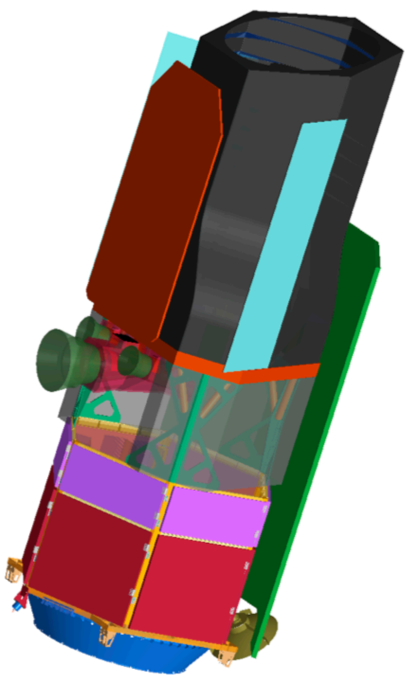
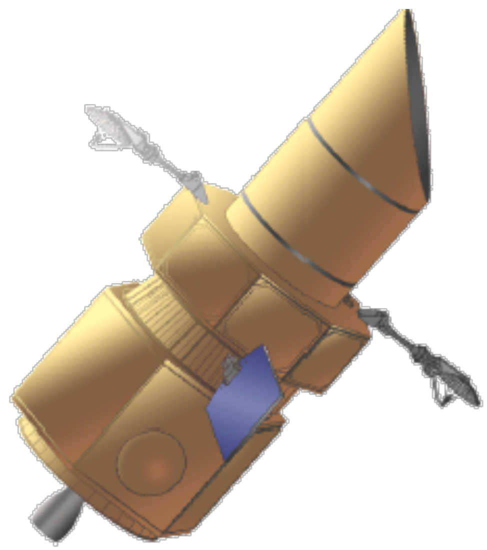
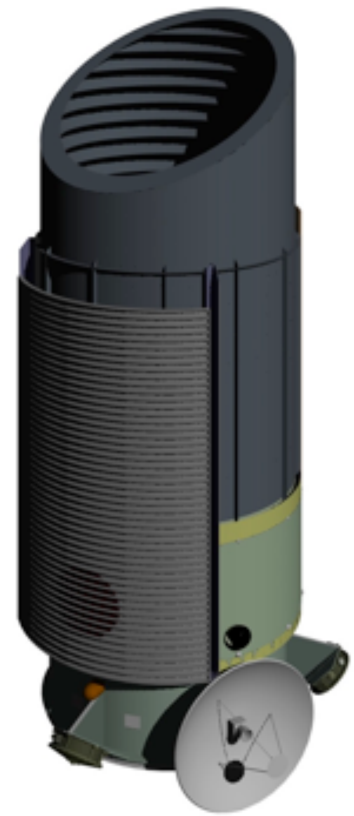
More Pixels for WFIRST Wide-Field Infra-Red Survey Telescope ?

David Bennett
University of Notre Dame

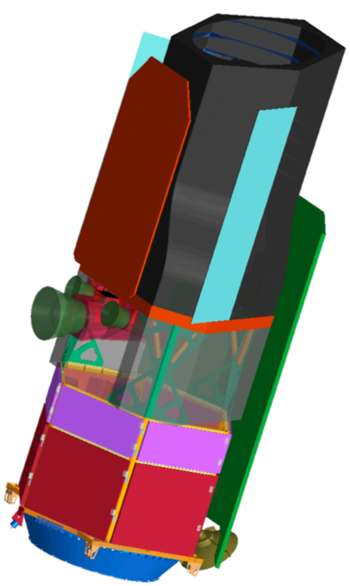






JDEM-Ω = WFIRST Strawman Design

- JDEM-Ω can do the science
  - But it is optimized only for DE
- NWNH: “general investigator program [is] an essential element of the mission, but … it should not drive the mission hardware design or implementation cost.”
- Is there a better design – closer to MPF
  - Maybe not - MPF requirements are mostly not so tight



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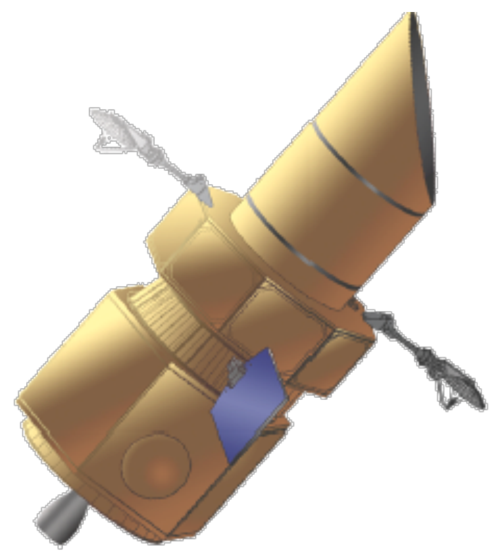

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MPF: More Pixels, But Cheaper, Why?

- ($330M + LV) * (Aerospace factor) ~ $650M
  - vs. ~ $600M for Kepler
  - Aerospace Corp. presumably tries to match Kepler cost data
- MPF "passed" 2006 Discovery review
  - Medium risk
  - Review panel fooled?
- Fewer readout channels (1 ASIC per 5 detectors)
  - Looser detector specs probably doesn't help
- Warmer telescope & focal plane
  - 1.7μm long wave cutoff
- Discovery reliability requirements weaker than those of a flagship mission

MPF Mission Design

- 1.1-m aperture consisting of a three-mirror anastigmat telescope feeding a 147 Mpixel HgCdTe focal plane (35 2048^2 arrays)
- The spacecraft bus is a near-identical copy of that used for *Spitzer*.
- The telescope system very similar to NextView commercial Earth-observing telescope designs.
- Detectors developed for JWST meet MPFs requirements.
- All elements at TRL ~6 or better
- Total Cost M$ 330 (plus launch vehicle)

Property	Value	Units
Orbit	Inclined GEO 28.7	degrees
Mission Lifetime	4×9	months
Telescope Aperture	1.1	meters (diam.)
Field of View	0.95 × 0.68	degrees
Spatial Resolution	0.240	arcsec/pixel
Pointing Stability	0.048	arcsec
Focal Plane Format	146.8	Megapixels
Spectral Range	600 – 1700	nm in 3 bands
Quantum Efficiency	> 75% > 55%	900-1400 nm 700-1600 nm
Dark Current	< 1	e-/pixel/sec
Readout Noise	< 30	e-/read
Photometric Accuracy	1 or better	% at J = 20.5
Data Rate	50.1	Mbits/sec

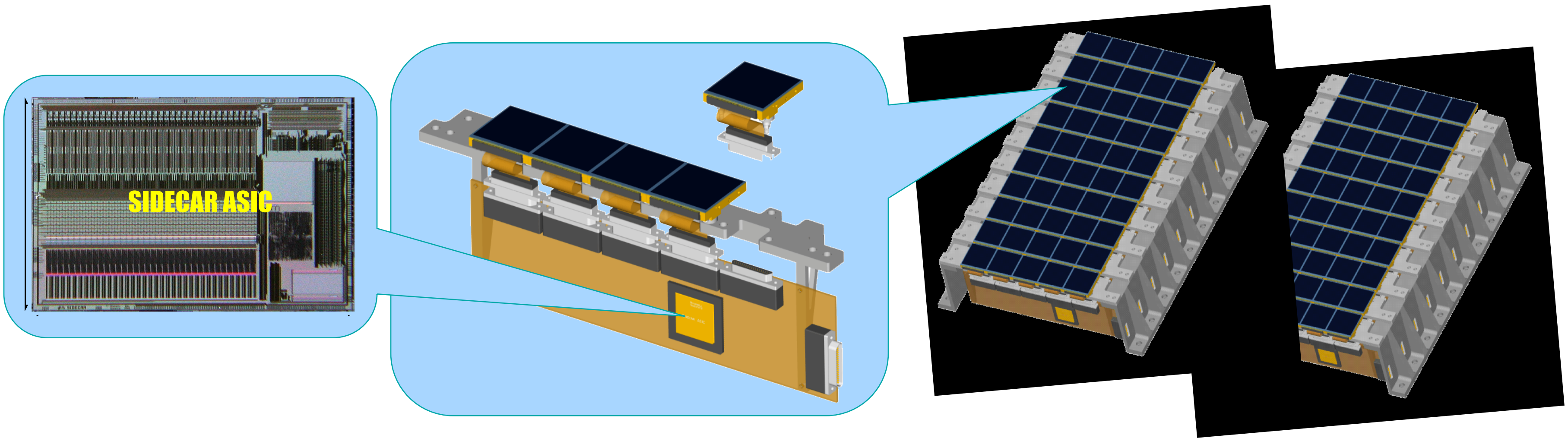
Key MPF Mission Requirements

MPF Technical Summary

- 1.1 m TMA telescope, ~ 1.5 deg FoV, at room temperature, based on existing ITT designs and test hardware
- 35 2Kx2K HgCdTe detector chips at 140 K, based on JWST and HST/WFC3 technology
- 0.24 arcsec pixels, and focal plane guiding
- 5 × 34 sec exposures per pointing
- SIDECAR ASICs run detectors, based on JWST work
- No shutter
- 3 filters: “clear” 600-1700nm, “visible” 600-900nm, “IR” 1300-1700nm
- 1% photometry required at J=20
- 28.5° inclined geosynchronous orbit
- Continuous viewing of Galactic bulge target (except when Sun passes across it)
- Cycling over 4 × 0.65 sq. deg. fields in 15 minute cycle
- Continuous data link, Ka band, 50 Mbits/sec

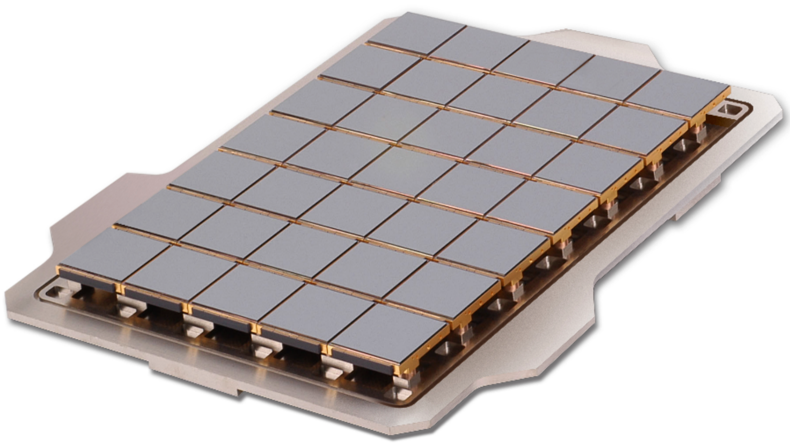
Focal Plane Concept

- 35 2Kx2K near IR HgCdTe detectors from Teledyne
- one bank of 5×7 detectors
- Sidecar ASIC – Reduces wire count, produces clock signals, provides 16-bit ADC's, and digital signal processing (Fowler sampling)
- One ASIC per 5 detectors
- Each detector can watch a guide star in a sub-window while taking long exposures



MPF Focal Plane Concept

- 35 2Kx2K near IR Teledyne Imaging (formerly Rockwell) HgCdTe detectors
- one bank of 5×7 detectors
- Sidecar ASIC – Reduces wire count, produces clock signals, provides 16-bit ADC's, and digital signal processing (Fowler sampling)
- Passively cooled to 140K
- One ASIC per 5 detectors
- Each detector can watch a guide star in a sub-window while taking long exposures



Pathfinder demonstration focal plane built by Teledyne.

More Pixel Options

- Ideally, reduce cost or increase observing efficiency for all programs
  - But improved efficiency for exoplanet survey allow more time for other programs
- More pixels in focal plane & reduced telescope aperture
  - MPF approach
  - If 4k×4k detectors were available, we could have more pixels with fewer detectors
- Exoplanet survey imaging with spectroscopic detectors
  - Poor image sampling - exoplanet photometry ok, but host detection difficult
- 4k×4k and 2k×2k detectors in the same focal plane
  - Better resolution for WL
  - Larger FOV for microlensing

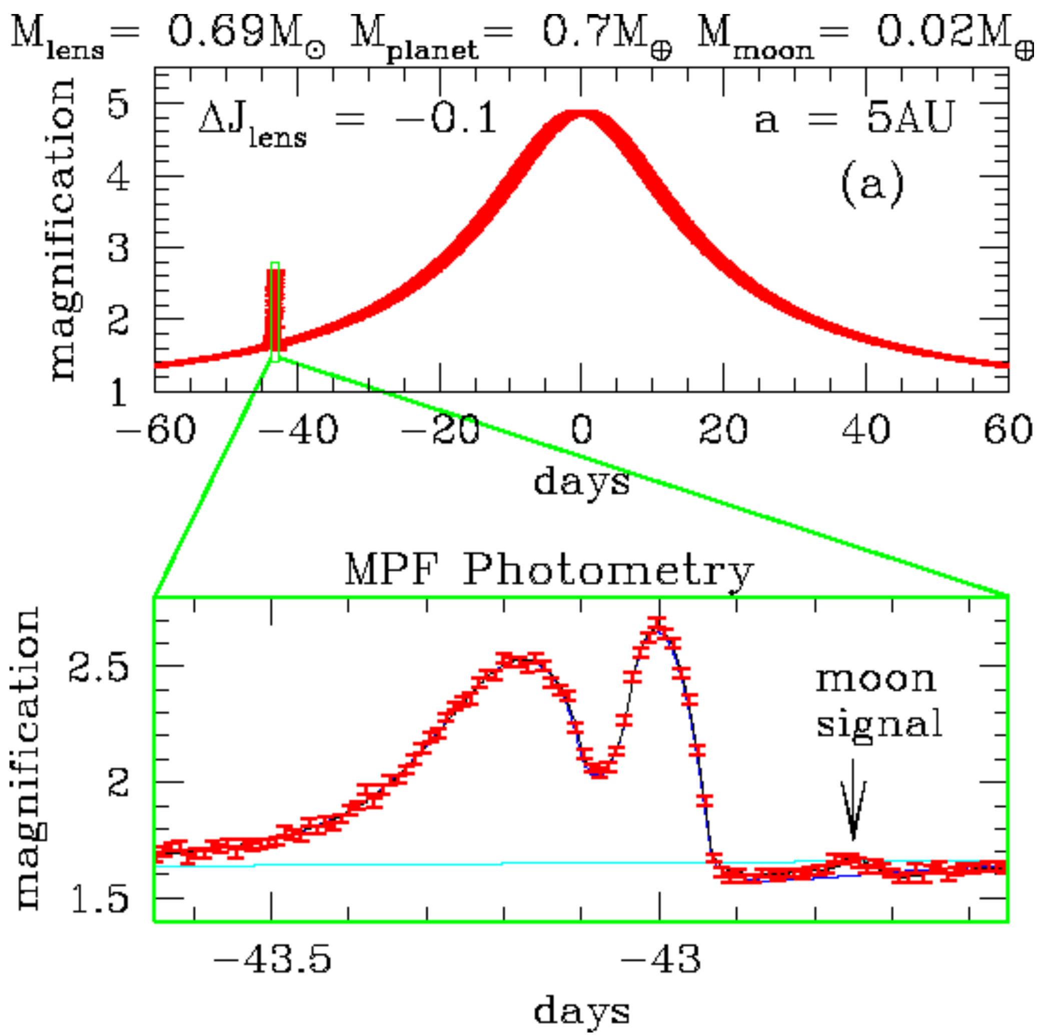
Imaging with Spectrometer Detectors

- Image sampling is worse 0.37”/pix or 0.45”/pix
- But planetary microlensing signals are often strong, so most will still be detectable
  - Inner planets (near HZ) are most affected
- Bypassing prisms may be complicated
  - Potential reduction in BAO sensitivity
- Host-Source relative proper motion is harder to measure
  - Typically 30mas over 5 years
  - Needed for host star mass measurements

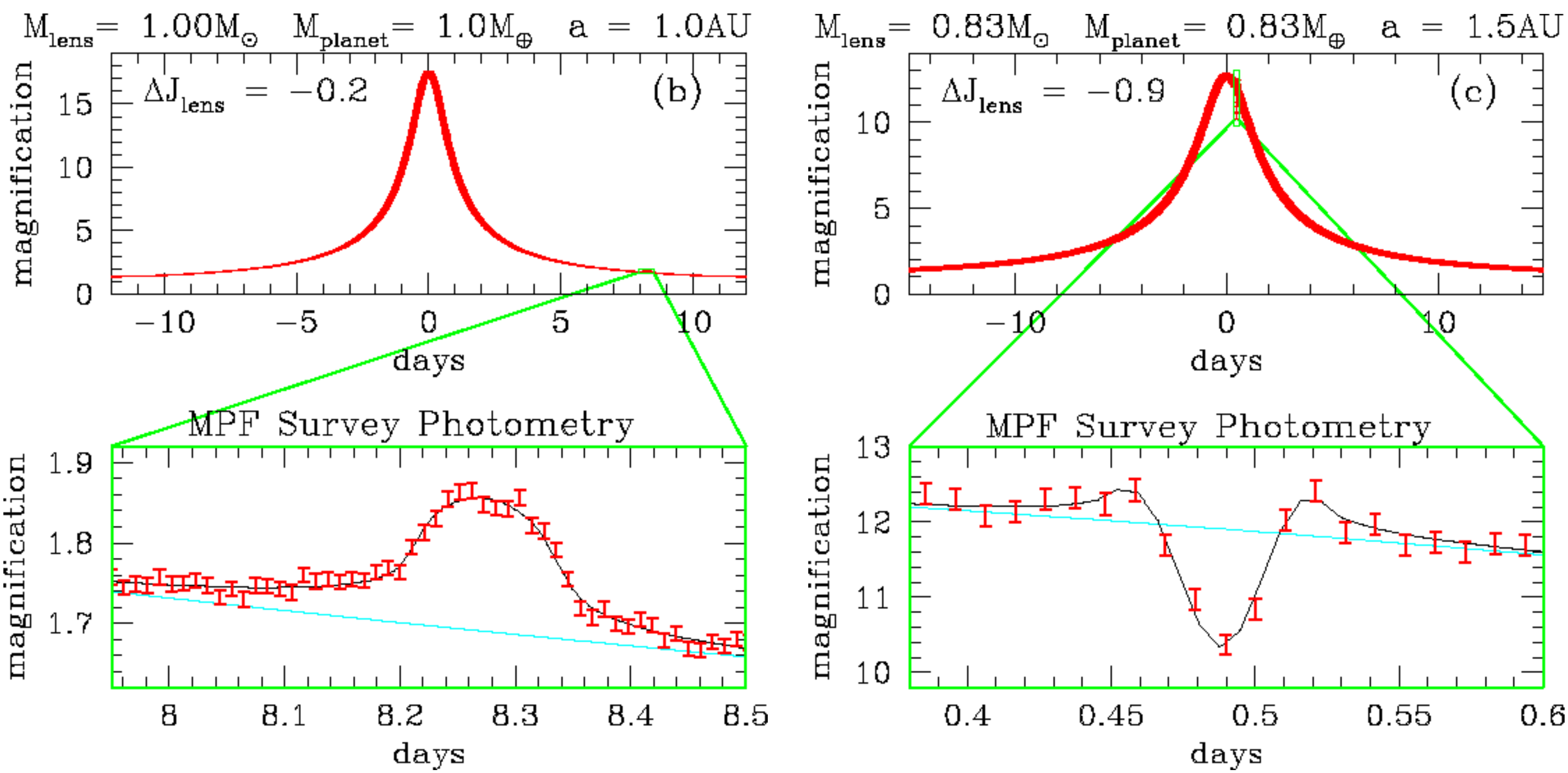
Simulated **WFIRST** Planetary Light Curves

Low-mass planets can have high S/N

- Planetary signals can be very strong
- There are a variety of light curve features to indicate the planetary mass ratio and separation
- Exposures every ~15 minutes
- The small deviation at day –42.75 is due to a moon of 1.6 lunar masses.

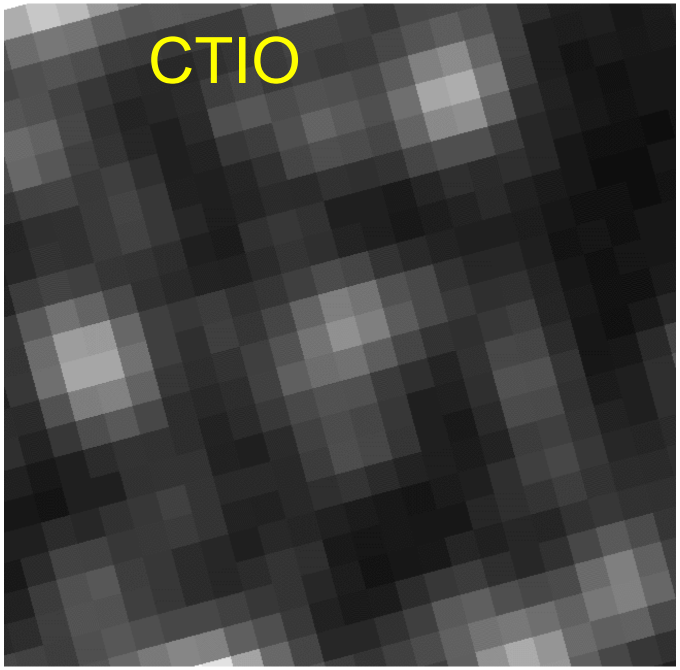


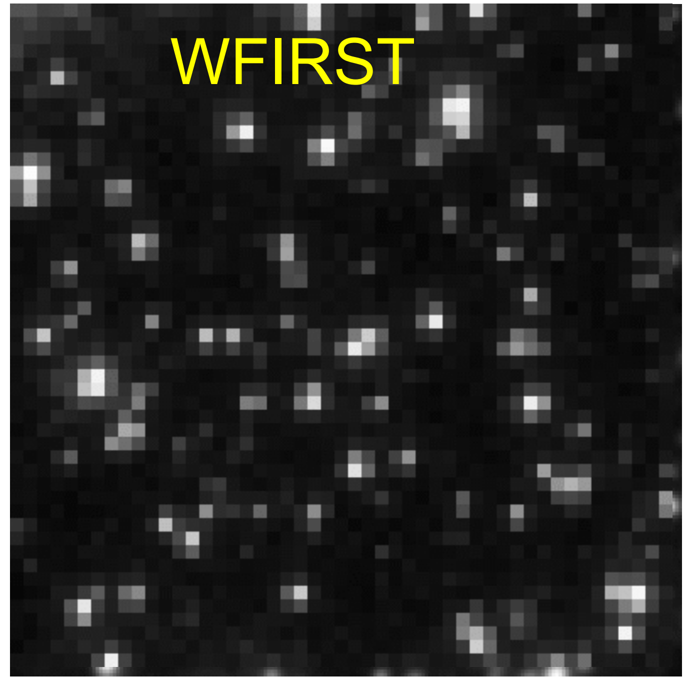
Simulated WFIRST Light Curves



The light curves of simulated planetary microlensing events with predicted WFIRST/MPF error bars. ΔJ_{lens} refers to the difference between the lens and source star magnitudes. The lens star is brighter for each of these events.

Ground-based confusion, space-based resolution

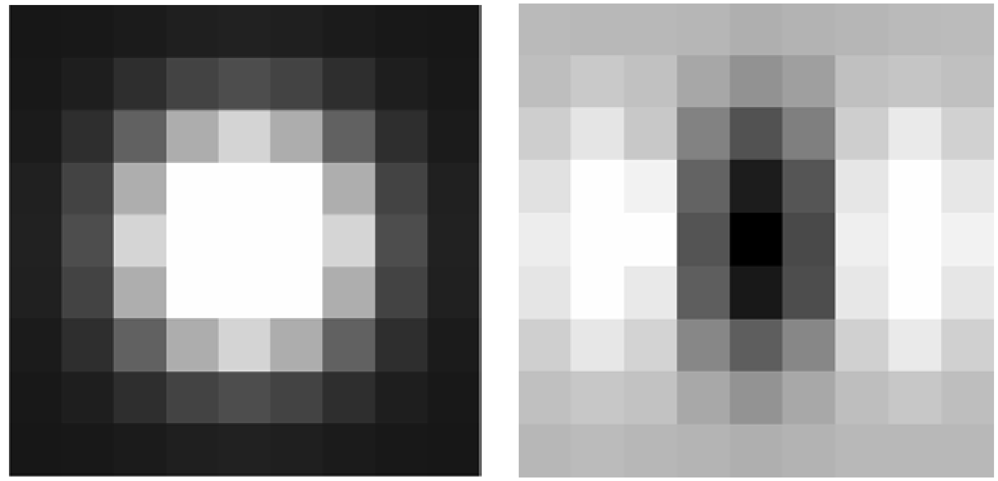




- Space-based imaging needed for high precision photometry of main sequence source stars (at low magnification) and lens star detection
- High Resolution + large field + 24hr duty cycle => Microlensing Planet Finder (MPF)
- Space observations needed for sensitivity at a range of separations and mass determinations

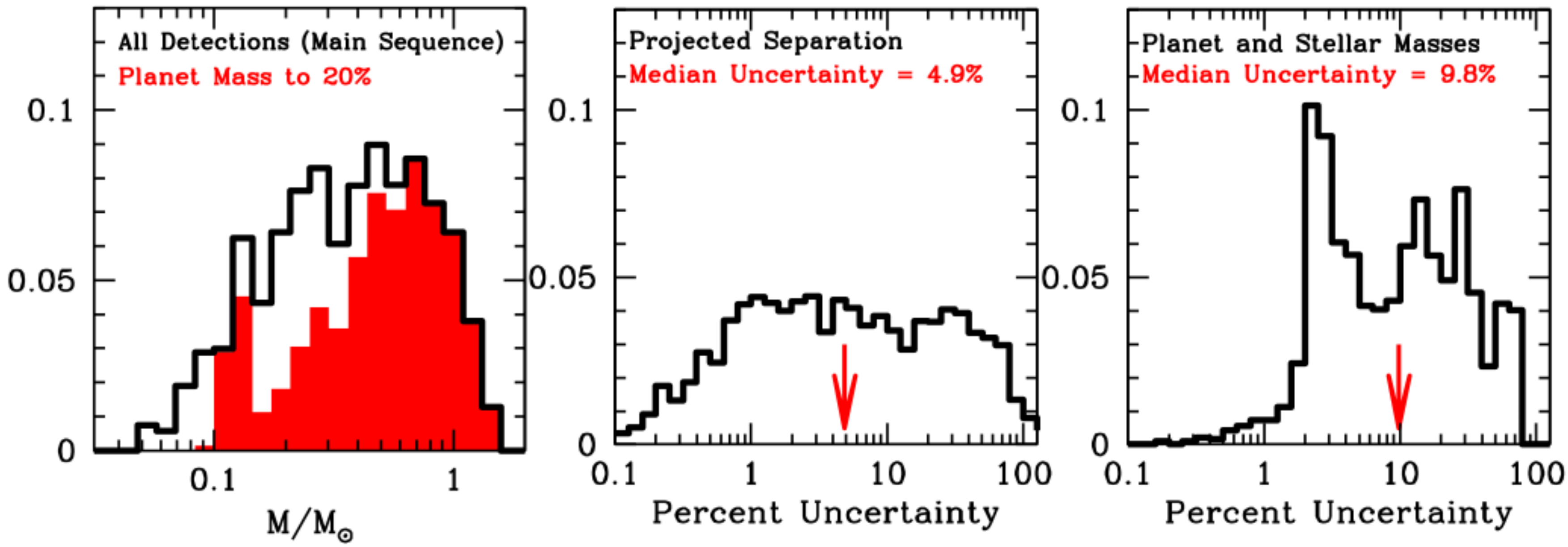
Lens Star Detection in **WFIRST** Images

- The typical lens-source relative proper motion is $\mu_{rel} \sim 5$ mas/yr
- This gives a total motion of >0.05 pixels over 3 years
- This is directly detectable in co-added MPF images due to MPF's stable PSF and large number of images of each of the target fields.
- μ_{rel} is also determined from the light curve fit.
- A color difference between the source and lens stars provides a signal of μ_{rel} in the color dependence of the source+lens centroid position



A 3× super-sampled, drizzled 4-month MPF image stack showing a lens-source blend with a separation of 0.07 pixel, is very similar to a point source (left). But with PSF subtraction, the image elongation becomes clear, indicating measurable relative proper motion.

Lens Detection Provides Complete Lens Solution



- The observed brightness of the lens can be combined with a mass-luminosity relation, plus the mass-distance relation that comes from the μ_{rel} measurement, to yield a complete lens solution.
- The resulting uncertainties in the absolute planet and star masses and projected separation are shown above.
- Multiple methods to determine μ_{rel} and masses (such as lens star color and microlensing parallax) imply that complications like source star binarity are not a problem.

Mixed Focal Plane

- Mix 4k × 4k (10μm) and 2k × 2k (18μm) pixel devices
- 0.15”/pixel and 0.27”/pixel or
- 0.13"/pixel and 0.24”/pixel or
- 0.10"/pixel and 0.18”/pixel
- Better resolution in the central region plus more area at course sampling.