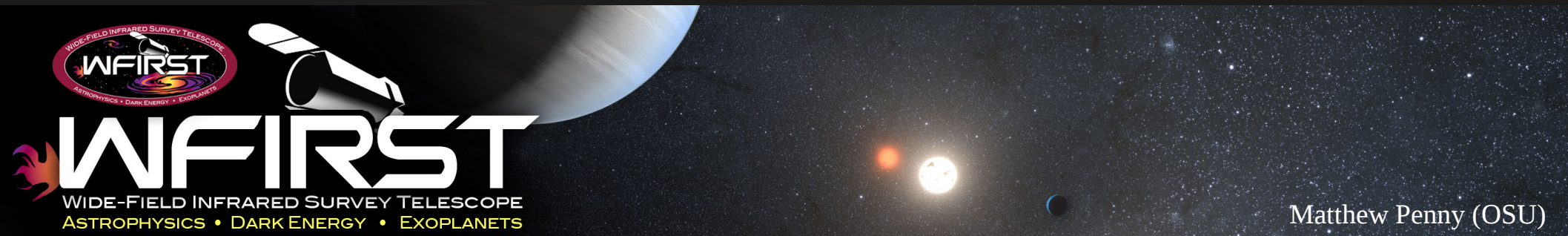
The *WFIRST* Microlensing Survey for Exoplanets

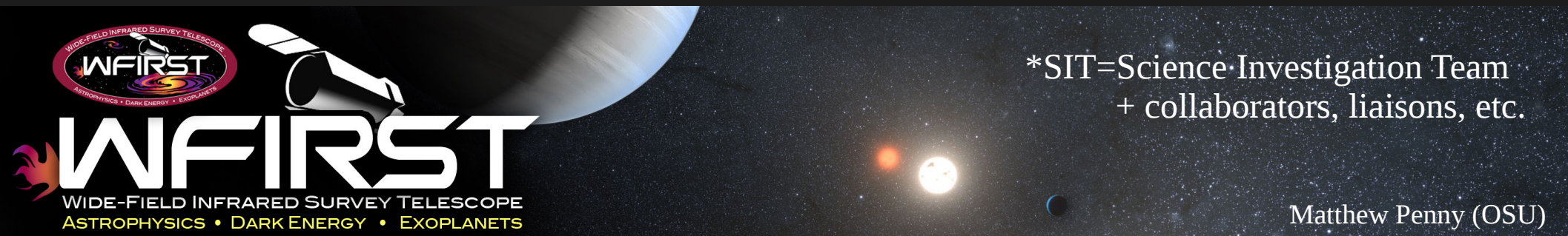
Matthew Penny
Ohio State University
penny@astronomy.ohio-state.edu

Science in Our Own Backyard, June 18th 2019



The *WFIRST* Microlensing SIT*

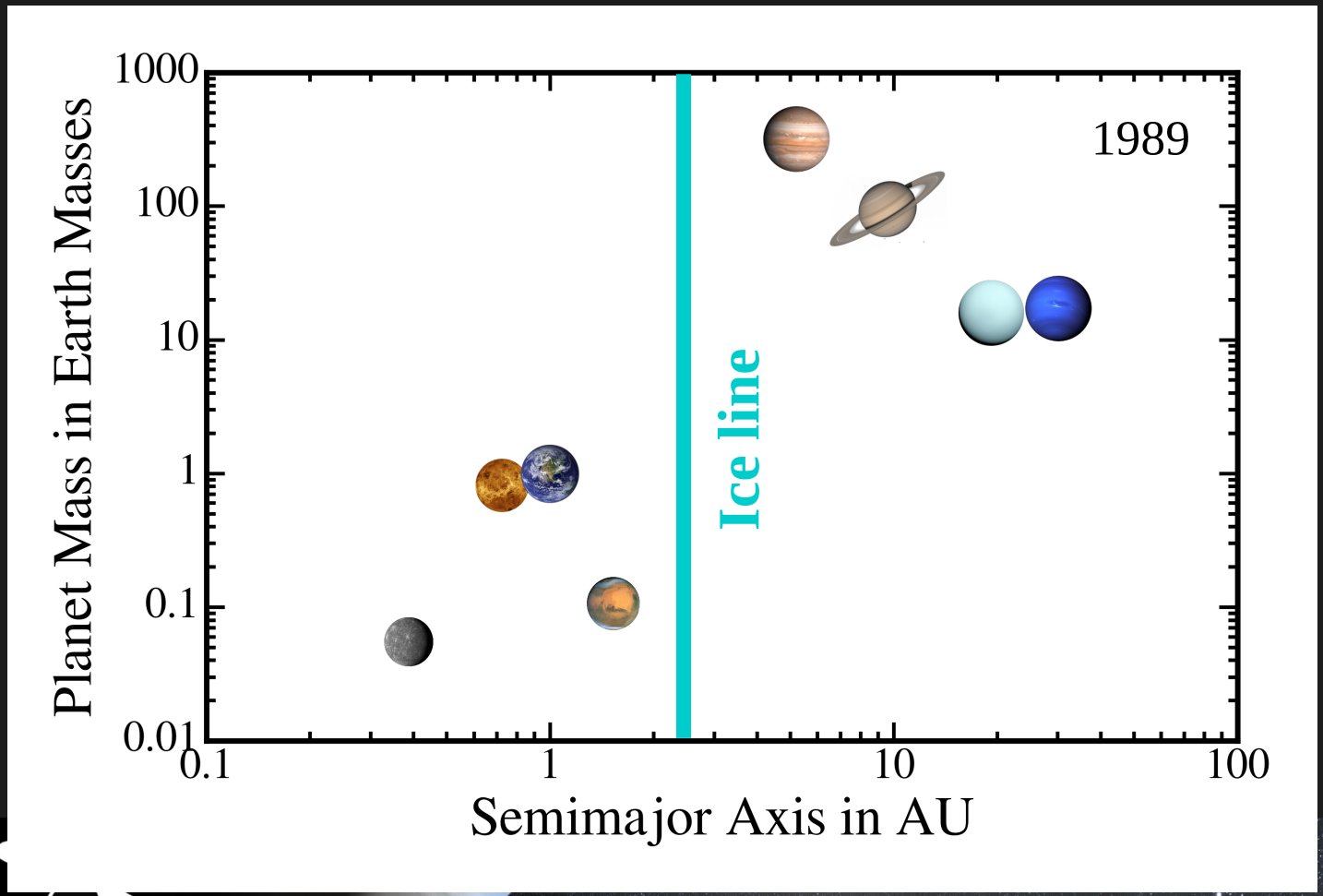
Scott Gaudi (Ohio State) – PI
David Bennett (GSFC) – Deputy PI
Rachel Akeson (IPAC)
Jay Anderson (STScI)
Andrea Bellini (STScI)
Chas Beichman (JPL)
Aparna Bhattacharya (GSFC)
Valerio Bozza (Salerno)
Geoff Bryden (JPL)
Sebastiano Calchi Novati (IPAC)
Sean Carey (IPAC)
Dan Forman-Mackey (Flatiron)
Andy Gould (Heidelberg)
Cheongho Han (Chungbuk)
Calen Henderson (IPAC)
Samson Johnson (Ohio State)
Savannah Jacklin (Vanderbilt)
Davy Kirkpatrick (IPAC)
Jessica Lu (Berkeley)
David Nataf (Johns Hopkins)
Matthew Penny (Ohio State)
Radek Poleski (Ohio State)
Kailash Sahu (STScI)
Yossi Shvartzvald (JPL)
Rachel Street (Las Cumbres Observatory)
Keivan Stassun (Vanderbilt, Fisk)
Takahiro Sumi (Osaka)
Daisuke Suzuki (Osaka)
Jennifer Yee (SAO)



*SIT=Science Investigation Team
+ collaborators, liaisons, etc.

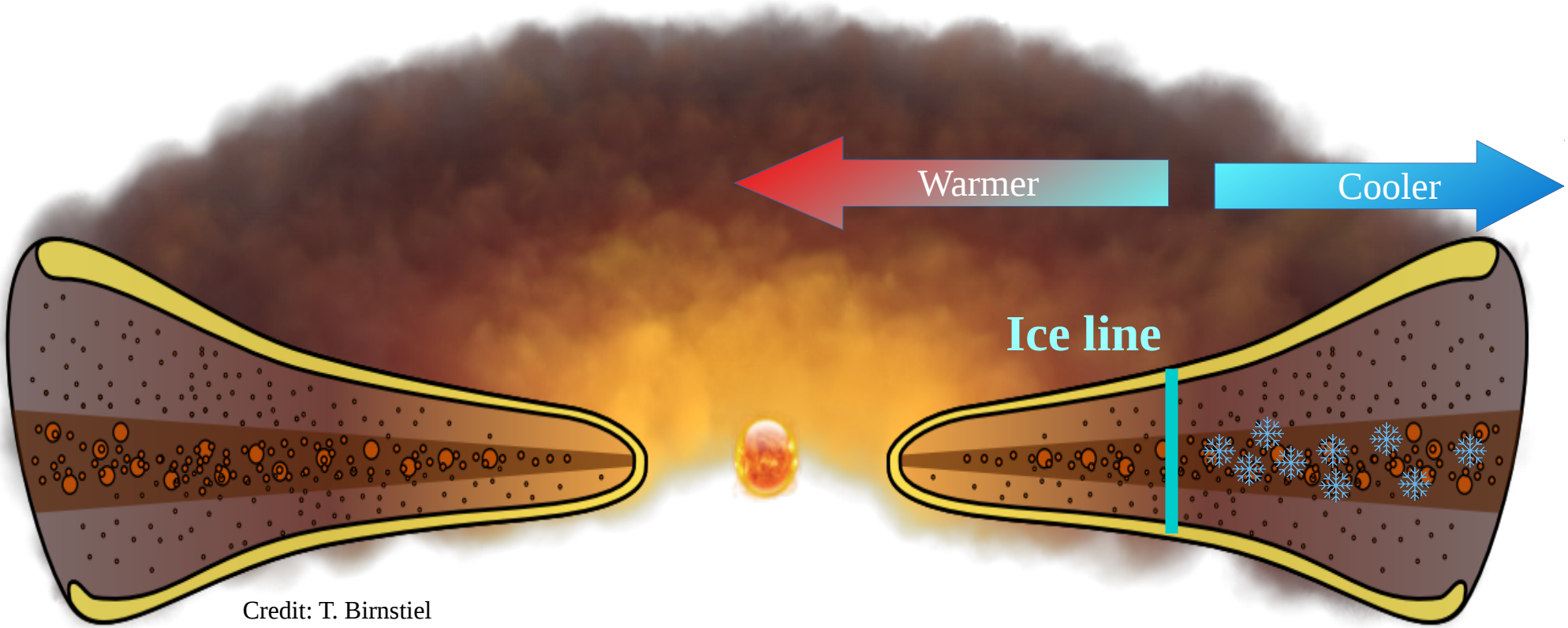
Matthew Penny (OSU)

The Solar System:
Small rocks inside, gas giants outside

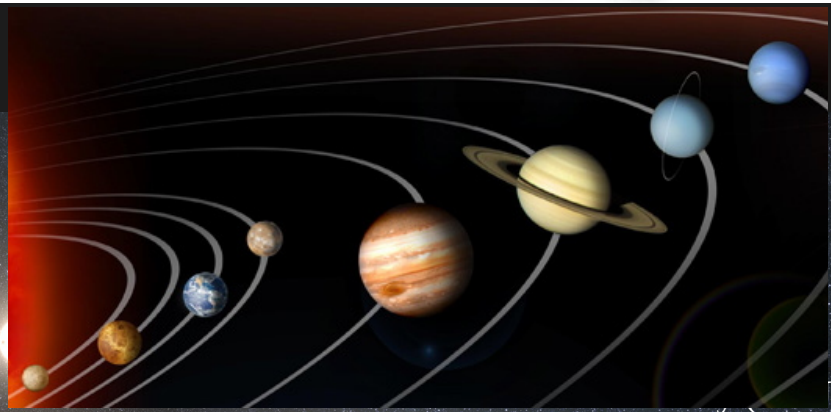


WFIRST
Wide-Field Infrared Survey Telescope
Astrophysics • Dark Energy • Exoplanets

Solar System → Core Accretion & Runaway Growth



Credit: T. Birnstiel

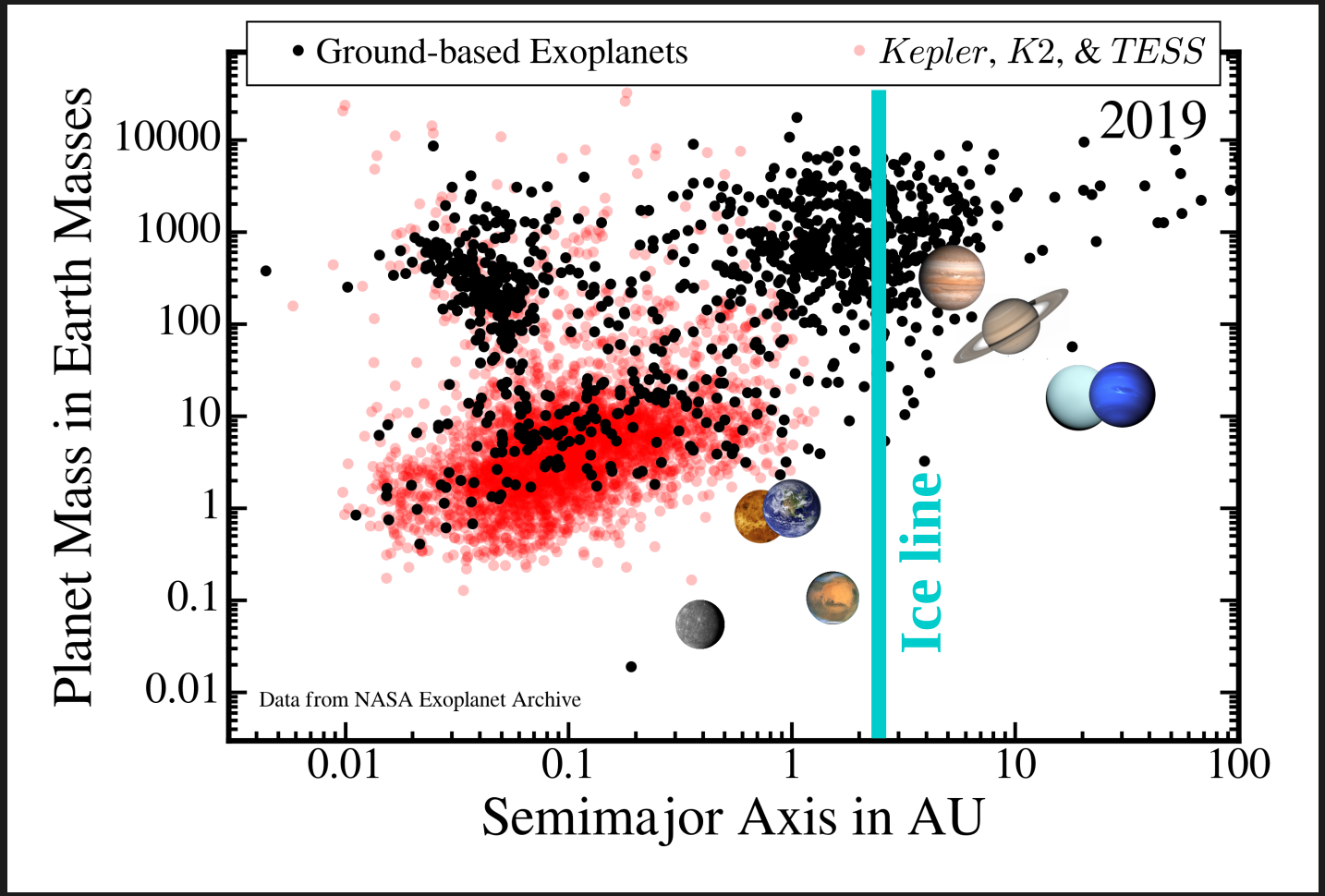


WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

The Status of Exoplanet Demographics

Hot Jupiters:
<~1%
e.g., Cumming+1999,
Udry+2003, Gould+2006

Super Earths,
Mini Neptunes, &
Scorched Rocks:
~30-50%
e.g., Howard+2012,
Fressin+2013, ...



Gas giants:
~10-30%
e.g., Cumming+2008
Gould+2010,
Suzuki+2016

Wide-orbit giants:
<1%
e.g., Bowler+2015,
Nielsen et al. 2019

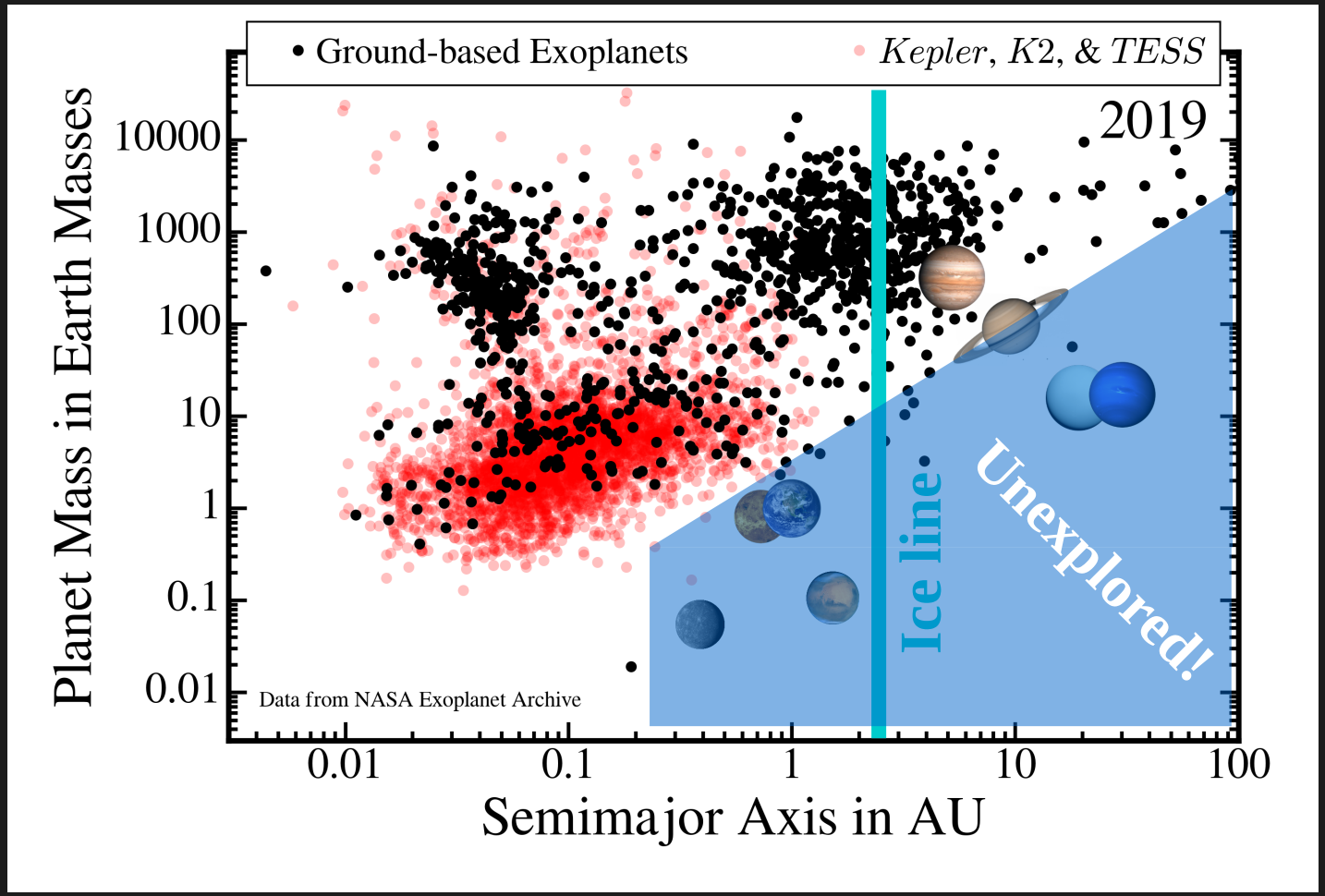
WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

Matthew Penny (OSU)

The Status of Exoplanet Demographics

Hot Jupiters:
<~1%
e.g., Cumming+1999,
Udry+2003, Gould+2006

Super Earths,
Mini Neptunes, &
Scorched Rocks:
~30-50%
e.g., Howard+2012,
Fressin+2013, ...



Gas giants:
~10-30%
e.g., Cumming+2008
Gould+2010,
Suzuki+2016

Wide-orbit giants:
<1%
e.g., Bowler+2015,
Nielsen et al. 2019

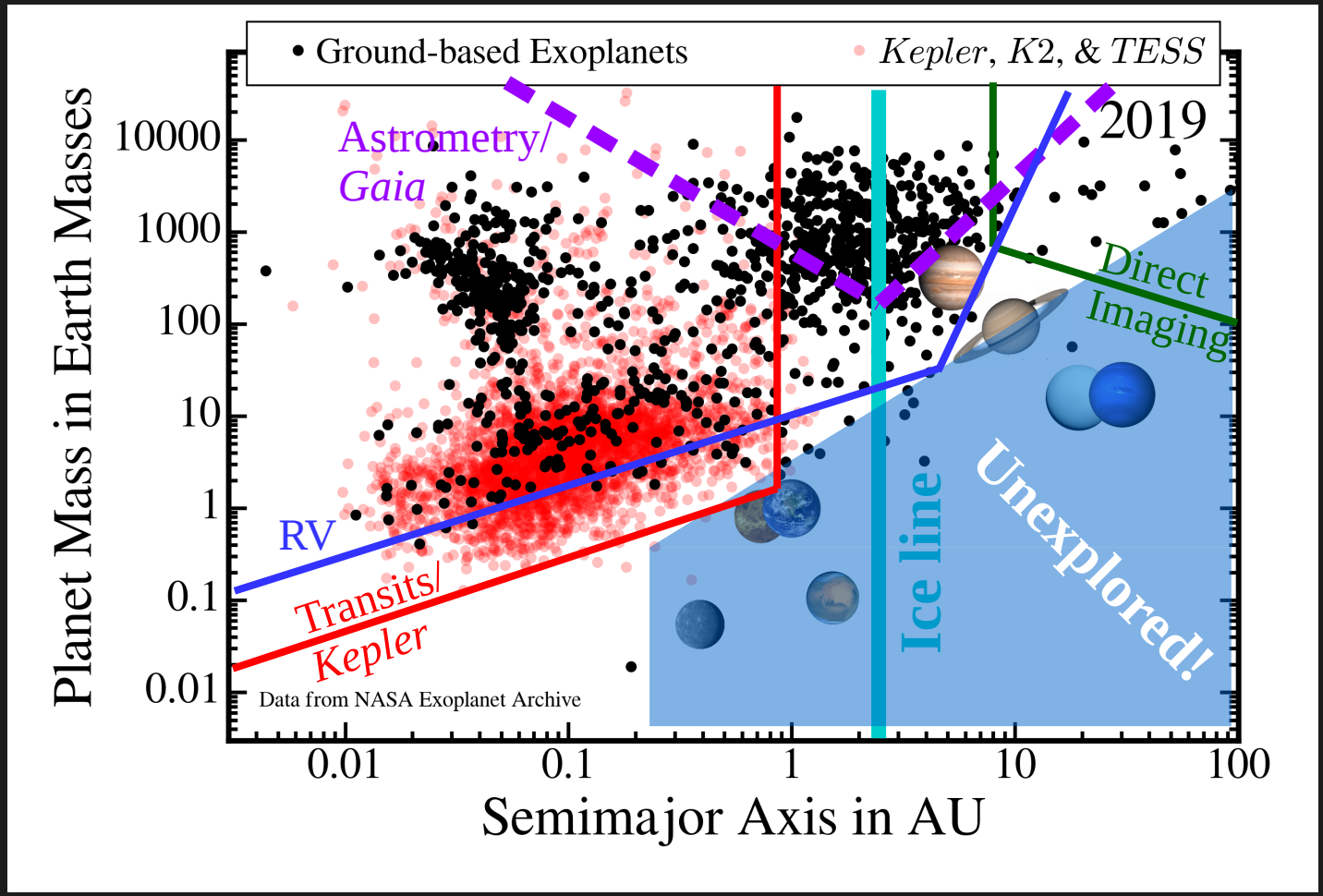
WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

Matthew Penny (OSU)

The Status of Exoplanet Demographics

Hot Jupiters:
<~1%
e.g., Cumming+1999,
Udry+2003, Gould+2006

Super Earths,
Mini Neptunes, &
Scorched Rocks:
~30-50%
e.g., Howard+2012,
Fressin+2013, ...



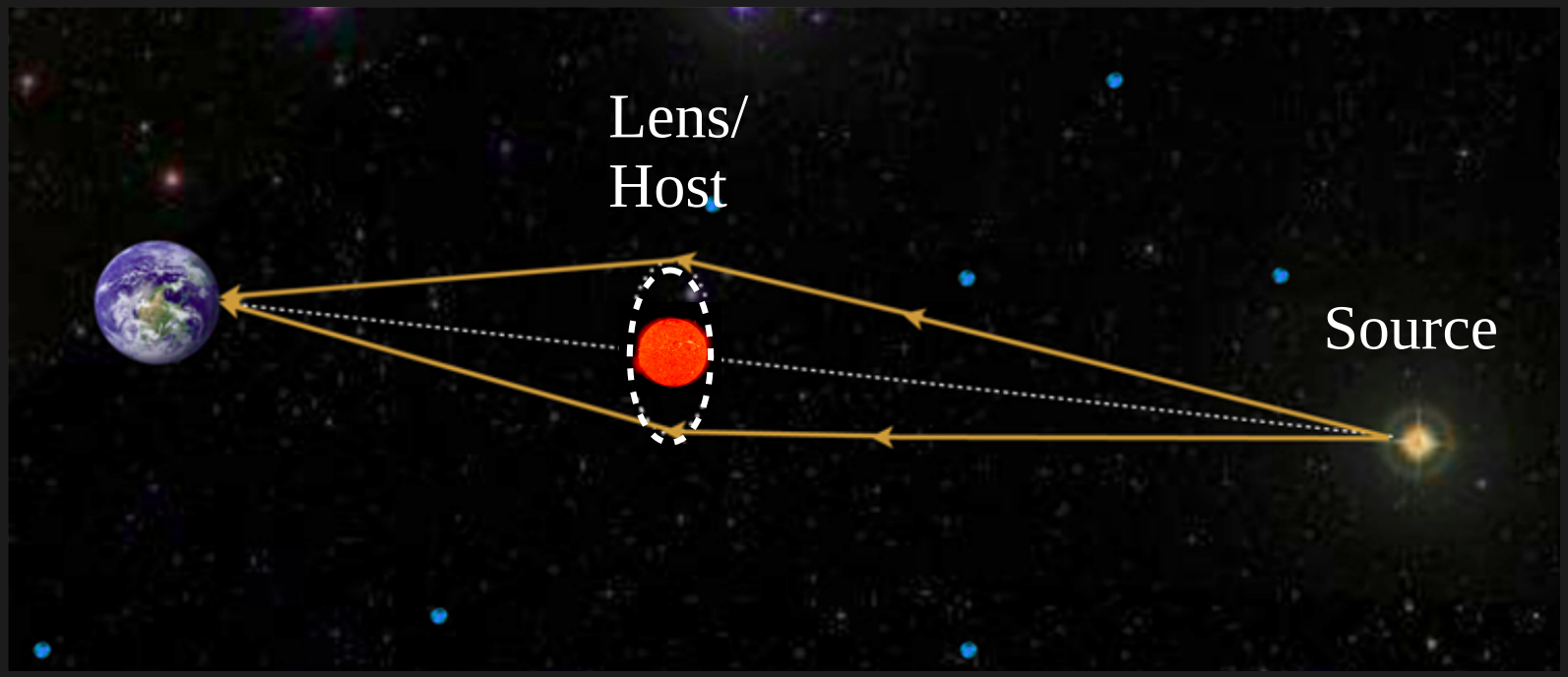
Gas giants:
~10-30%
e.g., Cumming+2008
Gould+2010,
Suzuki+2016

Wide-orbit giants:
<1%
e.g., Bowler+2015,
Nielsen et al. 2019

WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

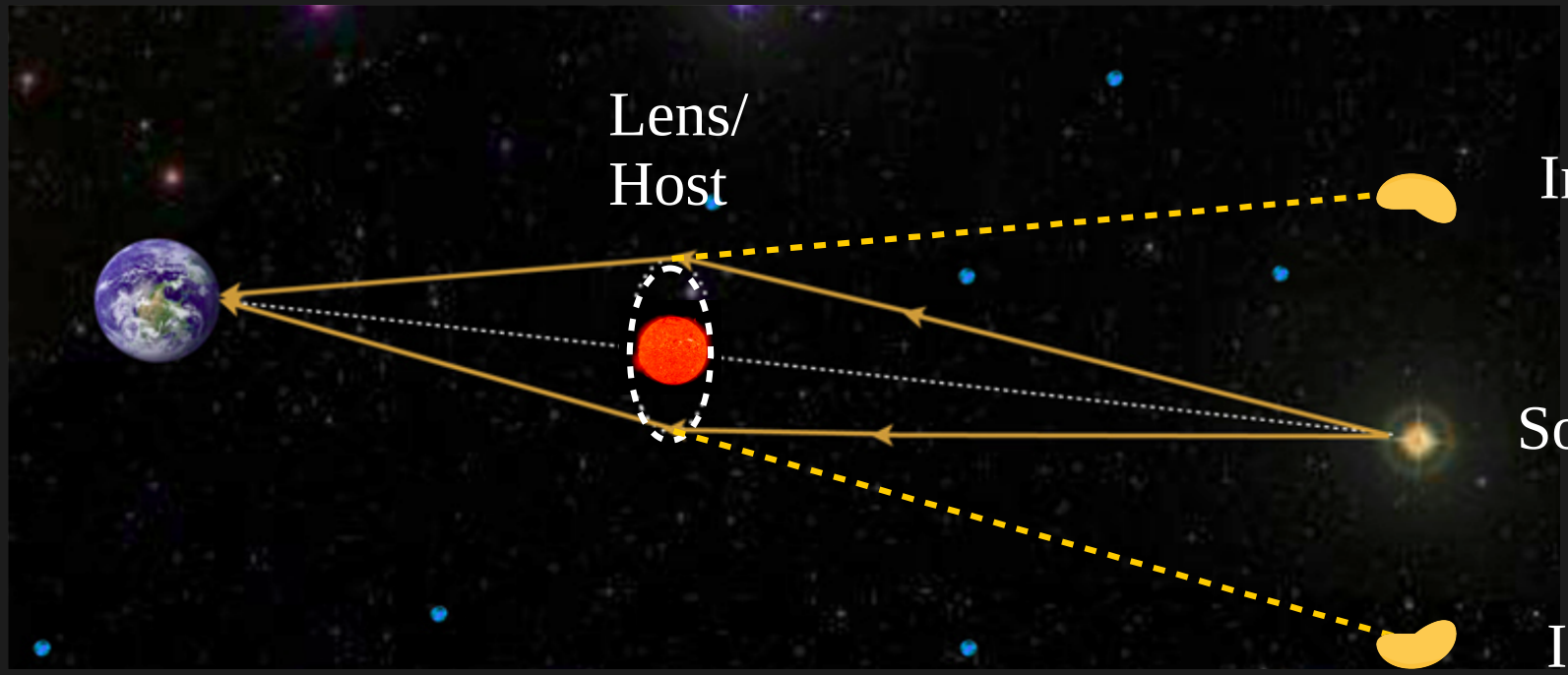
Matthew Penny (OSU)

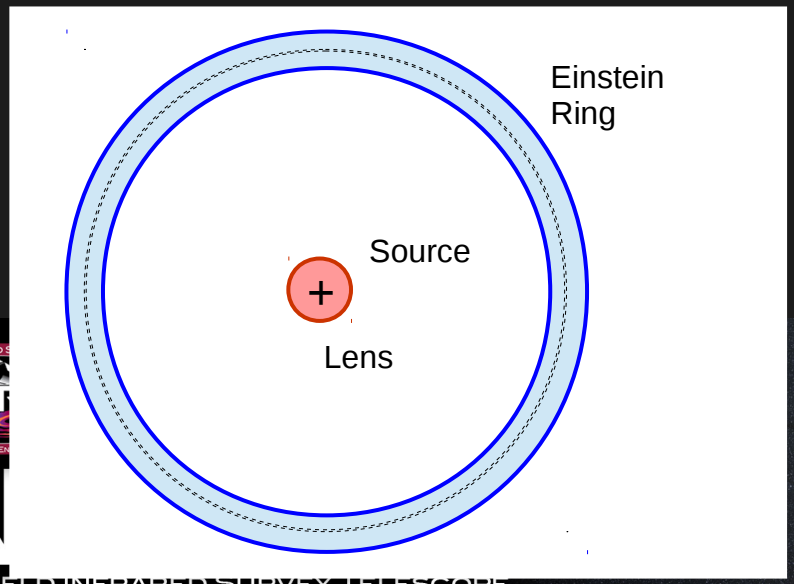
Microlensing 101

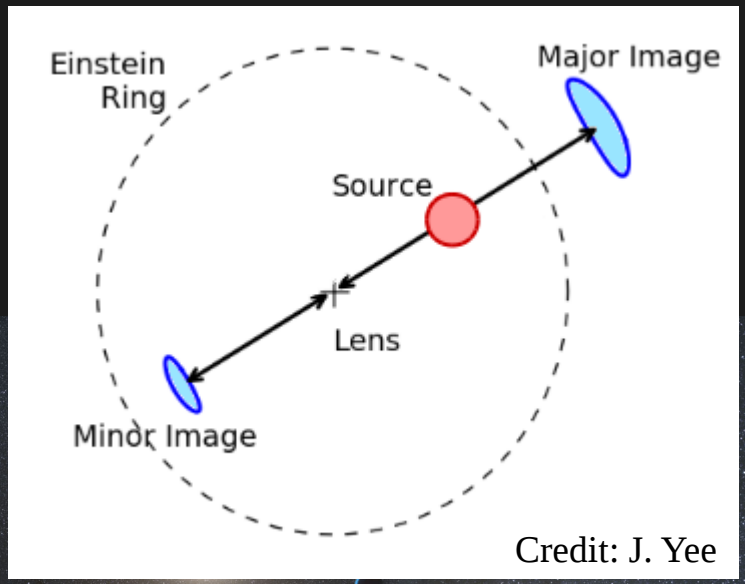


WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

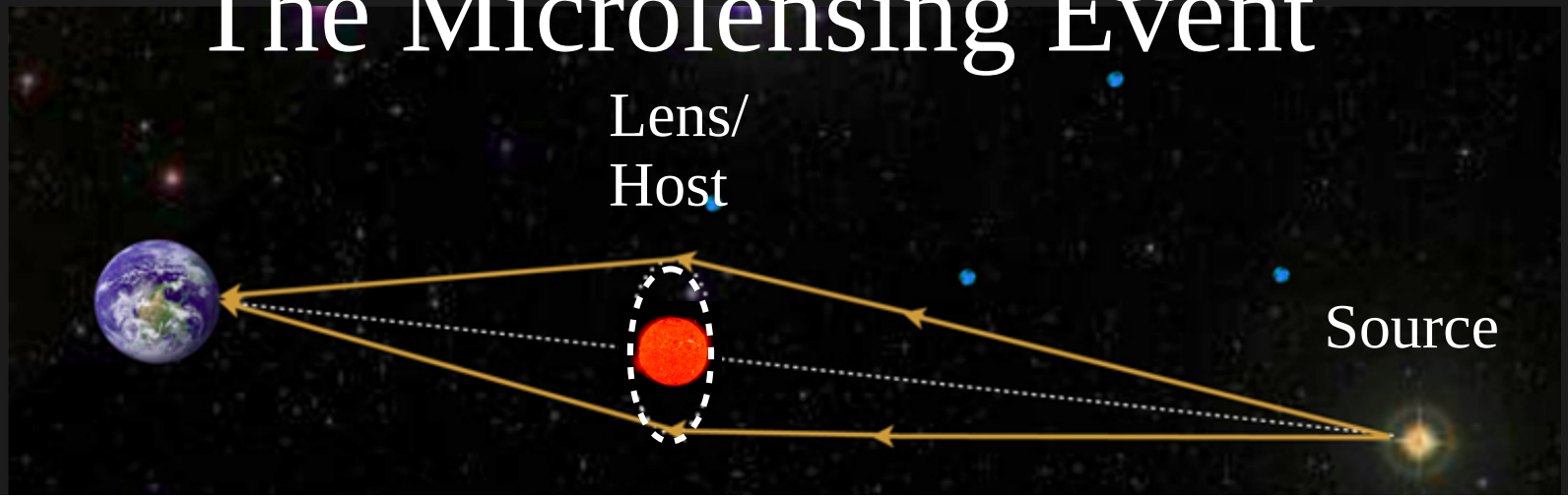
Microlensing 101

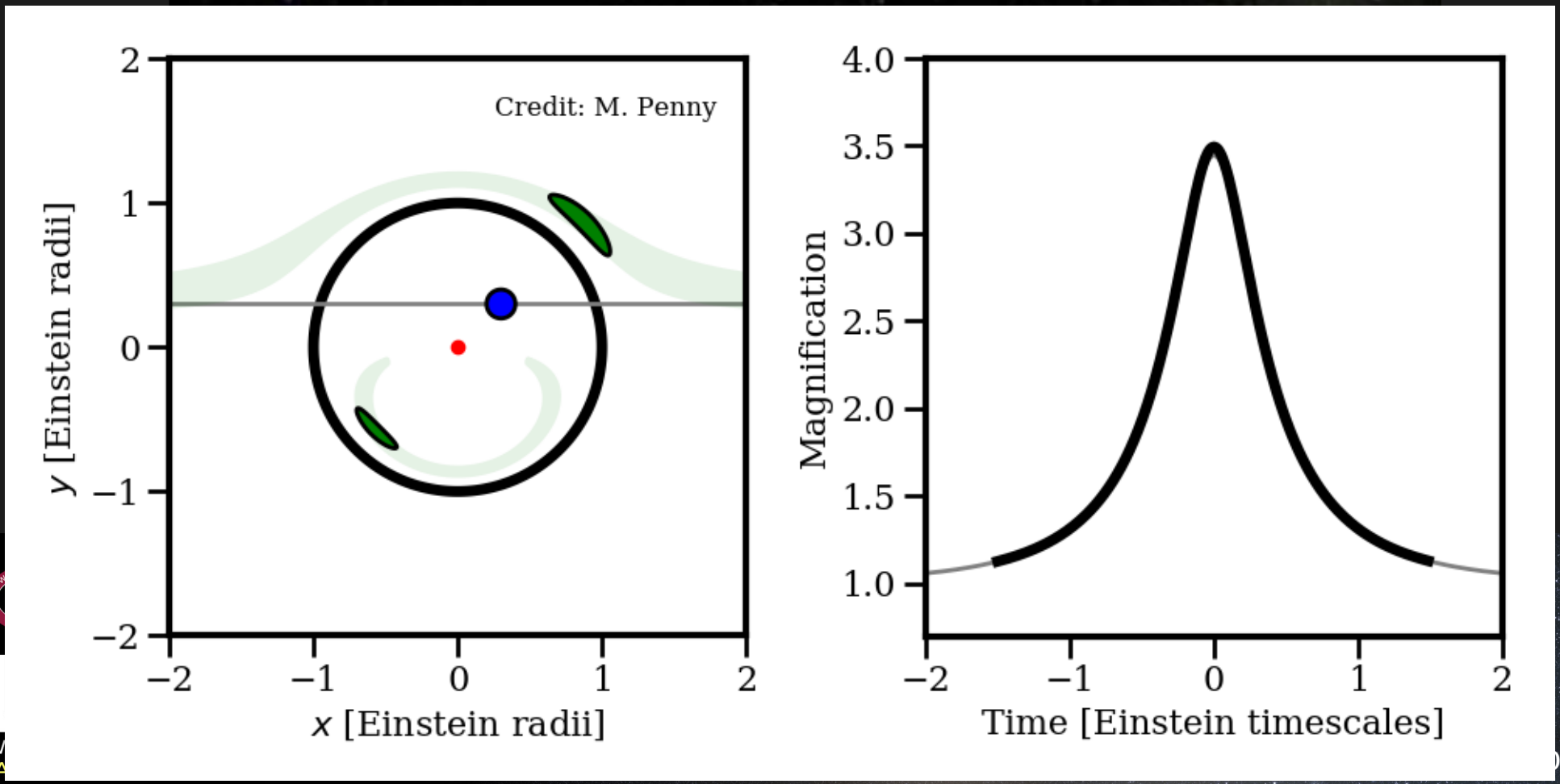




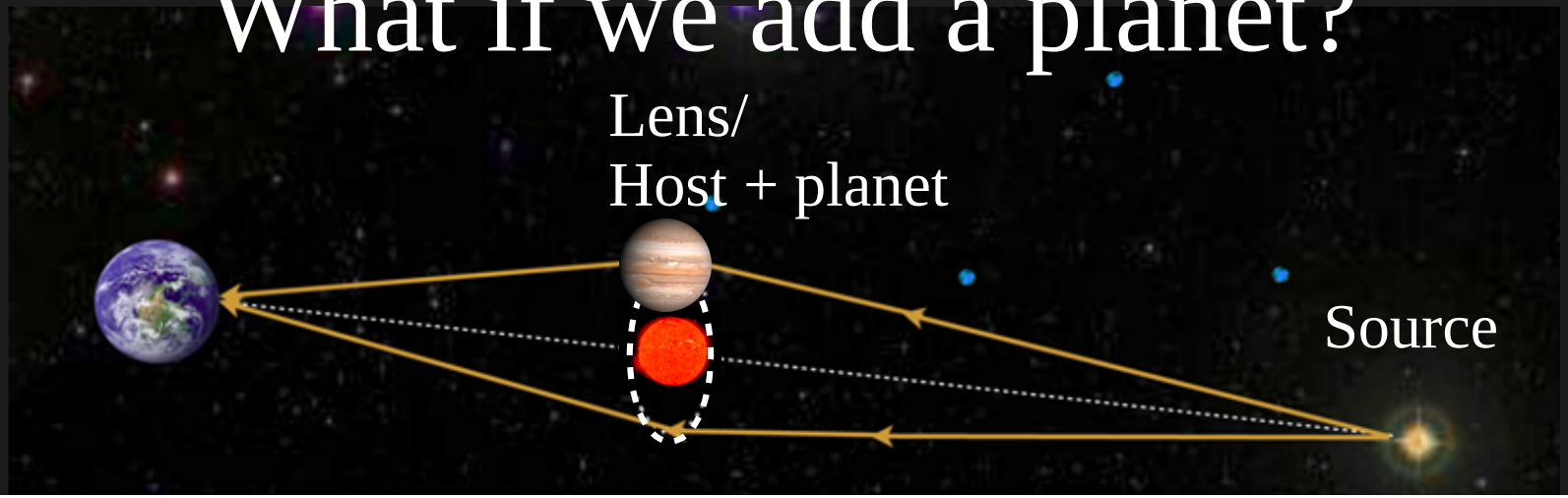


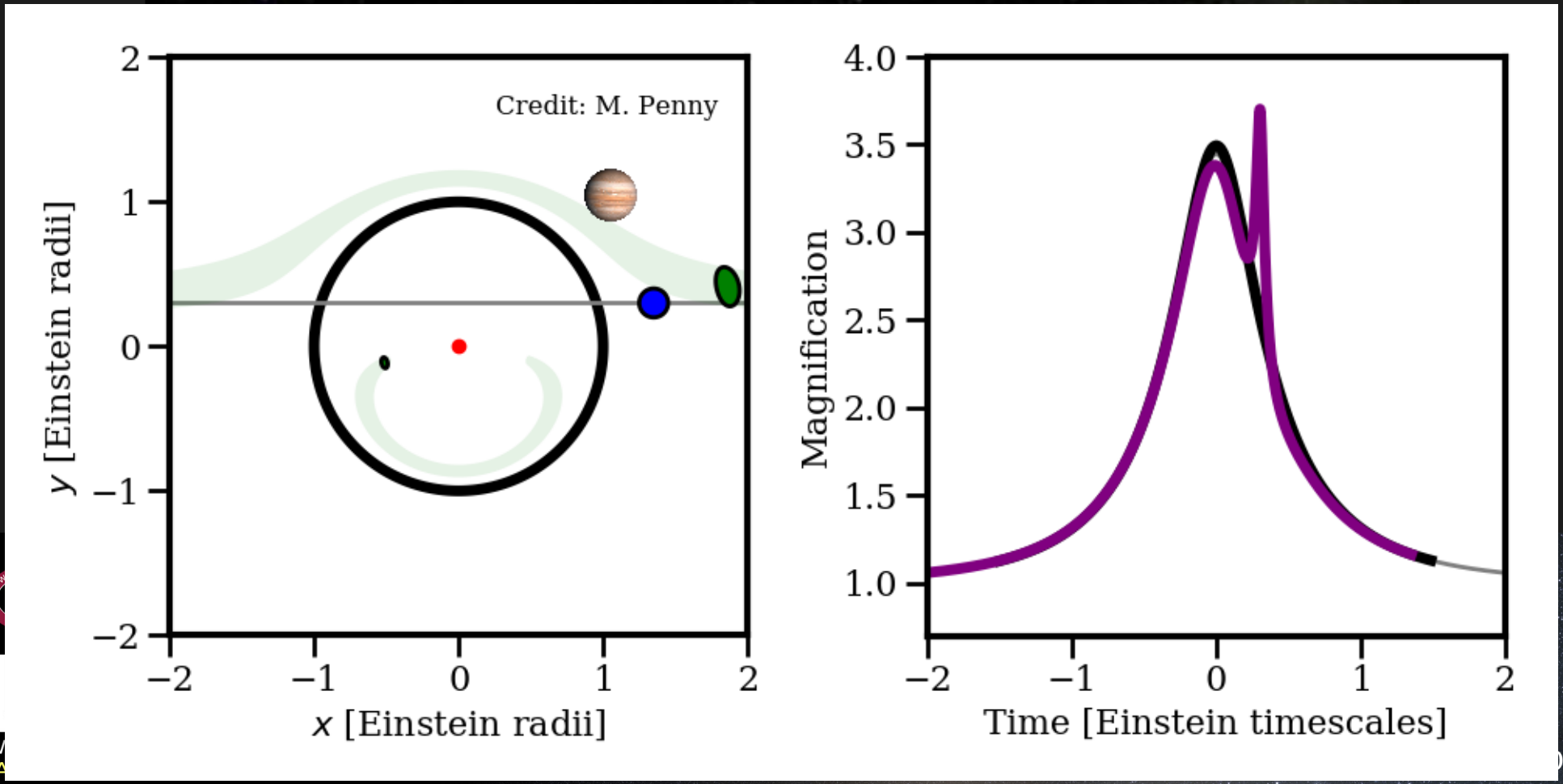
The Microlensing Event





What if we add a planet?





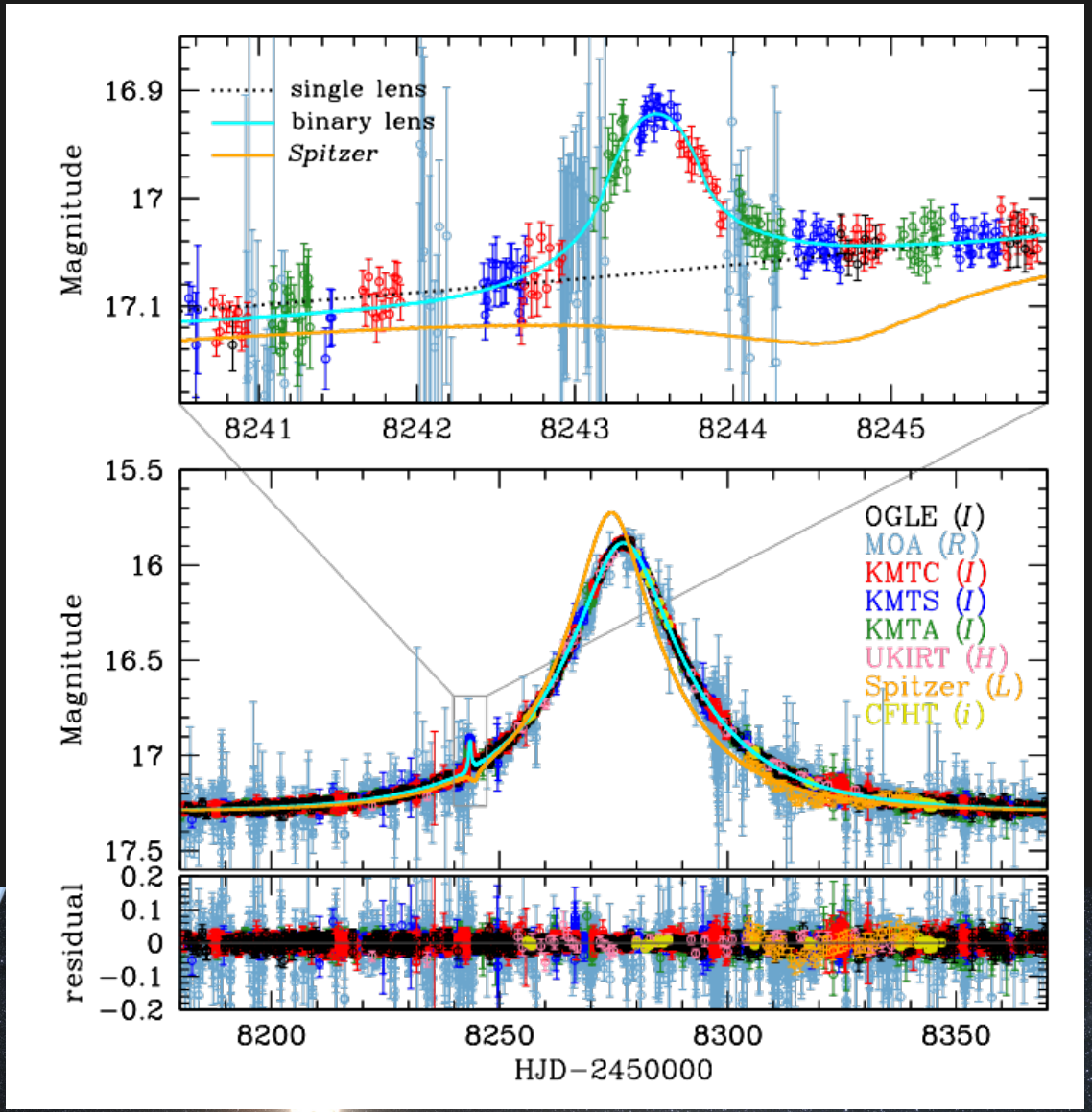
Timescale ~ $\sqrt{\text{Mass}}$

OGLE-2018-BLG-0596
Jung et al. (2019)

OGLE, KMTNet, MOA surveys
+ more

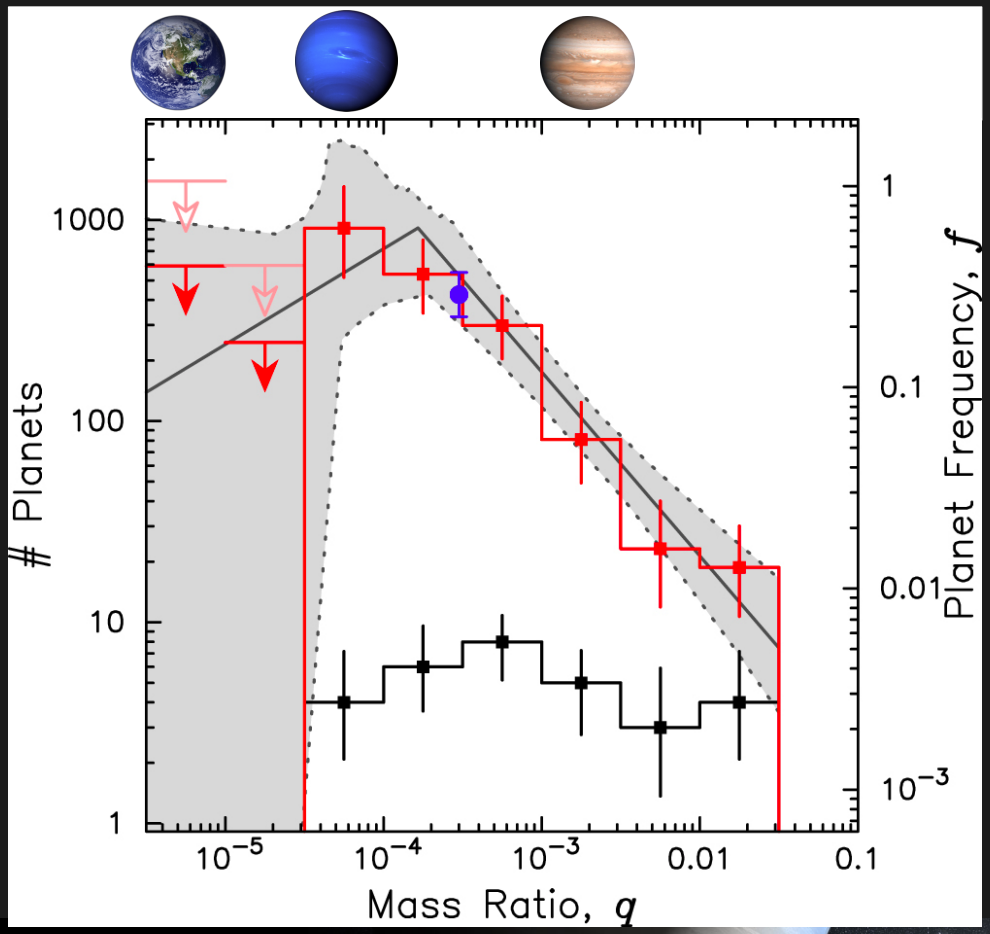
Mass ratio ~ (Duration ratio)^2
~10^{-4}

~14 M_{Earth} + ~0.2 M_{Sun}



WFIRST
Wide-Field Infrared Survey Telescope
Astrophysics • Dark Energy • Exoplanets

Microlensing Demographics So Far



Suzuki et al. (2016, 2018)

>70 Microlensing planets to date

Suzuki et al. (2016) used 22 detections from 5 years of data from the MOA survey

More cold Neptunes than Jupiters (confirms Sumi et al. 2010, Gould et al. 2010, Cassan et al. 2012)

Strong evidence for a break in the mass ratio function, corroborated by other studies (e.g., Udalski et al. 2018, Jung et al. 2018)

WFIRST
Wide-Field Infrared Survey Telescope
Astrophysics • Dark Energy • Exoplanets

Observing Microlensing: Making the stars align

Detecting microlensing by stars

- Rate:

  ~ 1 event/star/100,000 years
- Duration:

  ~few months

- Need to observe millions of stars, ~weekly, for ~year+

WFIRST
Wide-Field Infrared Survey Telescope
Astrophysics • Dark Energy • Exoplanets

Microlensing to find 100 Earths

Microlensing by Earth

Scale by ~ $\sqrt{3 \times 10^{-6}}$

- Rate:

  ~ event/star/10^7 years
- Duration:

  ~few hours

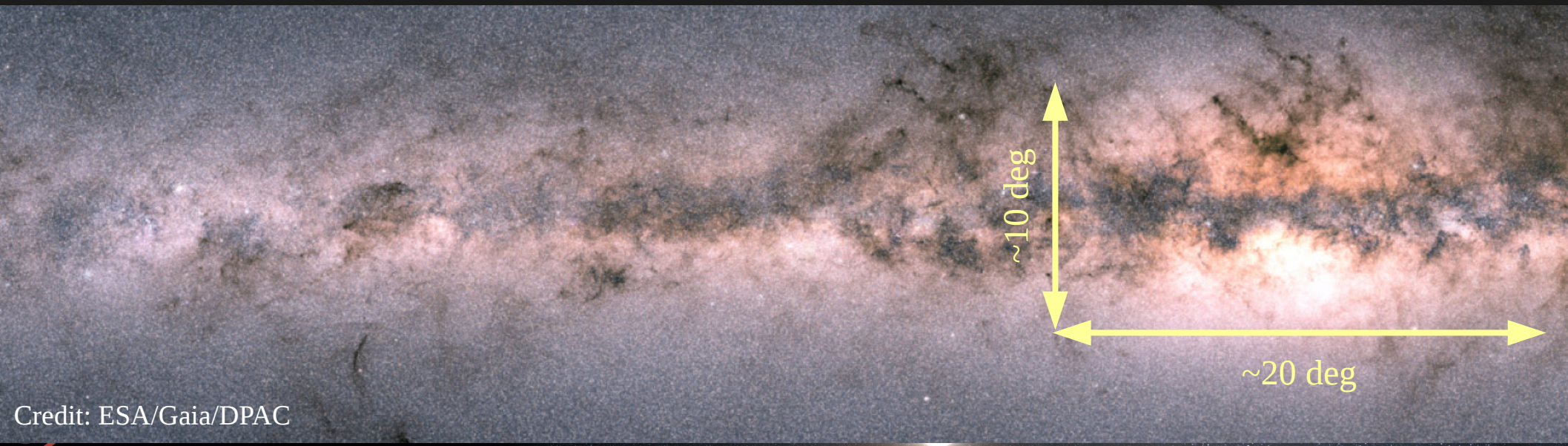
- Need to observe ~100 million of stars, every ~15 min, for ~year+

WFIRST
Wide-Field Infrared Survey Telescope
Astrophysics • Dark Energy • Exoplanets

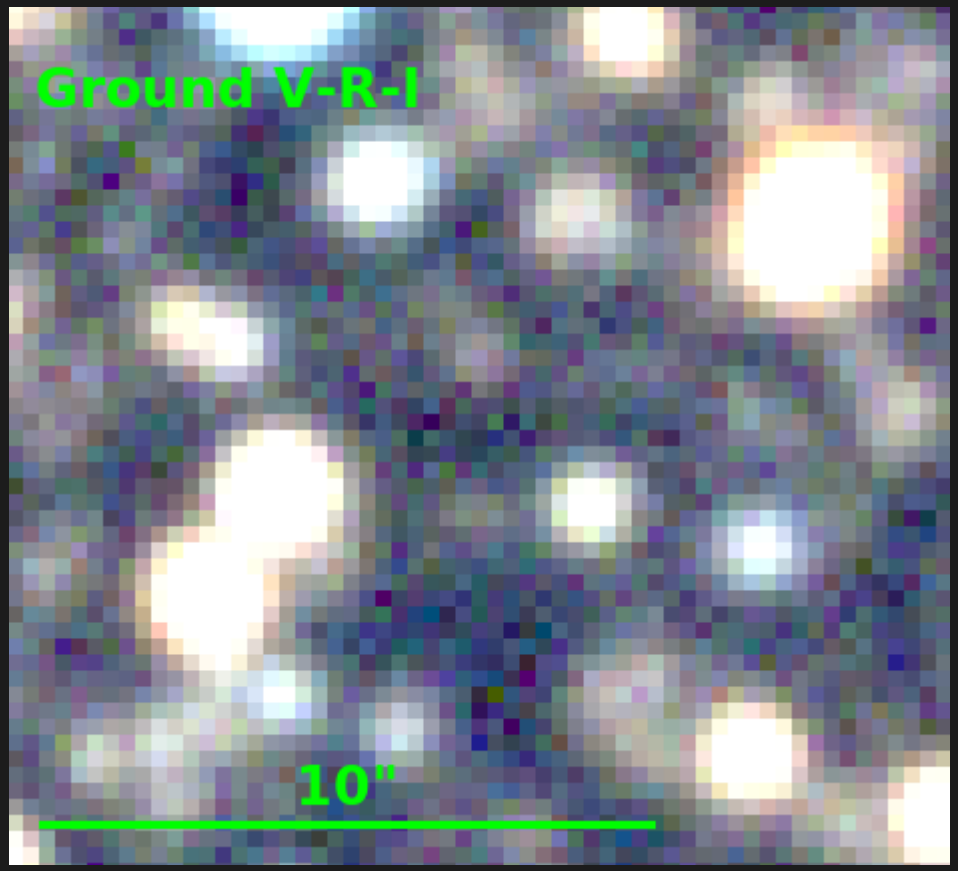
Requirements for a Planetary Microlensing Survey

Survey Requirements (100 Earths)

- monitor ~few **hundred** million stars every 15 min for ~year
- Bright stellar density (I<18): ~million stars/deg^2
  - **Survey size: ~100 deg^2**



Space Enables resolution of the bulge main sequence

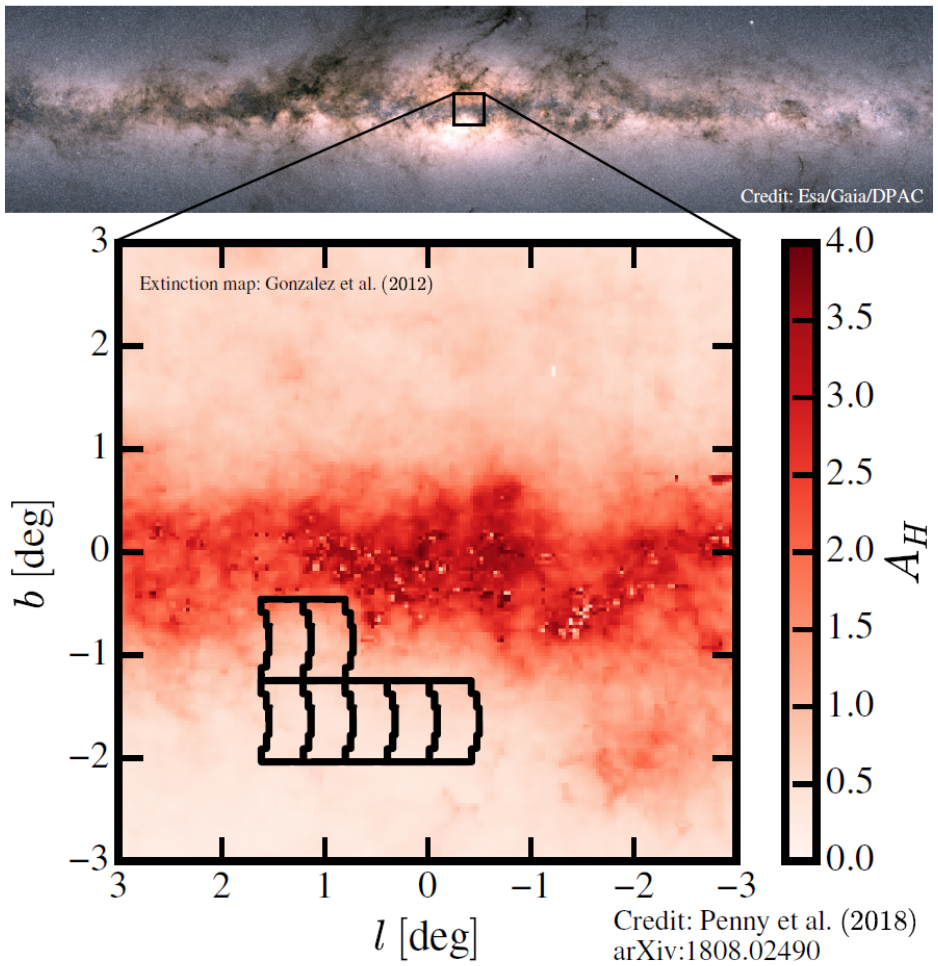


Penny et al. (2018)
https://github.com/mtpenny/wfirst-ml-figures

WFIRST
Wide-Field Infrared Survey Telescope
Astrophysics • Dark Energy • Exoplanets

Matthew Penny (OSU)

WFIRST's Microlensing Survey



https://github.com/mtpenny/wfirst-ml-figures

~2 deg² (7 fields)

6 x 72 day seasons

15 min cadence

<12 hour color cadence

(R or Z and F184)

4.5 yr baseline

1-2 μm bandpass

~100 million stars

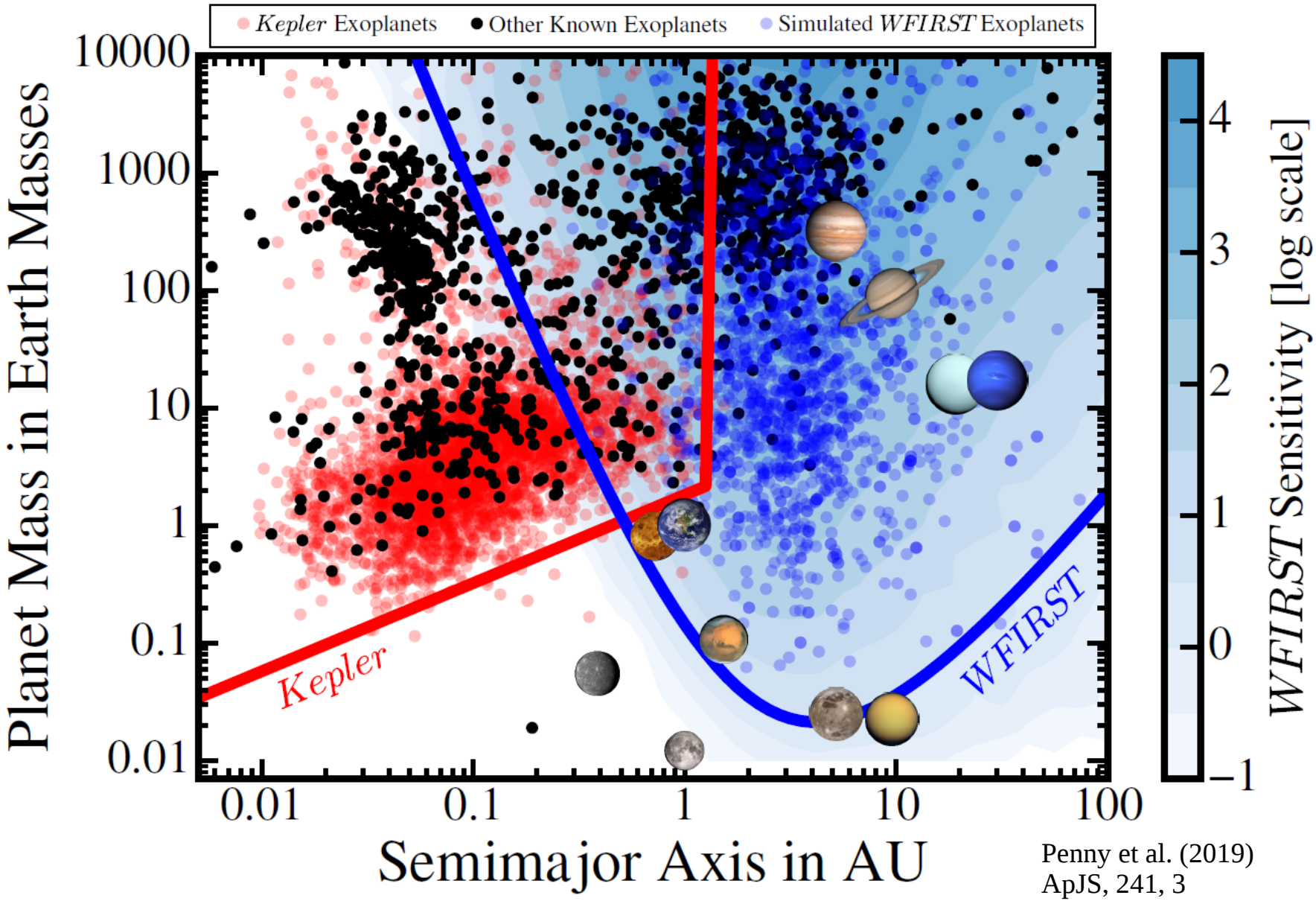
~20,000 microlensing events

WFIRST

Wide-Field Infrared Survey Telescope

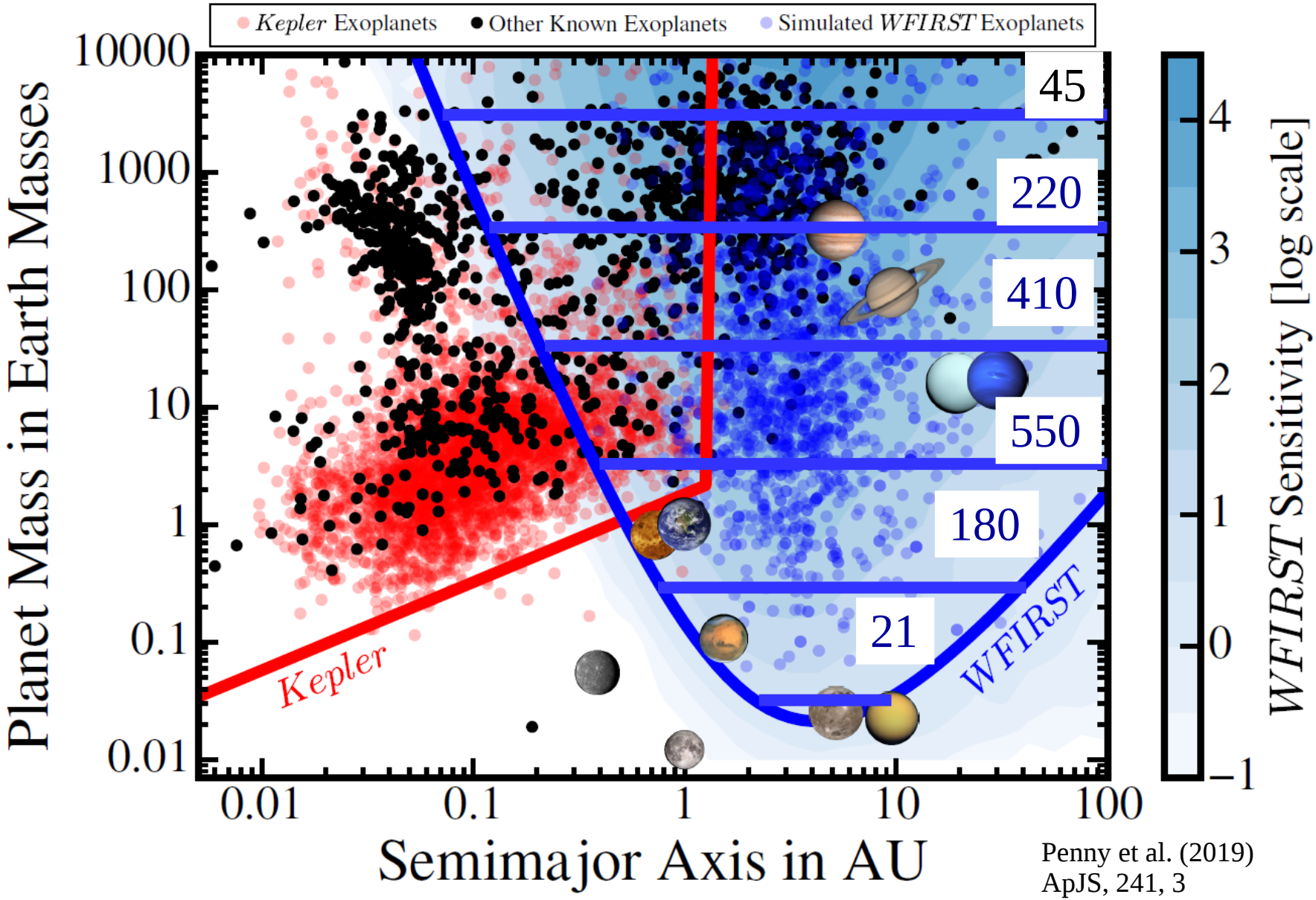
Astrophysics • Dark Energy • Exoplanets

WFIRST: ~1400 cold exoplanets



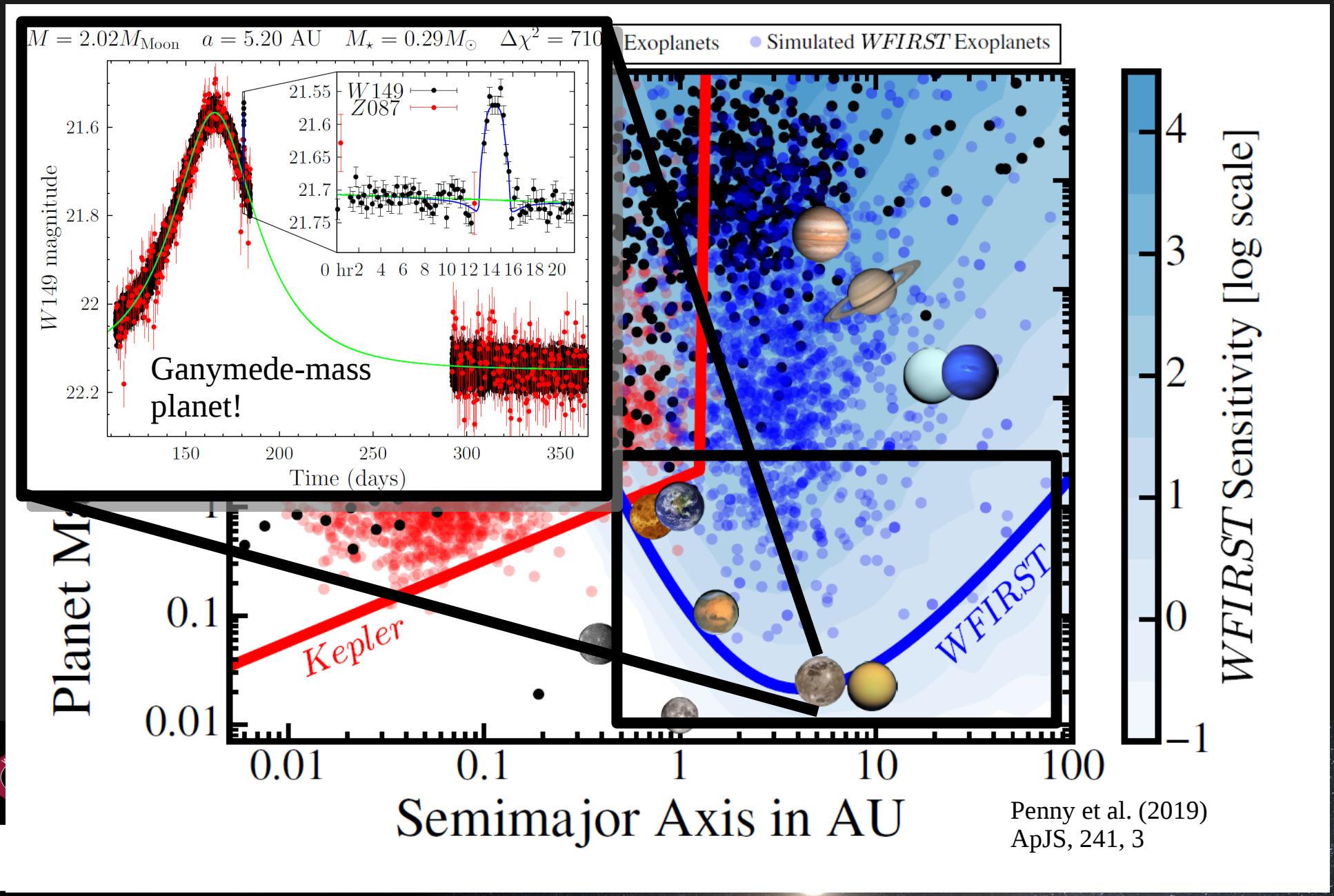
Penny et al. (2019)
ApJS, 241, 3

WFIRST: ~1400 cold exoplanets



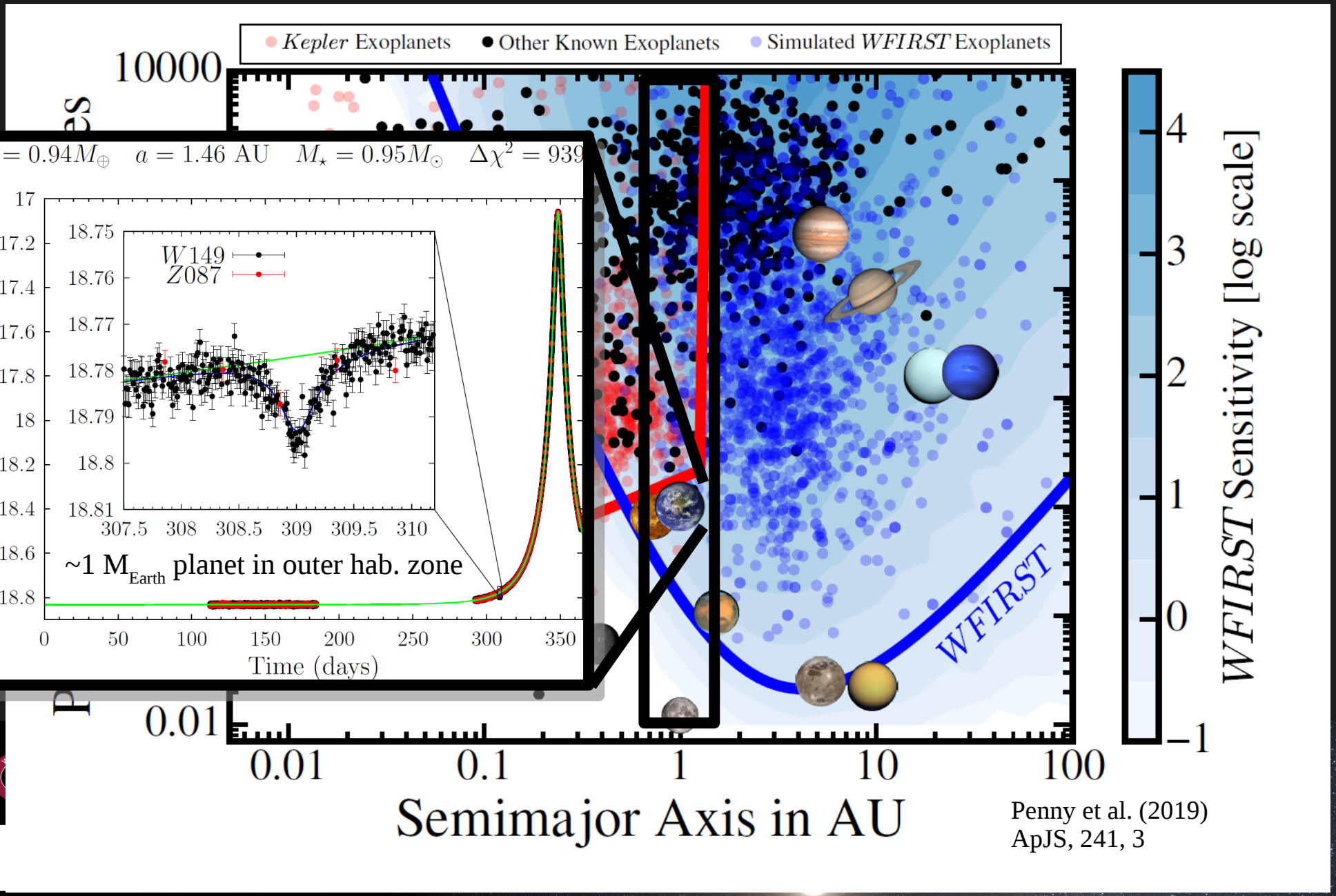
Penny et al. (2019)
ApJS, 241, 3

WFIRST: *Really* Low-Mass Exoplanets



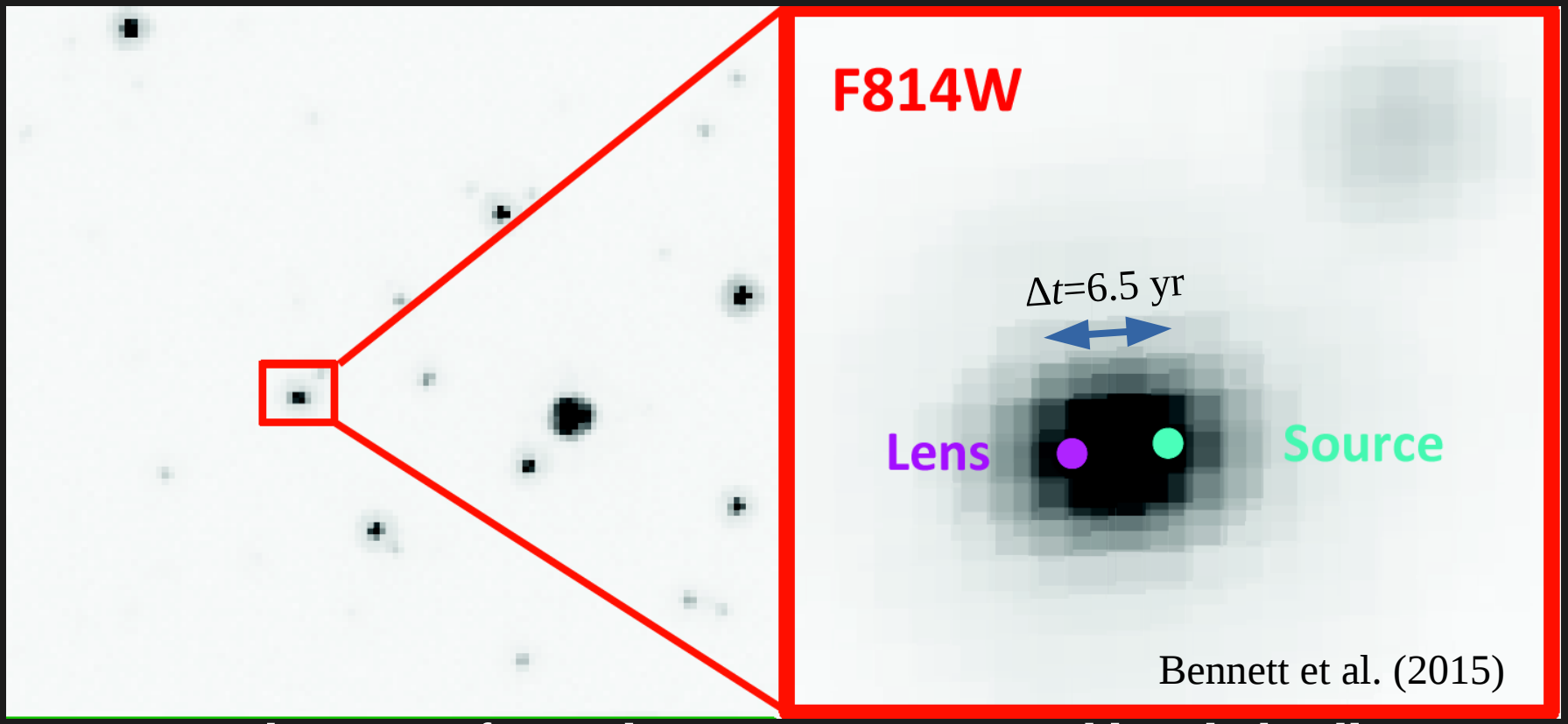
Penny et al. (2019)
ApJS, 241, 3

WFIRST: Habitable Zone Exoplanets



Penny et al. (2019)
ApJS, 241, 3

WFIRST's resolution enables measurement of host & planet masses

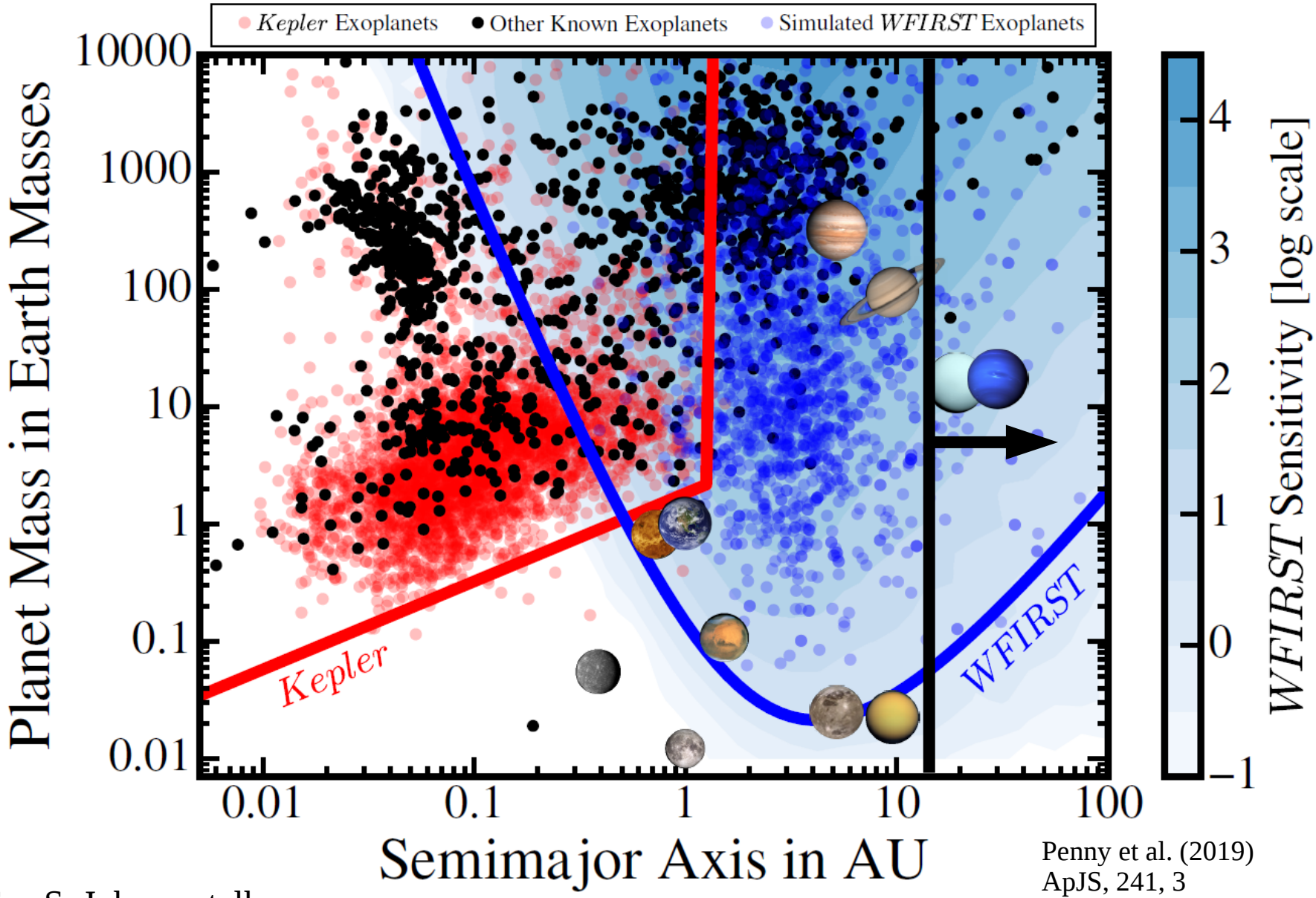


Combination of microlensing parameters and lens light allows estimate of lens mass

WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

Matthew Penny (OSU)

Distant and free floating planets

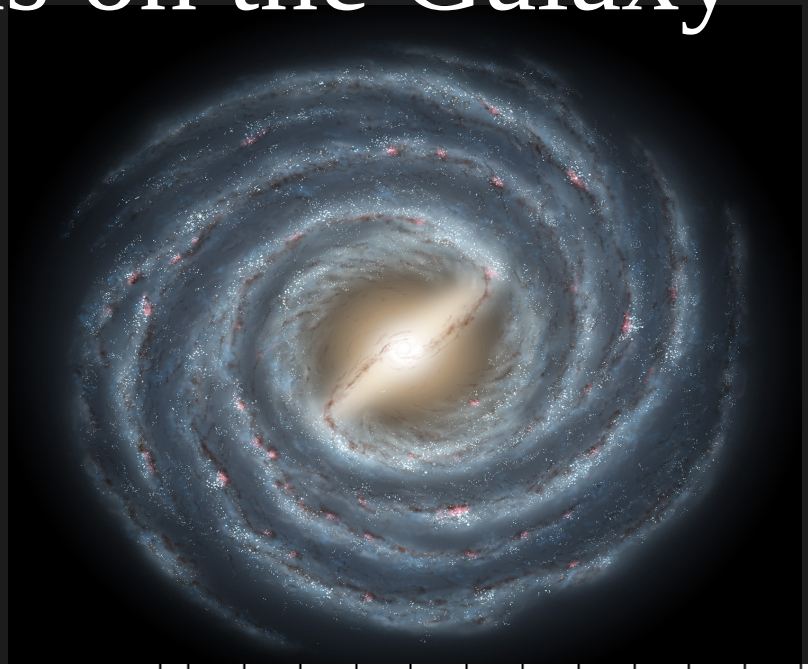


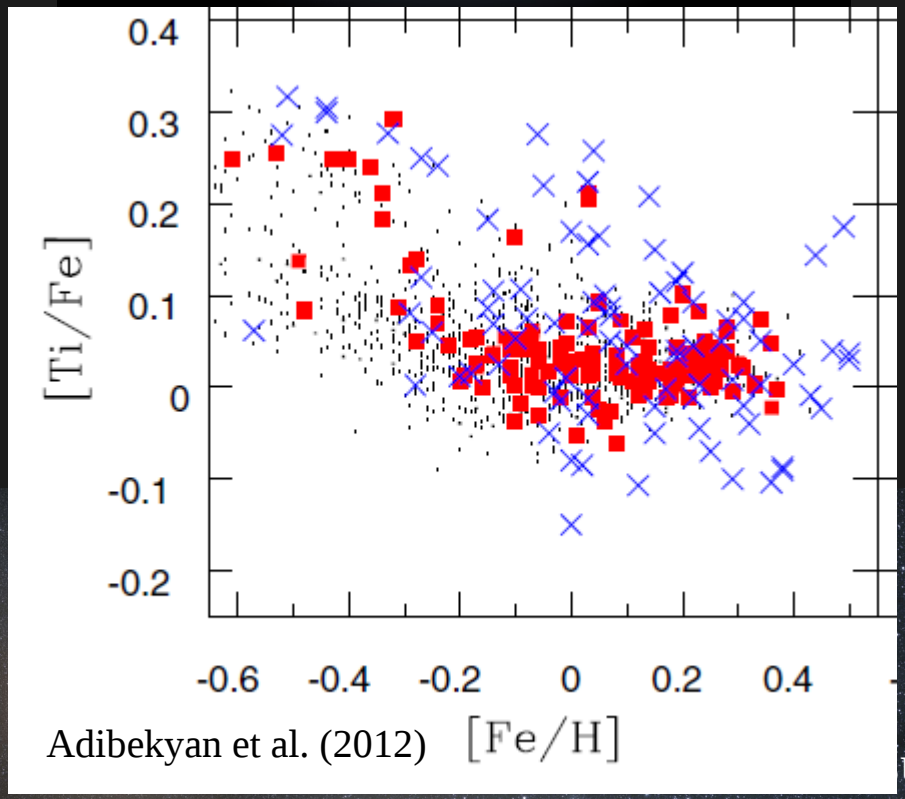
Penny et al. (2019)
ApJS, 241, 3

See S. Johnson talk

Microlensing Depends on the Galaxy

- Lensing by mix of disk and bulge stars
- Exact bulge-disk mix depends on densities, kinematics, populations, mass function, etc.
- Planet occurrence depends on [Fe/H] *and* [α/Fe]
- **Understanding *WFIRST* microlensing planets requires understanding the Milky Way**
- ***WFIRST* microlensing can be used to better understand the Milky Way**





Adibekyan et al. (2012)

WFIRST
Wide-Field Infrared Survey Telescope
Astrophysics • Dark Energy • Exoplanets

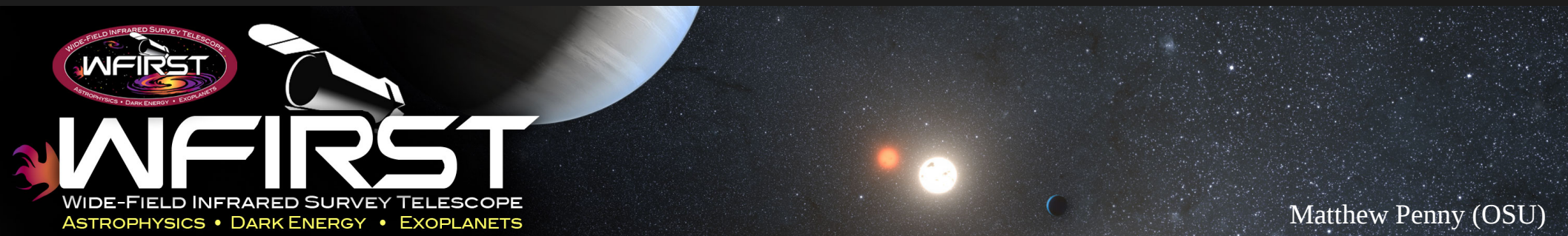
U)

Ongoing Efforts to Maximize the Return of the Microlensing Survey

- UKIRT microlensing survey to constrain IR event rate (see talk by Geoff Bryden)
- HST & Keck high-resolution follow-up programs to develop mass measurement methods
- Data challenges to improve modeling & analysis methods (see talk by David Bennett)
- Exploring parallaxes and masses of free-floating planets with simultaneous Euclid and ground-based observations
- Flexible population synthesis galactic models (Macy Huston & Abby Aronica)
- Much more work by the MicroSIT (e.g., pipelines, etc.)...

Additional Science with the *WFIRST* Microlensing Survey

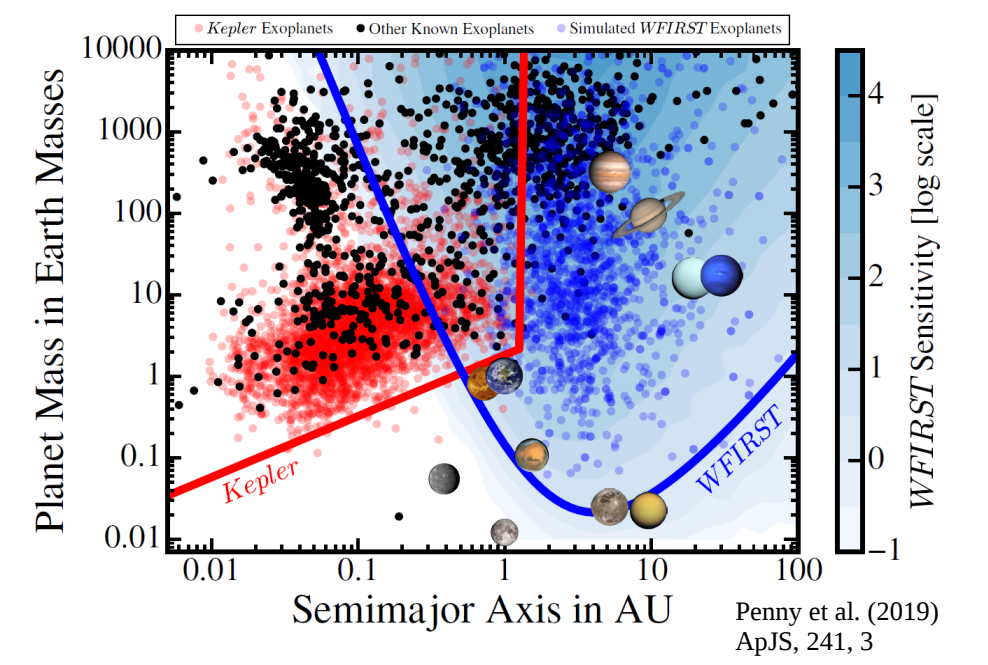
- 2 deg^2, ~41,000 epochs, 15 minute cadence, 4.5 year baseline, >100 million stars, 6-12 hour color cadence
- All data made public ASAP
- Support for guest investigators and guest observer programs
- See talks by Scott Gaudi, Casey Lam, & David Bennett
- How does your work impact the WFIRST microlensing survey?



Conclusions

Exoplanet demographics are incomplete beyond 1AU

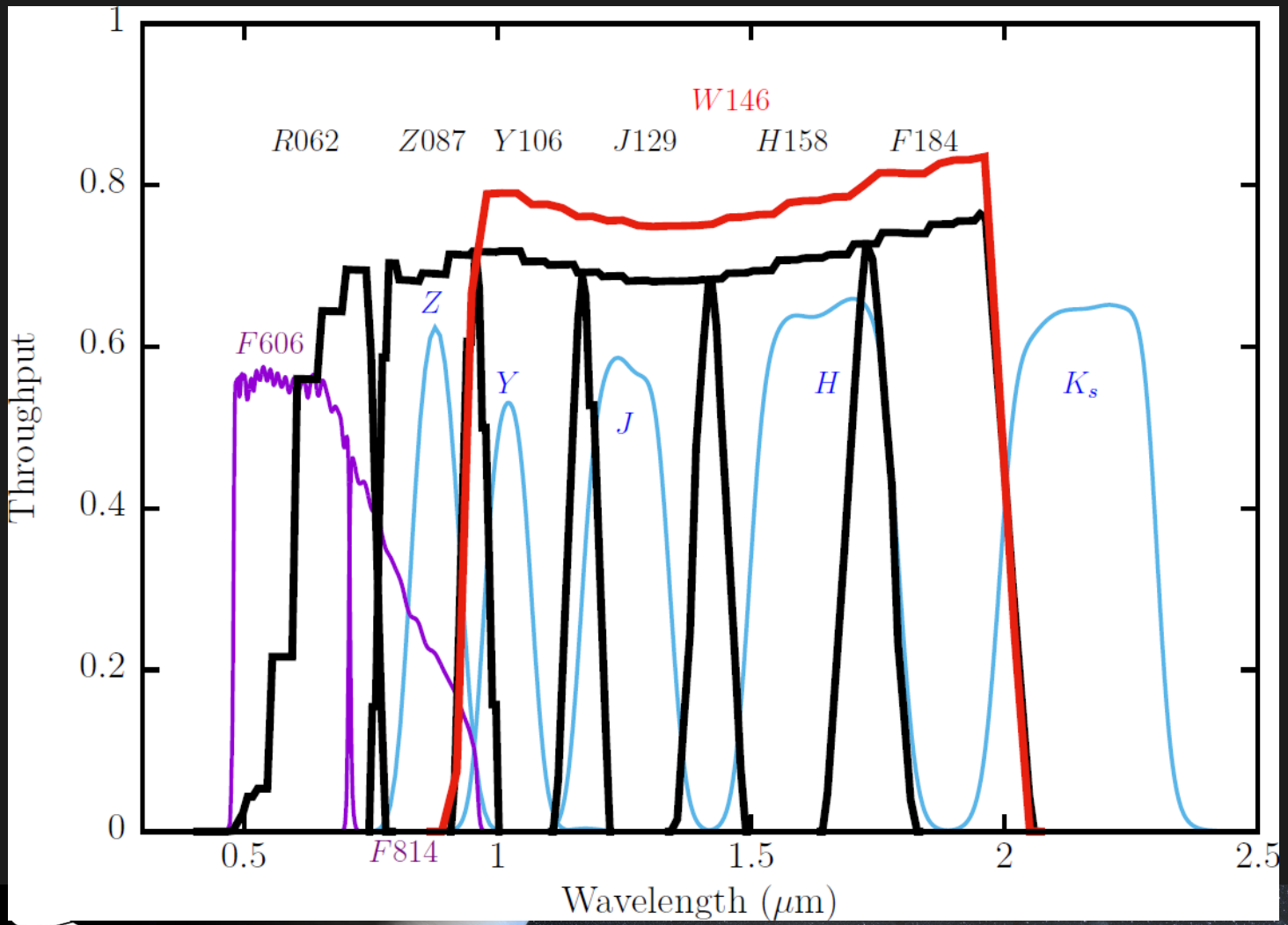
WFIRST will complete the exoplanet census and detect ~1400 planets >1AU, M>0.01 M_{Earth} + measure their masses



Penny et al. (2019)
ApJS, 241, 3

WFIRST
Wide-Field Infrared Survey Telescope
Astrophysics • Dark Energy • Exoplanets

WFIRST's Filters



WFIRST
Wide-Field Infrared Survey Telescope
Astrophysics • Dark Energy • Exoplanets

Matthew Penny (OSU)