Science Landscape in the 2030's
Wide Field Infrared Space Telescope (WFIRST)

Neil Gehrels – Project Scientist
(NASA-GSFC)

LISA Symposium
University of Florida, Gainesville
May 21, 2014

WFIRST-AFTA SDT

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- Neil Gehrels, NASA GSFC

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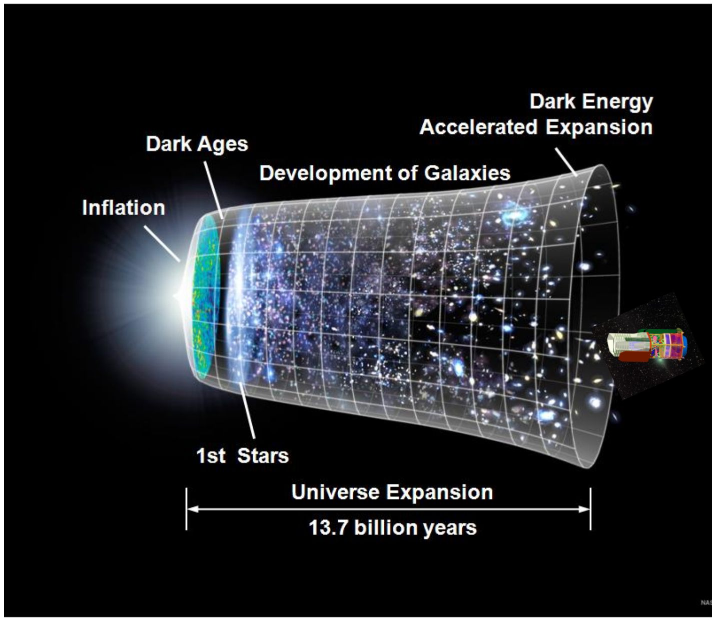
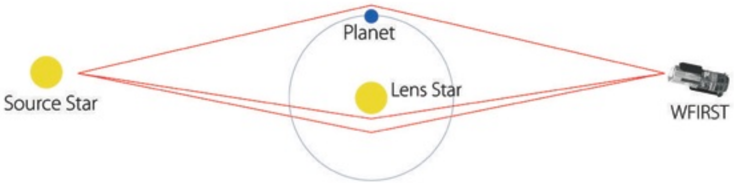
- Wes Traub, NASA JPL
- Toru Yamada, Japanese Aerospace Exploration Agency

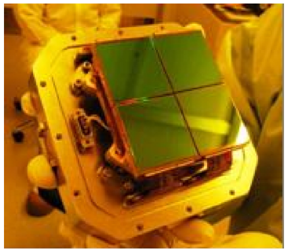
Consultants
- Matthew Penny, Ohio State University
- Dmitry Savransky, Cornell University
- Daniel Stern, NASA JPL

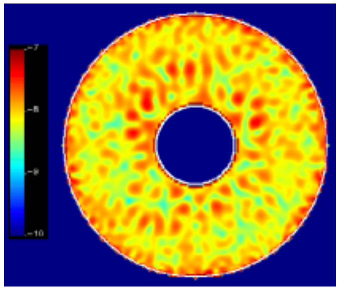
WFIRST Summary

- WFIRST is the highest ranked large space mission in 2010 US Decadal Survey
  - dark energy
  - exoplanet census and imaging
  - NIR sky for the community (GO program)
- WFIRST-AFTA uses 2.4m telescope from NRO
- Exoplanet coronagraph part of baseline
- WFIRST-AFTA will perform Hubble quality and depth imaging over 1000's sq deg
- WFIRST-AFTA enabled by large format HgCdTe detectors

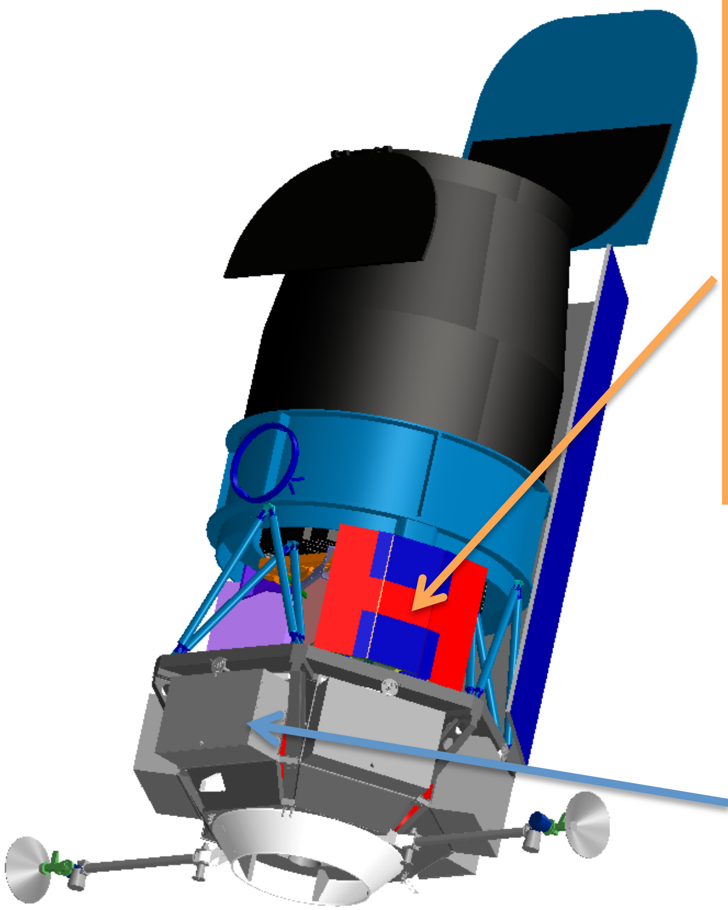








WFIRST-AFTA Instruments



Wide-Field Instrument

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

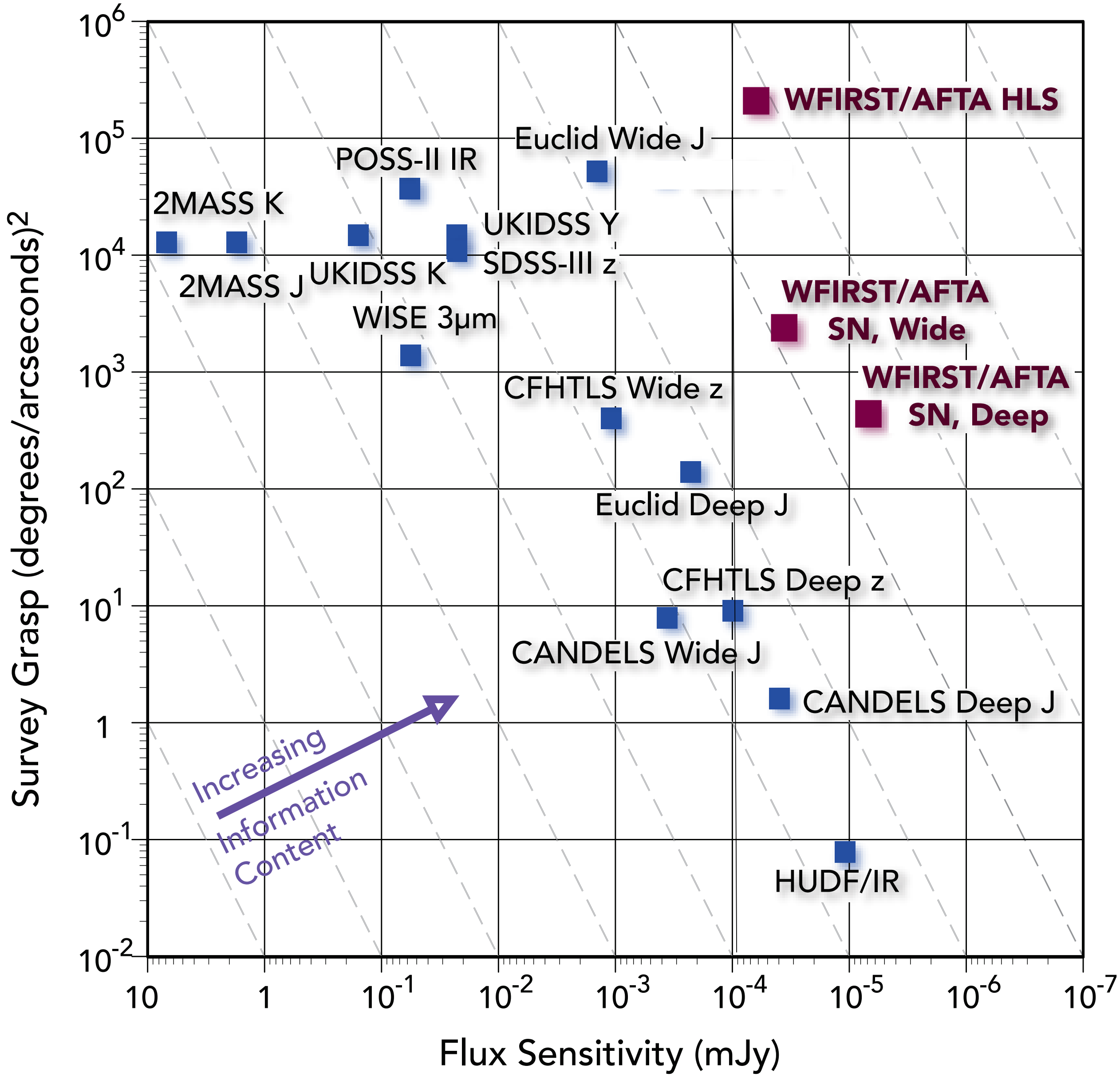
Coronagraph

- *Imaging of ice & gas giant exoplanets*
- *Imaging of debris disks*
- 400 – 1000 nm bandpass
- $\leq 10^{-9}$ contrast (after post-processing)
- 100 milliarcsec inner working angle at 400 nm

Capabilities & Status

- Same size and quality telescope as HST
- 2.5x deeper and 1.6x better resolution than NWNH WFIRST. Highly complementary to LSST, Euclid and JWST.
- Enables coronagraphy of giant planets and debris disks
- Use of donated telescope and addition of coronagraph have increased the interest in WFIRST in government, scientific community and public.
  - $66M add by Congress. Used for pre-Phase A risk reduction & schedule advancement
  - Funding ramps up in FY18, capturing the JWST funding "wedge" for astrophysics
- Cost with coronagraph is $2.1B to $2.4B depending on launcher
- Launch date is 2023 to 2024

IR Surveys

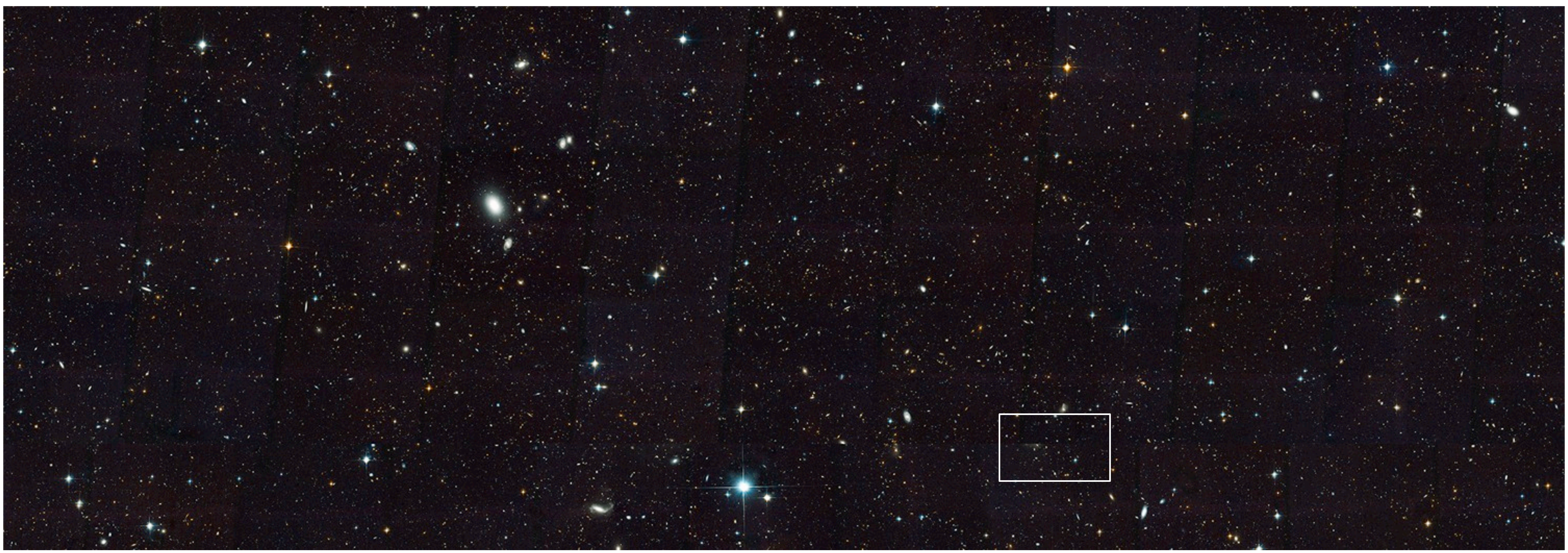


WFIRST/AFTA HLS
Euclid Wide J
POSS-II IR
2MASS K
UKIDSS Y
SDSS-III z
2MASS J
UKIDSS K
WISE 3μm
WFIRST/AFTA SN, Wide
WFIRST/AFTA SN, Deep
CFHTLS Wide z
Euclid Deep J
CFHTLS Deep z
CANDELS Wide J
CANDELS Deep J
HUDF/IR
Increasing Information Content
Survey Grasp (degrees/arcseconds)^2
10^6
10^5
10^4
10^3
10^2
10^1
1
10^{-1}
10^{-2}
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Flux Sensitivity (mJy)

WFIRST-AFTA vs Hubble

Hubble Ultra Deep Field - IR
~5,000 galaxies in one image
(60 orbits, 4 days)

PI: Illingworth



70,000 galaxies in each field
of AFTA survey

WFIRST-AFTA Deep Field
>1,000,000 galaxies in each image

WFIRST-AFTA Dark Energy

Weak Lensing (2400 deg^2)

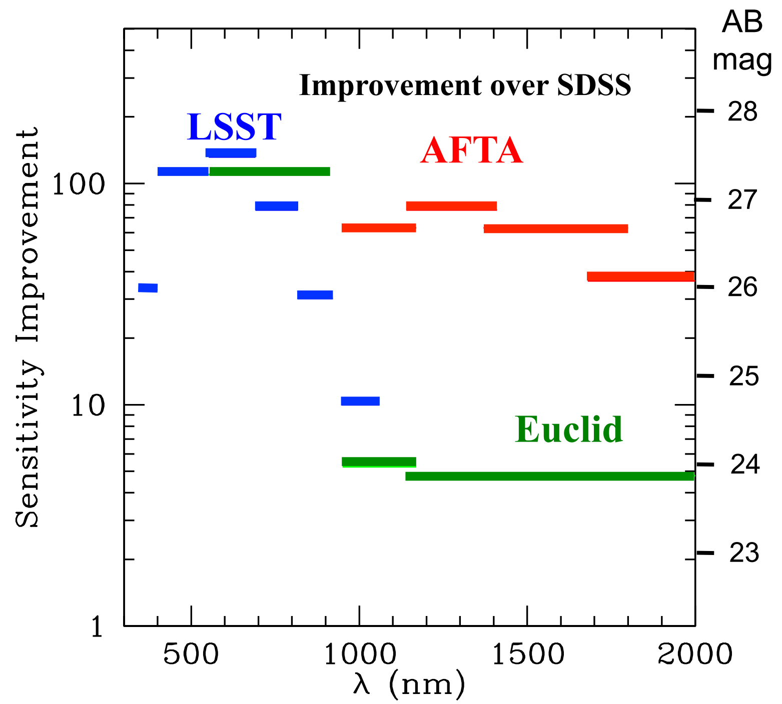
- High angular resolution
- Galaxy shapes in IR
- 400 million galaxies
- Photo-z redshifts
- 3 imaging filters

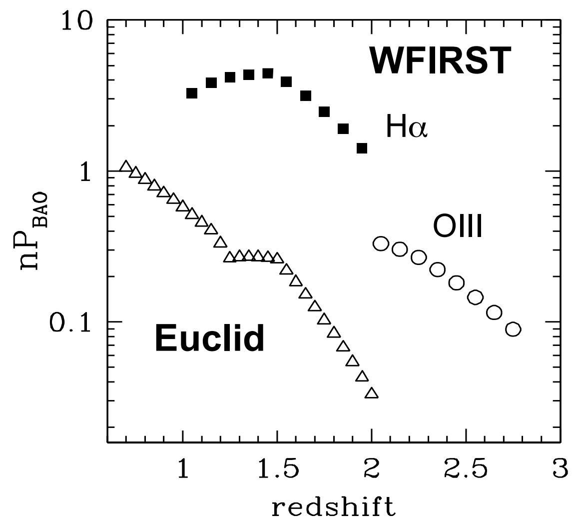
Supernovae

- High quality IFU spectra
- 5 day sampling of light curves
- 2500 SNe

Redshift survey (2400 deg^2)

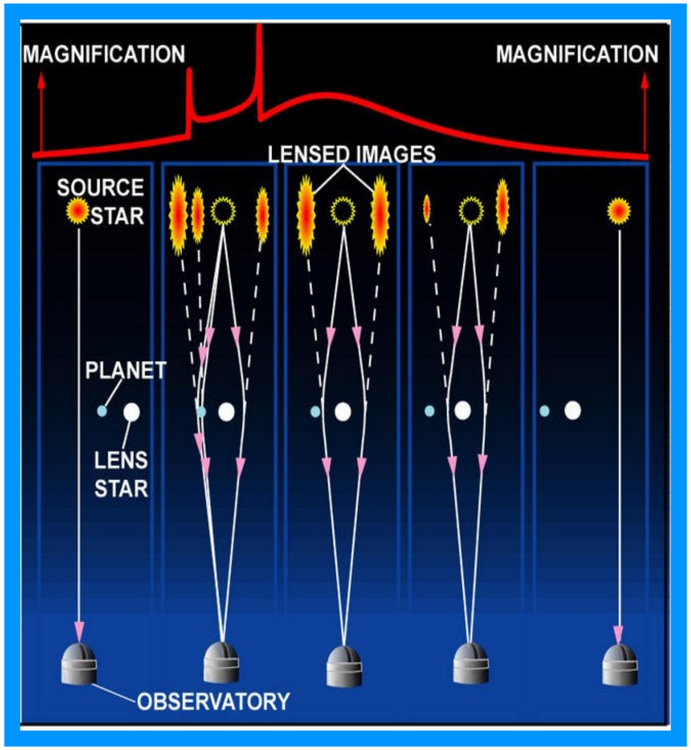
- BAO & Redshift Space Distortions
- High number density of galaxies
- 20 million galaxies

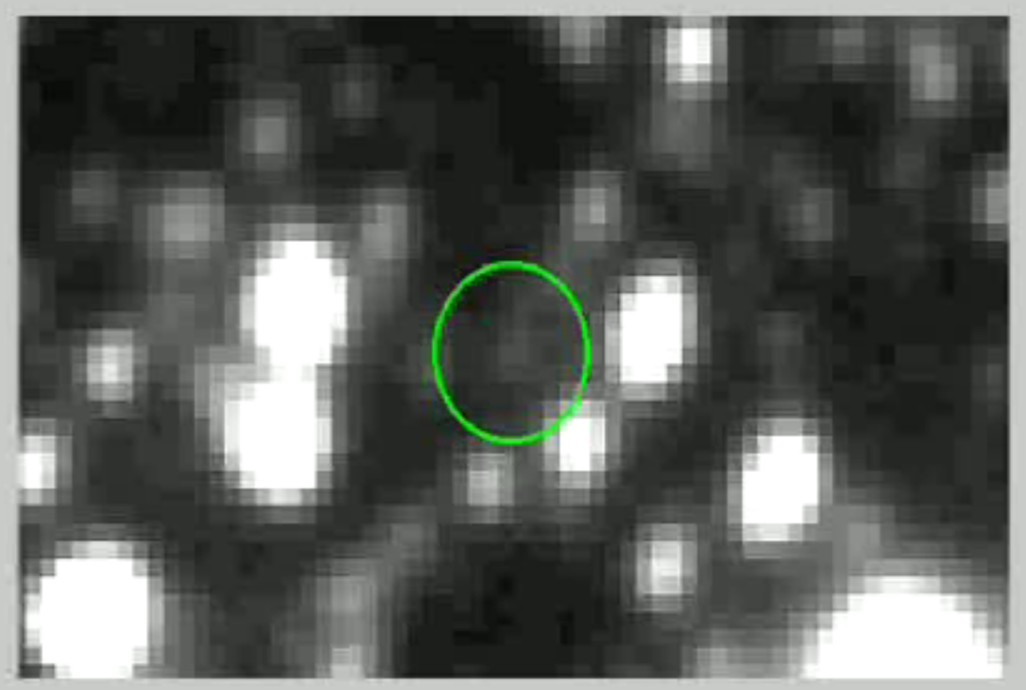


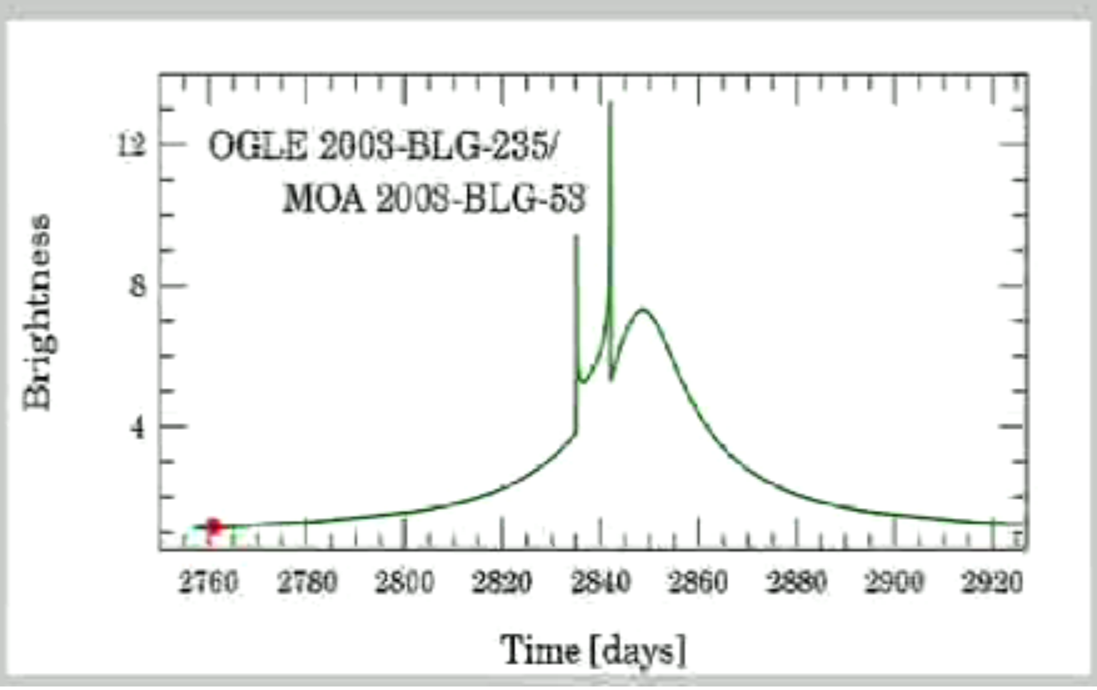


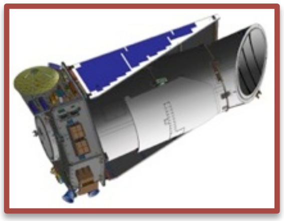
Exoplanet Microlensing

Monitor 3 sq deg
in galactic bulge

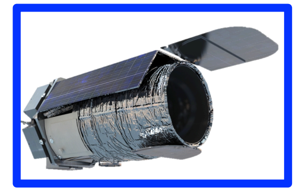


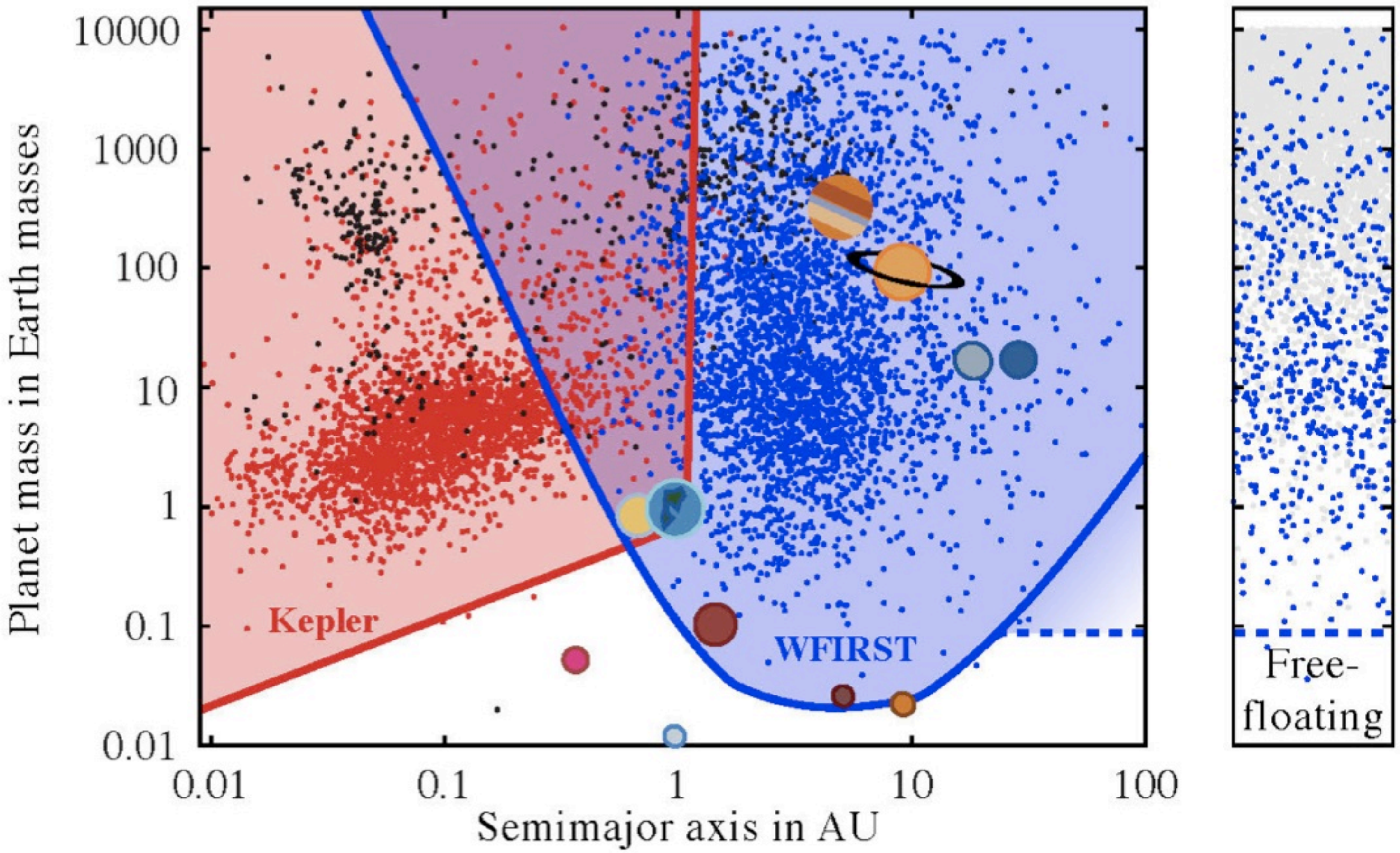




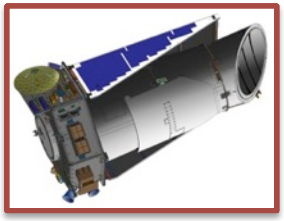


Exoplanet Surveys
Kepler & WFIRST

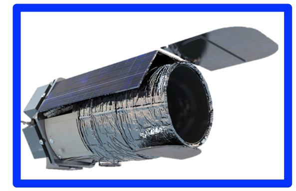




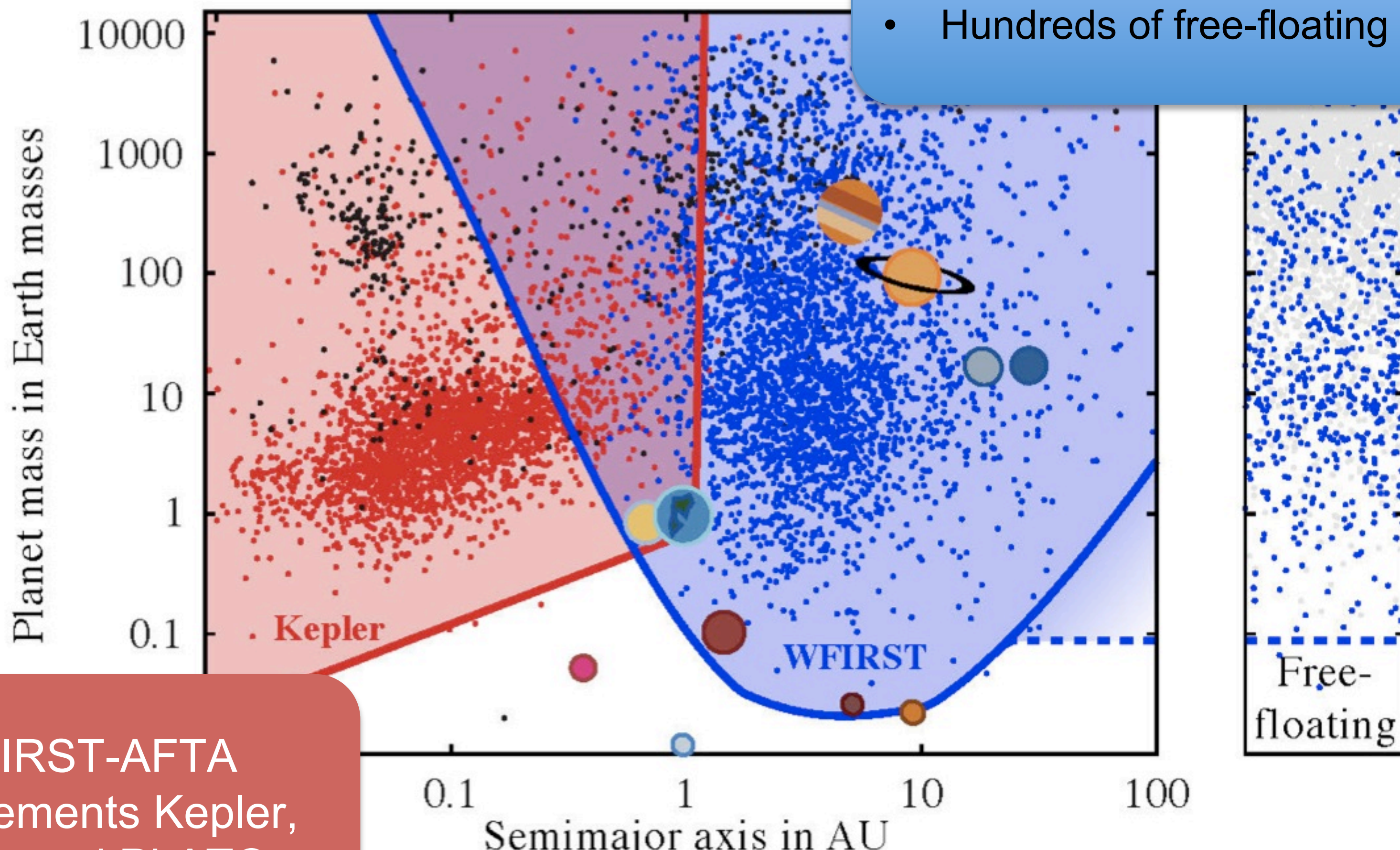
M. Penny (OSU)



Exoplanet Surveys
Kepler & WFIRST



- ~3000 planet detections.
- 300 with Earth mass and below.
- Hundreds of free-floating planets.



WFIRST-AFTA complements Kepler, TESS, and PLATO.

M. Penny (OSU)

AFTA Coronagraph Capability

Shaped Pupil Mask

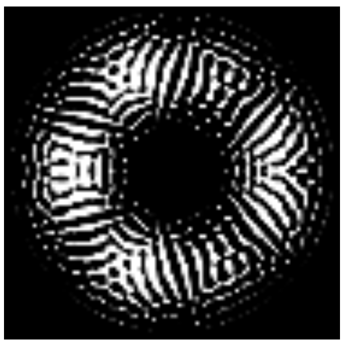
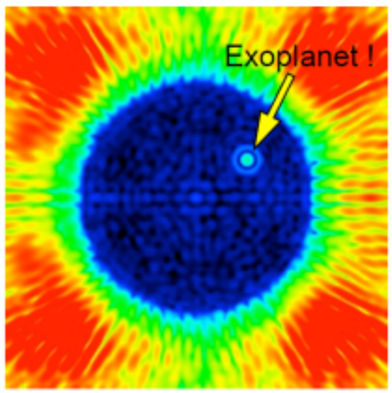
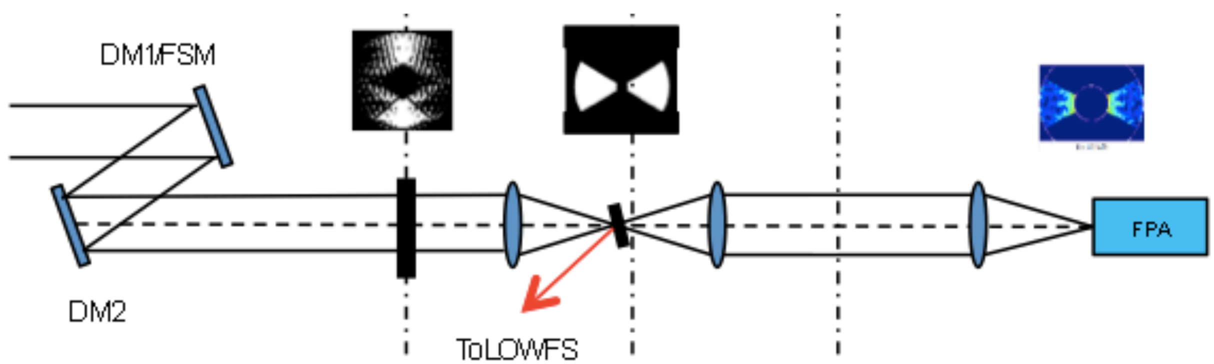


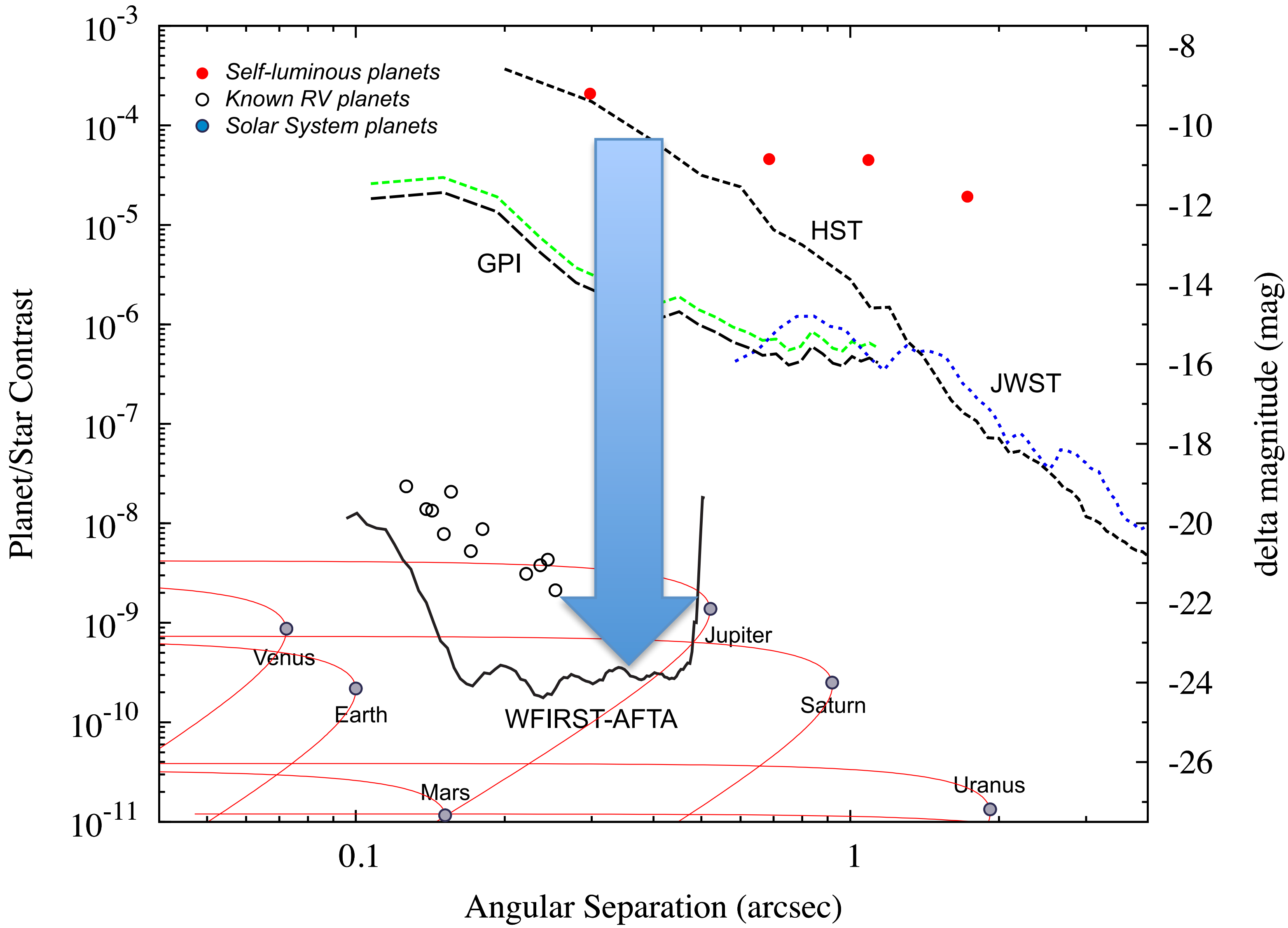
Image with Dark Hole



Bandpass	400 – 1000 nm
Inner working angle	100 – 250 mas
Outer working angle	0.75 – 1.8 arcsec
Detection Limit	Contrast ≤ 10^{-9} (after processing)
Spectral Res.	~70

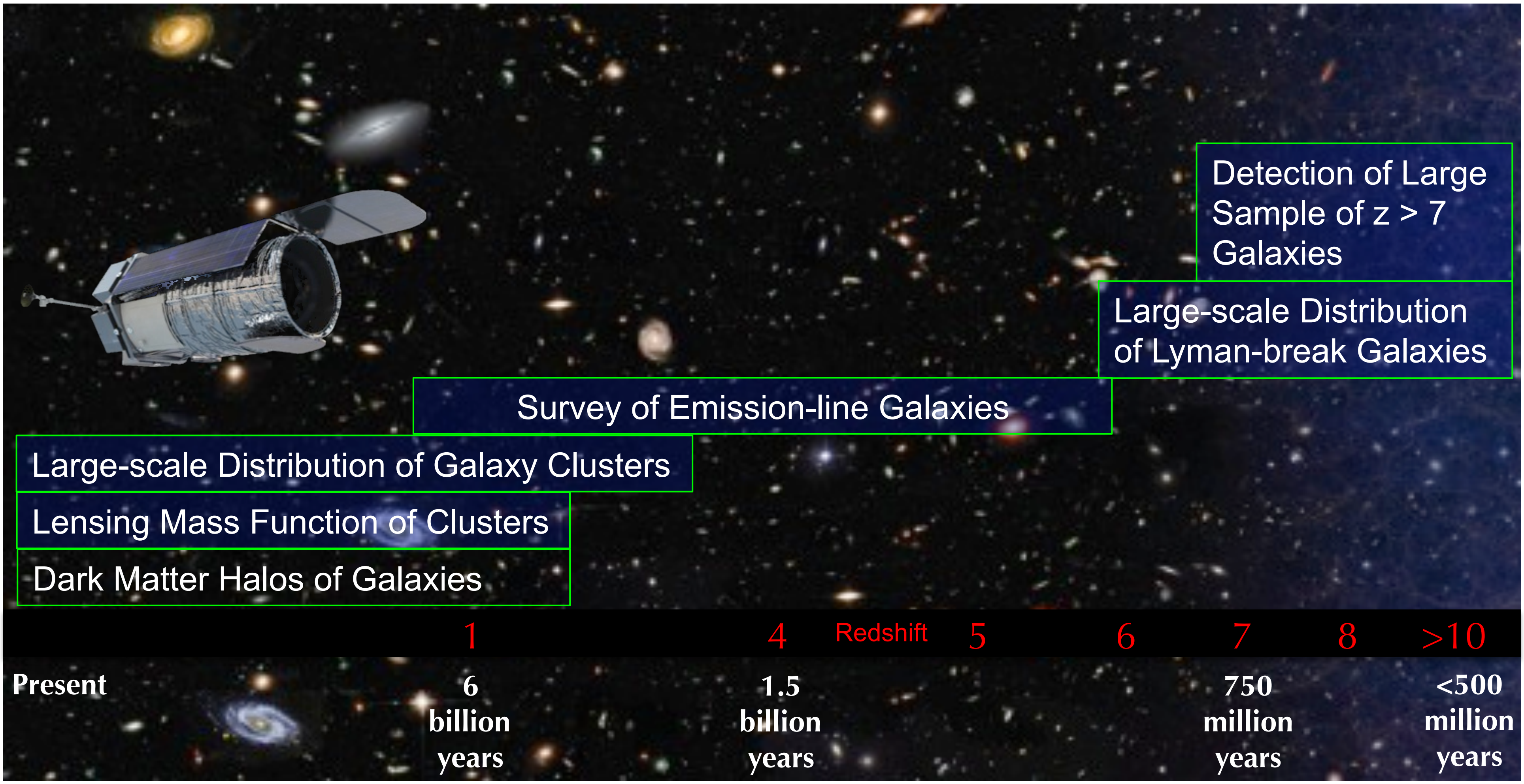


Coronagraph Sensitivity

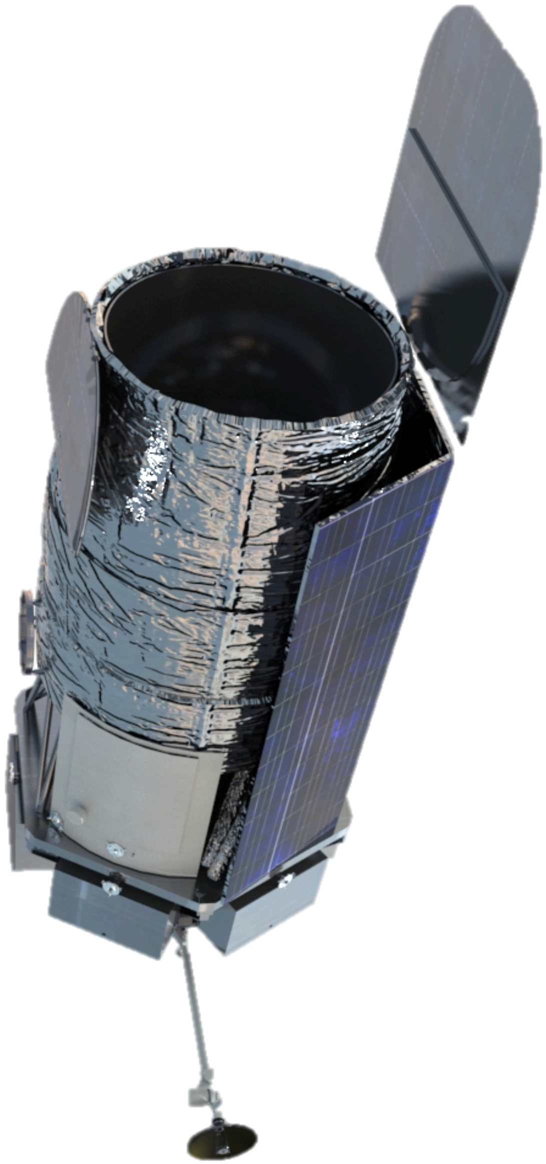


Cosmic Structure Formation History

Using Observations from the High Latitude Survey and GO Programs

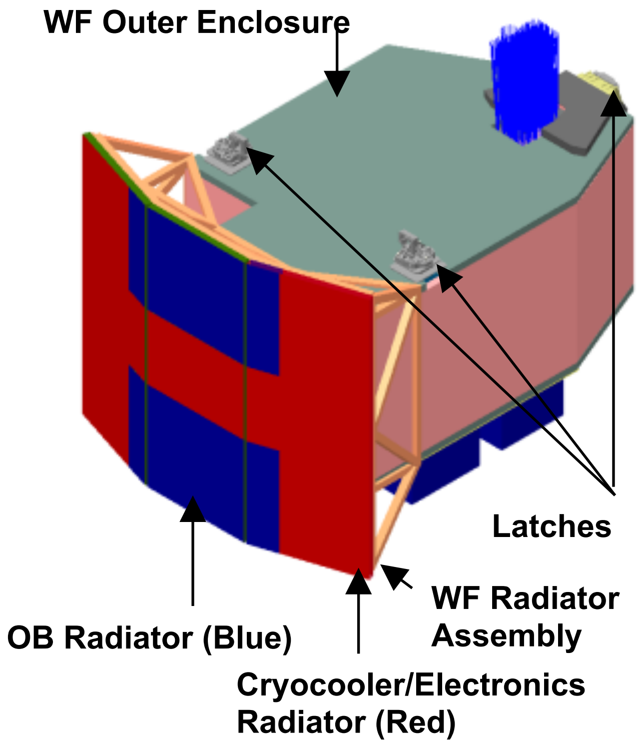


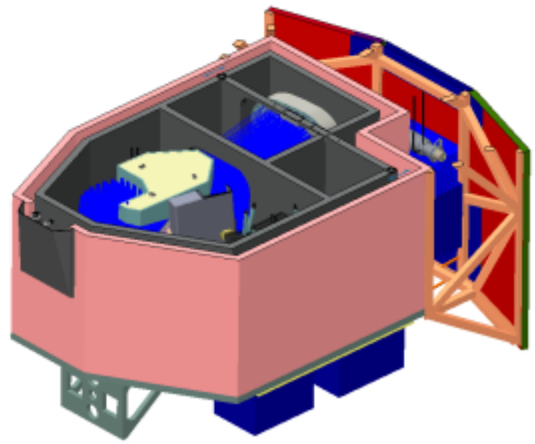
Observatory Concept



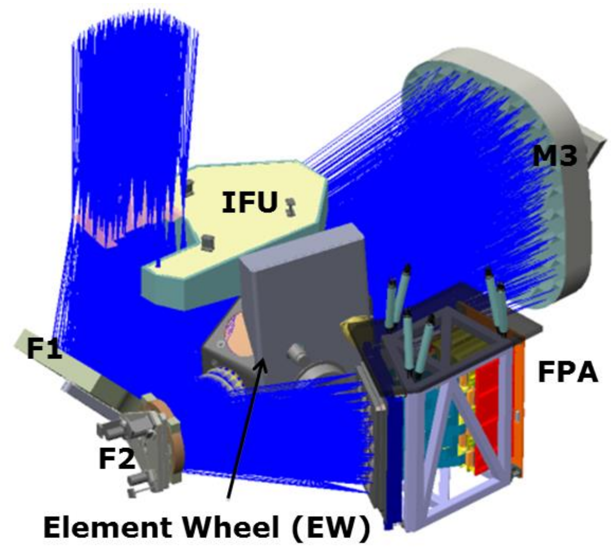
- **Telescope** – 2.4m aperture primary
- **Dry Mass** –3900 kg
- **Primary Structure** – Graphite Epoxy
- **Downlink Rate** – Continuous 150 Mbps Ka-band to Ground Station
- **Thermal** – passive radiator
- **Power** – 2100 W
- **GN&C** – reaction wheels & thruster unloading
- **Propulsion** – bipropellant
- **GEO orbit**
- **Launcher** – Atlas V 551
  or Falcon 9 heavy

Wide Field Instrument Layout

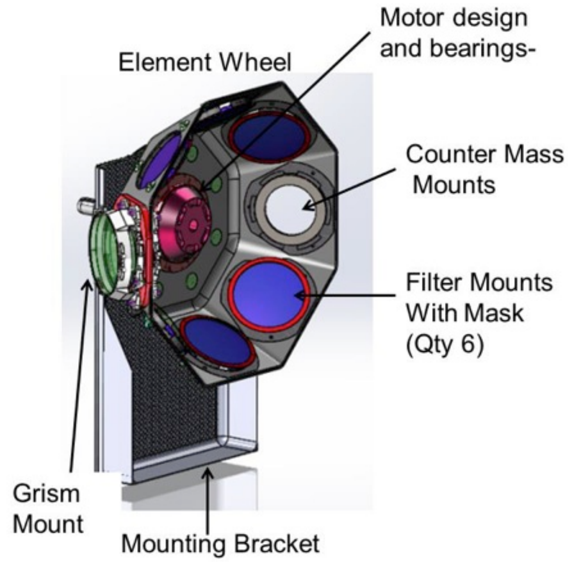


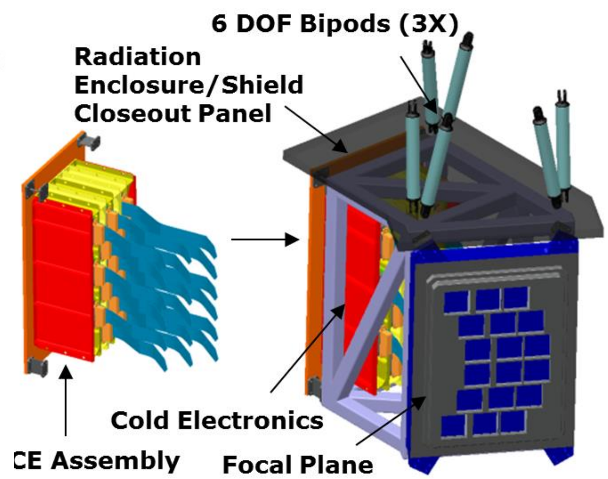


Outer enclosure (OE) and optical bench (OB) top panels removed

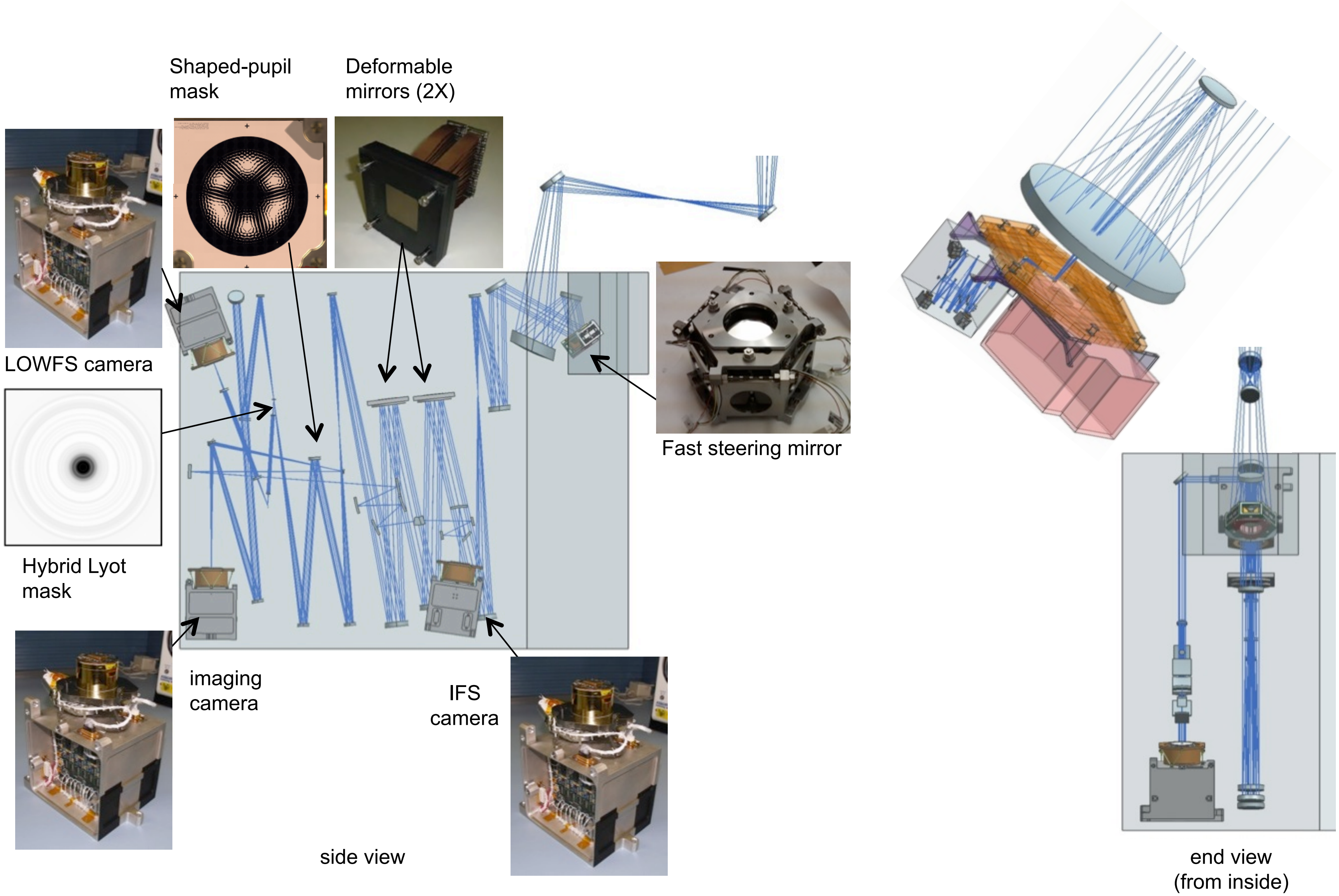


Wide field mirrors; Focal plane assembly (FPA); Integral field unit (IFU)





Coronagraph Instrument



EM Counterparts to GW Sources

"Ground-based detectors such as LIGO will detect high-frequency (HF) gravitational waves (~ 10 − 1000Hz). They can detect the **merging of binary black holes, and the tidal disruption and merger of neutron stars in black hole and neutron star binaries** at *~400Mpc* and *~200Mpc* respectively....

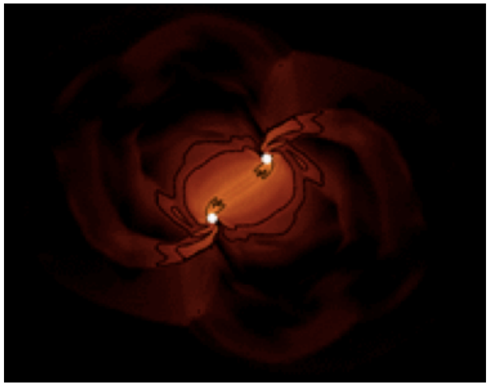
The space-based mission LISA will detect low-frequency (LF) gravitational waves (0.1-10mHz). It can detect **merging binary supermassive black holes (to z ~ 30), their captures of intermediate mass black holes (to z ~ 3), and their captures of the compact objects (stellar mass black holes to z ~ 1, neutron stars and white dwarfs to z ~ 0.1) in galactic nuclei.**"

Phinney Astro2010 WP

Notes on EM Counterparts

LIGO-Virgo:

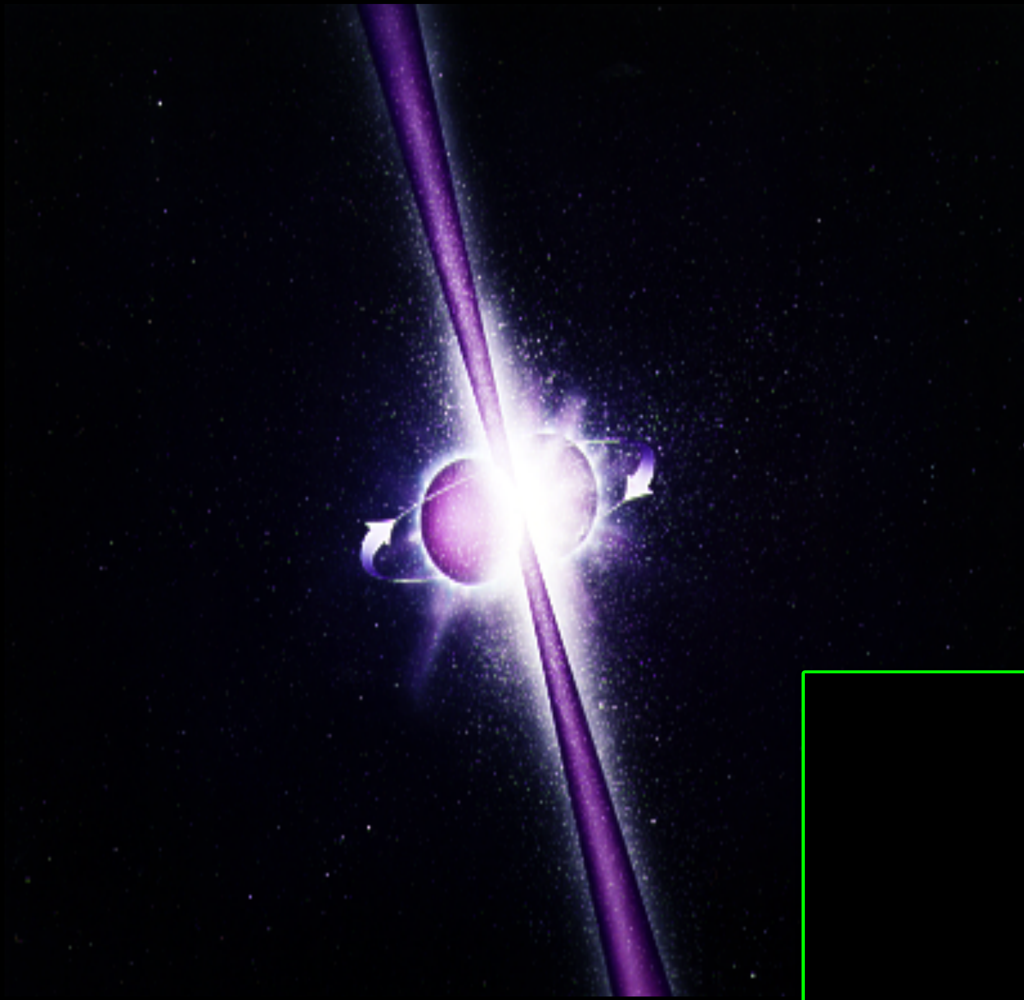
- Most likely early detections will be NS-NS or NS-BH mergers
- Range is 50 – 200 Mpc
- Accompanied by bright GRB and afterglow if on jet axis (1%)
- Accompanied by faint afterglow, possibly from kilonova nucleosynthetic radionuclides, if off-axis

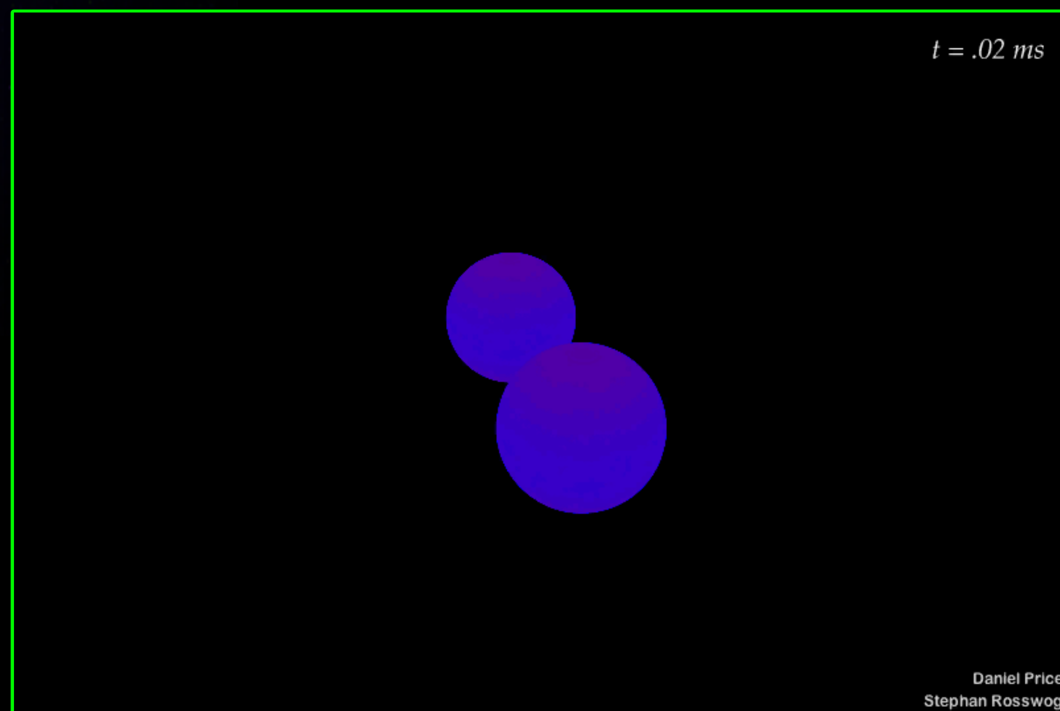


LISA:

- Most likely detections will be binary SMBH mergers
- Range is Gpc's
- Bare BH mergers have no EM radiation. However:
  - Gas around BHs will be stirred up and accrete forming quasar on years to decades time scales
  - Stars around BHs will be stirred up and create TDE events on years to decades time scales

Swift Finding: NS-NS Mergers Produce Short GRBs





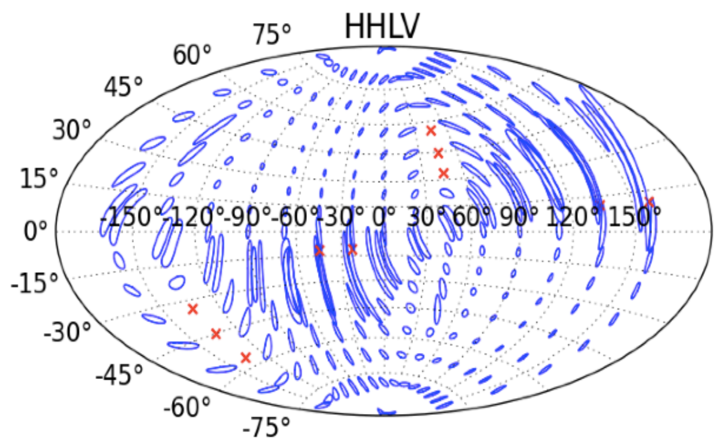
Credit: Daniel Price and Stephan Rosswog

Swift Finding:
Tidal Disruption Event Produces EM Transient

Source Localization Errors

LIGO-Virgo

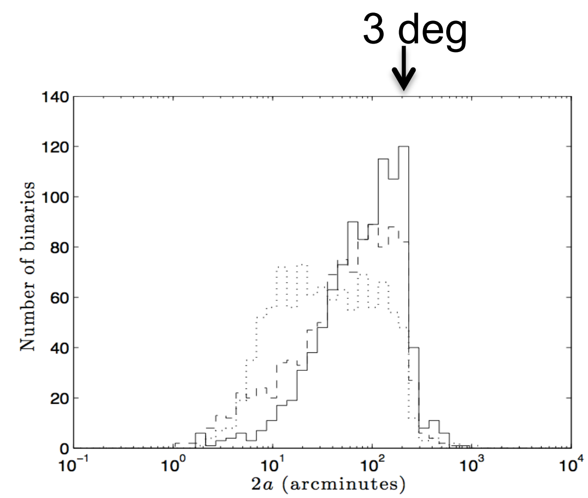
Sky localization with 3 sites ...



Epoch	BNS range (Mpc) LIGO	Virgo	Median Area (deg^2)
2015	60 ± 20	—	2000
2016–17	100 ± 20	40 ± 20	70
2017–18	140 ± 30	70 ± 15	84
2019+	200	100 ± 15	31
2022+ (India)	200	130	11

Aasi+ '13

LISA



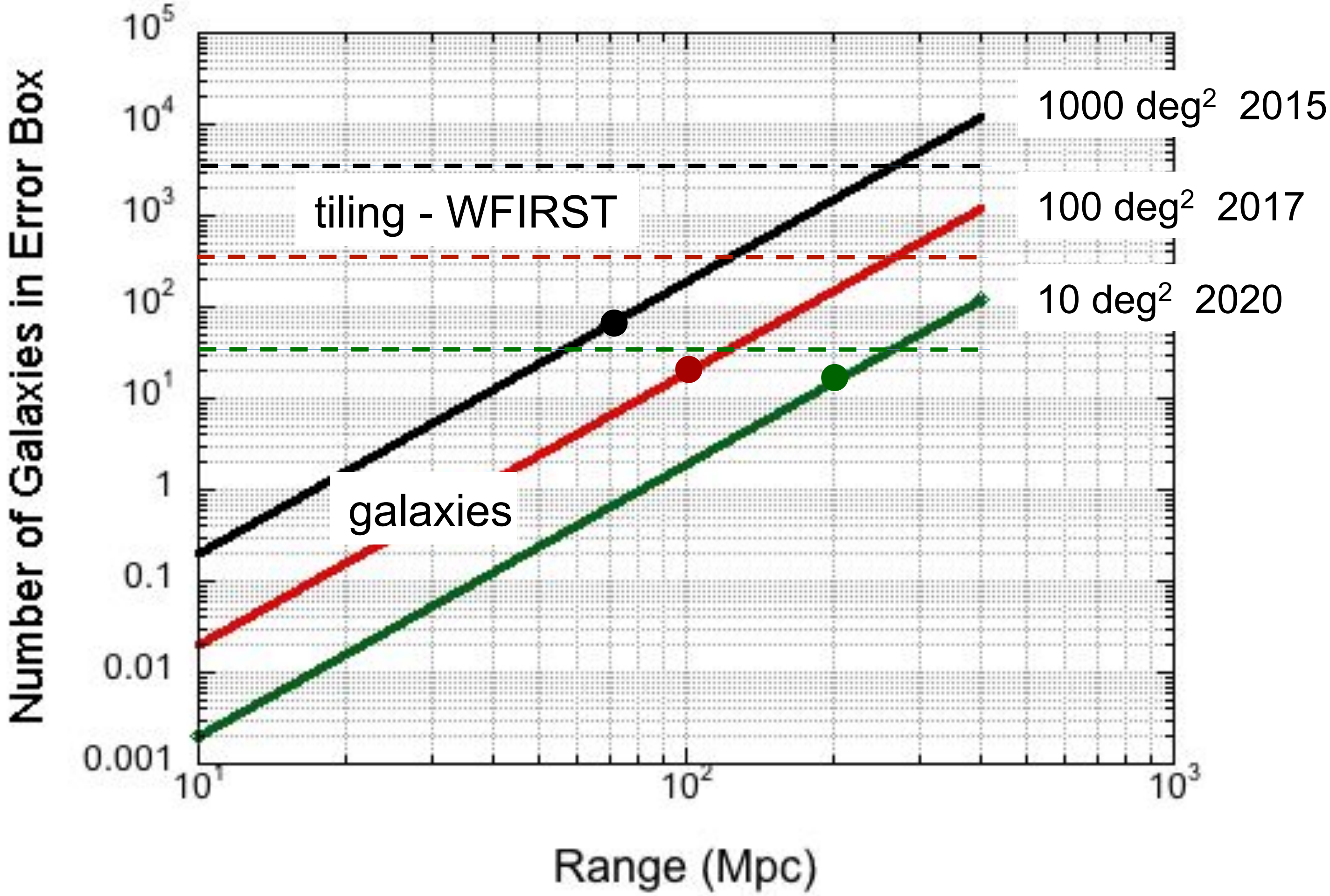
Lang, Hughes, Cornish '12

Mock Data Challenge

Group	Error (deg)
1	11.6
2	2.0
3	171.0

Babak+ '10

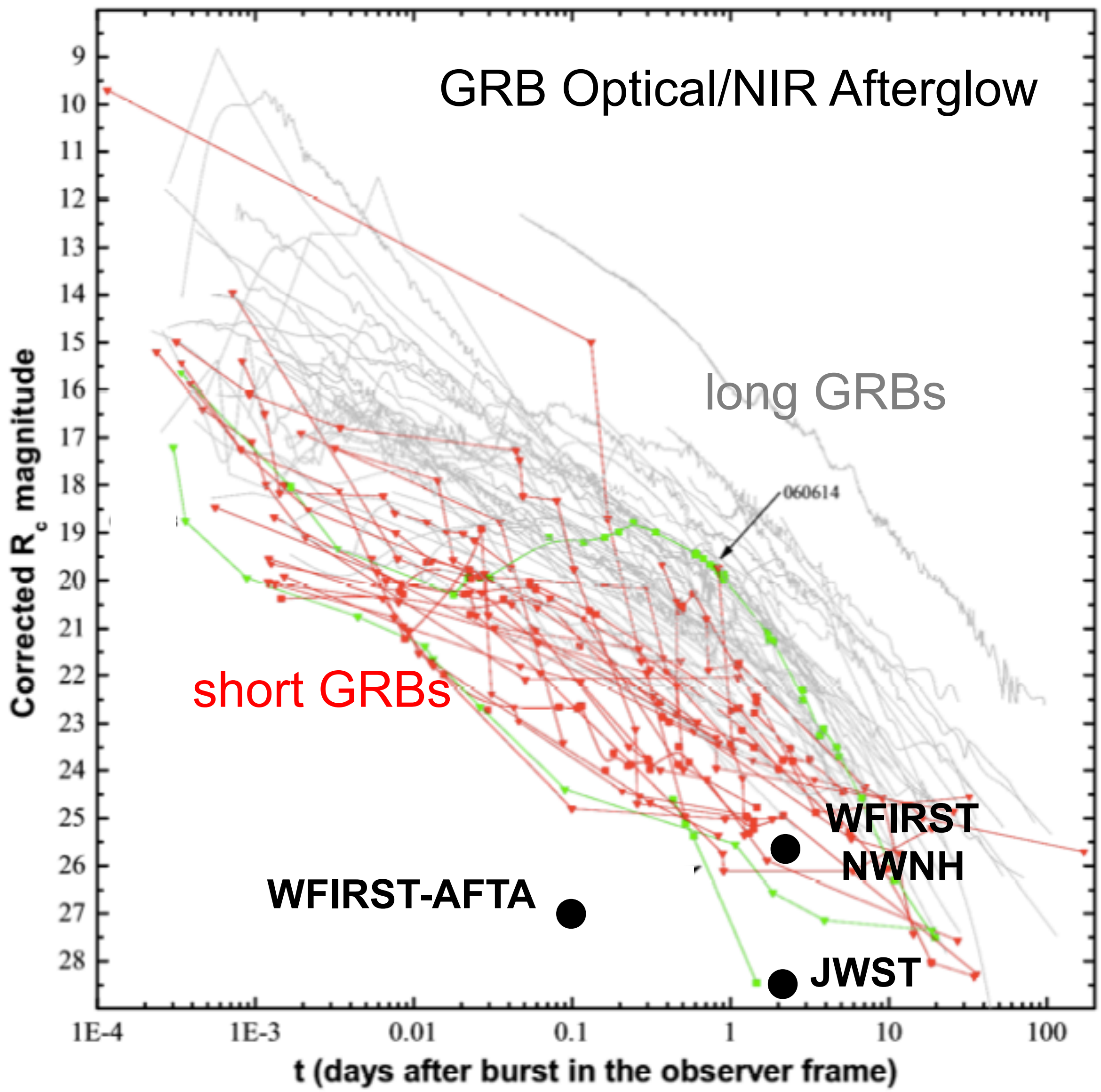
LIGO-Virgo Error Boxes – Galaxy Strategy



galaxies to cover 50% of light
WFIRST FoV = 0.28 deg^2

Kanner, Gehrels+ '12

GRB and GW Afterglows



Kann+ '08

NS-NS mergers produce GWs & GRBs

EM afterglows are bright, but short-lived

Summary

- WFIRST-AFTA is a (now more) powerful mission for NIR surveys and exoplanets
  - HST imaging & spectroscopy with 100x field of view
  - First high-contrast coronagraph for imaging exoplanet Jupiters and debris disks
  - First space microlensing census of exoplanets
- Coronagraph is descopable, but important scientifically and politically
- If WFIRST can launch in 2024, substantial funds for new future missions or involvement in missions will become available in ~2023.
- WFIRST-AFTA will be a useful tool for follow-up of LIGO-Virgo and LISA GW events