



The James Webb Space Telescope

will explore our Solar System:
asteroids; comets; Mars; giant
planets and their moons including
Europa; Pluto and other distant
objects; plus more...

www.jwst.nasa.gov

www.stsci.edu/jwst/science/solar-system
<http://iopscience.iop.org/1538-3873/128/959>

JWST Solar System Capabilities, Observation Planning Tools

Solar System ERS Webinar

2017-02-07



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Scientist for Solar System Science)

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JWST Solar System lead)

JWST Science Instrument Overview

Instrument Modes, Sensitivity Comparison

JWST Imaging Modes

Mode	Instrument	Wavelength (microns)	Pixel Scale (arcsec)	Full-Array* Field of View
Simultaneous Imaging	NIRCam*	0.6 – 2.3	0.032	2.2 x 2.2'
	NIRCam*	2.4 – 5.0	0.065	2.2 x 2.2'
	NIRISS	0.9 – 5.0	0.065	2.2 x 2.2'
	MIRI*	5.0 – 28	0.11	1.23 x 1.88'
Aperture Mask Interferometry	NIRISS	3.8 – 4.8	0.065	-----
	NIRCam	0.6 – 2.3	0.032	20 x 20"
	NIRCam	2.4 – 5.0	0.065	20 x 20"
	MIRI	10.65	0.11	24 x 24"
Coronography	MIRI	11.4	0.11	24 x 24"
	MIRI	15.5	0.11	24 x 24"
	MIRI	23	0.11	30 x 30"

** Most useful for solar system observations

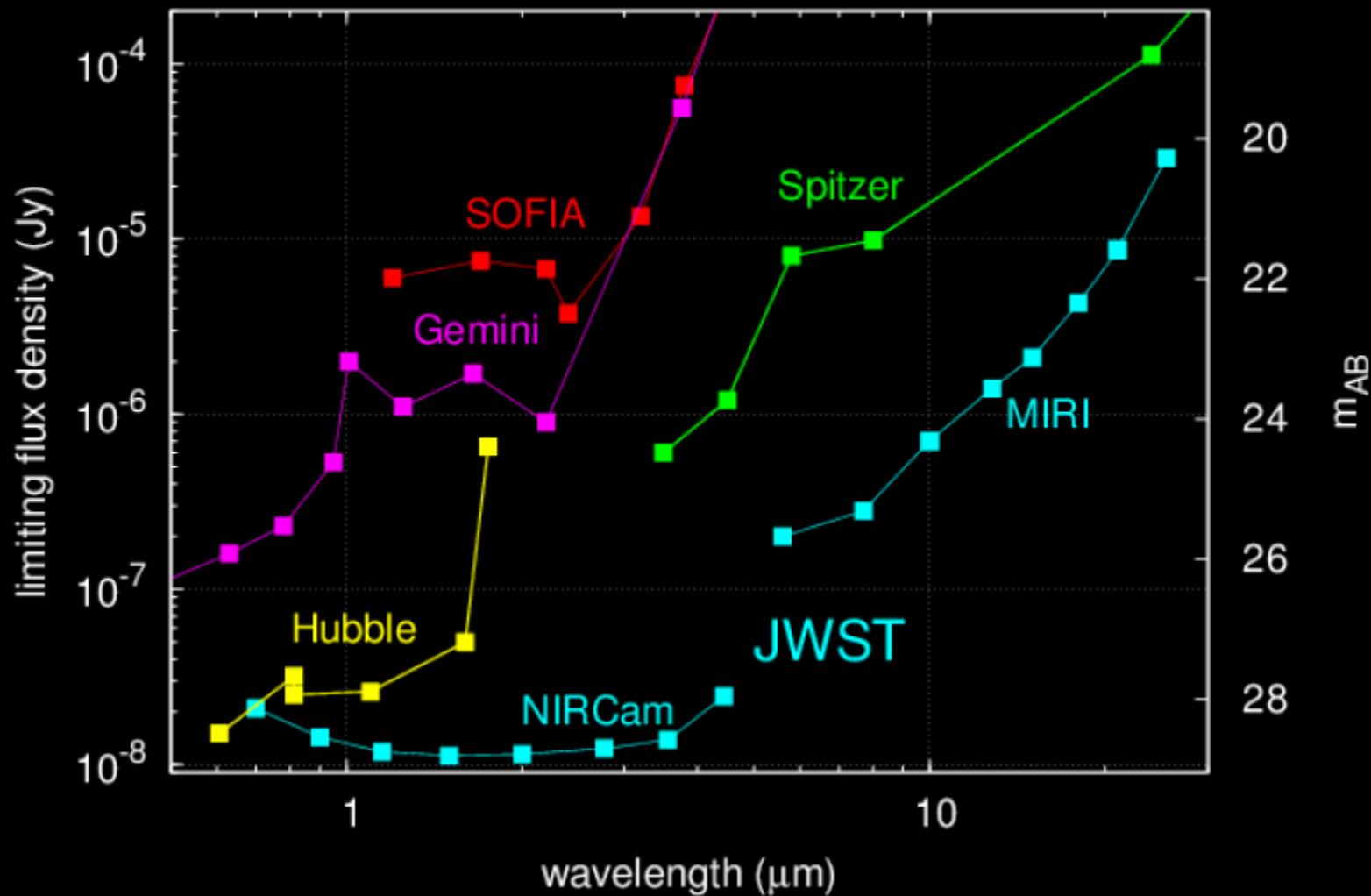
JWST Spectroscopy Modes

Mode	Instrument	Wavelength (microns)	Resolving Power ($\lambda/\Delta\lambda$)	Field of View / Slit Size
Slitless Spectroscopy	NIRISS	1.0 – 2.5	150	2.2' x 2.2'
	NIRISS	0.6 – 2.5	700	single object
	NIRCam	2.4 – 5.0	2000	2.2' x 2.2'
Multi-Object Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	3.4' x 3.4' with 250k 0.2 x 0.5" microshutters
Single Slit Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	0.4" x 3.8"
				0.2" x 3.3"
Spectroscopic Imaging (IFU)	NIRSpec	0.6 – 5.0	100, 1000, 2700	1.6" x 1.6"
				0.2" x 60" (MSA)
	MIRI	5.0 – ~14.0	~100 at 7.5 microns	0.6" x 5.5" slit
	MIRI	5.0 – 7.7	3500	3.0" x 3.9"
	MIRI	7.7 – 11.9	2800	3.5" x 4.4"
	MIRI	11.9 – 18.3	2700	5.2" x 6.2"
	MIRI	18.3 – 28.8	2200	6.7" x 7.7"

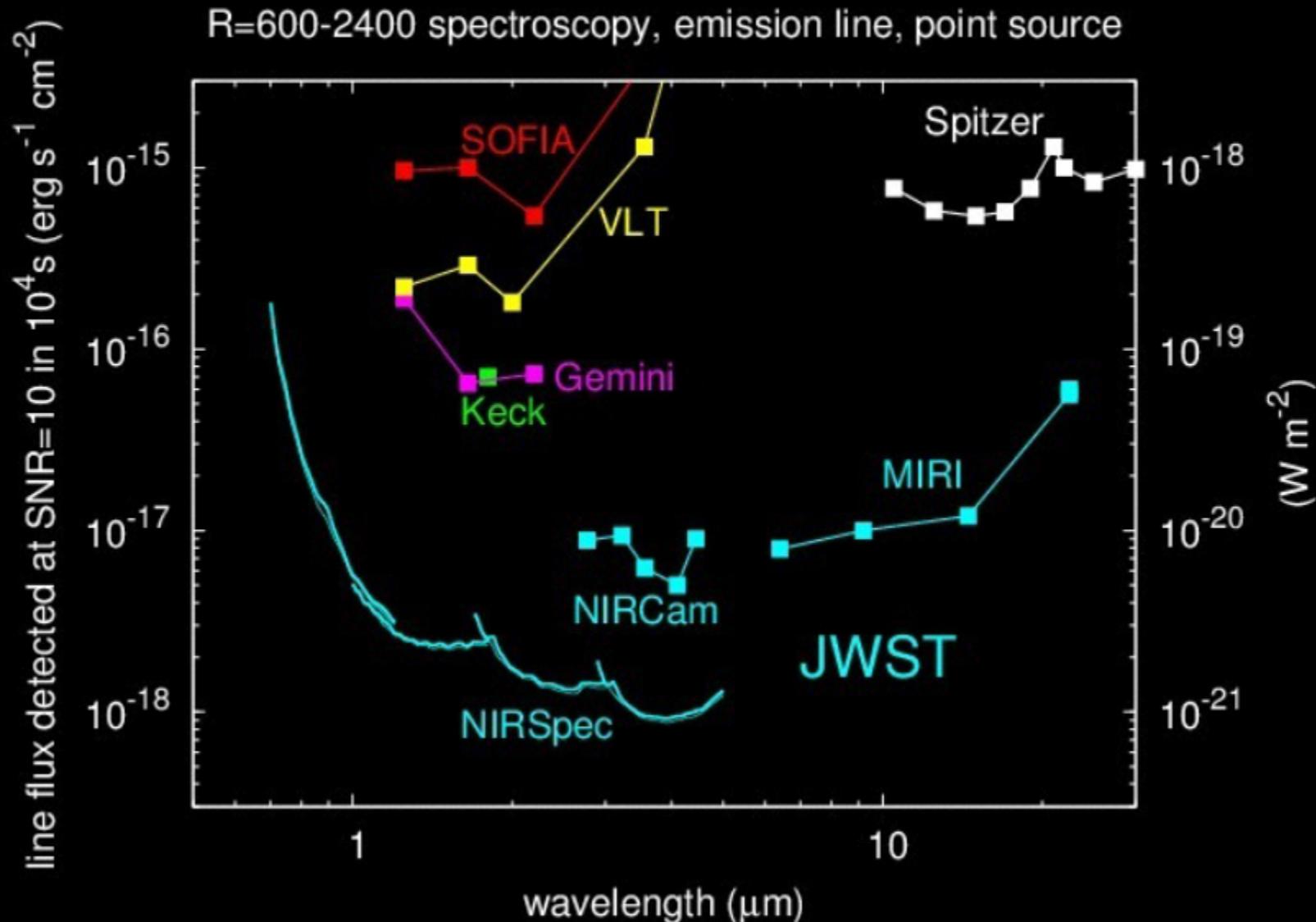
** Most useful for solar system observations

Photometric Sensitivity

photometric performance, point source, SNR=10 in 10^4 s

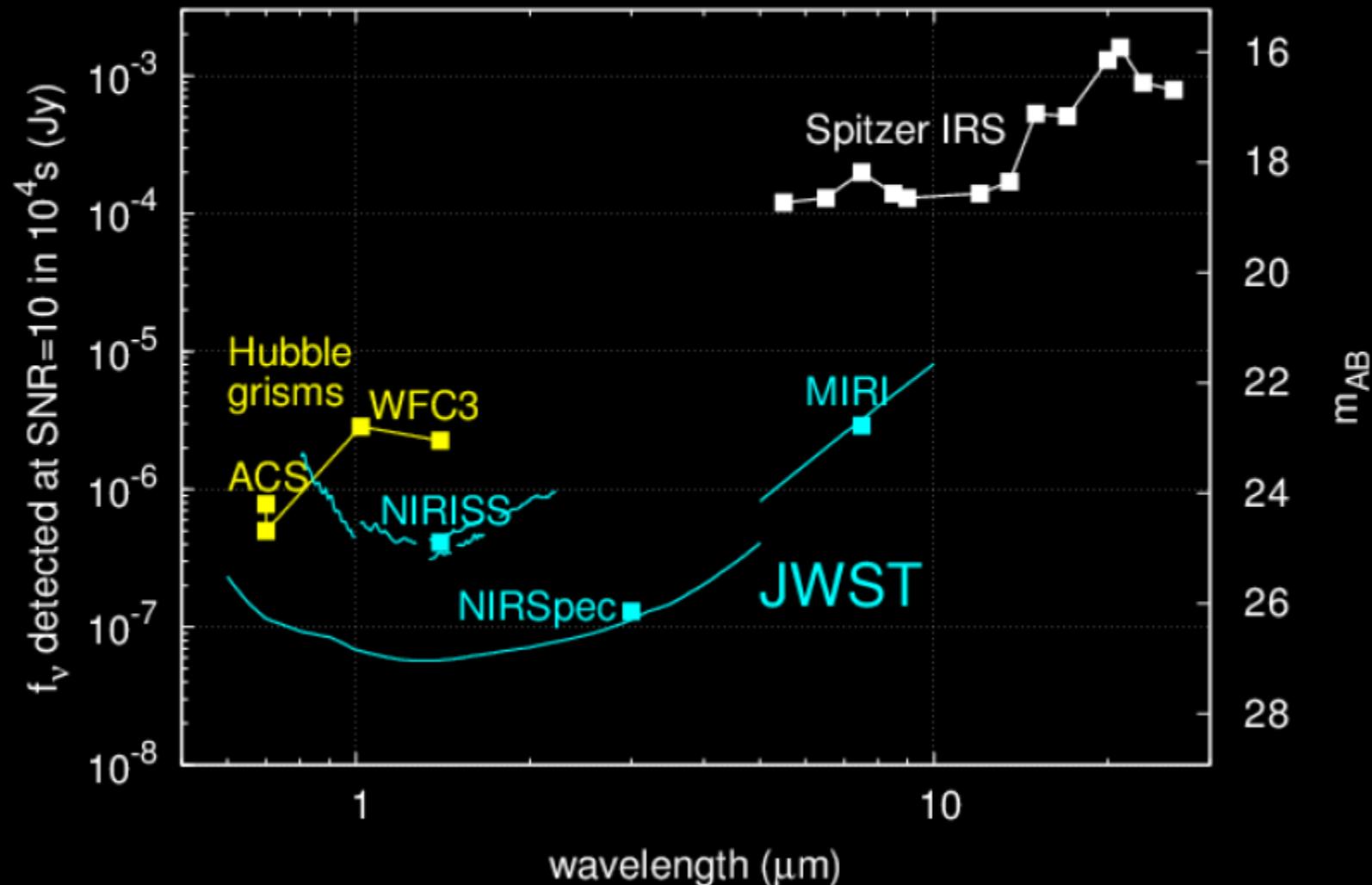


Medium Resolution Spectral Sensitivity



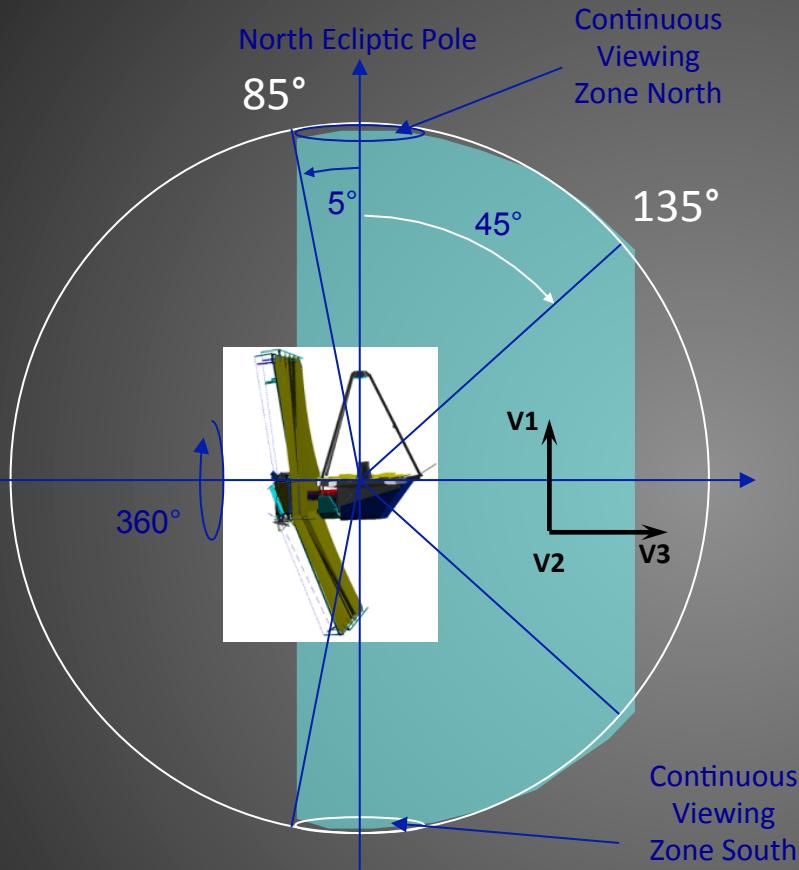
Low Resolution Spectral Sensitivity

Low resolution ($R \sim 100$) spectroscopy, point source



JWST Operations for Moving Targets

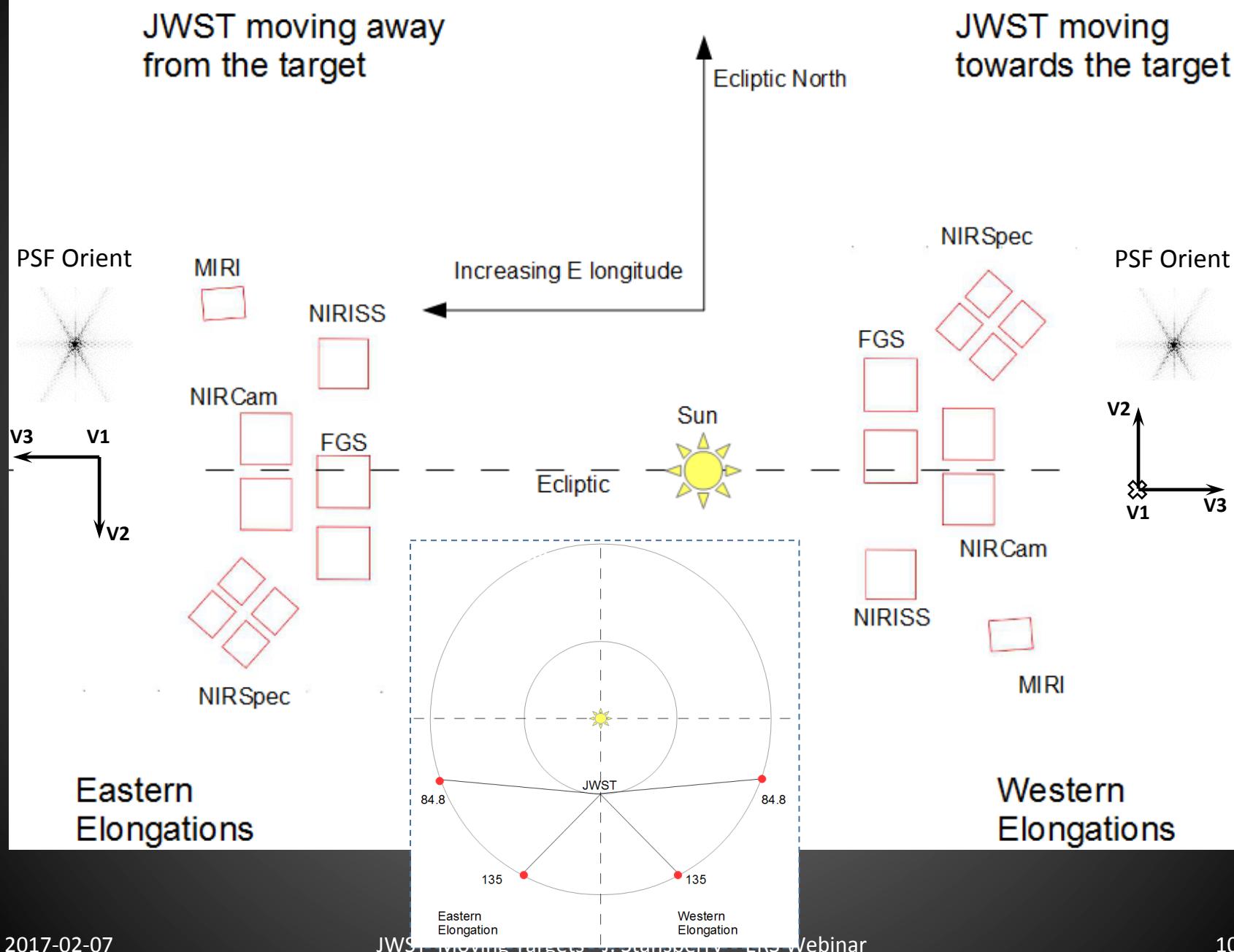
JWST Field of Regard



- Observatory thermal design defines the allowed Solar orientations
 - Solar elongation 85° to 135° (like Spitzer, Herschel)
 - Roll $\pm 5^\circ$ about line of sight
- JWST can observe the whole sky every year while remaining continuously in the shadow of its sunshield.
 - Instantaneous Field of Regard is an annulus covering 35% of the sky
 - The whole sky is covered twice each year with small continuous viewing zones at the Ecliptic poles

Solar System Targets: Observations occur near quadrature, not at opposition

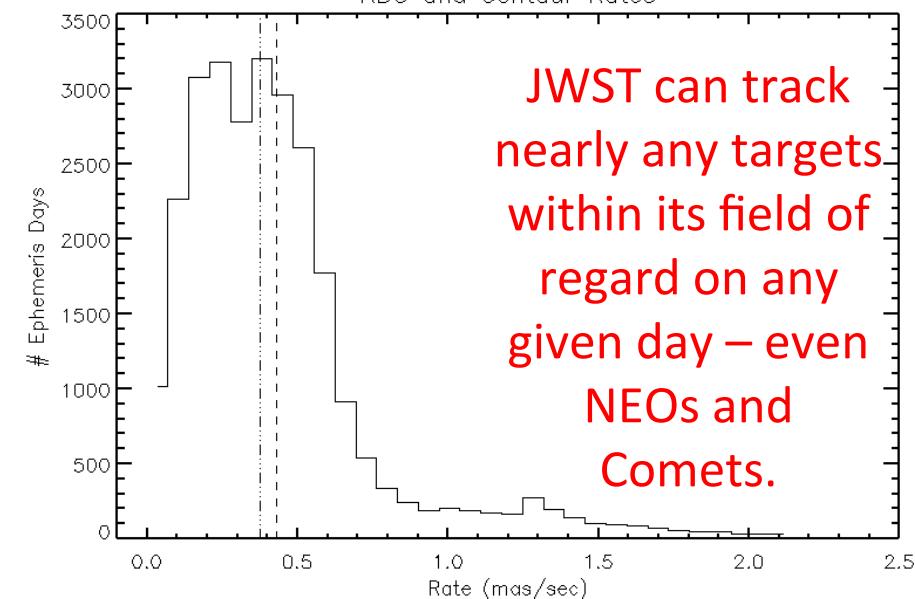
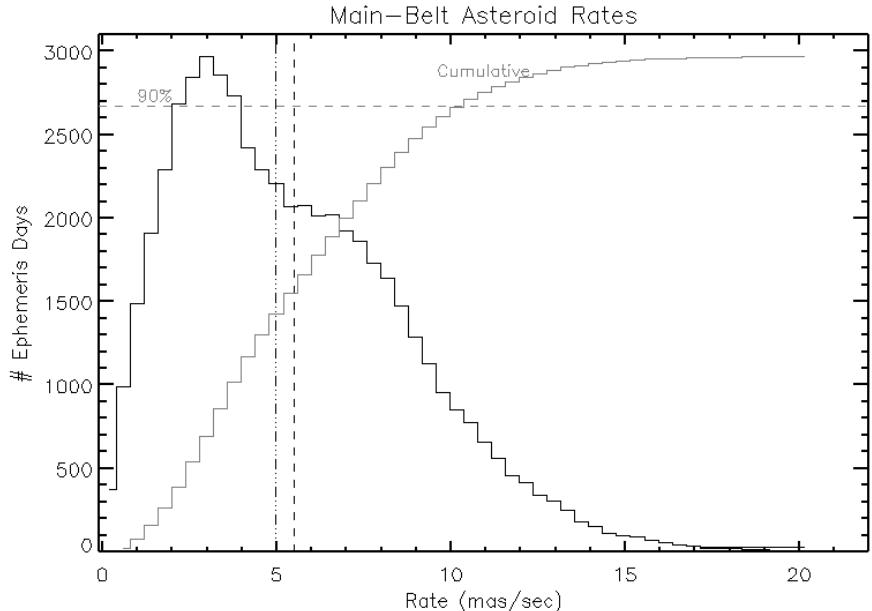
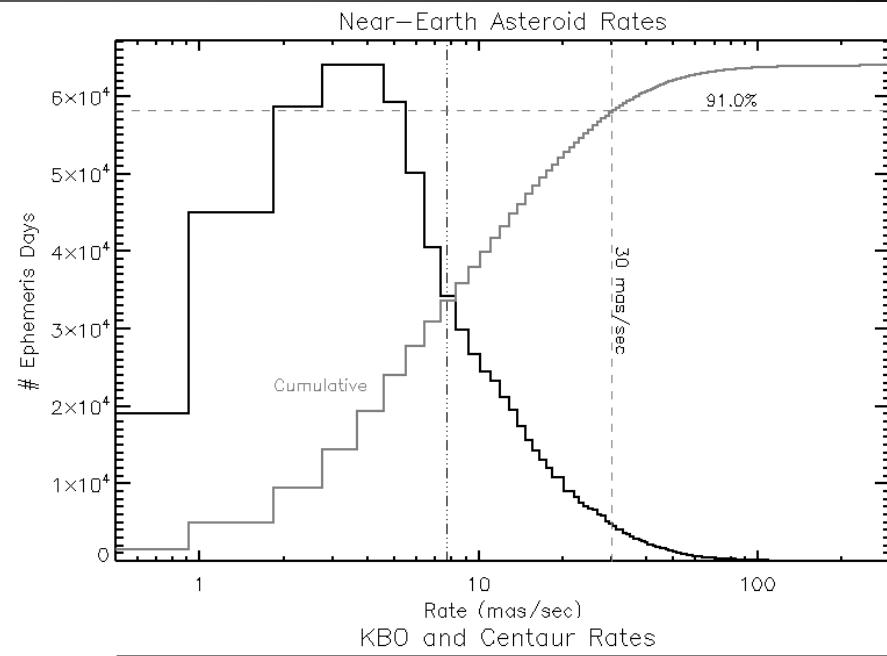
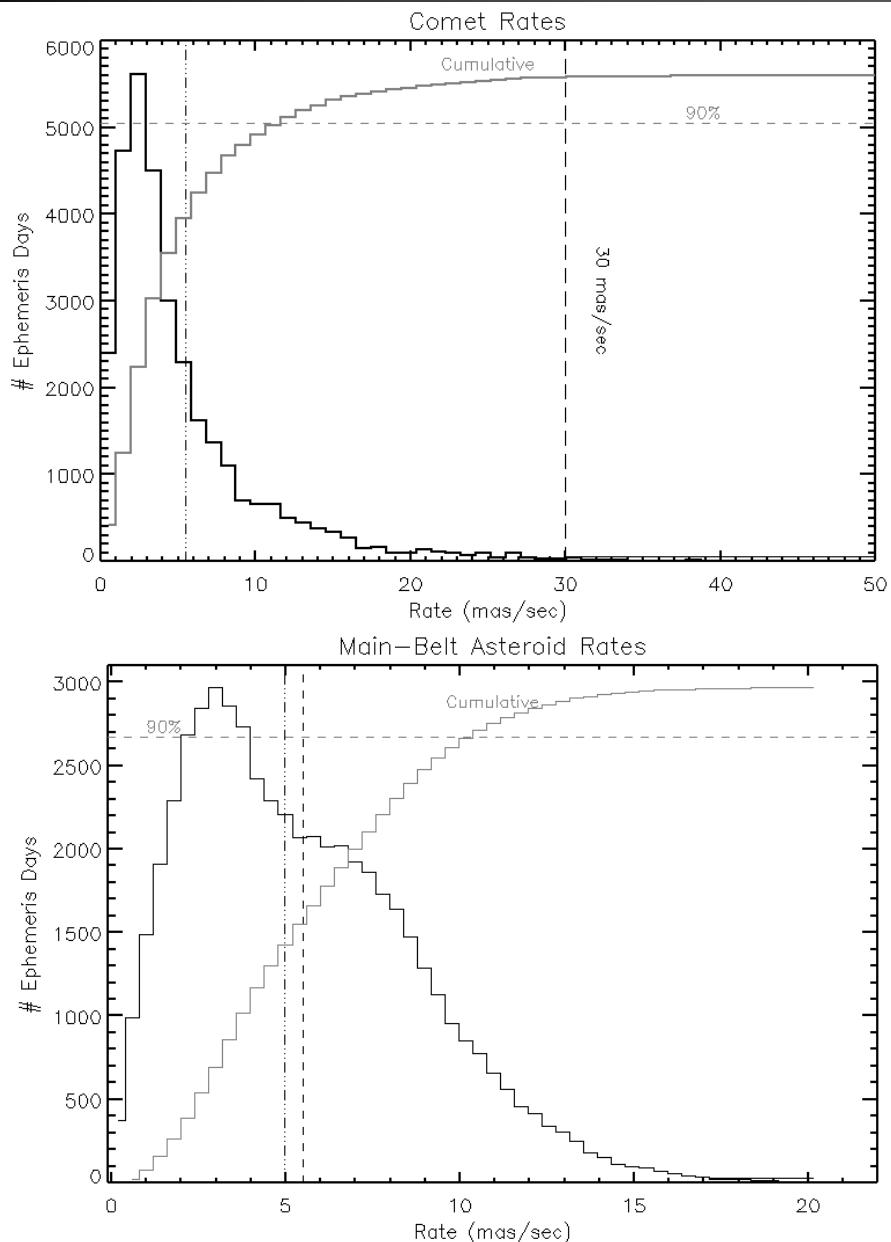
JWST Instrument FOVs for Targets in the Ecliptic Plane



Moving Targets Tracking

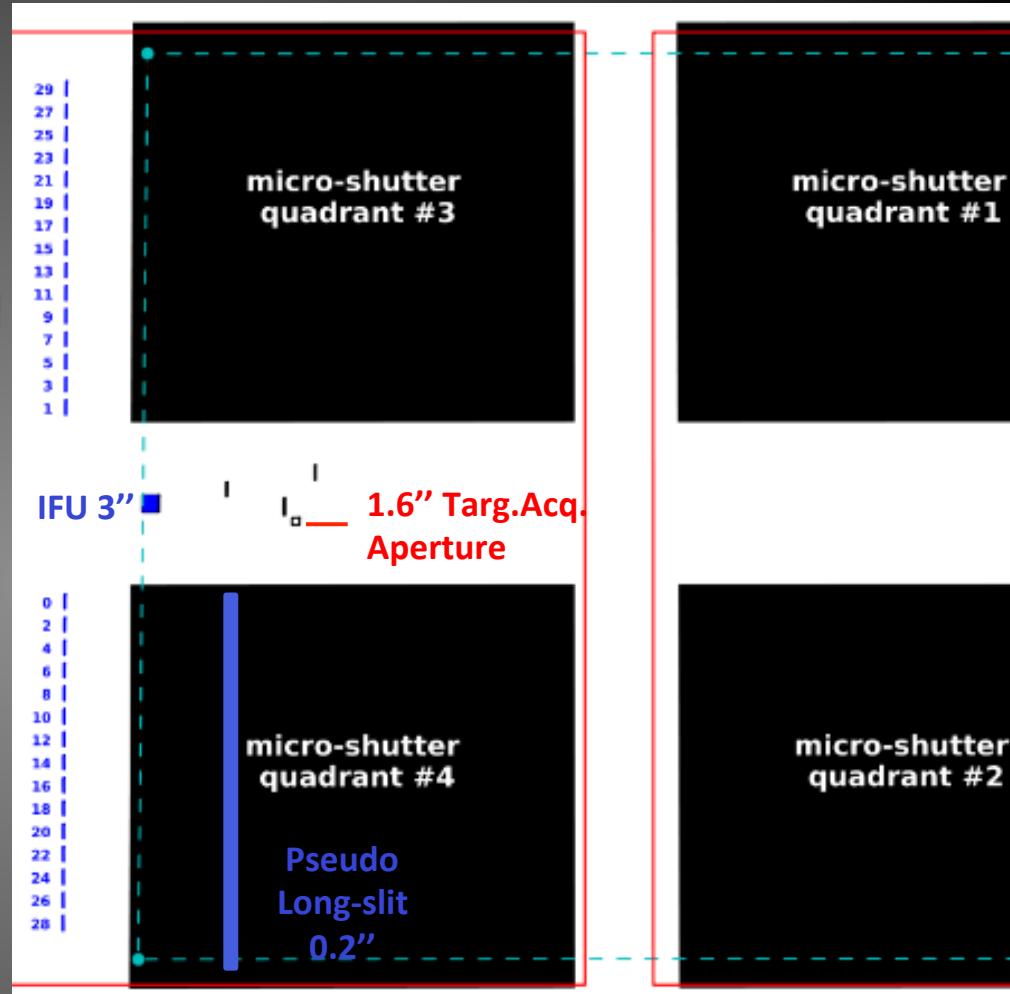
- Non-sidereal tracking – **Implemented.**
 - Rates up to 30 mas/s (108"/hr) supported (max rate of Mars)
 - Modeling shows excellent pointing stability (< 7mas NEA), ~same as fixed targets
 - The moving-target is fixed in detector frame while exposing
 - Dithers, mosaics supported (slightly higher overheads)
 - ~1 mag brighter guide stars required for moving targets
 - Some small impact on schedulability for targets at high galactic latitude
 - Long (~1hr+ tracks), and observations are possible
 - Will use multiple guide stars

How Fast are Moving Targets Moving?



NIRSpec Target Acquisition, Slits, IFU

- NIRSpec TA for moving targets is not easy
 - 1.6'' square aperture
 - Ephemeris of target must be accurate!
 - Centroid calculated on-board
 - Target can be accurately (<10mas) positioned in the IFU, any of the fixed slits, or in a pseudo long-slit in the microshutter array



Solar System Science Highlights

12 JWST Solar System Papers

<https://iopscience.iop.org/1538-3873/128/959> & 960

- **Asteroids** (Andy Rivkin, JHU/APL)
- **Comets** (Chick Woodward, U. Minnesota)
- **Giant Planets, JWST Overview** (Jim Norwood, NMSU)
- **Mars** (Geronimo Villanueva, GSFC)
- **NEOs** (Cristina Thomas, GSFC)
- **Occultations** (Pablo Santos-Sanz, IAA-CSIC, Spain)
- **Rings** (Matt Tiscareno, Cornell)
- **Satellites** (Laszlo Kestay, USGS)
- **Titan** (Conor Nixon, GSFC)
- **TNOs** (Alex Parker, SwRI)
- **JWST Solar System Capabilities** (Milam, GSFC)

JWST Instruments & APT Templates

NIRCam: 0.6 – 5 um imager, slitless grisms,
32 / 65 mas pixels (SW / LW)

Imaging **

Simultaneous 0.6-2.3 & 2.4-5.0 micron imaging
Mapping (2.2' x 5' FOV)
Bright extended sources (10'' – 1.1' FOV)

Coronagraphy

~0.5" inner working angle

Time Series **

High-cadence, long duration photometry

Grism Time Series **

High-cadence, long duration slitless spectroscopy

Grism Imaging

Wide-field slitless spectroscopy

NIRISS: 0.8 - 5 um imager & spectrometer

R = 150 0.8 – 2.2 um slitless spectra

R = 700 0.8 – 2.5 um slitless spectra

Imaging in 7 bands

Aperture-masking Interferometry **

2.6 – 5um, 65mas resolution

NIRSpec: 0.7 – 5 um spectrometer

R = 100, 1000, 2700

3 settings for full coverage at R > 100

IFU Spectroscopy **

3"x3" FOV, 100mas pixels

Fixed Slits

0.2" & 0.4" x 3.8", 1.6"x1.6"

Multi-shutter Array (Pseudo long-slit **)

0.2" x 0.46" slitlets

MIRI: 5 - 28 um imager & spectrometer

R = 100 5 – 14 um slit spectra

Imaging **

9 bands

110 mas pixels

IFU Spectroscopy **

4"x4" FOV, 110mas pixels, R=2000

5 – 28 um (4 settings for full coverage)

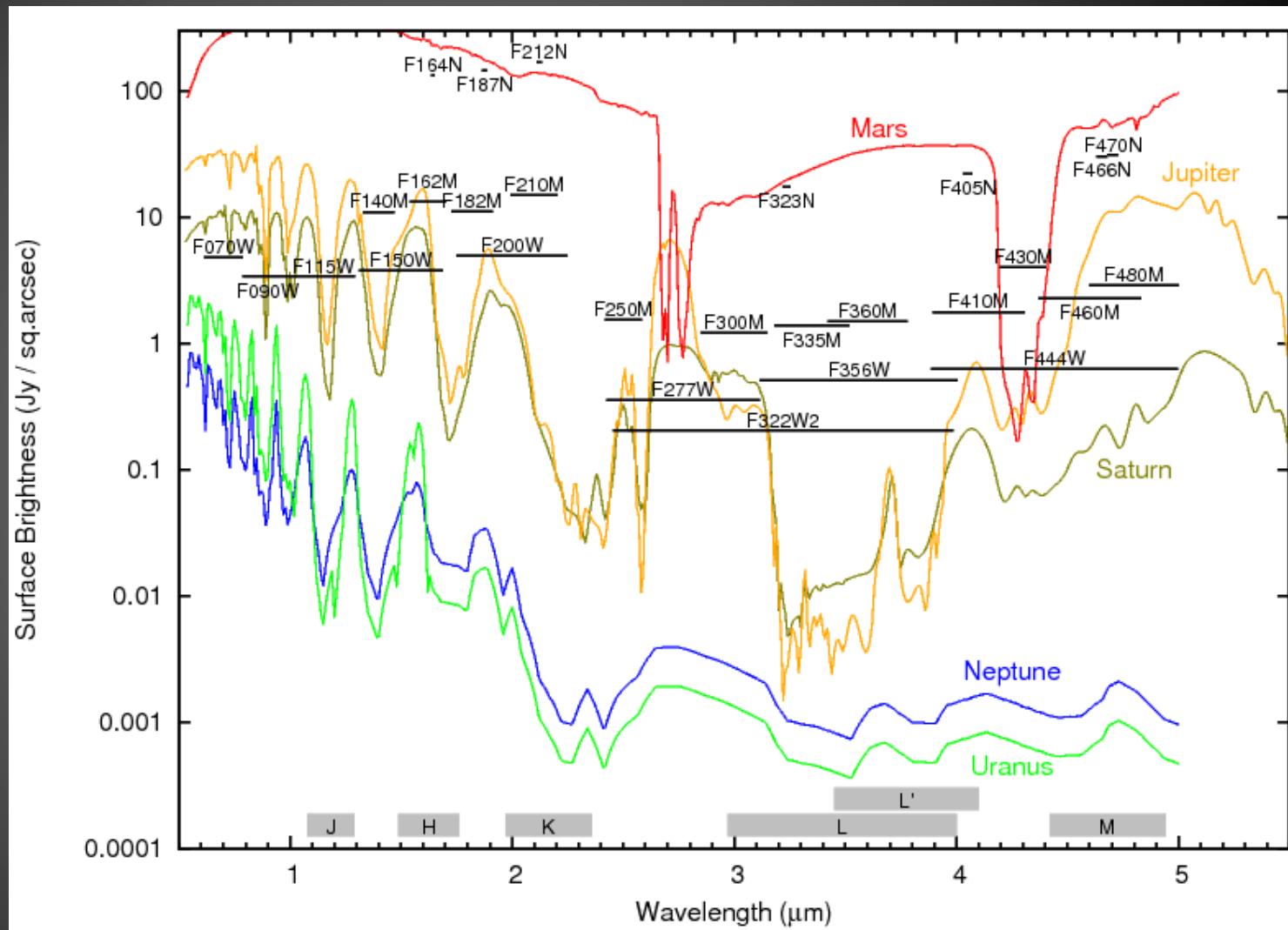
Fixed Slit **

0.6" x 5.5", R=100, 5 – 14 um in one shot

** Most useful for solar system observations

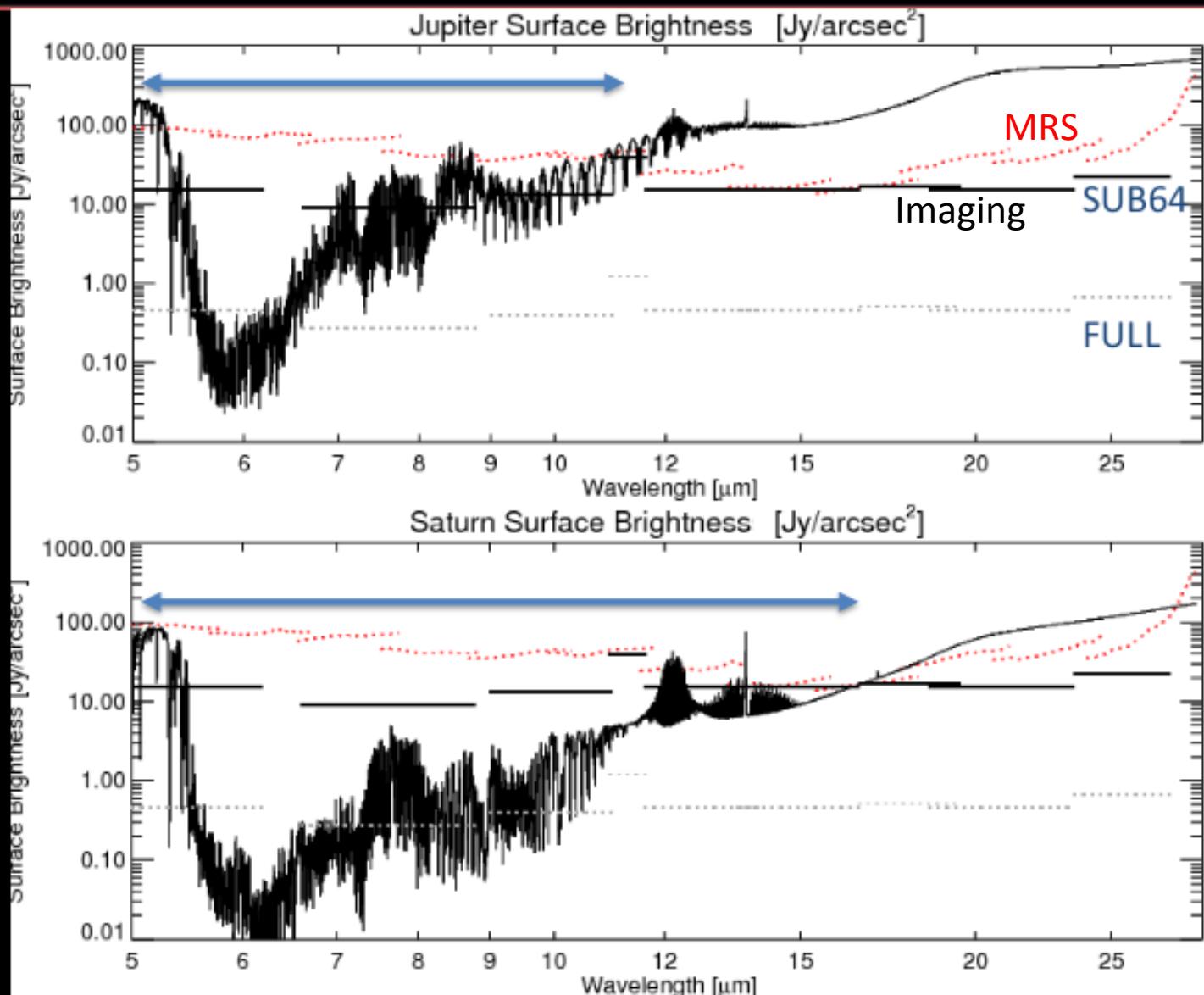
Giant Planet Imaging with NIRCam

- Bright limits for 640x640 subarrays
- 160x160 limits are 15x higher



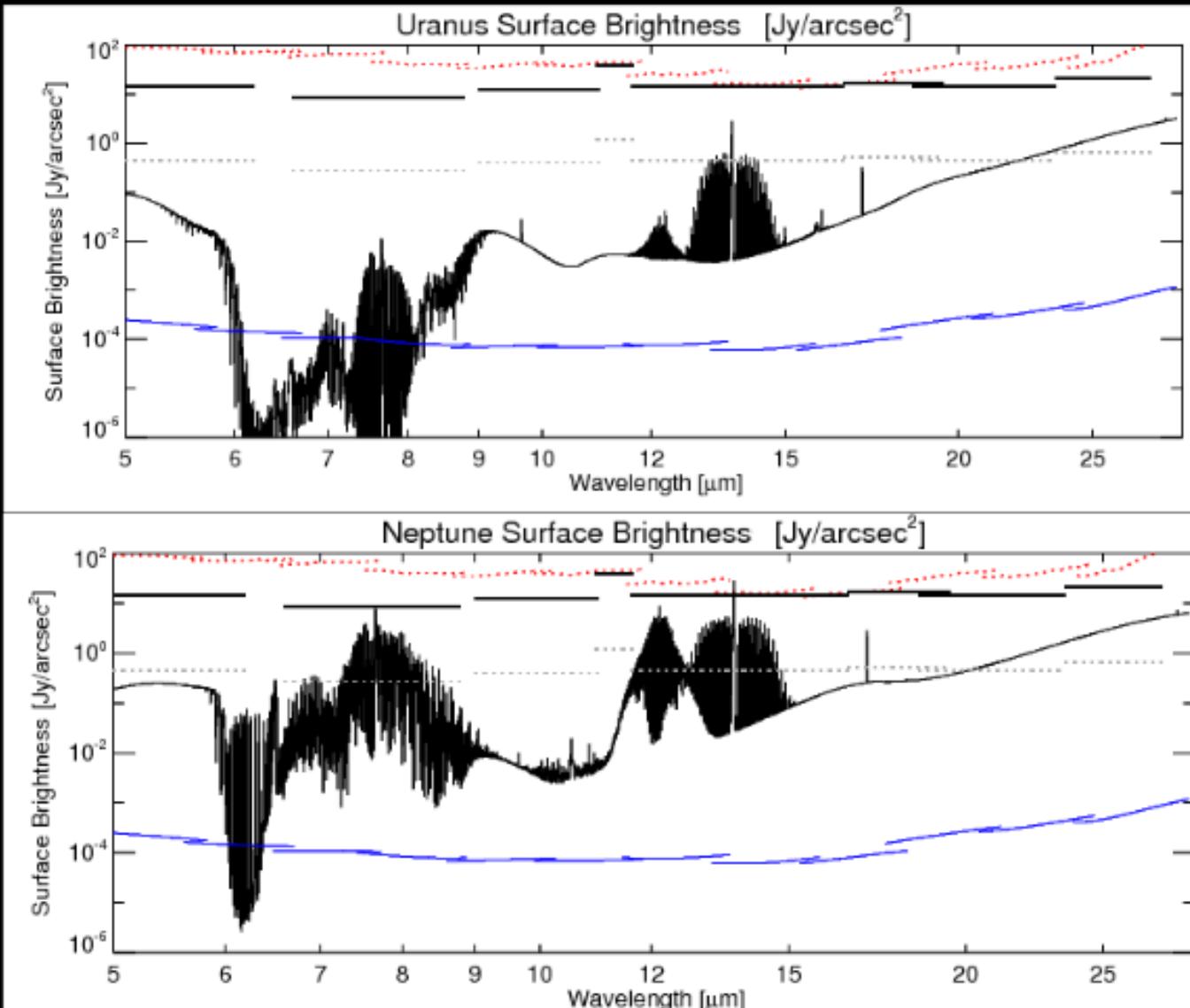
Saturation Issues for Jupiter/Saturn (MIRI)

- Jupiter saturates in all filters; MRS 5-11 μm may be feasible.
- Saturn imaging < 12 μm ; MRS 5-16 μm .
- Saturation doesn't break detectors – just renders data unusable in certain ranges.



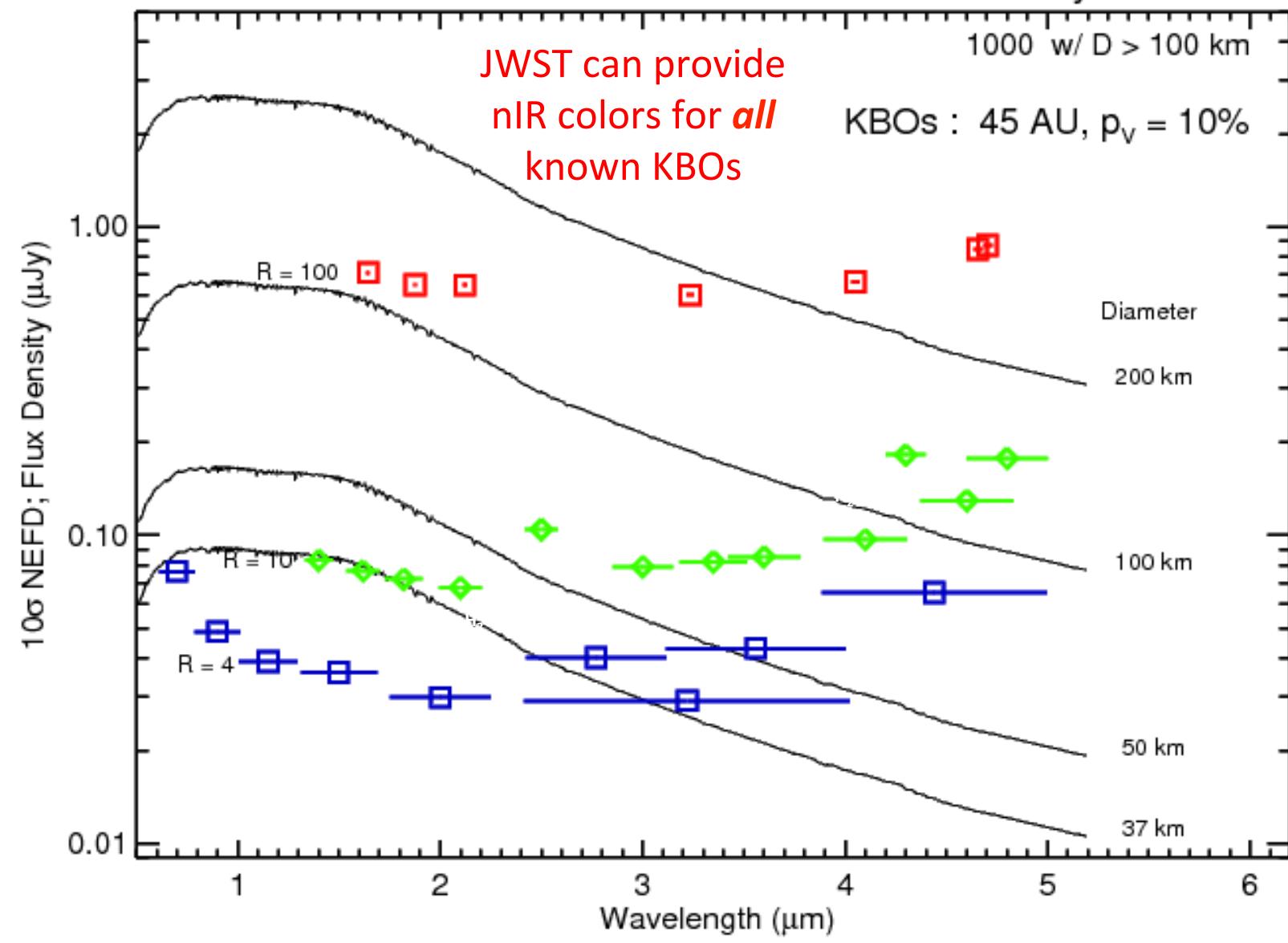
Full Capabilities for Uranus/Neptune (MIRI)

- Imaging and spectroscopy in all filters and MRS channels.
- Large contrasts within a channel – care to minimise latents between SHORT/MED/LONG G exposures.
- Blue line – MRS sensitivity to continuum source, SNR=10 in 10,000 sec (Glaebe et al., 2015).
- *Lacks shot noise, fails to account for higher noise as a target flux increases.*

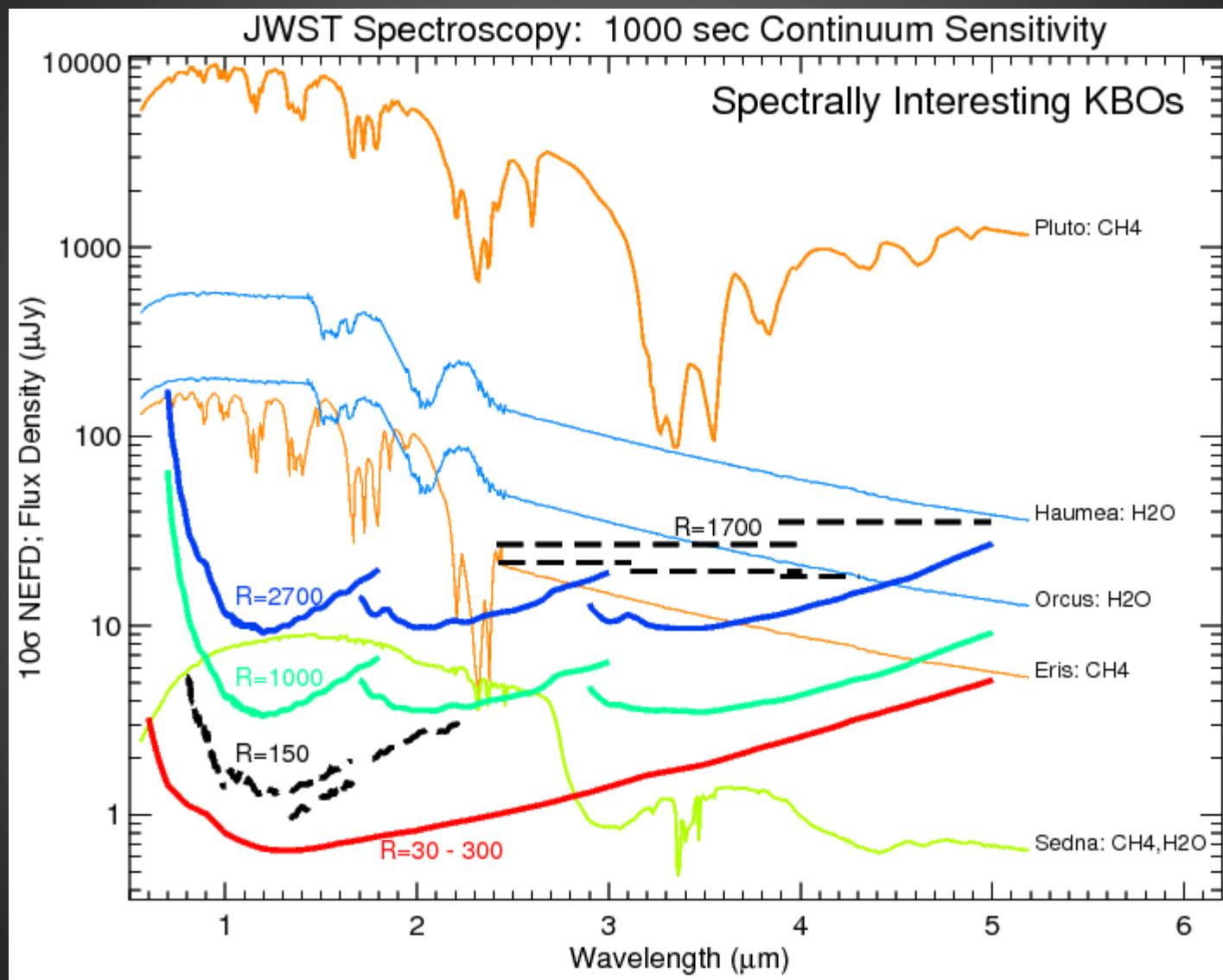


KBO Photometry with NIRCam

NIRCam: 1000 sec Point-Source Sensitivity

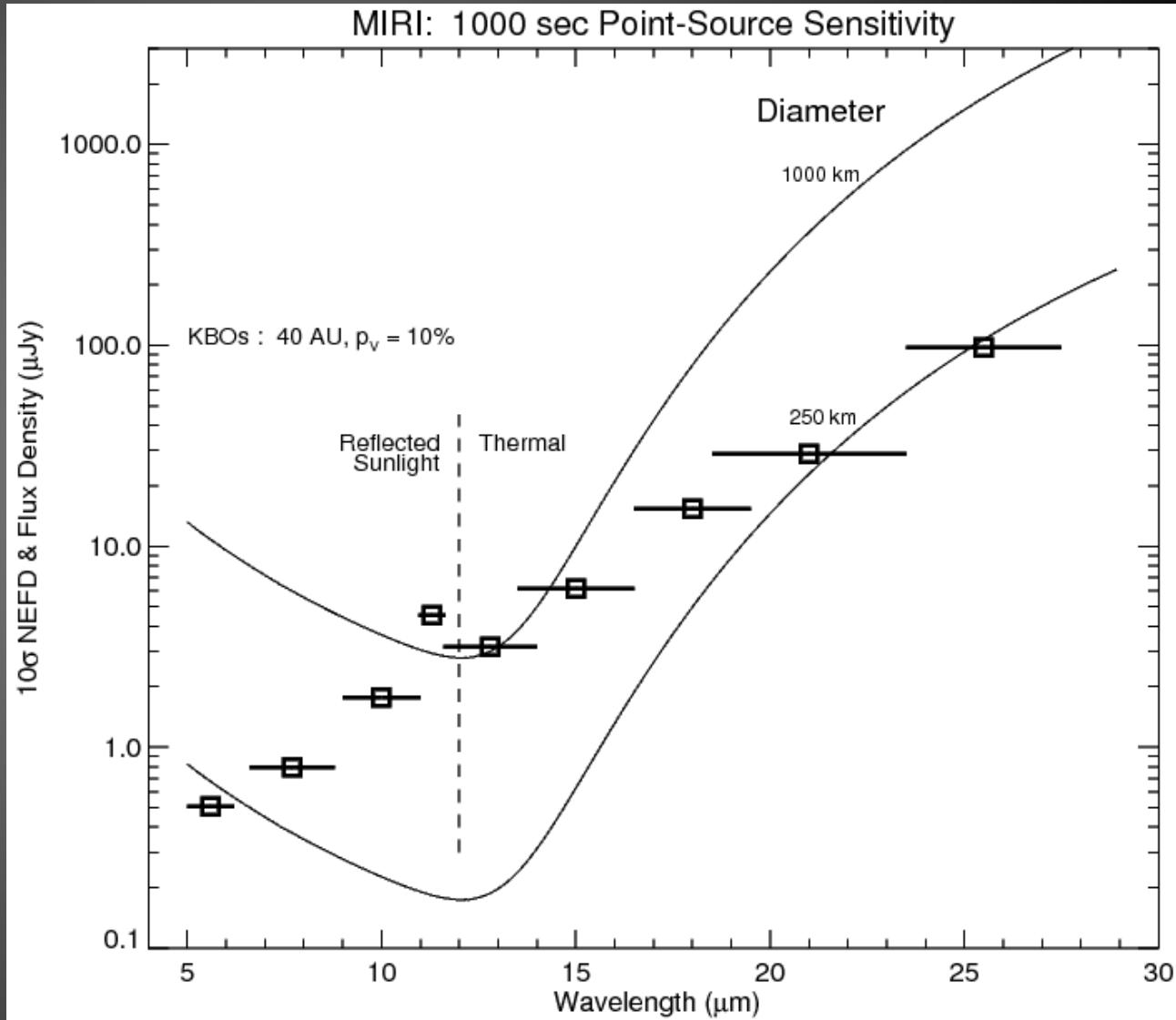


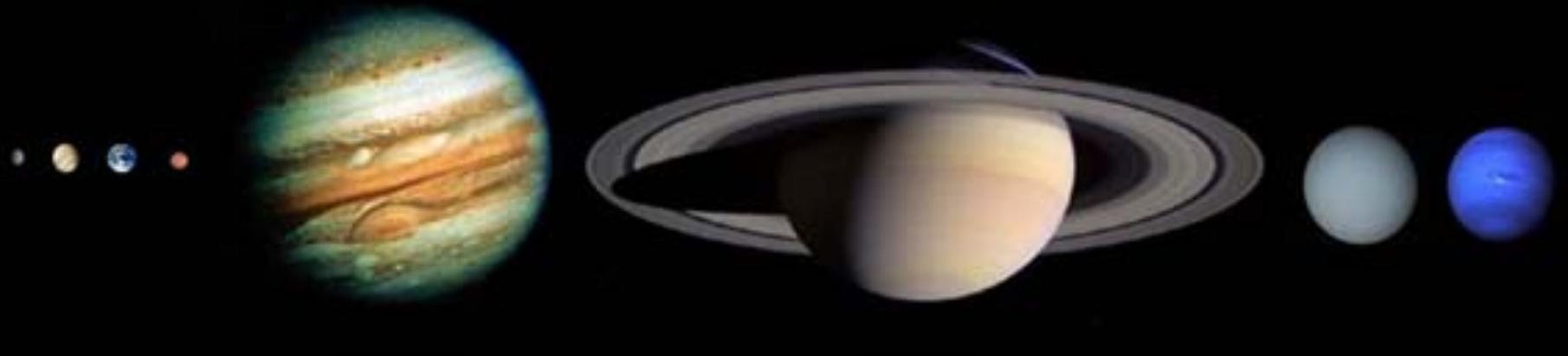
KBO Spectroscopy with NIRSpec



KBO Thermal Radiometry with MIRI

- MIRI can measure temperature distributions for medium-sized KBOs
- Sensitivity well matched to that of ALMA
- Valuable for
 - Thermal inertia
 - Composition
 - Regolith structure
- Emissivity
- Albedo
- Best when combined with measurements at >50 microns





PASP Special Issue

(Jan 4, 2016)

Innovative Solar System Science with the James
Webb Space Telescope

Stefanie Milam, Special Editor

<http://iopscience.iop.org/1538-3873/128/959>

11 topical papers

<http://iopscience.iop.org/1538-3873/128/960>

1 high-level paper (Norwood et al.)

Data Pipeline for Moving Targets

Moving-target Pipeline Overview

- Calibration pipeline data product “levels”:
 1. Data formatting, science-frame re-orientation, **MT WCS** information added
 2. Calibrated single-exposure count-rate images; flux conversion, wavelength cal.
 3. Combine Level-2 products → coadd exposures, mosaicking, etc.
- Single-exposure calibration processing (level 2):
 - **Science target is ‘fixed’ in the detector frame (telescope tracking)**
 - Detector-level calibration steps are the ~same as for fixed targets
- Multi-exposure calibration processing (level 3):
 - **Coaddition of exposures occurs in the co-moving frame of the target**
 - Existing fixed-target algorithms will be used
 - **HST Pipeline has never done this**
 - Same approach used by Spitzer and Herschel

Astronomer's Proposal Tool (APT) for Moving Targets

An extensive chart packet about APT for moving targets will be posted at jwst.stsci.edu/events

Look for today's event at that URL

APT example proposal for moving targets is also in the works
(accessible from APT -> File -> JWST Demonstration Proposals)

What is APT?

- APT is your tool for
 - Designing JWST (and HST) observations
 - Defining targets
 - Standard targets: Planets, Dwarf Planets, Satellites, Longitudes, etc.
 - Comets, asteroids, new satellites
 - Defining Observations
 - Pick Instrument (NIRCAM, NIRSpec, MIRI, NIRISS)
 - Pick Science Template (e.g. Imaging, IFU Spectroscopy, ...)
 - Optionally set up Target Acquisition
 - Define Exposure Specifications (filter and/or disperser plus detector readout parameters)
 - Defining scheduling constraints on observations
 - Date/time
 - Separation from another body
 - Apparent rate of motion
 - Phase angle, distance, etc.
 - Evaluating schedulability of observations
 - Submitting your Proposals

Java Application available at <http://apt.stsci.edu>

APT: Starting a Proposal

Astronomer's Proposal Tools Version 24.2 - JWST Draft Proposal (junk.aptx)

File Edit Tools Form Editor Help

Form Editor Spreadsheet Editor Orbit Planner Visit Planner View in Aladin BOT Target Confirmation PDF Preview Submission Errors and Warnings

Run All Tools Stop JWST What's New HST What's New Roadmap Feedback

New Document | **New Co-I**

JWST Draft Proposal (junk.aptx)

Proposal Information

- Proposal Description**
- Unnamed PI**
- Unnamed Col**
- Targets**
- Observations**
- Observation Links**

Title

Abstract

Proposal ID []

Category GO Calibration Treasury

Pure Parallel Proposal

Cycle 1

Explain unschedulable observations

Science Time (hours) 0.12

Charged Time (hours) 0.46

Request custom time allocation

Future cycles

Proprietary Period Default Default is 12 Months

Allow Restricted (this session only)

Scientific Category None Selected

Science Keywords
Choose 2 to 5 science keywords.

Alternate Category None Selected (Optional)

Coordinated telescopes

PDF Attachment []

Edit Previous

Proposa... Title Abstract Proposal ID Proposal P... Category Calibration Treasury Science Ti... Charged T... Pure Paral... Time Allo

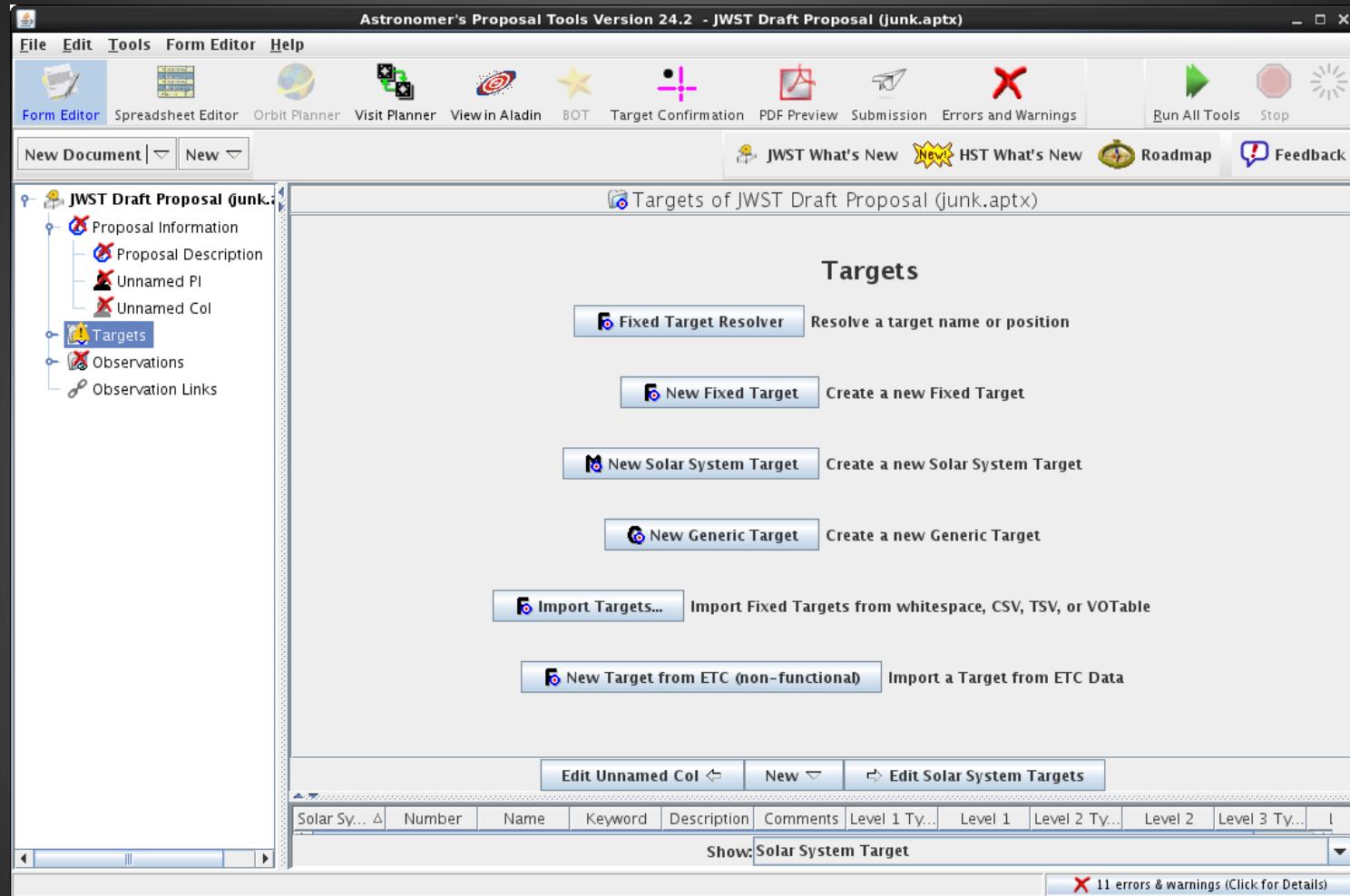
Show: **Proposal Information**

11 errors & warnings (Click for Details)

APT Moving Target Specifications

- Inherits many capabilities from HST
 - MT “Level-1 Types”
 - Standard (planets and their satellites)
 - Comet (supports non-gravitational orbit perturbations)
 - Asteroid (everything else)
 - Interface to JPL Horizons
 - Retrieval of NAIF ID/names and orbital elements
- The target specification is the only thing you do differently to observe moving targets
 - Observations may then be specified using all instrument modes

Top Level Target Interface



Minor Body Interface

Astronomer's Proposal Tools Version 24.2 - JWST Draft Proposal (junk.aptx)

File Edit Tools Form Editor Help

Form Editor Spreadsheet Editor Orbit Planner Visit Planner View in Aladin BOT Target Confirmation PDF Preview Submission Errors and Warnings Run All Tools Stop

New Document | New Solar System Target JWST What's New HST What's New Roadmap Feedback

JWST Draft Proposal (junk.aptx)

Number: 4
Name in the Proposal: SEDNA
Keyword: DWARF-PLANET
Description: Sedna, as in the TNO...

Level 1 Type: Asteroid Level 2 Type: None Selected Level 3 Type: None Selected

Summary: Level 1: TYPE=ASTEROID, A=, E=, I=, O=, W=, M=, EQUINOX=J2000, EPOCH=, EpochTimeScale=

Acquisition Fluxes
Enter Flux data for Instruments that need to know the Flux of this Target through the Acquisition filter

Instrument	Acquisition Filter	Flux Value (micro-Jy)
Acq Fluxes		

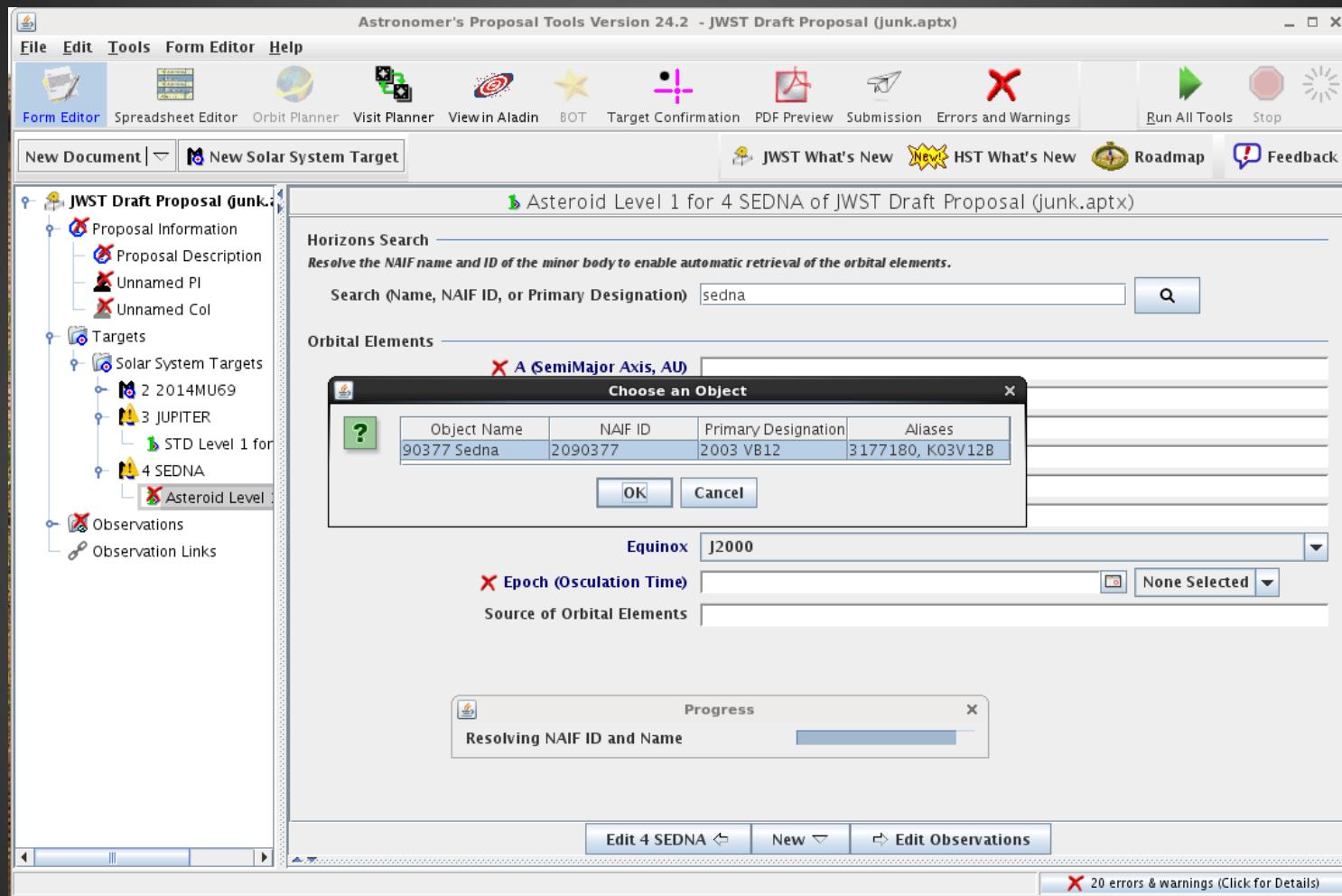
Add Duplicate Insert Above Remove

Comments

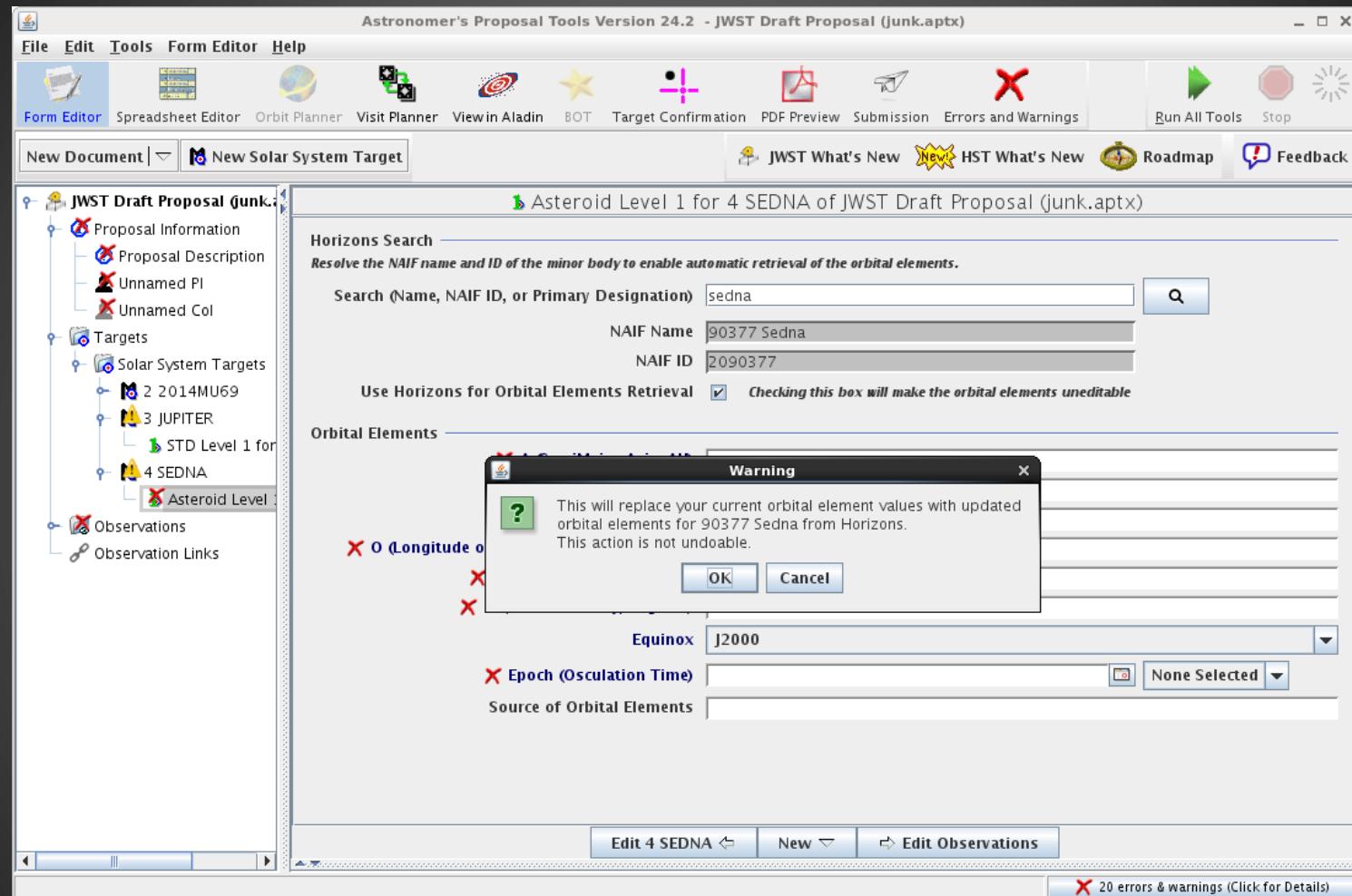
Edit STD Level 1 for 3 JUPITER New Edit Asteroid Level 1 for 4 SEDNA

20 errors & warnings (Click for Details)

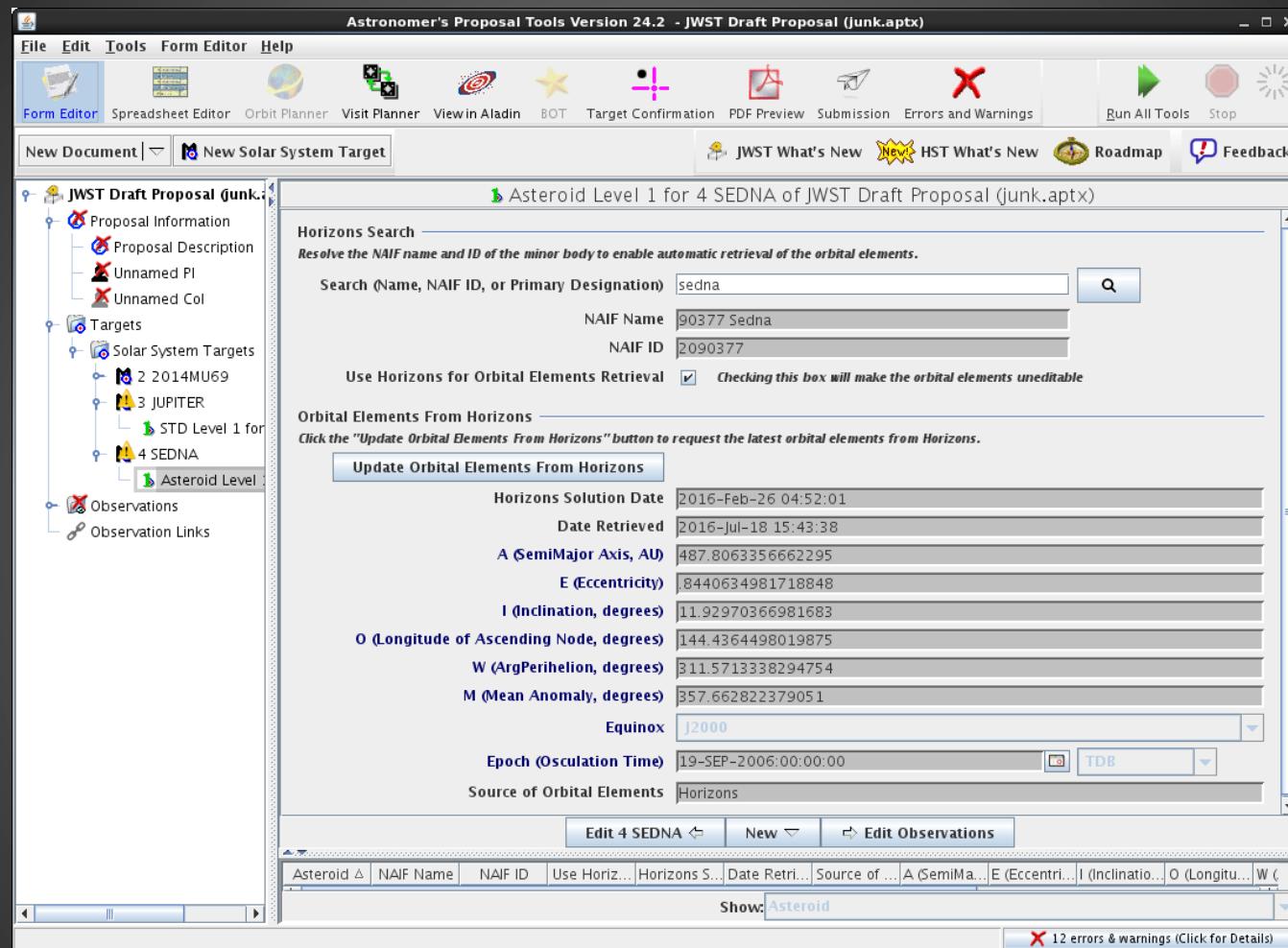
Minor Body: NAIFF Search Capability



Minor Body Elements Retrieval



Minor Body Elements Retrieval



Filling this form used to be a manual process of cut/paste.

“Standard” Targets – Levels 1 & 2

Astronomer's Proposal Tools Version 24.2 - JWST Draft Proposal (junk.aptx)

File Edit Tools Form Editor Help

Form Editor Spreadsheet Editor Orbit Planner Visit Planner View in Aladin BOT Target Confirmation PDF Preview Submission Errors and Warnings Run All Tools Stop

New Document | New Solar System Target JWST What's New HST What's New Roadmap Feedback

JWST Draft Proposal (junk.aptx)

Number: 3
Name in the Proposal: CALLISTO
Keyword: SATELLITE
Description: x

Level 1 Type: Standard Target | Level 2 Type: Standard Target | Level 3 Type: None Selected

Summary: Level 1: STD=JUPITER
Level 2: STD=CALLISTO

Acquisition Fluxes
Enter Flux data for Instruments that need to know the Flux of this Target through the Acquisition filter

Instrument	Acquisition Filter	Flux Value (micro-Jy)

Add | Duplicate | Remove

Comments

Edit Asteroid Level 1 for 2 2014MU69 ← | New | ↗ Edit STD Level 1 for 3 CALLISTO

✖ 13 errors & warnings (Click for Details)

The screenshot shows the APT software interface for creating a JWST draft proposal. The left sidebar displays the proposal structure, including 'Targets' (with 'Fixed Targets' and 'Solar System Targets' expanded), 'Observations' (with 'Observation Folder' and 'Observation 1' expanded), and 'Observation Links'. The main panel is focused on 'Target 3 CALLISTO'. It includes fields for 'Number' (3), 'Name in the Proposal' (CALLISTO), 'Keyword' (SATELLITE), and 'Description' (x). Below these are dropdown menus for 'Level 1 Type' (Standard Target), 'Level 2 Type' (Standard Target), and 'Level 3 Type' (None Selected). A 'Summary' section indicates 'Level 1: STD=JUPITER' and 'Level 2: STD=CALLISTO'. The 'Acquisition Fluxes' section contains a table with three columns: 'Instrument', 'Acquisition Filter', and 'Flux Value (micro-Jy)'. The table is currently empty. Below the table are 'Add', 'Duplicate', and 'Remove' buttons. The 'Comments' section is also empty. At the bottom, there are navigation buttons for 'Edit Asteroid Level 1 for 2 2014MU69' and 'Edit STD Level 1 for 3 CALLISTO', along with a 'New' button. A status bar at the bottom right indicates '13 errors & warnings (Click for Details)'.

Exposure Time Calculator (ETC) for Moving Targets

What is the ETC?

- The JWST ETC is... different from what you are probably used to
 - Web-based GUI interface
 - Simulates throughput, all noise components
 - Is ‘scene based’ – all calculations are 2D (3D for spectra)
 - Result is an SNR image, plus SNR for specified measurement method (aperture)
 - Is a complex tool that takes time to learn
 - Has no specific capabilities for simulating moving targets
- Use of the ETC is *required* to justify proposal time requests
 - Create a ‘MyST’ account to use it (and archive)
- ETC workbooks
 - Sets of user-defined calculations
 - May be shared with other users

Web Application available at <http://jwst.etc.stsci.edu>

ETC Example Workbooks

The screenshot shows a web browser window for the ETC Example Workbooks. The URL is <https://jwst.etc.stsci.edu/workbooklists.html>. The search bar contains "2017 solar eclipse". The user is John Stansberry.

Available Workbooks

#	Name	Load	Description	Options
2822	Small Body Examples for JWST Solar System London Workshop	[Load]	Prepared by J. Stansberry	[copy][remove]

Example Workbooks

Sharing w/ Other Users

Solar System Small Bodies Examples

Select a Workbook

Create New Workbook

Get a Copy of a Sample Workbook ▾

- Slitted Spec (including MSA)
- Sample Coronagraphy Calculations
- Slitless & IFU calculations
- Imaging + AMI
- Small Body Examples for JWST Solar System London Workshop
- Basic Point Source imaging

User

Write **Grant** **Revoke**

User Email **Add User by Email**

ETC Comet Nucleus + Coma Example

Calculations Scenes and Sources Upload Spectra Caveats and Limitations

ID	Name	Sources	# Calcs
1	Asteroid, reflected + 2,3	0	
2	Comet nucleus & co 2,3,4,5	3	

New Add Source Remove Source Delete

Select a Source

ID	PlotName	Scenes	# Calcs
2	<input type="checkbox"/> Nucleus Thermal 1,2	3	
3	<input checked="" type="checkbox"/> Nucleus Reflecte 1,2	3	
4	<input type="checkbox"/> Coma Reflected, 2	3	
5	<input type="checkbox"/> Coma Thermal, 2	3	

New Delete

Source Editor

IU Continuum Renorm Lines Shape Offset

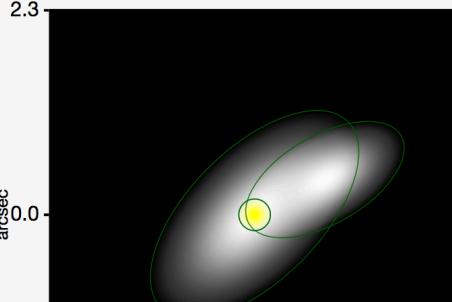
Normalize Source Flux Density
Renormalization applied after redshift

Normalize at wavelength
0.1 flam

Normalize in bandpass
18 vegamag
 JWST MIRI/IMAGING F560W
 HST WFC3/IR F098M

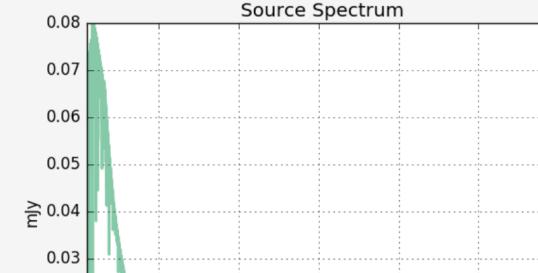
Source selected: 3 Reset Save

Scene Sketch
2: Comet nucleus & coma, reflected + thermal



Source Spectrum Plots

Source Spectrum



ID	Name	Scene
1	miri_imaging	2
2	nircam_lw_imaging	2
3	nircam_sw_imaging	2

Calculations Source Warnings Source Errors

ETC Demo / Training

- Example solar system workbook within the ETC are available now
- Info / Demos about the ETC
 - Available in JWST Community Lecture Series
 - jwst.stsci.edu/events
 - Look for 2017-01-17 lecture about Pandeia, by K. Pontoppidan
 - Attend 2017-02-21 event, ETC Demo, by S. Ravindranath
- Solar System ETC webinar
 - Need to schedule one SOON to support ERS.
 - Keep an eye on DPS and PEN email announcements
 - Community effort to provide moving target wrapper for Pandeia?
- Pandeia – the JWST ETC Engine
 - <https://jwst-docs.stsci.edu/display/JPP/JWST+ETC+Batch+Expansions>
 - <https://github.com/spacetelescope/JWSTUserTraining2016>

jwst.etc.stsci.edu

Summary

- Get the PASP special issue papers
 - iopscience.iop.org/1538-3873/128/959 & 960
- Download APT
 - apt.stsci.edu
- Start looking at user documentation
 - jwst-docs.stsci.edu
 - Moving target documentation is in the works...
- Form your ERS teams, submit NOI by March 3!

Contact / Follow-up / Help Desk:

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stefanie.milam@nasa.gov

stsci.service-now.com/jwst