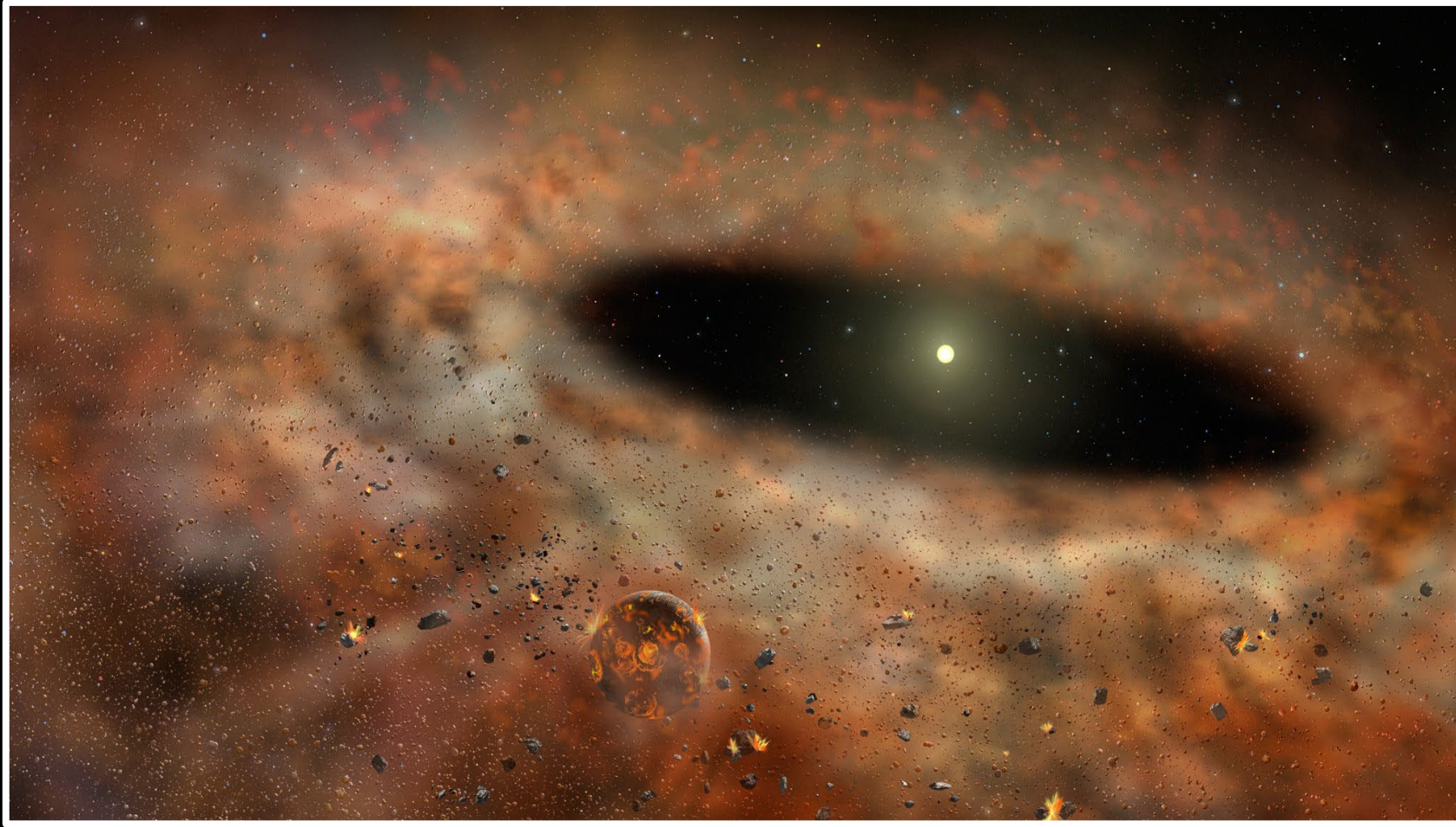


National Science Olympiad Astronomy 2024 Event

Stellar Evolution: Star Formation & Exoplanets



Supported by NASA's Universe of Learning (UoL) Informal STEM Outreach Network

NSO ASTRONOMY Event 2024

1. **DESCRIPTION:** Teams will demonstrate an understanding of **Stellar Evolution: Star Formation & Exoplanets.**

A TEAM OF UP TO: 2

APPROXIMATE TIME: 50 minutes

2. **EVENT PARAMETERS:**

- a. Each team may bring one of the following options containing information in any form and from any source: a **computer/tablet** and a **three-ring binder**, two computers/tablets, of any kind, or two three-ring binders.
- b. If three ring binders are used, they may be of any size and the information contained should be attached using the available rings. The information or pages may be removed during the event. Sheet protectors and laminated sheets are allowed.
- c. Each team may bring two stand-alone **calculators** of any type. If the participants are using a computer/tablet they may use the calculator app or other program on their device in place of a stand-alone calculator.
- d. Participants using computers/tablets as a resource should have all information stored so that it is available to them offline. However, teams may be asked to access a dedicated **NASA image analysis website** to answer some JS9 questions. If so, supervisors will provide an alternative (e.g., proctor-supplied computer) for teams that did not bring a laptop/tablet.

3. **THE COMPETITION:** Using information which may include Hertzsprung-Russell diagrams, spectra, light curves, motions, cosmological distance equations and relationships, stellar magnitudes and classification, multi-wavelength images (gamma-ray, X-ray, UV, optical, IR, radio), charts, graphs and JS9 imaging analysis software, teams will compete in activities and answer questions related to:

a. Stellar evolution including stellar classification, spectral features and chemical composition, luminosity, blackbody radiation, color index and H-R diagram transitions, **H I/II regions**, **molecular clouds**, **proto-stars**, **Herbig-Haro Objects**, **T Tauri variables**, **Herbig Ae/Be stars**, planet formation, **brown dwarfs**, **protoplanetary disks**, **debris disks**, and exoplanets including but not limited to **gas giants** and **terrestrial planets**.

b. Use **orbital mechanics**, **Kepler's laws**, **rotation and circular motion** to answer questions relating to the orbital motions of planetary systems; use **parallax**, **spectroscopic parallax**, and the **distance modulus** to calculate distances to stars and planetary systems; use the **radial velocity**, **transit**, and **direct imaging** methods to determine properties of exoplanets, use the **radiation laws** to answer questions relating to **planetary surface temperatures** and **habitability**.

c. Identify and answer questions relating to the content areas outlined above for the following objects: **Carina Nebula**, **NGC 1333**, **TW Hya**, **HH 7-11**, **AB Aurigae**, **HD 169142**, **Luhman 16**, **V830 Tau b**, **V 1298 Tau b**, **WASP-18b**, **WASP-39b**, **WASP-43b**, and systems: **HR 8799**, **Beta Pictoris**, **2M 1207**, **TRAPPIST-1**.

4. **SCORING:** All questions will have been assigned a predetermined number of points. The highest score wins. Selected questions will be used to break ties.

THIS EVENT IS SUPPORTED BY NASA's Universe of Learning STEM Literacy Program

Deep Sky Objects

- 1. Carina Nebula – Star Formation Region**
- 2. NGC 1333 – Star Formation Region**
- 3. TW Hya – Pre-Main Sequence Star – Classical T Tauri**
- 4. HH 7-11 – Pre-Main Sequence Star – Herbig Haro**
- 5. AB Aurigae – Pre-Main Sequence Star – Herbig Ae**
- 6. HD 169142 – Pre-Main Sequence Star – Herbig Ae/Be**
- 7. Luhman 16 (A & B) - 2 Brown Dwarfs**
- 8. 2M1207 System – Brown Dwarf & Gas Giant**
- 9. V1298 Tau b – Gas Giant**
- 10. WASP-18b – Gas Giant**
- 11. WASP-39b – Gas Giant**
- 12. WASP-43b – Gas Giant**
- 13. HR 8799 System – Gas Giant**
- 14. Beta Pictoris System – Gas Giant**
- 15. TRAPPIST-1 System – Terrestrial**

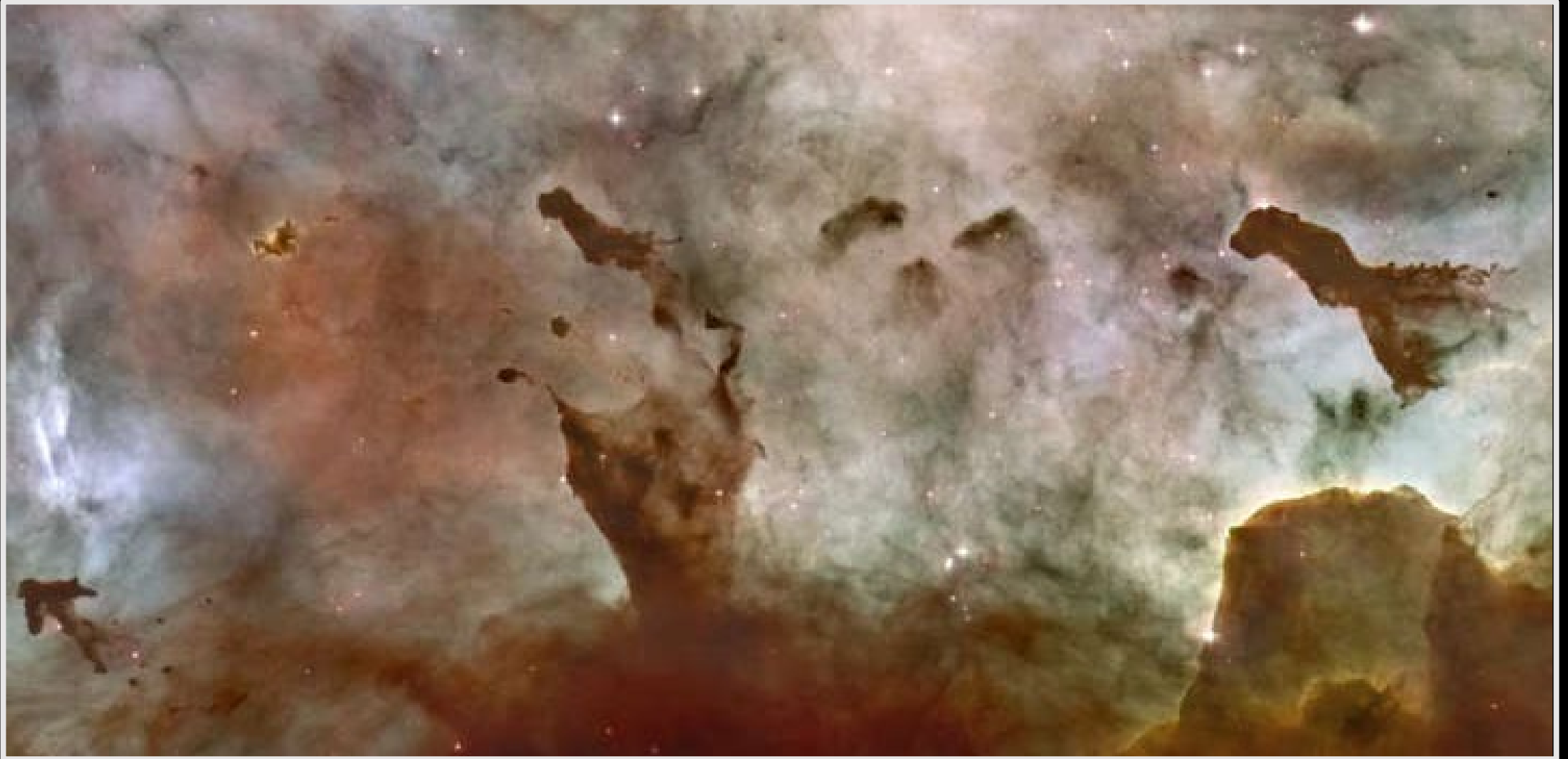


The Carina Nebula (NGC 3372) Star Formation Complex

Reflection, Emission, Dark Nebulas & Molecular Clouds



Molecular Clouds – AKA Dark or Absorption Nebulas



Molecular Clouds & Bok Globules:

Carina Nebula Details

HST•ACS/WFC



The “Mystic Mountain” in the Carina Nebula



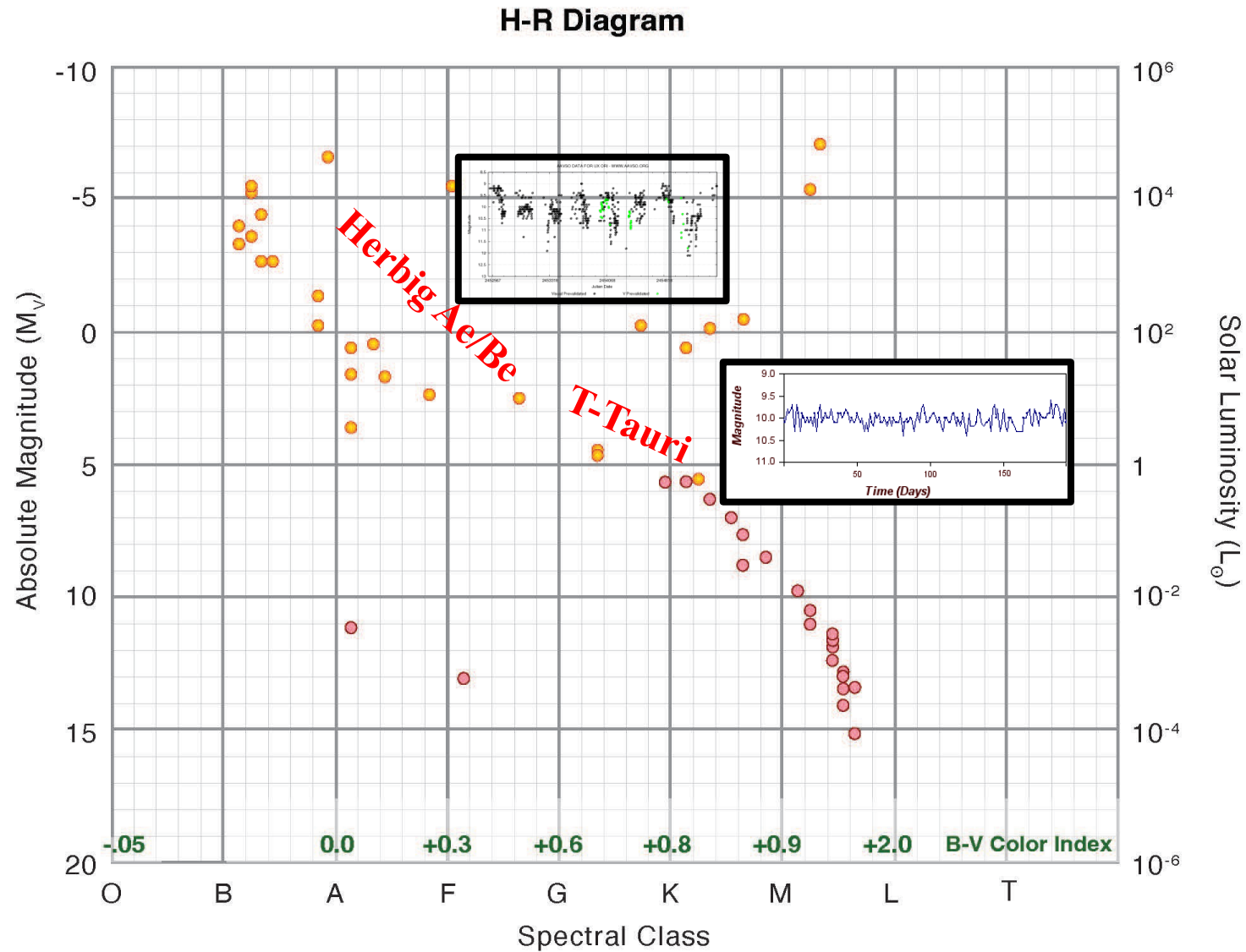
Multiwavelength Star Formation



NGC 1333 Star Formation Complex

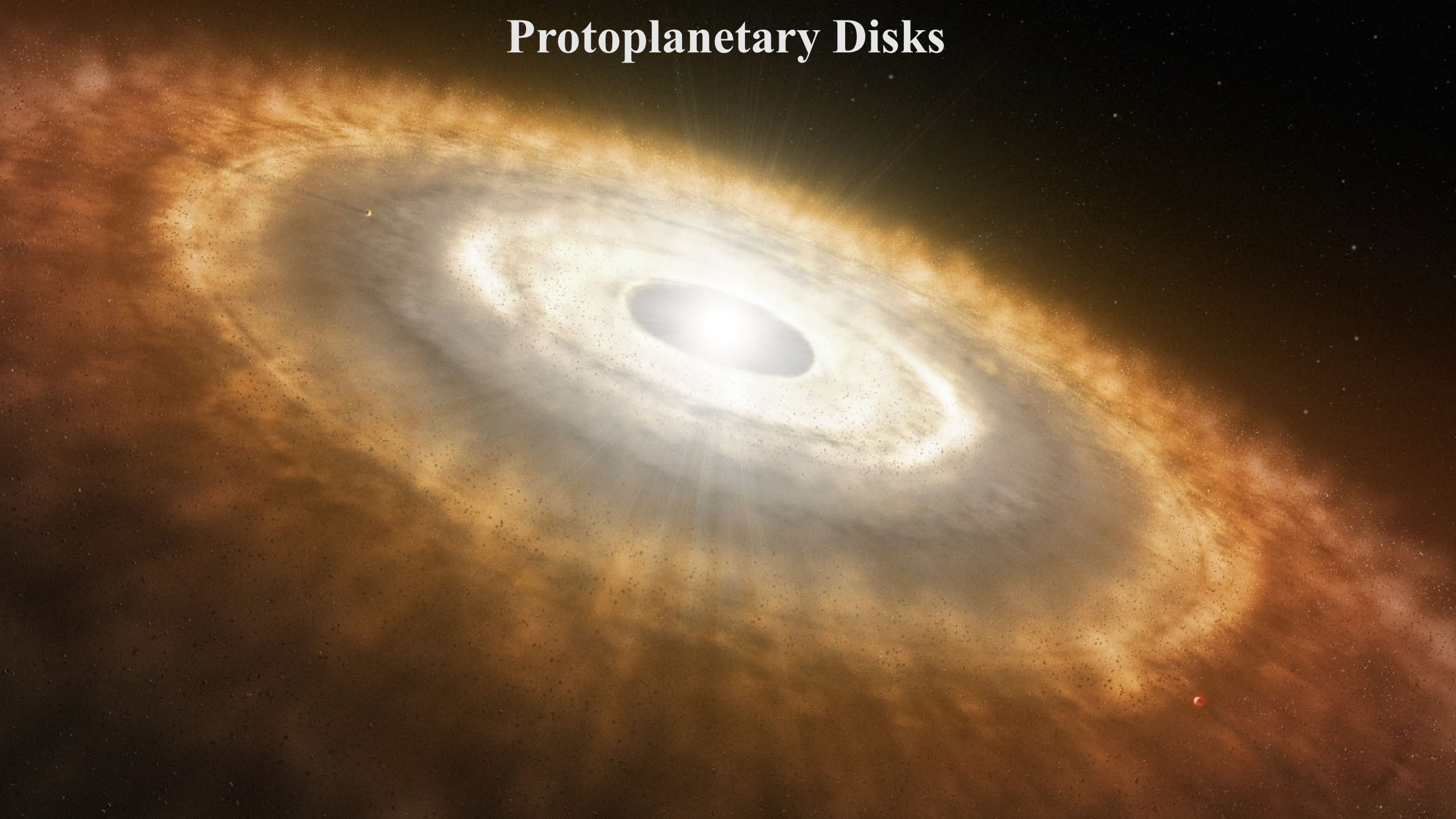


Pre-Main Sequence Stars: Classical T Tauri & Herbig Ae/Be

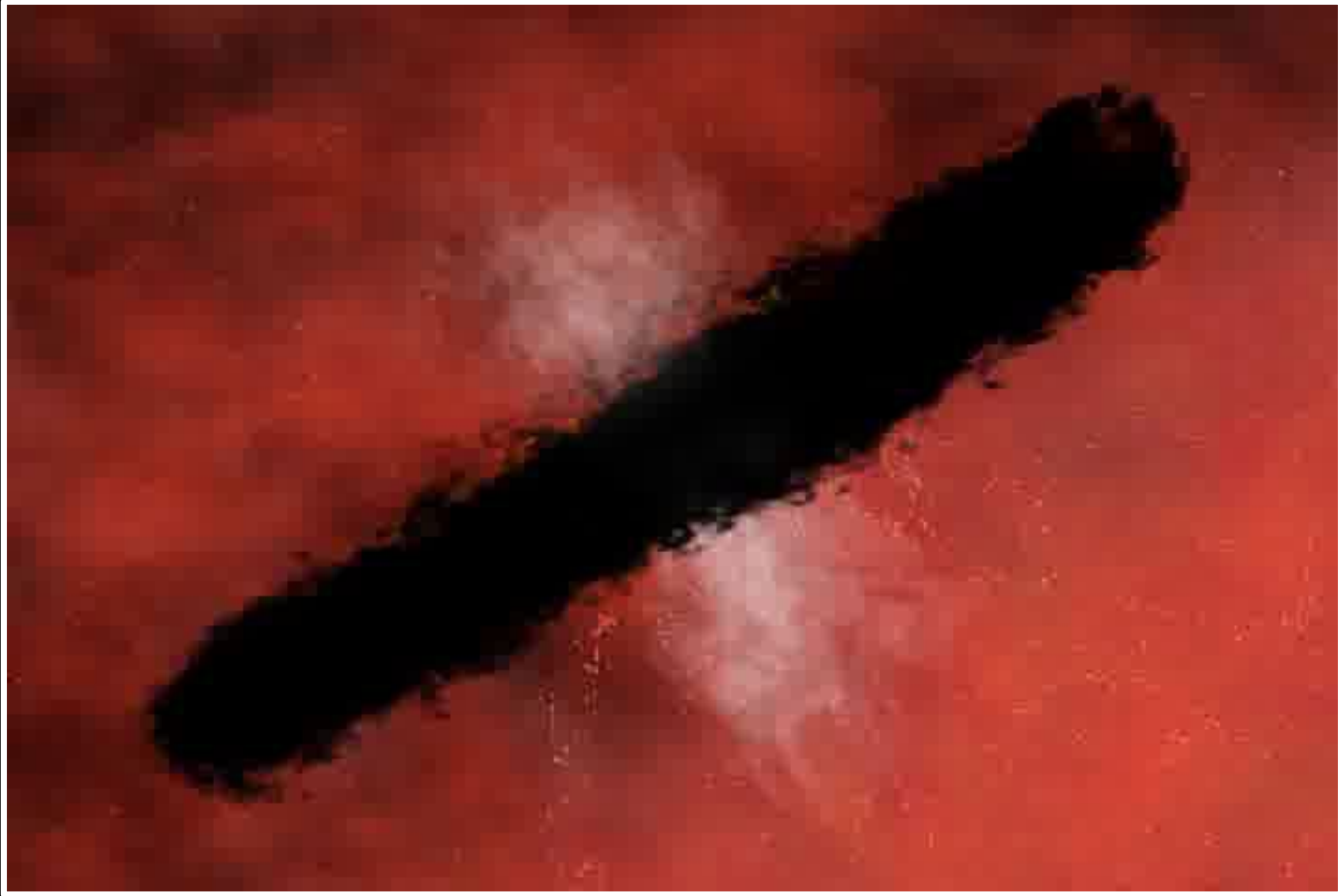


A 4x6 grid of 24 astronomical images showing various stages of a comet's outburst. The images display the comet's nucleus, coma, and tail against a dark background, with some images showing bright, glowing regions and others showing faint, diffuse structures.

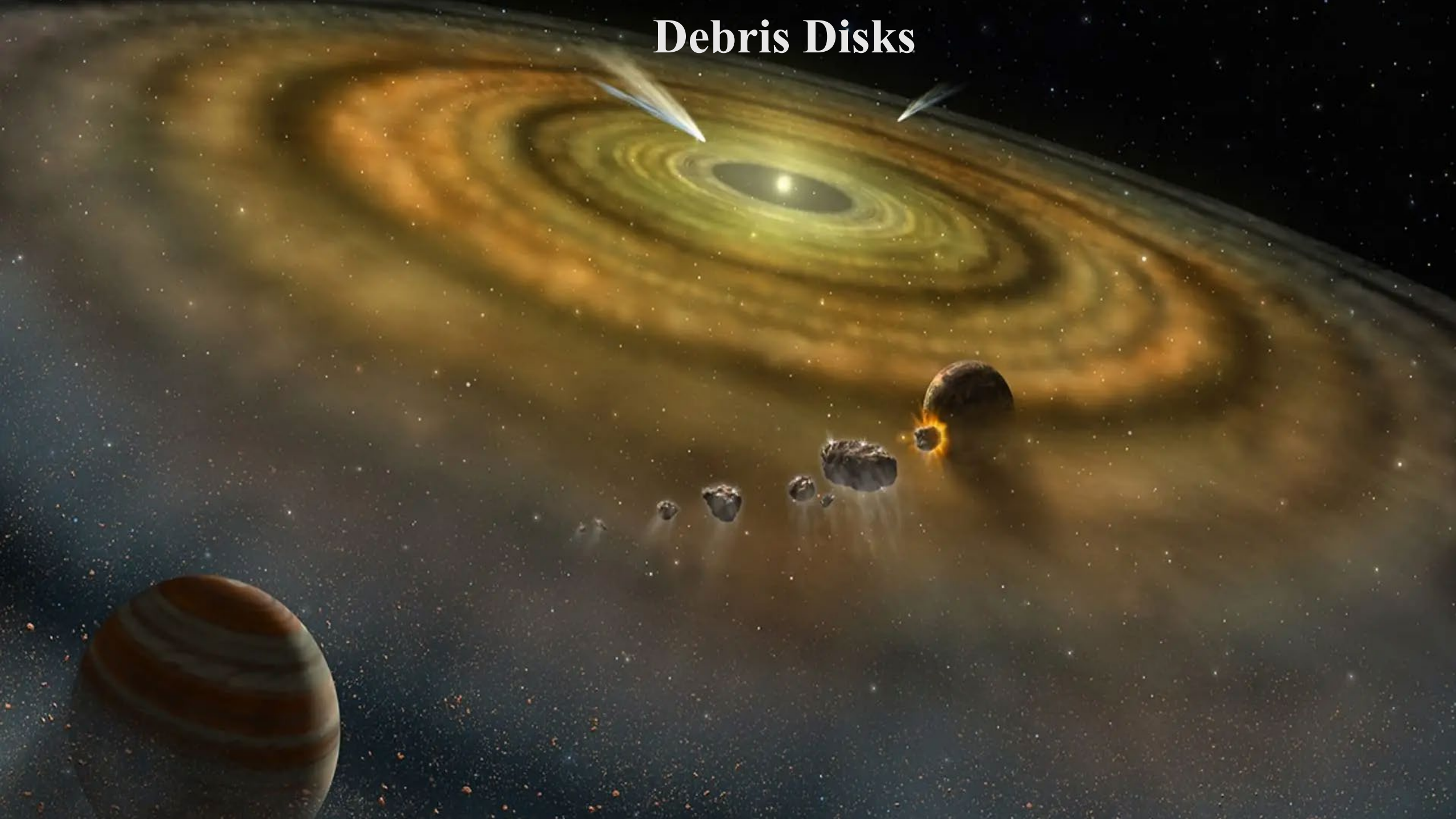
Protoplanetary Disks



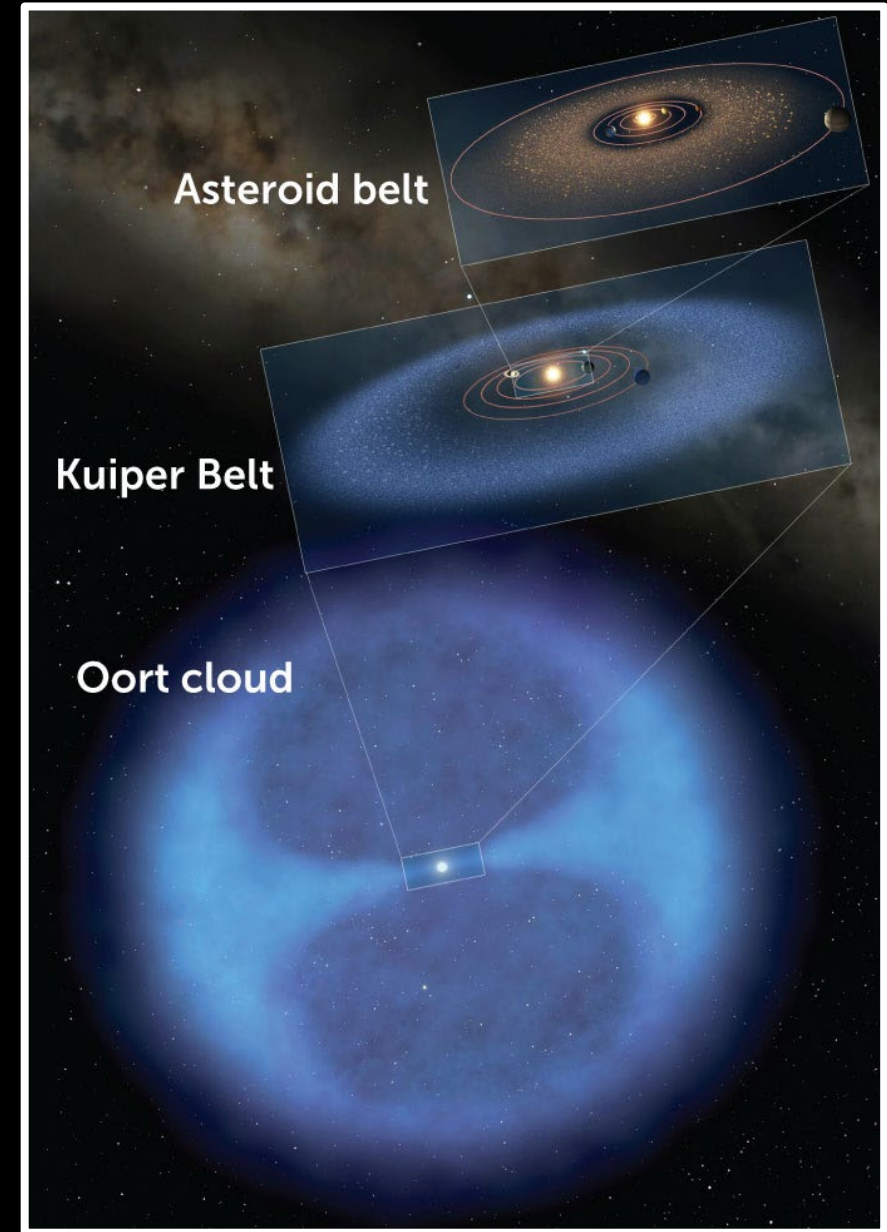
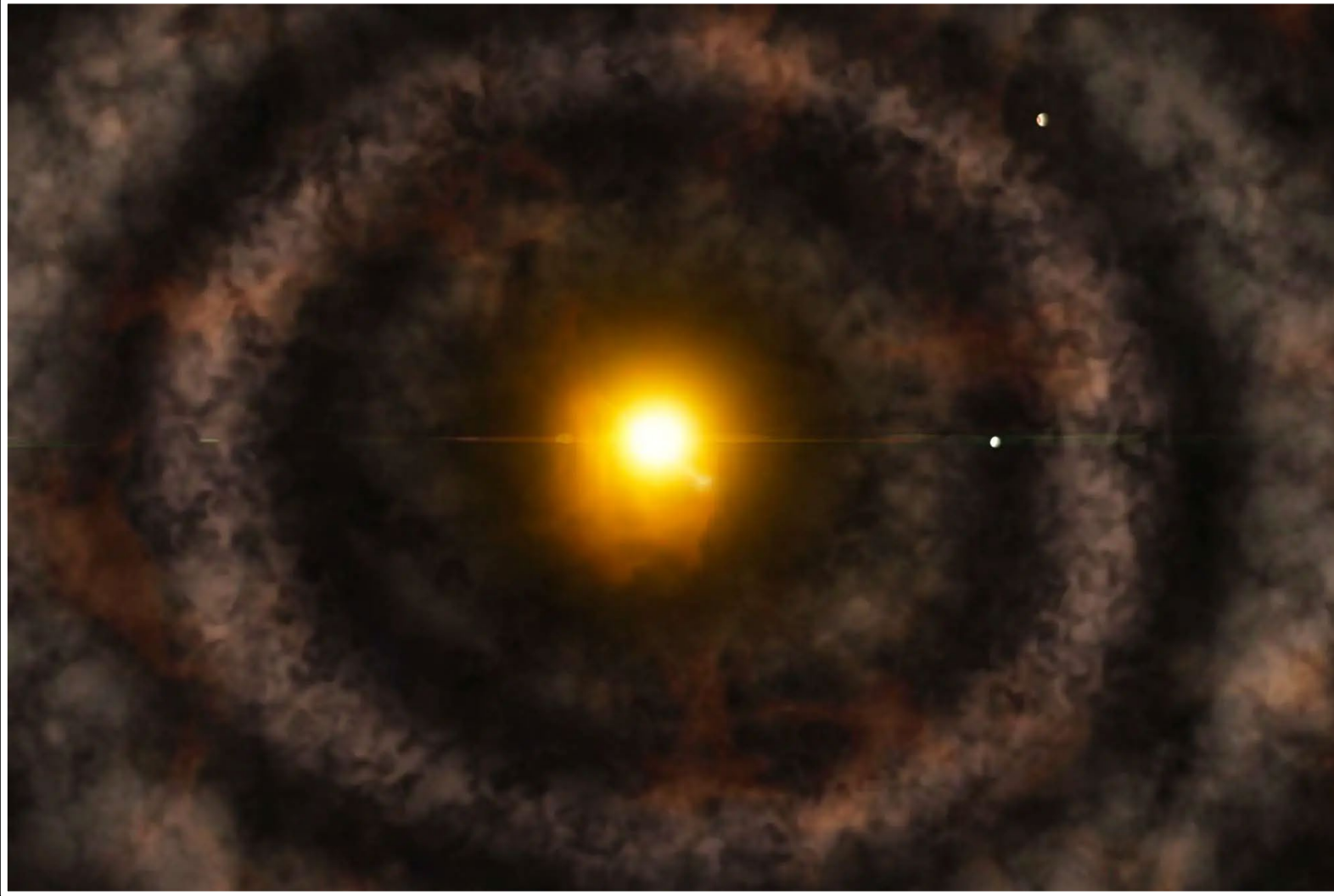
Formation of a Protoplanetary Disk Around a Sun-sized Star



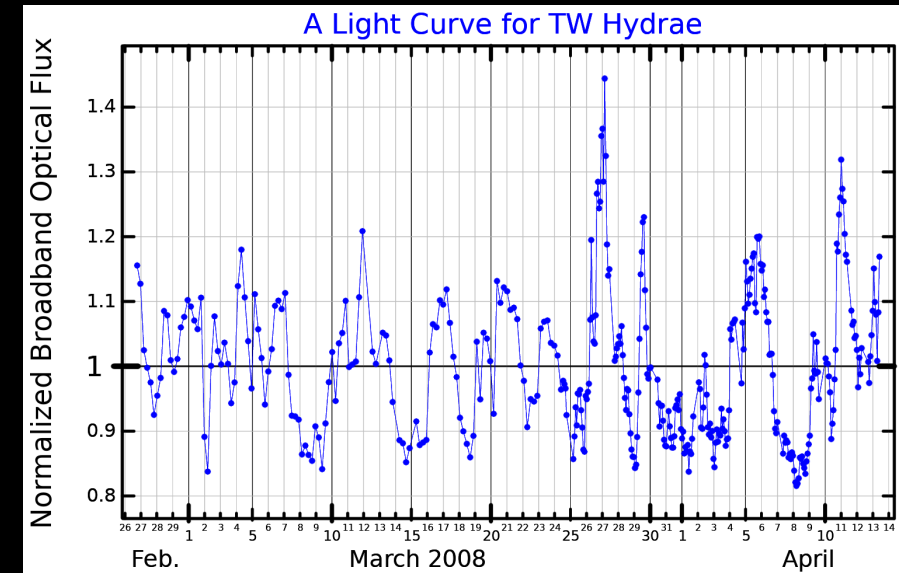
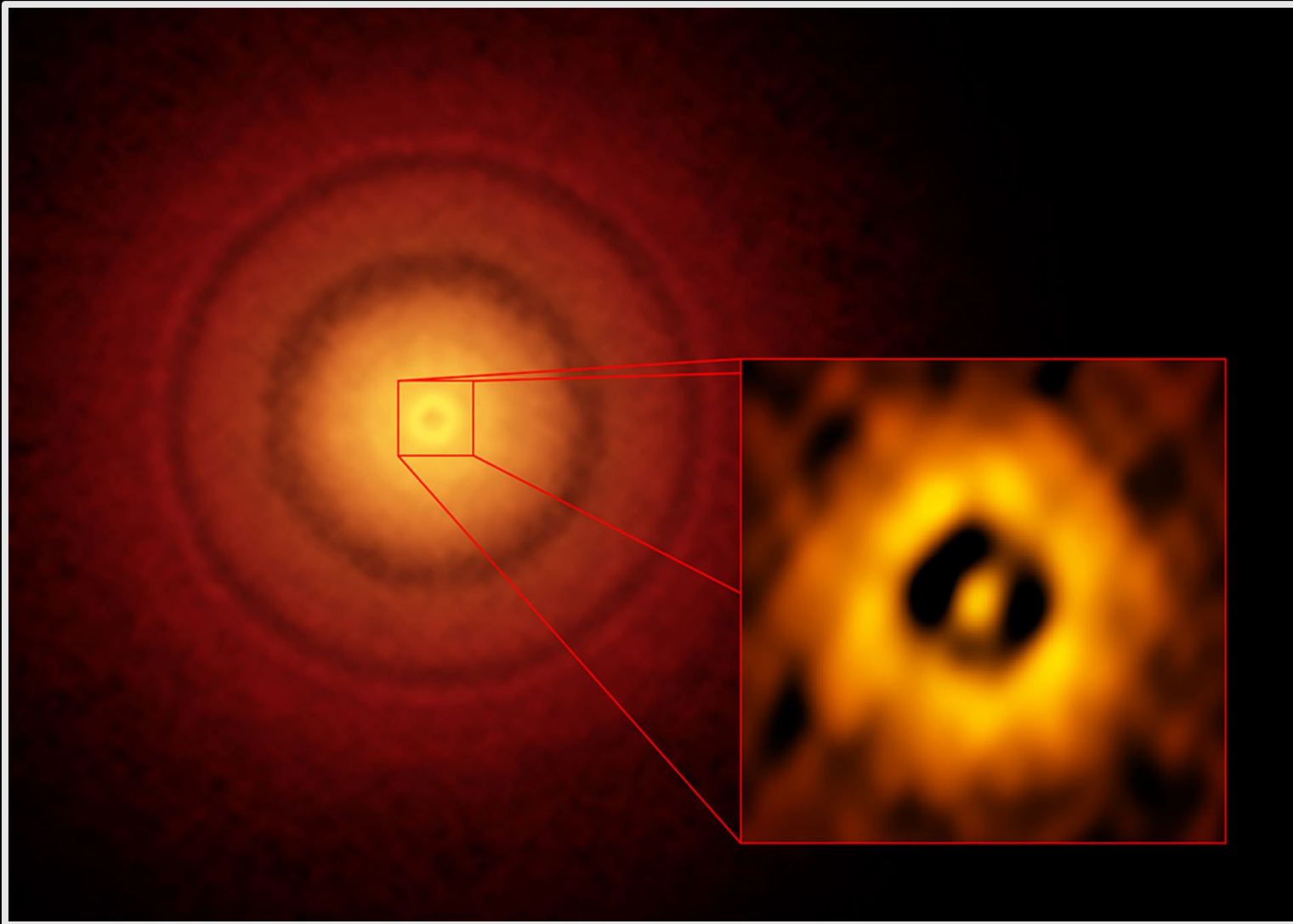
Debris Disks



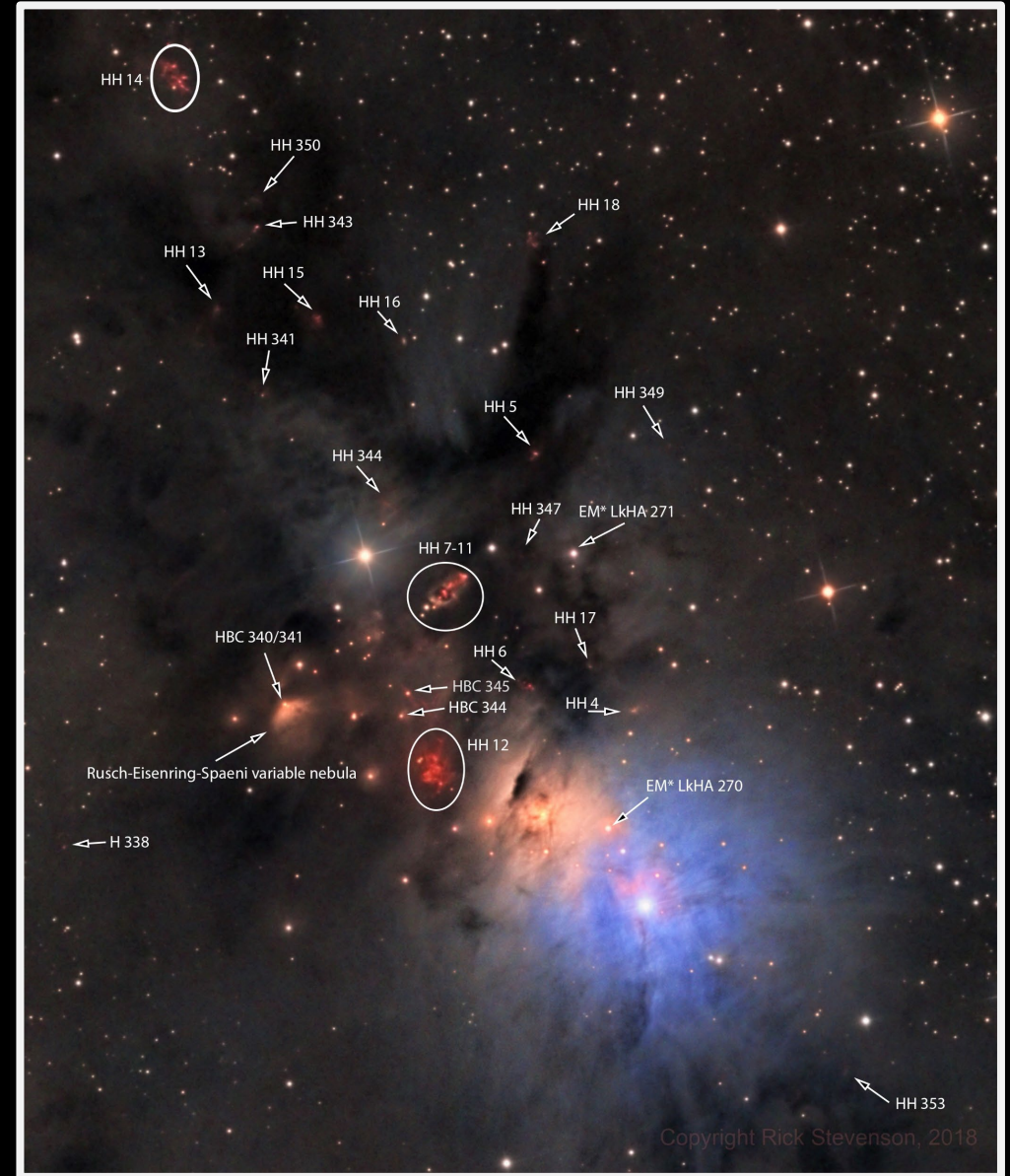
Debris Disks & the Solar System



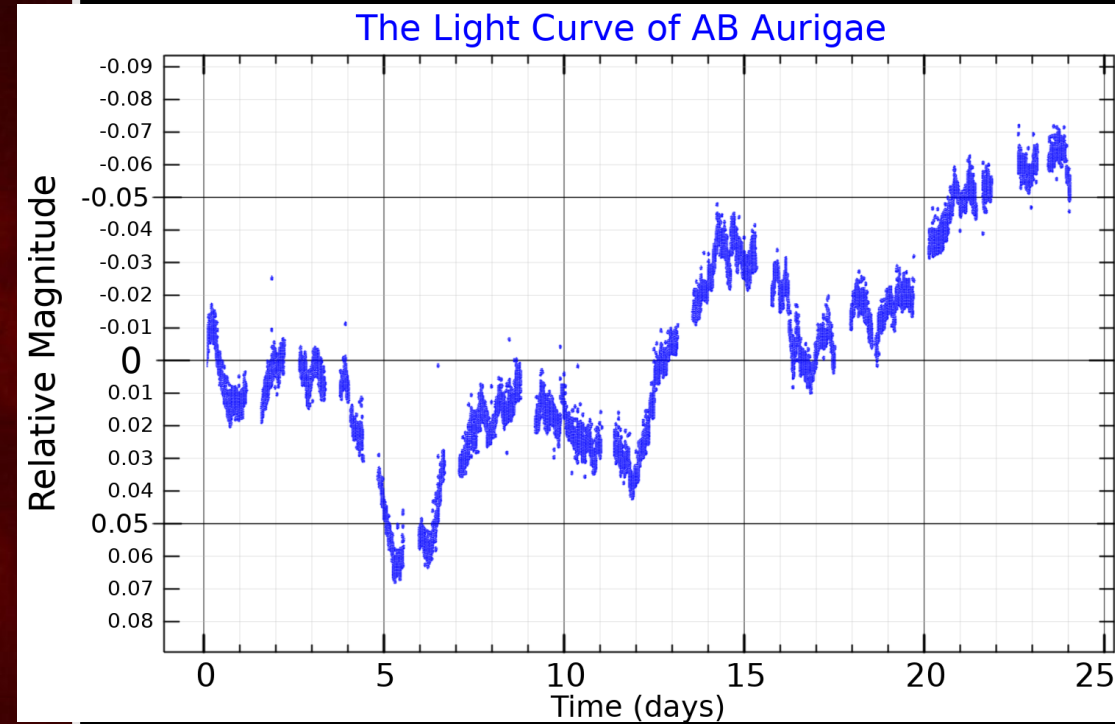
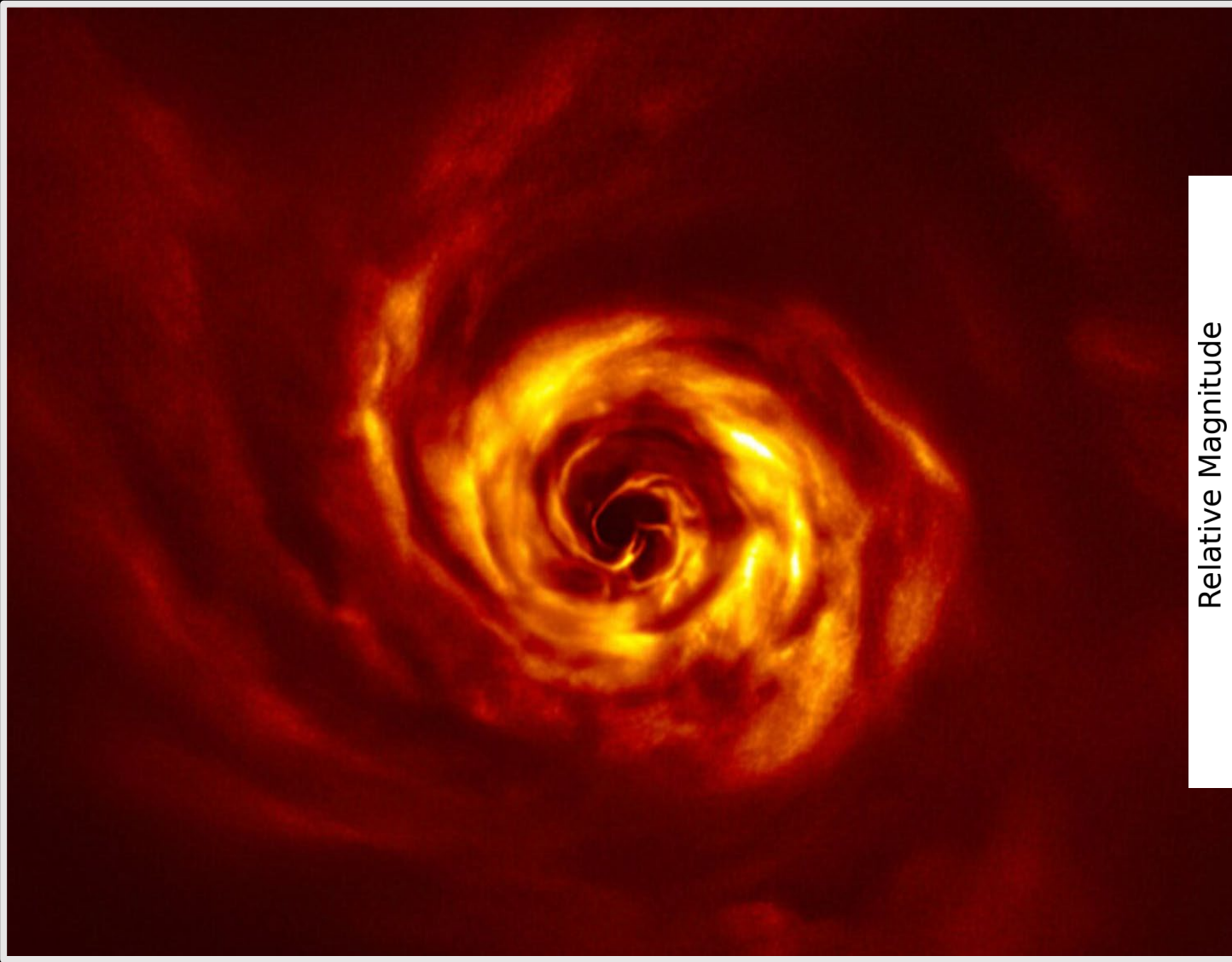
Pre-Main Sequence Star: TW Hya – Classical T Tauri



Pre-Main Sequence Star: HH 7-11 – Herbig-Haro Object



Pre-Main Sequence Star: AB Aurigae – Herbig AE



Pre-Main Sequence Star: HD 169142 – Herbig Ae/Be

2015-05-03

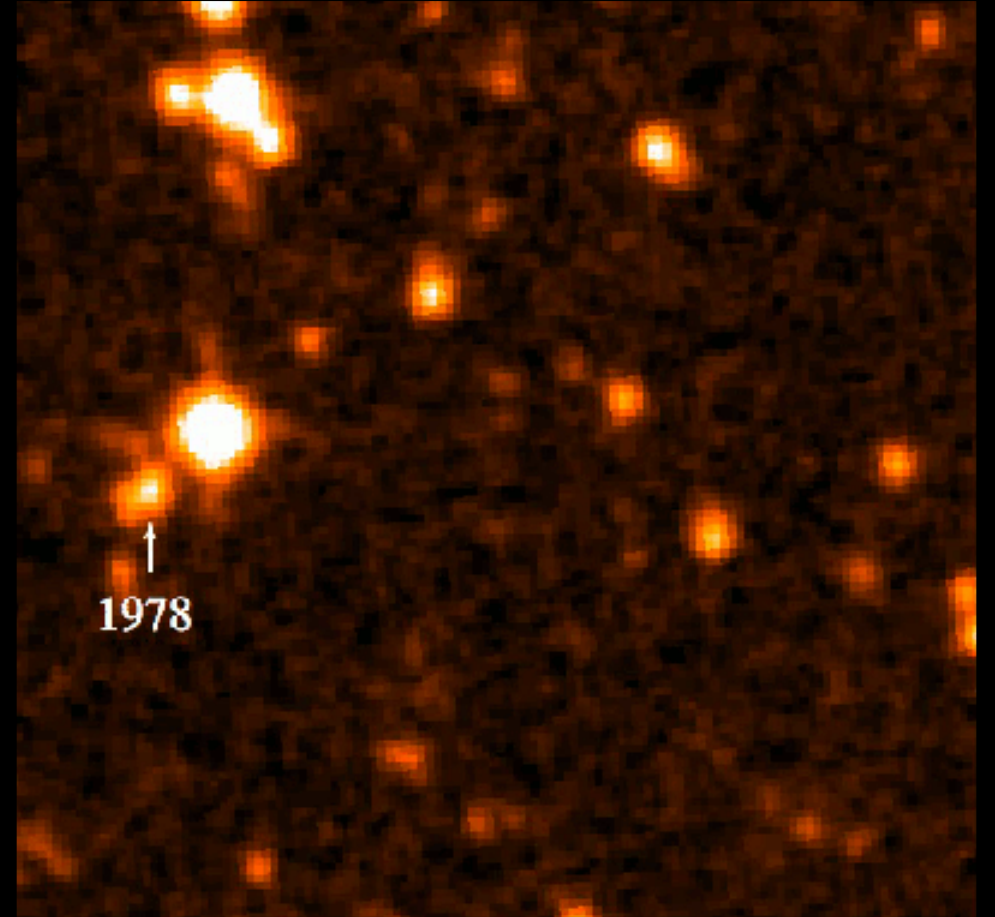
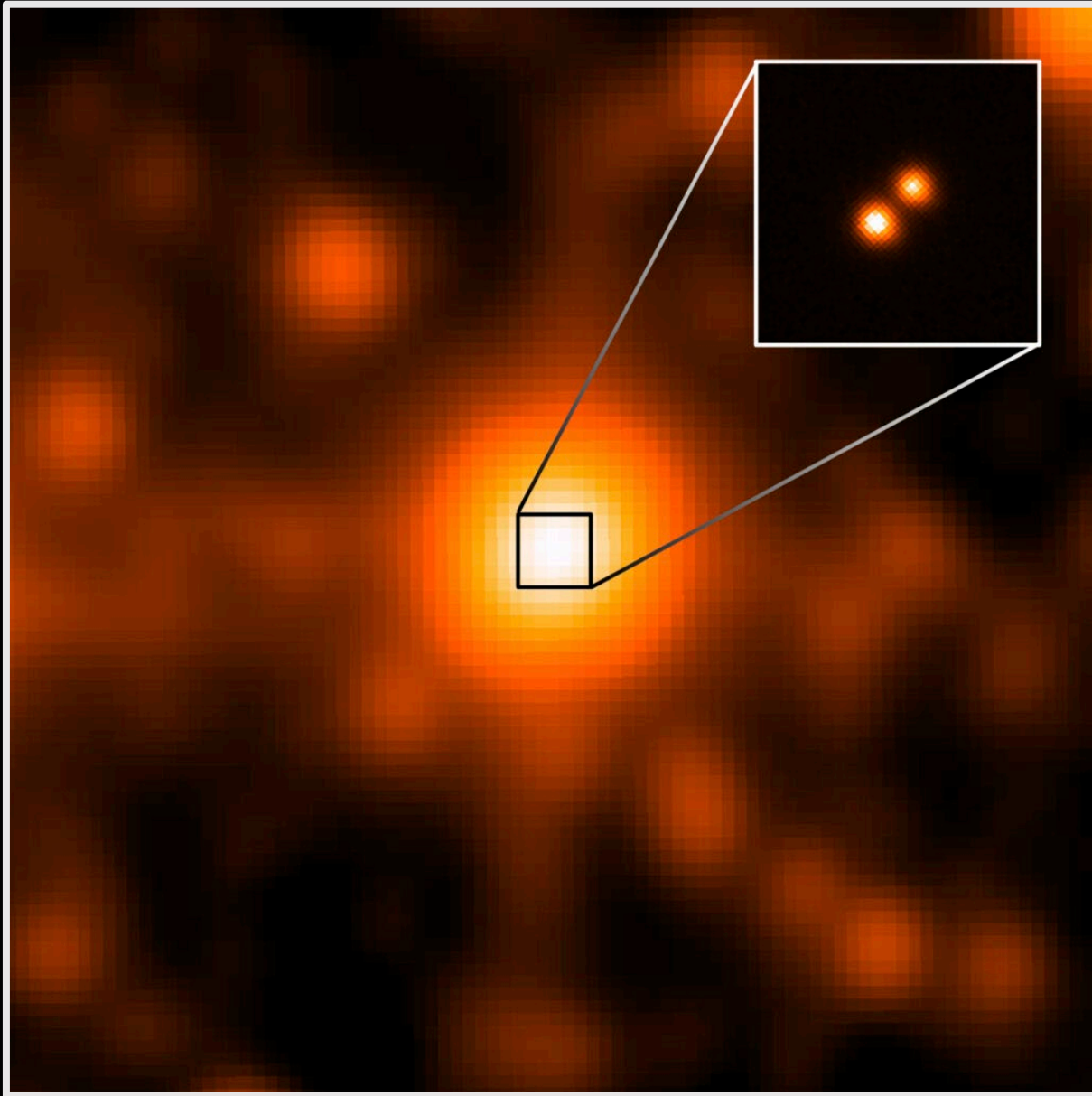


Size of the Solar System

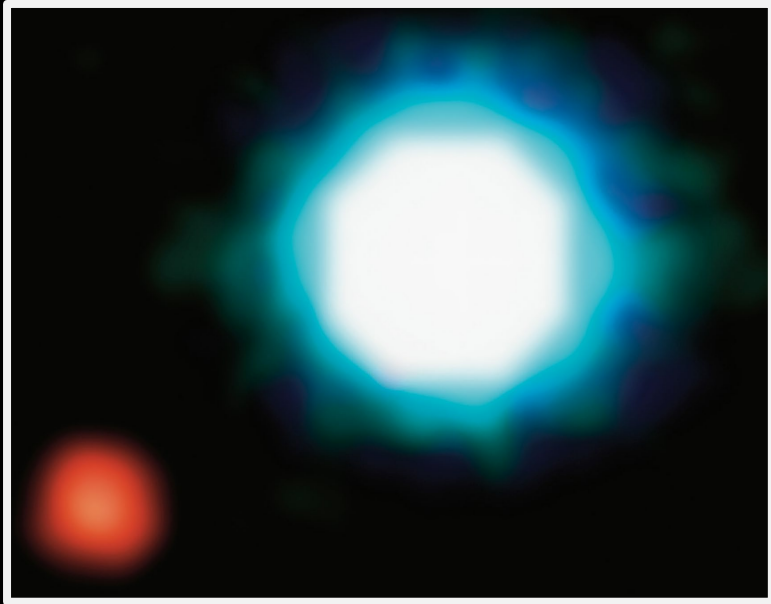
Forming planet

Planet-induced spiral

Brown Dwarf Binary System: Luhman 16 A & B



Brown Dwarf & Planetary Companion: 2M1207 System



2M1207A
HST WFC3/IR
F160W *H*

52 AU 1"

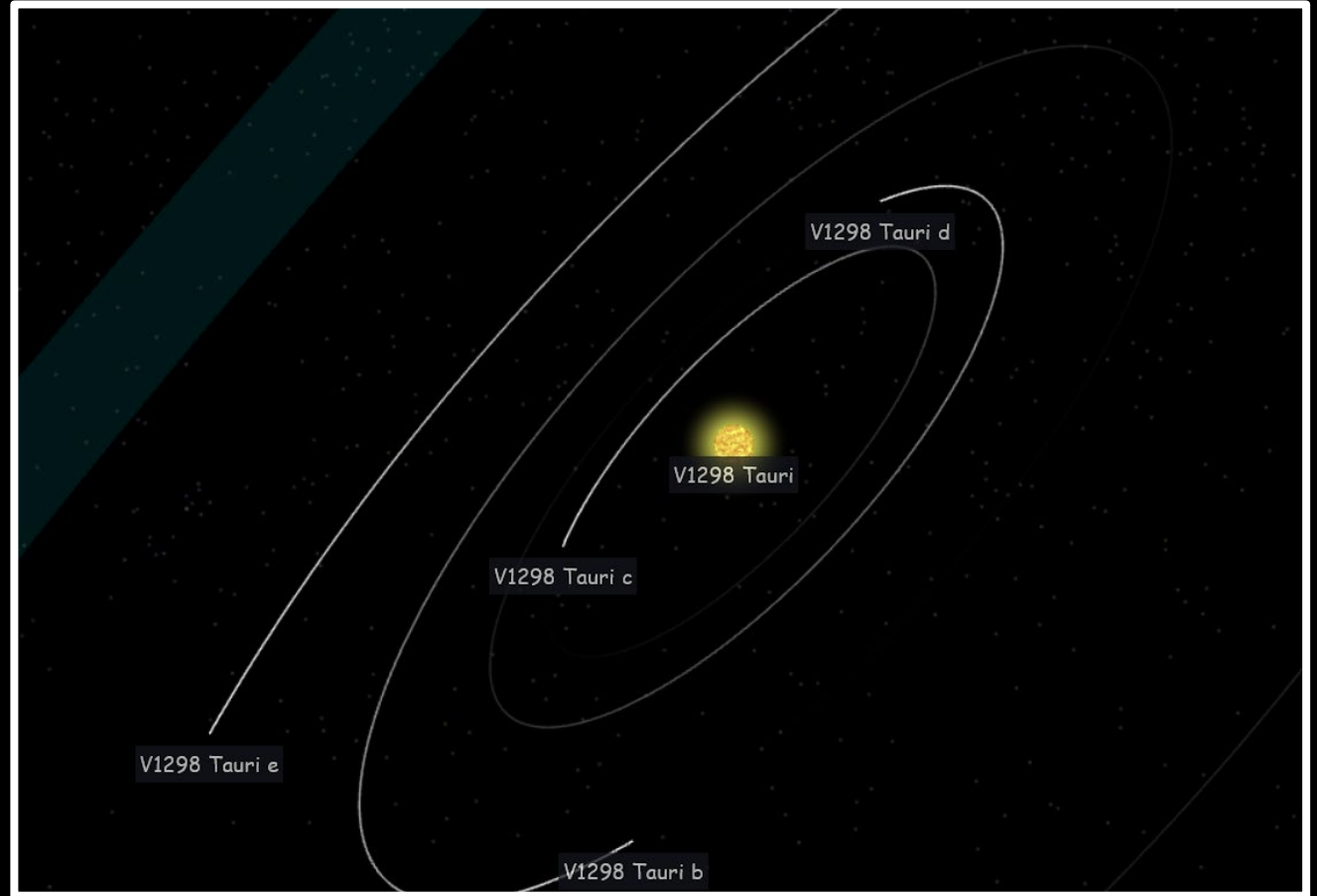
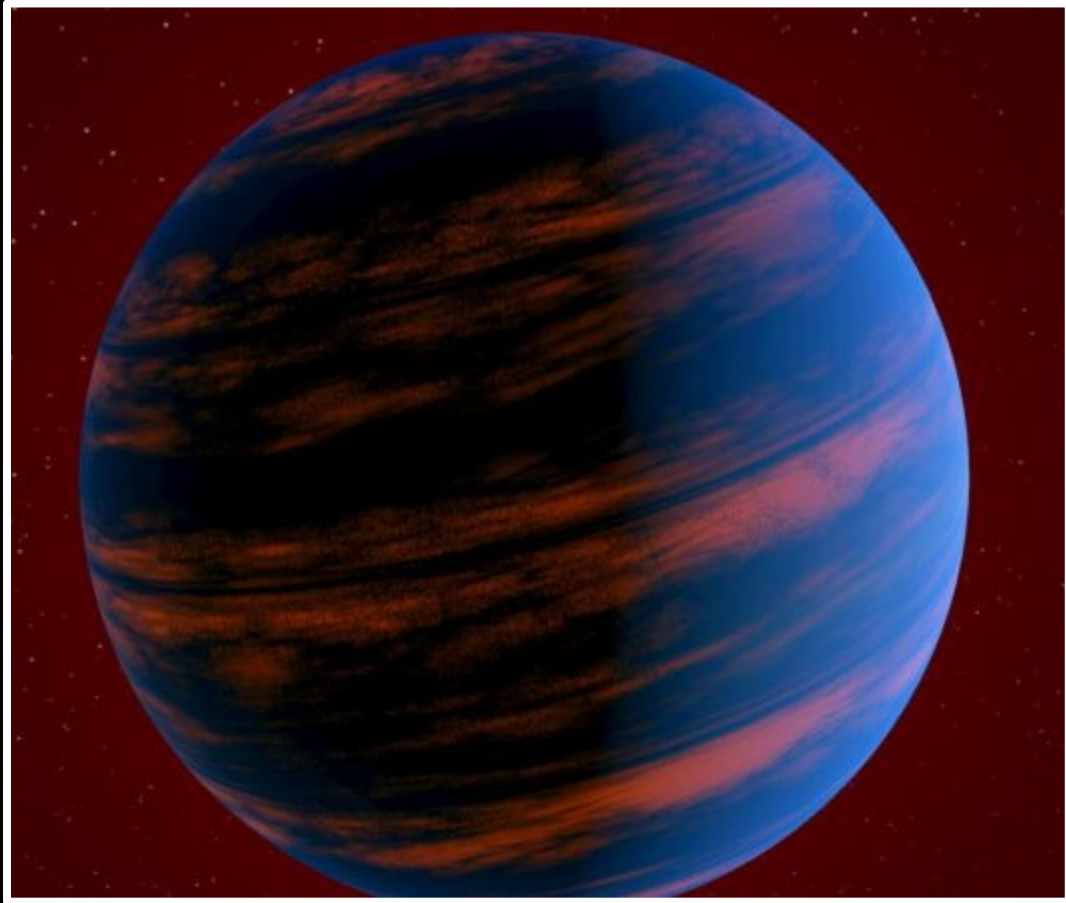
location of
companion

size of Uranus's orbit

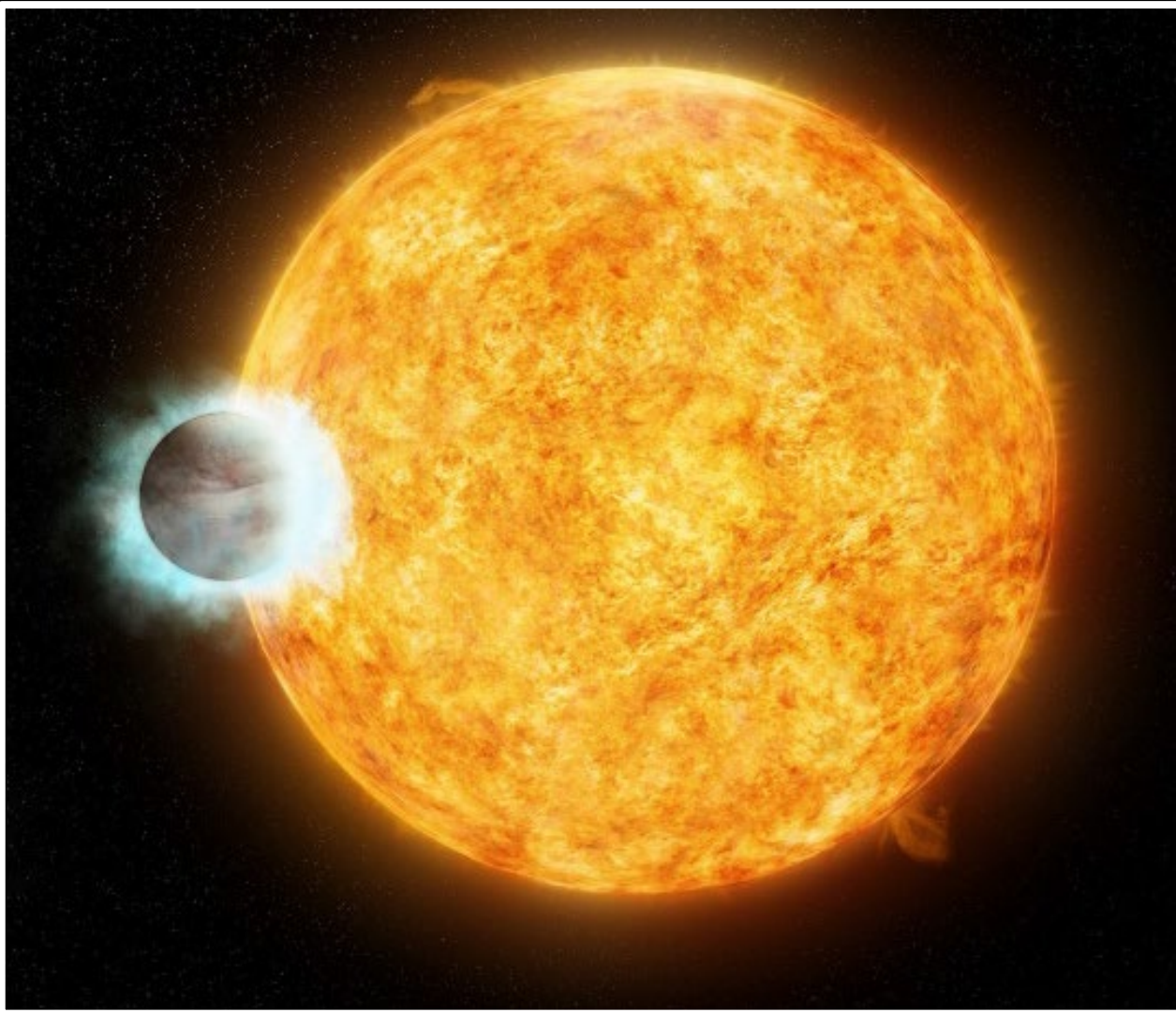
2M1207b
HST WFC3/IR
F160W *H*

location of
2M1207A
+

Gas Giant: V1298 Tau b



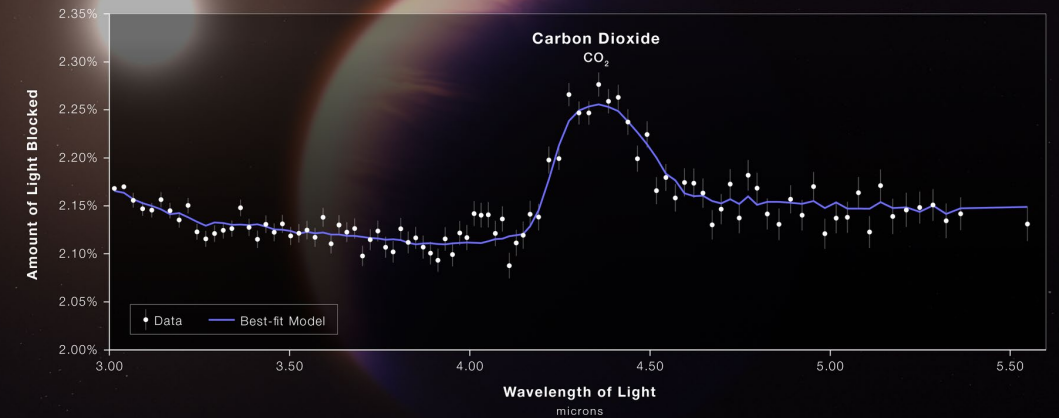
Gas Giant: WASP-18b



HOT GAS GIANT EXOPLANET WASP-39 b

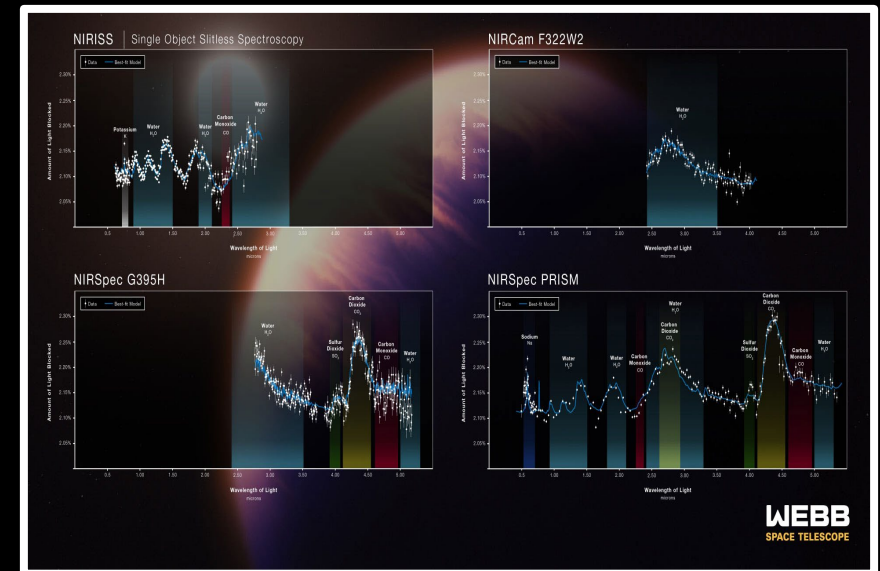
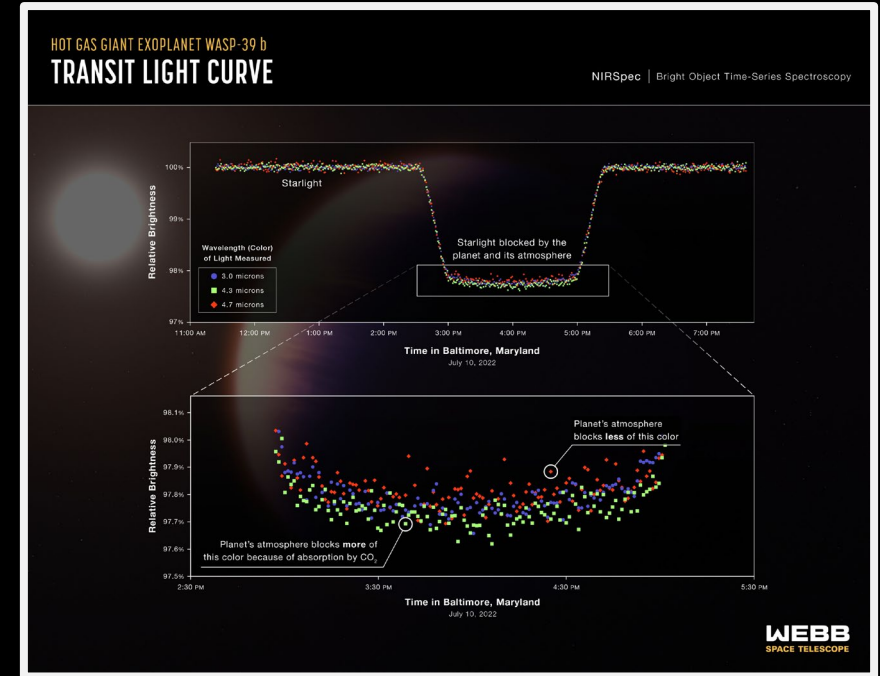
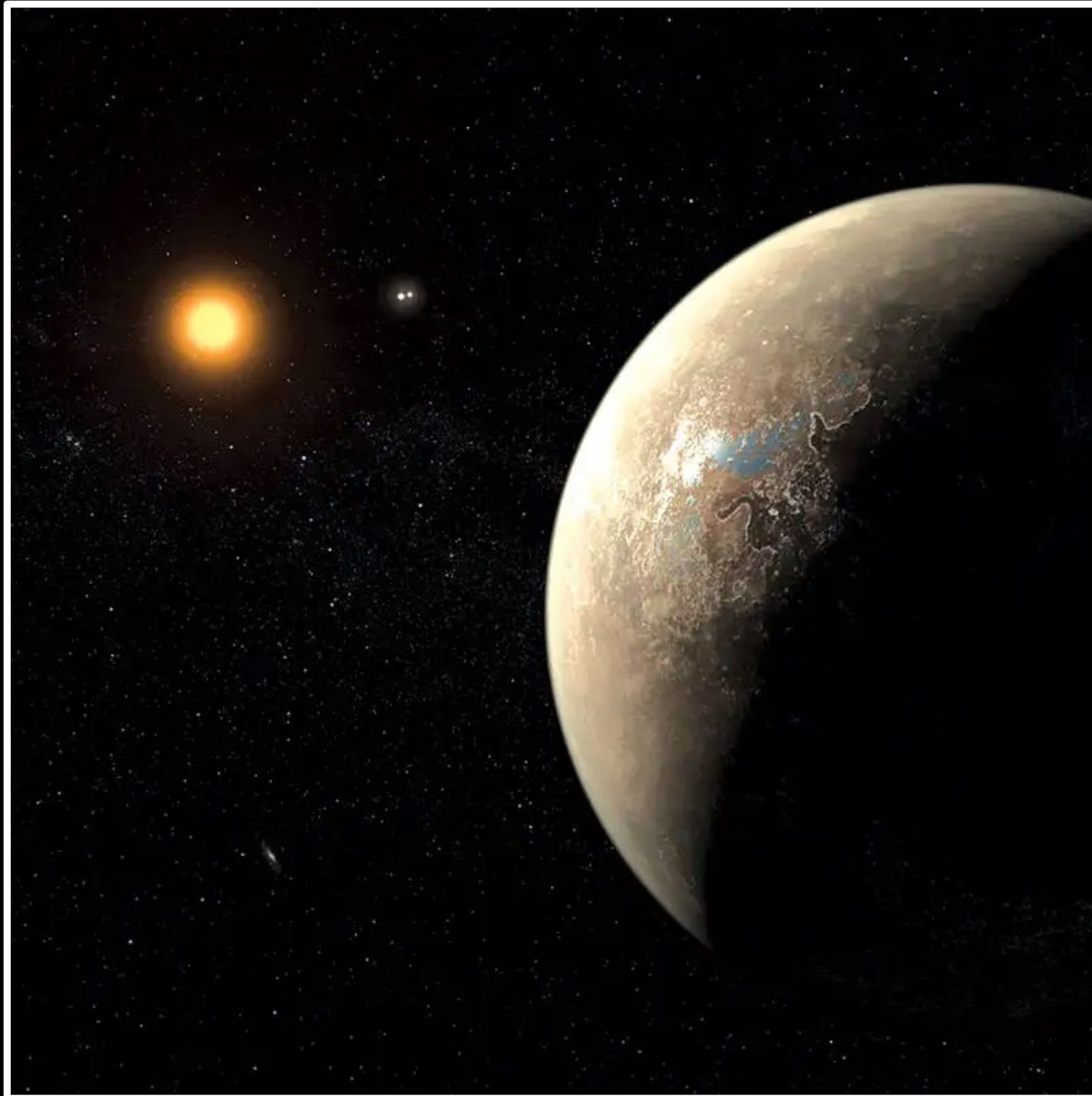
ATMOSPHERE COMPOSITION

NIRSpec | Bright Object Time-Series Spectroscopy

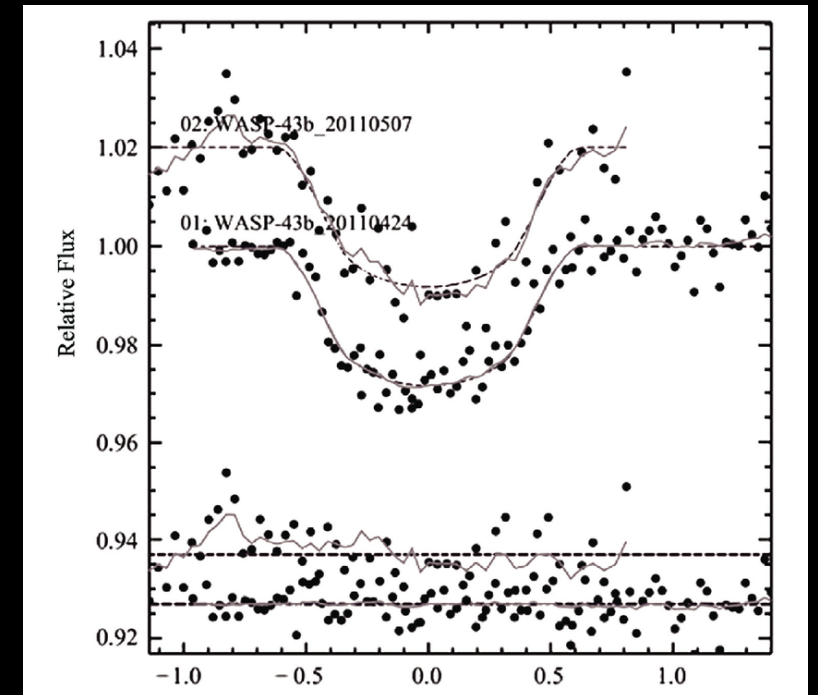
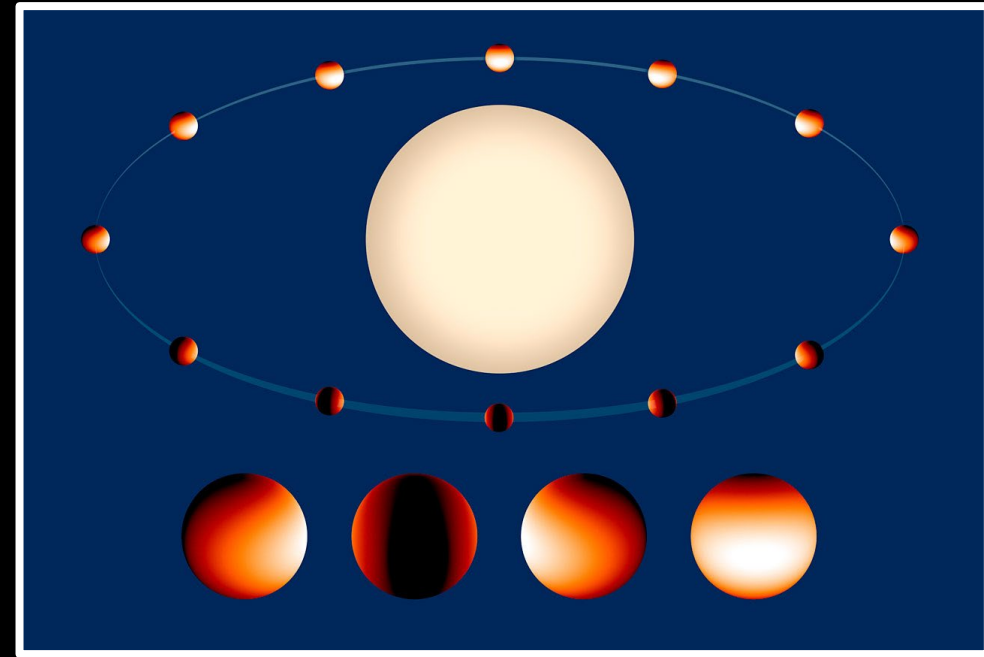


WEBB
SPACE TELESCOPE

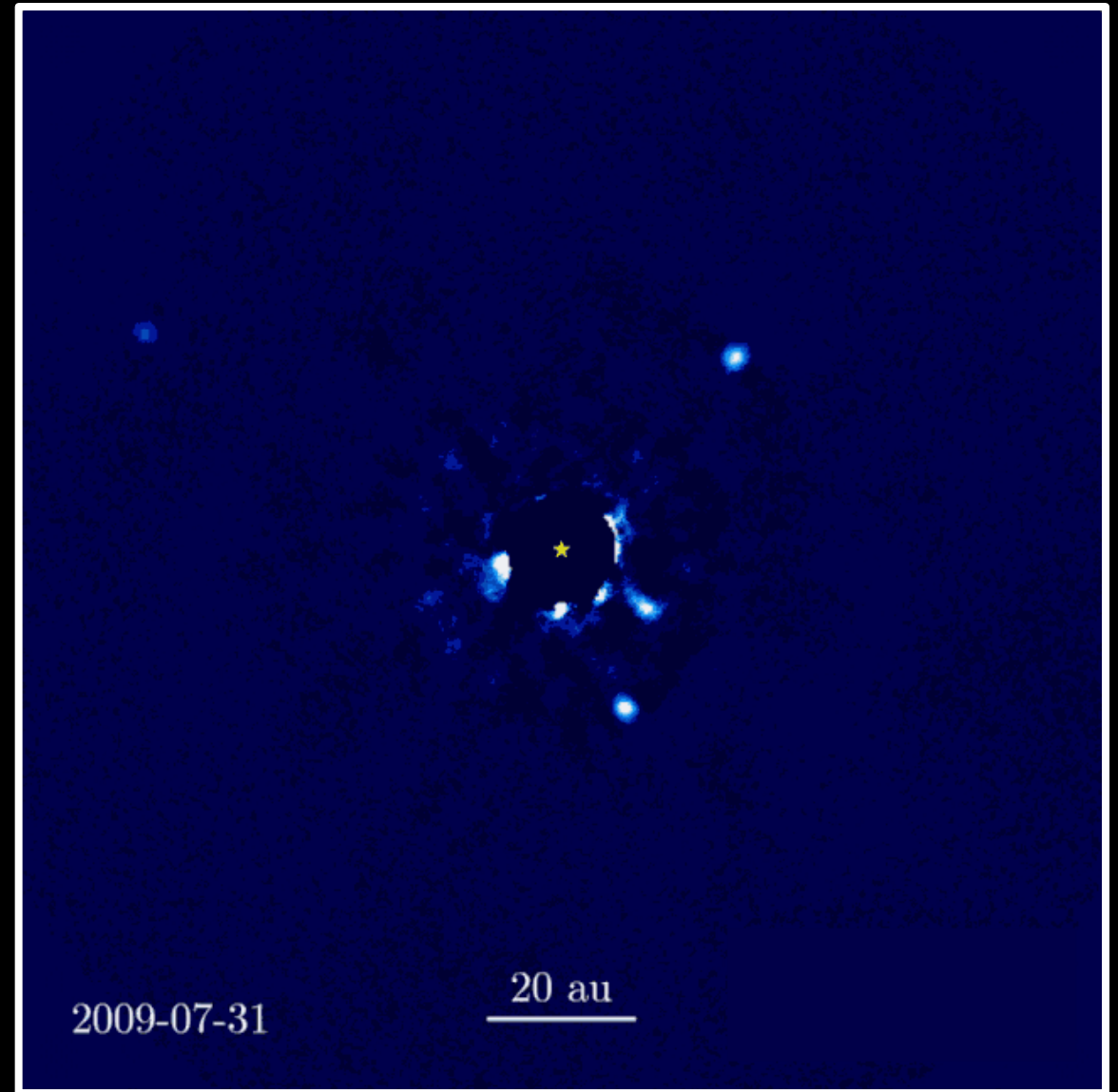
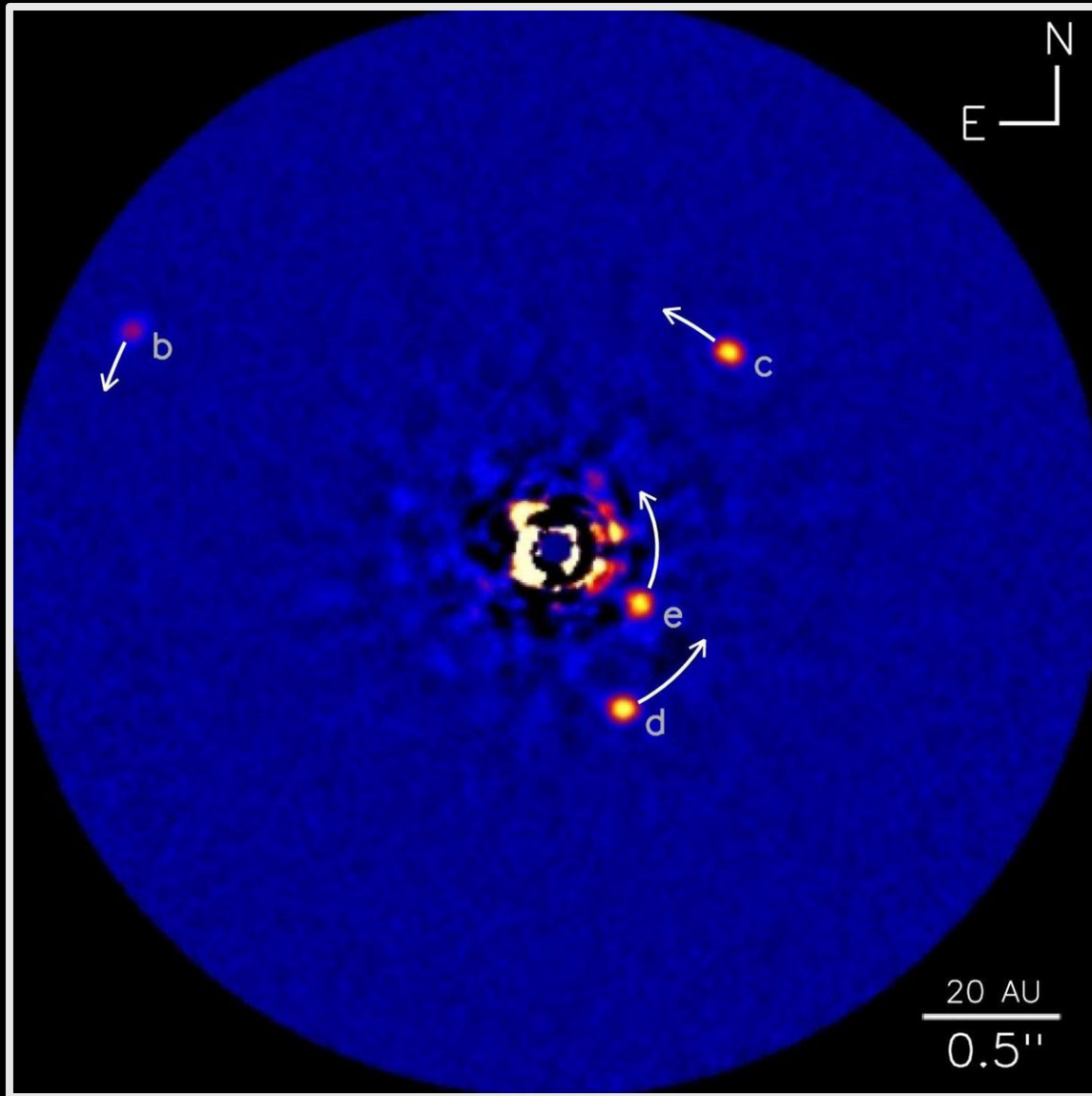
Gas Giant: WASP-39b



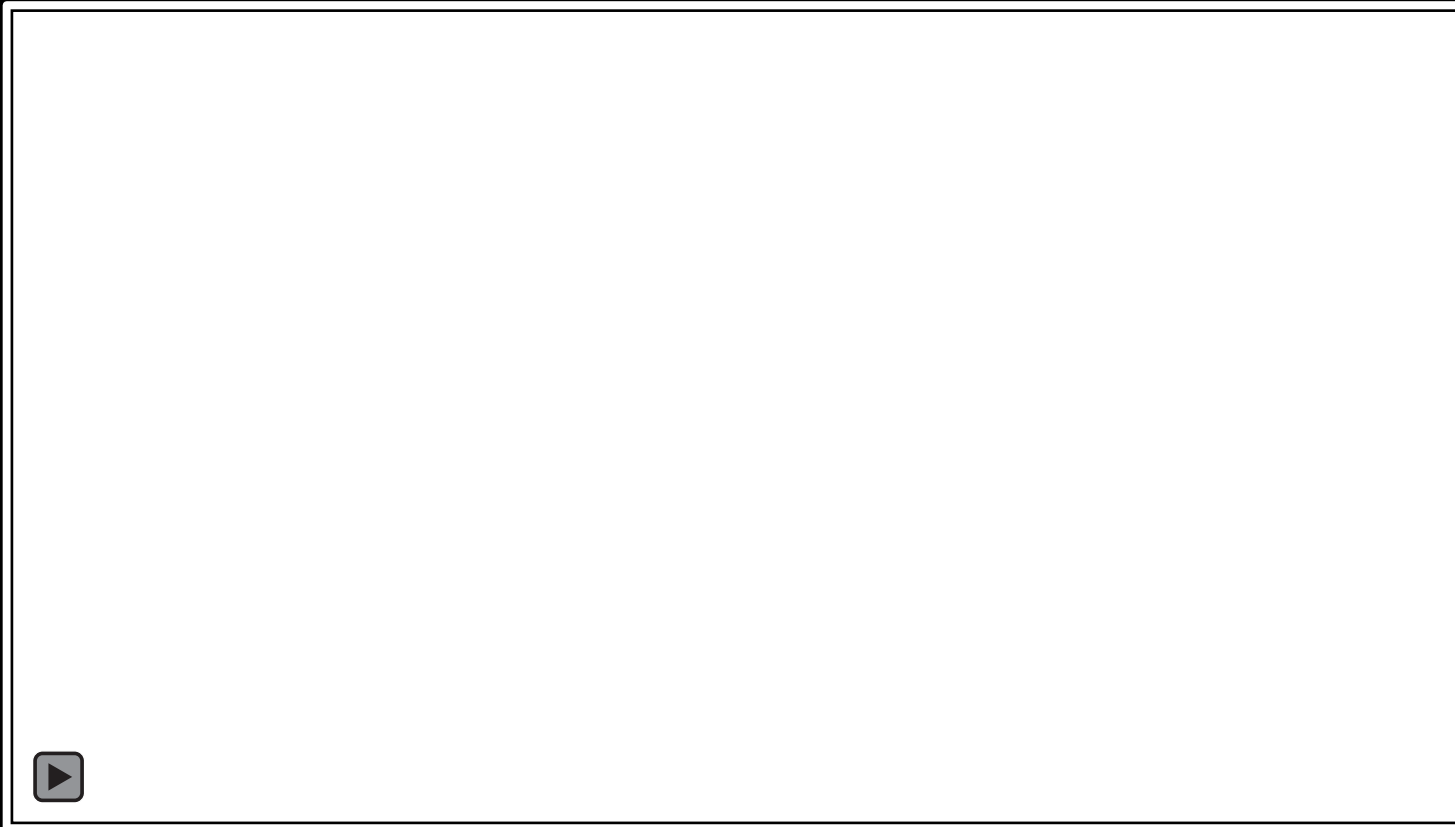
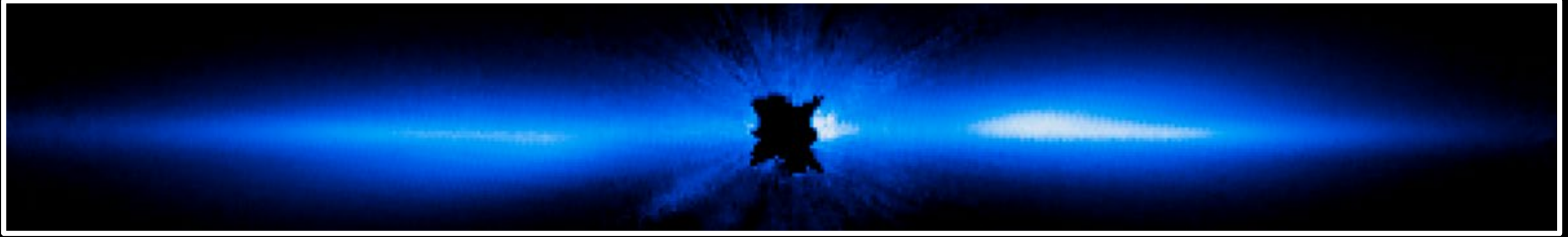
Gas Giant: WASP-43b



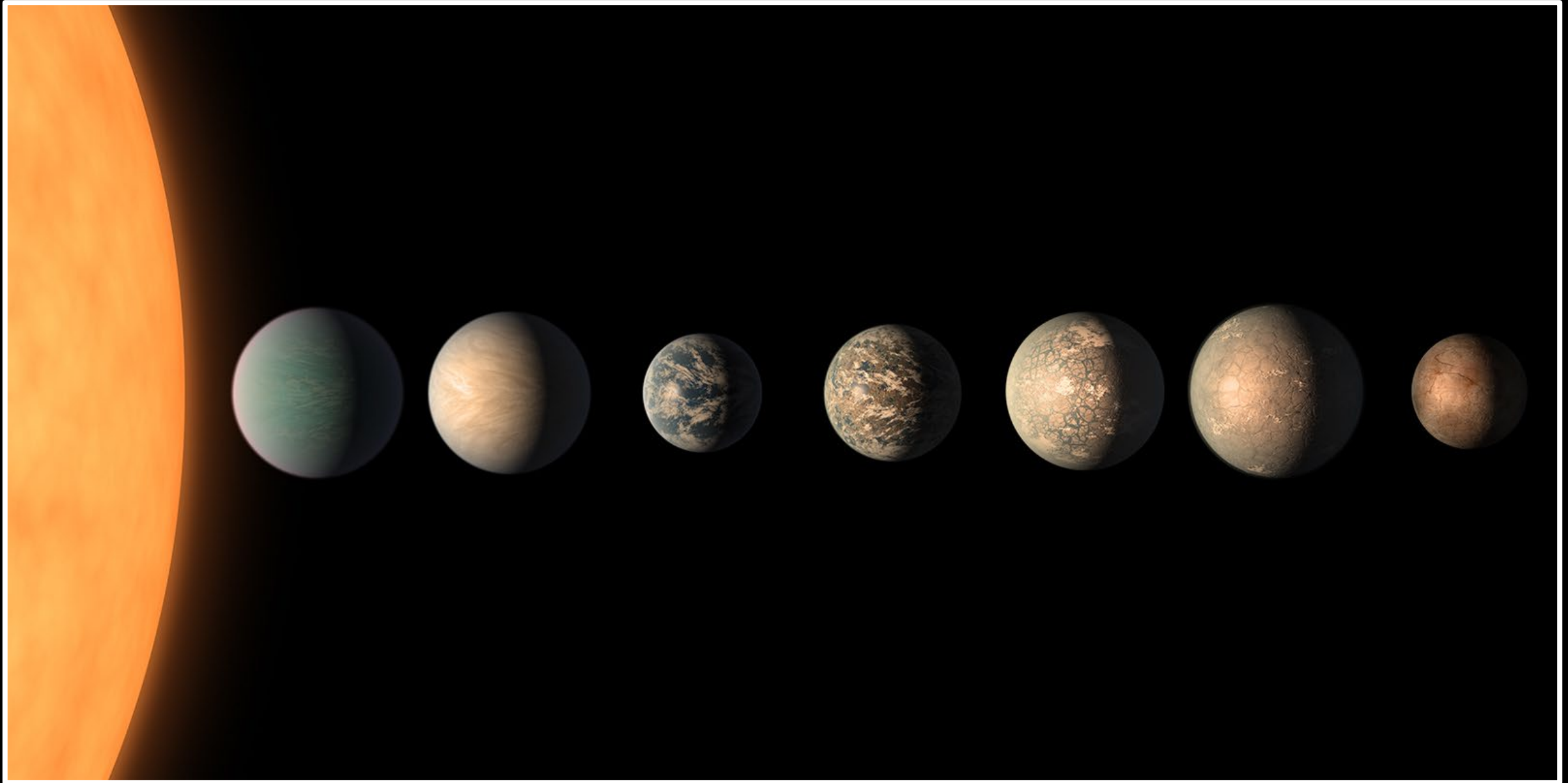
Gas Giant: HR 8799



Gas Giant: Beta Pictoris System



Terrestrial Planet System: TRAPPIST-1





Radial Velocity 913

Transit 3846

Imaging 58

Microlensing 129

Year: 2022

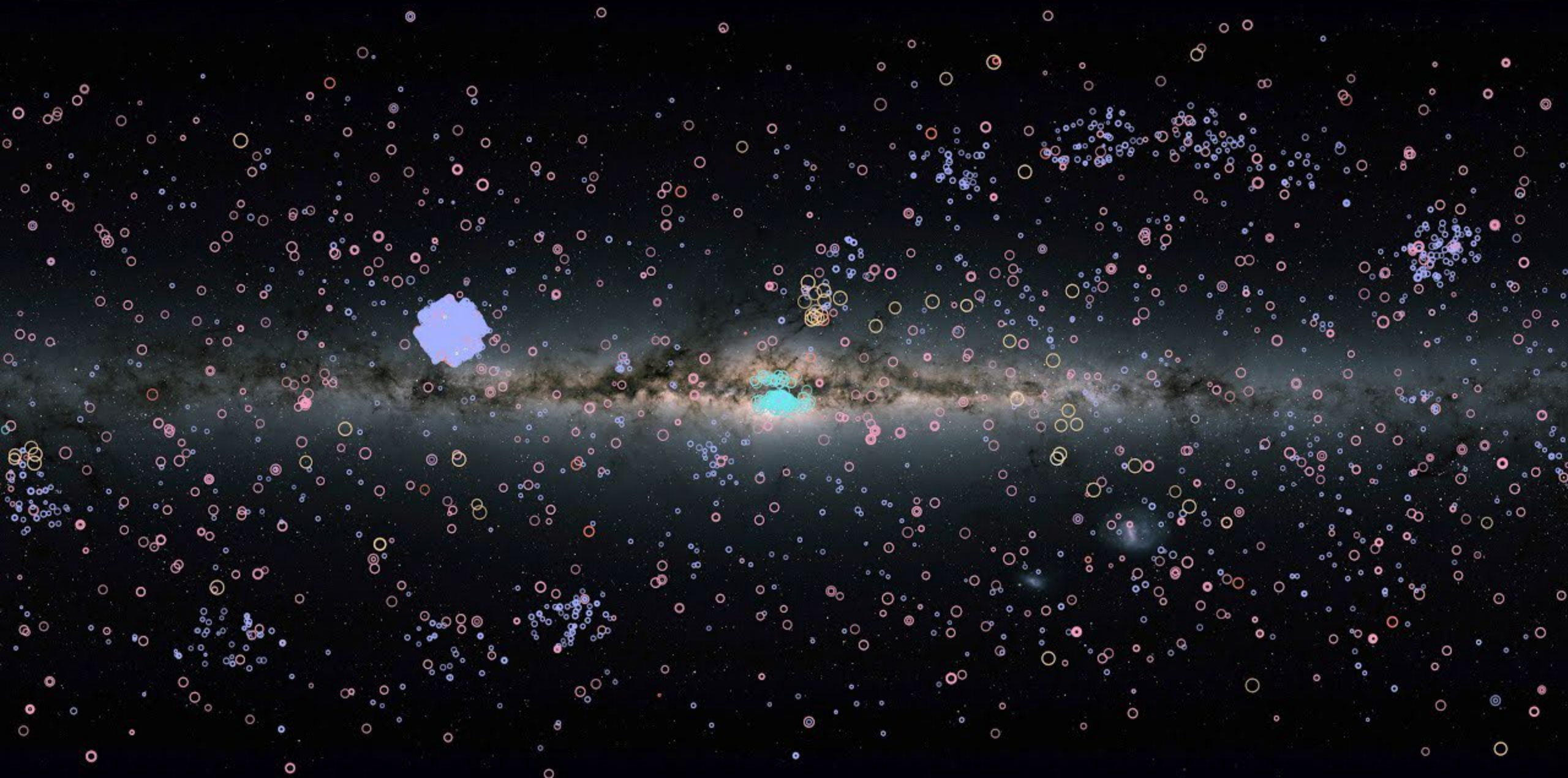
Exoplanets: 5005

48 Timing Variations

9 Orbital Brightness Modulation

1 Astrometry

1 Disk Kinematics





5 Ways to Find a Planet

RADIAL VELOCITY

Watching for Wobble

1036 planets discovered

TRANSIT

Searching for Shadows

4079 planets discovered

DIRECT IMAGING

Taking Pictures

67 planets discovered

GRAVITATIONAL MICROLENSING

Light in a Gravity Lens

200 planets discovered

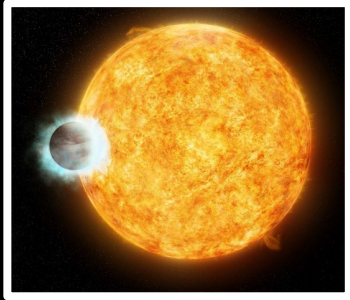
ASTROMETRY

Minuscule Movements

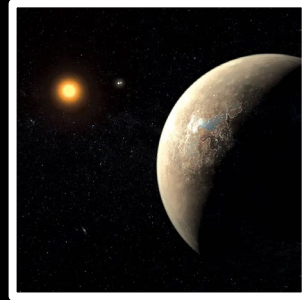
2 planets discovered

Methods of Detection for the DSO Exoplanets

WASP 18b
Transit Timing



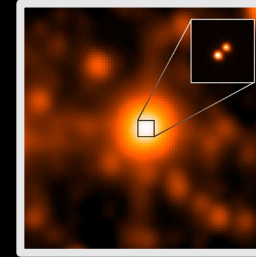
WASP-39b
Transit Timing



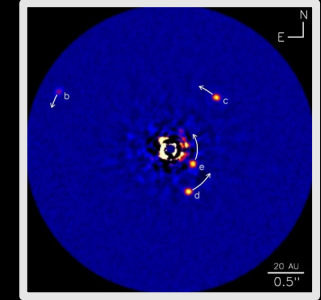
WASP 43b
Transit Timing



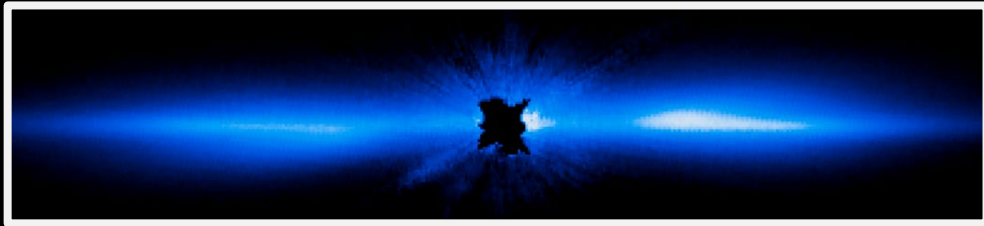
Luhman 16
Astrometry



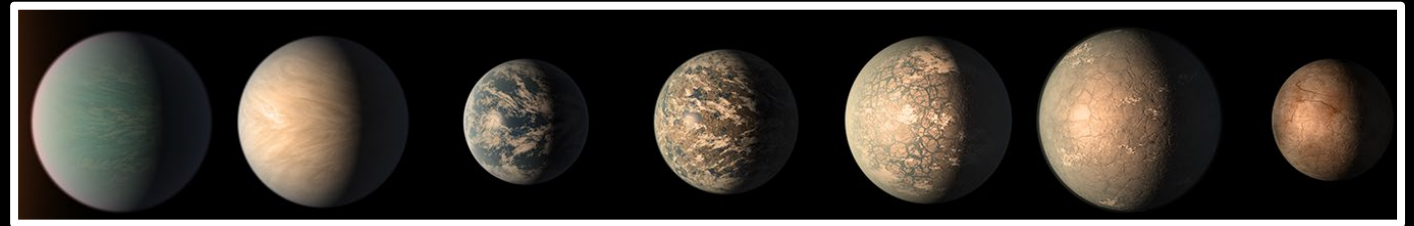
HR 8799
Direct Imaging



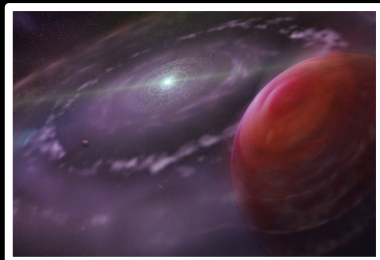
Beta Pictoris b
Direct Imaging



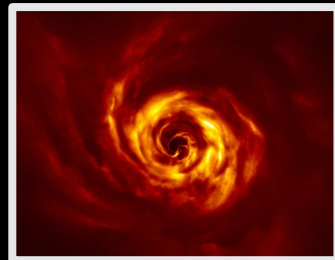
TRAPPIST-1 System
Transit



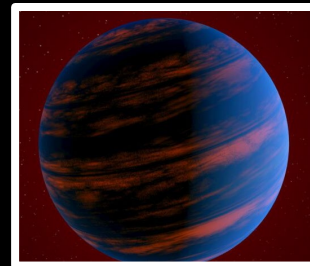
HR 8799
Direct Imaging



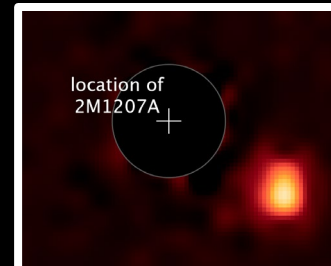
AB Aurigae
Direct Imaging



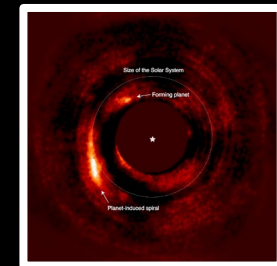
V1298 Tau b
Transit Timing



2M1207
Direct Imaging



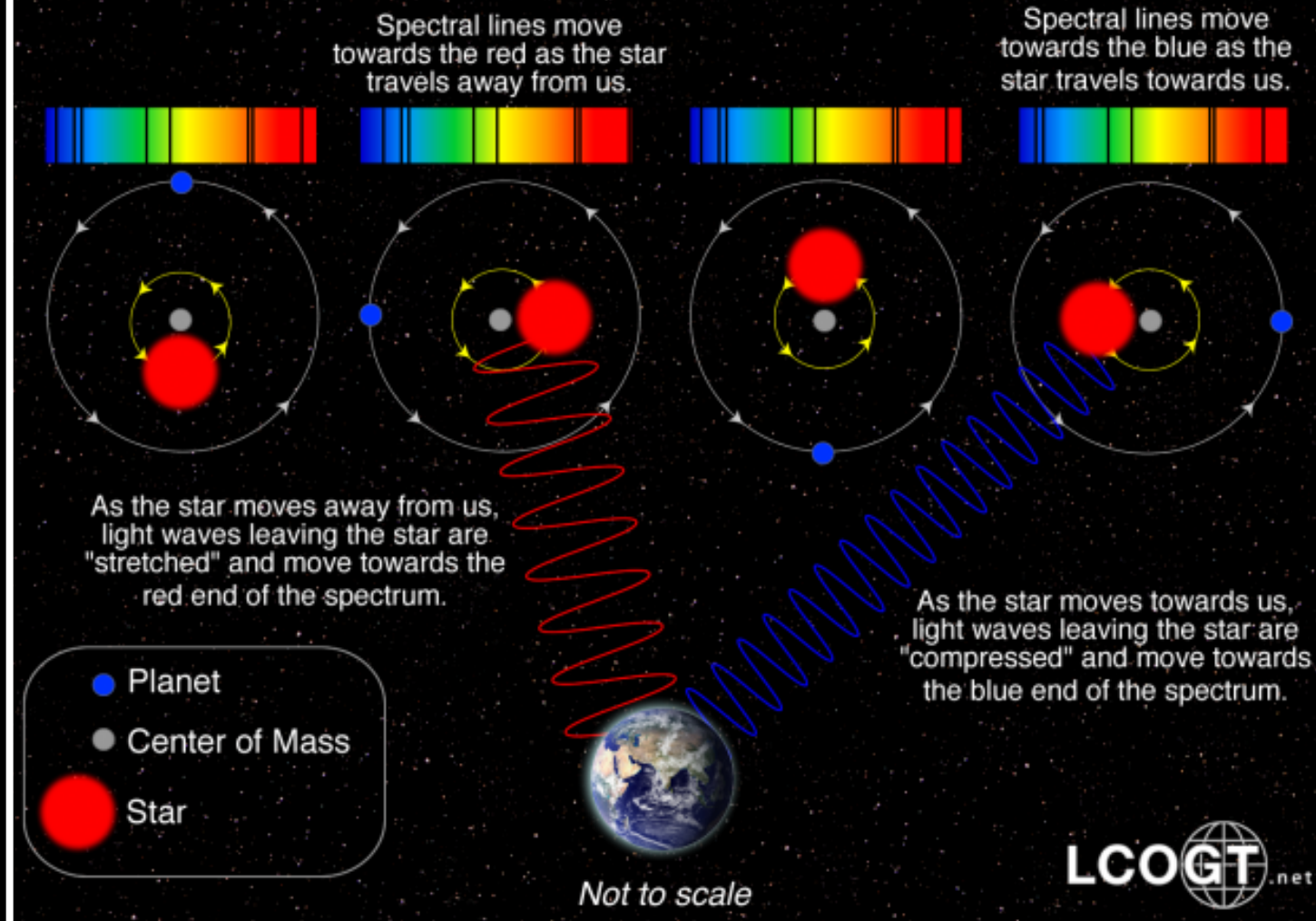
HD 169142
Direct Imaging



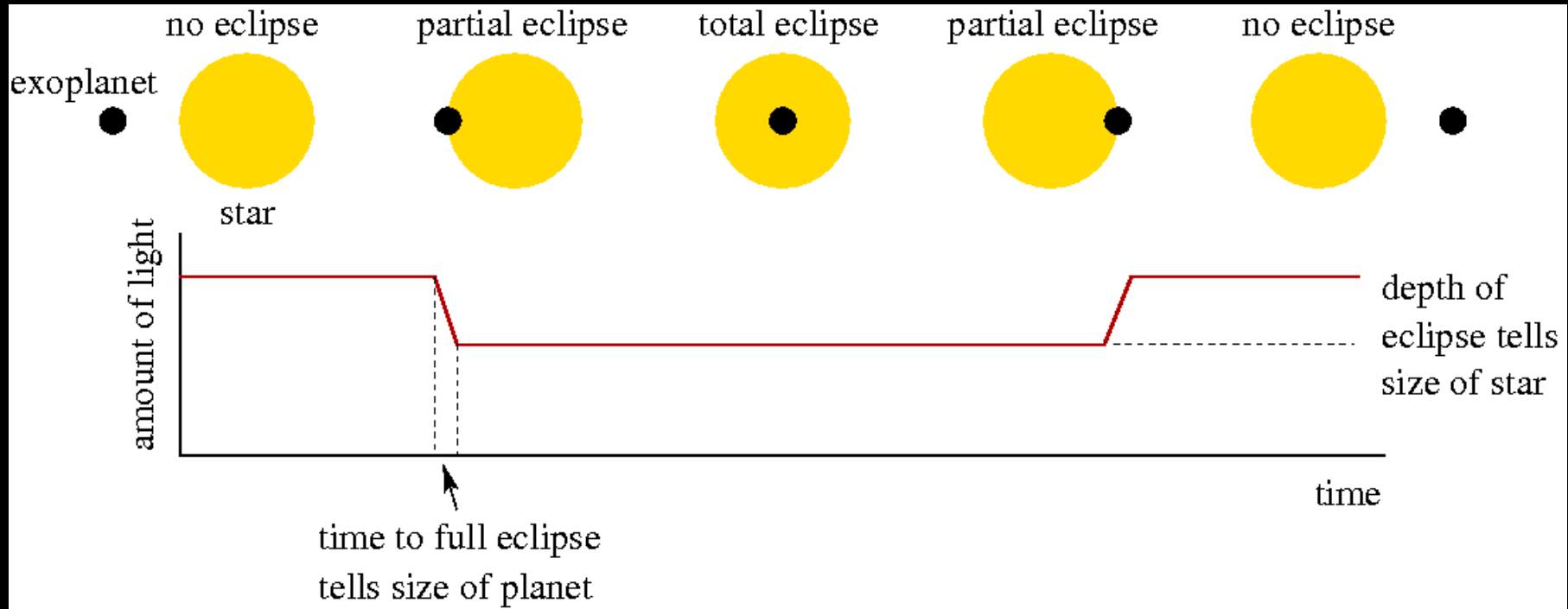
Radial Velocity (Doppler Spectroscopy)

Radial Velocity Method

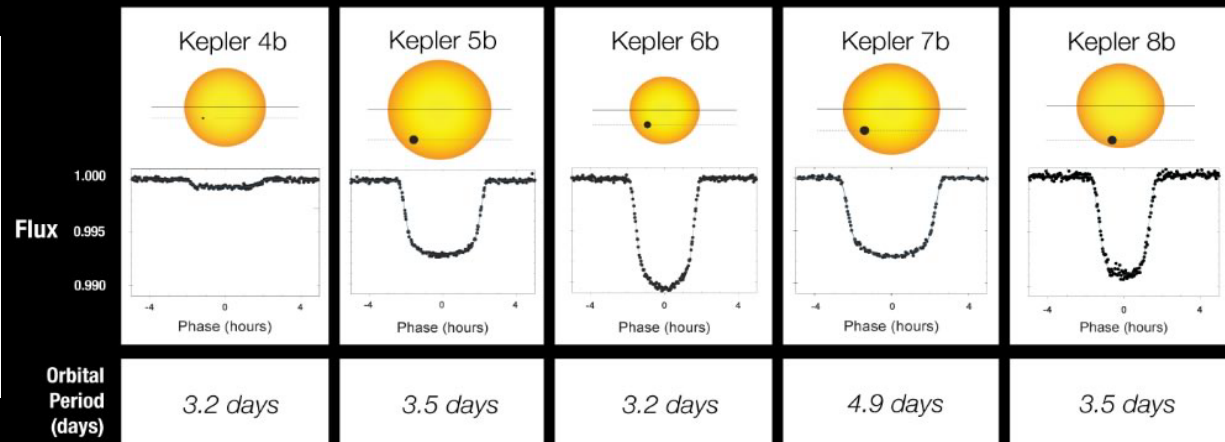
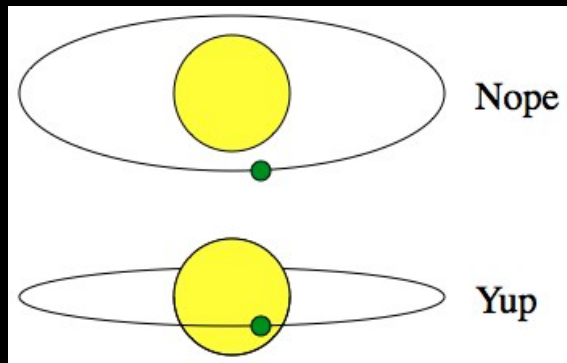
The star and planet orbit their common center of mass.



Transit Photometry – Transit Timing



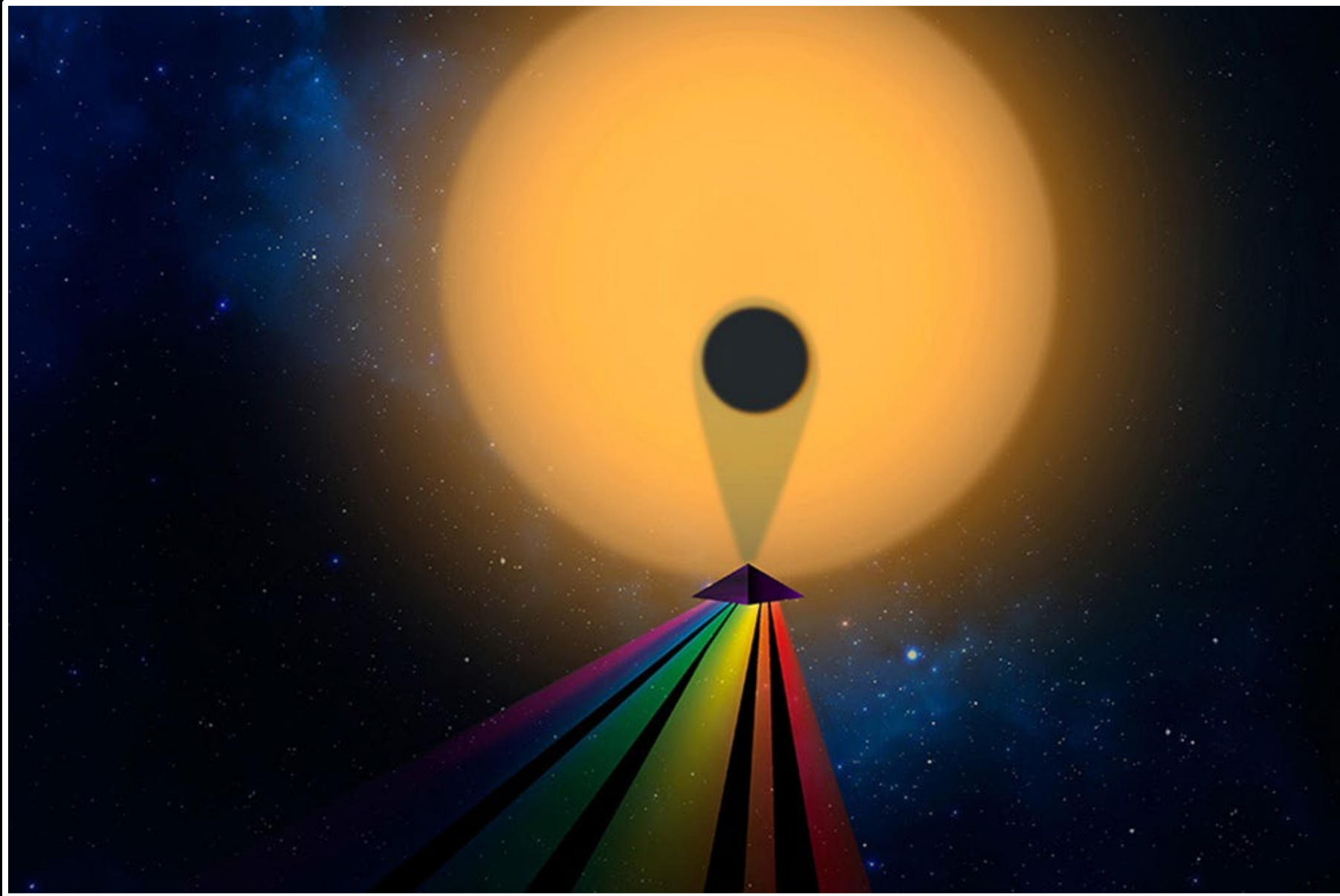
Transit Light Curves



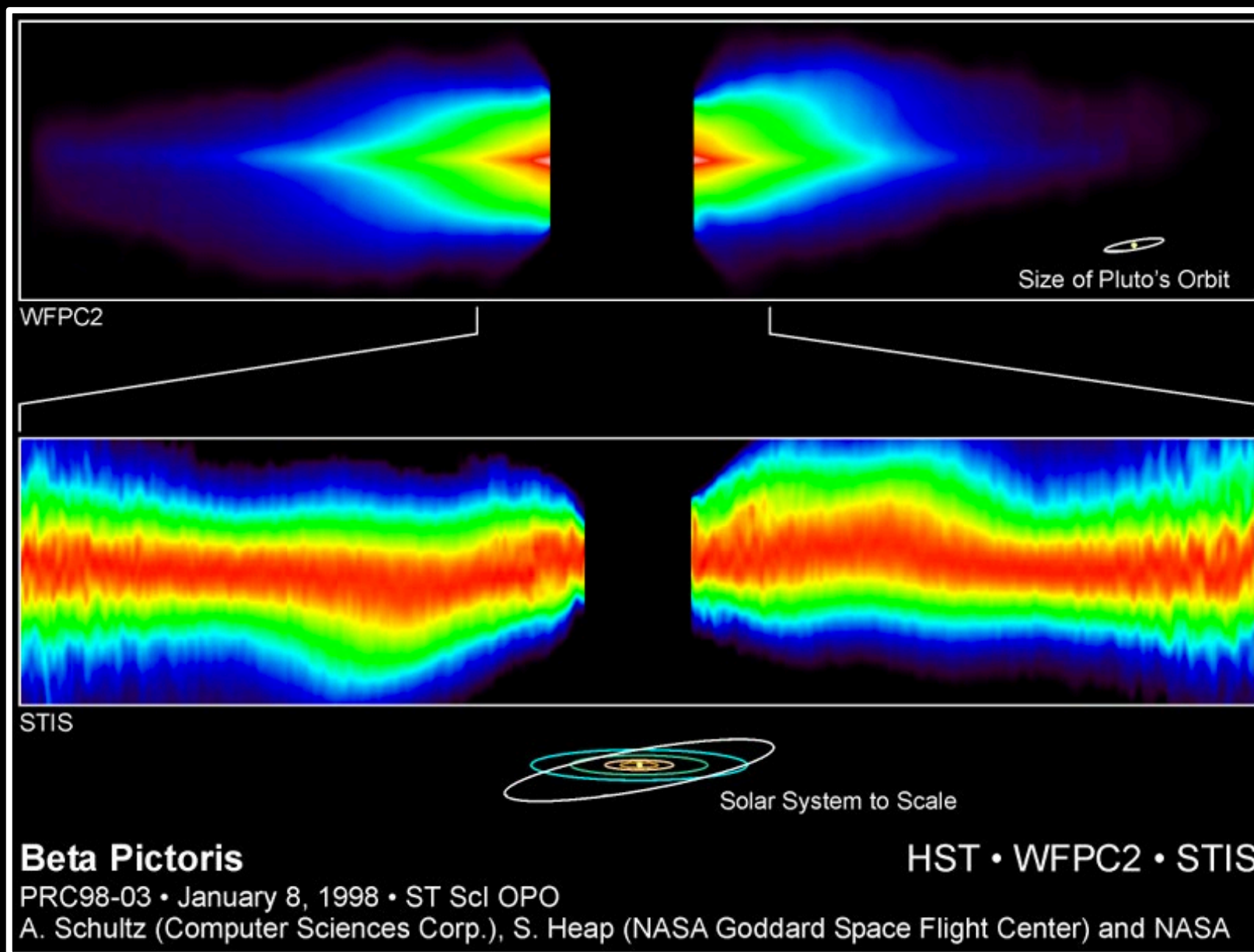
Transit Timing



Transit Photometry – Transmission Spectrum



Direct Imaging – Circumstellar Disks

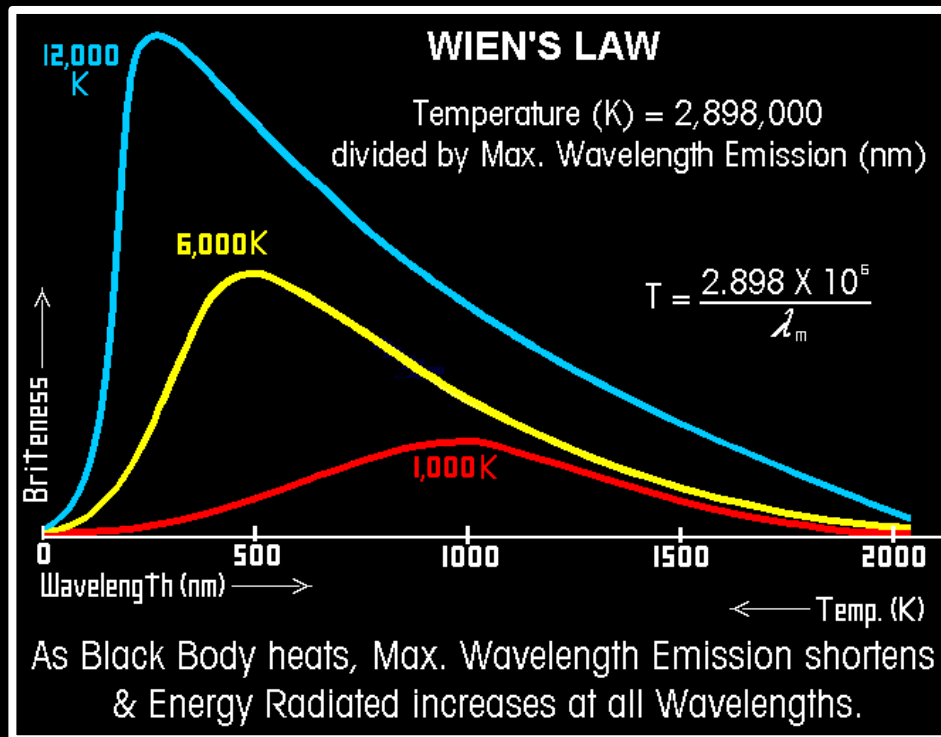
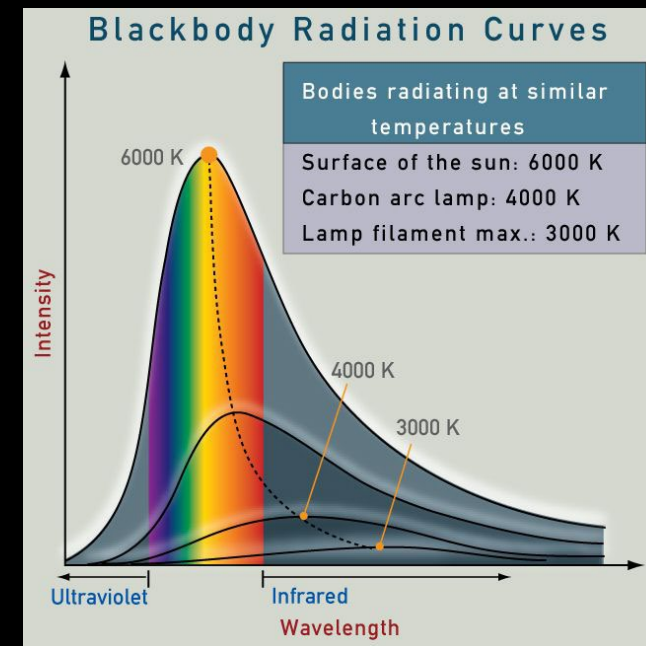


Stellar Radiation Laws:

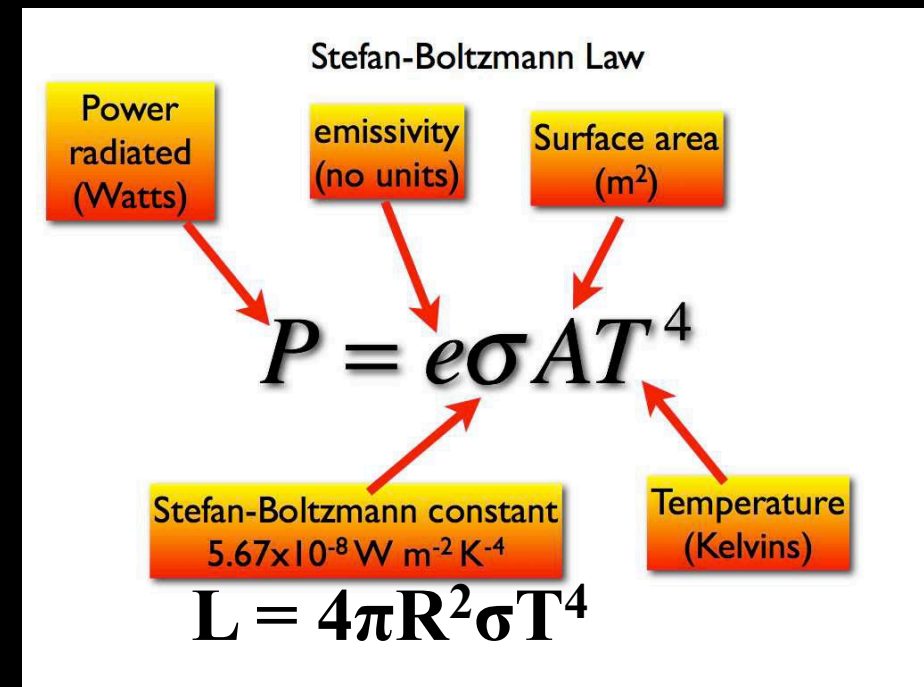
Planck's Law

Wien's Law

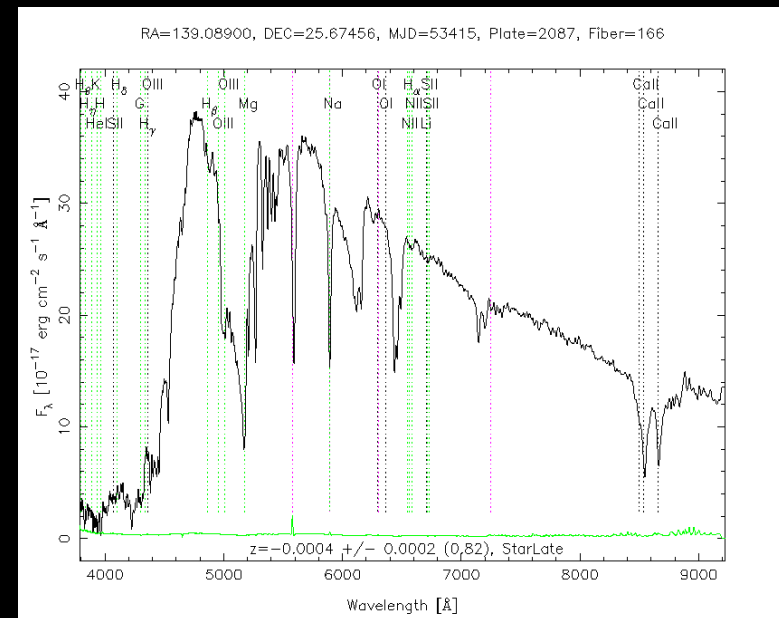
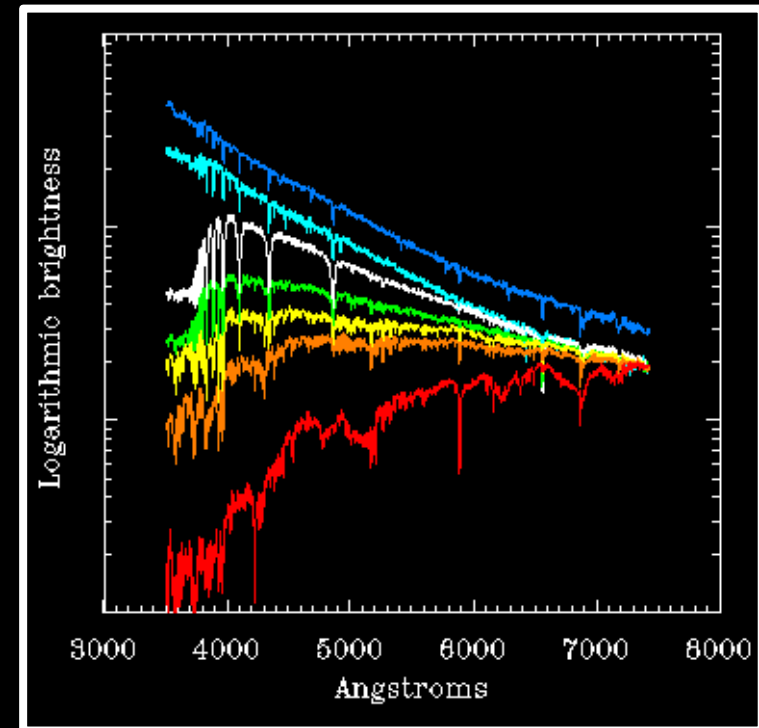
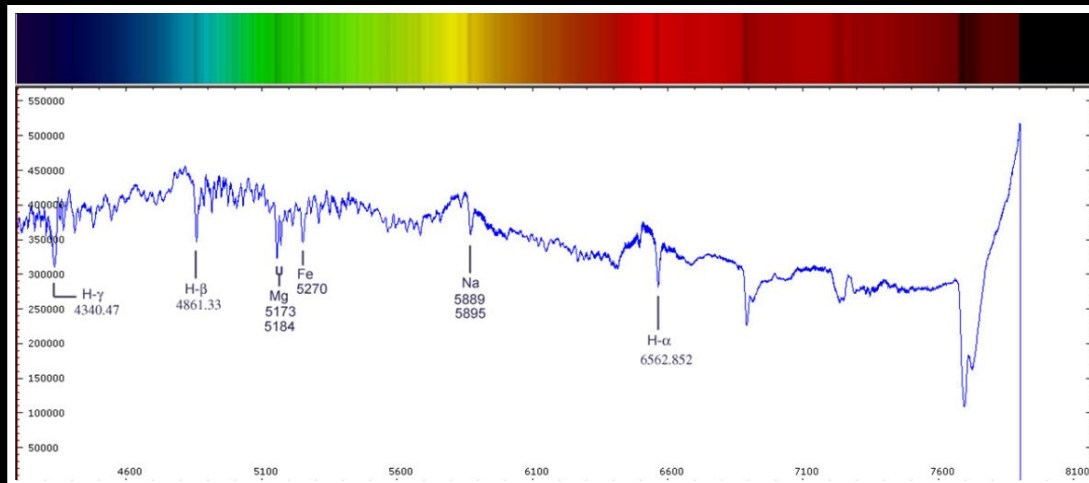
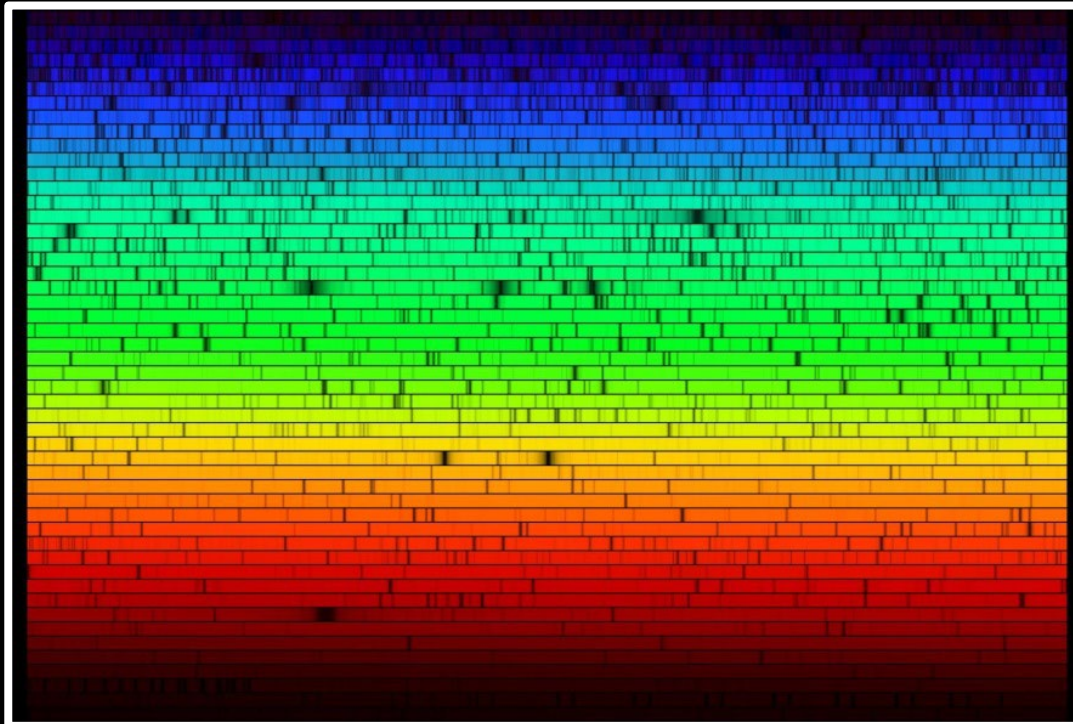
Stefan-Boltzmann's Law



$$\lambda_{\max} = 2.9 \times 10^7 / T$$



Spectra



Basic Equations and Relationships

The Distance Modulus: $M = m - 5 \log_{10} \frac{r}{10}$

Kepler's 3rd Law: $(M_A + M_B) = \frac{a^3}{p^2}$

$v = \frac{d}{t}$; $a = \frac{v}{t}$; $2\pi a = vP$; $F_c = ma_c$; $a_c = \frac{v^2}{r} = r\omega^2$

Small Angle Formula: $D = \frac{ad}{206,265}$

$1 \text{ pc} = 206,265 \text{ au} = 3.26 \text{ ly} = 3.08 \times 10^{16} \text{ m}$

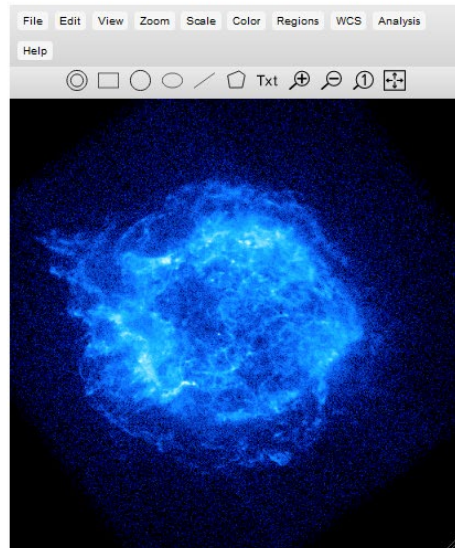
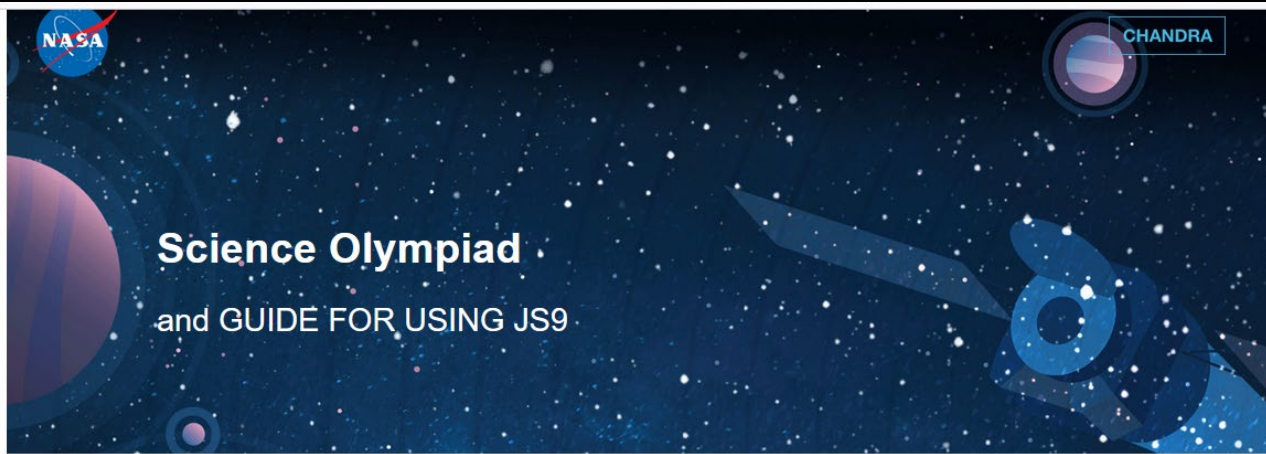
$1^\circ = 60 \text{ arcmin} = 60'$; $1' = 60 \text{ arcsec} = 60''$

Equilibrium Temperature $T_{eq} = T_{\odot} (1 - a)^{1/4} \sqrt{\frac{R_{\odot}}{2D}}$

Inverse Square Law: $L = 1/r^2$ equilibrium temperature

Circumference, Area, Surface Area, and Volume of a Sphere

JS9 Image Analysis Tools



The Unofficial Chandra Archive Search Page

Guided Tutorial

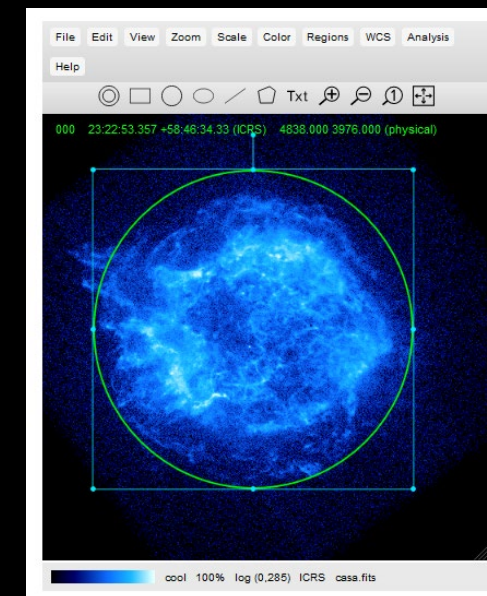
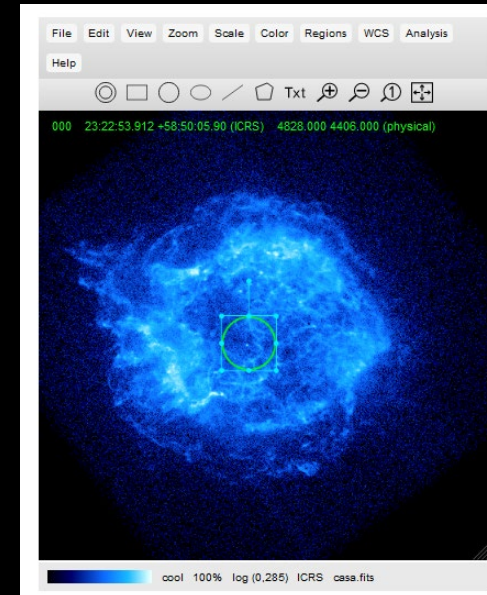
- [GUIDE FOR USING JS9 Part 1](#)
- [GUIDE FOR USING JS9 Part 2](#)
- [Decoding Starlight](#)
- [3 Color Composites](#)
- [X-ray Spectroscopy of Supernova Remnants](#)

JS9 Solutions from Prior Events

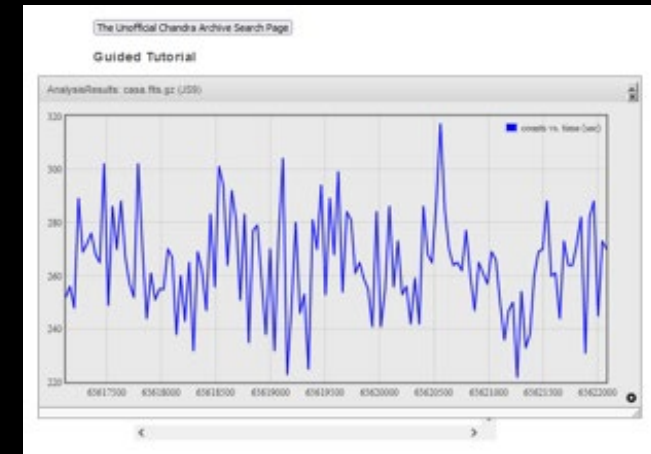
- [2021 National Event](#)
- [2020 MIT Invitational](#)
- [2019 National Event](#)
- [2018 National Event](#)

Other Useful Images

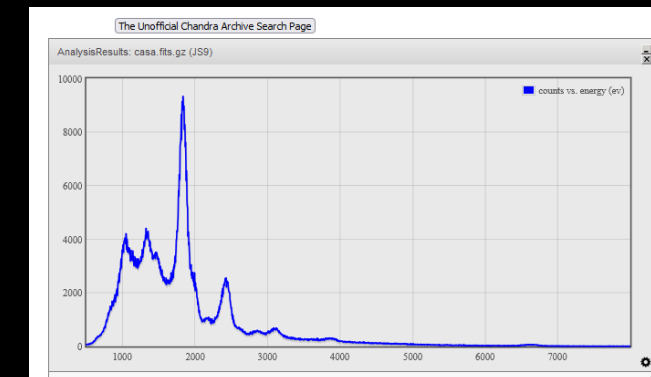
- [Bullet Cluster - optical lensing](#)



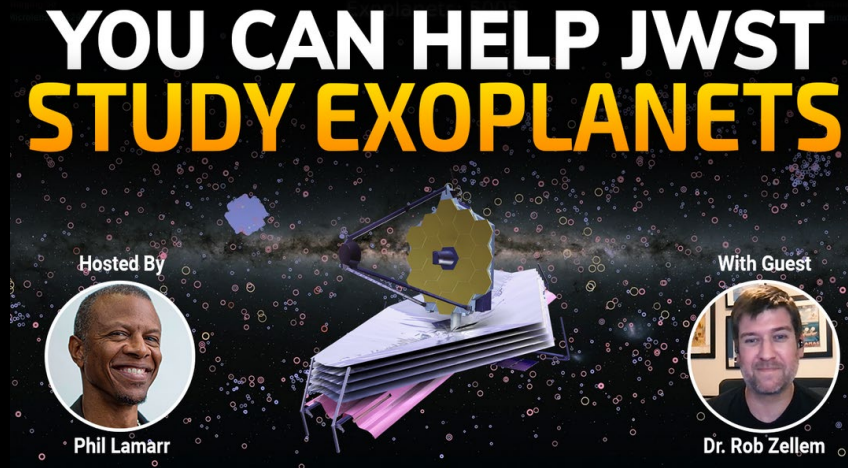
Light Curve



Energy Spectrum



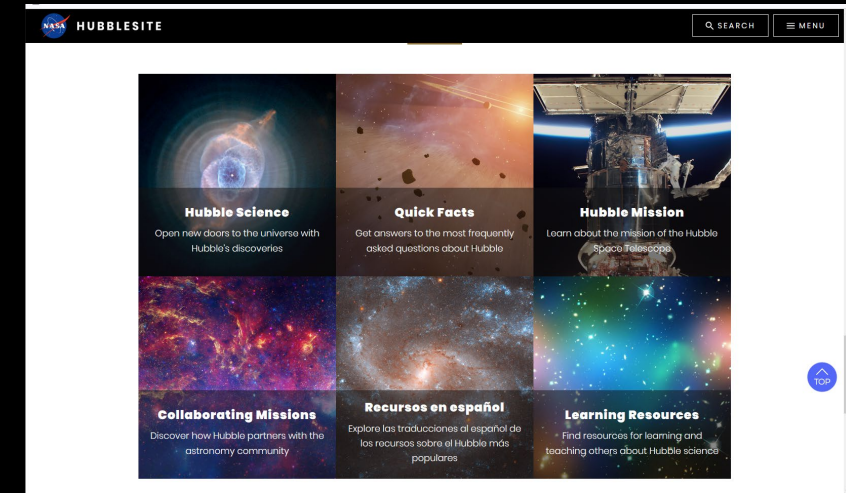
Resources



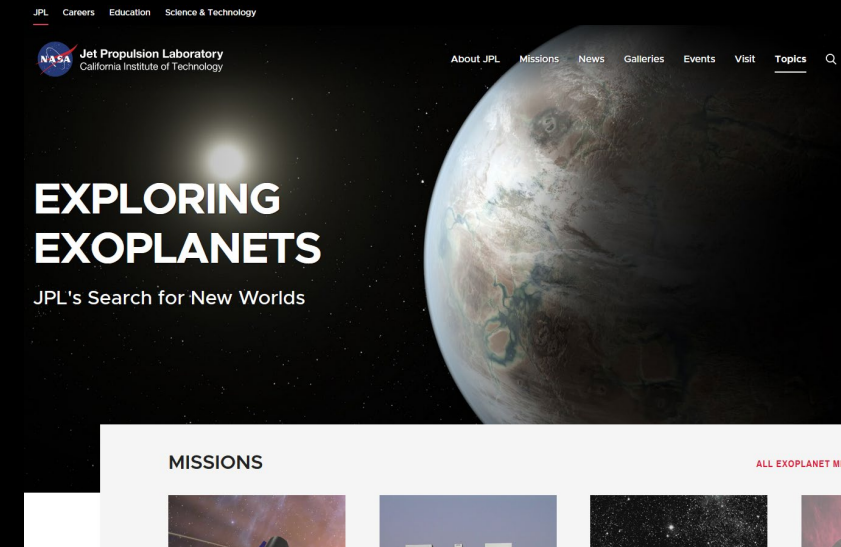
<https://www.universeunplugged.org/series/nso-webinars>



<https://www.universe-of-learning.org>



<https://hubblesite.org/home>

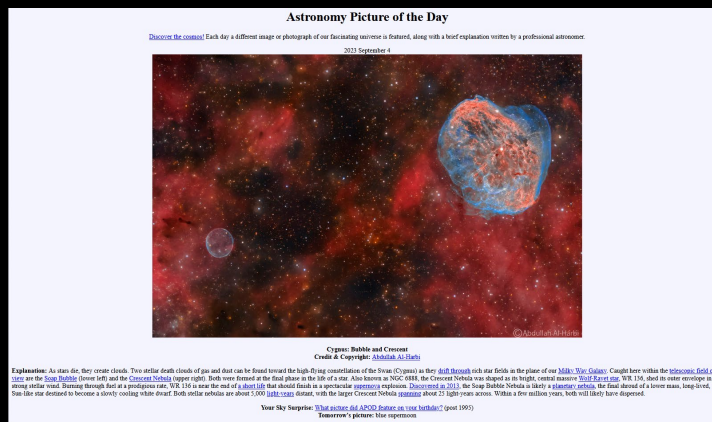


<https://www.jpl.nasa.gov/topics/exoplanets>

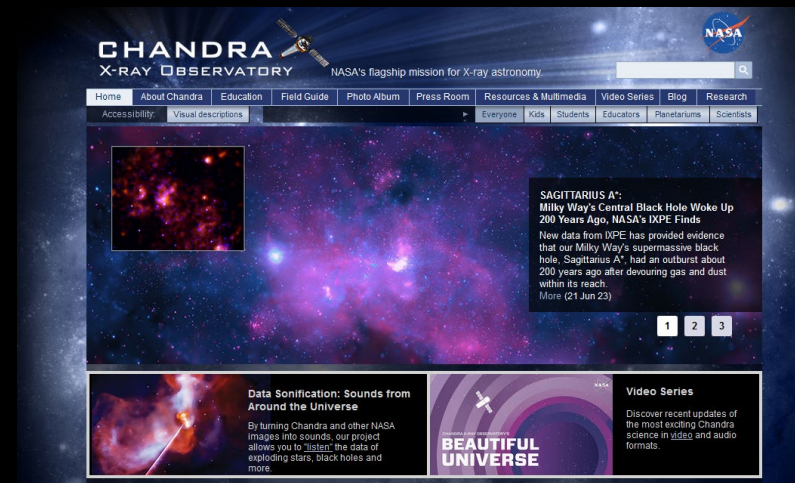
Resources



<https://webbtelescope.org/home>



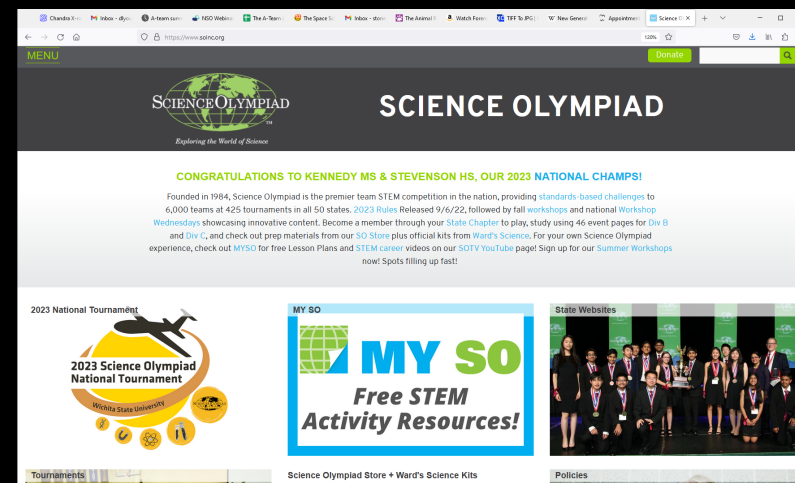
<https://apod.nasa.gov/apod/astropix.html>



<https://chandra.si.edu/>

<https://chandra.si.edu/edu/olympiad.html>

https://chandra.si.edu/edu/UTexas_Astro_Invitational.pdf



<https://www.soinc.org/astronomy-c>

National Astronomy Event Supervisors:

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Rules clarifications:

available at www.soinc.org under event information

Event Preparation:

1. Focus on the Event Rules for content and resources.
2. Check the NSO and Chandra websites for resources, which will be posted throughout the tournament year – webinar summaries of content and resources, talks from NASA content specialists in stellar evolution and exoplanets, as well as tests from invitationals to use for practice. The portal for JS9 is on the Chandra website.
3. Use the links and resources provided with the three previous slides to study the content and DSOs.

Enjoy the Journey!