Effect of AGN feedback seen in IFU studies

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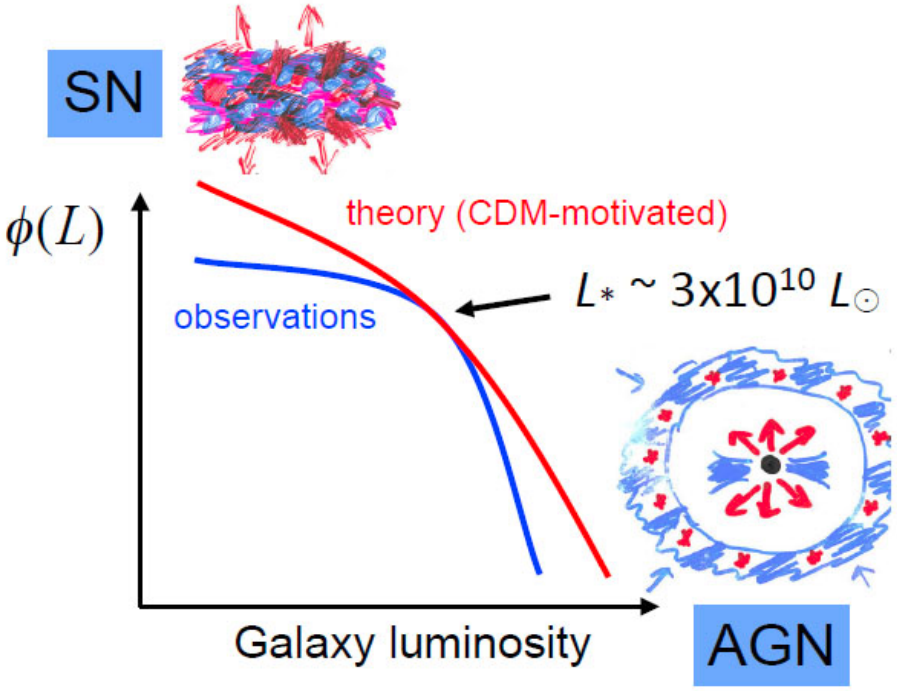
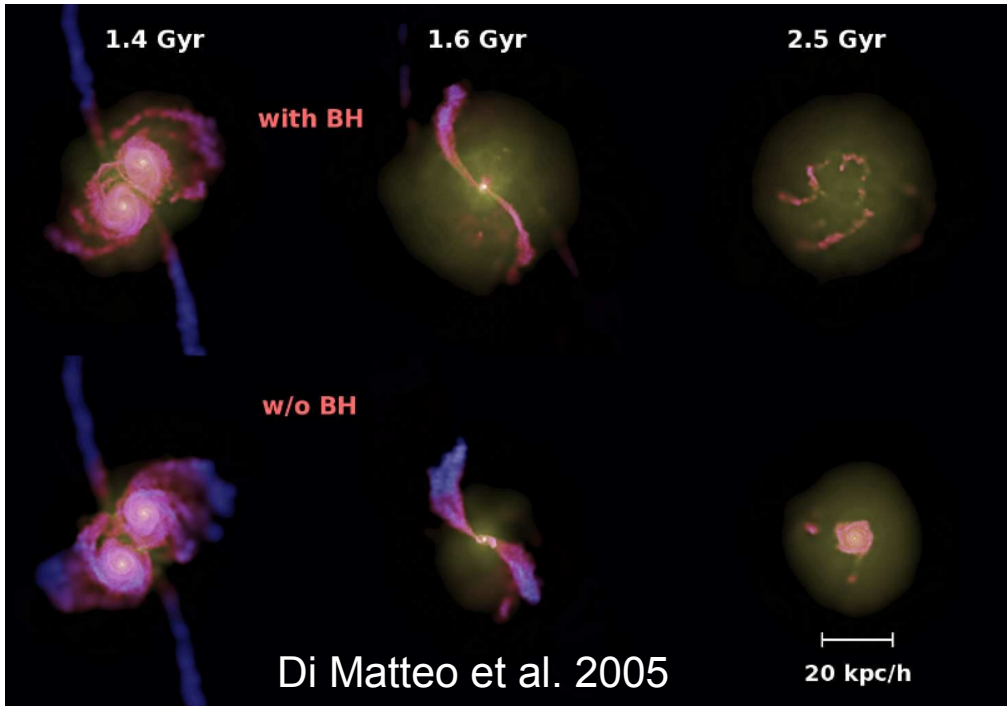
and the entire CLOSE AGN CARS REFERENCE SURVEY ***team***

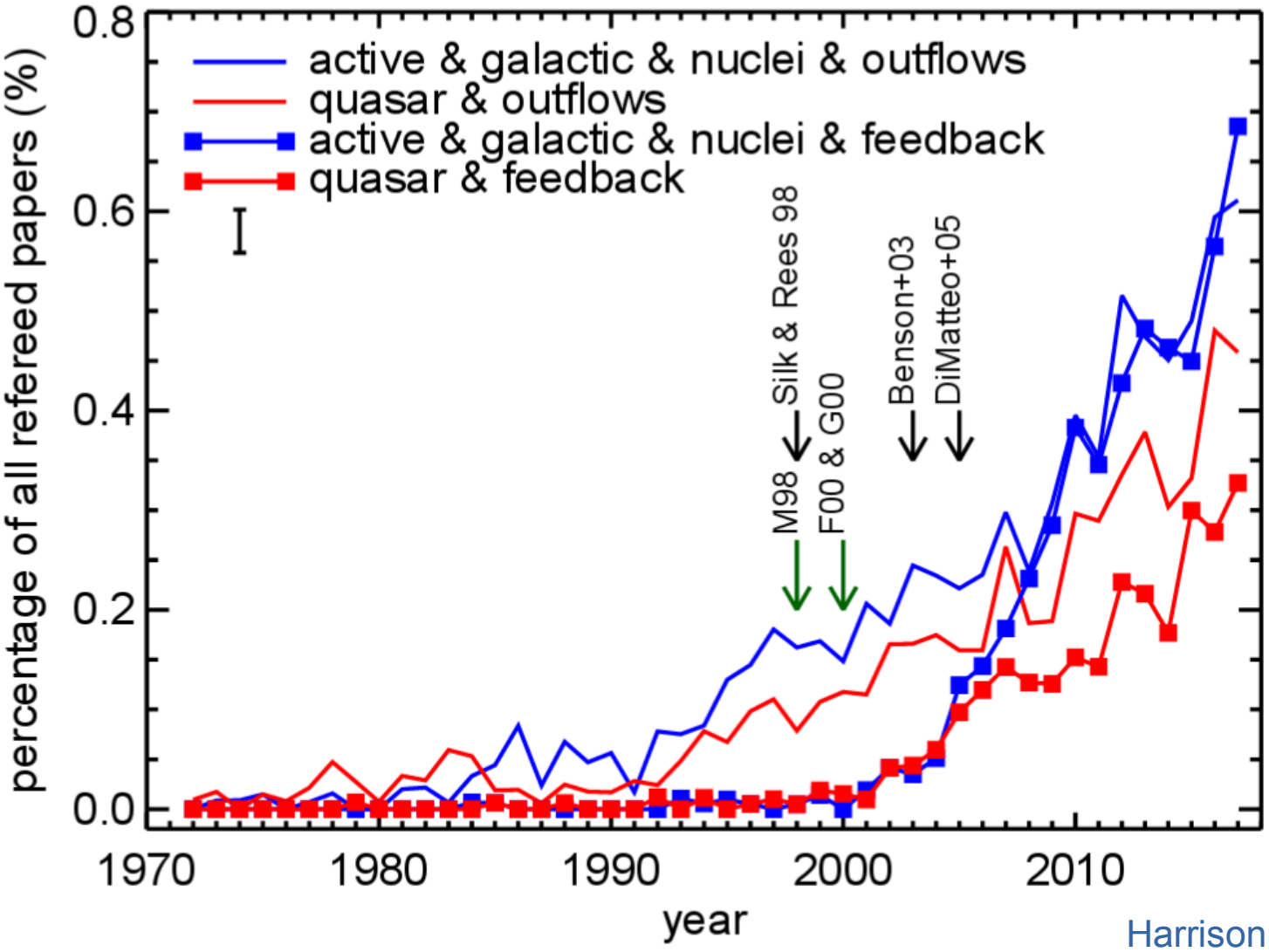
Energy released by AGN “rescue” ΛCDM





Most simulations require AGN feedback to stop star formation in massive galaxies >$10^{10}M_{sun}$

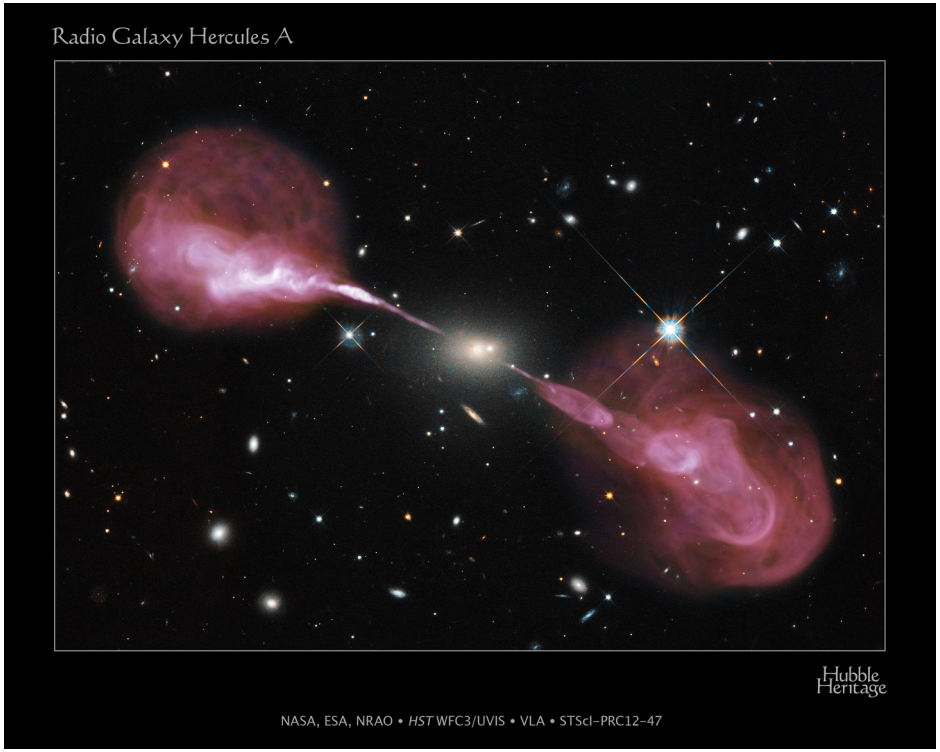
The hunt for AGN “feedback” is open!



Harrison et al. 2018

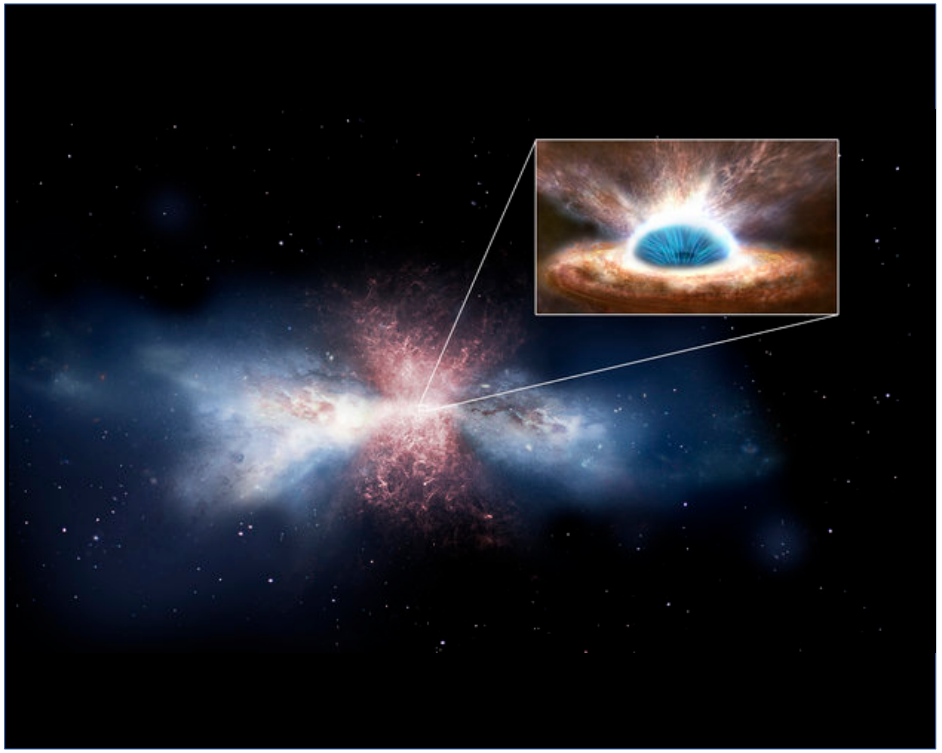
The two flavors of AGN feedback

Radio-mode feedback
preventive feedback



Radio jets keeps the halo hot
→ prevents cooling of gas

QSO-mode feedback
ejective feedback



Strong winds from the AGN
→ expels large fraction of gas

The two flavors of AGN feedback

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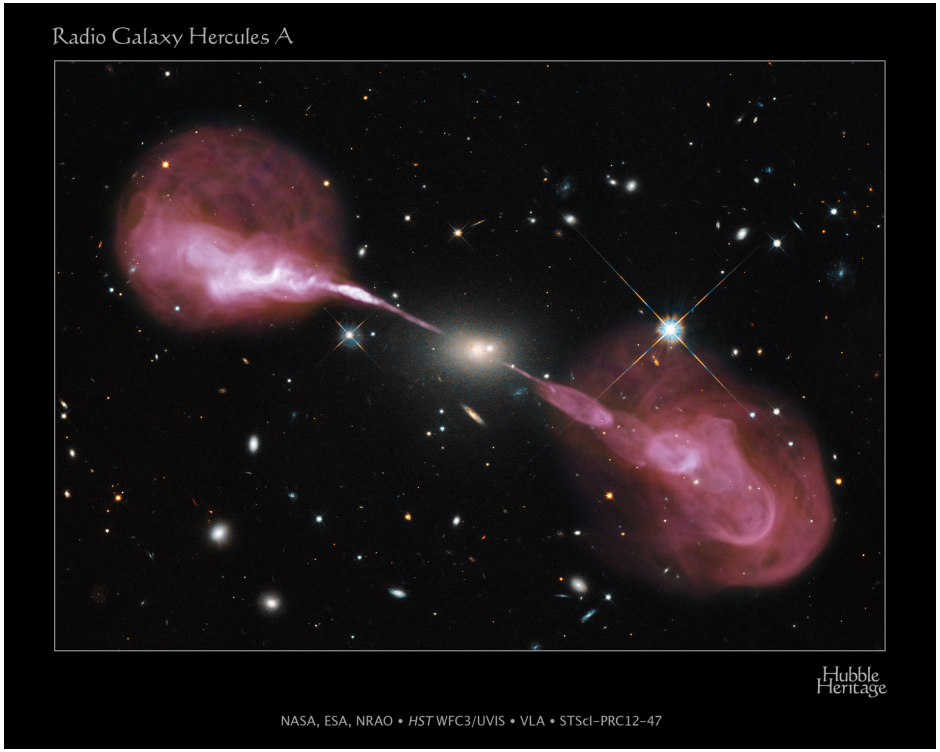

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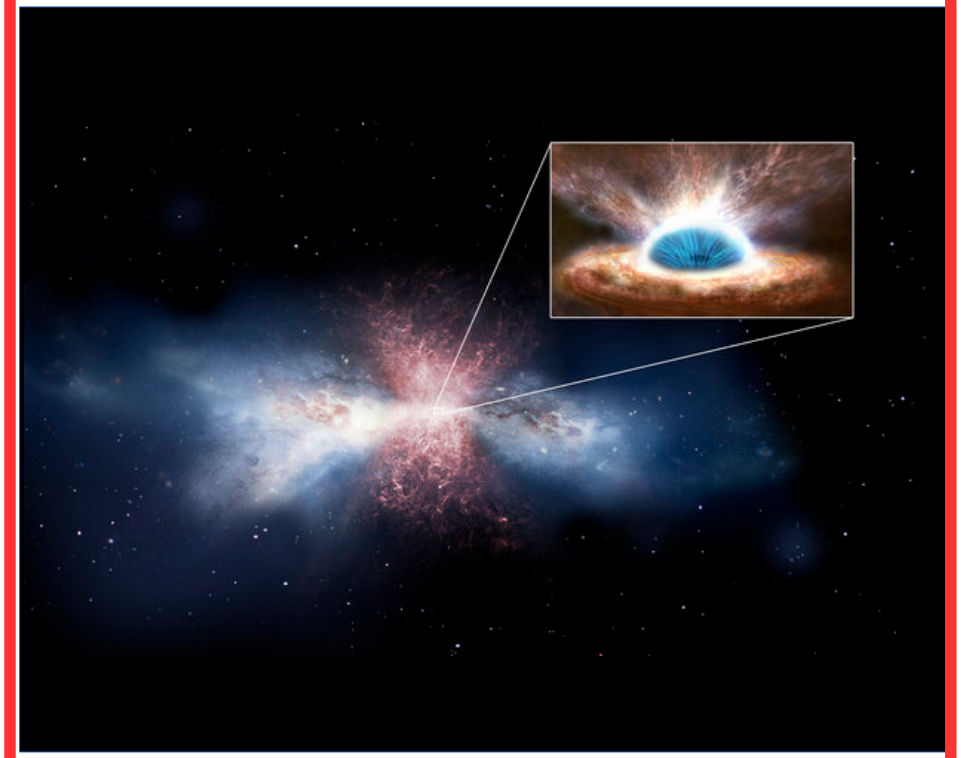
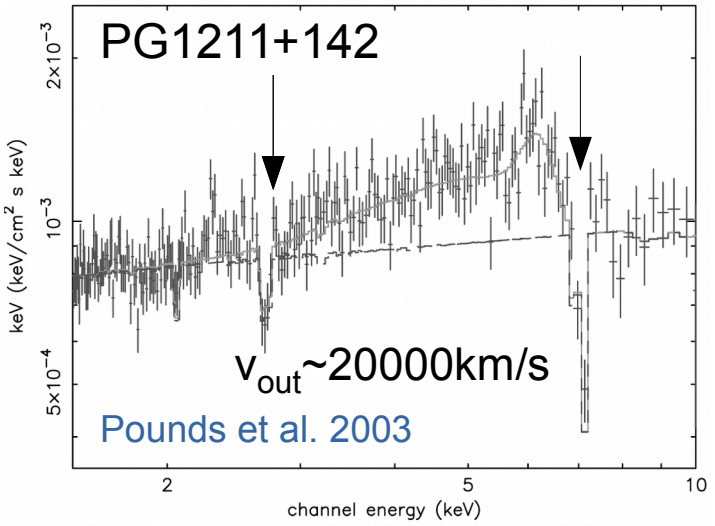


Strong wind from the AGN

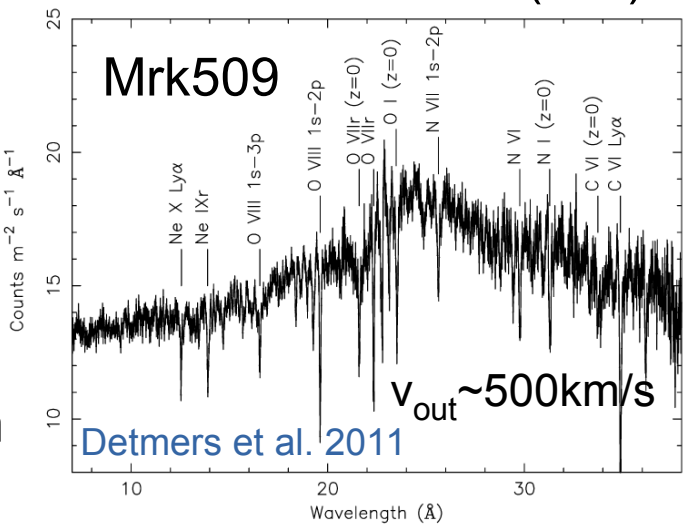
→ expels large fraction of gas

Evidence for ejective AGN feedback I

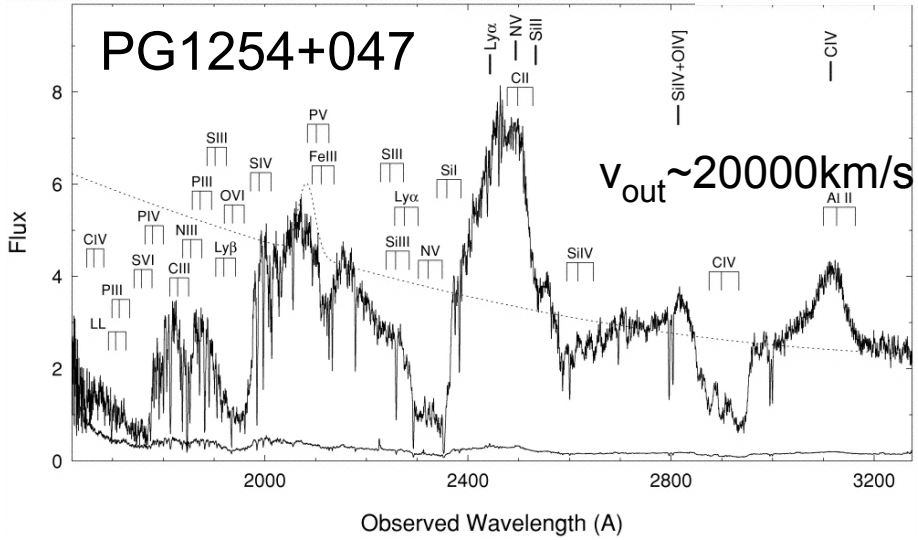
Ultra-fast outflows (UFOs)



Warm absorbers (WA)

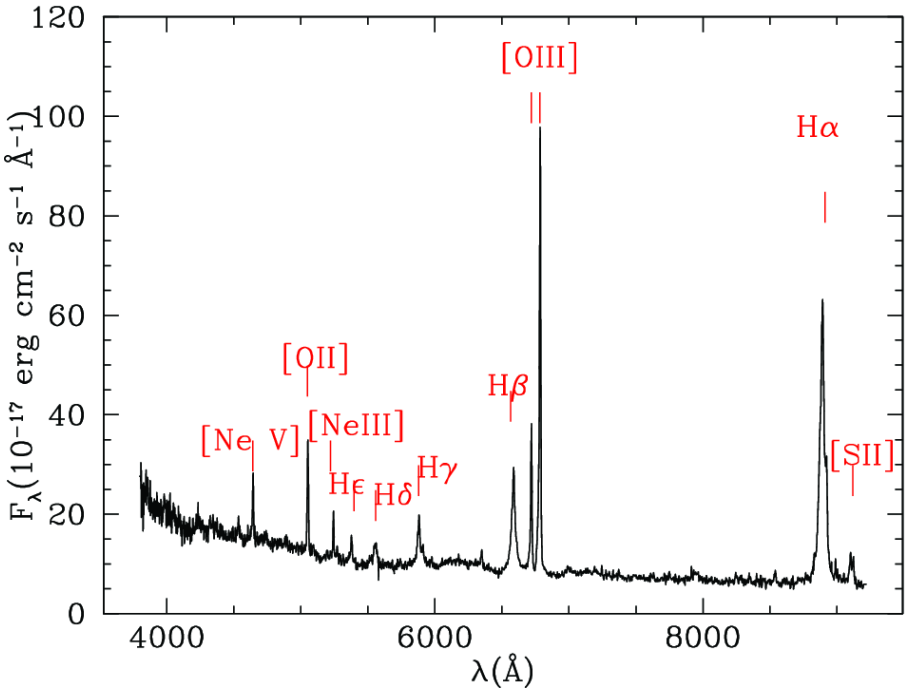


Broad-absorption lines (BALs)



Evidence for ejective AGN feedback II

Optical
AGN spectrum



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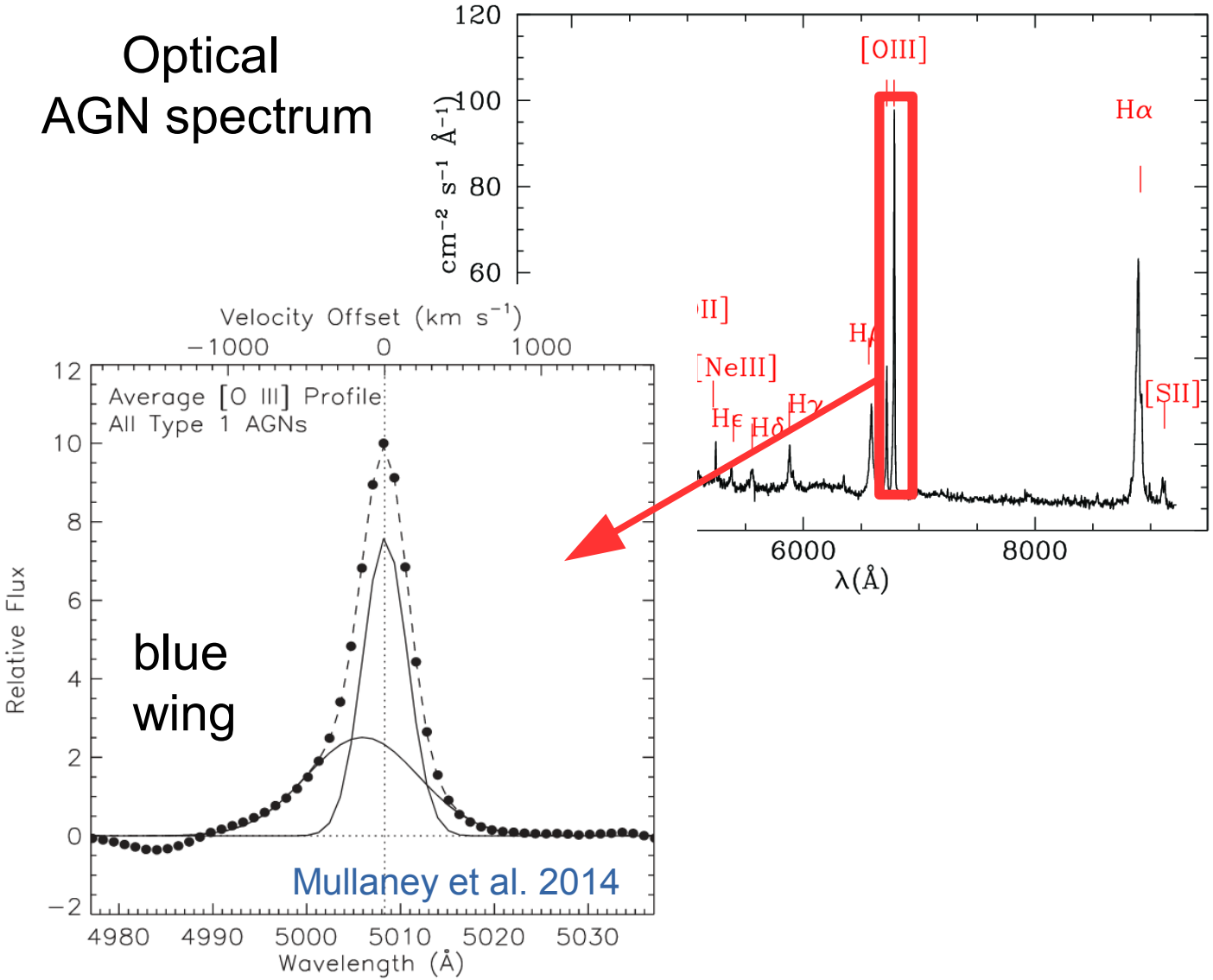

Evidence for ejective AGN feedback II

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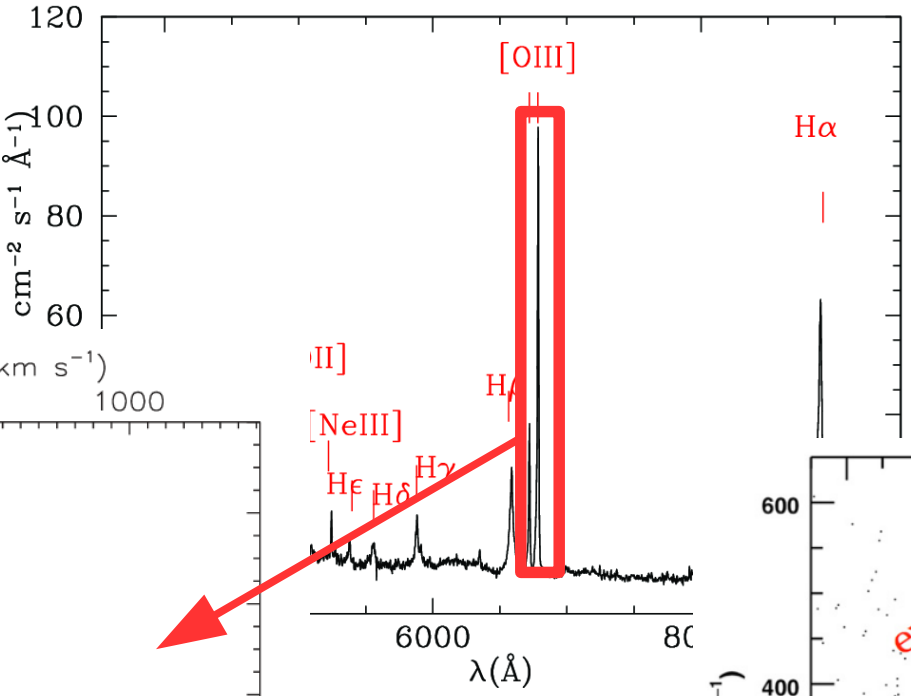
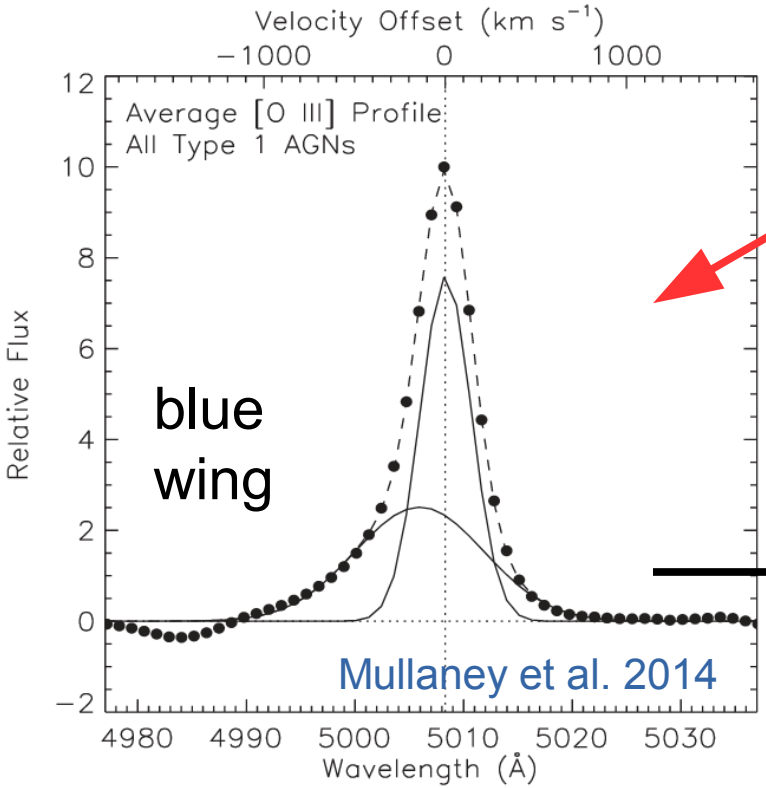
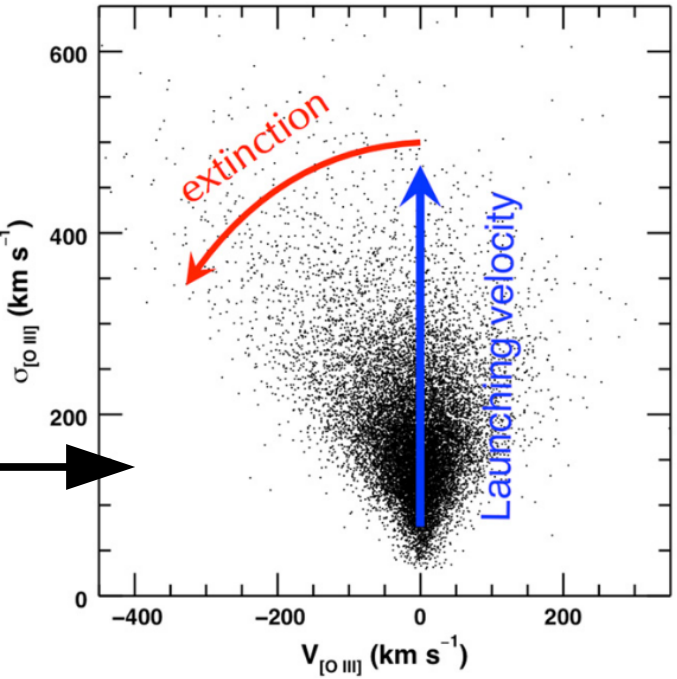




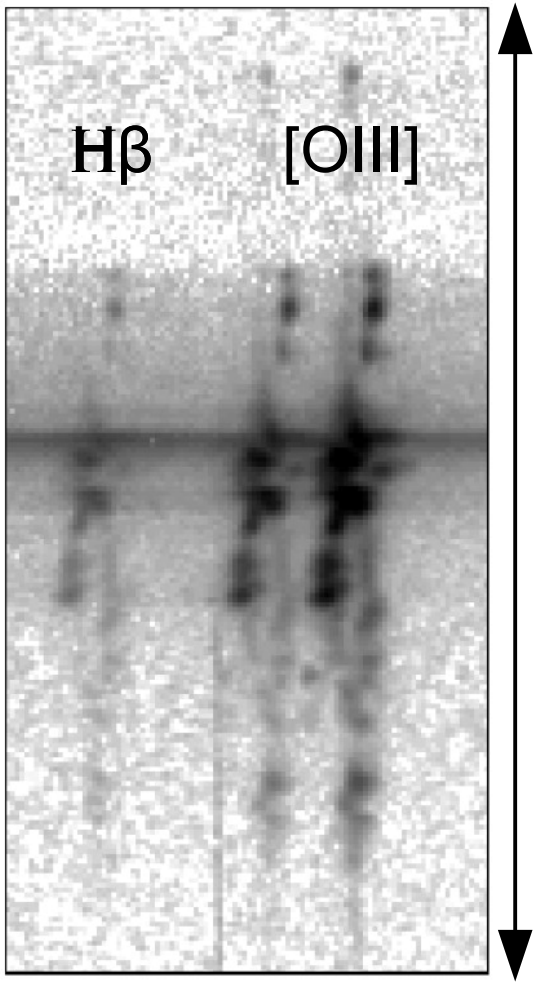
biconical outflow

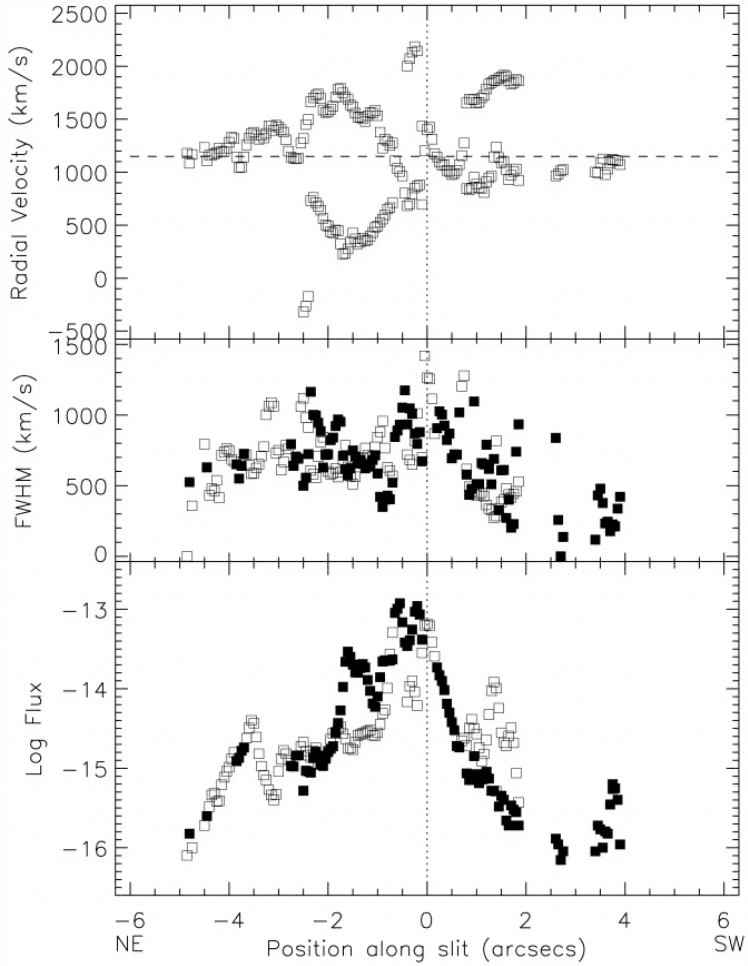
Woo et al. 2016



Resolving the NLR of NGC1068 with HST

HST STIS longslit

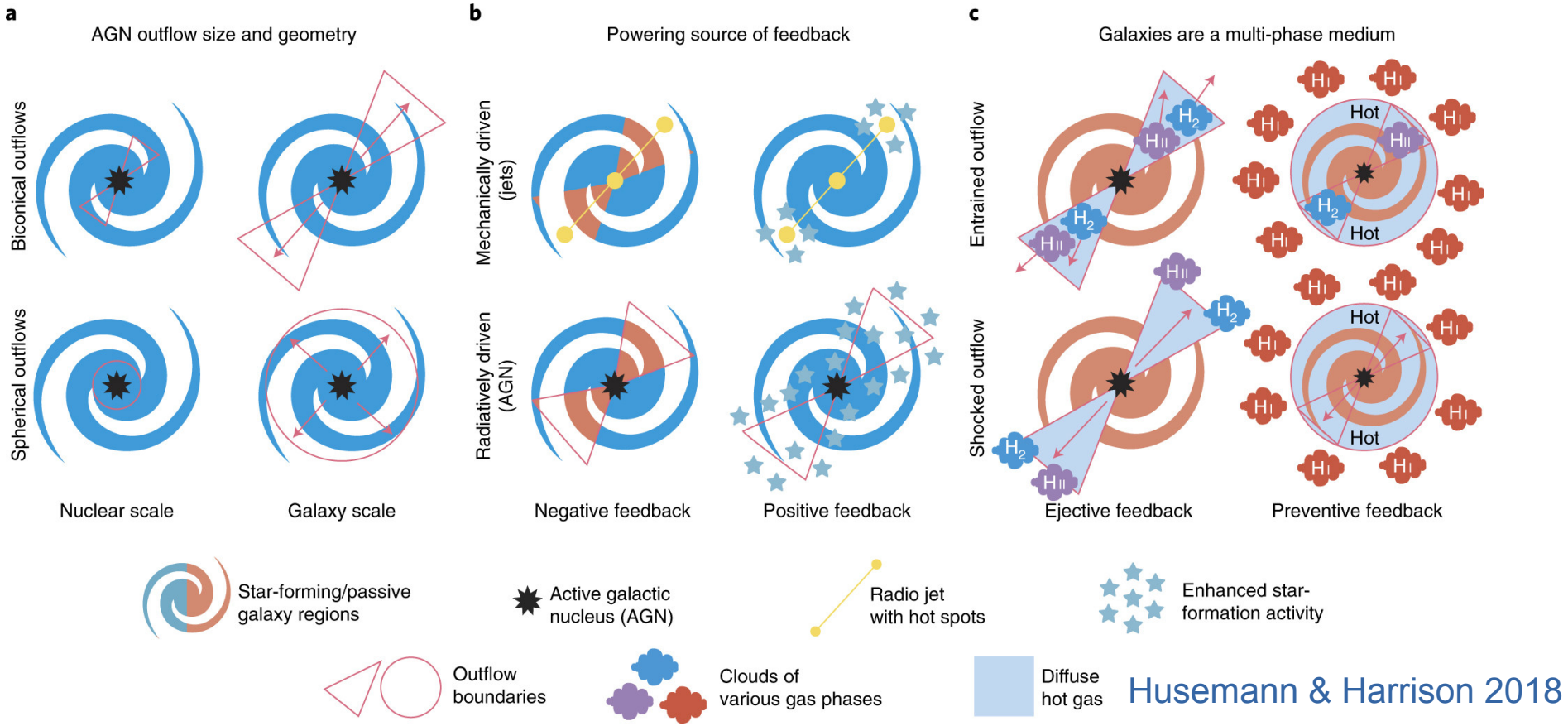




Kinematics consistent with a hollow bi-conical outflow!

Crenshaw et al. 2000

Still many open questions...



Husemann & Harrison 2018

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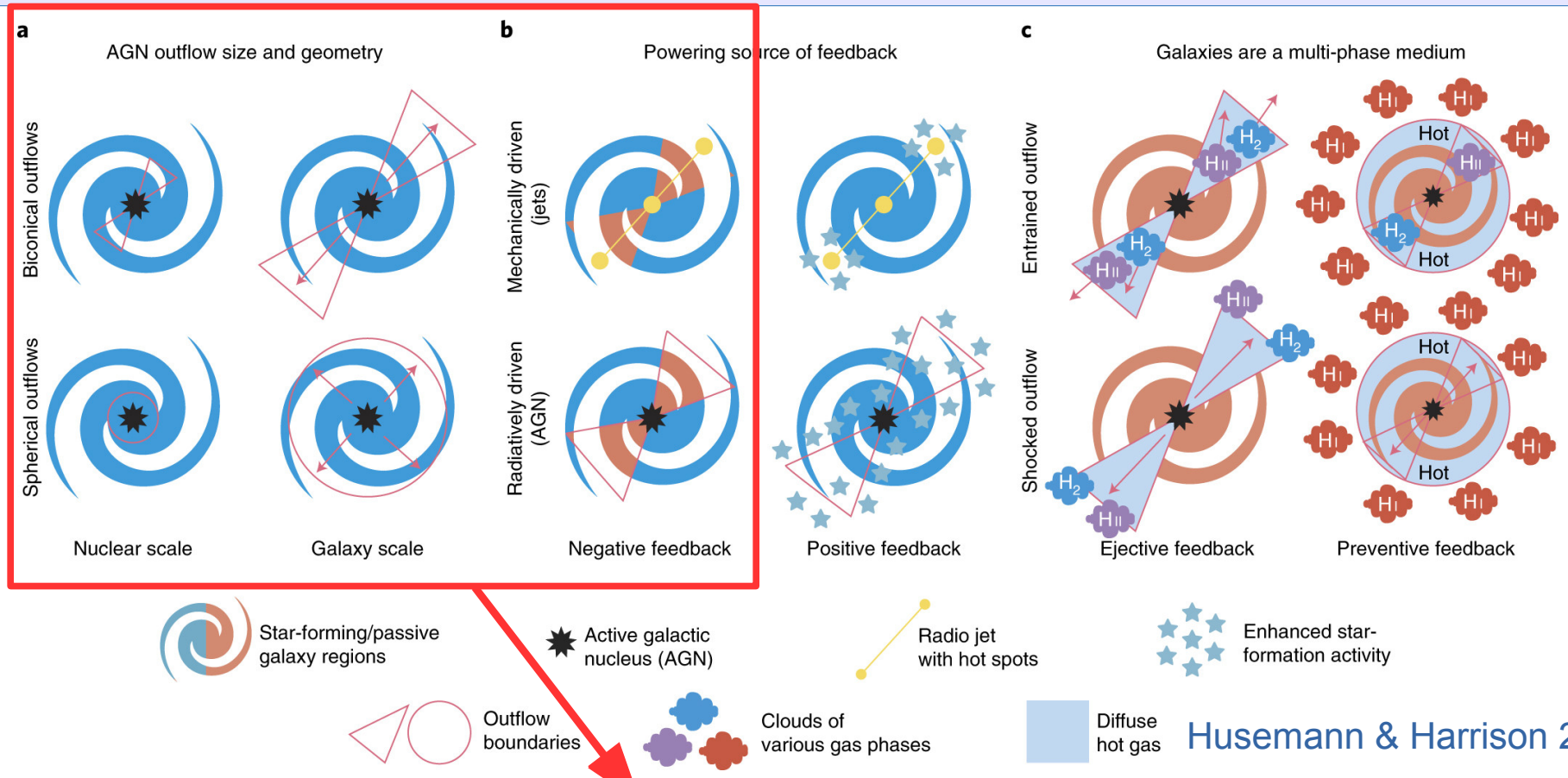
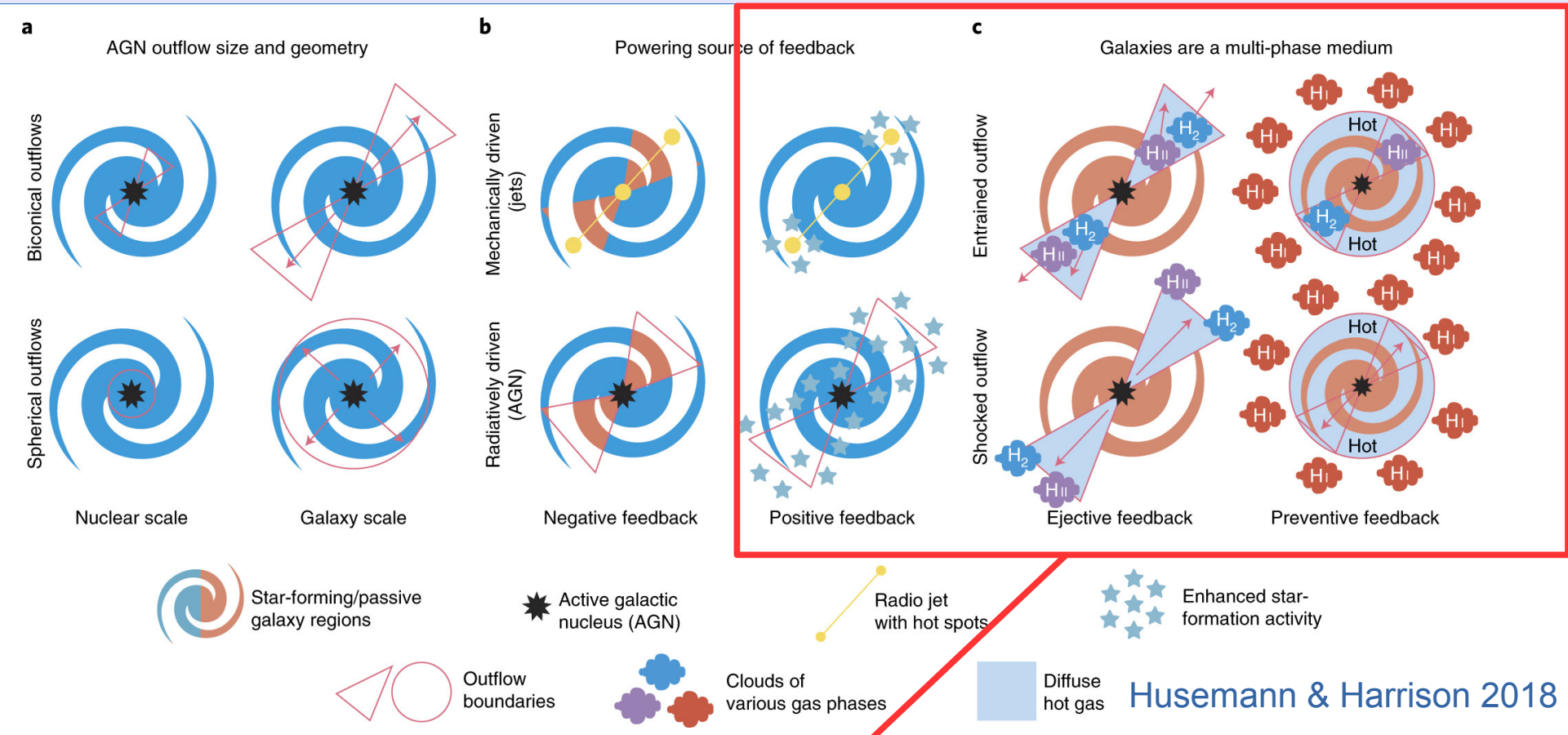


Husemann & Harrison 2018

Two approaches: 1) Constraints the properties of AGN outflow

Still many open questions...



Husemann & Harrison 2018

Two approaches: 1) Constraints the properties of AGN outflow

2) Characterize the feedback on AGN hosts

Measuring (ionized) outflow energetics

$$\dot{M}(R) = a(M \cdot v)/R$$ **Mass outflow rate**

$$\dot{P}(R) = \dot{M}(R) \cdot v$$ **Momentum injection**

$$\dot{E_{kin}}(R) = \dot{M}(R)/2(v^2 + b\sigma^2)$$ **Energy injection**

Key measurements from IFU data:

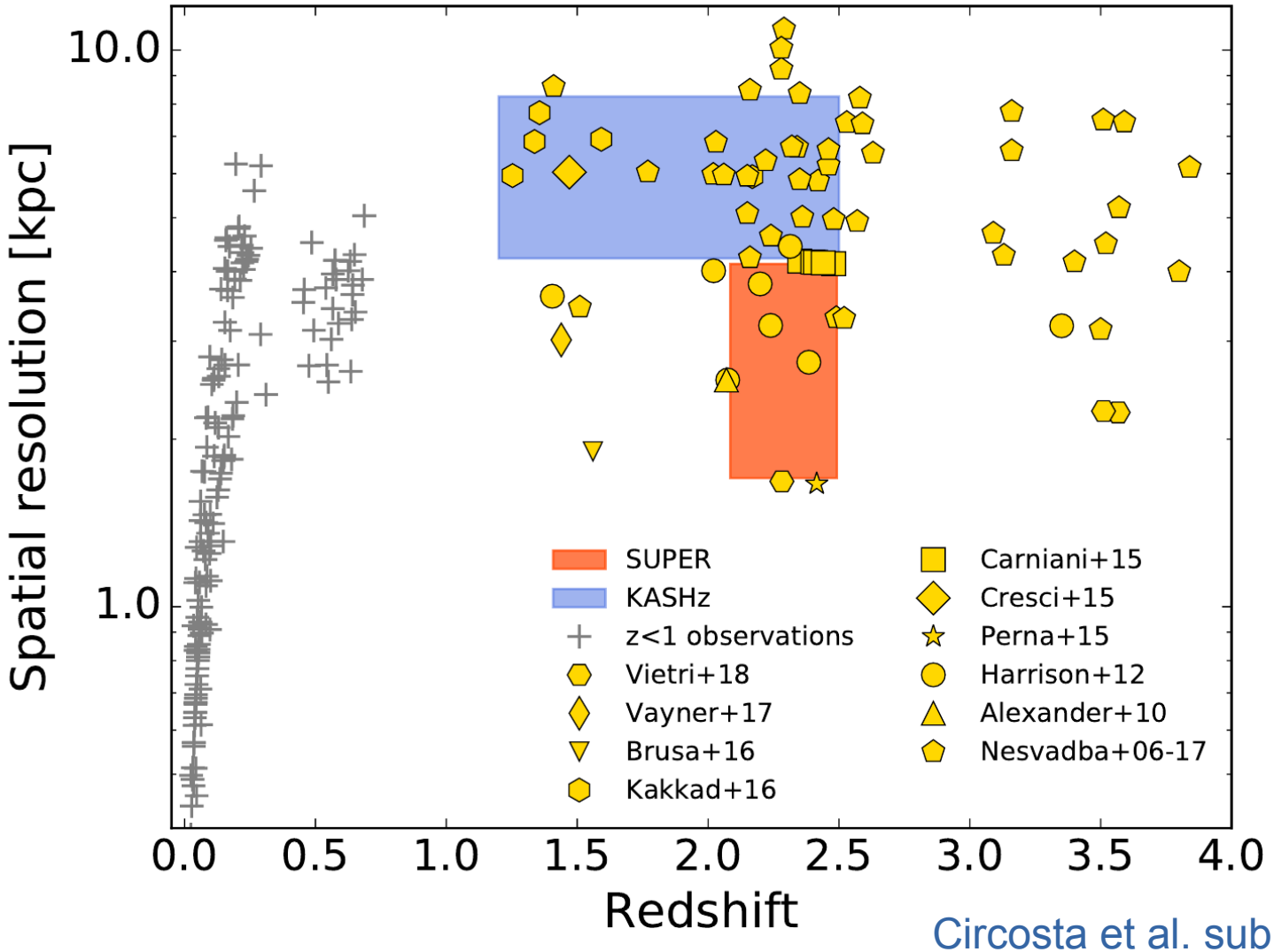
v - outflow velocity

σ - outflow dispersion

R - outflow radius

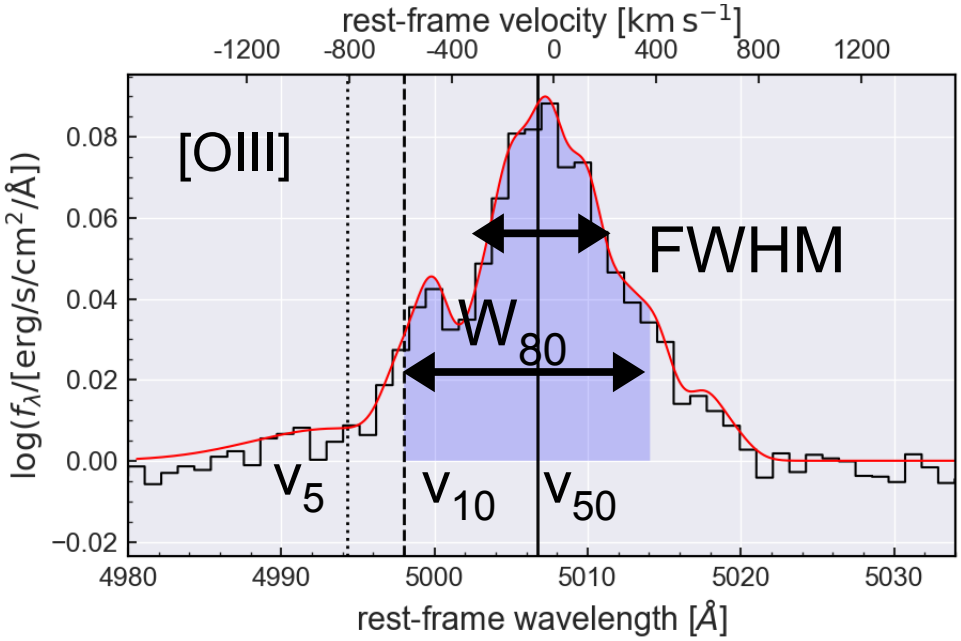
$M \rightarrow n_e$ - outflow mass → density

Large number of IFU studies on AGN



Circosta et al. subm.

Issue 1: Inferring the outflow velocity

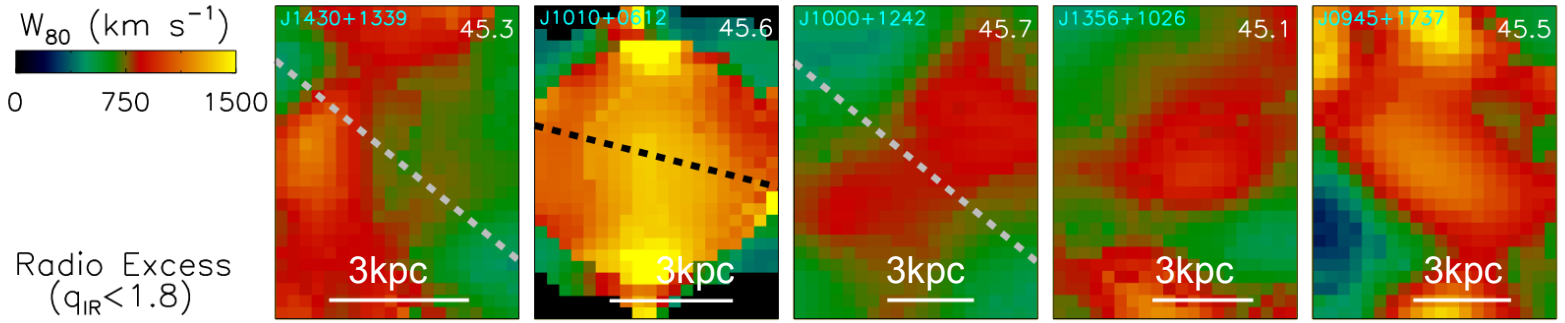


Complex [OIII] line profiles:

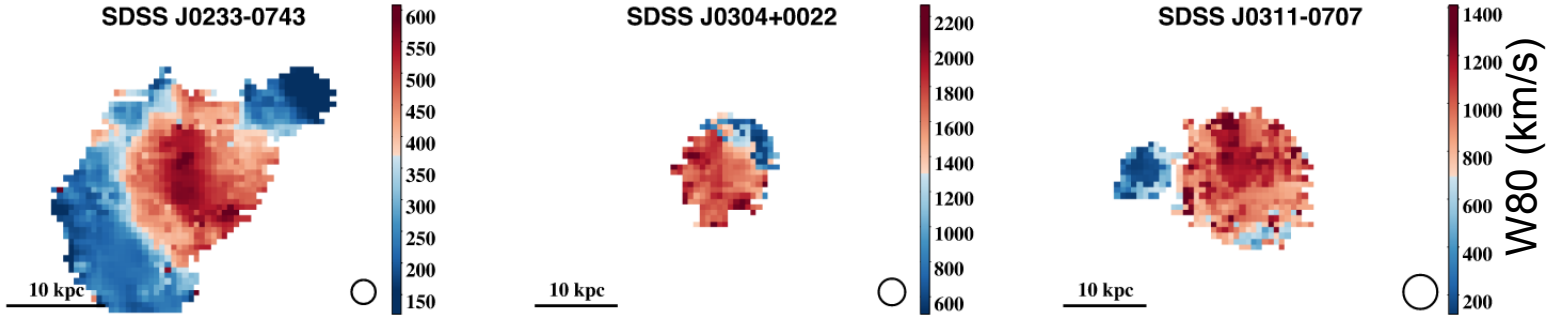
- Fitting multiple Gaussians
- Tests needed for #N of lines
- Non-parameteric measures
- Several different outflow velocities are used

- Non-parameteric line shape measure are easy and universal
  - ➔ Non-outflowing components included in the parameters
  - ➔ Physical interpretation of line shape is lost…

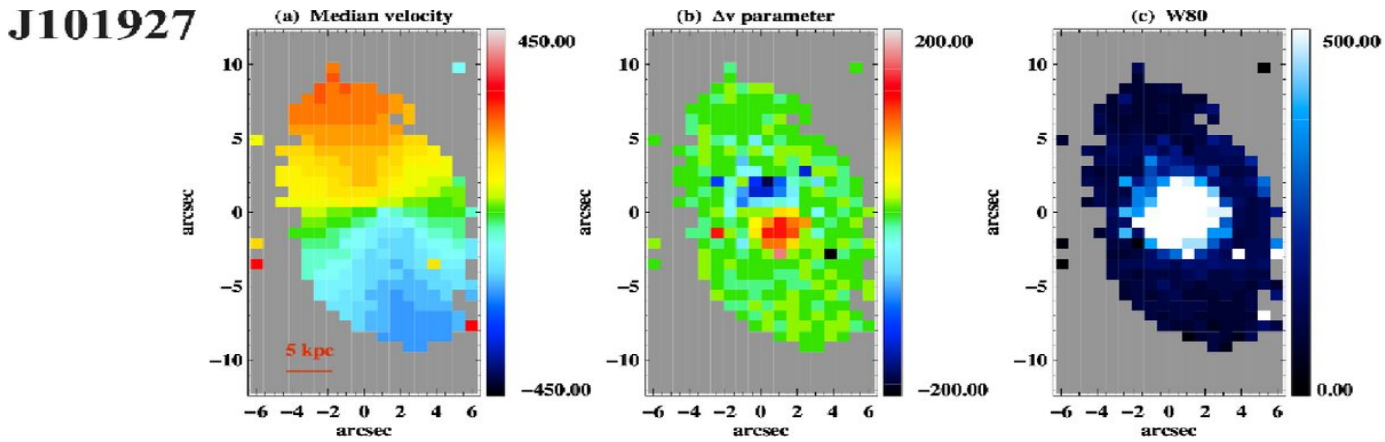
Kinematic mapping of outflows on kpc scales



Harrison et al. 2014



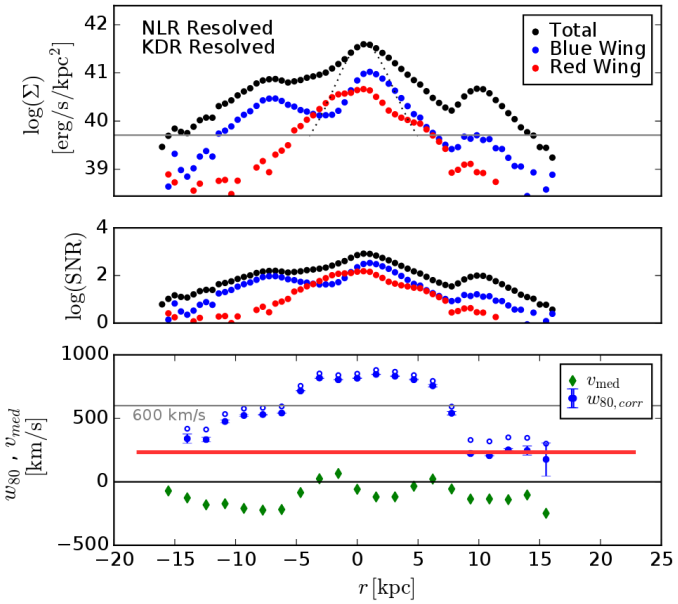
Liu et al. 2014
see also
Liu et al. 2013



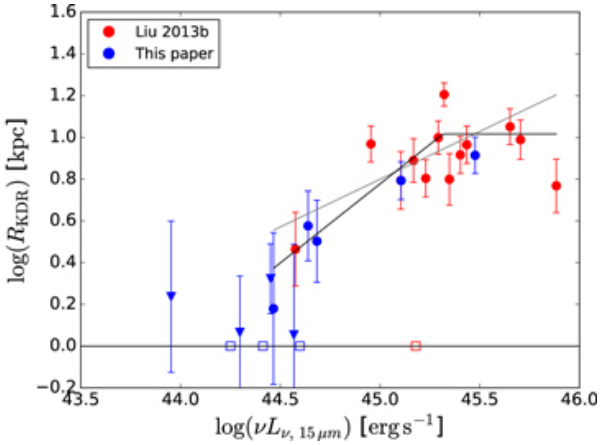
McElroy et al. 2015

Issue 2: Determining the outflow size

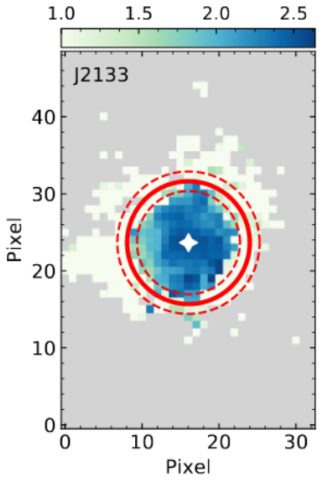
W_{80}>600km/s

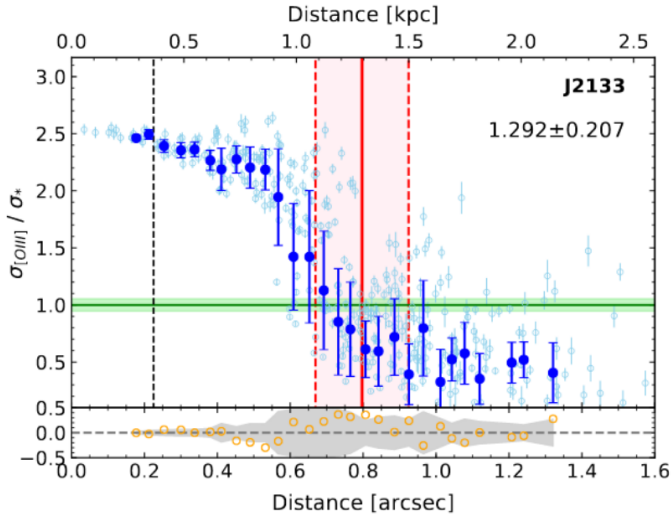


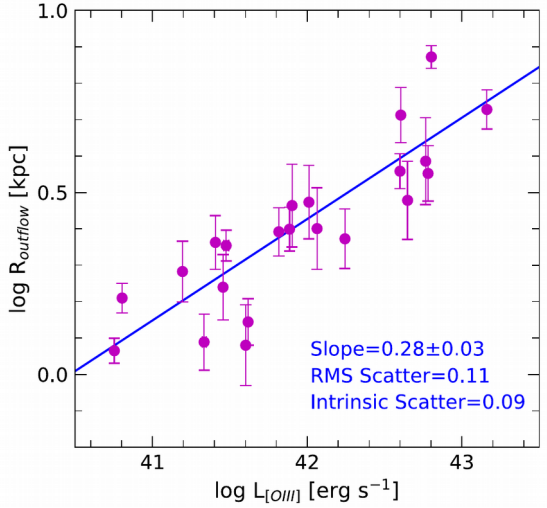
Sun et al. 2017



$\sigma_{[OIII]}$>σ_{stars}

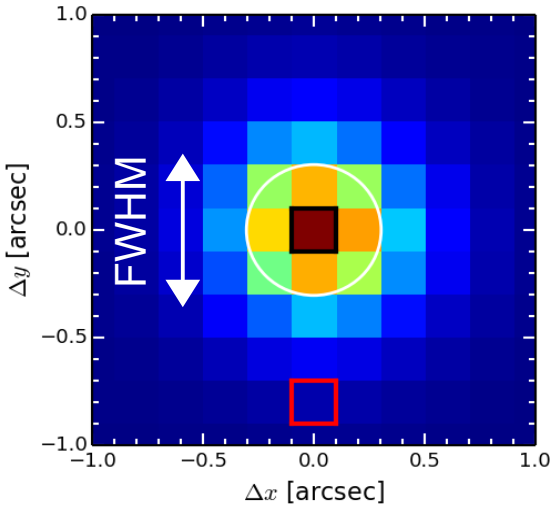


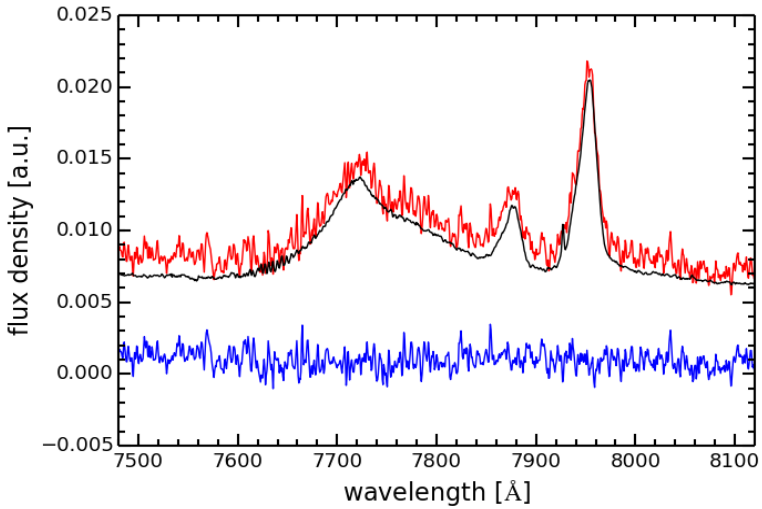


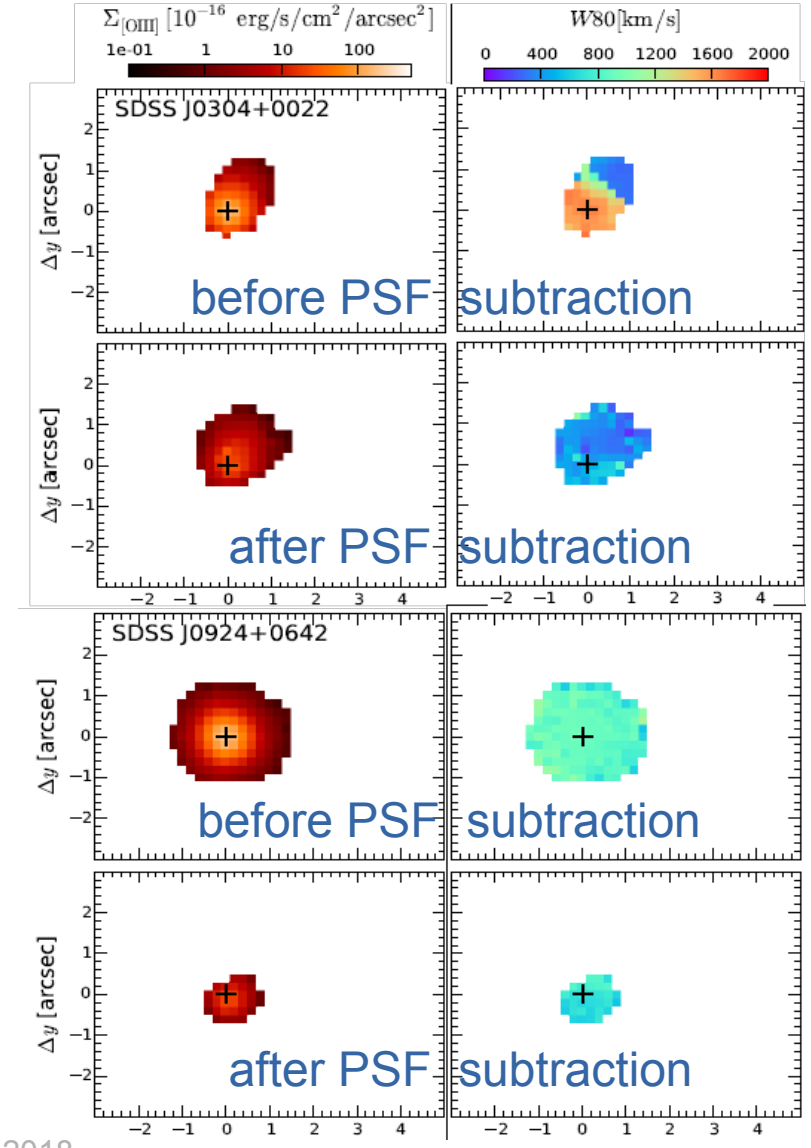


Kang & Woo 2018

Importance of beam smearing

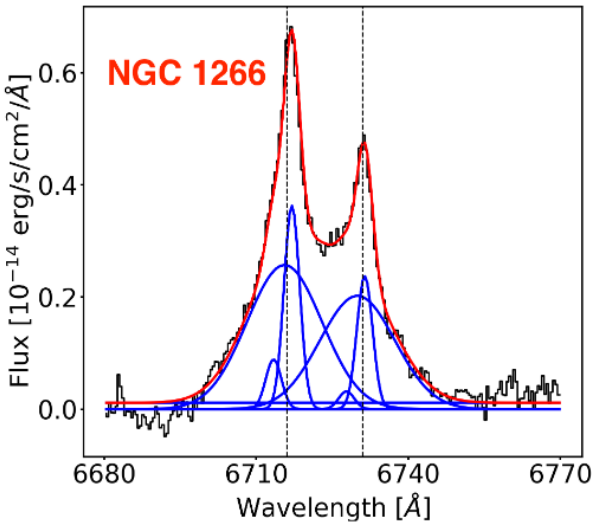


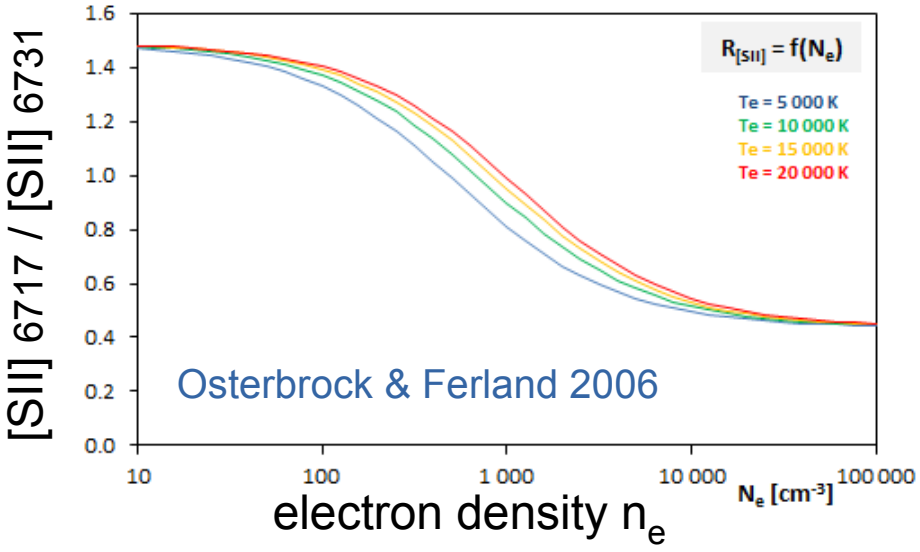


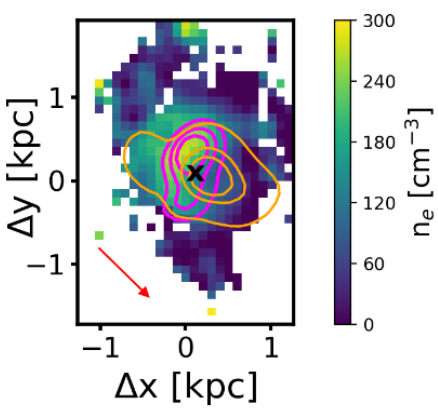


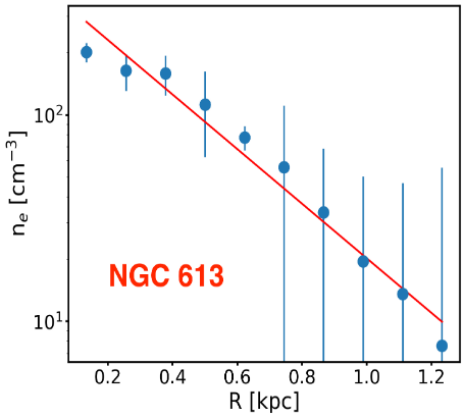
Husemann et al. (2016)

Issue 3: Measuring the electron density







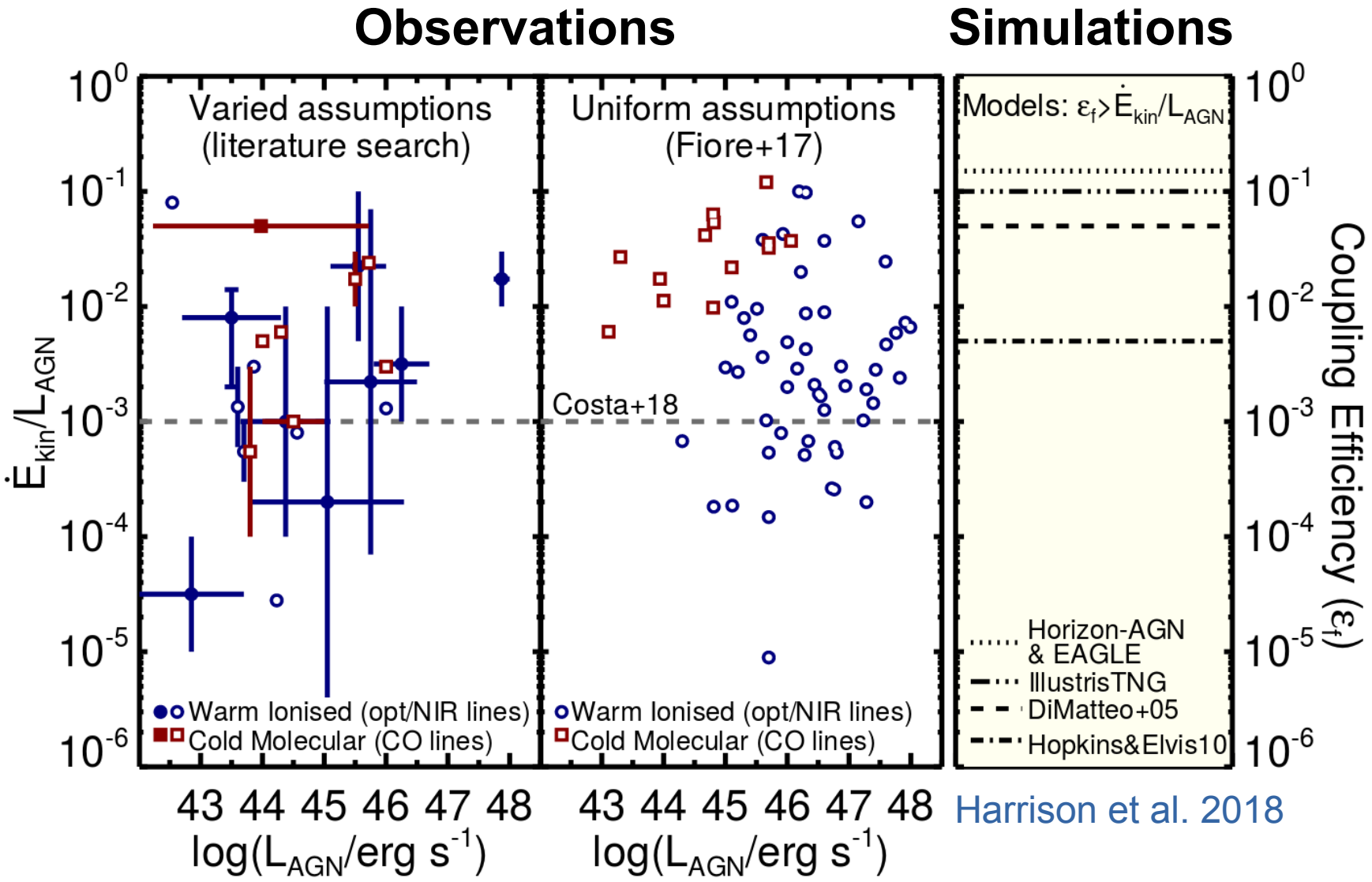


- Negative n_e gradients
- n_e>1000cm^{-3} in outflow
- [SII] often unavailable

→ n_e~200cm^{-3} assumed

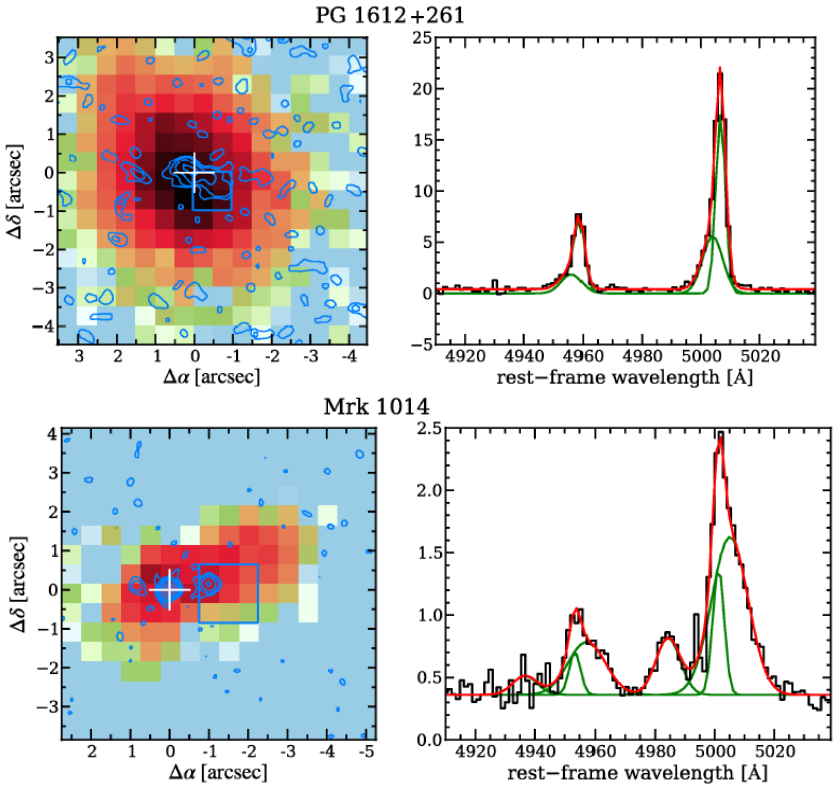
Kakkad et al. 2018

No concensus on outflow power!



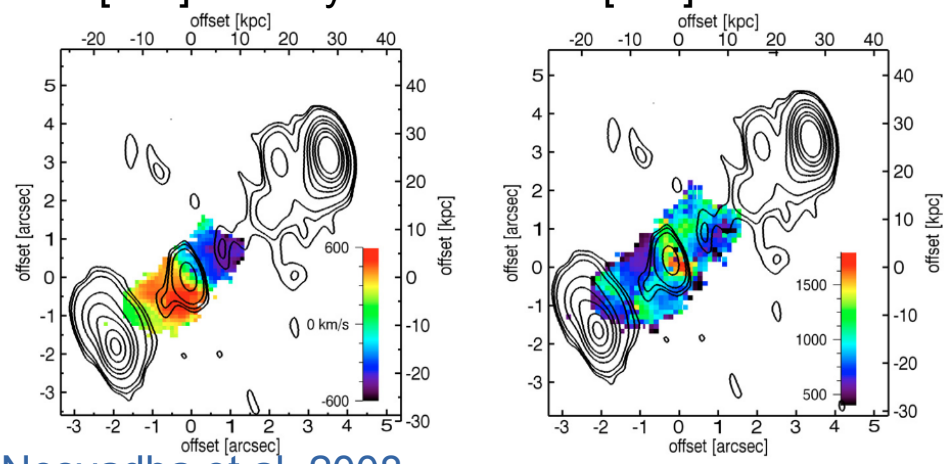
Harrison et al. 2018

Are radio jets powering (partly) the outflow?

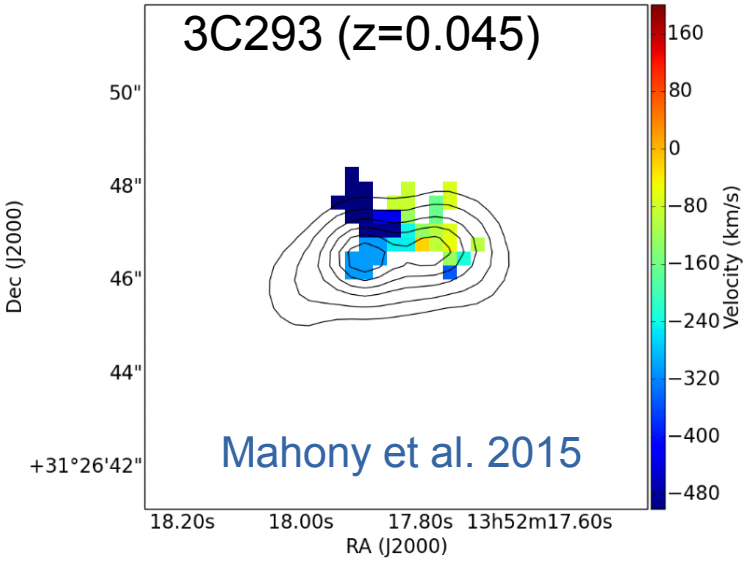


Husemann et al. 2013

MRC0406-244 (z=2.42)



Nesvadba et al. 2008

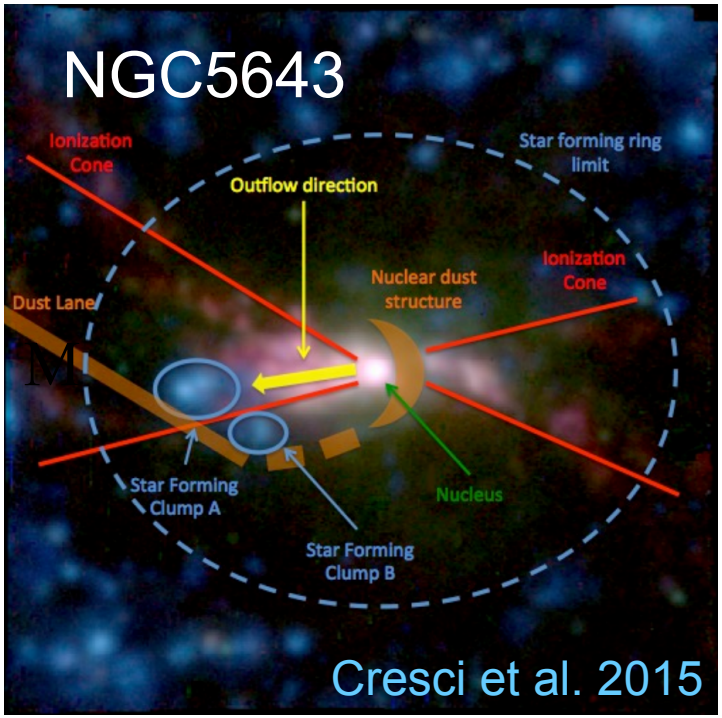


High velocities often associated with jets

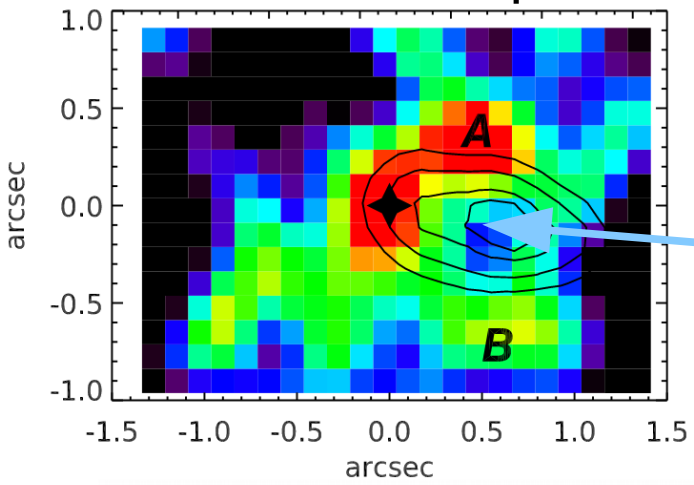
→ What drives the outflow on kpc scales?

Positive or negative AGN feedback?

MAGNUM survey

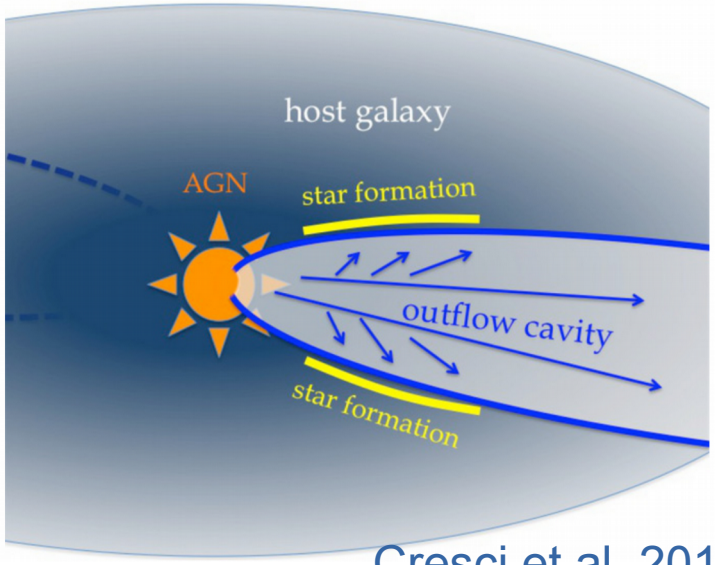


Ha flux map



QSO
z=1.59

[OIII] outflow



Cresci et al. 2015

- star formation suppressed in outflow → negative feedback
- star formation enhanced at the edge of cavity → positive feedback

The Close AGN Reference Survey (CARS)

CARS nutshell:

- 40 type-1 AGN
- 0.01<z<0.06
- $10^{44}<L_{bol}<10^{45}$
- Single-dish CO

Spatially-resolved multi-wavelgenth!

Optical IFU

radio

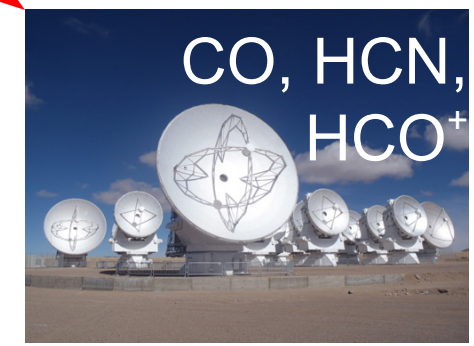
CLOSE AGN REFERENCE SURVEY

FIR

ALMA

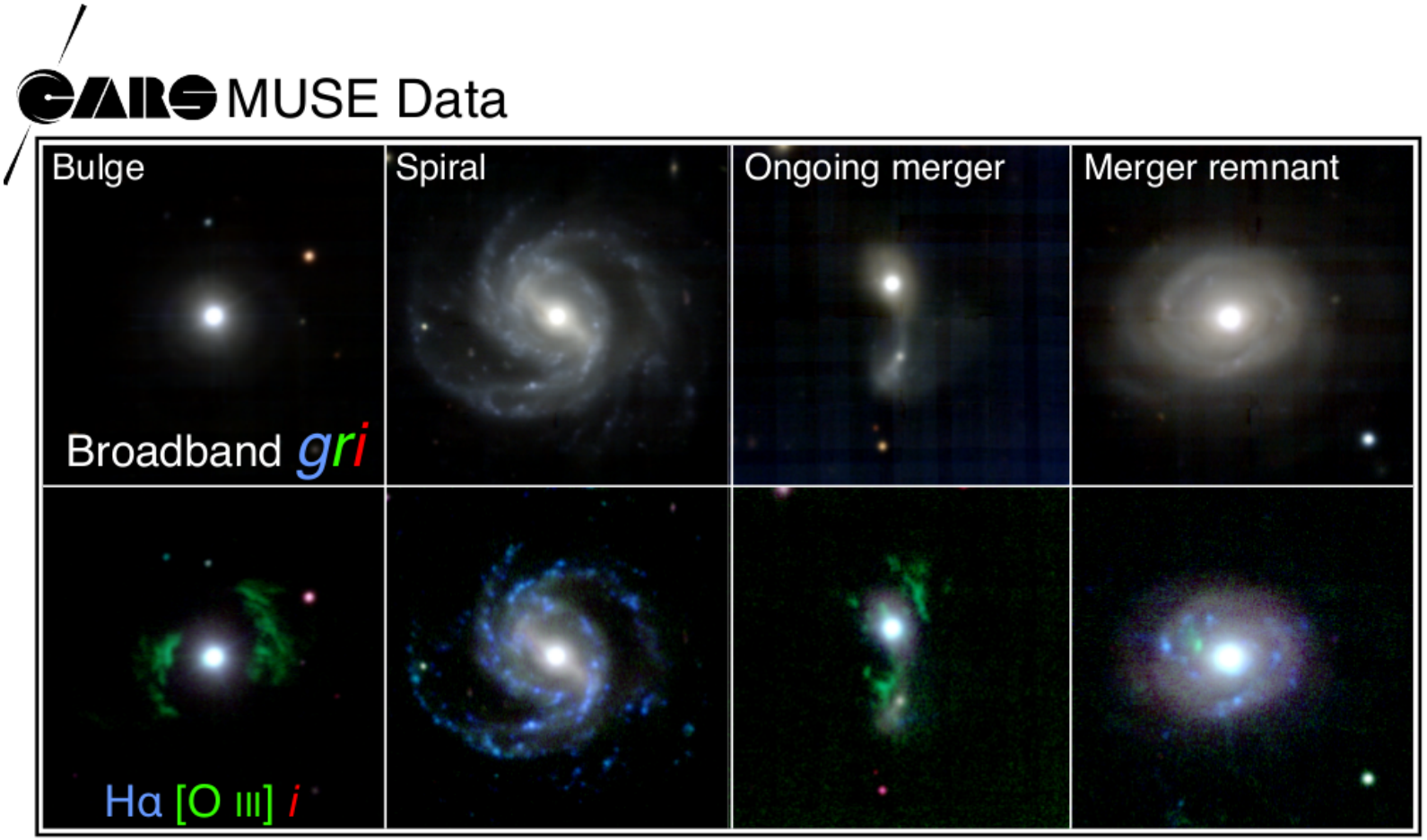
X-rays

NIR



see www.cars-survey.org

MUSE: The new power IFU

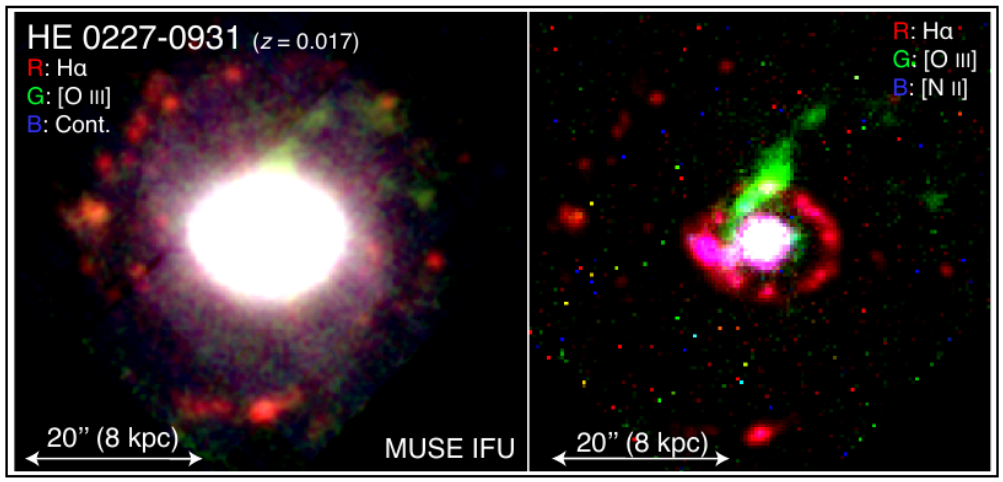


1’x1’ FoV with 0.2” sampling → 90 000 spectra at once

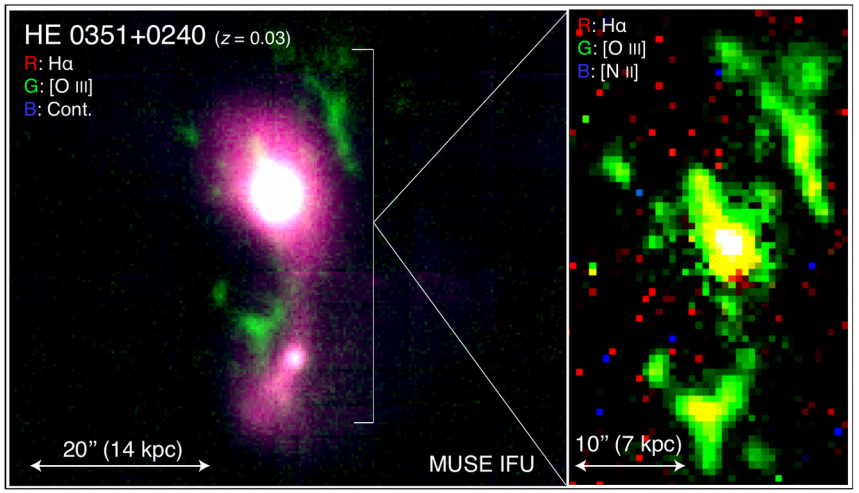
CLOSE AGN REFERENCE SURVEY

Testing hot gas outflow scenarios

$L_{bol}=3x10^{44}erg/s$ $L_{bol}/L_{Edd}\sim1$



$L_{bol}=10^{45}erg/s$ $L_{bol}/L_{Edd}\sim0.5$



Powell et al. 2018

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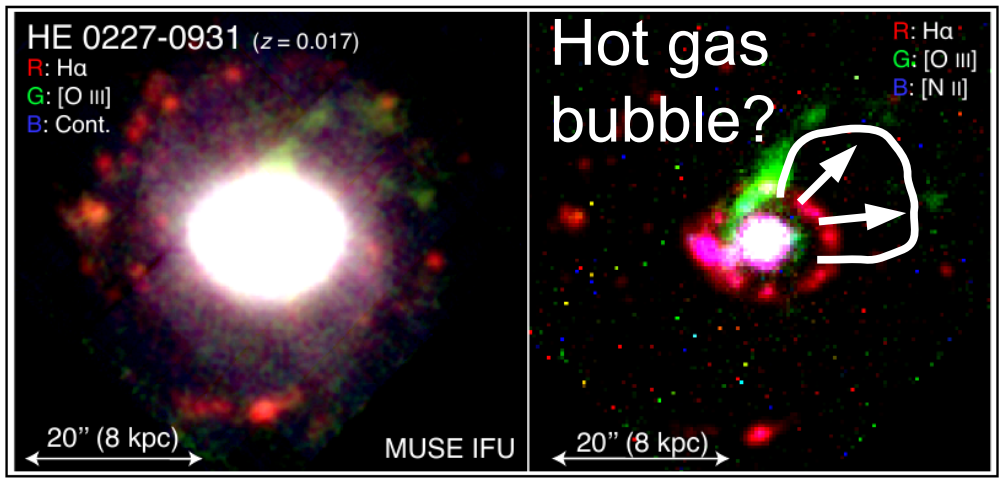

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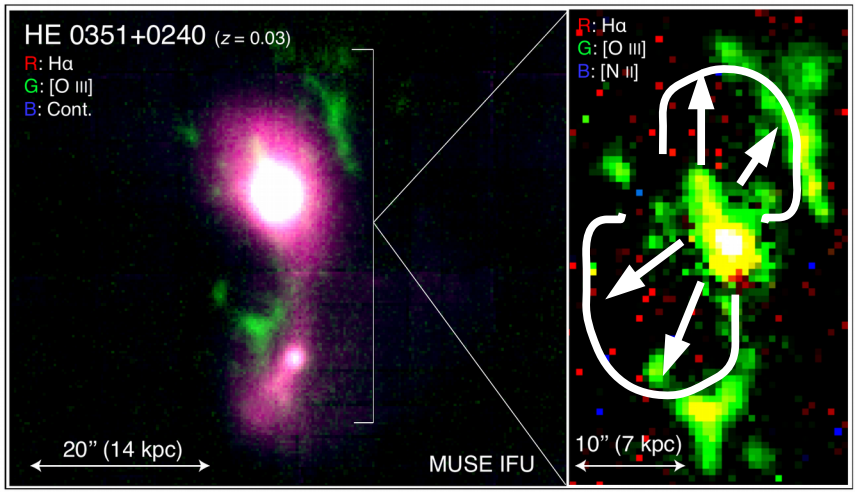

Powell et al. 2018

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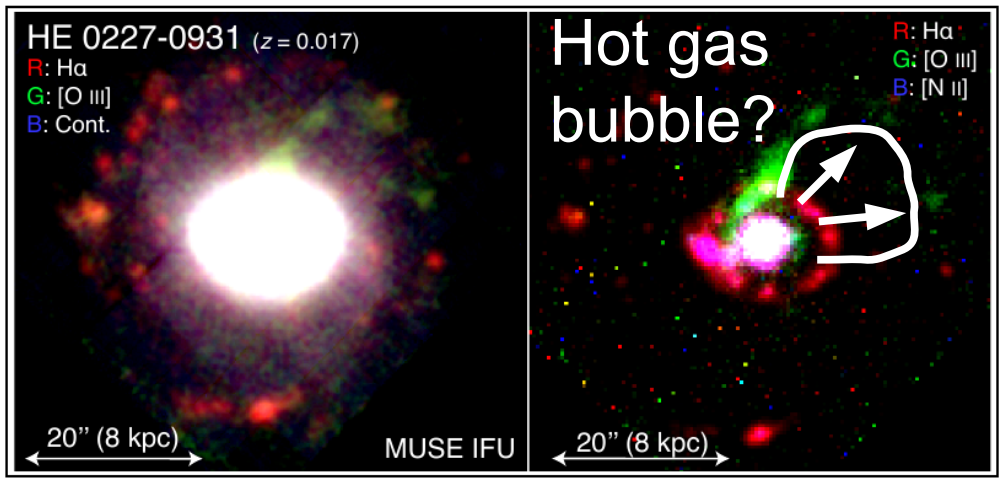
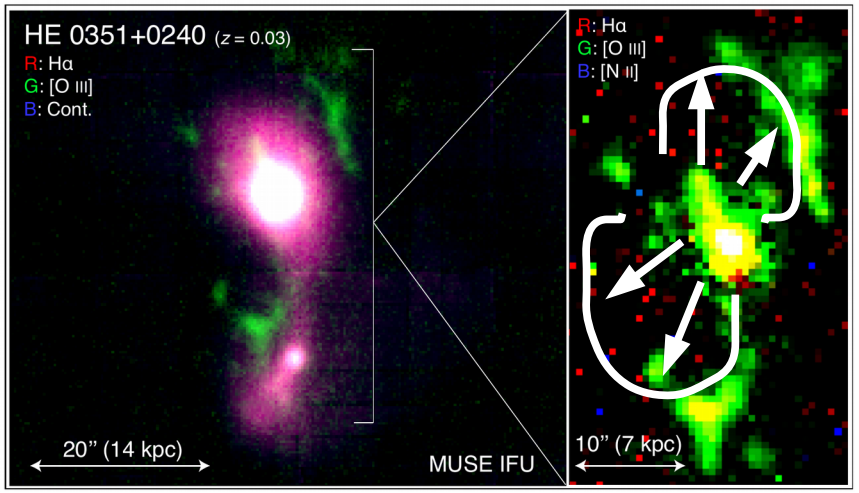
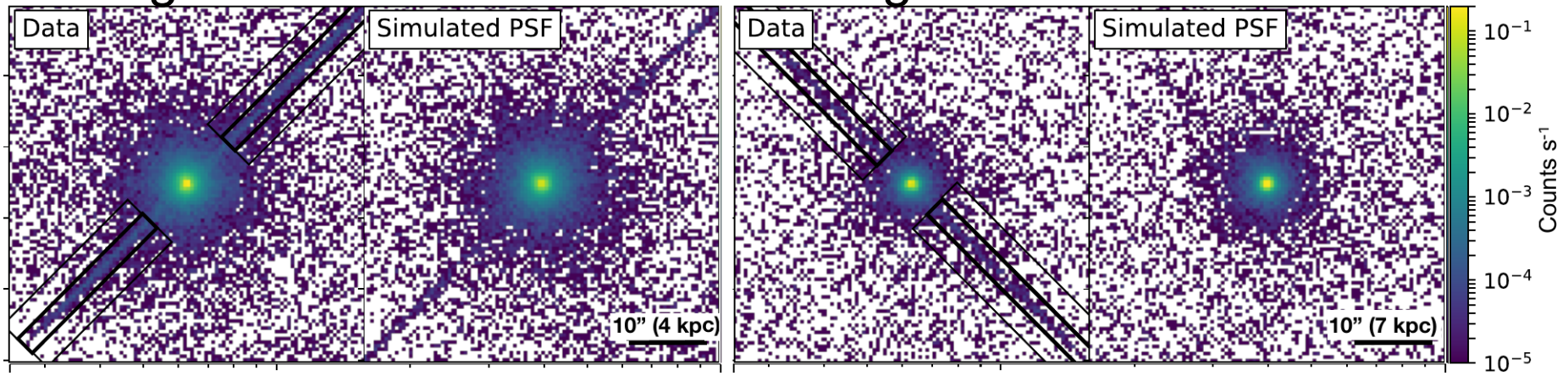


$L_{bol}=10^{45}erg/s$ $L_{bol}/L_{Edd}\sim0.5$



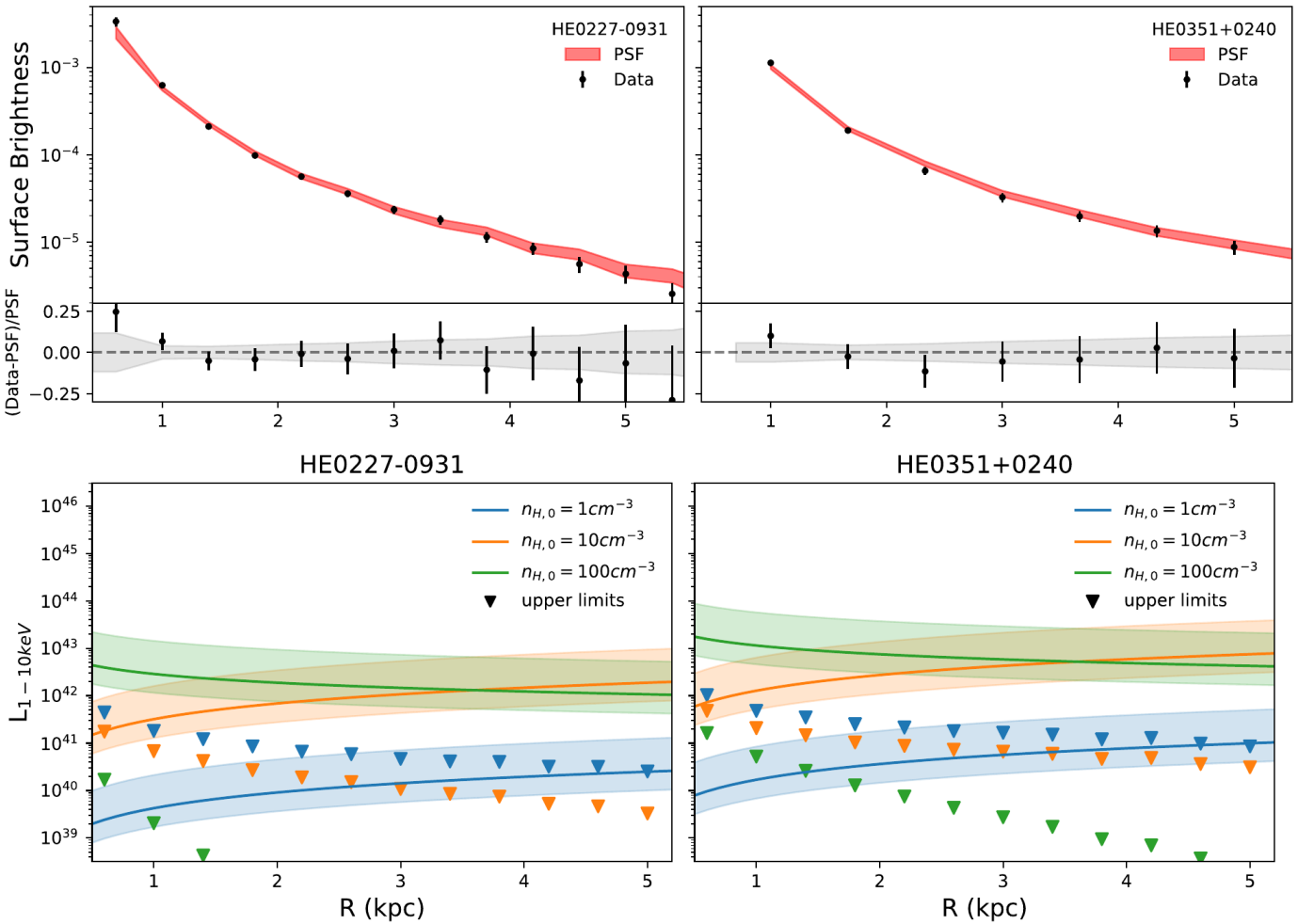
Burning 100ksec with Chandra on target!

Powell et al. 2018



Testing hot gas outflow scenarios

Radial X-ray surface brightness

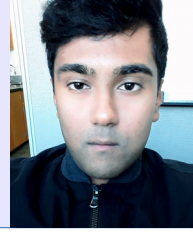


No extended X-ray emission...

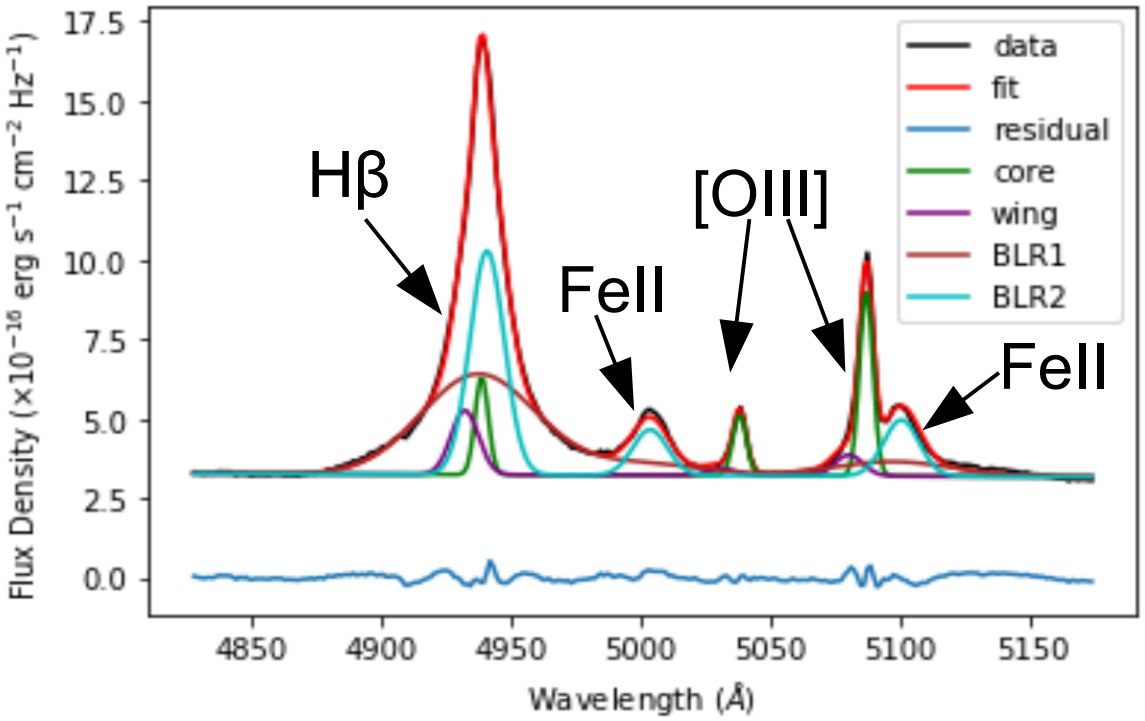
Much fainter than hot gas outflow predictions by Nims et al (2015)

Powell et al. 2018

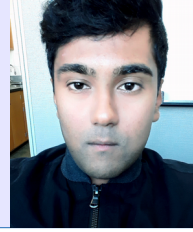
Where is the broad [OIII] emitted?



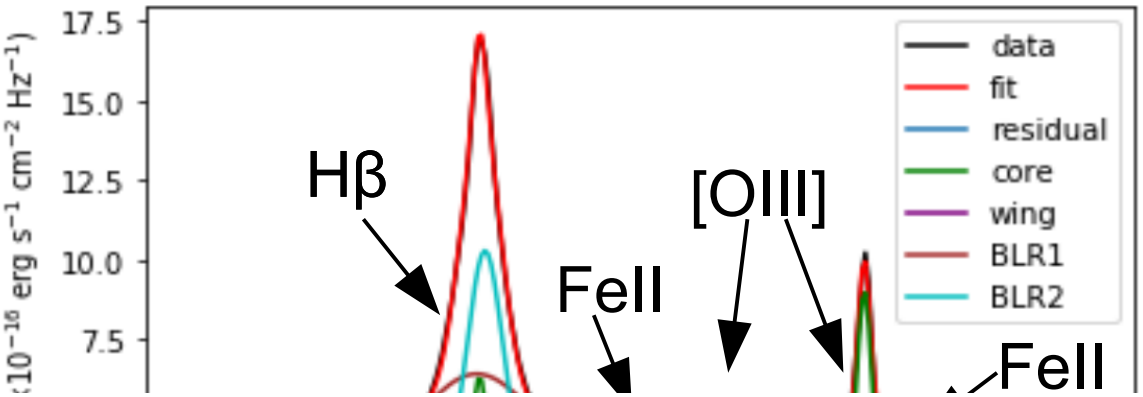
Singha et al.
in prep.



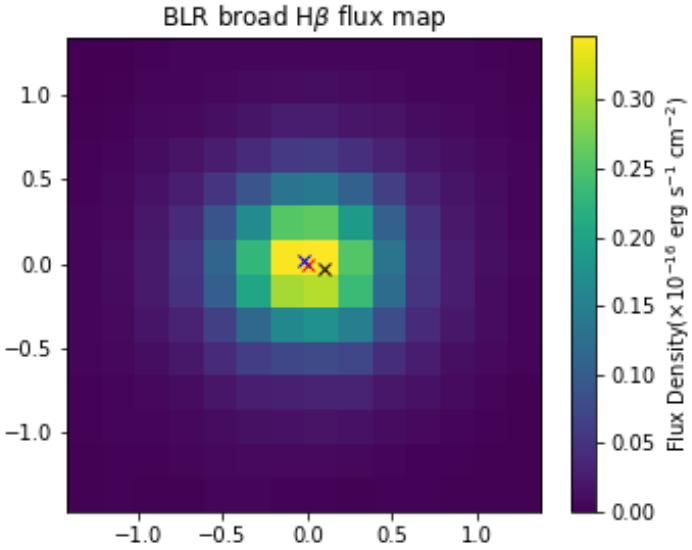
Where is the broad [OIII] emitted?

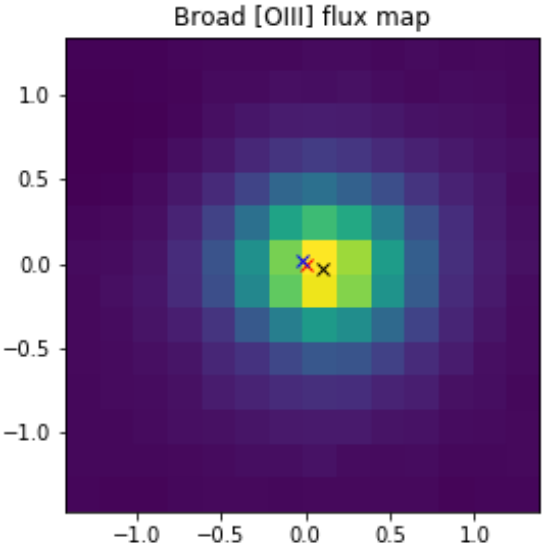


Singha et al.
in prep.



BLR is point-like → PSF



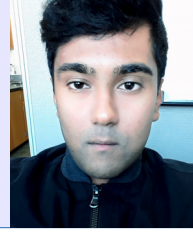


broad [OIII] PSF-like

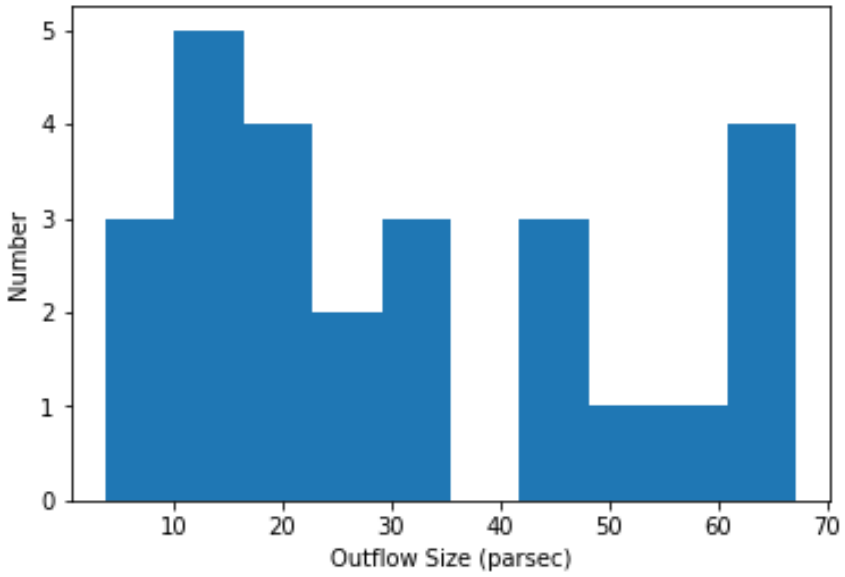
centroid shifted by ~0.15”

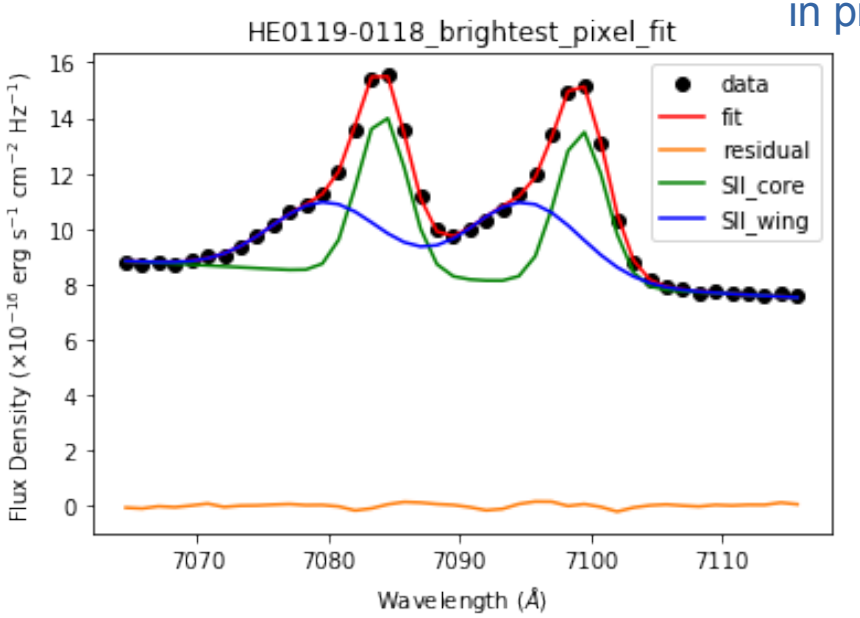
Flux mapping of [OIII]→ Spectroastrometry

Precision outflow energetics



Singha et al. in prep.





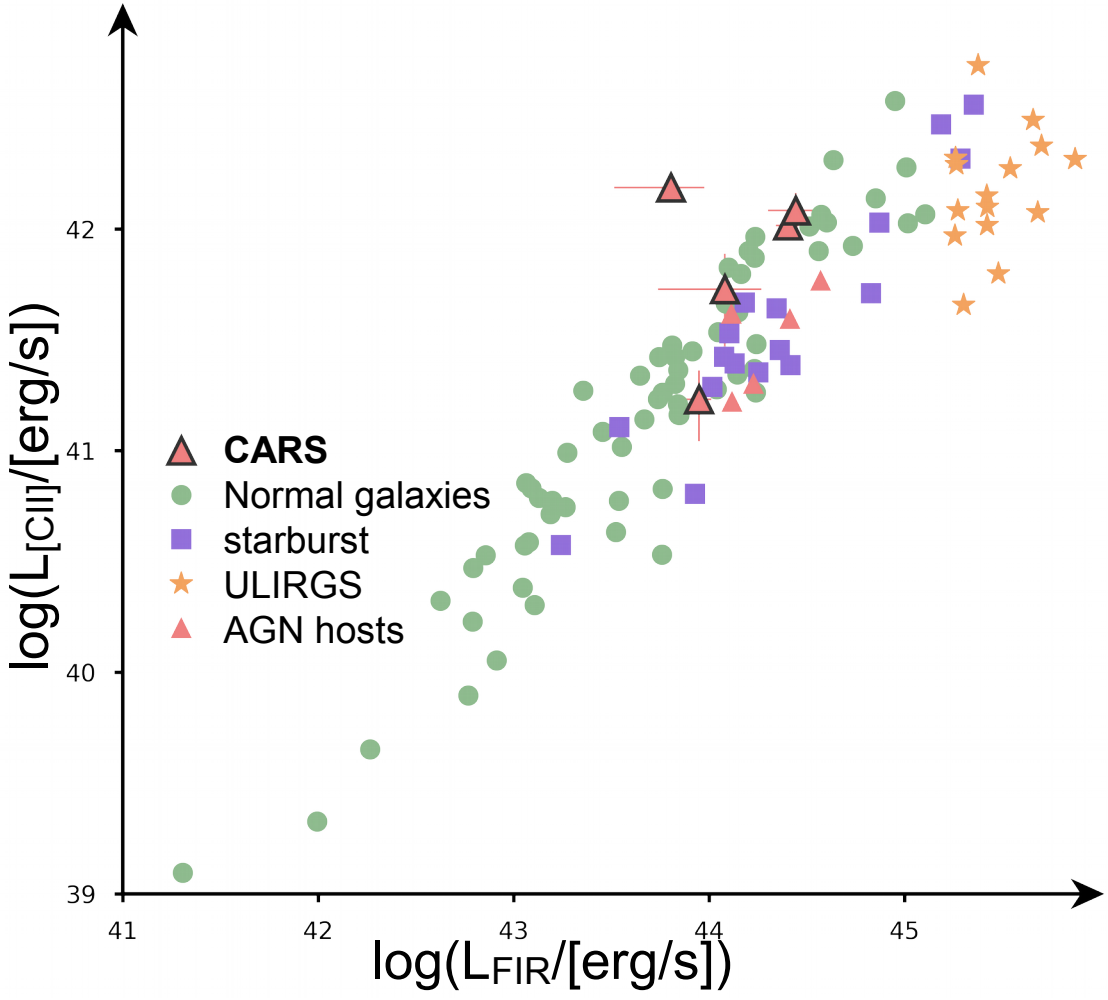
- Offsets <100pc except one case
- >90% of broad [OIII] flux is point-like
- very similar to HST studies

- Broad and narrow [SII] resolved in many cases
- n_e(broad [OIII])~2000cm^{-3}
- n_e(narrow [OIII])~200cm^{-3}

→ typical outflow rates of the order of 5$M_\odot$/yr (at R~50pc)

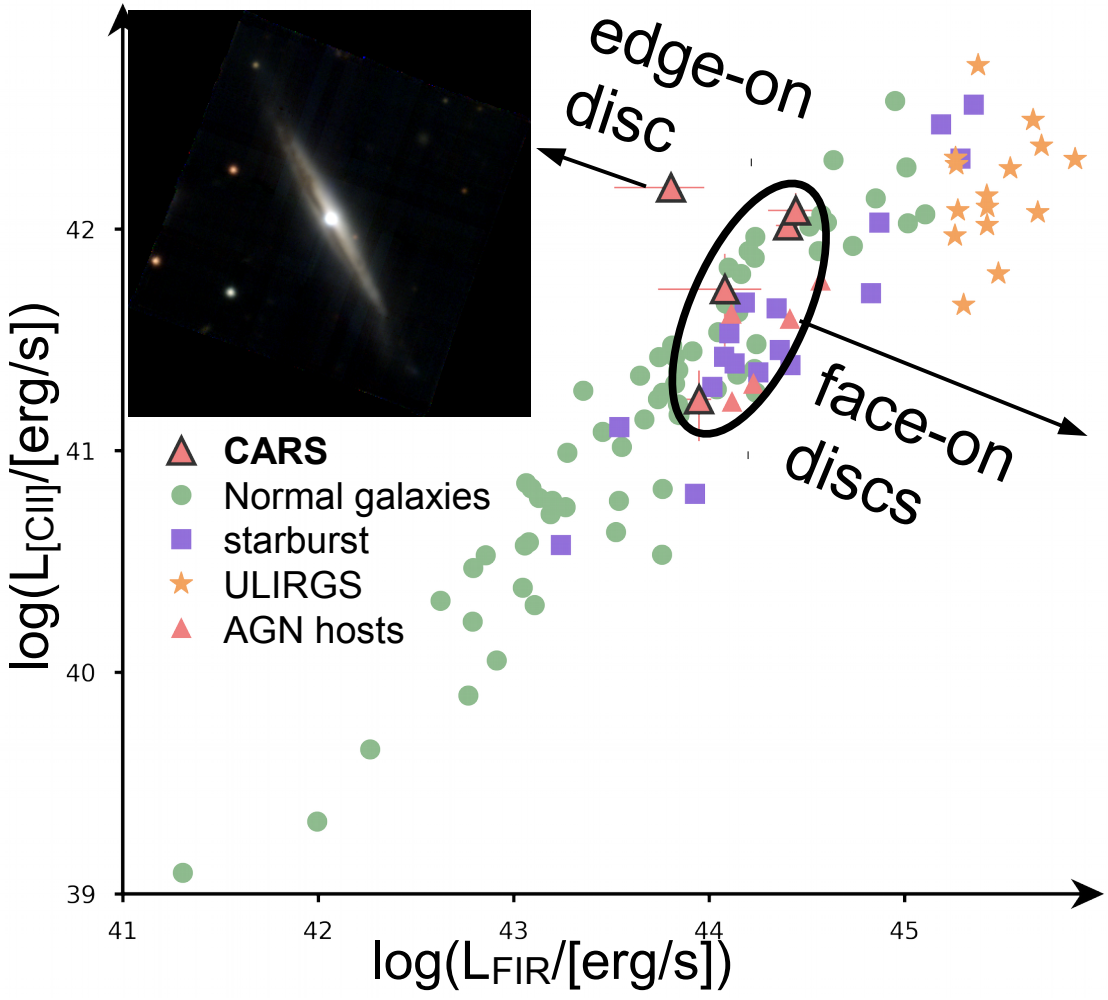
[CII] as a star formation rate tracer?

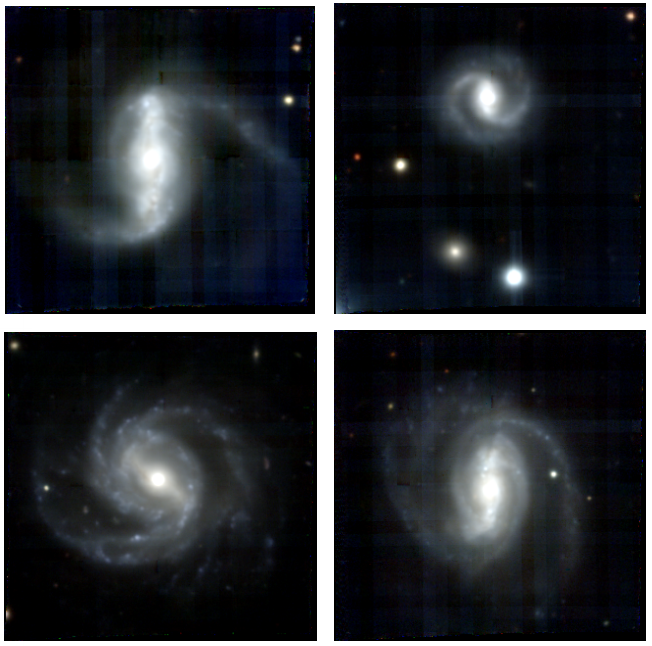
Sirmova-Pinchukova et al. in prep.



[CII] as a star formation rate tracer?

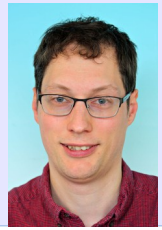
Sirmova-Pinchukova et al. in prep.



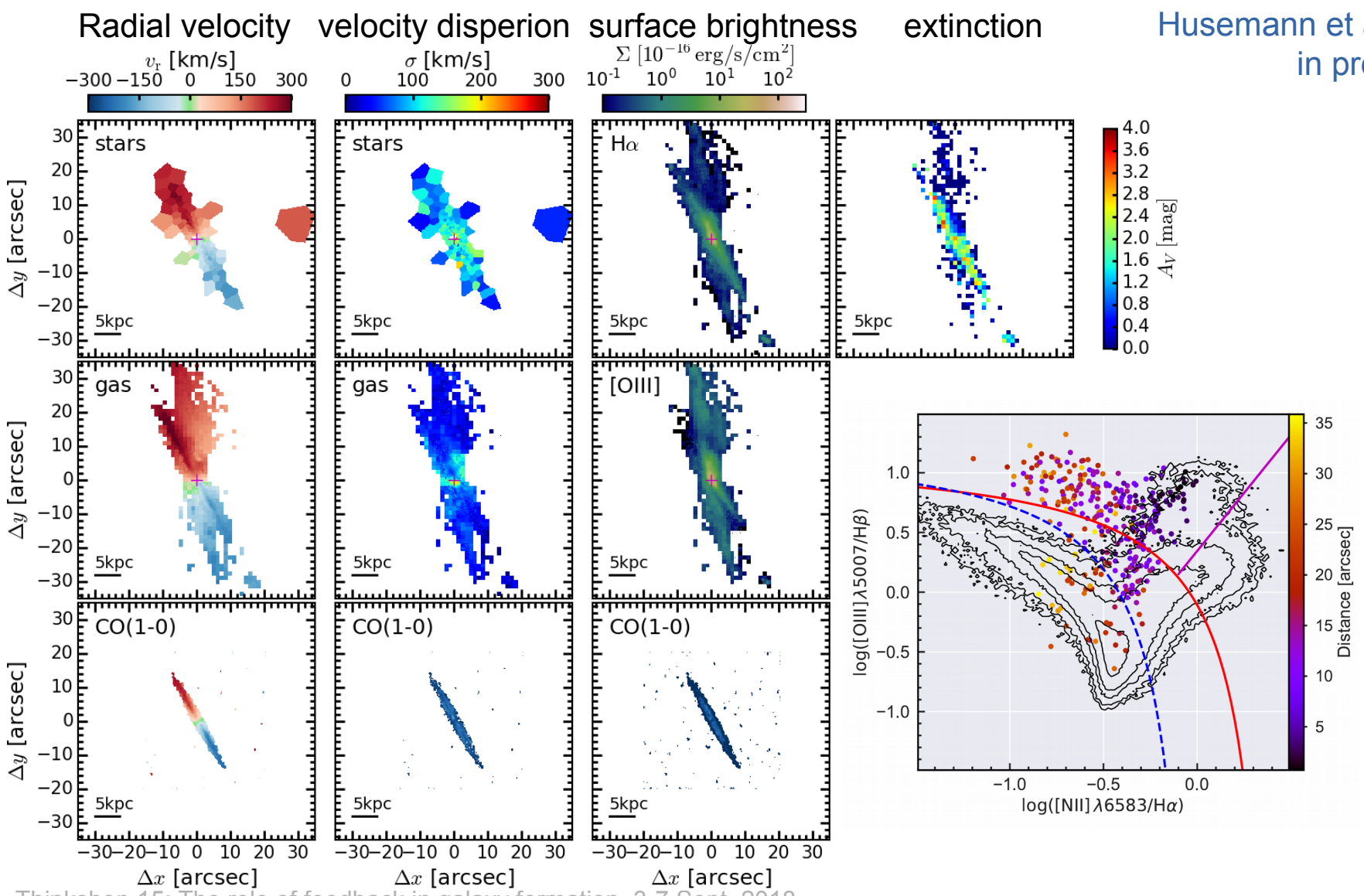


Full AGN luminosity impacts on disc → strongest feedback?

Mapping the multi-phase gas



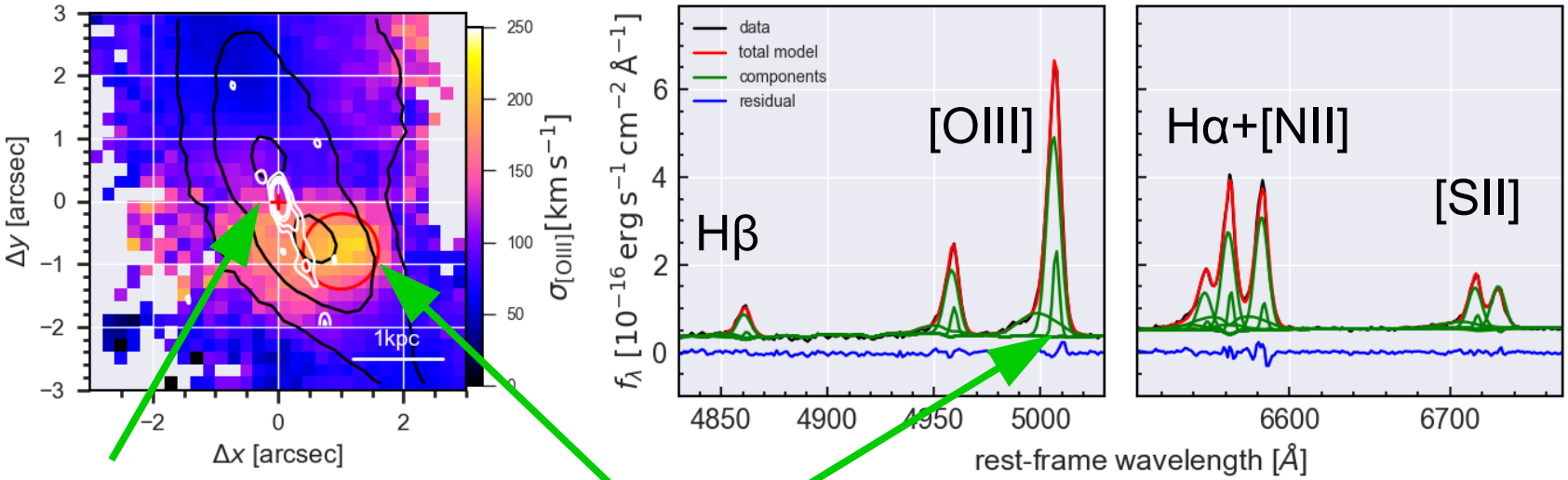
Husemann et al.
in prep.



Anatomy of an AGN outflow

Husemann et al. in prep.

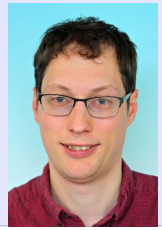
Ionized gas



Radio jet

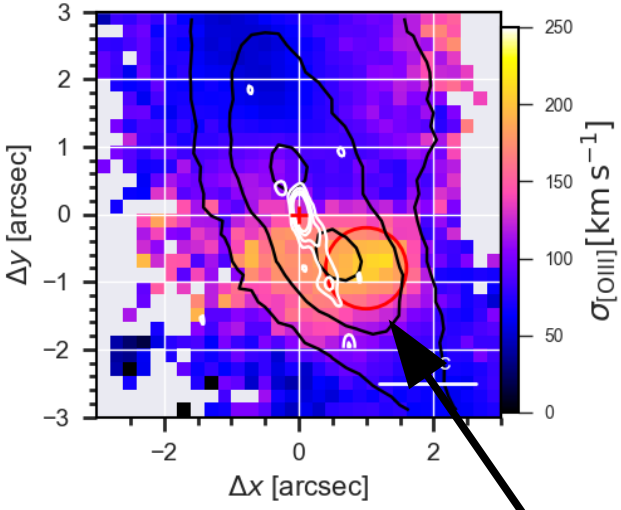
“hot spot” with multiple line components
Broad component ~1000km/s FWHM

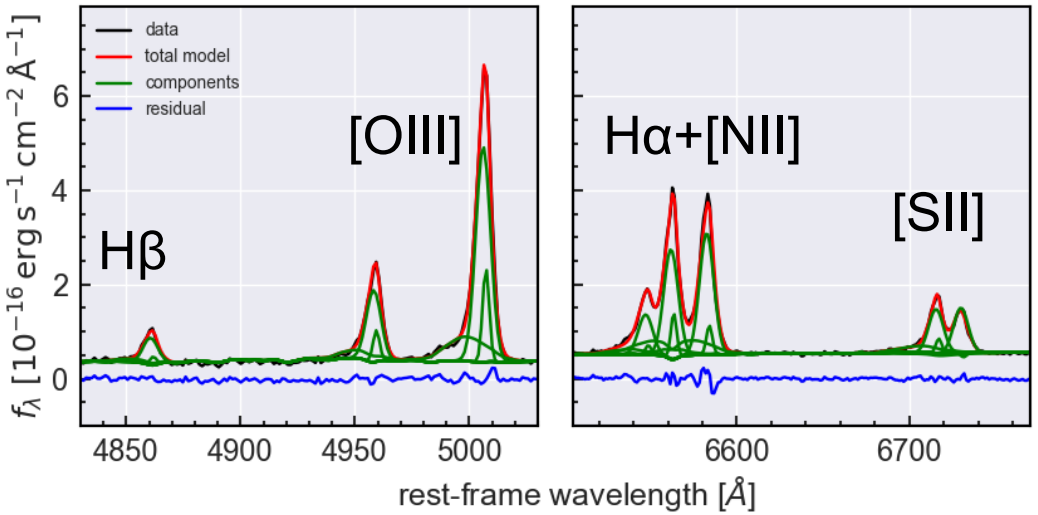
Anatomy of an AGN outflow



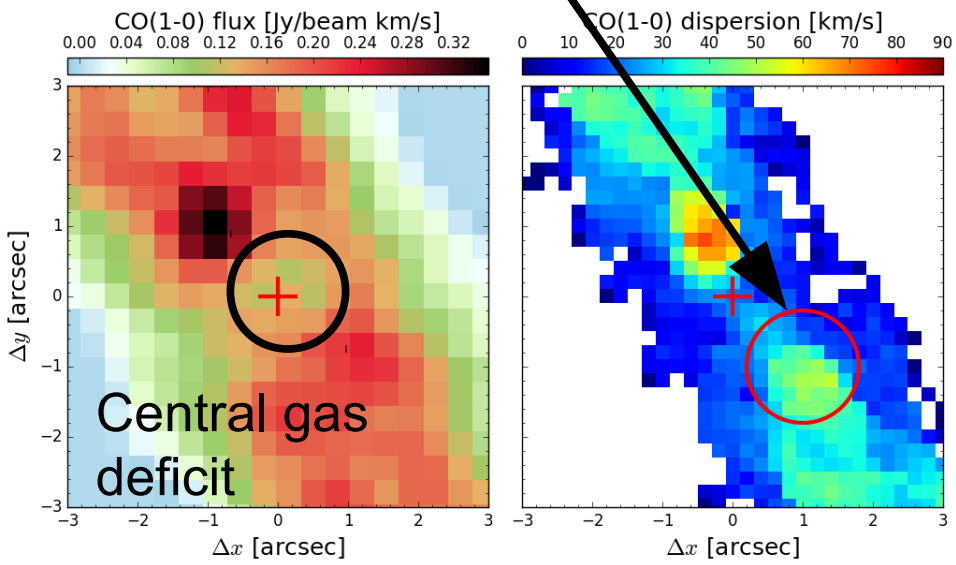
Husemann et al. in prep.

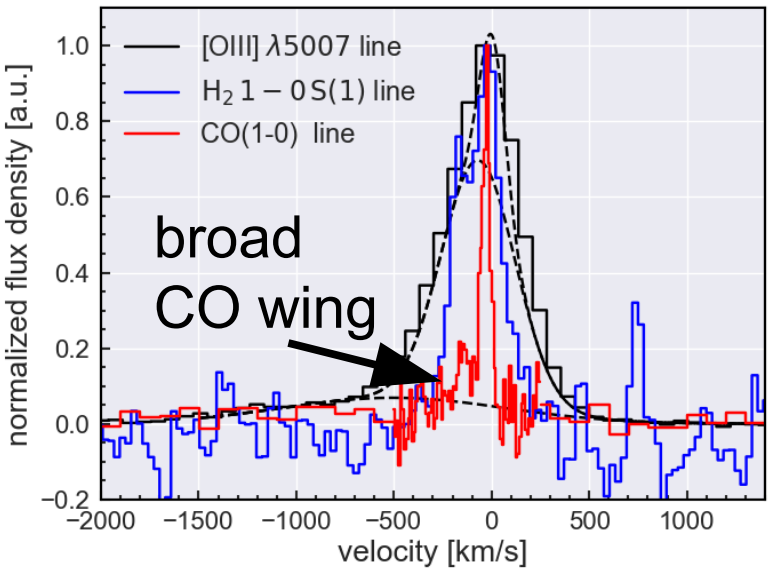
Ionized gas





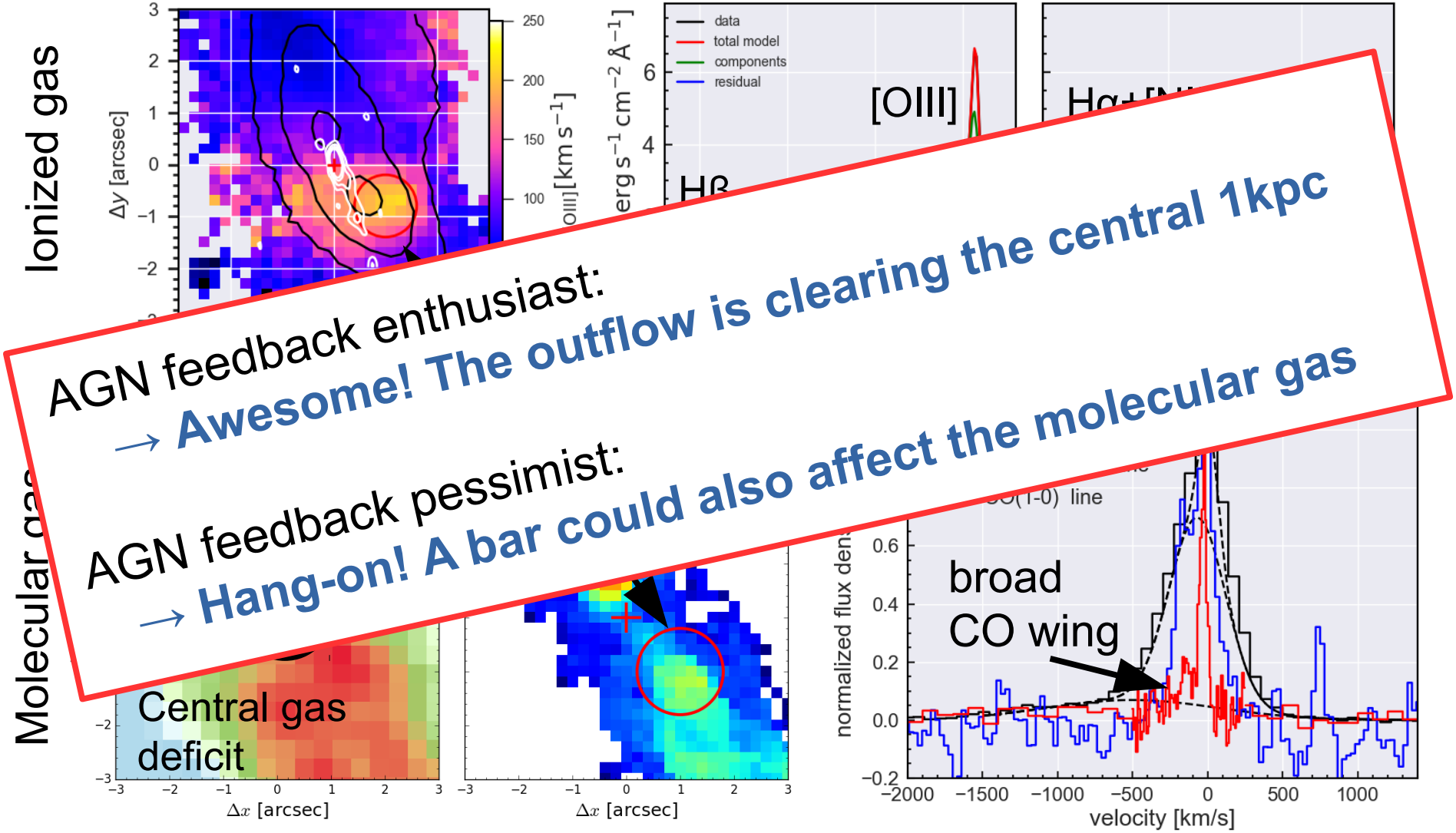
Molecular gas



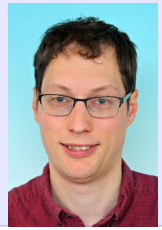


Anatomy of an AGN outflow

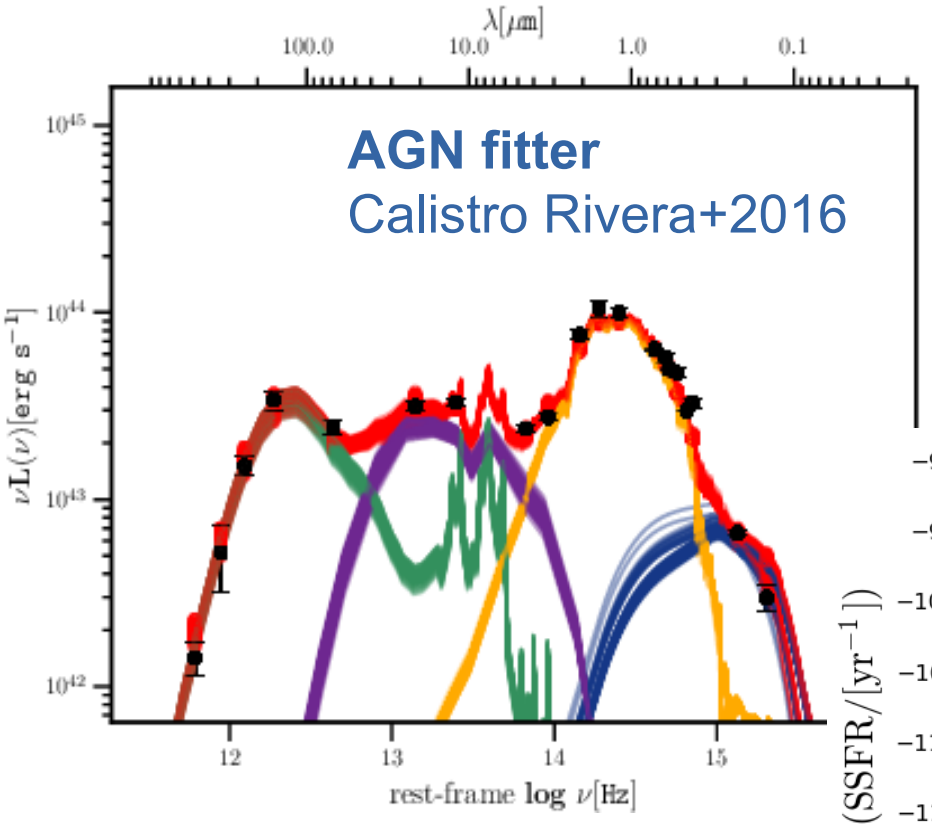
Husemann et al. in prep.



Direct evidence for AGN feedback?



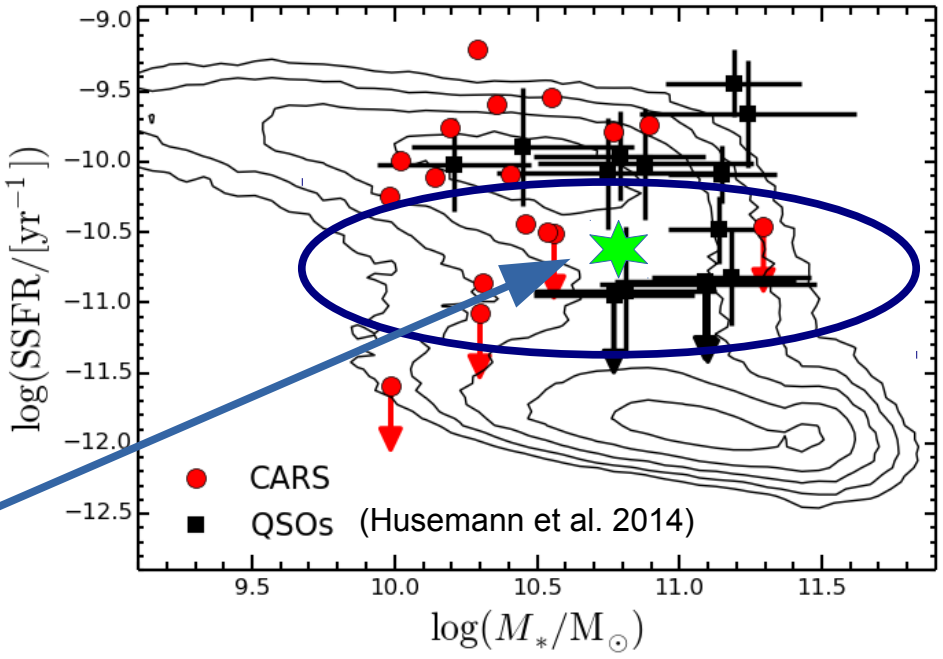
Husemann et al. in prep.



log M_*=10.80±0.05$M_\odot$

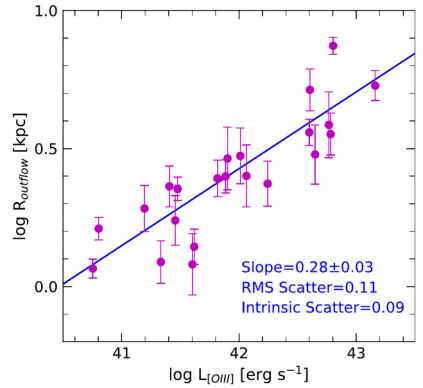
SFR(IR)=2.1±0.3$M_\odot$/yr

SFR(Hα)=1.2±0.2$M_\odot$/yr

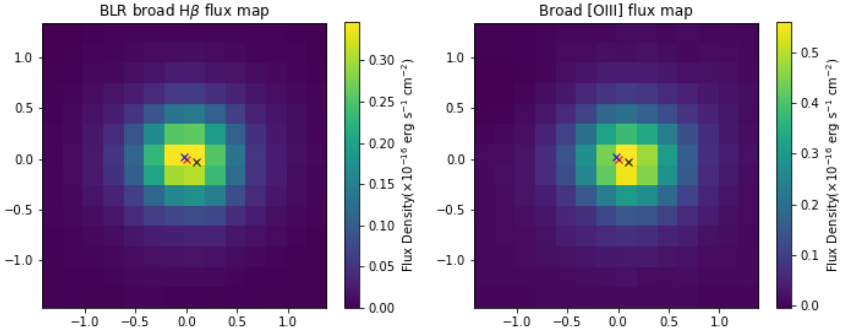


In the quenching phase?

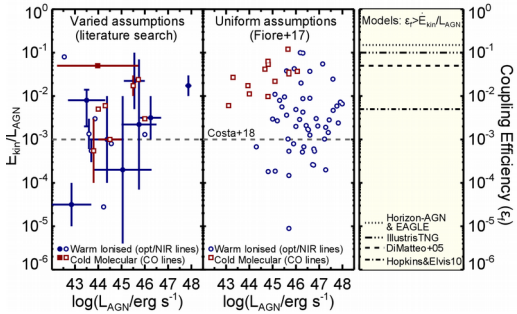
Conclusions



Ionized gas outflows are common in AGN and their size scale with luminosity



Beaware of beam smearing improved analysis needed



Outflow energetics very uncertain with impact of radio jets unclear

Many systematic multi-wavelength IFU surveys are currently ongoing

CLOSE AGN REFERENCE SURVEY