Announcements

- Exploration paper 4 due **Mar 29**
  - Topic: Extraterrestrial Intelligence; see Canvas for details

- Quiz 5 coming up next Monday, Apr 1 (not a joke!)
  - Topic: chapter 5 & this week's lectures

For exploration paper 4: you can choose any article from the August 2022 special edition of Scientific American to explore in more detail; otherwise, you can use the topics in the book/on Canvas

Today: “Are We Alone in the Universe?

The search for extraterrestrial intelligence

Who is funding the search?

What should we be looking for?

How should we go about our search?

Where is the best place to look?

When did the search begin in earnest?

When did the search begin?

1959: Nature paper led by Giuseppe Cocconi & Philip Morrison propose radio searches for extraterrestrial transmission

1960: Project Ozma led by Frank Drake

The Drake Equation

$$N = R^{\star} \times f_p \times n_E \times f_l \times f_i \times f_c \times L$$

$R^{\star}$: average star formation rate in the Galaxy

f_p : fraction of stars with planets

n_E : number of Earth-like planets per star

f_l : fraction of Earth-like planets with life

f_i : fraction of life sustaining planets with intelligent life

f_c : fraction of intelligent civilizations capable of communication

L : average lifetime of radio-communicating civilization

The Drake Equation

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$R^{\star}$: average star formation rate in the Galaxy (assumed 10 ★/yr)

f_p : fraction of stars with planets (assumed < 1)

n_E : number of Earth-like planets per star (assumed > 1)

f_l : fraction of Earth-like planets with life (assumed ~1)

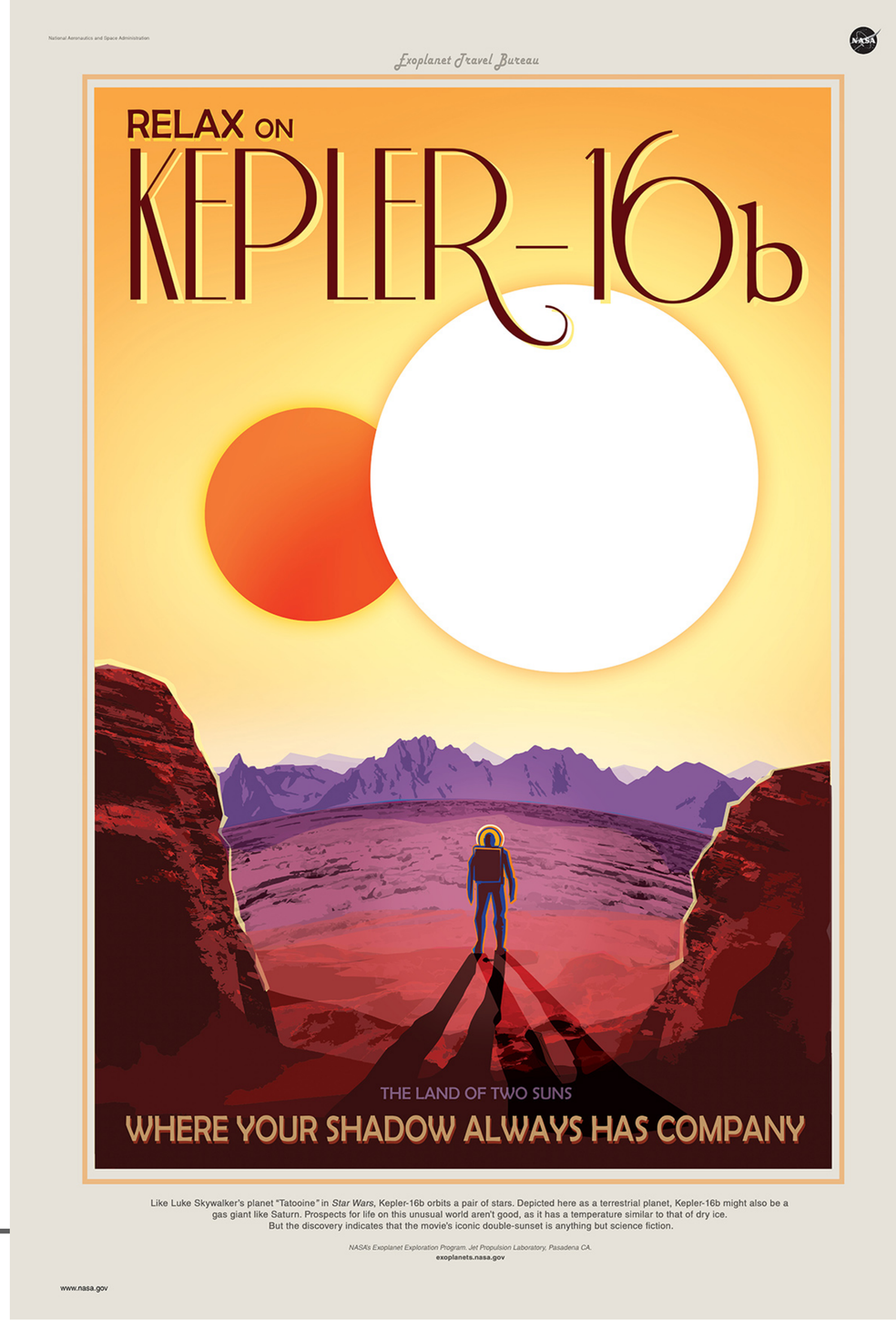
f_i : fraction of life sustaining planets with intelligent life (assumed ~1)

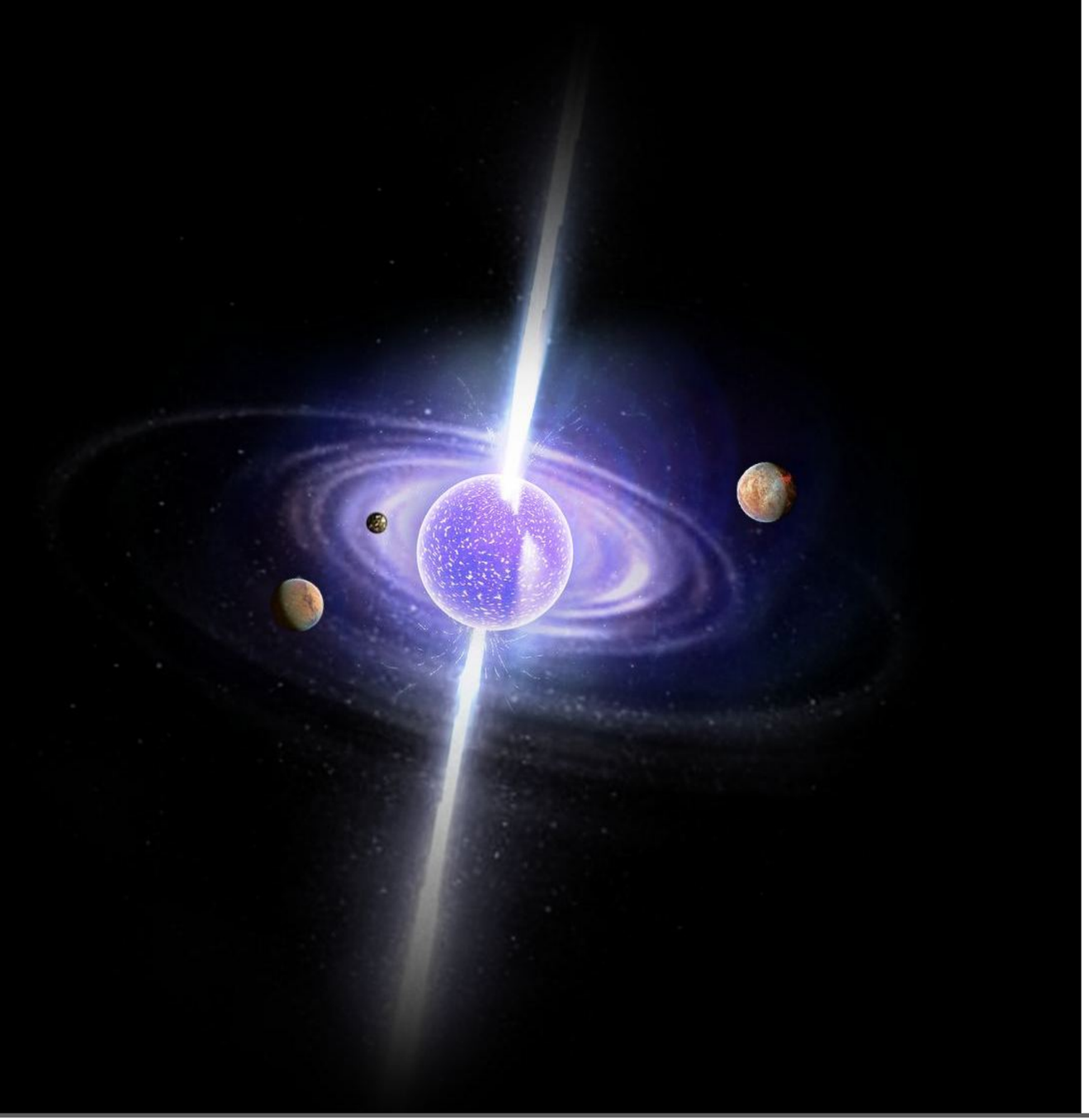
f_c : fraction of intelligent civilizations capable of communication (assumed ~1)

L : average lifetime of radio-communicating civilization (assumed 10^4 yr)

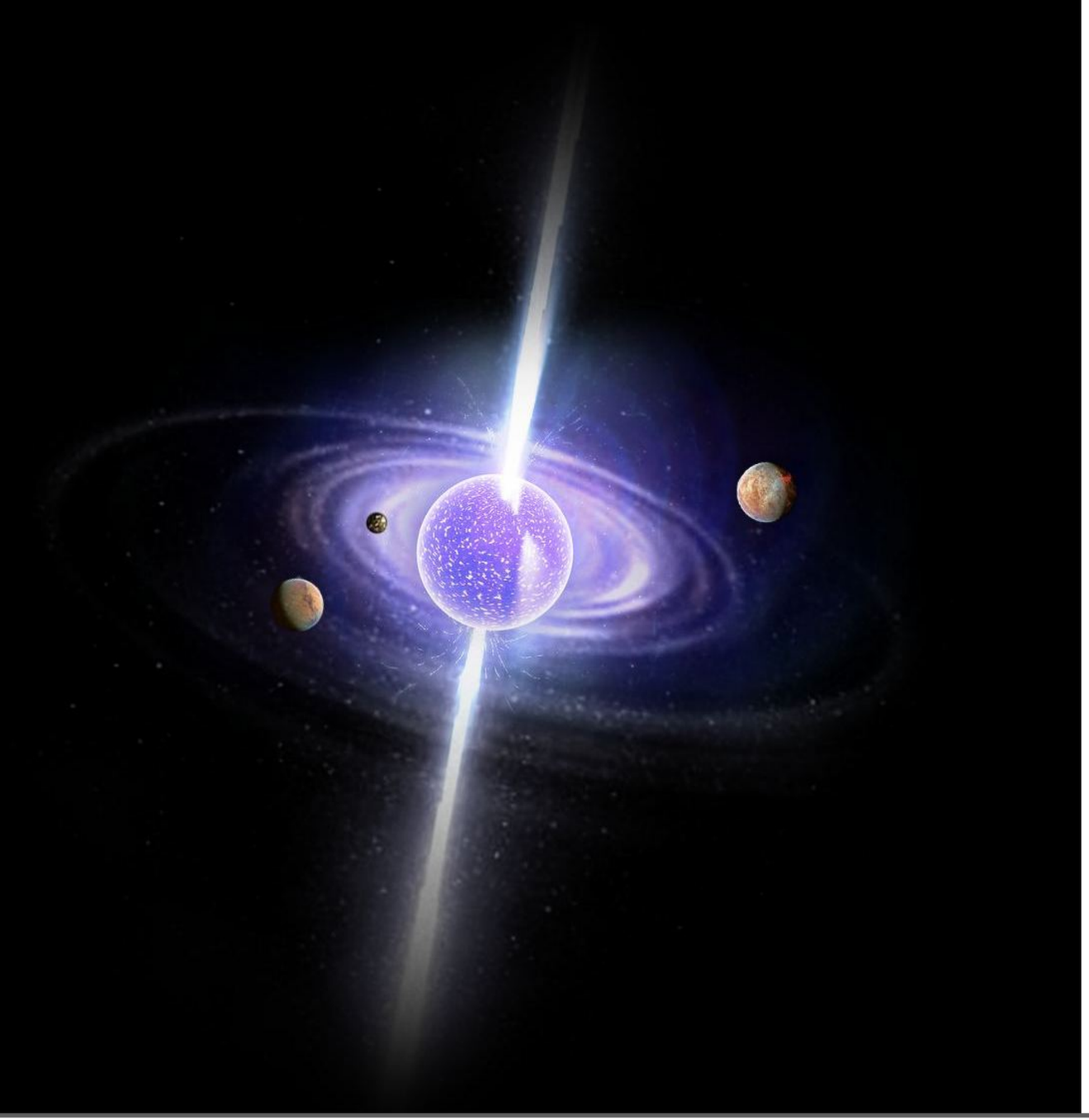
The search for extrasolar planets

You can download your own exoplanet travel posters from NASA





The first exoplanet was confirmed in 1992 by Frail & Wolszczan to be orbiting a pulsar (a rapidly rotating neutron star) whose pulses arrived at varying times due to the gravitational tug of the planet!



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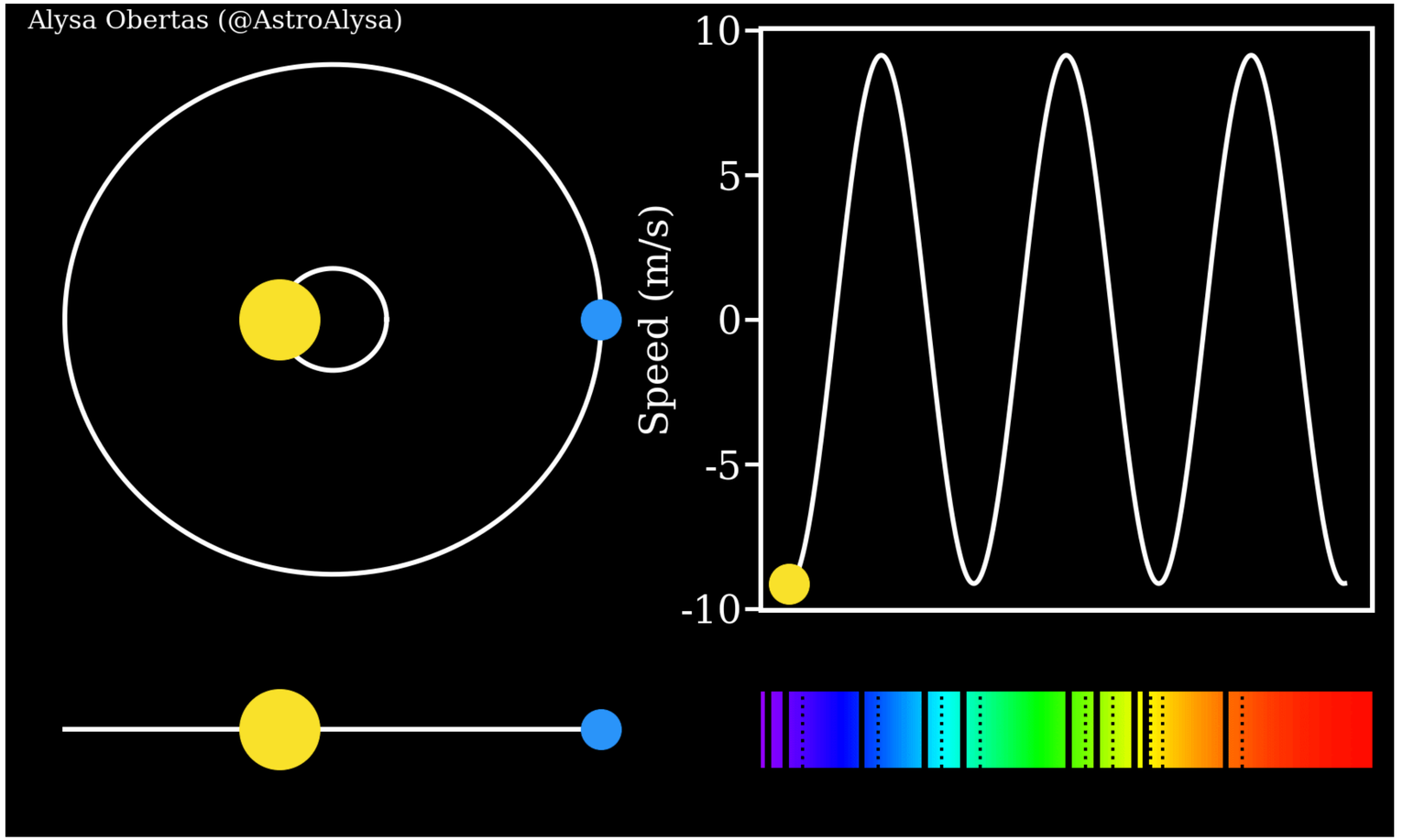
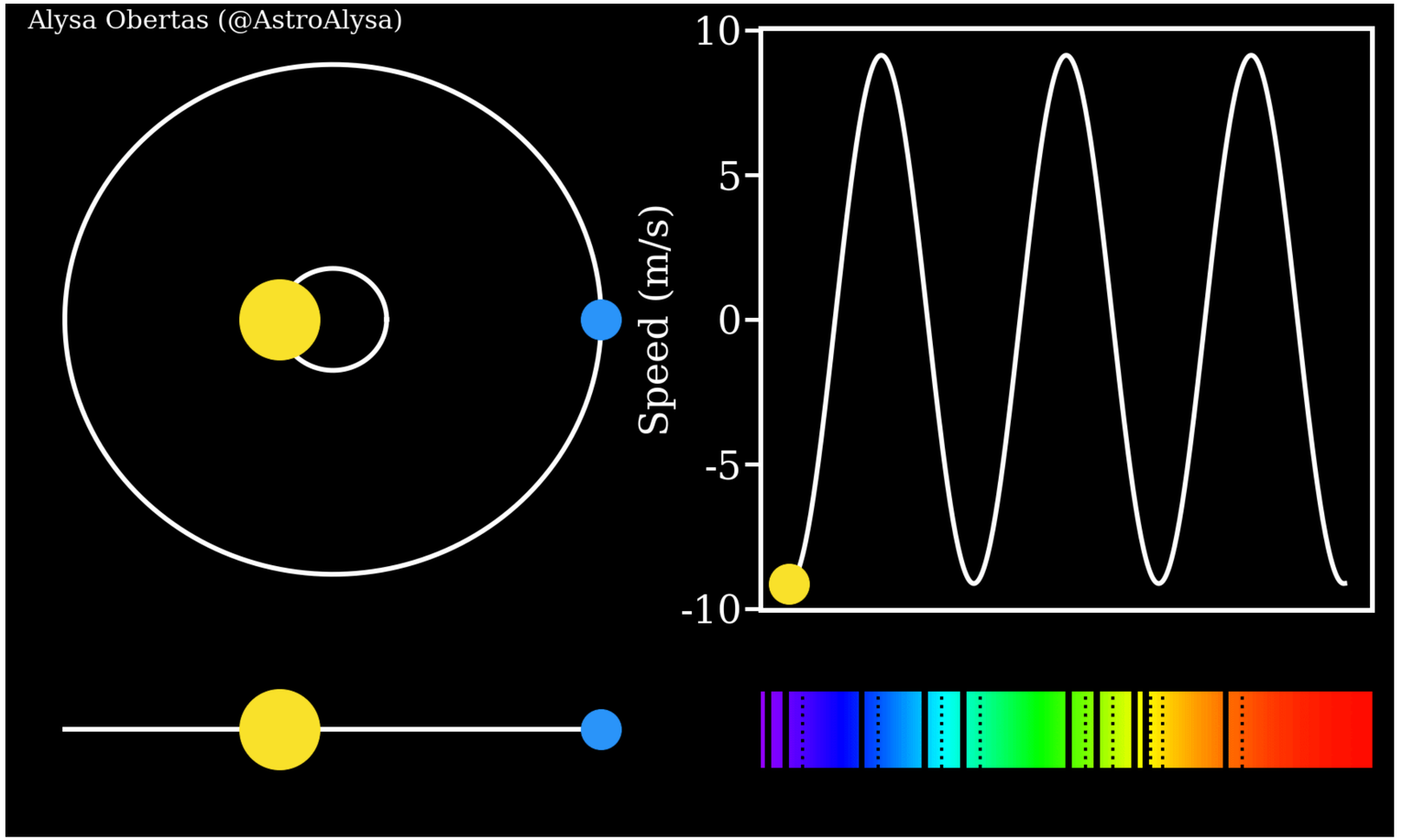
Planets likely formed *after* the supernova explosion that formed the pulsar
—> non standard case for SETI



The radial velocity method takes multiple spectra of a star to track the motion caused by planets' gravity

The RV method is biased toward *massive* planets



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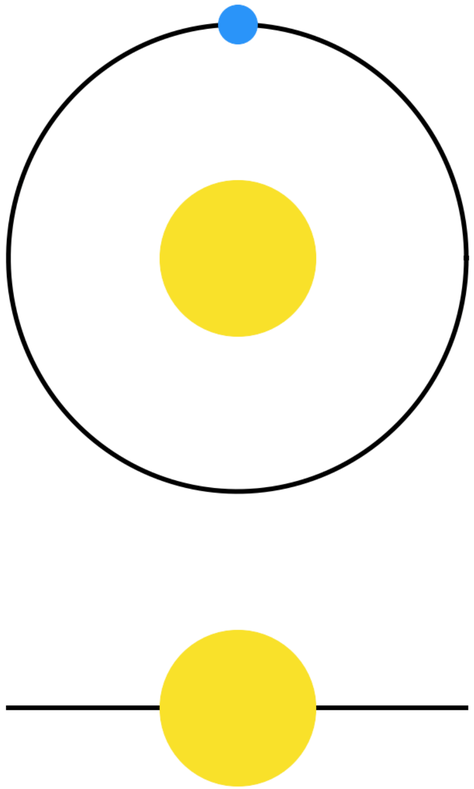

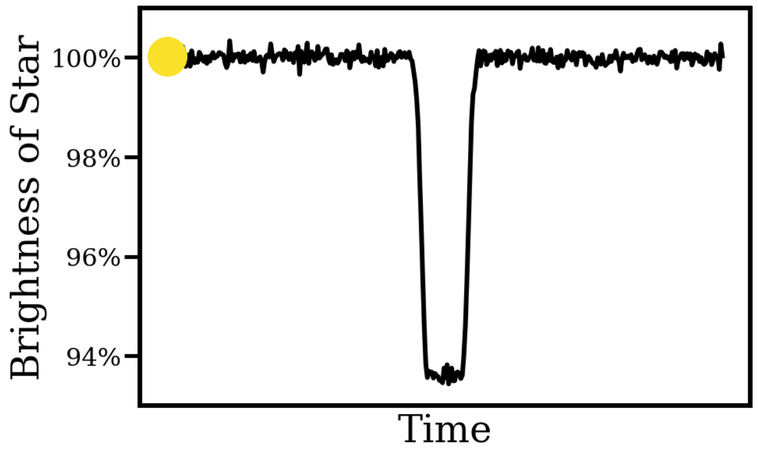

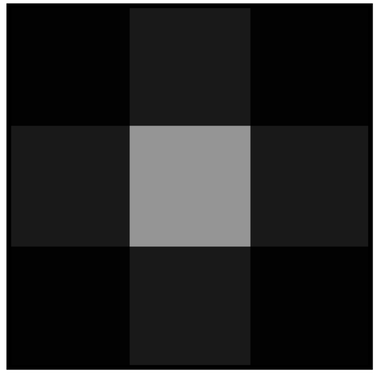

The transit method relies on photometry (brightness) measurements but requires the planet to eclipse its stellar host along our line of sight

It is biased toward *large* planets that orbit *close* to their hosts

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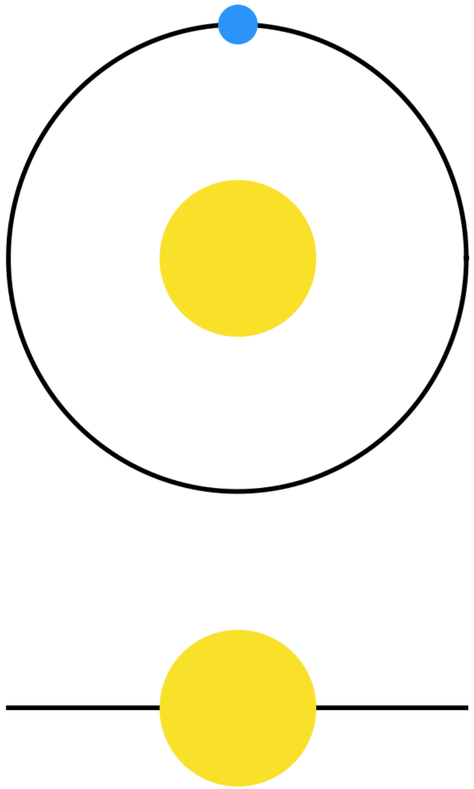

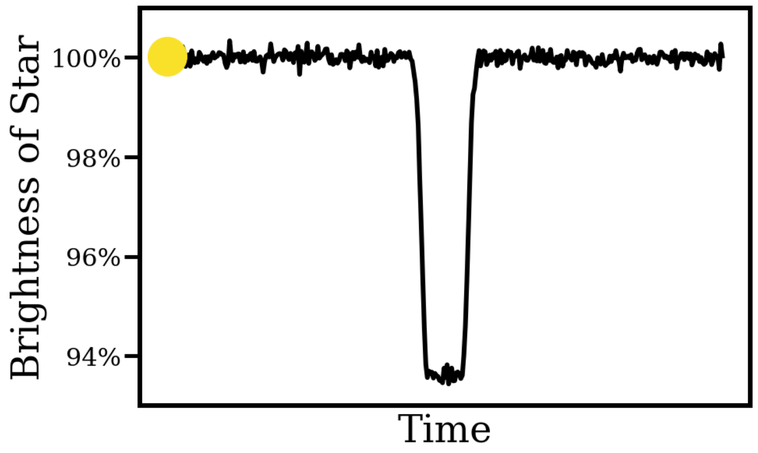

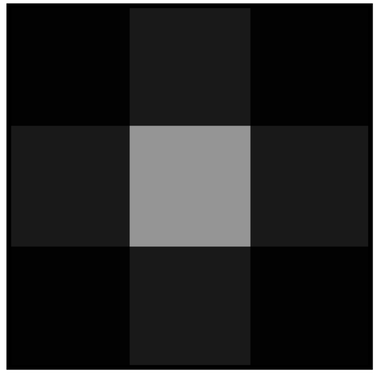

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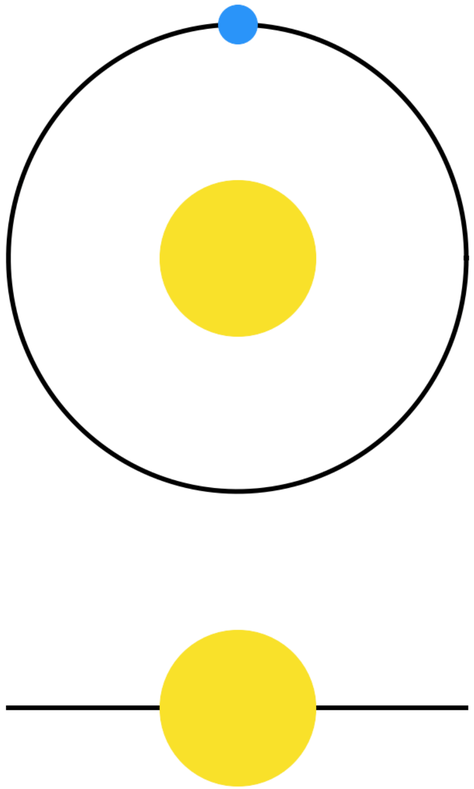

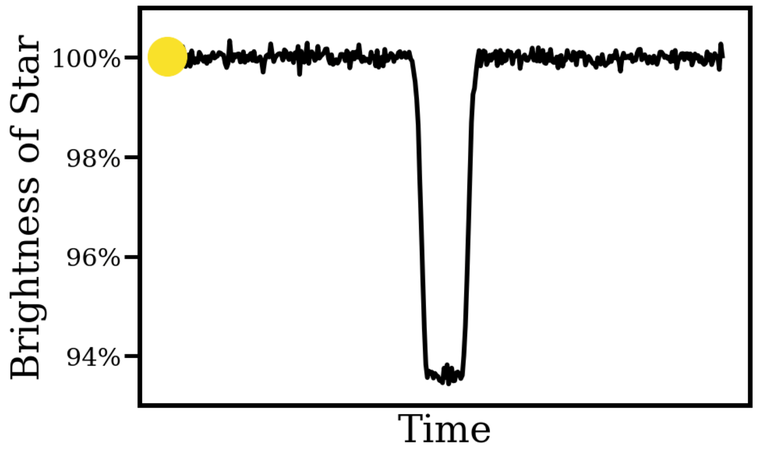

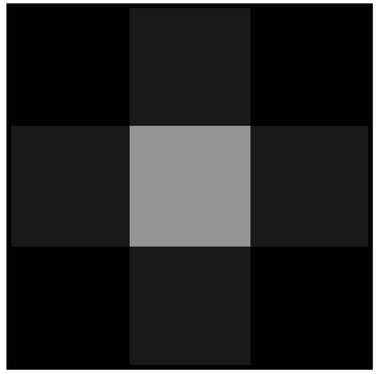

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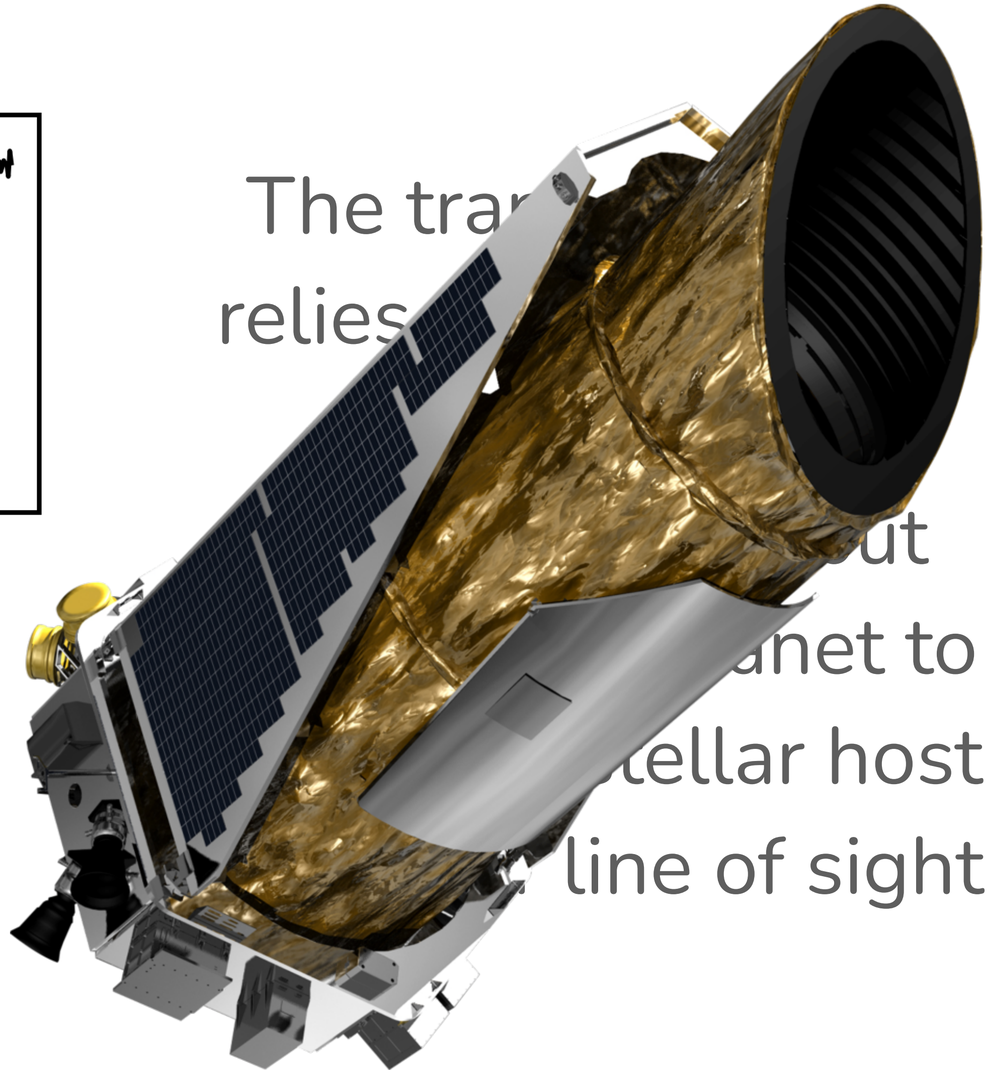

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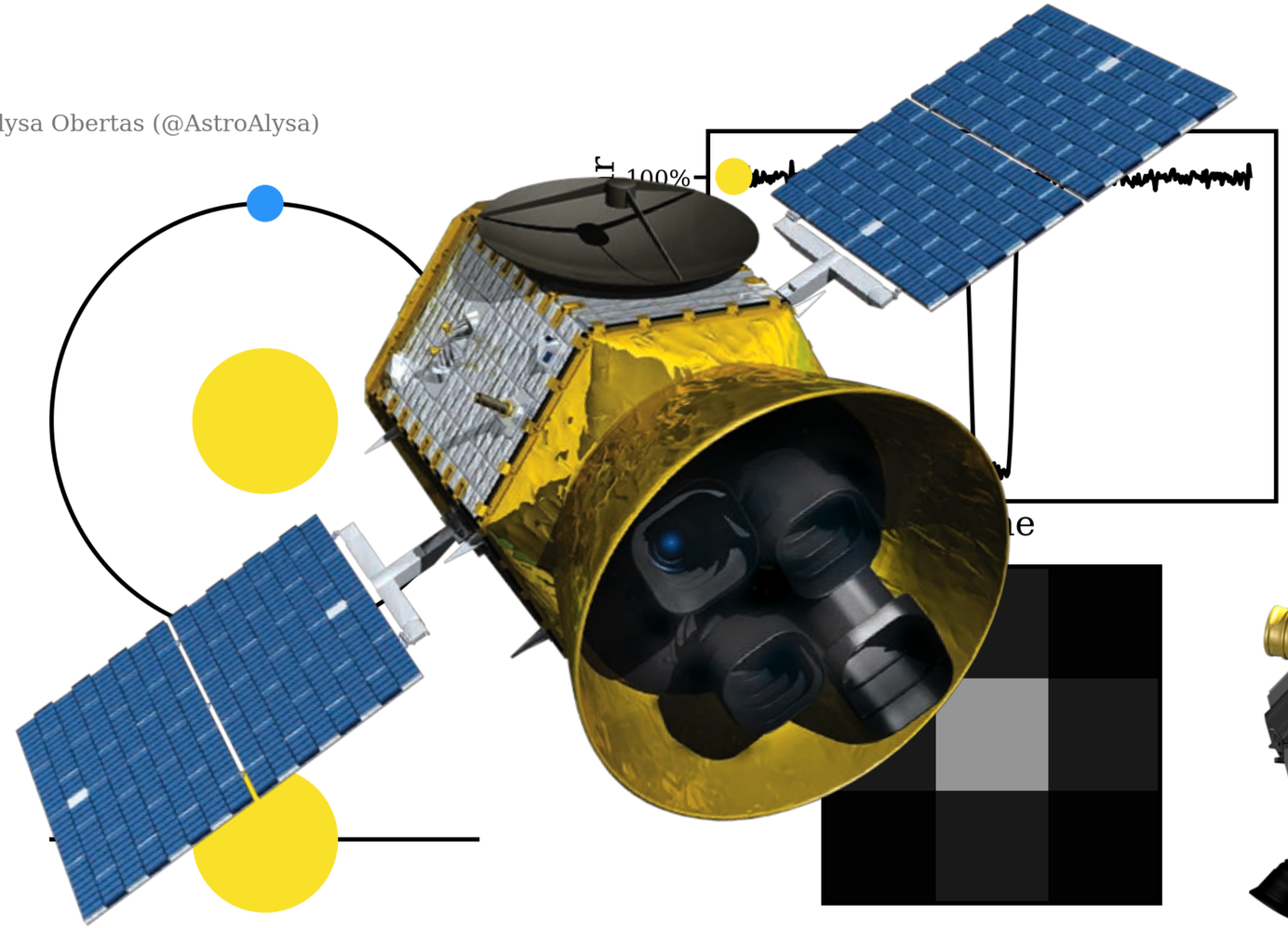

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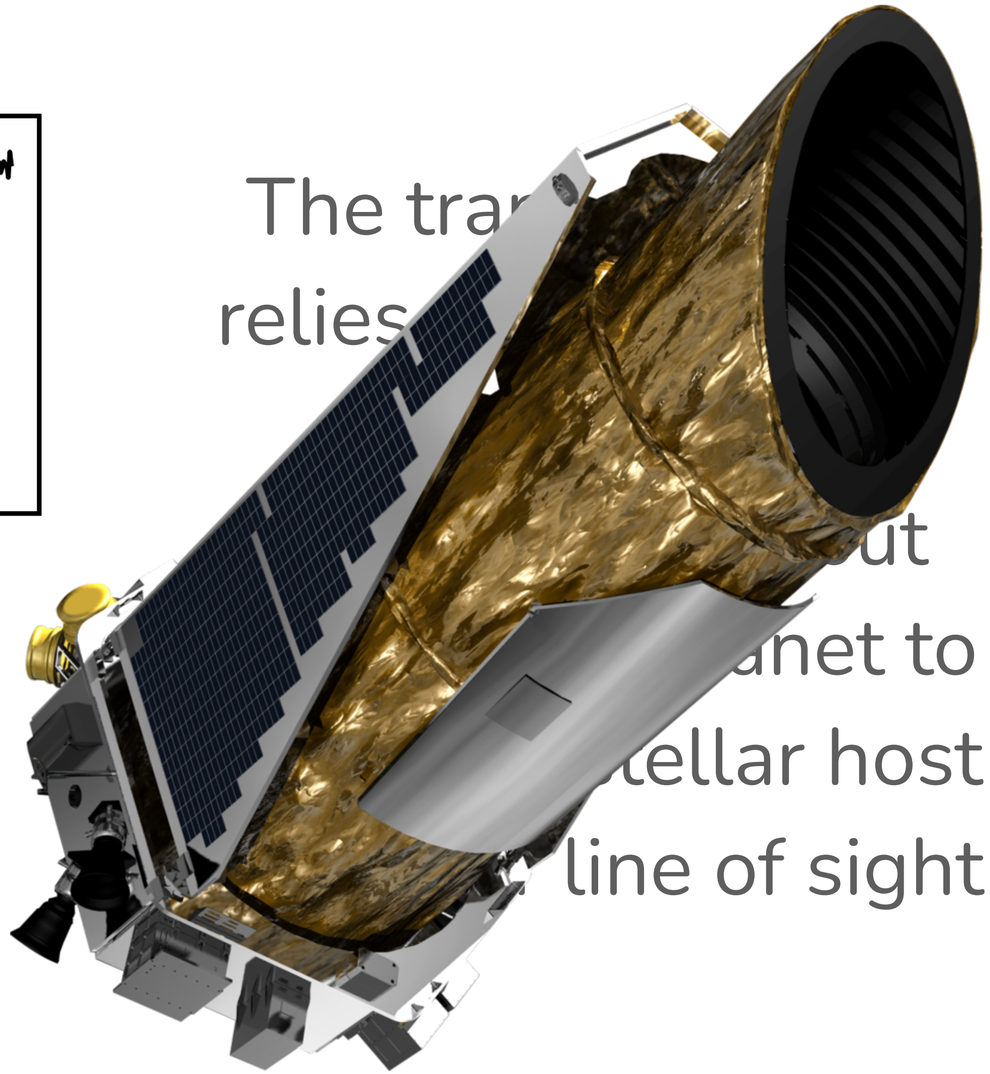

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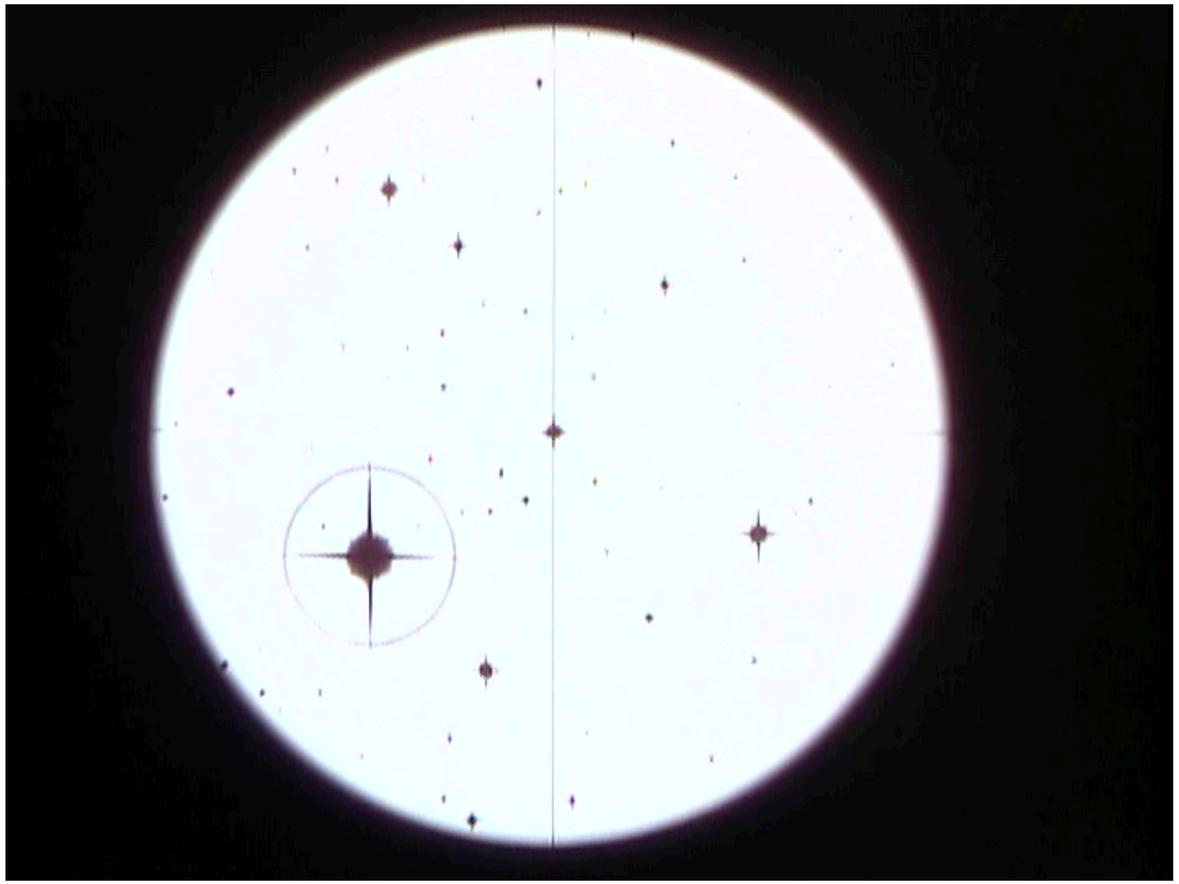
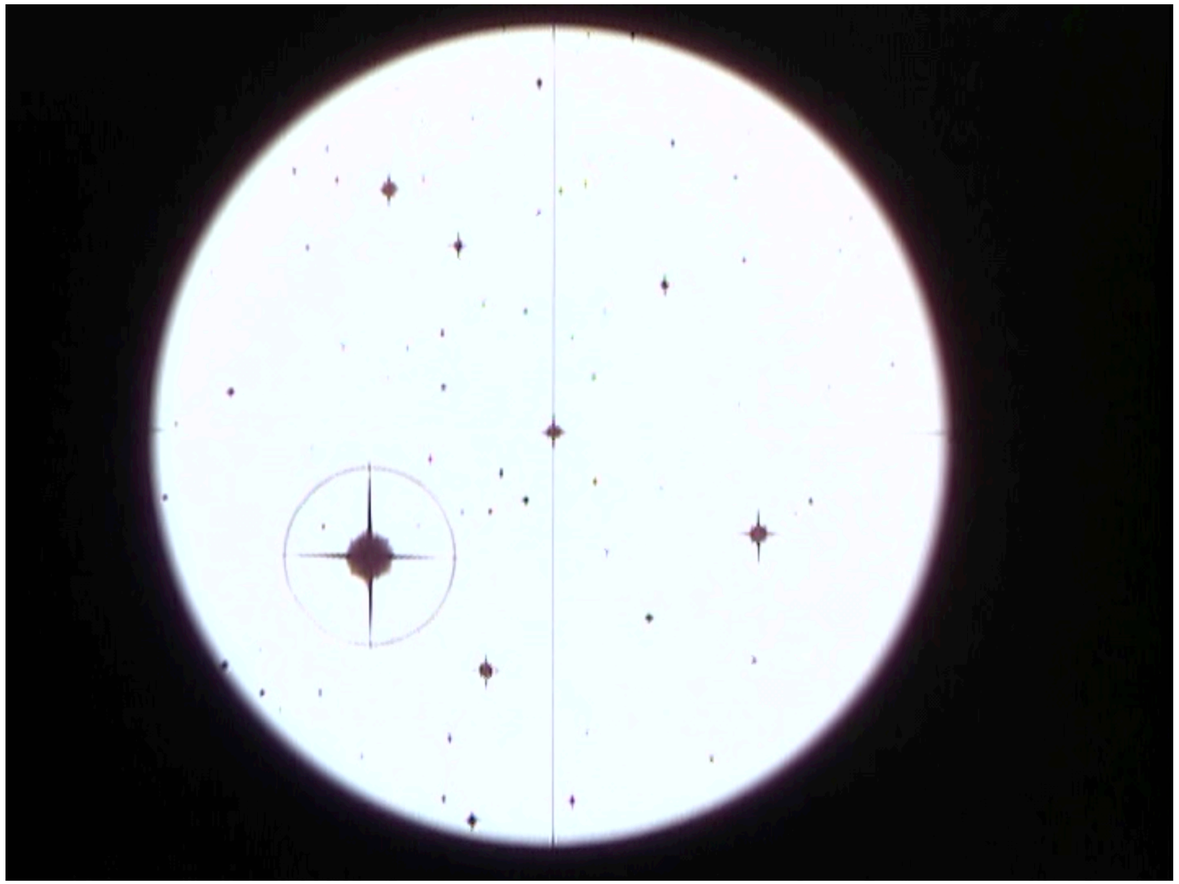


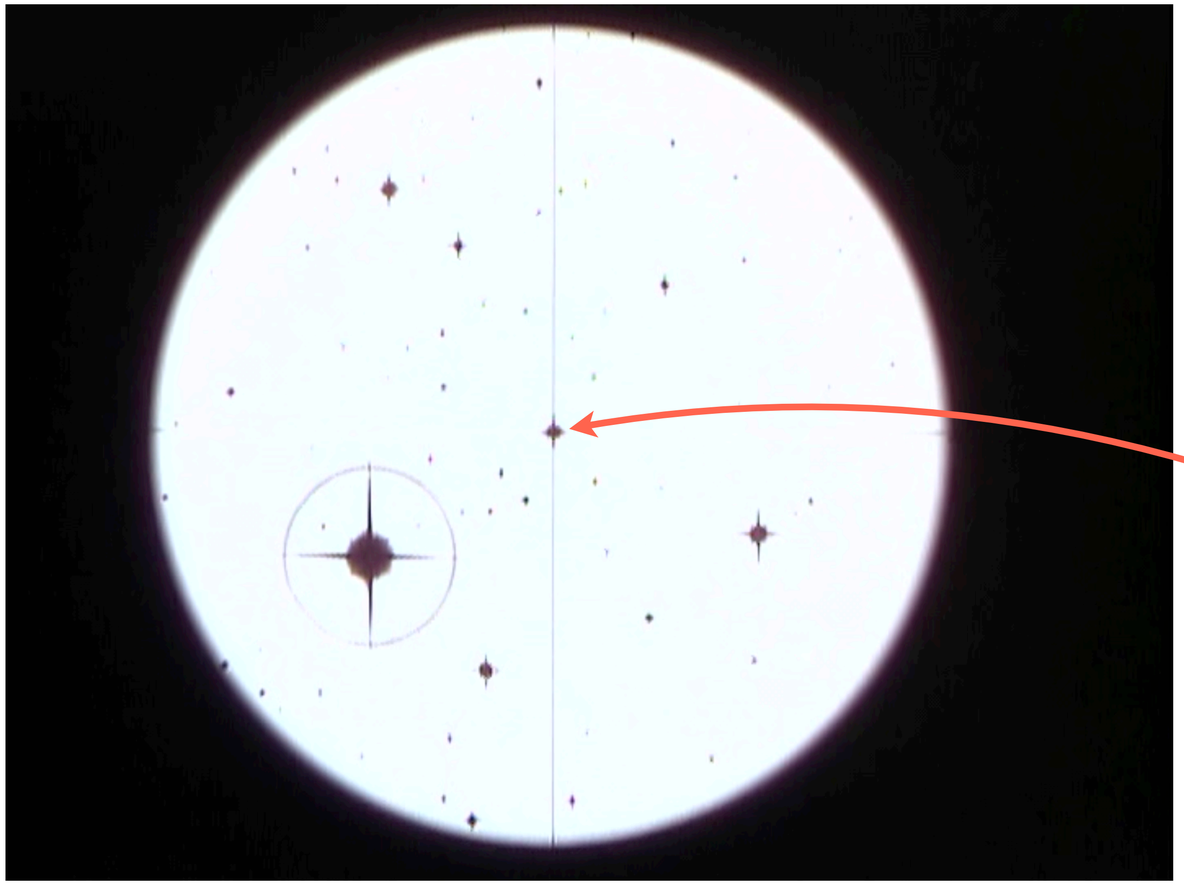
When Worlds Collide

Directed:
Rudolph Mate

Paramount (1951)



A forecast of *both* the wobble/ astrometric method and *direct imaging*



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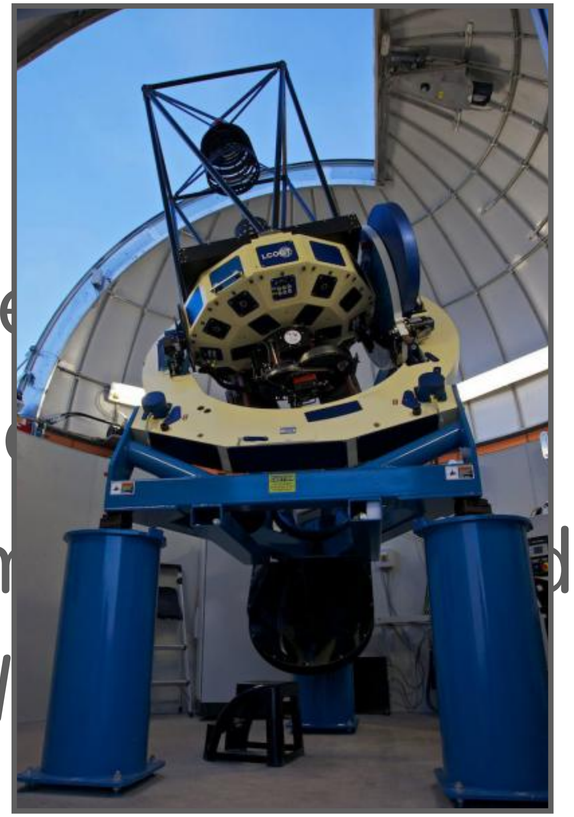
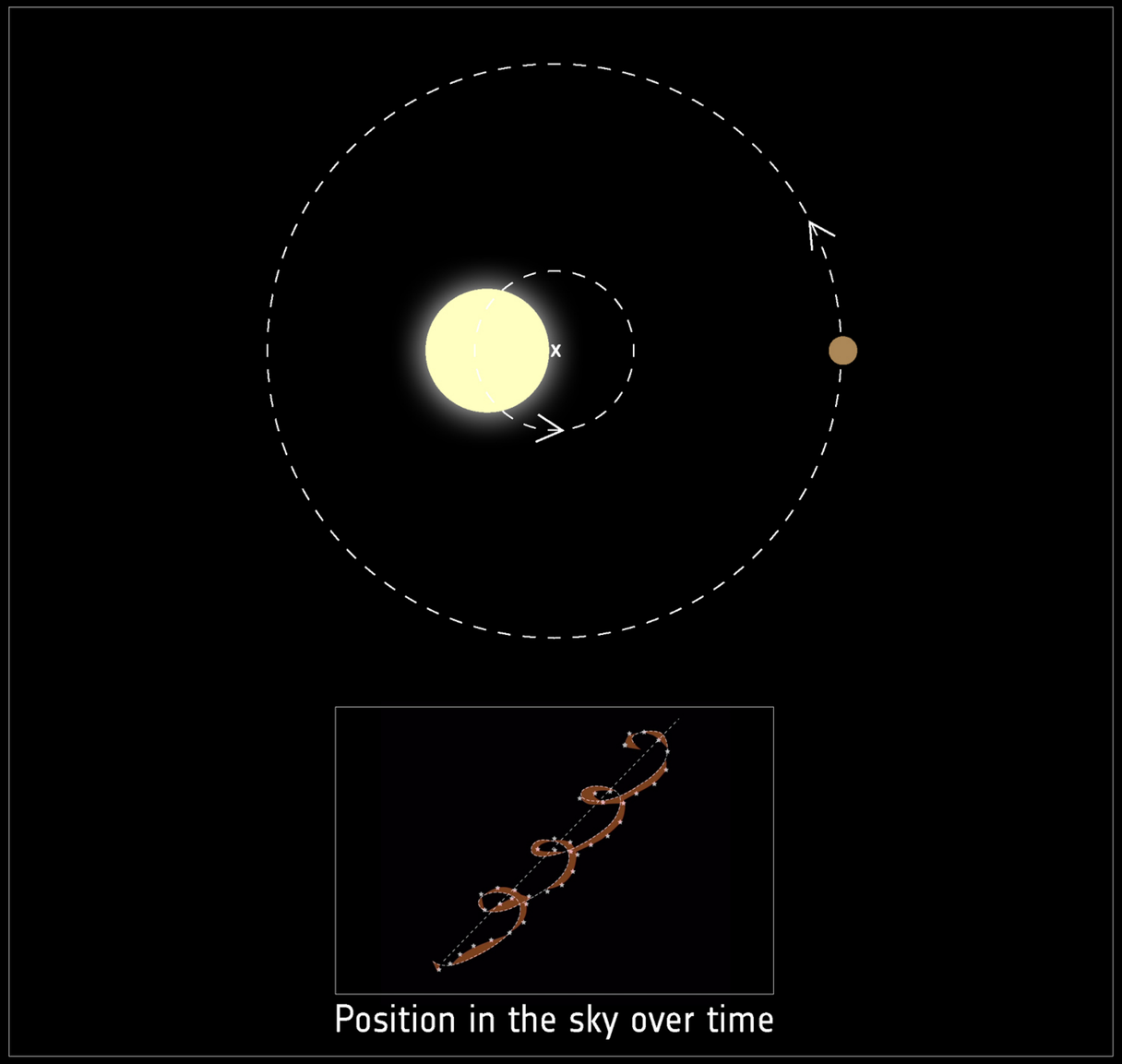


* planets don't emit enough light to have diffraction spikes

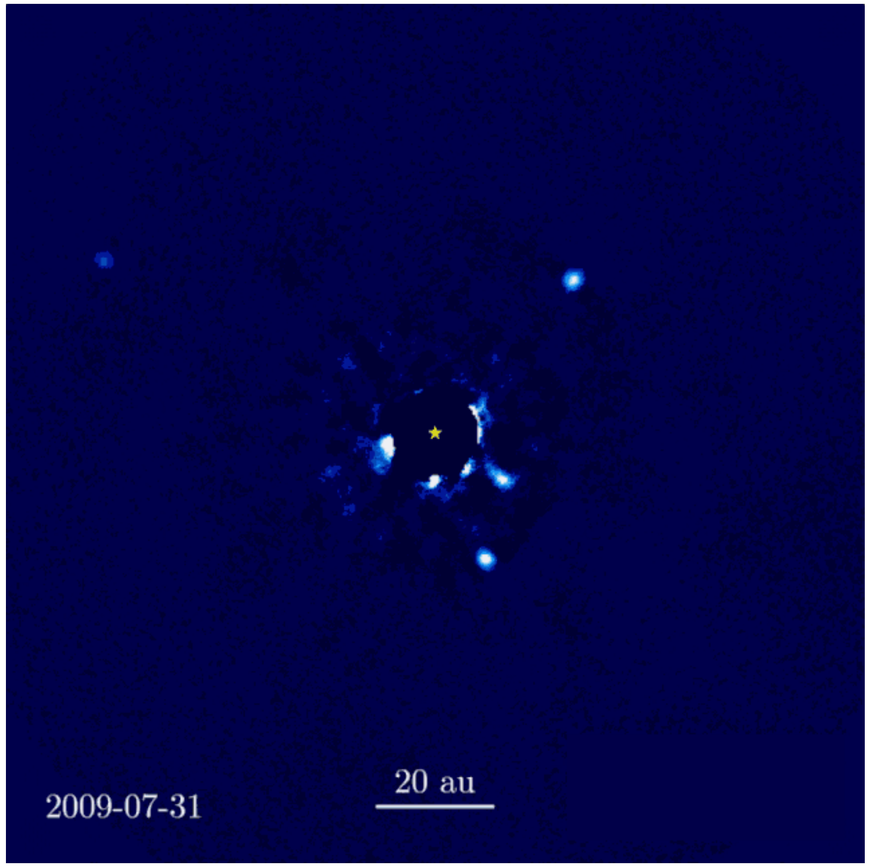
Astrometry



Astrometry measures the position of stars precisely and sees motion due to planets' gravity

Biased toward *nearby* planetary systems and *massive* planets

Direct imaging

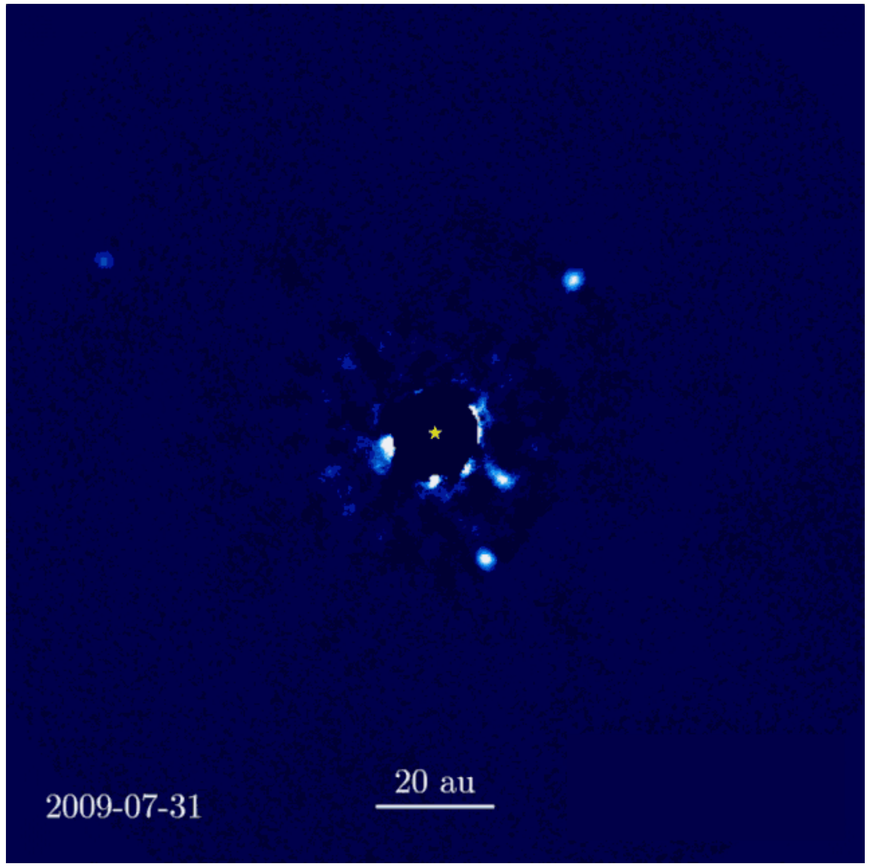


HR8799

Direct imaging searches for planets orbiting in real time by blocking out the light from the star and using infrared light combined with adaptive optics

Biased toward *wide* planetary orbits and against *bright* stars

Direct imaging



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Extra credit opportunity (10 pts total):

How many exoplanets have been confirmed with data to date?

How many stars in our Galaxy are expected to host planets?

Email your answers (and source citations) to kbreivik@andrew.cmu.edu by class time on Friday

Conditions necessary for habitability

Planets/moons

Stars

The Universe

Conditions necessary for habitability

Planets/moons

“Habitable zone” which allows for liquid water

Stars

The Universe

Conditions necessary for habitability

Planets/moons

"Habitable zone" which allows for liquid water

Stars

The Universe

Plumes of liquid water have been observed erupting out of Enceladus, a moon of Saturn that experiences strong tides that heat the moon

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Conditions necessary for habitability

Planets/moons	Stars	The Universe
“Habitable zone” which allows for liquid water		
Moon that can enable tidal pools		

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Star must be old enough for life to evolve

The Universe

Conditions necessary for habitability

Planets/moons

"Habitable zone" which allows for liquid water

Moon that can enable tidal pools

Stars

Star must be old enough for life to evolve

Gas giants which protect inner rocky planets from comets & asteroids

The Universe

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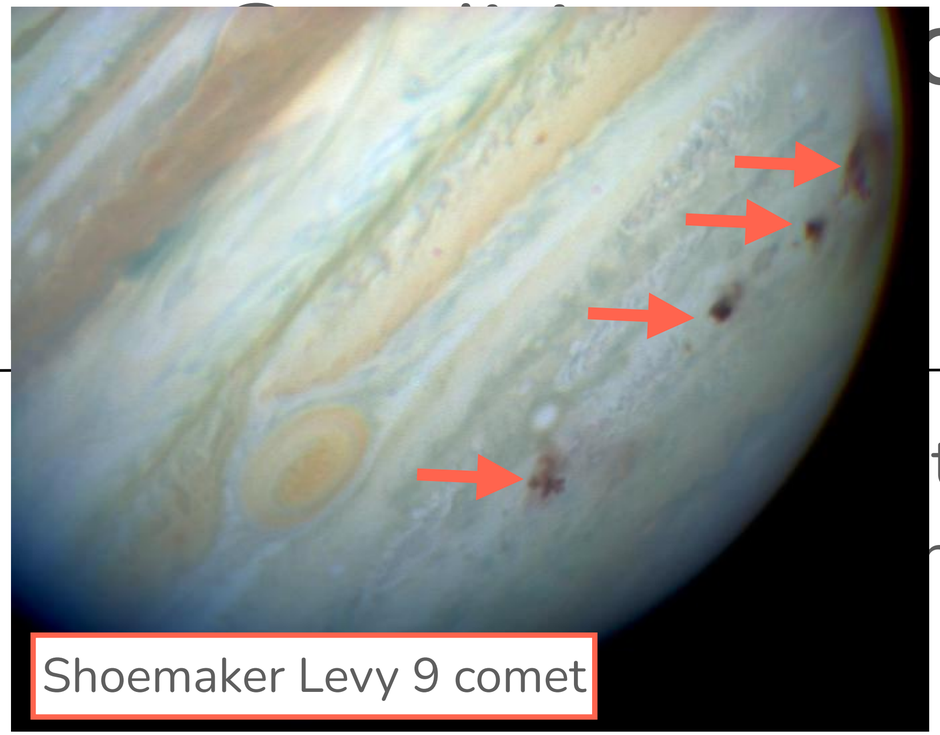
Shoemaker Levy 9 comet

Stars

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Gas giants which protect inner rocky planets from comets & asteroids

The Universe

Moon that can enable tidal pools

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Flat: perfect expansion rate allows formation of stars & galaxies

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Matter imbalance: perfect rate of 1 proton per 10^{10} proton-antiproton pairs

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The Universe

Flat: perfect expansion rate allows formation of stars & galaxies

Matter imbalance: perfect rate of 1 proton per 10^{10} proton-antiproton pairs

Mass of proton is 1/1000 times **smaller** than mass of neutron —> right β-decay rate for stable elements

The Drake Equation

$$N = R^{\star} \times f_p \times n_E \times f_l \times f_i \times f_c \times L$$

$R^{\star}$: average star formation rate in the Galaxy (assumed 10 ★/yr)

f_p : fraction of stars with planets (assumed < 1)

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L : average lifetime of radio-communicating civilization (assumed 10^4 yr)

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Contact

Directed:
Robert Zemeckis

Warner Brothers (1997)