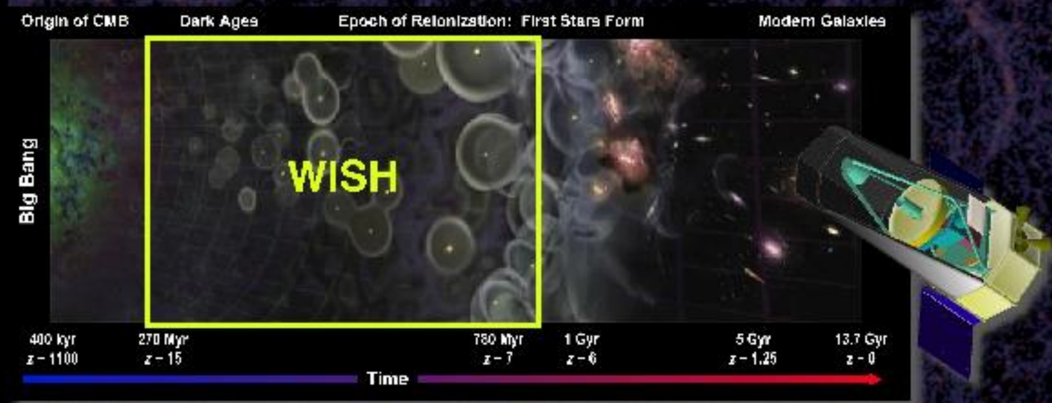
Participation in the JAXA/ISAS Mission WISH: Wide-field Imaging Surveyor for High-redshifts



Principal Investigator
Giovanni G. Fazio

Prepared for the National Aeronautics and Space Administration
in Response to AO NNH12ZDA006O for
NASA's Second Stand Alone Missions of Opportunity (SALMON-2)

For the period 1 October 2013 through 30 September 2025

Smithsonian Astrophysical Observatory
Cambridge, Massachusetts 02138

Charles Alcock

Dr. Charles Alcock, Director

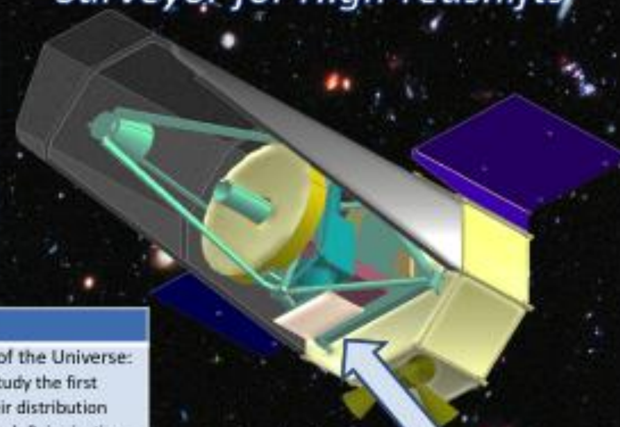
Dr. Giovanni G. Fazio, PI

The Smithsonian Astrophysical Observatory
is a member of the
Harvard Smithsonian Center for Astrophysics
Director: Dr. Charles Alcock

WISH

Participation in the JAXA/ISAS Mission WISH: Wide-field Imaging Surveyor for High-redshifts

Smithsonian Astrophysical Observatory proposes to team with JAXA/ISAS to perform ground-breaking surveys of the Cosmic Dawn with WISH, supply the WISH focal plane consisting of 32 H2RG HgCdTe (0.9 – 5.0 μm) arrays, and to operate the U.S. WISH Data Center



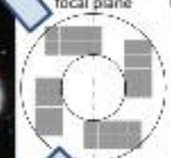
WISH Scientific Program

Unveiling the Cosmic Dawn and the Evolution of the Universe:

- Wide field and deep surveys from 1 – 4 μm to study the first generation ($z = 8 - 15$) of galaxies, revealing their distribution and properties from the cosmic Dark Ages through Reionization.
- Expansion history of the universe and dark energy using a large sample of Type Ia supernovae observed in their rest frame *H*-band emission.
- Galaxy formation and evolution at $0 < z < 4$ using a very wide area near-infrared survey.

Other science: Galactic structure and star formation, exoplanets.

32 H2RGs (in 2x4 mosaics) in WISH focal plane



Teledyne H2RG
2048×2048 pixel
0.9 – 5 μm array

2×2 mosaic of four H2RG arrays

2010 Decadal Science Addressed by WISH

- "What objects lit up the Universe, and when?"
- "How has the Universe evolved over time?"
- "How do stars and planets form?"
- "What are other planetary systems like?"

WISH Surveys

Survey	Filters (μm)	Area (deg²)	Depth (5σ) (AB mag)	Duration (years)	Science Objectives
Ultra-Deep (UDS)	1.0, 1.4, 1.8, 2.3, 3.0	100	28	3.48	Galaxies at $8 < z < 15$; Type Ia SN
Ultra-Deep 4μm (UDS-II)	UDS + 4.0	10 (within UDS)	28	0.24	Galaxies at $8 < z < 15$; Type Ia SN
Ultra-Wide (UWS)	1.0, 1.4, 1.8, 2.3, 3.0, 4.0	1000	25	0.24	Quasars $z > 7$; Evolution of galaxies $0 < z < 4$
Extreme (ES)	1.0, 1.4, 1.8, 2.3, 3.0	0.24	29 .5	0.13	Faint end of luminosity function $10 < z < 15$

WISH Mission Characteristics

SAO-WISH Management Summary

WISH is a JAXA/ISAS mission concept; Working Group established in 2008.

SAO proposes to supply the WISH focal plane array detectors consisting of 32 Teledyne H2RG HgCdTe (0.9-5 μm) and ASIC readout electronics and to operate the US WISH Data Center.

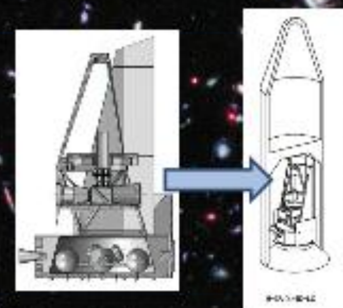
WISH will be proposed for flight to JAXA/ISAS; AO expected in 2013.

Dr. Giovanni Fazio, SAO, is the SAO-WISH Principal Investigator.

Prof. Toru Yamada, Tohoku University, is the WISH Principal Investigator.

WISH Payload

Telescope aperture	1.5 m
Telescope optics	3 mirror anastigmat
Diffraction-limited wavelength	1 μm and above
Pixel Scale	0.155 arcsec/pixel
Focal plane Field of View	0.24 deg^2
Wavelength Range	0.9 – 5 μm
Telescope Temperature	<100K
Detectors	32 H2RG (2048 ×2048 pixel)
Detector Temperature	46K
Observation mode	Step and stare
On-chip integration time	300 sec
Grism option	1 – 5 μm



WISH Mission Characteristics

Launch Date	2019
Mission Lifetime	>5 years
Launcher	JAXA H-IIA
Orbit	Sun-Earth L2
Observatory Size	3.3m x 5.2m
Launch Mass	1,300 kg
Solar Array Power	Dual Fixed-Wings
Pointing Control	IRU + focal plane
Pointing Accuracy	< 0.03 arcsec (300 sec)
Telecom	NASA DSN Ka-Band (32 Mb/s), S-Band Uplink, 1 pass/day
On-board Data Storage	96 GB
Thermal	Passively cooled

Total WISH Costs ($RY-K)

PI-Managed Mission Cost	$62,371.0
Total Mission Cost	$72,197.5
SAO Contributed Costs:	$200.0

WISH Filters

Name	Filter 0	Filter 1	Filter 2	Filter 3	Filter 4	Filter 5	Filter 5e	Filter 6
Center (μm)	1.040	1.360	1.775	2.320	3.030	3.965	4.215	4.500

WISH Schedule

Table D3. Traceability Matrix

Fundamental Objective: "Understand the origin of the universe...and processes associated with galaxy, stellar and planetary system formation and evolution ..." [SALMON-2 PEA-L p3]		Scientific Measurement Requirements		Instrument Functional Requirements	Projected Performance	Mission Functional Requirements
Science Goals (National Academy Decadal: *2020 Vision* "The Big Questions")	Science Objectives	Observables	Physical Parameters	(5-σ sensitivity limits everywhere)	(all the functional requirements are achieved in the surveys: see Table D2)	(Top Level)
"What objects lit up the Universe, and when?"	Identify the first galaxies (§D2.1.1, 2.4)	galaxies and quasars $8<z<15$	near infrared spectral energy distributions and Lyman breaks	maximum depth to 29.5mag AB between 1μm and 3μm, to 28mag AB at 4μm; diffraction-limited imaging; 128 million infrared pixels; 6 photometric filters; large area surveys (up to 1000 deg^2)	up to ~100 galaxies at $z\sim15$; ~10^5 galaxies at $z>8$; >200 quasars at $z>7$	1.5-m aperture; 5-year mission; L2 orbit; <0.03" tracking; passive cooling of optics to 100K; 128Mpixel FPAs passively cooled to 46K with milli-K stability; absolute calibration to 5%, relative cal to 1%; stability to 1 milli-mag/week; 0.24 deg^2 instantaneous FOV; seven photometric filters; 96GB data storage
	Trace the Epoch of Reionization and contributions of early galaxies (§D2.1, 2.2)					
	Trace the development of active galactic nuclei and supermassive black holes (§D2.3)					
"How has the Universe evolved over time?"	Measure evolution in the UV luminosity function beyond z~8 (§D2.1.1, 2.4)					
	Constrain cosmic acceleration (§D2.1.2)	supernovae to $z\le3$	rest-frame *H*-band light-curves of Type Ia SNe	cadenced multi-band imaging to 26.6mag AB	~3000 SNe to $z\sim1$	
<u>Secondary Science Goals</u>: "How do stars and planets form?"	Reveal properties of obscured young protostars ($t<10^5$ yr) and their environments (§D2.6.1)	protostars in dark clouds	near infrared spectral energy distributions; disks; stellar clustering; ice features	depth (in galactic plane) to ≥23mag AB; 7 filters 1μm-5μm; 128Mpix detectors; 500 deg^2 survey	~10^4 protostars; ice features	
"What are other planetary systems like?"	Detect exoplanets in microlensing survey; characterize known exoplanets (§D2.6.1)	light-curves in 1-5μm filter bands	microlensing events; transits	1-5μm response; 128Mpix	~1000 planets and free-floaters	

Table D1. Comparison of WISH to the Euclid, WFIRST, and JWST Missions

	Euclid[a]	WFIRST (DRM1)[b]	WFIRST (NRO)[c]	JWST	WISH
Mirror	1.2m	1.3m	2.4m	6.5m	1.5m
FOV	0.55 deg^2	0.375 deg^2	0.375 deg^2	0.0026 deg^2	0.24 deg^2
Visible Imager	0.55 – 0.90 μm	——	——	0.6 – 2.3 μm	——
NIR Imager	0.92 – 2.0 μm	0.73 – 2.4 μm	0.92 – 2.0 μm	2.4 – 5 μm	0.90 – 5.0 μm
Lim. Mag. (5σ)	24 AB	26 AB	27.5 AB	29.1 AB [d]	28 AB [e]
Survey Area	15,000 deg^2	3,400 deg^2	~ 3,400 deg^2	0.044 deg^2 [d]	100 deg^2 [e]
NIR Spectroscopy	1.1 – 2.0 μm	——	Grism 1.3 – 2.0 μm	Grism 2.4 – 5.0 μm	Grism Option 1 – 5 μm
Primary Science	Dark Energy, Dark Matter	Dark Energy, Exoplanets, Deep NIR Surveys	Dark Energy, Exoplanets, Deep NIR Surveys	First Galaxies	First Galaxies, Reionization, Galactic Science

[a] [27]; [b] Green et al. [35]; [c] Dressler et al. [22]; [d] JWST NIRCam Mosaic of the Chandra Deep Field South [44];
[e] WISH Ultra-Deep Survey; the WISH Extreme Survey reaches 29.5 AB mag within 0.24 deg^2.

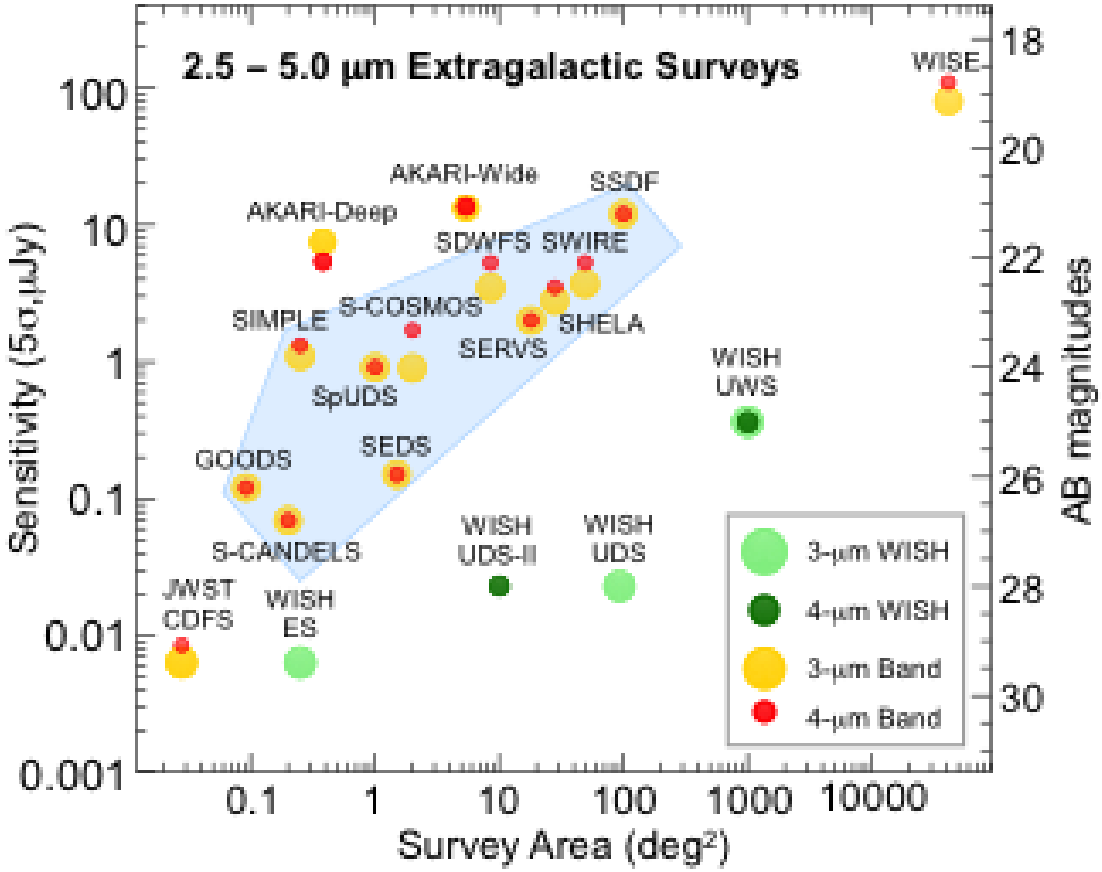


Fig. D-1. Comparison of WISH survey sensitivity and areal coverage to that of other surveys in the critical 2.5 – 5 μm band that enables characterization of high-z galaxies (especially those at $z > 12$) and rest H band detections of $0.5 < z < 1.5$ SNe (Sections D2.1 and 2.2). Green circles show the WISH surveys (Sections D2.1, 2.2, 2.3, and 2.4). The shaded area encompasses surveys conducted by the Spitzer/IRAC. Although not shown because its area is too small, the Ultra-Deep Field Imaging Survey from the JWST DRM will reach ~ 31.5 AB mag (10σ) over 0.0027 deg^2.

Table D2. Prime WISH Surveys

	Depth (5σ) (AB Mag.)	Area (deg^2)	Center Wavelengths (μm)	Survey Time[a] (years)	Proposal Section
Ultra-Deep Survey (UDS)	28	100	1.0, 1.4, 1.8, 2.3, 3.0	3.48	D2.1
Ultra-Deep Survey, 4μm (UDS-II)	28	10[b]	UDS + 4.0	0.24	D2.2
Ultra-Wide Survey (UWS)	25	1,000	1.0, 1.4, 1.8, 2.3, 3.0, 4.0	0.24	D2.3
Extreme Survey (ES)	29.5	0.24	1.0, 1.4, 1.8, 2.3, 3.0	0.13	D2.4

[a] Assumes 85% observing efficiency toward the ecliptic pole, a QE of 70%, a dark current of 0.05 e^-/s, a read noise of 15 e^- (for N=1, CDS), a throughput of 74%, and Fowler 4 sampling (see Section E1.3); [b] Within the UDS field.

WISH SNe Search Proposal. I.

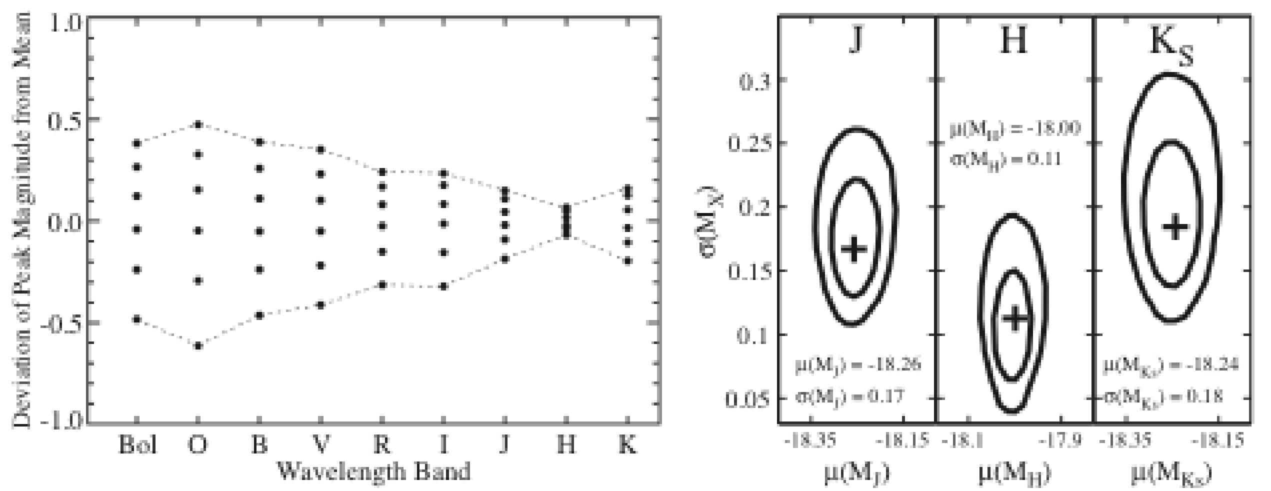


Fig. D-7. *Left:* Variation in peak SN Ia magnitude as a function of wavelength, based on simulations [46]. Note the small dispersion in the NIR and particularly the H band. *Right:* Contours of best-fit magnitudes and dispersions for nearby SNe at J, H, and K_s, confirming the models[64]. The inner contours (95% probability) for H-band observations span 0.11 ± 0.03 mag; the corresponding values for J and K_s are 0.17 ± 0.03, and 0.19 ± 0.04 mag, respectively.

- WISH excels at $0.5 < z < 1.0$ (rest-*H*)
  - Low instrinsic scatter, low systematics

WISH SNe Search Proposal. II.

- Design UDS to facilitate SNe Search?
  - Repeat observations of ‘tiles’ 12 times
    - 9X `early,’ 3X `late’
  - Rotate filters in each tile; use full UDS set
    - 14-day cadence to cover SN rise time
    - Single-epoch depth: 26.6 AB mag, 5σ
  - ~750 SNe Ia in each $\Delta z=0.1$ over $z=0.5$-1.0 with $\sigma<0.25$ mag
  - Better reduction of systematics than any other IR SNe survey

SAO Participation in the Wide-field Imaging Surveyor for High-redshifts (WISH) Page F-6

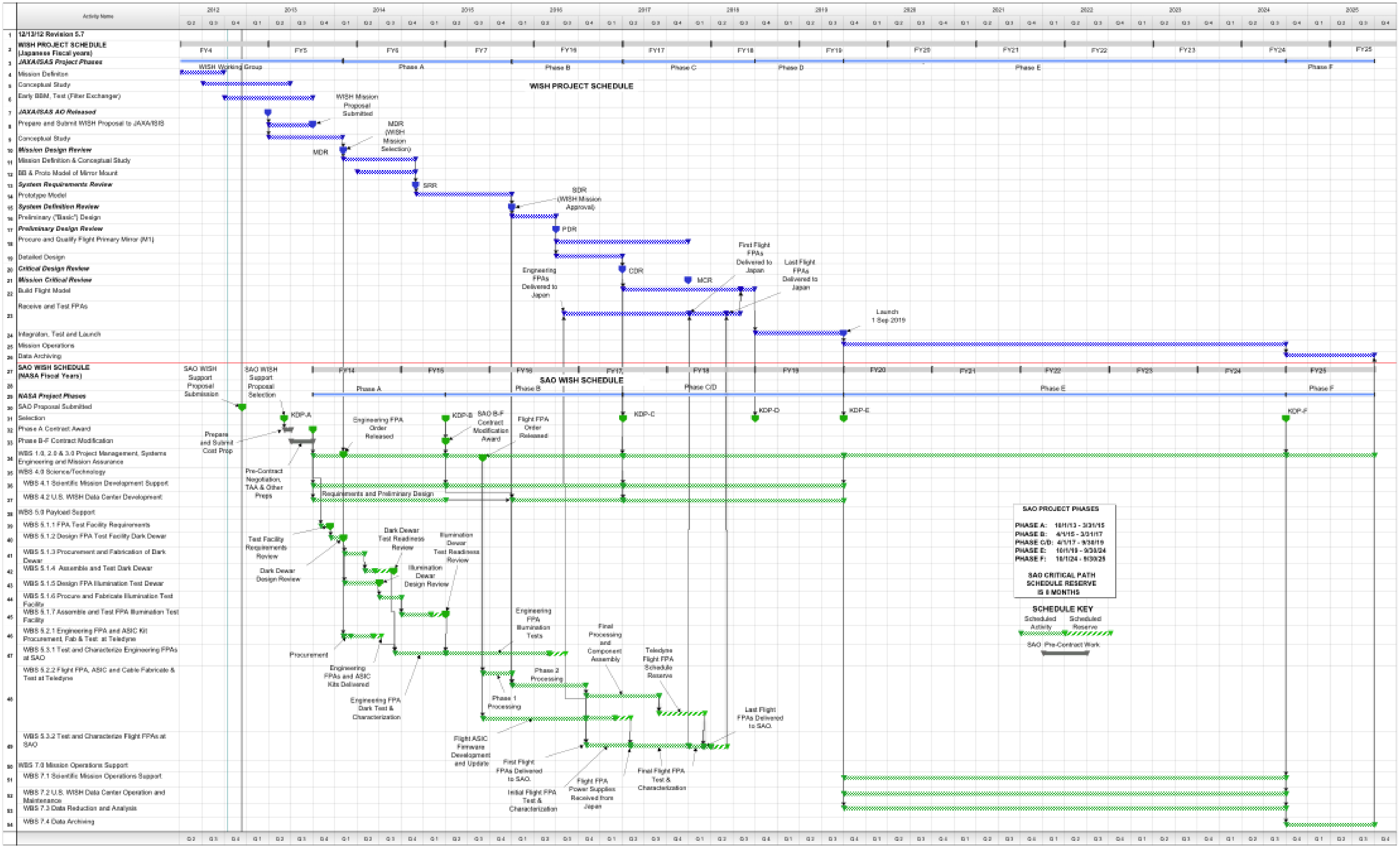
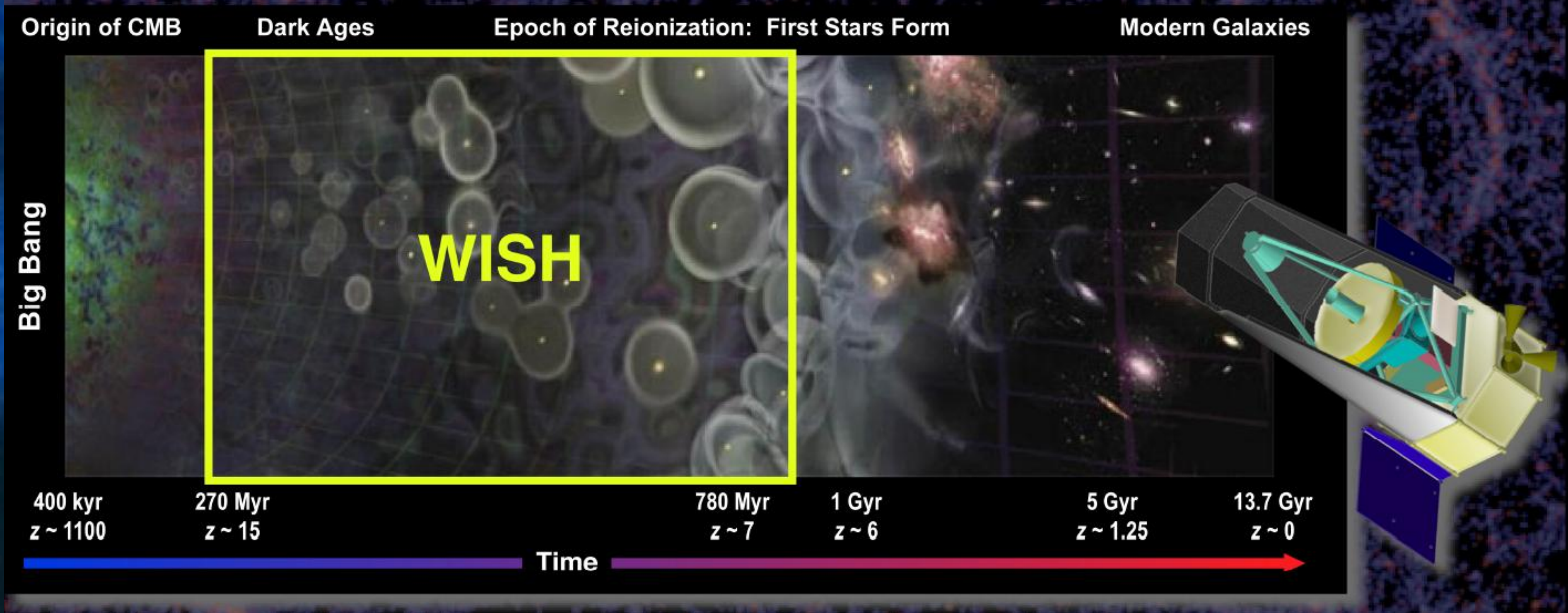


Fig. F-2. WISH and SAO-WISH Project Schedules

Participation in the JAXA/ISAS Mission WISH: Wide-field Imaging Surveyor for High-redshifts



Matt Ashby
Joe Hora

Smithsonian Astrophysical Observatory has proposed to NASA to team with the JAXA/ISAS WISH project to

- perform groundbreaking surveys of the Cosmic Dawn
- supply the WISH focal plane consisting of 32 H2RG HgCdTe (0.9 – 5.0 μm) arrays
- Operate the U.S. WISH Data Center

SAO-WISH Science Team

- Giovanni Fazio – SAO WISH P. I.
- Gary Melnick – SAO WISH Deputy P. I.
  - will assist Dr. Fazio in leading the SAO science team,
  - develop the survey observing plans
- Matthew Ashby
  - US lead for source extraction, bandmerging, catalog construction, and identification of high-redshift sources in the WISH surveys.
  - Help establish the US-WDC
  - FPA testing
- Joseph Hora
  - lead FPA test effort at SAO
  - support the science survey planning
  - data reduction and analysis techniques
  - Galactic science programs.
- Howard Smith
  - science and data programs
  - direct the US-WDC.
- Volker Tolls
  - FPA testing, develop on-ground science tests
  - on-orbit check-out and performance monitoring
  - Galactic science programs.
- Zhong Wang
  - Participate in FPA testing
  - oversee the science data pipeline design and implementation
  - statistical analysis of the faintest galaxy population.
- Steven Willner
  - participate in FPA testing
  - Observing program design, and
  - science analysis of distant galaxies and active galactic nuclei.
- Daniel Eisenstein
  - study of intermediate and high-redshift galaxies with WISH, focusing on the impact of large-scale structure.
- Lars Hernquist
  - participate in the interpretation of the observations
  - perform cosmological simulations of galaxy and structure formation.
- Avi Loeb
  - will develop state-of-the-art models of high-redshift galaxies in the WISH wavelength range.

SAO Proposal Status

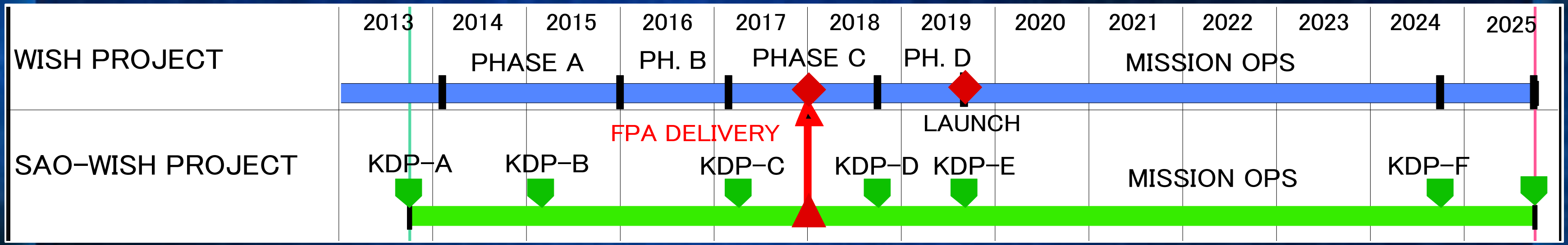
- Proposal to NASA prepared in Fall 2012
  - Second Stand Alone Missions of Opportunity Notice (SALMON-2) Astrophysics Mission of Opportunity (MO) science investigations through the Explorer Program
  - Rough Order of Magnitude (ROM) price estimate obtained from Teledyne ~ $35M
  - Science case and Management Plan written, level of effort at SAO determined for FPA testing and science participation
  - Proposal submitted in December 2012, total $59.5M including ~25% reserves
- Decision expected in mid-2013

Comparison of WISH, Euclid, WFIRST, JWST

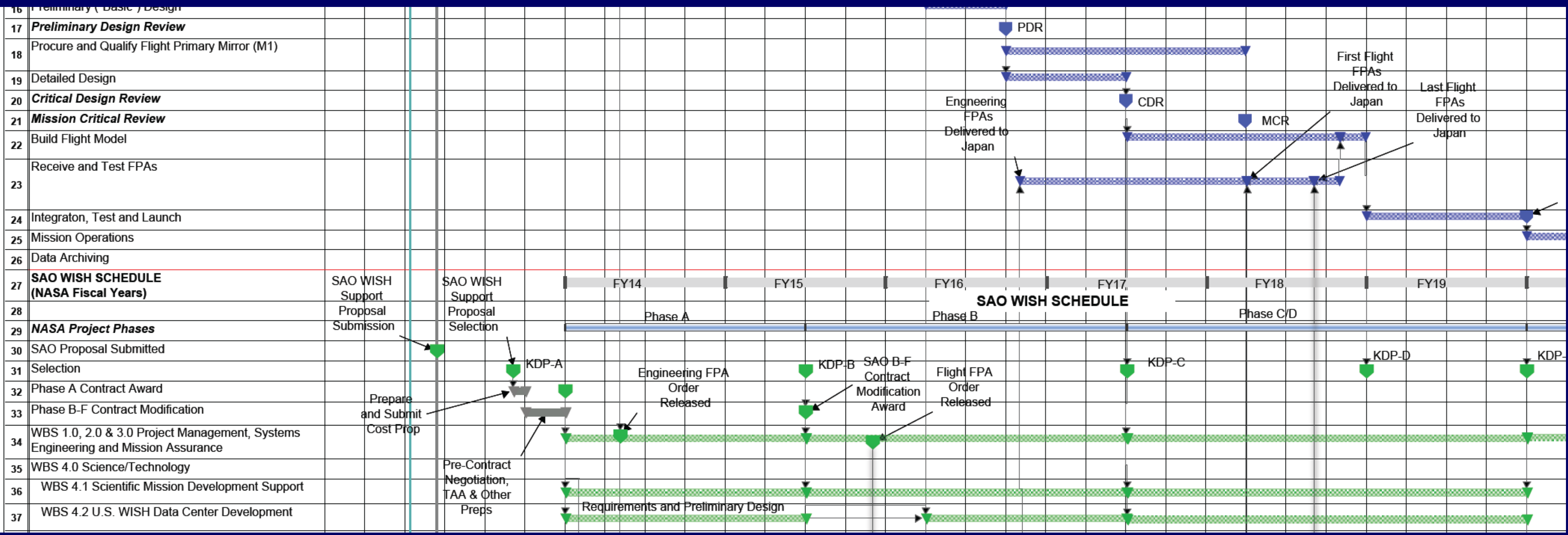
	Euclid[a]	**WFIRST** (DRM1)[b]	**WFIRST** (NRO)[c]	**JWST**	**WISH**
Mirror	1.2 m	1.3 m	2.4 m	6.5 m	1.5 m
FOV	0.55 deg^2	0.375 deg^2	0.375 deg^2	0.0026 deg^2	0.24 deg^2
Visible Imager	0.55 – 0.90 μm	——	——	0.6 – 2.3 μm	——
NIR Imager	0.92 – 2.0 μm	0.73 – 2.4 μm	0.92 – 2.0 μm	2.4 – 5 μm	0.90 – 5.0 μm
Lim. Mag. (5σ)	24 AB	26 AB	27.5 AB	29.1 AB [d]	28 AB [e]
Survey Area	15,000 deg^2	3,400 deg^2	~ 3,400 deg^2	0.044 deg^2 [d]	100 deg^2 [e]
NIR Spectroscopy	1.1 – 2.0 μm	——	Grism 1.3 – 2.0 μm	Grism 2.4 – 5.0 μm	Grism Option 1 – 5 μm
Primary Science	Dark Energy, Dark Matter	Dark Energy, Exoplanets, Deep NIR Surveys	Dark Energy, Exoplanets, Deep NIR Surveys	First Galaxies	First Galaxies, Reionization, Galactic Science

[a] [27]; [b] Green et al. [35]; [c] Dressler et al. [22]; [d] JWST NIRCam Mosaic of the Chandra Deep Field South [44]; [e] WISH Ultra-Deep Survey; the WISH Extreme Survey reaches 29.5 AB mag within 0.24 deg^2.

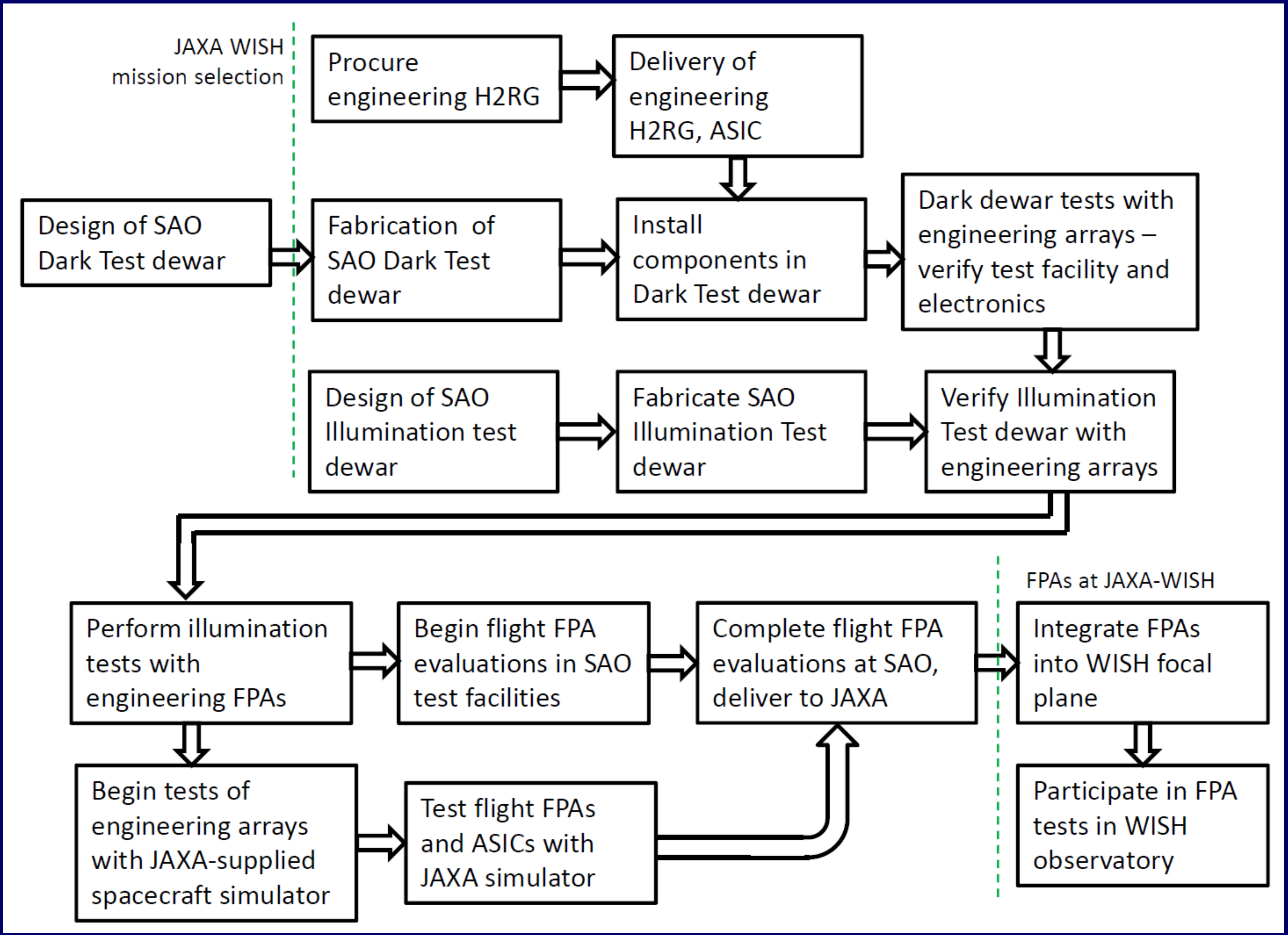
Project Schedule Summary



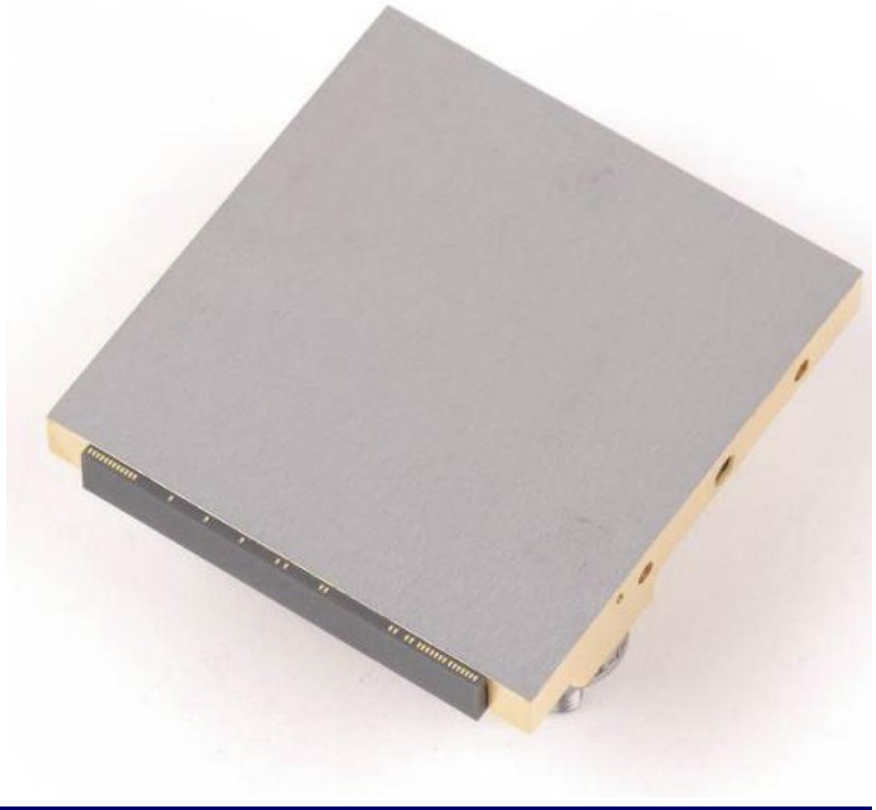
Schedule Detail

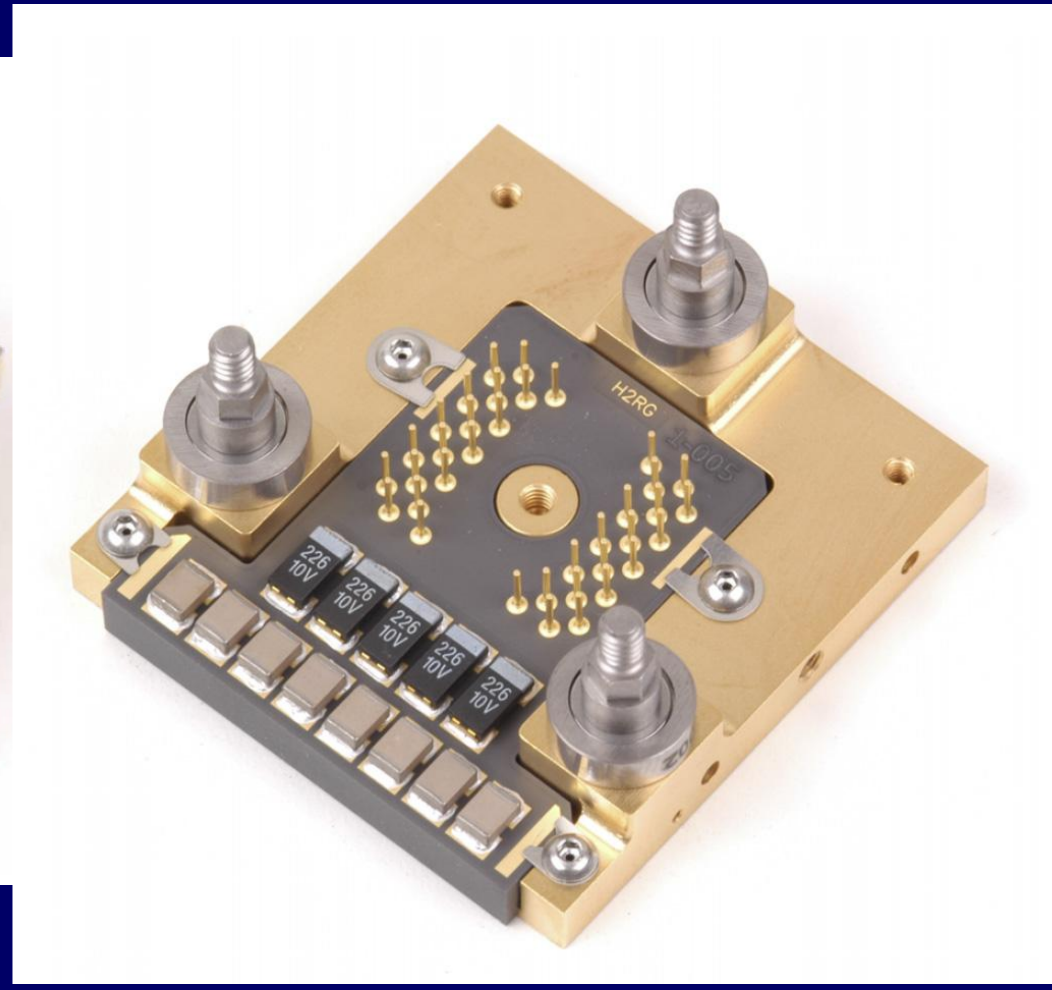


FPA Test Flow



H2RG Flight Packaging





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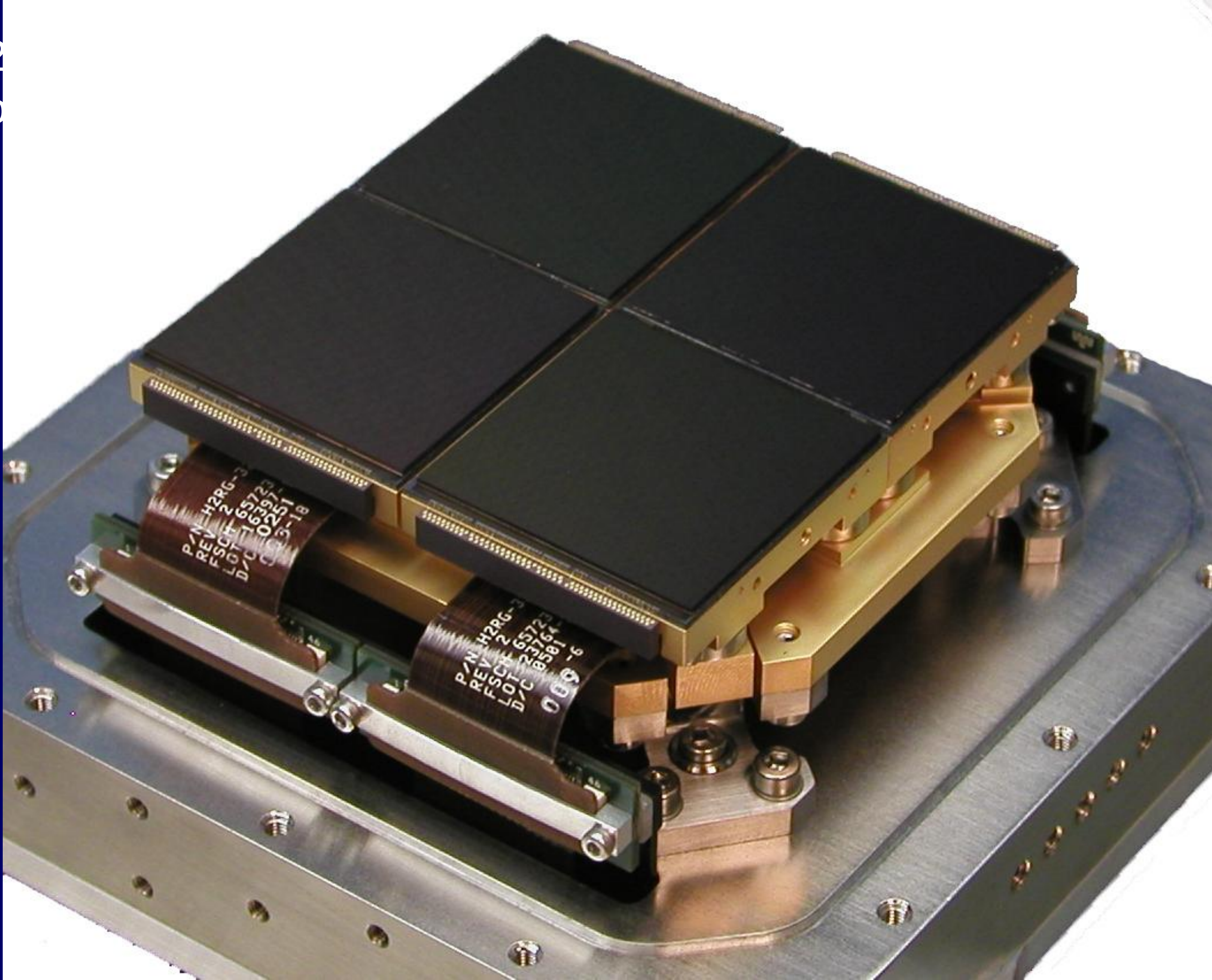

FPA Requirements and Margin

FPA Parameter	Requirement	Expected	% Margin
Median read noise	≤15 e-/sec	≤12 e-/sec	25
Median pixel-pixel crosstalk	≤4 %	≤2%	100
Median quantum efficiency	≥70%	≥80%	14
Median dark current	≤0.05 e-/sec	≤0.01 e-/sec	400
Median well capacity	≥65000	≥85000 e-	30
Inoperable pixels	≤5%	≤1%	400

Time Requirements for Surveys

	Depth (5σ) (AB Mag.)	Area (deg^2)	Center Wavelengths (μm)	Survey Time[a] (years)
Ultra-Deep Survey (UDS)	28	100	1.0, 1.4, 1.8, 2.3, 3.0	3.48
Ultra-Deep Survey, 4μm (UDS-II)	28	10[b]	UDS + 4.0	0.24
Ultra-Wide Survey (UWS)	25	1,000	1.0, 1.4, 1.8, 2.3, 3.0, 4.0	0.24
Extreme Survey (ES)	29.5	0.24	1.0, 1.4, 1.8, 2.3, 3.0	0.13

Assumes 85% observing efficiency toward the ecliptic pole, detector QE =70%, dark current =0.05 e^-/s, read noise = 15 e^- (for N=1, CDS), throughput of 74%, and Fowler 4 sampling

FPA testing at SAO

- All FPAs will be screened at Teledyne
  - Must meet procurement specs in order to deliver
- Each FPA will be tested at SAO to confirm performance, tune parameters to optimize for individual ASIC operation
- Subset of FPAs will be tested for
  - more extensive exploration of detector characteristics: point source response, bright source effects, etc.
  - development and verification of flight ASIC code
  - interface to WISH electronics

Low Background Tests

- “Dark Dewar” with arrays in 2x2 configuration
- For testing low background operation
  - Read noise
  - Dark current
- Simple flood illumination of detectors to measure
  - Operability
  - Radiometric stability
  - Quantum efficiency
  - Uniformity
  - Linearity
  - Well depth
  - Residual images

Spot Illumination Tests

- Second test facility will provide focused point sources on the arrays, wheel for filters in 1-5 μm range
- Detector parameters to be measured:
  - Quantum efficiency
  - Linearity
  - Well depth
  - Residual images
  - Radiometric stability
  - ASIC readout modes and functionality (e.g. windowing and guide modes)
  - Crosstalk – inter-pixel and between SCAs in the 2×2 configuration

FPA Characterization

- Operate FPAs in flight-like modes – pointing, guiding, science frame readout
- Use flight ASIC code, WISH electronics simulator
  - Effects of guiding windows on science data
  - Crosstalk between arrays
- Perform optimization of biases, operating modes