Developing and Improving The ELT/HARMONI Science Simulation Pipeline, HSIM

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Introduction

- The High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (HARMONI) is an upcoming instrument being developed for the ELT[1].
- The HARMONI SIMulator 2 (HSIM2) is the updated cube-in-cube-out simulation tool to enable science prediction for HARMONI on the ELT[2]
- HSIM2 has been updated to a 'follow-the-photons' architecture to more accurately simulate the effects seen in observed data.
- HSIM2 now incorporates improved PSF models, and in particular has non-axisymmetric AO PSFs. Additionally, new in HSIM2 is the ability to add detailed detector systematic effects.
- HSIM2 takes a 3D input data cube in lambda-x-y and then adds the effects of the sky, telescope, HARMONI instrument, and finally the detector.
- The end result is a set of lambda-x-y data cubes that can be analysed as if they were observed data.

Detailed Detector Systematics

- New to HSIM2 is the ability to add detailed detector systematic effects to the simulation when observing in the infrared.
- Previous versions of HSIM had very simplistic detector noise, simply drawing from a normal distribution centred on zero and scaled by a fixed read noise value defining the entire detector.
- Through detailed analysis of KMOS H2RG darks, and an engineering grade H4RG detector at ESO, we have characterised a read noise distribution for the HxRG detectors.
- This distribution peaks at the quoted read noise for a detector, but has a large tail to pixels with significantly higher noise.

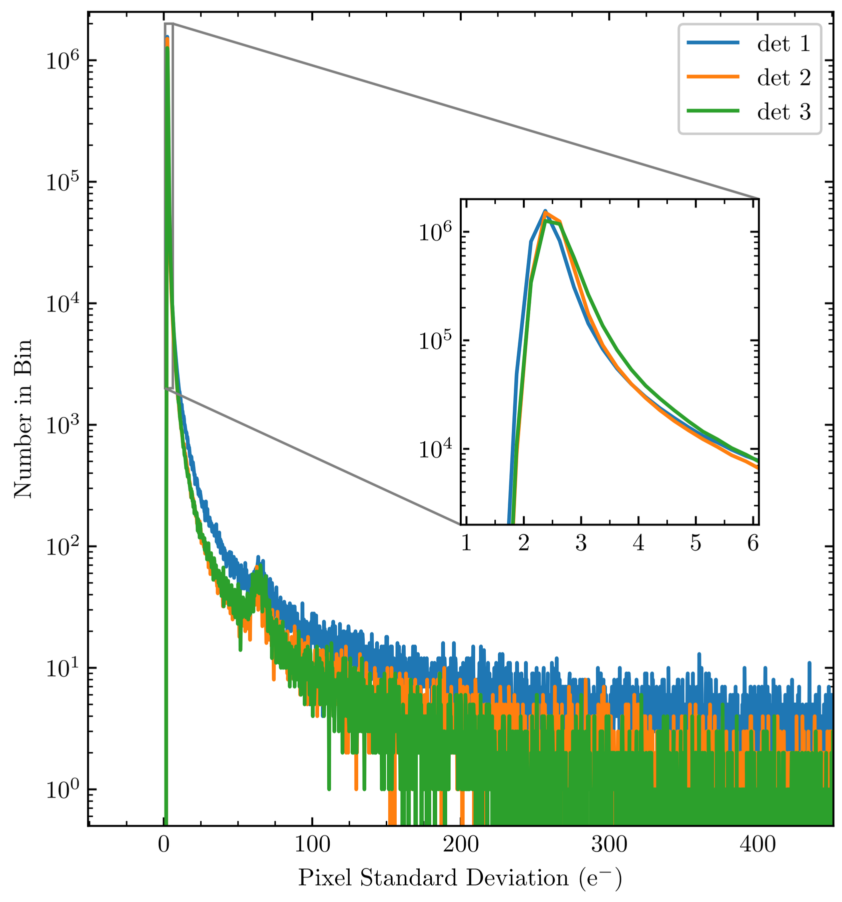


Figure 1: Distribution of read noise from analysis of over 100 KMOS dark images. The value peaks around the expected read noise of the detector, but has a large number of pixels with high read noise.

- We incorporate this distribution with the existing HxRG noise generation tool provided by Teledyne[3] to be able to create realistic detector noise similar to that expected on the HARMONI H4RGs.
- The Teledyne noise generator includes effects such as ACN, bias drift, 'picture frame' noise and amplifier bias offsets.
- This allows us to add more realistic noise into our simulations, as well as to test the impact of the levels of noise on our results.

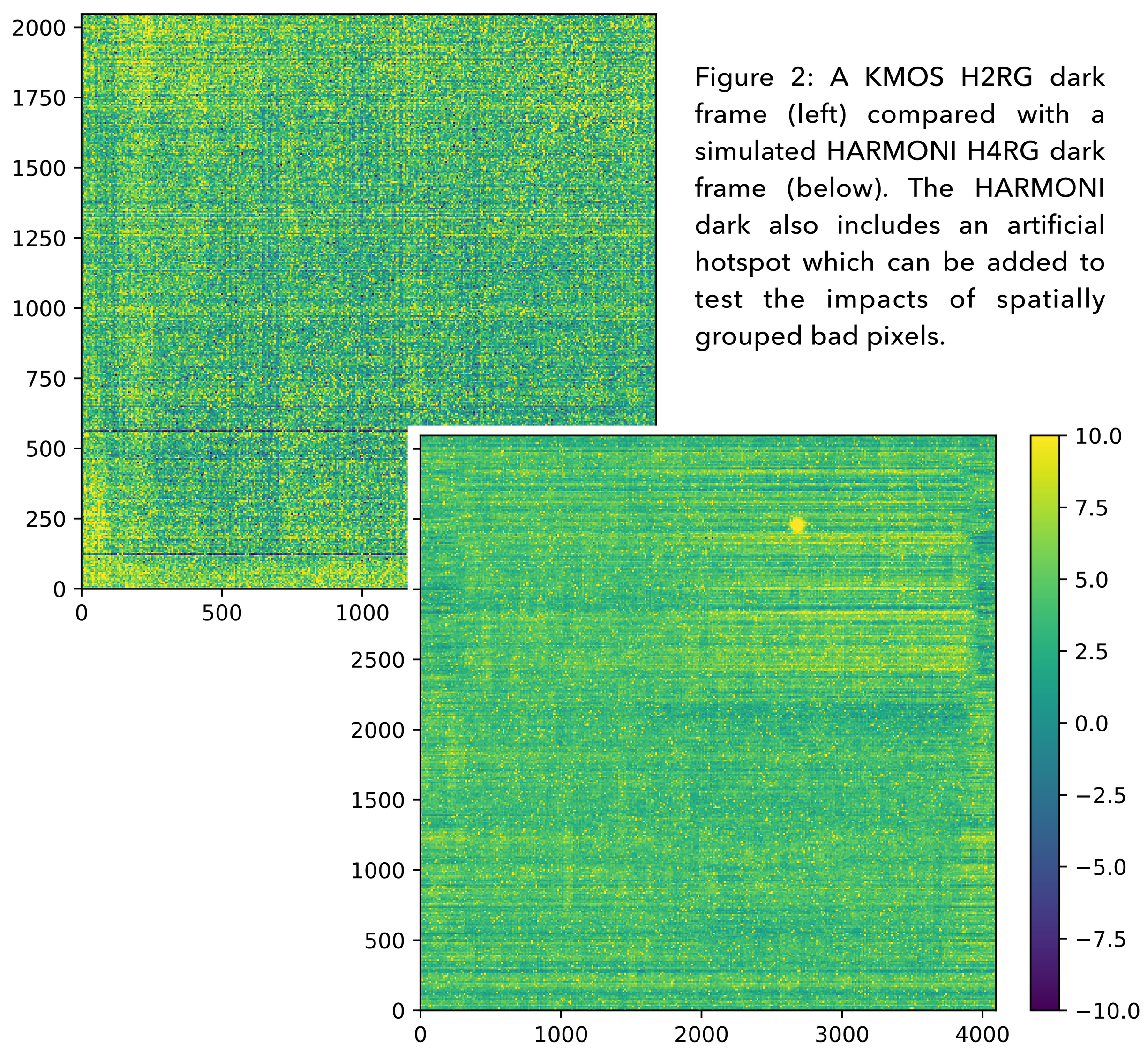
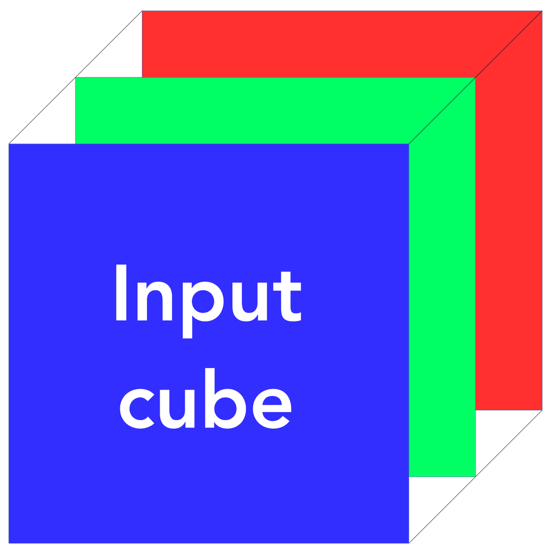


Figure 2: A KMOS H2RG dark frame (left) compared with a simulated HARMONI H4RG dark frame (below). The HARMONI dark also includes an artificial hotspot which can be added to test the impacts of spatially grouped bad pixels.

Follow-the-Photons Architecture



Sky

- ADR
- Background (lines + continuum + thermal)
- Transmission (Sky)
- Airmass + moon illumination

Telescope

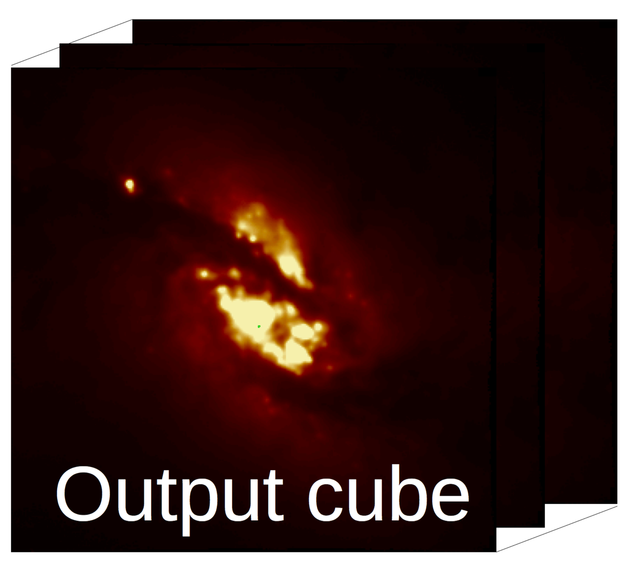
- AO PSF + Jitter
- Background (T = 285K)
- Transmission (Telescope + AO dichroic)

HARMONI (w/o detector)

- Spectrograph PSF
- Background
- Transmission (FPRS, Cryostat, Pre-optics, IFU, Spectrograph, Grating)

Detector

- QE
- Dark
- Read noise
- Systematics
- Crosstalk



Improved Instrumental PSFs

- HSIM2 now generates PSFs incorporating the chosen airmass and seeing, and are produced for each wavelength in the simulation.
- This is achieved through modelling the optical system in the Fourier domain, and obtaining the power spectral density, which characterises the phase and noise statistics[4].
- Includes the static and dynamic instrument PSF, with non-axisymmetric features such as those from the LTAO laser guide stars.
- Can also include additional jitter to the PSFs.

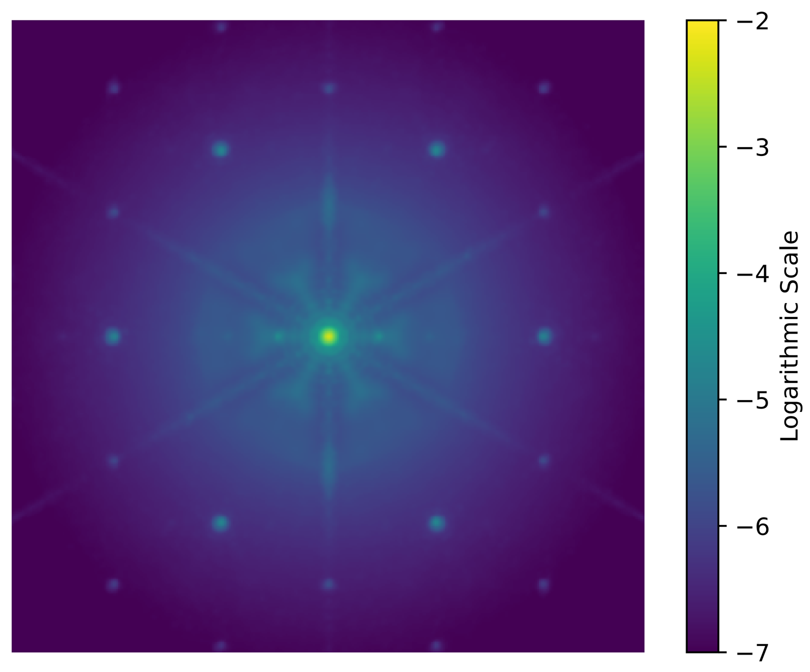


Figure 3: An example of an LTAO PSF used in HSIM2, in this example at ~1.6 microns. This is shown on a logarithmic scale to highlight the small scale structure and emphasis the non-axisymmetric nature of the AO PSFs.

Using HSIM2

- An example of using HSIM2 can be seen below, in which a mock observation is made of a galaxy extracted from cosmological simulations with the RAMSES code[5], and is placed at a redshift of z=1.44.
- We run HSIM2 for a simulated observation time of 5 hours, at the 10 mas spaxel scale.
- HSIM2 incorporates all the relevant information to produce the simulated observation, as well as a reduced cube which has perfect background subtraction.
- From this we can analyse the data as if it was an observation with HARMONI.

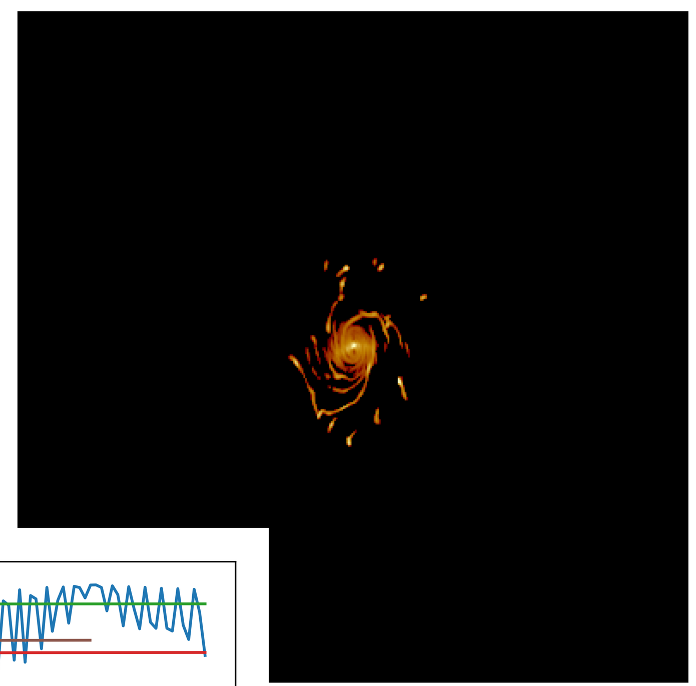
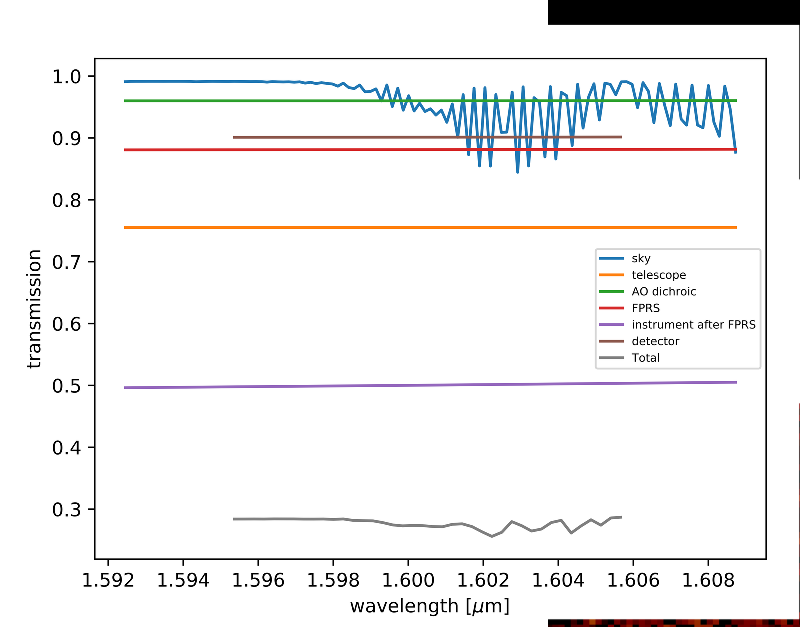


Figure 4a (right): Hα linemap of the galaxy generated from the input cube to HSIM2.

Figure 4b (below): Transmission from each component in the HSIM2 simulator, with the total transmission shown in grey.



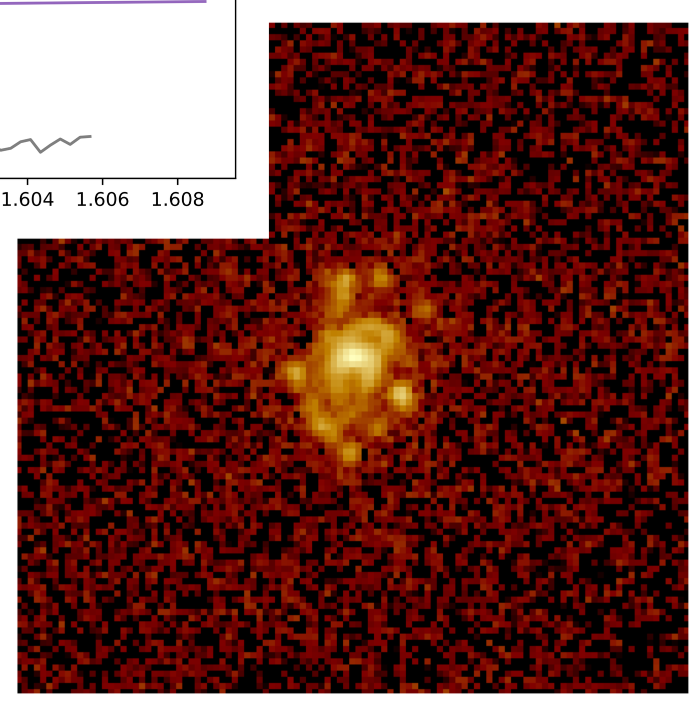


Figure 4c (right): Hα linemap of the galaxy generated from a reduced output cube from HSIM2.

Summary

- HSIM2 produces more realistic simulations for science prediction for HARMONI.
- The 'follow-the-photons' architecture more accurately represents the path of light through the instrument.
- Detailed detector systematics allow for the inclusion of noise effects within the plane of the detectors.
- Improvements to the AO PSFs dramatically improve the ability for HSIM2 to accurately predict the performance of HARMONI.
- Output cubes can be analysed as if they were observed data to predict the performance of HARMONI.

HSIM2 is available at: **github.com/HARMONI-ELT/HSIM**

References

[1] Thatte, N. et. al (2010) **doi.org/10.1117/12.857445**
[2] Zieleniewski, S. et. al. (2015) **arxiv.org/abs/1508.04441**
[3] Rauscher, B. (2015) **dx.doi.org/10.1086/684082**
[4] Neichel, B. et. al (2009) **doi.org/10.1364/JOSAA.26.000219**
[5] Teyssier, R. (2002) **arxiv.org/abs/astro-ph/0111367**

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