HARMONI PRELIMINARY DESIGN

Scientific impact of PSF knowledge for AO assisted spectrographs

Niranjan Thatte

PI – HARMONI@ELT

(on behalf of HARMONI Science Team)

HARMONI – spatial setup

60 mas × 30 mas	20 mas	10 mas	4 mas
For non-AO & visible observations	For optimal sensitivity (faint targets)	Best combination of sensitivity and spatial resolution	Highest spatial resolution (diffraction limited)

Equivalent slit length: 16 arcmin

or

3.2 metres in ELT focal plane

6.42” × 9.12”

3.04” × 4.28”

1.52” × 2.14”

0.61” × 0.86”

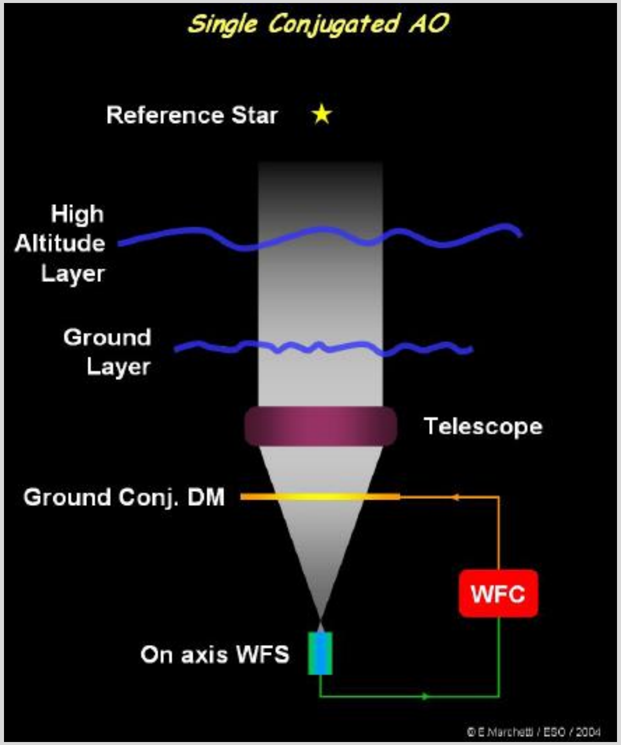
~152 × 214 (32000) spaxels at all scales

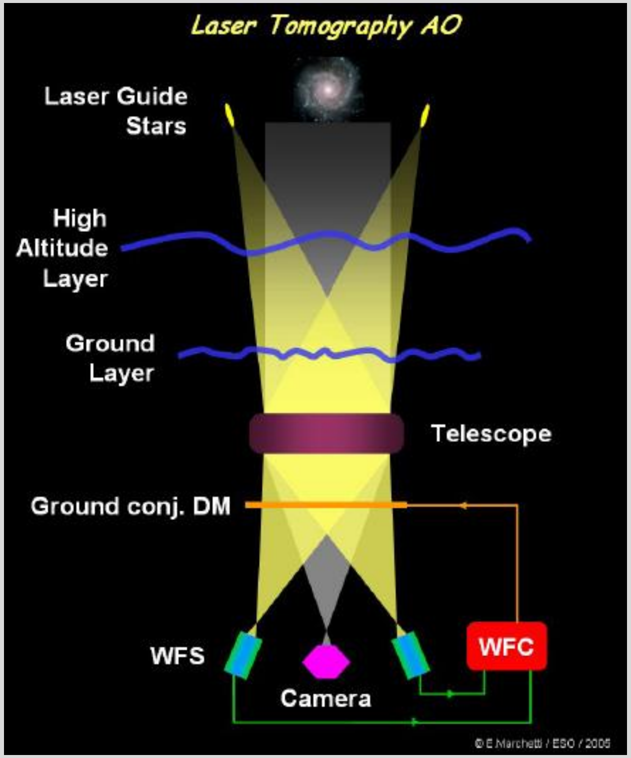
CSIC · Instituto de Astrofísica de Canarias · Durham University · University of Oxford · RAL Space · Science & Technology Facilities Council UK Astronomy Technology Centre · LAM Laboratoire d'Astrophysique de Marseille · ONERA · CRAL · irap · IPAG · ESO

HARMONI spectral setup

Bands	Wavelengths (μm)	R
“V+R” or “I+z+J” or “H+K”	0.45-0.8, 0.8-1.35, 1.45-2.45	~3000
“I+z” or “J” or “H” or “K”	0.8-1.05, 1.05-1.35, 1.45-1.85, 1.95-2.45	~7500
“Z” or “J_high” or “H_high” or “K_high”	0.9, 1.2, 1.65, 2.2 (TBD)	~20000

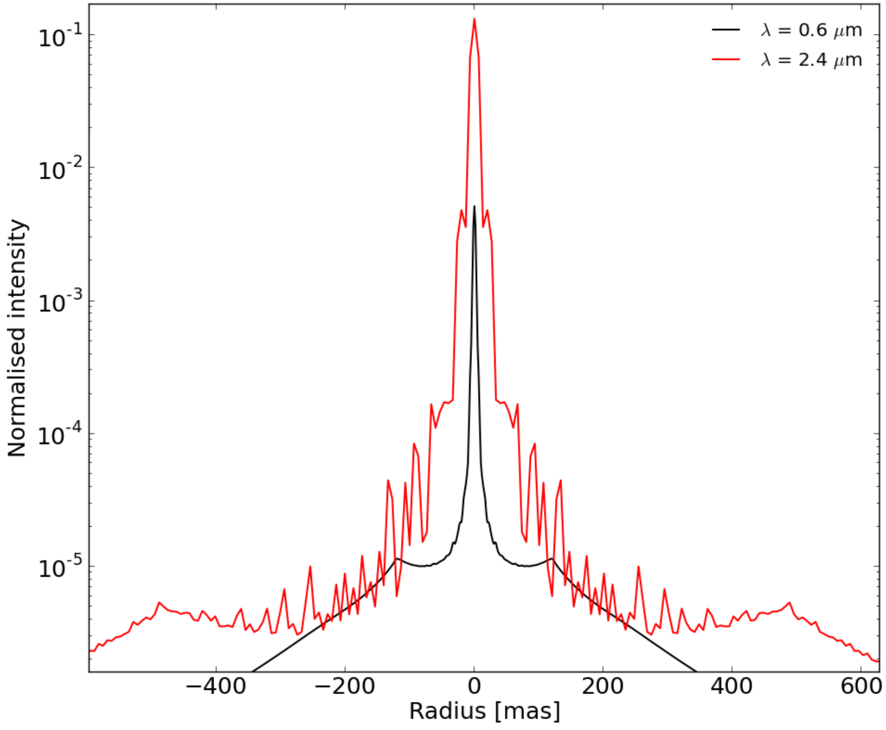
HARMONI Adaptive Optics Flavours

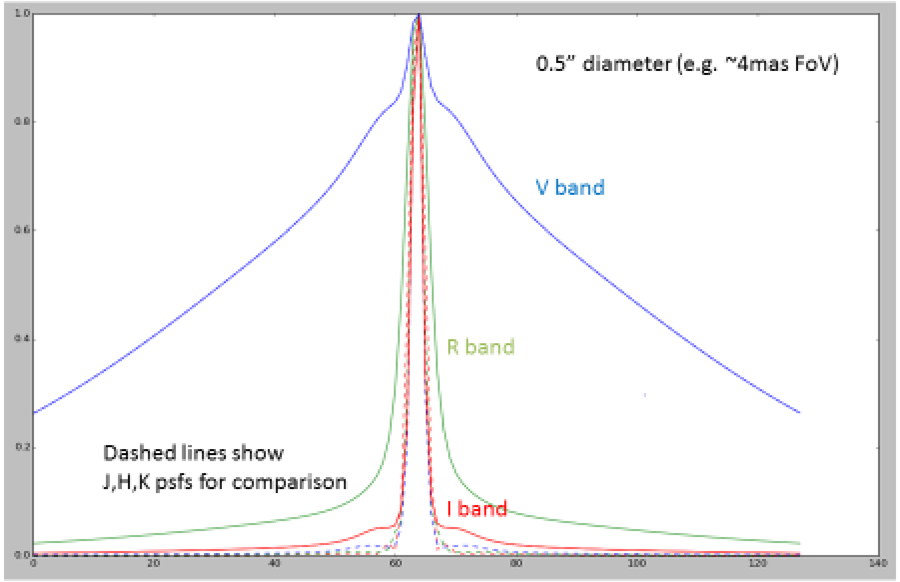




SCAO	NOAO	LTAO
1% sky coverage	100% sky coverage	30-50% sky coverage
Diffraction limited (0.01”)	Seeing limited (0.7”)	Diffraction limited (0.01”)

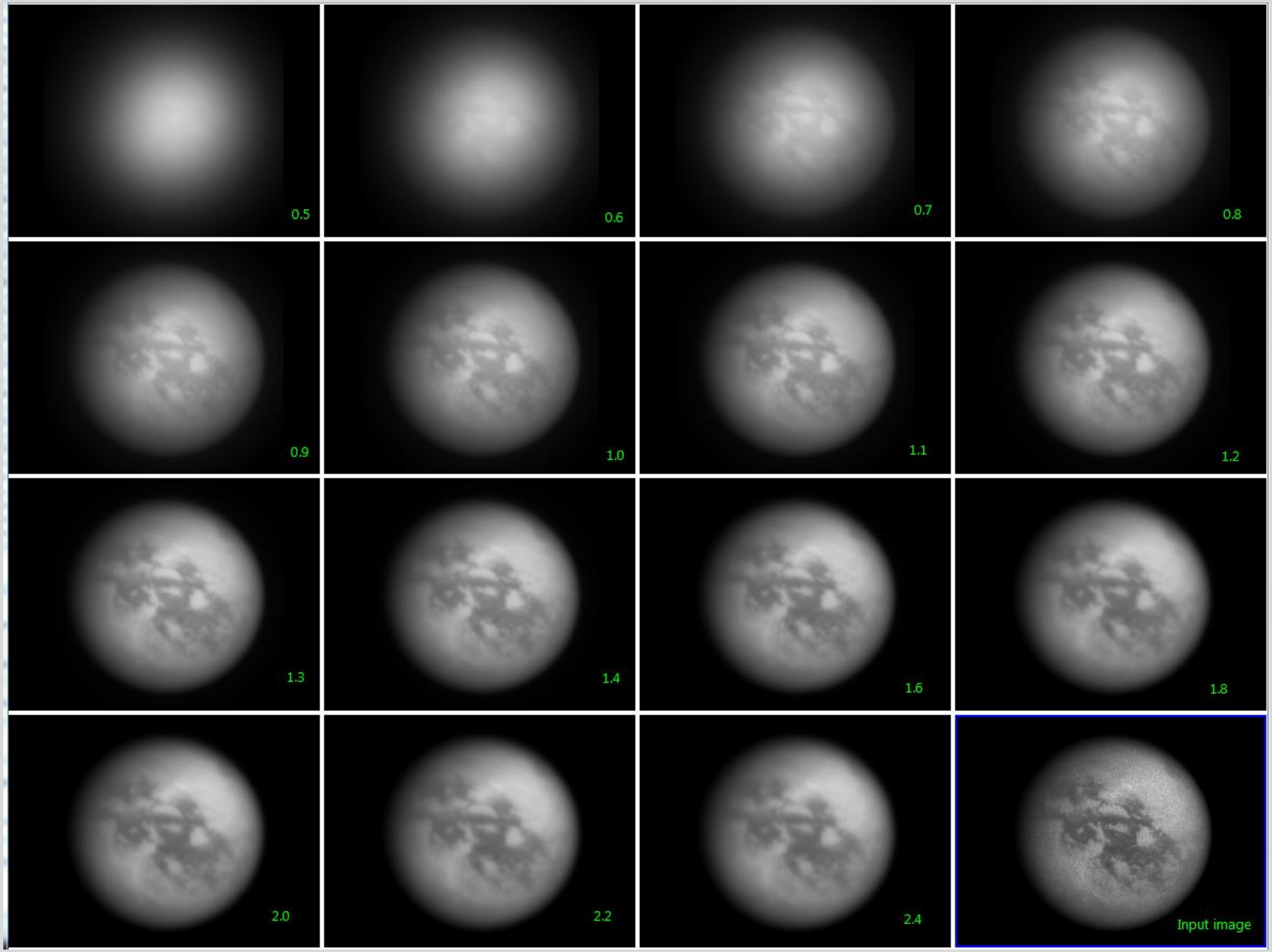
ELT AO PSF varies strongly with λ





S. Zieleniewski et al. (MNRAS 2015)

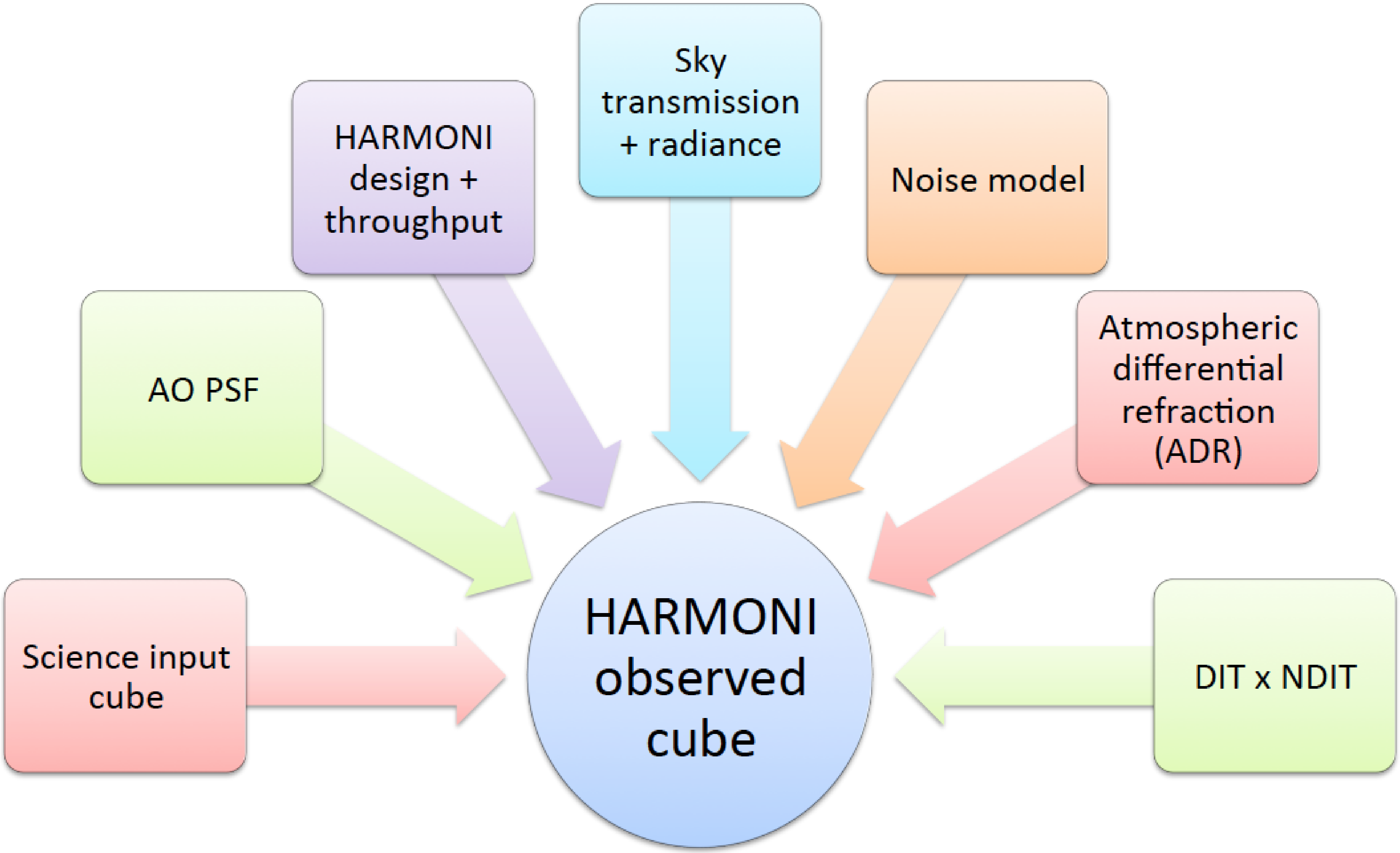
Titan at many wavelengths



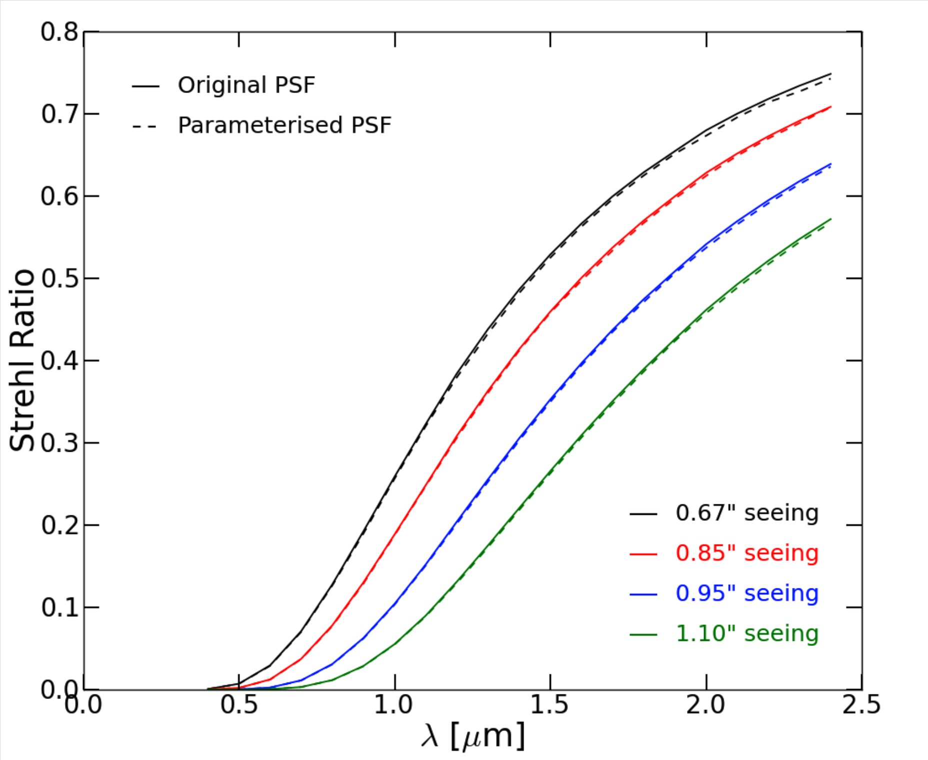
Motivation for PSF reconstruction

- Create mock observations of sources with simulated PSF, using HSIM
- Analyse (noisy) data using Original PSF, and ”wrong” PSFs, with different Strehl, jitter, and elongation.
- Quantify dependence of extracted parameters on PSF knowledge ☞ required accuracy

HARMONI Simulator Scheme



PSF effects



- Strong variation of PSF with wavelength
- Parameterize PSF (axi-symmetric) with a few parameters, which vary smoothly with wavelength.
- Allows quick computation of PSF at any wavelength, with high accuracy.
- Extended to allow user defined PSF, interpolated in λ

Motivation for PSF reconstruction

- Create mock observations of sources with simulated PSF, using HSIM
- Analyse (noisy) data using Original PSF, and ”wrong” PSFs, with different Strehl, jitter, and elongation.
- Quantify dependence of extracted parameters on PSF knowledge ☞ required accuracy

PSFs used in simulations

PSF name	LGS asterism diam.	Residual jitter	Orientation
Original	2.2 arcmin	3 mas rms	N/A
New_PSF1	1 arcmin	2 mas rms	N/A
New_PSF2	1 arcmin	4 mas rms	N/A
New_PSF3	1 arcmin	4 mas × 2 mas rms	45 degrees
New_PSF4	1 arcmin	4 mas × 2 mas rms	0 degrees

Motivation for PSF reconstruction

- Create mock observations of sources with simulated PSF, using HSIM
- Analyse (noisy) data using Original PSF, and ”wrong” PSFs, with different Strehl, jitter, and elongation.
- Quantify dependence of extracted parameters on PSF knowledge ☞ required accuracy

Study three science cases

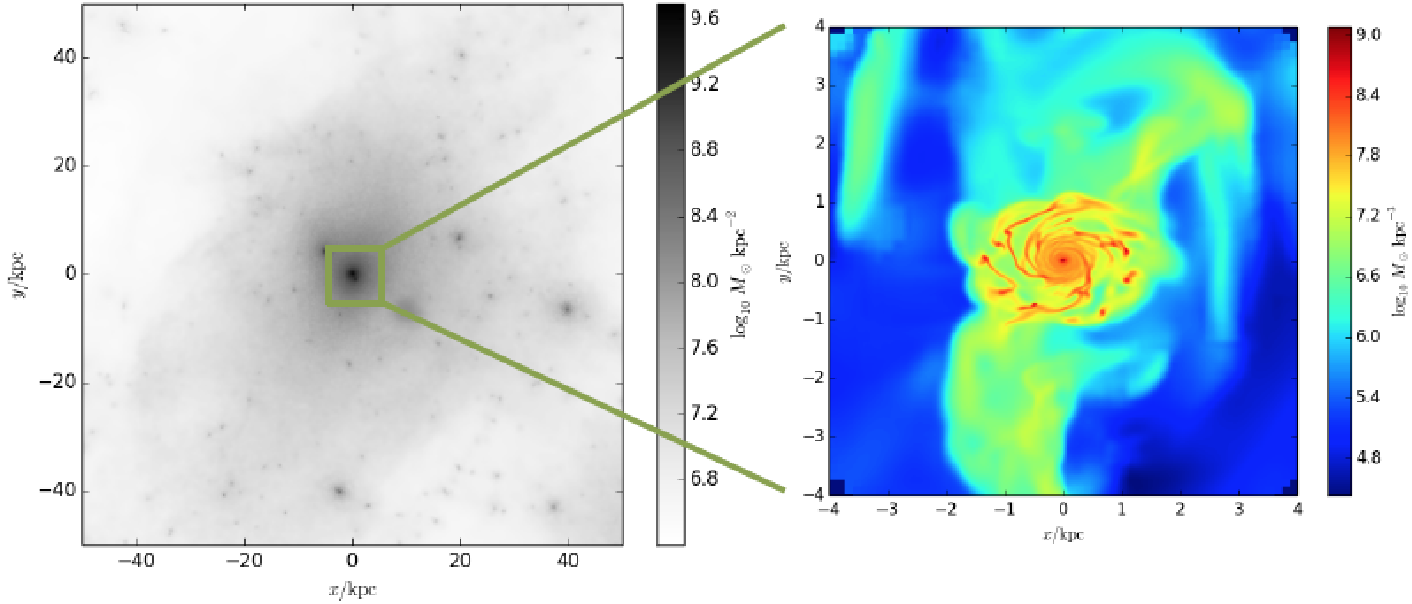
- Effective radius of high-z star forming galaxy (with S. Kendrew, B. Haußler, M. Richardson)

- Rotation curves of high-z galaxies (long slit and IFS) (with L. Routledge, M. Richardson, M. Pereira)

- Stellar kinematic signatures of intermediate mass black holes in nuclear stellar clusters (with T. Yasin, R. Houghton, J. Magorrian)

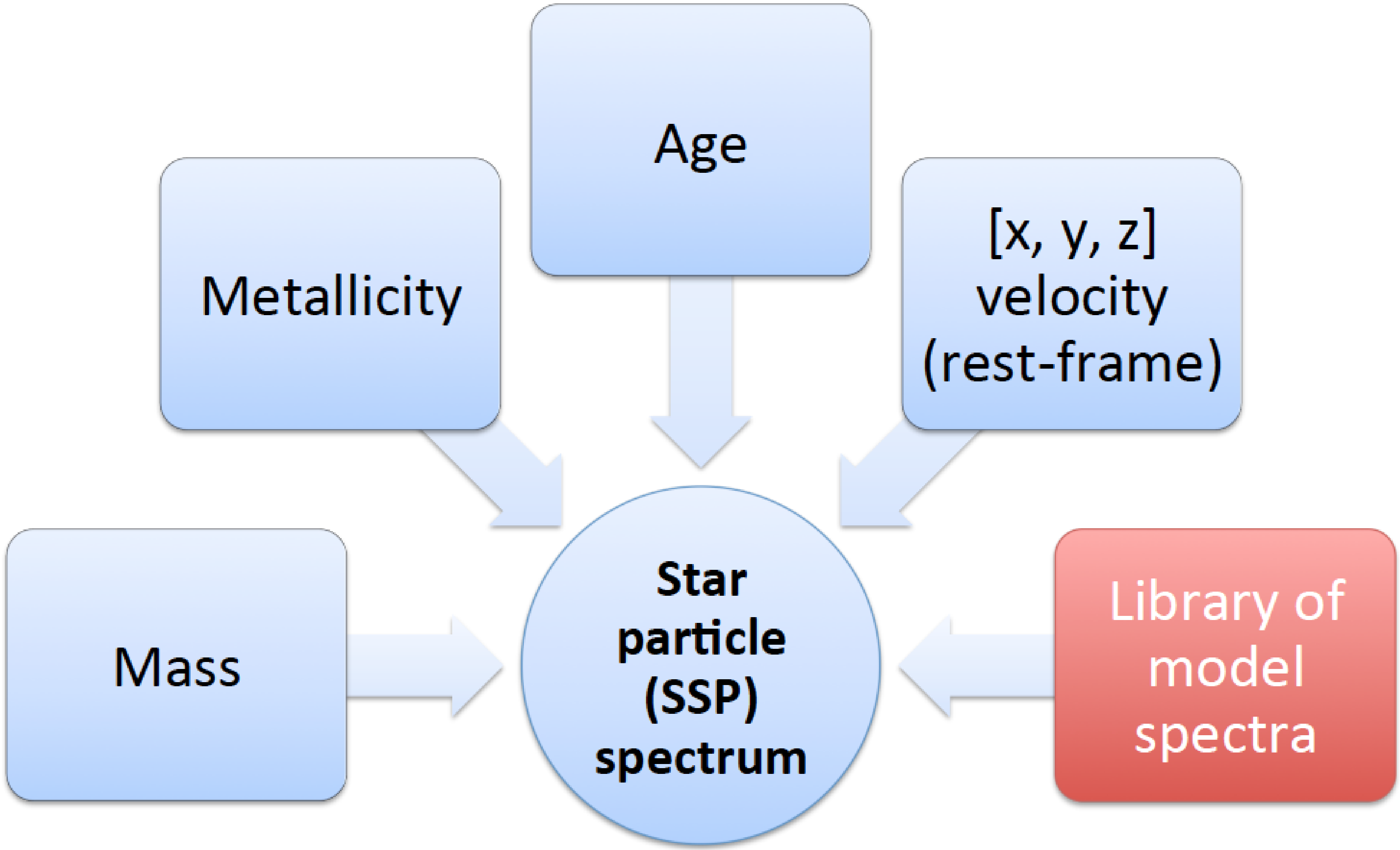
NUTFB simulation@ z=3

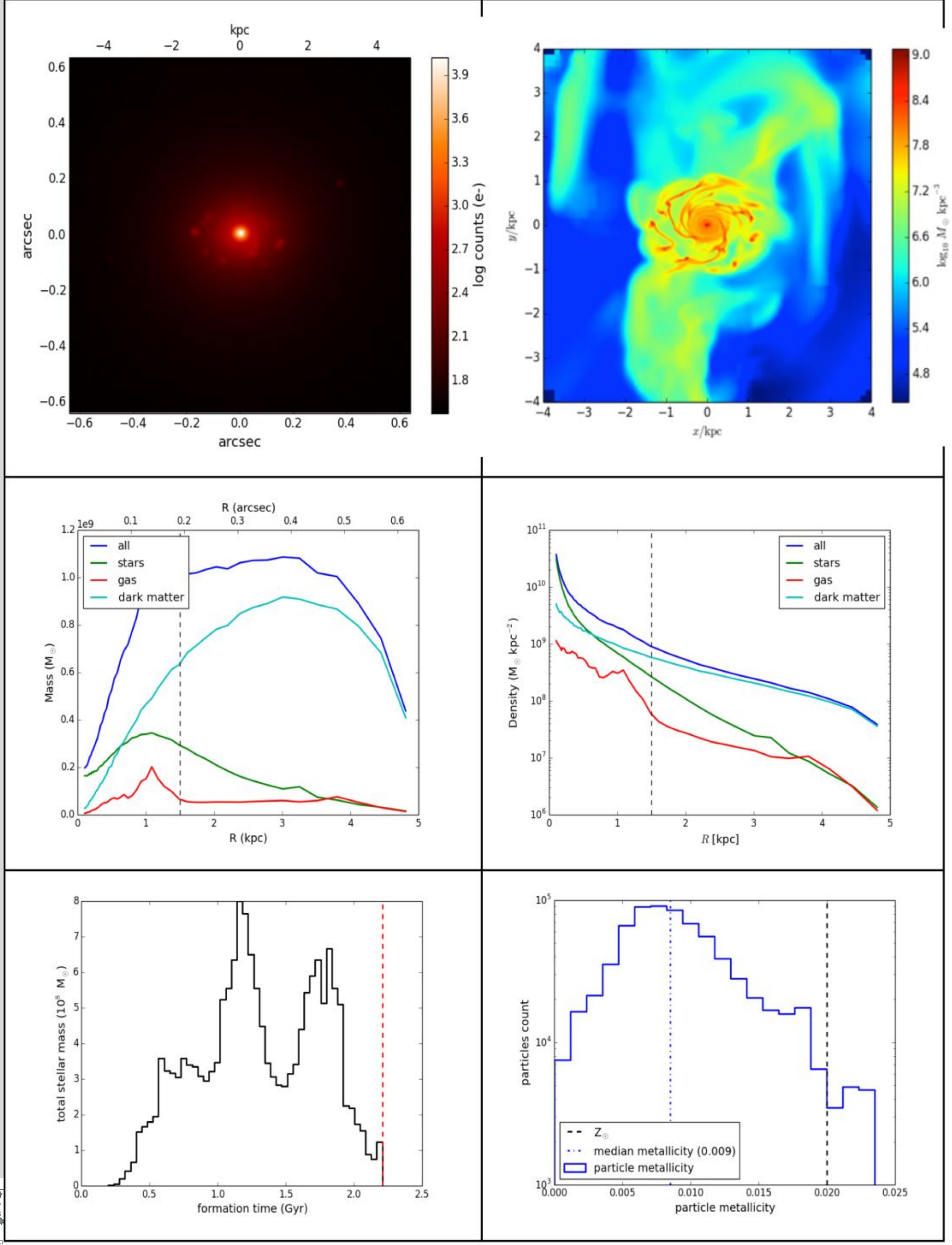
M_{DM} = 5e4 $M_\odot$
M_{star} = 2e4 $M_\odot$
nth = 400 cm^{-3}
z_{end} = 3
z_{UV} = 8.5
SFE = 1%
SN Type II feedback



- Zoom-in sim from the NUT suite (Powell+ 2011; Kimm + 2011) using RAMSES (Teyssier 02)
- Terminates @ z=3 (@ ~2.2 Gyr), physical spatial resolution of 12 pc

Every star particle represents a simple stellar population (SSP)





Stars

Compare star formation history deduced from fit to absorption line spectra with input

Compare observed metallicity & gradients with intrinsic ones

Use stellar kinematics to infer a dynamical mass, and compare with DM and baryonic mass

Look at dependence of observed features on IMF, to determine diagnostics

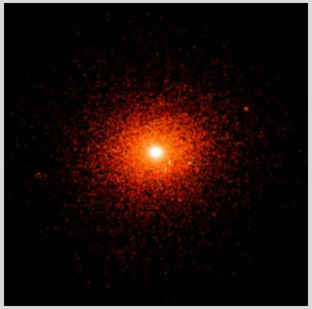
Important to disentangle PSF effects!

S. Kendrew et al. (2016)

CSIC LAM ONERA CRAL irap IPAG ESO

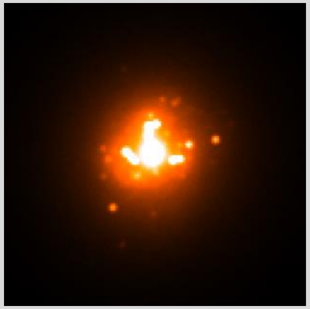
Effective radius of the galaxy

Galaxy 1: faint, almost round, R_eff (actual) = 40 mas (0.3 kpc at z = 3)
Observed (with no PSF effect taken into account): R_eff = 140 mas



PSF used	R_eff (PSF deconvolved)
original	43.4 ± 3.9 mas
Higher Strehl, round (2mas rms jitter)	71.8 ± 8.8 mas
Higher Strehl, elongated, rotated (4 x 2 mas)	162.4 ± 40.7 mas

Galaxy 2: brighter, not round

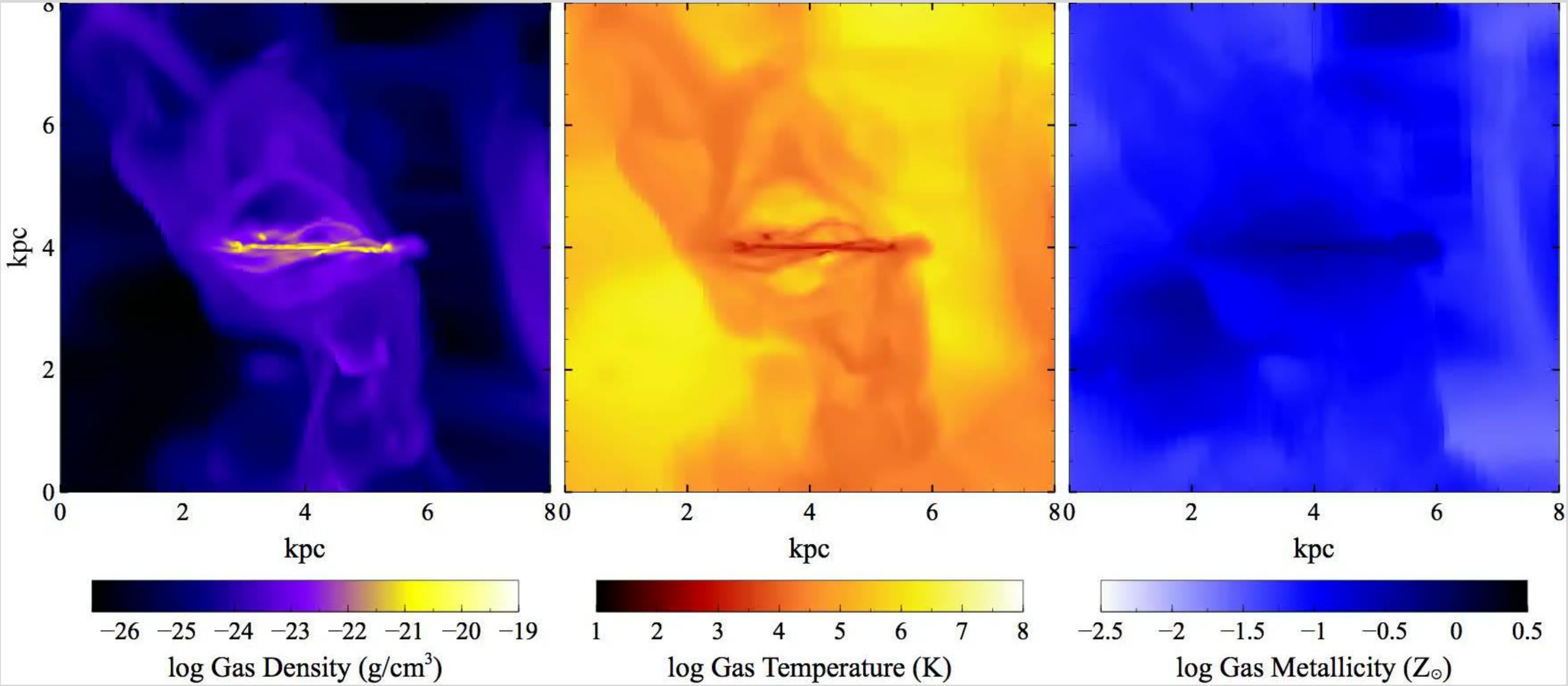


PSF used	R_eff (PSF deconvolved)
original	85.8 ± 0.6 mas
Higher Strehl, round (2mas rms jitter)	189.2 ± 1.2 mas
Higher Strehl, elongated, rotated (4 x 2 mas)	189.4 ± 1.2mas

Study three science cases

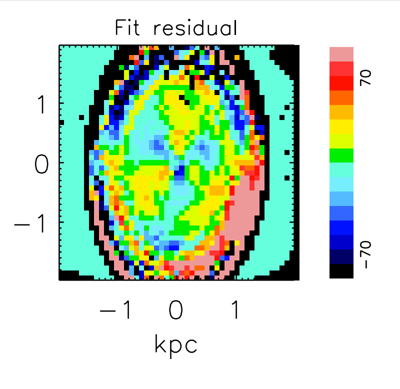
- Effective radius of high-z star forming galaxy (with S. Kendrew, B. Haußler, M. Richardson)
- Rotation curves of high-z galaxies (long slit and IFS) (with L. Routledge, M. Richardson, M. Pereira)
- Stellar kinematic signatures of intermediate mass black holes in nuclear stellar clusters (with T. Yasin, R. Houghton, J. Magorrian)

Gas kinematics at z = 1.44

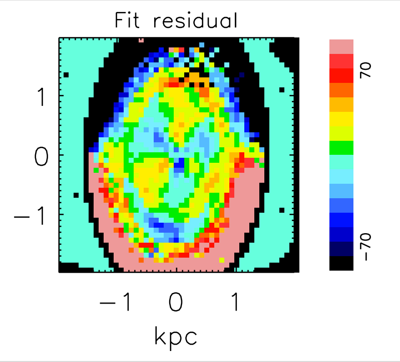


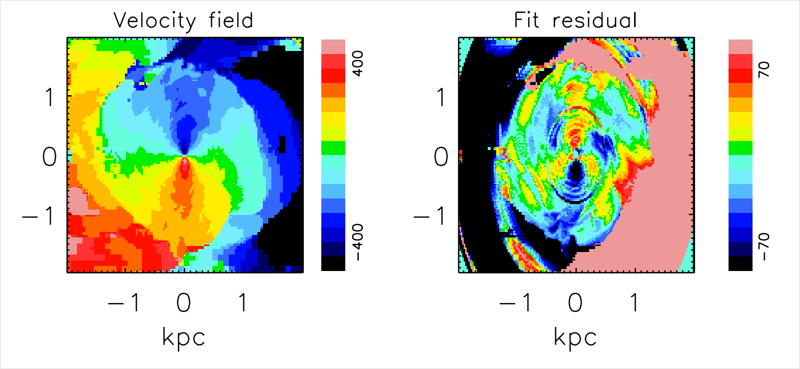
Velocity fields & warps

1’-2mas-0

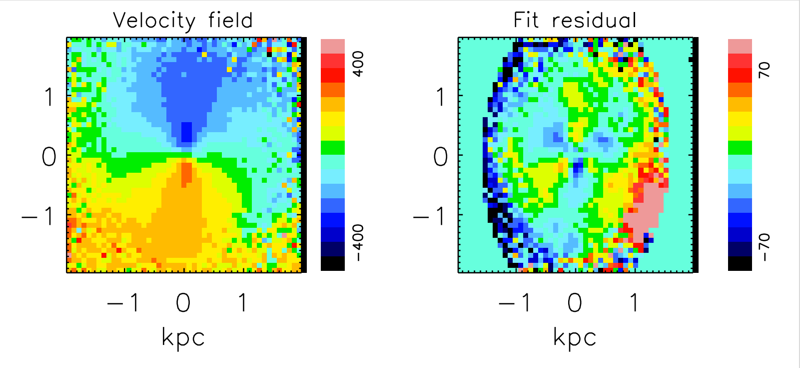


1’-4mas-0

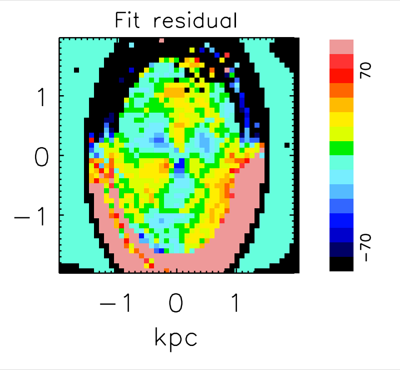




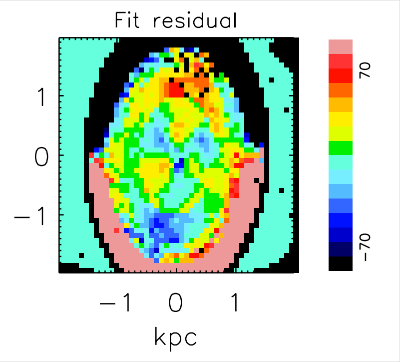
Input cube



2.2’-3mas-0 (original)

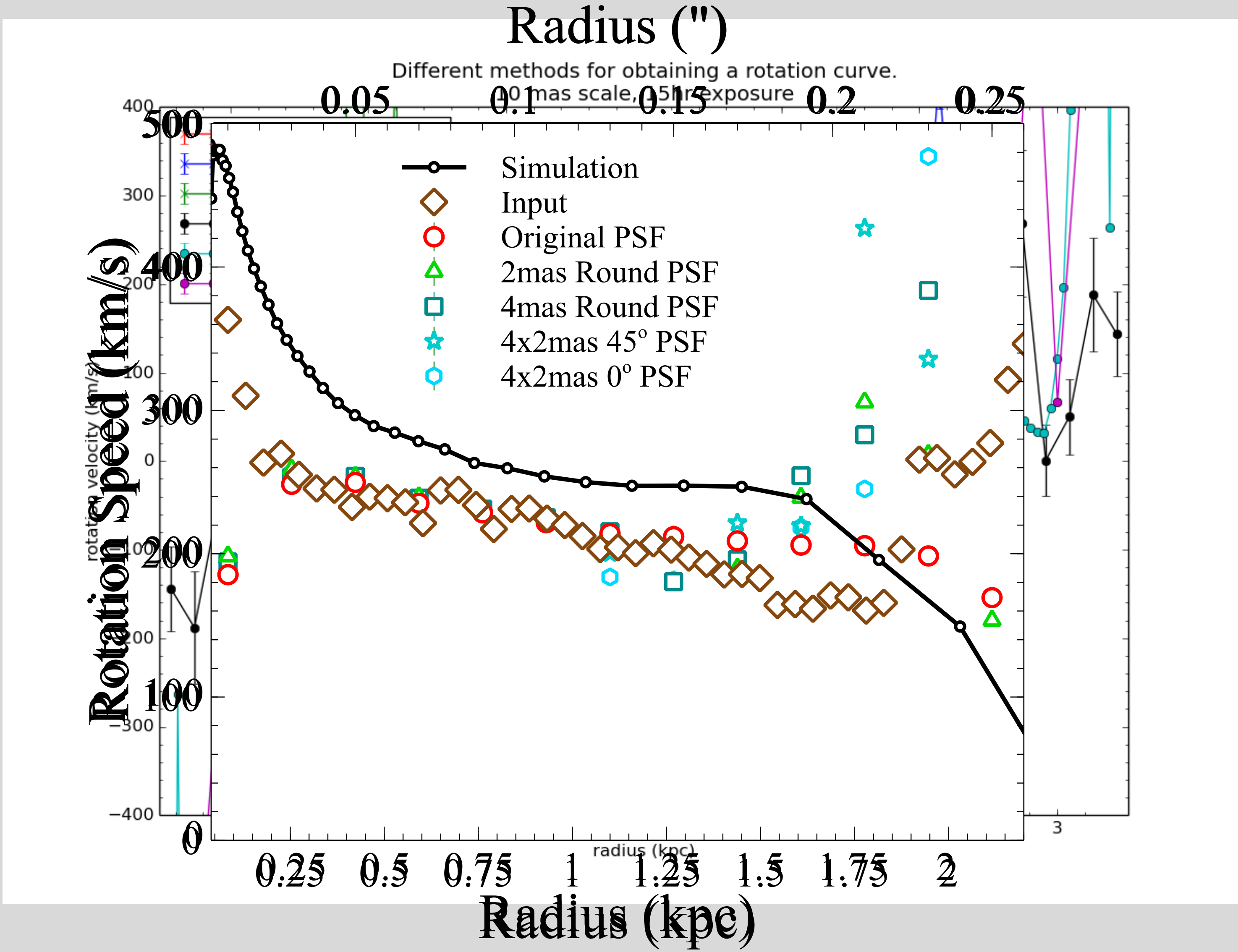


1’-4x2mas-45



1’-4x2mas-0

Extracted rotation curves

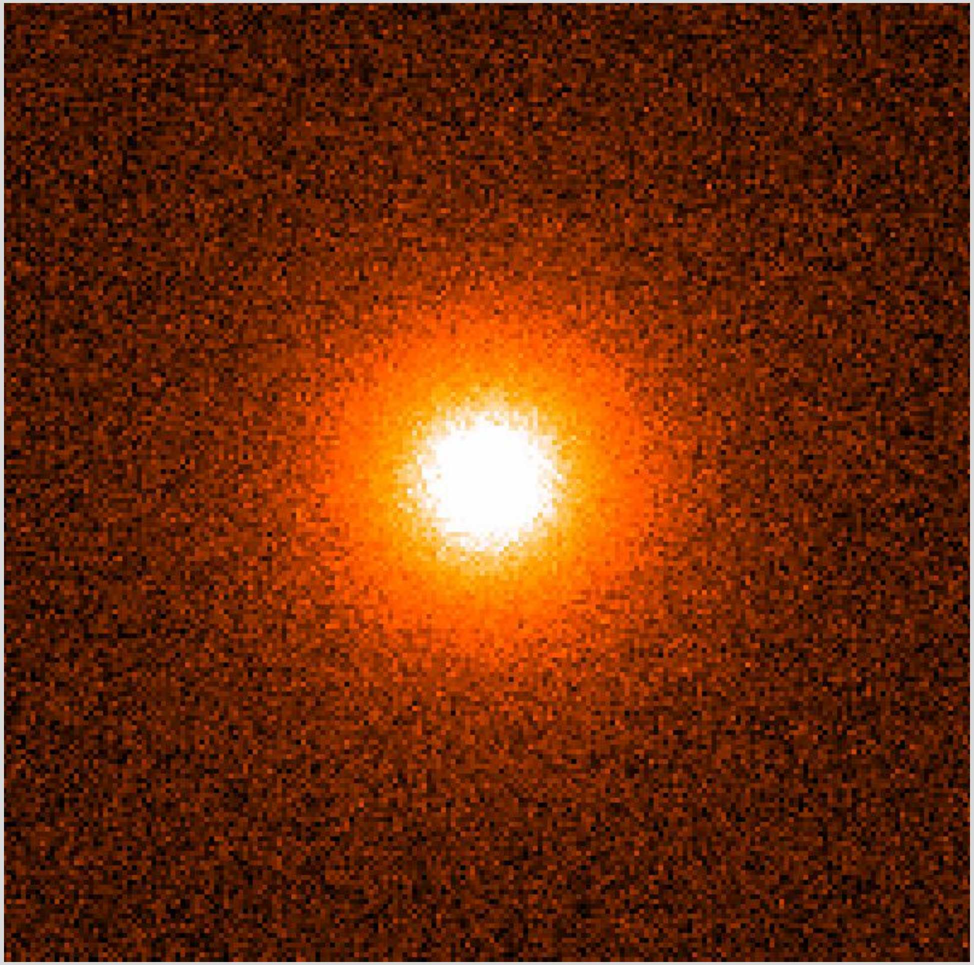


Study three science cases

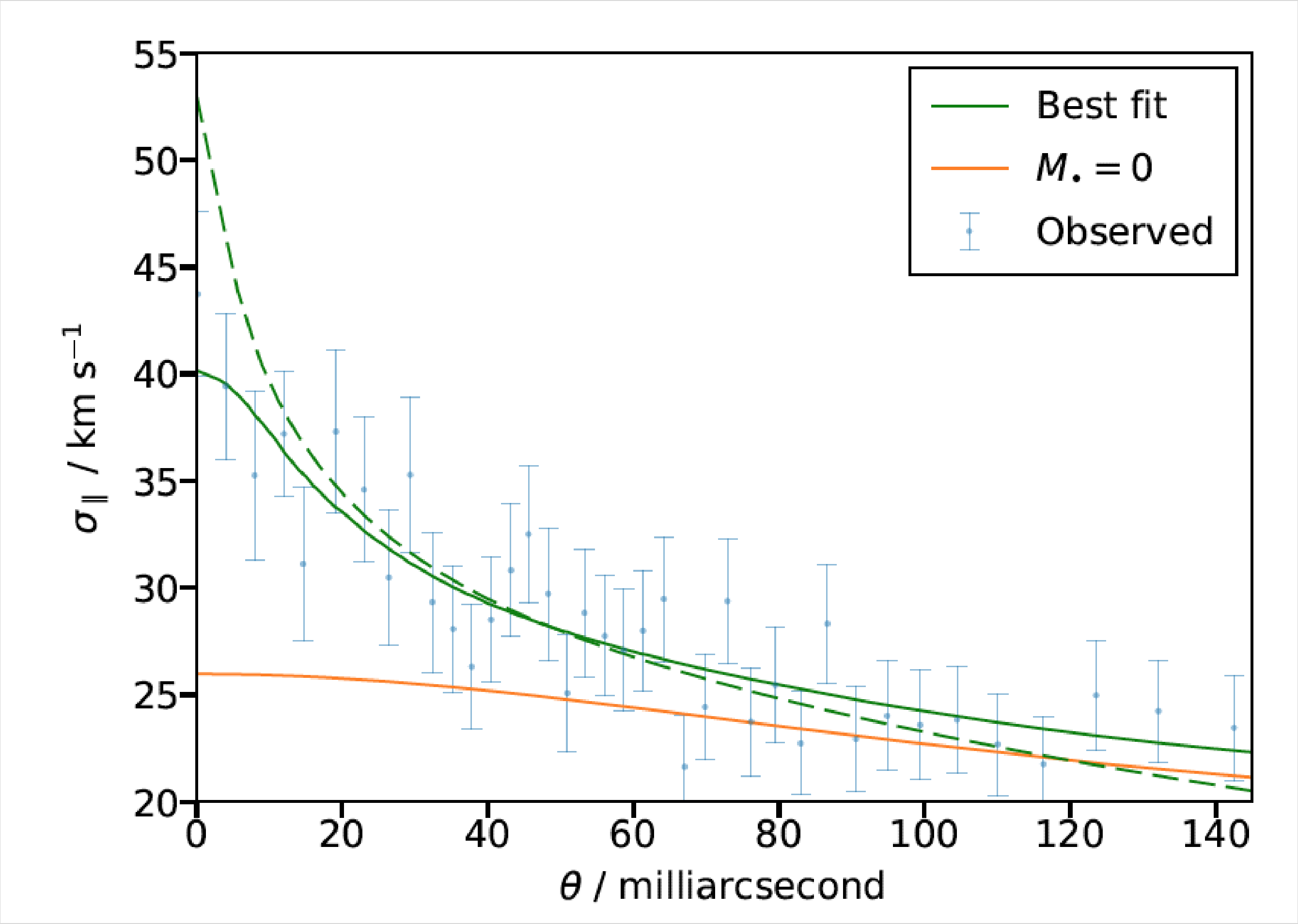
- Effective radius of high-z star forming galaxy (with S. Kendrew, B. Haußler, M. Richardson,
- Rotation curves of high-z galaxies (long slit and IFS) (with L. Routledge, M. Richardson, M. Pereira)
- Stellar kinematic signatures of intermediate mass black holes in nuclear stellar clusters (with T. Yasin, R. Houghton, J. Magorrian)

Plummer model of NSC

- Observed at 4 mas spaxels
- 900s × 40 (5 hours)
- LTAO PSF
- K band (2.25 µm, single abs. line)
- R = 7500
- 0.7” seeing, 10 deg ZD
- R_h= 3.5 pc
- 10 Mpc distance
- M_{BH}/M_{NSC} = 0.1
- M/L = 1

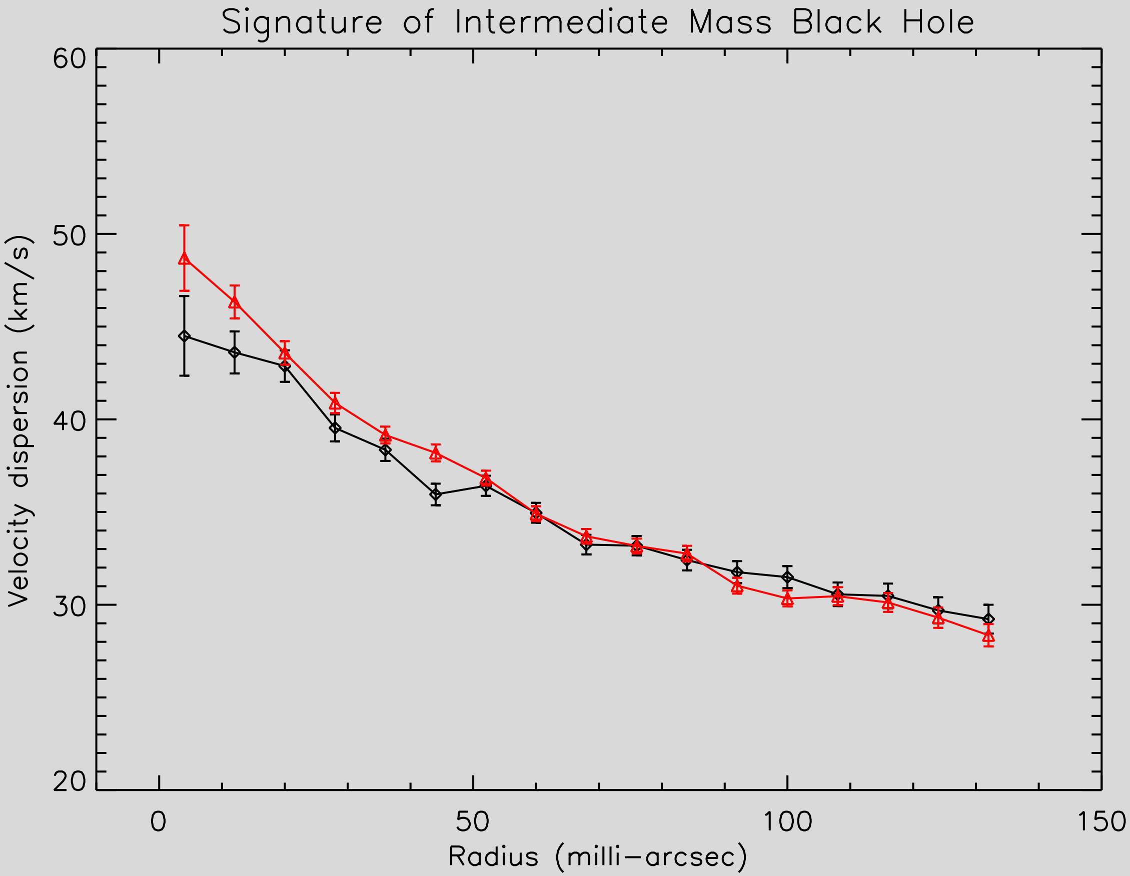


Fit using forward modelling

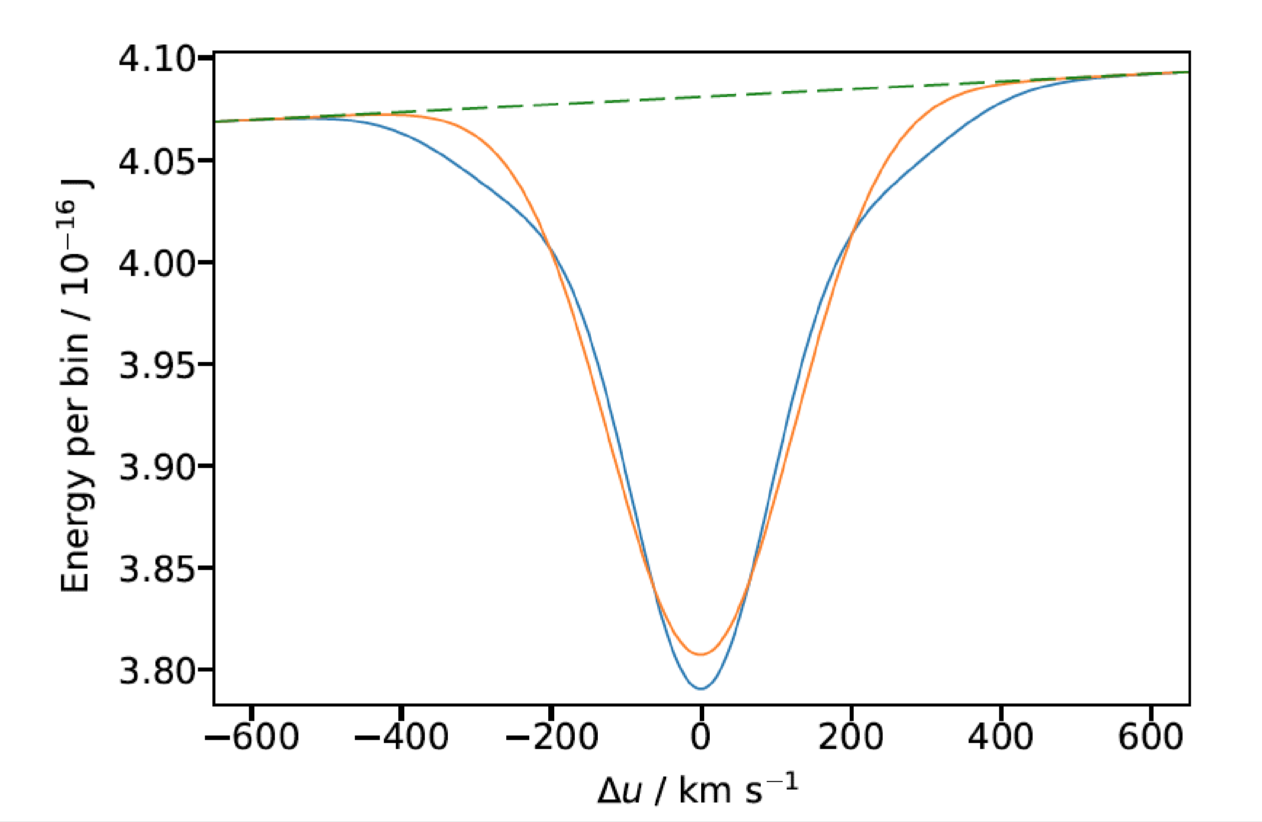


Impact of PSF knowledge

!! Work in progress !!



PSF effects ☞ ”Fake News”



- The Donald will be happy!