The Impact of Kepler

Professional Tools & Opportunities
PROTO

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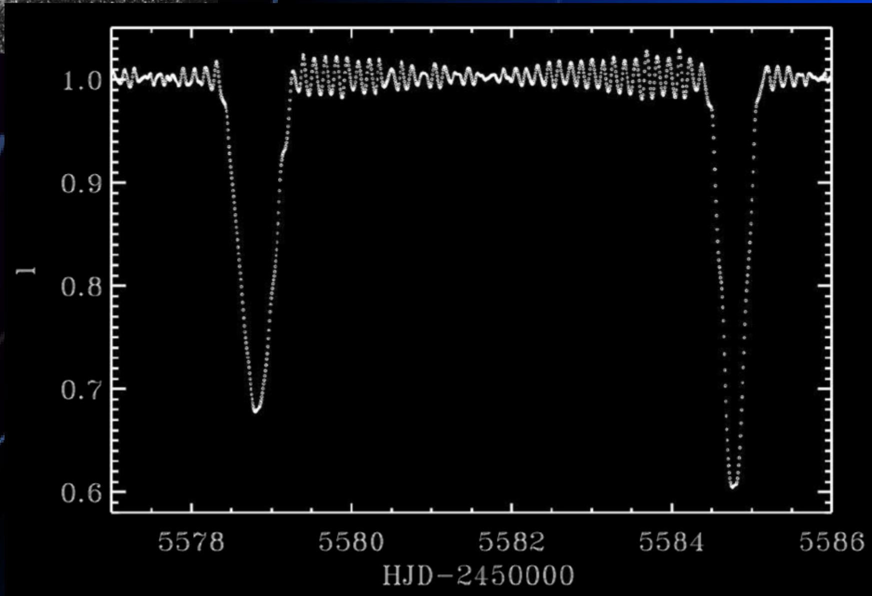


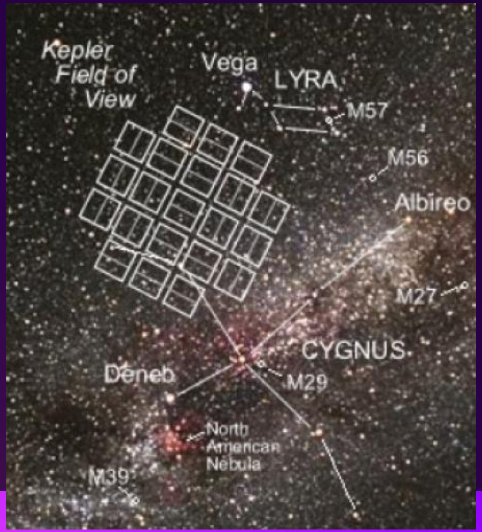
WHAT WERE KEPLER AND K2

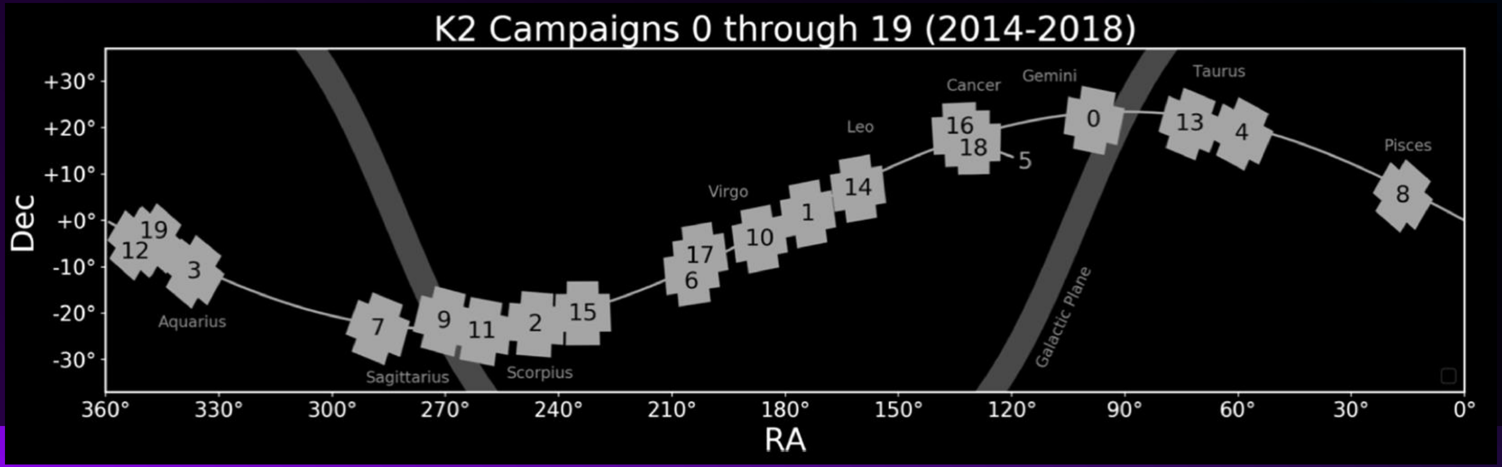
Kepler: 2009-2013

- 1 field
- 3.5 years
- 170,000 stars

K2: 2013-2018

- 19 fields
- 90 days per field, 6 yrs
- 360,000 stars

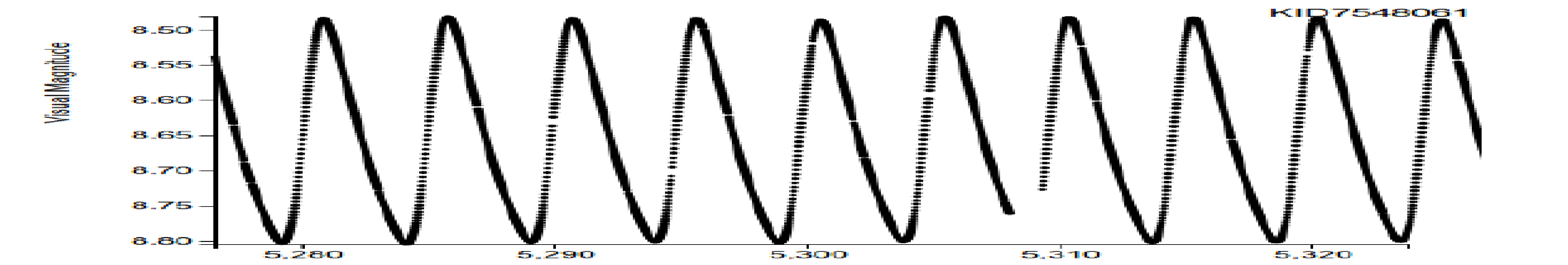




WHAT DID KEPLER AND K2 OFFER?

Long time-period, uninterrupted, extremely high precision, well-sampled, time series photometry

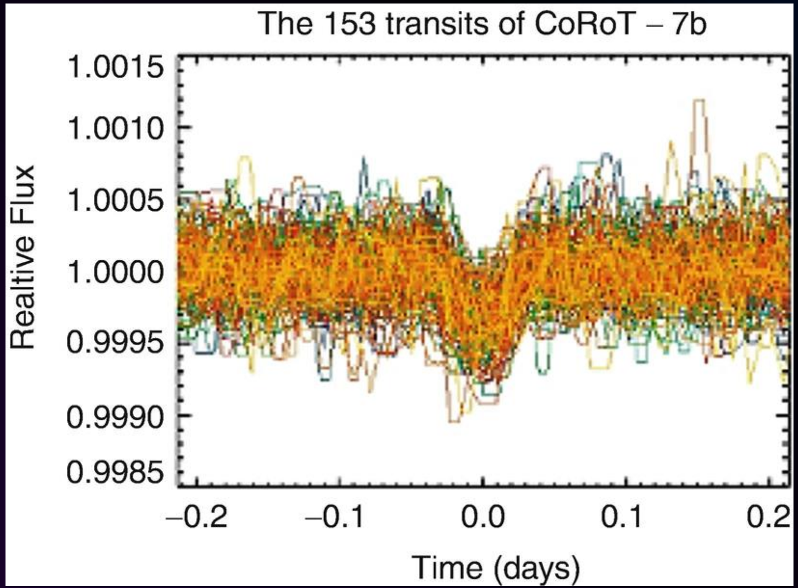
Ground-Based	CoRoT (2006-2012)	Kepler (2009-2018)
1000 ppm	100 ppm	20 ppm



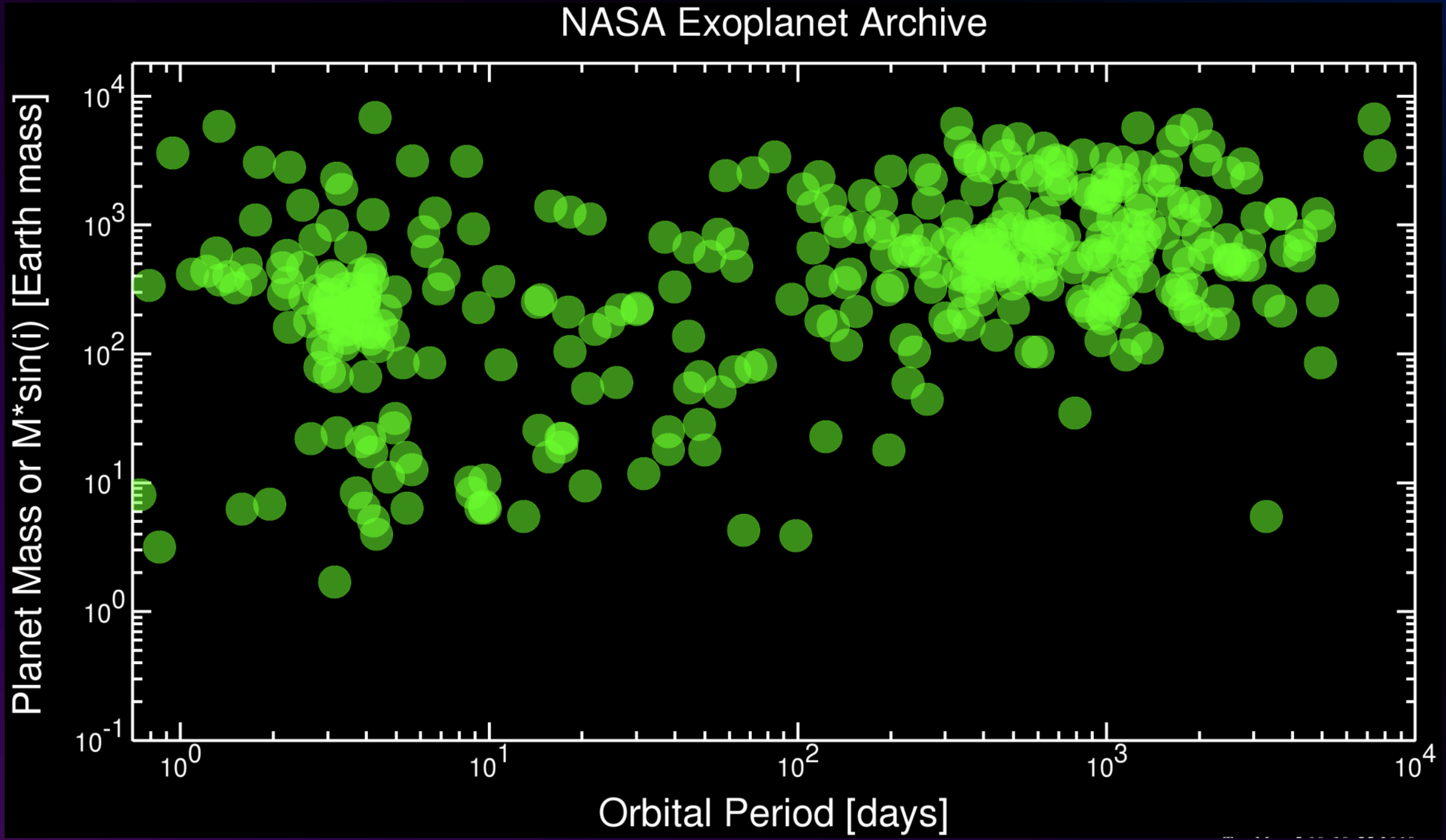
"When I first saw the light curves, I thought they had sent the simulation data and not the real data."

EXOPLANETS BEFORE KEPLER

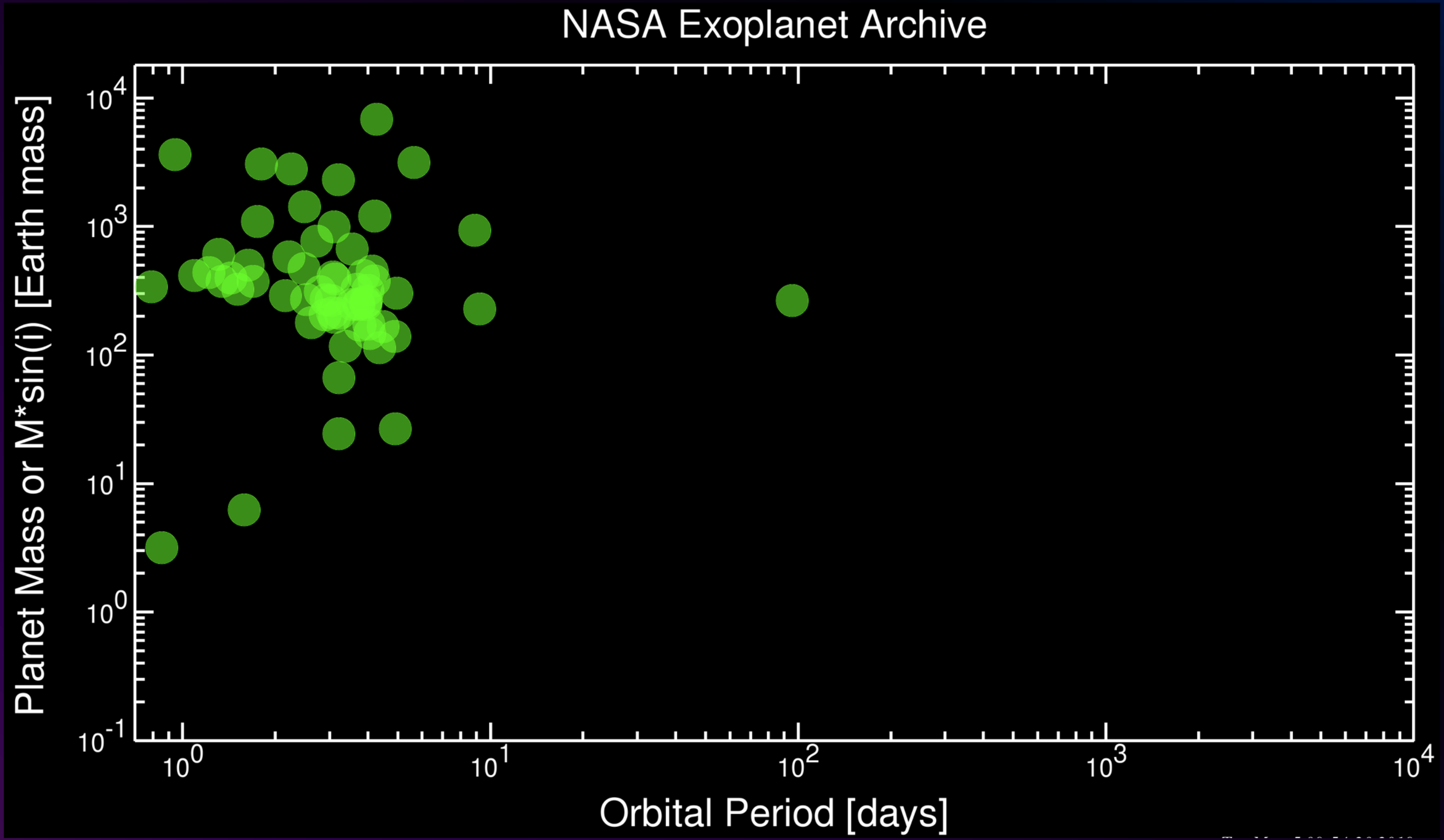
- First planets were discovered from timing variations in pulsars (1992)
- Discoveries dominated by RVs from the ground starting with 51 Peg (1995)
- CoRoT (2006): first mission flown dedicated to the discovery of exoplanets (via transits)



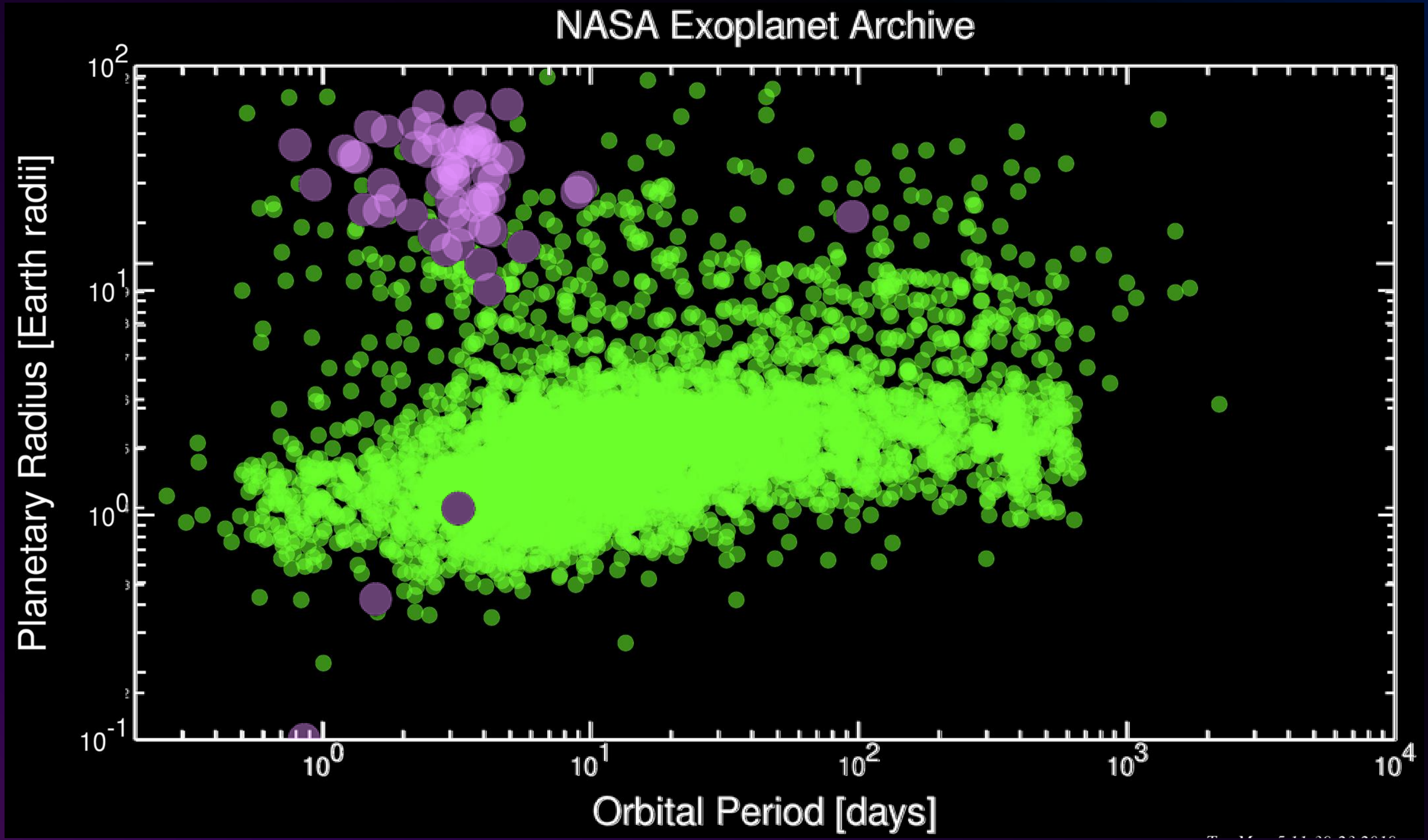
318 EXOPLANETS KNOWN BEFORE KEPLER



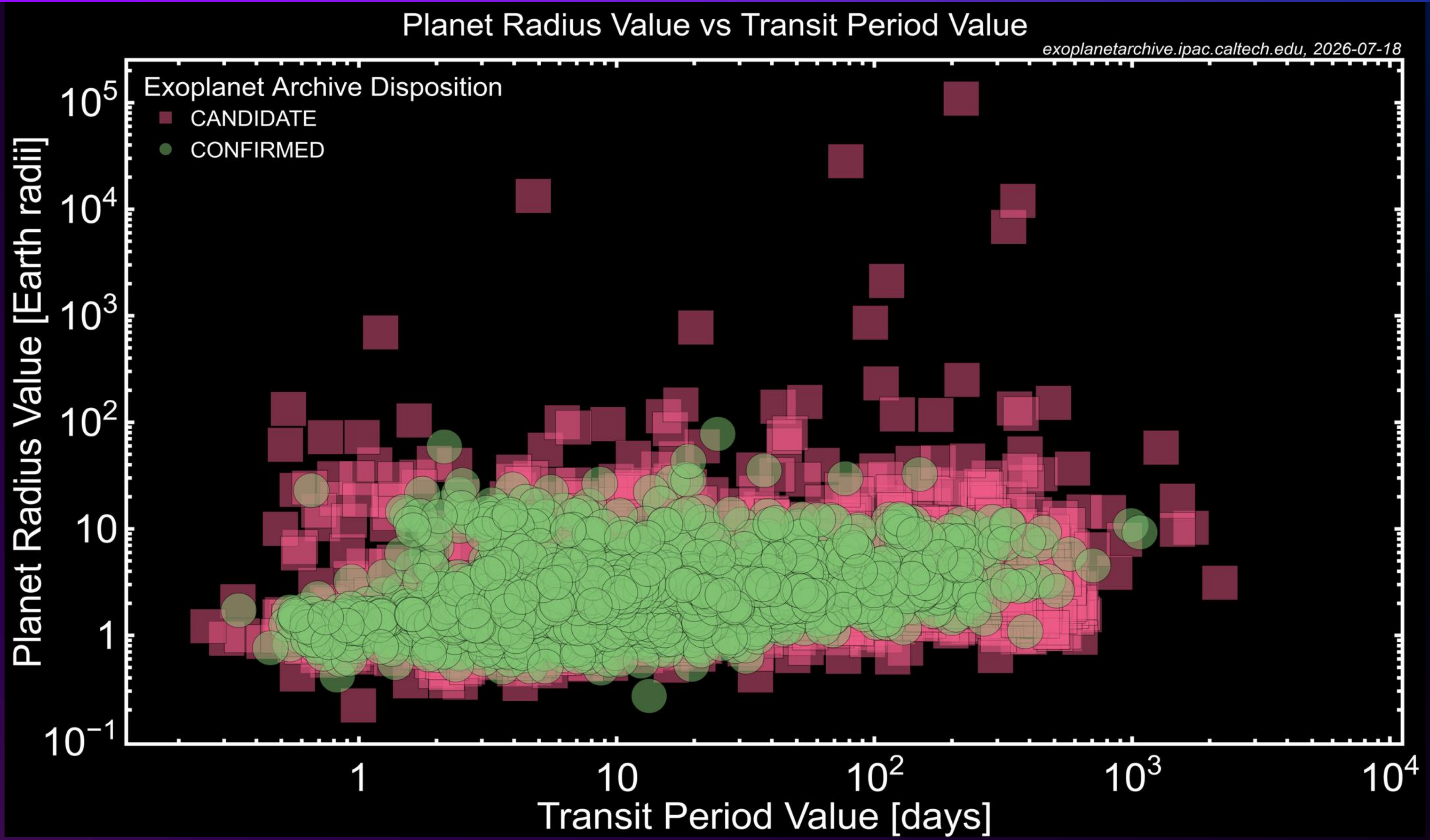
50 TRANSITING EXOPLANETS KNOWN



A WHOLE NEW PARAMETER SPACE OPENED

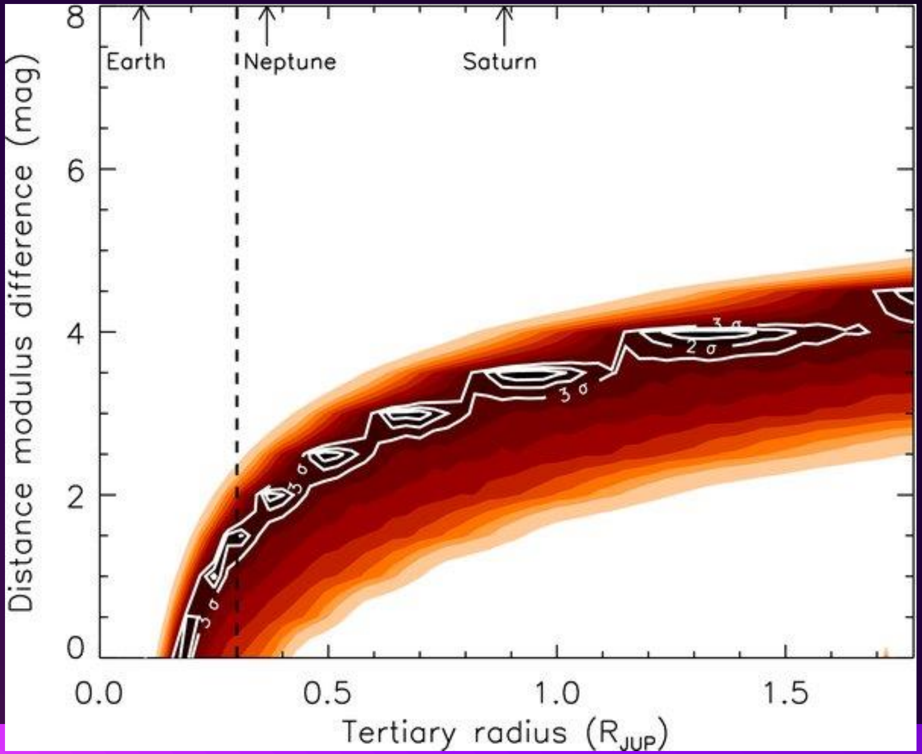


AND, OF COURSE, KEPLER CANDIDATES



STATISTICAL VALIDATION OF PLANETS

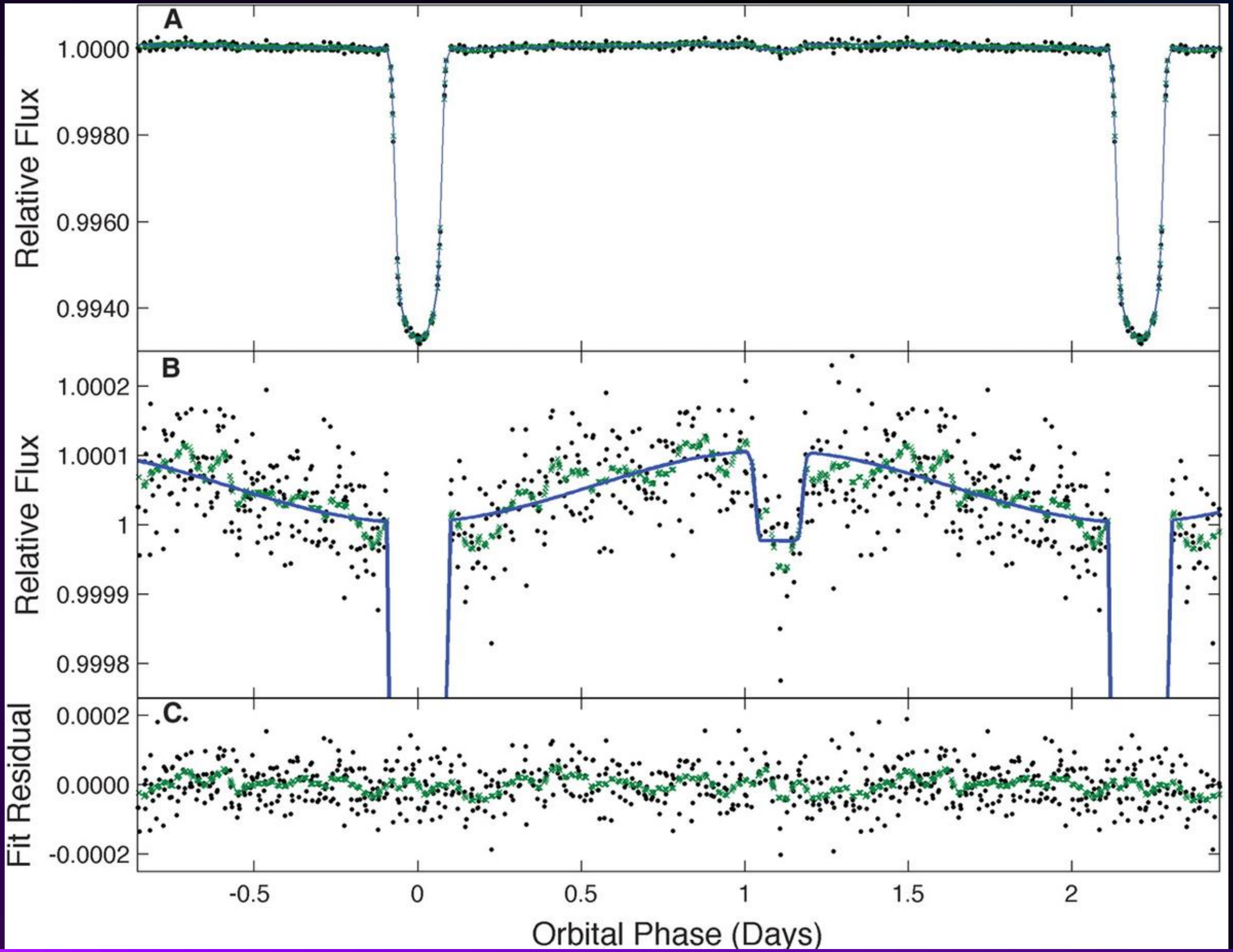
- Planets were often too small or orbited stars that were too faint for effective RV determination of the masses
- Statistical validation was created to assess the discoveries



False positive configuration[a]	Result	Blends ruled out
Hierarchical triple with stellar tertiary, MS	Poor fits	Yes
White dwarf tertiaries	Poor fits	Yes
Hierarchical triple with planetary tertiary, MS	Twin star	Yes (imaging/spec./centr.)
Background EB with stellar tertiary, MS		
With and without extinction	Good fits	Not all
Giant secondaries	*P* too short	Yes
White dwarf tertiaries	Poor fits	Yes
Twice the period	Poor fits/sec. ecl.	Yes
Background EB with planetary tertiary, MS		
Jupiters, Neptunes, super-Earths, with extinction	Good fits	super-Earths
Giant secondaries	*P* too short	Yes
White dwarfs, with extinction	Good fits	Yes (imaging/spec./centr.)
Foreground EB with stellar tertiary, MS	Poor fits	Yes
Foreground EB with planetary tertiary, MS	Poor fits	Yes

Kepler-9; Torres et al. 2011

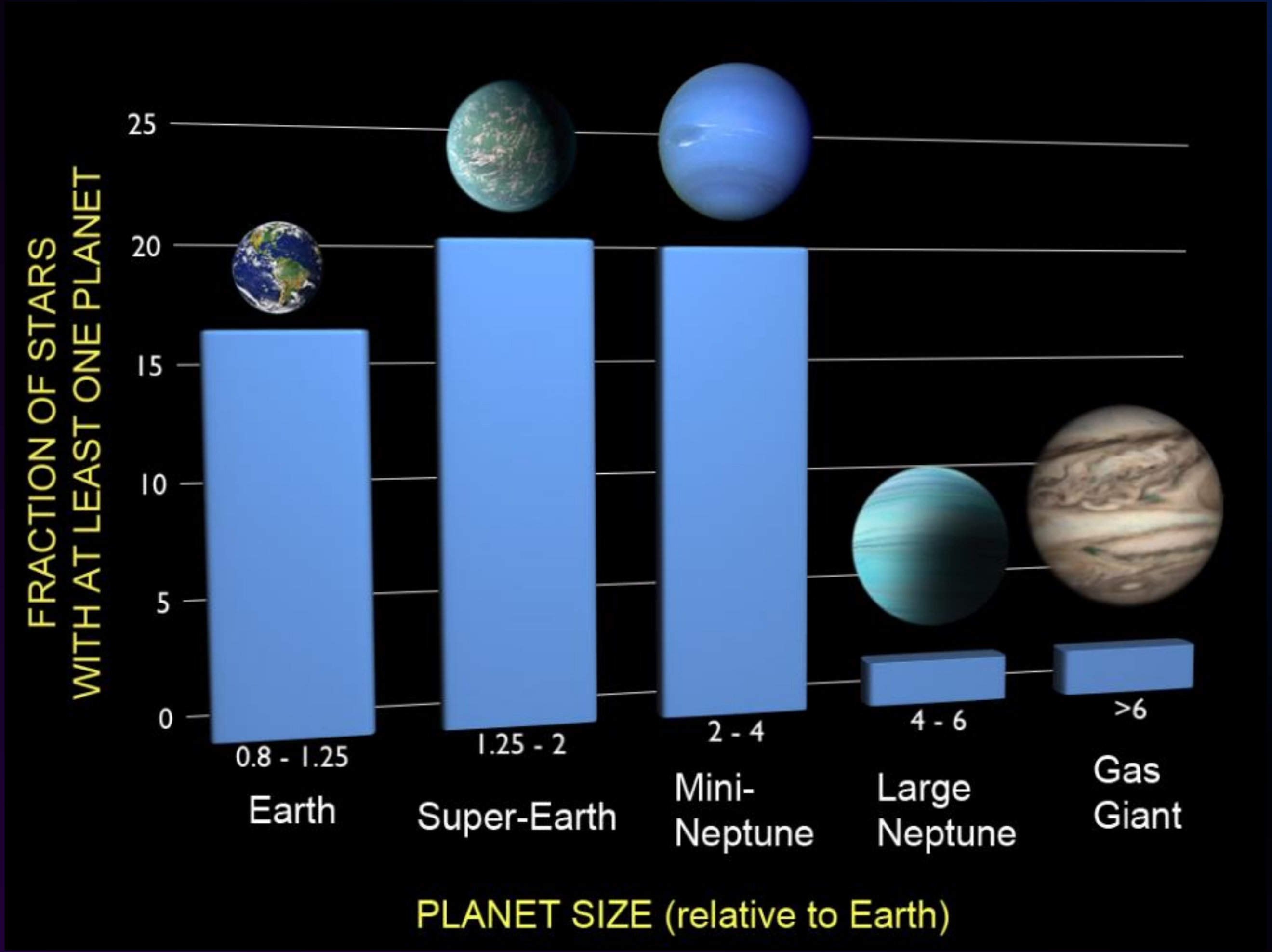
DETAILED STUDIES OF INDIVIDUAL SYSTEMS



HAT-P7
Borucki et al. 2009

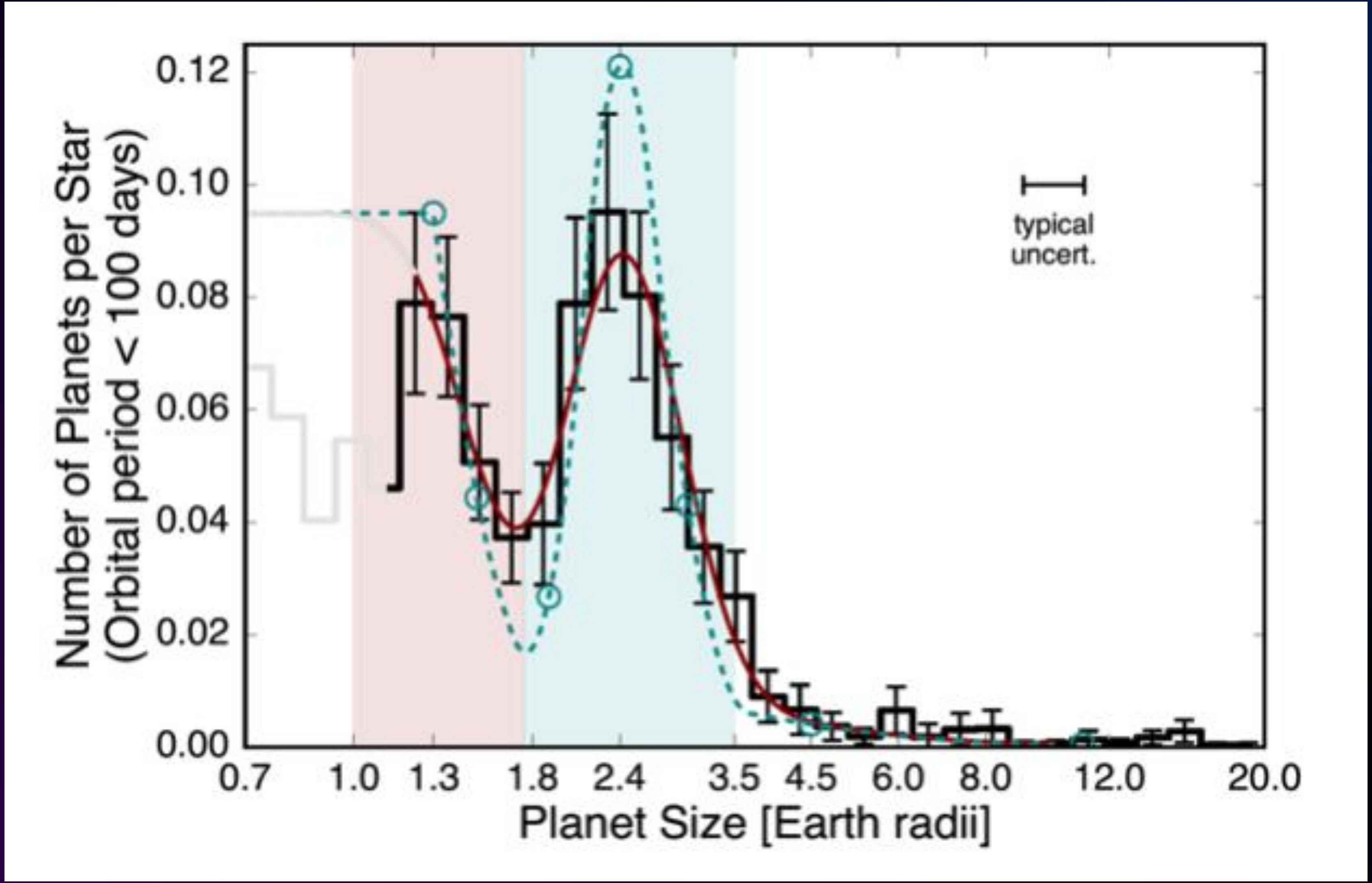
DEMOGRAPHIC STUDIES

Existence of a planet size not in our Solar System (super-earths, sub-Neptunes)



DEMOGRAPHICS STUDIES

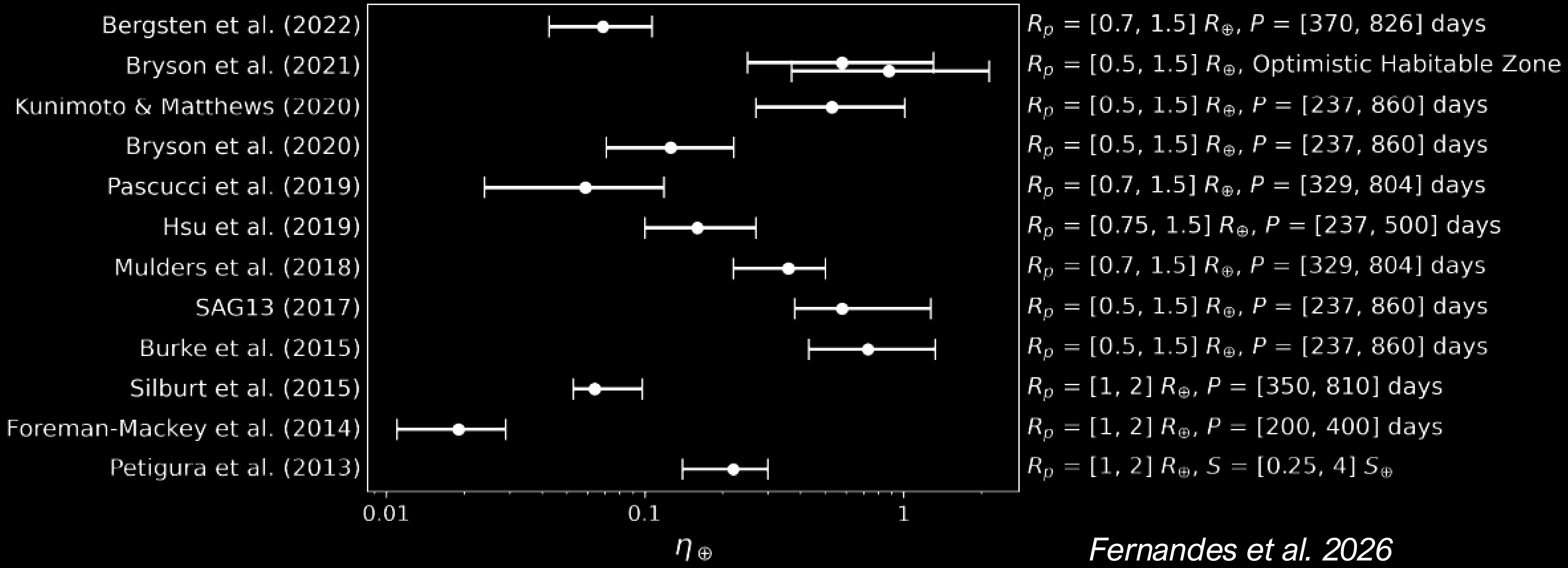
With a gap!



Fulton et al. 2009

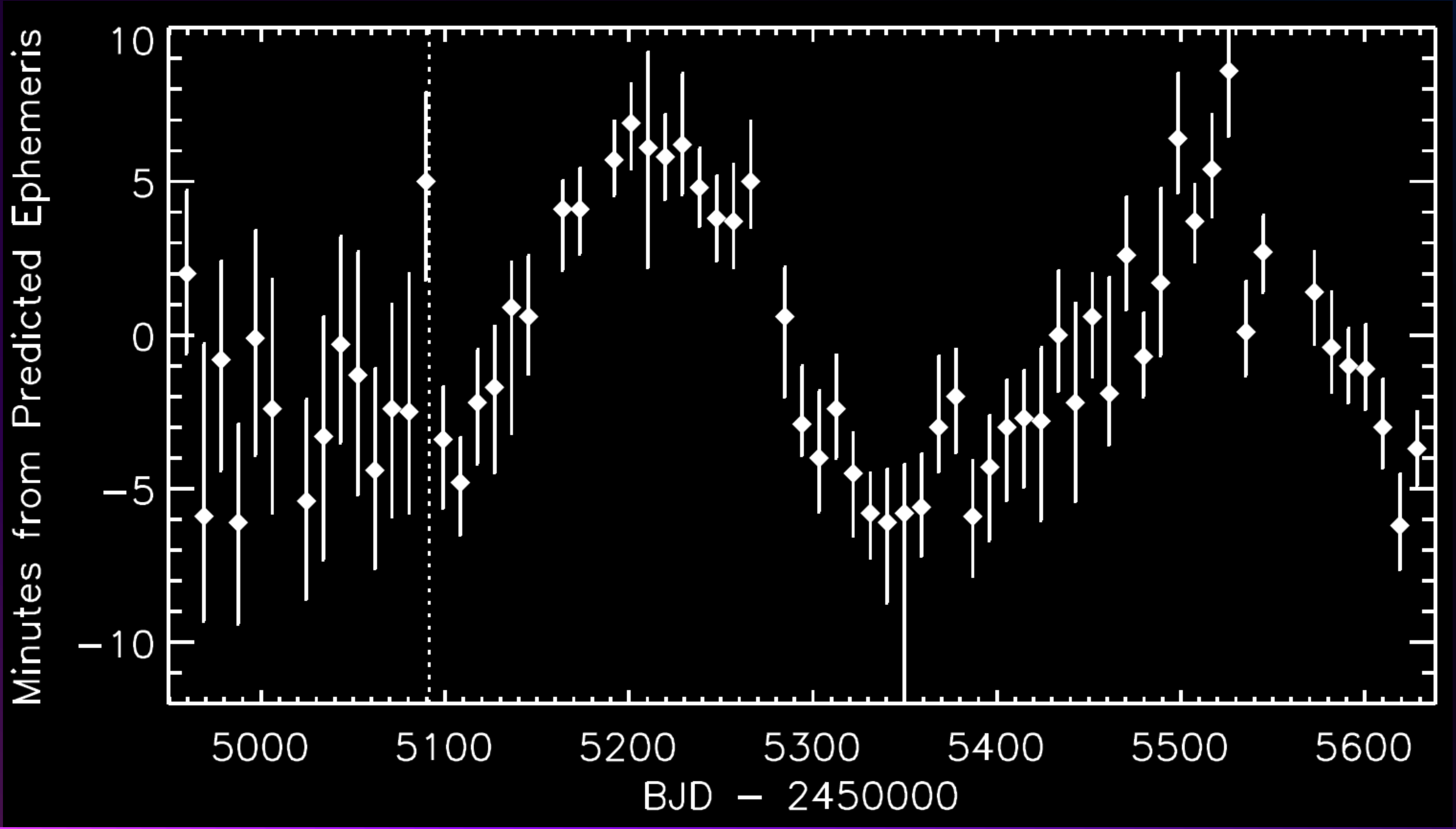
DEMOGRAPHICS STUDIES

- Estimating the frequency of Earths



Fernandes et al. 2026

FIRSTS: TRANSIT TIMING VARIATIONS

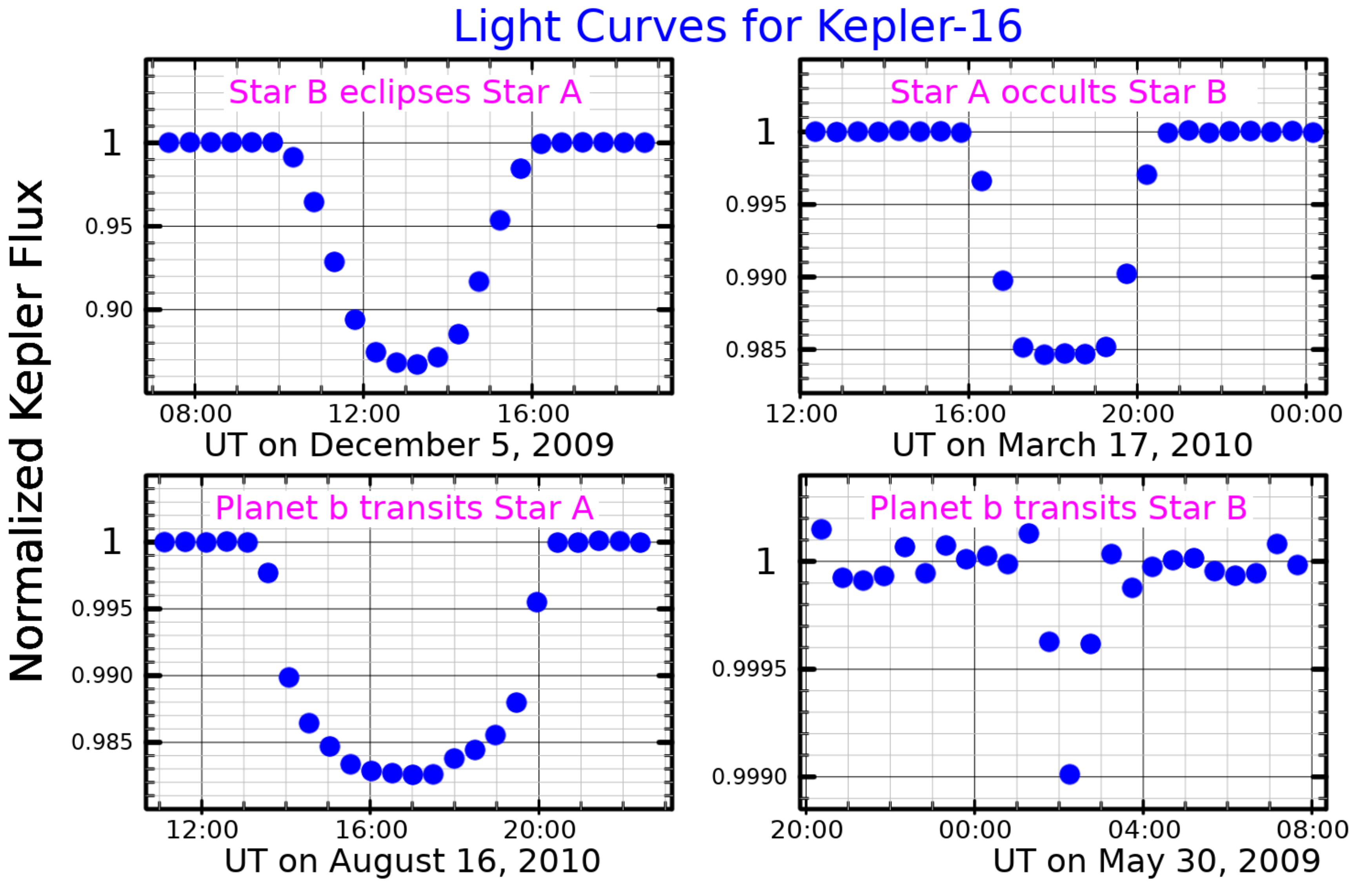


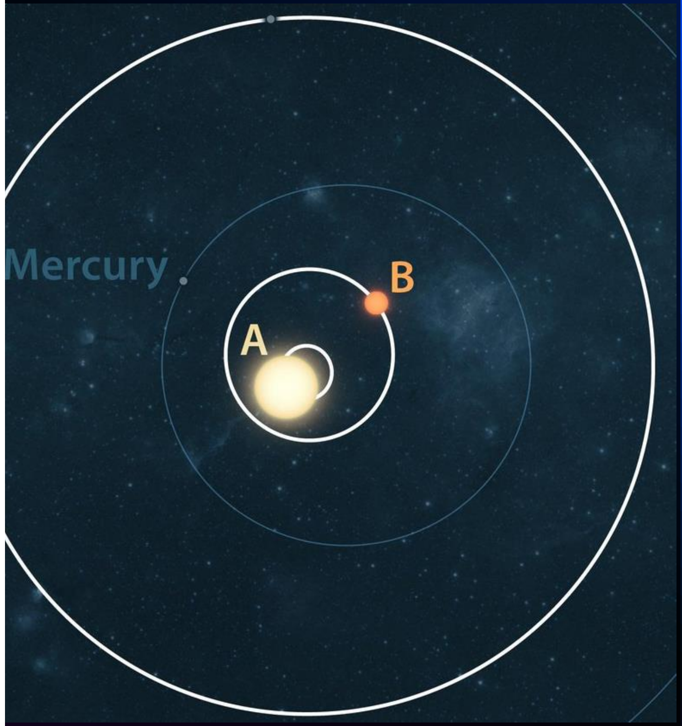
Kepler-19 has three planets

b: transit
c: TTV
d: RV

Kepler-19
Ballard et al. 2011

FIRSTS: CIRCUMBINARY PLANETS



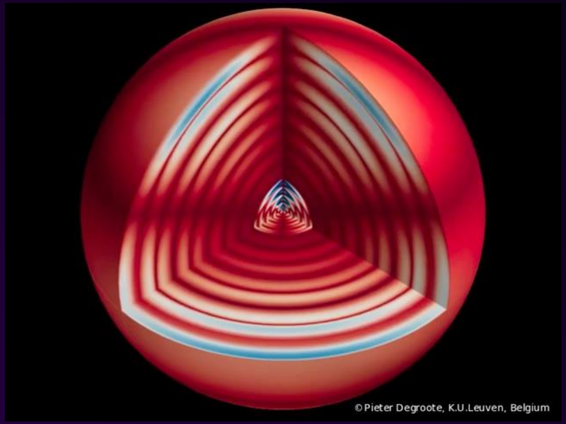


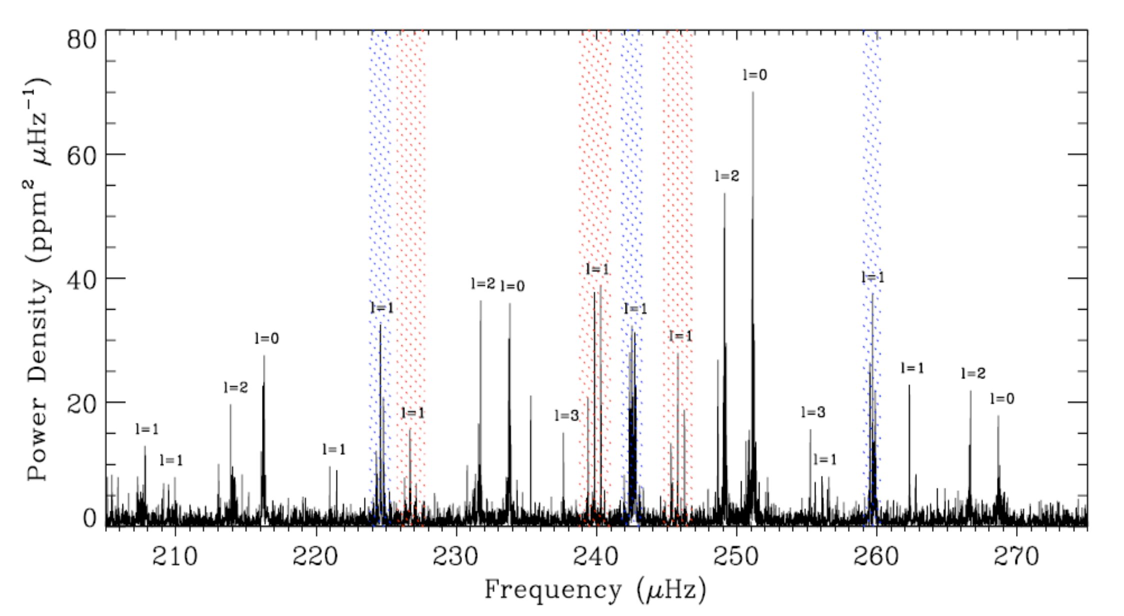
Kepler-16
Doyle et al. 2011

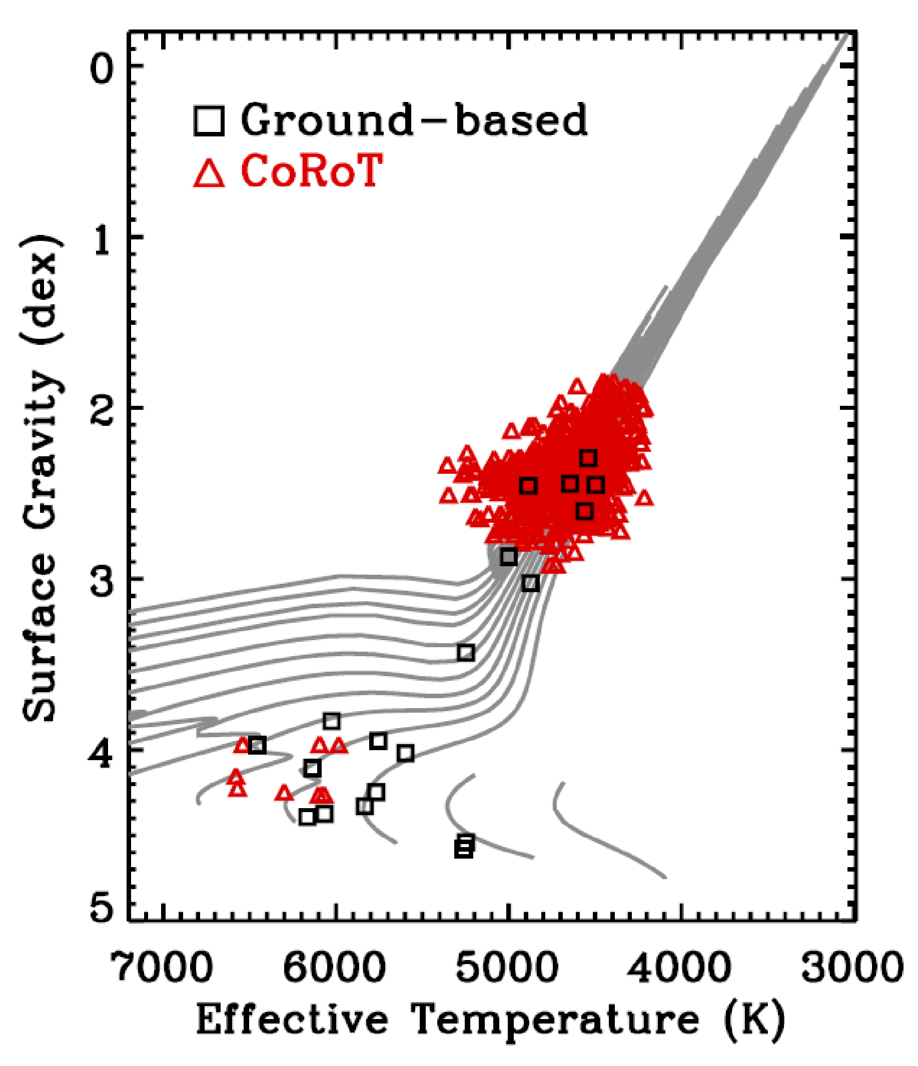
STELLAR ASTROPHYSICS

“We will be talking about stellar astrophysics in terms of ‘Before’ and ‘After’ Kepler”

ASTEROSEISMOLOGY REVOLUTION

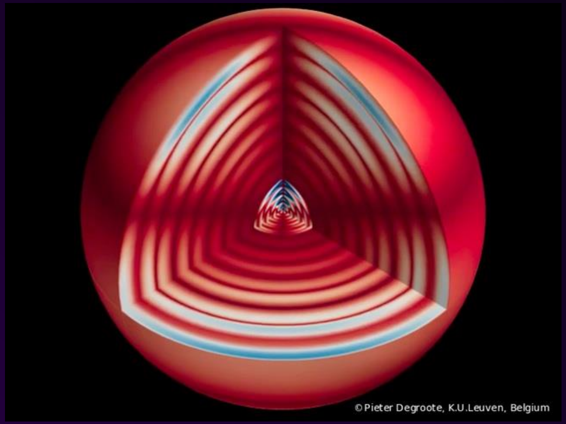


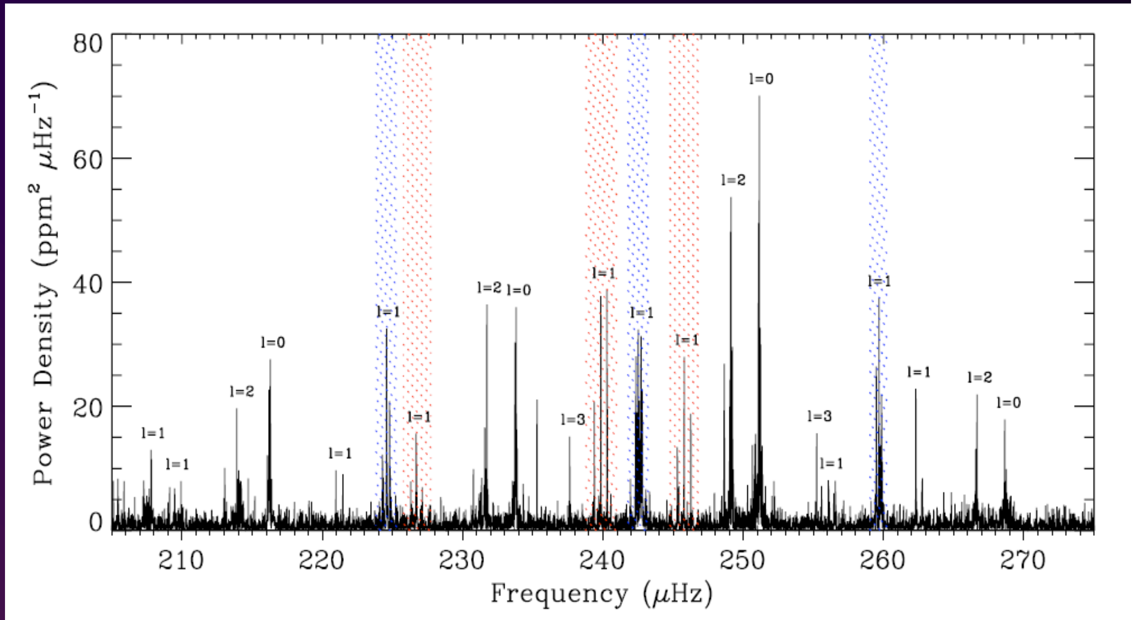


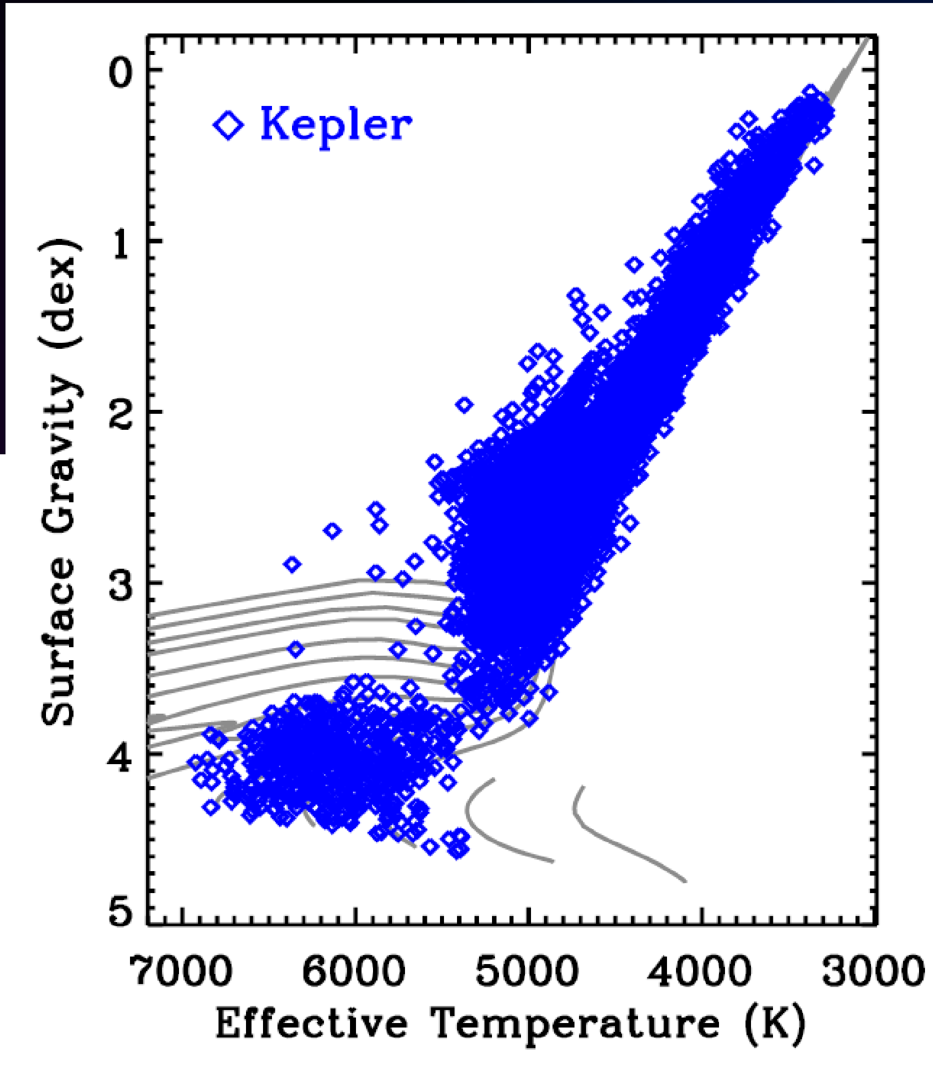


Huber et al. 2016

ASTEROSEISMOLOGY REVOLUTION

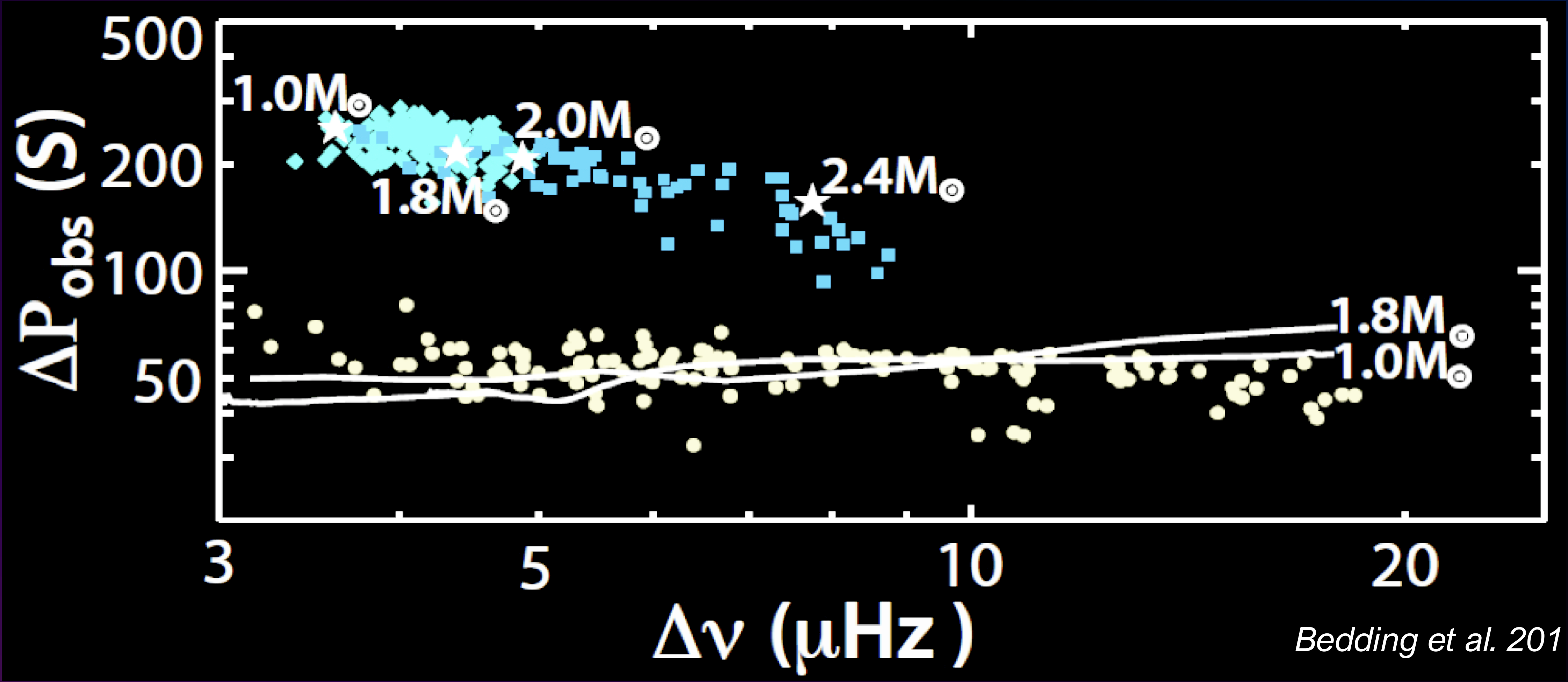






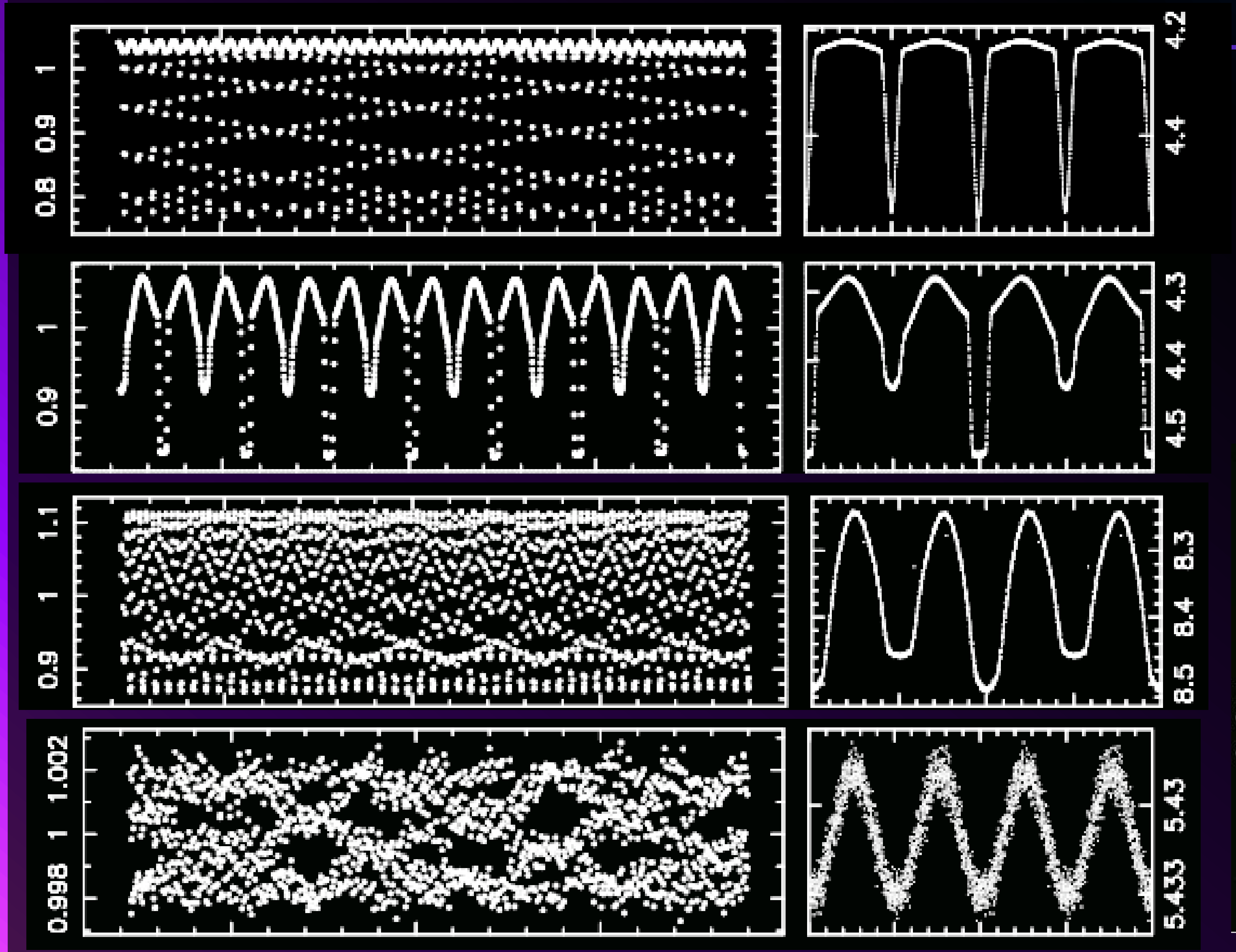
Huber et al. 2016

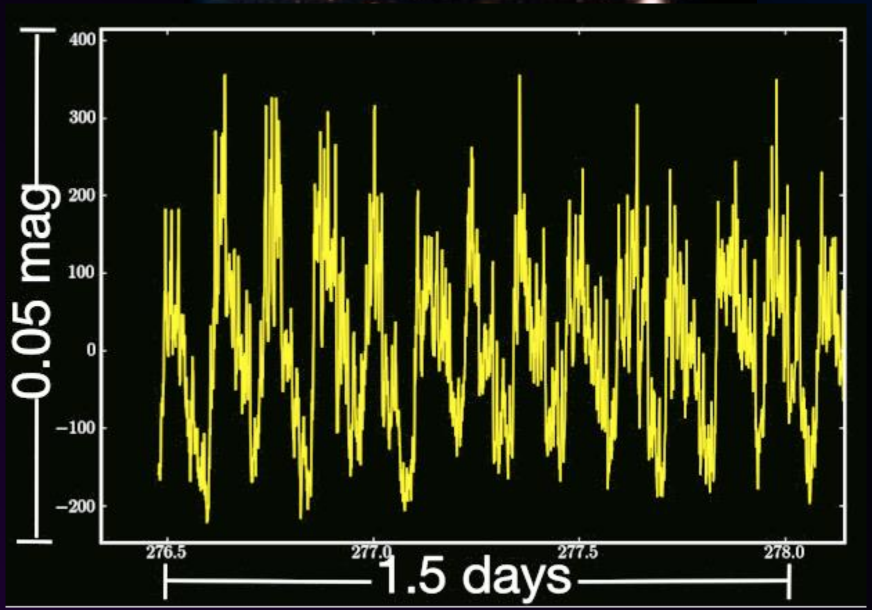
SEPARATING H-SHELL vs He-CORE RED GIANTS



Bedding et al. 2011

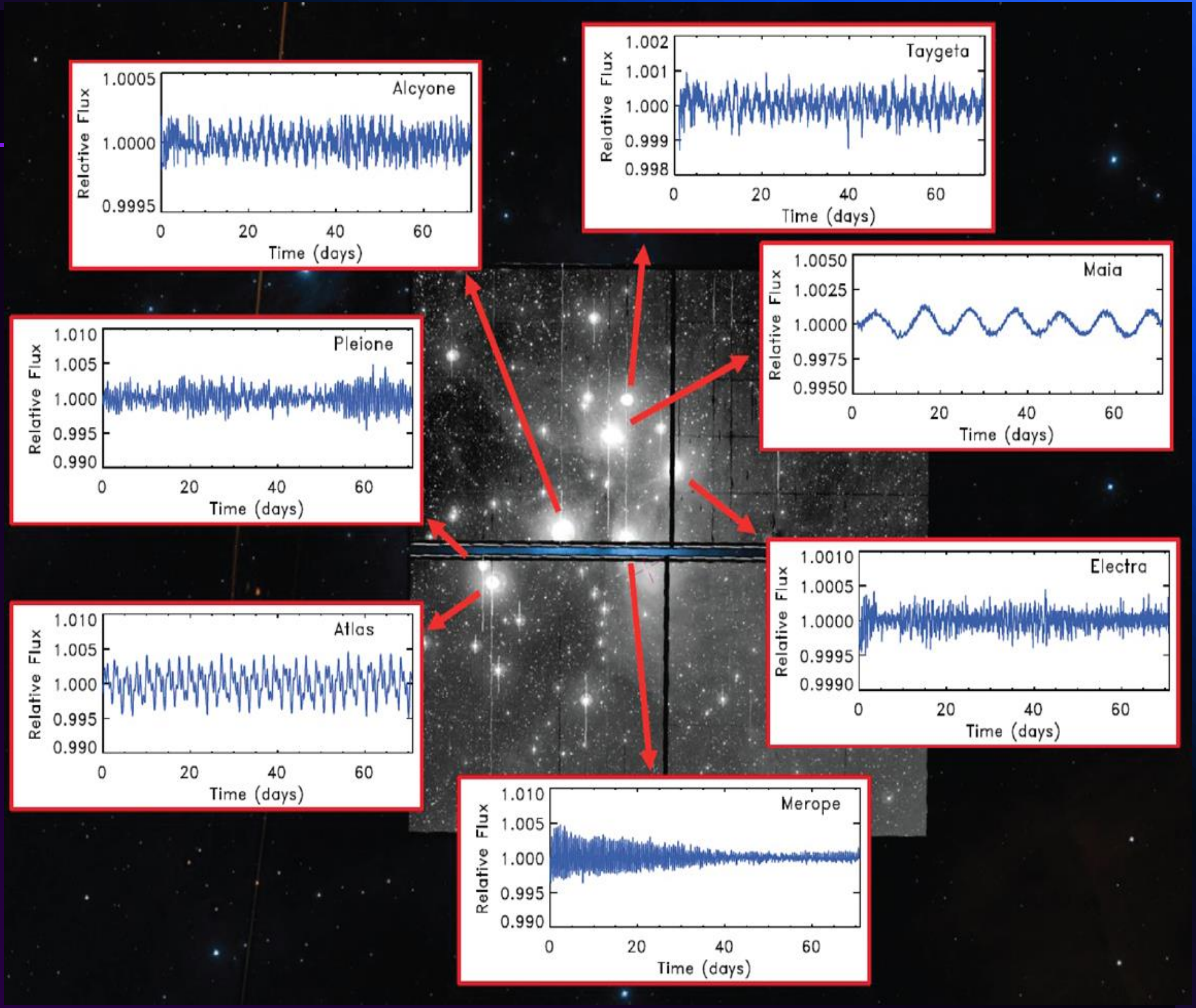
BINARIES, BINARIES, BINARIES ...



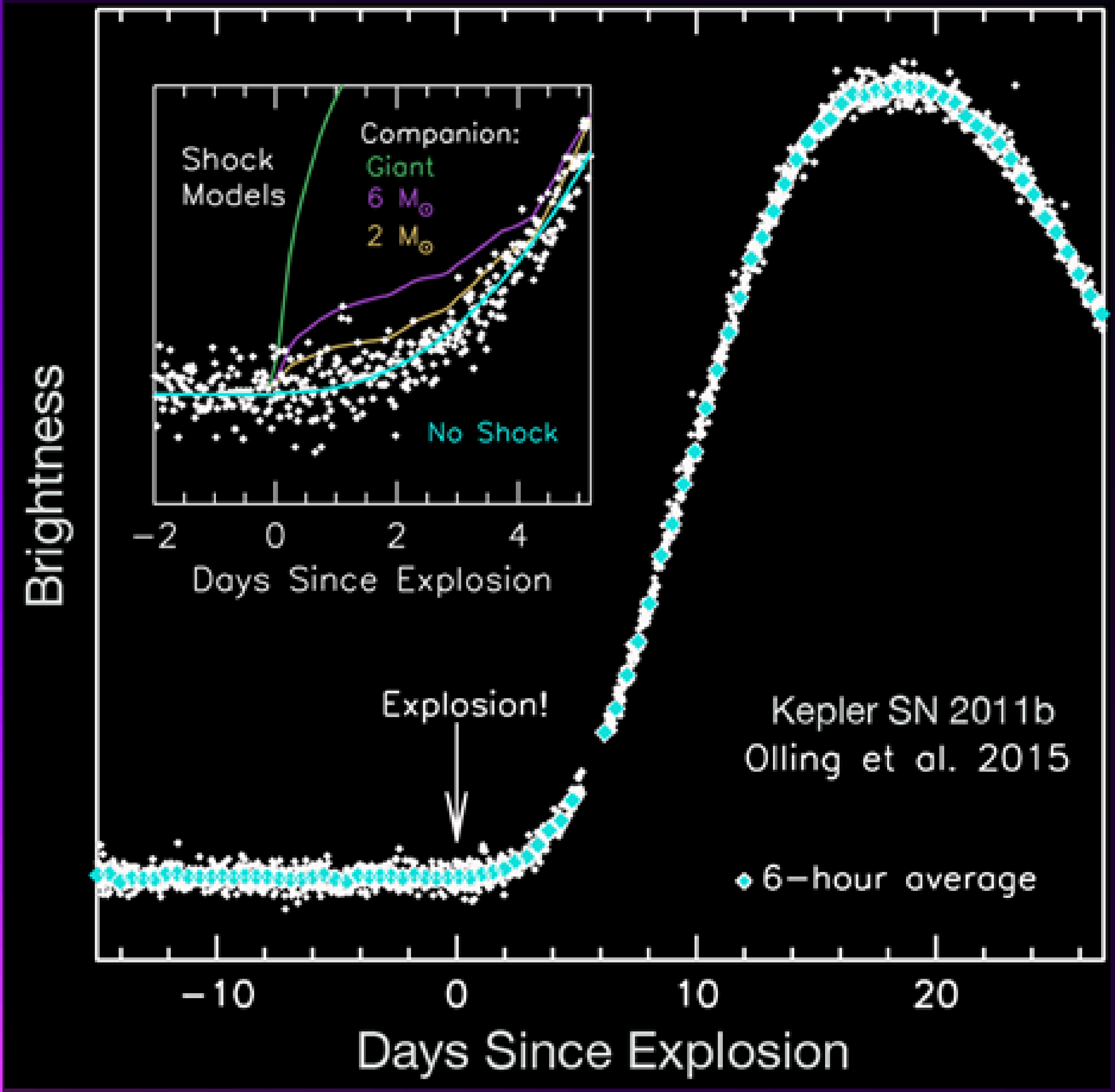


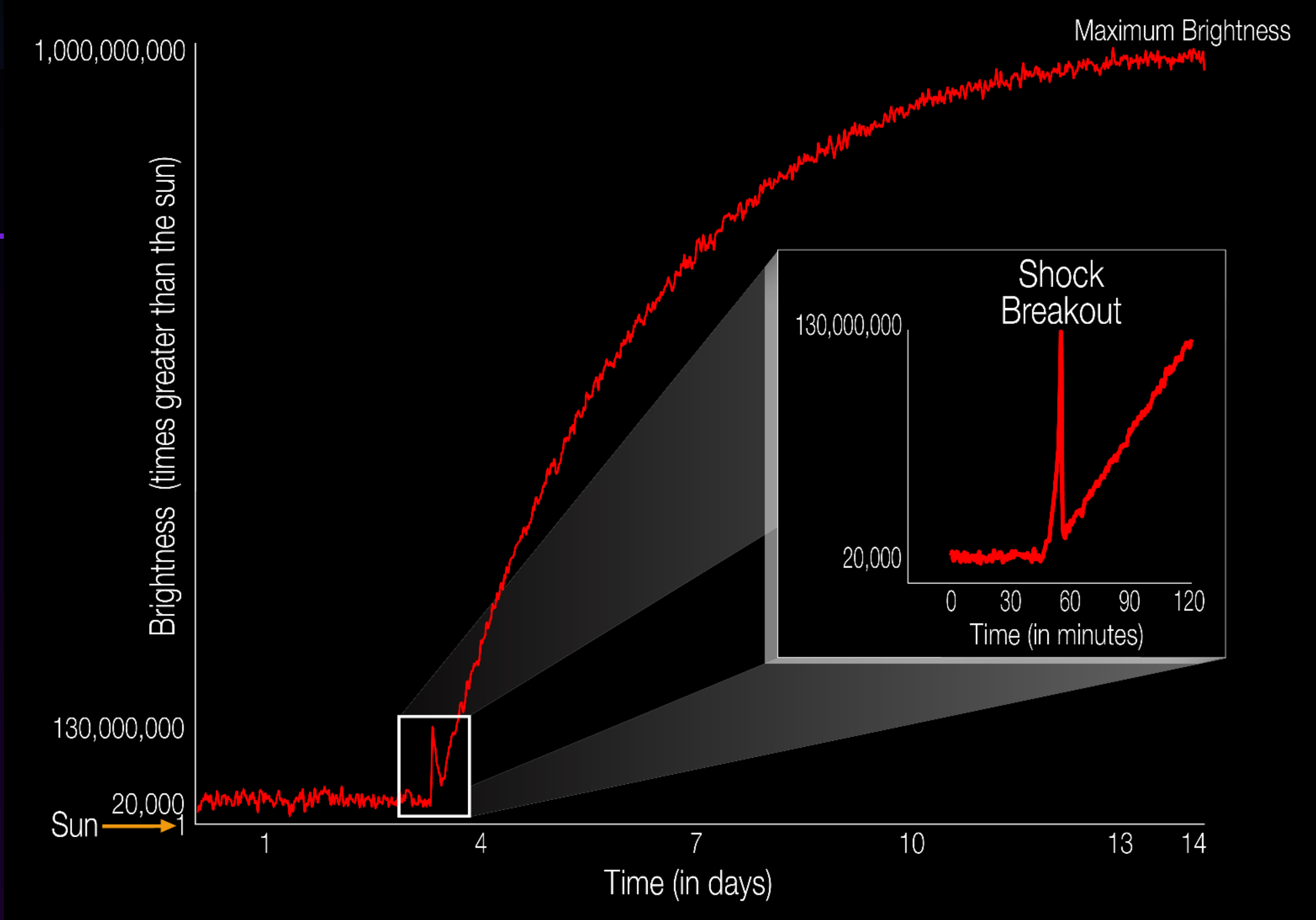
YOUNG STARS

Pleiades stars nearly equal in mass and age but pulsation, rotation, and binarity are all different



SUPERNOVAE





More than 2 dozen SN observed
Enables detailed modeling of progenitors and explosion

BUT THE REAL CHANGE ...

BUT THE REAL CHANGE …

… was sociological

BUT THE REAL CHANGE …

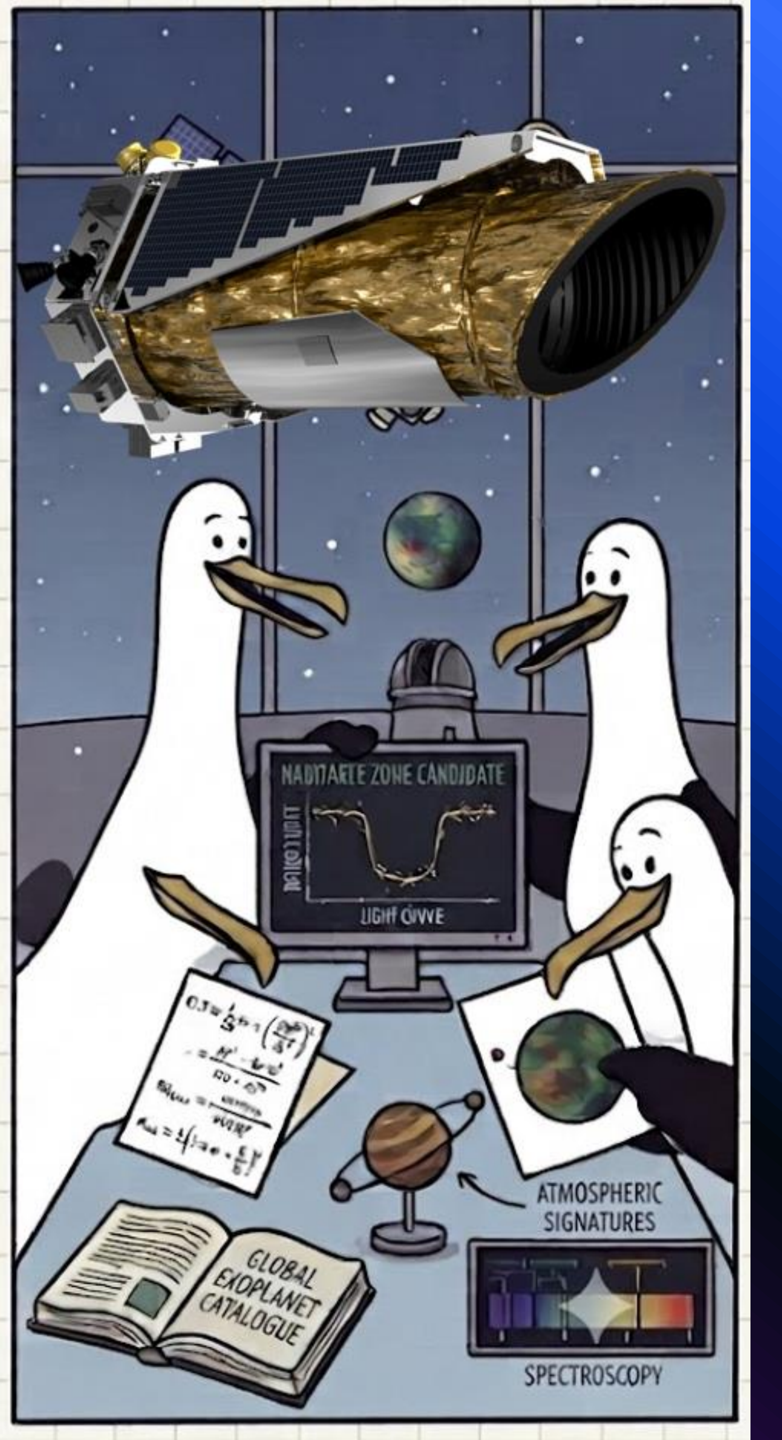
The exoplanet field was incredibly competitive dominated by discovery of individual planets

BUT THE REAL CHANGE …

The plethora of planets from Kepler fundamentally changed how we worked and interacted as a community

BUT THE REAL CHANGE ...

Public release of the Kepler data and planet candidates opened the science to everyone



DEMOCRATIZING THE SCIENCE

- The availability of Kepler and K2 data/candidates enabled a breadth of science previously only imagined and necessitated the community coming together to share results and resources like never before
- TESS data and planet candidates were all immediately open to the public
- All Roman data will be immediately public as well

FUNDED GROUND-BASED PROGRAM

- Ground-based follow-up critical to Kepler's success (KFOP)
  - Spectroscopt
  - High resolution imaging
  - Radial velocities
- Led to today's TESS Follow-up Observation Program (TFOP)
  - Over 1 million files shared on ExoFOP
- Gaia and Plato are organizing community follow-up programs

THE LEGACY OF KEPLER IS FAR-REACHING

Scientifically and Sociologically