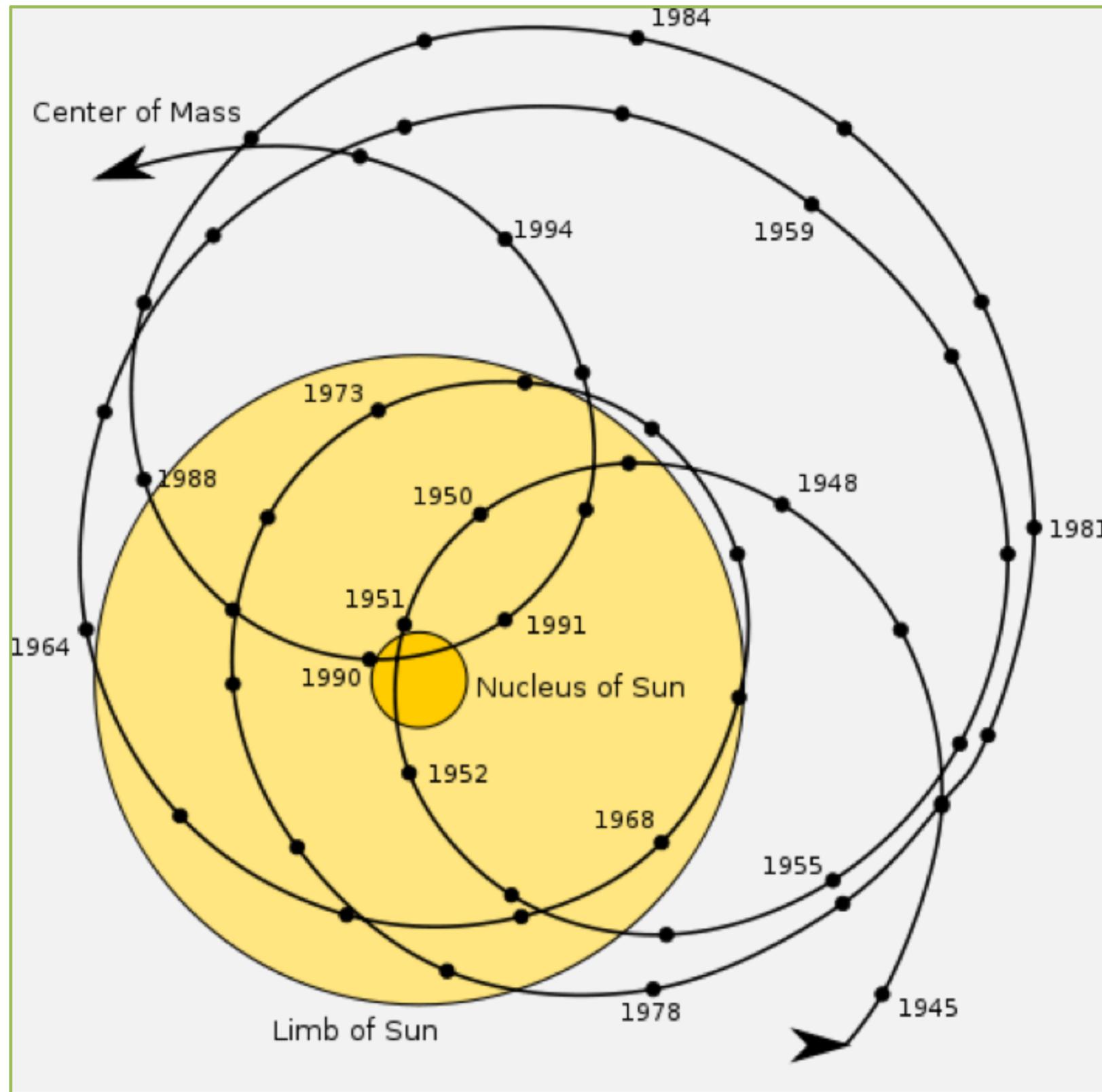
## Spectroscopic Binary

A spectroscopic binary is where there is evidence of orbital motion in the spectral features due to the Doppler effect



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

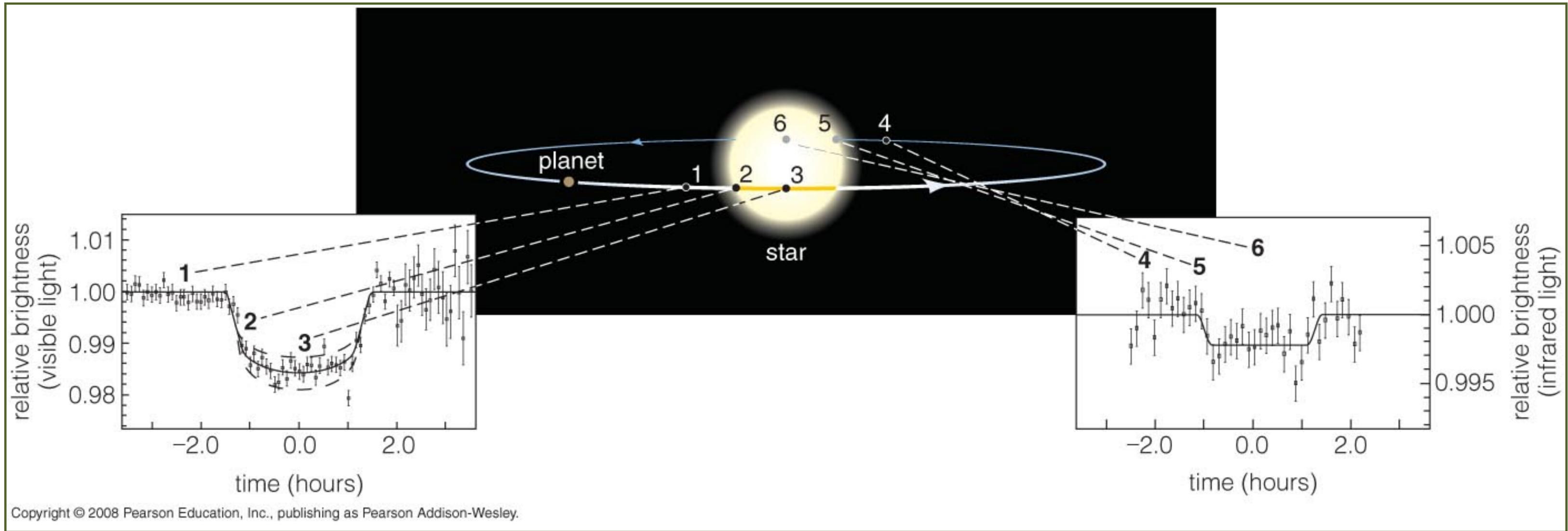




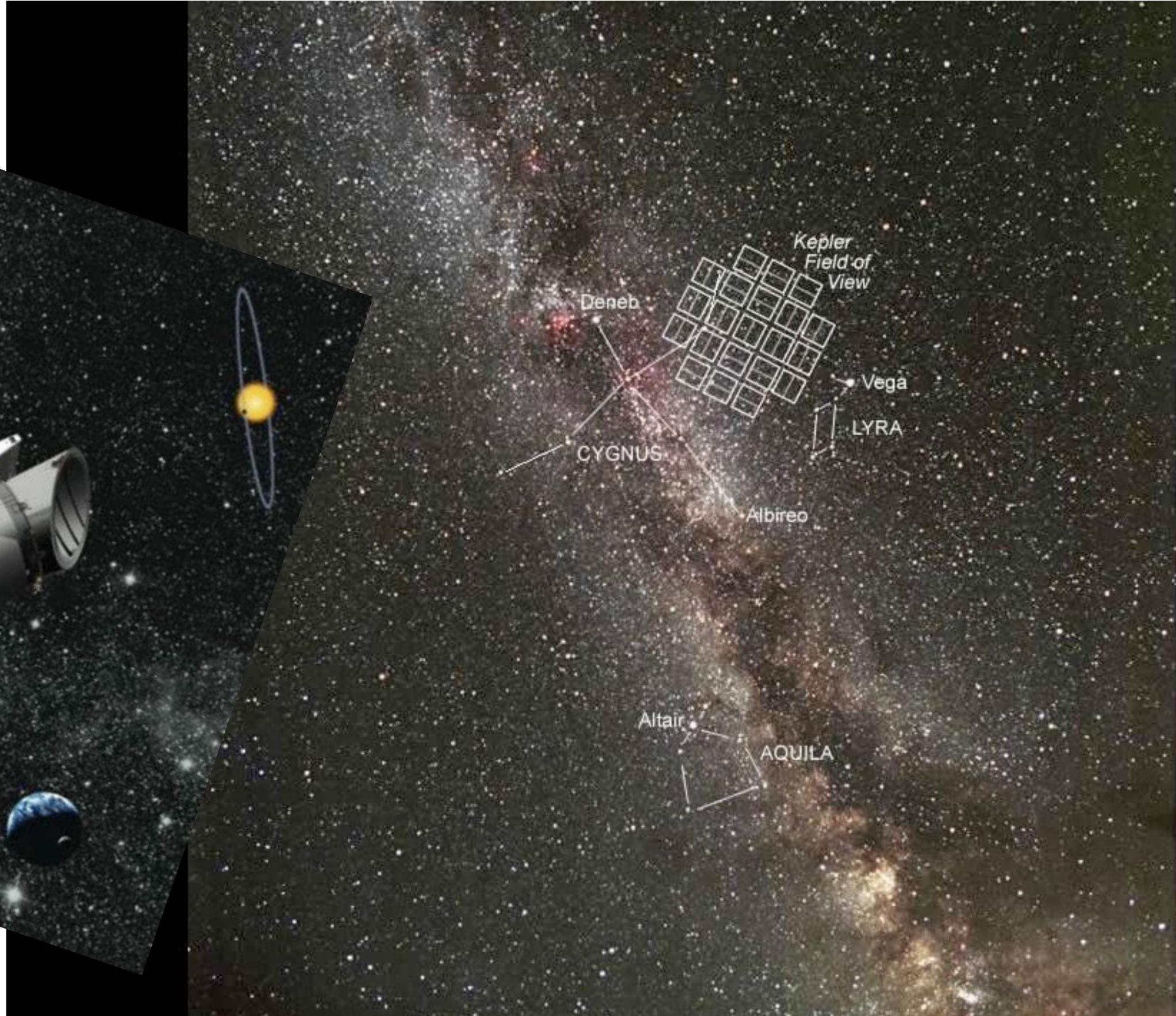
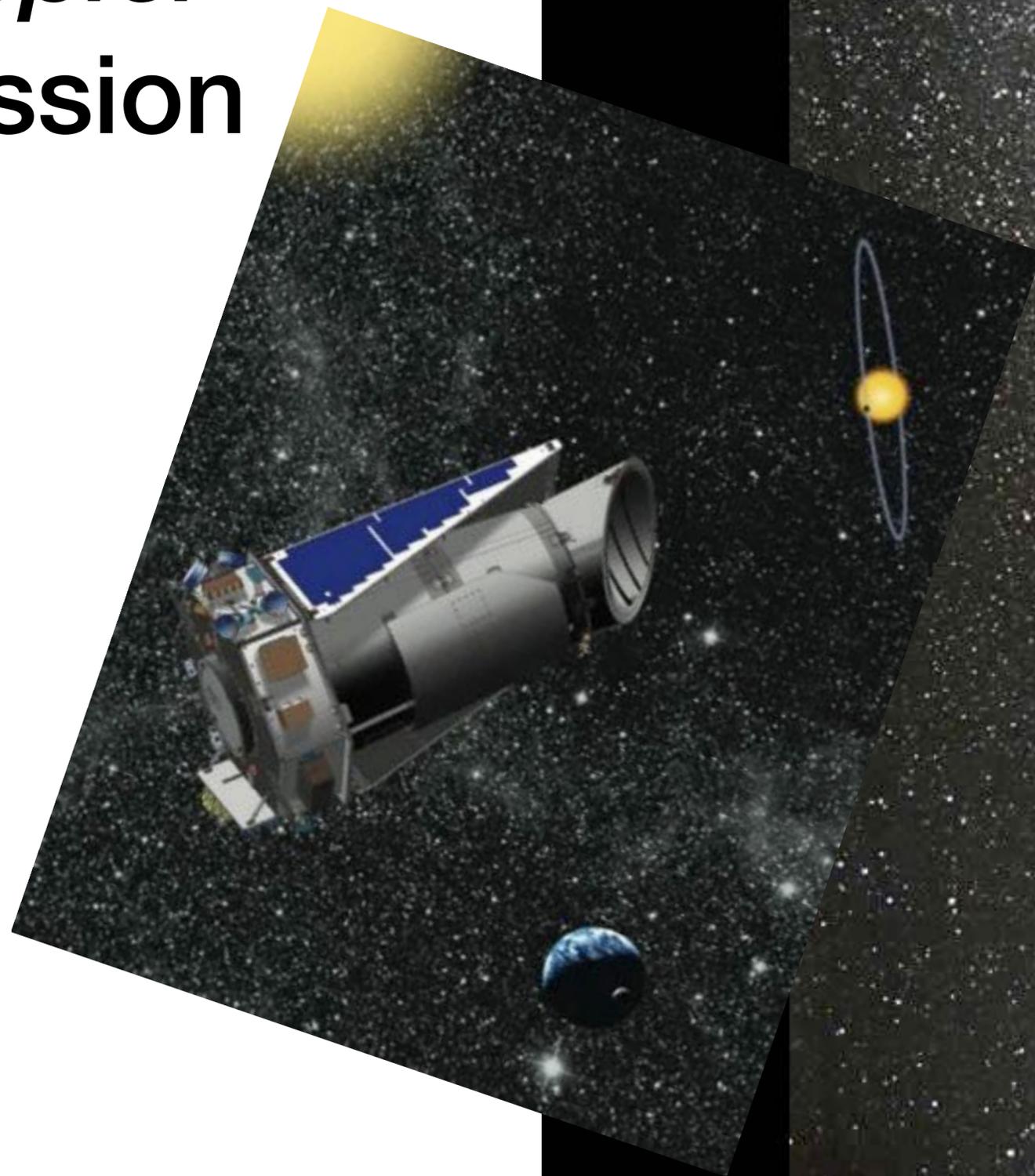
**Motion of the Sun  
relative to its center  
of mass could be  
detectable by (more  
advanced than us)  
aliens**

# Transit Method

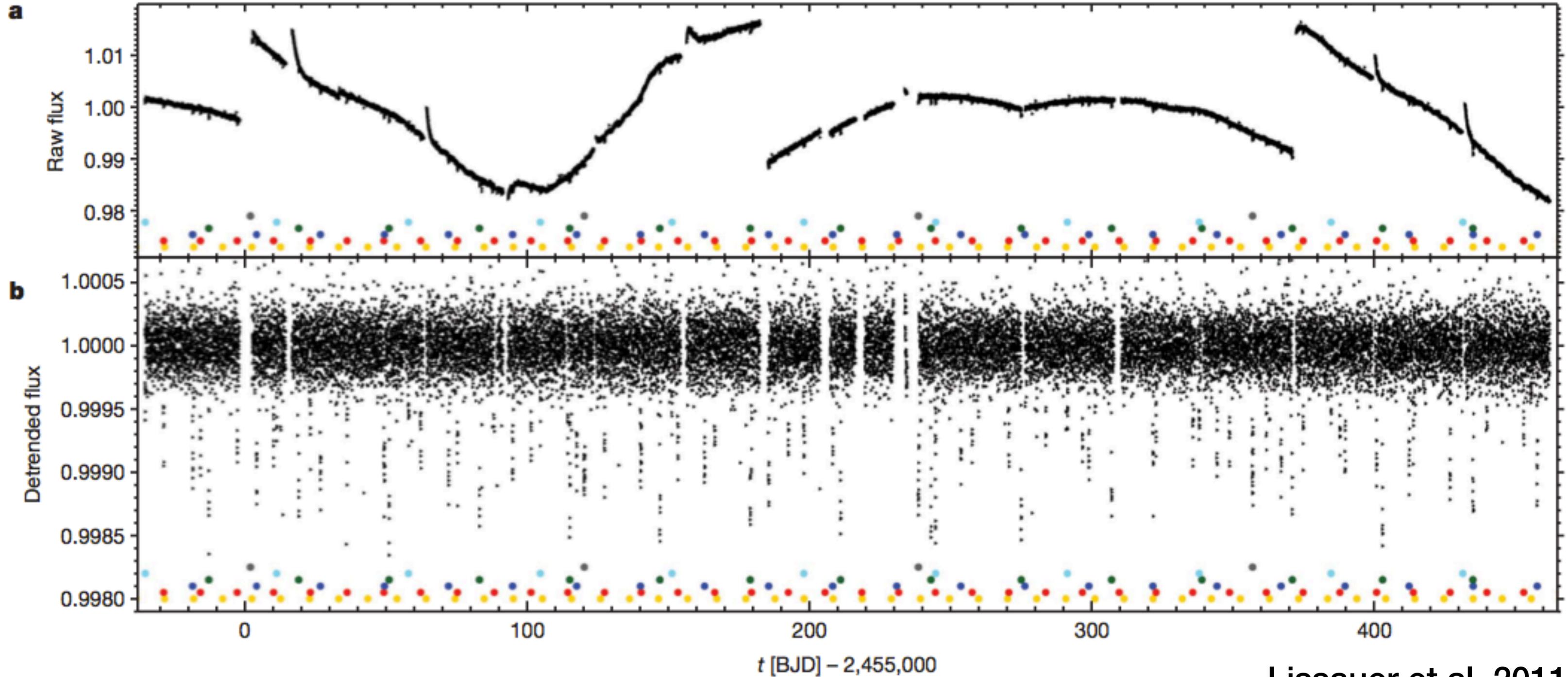
Starlight is blocked by the planet, reducing the amount of light detected from the star



# Kepler Mission

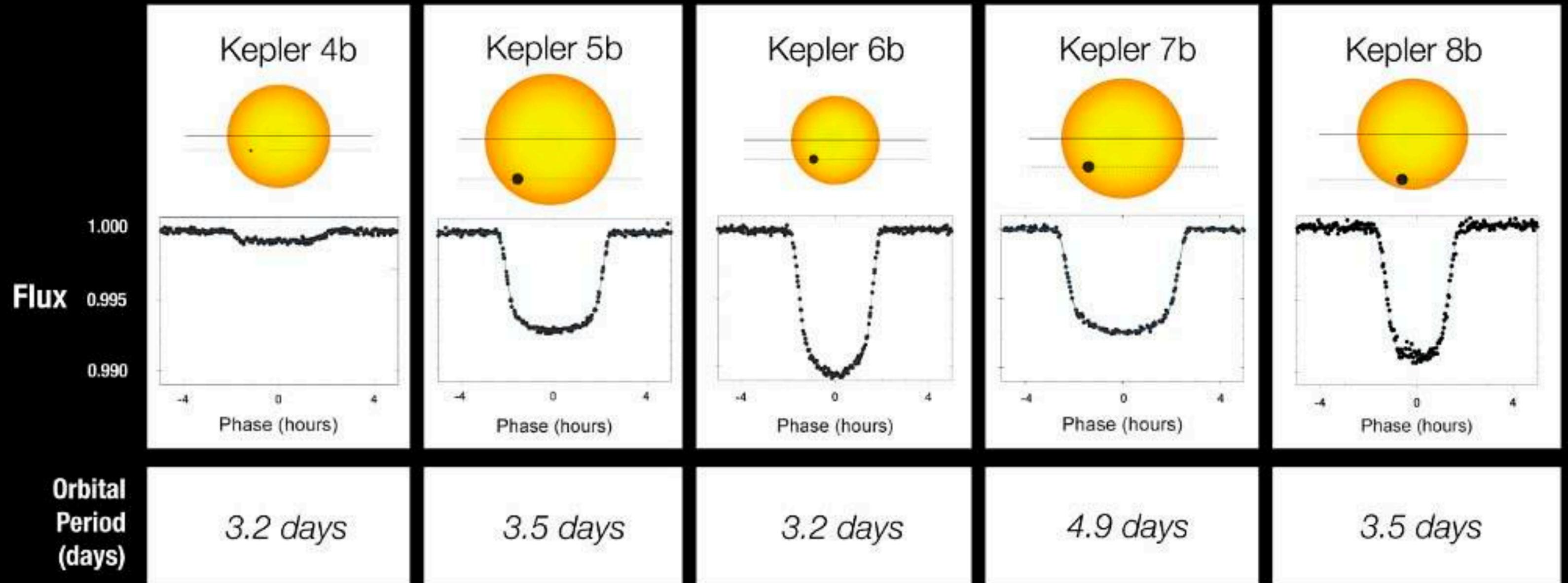


# Kepler-11 System (6 planets)



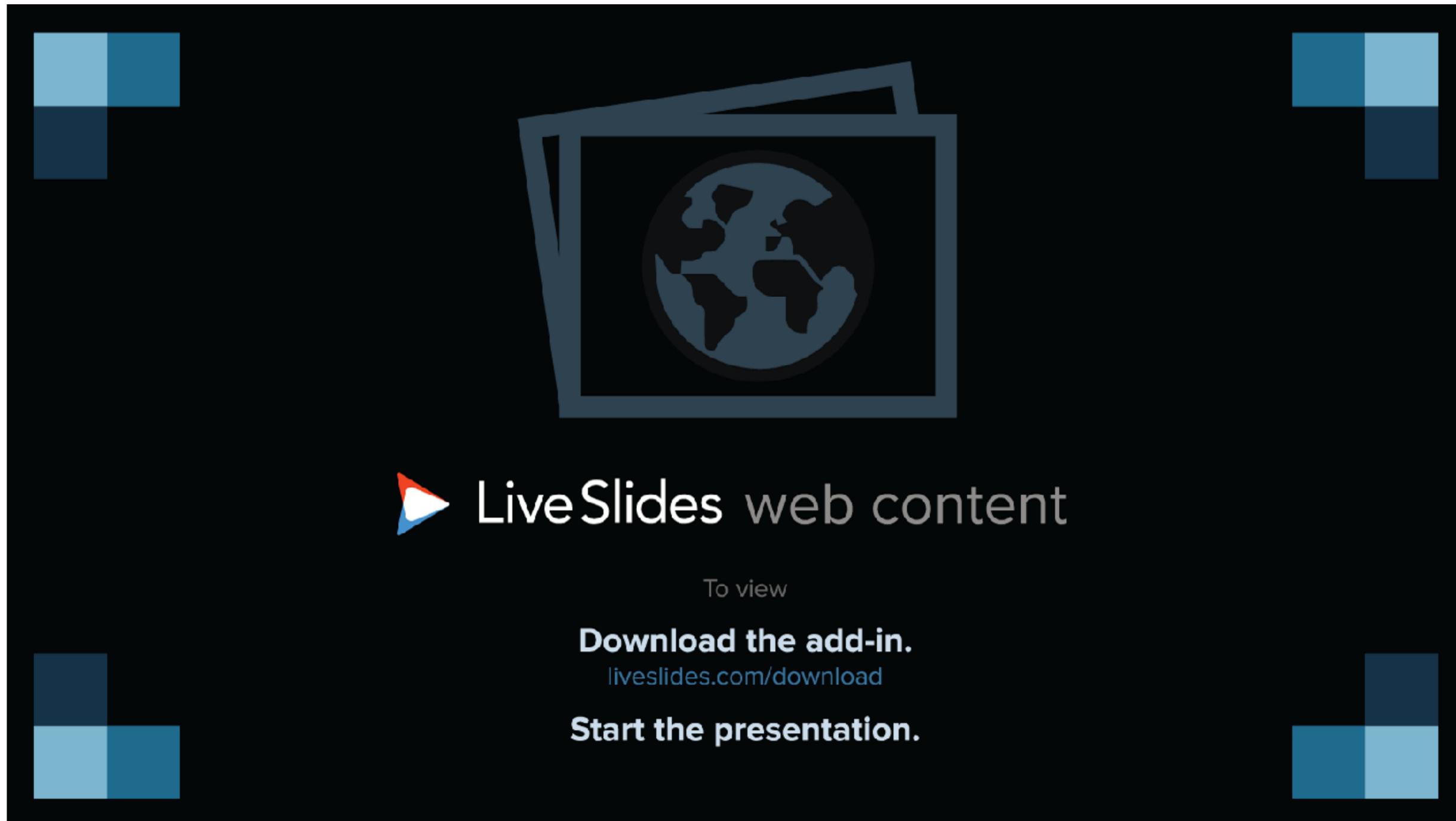
Lissauer et al. 2011

# Transit Light Curves





# *Kepler* Planetary Systems

A screenshot of a presentation slide titled "Kepler Planetary Systems". The slide features a dark background with a central graphic of a globe inside a blue frame. Below the graphic, there is a play button icon followed by the text "LiveSlides web content". Underneath, it says "To view" followed by "Download the add-in." and a link "liveslides.com/download". At the bottom of the slide, it says "Start the presentation." The slide is framed by a black border with four blue square accents in the corners.

 LiveSlides web content

To view

**Download the add-in.**  
[liveslides.com/download](https://liveslides.com/download)

**Start the presentation.**

[https://www.youtube.com/watch?v=Td\\_YeAdygJE](https://www.youtube.com/watch?v=Td_YeAdygJE)