Investigating the synergies between CHEOPS and JWST/NIRSpec

García Muñoz, A.[a,*], .Isaak, K.[b,**], Ferruit, P.[b#]

[a]Technische Universität Berlin, Berlin; [b] ESTEC, Noordwijk, Netherlands

* garciamunoz@astro.physik.tu-berlin.de; ** ESA CHEOPS Project Scientist: kate.isaak@esa.int; # ESA JWST Project Scientist pierre.ferruit@esa.int

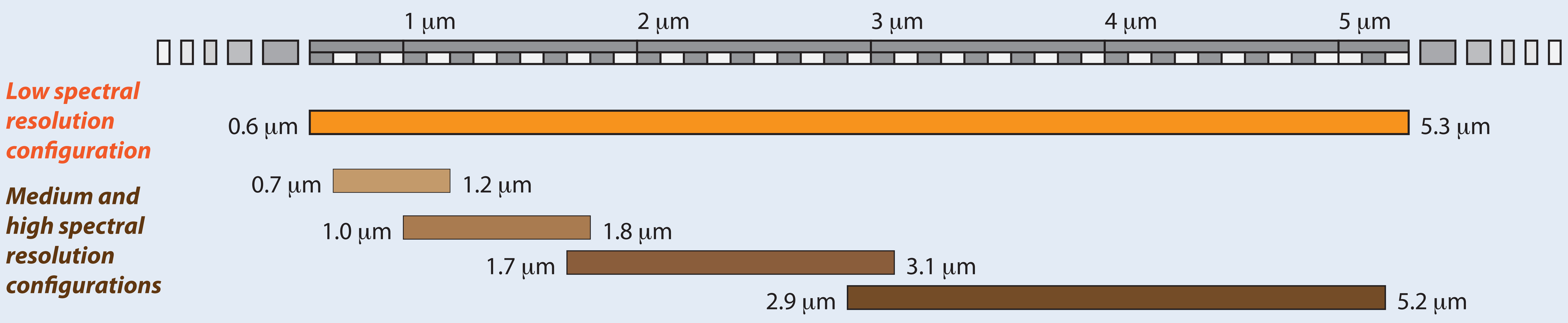
Abstract: Multi-facility, multi-wavelength observations will play a key role in the characterisation of exoplanet atmospheres. The CHEOPS mission, a partnership between ESA and Switzerland, is foreseen to be launch-ready by the end 2017 and will deliver high-precision photometry of bright (m_V<12) planet-hosting stars over a nominal mission duration of 3.5 years. CHEOPS' broadband optical (0.4–1.1 µm) broadband capabilities are expected to yield unique insight into the albedos, temperatures and occurrence of clouds on the planets. Contemporaneously with CHEOPS, JWST will yield spectral discrimination power from 0.7 to 28 µm, essential to disentangling the effect of gases and condensates in the atmospheres of the most interesting CHEOPS targets. In this poster we illustrate the synergies between the two missions for the characterisation of exoplanet atmospheres, with a focus on JWST NIRSpec.

Context: Spectroscopic characterisation of transiting exoplanets is one of a many scientific areas that will benefit greatly from the JWST, as amply demonstrated by the breadth and depth of contributions to this meeting. It is therefore very likely that this general-purpose observatory will have a high level of over-subscription, particularly in its early years. Whilst it is unlikely that "fishing" experiments will be ruled out, particularly if the science return is considered to be worth the risk, proposals that focus on observations of exoplanetary systems that are already well characterised will likely have an edge. In-orbit at the same time as JWST, CHEOPS will measure precise radii for smaller-radius/mass planets (shallow transit depths), identifying the optimal targets for follow-up with JWST.

Observing exoplanets with JWST/NIRSpec

The near-infrared spectrograph NIRSpec is one of the four instruments of the James Webb Space Telescope (JWST). It was developed by the European Space Agency (ESA) with Airbus Defence & Space as prime contractor. It harbours a square 1.6"×1.6" aperture designed specifically for exoplanet transit spectroscopy that will serve as the primary mode for observing exoplanets with NIRSpec.

JWST/NIRSpec - spectral configurations



NIRSpec transit spectroscopy				
Instrument mode	SLIT/A1600			
Aperture size (projected on the sky)	1.6"×1.6"			
Aperture size (projected on the detectors)	~16×16 pixels			
Low spectral resolution spectroscopy (R~100)				
Wavelength range:				from 0.6 µm to 5.3 µm in a single band
Spectral resolution:				30-300
Instrument configuration:				CLEAR/PRISM
Readout subarray size:				512×32 pixels (spectral × spatial)
Frame readout time:				0.226 s (single frame)
Medium spectral resolution spectroscopy (R~1000)				
Instrument configuration:	Range	Resolution	Readout subarray size	Frame readout time
F070LP/G140M	[0.7µm, 1.2µm]	500-850	2048×32 pixels	0.902 s
F100LP/G140M	[1.0µm, 1.8µm]	700-1300	2048×32 pixels	0.902 s
F170LP/G235M	[1.7µm, 3.1µm]	700-1300	2048×32 pixels	0.902 s
F290LP/G395M	[2.9µm, 5.2µm]	700-1300	2048×32 pixels	0.902 s
High spectral resolution spectroscopy (R~2700)				
Instrument configuration:	Range	Resolution	Readout subarray size	Frame readout time
F070LP/G140H	[0.7µm, 1.2µm]	1300-2300	2048×32 pixels	0.902 s
F100LP/G140H	[1.0µm, 1.8µm]	1900-3600	2048×32 pixels	0.902 s
F170LP/G235H	[1.7µm, 3.1µm]	1900-3600	2048×32 pixels	0.902 s
F290LP/G395H	[2.9µm, 5.2µm]	1900-3600	2048×32 pixels	0.902 s

Table 1. Characteristics of the NIRSpec SLIT/A1600 mode for transit spectroscopy.

Characteristics of the NIRSPEC SLIT/A1600 mode for transit spectroscopy (Taken from Ferruit et al., SPIE 2014)

CHEOPS (CHaracterising ExOPlanet Satellite)

- Partnership between ESA's Science Programme and Switzerland; Mission Consortium of 11 member states, led by Prof Willy Benz @ University of Bern.
- First mission dedicated to the search for transits by exoplanets of bright starts already known to host planets, by means of ultrahigh precision photometry: knowing when and where to look provides an efficient way of searching for the shallow transits of Earth- and Neptune-like planets.
- Science objectives: first-step characterisation of super-Earths, formation processes of Neptunes, golden targets for spectroscopic follow-up from ground- and space-based facilities, energy balance in hot Jupiters.
- High-precision photometer covering 0.4 –1.1 µm waveband, made up of a single, frame-transfer CCD (cooled) behind a ~ Ø 30cm (effective aperture) f/5, on-axis Ritchy-Chrétien telescope; defocused PSF (Ø ~30") employed to minimise impact of spacecraft jitter and inter-pixel variation on photometric stability. Stringent level of stray light rejection required to meet the sensitivity requirement provided by the multi-stage baffle.
- Shared launch (CHEOPS secondary passenger) to a Sun-Synchronous Orbit with a local time of the ascending node of 6am (baseline, 6pm backup) and an orbit altitude of 650 – 800km. Launch-readiness expected by end 2017.

Key science requirements:

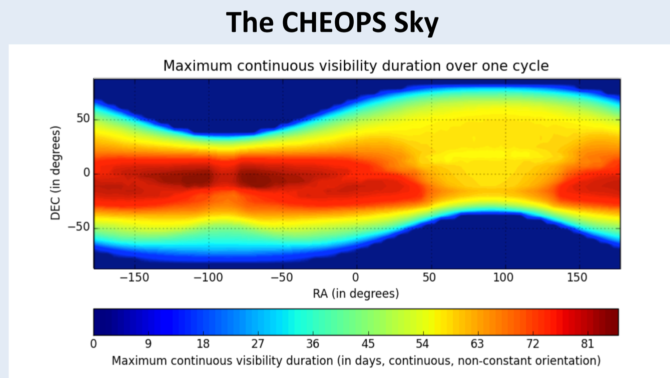
- Photometric precision → drives precision of transit depth
- Sky coverage → maximises ability to catch an exoplanet as it transits

Sizing cases:

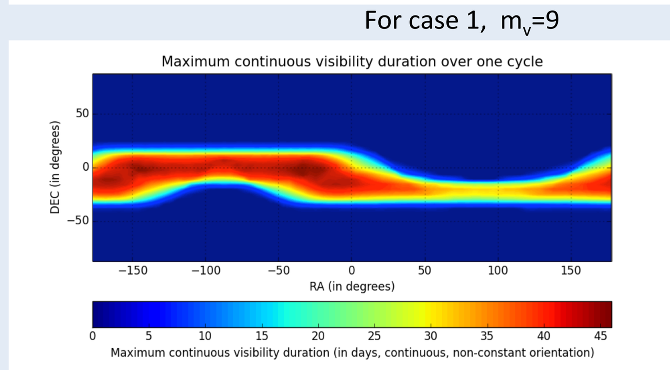
1: Earth-size planet orbiting G-type star (6 <m_V<9), orbital period 50 day, photometric precision 20 ppm in 6 hrs (equivalent transit duration = 6hrs, transit depth 100ppm, SNR=5)
→ 50% of whole sky to be accessible for 50 cumulative day/yr per target; target observable for a minimum of 50% of each spacecraft orbit

2: Neptune-size planet orbiting K-type star (m_V<12, goal 13), orbital period 13 days, photometric precision 85 ppm in 3 hrs (equivalent transit duration = 3hrs, transit depth 2500ppm, SNR=30)
→ 25% of sky, 2/3rd in the south, to be accessible for 13 cumulative day/yr per target; target observable for a minimum of 85% of each spacecraft orbit

The CHEOPS Sky



For case 1, m_V=9



For case 2, m_V=12

Sky simulations by Andrea Fortier/Thibault Kuntzer (CHEOPS Mission Consortium).

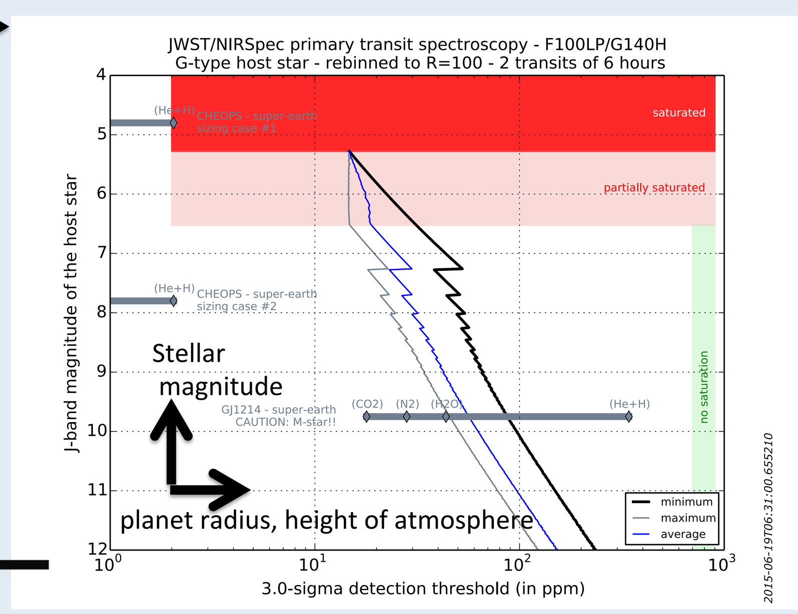
Following up CHEOPS Observations: NIRSpec transmission spectroscopy and orbital phase curves

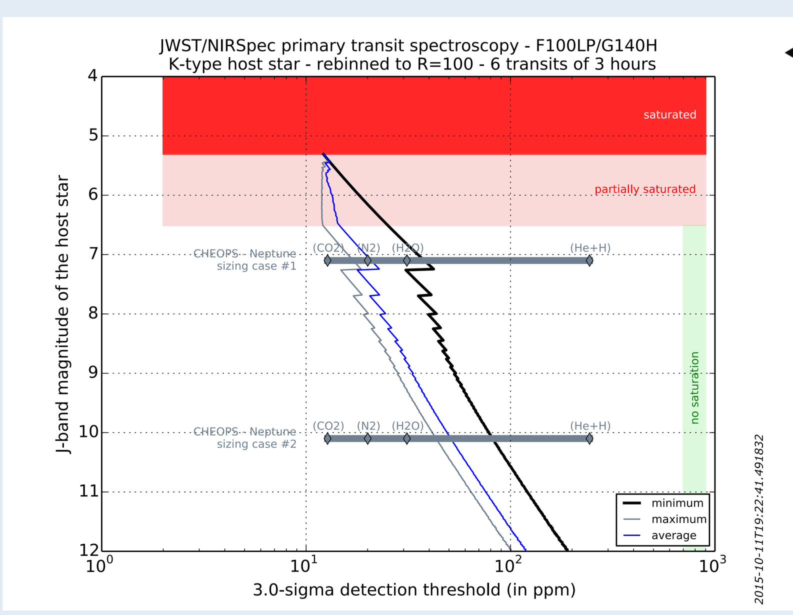
Transmission spectroscopy for Sizing Case 1 →

- R_{planet}=R_{Earth};G5 host star (R_{star} = 0.9 R_{sun}) m_V= 6 (9)
- Spectral binning to R (λ/Δλ) = 100
- each observation = transit duration (6hrs) x3
- signal from atmosphere prop. 1 scale height
- x 2 observations

→ Spectrometer saturates for brightest targets, detection not feasible for faintest end

→ Need more transits, largest possible radius, atmospheric signature to span > 1 scale height)





Transmission spectroscopy for Sizing Case 2

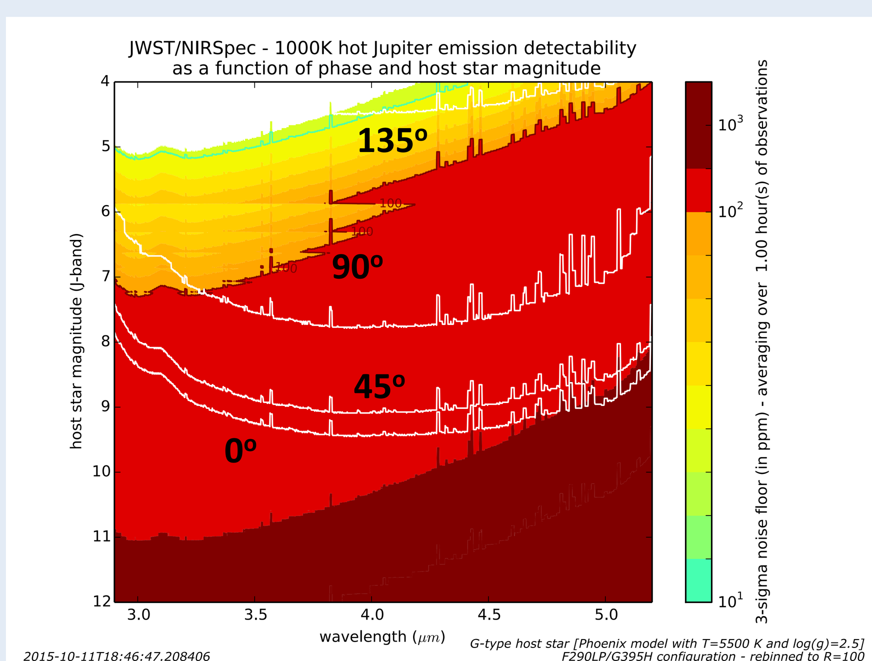
- R_{planet}=4R_{Earth};K host star (R_{star}= 0.7R_{sun}) m_V= 9(12)
- Spectral binning to R (λ/Δλ) = 100
- each observation = transit duration (3hrs) x3
- signal from atmosphere prop. 1 scale height
- x 6 observations

→ 3-sigma detection possible, more challenging at longer wavelengths as the parent star gets fainter.

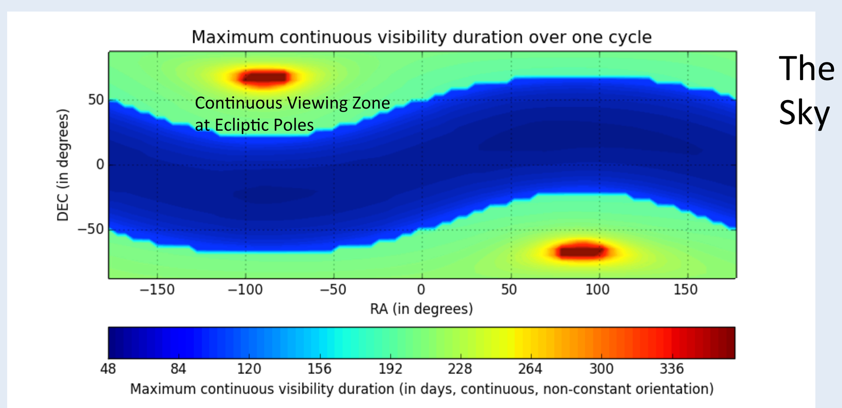
Orbital phase curves of hot Jupiters(T=1000K)

- Emission model from [3]
- observation duration = 1hr
- Colours represent expected SNR on the stellar signal
- White loci give host star magnitude needed to detect planet emission (3σ) for phase angles of 0,45,90 and 135 °
- Larger phase angles → larger contribution from planet night side → brighter stellar host/hotter planet needed
- Highly desirable to get > 1 orbital phase curve to look for signs of stellar activity

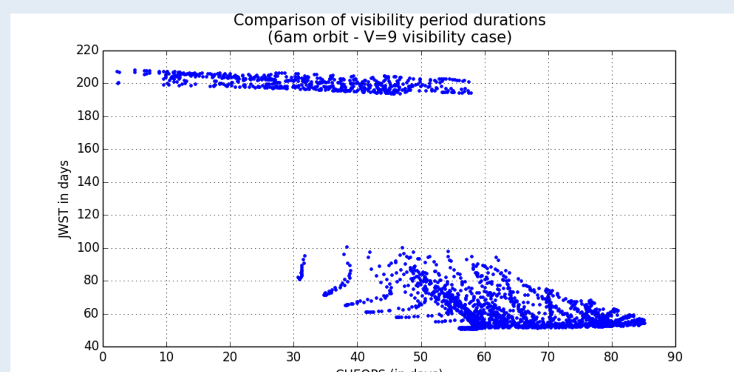
→ Orbital phase curve studies of hot Jupiters with JWST feasible: emission spectroscopy of smaller planets also possible.

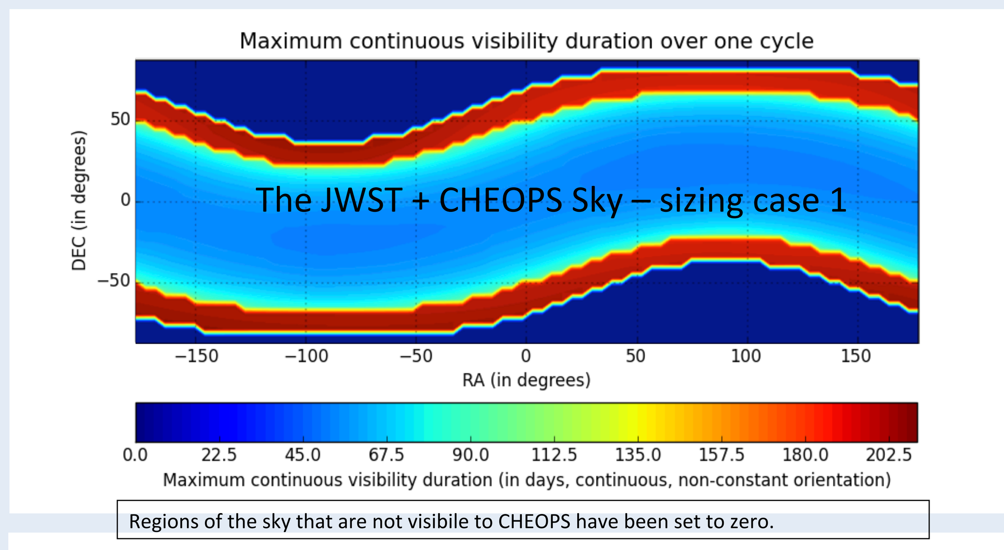


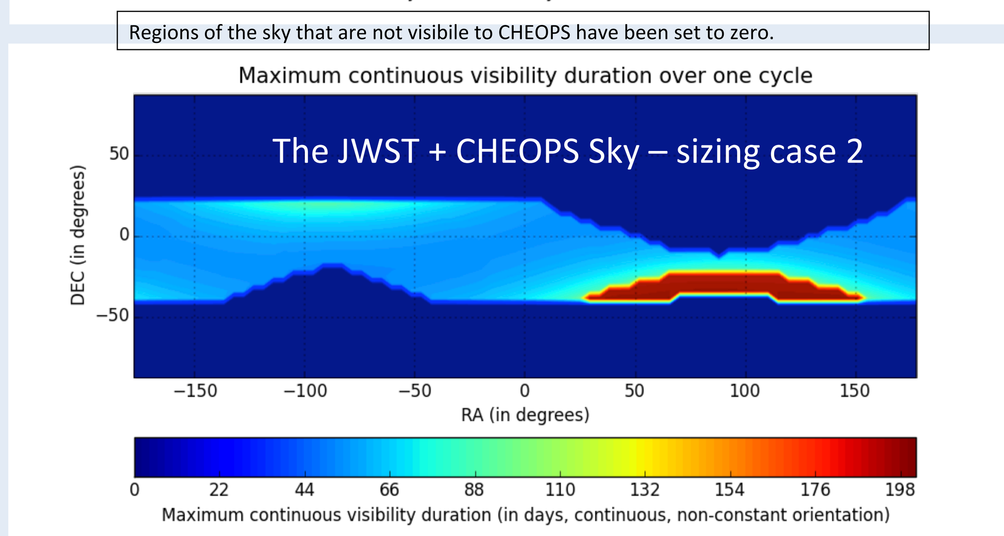
Following up CHEOPS Observations: the CHEOPS/JWST sky



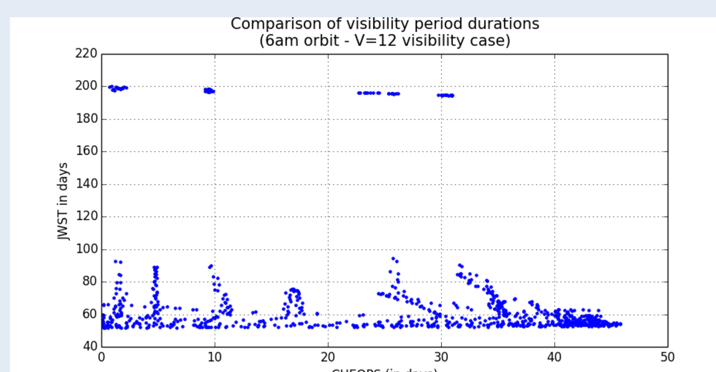
The JWST Sky







- JWST can observe between 30-40% of the sky at any one time
- Bulk of the visibility windows are in the 50-60 day range, and occur twice/yr
- CHEOPS sizing case 1:
  - Possible to fit max 2 transits/yr
- CHEOPS sizing case 2:
  - Possible to fit min. 6 transits/yr
  - BUT planning/scheduling will be an issue



Conclusions:

- Strong synergies exist between JWST and CHEOPS, with CHEOPS providing pre-selection of targets through first-step characterisation of the smaller planets.
- Emission and transmission spectroscopy of CHEOPS targets by NIRSpec is feasible: careful selection of targets will be needed and scheduling of observations will require attention.

References: Further details on NIRSpec in [1] Ferruit, P. et al., Space Telescopes and Instrumentation 2014: Optical, Infrared, and Millimeter Wave, edited by Jacobus M. Oschmann, Jr., Mark Clampin, Giovanni G. Fazio, Howard A. MacEwen, Proc. of SPIE Vol. 9143, 91430A, and at http://sci.esa.int/jwst/ ; Further details on CHEOPS in [2] from Fortier, A. et al., Proc. SPIE Vol. 9143, 91432J, and at http://cheops.unibe.ch/ and http://sci.esa.int/cheops/ ; Details on spectral modeling in [3] Garcia Muñoz et al., ApJ (2012) 755, 103

Acknowledgements: Thanks to the CHEOPS Consortium/Andrea Fortier and Thibault Kuntzer from the CHEOPS Mission Consortium for the results of simulations of the CHEOPS sky.