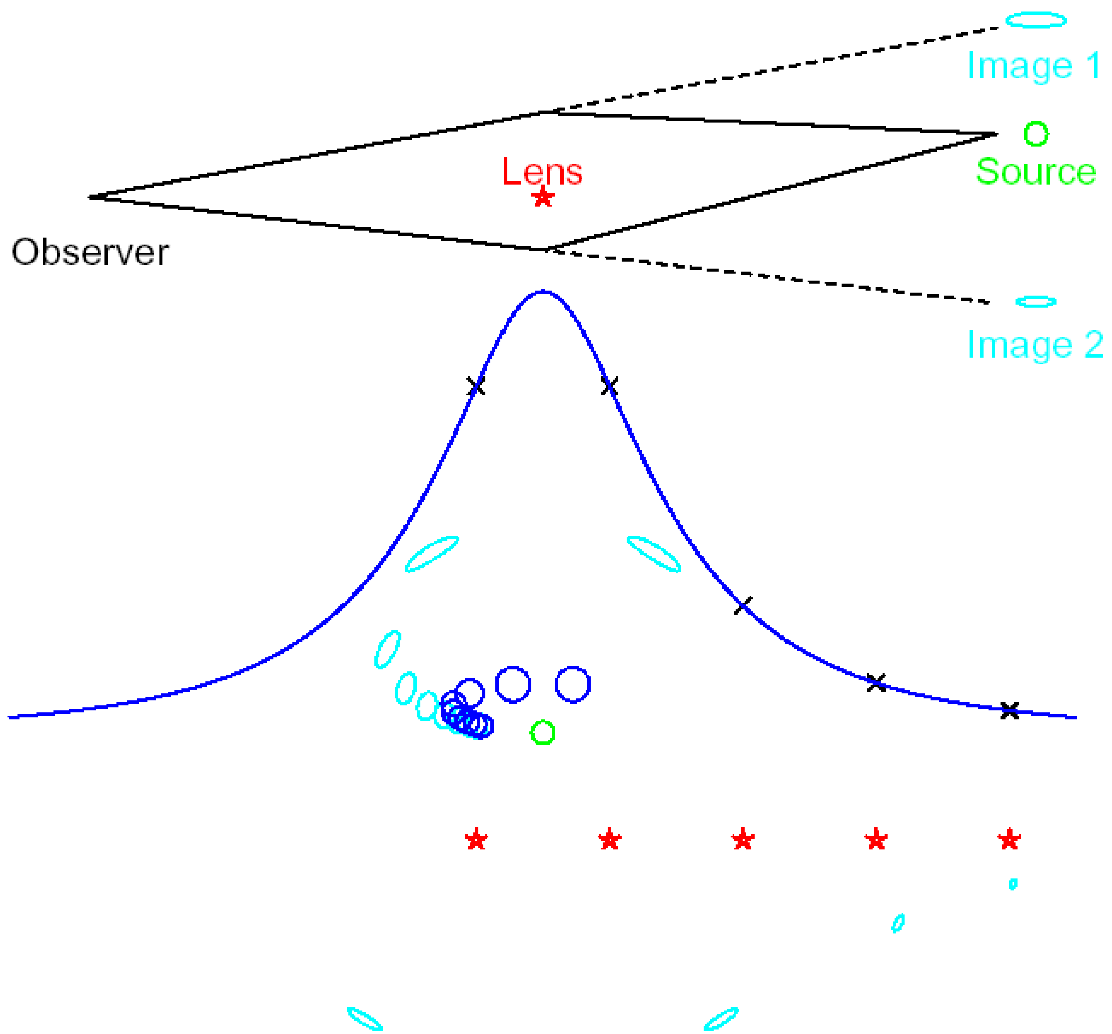
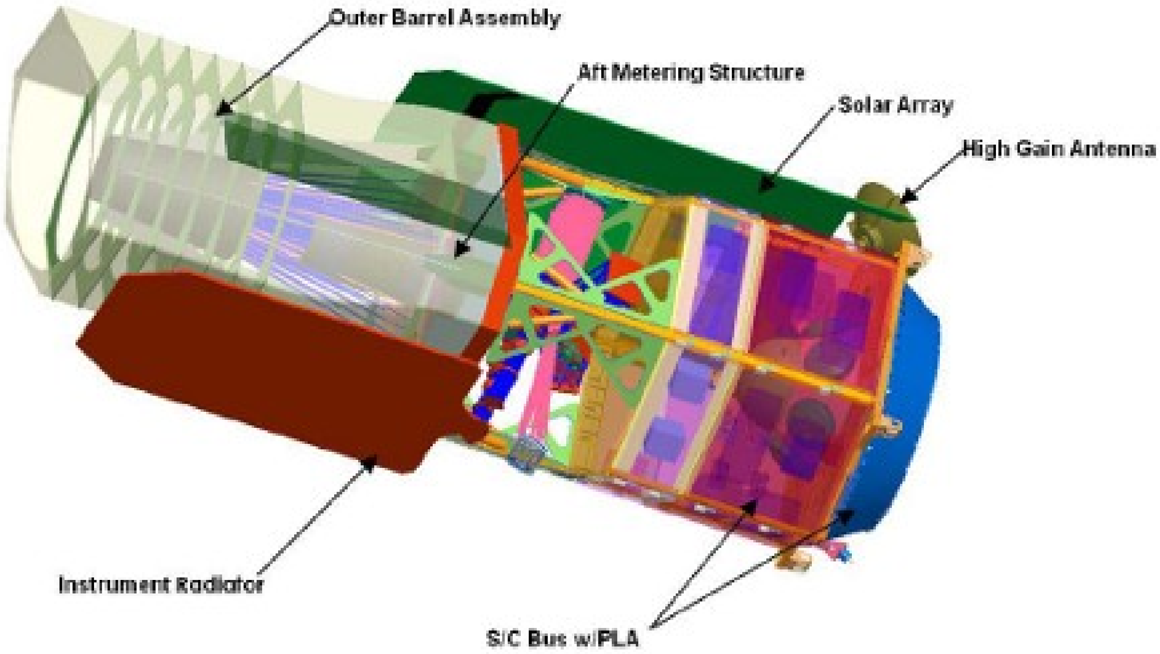
Non-Microlensing Science from WFIRST Microlensing Data

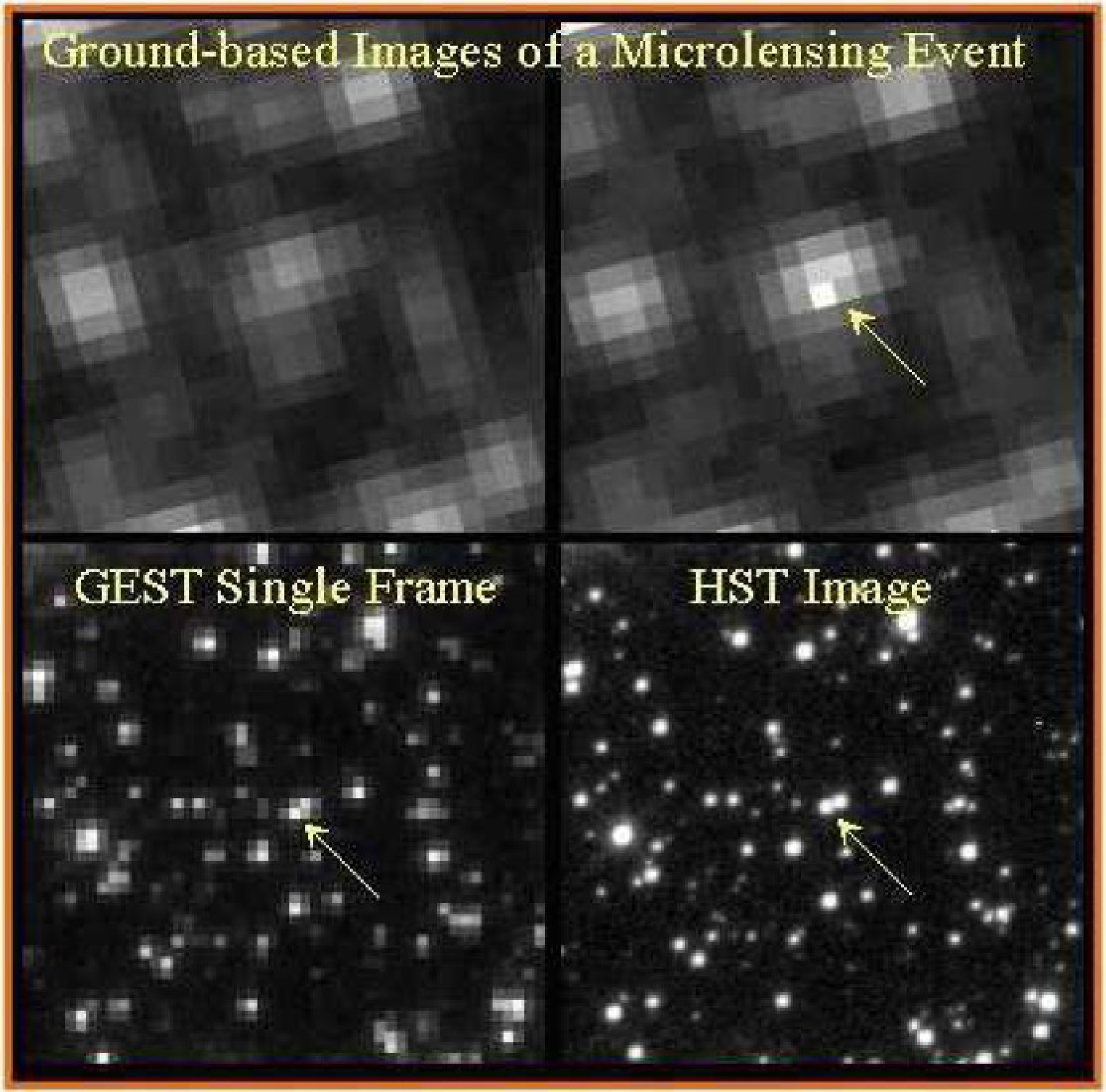
Andy Gould (MPIA/KASI/OSU)

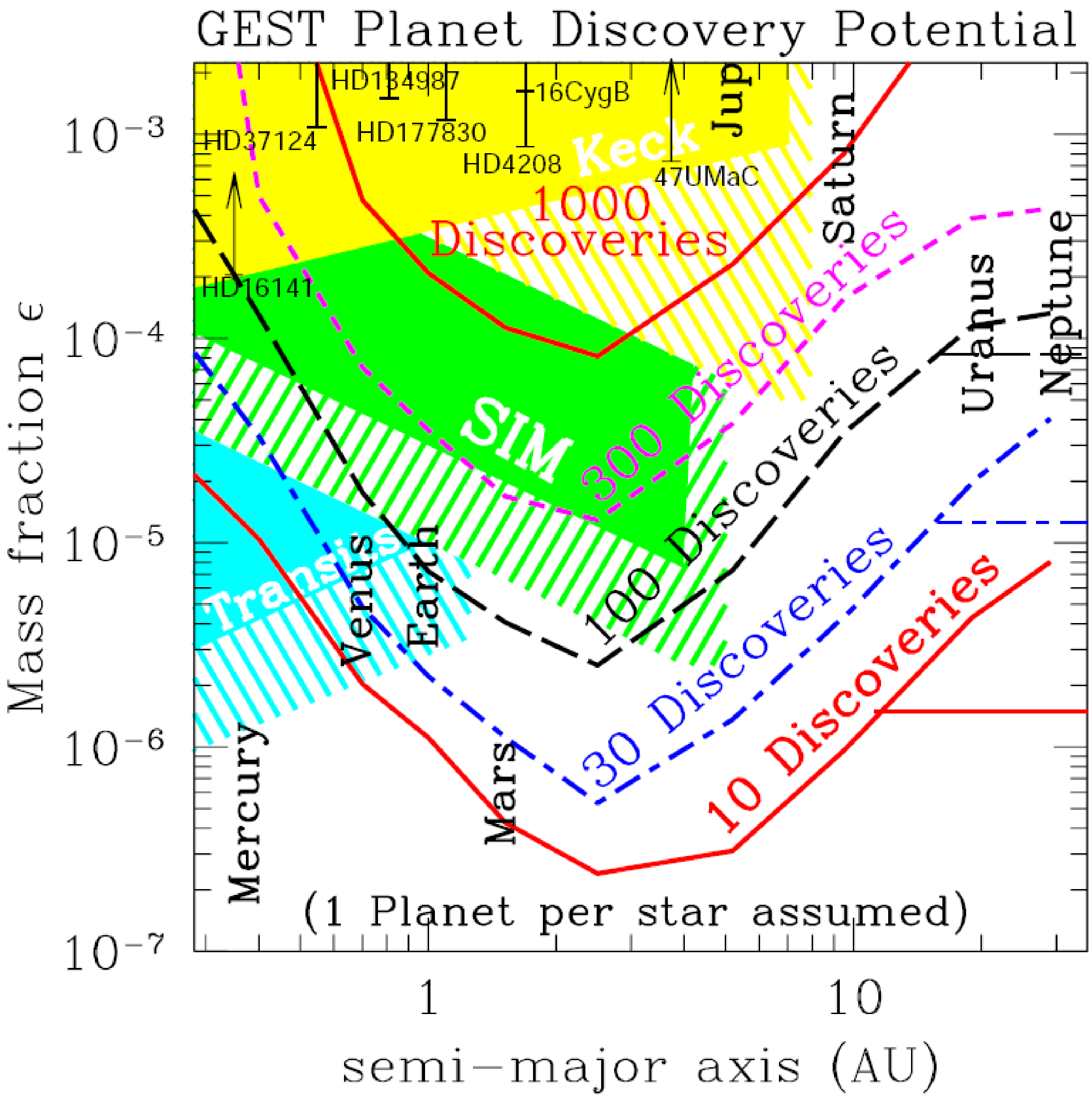


WFIRST


Outer Barrel Assembly
Aft Metering Structure
Solar Array
High Gain Antenna
Instrument Radiator
S/C Bus w/PLA

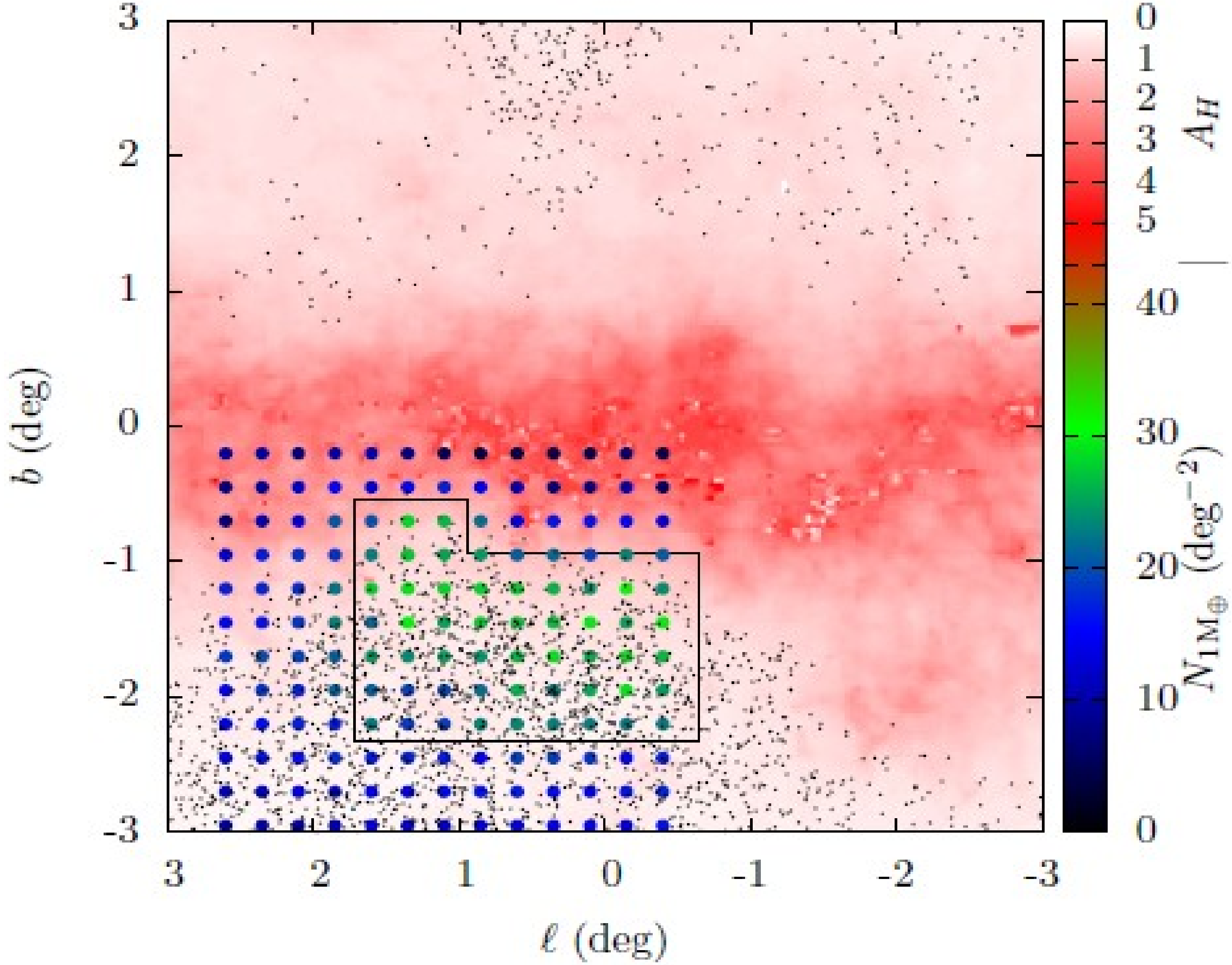
Seeing Better In Space (also weather)





Bennett & Rhie 2002, ApJ, 574, 985

WFIRST Microlensing Field

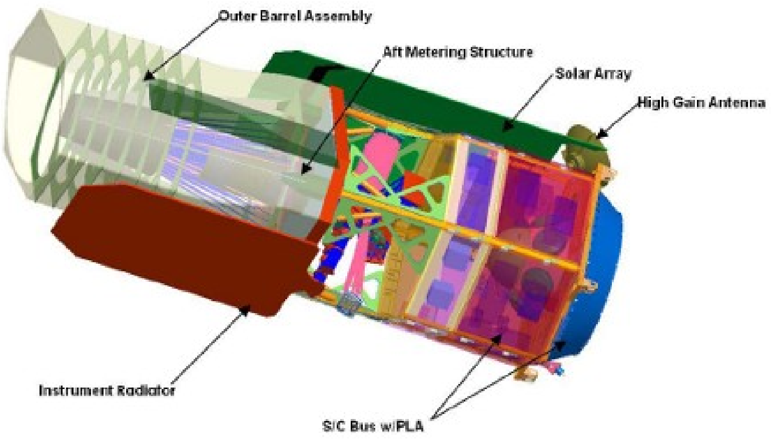


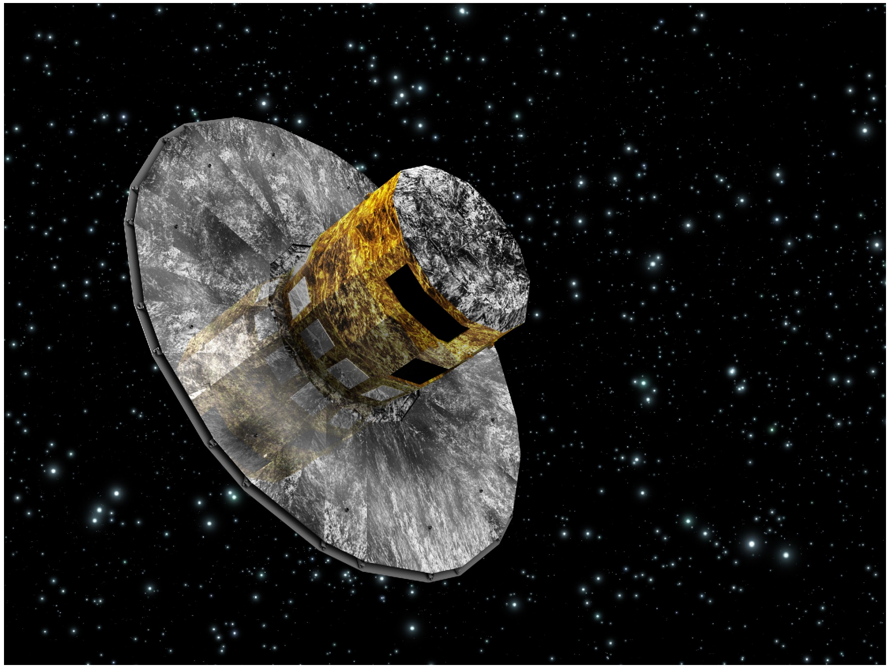
WFIRST "Microlensing" Survey Characteristics

- 40,000 images (52 sec)
- 2.8 sq.deg.
- 6 continuous 72-day campaigns (at quadrature)
- 100 images per day
- SNR = 10^{0.4(Hzero-H)} Hzero = 26.1

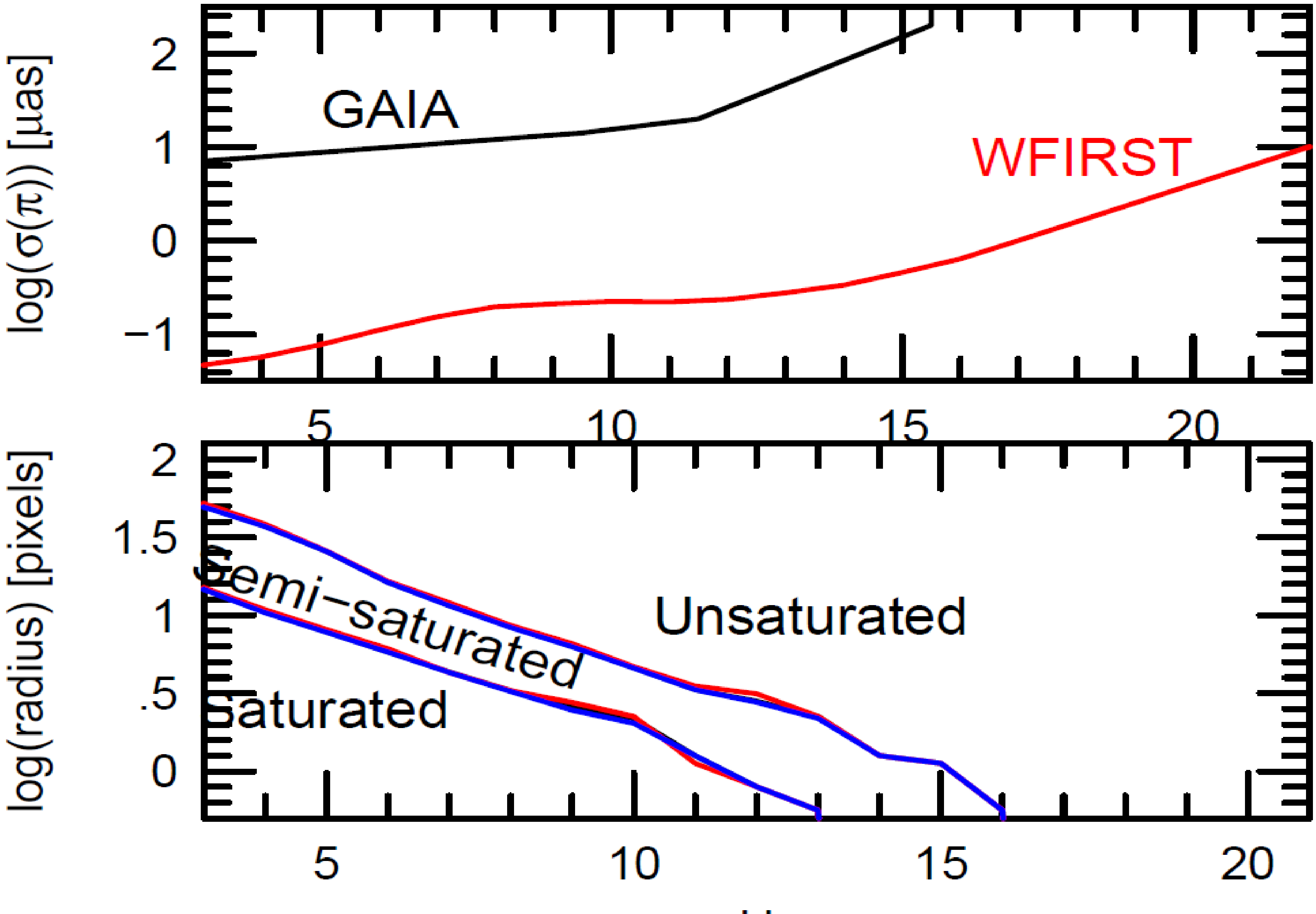
Gould 2014 JKAS, 47, 279

WFIRST vs. GAIA





WFIRST vs GAIA
Parallax Precision

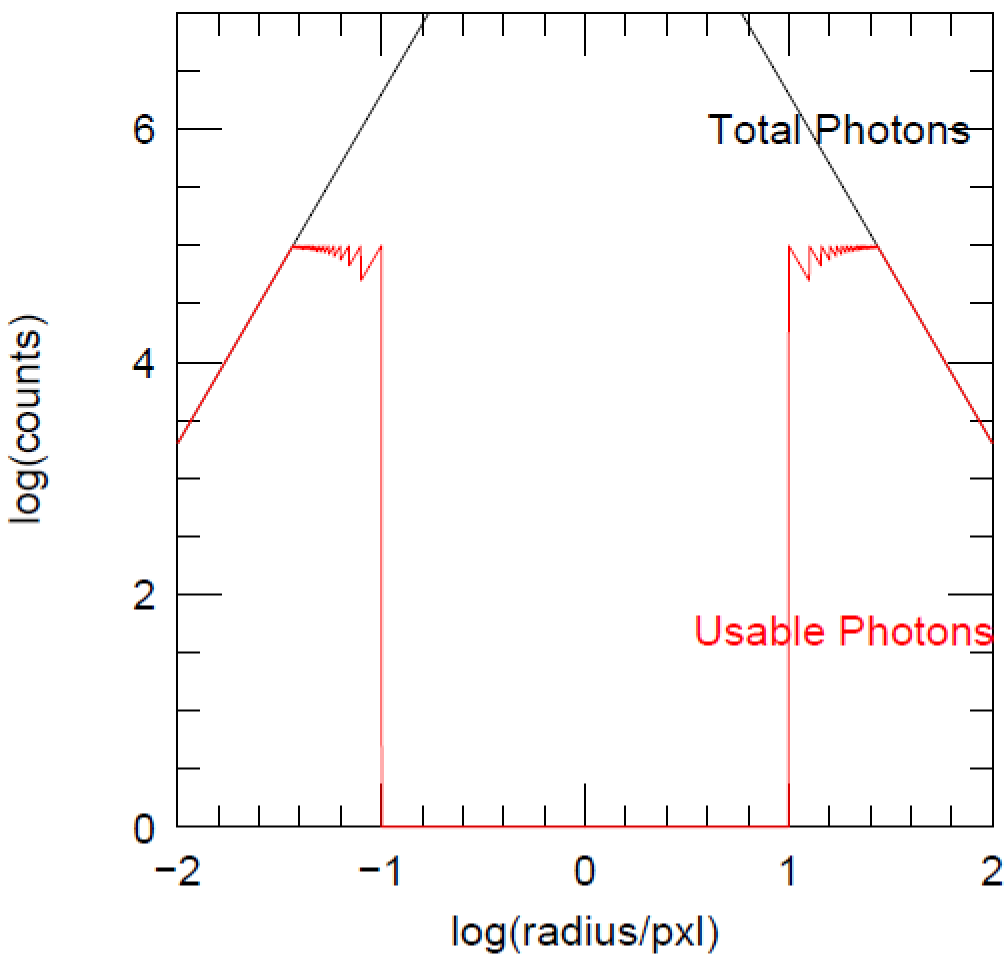


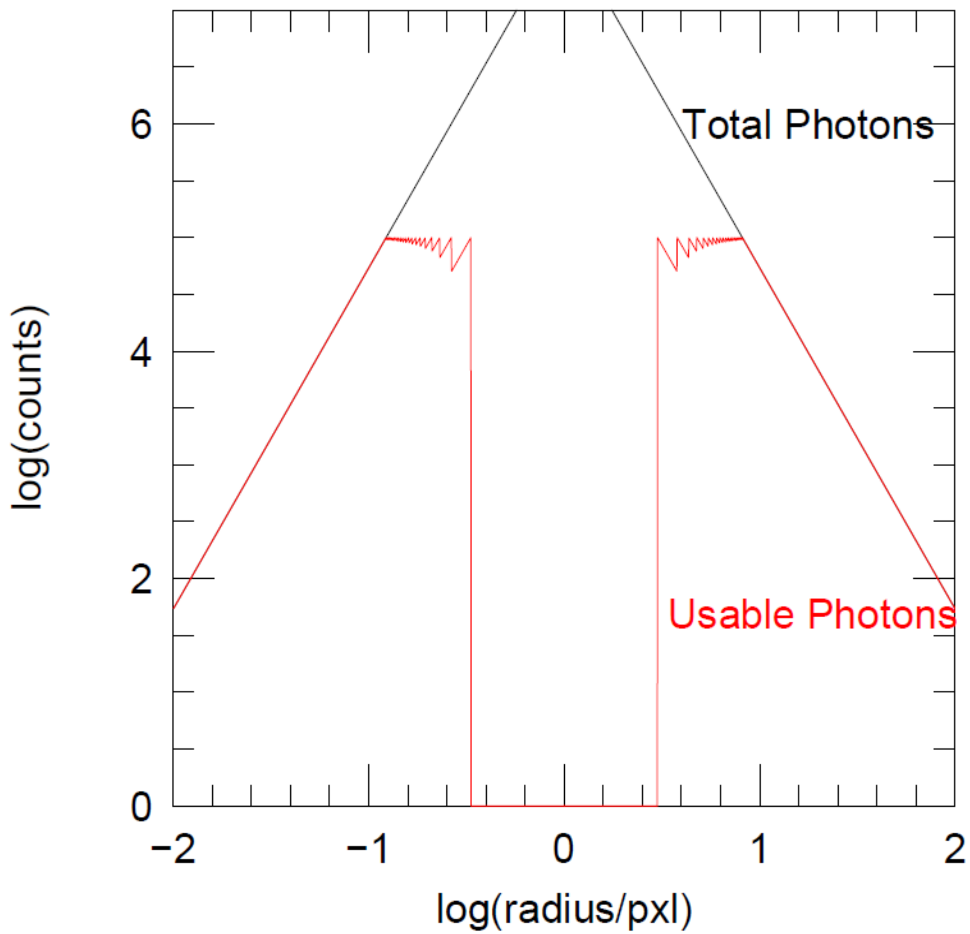
Non-Microlensing WFIRST Science: Ultra-precise Parallaxes

- $H<14.0$; $\sigma(\pi) < 0.3$ μas; 1,000,000 stars
- $H<19.6$; $\sigma(\pi) < 3.7$ μas; 40,000,000 stars
- $H<21.6$; $\sigma(\pi) < 10$ μas; 120,000,000 stars

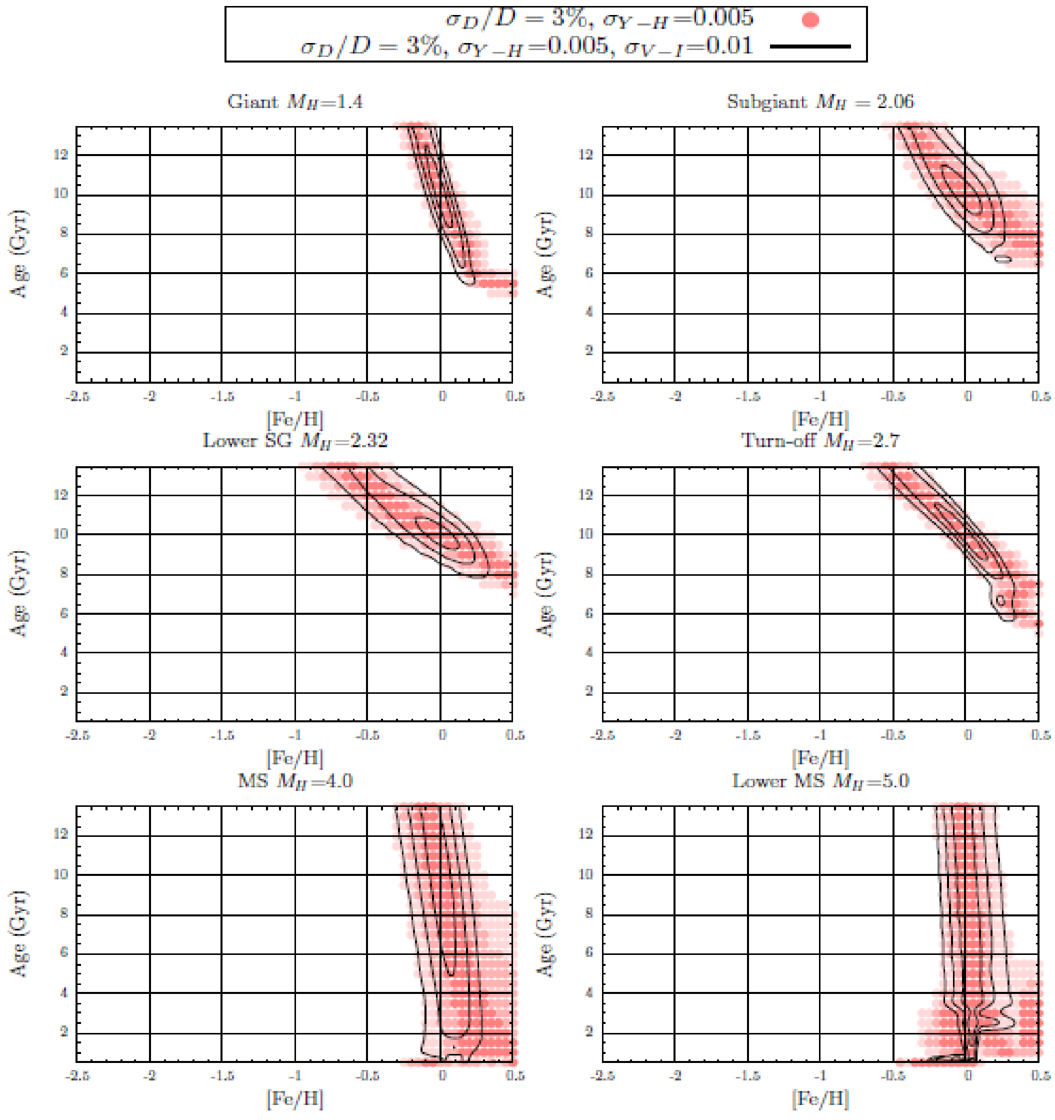
Gould, Huber, Penny, Stello, 2015 JKAS, 48, 93

WFIRST
Astrometric Information Flow

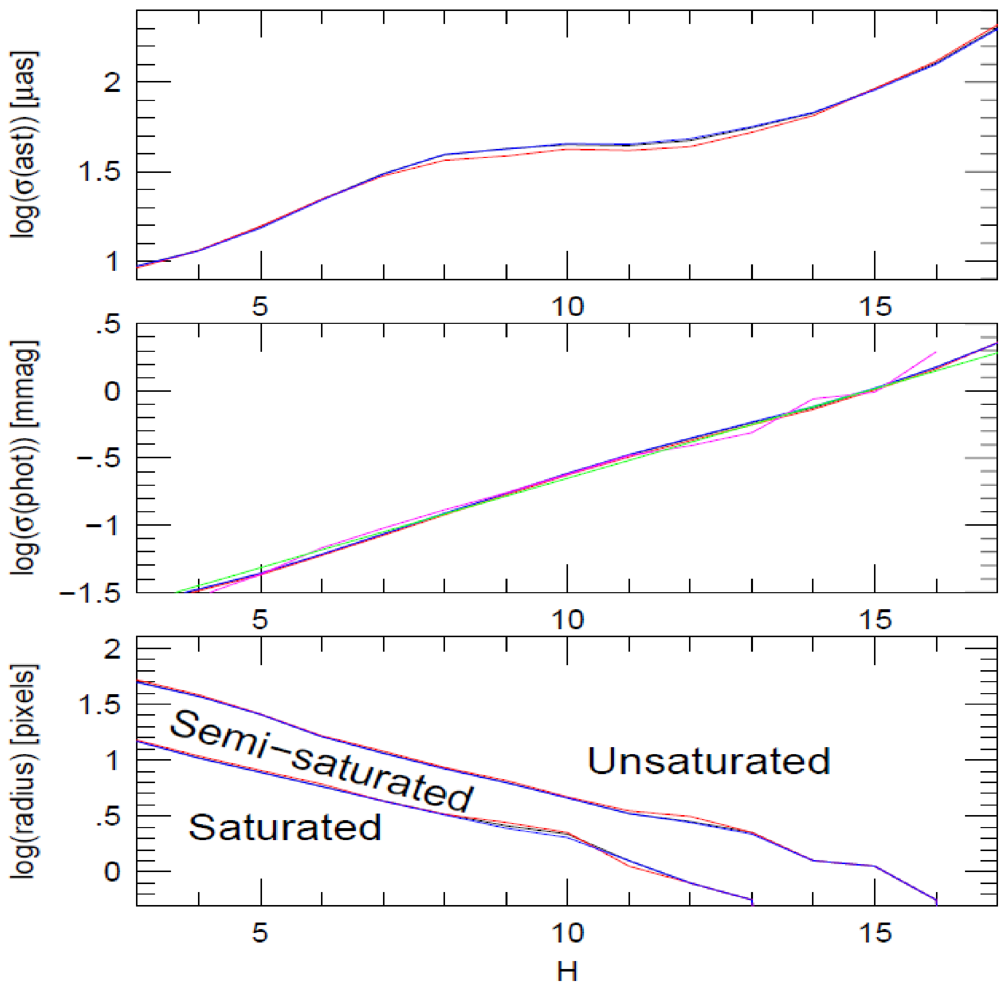




Age & [Fe/H] for 7,000,000 stars (first four panels) [needs V/I-band]

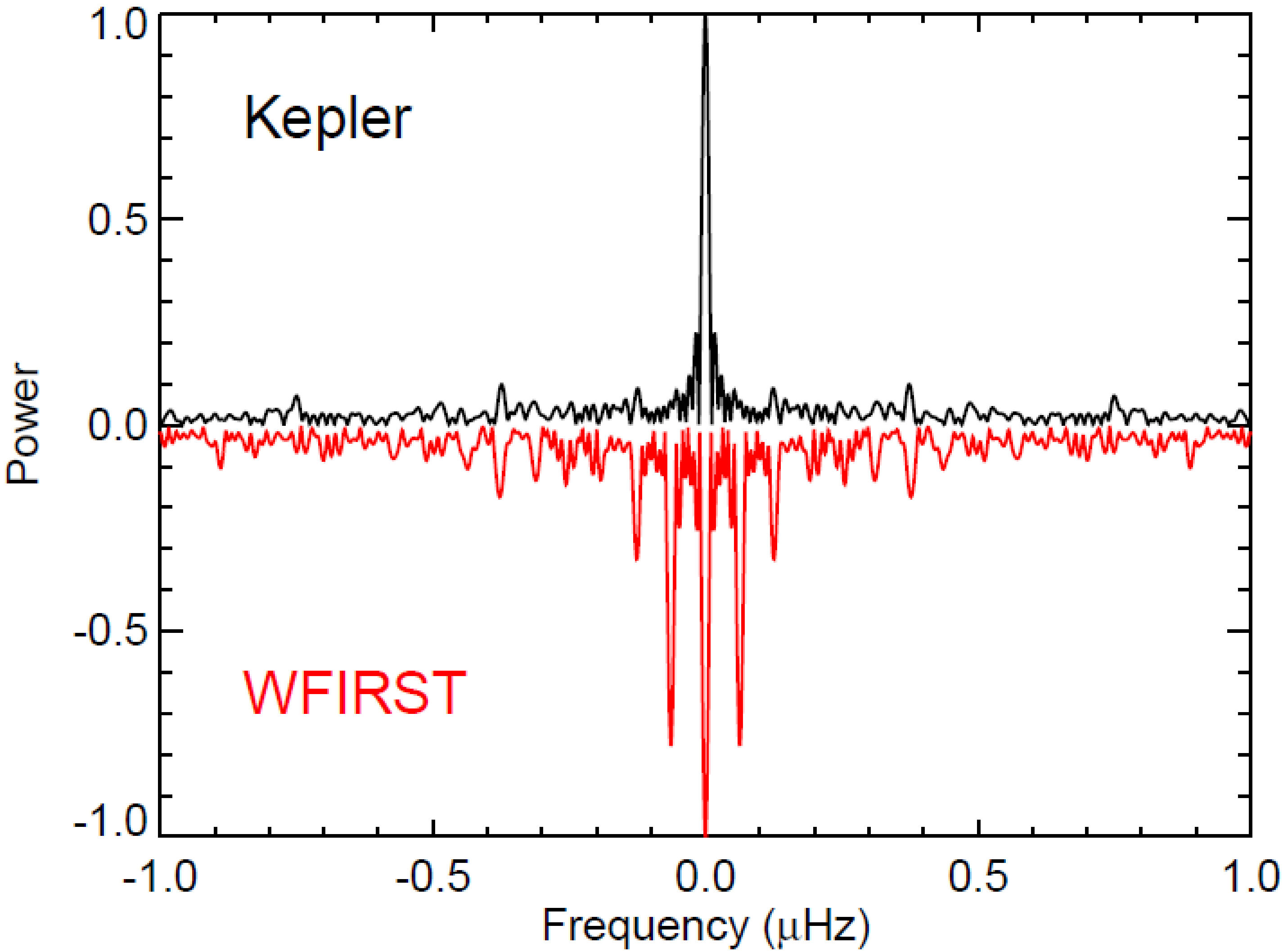


Non-Microlensing WFIRST Science:
Ultra-precise Parallaxes and Photometry



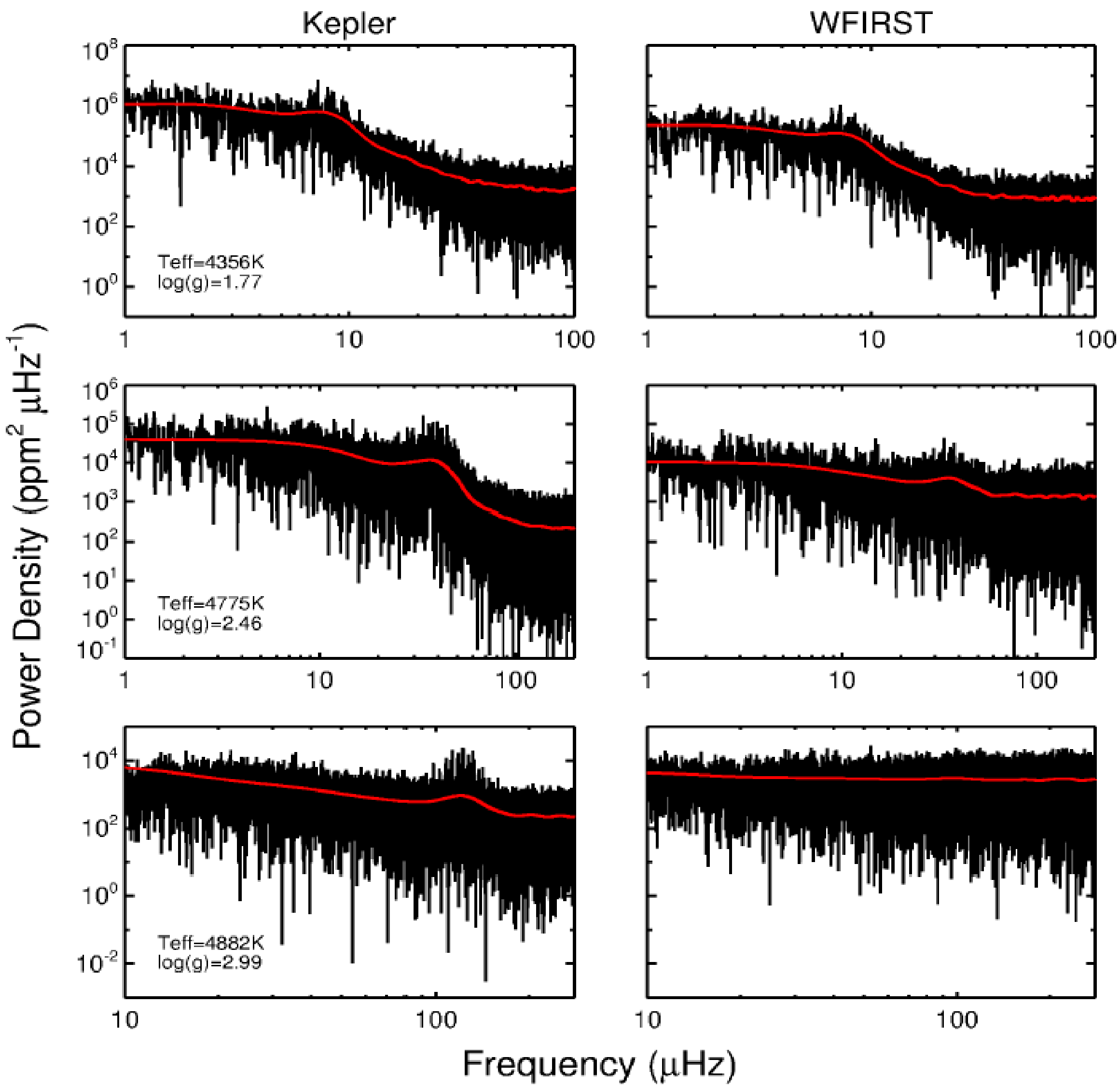
Gould, Huber, Penny, Stello, 2015 JKAS, 48, 93

Non-Microlensing WFIRST Science: Asteroseismic Window Function



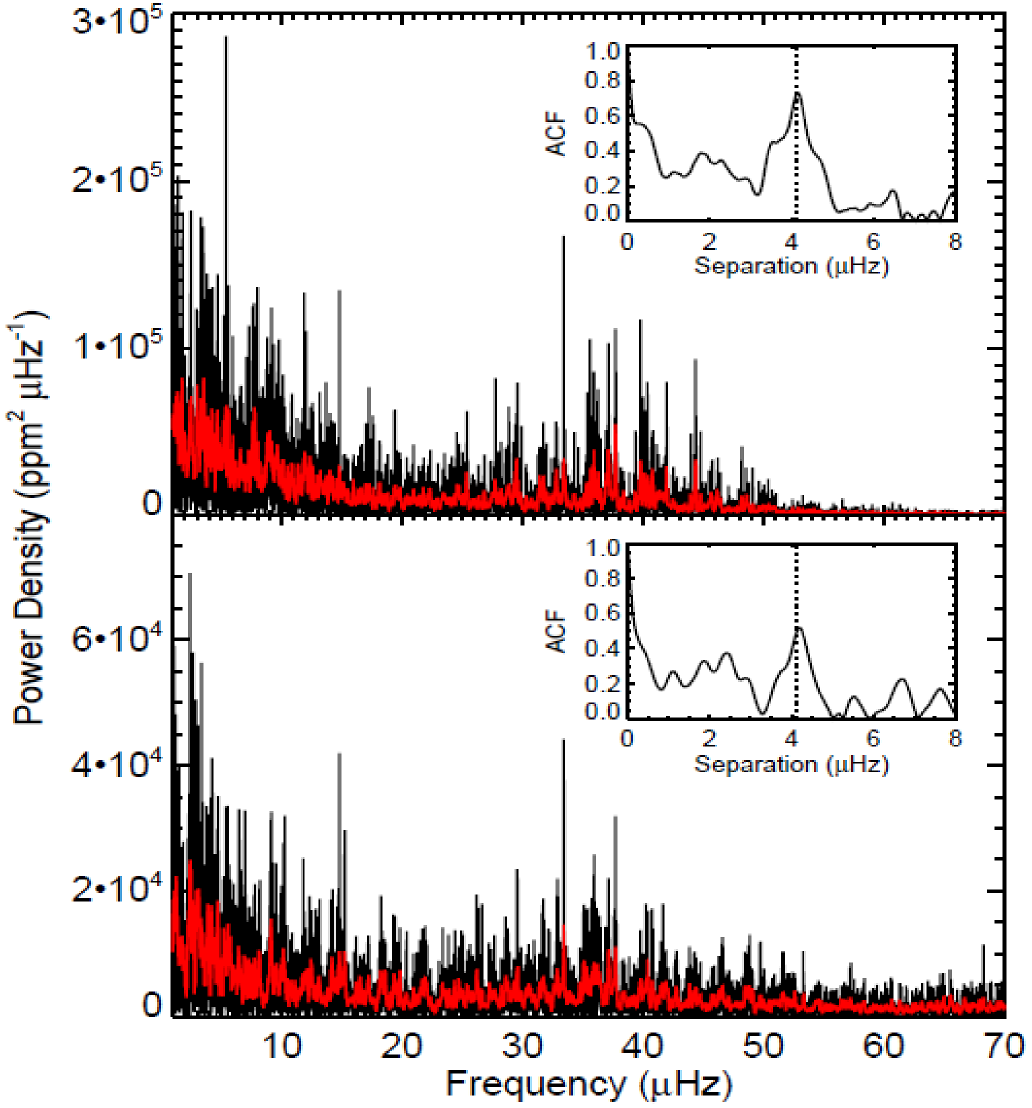
Gould, Huber, Penny, Stello, 2015, JKAS, 48, 93

Non-μlens WFIRST Science: ν_{max}



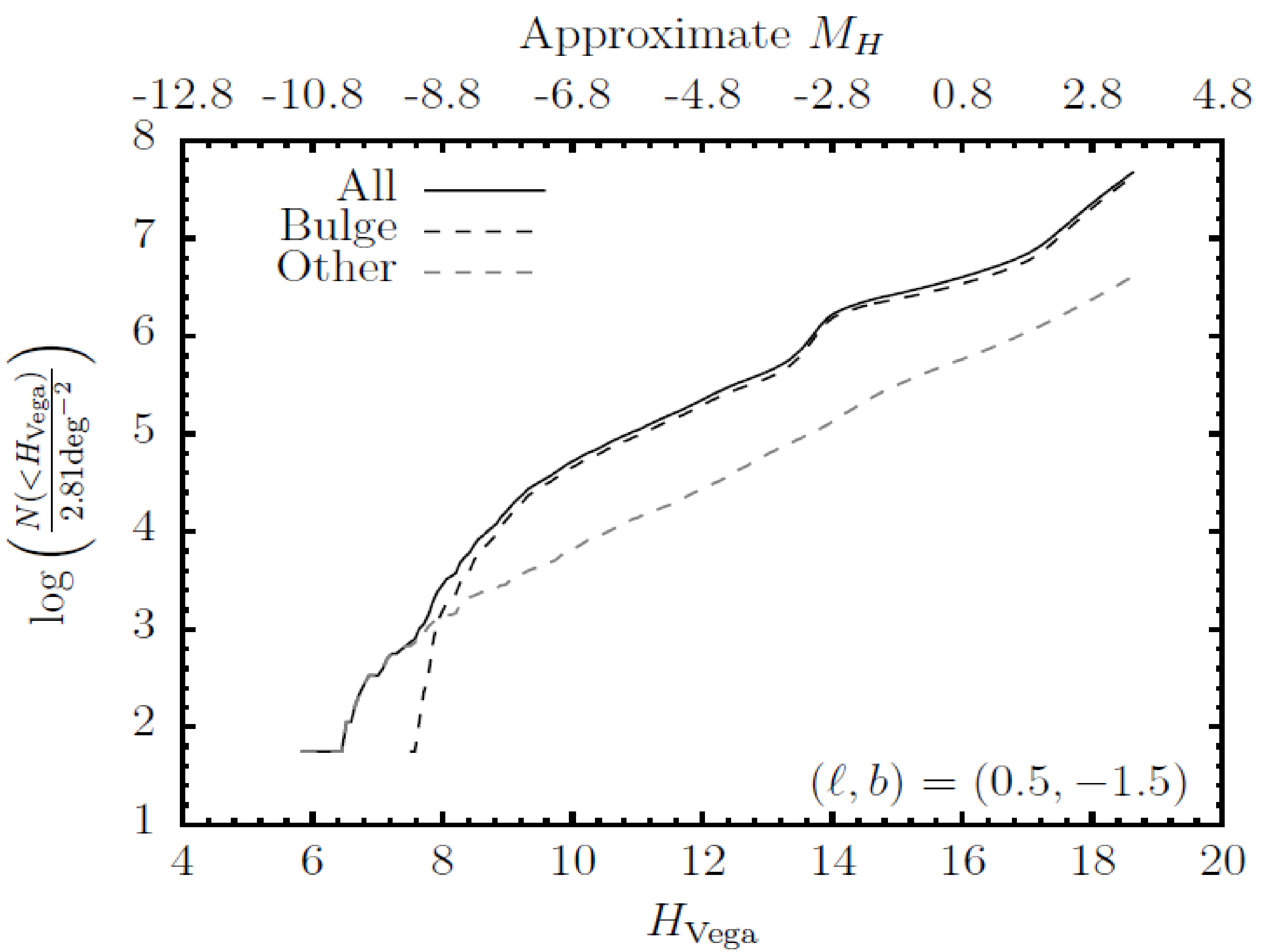
Gould, Huber, Penny, Stello, 2015, JKAS, 48, 93

Non-μlens WFIRST Science: Δν



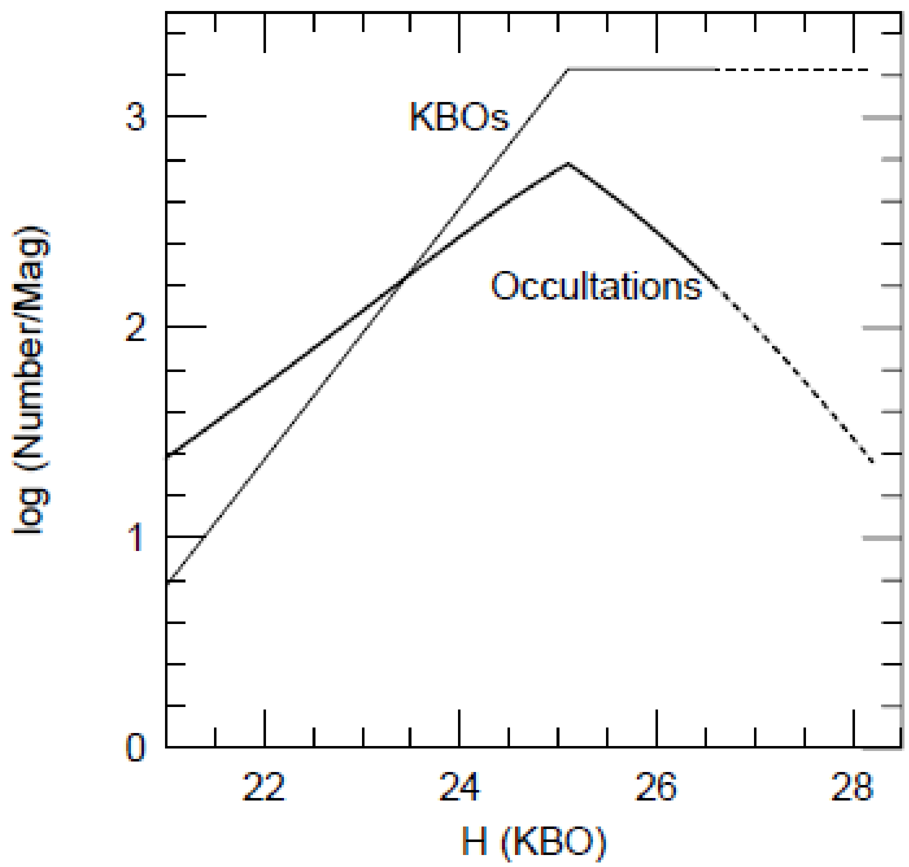
Gould, Huber, Penny, Stello, 2015, JKAS, 48, 93

Non-μlens WFIRST Science:
10% Disk Stars



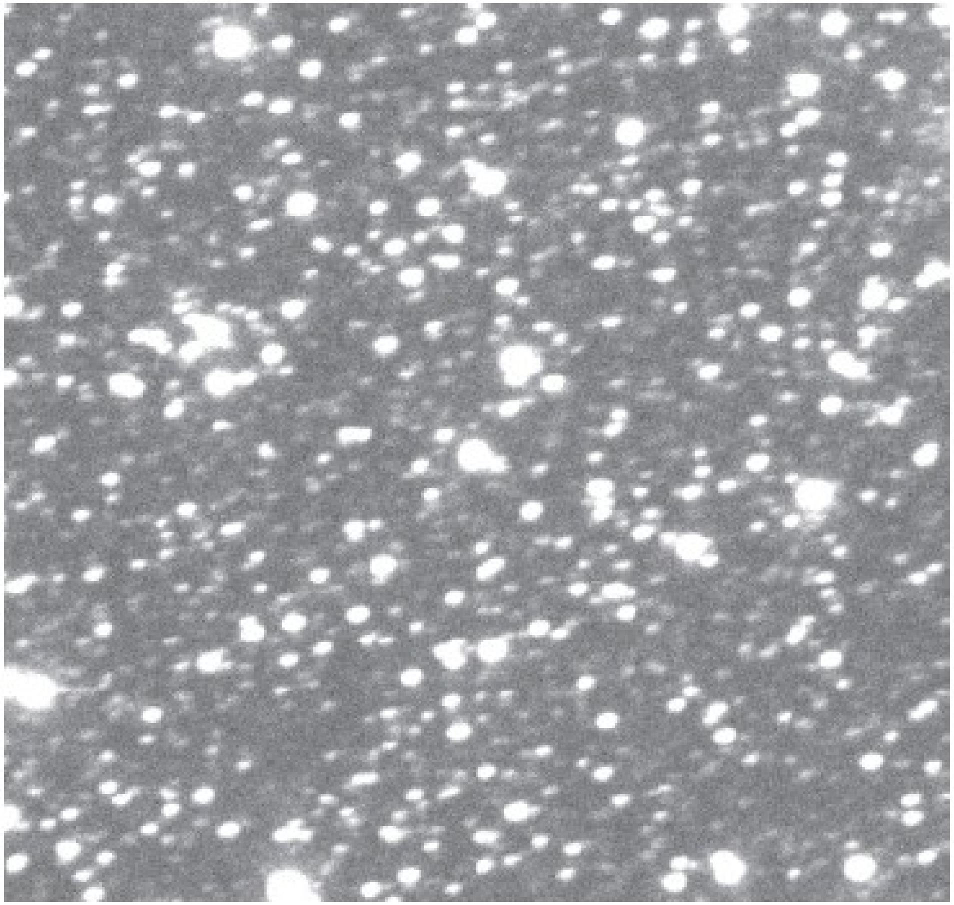
Gould, Huber, Penny, Stello, 2015, JKAS, 48, 93

Non-μlens WFIRST Science: KBOs



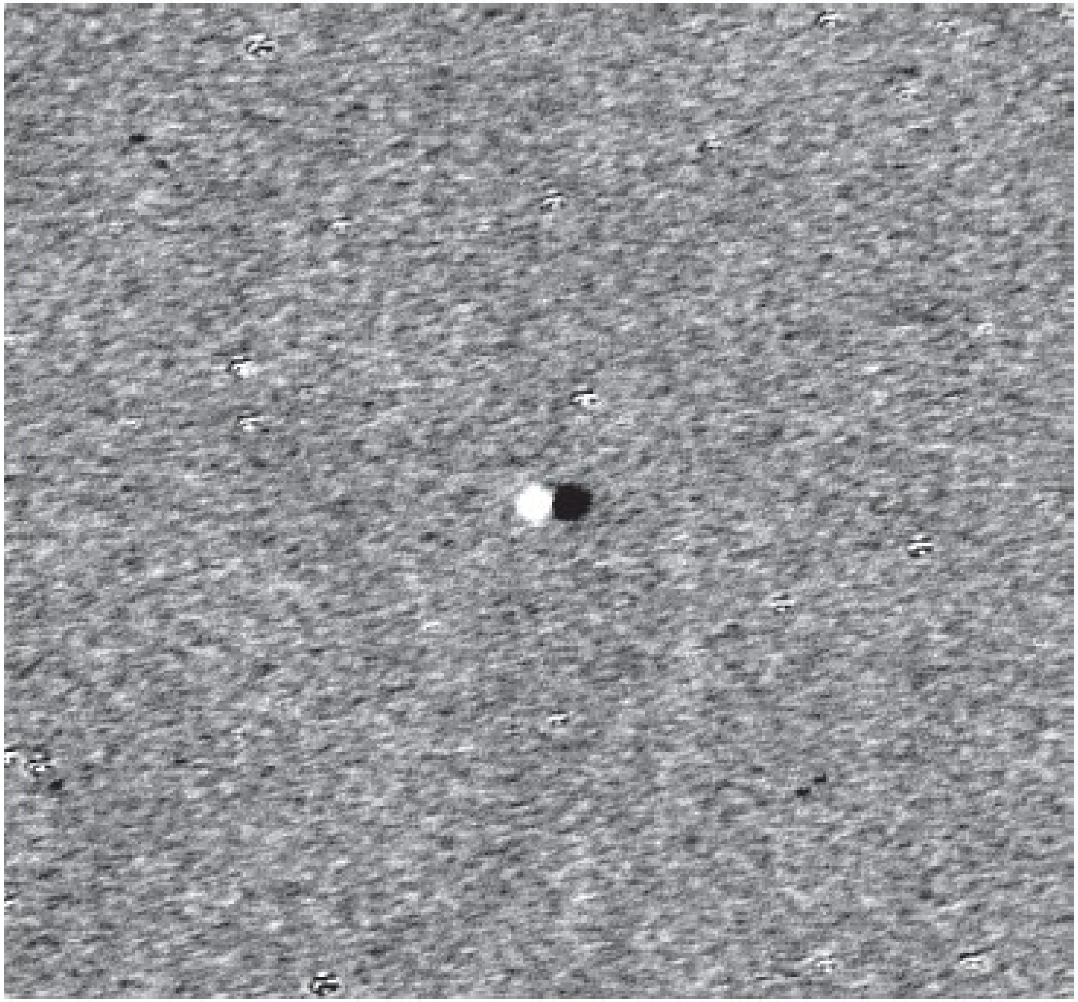
Gould 2014 JKAS, 47, 279

KBOs possible in microlensing fields?



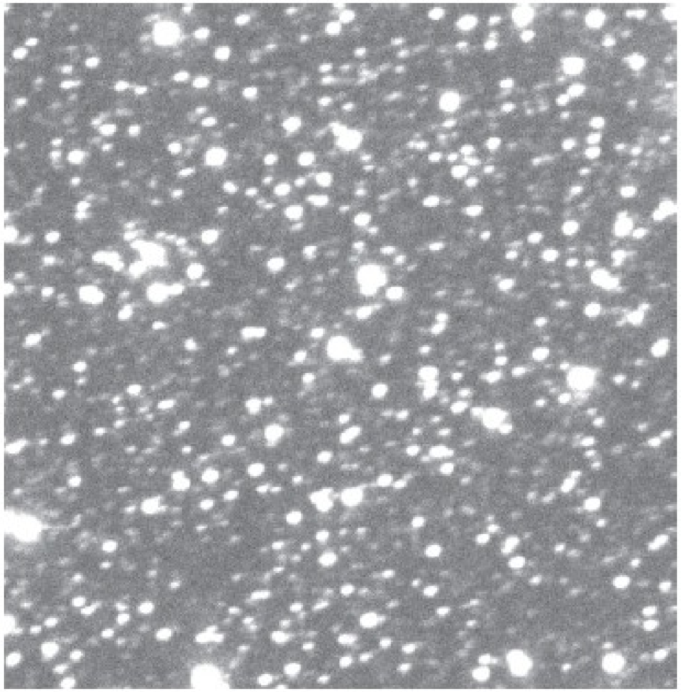
Sheppard et al. 2011, AJ, 142, 98

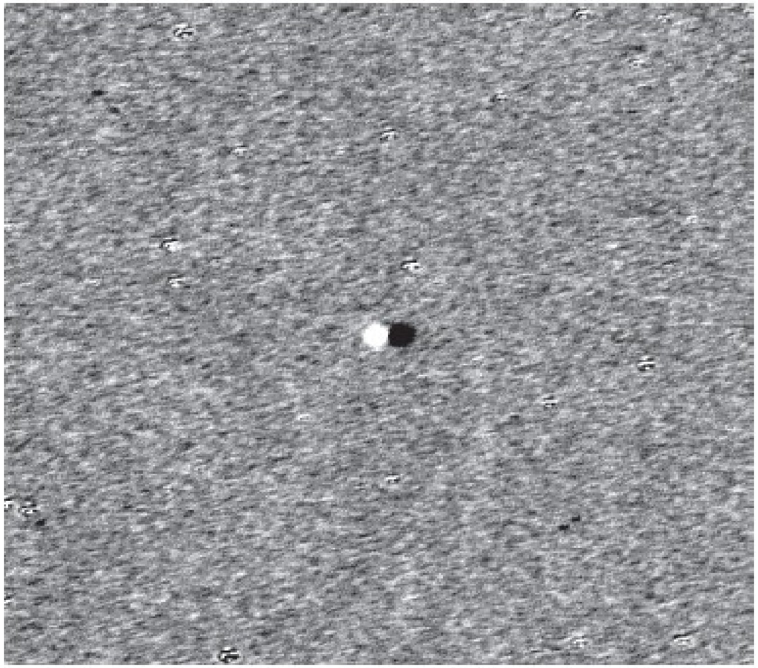
Yes! Microlensing fields are not crowded ...



Sheppard et al. 2011, AJ, 142, 98

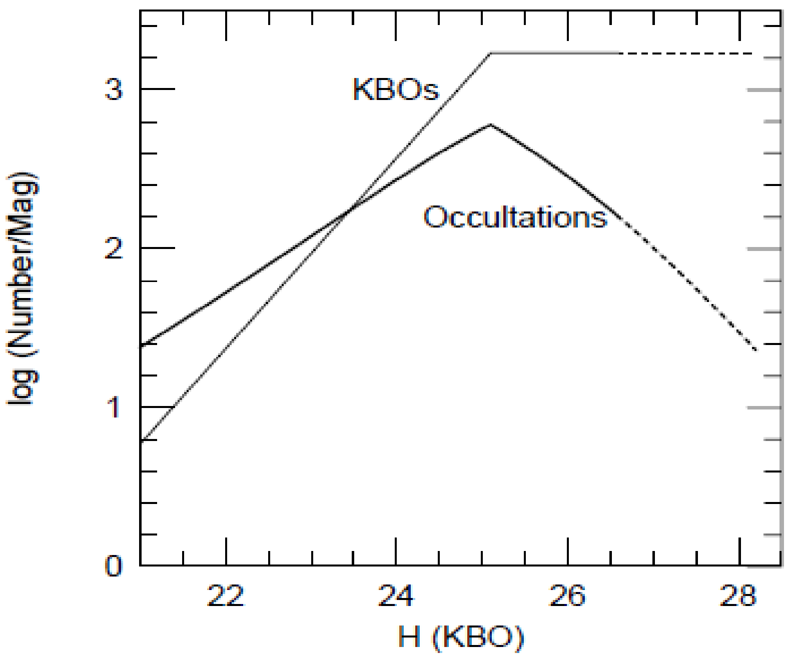
Yes! Microlensing fields are not crowded after image subtraction!





Sheppard et al. 2011, AJ, 142, 98

Non-μlens WFIRST Science:
KBO Precision orbits

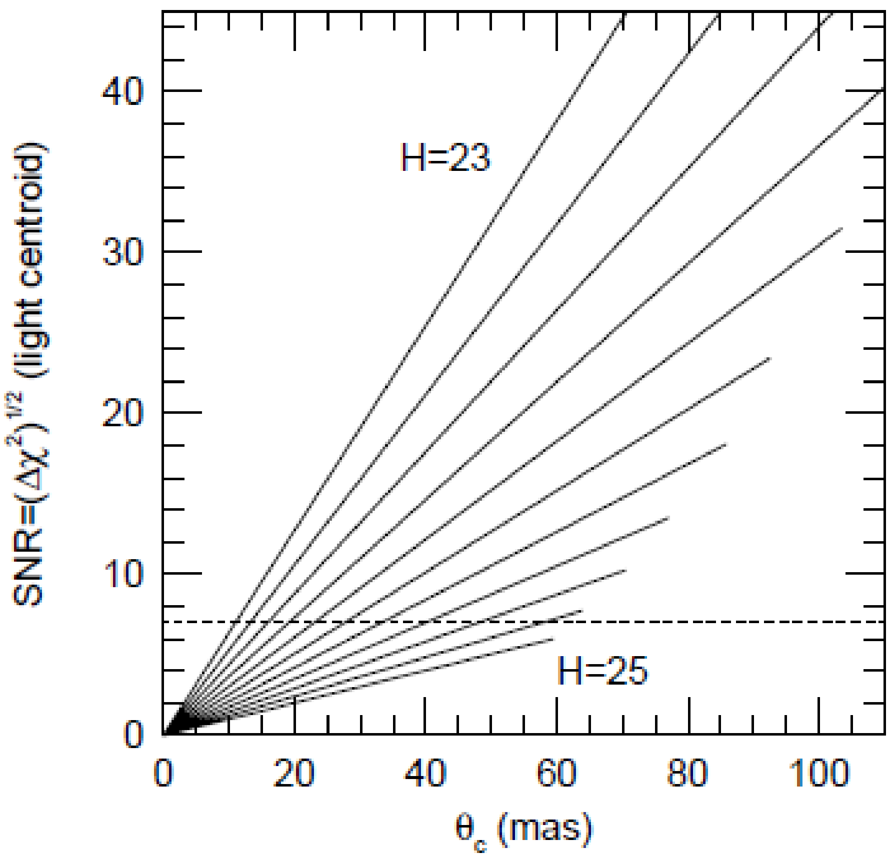


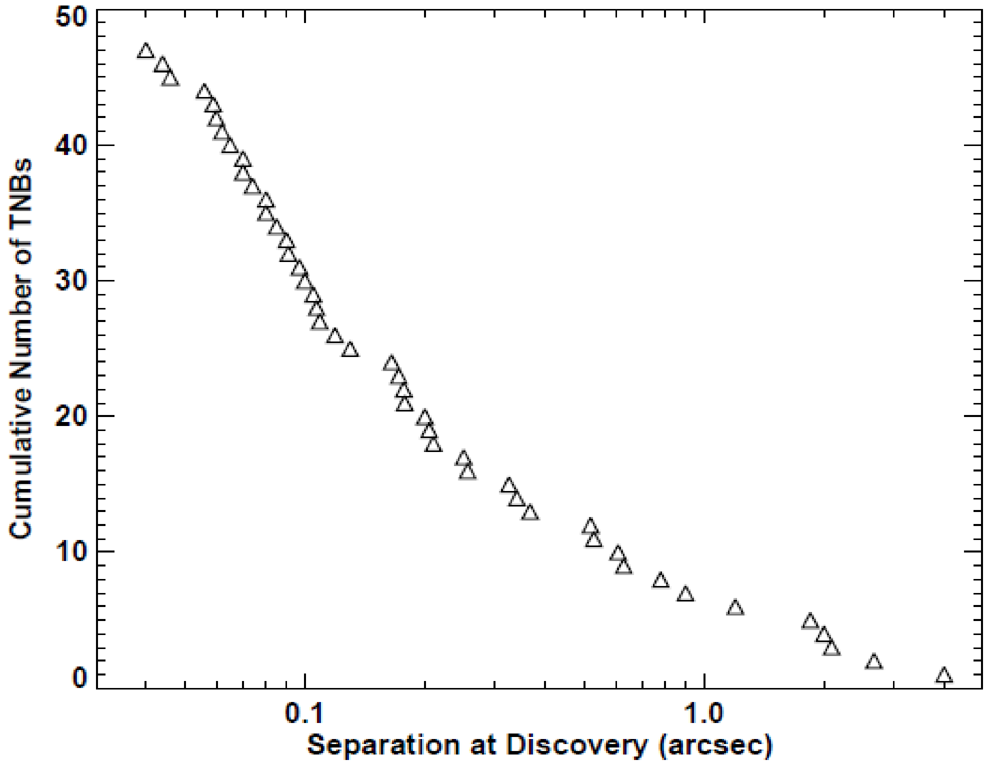
$$\sigma(P)/P \sim 0.09\%$$

$$H \sim 25.1$$

Gould 2014 JKAS, 47, 279

Non-μlens WFIRST Science:
KBO Binaries





Gould 2014 JKAS, 47, 279

Noll et al. 2008

Non-μlens WFIRST Science: Transits: -> Galactic Distribution of Hot Planets

- Bulge G dwarf: 8 mmag
- $\Delta\chi^2 = 100$ requires: $p_{transit} = 0.0025/(\delta/0.008)$
- Jupiters: $a < 160\ R_{sun}$; $P < 250$ days
- Neptunes: $a < 25\ R_{sun}$; $P < 15$ days
- Earths: (not feasible at bulge)

Non-μlens WFIRST Science: BH + NS in Wide Orbits

- BH+star (5+1) -> 500 μas orbit at P = 5 yr
  - ==> 50 σ detection for 120,000,000 stars
  - ==> 17 σ at P=1 yr
- NS+star (1.4+1) -> 270 μas orbit at P = 5 yr
  - ==> 27 σ detection for 120,000,000 stars
  - ==> 9 σ at P=1 yr

Non-Planet WFIRST μlens Science:
Isolated BH Mass & Velocity Functions

(Gould & Yee 2014 ApJ 784 64)

Complementary Ground-Based Survey For Microlens Parallaxes

- Free-Floating Planet Characterization

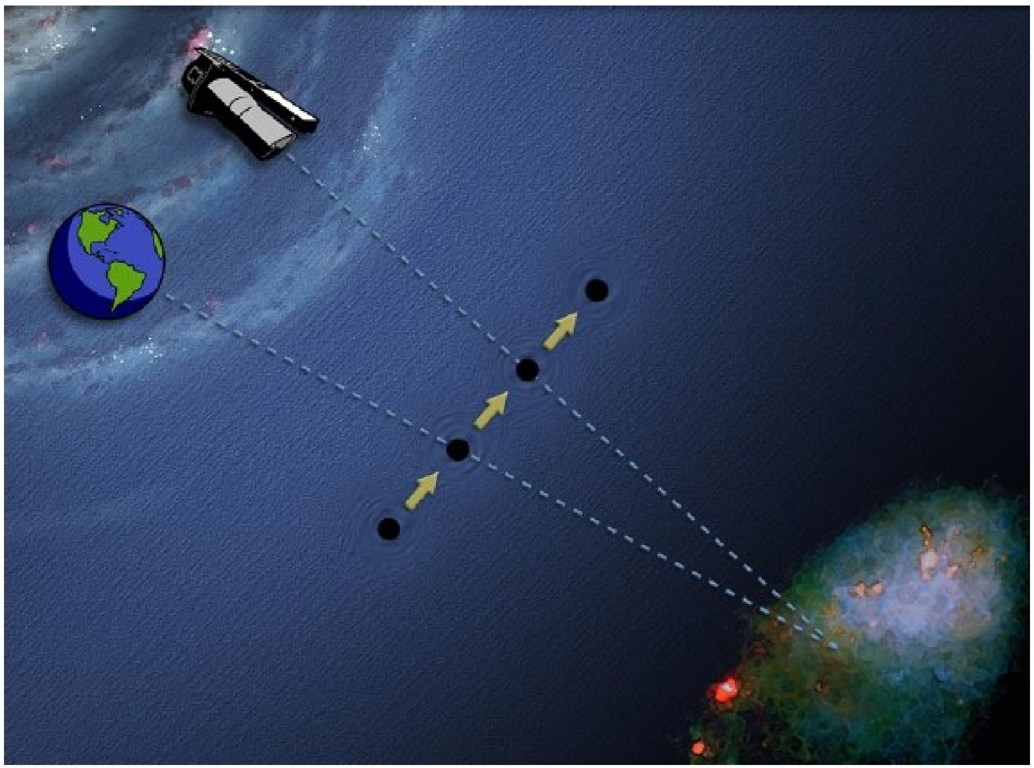
Complementary Ground-Based
Survey For Microlens Parallaxes

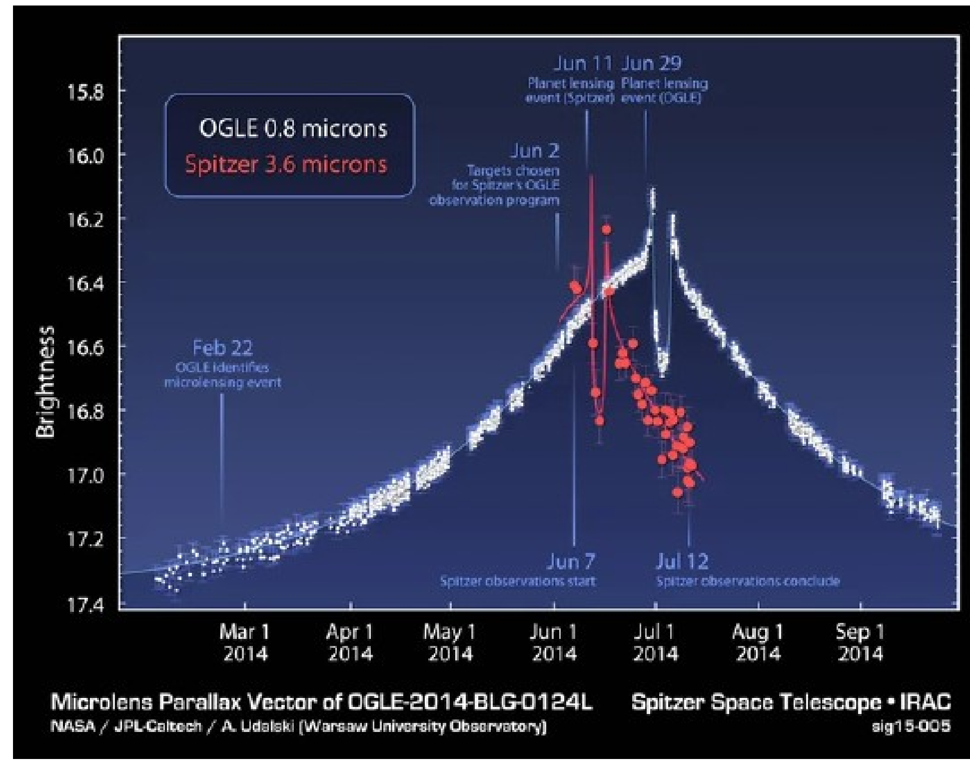
- Free-Floating Planet Characterization
- Brown Dwarf Characterization

Complementary Ground-Based Survey For Microlens Parallaxes

- Free-Floating Planet Characterization
- Brown Dwarf Characterization
- Bound Planet Masses

Spitzer Microlensing





Dong et al., 2007, ApJ, 664, 862

Udalski et al., 2015, ApJ, 799, 237

Spitzer vs. WFIRST
Microlens Parallaxes

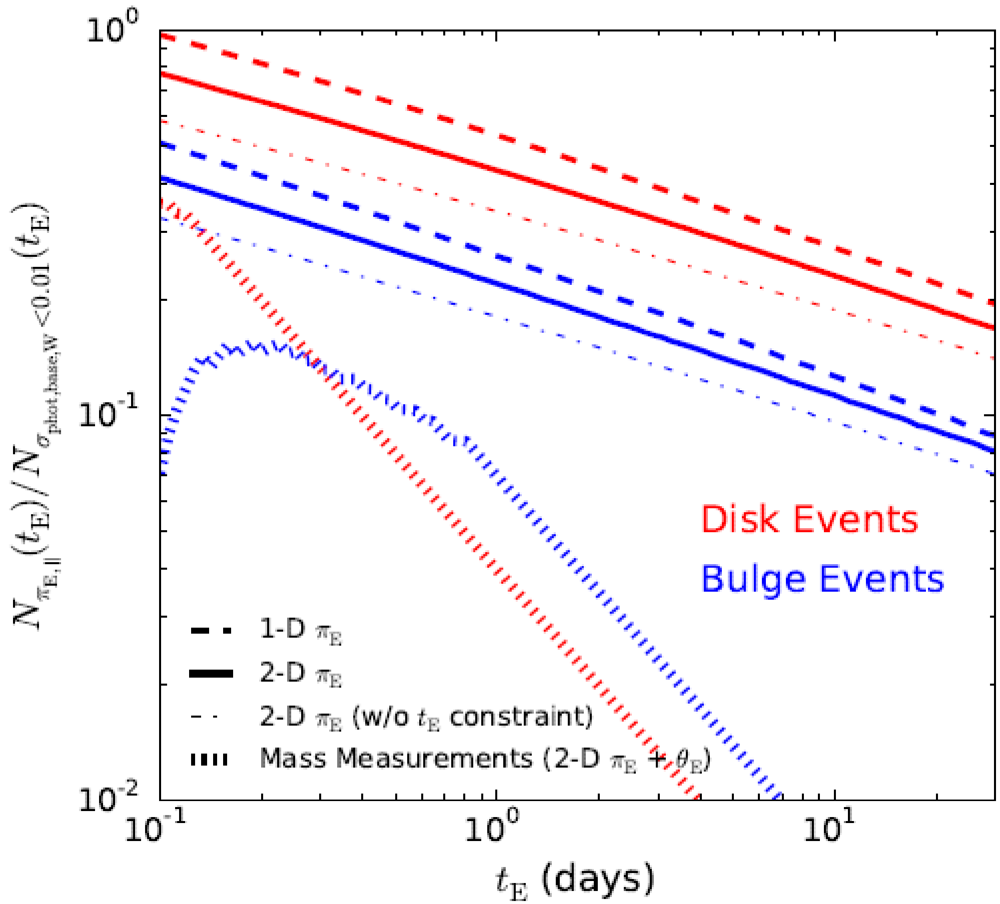
- Spitzer: Solar Orbit: $D_{sat} = 1$ AU

Spitzer vs. WFIRST
Microlens Parallaxes

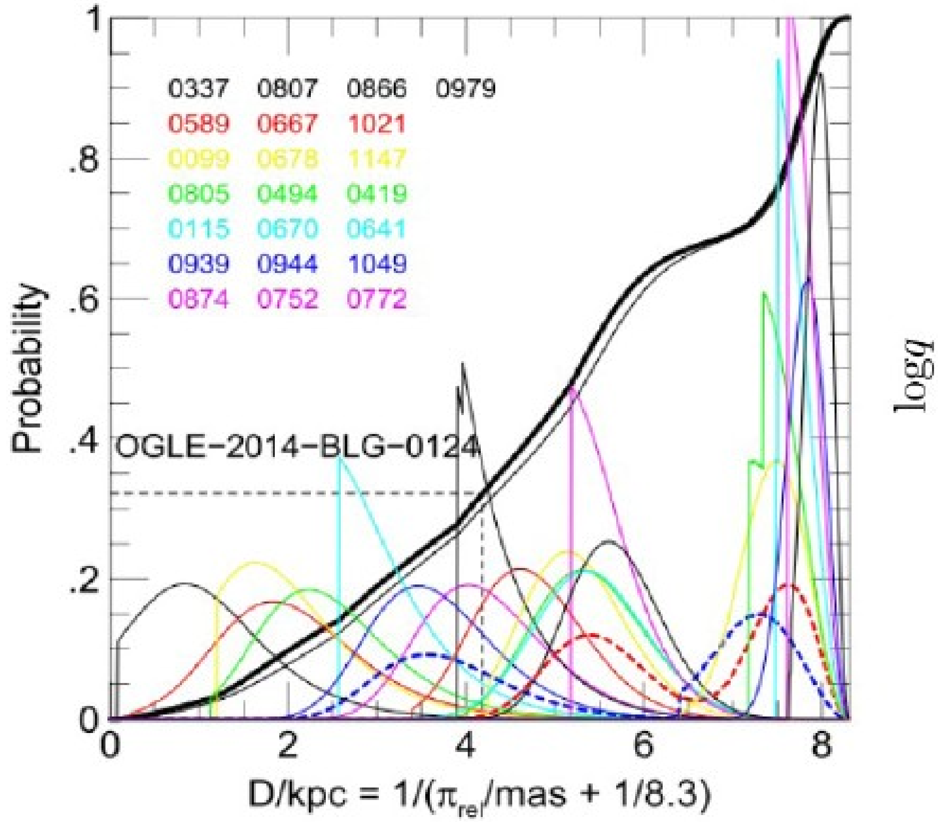
- Spitzer: Solar Orbit: $D_{sat} = 1$ AU
- WFIRST: L2: $D_{sat} = 0.01$AU

Full (2-D) Microlens Parallaxes For Free-Floating Planets and low-mass Brown Dwarfs

(Zhu & Gould 2016, JKAS, subm)



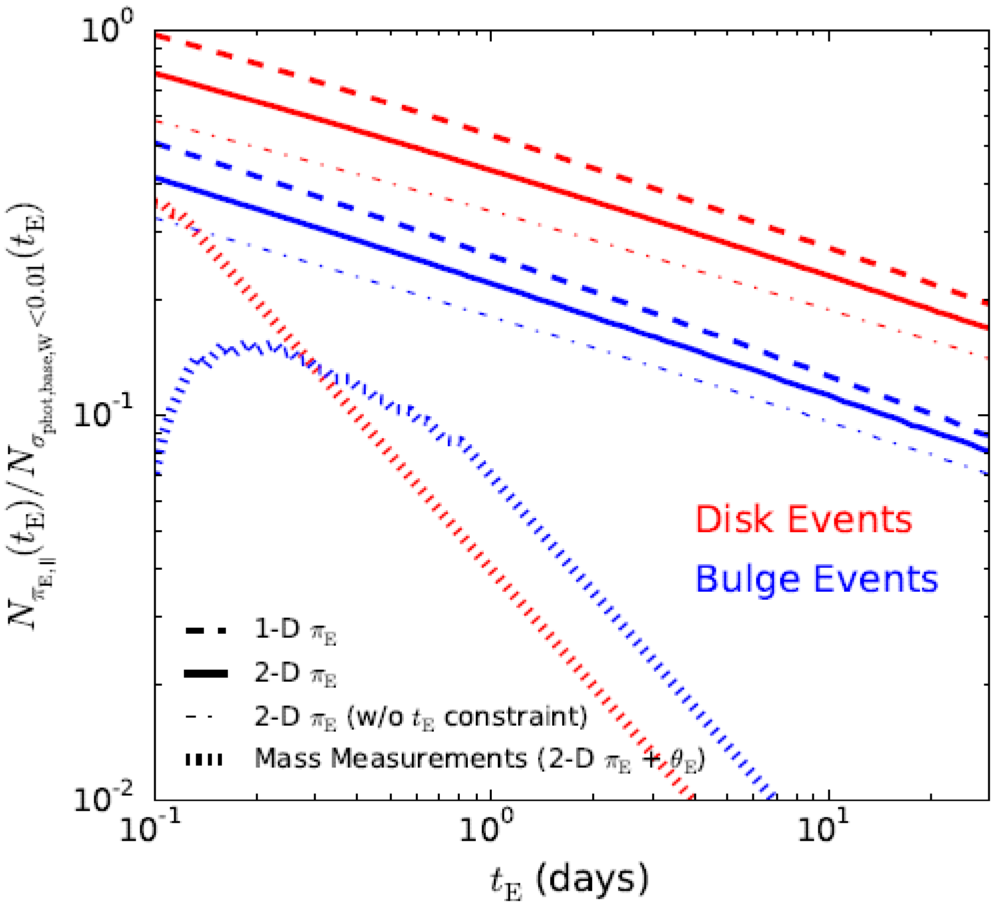
2-D Microlens Parallaxes
Give Good Mass/Distance Constraints
(subject to Galactic model)



Calchi Novati et al., 2015, ApJ, 804, 20

And model-independent mass measurements for ~1/2 at low mass

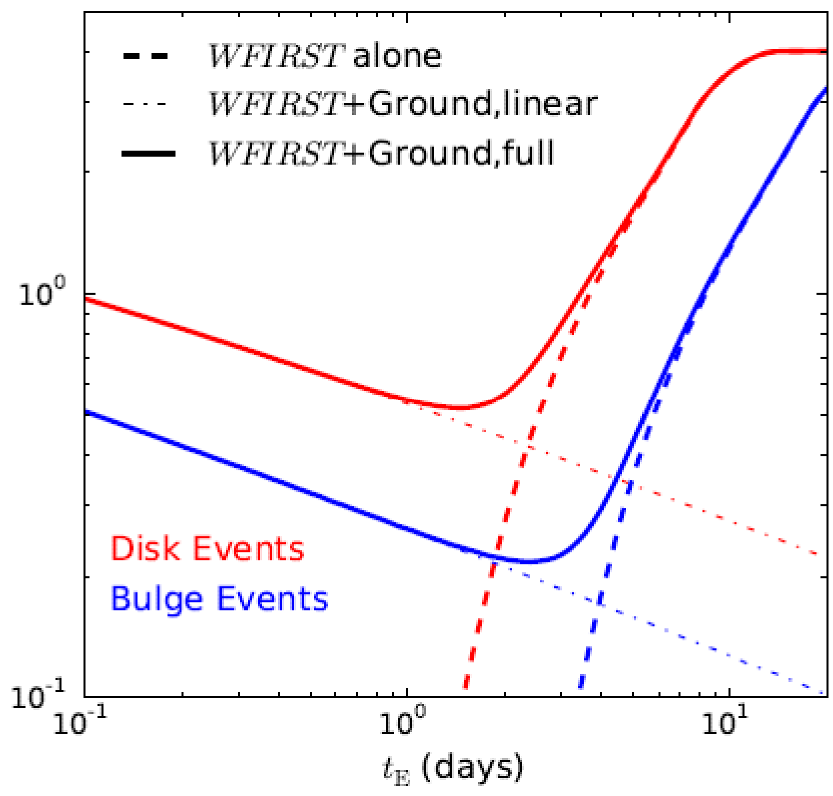
(Zhu & Gould 2016, JKAS, subm)



And 1-D parallaxes at all masses

(Can promote to 2-D for stellar lens)

(Zhu & Gould 2016, JKAS, subm)



Conclusions

- WFIRST "microlensing" survey:
  - Will deliver far more astrophysics than μlensing
- WFIRST astrometry: 100 X better than GAIA
  - 40,000,000 stars: $\sigma(\pi) < 4$ μas
  - 1,000,000 stars: $\sigma(\pi) < 0.3$ μas
  - Will RESOLVE Galactic Bulge in Depth
- WFIRST Ages 7,000,000 stars
- WFIRST photometry < 1mmag: 1,000,000 stars
  - Asteroseismology for bulge clump & brighter
- At faint end: Precision orbits for 4000 KBOs
- \+ Transits, BH/NS companions for 1.2e8 stars