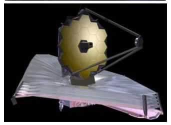
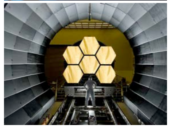
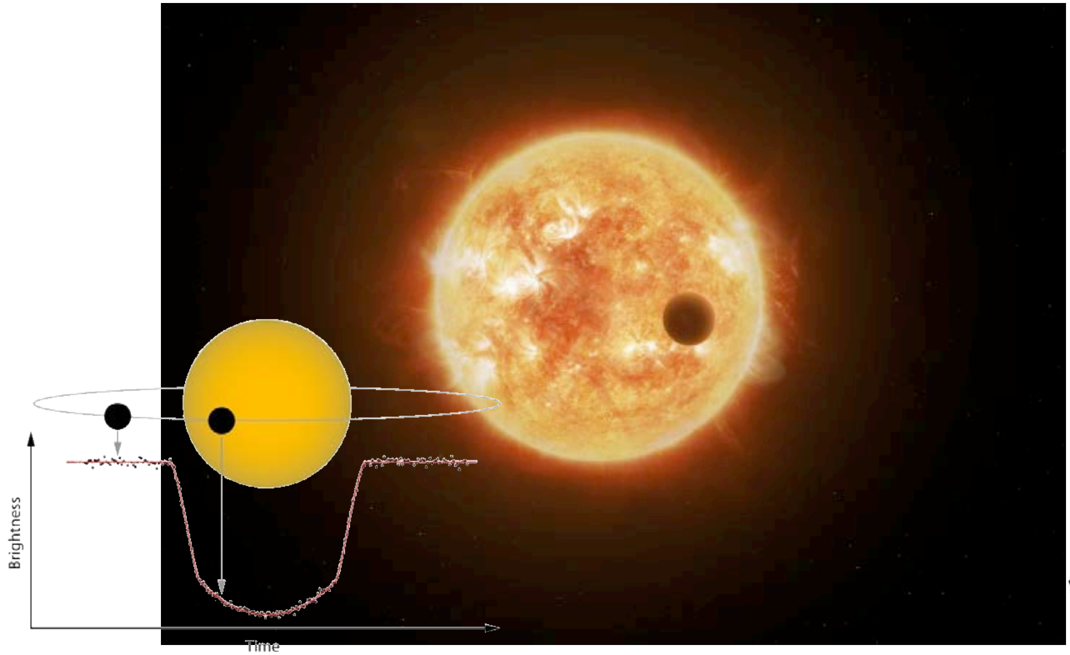
Characterisation of CHEOPS planets with JWST

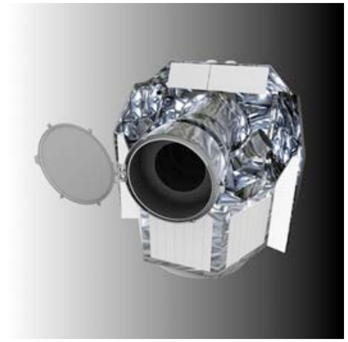
P. Ferruit, K. Isaak, A. Garcia Muñoz,
S. Birkmann, J. Valenti, G. Giardino
& the ESA team

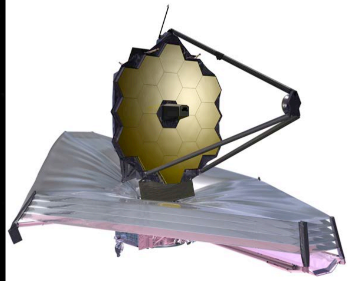
JAMES WEBB SPACE TELESCOPE







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Acknowledgements

- Thanks to the organisers of the CHEOPS workshop for giving us the opportunity to present JWST capabilities and how it could be used to follow-up CHEOPS targets.

- All along this presentation you will see the results of work conducted by a large number of teams in Europe, USA and Canada.
- Many elements of this presentation are based on existing presentations prepared by other members of the JWST project, the instrument teams and STScI.

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- **Characterisation of Cheops planets with JWST.**
  - JWST - Timeline for scientific operation.
  - Orbit, field-of-regard and visibility constraints.
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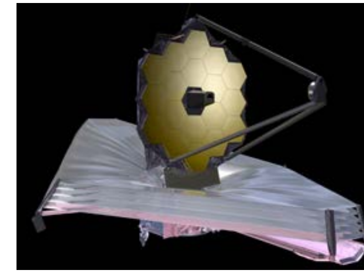
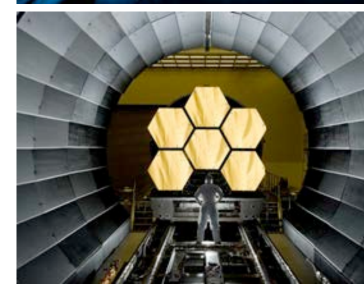
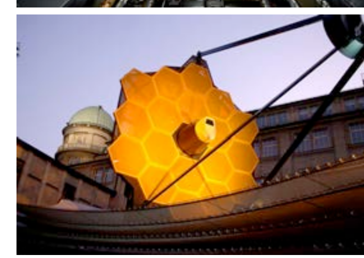
The James Webb Space Telescope (JWST)
The mission in a nutshell

JAMES WEBB SPACE TELESCOPE

- **JWST will be one of the "great observatories" of the next decade.**
    - Often presented as the next step after the Hubble Space Telescope (HST)
- **Joint mission between NASA, ESA and CSA.**
    - High-priority endeavor for the associated astrophysical communities.
- **Setup similar to the HST one.**
    - Over the duration of the mission, > 15% of the total JWST observing time goes to ESA member states applicants.
- **To be launched at the end of 2018 for a minimum mission duration of 5 years (10-year goal).**







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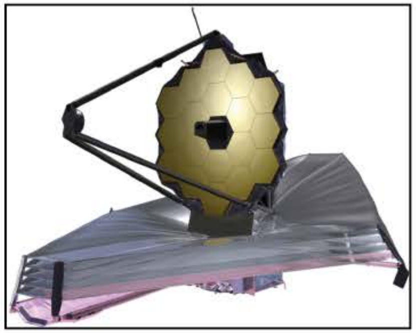
The James Webb Space Telescope (JWST)

Launch segment

- Payload adapter
- Launcher (Ariane 5)
- Launch site services

Observatory segment

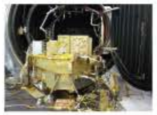


- Spacecraft (bus, sunshield...)
- Telescope

Payload module (ISIM) and instruments

- NIRCam

- NIRSpec
- FGS / NIRISS



- MIRI

Ground segment

- Science and operation center (STScI)
  - 15 ESA staff members
- Common systems (deep space network)

☐ Provided by NASA ☐ Provided by ESA and Europe ☐ Provided by CSA

The James Webb Space Telescope (JWST)
The mission in a nutshell

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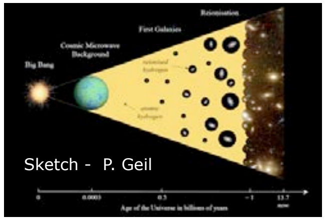
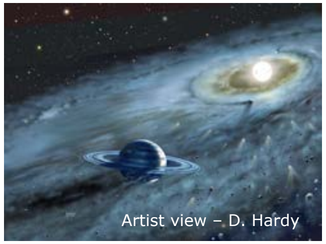
- The end of the dark ages: first light and re-ionization.


Sketch - P. Geil

- The assembly of galaxies: the formation and evolution of galaxies.


Hubble Ultra-deep Field

- The birth of stars and proto-planetary systems.


Artist view – D. Hardy

- Planetary systems (including our solar system and exoplanets) and the origin of life.


Artist view – R. Hurt

And a wealth of other scientific programs as JWST will be a general observatory.

See Gardner et al., 2006, Space Science Reviews, 123, 485

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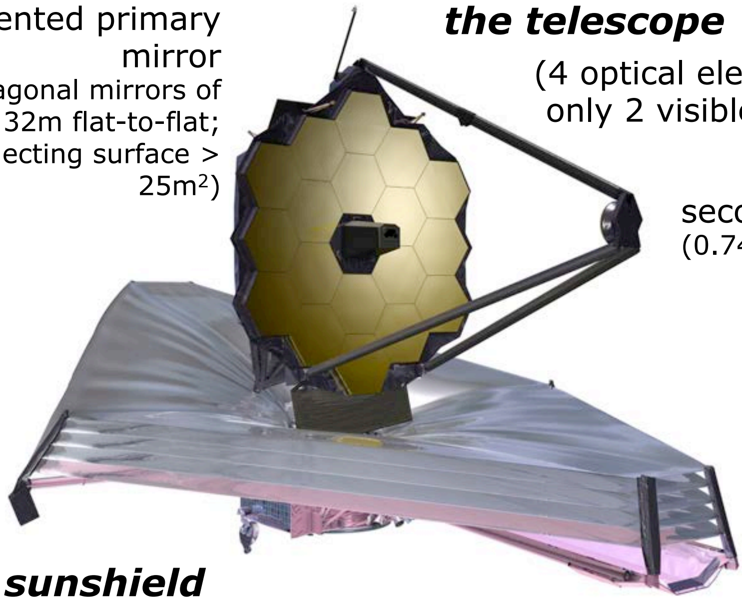
The James Webb Space Telescope (JWST)
The mission in a nutshell

segmented primary mirror
(18 hexagonal mirrors of 1.32m flat-to-flat; collecting surface > 25m^2)

the telescope

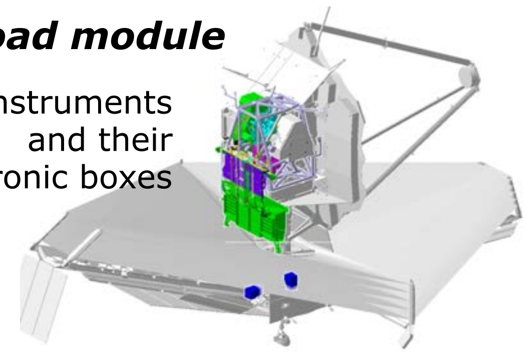
(4 optical elements, only 2 visible here)

secondary mirror
(0.74m diameter)



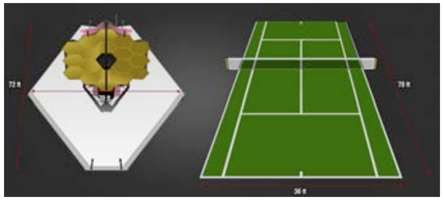
payload module

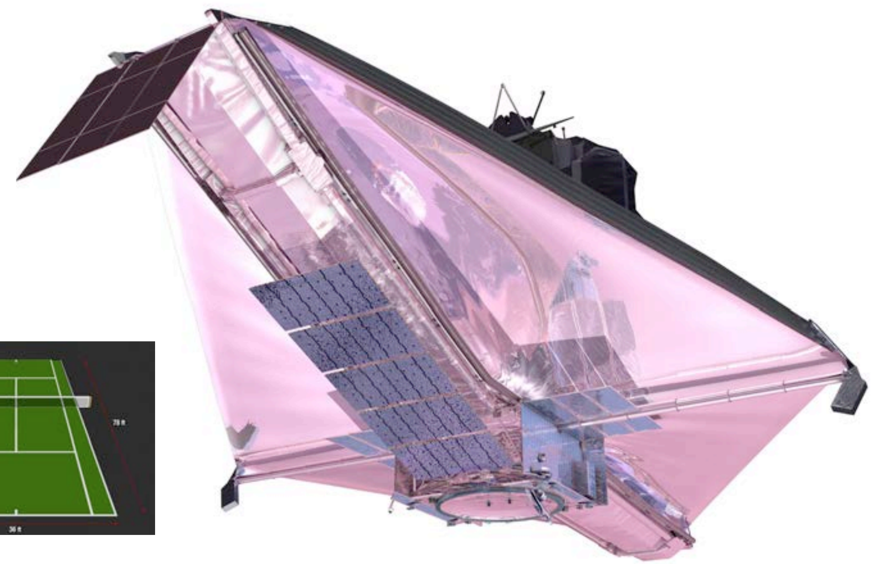
the 4 instruments and their electronic boxes



the sunshield

5 membranes of Kapton foil allowing **passive cooling of the telescope and the instruments down to ~40K**
the size of a tennis court

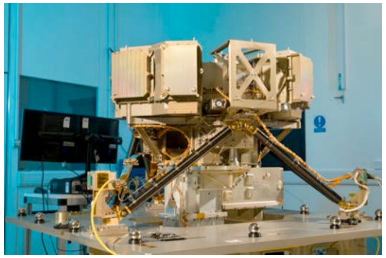




the spacecraft bus and solar panels

Note that a cryogenic cooler is used to cool JWST's mid-infrared instrument (MIRI) down to 6-7K.

The James Webb Space Telescope (JWST) The mission in a nutshell



MIRI = Mid-InfraRed Instrument

50/50 partnership between a nationally funded consortium of European institutes (MIRI EC) under the auspices of ESA and NASA/JPL.

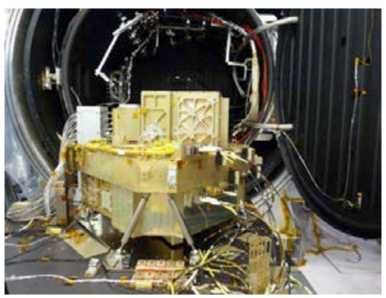
PIs: G. Wright and G. Rieke

NIRSPEC
NEAR-INFRARED SPECTROGRAPH

NIRSpec = Near-infrared Spectrograph

FGS = Fine Guidance Sensor

Provided by the European Space Agency. Built by an industrial consortium led by Airbus Defence and Space.



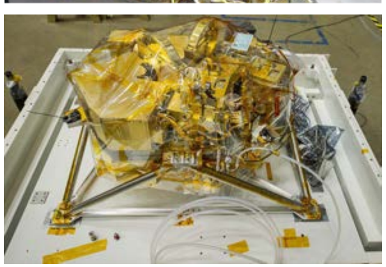
FGS NIRISS

NIRISS = Near-infrared Imager and Slit-less Spectrograph

FGS = Fine Guidance Sensor

Provided by the Canadian Space Agency.

PIs: R. Doyon & C. Willott



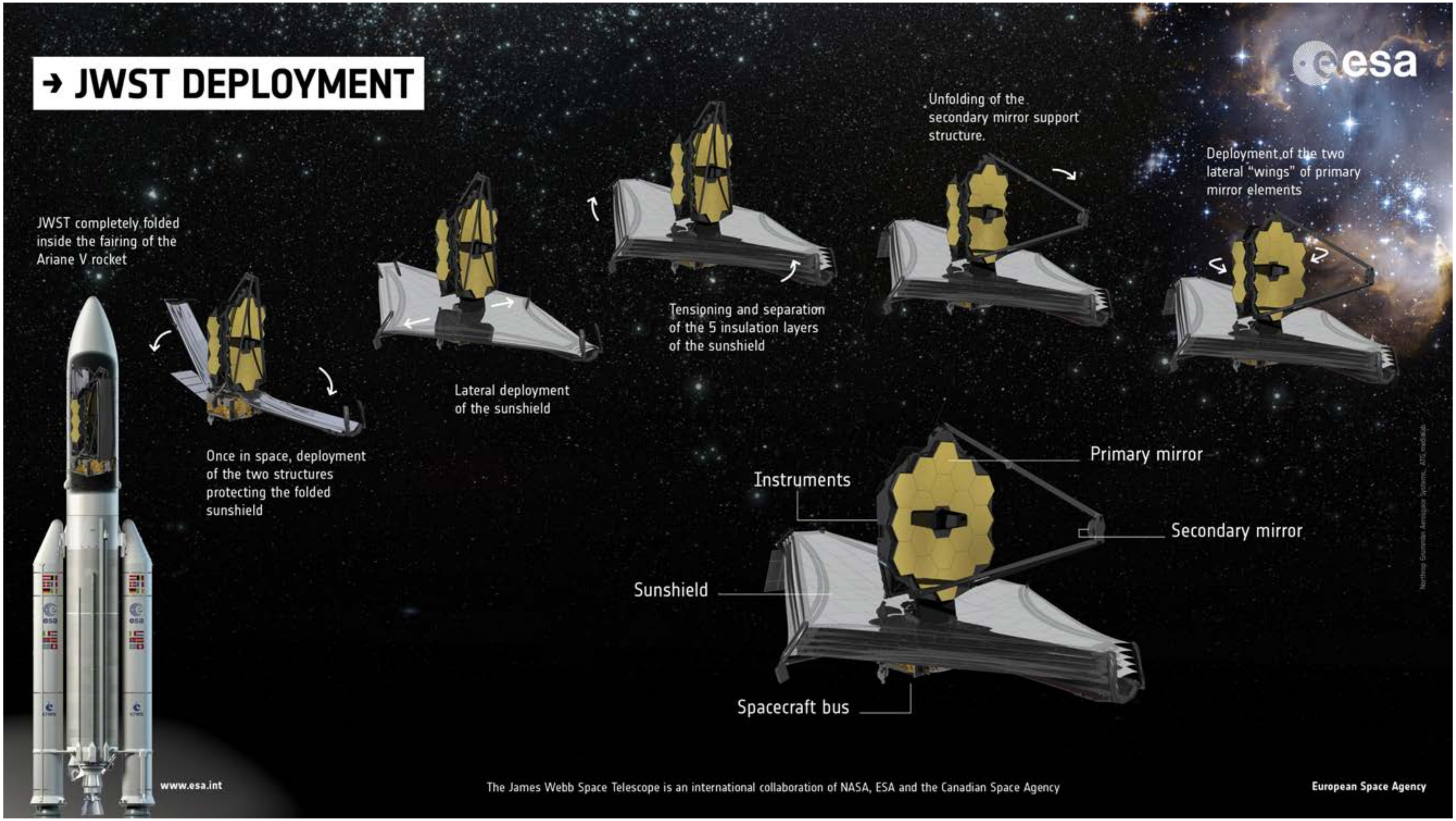
NIRCam = Near-InfraRed Camera

Developed under the responsibility of the University of Arizona.

PI: M. Rieke

JWST's instruments

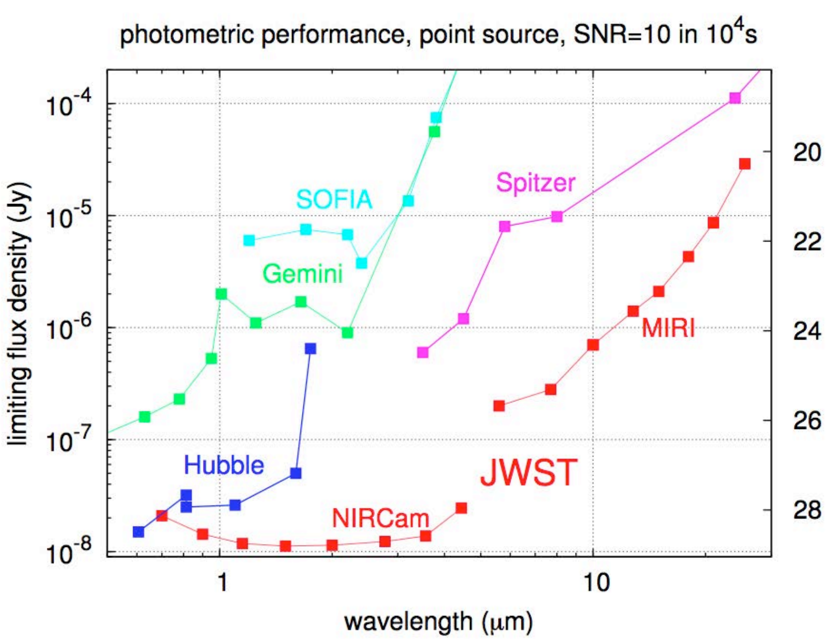
The James Webb Space Telescope (JWST)
The mission in a nutshell

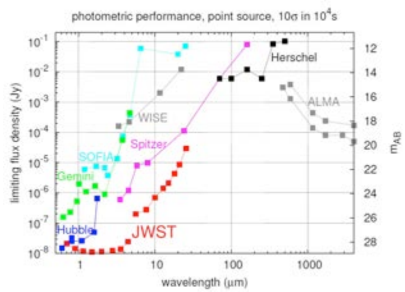


http://jwst.nasa.gov/videos_deploy.html

JWST imaging capabilities

Instrument	Wavelength (in microns)	Pixel scale (in mas/pixel)	Field of view (arcmin x arcmin)
NIRCam	0.6-2.3	32	2.2′ x 4.4′
NIRCam	2.4-5.0	65	2.2′ x 4.4′
NIRISS	0.9-5.0	65	2.2′ x 2.2′
MIRI	5.0-28	110	1.3′ x 1.7′



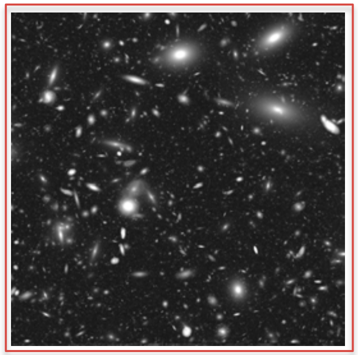


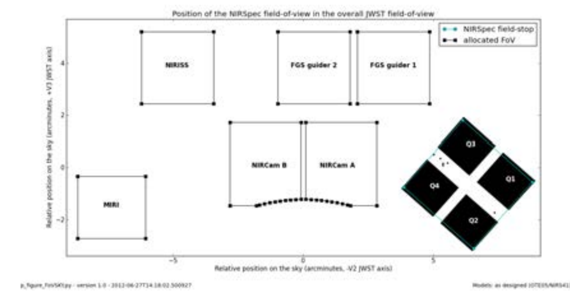
NIRCam: Simultaneous imaging of the same field of view in the 'blue' and 'red' channels.

- **More than one order of magnitude sensitivity improvement in some bands.**
- Extremely powerful observatory, a lot of discovery space.

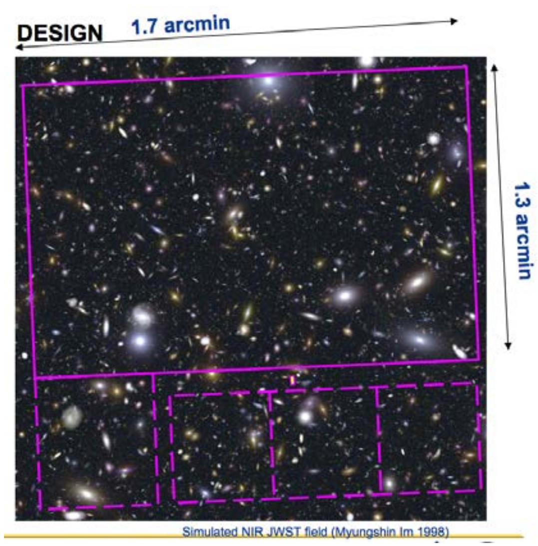
JWST imaging capabilities

NIRISS (2.2′ x 2.2′)

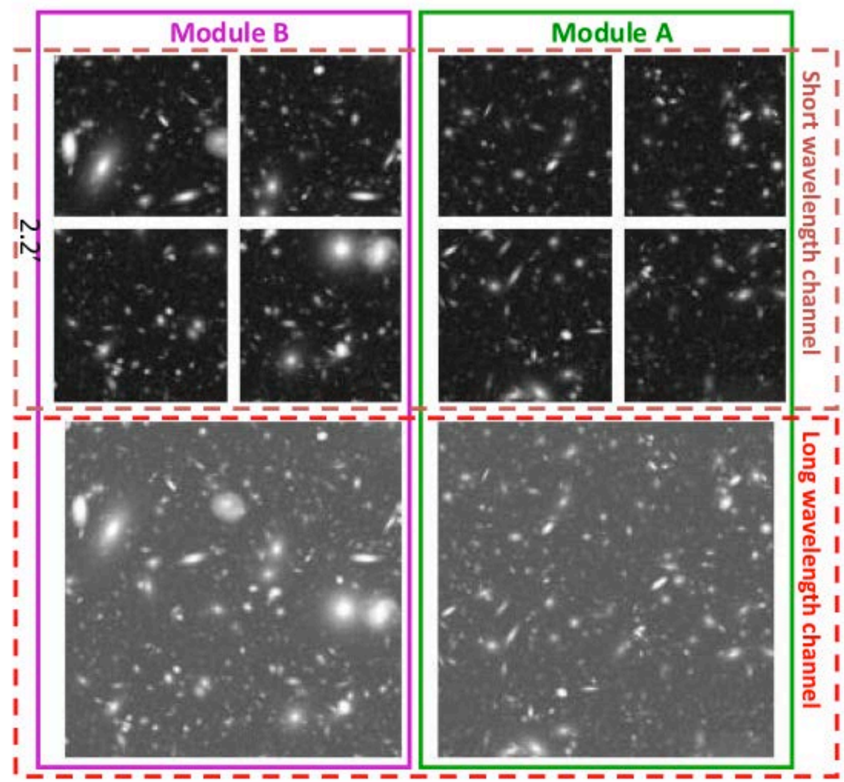




MIRI (1.7′ x 1.3′)



NIRCam (4.4′ x 2.2′)



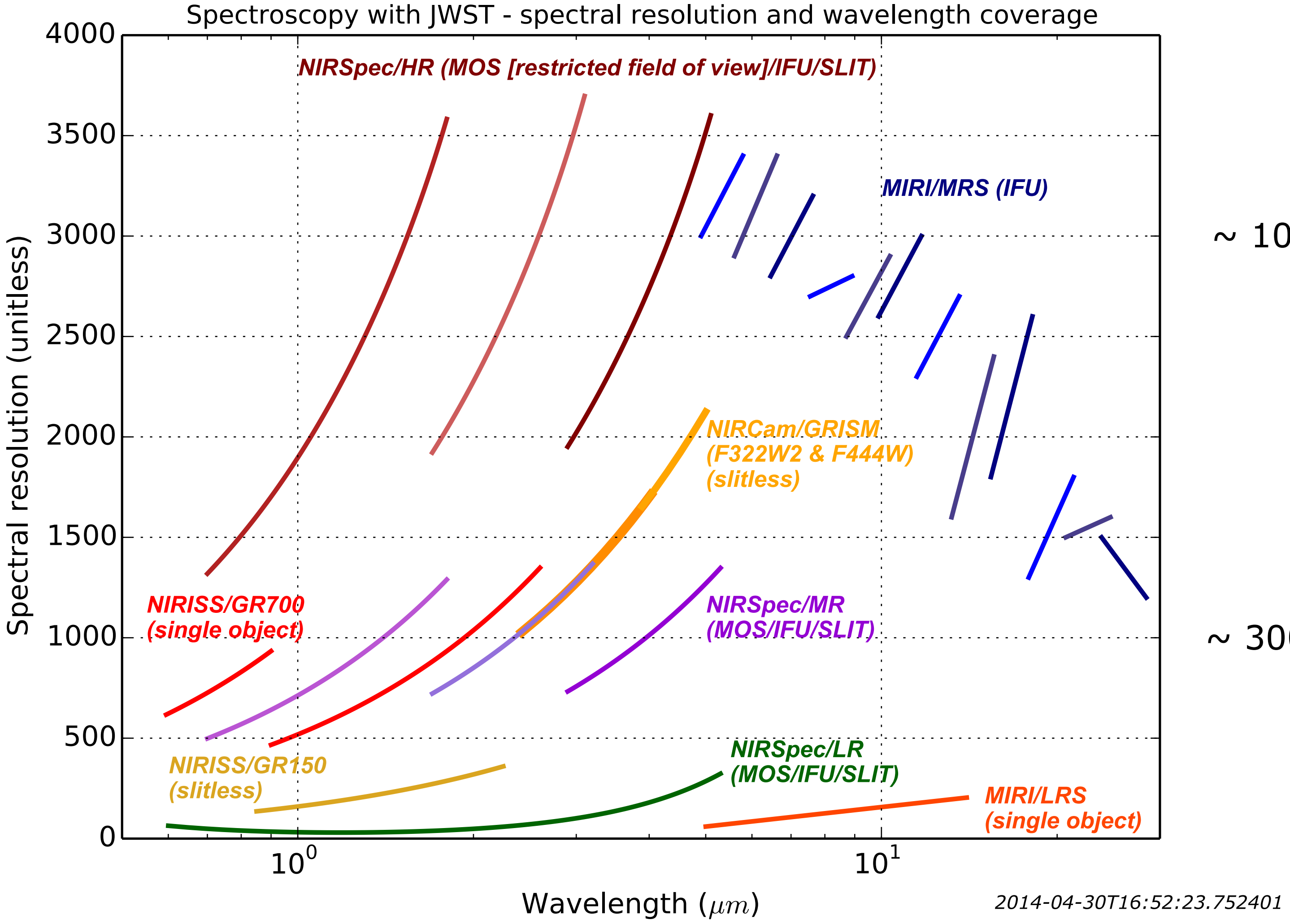
Not to scale.

JWST spectroscopic capabilities

- **Take-home message: in JWST, spectroscopy comes in many different flavors…**
    - Can address many different scientific needs.
    - Unique combination of sensitivity & spatial resolution.

Instrument	Type	Wavelength (microns)	Spectral resolution	Field of view
NIRISS	slitless	1.0-2.5	~150	2.2′ x 2.2′
NIRCam	slitless	2.4-5.0	~2000	2.2′ x 2.2′ (TBC)
NIRSpec	MOS	0.6-5.0	100/1000/2700	9 square arcmin.
NIRSpec	IFU	0.6-5.0	100/1000/2700	3″ x 3″
MIRI	IFU	5.0-28.8	2000-3500	>3″ x >3.9″
NIRSpec	SLIT	0.6-5.0	100/1000/2700	Single object
MIRI	SLIT	5.0-10.0	60-140	Single object
NIRISS	Aperture	0.6-5.0	100/1000/2700	Single object
NIRSpec	Aperture	0.6-2.5	700	Single object

JWST spectroscopic capabilities
Spectral resolution



~ 100 km/s

~ 300 km/s

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JWST coronagraphic and aperture masking interferometry capabilities

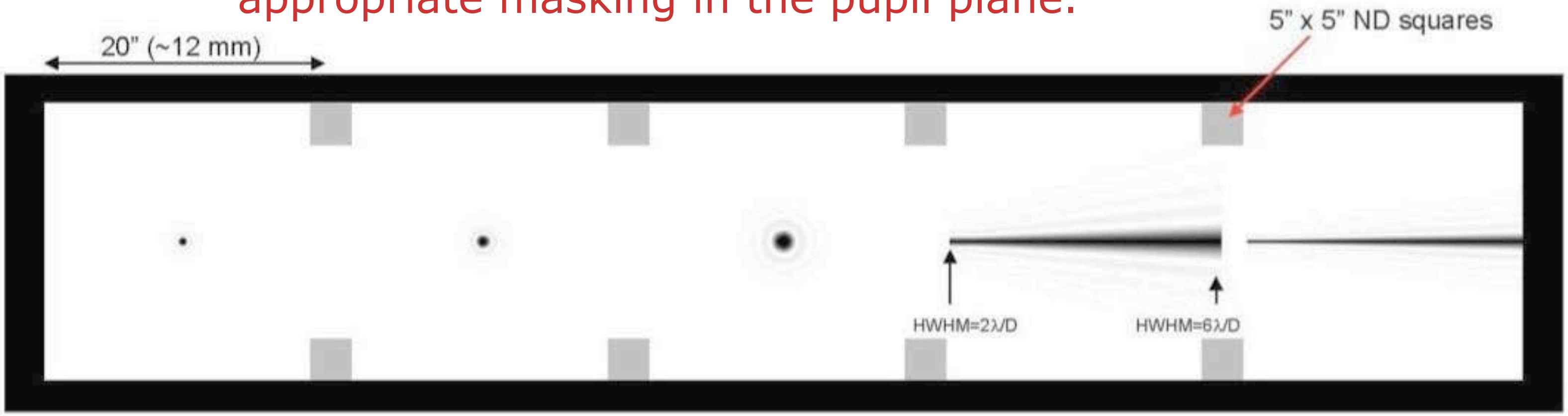
- **Like for spectroscopy a variety of modes are available, spread over the wavelength range covered by JWST.**

Instrument	Wavelength (in microns)	Pixel scale (in mas/pixel)	Field of view	Type
NIRCam	0.6-2.3	32	20″ x 20″	Lyot
NIRCam	2.4-5.0	65	20″ x 20″	Lyot
NIRISS	3.8-4.8	65	0.1-0.5″	Aperture masking interferometry
MIRI	10.65	110	24″ x 24″	4QPM
MIRI	11.4	110	24″ x 24″	4QPM
MIRI	15.5	110	24″ x 24″	4QPM
MIRI	23	110	30″ x 30″	Lyot

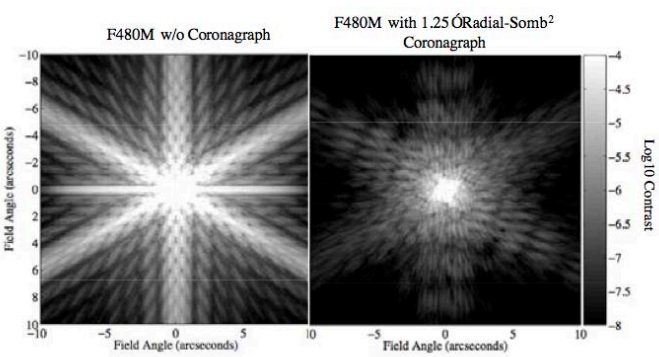
- **QPM = four-quadrant phase masks**

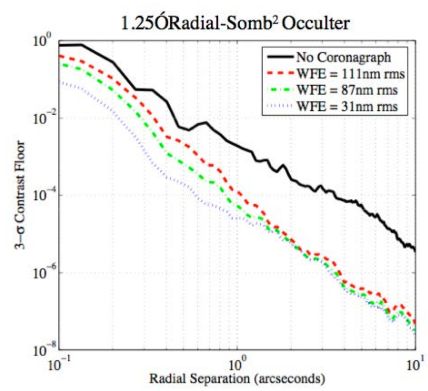
JWST coronagraphic and aperture masking interferometry capabilities

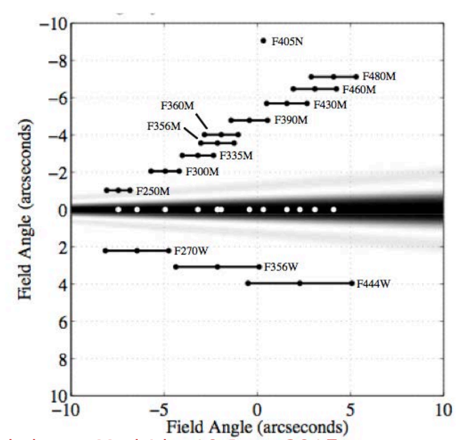
- **Lyot-stops**
  - Dedicated masks in the image plane associated to the appropriate masking in the pupil plane.



HWHM = 0.40" (6λ/D @ 2.1 μm)	HWHM = 0.64" (6λ/D @ 3.35 μm)	HWHM = 0.82" (6λ/D @ 4.3 μm)	$HWHM_c$ = 0.58" (4λ/D @ 4.6 μm)	$HWHM_c$ = 0.27" (4λ/D @ 2.1 μm)







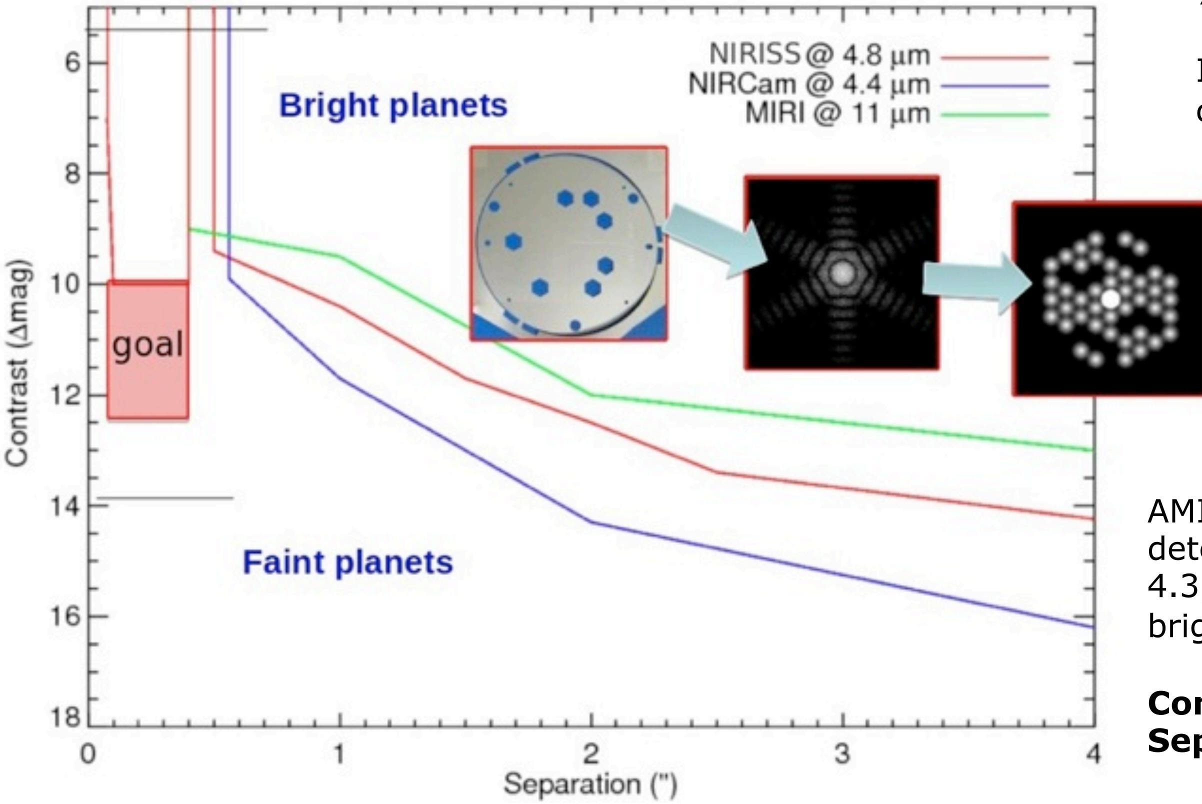
From Green at al., SPIE, 2005. Simulations

JWST/NIRISS – Aperture masking interferometry

- **Specially designed for high-contrast observations around bright sources.**

PSF with a concentrated core corresponding to a resolution of 75 mas at 4.6 microns.

I need to go through the corresponding computation!!!

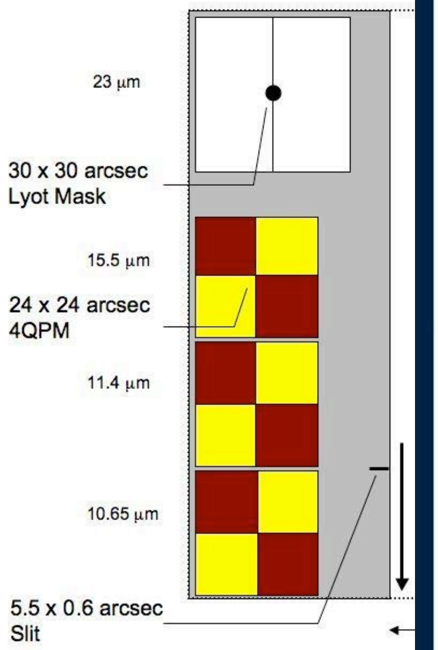


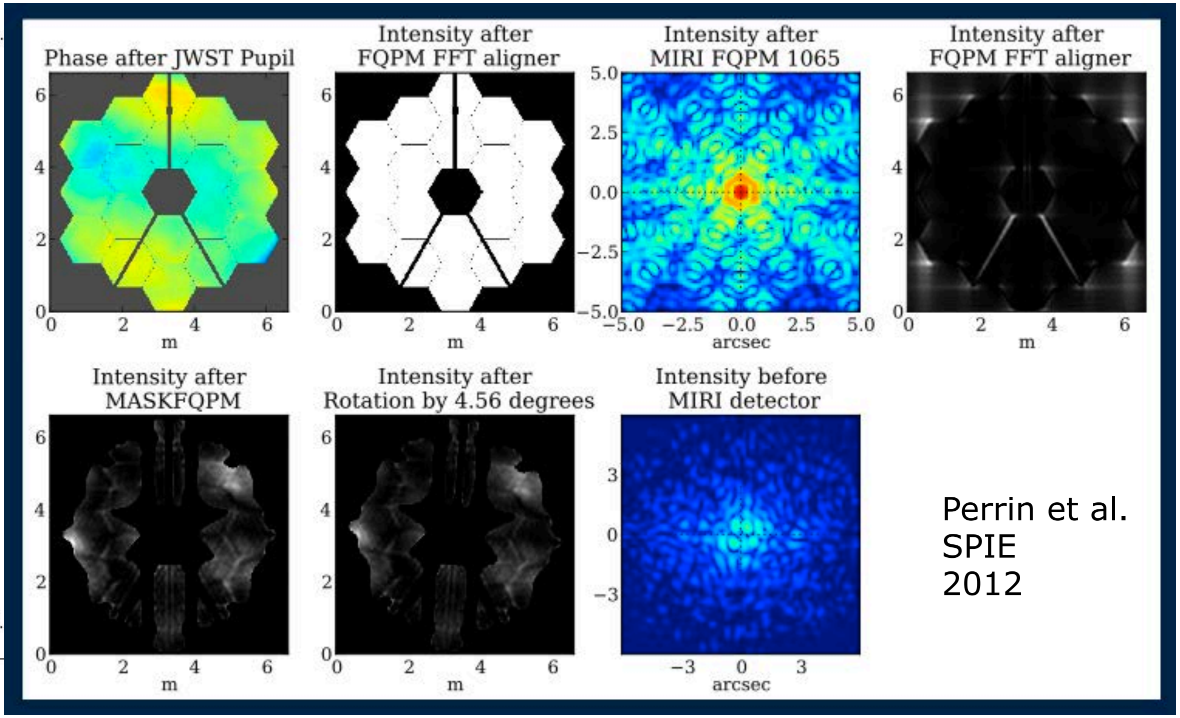
AMI with NIRISS enables the detection of exoplanets at 3.8, 4.3, and 4.8 μm around stars as bright as **M' ~ 5** with:

Contrast: ~2×10-5 (S/N~5)
Separations: 70 – 400 mas

JWST/MIRI – Coronagraphy

- **4 coronagraphic modes on the side of the imaging field of view.**



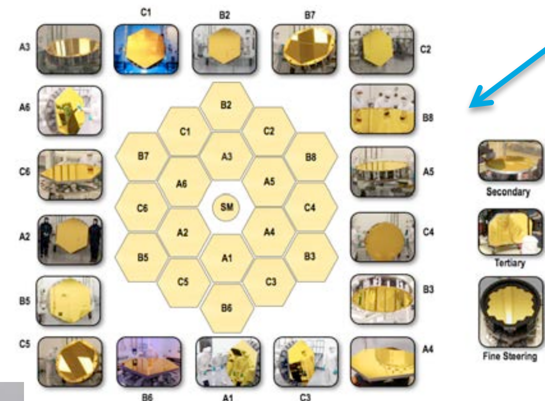


Perrin et al.
SPIE
2012

JWST status - hardware

- **We really entered the assembly, integration and testing phase.**

Integrated payload module with all four instruments in flight configuration



Family picture! All mirrors are ready to be mounted on the telescope backplane.

Testing the deployment of the sunshield while manufacturing the flight membranes

Primary mirror backplane structure

Secondary mirror support structure

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jwst

esa

JWST – Status - Programmatic

- **Since the "replan" that took place on the US side around 2010-2011, the development of the JWST mission has been progressing steadily.**
    - Within cost and within schedule for a ***launch in October 2018***.
    - 9.75 months of funded schedule contingencies available along the critical path (38 months before launch)

➔ we are on track.

- **Does this mean that we do not encounter any problem? Of course not.**
    - But we have the necessary schedule and funding contingencies.

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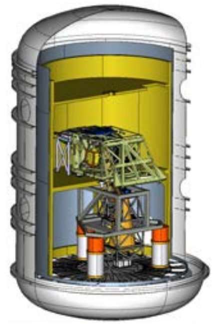
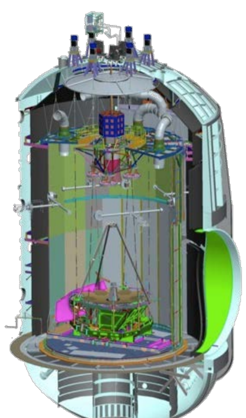
JWST – What happens next?

End 2015: Final payload module testing at the Goddard Space Flight Center.

End 2015 – Beginning 2016: integration of the telescope.

2016-2017: testing of the telescope and the instruments together at the Johnson Space Center.

JWST – What happens next?

2017-2018: final integration and testing of the spacecraft and…

… LAUNCH!

But this will only be the beginning of the story for the scientific life of JWST!

Characterisation of transiting exoplanets with JWST.

Reference: white paper "Observations of transiting exoplanets with JWST"

Beichman et al., 2014, PASP, 126, 1134

http://www.stsci.edu/jwst/doc-archive/white-papers


arXiv:1411.1754v1 [astro-ph.IM] 6 Nov 2014

Observations of Transiting Exoplanets with the James Webb Space Telescope (JWST)

Charles Beichman
NASA Exoplanet Science Institute, California Institute of Technology, Jet Propulsion Laboratory

Bjoern Benneke, Heather Knutson, Roger Smith
California Institute of Technology

Pierre-Olivier Lagage
CEA, Saclay

Courtney Dressing, David Latham
Center for Astrophysics, Harvard University

Jonathan Lunine
Cornell University

Stephan Birkmann, Pierre Ferruit, Giovanna Giardino
European Space Agency

Eliza Kempton
Grinnell College

Sean Carey, Jessica Krick
Infrared Processing and Analysis Center, California Institute of Technology

Pieter D. Deroo, Avi Mandell, Michael E. Ressler, Avi Shporer, Mark Swain, Gautam Vasisht
Jet Propulsion Laboratory, California Institute of Technology

(+ brown dwarfs, + solar system + direct imaging…)

Observation	Targets	R	Science
Transit light Curves	Gas giants Intermediate planets Superearths	5 5 5	- Exoplanet properties e.g. Mass, radius -> Physical structure - Confirmation of Terrestrial planet transits - Transit timing: detection of unseen planets
Phase light curves	Gas giants Intermediate planets	5 5	- Day to night emission mapping: dynamical models of Exoplanet atmospheres
Transmission Spectroscopy	Gas giants Gas giants Intermediate planets Superearths planets	3000 100-500 100-500 ≤100	Spectral line diagnostics - atmospheric composition e.g. C, CO_2, CH_4 - follow-up of survey detections: TESS & Kepler & CHEOPS "golden" targets!
Emission Spectroscopy	Gas giants Gas giants Intermediate planets Superearths planets	3000 100-500 100-500 ≤100	- Spectral line diagnostic - Planet temperature measurements - follow-up of survey detections: TESS & Kepler & CHEOPS "golden" targets!

Table from P.-O. Lagage / presentation SF2A 2015.

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Characterisation of transiting exoplanets with JWST.

It is important to keep in mind that JWST is a general purpose observatory that will likely have a high level of oversubscription.

- ***Definitely more a "follow-up" rather than "survey" type of mission.***
- ***Going "fishing" will only be possible if the TAC can be convinced that the possible scientific return is worth the risk.***

➔ ***Proposals to observe well-characterised targets with JWST will definitely get an edge.***

➔ ***CHEOPS…***

Characterisation of transiting exoplanets with JWST.

	Instrument Mode	λ (μm)	R (λ/δλ)	FOV	Application
Imaging	NIRCam	0.6 - 2.3 2.4 - 5.0	4, 10, 100 4, 10, 100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	High precision light curves of primary and secondary eclipses
	NIRCam (Defocused)	0.6 - 2.3	4, 10, 100	Defocused images radius = 0.74" radius = 1.42" radius = 2.11"	High precision light curves of primary and secondary eclipses for - bright targets that need to be defocused to avoid rapid saturation - reduction of flat field and pointing errors
	MIRI	5 - 28	4 - 6	1.9' x 1.4'	High precision light curves of secondary eclipses
	TFI	1.6 - 2.6 3.2 - 4.9	100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	High precision light curves of primary and secondary eclipses - bright targets that need to be defocused to avoid rapid saturation
Spectroscopy	NIRCam	2.4 - 5.0	1700	2 x (2.2' x 2.2')	Transmission and emission spectroscopy of transiting planets
	NIRSpec	1.0 - 5.0	100, 1000, 2700	1.6" x 1.6"	Transmission and emission spectroscopy of transiting planets
	MIRI-LRS	5 -11	100	Slitless	Emission spectroscopy of transiting planets - Low spectroscopy
	MIRI-MRS	5.9 - 7.7 7.4 - 11.8 11.4 - 18.2 17.5 - 28.8	3000 3000 3000 3000	3.7" x 3.7" 4.7" x 4.5" 6.2" x 6.1" 7.1" x 7.1"	Emission spectroscopy of transiting planets - suitable for specific spectral features e.g. CO_2 @ 15 μm

Table from P.-O. Lagage / presentation SF2A 2015.

Note that contrary to what is done with HST, we do not expect spatial scanning (moving the target continuously during the observation) to be possible with JWST.

Characterisation of transiting exoplanets with JWST.

Table 4. Brightness Limits for Various Instrument Modes

Instrument	Mode	Brightness Limit (mag)[a]
NIRSpec		
	Low-resolution spectroscopy	$J > 11$
	Medium-resolution spectroscopy	$J \gtrsim 6$ (best-case)
NIRISS		
	Standard spectroscopy	$J > 8.1$
	Subarray spectroscopy	$J > 6.9$
NIRCam	L (mag) limits	
	Long-wavelength spectroscopy	32×2048 Subarray
	F277W	3.7
	F322W2	3.7
	F356W	3.8
	F410M	3.8
	F444W	3.8
	Photometry	64×64 Subarray
	F277W	9.2
	F322W2	10.0
	F356W	9.3
	F410M	8.2
	F444W	9.2
MIRI		
	8 μm imaging (F770W)	$K > 6$
	15 μm imaging (F1500W)	$K > 3-4$
	LRS Spectroscopy	$K > 3-4$

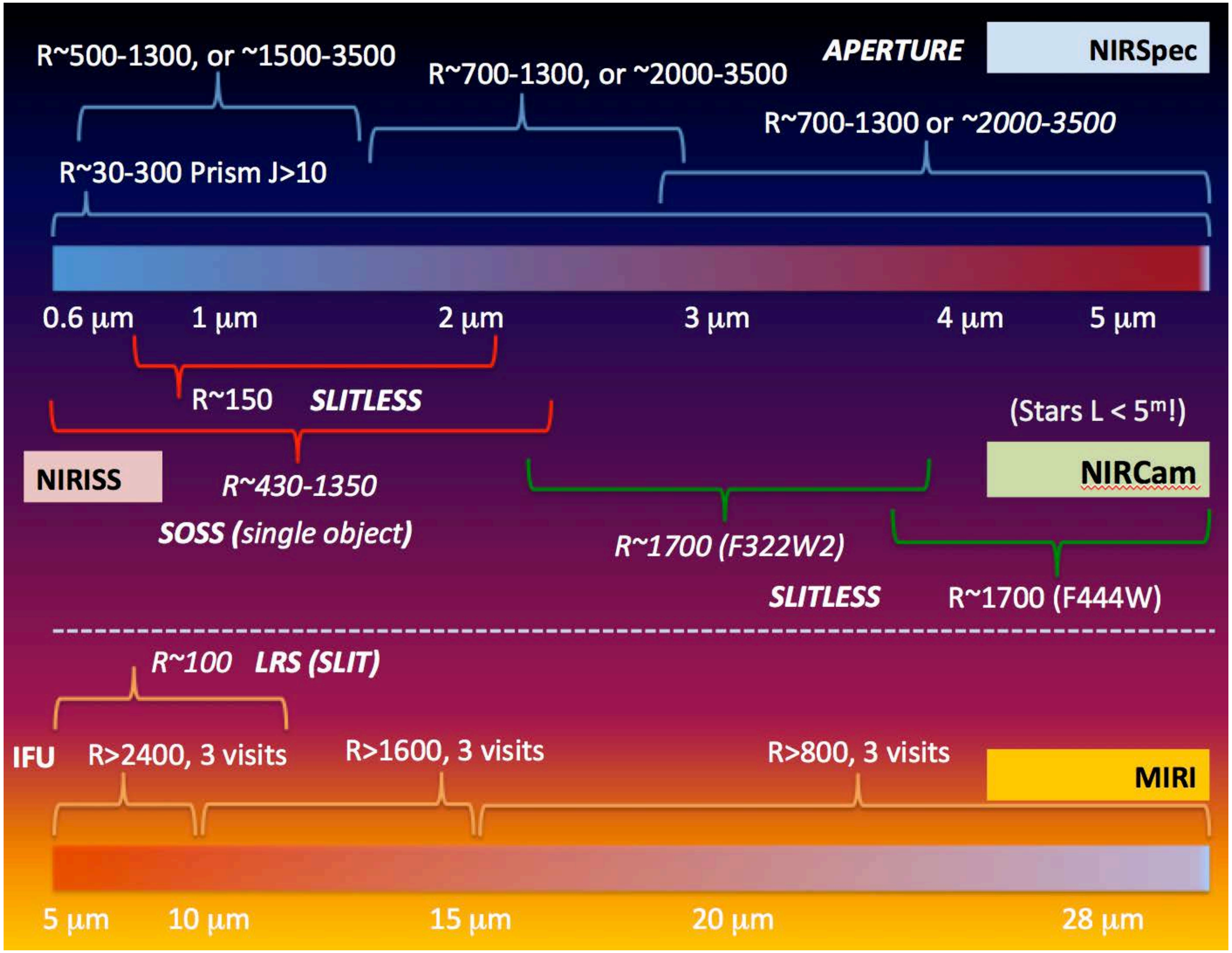
[a]For integrations with NFRAMES=1, NGROUPS=2.

White paper 2014 – Beichman et al.

Brightness limits are evolving (mainly in the right direction!) as the instruments are put in their final flight configuration and as we optimise the observation strategies.

But clearly exoplanets orbiting very bright stars can be difficult to observe with JWST!

Characterisation of transiting exoplanets with JWST.



Spectroscopy

Multiple choices available (pick the most suited).

Full wavelength coverage will require multiple observations.

Presentation of M. Meyer – SF2A 2015

Characterisation of transiting exoplanets with JWST.

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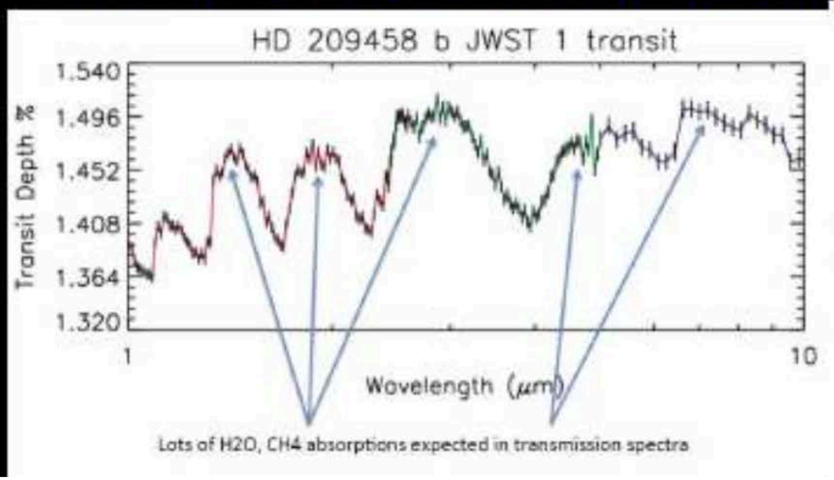
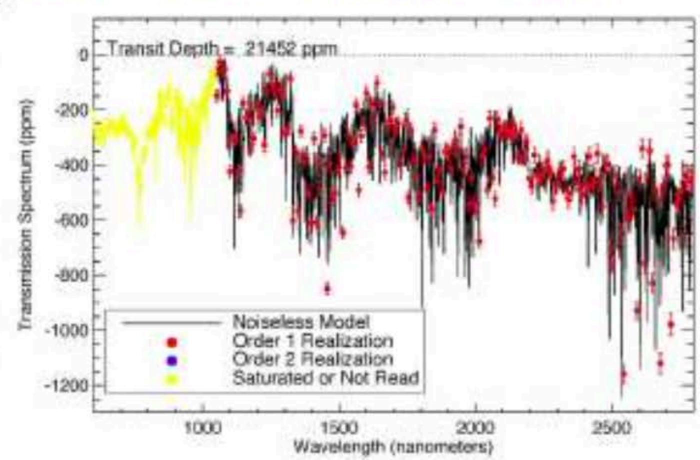
Continuous λ-Coverage with Multiple Transits

- Typical 2-4 hr transit requires 6-12 hours of observing (equal time before/after transit)
- NIRISS 0.6 – 2.5 μm @ R ~ 700
- NIRCam grisms/NIRSpec grating: 2.4 – 5 μm @ R ~ 1000 – 2700
- Fainter stars (J>11) can use NIRSpec prism (1-5 μm; R~30-100)
- MIRI LRS 5 – 12 μm @ R ~ 100
- Approx 25 hr/transit or eclipse for full coverage (4 modes)
- PASP + http://nexsci.caltech.edu/committees/JWST/agenda.shtml



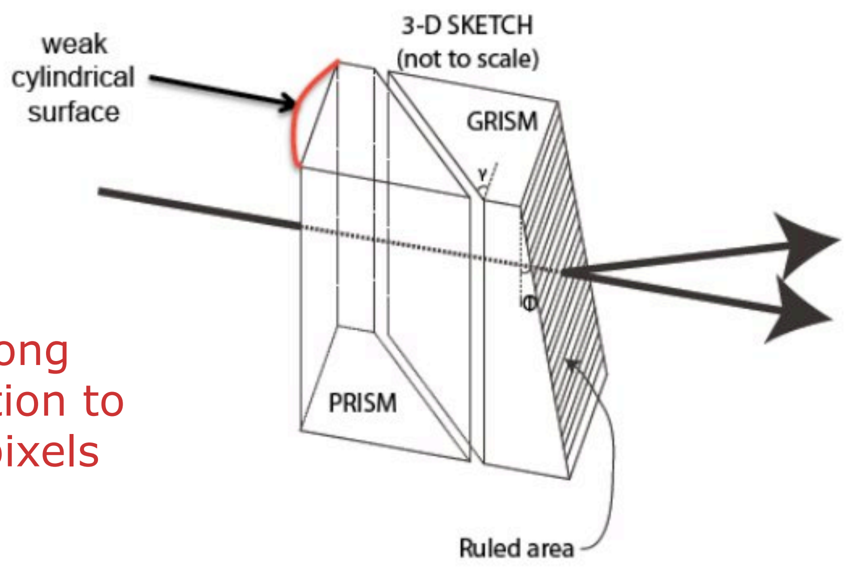


Presentation of C. Beichman– Heidelberg exoplanet conference 2014

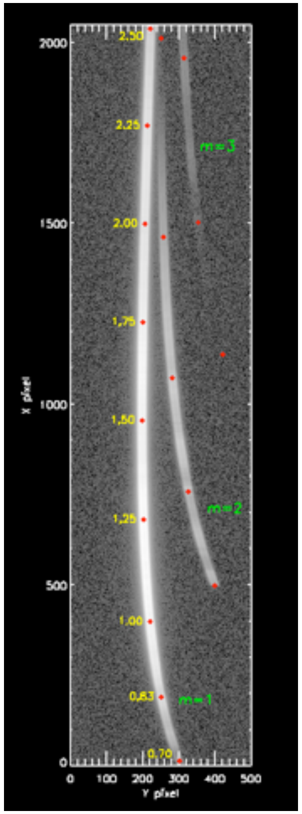
European Space Agency

A mode specially designed for the study of exoplanets: NIRISS "SOSS"

- **NIRISS has implemented a single object mode dedicated to transit spectroscopy and providing a 1-2.5 micron coverage at a resolution of ~430-1350.**
  - Optimized to minimize systematics & to observe bright targets..



Weak lens defocuses along spatial direction to allow more pixels to sample spectrum



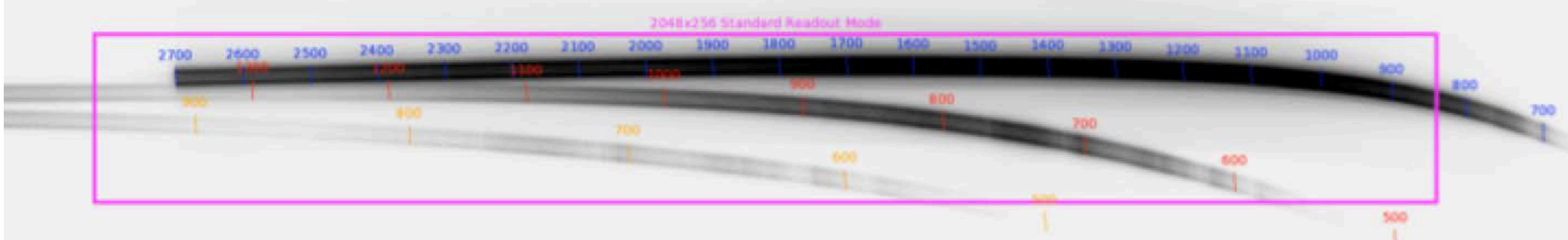
This allows the observation of very bright parent stars and minimizing the impact of pixel-level signatures in the signal.

A mode specially designed for the study of exoplanets: NIRISS "SOSS"

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-), 33% efficiency
- Bright mode
  - Wavelength coverage: 1.05-2.8 μm
  - Subarray: 80x2048 (m=1 only)
  - Saturation limit: J=6.8

NIRISS



Presentation of M. Meyer – SF2A 2015

A mode specially designed for the study of exoplanets: NIRISS "SOSS"

Transit spectroscopy: possibilities

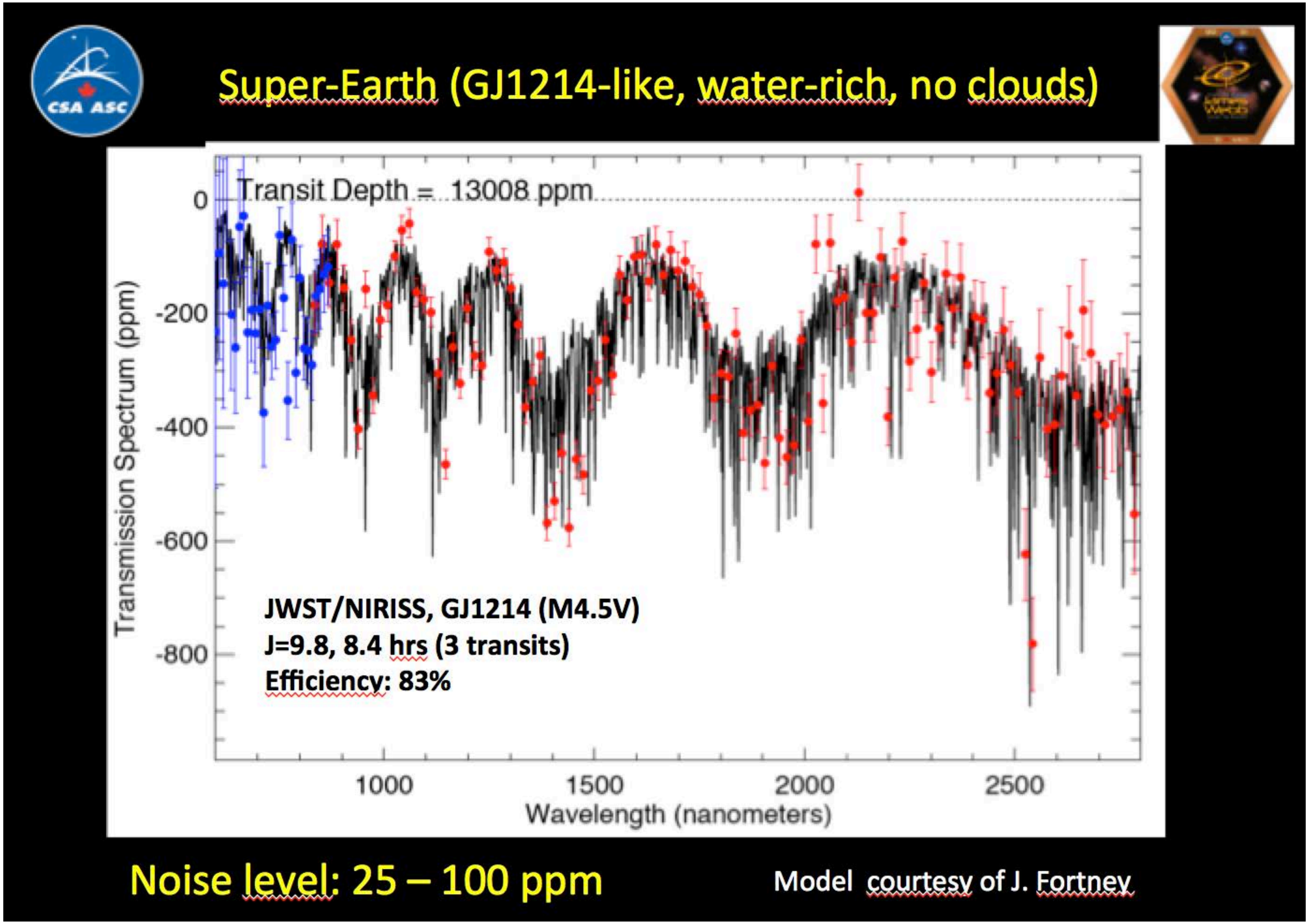
NIRISS

Host	Name	T_p (K)	ρ (g/cm³)	$R_\star$ ($R_\odot$)	Δf/f (ppm) H₂-rich μ=2	Δf/f (ppm) H₂O-rich μ=18	Δf/f (ppm) 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							
M3V	TESS-xxx	600	5.5	0.2	-	95	60
M3V	TESS-xxx	300	5.5	0.2	-	50	30

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

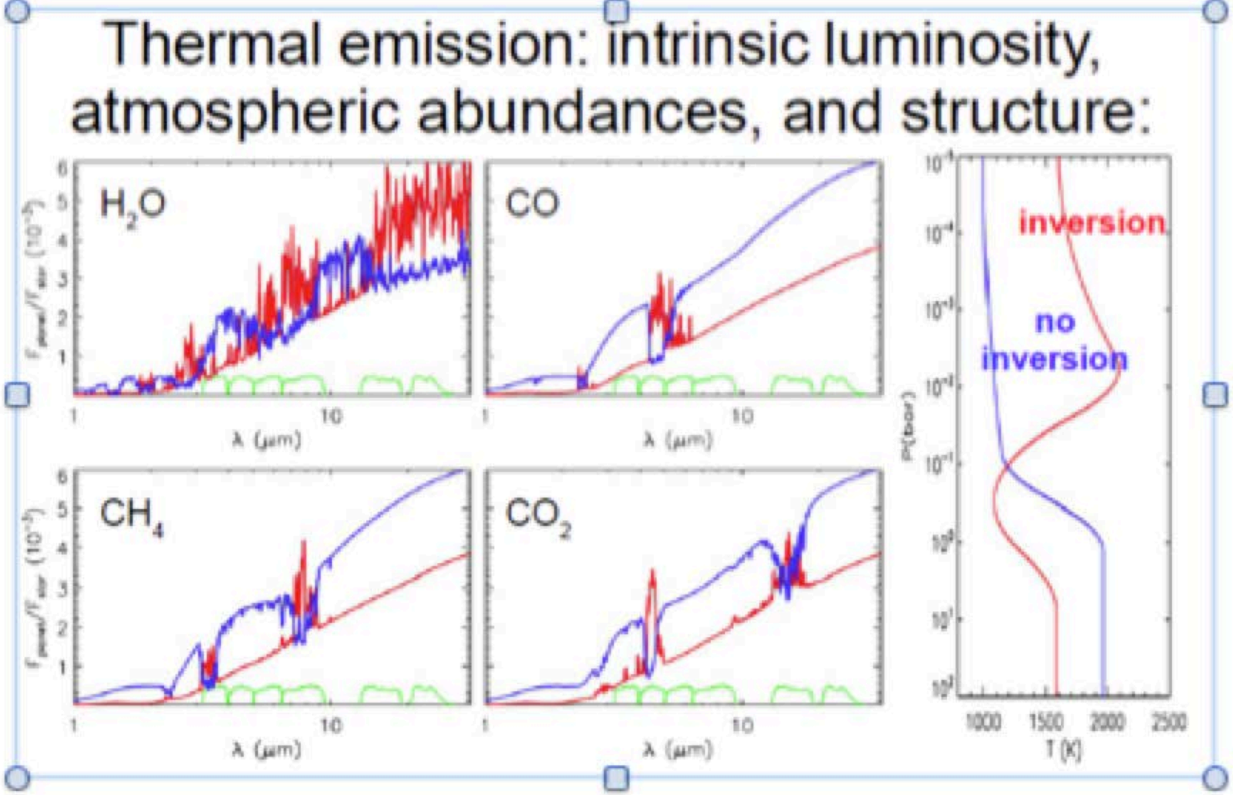
Presentation of M. Meyer – SF2A 2015

A mode specially designed for the study of exoplanets: NIRISS "SOSS"



Presentation of M. Meyer – SF2A 2015

Temperature/pressure profiles in atmospheres.
Origin of high altitude temperature inversions?



MIRI

The mid-IR important → JWST

Presentation of P.-O. Lagage – SF2A 2015

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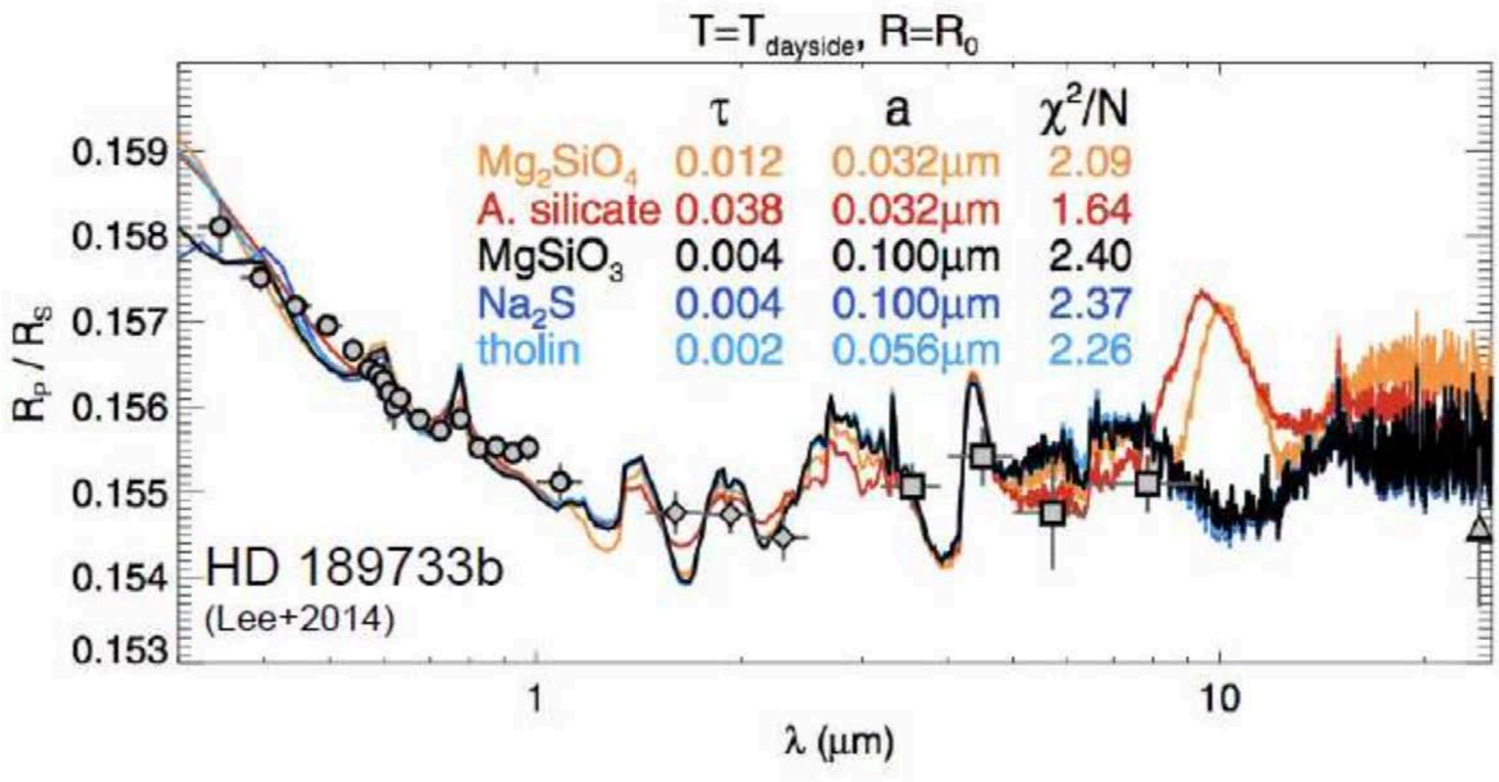
MIRI and the composition of Haze

MIRI European Consortium

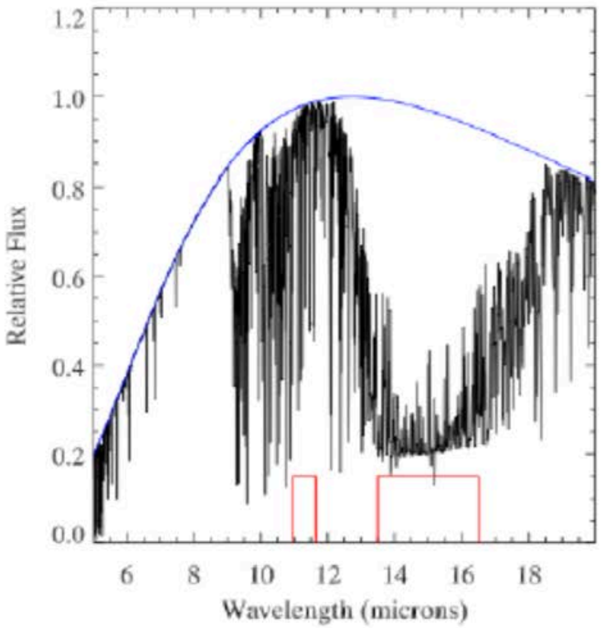


Presentation of P.-O. Lagage – SF2A 2015

MIRI - An amazing window in the mid-infrared.

MIRI detection of CO2 in super-Earth

MIRI European Consortium



Deming et al. (2009) showing Miller-Ricci (2009) Super-Earth Emission spectrum and MIRI filters

- JWST MIRI filters (red boxes, left) may detect deep CO2 absorption in Super-Earth emission observations if hosts are nearby M dwarfs.
- Modeling shows that modest S/N detections possible on super-Earth planets around M stars IF data co-add well (Deming et al. 2009).
- Could detect CO2 feature in ~50 hr for ~300-400K 2 R_e planet around M5 star at 10 pc: IF the data SNR improves with co-additions

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P.-O. Lagage; Star – Planet Interaction, Saclay, November 2014

NIRSpec – a dedicated aperture spectroscopy mode

Dedicated slides in the last part of the presentation.

Characterisation of transiting exoplanets with JWST.

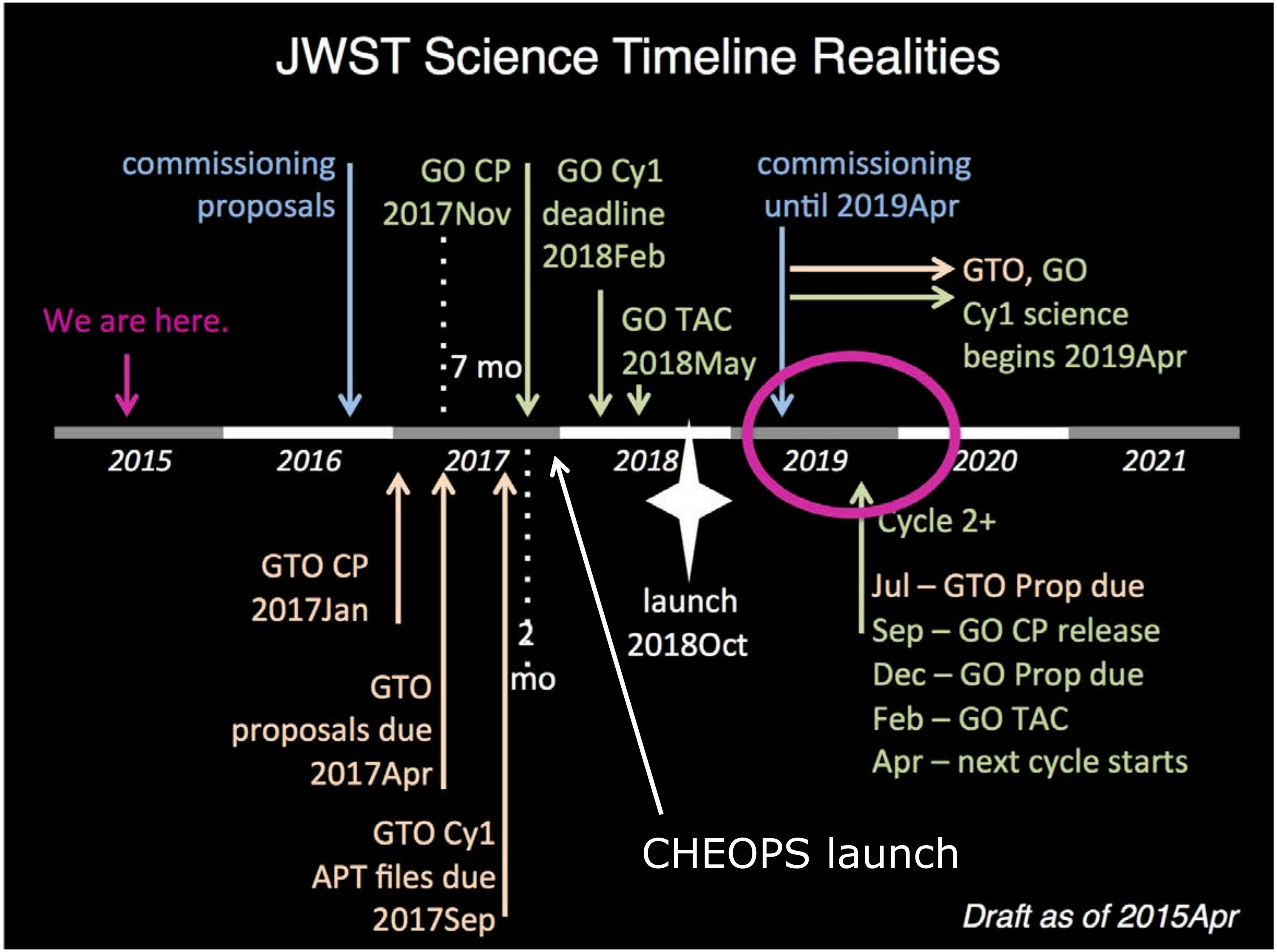
Unique capabilities. JWST will be a major player for the next decade.

Work on-going:

- *Performances of the instruments (sensitivity, saturation limits, understanding and controlling the systematics, improving the stability).*
- *At observatory level, optimising the observation strategy.*

JWST – timeline for the preparation of scientific operation

Presentation J. Lee (STScI) – JWST SWG Apr. 2015



Comparing JWST/CHEOPS timelines

JWST cycle 2 proposals will be due ~2 years after CHEOPS launch.

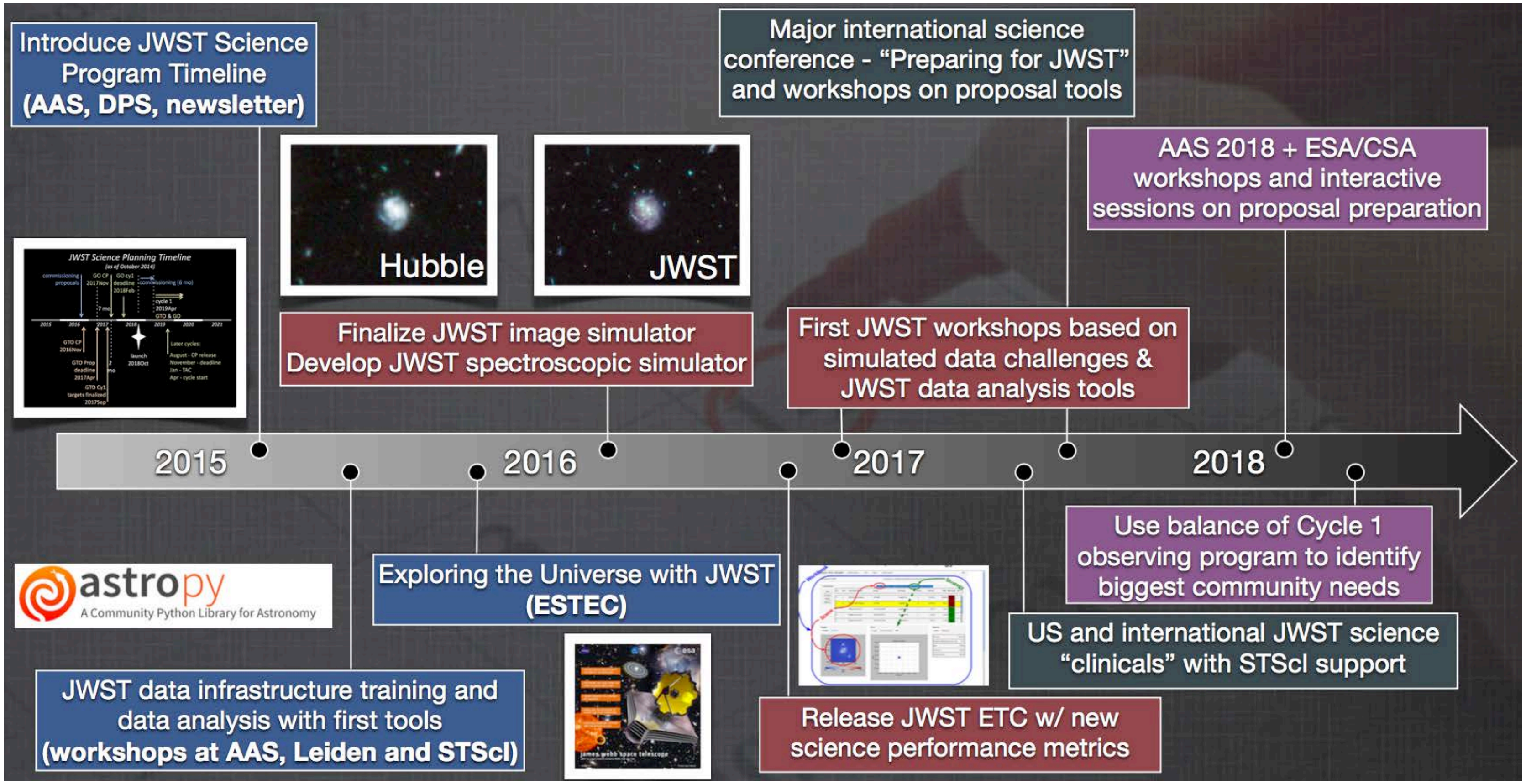
Candidates to be extracted from CHEOPS cycle-1 targets. → selected quite early.

- **The good thing is that work can start upstream during the selection of CHEOPS cycle 1 targets.**
- **The possibility to follow-up with JWST could be part of the criteria used for the selection (up to the CHEOPS science team to decide!).**

→ See also visibility considerations & their impact on the follow-up (later during the presentation).

JWST – timeline for the preparation of scientific operation

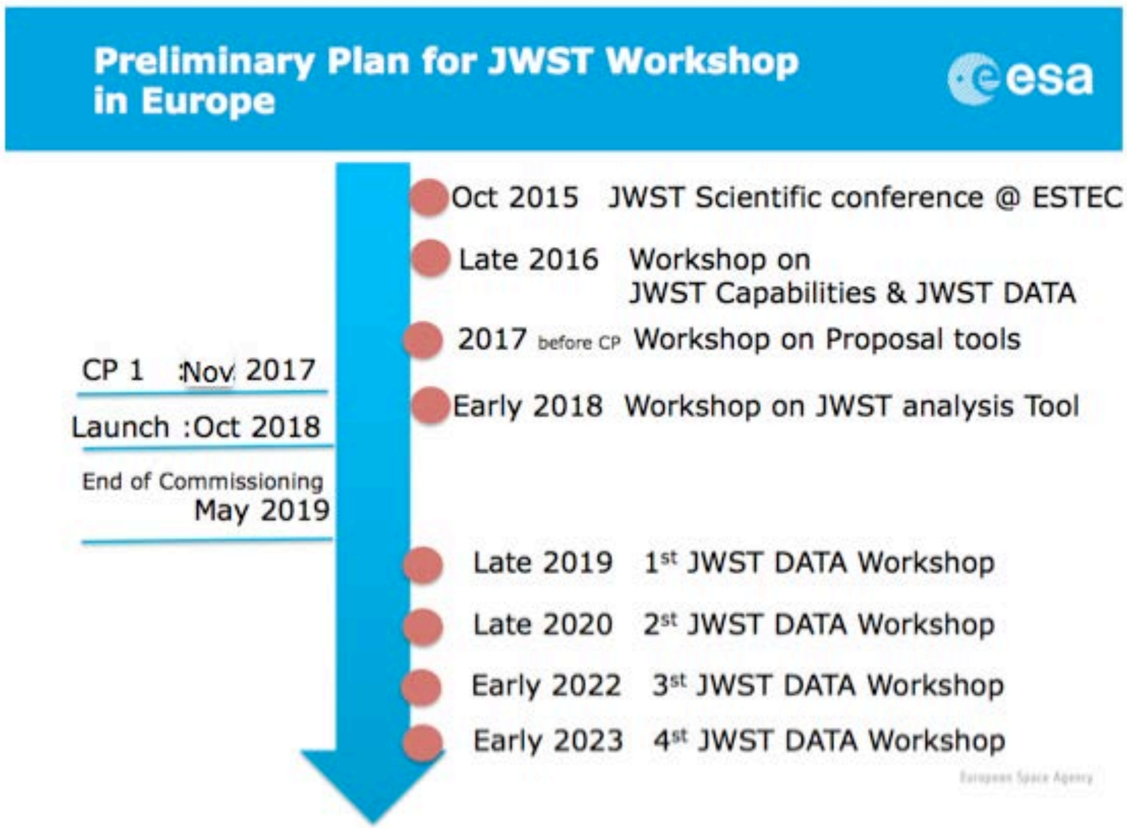
- **STScI is the scientific operation center for JWST (like for HST).**
- **STScI's timeline for the preparation of scientific operation.**



Presentation J. Kalirai
(STScI) – Dec. 2014

JWST – timeline for the preparation of scientific operation

- **There will also be dedicated activities in Europe supported by ESA.**
  - Will be harmonised with those of STScI and initiatives in individual countries.



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JWST – timeline for the preparation of scientific operation

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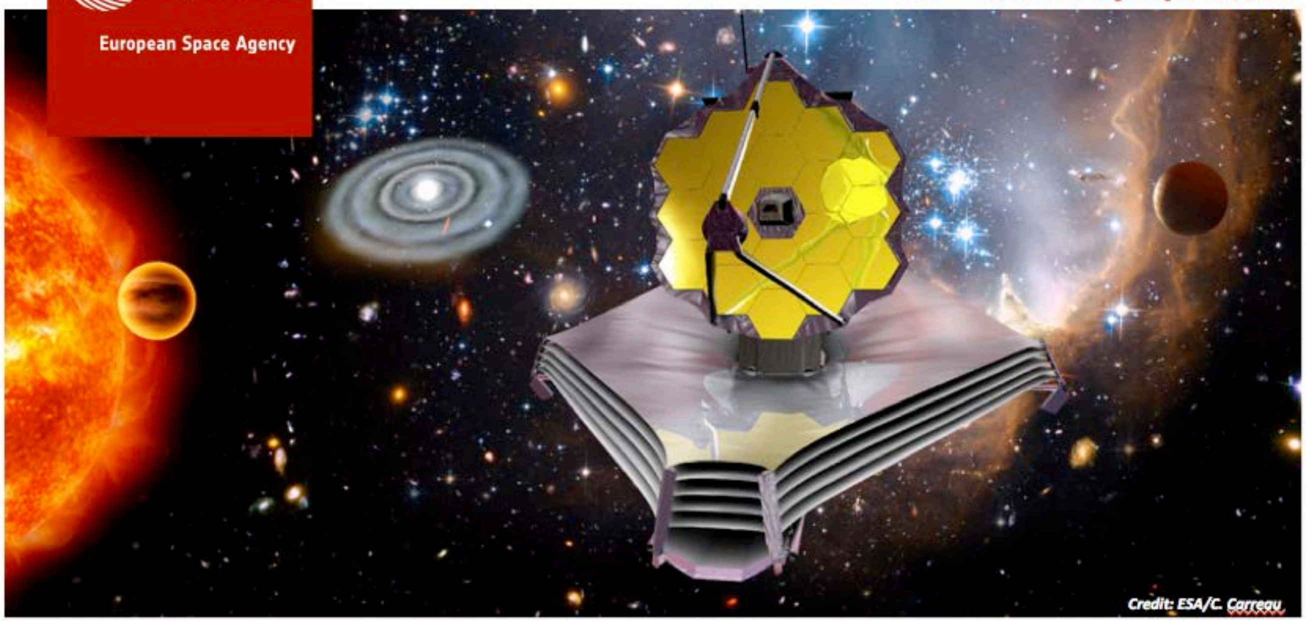
esa
European Space Agency

"Exploring the Universe with JWST"

49th ESLAB symposium



ESA/ESTEC

October 12-16 2015

An international conference dedicated to the presentation and discussion of future scientific research that will be enabled by the James Webb Space Telescope.

REGISTRATION AND ABSTRACT SUBMISSION EXTENDED TILL 22 JUNE 2015

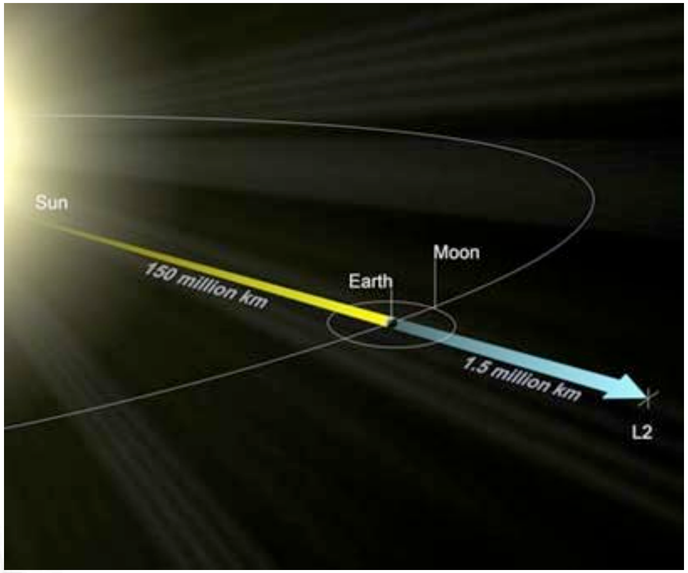
http://congrexprojects.com/15a02

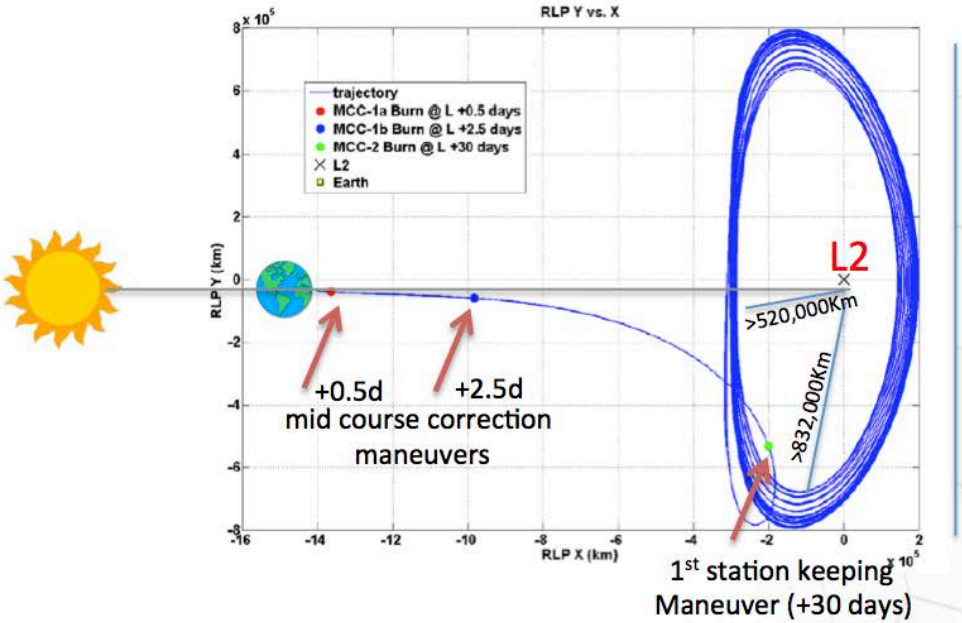
Abstract submission deadline is: 22 June 2015 (next Monday). Hurry up!

European Space Agency

JWST - Orbit and field-of-regard

L2 "halo" orbit. Keeping the Sun, the Earth and the Moon on the same side of the sunshield.



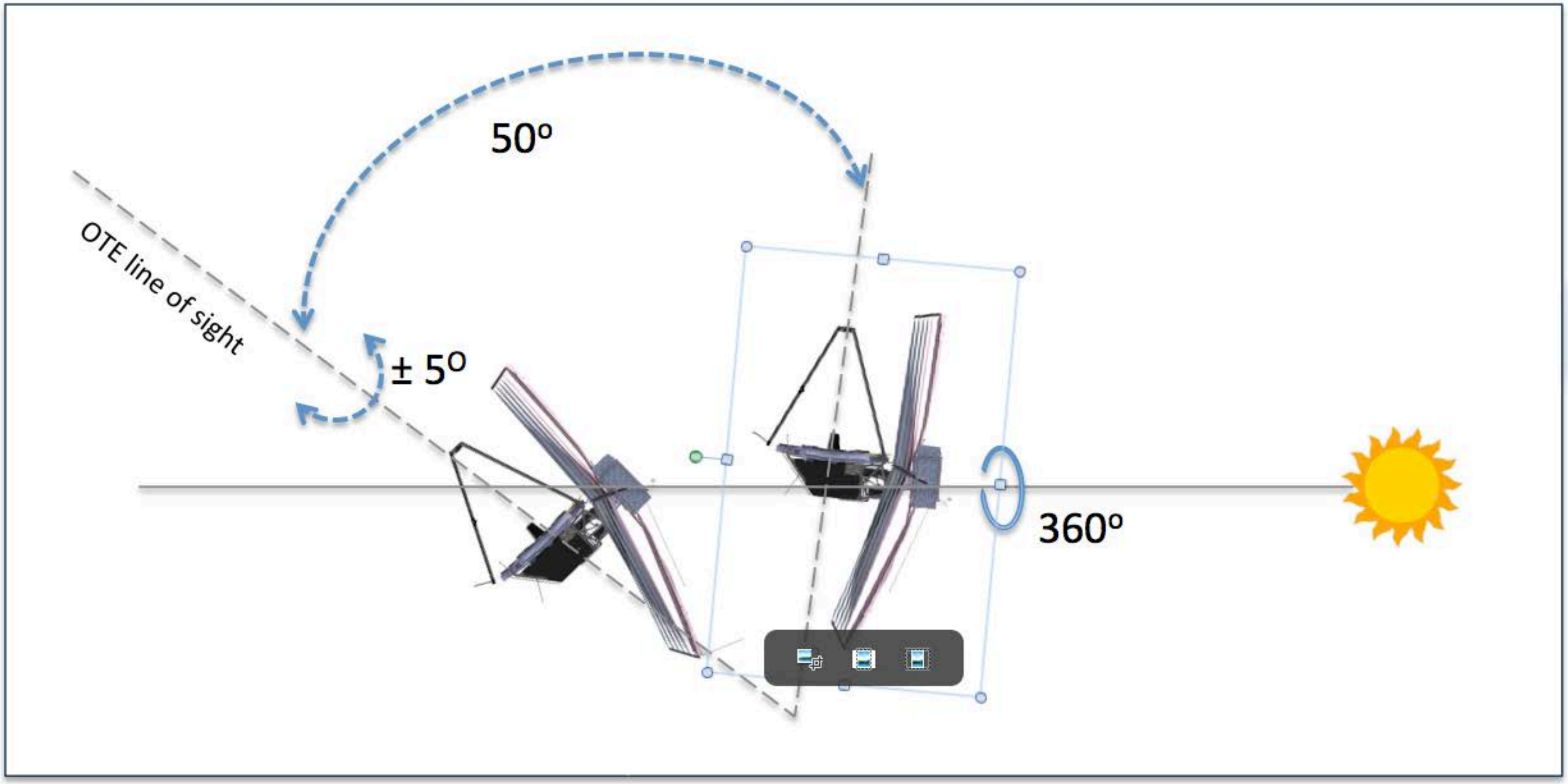


Halo orbit period is ~ 6 months

Final details on the orbit depend on launch window

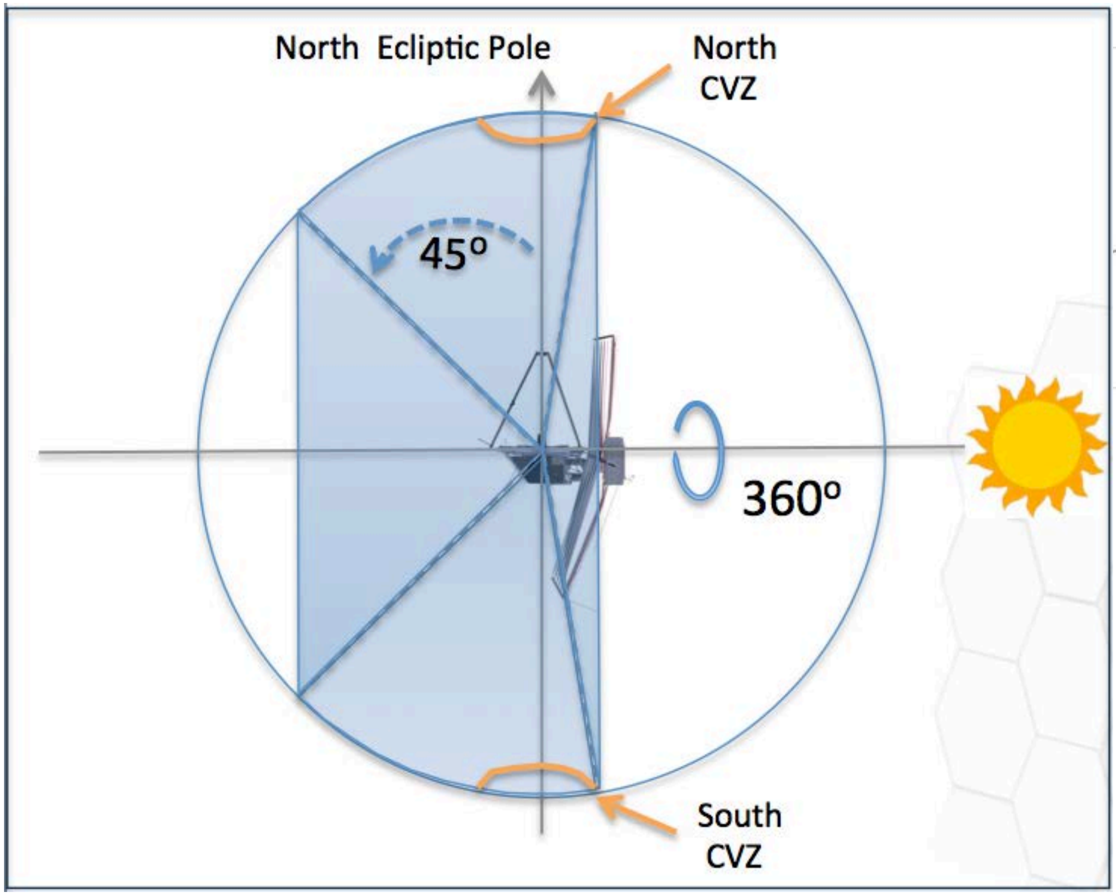
JWST - Orbit and field-of-regard

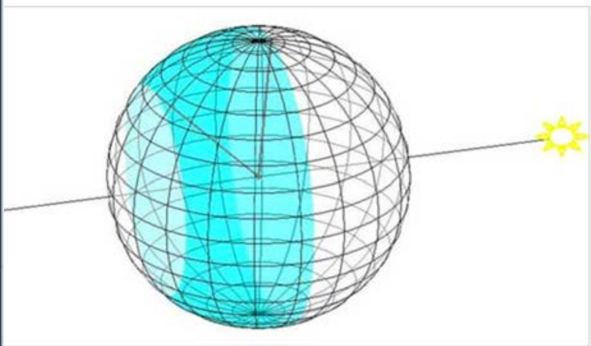
How mobile is the telescope given that it needs to remain constantly in the shade?



The James Webb Space Telescope (JWST)
Orbit and field-of-regard

At any time during the year, JWST will be able to observe an "annulus" corresponding to 35-40% of the sky.

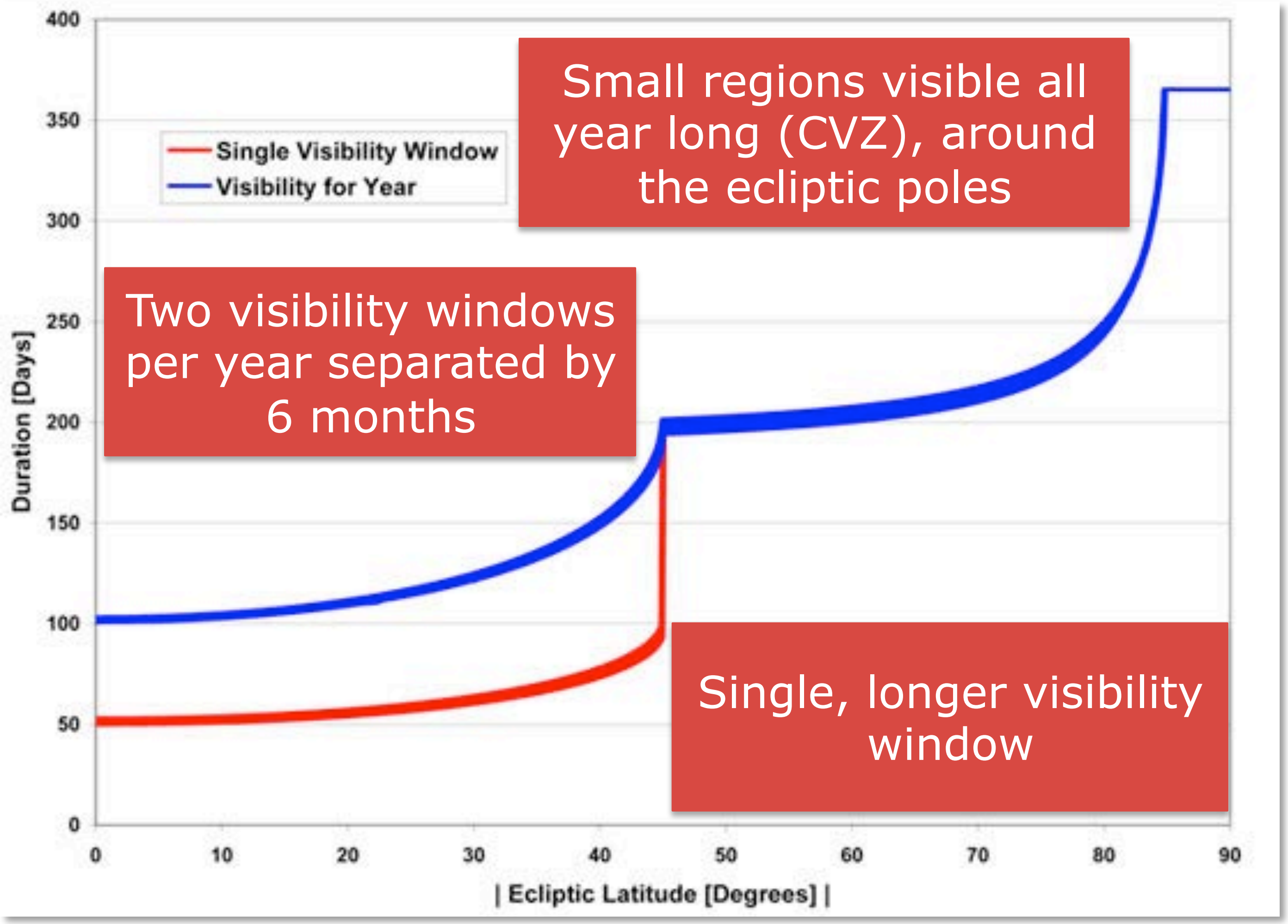




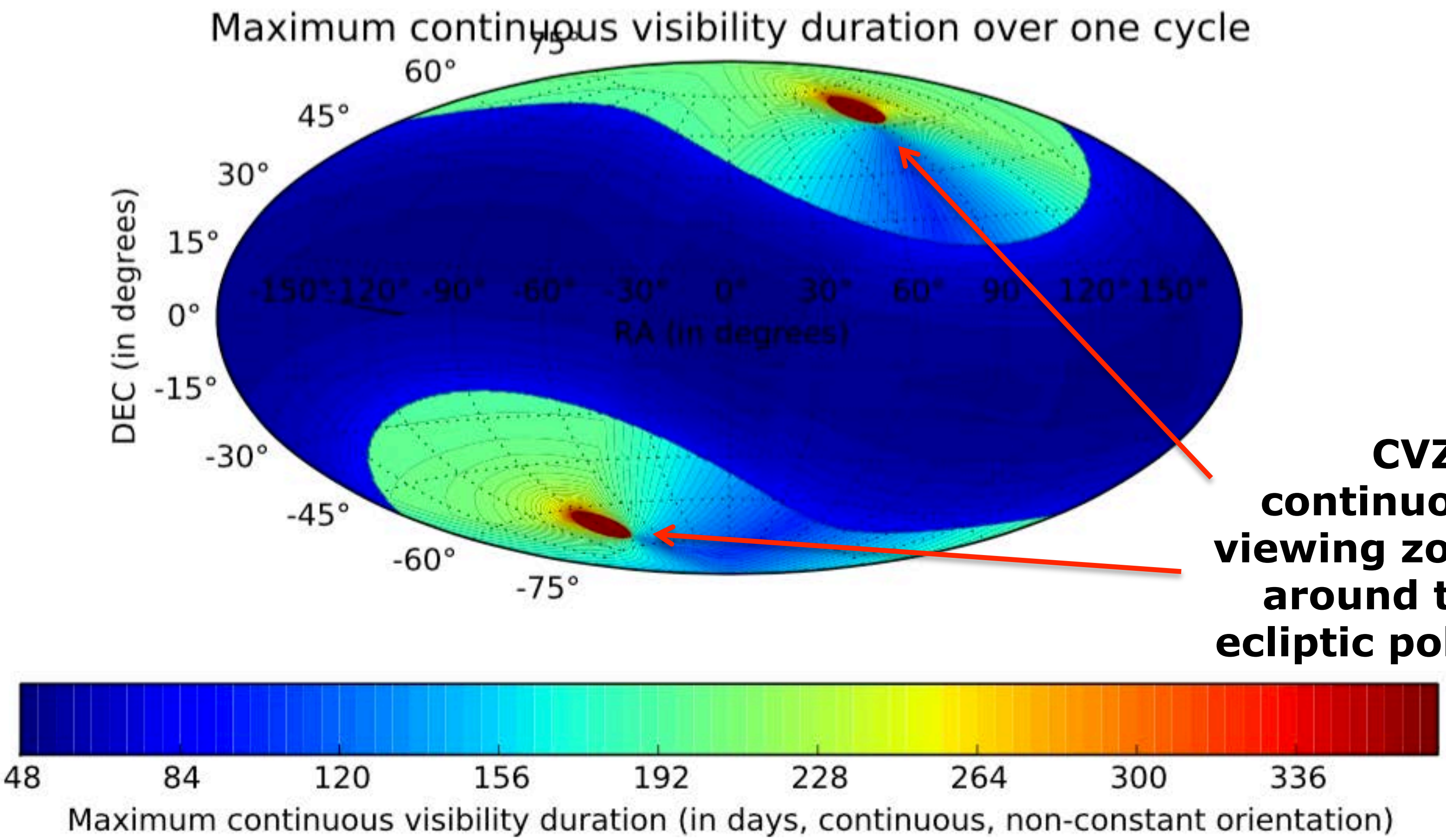
http://www.stsci.edu/jwst/overview/design/field-of-regard

The James Webb Space Telescope (JWST)
Orbit and field-of-regard

Periods of visibility / orientation of the field of view

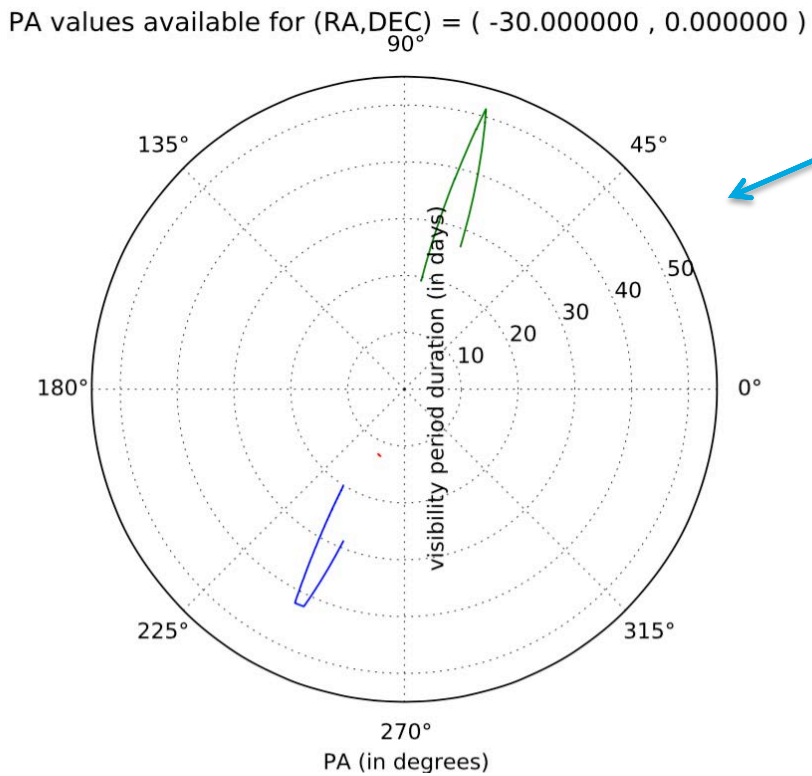


Visibilities and orientation during a 1-year cycle

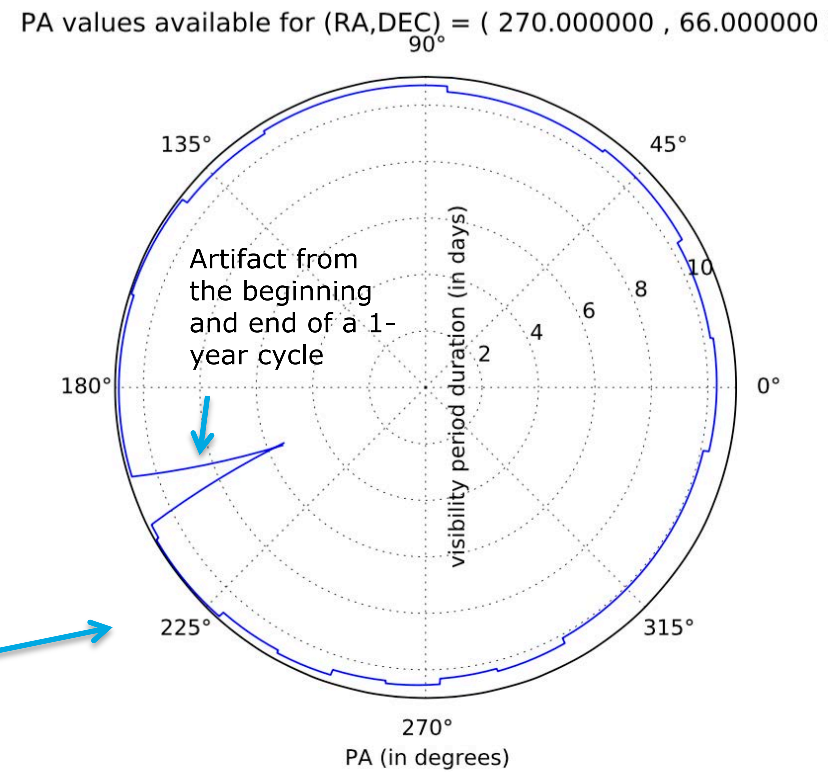


CVZ = continuous viewing zone around the ecliptic poles

Visibilities and orientation during a 1-year cycle



Along the ecliptic: restricted range of orientations, 2 windows per year, long time with the same orientation (~50 days).



CVZ: visible all year long, all orientations possible along the year, short time with the same orientation (~10 days).

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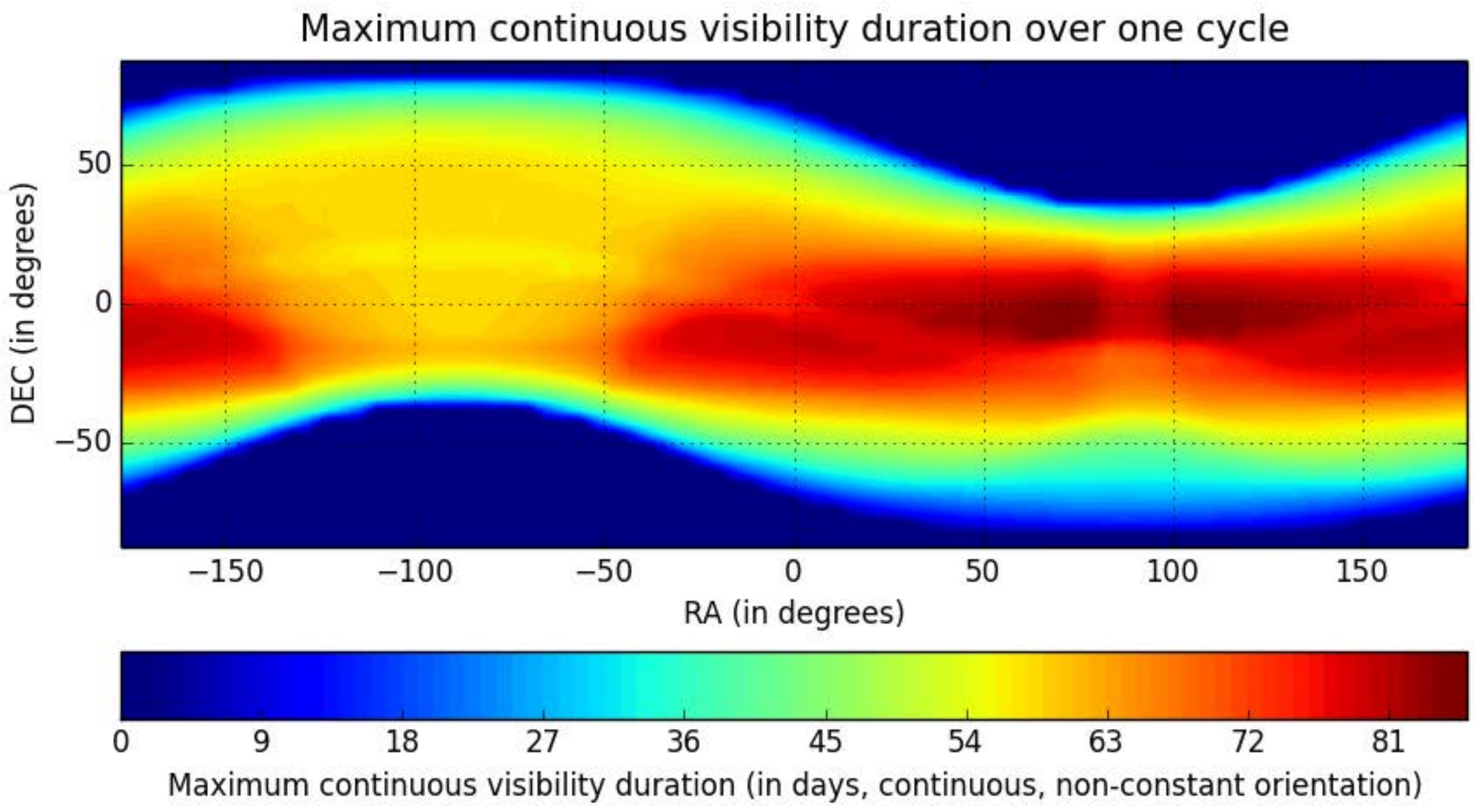
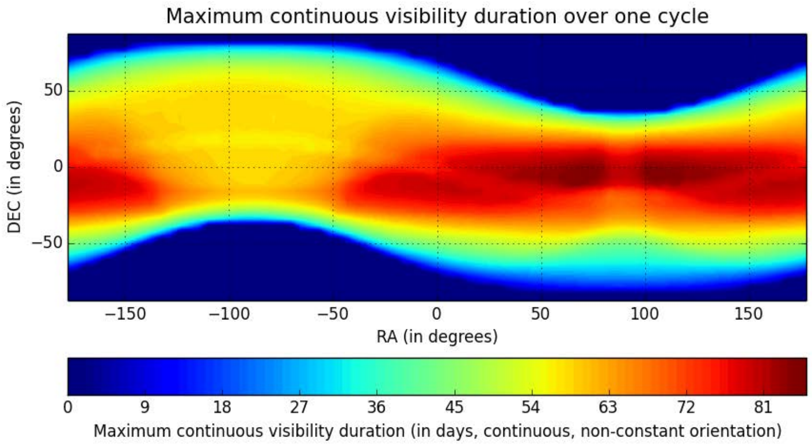
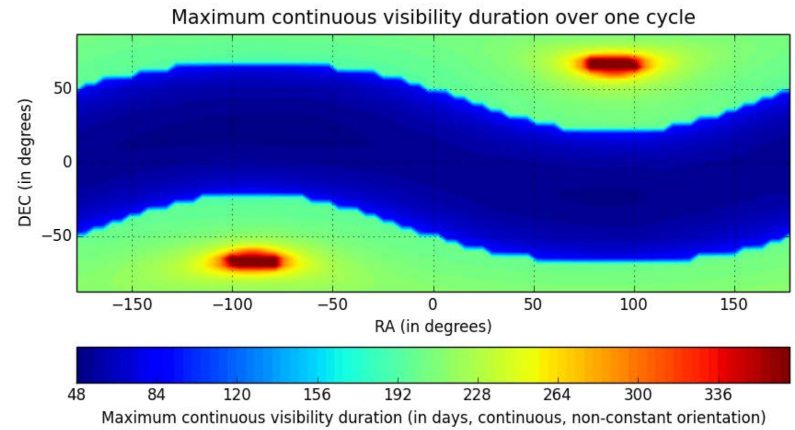
CHEOPS visibility regions
V=9 case (tolerant to interruptions)



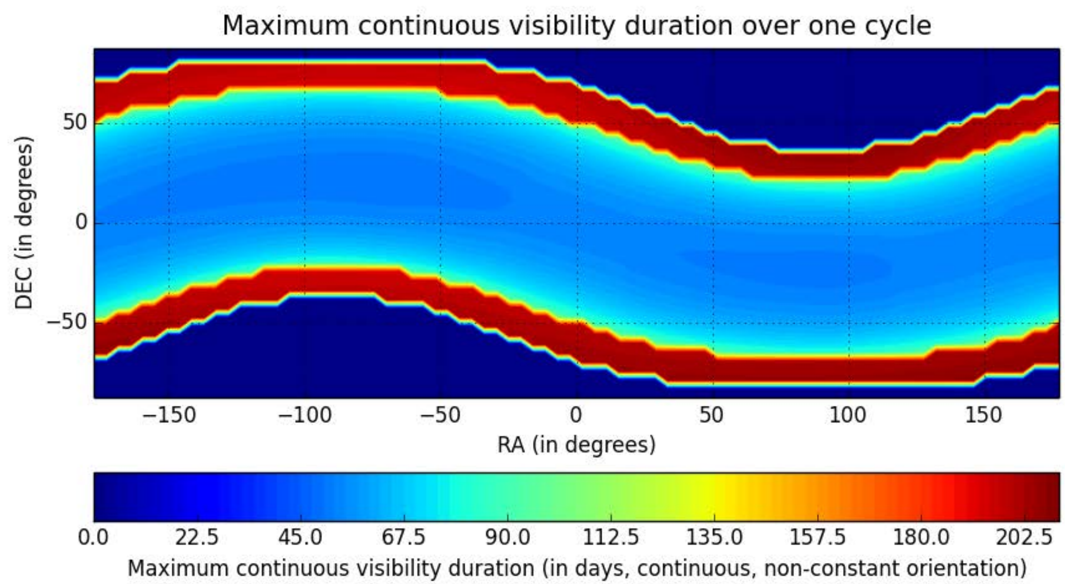
Rotated with respect to the maps presented during the workshop (there could be a parity issue but this would not change the results as the JWST visibility maps are very symmetric).

CHEOPS visibility regions
V=9 case (tolerant to interruptions)



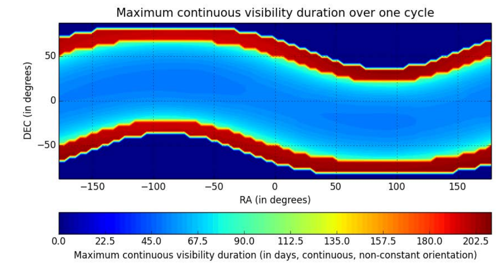


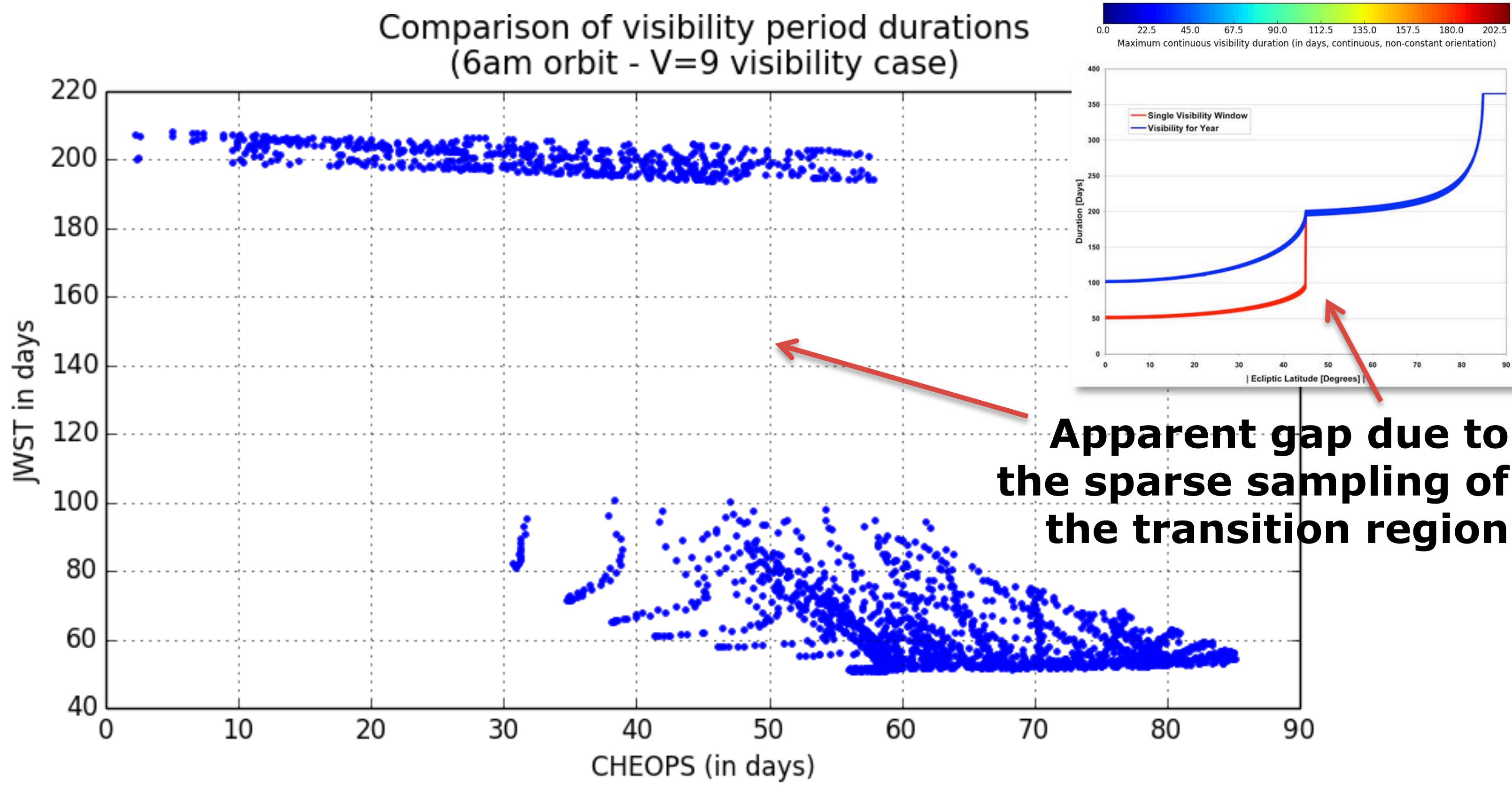
Clipped version of the JWST visibility map (areas not reachable with CHEOPS have been set to 0 days.



CHEOPS visibility regions
V=9 case (tolerant to interruptions)

Bulk of the JWST visibility windows in the 50-60 days range (2 times per year)





Apparent gap due to the sparse sampling of the transition region

"Tracks" in this plot reflect the fairly sparse & regular sampling in RA,DEC

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CHEOPS visibility regions
V=12 case (interruptions not welcomed)

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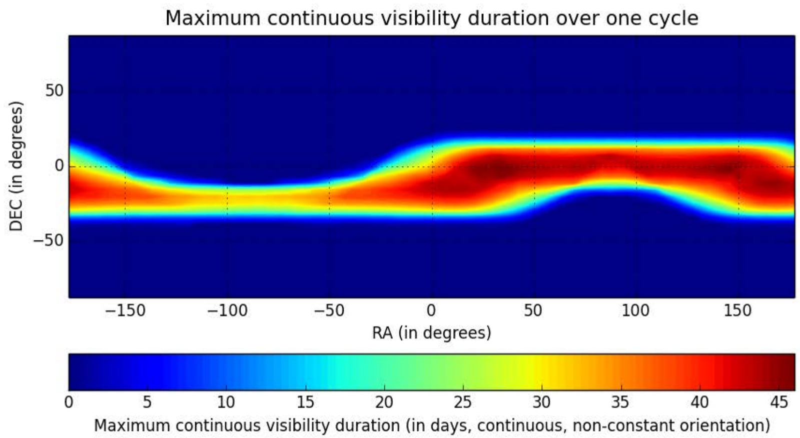
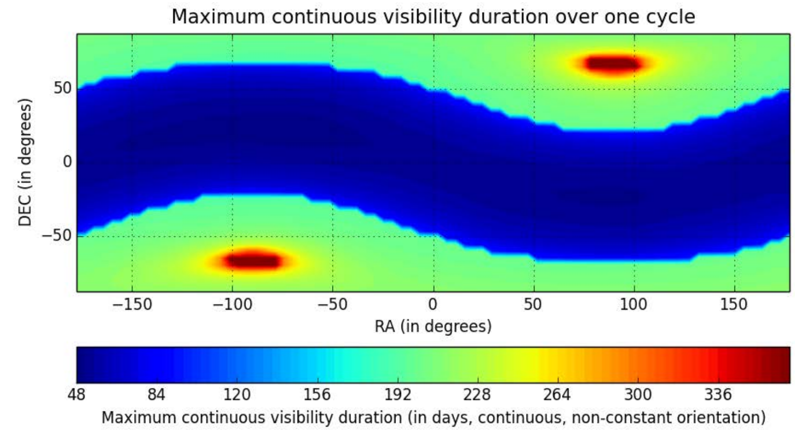
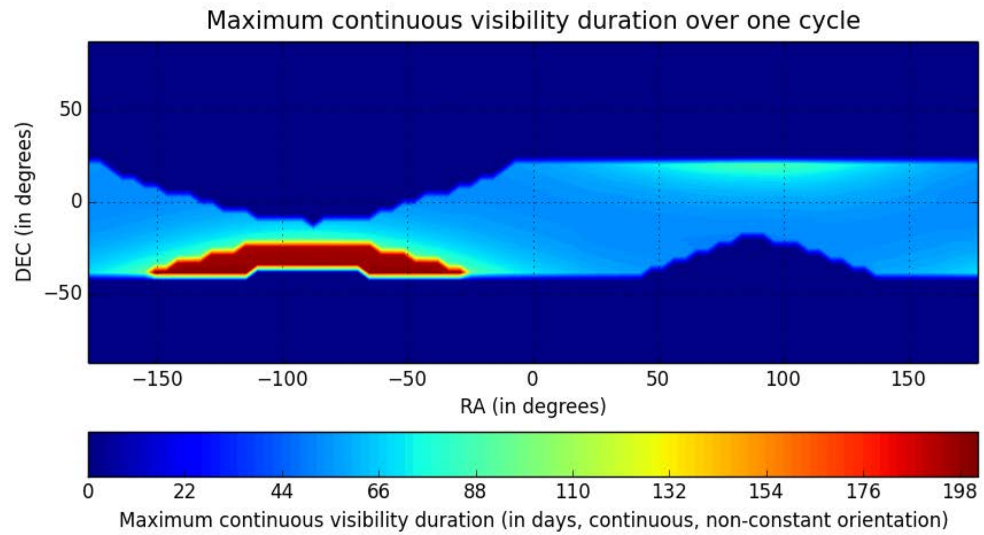




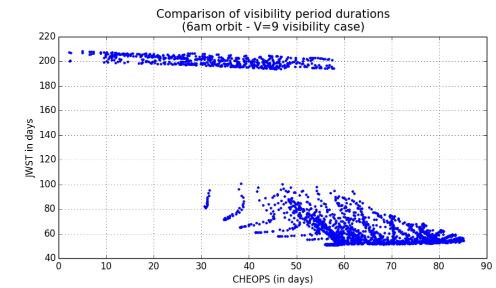
Clipped version of the JWST visibility map (areas not reachable with CHEOPS have been set to 0 days.

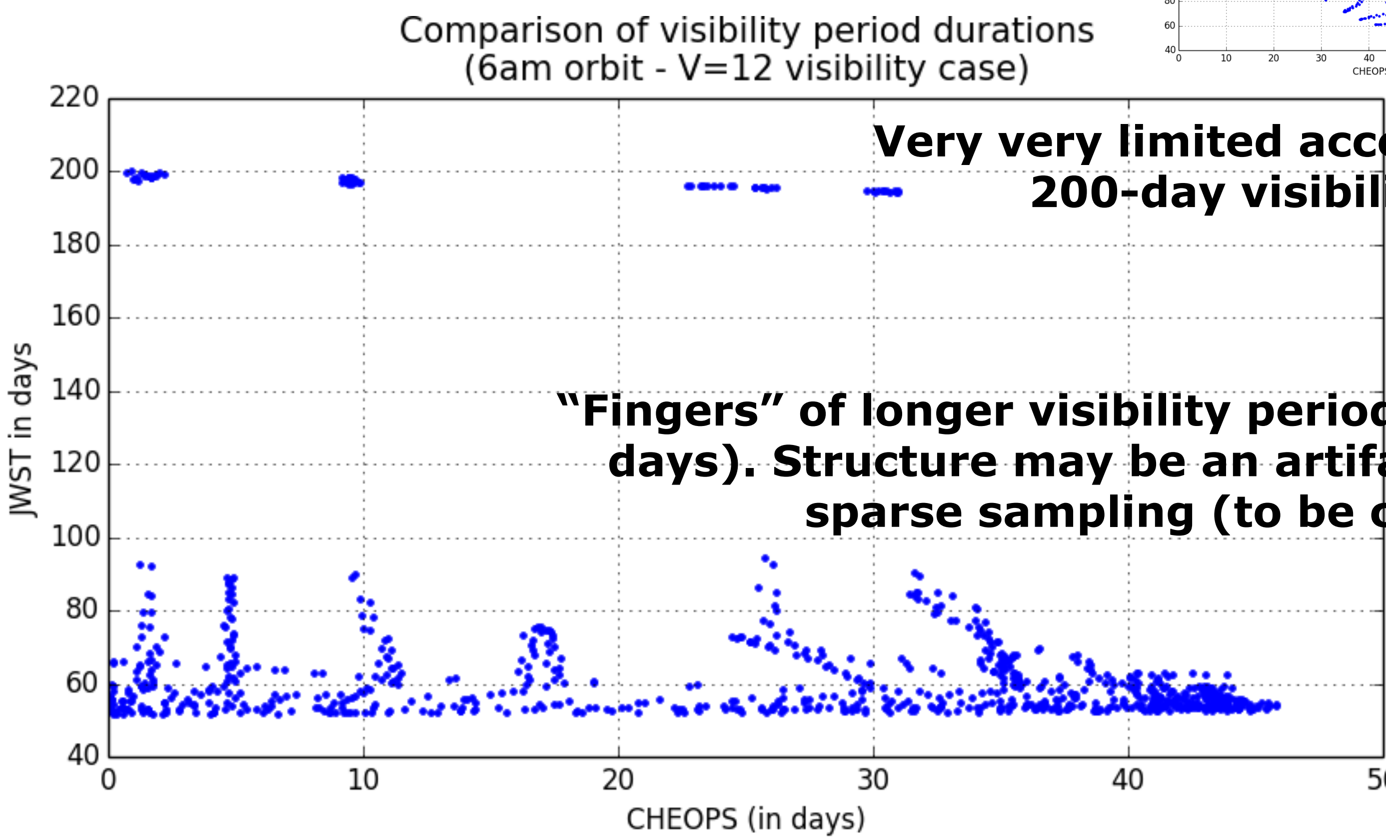


European Space Agency

CHEOPS visibility regions
V=12 case (interruptions not welcomed)

Bulk of the JWST visibility windows in the 50-60 days range (2 times per year).





Very very limited access to the 200-day visibility range.

"Fingers" of longer visibility periods (60-90 days). Structure may be an artifact of the sparse sampling (to be checked).

"Tracks" in this plot reflect the fairly sparse & regular sampling in RA,DEC

Combining JWST/CHEOPS visibility maps

More work needed but combining the maps brings in some restrictions that can significantly impact the planning of the follow-up observations (see later in this presentation).

Following up CHEOPS targets with JWST/ NIRSpec

- **While optimized for faint target multi-object spectroscopy, NIRSpec features a dedicated large aperture (1.6" x 1.6") for exoplanet transit spectroscopy.**
    - In a more general way, exoplanet atmosphere characterisation.
- **Ironically, one of the main worry for this mode was the saturation limit!**

Reference: Ferruit et al., 2014, SPIE, 91143

REMINDER: the other near-infrared instruments also have modes dedicated to exoplanet transit spectroscopy. ➔ pick the one best suited for your needs.

Following up CHEOPS targets with JWST/ NIRSpec

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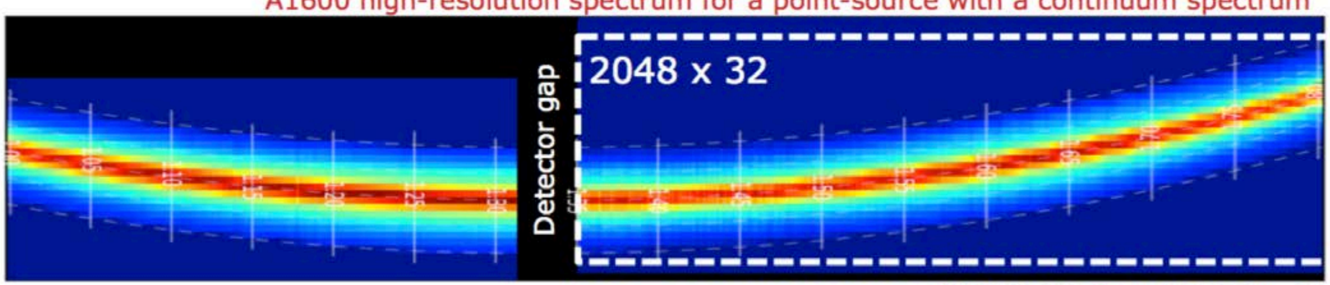
James Webb Space Telescope

NIRSpec: a MOS/IFU spectrograph with a twist

- In order to accommodate the needs of transit spectroscopy, one of the 5 slits of NIRSpec has been turned into an aperture of 1.6” x 1.6” (labeled A1600)
  - Can be used with all spectroscopic configurations
  - Large enough to get rid of systematics related to (changing) aperture losses
  - Not wide enough to use the “spatial-scanning” strategy recently used for HST spectroscopic observations.

A1600 high-resolution spectrum for a point-source with a continuum spectrum

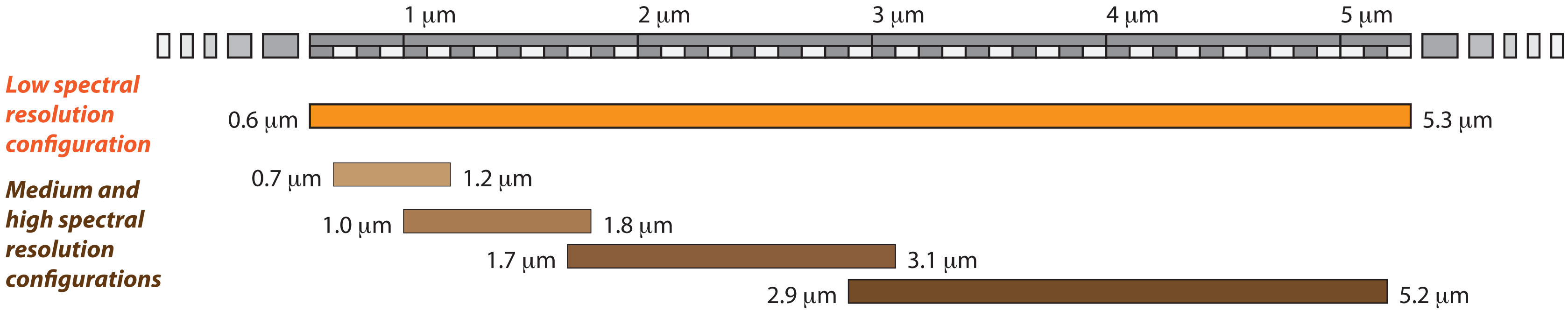


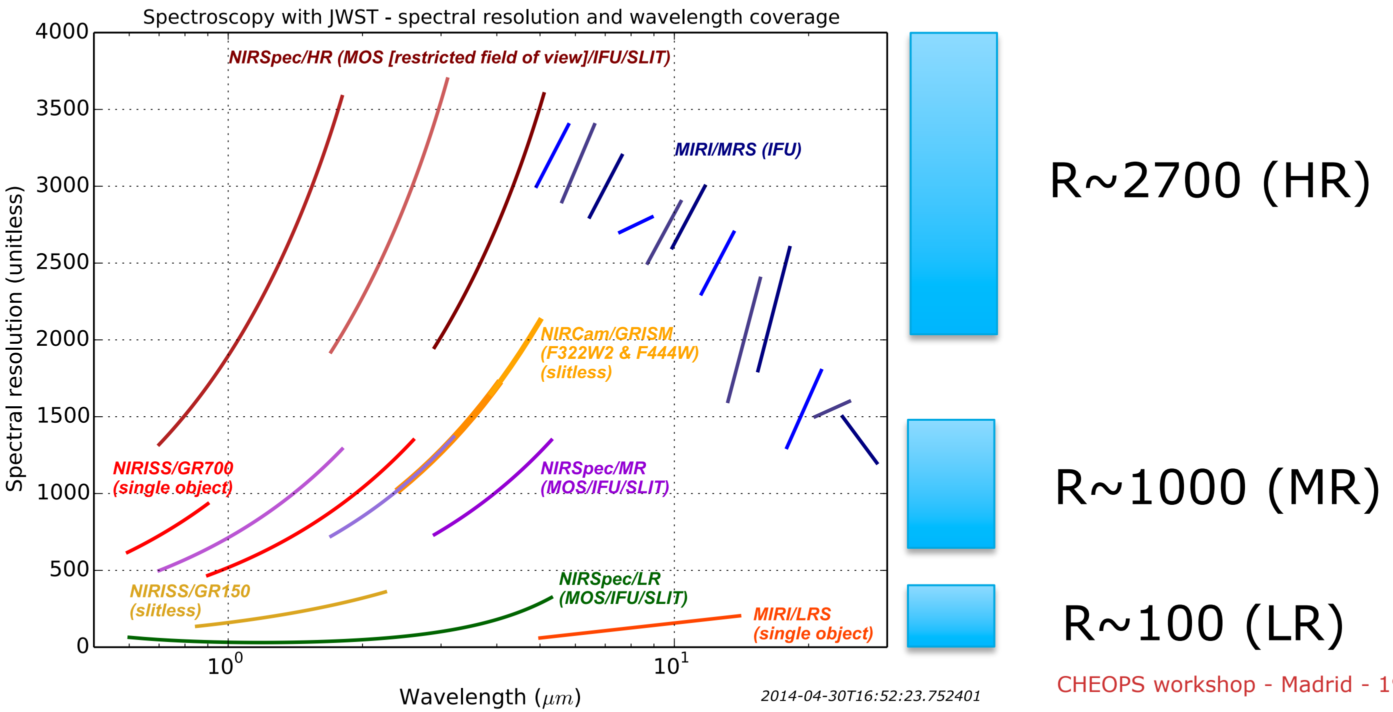
SPIE AT&I 2014, Montreal, 22-27 June 2014

European Space Agency

Following up CHEOPS targets with JWST/ NIRSpec

JWST/NIRSpec - spectral configurations





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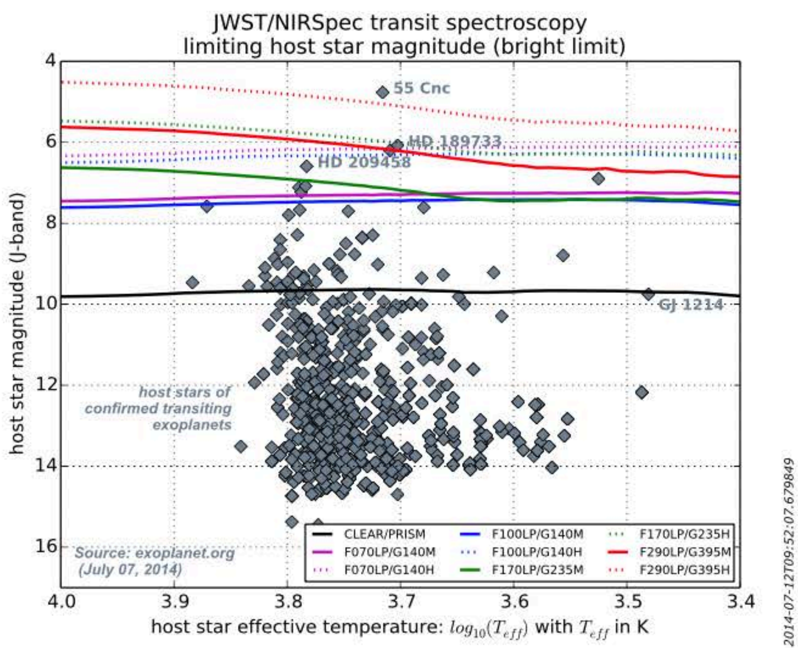
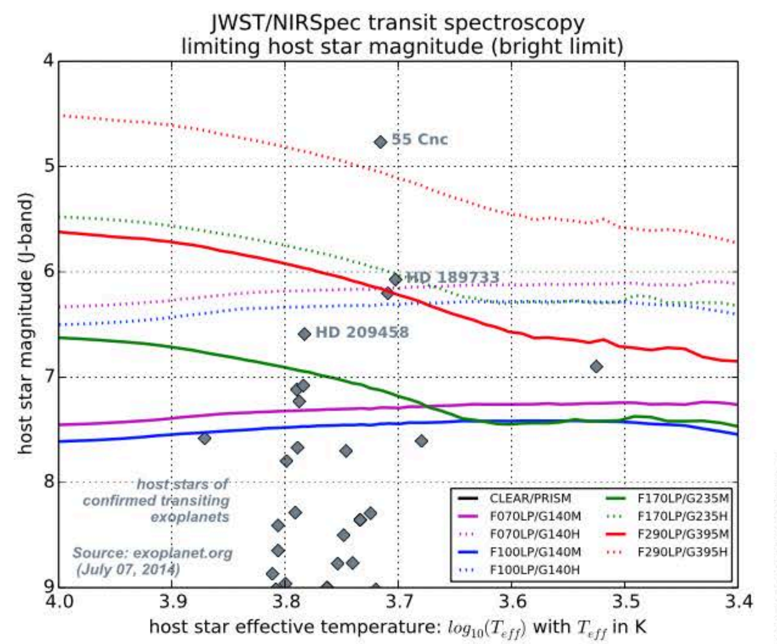
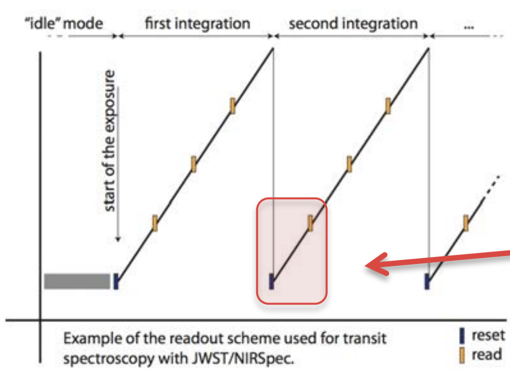
Following up CHEOPS targets with JWST/ NIRSpec

Most up-to-date information for NIRSpec: Ferruit et al. 2014, SPIE, 9143





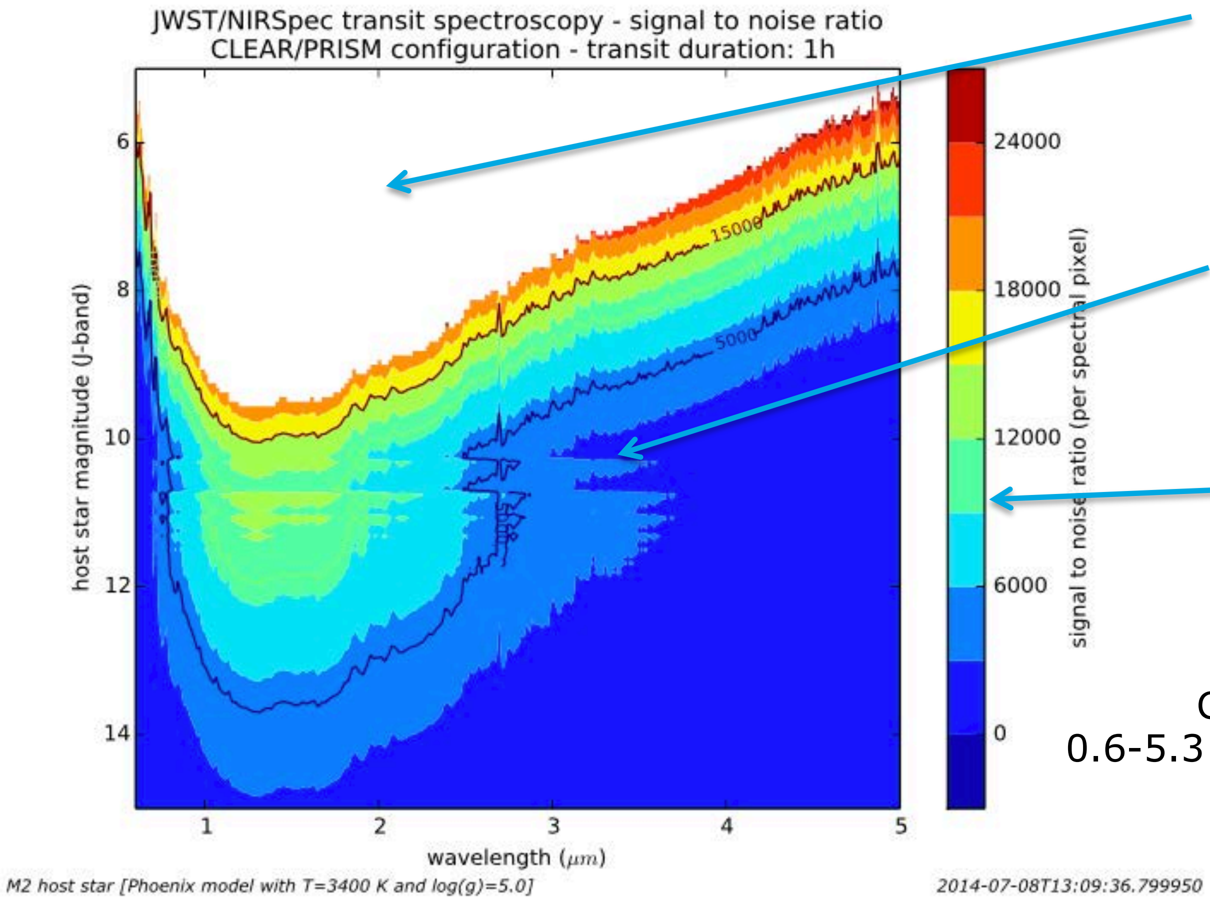


Typical uncertainties of 20-30% (i.e. up to ½ mag).

Allowing the use of the reset-read as the shortest possible exposure when computing the saturation limits.

Following up CHEOPS targets with JWST/ NIRSpec

Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.



saturated

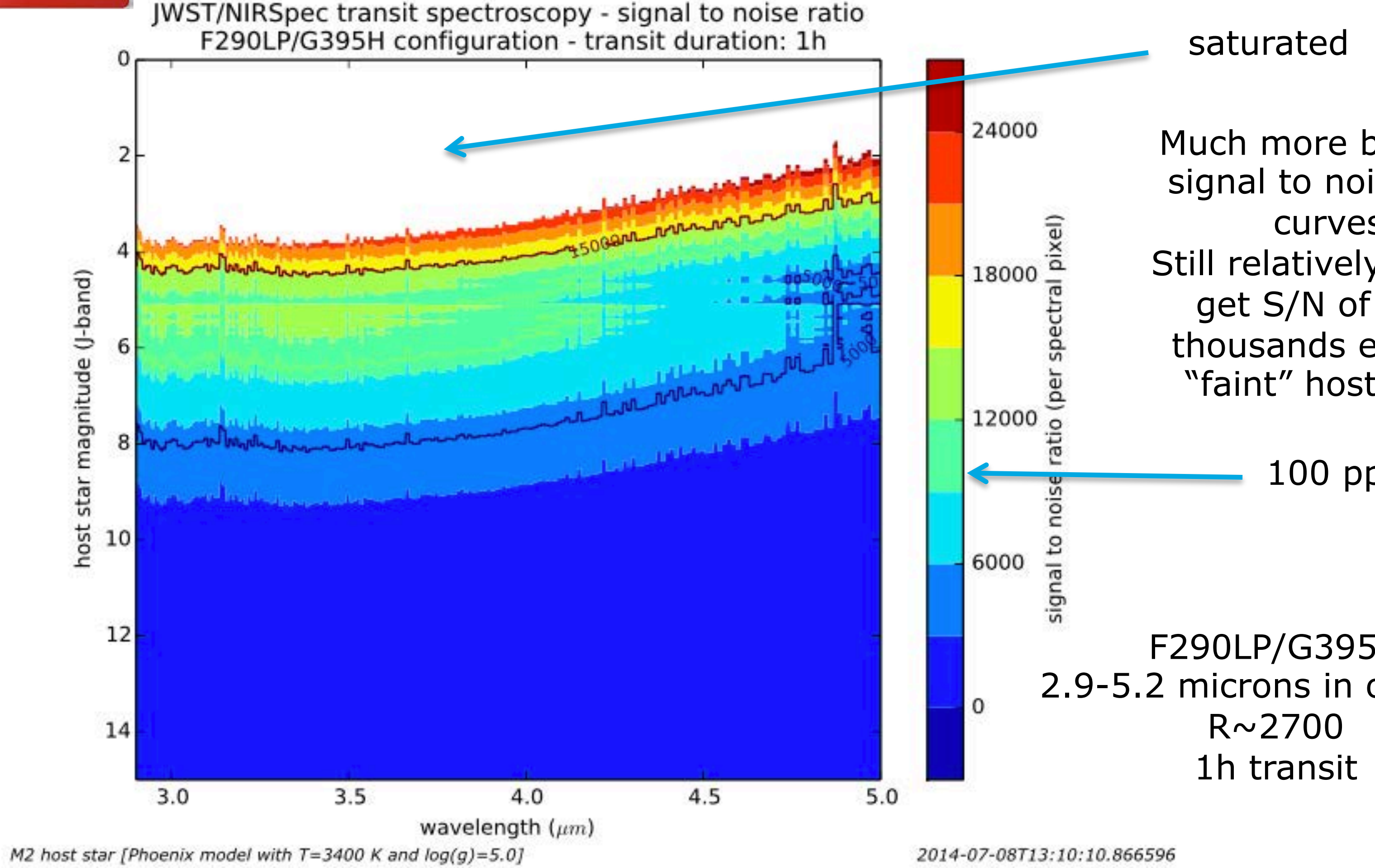
discontinuities that appear when the host start becomes faint enough to get an additional readout per integration

100 ppm

CLEAR/PRISM
0.6-5.3 microns in one shot
R~30-300

Following up CHEOPS targets with JWST/ NIRSpec

Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.



Much more balanced signal to noise ratio curves.
Still relatively easy to get S/N of a few thousands even for "faint" host stars.

F290LP/G395H
2.9-5.2 microns in one shot
R~2700
1h transit

Following up CHEOPS targets with JWST/ NIRSpec

Huge parameter space, using CHEOPS sizing cases as a benchmark / to set up the scene.

Work with K. Isaak & Antonio Garcia Muñoz

CHEOPS sizing cases

- SciReqs based around two sizing targets:

SciReq 1.1 **Photometric precision for transit detection (L1)**
CHEOPS shall be able to detect Earth-size planets transiting G5 dwarf stars (stellar radius of 0.9 $R_{\odot}$) with V-band magnitudes in the range $6 \leq V \leq 9$ mag. Since the depth of such transits is 100 parts-per-million (ppm), this requires achieving a photometric precision of 20 ppm (goal: 10 ppm) in 6 hours of integration time. This time corresponds to the transit duration of a planet with a revolution period of 50 days.

Earth / super-Earth size

SciReq 1.2 **Photometric precision for transit characterization (L1)**
CHEOPS shall be able to detect Neptune-size planets transiting K-type dwarf stars (stellar radius of 0.7 $R_{\odot}$) with V-band magnitudes as faint as V=12 mag (goal: V=13 mag) with a signal-to-noise ratio of 30. Such transits have depths of 2500 ppm and last for nearly 3 hours, for planets with a revolution period of 13 days. Hence, a photometric precision of 85 ppm is to be obtained in 3 hours of integration time. This time corresponds to the transit duration of a planet with a revolution period of 13 days.

Neptune size

Following up CHEOPS targets with JWST/ NIRSpec

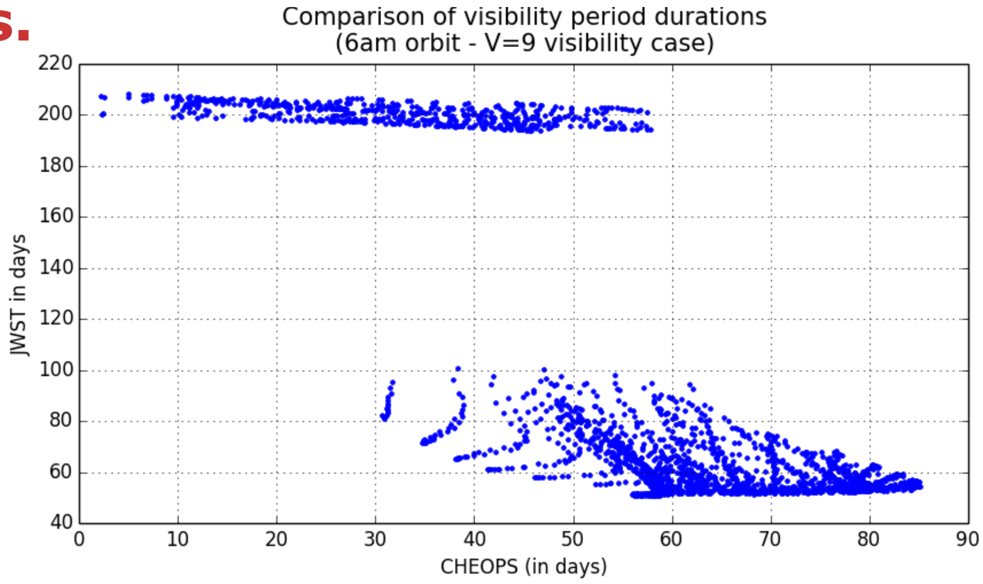
Case #1: super-Earth size planet with a transit time of 6 hours, a period of 50 days and orbiting a bright G star of V < 9.

- **Assuming that the observations are done during one JWST cycle.**
- **Most of the time, 2 windows of 50-60 days.**

➔ 2 transits of 6 hours. (not a lot)

100

40



Following up CHEOPS targets with JWST/ NIRSpec

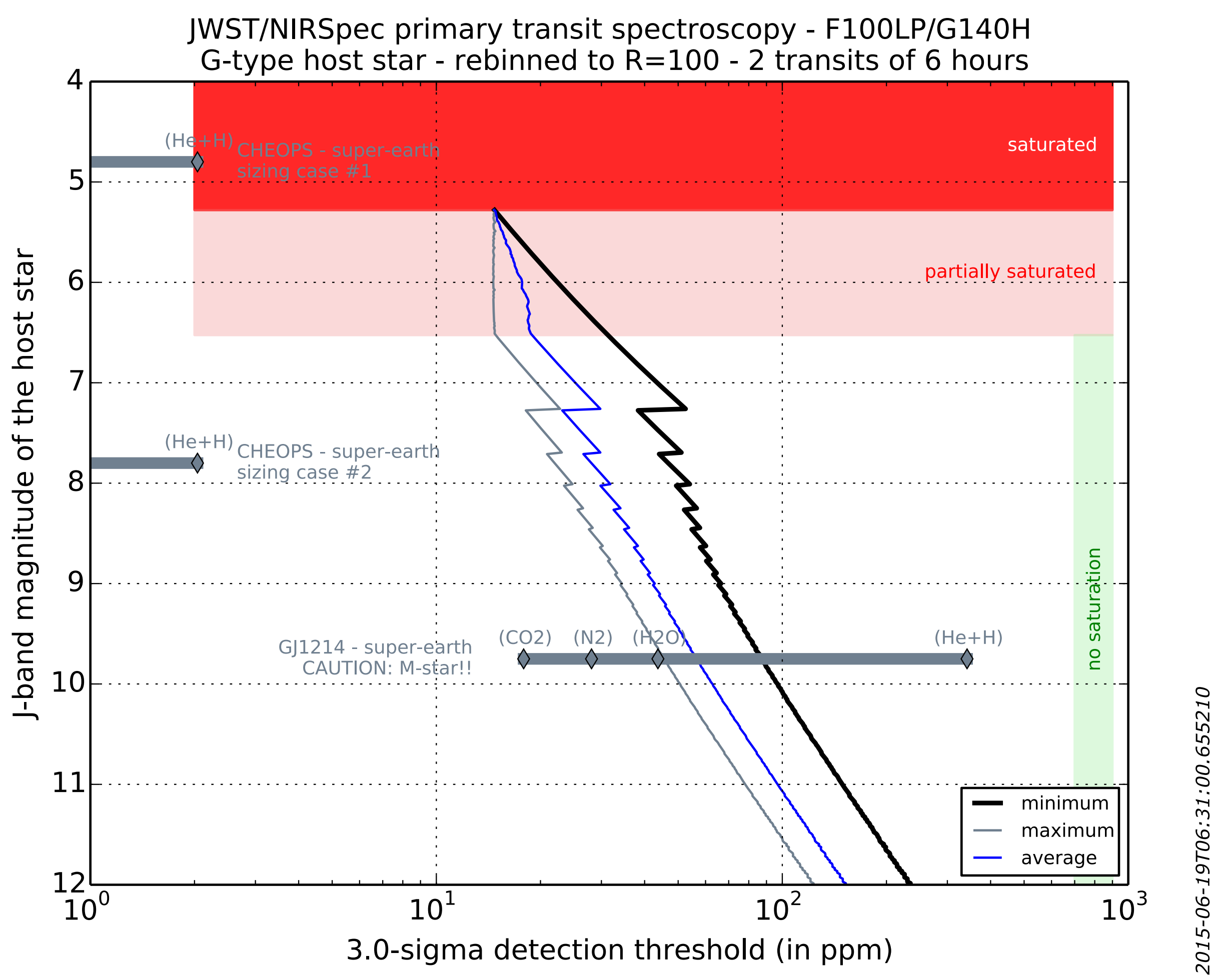
Case #1: super-Earth size planet with a transit time of 6 hours, a period of 50 days and orbiting a bright G star of V < 9.

Additional assumptions:

- **ppm levels corresponding to 3 sigma.**
- **rebinning to a spectral resolution of 70-130**
  - 10 pixels (MR), 27 pixels (HR), no rebin for LR.
- **Sizing cases reported as 1 scale height for atmospheres with different mean molecular weights.**
  - Conservative.

Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.

Following up CHEOPS targets with JWST/ NIRSpec



Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.

Following up CHEOPS targets with JWST/ NIRSpec

Case #1: super-Earth size planet with a transit time of 6 hours, a period of 50 days and orbiting a bright G star of V < 9.

In our *conservative* scenario, case #1 is beyond our reach for spectroscopic follow-up.

➔ Will require picking the candidates orbiting stars as bright as possible, with "fluffier" atmospheres, with more observations possible during a year.
➔ Some "tuning" to be done.

Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.

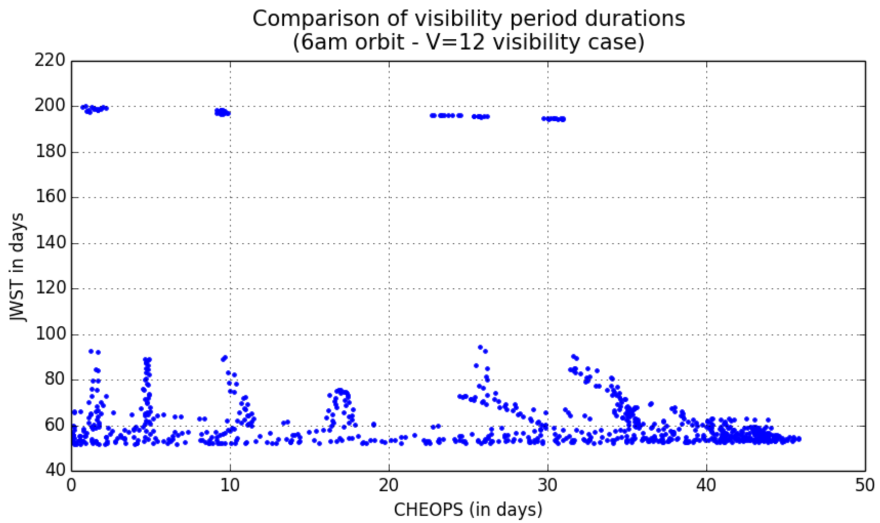
Following up CHEOPS targets with JWST/ NIRSpec

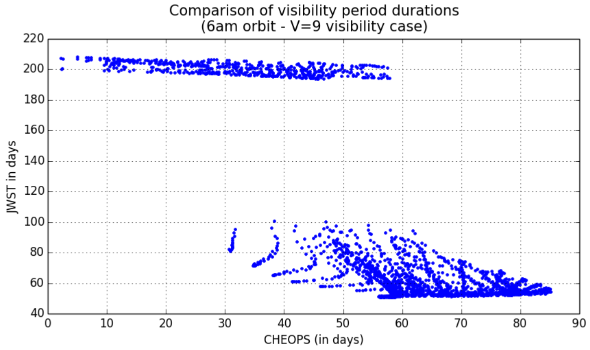
Case #2: Neptune-size planet with a transit time of 3 hours, a period of 13 days and orbiting a K star of V < 12.

- Assuming that the observations are done during one JWST cycle.
- Most of the time, 2 windows of 50-60 days.

➔ 6 transits of 3 hours (conservative once more).

The target does not "have to" be faint so it is possible to take advantage of case #1 visibilities.





Following up CHEOPS targets with JWST/ NIRSpec

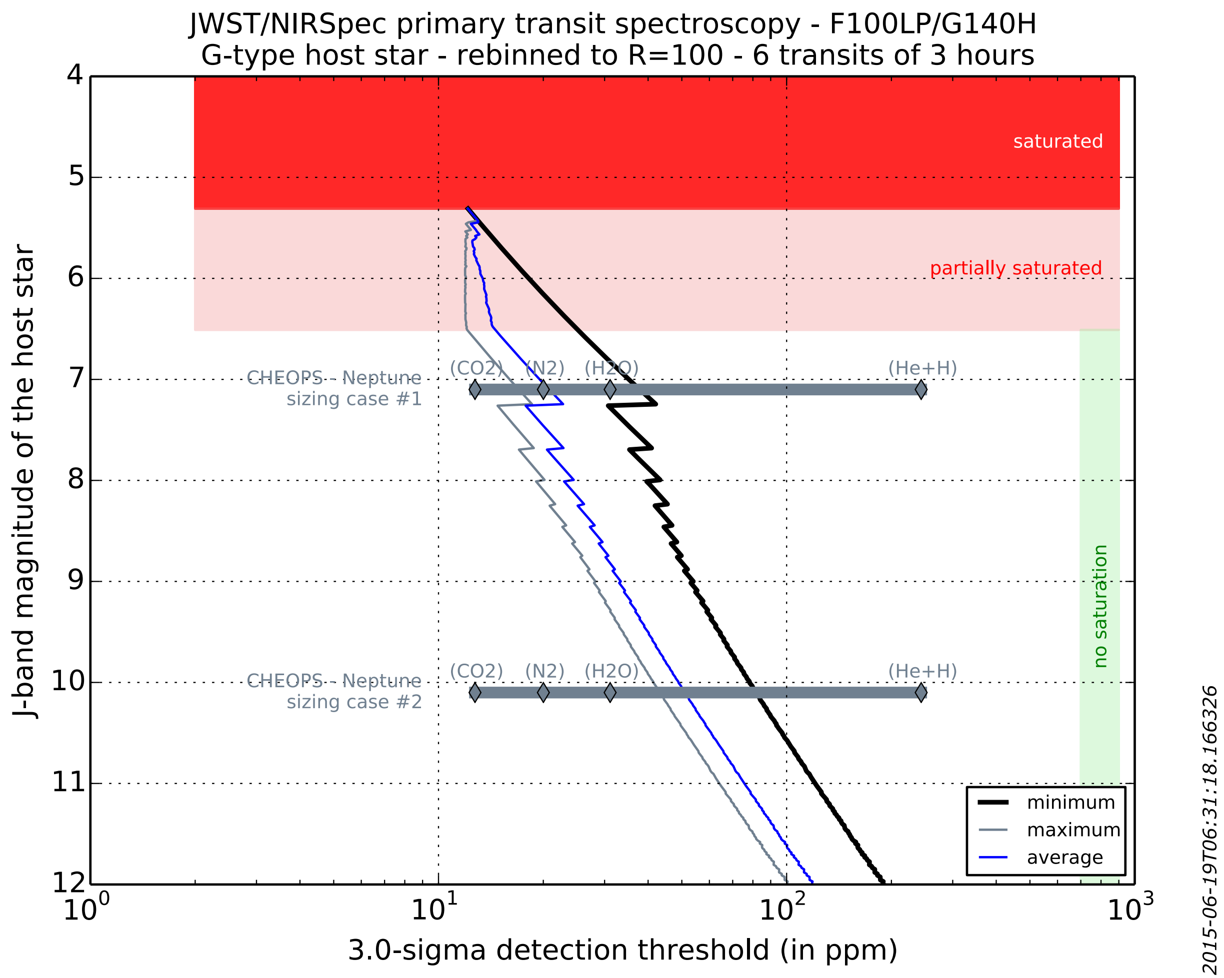
Case #2: Neptune-size planet with a transit time of 3 hours, a period of 13 days and orbiting a K star of V < 12.

Additional assumptions:

- **ppm levels corresponding to 3 sigma.**
- **rebinning to a spectral resolution of 70-130**
  - 10 pixels (MR), 27 pixels (HR), no rebin for LR.
- **Sizing cases reported as 1 scale height for atmospheres with different mean molecular weights.**
  - Conservative.

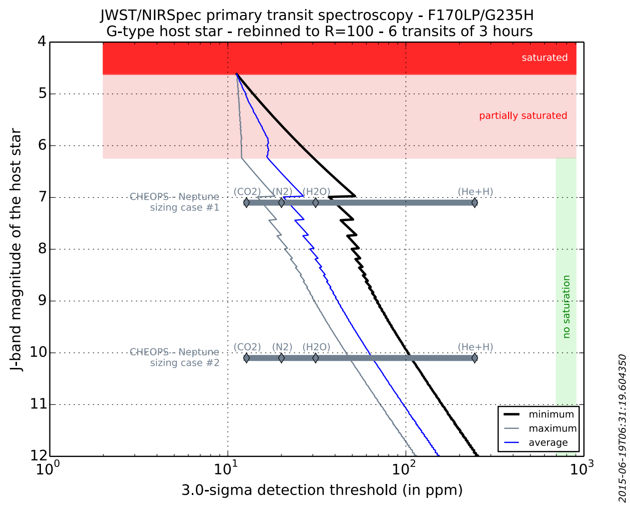
Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.

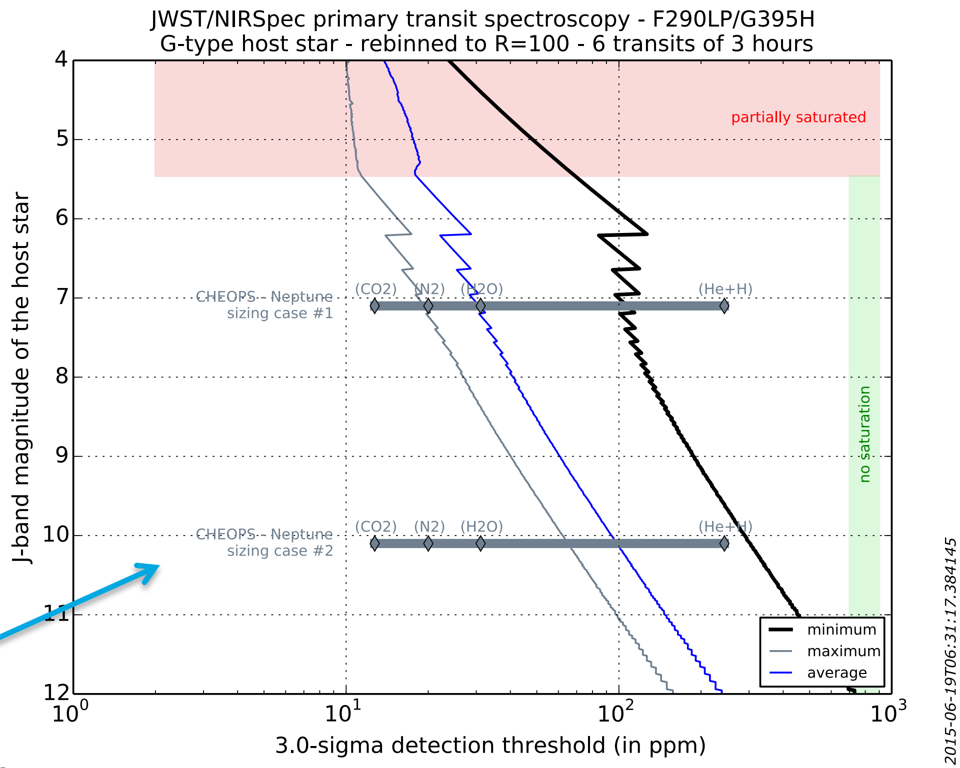
Following up CHEOPS targets with JWST/ NIRSpec



Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.

Following up CHEOPS targets with JWST/ NIRSpec





More challenging in the red

Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.

Following up CHEOPS targets with JWST/ NIRSpec

Case #2: Neptune-size planet with a transit time of 3 hours, a period of 13 days and orbiting a K star of V < 12.

In our *conservative* scenario, case #2 is within reach of NIRSpec.

➔ Still not an easy one, program of 50-60 hours per target.
➔ Need to pick one configuration (carefully look at all the options in terms of instruments & diagnostics).

➔ Here also, careful tuning is necessary.

Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.

Following up CHEOPS targets with JWST/ NIRSpec

Case #3 (non-specific to CHEOPS): Taking a look at the detection of the emission of a Jupiter-sized planet orbiting e.g. a G-star and with planet temperatures of 500, 1000 and 2000 K.

Assumptions:

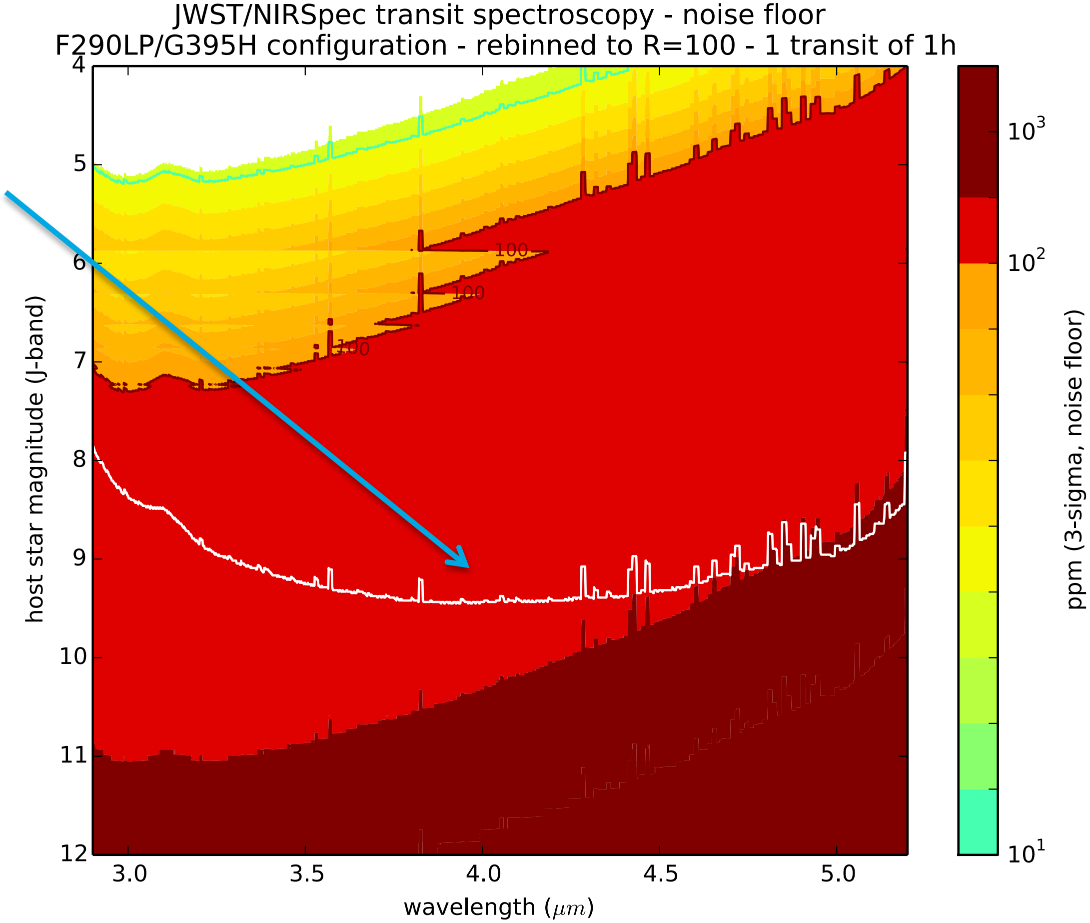
- **ppm levels corresponding to 3 sigma.**
- **rebinning to a spectral resolution of 70-130**
  - 10 pixels (MR), 27 pixels (HR), no rebin for LR.
- **Toy-model to evaluate the "contrast" of the planet black-body with respect to the stellar black body.**
  - Can vary widely as a function of the model used so we went for the "toy-model" approach.

Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.

Following up CHEOPS targets with JWST/ NIRSpec

Magnitude at which the thermal emission of a 1000 K Jupiter-size planet can be detected at 3 sigma.

Single transit of 1 hour.



M2 host star [Phoenix model with T=3400 K and log(g)=5.0] *2015-06-18T17:26:14.665472*

Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.

Following up CHEOPS targets with JWST/ NIRSpec

Case #3 (non-specific to CHEOPS): Taking a look at the detection of the emission of a Jupiter-sized planet orbiting e.g. a G-star and with planet temperatures of 500, 1000 and 2000 K.

The "toy-model" approach indicates that this is well within reach of NIRSpec.

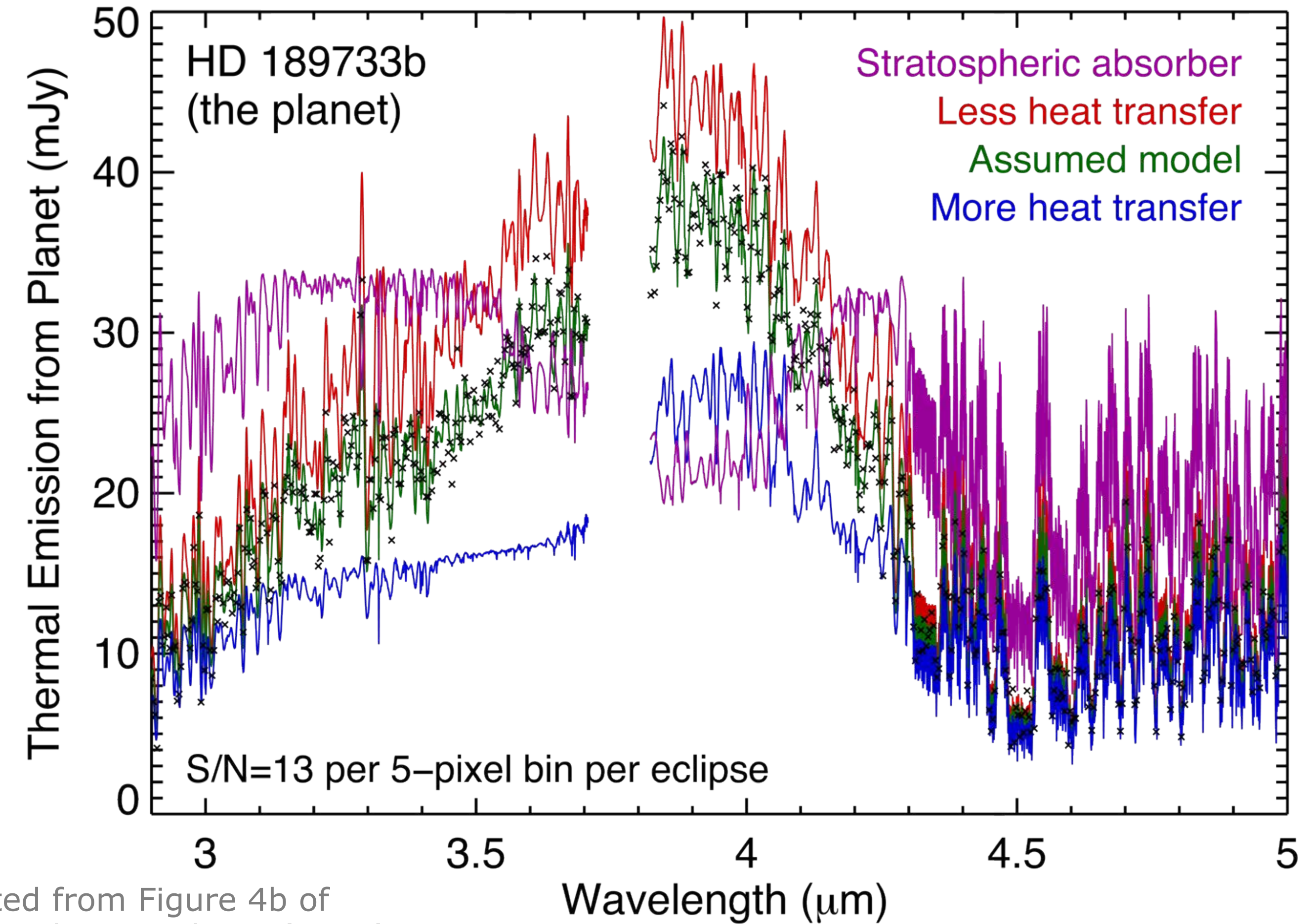
Averaging done over 1 hour only so this also opens the door for phase curve observations!

[note that phase curve observations are less time critical and therefore "easier" form the scheduling / visibility point of view]

Noise floor = benchmark lowest noise level that would be achieved if we had only two noise components: detector noise + shot noise from the host star.

JWST spectroscopic capabilities
Transit spectroscopy – Example with NIRSpec

- **Thermal emission from a hot Jupiter (secondary eclipse)**
  - Credit for the slide: J. Valenti (STScI).



Adapted from Figure 4b of
Burrows, Budaj, & Hubeny (2008)

Conclusion

JWST is on track for a launch in October 2018 and for a start of scientific operation in the first half of 2019!

Unique capabilities for the characterisation of exoplanets and the follow-up of candidates provided by missions like CHEOPS.
→ Some tuning needed as there is nothing like an "easy" case...

JWST dates you want to put in your calendar:

- *November 2017 – First call for proposals!*
- Spring 2019 – Start of scientific operation!

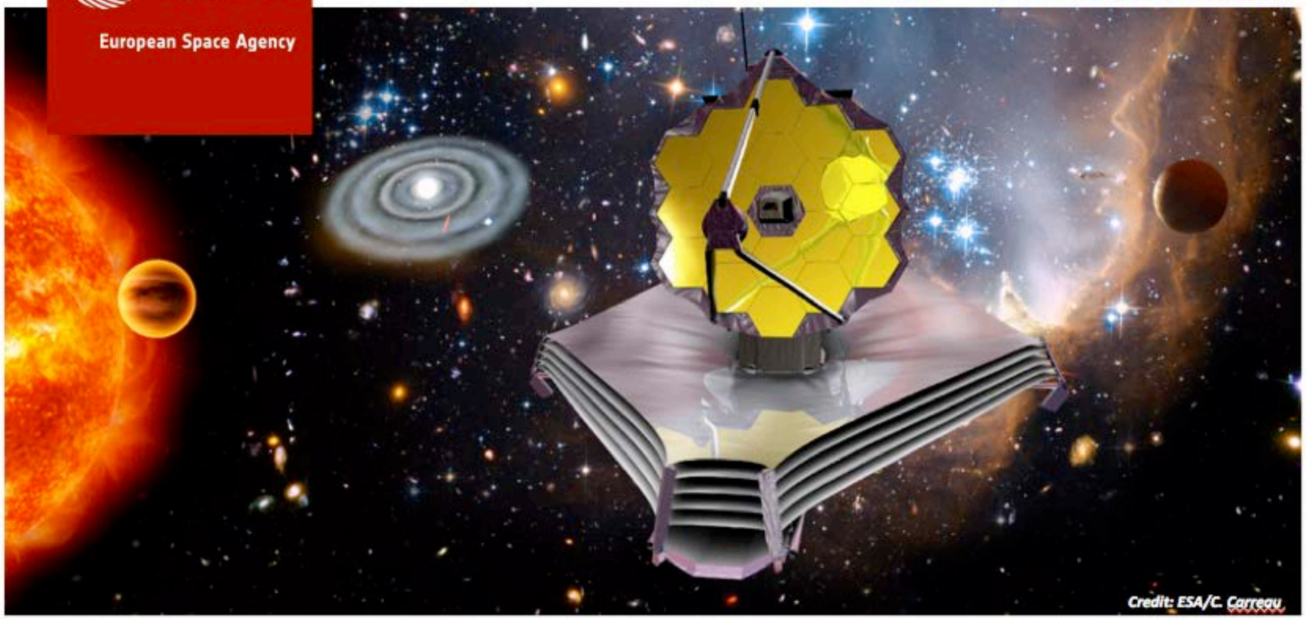
THANK YOU FOR YOUR ATTENTION!

esa

European Space Agency

"Exploring the Universe with JWST"

49th ESLAB symposium



ESA/ESTEC

October 12-16 2015

An international conference dedicated to the presentation and discussion of future scientific research that will be enabled by the James Webb Space Telescope.

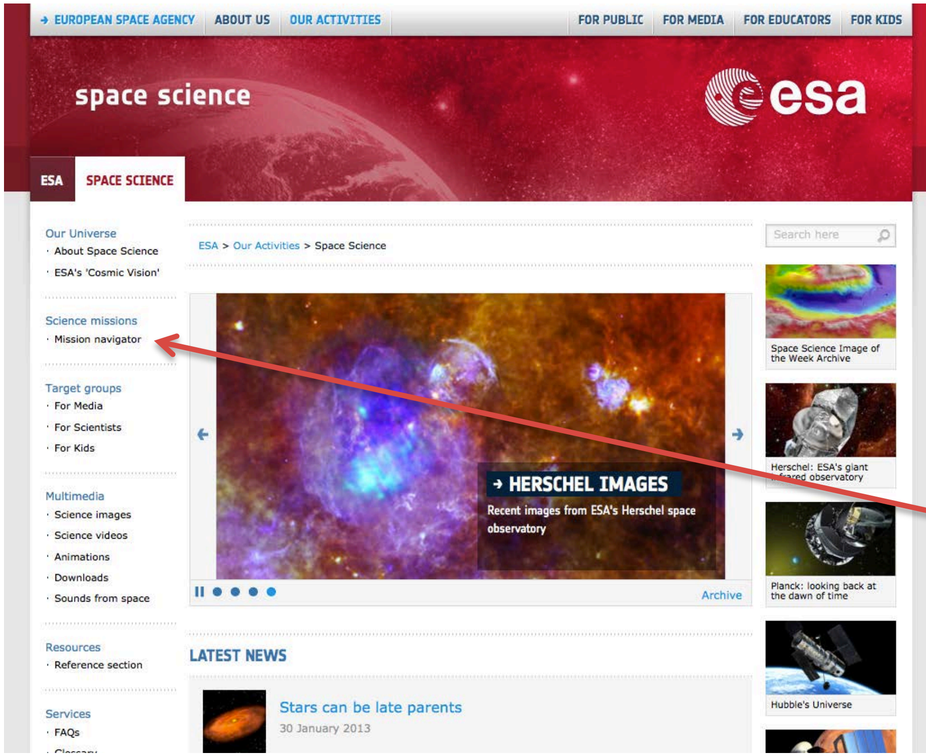
REGISTRATION AND ABSTRACT SUBMISSION EXTENDED TILL 22 JUNE 2015

http://congrexprojects.com/15a02

Abstract submission deadline is: 22 June 2015 (next Monday). Hurry up!

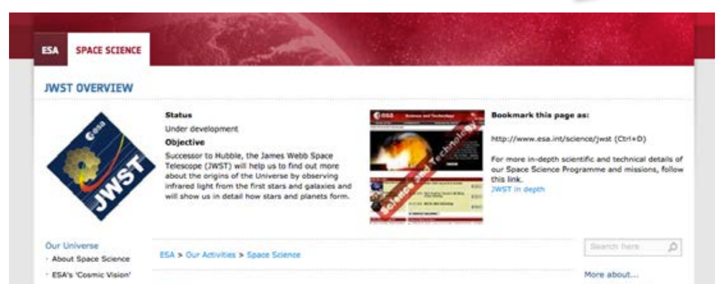
European Space Agency

JWST on the web – Resources – ESA web sites



- Overall ESA science missions web site
- www.esa.int/Our_Activities/Space_Science/

- JWST overview page available through the "Mission navigator" page.



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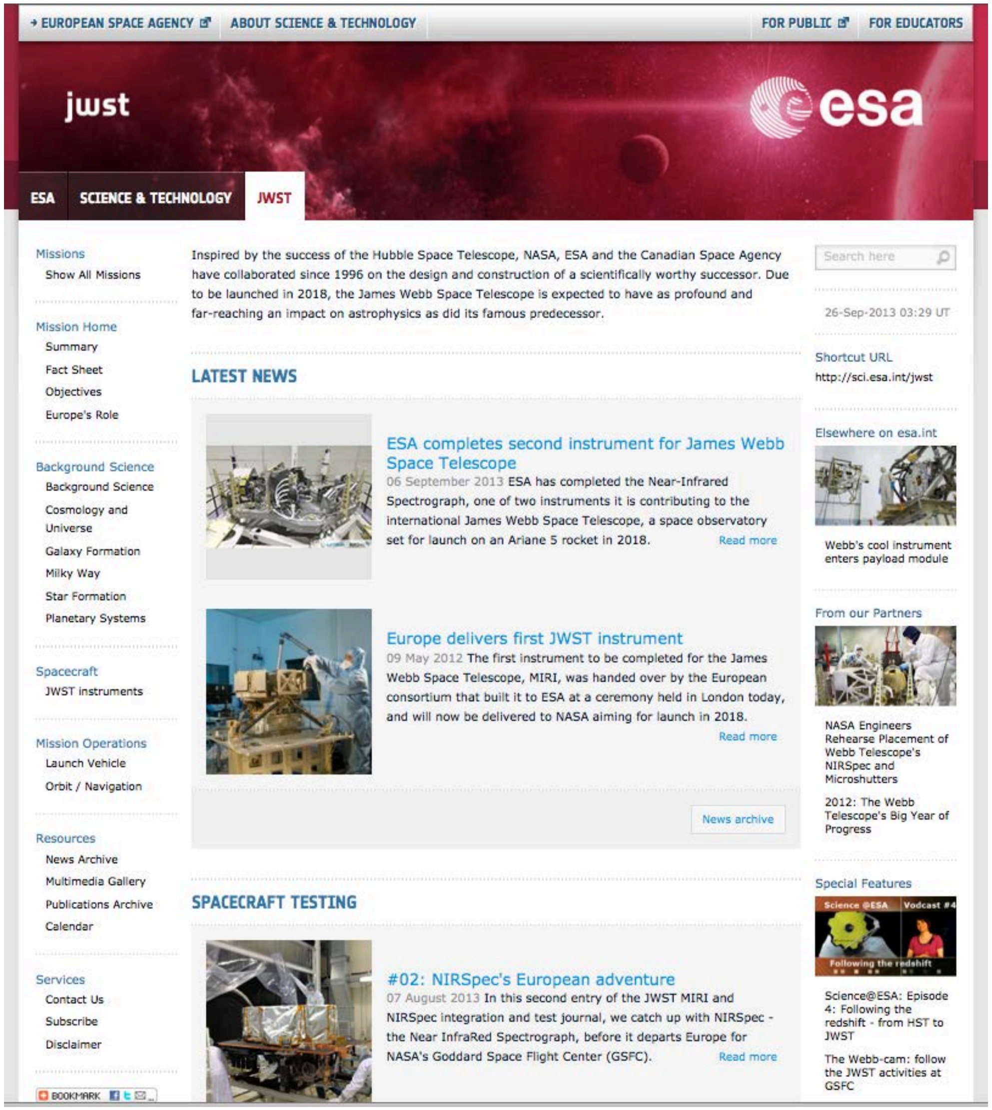
JWST on the web – Resources – ESA web sites



- "Science and technology" section dedicated to JWST
- http://sci.esa.int/jwst/

- Latest news with the press releases for major milestones.
- Spacecraft testing section with a "journal" following what happens to MIRI and NIRSpec.

JWST on the web – Resources – ESA web sites

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- Internal

ESA AND THE JAMES WEBB SPACE TELESCOPE

The James Webb Space Telescope (JWST) is a collaborative project between NASA, ESA, and the Canadian Space Agency (CSA). Although radically different in design, and emphasizing the infrared part of the electromagnetic spectrum, JWST is widely seen as the successor to the Hubble Space Telescope (HST).

The JWST observatory will consist of a deployable 6.6 meter passively cooled telescope optimized for infrared wavelengths, and will be operated in deep space at the anti-Sun Earth-Sun Lagrangian point (L2). It will carry four scientific instruments: a near-infrared camera (NIRCam), a near-infrared multi-object spectrograph (NIRSpec) covering the 0.6 - 5 μm spectral region, a near-infrared slit-less spectrograph (NIRISS), and a combined mid-infrared camera/spectrograph (MIRI) covering 5 - 28 μm. The JWST focal plane (see image to the right) contains apertures for the science instruments and the Fine Guidance Sensor (FGS).

The scientific goals of the JWST mission can be sorted into four broad themes:

- The end of the dark ages: first light and re-ionization
- The assembly of galaxies
- The birth of stars and proto-planetary systems
- Planetary systems and the origins of life

Vertical Field Position (arc minutes)
Horizontal Field Position (arc minutes)
NIRISS FGS NIRCAM MIRI NIRSpec

The focal plane of the JWST telescope with the assigned field of views for the instruments.

Although the first two of these themes are extragalactic in nature and concerned with exploring the formation of stars and galaxies in the remote Universe at the earliest times, they are intimately linked to the latter two mainly galactic themes, which aim at understanding the detailed process of star and planet formation in our own galaxy.

The European Space Agency is responsible for providing NIRSpec from ESA funds, and approximately half of MIRI through special contributions from the member states via a consortium of European science institutions (EC). As its non-instrument contribution, ESA will provide the Ariane 5 launcher that will place the JWST observatory in its orbit around L2. Furthermore, a number of ESA staff will be posted at the Space Telescope Science Institute (STScI) in Baltimore in support of the European payload components as ESA's contribution to JWST operations.

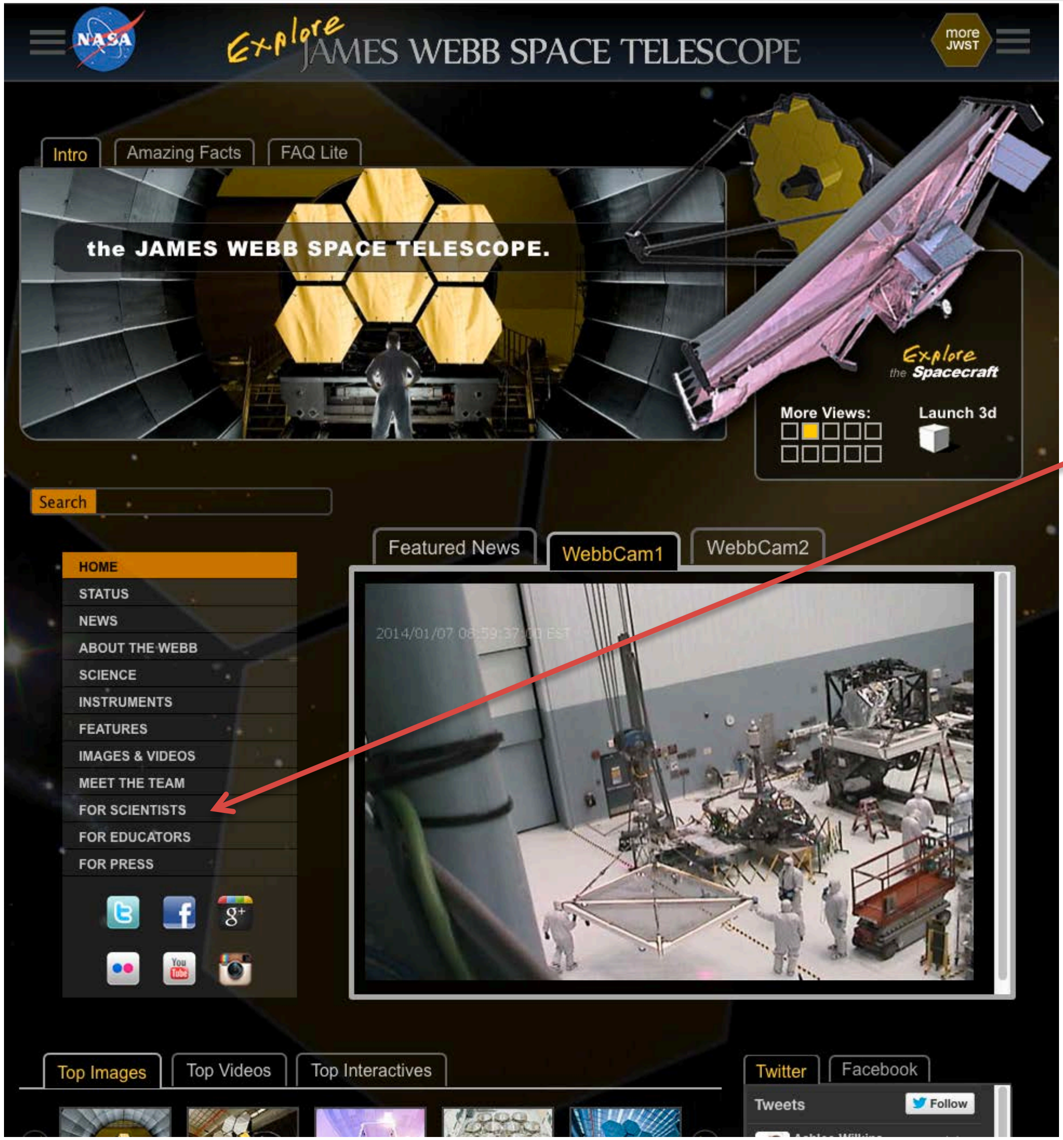
The purpose of this web-site is to provide information specific to the NIRSpec instrument, its performances and calibration. Designed as a multi-object spectrograph (MOS), NIRSpec will be able to observe more than 100 astronomical objects simultaneously. It has a large field of view (≈ 3' × 3') and is highly sensitive over its wavelength range (0.6 to 5 μm). The purpose of NIRSpec is to provide low (R~100), medium (R~1000), and high-resolution (R~2700) spectroscopic observations in support of the four main science themes of JWST. NIRSpec is developed by ESA with EADS Astrium Germany GmbH as the prime contractor.

If you are looking for more general information on

- JWST and NIRSpec web site maintained by the science and operation team at ESA.
- http://www.rssd.esa.int/JWST/

- The main focus is the NIRSpec instrument.
- Work in progress…
- More information will be added as time goes on.

JWST on the web – Resources – NASA JWST web site



- **NASA JWST site**
- **jwst.nasa.gov**

- **A lot of information.**
- **In the "FOR SCIENTISTS" section, you can register to receive the JWST newsletter, "The Webb update".**

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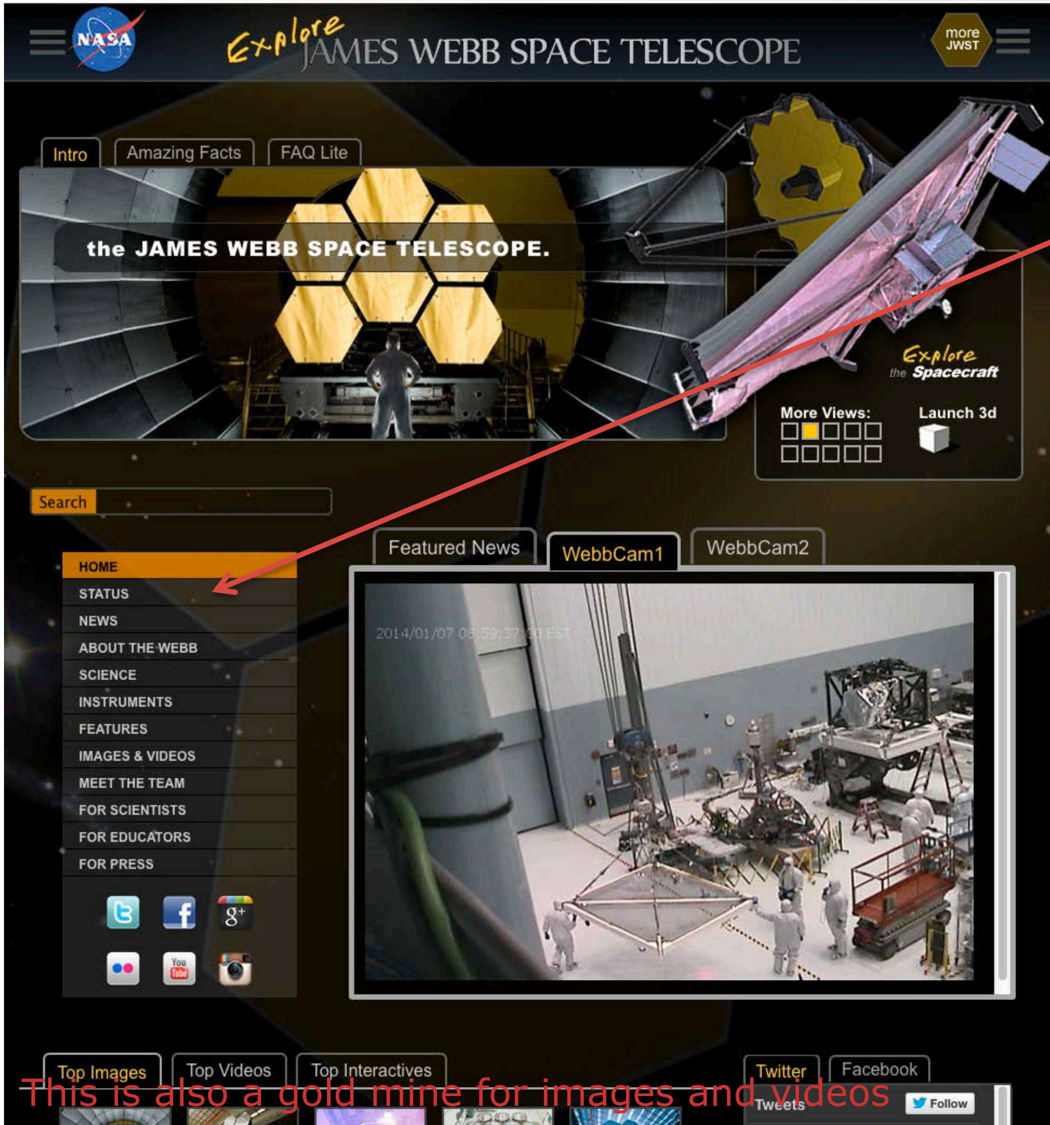
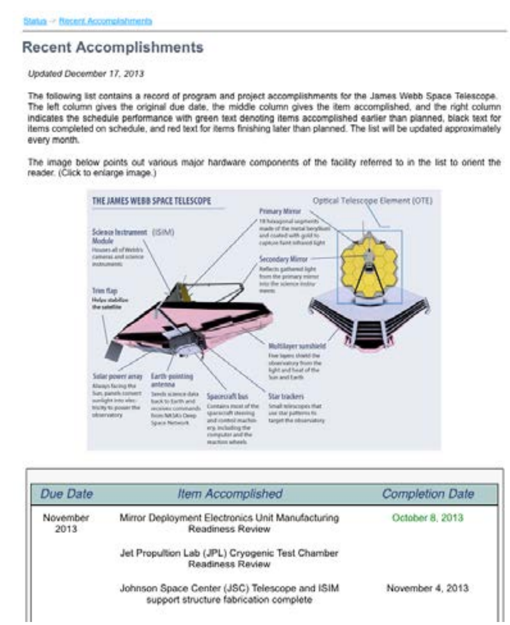
European Space Agency

JWST on the web – Resources – NASA JWST web site



This is also a gold mine for images and videos

- In the "STATUS" section, you can have a look at the progress of the project (achievements, milestones, next steps…)



Status → Recent Accomplishments

Recent Accomplishments

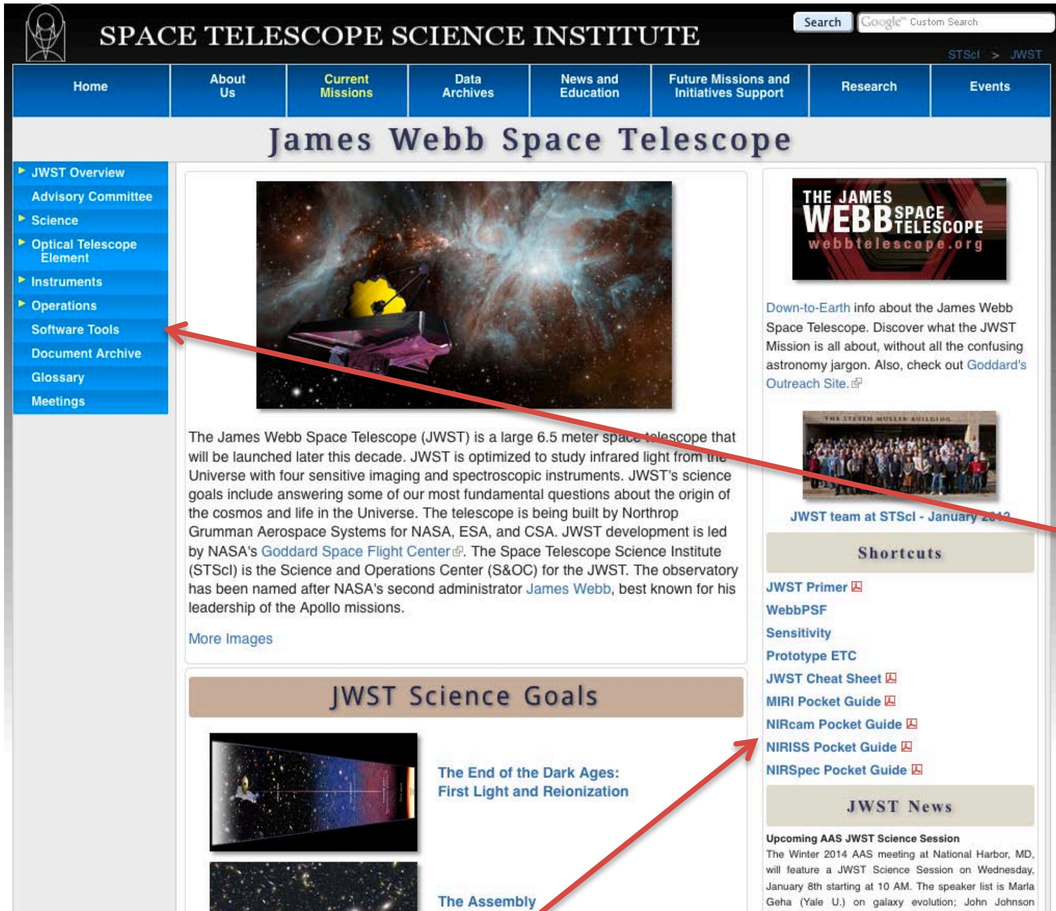
Updated December 17, 2013

The following list contains a record of program and project accomplishments for the James Webb Space Telescope. The left column gives the original due date, the middle column gives the item accomplished, and the right column indicates the schedule performance with green text denoting items accomplished earlier than planned, black text for items completed on schedule, and red text for items finishing later than planned. The list will be updated approximately every month.

The image below points out various major hardware components of the facility referred to in the list to orient the reader. (Click to enlarge image.)

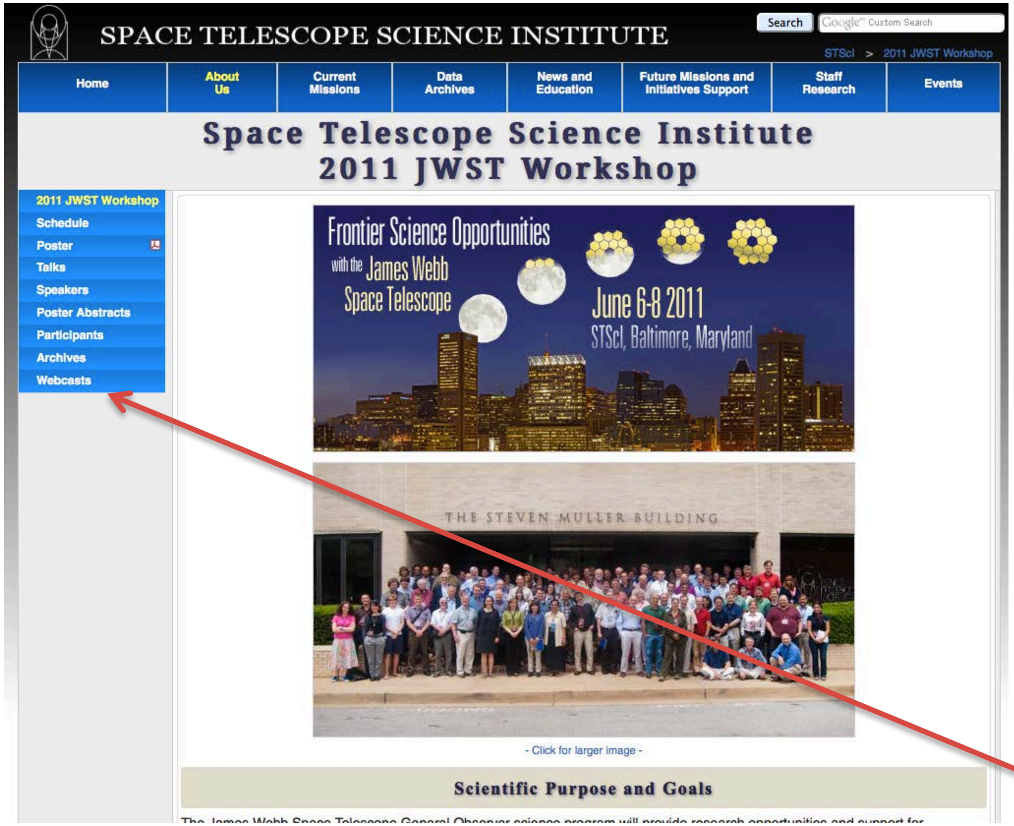
Due Date	Item Accomplished	Completion Date
November 2013	Mirror Deployment Electronics Unit Manufacturing Readiness Review	October 8, 2013
	Jet Propultion Lab (JPL) Cryogenic Test Chamber Readiness Review	
	Johnson Space Center (JSC) Telescope and ISIM support structure fabrication complete	November 4, 2013

JWST on the web – Resources – STScI JWST web site

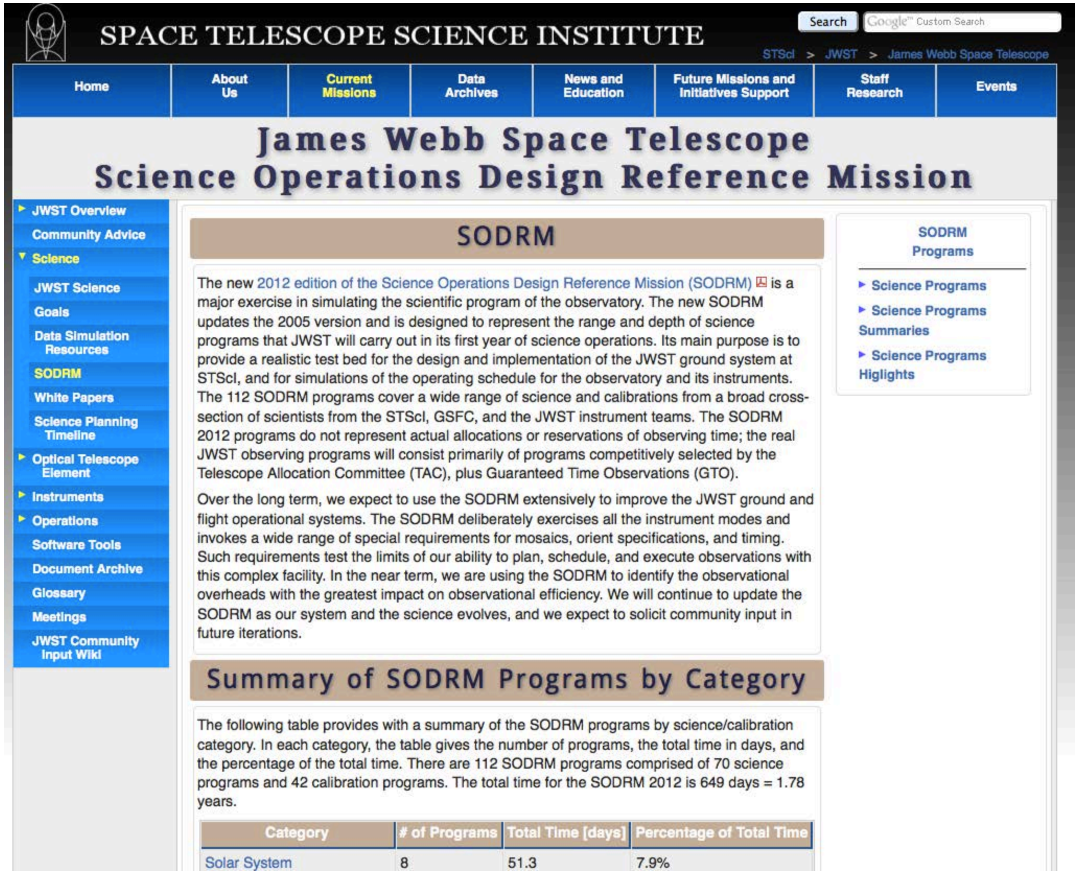


- JWST web site at STScI.
- http://www.stsci.edu/jwst/
- A lot of information.
- Prototype ETCs can be found in the "Software Tools" section.
- Note also the presence of development versions of the JWST APTs (astronomer's proposal tools)
- Pocket guides

JWST on the web – Resources – STScI JWST web site



- Web site of the 2011 STScI workshop on "Frontier Science Opportunities with JWST"
- http://www.stsci.edu/institute/conference/jwst2011/
- Look at the STScI webcast archive to view the various talks.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James Webb Space Telescope
Science Operations Design Reference Mission

- JWST Overview
- Community Advice
- Science
  - JWST Science
  - Goals
  - Data Simulation Resources
  - SODRM
  - White Papers
  - Science Planning Timeline
- Optical Telescope Element
- Instruments
- Operations
- Software Tools
- Document Archive
- Glossary
- Meetings
- JWST Community Input Wiki

SODRM

The new 2012 edition of the Science Operations Design Reference Mission (SODRM) is a major exercise in simulating the scientific program of the observatory. The new SODRM updates the 2005 version and is designed to represent the range and depth of science programs that JWST will carry out in its first year of science operations. Its main purpose is to provide a realistic test bed for the design and implementation of the JWST ground system at STScI, and for simulations of the operating schedule for the observatory and its instruments. The 112 SODRM programs cover a wide range of science and calibrations from a broad cross-section of scientists from the STScI, GSFC, and the JWST instrument teams. The SODRM 2012 programs do not represent actual allocations or reservations of observing time; the real JWST observing programs will consist primarily of programs competitively selected by the Telescope Allocation Committee (TAC), plus Guaranteed Time Observations (GTO).

Over the long term, we expect to use the SODRM extensively to improve the JWST ground and flight operational systems. The SODRM deliberately exercises all the instrument modes and invokes a wide range of special requirements for mosaics, orient specifications, and timing. Such requirements test the limits of our ability to plan, schedule, and execute observations with this complex facility. In the near term, we are using the SODRM to identify the observational overheads with the greatest impact on observational efficiency. We will continue to update the SODRM as our system and the science evolves, and we expect to solicit community input in future iterations.

SODRM Programs

- Science Programs
- Science Programs Summaries
- Science Programs Higlights

Summary of SODRM Programs by Category

The following table provides with a summary of the SODRM programs by science/calibration category. In each category, the table gives the number of programs, the total time in days, and the percentage of the total time. There are 112 SODRM programs comprised of 70 science programs and 42 calibration programs. The total time for the SODRM 2012 is 649 days = 1.78 years.

Category	# of Programs	Total Time [days]	Percentage of Total Time
Solar System	8	51.3	7.9%

- **The so-called SODRM**
- **http://www.stsci.edu/jwst/science/sodrm/**

- **Exercise aiming at simulating what could be one year of JWST observations.**

JWST on the web – Resources – "Behind the Webb"

- **Series of short videos showing various moments in the development of JWST**
- **http://webbtelescope.org/webb_telescope/behind_the_webb/**
- **Oriented toward a fairly wide audience.**

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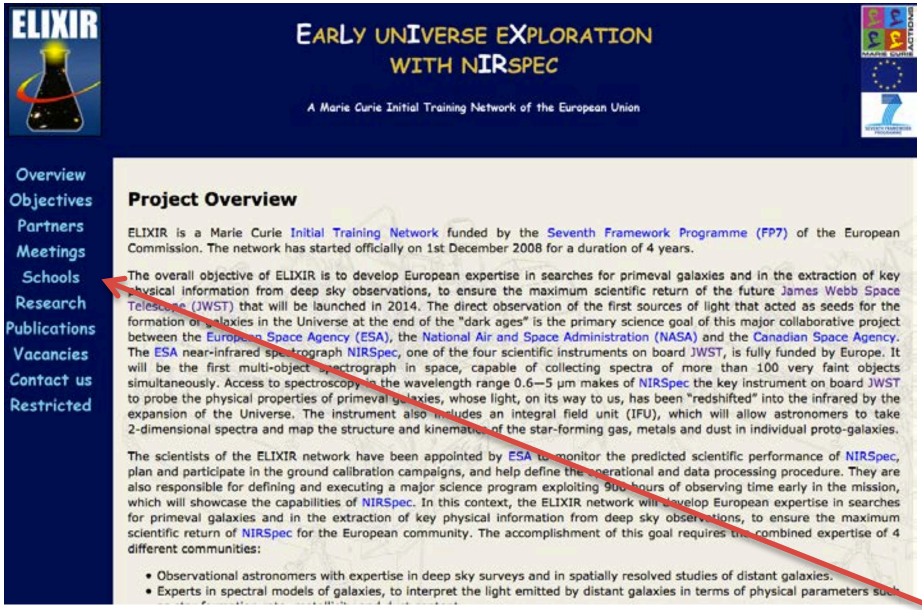
JWST on the web – Resources – The ELIXIR network web site



ELIXIR

EARLY UNIVERSE EXPLORATION WITH NIRSPEC

A Marie Curie Initial Training Network of the European Union

Overview
Objectives
Partners
Meetings
Schools
Research
Publications
Vacancies
Contact us
Restricted

Project Overview

ELIXIR is a Marie Curie Initial Training Network funded by the Seventh Framework Programme (FP7) of the European Commission. The network has started officially on 1st December 2008 for a duration of 4 years.

The overall objective of ELIXIR is to develop European expertise in searches for primeval galaxies and in the extraction of key physical information from deep sky observations, to ensure the maximum scientific return of the future James Webb Space Telescope (JWST) that will be launched in 2014. The direct observation of the first sources of light that acted as seeds for the formation of galaxies in the Universe at the end of the "dark ages" is the primary science goal of this major collaborative project between the European Space Agency (ESA), the National Air and Space Administration (NASA) and the Canadian Space Agency. The ESA near-infrared spectrograph NIRSpec, one of the four scientific instruments on board JWST, is fully funded by Europe. It will be the first multi-object spectrograph in space, capable of collecting spectra of more than 100 very faint objects simultaneously. Access to spectroscopy in the wavelength range 0.6—5 μm makes of NIRSpec the key instrument on board JWST to probe the physical properties of primeval galaxies, whose light, on its way to us, has been "redshifted" into the infrared by the expansion of the Universe. The instrument also includes an integral field unit (IFU), which will allow astronomers to take 2-dimensional spectra and map the structure and kinematics of the star-forming gas, metals and dust in individual proto-galaxies.

The scientists of the ELIXIR network have been appointed by ESA to monitor the predicted scientific performance of NIRSpec, plan and participate in the ground calibration campaigns, and help define the operational and data processing procedure. They are also responsible for defining and executing a major science program exploiting 900 hours of observing time early in the mission, which will showcase the capabilities of NIRSpec. In this context, the ELIXIR network will develop European expertise in searches for primeval galaxies and in the extraction of key physical information from deep sky observations, to ensure the maximum scientific return of NIRSpec for the European community. The accomplishment of this goal requires the combined expertise of 4 different communities:

- Observational astronomers with expertise in deep sky surveys and in spatially resolved studies of distant galaxies.
- Experts in spectral models of galaxies, to interpret the light emitted by distant galaxies in terms of physical parameters such

Schools

The ELIXIR network will organize 3 "technology-oriented" schools on the NIRSpec project.

First ELIXIR School: ***"The JWST/NIRSpec Project" (31 May-2 June 2010)***

Location: EADS/Astrium GmbH (Ottobrunn, Germany)

Second ELIXIR School: ***"How Does a Space Project Work?" (19-20 May 2011)***

Location: ESA/ESTEC (Noordwijk, The Netherlands)

Third ELIXIR School: ***"What Will it Look Like to Observe with NIRSpec?" (26-27 September 2012)***

Location: ESA/ESTEC (Noordwijk, The Netherlands)

- **Web site of the ELIXIR network (PI: S. Charlot, NIRSpec related)**
- **http://www.iap.fr/elixir/index.html/**

- **A lot of interesting material in the "Schools" section (presentations made during the 3 network schools).**

JWST on the web – Resources – Miscellaneous

- **MIRI at RAL, ROE and JPL**
  - http://www.stfc.ac.uk/RALSpace/18419.aspx/
  - http://jwst-miri.roe.ac.uk/
  - http://www.jpl.nasa.gov/missions/details.php?id=5921

- **NIRCam at the University of Arizona**
  - **http://ircamera.as.arizona.edu/nircam/**

- **FGS/NIRISS at CSA**

  http://www.asc-csa.gc.ca/eng/satellites/jwst/facts.asp