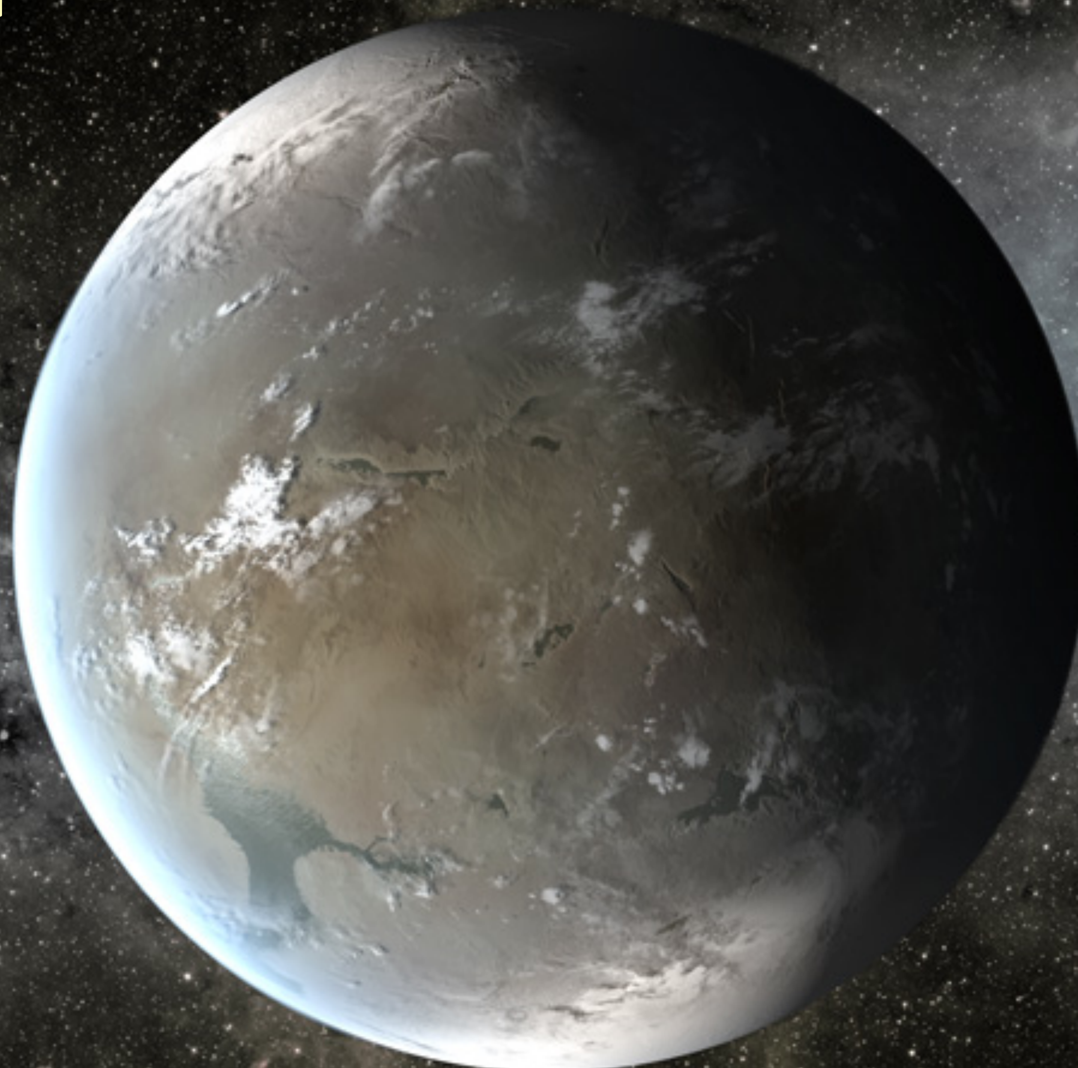
The Search for Other Earths

Class 8: Looking Forward

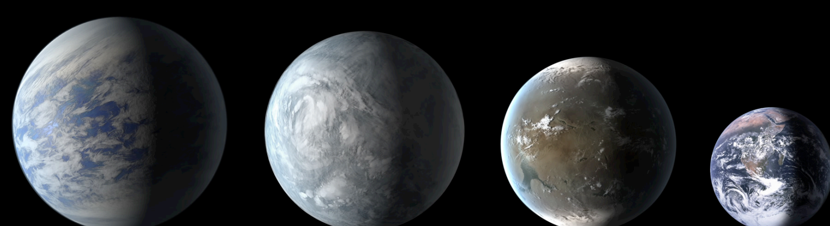


Steve Bryson

Questions?

What About Life?

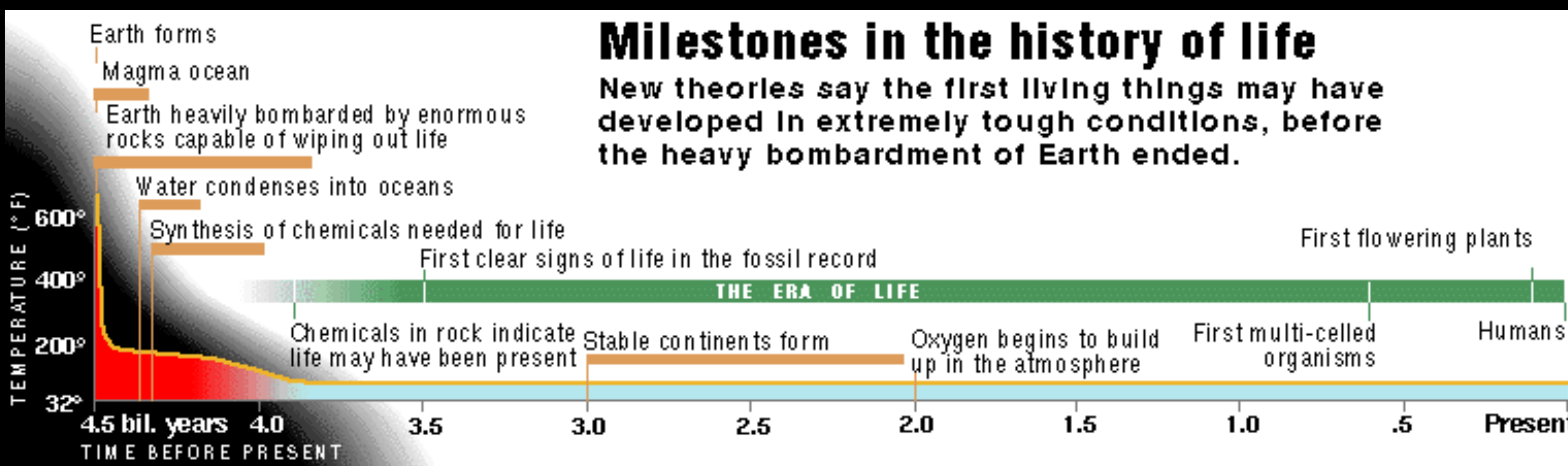
- Currently we can't detect life on exoplanets
- We know a lot about how biology works
- But not much about how biology got started
- So we don't know what is required for life
  - Stick to what we know
    - But don't ignore other possibilities
- Perhaps Super Earths are good for life
  - More active geology provides more good minerals



The Infant Solar System was a Very Unfriendly Place

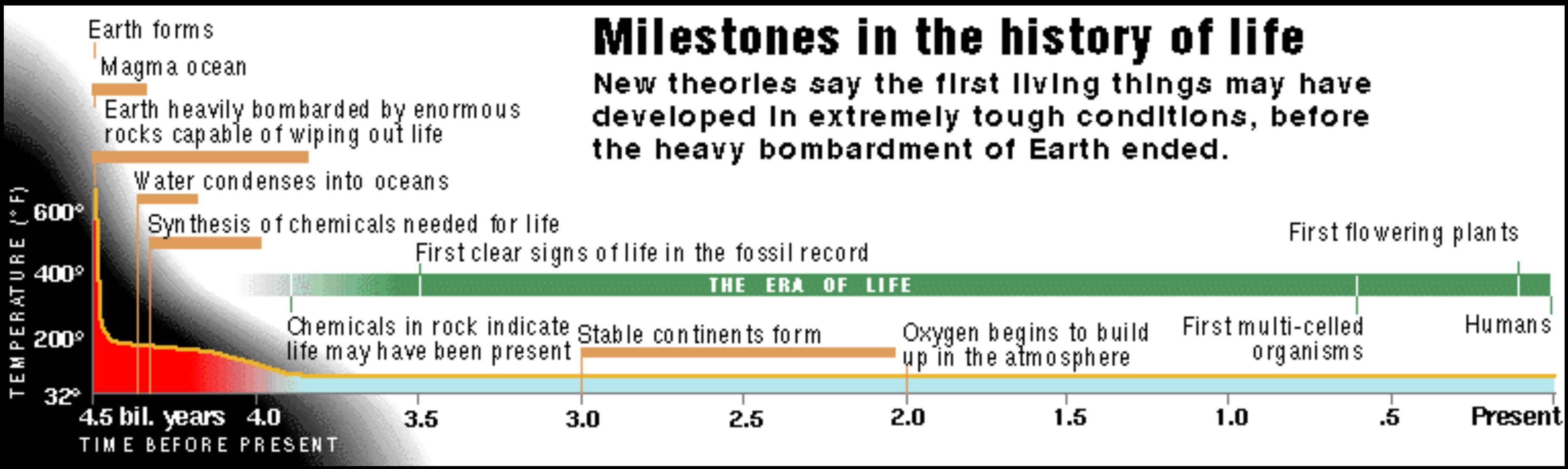
Life on Earth Happened Quickly

- We have evidence for simple life almost as soon as Earth was cool enough to allow it
  - Does this mean that the creation of life is probable?



But Complex Life Took a Long Time

- Multi-celled animals took a lot longer
  - Does this mean that the evolution of complex life is less probable?

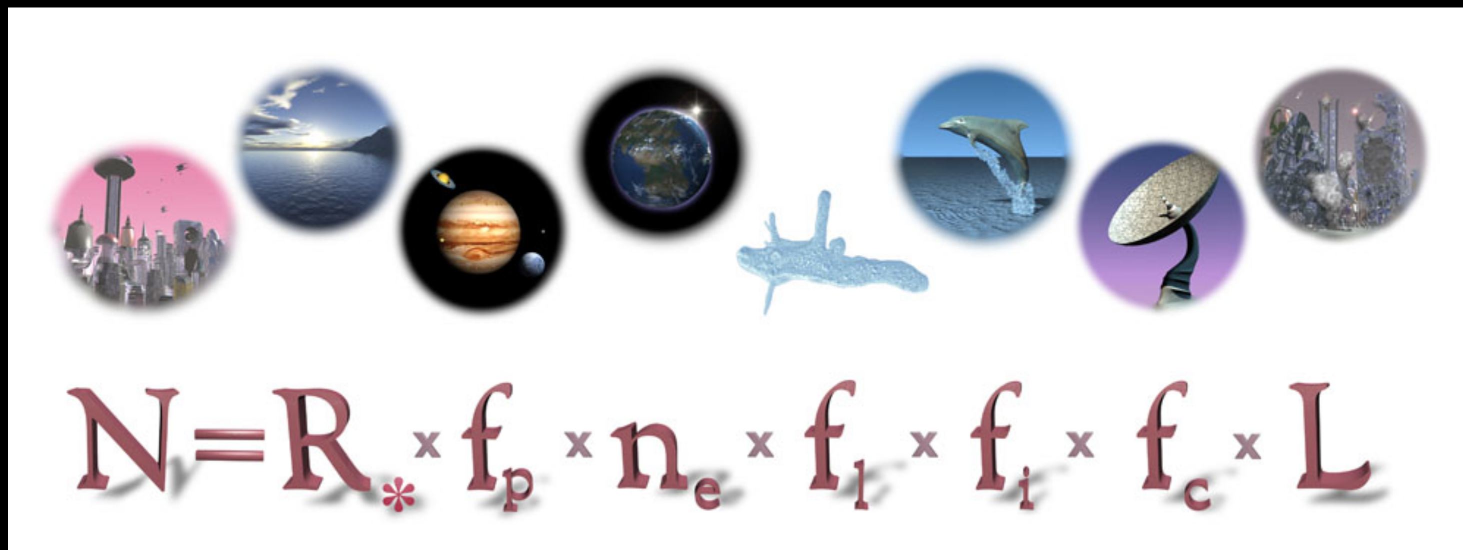


What About Other Civilizations?

- Depends on
  - How many stars
  - What fraction of those stars have planets
  - What fraction of those planets are Earth-size
  - What fraction of those planets have life
  - What fraction of that life evolves intelligence
  - What fraction develop the ability to communicate
  - How long such civilizations live
- Multiply all these together and get the *Drake Equation*

The Drake Equation

Drake Equation

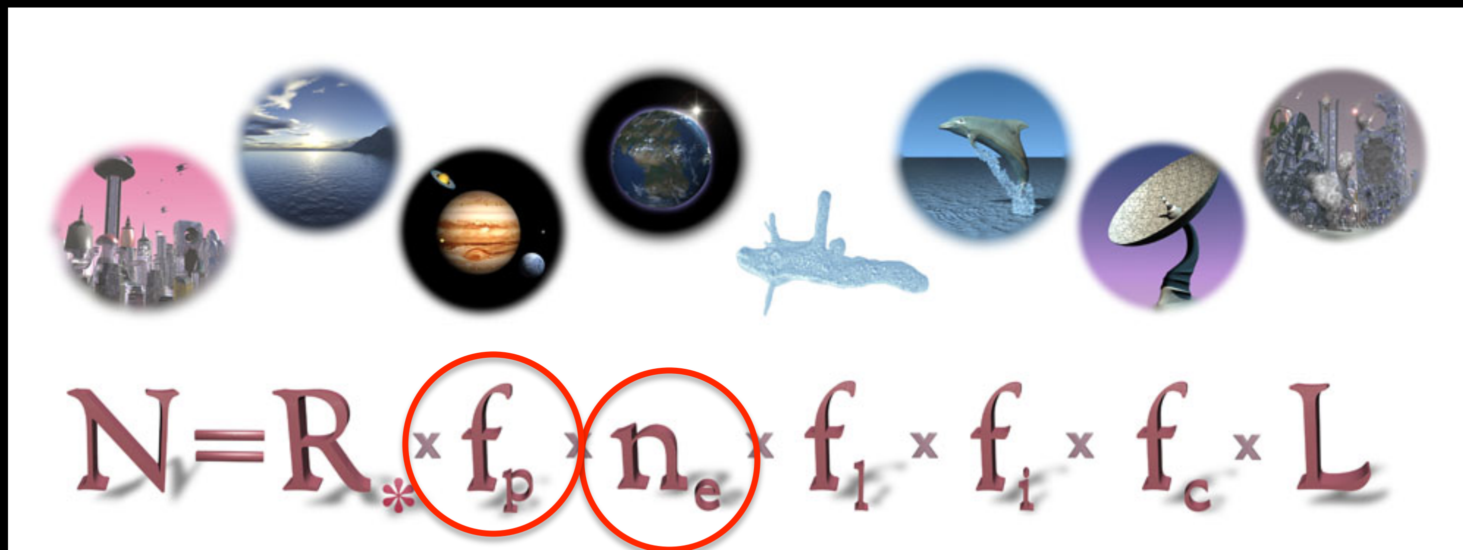


Graphic by Chris Short
http://www.cyrstudio.com/short

- 30 years ago we only knew how many stars there are (R_*)

The Drake Equation

Drake Equation

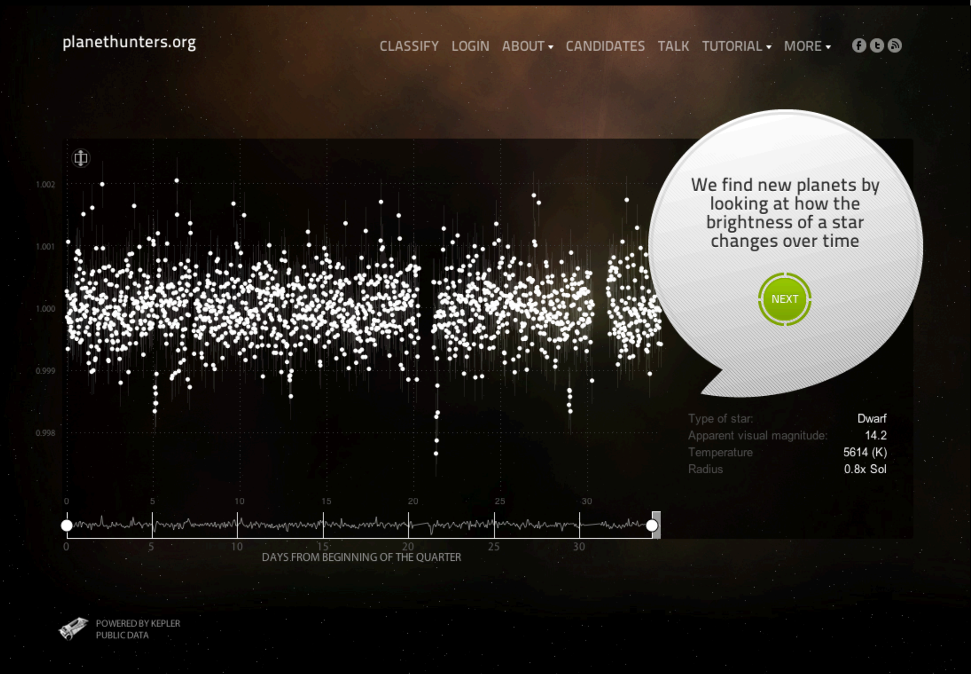


Graphic by Chris Short
http://www.cyrstudio.com/short

- Now we know what fraction of stars have planets (all) and the fraction of planets that are Earth-size (~15%)
- We have to dig more deeply in the data to measure how many Earth-like planets are in the habitable zone

Continuing to Dig Into the Data

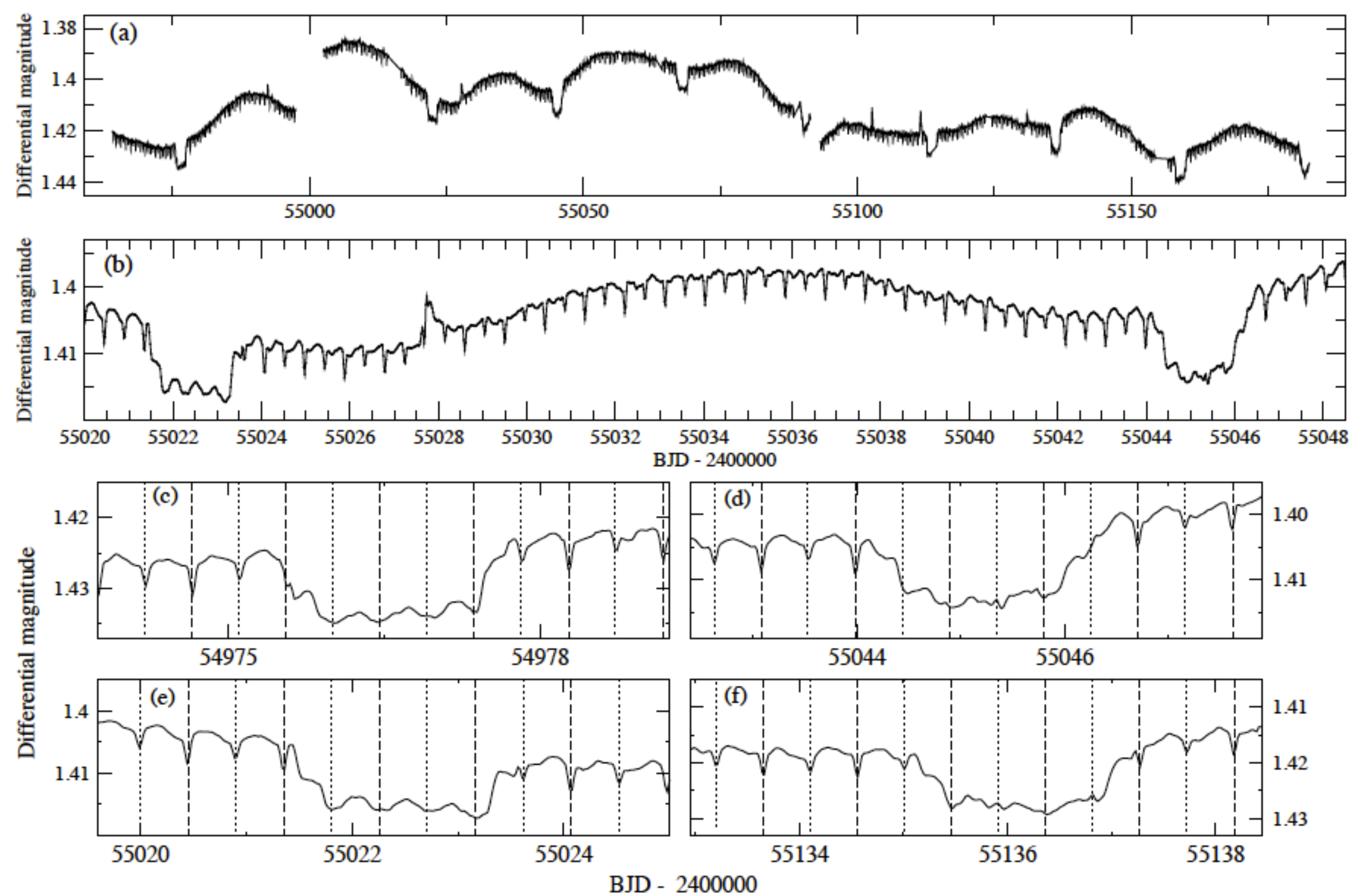
- Astronomers will continue to look at Kepler data for years to come
- You can help! www.planethunters.org
  - Help find new planets!
  - Some already found
    - Missed by the Kepler team



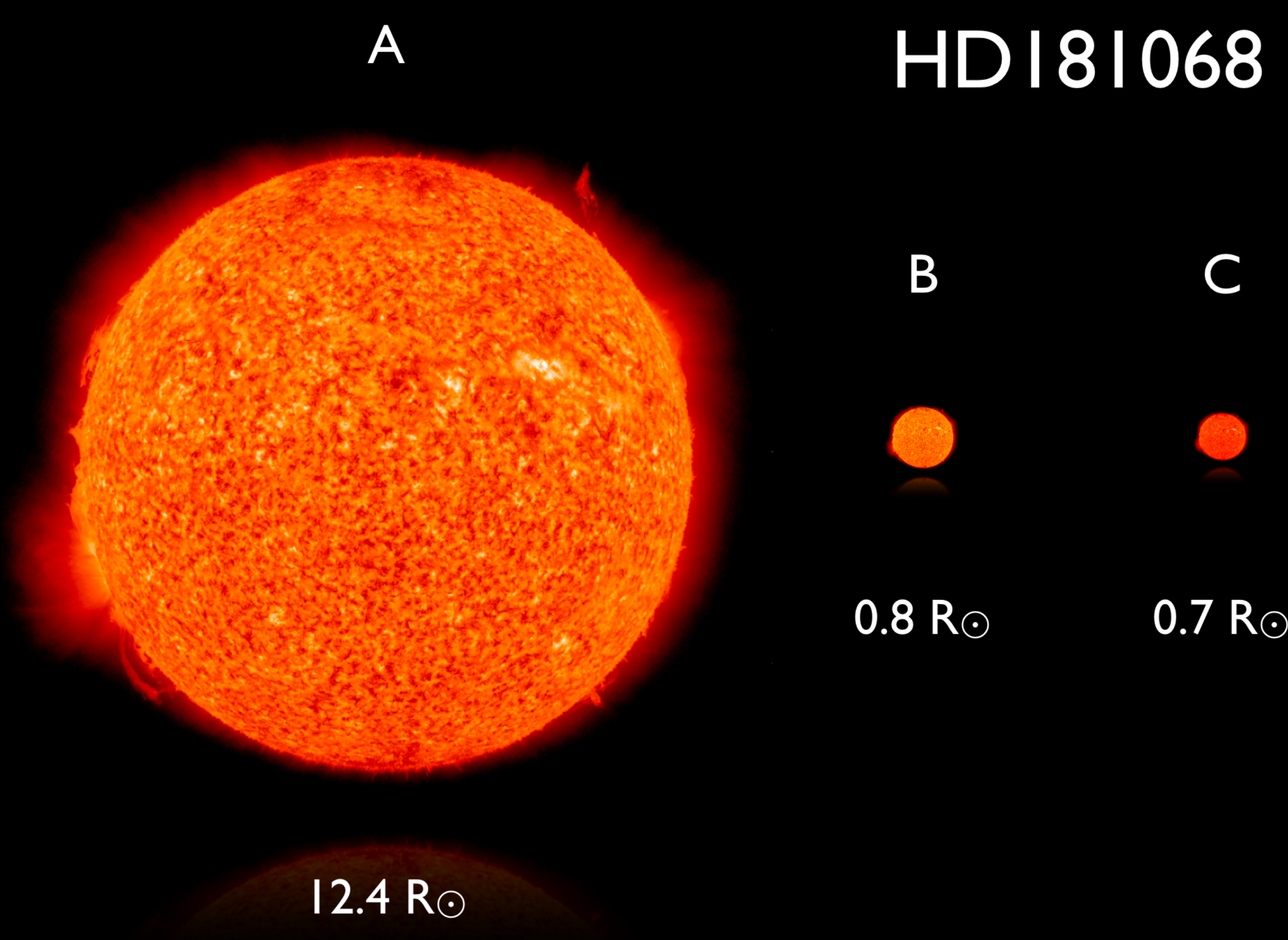
Kepler Also Observes Stars

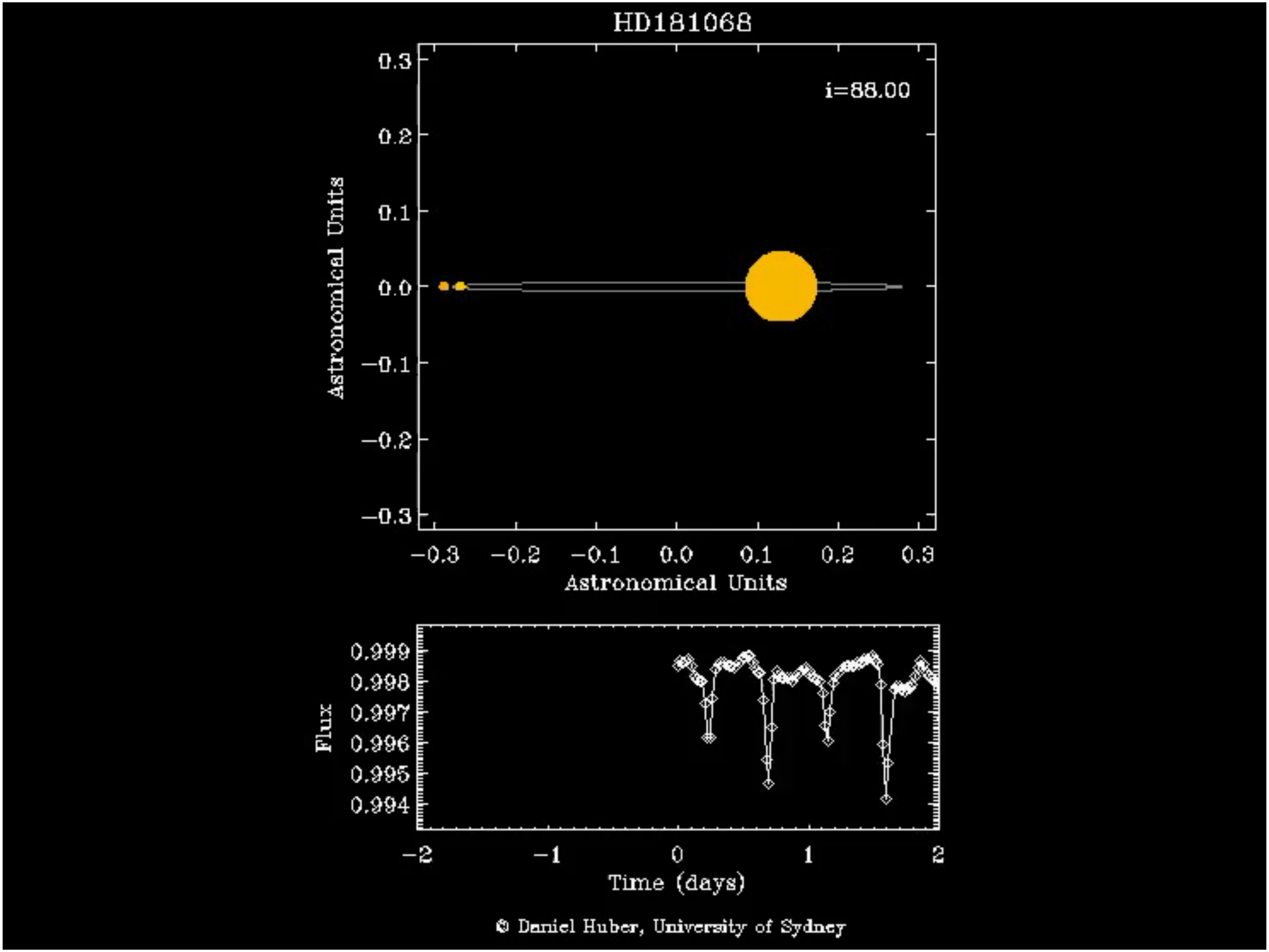
- Most Boring Telescope?
  - It always looks at the same thing
- But wait! Kepler always looks at the same thing!
  - Fantastic opportunity to make long-term observations of stars at high precision

“Trinity”


(a)
(b)
(c)
(d)
(e)
(f)
Differential magnitude
1.38
1.4
1.42
1.44
55000
55050
55100
55150
1.41
55020
55022
55024
55026
55028
55030
55032
55034
55036
55038
55040
55042
55044
55046
55048
BJD - 2400000
1.42
1.43
54975
54978
1.40
55044
55046
55134
55136
55138
BJD - 2400000

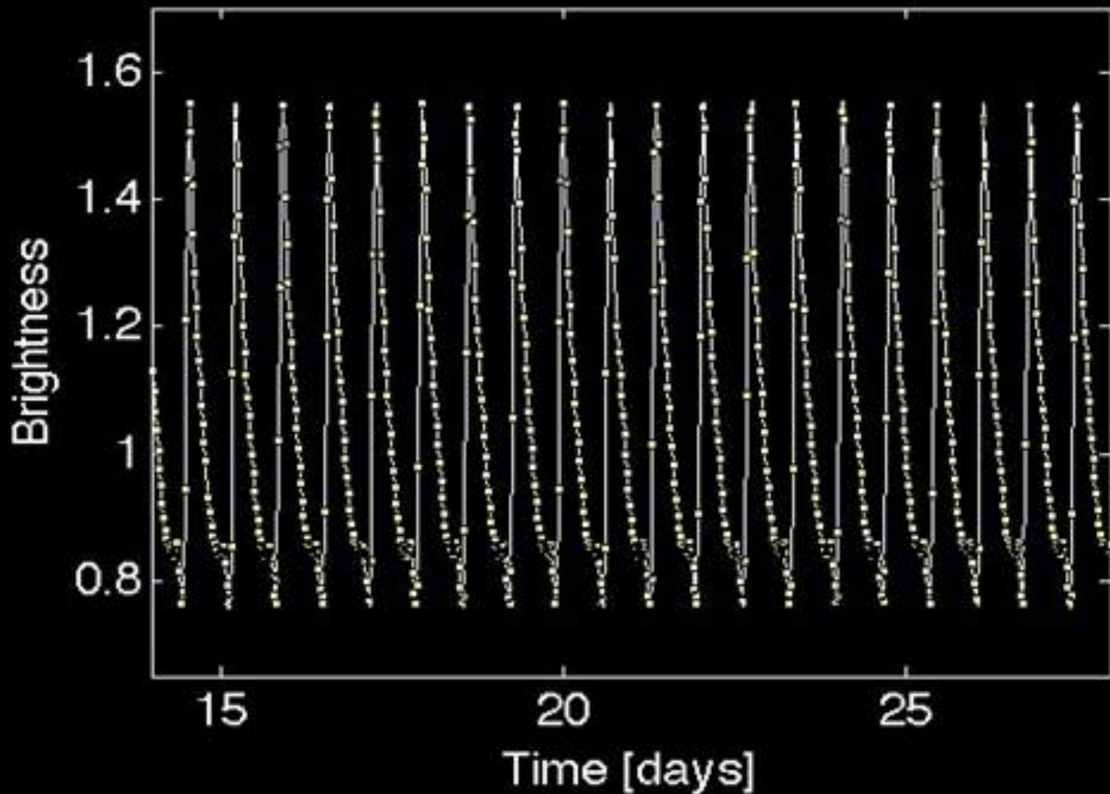
Trinity

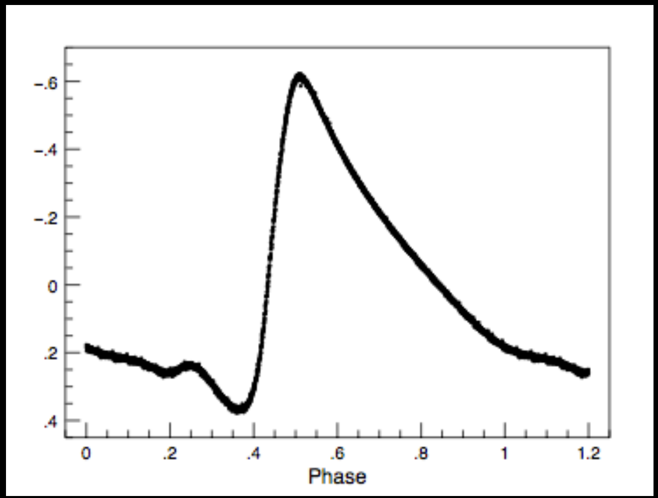



HD181068
i=88.00
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
Astronomical Units
−0.3 −0.2 −0.1 0.0 0.1 0.2 0.3
Astronomical Units
0.999
0.998
0.997
0.996
0.995
0.994
Flux
−2 −1 0 1 2
Time (days)
© Daniel Huber, University of Sydney

RR Lyrae Stars

- Variable stars that double in brightness in only a couple hours more than once a day

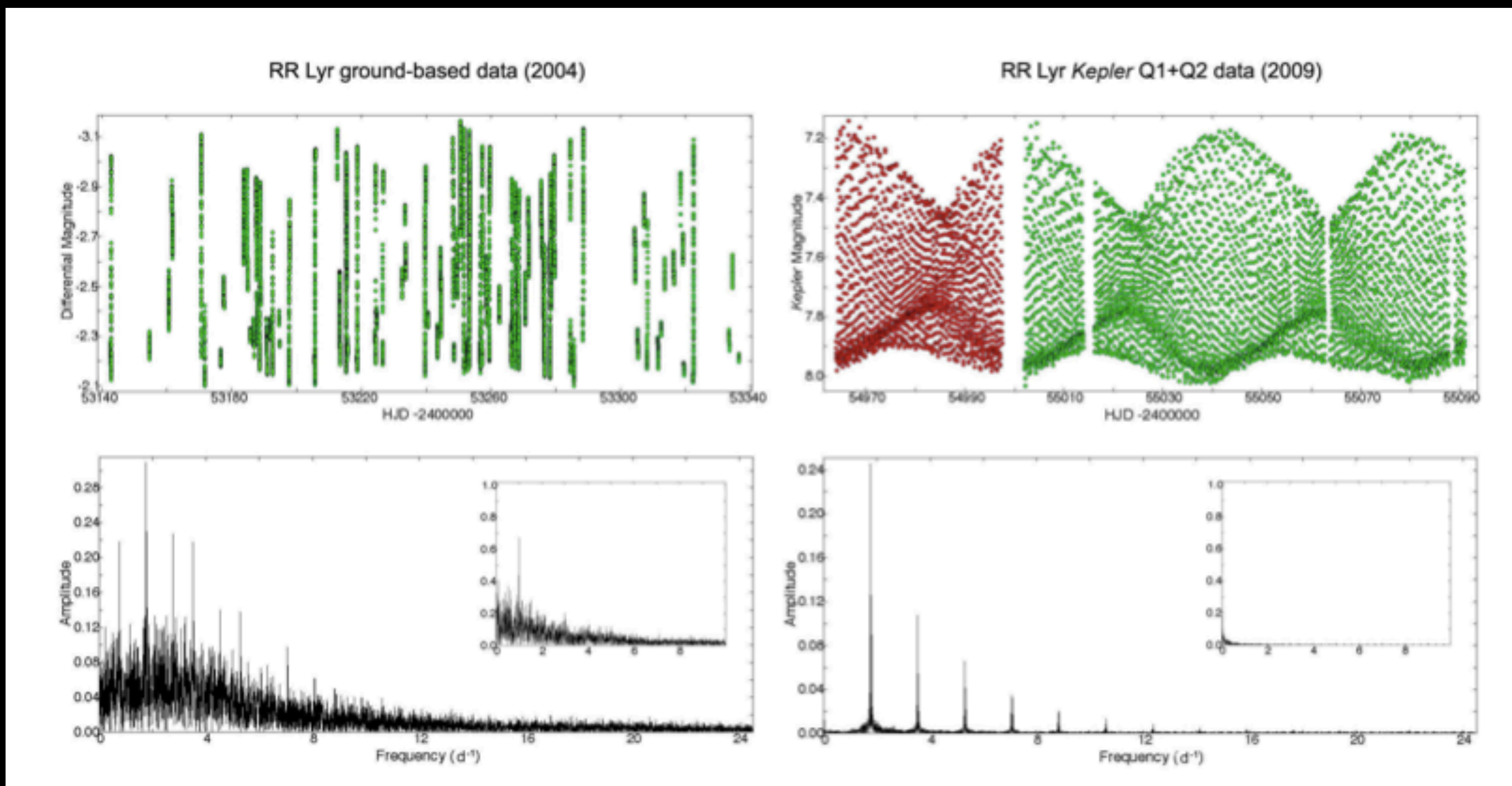




One period close up

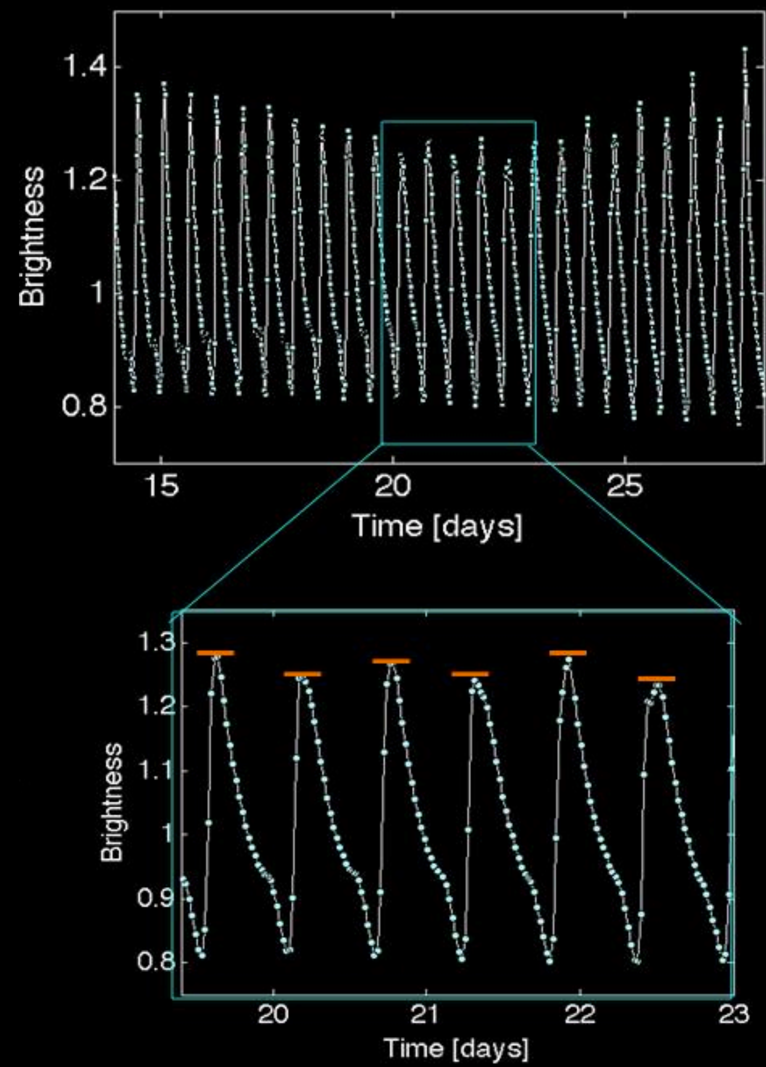
Example of RR Lyrae

- Happens to be in the Kepler field
  - New discovery of period doubling

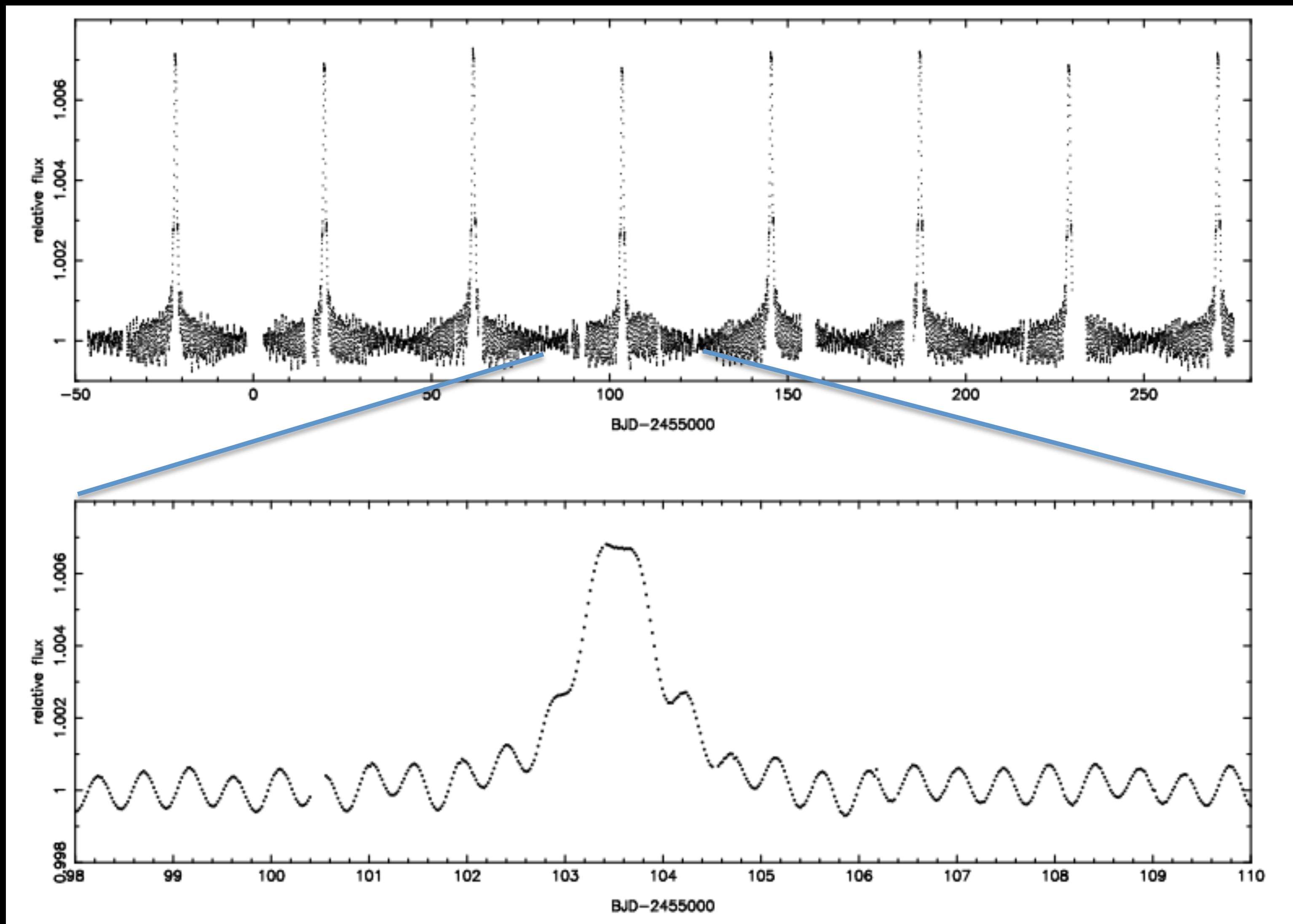


RR Lyrae Stars

- On some RR Lyrae stars the variation is very steady, like on the previous slide
  - We have a good idea why these steady variations happen
- On other RR Lyrae stars the variation is complicated
- We don't understand why there are these complications, but Kepler is helping make better theories

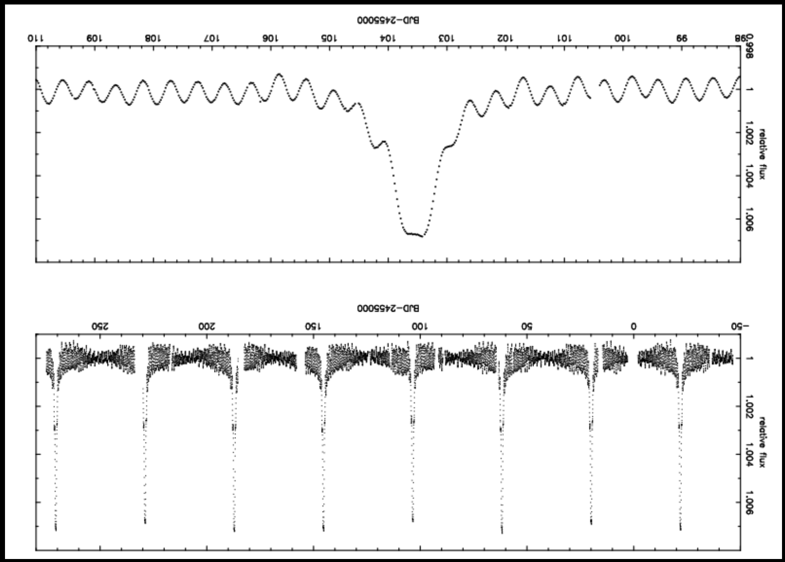


The Mystery of KOI-54



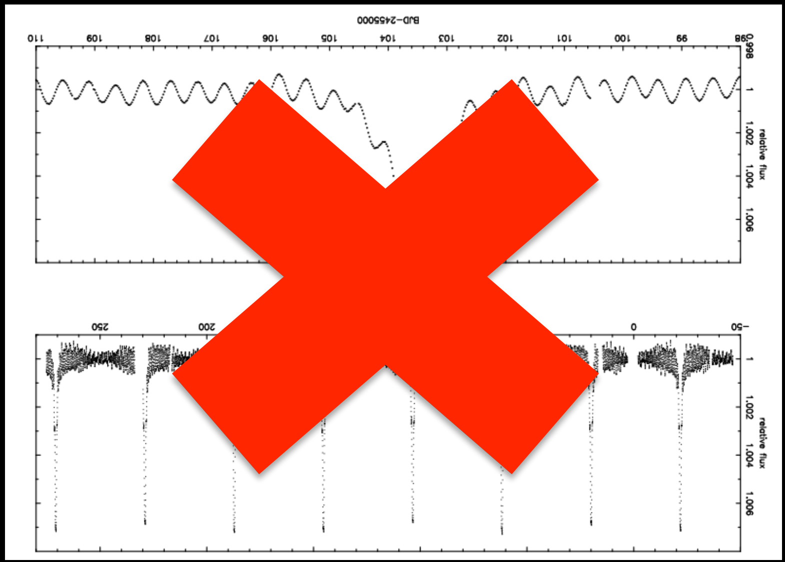
KOI-54: What Is It?

- Upside down?



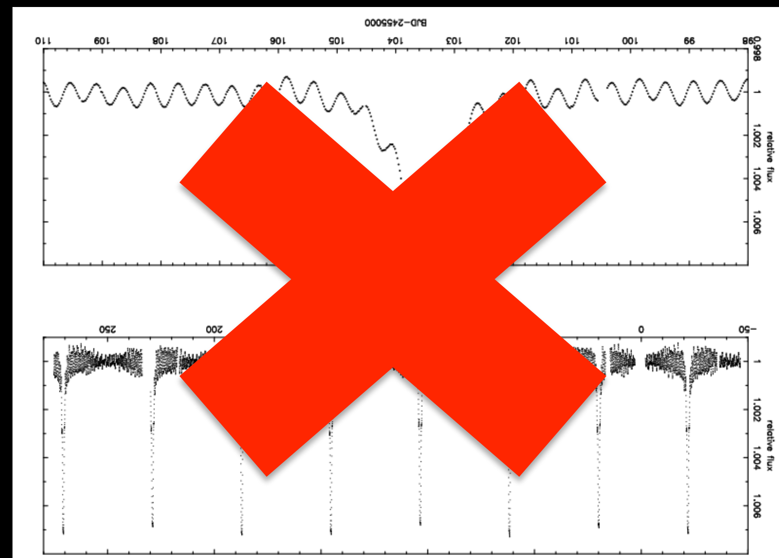
KOI-54: What Is It?

- Upside down?

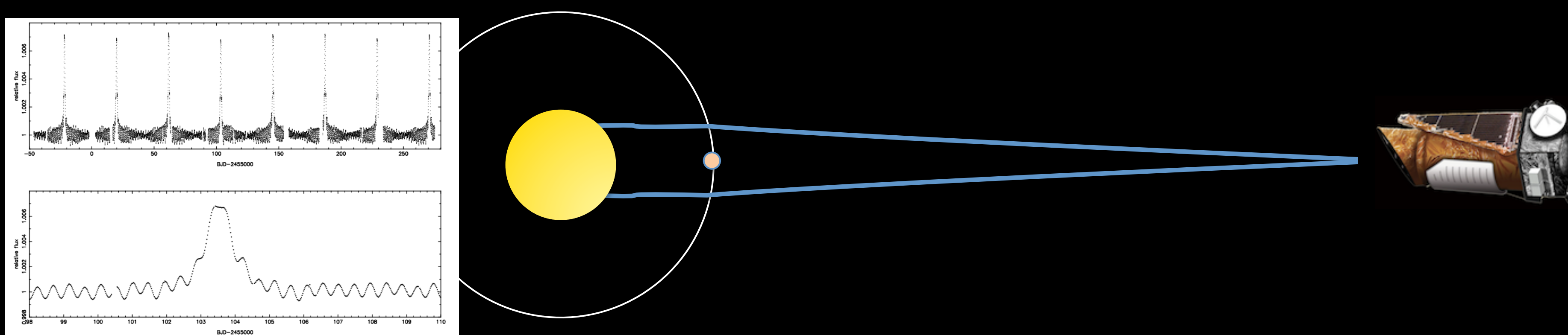


KOI-54: What Is It?

- Upside down?

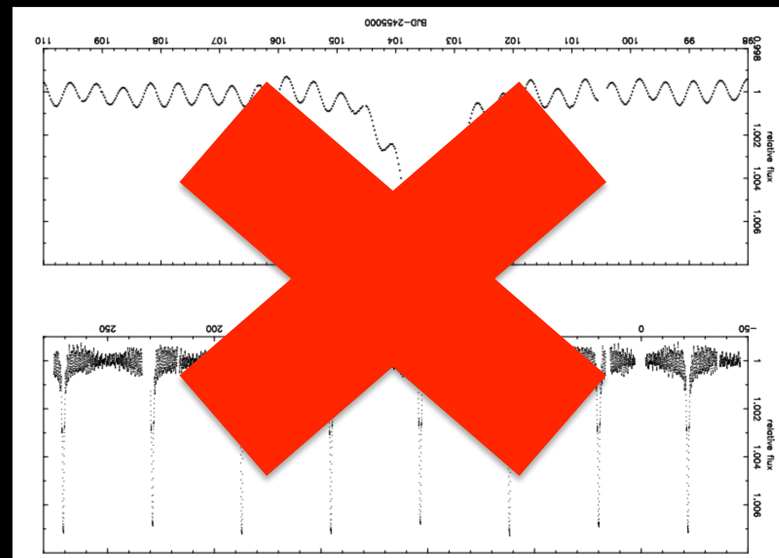


- Gravitational Lensing by a Neutron Star or Black Hole?

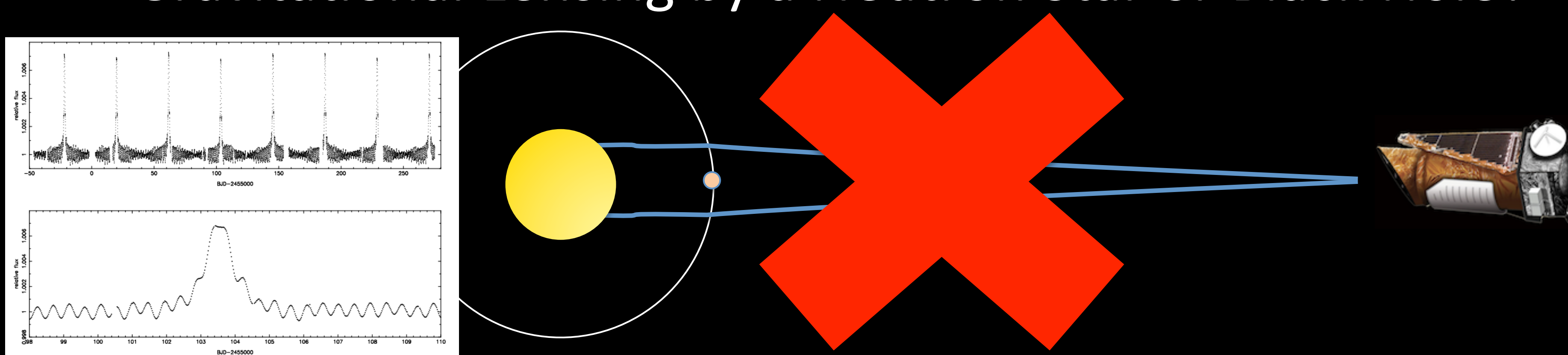


KOI-54: What Is It?

- Upside down?

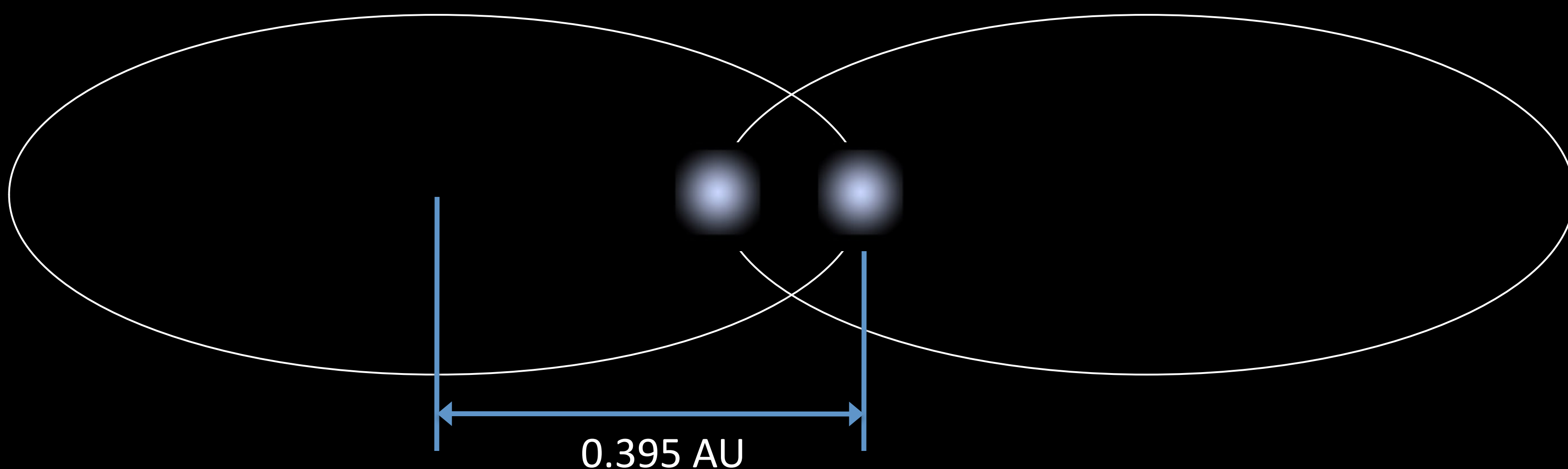


- Gravitational Lensing by a Neutron Star or Black Hole?

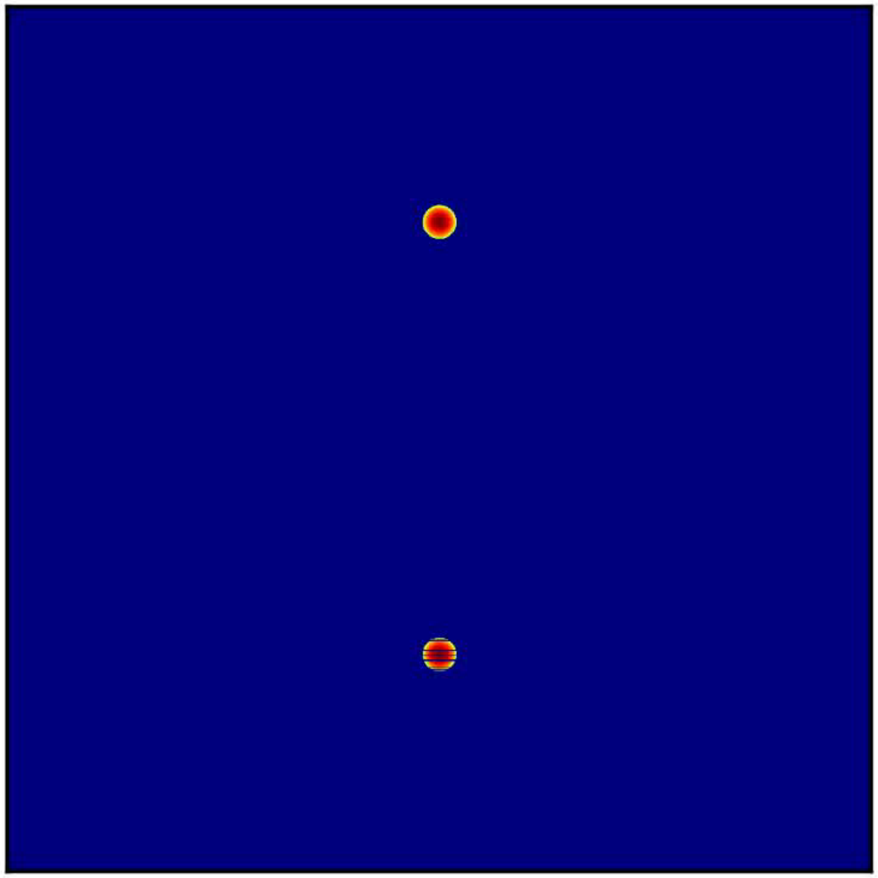


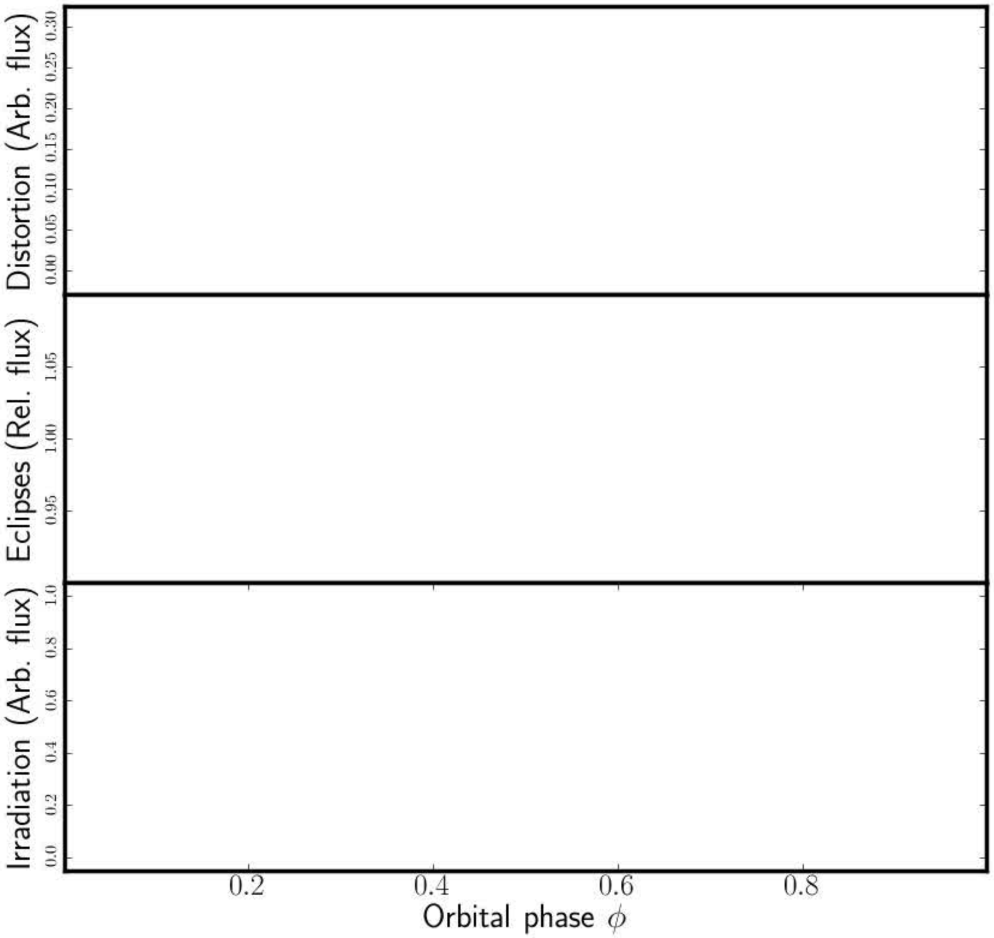
KOI-54: The Answer

- Two, almost identical A (blue giant) stars in very elliptical orbits (41.8 day period)
  - Every 41.8 days the stars are very close together and heat each other up increasing the brightness
  - The close encounter also creates oscillations in both star's size



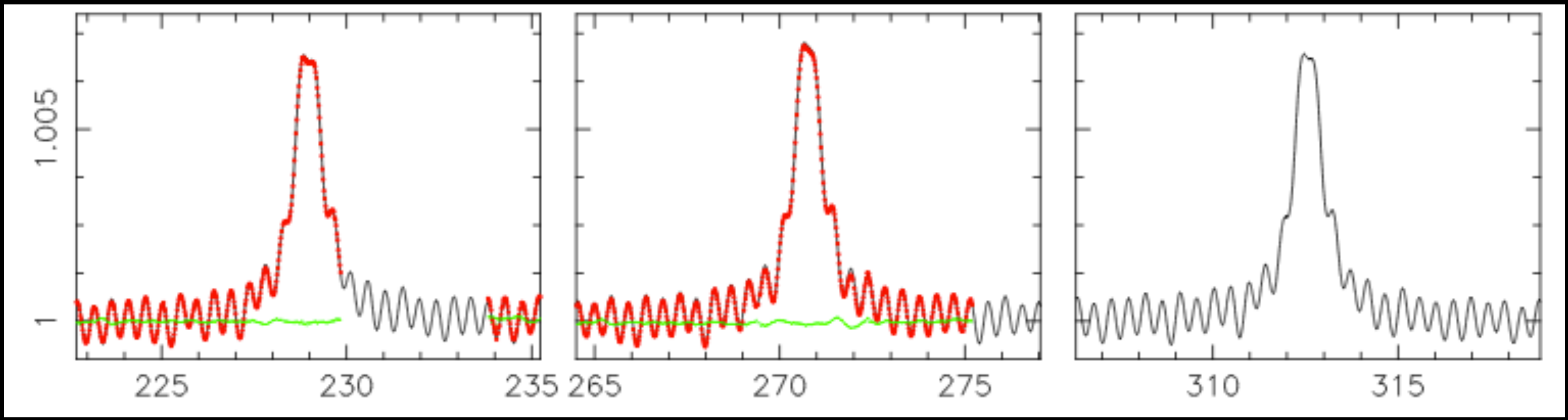
KOI-54: The Answer





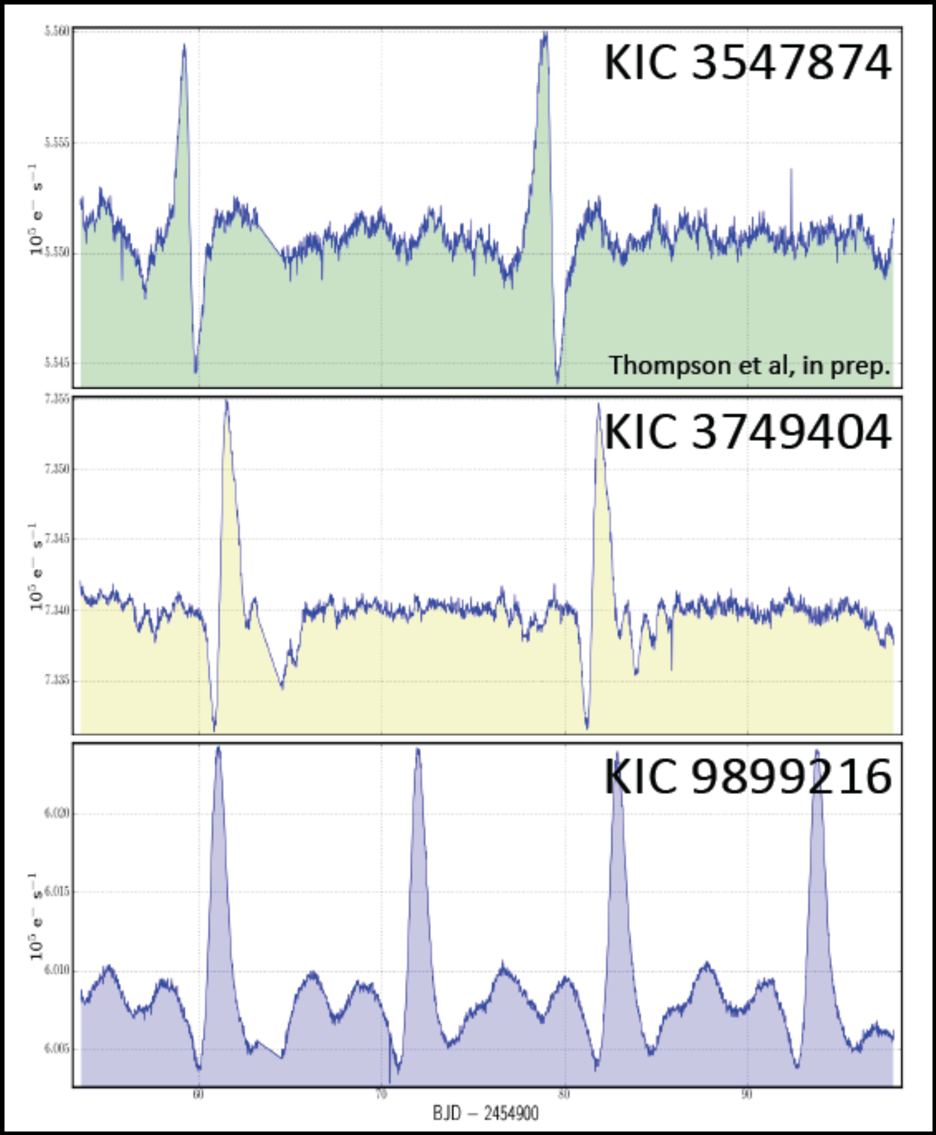
KOI-54: How Do We Know?

- We make a theoretical model of how such stars would behave if it were true
- The data matches the model exactly!



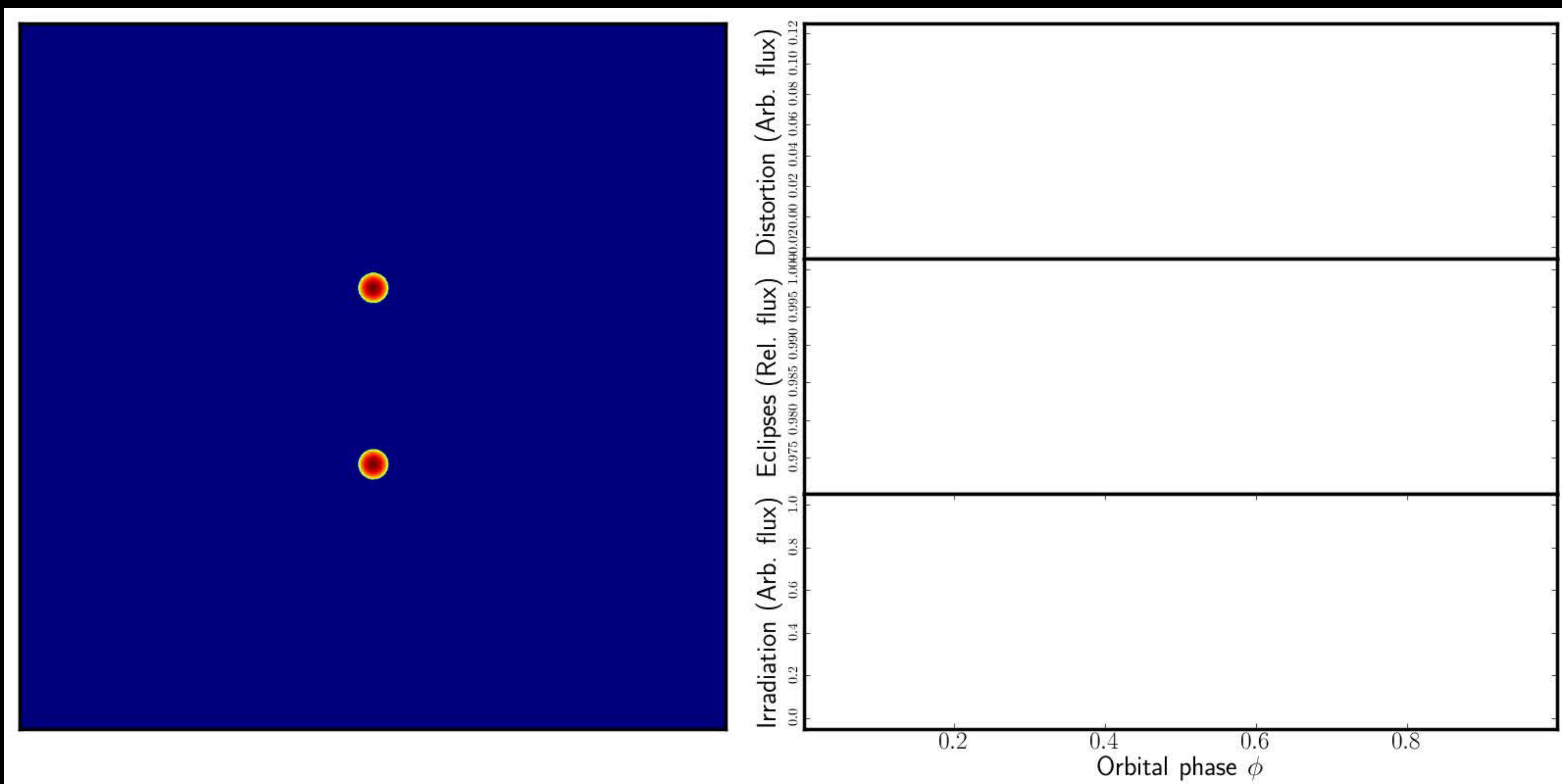
Red: observed light curve
Gray: model

Heartbeat Stars



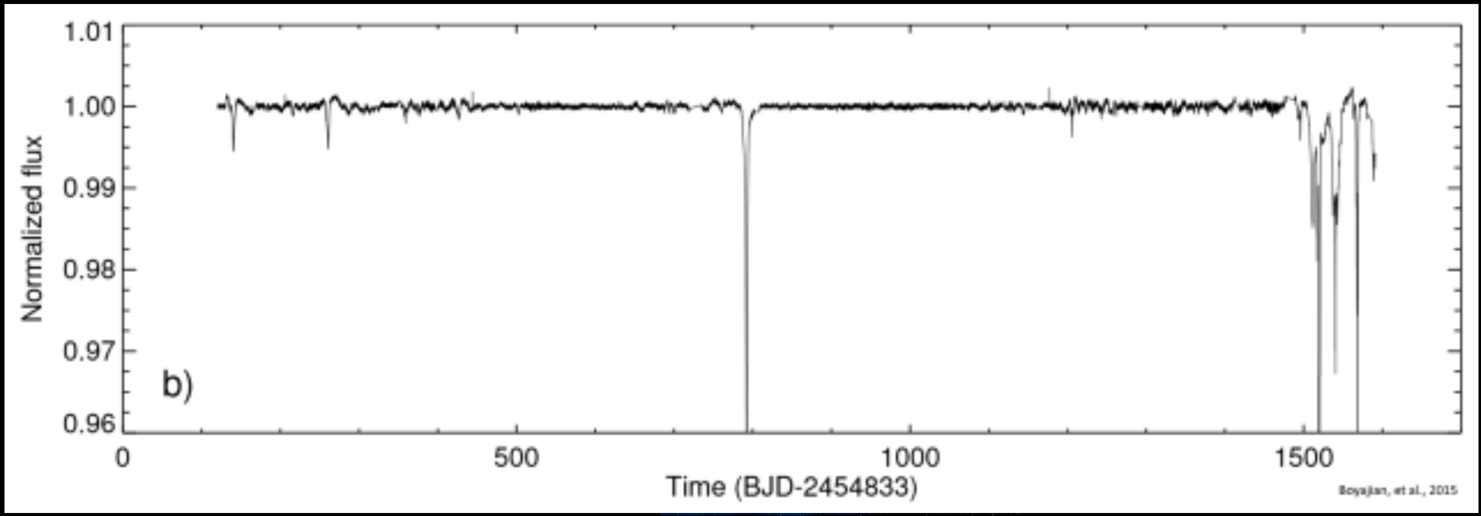
Heartbeat Stars are Close Binaries

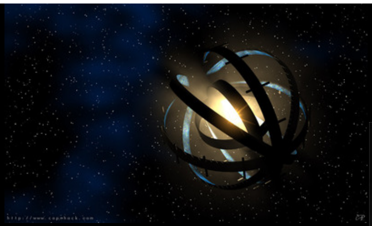
- Like KOI-54 but also eclipsing!

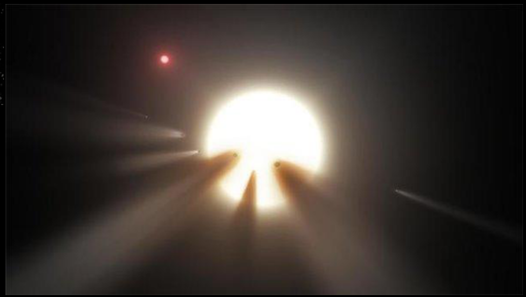


Mysterious KIC 8462852

- Very strange light curve



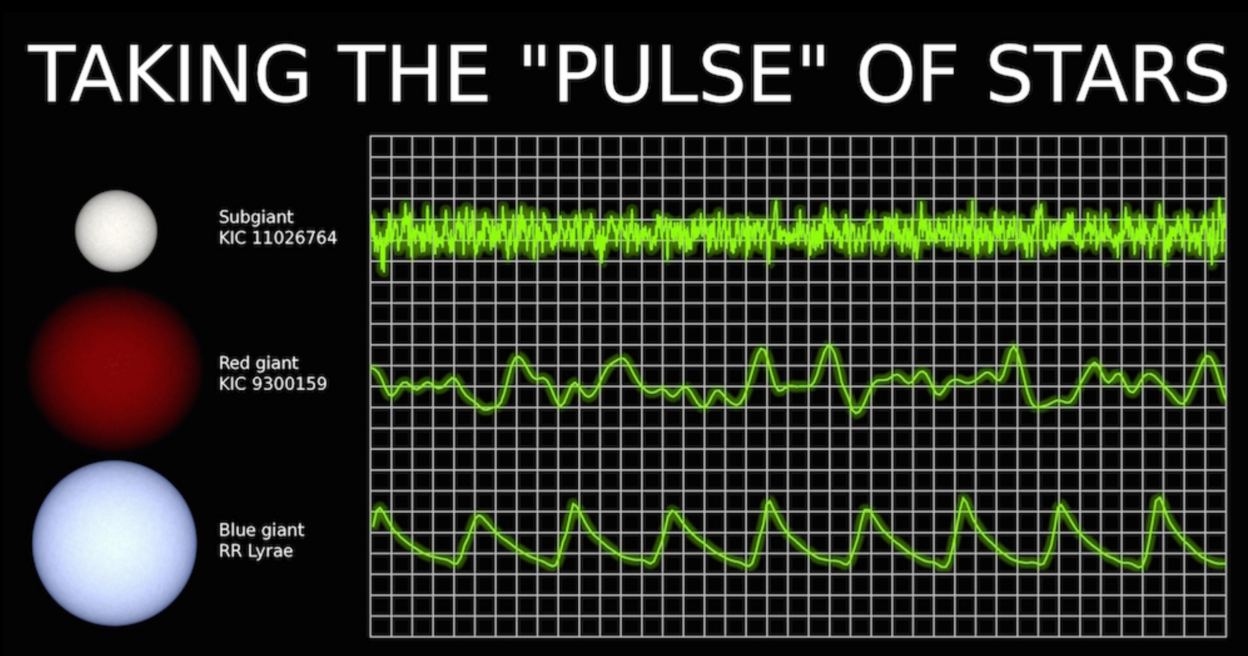


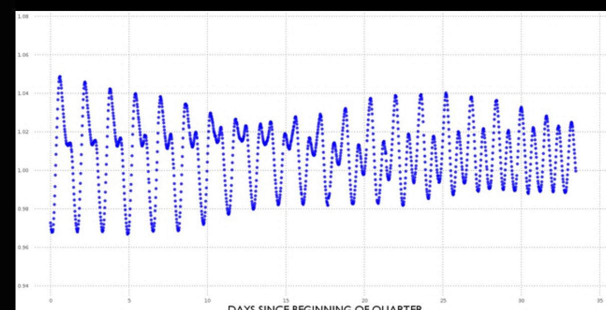


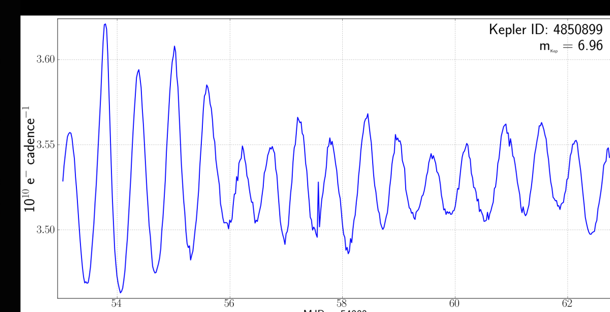
- Alien Megastructures?
  - Almost certainly not
- Comet-like swarm?
  - More likely

Kepler Measures Starlight!

- Changes in the starlight tell us almost everything about the star
  - Size, temperature, structure, age…

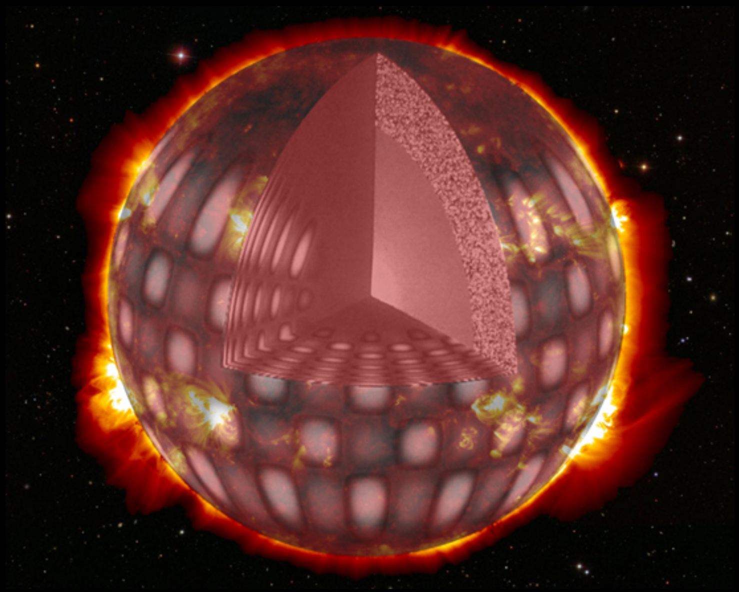


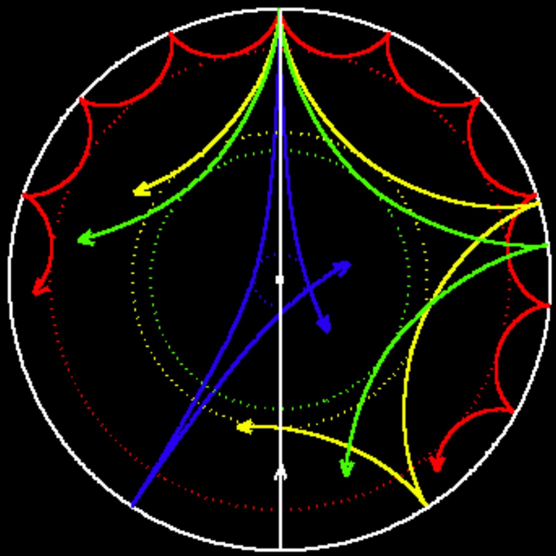


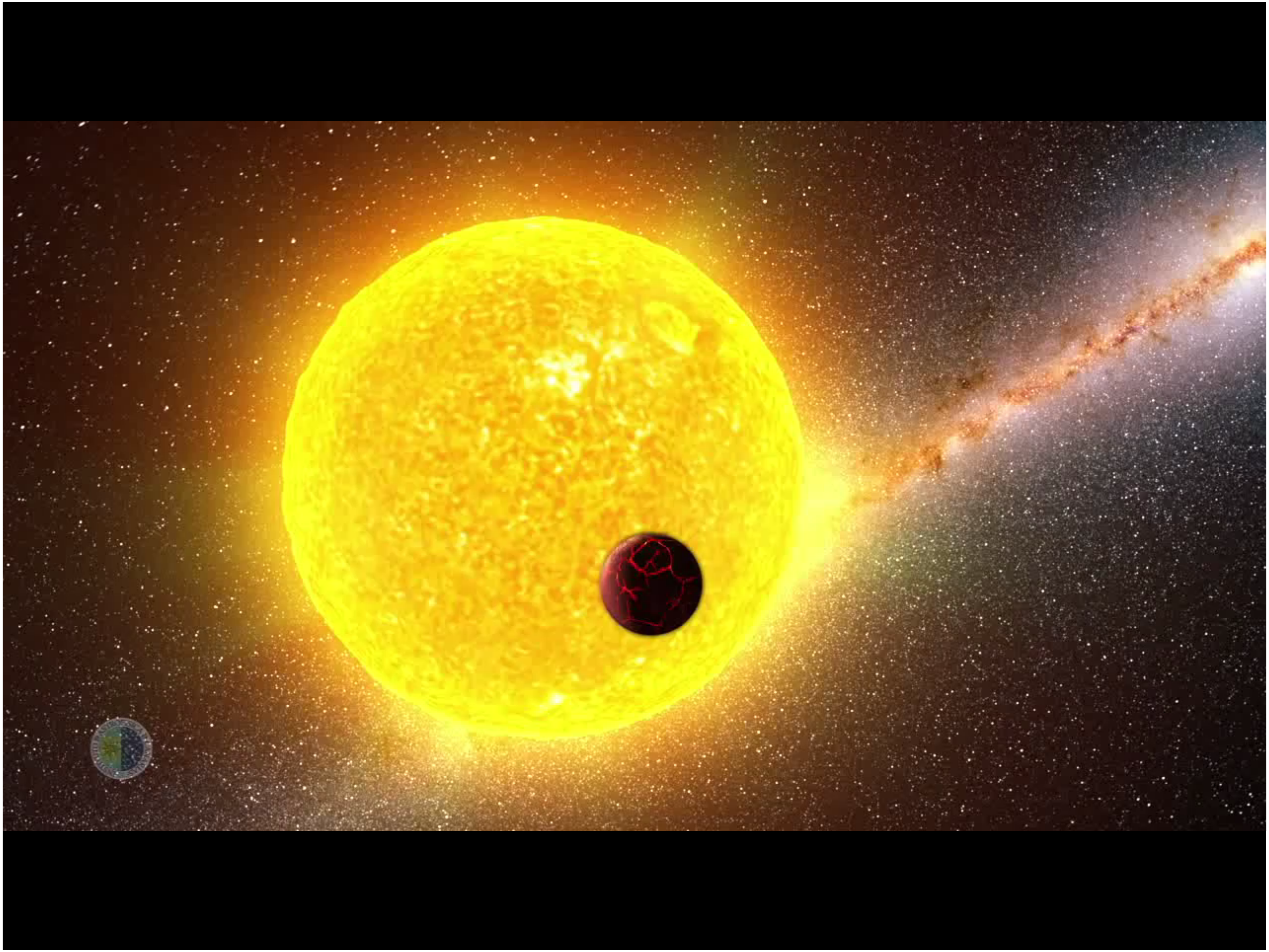


Asteroseismology

- Subtle oscillations in a star's brightness reflect acoustic waves bouncing around inside the star
- These waves tell us the temperature and density structure of the star
  - Just like in geological seismology

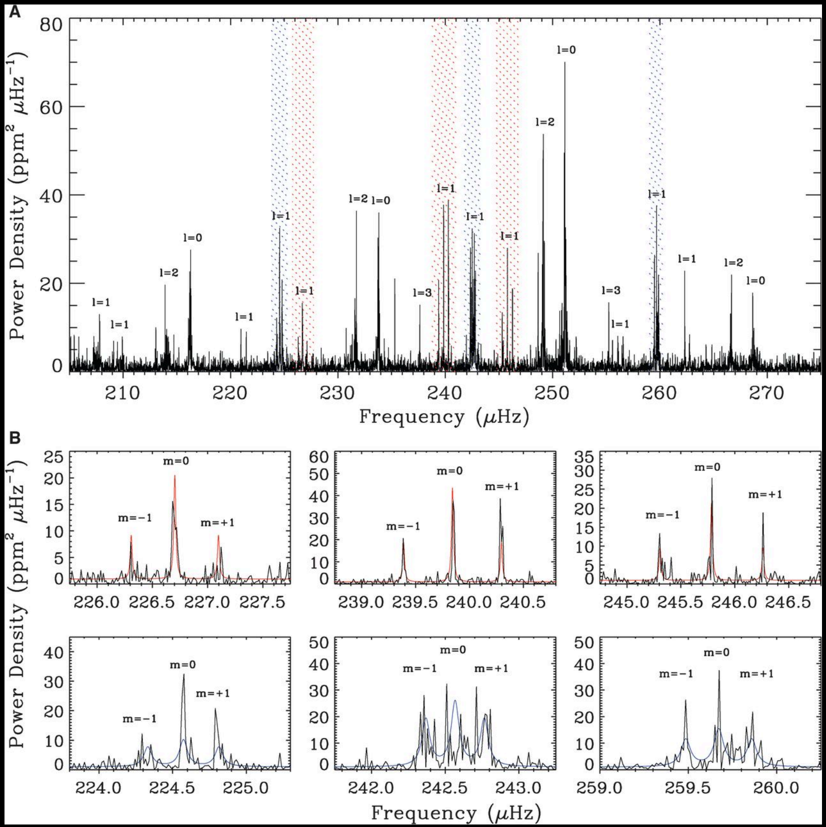






Kepler's Asteroseismology

- The precision and long time base to find planets is perfect for asteroseismology!

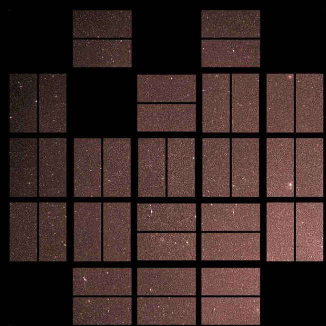


Exploding Stars in Other Galaxies

- Kepler caught the initial flash of an exploding star
  - Predicted but never before seen

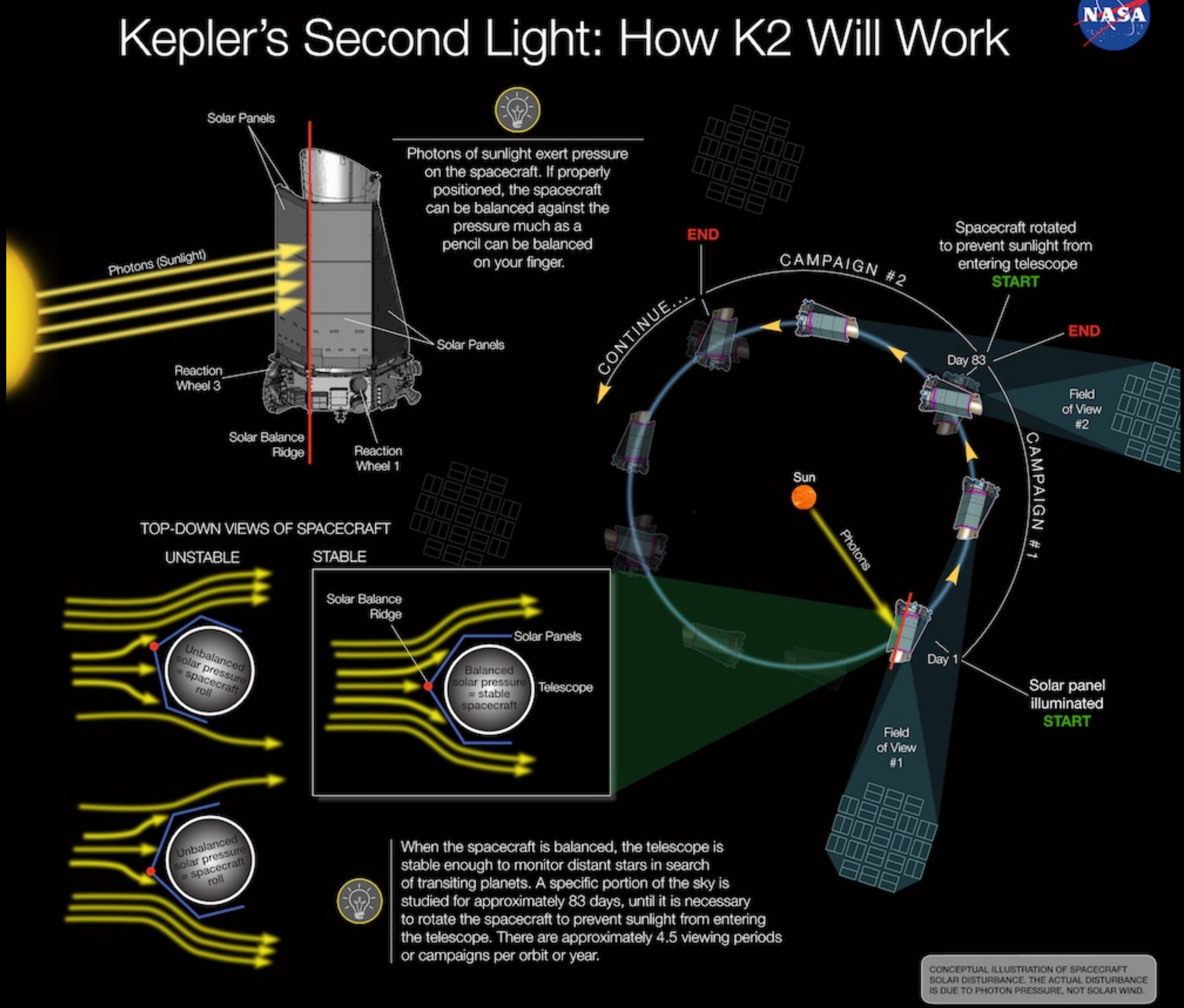
And Then Kepler Broke

- Lost the ability to control pointing in 3 dimensions
  - Can control two, such as pitch and yaw
  - Kepler can no long resist the push of photon pressure from the Sun
- Almost 4 years after launch
- Just after getting a 4-year mission extension
- We also lost almost 10% of the pixels
- But otherwise a wonderful telescope
  - On a wobbly mount



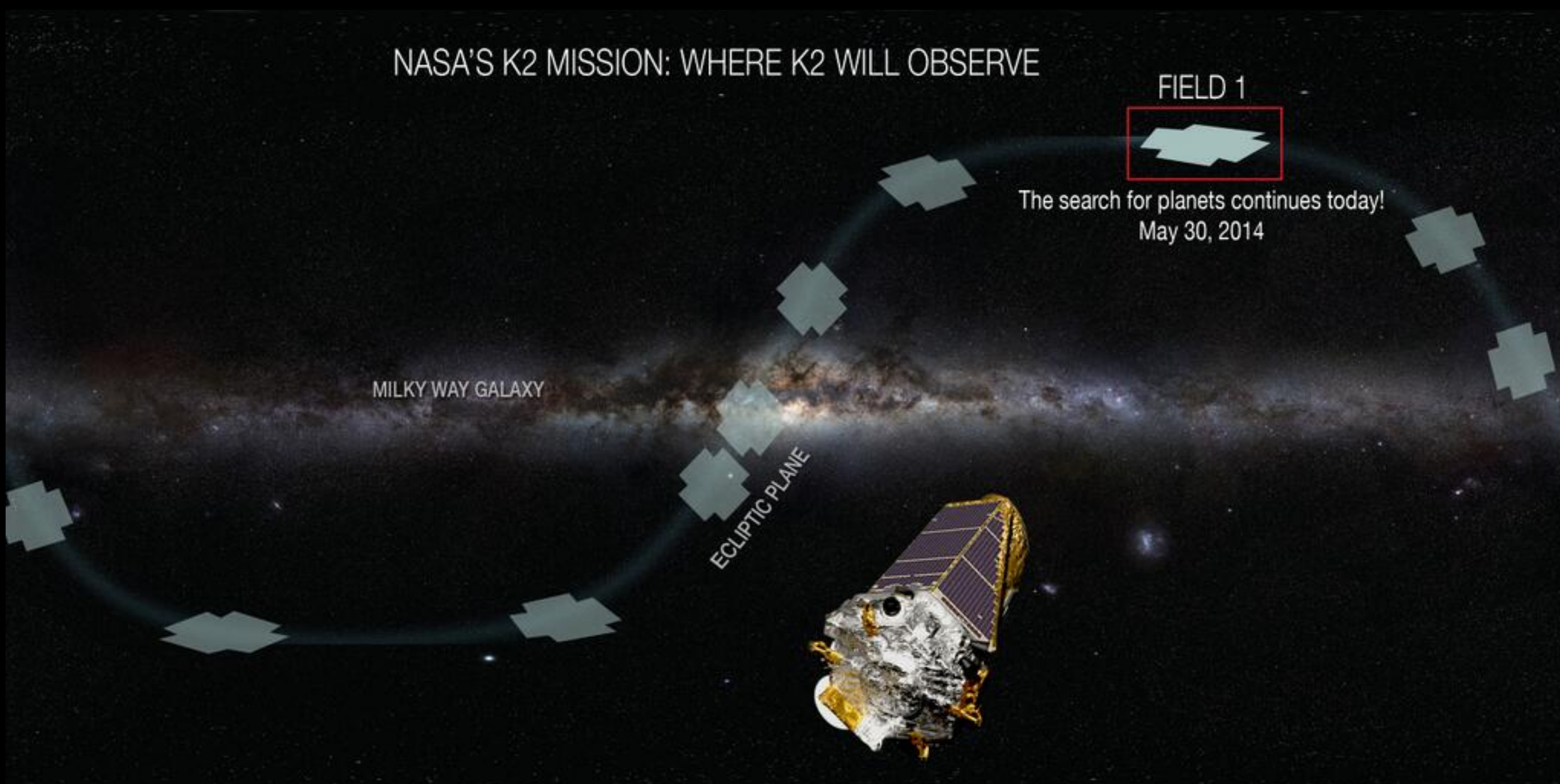
Balance the Photon Pressure to Control Roll!

Ball Aerospace to the Rescue!



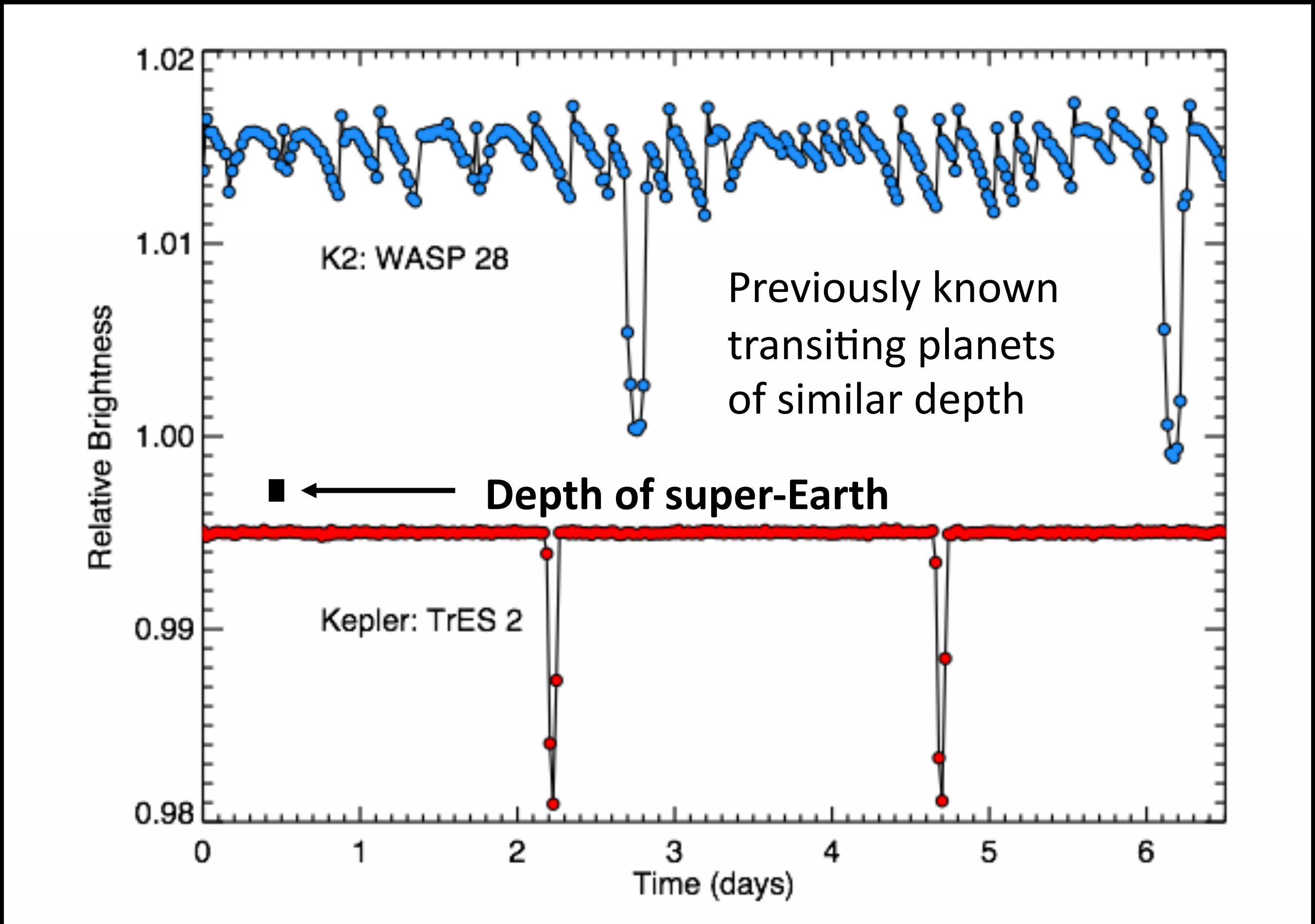
K2 Mission Profile

- Point at a field on the ecliptic for about 80 days
- Switch to a new field
- Entirely proposal driven: any astrophysics is fair game



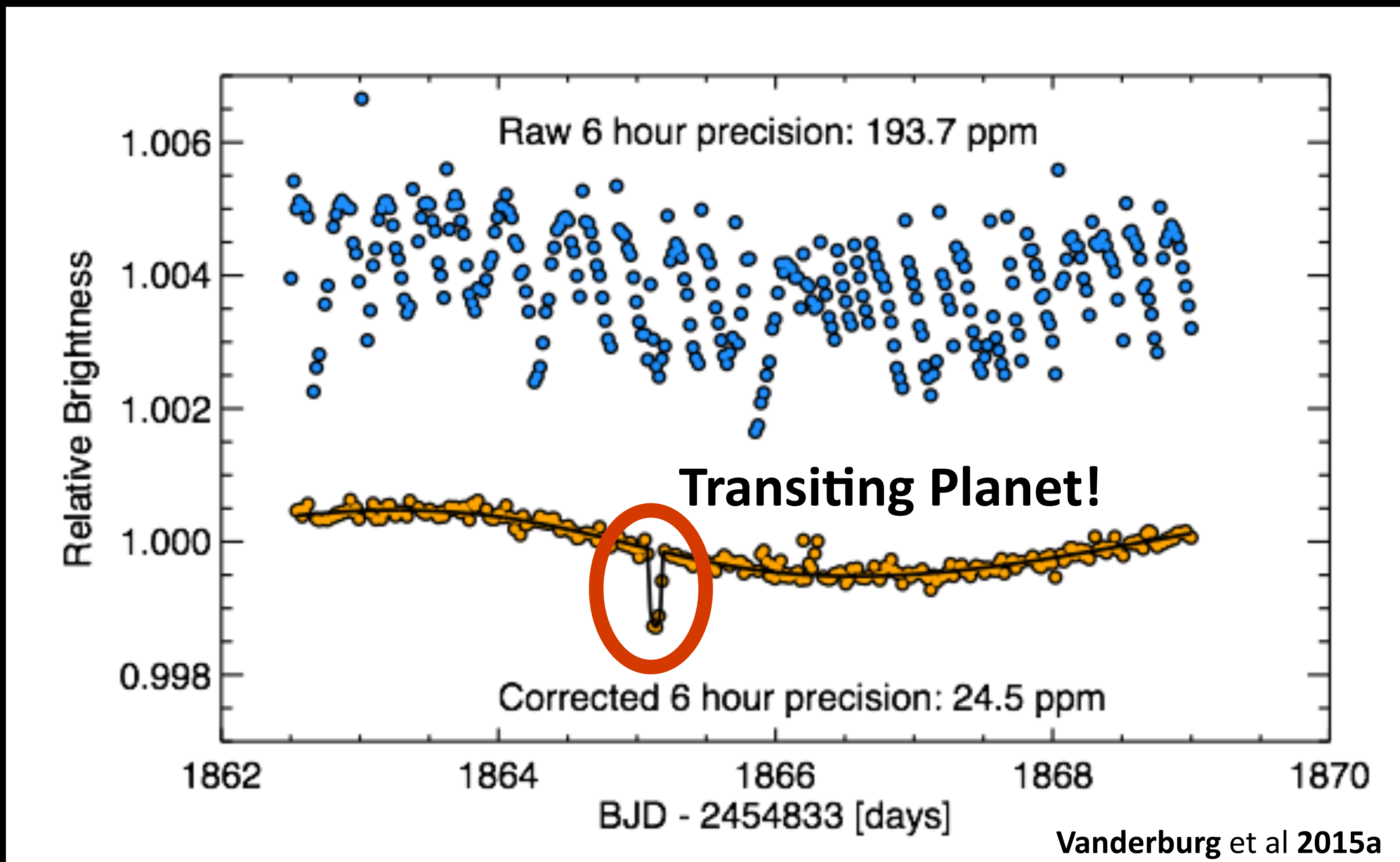
K2's Light Curves

- K2's small roll motion damages the light curves

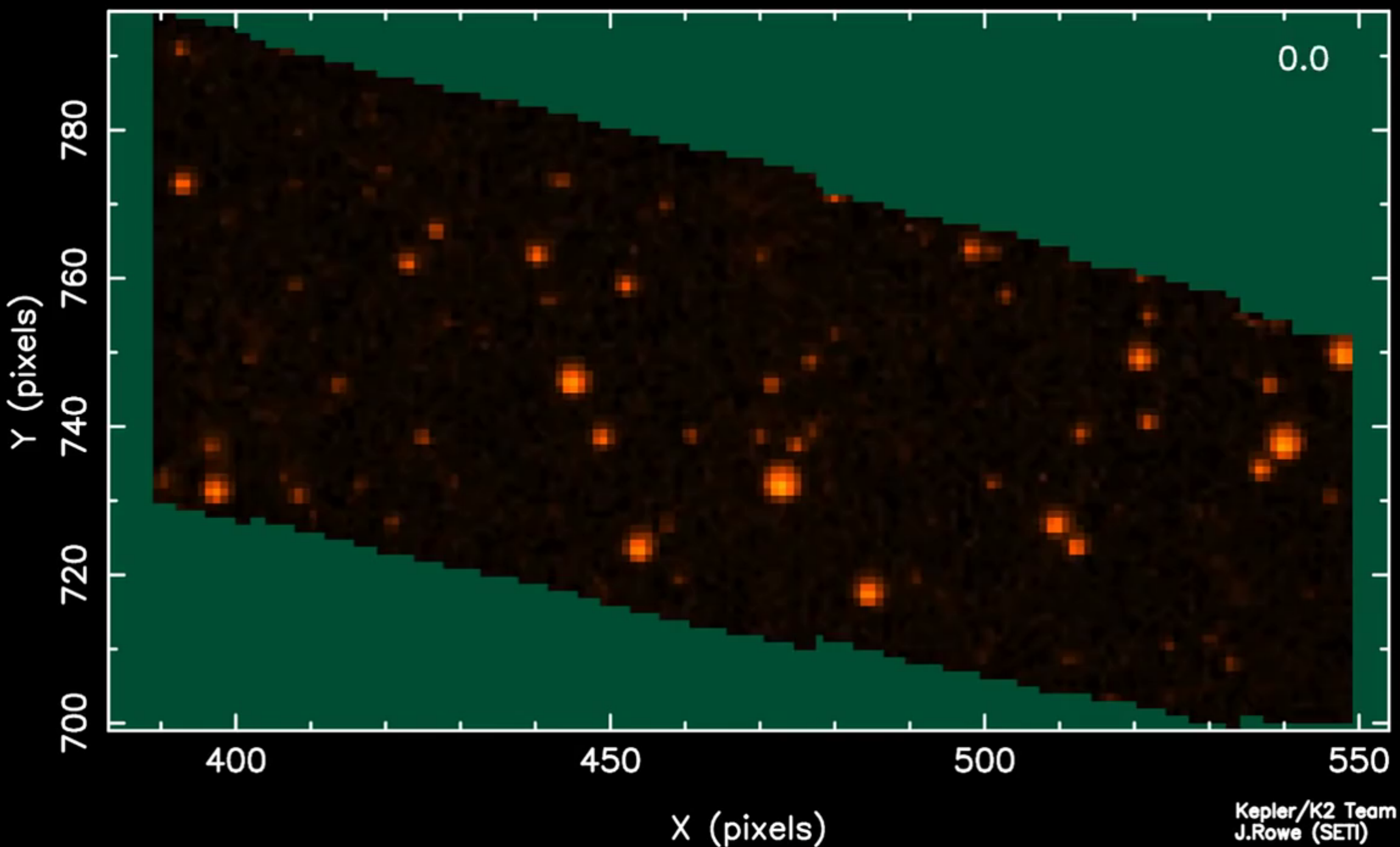


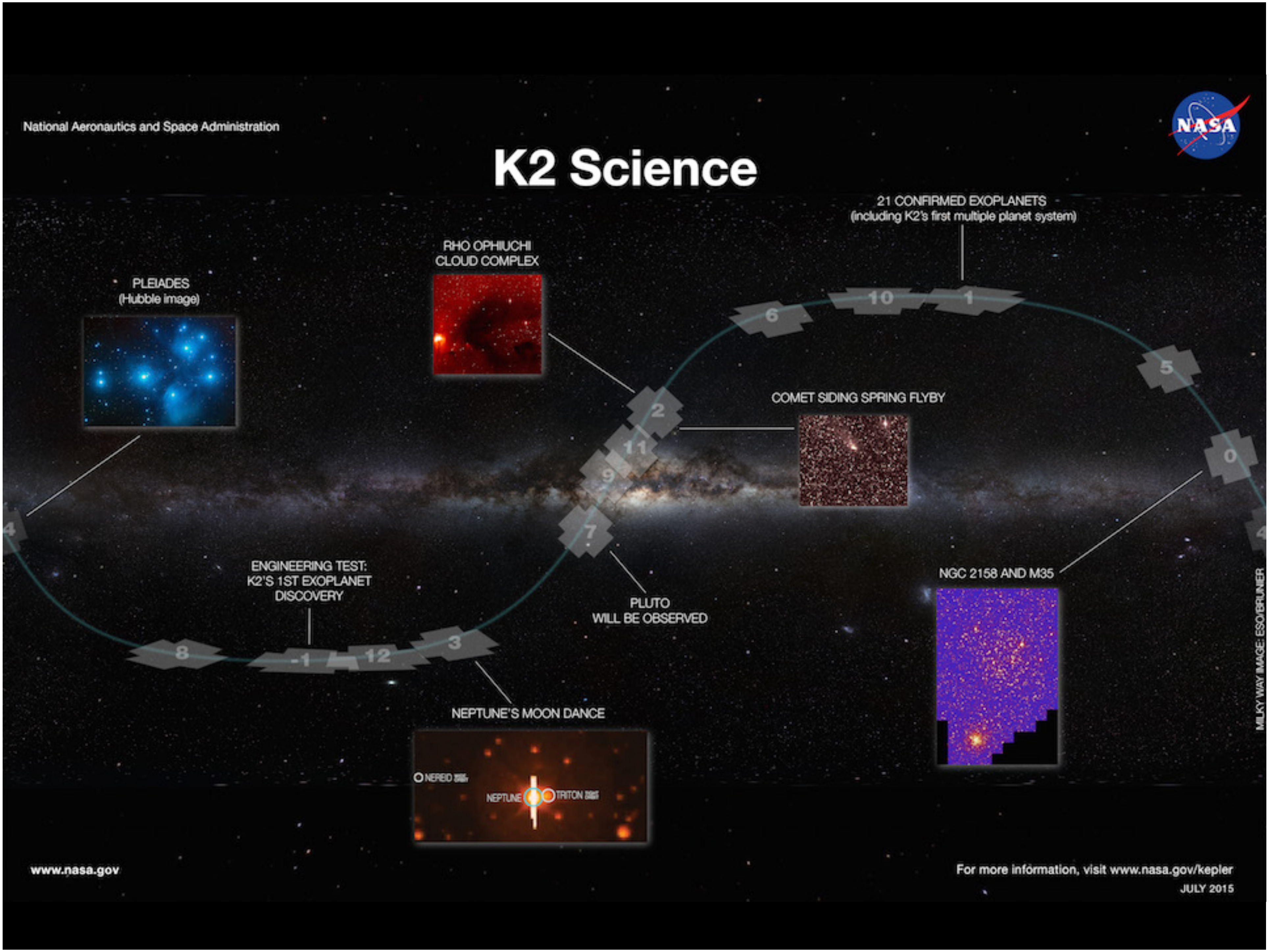
K2's Light Curves

- But they can be corrected: 39 confirmed K2 planets



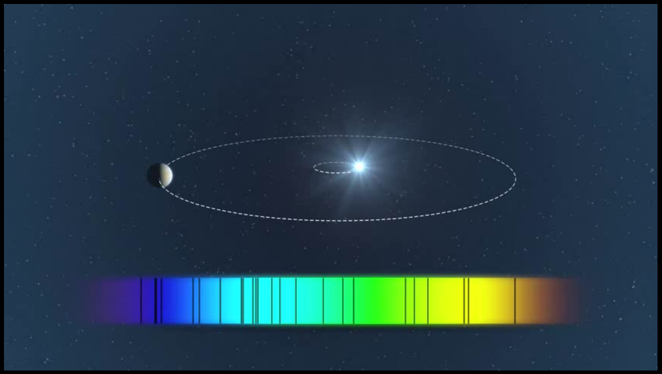
Neptune!


0.0
Y (pixels)
700
720
740
760
780
400
450
500
550
X (pixels)
Kepler/K2 Team
J.Rowe (SETI)



National Aeronautics and Space Administration
NASA
K2 Science
21 CONFIRMED EXOPLANETS
(including K2's first multiple planet system)
RHO OPHIUCHI
CLOUD COMPLEX
PLEIADES
(Hubble image)
COMET SIDING SPRING FLYBY
NGC 2158 AND M35
ENGINEERING TEST:
K2'S 1ST EXOPLANET
DISCOVERY
PLUTO
WILL BE OBSERVED
NEPTUNE'S MOON DANCE
NEREID
NEPTUNE
TRITON
10
1
6
5
2
11
9
0
7
4
8
-1
12
3
MILKY WAY IMAGE: ESO/BRUNIER
www.nasa.gov
For more information, visit www.nasa.gov/kepler
JULY 2015

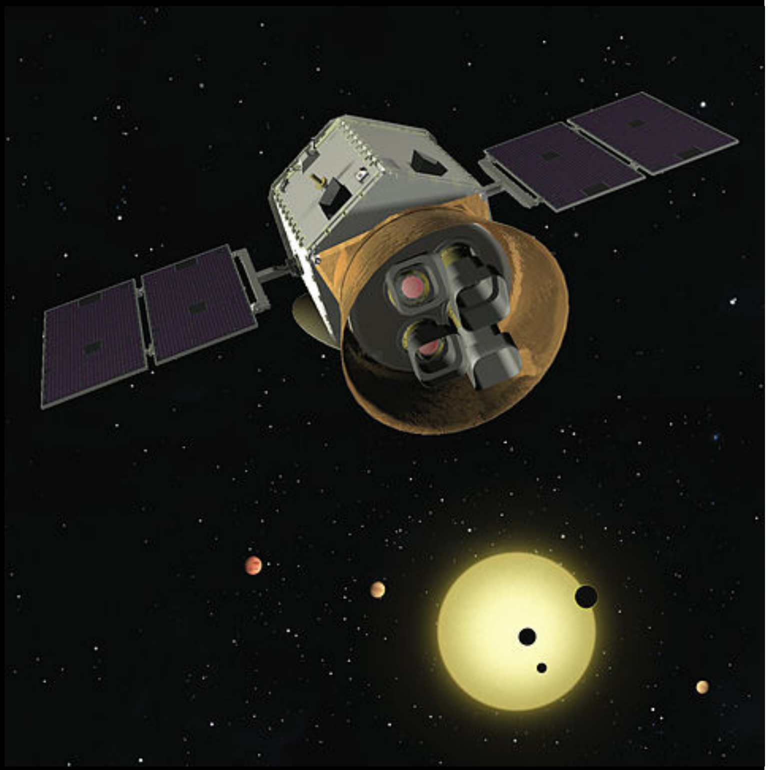
The Future: Doppler Method



- Doppler will get better
  - HARPS North
    - On La Palma
    - Can detect speeds of 50 cm/sec
      - Earth moves the Sun 9 cm/sec
  - Doppler will maybe get to 10 cm/sec in a decade

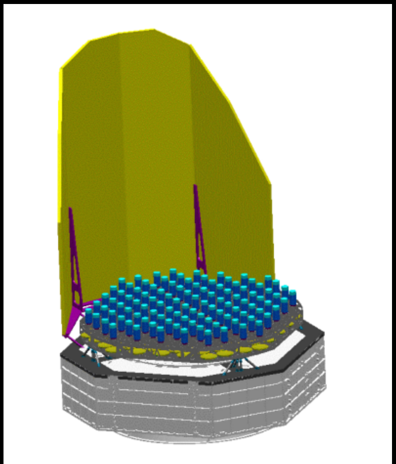
The Future: Transit Method

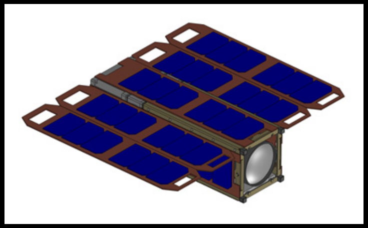
- Transiting Exoplanet Survey Satellite (TESS)
  - Selected for launch in 2017
    - Very high Earth orbit
  - Will survey the entire sky
    - 2 million brightest stars
    - Search the closest stars
    - Look at one star field for a few weeks, then move to another, and later return
  - Sensitive to Super Earths and larger
    - In short (2-month) orbits



The Future: Transit Method

- Space missions on the Drawing Board
  - PLATO: European satellite with many cameras
    - Similar to TESS
  - ExoplanetSat: many small telescopes in space, each dedicated to a single star

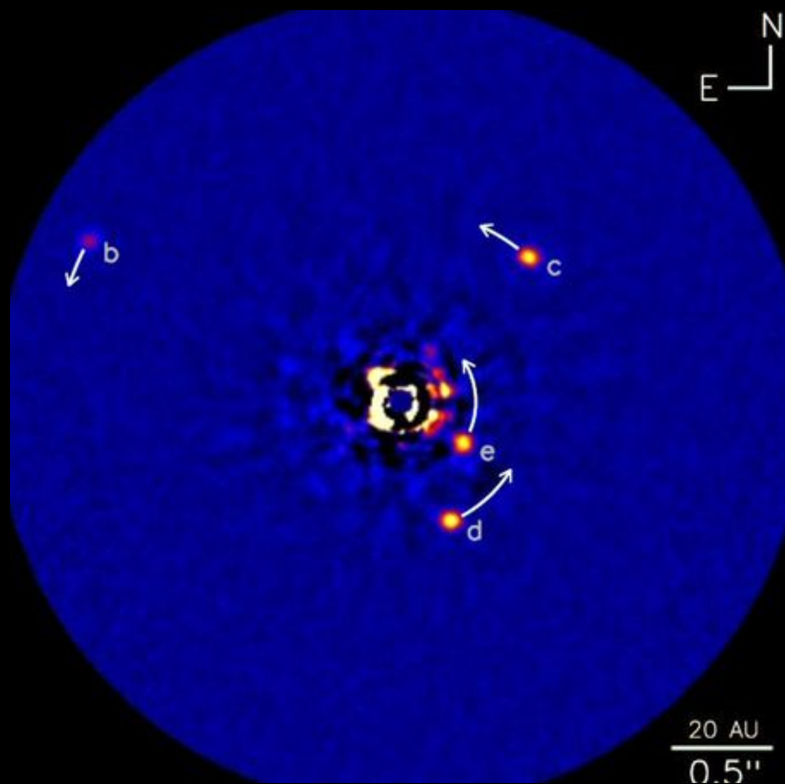




- Several continuing Earth-based surveys

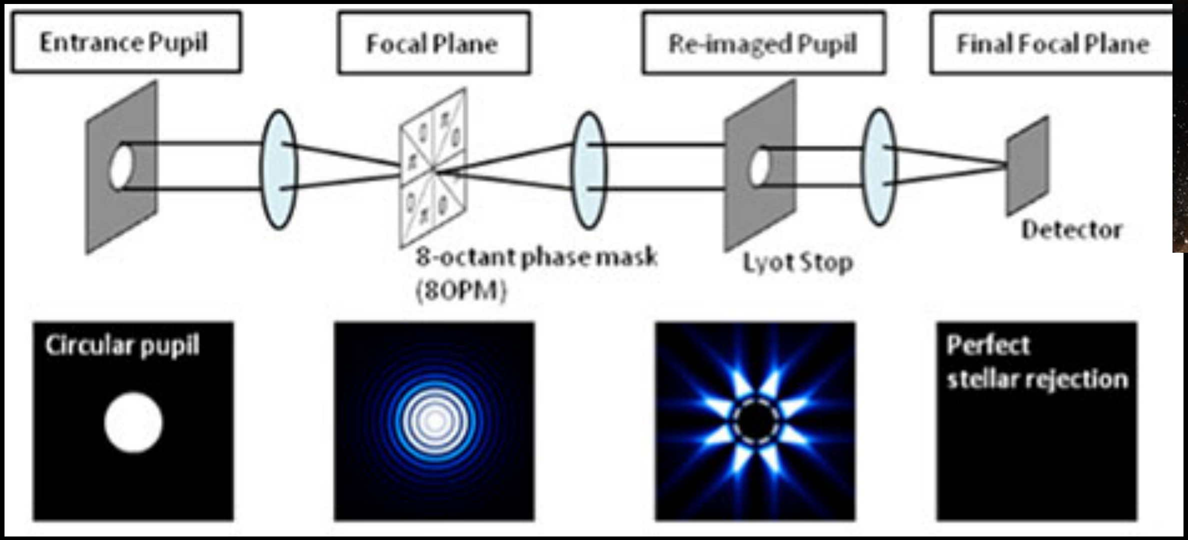
The Future: Direct Imaging

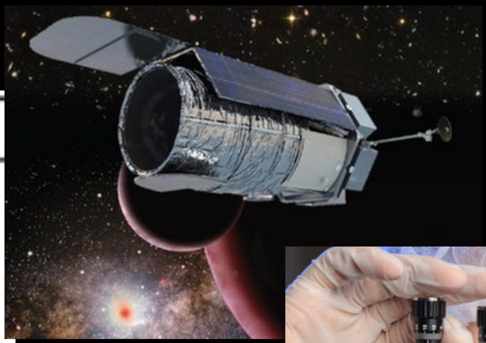
- Problem: block light from the star and not the planet
  - Done from the ground for Jupiter-size planets far from their star: HR 8799
  - Very difficult to get close to Earth-like distances from the star

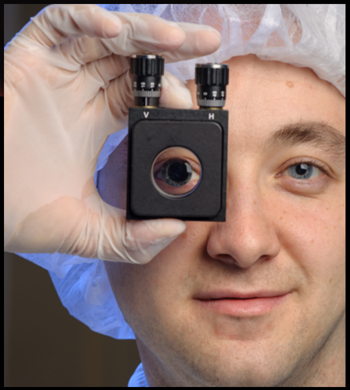


The Future: Direct Imaging

- Approach 1: block the star's light inside the telescope (coronagraph)
  - Difficult, requires extreme precision
  - Current status: Planned for the WFIRST telescope, to launch in the mid 2020's

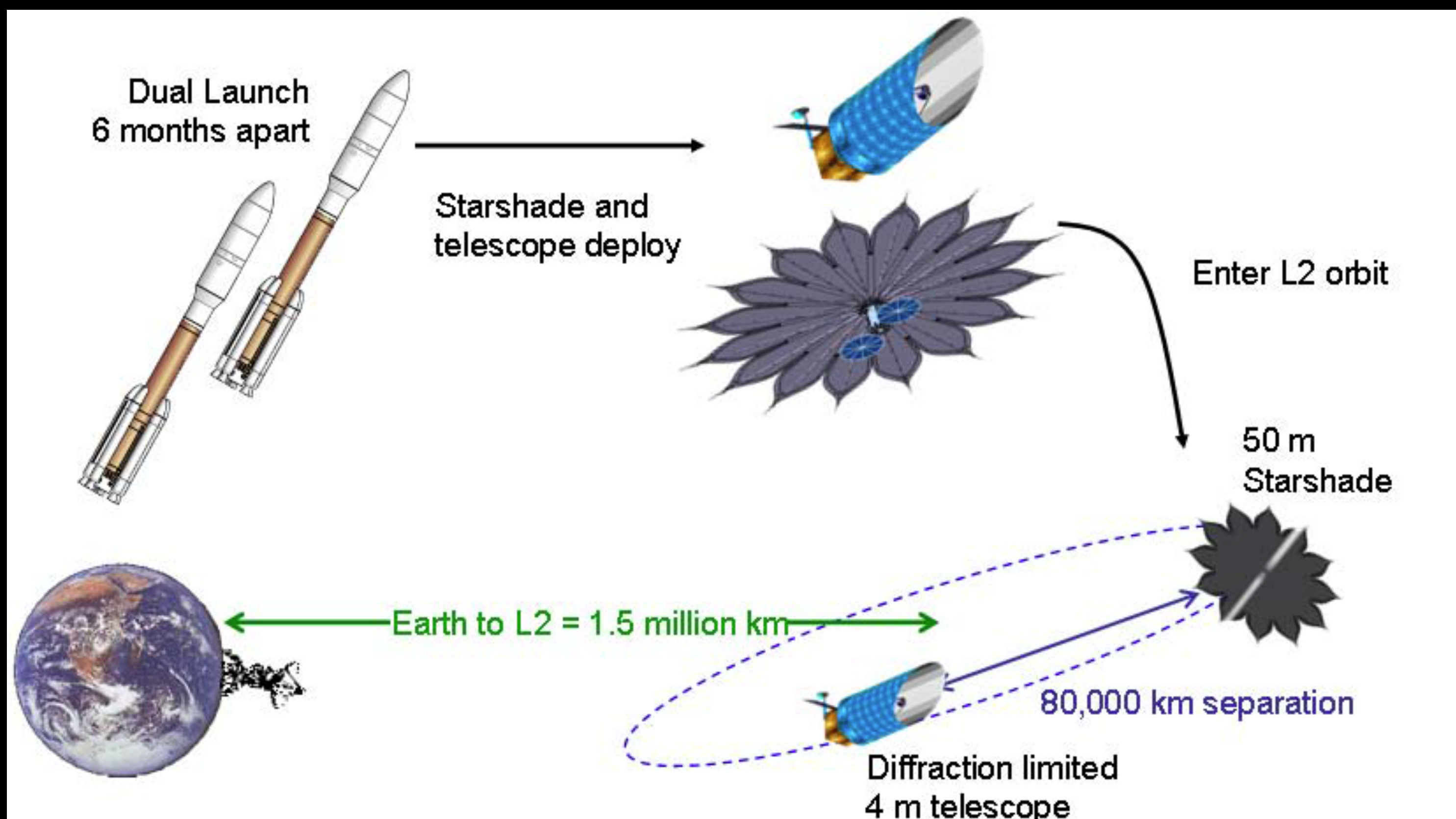






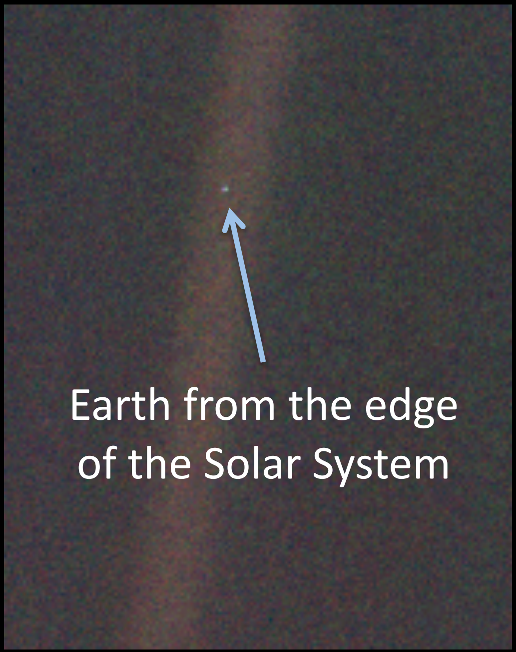
The Future: Direct Imaging

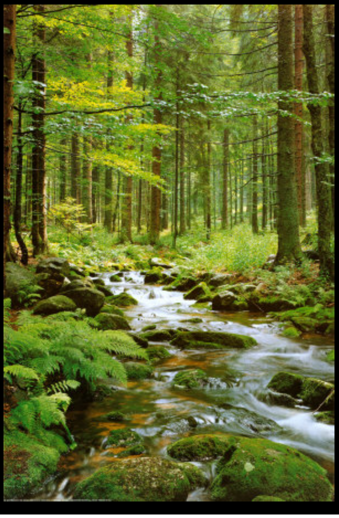
- Approach 2: Block the star's light with a starshade in front of the telescope



Direct Imaging: Difficult but Worth It!

- The best picture of a planet will be just a dot
- But from that dot we can measure its atmosphere
  - Oxygen would mean life!
    - Left by itself, oxygen is absorbed by the ground (rust)
    - The only way we know to replace oxygen is photosynthesis by living organisms





Conclusion

- The search for exoplanets takes us closer to answering
  - Why are we here?
    - Is the Earth common or rare?
      - Preliminary result: looks common!
  - Are we alone?
    - Is there life on other planets?
      - Don’t know yet, but there are many places where life is possible
  - How did we get here?
    - How did our planet form?
      - Comparing with other planet systems helps us understand ours