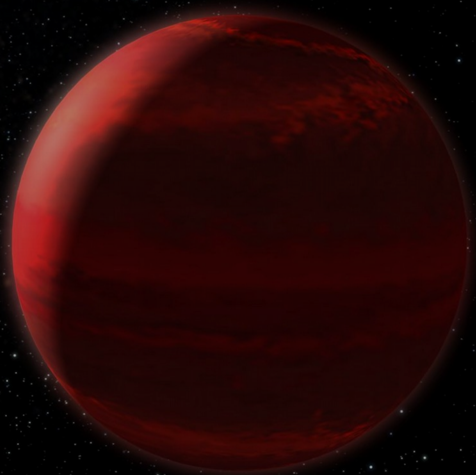
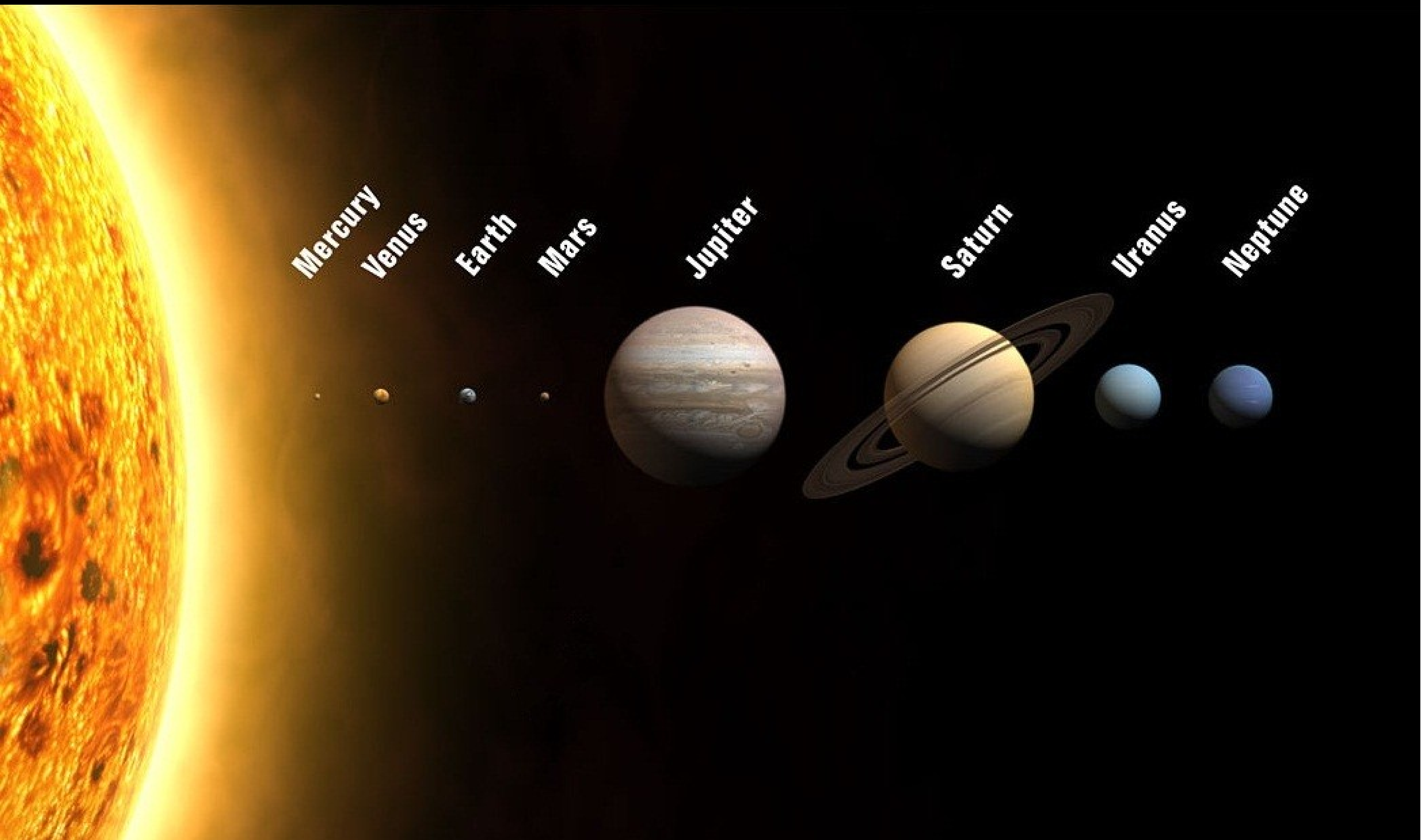
Observing Exoplanets and looking for Life around other Stars

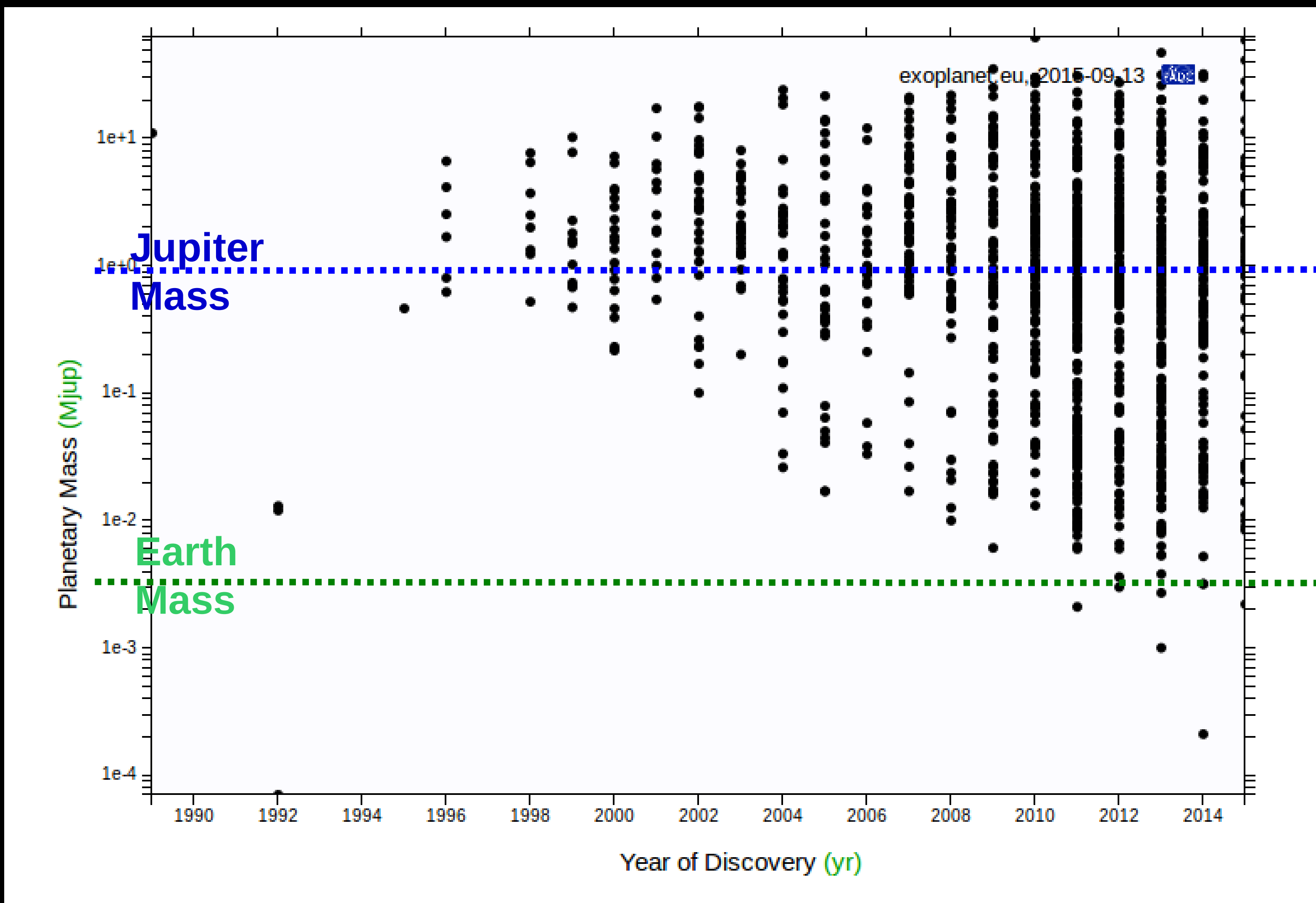


Contact:

ALL known Planets until 1989



Exoplanets identified – we are now starting to identify Earth-size planets



Current Planet Counts

Total Exoplanet Discoveries	5,594
Confirmed Exoplanets	1,890

Kepler Discoveries

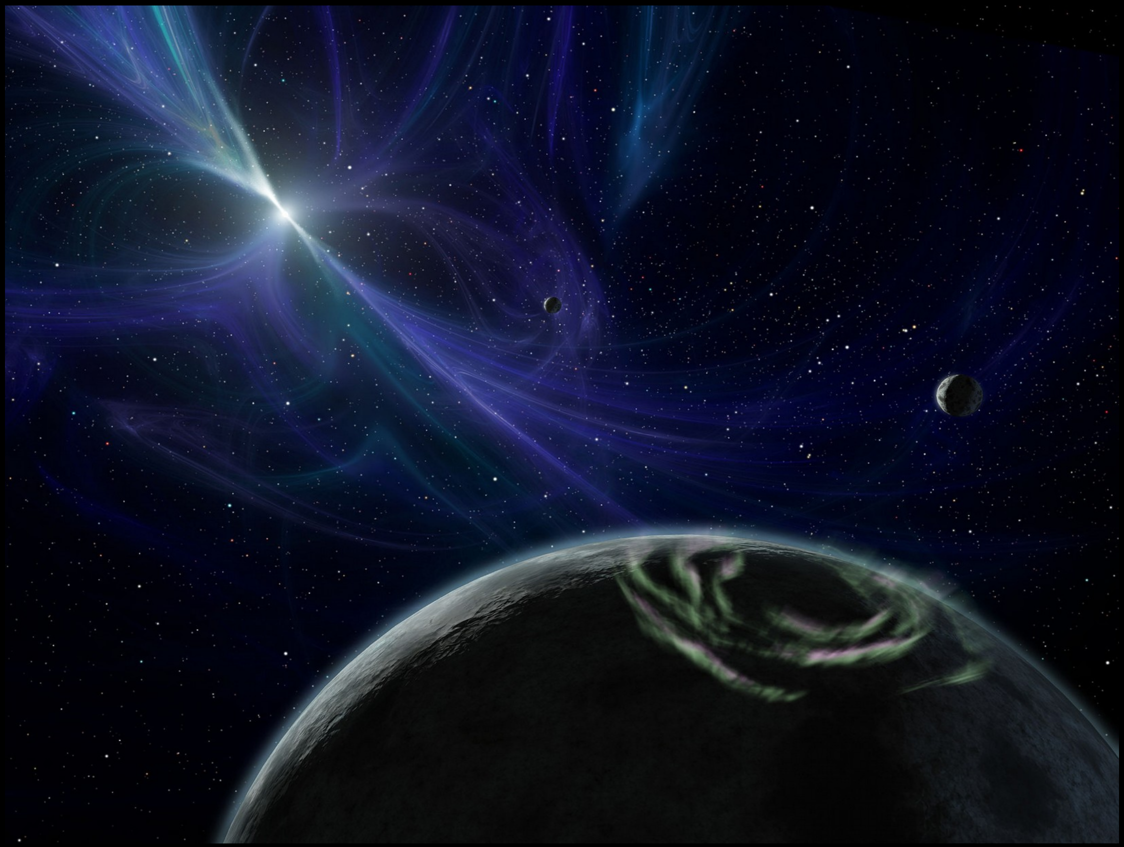
Kepler Confirmed Exoplanets	1,033
Kepler Exoplanet Candidates *	3,704

Size Breakdown

Stars with Planets	1174
Multi-planet Systems	473
Gas Giant	471
Hot Jupiter	1103
Super Earth	213
Terrestrial	91
Unknown	12

* Exoplanet candidates are discoveries that have yet to be confirmed as actual exoplanet discoveries. These candidates are 80-90% likely to be actual exoplanet discoveries.

First discoveries: Oddballs



PSR 1257+12 : 3 planets around a pulsar

How could planets survive a supernova ?
Planets may have formed from debris after the supernova explosion

51 Peg b : The first confirmed "Hot Jupiter"

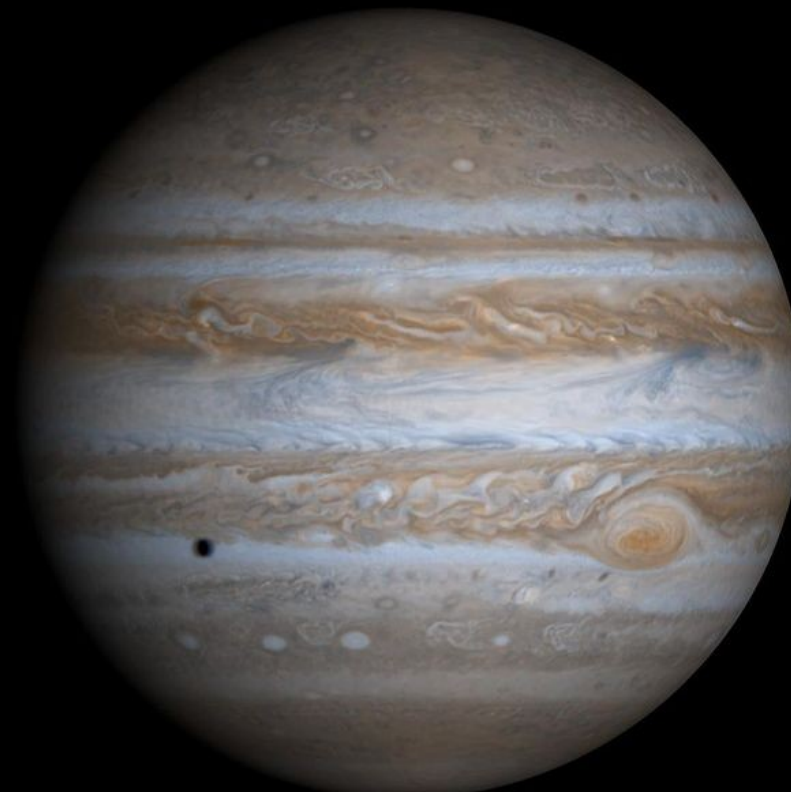
A Jupiter-size planet at only 5.3% of the Sun-Earth distance from its host star, orbiting in 4.2 days

What makes planets habitable ?

Size matters:
not too big, not too small

Moon: too small
No atmosphere

Earth



Jupiter: too big
Mostly gas

What makes planets habitable ?

The planet must be in the **habitable zone** of its star: not be too close or too far

Venera 13 lander, survived 127mn at 457 C, 89 atm

Venus: too close, too hot

Mars: too far, too cold

Approximately 10% of stars have a habitable planet

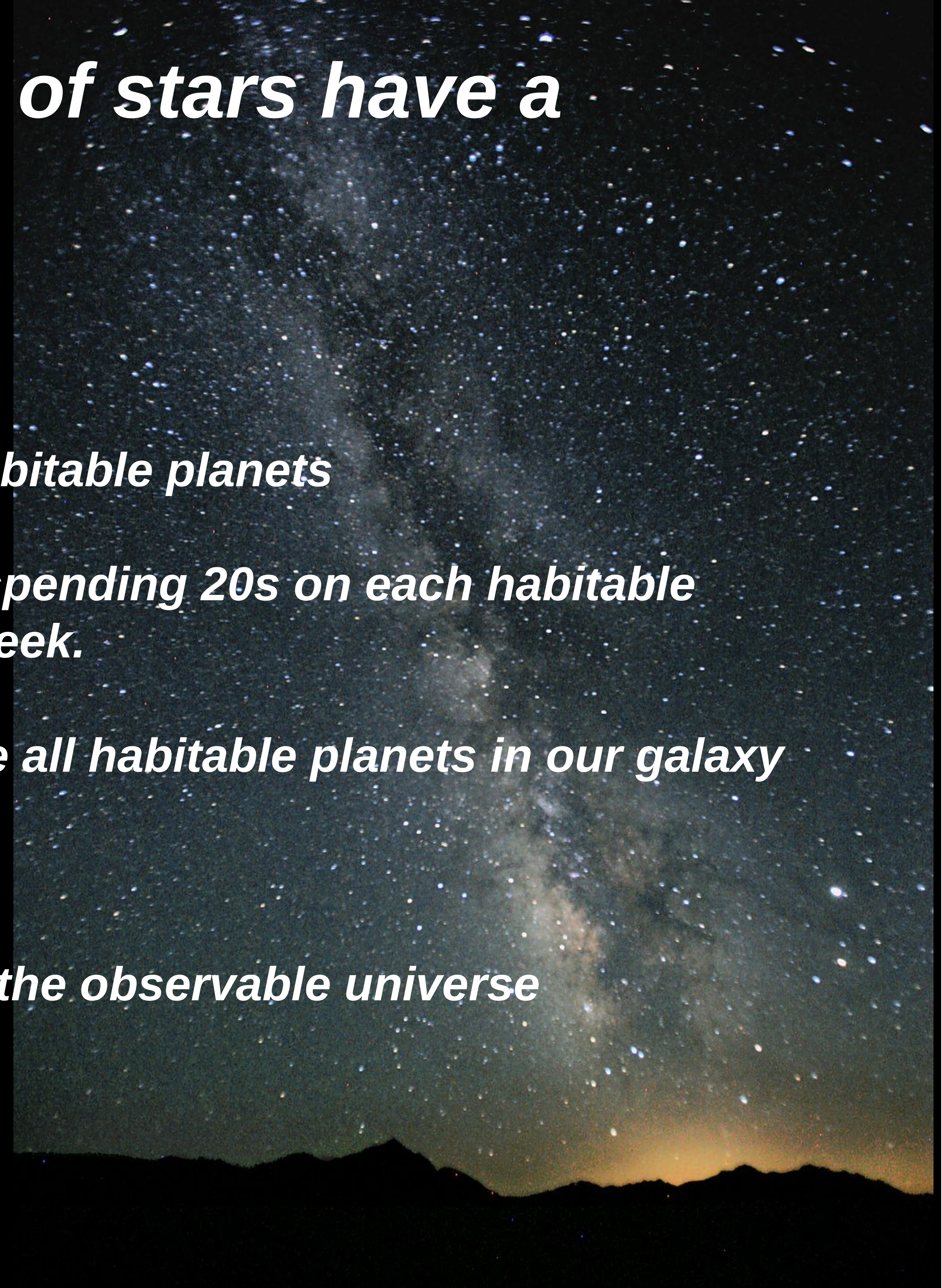
200 billion stars in our galaxy

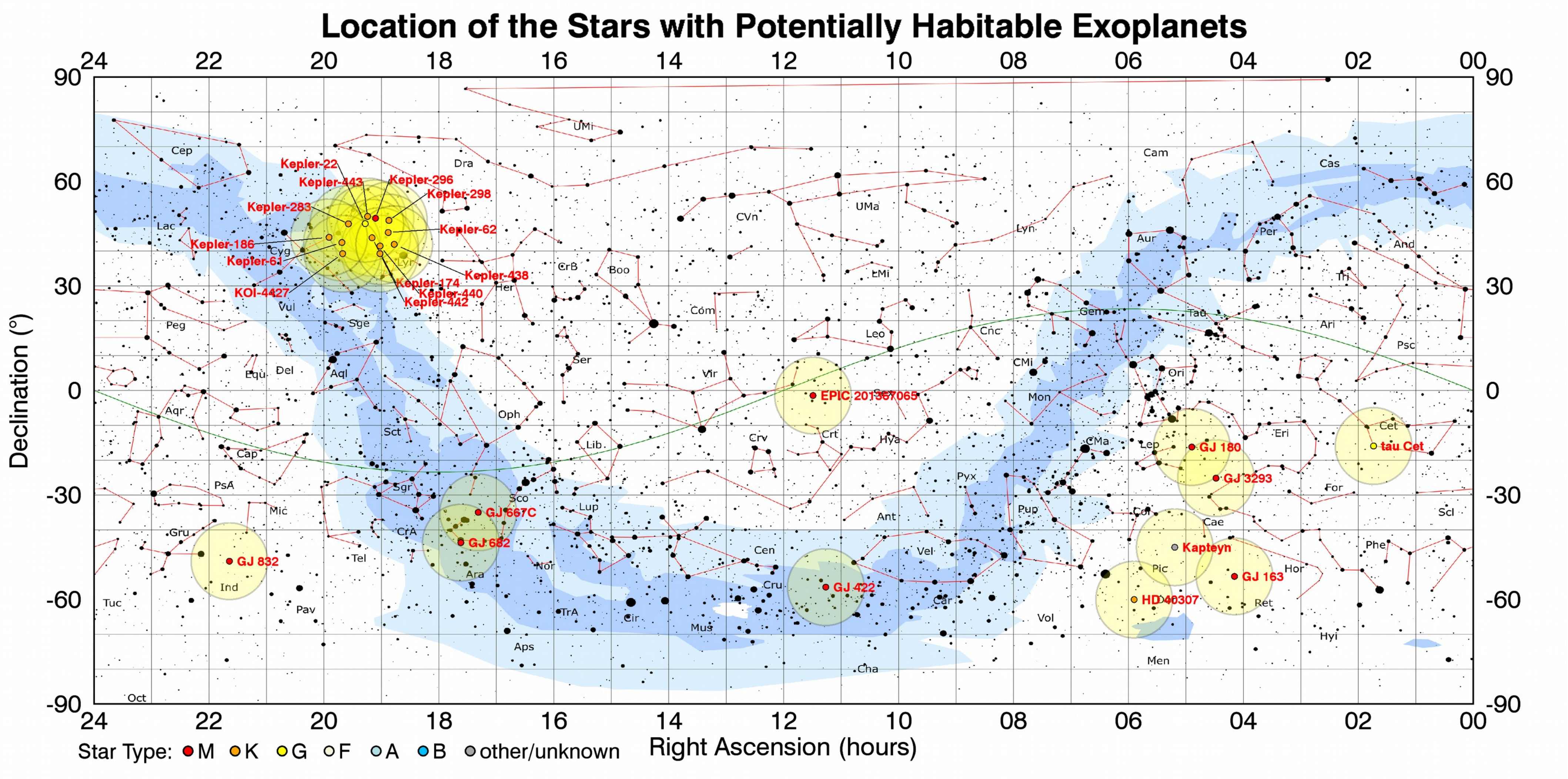
→ approximately 20 billion habitable planets

Imagine 200 explorers, each spending 20s on each habitable planet, 24hr a day, 7 days a week.

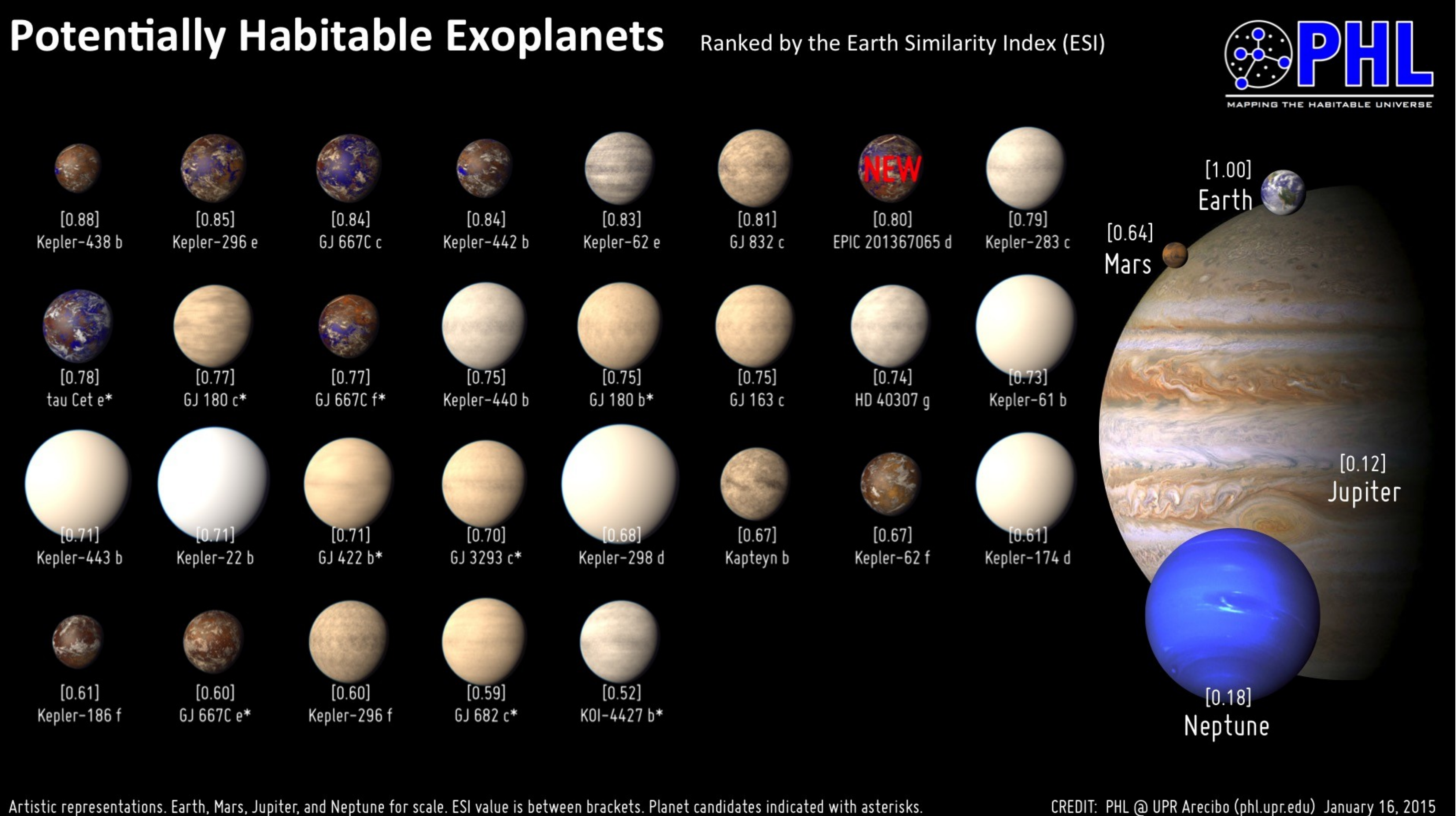
It would take >60yr to explore all habitable planets in our galaxy alone.

x 100,000,000,000 galaxies in the observable universe




Location of the Stars with Potentially Habitable Exoplanets
Declination (°)
Right Ascension (hours)
Star Type: M K G F A B other/unknown
Kepler-22
Kepler-443
Kepler-296
Kepler-298
Kepler-283
Kepler-62
Kepler-186
Kepler-61
KOI-4427
Kepler-438
Kepler-174
Kepler-440
Kepler-442
EPIC 201367065
GJ 180
tau Cet
GJ 3293
GJ 667C
GJ 682
GJ 832
Kapteyn
GJ 163
GJ 422
HD 40307

>~10% of stars have potentially habitable planet
First potentially habitable planets now identified



How do astronomers identify exoplanets ?

HIGH PRECISION OPTICAL MEASUREMENTS OF STARLIGHT (indirect techniques)

Earth around Sun at ~30 light year

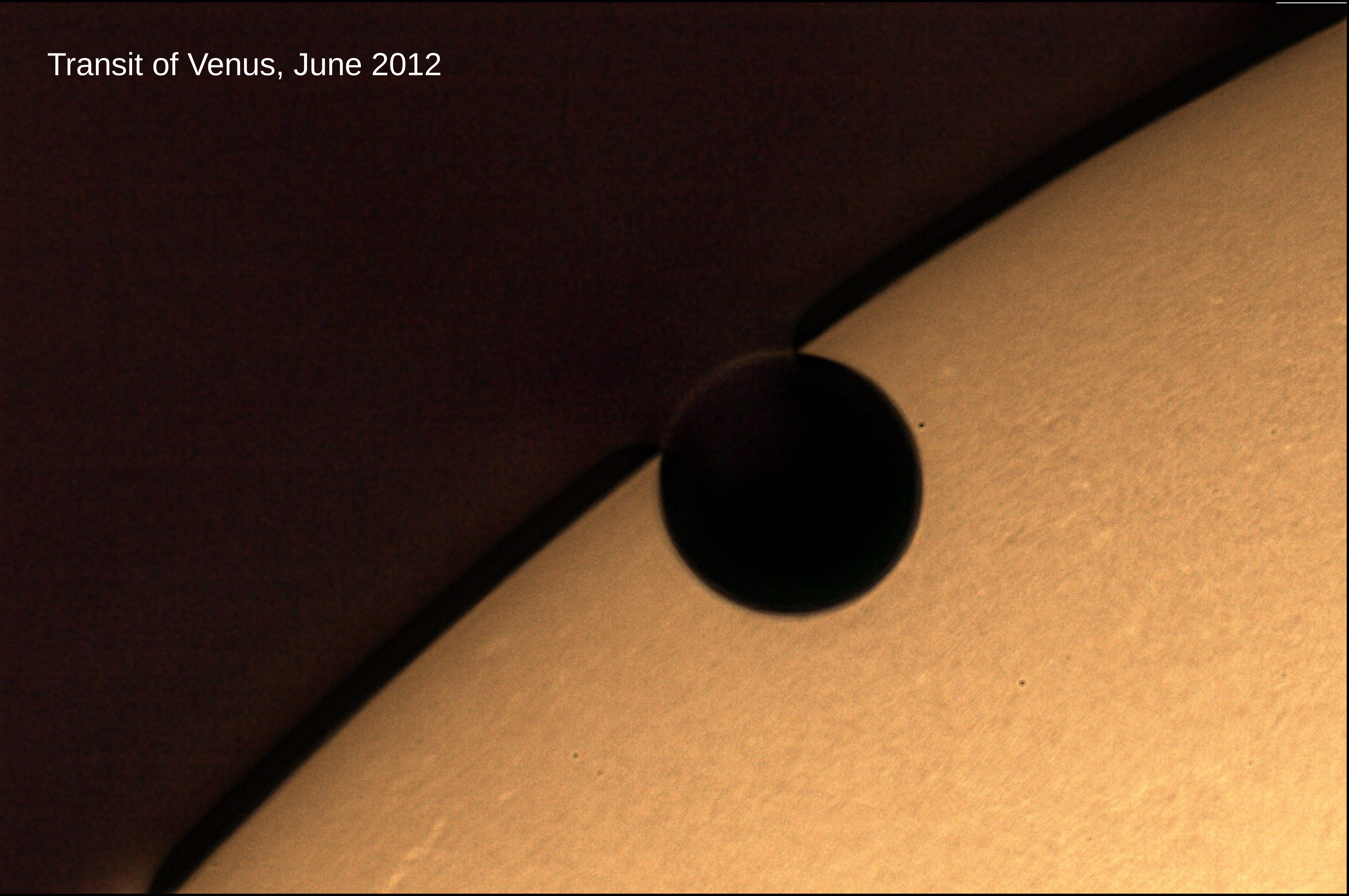
→ Star position moves by 0.3 micro arcsecond
(thickness of a human hair at 20,000 miles)

→ Star velocity is modulated by 10cm / sec
(changes light frequency by 1 part in 3,000,000,000)

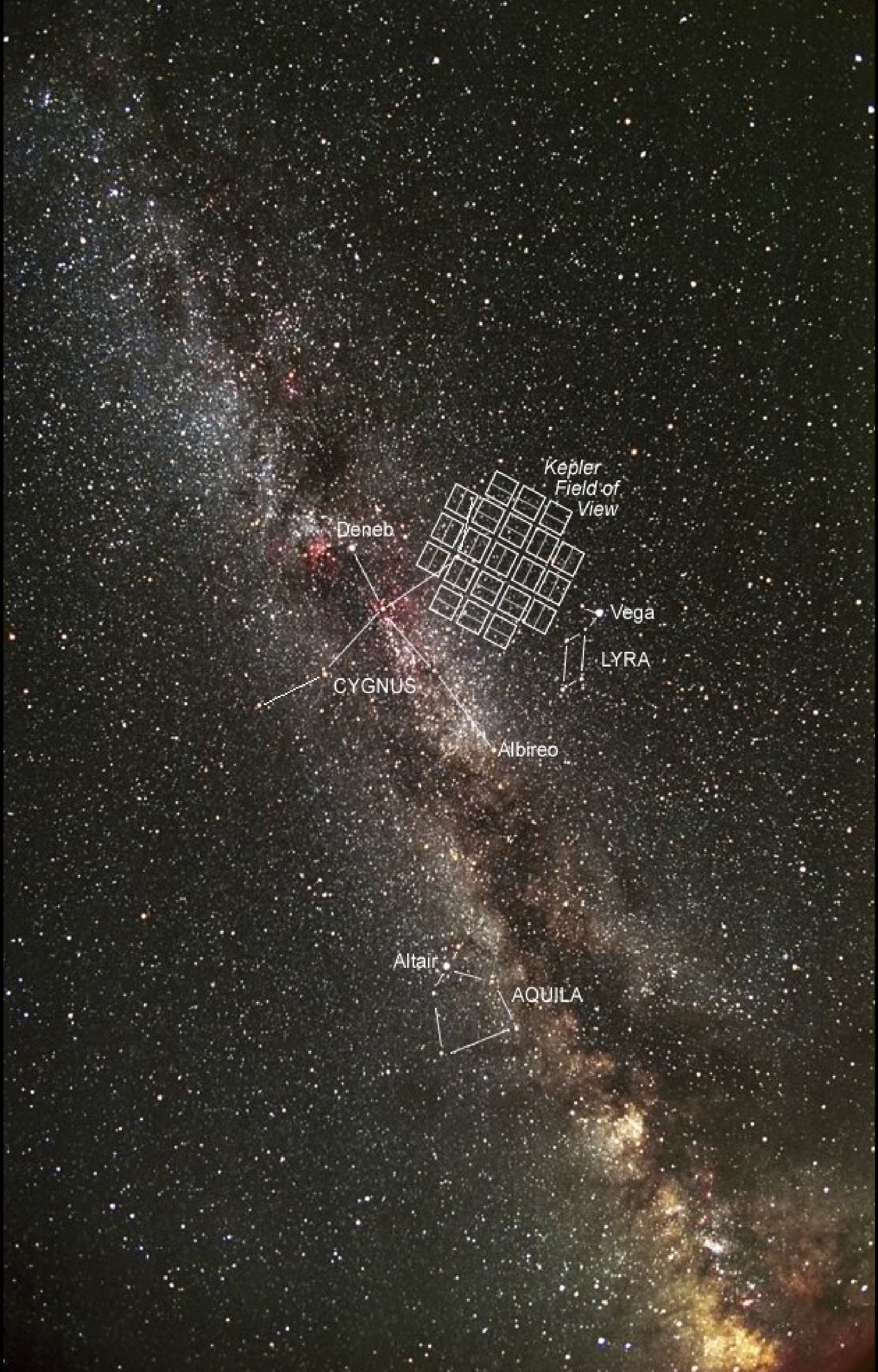
If Earth-like planet passes in front of Sun-like star, star dims by 70 parts per million
(12x12 pixel going dark on a HD TV screen 70 miles away)

Exoplanet transit

If the planet passes in front of its star, we see the star dimming slightly



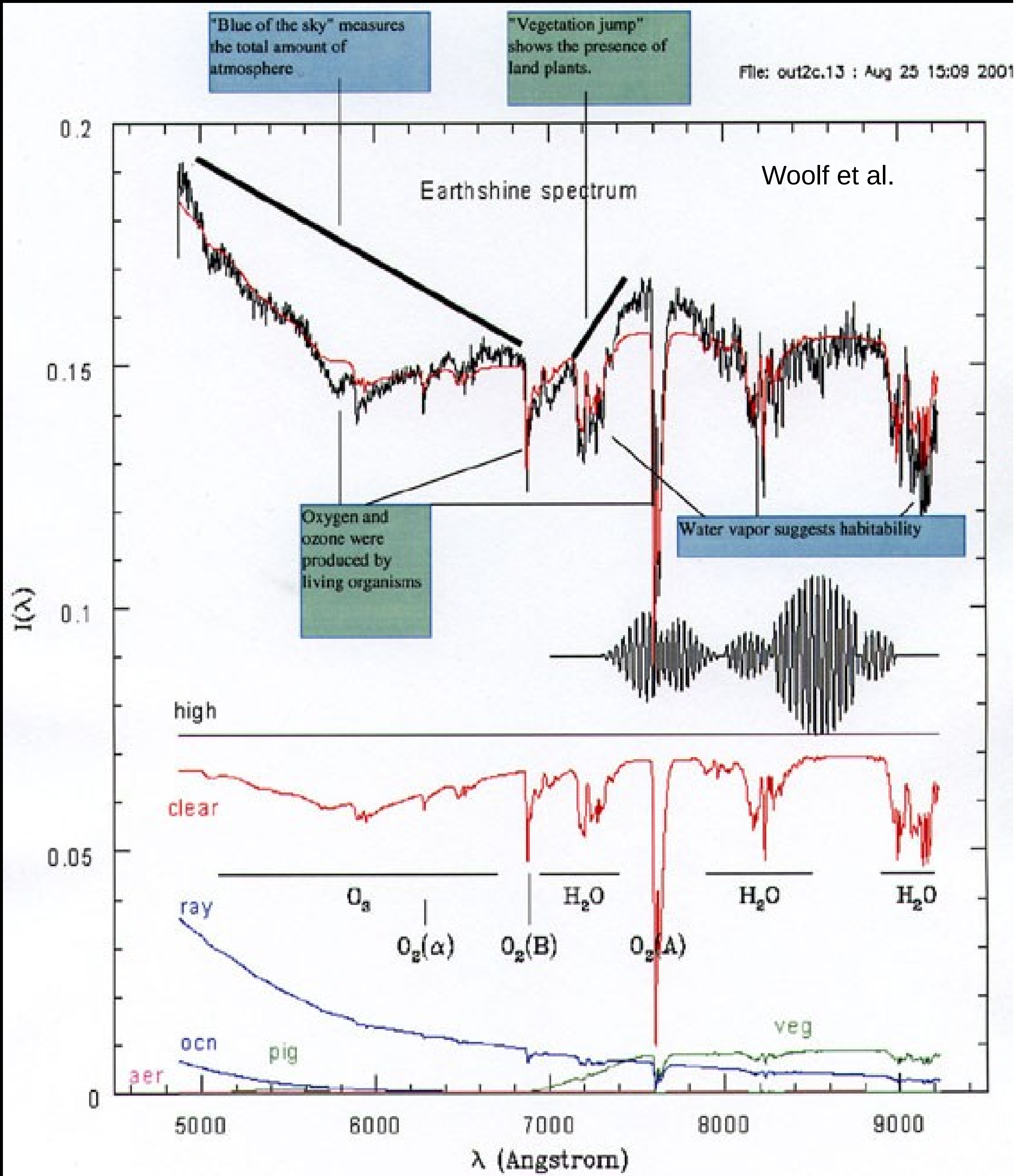
Kepler (NASA)


Kepler
Field of
View
Deneb
Vega
LYRA
CYGNUS
Albireo
Altair
AQUILA

Directly imaging planet is necessary to find life

We need to take spectra of habitable planets

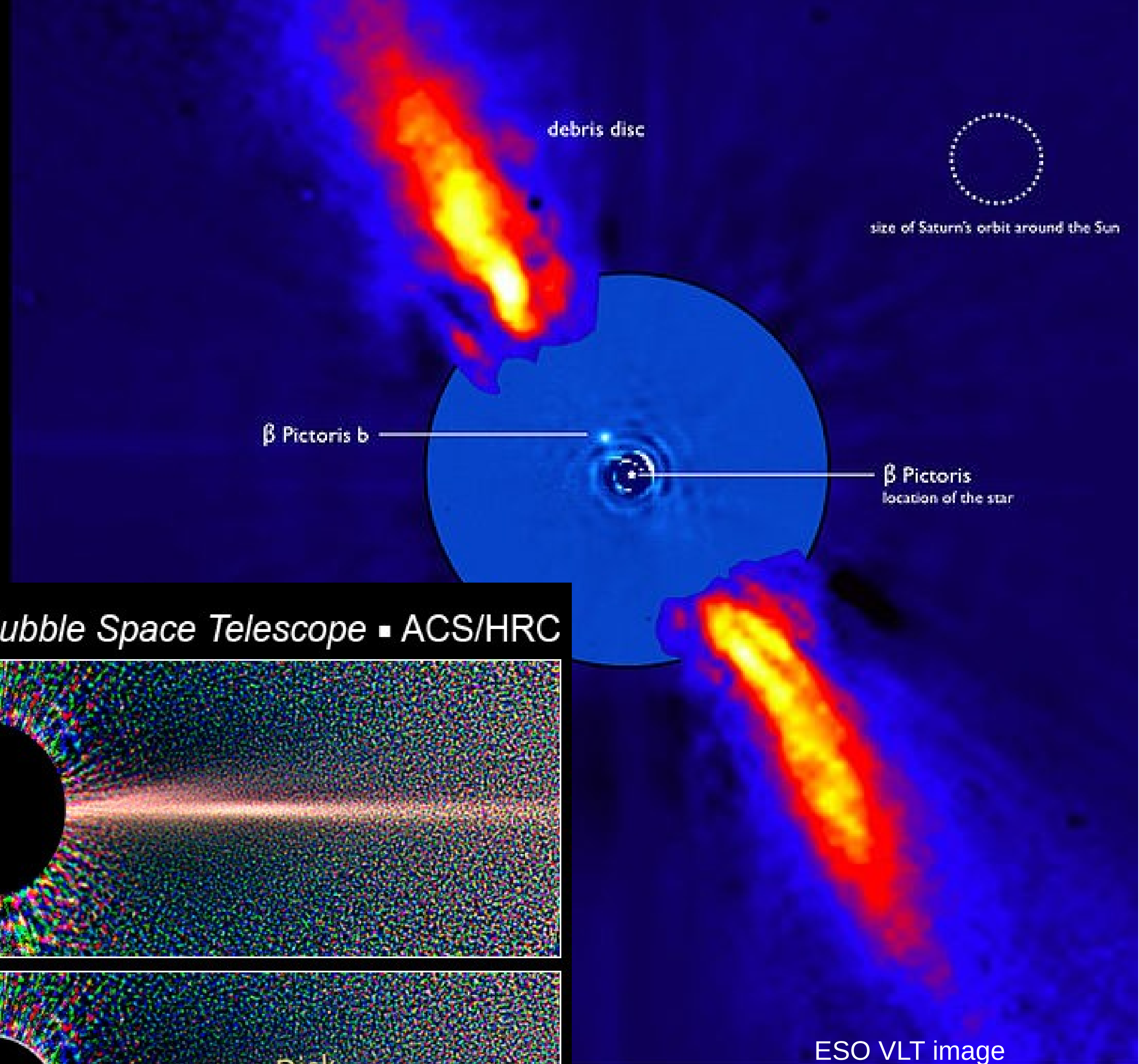
Spectra of Earth (taken by looking at Earthshine) shows evidence for life and plants



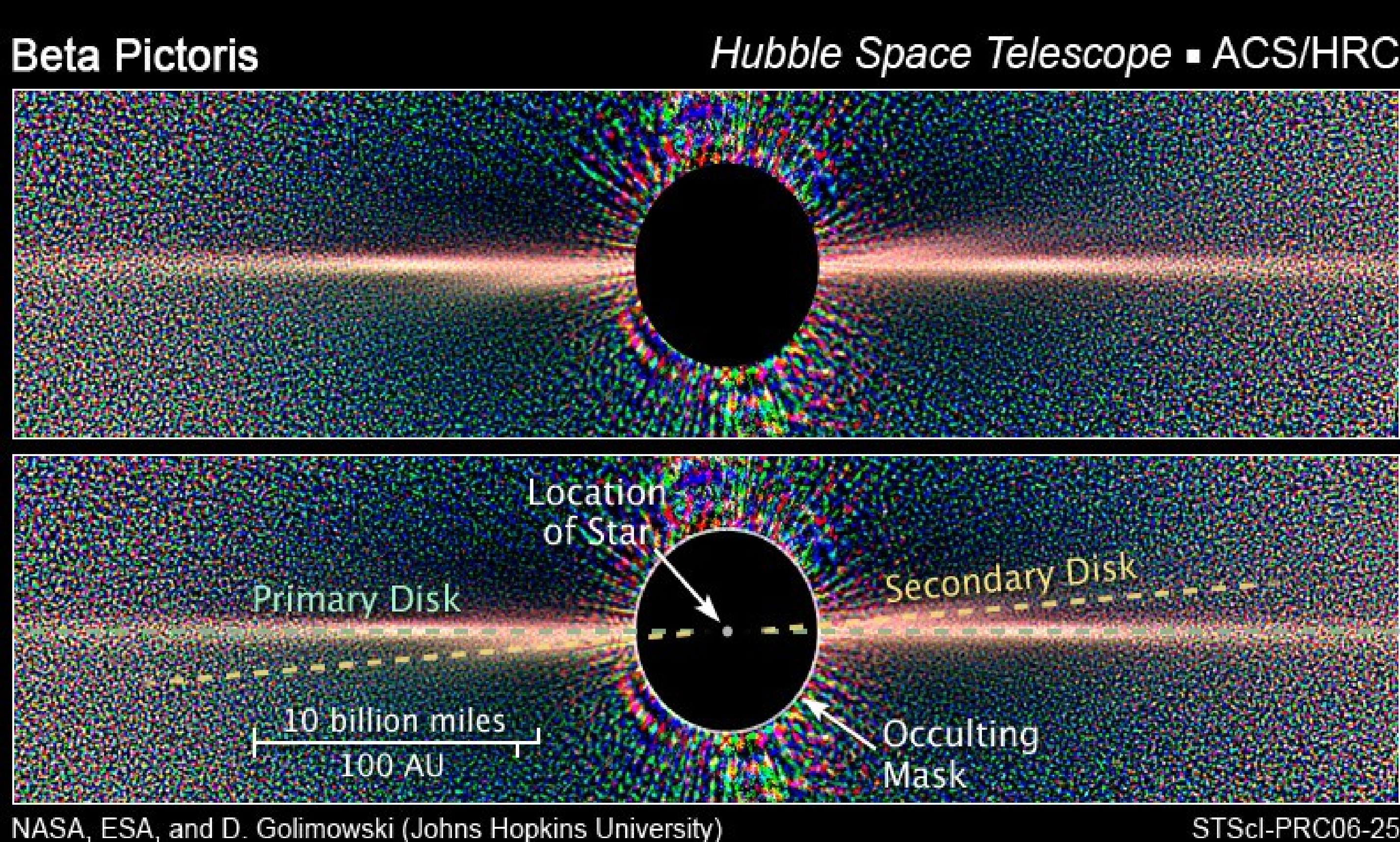
Beta Pictoris

8 Jupiter mass planet

Orbits young massive star in ~20yr



ESO VLT image
(Lagrange et al.)

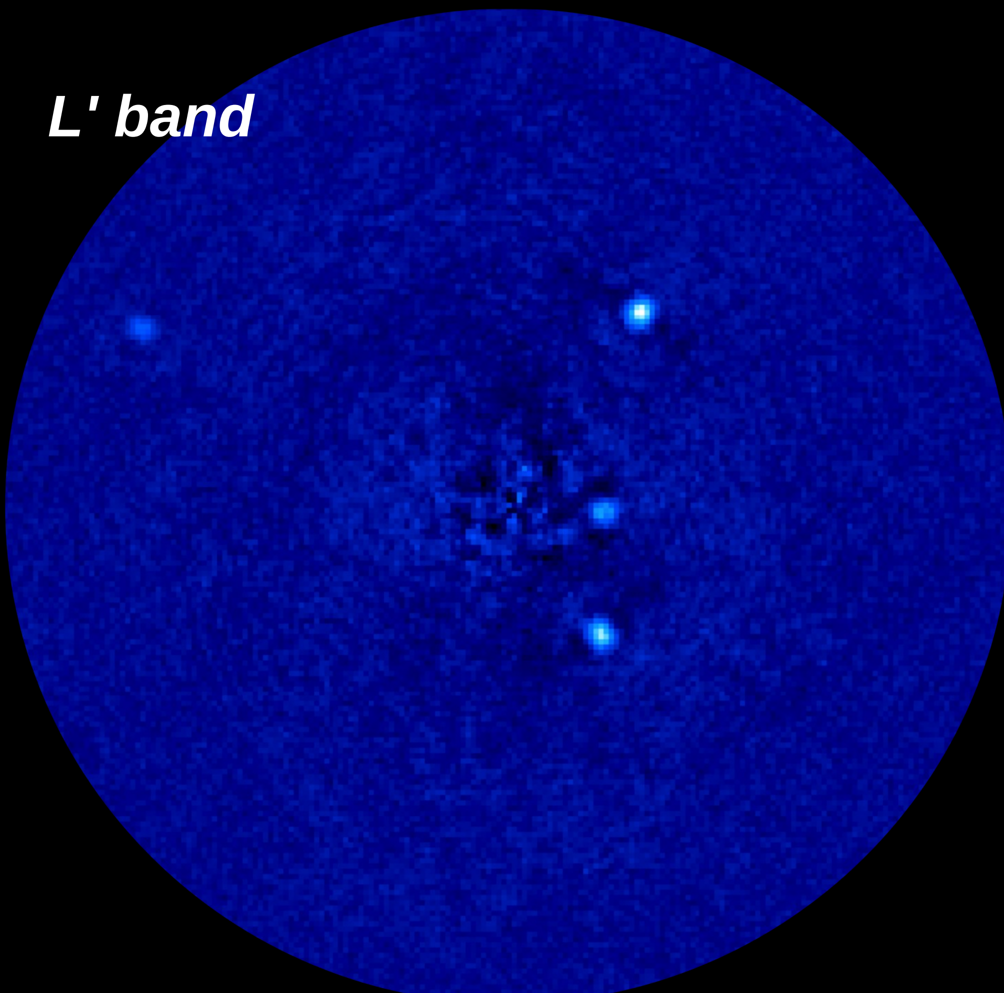


HR8799 imaged with Large Binocular Telescope

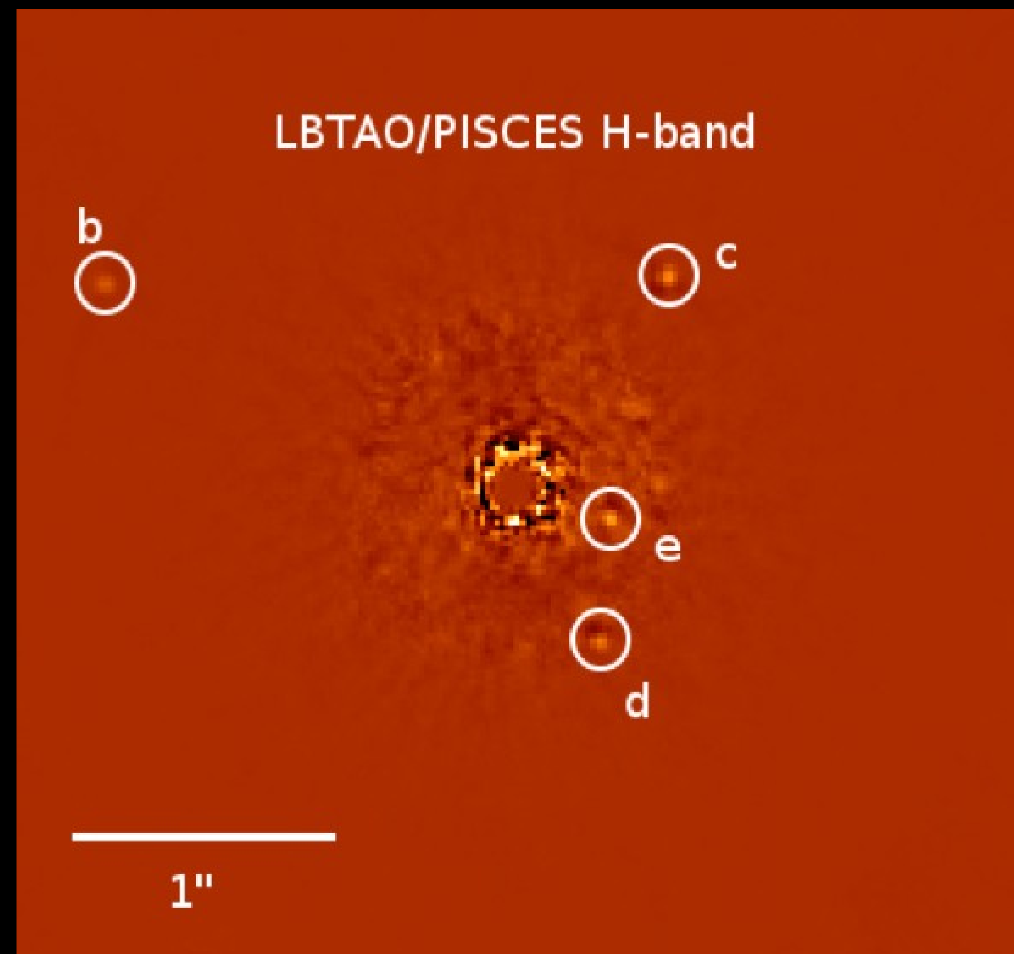
Four planets, orbital periods on the order of 100yr

Each planet 5 to 7 Jupiter Mass

L' band

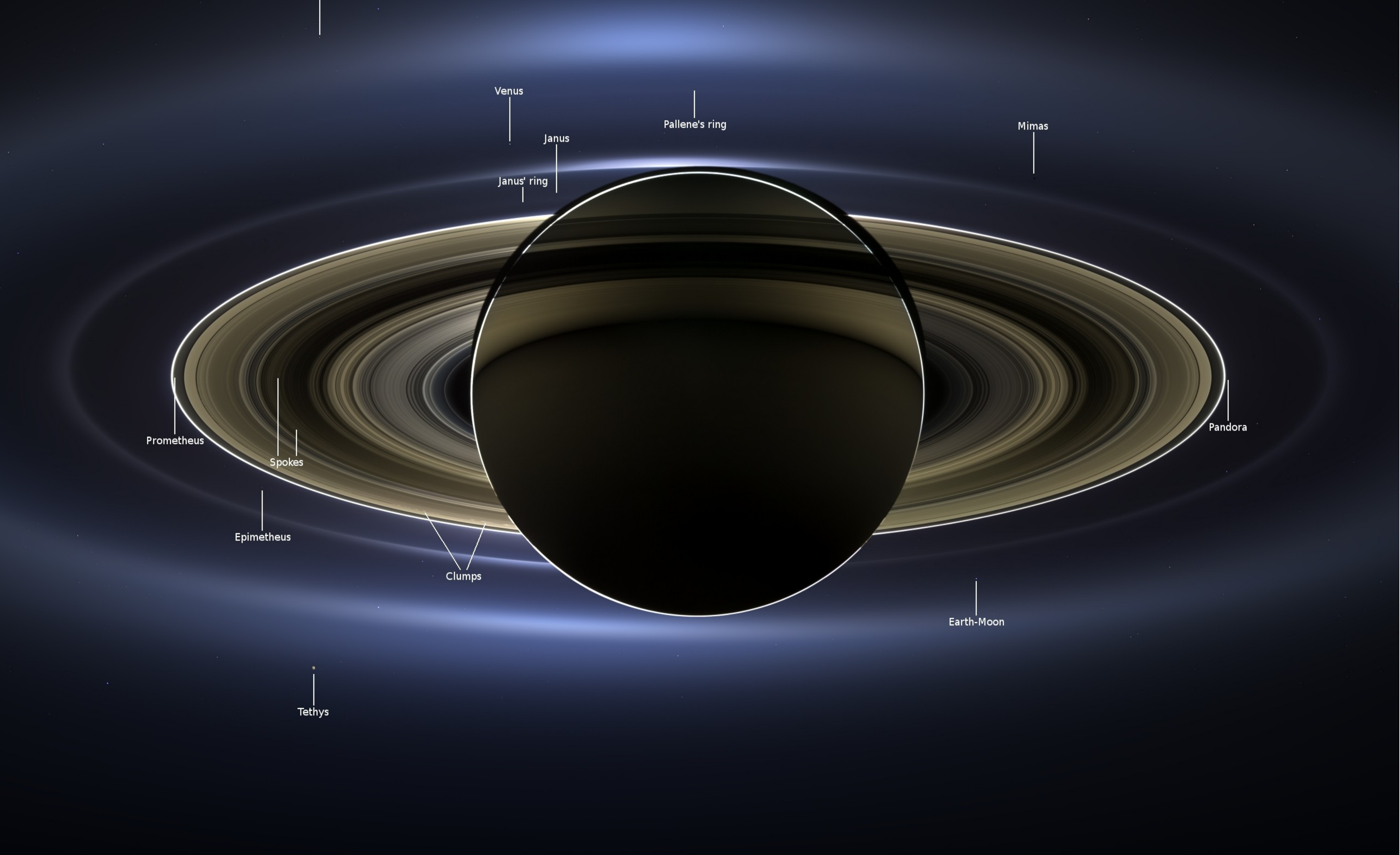


Defrere et al.



Skemer et al..

Taking images of habitable exoplanets: Why is it hard ?



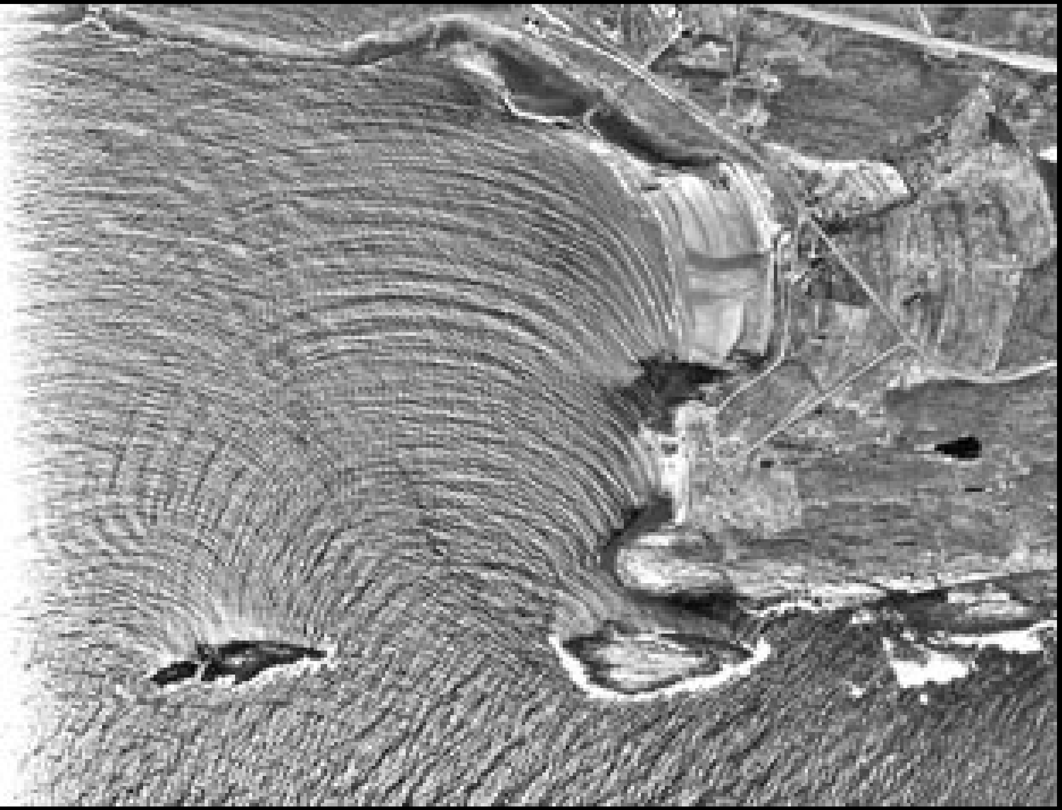

Saturn
Earth

Coronagraphy … Using optics tricks to remove starlight (without removing planet light)

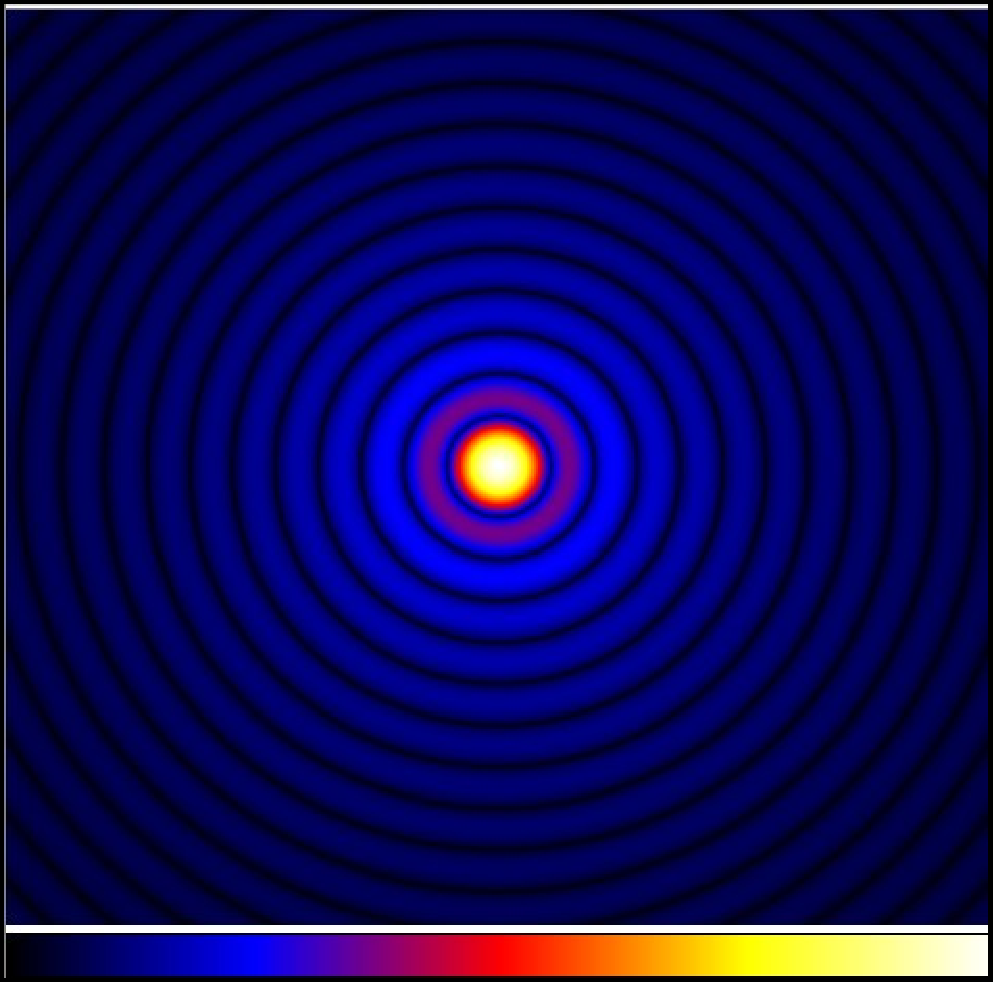
← Olivier's thumb...
the easiest coronagraph
Doesn't work well enough to
see planets around other stars

We need a better coronagraph... and a larger eye (telescope)

Water waves diffract around obstacles, edges, and so does light

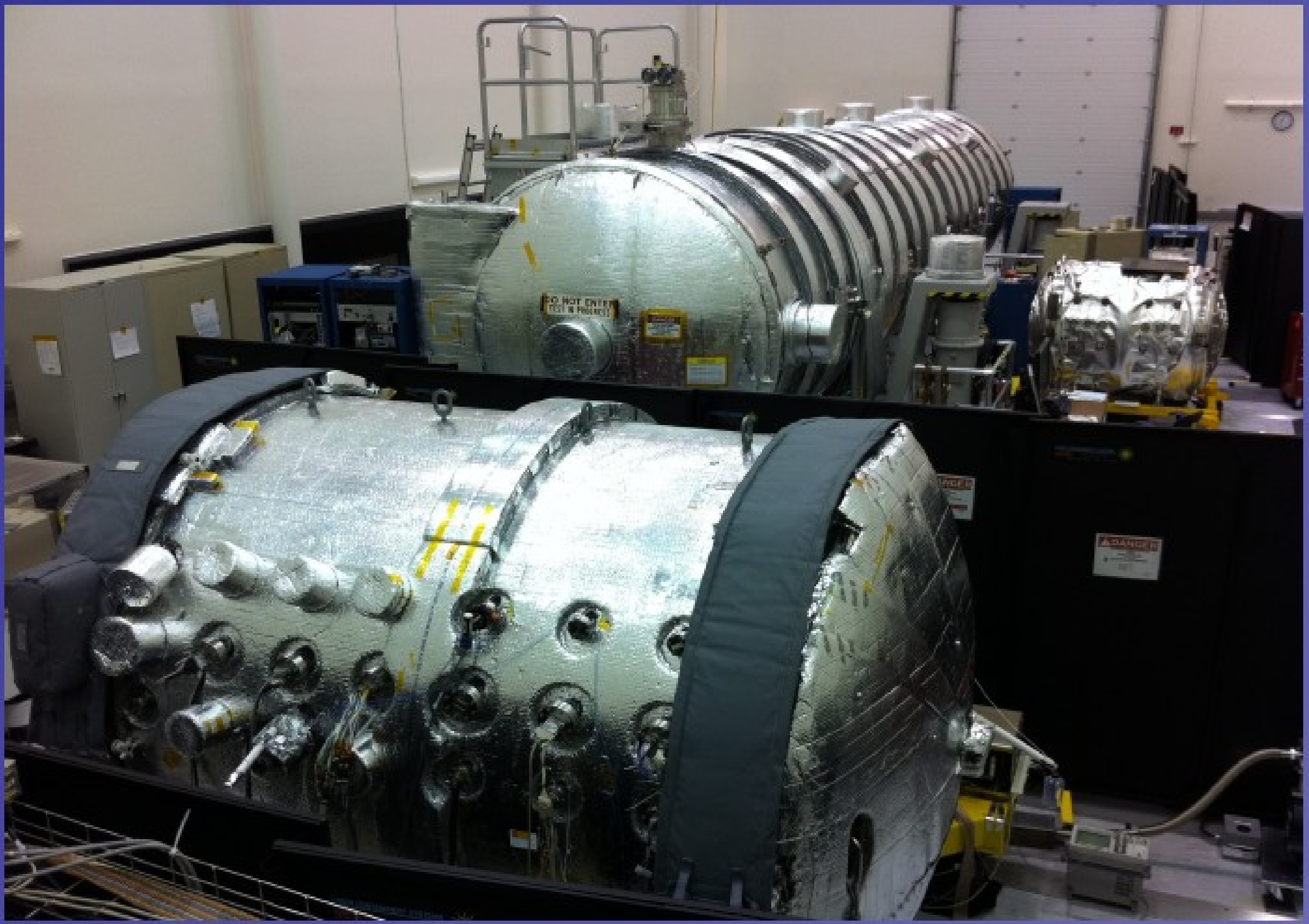


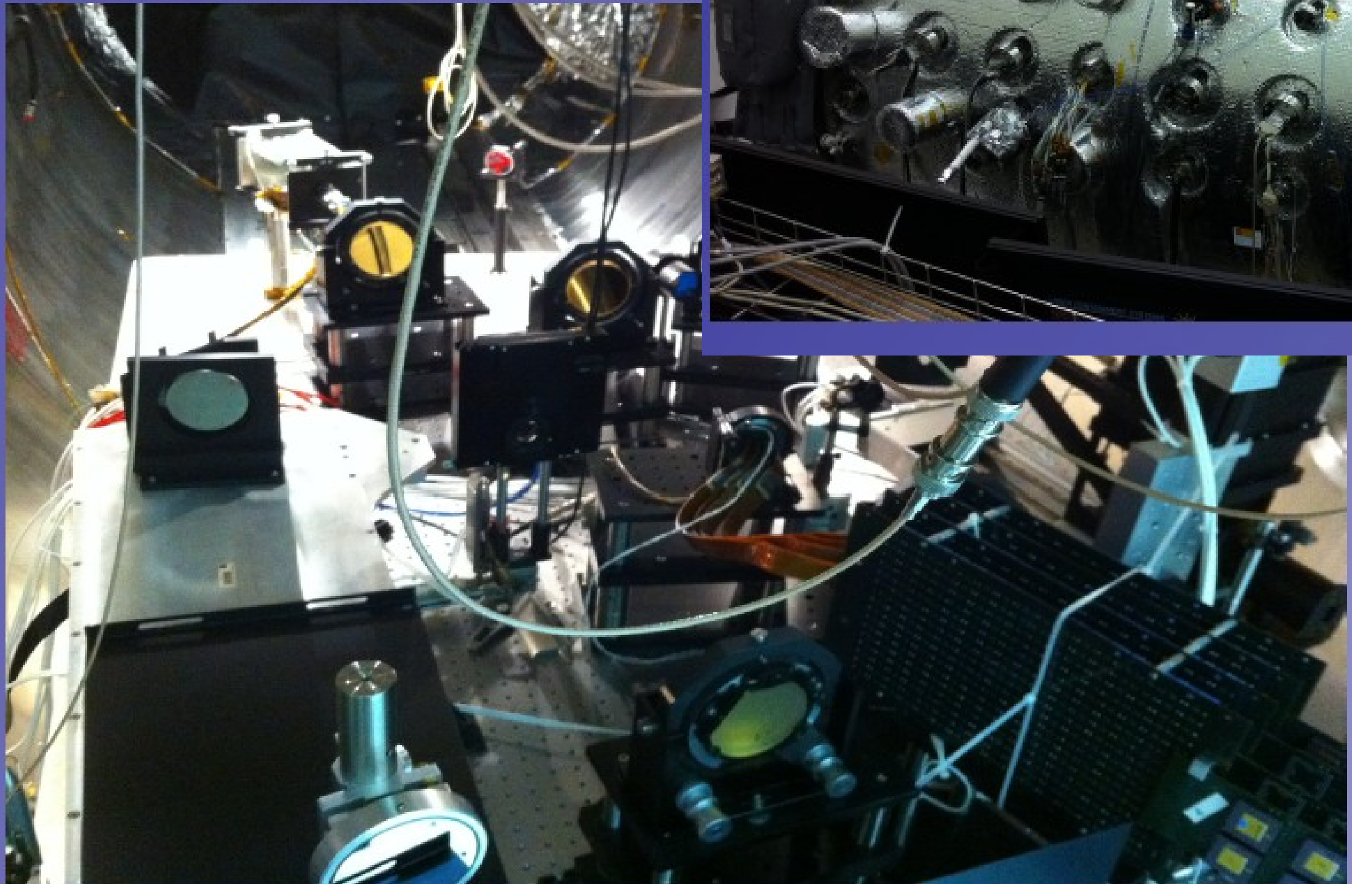
Waves diffracted by coastline and islands



Ideal image of a distant star by a telescope
Diffraction rings around the image core

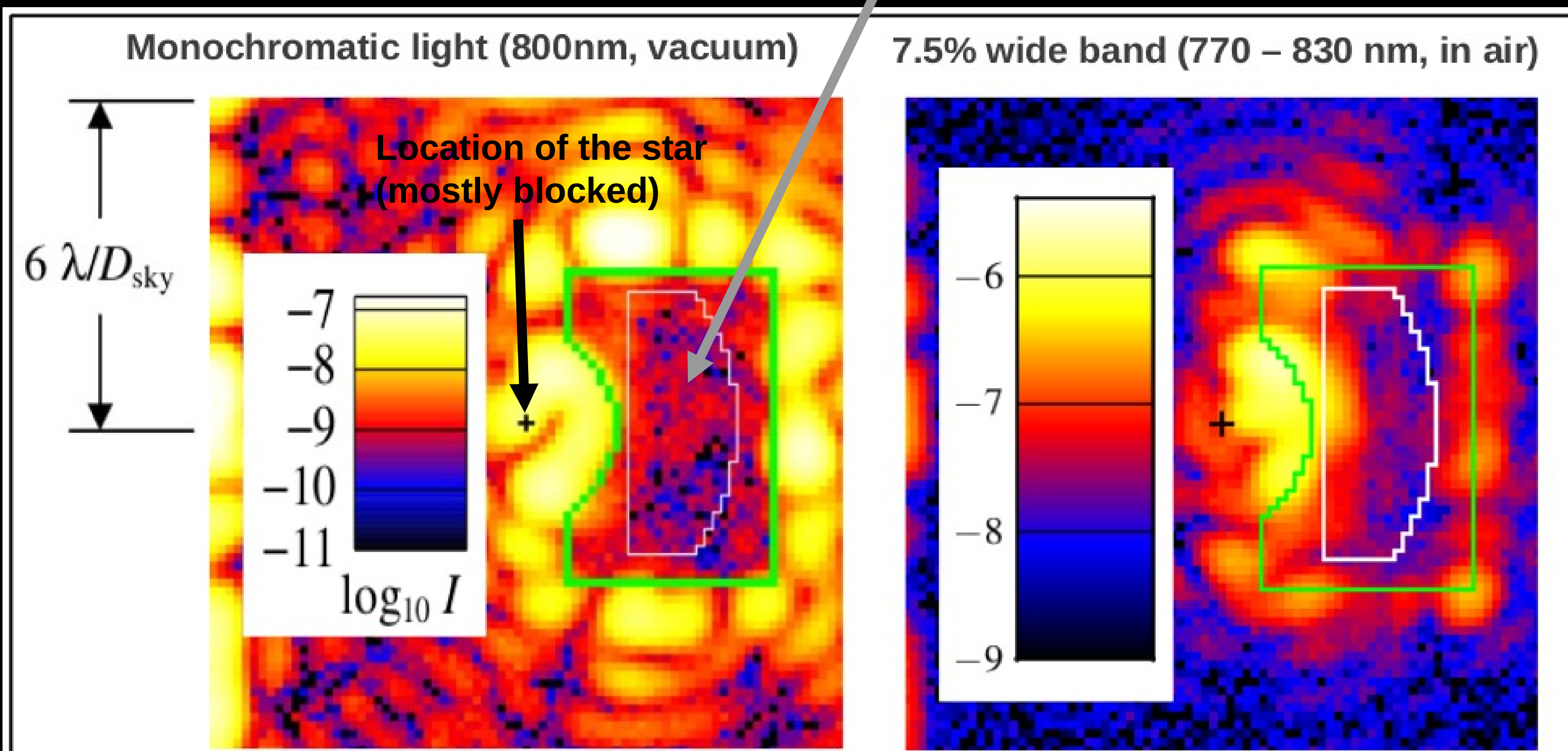
Vacuum testbeds at NASA JPL





PIAA testbed at NASA JPL : lab results

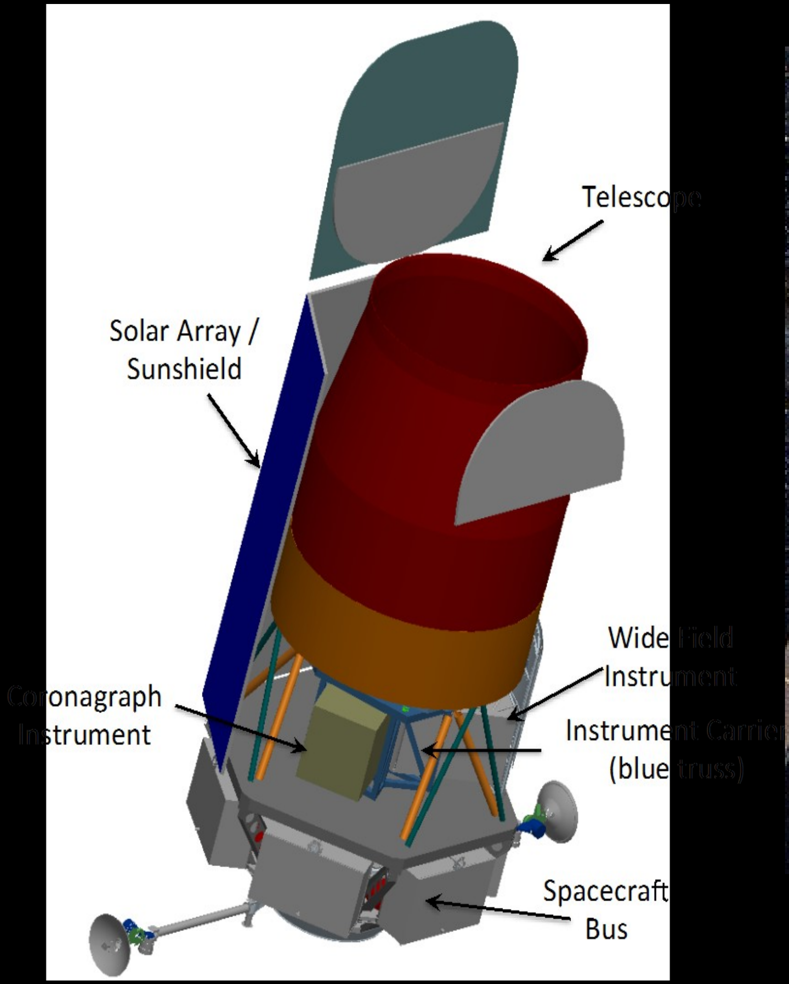
An Earth-like planet could be seen !



3 runs, contrast values averaged from 2 to 4 λ/D between 5.10^{-10} to 9.10^{-10} (figure shows $7.3.10^{-10}$ result)

5.10^{-8} contrast from 2 to 4 λ/D,
2.10^{-8} contrast from 3 to 4 λ/D
Contrast performance limited by wavefront instability (test in air)

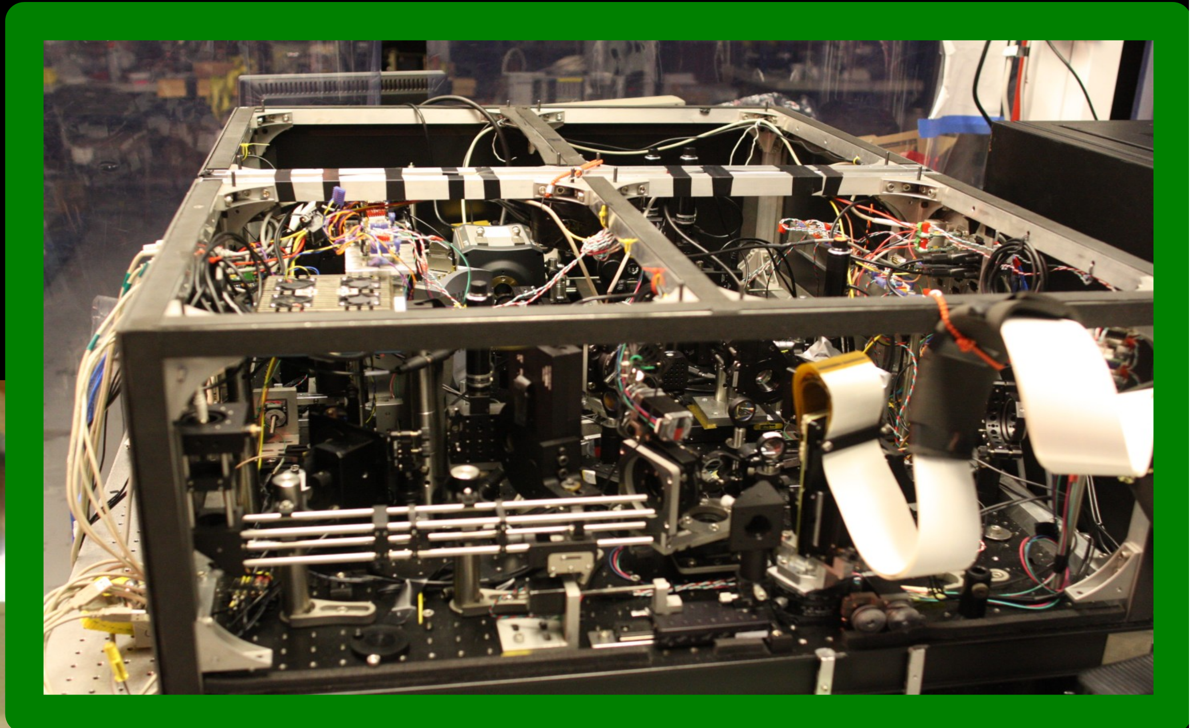
Space telescopes

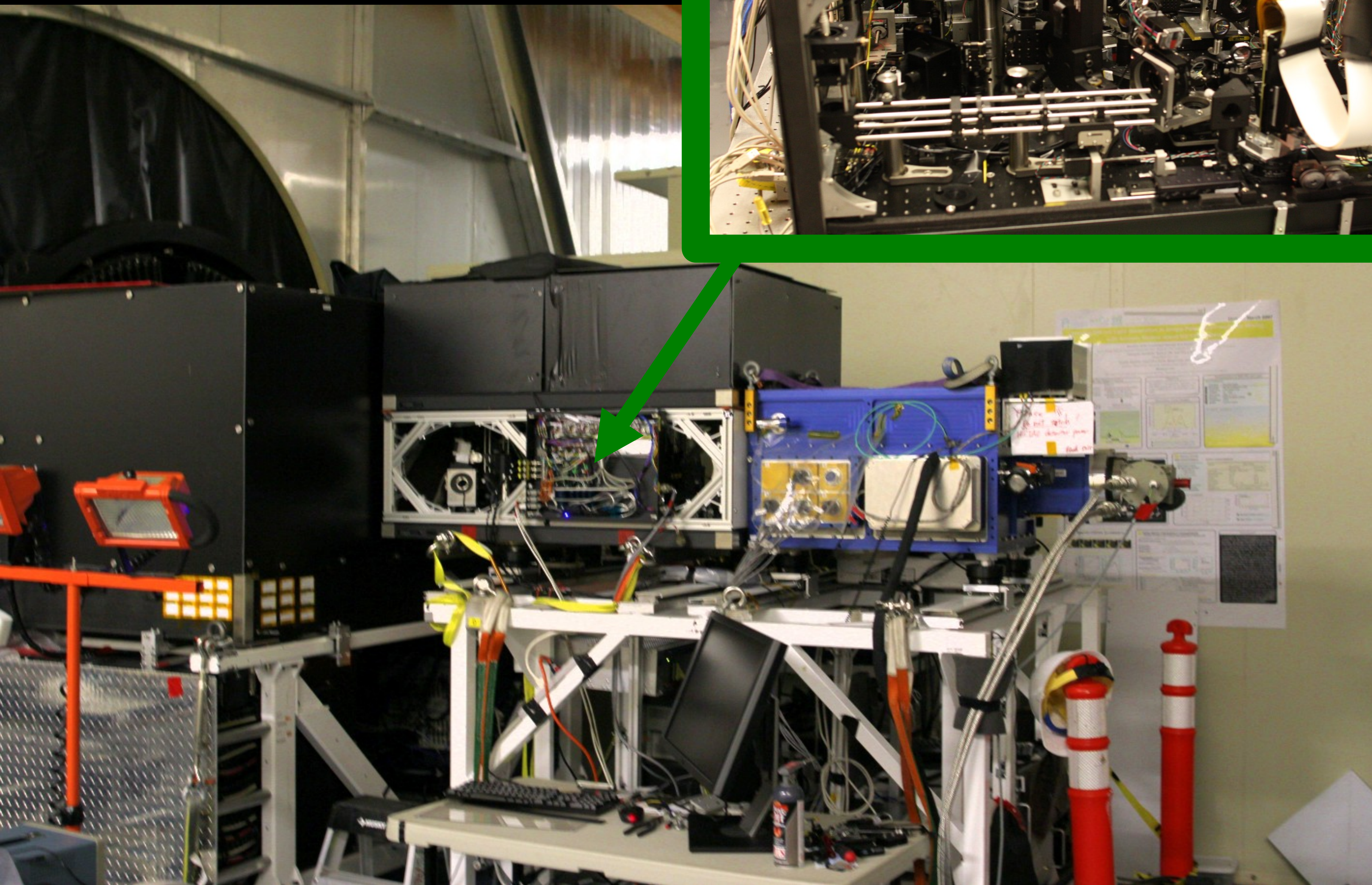


ATLAS 8m telescope project

WFIRST-AFTA telescope, 2.4m diameter

The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) system

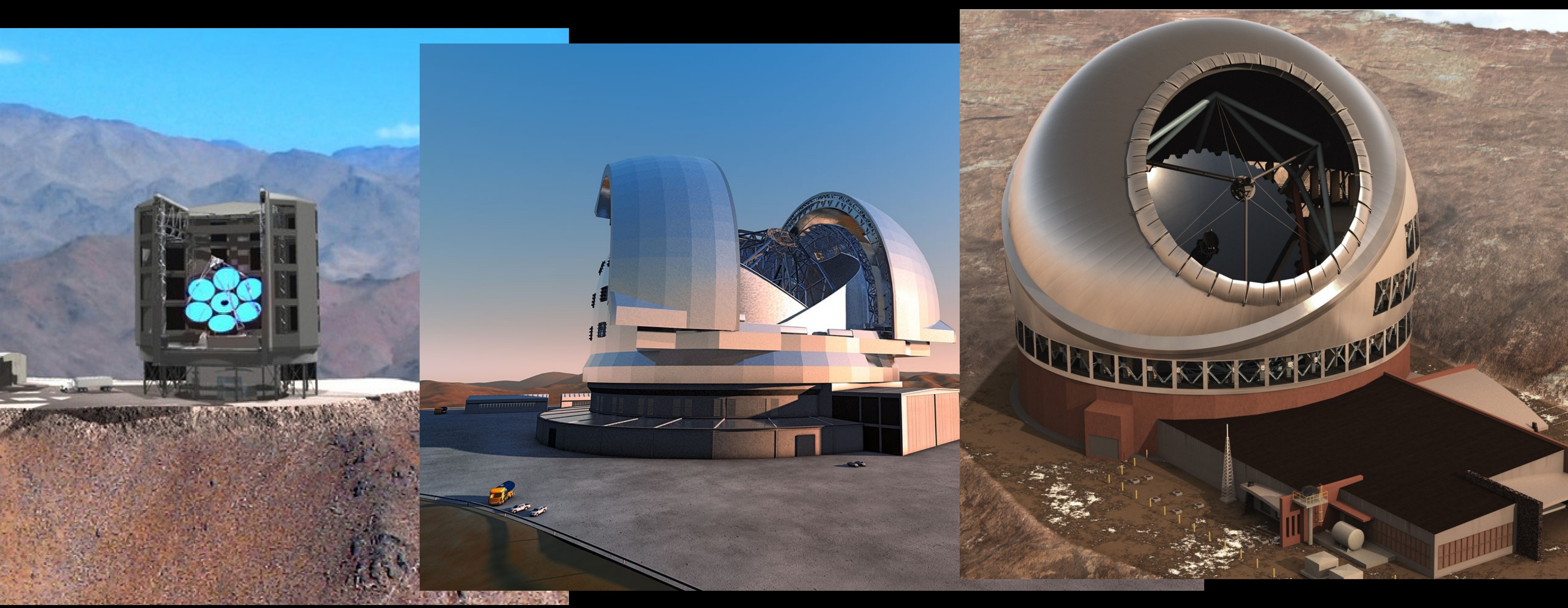




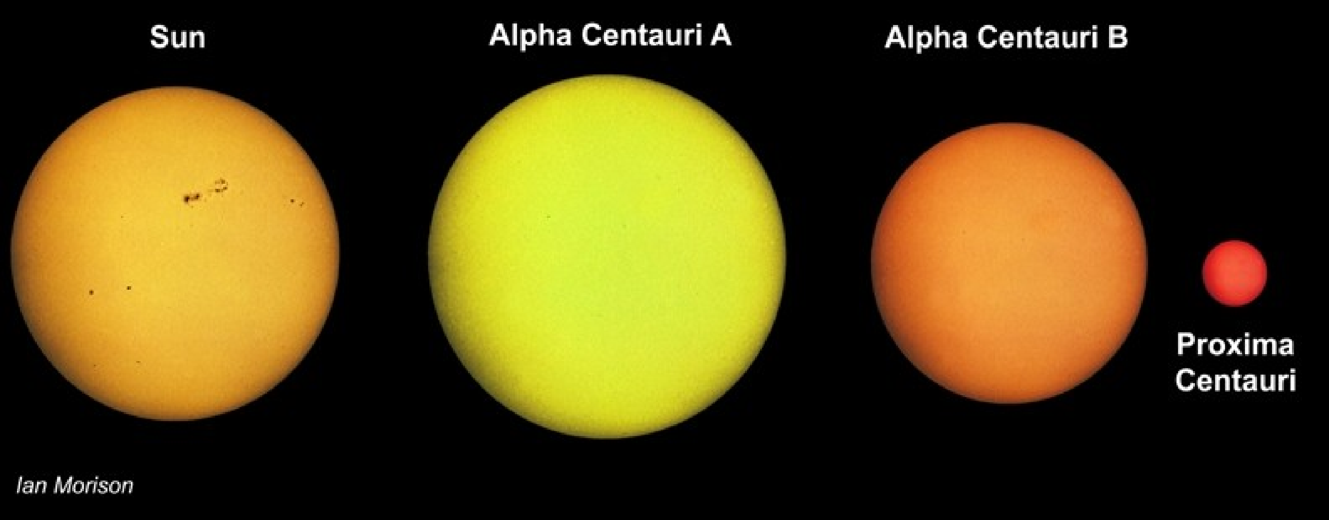
Exciting future opportunities

Next generation of large telescopes on the ground will be able to image habitable planets around nearby low mass red stars
3 projects, ~30m diameter

Space telescopes with coronagraphs will be able to image and study Earth-like planets around sun-like stars



Proxima Centauri

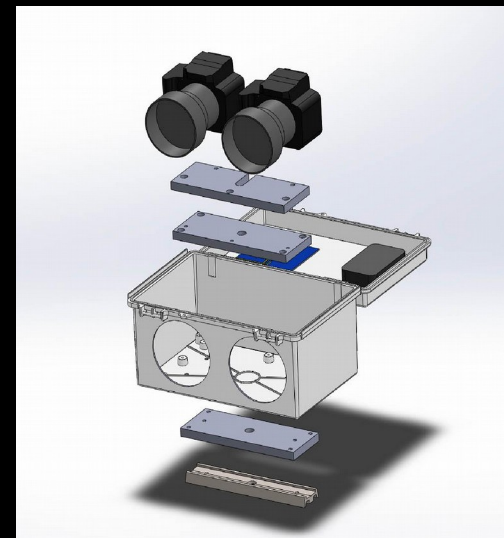


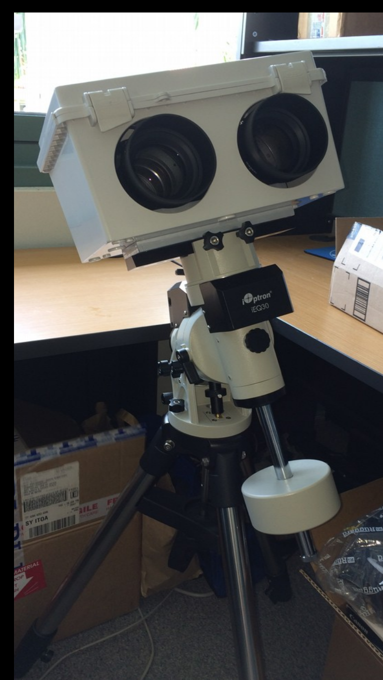
PANOPTES **P**anoptic **A**stronomical **N**etworked **OP**tical observatory for **T**ransiting **E**xoplanets **S**urvey

Discovering transiting exoplanets requires monitoring large parts of the sky for long periods of time

The most efficient way to do this is to use inexpensive digital cameras

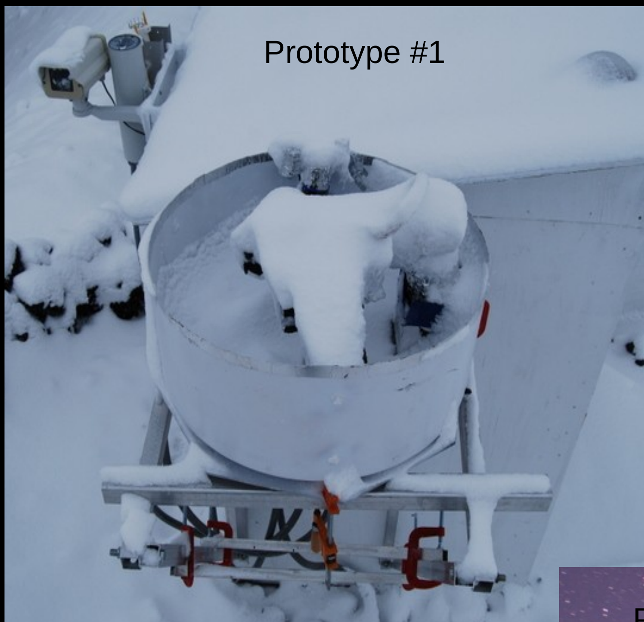
PANOPTES is a citizen science project aimed at discovering a large number of exoplanets





Cameras: Canon EOS SL1 (x2), Lenses: Rokinon 85mm F1.4 (x2)
Mount: iOptron IEQ30
Weather and cloud sensor
12V computer. All system runs on 12V battery charged by 120V AC (resilient to short power failures)
Python-based software

PANOPTES prototypes (2010-2014)

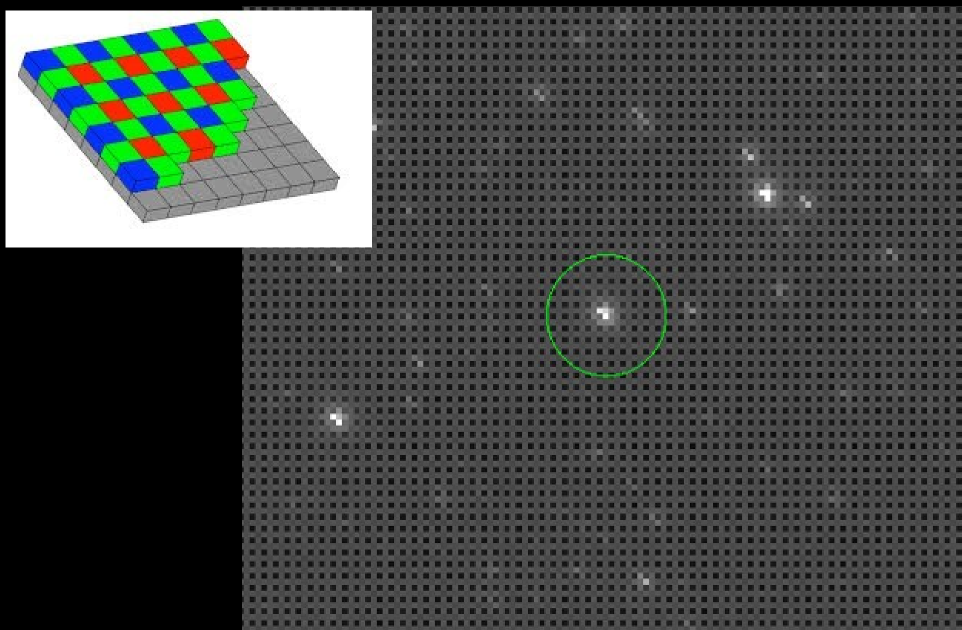

Prototype #1

Project started in 2010 with deployment of prototype #1 at the Mauna Loa observatory (Hawaii, USA).
2013: prototype #3 deployed at Mauna Loa observatory
Quasi-continuous robotic operation of prototypes since early 2011


Prototype #3

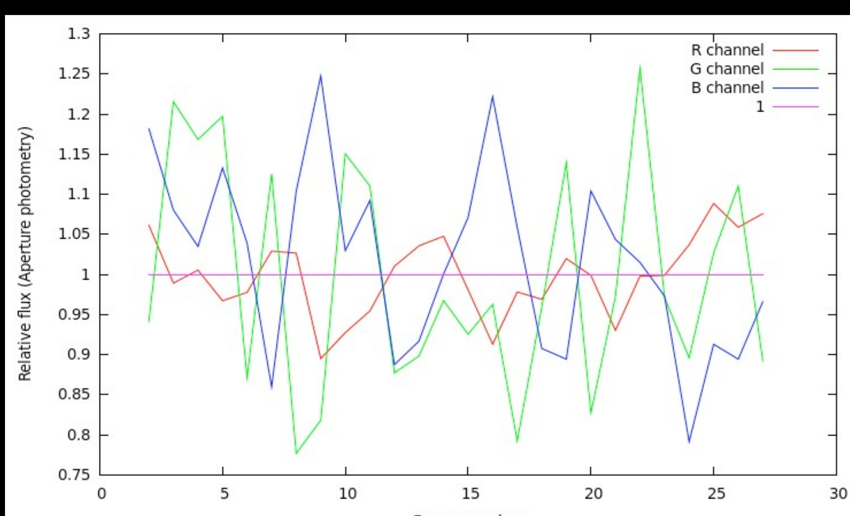

Prototype #2

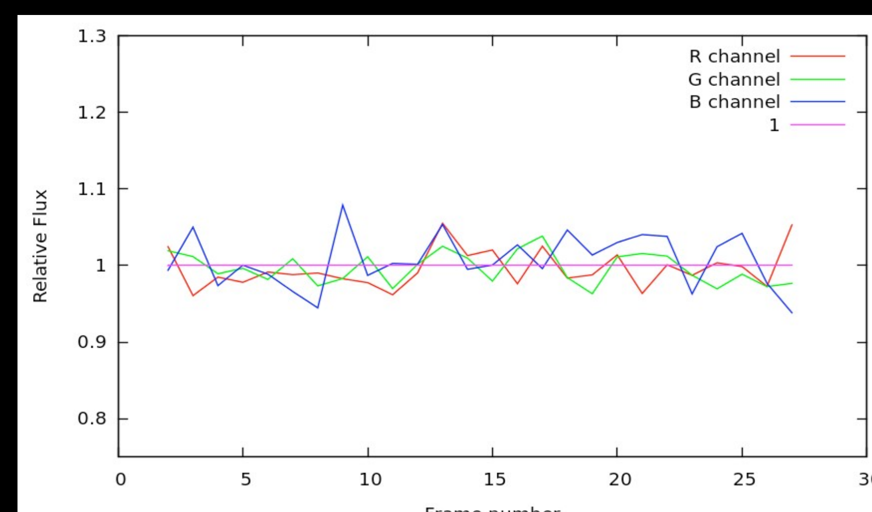
Precision flux measurement



Color DSLR cameras have “colored” pixels → we can't simply add pixel values to measure star brightness

We use comparisons between ~100,000 star images available in each field to calibrate flux

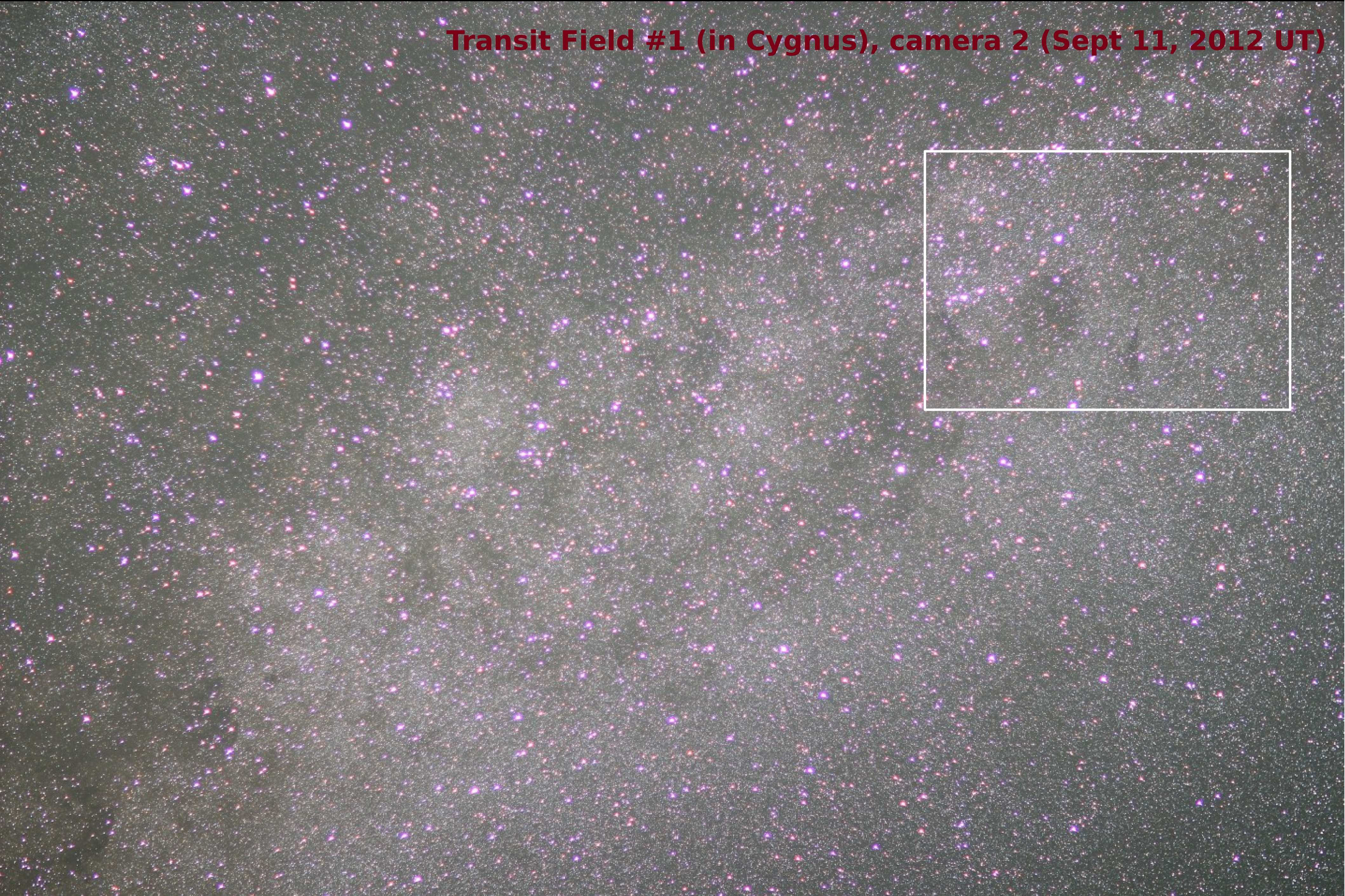


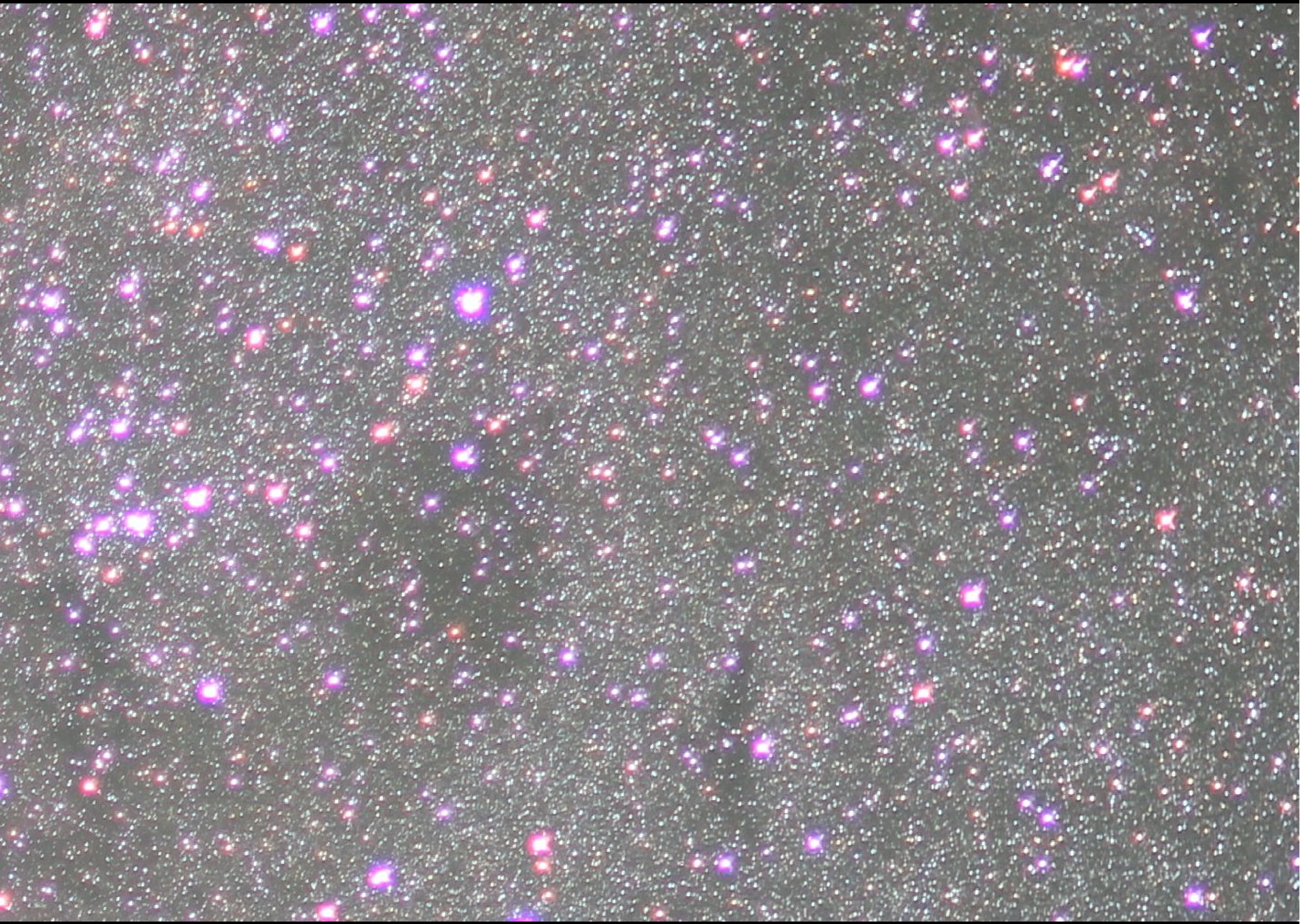


Orion field (image processed by Jon Talbot)

Comet Lovejoy (image processed by Jon Talbot)

Example image (Cygnus field): >100,000 stars in a single image





More info, how to join PANOPTES

Project website: www.projectpanoptes.org
Software: https://github.com/panoptes
Joining request: info@projectpanoptes.org