Future multi-objects spectrographs at ESO

Vincenzo Mainieri
MOS Project Scientist

Current MOS facilities at ESO

FORS2 FLAMES VIMOS KMOS

2000 2003 2003 2013 time

Future MOS facilities at ESO

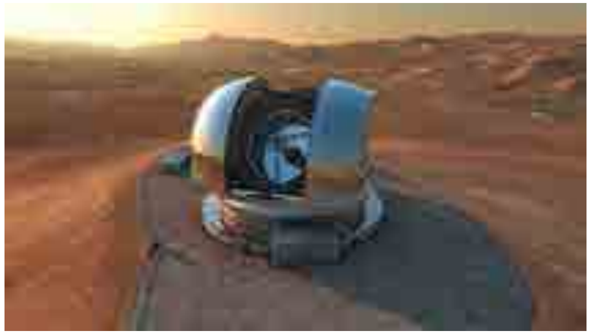
MOONS/VLT

PDR: Oct 2015
Star of operations: 2019

4MOST/VISTA

PDR: June 2016
Star of operations: 2020

E-ELT MOS



Phase-A of 24 months
Start: Mar 2016

time

MOONS

Multi-Object Optical and Near-infrared Spectrograph for the VLT

PI Michele Cirasuolo

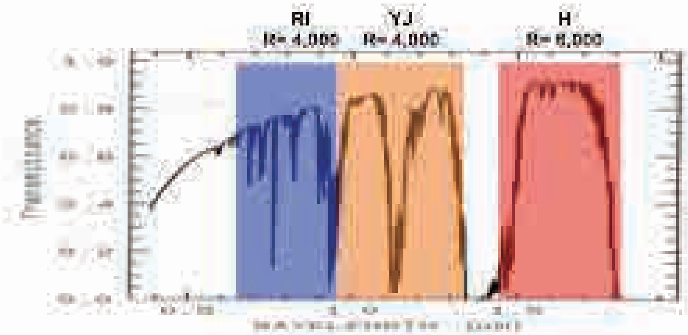
MOONS in a nutshell

Field of view: 500 sq. arcmin at the 8.2m VLT

Multiplex: 1024 fibers, with the possibility to deploy them in pairs

Medium resolution:

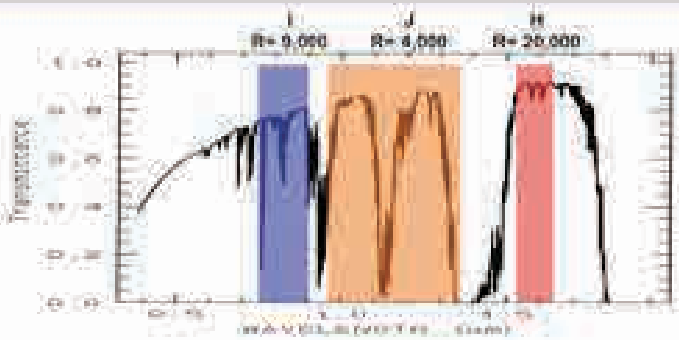
Simultaneously 0.64µm-1.8µm
at
R=4,000 – 6,000



High resolution:

Simultaneously 3 bands:

- 0.76-0.90µm at R = 9,000
- 0.95-1.35µm at R=4,000
- 1.52-1.63µm at R=20,000



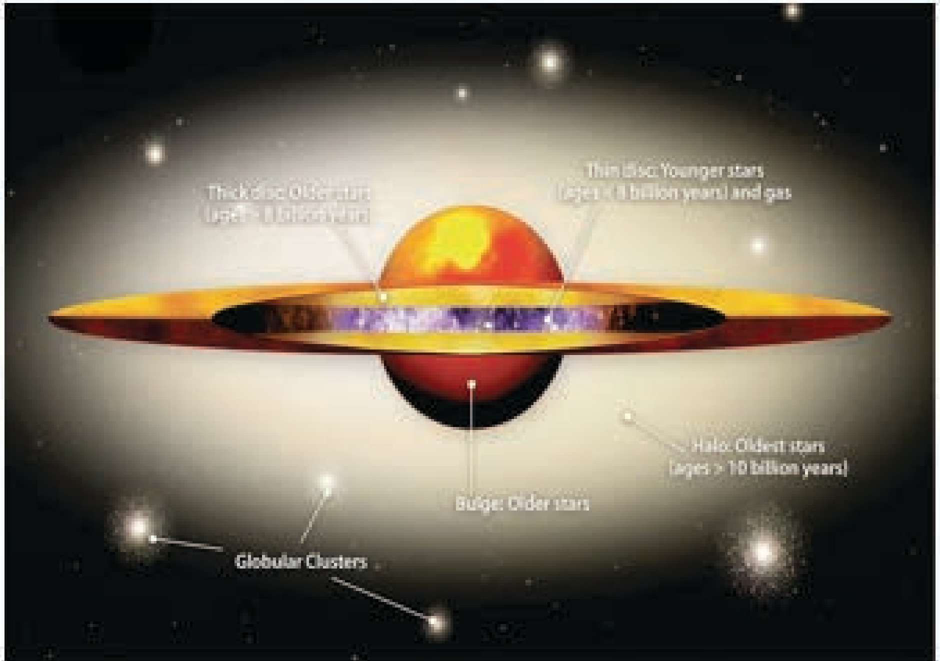
Throughput: ~ 30 %

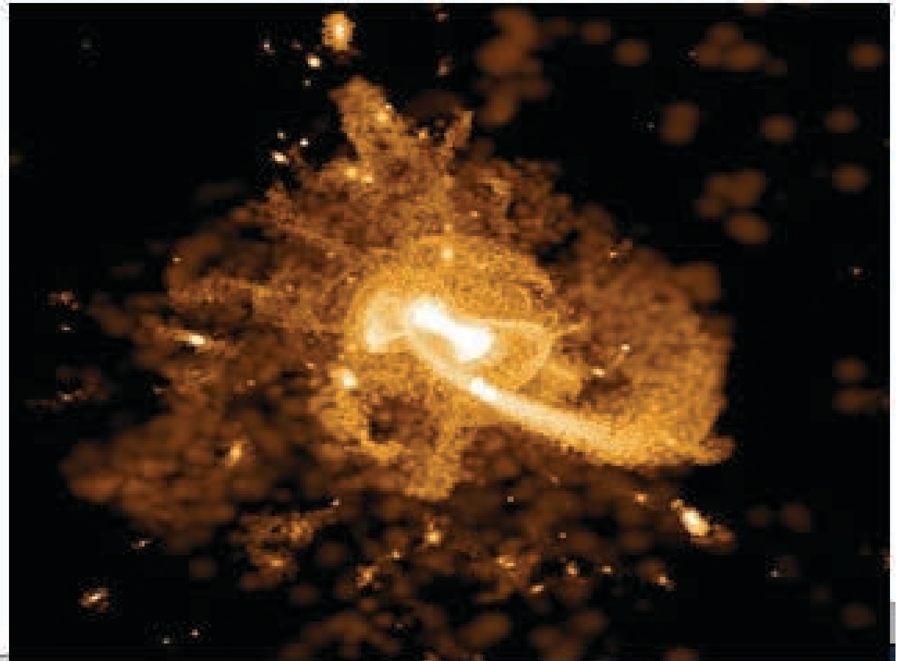
Galactic science case

Galactic Archaeology

The evolution of stars and galaxies remains among the key unanswered questions.

The resolved stellar populations of the Milky Way provide us with a fossil record of the chemo-dynamical and star-formation histories over many gigayears timescale.





Galactic Archaeology

Follow-up of VISTA, Gaia and LSST imaging surveys

MOONS will provide

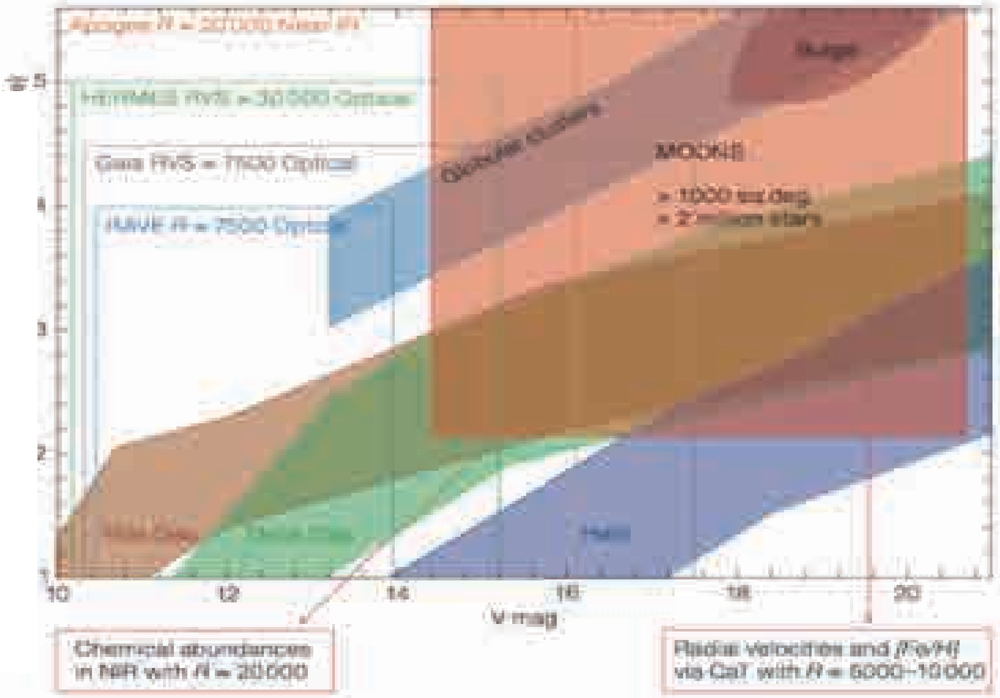
Medium resolution mode

Radial velocities via
CaT @R=9,000 for I<21
+
[M/H] (via Fe,Si,Ti,Mg)
@R=4000-6000 (J+H)

High resolution mode

Detailed chemical abundances
(Si, Ca, Ti, Mg, Fe, Cr, Mn, CNO …)
@R=20,000 for H_{Vega}<15.5
+
CaT @R=9,000

Galactic Archaeology



Gaia

- astrometry for all stars with V<20
- Chemical abundances V<13
- Radial velocities V<17

MOONS will provide

Medium resolution mode

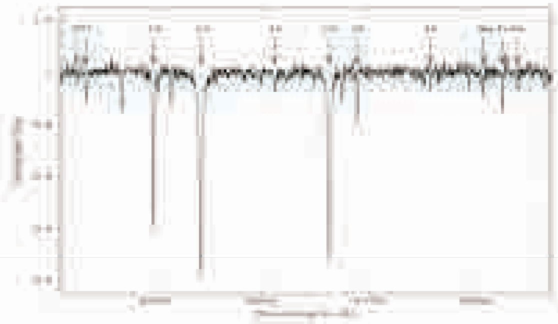
Radial velocities via
CaT @R=9,000 for I<21
+
[M/H] (via Fe,Si,Ti,Mg)
@R=4000-6000 (J+H)

High resolution mode

Detailed chemical abundances
(Si, Ca, Ti, Mg, Fe, Cr, Mn, CNO …)
@R=20,000 for H_{Vega}<15.5
+
CaT @R=9,000

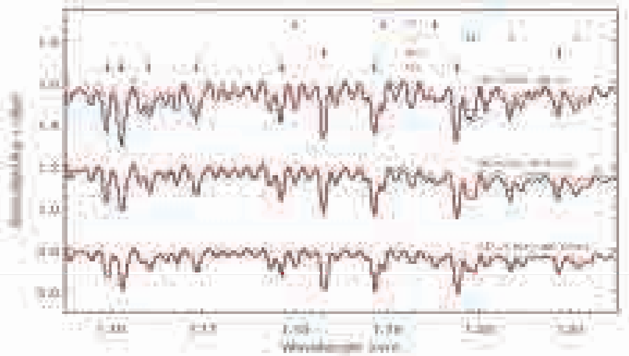
MOONS for Galactic studies

I-band
R=9,000



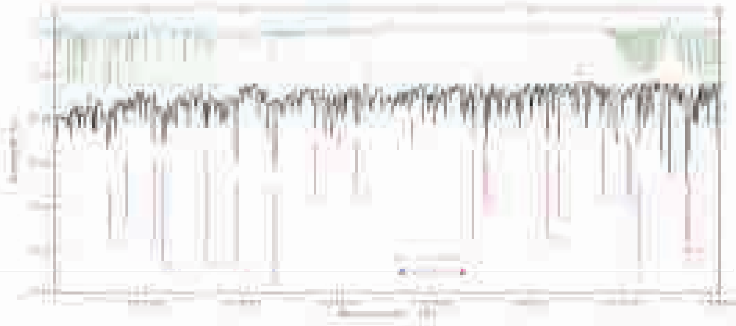
FLAMES
(multiplex = 130)

YJ-band
R=4,500



KMOS
(multiplex = 24)

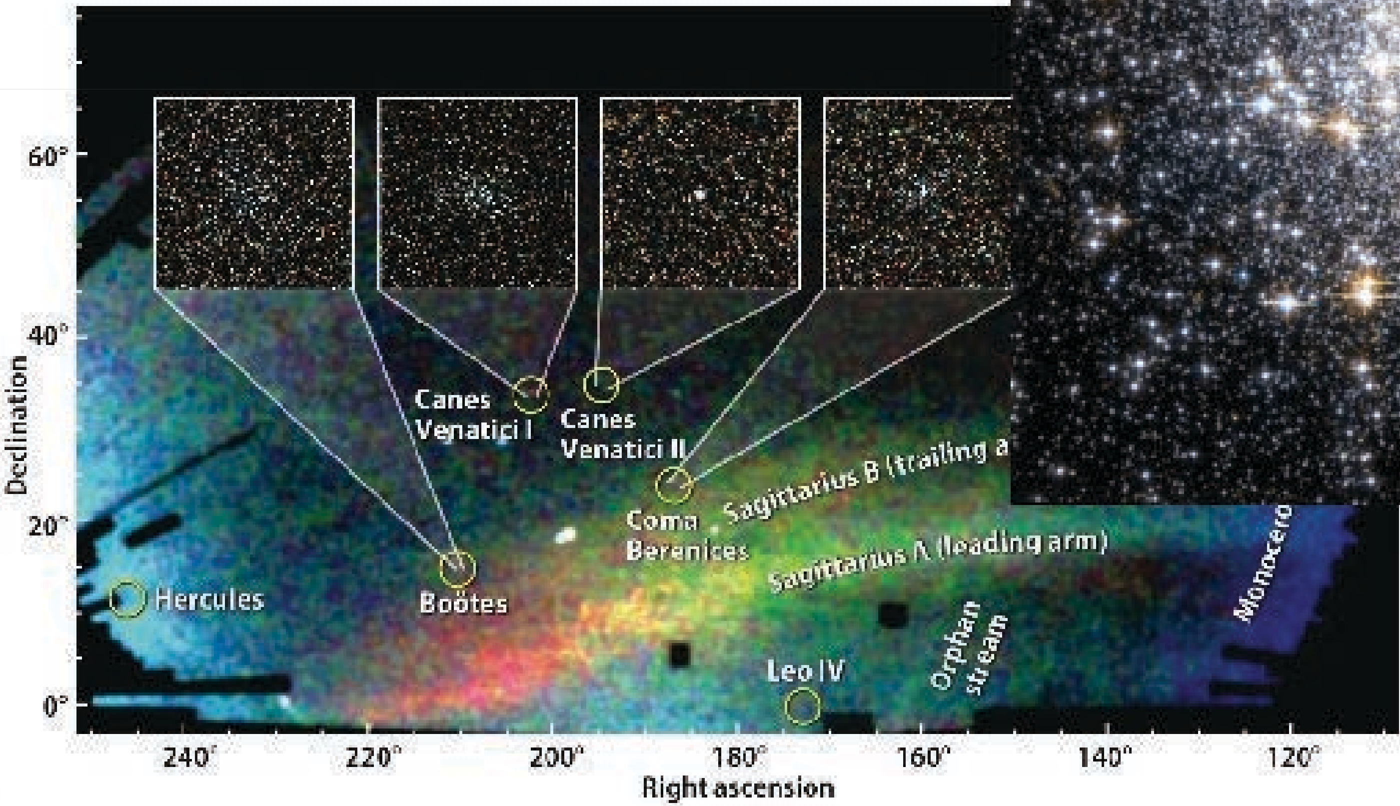
H-band
R=20,000



APOGEE
(multiplex = 300)

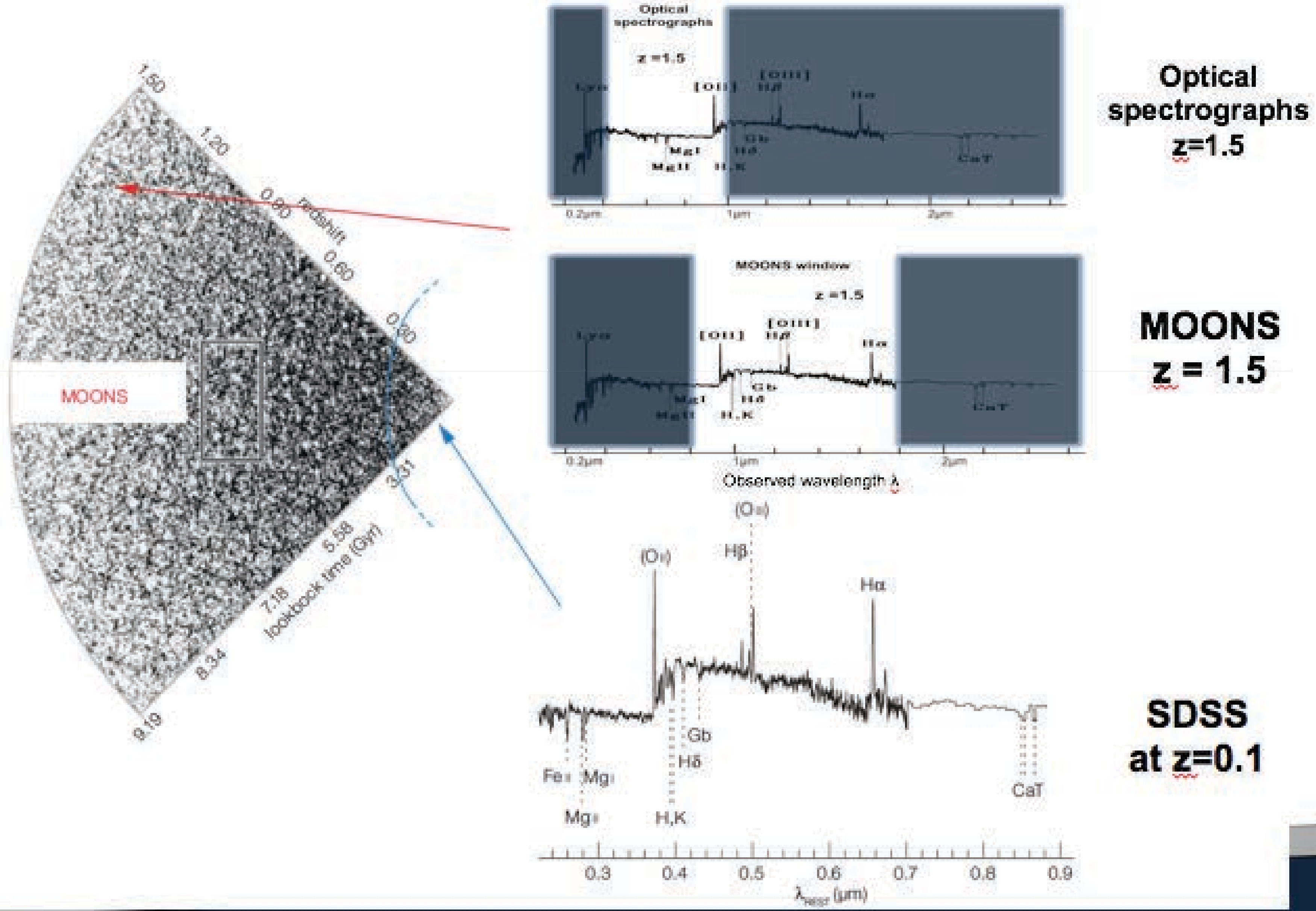
Streams in the Halo and globular clusters

Photometrically selected with Gaia, SDSS, Pan-STARRS, VISTA, UKIDSS, LSST etc.



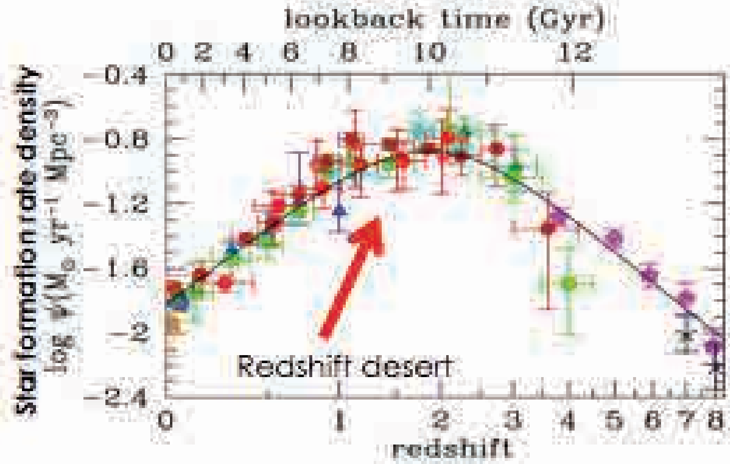
Extragalactic science case

MOONS: a SDSS-like machine probing the peak of galaxy and black hole formation



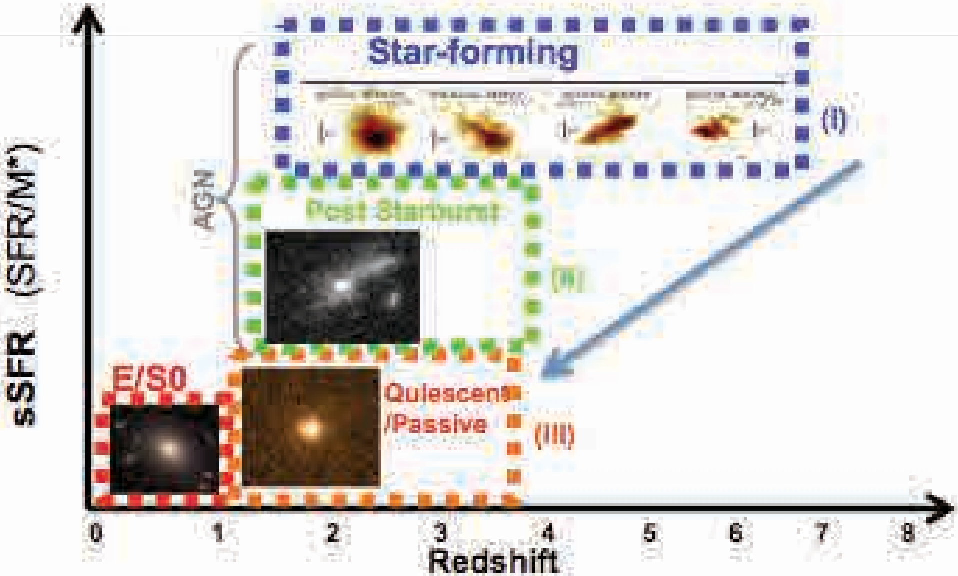
Extra Galactic Science Case

SDSS-like survey
galaxies at z>1 across the peak of star-formation and black hole accretion, up to the very first galaxies at z>7-8



Galaxy Evolution: Diagnostics for passive and star-forming galaxies

- *Metallicity (R_{23},N_2)*
- *SFR (Hα, Hβ, [OII])*
- *AGN power (BPT)*
- *Dust extinction (Hα/Hβ)*
- *Galaxy mass (σ_v)*
- *BH mass (BLR)*



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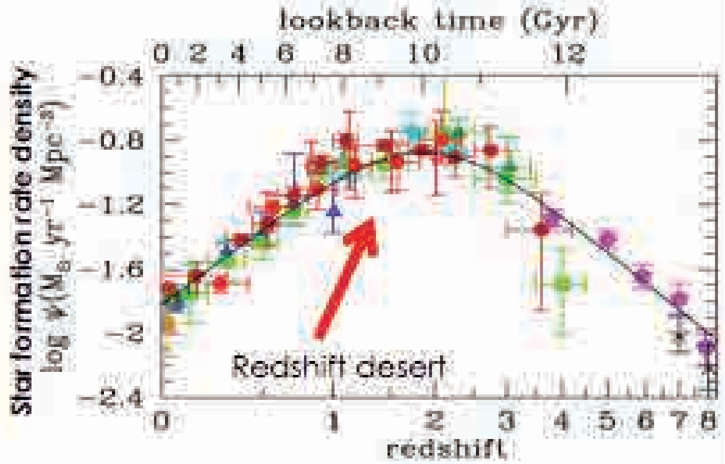

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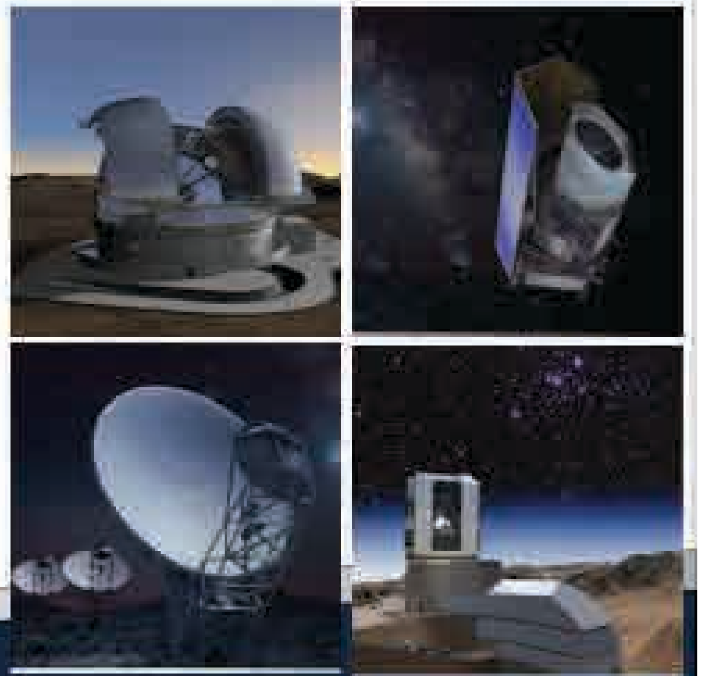
- *BH mass (BLR)*

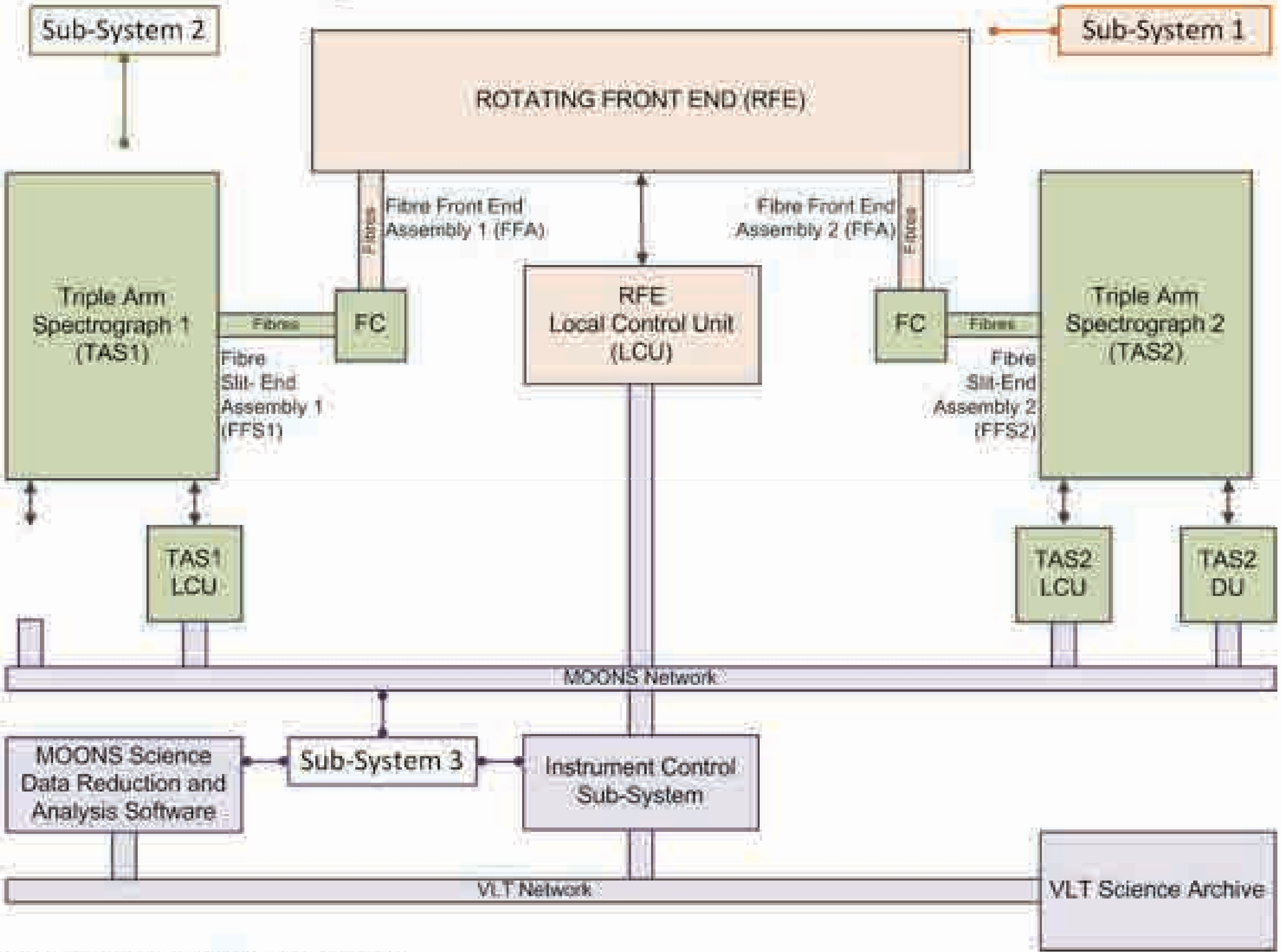
✓Follow-up of large-area imaging surveys: VISTA, Herschel, DES, UKIDSS, eRosita, etc.

✓ Strong synergies: Euclid, SKA, LSST and E-ELT



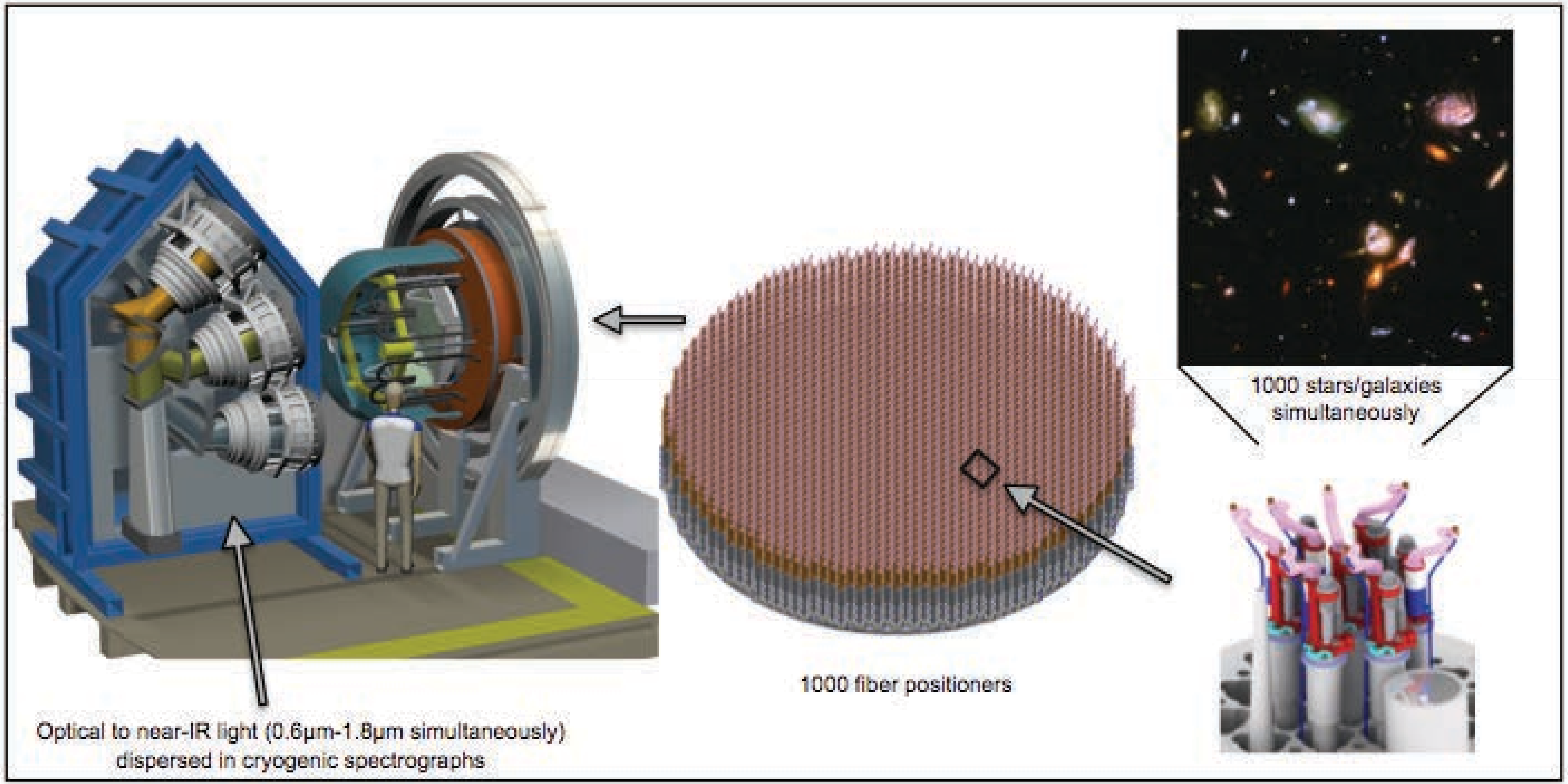
MOONS basic layout

System Overview

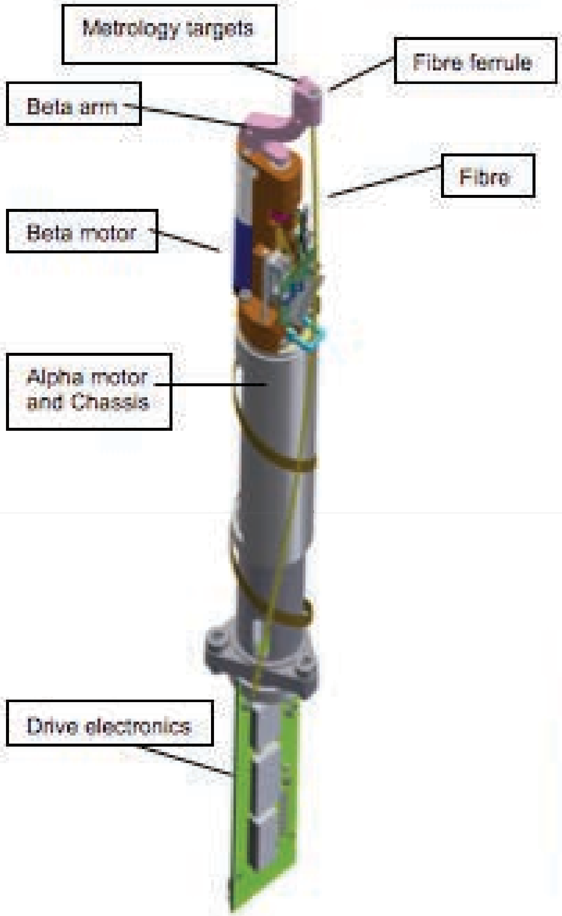


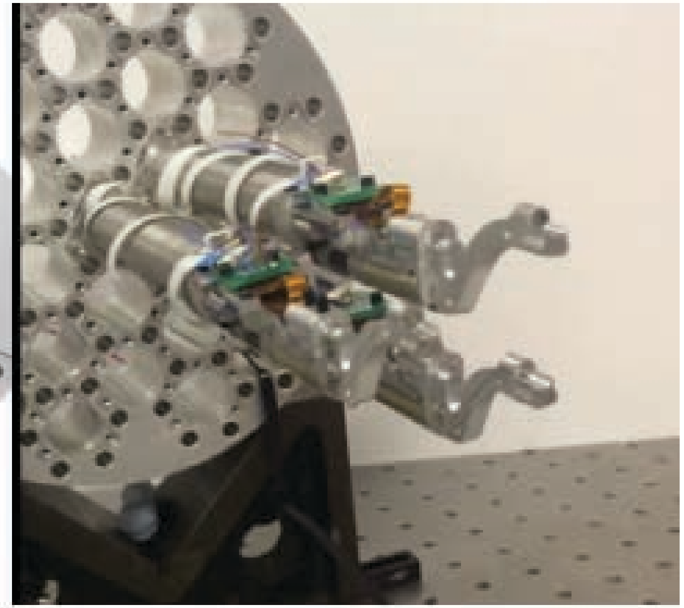
See H. Schnetler et al, SPIE 9150-23

System Overview



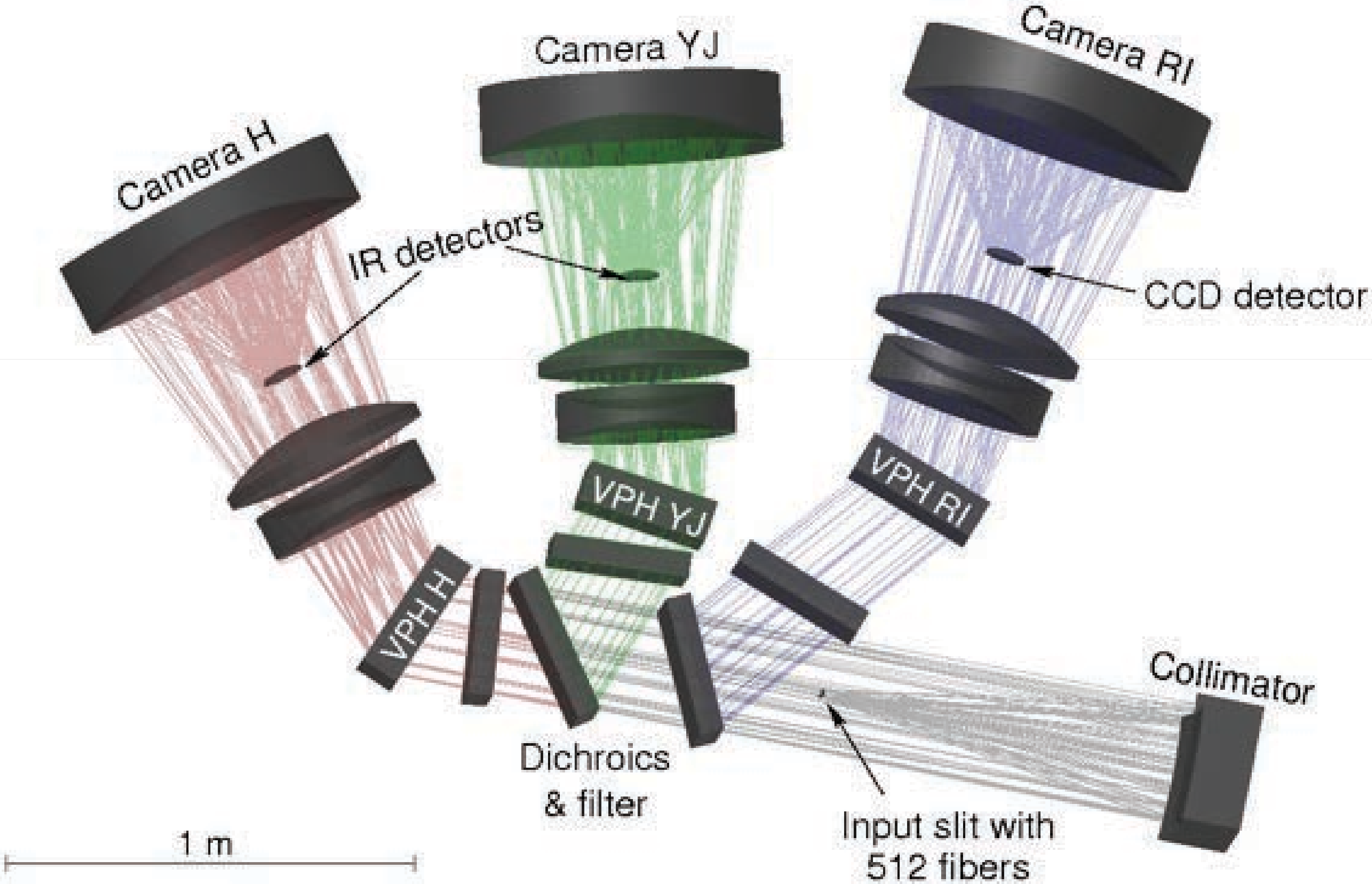
Fiber positioner
micro-mechanical pick-off system





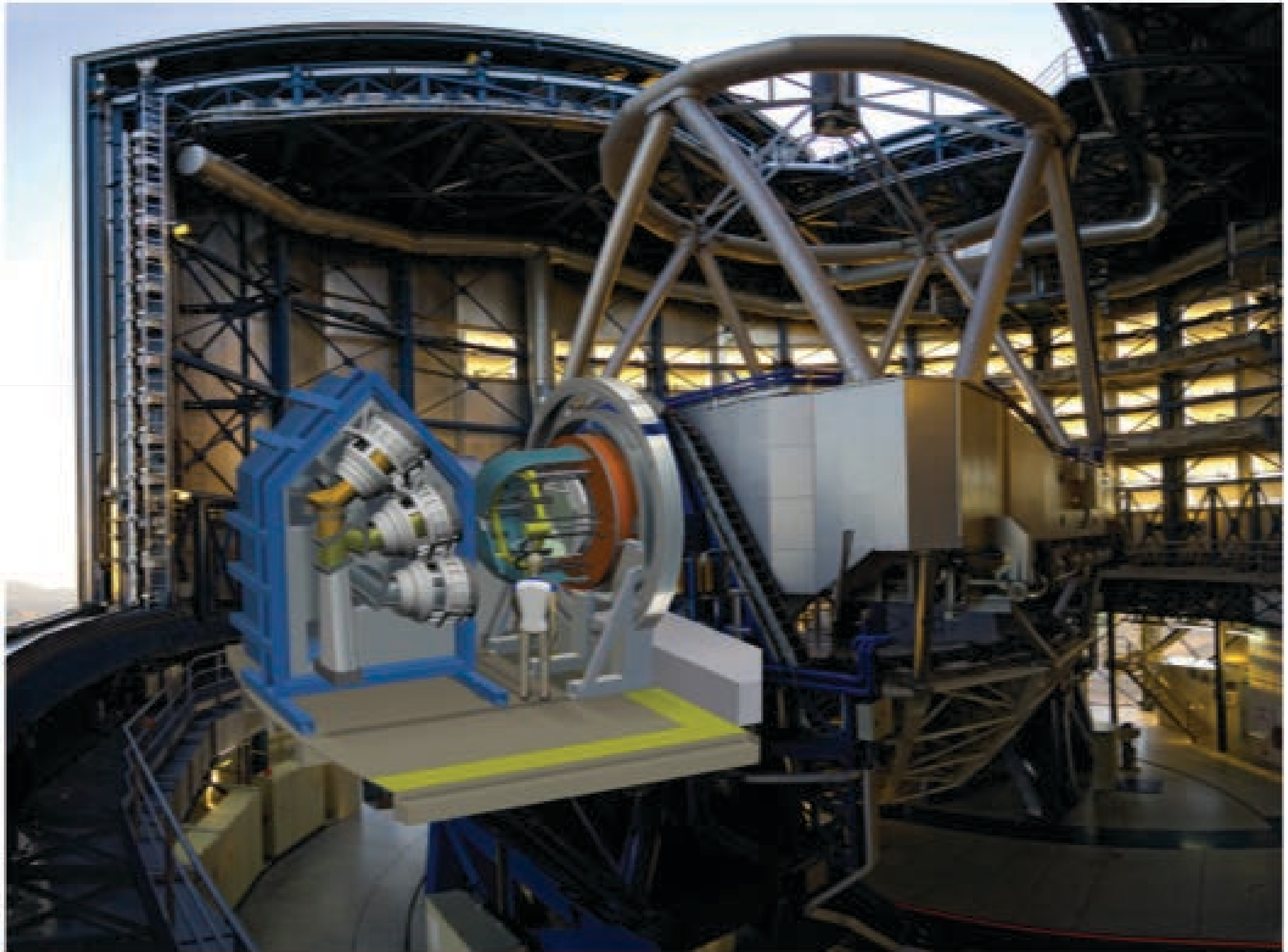
- ✓ Large overlap between positioners
- ✓ Possibility to pair all fibers for optimal sky subtraction
- ✓ Both motors with encoders and anti-backlash
- ✓ Fast reconfiguration time (< 1min)

Spectrograph optical design



See E. Oliva et al, SPIE 9147-337

MOONS on the Nasmyth platform



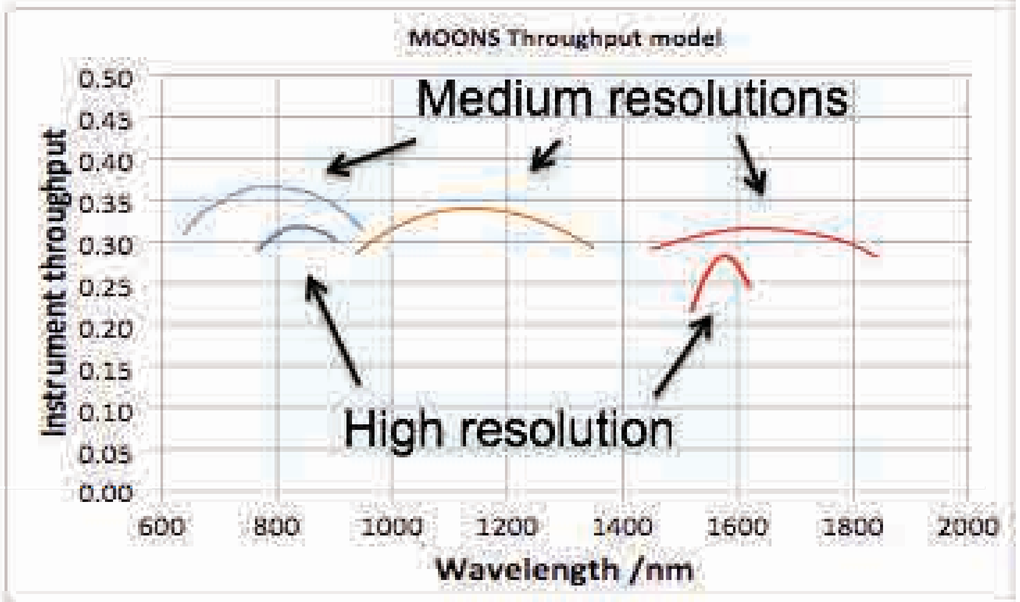
Expected performances

Sensitivities in 1hr integration:

Emission lines:
2×10^{-17} erg/s/cm^2 (5σ)

Continuum:
AB = 22.7 (5σ) with the spectrum rebinned, after sky subtraction, to an effective resolution of R=1,000

Continuum high resolution:
H_{vega} = 15.5 S/N > 30



MOONS Summary

Construction phase started in June 2014
Operational by 2019

Field of view	500 sq. arcmin
Multiplex	1000 fibres
Low resolution mode	R = 4,000-6000 λ = 0.64μm – 1.8μm simultaneously
High resolution mode	R=9,000 for CaT + R=4,000 in YJ-band + R=20,000 in H band
Throughput	> 30 %

Main science cases:

Galactic Archaeology:

✓ Radial velocities and detailed chemical abundances for **several million stars** over **>500 sq. deg** in our own Galaxy.

Galaxy evolution:

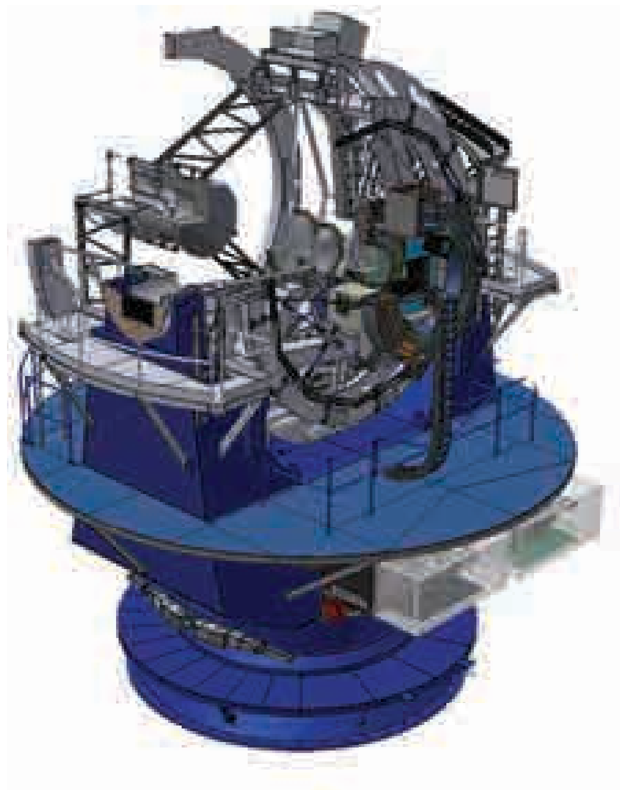
✓Formidable **SDSS-type survey for >1M galaxies at z>1**. Unique insight into the effect of environment, chemical and physical evolution.

Synergies:

✓Essential follow-up of large-area imaging surveys: Gaia, VISTA, Herschel, DES, UKIDSS, LOFAR, eRosita, Euclid, LSST, SKA

4MOST – 4m Multi-Object Spectroscopic Telescope

P.I. Roelof de Jong (AIP)



VISTA

Main science drivers

A 5 year 4MOST survey provides

- Euclid/LSST/SKA (and other surveys) complement:
  - Dark Energy & Dark Matter (BAO, RSD, lensing, Ly forest)
  - Galaxy evolution (groups & clusters)
  - Transients (SNe Ia, GRB)
  - $>13 \times 10^6$ spectra of m_V~20-22.5 mag LRGs & ELGs
- eROSITA complement:
  - Cosmology with x-ray clusters to z~0.8
  - X-ray AGN/galaxy evolution and cosmology to z~5
  - Galactic X-ray sources, resolving the Galactic edge
  - 2×10^6 spectra of AGN and galaxies in 50,000 clusters
- Gaia complement:
  - Chemo-dynamics of the Milky Way
  - Stellar radial velocities, parameters and abundances
  - 13×10^6 spectra @ R~5000 of m_V~15-20 mag stars
  - 2×10^6 spectra @ R~20,000 of m_V~14-16 mag stars

+ ~15 million spectra for community proposals

4MOST is a general purpose spectroscopic survey facility serving many astrophysical communities

Science Requirements

- 4MOST shall be able to obtain:
  - *Redshifts* of AGN and galaxies (also in clusters)
    - R~5000 spectra of 22 r-mag targets with S/N=5/Å with >3 targets in ⌀=2'
  - *Radial velocities* of ≤2 km/s accuracy and *Stellar parameters* of <0.15 dex accuracy of any Gaia star
    - R~5000 spectra of 20 r-mag stars with S/N=10 per Ångström
  - *Abundances* of up to 15 chemical elements
    - R~20000 spectra of 16 V-mag stars with S/N=140 per Ångström
- In a 5 year survey 4MOST shall obtain:
  - *15 (goal 30) million targets* at R~5000
  - *1.0 (goal 3.0) million targets* at R~20,000
  - *16,000 (goal 23,000) degree^2* area on the sky at least two times

Schnurr et al., Paper 9150-46

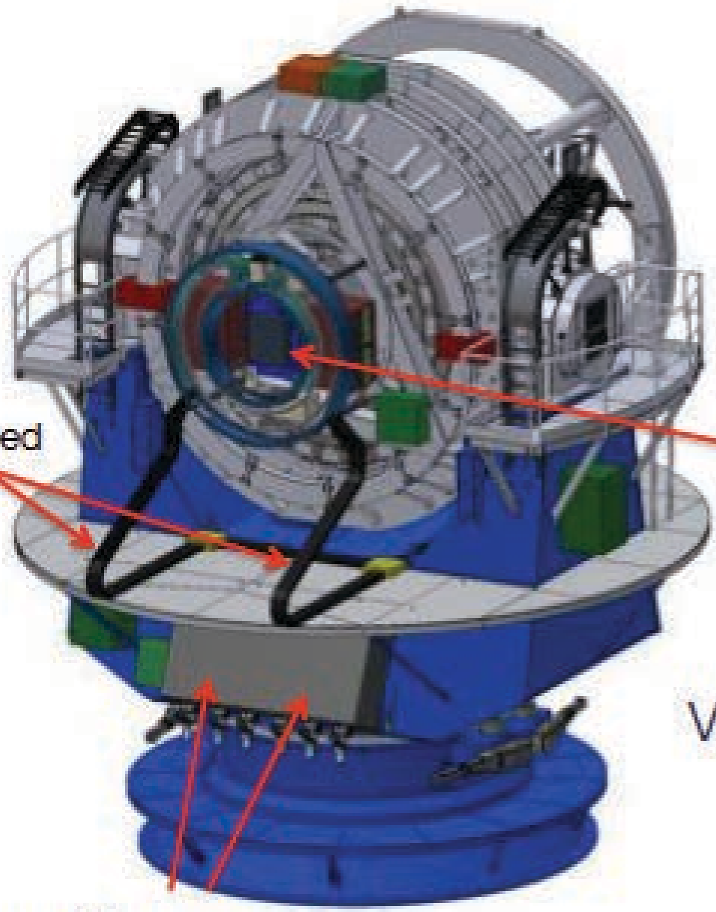
Instrument Specification

Specification	Design value
Field-of-View (hexagon)	>4.0 degree^2 (ø>2.5°)
Multiplex fiber positioner	~2400
Medium Resolution Spectrographs (2x) # Fibres Passband Velocity accuracy	R~5000–7000 1600 fibres 390-930 nm < 2 km/s
High Resolution Spectrograph (1x) # Fibres Passband Velocity accuracy	R~20,000 800 fibres 392-437 & 515-572 & 605-675 nm < 1 km/s
# of fibers in Ø=2' circle	>3
Fibre diameter	Ø=1.4 arcsec
Area (first 5 year survey)	>2h x 16,000 deg^2
Number of science spectra (5 year)	~75 million of 20 min

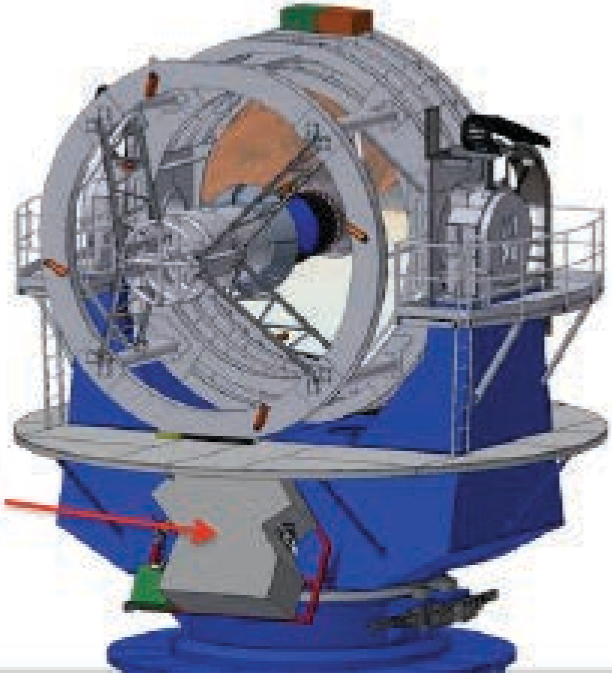
Bellido et al., Paper 9150-45

Facility instrument overview

- New Wide-field Corrector, fibre positioner and three spectrographs
- Spectrographs mounted on telescope fork (gravitation invariant)
- Short fibre run (~15 m)

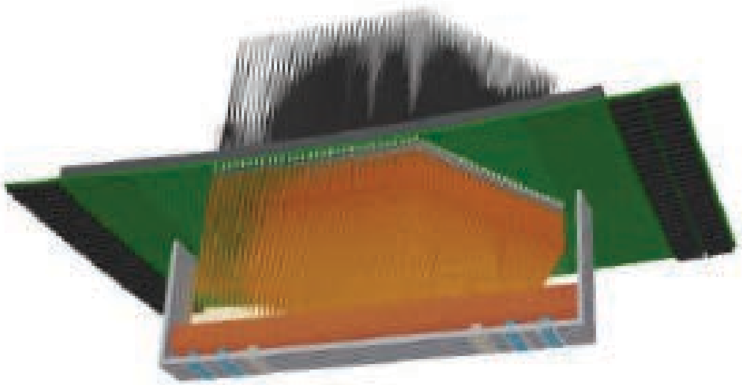


VISTA telescope

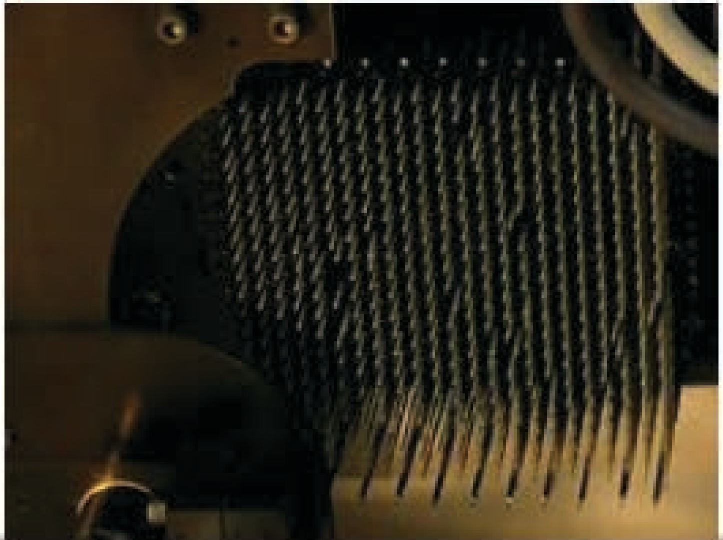


R. Haynes et al., Paper 9147-243
D. Haynes et al., Paper 9147-235

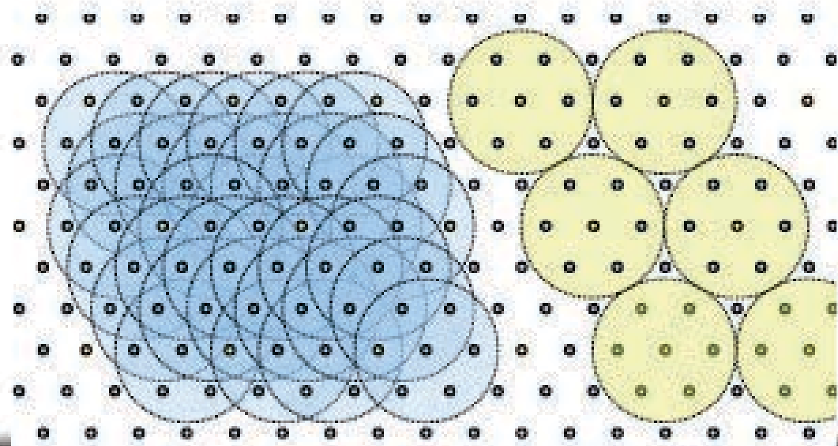
Tilting Spine (Echidna) positioner



- ~2400 fibres
- Large, overlapping patrol areas enables dense target packing and special high-resolution fibres
- Closest separation ~15 arcsec
- Reconfiguration time <2 min during science CCD readout



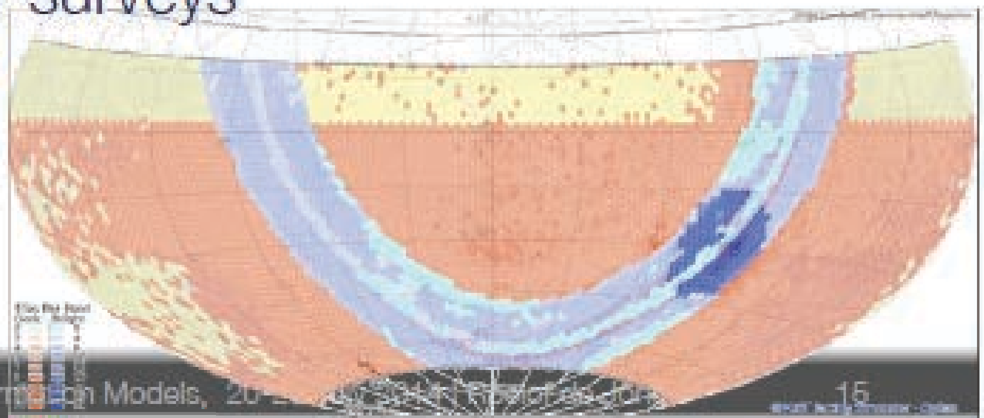
FMOS Echidna on Subaru



AAO, Sheinis et al., Paper 9151-67

How are we going to run 4MOST?

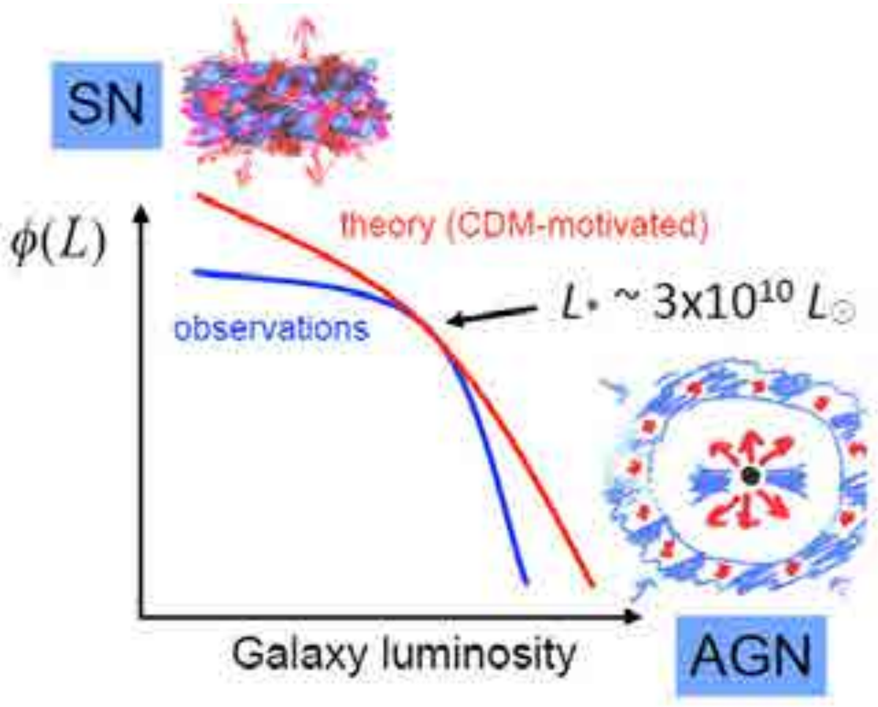
- Unique operations for MOS instruments that allows observations *for most* science cases
- 4MOST program defined by *Public Surveys* of 5 years
- Surveys will be defined by ***Consortium*** and ***Community***
- All Surveys will run *in parallel*
  - Surveys share fibres per exposure for increased efficiency
- *Key Surveys* will define observing strategy
  - Millions of targets all sky
- *Add-on Surveys* for smaller surveys
  - Small fraction fibers all sky
  - Dedicated small area
  - 10^3 to 10^6 targets



AGN feedback studies:
combining SINFONI and ALMA

Vincenzo Mainieri

AGN feedback:

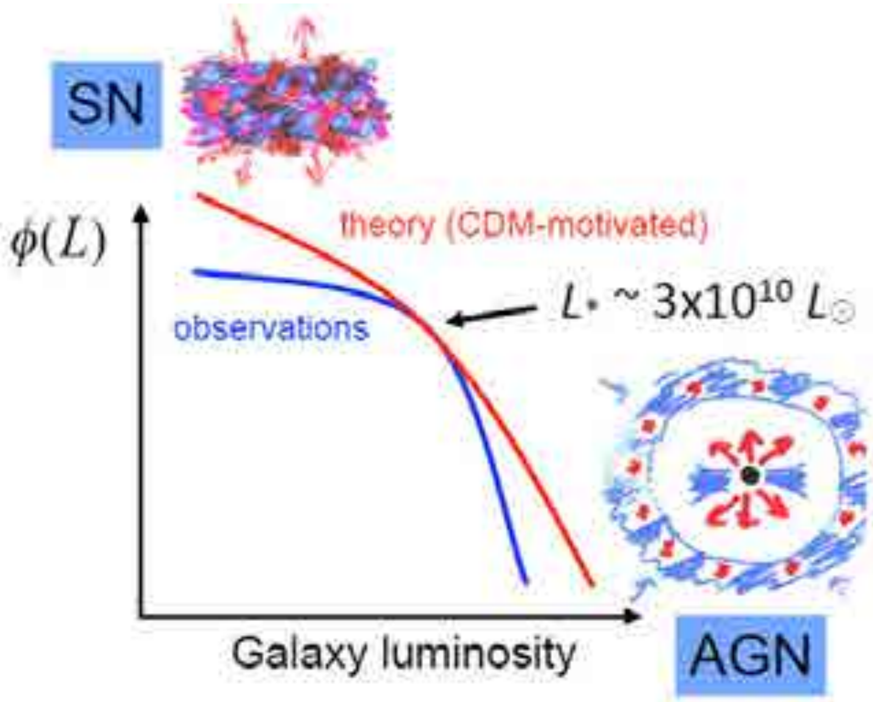


Silk+12

"It has been realized over the past decade that the black hole at the center of a galaxy bulge is no mere ornament but may play a major role in determining the final stellar mass of the bulge. The process by which this occurs is known as AGN (active galactic nuclei) feedback"

Fabian+12

AGN feedback:



Silk+12

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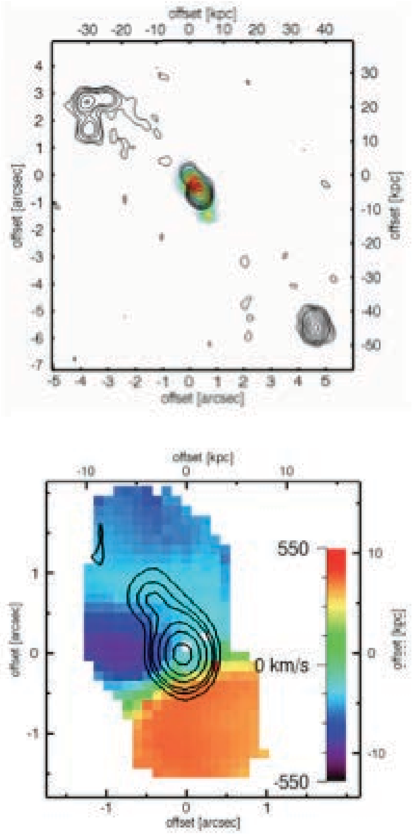
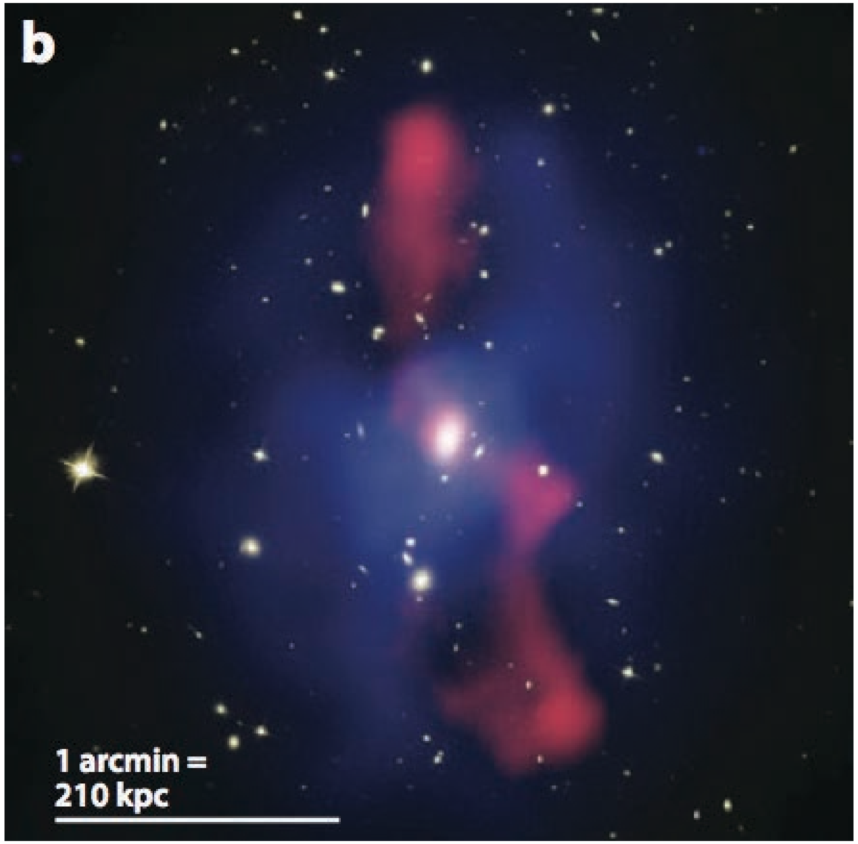
Fabian+12

Does the AGN triggered outflows affect the gas reservoir and modify the SFE of its host?

AGN feedback: radio mode

Nesvadba+08

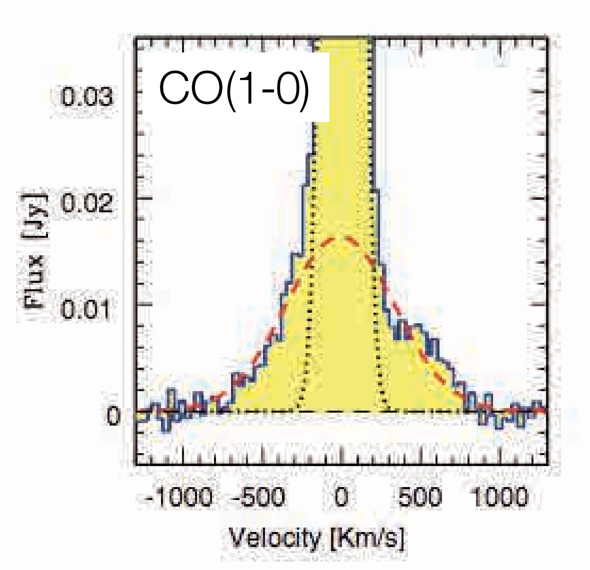




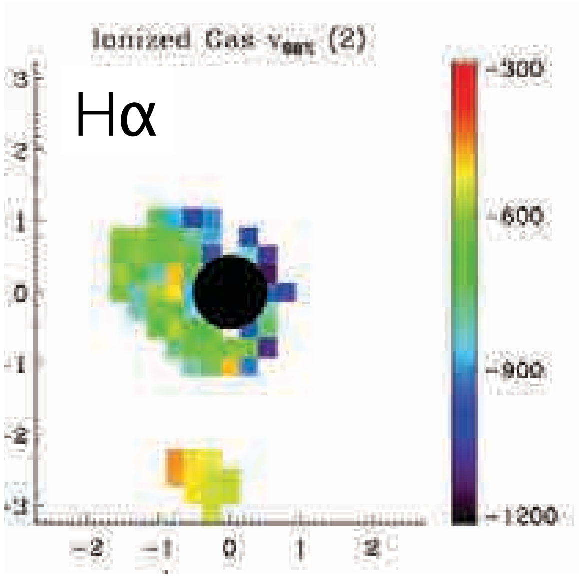
McNamara+09

AGN feedback: local Universe

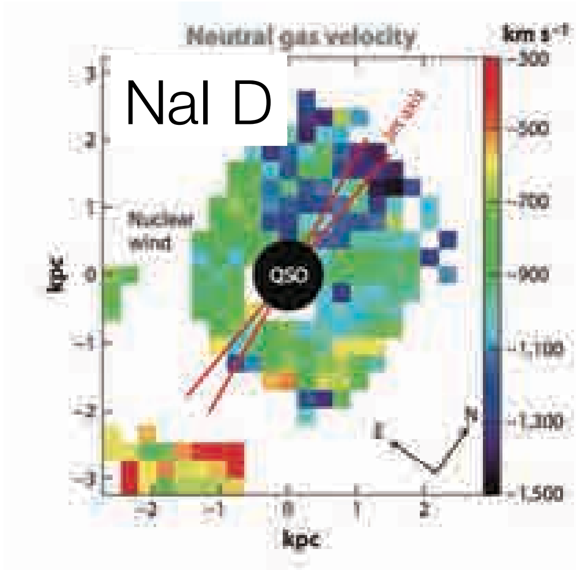
Molecular gas



Ionized gas



Neutral gas



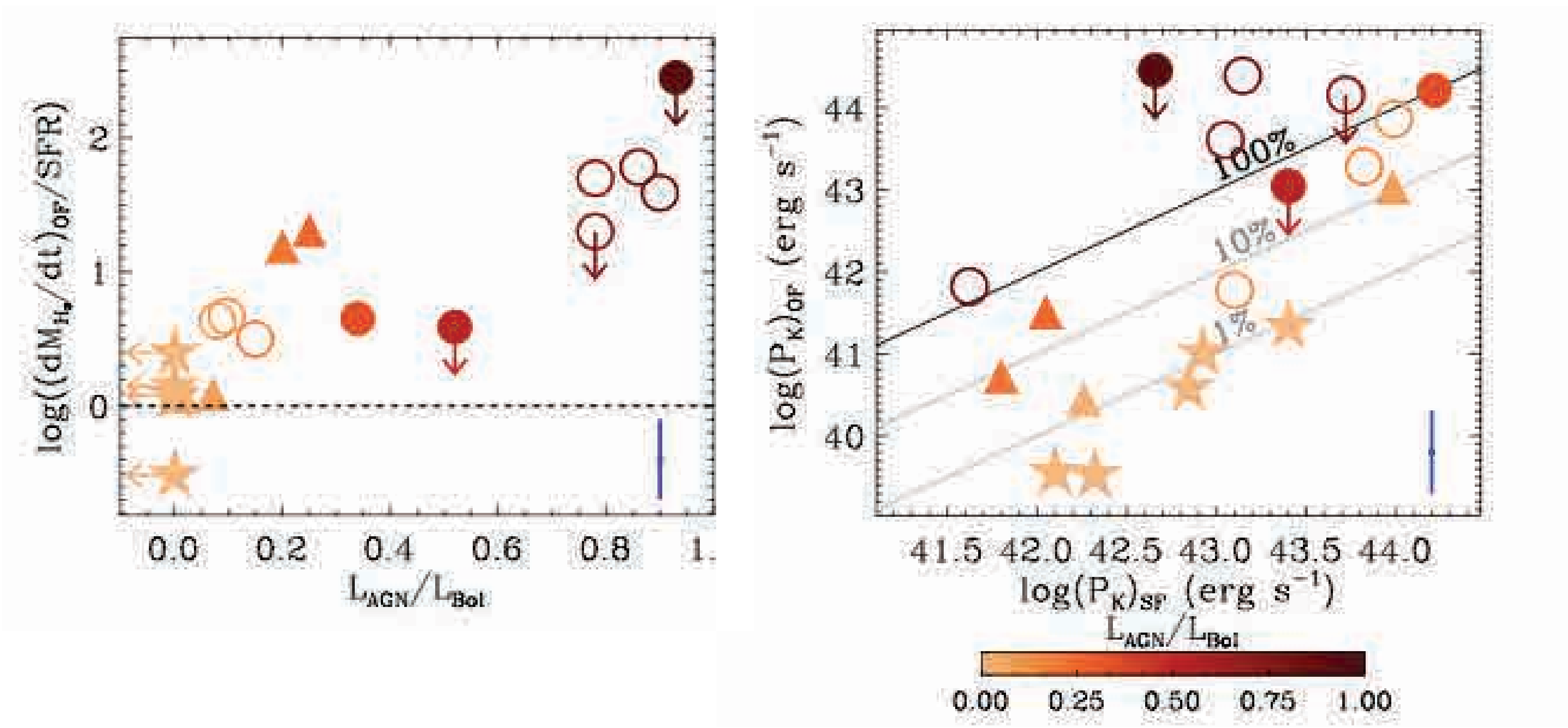
Mrk231 (Feruglio+10)

Mrk231(Rupke & Veilleux 11)

Massive multi-phase outflows extended on kpc scales.

AGN-driven outflows

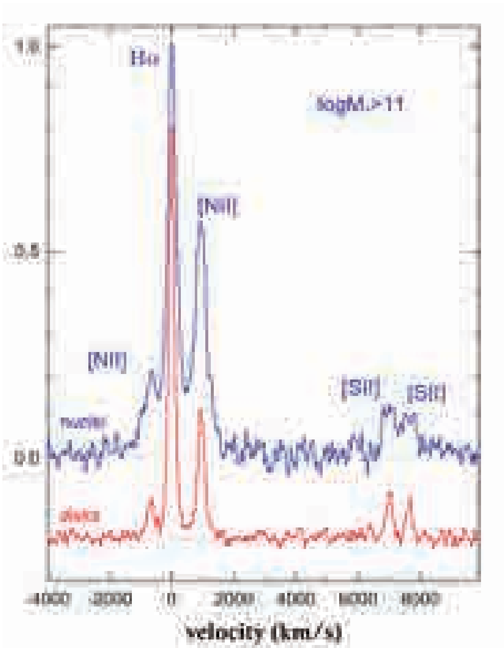
Cicone+14



AGN feedback: high-z

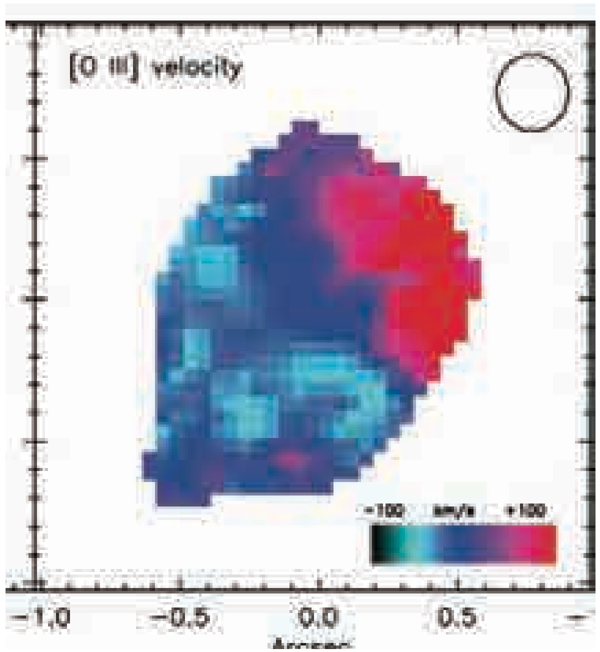
Ha @ 1.5<z<2.4

Förster Schreiber+14



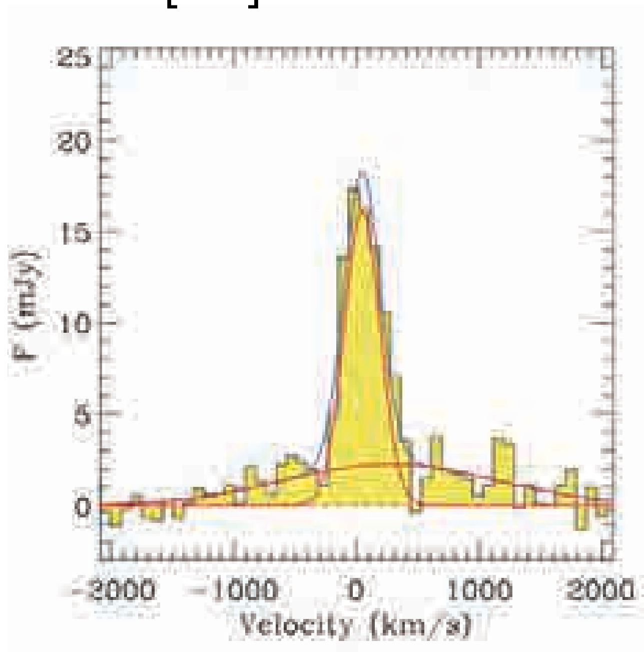
[OIII] @ z~2

Alexander+10



v~300 km/s
size ~ 8 kpc

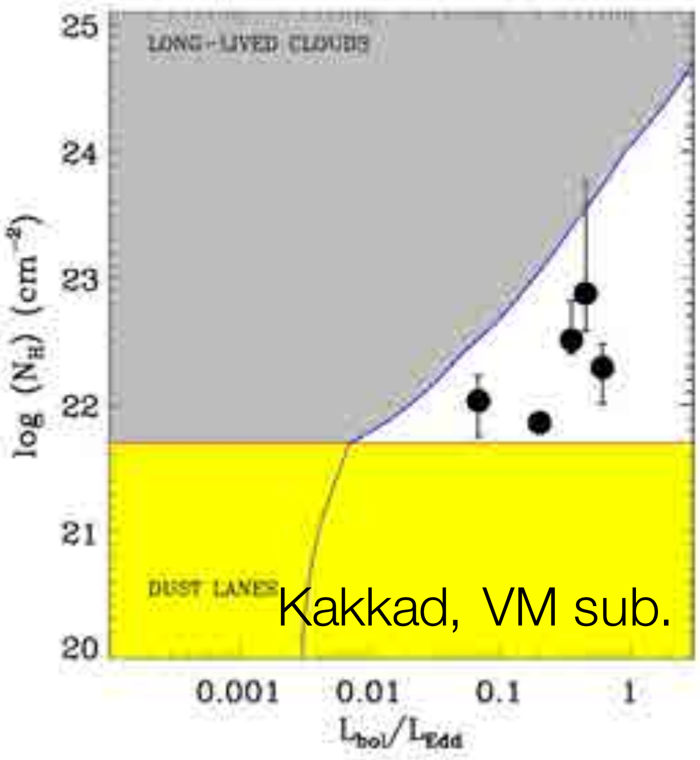
[CII] @ z=6.4



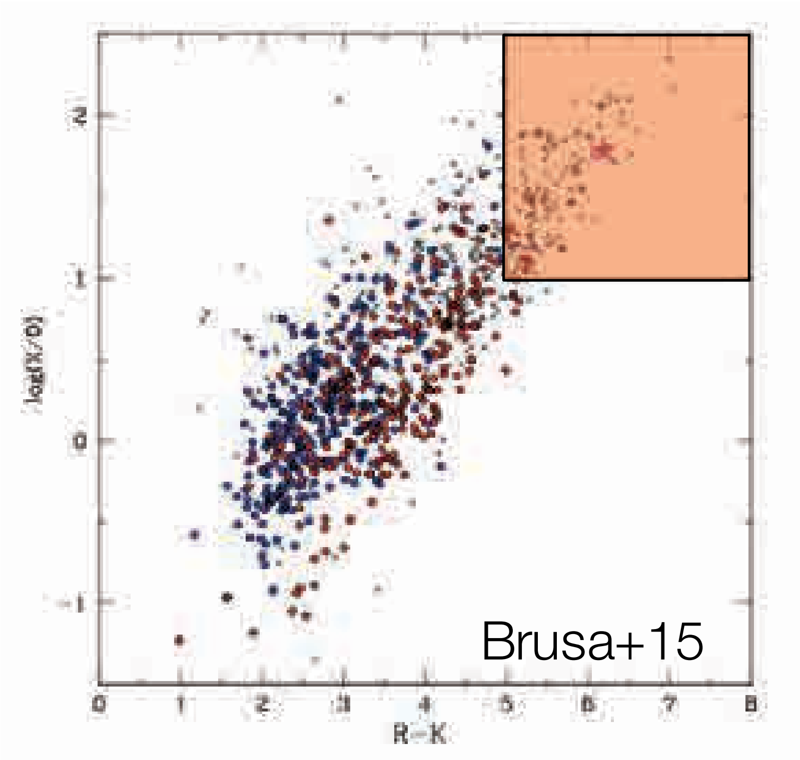
Maiolino+12

v~1300 km/s
size ~ 16 kpc
$M_{outflow}$ > 3500 M_{sun}/yr

First: detect AGN-driven outflows



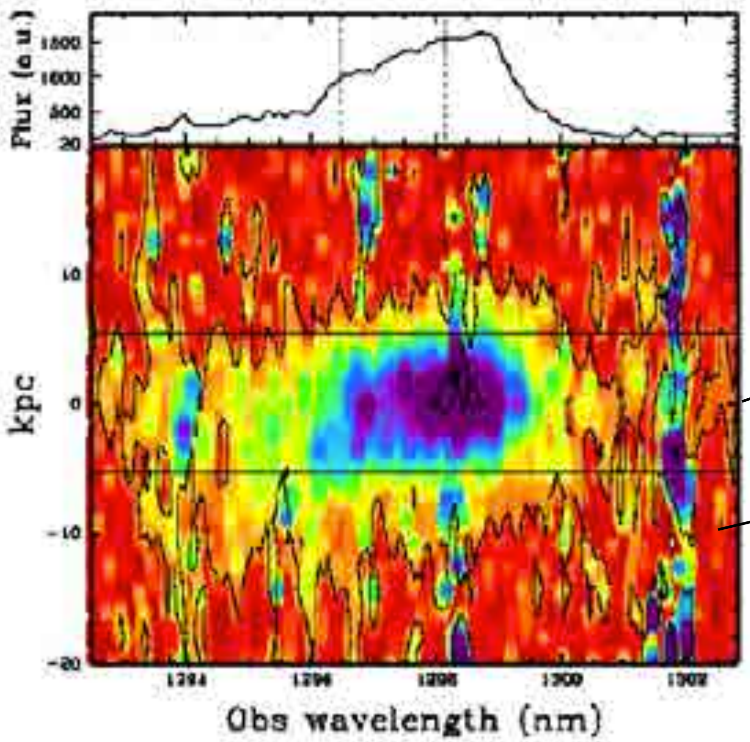
SINFONI/VLT



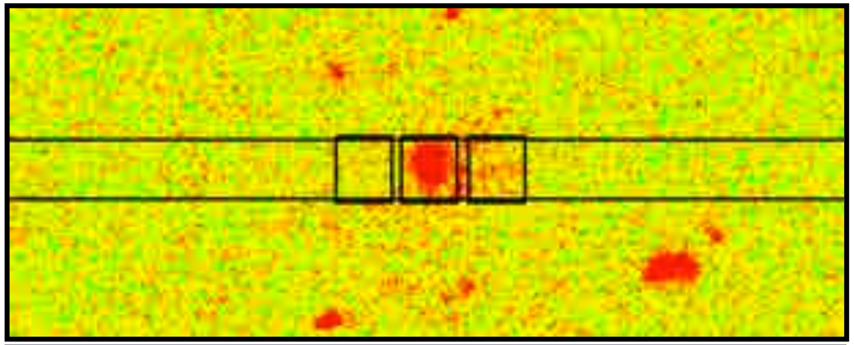
X-shooter/VLT

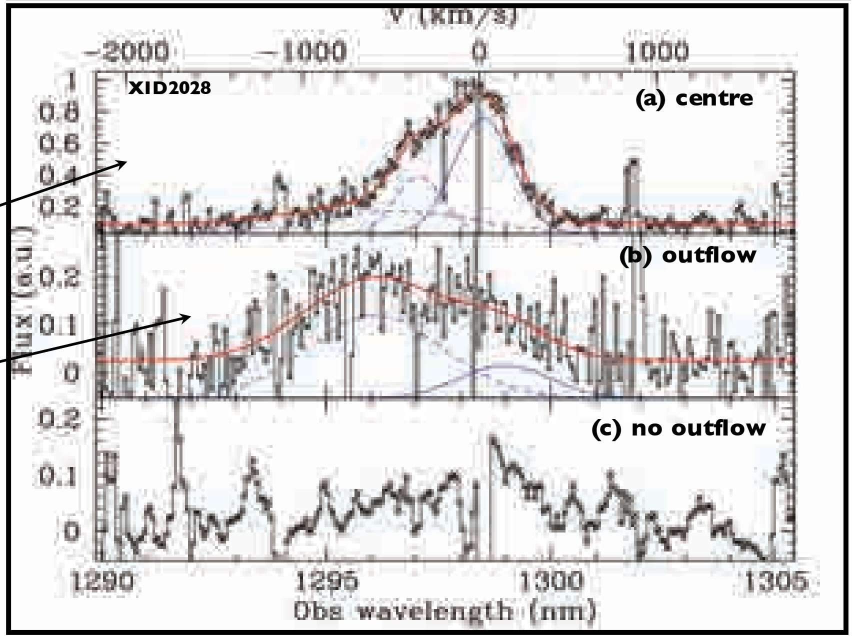
X-shooter slit resolted spectroscopy

Perna, Brusa+2015, A&A

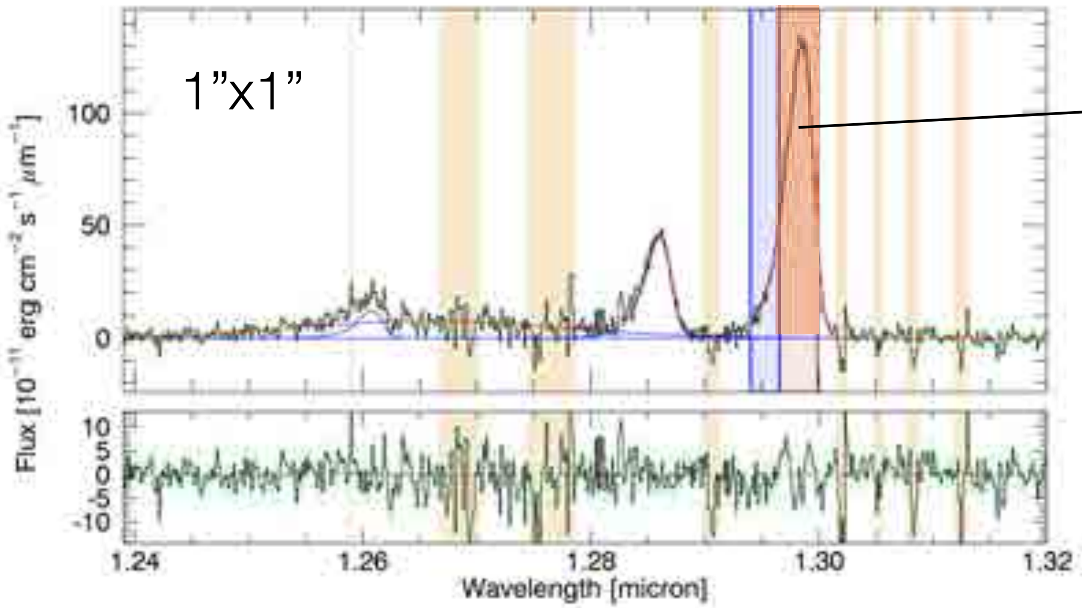


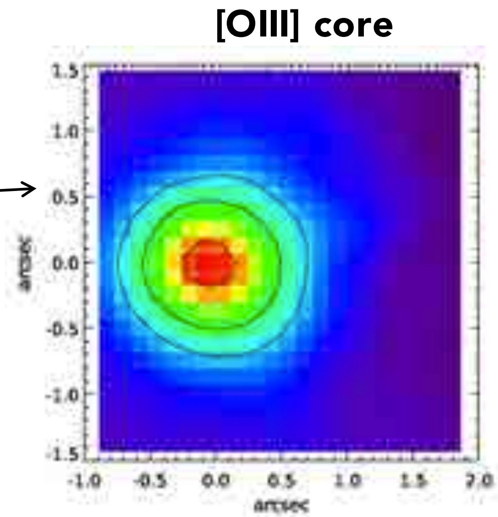
X-shooter 2D spectrum on [OIII]5007





AGN-driven outflows on kpc scale

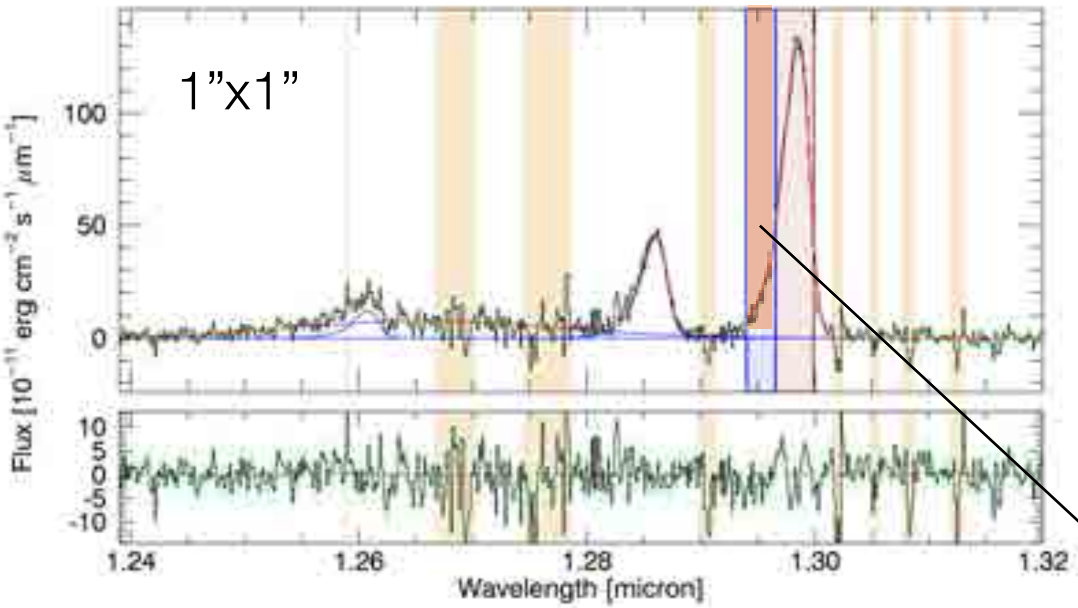




1.296<λ<1.300 μm

Scale 250x125 mas, noAO
6 hours on target
z=1.594
L(AGN)~2 x 10^46 erg/s
q_{24}=1.36
M_{BH}(Hα)~2.7 x 10^9 $M_{\odot}$

AGN-driven outflows on kpc scale



Scale 250x125 mas, noAO
6 hours on target
z=1.594
L(AGN)~2 x 10^46 erg/s
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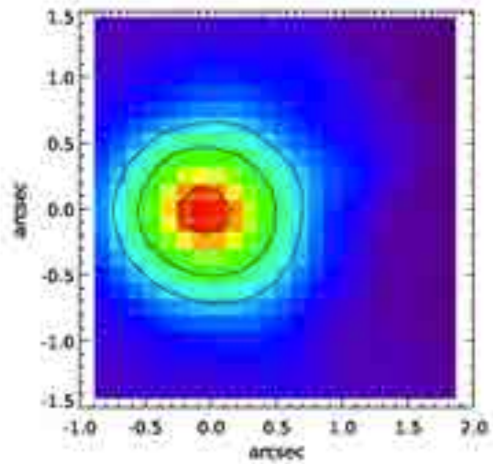
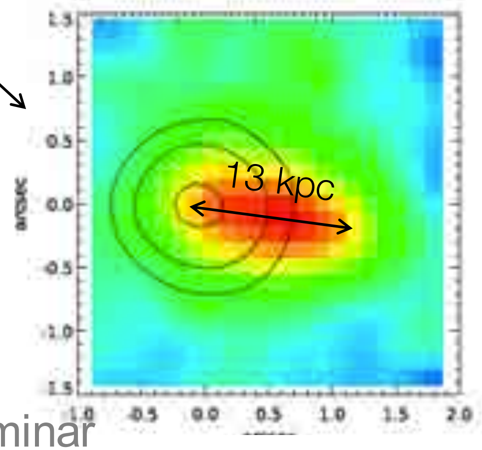
M_{BH}(Hα)~2.7 x 10^9 $M_\odot$

[OIII] core



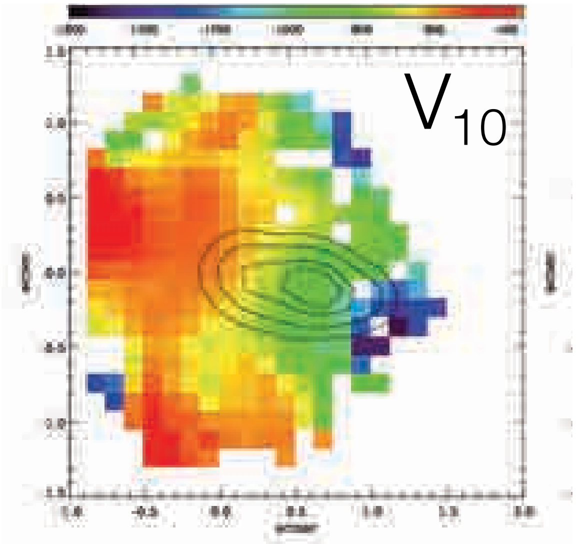
1.296<λ<1.300 μm

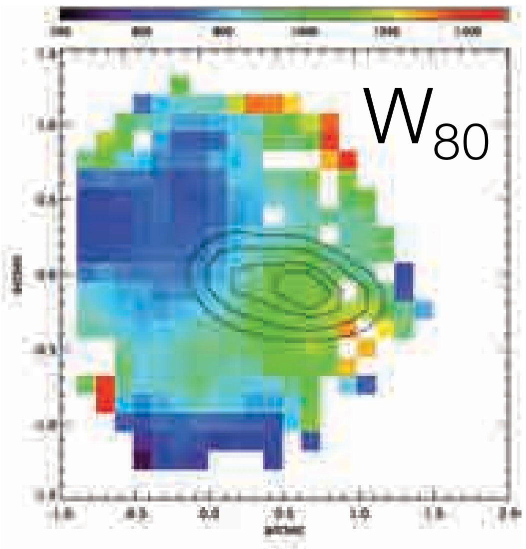
[OIII] blue wing



1.294<λ<1.296 μm

AGN-driven outflows on kpc scale



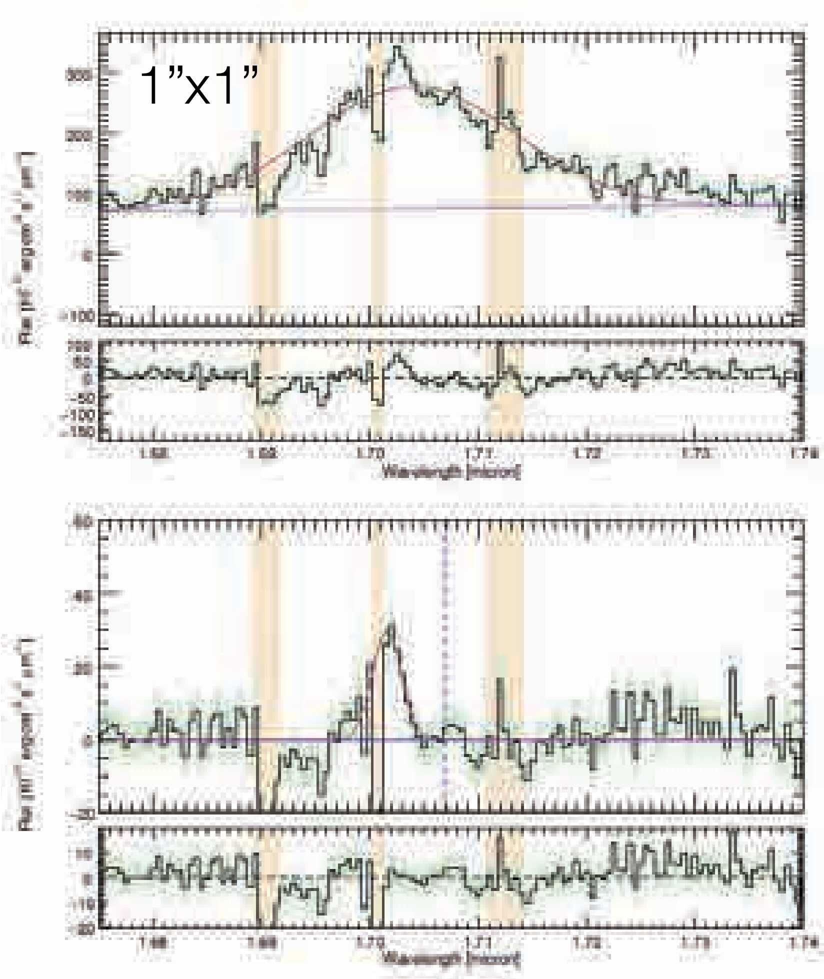


- V_{10} ~ -1500 km/s
- $M_{ion} > 8.5 \times 10^{8}\ M_{\odot}$
- $T_d \approx R_{out} / v_{out}$ ~ 8.5 Myr
- $M_{out,ion} > 300\ M_{\odot}/yr$
- $P_{kin,tot} > 0.5\ M_{out}\ v_{out}^2 = 5.3 \times 10^{44}$ erg s^{-1}

What powers the outflow?

P(SF) ~$7 \times 10^{41} \times SFR(M_{\odot}/yr)$ [Veilleux+05]
$P_{kin,tot}$ / P(SF) ~ 2.5

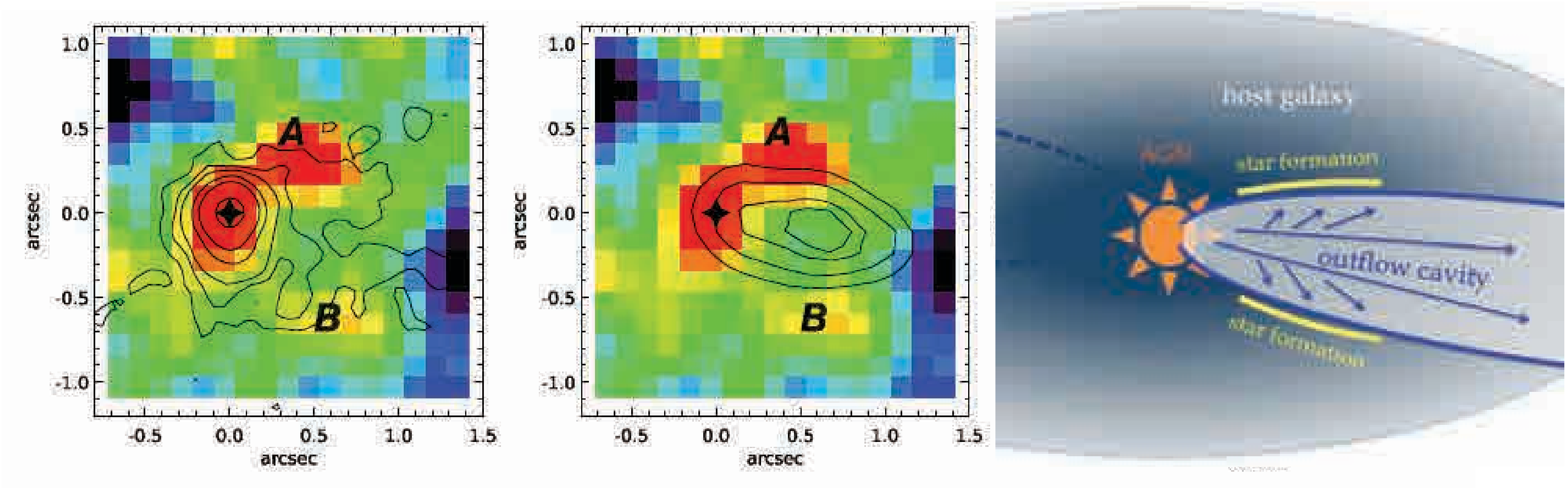
AGN feedback impact on the host: detailed studies



H+K archival observations
Scale 250x125 mas, noAO
20 min on target
SFR (narrow Ha) ~ 230 $M_{\odot}$/yr
SFR (PACS Herschel) ~ 275 $M_{\odot}$/yr

AGN feedback impact on the host: detailed studies

Cresci, VM+2015



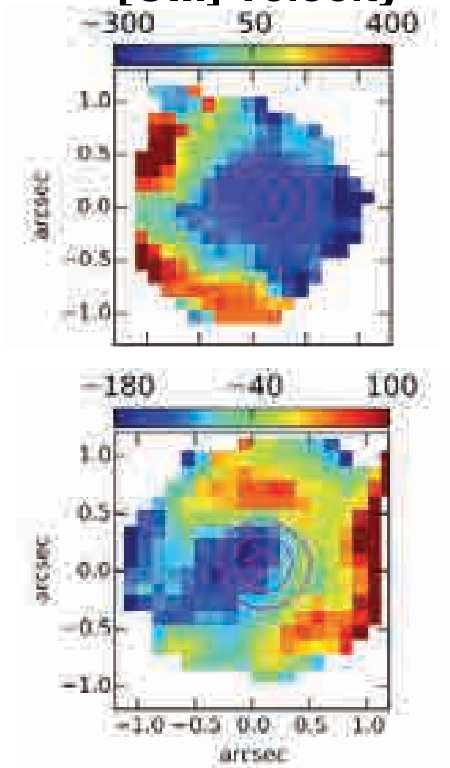
- o SF in blobs A&B: log([NII]/Hα)<-1.1
- o Casual connection outflow-SF → **timescales**

1000 km/s x 1 Myr ~3kpc < SF(Ha)<10 Myr < AGN lifetime ~20-30 Myr

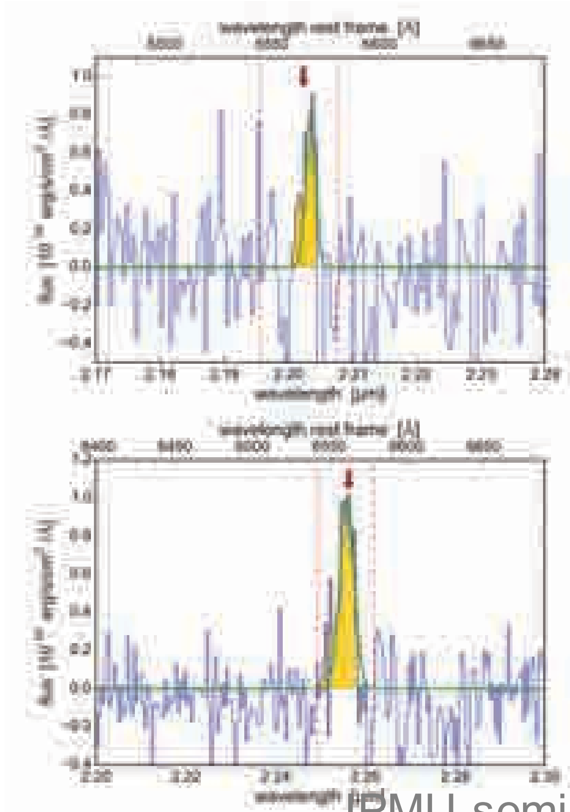
AGN feedback impact on the host: detailed studies

- Origin of “narrow” [OIII] emission? AGN or Star Formation excited?
- K band observations targeting *Hα … subtract broad Hα and outflow component … narrow Hα residual*

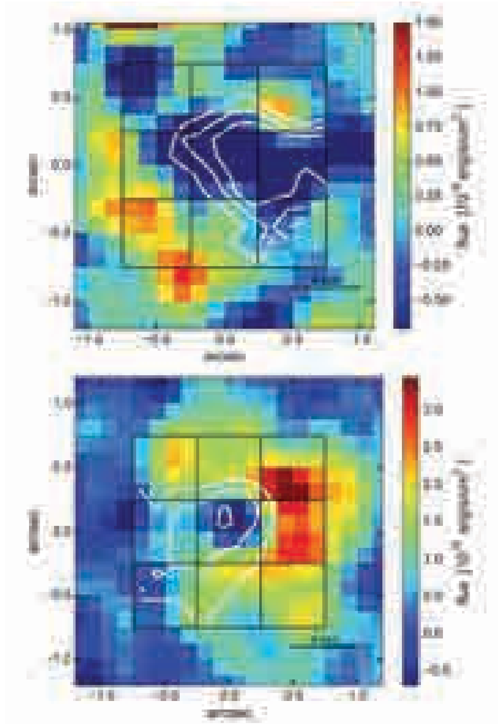
[OIII] velocity



K band: broad Hα subtracted



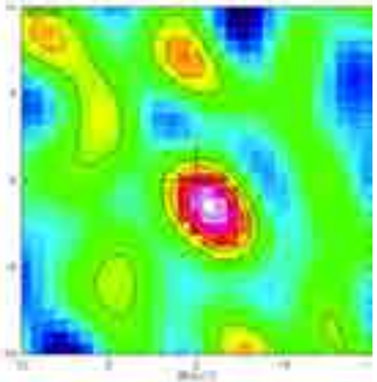
Narrow Hα flux

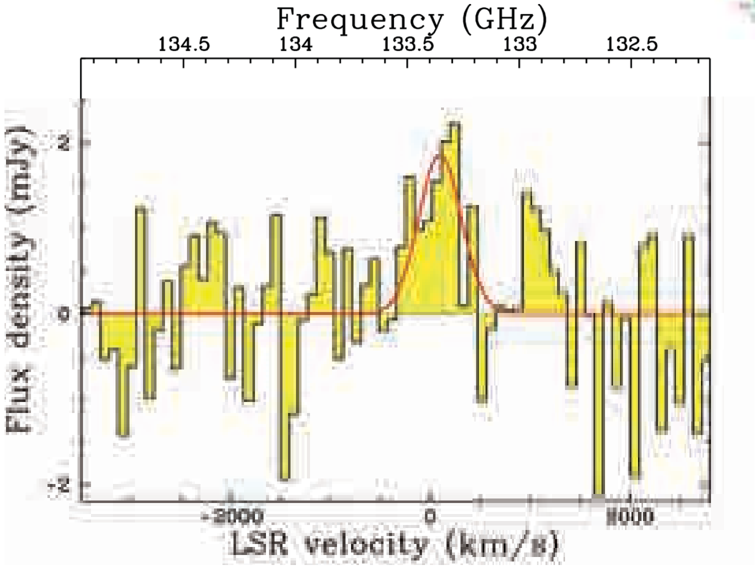


Carniani+15

Gas content of XID2028

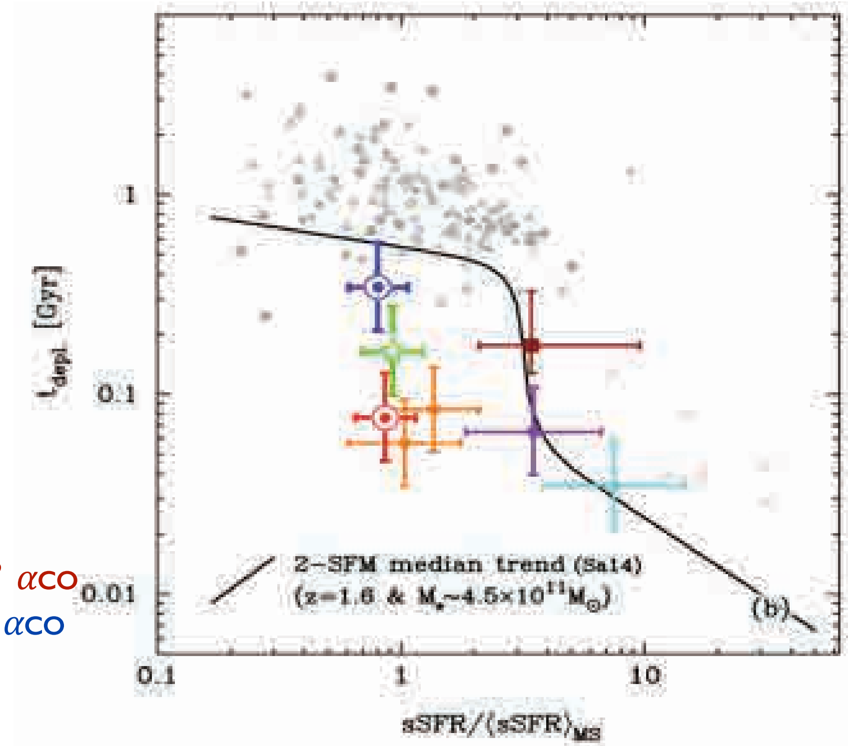
IRAM PdBI observations
CO(3-2) observed
@133.37 GHz; 5σ
detection in 2.5 hrs





Log L'(CO) ~ 10.55 K km/s pc^2
M_{gas}~ 2-20 x 10^{10} $M_\odot$
(depending on α_{CO})

RED: "ULIRG" α_{CO}
BLUE: "MS" α_{CO}



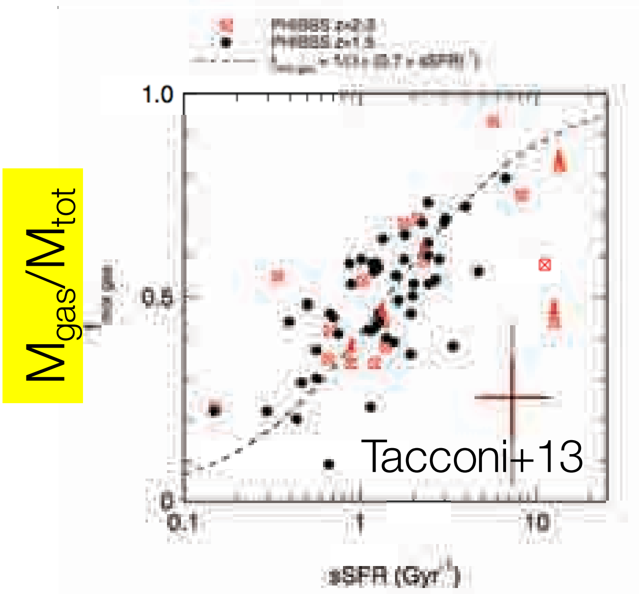
Brusa, Feruglio et al. 2015, A&A

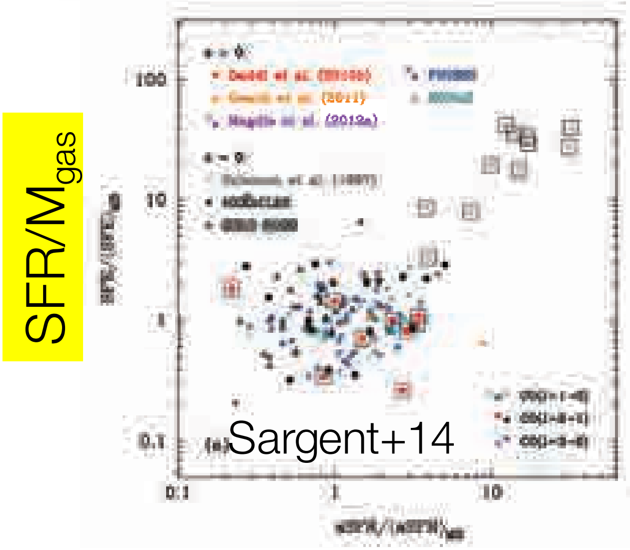
XID2028 has one of lowest gas fractions (<30%) for its sSFR at high-z, clear outlier in t_{depl}-sSFR plane, ~x2 to x10 below expected position on plot

QSO feedback
Removing gas from the host ?

→ *ALMA cycle 3*

AGN feedback impact on the host: statistical studies





Does the AGN triggered outflows affect the cold gas reservoir and modify the SFE of its host?

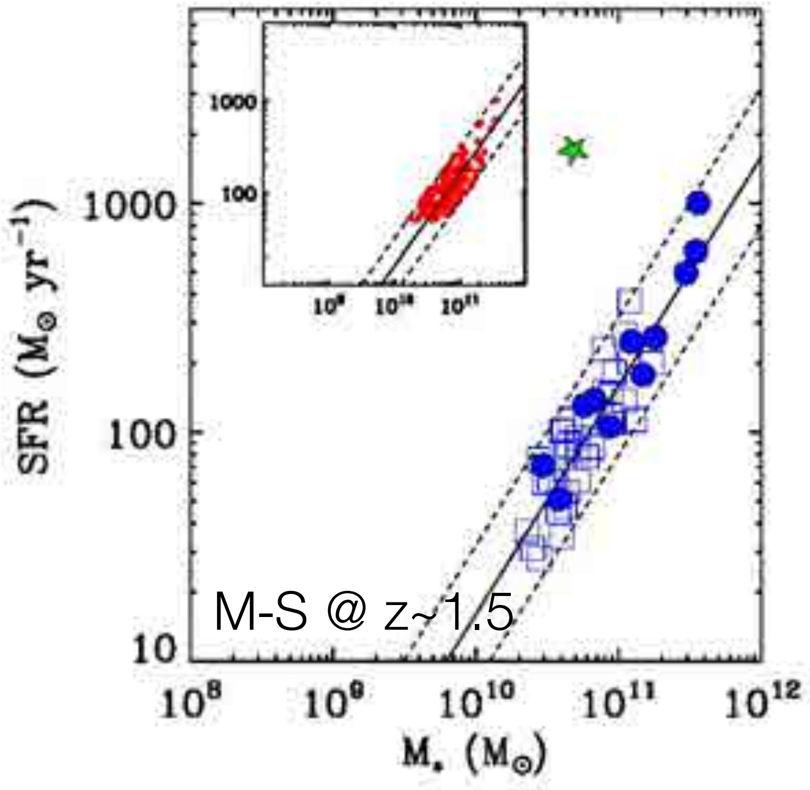
“Normal” galaxies at z>1: PdBI and now ALMA (Daddi+10; Tacconi+10; Genzel+14)

SFE, f_{gas} for statistical samples of AGN hosts (sampling the MS) in comparison to “normal” galaxies (e.g sSFR, z, $M_{\bigstar}$)

ALMA (CO and continuum)

(e.g. Genzel+14 ; Scoville+14)

Molecular gas in AGN MS hosts at z~1.5



Previous CO studies of AGNs focused on high luminosity QSOs

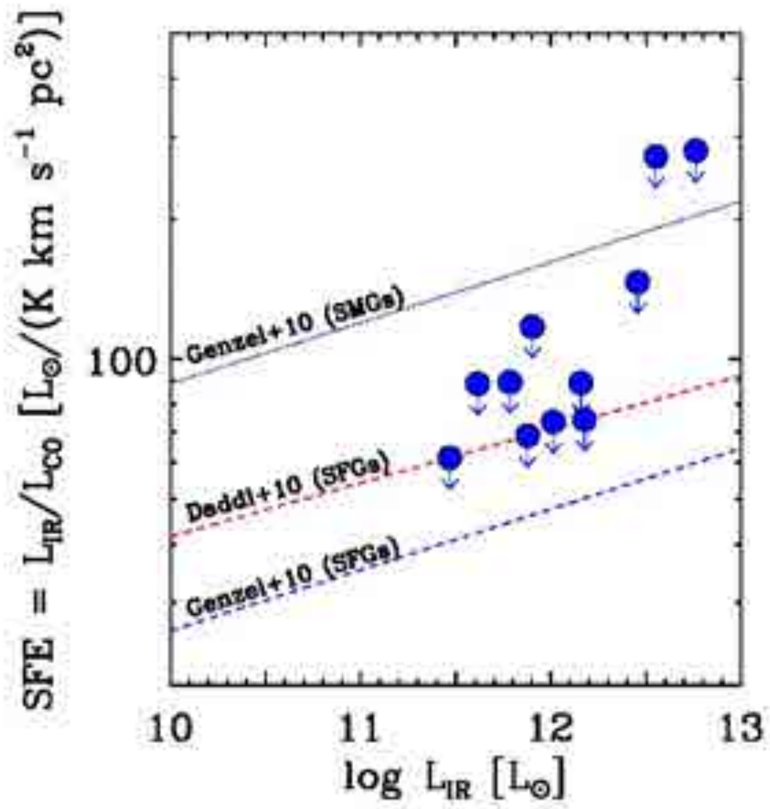
ALMA Cycle-2 program

Goal: compare the mean gas content in active and inactive galaxies on the main-sequence

11 "main-sequence" AGNs at z~1.5

- Secure redshift
- Herschel PACS detection –> SFR
- CO(2-1) @ z~1.5 (Band 3)

Molecular gas in AGN MS hosts at z~1.5



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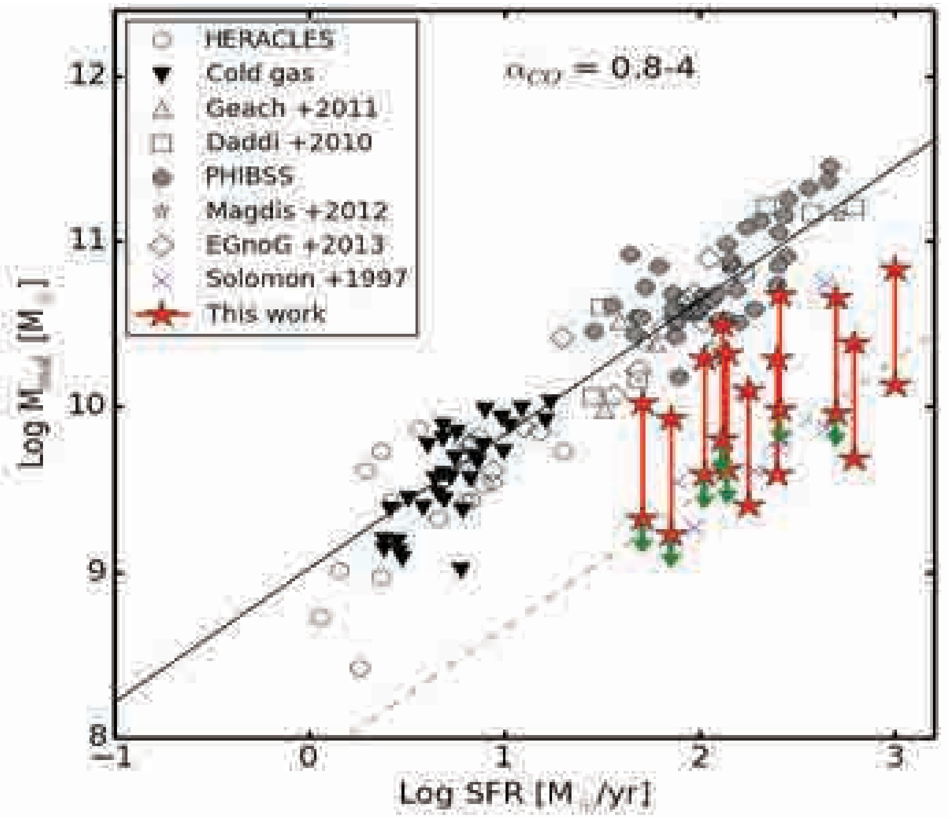
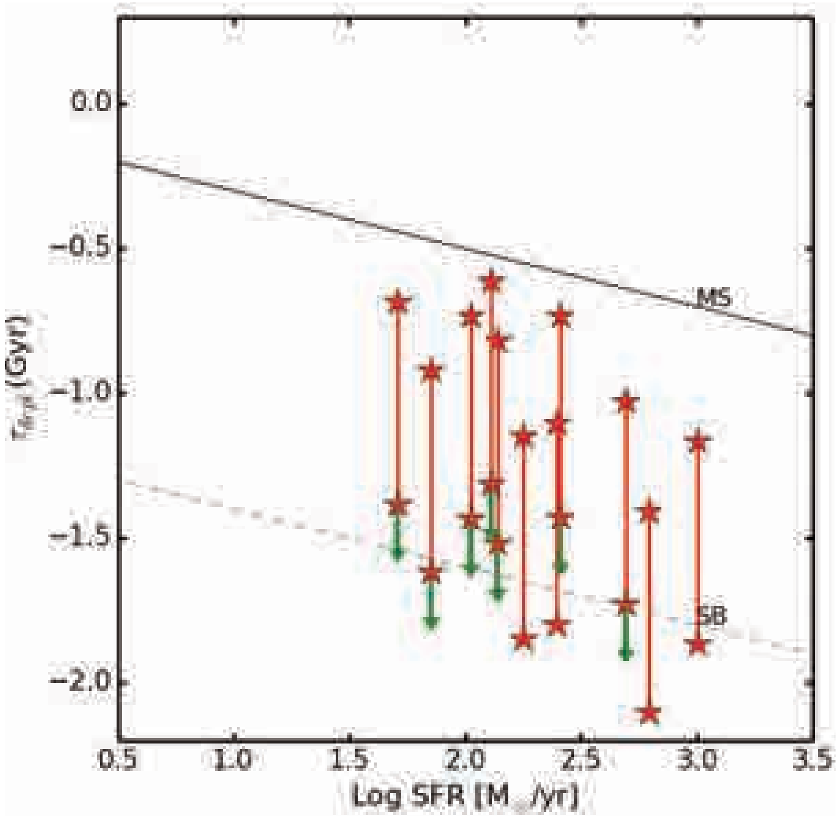
M_{gas} & SFE

Molecular gas in AGN MS hosts at z~1.5





Kakkad, VM + in prep.

Lower gas fraction and shorter t_{depl} compared to inactive MS galaxies

Limitations of current AGN IFU studies

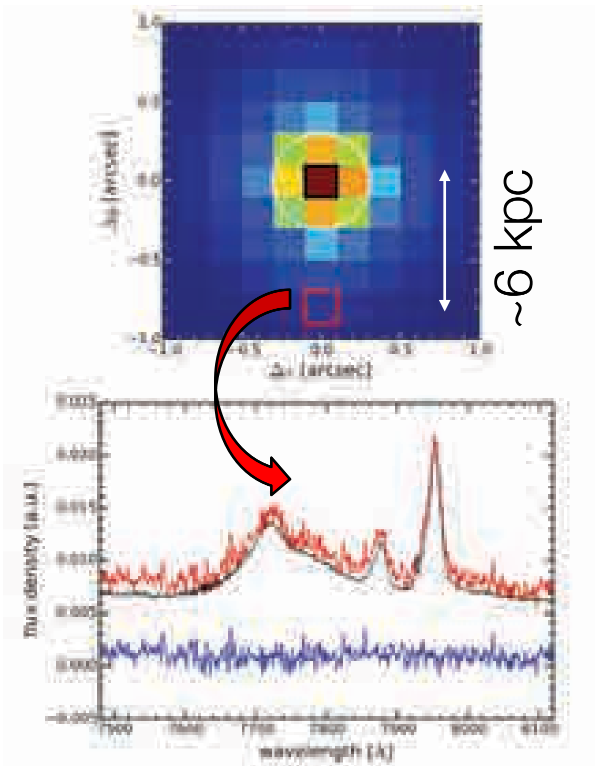
- Beam smearing

- Which fraction of the outflowing gas is in a ionised phase?

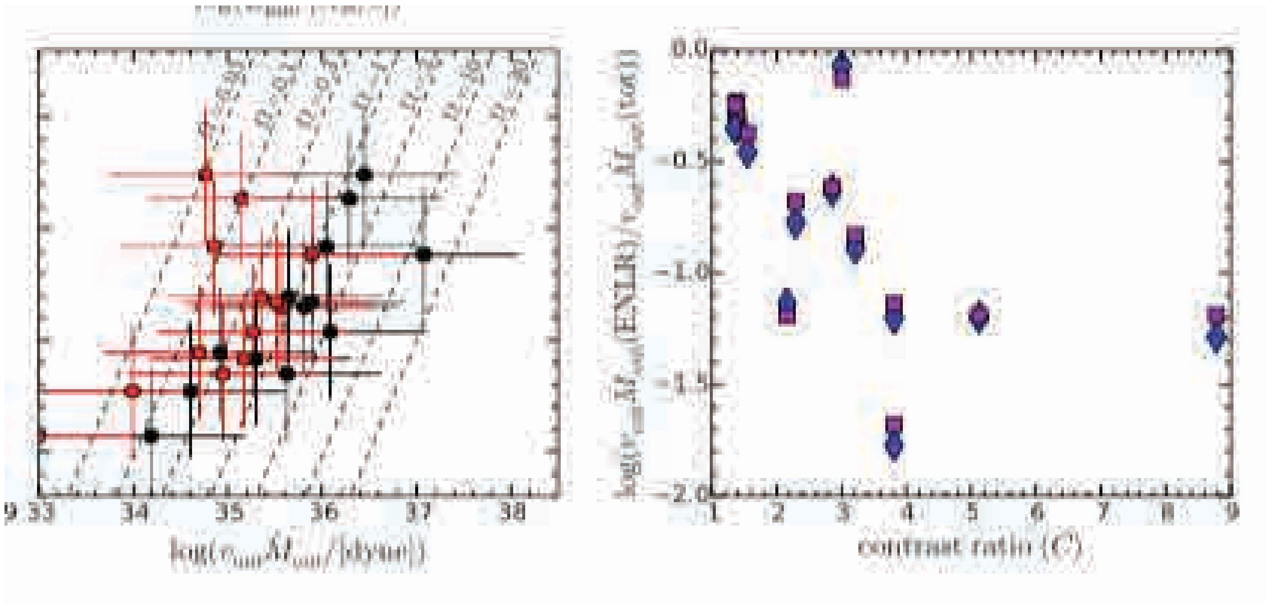
- There are uncertainties implicit in the ionised mass measured (e.g. electron density)

Beam smearing: impact on outflow energetics.

Beam smearing: the compact NLR on <<1kpc scales is unresolved at >1 → need to model the PSF to properly study the extended emission.



Ty-1: use the broad Hb to sample the PSF



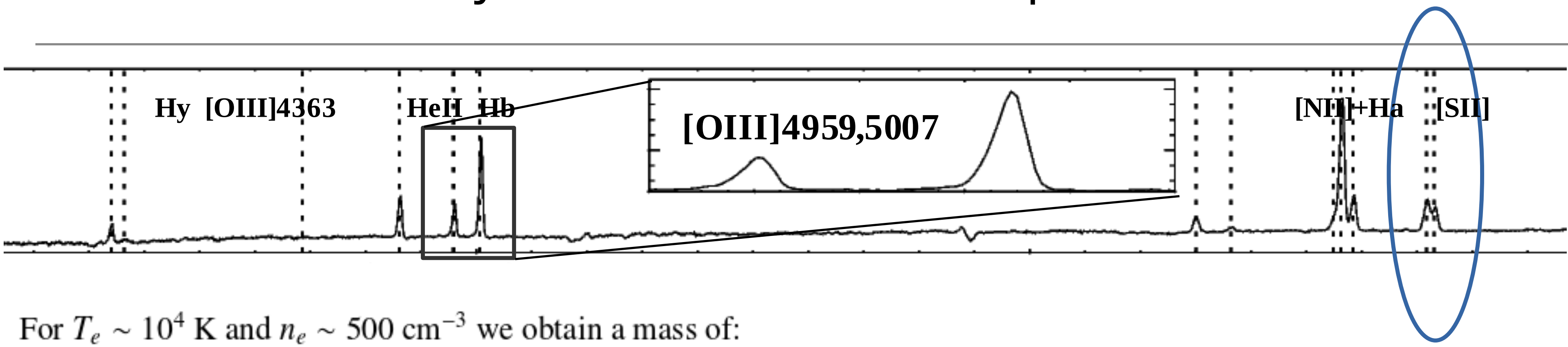
Husemann+16

Liu+14 revised: [OIII] line width significantly smaller than prior of PSF de-blending

↓

Outflow kinetic power reduced up to 2 orders of magnitude

Electron density and electron temperature



For $T_e \sim 10^4$ K and $n_e \sim 500$ cm^{-3} we obtain a mass of:

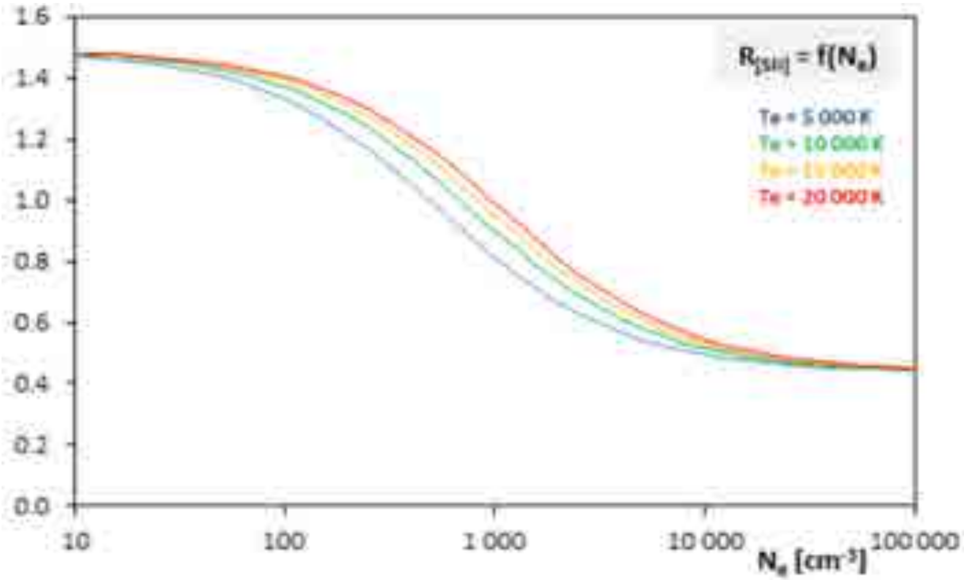
$$M_{[\mathrm{OIII}]} = 0.8\times10^8 \mathrm{M}_\odot \left(\frac{C}{10^{[O/H]-[O/H]_\odot}}\right)\left(\frac{L_{[OIII]}}{10^{44} erg/s}\right)\left(\frac{<n_e>}{500cm^{-3}}\right)^{-1}$$

$$M_{[\mathrm{OIII}]} = 0.8\times10^8 \mathrm{M}_\odot \left(\frac{C}{10^{[O/H]-[O/H]_\odot}}\right)\left(\frac{L_{[OIII]}}{10^{44} erg/s}\right)\left(\frac{<n_e>}{500cm^{-3}}\right)^{-1}$$

$$M_{H\beta} = 1.7\times10^9 \mathrm{M}_\odot C \left(\frac{L_{H\beta}}{10^{44} erg/s}\right)\left(\frac{<n_e>}{500cm^{-3}}\right)^{-1}$$

$$R_{[SII]} = \frac{I(6716)}{I(6731)}$$

$$Ne = 10^2\, Te^{1/2} . \left(\frac{R_{[SII]} - 1.49}{5.62 - 12.8 R_{[SII]}}\right)$$

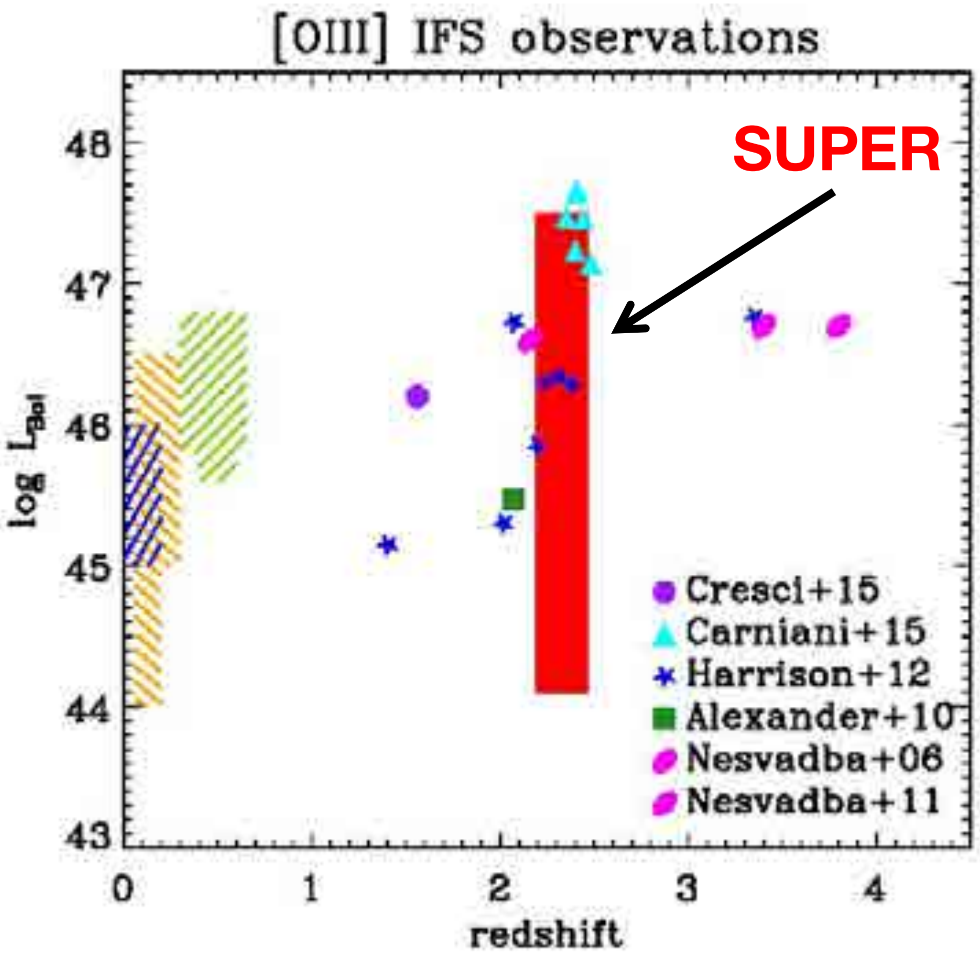


Electron density and electron temperature

Ne > 1000 cm^{-3}: Villar Martin+14; Rodriguez-Zaurin+13
Ne = 500 cm^{-3}: Carniani+15; Harrison+14,+12; Nesvadba+08
Ne = 100 cm^{-3}: Brusa+15; Cresci+15; Perna+15; Liu+13; Genzel+14

Measured (assuming Te=10'000 K):
Rodriguez-Zaurin+13 (**Ne > 4'000 cm^{-3}**)
Harrison+12 (**Ne = 500 cm^{-3}** - staked ULIRGs)
Harrison+14; Westmoquette+12 (**Ne = 200-1000 cm^{-3}**)
Genzel+14 (**Ne = 80 cm^{-3}**)
Perna+15 (**Ne = 120 cm^{-3}** - single obj)
Nesvadba+06 (**Ne = 240-570 cm^{-3}** - single obj)
...
Measured:
Brusa+16 (**Ne = 780 cm^{-3}** w/ **Te = 13'000** - single obj [IFS])
Villar Martin+14 (**Ne =800-3200 cm^{-3}** w/ **Te ≈ 16'000** – 4 obj [SDSS spectra])
Nesvadba+08 (**Ne=500 cm^{-3}** w/ **Te ≈ 11'000 K** – 1 obj [IFS])

SUPER: a SINFONI **S**urvey for **U**nveiling the **P**hysics and the **E**ffect of **R**adiative feedback



PI: V. Mainieri ; Co-Is: Fiore, Marconi, Balmaverde, Bongiorno, Brusa, Carniani, Civano, Comastri, Cresci, Feruglio, Georgakakis, Husemann, Kakkad, Lamastra, Lanzuisi, Liu, Mannucci, Menci, Menzel, Merloni, Netzer, Padovani, Perna, Piconcelli, Popesso, Salvato, **Schramm**, **Schulze**, **Silverman**, Vietri, Vignali, Zamorani, Zappacosta

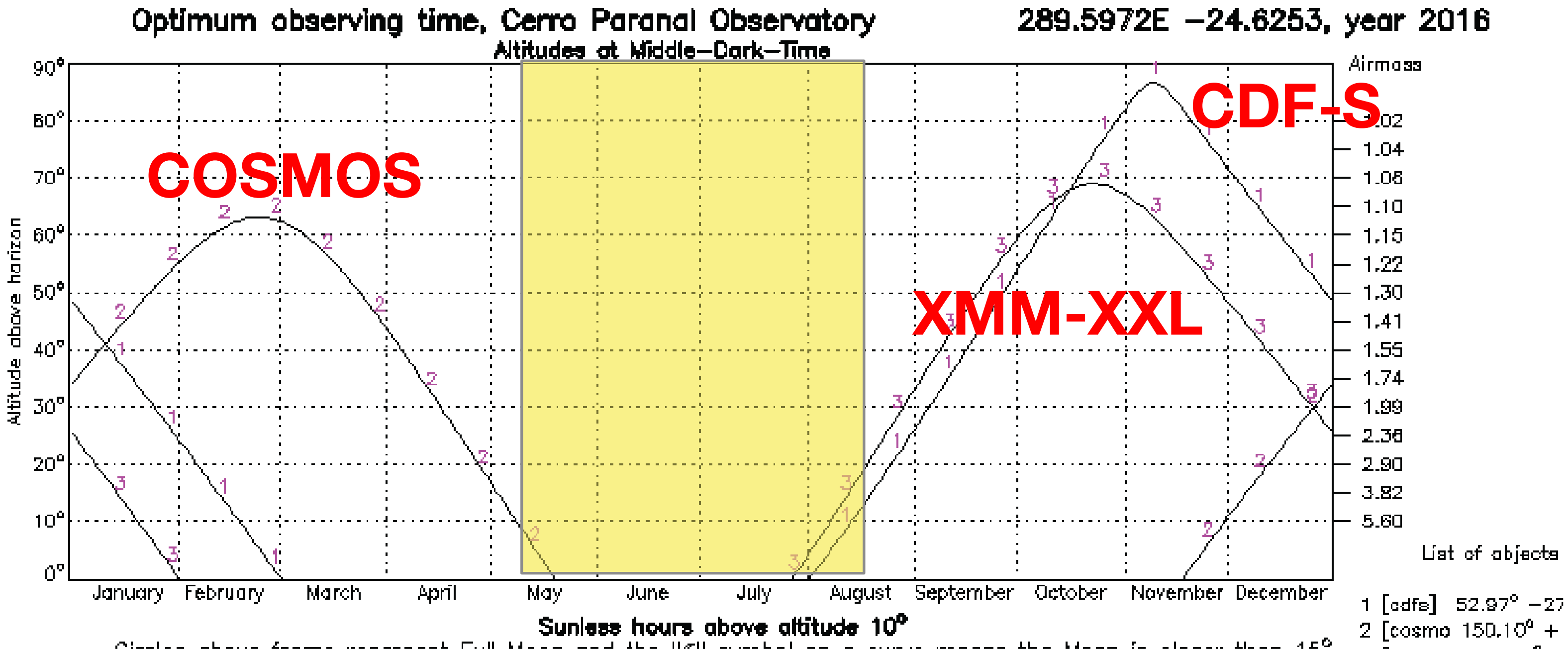
280 hours in LGS/SE
(PSF FWHM ~0.2”-0.3”)
41 AGNs
Comparison samples of inactive galaxies
(SINS/zC-SINF)

z=[2.12-2.49] → **Hβ [OIII]** **Hα [SII]**

H K

https://sites.google.com/site/supersinfonisurvey/

SUPER: a SINFONI Survey for Unveiling the Physics and the Effect of Radiative feedback



- **P96 (Oct 15-Mar 16) : 70h**
- P97 (Apr 16-Sep 16) : 70h
- P98 (Oct 16-Mar 17) : 70h
- P99 (Apr 17- Sep 17) : 70h

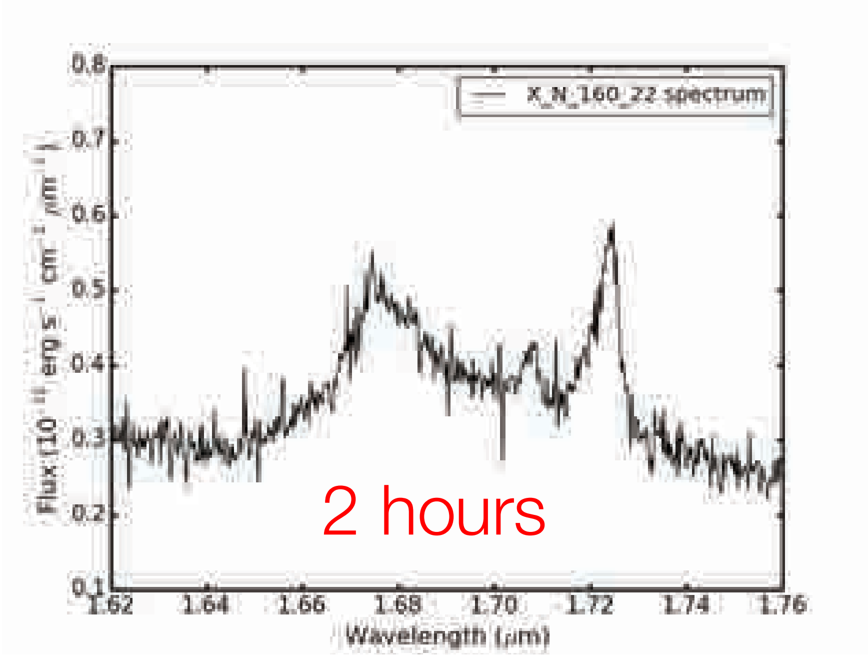
Observing strategy for P96:
first pass (1.5h) in H (Hb and [OIII]) and K (Ha) for all targets.Goal: verify the predicted [OIII] flux

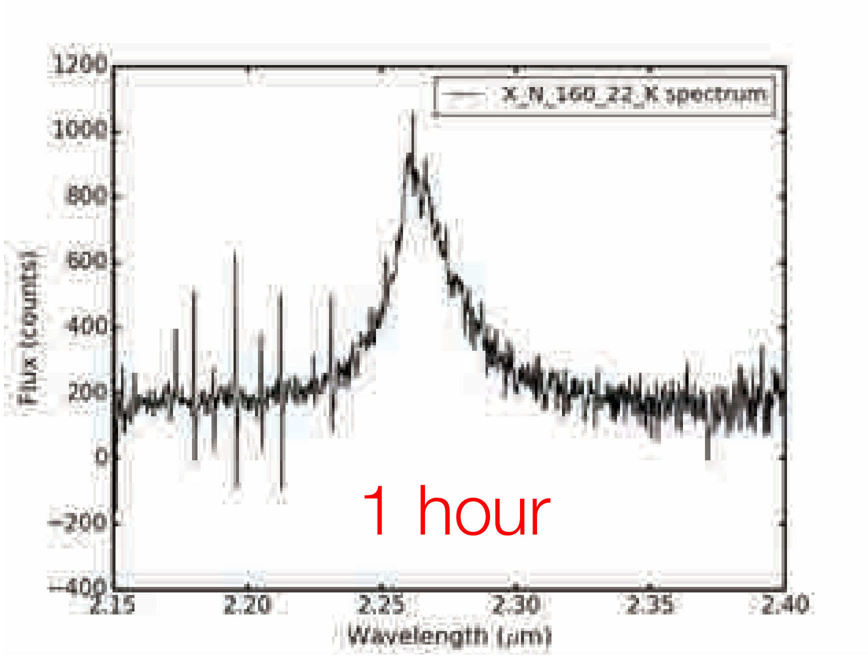
SUPER: a SINFONI **S**urvey for **U**nveiling the **P**hysics and the **E**ffect of **R**adiative feedback

X_N_160_22:

L_{bol}=47.1 erg s^{-1}
N_H=21.7 cm^{-2}

Edd ratio=1.0
M_{BH}=8.9 M_{sun}

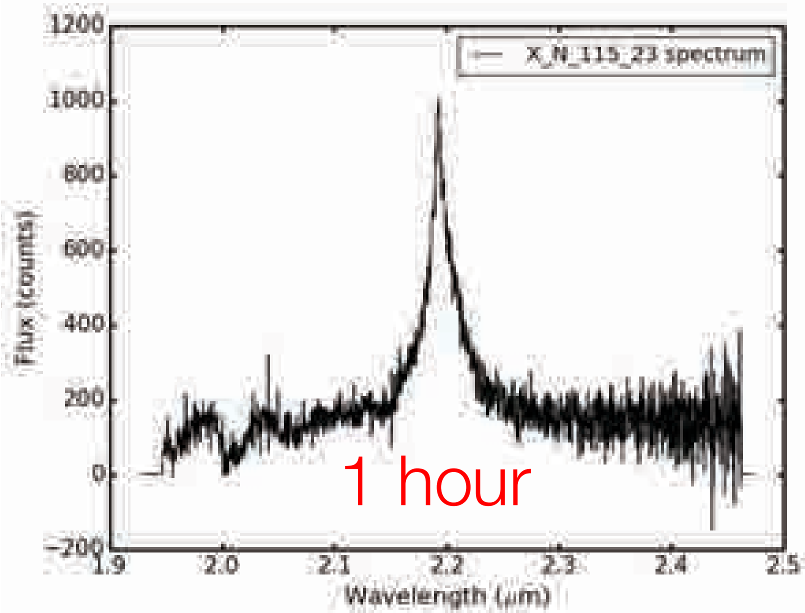


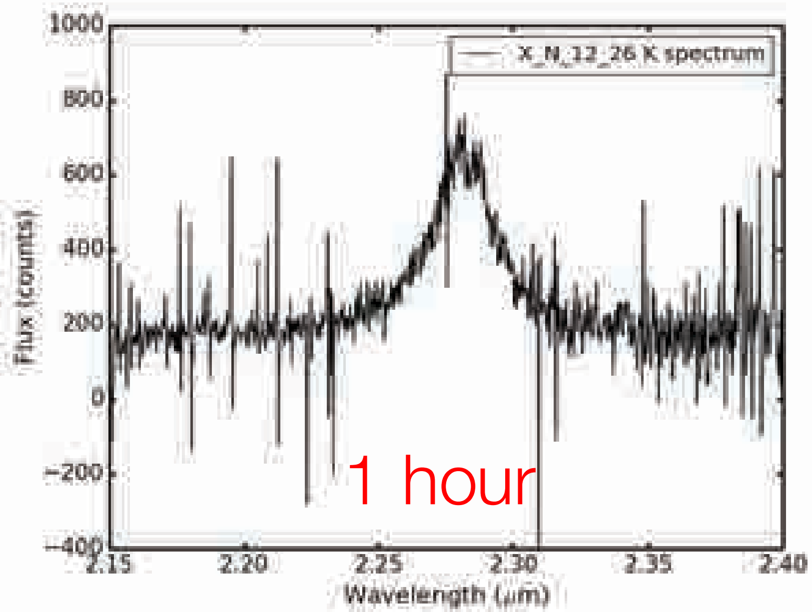


SUPER: a SINFONI Survey for Unveiling the Physics and the Effect of Radiative feedback

X_N_115_23: L_{bol}=46.6 erg s^{-1} N_H= 21.0 cm^{-2} Edd ratio=1.1 M_{BH}=8.4 M_{sun}

X_N_12_26: L_{bol}= 46.3 erg s^{-1} N_H=20.9 cm^{-2} Edd ratio= 0.21 M_{BH}= 8.9 M_{sun}





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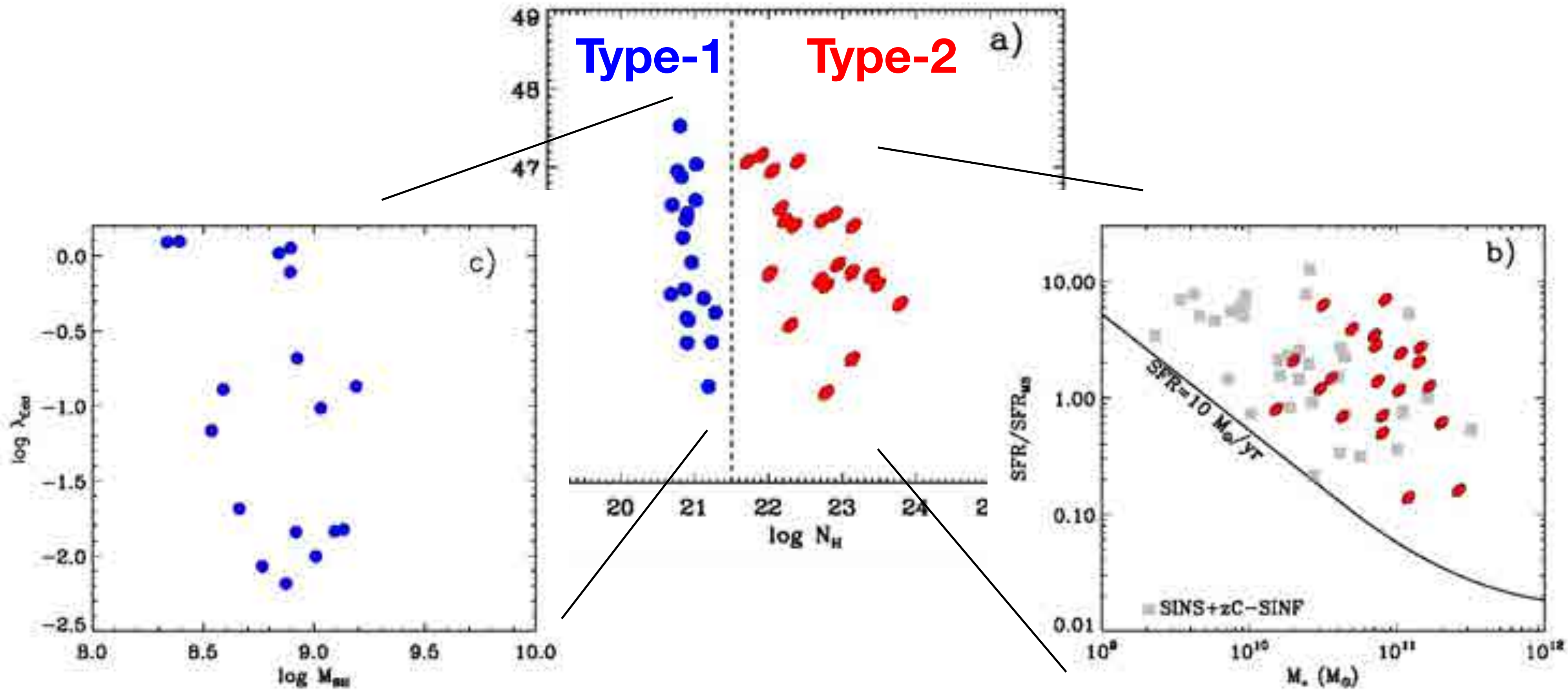

Blind survey: representative sub-sample of the AGN population.

Summary and outlook

- ✧ AGN outflows are common: but do they really affect the ability of the host to form stars? [OIII] vs narrow Ha

- ✧ Molecular gas content in MS AGN hosts seems to be lower than comparable inactive galaxies: indirect evidence of feedback?

Extend these studies to statistically-sound samples:
AGN outflows physics and AGN feedback impact

SINFONI-LP   ALMA