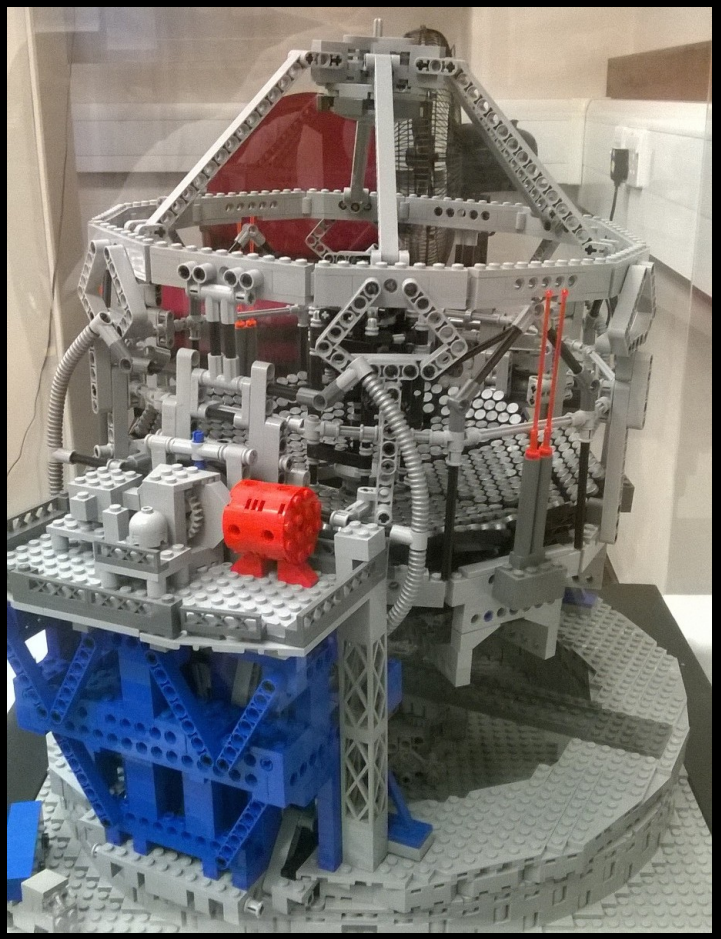
HSIM: Simulation pipeline for HARMONI on the E-ELT



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29th June 2015

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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 Projecrs

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Motivation for a Simulator

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

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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

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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

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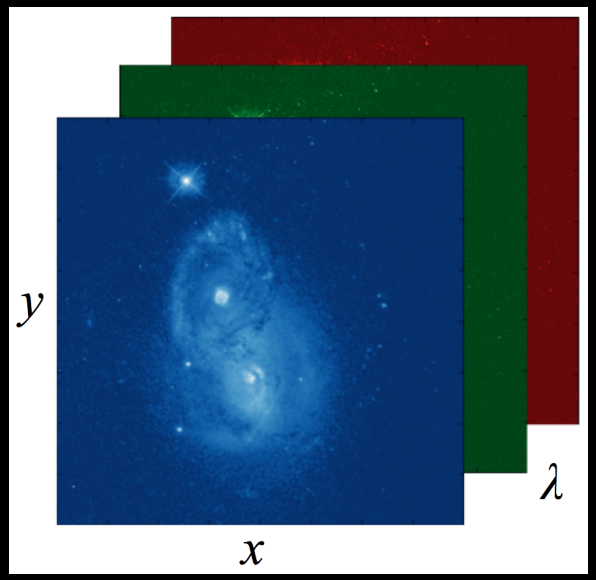
The Challenge of Input Cubes

- Input cube is a FITS file of shape (RA, DEC, λ).

- Input encodes physical description of object:
  - Morphology
  - Spectral continuum & absorption/emission
  - Kinematics
  - Chemical abundances
  - etc



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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!

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Interface

HARMONI Simulator Interface

Instrument

Input Cube [ ] Browse

Output Dir /Users/zieleniewski/Docume Browse

DIT [s] 900

NINT 1

X Scale [mas] 20

Y Scale [mas] 20

Grating V+R [0.47-0.81 um] (R=3500)

Telescope

Telescope: E-ELT

AO Mode: LTAO

Zenith Seeing [arcsec]: 0.67

Zenith Angle [deg] 0

User PSF (replaces AO choice) None Browse

Telescope Temperature [K]: 280.5

Commence Simulation

Miscellaneous

Subtract Background

Return Object Cube

Return Transmission Cube

No. of processors (1-4) 3

Noise Seed Random

Set Spec Samp [A/pix]

Additional PSF Blur [mas]: 0

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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}

Spectral LSF convolution

Atmospheric differential refraction

Spatial PSF convolution

Spaxel rebinning

Sky, telescope, instrument, detector background & throughput models

Poisson and systematic noise

Outputs:

Mock observed cube (& variance)
Background cube (& variance)
SNR cube

Analysis of observed cube:

Kinematics, spectral aperture extraction, dynamical masses, line indices….

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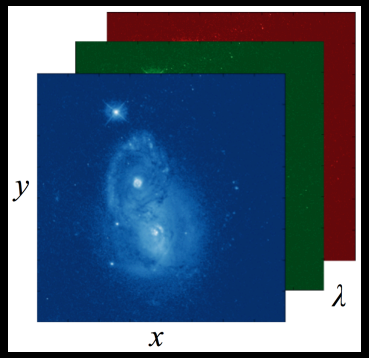
Spectral LSF



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

$$\Delta\lambda_{\mathrm{conv}} = \sqrt{(\Delta\lambda_{\mathrm{out}})^2 - (\Delta\lambda_{\mathrm{in}})^2}$$

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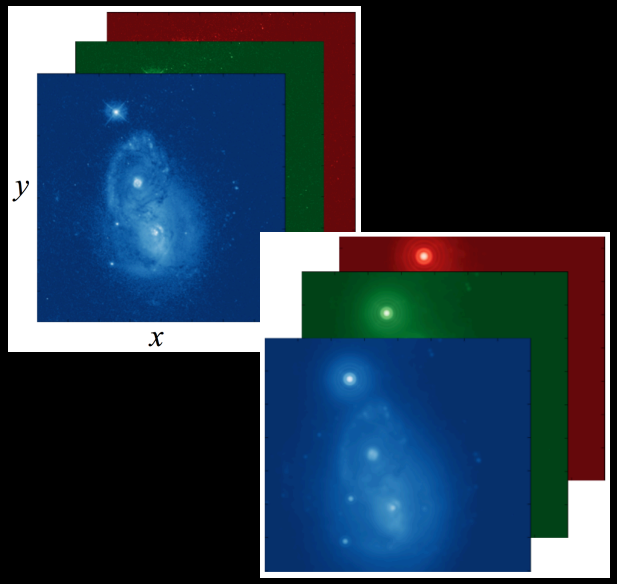
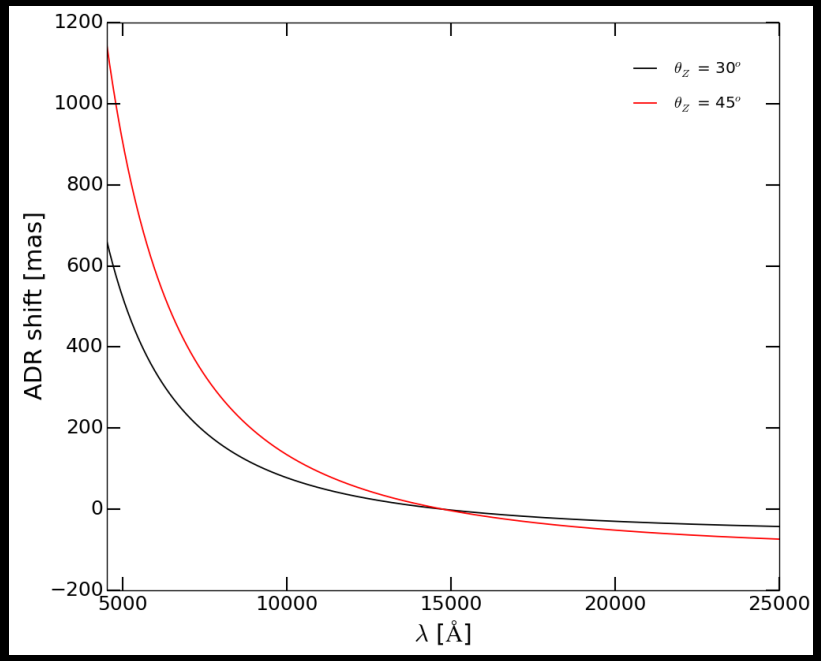
ADR



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



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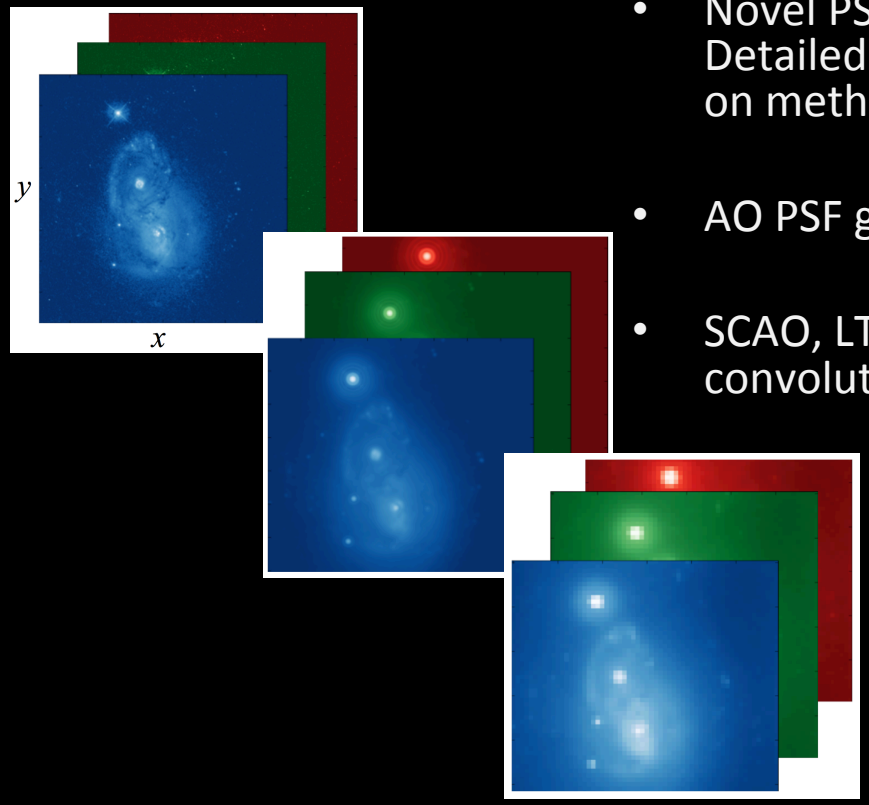
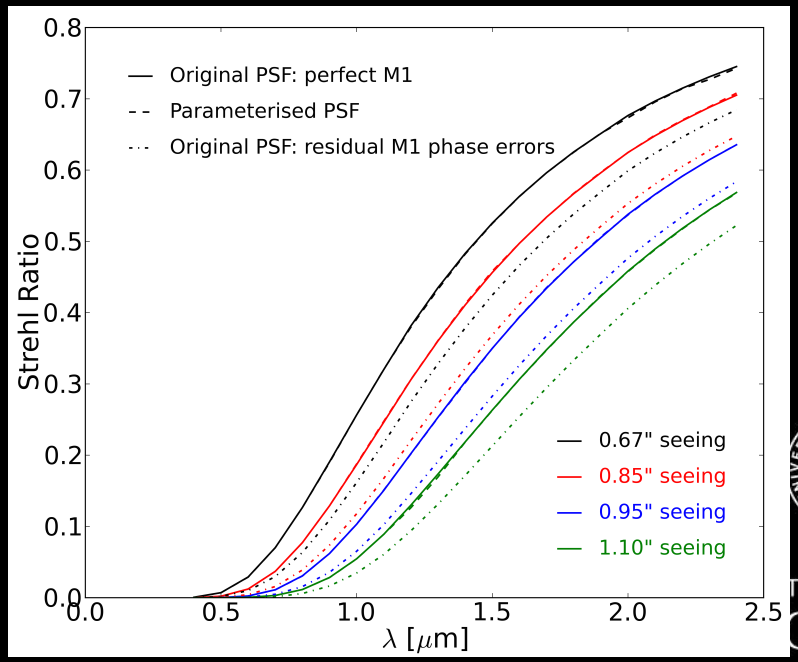
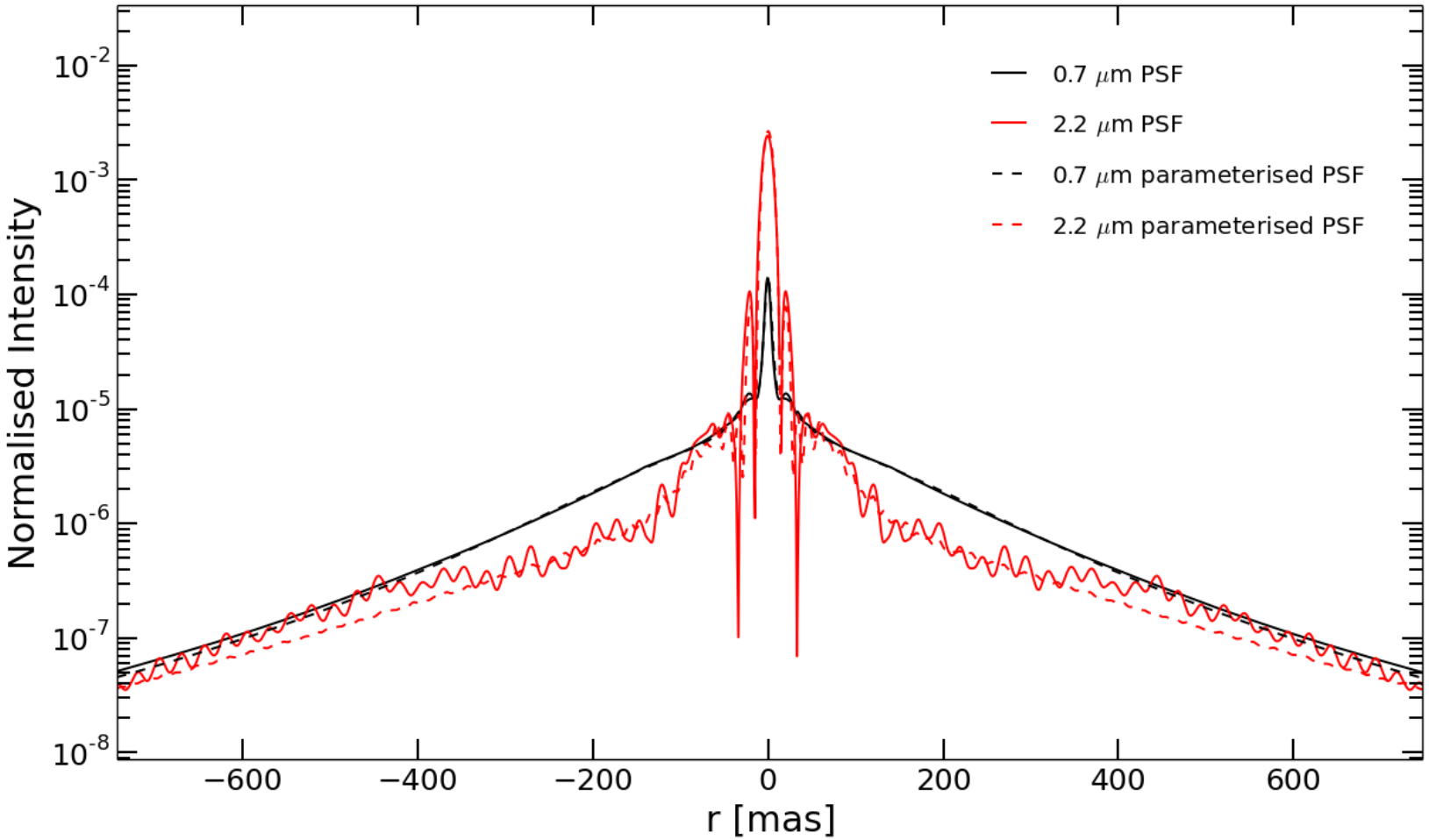
E-ELT PSF



- Novel PSF parameterisation using *eltpsffit* (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


0.7 μm PSF
2.2 μm PSF
0.7 μm parameterised PSF
2.2 μm parameterised PSF
Normalised Intensity
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
−600
−400
−200
0
200
400
600
r [mas]

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

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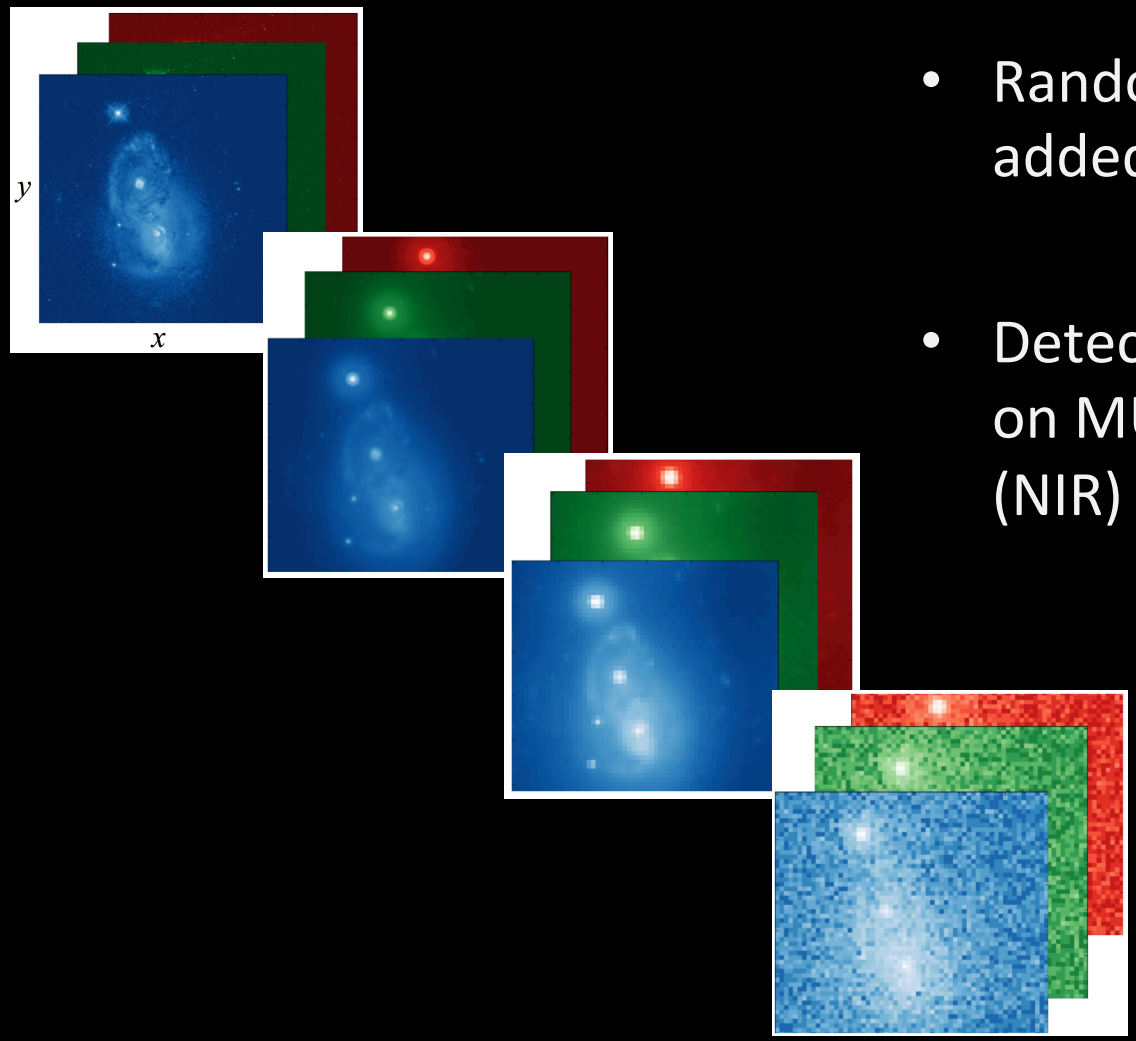
Noise



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

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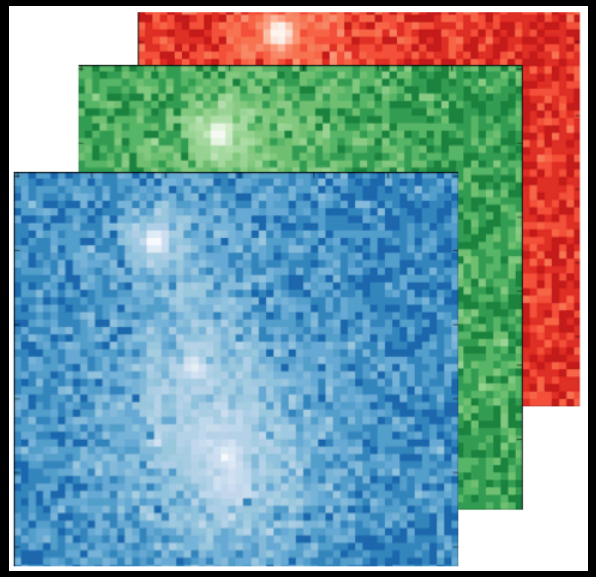
Outputs

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



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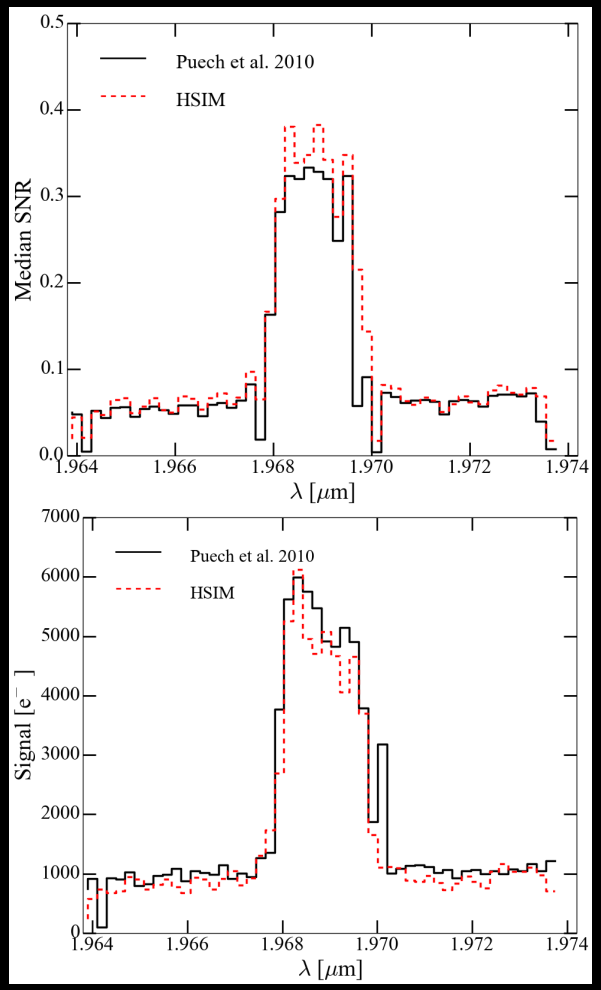
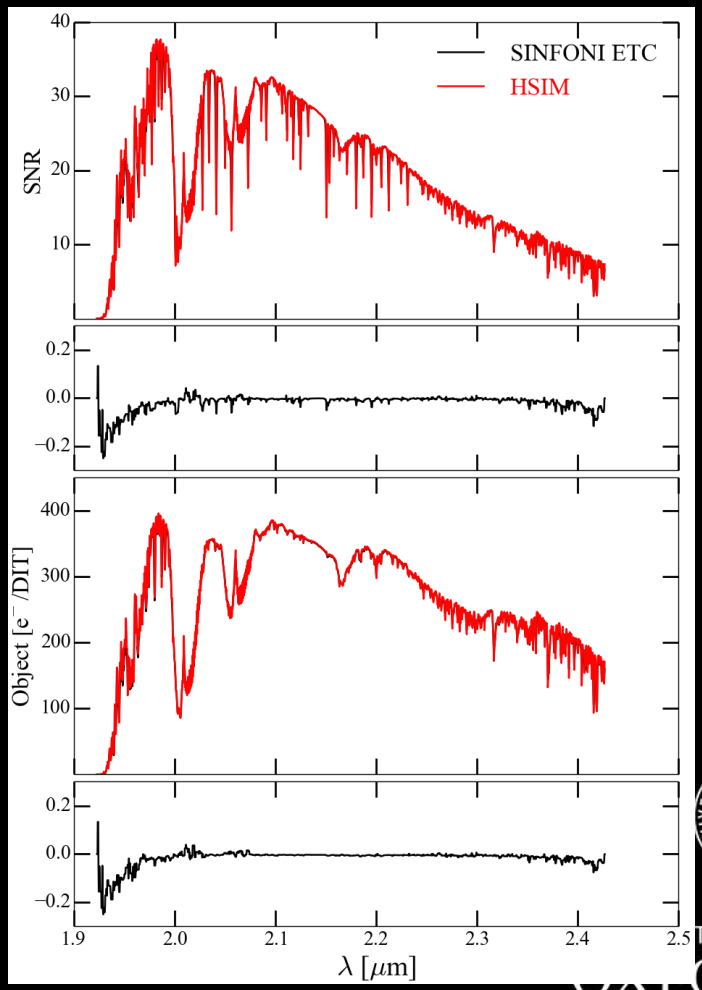
Verification

Puech et al. 2008, 2010a, 2010b



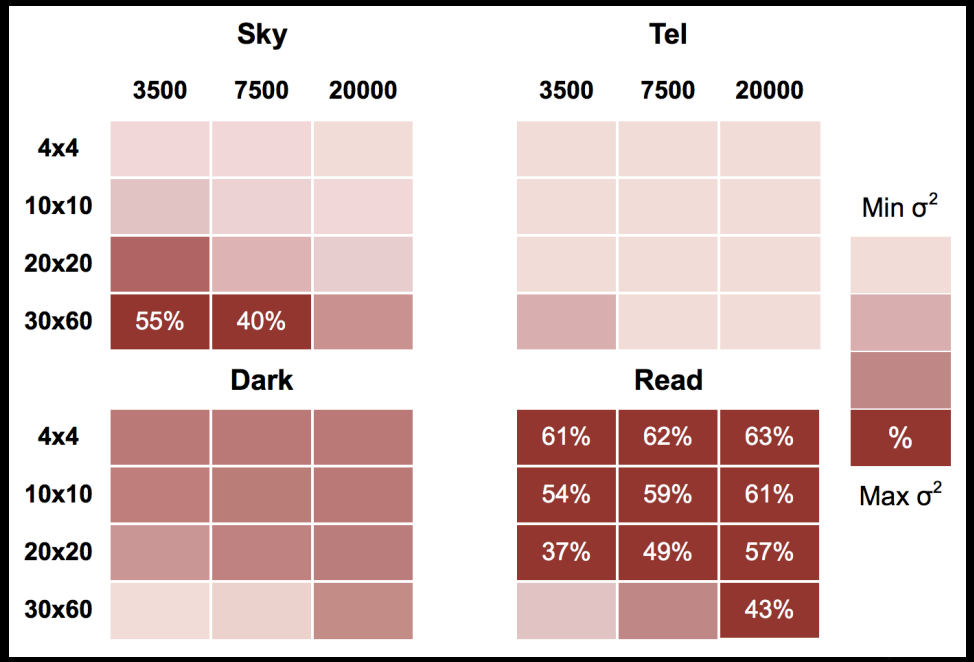
ESO SINFONI ETC



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.

		2×2 spaxel aperture			
Band	R	4×4	10×10	20×20	30×60
R	3500	22.7	23.6	24.3	25.1
H	3500	26.2	27.0	27.0	26.4
	7500	25.2	26.0	26.1	25.7
	20000	24.1	25.0	25.1	24.9
K	3500	25.7	26.3	25.8	24.8
	7500	25.2	25.8	25.4	24.5
	20000	24.2	25.1	24.8	23.9



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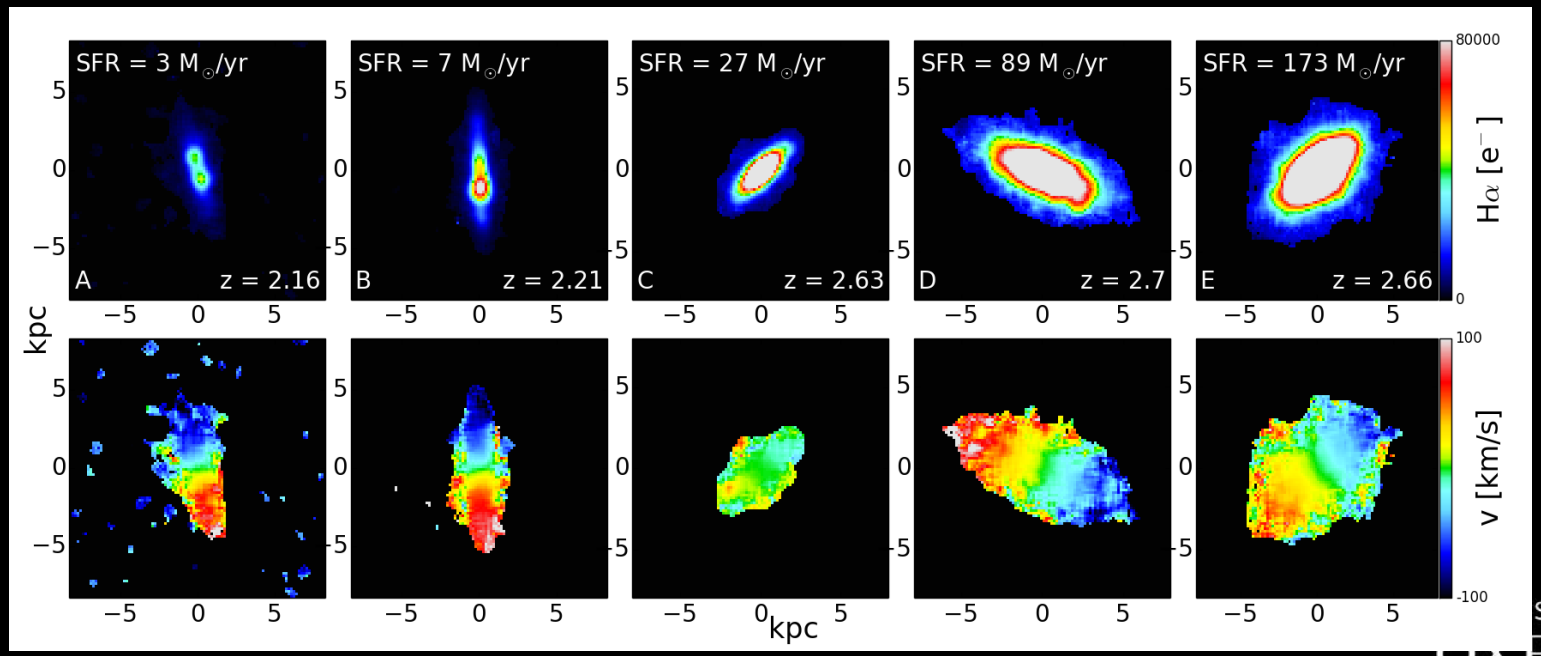
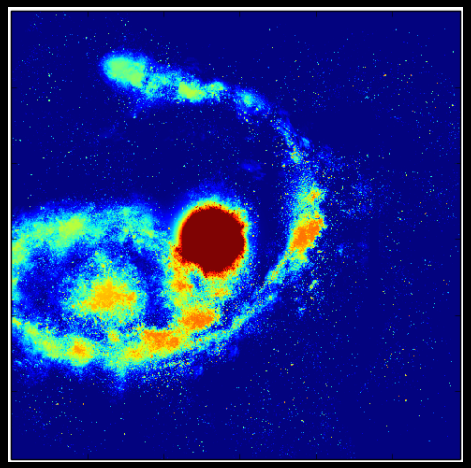
Current Projects: z = 2-3 galaxies

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

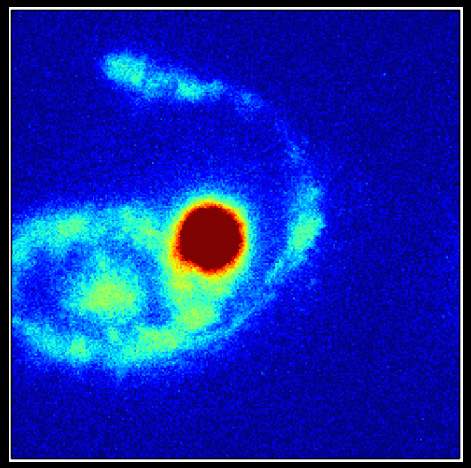


Current Projects: ULIRGs

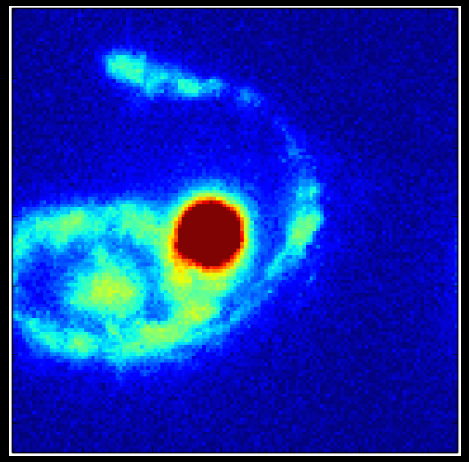
4 mas input at z=2



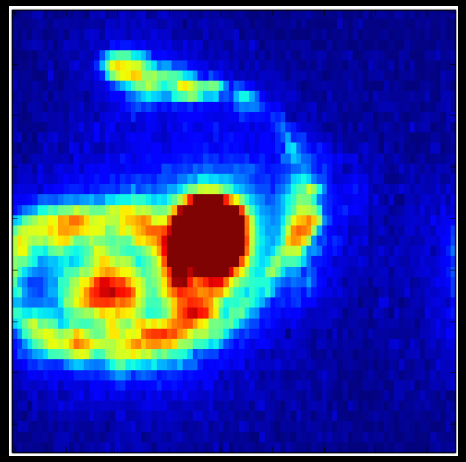
10 mas



20mas



60 mas



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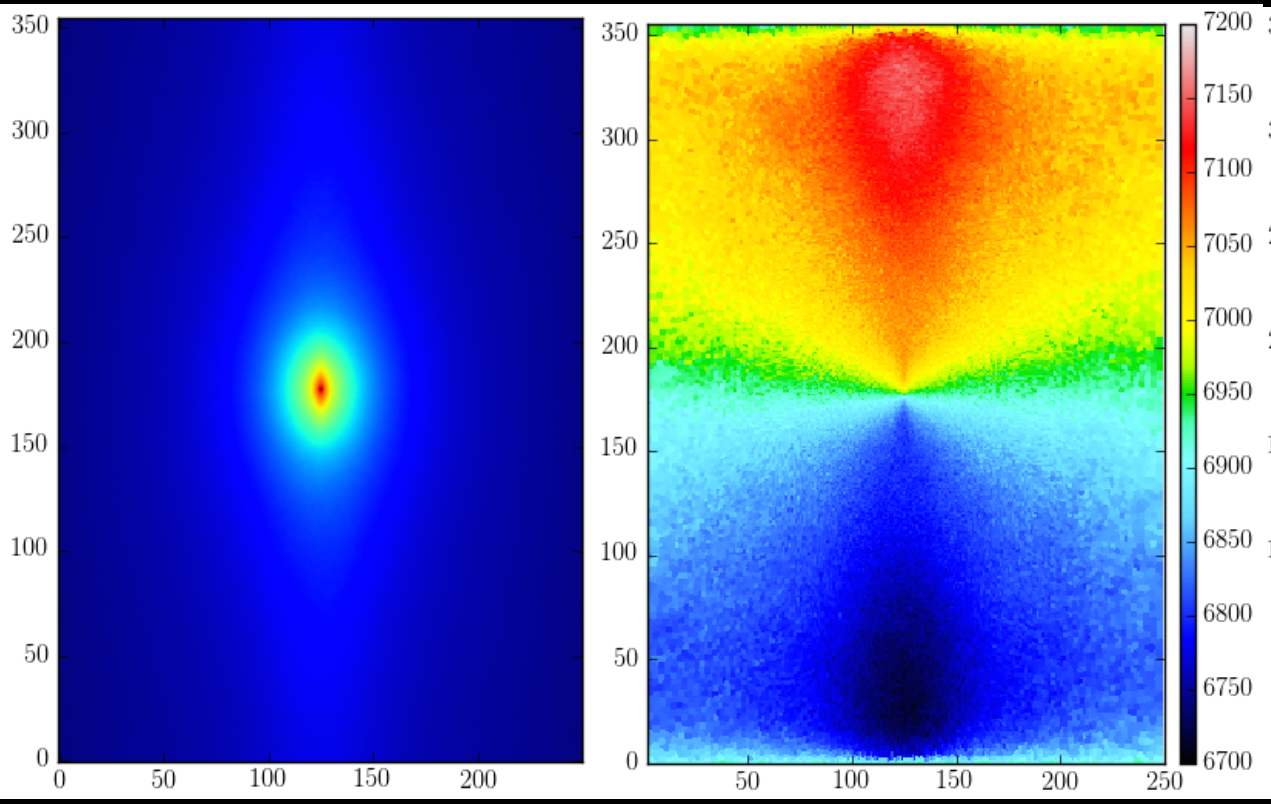
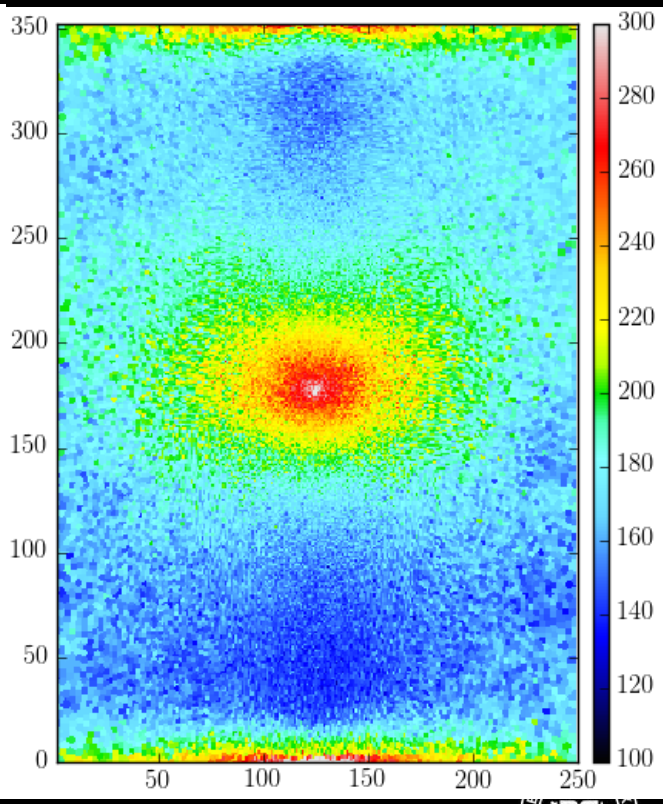
Current Projects: SMBHs





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Current Projects: Plenty More!

- RAMES cosmological simulation output → HSIM input! (Sarah Kendrew – Wednesday 16:50)
- Resolved stellar populations using SWIFT M31 observations (Niranjan Thatte)
- Supernovae and GRBs (Isobel Hooke, Nial Tanvir)
- Absorption spectroscopy in passive galaxies (Ryan Houghton – Thursday 13:45)

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And anything else?

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HSIM: Workshop

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

- Information on website:

http://www-astro.physics.ox.ac.uk/instr/HARMONI/Simulator/simulator.html

- 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

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