Lecture 2: Transit surveys

Instrumentation

Wide versus deep

Space versus ground

Review of results to date

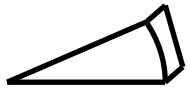
Future surveys

Ground-based transit surveys

- **Photometry at <1% precision is possible from the ground**
- **Successful ground-based surveys have detected over 200 (mostly gas-giant) planets:**
  - **OGLE**
  - **TrES**
  - **SuperWASP + WASP-South**
  - **HAT + HAT-South**
  - **XO**
  - **QES**
  - **KELT**

Transit Surveys

Wide vs Deep



$D \sim 10$ cm $\quad \theta \sim 10^{\circ}$

$d \sim 300$ pc $\quad \Delta\theta \sim 30$ arcsec

$D \sim 1-4$ m $\quad \theta < 1^{\circ}$

$d \sim 1-4$ kpc $\quad \Delta\theta \sim 1$ arcsec

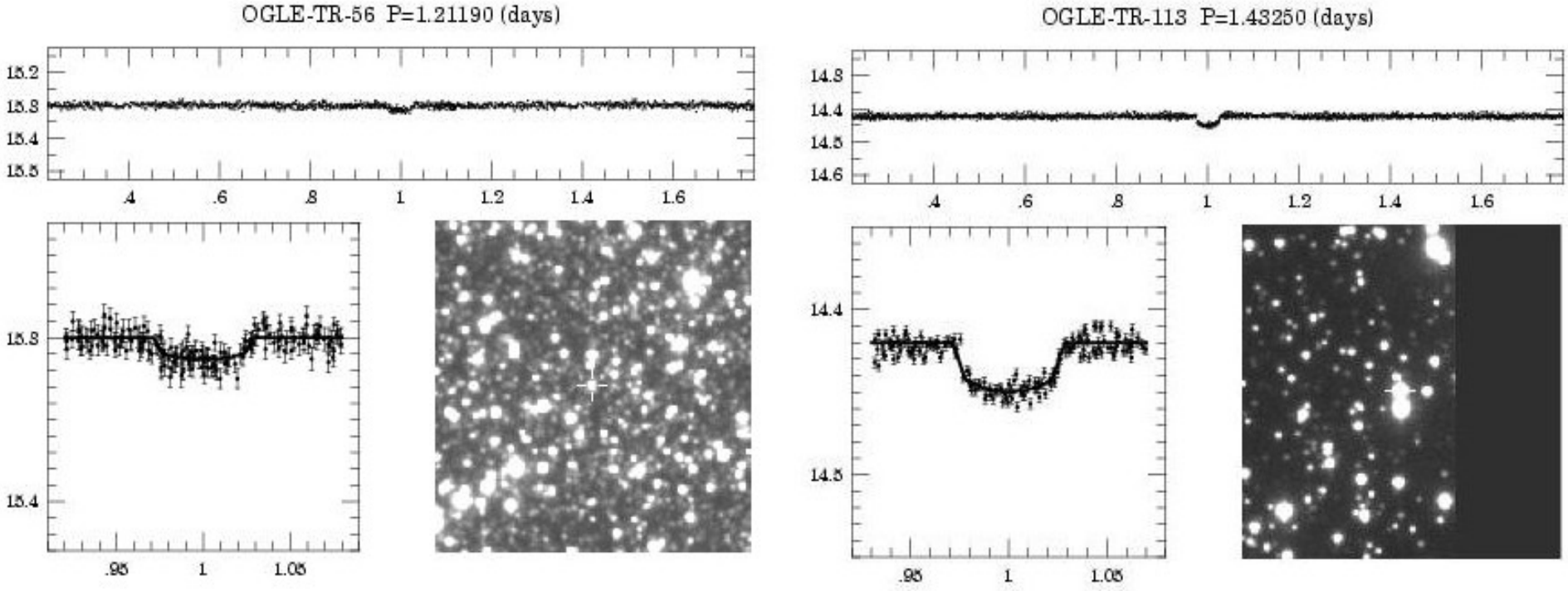
All-sky surveys

Small wide-angle cameras survey bright nearby stars

Galactic plane fields

Larger telescopes (narrow fields) survey faint distant stars

OGLE III Deep Transit Survey



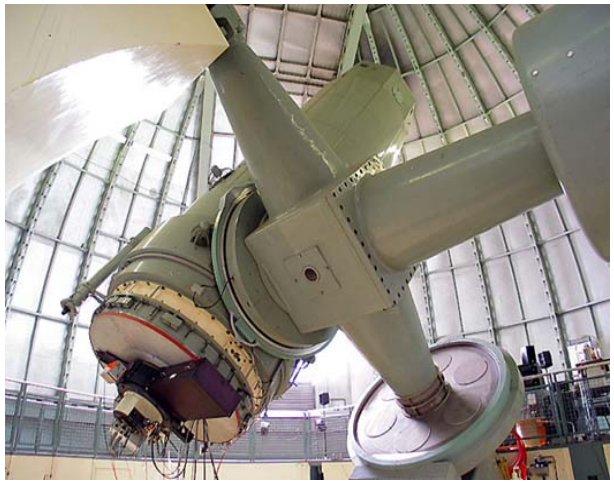
1.3m microlens survey telescope Las Campanas, Chile.
Mosaic 8-chip CCD camera. 2001 Galactic Bulge -- 64 candidates
2002 Carina -- 73 candidates

Spectroscopic follow-up of OGLE-TR-56b with VLT/UVES confirmed planetary nature with $m_p = 0.9\ m_J$ and $P = 1.2$ days

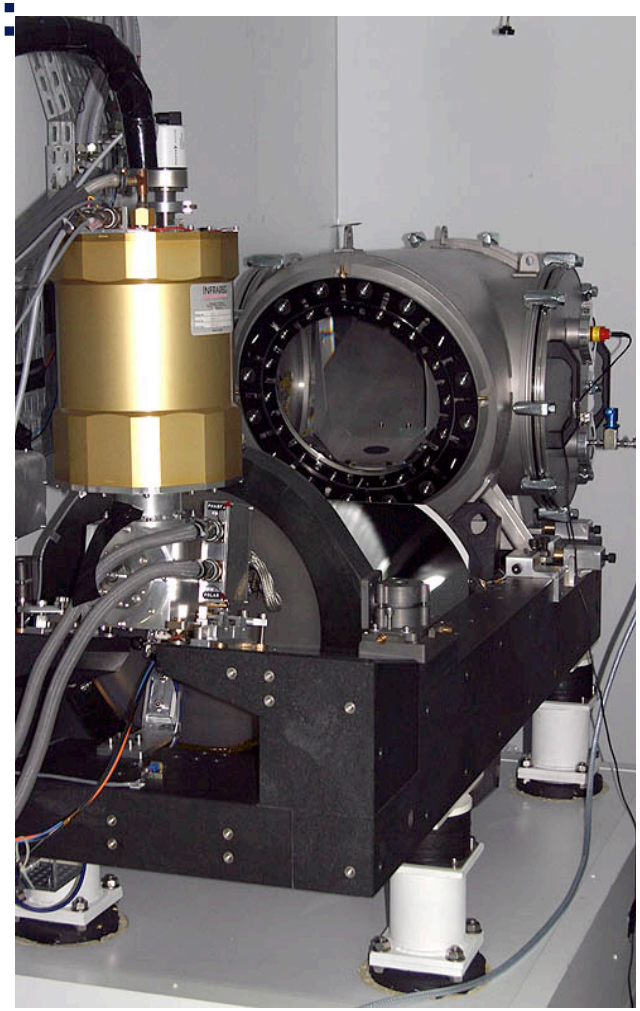
⇒ first exoplanet discovered using transits.

It isn't a planet until you've weighed it

- **All transit surveys operate in partnership with RV surveys.**
- **Magnitude range matches capabilities of RV spectrometers on 2-10m telescopes:**
  - **OGLE: VLT8.2m/UVES**
  - **TrES: Keck10m/HIRES**
  - **HAT: OHP1.93/SOPHIE; SUBARU8.4/HDS**
  - **XO: McDonald2.7, HET11.0**
  - **WASP-N: OHP1.93/SOPHIE, NOT2.4/FIES**
  - **WASP-S: Swiss Euler 1.2m, ESO3.6/HARPS**

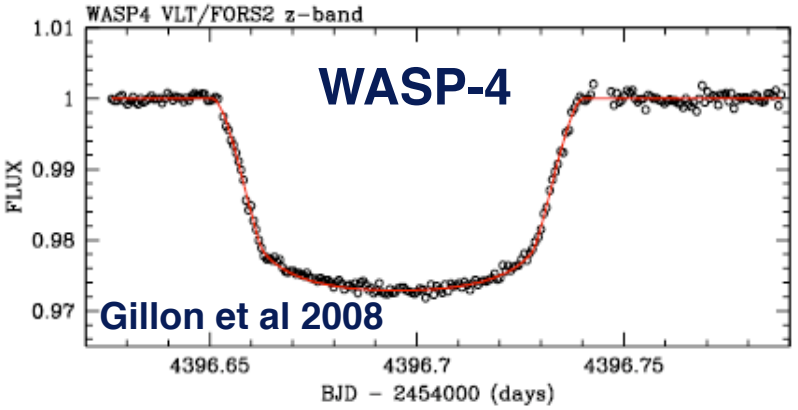


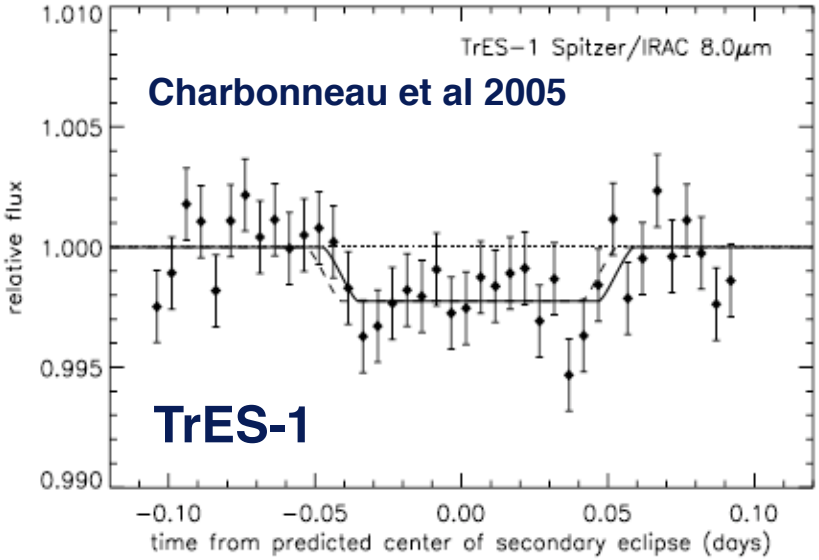
Vietri Sul

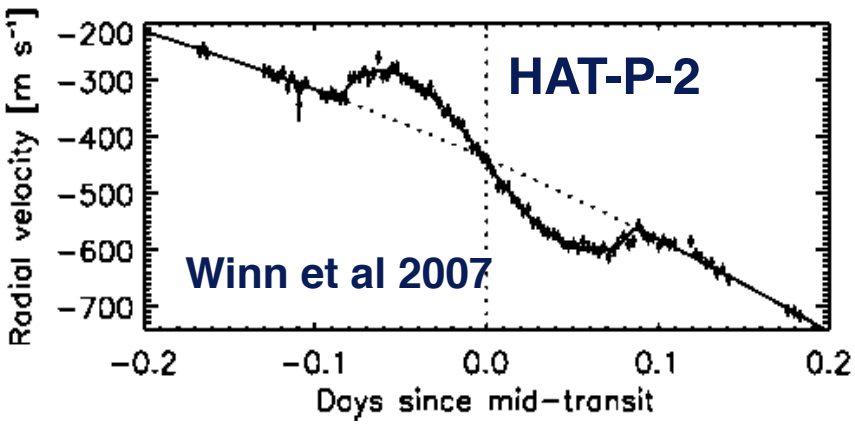


Followup studies need bright planets

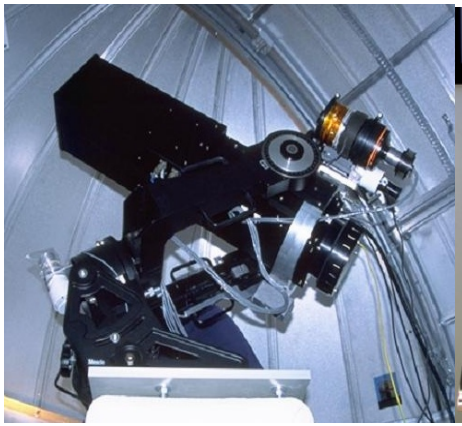
- **Optical/IR transit photometry**
  - **Transmission spectrum of atmosphere**
  - **SPITZER/IRAC well-suited to 7 < V < 12**
- **Optical/IR secondary-eclipse spectrophotometry**
  - **Thermal spectrum of dayside**
  - **SPITZER/IRAC matched to 7 < V < 12**
- **High-precision RV followup**
  - **E.g. Rossiter effect in HAT-P-2 with SUBARU**



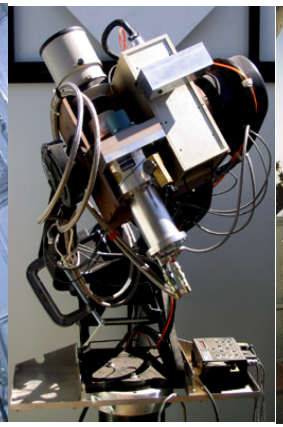




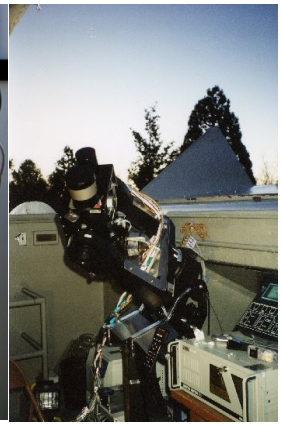
Ground-based transit surveys



STARE

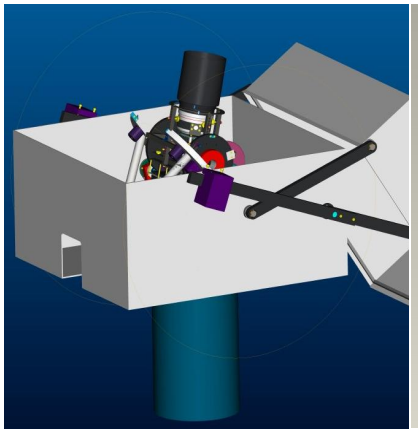


PSST

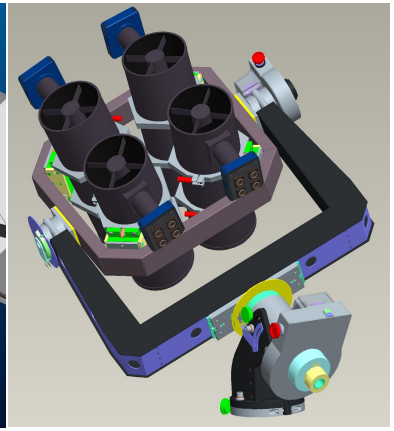


SLEUTH

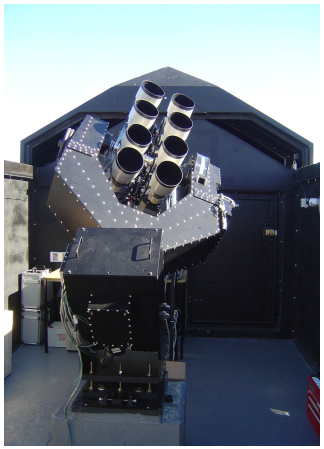
XO



HAT



HAT-S



WASP

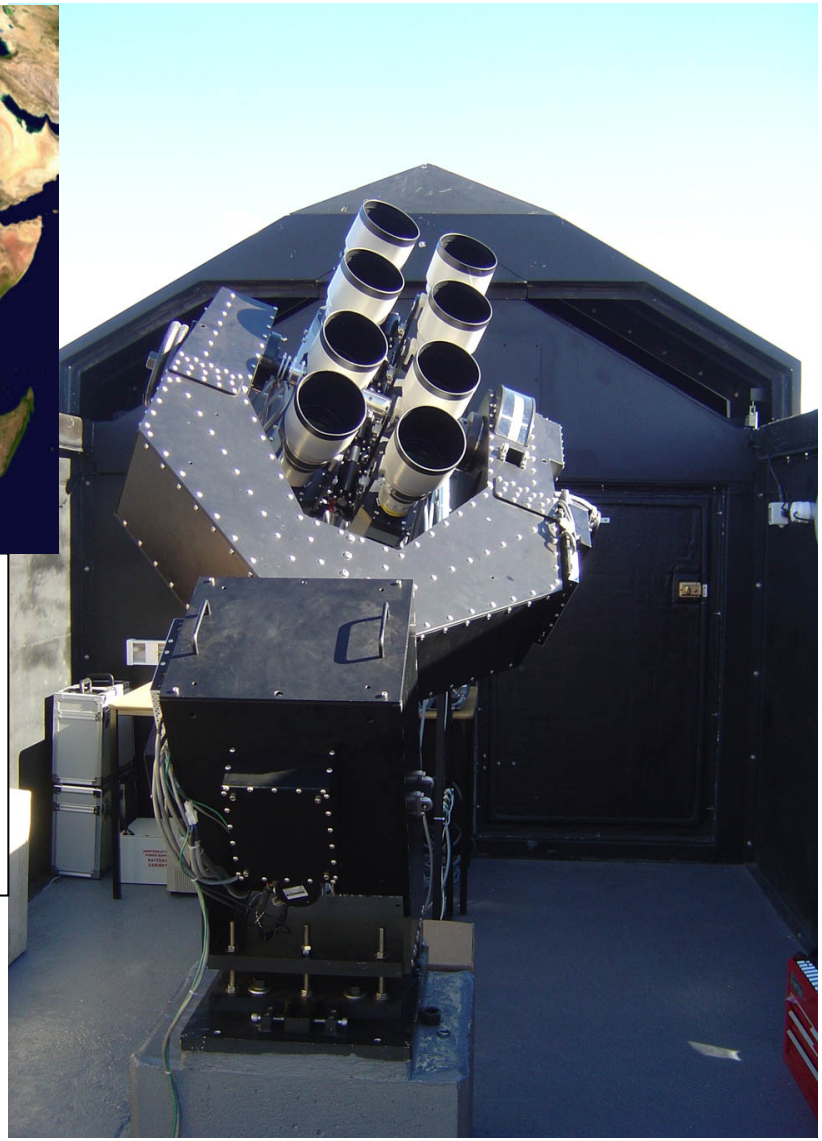
QES

Super-WASP: Hot Jupiters

Wide-Angle Search for Planets

2004 WASP North (La Palma, Canary Is.)

2006 WASP South (South African Astronomical Obs.)



UK WASP Consortium:

Belfast, St Andrews, Keele, Open, Leicester, Cambridge, IAC, SAAO.

PI: Don Pollacco

Super-WASP: Hot Jupiters

Wide-Angle Search for Planets

Robotic Mount with 8 cameras:

Canon f=200mmf/1.8 lens, aperture D=11cm.

Image scale:

$$3600 \times \frac{180}{\pi} \frac{1}{f} = 1031 \text{arcsec/mm}$$

Detectors: Thinned e2v CCD (Andor, Belfast): 2048x2048 13.5μm pixels

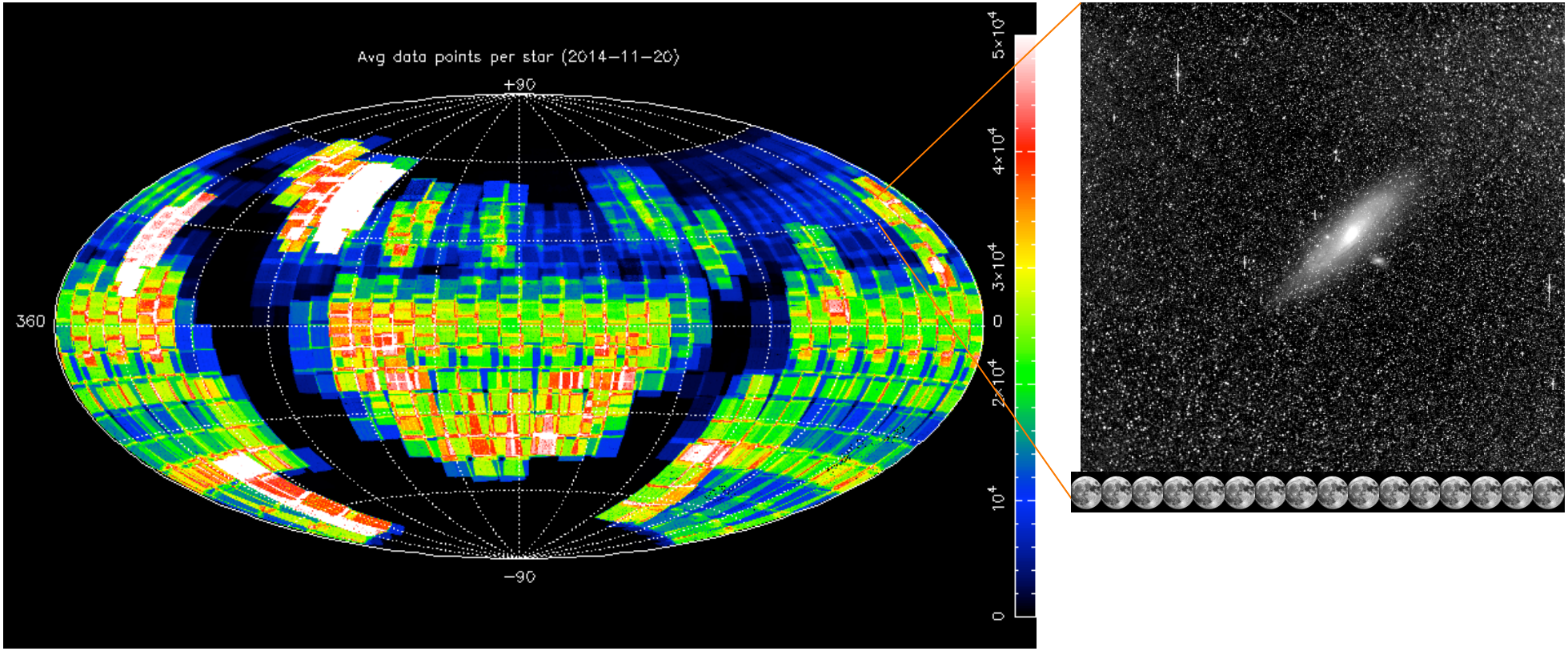
Pixel scale:

$$0.0135 \times 1031 = 13.9 \text{arcsec/pixel}$$

Field of view:

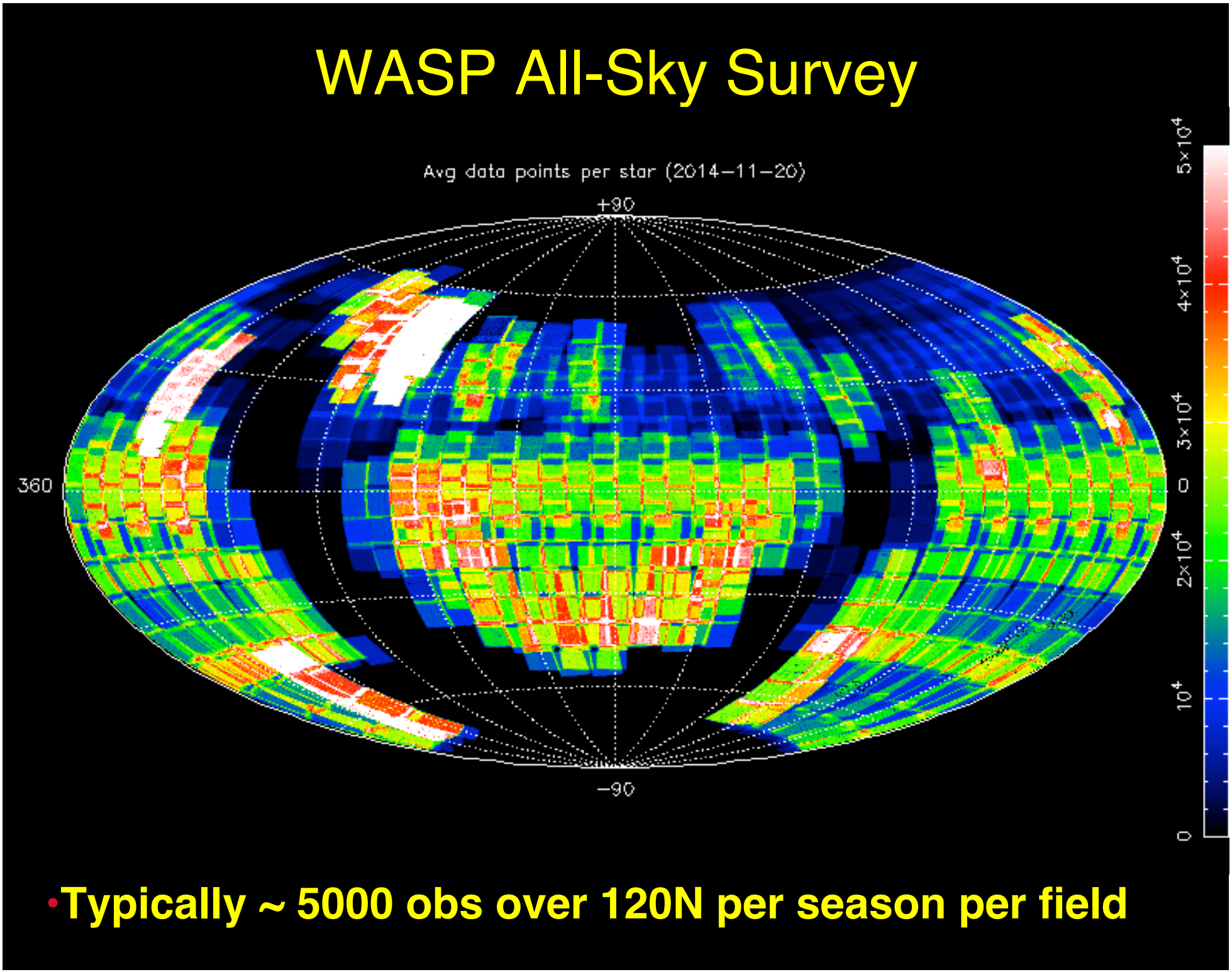
$$\frac{2048 \times 13.9}{3600} = 7.9 \text{ degrees}$$

WASP Magnitude limits & sky coverage



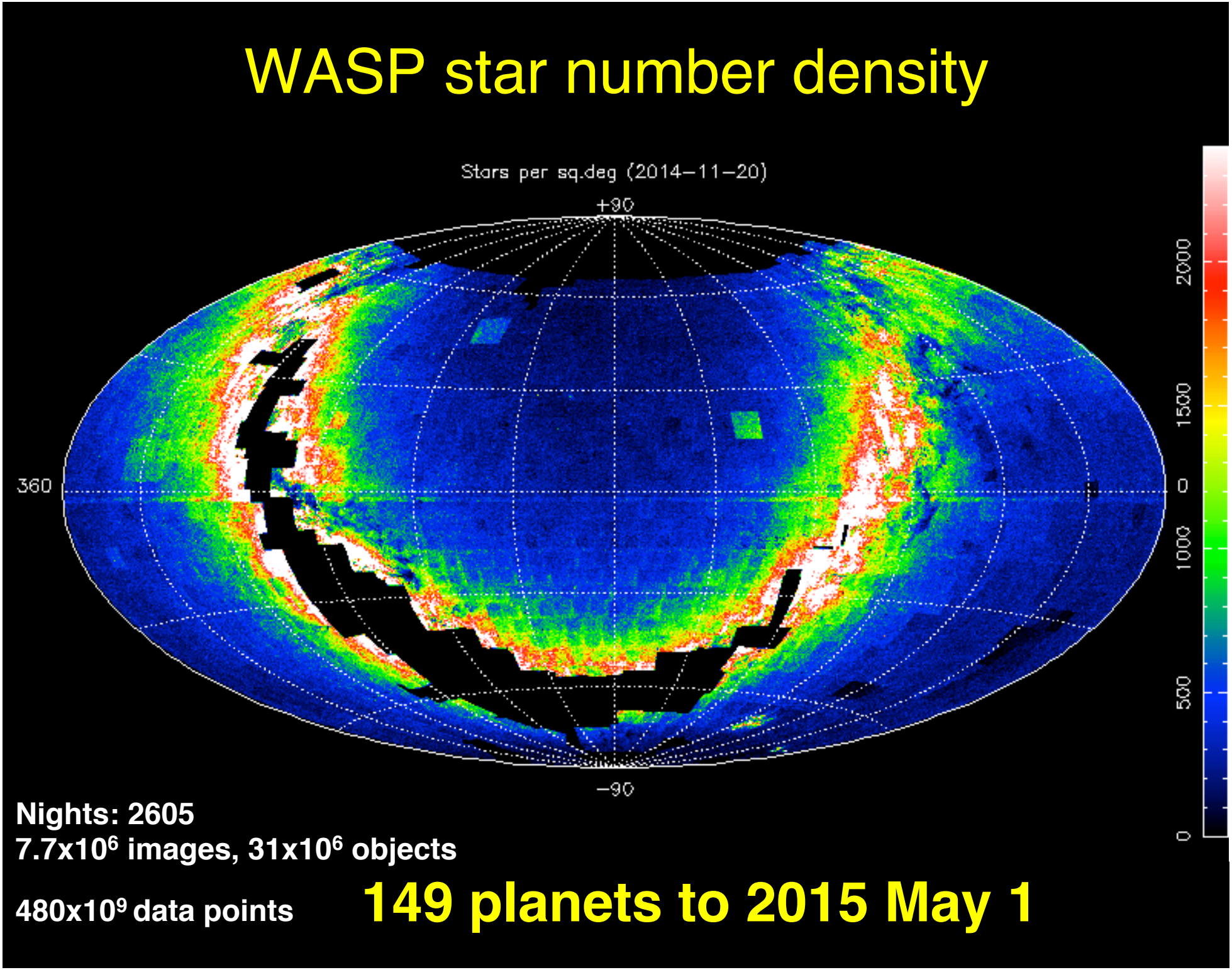
- **Magnitude limits (~30-s exposure**
  - **Bright limit V~8.5 (saturation)**
  - **Faint limit V~13 (photon noise)**
- **Raster pattern:**
  - **8 fields observed every 10 minutes**

WASP All-Sky Survey



- **Typically ~ 5000 obs over 120N per season per field**

WASP star number density

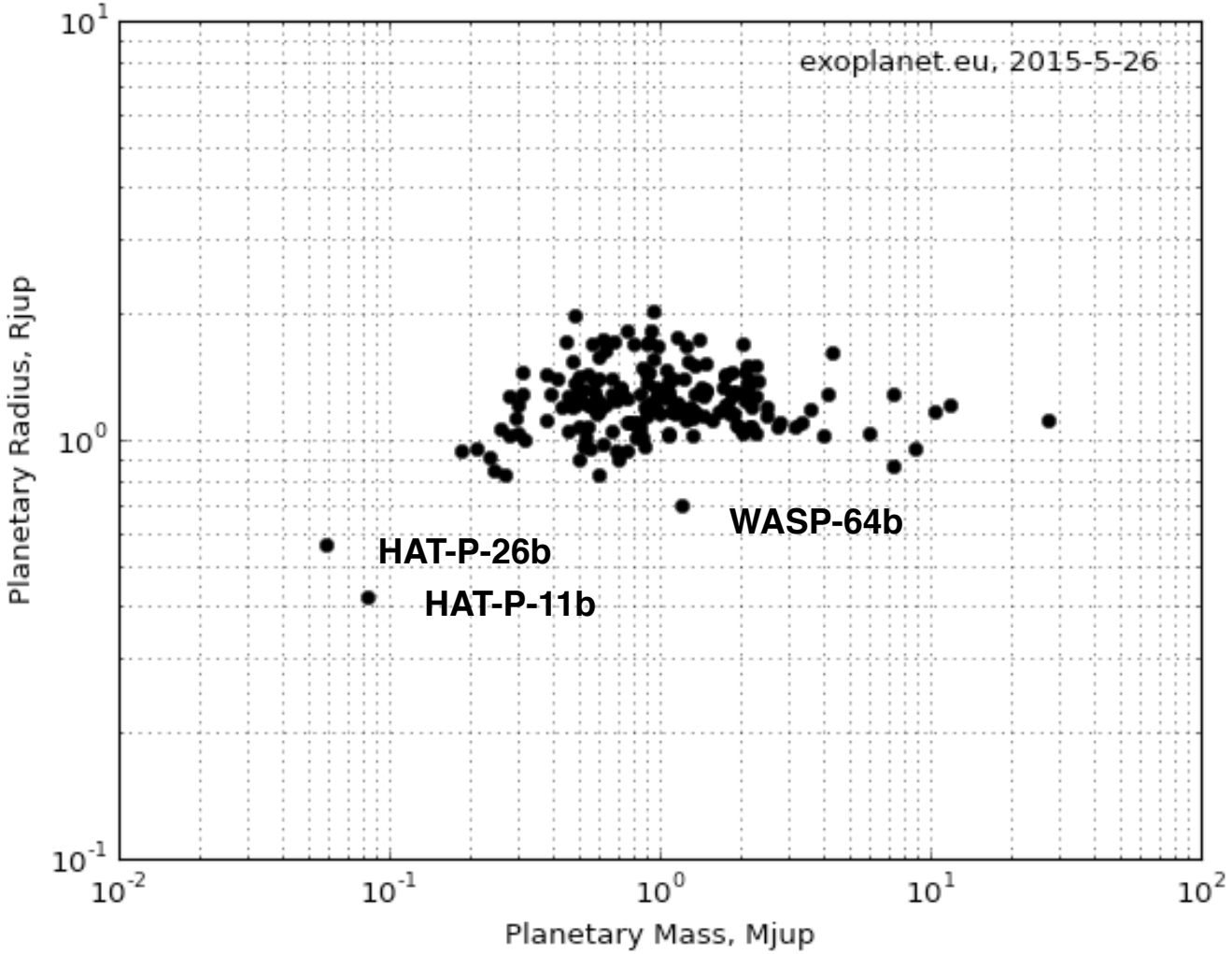


Nights: 2605
7.7x10^6 images, 31x10^6 objects

480x10^9 data points

149 planets to 2015 May 1

Mass-radius diagram: ground-based



Space-based transit surveys

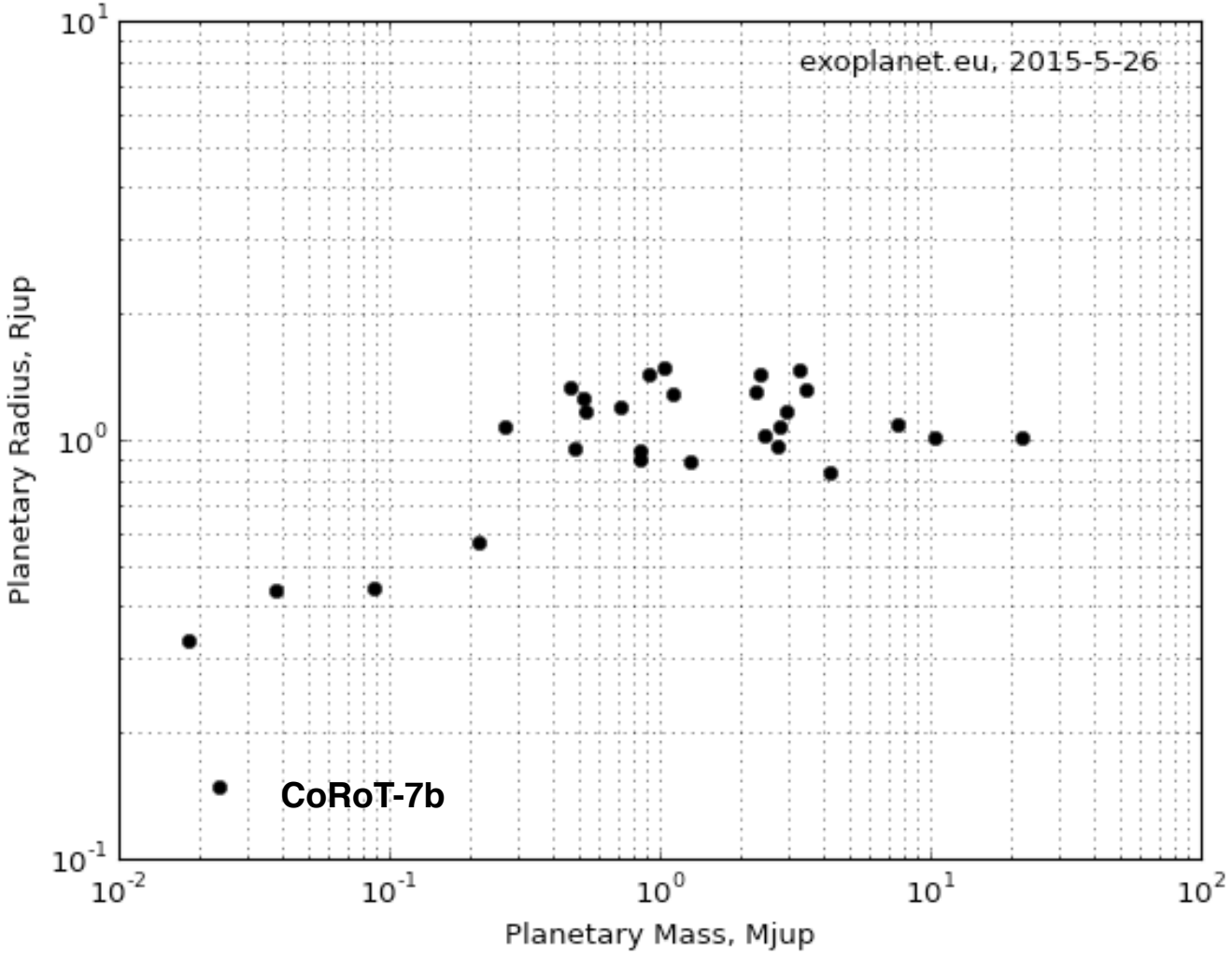
- **Earth-sized planets have radii ~10x smaller than Jupiters:**

$$\left(\frac{R_{\text{Earth}}}{R_{\text{Sun}}}\right)^2 \approx 8 \times 10^{-5}$$

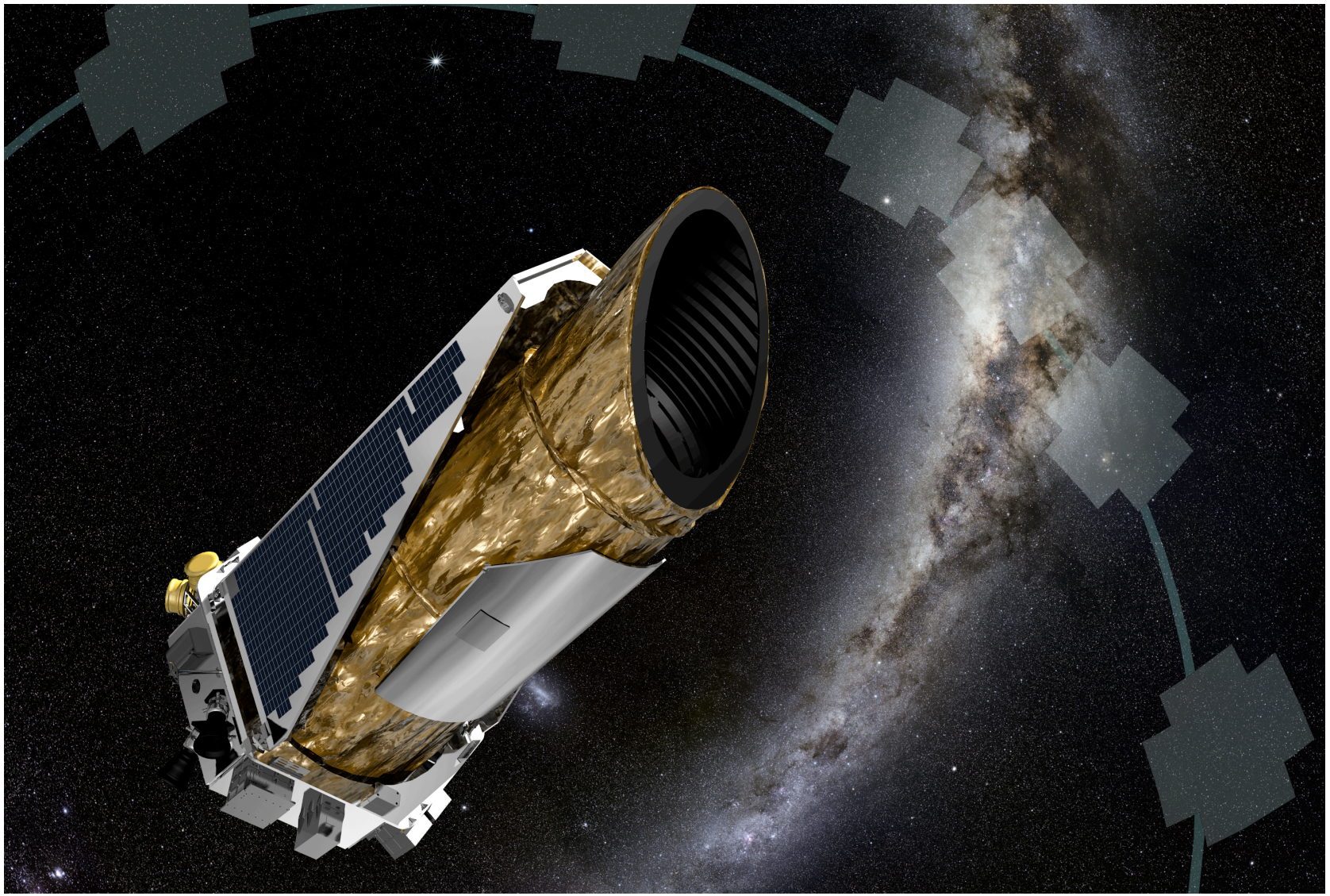
- **Photometric precision of order 10^{-5} can be achieved from space:**
- **Exoplanet survey missions:**
  - **CoRoT – 2006-2013**
  - **Kepler – 2009-2013**
  - **K2 – 2014-present**
  - **TESS – 2017 Launch**
  - **PLATO-2 – 2024 launch**
- **Pointed Exoplanet followup missions:**
  - **MOST – 2006-2013**
  - **CHEOPS – 2018 Launch**

Transits from space

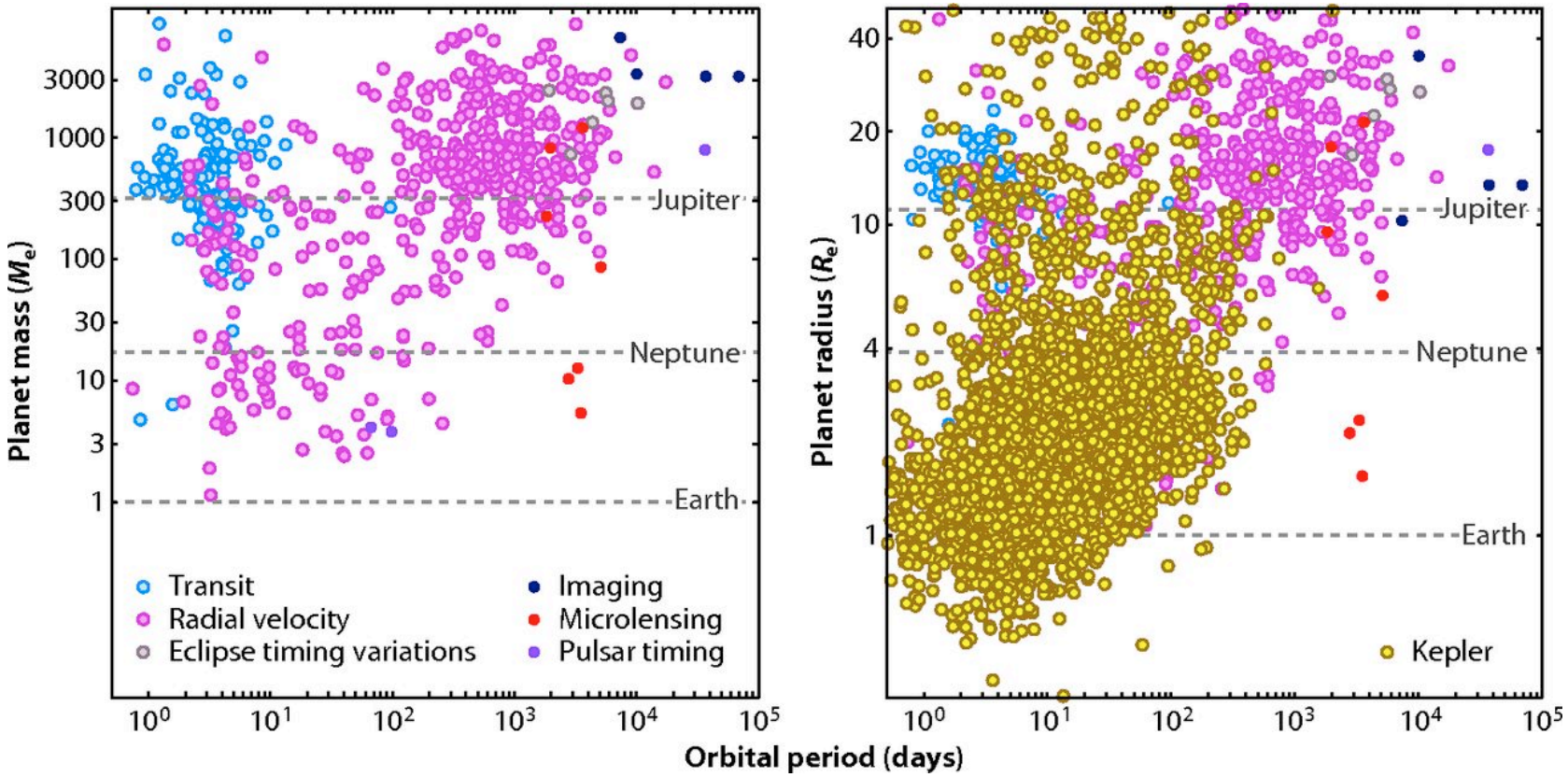
CoRoT mass-radius diagram



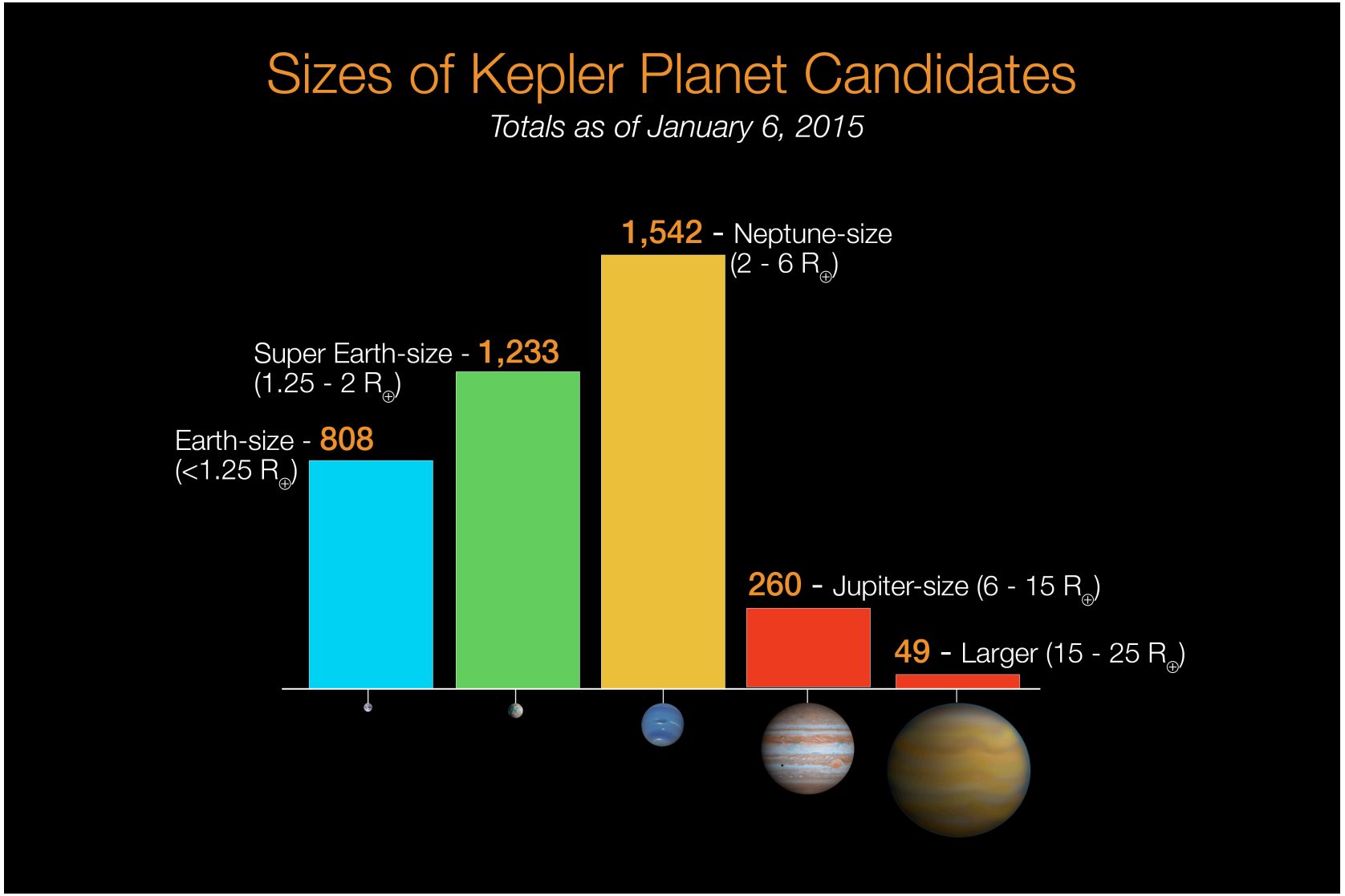
Kepler and K2



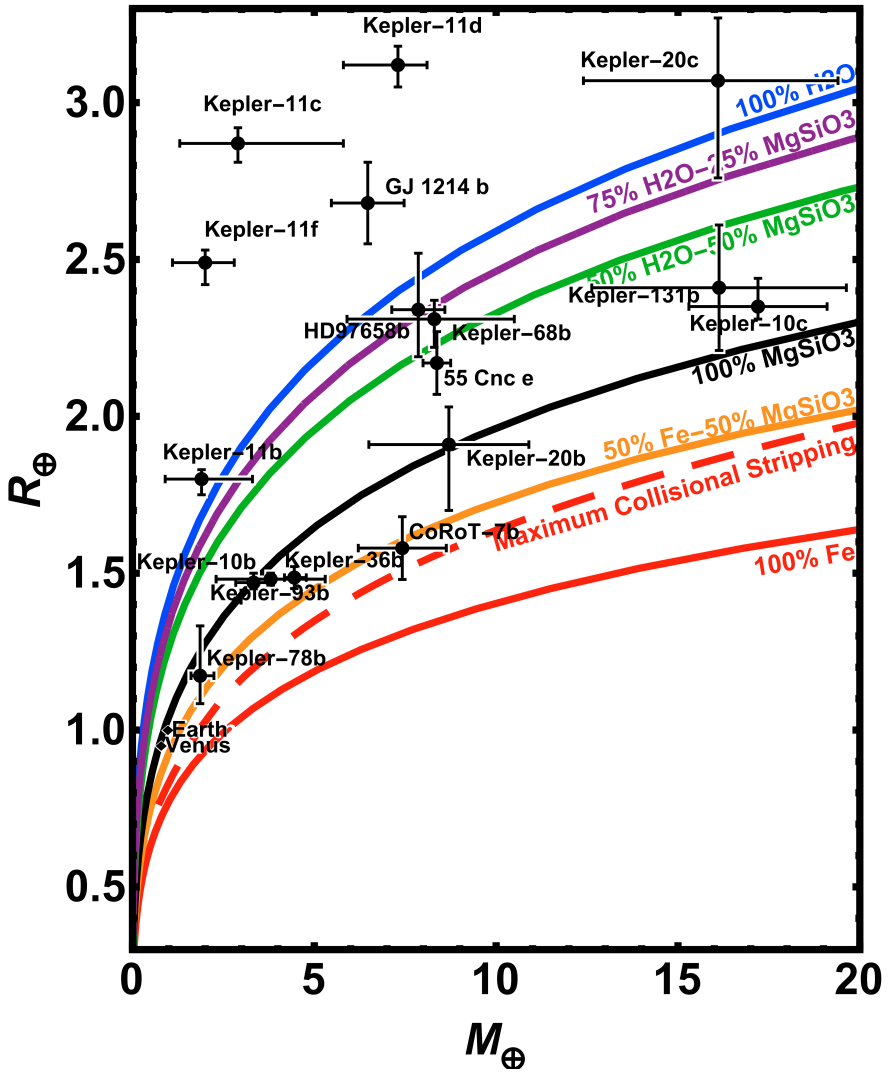
Mass, radius, orbital separation



Many small planets, few big ones

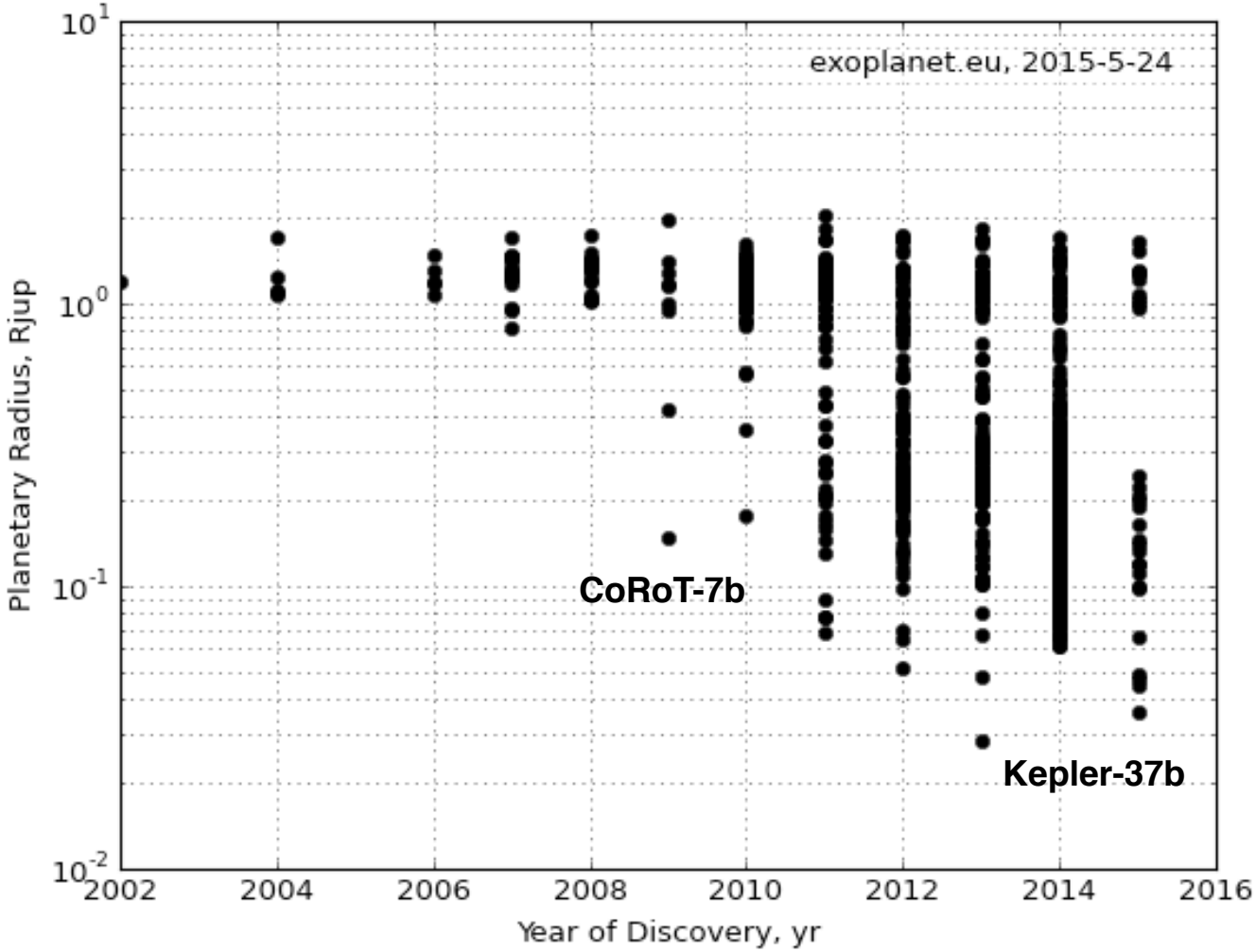


Super-Earths and mini-Neptunes: M-R



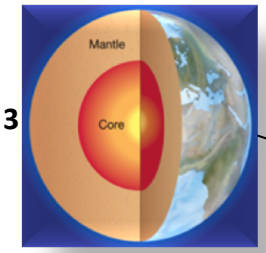
www.astrozeng.com

Radius vs year of discovery



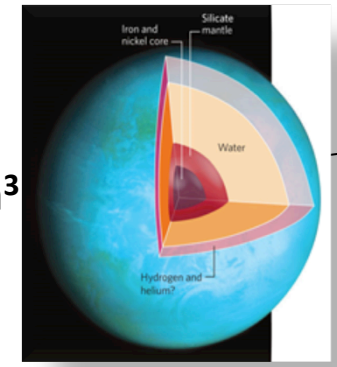
Planet diversity and planet formation

Earth



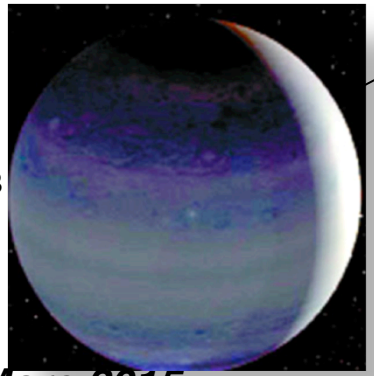
5.5 g/cm³

GJ1214b

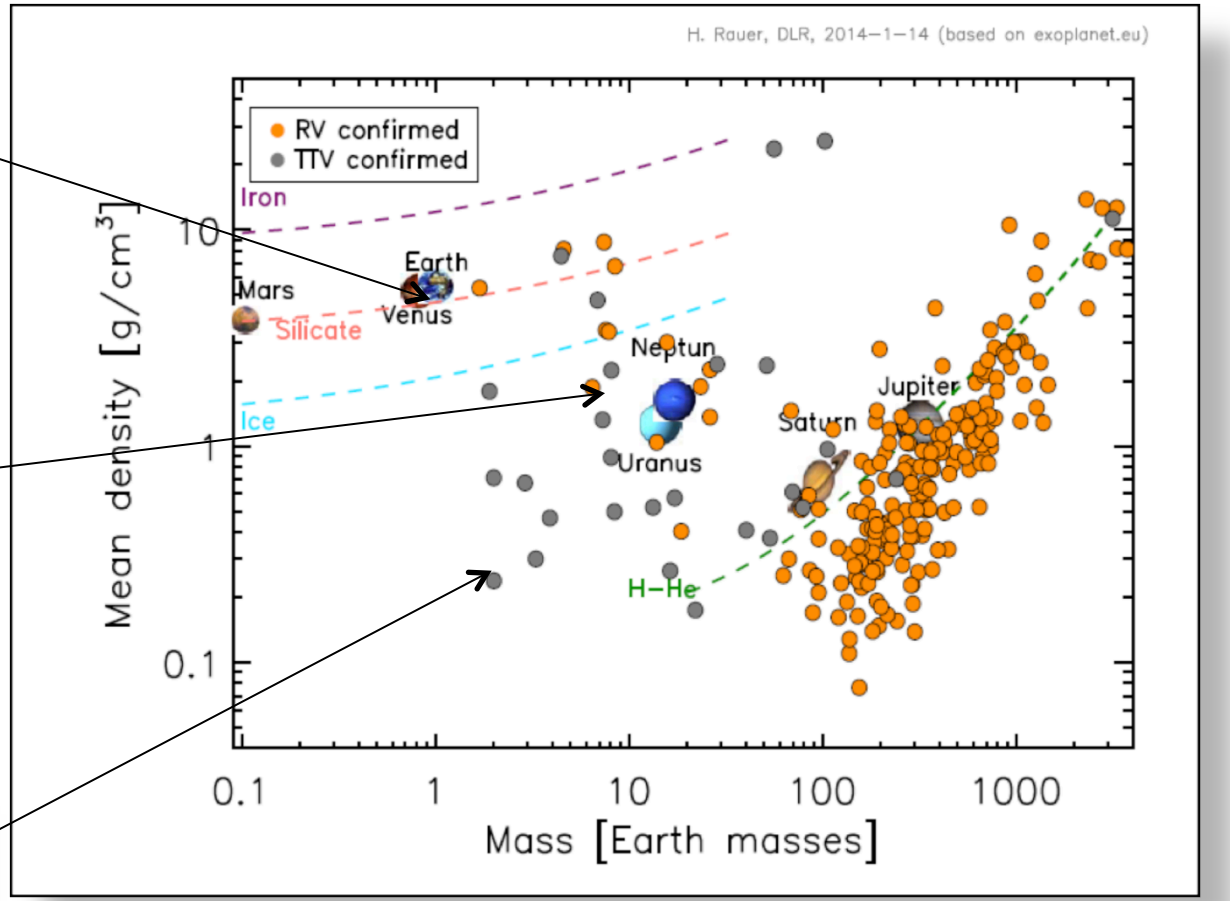


1.6 g/cm³

Mini gas planets



<~1 g/cm³

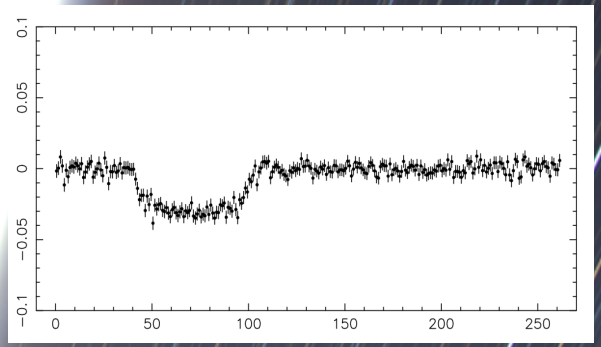


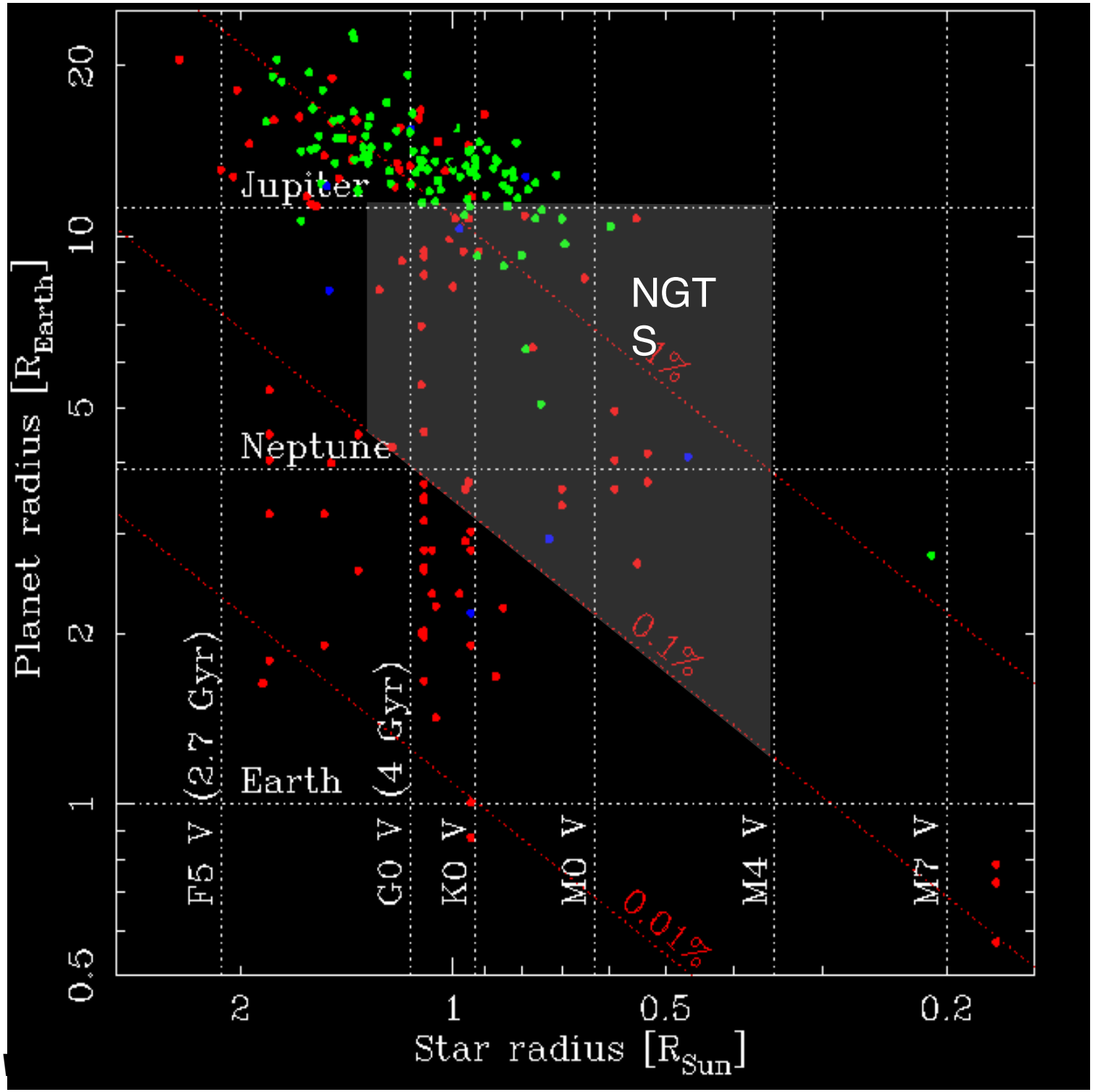
Low-mass planets have a range of compositions and interior structures for similar masses.

Future surveys

- **NGTS - ground**
- **TESS - space**
- **PLATO-2 - space**

NGTS Commissioning November 2014

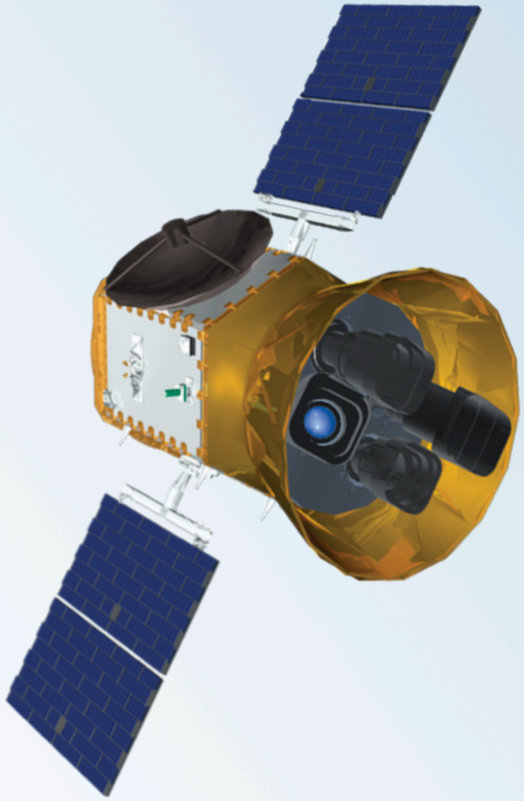




Ground-based
Space-based
Radial velocity

The Transit Method

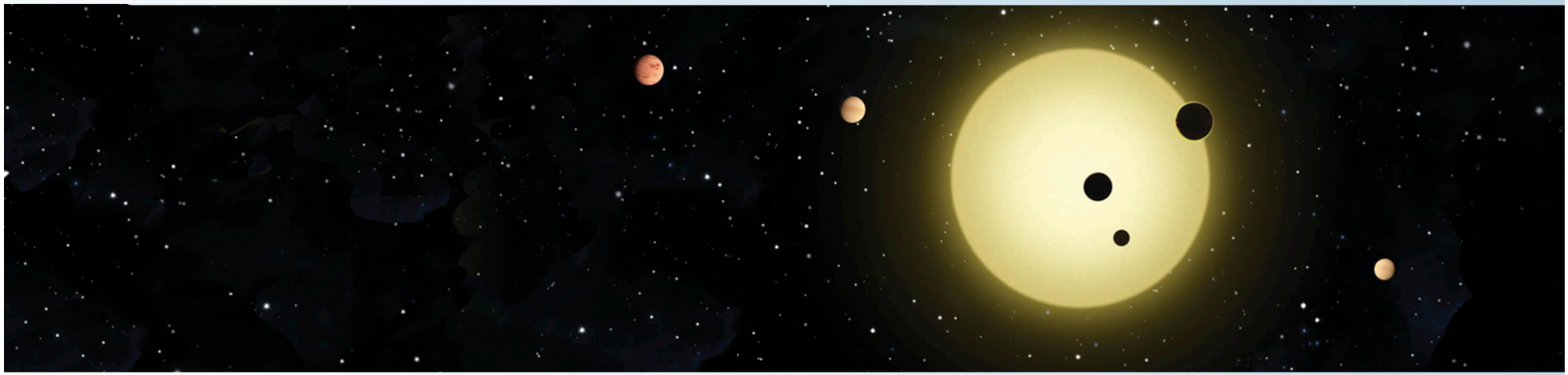
Transiting Exoplanet Survey Satellite



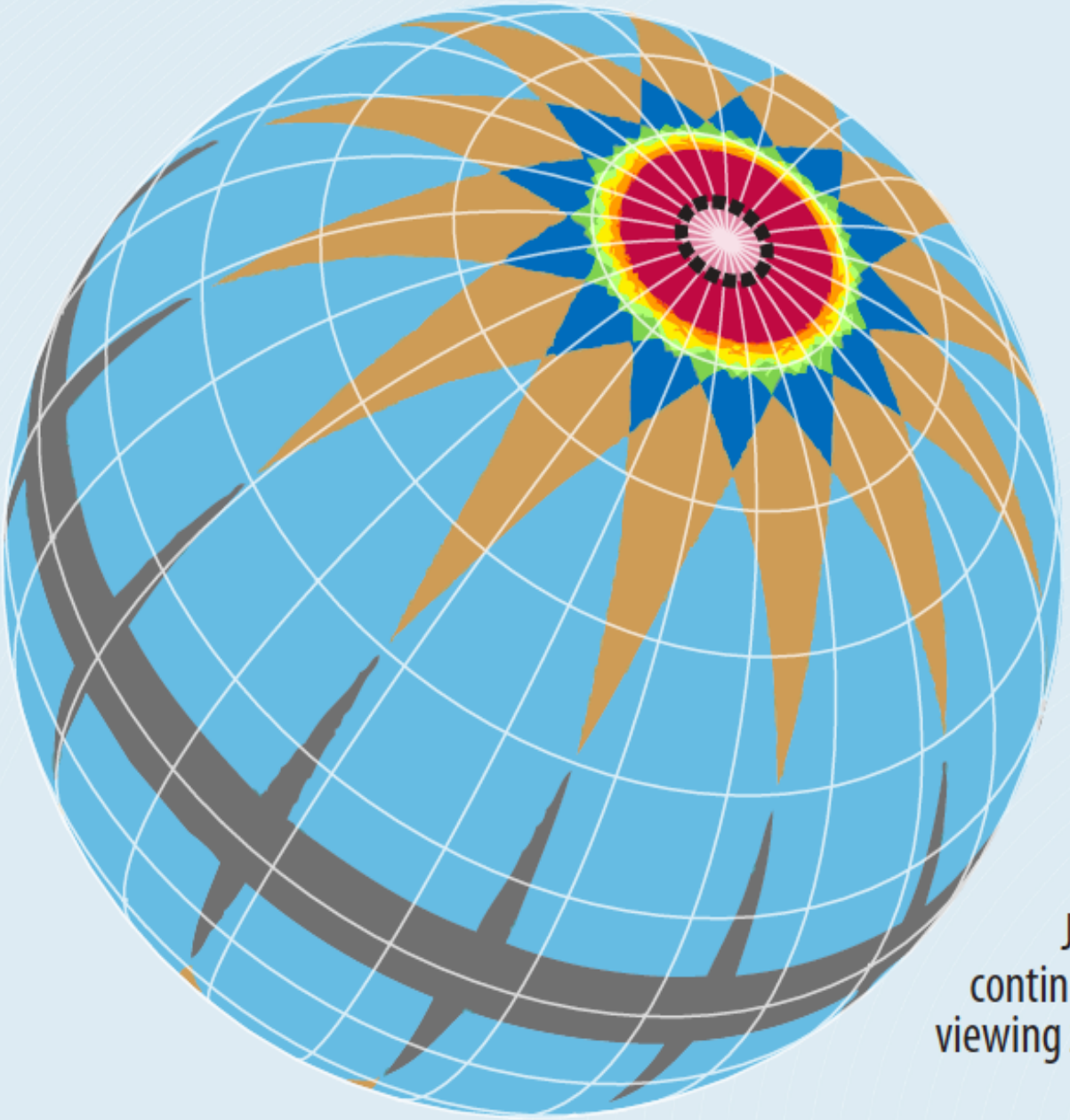
The Legacy of Kepler and the Role of TESS

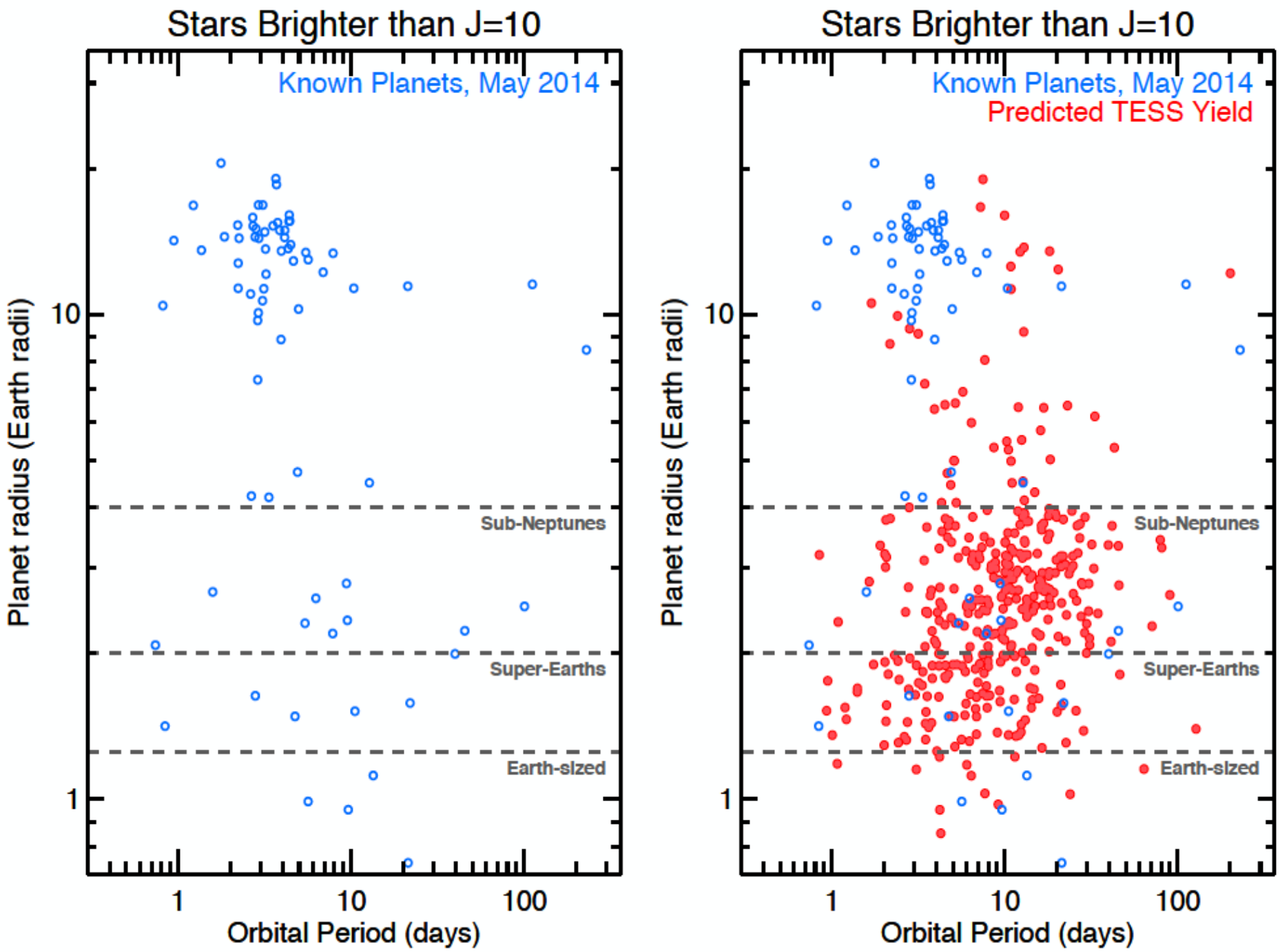
Carl Sagan Institute Inauguration, 8 May 2015

David W. Latham, CfA, for the TESS Team

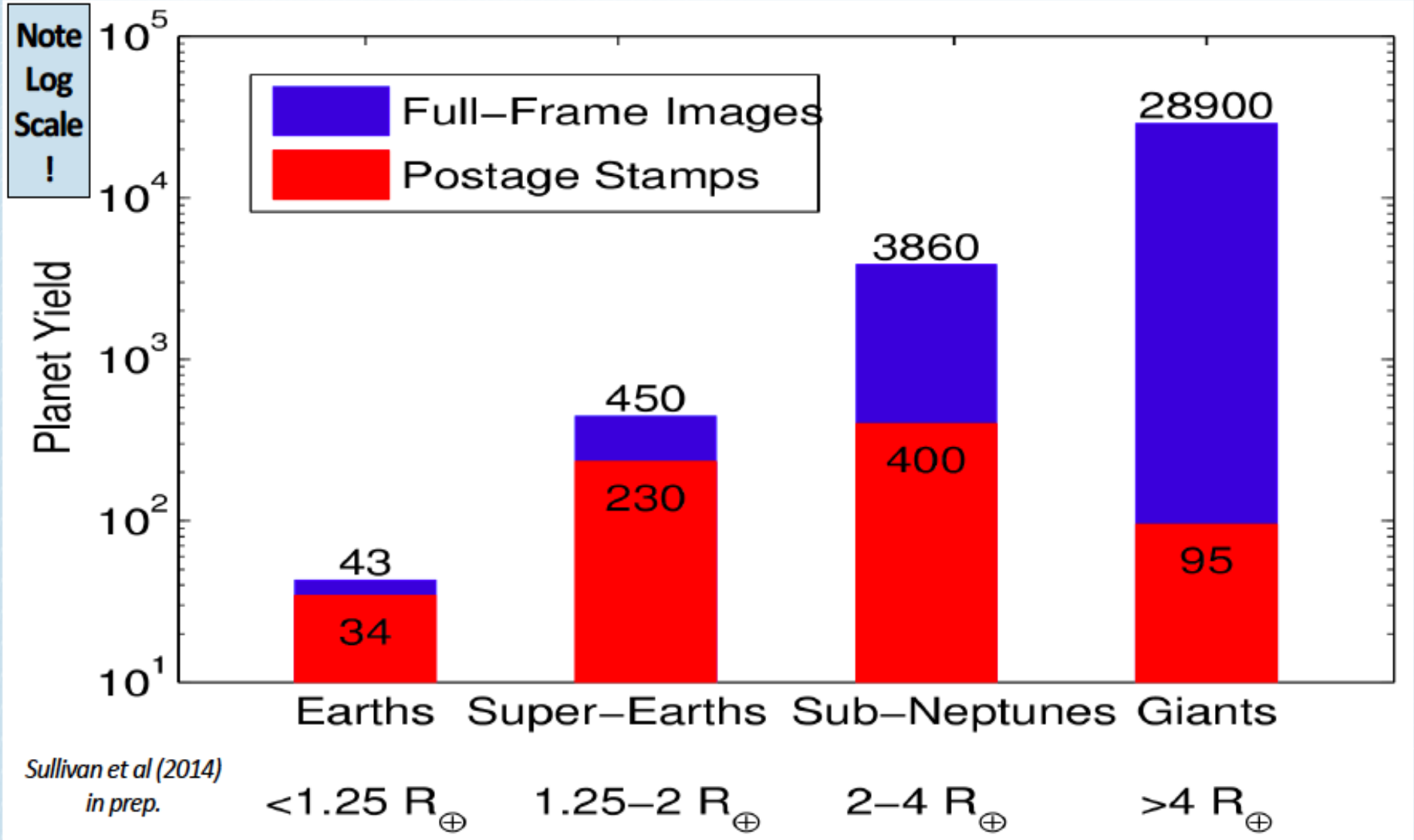


TESS 2-year Sky Coverage Map




Stars Brighter than J=10
Known Planets, May 2014
Planet radius (Earth radii)
10
1
Sub-Neptunes
Super-Earths
Earth-sized
1
10
100
Orbital Period (days)
Stars Brighter than J=10
Known Planets, May 2014
Predicted TESS Yield
Planet radius (Earth radii)
10
1
Sub-Neptunes
Super-Earths
Earth-sized
1
10
100
Orbital Period (days)

Predicted TESS Yields in Two Year Mission



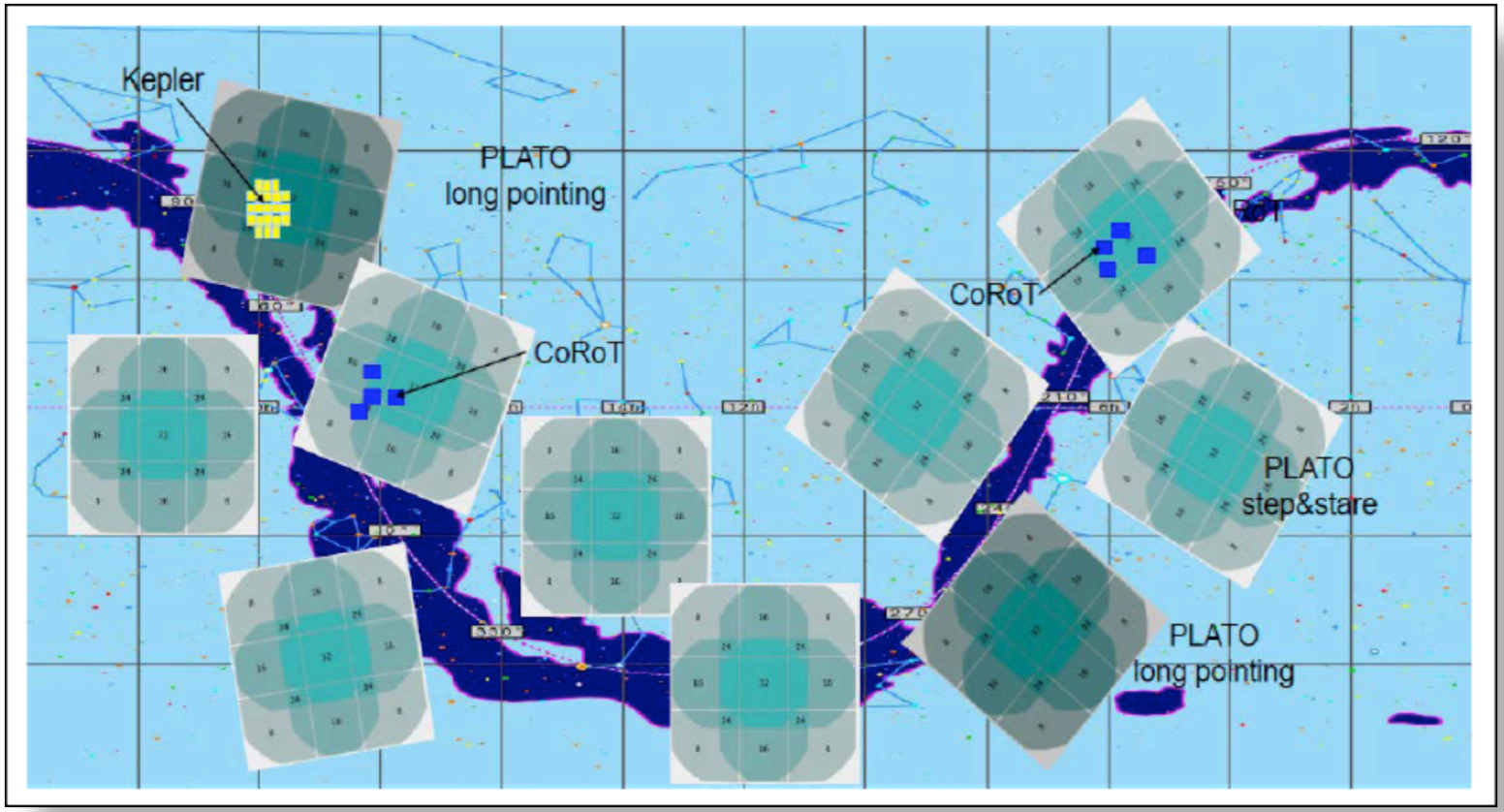
Sullivan et al (2014) in prep.

Postage Stamp yield alone is projected to meet/exceed all L1 science requirements

PLATO: Baseline observing strategy

6 years nominal science operation:

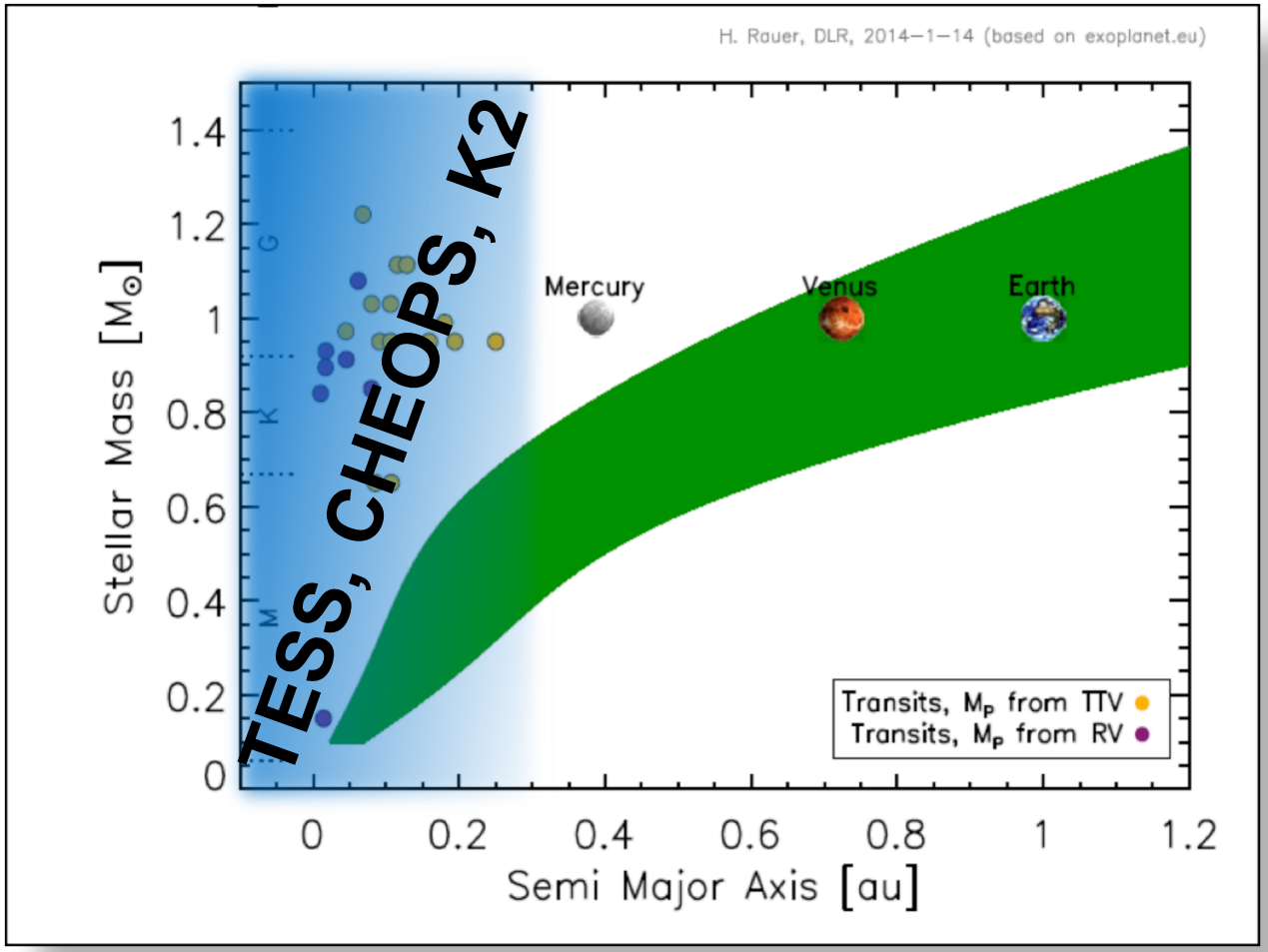
- **2 long pointings of 2-3 years**
- **step-and-stare phase (2-5 months per pointing)**



→ covers ~50% of the sky

Prospects: Characterized „super-Earths“ in their habitable zone

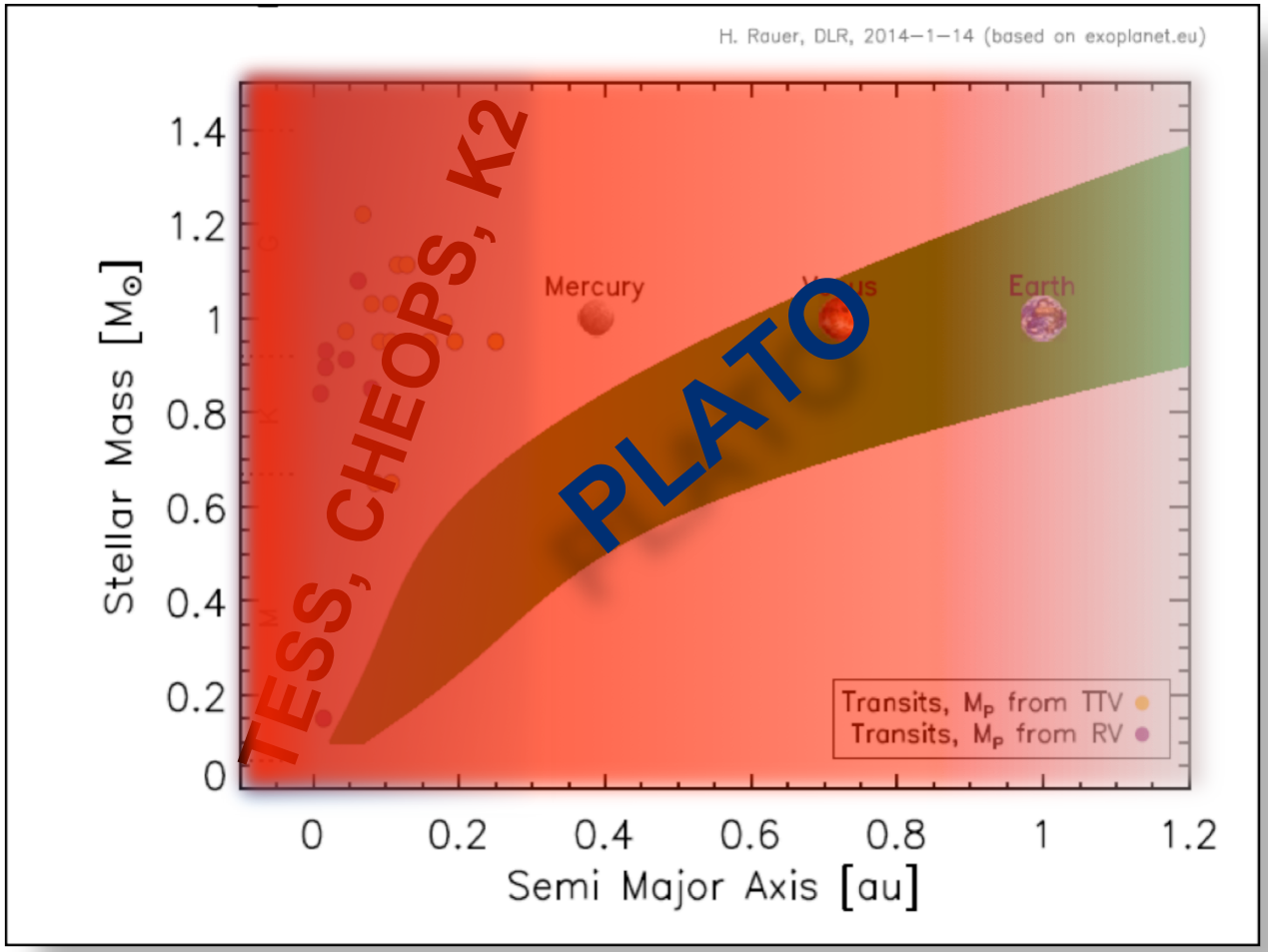
„Super-Earths“ with characterized radius and mass



- No rocky planets in the habitable zone known with certainty
- TESS, CHEOPS, K2 will cover orbital periods up to ~80 days
- In Solar-System analogues: No planets characterized outside Mercury‘s orbit without PLATO!

Prospects: Characterized „super-Earths“ in their habitable zone

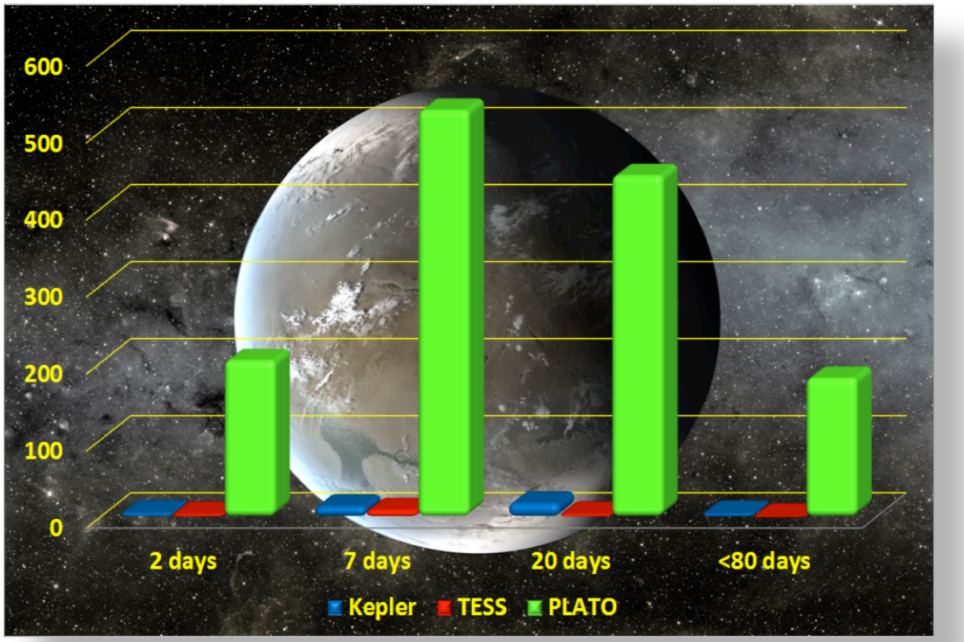
„Super-Earths“ with characterized radius and mass



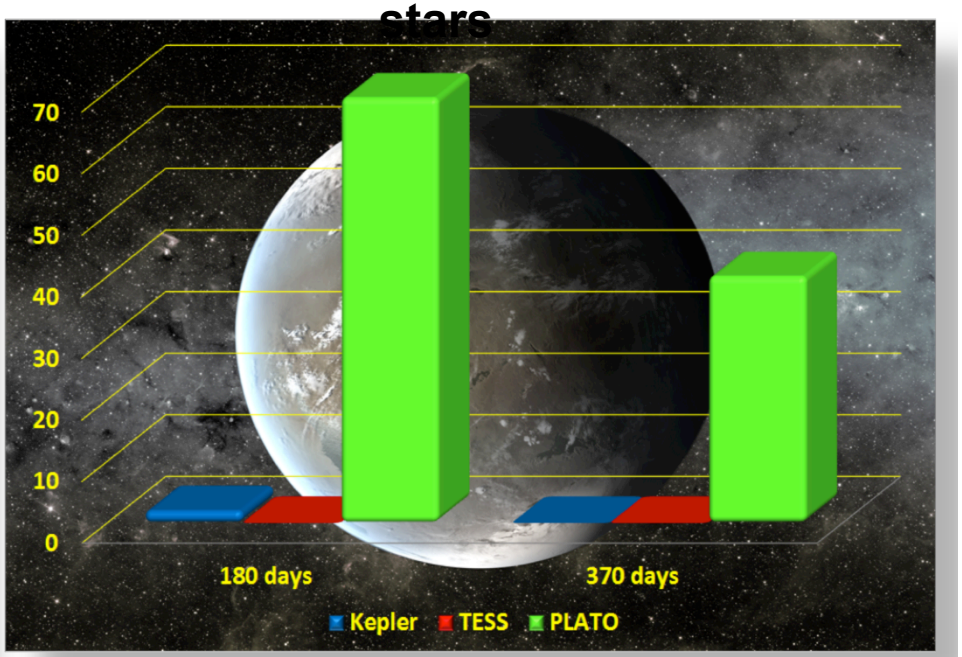
PLATO will detect and bulk characterize small planets up to the habitable zone of solar-like stars.

PLATO: Potential for characterized ‘super-Earths’

Short-period planets



Habitable zone of solar-like stars



Earth to super-Earth detections around stars bright enough for RV follow-up and asteroseismology

PLATO will provide >1000 Earths to „super-Earths“ for characterization