AO observations of AGNs:
from the present to **ERIS** and **MAVIS**

ASTROFISICA DI FRONTIERA CON L'OTTICA ADATTIVA ITALIANA
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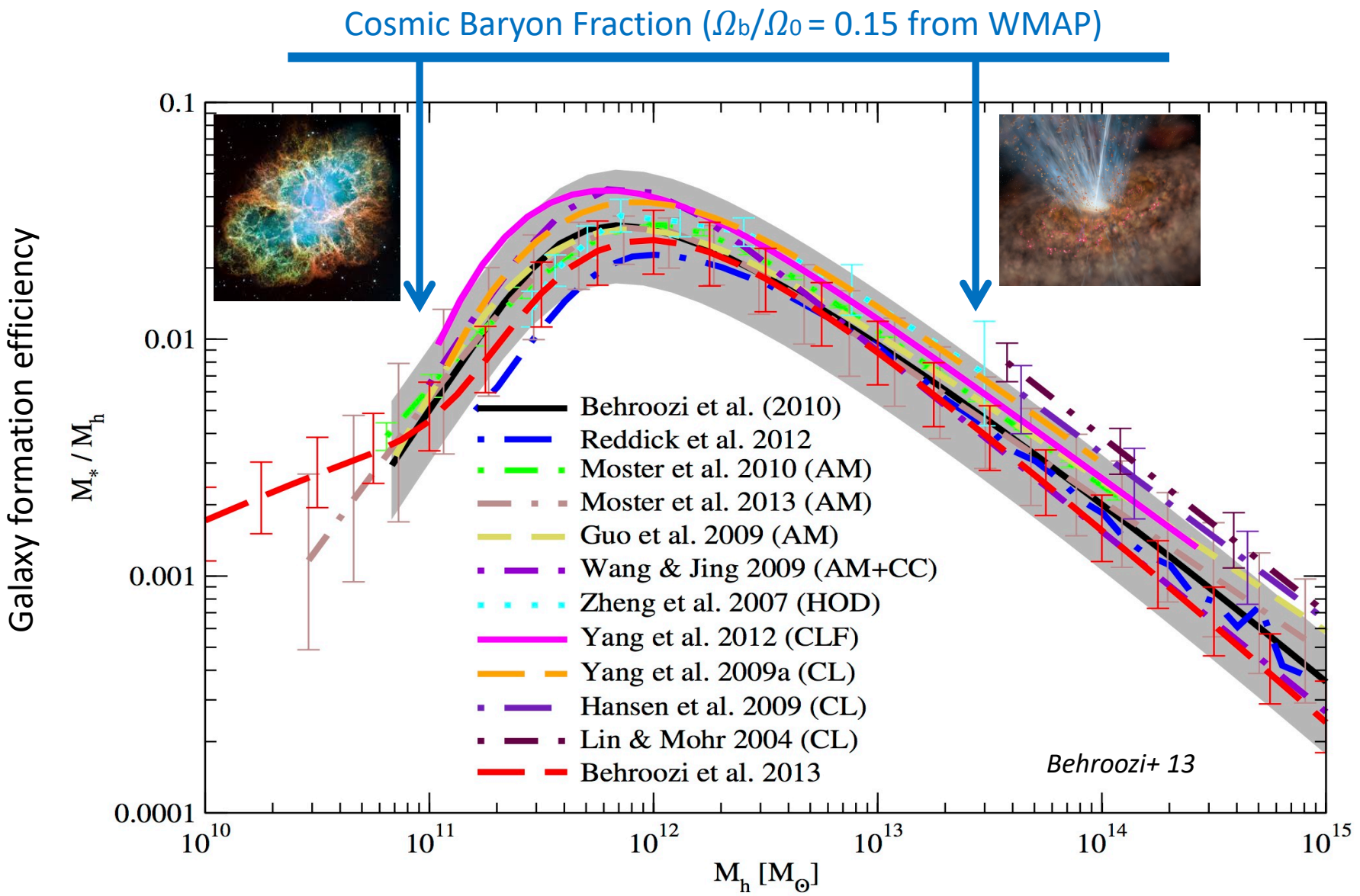
Accademia Nazionale dei Lincei

Giovanni Cresci INAF – Arcetri

A. Marasco, F. Mannucci, A. Marconi, M. Perna, M. Brusa, G. Tozzi, …

The need for AGN feedback

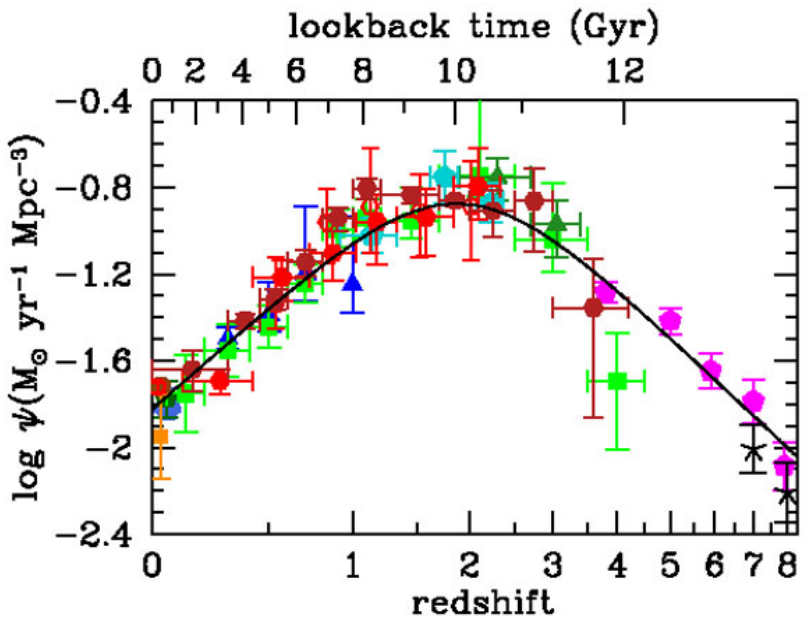


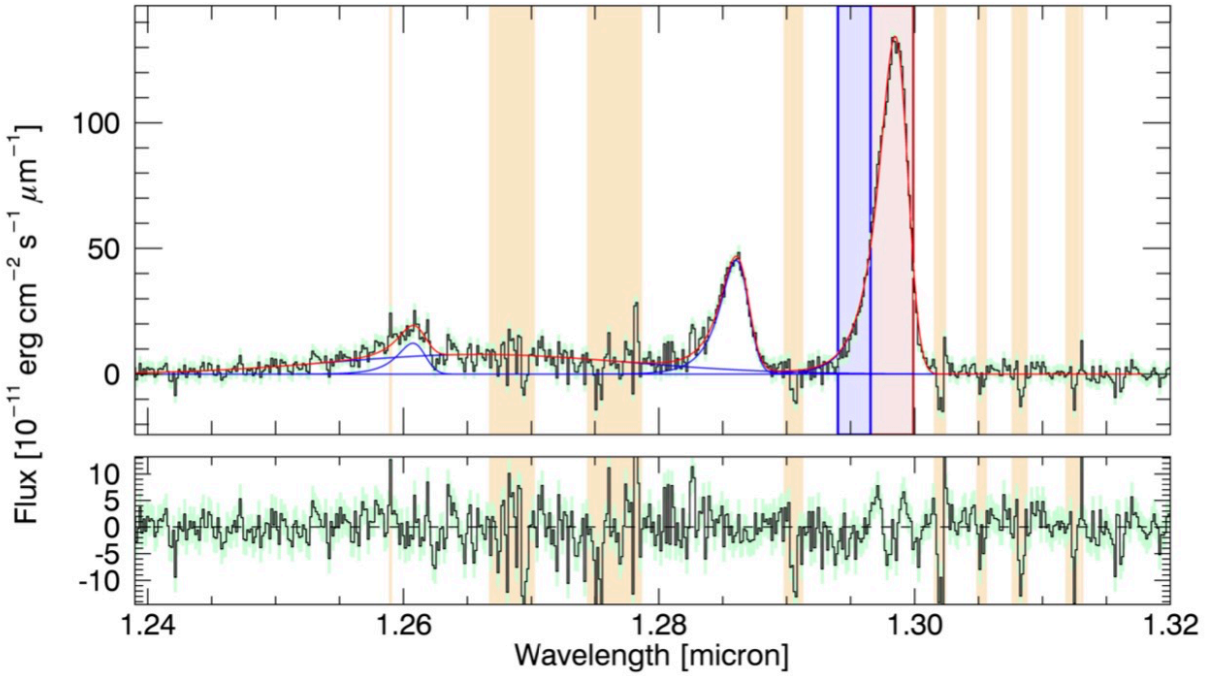
Stellar feedback can't explain reduced efficiency in massive galaxies (e.g. Hopkins+06, Croton+06, Murray+05, Menci+08 …)

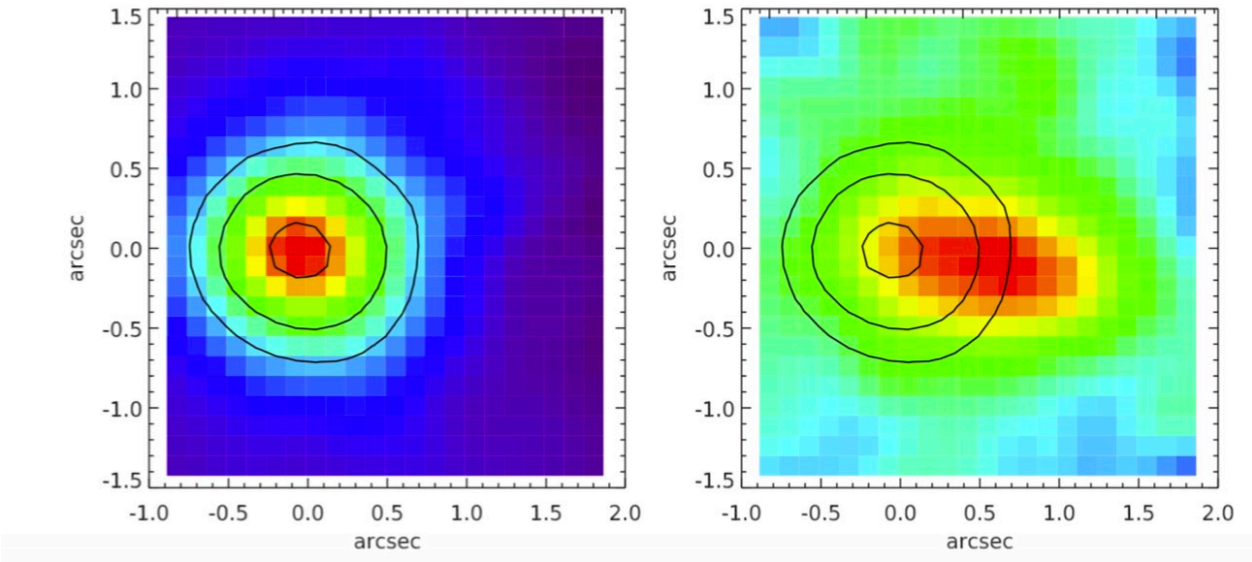
Bimodality in color - mag or M_* diagram (e.g. Blanton +2003…): Red sequence, Blue Cloud: *what makes galaxies red and dead?*

Many theoretical predictions, but still few observations of feedback effects on host galaxies…

Searching for feedback



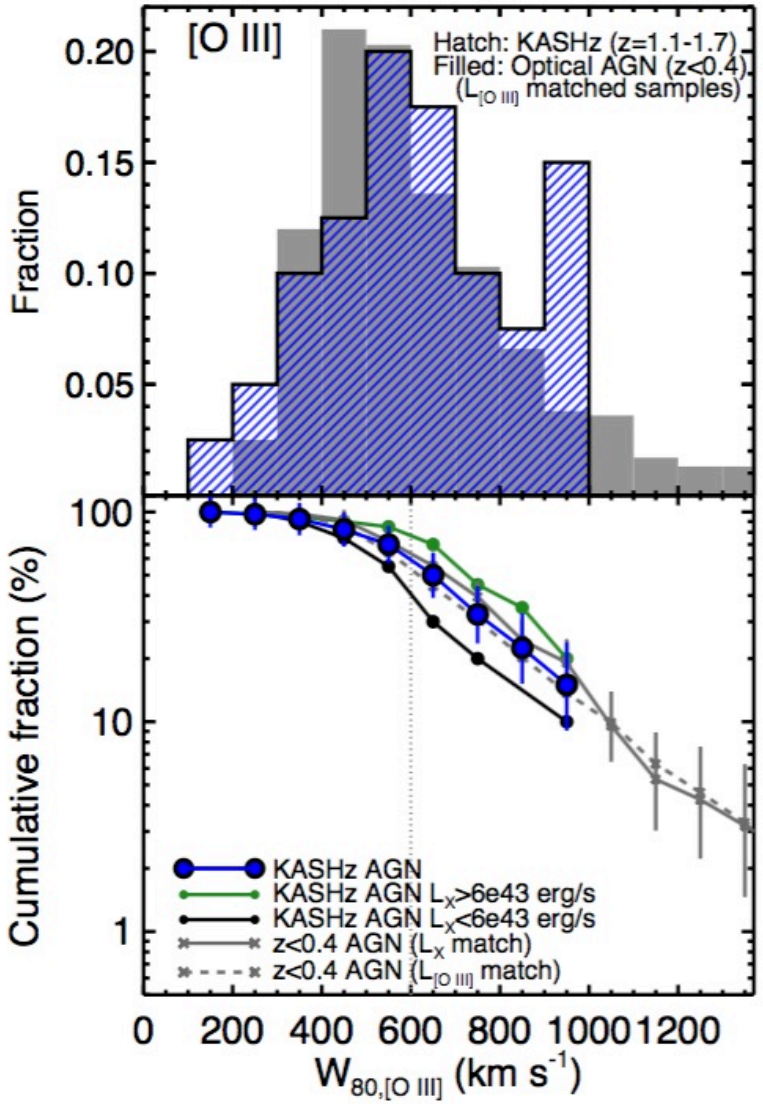


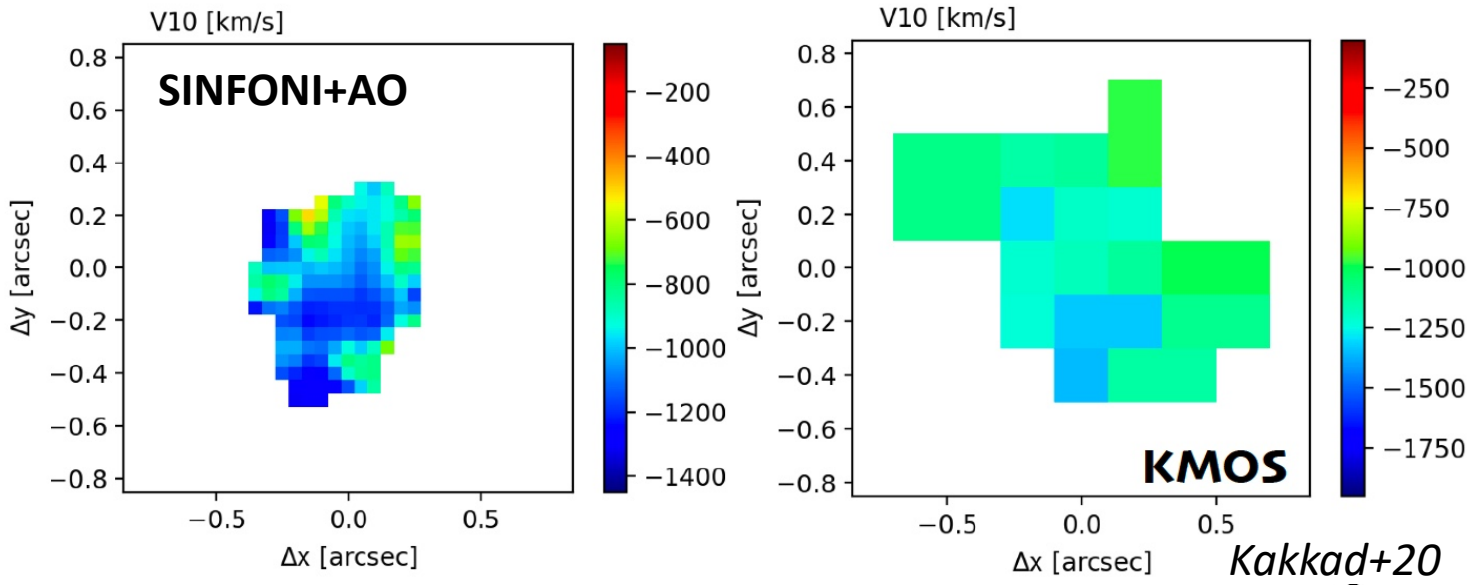


- Maximum feedback effect expected at z~1-3
- 0.5” seeing → ~4 kpc: outflows usually unresolved except few exceptional cases

Cresci+2015a

Widespread outflows at high-z, but unresolved



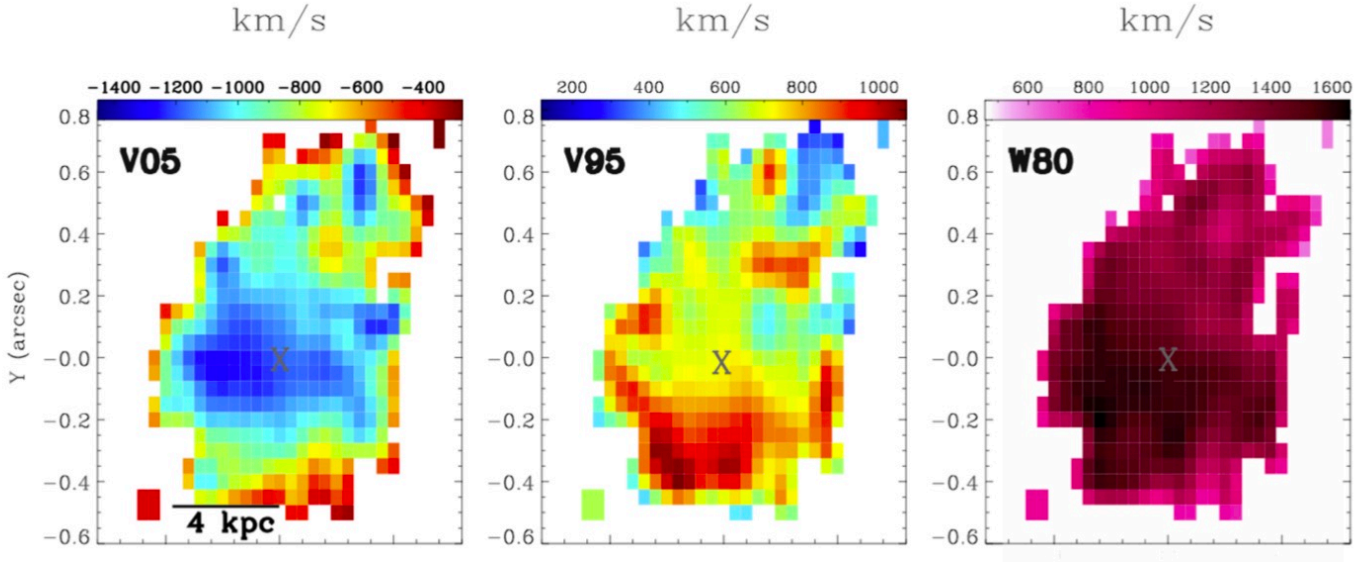


Kakkad+20

Harrison et al. (2015) – KASHz survey
82 x-ray selected AGNs with KMOS
(see also e.g. Forster-Schreiber+15)

High-z outflows with SINFONI+NGS AO

Limited to the few sources close to a bright enough star… only 1 in COSMOS with our selection!



Brusa et al. 2016

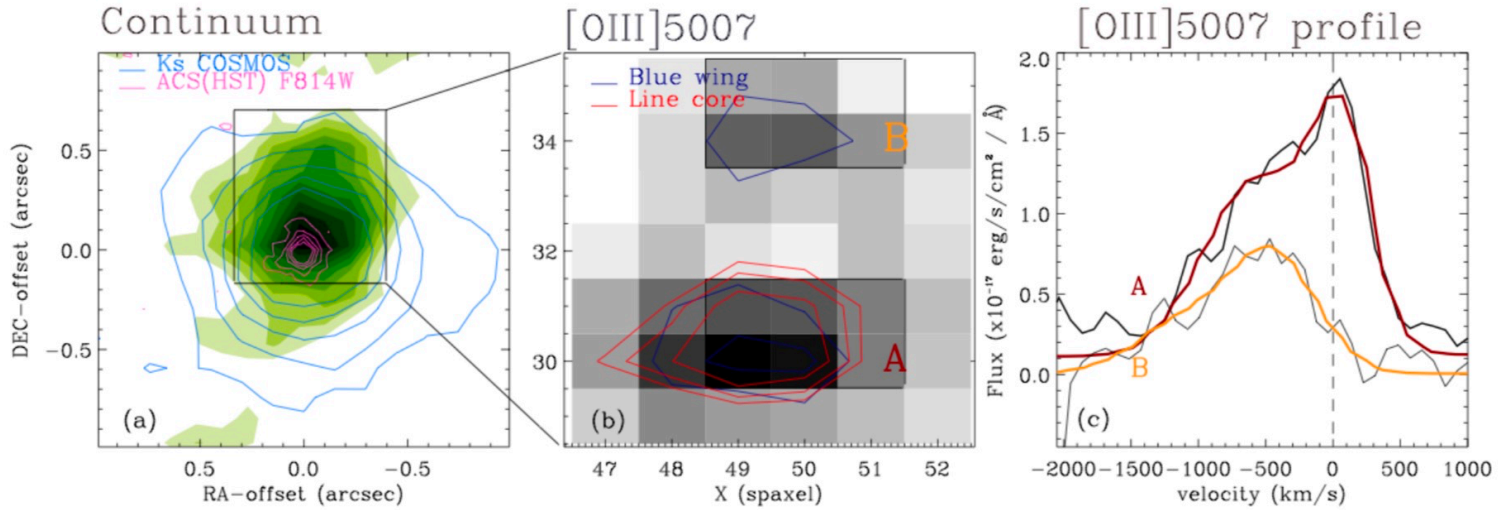
XID5395 at z=1.5

- v_{out}=1300 km/s
- R_{out}=4.3 kpc / 0.5”
- Mdot=45 $M_{\odot}$/yr

Perna et al. 2015

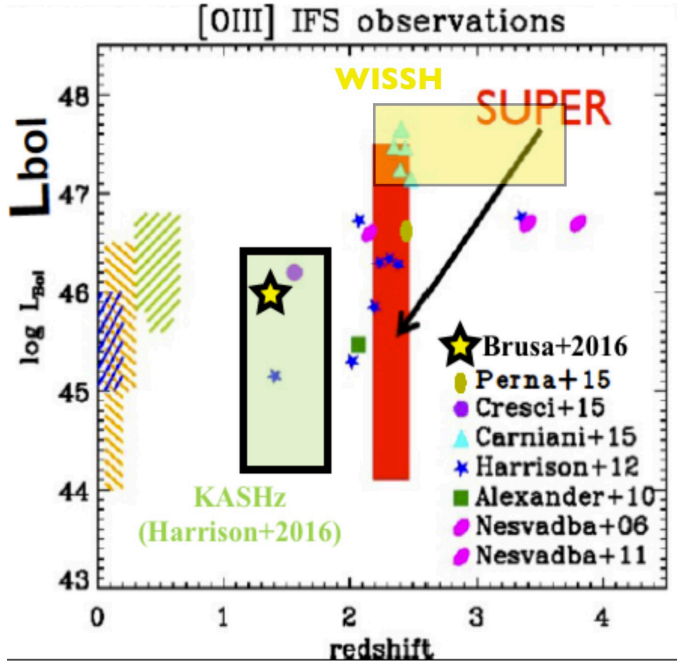
MIRO20581 at z=2.45

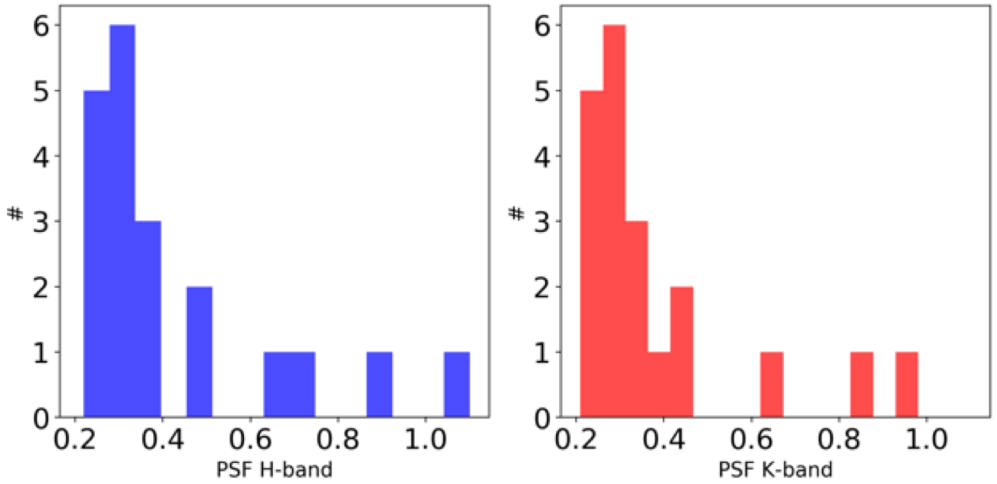
- v_{out}=1600 km/s
- R_{out}=4.8 kpc / 0.6”
- Mdot=190 $M_{\odot}$/yr



High-z outflows with SINFONI+LGS AO

- PI V. Mainieri (ESO)
- **S**urvey for **U**nveiling the **P**hysics and the **E**ffect of **R**adiative feedback
- An ESO large program, 280 hrs in 2 years
- ~7 hrs/obj in 40 X-ray selected AGNs at z=2.3
- observing Large range in L_{BOL}, L_{edd}, Type 1 and Type 2, N_H
- LGS-AO, H+K bands: both outflows from [OIII] and SF from Hα
- Explore outflow power and demography as a function of AGN & host properties in unbiased sample

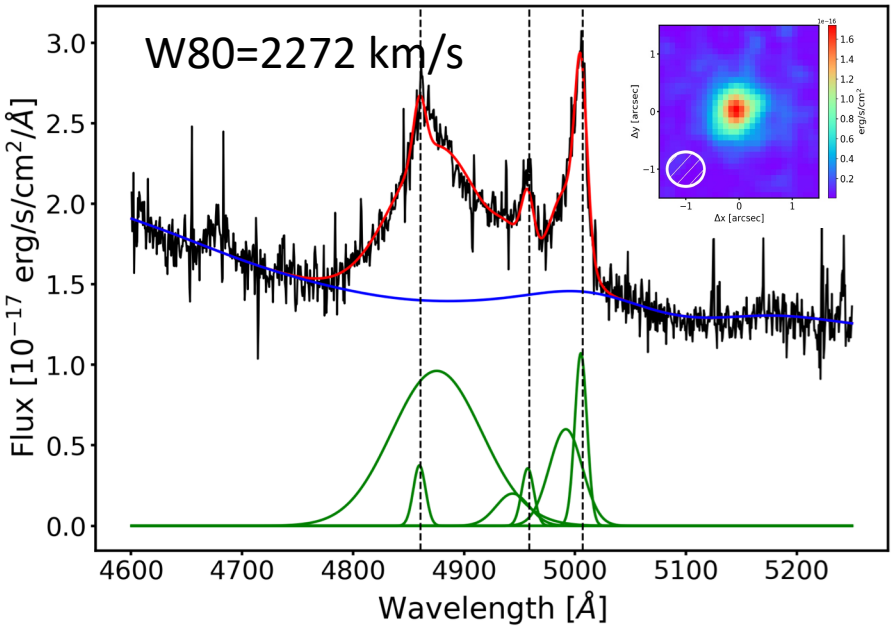


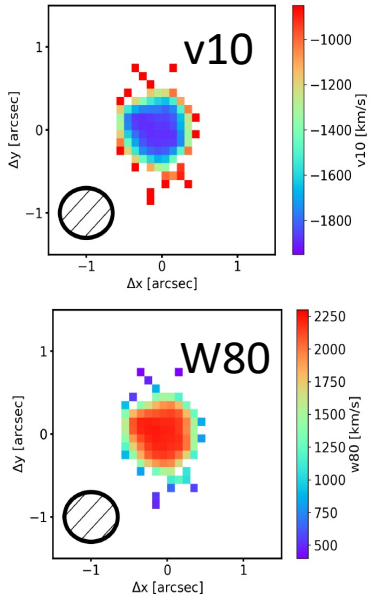


BUT:

- the program started in service mode, with very low observation rate
- we changed in vistor mode, but without scheduling optimization for AO
- targets observed in no-tip tilt mode: resolution obtained FWHM~0.2”-0.4”

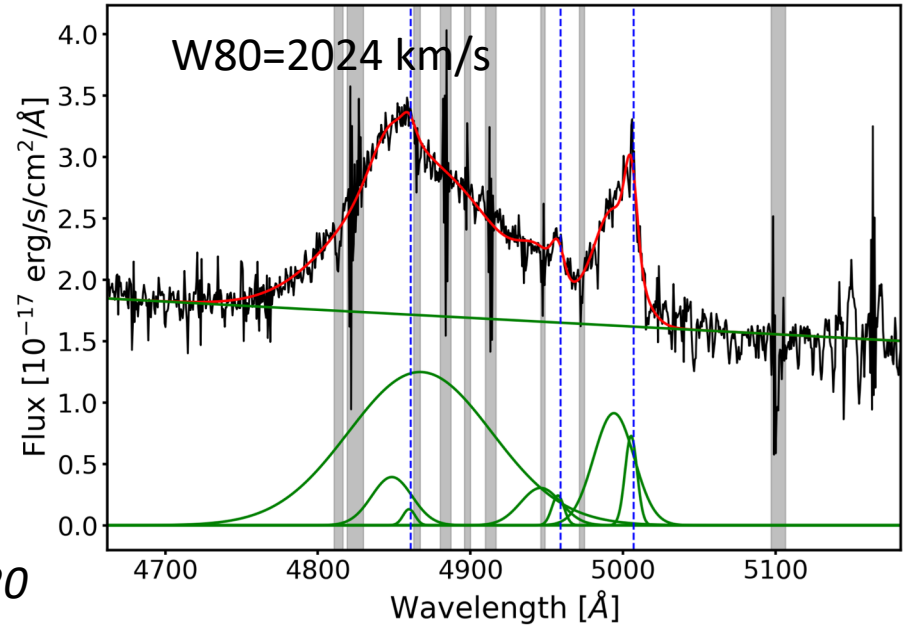
High-z outflows with SINFONI+LGS AO

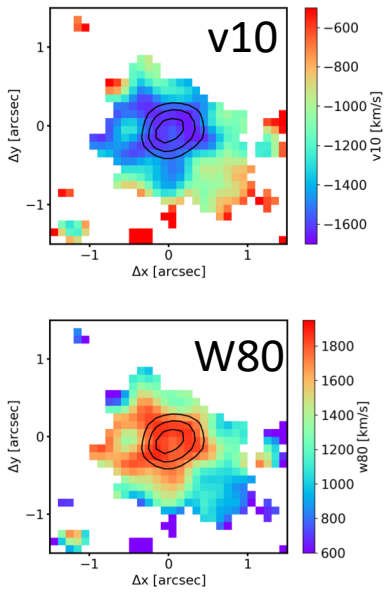




~25% still spatially unresolved with AO-assisted observations at the VLT (PSF~0.25“)

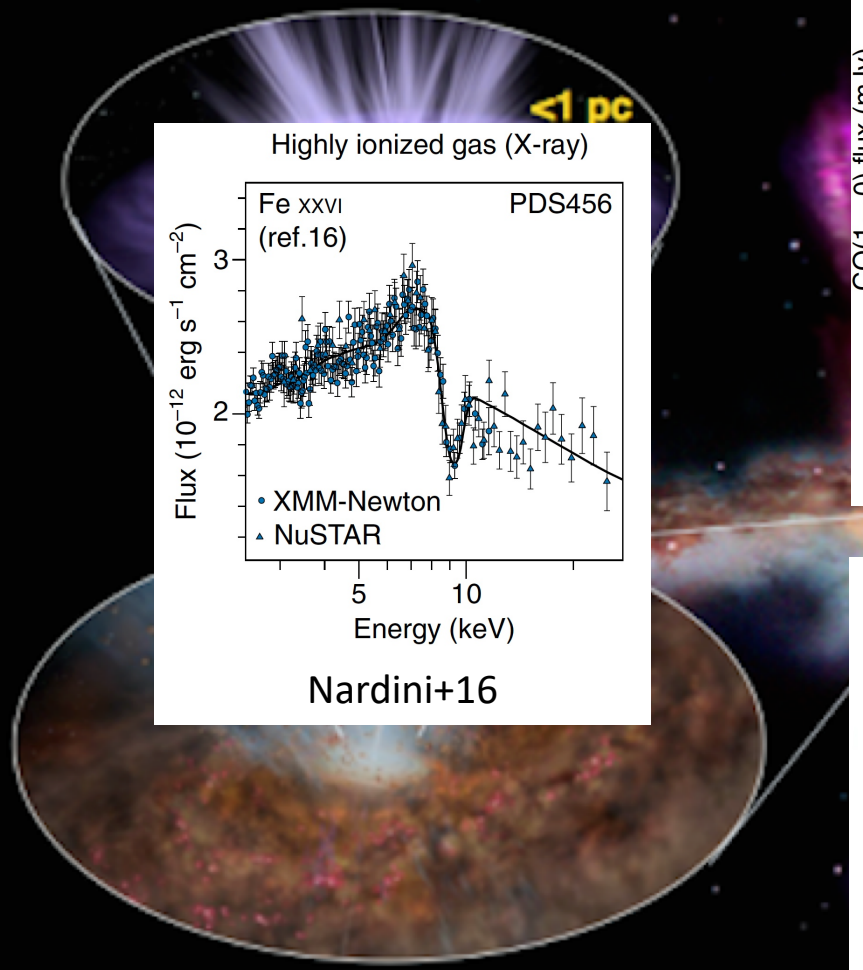
~75% spatially resolved,
but most of them only marginally



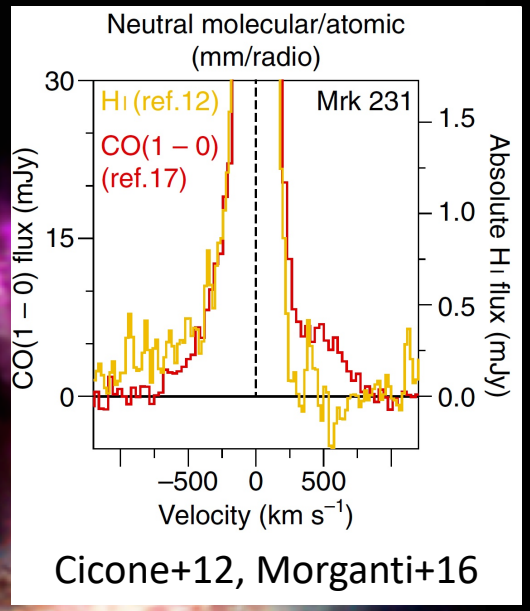


Kakkad et al. 2020, Vietri et al. 2020

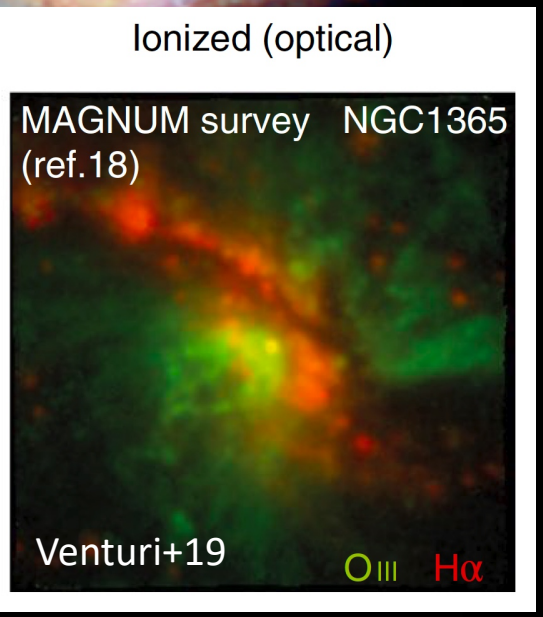
AGN outflows are multi-scale and multi-phase



Nardini+16

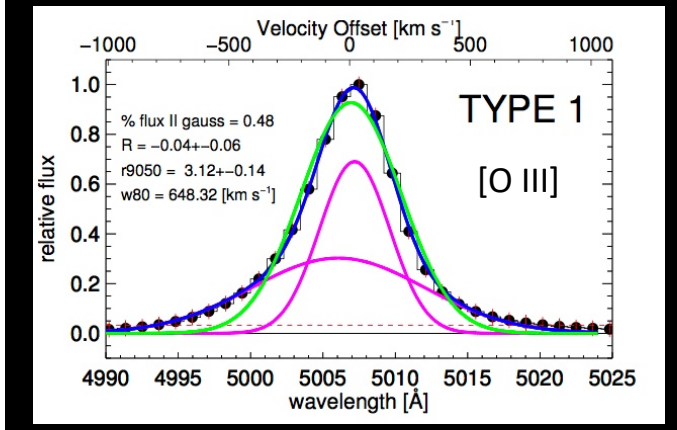


Cicone+12, Morganti+16



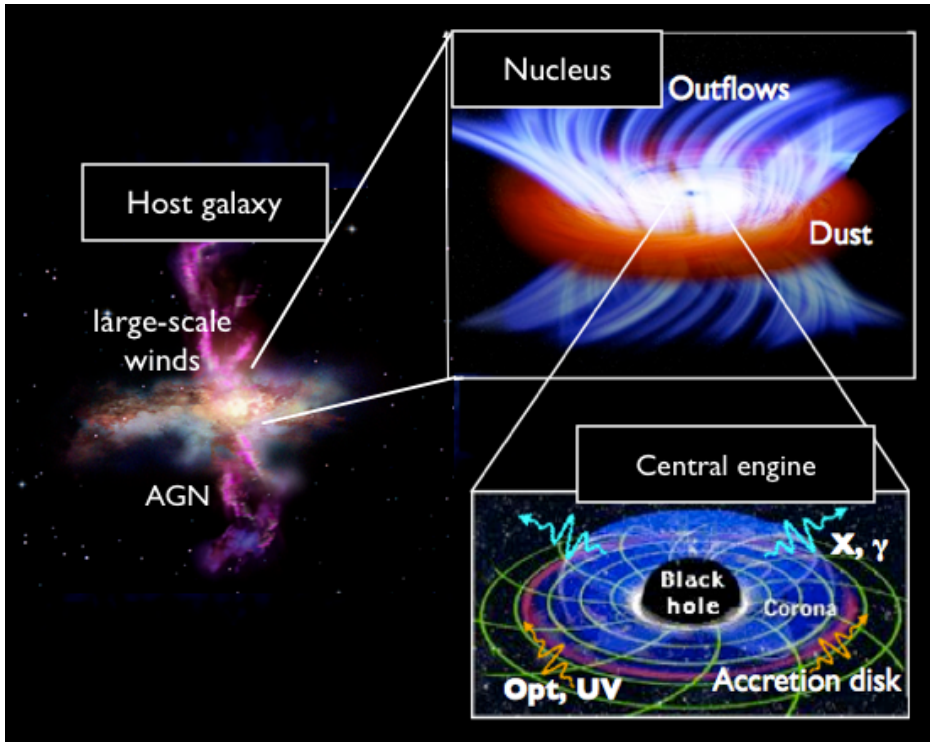
Different observational tracers

- Highly ionized accretion disk winds (X-rays highly ionized Fe lines) – UFOs):
  R<1 kpc; v ~ 0.01-0.3 c
- Cold molecular gas winds (mm and sub-mm, CO, OH): R~1-10 kpc; v~300-1000 km/s
- Ionized and atomic outflows (optical/NIR):
  R~1-10 kpc v~300-2000 km/s



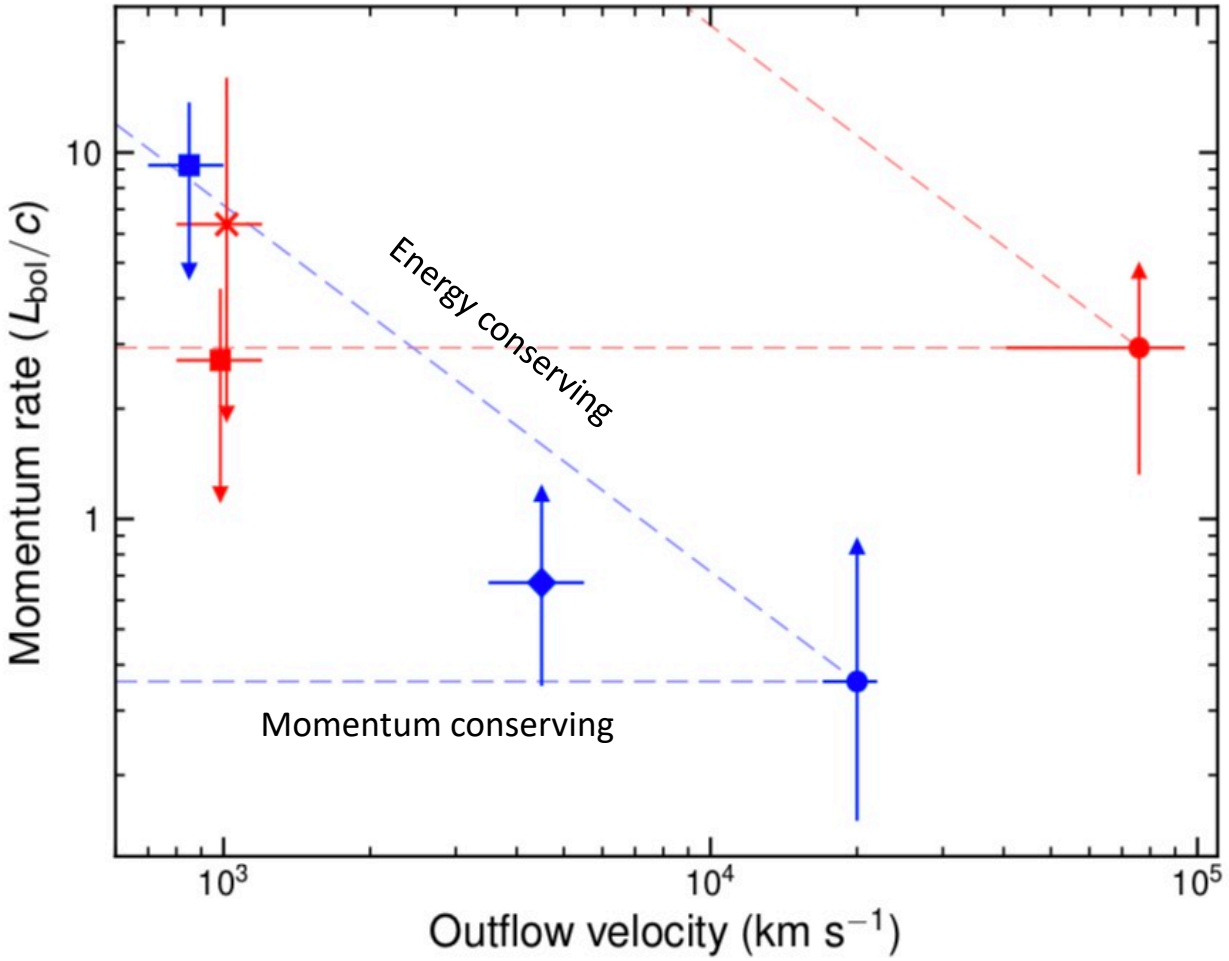
Concas+17

Connecting UFOs with large scale outflows



Are large scale outflows energy conserving?

Link between pc-scale and kpc-scale
but till now only few sources…

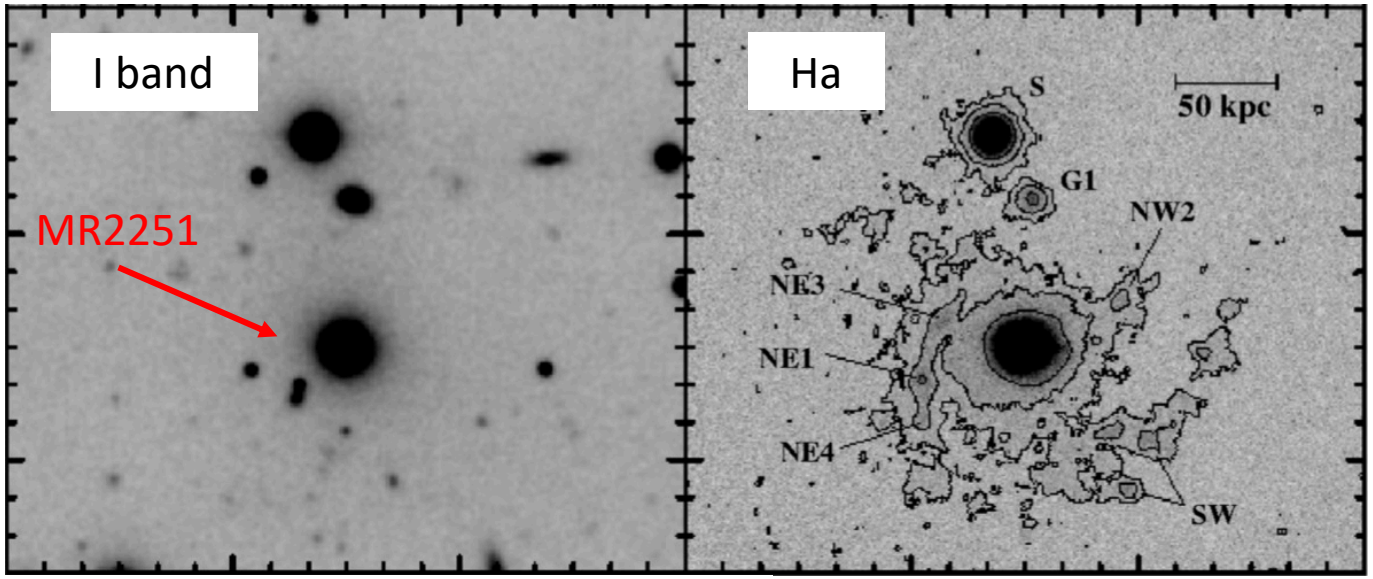


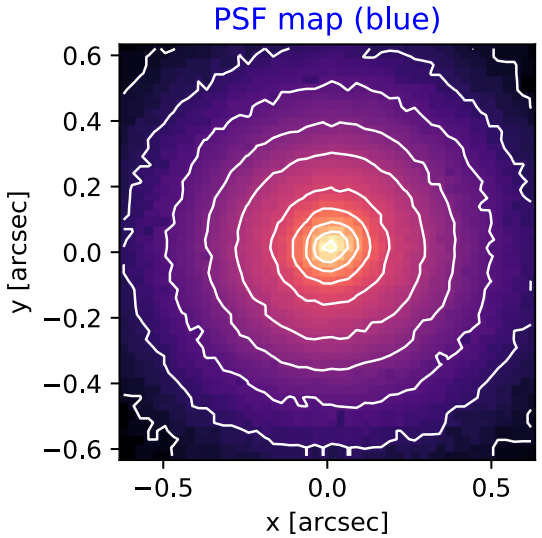
Nardini & Zubovas 2018
(see also Tombesi+15 Nature, Feruglio+15, Veilleux+17, Feruglio+17)

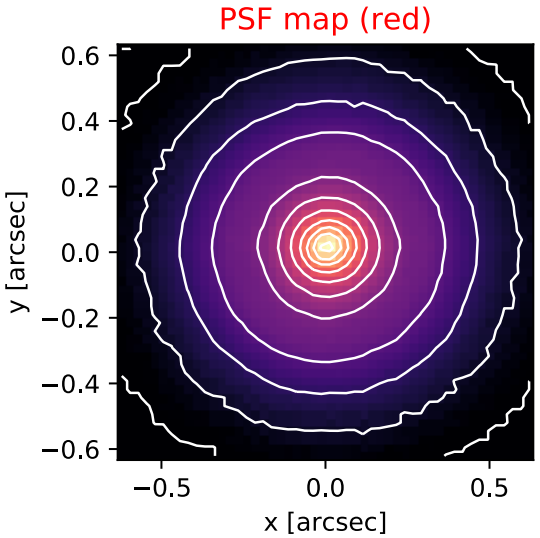
Connecting UFOs with large scale outflows with MUSE NFM

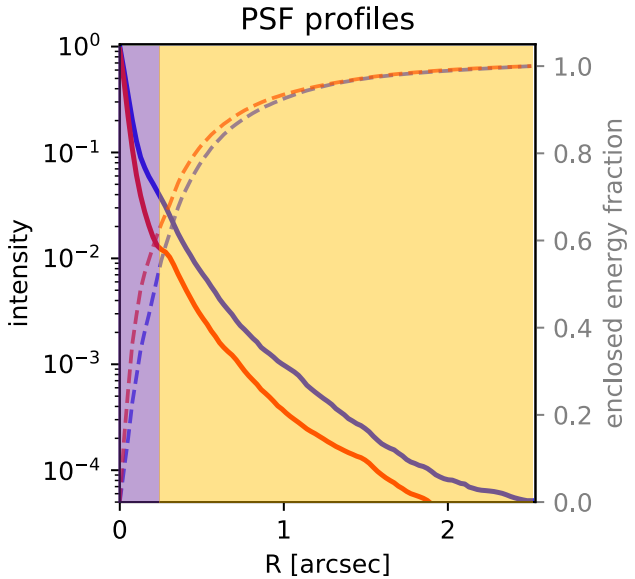
Close encounters of the third kind: P103 proposal for MUSE NFM+AO (PI Cresci) to resolve the large scale ionised outflows in 3 bright UFO hosts :

50% completed, 2 sources observed MR2251 and PG1126







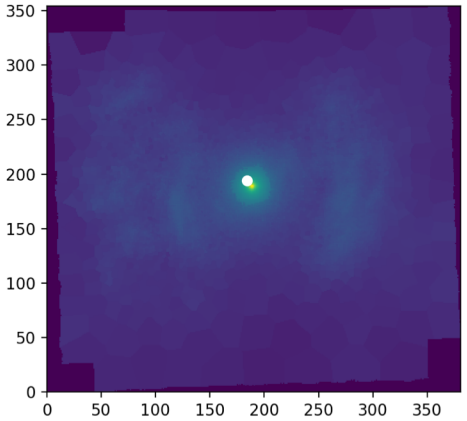


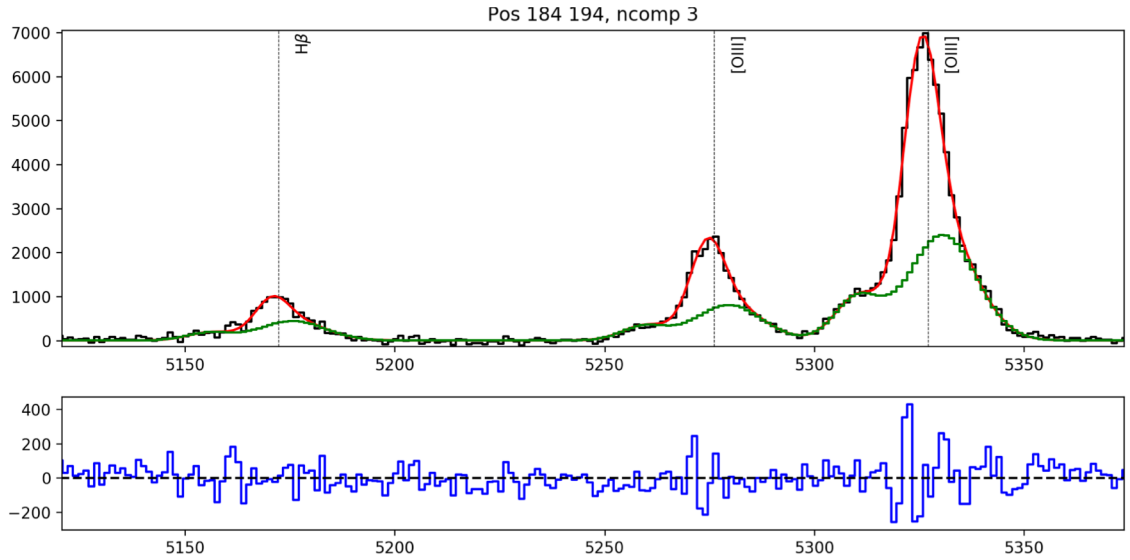
PG1126 (H=11.9)
PSF images
from Ha (red)
and Hb (blue) BLR

Corrected core
(FWHM ~ 50mas
~ 70 mas)
Halo (FWHM ~ 600 mas)

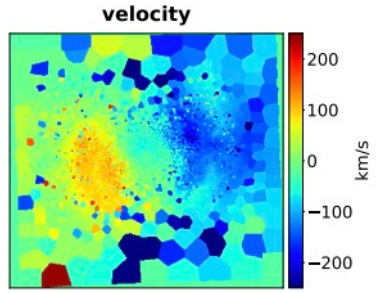
Marasco et al. 2020

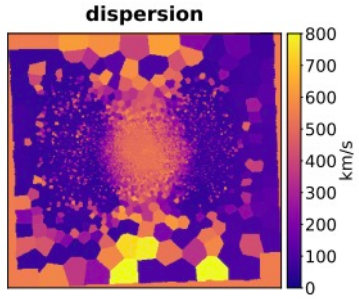
Connecting UFOs with large scale outflows with MUSE NFM

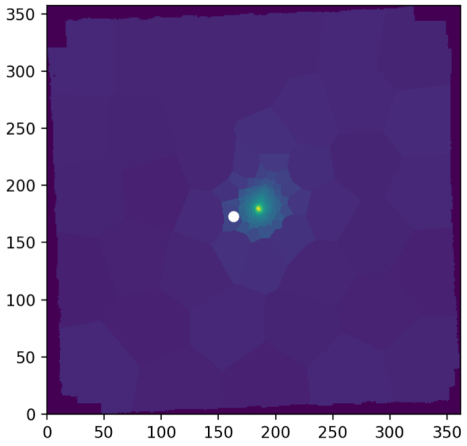


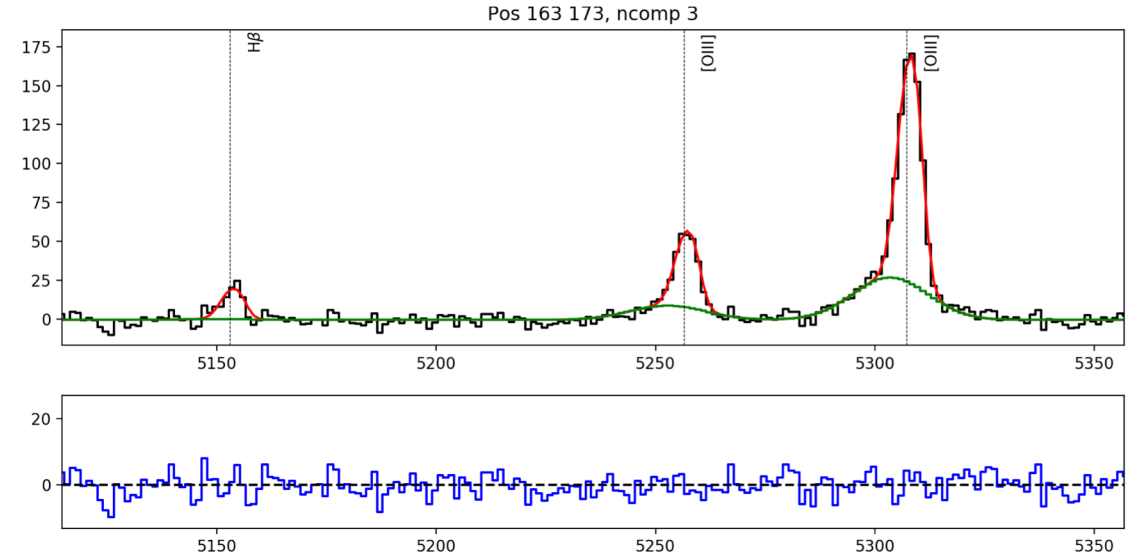


MR2251

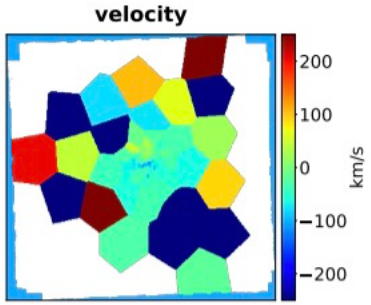


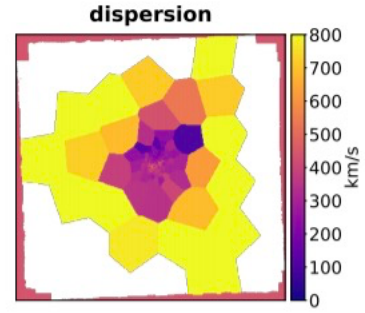






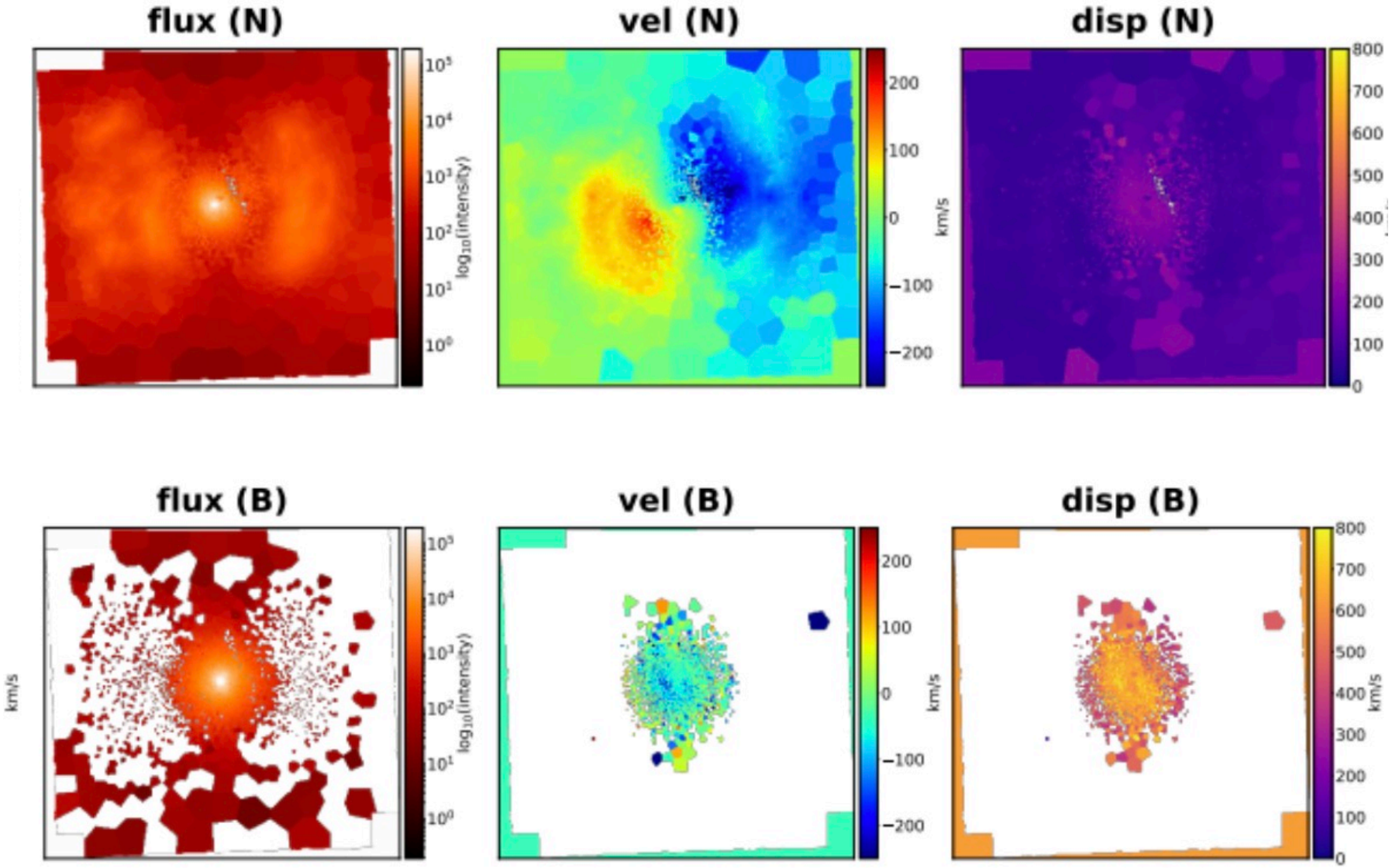
PG1126





Marasco et al. 2020

A large scale outflow and an intriguing nebula in MR2251



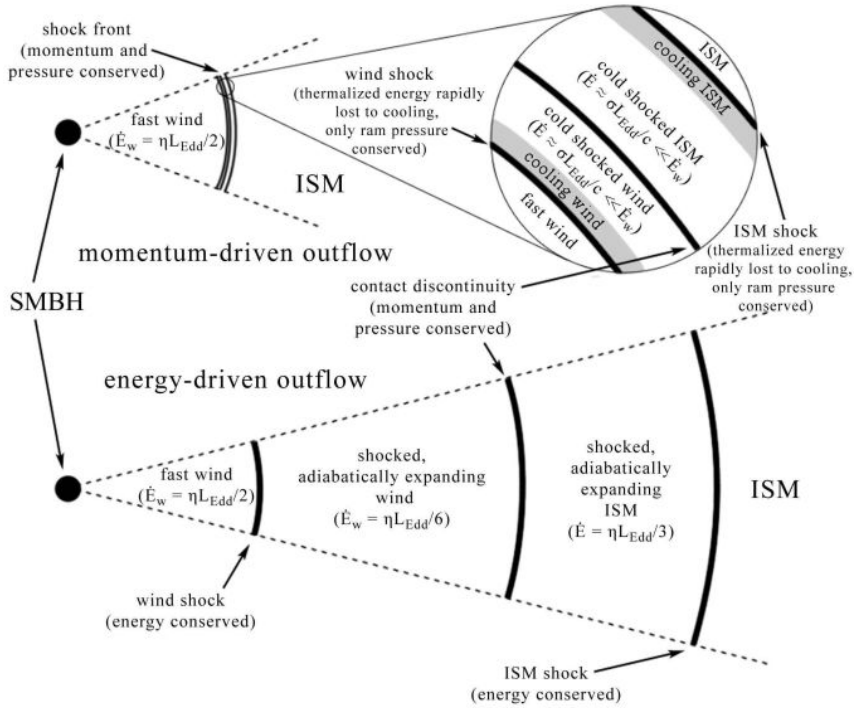
Narrow component

Outflow component

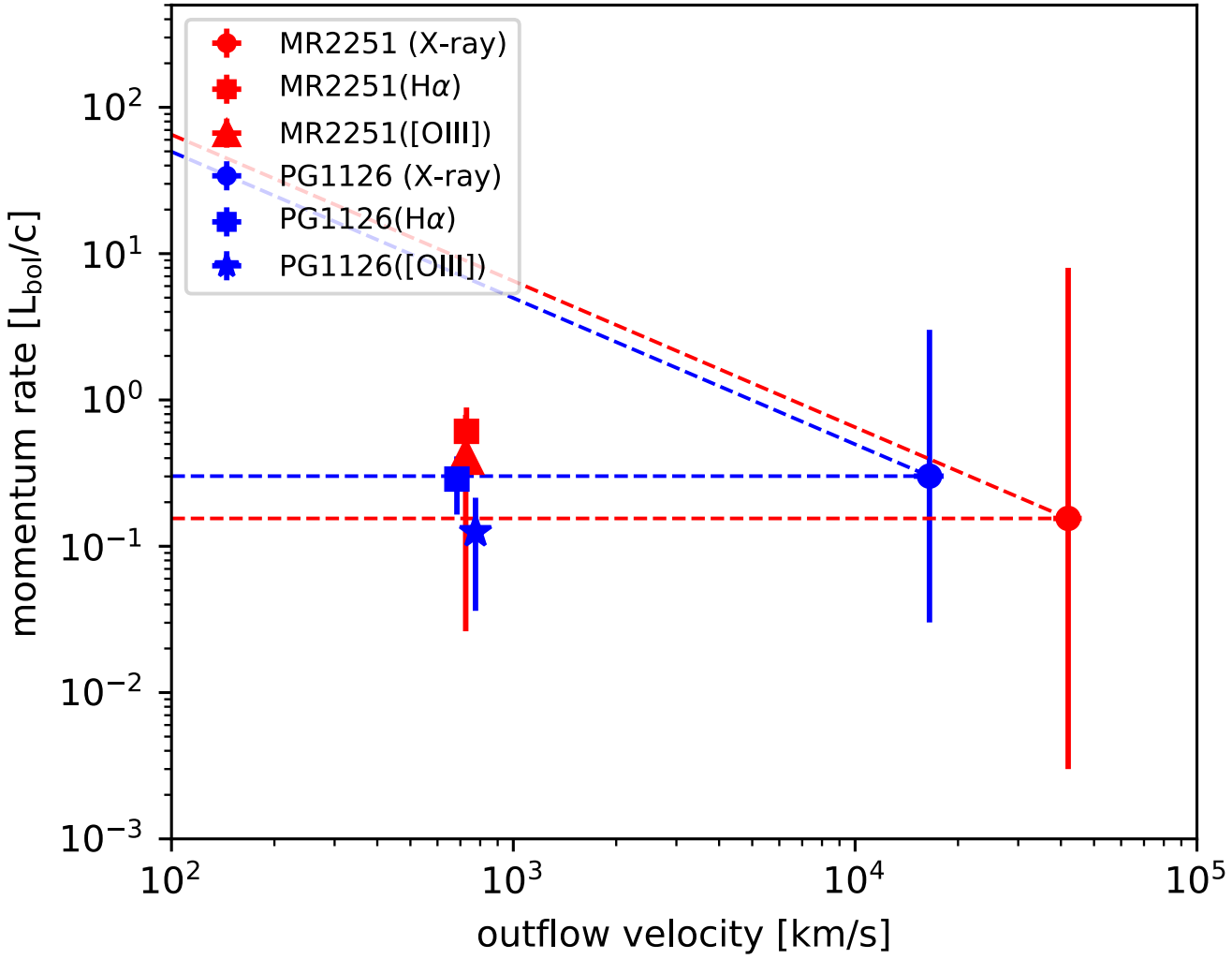
Marasco et al. 2020

Connecting UFOs with large scale outflows with MUSE NFM

Preliminary results seem to show better agreement with a momentum conserving scenario for the two AO QSO



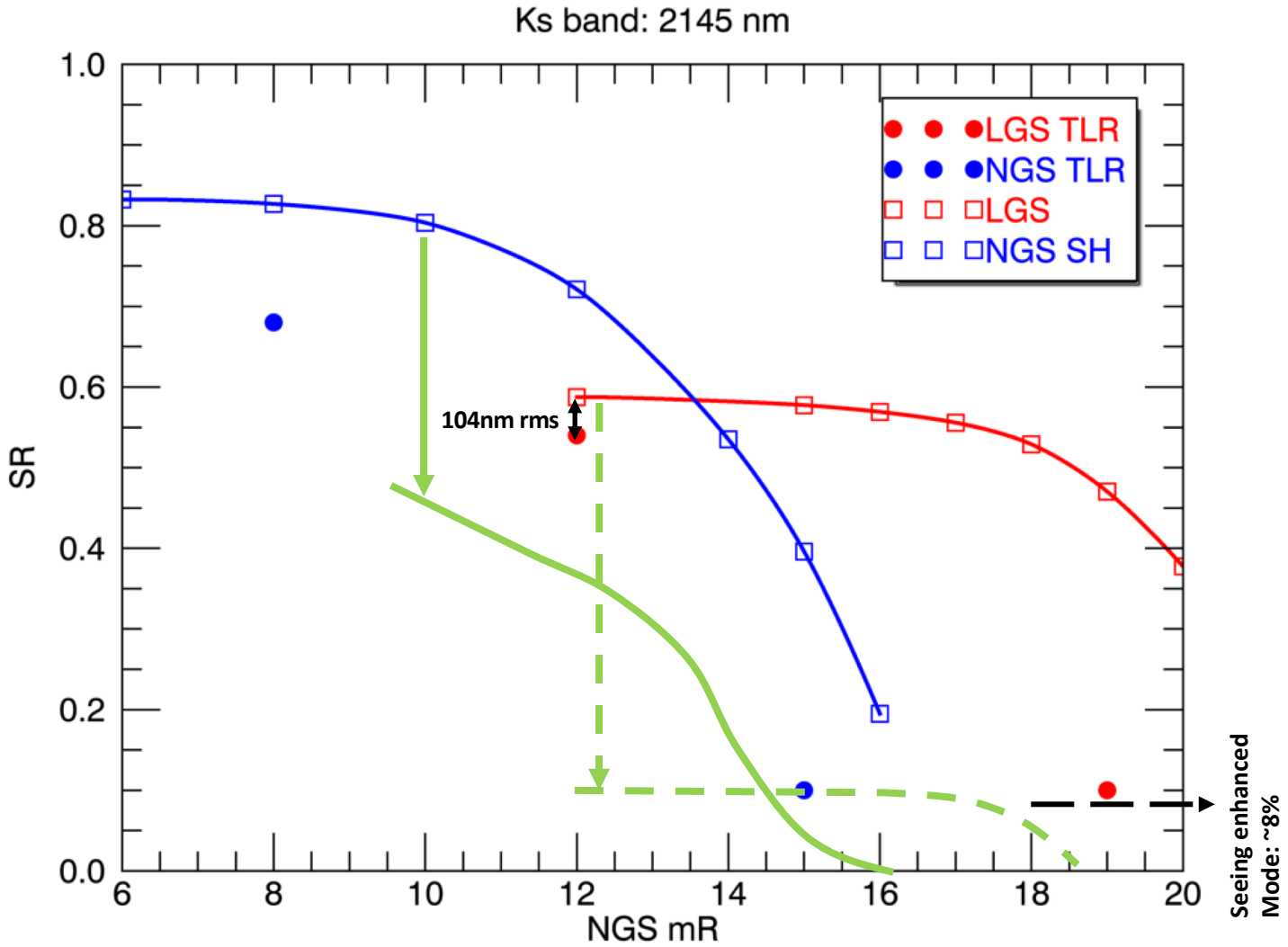
King & Pounds 2015



Marasco et al. 2020

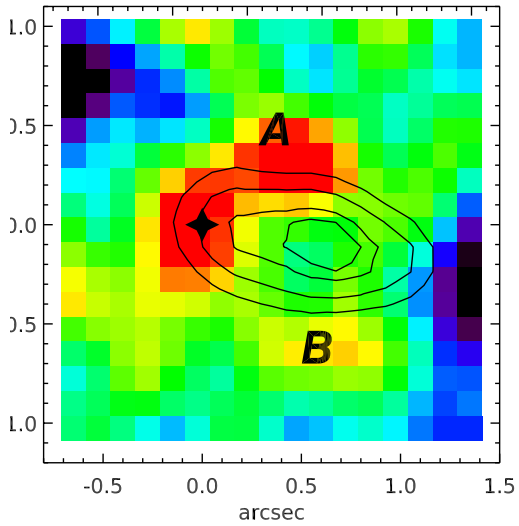
The future: from SUPER to HIPER

(High resolution Investigation of Feedback Processes with ERis)



Main advantages of ERIS:

- Higher AO correction
- Larger sky coverage
- R=8000 resolution available for better kinematic studies and BLR/narrow Ha decomposition

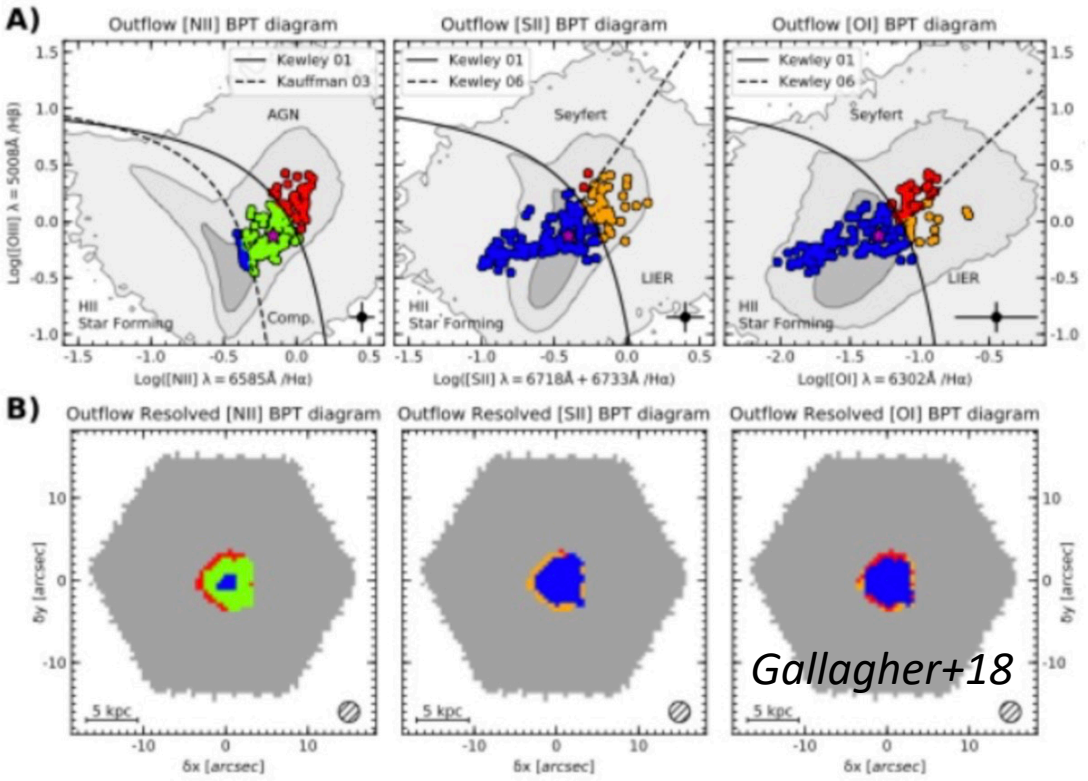


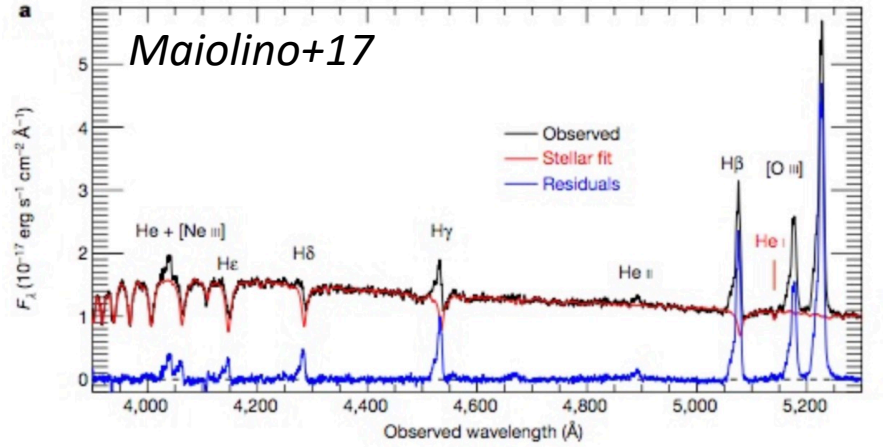
Narrow Ha map

[OIII] wing contours

(Cresci+15a)

The future: star formation in outflows





Star formation in clumpy, dense molecular gas in outflow claimed as a new mode of star formation (e.g. Ishibashi & Fabian 2013, Zubovas & King 2014)

First claims in Maiolino+17 (Nature), Gallagher+18, Belfiore+ in prep, Mingozzi+ in prep.

Hard to detect because:

- SF dominated excitation hidden in the AGN emission → high spatial resolution and high sensitivity needed
- stellar absorption features from young stars have to be detected below the bright line emission → higher spectral resolution than MUSE needed

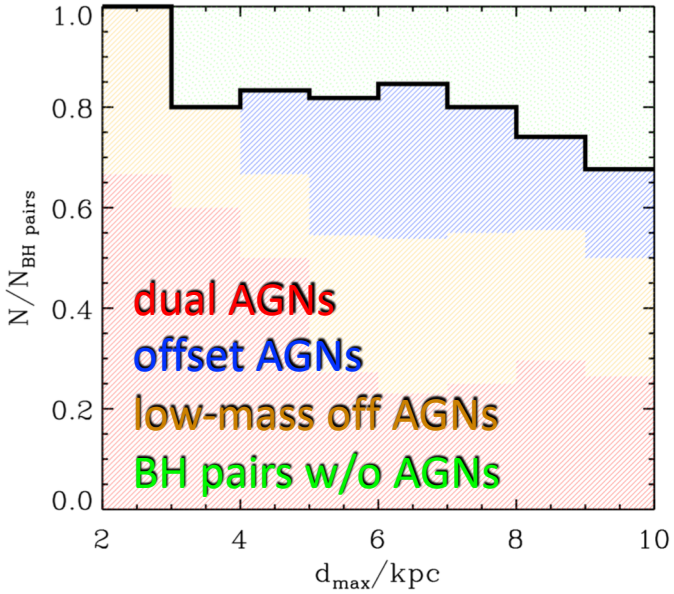
MAVIS

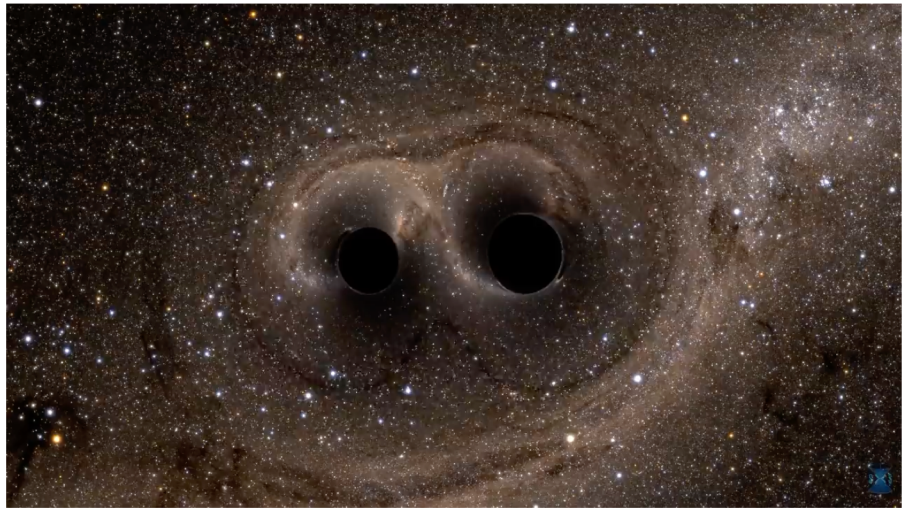
Perfectly suited for the task!
R~12000; 20 mas FWHM

Not only outflows: the hunt for binary BH

- Fundamental prediction of hierarchical cosmology: galaxies and SMBH merge
- Extensive population of multiple SMBHs in-spiraling after a merger event
- Most BH are expected to be active (Steinborn et al 2016)
- However, not much evidence for binary SMBHs

Steinborn et al 2016





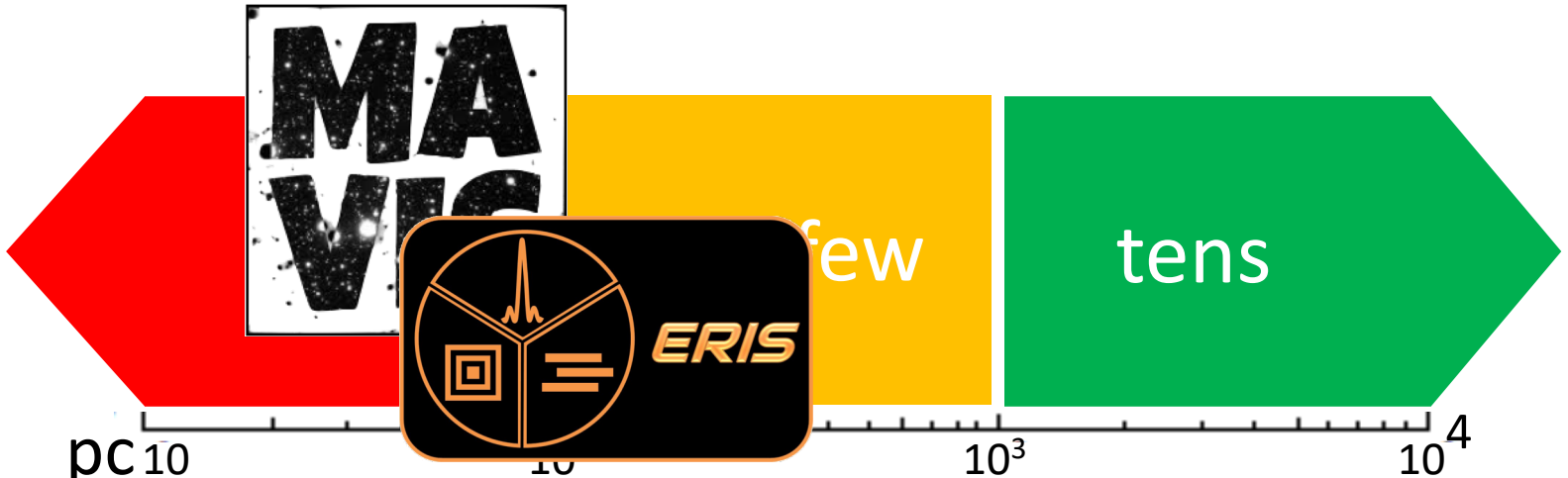
Binary BH system important for:

- test the models of SMBH formation
- physics of BH merging to compare with GW detection
- determination of the stochastic GW background at low frequencies (Sesana+08, Goulding+19)
- Sub kpc systems especially important!

Not only outflows: the hunt for binary BH

Current situation:

- **Local merging galaxies:** a few systems, d=0.5-5 kpc
- Binary AGNs in **SDSS** (Hou+19): many at 3-10 arcsec → d > few kpc
- **HST imaging**: (Komossa+09, Civano+10, Fu+12, Gouldling+19) few systems, d>0.5" = 2-10 kpc
- **X-ray/Chandra** (Civano+10, Fabbiano+11, Comeford+15, Hou+19): many at 1 arcsec, d>2kpc
- Peculiar [OIII] **emission line profile** (Wang+09, Liu+10, Smith+10, Green+11, Shen+11, Fu+12, Mullaney+13), a few systems later confirmed
- **Near-IR AO**: mostly imaging (Fu+11, Medling+11, U+13,19, Imanishi+14, Koss+18, Iwasawa+18, Müller-Sánchez+18), few systems, d>200pc
- **Radio** VLBI/VLBA: (Rodriguez+01, Burke-Spolaor+11, An+18): rare, few systems, 1 system at 7pc



50 mas resolution →

- 20 pc at z=0.02
- 420 pc at z=2
- Δv ~ 30-140 km/s for 10^8 $M_\odot$

Pilot study: HST imaging of AGNs in COSMOS

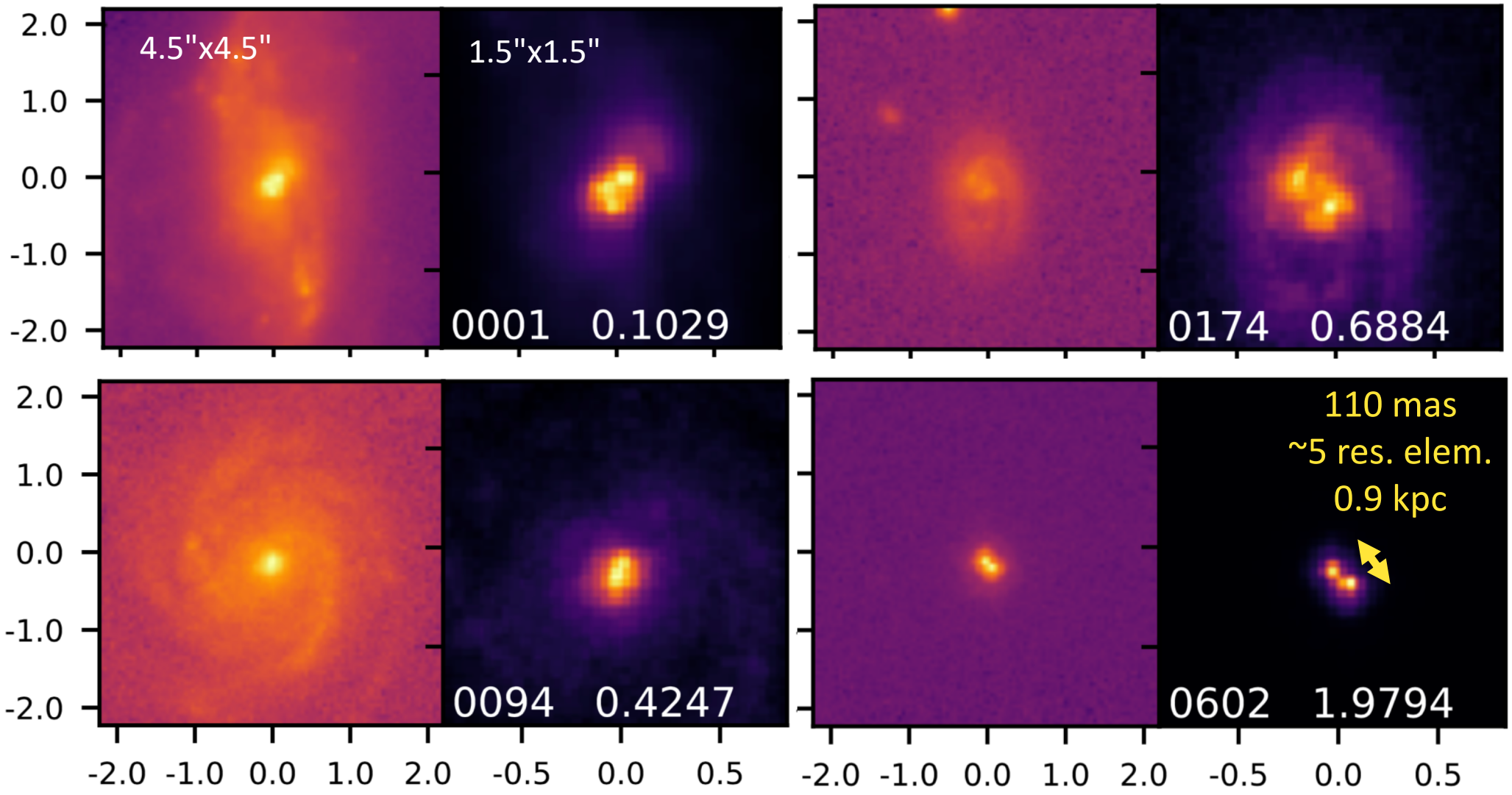
Mannucci et al. in prep.

Lanzuisi+17:
~700 objects

ACS F814W

~15 objects with multiple point-sources with d<1"

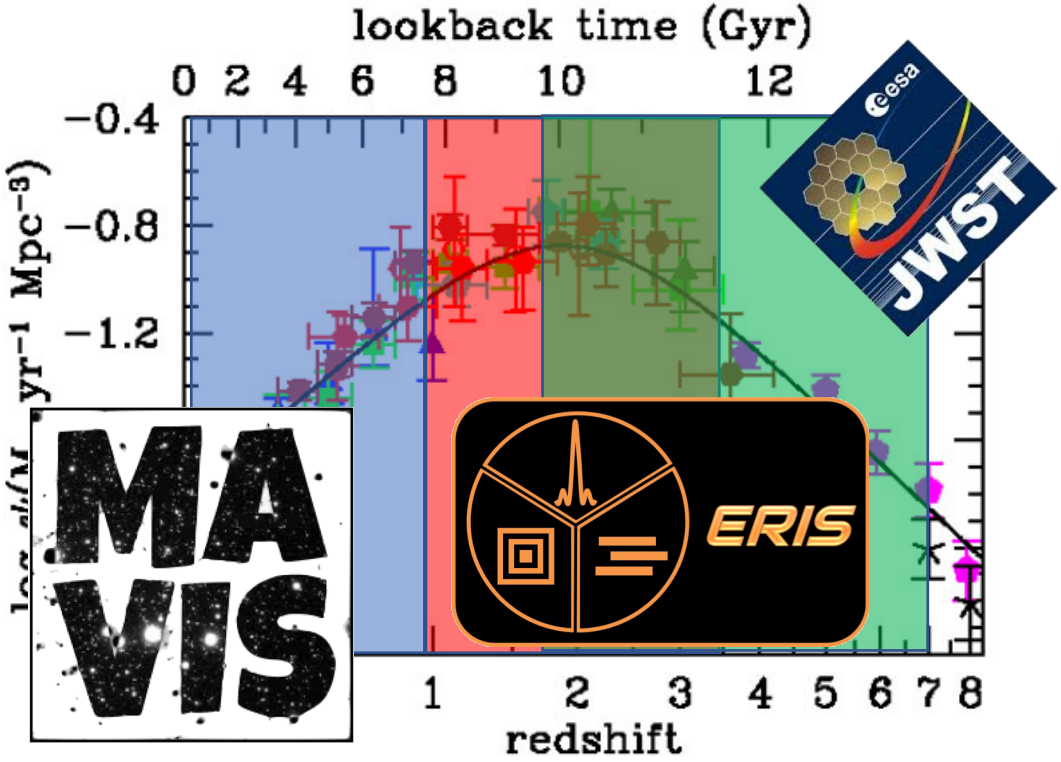
Spectroscopic confirmation needed!



Other preselections: Line profile? Fu+12, Mullaney+13; GAIA varstrometry? Hwang+19

Conclusions

- AGN observations with AO already a reality
- However, full AO potential not realized yet
  - limited Strehl ratios and FWHM
  - limited to brightest sources due to sky coverage
  - limitation in the scheduling → hard to get data



- Forthcoming IFU system AO-fed in the NIR and Optical will open a new window in our understanding of AGN physics and their interplay with the host galaxy:
  - Detailed study of AGN accretion and outflows physics and their feedback on the hosts
  - from the peak epoch of SF and BH accretion to present
  - complementary to other facilities like JWST