Introduction to Astronomy and Astrophysics I

Lecture 3

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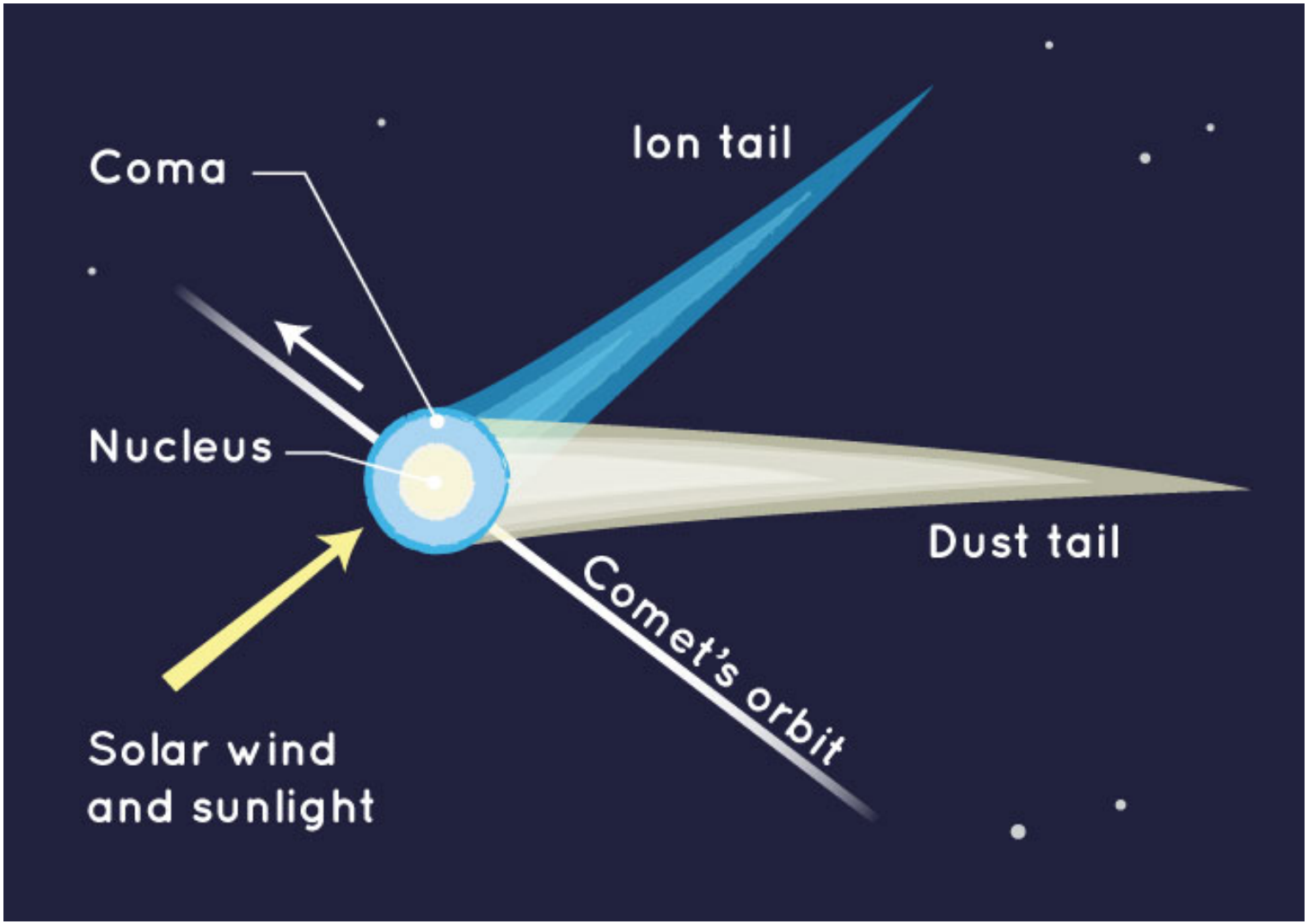
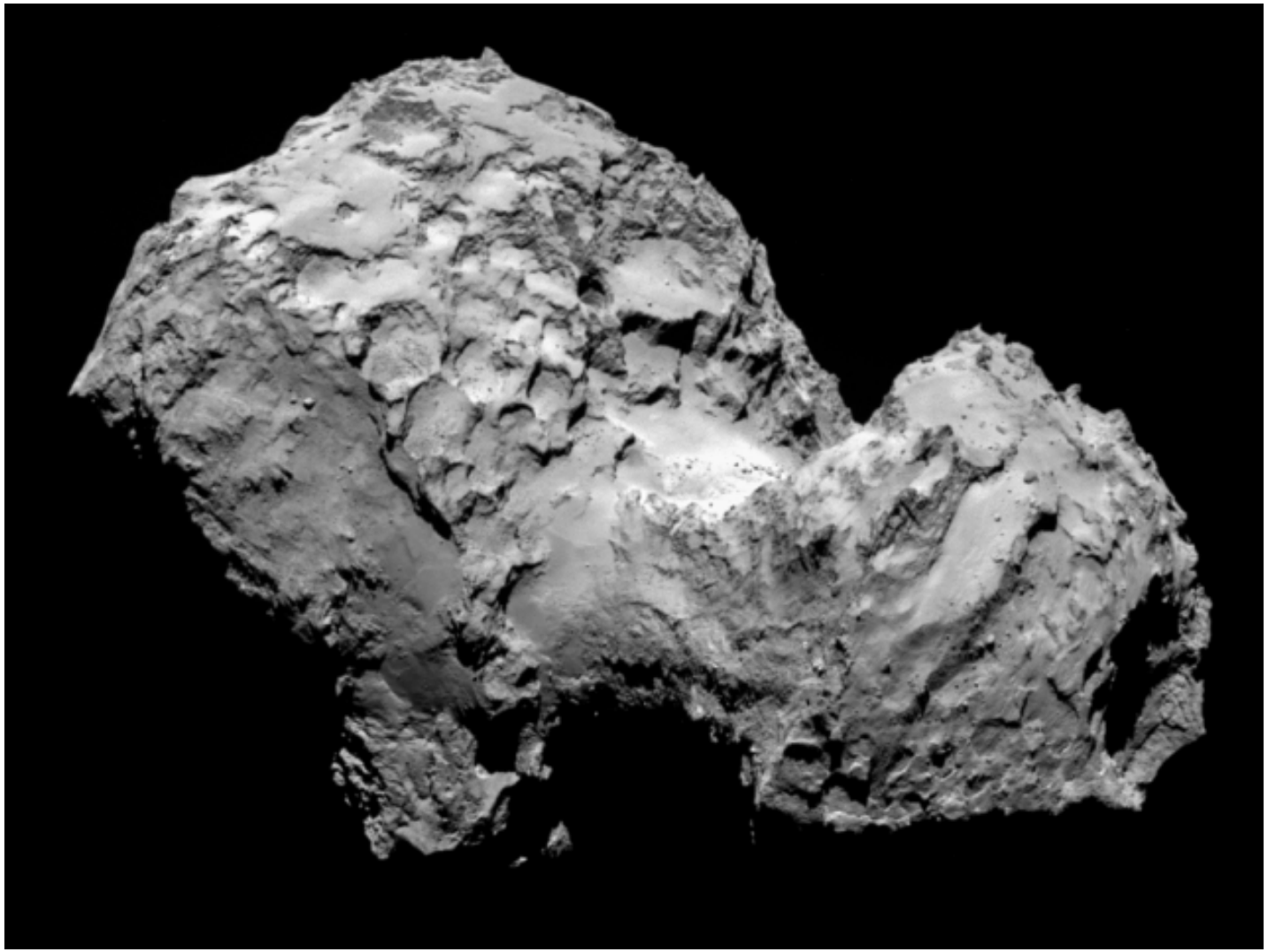
Comets

- Icy bodies that release gas and dust when near the Sun
- Composed of ice, rock, dust, and frozen gases
- Highly elliptical (closed) or even open orbits
- Two main types: short-period and long-period comets
- Famous example: Halley's Comet (visible every 76 years)

Comet Structure



67P/C-G Comet nucleus from Rosetta

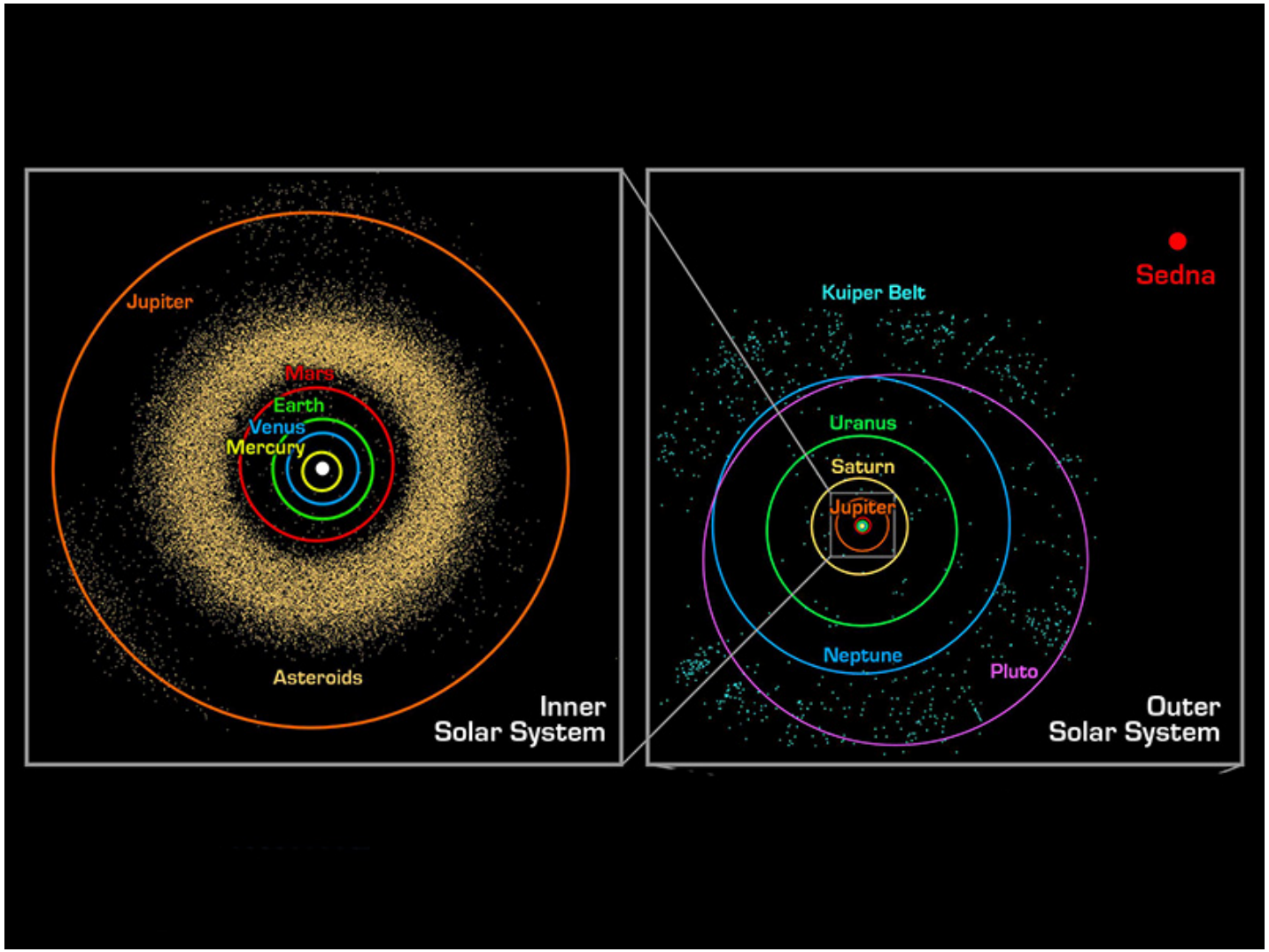


Credit: ESA

Kuiper Belt

- Disc-shaped region beyond Neptune's orbit
- Contains many small, icy bodies (Kuiper Belt Objects or KBOs)
- Home to Pluto and other dwarf planets
- Source of short-period comets
- Extends from about 30 to 50 AU from the Sun

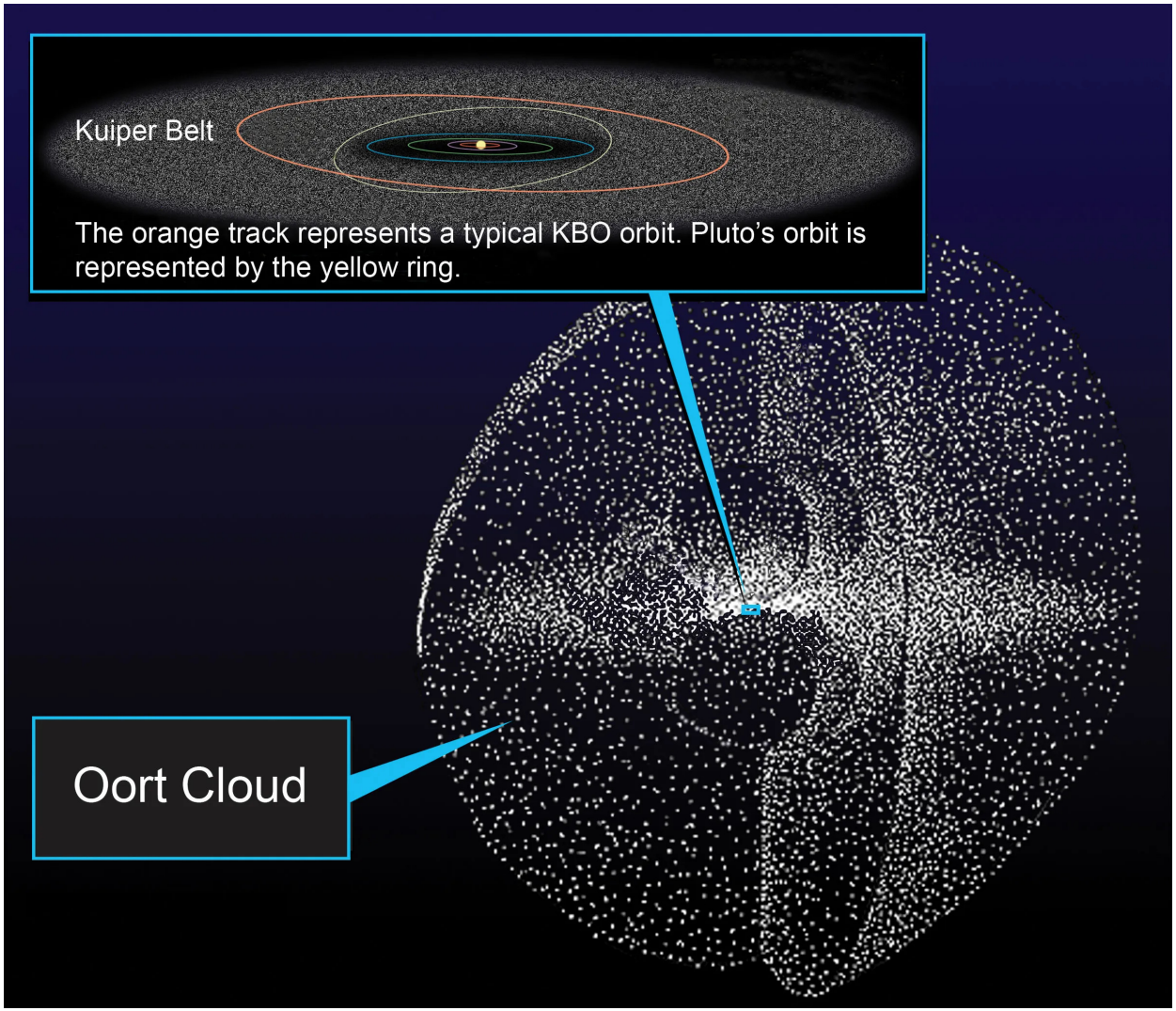
The Asteroid Belt and the Kuiper Belt



Oort Cloud

- Theoretical cloud of icy bodies surrounding the Solar System
- Extends from about 2,000 to 100,000 AU from the Sun
- Believed to be the source of long-period comets
- Contains trillions of objects larger than 1 km
- Marks the outer boundary of the Solar System

Oort Cloud


Kuiper Belt
The orange track represents a typical KBO orbit. Pluto's orbit is represented by the yellow ring.
Oort Cloud

Zodiacal Dust

- Tiny particles of dust in the inner Solar System
- Primarily produced by asteroid collisions and comet outgassing
- Scatters sunlight to create the Zodiacal light: a faint glow visible in dark skies
- Contributes to the interplanetary medium
- Constantly replenished as larger particles spiral into the Sun

Zodiacal Light

Credit: Rubin/LSST

Earth's Uniqueness for Life

- Location in the "Goldilocks zone" or habitable zone
- Liquid water on the surface
- Stable, oxygen-rich atmosphere
- Magnetic field protecting from harmful radiation
- Plate tectonics regulating the carbon cycle
- Large moon stabilizing Earth's axial tilt
- Diverse range of environments supporting biodiversity
- Complex organic chemistry
- Presence of a protective ozone layer
- Unique combination of these factors not found elsewhere in the Solar System

Summary: Solar System Structure

- Central star: The Sun
- Inner Solar System: Terrestrial planets and asteroid belt
- Outer Solar System: Gas giants and ice giants
- Trans-Neptunian region: Kuiper Belt
- Outer boundary: Oort Cloud

Summary: Diversity in the Solar System

- Wide range of planetary sizes and compositions
- Varied environments: from scorching heat to extreme cold
- Numerous moons with diverse characteristics
- Complex systems of rings, particularly around gas giants
- Small bodies: asteroids, comets, and trans-Neptunian objects

What are Extrasolar Planets?

- Planets orbiting stars other than our Sun
- Also known as exoplanets
- First confirmed detection in 1992
- As of Aug 2024, over 7,000 confirmed exoplanets

Early Speculations and Attempts

- Ancient Greek and Indian philosophers: Concept of other worlds
- 16th century: Giordano Bruno's infinite universe with inhabited worlds
- 1950s-1980s: Several unconfirmed detections

Why is detecting exoplanets so difficult?

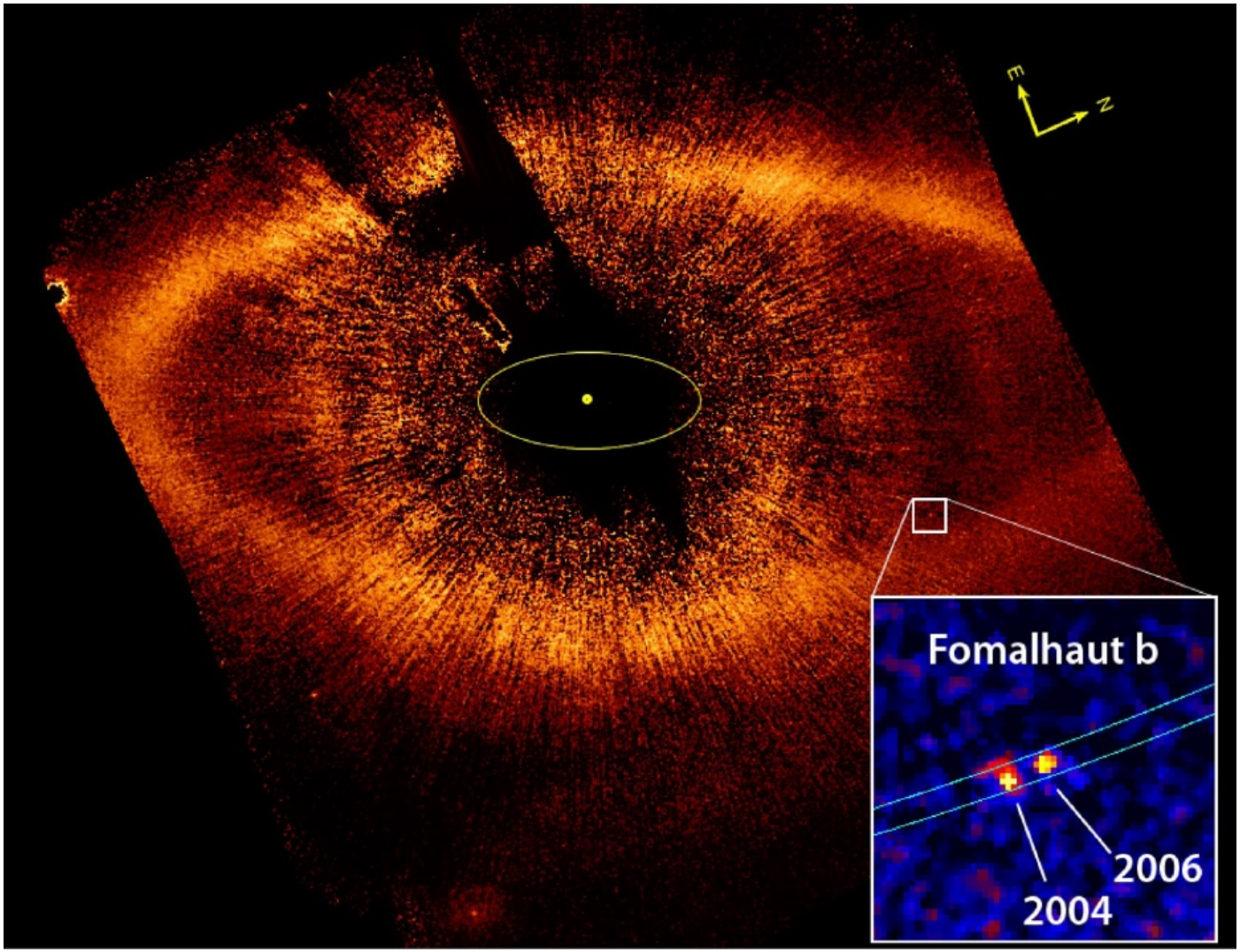
First Confirmed Detections

- 1992: Aleksander Wolszczan and Dale Frail
  - Discovered planets orbiting pulsar PSR B1257+12
- 1995: Michel Mayor and Didier Queloz
  - Discovered 51 Pegasi b, first exoplanet orbiting a main-sequence star
- These discoveries opened the floodgates for exoplanet research

Overview of Detection Methods

- Direct Imaging
- Radial Velocity
- Transit (Occultation)
- Gravitational Microlensing
- Astrometry
- Transit Timing Variations

Direct Imaging - Fomalhaut B



Credit: AURA/STScI

Radial Velocity Method

- Measures star's "wobble" due to planet's gravitational pull
- Detected through Doppler shift in star's spectrum
- More sensitive to massive planets close to their stars
- Key equation: $K = \left(\frac{2\pi G}{P}\right)^{1/3} \frac{M_p \sin i}{(M_s+M_p)^{2/3}}$
- K semi-amplitude of the radial velocity variation of the star for a planet in circular orbit around it. Why does it not depend on the radius of the orbit?

Transit (Occultation) Method

- Detects dimming of starlight as planet passes in front
- Provides information on planet size and orbital period
- Can detect smaller planets than radial velocity method
- Key equation: $\frac{\Delta F}{F} \approx \left(\frac{R_p}{R_s}\right)^2$

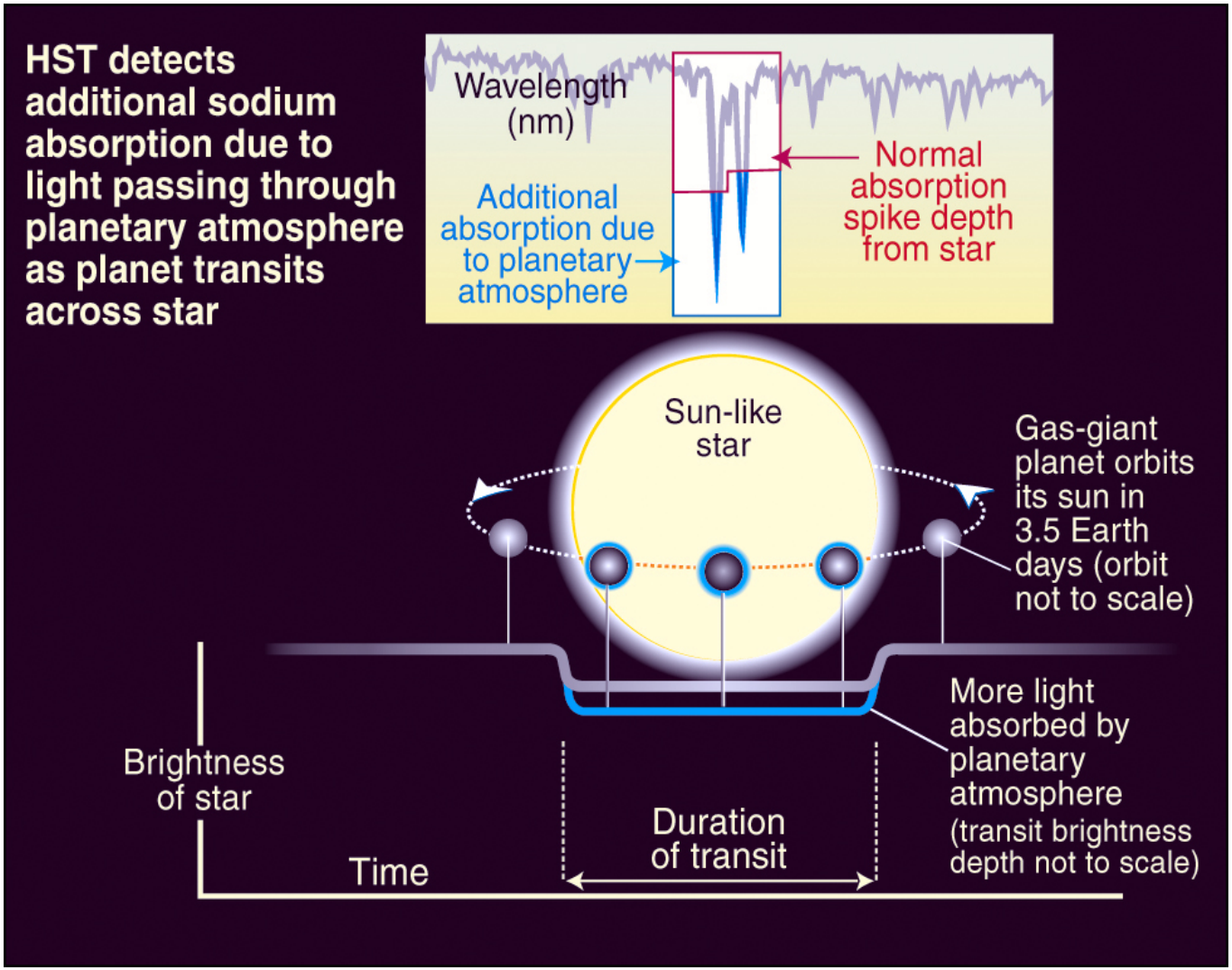
Advantages of the Transit Method

- Can detect Earth-sized and smaller planets with accurate photometry
- Allows for atmospheric characterization through transmission spectroscopy
- Enables detection of multiple planets in a system
- Can be used for large-scale surveys of many stars simultaneously

Transiting Extrasolar planets

If Jupiter were in a 1 day orbit around the Sun, what fraction of the Sun ’s light would it block during a transit? Assume that Jupiter survives long enou gh. What fraction is blocked at Jupiter’s distance?

Spectroscopy of extrasolar planets with HST

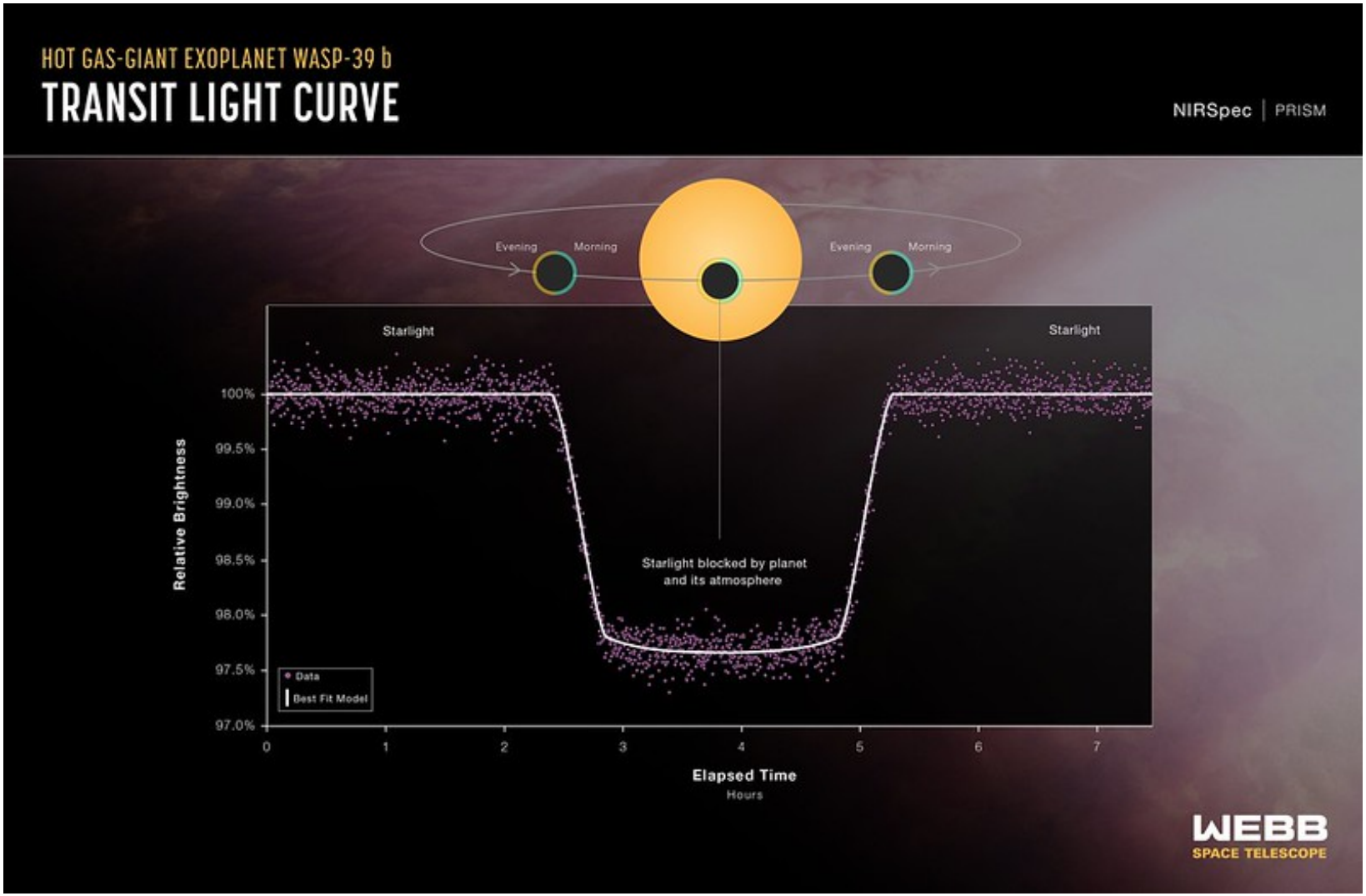


Sunset on Osiris

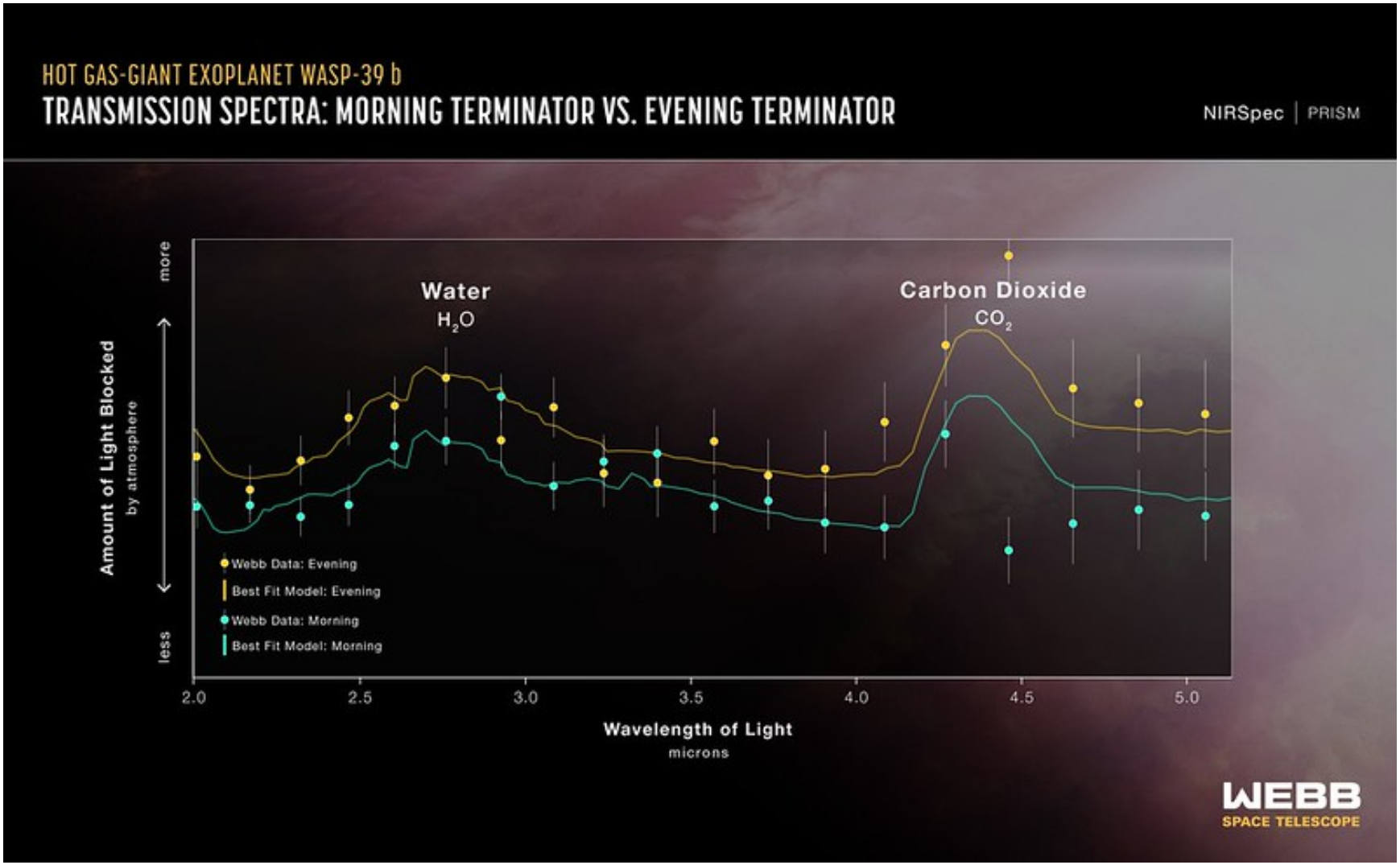
Show movie

Credit: Alain Lecavalier des Etangs

WASP-39 b - a tidally locked planet



Temperature difference between night and day side



Kepler Space Telescope

- Launched: March 7, 2009
- Primary mission: 3.5 years, extended to 9 years
- Observed over 530,000 stars
- Discovered over 2,600 confirmed exoplanets
- Revolutionized our understanding of exoplanet populations

Show Kepler movie

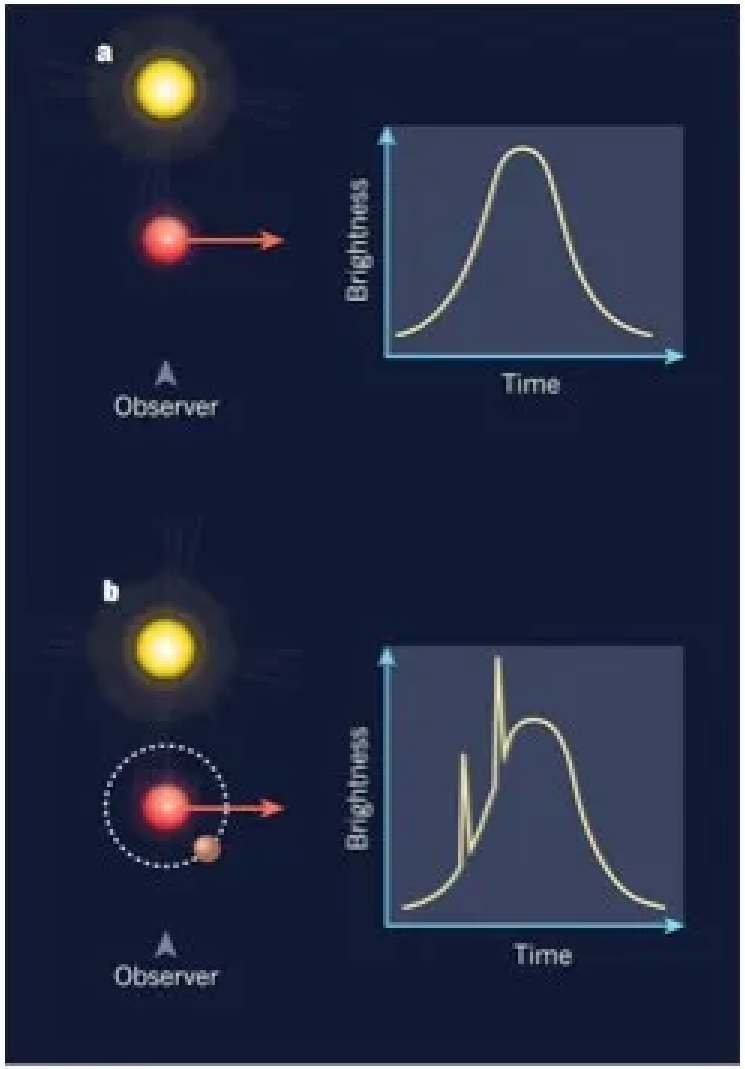
Kepler's Key Findings

- Planets are common in our galaxy (1.4 planets per star)
- Small planets (super-Earths, mini-Neptunes) are abundant
- Multiplanet systems are common
- Discovered potentially habitable planets (e.g., Kepler-186f)
- **Copernican principle seems to apply**

TESS (Transiting Exoplanet Survey Satellite)

- Launched: April 18, 2018
- All-sky survey focusing on nearby bright stars
- Expected to find thousands of exoplanets
- Designed to find promising targets for follow-up studies

Microlensed planet light curve



Exoplanet Size Distribution

- Terrestrial planets: $<$ 1.6 Earth radii
- Super-Earths: 1.6 - 2 Earth radii
- Mini-Neptunes: 2 - 4 Earth radii
- Gas Giants: $>$ 4 Earth radii

Last 3 categories are in roughly equal numbers today.

Current Exoplanet Census (as of 2024)

- Total confirmed exoplanets: $>$ 7,000 (majority by transit metohd)
- Planetary systems: $>$ 800
- Super-Earths and Mini-Neptunes: Most common
- Hot Jupiters: Rare but easier to detect
- Earth-sized planets in habitable zone: Several candidates