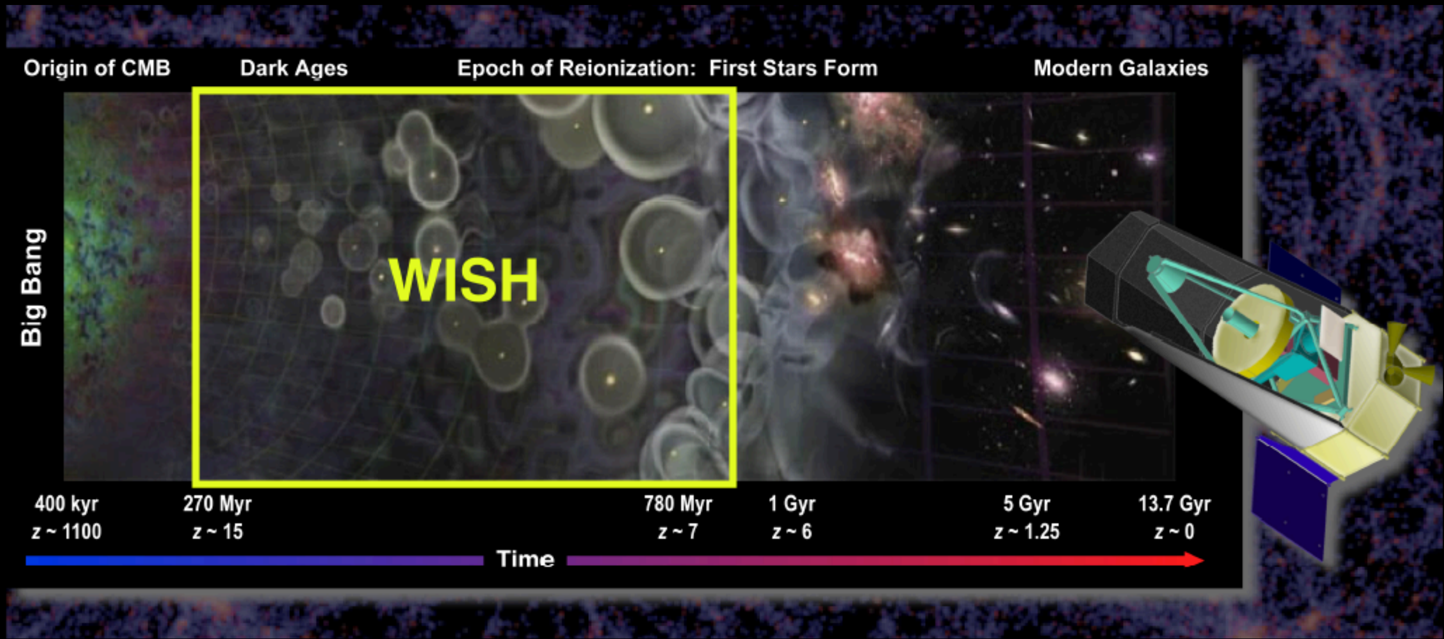
Smithsonian Astrophysical Observatory's (SAO) Contribution to WISH



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Science Team Members

SAO

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- Daniel Eisenstein
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SAO Contribution to WISH

- Active participation in the WISH scientific programs of wide-area cosmological and galactic surveys.
- Provide fully characterized infrared array detectors (32) with readout electronics for WISH.
- Operate the U.S. WISH Data Center at SAO.
- Contributions based on extensive experience and leadership of the Spitzer Space Telescope/Infrared Array Camera (IRAC).

Current Status

- Proposal submitted to NASA Second Stand Alone Mission of Opportunity AO in December 2012.
- NASA announced in September 2013 that reviews were completed but all proposals were declined due to lack of expected funding.
- Received comments from reviewers in November 2013.
- Next opportunity to propose: Fall 2014.
- Selection for competitive Phase A study: Summer 2015.

Future Opportunity for NASA Proposal

- Release of draft AO: Spring 2014
- Explorer Workshop: + 2 weeks
- Release of final AO: Late Summer/Fall 2014
- Proposal conference: + 3 weeks
- Proposal due: +90 days after AO release
  - $65 million cost cap
- Selection for competitive Phase A: Summer 2015
  - One to three missions selected ($250 K; 1 year)
- Down selection to start Phase B: Early 2017
- Launch: 2020 (?)

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.

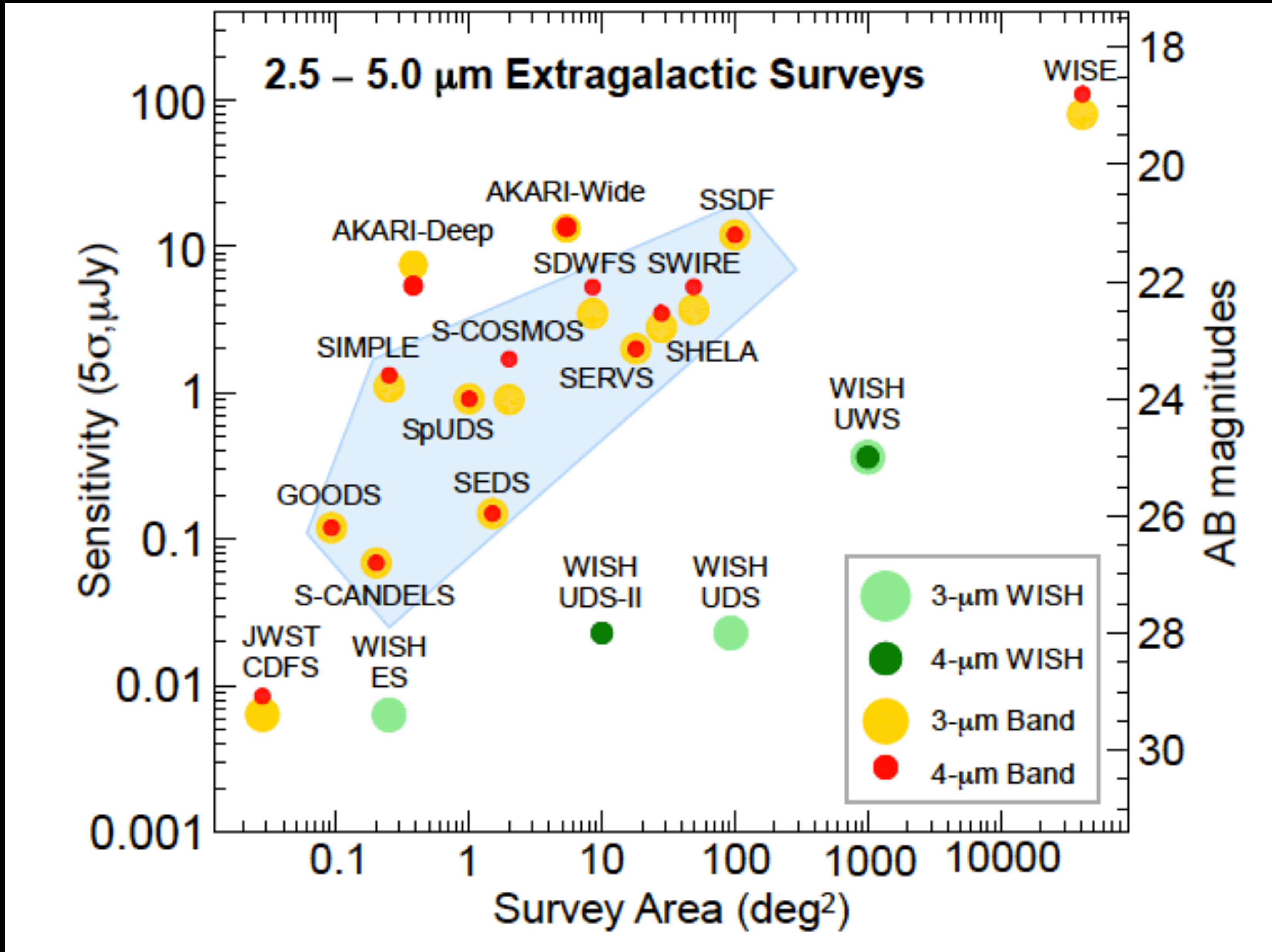
WISH Scientific Program

- The Ultra-Deep Survey (UDS)
  - The first galaxies (luminosity functions, stellar masses and ages, star formation rates as a function of z)
  - Origin of the era of reionization
  - Nature of Dark Energy (observation of Type 1a SNe in H-band at cosmological distances)
- The Ultra-Wide Survey (UWS)
  - Observations of quasars at $z>7$
  - Evolution of galaxies at $0 < z < 4$
- The Extreme Survey (ES)
  - Observations of galaxies at $z>10$
  - Origin of era of reionization
- Galactic Plane Survey
  - Stellar and planetary formation
  - Protostellar environments
  - Stellar evolution

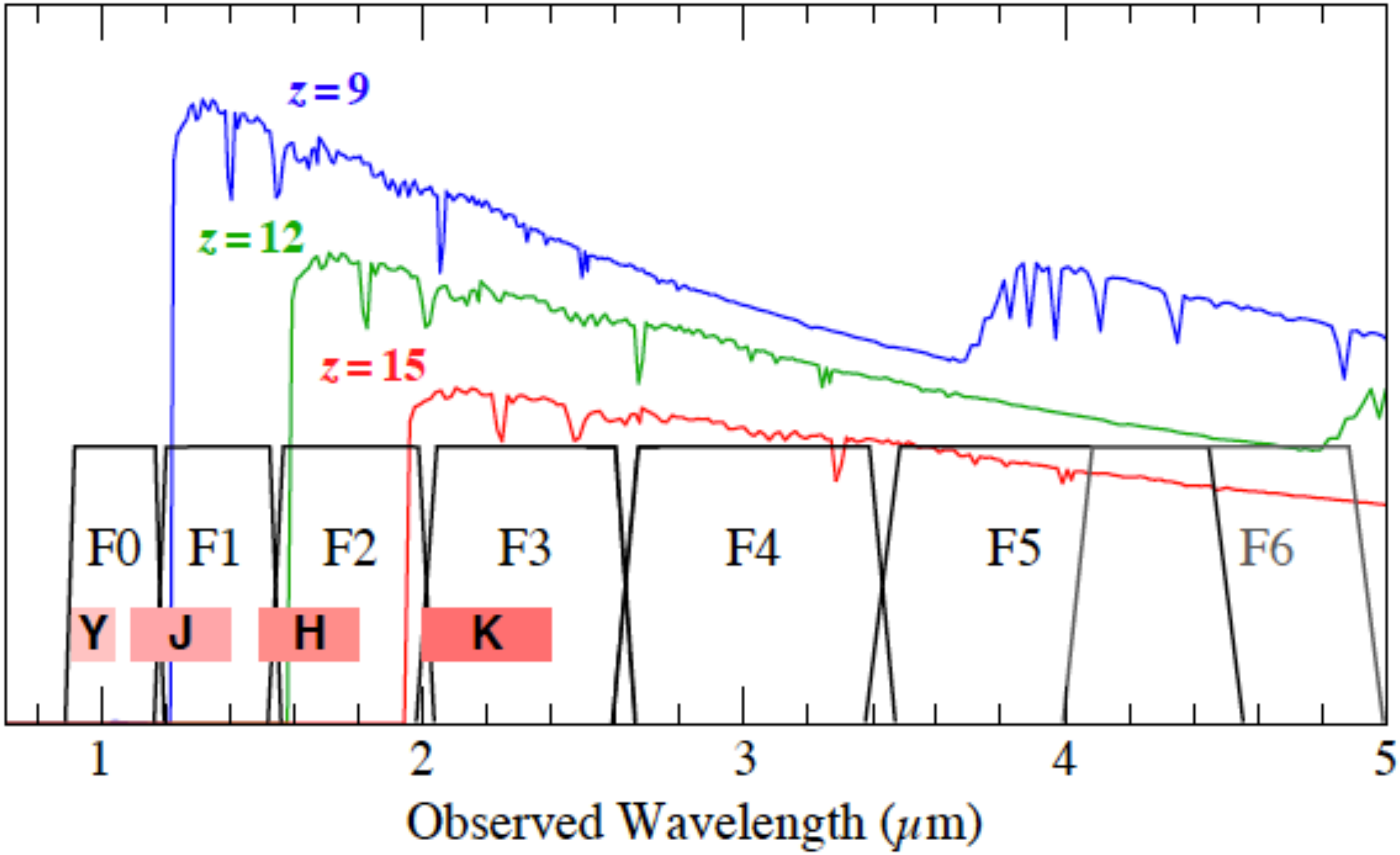
Table D2. Prime WISH Surveys

	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.


2.5 – 5.0 μm Extragalactic Surveys
WISE
AKARI-Wide
SSDF
AKARI-Deep
SDWFS
SWIRE
S-COSMOS
SIMPLE
SHELA
SERVS
SpUDS
WISH
UWS
GOODS
SEDS
S-CANDELS
WISH
UDS-II
WISH
UDS
JWST
CDFS
WISH
ES
3-μm WISH
4-μm WISH
3-μm Band
4-μm Band
Sensitivity (5σ,μJy)
100
10
1
0.1
0.01
0.001
0.1
1
10
100
1000
10000
Survey Area (deg²)
18
20
22
24
26
28
30
AB magnitudes

Passbands for the WISH Filters



Expected Number of Galaxies Detected by the WISH Ultra-Deep Survery

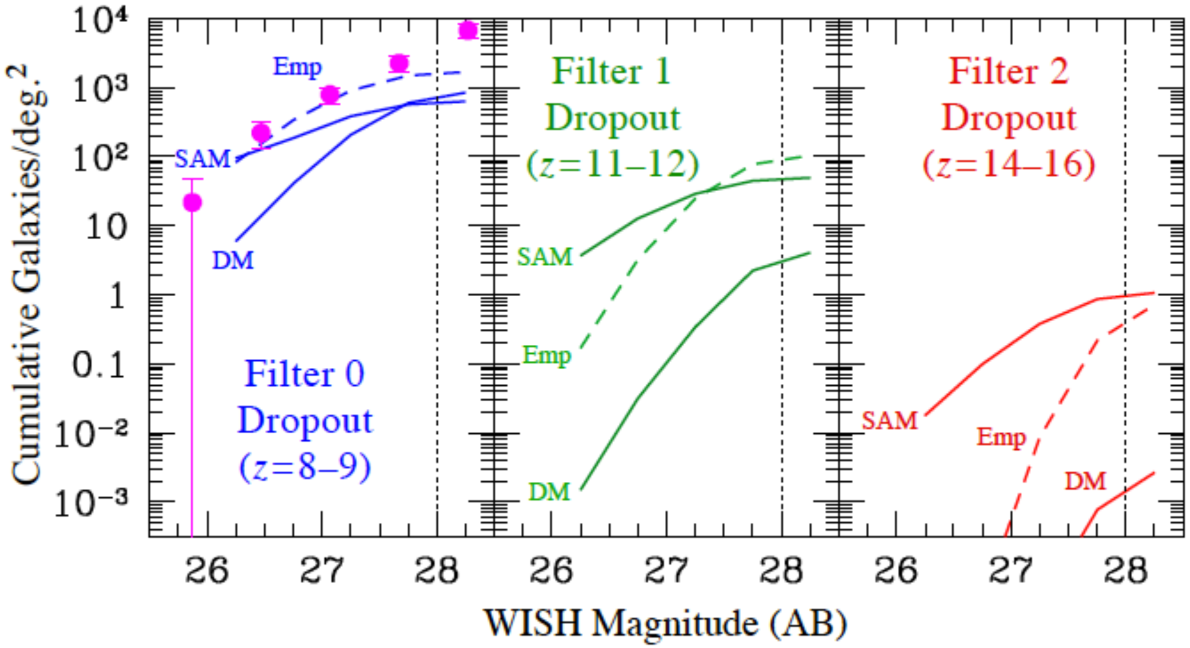
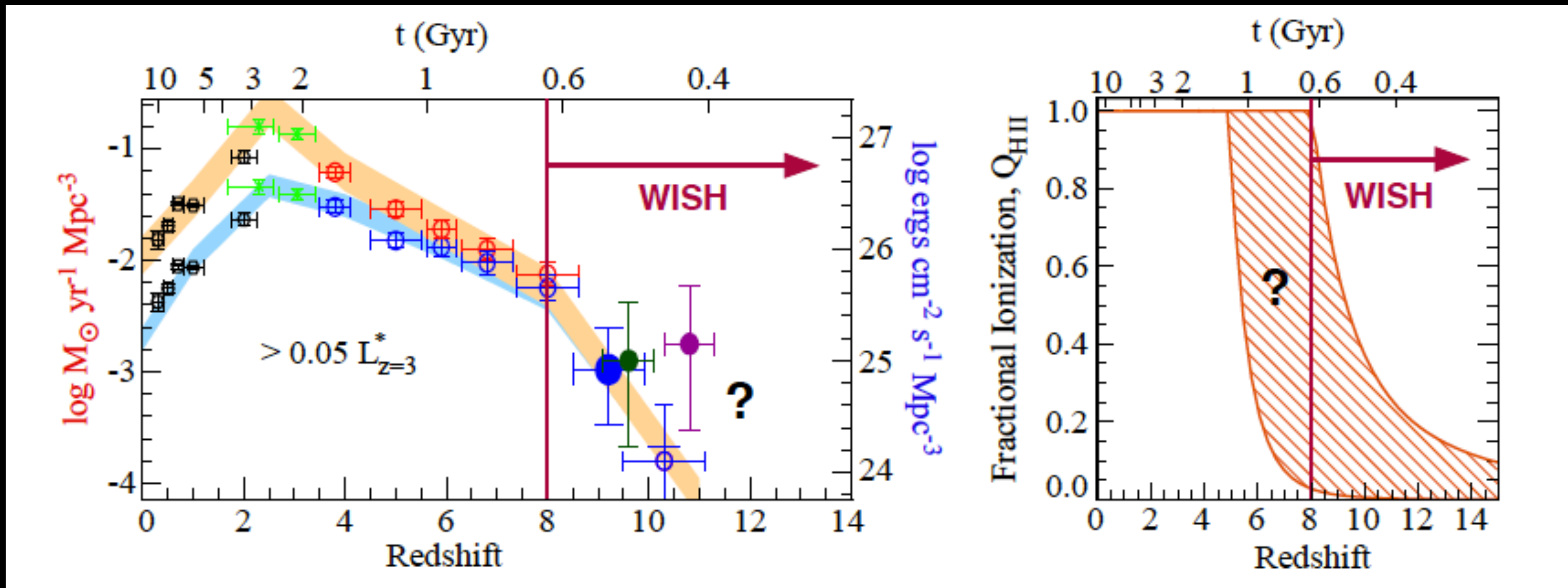


Table D4. Expected Number of UDS Detections at $8 < z < 16$ from Fig. D-5.

	Redshift	Empirical LF	DM Evolution	SAM
Filter 0-Dropout	8–9	170,000	85,000	63,000
Filter 1-Dropout	11–12	10,000	410	5000
Filter 2-Dropout	14–16	72	0.3	110



t (Gyr)
10 5 3 2 1 0.6 0.4
log M⊙ yr⁻¹ Mpc⁻³
-1
-2
-3
-4
> 0.05 L*z=3
WISH
?
27
26
25
24
log ergs cm⁻² s⁻¹ Mpc⁻³
0 2 4 6 8 10 12 14
Redshift
t (Gyr)
10 3 2 1 0.6 0.4
Fractional Ionization, Q_HII
1.0
0.8
0.6
0.4
0.2
0.0
WISH
?
0 2 4 6 8 10 12 14
Redshift

WISH Focal Plane Layout

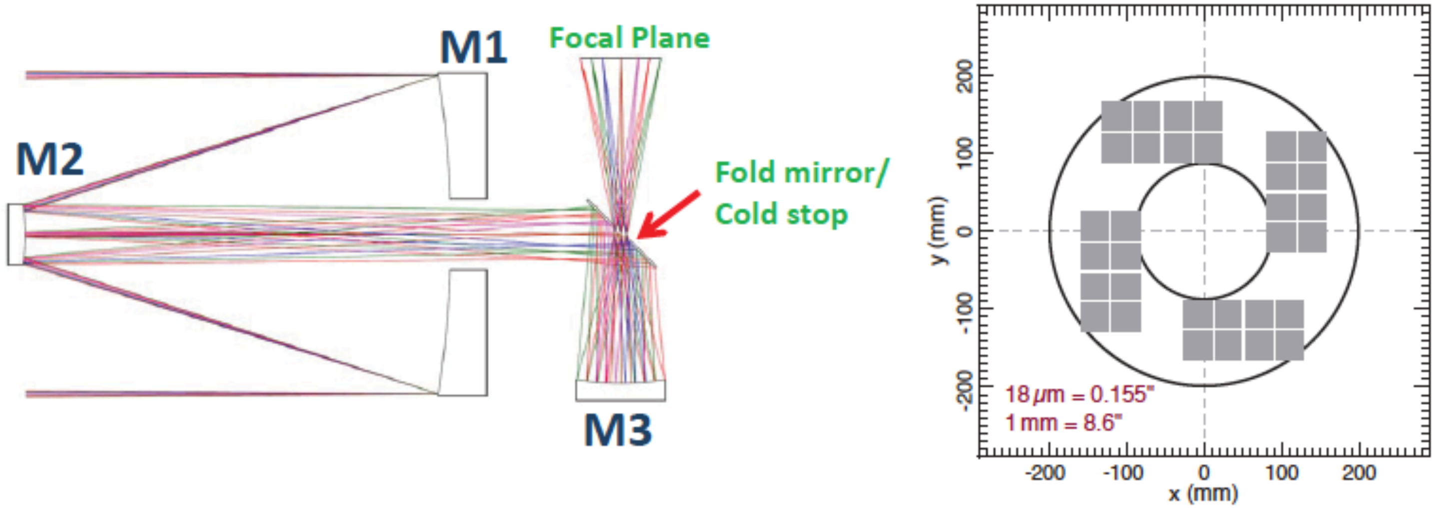
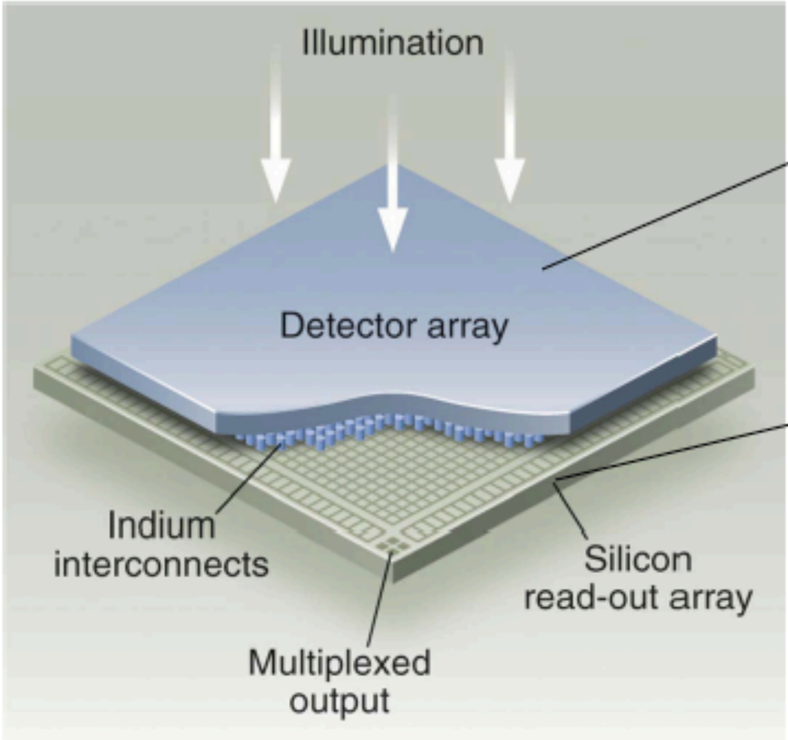


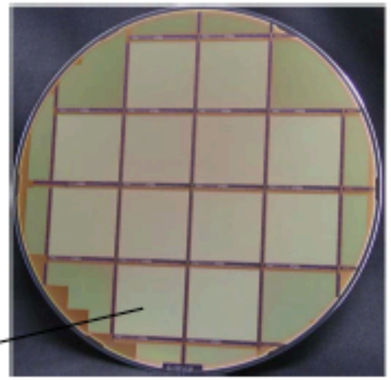
Fig. E-2. *Left:* WISH optical layout. The M1 and M3 mirrors are ellipsoids; M2 is a hyperboloid. *Right:* Layout of FPAs in the WISH focal plane. The annular region shown has an inner radius of 0.2° and an outer radius of 0.45°. Four 2×4 mosaics of H2RG FPAs are arranged around the focal plane for a total of 32 devices covering a combined area of 0.237 deg^2.

WISH Detectors

- Teledyne Imaging Sensors 2048x2048 pixel H2RG Focal Plane Arrays (FPAs) with 5.3 μm cutoff wavelength.
- SIDECAR ASIC focal plane electronics (one ASIC per array 4-output mode).
- Used also in JWST (NIRCam, NIRSpec, & FGS)
- H2RG FPAs: NASA TRL-9, operated in space.
- Off-the-shelf purchase, fixed-price contract

Hybrid CMOS Infrared Imaging Sensors





Three Key Technologies

- Growth and processing of the HgCdTe detector layer
- Design and fabrication of the CMOS readout integrated circuit (ROIC)
- Hybridization of the detector layer to the CMOS ROIC

TELEDYNE IMAGING SENSORS
A Teledyne Technologies Company

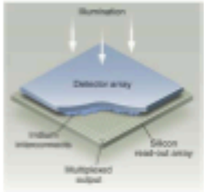
HxRG Family of Hybrid Imaging Sensors

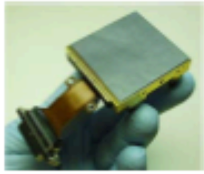
<u>H</u>: **HAWAII:** <u>H</u>gCdTe <u>A</u>stronomical <u>W</u>ide <u>A</u>rea <u>I</u>nfrared <u>I</u>mager

<u>x</u>: Number of 1024 (or 1K) pixel blocks in x and y-dimensions

<u>R</u>: <u>R</u>eference pixels

<u>G</u>: <u>G</u>uide window capability





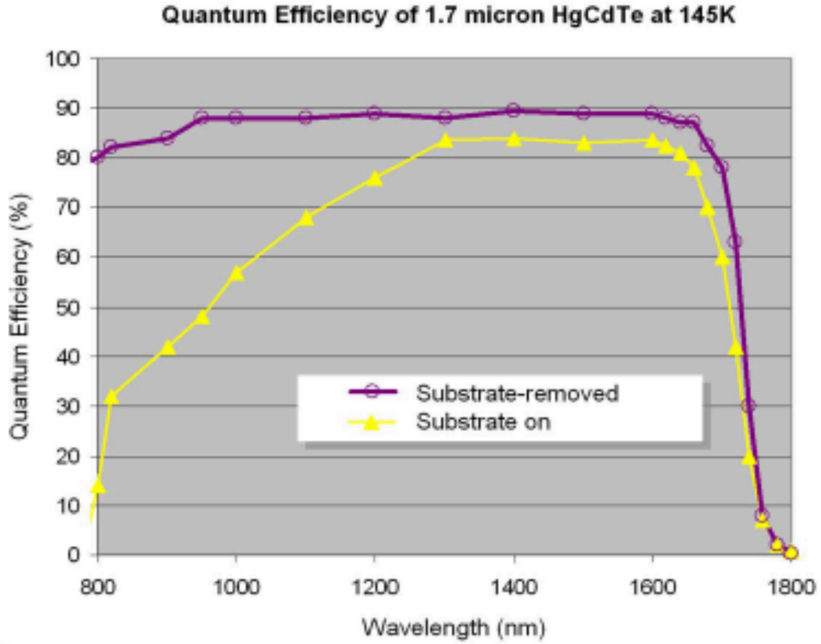
- ➔ Substrate-removed HgCdTe for simultaneous visible & infrared observation
- ➔ Hybrid Visible Silicon Imager; Si-PIN (HyViSI)

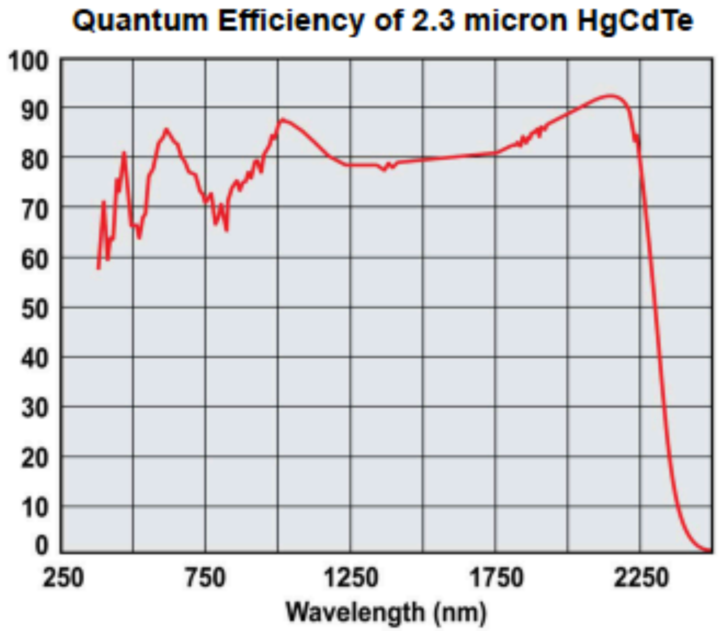
Name	Format (# of Pixel)	Pixel Pitch (micron)	# of Outputs	NASA TRL	Institutions, Observatories, and Programs using HxRG Arrays
H1RG	1024 x 1024	18	1, 2, 16	9	Wide Field Survey Explorer (WISE) Orbiting Carbon Observatory (OCO), Development Programs in Astronomy and Earth Science
H2RG	2048 x 2048	18	1, 4, 32	9	Calar Alto, Caltech, CFHT, ESO, ESA (EUCLID), ESTEC, IRTF, ISRO, IUCAA, JHU-APL, Keck, Kyoto Sangyo Univ., LBNL, LMU, MIT, MPIA, MPS, NASA (James Webb Space Telescope (JWST), Joint Dark Energy Mission (JDEM(), OCIW, PSU, RIT, SALT, SAO, Subaru, TAT, U. Arizona, UCLA, UC Berkeley, U. Hawaii, U. Rochester, U. Tokyo, U. Toronto, U. Wisconsin, Space Surveillance Applications, and Development Programs in Astronomy and Earth Science
H4RG-10	4096 x 4096	10	1, 4, 16, 32, 64	6	Joint Miliarcsecond Pathfinder Survey (JMAPS), Development Programs in Astronomy
H4RG-15	4096 x 4096	15	1, 4, 16, 32, 64	4	Design & Prototype Phase Complete, In Pilot Production, First Array in Sky in May 2012

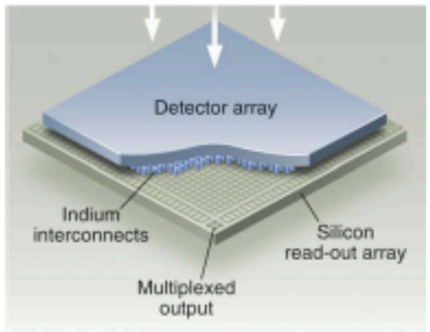
H2RG, H4RG-10, and H4RG-15: Feature Comparison

Features	H2RG	H4RG-10	H4RG-15
Format	2048 X 2048	4096 X 4096	4096 X 4096
Pixel size	18µm	10µm	15um
Guide window	Yes	Yes	Yes
Single/line/global reset	Yes	Yes	Yes
Number of output	1,4,16,32	1,4,16,32,64	1,4,16,32,64
Slow Mode (100KHz), buffered/unbuffered	Yes	Yes	Yes
Fast Mode (5MHz), buffered/unbuffered	Yes	Yes	Yes
Enhaced clocking mode	Yes	Yes	Yes
Temperature sensors	Yes	Yes	Yes
Single reference pixel read out	Yes	Yes	Yes
Row of reference pixel read out	No	Yes	Yes
Interleaved reference pixel read out	No	Yes	Yes
Sub sampling	No	Yes	Yes
NMOS source follower buffered slow mode	No	Yes	Yes
Column de-select	No	No	Yes
Control register content read back	No	No	Yes

Quantum Efficiency of substrate-removed HgCdTe

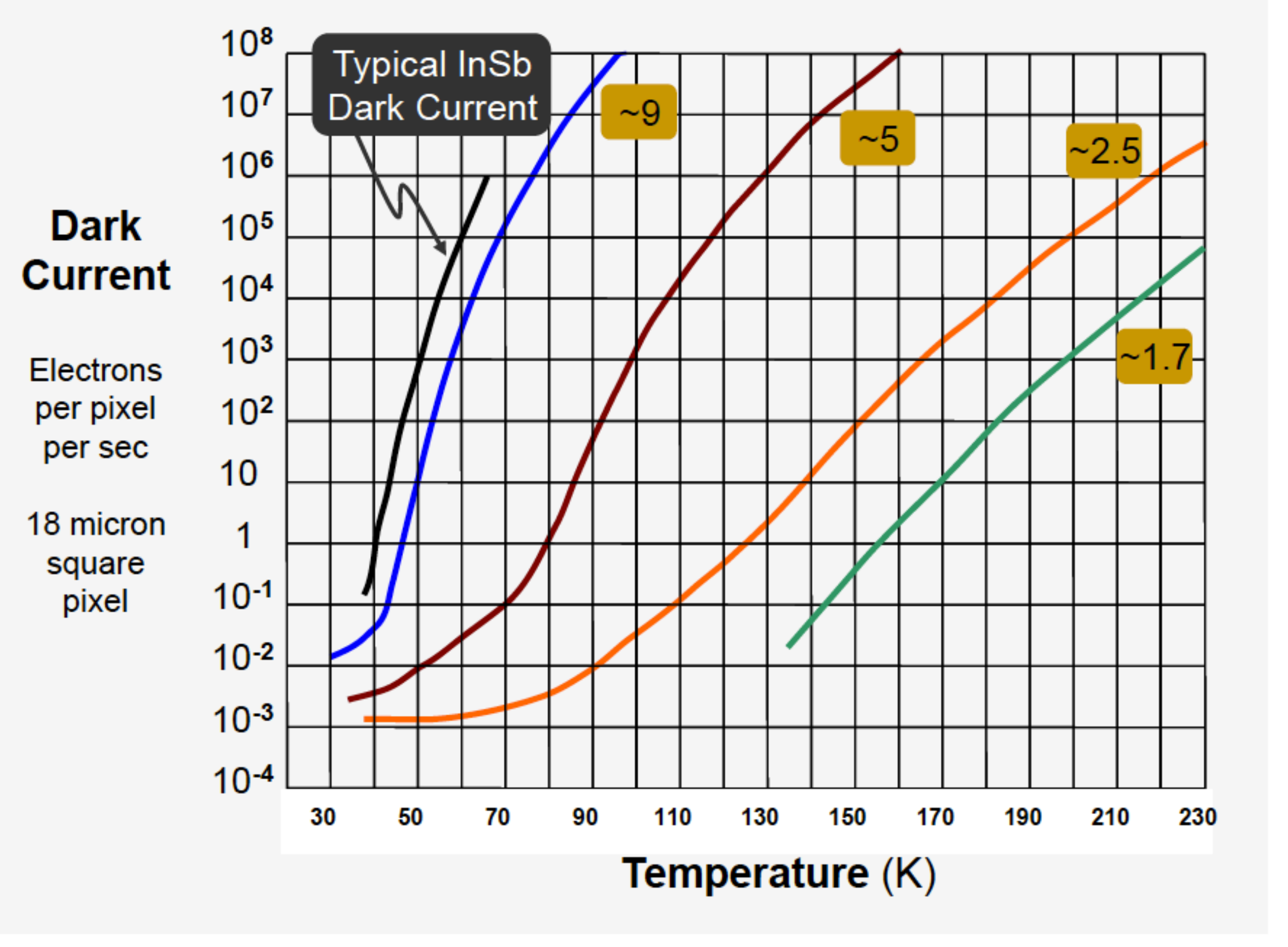






- Overall improved QE
- Response to visible and UV
- Less susceptible to cosmic rays
- Eliminates fringing in substrate material

HgCdTe Dectector Dark Current



HgCdTe cutoff wavelength (microns)

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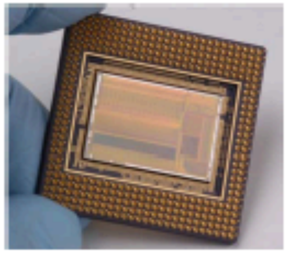
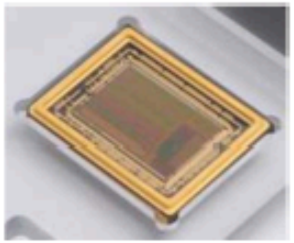
SIDECAR ASIC – Focal Plane Electronics on a Chip

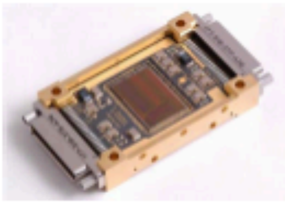


SIDECAR ASIC
Ground-based package

Hubble Space Telescope
SIDECAR ASIC package
(Hermetically Sealed)



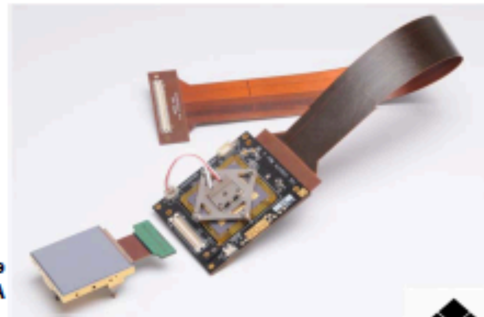
Cryogenic SIDECAR Package
(Hermetically Sealed)



JWST SIDECAR ASIC package

SIDECAR ASIC

- 36 analog input channels
- 36 16-bit ADCs: up to 500 kHz
- 36 12-bit ADCs: up to 10 MHz
- 20 output bias channels
- 32 digital I/O channels
- Microcontroller (low power)
- LVDS or CMOS interface
- Low power:
- <15 mW, 4 channels, 100 kHz, 16-bit ADC
- <150 mW, 32 channels, 100 kHz, 16-bit ADC
- Operating temperature: 30K to 300K
- Interfaces directly to H1RG, H2RG, H4RG
- **Qualified to NASA TRL-9**
- Vibration, radiation, thermal cycling
- Radiation hard to ~100 krad



SIDECAR ASIC cryogenic focal plane
electronics with H2RG FPA

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GL SCIENTIFIC

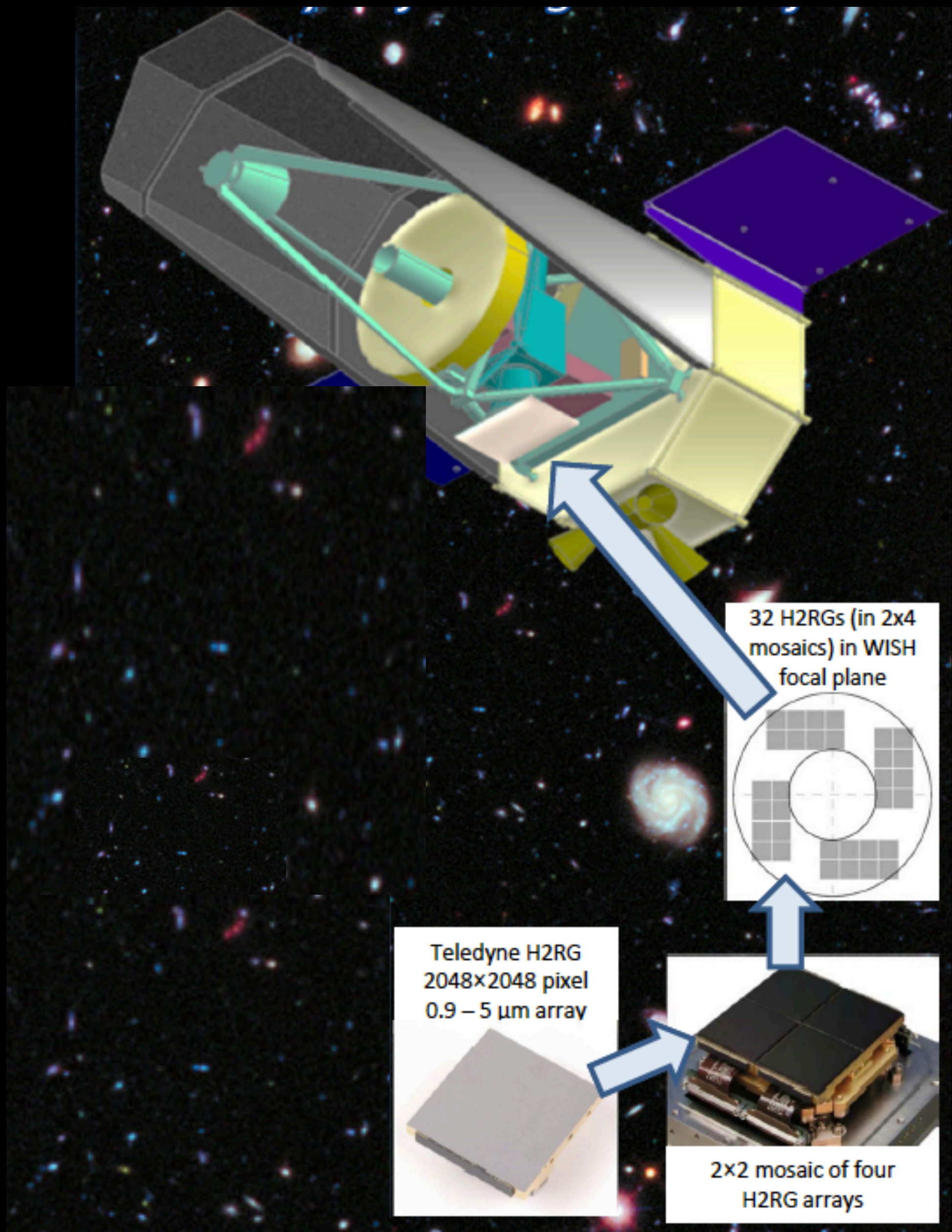
32 H2RGs (in 2x4 mosaics) in WISH focal plane
Teledyne H2RG 2048×2048 pixel 0.9 – 5 µm array
2×2 mosaic of four H2RG arrays

TABLE F1. WISH FPA Requirements and Margins

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

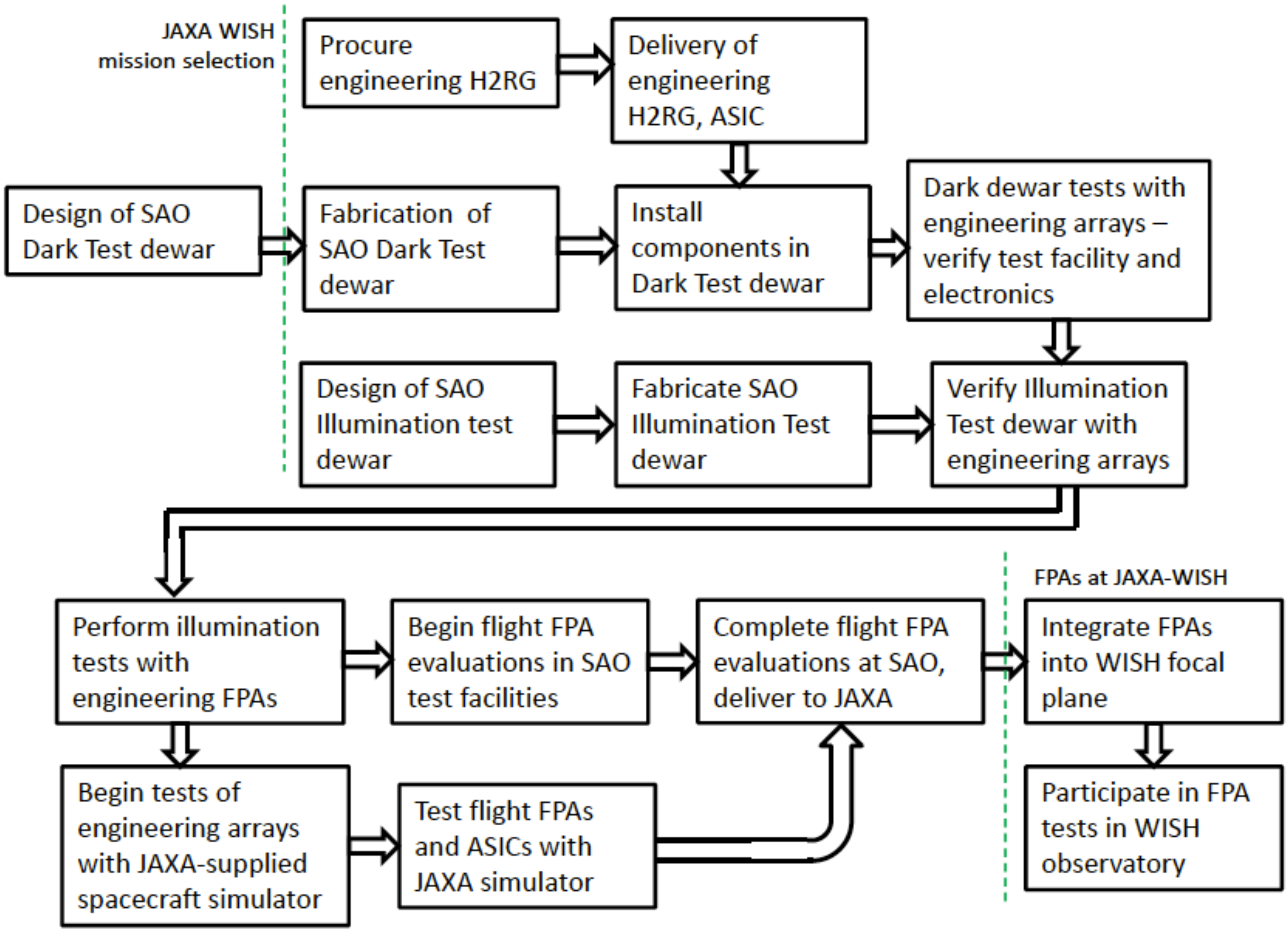

Fig. F-1. The SAO-WISH Test Flow.

NASA Astrophysics Explorer Mission of Opportunity Reviewer Comments

- No major weaknesses for primary instrument, science program, and technical aspects, including SAO's capabilities.
  - "WISH's primary science mission will provide an excellent complement to other NASA missions such as JWST, Euclid, and WFIRST."
  - "WISH will be an excellent target finder for future ELTs and ALMA."
  - "The likelihood of scientific success for the mission is high...."
  - "The scientific goals of WISH are compelling and clear."
  - "….addresses directly the Astro2010 Decadal Survey major science theme Cosmic Dawn….."

NASA Astrophysics Explorer Mission of Opportunity Reviewer Comments

- Need for a well-planned schedule.
- More accurate cost estimate and justification.
- More details of the system configuration and allocations, including margins.
- Definition of spectroscopic capability.
- Description of Threshold Mission.
  - Cost and schedule savings; reduced FPA; shorter mission.
  - Reduced science mission (comparison).

NASA Astrophysics Explorer Mission of Opportunity Reviewer Comments

- Better description of auxiliary science mission.
- Assignment of NASA DSN costs.
- Electrical power and cooling capacity for array detectors.
- Availability of data products to the community: 6 months or 1 year?
- Inadequate description of science operations from spacecraft to the USA WISH Data Center.