WFIRST-AFTA:
BEYOND THE LOCAL GROUP

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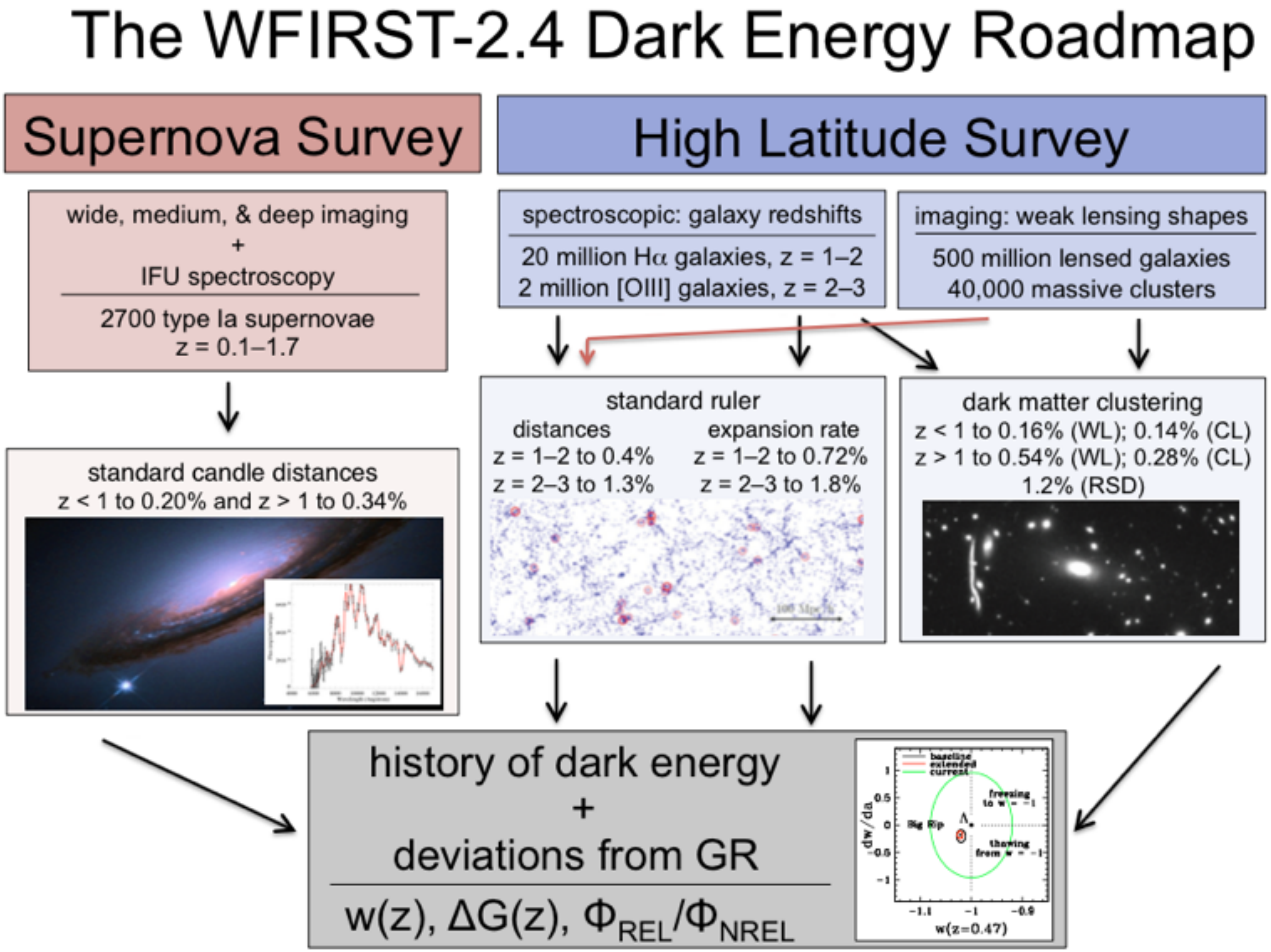
UNIVERSITY OF TORONTO

What I will not talk about



PLAN: HIGHLIGHT & SYNTHESIZE THE EXCITING "BEYOND THE LOCAL GROUP" ONE PAGE SCIENCE IDEAS PRESENTED IN THE SCIENCE DEFINITION TEAM'S 2013 AND 2014 REPORTS.

5 (OR 6) YEAR PRIME MISSION

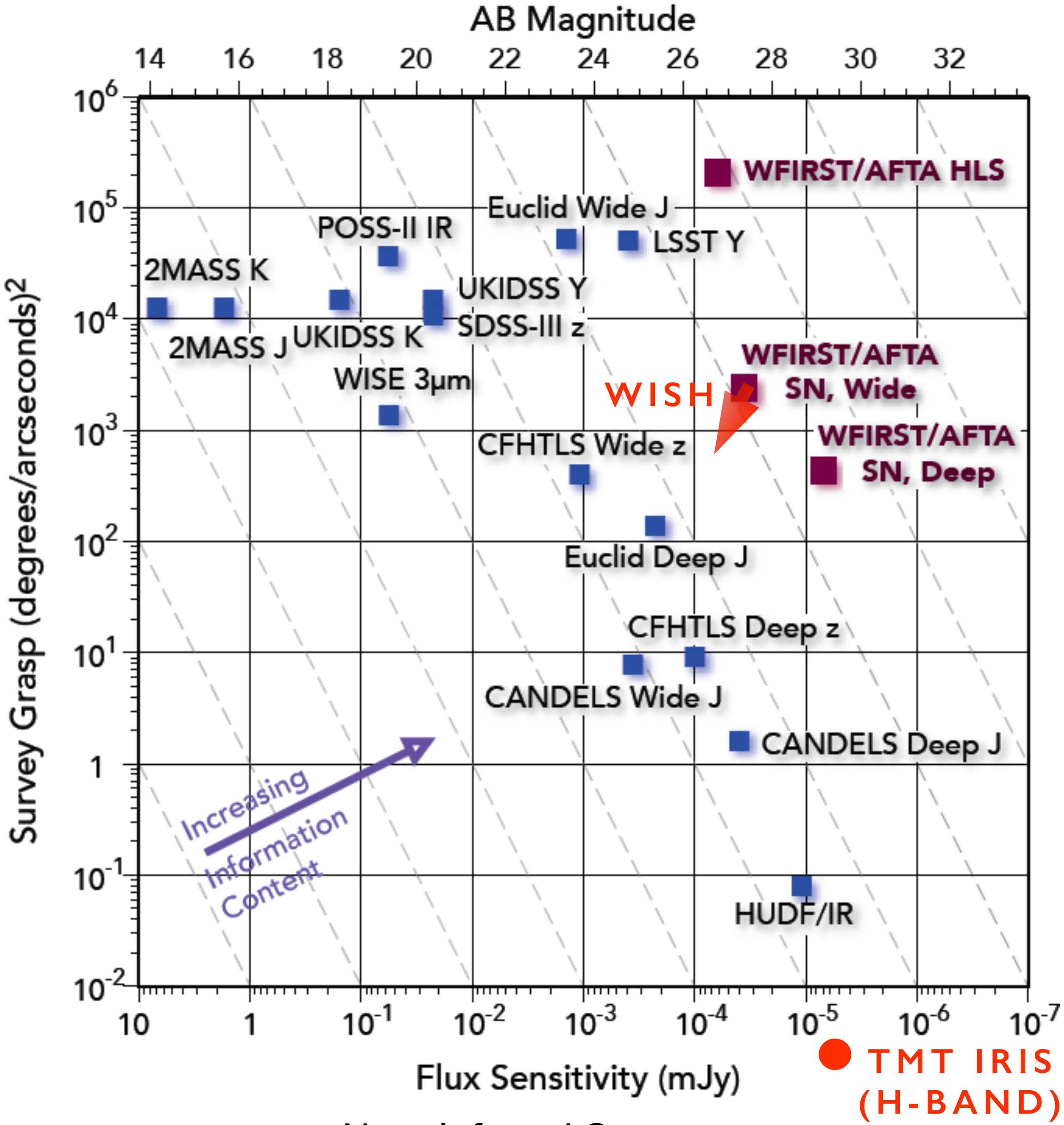
WFIRST-2.4 Design Reference Mission Capabilities						
Imaging Capability	0.281 deg^2		0.11 arcsec/pix		0.6 – 2.0 μm	
Filters	Z087	Y106	J129	H158	F184	W149
Wavelength (μm)	0.760-0.977	0.927-1.192	1.131-1.454	1.380-1.774	1.683-2.000	0.927-2.000
PSF EE50 (arcsec)	0.11	0.12	0.12	0.14	0.14	0.13
Spectroscopic Capability	Grism (0.281 deg^2) 1.35 – 1.95 μm, R = 550-800			IFU (3.00 x 3.15 arcsec) 0.6 – 2.0 μm, R = ~100		
Baseline Survey Characteristics						
Survey	Bandpass	Area (deg^2)	Depth	Duration	Cadence	
Exoplanet Microlensing	Z, W	2.81	n/a	6 x 72 days	W: 15 min Z: 12 hrs	
HLS Imaging	Y, J, H, F184	2000	Y = 26.7, J = 26.9 H = 26.7, F184 = 26.2	1.3 years	n/a	
HLS Spectroscopy	1.35 – 1.95 μm	2000	0.5×10^{-16} erg/s/cm^2 @ 1.65 μm	0.6 years	n/a	
SN Survey				0.5 years (in a 2-yr interval)	5 days	
Wide	Y, J	27.44	Y = 27.1, J = 27.5			
Medium	J, H	8.96	J = 27.6, H = 28.1			
Deep	J, H	5.04	J = 29.3, H = 29.4			
IFU Spec	7 exposures with S/N=3/pix, 1 near peak with S/N=10/pix, 1 post-SN reference with S/N=6/pix Parallel imaging during deep tier IFU spectroscopy: Z, Y, J, H ~29.5, F184 ~29.0					
Guest Observer Capabilities						
1.4 years of the 5 year prime mission						
	Z087	Y106	J129	H158	F184	W149
Imaging depth in 1000 seconds (m_{AB})	27.15	27.13	27.14	27.12	26.15	27.67
t_{exp} for $\sigma_{read} = \sigma_{sky}$ (secs)	200	190	180	180	240	90
Grism depth in 1000 sec	S/N=10 per R=~600 element at AB=20.4 (1.45 μm) or 20.5 (1.75 μm) t_{exp} for $\sigma_{read} = \sigma_{sky}$: 170 secs					
IFU depth in 1000 sec	S/N=10 per R~100 element at AB=24.2 (1.5 μm)					
Slew and settle time	chip gap step: 13 sec, full field step: 61 sec, 10 deg step: 178 sec					
Optional Coronagraph Capabilities						
1 year in addition to the 5-year primary mission, interspersed, for a 6-year total mission						
Field of view	Annular region around star, with 0.2 to 2.0 arcsec inner and outer radii					
Sensitivity	Able to detect gas-giant planets and bright debris disks at the 1 ppb brightness level					
Wavelength range	400 to 1000 nm					
Image mode	Images of full annular region with sequential 10% bandpass filters					
Spectroscopy mode	Spectra of full annular region with spectral resolution of 70					
Polarization mode	Imaging in 10% filters with full Stokes polarization					
Stretch goals	0.1 arcsec inner annulus radius, and super-Earth planets					

Other stuff I'll try to do as time permits:

- Think about the guest observer program and how it relates to the baseline surveys.
- Ponder the importance of the evil word synergy and timing with respect to JWST.
- Generally try to understand where WFIRST fits into the experiment vs. facility models for doing astrophysics, and how one might best sell the project to an agency.

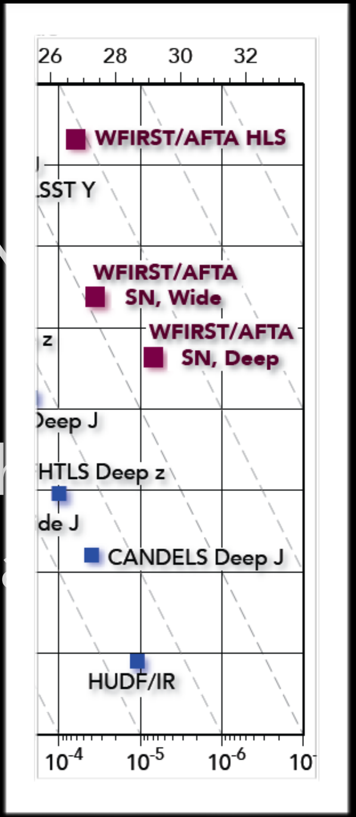
WFIRST-AFTA Surveys

- Multiple surveys:
  - High Latitude Survey
    - Imaging, spectroscopy, supernova monitoring
  - Repeated Observations of Bulge Fields for microlensing
  - 25% Guest Observer Program
  - Coronagraph Observations
- Flexibility to choose optimal approach



Near Infrared Surveys

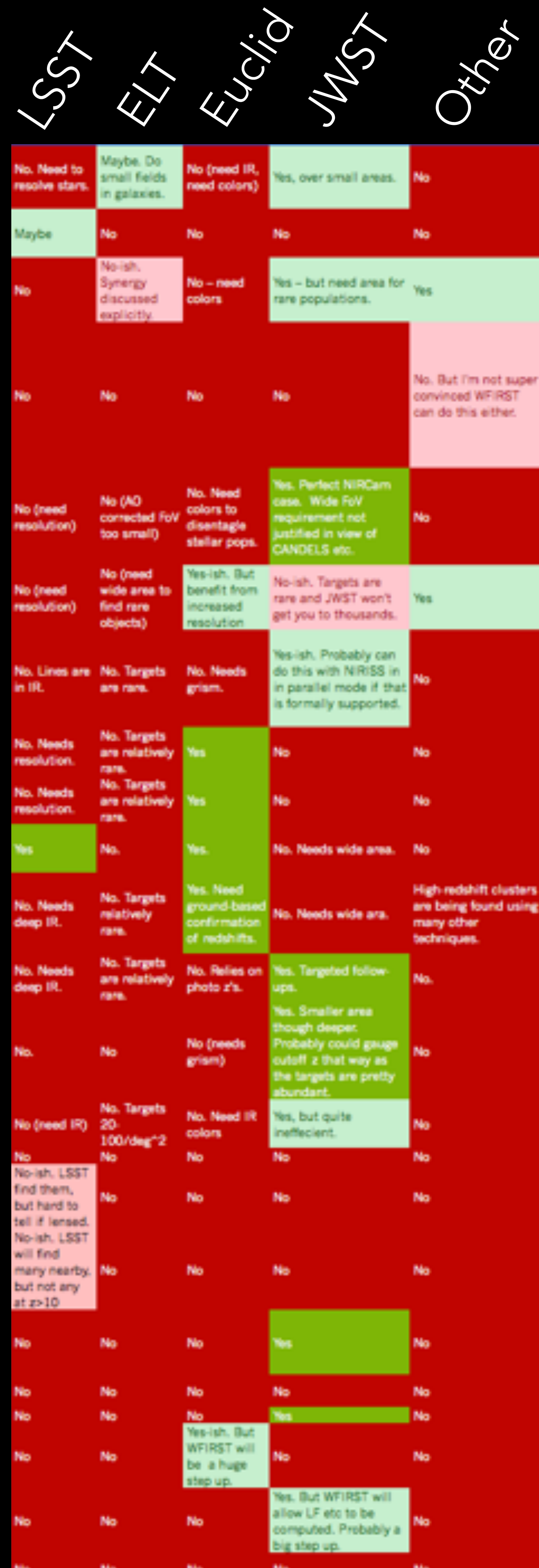
A POMPOUS APPROACH TO WFIRST "BEYOND THE LOCAL GROUP" SCIEN

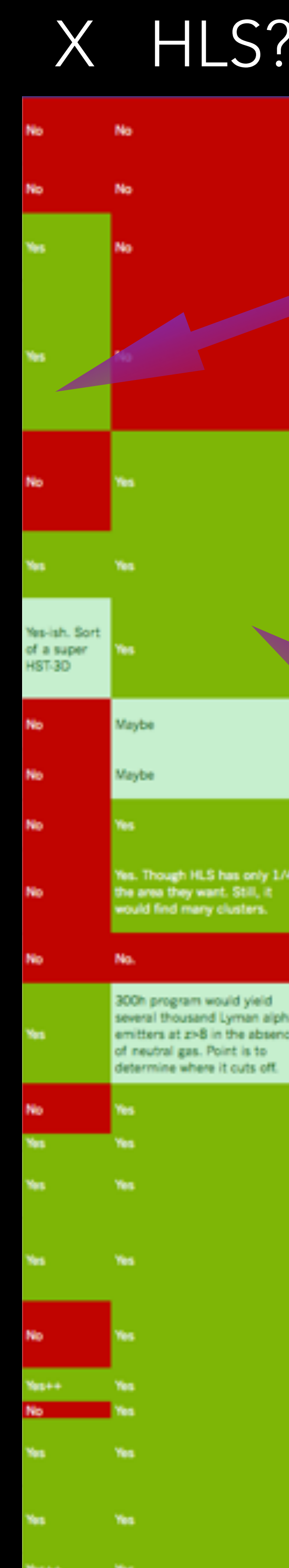


- **Thesis**: It's a well-defined physics experiment. A dark energy mission th counting and photometering *known* things. We need to understand da energy so this is a good thing.
- **Antithesis**: No. It's "Sloan in Space". It allows proper statistical characterization of *known* things, from which tons of astrophysics emerges (including *unknown relationships*). Like SDSS, it will also *discover new rare things*. SDSS is the most productive telescope in history, so this is another good thing.
- **Synthesis**: Both are true. It's a rare example of Sloan in Space emerging naturally from within the constraints of a physics experiment.
- **Irrelevant but true**: it's easier to predict the scientific return from WFIRST-AFTA than it is to predict the scientific return from JWST.

Focus on the **"Sloan in Space"** aspect. There are two broad approaches opening up discovery space in this model:

RED is good GREEN is good





Green means it has that 'X-factor'. For me, this was mainly how exciting it felt, and with bonus points for how synergistic it felt.

Red on the left means the facility in the column cannot do it. So if a row is all red then it means it's unique to WFIRST.

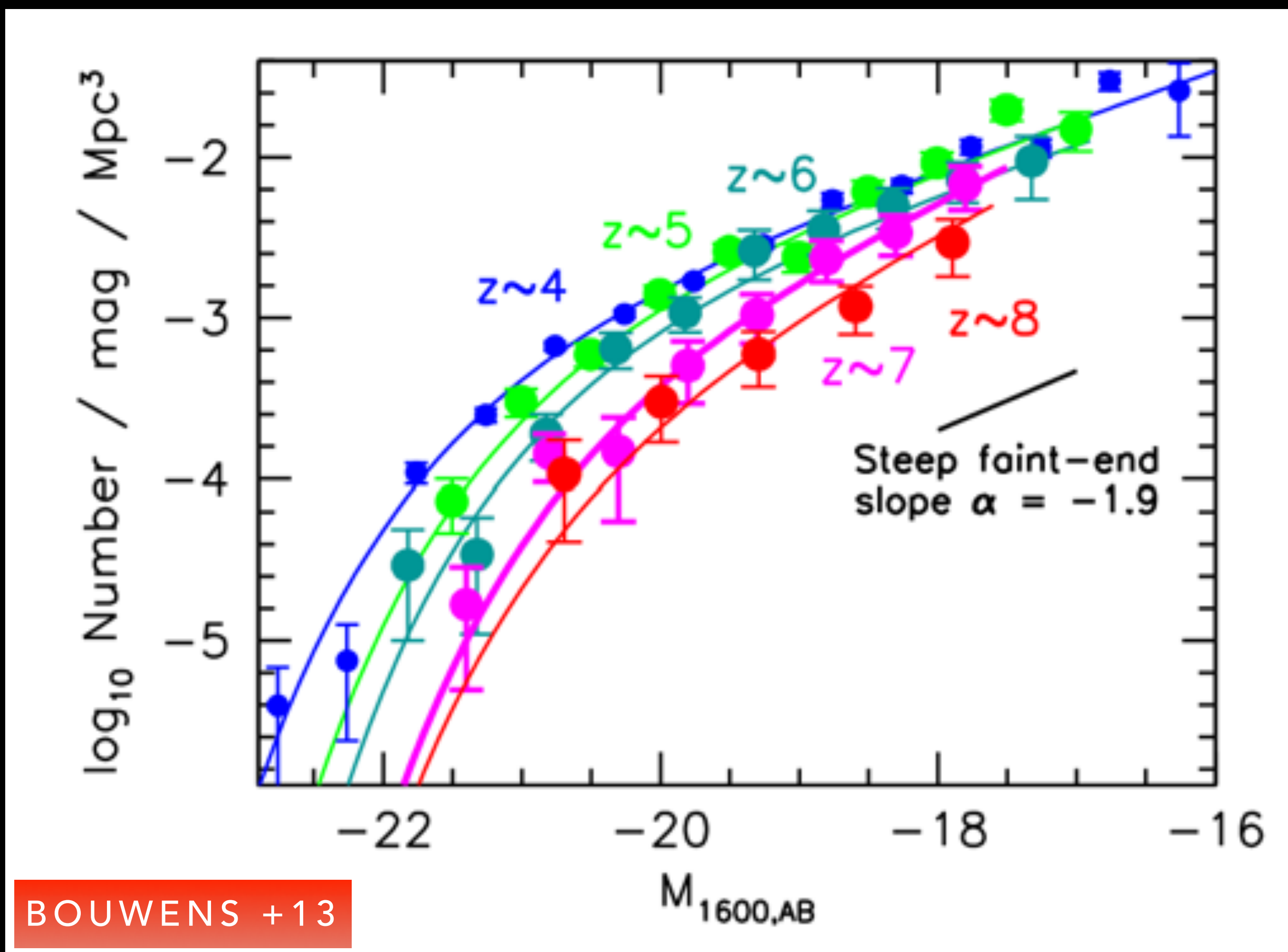
Green means it can be done as part of the high-latitude survey so guest observer time would be pointless.

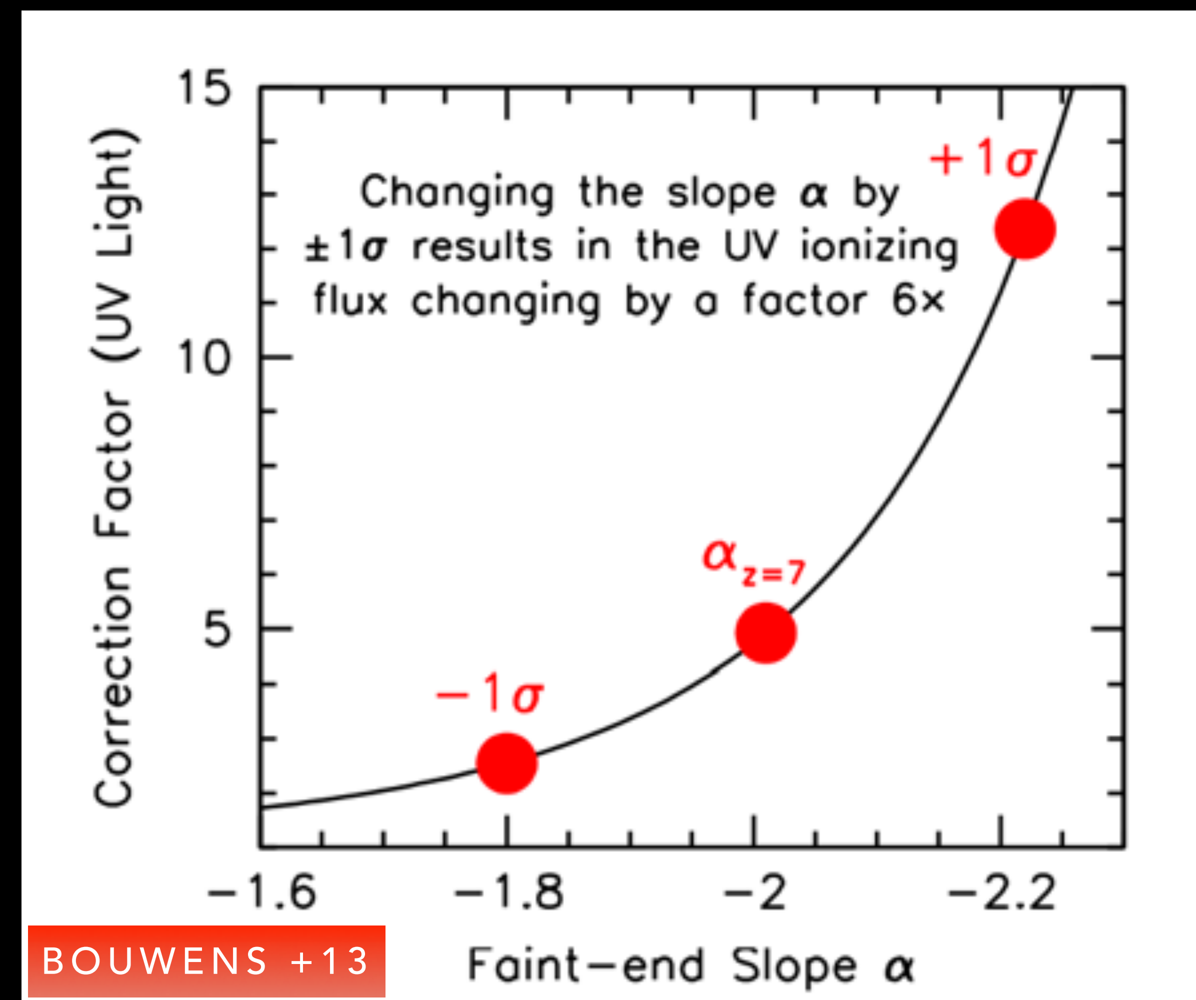
Names are omitted. Text is intentionally illegible… don't even try. Just look at the colours.

At high-z, this is who we got:

Who we need:

LUMINOSITY FUNCTION OF HIGH-Z GALAXIES






TEPLITZ


CAPAK


MALHOTRA


RHOADS


COE


PANELS CREDIT: MOUSTAKAS

Dan Coe
(STScI)

Appendix B,
p. B-4
SDT Final Report

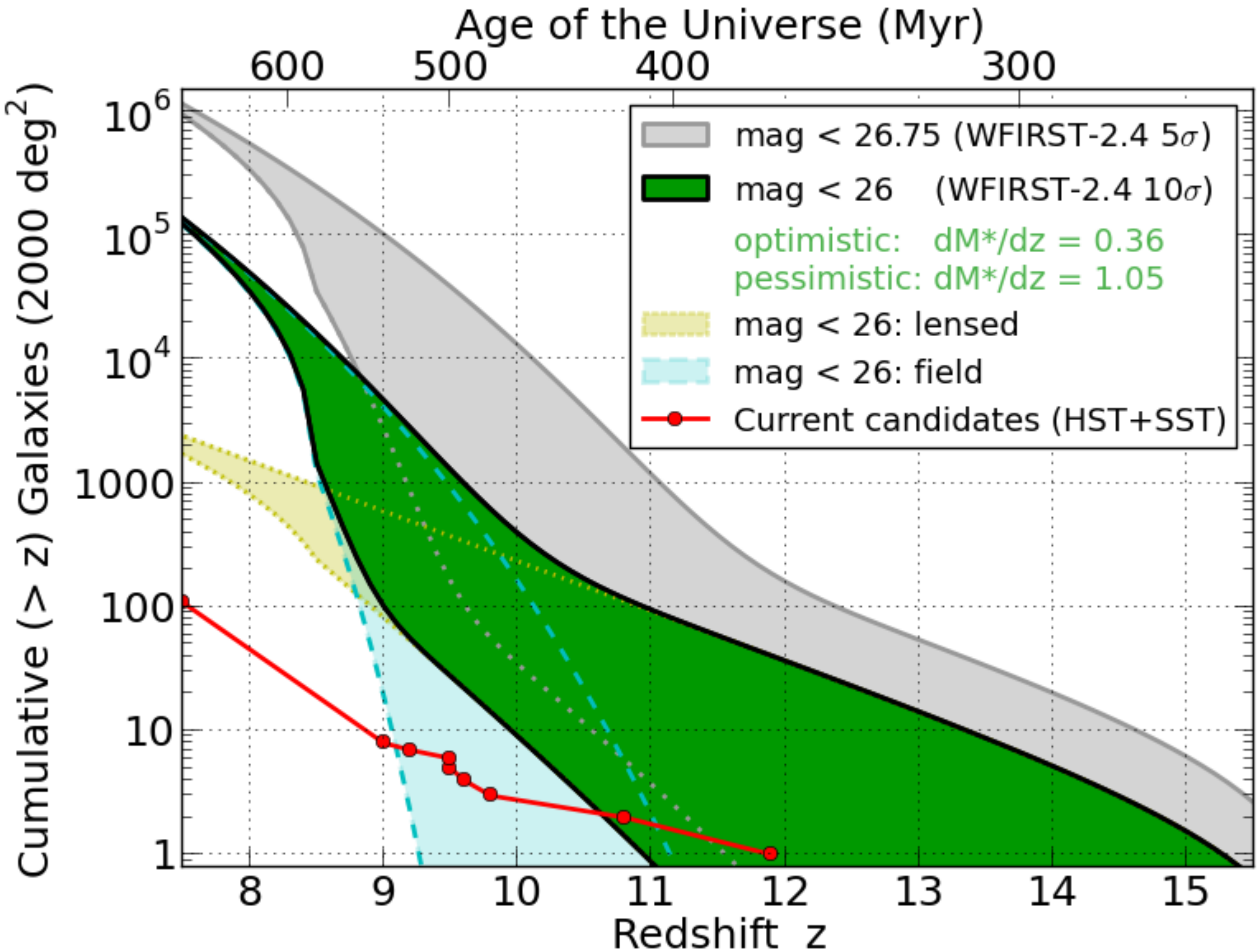
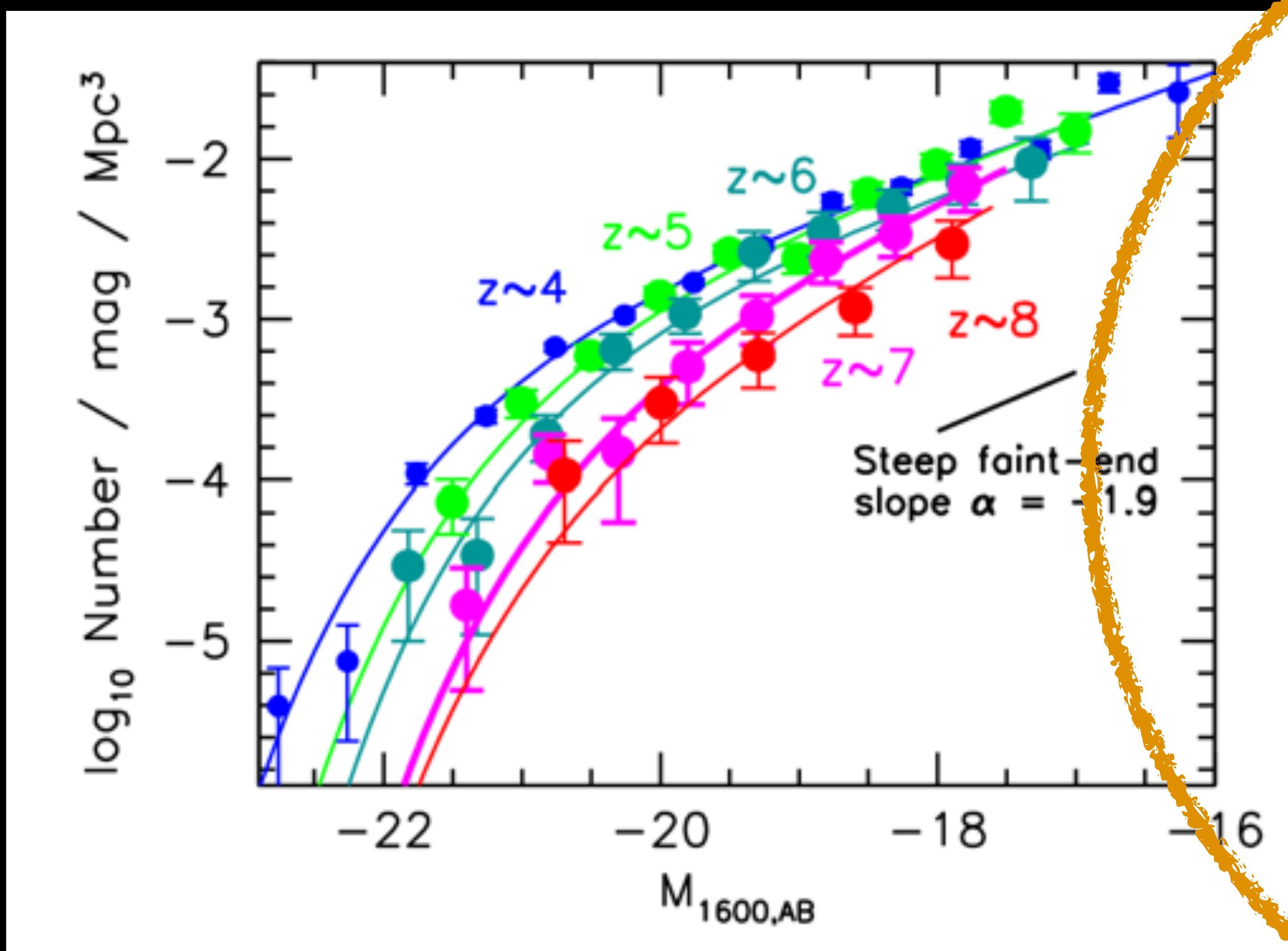


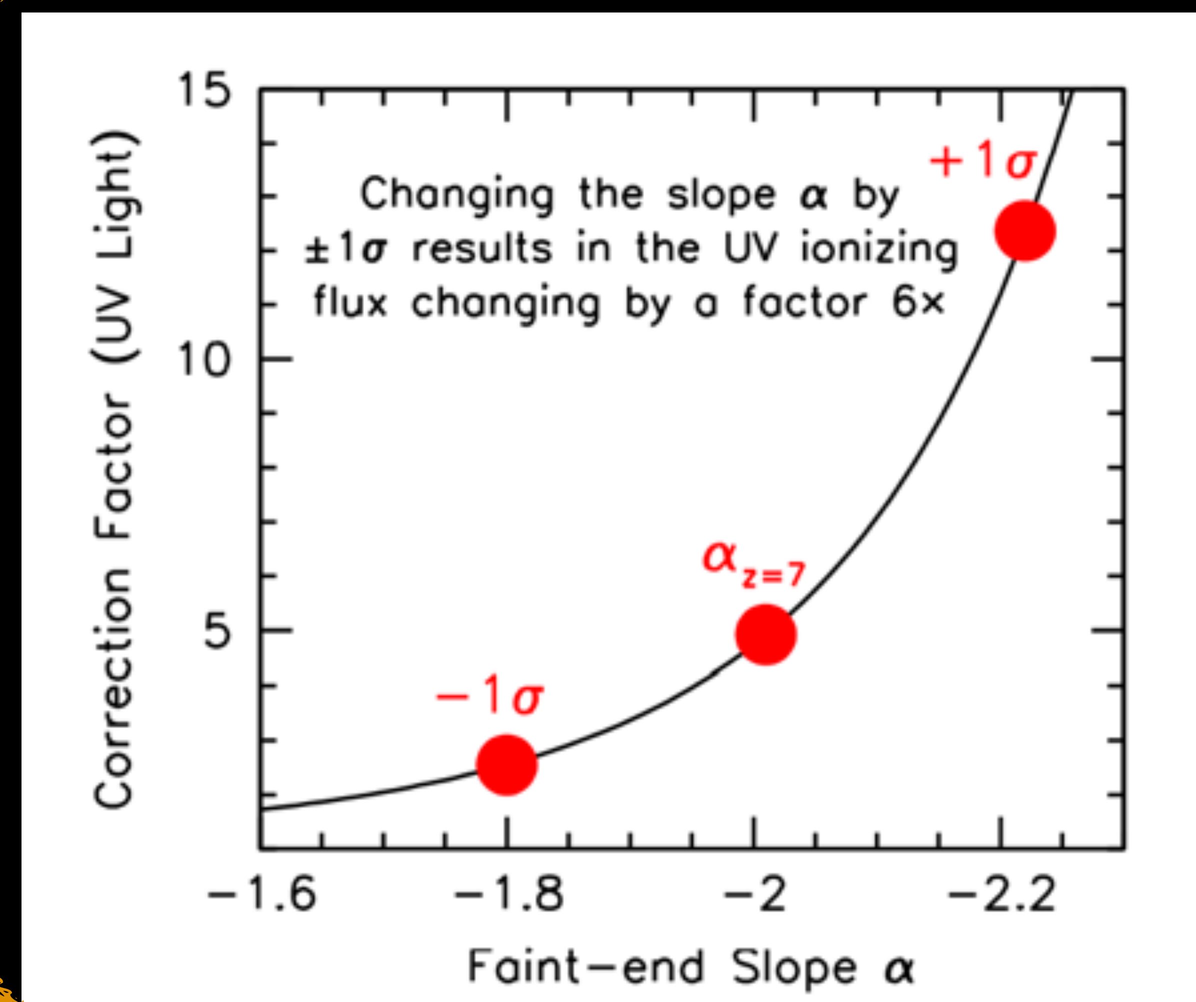
Figure 2-10: Cumulative number of high-z galaxies expected in the HLS. JWST will be able to follow-up on these high z galaxies and make detailed observations of their properties. For understanding the earliest galaxies, the synergy of a wide-field telescope that can discover luminous or highly magnified systems and a large aperture telescope that can characterize them is essential; WFIRST-2.4 and JWST are much more powerful than either one alone.

At high-z, this is who we got: 

Who we need: 

LOOK A LITTLE MORE CLOSELY AT THIS...





Bouwens +13

FINDING 100,000+ Z>6 GALAXIES, WHILE SPECTACULAR, DOESN'T SOLVE EVERYTHING. NEED TO INVOKE THE 'S WORD'.

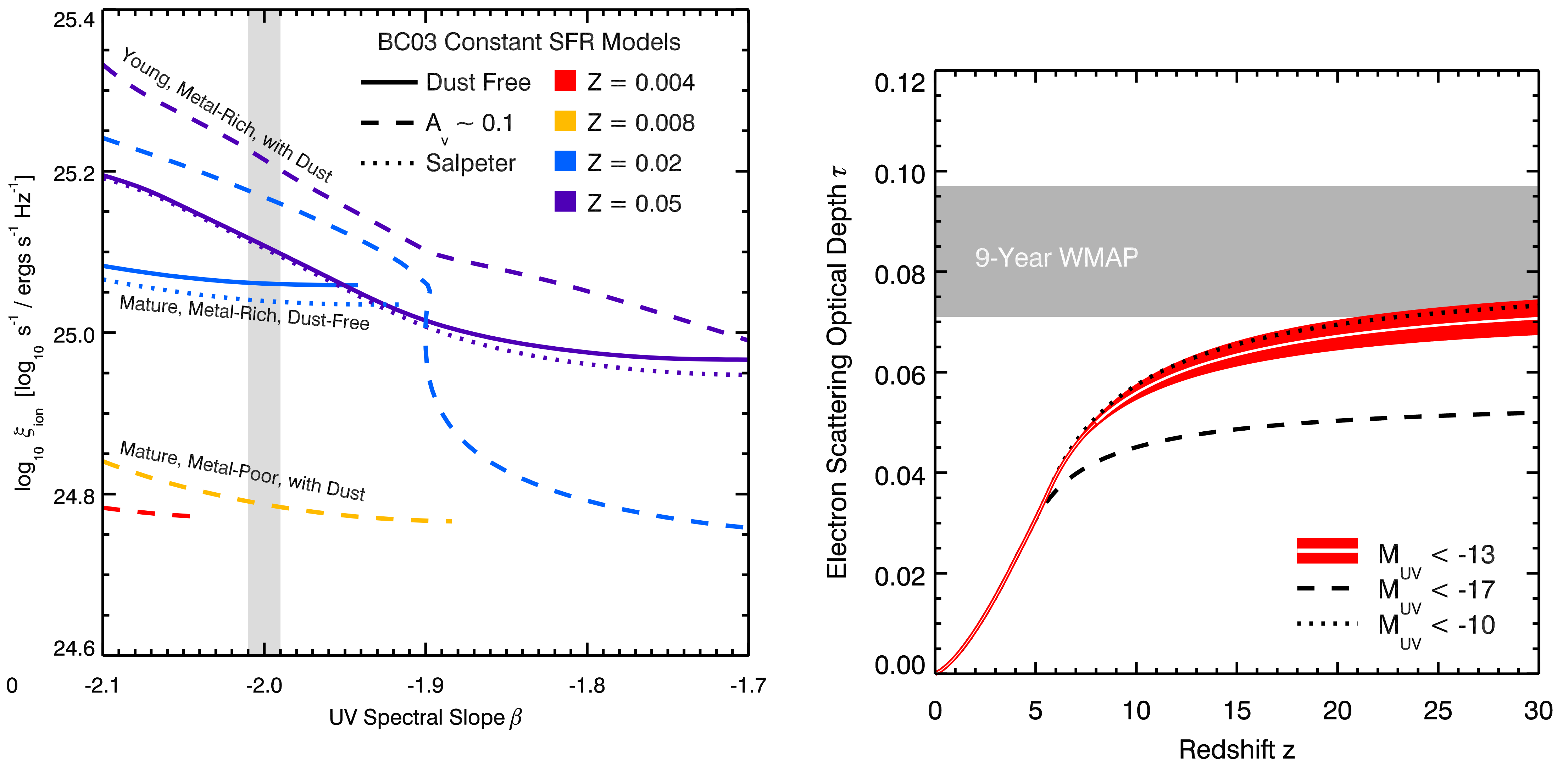
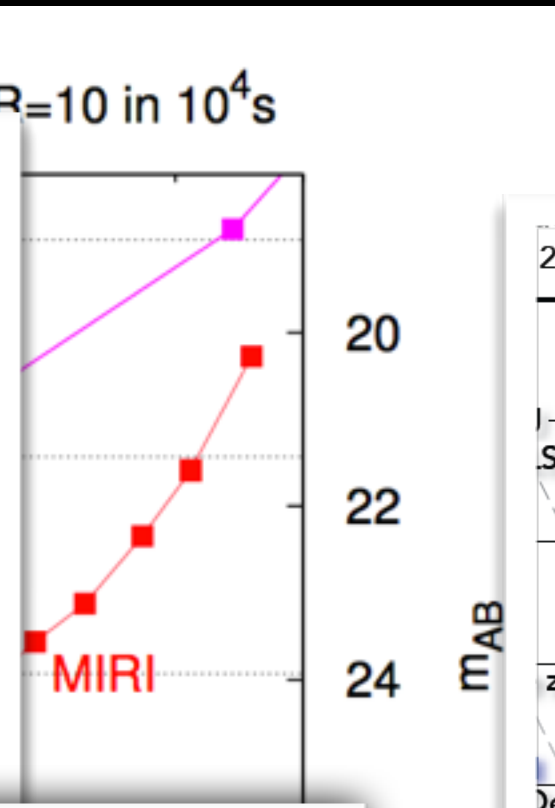
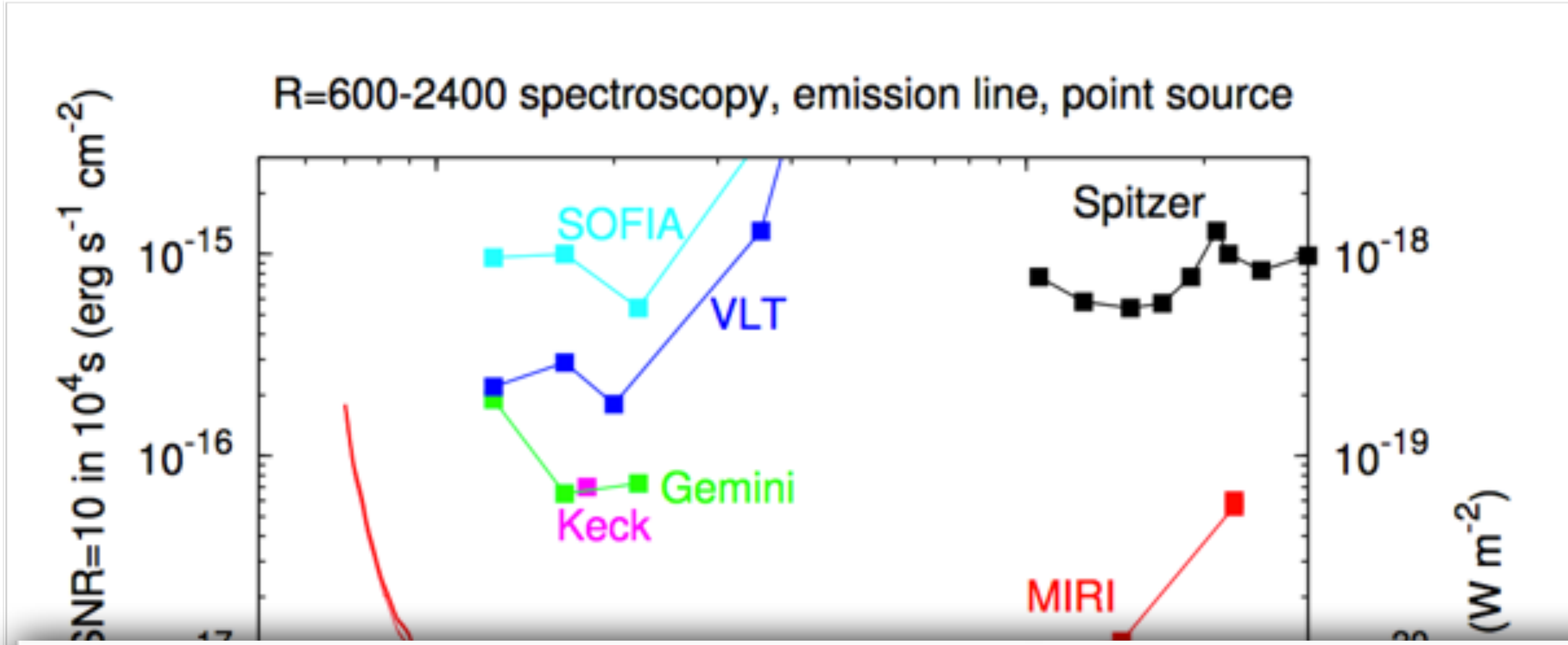
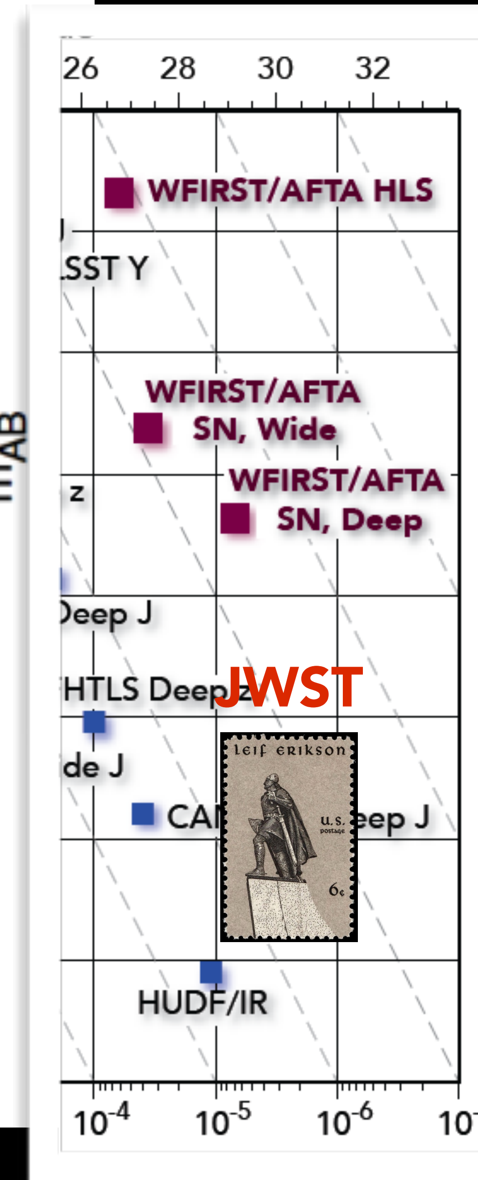


Fig. 4. **Left:** Degeneracies in inferring the ionizing photon production factor ξ_{ion} in terms of the observed slope β of the ultraviolet continuum, the gray shaded area being that observed for $z \simeq 7-8$ galaxies[42] . Time tracks are shown for stellar population synthesis models of varying dust content, metallicity and the initial mass function[30] . **Right:** One aspect of the UV 'photon shortfall' for galaxies as agents of reionization given the abundance of galaxies in the UDF. Assuming a 20% escape fraction and continuity in the declining star formation rate density beyond $z \simeq 10$, the figure shows the need to extend the UV luminosity function lower than the current $M_{UV} = -17$ detection limit to reproduce the optical depth of electron scattering in the WMAP data[30] .

CREDIT: ELLIS REVIEW ON ASTRO-PH: 1411:3330







TMT IRIS

Table 8: Imager point source sensitivity for Y, J, H, K using a 2l/D aperture size to achieve a signal-to-noise of 100 in a 5 hour integration.

Filter	Exp. Time (secs)	Number of Frames	Magnitude (AB)
Y	900	20	28.4
J	900	20	27.8
H	900	20	27.3
K	300	60	26.9

Table 10: Spectrograph point source sensitivity in 0.004" scale using a 2l/D aperture size to achieve a signal-to-noise per spectral channel of 10 between OH sky emission lines

Filter	Scale (mas)	Exp. Time (secs)	Number of Frames	Magnitude (AB)
Y	4	900	20	26.20
J	4	900	20	26.42
H	4	900	20	26.39
K	4	300	60	25.13

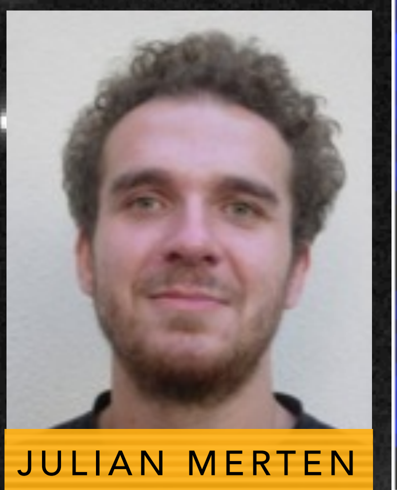
NOT
UE?

Jane Rigby

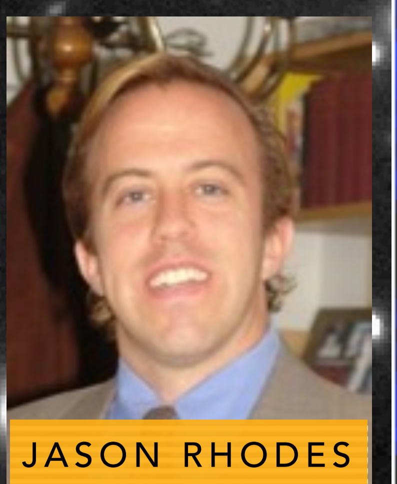
LENSING

FIELD: INCREASE # KNOWN STRONG LENSES BY 100X

DAN STERN



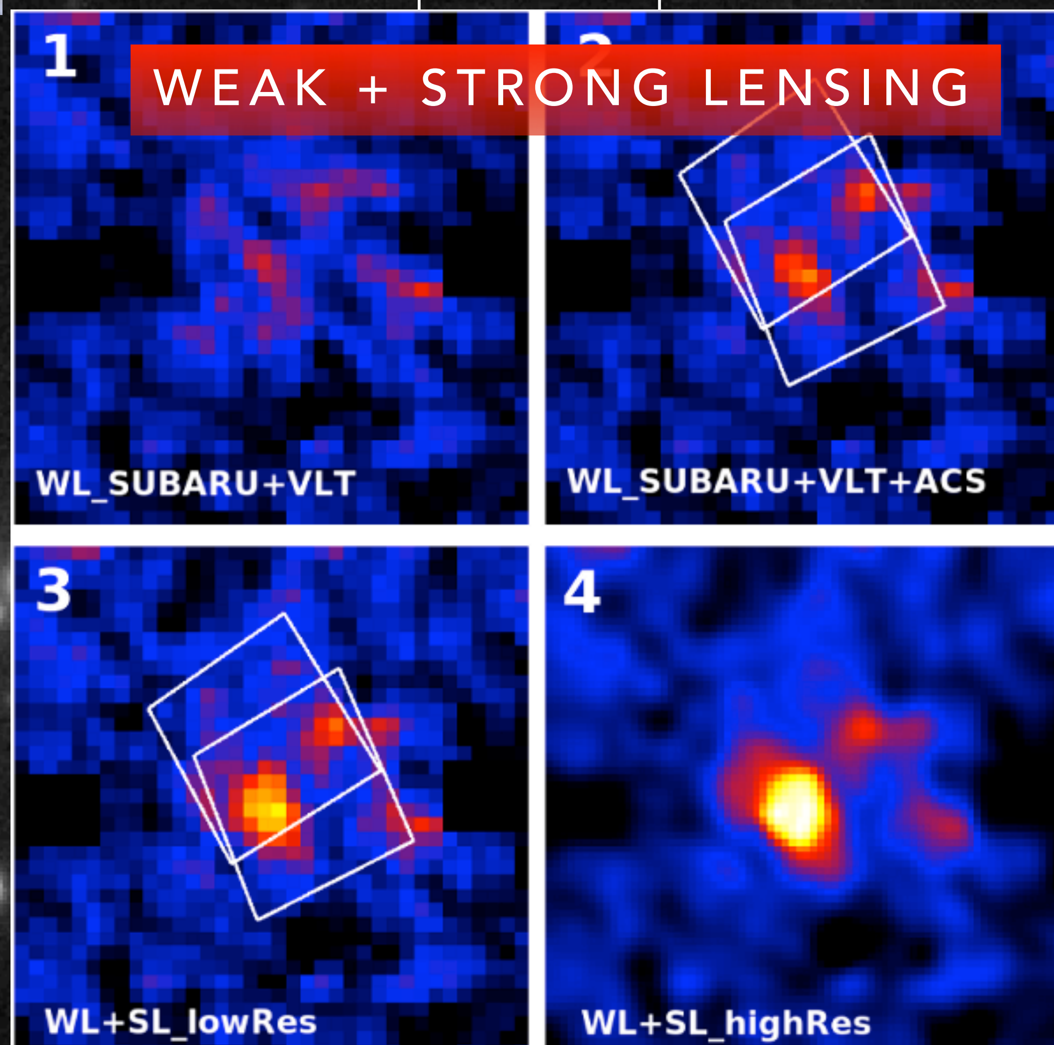
JULIAN MERTEN



JASON RHODES

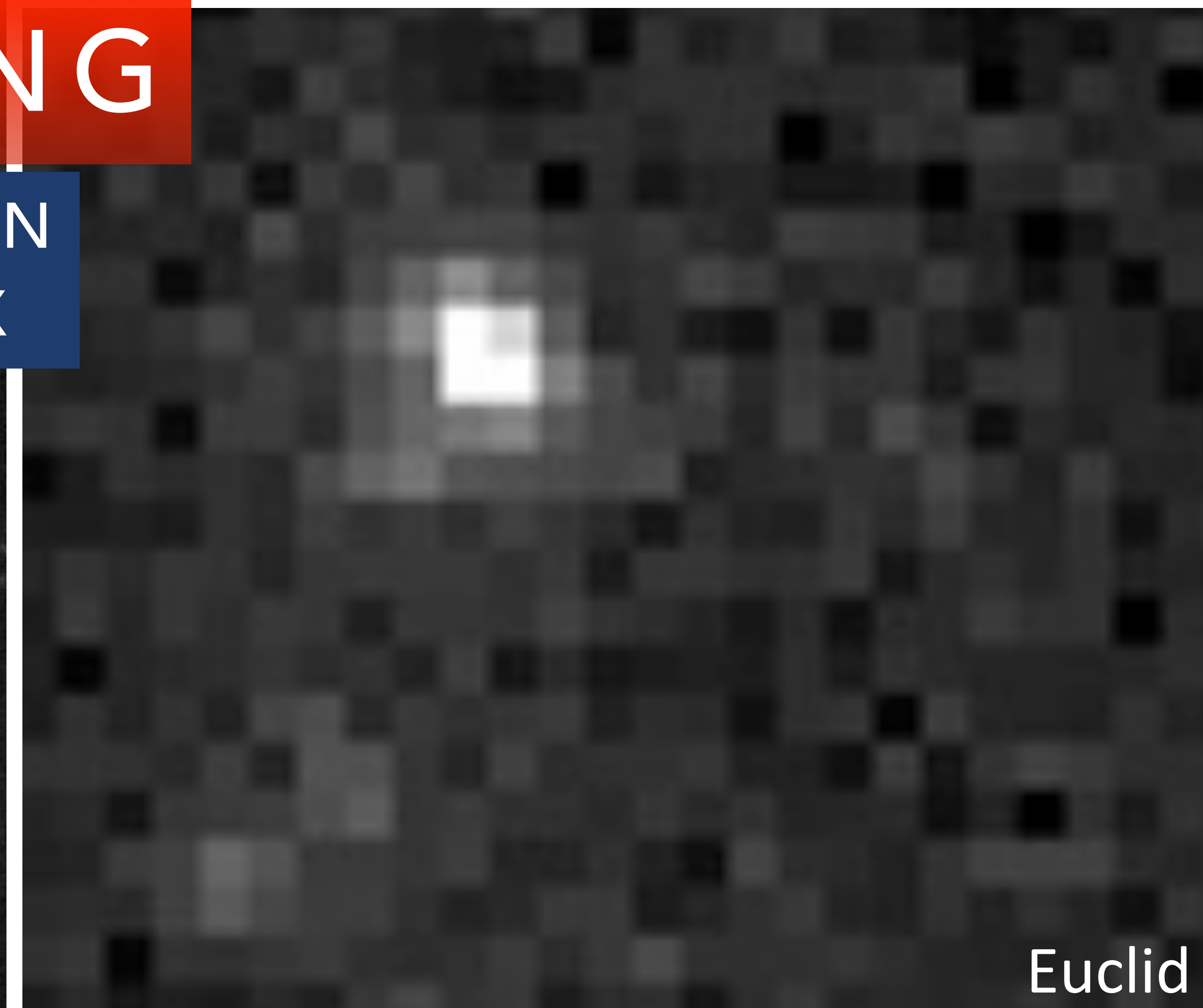
TOMMASO TREU

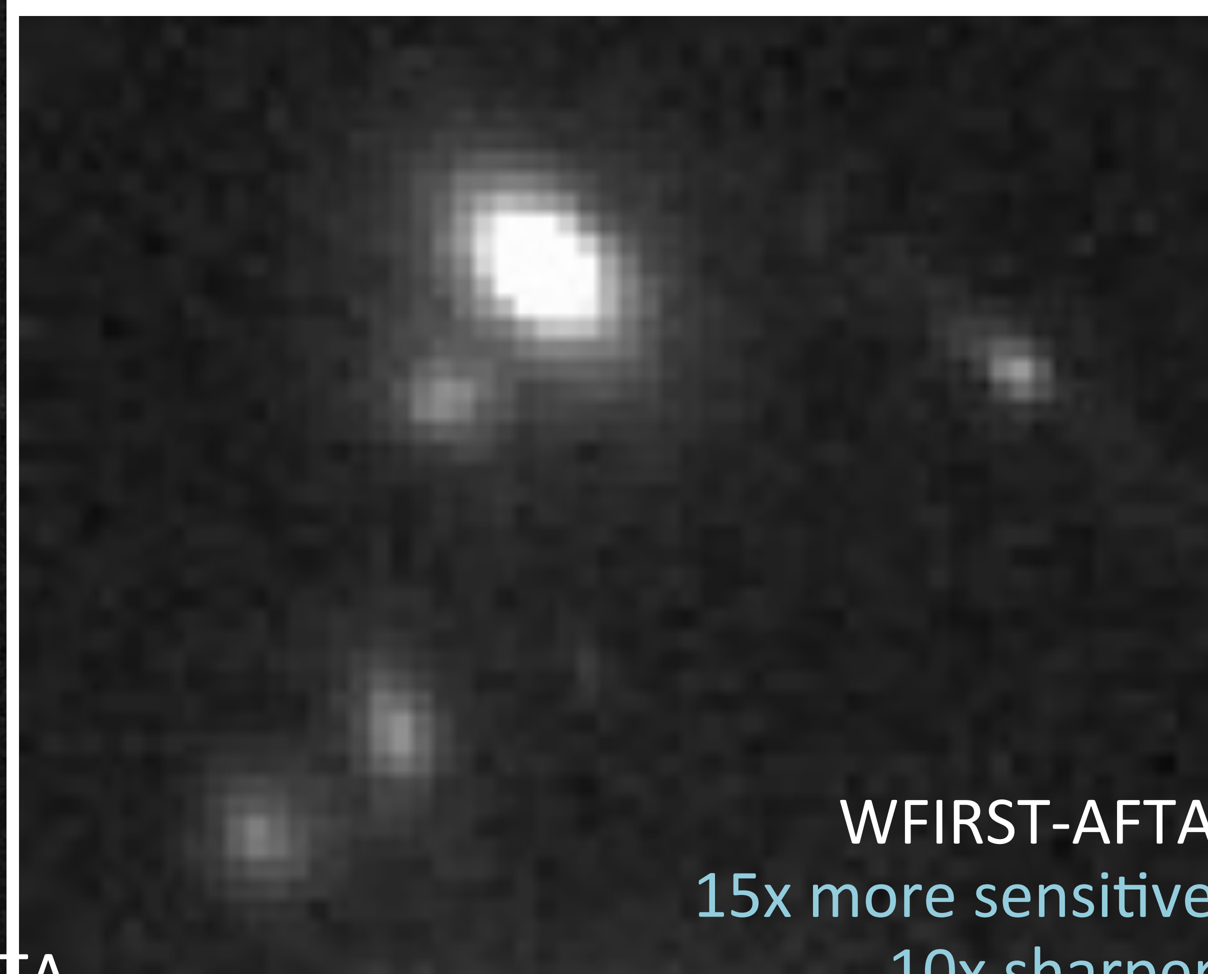
WEAK + STRONG LENSING



FIELD:
DM SUBSTRUCTURE
COSMOLOGY

CLASH cluster, simulated to WFIRST-AFTA



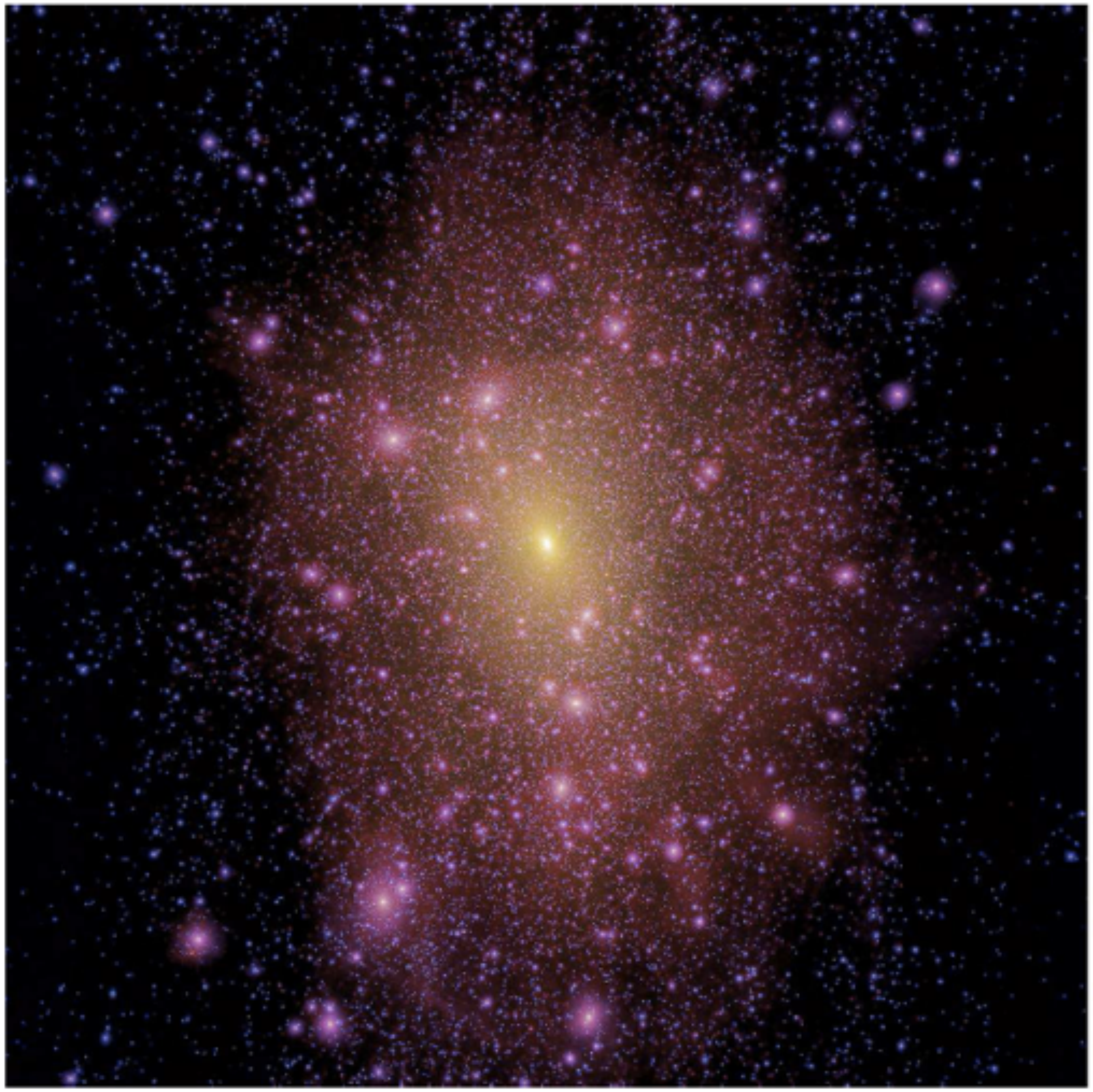


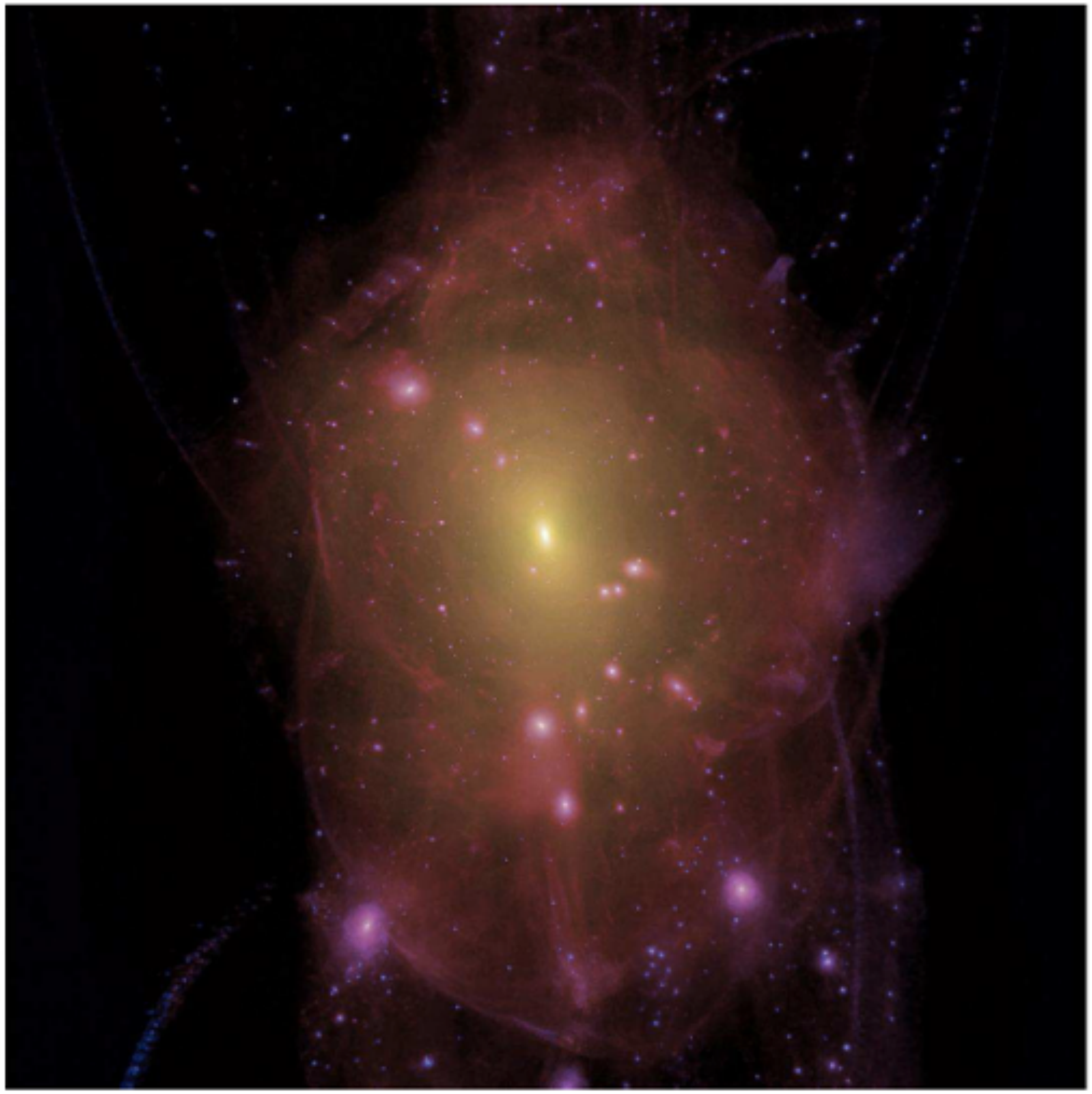
RED is good GREEN is good

LSST	ELT	Euclid	JWST	Other	X	HLS?
No. Need to resolve stars.	Maybe. Do small fields in galaxies.	No (need IR, need colors)	Yes, over small areas.	No	No	No
Maybe	No	No	No	No	No	No
No	No-ish. Synergy discussed explicitly.	No – need colors	Yes – but need area for rare populations.	Yes	Yes	No
No	No	No	No	No. But I'm not super convinced WFIRST can do this either.	Yes	No
No (need resolution)	No (AO corrected FoV too small)	No. Need colors to disentagle stellar pops.	Yes. Perfect NIRCam case. Wide FoV requirement not justified in view of CANDELS etc.	No	No	Yes
No (need resolution)	No (need wide area to find rare objects)	Yes-ish. But benefit from increased resolution	No-ish. Targets are rare and JWST won't get you to thousands.	Yes	Yes	Yes
No. Lines are in IR.	No. Targets are rare.	No. Needs grism.	Yes-ish. Probably can do this with NIRISS in in parallel mode if that is formally supported.	No	Yes-ish. Sort of a super HST-3D	Yes
No. Needs resolution.	No. Targets are relatively rare.	Yes	No	No	No	Maybe
No. Needs resolution.	No. Targets are relatively rare.	Yes	No	No	No	Maybe
Yes	No.	Yes.	No. Needs wide area.	No	No	Yes
No. Needs deep IR.	No. Targets relatively rare.	Yes. Need ground-based confirmation of redshifts.	No. Needs wide ara.	High-redshift clusters are being found using many other techniques.	No	Yes. Though HLS has only 1/4 the area they want. Still, it would find many clusters.
No. Needs deep IR.	No. Targets are relatively rare.	No. Relies on photo z's.	Yes. Targeted follow-ups.	No.	No	No.
No.	No	No (needs grism)	Yes. Smaller area though deeper. Probably could gauge cutoff z that way as the targets are pretty abundant.	No	Yes	300h program would yield several thousand Lyman alpha emitters at z>8 in the absence of neutral gas. Point is to determine where it cuts off.
No (need IR)	No. Targets 20-100/deg^2	No. Need IR colors	Yes, but quite ineffecient.	No	No	Yes
No	No	No	No	No	Yes	Yes
No-ish. LSST find them, but hard to tell if lensed.	No	No	No	No	Yes	Yes
No-ish. LSST will find many nearby, but not any at z>10	No	No	No	No	Yes	Yes
No	No	No	Yes	No	No	Yes
No	No	No	No	No	Yes++	Yes
No	No	No	Yes	No	No	Yes
No	No	Yes-ish. But WFIRST will be a huge step up.	No	No	Yes	Yes
No	No	No	Yes. But WFIRST will allow LF etc to be computed. Probably a big step up.	No	Yes	Yes
No	No	No	No	No	Yes++	Yes

Tommaso Treu
wrote this one

Warm Dark Matter





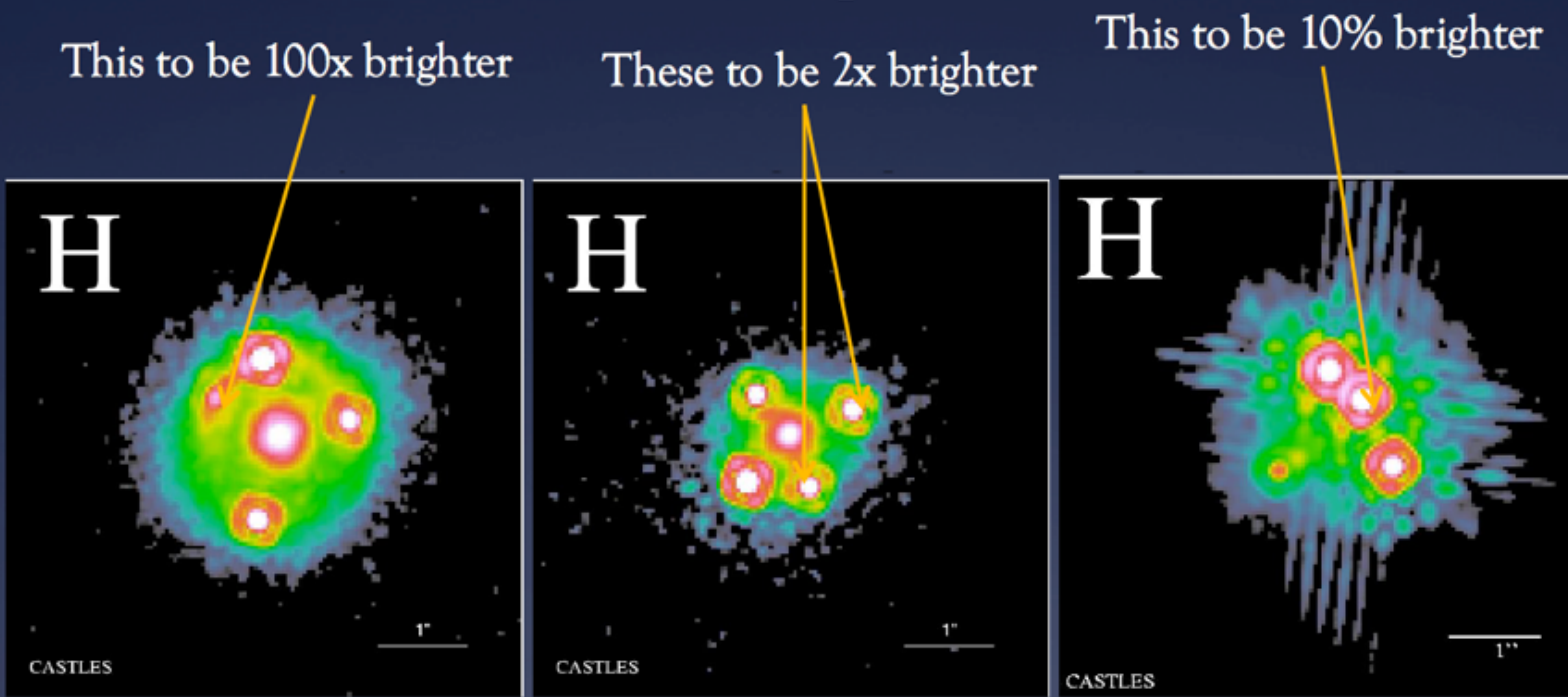
Free streaming ~kev scale thermal relic

Lovell et al. 2012

Slide credit: T. Treu

Flux Ratio Anomalies

A smooth mass distribution would predict:



What causes this the anomaly?
1.Dark satellites?
2.Astrophysical noise (i.e. microlensing and dust)?

Slide credit: T. Treu

In addition to probing substructure, strong lenses used for time delay *cosmology* will be interesting.

SUYU ET AL.

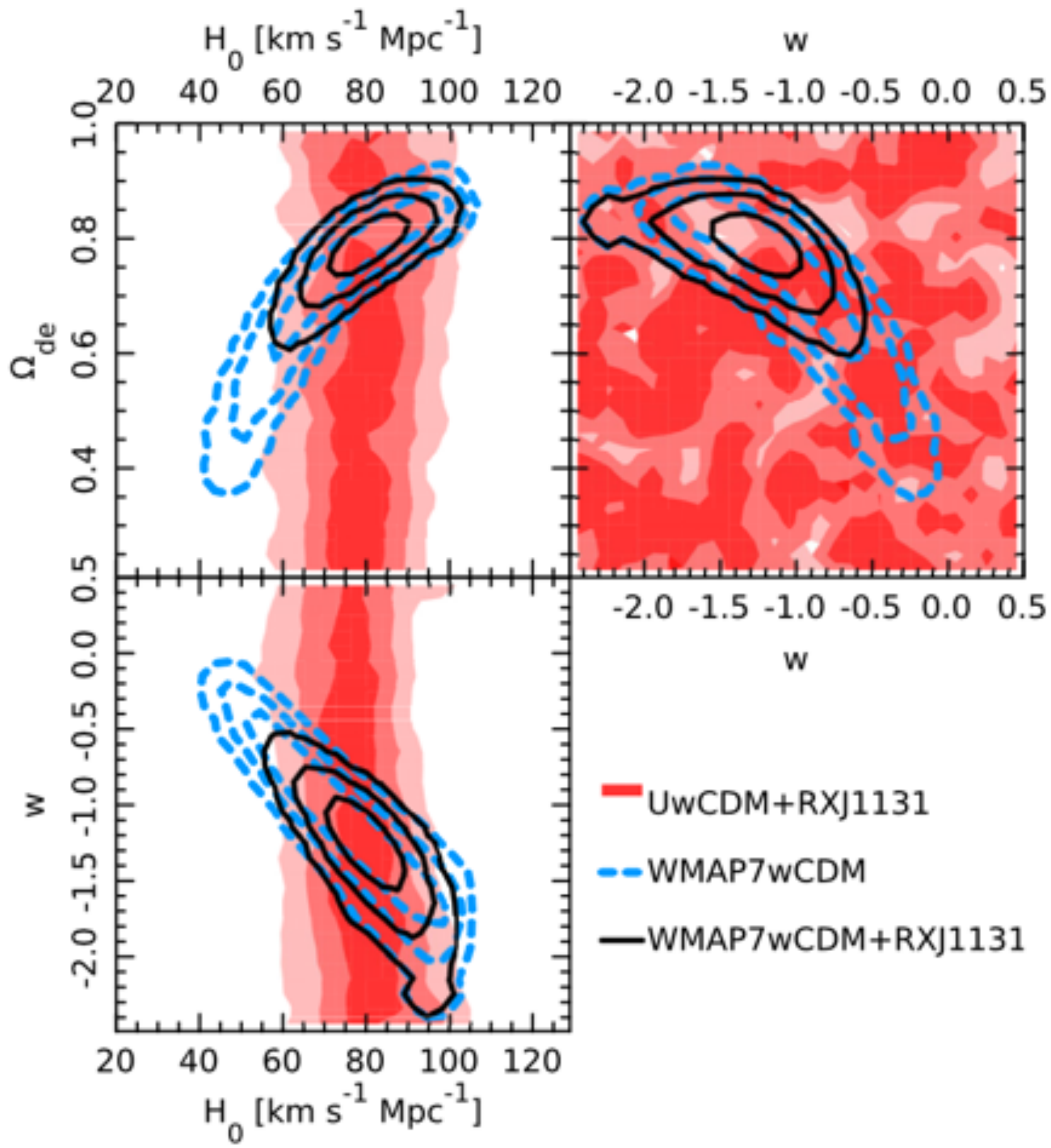
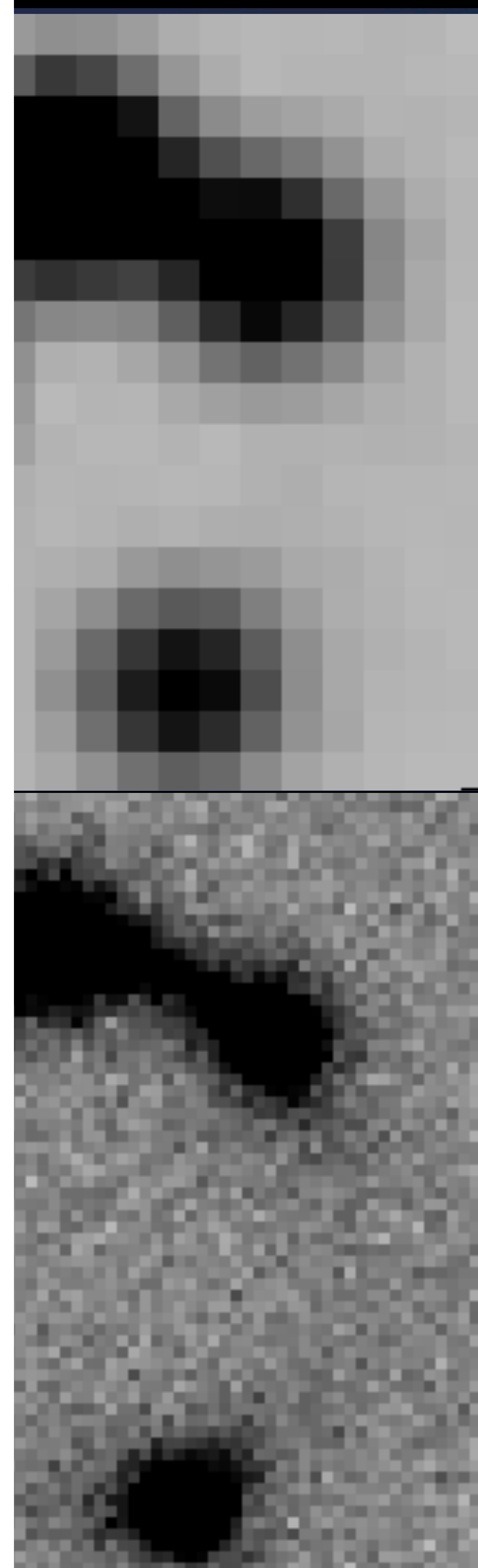


Figure 8. RXJ1131−1231 marginalized posterior PDF for H_0, Ω_{de} , and w in flat wCDM cosmological models. Contours/shades mark the 68.3%, 95.4%, 99.7% credible regions. The three sets of contours/shades correspond to three different prior/data set combinations. Shaded red: RXJ1131−1231 constraints given by the UwCDM prior; dashed blue: the prior provided by the WMAP7 data set alone; solid black: the joint constraints from combining WMAP7 and RXJ1131−1231.

(A color version of this figure is available in the online journal.)

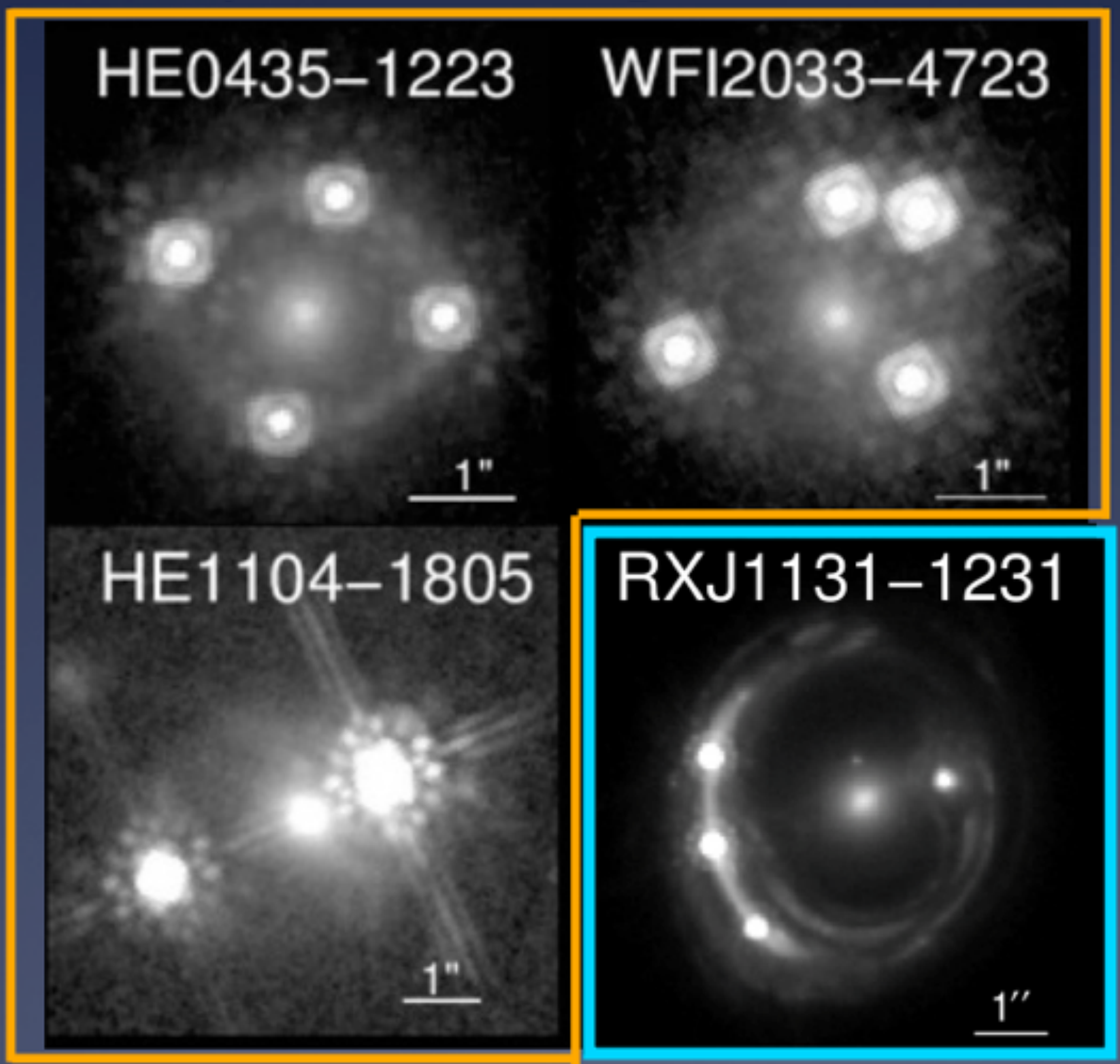


Meng, Treu + 14 (in prep)

Immediate Prospects

- time delays of lensed quasars from optical monitoring
- expect to have delays with a few percent error for ~20 lenses

HST
cycle 20
follow up

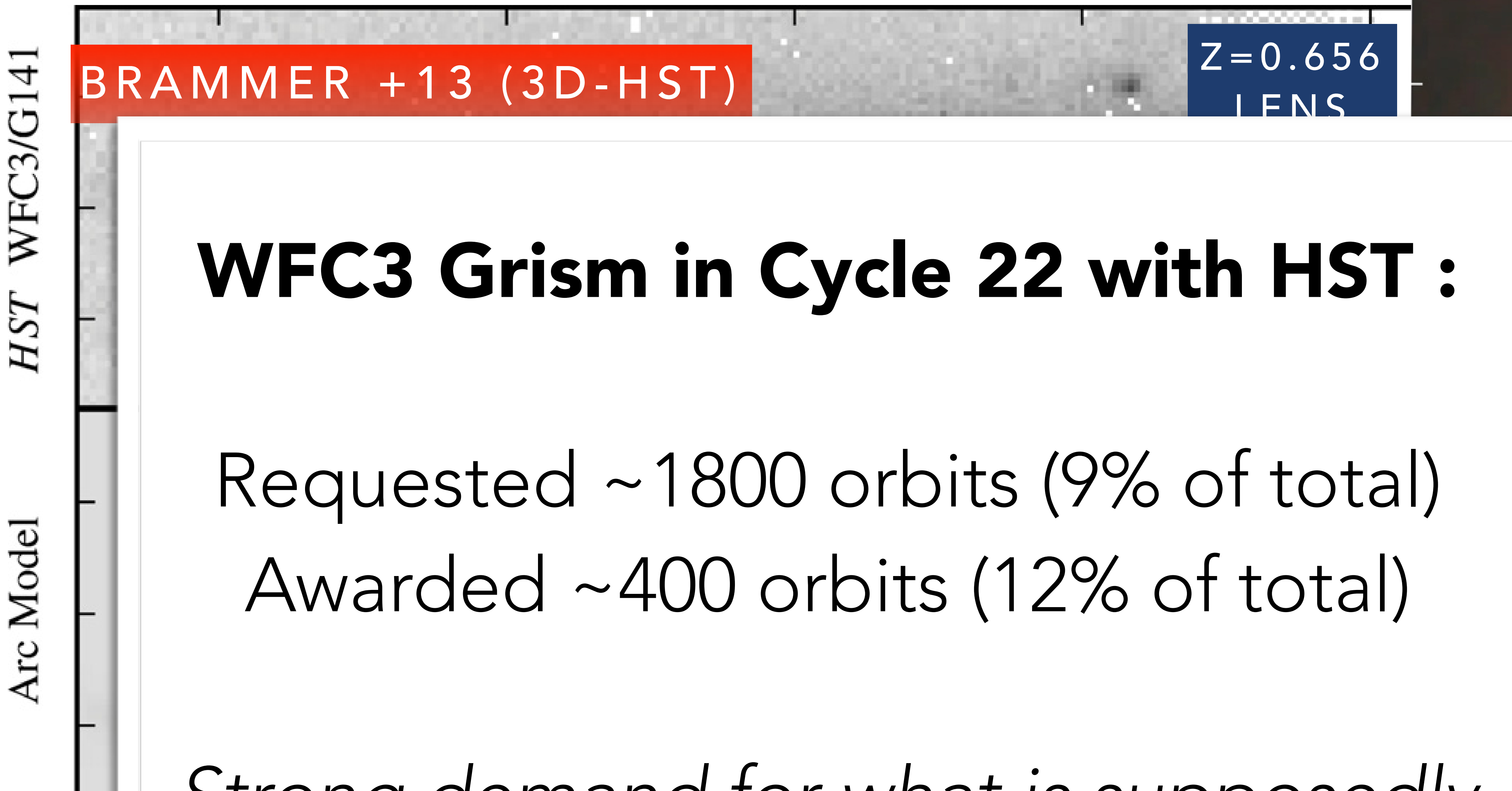


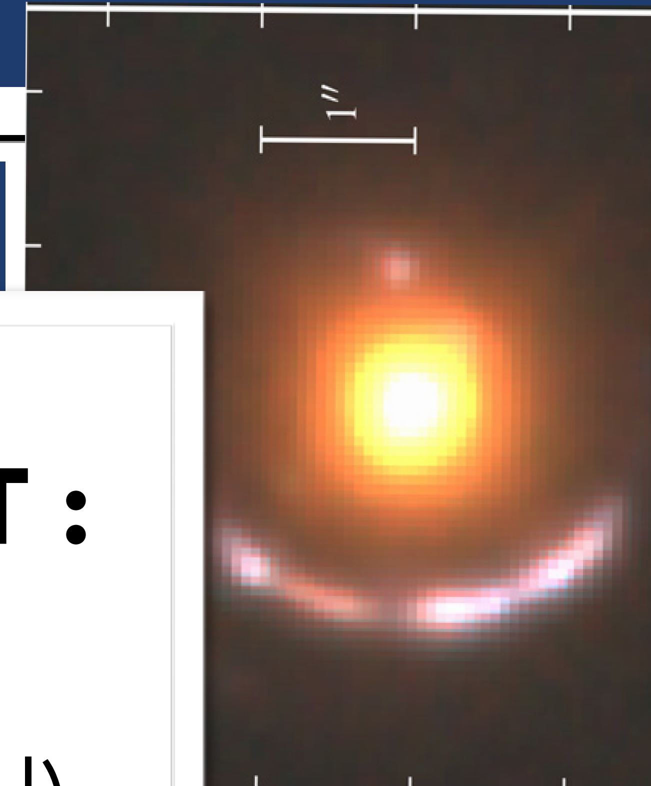
HST archival
images for
lens modeling

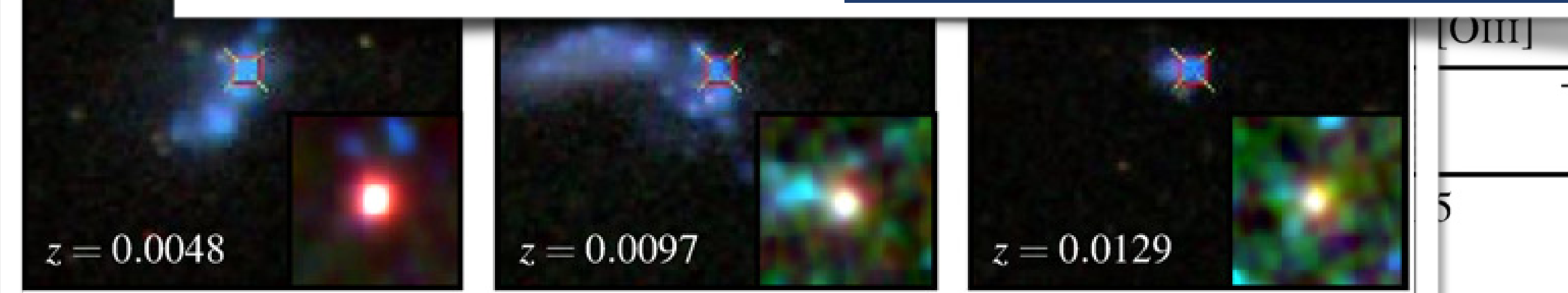
How to find the lenses

- Carry out large imaging survey.
  - QSO forecasts by Oguri & Marshall (2010)
    - DES (~1000 lensed QSOs, including 150 quads)
    - LSST (~8000 lensed QSOs, including 1000 quads) after 10 years to get enough depth.
    - Or: WFIRST (>10000 lensed QSOs, including >1000 quads) from HLS.
- Find lenses:
  - Different strategies for lensed QSOs and galaxies (Marshall+, Gavazzi+,Kubo+,Belokurov+,Kochanek +,Faure+,Pawase+) and under development (Marshall, Treu, LSST collaboration)
  - Successfully demonstrated by Treu group

Slide credit: T. Treu







WFC3 Grism in Cycle 22 with HST :

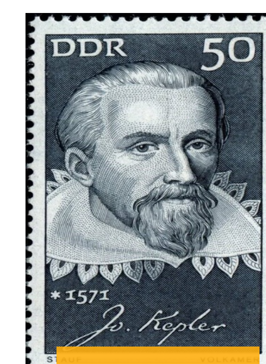
Requested ~1800 orbits (9% of total)

Awarded ~400 orbits (12% of total)

Strong demand for what is supposedly a "niche mode".

NUMBERS FROM: N. REID, STSCI


H. TEPLITZ



RHOADS


MALHOTRA

NOTE: NIRISS WILL HAVE ~20% THE RESOLUTION OF THE WFIRST GRISM R~150 VS R~700

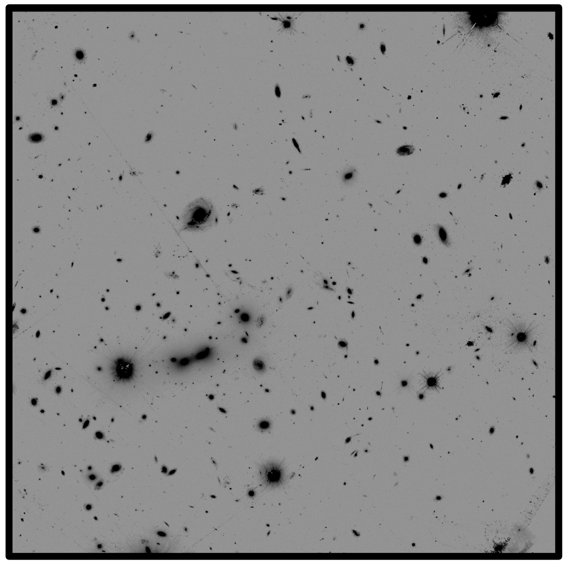
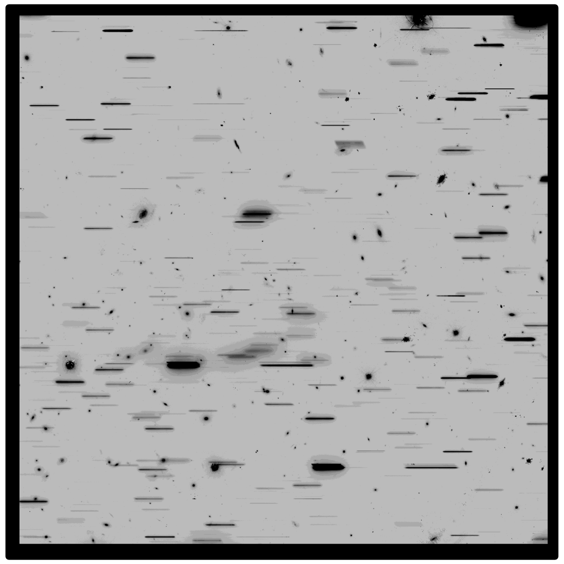
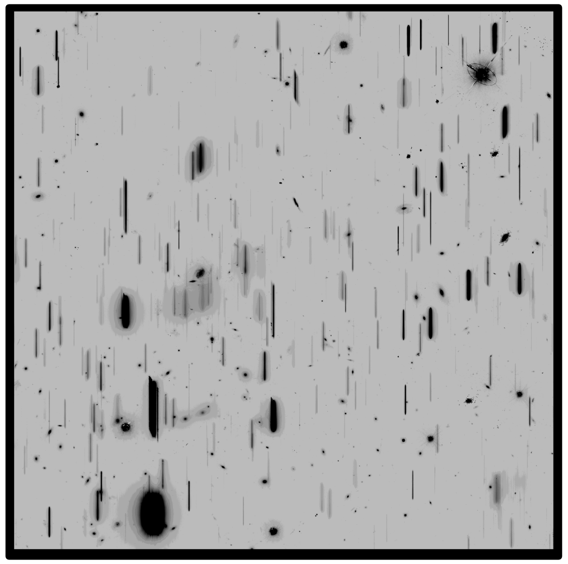


Image: F200W



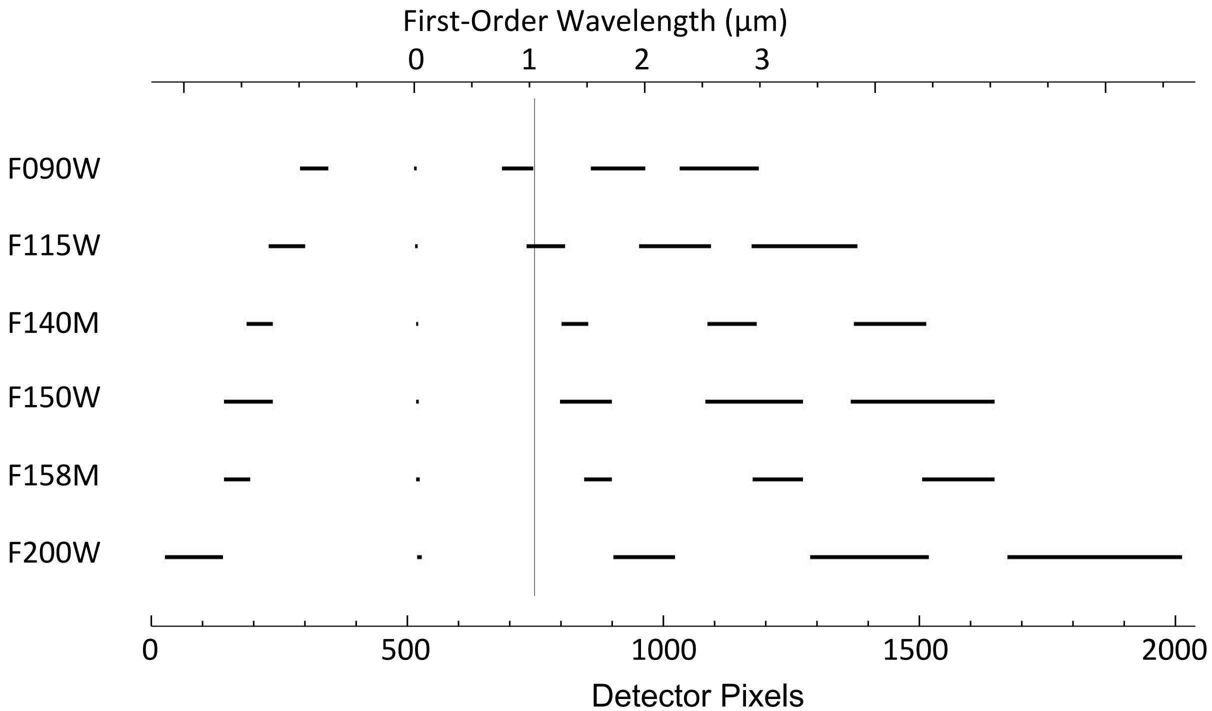
Spectra: GR150R, F200W



Spectra: GR150C, F200W

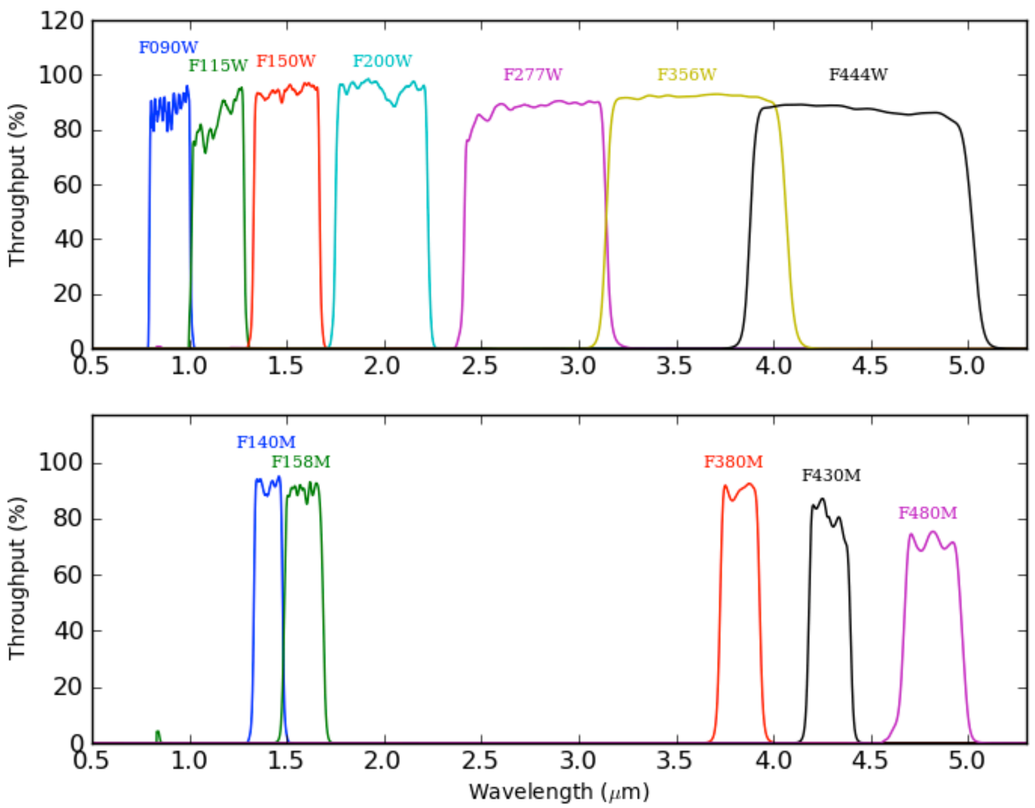
NIRISS ON JWST

Layout of Spectral Orders



Note: Direct image falls at 1.05 µm.

Filter Transmission Profiles



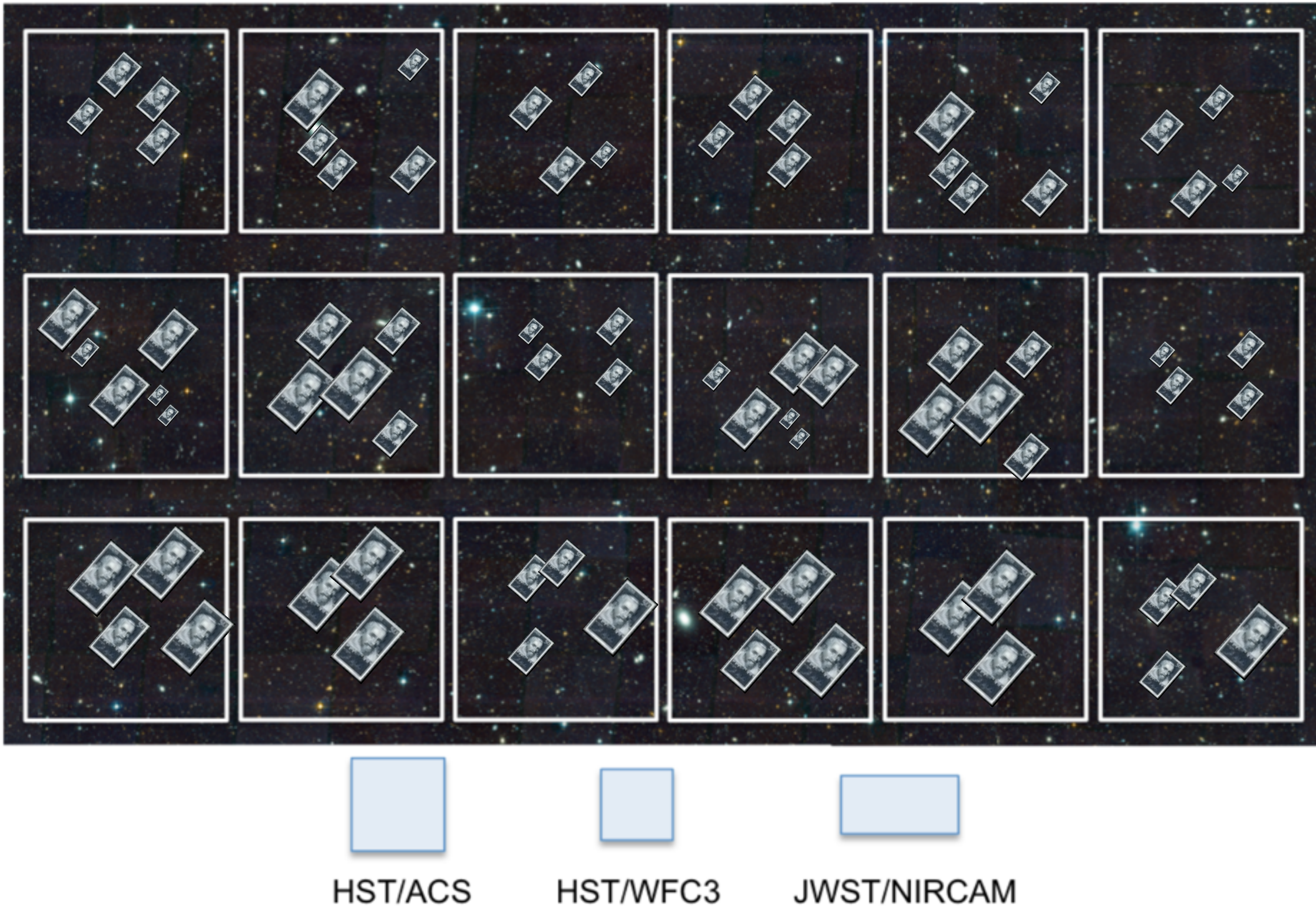


Figure 1-1: Field of view comparison, to scale, of the WFIRST-2.4 wide field instrument with wide field instruments on the Hubble and James Webb Space Telescopes. Each square is a 4k x 4k HgCdTe sensor array. The field of view extent is about 0.79 x 0.43 degrees. The pixels are mapped to 0.11 arcseconds on the sky.

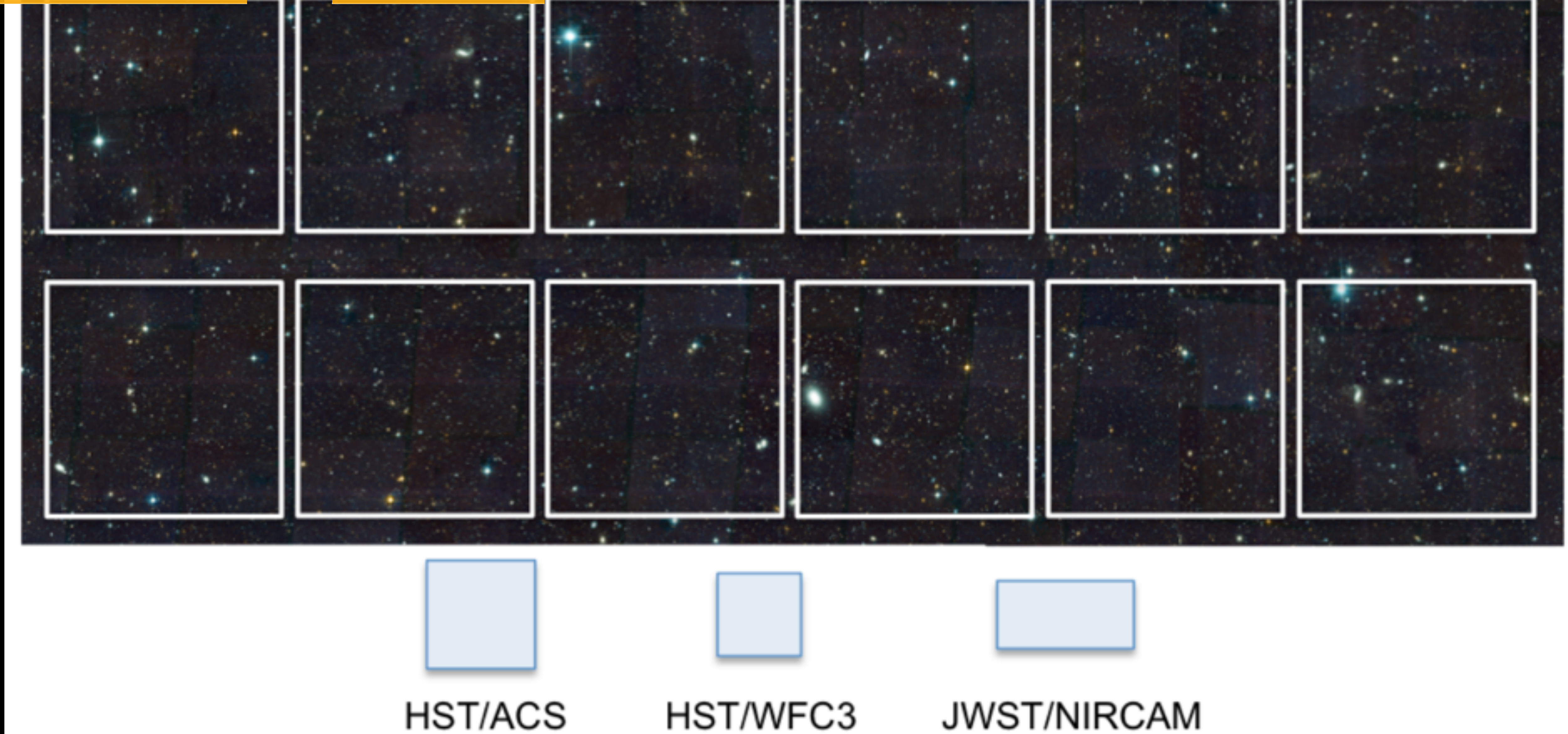


Figure 1-1: Field of view comparison, to scale, of the WFIRST-2.4 wide field instrument with wide field instruments on the Hubble and James Webb Space Telescopes. Each square is a 4k x 4k HgCdTe sensor array. The field of view extent is about 0.79 x 0.43 degrees. The pixels are mapped to 0.11 arcseconds on the sky.

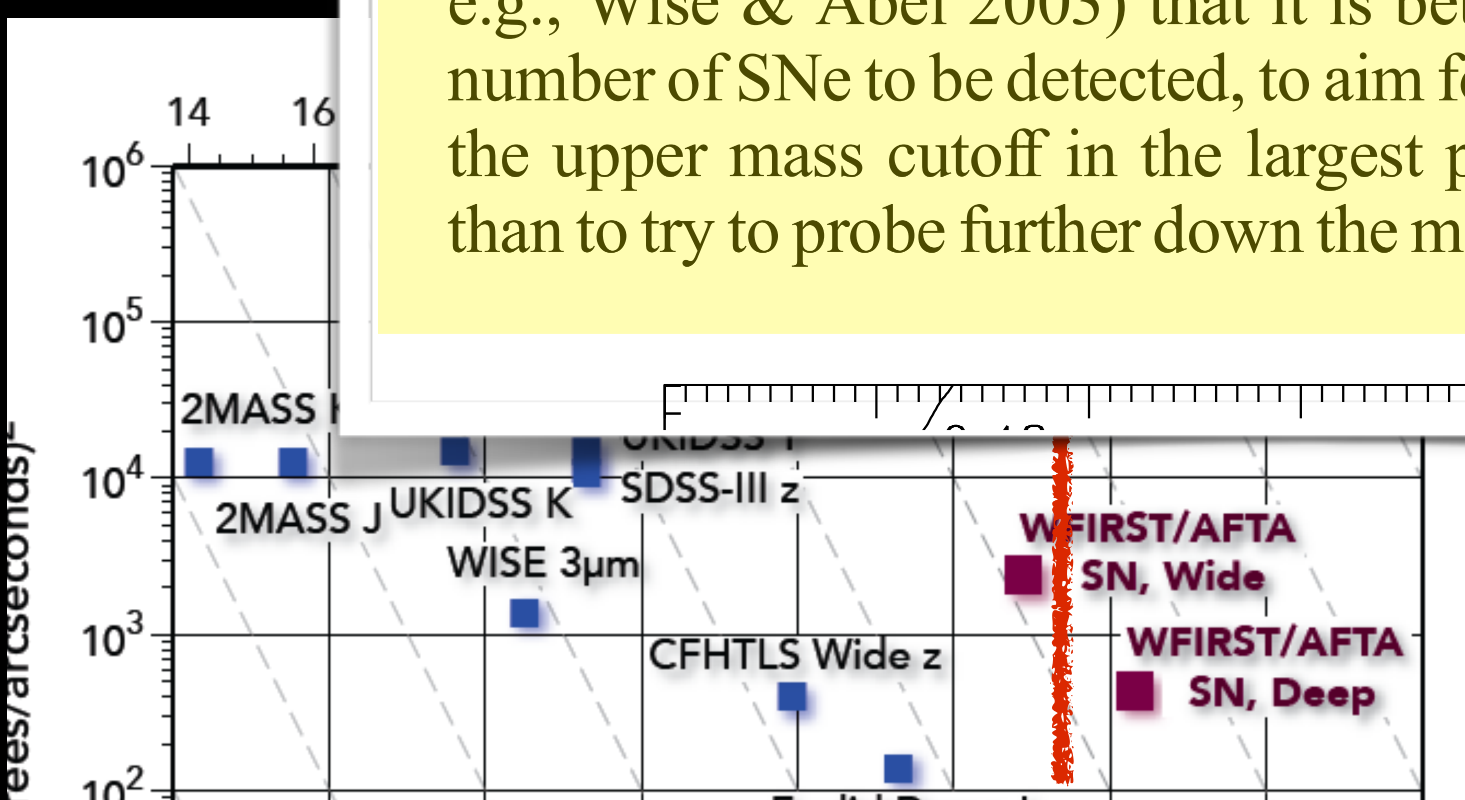
MASSIMO STIAVELLI

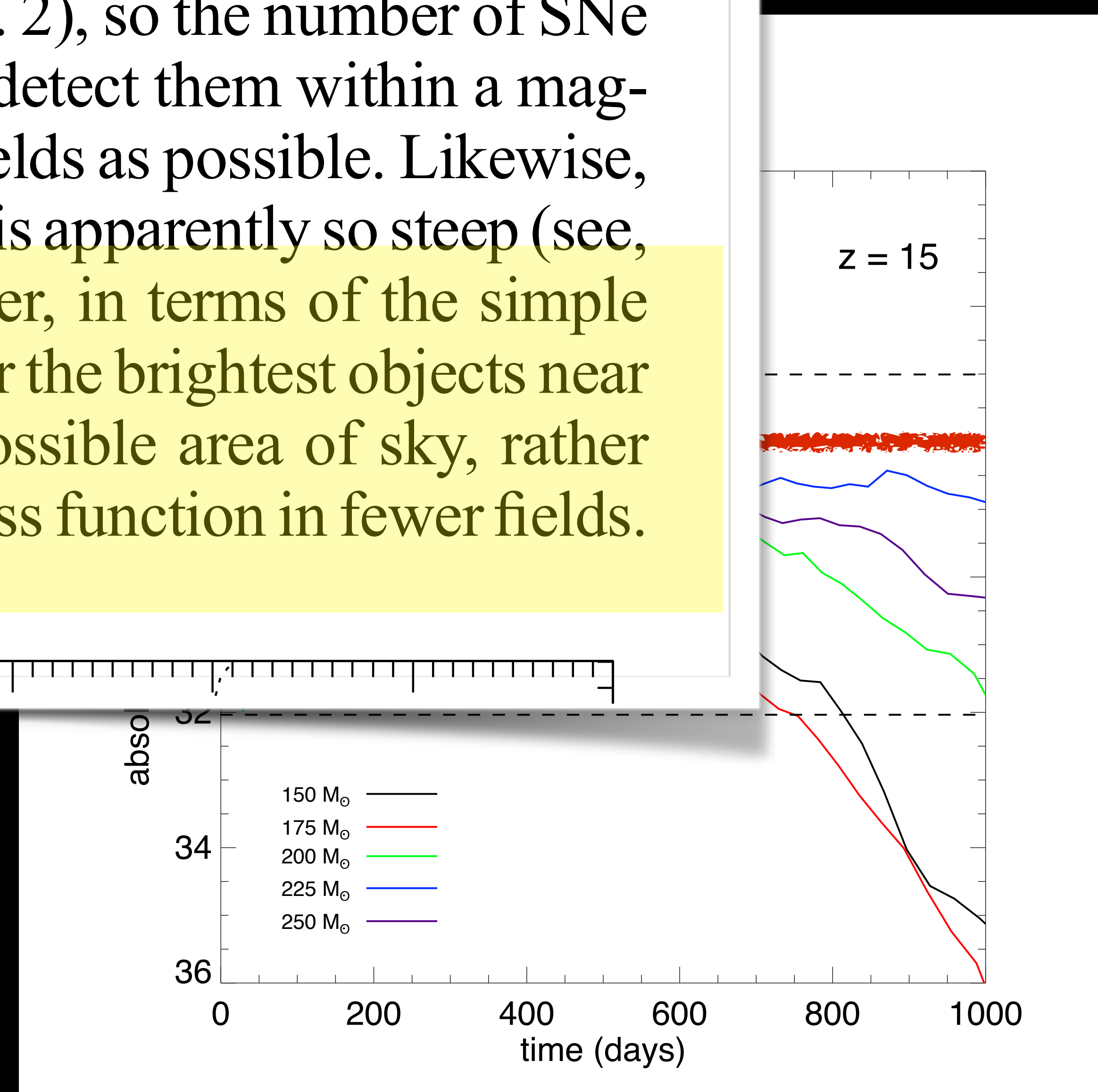
DAN WHALEN

POPULATION III PAIR INSTABILITY SUPERNOVAE

Huge variation in predicted rate:

further will also increase $\Delta t_{\rm vis}$, but the gain in $\Delta t_{\rm vis}$ varies as less than the square of the limiting flux (Fig. 2), so the number of SNe discovered is maximized by aiming to detect them within a magnitude or so of maximum, in as many fields as possible. Likewise, the mass-luminosity relation for PISNe is apparently so steep (see, e.g., Wise & Abel 2003) that it is better, in terms of the simple number of SNe to be detected, to aim for the brightest objects near the upper mass cutoff in the largest possible area of sky, rather than to try to probe further down the mass function in fewer fields.





HOW DOES ON DO THE"BEYOND THE LOCAL GROUP" SCIENCE MOST EFFICIENTLY?

COMMUNITY IMPACT

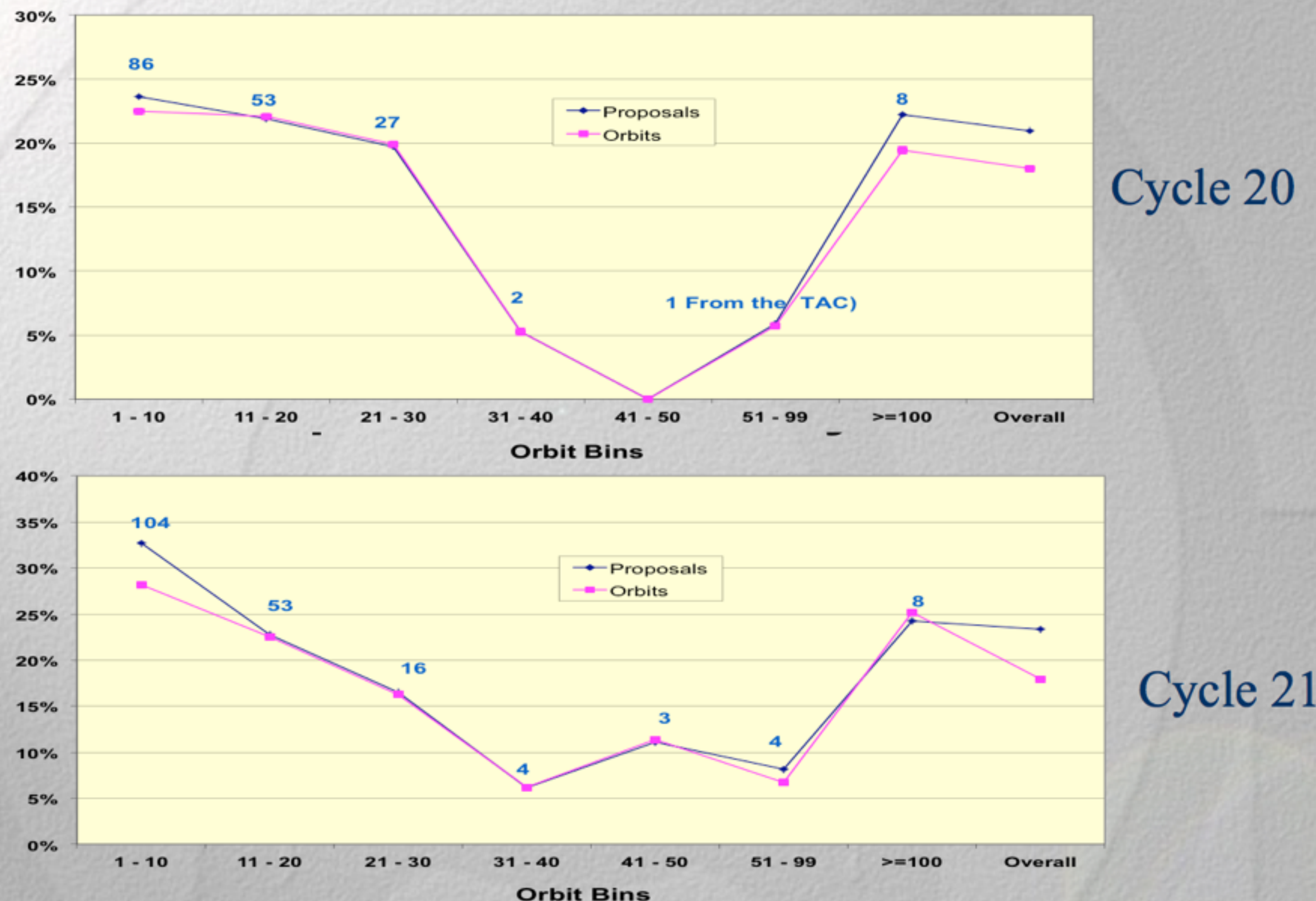
- Analysis of publications from HST programs (Apai et al, 2010, PASP) shows that
  - Small programs produce more papers per orbit, but individual papers have relatively low impact.
  - Large programs produce fewer papers/orbit, but more papers per program, and generally have a higher impact (more citations/ paper).
  - Programs on different scales tackle different scale science questions .
  - Treasury programs have more publications than Large programs.
  - Multi-cycle Treasury programs have the prospect of being more productive that Treasury programs (to be tested).

Credit: N. Reid (STScI) for STUC: 8 May 2014

PRODUCTIVITYOF BIG PROGRAMS

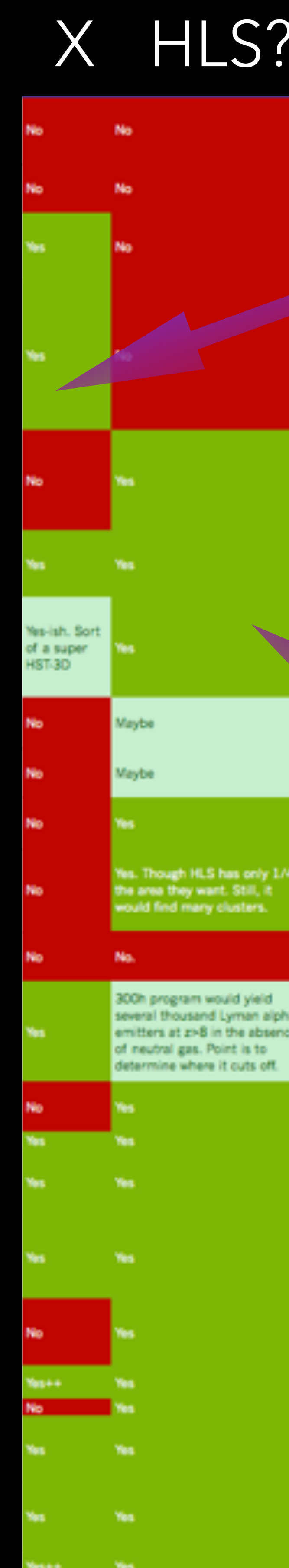
PROGRAM	TYPE	CYCLE	SCIENCE FOCUS	ORBITS	PUBLICATIONS	NOTES
HDF	DD	5	GALAXY EVOLUTION	150	201	IMAGING
PANS	LARGE	11	HIGH-Z SUPERNOVAE	420	41	IMAGING
GOODS	TREASURY	11	GALAXY EVOLUTION	398	584	IMAGING
UDF	DD	12	GALAXY EVOLUTION	400	126	IMAGING
COSMOS	TREASURY	13	GALAXY EVOLUTION	590	232	IMAGING
PEARS	TREASURY	14	GALAXY EVOLUTION	200	37	GRISM SPECTRA
UV UDF	LARGE	14	GALAXY EVOLUTION	204	21	IMAGING
DEC_DUST-FREE	LARGE	14	HIGH-Z SUPERNOVAE	219	32	IMAGING
ANGST	TREASURY	15	STELLAR POPULATIONS	218	58	IMAGING
SHOES	LARGE	15	HIGH-Z SUPERNOVAE	208	7	IMAGING
WFC3 ERS	DD	17	STAR FORMATION	214	128	IMAGING, GRISM SPECTRA
UDF09	TREASURY	17	GALAXY EVOLUTION	193	91	IMAGING
3D-HST	TREASURY	18	GALAXY EVOLUTION	248	38	GRISM SPECTRA
PHAT	MCT	18-20	STELLAR POPULATIONS	834	28	IMAGING
CANDELS	MCT	18-20	GALAXY EVOLUTION, SNE	902	158	IMAGING
CLASH	MCT	18-20	GALAXY CLUSTERS, SNE	524	45	IMAGING
FRONTIER FIELDS	DD	20-21 (22?)	GALAXY CLUSTERS, GALAXY EVOLUTION	560-840	37	IMAGING
SPECTRAL LIBRARY	TREASURY	21	HOT STARS	200	0	SPECTRA
<CYCLE 14>	LARGE	14	6 PROGRAMS	<245> (874)	<14> (85)	IMAGING
<CYCLE 14>	TREASURY	14	2 PROGRAMS	<167> (334)	<72> (144)	IMAGING

Into and out of the valley of death



Credit: Neill Reid (STScI)

RED is good GREEN is good



Green means it has that 'X-factor'

Green means it can be done as part of the high-latitude survey so guest observer time would be pointless.

Red on the left means the facility in the column cannot do it. So if a row is all red then it means it's unique to WFIRST.

Names are omitted. Text is intentionally illegible... don't even try. Just look at the colours.

CONCLUSION

- #WFIRST is Sloan in Space disguised as a dark energy mission.