Epoch of Galaxy Quenching

“Virtual Cambridge” - 10 Sep, 2020

Dissecting ionised gas outflows and feedback in nearby AGN through integral field spectroscopy

Giacomo Venturi

FONDECYT Fellow

Instituto de Astrofísica - Pontificia Universidad Católica de Chile, Santiago, Chile

In collaboration with:
A. Marconi, M. Mingozzi, G. Cresci, E. Nardini,
S. Carniani, E. Treister, R. Maiolino, F. Mannucci, M. Perna

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Centro de Astrofísica y Tecnologías Afines

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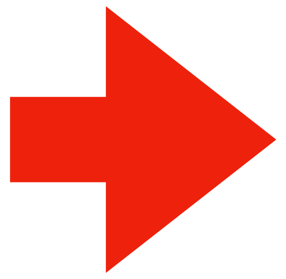
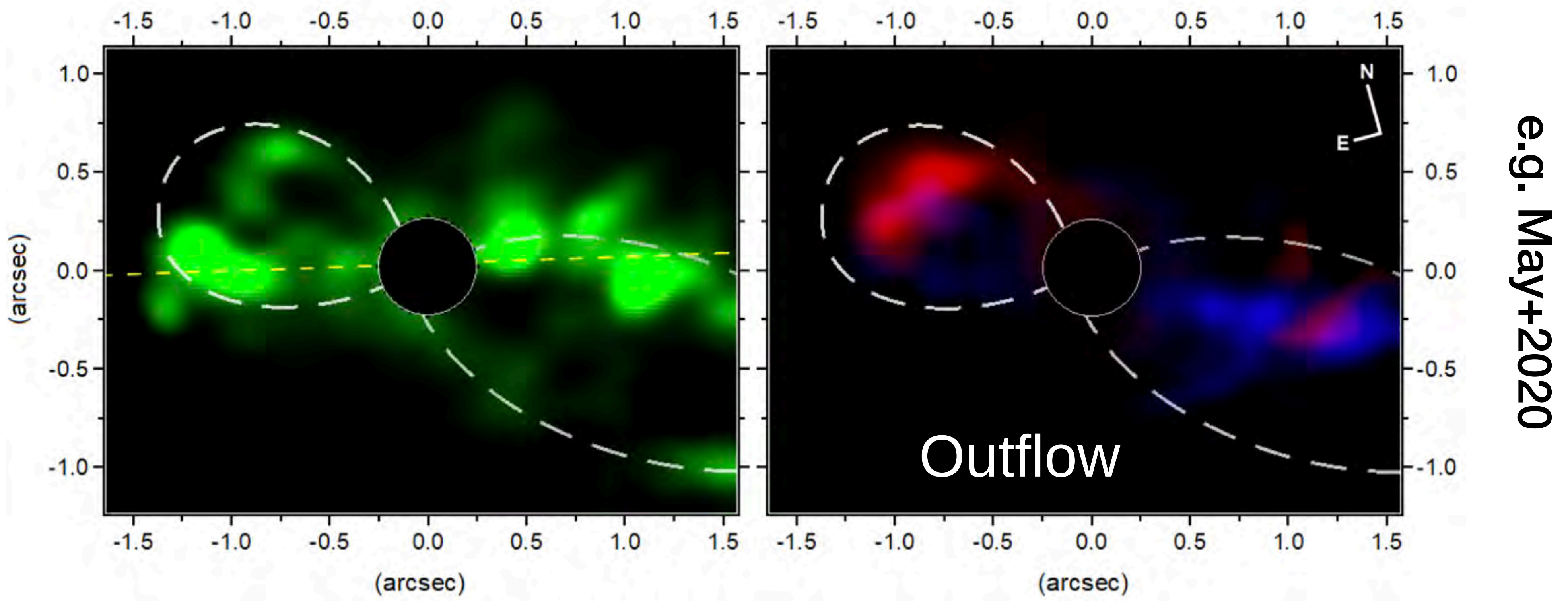
INAF Istituto Nazionale di Astrofisica Osservatorio Astrofisico di Arcetri

AGN can exert feedback on host galaxies through outflows, radiation, jets…

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



Nearby AGN allow to study feedback and outflow properties and structure in detail

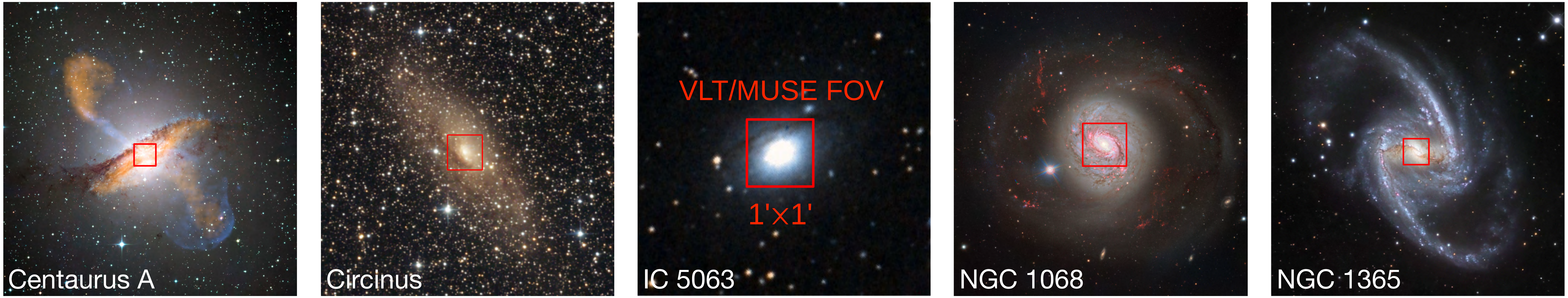


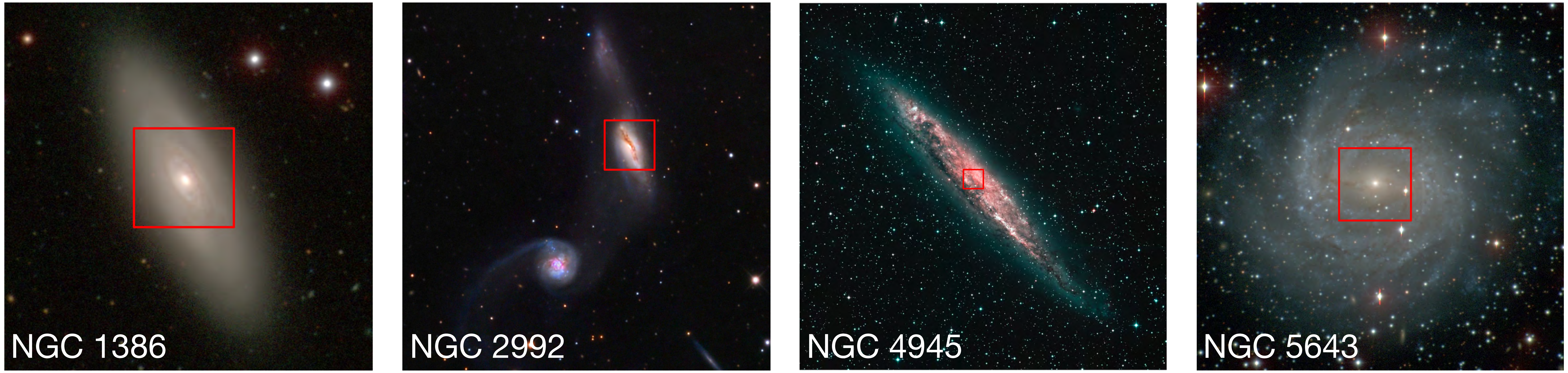
MAGNUM SURVEY OF NEARBY AGN

Nearby (*D*<50 Mpc) **Seyferts** (9 so far): **high intrinsic spatial resolution**

to characterise outflow properties and feedback in detail

VLT/MUSE FOV covers **1 to 15 kpc** with **resolution: 15 pc** (@4Mpc) to **115 pc** (@30Mpc)





Publications:

Cresci+15,

Venturi+17,18,

Mingozzi+19

…and others coming

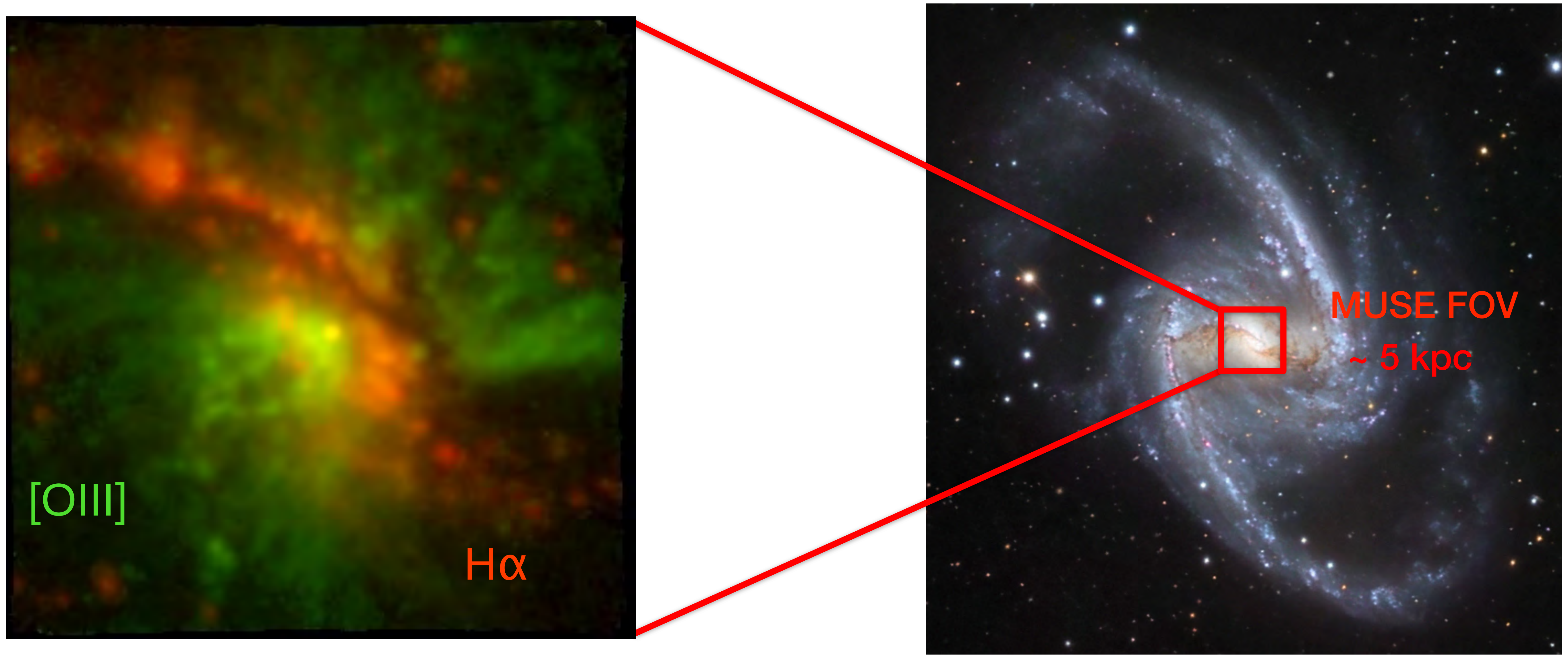
Part 1

Detailed study of ionised gas outflow properties in central kpcs

of NGC 1365 through VLT/MUSE integral field spectroscopy

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

NGC 1365: MAPPING BICONICAL OUTFLOW KINEMATICS

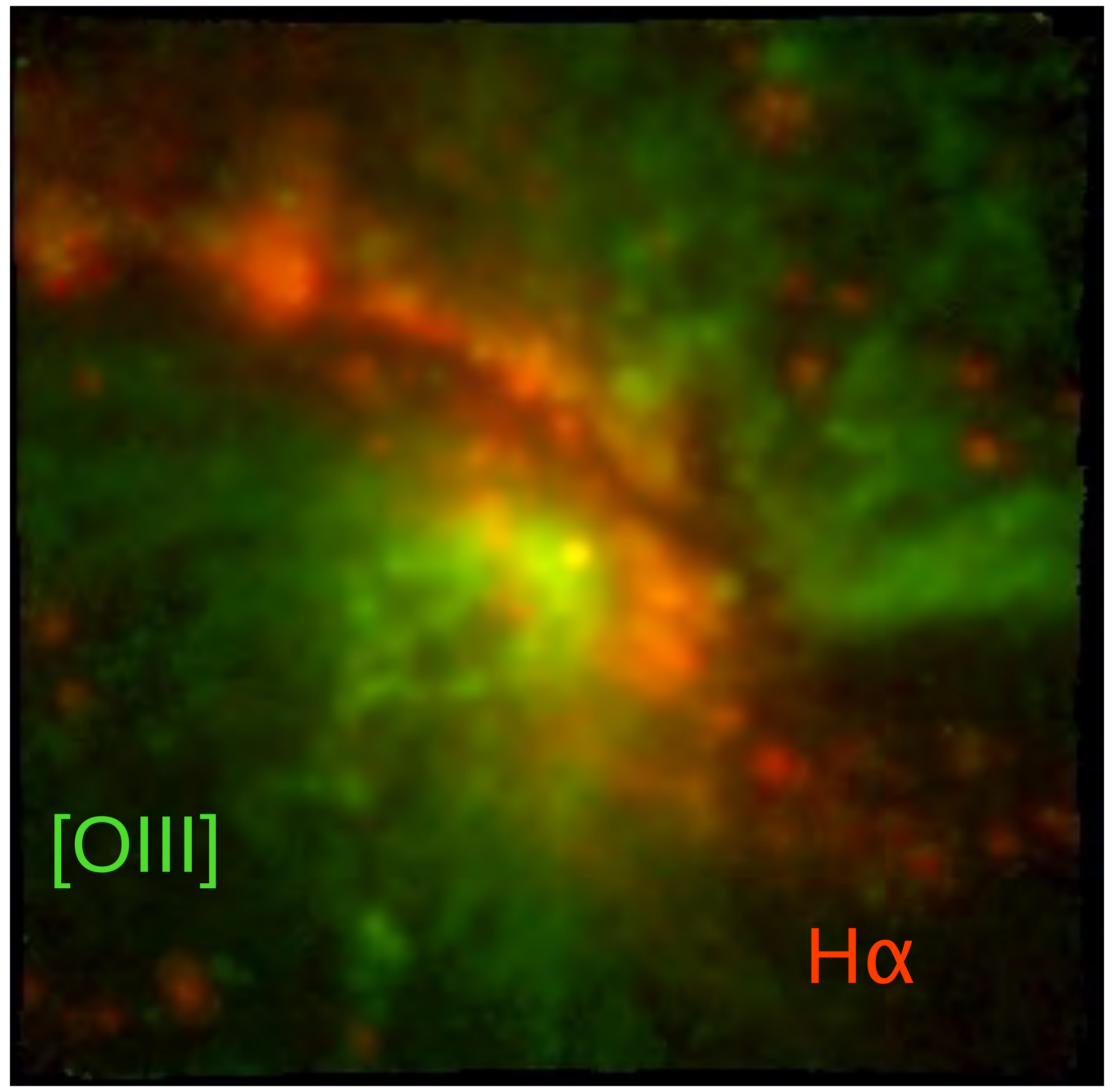


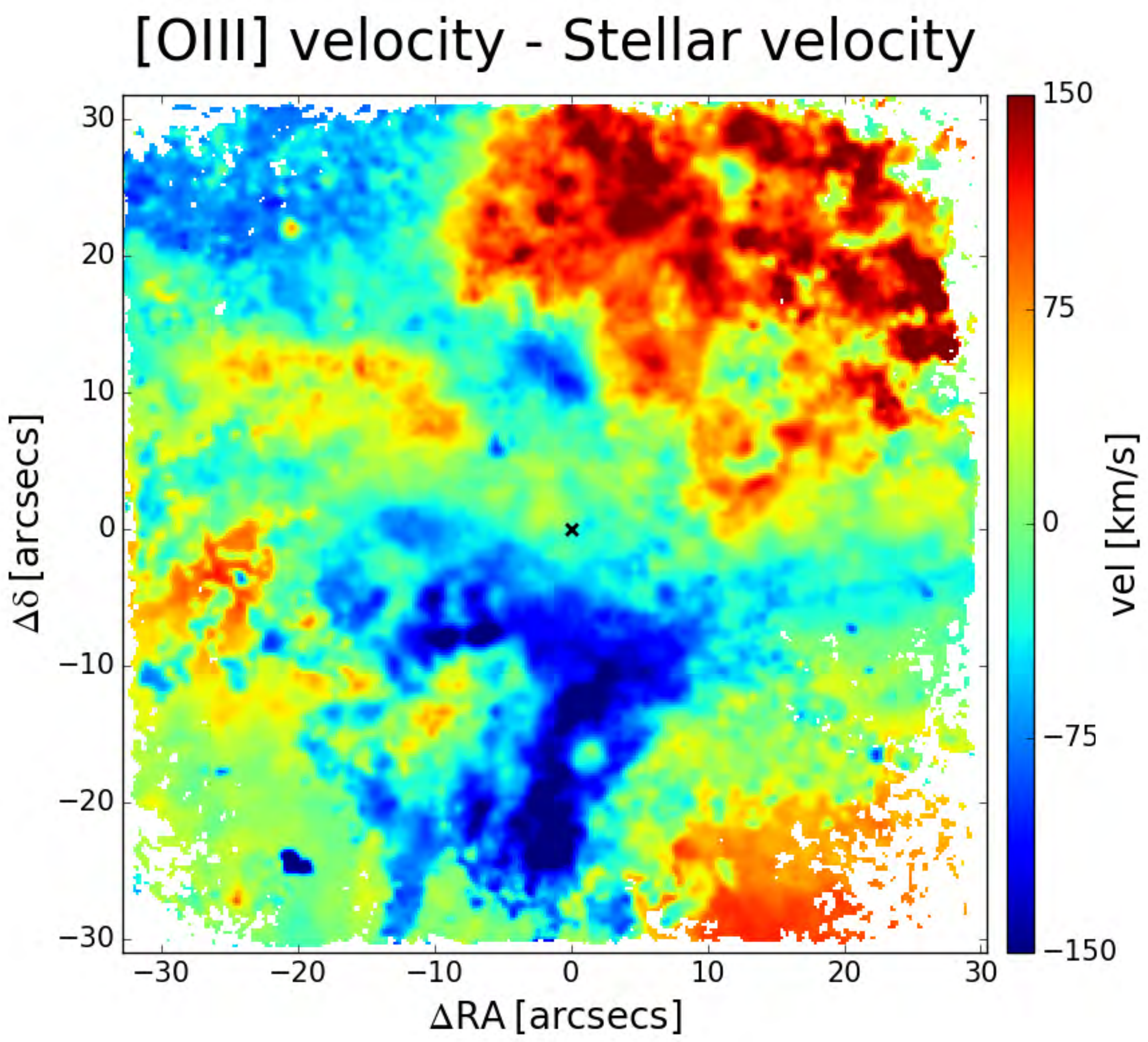
Massive barred galaxy (4×10^{11} $M_{\odot}$)

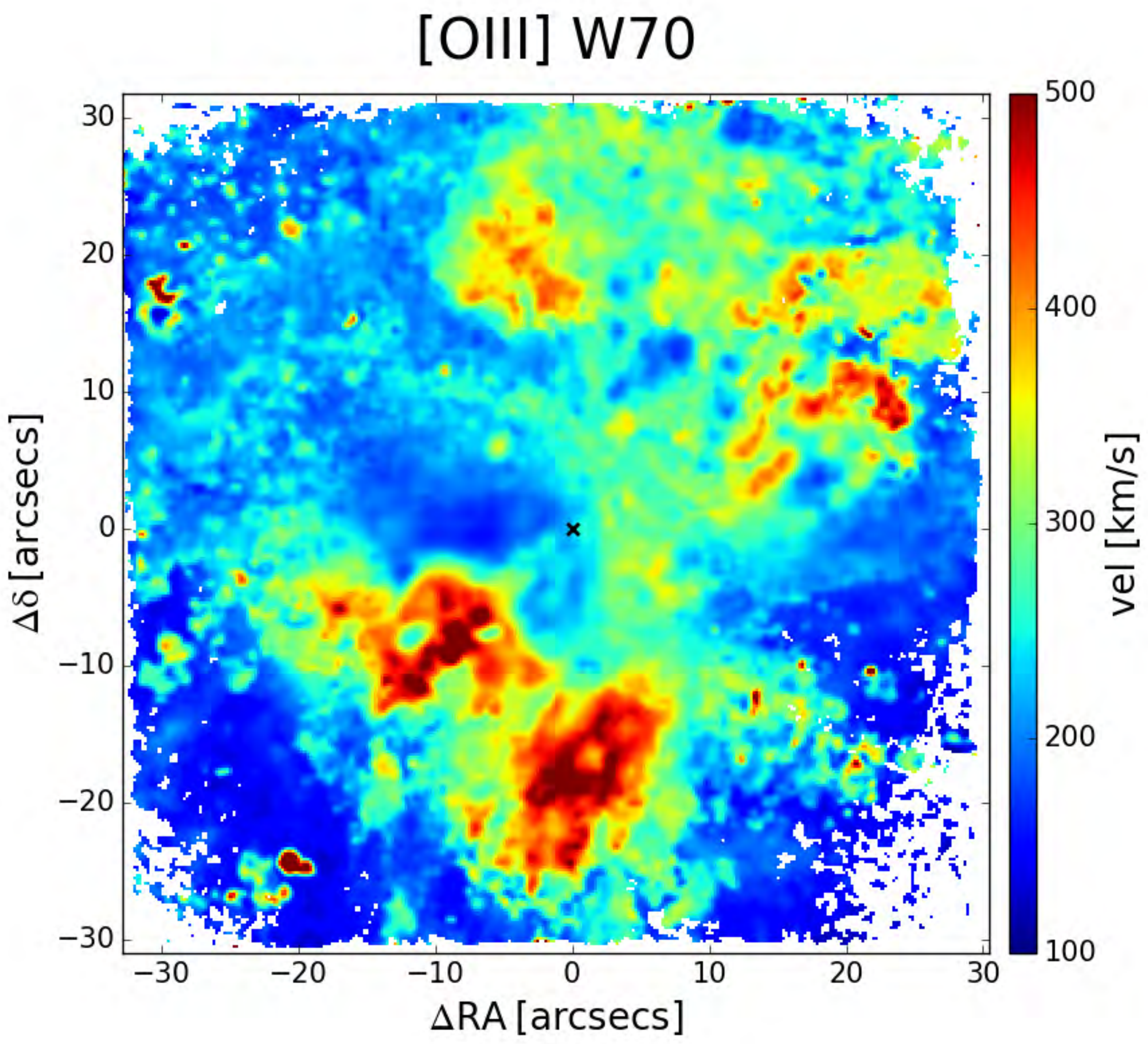
hosting a low-luminosity AGN:

L_{AGN} ~ 2×10^{43} erg/s

NGC 1365: MAPPING BICONICAL OUTFLOW KINEMATICS







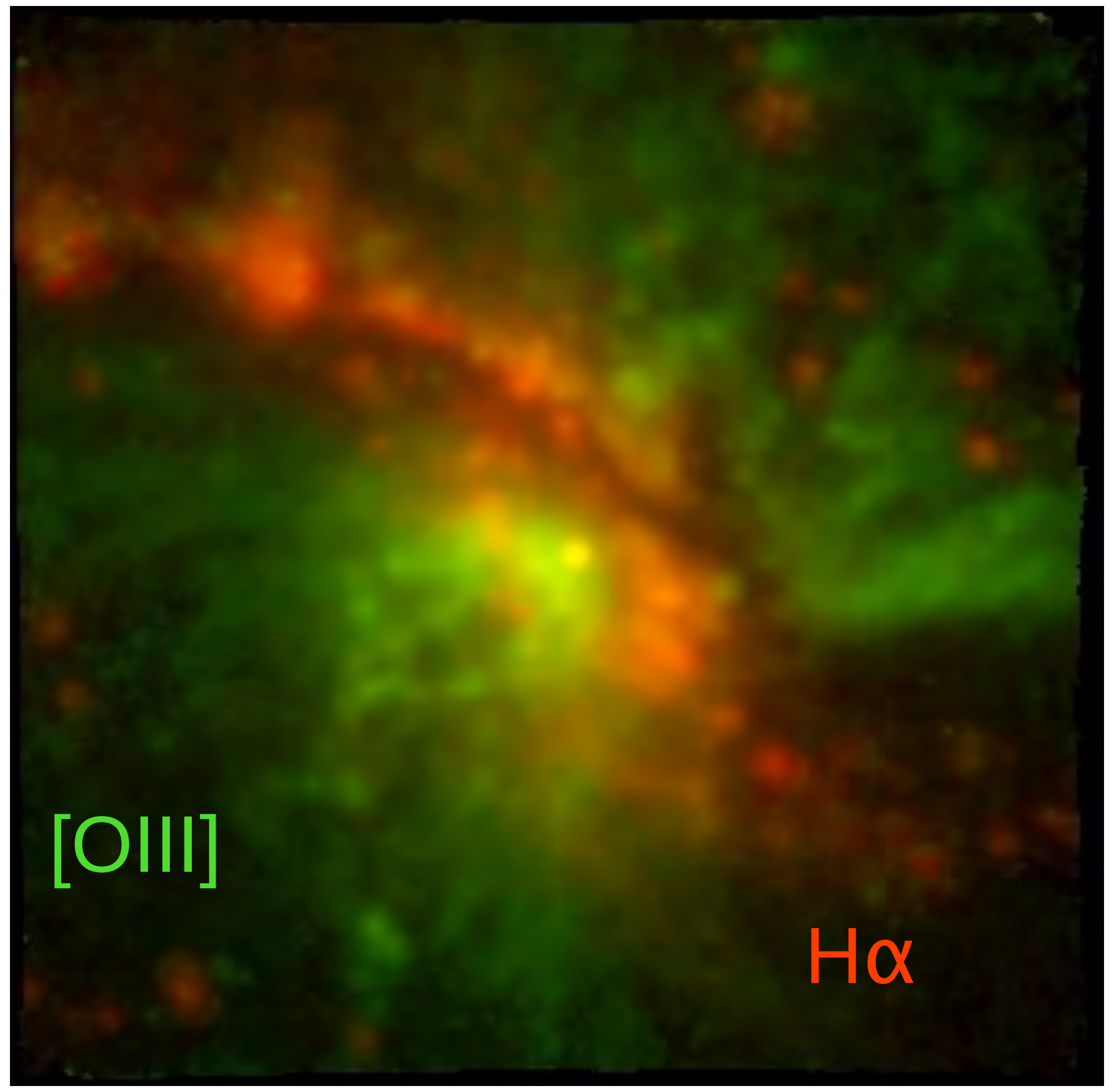
NW cone: positive velocity

→ receding

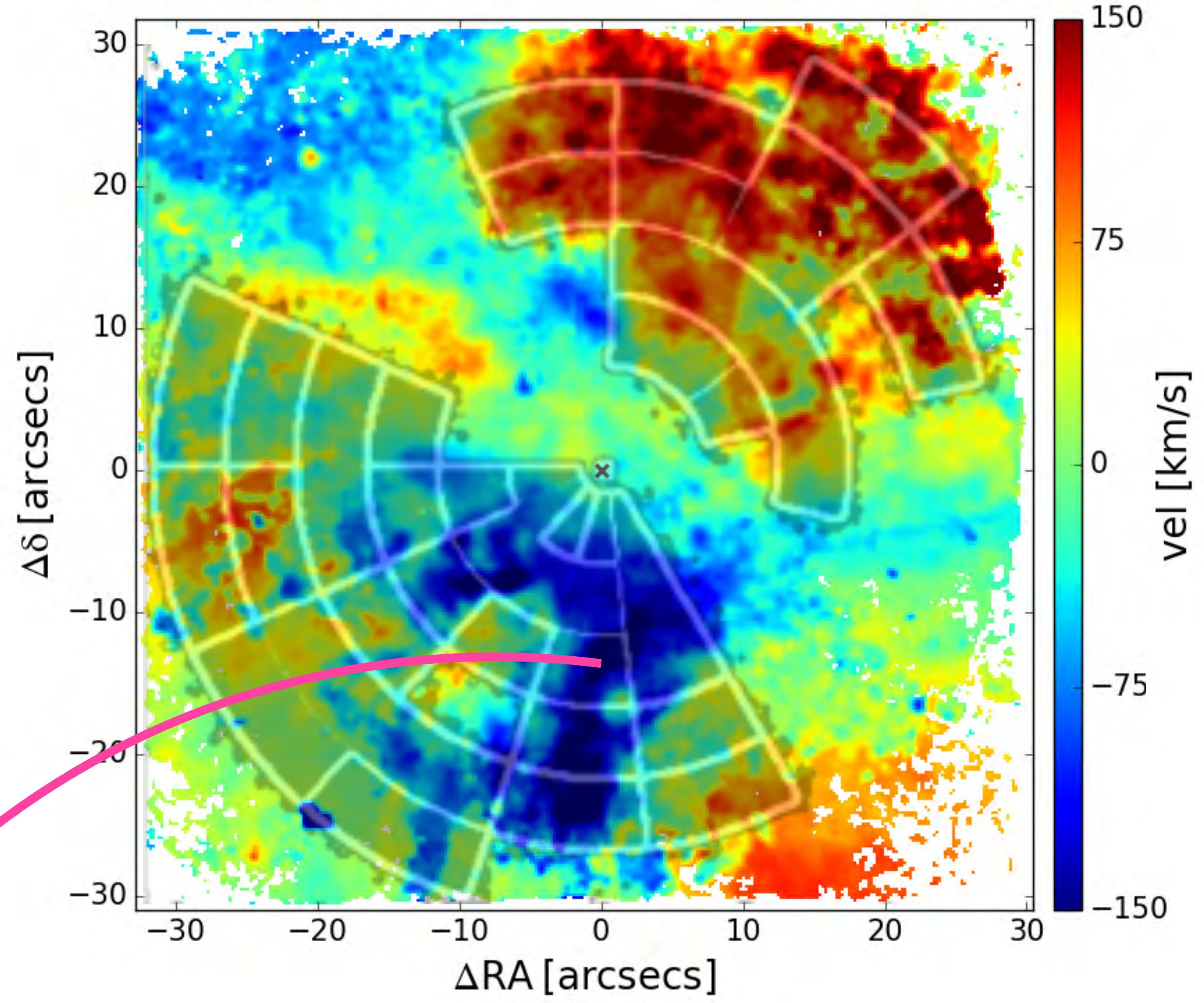
SE cone: negative velocity

→ approaching

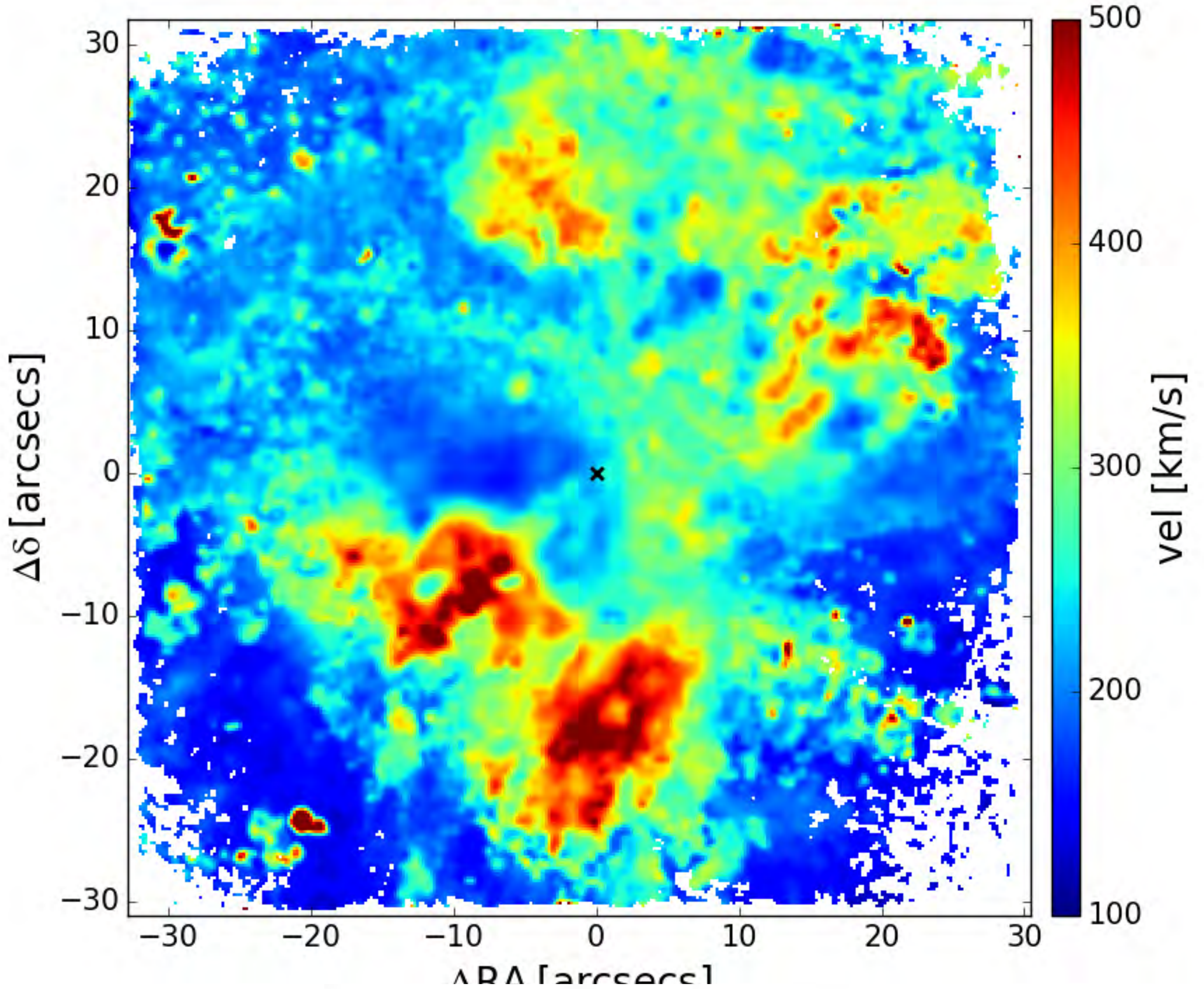
NGC 1365: MAPPING BICONICAL OUTFLOW KINEMATICS



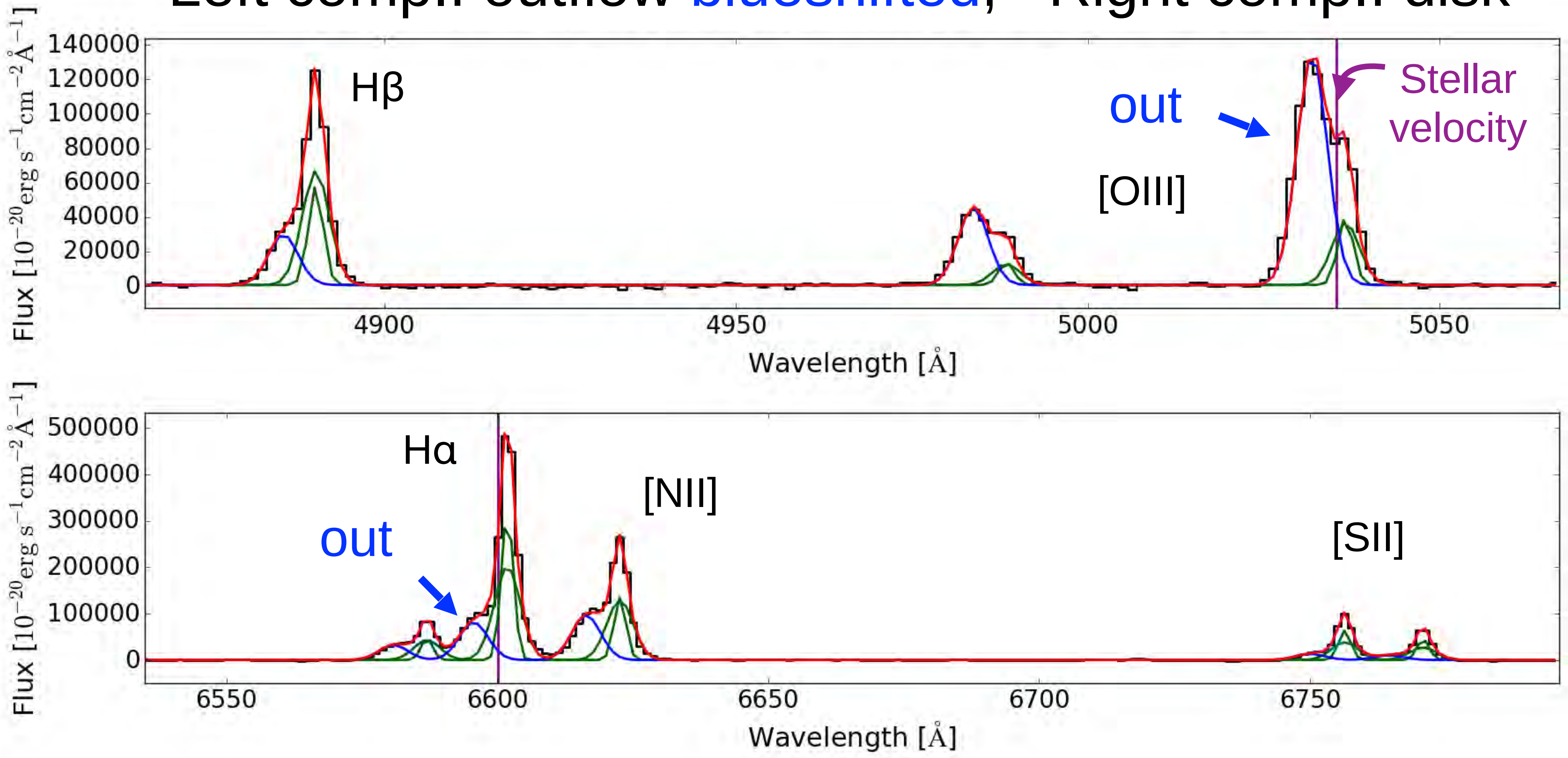
[OIII] velocity - Stellar velocity



[OIII] W70



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



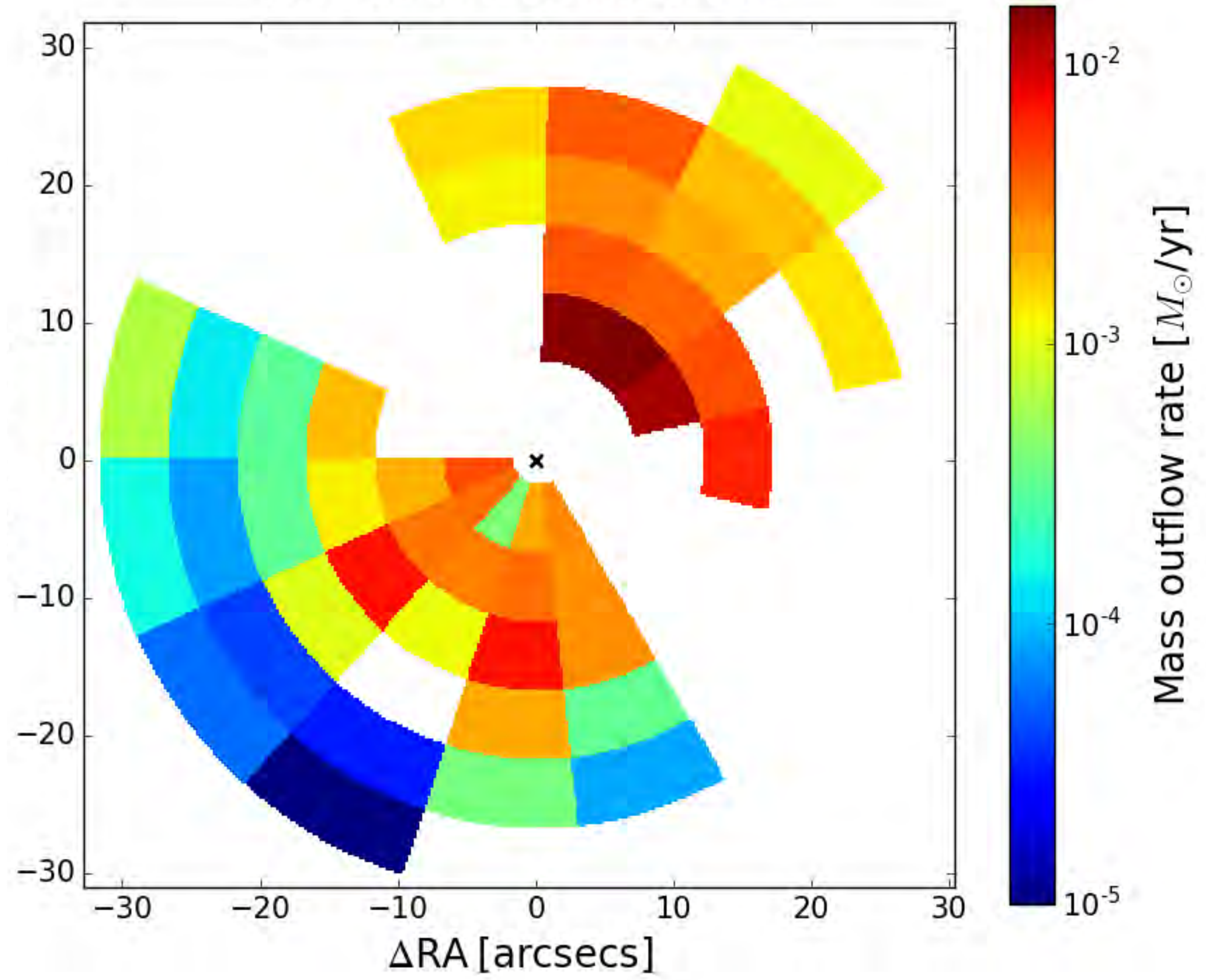
Outflow is not a broad wing

← as at low resolution

in more powerful AGN

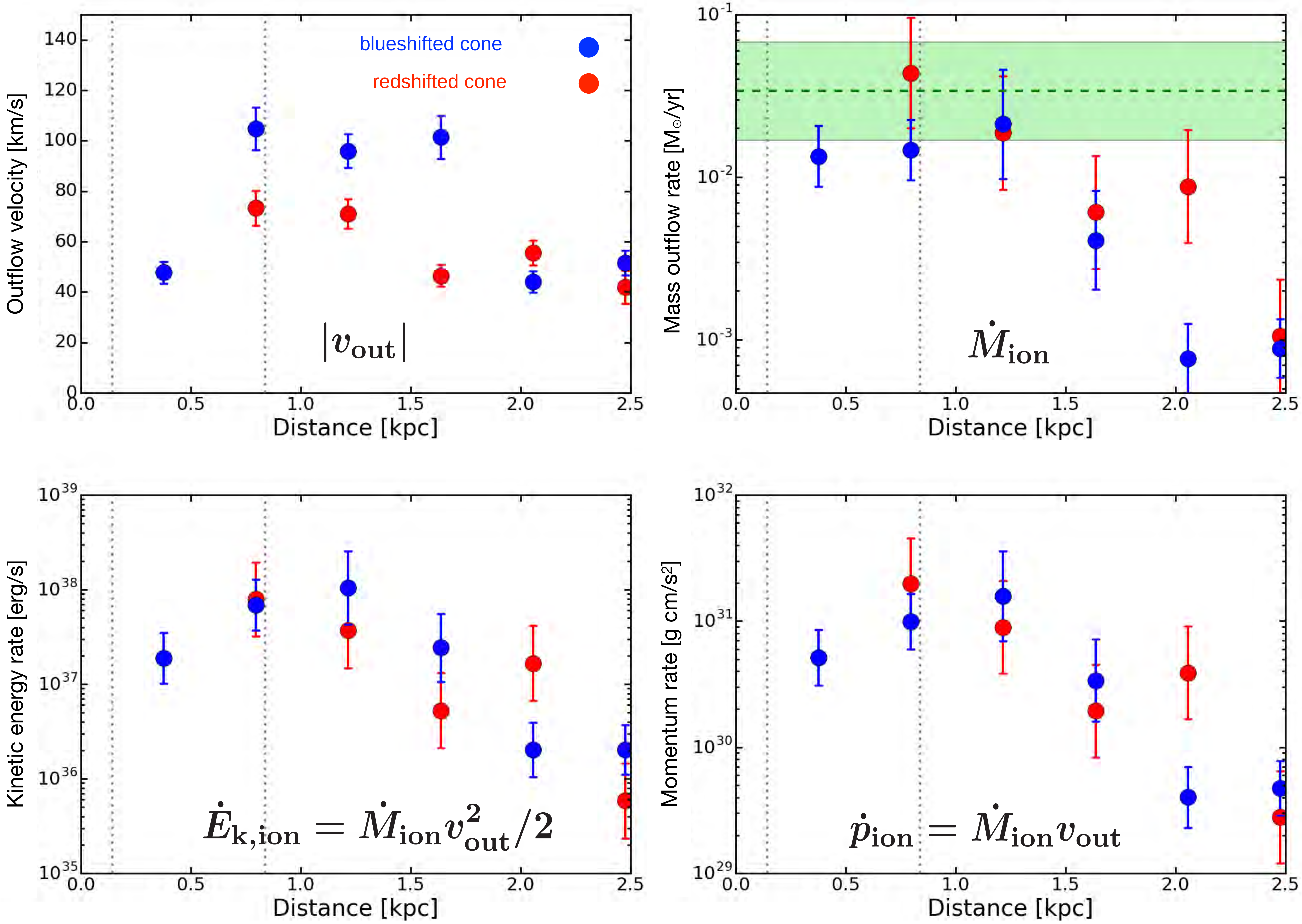
$$\dot{M}_{\rm out} = \frac{M_{\rm out} v_{\rm out}}{\Delta R}$$

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

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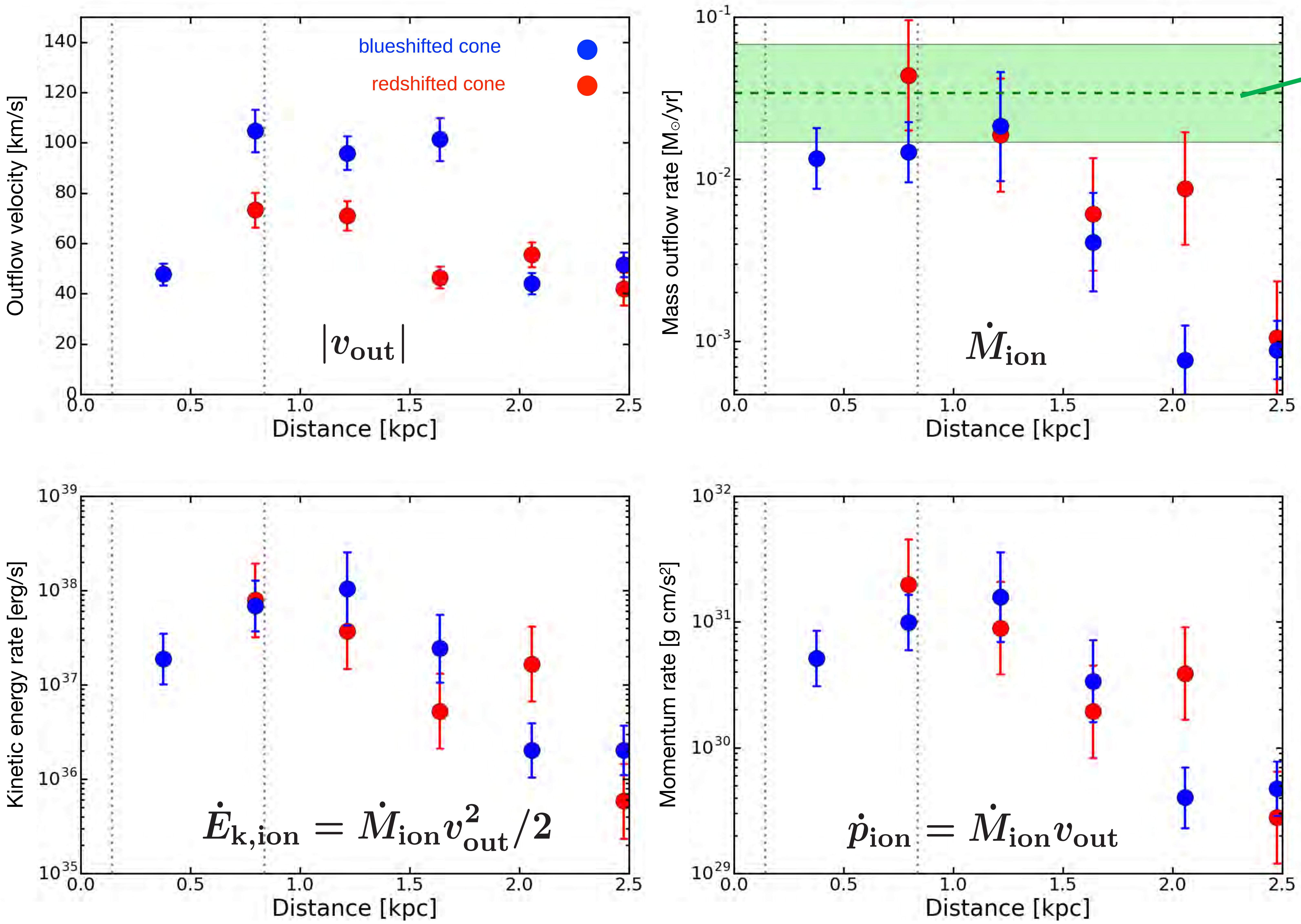
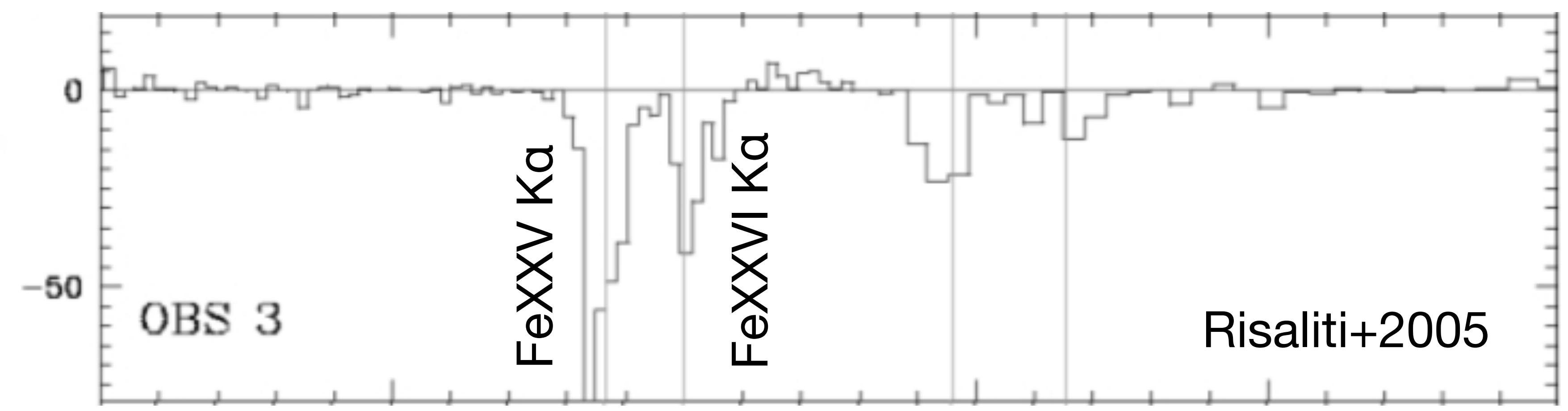


Mass outflow rate of nuclear X-ray wind ($v_{\rm out,X}$ ~ 3000 km/s) from FeXXV and FeXXVI absorption lines



- **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: $\dot{p}_{\rm ion+neutr}$ ~ 1-5 $L_{\rm AGN}/c$)

  —> feasible driver in principle!

Part 2

Enhanced line velocity widths perpendicular to radio jets and

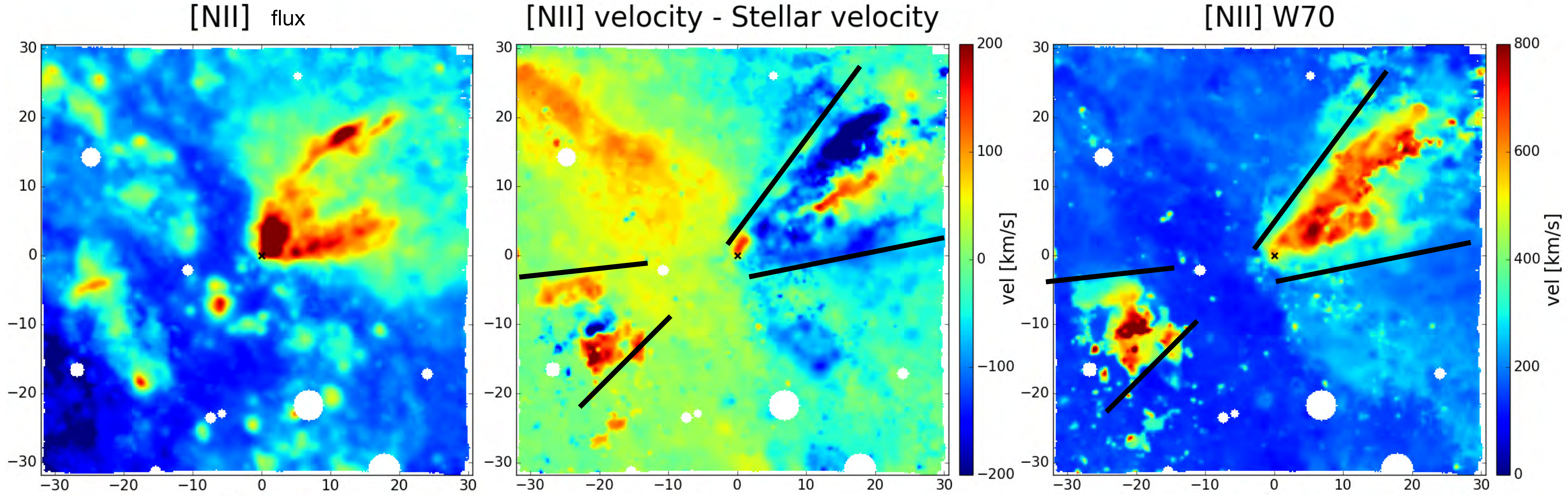
AGN cones as tracers of jet-disc interaction

(Venturi et al., to be subm.)

OUTFLOWS IN AGN

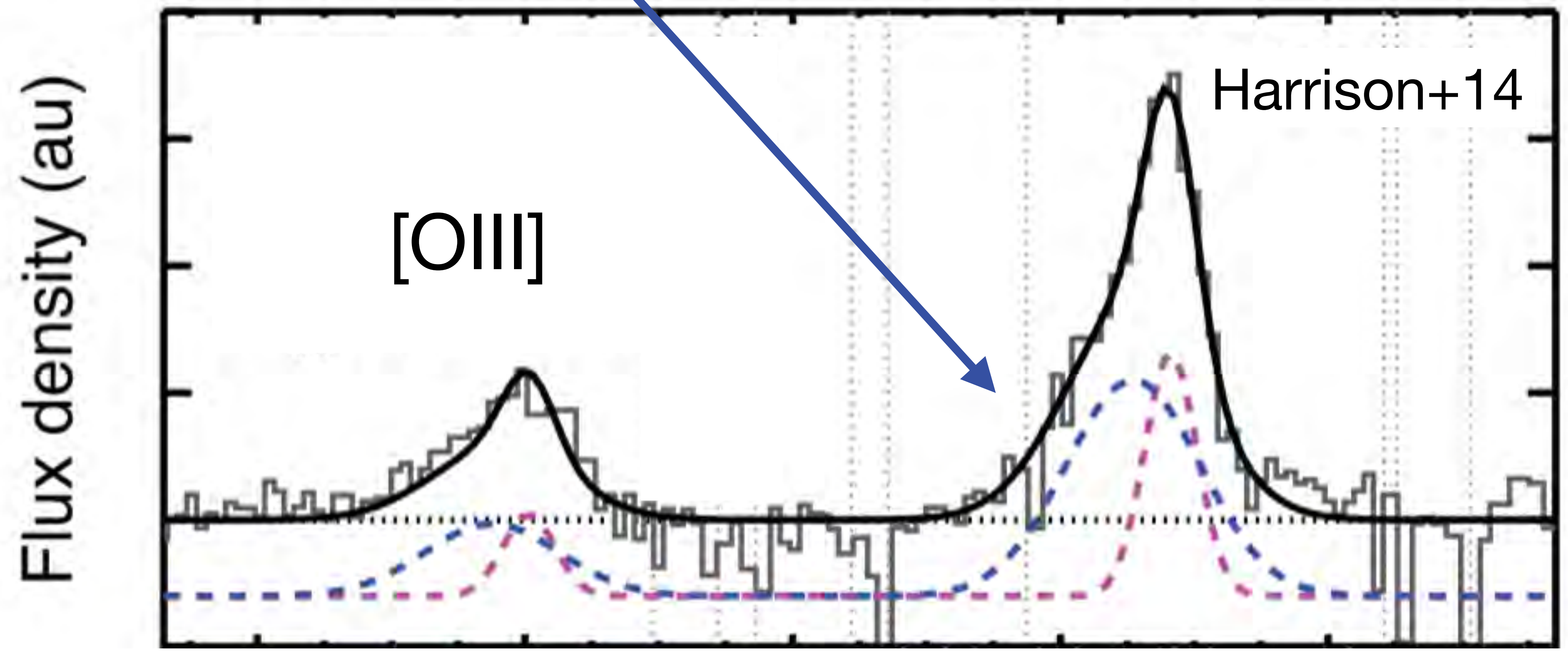
Galactic **outflows** normally observed in the **direction** of the **AGN ionisation cones** or **jets**

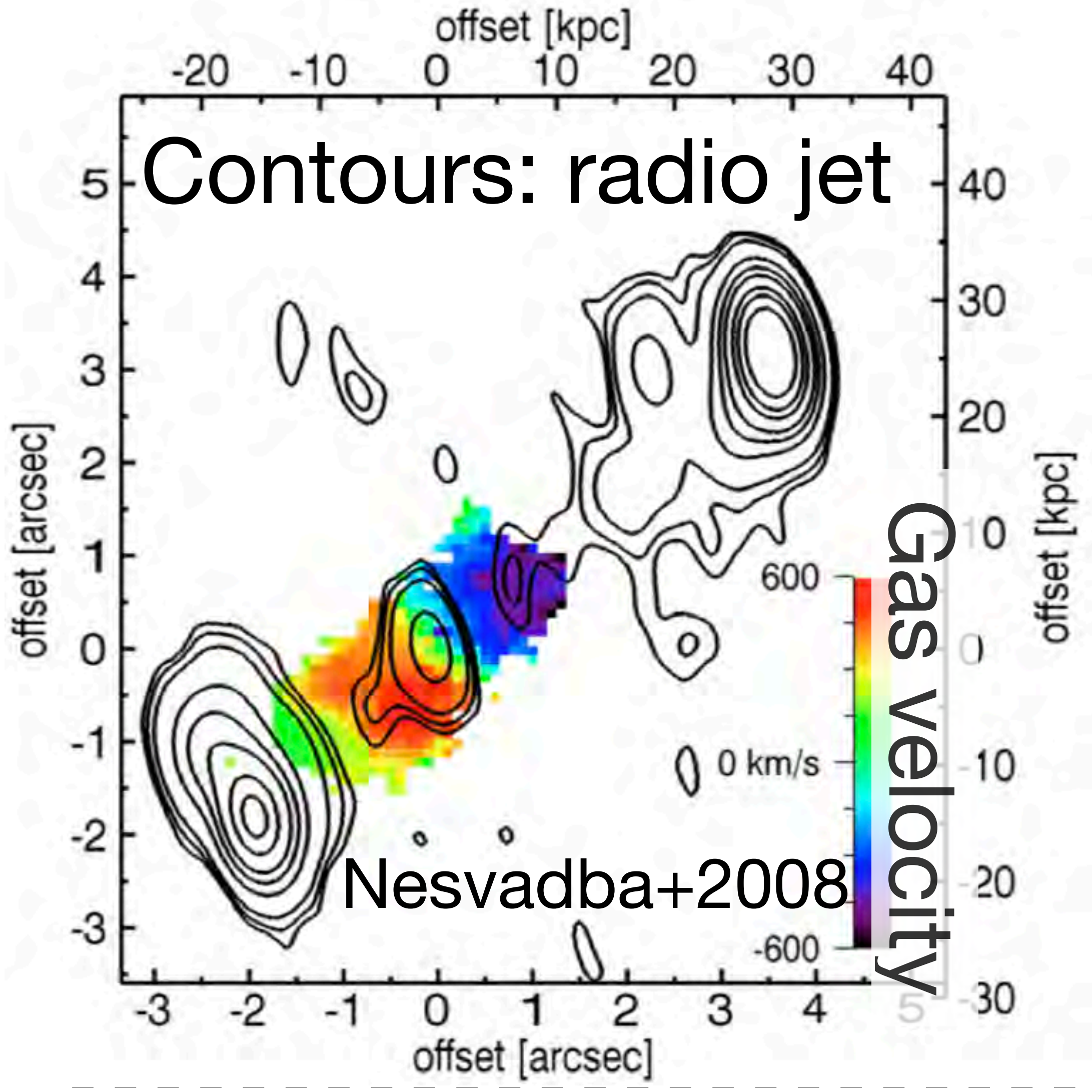
NGC 4945



Venturi+2017

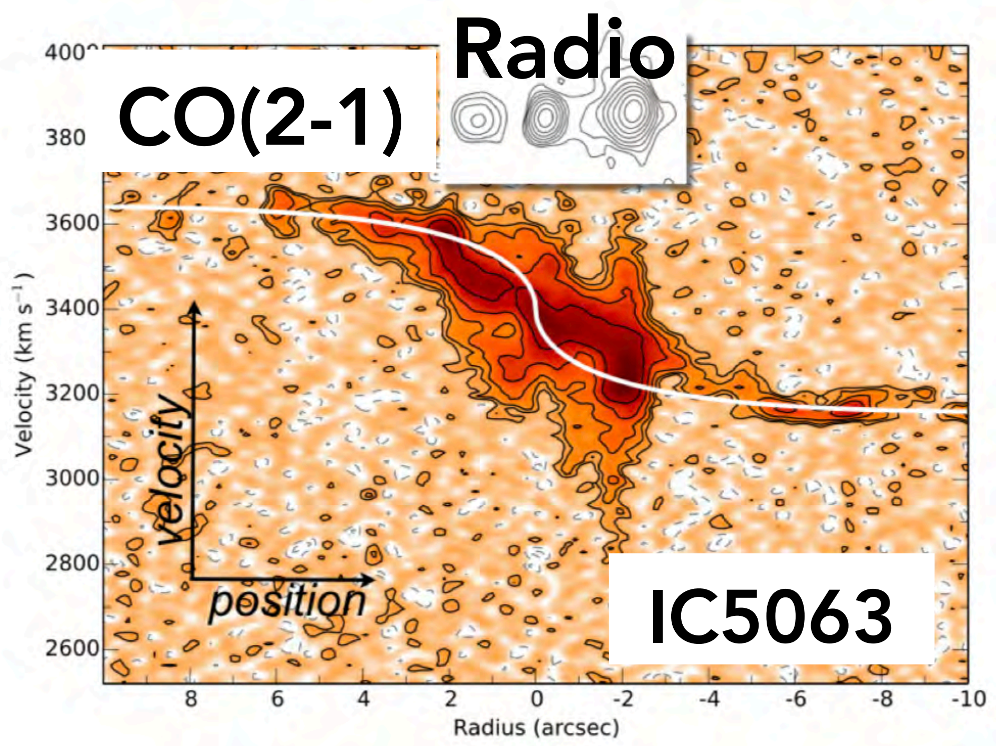
Asymmetric wings in emission lines



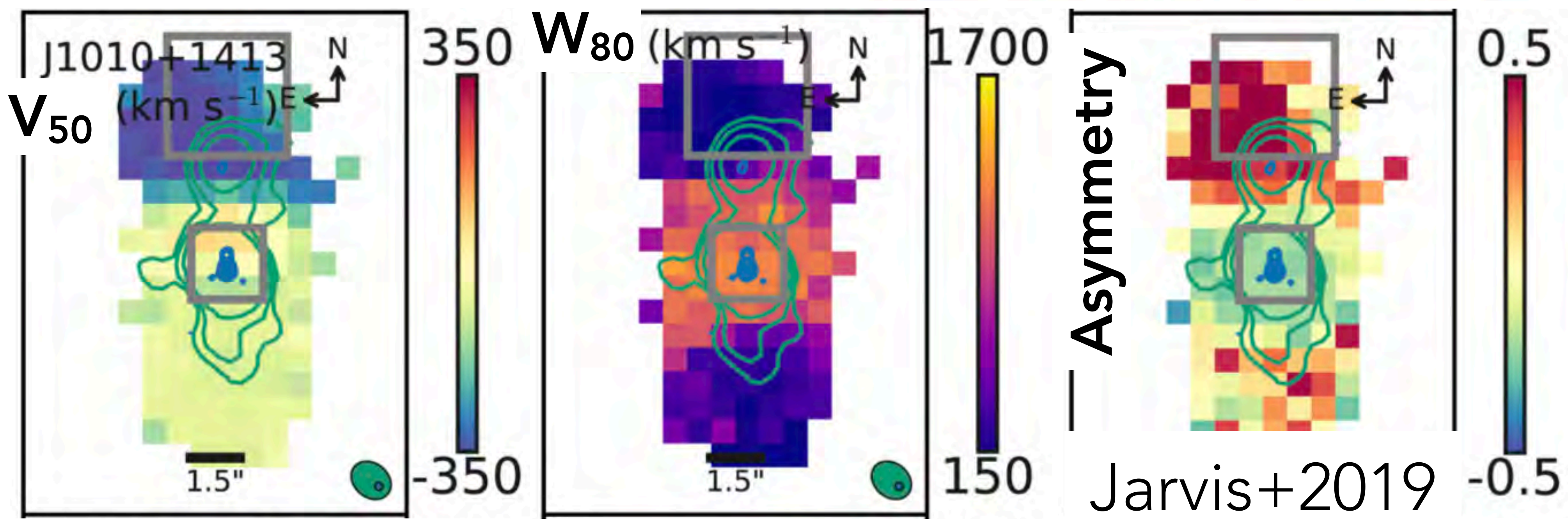


Radio-loud AGN
(see also e.g. Vayner+17,20)

Recently found that also **low-power jets** (≲10^{44} erg/s) can induce outflows!

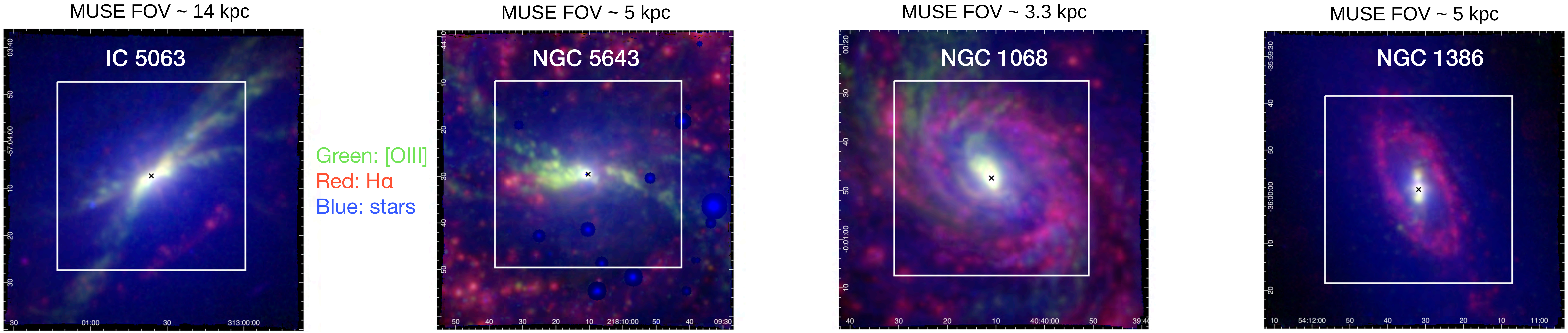


Morganti+2015,2016, Oosterloo+2017



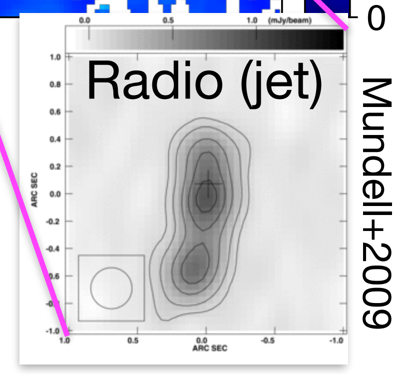
Jarvis+2019

ENHANCED LINE WIDTHS PERPENDICULAR TO JETS



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

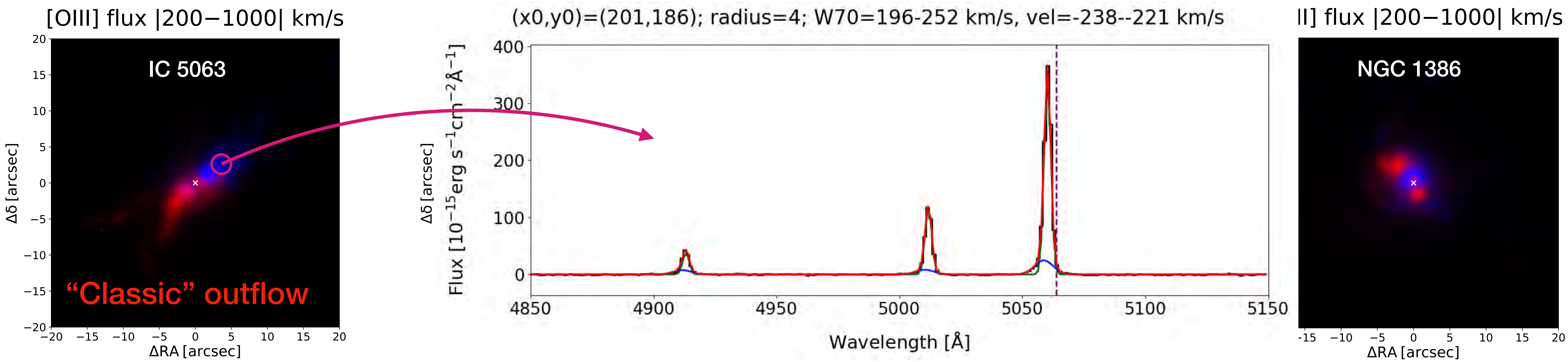
ENHANCED LINE WIDTHS PERPENDICULAR TO JETS

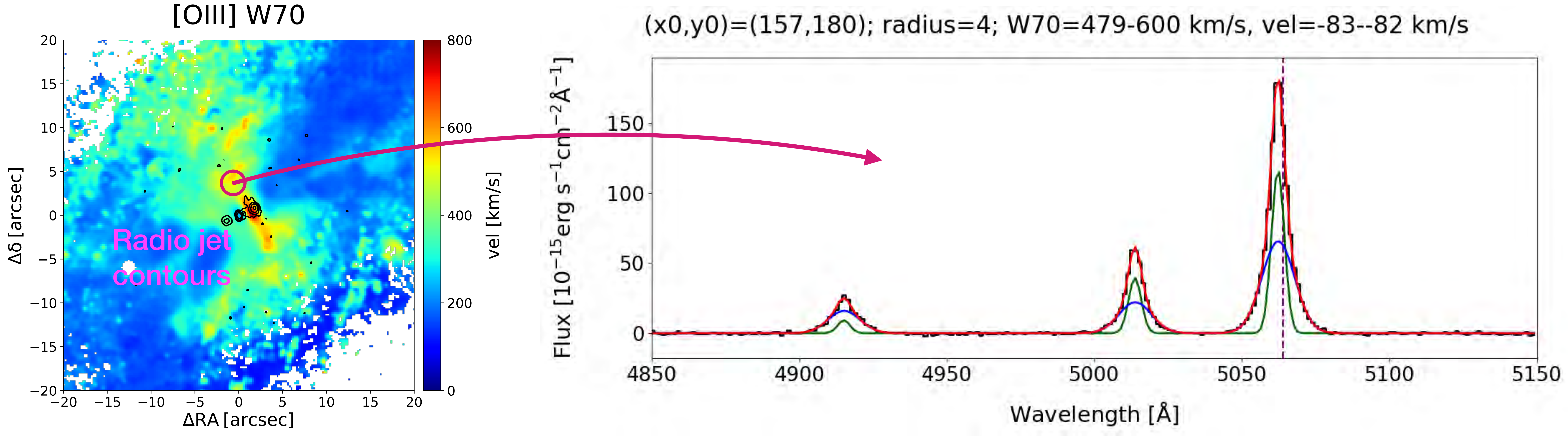


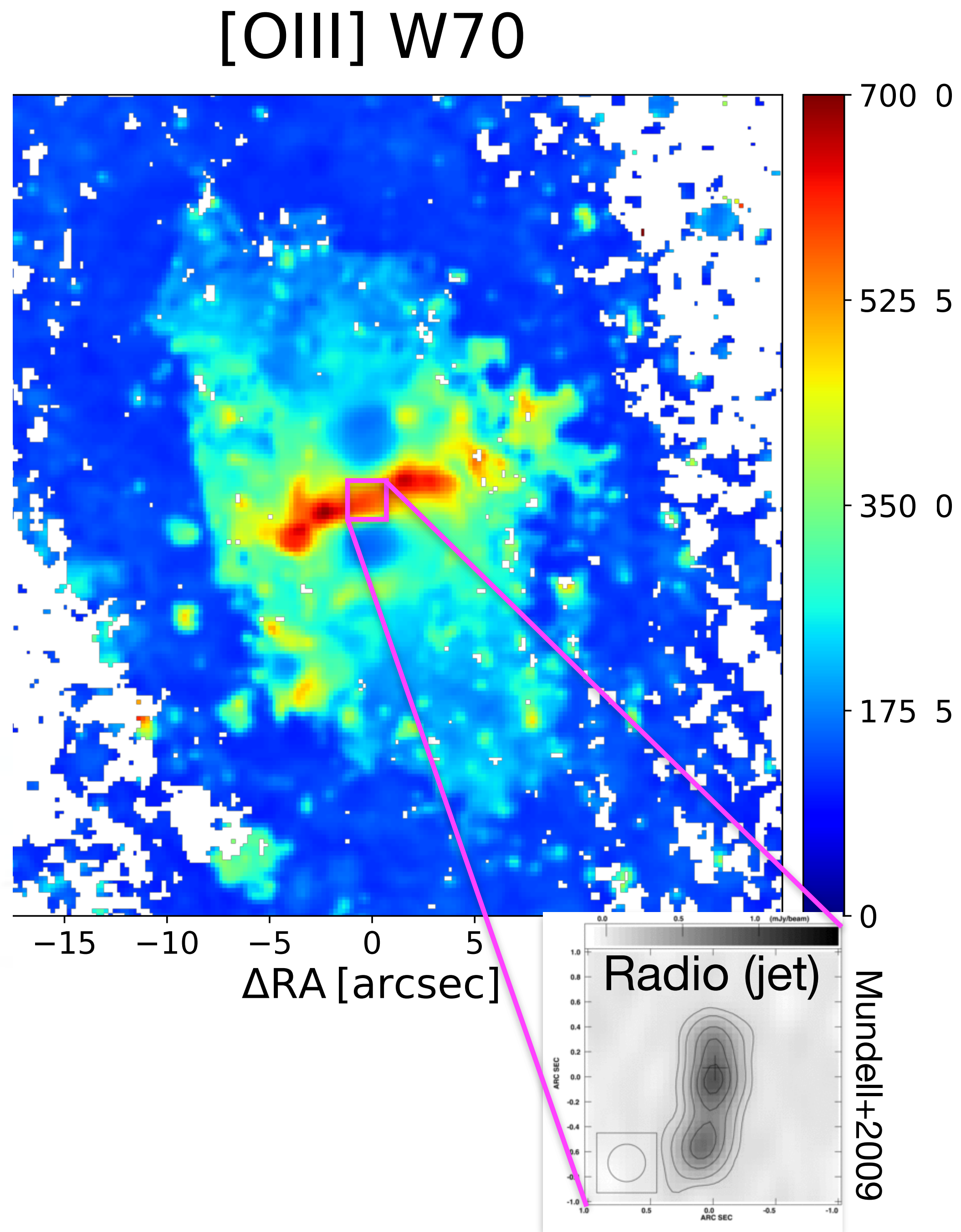
And also perpendicular to "classic" asymmetric high-velocity outflow

Venturi+ to be subm.

ENHANCED LINE WIDTHS PERPENDICULAR TO JETS







And also perpendicular to "classic" asymmetric high-velocity outflow

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ENHANCED LINE WIDTHS PERPENDICULAR TO JETS

Spatially-resolved **BPT diagrams**, intensity-coded in **[OIII] W70 (line width)**

ENHANCED LINE WIDTHS PERPENDICULAR TO JETS

Spatially-resolved **BPT diagrams**, intensity-coded in **[OIII**

High-W70 regions correspond to shock-like ratios (high [SII]/Hα) —> turbulent gas

Enhanced velocity dispersion perpendicular to radio jets and ionisation cones **observed in other galaxies hosting 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)

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

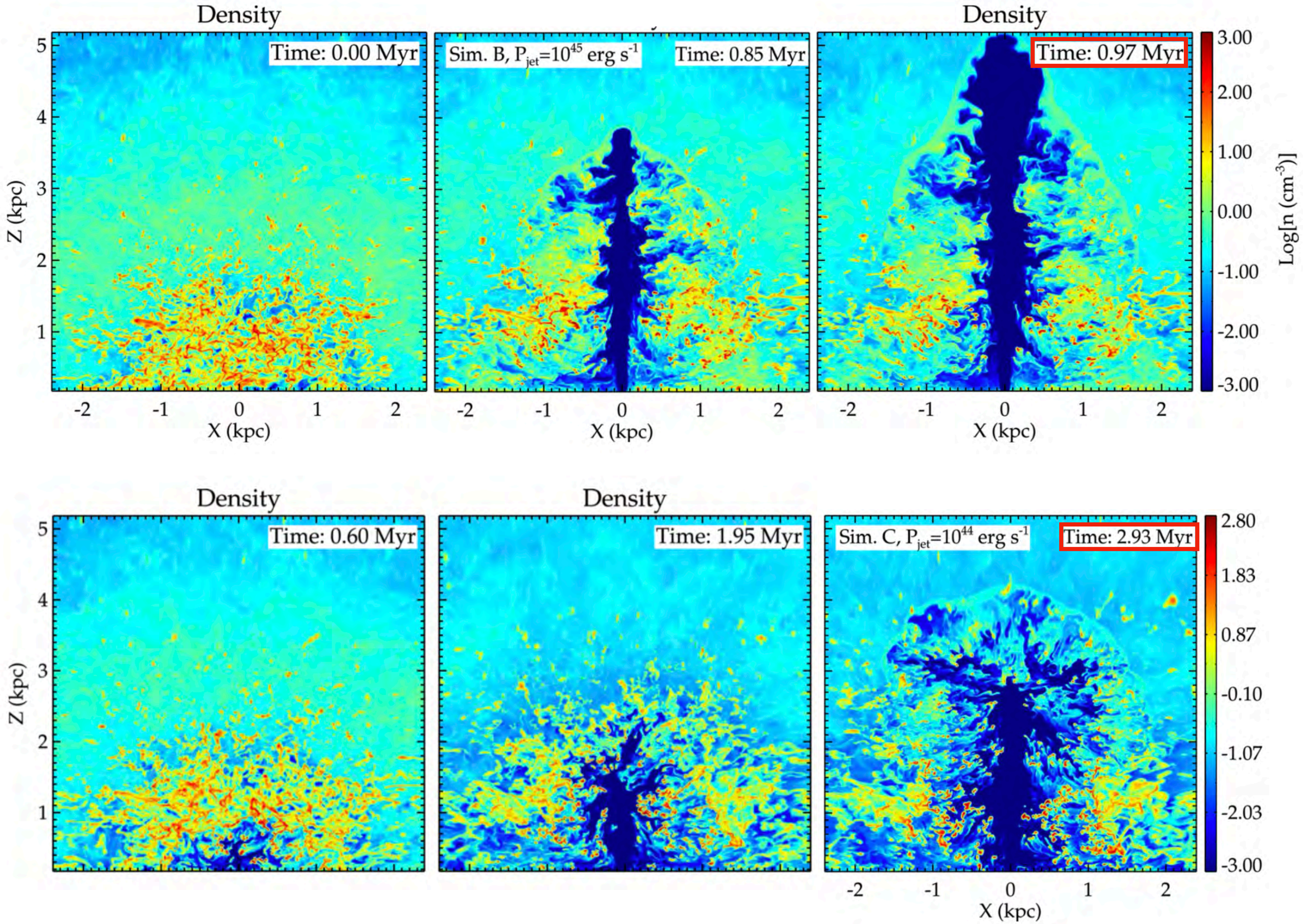
JET-ISM INTERACTION SIMULATIONS: EFFECT OF JET POWER

Higher-power jet
10^{45} erg/s

Jet easily and quickly propagates through ISM, with weak impact on it

Lower-power jet
10^{44} erg/s

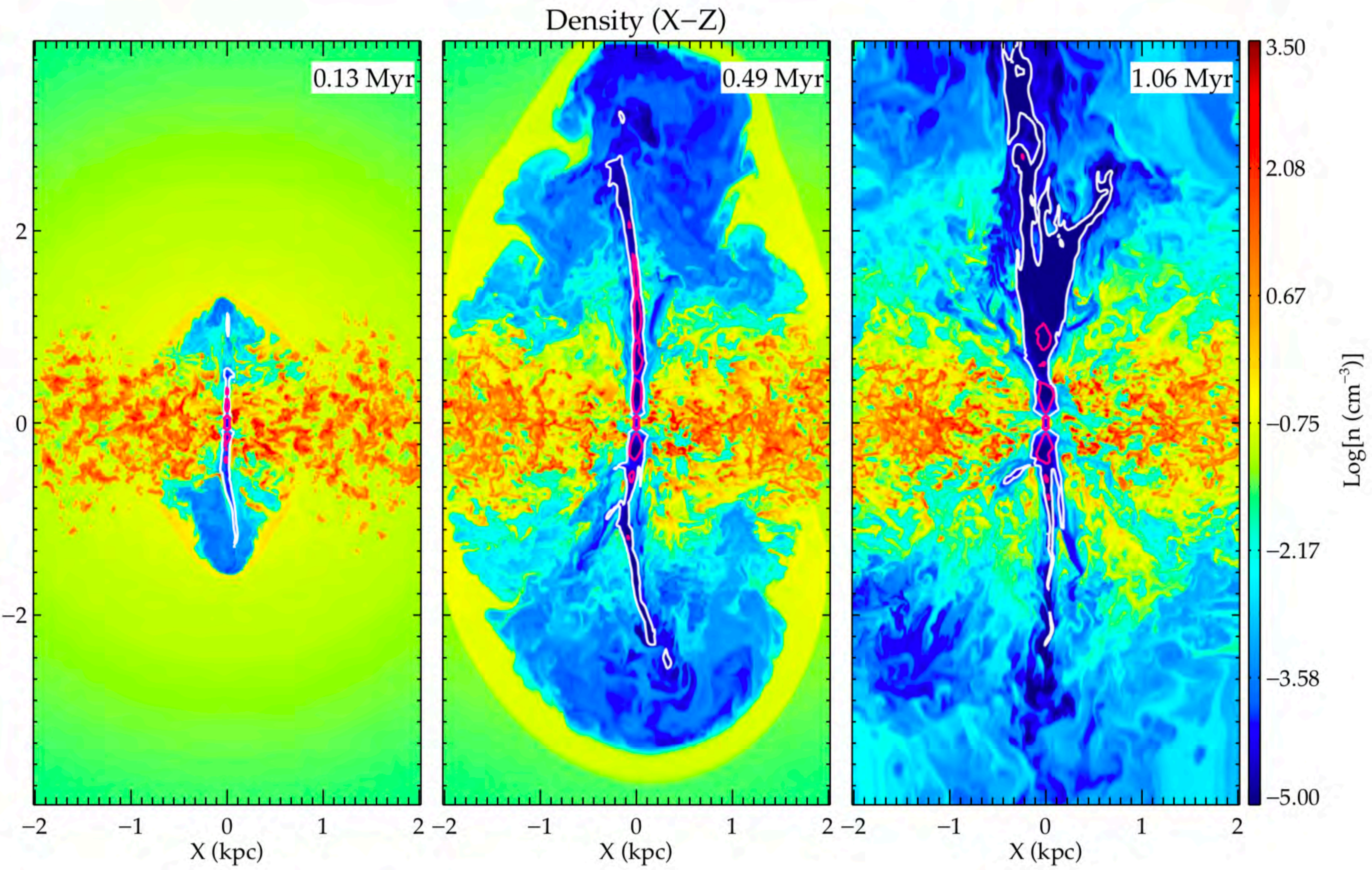
Jet struggles to propagate, trapped for longer time: shows much more vigorous interaction with ISM



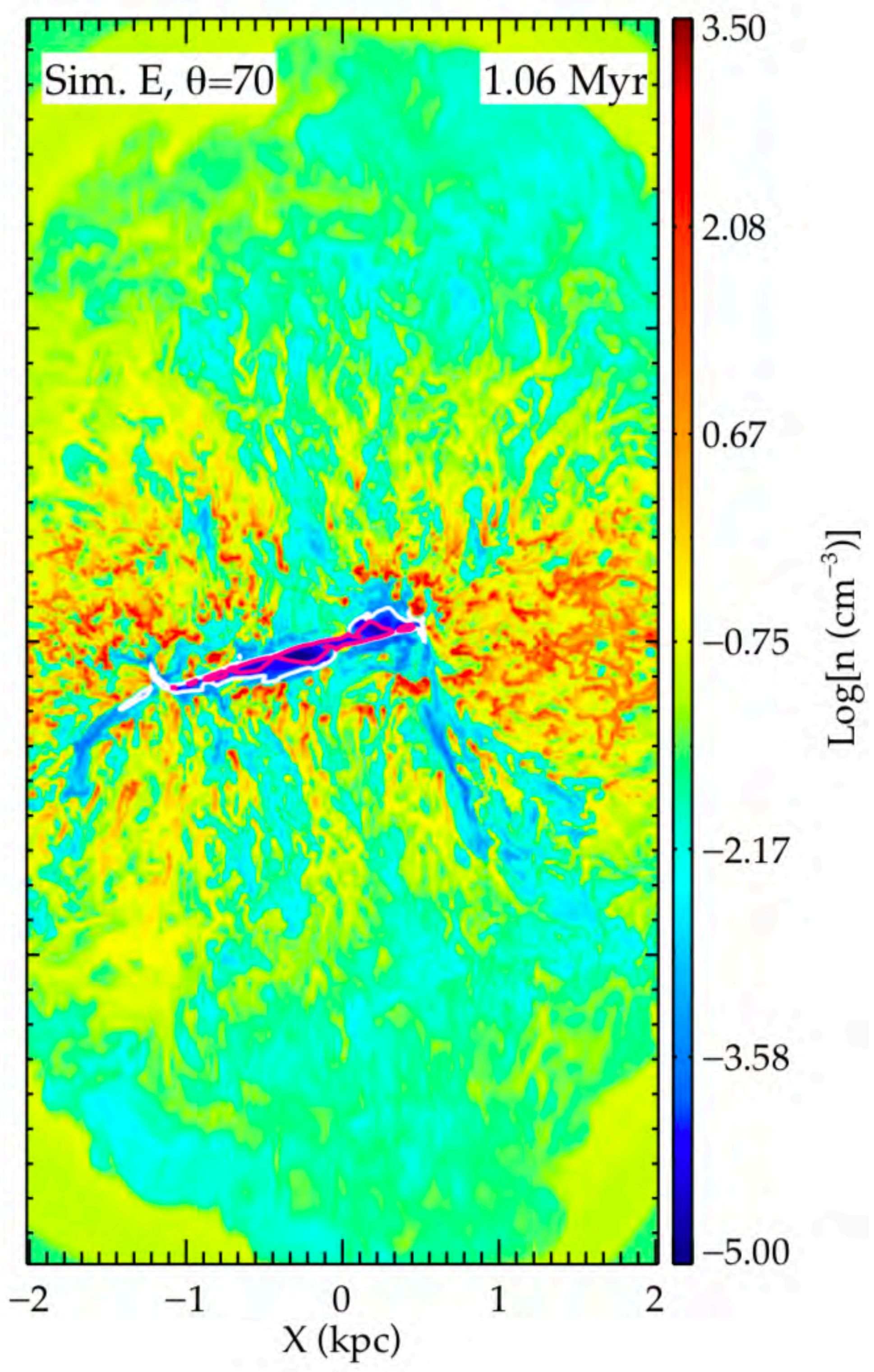
Mukherjee+2017

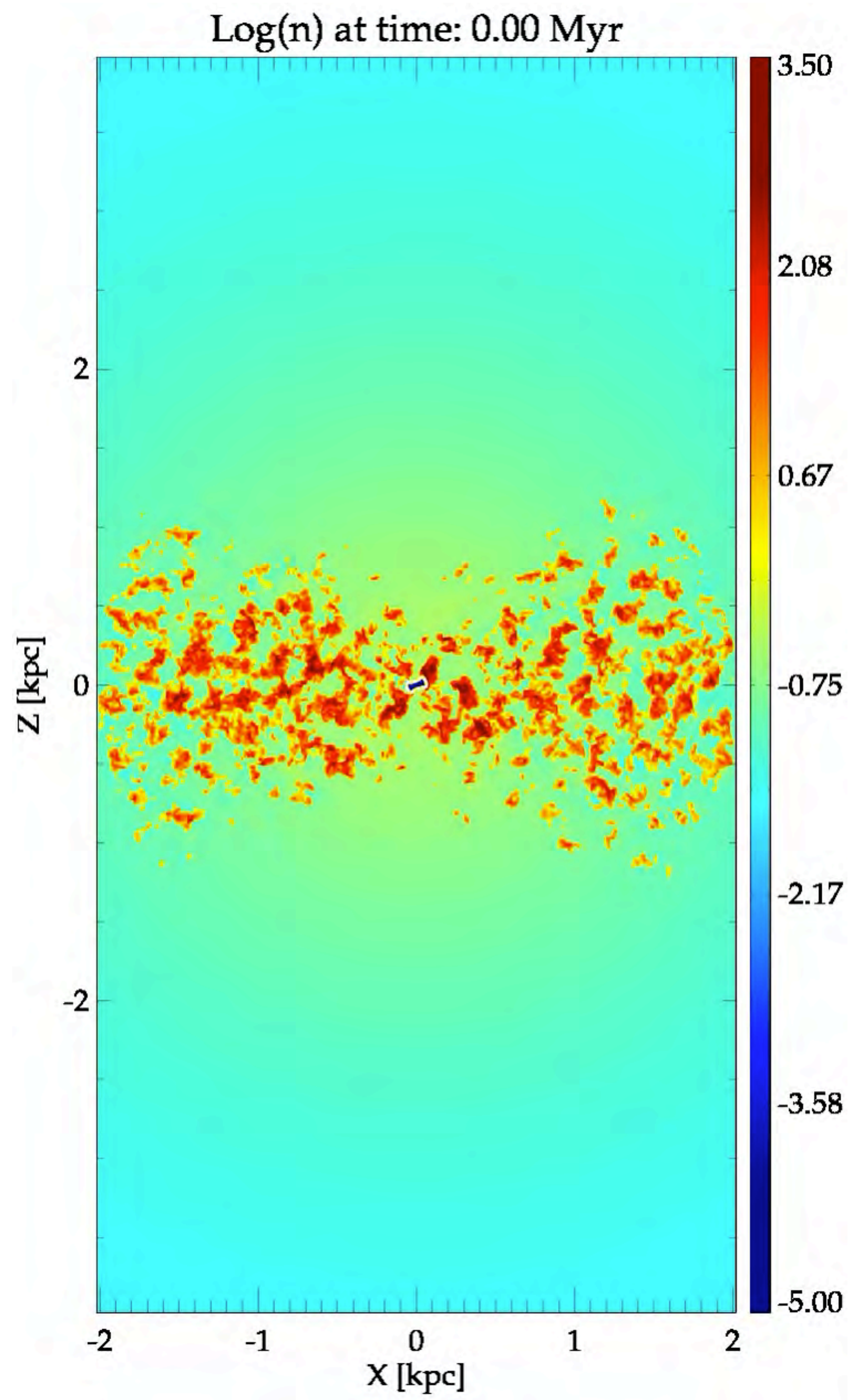
JET-DISC INTERACTION SIMULATIONS: EFFECT OF INCLINATION

Jet perpendicular to galaxy disc:
weak/no interaction



Jet with low inclination to galaxy disc:
trapped in disc and strong impact on ISM





Mukherjee+2018a

ORIGIN OF ENHANCED PERPENDICULAR LINE WIDTHS: JETS

We conclude that the **low-power jets** through **jet-disc interaction** are responsible for the enhanced line widths (velocity dispersions) observed perpendicularly to jets and ionisation cones, since:

1) All galaxies exhibiting the phenomenon host a low-power ($\lesssim 10^{44}$ erg/s) jet, at low inclinations w.r.t. to galaxy disc
2) Simulations predict that low-power jets with low inclinations w.r.t. to galaxy disc give maximum jet-disc interaction
3) Other explanations disfavoured:
   a) Beam smearing: enhanced line widths observed on scales of several arcsec
   b) Equatorial outflow from accretion disc or dusty torus: i) there is always a jet + ii) line profiles really broad and symmetric, differently from a “classic” outflow with asymmetric profiles and spatially-coherent net velocity shift
   c) Precessing jet: why perpendicular? And kinematic properties of line width-enhanced region different from “classic” outflow observed in ionisation cone and jet direction

SUMMARY

- Nearby Seyferts observed with VLT/MUSE provide high spatial resolution to characterise in detail ionised gas outflow properties and feedback; MAGNUM survey: 9 objects so far, <50 Mpc

- 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

- New phenomenon: Enhanced line velocity widths observed perpendicularly to low-power low-inclination radio jets and AGN ionisation cones observed in 4 MAGNUM galaxies and a few recent works

  —> Jet-ISM interaction within galaxy disc favoured mechanism

Low-power jets have larger impact on host galaxies than previously thought…