The Kepler/K2 Revolution and Prospects for TESS

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Jet Propulsion Laboratory

California Institute of Technology

K2/TESS Splinter Session
231st AAS meeting

National Harbor, MD

URS271451

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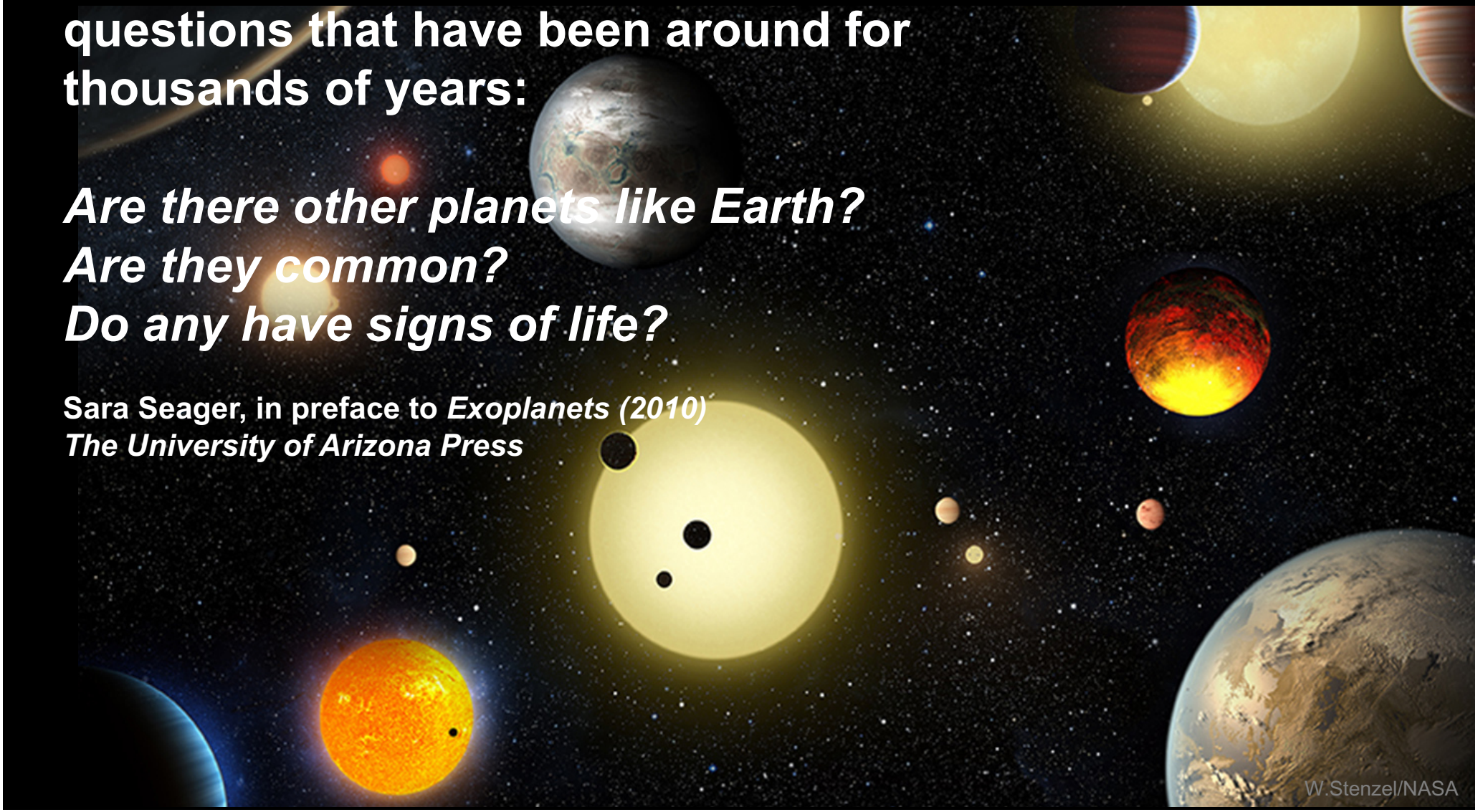
Artist concept of Kepler-16b
Credit: NASA/JPL-Caltech/T. Pyle

“This is a unique time in human history – for the first time, we are on the technological brink of being able to answer questions that have been around for thousands of years:

Are there other planets like Earth?
Are they common?
Do any have signs of life?

Sara Seager, in preface to *Exoplanets (2010)*
The University of Arizona Press



W.Stenzel/NASA

A generation of exoplanets: 30 years ago….

THE ASTROPHYSICAL JOURNAL, 331:902–921, 1988 August 15
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A SEARCH FOR SUBSTELLAR COMPANIONS TO SOLAR-TYPE STARS

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ABSTRACT

Relative radial velocities with a mean external error of 13 m s^{-1} rms have been obtained for 12 late-type dwarfs and four subgiants over the past six years. Two stars, χ^1 Ori A and γ Cep, show large (few $\times 10^3$ m s^{-1}) velocity variations probably due to stellar companions. In contrast, the remaining 14 stars are virtually constant in velocity, showing no changes larger than $\sim$50 m s^{-1}. No obvious variations due to effects other than center-of-mass motion, including changes correlated with chromospheric activity, are observed.

Seven stars show small, but statistically significant, long-term trends in the relative velocities. These cannot be due to $\sim$10–80 Jupiter mass brown dwarfs in orbits with $P \lesssim 50$ yr, since these would have been previously detected by conventional astrometry; companions of $\sim$1–9 Jupiter masses are inferred. Since relatively massive brown dwarfs are rare or nonexistent, at least as companions to normal stars, these low-mass objects could represent the tip of the planetary mass spectrum. Observations are continuing to confirm these variations, and to determine periods.

p) HR 8974 (γ Cep).—Probable third body variation of 25 m s^{-1} amplitude, 2.7 yr period, superposed on a large velocity gradient. Status of astrometric perturbations is unknown.

For γ Cep, the third body in the system has $M_c \sin i \sim 1.7 M_{♃}$. Since we have identified a period to the radial velocity variations, the lack of information on astrometric perturbations is not a concern in this case. This star therefore has the firmest evidence for a very low mass companion.

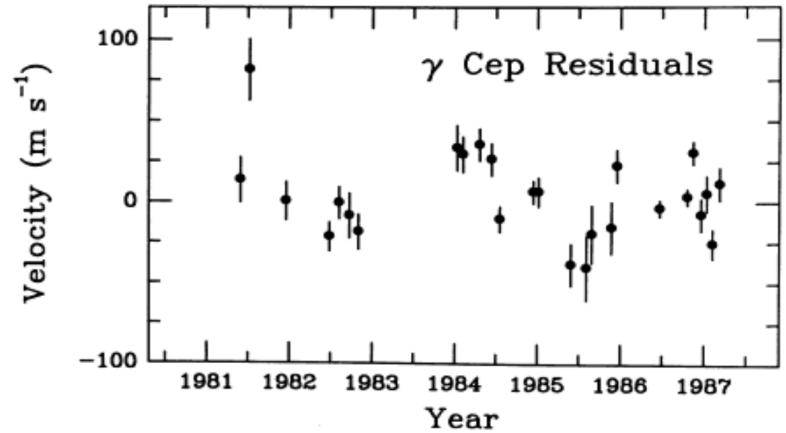
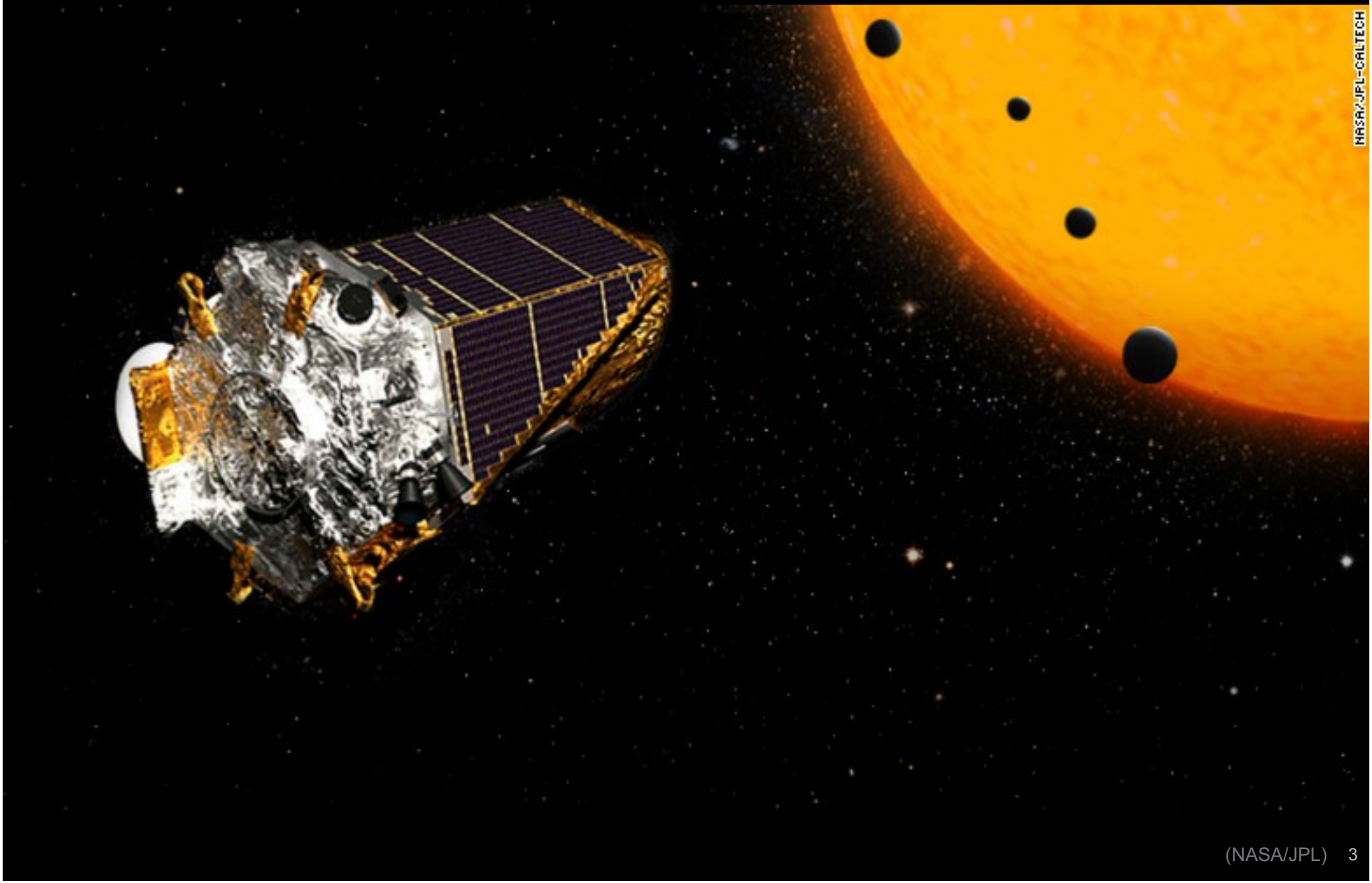


FIG. 5.—Velocity residuals for γ Cep after subtraction of a second order fit to the original velocities

Gamma Cephei Ab (Tadmor)

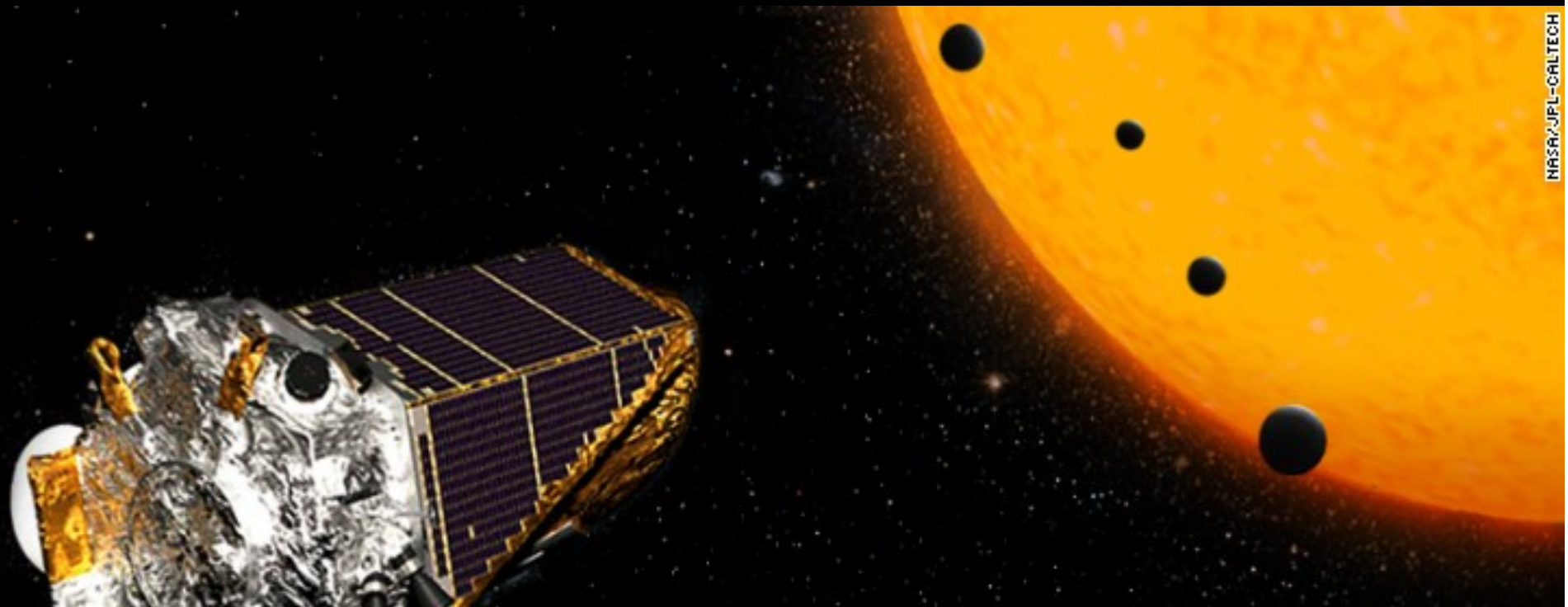
	Msini (M_{jup})	Period (days)
Campbell et al.1988	1.7	986
Endl et al. 2011	1.85 +-0.16	903.3 +-1.5

Kepler mission highlights



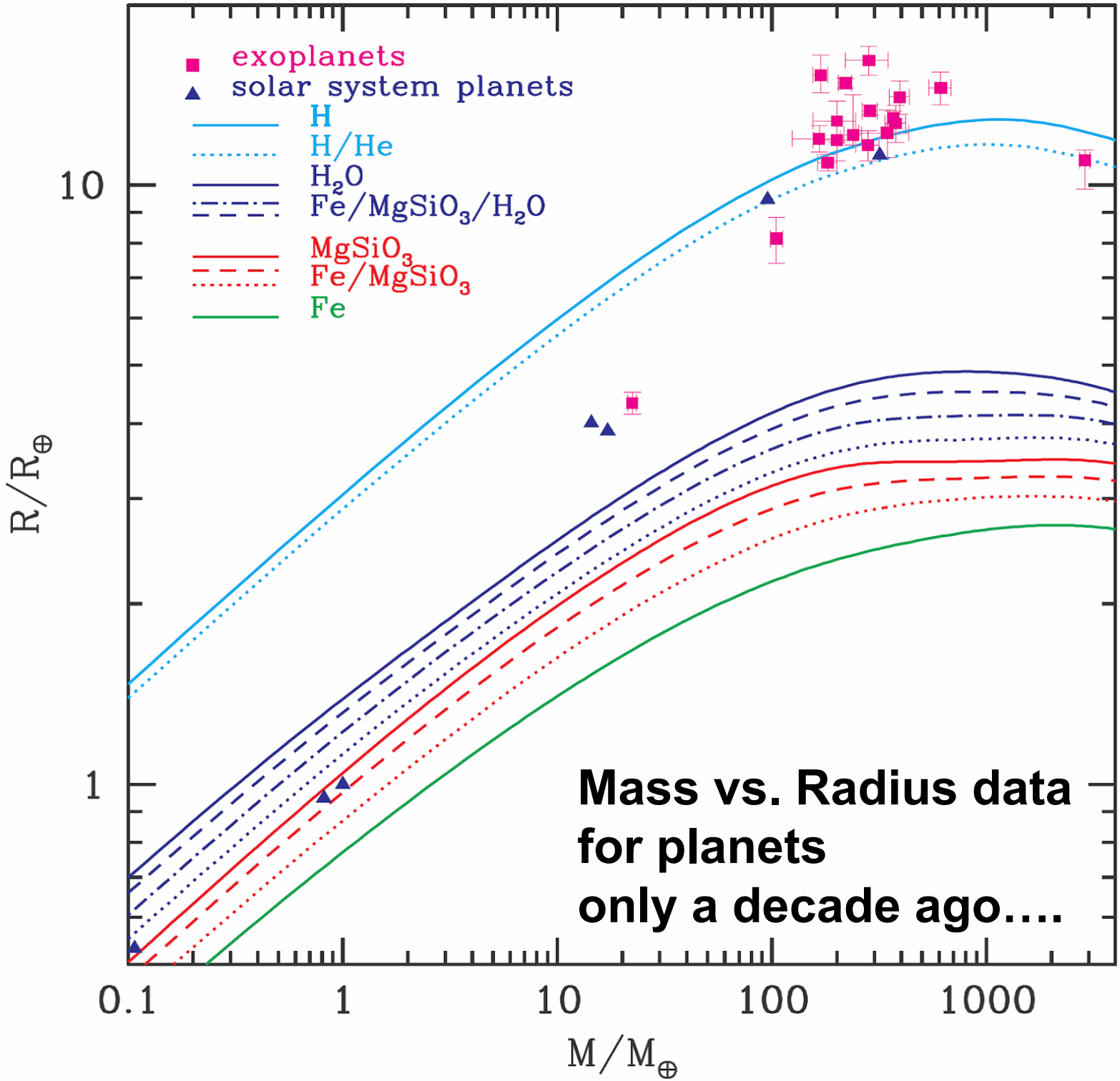
(NASA/JPL)

Kepler mission highlights



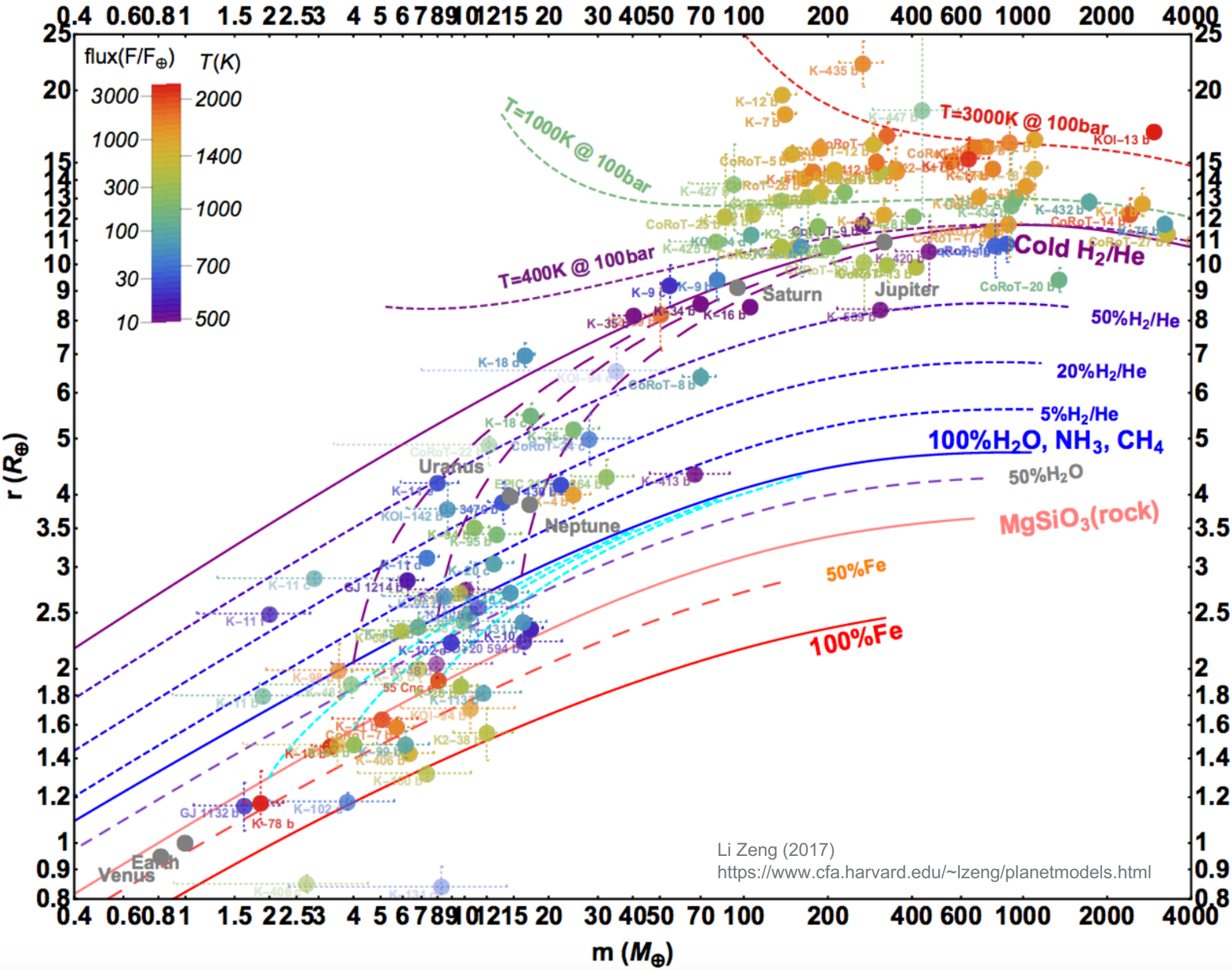
Short short list of highlights:

- Exoplanet ubiquity (frequency)
- Earth-size planets in Hab Zones
- Exoplanet variety (types)
- Stellar astrophysics
  (*know thy star, know thy planet*)

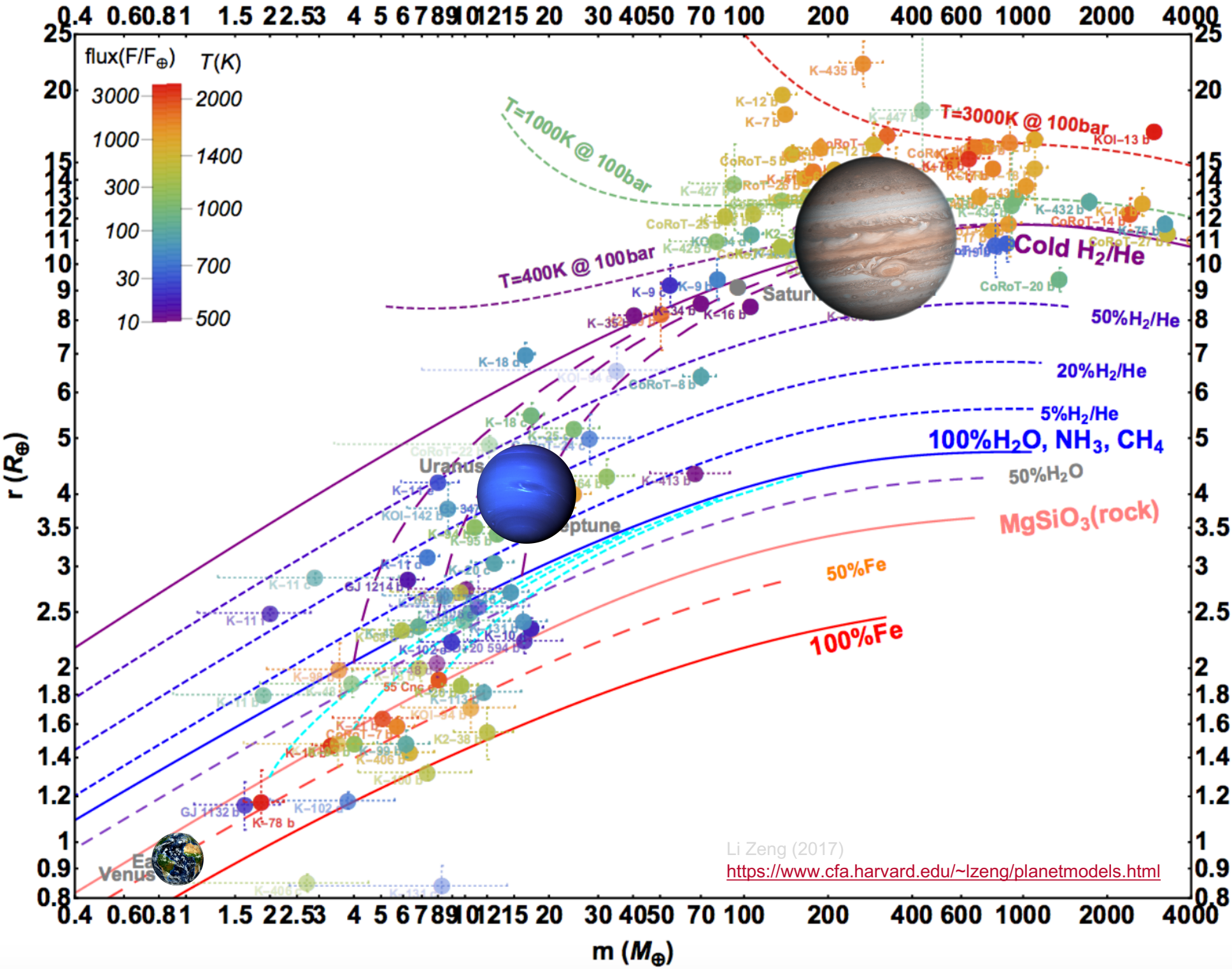


Mass vs. Radius data for planets only a decade ago….

Seager+ 2007 ApJ 699, 1279



Li Zeng (2017)
https://www.cfa.harvard.edu/~lzeng/planetmodels.html



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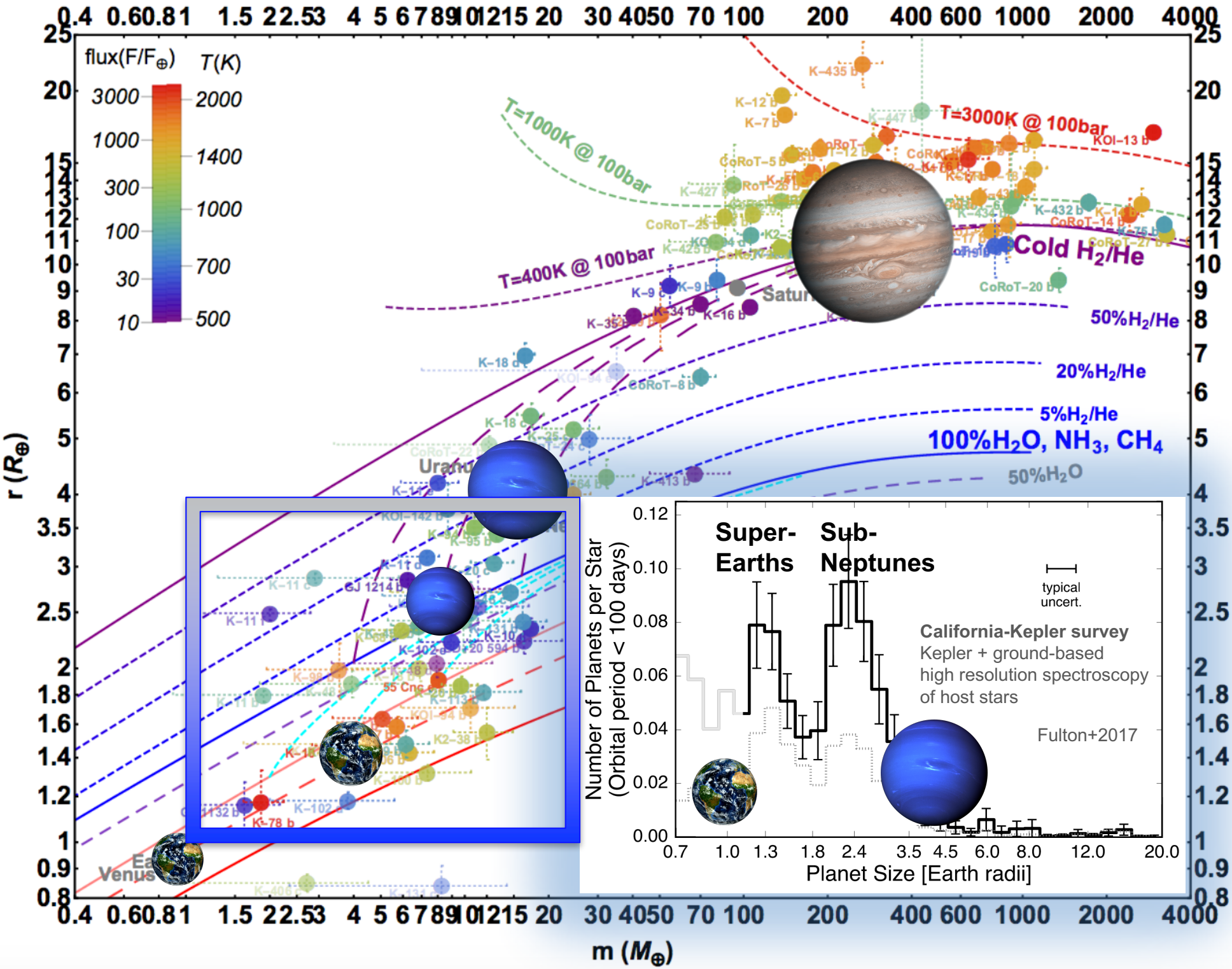

flux(F/F⊕)
T(K)
3000
1000
300
100
30
10
2000
1400
1000
700
500
T=1000K @ 100bar
T=3000K @ 100bar
T=400K @ 100bar
Cold H2/He
50%H2/He
20%H2/He
5%H2/He
100%H2O, NH3, CH4
50%H2O
Saturn
Uranus
Venus
r (R⊕)
m (M⊕)
Super-Earths
Sub-Neptunes
typical uncert.
California-Kepler survey
Kepler + ground-based high resolution spectroscopy of host stars
Fulton+2017
Number of Planets per Star (Orbital period < 100 days)
Planet Size [Earth radii]

NN·EXPLORE

Partnership for Exoplanet Discovery and Characterization

- Extreme precision radial velocity spectrometer (<0.5 m/s) for WIYN telescope
- Passed Instrument and Port Adapter Detailed Design Reviews, on track for commissioning by August 2019
- Ongoing Guest Observer program using 40% NOAO share of telescope time for exoplanet research with *existing* instruments. Proposals due in late March & September.
- **Advertisement**: splinter session "Ground-based support for NASA Exoplanet missions" on Thursday 2pm splinter (Nat'l Harbor 7) including talks on NN-Explore (John Callas), Exoplanet Follow-up program (Rachel Akeson), NASA Keck update (Dawn Gelino), NASA IRTF update (John Rayner), LBTI exo-zodi survey update (Phil Hinz)

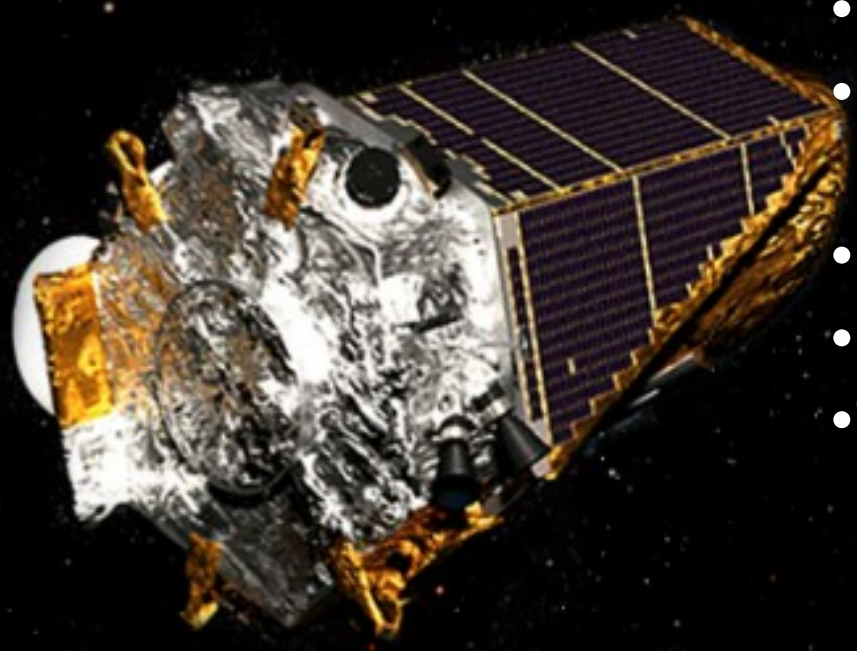
NN-Explore Exoplanet Investigations with Doppler Spectroscopy

PennState

PI: S. Mahadevan

NOAO 3.5-m WIYN Telescope, Kitt Peak National Observatory, Arizona

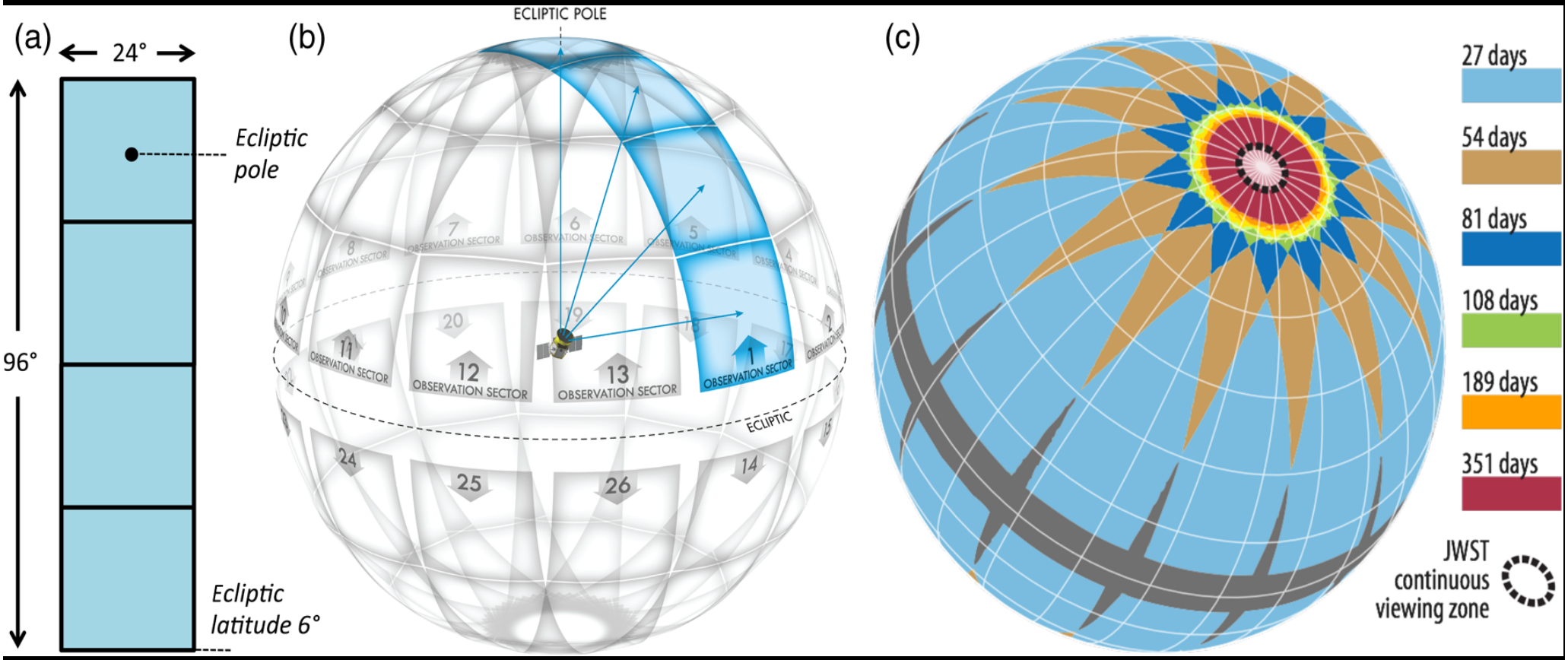
K2 mission highlights



Short short list of highlights:

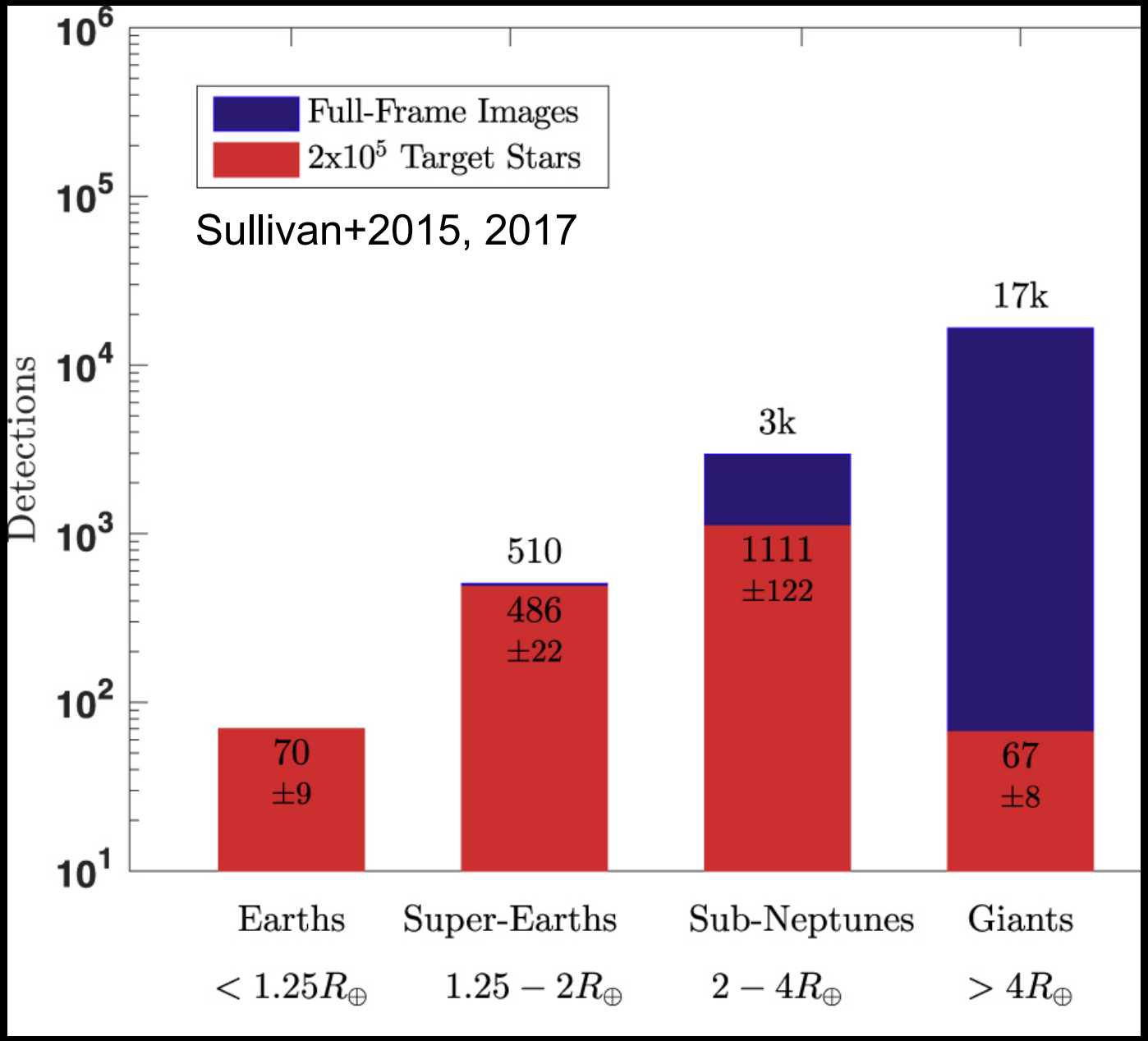
- TRAPPIST-1 !
- Nearby bright, transiting multi-planet systems
- New (young) planets in clusters
- Dead (disintegrating) planets
- More stellar astrophysics (*know thy star even better, know thy planet even better*)
- Bulge microlensing campaign
- Supernovae/cosmology!

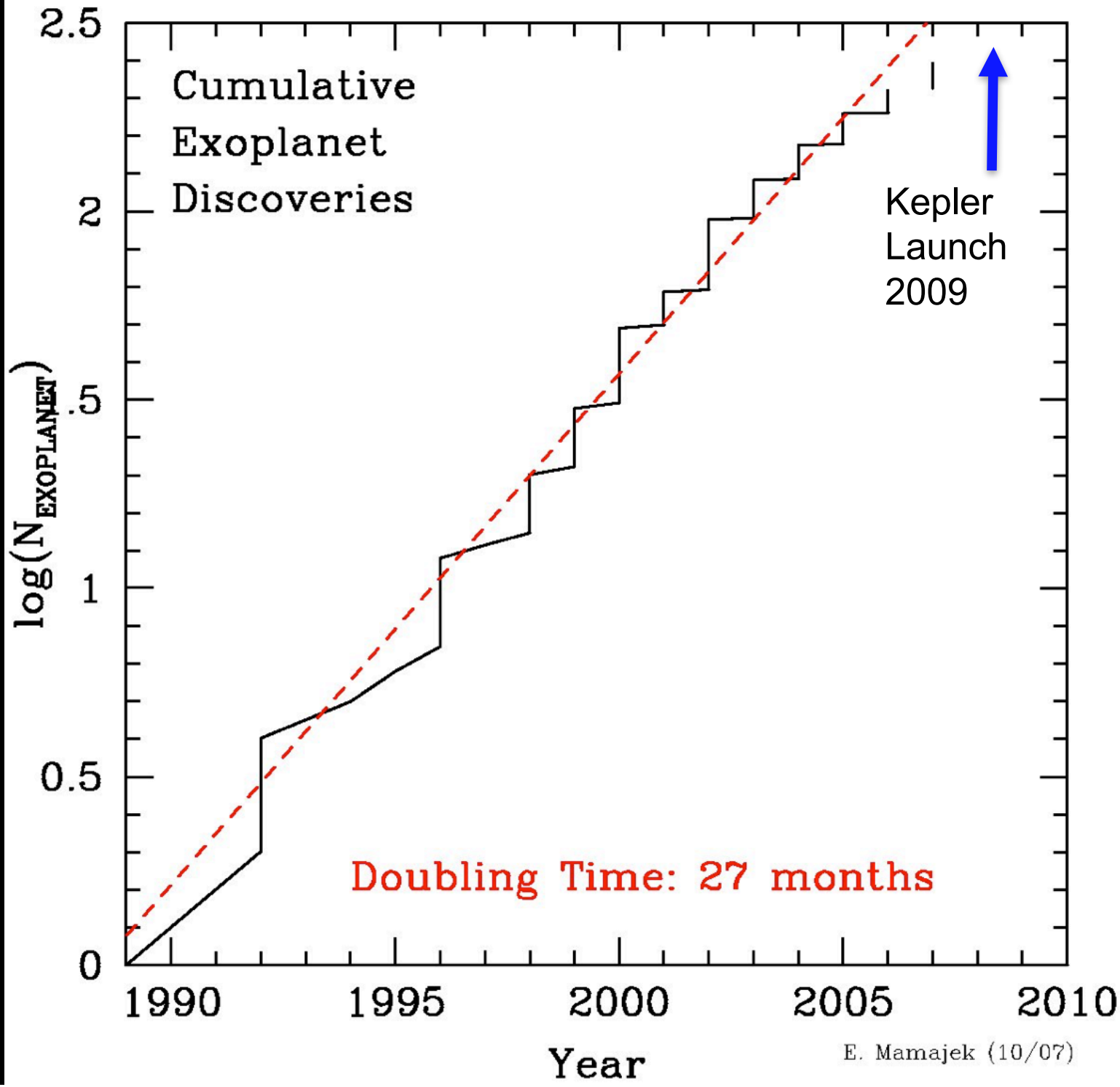
Overheard at Ages of Stars^2 meeting in September:
"*the best thing to ever happen to Kepler was K2*!"

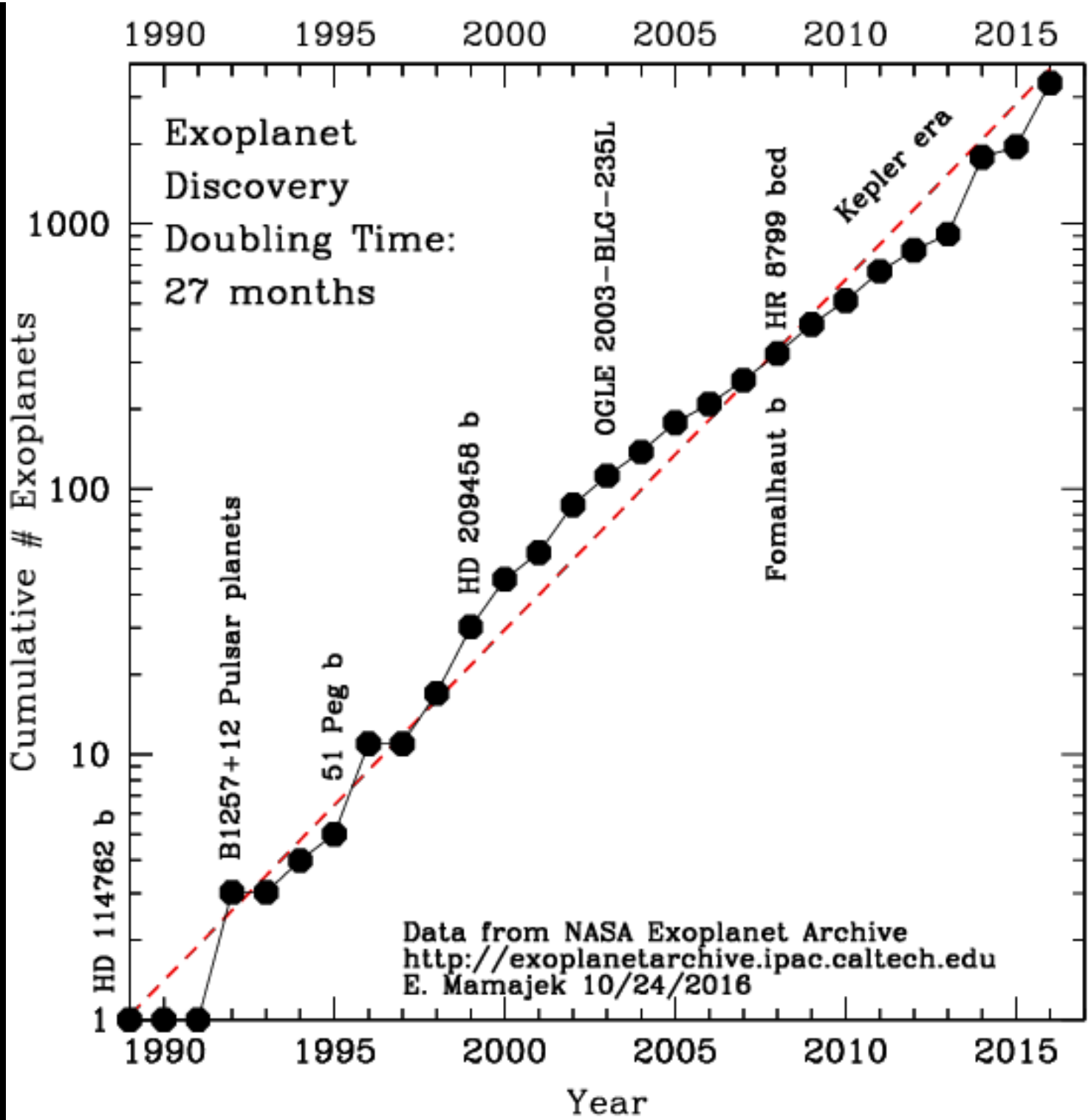


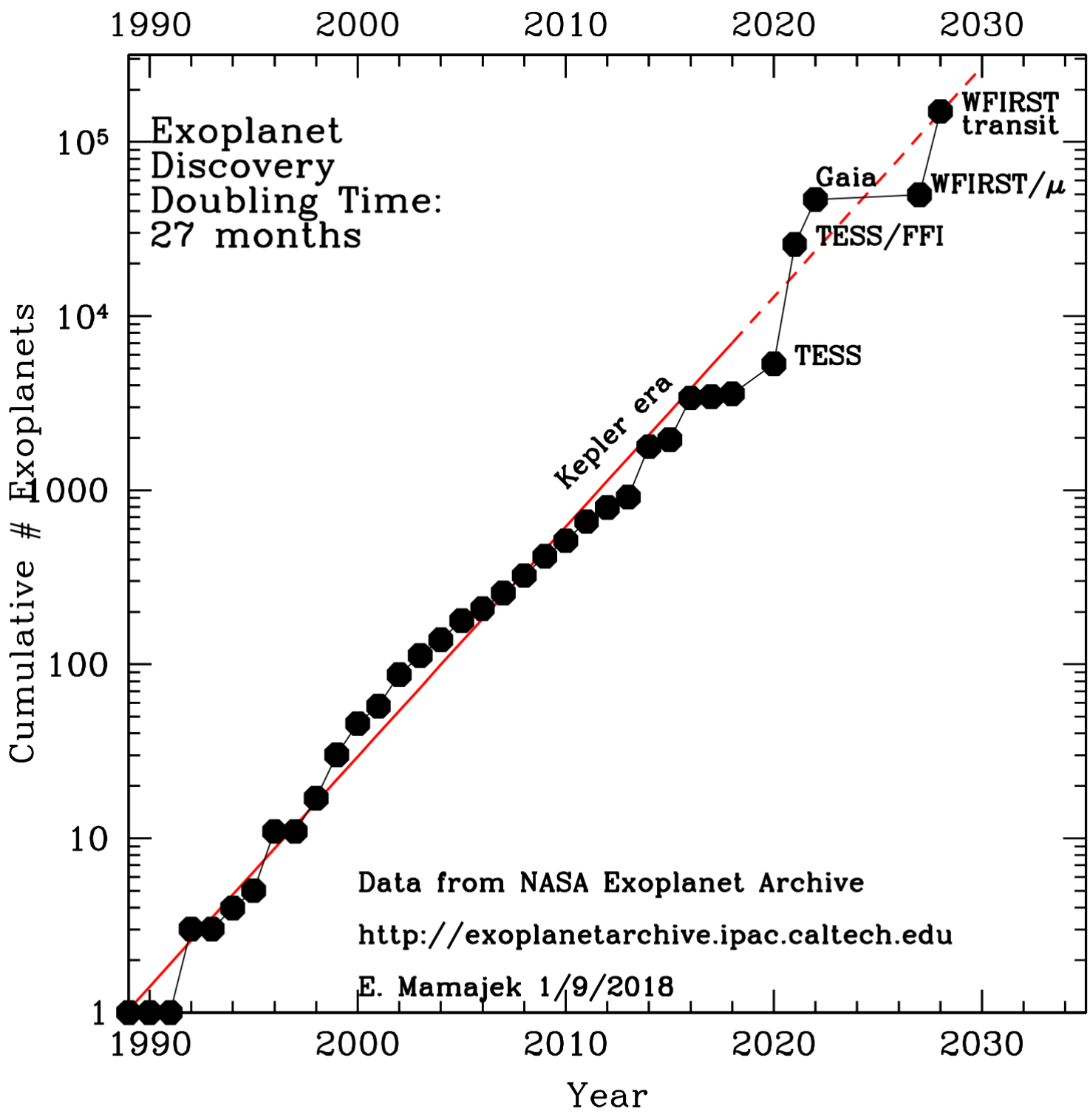
Ricker et al. 2014

TESS exoplanet yields




Cumulative
Exoplanet
Discoveries
Kepler
Launch
2009
Doubling Time: 27 months
log(N_EXOPLANET)
2.5
2
1.5
1
0.5
0
1990
1995
2000
2005
2010
Year
E. Mamajek (10/07)

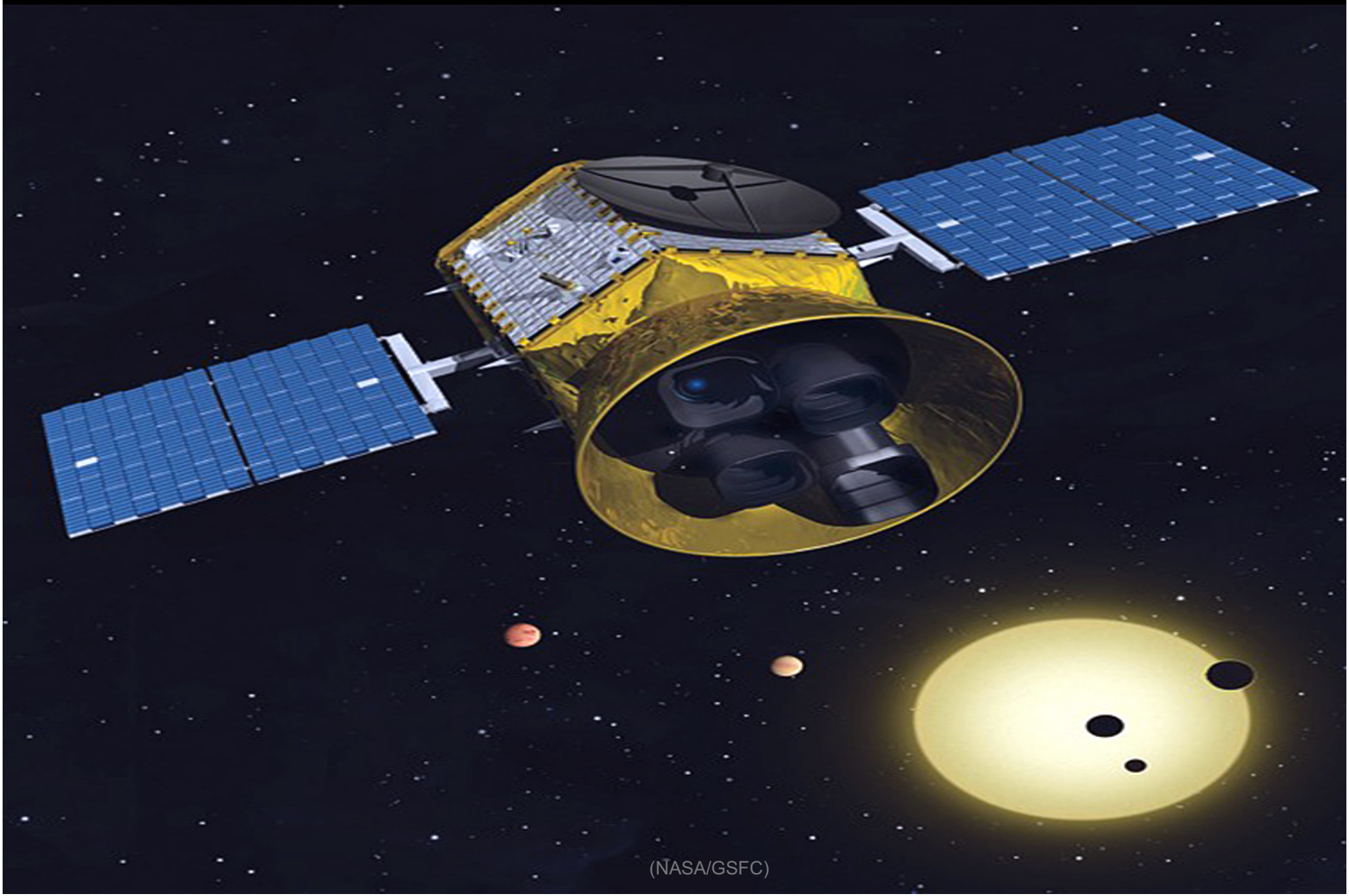

Exoplanet
Discovery
Doubling Time:
27 months
HD 114762 b
B1257+12 Pulsar planets
51 Peg b
HD 209458 b
OGLE 2003-BLG-235L
Fomalhaut b
HR 8799 bcd
Kepler era
Data from NASA Exoplanet Archive
http://exoplanetarchive.ipac.caltech.edu
E. Mamajek 10/24/2016
Cumulative # Exoplanets
1
10
100
1000
1990
1995
2000
2005
2010
2015
Year


Exoplanet
Discovery
Doubling Time:
27 months
Kepler era
TESS
TESS/FFI
Gaia
WFIRST/μ
WFIRST
transit
Data from NASA Exoplanet Archive
http://exoplanetarchive.ipac.caltech.edu
E. Mamajek 1/9/2018
Cumulative # Exoplanets
Year
1
10
100
1000
10⁴
10⁵
1990
2000
2010
2020
2030

TESS

(NASA/GSFC)

TESS



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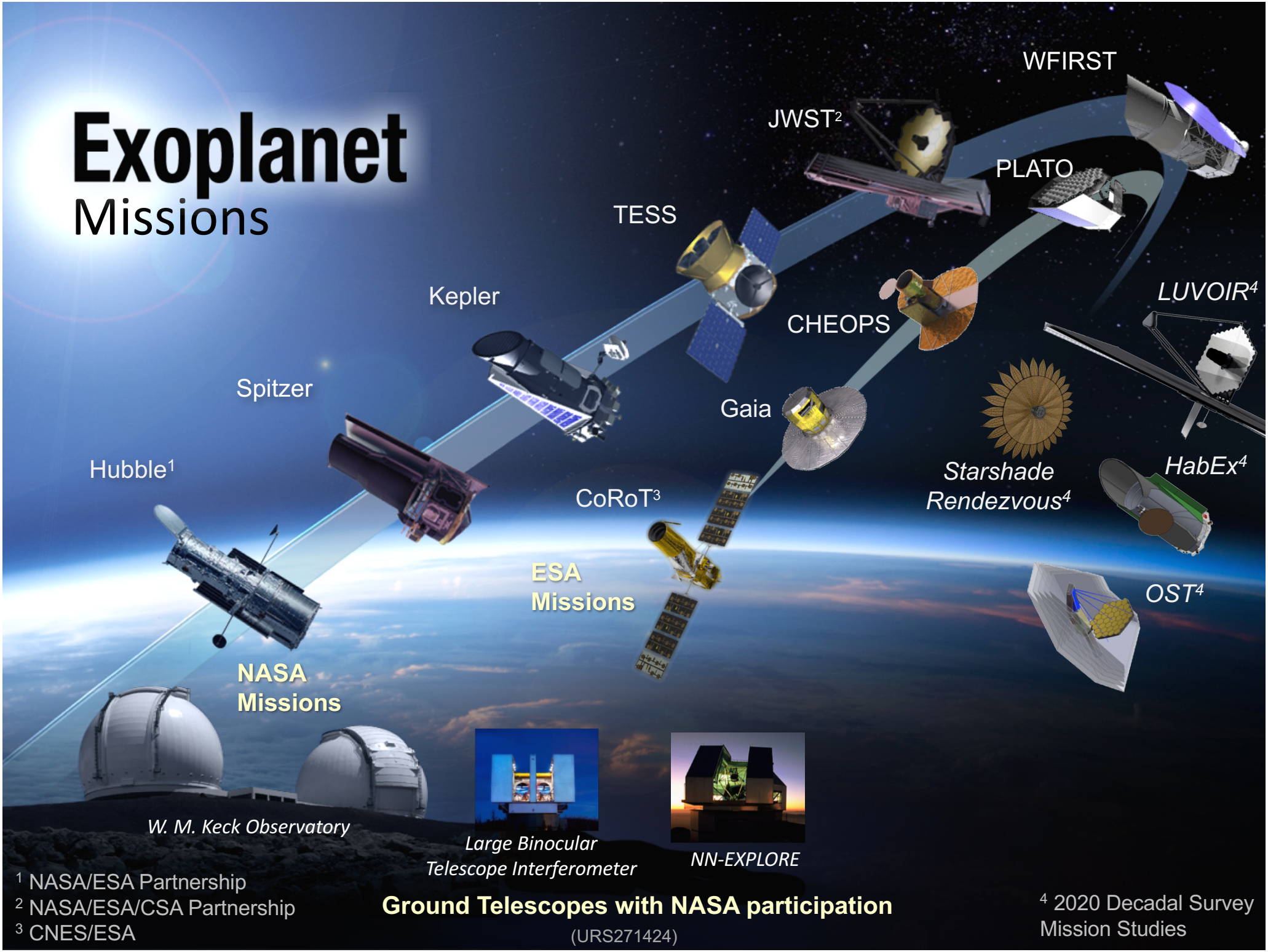


[1] NASA/ESA Partnership
[2] NASA/ESA/CSA Partnership
[3] CNES/ESA

[4] 2020 Decadal Survey
Mission Studies

Present: have fun collaborating on great science with the abundance of great data coming from Kepler/K2. Share ideas, share code, share supporting observations

Write great papers together

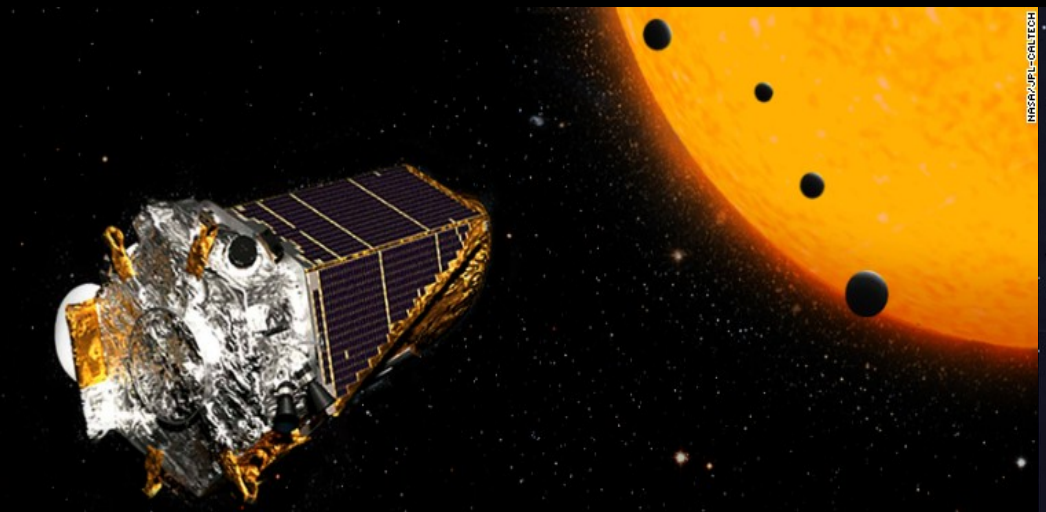
Near-Future: think about great science that can be done that hasn't been done yet with existing observatories or those about to launch soon (TESS, JWST)

Write great proposals together

Far-Future: think about great science that can't be done yet, and what resources/instruments/technologies will be needed to deliver that science.

Write white papers together for exoplanet strategic plan (2018) and 2020 Decadal Survey

Many thanks and congratulations to all of those that made Kepler & K2 an incredible success!
K2 is not done yet! Keep up momentum of getting great science out of K2!



…and here is wishing the best of luck to the TESS team and the rest of the exoplanet community for a very successful* TESS mission!

*** and long, scientifically productive, surprising, and inspiring**

(NASA/JPL) (NASA/GSFC)

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California Institute of Technology

jpl.nasa.gov