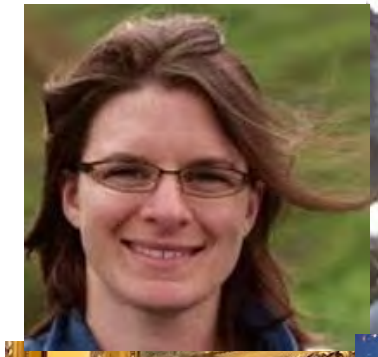
JWST Calibration in Normal Operations

Greg Sloan
Lead, Cycle 1 and 2 Calibration Coordination Teams

Cycle 2 Calibration Coordination Team










NIRCam – Martha Boyer, Anton Koekemoer

NIRSpec – Nimisha Kumari, James Muzerolle

NIRISS – Kevin Volk, Andre Martel

MIRI – Greg Sloan, Stacey Bright

FGS – Sherie Holfeltz

Absolute flux calibration – Karl Gordon

JWST calibration

Goal – **Enable the best possible science with the James Webb Space Telescope**

Means

Generate and improve Calibration Data Products (pipeline input files)
Quantify performance (telescope, detectors, instrument modes)

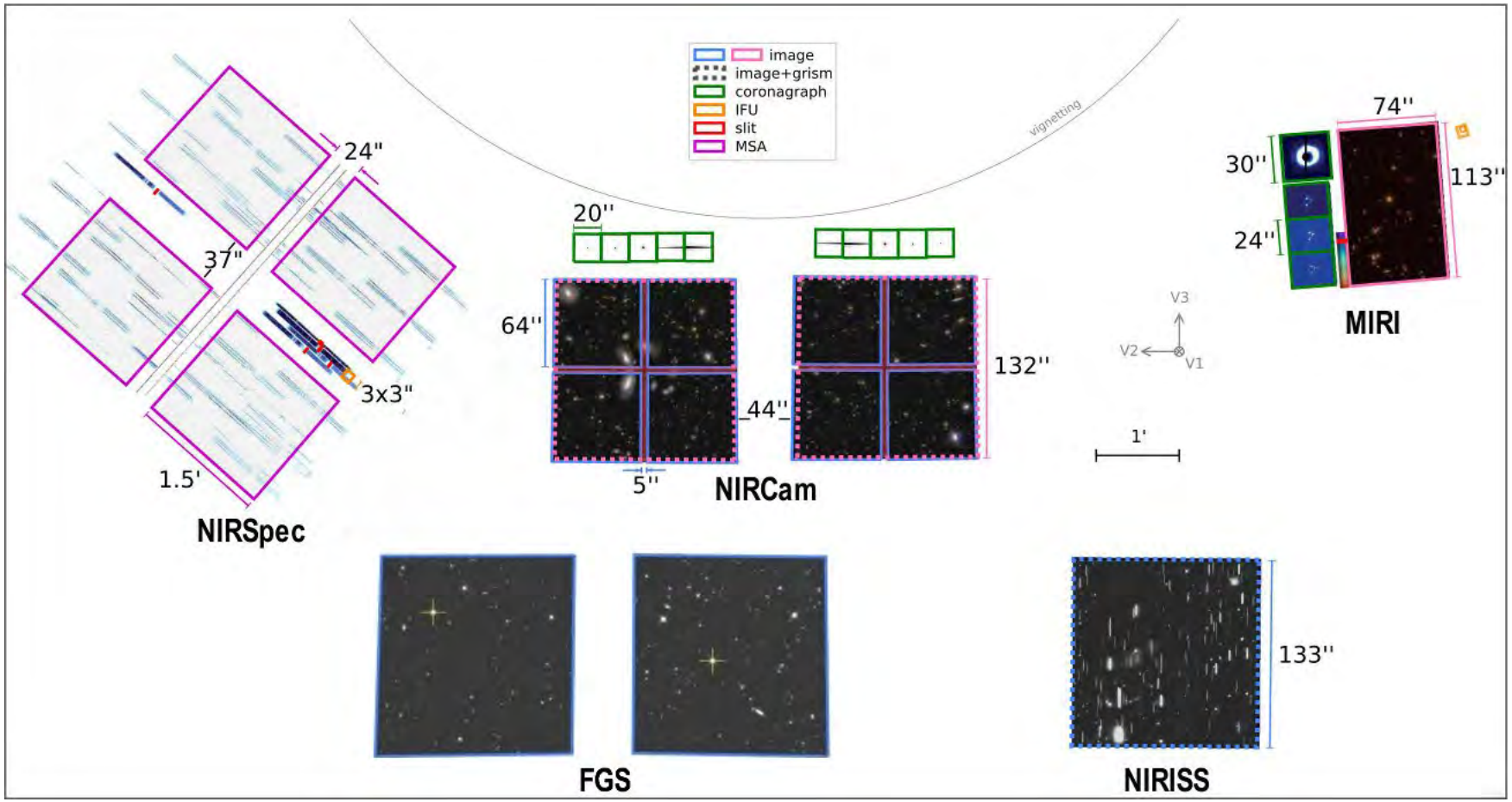
Monitor changes in calibration, system performance, instrument health
Obtain reference data needed to troubleshoot likely challenges

JWST in a nutshell

18 primary mirror segments

18 detectors in focal plane

18* scientific observing modes



*Counting LRS slitless separately

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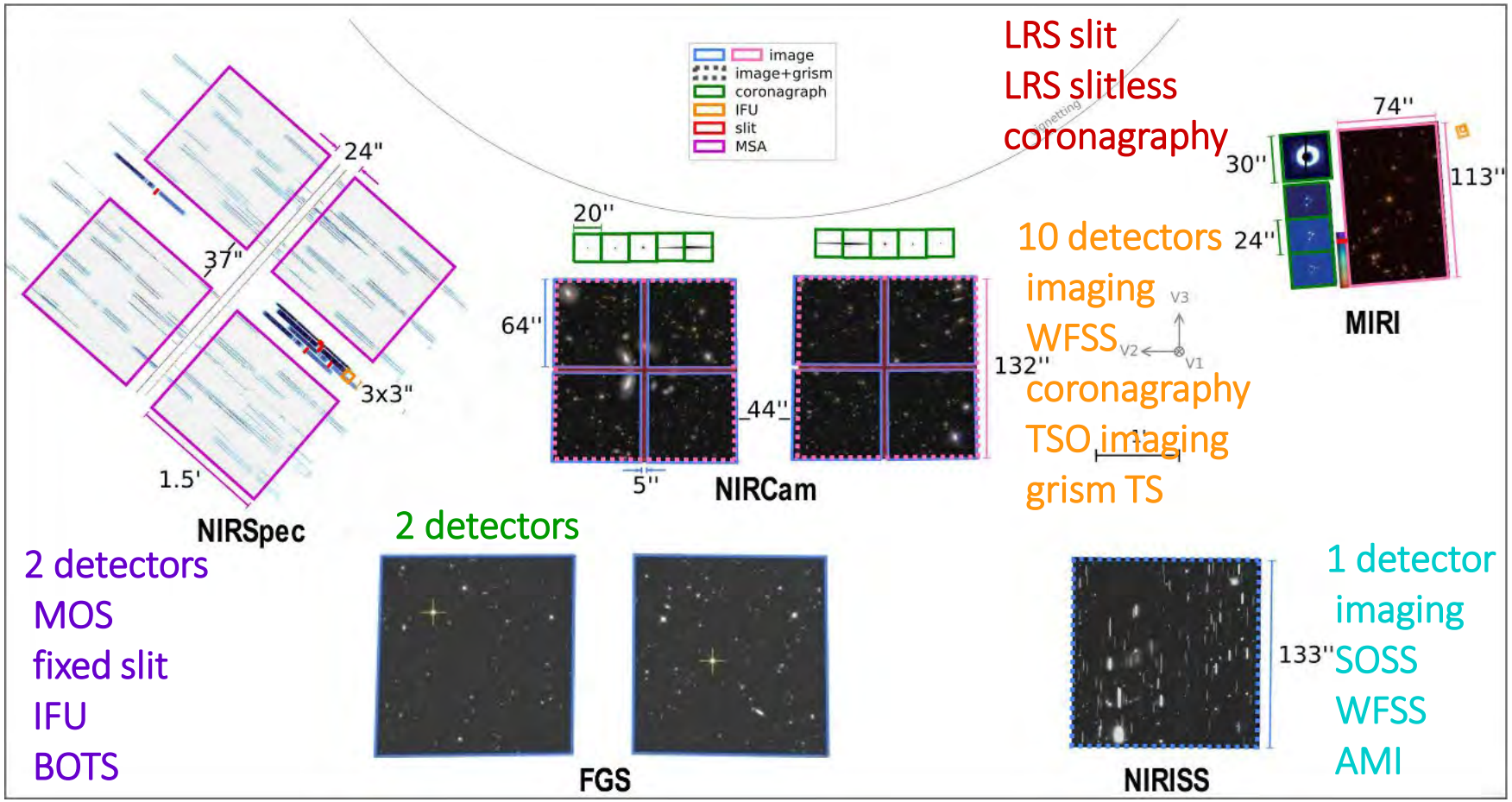


3 detectors
imaging
MRS
LRS slit
LRS slitless
coronagraphy

10 detectors
imaging
WFSS
coronagraphy
TSO imaging
grism TS

2 detectors
MOS
fixed slit
IFU
BOTS

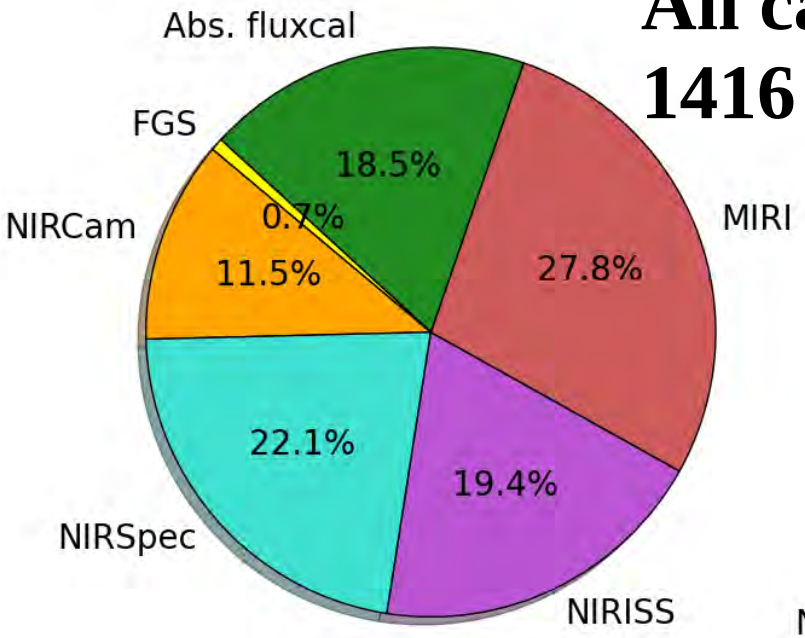
2 detectors

1 detector
imaging
SOSS
WFSS
AMI

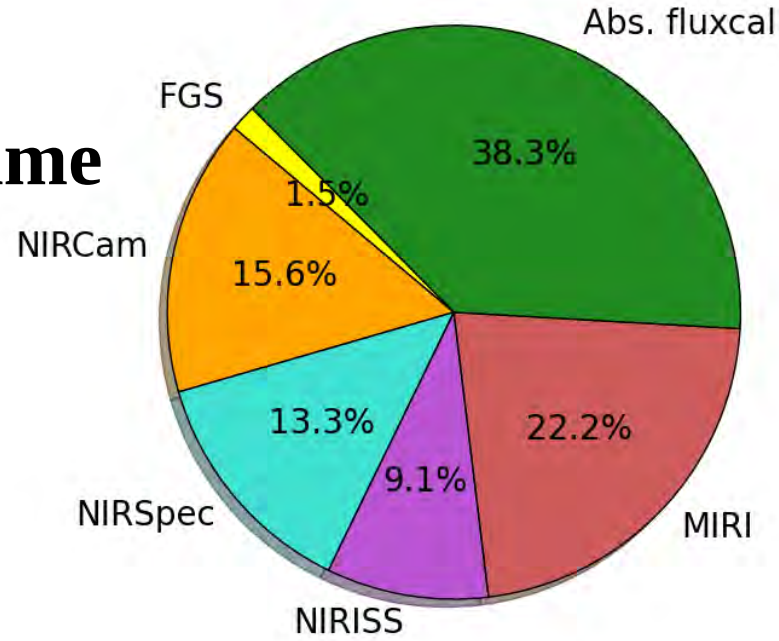
*Counting LRS slitless separately

Cycle 1 Cal plan – as of May 2021

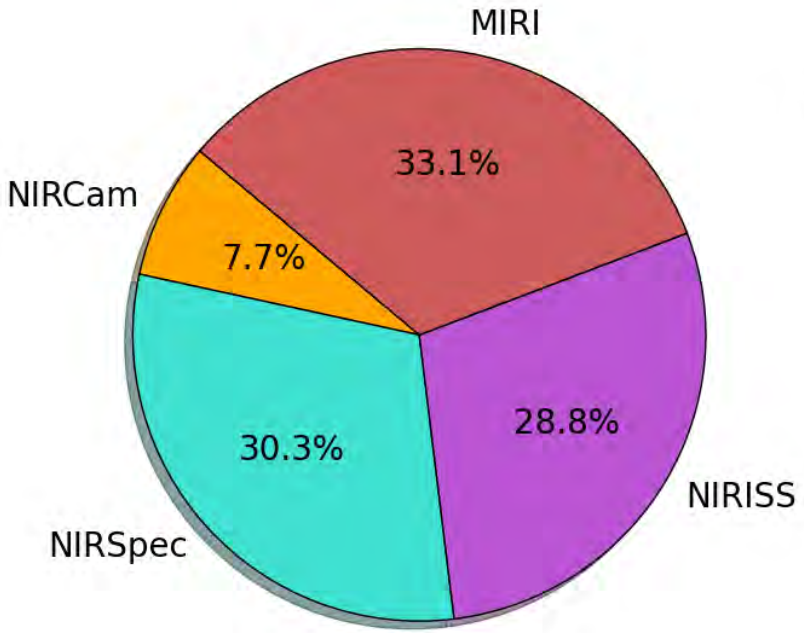
All calibrations
1416 h



Prime time
682 h

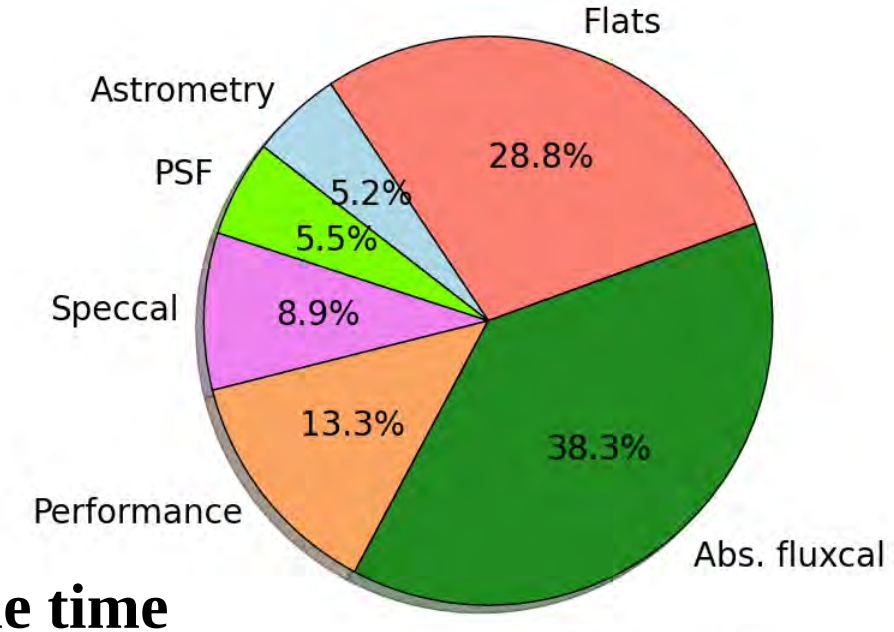


All parallels
734 h

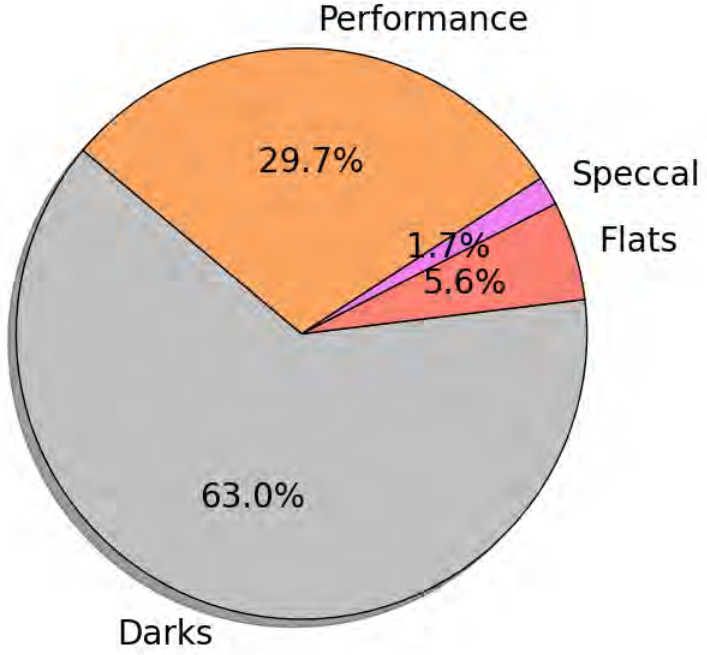


By calibration type

Cal type	Prime (h)	Pure Parallels (h)	Slew parallels (h)
Abs. fluxcal	262	0	0
Darks	0	463	0
Flats	196	32	9
Astrometry	35	0	0
PSF	38	0	0
Speccal	60	0	12
Performance	91	0	218



Prime time
682 h



All parallels
734 h

Cycle 1 Cal – progress

After some updates:

Instr.	Prime (h)	Parallel (h)
NRC	106	57
NRS	91	222
NIS	62	211
MIRI	151	243
Cross	310	0
FGS	10	0
total	730	734

OTE is on a separate budget

Most Cycle 1 Cal observations completed

Some placed on hold, some permanently

Reference files

Most now based on Commissioning data

Files based on C1C data coming online now

Cross-instrument calibration

Will tie photometric calibration with common standards in next 2 months

Planning Cycle 2 Cal

Cycle 1 plan

Instr.	Prime (h)	Parallel (h)
NRC	106	57
NRS	91	222
NIS	62	211
MIRI	151	243
Cross	310	0
FGS	10	0
total	730	734

OTE is on a separate budget

Cycle 2

Prime observations

Assessing C1C and applying lessons learned
Some programs can be discontinued
Newly identified issues require new obs

Parallel observations

Not (yet) heavily utilized by GOs
The more we can do in parallel, the better

Absolute flux calibration

Instr.	Prime (h)	Parallel (h)
NRC	106	57
NRS	91	222
NIS	62	211
MIRI	151	243
Cross	310	0
FGS	10	0
total	730	734

Cross calibration

= Cross-instrument calibration

= Absolute flux calibration

~300 h is ~40% of all prime cal time

That is a significant commitment

The challenge of calibration

$$\vec{S}_T = \vec{S}_o \frac{\vec{C}_T}{\vec{C}_o}$$

$\vec{S}_T \equiv true\ spectrum\ of\ science\ target$

$\vec{S}_o \equiv observed\ spectrum\ of\ science\ target$

$\vec{C} \equiv spectrum\ of\ calibrator$

Philosophy of absolute flux calibration

Next-generation calibration

Our standards ***tied*** to Sirius via **BD+60 1753** (A1 V; Rieke et al. 2022, *AJ*, **163**, 45)

Cross-instrument by design

Standards observed by different instruments ***tie*** them together

Cross-mission calibration by design

All *JWST* standards observed by STIS on *HST*, many by *Spitzer*

Some *JWST* standards (white dwarfs) are also *HST* standards

Absolute Flux Calibration Expert Team

Ties *JWST* directly to the community through external team members

Ultimate test of all parts of the JWST pipeline

Observations of standard stars are the canary in the coal-mine

Objectives of absolute flux calibration

Calibrate all *JWST* instruments and modes

Calibrate *past* formal requirements

imagers – 5%
spectrographs – 10-15%
coronagraphs – 5-15%

Correct for systematic errors in standards

Need a minimum of **three classes** of stars – to test models
Need several of each class – because each star is unique (weather)

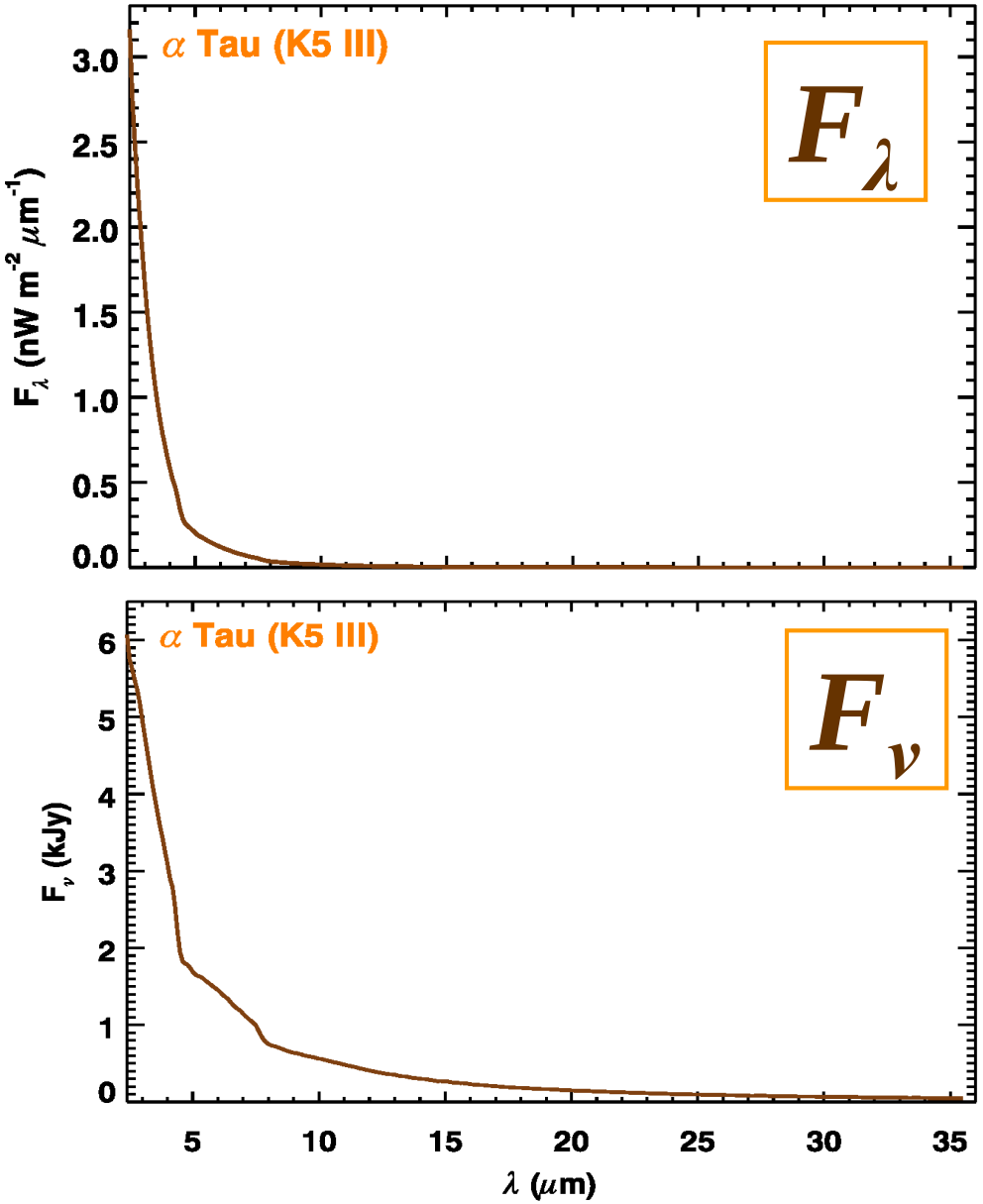
Cross-calibration

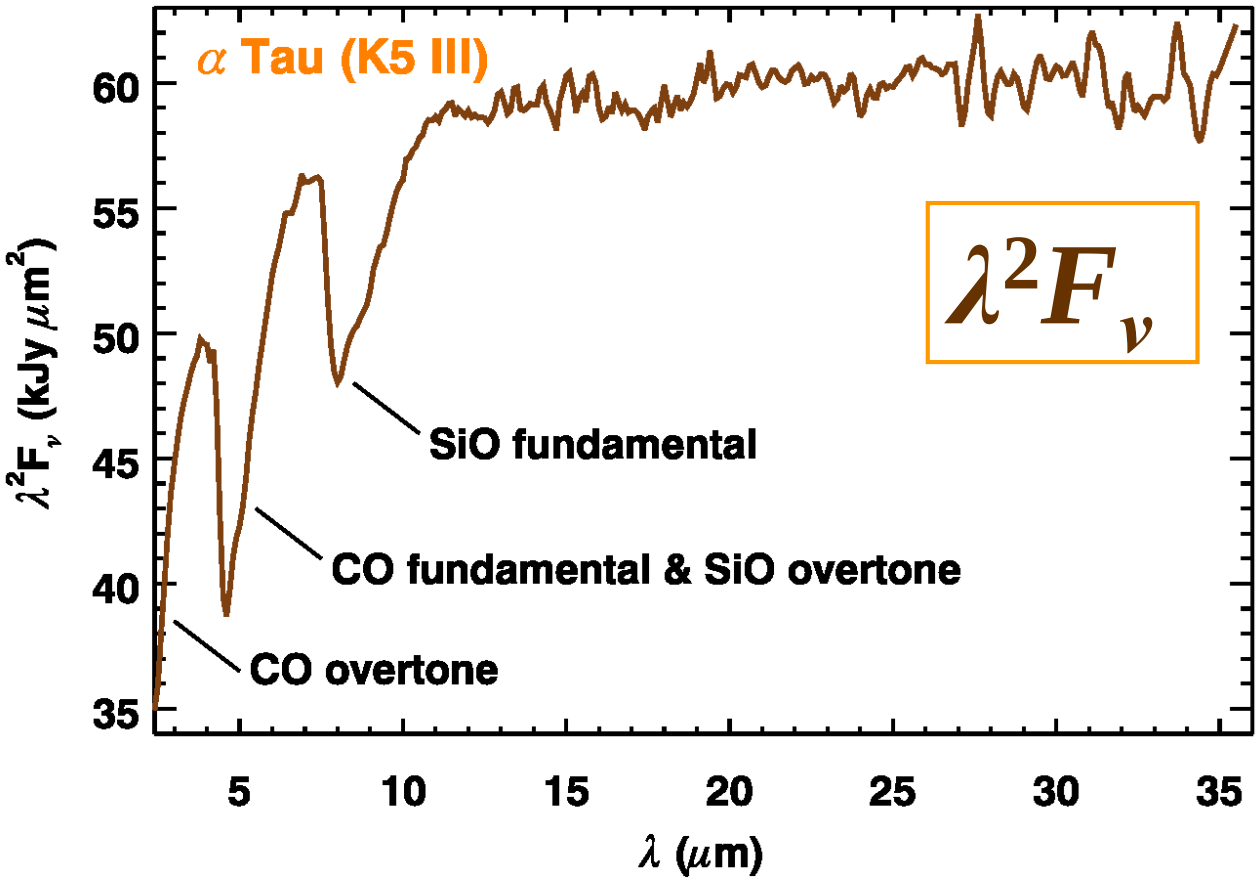
Between *JWST* instruments and with *HST* and *Spitzer*

Document clearly what we're doing

e.g., Gordon et al. (2022, *AJ*, **163**, 267)

Rayleigh-Jeans units hide no sins





RJ units can be $\lambda^2 F_\nu$ or $\lambda^4 F_\lambda$

Standards for absolute flux calibration

Stars – Straightforward to model

Primary standards for *HST*, *Spitzer*, ground-based infrared observatories

A dwarfs

Primary standards for *Spitzer*

G dwarfs (Solar analogs)

Strong heritage in infrared

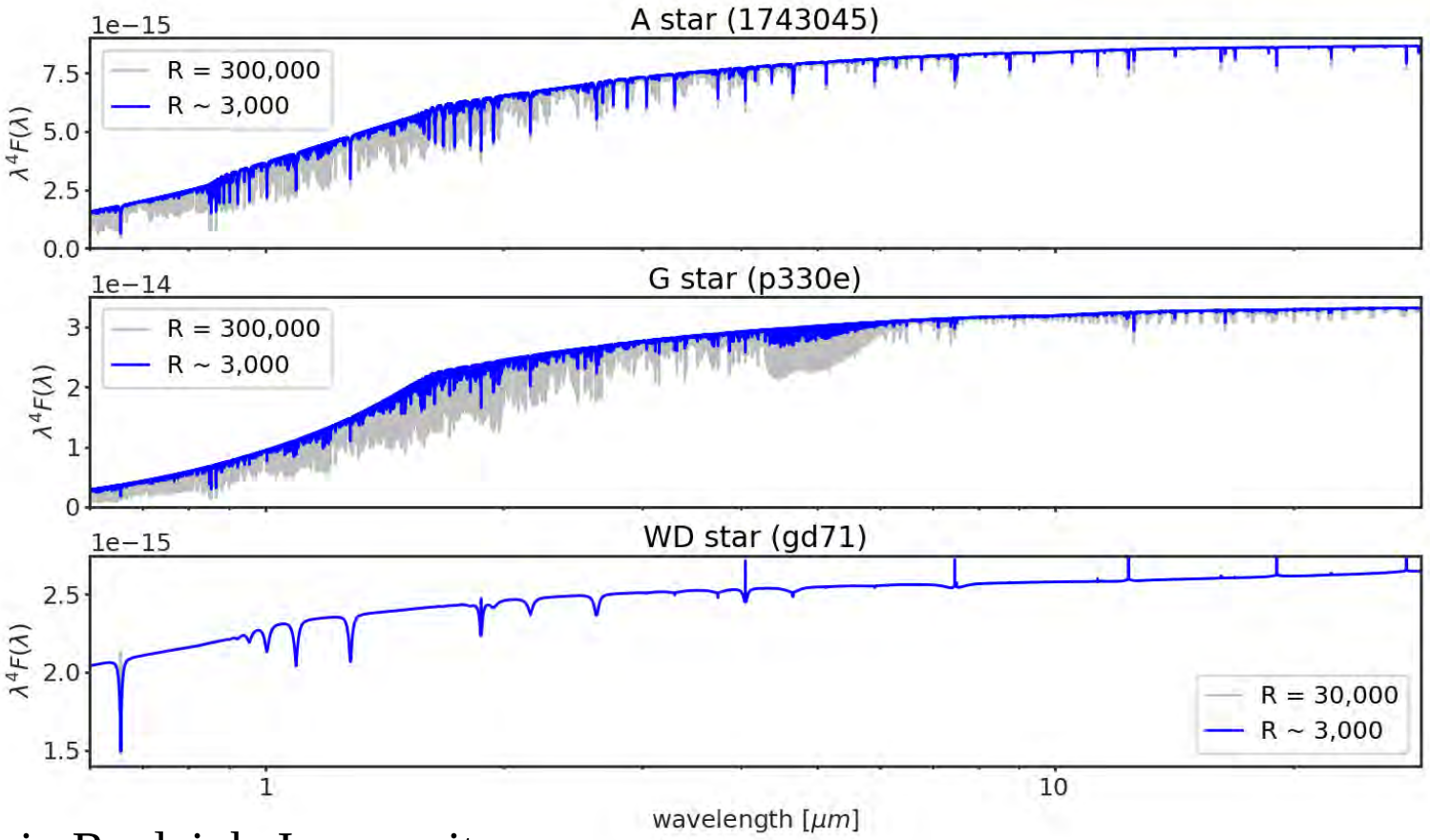
Used by *Spitzer*

Hot dwarfs

White dwarfs

Primary standards for *HST*

OB stars planned in Cycle 2



Flux density in Rayleigh-Jeans units

Abs fluxcal – the Cycle 1 plan

Part 1 – A star in every filter, optical element, detector …

NIR instruments and MIRI imager– 3 stars – 1 star of each type

MIRI MRS, LRS, coronagraph – 1 A dwarf and 1 G dwarf

Part 2 – Building the sample

Objective – 5 stars of each type, to beat down random and systematic noise

After rejecting misbehaving standards, need a minimum of 3 of each type

Fewer bad standards = lower systematic noise

More stars = lower random noise

Part 3 – Repeatability

Observe 1 star with a monthly cadence on each detector

Abs fluxcal – general results

Still in Cycle 1, and already looking good

Repeatability

~0.5% (1-sigma)

Variations between full and subarrays

1–4%

Scatter between standards

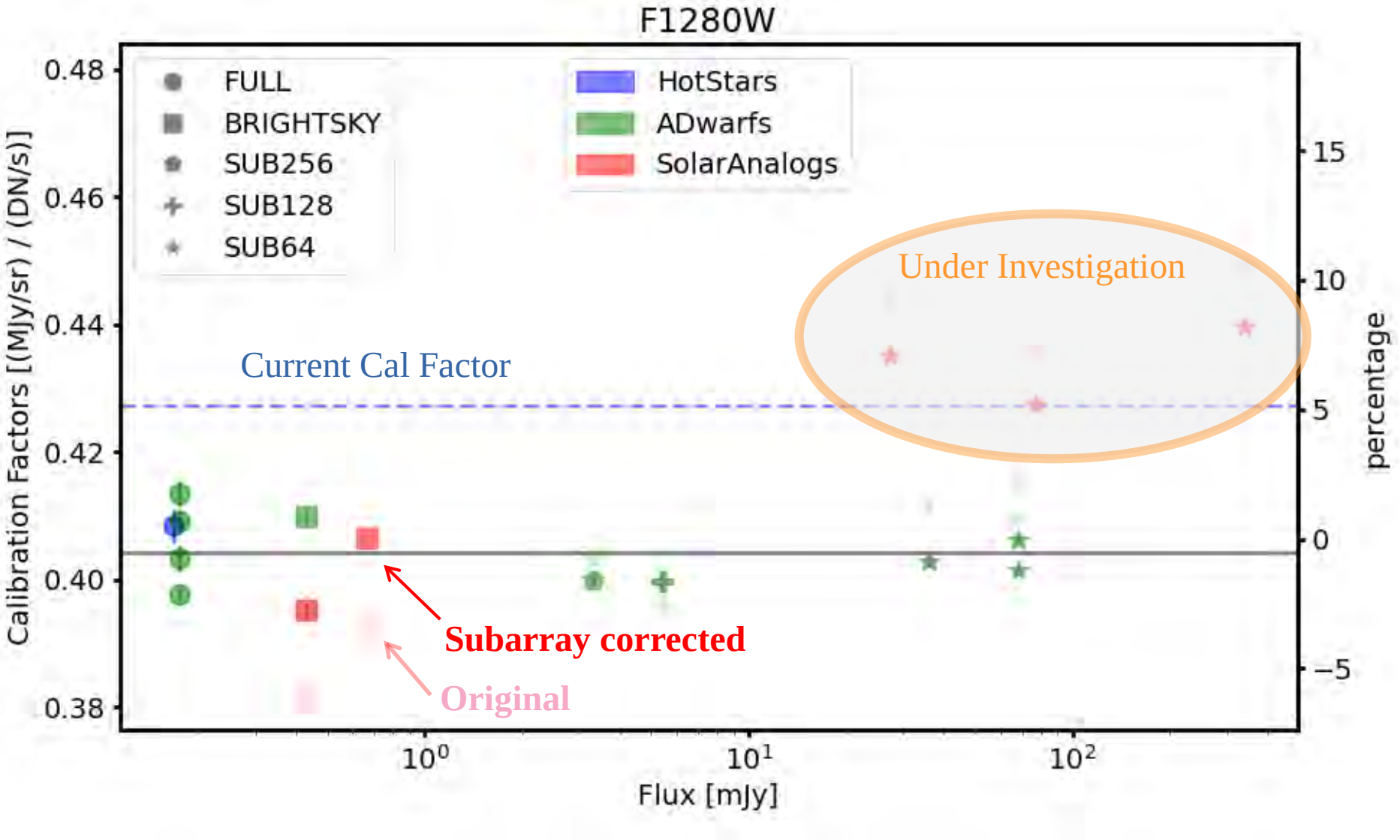
Generally <2%

Some filters (e.g. MIRI F560W) show more scatter

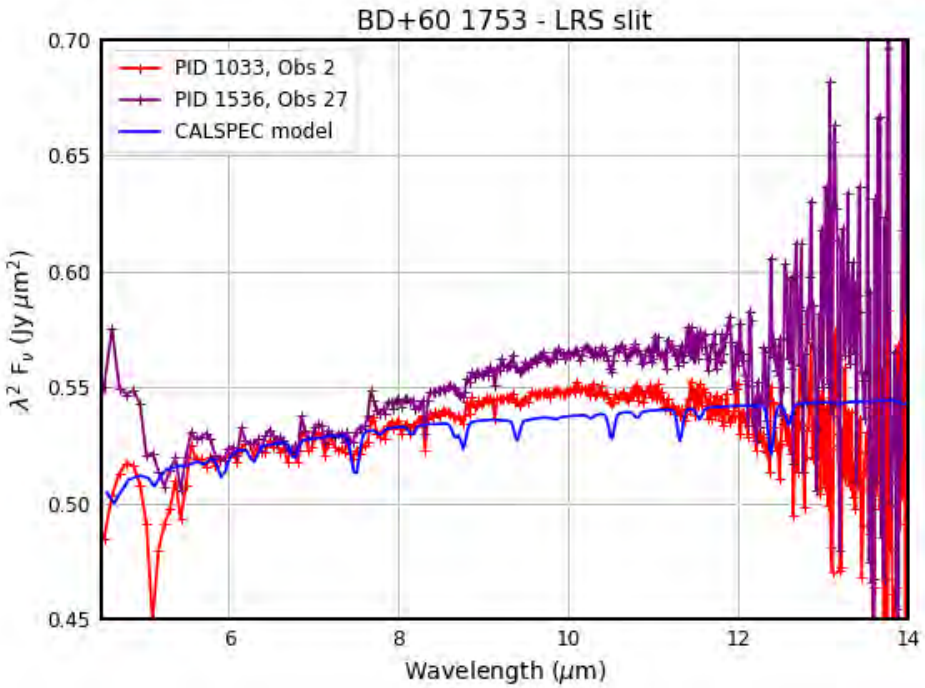
4 bright standards (for MIRI) below model predictions

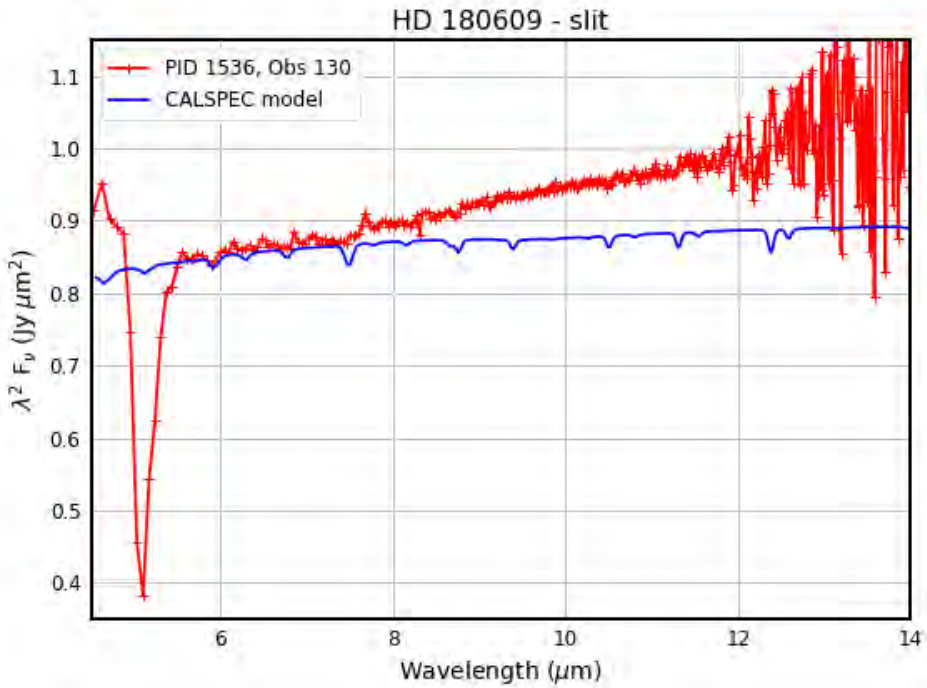
New reference files based on Cycle 1 standards are on the way

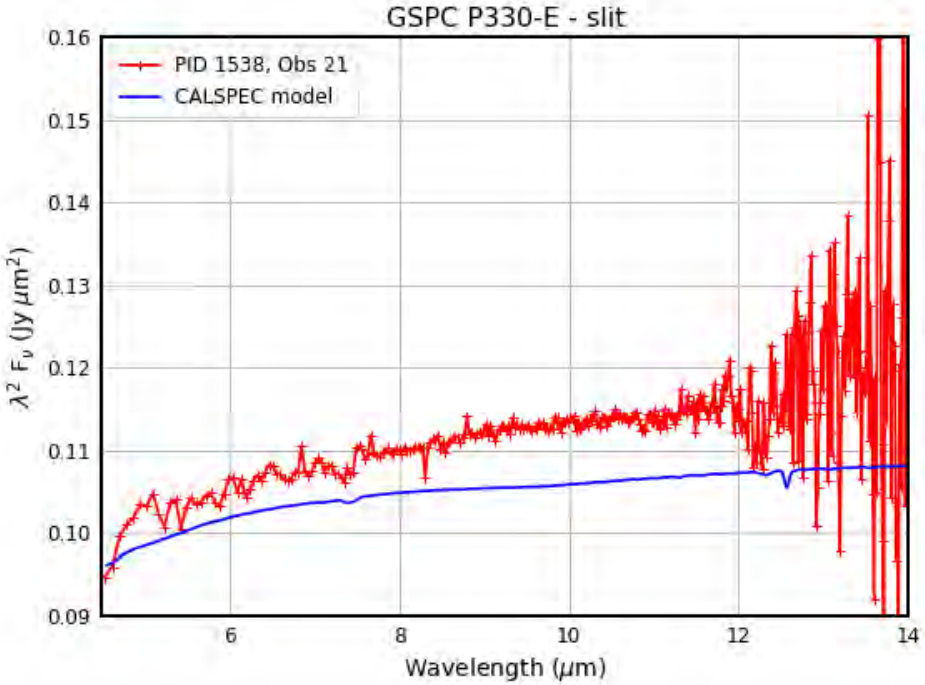
Abs fluxcal – an example from MIRI imager

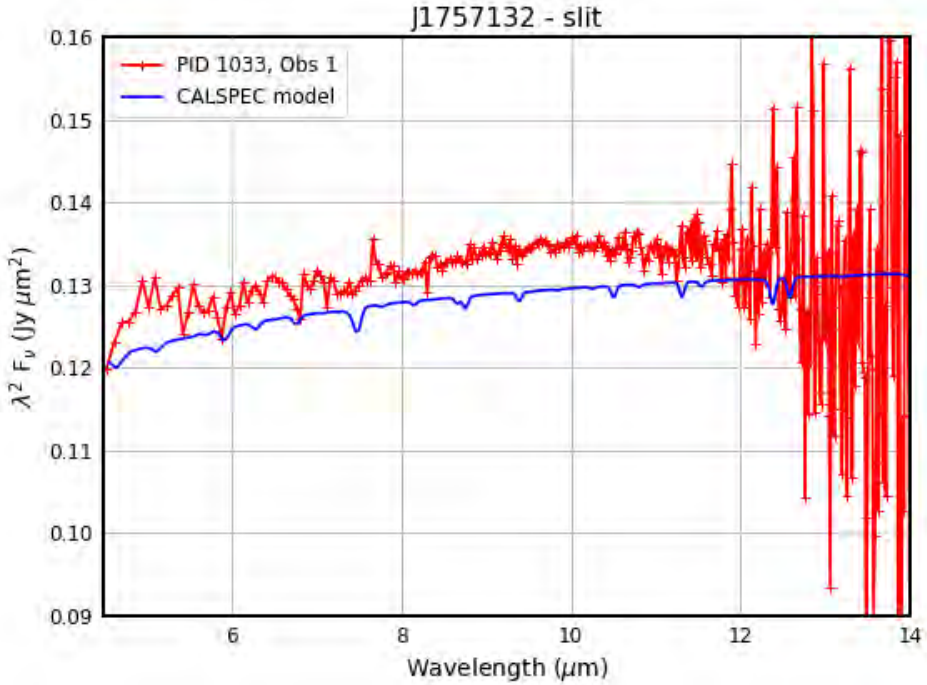


LRS slit









Integrate spectra (in RJ units) from 5.6 to 8.0 um

Target	LRS/CALSPEC
BD+60 (1033)	0.9996
BD+60 (1536)	1.0106
HD 180609	1.0168
GSPC P330-E	1.0403
J1757132	1.0289

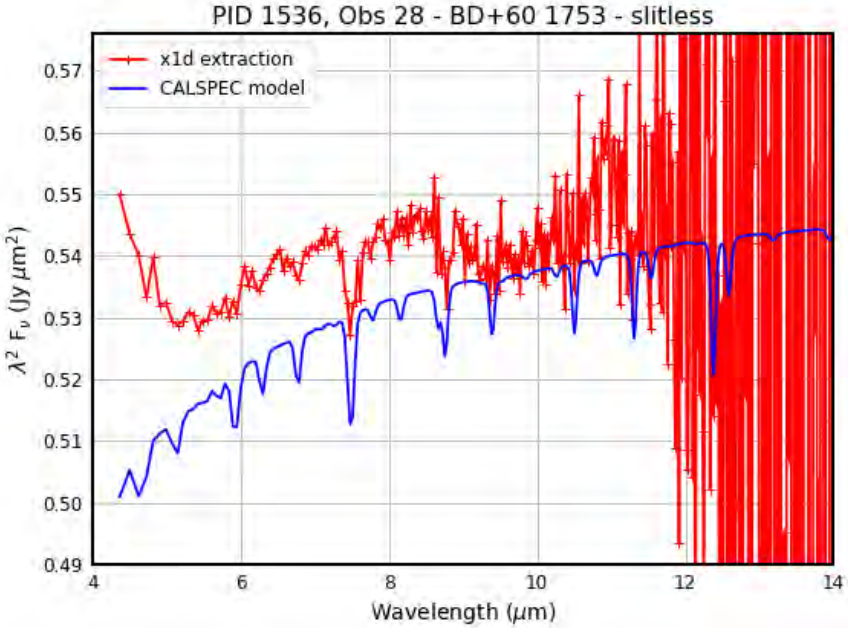
Good news: See above

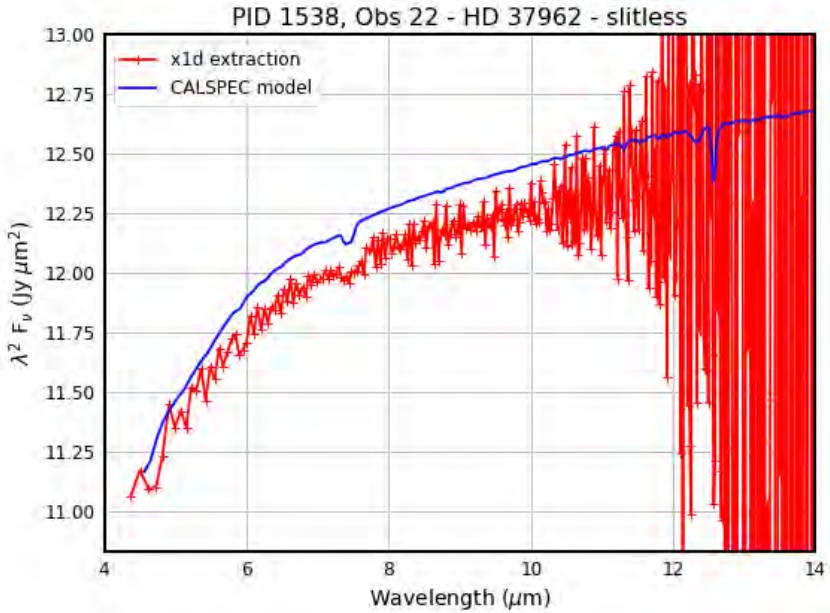
Under investigation:
Deviations from models

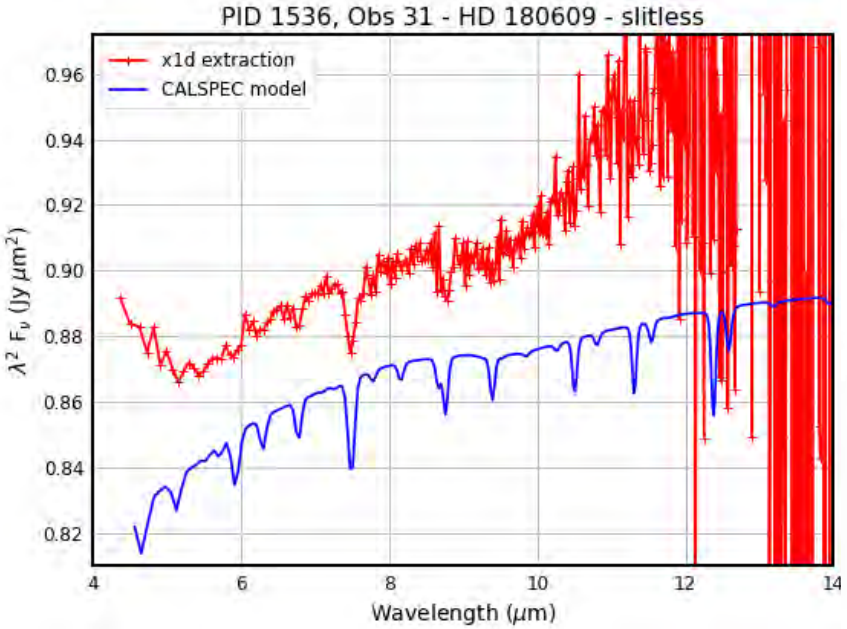
LRS slitless

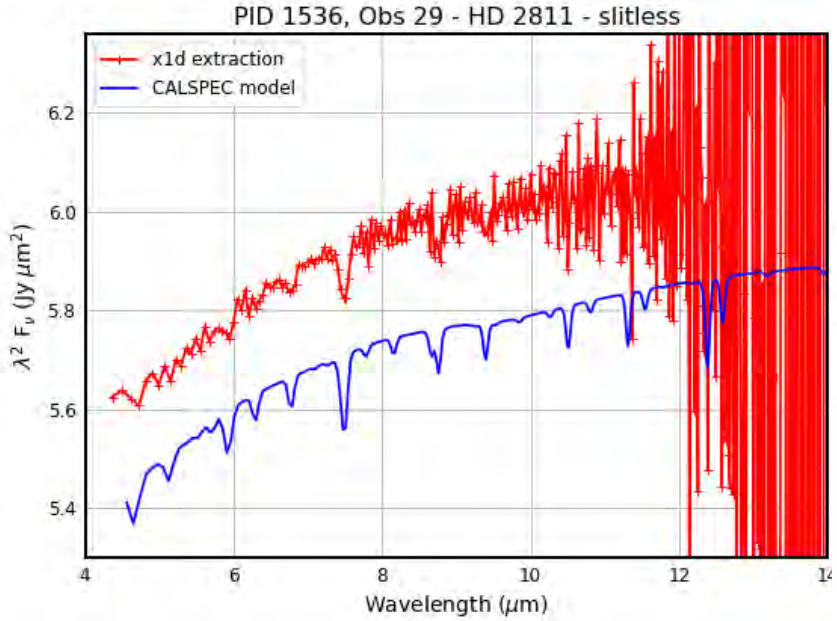
Absolute flux calibration is ***arbitrary***

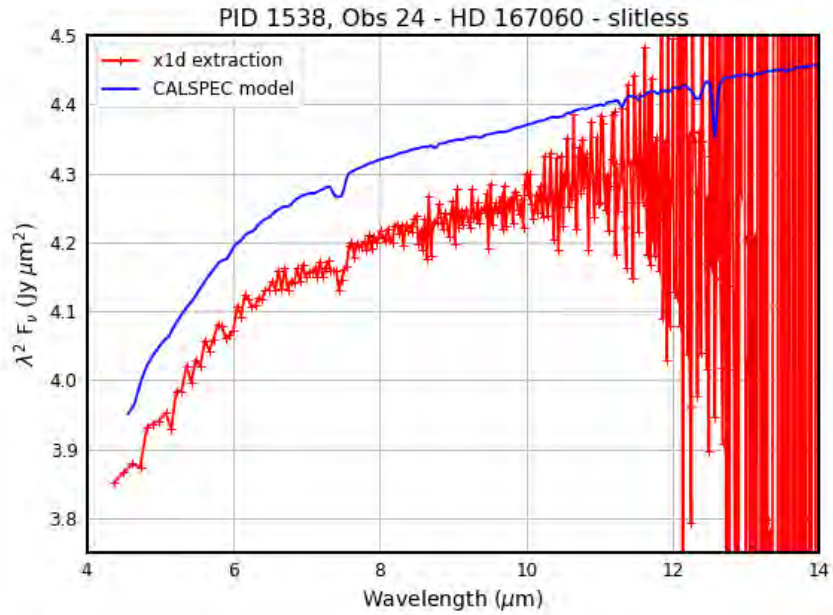
Calibration tied to average of
HD 2811, HD 37962, HD 167060











Abs fluxcal – planning for Cycle 2 Cal

Part 3 – Repeatability

Plan – 1 star per month on each detector

Cycle 1 – Planned cadence disrupted by some observing failures

Cycle 2 – Continue with 1 star per month on each detector

Part 2 – Building the sample

Objective – 5 stars of each type, to beat down random and systematic noise

Cycle 1 – 3 stars of each type

Cycle 2 – 3 stars of each type, but with new stars

Part 1 – A star in every filter, optical element, detector …

Cycle 1 – Had 3 stars in NIR, 2 stars in MIR

Cycle 2 – Just 1 star per element, to be selected by the abs flux cal team