HST and JWST Photometric Calibration

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Charge

On the HST (and JWST) photometric calibrators, in particular the white dwarf standards including concept for absolute calibrations , present status, and lessons learned.

EUCLID: 36 4kx4k CCDs, 0.1”/pix,
16 2kx2k H2RG MCT, 0.3”/pix

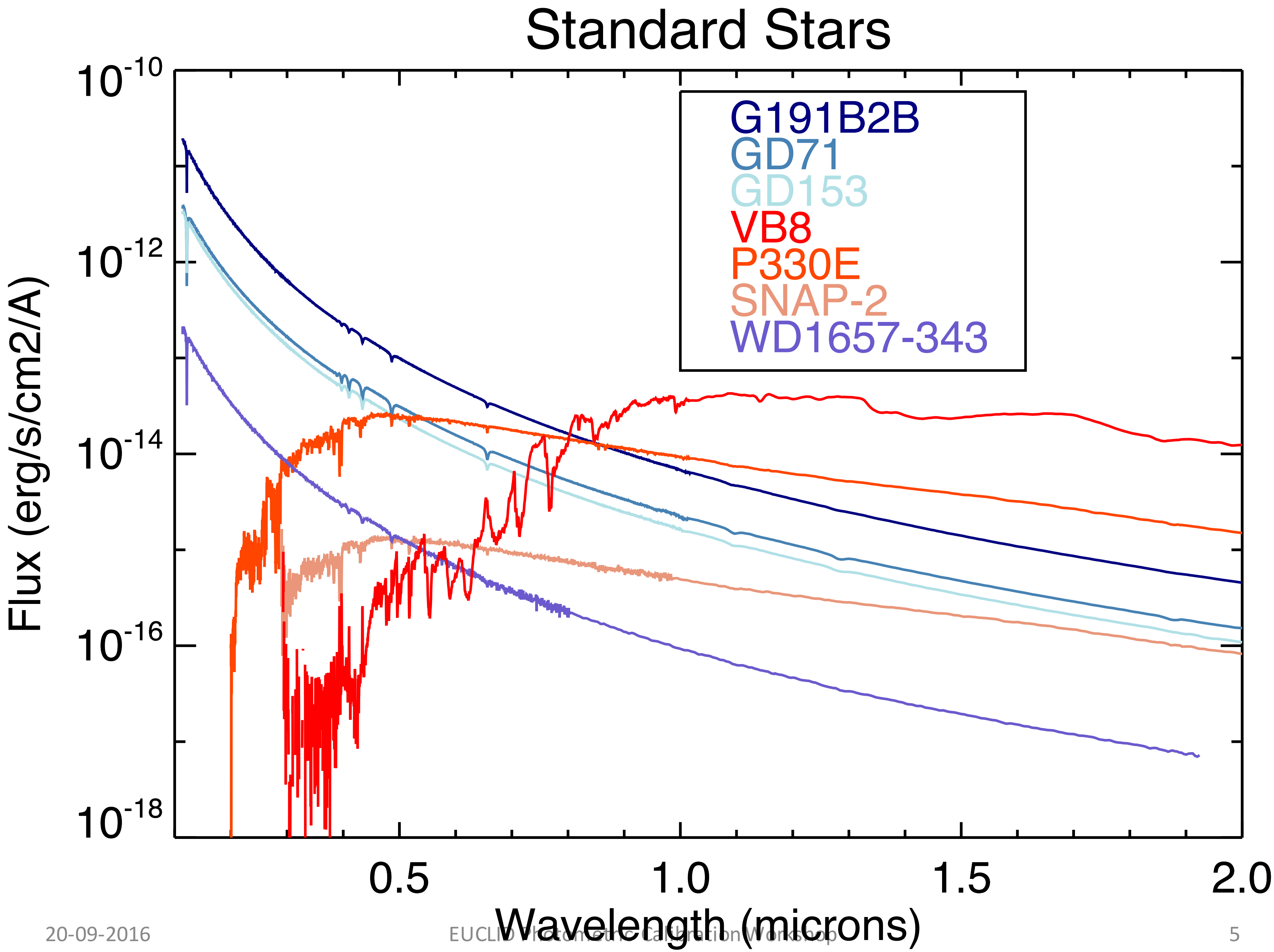
HST WFC3/UVIS: 2 4kx4k e2v CCDs, 0.04”/pix
WFC3/IR: 1 1kx1k H1RG MCT, 0.13”/pix

HST Standard Stars

- Normalized to Vega flux at 5557Å
  - $3.44 \times 10^{?9}$ erg cm^{-2} s^{-1} Å (Bohlin, 2014 AJ, 147, 127)
  - Kurucz Vega Model (2013 kupdated)
- Originally LTE WD models (Finley, Hubeny)
- Now use NLTE WD models (Rauch)

	Name	Sp. Type	Vega mag B	V	R	I	J	H
HST Primary Standards	G191B2B	DA.8	-	11.69	11.93	12.108	12.543	12.669
	GD71	DA1	12.783	13.032	13.169	13.337	13.728	13.901
	GD153	DA1.2	13.17	13.346	13.8	13.3	14.012	14.2
Secondary Standards	WD1657+343	DA1	16.12	16.16 (g)	16.69 (r)	17.06 (i)	>17	>17
	WD1057+719	DA1.2	14.95	14.68	15.23	-	15.472	15.585
	P330E	G2V	12.972	13.03	12.56	12.212	11.76	11.45
	SNAP-2	G0-5	17.09	16.23	16.41	--	14.97	14.59
	VB08	M7V	18.7	16.7	16.61	12.24	9.776	9.2

CALSPEC PEDIGREE: _stisnic_006



Standard Stars
G191B2B
GD71
GD153
VB8
P330E
SNAP-2
WD1657-343
Flux (erg/s/cm2/A)
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
0.5
1.0
1.5
2.0
Wavelength (microns)

Accuracy and Precision

Uncertainty in Vega Flux: ~0.7% @ 5557Å

Uncertainty in models : <1% in UVIS, ~ 2% in NIR

Measurement Precision:

- Poisson: 0.2%
- Flat fields: ~0.4%-0.6% (filter/detector dependent)
- Repeatability: 0.2-0.5% (detector dependent)
- Other: = 0.5% - 1%
  - Processing noise (bias & dark subtraction, flatfielding), gain, readnoise, CTE(CCDS), persistence (HgCdTe), count rate and count non-linearities

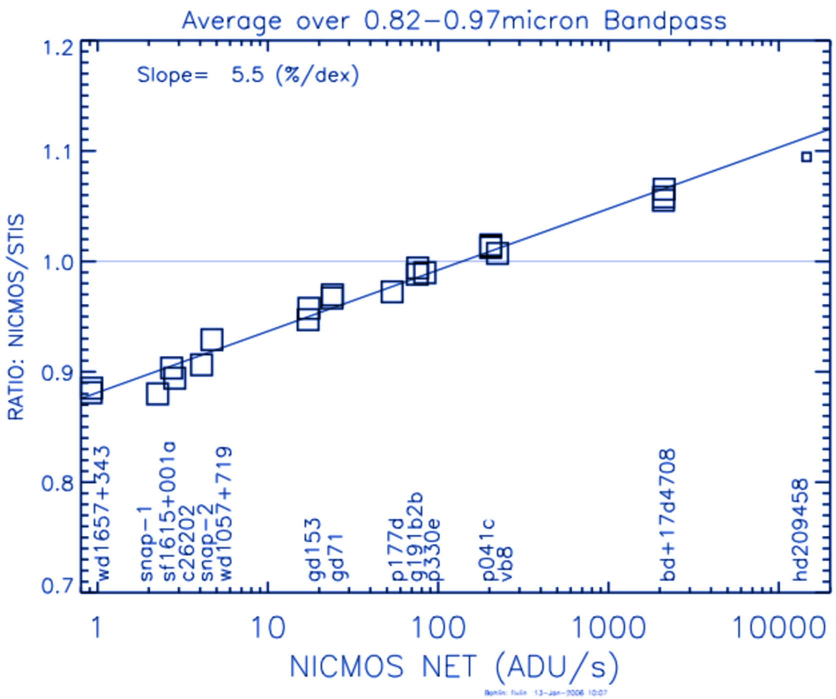
- WFC3/UVIS: 1.3% (stat)+ 1.22%(syst)
- WFC3/IR: ~1.6% (stat) + 2.1%(syst)

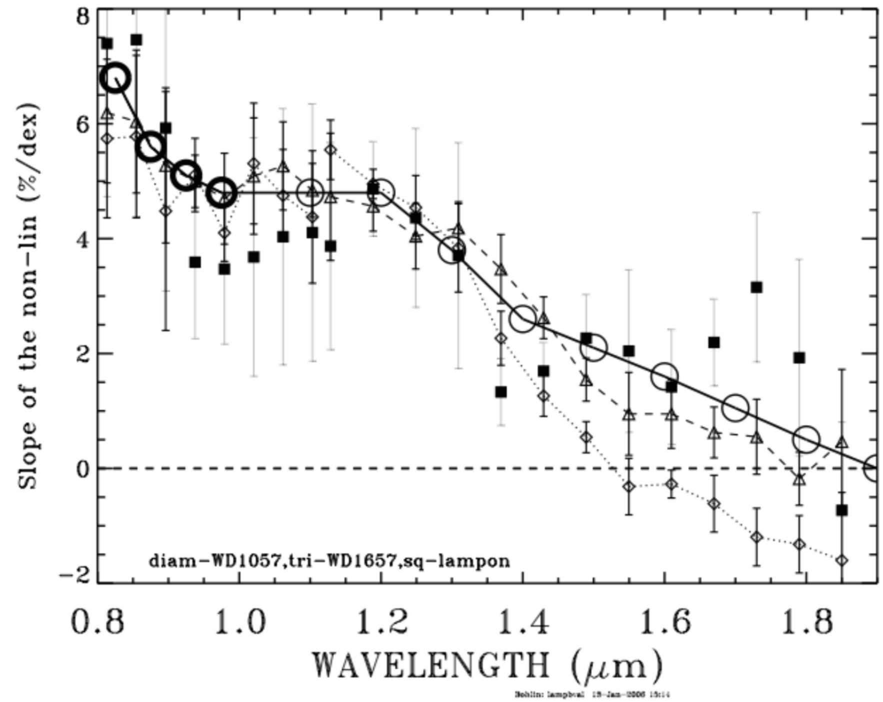
Principal Detector Effects

- CCD Charge Transfer Efficiency (CTE, or CTI)
  - Most affected:
    - Sources furthest from readout
    - Faint sources, can "disappear"
    - All CCD detectors on HST
  - Effect: bright stars < 0.1%, faint sources larger
  - Mitigation:
    - Post-Flash (add background e- to fill traps)
    - Place science targets near readouts.

Principal Detector Effects

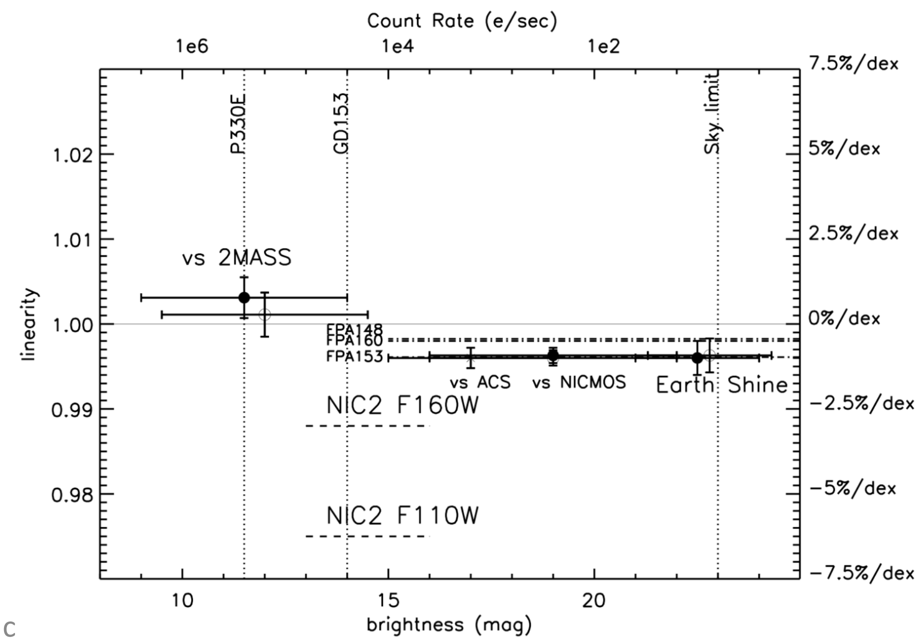
- HgCdTe non-linearities
  - Count rate non linearity (may be wavelength dependent)
    - WFC3/IR: 1%/dex
    - NICMOS:
  - Count non linearity
  - Persistence
    - Count rate dependent decay
    - Exponential-ish time decay
    - Hard to characterize in orbit





From Bohlin, Riess, DeJong, ISR NICMOS 2006-002

5.5% per dex at shortest wavelengths



WFC3/IR: <0.01 mag per dex (Riess ISR WFC3 2011-15)

Principal Detector Effects

- HgCdTe non-linearities
  - Count rate non linearity (may be wavelength dependent)
    - WFC3/IR: 1%/dex
    - NICMOS:
  - Count non linearity
  - Persistence
    - Count rate dependent decay
    - Exponential-ish time decay
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Persistence

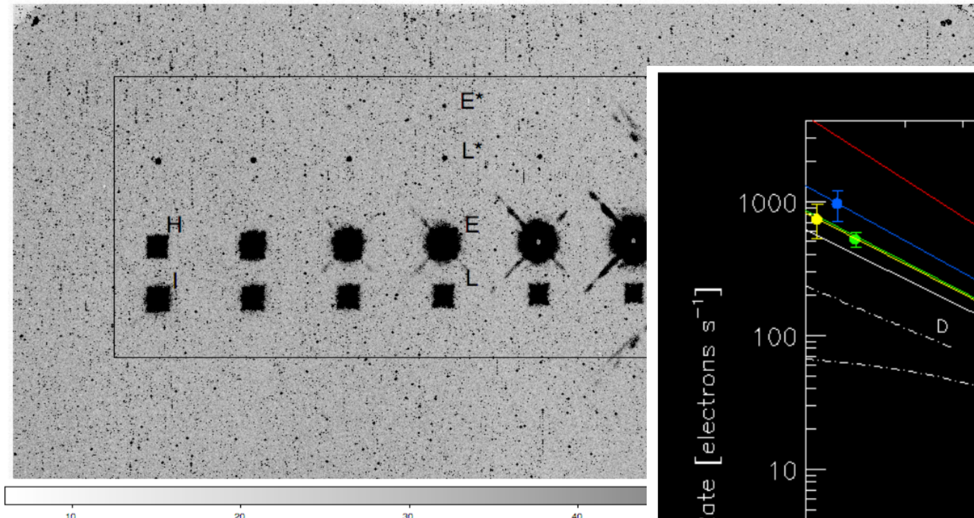
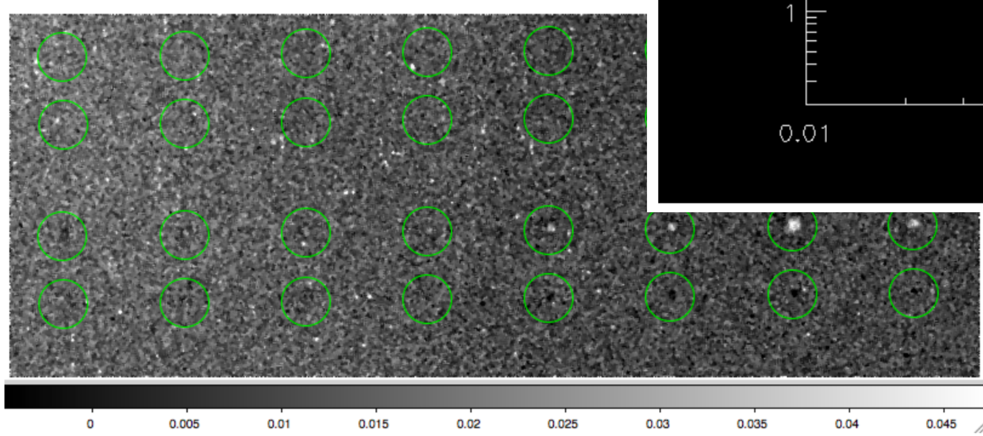
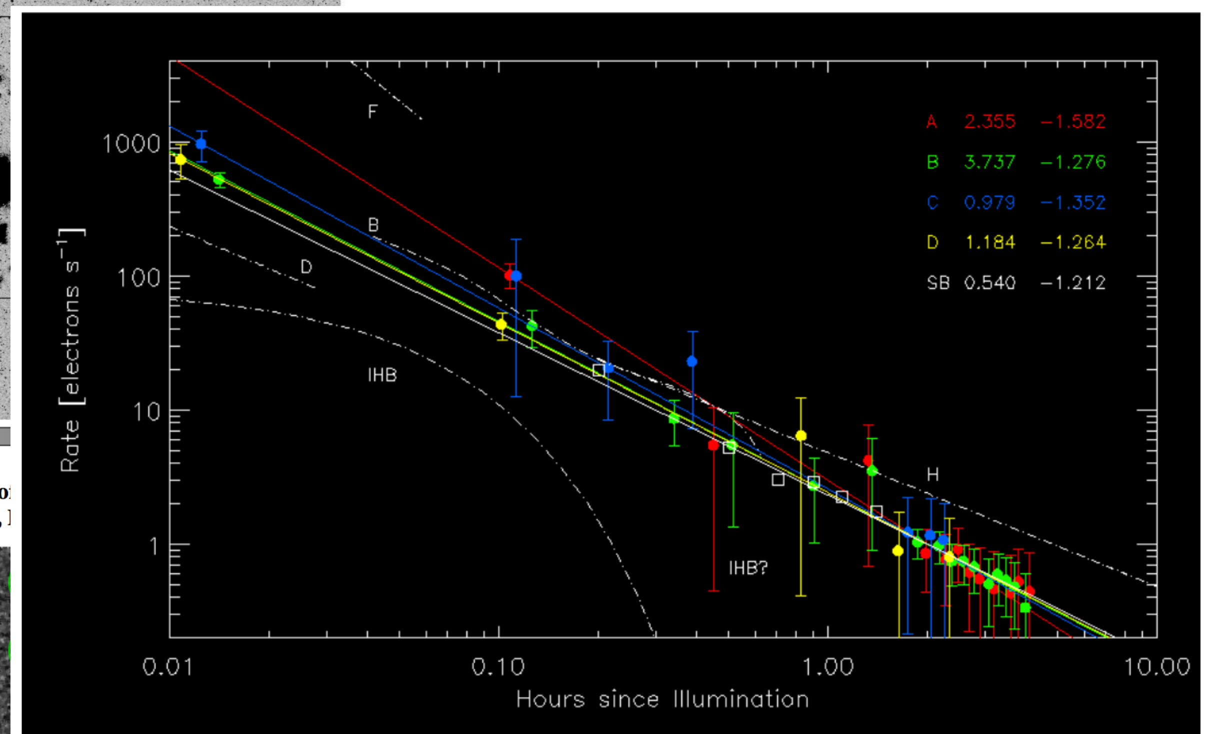


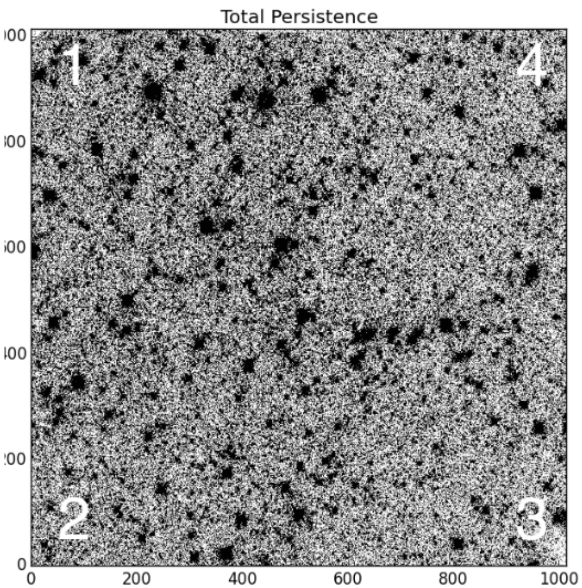
Figure 3b: Same as Figure 3a, but at higher contrast. The wings o
P) now are clearly visible, as are some of the secondary spots (B*,]

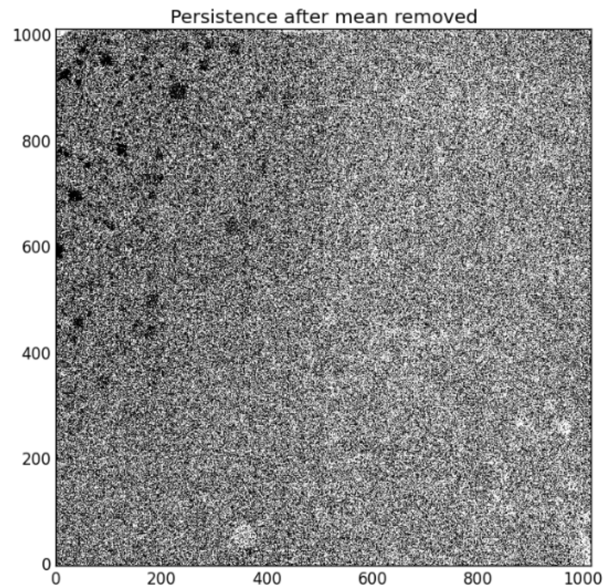


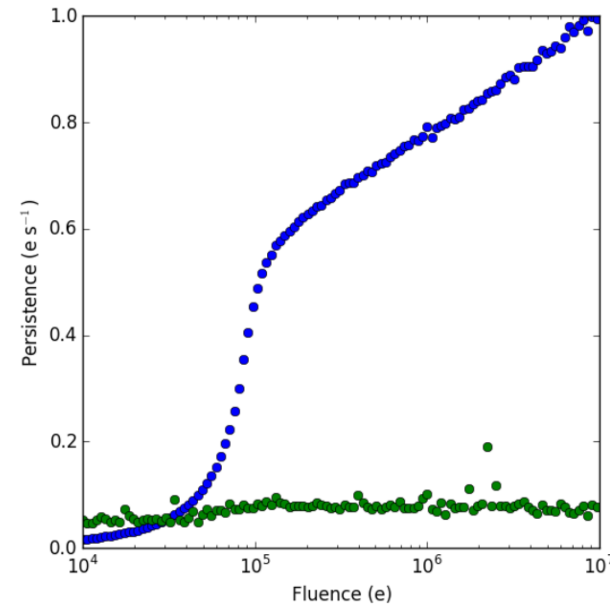


McCullough&Deustua WFC3 ISR 2008-33

Persistence







Left: dark image 400 seconds after Omega Cen exposure
Middle: after subtracting the persistence correction (model)
Right: persistence by fluence

Knox et al WFC3 ISR 2015-16

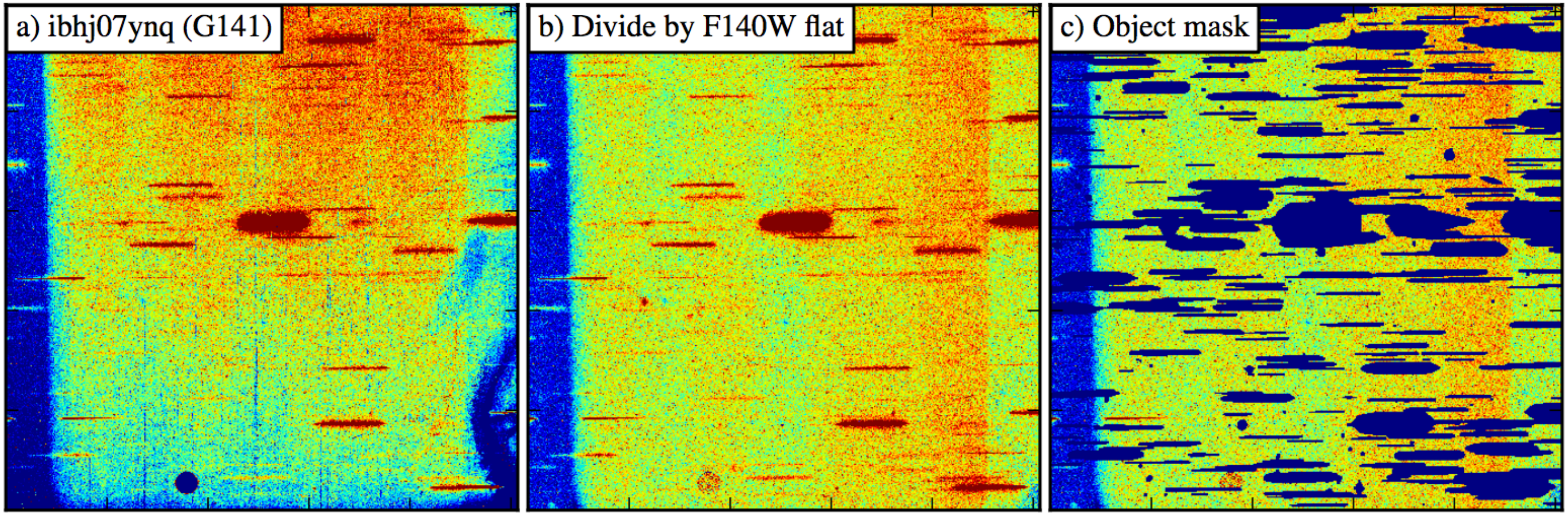
Flat Fields (imaging)

- Pixel-to-pixel variation (Pflats)
  - Acquired during thermal-vaccuum testing on the ground
    - Minimal set typically 4 to 5 images of 20K+ electrons per filter
    - Limited by schedule, typically
- Low frequency spatial variation (Lflats)
  - Created in orbit
    - star cluster(s) on different locations on the detector(s)
    - limited by spectral type, crowding, time
- Sky flats
  - Created from on orbit images
    - Better fidelity to the actual data
    - Requires hundreds of observations, more for bandpasses with low natural background

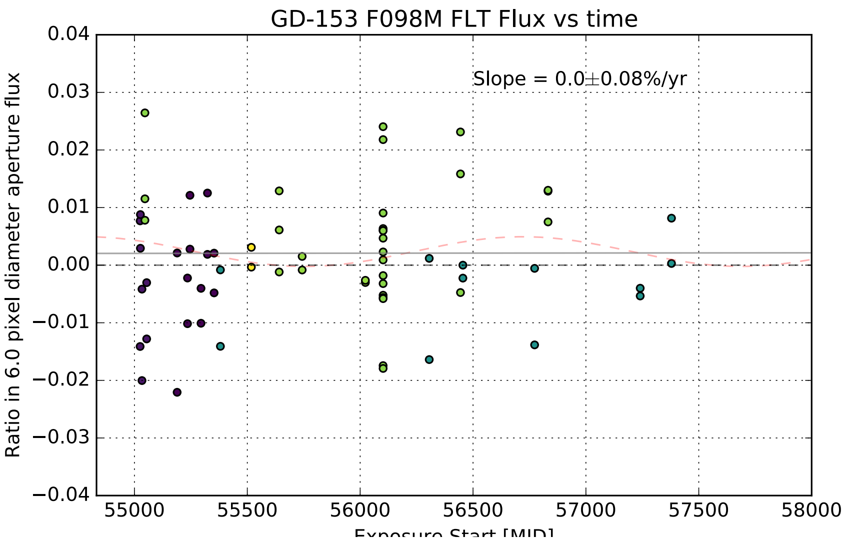
Flat Fields and sky (spectroscopy)

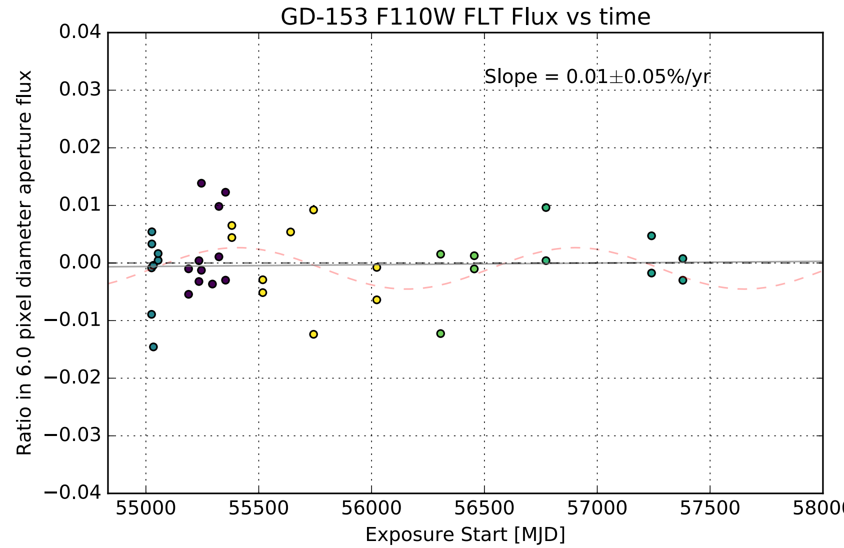
- Slitless spectroscopy
  - Every pixel ‘sees’ every wavelength
  - Monochromatic flats acquired during thermal-vac with disperser
    - Grisms: best not to use disperser
    - Beware overlapping orders

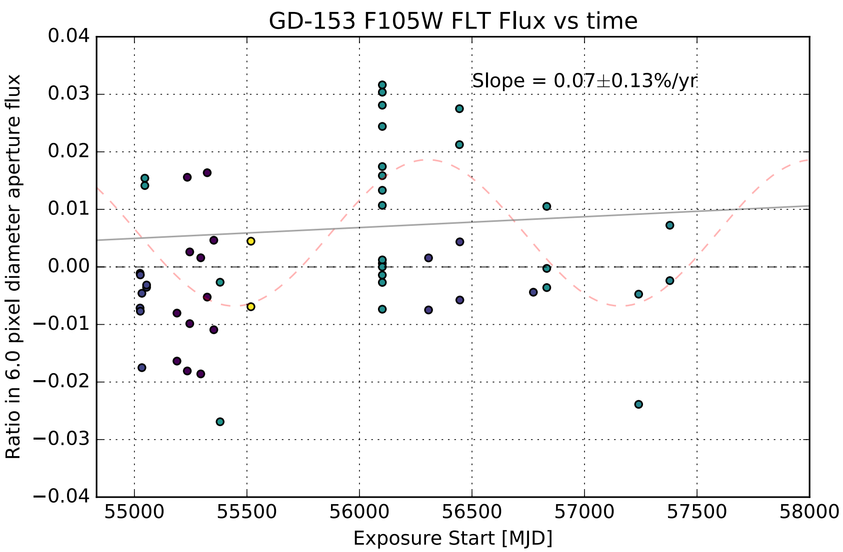
IR Grism Flats and Sky

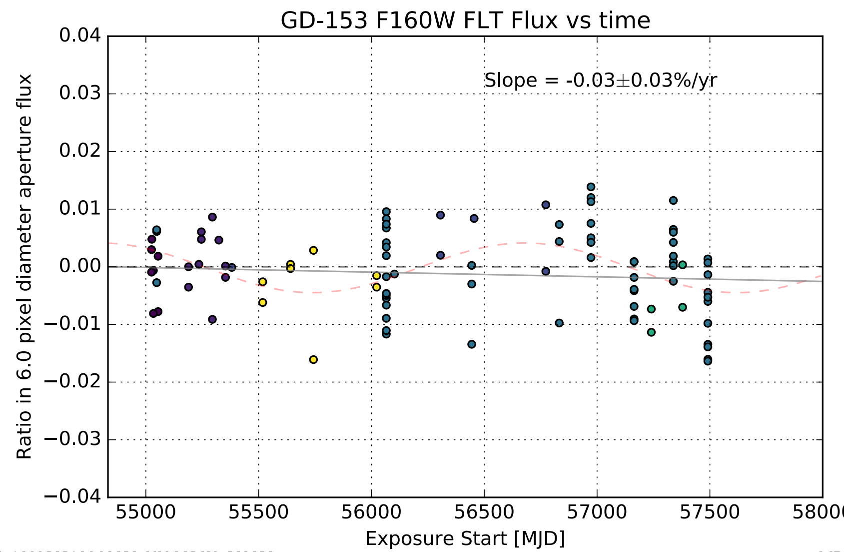


Repeatability WFC3 IR

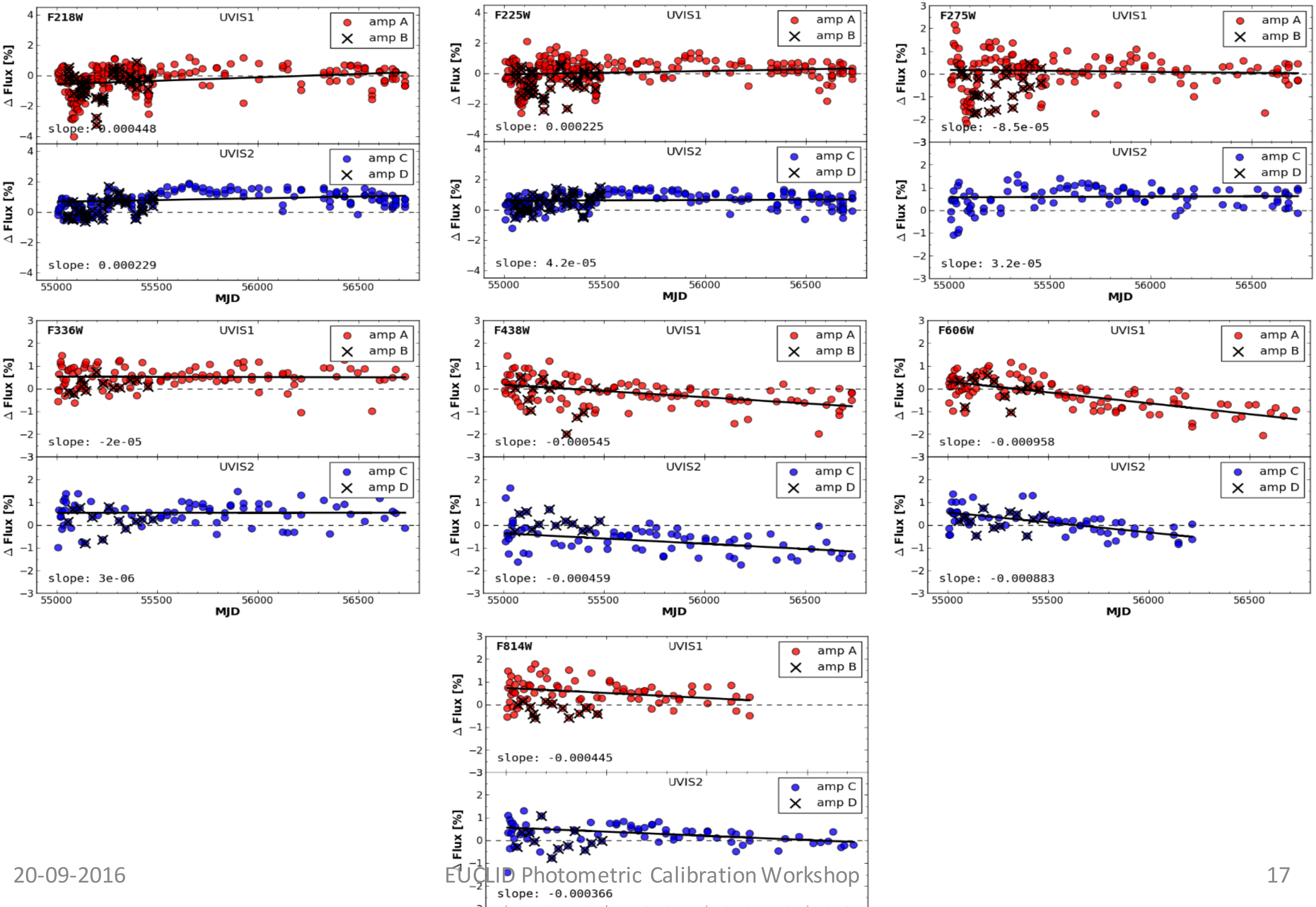








Temporal Variation: WFC3 UVIS



Spatial Variation: WFC3 UVIS

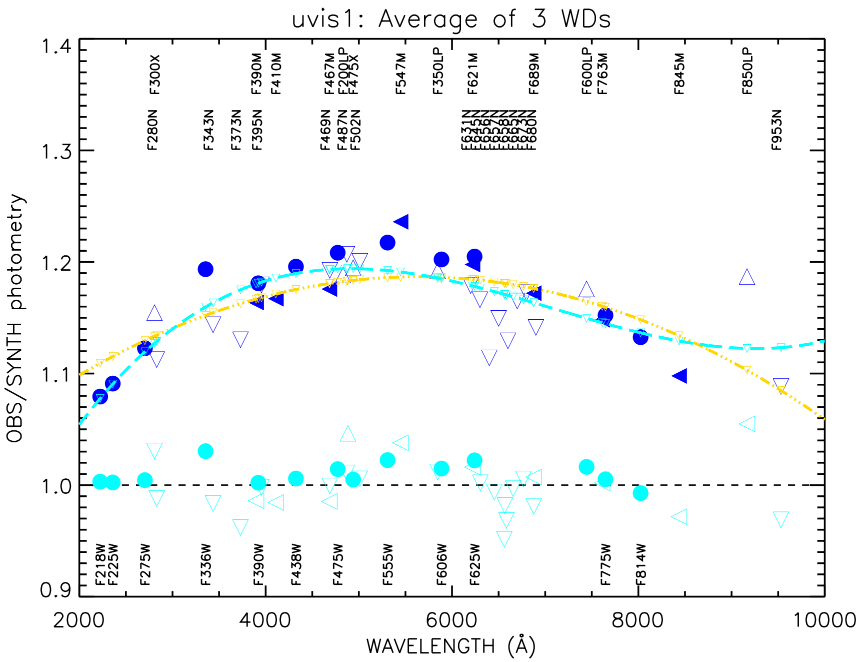
Filter	Number of Steps	Poisson Error	Stddev (2011)	Stddev (2016)	P2P (2011)	P2P (2016)
F218W	44	0.2%	1.5 %	0.7 %	6.7 %	3.0 %
F225W	44	0.2%	1.3 %	0.4 %	4.5 %	1.8 %
F275W	41*	0.2%	0.8 %*	0.6 %	3.3 %*	2.7 %
F280N	44	0.2%	1.8 %	0.5 %	6.6 %	2.4 %
F336W	46	0.4%	0.3 %	0.4 %	1.5 %	1.7 %
F438W	50	0.2%	0.5 %	0.5 %	2.0 %	2.3 %
F606W	20	0.3%	0.7 %	0.7 %	2.7 %	2.7 %
F814W	50	0.3%	0.4 %	0.4 %	1.3 %	1.7 %

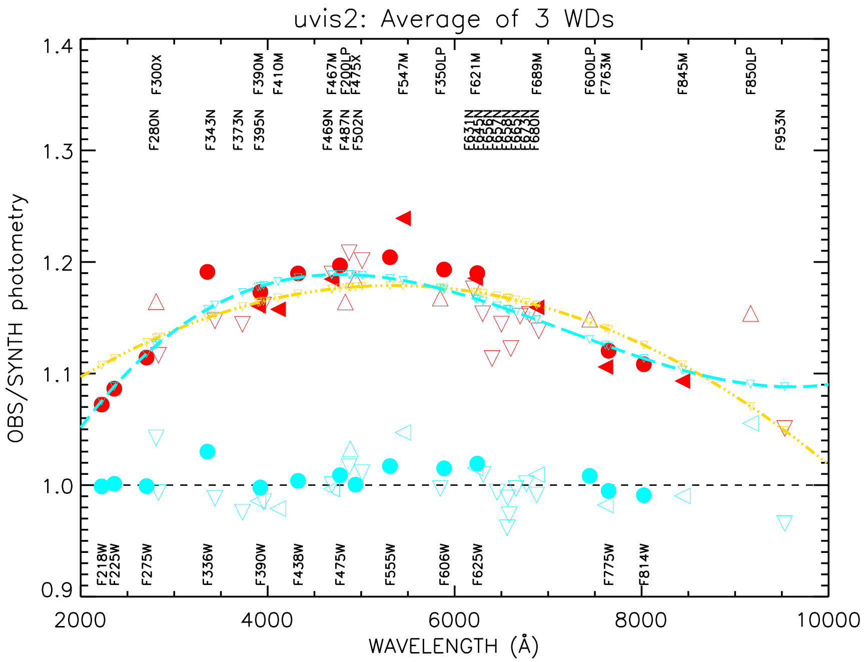
J. Mack, A. Bowers

Inverse Sensitivity aka “Zeropoints”

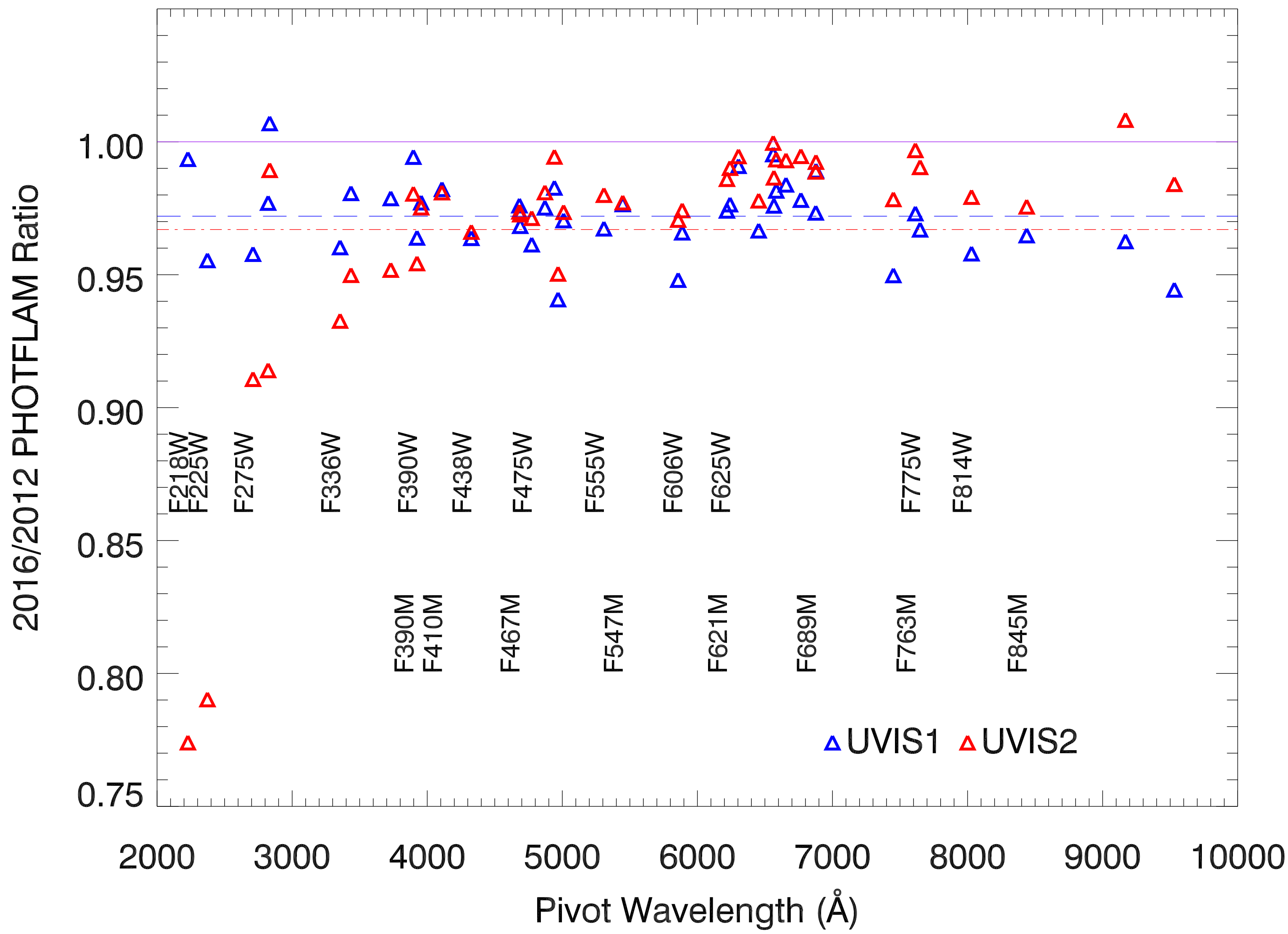
- WF/PC: 8 CCDs, each calibrated independently
- WFPC2: 4 CCDs, each calibrated independently
- ACS: 2 CCDS, treated as a single detector
  - Diced from same wafer, same QE
- WFC3/UVIS: 2 CCDs, initially calibrated as ACS
  - Different wafers, different runs, different QE
  - Since March 2016, each CCD calibrated independently
    - Flat fields improved by 2x in UV.
    - Accuracy improved by almost 3% (astrodrizzle subtlety)
- NICMOS: 3 HgCdTe detectors, individually calibrated
- WFC3/UVIS: 1 HgCdTe detector

WFC3 2016
Observed to Synthetic Photometry





Inverse Senstivity Comparison: 2016 to 2012



Calibration Allocation

Time spent on calibration activities per cycle (steady state)

- External orbit: on astrophysical sources
- Internal orbit: during occultation.
- 1 orbit ~ 45 min

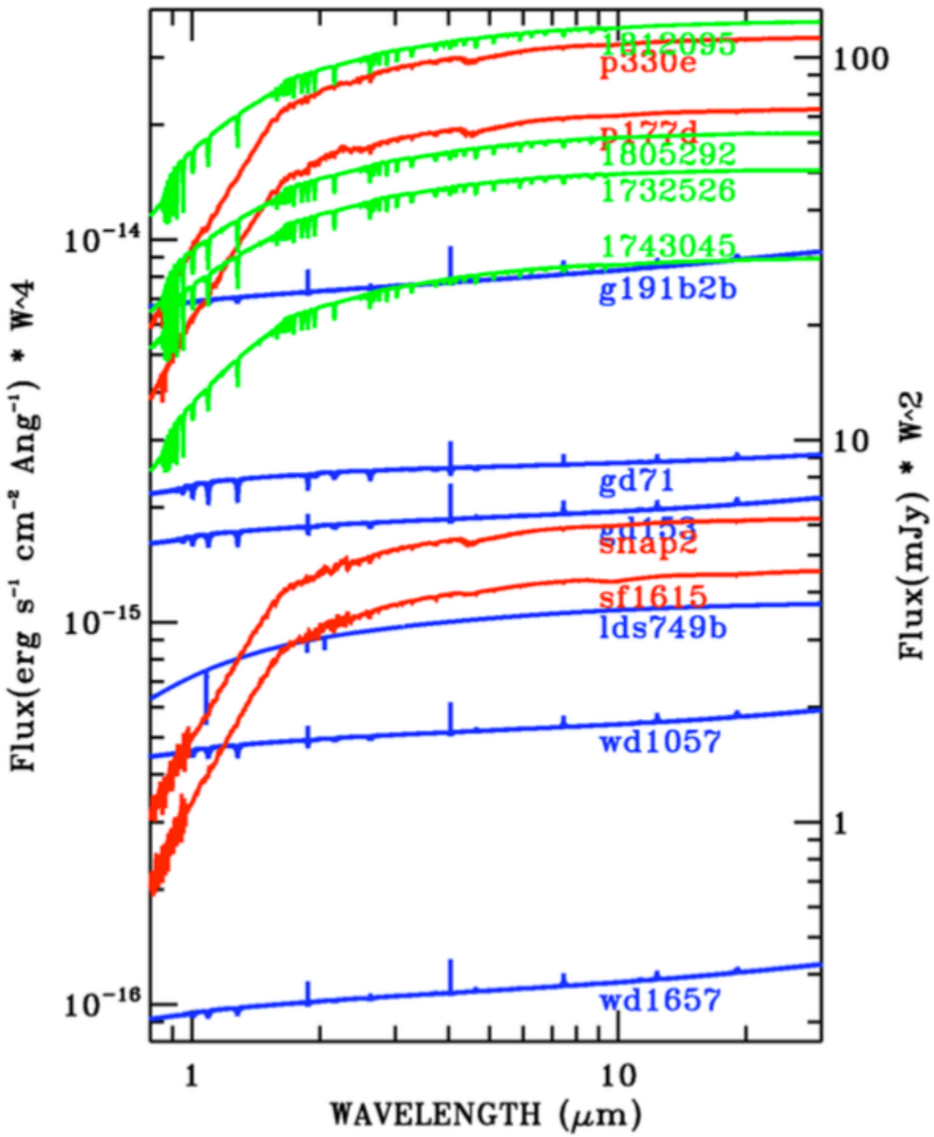
- WFC3: 100/2000
- ACS: 30/1000
- STIS: 30/1400
- COS: 40/320

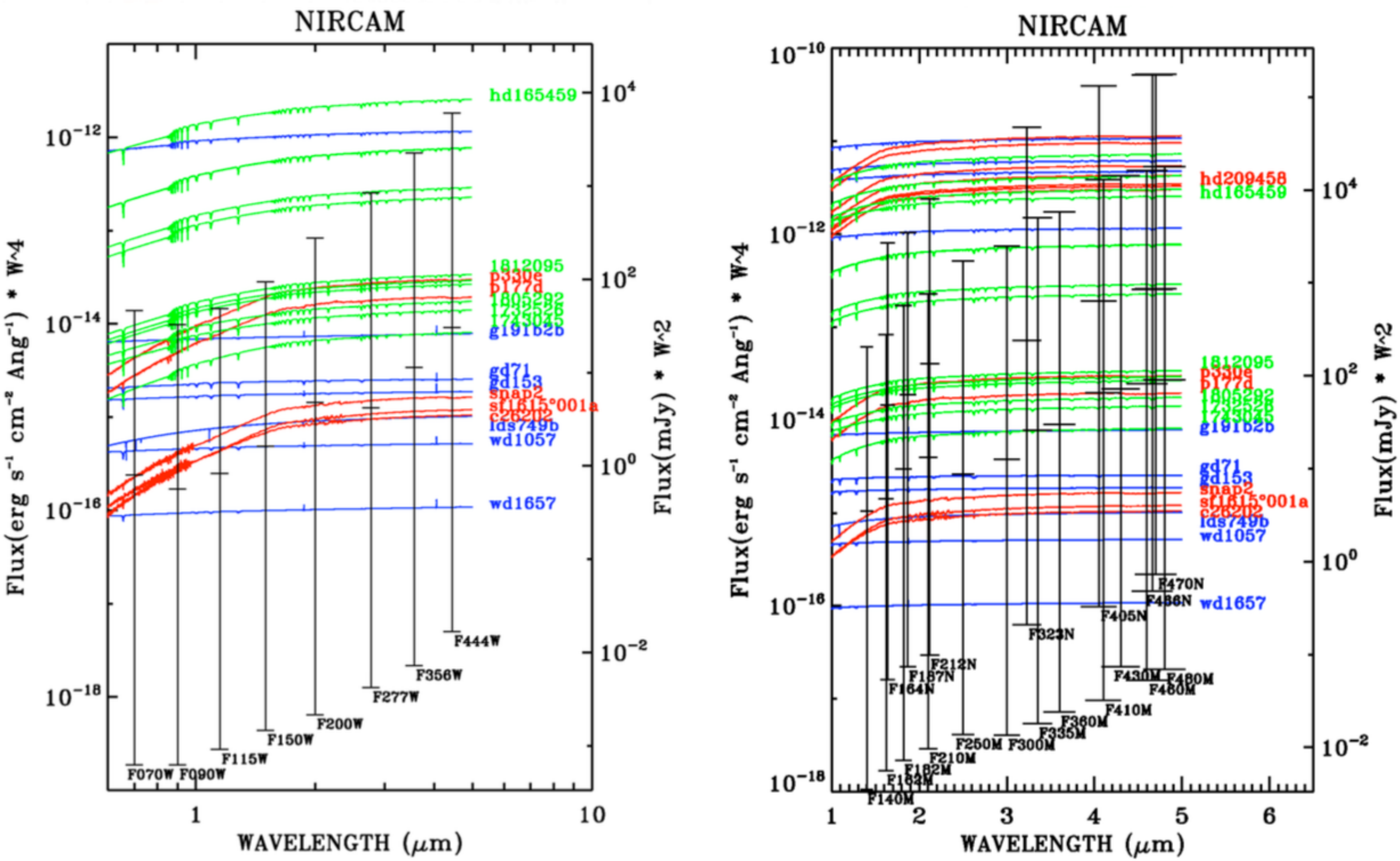
JWST Photometry

- JWST Primary Standards
  - Hot (O, B, WD), A and G stars
  - From K= 4 to 16 mag
  - Match (mostly) sensitivity of the many JWST instruments and mode

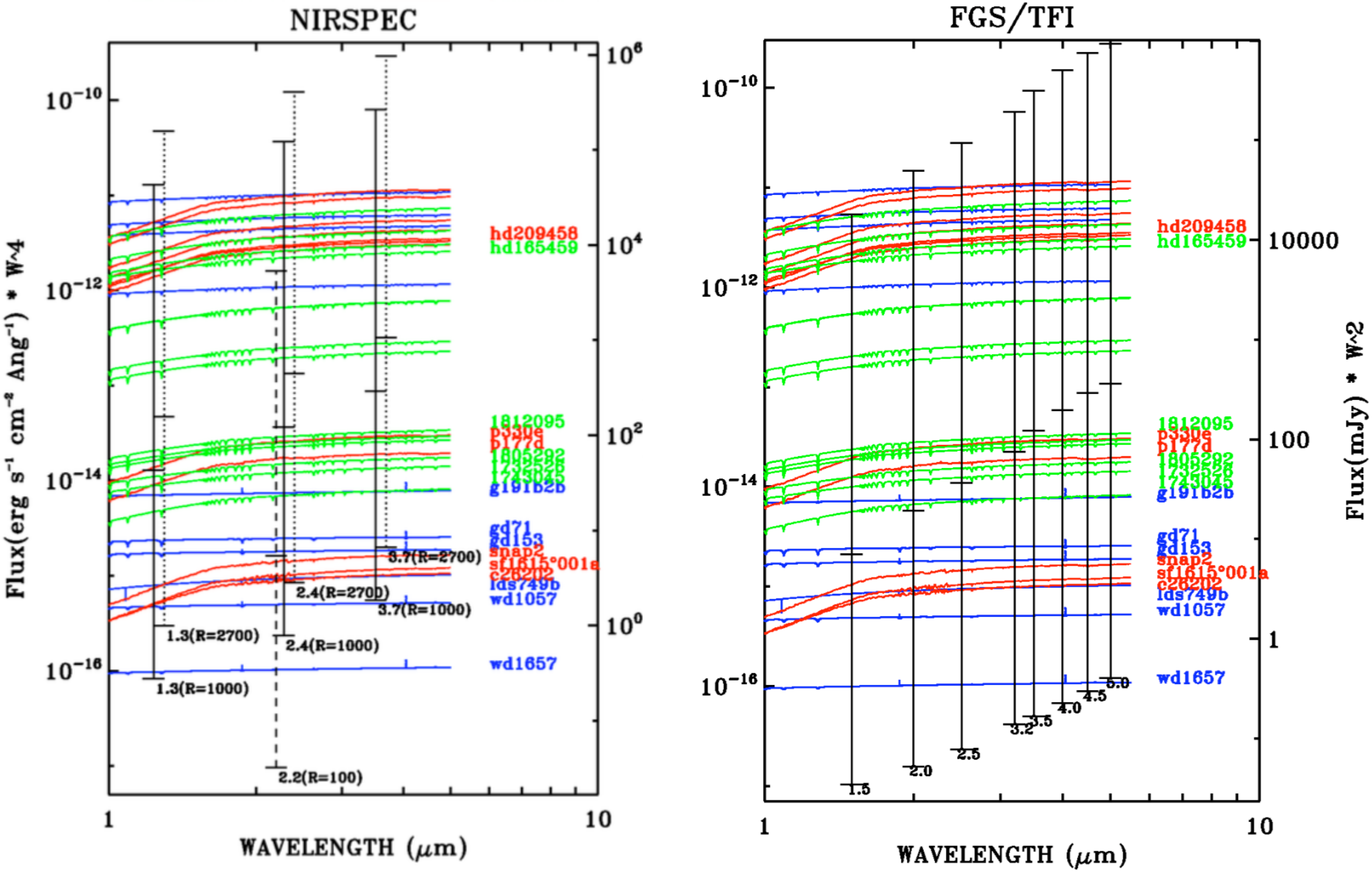
Star	V	K	Star	V	K	Star	V	K
x2 Cet	4.28	4.39	HD 37725	8.35	7.90	1732526	12.530	12.254
I Lep	4.28	5.00	HD 163466	6.86	6.34	1743045	13.5	12.772
10 Lac	4.88	5.50	HD 116405	8.34	8.48	HD 159222	6.56	5.00
µ Col	5.17	5.99	HD 180609	9.41	9.12	HD 205905	6.74	5.32
HD 60753	6.68	6.83	HD 163466	6.86	6.34	HD 106252	7.36	5.93
G191B2B	11.781	12.764	HD 116405	8.34	8.48	HD 27836	7.6	6.01
GD71	13.032	14.115	HD 180609	9.41	9.12	HD 37962	7.85	6.27
GD153	13.346	14.308	BD+60 1753	9.67	9.64	HD 38949	8.0	6.44
LDS749B	14.73	15.217	1757132	12.0	11.16	P330E	13.01	11.379
WD1057+719	14.8		1812095	11.736	11.286	P177D	13.48	11.857
WD1657+343	16.1		1808347	11.9	11.53	C26202	16.64	
HD 158485	6.50	6.14	1802271	11.985	11.832	SF1615+001A	16.75	
HD 14943	5.91	5.44	1805292	12.278	12.005	SNAP-2	16.2	

JWST Primary Standards

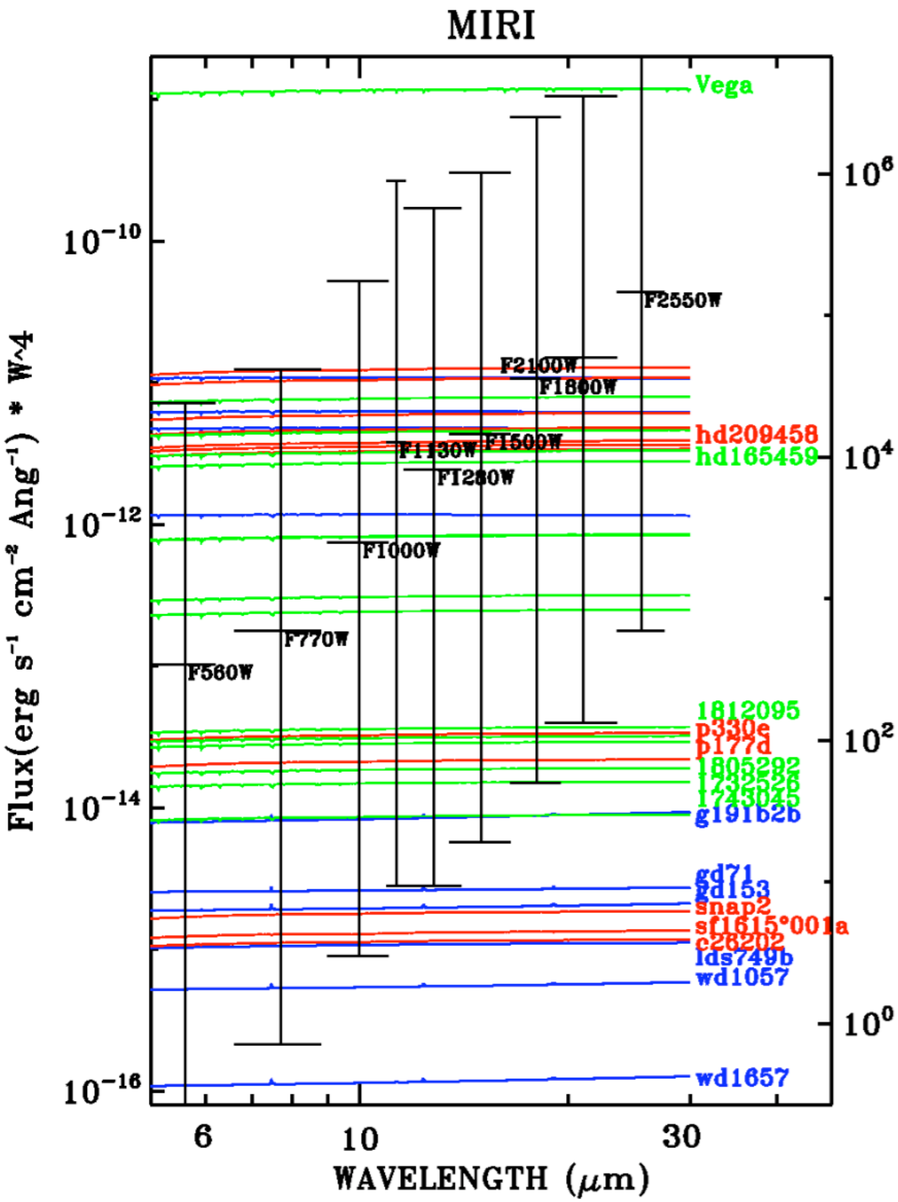


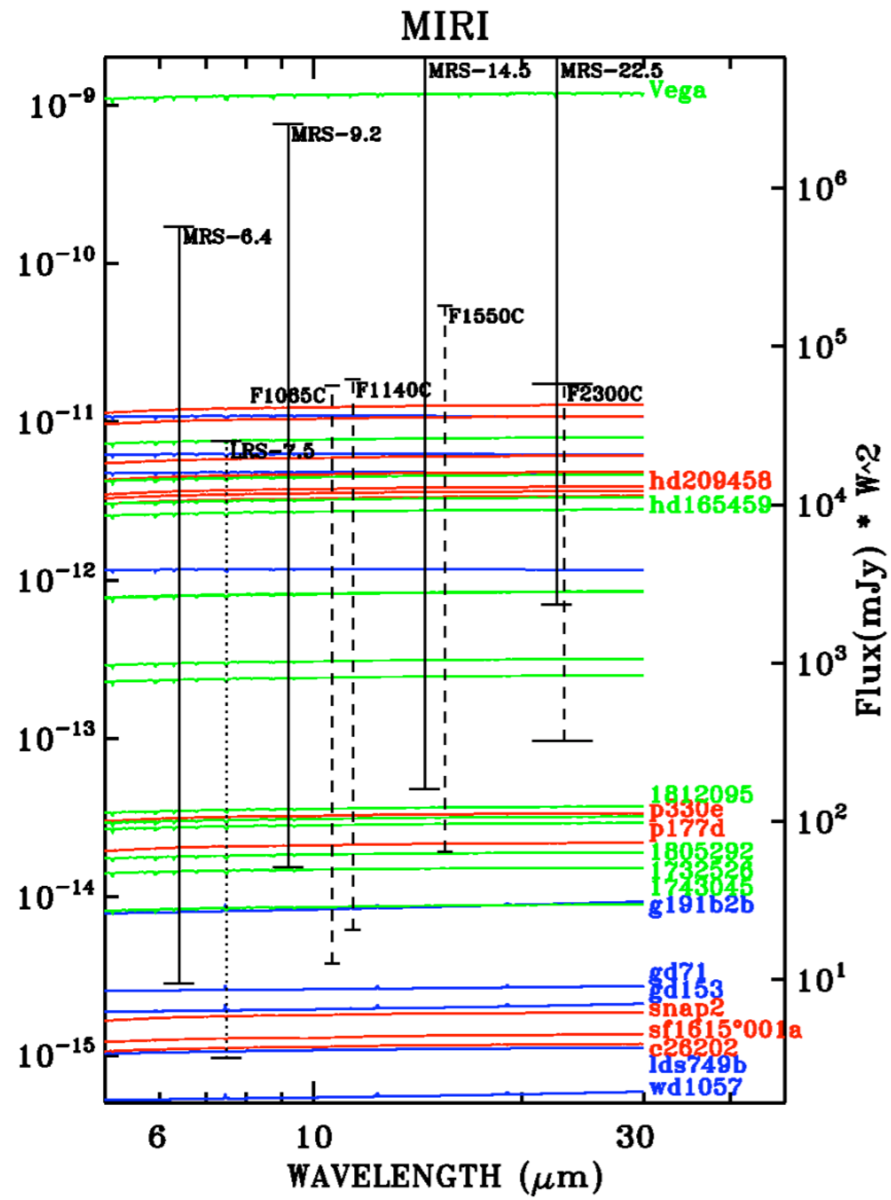


Broad Band (left) and Medium and Narrow Band Imaging (right)



Spectroscopy: min, max full frame and max subarray sensitivities





Left. Broad Band Imaging. Right: Coronagraphy, medium and low resolution spectroscopy

Future Plans (next few years)

- Obtain Teff and g for primary standards (where needed)
- Create bespoke models for each standard
- Need faint (>17 mag) secondary standards, particularly for mid-IR (NIRCAM)