Extragalactic Spectroscopic Surveys: Past, Present and Future of Galaxy Evolution (GALSPEC2021)

“Virtual” Santiago — 12-16 Apr, 2021

MAGNUM survey: dissecting galactic outflows in nearby AGN with VLT/MUSE

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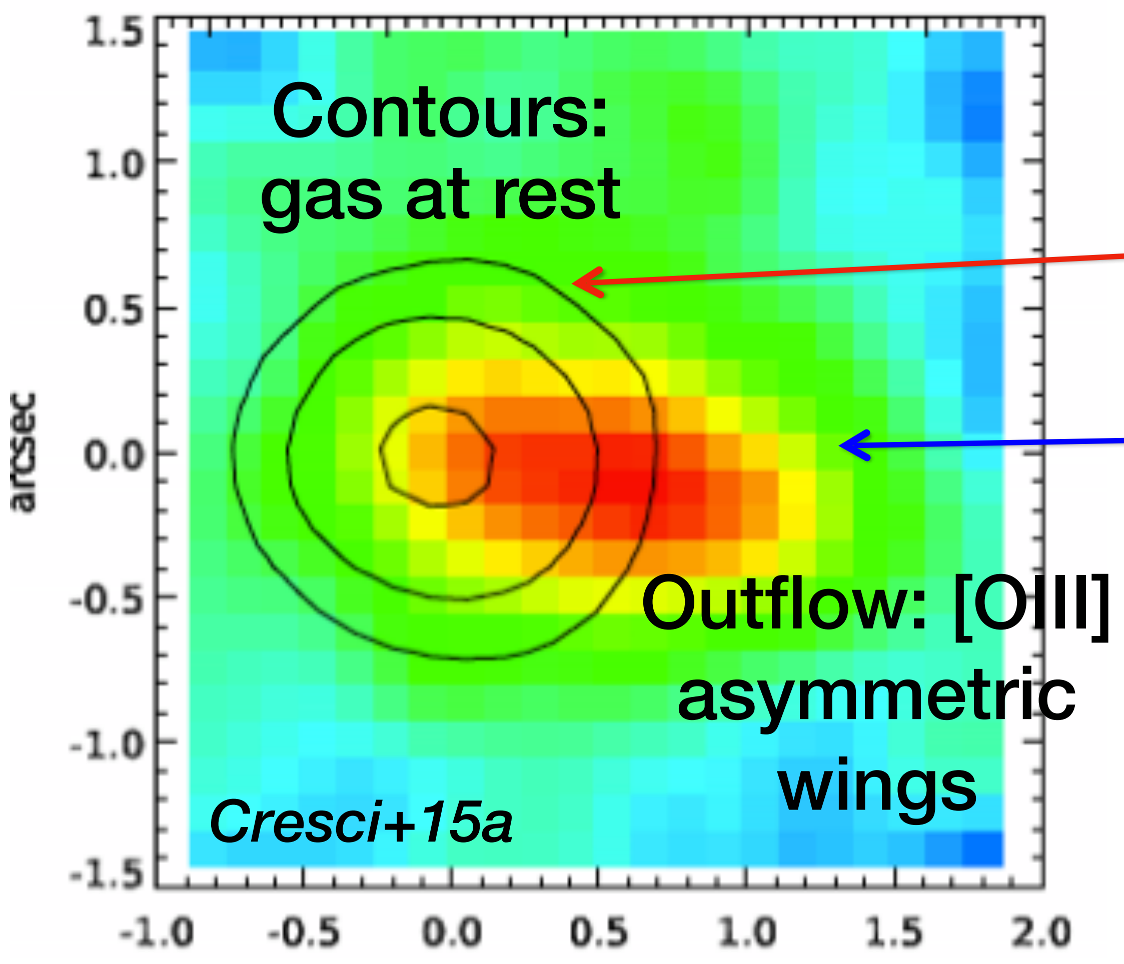
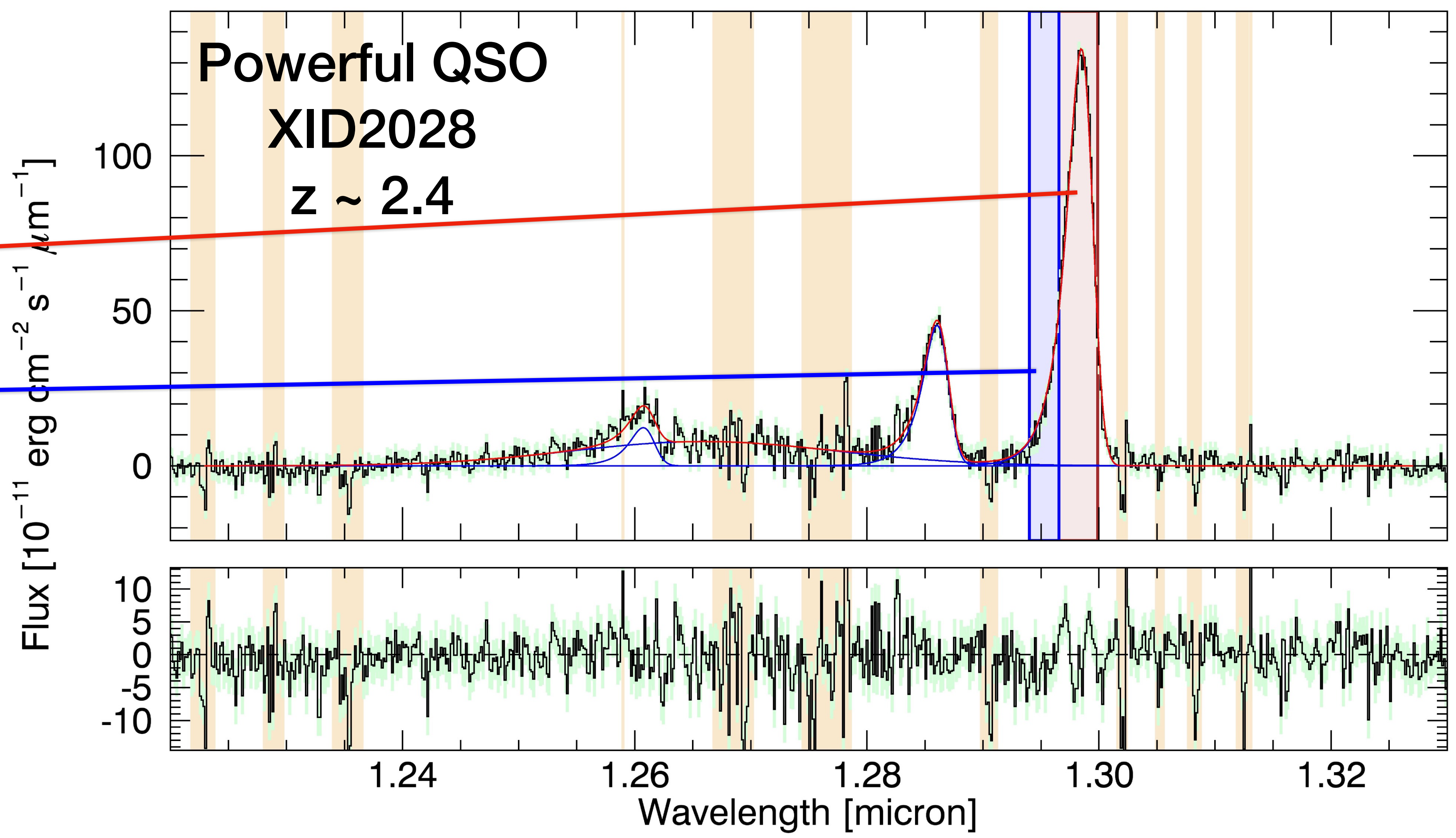
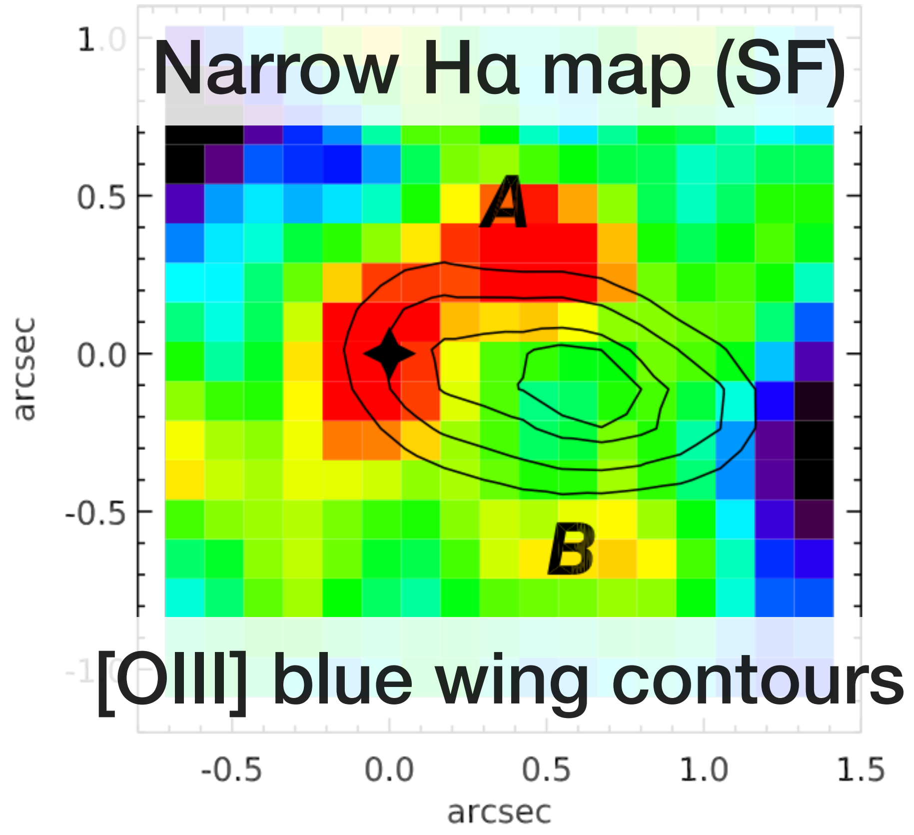
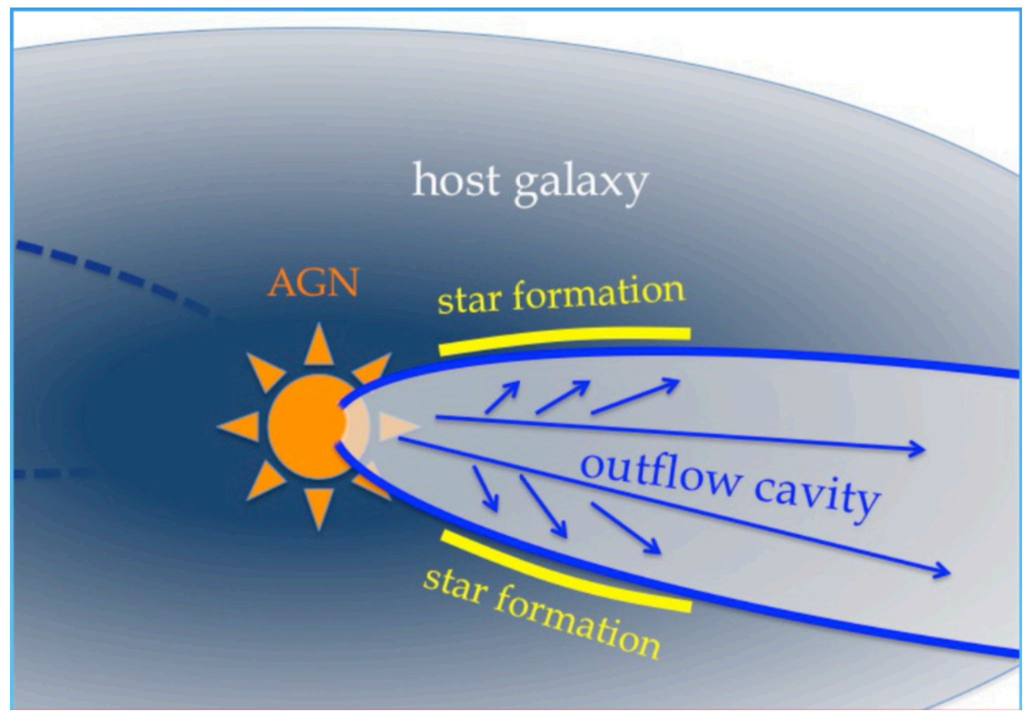
AGN FEEDBACK

AGN are thought to exert feedback on host galaxies through outflows, radiation, jets…







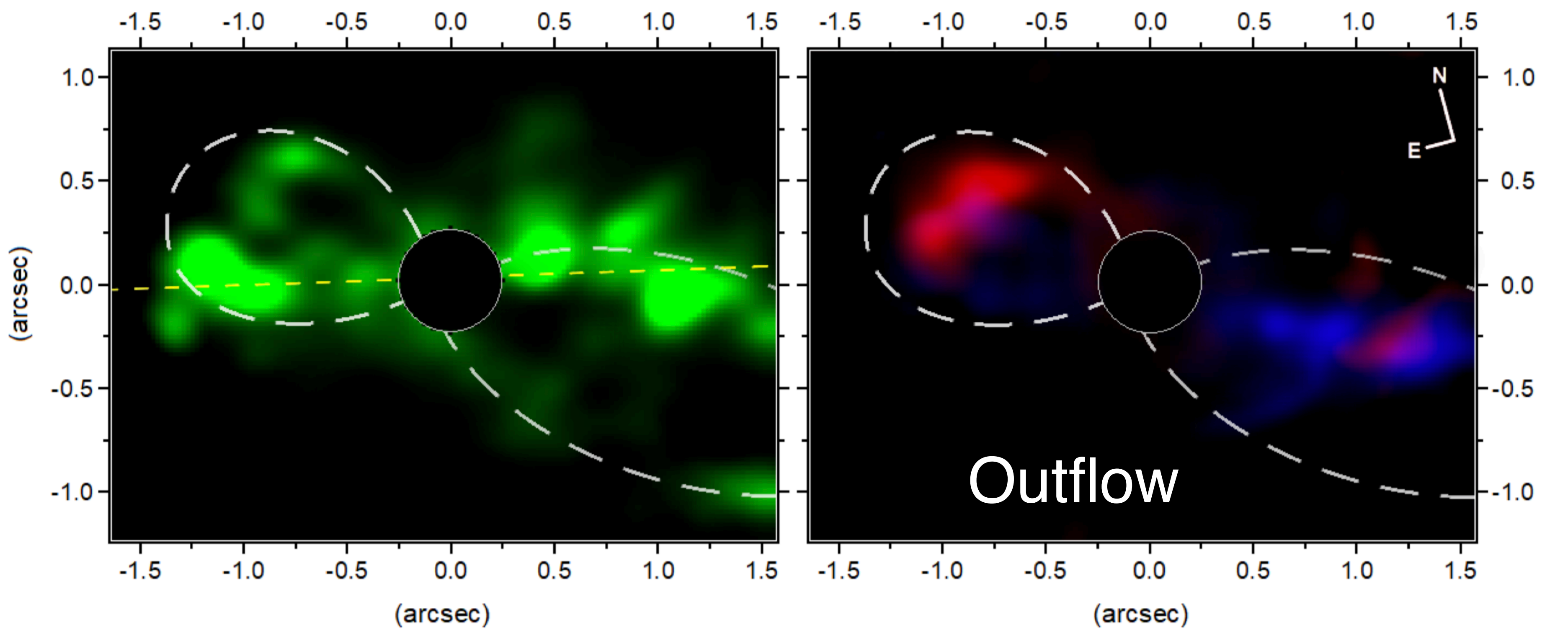


Actual impact of AGN feedback and how it operates are still hot and debated topics!

(See e.g. Maiolino+12, Cano-Diaz+12, Cicone+14, Harrison+14,16, Carniani+15,16,17, Wylezalek+16,20, Fiore+17, Bischetti+17,18, Brusa+18, Forster-Schreiber+18,19, Leung+19, Scholtz+20, Fluetsch+19,20)

However, low-resolution at high-z makes difficult to study in detail feedback and outflow physical properties and compare with models, due to many uncertainties involved

➔ Nearby AGN allow to spatially resolve outflow+galaxy structure to study feedback and outflow properties and structure in detail

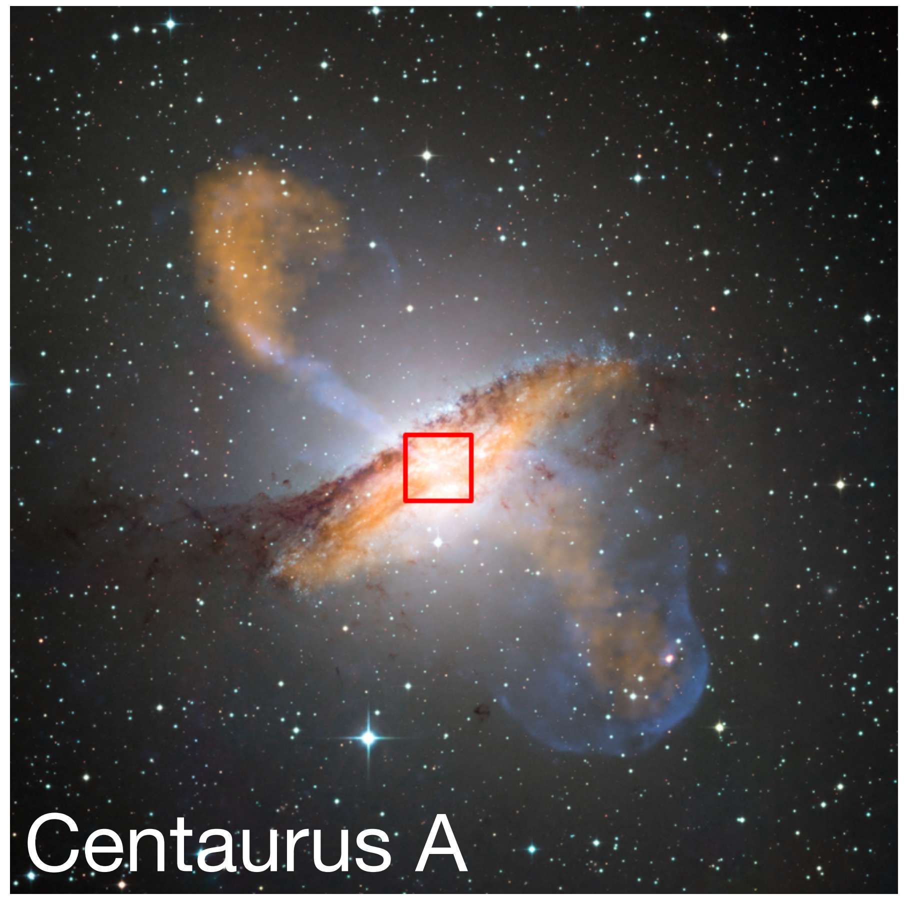


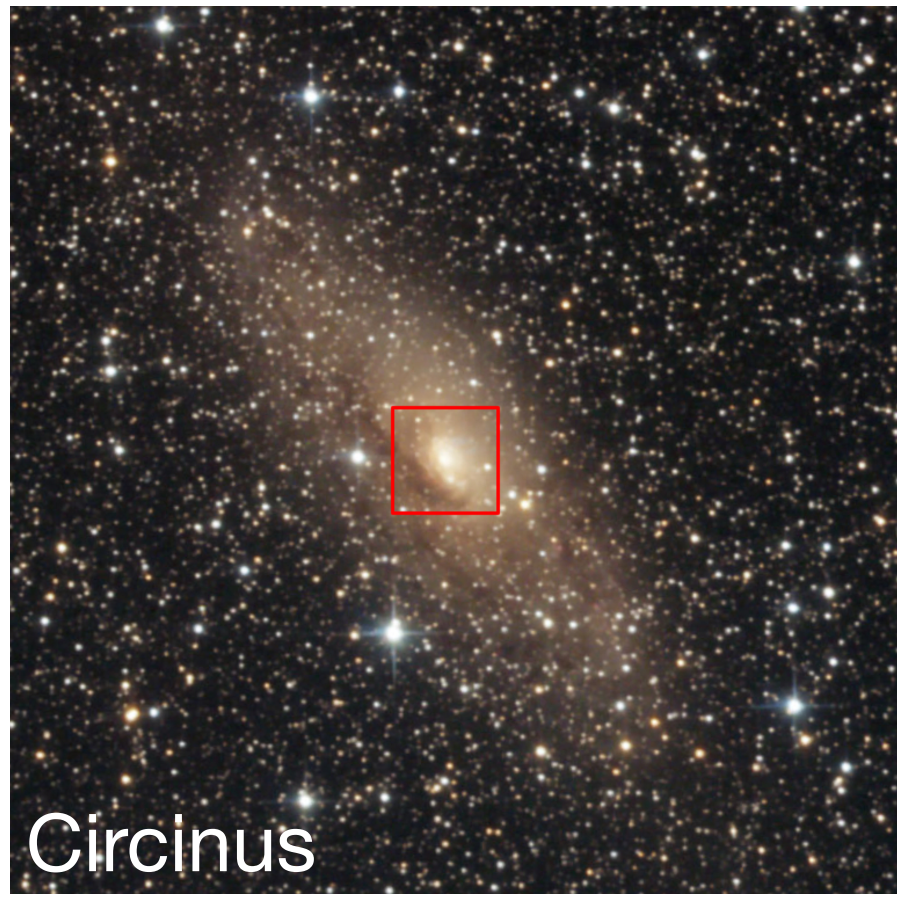
e.g. May+2020

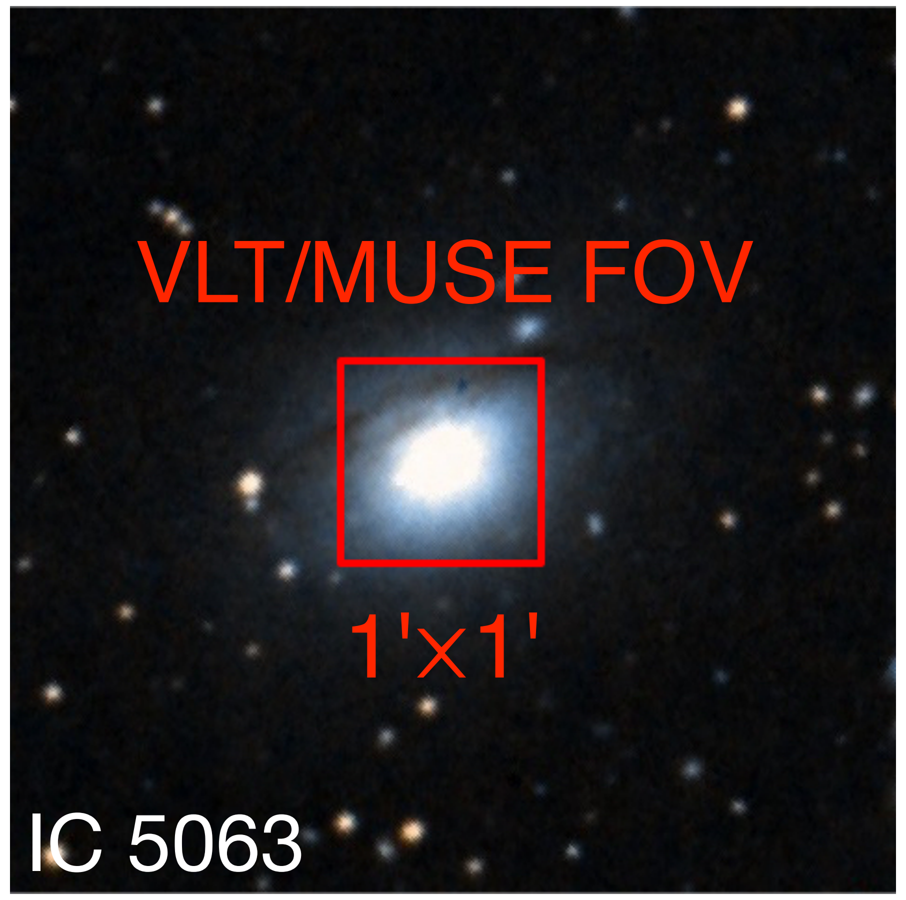
MAGNUM SURVEY OF NEARBY AGN

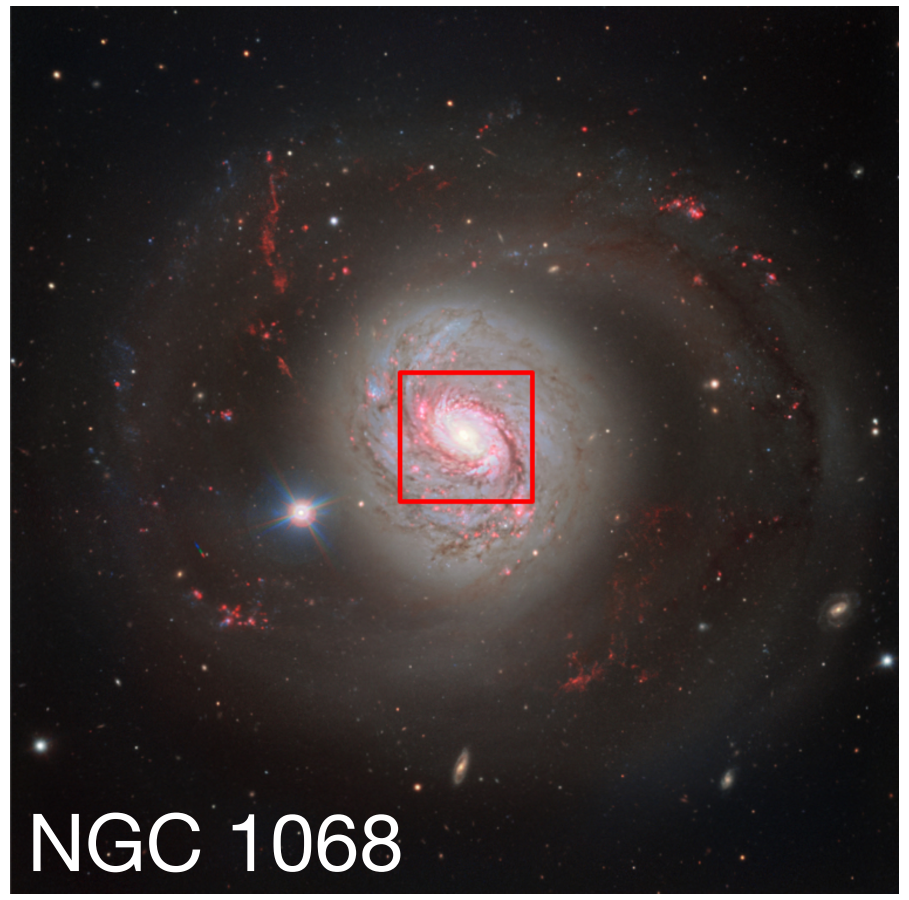
Nearby (*D*<50 Mpc) Seyferts (9 so far) with VLT/MUSE: high resolution 10-100 pc covering central 1-15 kpc

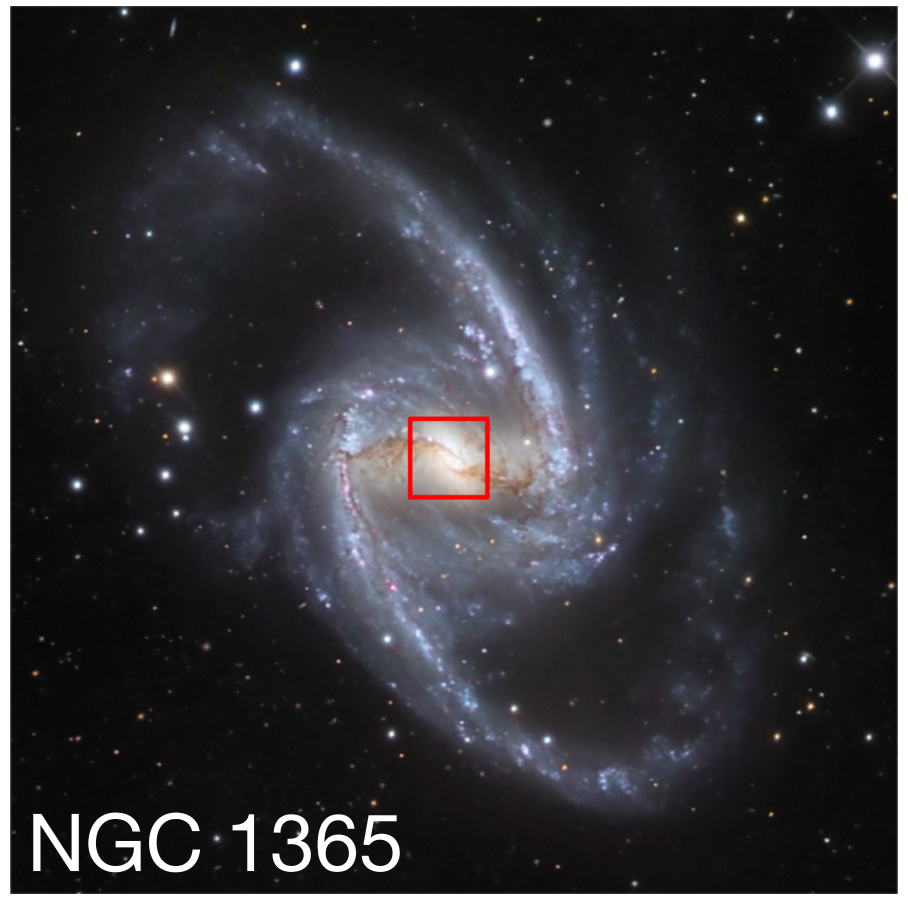
- *Gas kinematics*: outflows, inflows…
- *Gas excitation*: from AGN, stars, shocks…
- Map *outflow properties*: velocity, mass rate, energetics, density…
- Evaluate *impact of outflows on galaxy*, model comparison

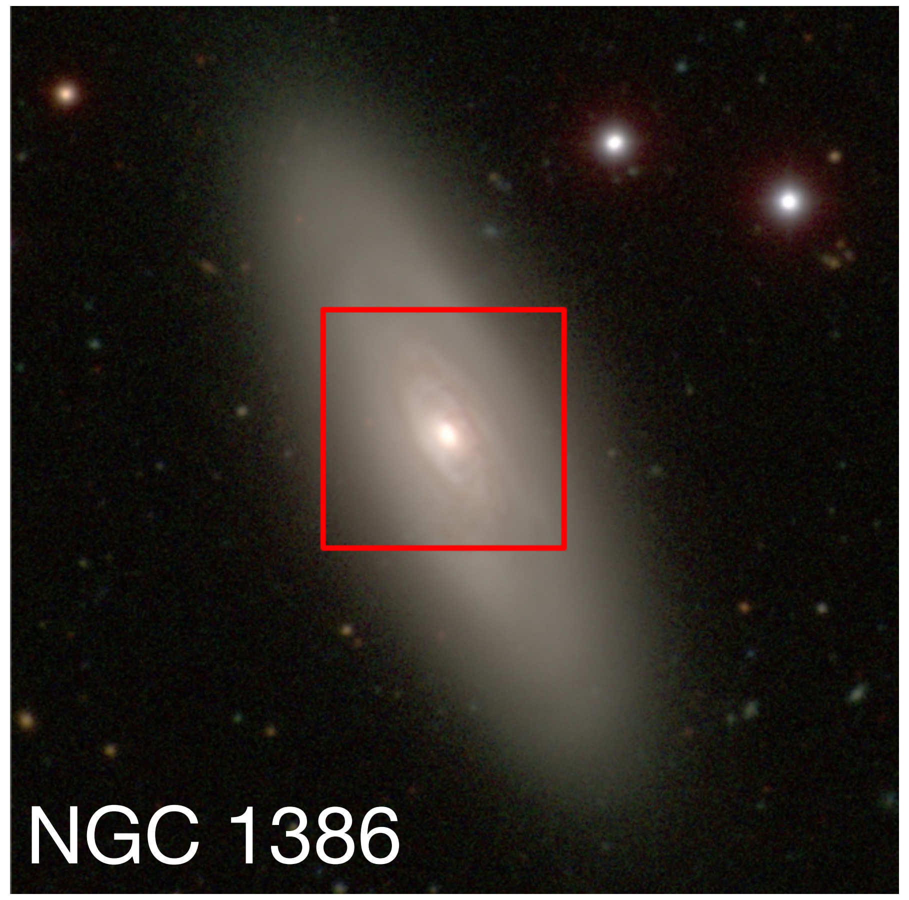


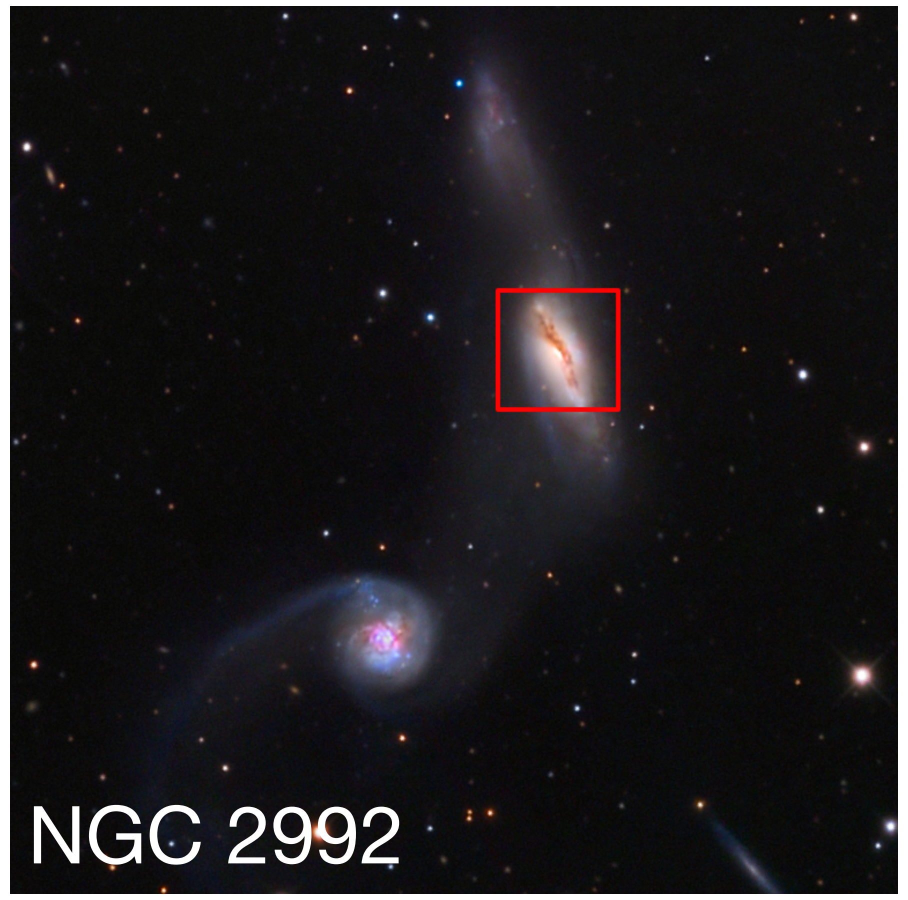


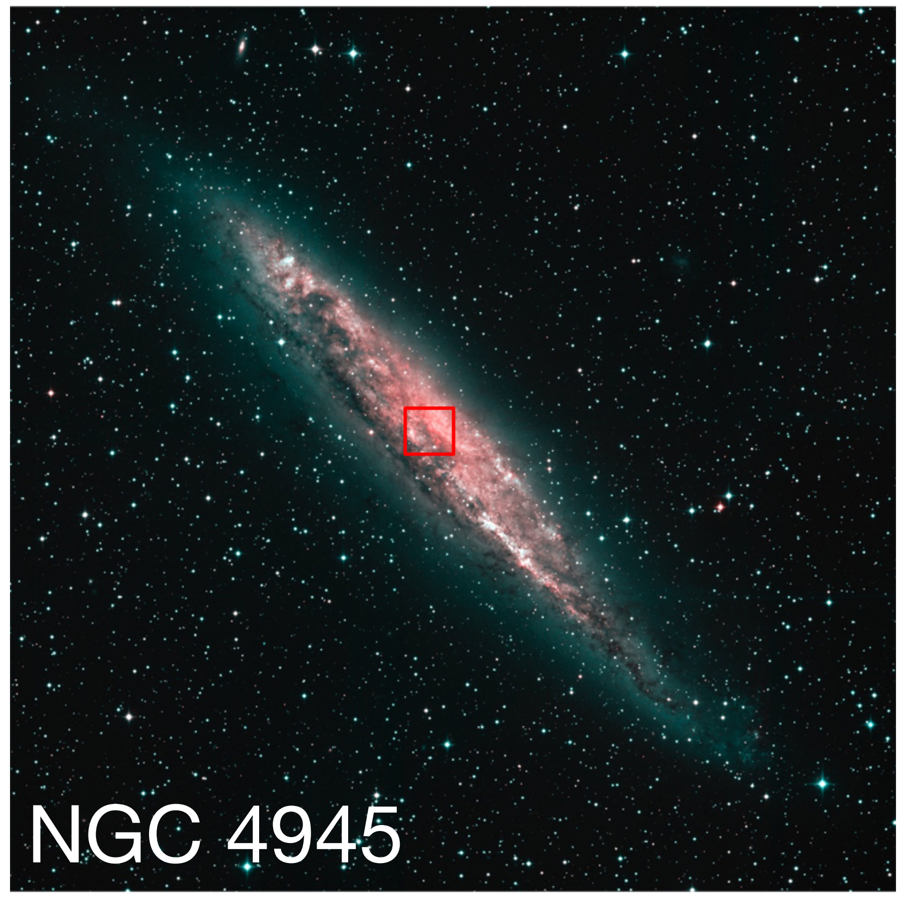


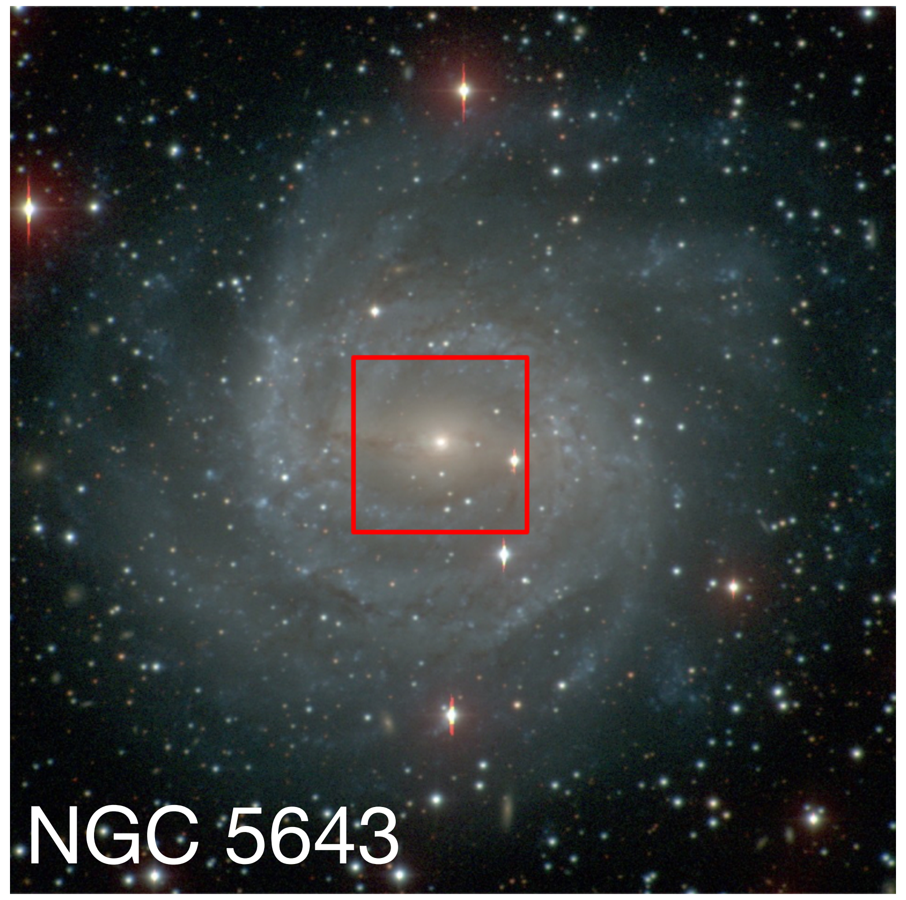












Publications:

Cresci+15,

Venturi+17,18,

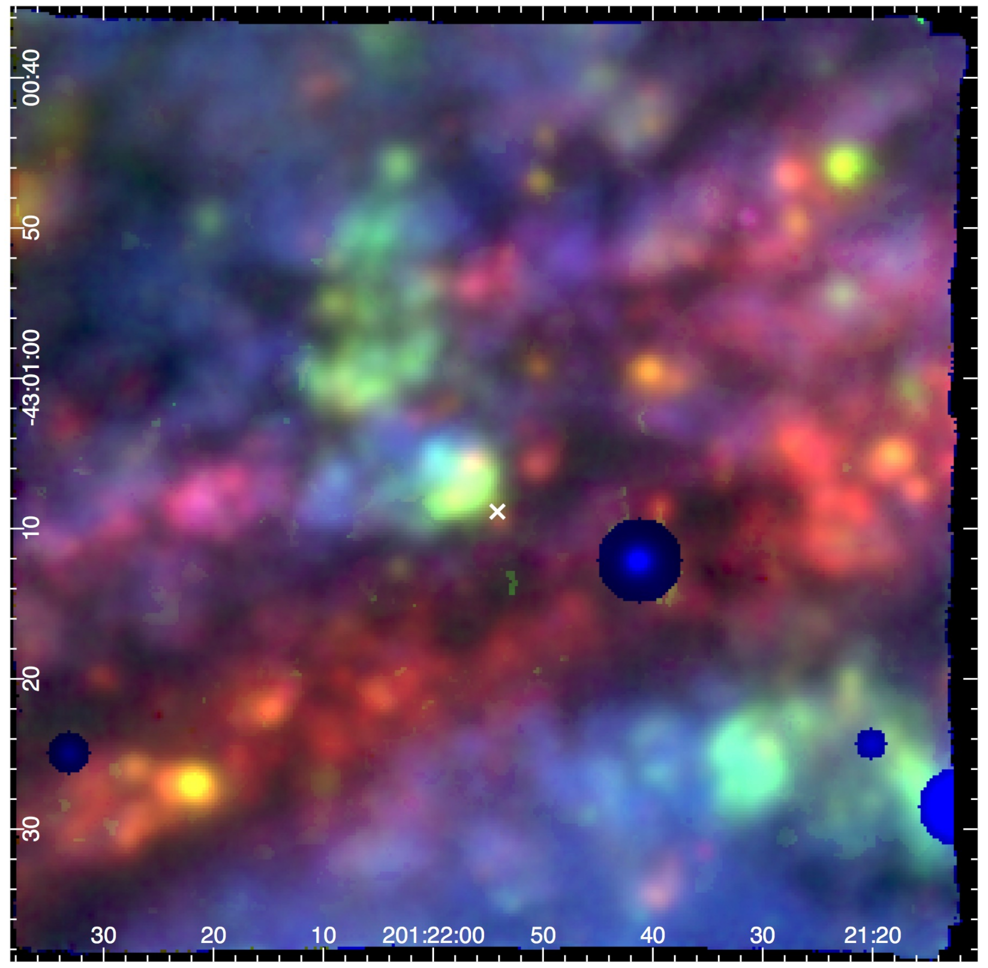
Mingozzi+19,

Venturi+20

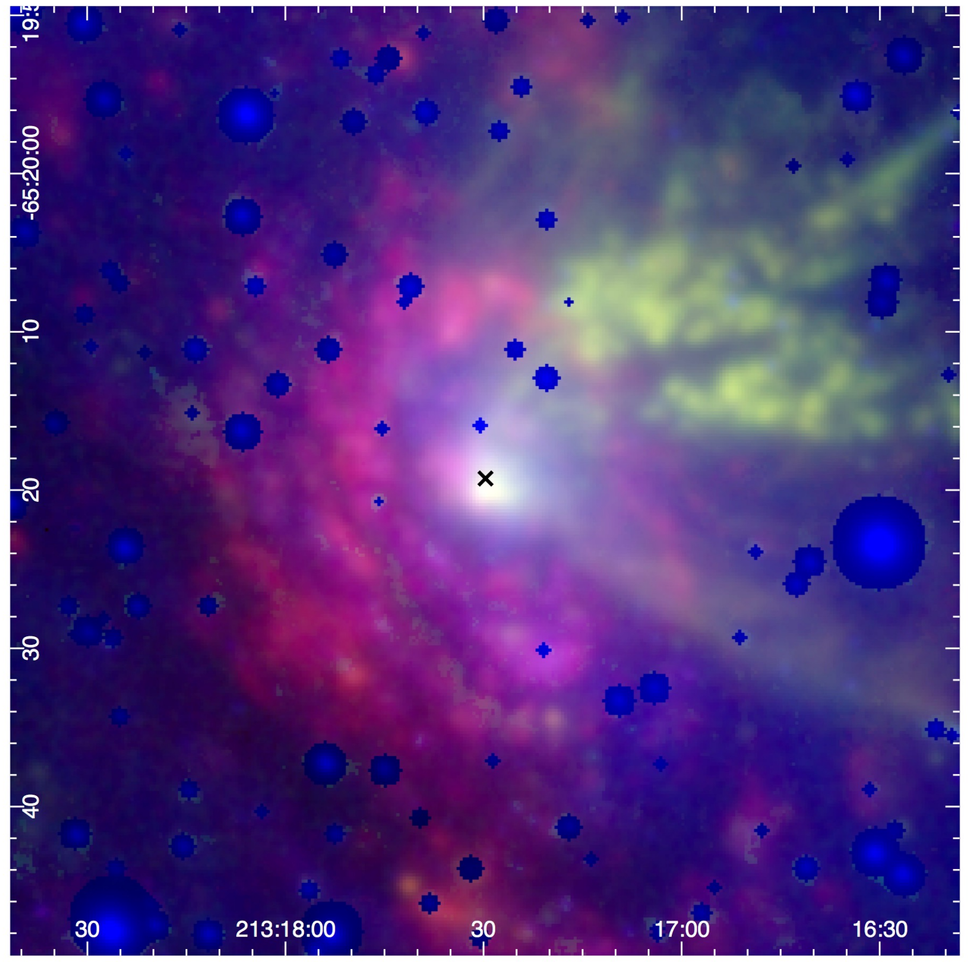
…and others coming

MAGNUM SURVEY OF NEARBY AGN

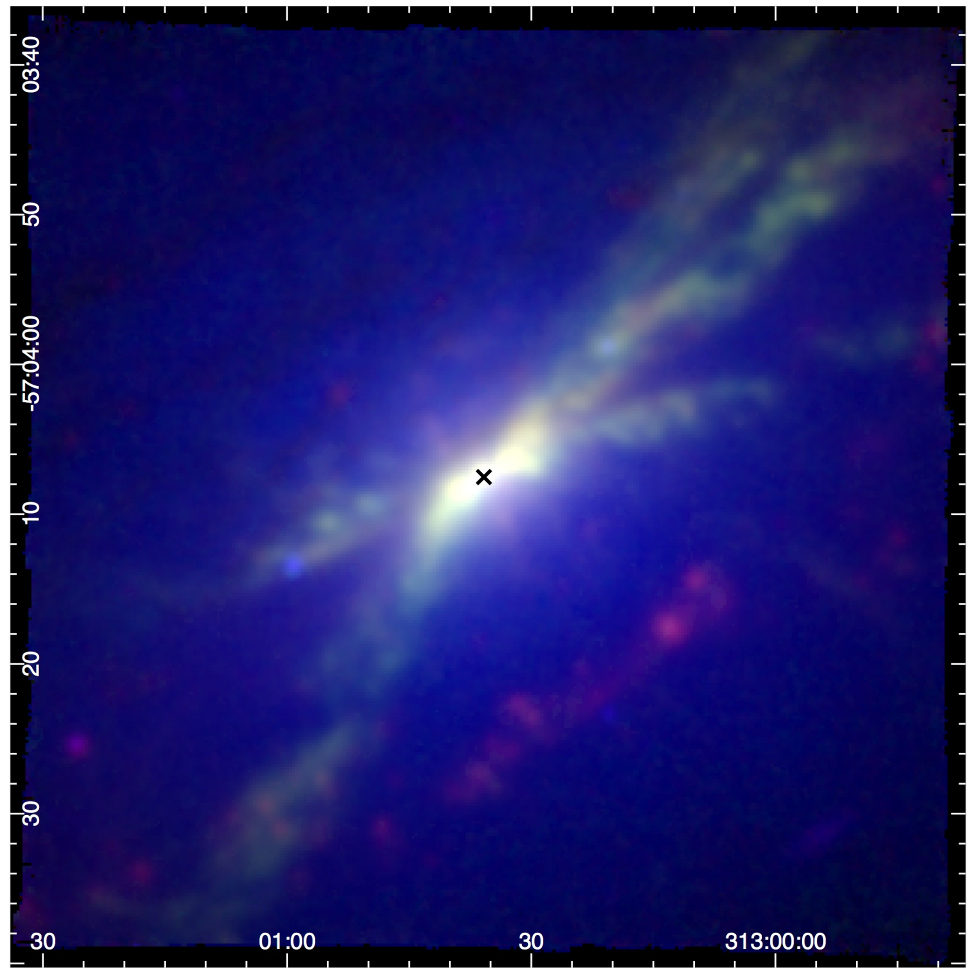
MUSE 3-color images:



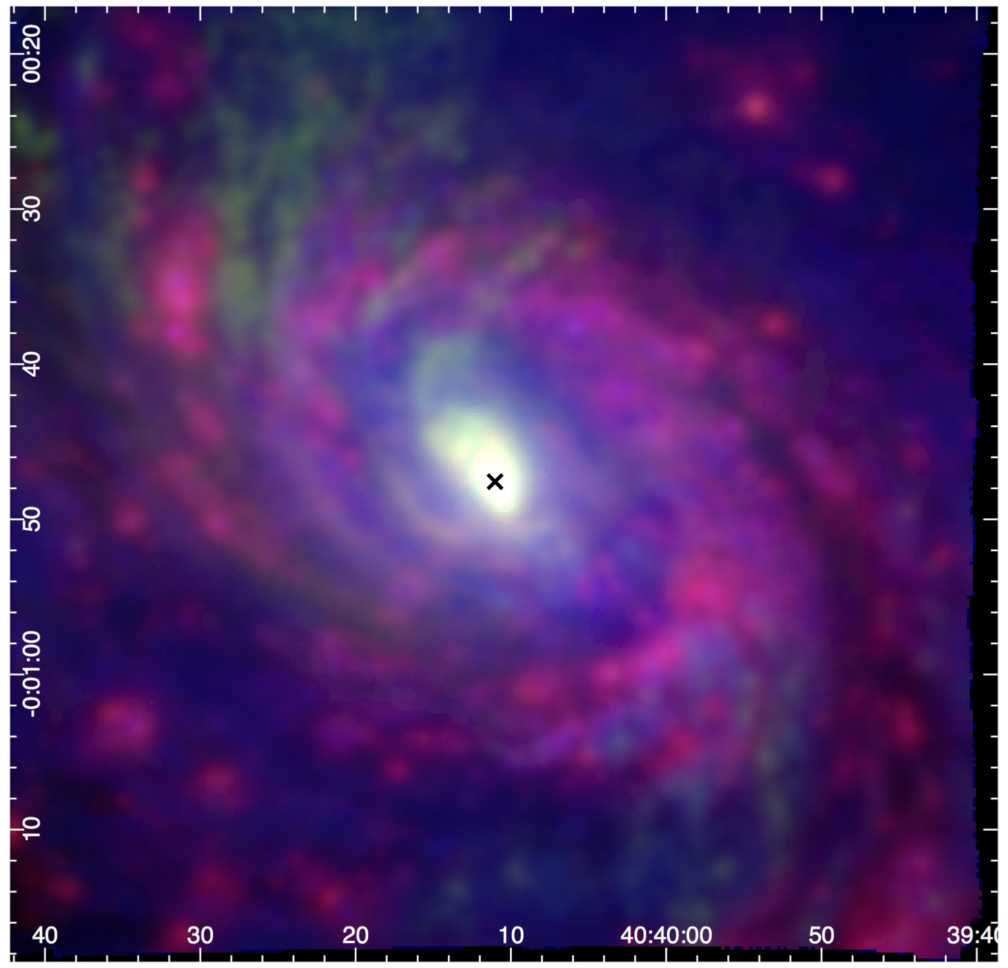
Centaurus A



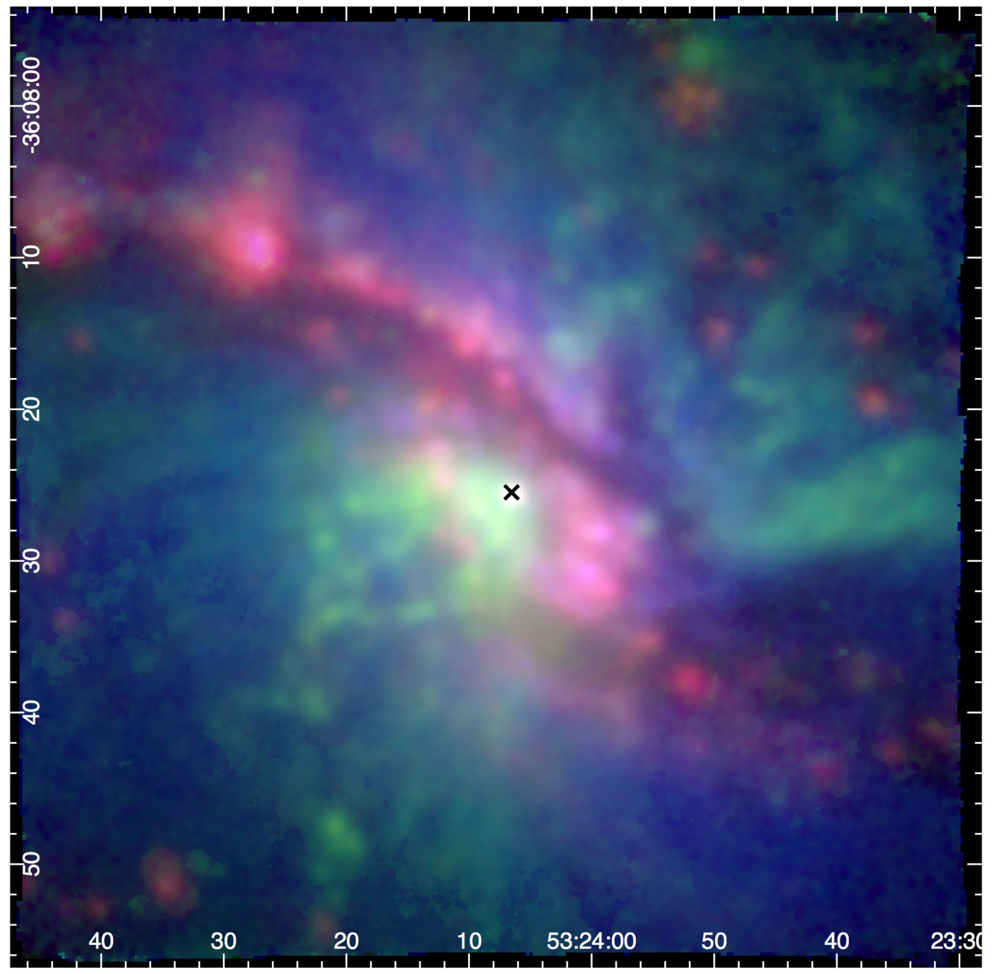
Circinus



IC 5063



NGC 1068



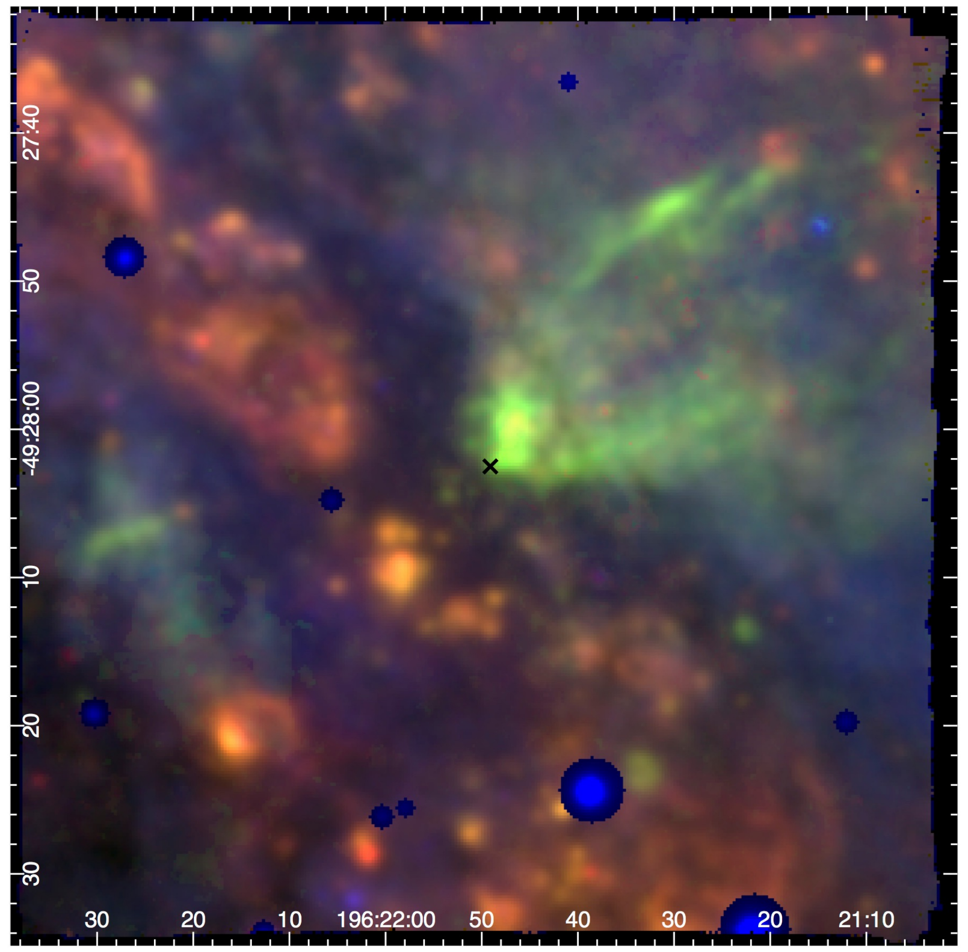
NGC 1365

[OIII]

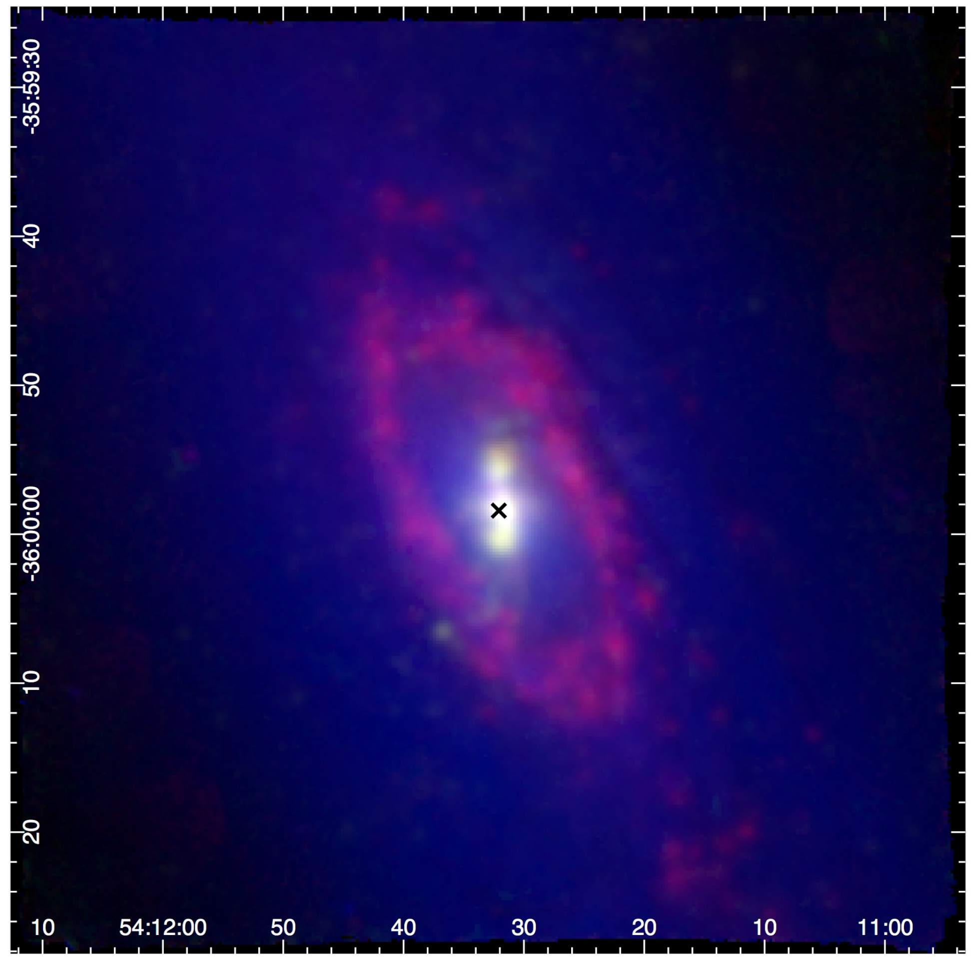
Hα

Blue stellar continuum

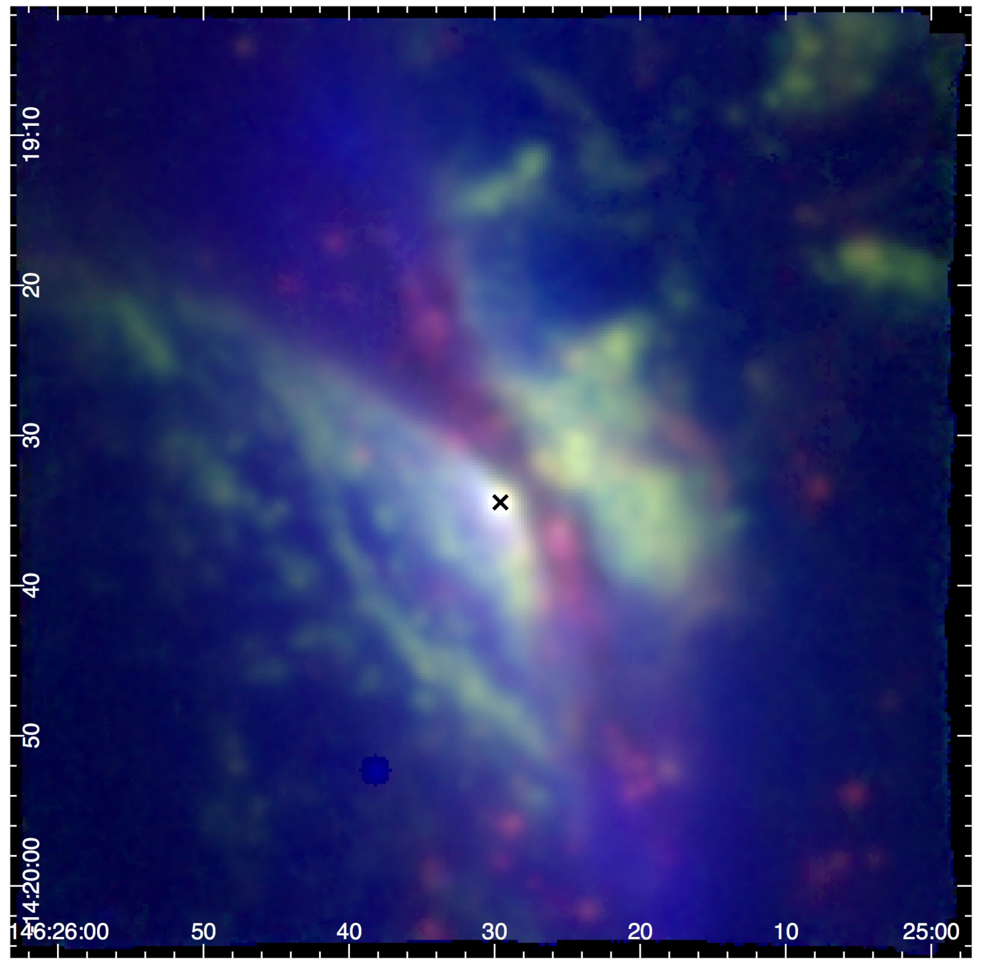
NGC 4945



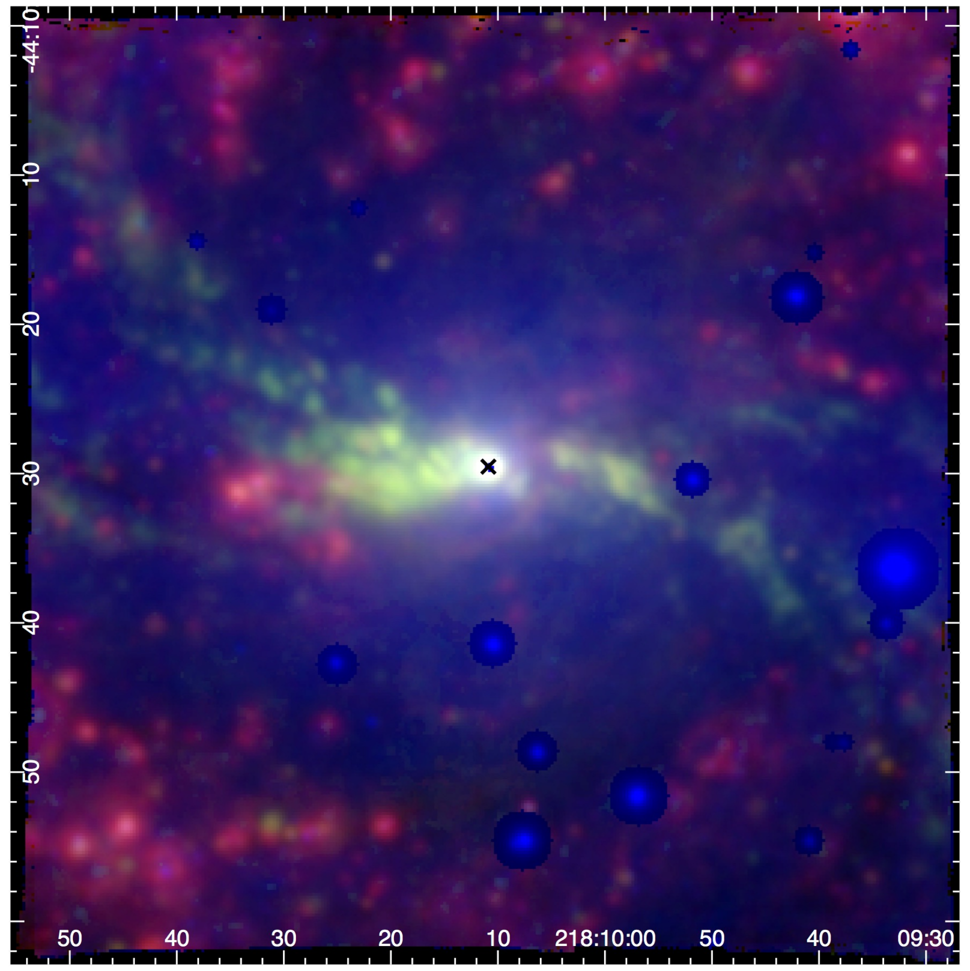
NGC 1386



NGC 2992



NGC 5643

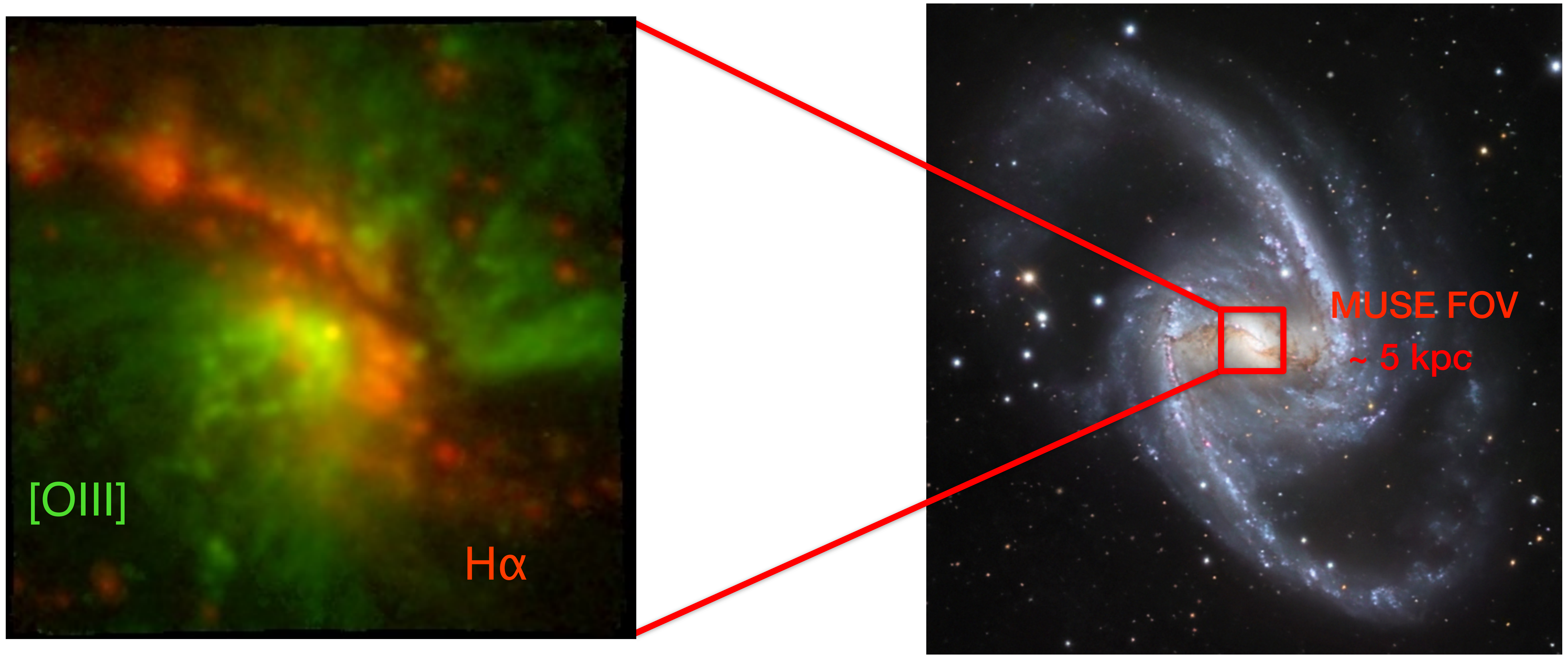


Detailed study of ionised gas outflow properties in central kpcs

of NGC 1365 through VLT/MUSE

(Venturi et al. 2018, 2018A&A...619A..74V)

NGC 1365: MAPPING BICONICAL OUTFLOW KINEMATICS

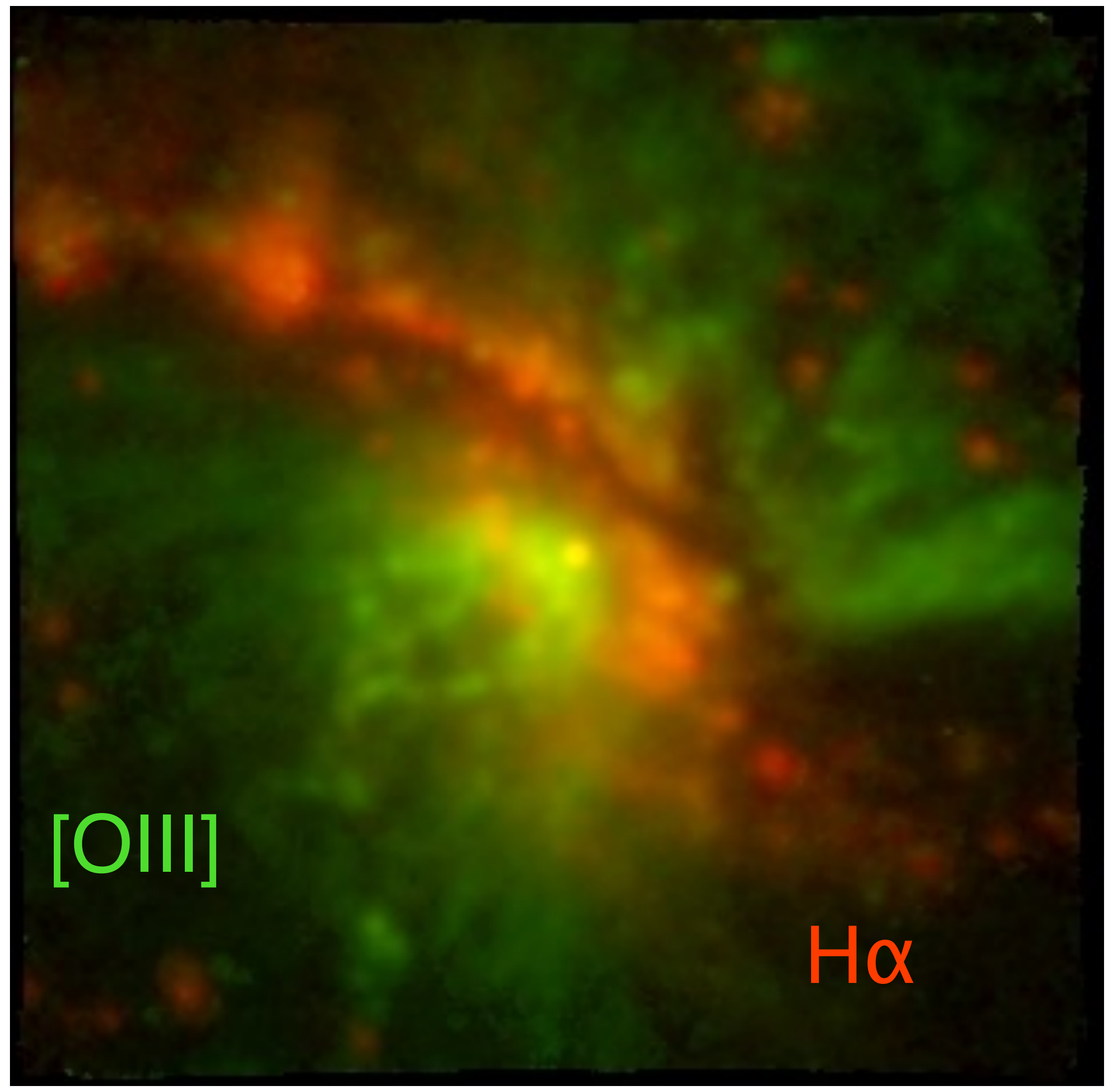


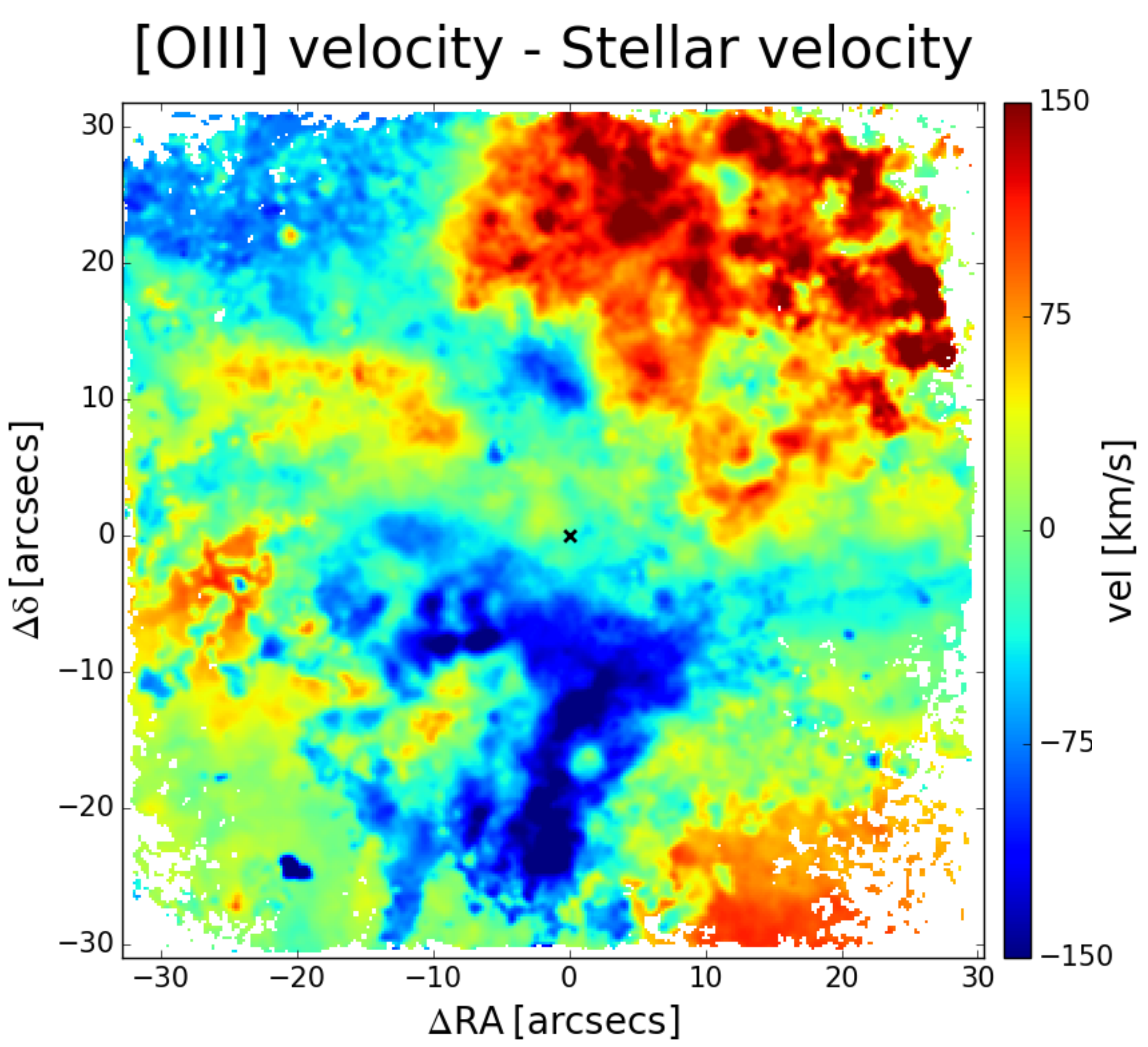
Massive barred galaxy (4×10^{11} $M_\odot$)

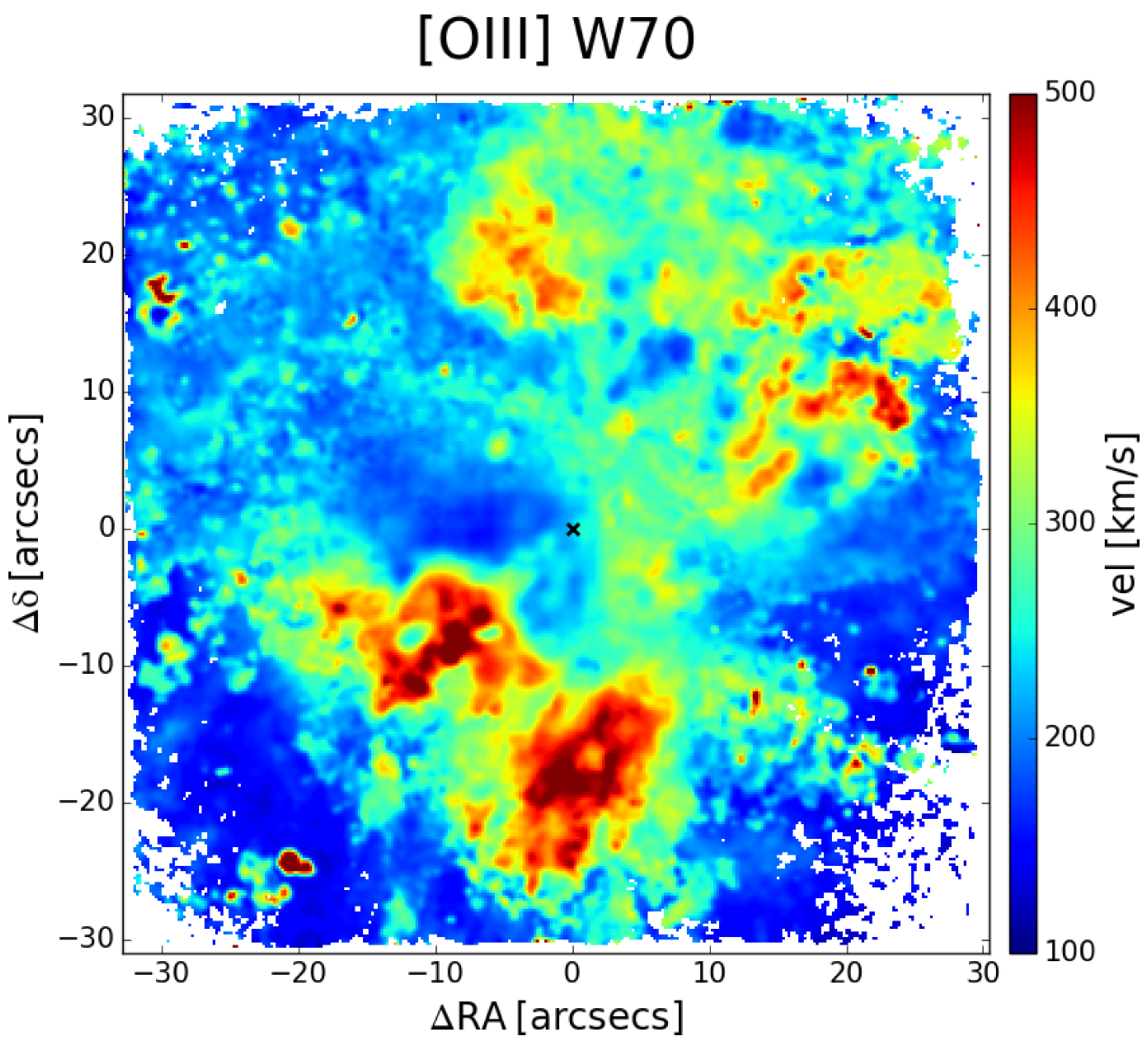
hosting a low-luminosity AGN:

$L_{AGN} \sim 2\times10^{43}$ erg/s

NGC 1365: MAPPING BICONICAL OUTFLOW KINEMATICS







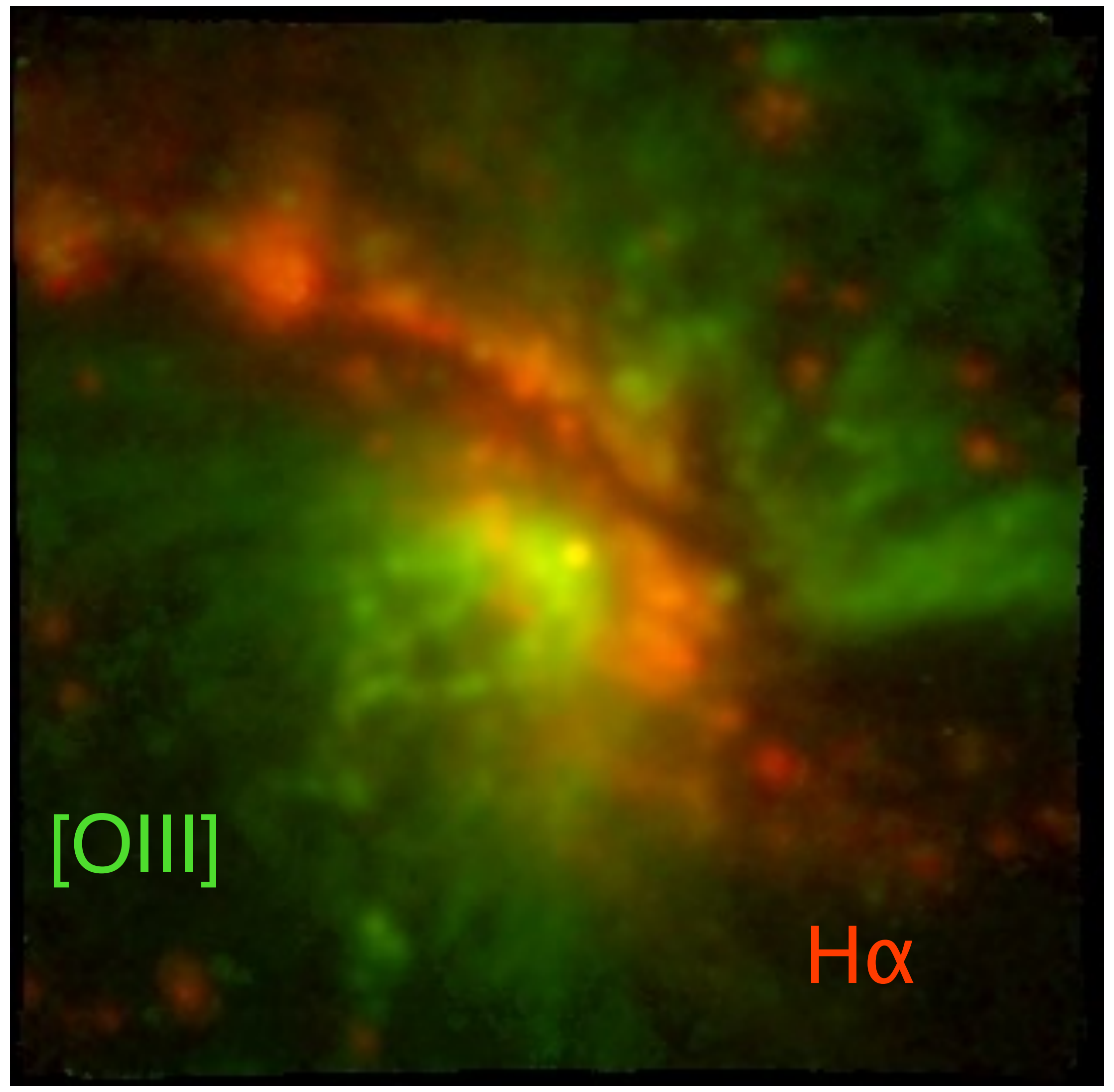
NW cone: positive velocity

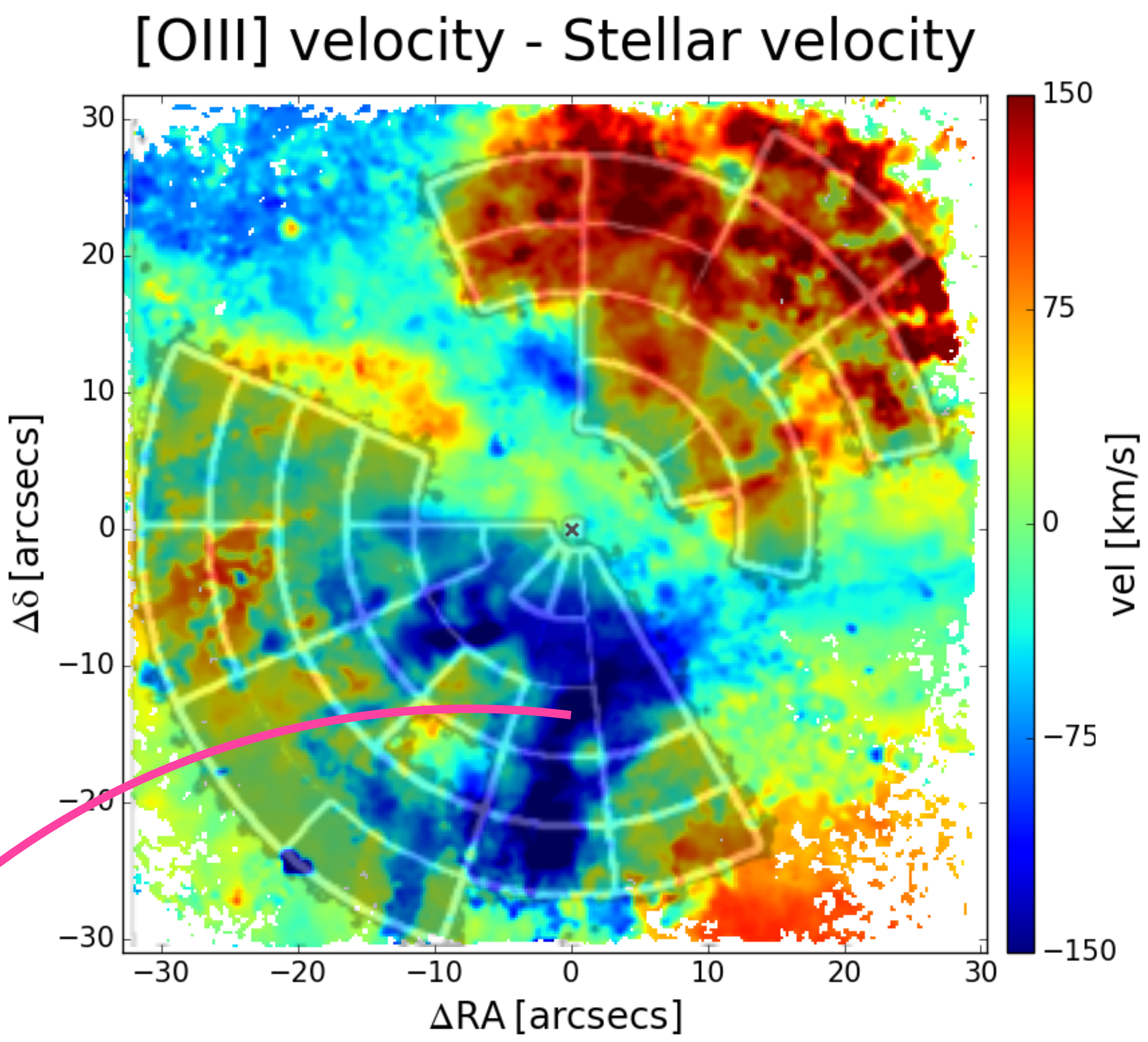
→ receding

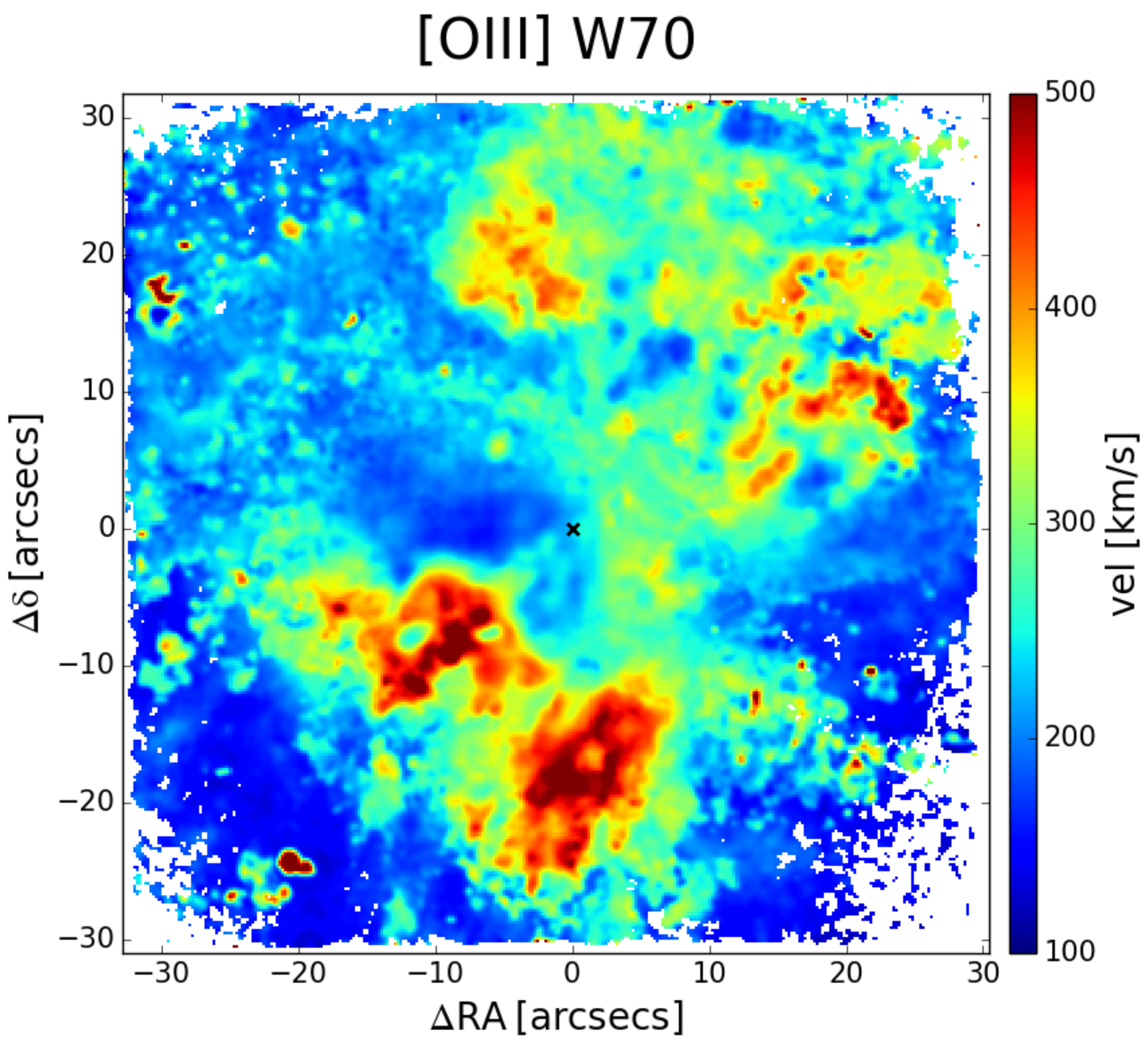
SE cone: negative velocity

→ approaching

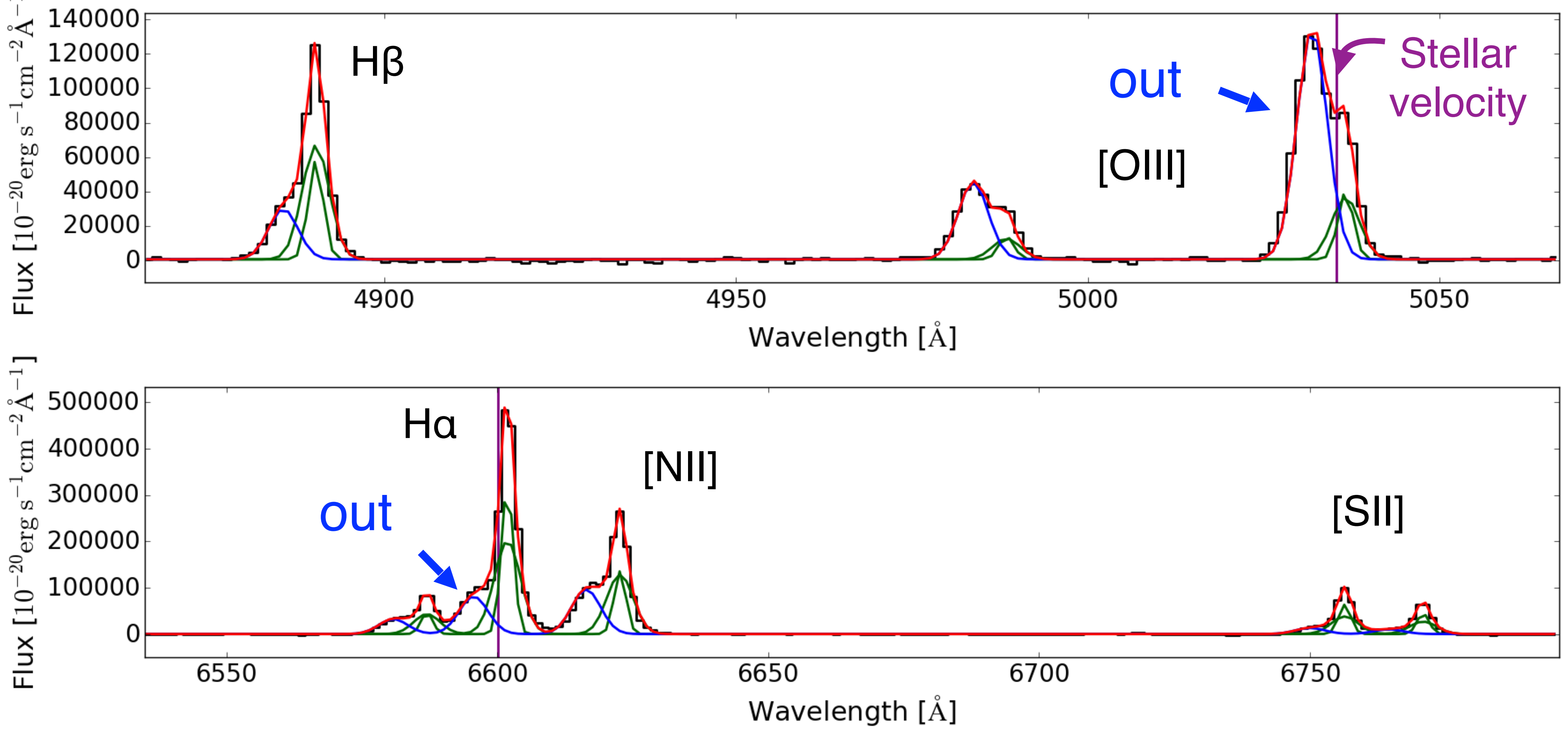
NGC 1365: MAPPING BICONICAL OUTFLOW KINEMATICS







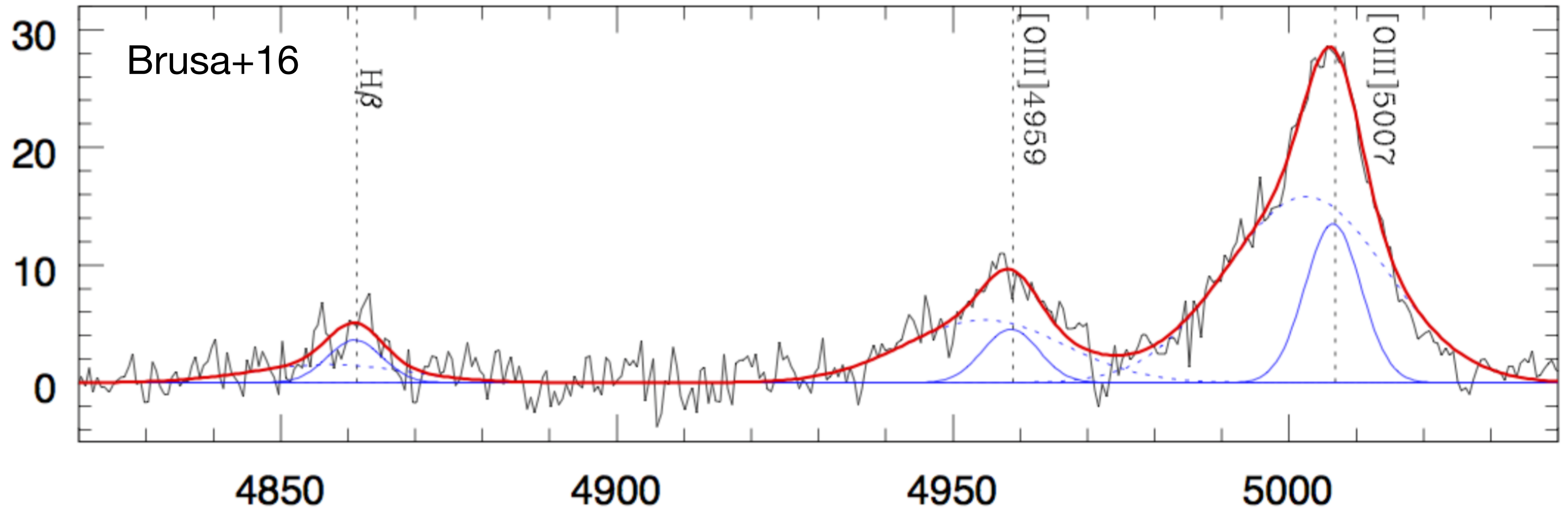
Left comp.: outflow blueshifted; Right comp.: disk



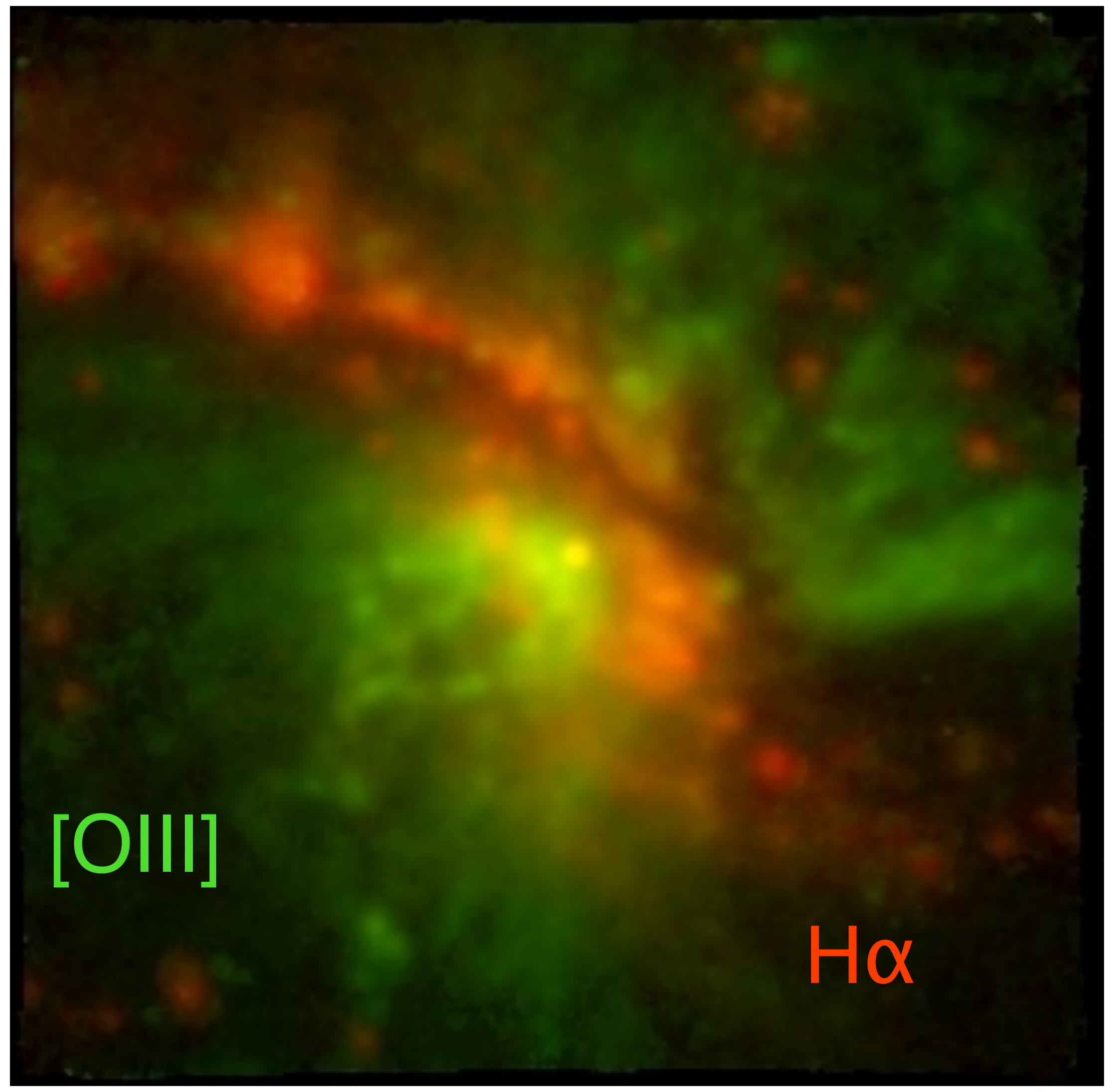
Outflow is <u>not</u> a <u>broad wing</u>

← as at low resolution

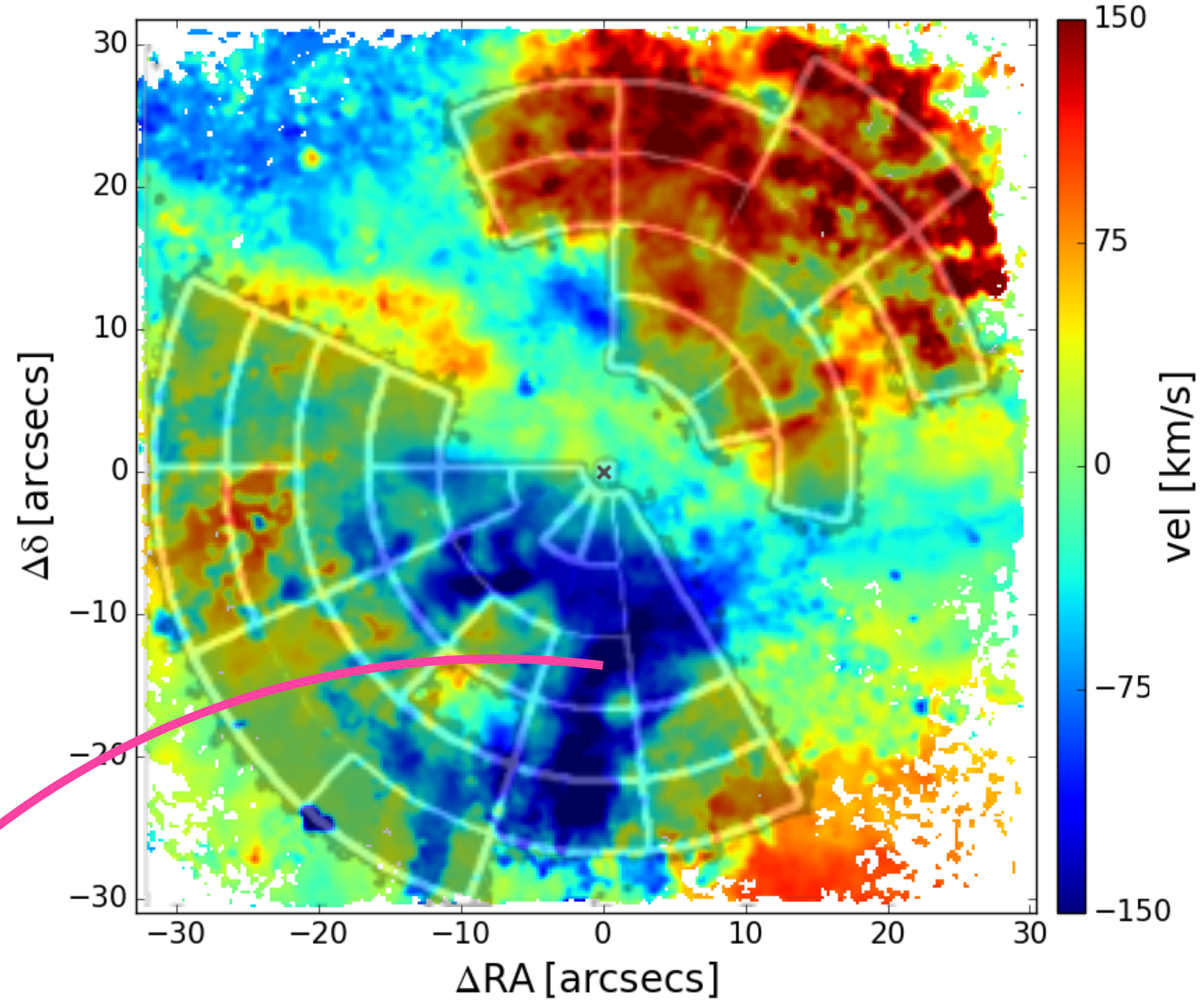
in more powerful AGN



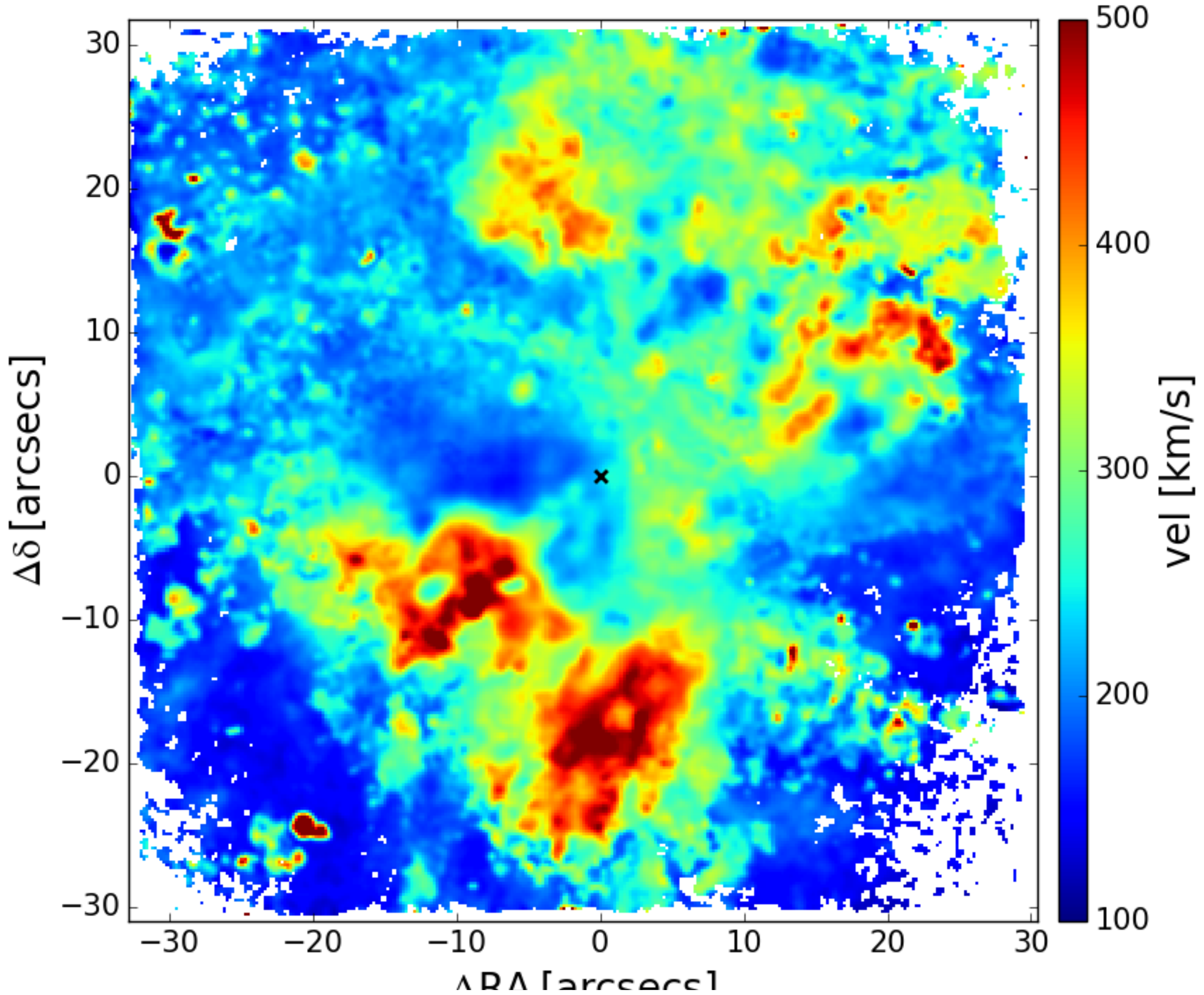
NGC 1365: MAPPING BICONICAL OUTFLOW KINEMATICS



[OIII] velocity - Stellar velocity



[OIII] W70



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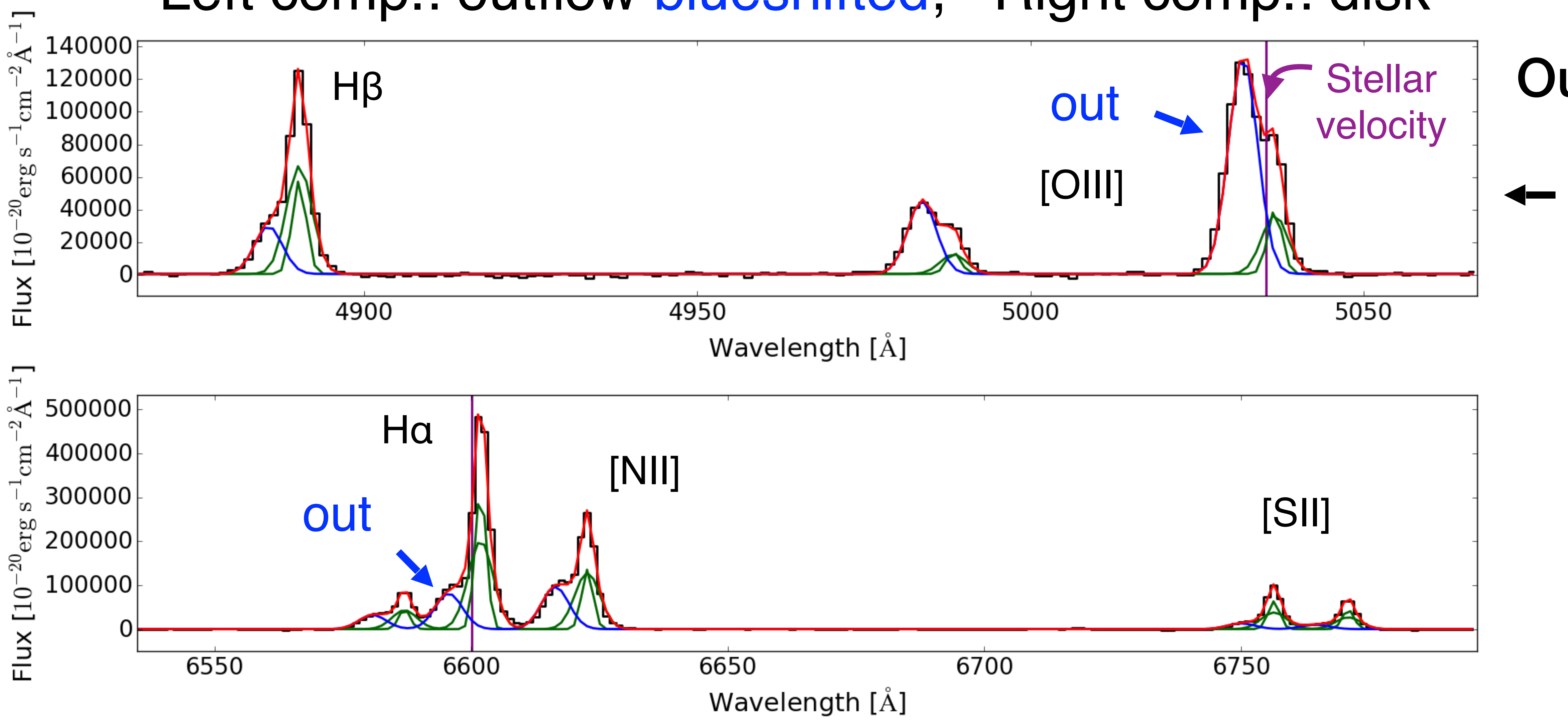


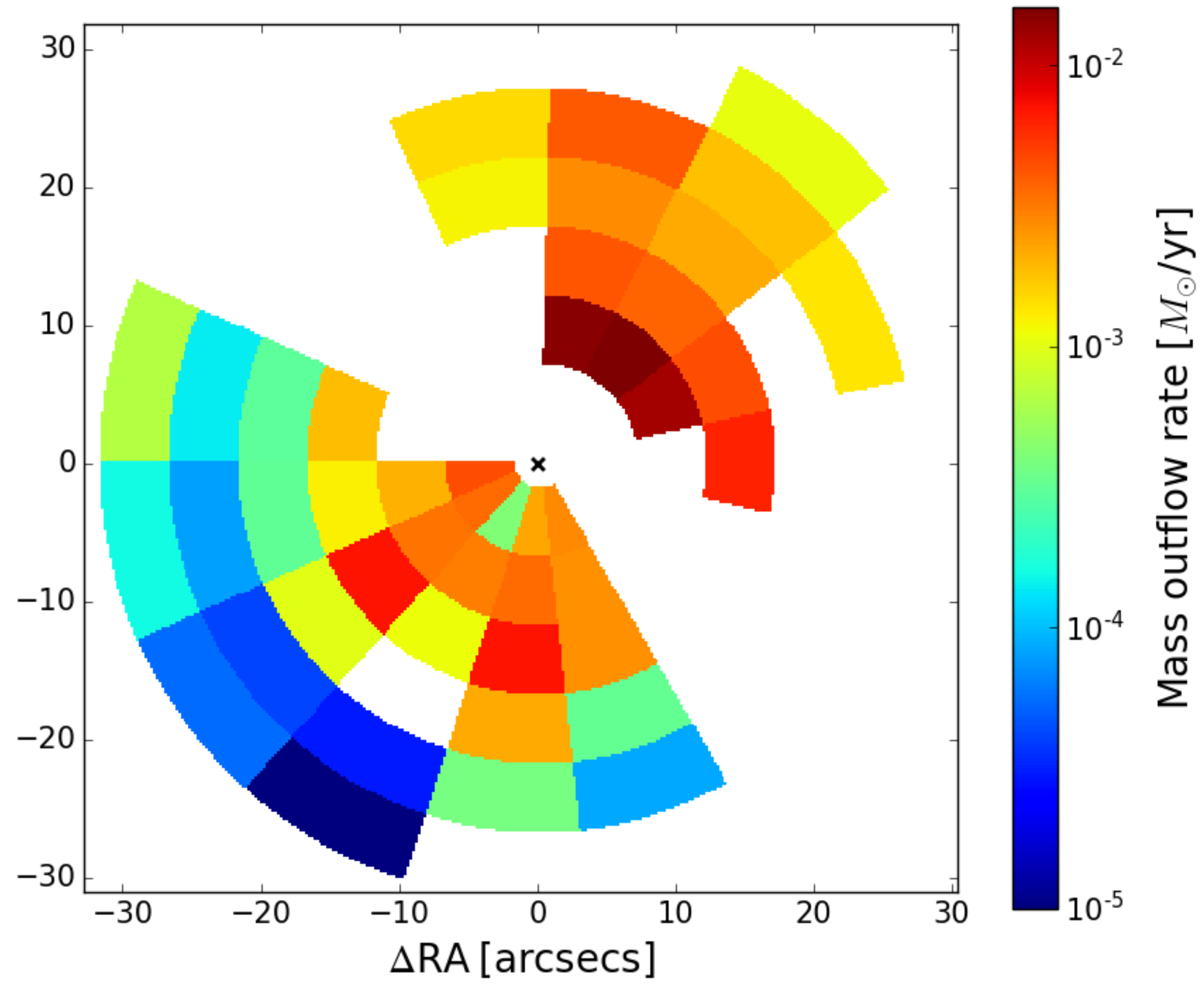
Outflow is <u>not</u> a <u>broad wing</u>

← as at low resolution

in more powerful AGN

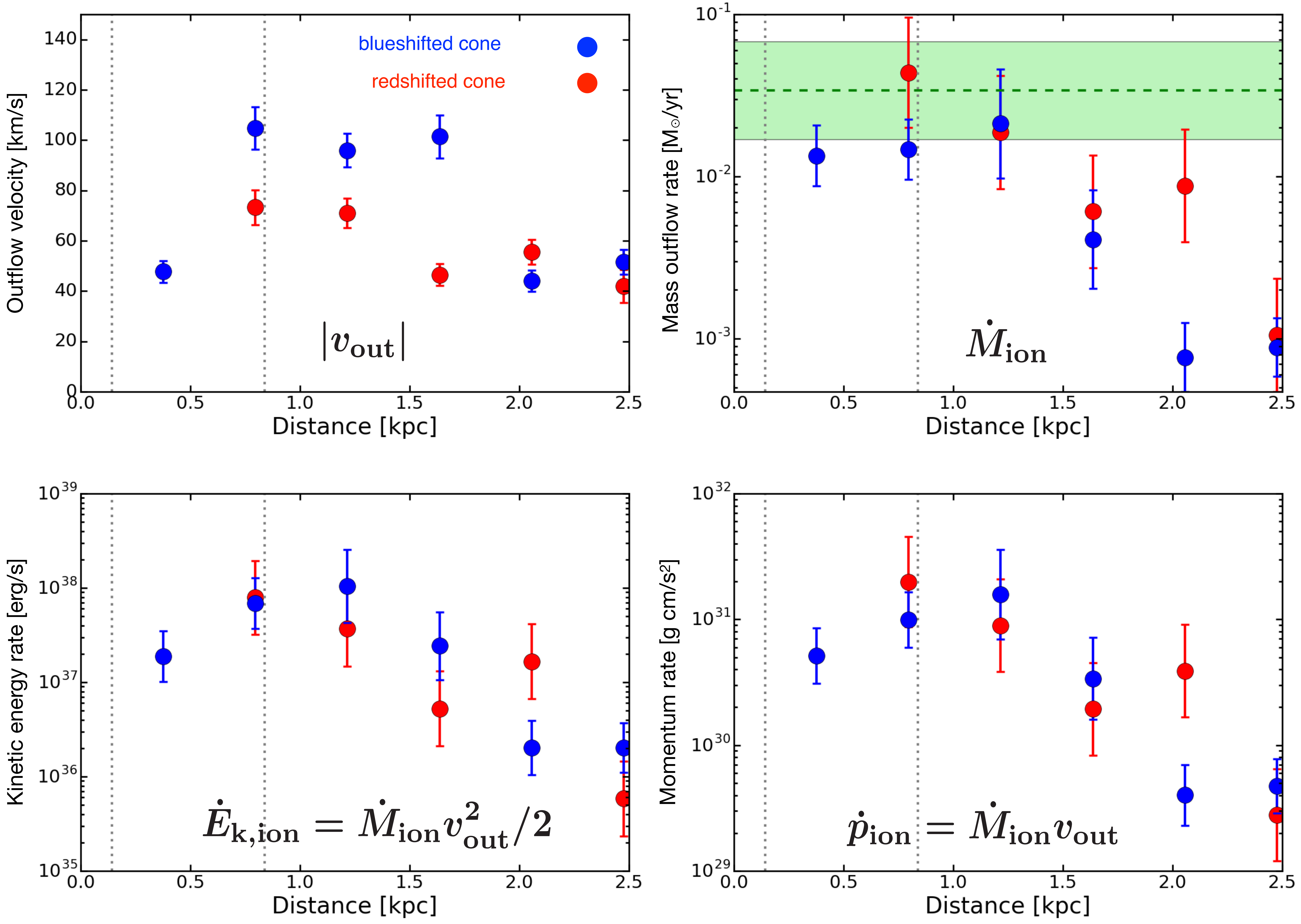
$$\dot{M}_{\rm out} = \frac{M_{\rm out} v_{\rm out}}{\Delta R}$$

Mass outflow rate



NGC 1365: OUTFLOW RADIAL PROFILES

Radial profiles as a function of distance from the AGN



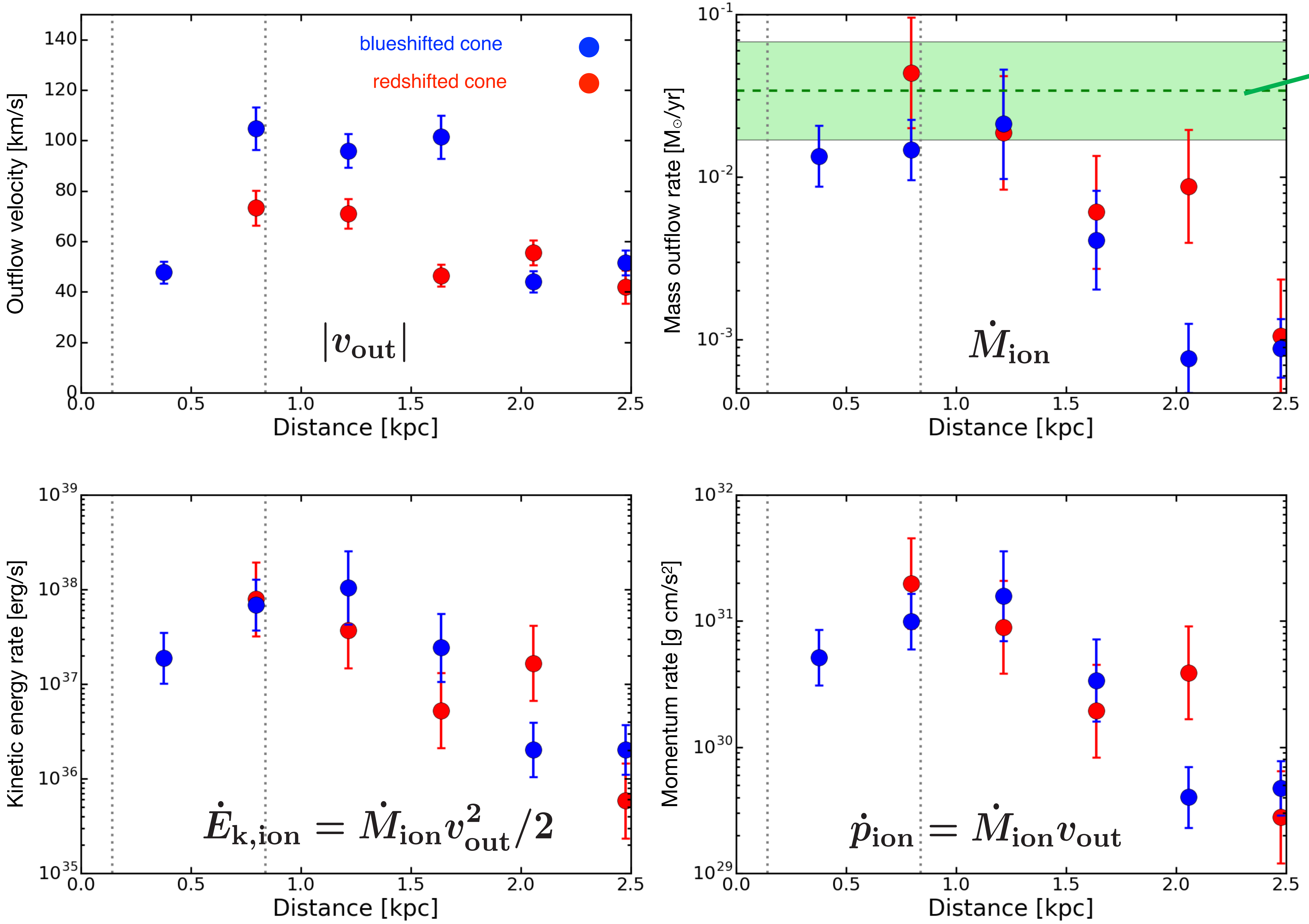
Decreasing trend with distance

(see also Karouzos+16a,16b, Bae+17, Crenshaw+15, Revalski+18)

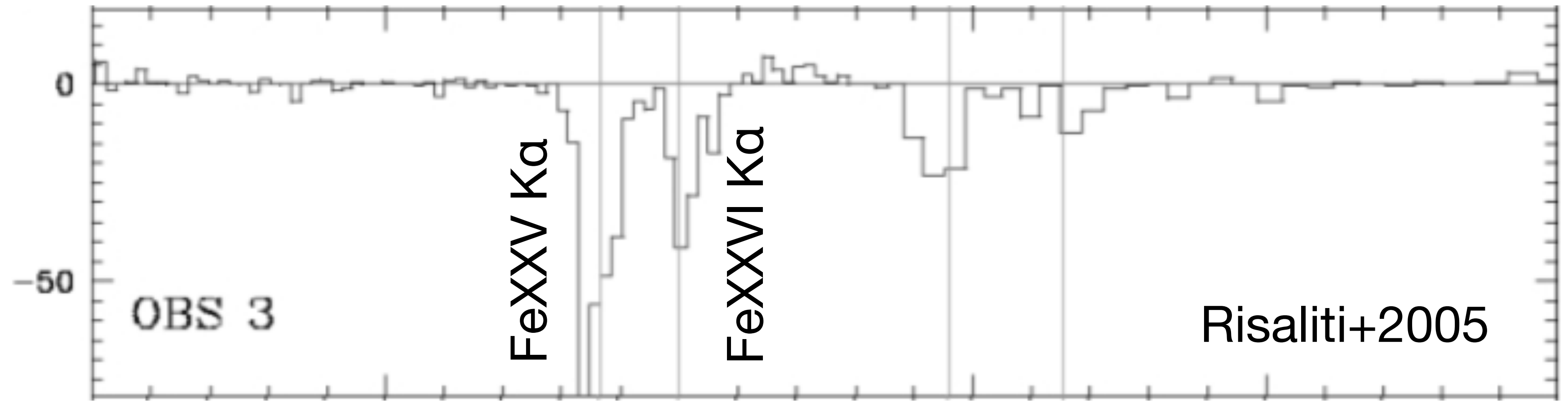
- But sampled only ionised gas (no neutral atomic + molecular), depending on ionising flux $\propto r^{-2}$

NGC 1365: OUTFLOW RADIAL PROFILES

Radial profiles as a function of distance from the AGN



Mass outflow rate of nuclear X-ray wind ($v_{\rm out,X} \sim 3000$ km/s) from FeXXV and FeXXVI absorption lines



- **Energy-driven excluded**: $\dot{E}_{\rm k,ion} \lesssim 10^{-3}\, \dot{E}_{\rm k,X}$: too much neutral gas needed for $\dot{E}_{\rm k,ion+neutr} = \dot{E}_{\rm k,X}$
- **Direct** AGN **radiation pressure** on dust (Thomson+15, Ishibashi+18, Costa+18): $\dot{p}_{\rm ion} \lesssim 1/20\ L_{\rm AGN}/c$ (models: $\dot{p}_{\rm ion+neutr} \sim$ 1-5 $L_{\rm AGN}/c$)
  Need $M_{\rm neutr} \sim$ 20-100 $M_{\rm ion}$ —> feasible!

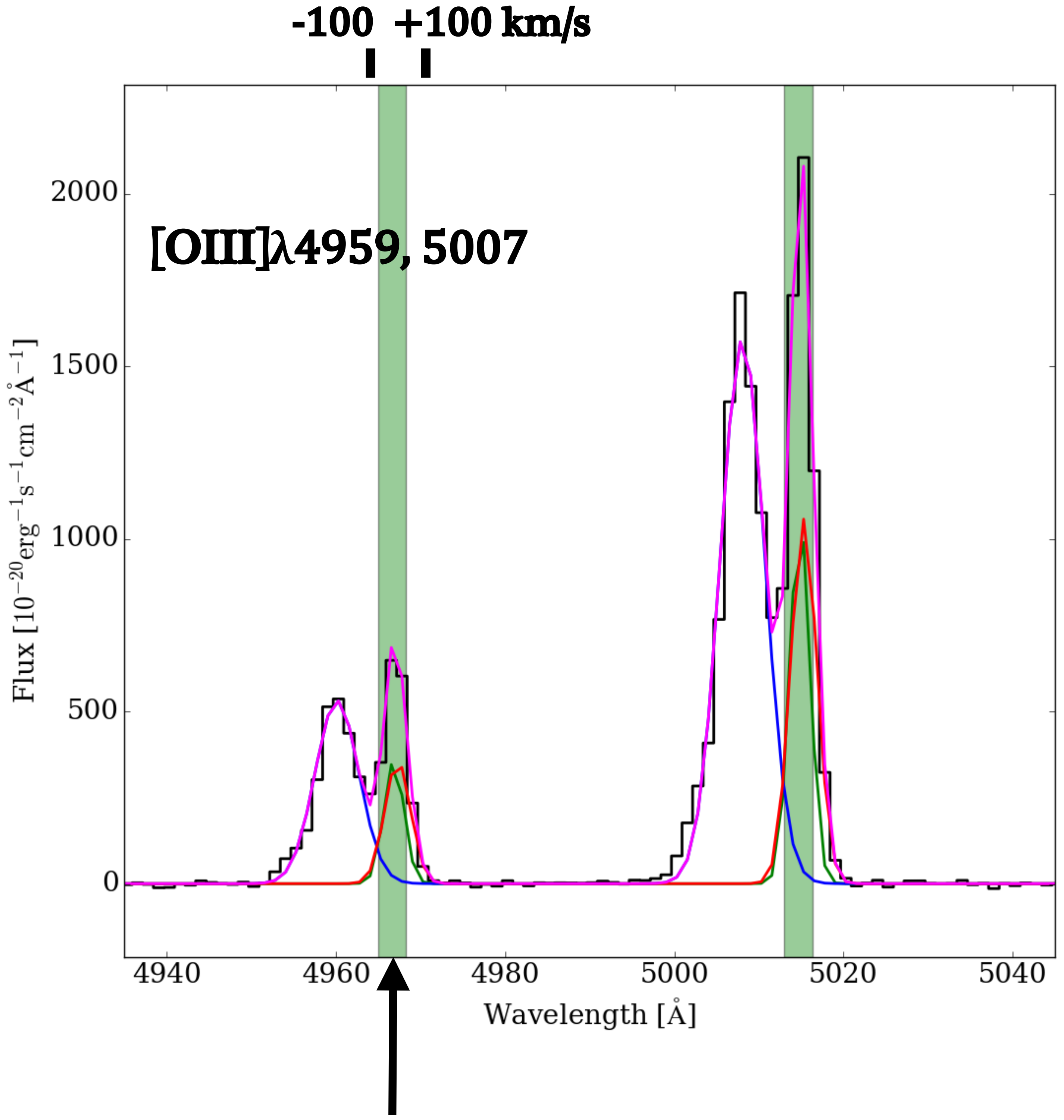
Dissecting the physical properties of outflow vs galaxy disc

(Mingozzi, GV et al., 2019, 2019A&A...622A.146M)

PHYSICAL PROPERTIES: OUTFLOW VS GALAXY DISC

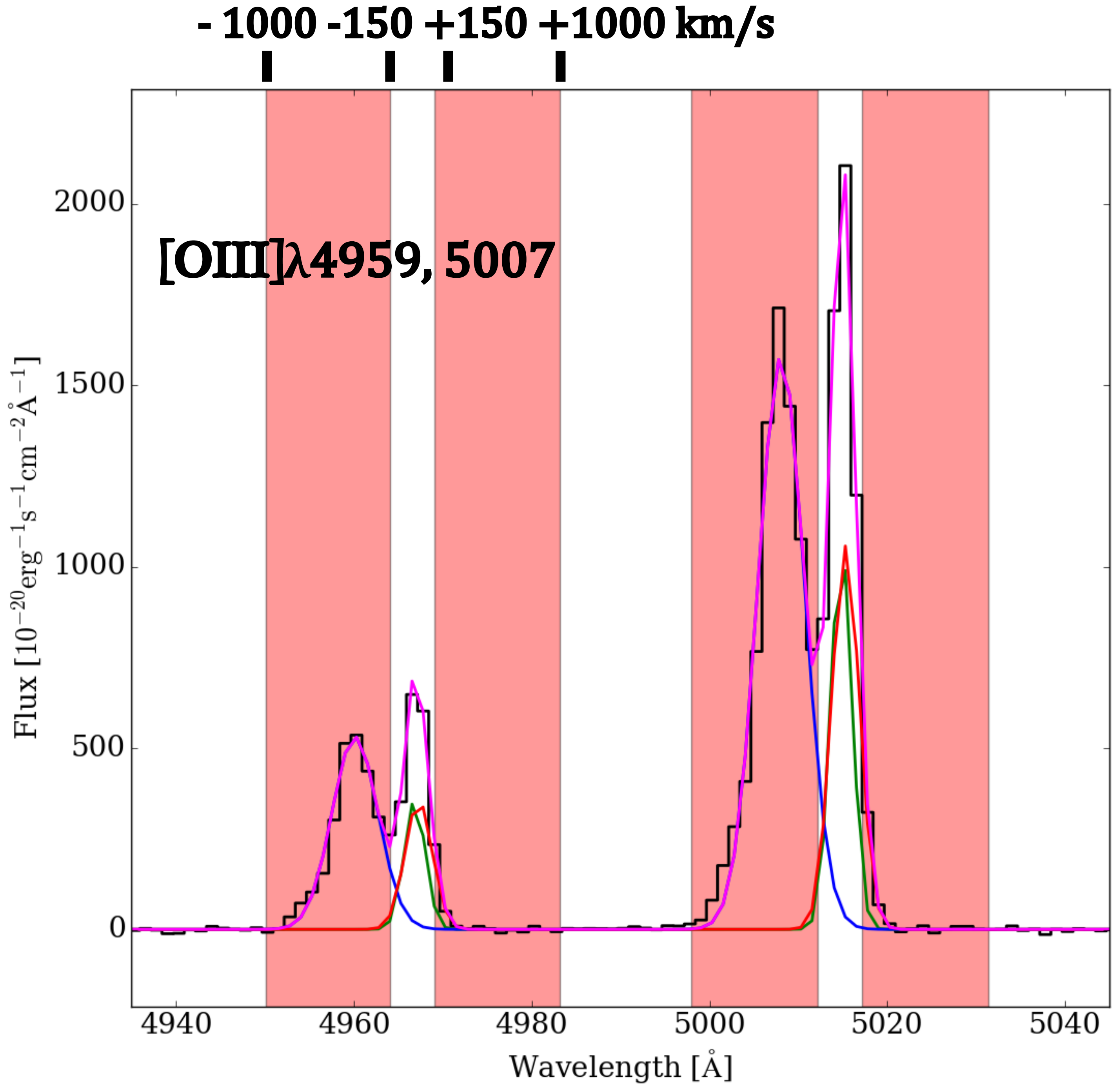
[OIII], Hβ, [OI], Hα, [NII], [SII] and [SIII]
divided in velocity bins

Disc



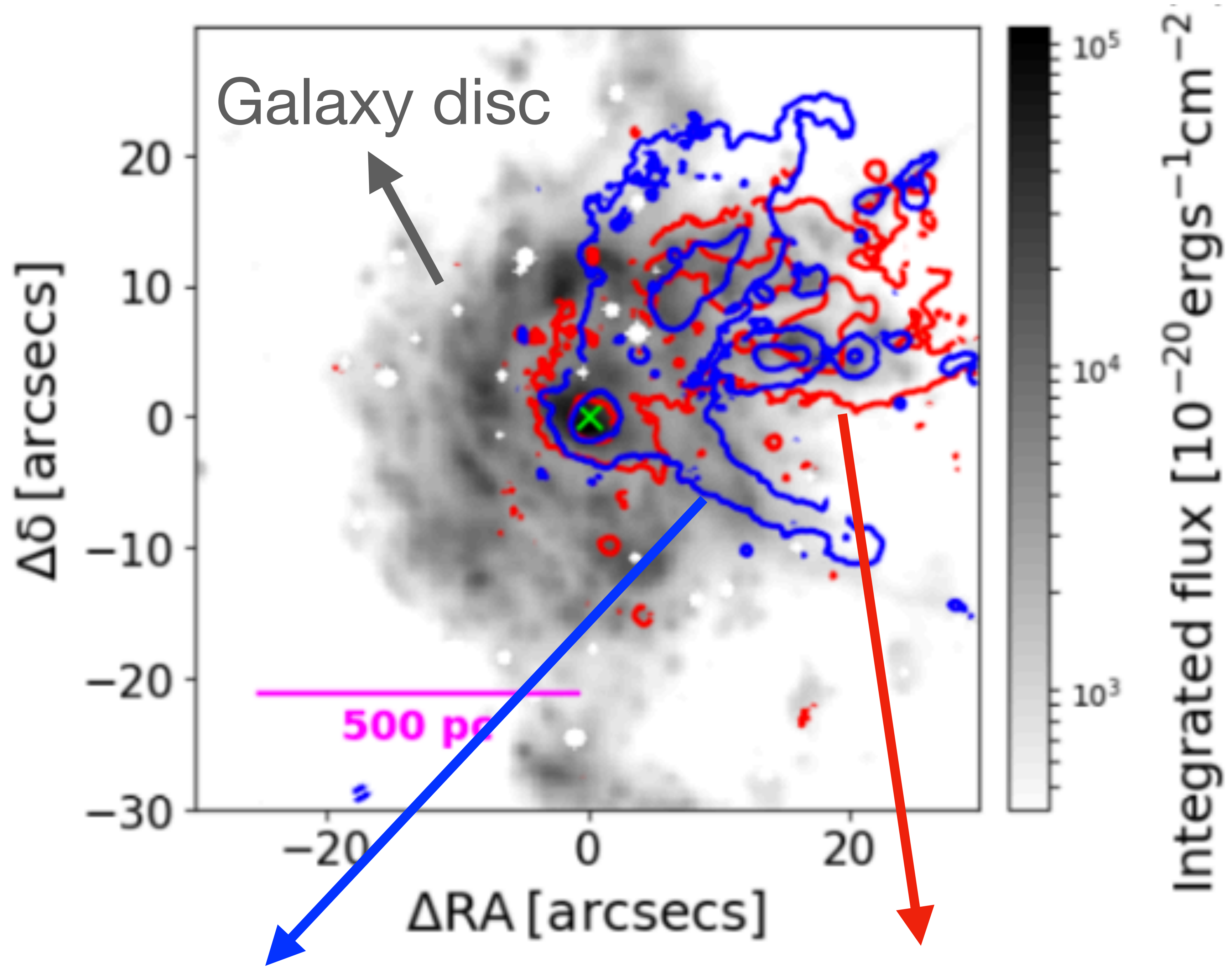
Stellar velocity
in given spaxel

Outflow



$\Longrightarrow$ Spatially and kinematically resolved maps

Example of Circinus



Blueshifted (approaching) outflow

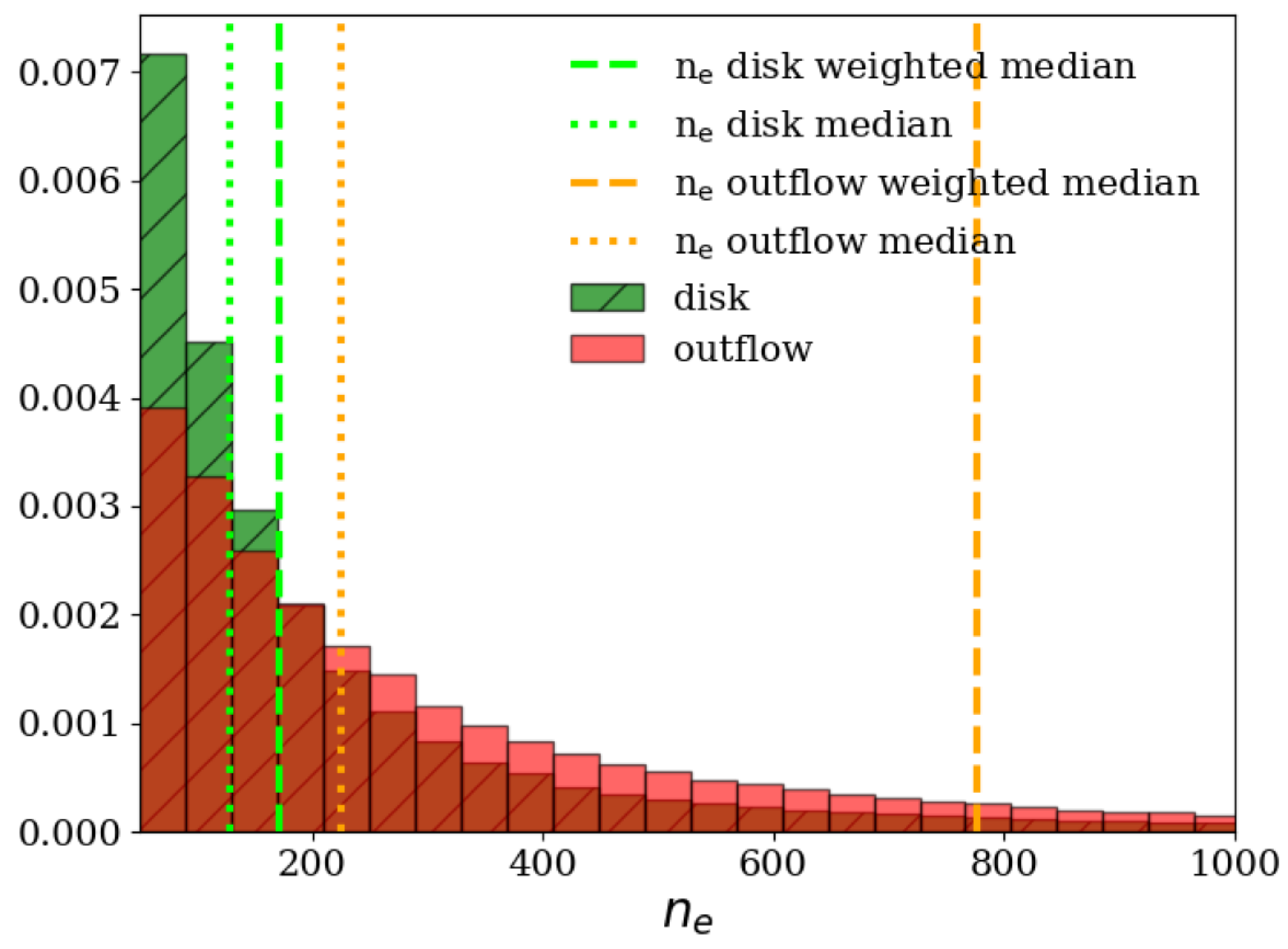
Redshifted (receding) outflow

Mingozzi, GV+2019

PHYSICAL PROPERTIES: OUTFLOW VS GALAXY DISC

Physical properties of outflow vs disc for every spaxels of all 9 MAGNUM galaxies

ELECTRON DENSITY
(from [SII]6716/6731)

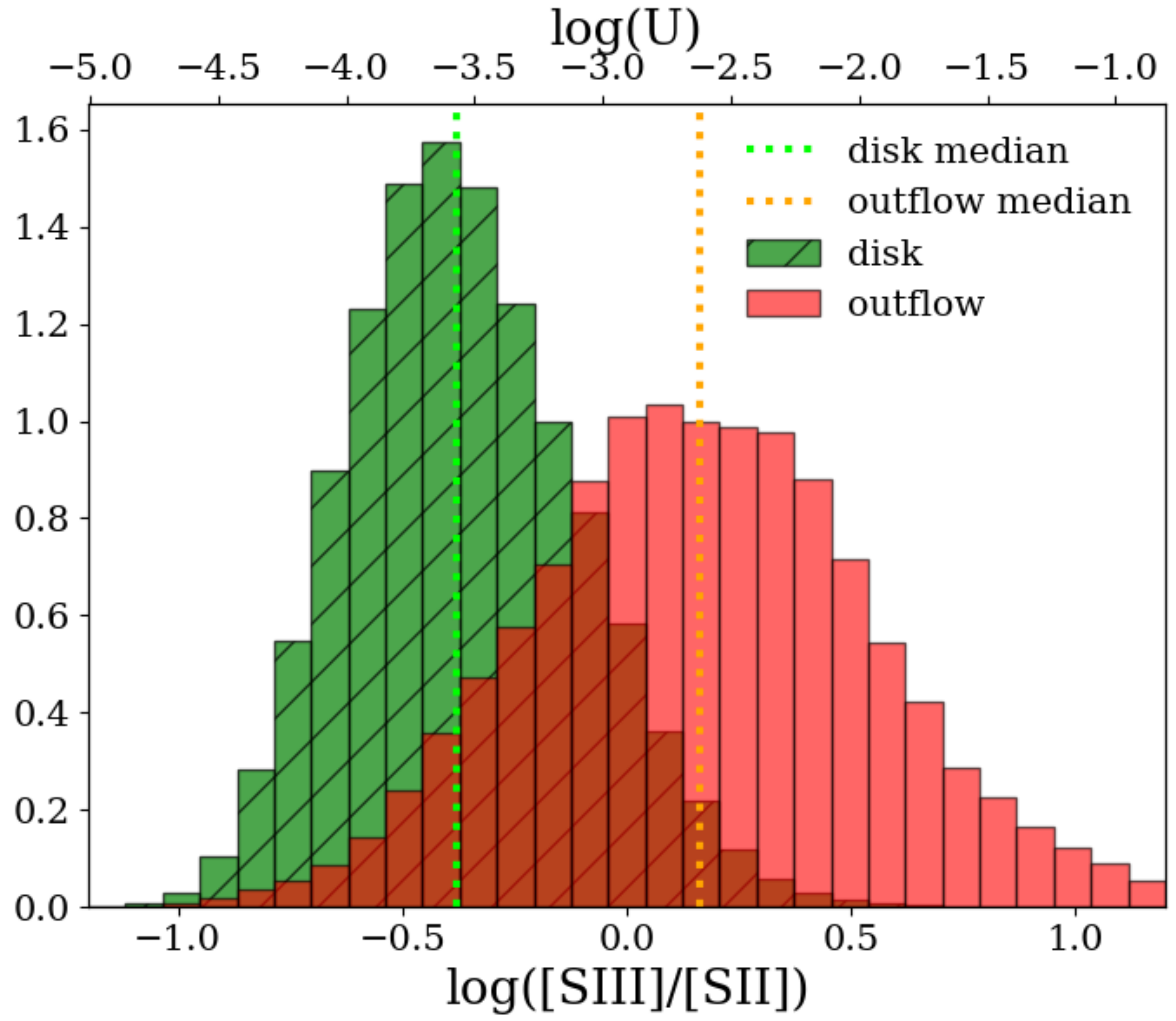


MEDIAN VALUES

✽ Disk : $n_e \sim$ 130 cm^{-3} (170 cm^{-3})

✽ Outflow : $n_e \sim$ 250 cm^{-3} (815 cm^{-3})

IONISATION PARAMETER
(from [SIII]/[SII])

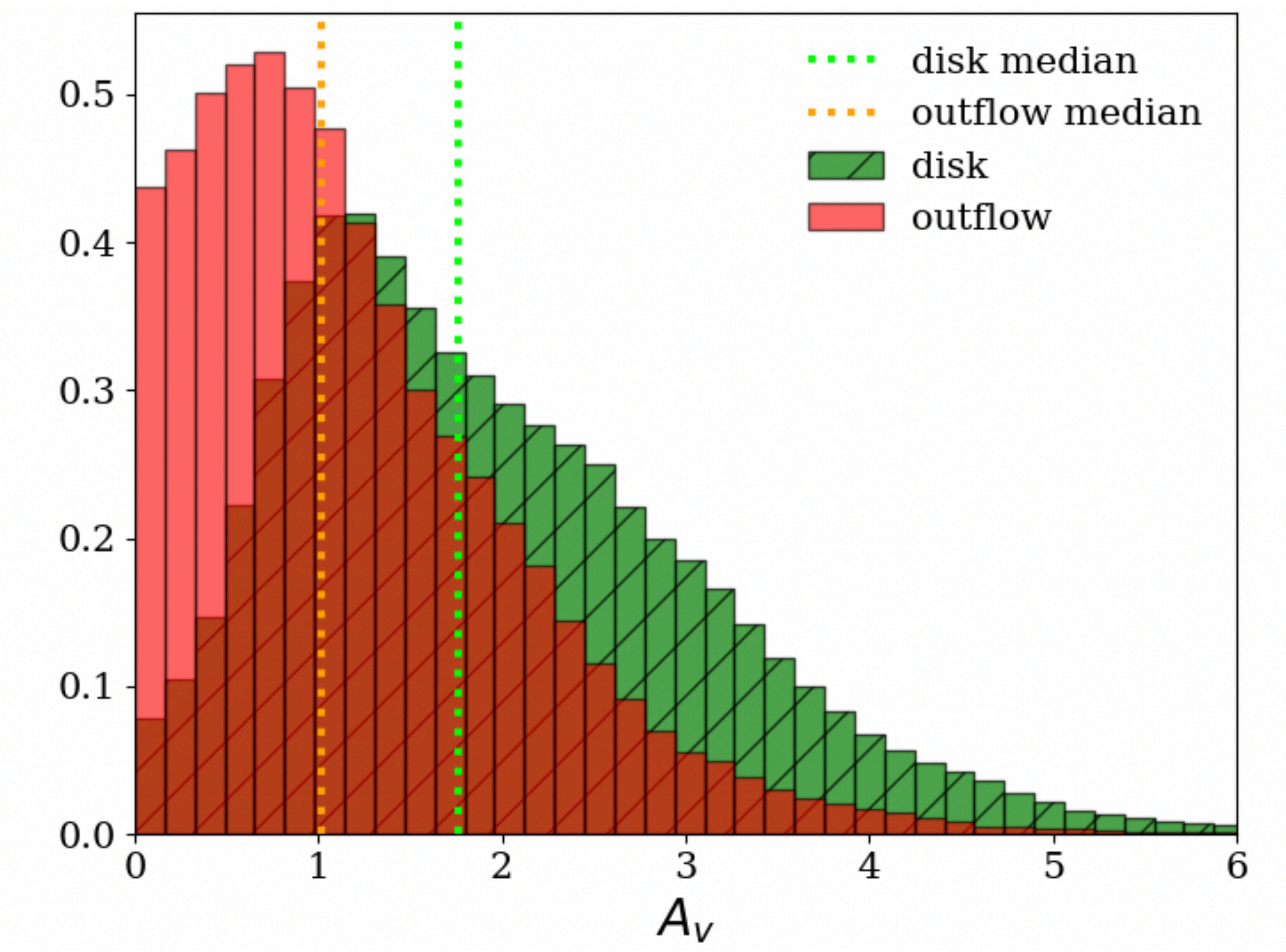


MEDIAN VALUES

✽ Disk : log(U) ~ -3.6

✽ Outflow : log(U) ~ -2.75

DUST EXTINCTION
(from Hα/Hβ)



MEDIAN VALUES

✽ Disk : log(A_V) ~ 1.75

✽ Outflow : log(A_V) ~ 1.02

Mingozzi, GV+2019

Impact of low-power, compact jets on host

galaxy in radio-quiet sources

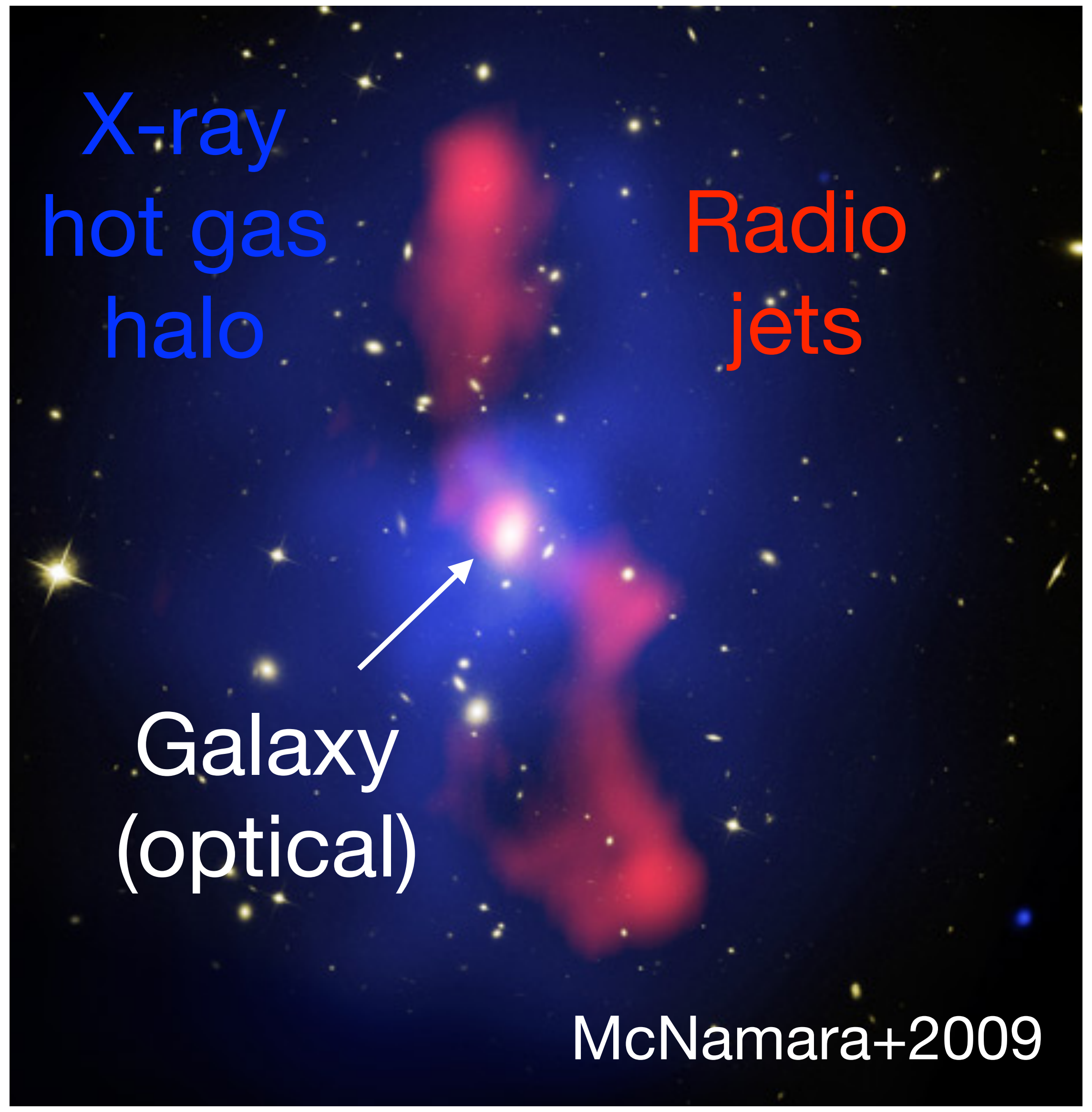
(Venturi et al. 2020, in press. arXiv:2011.04677)

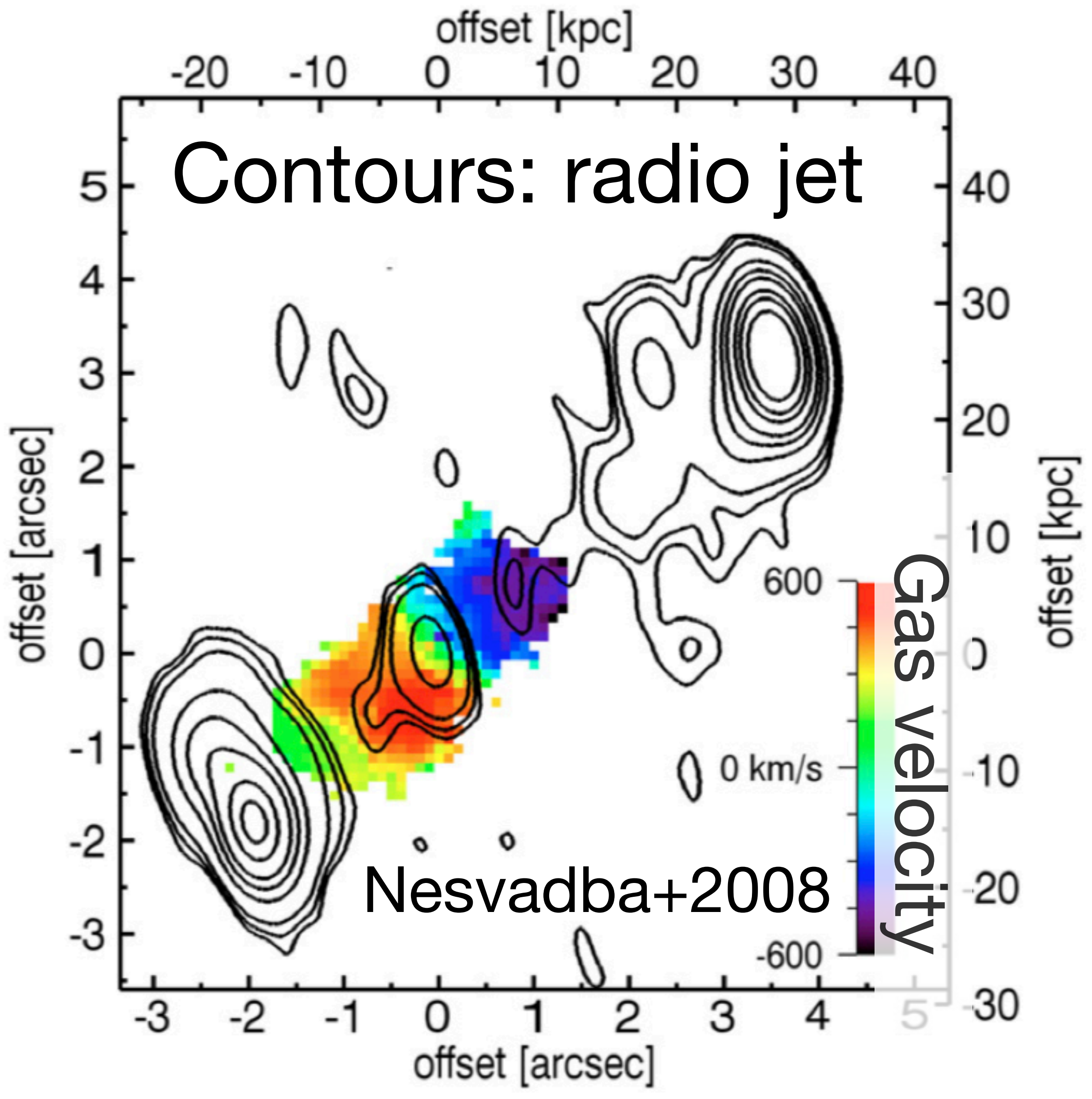
BACKGROUND: AGN FEEDBACK FROM JETS

Traditionally, jet-feedback comes from powerful 10s-100s kpc jets in radio-loud AGN ($F_{radio}/F_{opt} > 10$)

Jets keep galaxy halo hot preventing accretion and SF (kinetic feedback)

Capable of accelerating massive outflows

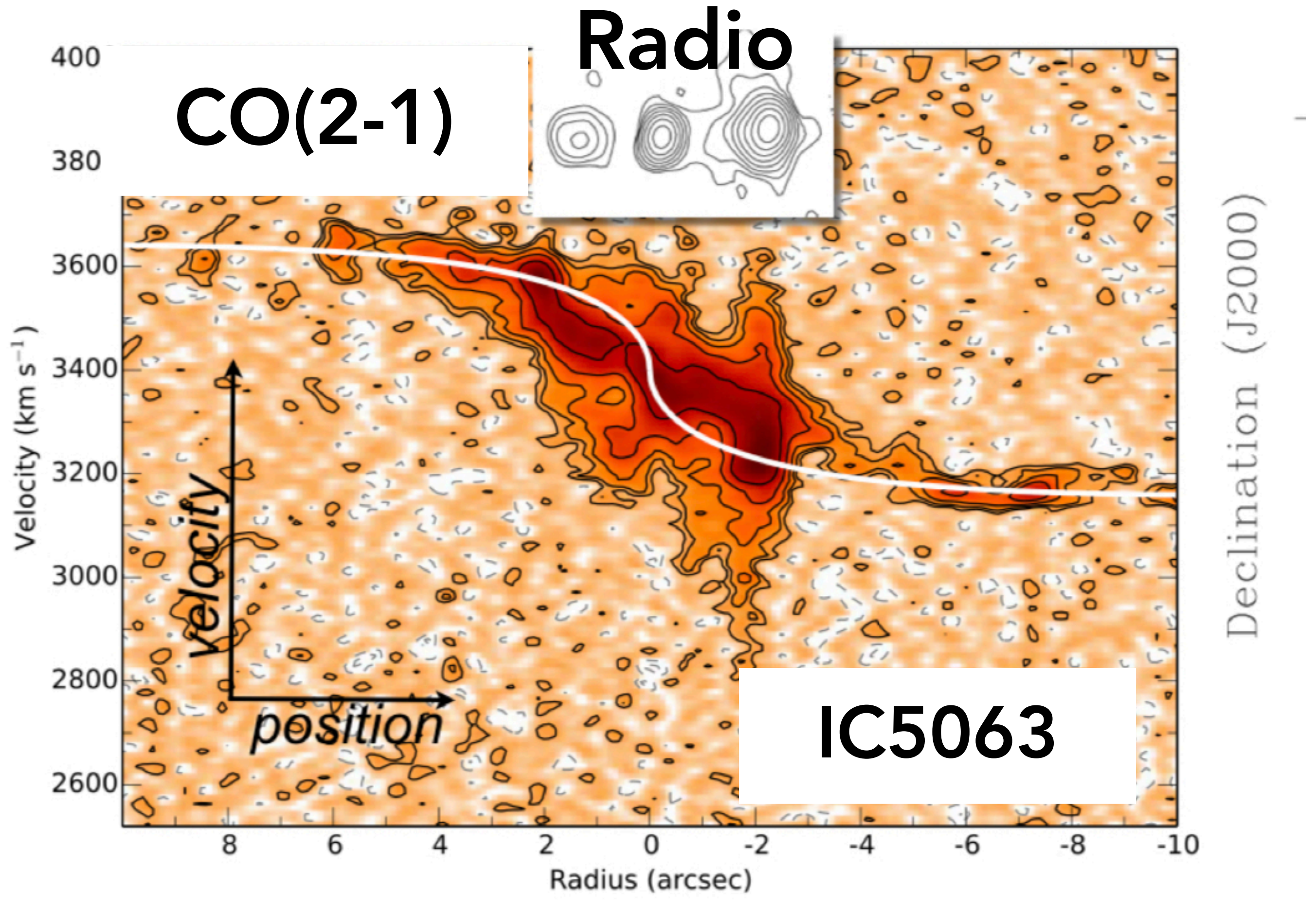




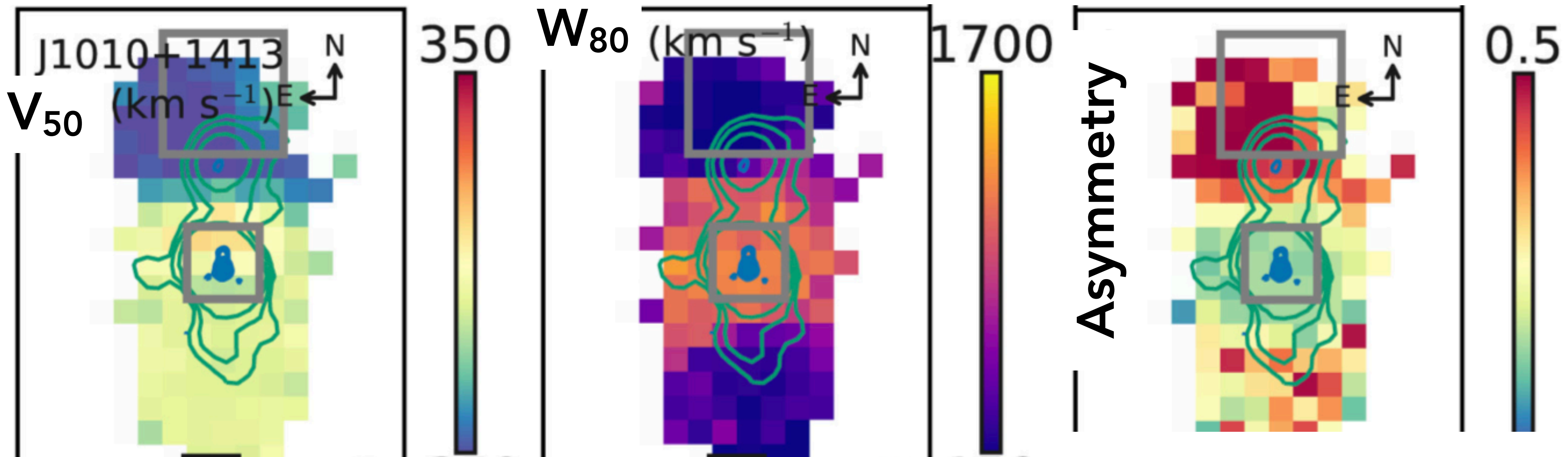
(also e.g. Boehringer+1993, Carilli+1994, Rizza+2000, McNamara+2000, Bîrzan+2004,2012, Balmaverde,GV+18)

(also e.g. Vayner+17,20, Nesvadba+21)

Recent works indicate that also low-power ($\lesssim 10^{44}$ erg/s), compact (~kpc) jets can affect their host galaxies by pushing outflows!

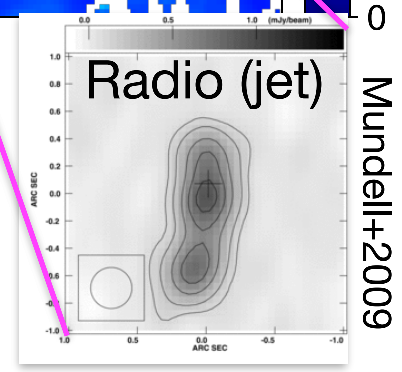


Morganti+2015,2016, Oosterloo+2017



Jarvis+2019,2020

ENHANCED LINE WIDTHS PERPENDICULAR TO JETS!

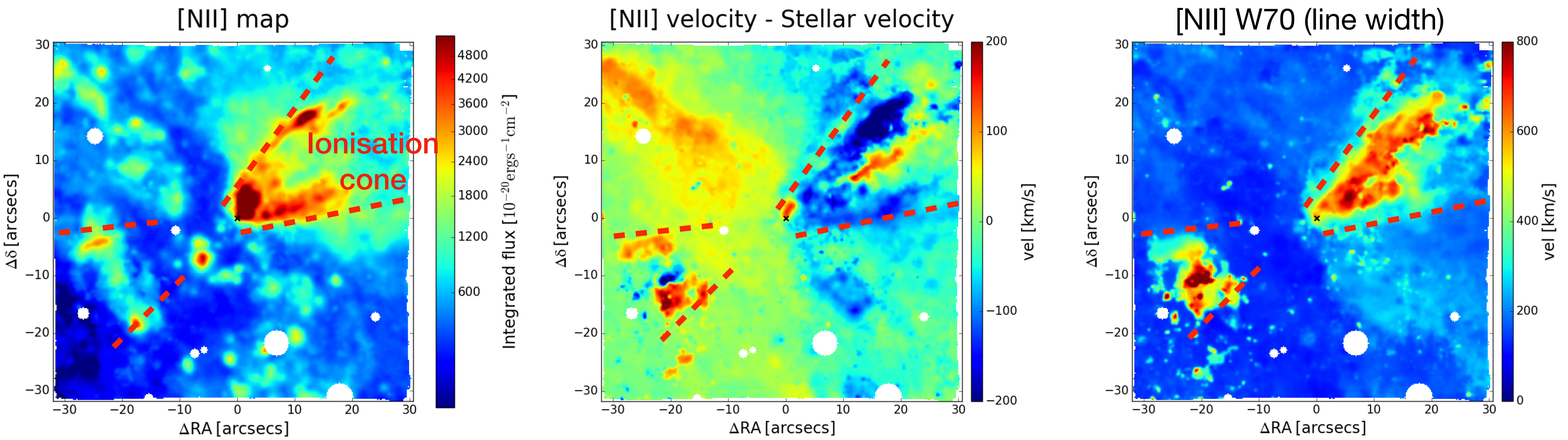


Broad line velocity widths (turbulence) perpendicular to radio jets and AGN cones!

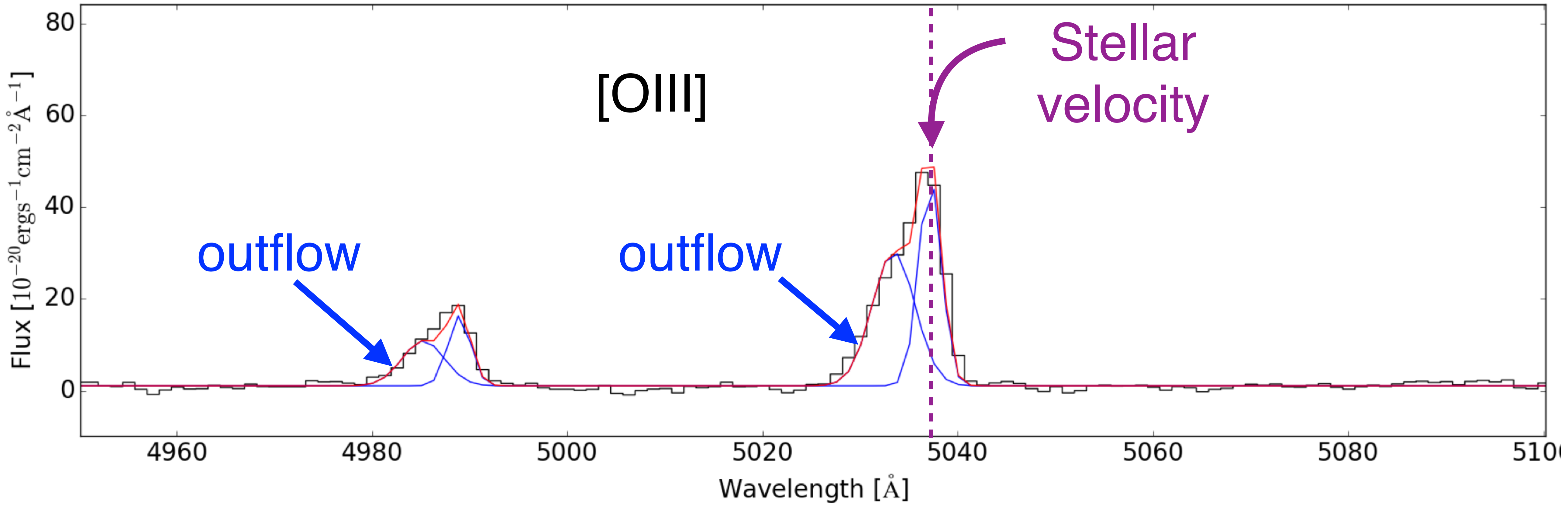
ENHANCED LINE WIDTHS PERPENDICULAR TO JETS!

But outflows are normally expected and observed in the direction of the AGN-ionisation cones!

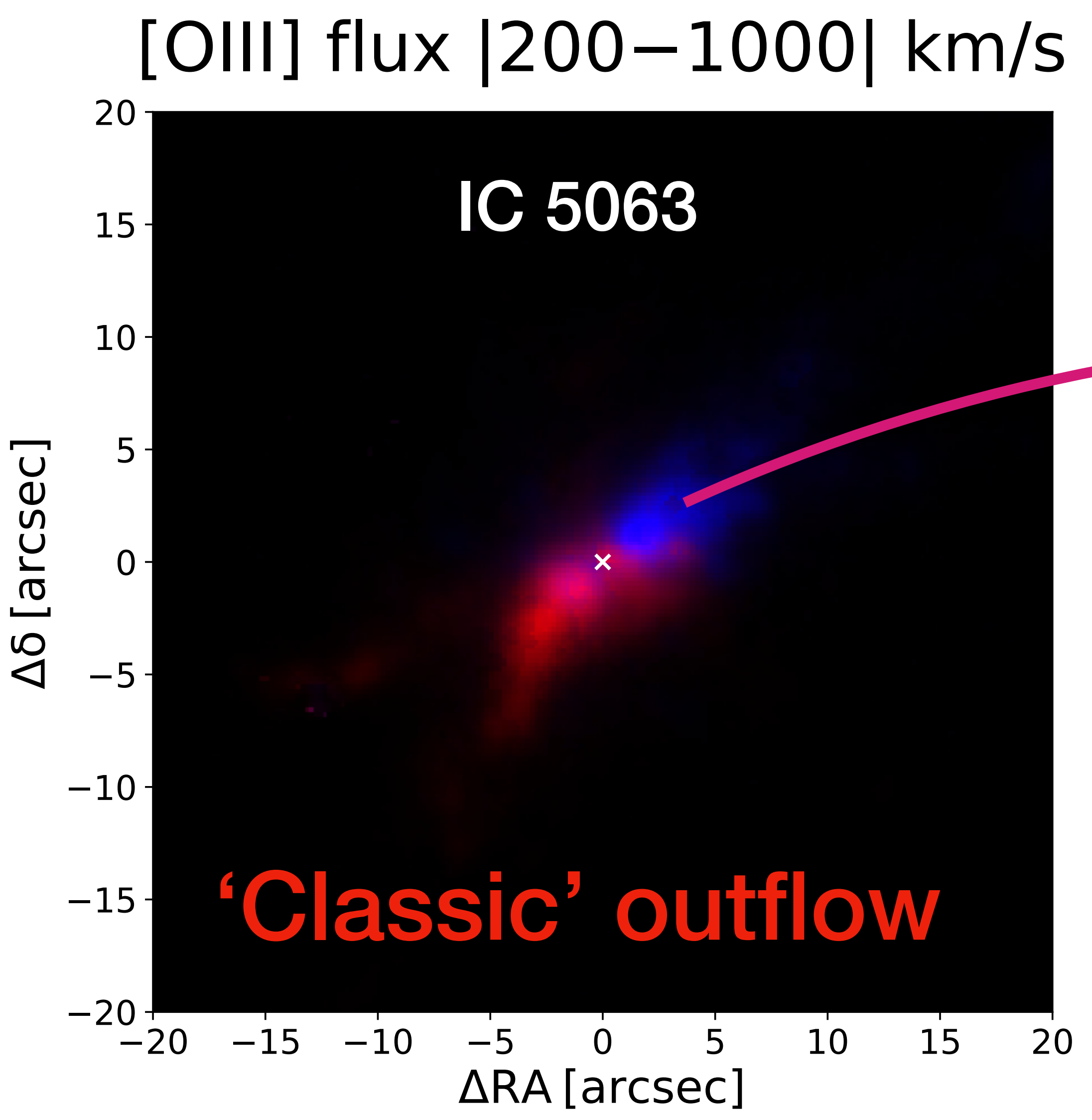
Example of NGC 4945 from MAGNUM survey:

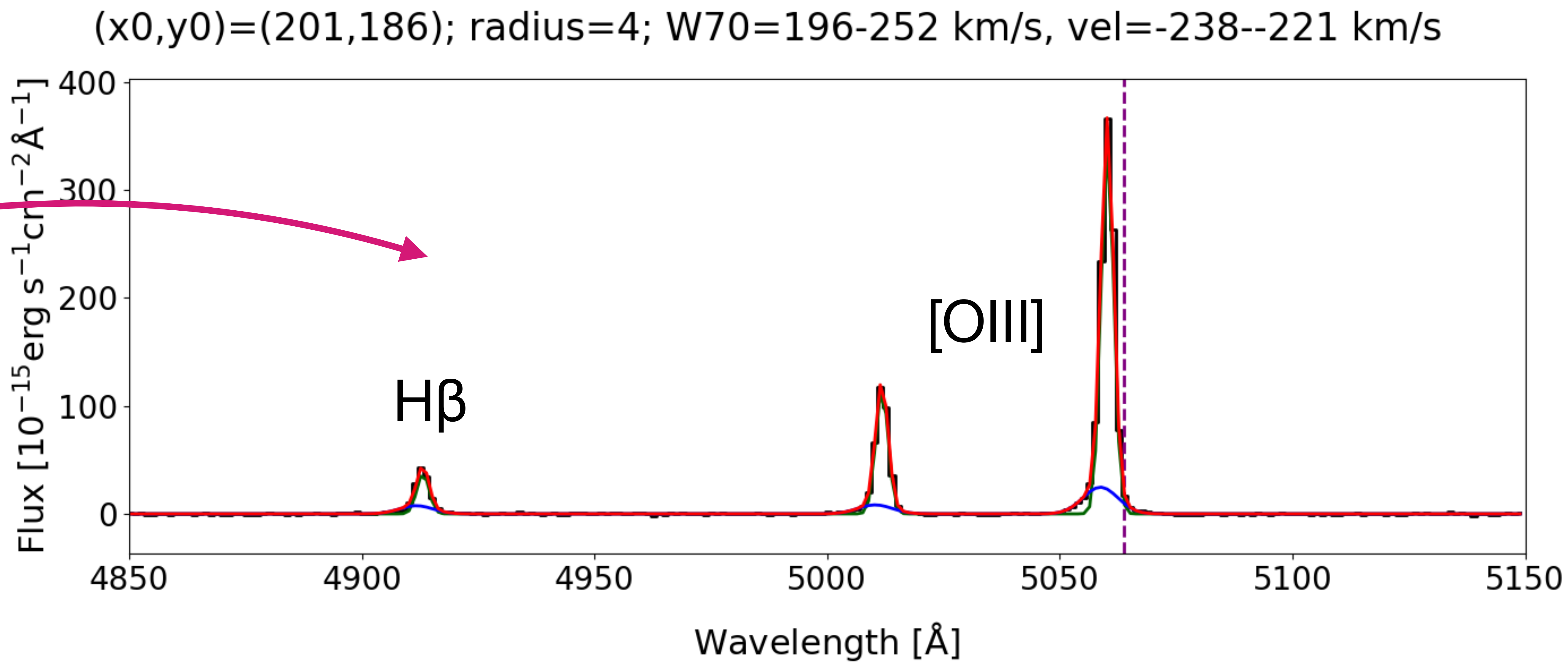


Traced by asymmetric wings in emission lines

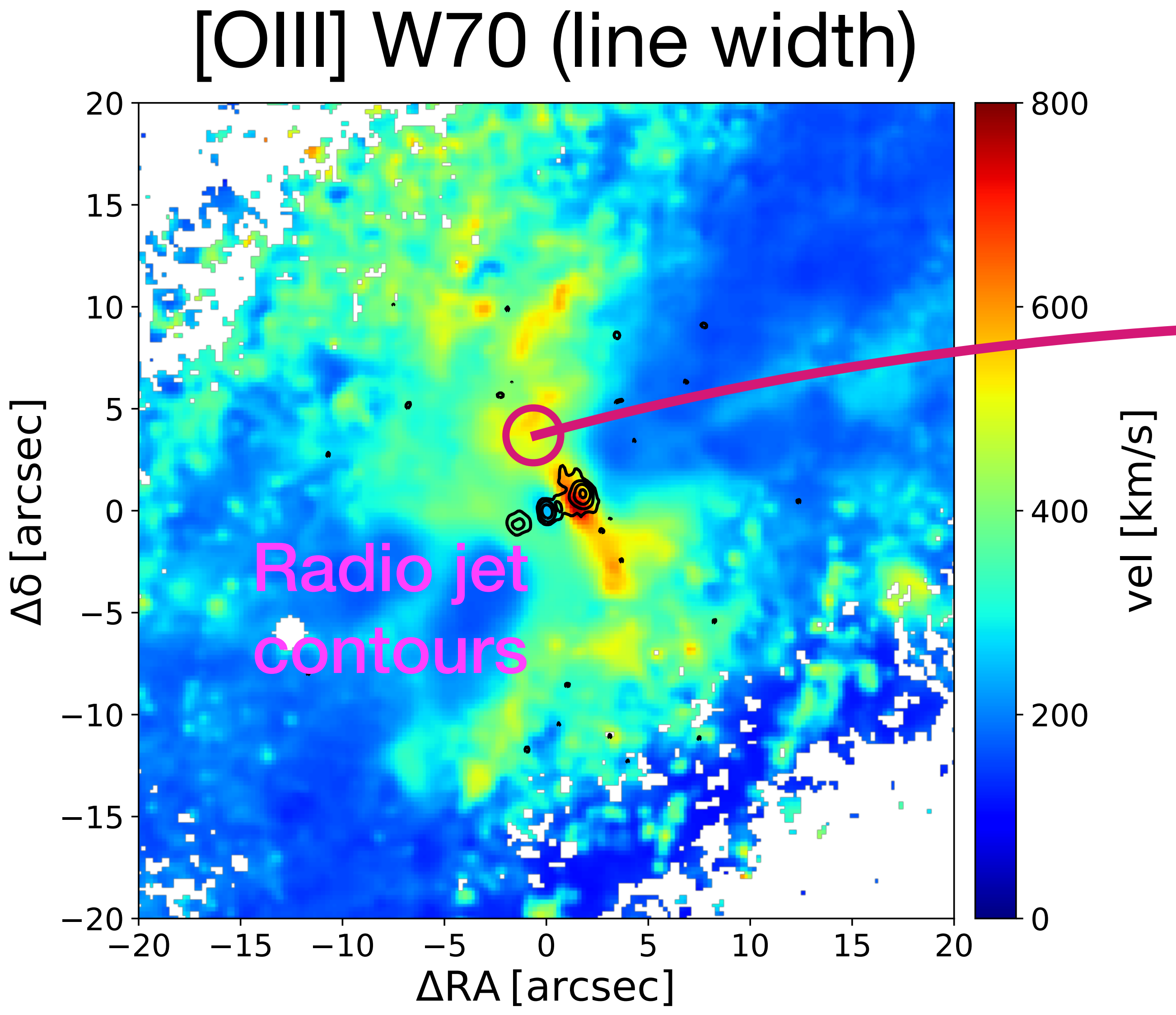


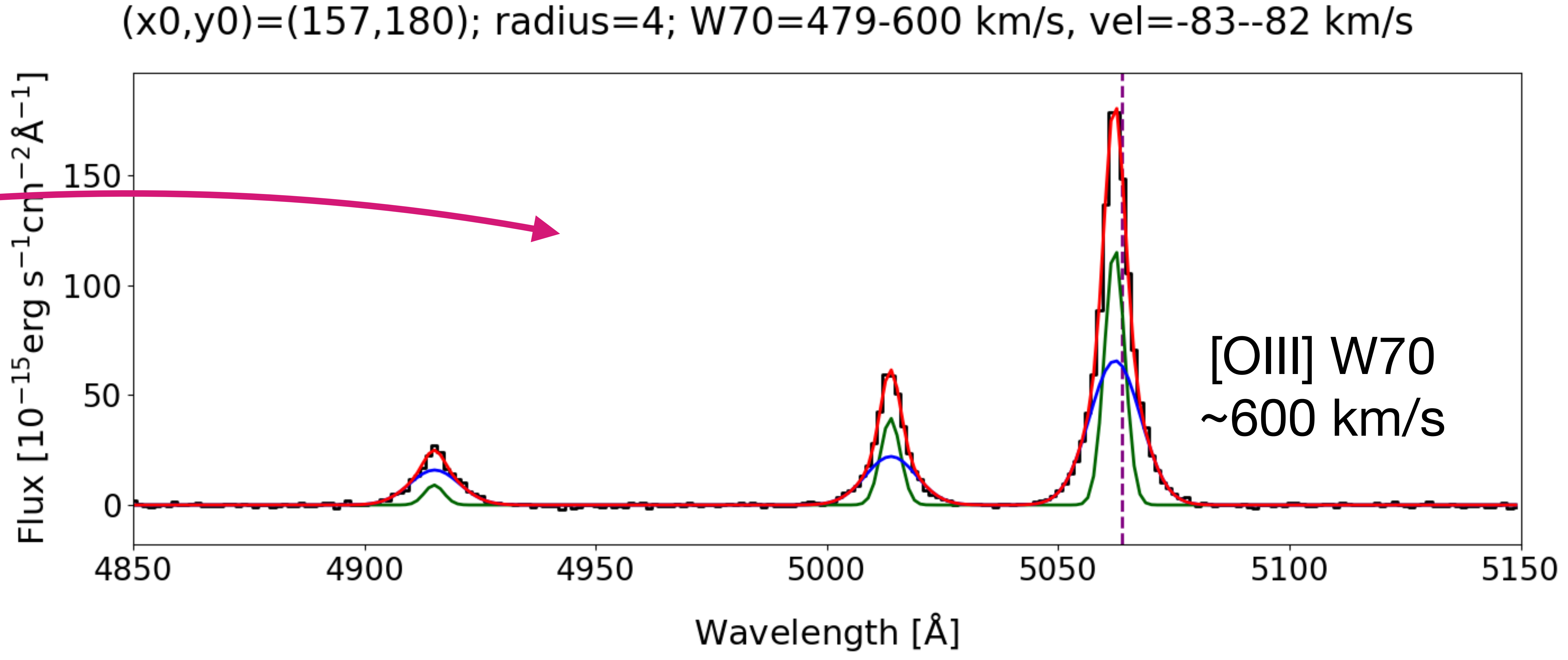
ENHANCED LINE WIDTHS PERPENDICULAR TO JETS!





Also these 4 galaxies show 'classic' asymmetric-line outflow along AGN cones and jet direction





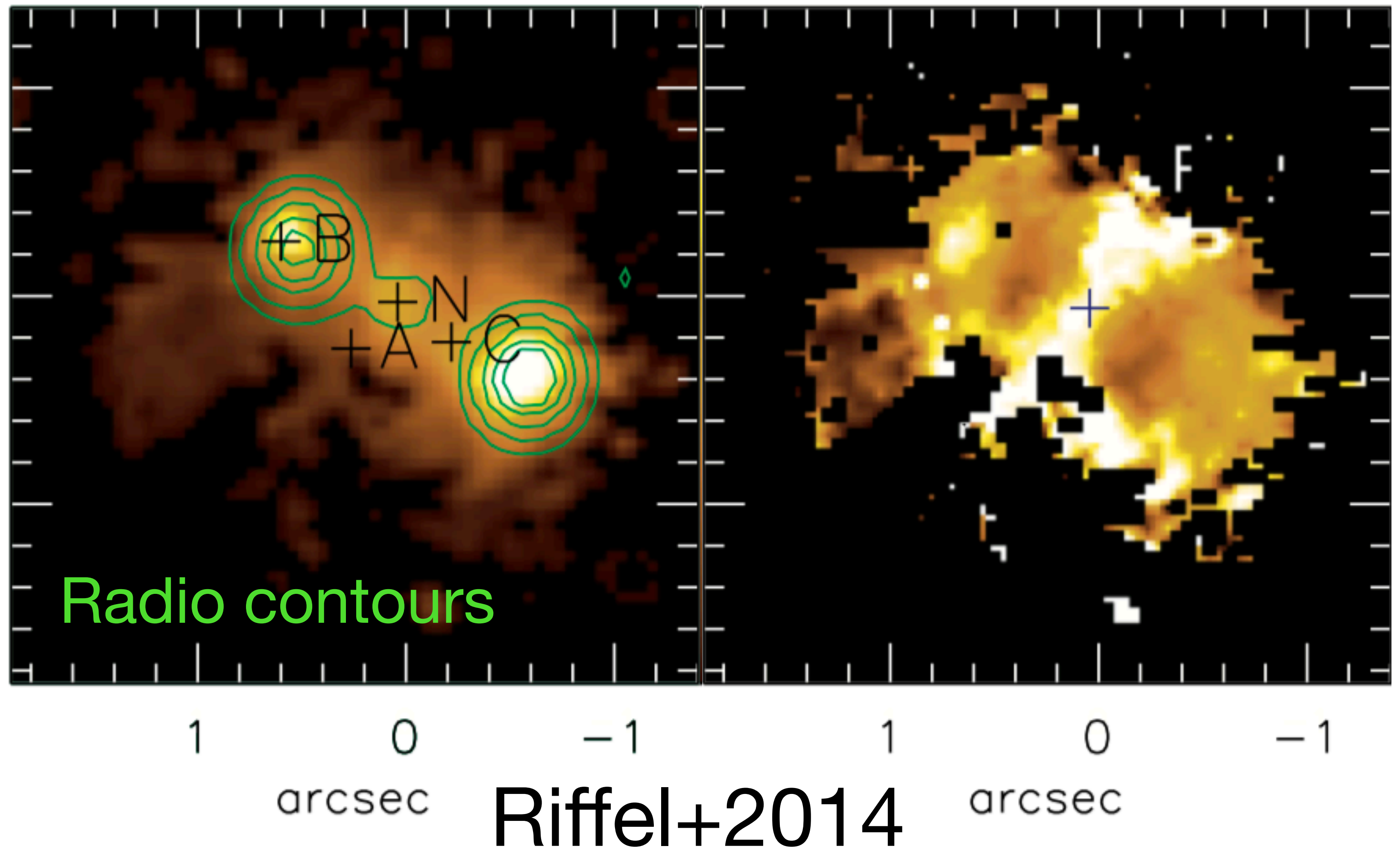
But perpendicular gas is really different, with very broad and fairly symmetric profiles

OBSERVATION OF THE PHENOMENON IN OTHER WORKS

Enhanced velocity dispersion perpendicular to radio jets and ionisation cones **observed in other galaxies hosting compact low-power jets!**

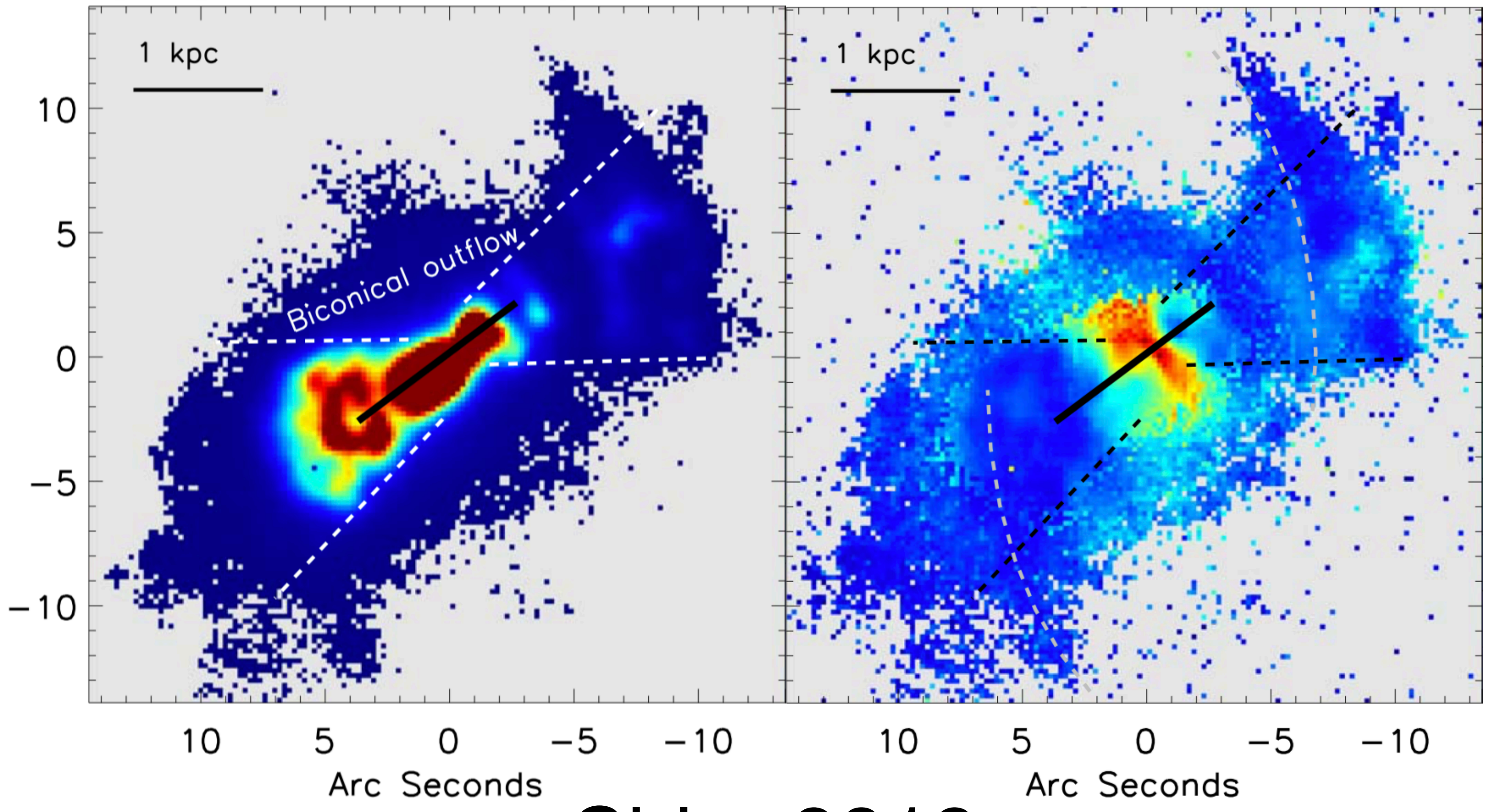
(Couto+13, Riffel+14,15, Schnorr-Müller+14, Lena+15, Diniz+15, Freitas+18, Finlez+18, Shimizu+19, Durré&Mould19, Shin+19, Feruglio+20)

[FeII] flux | [FeII] vel. dispersion



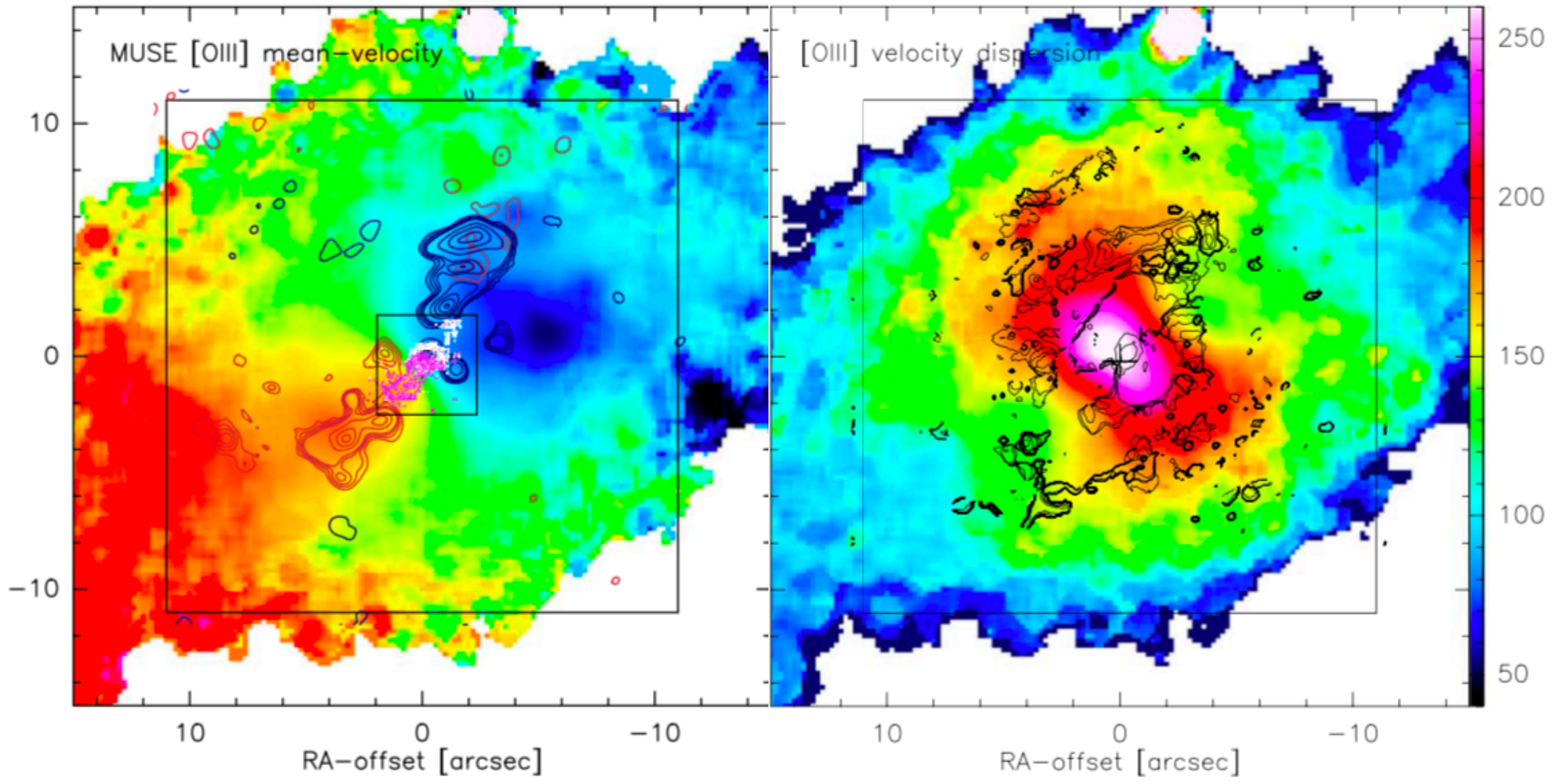
Riffel+2014

[OIII] flux | [OIII] vel. dispersion



Shin+2019

[OIII] velocity: outflow | [OIII] vel. dispersion



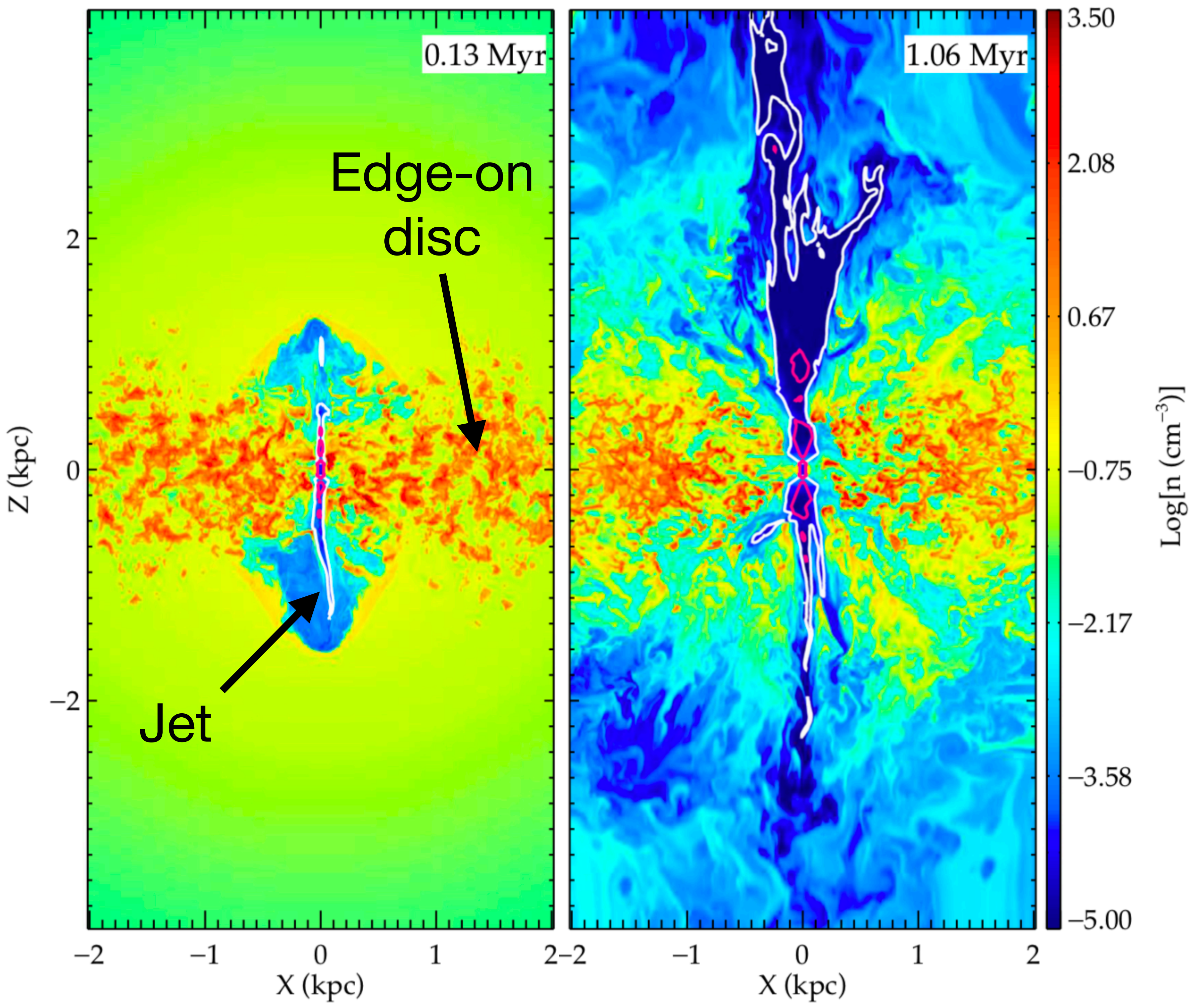
Feruglio+2020

The **jets** in all these galaxies show evidence of being at **low inclinations** (≲40°) w.r.t. **galaxy disc** —> strong **jet-disc interaction!**

JET-DISC INTERACTION SIMULATIONS: EFFECT OF INCLINATION

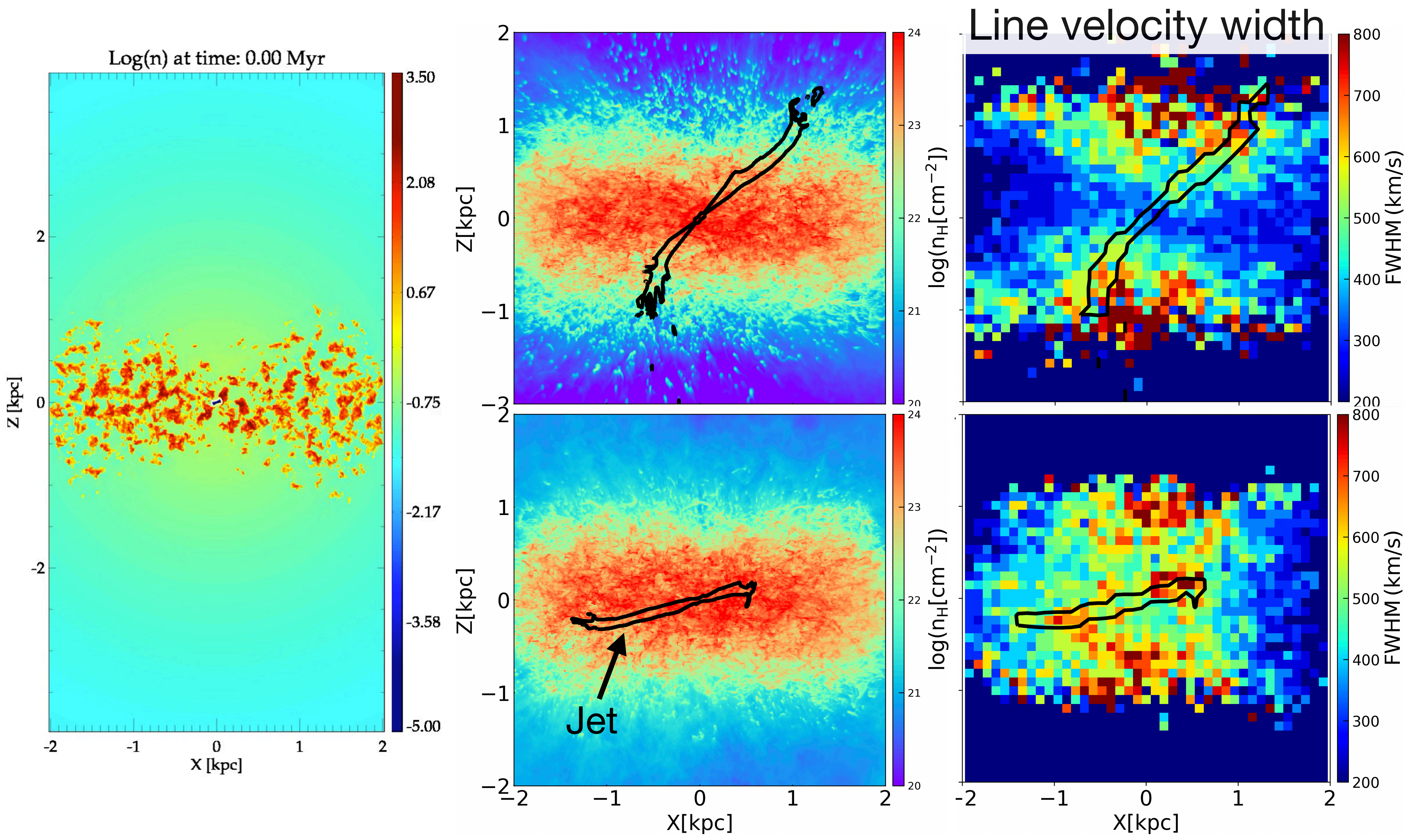
Jet perpendicular to galaxy disc:

weak interaction



Jet with low inclination to galaxy disc:

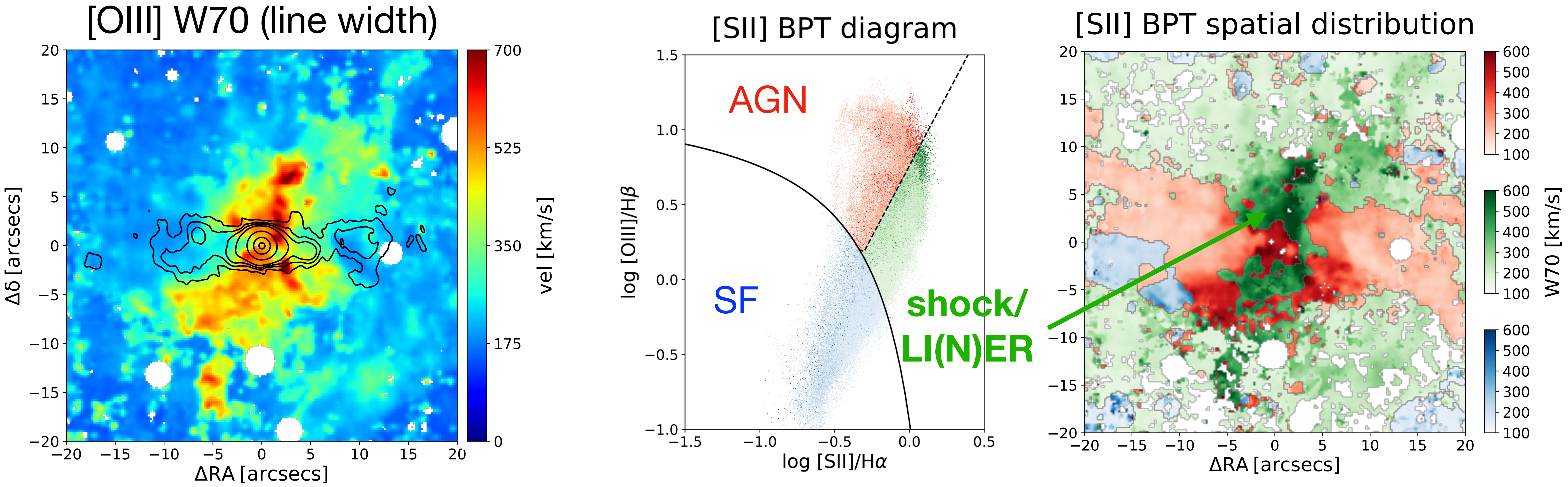
jet trapped in disc and strongly impacts on ISM, by shocking gas clouds and enhancing line velocity width perpendicularly



Mukherjee+2018a, Meenakshi+in prep.

ENHANCED LINE WIDTHS PERPENDICULAR TO JETS!

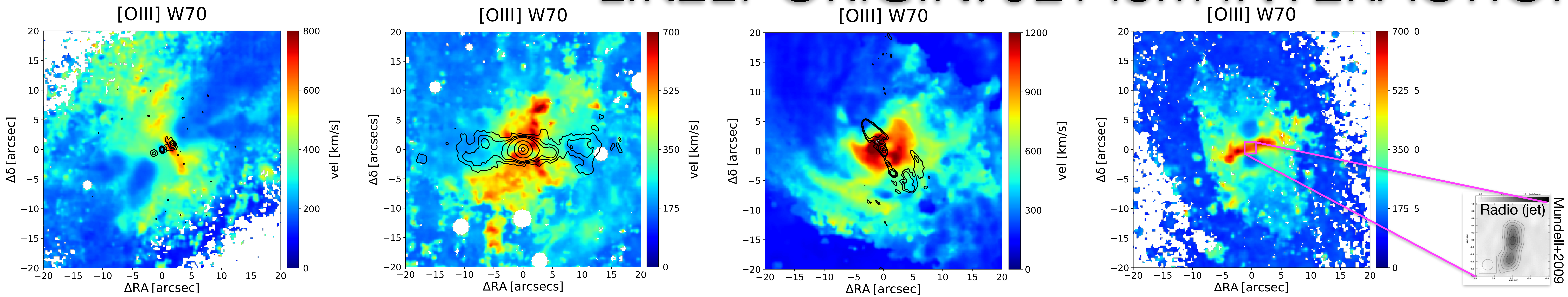
Spatially-resolved **BPT diagrams**, tracing gas ionisation source



High-linewidth regions have shock-like ratios!

Venturi+2020

LIKELY ORIGIN: JET-ISM INTERACTION

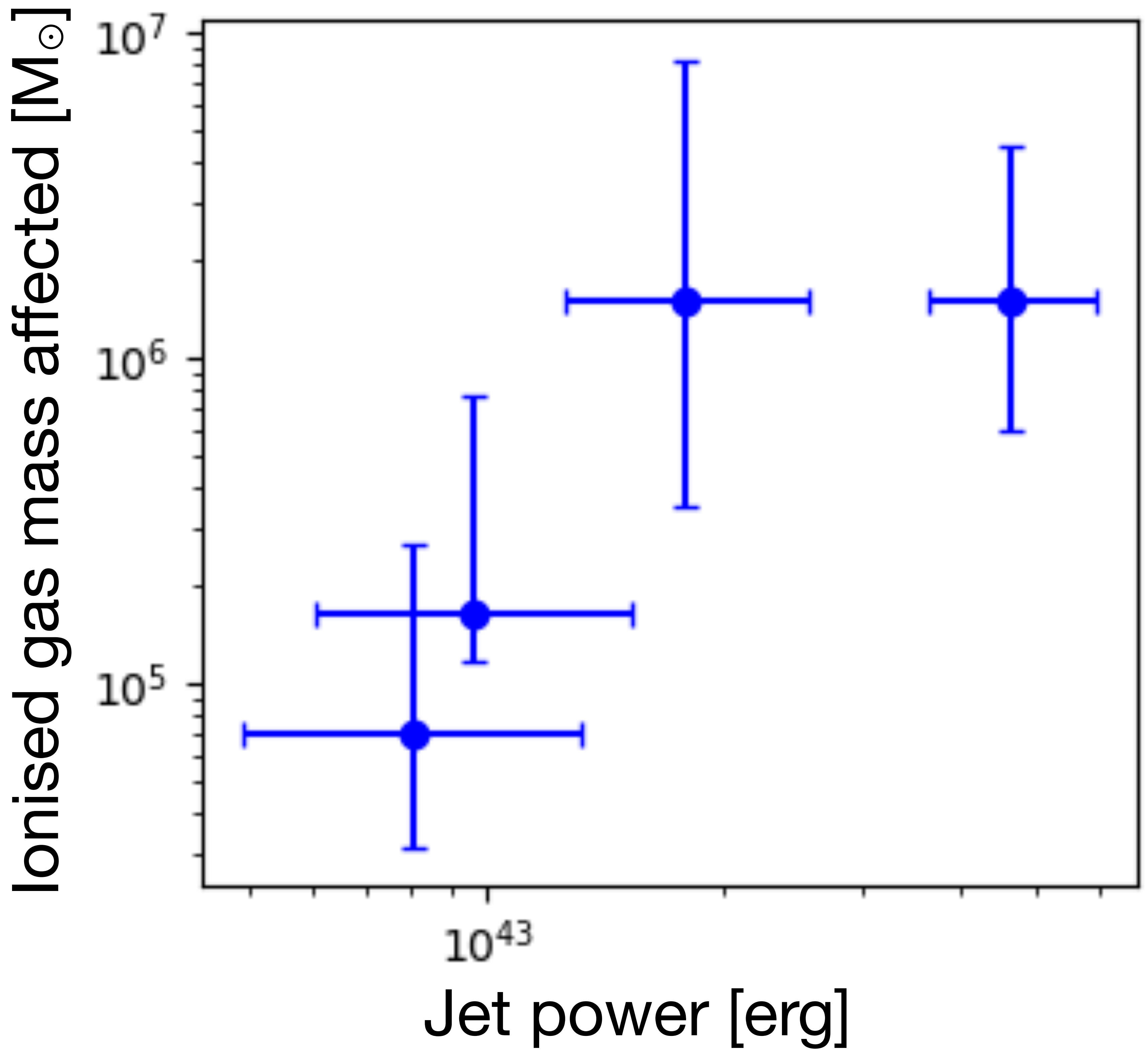


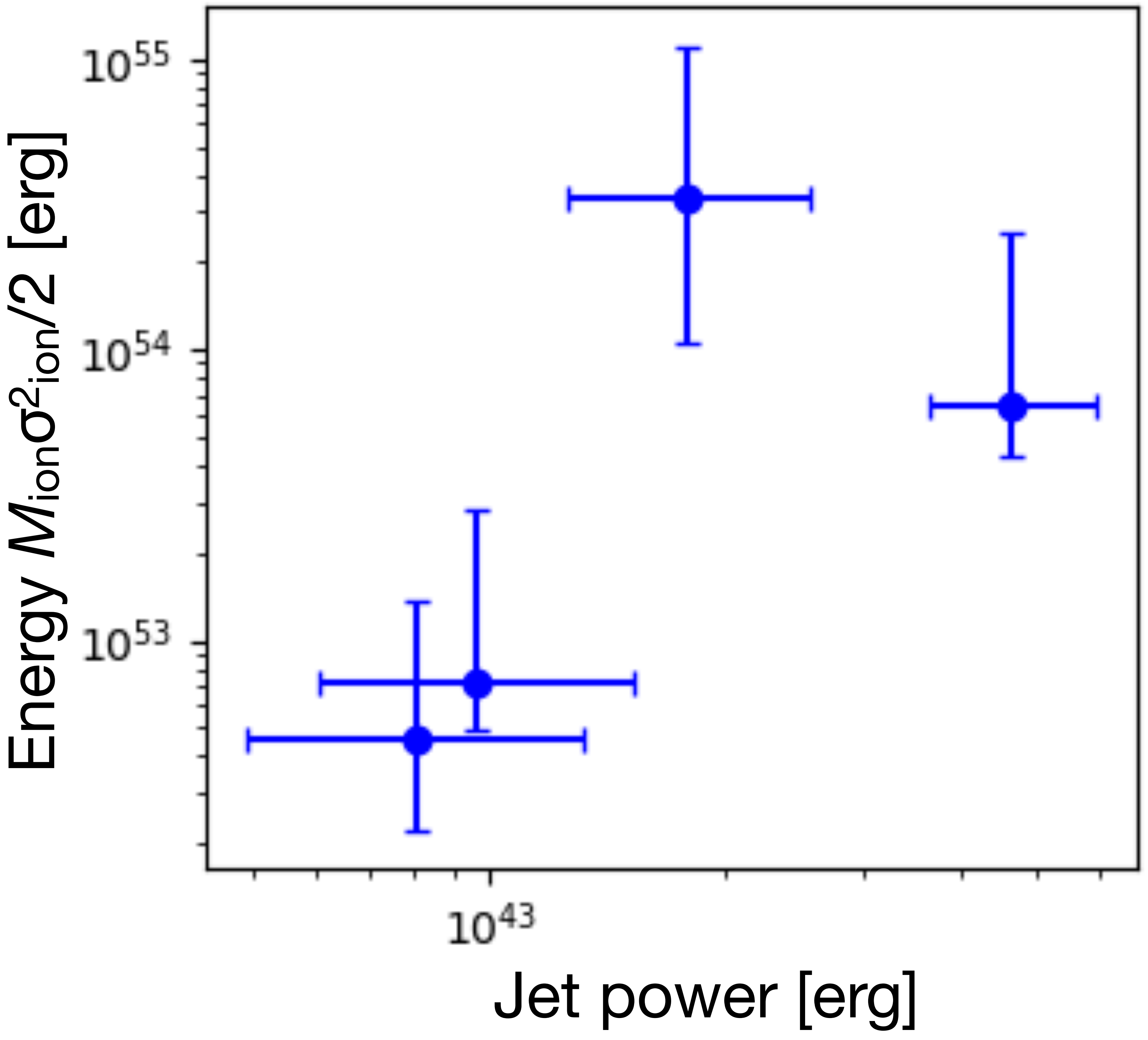
All the galaxies exhibiting the phenomenon of perpendicular enhanced line velocity widths:

- All host a small-scale (≲1 kpc), low-power (≲10^{44} erg/s) jet
- The jets have small inclinations (≲40°) to galaxy disc —> strong jet-ISM interaction
- The perpendicular linewidth-enhanced gas (broad & symmetric lines with no coherent velocity) different from 'classic' AGN NLR outflow (asymmetric lines & coherent velocity) —> Different origin
- The perpendicular linewidth-enhanced gas exhibits shock-ionisation

⟶ **Jet-galaxy disc interaction, perturbing/shocking ISM and driving turbulence perpendicular to propagation, most likely origin for the phenomenon**

AFFECTED IONISED GAS MASS





Ionised mass and energy of gas affected ($W70_{[OIII]}$ > 300 km/s) seems to increase with jet power (but only four objects)

(Couto+13, Riffel+14,15, Schnorr-Müller+14, Lena+15, Diniz+15, Freitas+18, Finlez+18, Shimizu+19, Durré&Mould19, Shin+19, Feruglio+20, Venturi+20)

The phenomenon has been recently observed in a number of sources:

It could potentially be a widespread phenomenon and constitute an additional channel for AGN feedback —> turbulent gas may mix ISM and enrich the CGM…

CONCLUSIONS

- MAGNUM survey: nearby (<50 Mpc) Seyferts observed with VLT/MUSE, high spatial resolution and spectral coverage to study in detail ionised gas outflow physical properties and feedback

- Focus on NGC 1365 MUSE—X-rays: AGN-ionised bi-conical outflow ([OIII]) vs SF (Hα); Radial profiles of v_{out}, $\dot{M}_{out}$, $\dot{E}_{k,out}$, $\dot{P}_{out}$; Extended (optical) vs nuclear (X-ray) wind give insights on driving mechanism

- Peculiar phenomenon: Enhanced line velocity widths observed perpendicularly to low-power low-inclination radio jets and AGN ionisation cones in 4 MAGNUM galaxies and in few recent works —> Jet-ISM interaction within galaxy disc favoured mechanism

Low-power jets have larger impact on host galaxies than previously thought… Potentially important implications for AGN feedback on galaxies