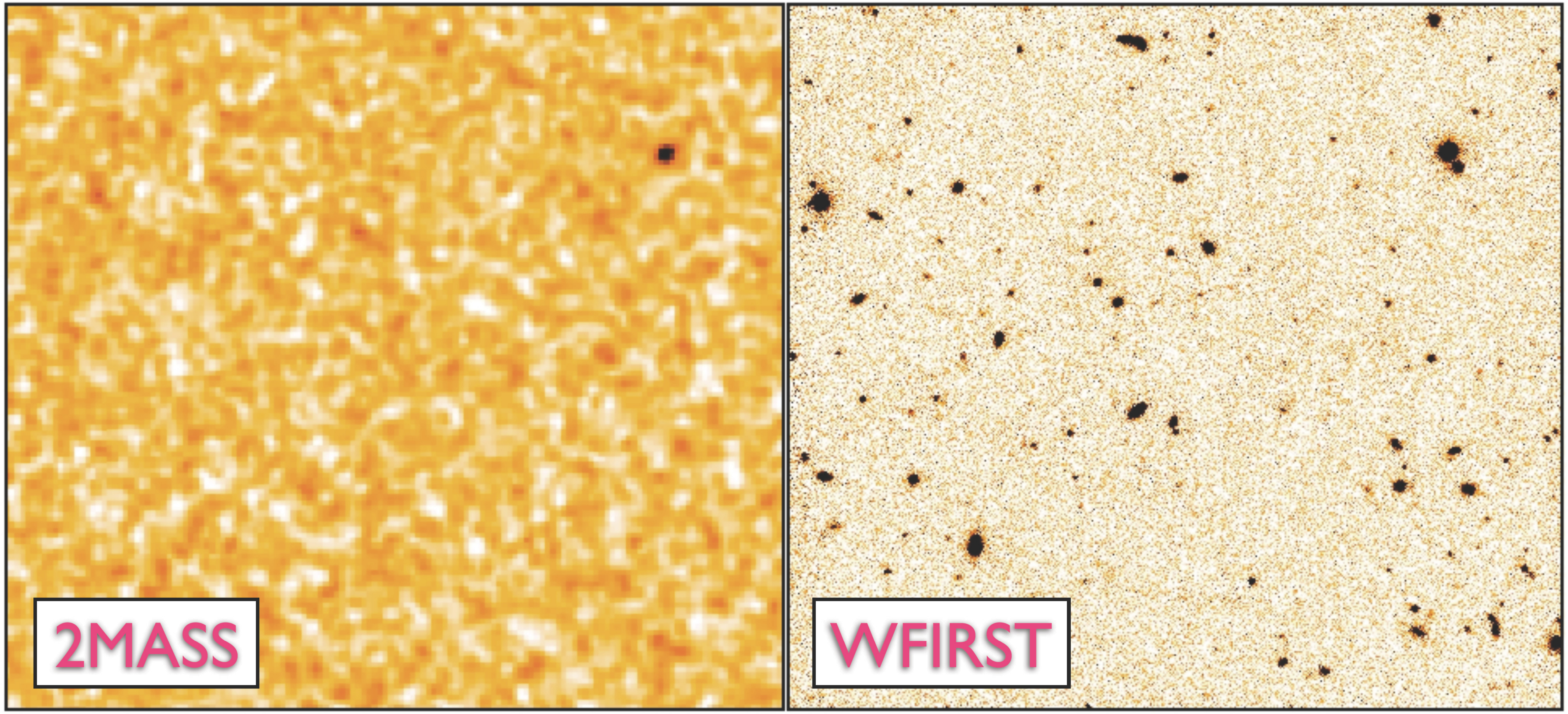
WFIRST:
Near-Infrared Survey Science

Daniel Stern (JPL/Caltech)

The Science of WFIRST
Caltech: 2011 May 27



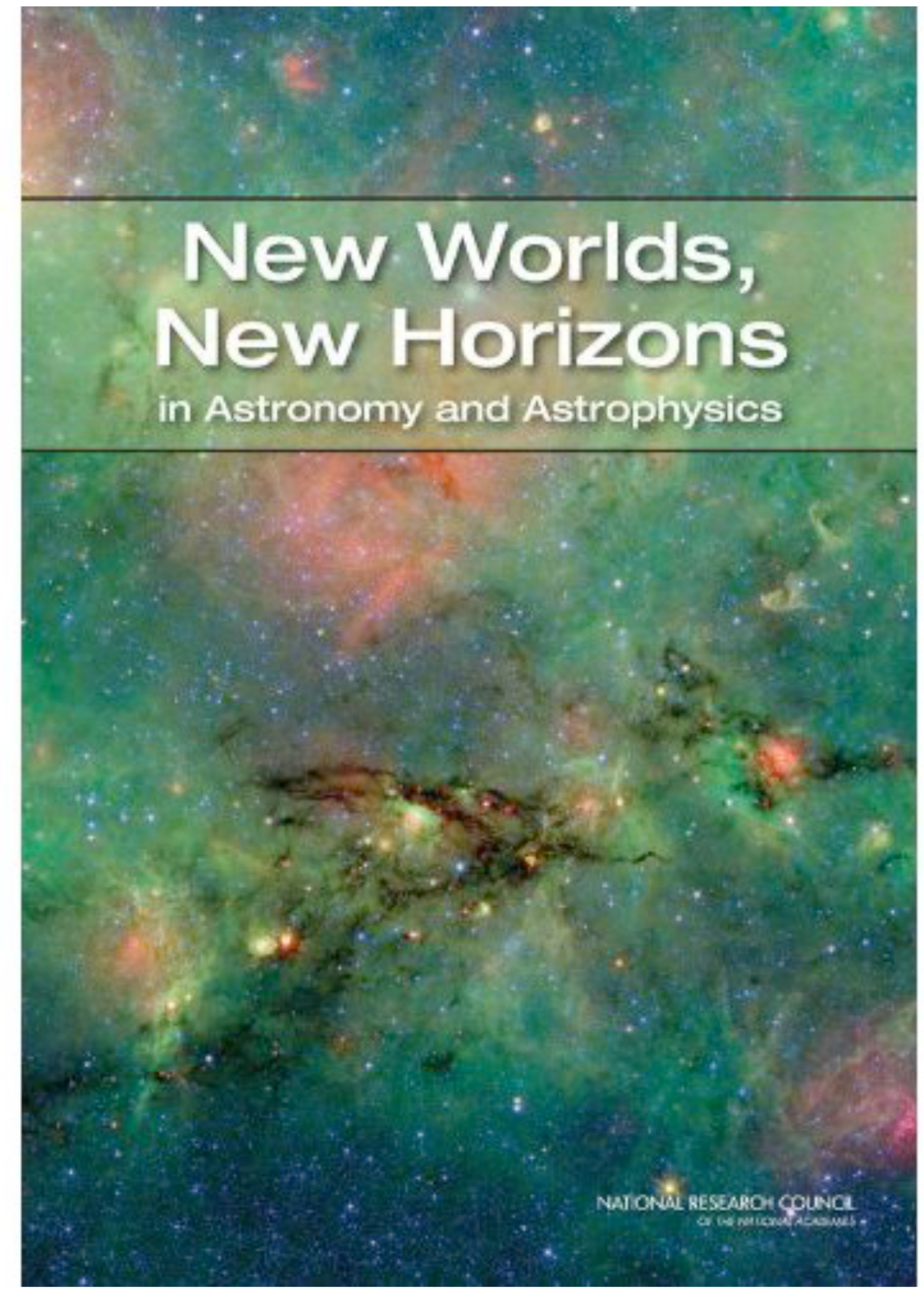
WFIRST will obtain deep, wide-field near-infrared images over large areas of Galactic and extragalactic sky

Images of GOODS-S field at 2.2 μm (K-band; 2.4 arcmin/side), obtained by 2MASS (left) and deep VLT/ISAAC observations (right). WFIRST would reach deeper than the VLT observations with better spatial resolution ... and across 1000's of deg^2!

Key Quotes from NWNH

pg. 206: "WFIRST will also offer a guest investigator program supporting both key projects and archival studies to address a broad range of astrophysical research topics."

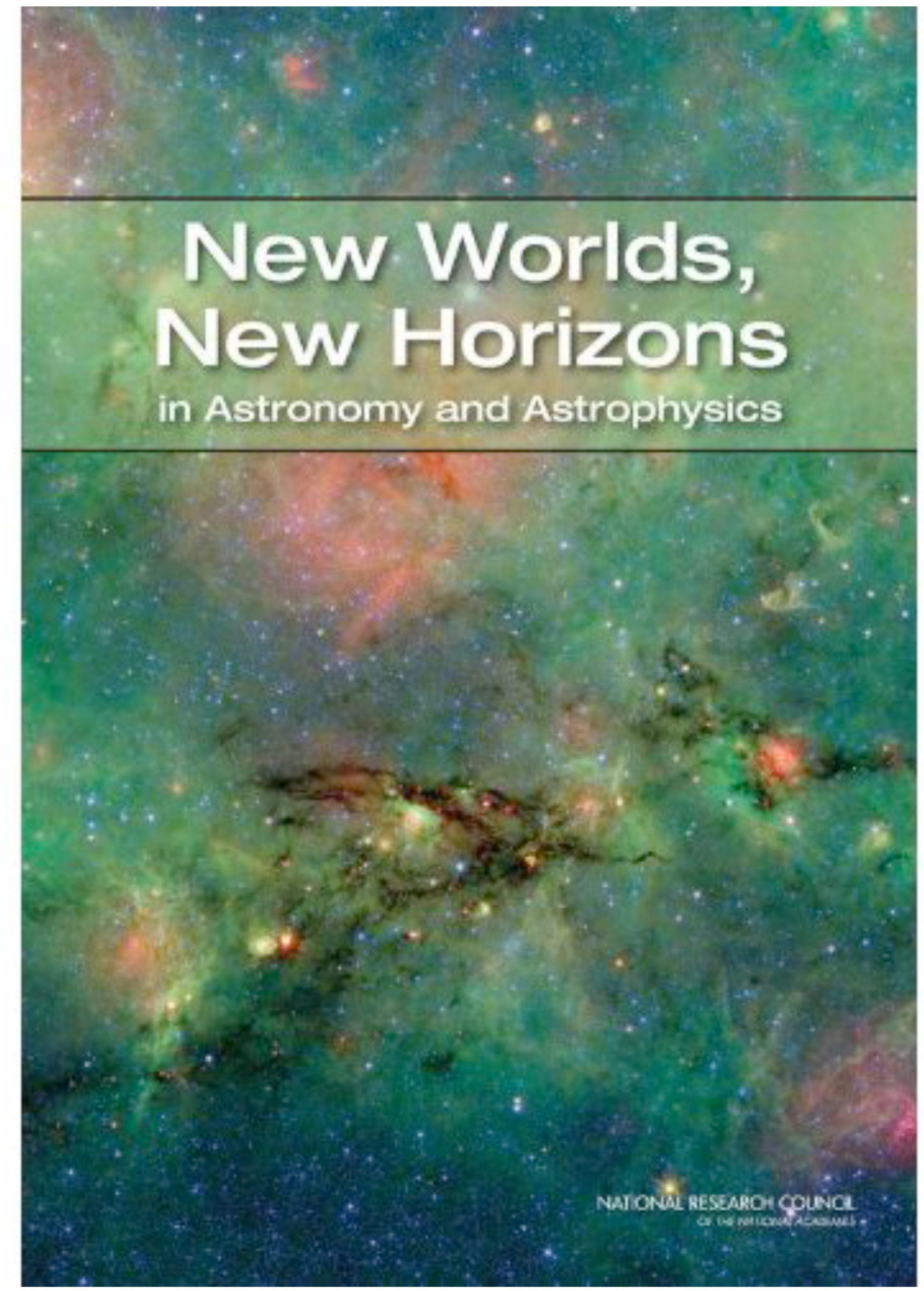
pg. 207: "The committee considers the general investigator program to be an essential element of the mission, but firmly believes it should not drive the mission hardware design or implementation cost."



Key Quotes from EOS Panel Report

pg. 6-12: "A significant fraction of the first 5 years will also be used for surveys and smaller peer-reviewed guest-observer projects that will investigate, for example, galaxy evolution, stellar populations of nearby galaxies, and the plane of the Milky Way galaxy. ... As the mission unfolds ... "Guest Observer" programs will assume more importance."

pg. 6-17: "As a strawman example of how the first 5 years ... might be allocated, the panel imagines ... a Galactic plane survey of one-half year, together with about 1 year allocated by open competition."



WFIRST Near-IR Survey Science

- **Ancillary science from WFIRST core surveys**
  - WFIRST SDT task group (consisting of C. Conselice, P. Schechter, D. Stern and N. Wright) considering ancillary science from DE high latitude survey (HLS) and defining associated figures of merit (FOMs); goal is to optimize HLS for DE + survey science
  - significant ancillary science also expected from supernova survey and microlensing survey

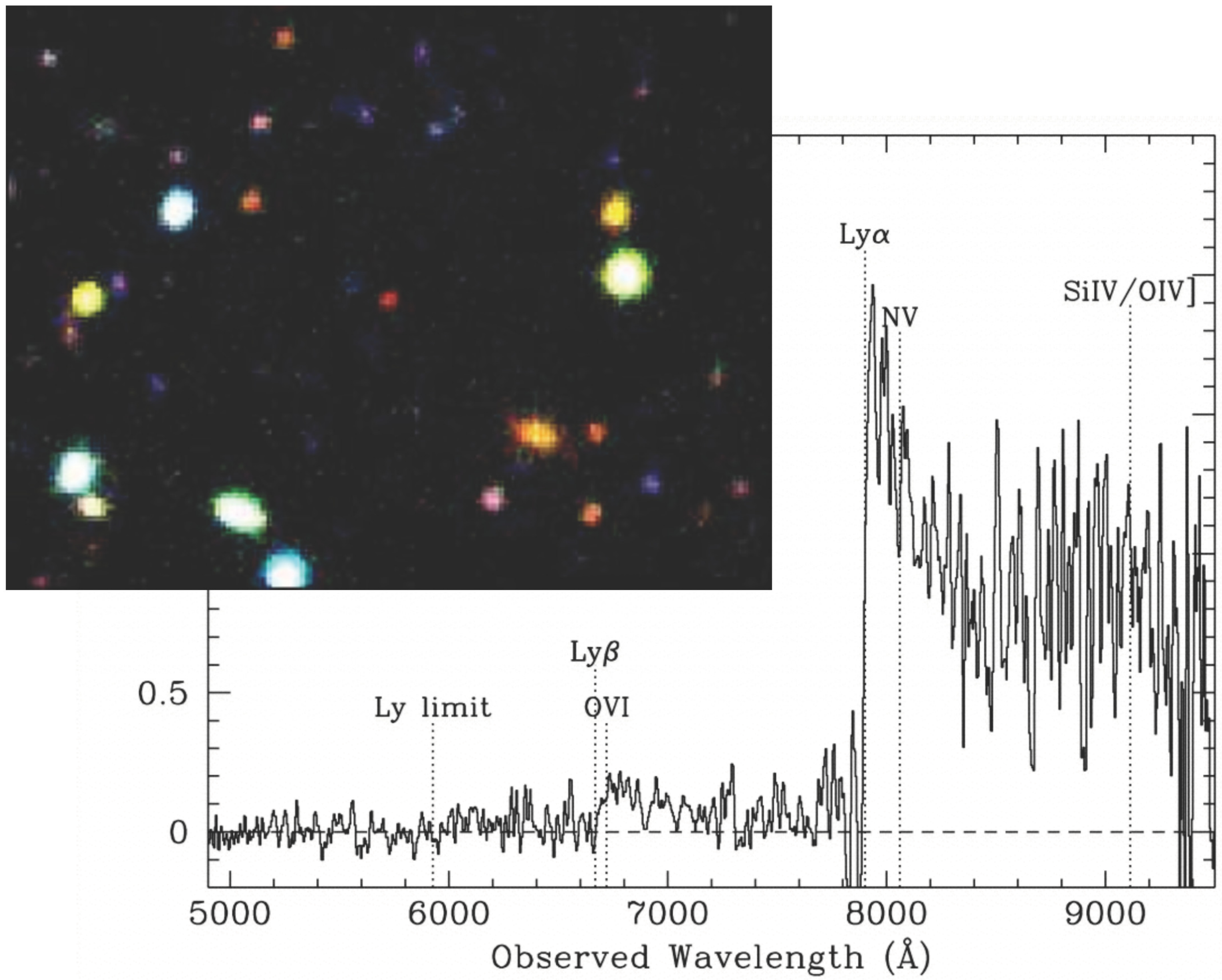
- **Galactic plane survey**
  - WFIRST SDT task group looking into this

- **Guest observer programs**
  - WFIRST SDT task group looking into this (combined with Galactic plane survey task group)

I. High Latitude Survey Science

WFIRST SDT Task Group:
C. Conselice (Nottingham)
P. Schechter (MIT)
D. Stern (JPL/Caltech)
E. Wright (UCLA)

1. High-Redshift Quasars



Redshift	UKIDSS	NIRSS
6<z<8	70-150	~100,000
8<z<10	1.3-2.6	~35,000
z>12	–	~7,000
z>20	–	~100

predicted number of high-redshift quasars from SDSS QLF (Fan et al. 2001, 2004)

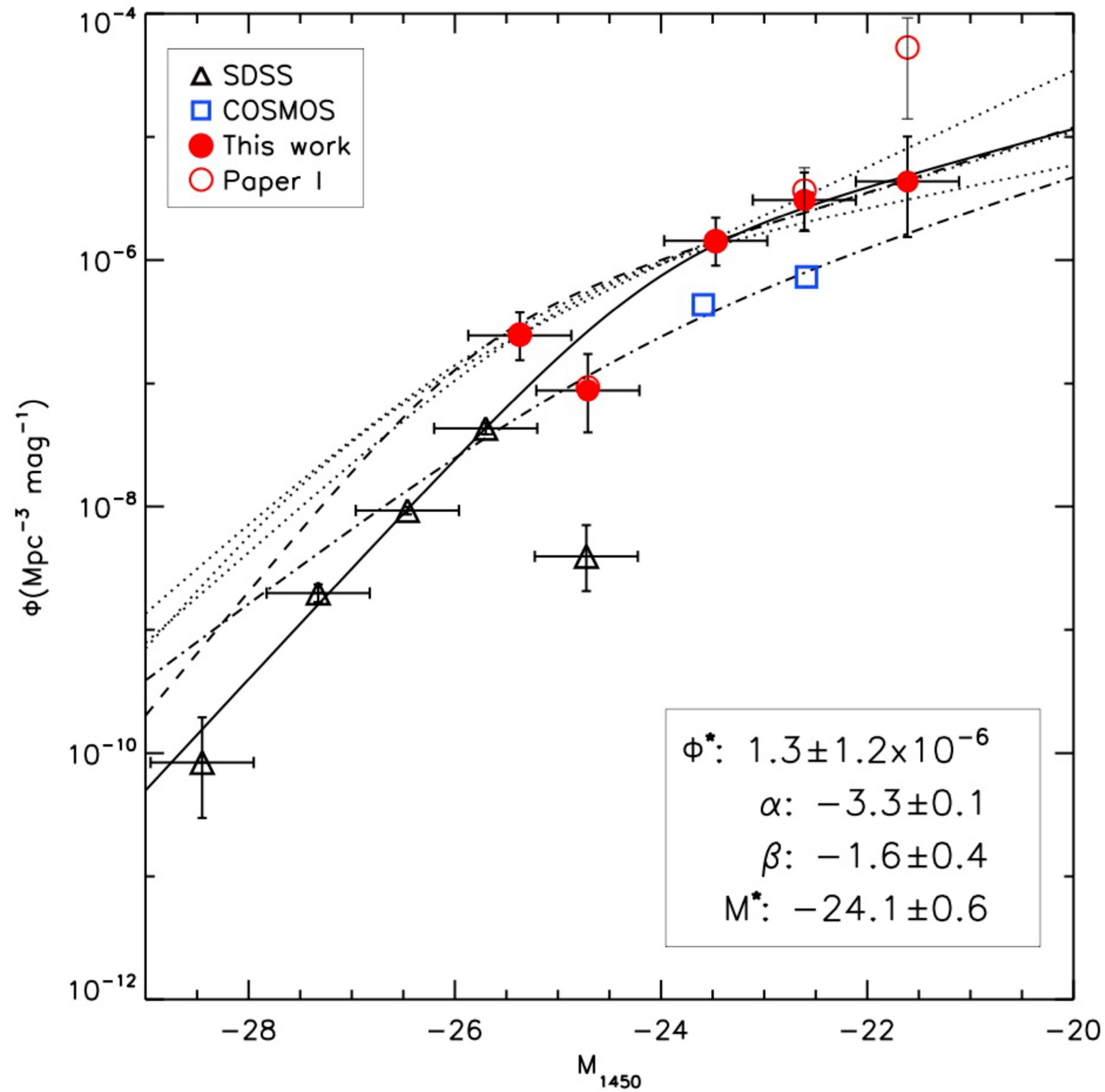
1. High-Redshift Quasars

- WFIRST HLS will identify quasars at z>6 in unprecedented numbers.

- Science afforded by high-redshift quasars (QSOs):
  - probe the epoch of reionization in several ways:
    - luminous background probes for studying intervening universe
    - Lyα profiles probe state of local gas (e.g., Strömgren sphere radii)
    - QSO luminosity function (QLF) gives contribution to ionizing budget
    - radio-loud QSOs provide additional 21 cm probe of reionization
  - early history of black hole growth
  - proxy for early galaxy growth / growth of large-scale structure (LSS)
  - large numbers of high-redshift QSO pairs
  - brightest (e.g., tip of the luminosity function + lensed) galaxies will likely be selected by the same color criteria. Such sources buy significant additional science, such as early IMF, metallicities, ages of first galaxies (c.f., substantial panchromatic literature on cB58, a strongly lensed z~3 LBG)

1. High-Redshift Quasars

- Current uncertainty on faint end of the quasar luminosity function (QLF) at z~4.



Glikman, Djorgovski, Stern et al. 2011, ApJ, 728, 26

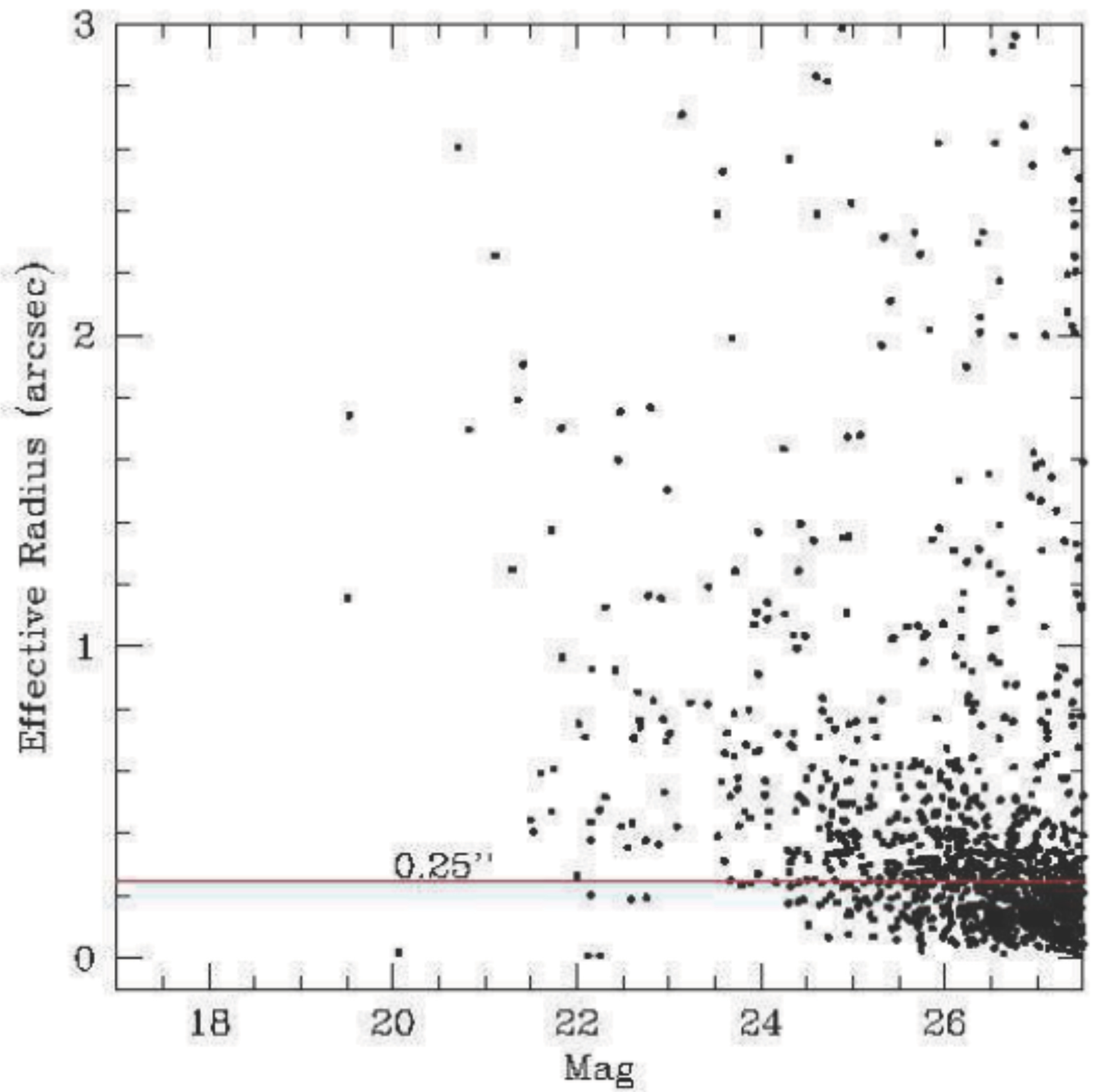
1. High-Redshift Quasars

- We've defined two QSO FoM's, based on two distinct scientific questions:
  - The small number of brightest, highest redshift ($z>10$) QSOs, which are the best background probes of the intervening universe.
  - The large number of $z>6$ QSOs, pushing down the QLF: faint-end of the QLF, AGN contribution to ionizing budget, QSO pairs, LSS, clustering to get halo masses, etc...

2. Normal Galaxies

• HLS will detect vast numbers of normal galaxies
• near-IR data buys improved photometric redshifts: necessary for weak lensing cosmology program, but also essential for studying galaxy evolution
• though WFIRST resolution < HST resolution, still expect to resolve most (~80%) of sources brighter than H ~ 25
• grism data too...

• depth slightly lower than COSMOS, but covering >1000x greater area

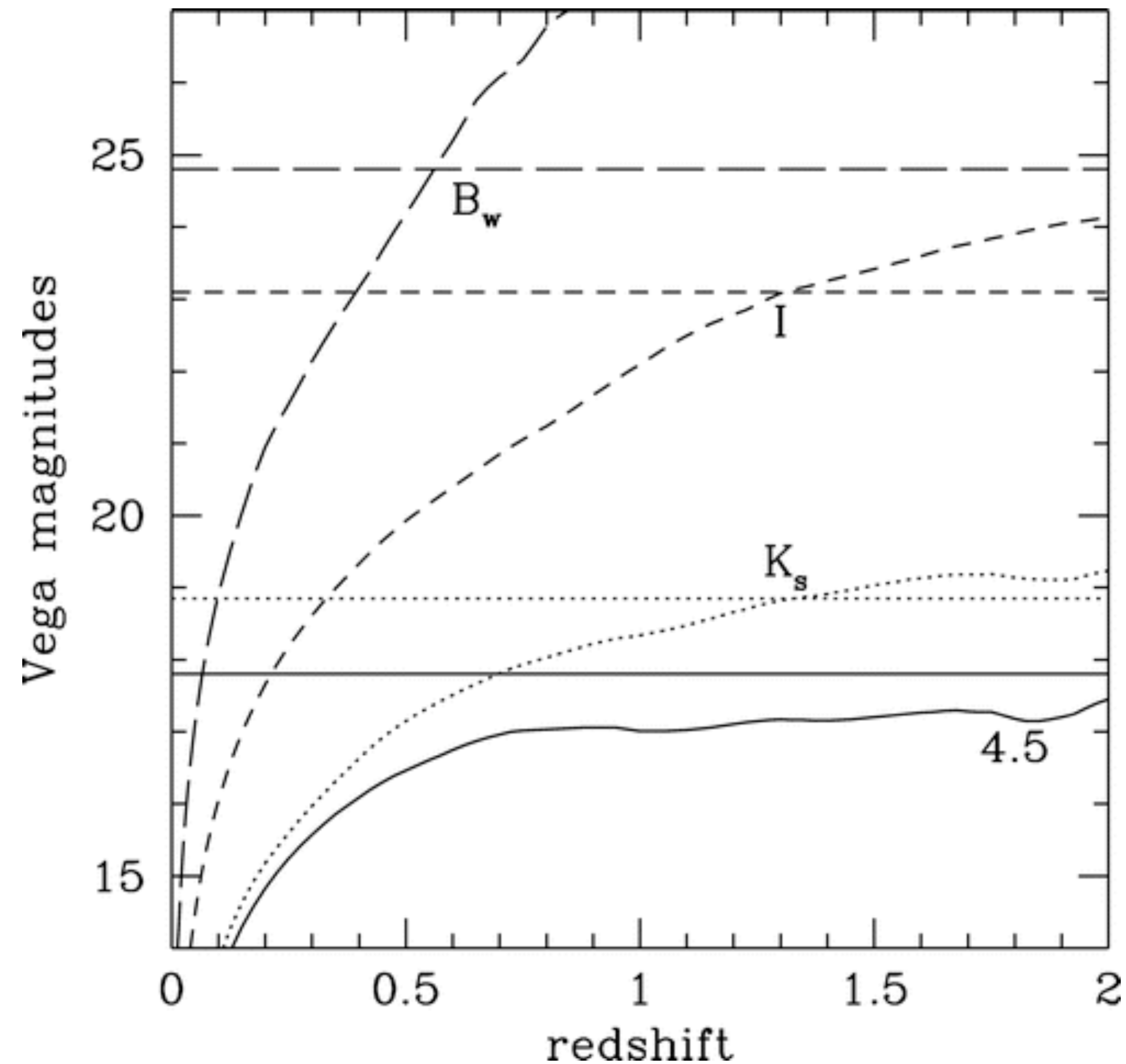


size-magnitude relation for Hubble UDF (Conselice)

3. Galaxy Clusters

- near-IR very powerful for identifying massive galaxies at z>1.

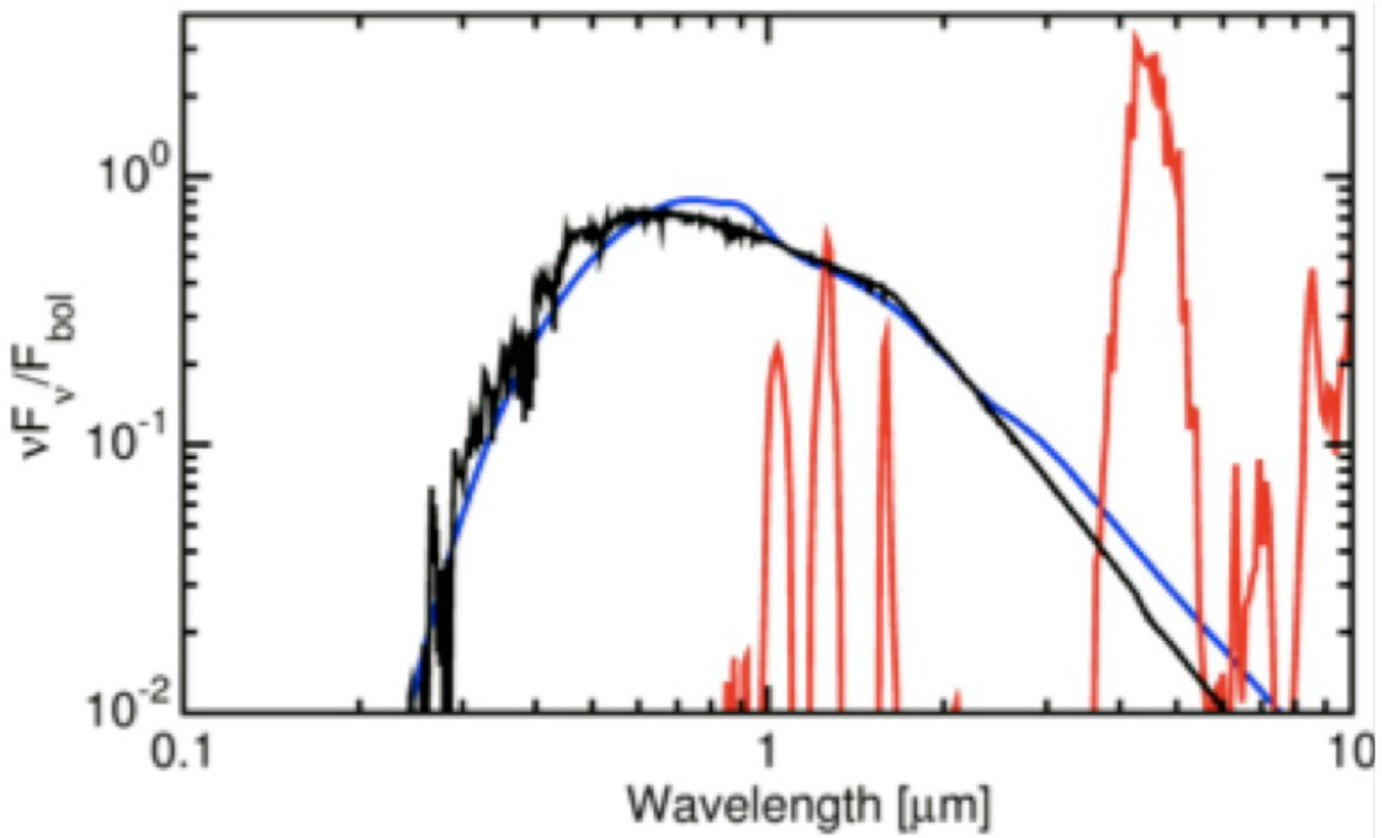
- WFIRST HLS will be very powerful tool for studying galaxy clusters:
  - one of the 4 cosmological probes in the DETF report
  - follow-up of clusters found by SZ surveys (e.g., SPT, Planck, ACT), X-ray surveys (e.g., eROSITA), optical surveys (e.g., DES)
  - photo-z's + WL masses



L* galaxy, formed at z=3 (BC03).

Eisenhardt et al. 2008, ApJ, 684, 905

4. Rare, Cold Stars

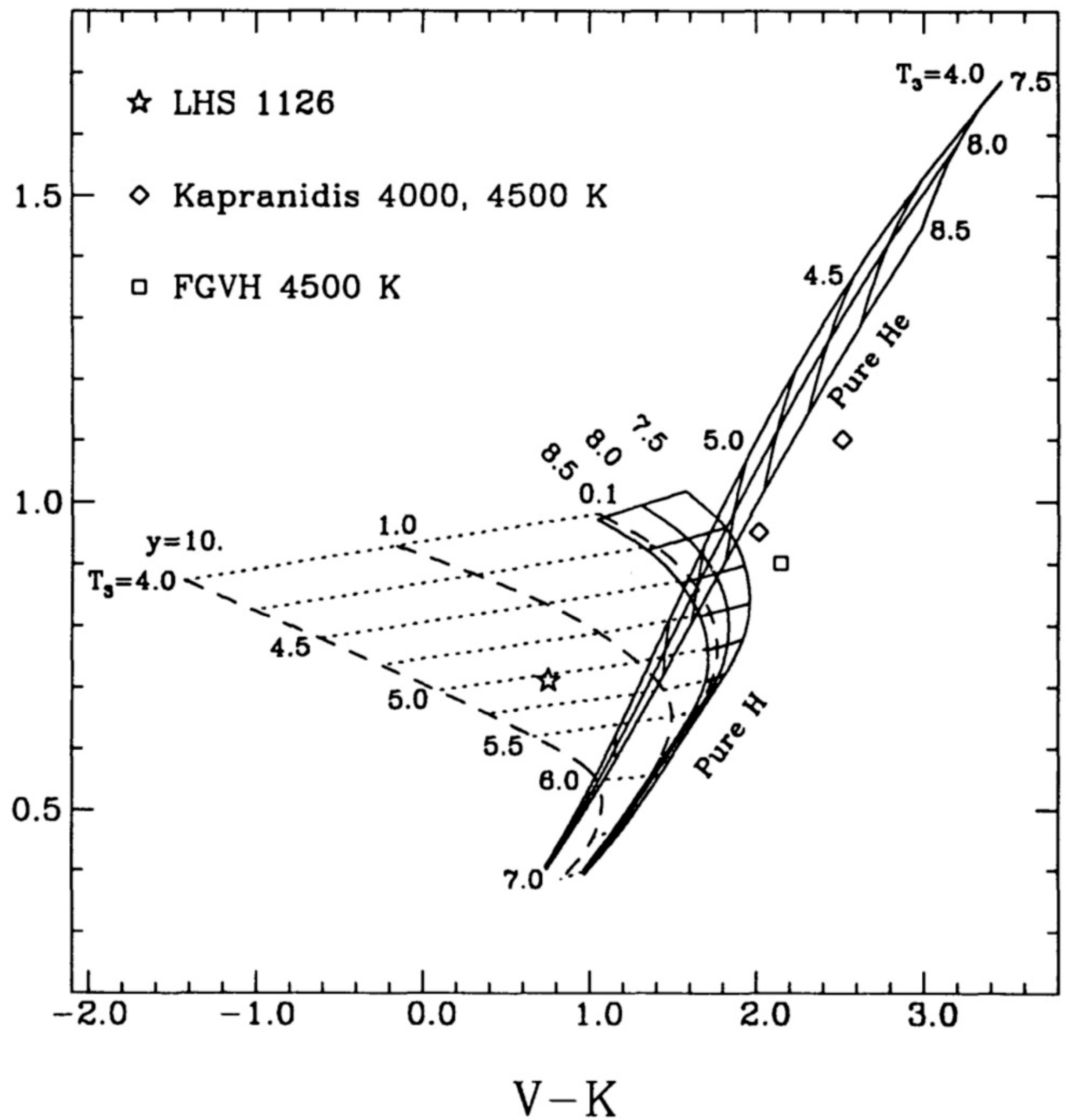


- 4000 K WD showing H_2 CIA
- 325 K BD showing CH_4 dominated spectrum
- Best MS match to WD

• HLS (ala WISE) will also be very useful for identifying rare, cold Galactic sources: late-type brown dwarfs (BDs) and cold white dwarfs (WDs)
• BD spectra peak at JH and M, so long(er) wavelength data ideal
• WD spectra suppressed at 1.1 and 2.2 um, so identifiable from optical + near-IR imaging

• BD's: probe star/planet boundary
• WD's: probe history of the Milky Way Galaxy

4. Rare, Cold Stars

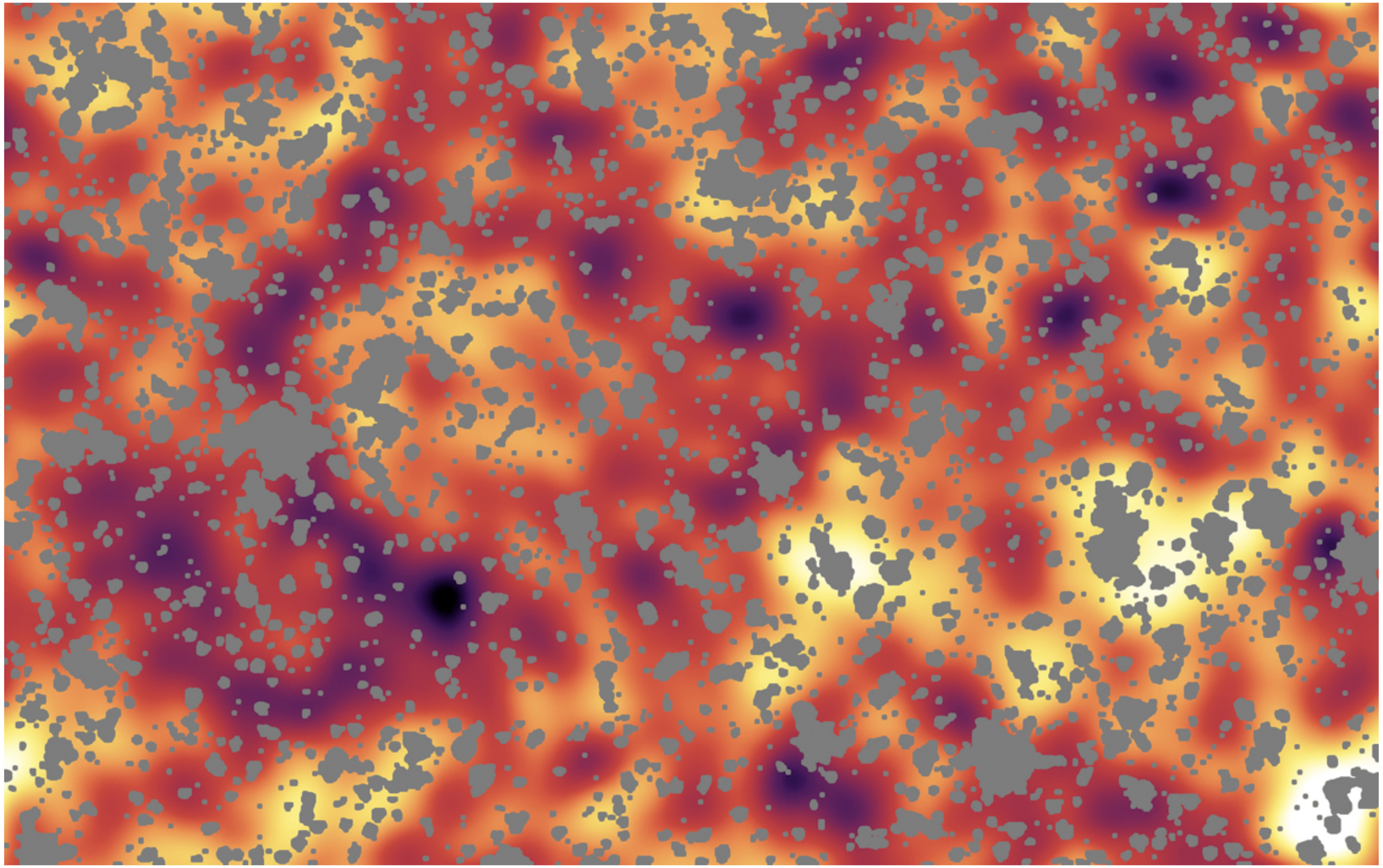


- hydrogen-atmosphere WDs become bluer due to the formation of molecular hydrogen

- helium-atmosphere WDs, on the other hand, become redder as they cool; e.g., a 3500 K He WD has V-H = 4

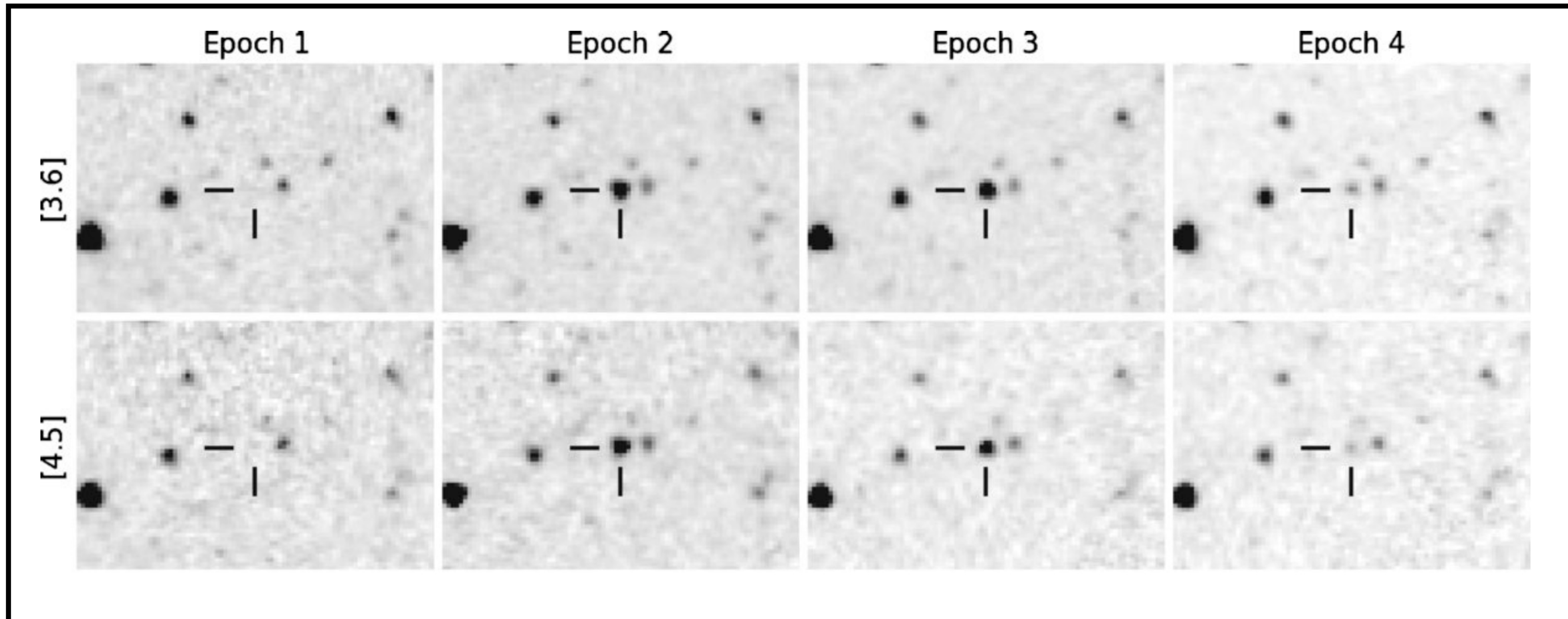
Bergeron, Saumon & Wesemael 1995, ApJ, 443, 764

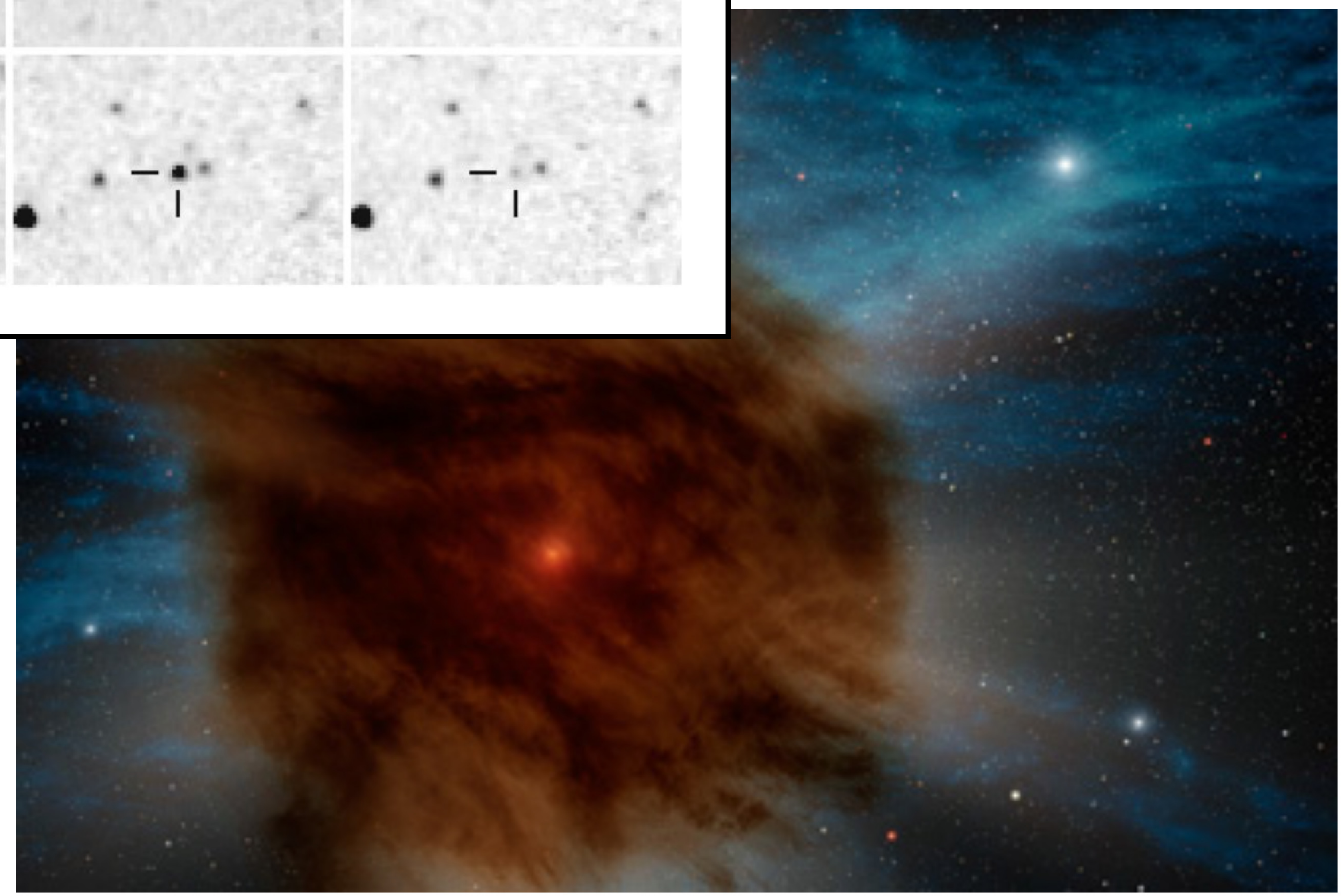
5. Cosmic Near-IR Background



clustered emission from **first** generation of star formation in the Universe;
expected at near-infrared wavelengths (controversial claims already by Spitzer)

6. Serendipity



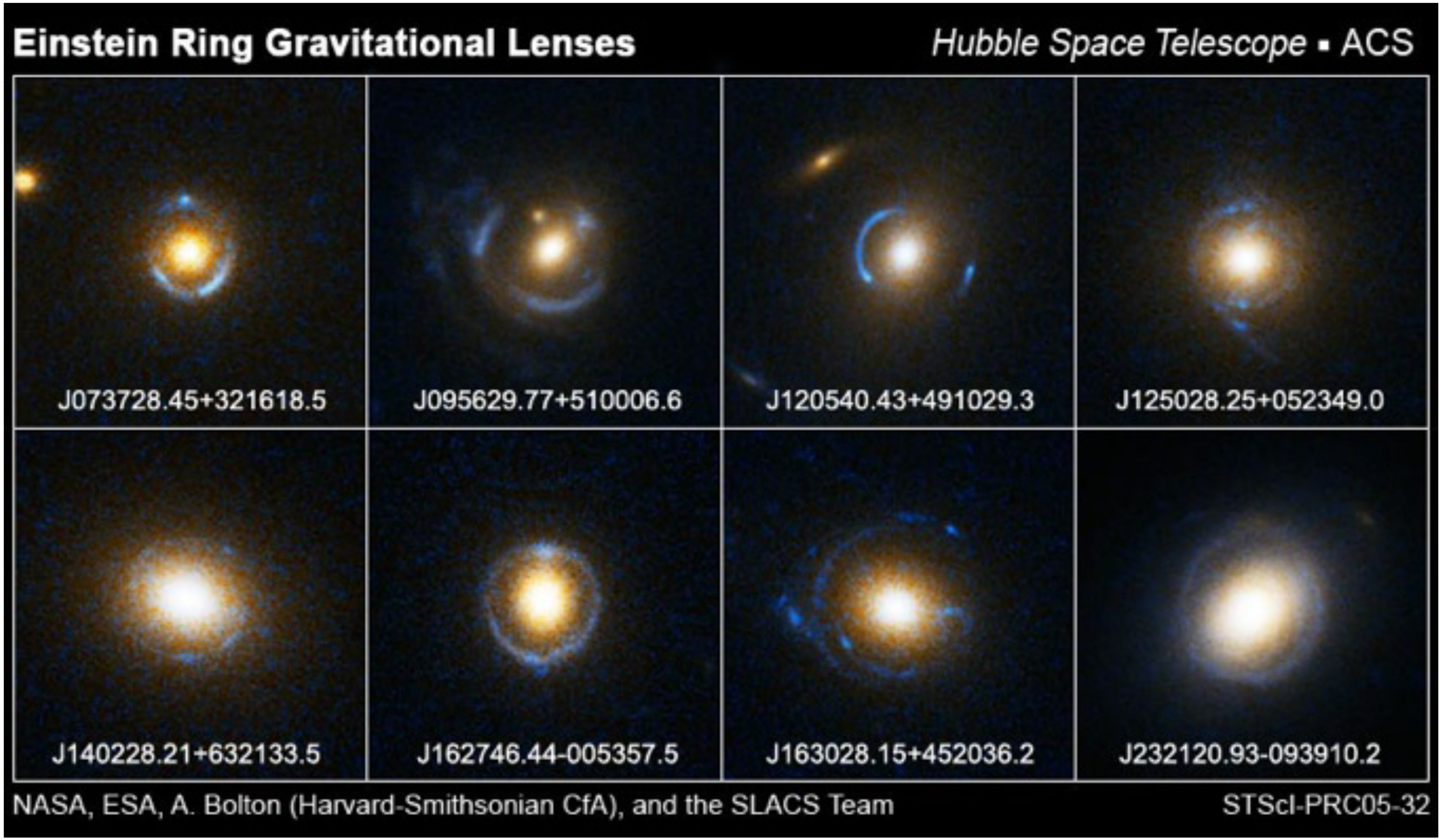


most variable source in Spitzer Deep, Wide-Field Survey (SDWFS):

- a dust-enshrouded supernova at z~0.2 (SN 2007va)
- ηCarinae analog

Kozłowski, Kochanek, Stern et al. 2010, ApJ, 722, 1624

6. Serendipity



SLACS Survey

And don't forget about the other surveys...

SN survey

WL survey

BAO survey

GO program for additional wedding cake layers?

microlensing survey?

2. Galactic Plane Survey

WFIRST SDT Task Group:

S. Carey (IPAC)
K. Cook (Livermore)
M. Donahue (Michigan State Univ.)
N. Gehrels (GSFC)
L. Hillenbrand (Caltech)
R. van den Marel (STScI)
G. Rieke (Univ. of Arizona)
J. Stauffer (Spitzer Science Center)
D. Stern (JPL)
A. Tanner (Georgia State Univ.)

WFIRST Galactic Plane Survey

- expected to very rapidly reach the confusion limit. [calculations ongoing as a function of Galactic latitude; off-axis design better than on-axis design.]
- expected to be ~3 mag deeper than 2MASS and ~1.5 mag deeper than UKIDSS for imaging
- grism data unlikely to be useful (due to confusion)
- covering GLIMPSE 360° x 2° strip to confusion limit takes ~1 mo.: do it more than once?

WFIRST Galactic Plane Survey

- science from WFIRST Galactic Plane Survey:
  - structure of the Milky Way Galaxy: edge of the disk, shape and extent of the Galactic warp, study IMF to H-burning limit as function of environment, tidal streams, probe time-domain (e.g., variable sources, moving sources; e.g., identify the deuterium instability region)
  - identify proto-stars
  - find low-mass BD's: star/planet boundary
  - find cool WD's: history of the Milky Way Galaxy

- 2-epoch studies of Galactic clusters:
  - identify members through proper motions

WFIRST Galactic Plane Survey

- concerns for WFIRST Galactic Plane science:
  - current design has 2.0 µm cutoff: doesn't probe red enough to disentangle temperature and reddening

3. Guest Observer Programs

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(it’s a mirror)

Potential GO WFIRST Programs

- exoplanet work besides microlensing:
  - transit imaging / spectroscopy
  - near-IR transits, complementary to optical Kepler transit survey
  - astrometric exoplanet searches?

Potential GO WFIRST Programs

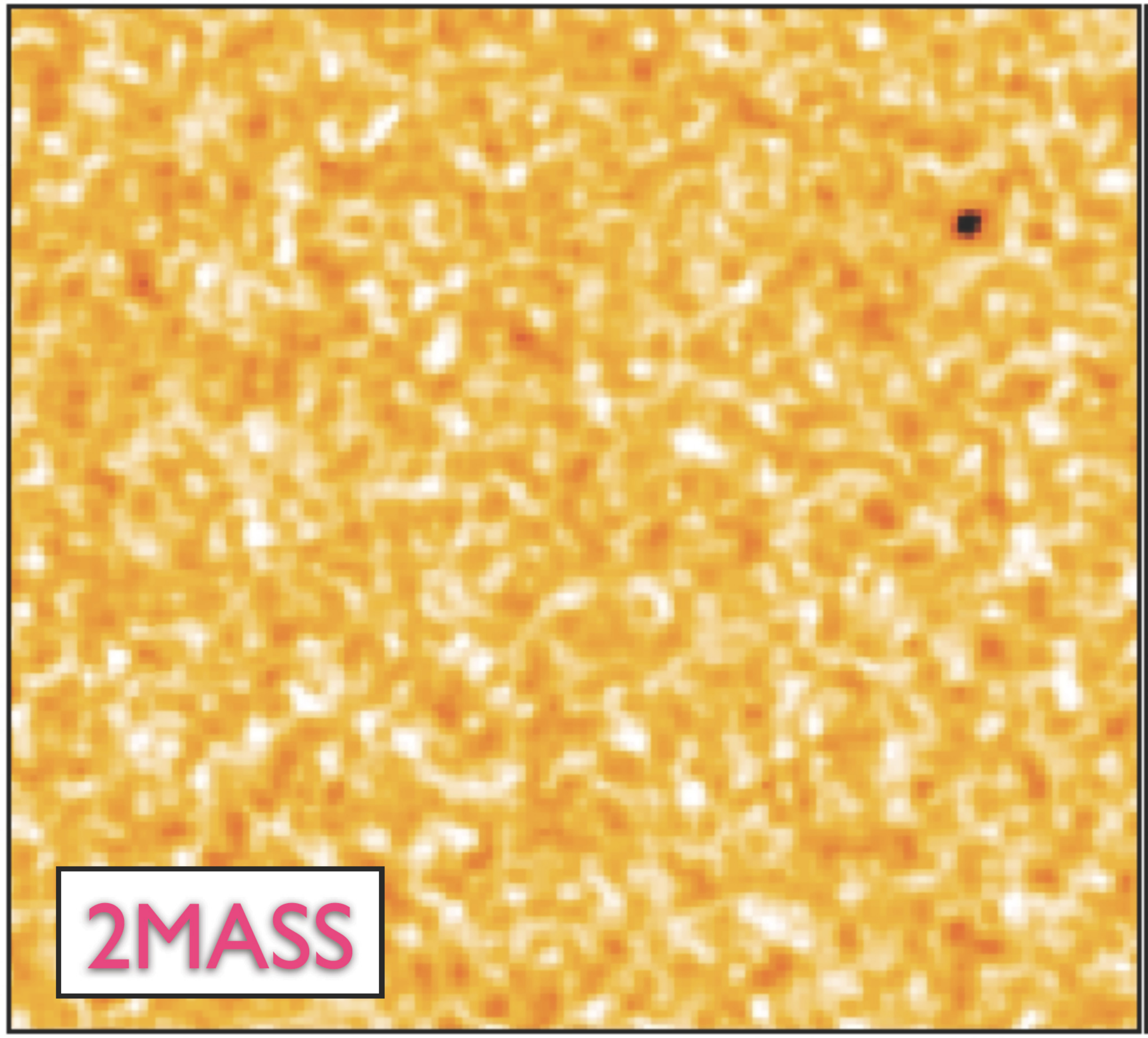
• resolved stellar populations in local galaxies and tidal streams (ala SAGE, SINGS, ANGST, PHAT, etc...; 100 pages on this science in LSST Science Book): a ~1 mo. GO program could fully map ~100 nearby galaxies to depths comparable to what LSST will do in 10 yr (at different wavelengths):

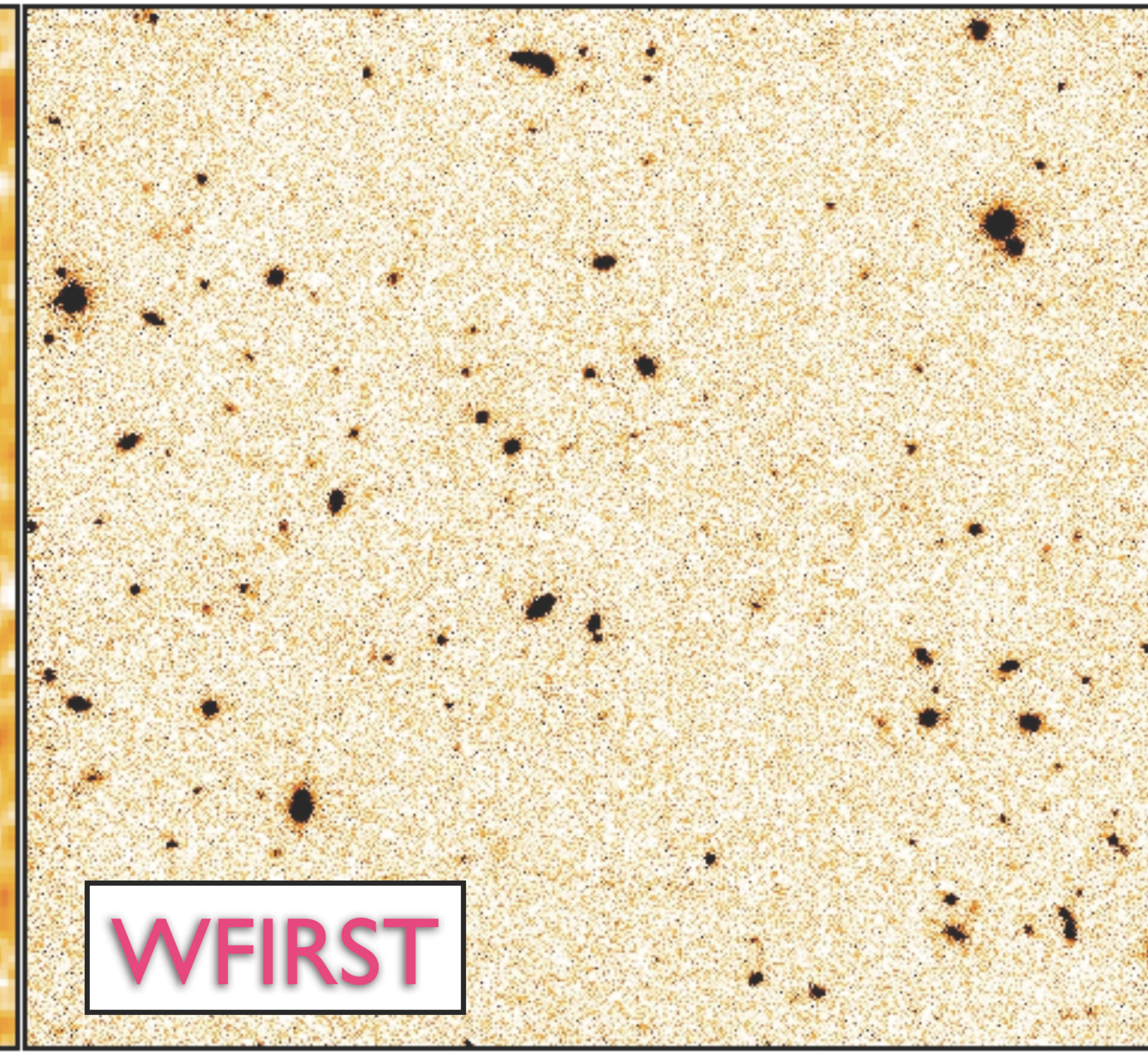
- galaxy structure
- tidal streams of nearby galaxies
- detailed studies of stellar populations

Potential GO WFIRST Programs

- massive galaxy clusters
  - ala Hubble MCT CLASH program
  - weak-lensing masses (and mass substructure?)
  - faint, background lensed sources
  - cluster galaxy luminosity function
  - spectroscopic confirmation / velocity dispersion for clusters

Summary

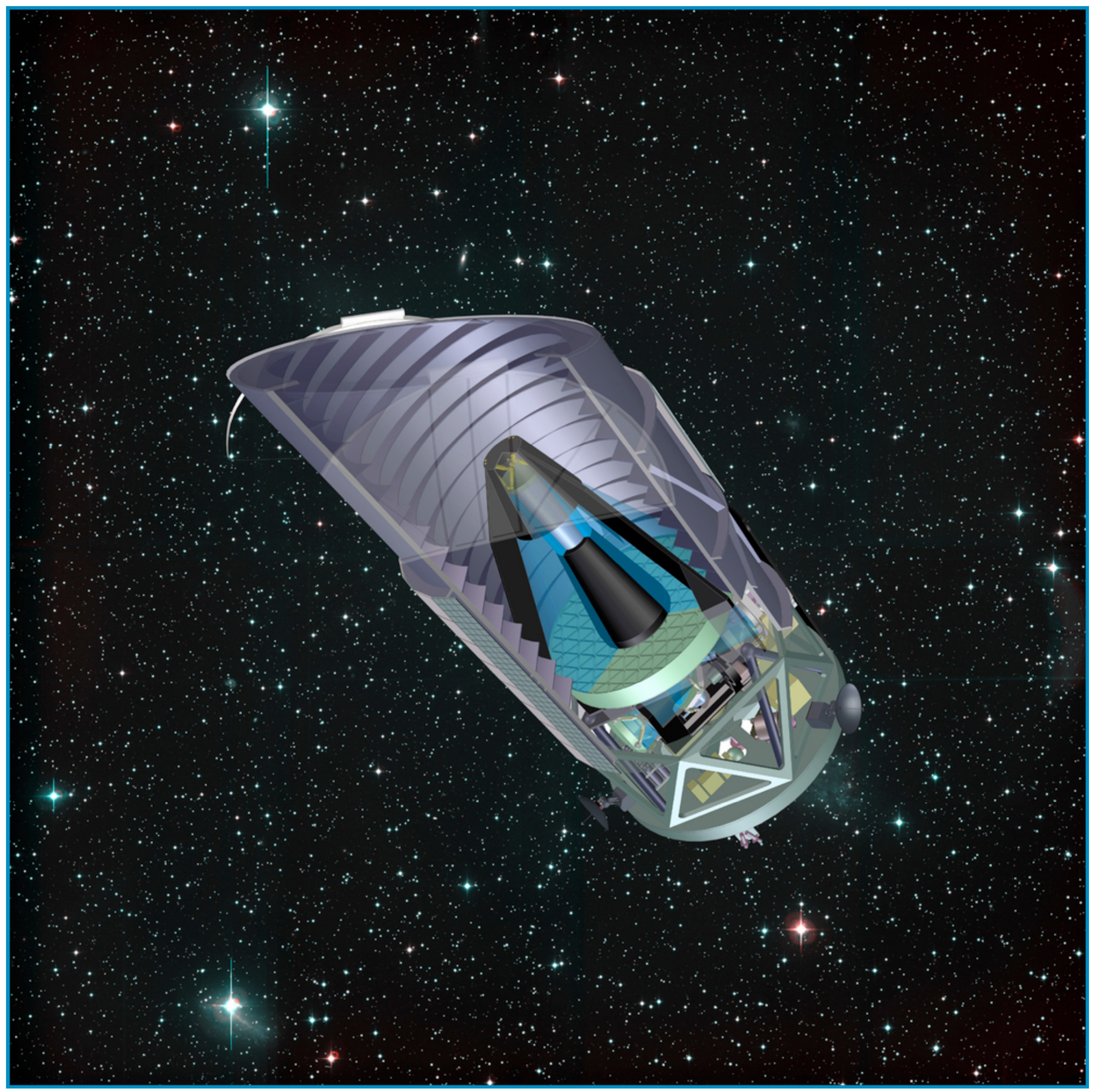




- Targets for JWST and TMT/ELT's.
- Compliments WISE, Planck, DES/Pan-STARRS/LSST, eROSITA/ART-XC, ...

Backup Slides

Dark Energy Mission Synergy with Wide-Field Surveys



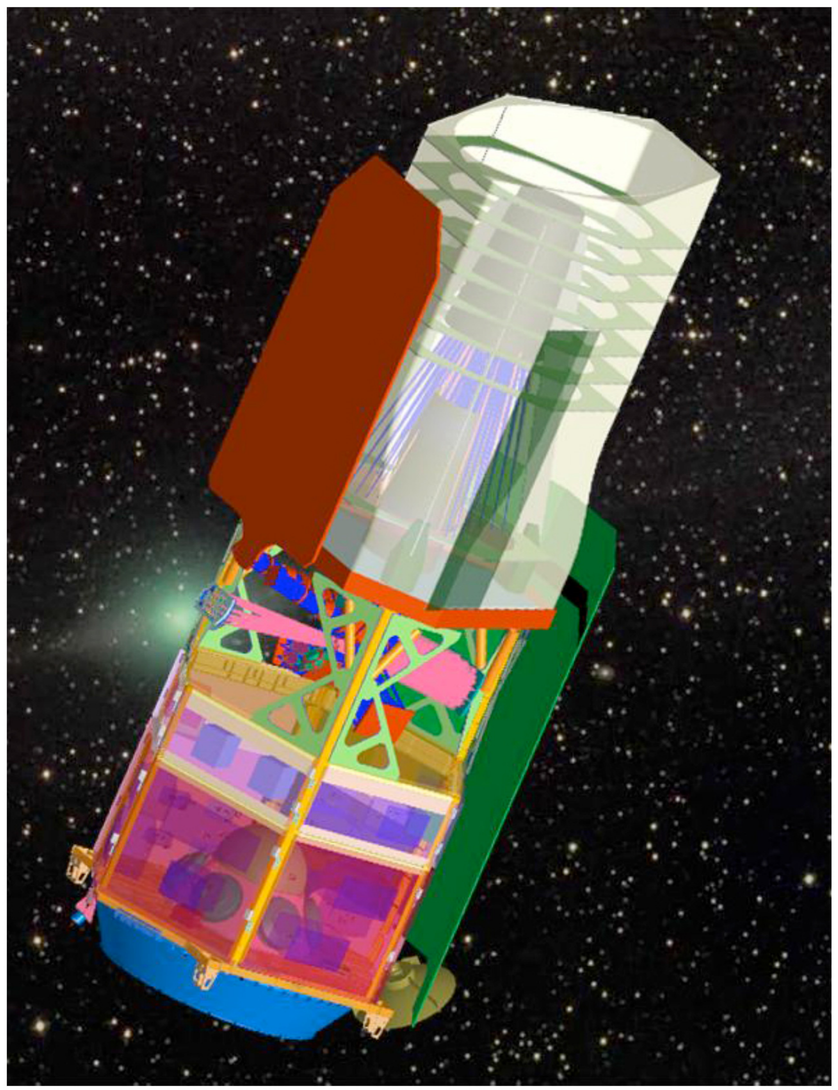
• natural synergy between dark energy surveys and wide-field surveys

• NIRSS was born out of work done looking at ancillary science with SNAP

• even without dark energy, a mission like WFIRST has very strong motivation

• [*if WFIRST merges w/ Euclid to create an optical + near-IR mission, the optical data also buys significant ancillary science (e.g., dwarfs in the local group, Kuiper belt objects)*]

WFIRST =



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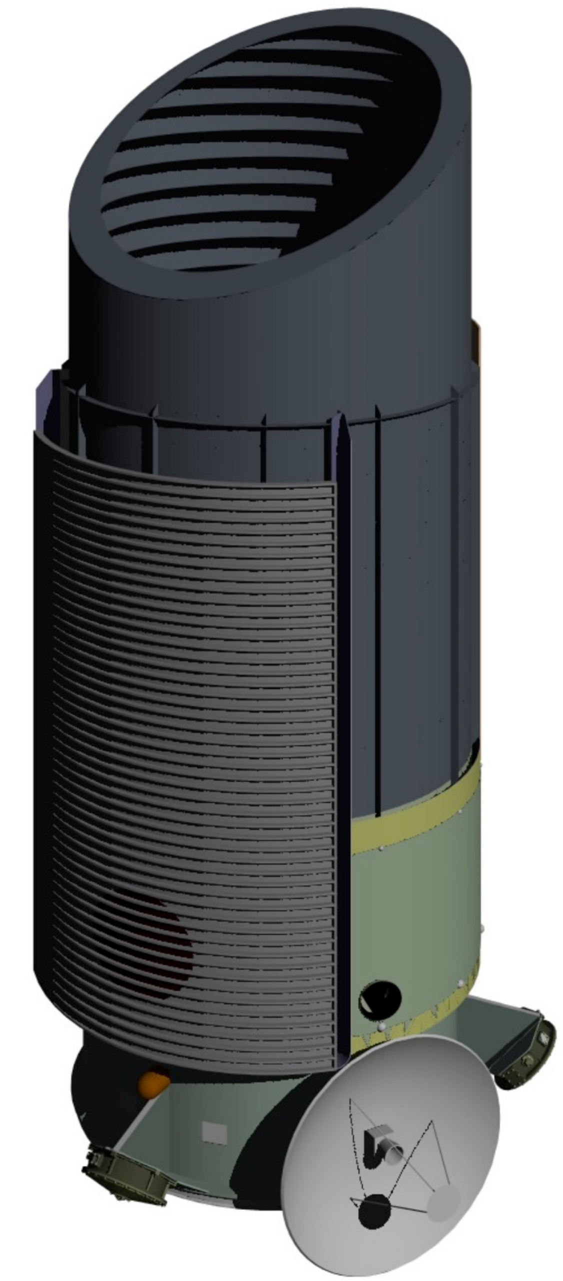


JDEM-Ω

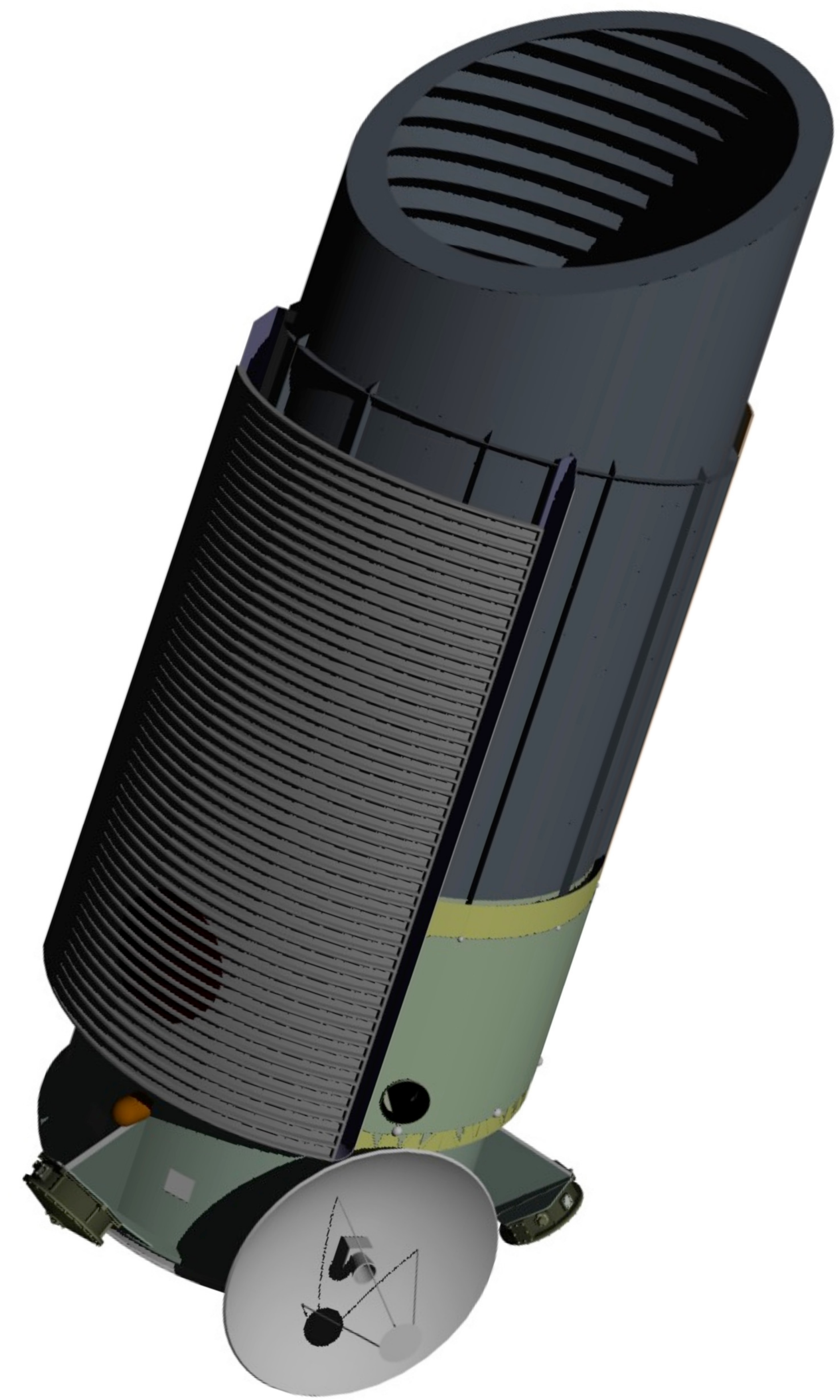
MPF

NIRSS

Near-IR Sky Surveyor: NIRSS

P.I.: Daniel Stern (JPL/Caltech)

Co-Investigators:
Mark Brodwin (Harvard/CfA)
Asantha Cooray (UC-Irvine)
Roc Cutri (IPAC/Caltech)
Arjun Dey (NOAO)
Peter Eisenhardt (JPL/Caltech)
Anthony Gonzalez (Univ. Florida)
Jason Kalirai (STScI)
Amy Mainzer (JPL/Caltech)
Leonidas Moustakas (JPL/Caltech)
Jason Rhodes (JPL/Caltech)
S. Adam Stanford (UC-Davis, IGPP)
Edward L. Wright (UCLA)



WFIRST Science Goals

- **Joint Dark Energy Mission** (JDEM-Ω; P.I. N. Gehrels, GSFC)
  - focused cosmology mission to study dark energy / growth of structure

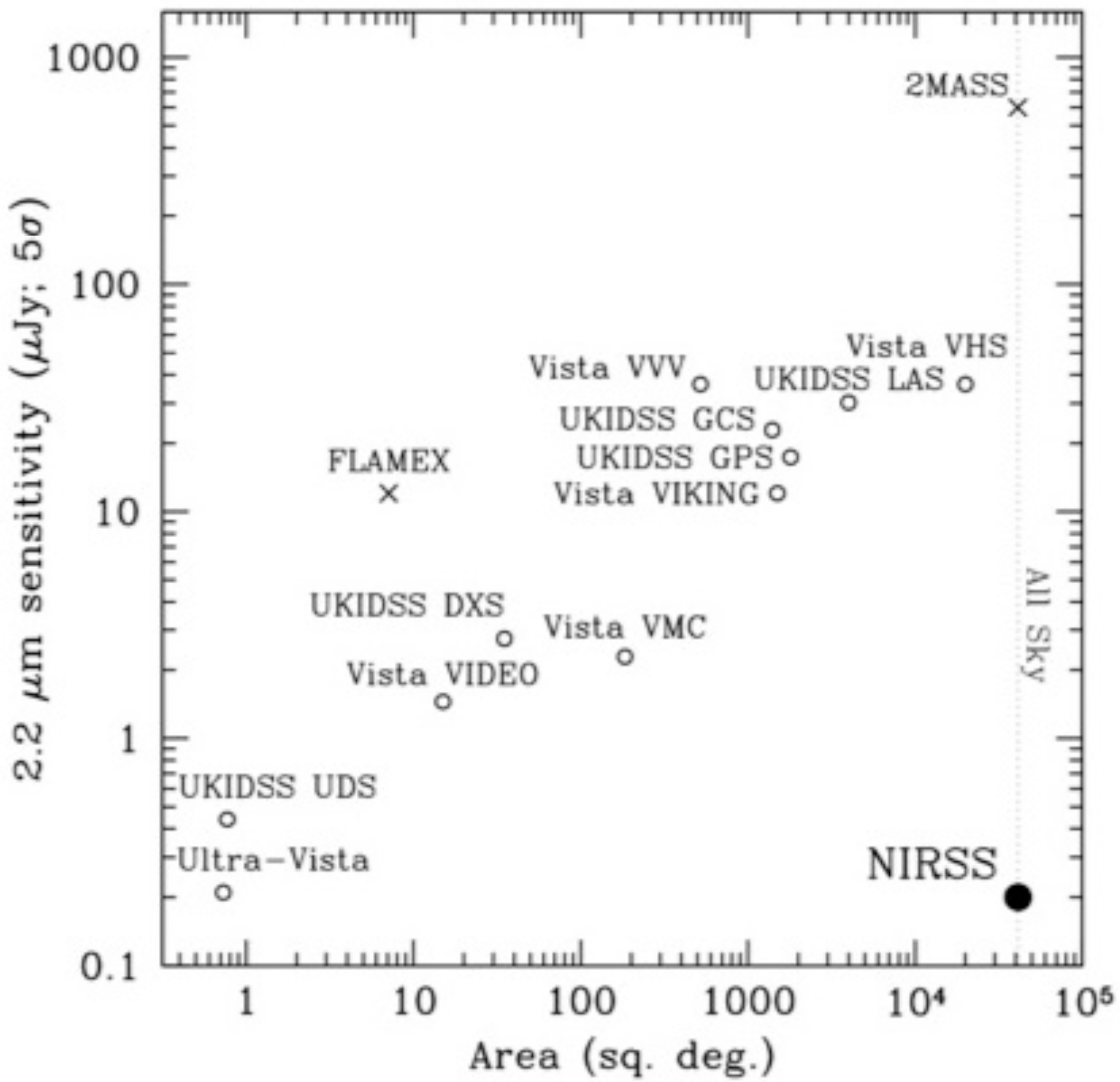
- **Microlensing Planet Finder** (MPF; P.I. D. Bennett, Notre Dame)
  - focused exoplanet mission to find planets through microlensing

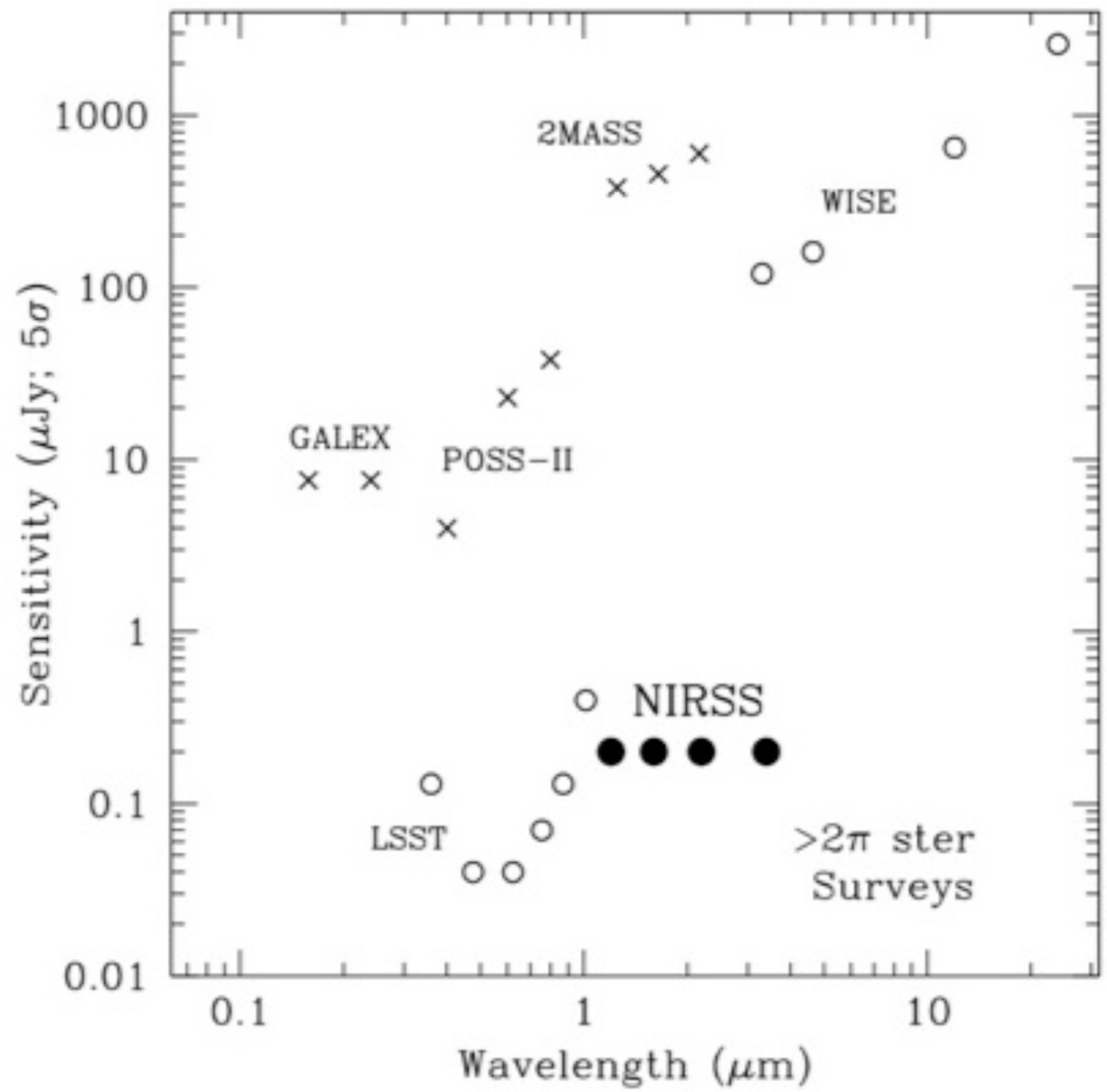
- **Near-Infrared Sky Surveyor** (NIRSS; P.I. D. Stern, JPL)
  - broad utility (e.g., less focused) mission taking advantage of advances in near-IR detector technology and the benign thermal environment of space to map the sky at near-IR wavelengths
  - many science drivers, ranging from cool stars to the highest redshift quasars in the cosmic infrared background

Strawman NIRSS Design

Primary Mirror Diameter:	1.5 meter (0.2” diff. limit at 1.2 μm)
Focal Plane:	36 HgCdTe arrays
Image Scale:	0.25”/pixel
Wavelength Coverage:	4 bands, 1-4.2 μm
Survey Depth:	0.2 μJy, full-sky
Optical Design:	f/10.6 TMA
Launch Vehicle/Orbit:	Delta IV / L2 orbit
Temperature:	65 K (passive cooling)
Mission Duration:	4 yr. core mission

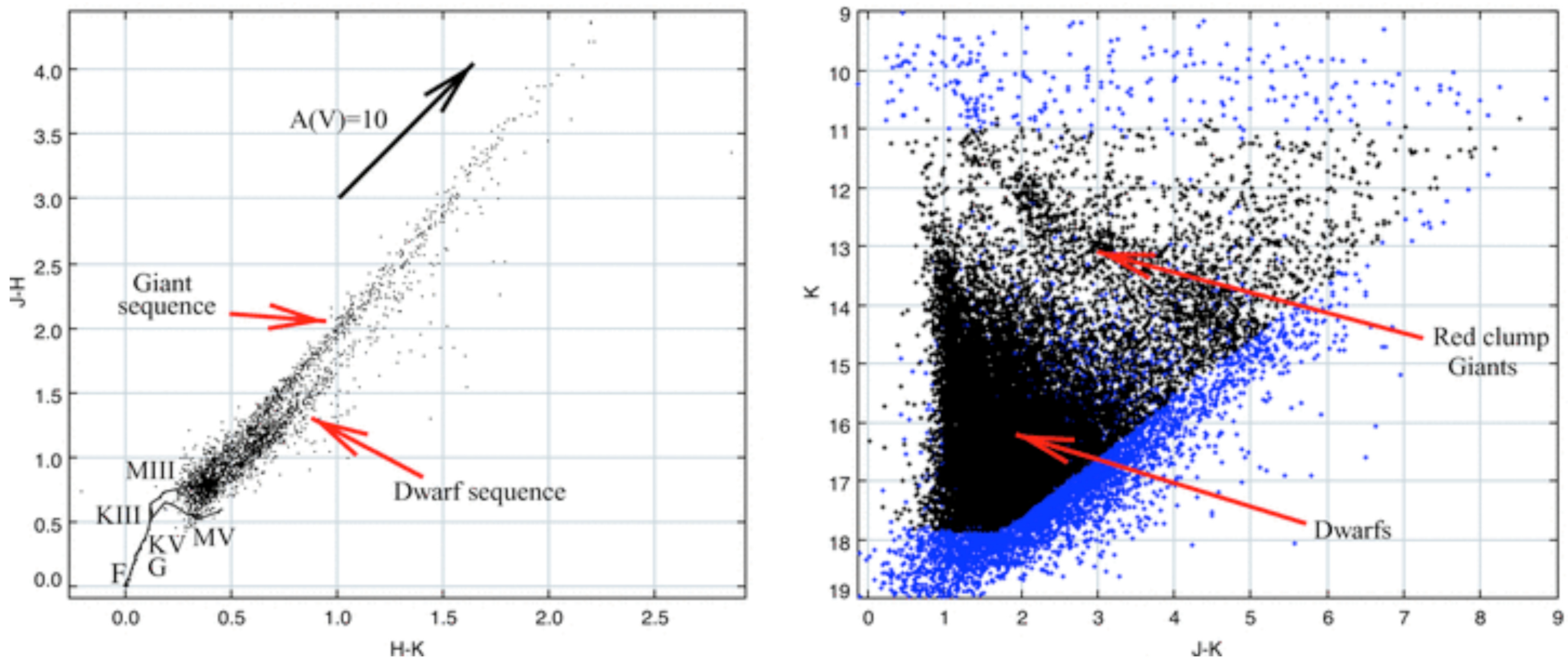
Near-Infrared Surveys





"2MASS/WISE on steroids"

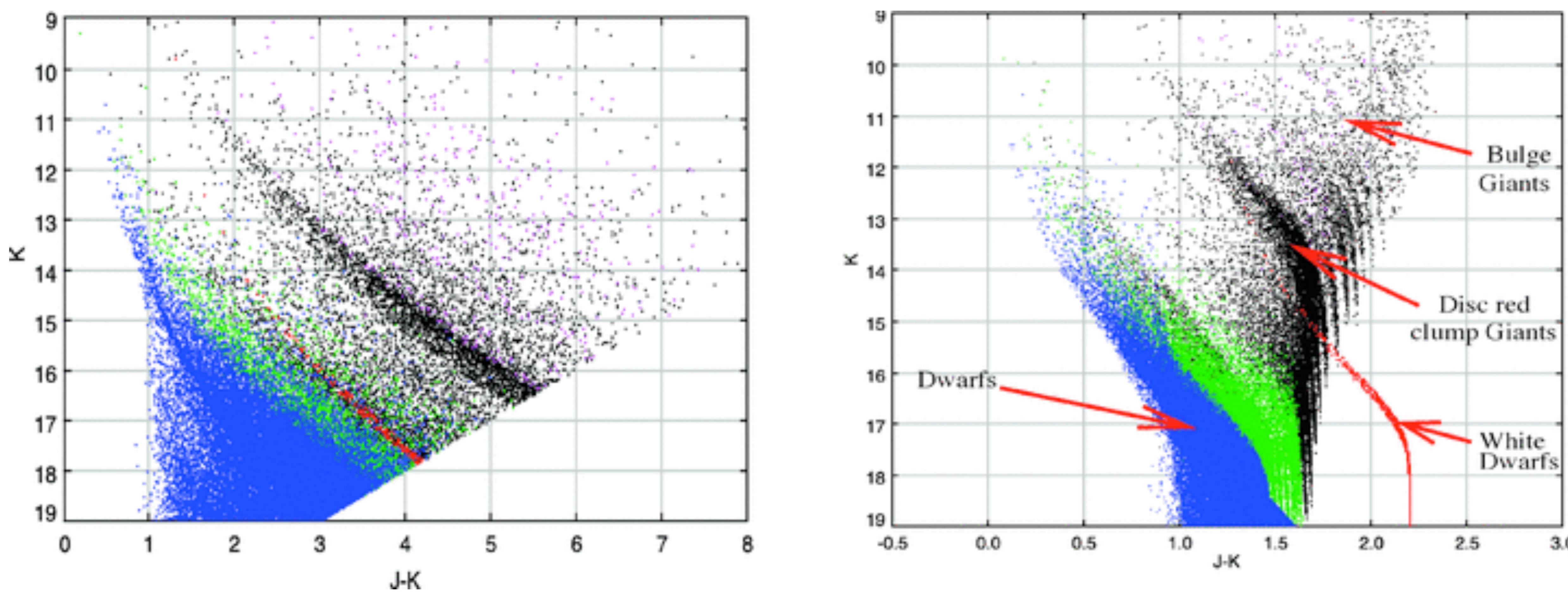
UKIDSS Galactic Plane Survey



• (l, b) = (31, 0) from UKIDSS Galactic Plane Survey. Unreddened stars from Hewett et al. (2006) shown by lines in left panel. K-band allows for robust separation of dwarfs and giants. The winding red clump track in right panel indicates variable reddening.

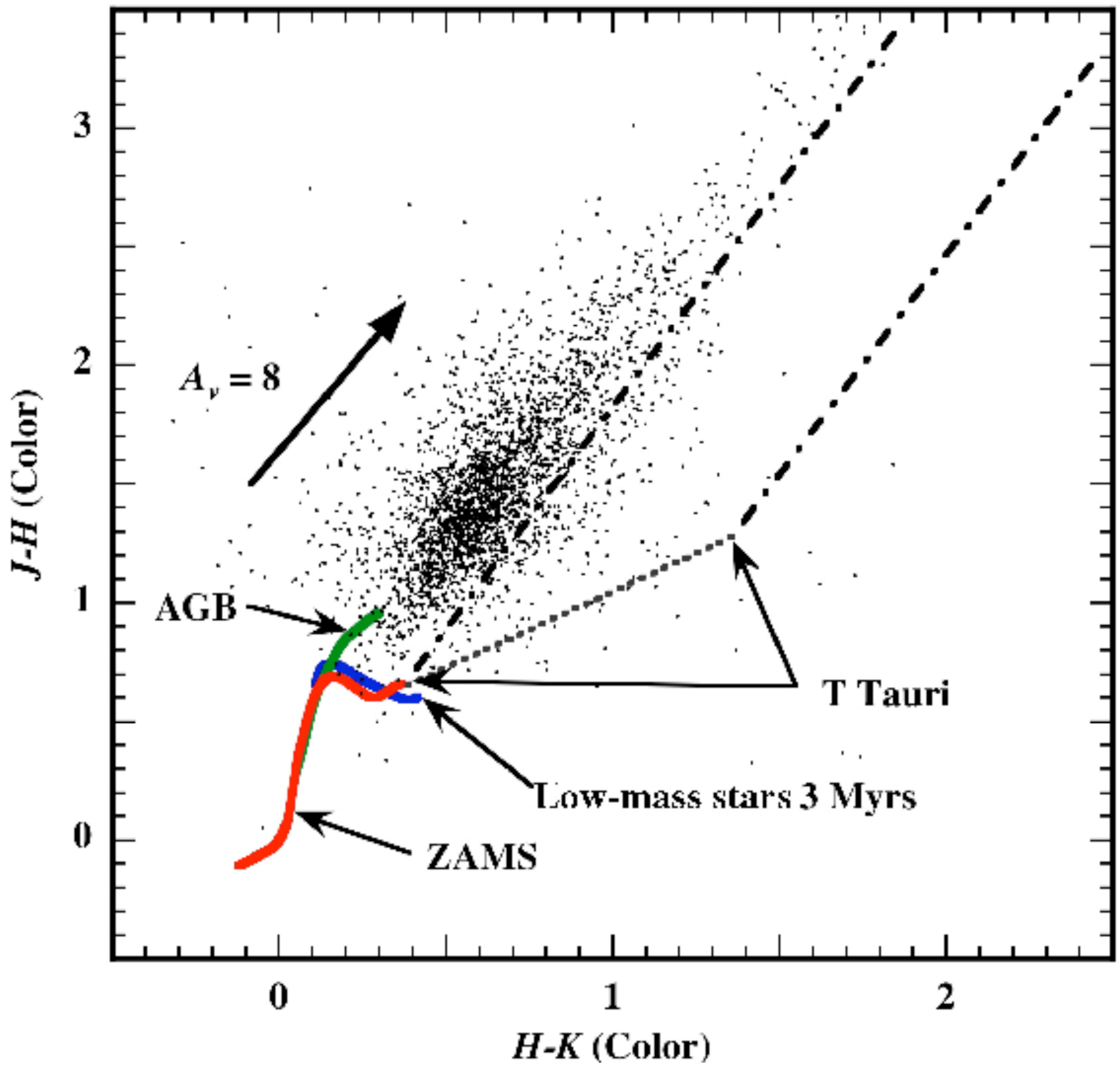
Lucas et al. (2008, MNRAS 391, 136)

UKIDSS Galactic Plane Survey



• Besancon model color-magnitude diagram in two regions of the Galactic plane: left corresponds to (l, b) = (31, 0); right corresponds to (l, b) = (15, 1). K-band data allows for robust separation of dwarfs (blue) from subgiants (class IV; green) and giants (class V; black).

Lucas et al. (2008, MNRAS 391, 136)



Klotz et al. (2004, A&A, 425, 927)