Exoplanet studies with NIRISS

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Université de Montréal

October 15, 2015

INSTITUT DE RECHERCHE SUR LES EXOPLANÈTES
INSTITUTE FOR RESEARCH ON EXOPLANETS

NIRISS team

- Core science team
  - **René Doyon (PI)**
  - Roberto Abraham
  - Laura Ferrarese
  - Lisa Kaltenegger
  - Ray Jayawardhana
  - Doug Johnstone
  - John Hutchings
  - David Lafrenière (leader)
  - Michael Meyer
  - Judith Pipher
  - Marcin Sawicki
  - Anand Sivaramakrishnan
  - Chris Willott

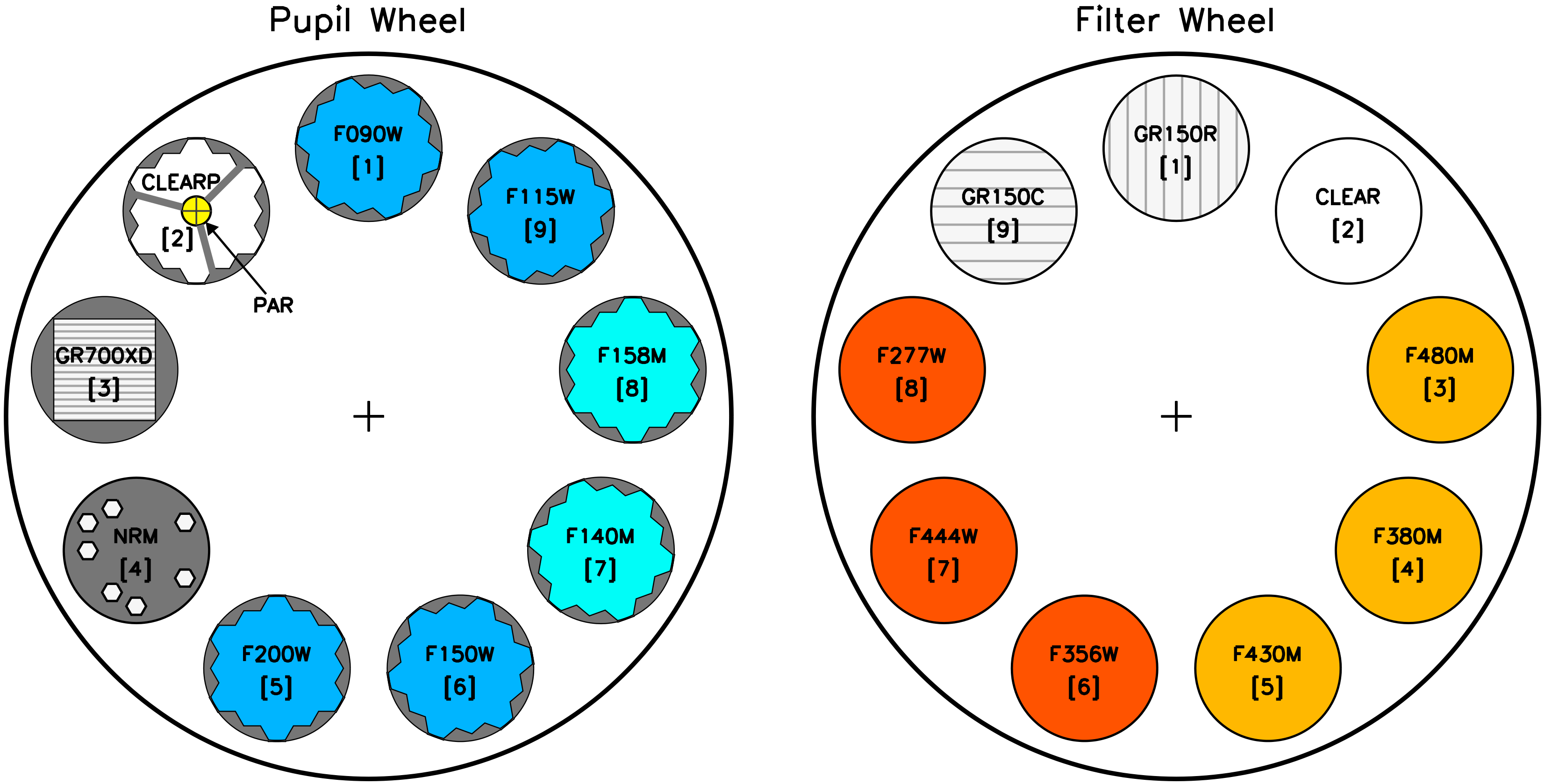
Strong exoplanet interest

- Instrument team
  - Loïc Albert
  - Étienne Artigau
  - Pierre Chayer
  - Van Dixon
  - Alex Fullerton
  - Paul Goudfrooij
  - Nikole Lewis
  - André Martel
  - Swara Ravindranath
  - Kevin Volk
- Collaborators
  - Michael Ireland
  - Aleks Scholz
  - Peter Tuthill

FGS/NIRISS overview

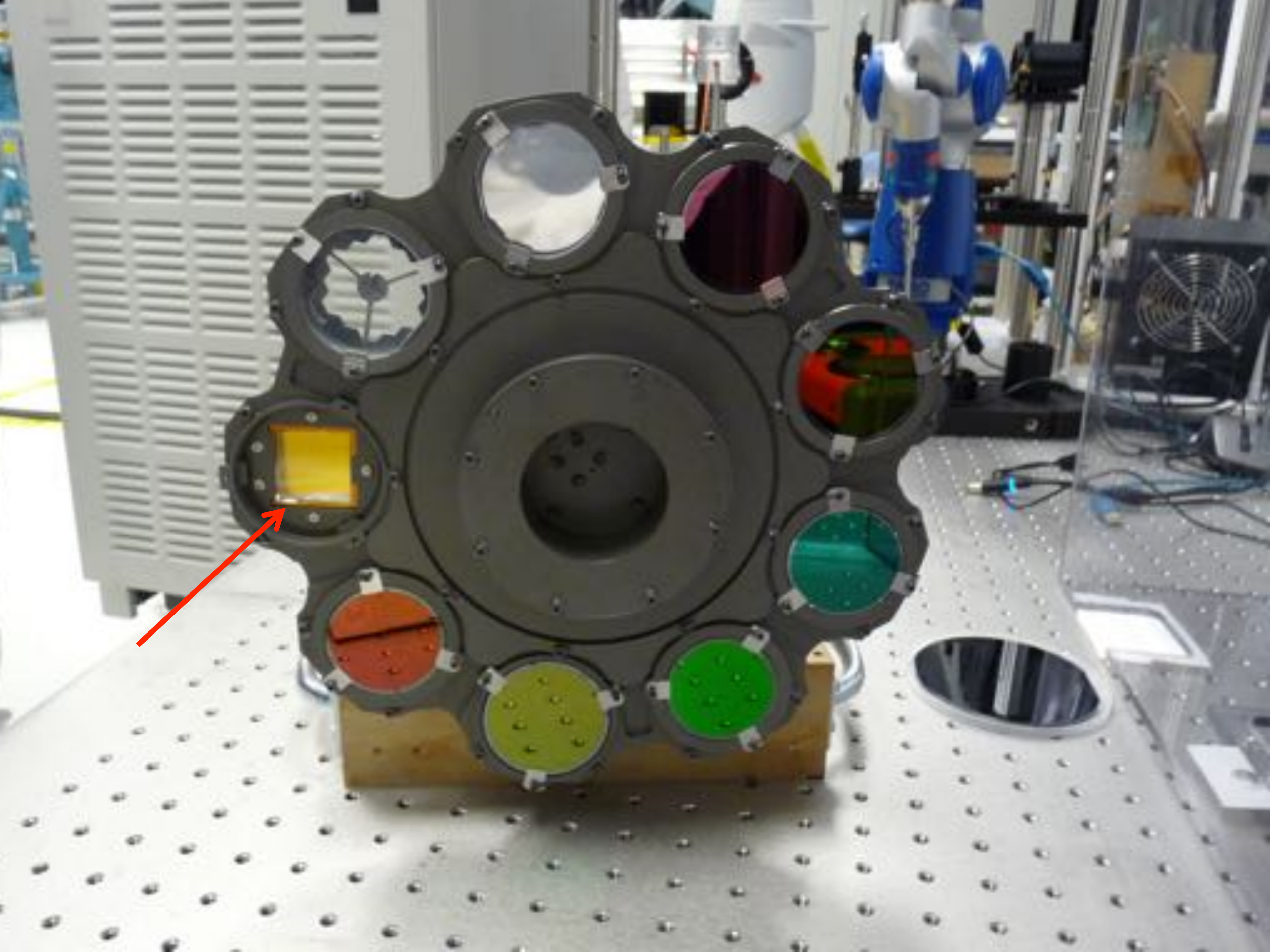
- Two instruments in one box provided by CSA
- FGS (Fine Guidance Sensor)
  - Provides fine guiding to the observatory
  - 0.6-5 μm IR camera. No filters, single optical train with two redundant detectors each with a FOV of 2.3’x2.3’
    - Noise equivalent angle (one axis): 4 milliarcsec
    - 95% sky coverage down to J_{AB}=19.5
- NIRISS (Near-Infrared Imager and Slitless Spectrograph)
  - 0.6-5 μm IR camera.
  - Four observing modes
  - Main science drivers
    - First Light: high-z galaxies
    - Exoplanet detection and characterization

NIRISS Dual Wheel components

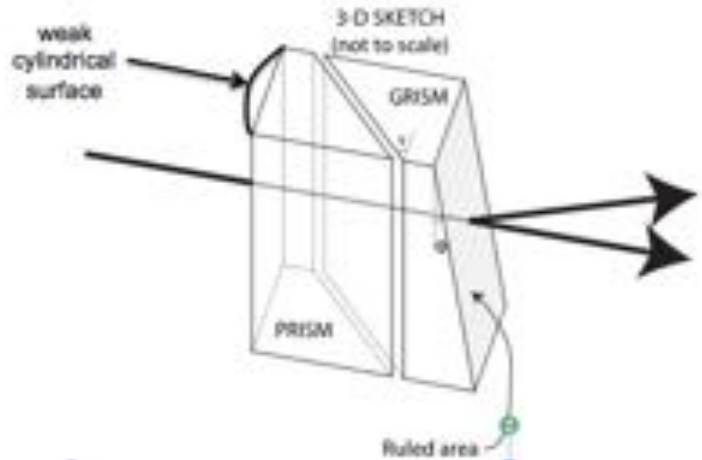


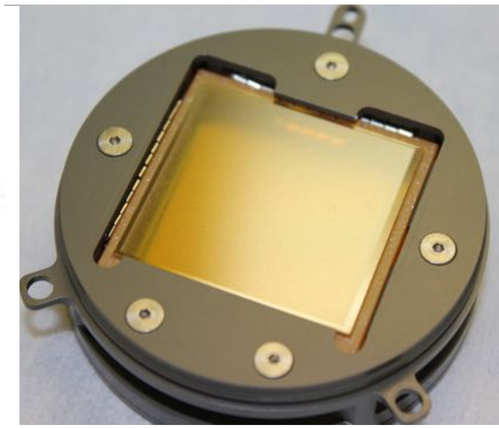
Single Object Slitless Spectroscopy (SOSS)

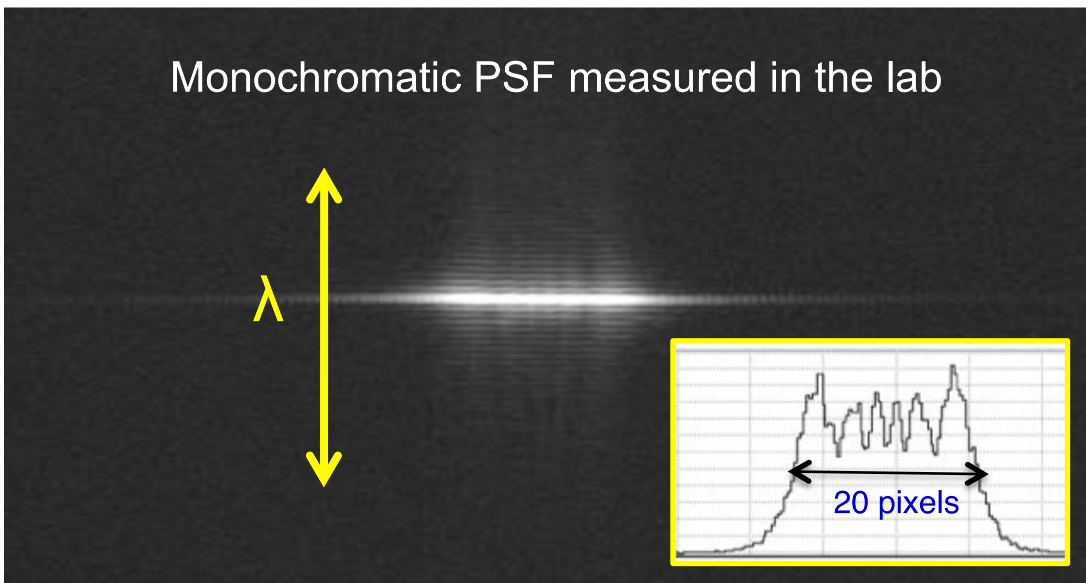
- ✧ Specifically optimized for transit spectroscopy
  - ➢ Grism with built-in defocussing weak lens to increase dynamic range and minimize systematic ''red noise'' due to undersampling and flatfield errors
  - ➢ Optical implementation to the successful « scanning mode » used on HST
- ✧ Broad simultaneous wavelength range: 0.6-2.8 um
  - ➢ Cross-dispersed (orders 1 and 2), no blocking filter.
- ✧ Spectral resolution: ~1000 (700 @ 1.2) um in first order
  - ➢ 500-2000 across wavelength range

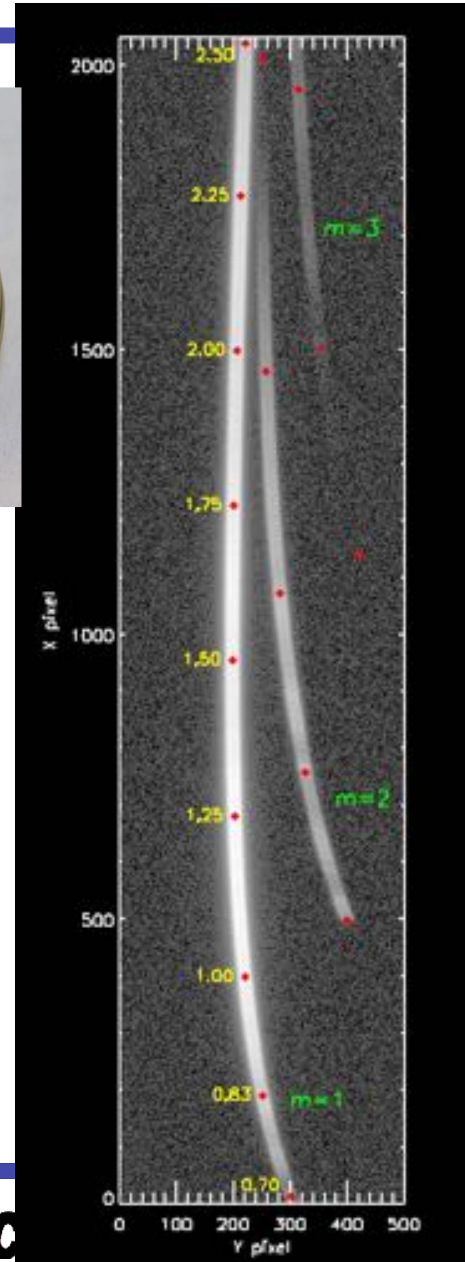


SOSS Hardware implementation









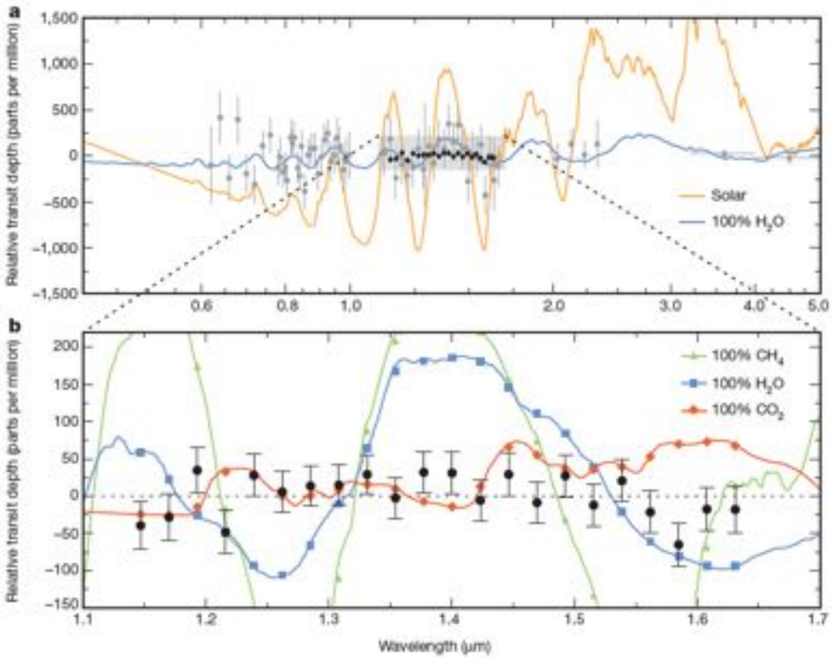
LETTER

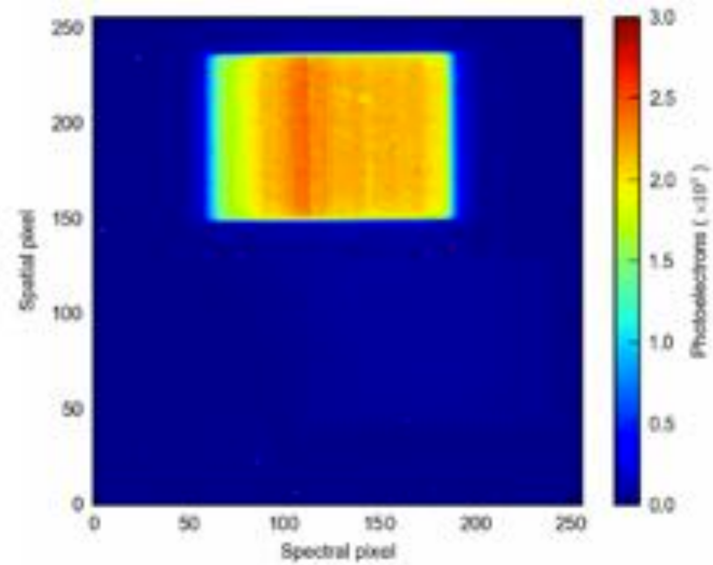
Kreidberg et al, 2014

doi:10.1038/nature12888

Clouds in the atmosphere of the super-Earth exoplanet GJ 1214b

Laura Kreidberg[1], Jacob L. Bean[1], Jean-Michel Désert[2,3], Björn Benneke[4], Drake Deming[5], Kevin B. Stevenson[1], Sara Seager[4], Zachory Berta-Thompson[6,7], Andreas Seifahrt[1] & Derek Homeier[8]



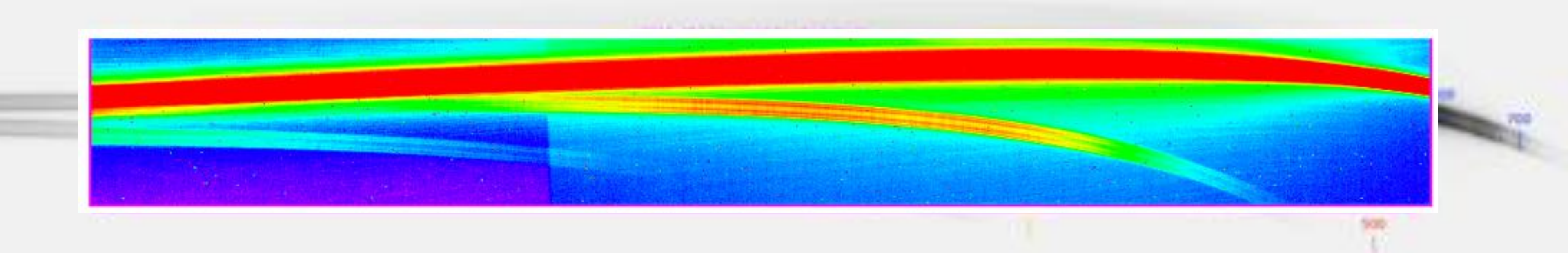


HST data. ~30 ppm noise level, within ~10% of the photon noise limit !

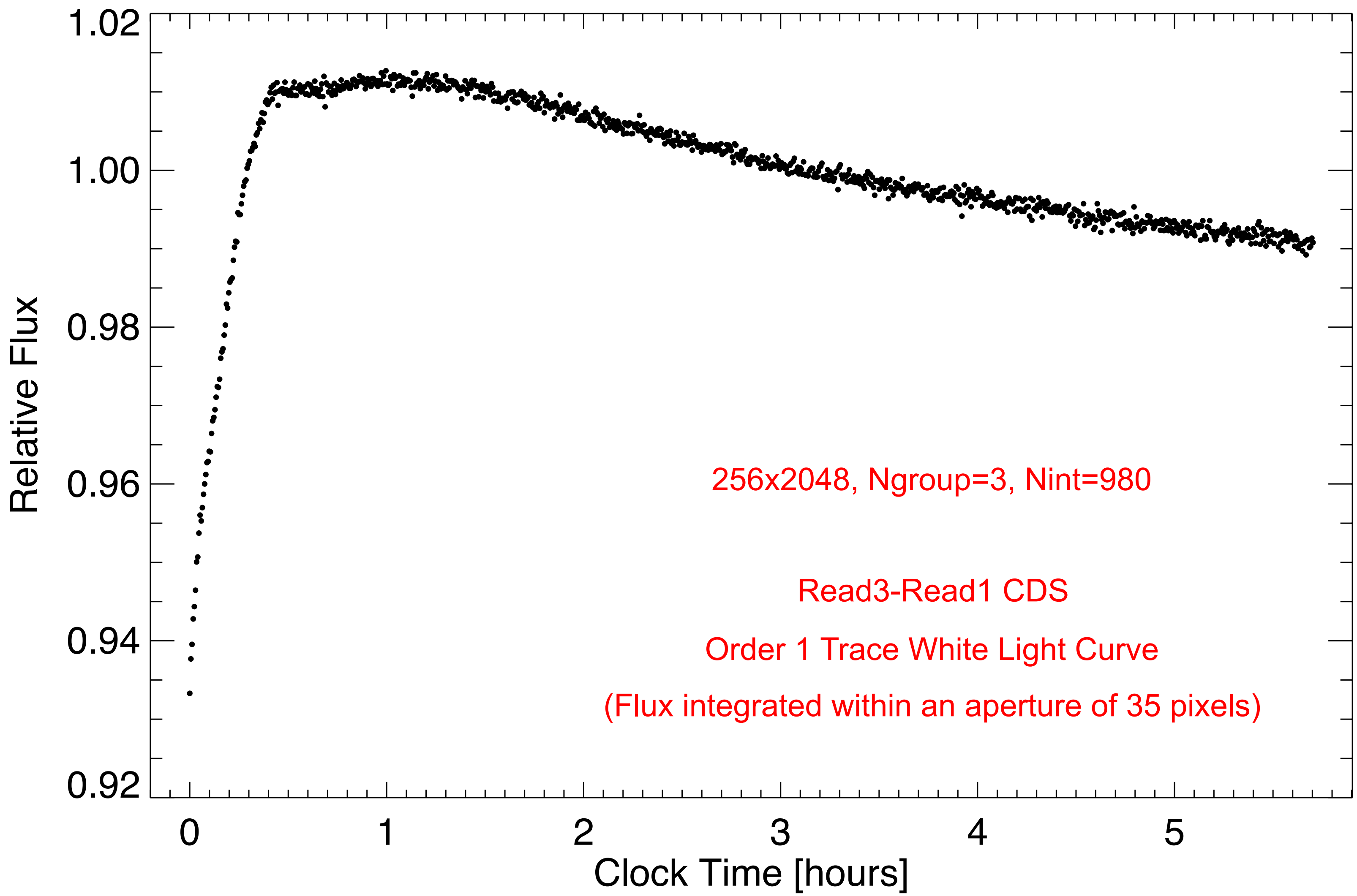
SPACE TELESCOPE SCIENCE INSTITUTE Université de Montréal NRC·CNRC COM DEV

SOSS observing modes

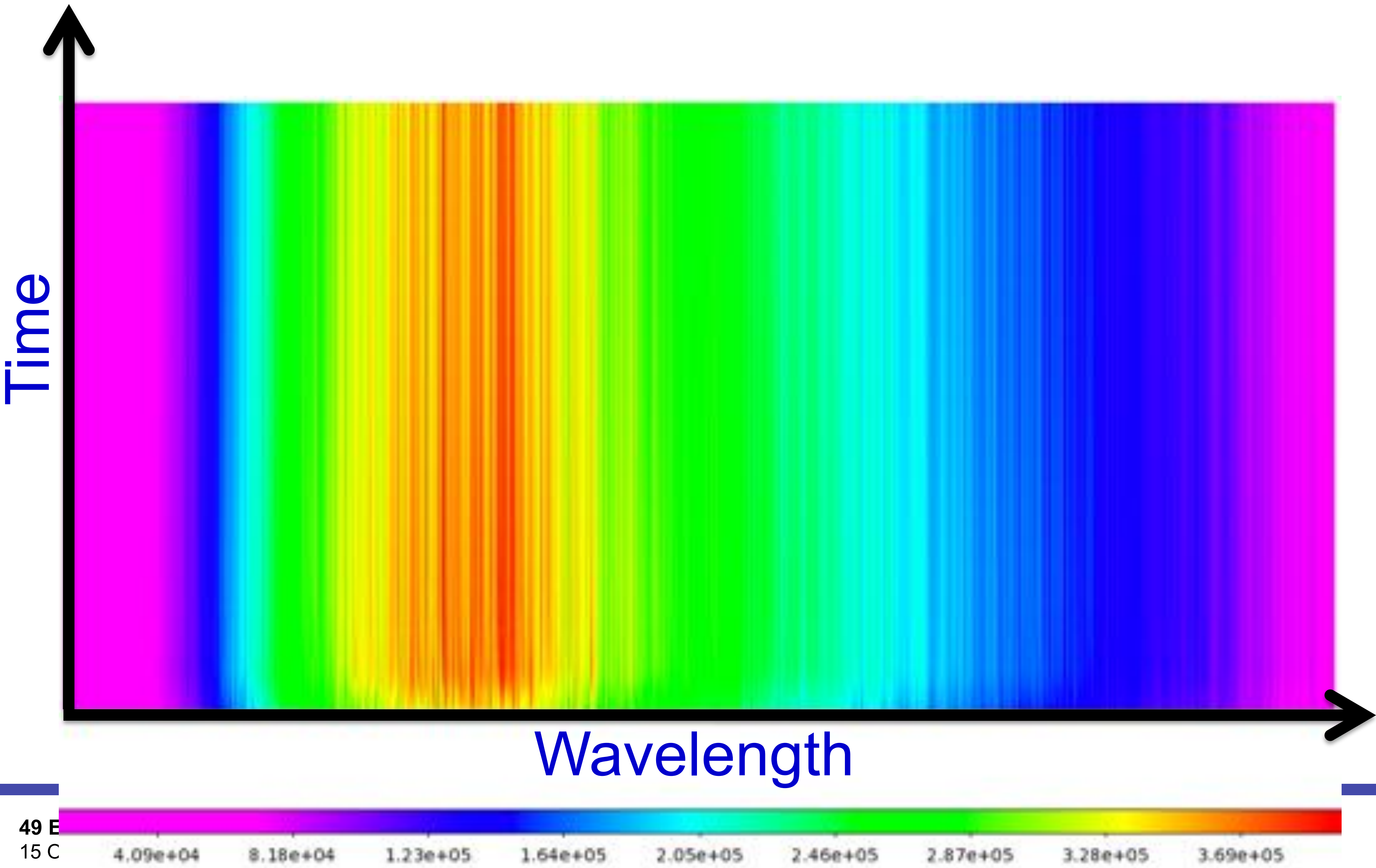
- Standard Mode:
  - Wavelength coverage: 0.6-2.8 μm
  - Subarray: 256x2048 (order m=1 and 2)
  - Saturation limit: J=8.0 (CDS; 70 000 e-)
- Bright mode
  - Wavelength coverage: 1.05-2.8 μm
  - Subarray: 80x2048 (m=1 only)
  - Saturation limit: J=6.8



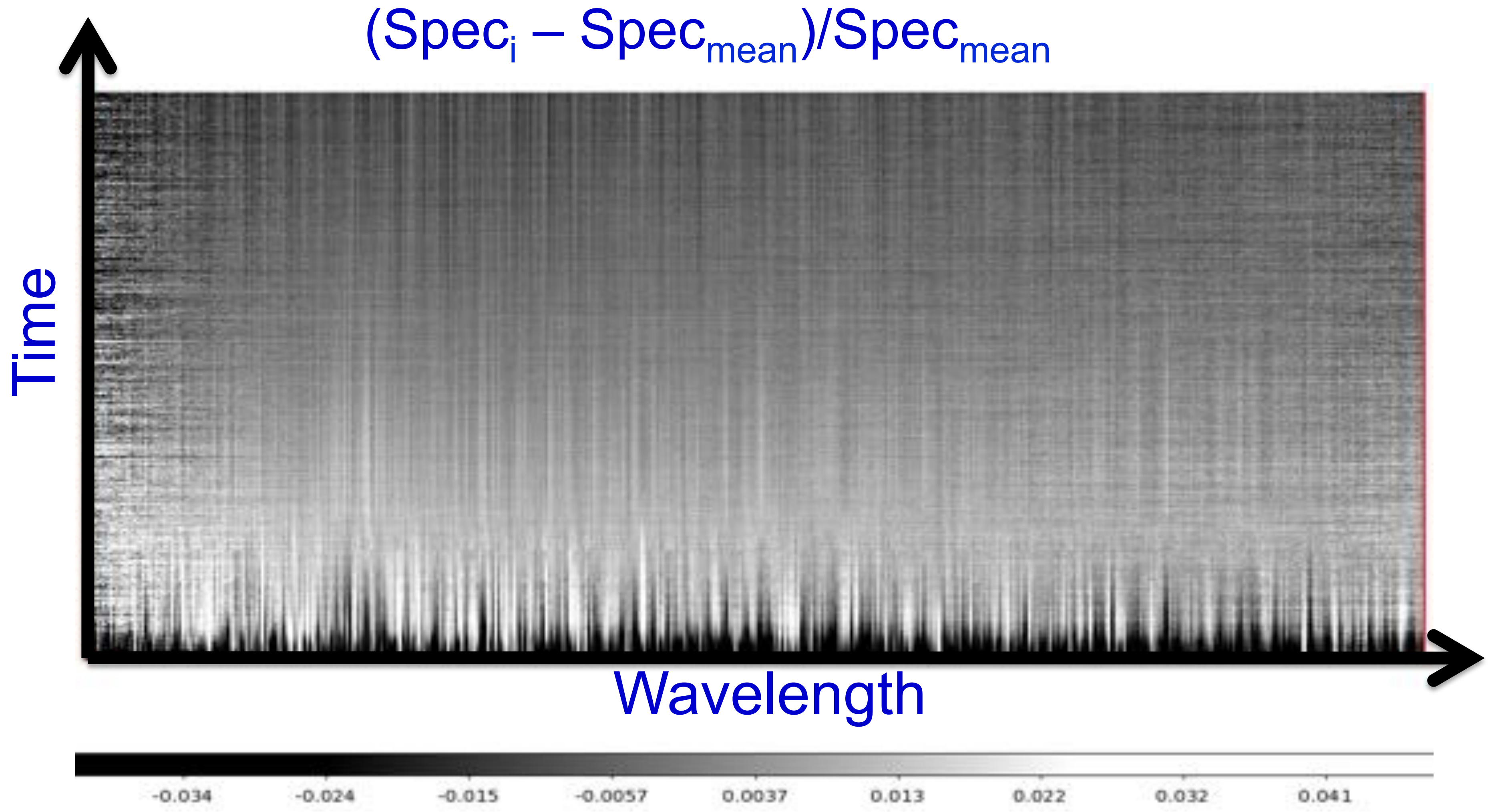
SOSS white light curve (CV3 data)



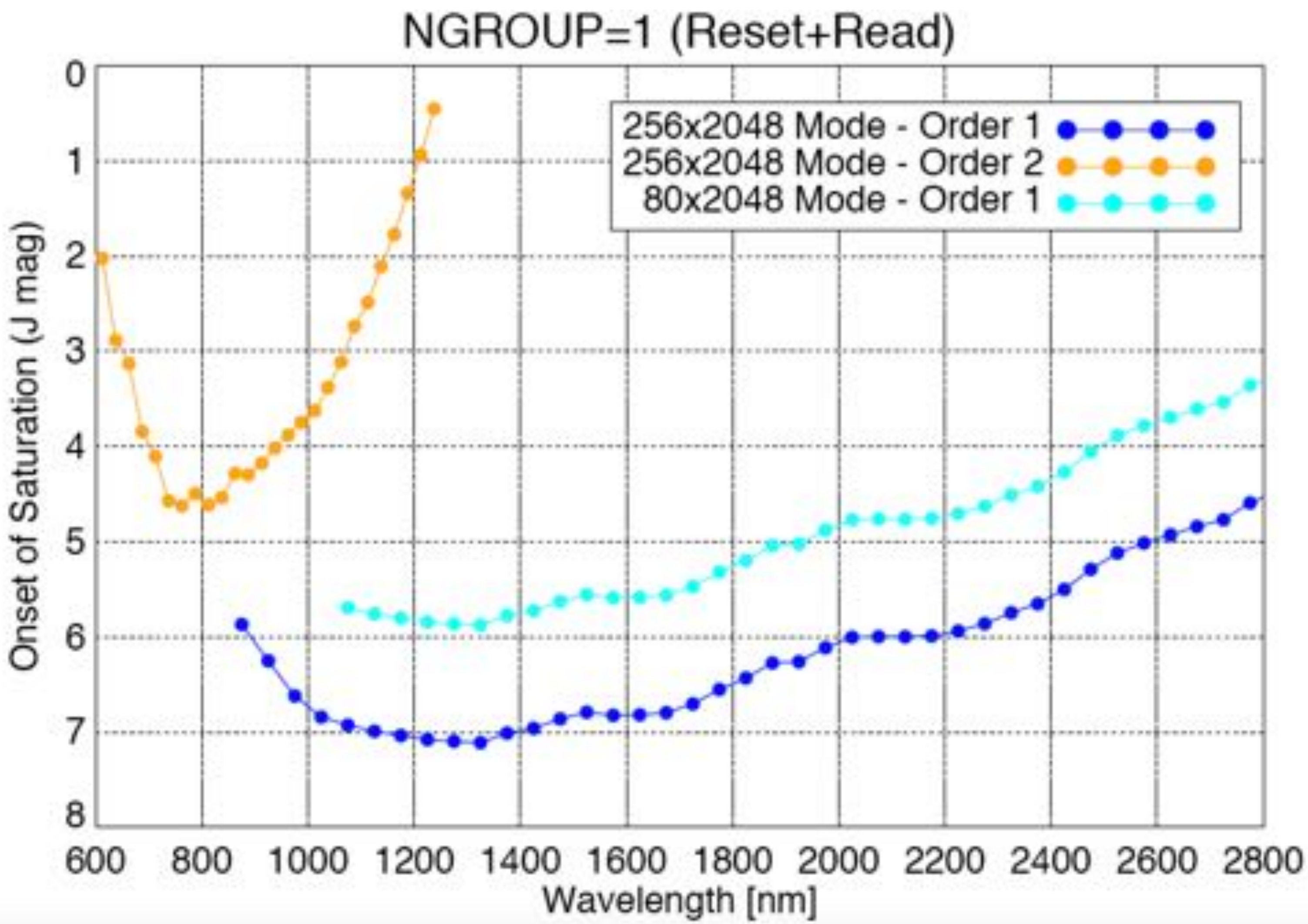
Spectrum time series



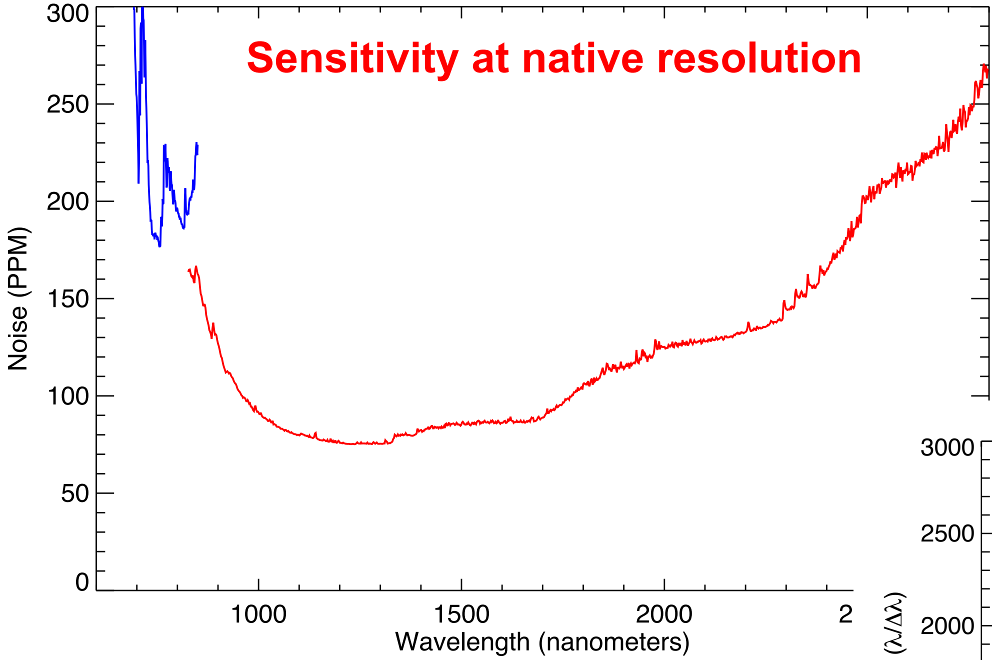
Spectrum time series – Deviations



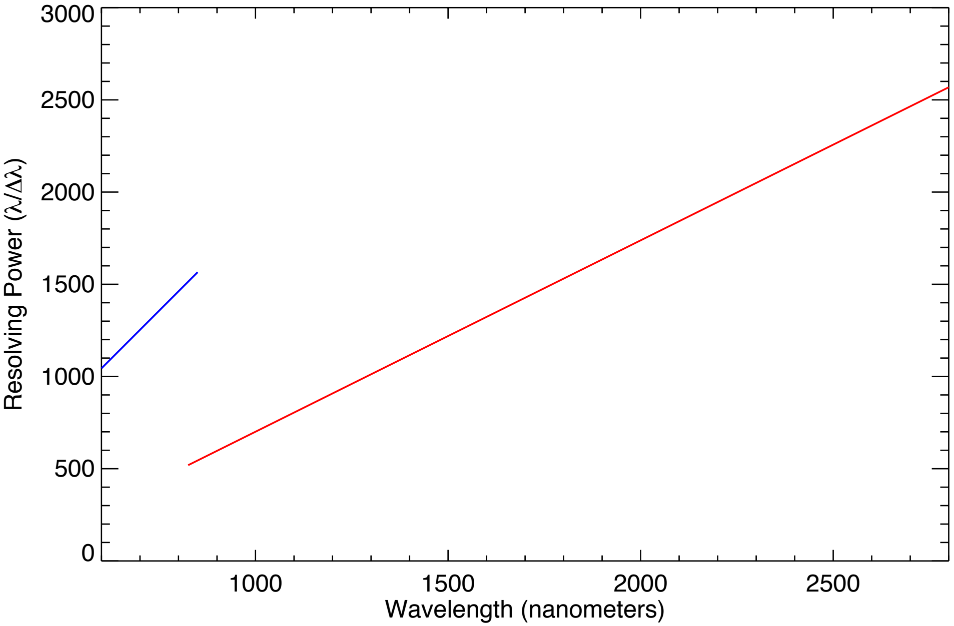
SOSS saturation limit



NIRISS capabilities for transit/eclipse spectroscopy



- 4 hr clock time, incl. 30 min setup
- J=8 mag target
- ~80-150 ppm per res. element
- ~1000 resolution (see below)
- Standard mode, 0.6 to 2.8 um in one shot



NIRISS will miss very few Earth/Super-Earths found by TESS

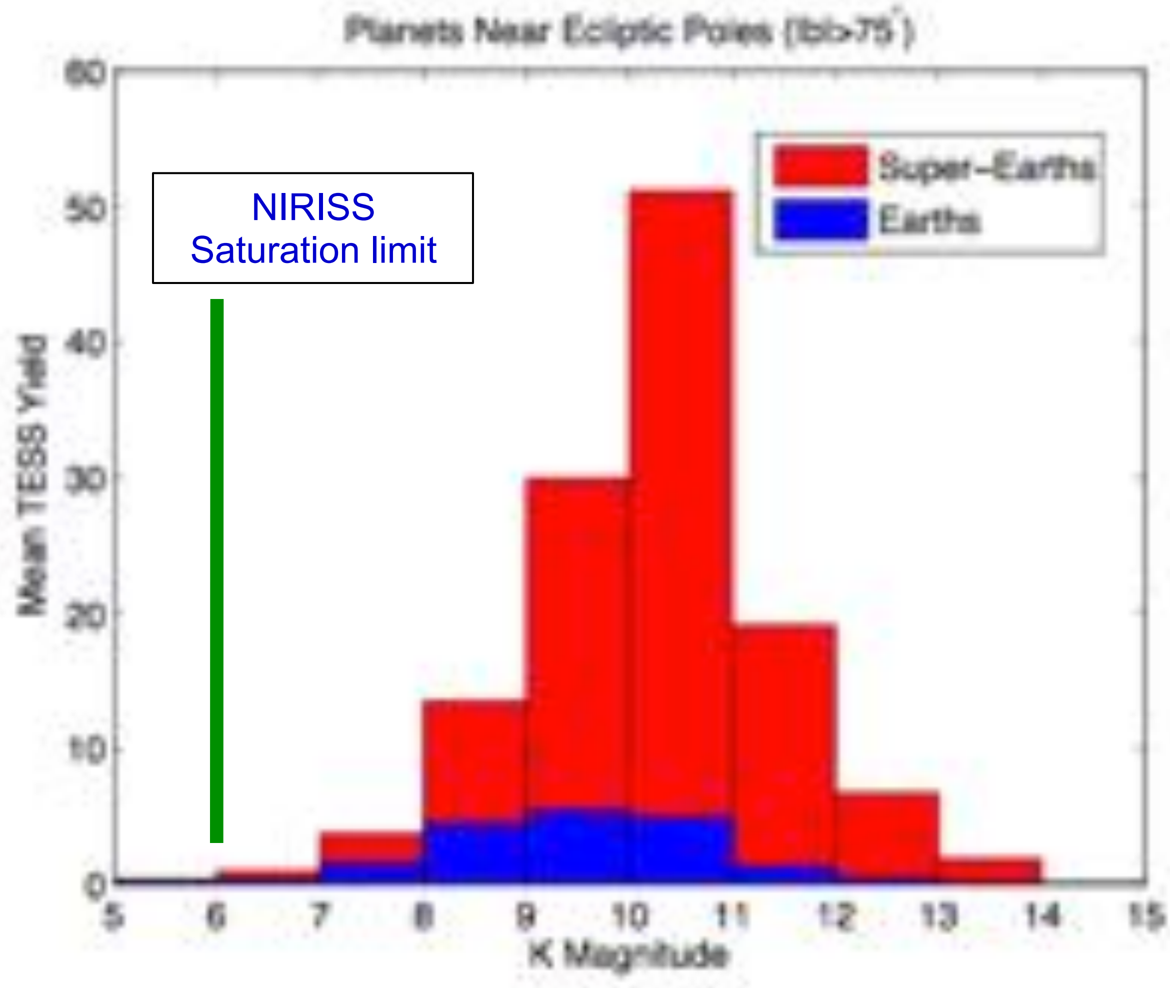


Figure courtesy of George Ricker (TESS PI)

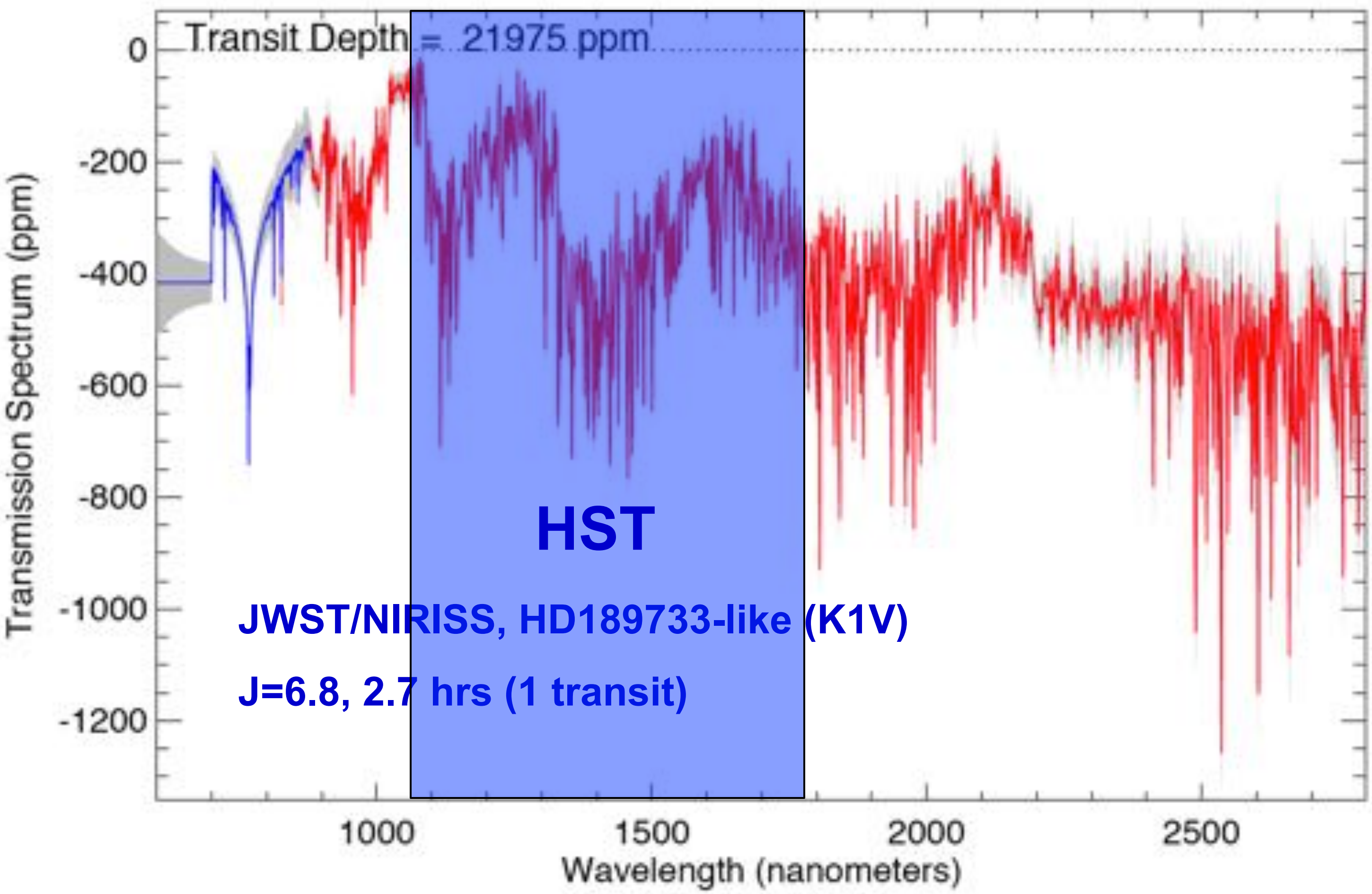
Transit spectroscopy: possibilities with NIRISS

Host	Name	T_p (K)	ρ (g/cm³)	$R_\star$ ($R_\odot$)	Expected Δf/f from atm. (ppm)		
					H_2-rich μ=2	H_2O-rich μ=18	Earth μ=29
Hot Jupiters/Neptunes							
G0V	HD209458b	1130	0.37	1.14	**700**	-	-
M3V	GJ436b	700	1.5	0.42	**800**	-	-
Super Earths							
M4V	GJ1214b	600	2	0.2	**2300**	**250**	**160**
K1V	HD97658b	800	3.4	0.7	**150**	**20**	**10**
Earths							
M0V	K2-3b	500	4.2	0.56	**120**	**15**	**10**
M0V	TESS	600	5.5	0.2	-	**95**	**60**
M6V	NGTS	300	5.5	0.15	-	**80**	**50**

Easy, single visit — Doable, needs more than one visit — Hard, needs several visits

$$\frac{\Delta f_{\mathrm{atm}}}{f} \propto \frac{R_{\mathrm{pl}} H_{\mathrm{atm}}}{R_\star^2} \rightarrow \frac{\Delta f_{\mathrm{atm}}}{f} = 615 \left(\frac{T_{\mathrm{pl}}}{1000\ K}\right) \left(\frac{\mathrm{u}}{\mu}\right) \left(\frac{1\ g/cm^3}{\rho}\right) \left(\frac{R_\odot}{R_\star}\right)^2 \mathrm{ppm}$$

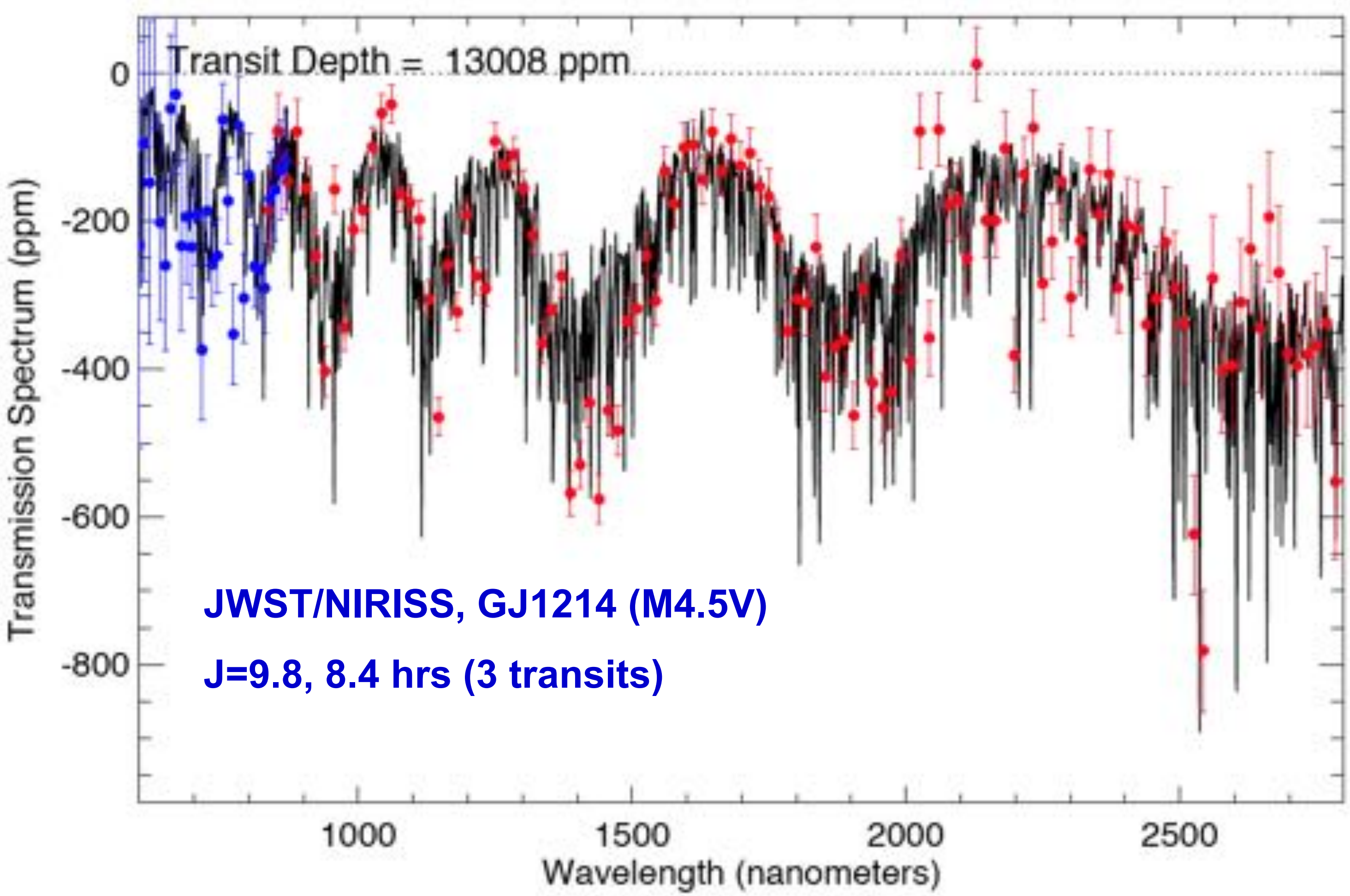
Hot Jupiter



Noise level: 30 – 60 ppm

Model courtesy of J. Fortney

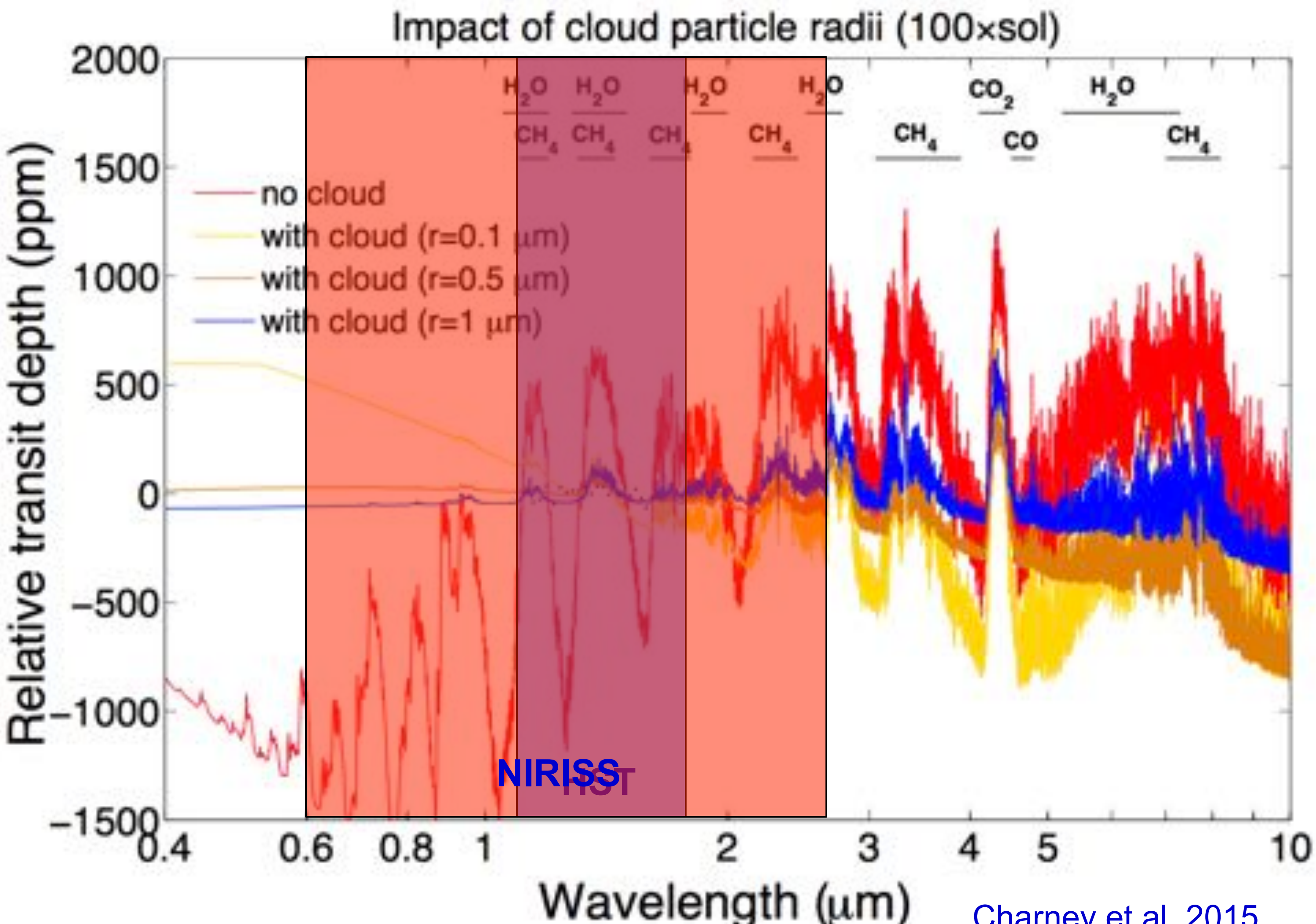
Super-Earth (GJ1214-like, water-rich, no clouds)



Noise level: 25 – 100 ppm

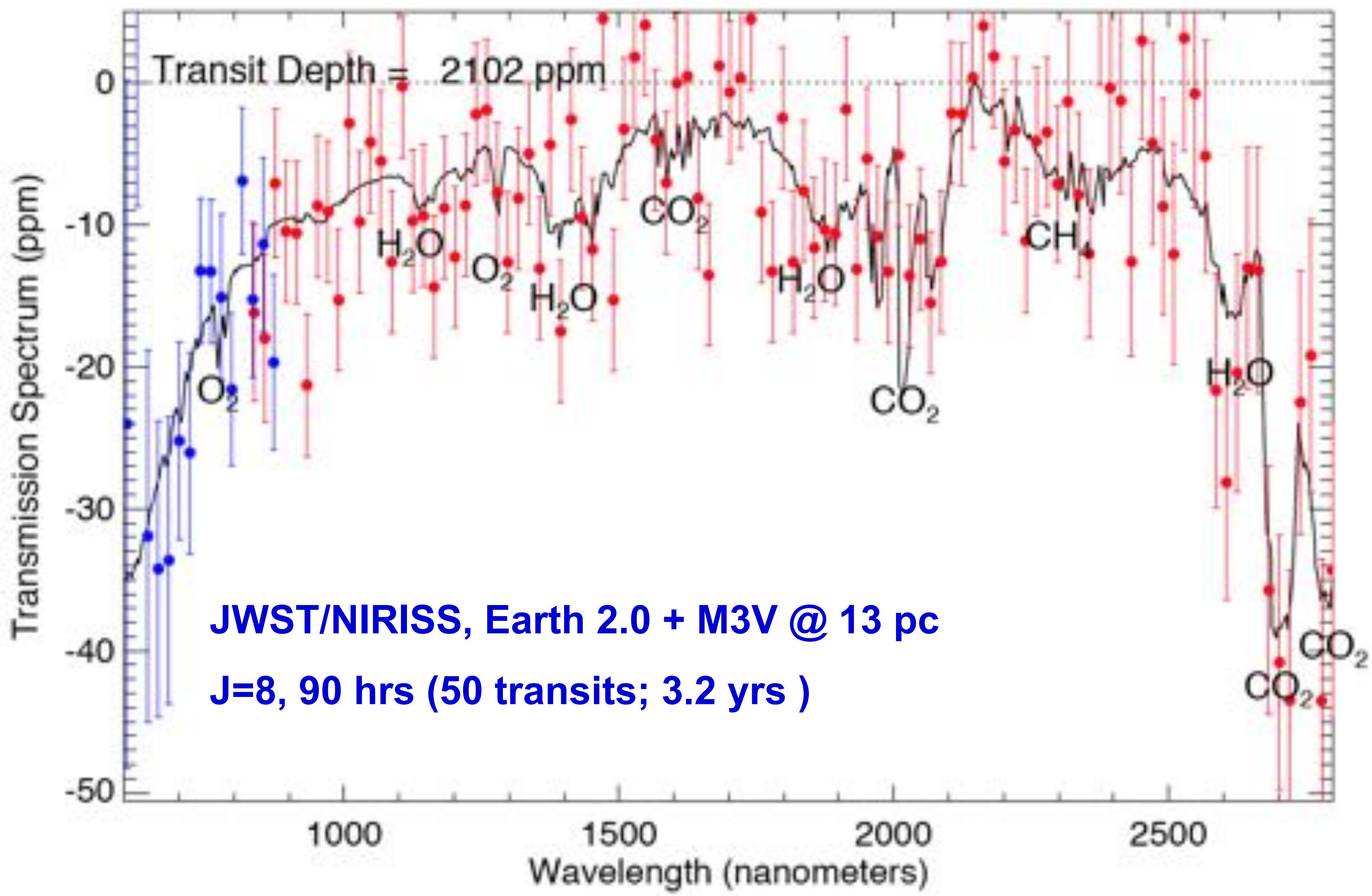
Model courtesy of J. Fortney

The power of broad λ coverage



Charney et al. 2015

Earth 2.0 + ~M3V @ 13 pc (1 $R_{\oplus}$, $\rho=\rho_{\oplus}/2$) (likely TESS HZ planet)



Noise level: 5 – 10 ppm

Model courtesy of L. Kaltenegger

Lots of much needed work ahead

TESS Simulation Yields: All-Sky, Two Years

Summary

- ✧ JWST Transit Legacy Survey
  - ➢ Sub-Neptunes/Hot Jupiters (~700 targets) 2000 hrs
  - ➢ Earths/Super-Earths (~200 targets) 2000 hrs
- ➢ More λ coverage/follow ups: 4000 hrs
- ✧ Small HZ planets (<10 targets) 1000 hrs

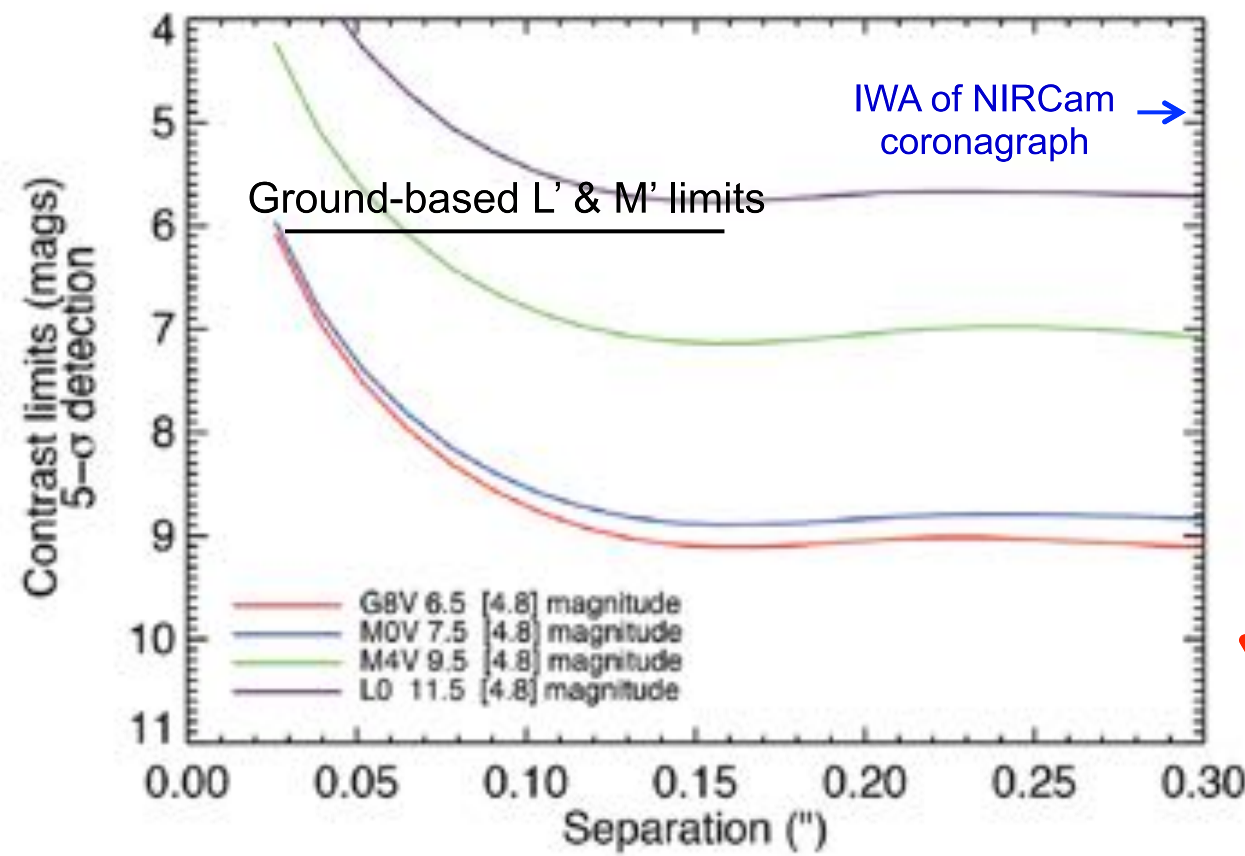
Total: 9000 hrs

~20% of JWST's time over 5 yrs

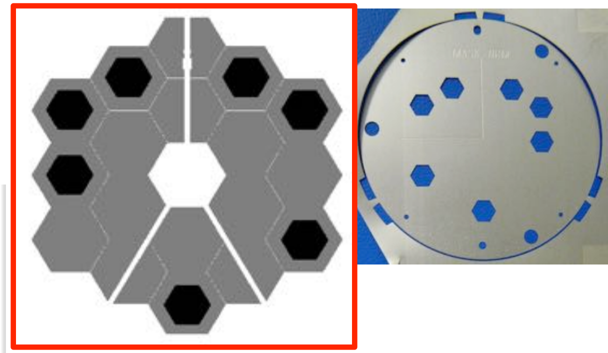
Figure courtesy of George Ricker (TESS PI)

NIRISS Aperture Masking Interferometry (AMI)

- **Probe separations of ~40 to 400 mas**
- **At contrast of up to 9 mag**
- Filters: F380M, F430M, F480M, (and F277W)



7-aperture mask, in pupil wheel



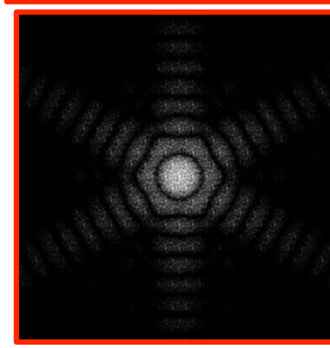
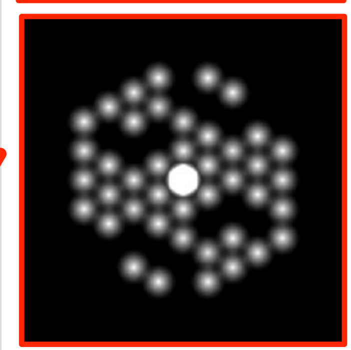


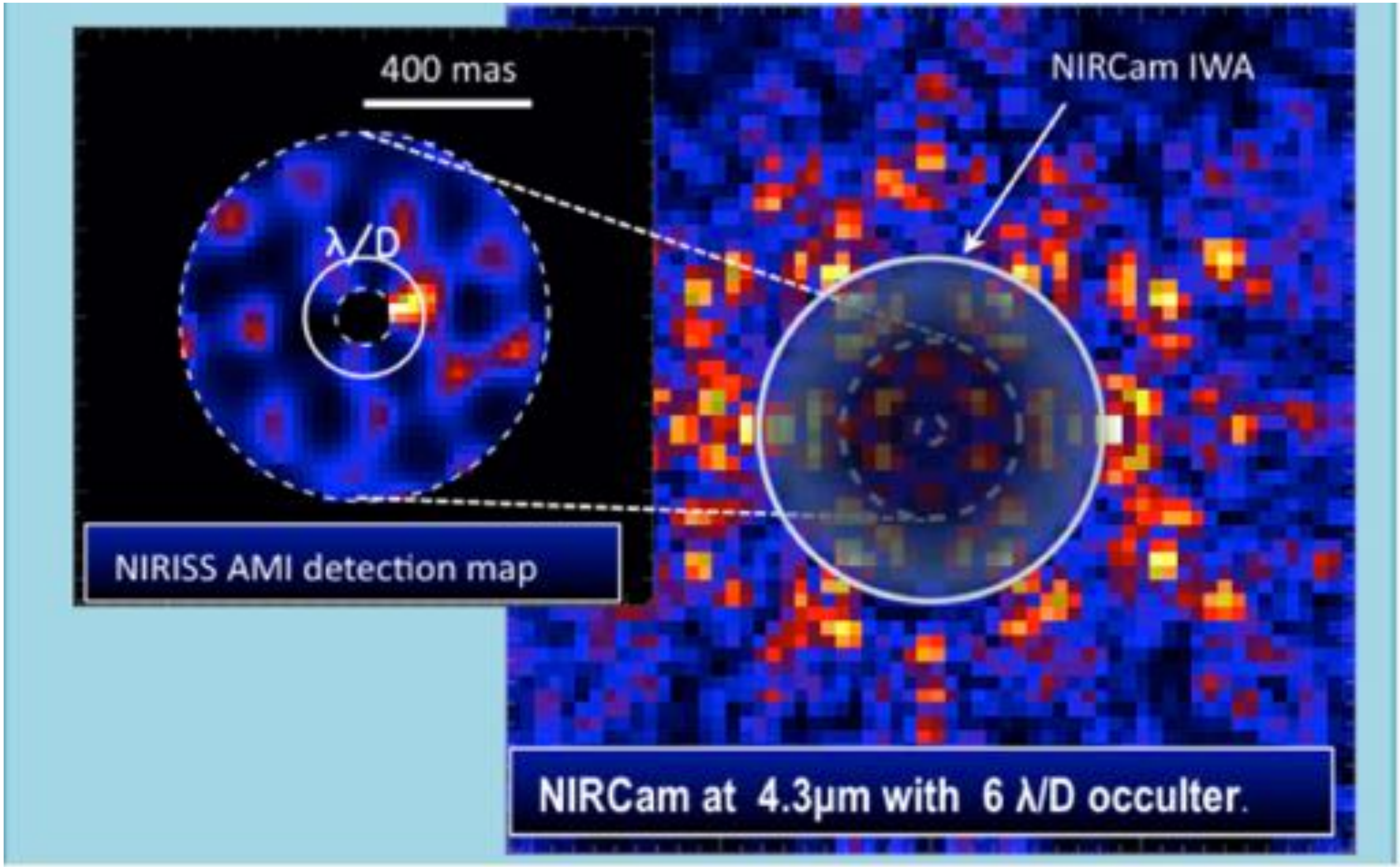
Image recorded at detector: interferogram



Its Fourier transform amplitude (and phase)

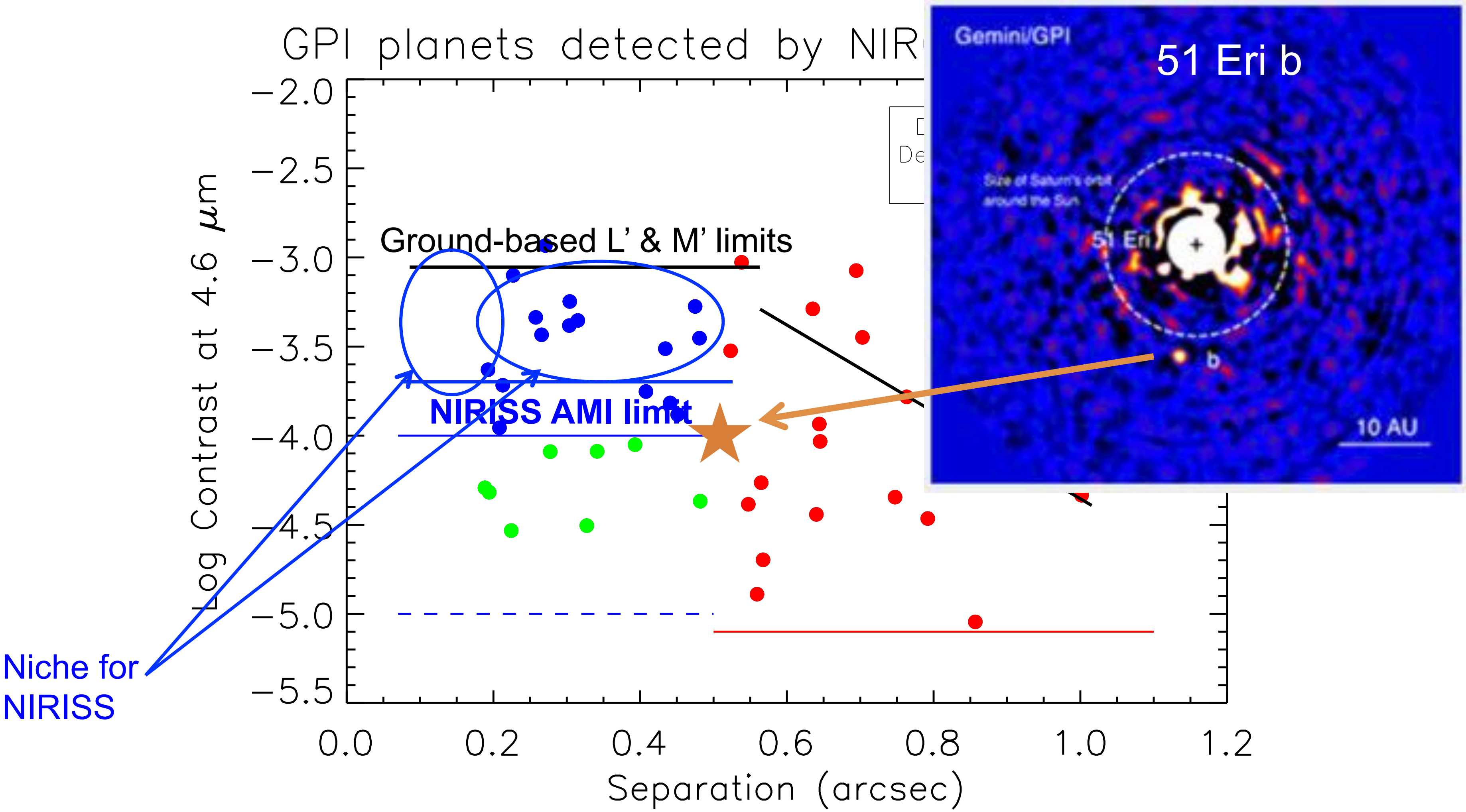
→reveals presence of companion

Probing JWST's highest angular resolution



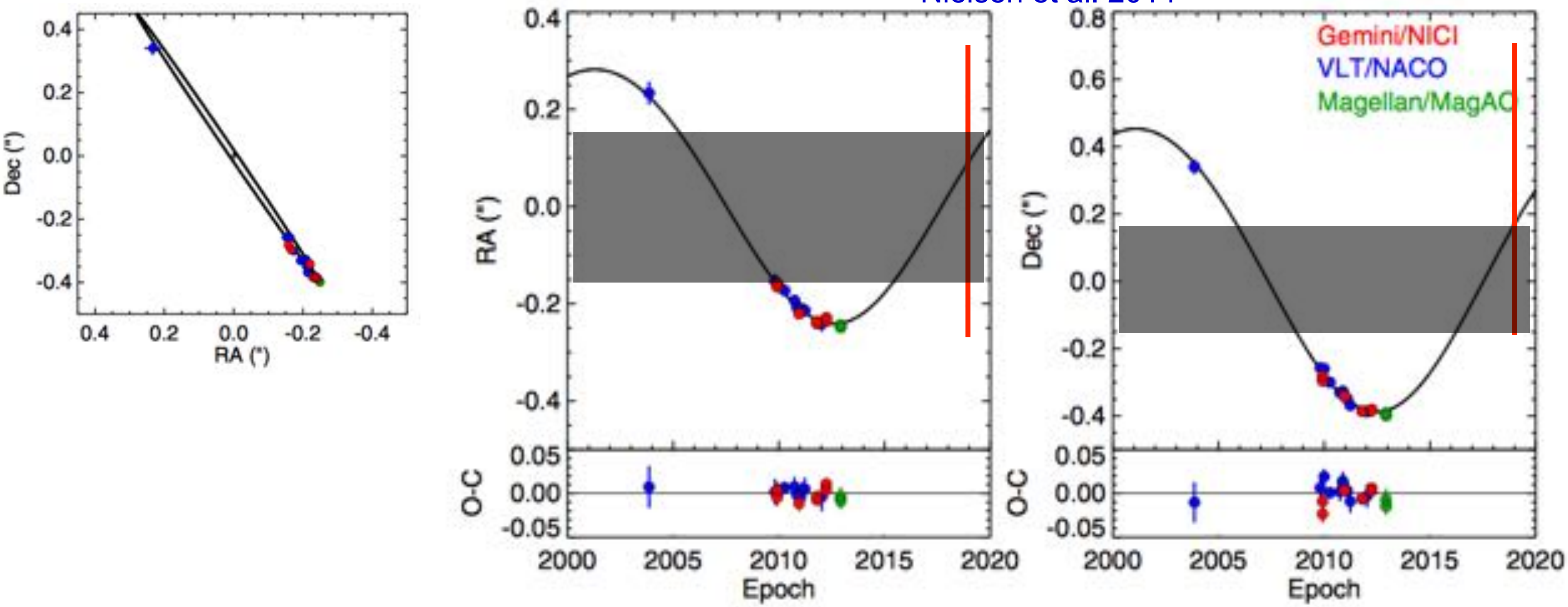
Simulation of 1-2 Mjup planet at 1 AU of an M0V located at 10 pc. Observing time: 3 hrs

AMI follow-up of ground-based ExAO planets



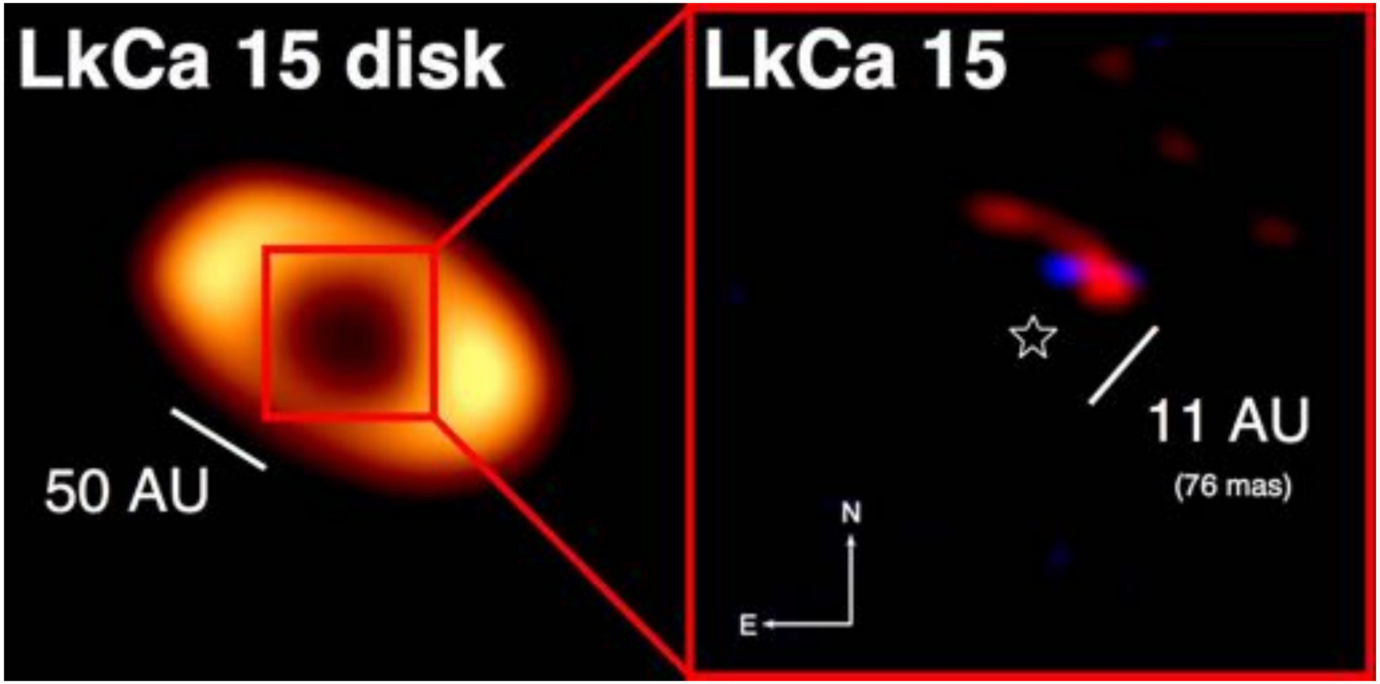
Follow-up of β Pic b in early 2019

Nielsen et al. 2014



- ✧ The planet has entered a phase where it is too close to the star to be imaged with current imaging, it will come out only in ~2020
- ✧ But NIRISS AMI can see it in 2019
  - ➢ Star mag (3.5), planet separation (0.15″-0.18″) and contrast (~7.5 mag) just in the sweet spot!
  - ➢ Important SED and astrometry measurements

Detection/confirmation/follow-up of suspected protoplanets in transitional disks



Kraus et al. 2012

0.5”

NIRISS GTO program
Main themes and guiding principles

- Overall exoplanet program: ~200 hr (out of 450 hr)
  - Single Object Slit-less Spectroscopy (SOSS)
    - Exoplanet spectroscopy
  - Aperture Masking Interferometry (AMI)
    - Exoplanet “imaging”, photometry
- Focus on low-risk
  - ~guaranteed scientific payoff, albeit perhaps not the highest
  - …but room for a few higher risk observations
- Demonstrate NIRISS capabilities
- In general short observations per target
- Good legacy value

NIRISS strawman GTO program

# hr	# targets	What	Mode
120	10-15	Jupiters/Neptunes transit+eclipse spectro.	SOSS 0.6-2.8 um
30	~2	Small planets transit spectroscopy	SOSS 0.6-2.8 um
40	~2	Orbital phase curve spectroscopy	SOSS 0.6-2.8 um
30	5-10	Follow-up of ground-based ExAO planets	AMI
30	5	Protoplanets in transitional disks	AMI

Summary

- NIRISS will provide a powerful "workhorse" transit spectroscopy capability

- NIRISS will alllow detection and characterization of exoplanets at the highest possible angular resolution achievable by JWST

- Exoplanets@JWST will require >25% of JWST's observing time.