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

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

MAC J1206.2-0847

Postman

HST

WFIRST

0.79 deg
Gravitational Lensing

WFIRST

MACS J1206.2-0847

HST

0.79 deg
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 deg² 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

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
  - z = 1–2 to 0.5%
  - z = 2–3 to 1.3%

- expansion rate
  - z = 1–2 to 0.9%
  - 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

\[ w(z), \Delta G(z), \Phi_{\text{REL}}/\Phi_{\text{NREL}} \]
Example Observing Schedule

• High-latitude survey (HLS: imaging + spectroscopy): 2.01 years
  – 2227 deg² @ ≥3 exposures in all filters (2279 deg² 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)
<table>
<thead>
<tr>
<th>Attributes</th>
<th>WFIRST-AFTA Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging survey</td>
<td>J ~ 27 AB over 2200 sq deg</td>
</tr>
<tr>
<td>Slitless spectroscopy</td>
<td>J ~ 29 AB over 3 sq deg deep fields</td>
</tr>
<tr>
<td></td>
<td>R~461(\lambda) over 2200 sq deg</td>
</tr>
<tr>
<td>Number of SN Ia SNe</td>
<td>2700 to z~1.7</td>
</tr>
<tr>
<td>Number galaxies with spectra</td>
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</tr>
<tr>
<td>Number galaxies with shapes</td>
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<tr>
<td>Number of galaxies detected</td>
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<tr>
<td>Number of massive clusters</td>
<td>4x10^4</td>
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<tr>
<td>Number of microlens exoplanets</td>
<td>2600</td>
</tr>
<tr>
<td>Number of imaged exoplanets</td>
<td>10s</td>
</tr>
</tbody>
</table>
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 very 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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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**

**Discover and Characterize Nearby Worlds**

- 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?
Toward the “Pale Blue Dot”

WIFIRST 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

Extrasolar planet detected by gravitational microlensing

1. When a foreground star (red) passes in front of a background star, it brightens the light of the background star. The gravitational field of the foreground star warps space to create a gravitational lens that magnifies light.

2. If a planet is orbiting the foreground star, it, too, will gravitationally lens the background star for a shorter duration.

Magnification by stellar lens

Deviation due to planet

8 hours

30 days
The *WFIRST* Microlensing Survey

- Continuous 15-min cadence monitoring of up to 2.8 deg² 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
- Outer HZ + Kepler overlap
- Free-floating planets down to Mars-mass
- Abundance of cold sub-Earths

![Graph showing distribution of planets and their properties.]

- 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

$M = 2.02 M_{\text{Moon}} \quad a = 5.20 \text{ AU} \quad M_* = 0.29 M_\odot \quad \Delta \chi^2 = 710$

"Jupiter’s four largest satellites and the Earth and the Moon compared"

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http://www.arcadestreet.com

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Habitable Zone planets

\[ M = 0.94M_\oplus \quad a = 1.46 \text{ AU} \quad M_* = 0.95M_\odot \quad \Delta \chi^2 = 939 \]

Image Credit: NASA Ames/SETI Institute/JPL-Caltech
Free-Floating Planets

The graph shows the total mass in ejected objects as a function of mass per star. The data points are marked with different symbols, indicating various studies and observations. The axes are labeled as follows:

- Logarithmic scale for mass $M$ (in $M_\oplus$ per star)
- Logarithmic scale for semi-major axis $a$ (in AU)

Key studies and observations include:
- Kepler
- MACHO+EROS
- Sumi+11
- Solar System
- Raymond+11
- Cassan+12

The graph also includes upper limits and 95% upper limits for certain mass ranges. The right side of the graph shows a time series plot with a peak magnitude at $M = 0.1M_\oplus$ and $\Delta \chi^2 = 552$.
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.