SYSTEMS ENGINEERING
OF THE
WIDE-FIELD INFRARED SURVEY TELESCOPE (WFIRST)
IN
PRE-PHASE A

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ABSTRACT

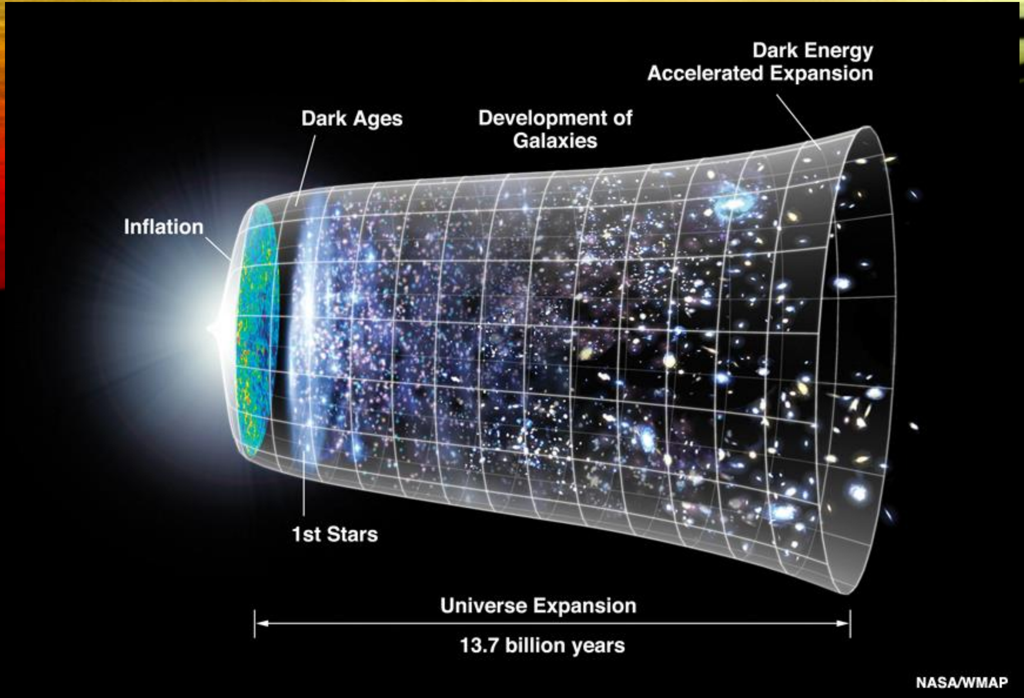
The Wide-Field Infrared Survey Telescope (WFIRST) is the next large space telescope, following in the footsteps of the Hubble and James Webb Space Telescopes. This flagship mission will perform extra-galactic and galactic surveys to study the nature of dark energy and complete the census of planets in our galaxy started by Kepler as described in the 2010 New Worlds New Horizons Decadal Survey. It will also advance the technology required for an Exo-Earth Imaging mission in the next decade.

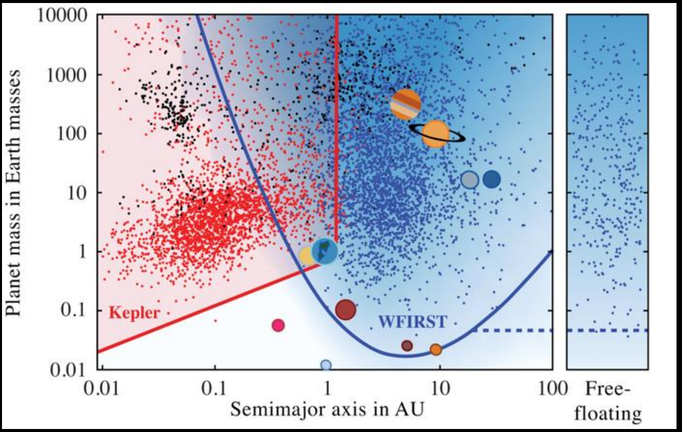
With WFIRST poised to enter formulation, this talk will look at systems engineering challenges encountered during pre-formulation.

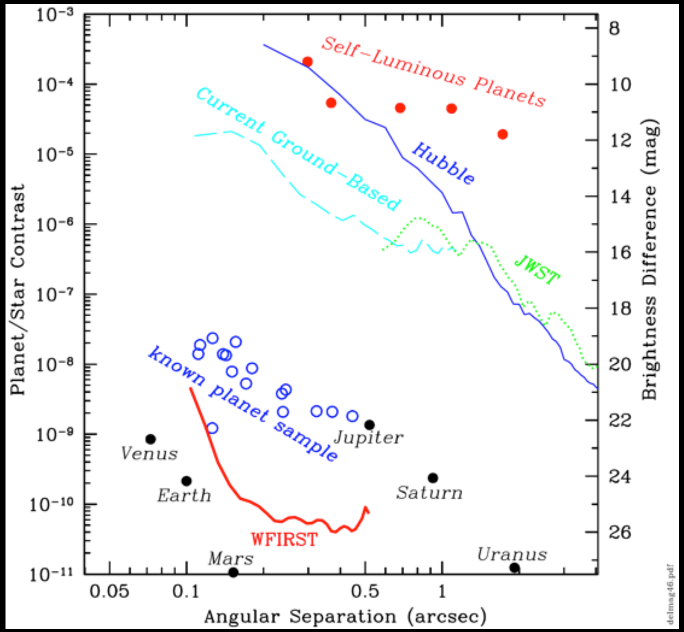
Presented March 8th, 2016 at Goddard's Systems Engineering Seminar

ASTROPHYSICS
Decadal Survey
Missions
1972
Decadal
Survey
Hubble
and Astrophysics
for the 1970s
1982
Decadal
Survey
Chandra
Astronomy
and Astrophysics
for the 1980s
1991
Decadal
Survey
Spitzer
ASTRONOMY
ASTROPHYSICS
2001
Decadal
Survey
JWST, SOFIA
2010
Decadal
Survey
WFIRST
New Worlds,
New Horizons

WFIRST SCIENCE OBJECTIVES







1. ***Measure acceleration of the expansion of the Universe.***
   - Measure the expansion history of the Universe and…
   - Characterize the growth of large-scale structures within it.

2. ***Search for extra-solar planets.***
   - Perform a microlensing survey and complete the census of extra-solar planets in our galaxy.
   - Develop and fly a technology demonstration in which a coronagraph instrument is used for direct imaging and spectroscopy of nearby planets and debris disks.

3. ***Host a Guest Observer (GO) program for general astrophysics.***

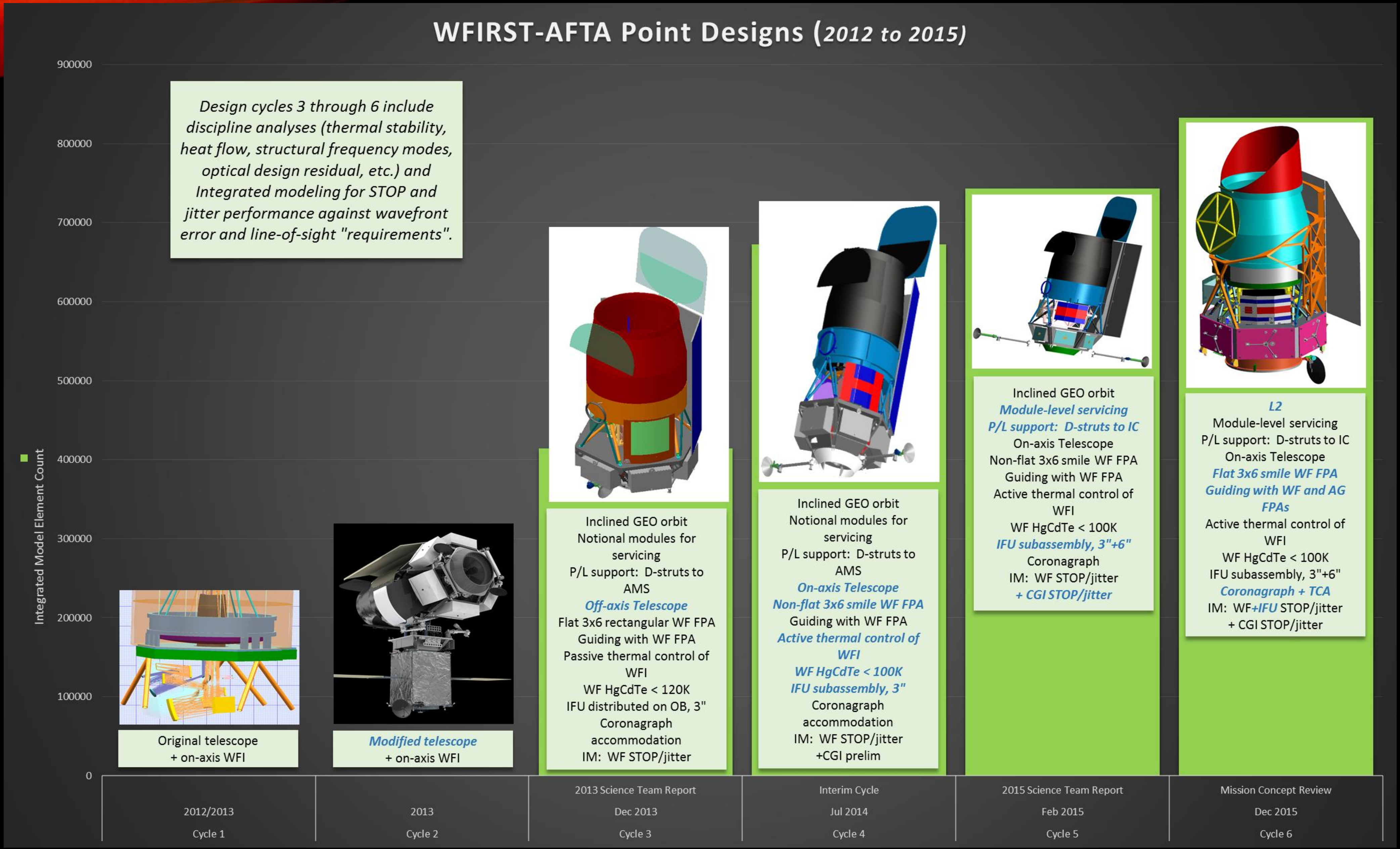
WFIRST MEASUREMENTS

	Measurement	Science Survey
1. Measure acceleration of the expansion of the Universe.	Measure positions and redshifts of emission-line galaxies at high latitudes. Standard ruler to measure density of galaxies vs. redshift.	High Latitude Survey (BAO/RSD)
	Measure shapes and fluxes of galaxies at high latitudes. Indirect measure of dark matter and measurement of growth of cosmic structure by measuring galaxy clumping. Distribution of cosmic mass vs. redshift.	High Latitude Survey (Weak Lensing)
	Measure the spectra, light curves, fluxes, and redshifts of Type Ia supernovae. Distance via standard candle and acceleration via redshift.	Supernova Survey
2. Search for extra-solar planets.	Monitor microlensing events toward the Galactic Bulge. Detect presence of planet by brightening of background star. Statistical census.	Microlensing Survey
	Image known planets and perform a blind search for new planets in multiple colors.	Coronagraph Survey
	Characterize the atmospheres of imaged planets with spectroscopy.	
	Make imaging observations of disks.	

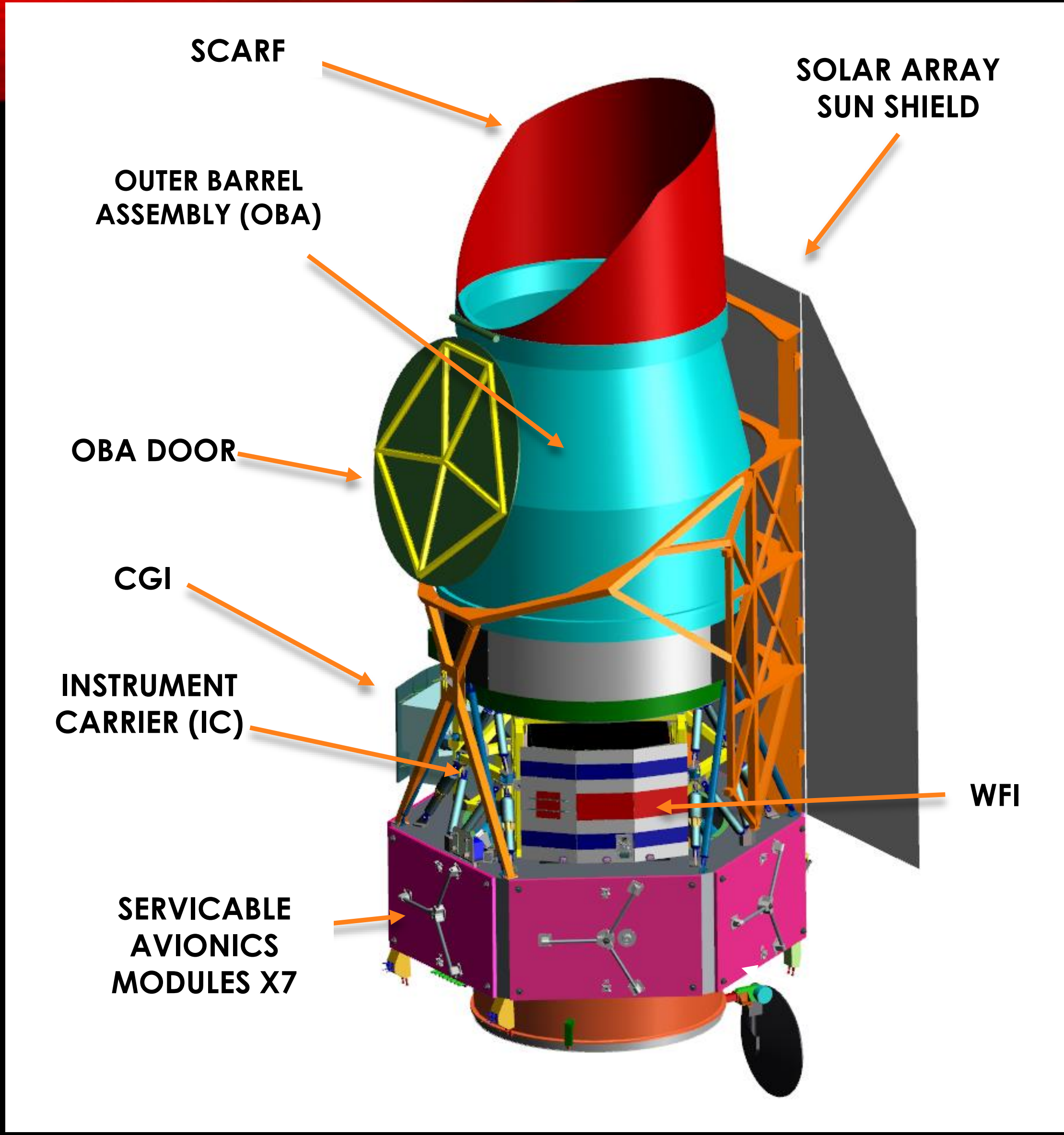
SCIENCE OBJECTIVES vs. SURVEYS vs. INSTRUMENTS

	OBJECTIVES ➲	1. Measure acceleration of the expansion of the Universe.			2. Search for extra-solar planets.				3. Host a guest observer program.
	SURVEYS ➲	Dark Energy Surveys			Exo-planet Micro-lensing	Exoplanet Coronagraphy			Guest Observer / Guest Investigator
		Super-nova	High Latitude Imaging	High Latitude Spectro-scopy		Planet Image	Planet Spec	Disk image	
INSTRUMENTS ➲ Wide Field Instrument	Wide field imaging	✓	✓		✓				✓
INSTRUMENTS ➲ Wide Field Instrument	Wide field spectroscopy			✓					✓
INSTRUMENTS ➲ Wide Field Instrument	Spectrograph	✓							✓
INSTRUMENTS ➲ Corona-graph	High contrast imaging					✓		✓	✓
INSTRUMENTS ➲ Corona-graph	High contrast spectroscopy						✓		✓

DESIGN CYCLES



MISSION OVERVIEW
MCR DESIGN CONCPT



Mission Life: 6 years (+ ~3 month checkout)

Mission Orbit: Sun-Earth L2

Baseline Launch Vehicle: Delta-IV Heavy

Mission Classification:

- Class B Overall
- Class C Coronagraph technology demonstration

Observatory:

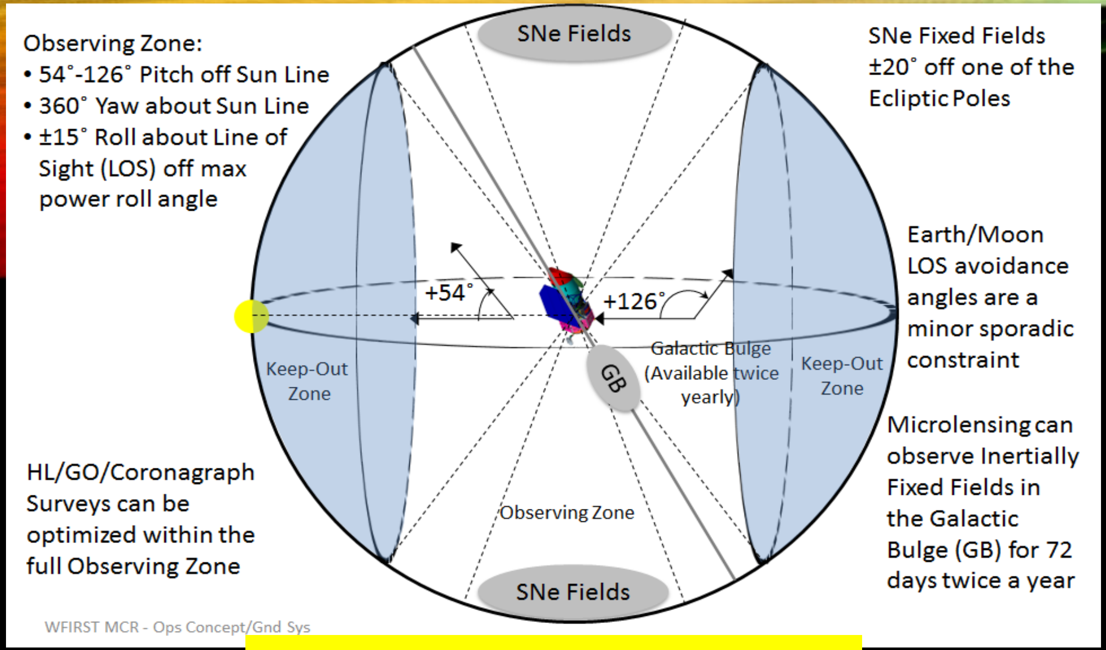
- 2.4 m primary mirror Telescope (existing)
- Wide Field Instrument (WFI)
- Coronagraph (CGI)
- S/C Bus
- Modular Serviceable Design

Ground System: Dual site dedicated ground stations

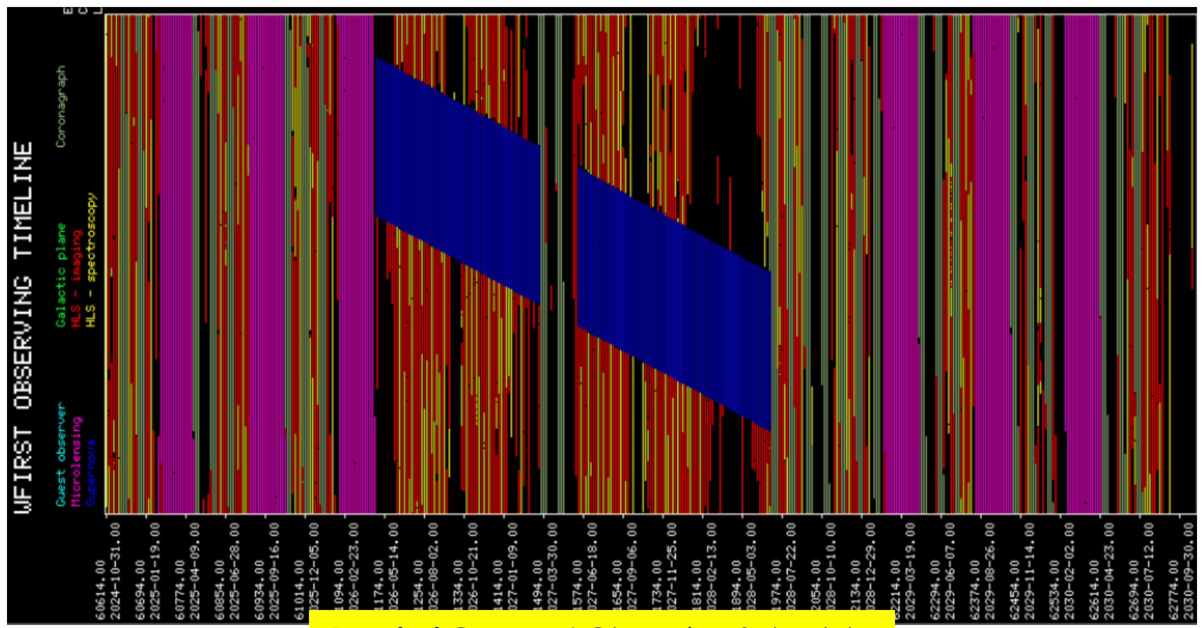
- Northern GS- White Sands, Southern GS- Punta Arenas

MISSION OVERVIEW

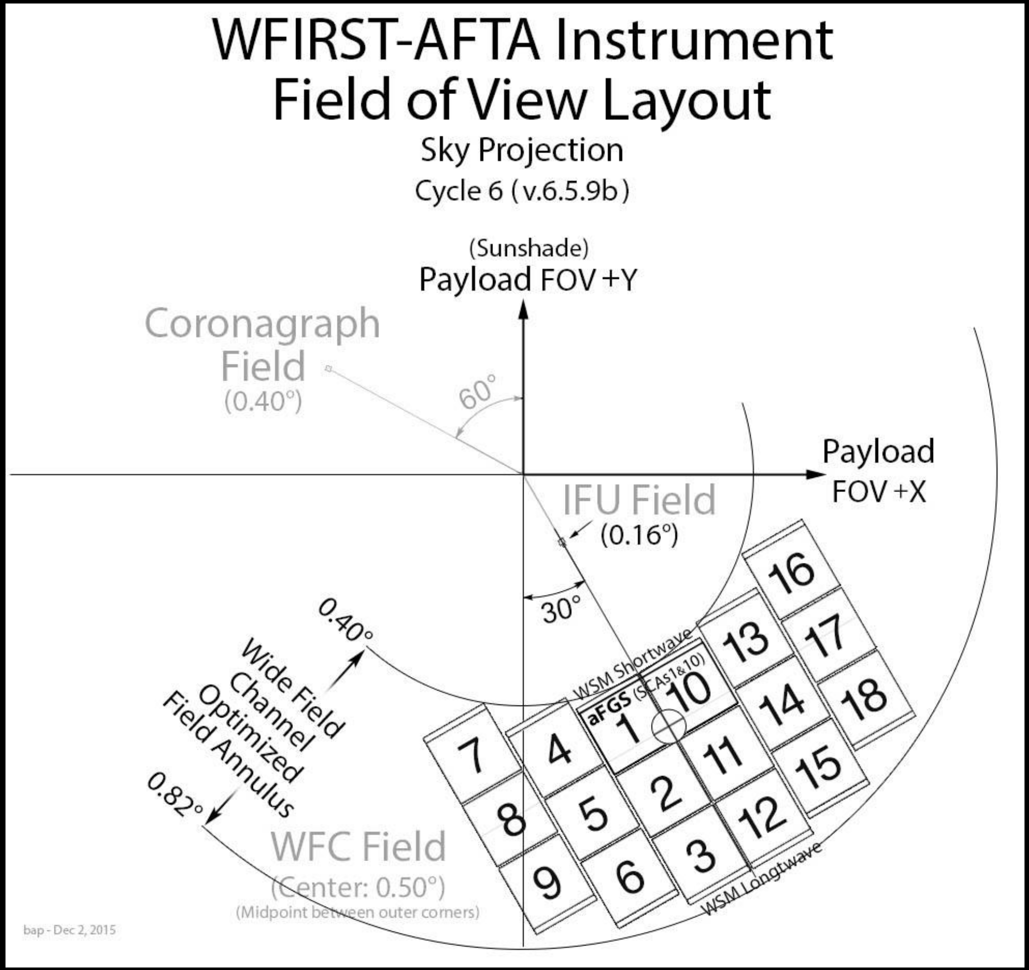
MCR DESIGN CONCPT



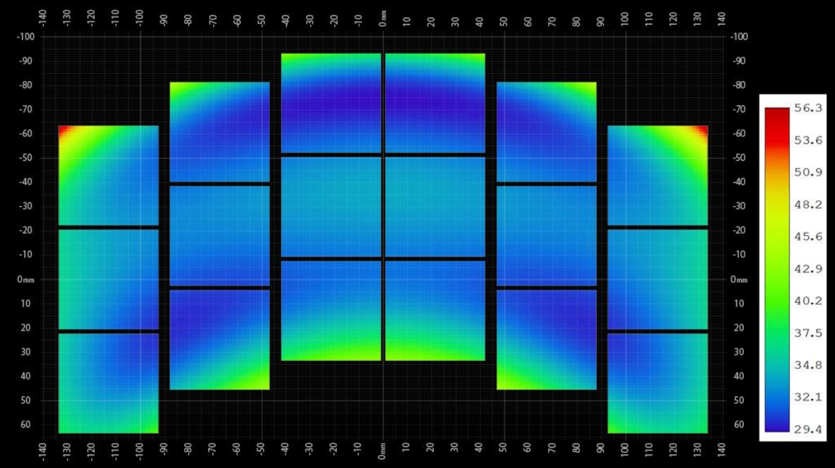
Central Line of Sight and Field of Regard



Proof of Concept Observing Schedule

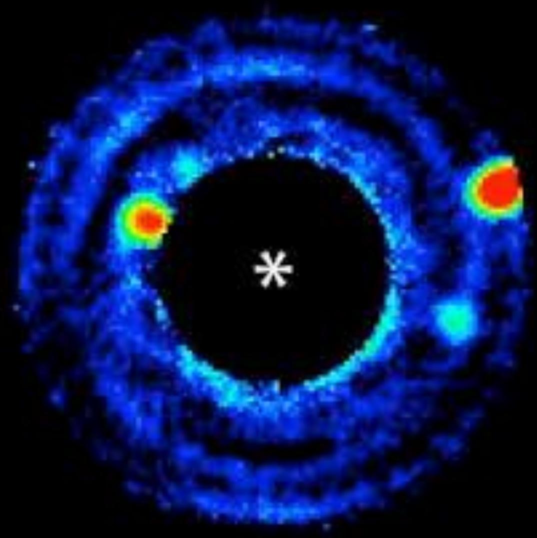


WFIRST SCIENCE IMAGING: *REQUIREMENTS*



Wide Field Instrument

- Small point spread function (PSF) diffraction limited at 1.2um
- PSF Ellipticity knowledge to < 4.7 x 10^{-4} rms
- Nanometer stability over minutes of exposure time

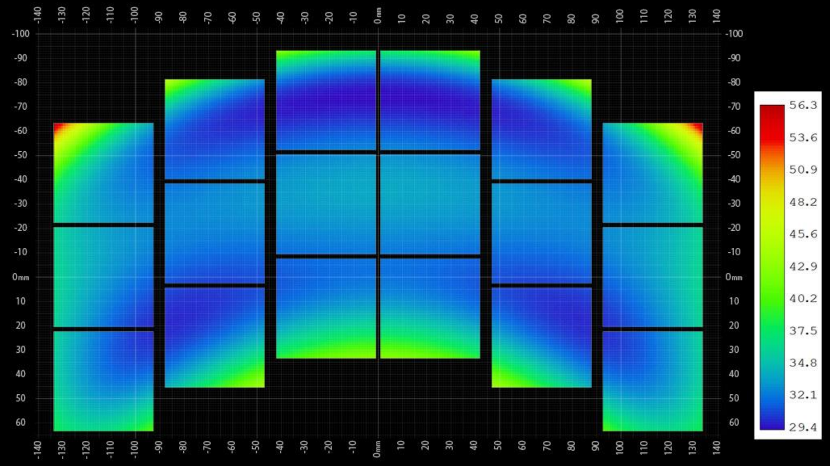


Coronagraph

- 10^{-9} contrast requirement
- Picometer stability over hours of an observation

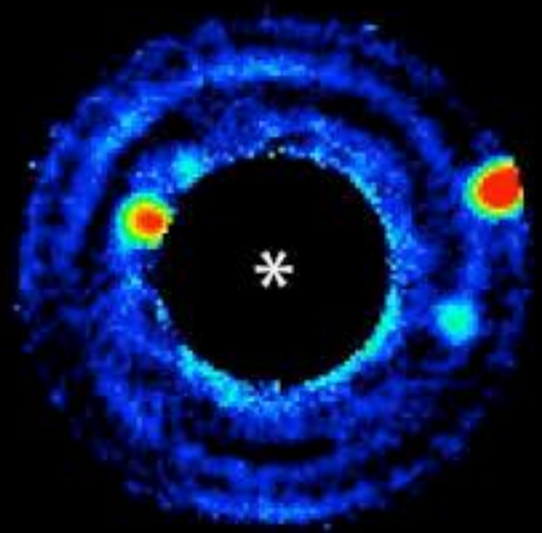
…but Coronagraph is a technology demonstration and cannot drive Observatory requirements.

WFIRST SCIENCE IMAGING: *CHALLENGES*



Wide Field Instrument

- Detector technology – 4kx4k, 10μm pixels with low dark current and low persistence
- Large data volume – 302Mpixels per exposure
- Optical alignment and verification of system with large mirrors (which sag with gravity))



Coronagraph

- Occulting mask technology….and achieving contrast with an obscured aperture
- Internal jitter, drift and wavefront error correction (complicated flight software and deformable mirror development)

MISSION CONCEPT TRADE EXAMPLE: *GEO VS. L2 ORBIT*

GEO Orbit

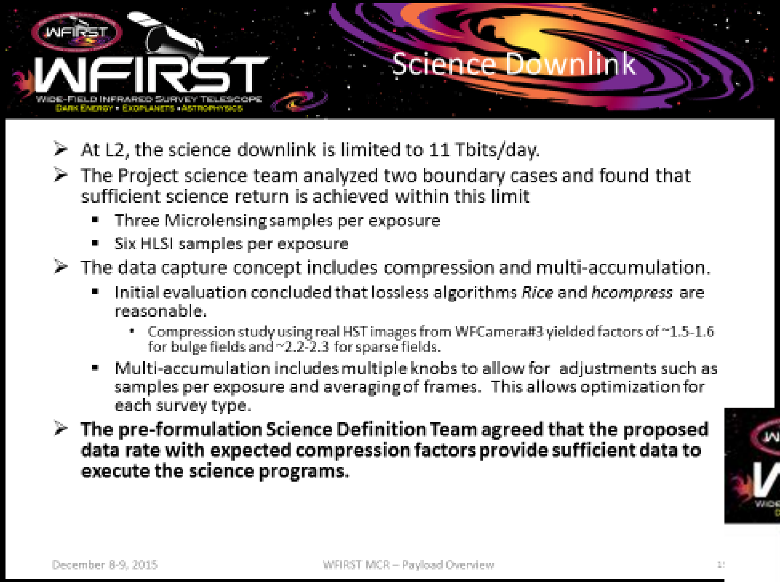
- Bent-pipe downlink to a dedicated ground station
- Harsher radiation environment
- Smaller propulsion system
- Observing constraints due to Earth and Moon

L2 Orbit

- Limited downlink requiring compression and on-board storage with ground station contact schedule
- Lower charged particle flux (less shielding required)
- Reduced thermal and mechanical disturbances (no Earth load and reduce HGA stepping)
- More efficient observation schedule

MISSION CONCEPT TRADE EXAMPLE:
DOWNLINK CONCEPT FOR L2 ORBIT

Science survey data set requirements



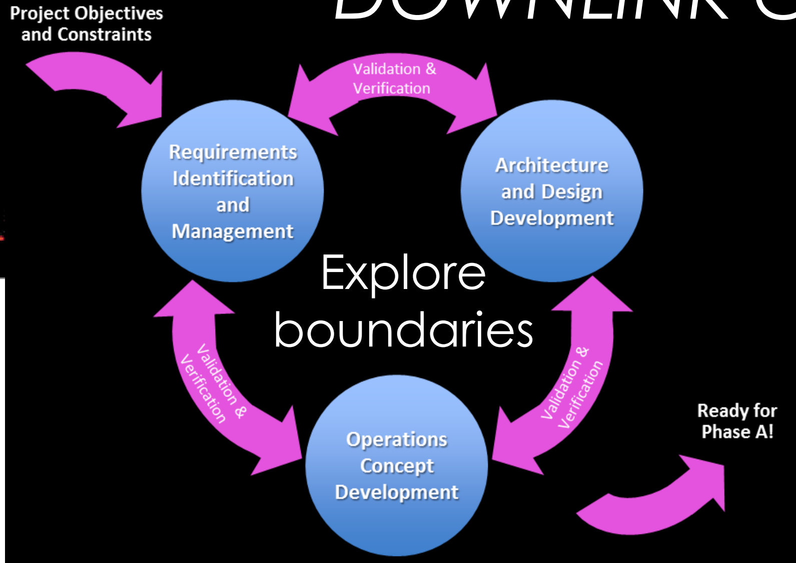
Science Downlink

WFIRST WIDE-FIELD INFRARED SURVEY TELESCOPE DARK ENERGY • EXOPLANETS • ASTROPHYSICS

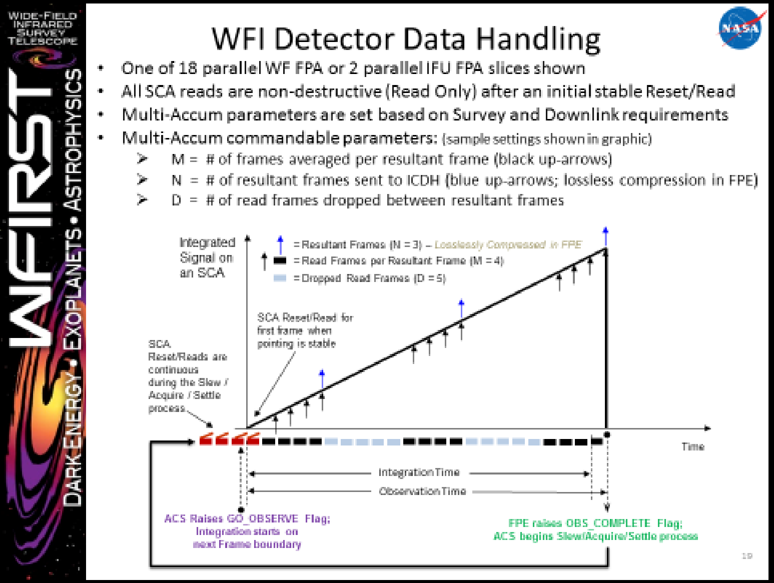
- At L2, the science downlink is limited to 11 Tbits/day.
- The Project science team analyzed two boundary cases and found that sufficient science return is achieved within this limit
  - Three Microlensing samples per exposure
  - Six HLSI samples per exposure
- The data capture concept includes compression and multi-accumulation.
  - Initial evaluation concluded that lossless algorithms *Rice* and *hcompress* are reasonable.
    - Compression study using real HST images from WFCamera#3 yielded factors of ~1.5-1.6 for bulge fields and ~2.2-2.3 for sparse fields.
  - Multi-accumulation includes multiple knobs to allow for adjustments such as samples per exposure and averaging of frames. This allows optimization for each survey type.
- **The pre-formulation Science Definition Team agreed that the proposed data rate with expected compression factors provide sufficient data to execute the science programs.**

December 8-9, 2015 WFIRST MCR – Payload Overview

From "Payload Overview", WFIRST MCR, Lisa Bartusek, Payload System Engineer



From "Operations Concept", WFIRST MCR, Steve Tompkins, Ground System Manager



WFI Detector Data Handling

WIDE-FIELD INFRARED SURVEY TELESCOPE WFIRST DARK ENERGY • EXOPLANETS • ASTROPHYSICS

- One of 18 parallel WF FPA or 2 parallel IFU FPA slices shown
- All SCA reads are non-destructive (Read Only) after an initial stable Reset/Read
- Multi-Accum parameters are set based on Survey and Downlink requirements
- Multi-Accum commandable parameters: (sample settings shown in graphic)
  - M = # of frames averaged per resultant frame (black up-arrows)
  - N = # of resultant frames sent to ICDH (blue up-arrows; lossless compression in FPE)
  - D = # of read frames dropped between resultant frames

From "Wide Field Instrument", WFIRST MCR, Art Whipple, WFI IM, and Steve Andrews, WFI ISE

TELESCOPE PEDIGREE AND CAPABILITY INVESTIGATION

- The original application is very different than the WFIRST application.
  - ➲Will the Telescope perform adequately within the WFIRST application?
- The hardware was built in early 2000, will not launch until the 2020s and needs to survive a 6-year mission life and 10-year goal.
  - ➲Are there any issues or risks due to aging?
- The hardware was built for a non-NASA customer.
  - ➲Do the original Mission Assurance standards meet NASA requirements?
- The previous Program was shut down part way through its verification program. We need to understand the current state of the hardware including traceability, what environments it was exposed to, what problems it encountered and how they were resolved, etc.
  - ➲What is the state of the Telescope hardware?

TELESCOPE PEDIGREE AND CAPABILITY INVESTIGATION

Perform trade studies and investigate concepts

- Science return for given FOA temperature
- Viable FOA operating temperature range
- OBA configuration
- Heater control scheme for temperature control stability
- Etc.

What is the WFIRST application?

- Operating temperature
- Temperature stability
- On-orbit environment (thermal, radiation, sun exposure)
- Launch loads
- Ground test environment
- Prescription
- Risk classification
- Redundancy, sparing policy
- Door, actuator CONOPs
- Parts requirements
- Interfaces (electrical, mechanical, optical, thermal)
- Etc.

What is the pedigree of the Telescope?

- Current configuration
- Models (thermal, FEM, CAD, etc.)
- MEL
- Parts & materials
- Actual vs. drawings
- Previous qualification and verifications
- Workmanship standards
- Implications of security classification
- Etc.

What is the Telescope capability?

- Allowable thermal gradients
- AMS loads
- Coatings life
- Aging effects
- Bonded joints and laminates
- Interfaces (electrical, mechanical, optical, thermal)
- Alignment, focus control
- Temperature control
- Etc.

Perform gap analysis

1. Compare capability to application

2. Compare pedigree to NASA standards

3. Determine how to fill the gaps.

- Extend qualification?
- Add verifications?
- Replace, rework or refurbish?
- Document risk and mitigate?
- Etc.

TELESCOPE PEDIGREE AND CAPABILITY INVESTIGATION

Will the Telescope perform adequately within the WFIRST application?

Working Group Meetings
- Payload Systems
- Payload I&T
- Alignment
- Ad hoc

Trade Studies
- OBA configuration
- FOA operating temperature
- Thermal control optimization

Requirements and ICD Development
- Level 2 → Level 3
- Telescope/Spacecraft ICD
- Resource allocations (mass, power, WFE, SNR)

Analysis
- Thermal Modeling
- Structural Modeling
- Integrated Modeling (STOP, jitter)

Capability vs. Application Assessment

Are there any issues or risks due to aging?
Do the original Mission Assurance standards meet NASA requirements?
What is the state of the Telescope hardware?

Assembly Audits (high & low side)
- Build books
- Tech notes
- SMA Standards
- Problem reports
- Verification reports

Hardware Inspections
- Initial ID & Damage
- Ongoing, as needed

Hardware Aging Assessment
- Materials audit
- GIDEP review
- Witness coupons

Pedigree Assessment

Phase A

Telescope Inheritance Review
- Reuse / Rework Plan
- Verification Plan

Application ♦ Pedigree

WFIRST DRIVING "REQUIREMENTS"

…AS WE UNDERSTAND THEM TODAY

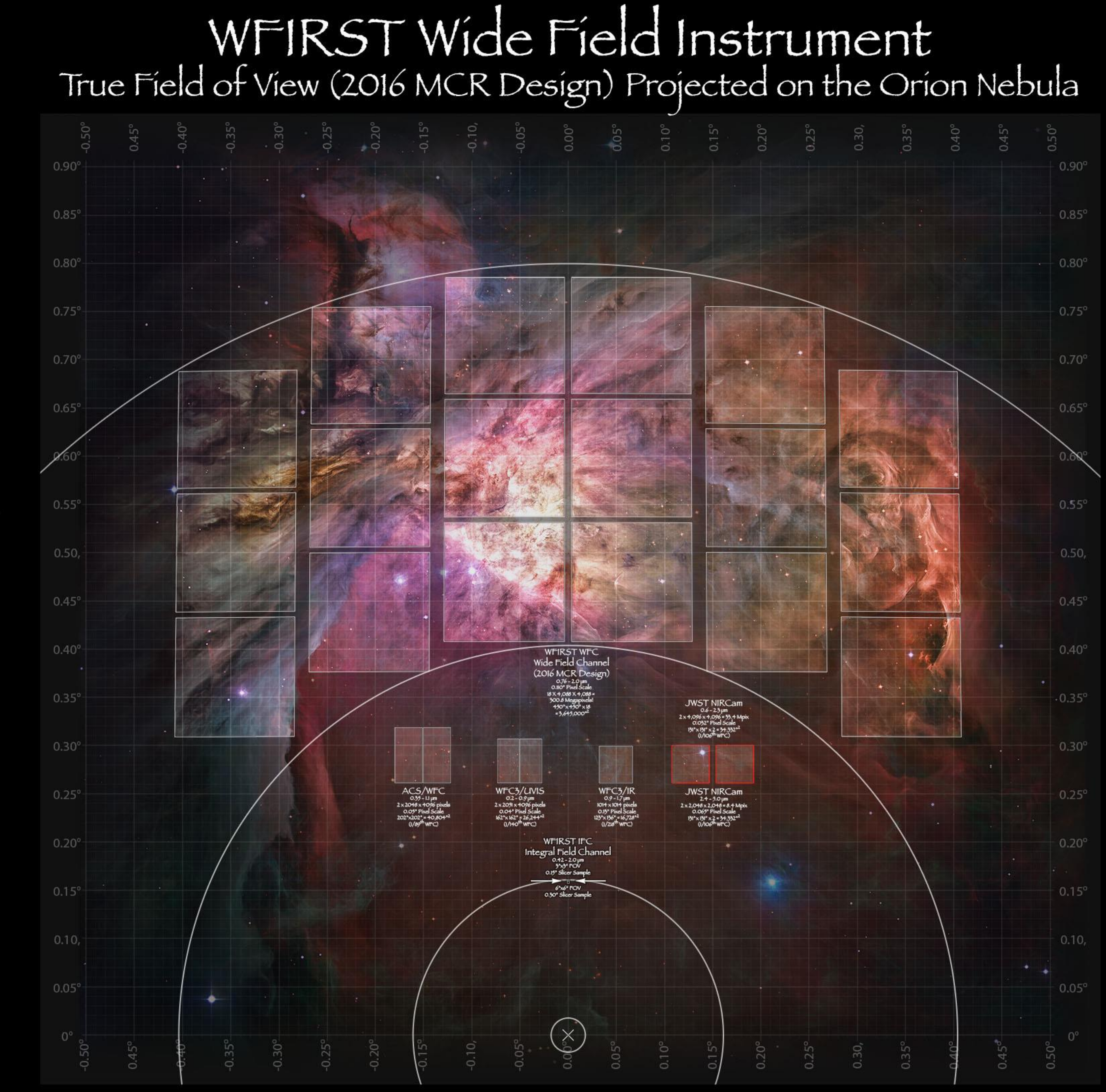
Science

- Image quality and stability
- High signal-to-noise ratio
- Observing efficiency
- Data volume and completeness

Programmatic

- Existing telescope
- Technology demonstration of coronagraphy for exoplanet characterization
- On-orbit servicing

WFIRST/WFI WILL DELIVER "HST QUALITY" NIR IMAGING AND SPECTROSCOPY WITH MUCH BETTER STABILITY OVER 1000'S OF SQUARE DEGREES!



Orion Image: HST Gallery

FOR MORE INFORMATION

http://wfirst.gsfc.nasa.gov

https://www.facebook.com/NASAWFIRST

http://twitter.com/NASAWFIRST

http://www.nasa.gov/press-release/nasa-introduces-new-wider-set-of-eyes-on-the-universe

https://youtu.be/LbJpVHMV1m4

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- ★Dave Content, WFIRST Payload Systems Manager, GSFC/448
- ★Brooke Hsu, WFIRST Education and Public Outreach Coordinator, ASRC
- ★Clifton Jackson, WFIRST Instrument Systems Engineer, SGT
- ★Mark Melton, WFIRST Deputy Mission Systems Engineer, GSFC/599
- ★Bert Pasquale, WFIRST WFI Optical Engineer, GSFC/551
- ★John Ruffa, WFIRST Mission Systems Engineer, GSFC/599
- ★Steve Tompkins, WFIRST Operations Manager, GSFC/581
- ★Art Whipple, WFIRST WFI Instrument Manager (Acting), Conceptual Analytics