HSIM: Simulation pipeline for HARMONI on the E-ELT

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HSIM: Simulation pipeline for HARMONI on the E-ELT

- Motivation for a Simulator
- Methodology
- Development & Overview
- AO PSF Parameterisation
- Current and Future Projects
Motivation for a Simulator

- Many instrument (IFU) simulators exist!
- EAGLE/ELT-MOS: Puech et al. 2010
- KMOS - SPECSIM: Lorente et al. 2008
- JWST/NIRSpec: Piqueras et al. 2010, Dorner et al. 2011
Motivation for a Simulator

• Developed as part of my D.Phil thesis.

• 3 key reasons:
  
  – Step above normal ETCs: quantify feasibility of achieving particular science goal.
  
  – Develop and test new analysis software
  
  – Trade-offs between different instrument designs/configurations
Method

Based on pipeline developed by Puech et al. (2008, 2010a,b) and described in Zieleniewski et al. (2015b, submitted)

• A) Input data-cube (3D FITS file) encoding physical characteristics of object

• B) Simulation pipeline that adds first-order sky, telescope, instrument and detector effects (& random/systematic noise)

• Analysis of output mock data – what information can be extracted – compare output to input cubes
The Challenge of Input Cubes

• Input cube is a FITS file of shape (RA, DEC, $\lambda$).

• Input encodes physical description of object:
  – Morphology
  – Spectral continuum & absorption/emission
  – Kinematics
  – Chemical abundances
  – etc
The Challenge of Input Cubes

Need high spatial and spectral resolution inputs!

Numerous methods developed so far:

- Analytical models describing object
- High resolution simulations (e.g. RAMSES cosmo+hydro code)
- Redshift high resolution local object data-cube
- Point source spectrum in a single spaxel!
Interface

HARMONI Simulator Interface

Instrument

Input Cube
Output Dir
DIT [s]
NINT
X Scale [mas]
Y Scale [mas]
Grating

Telescope

Telescope:
AO Mode:
Zenith Seeing [arcsec]:
Zenith Angle [deg]:
User PSF (replaces AO choice): None
Telescope Temperature [K]:

Miscellaneous

Subtract Background
Return Object Cube
Return Transmission Cube
No. of processors (1–4)
Noise Seed
Set Spec Samp [A/pix]
Additional PSF Blur [mas]:

Commence Simulation
Method

**Input data-cube**
- Spatial structure
- Velocity scale
- Emission/absorption lines
- Spectral continuum

**Observing parameters**
- DIT, NDIT, grating, spaxel scale,
- AO mode, seeing, Z_D, T_{exp}

**Outputs:**
- Mock observed cube (& variance)
- Background cube (& variance)
- SNR cube

**Analysis of observed cube:**
- Kinematics, spectral aperture extraction, dynamical masses, line indices....

**Steps:**
- Spectral LSF convolution
- Atmospheric differential refraction
- Spatial PSF convolution
- Spaxel rebinning
- Sky, telescope, instrument, detector background & throughput models
- Poisson and systematic noise
Spectral LSF

- Cube convolved with Gaussian LSF (constant width) to approximate resolution of a slit-width limited grating spectrometer

\[ \Delta \lambda_{\text{conv}} = \sqrt{(\Delta \lambda_{\text{out}})^2 - (\Delta \lambda_{\text{in}})^2} \]
ADR

- Atmospheric Differential Refraction added
- Effect prominent both in visible at at fine spaxel scales!
- Model with equations from Roe (2002)
E-ELT PSF

- Novel PSF parameterisation using *eltpsf fit* (J. Liske). Detailed in Zieleniewski et al. (2013, 2014), and expansion on method of Serre et al. (2010) for VLT MUSE.

- AO PSF generated for each channel in datacube.

- SCAO, LTAO and seeing-limited available. Uses FFTs for convolutions.
E-ELT PSF

- Novel PSF parameterisation using eltpsffit (J. Liske).
- Detailed in Zieleniewski et al. (2013, 2014).
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- Uses FFTs for convolutions.
Background & Throughput

• Sky background and transmission from ESO Skycalc model (Noll et al. 2012 and Jones et al. 2013)

• Telescope modelled as grey-body with:
  – 7 warm reflections through to instrument
  – 6 spider arms
  – central obscuration

• Cryogenic instrument

• Detectors modelled on visible CCDs and NIR arrays
Noise

- Random and systematic noise added from all sources
- Detector noise statistics based on MUSE (visible) and KMOS (NIR)
Outputs

Main Outputs:
• Observed cube – mock observation
• Background cube – mock “sky” observation
• SNR cube: gives S/N for each pixel.

Further options to output:
• Reduced cube: Object cube – Background cube
• Object cube (no noise)
• Atmospheric transmission spec
Verification

Puech et al. 2008, 2010a, 2010b

ESO SINFONI ETC
Current Projects: Point Sources

Table 2. Point source sensitivity predictions for HARMONI with LTAO calculated from a 2 × 2 spaxel aperture centred on the object.

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<th>Band</th>
<th>R</th>
<th>4 × 4</th>
<th>10 × 10</th>
<th>20 × 20</th>
<th>30 × 60</th>
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<td>23.6</td>
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<td>26.3</td>
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</tr>
</tbody>
</table>

![Graph showing sensitivity predictions](image-url)
Current Projects: $z = 2-3$ galaxies

- Analytical models for galaxies
- Smooth-disc and clumpy morphologies
- Extract kinematics
- Resolve star forming regions
Current Projects: ULIRGs

4 mas input at z=2

10 mas

20 mas

60 mas
Current Projects: SMBHs
Current Projects: Plenty More!

- RAMES cosmological simulation output → HSIM input! (Sarah Kendrew – Wednesday 16:50)

- Resolved stellar populations using SWIFT M31 observations (Niranjan Thanate)

- Supernovae and GRBs (Isobel Hooke, Nial Tanvir)

- Absorption spectroscopy in passive galaxies (Ryan Houghton – Thursday 13:45)
And anything else?
HSIM: Workshop

- Thursday 4:45pm & Friday 9am-1pm


- Code written in Python and uses 5 external packages:
  - numpy
  - scipy
  - astropy
  - wxPython (optional but strongly recommended for GUI)
  - pprocess (OSX/Linux only)

- Please check modules have installed correctly!

- Any problems: contact myself or Sarah Kendrew