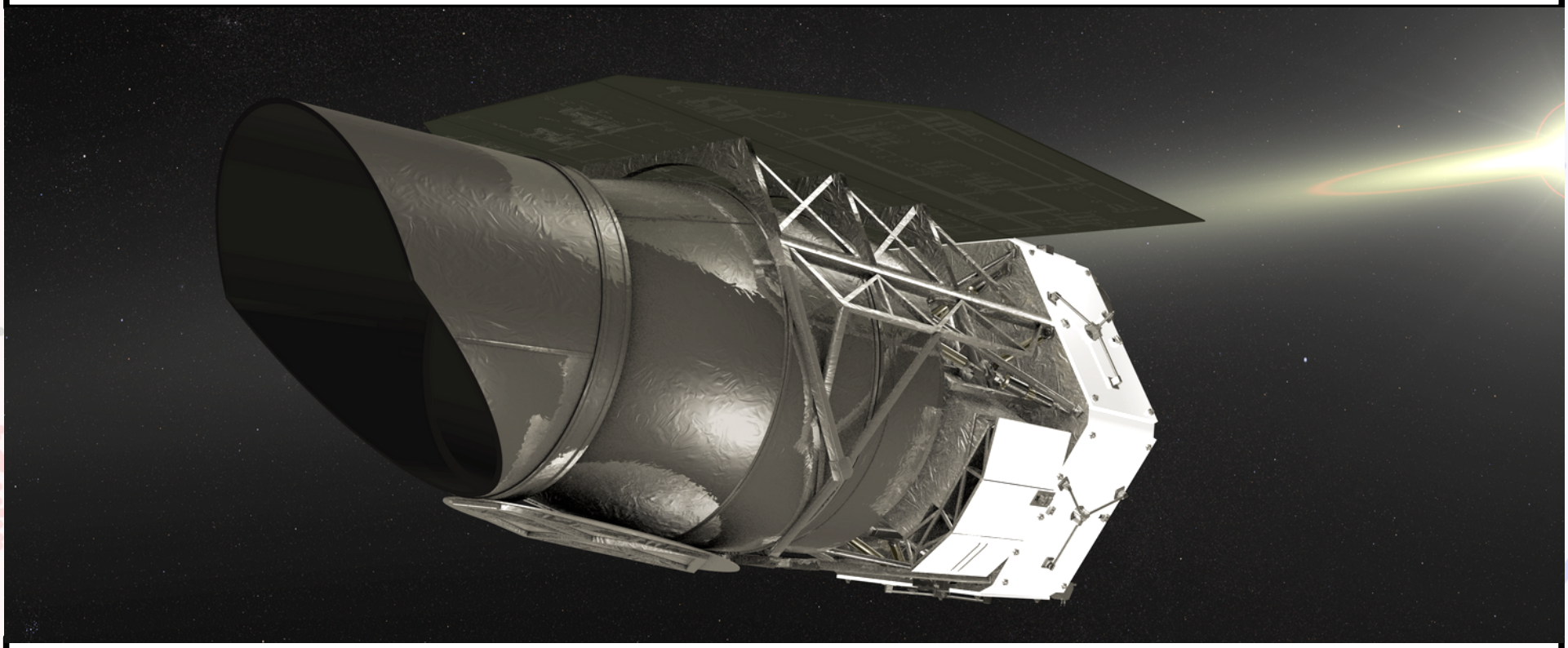
WFIRST: The Wide-Field InfraRed Survey Telescope

and what we can learn from its microlensing survey



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Overview

- An Overview of and Update on *WFIRST*
- WFIRST's Time Domain Surveys
- The *WFIRST* Microlensing Survey

Spergel et al. - https://arxiv.org/abs/1503.03757

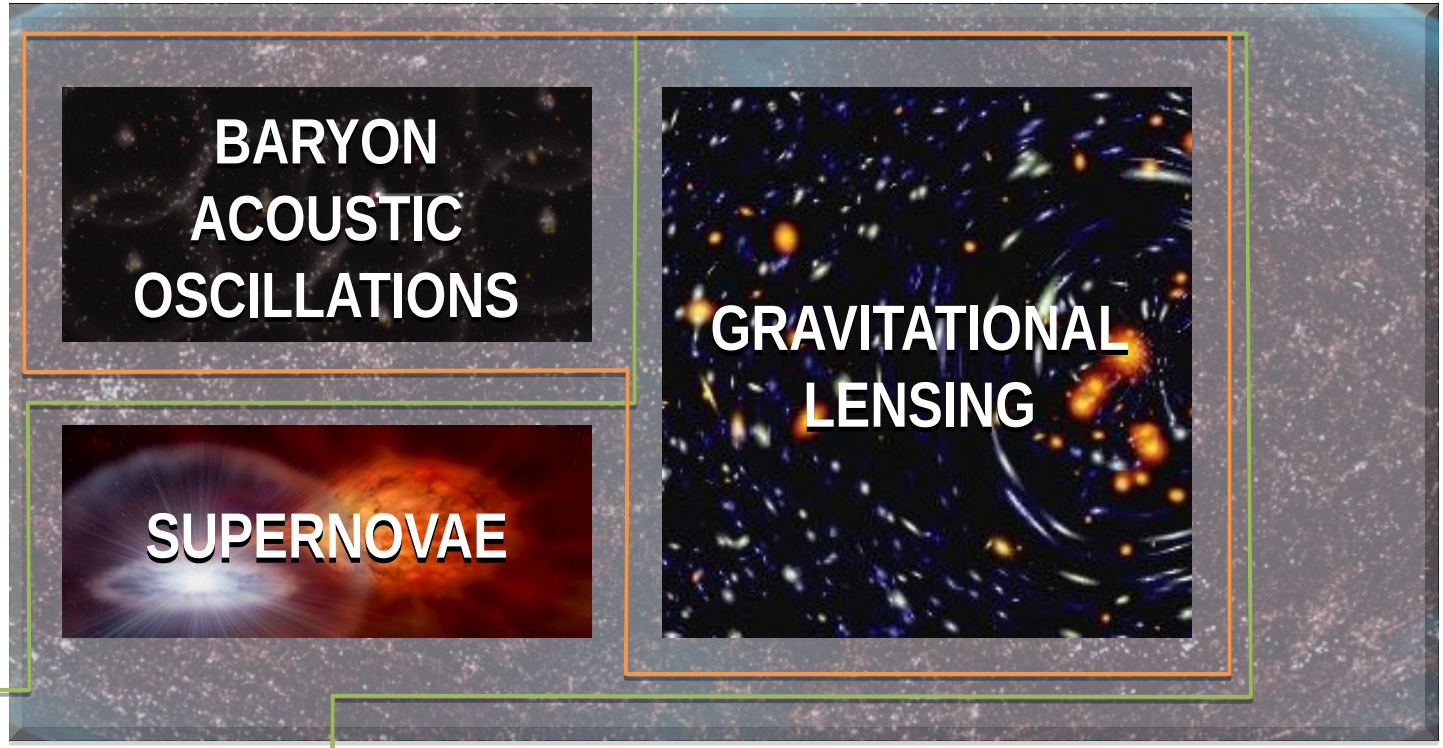
http://http://wfirst.gsfc.nasa.gov/

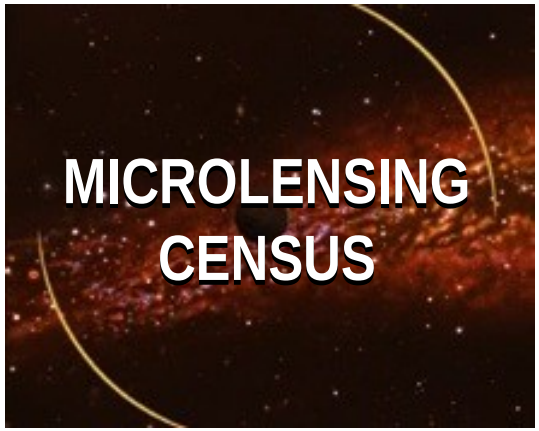
WFIRST Science

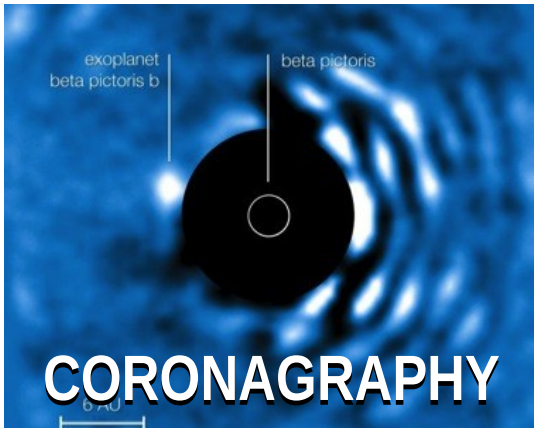
complements Euclid

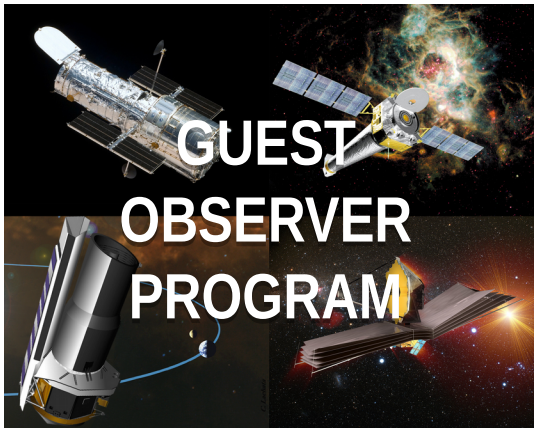
complements LSST

complements Kepler





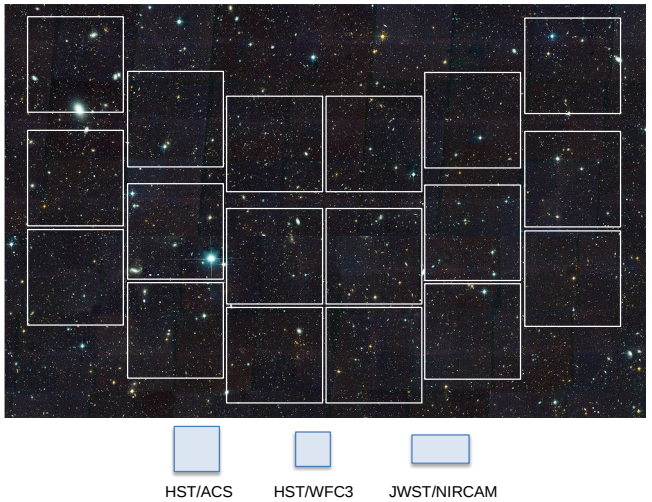


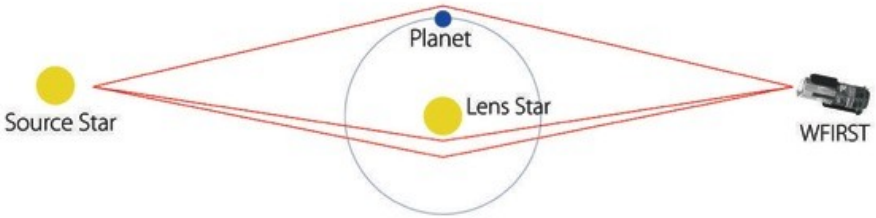


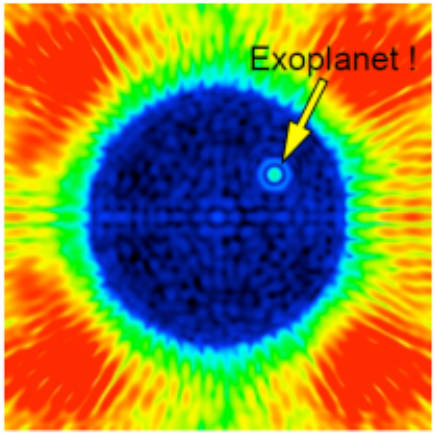
continues Great Observatory legacy

WFIRST Summary

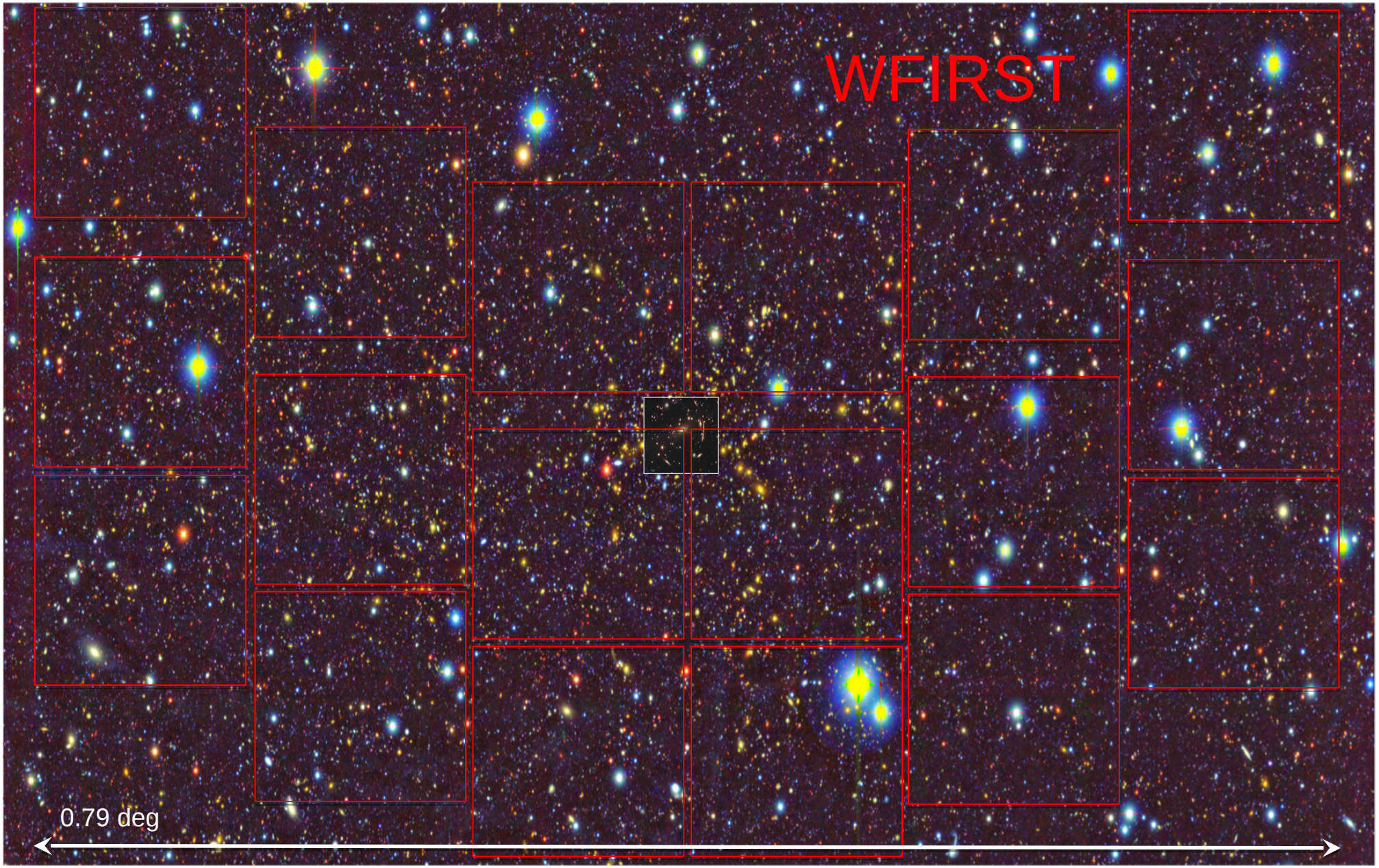
- WFIRST is the highest ranked NWNH large space mission.
  - Determine the nature of the dark energy that is driving the current accelerating expansion of the universe
  - Perform statistical census of planetary systems through microlensing survey
  - Survey the NIR sky
  - Provide the community with a wide field telescope for pointed wide observations
- Coronagraph characterizes planets and disks, broadens science program and brings humanity closer to imaging Earths.
- WFIRST gives Hubble-quality and depth imaging over thousands of square degrees
- The WFIRST-AFTA Design Reference Mission has
  - 2.4 m telescope (already exists)
  - NIR instrument with 18 H4RG detectors
  - Baseline exoplanet coronagraph
  - 6 year lifetime



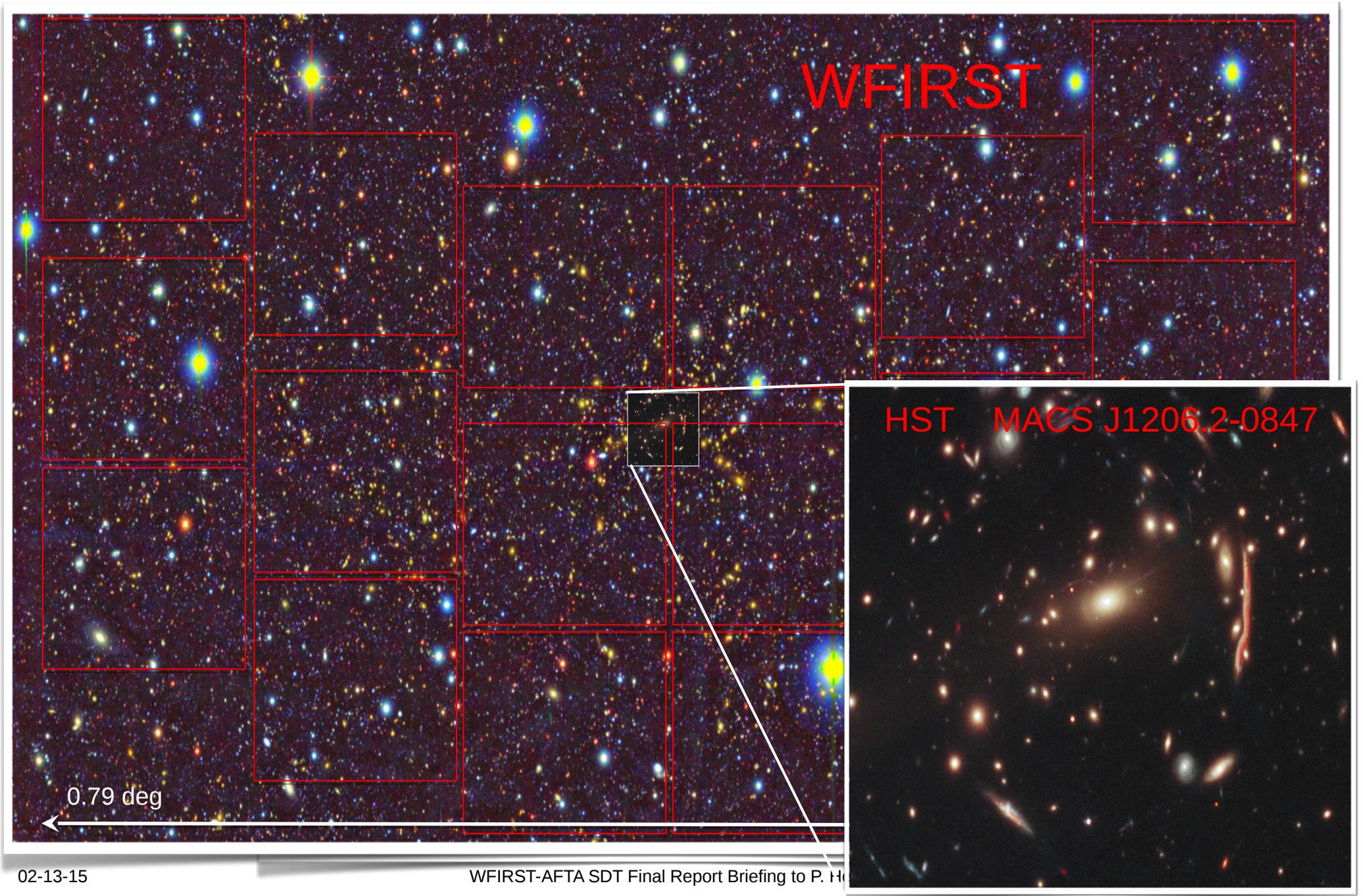




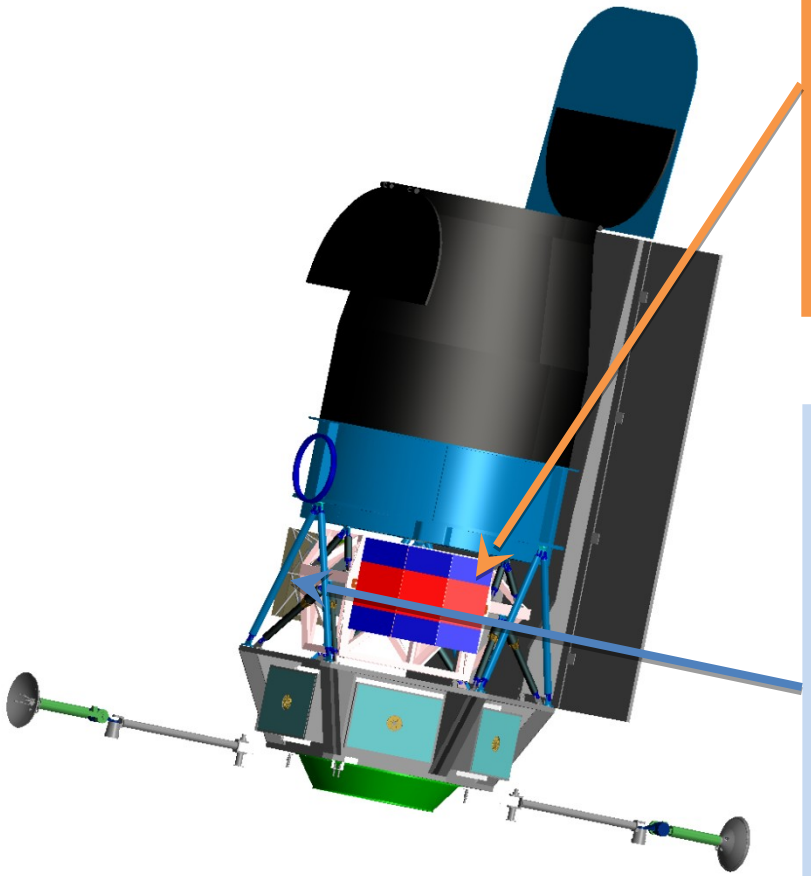
Gravitational Lensing



Gravitational Lensing



WFIRST Instruments



Wide-Field Instrument

- *Imaging & spectroscopy over 1000s of sq. deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 μm (imaging) & 1.35-1.89 μm (spec.)
- 0.28 deg^2 FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 6 filter imaging, grism + IFU spectroscopy

Coronagraph

- *Image and spectra of exoplanets from super-Earths to giants*
- *Images of debris disks*
- 430 – 970 nm (imaging) & 600 – 970 nm (spec.)
- Final contrast of 10^{-9} or better
- Exoplanet images from 0.1 to 1.0 arcsec

Capabilities

WFI:

Imager **0.76-2.0 microns** 0.28° FoV, 0.11" pixel scale

Filters: z (0.76 - 0.98), Y (0.93-1.19), J (1.13-1.45), H(1.38-1.77),

F184 (1.68-2.0), W149 (0.93-2.00)

Grism: **1.35-1.89 microns** 0.28° FoV, R=461λ, 0.11" pixel scale

IFU: **0.6-2.0 microns** 3" & 6" FoV, R~100, 0.075" pixel scale

Coronagraph:

Imager: **0.43-0.97 microns** 1.63" FoV (radius), 0.01" pixel scale, 1k x 1k EMCCD, 10^{-9} final contrast, 100-200 mas inner working angle

IFS: **0.60-0.97 microns** 0.82" FoV (radius), R~70

Field of Regard: 54° - 126° 60% of sky

Expected WFIRST Data Policy

- Project recognizes that Wide-Field data can be useful on short timescales for many applications → aim for zero proprietary period for all surveys + GO observations
- Make raw data available ~immediately
- Routine calibrated images available on ~2 day timescales
- Higher level products (e.g. source catalogs), etc. available on ~3 month timescale
- Faster processing for time critical surveys (Supernovae, microlensing)

WFIRST current status

- $203M funding 2014-2016
- $120M funding 2017 (Senate budget)
- Currently in Phase A, Phase B expected Oct 2017
- 11 funded Science Investigation Teams reporting to Science Formulation Working Group
- Launch ready by Q3 2024

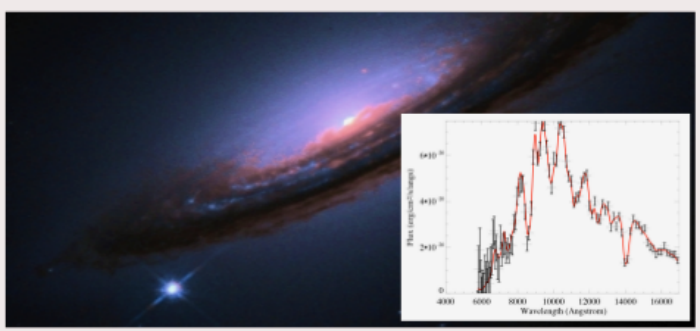
WFIRST-AFTA Dark Energy Roadmap

Supernova Survey

wide, medium, & deep imaging
+
IFU spectroscopy

2700 type Ia supernovae
z = 0.1–1.7

standard candle distances
z < 1 to 0.20% and z > 1 to 0.34%



High Latitude Survey

spectroscopic: galaxy redshifts

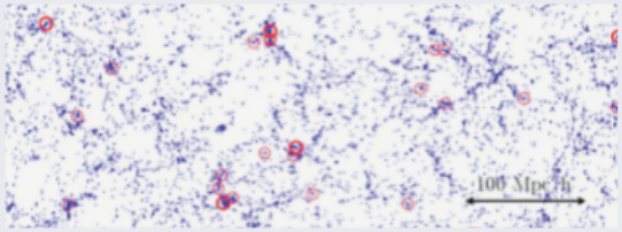
16 million Hα galaxies, z = 1–2
1.4 million [OIII] galaxies, z = 2–3

imaging: weak lensing shapes

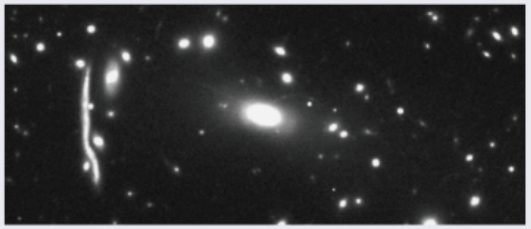
380 million lensed galaxies
40,000 massive clusters

standard ruler

distances	expansion rate
z = 1–2 to 0.5%	z = 1–2 to 0.9%
z = 2–3 to 1.3%	z = 2–3 to 2.1%

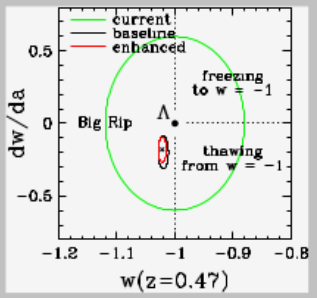


dark matter clustering
z < 1 to 0.21% (WL); 0.24% (CL)
z > 1 to 0.78% (WL); 0.88% (CL)
1.1% (RSD)



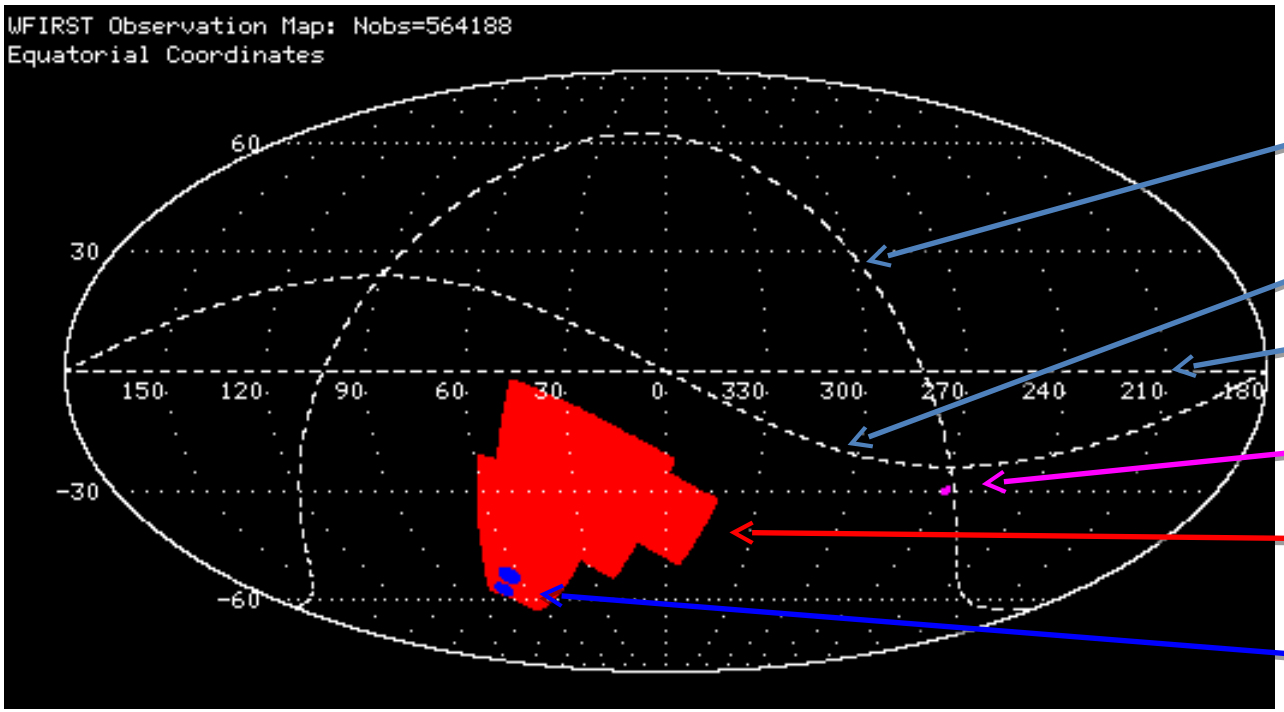
history of dark energy
+
deviations from GR

$w(z)$, $\Delta G(z)$, Φ_{REL}/Φ_{NREL}



Example Observing Schedule

- High-latitude survey (HLS: imaging + spectroscopy): 2.01 years
  - 2227 deg^2 @ ≥3 exposures in all filters (2279 deg^2 bounding box)
- 6 microlensing seasons (0.98 years, after lunar cutouts)
- SN survey in 0.63 years, field embedded in HLS footprint
- 1 year for the coronagraph, interspersed throughout the mission
- Unallocated time is 1.33 years (includes GO program)



Galactic Plane

Ecliptic Plane

Celestial Equator

Microlensing Fields

High-Latitude Survey Area

SN Fields

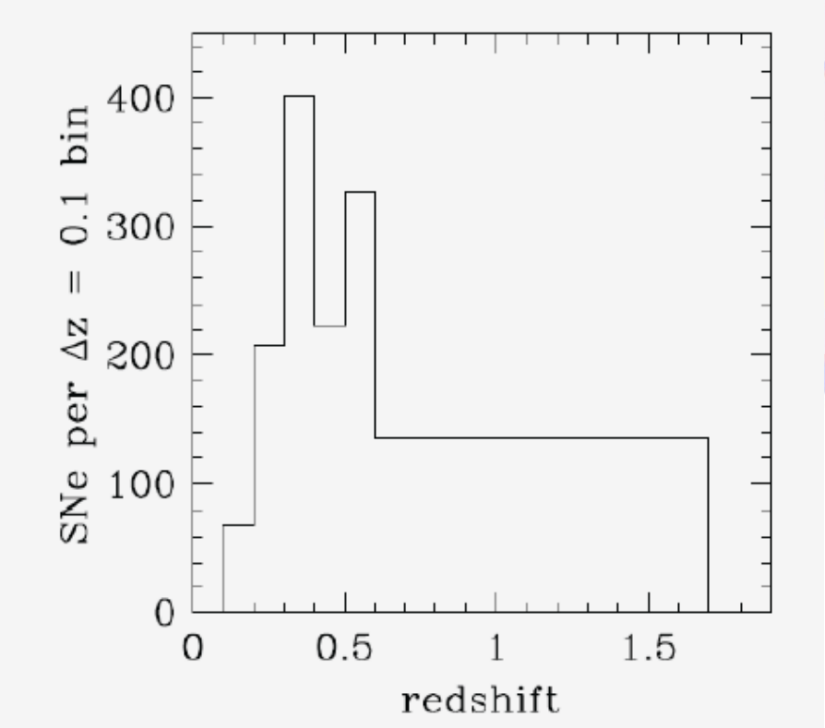
DRM Yields

Attributes	WFIRST-AFTA Yields
Imaging survey	J ~ 27 AB over 2200 sq deg
	J ~ 29 AB over 3 sq deg deep fields
Slitless spectroscopy	R~461λ over 2200 sq deg
Number of SN Ia SNe	2700 to z~1.7
Number galaxies with spectra	$2x10^7$
Number galaxies with shapes	$4x10^8$
Number of galaxies detected	few x 10^9
Number of massive clusters	$4x10^4$
Number of microlens exoplanets	2600
Number of imaged exoplanets	10s

The WFIRST Supernova Survey

Survey Goals

- Discover ~2000 Type Ia supernovae over redshifts 0.5-1.7 and measure their distances
- Minimize systematics by recreating rest-frame photometry from IFU spectrophotometry

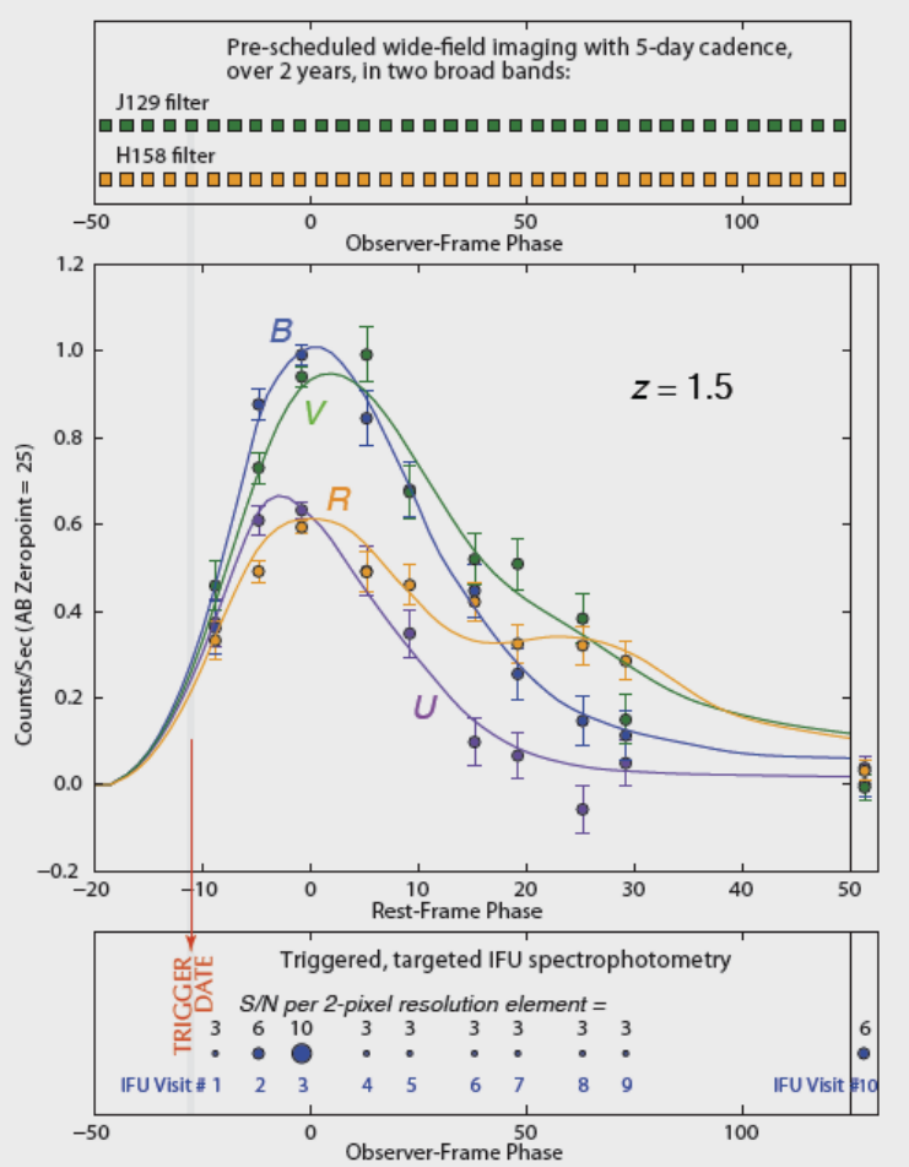


Survey Strategy

- Proof of concept, still can change*
- 5 day cadence, 2 year duration
- 3-Tiered:
  - Wide: 27.4 deg^2, z<0.5
  - Med: 9.0 deg^2, z<0.8
  - Deep: 5.0 deg^2, z<1.7
- Discovery 2 filter imaging (Y-J wide, J-H med+deep) → ~50% type Ia sample purity
- Type classification and lightcurves through IFU spectra

*Active cross-SIT discussions on the relative benefits/drawbacks of IFU vs imaging for lightcurves

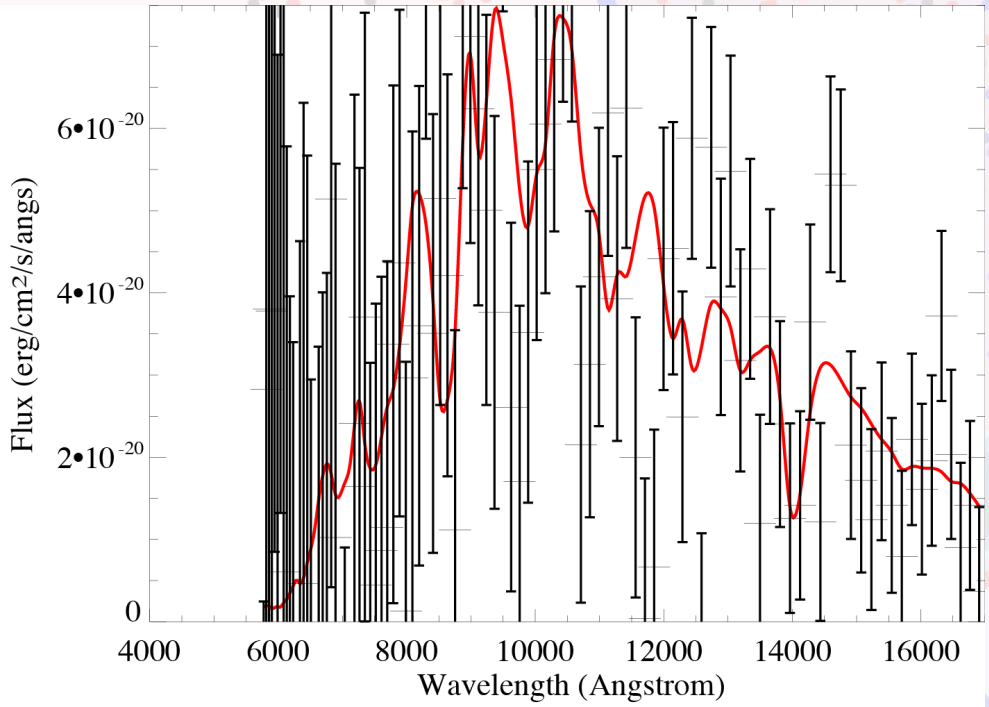
Supernovae Lightcurves



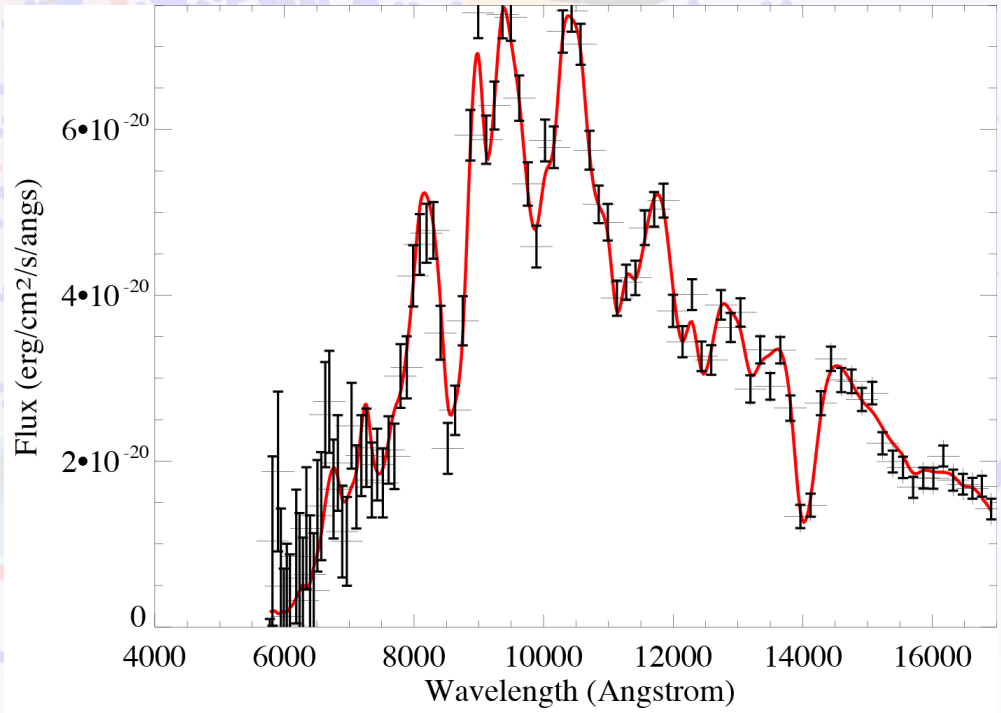
- 2-filter imaging only used for discovery and v. rough typing
- Targetted IFU observations of single SNe from 12-7 RF-days before to 30 RF-days after peak
- 2nd spectrum near peak used for final typing selection
- Rest frame UBVR photometry constructed from 0.6-2.0 um IFU spectra
  - Removes need for K corrections
  - IFU gives better host subtraction than GRISM
- No plans for Non-Ia SNe

Supernova Spectra Comparison Prism vs. IFU

S/N=1 with prism

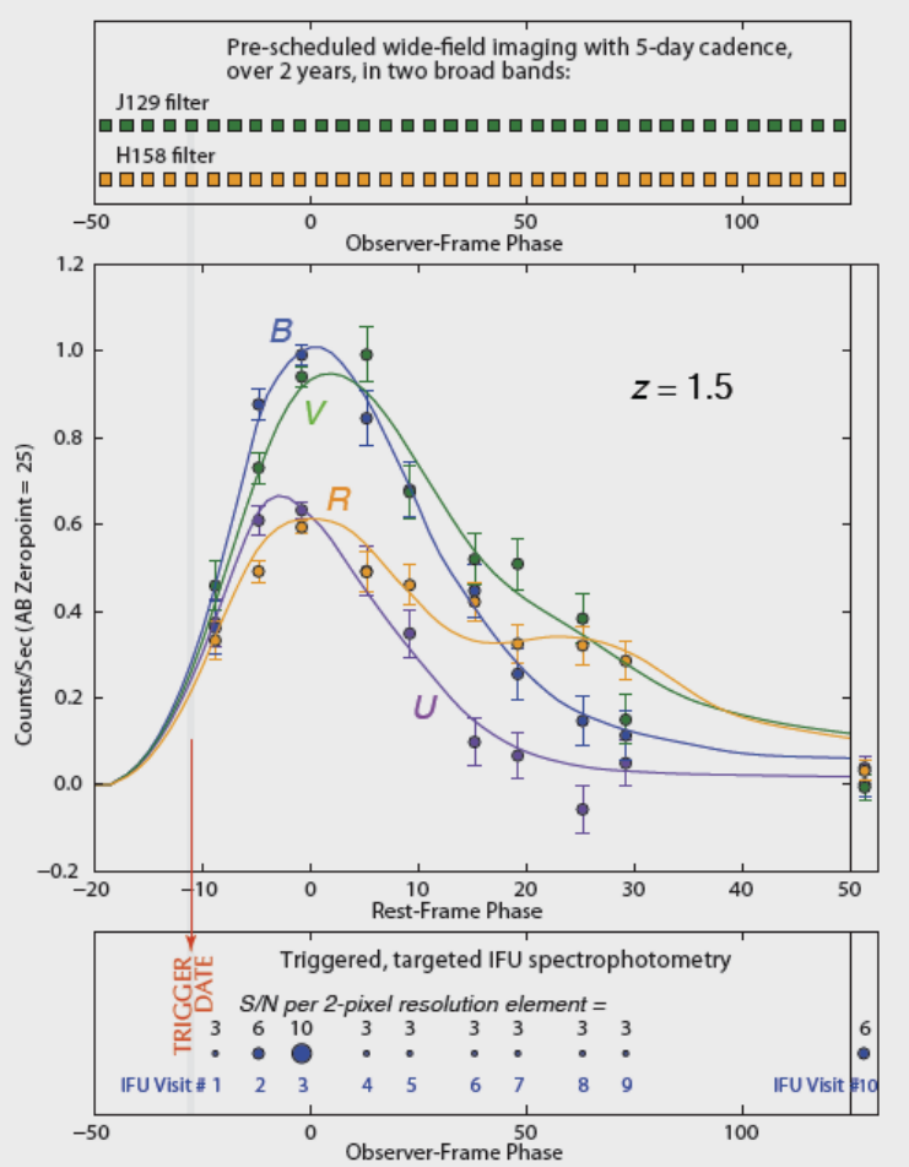


S/N=7 with IFU



SN Ia spectrum at z = 1.3

Supernovae Lightcurves



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WFIRST-AFTA Exoplanet Science

The combination of microlensing and direct imaging will dramatically expand our knowledge of other solar systems and will provide a first glimpse at the planetary families of our nearest neighbors.

Microlensing Survey

Monitor 200 million Galactic bulge stars every 15 minutes for 1.2 years

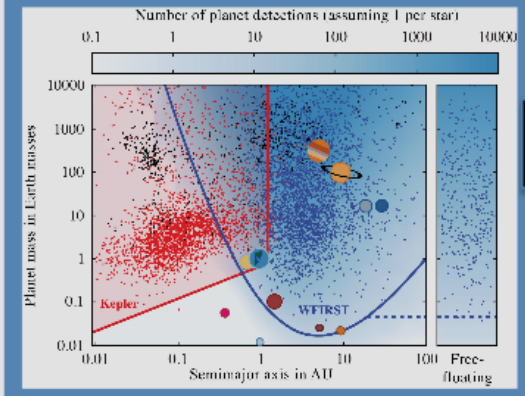
2600 cold exoplanets
370 Earth-mass planets
50 Mars-mass or smaller planets
30 free-floating Earth-mass planets

High Contrast Imaging

Survey up to 200 nearby stars for planets and debris disks at contrast levels of 10^{-9} on angular scales > 0.1"
R=70 spectra and polarization between 430-970 nm

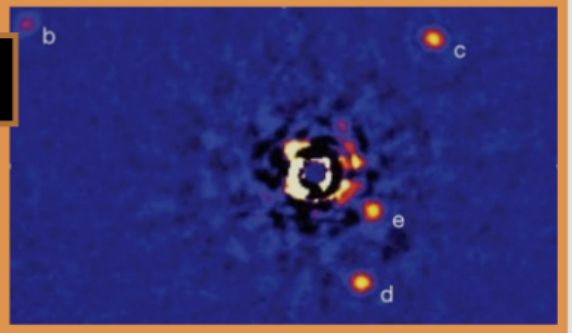
Detailed characterization of up to a dozen giant planets.
Discovery and characterization of several Neptunes
Detection of massive debris disks.

Complete the Exoplanet Census



- How do planetary systems form and evolve?
- What are the constituents and dominant physical processes in planetary atmospheres?
- What kinds of unexpected systems inhabit the outer regions of planetary systems?
- What are the masses, compositions, and structure of nearby circumstellar disks?
- Do small planets in the habitable zone have heavy hydrogen/helium atmospheres?

Discover and Characterize Nearby Worlds



Toward the "Pale Blue Dot"

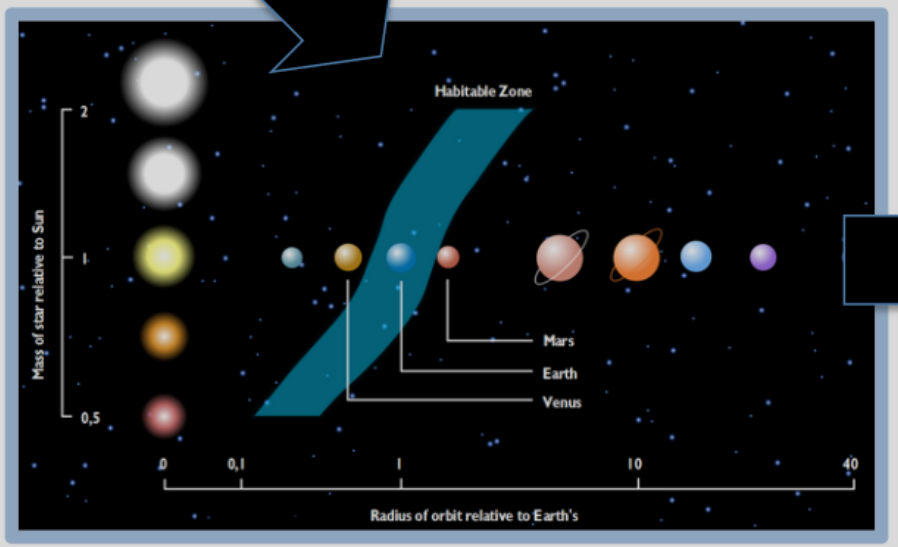
WIFRST will lay the foundation for a future flagship direct imaging mission capable of detection and characterization of Earth-like planets.

Microlensing Survey

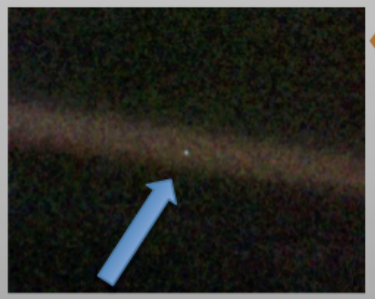
- Inventory the outer parts of planetary systems, potentially the source of the water for habitable planets.
- Quantify the frequency of solar systems like our own.
- Confirm and improve Kepler's estimate of the frequency of potentially habitable planets.
- When combined with Kepler, provide statistical constraints on the densities and heavy atmospheres of potentially habitable planets.

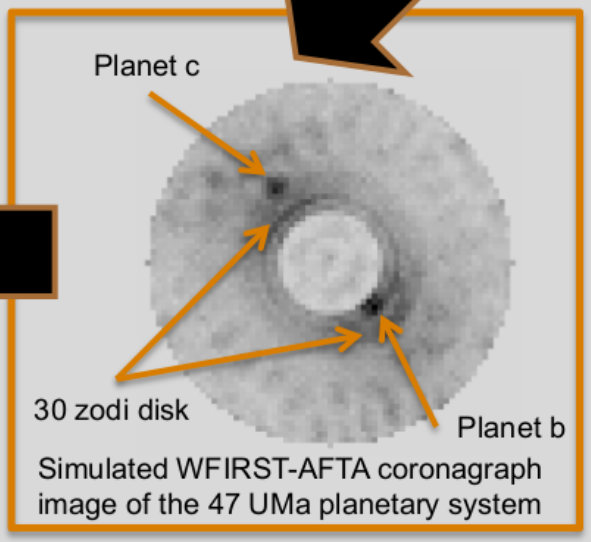
High Contrast Imaging

- Provide the first direct images of planets around our nearest neighbors similar to our own giant planets.
- Provide important insights about the physics of planetary atmospheres through comparative planetology.
- Assay the population of massive debris disks that will serve as sources of noise and confusion for a flagship mission.
- Develop crucial technologies for a future mission, and provide practical demonstration of these technologies *in flight*.



Science and technology foundation for the New Worlds Mission.

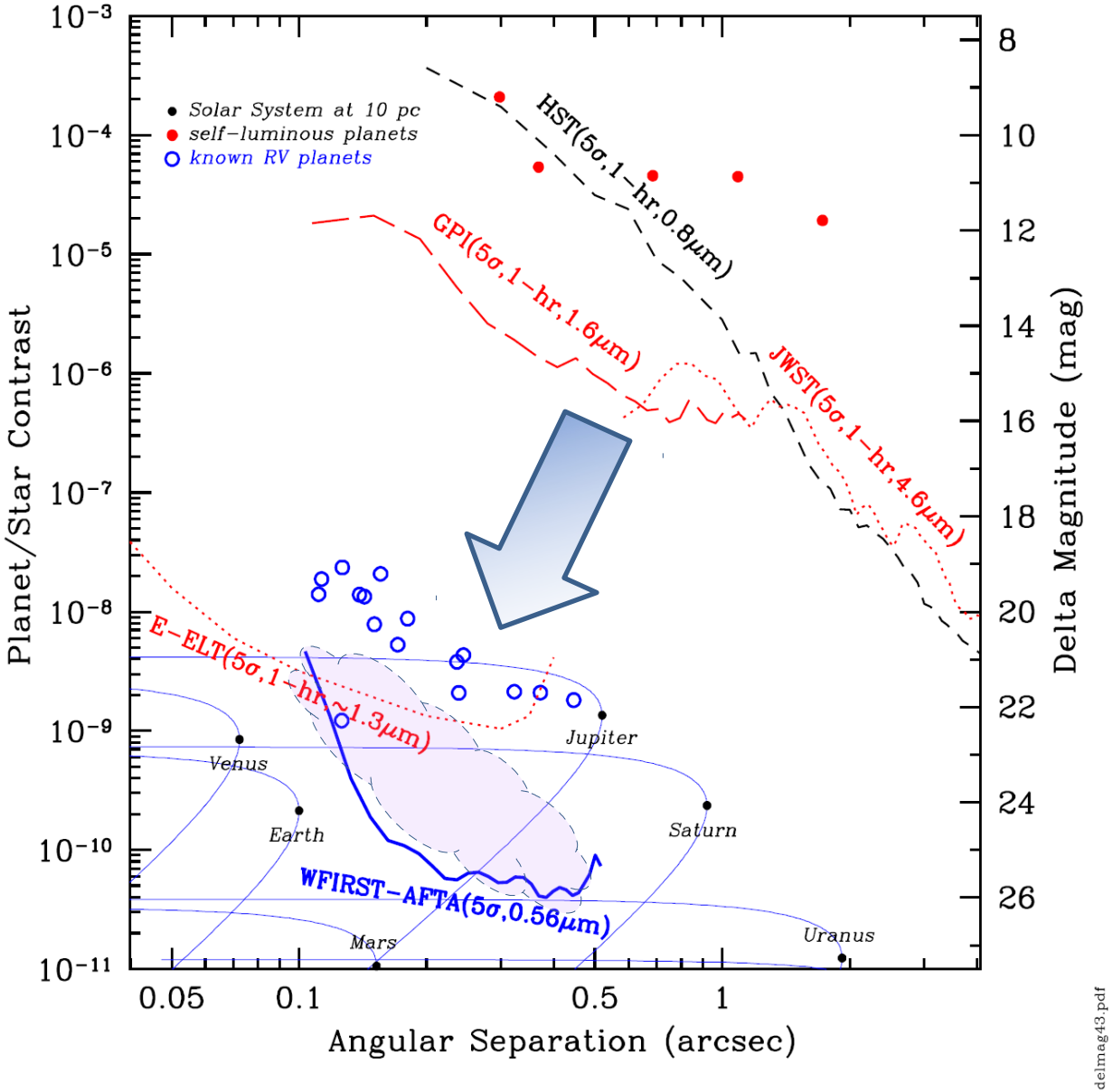




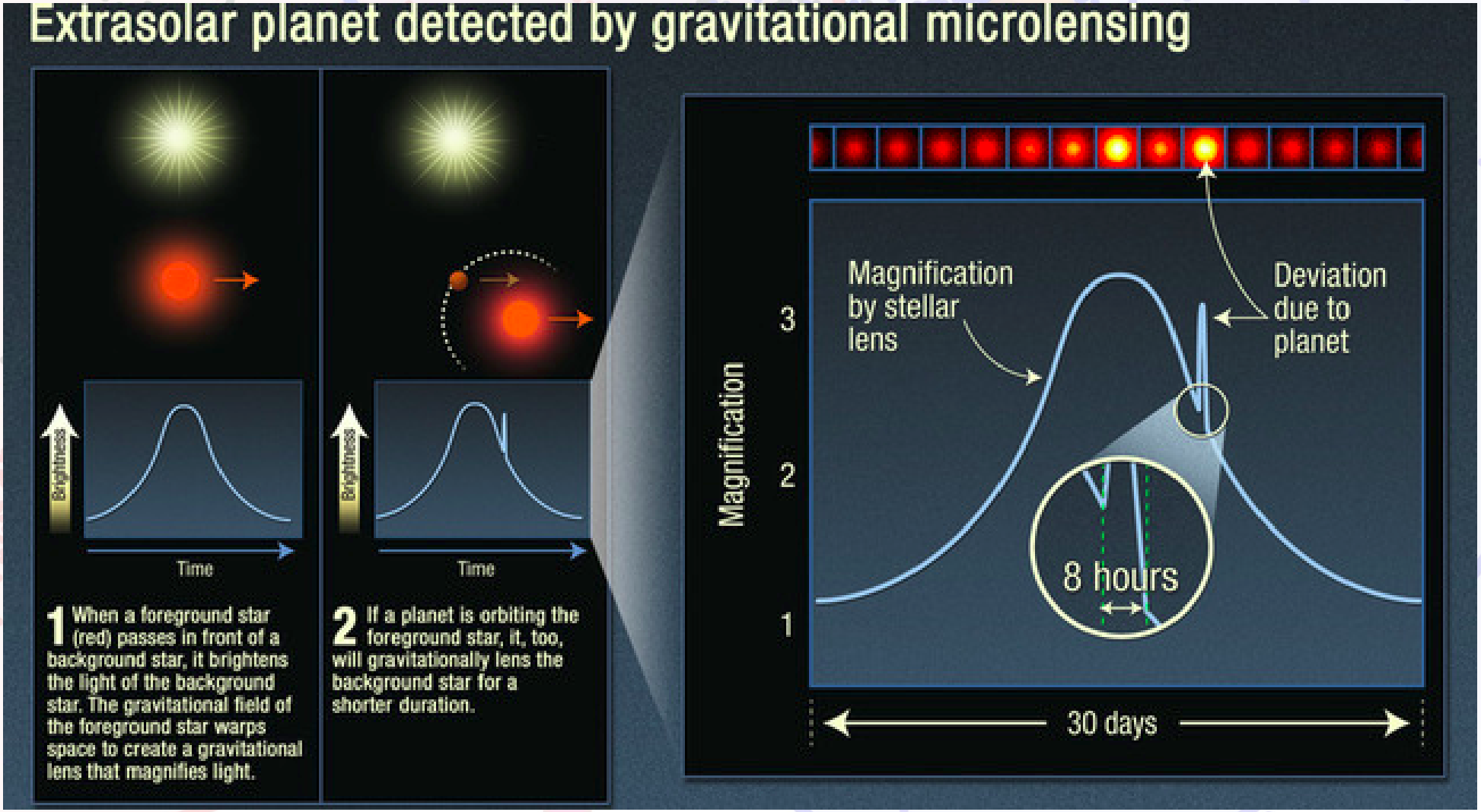
Simulated WFIRST-AFTA coronagraph image of the 47 UMa planetary system

WFIRST-AFTA Brings Humanity Closer to Characterizing exo-Earths

- WFIRST-AFTA advances many of the key elements needed for a coronagraph to image an exo-Earth
  - ✓ Coronagraph
  - ✓ Wavefront sensing & control
  - ✓ Detectors
  - ✓ Algorithms

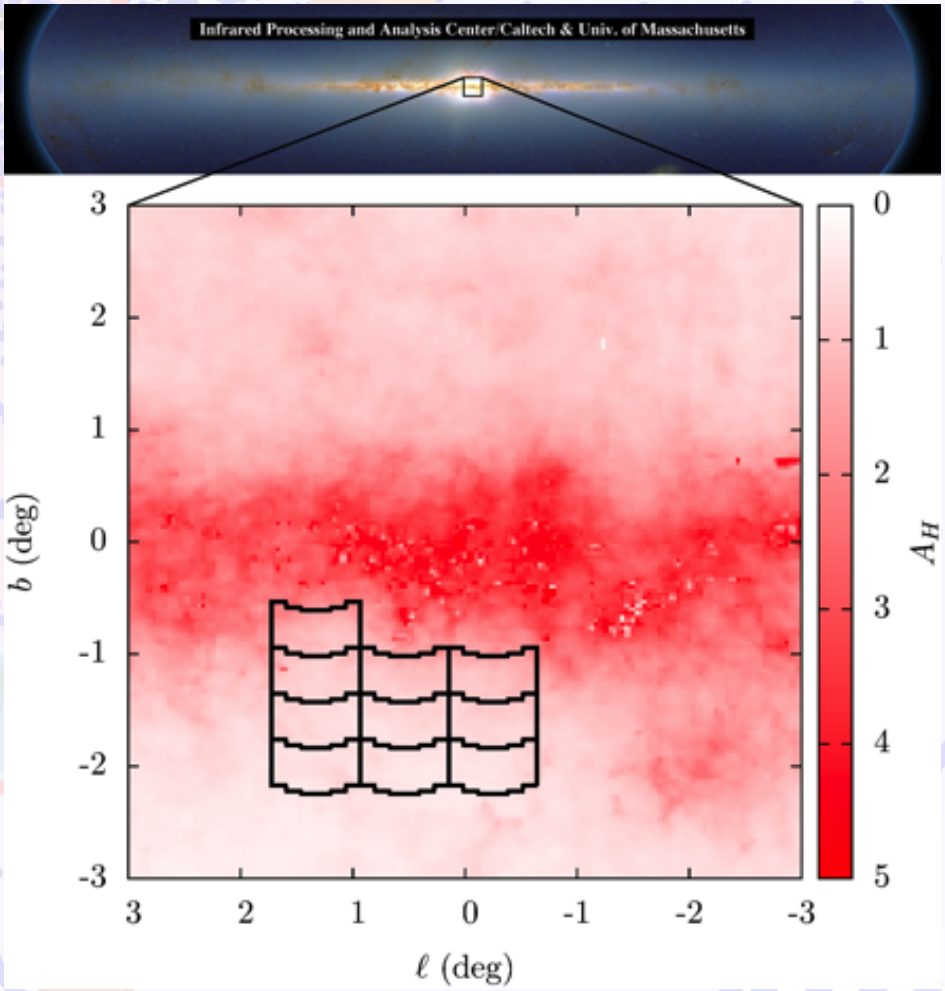


Finding Planets with Microlensing

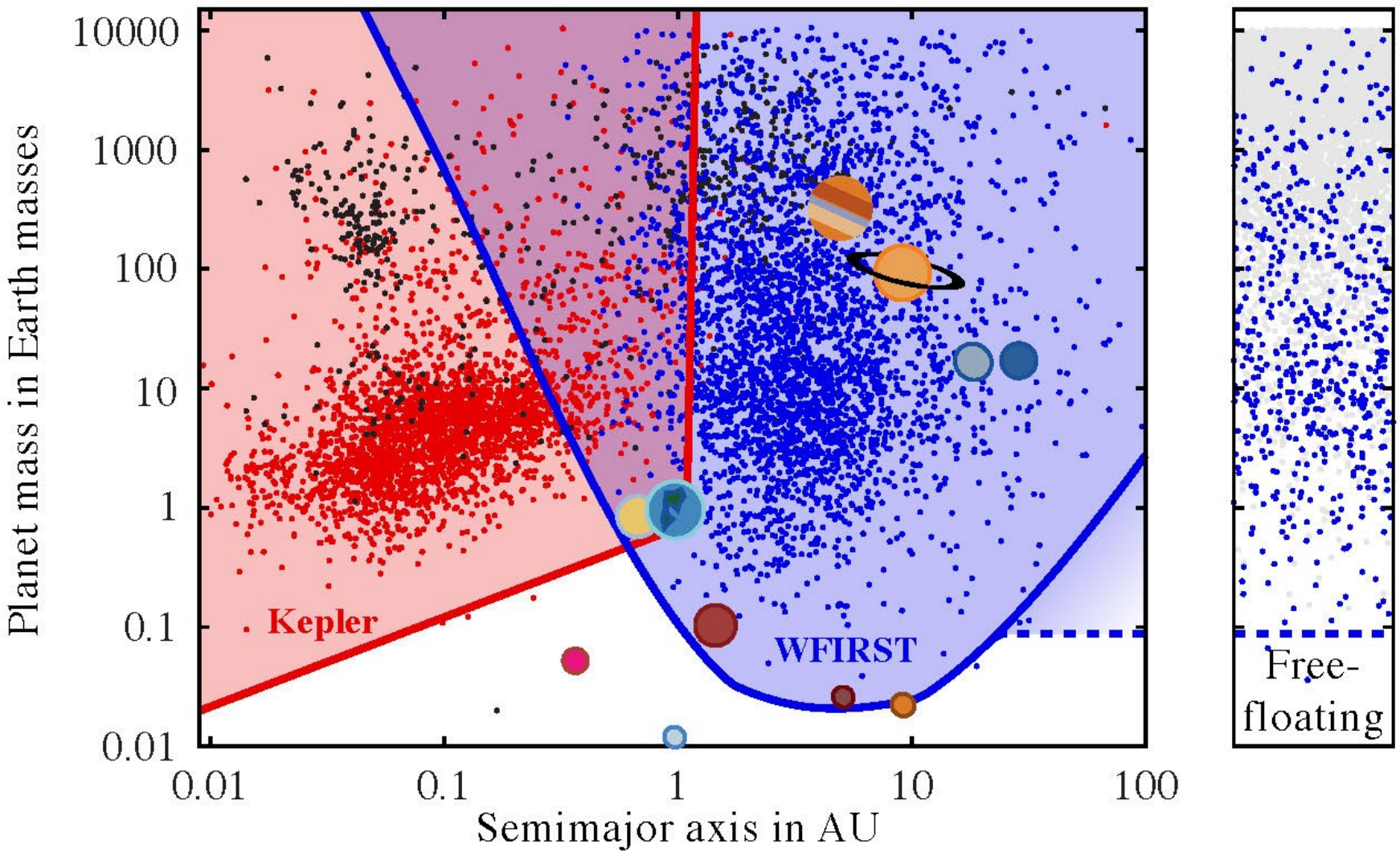


The *WFIRST* Microlensing Survey

- Continuous 15-min cadence monitoring of up to 2.8 deg^2 near the Galactic center
- Wide 1-2 um filter, plus color(s?) every 12 hours
- 6 seasons of 72 days spread over 6 year mission



The WFIRST microlensing survey



The WFIRST microlensing survey: What do we learn?

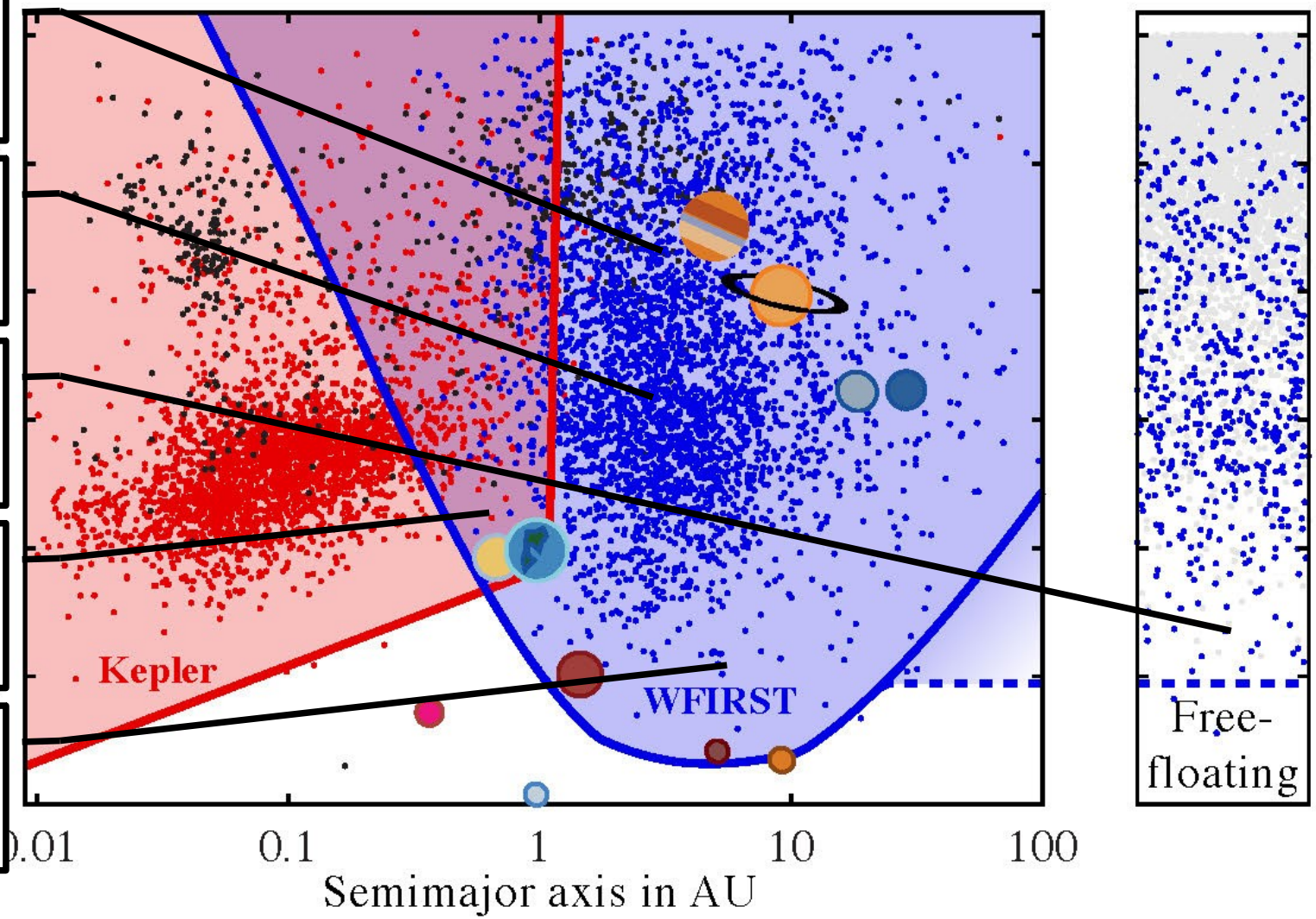
Thousands of bound planets

Mass + distance of most

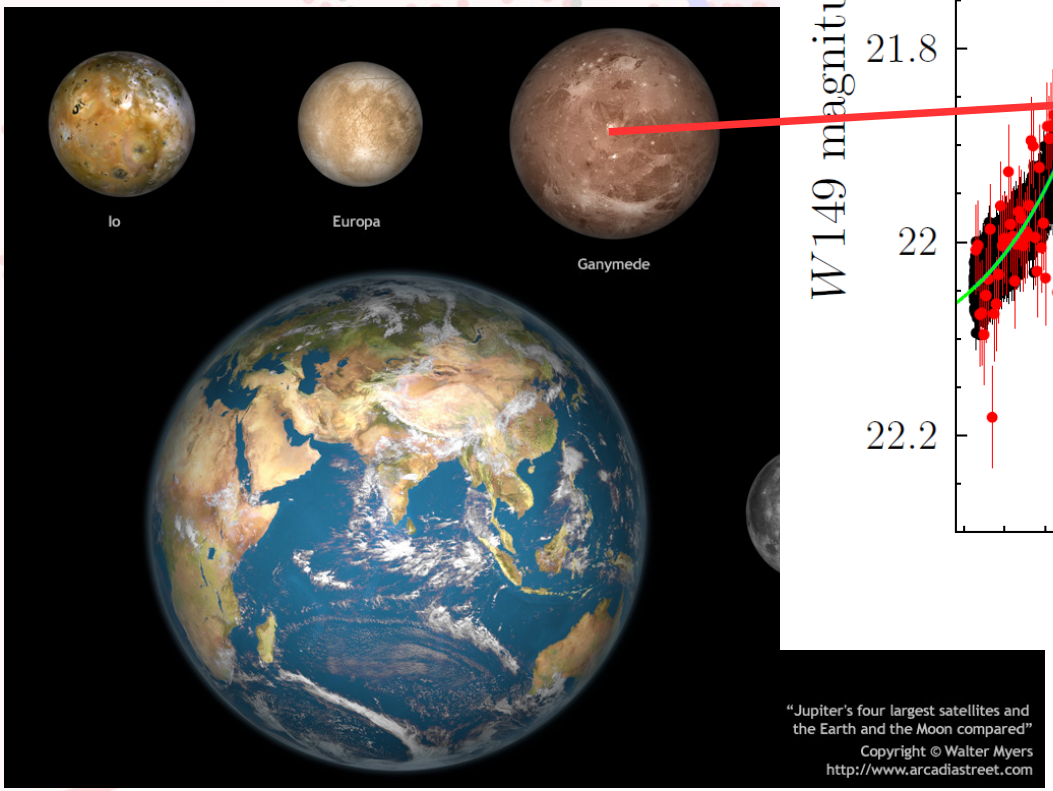
Free-floating planets down to Mars-mass

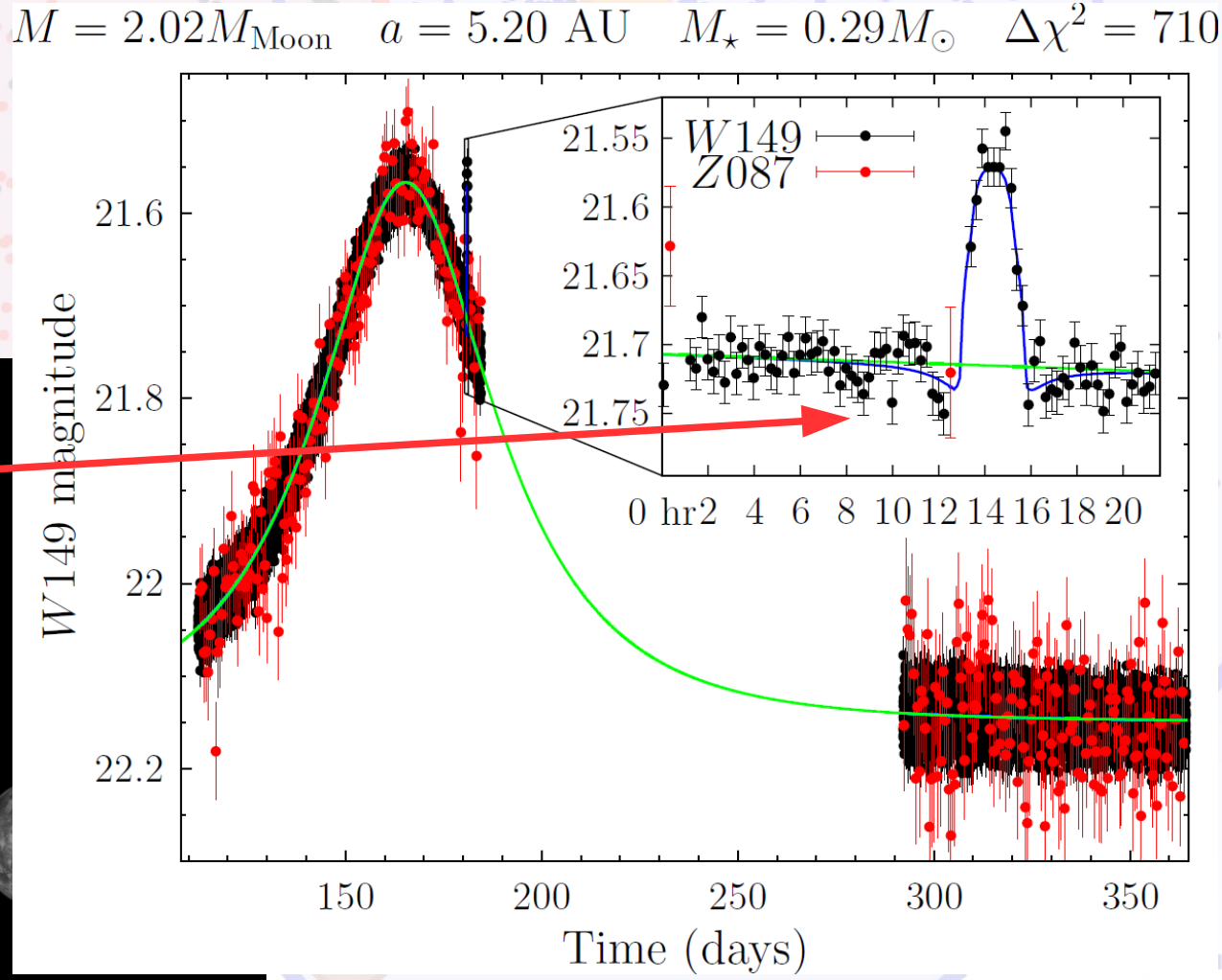
Outer HZ + Kepler overlap

Abundance of cold sub-Earths

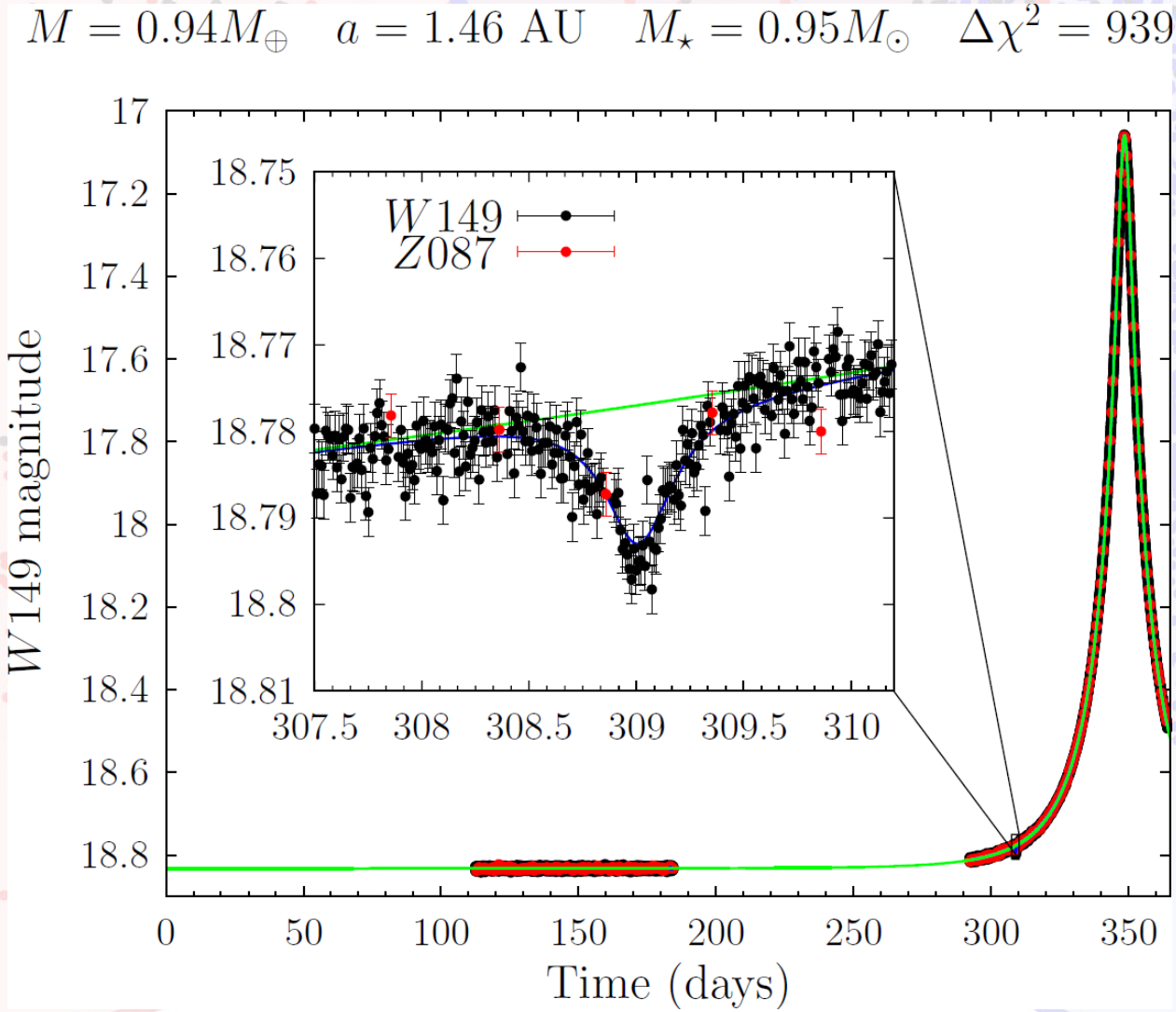


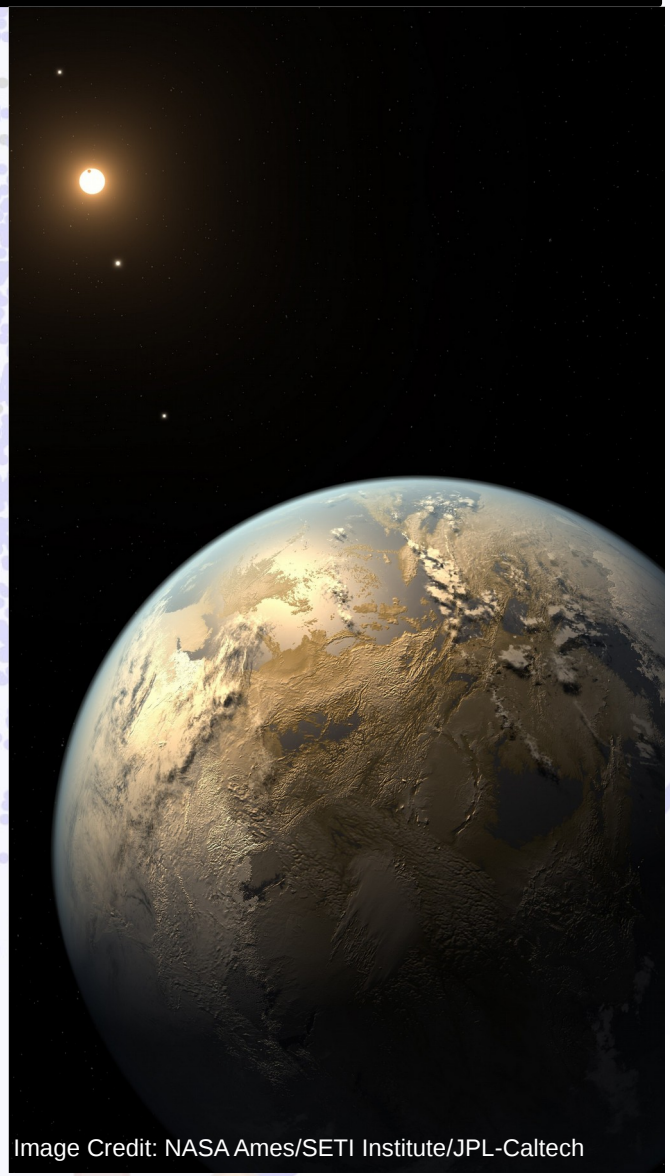
Really low-mass planets



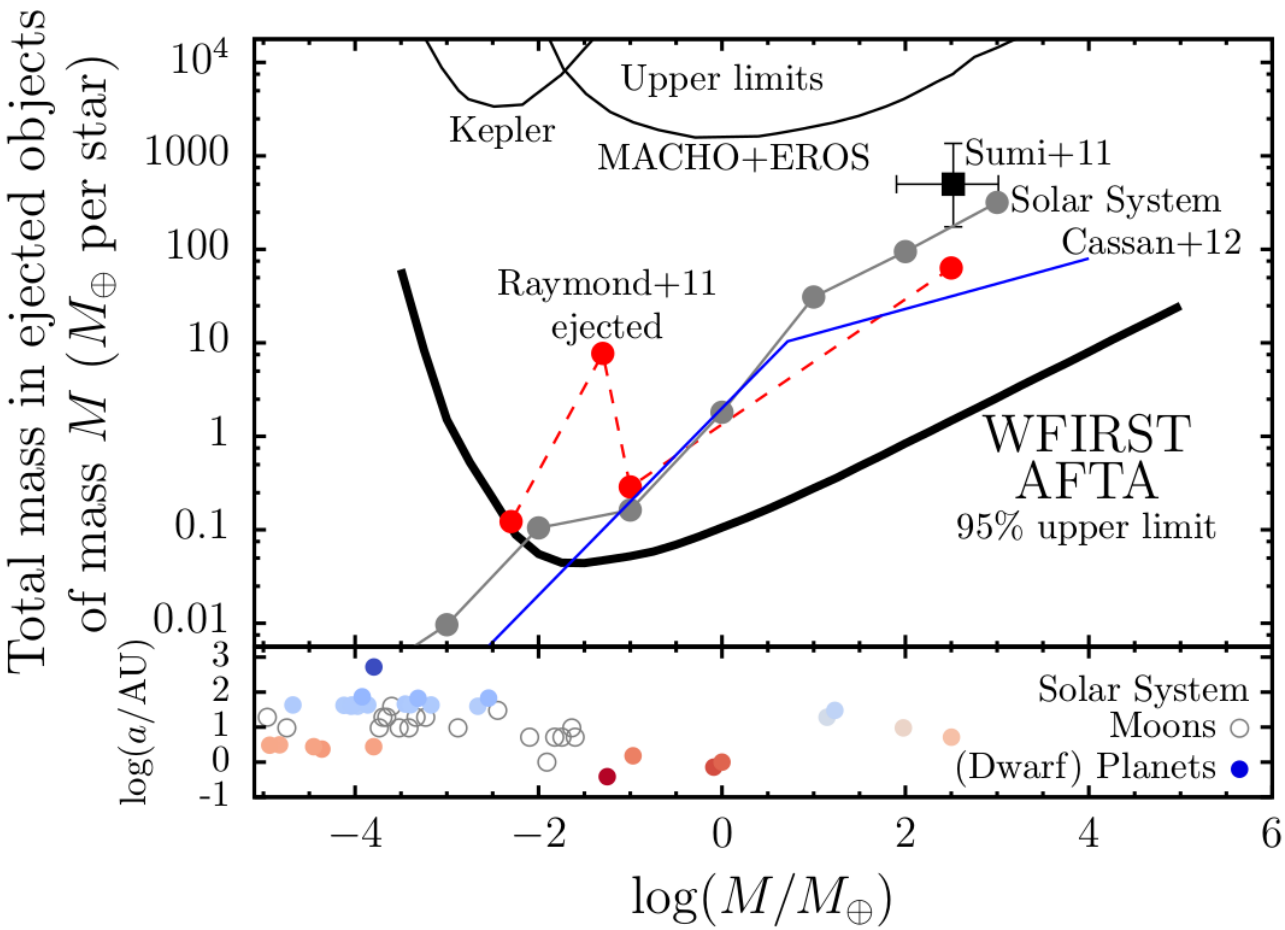


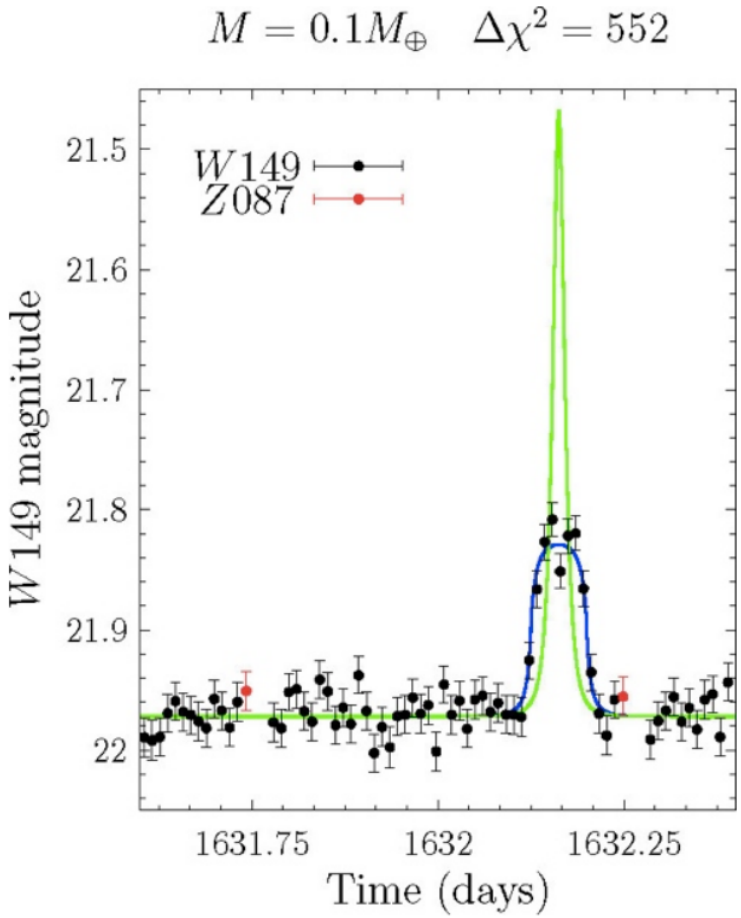
Habitable Zone planets



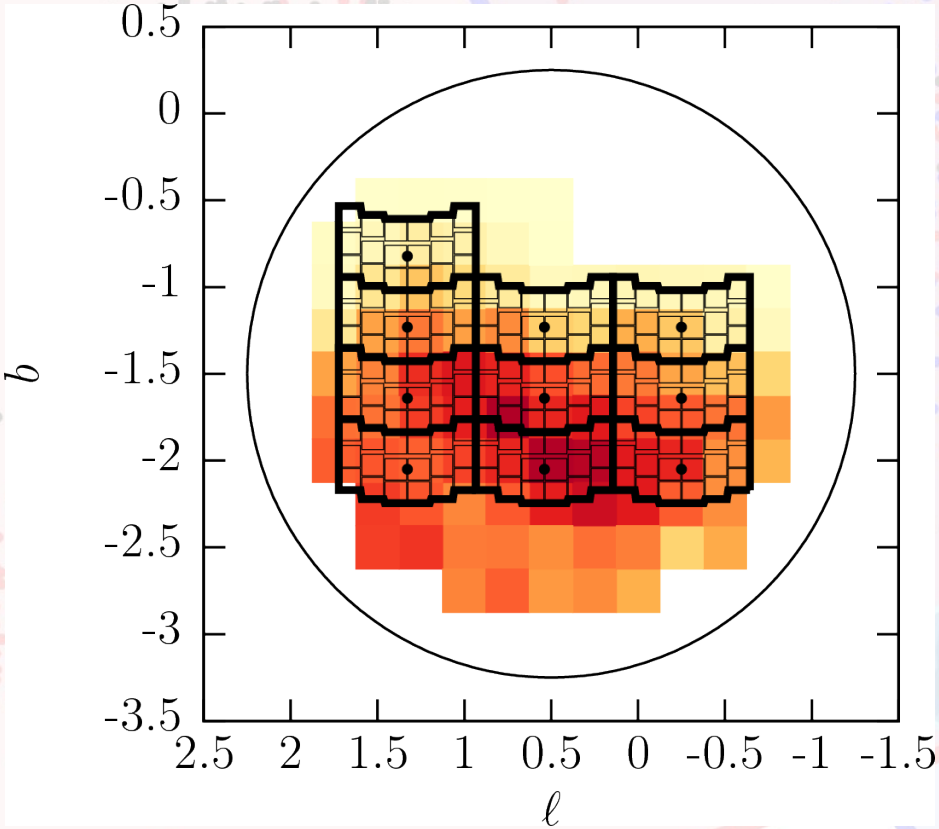


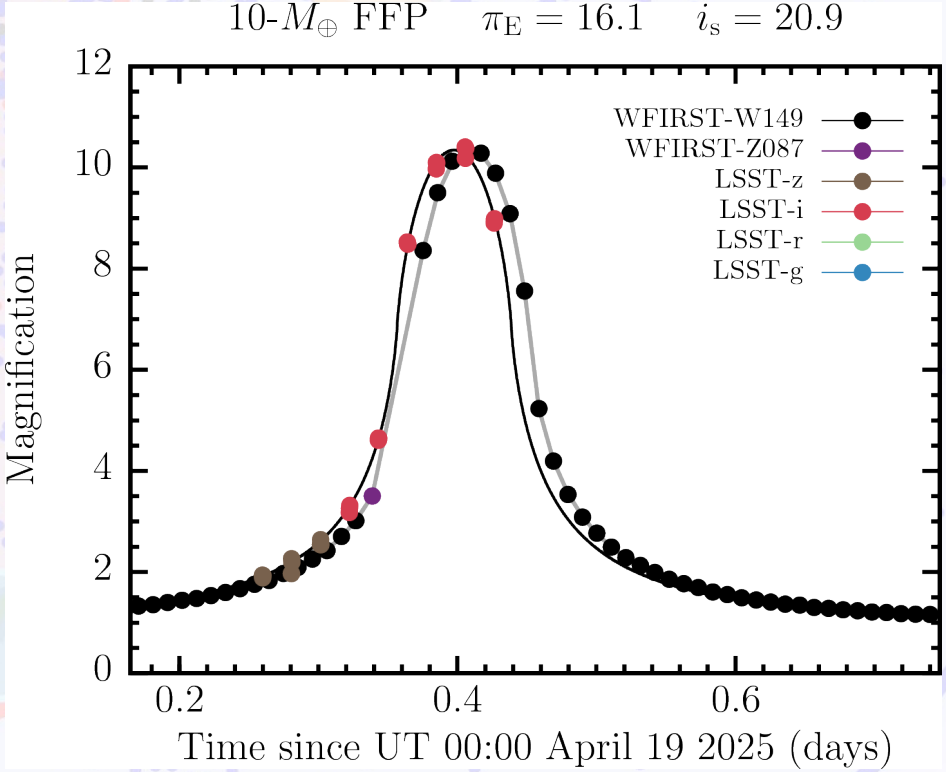
Free-Floating Planets





WFIRST+LSST = FFP Masses





WFIRST Microlensing Expectations

Bound Planets

- WFIRST will do for cold planets what Kepler has done for hot planets
- Will measure abundance of cold bound planets down to mass of solar system moons
- Has sensitivity in the habitable zone, but Earth-masses there are a stretch
- Measure the relative abundance of planets in the disk and bulge as a function of planet mass

Free-floating Planets

- WFIRST will find hundreds of FFPs
- Sensitive to planetesimals pushed beyond ~10 AU or ejected
- Will measure “total loosely- or un-bound mass in objects of mass M per star” for Plutos to Jupiters if it is above 1 Mearth/star