

Supermassive Black holes Environment & Evolution

22 Jun, 2019 - Corfù

Dissecting ionized galactic outflows in nearby AGN



Giacomo Venturi

Instituto de Astrofísica (PUC), Santiago, Chile



working with E. Treister and AGN group

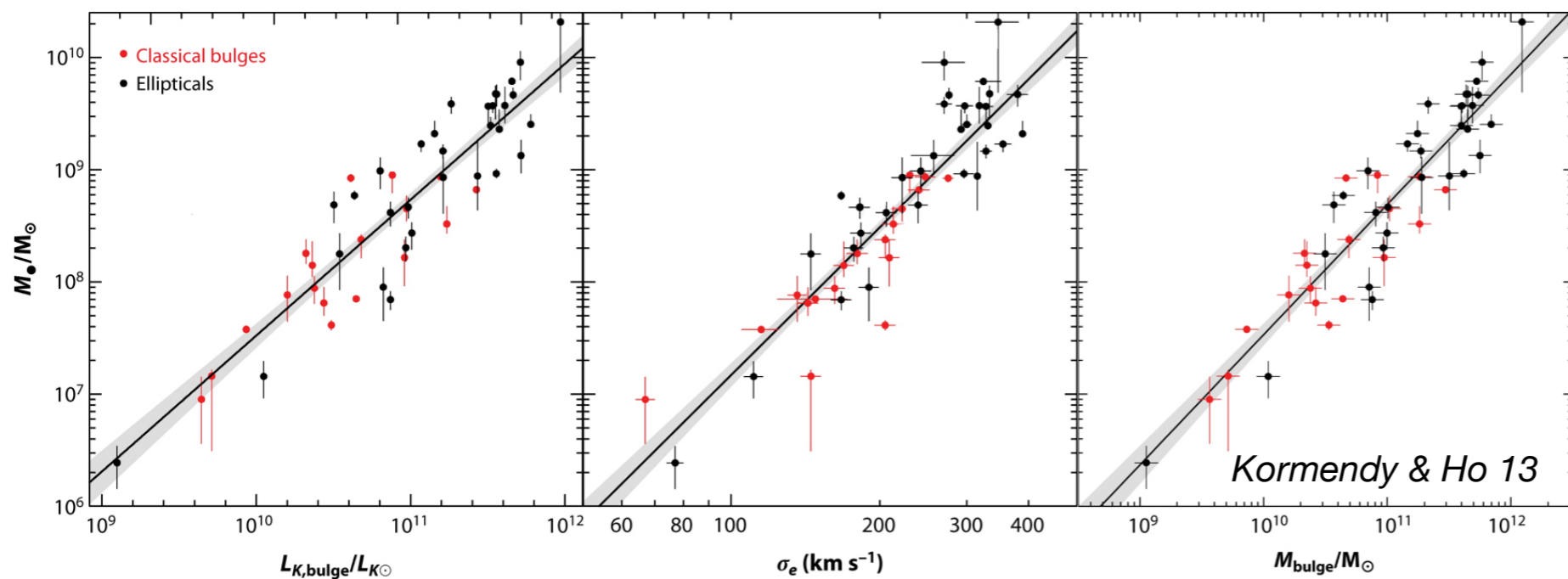
In collaboration with:

A. Marconi, M. Mingozi, E. Nardini, G. Cresci, S. Carniani,
R. Maiolino, F. Mannucci, G. Risaliti, M. Perna

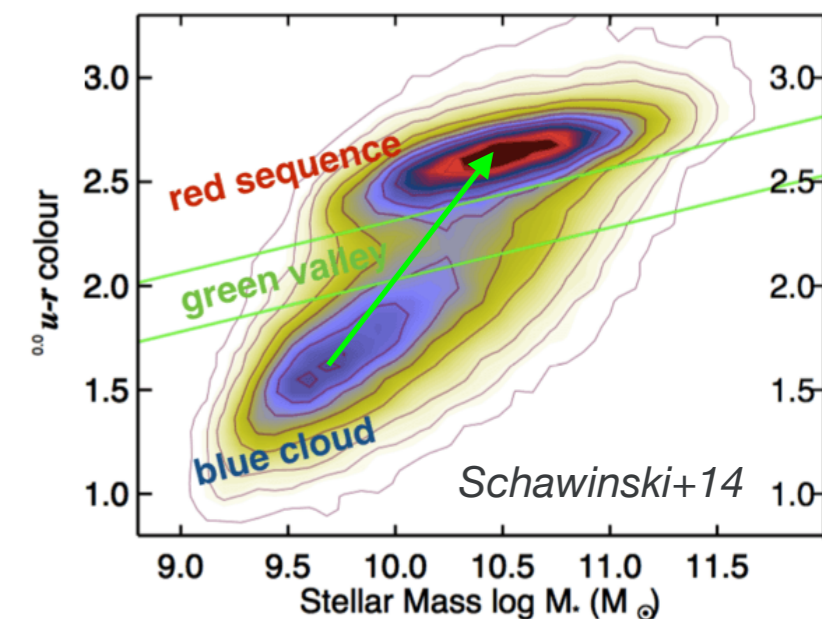


Galaxy evolution: the need for feedback

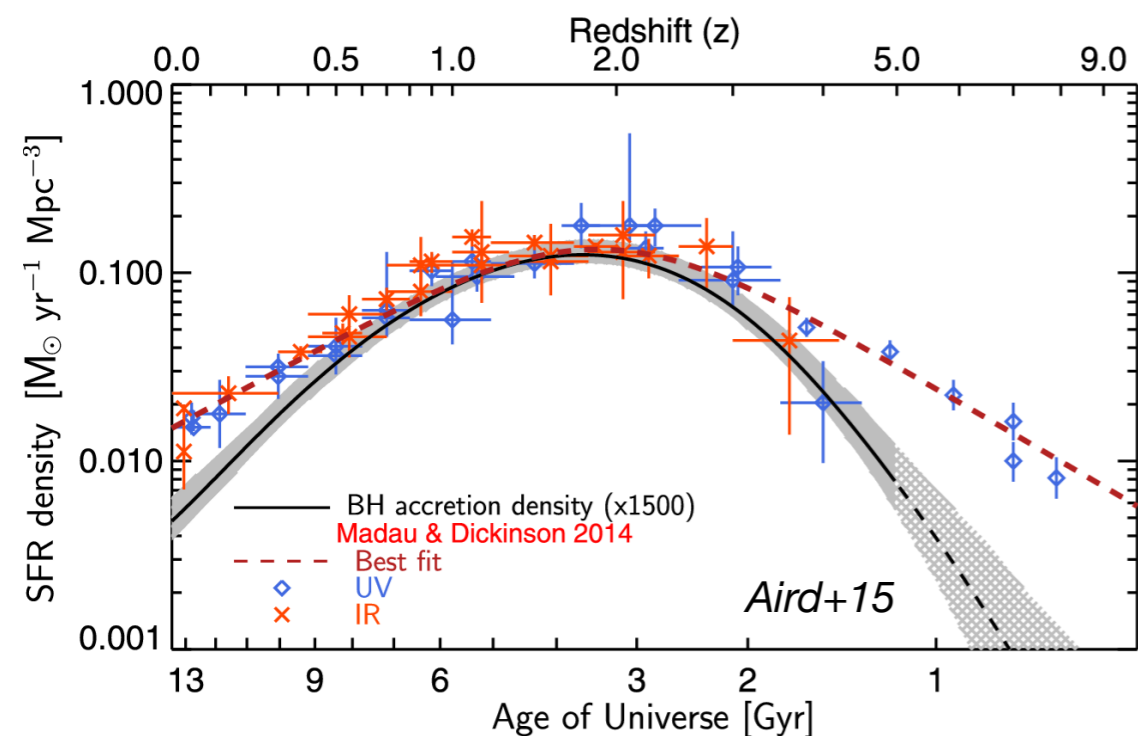
1) $M_{\text{BH}}-L_{\text{bul}}$, $M_{\text{BH}}-\sigma_{\text{bul}}$, $M_{\text{BH}}-M_{\text{bul}}$ scaling relations



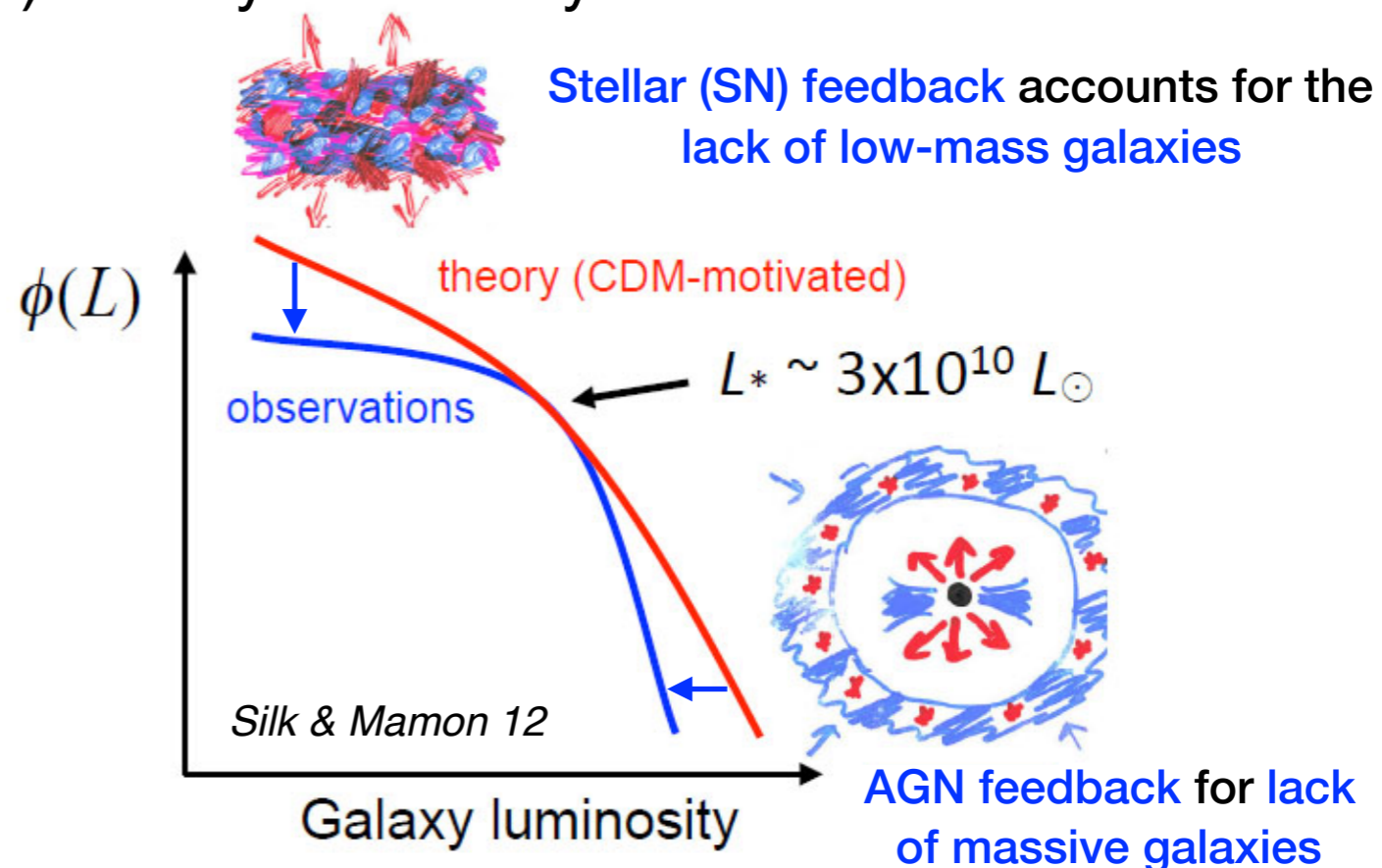
2) Galaxy bimodality



3) SFR similar to BH accretion history

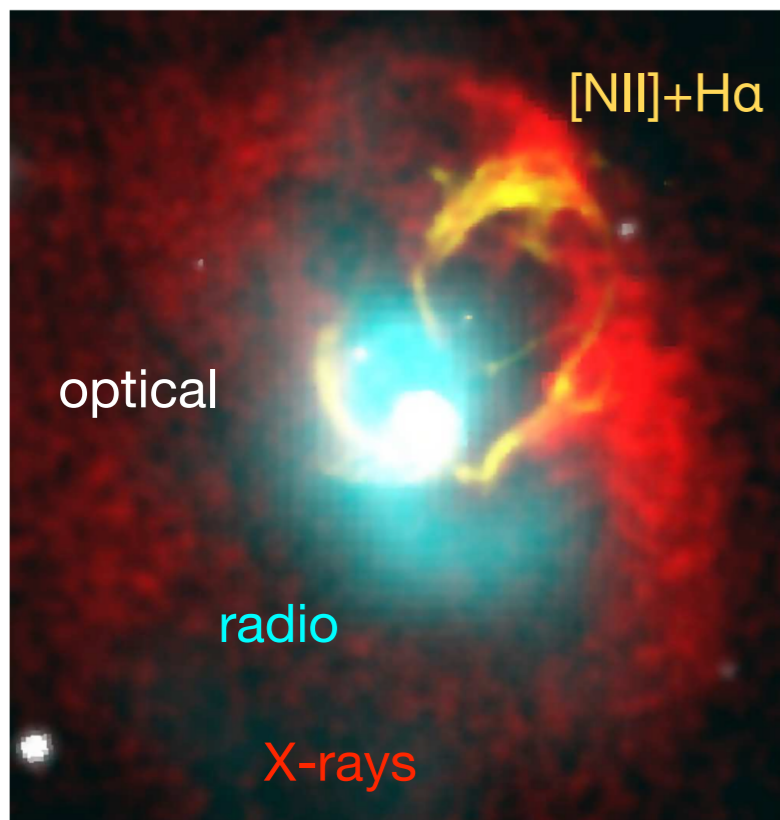


4) Galaxy luminosity function



Searching for feedback in action

Feedback from radio jets in massive elliptical galaxies

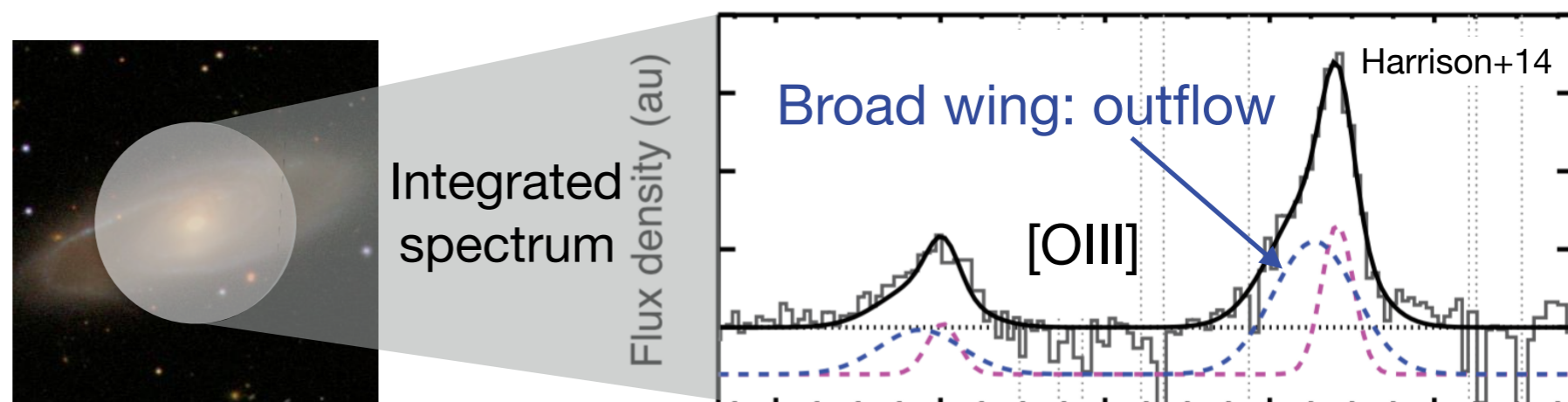


Balmaverde, GV+18

Outflows ubiquitously observed...

But not clear actual impact of outflows on host galaxy, and their driving mechanisms: major challenge!

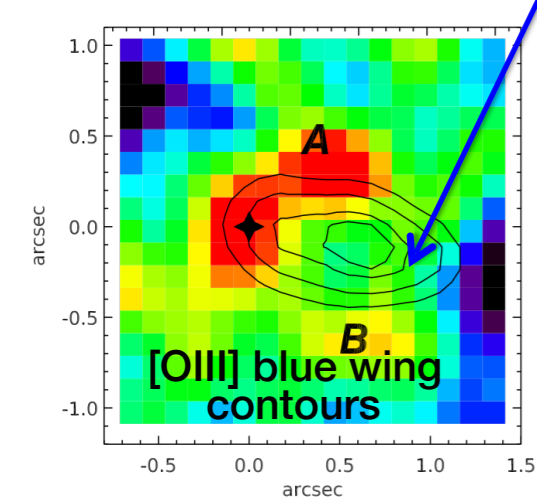
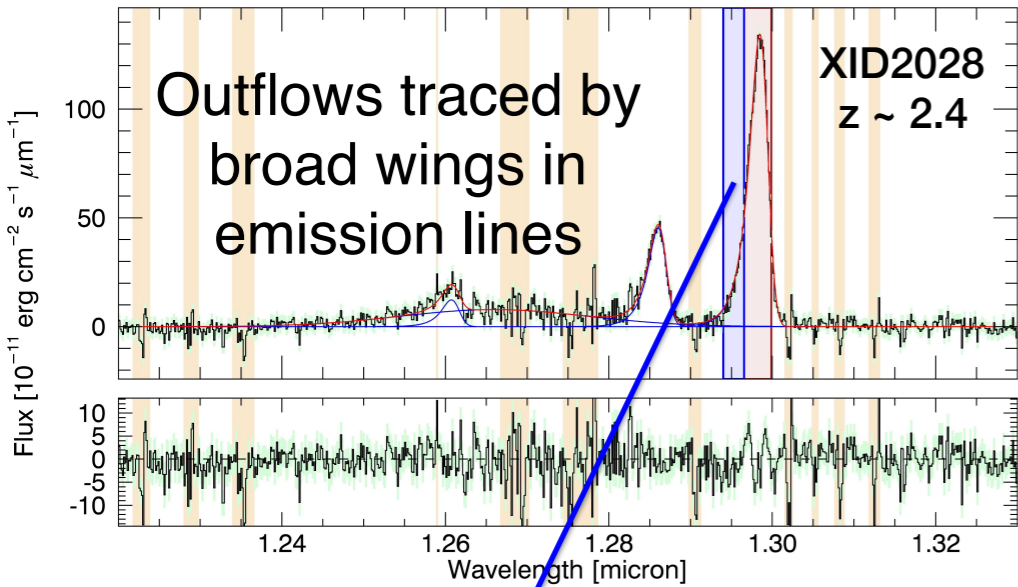
Indeed, usually outflows observations are spatially unresolved/marginally resolved



—> Outflow properties (e.g. extension) need to be assumed; no spatial information on structure and different properties throughout the outflow (velocity, mass, density, shape, direction etc...)

Outflows: open problems and questions

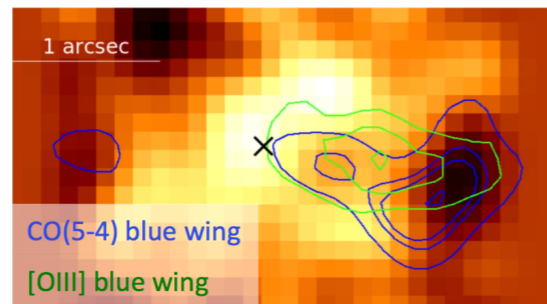
Spatially-resolved observations of powerful quasars at $z \sim 1-3$ (peak of AGN activity) successfully found few cases of feedback from outflows



Cresci+15a

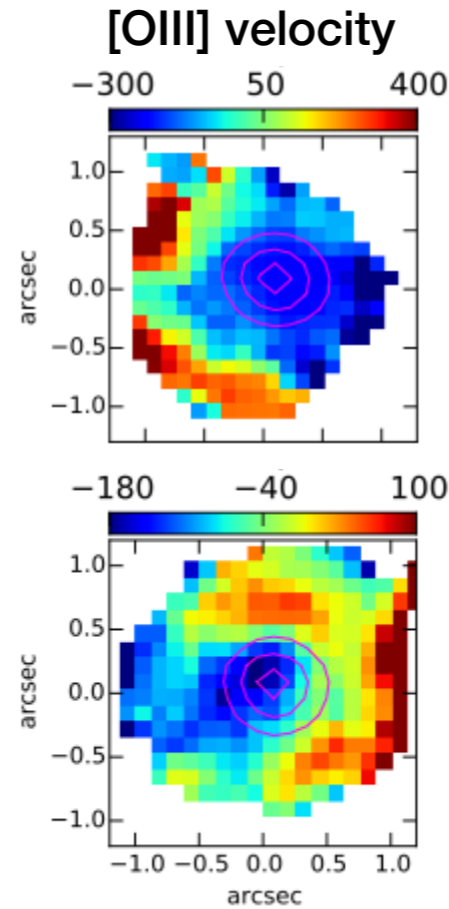
Cresci+15a

Molecular + ionized outflow



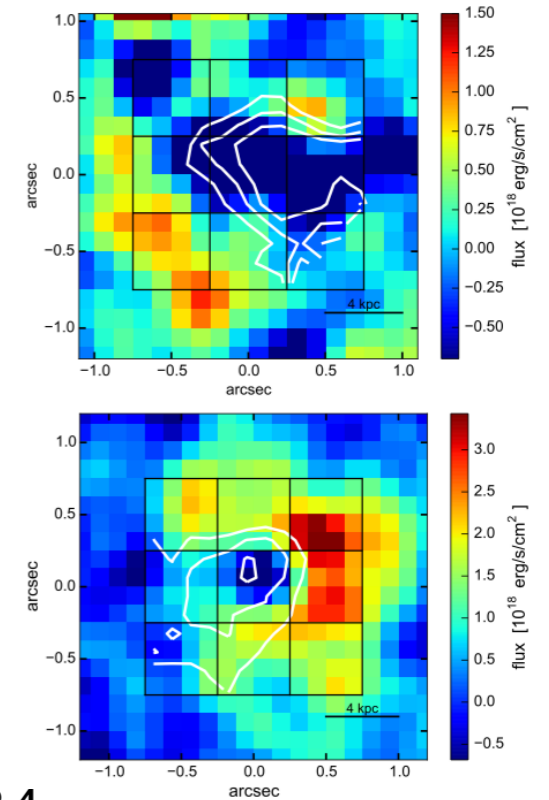
Low gas fraction ($<5\%$) and depletion timescales ($<10^8$ yr)

Brusa+18



$z \sim 2.4$

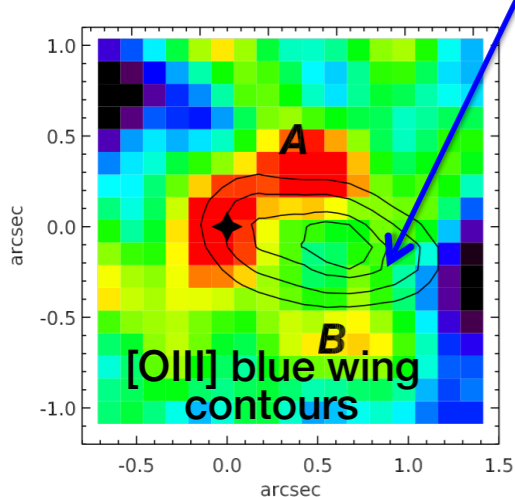
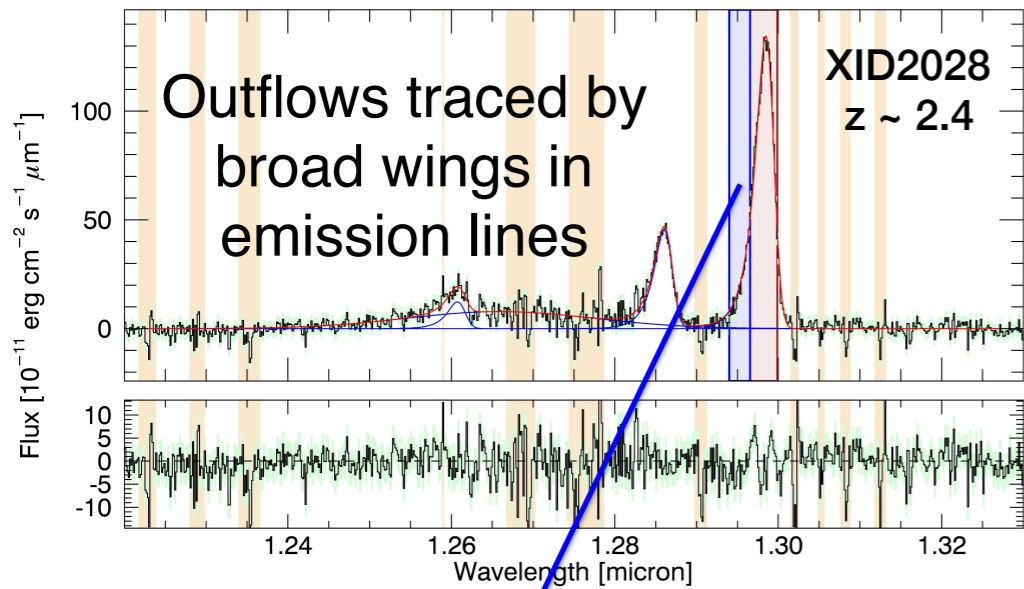
Star Formation (H α) vs [OIII] blue wing contours



Carniani+15,16

Outflows: open problems and questions

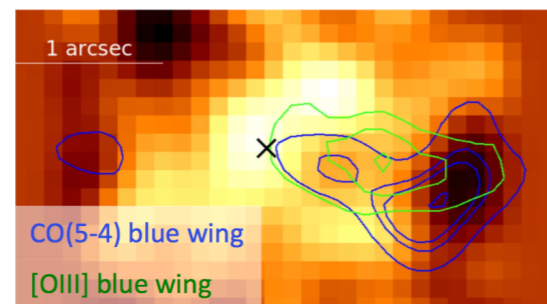
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Star Formation (H α)

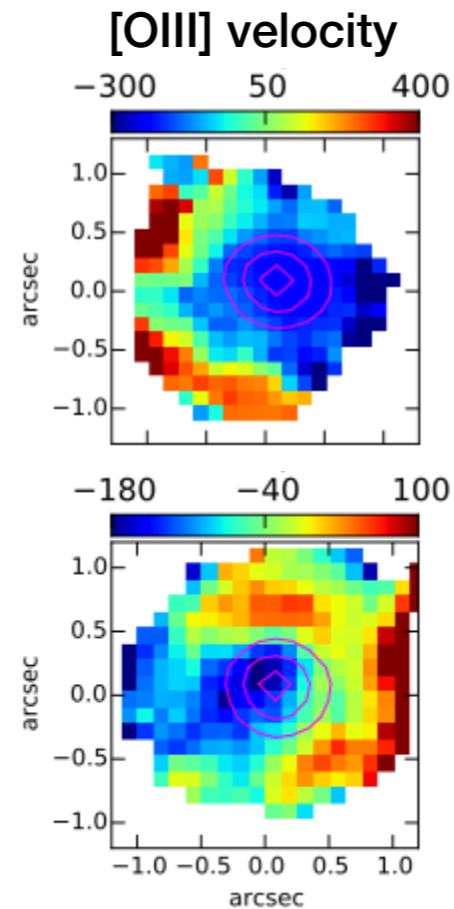
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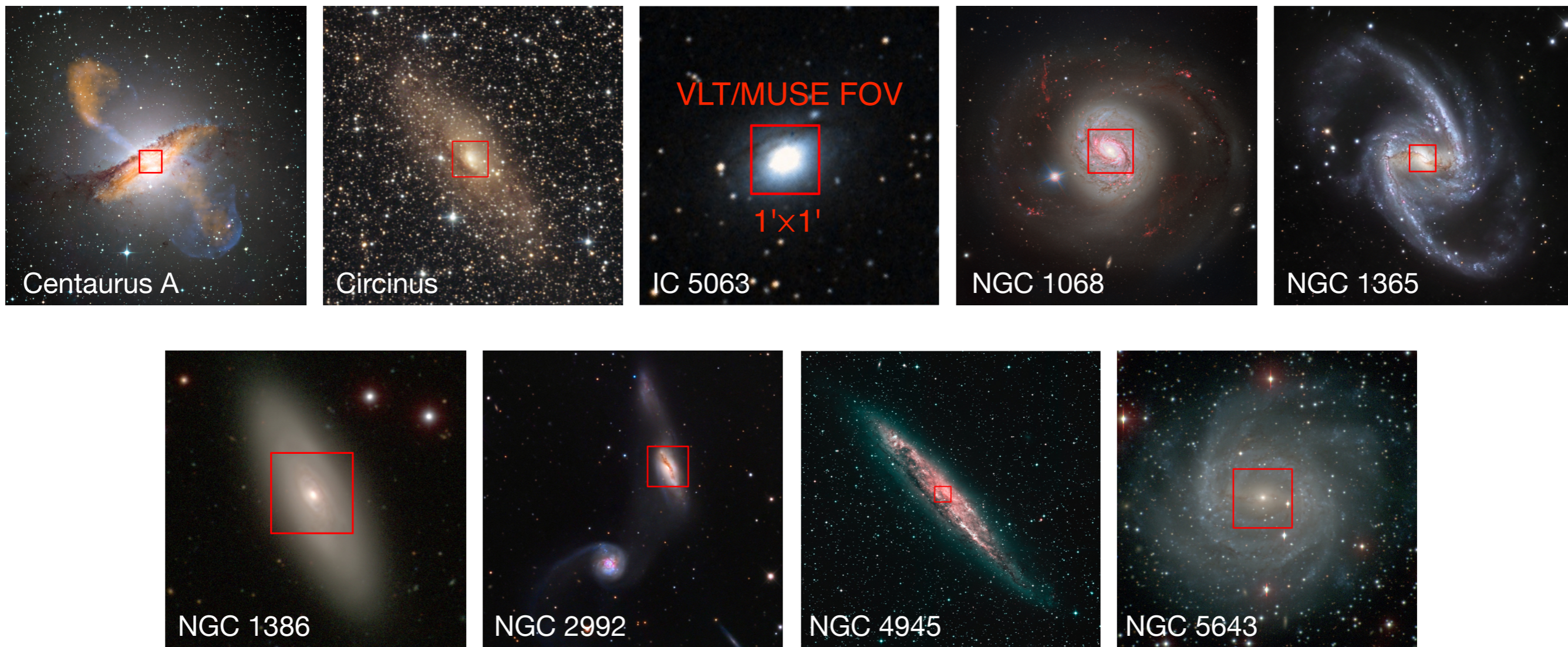
Carniani+15,16

But **low spatial resolution** due to distance and data quality \rightarrow **difficult** to study in detail feedback and outflow physical properties...

MAGNUM survey

Nearby ($D < 50$ Mpc) Seyferts provide much larger intrinsic spatial resolution to characterize outflow properties and feedback in detail

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



Venturi+17, 18, Mingozzi+19, Venturi+in prep.

Detailed study of ionized gas in the central kpcs of **NGC 1365**:

AGN vs star formation, mapping the **outflow properties**

from optical (**MUSE**) and X-ray (**Chandra**) data

Venturi et al., 2018

NGC 1365: complex environment in central kpcs

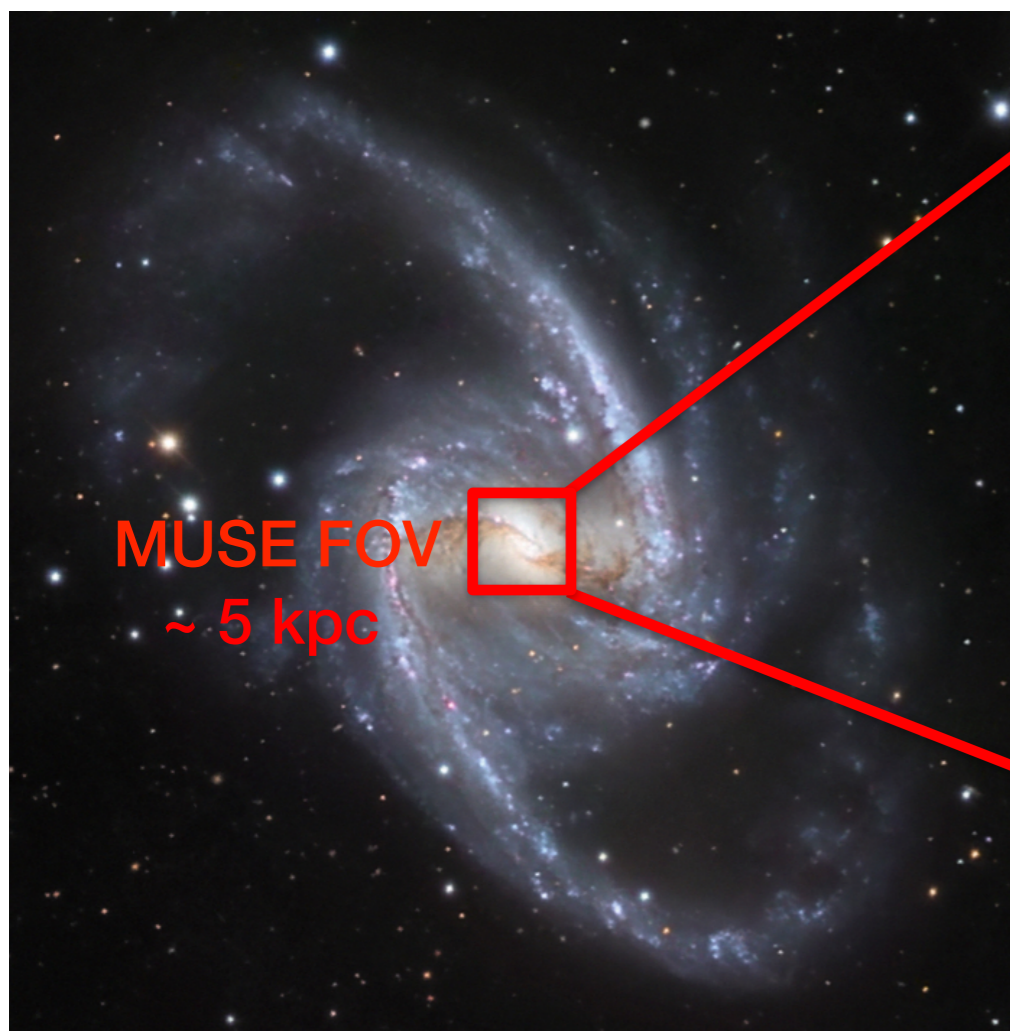


Massive barred galaxy ($4 \times 10^{11} M_{\odot}$)

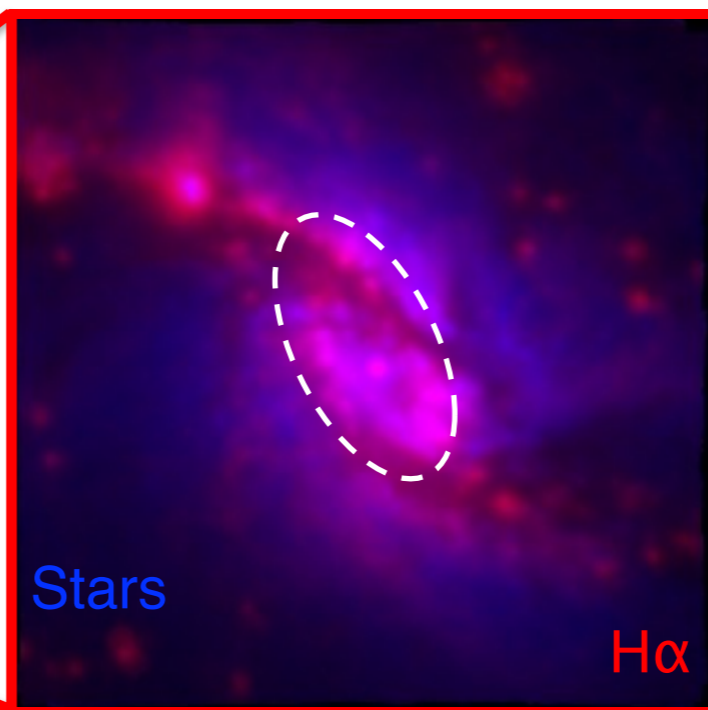
hosting a low-luminosity AGN:

$$L_{\text{AGN}} \sim 2 \times 10^{43} \text{ erg/s}$$

NGC 1365: complex environment in central kpcs



Spatial res. \rightarrow ~ 60 pc



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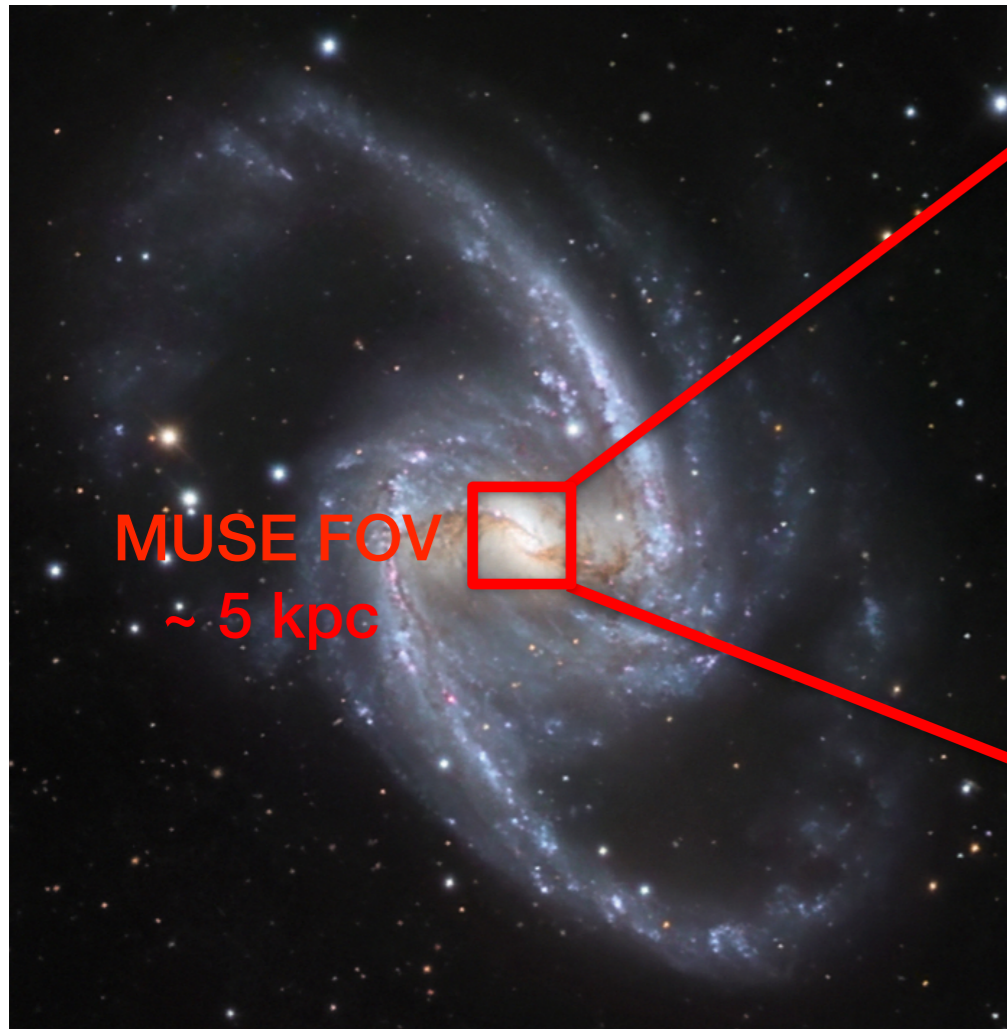
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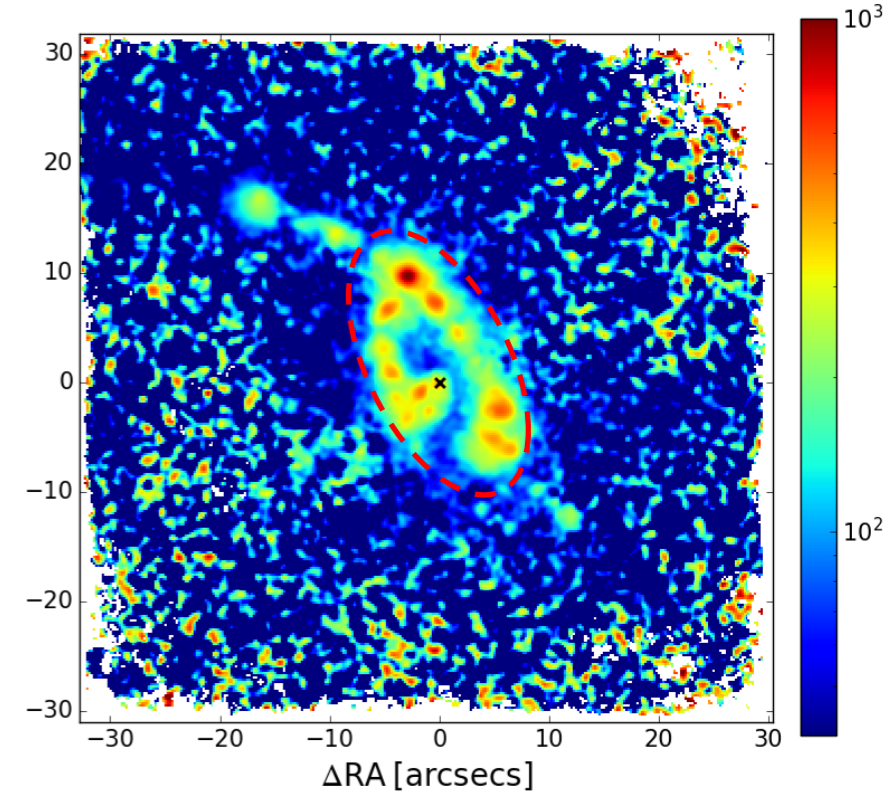
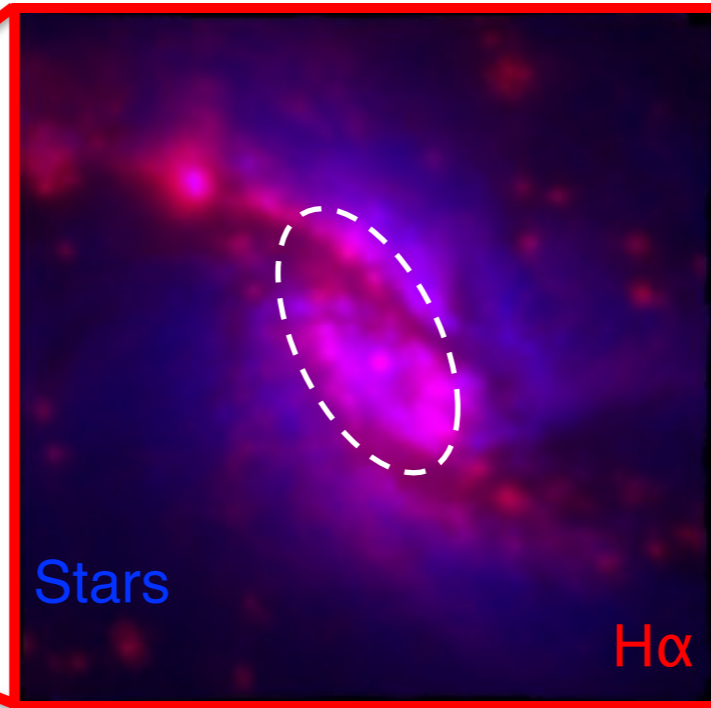
Star formation ($\sim 7 M_{\odot}/\text{yr}$):

H α follows dust lanes along
the bar + circumnuclear
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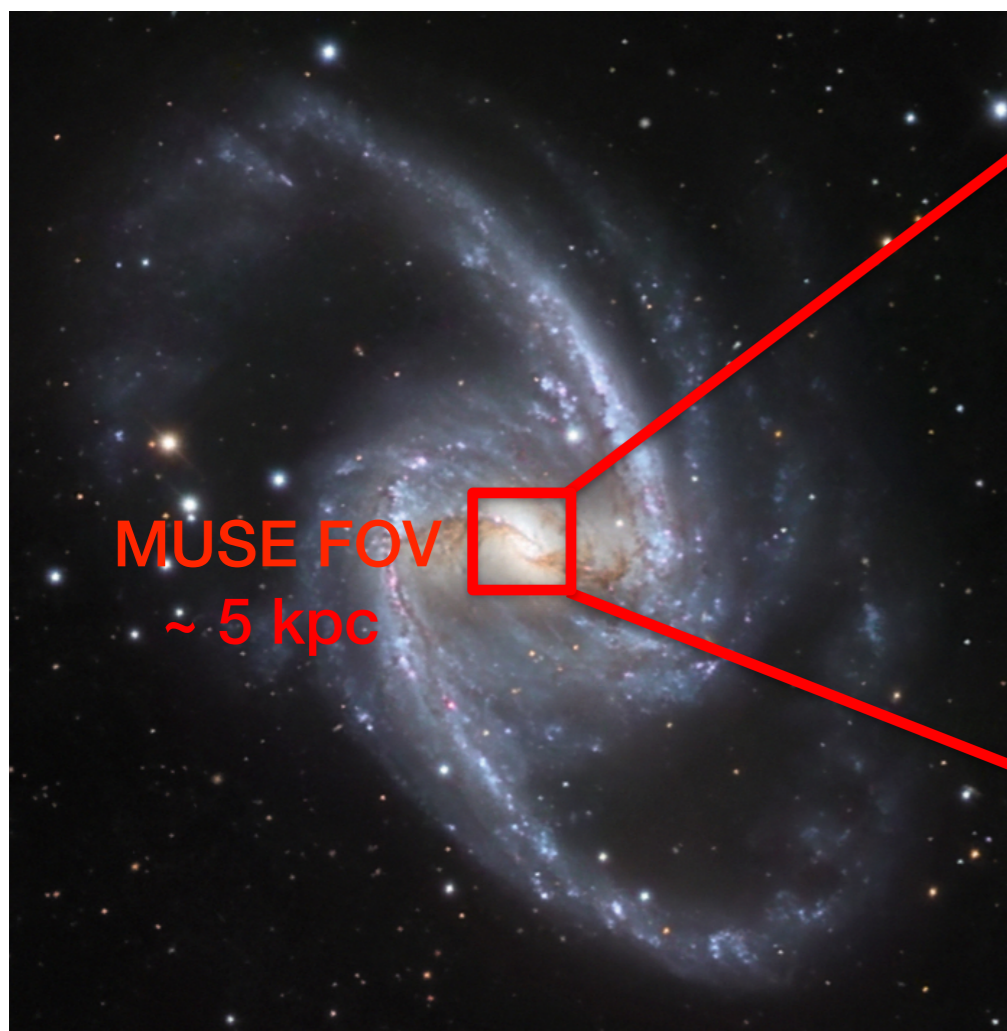
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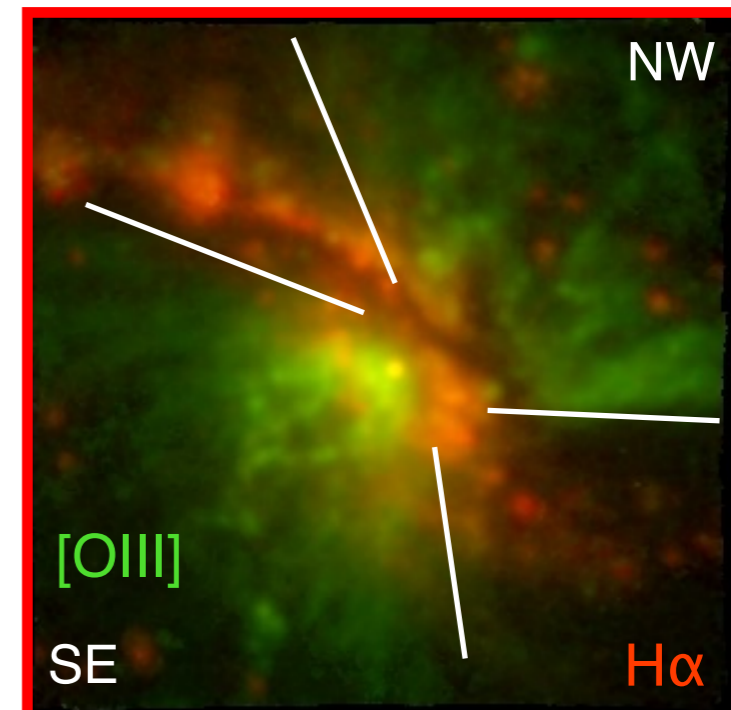
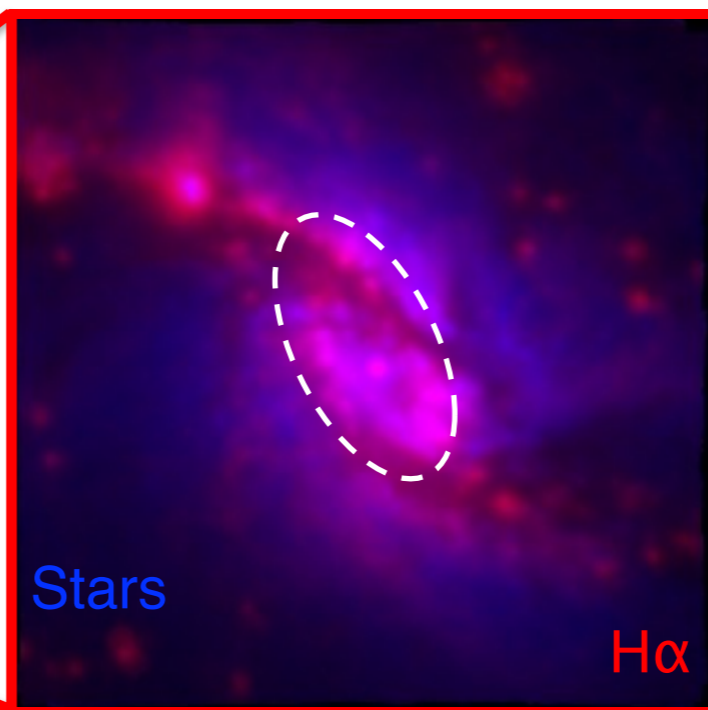
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[OIII] \perp double cone

SE less obscured
 \rightarrow above disk,

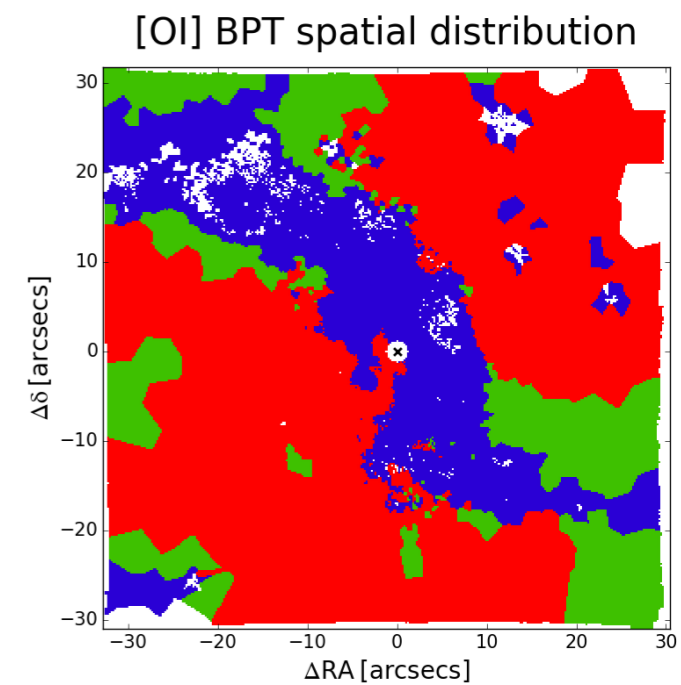
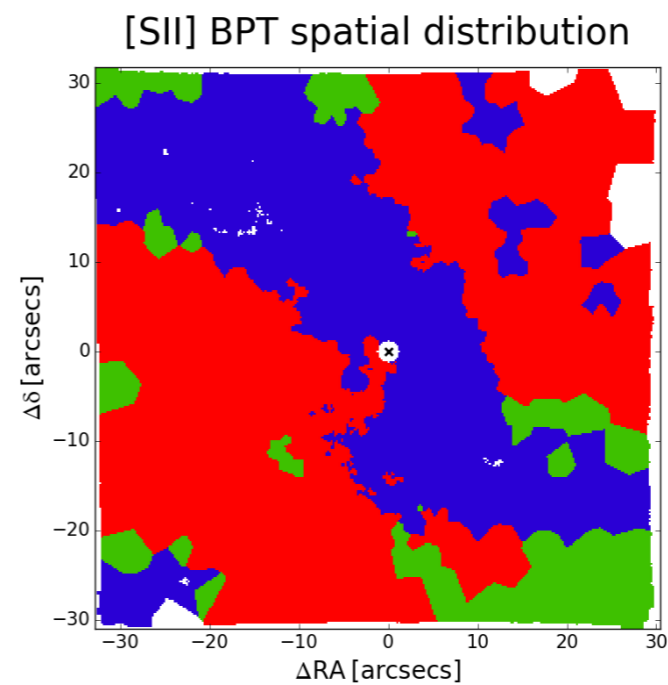
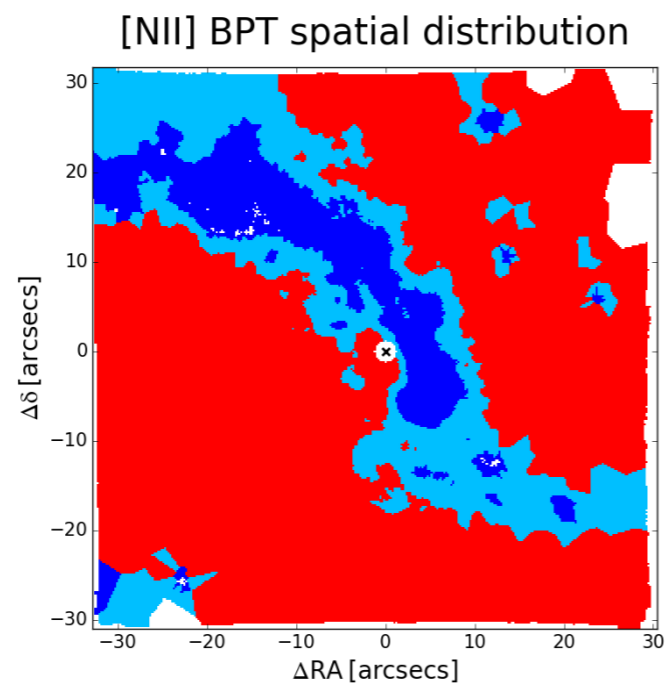
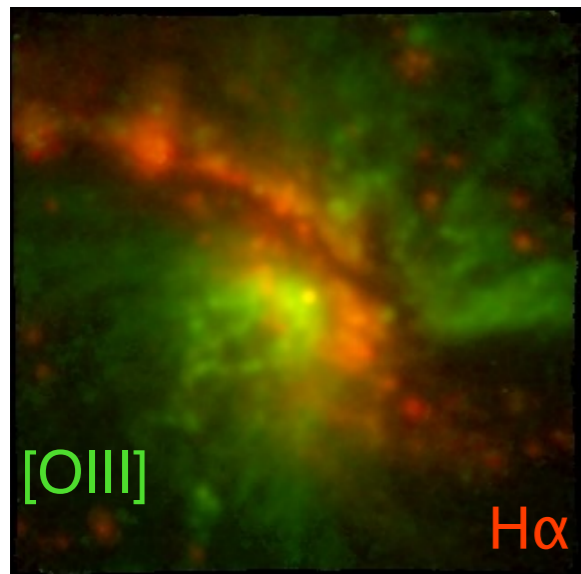
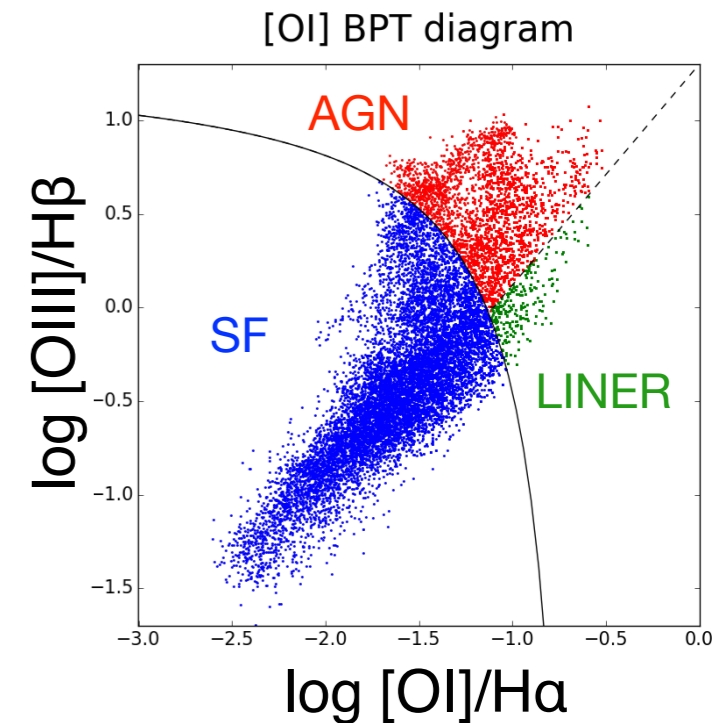
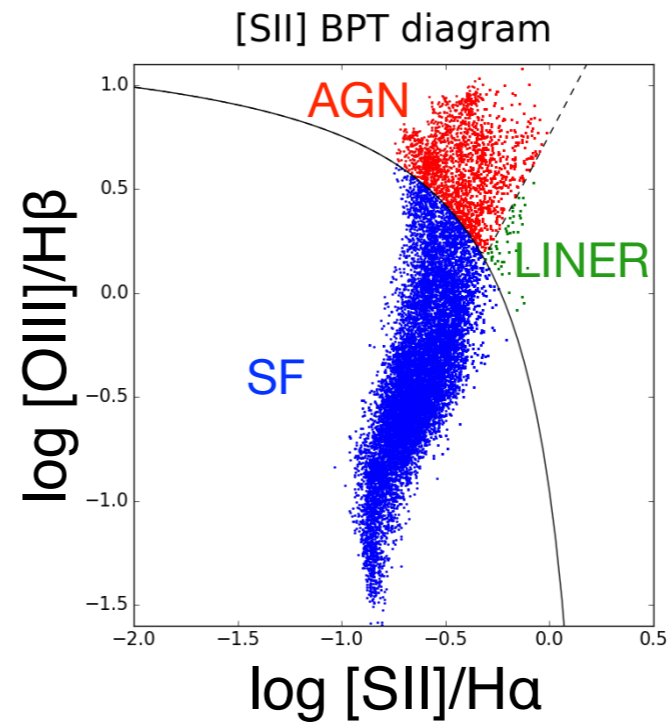
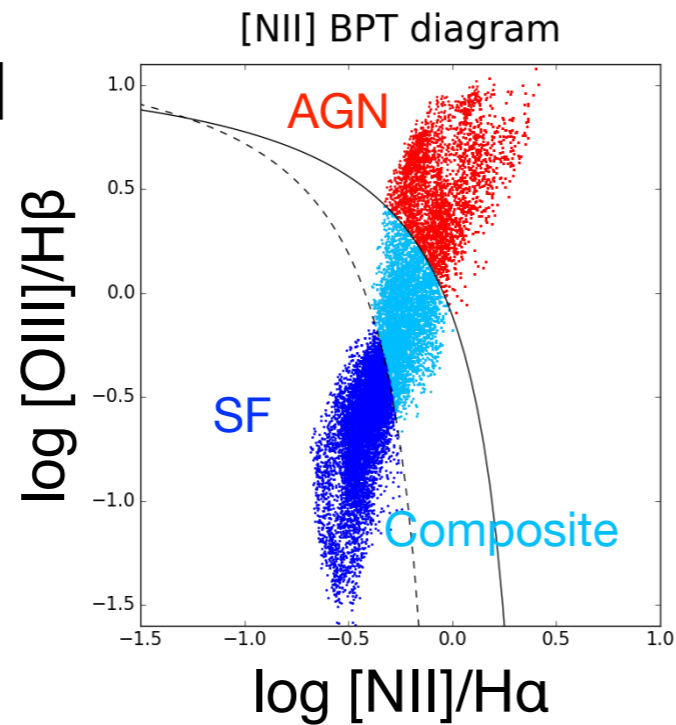
NW \rightarrow behind disk

NGC 1365: source of gas ionization

Spatially resolved
BPT diagrams

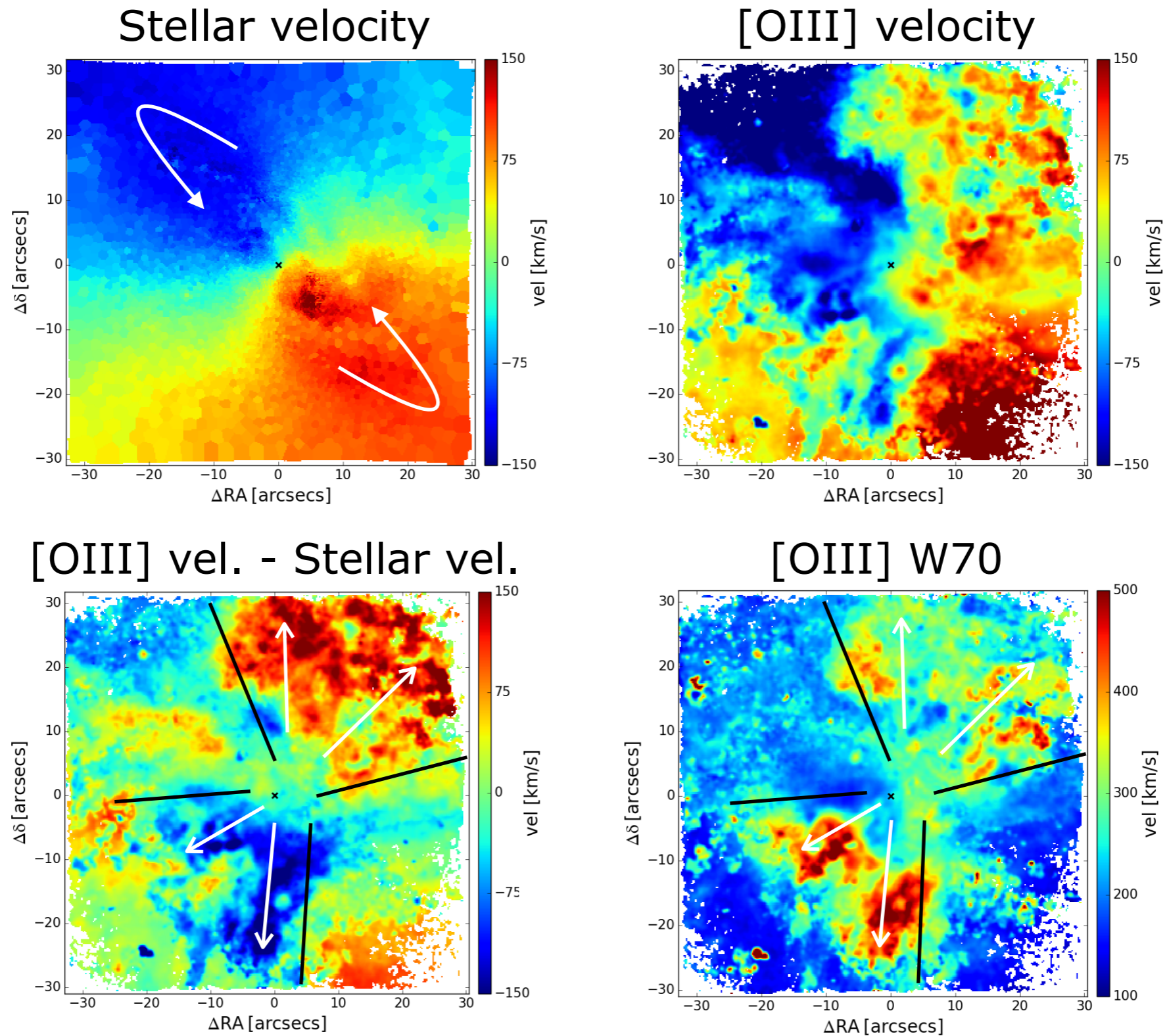
Double cone
ionized by AGN

SF dominates
along the bar



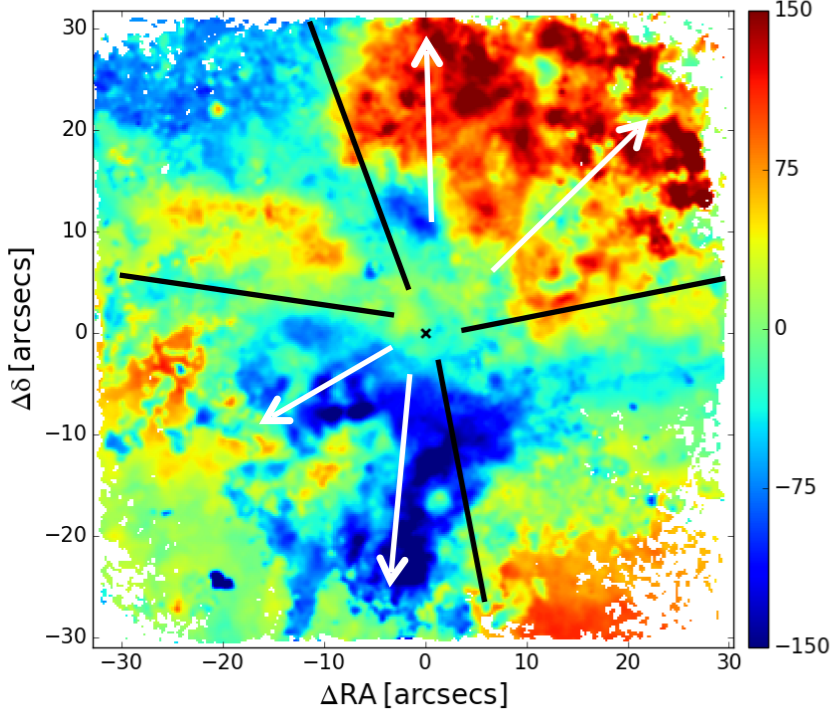
NGC 1365: double-conical outflow

Outflow spatially traced by motions deviating from rotation



NGC 1365: mapping the mass outflow rate

[OIII] vel. - Stellar vel.



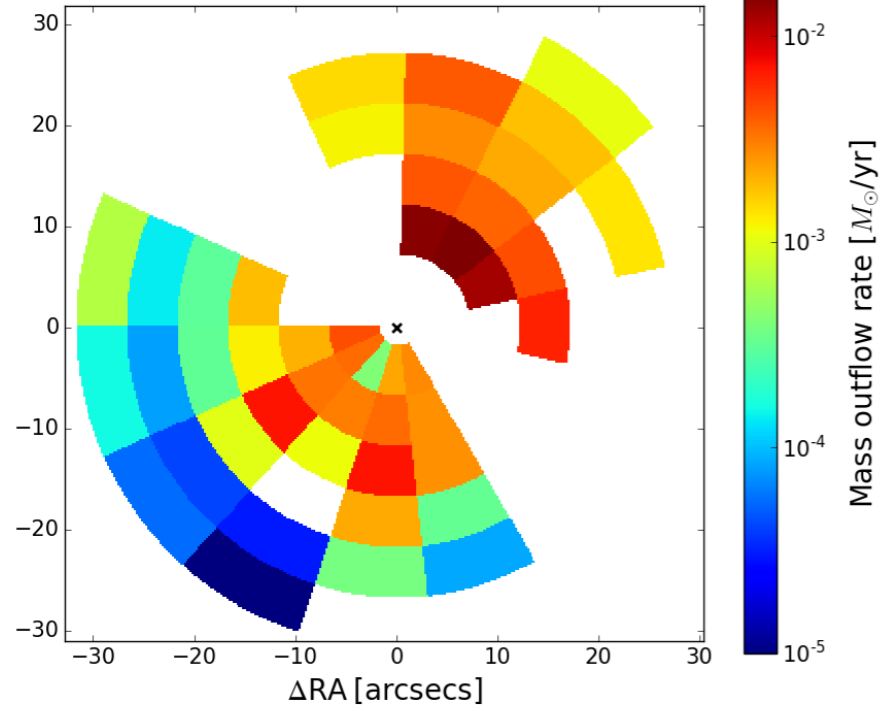
NW cone: positive velocity

→ receding

SE cone: negative velocity

→ approaching

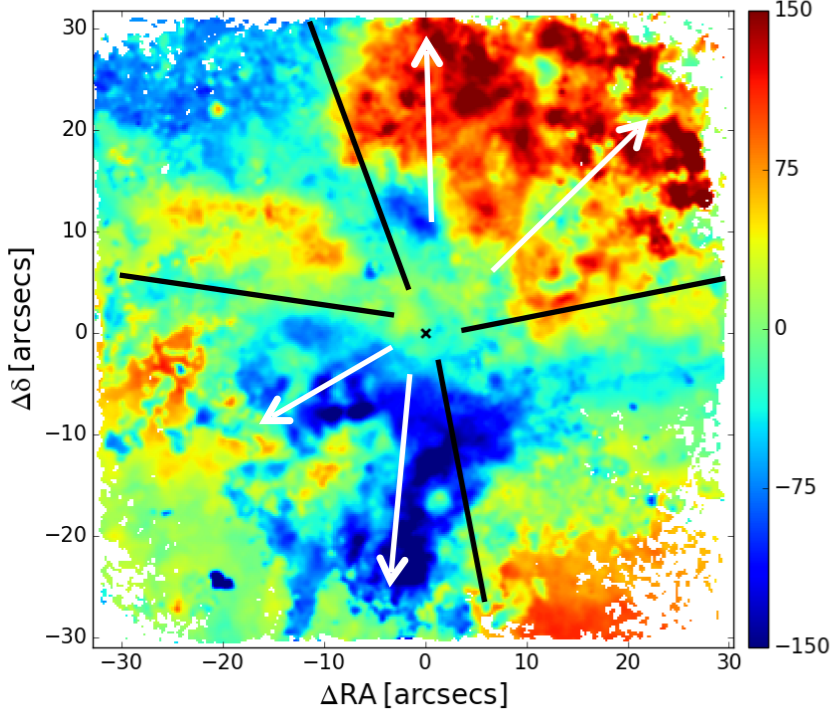
Mass outflow rate



Outflow sliced in a grid to separate outflow from disk component in fitting

NGC 1365: mapping the mass outflow rate

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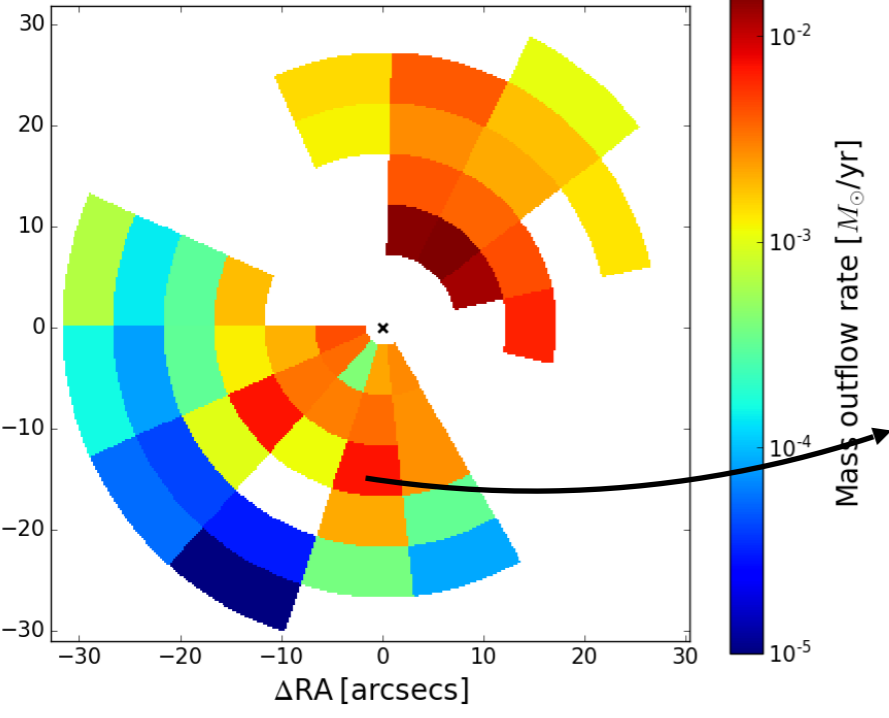
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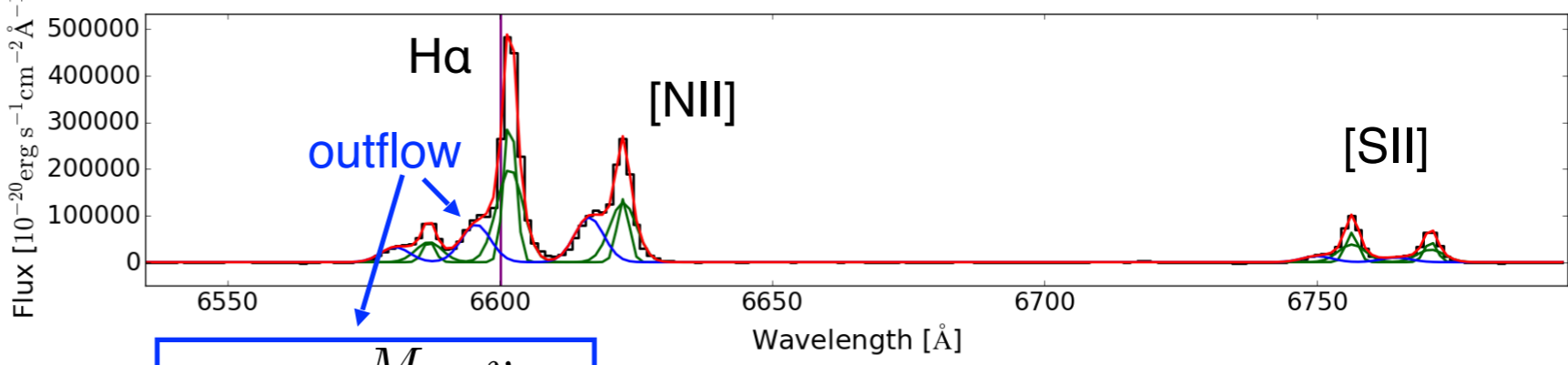
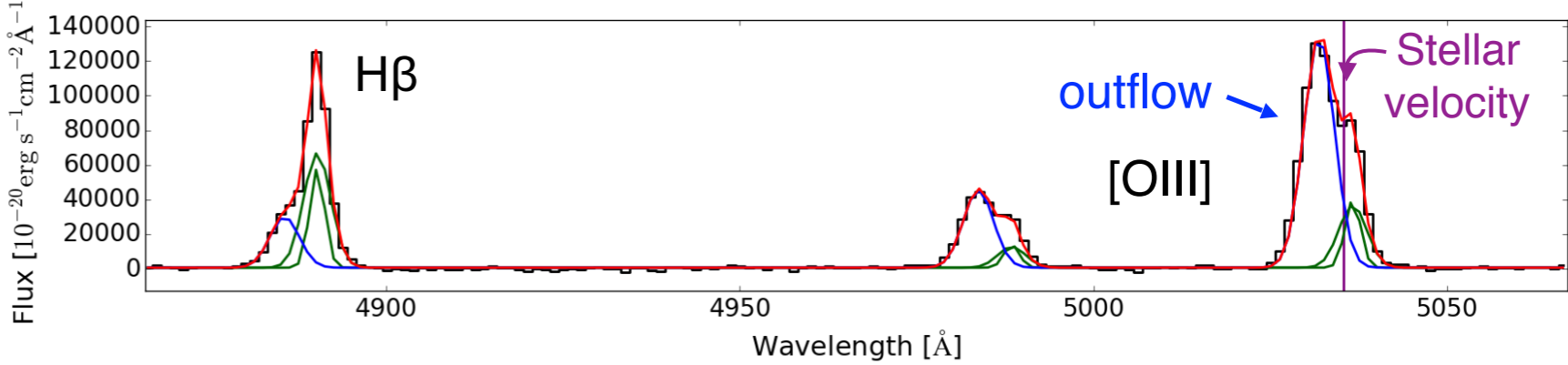
SE cone: negative velocity

→ approaching

Mass outflow rate



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

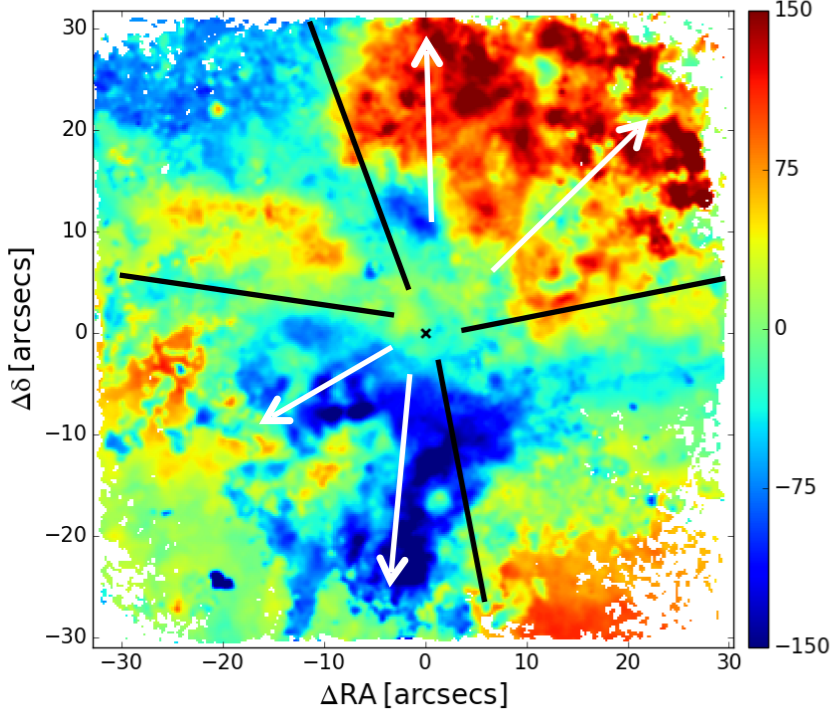


Outflow sliced in a grid to separate outflow from disk component in fitting

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

NGC 1365: mapping the mass outflow rate

[OIII] vel. - Stellar vel.



NW cone: positive velocity

→ receding

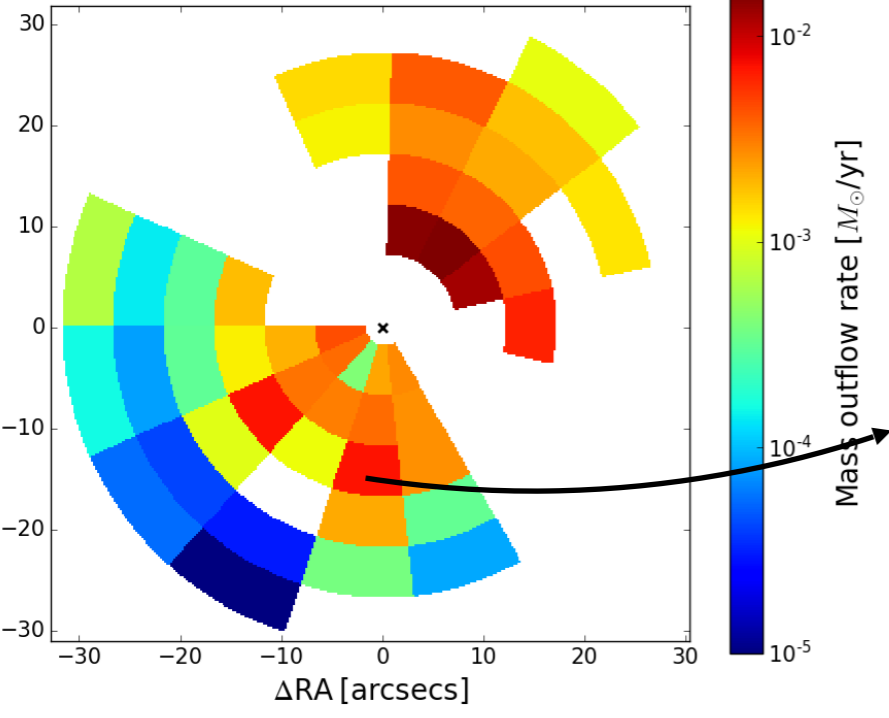
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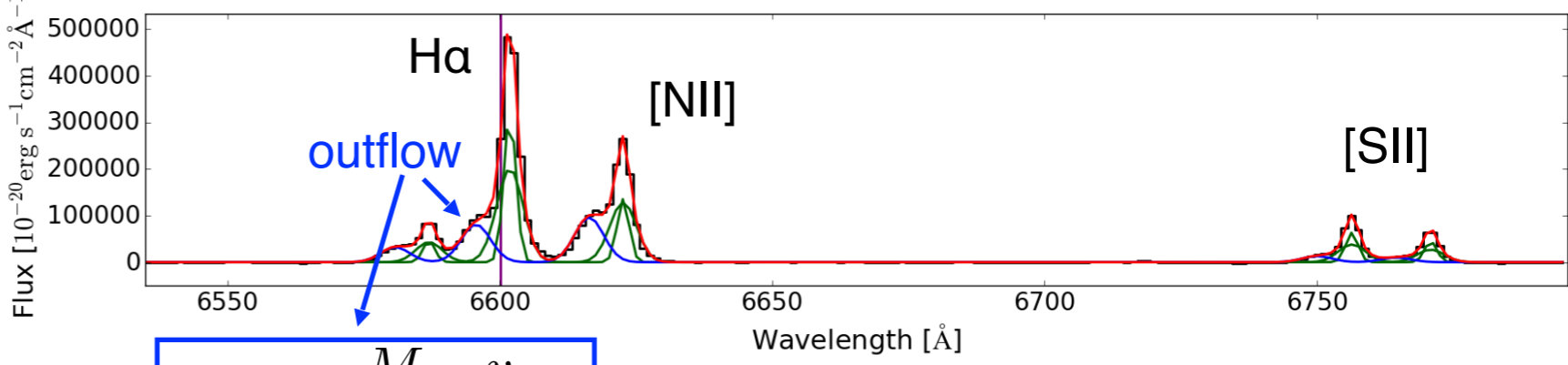
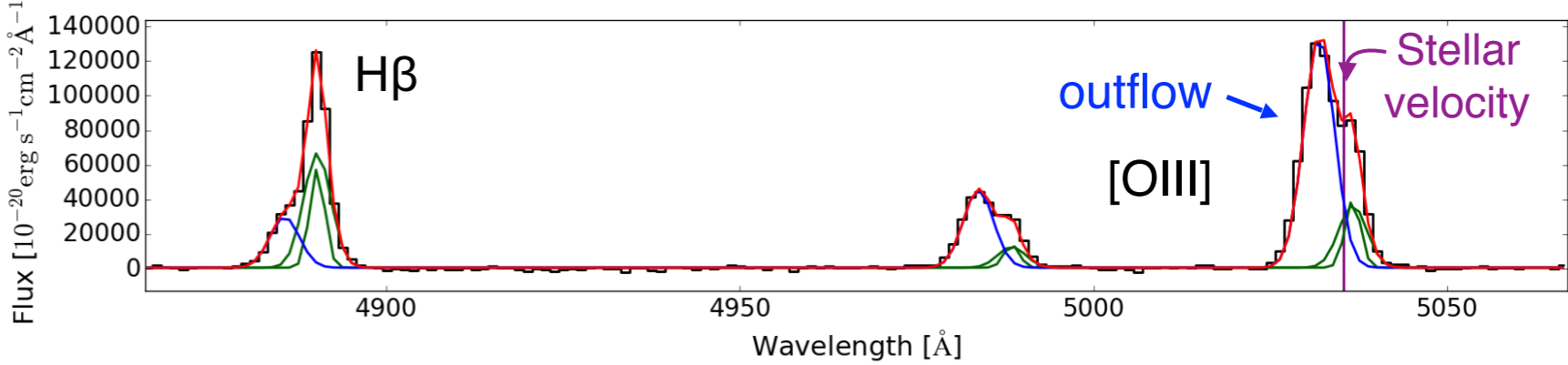
[OIII] dominated by outflow,

Hα dominated by disk

Mass outflow rate



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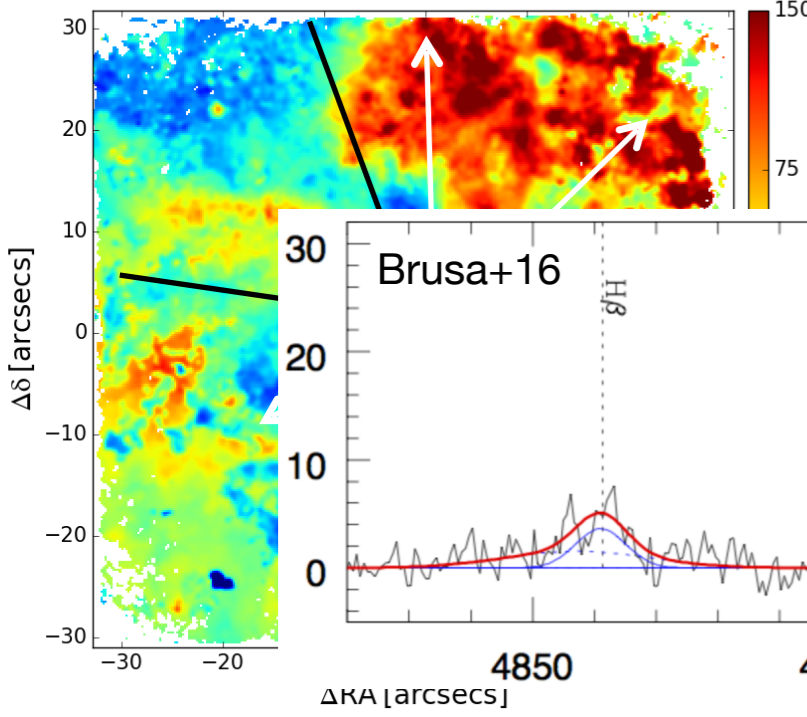


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NGC 1365: mapping the mass outflow rate

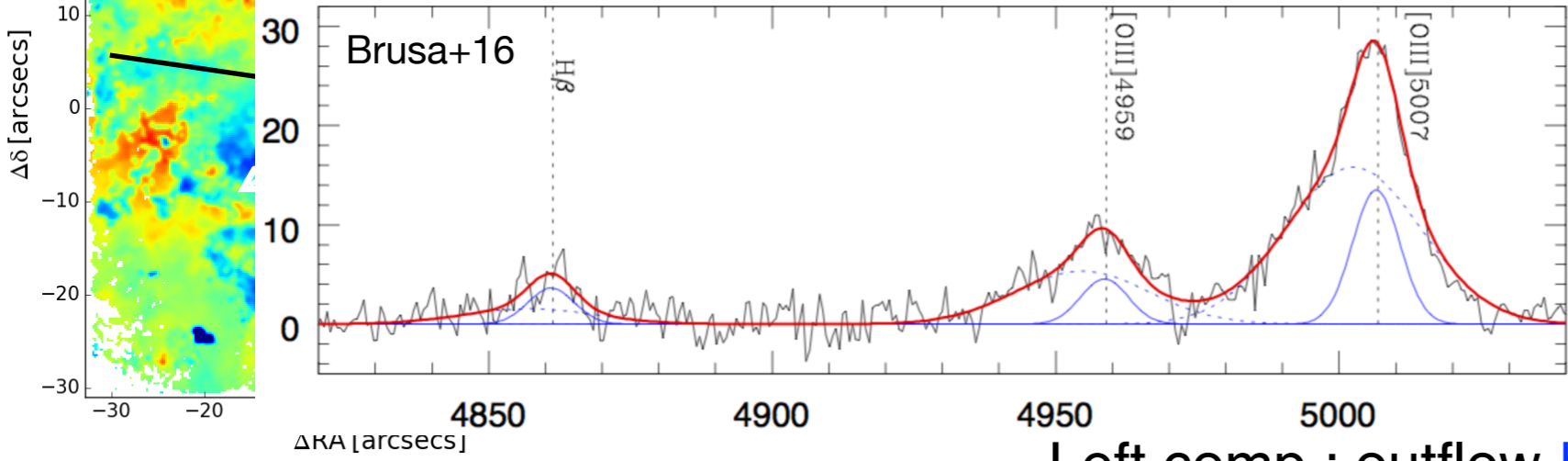
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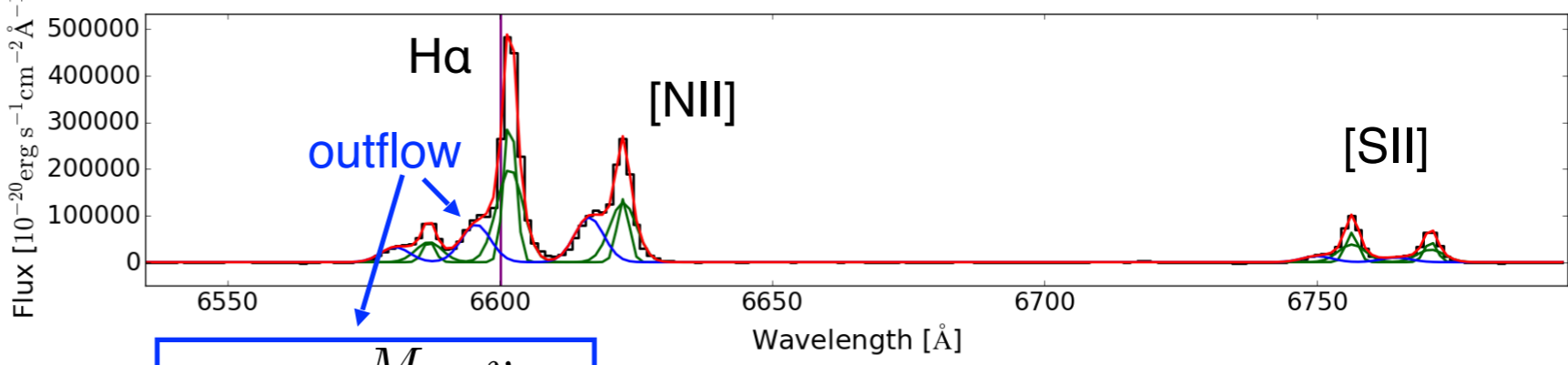
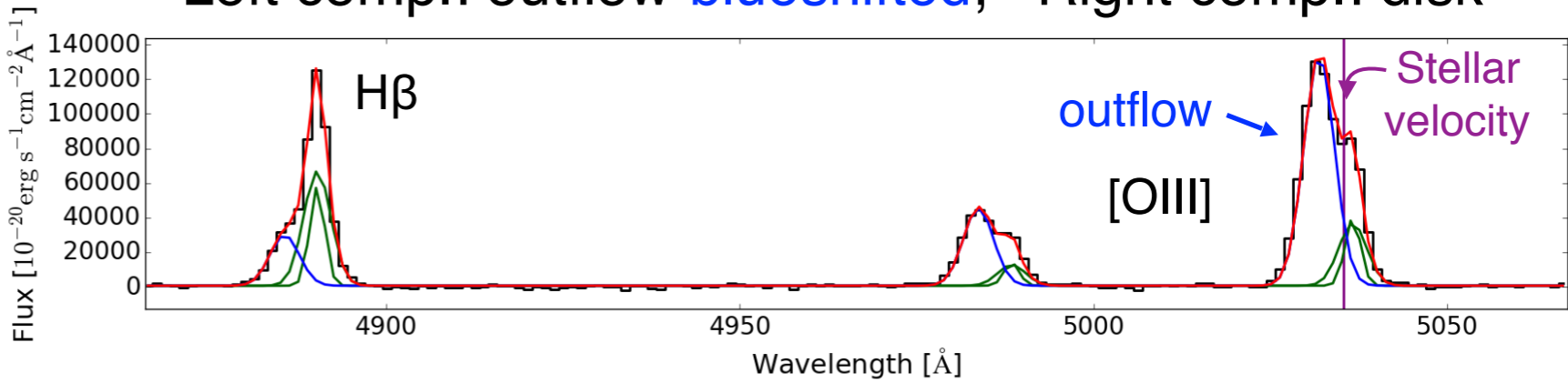
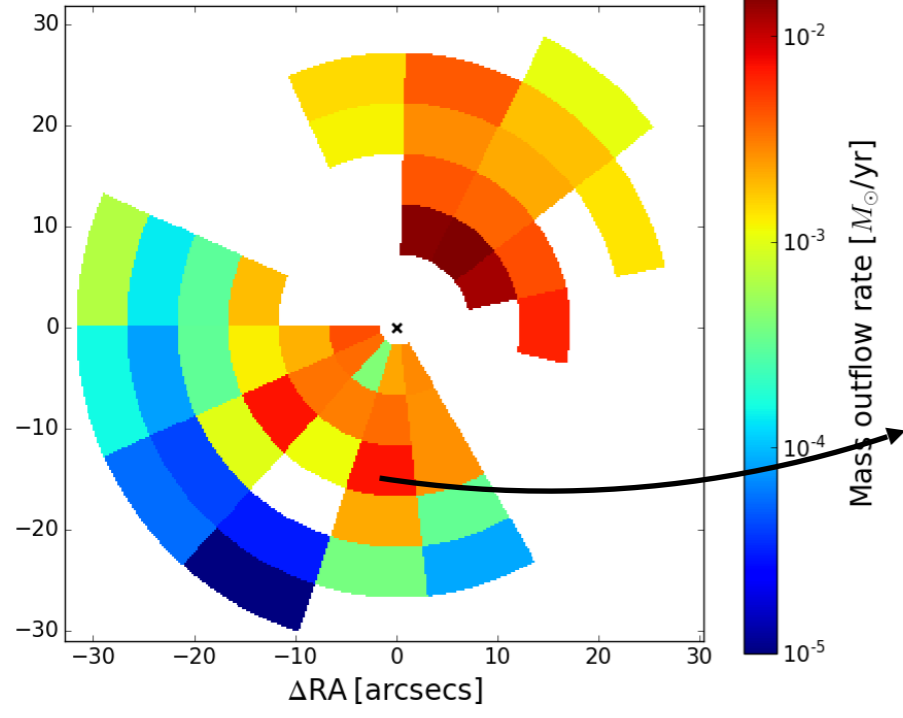
[OIII] dominated by outflow,
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Outflow is not a broad wing
as at low resolution
in more powerful AGN



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

Mass outflow rate

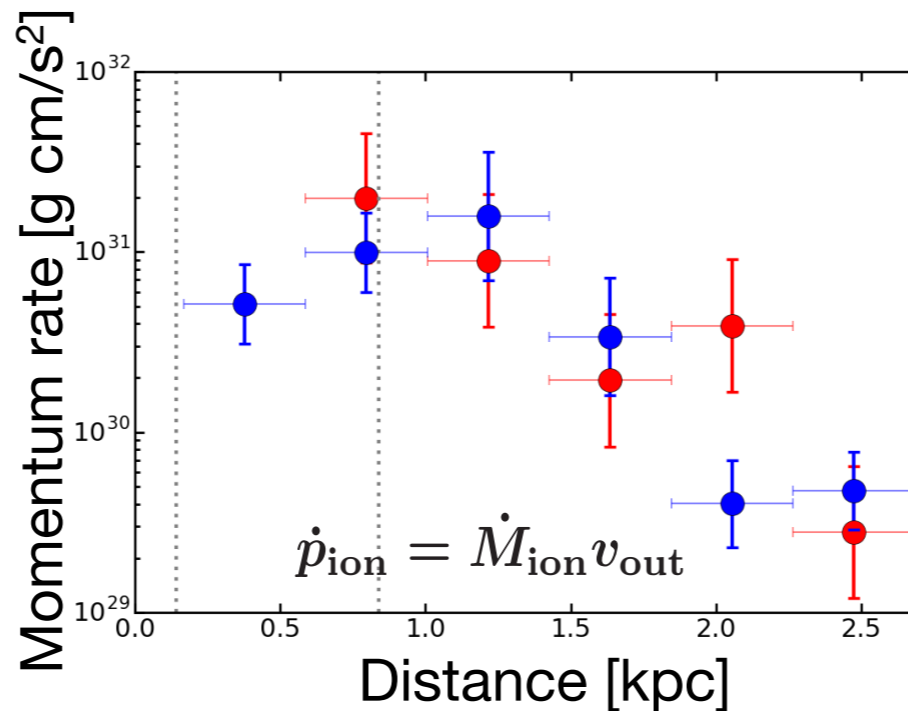
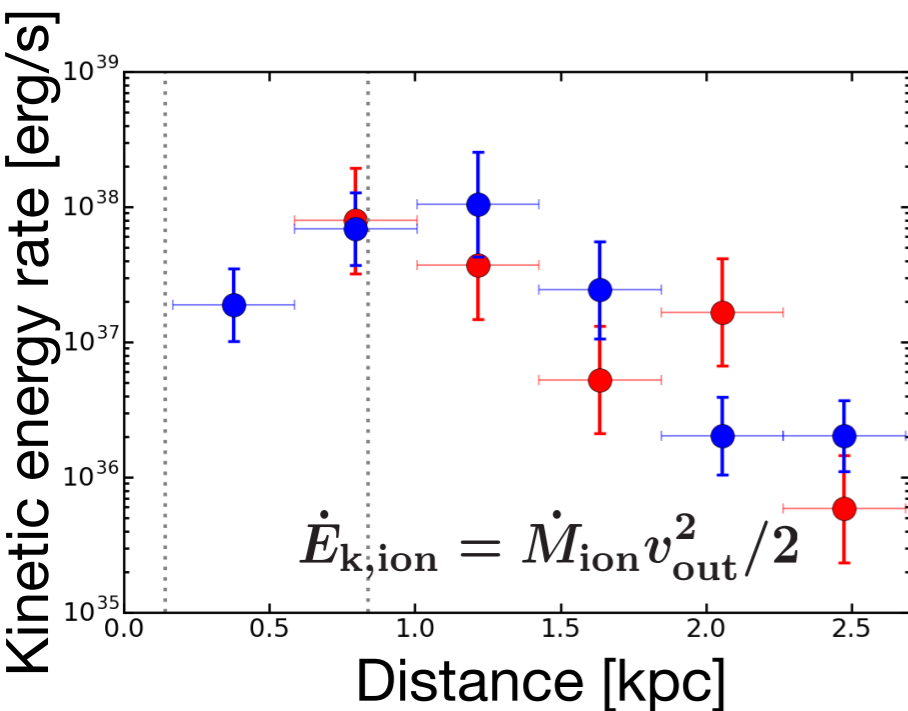
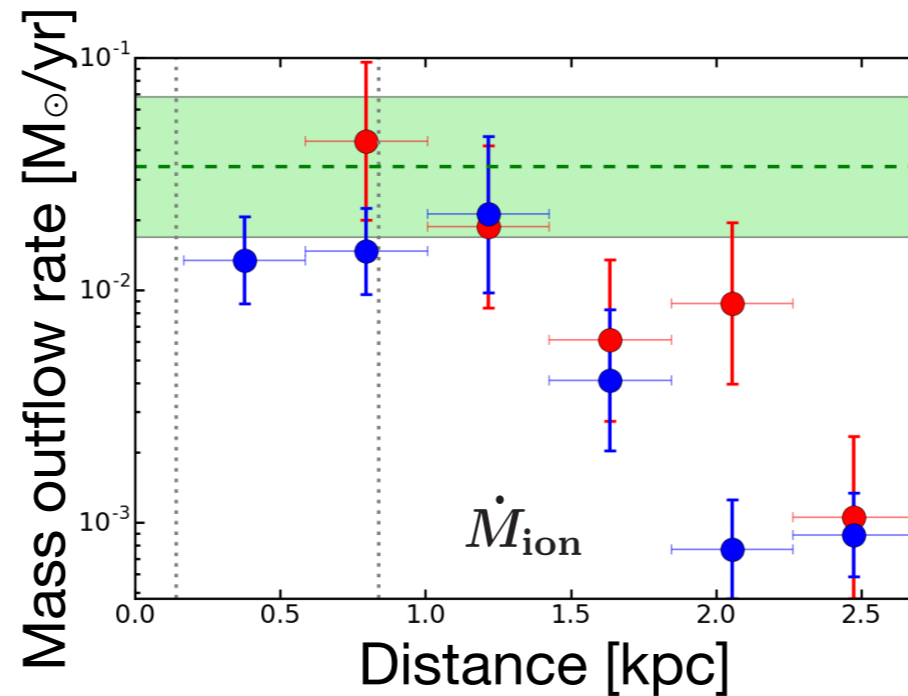
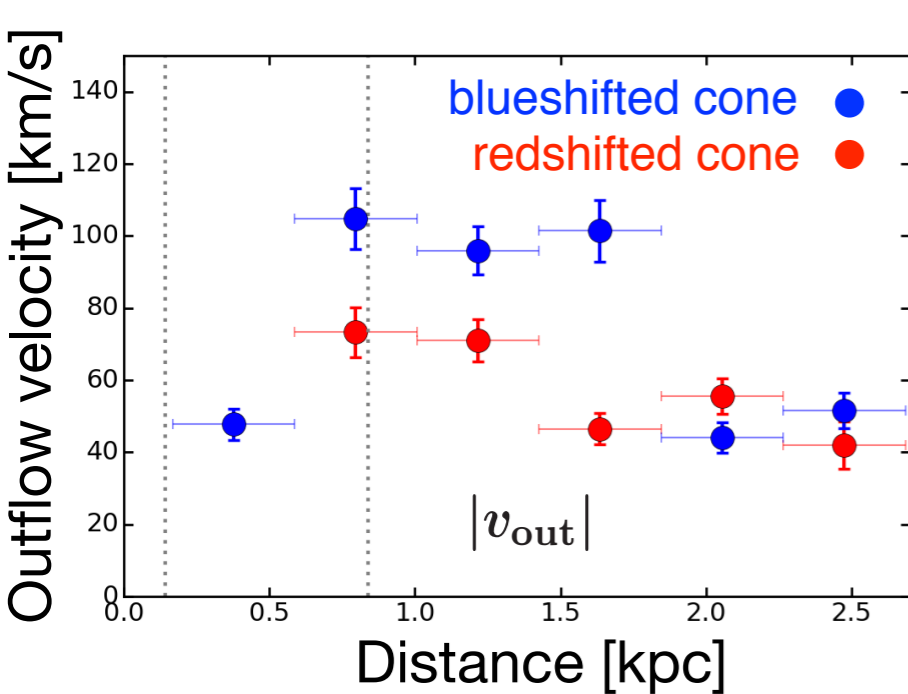


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NGC 1365: outflow radial profiles

Radial profiles as a function of distance from the AGN



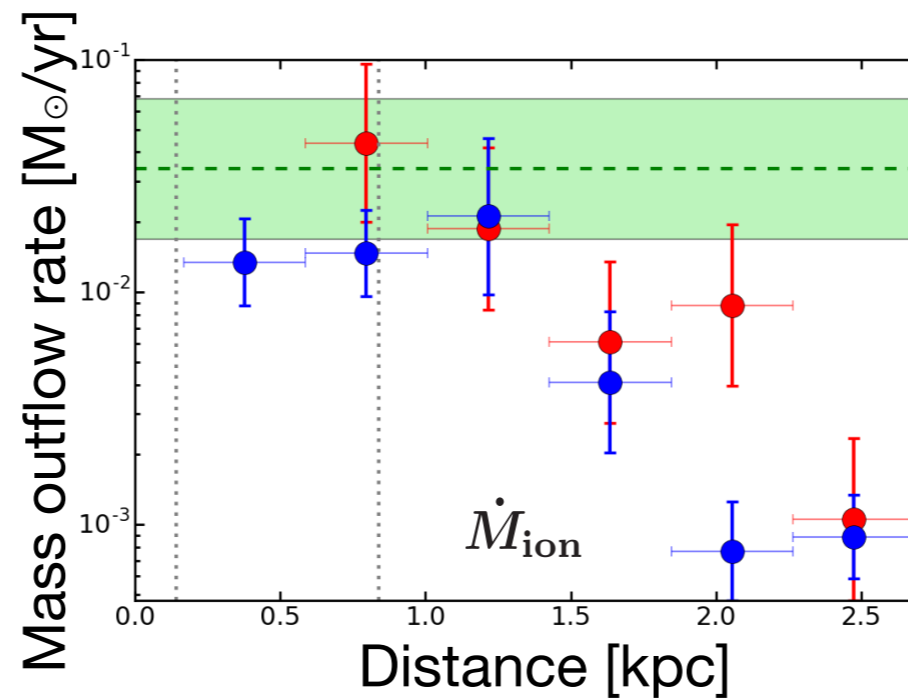
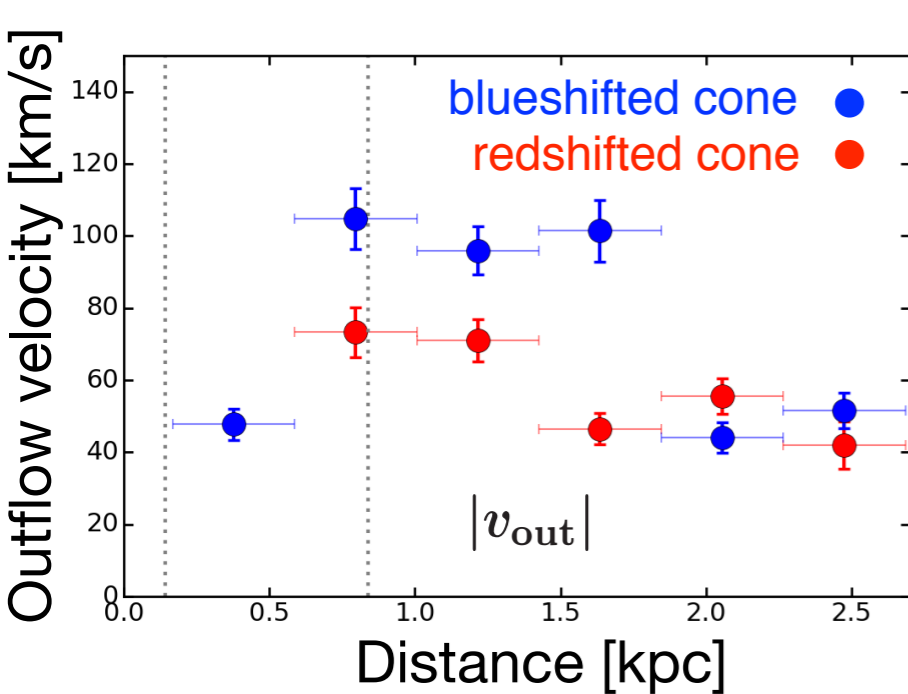
Decreasing trend with distance

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

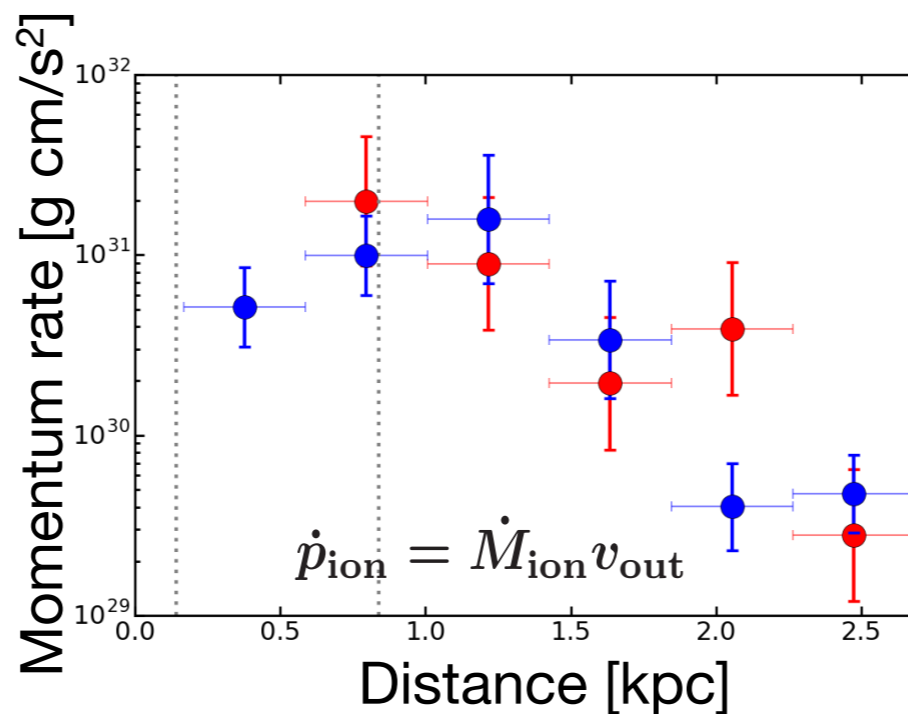
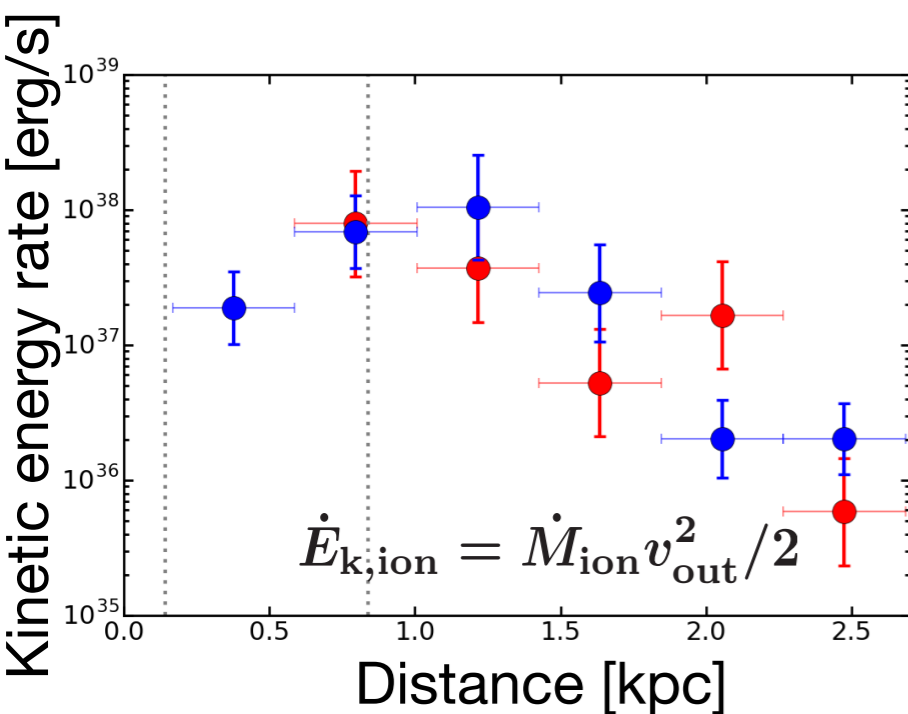
- AGN more powerful recently than in the past
- Outflow does mass loading and slows down (but mass not radially increasing)
- We sample only ionized gas (lacking neutral atomic + molecular), which depends on ionizing flux $\propto r^{-2}$

NGC 1365: outflow radial profiles

Radial profiles as a function of distance from the AGN

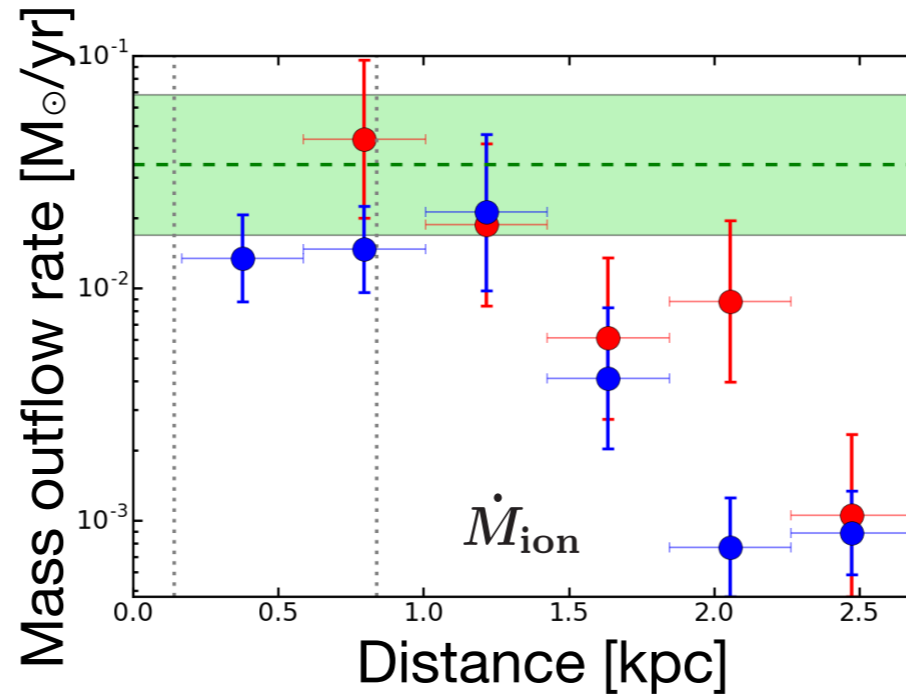
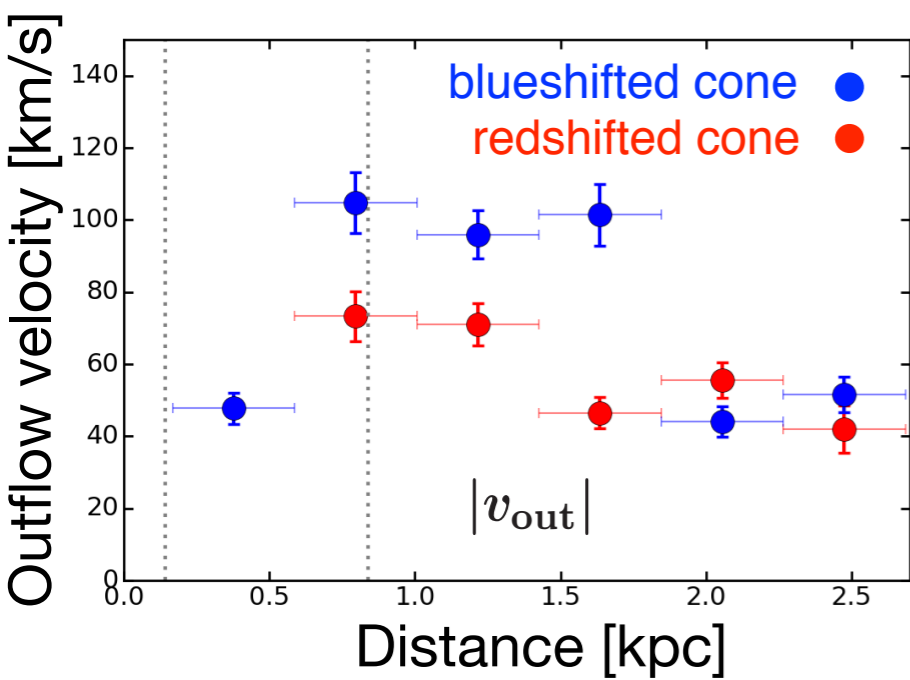


$\dot{M}_{\text{ion}} \ll \text{SFR} (7 M_{\odot}/\text{yr})$
—> outflow unable
to affect SF
(at least in the ionized
phase)



NGC 1365: outflow radial profiles

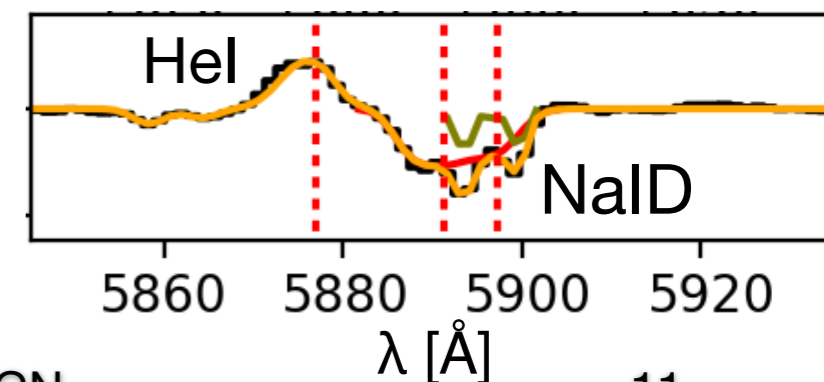
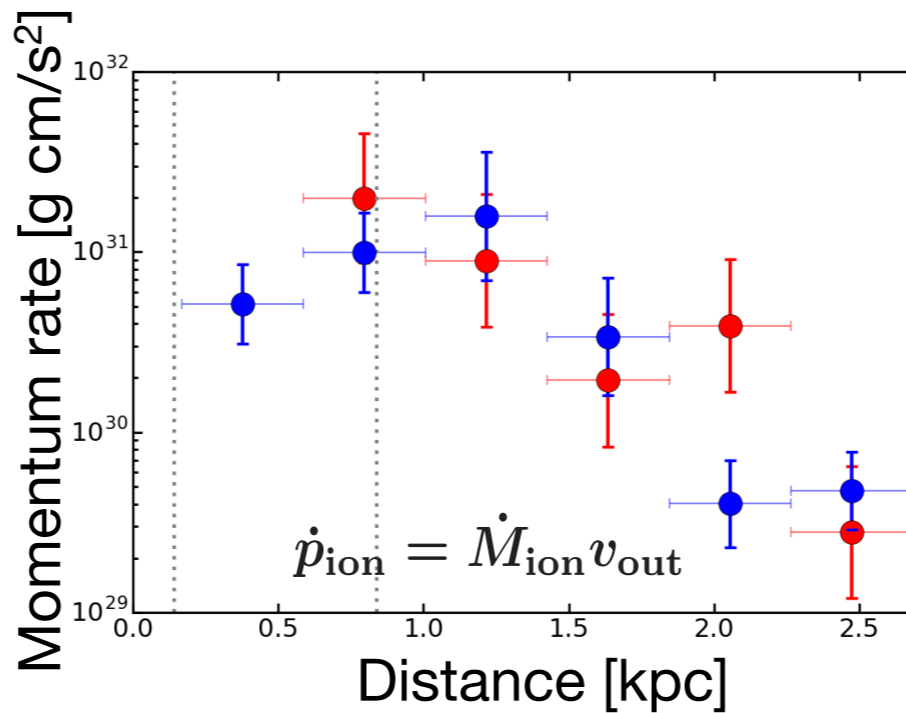
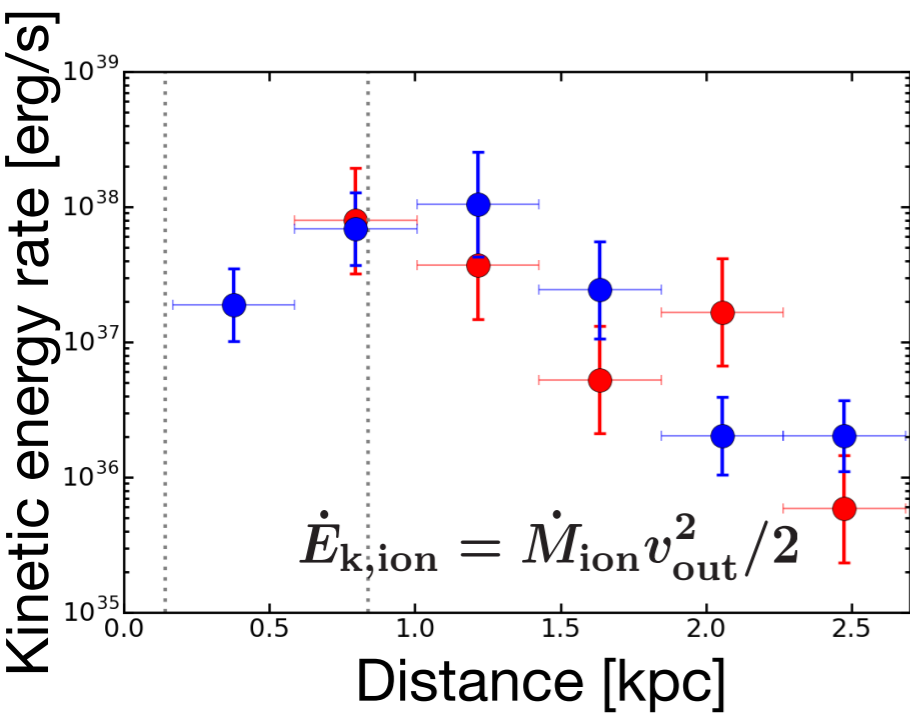
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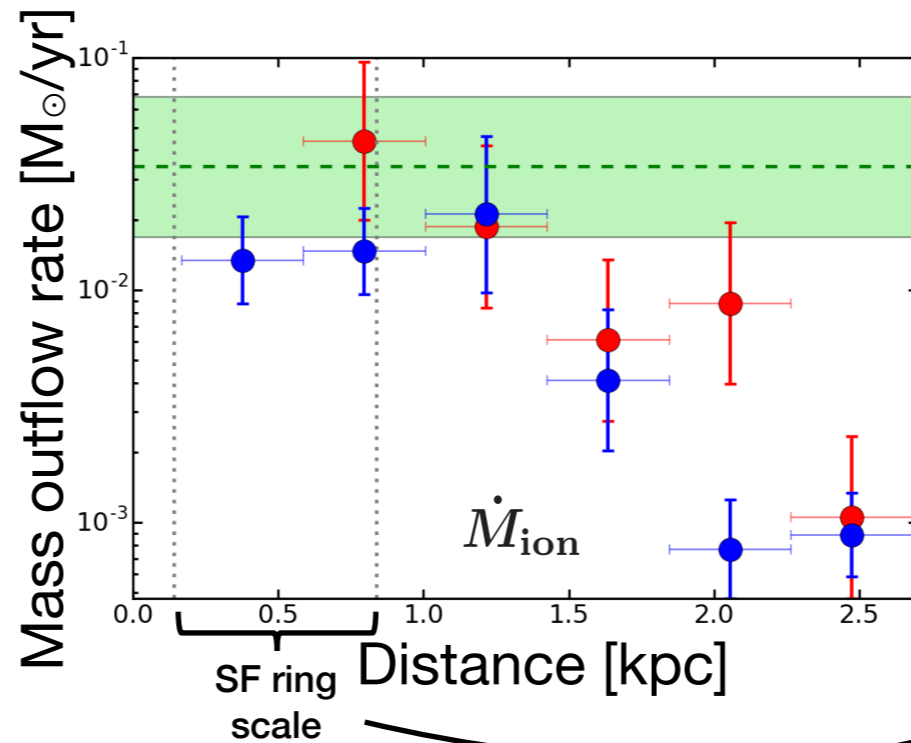
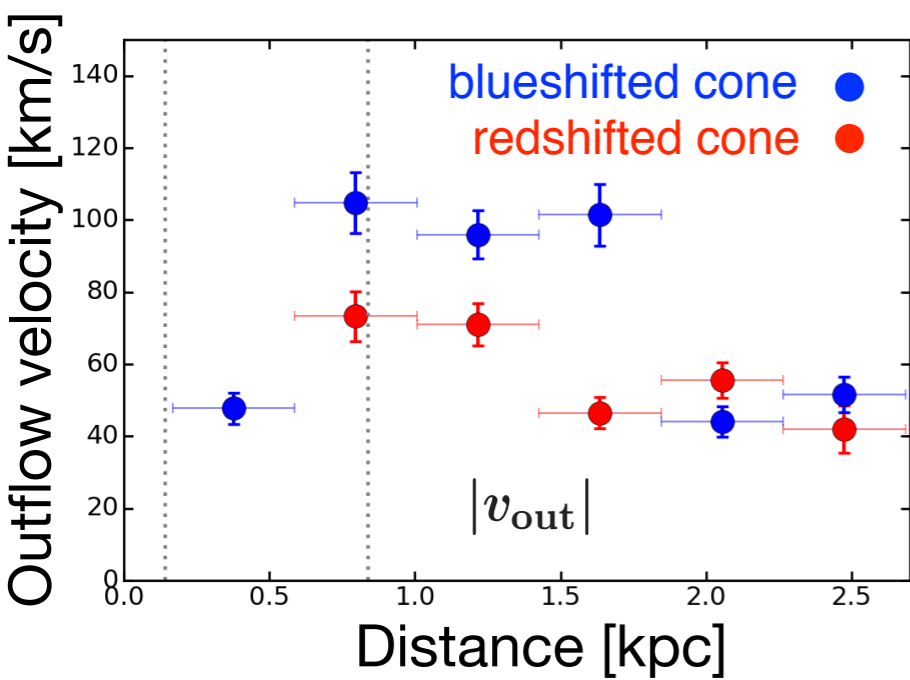


Working on NaID absorption lines to add neutral atomic gas to mass and energy budget of the outflow (Perna, GV+ in prep.)

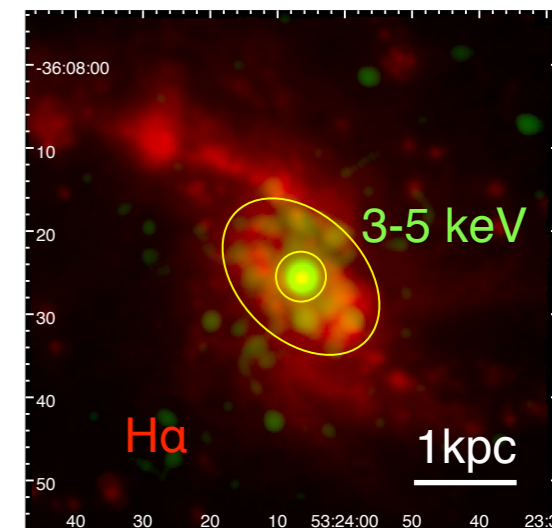
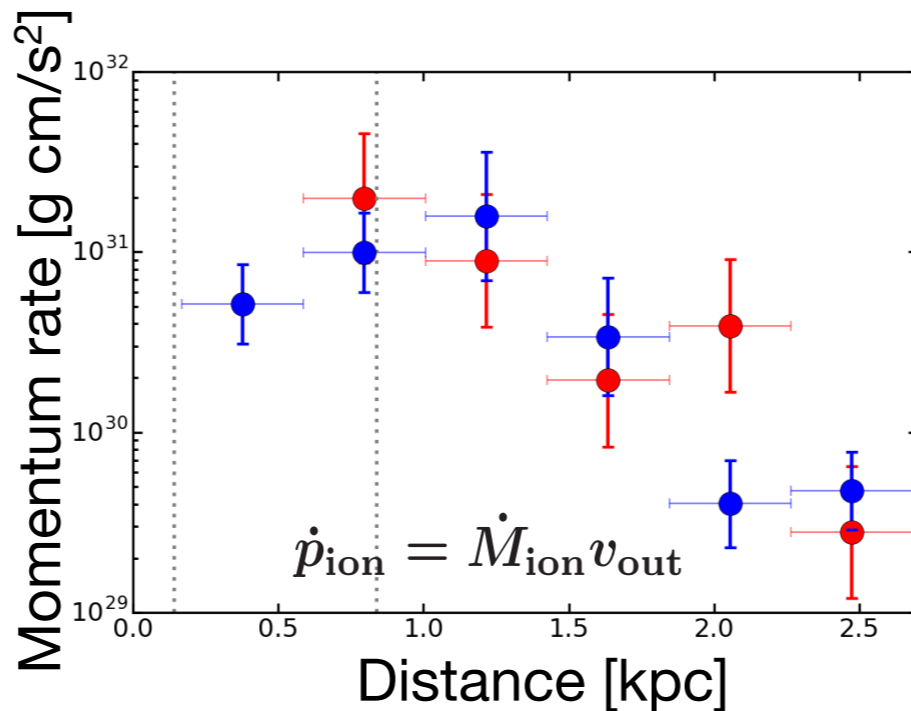
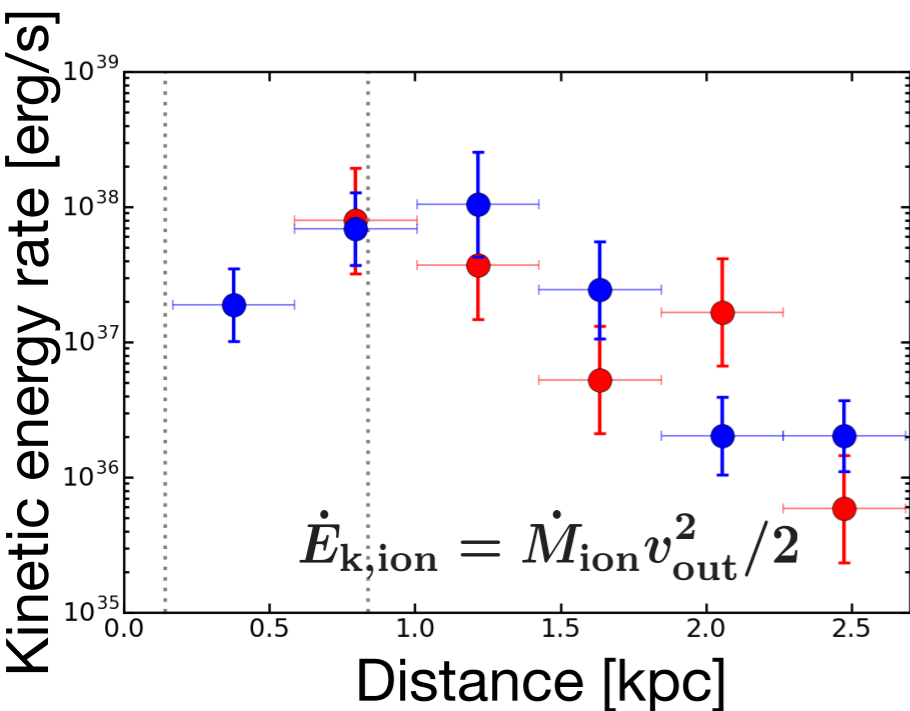


NGC 1365: outflow radial profiles

Radial profiles as a function of distance from the AGN



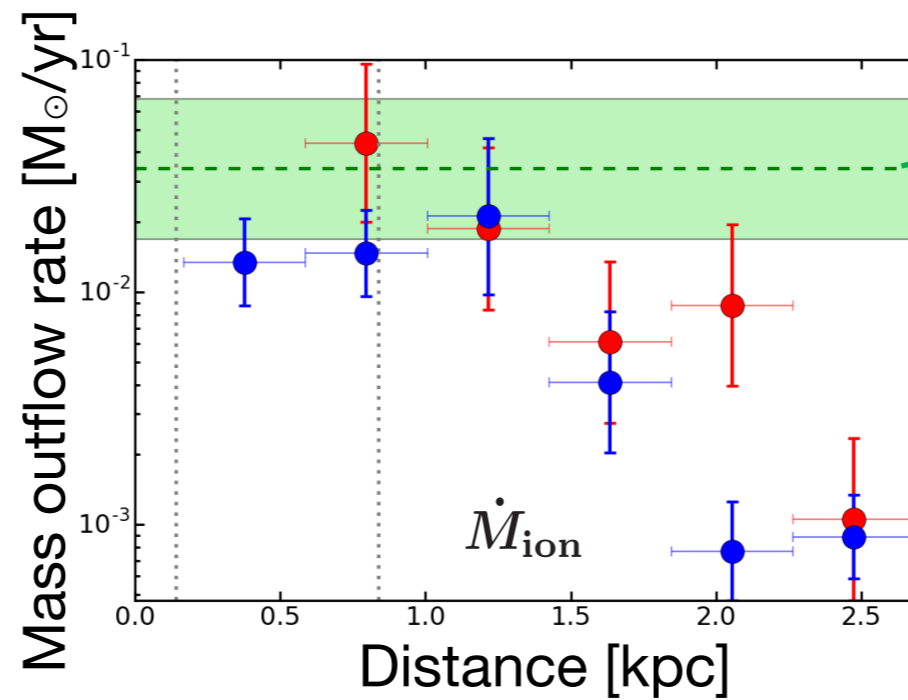
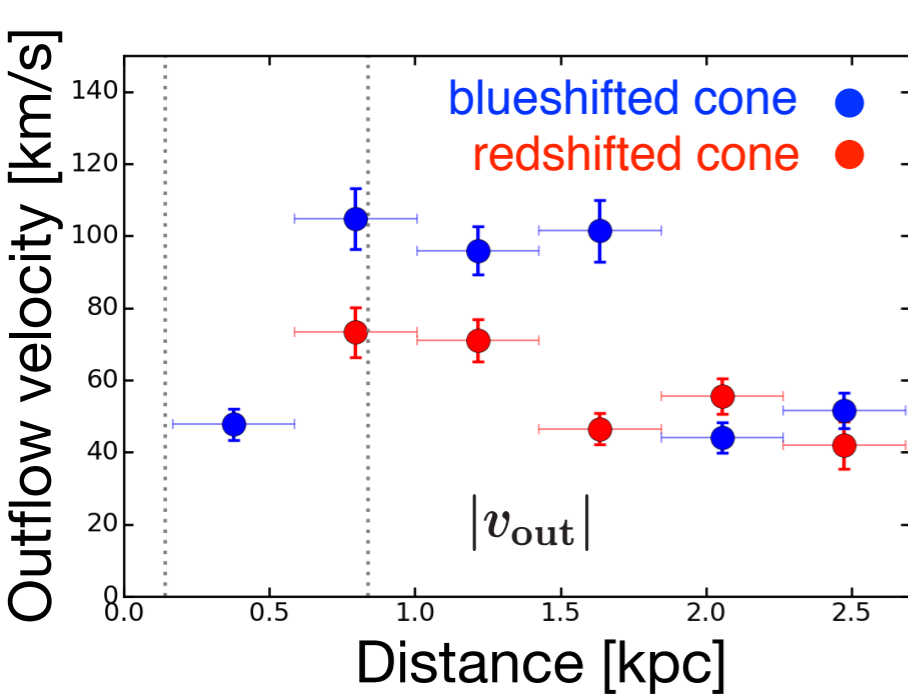
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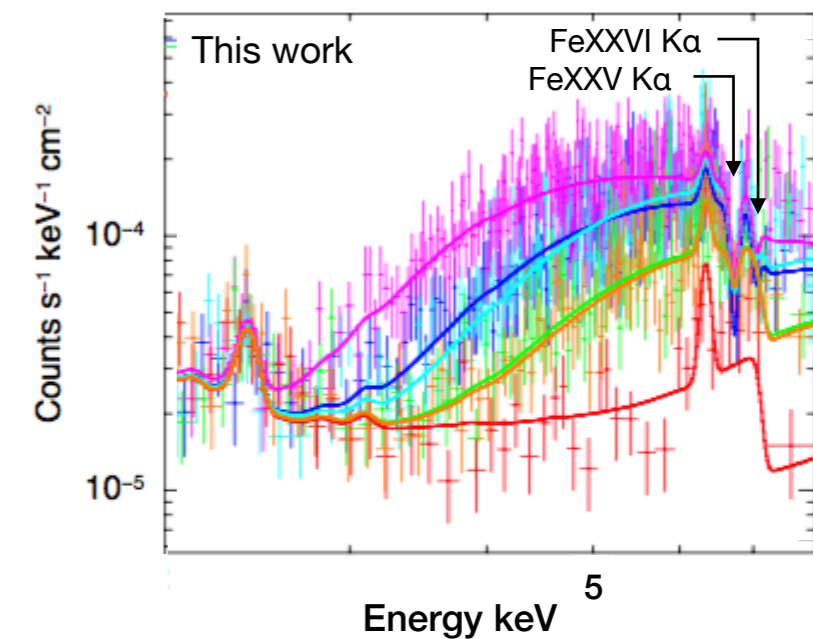
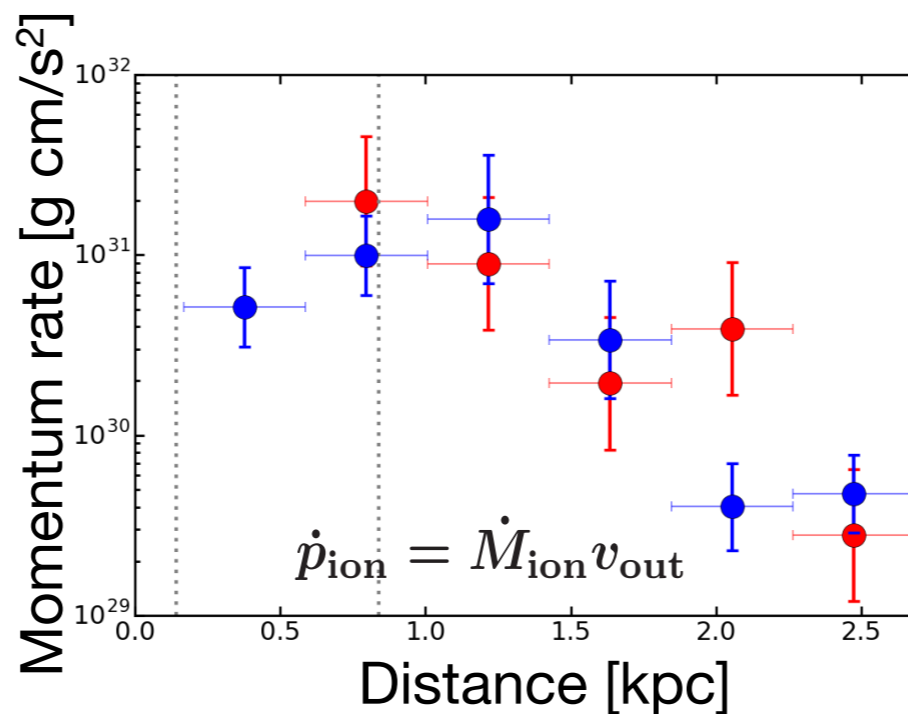
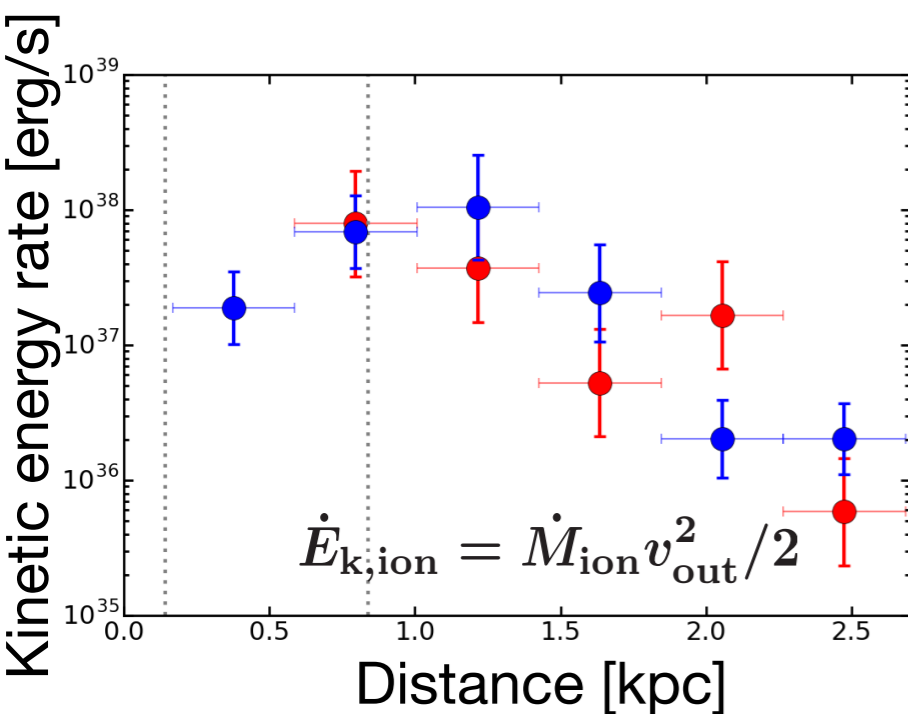
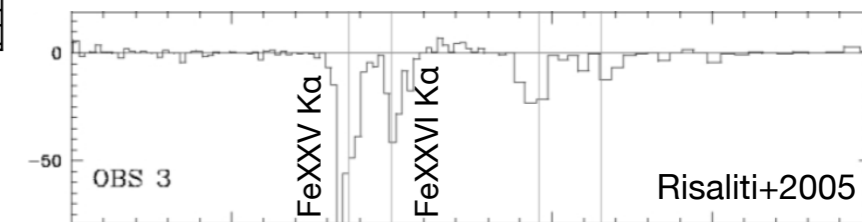
Not excluded that SF ring contributes to outflow, as we observe hard X-ray emission from ring in principle ascribable to SNe producing shocked wind

NGC 1365: outflow radial profiles

Radial profiles as a function of distance from the AGN

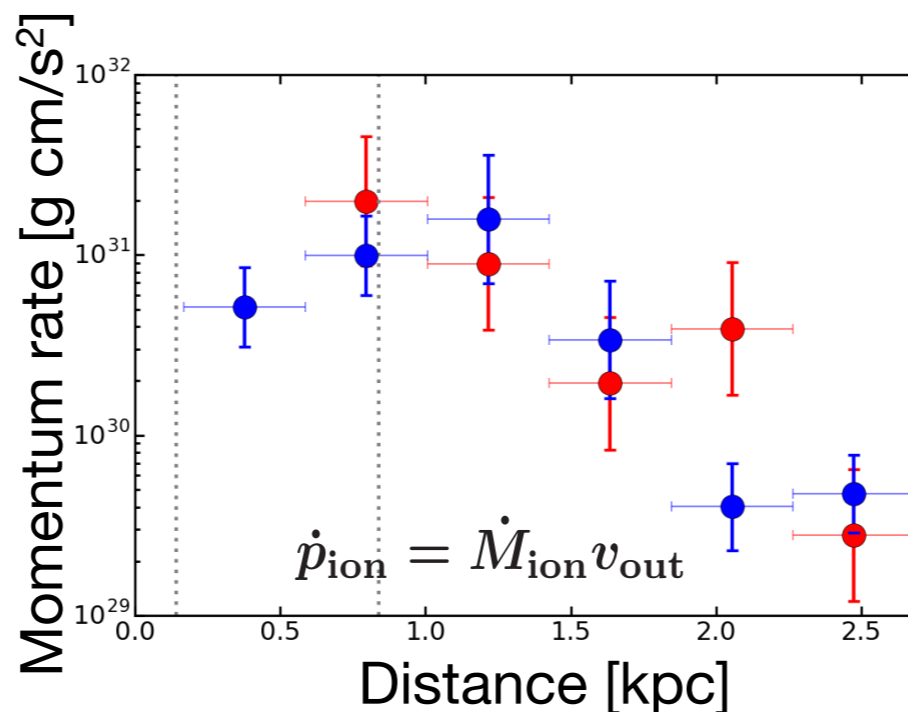
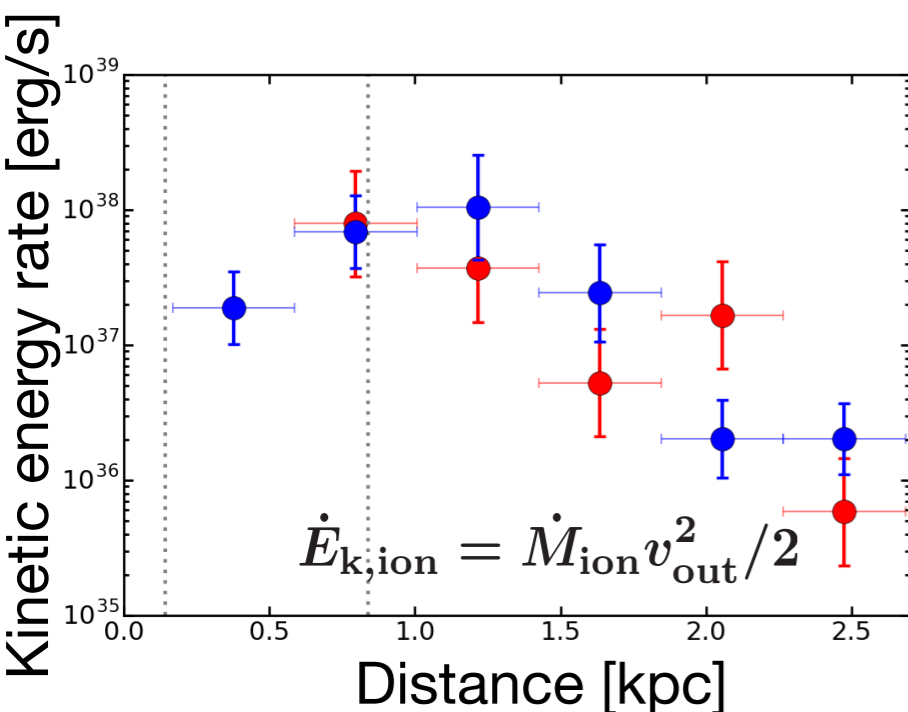
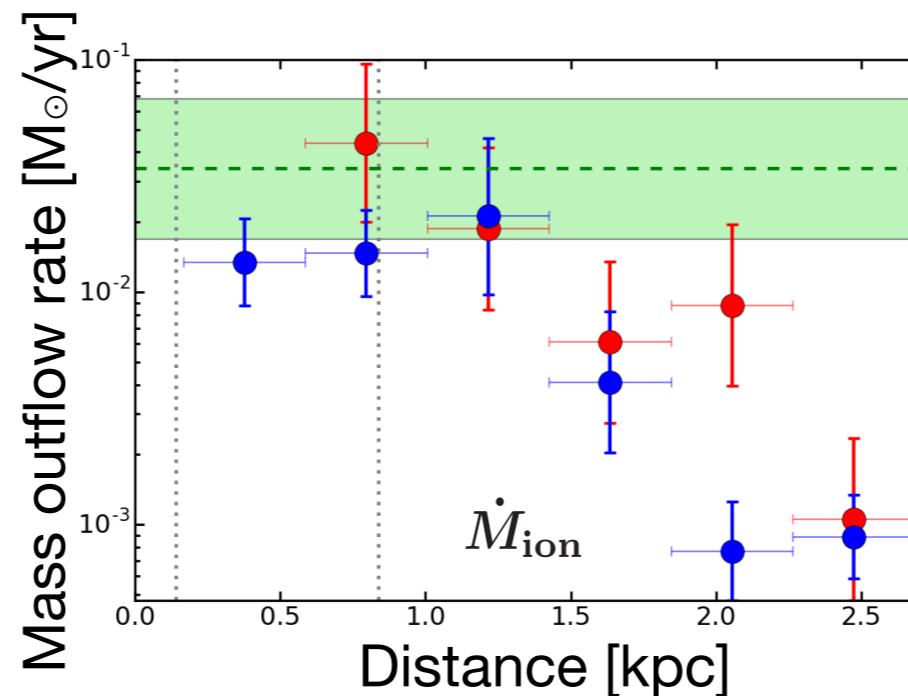
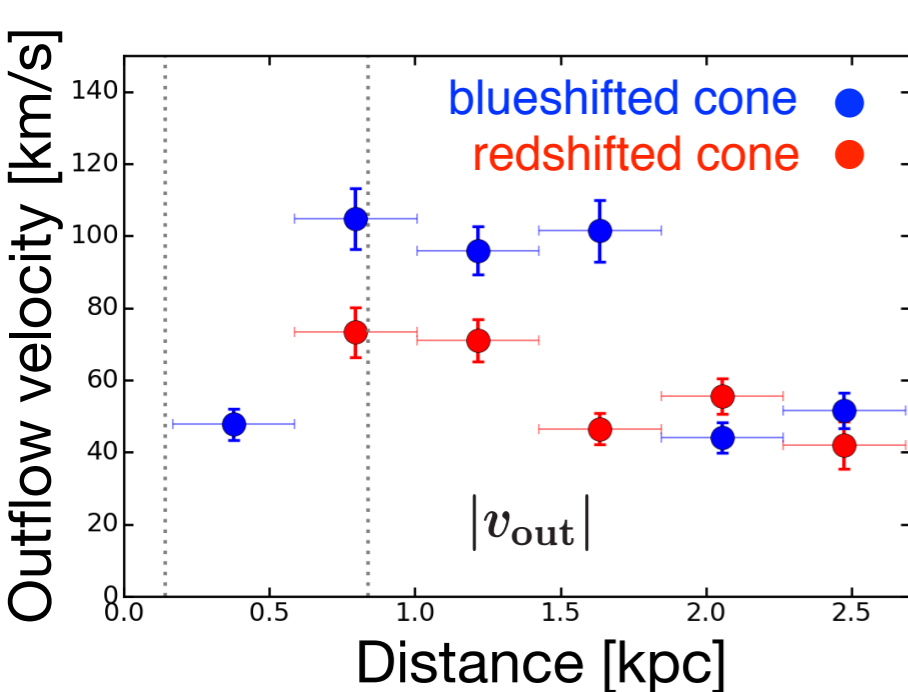


Mass outflow rate of nuclear X-ray wind ($v_{\text{out,X}} \sim 3000$ km/s) from FeXXV and FeXXVI abs. lines



NGC 1365: outflow radial profiles

Radial profiles as a function of distance from the AGN



- **Energy-driven:**

$$\dot{E}_{k,\text{ion}} \lesssim 10^{-3} \dot{E}_{k,X}$$

→ would need too much neutral atomic + molecular for $\dot{E}_{k,\text{tot}} \sim \dot{E}_{k,X}$ (see Carniani+15, Fiore+17, Fluetsch+19)

- **Direct AGN radiation**

pressure on dusty clouds (e.g. Thomson+15, Ishibashi+18):

$$\dot{p}_{\text{ion}} \lesssim 1/20 L_{\text{AGN}}/c$$

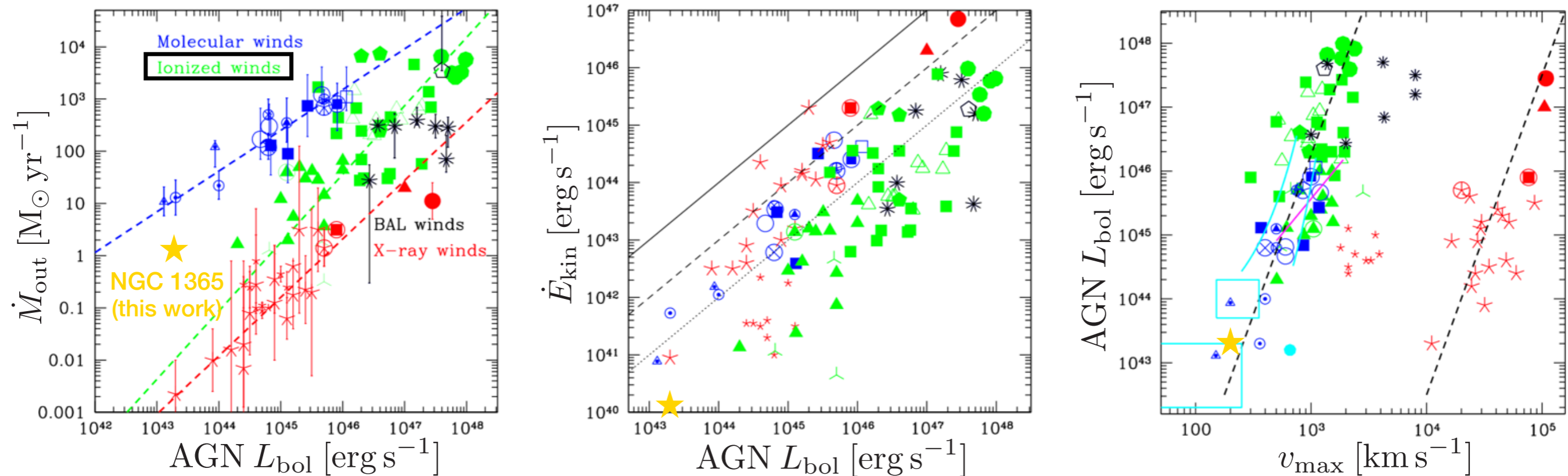
(models: $\dot{p}_{\text{tot}} \sim 1-5 L_{\text{AGN}}/c$)

→ in principle could be the driver

Comparison with AGN outflow samples

Extend at low luminosity the AGN ionized outflow sample of **Fiore+2017**

(NGC 1365: AGN $L_{\text{bol}} \sim 2 \times 10^{43}$ erg/s)



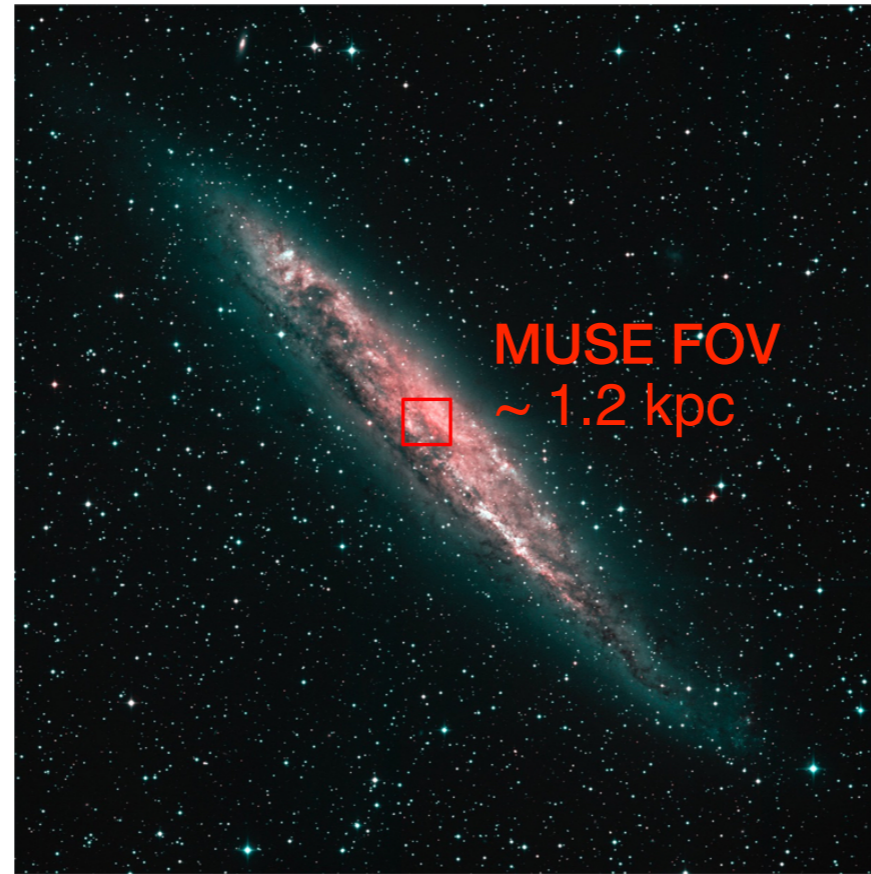
—> \dot{E}_{kin} and v_{max} for the integrated outflow **consistent** with extrapolation of relations from Fiore+2017 within scatter, \dot{M}_{out} barely consistent

Insights on **outflow 3D structure**

with **MUSE** data of nearby galaxies

MAGNUM survey: outflow structure

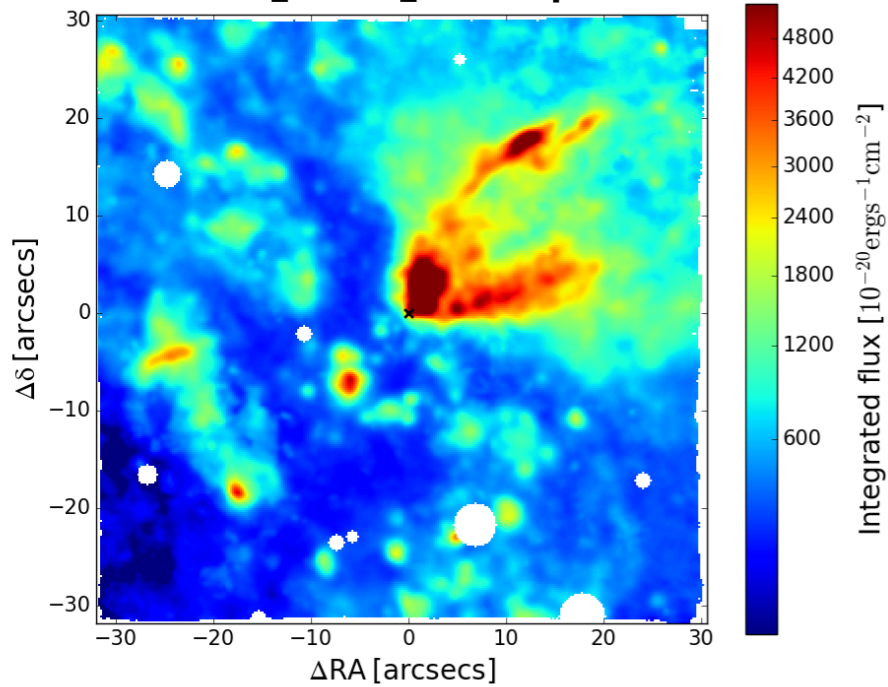
NGC 4945



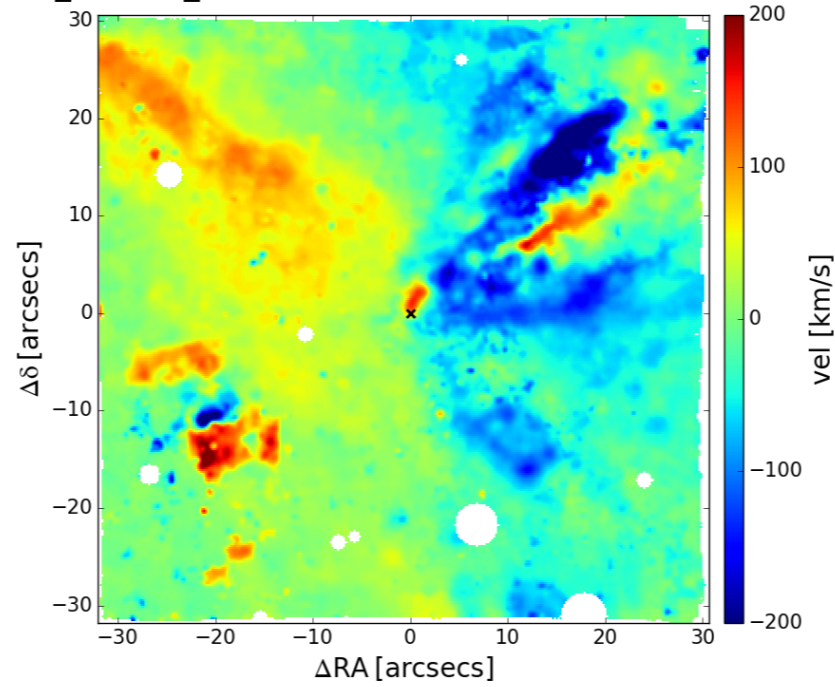
MAGNUM survey: outflow structure

NGC 4945

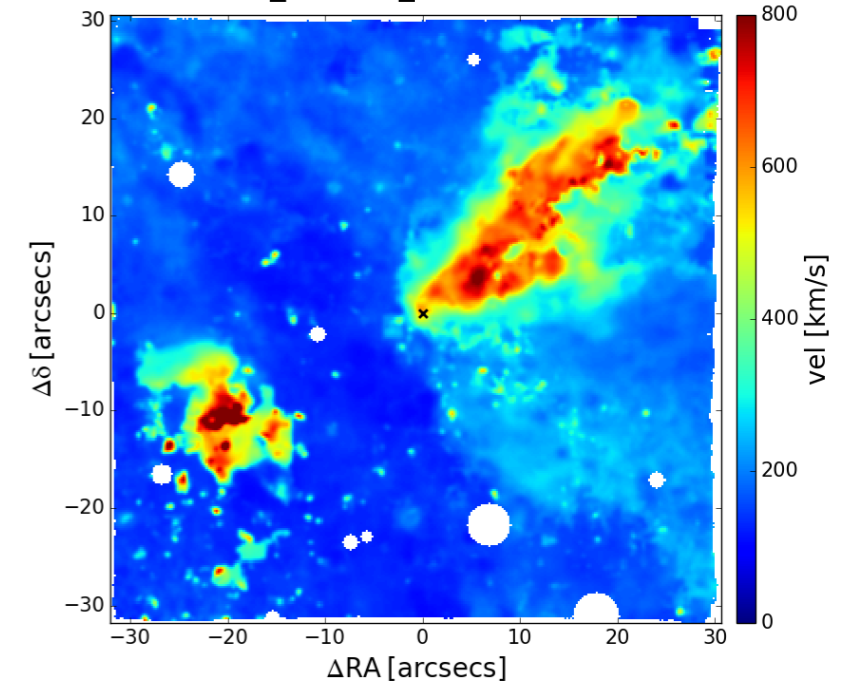
[NII] map



[NII] vel. - Stellar vel.



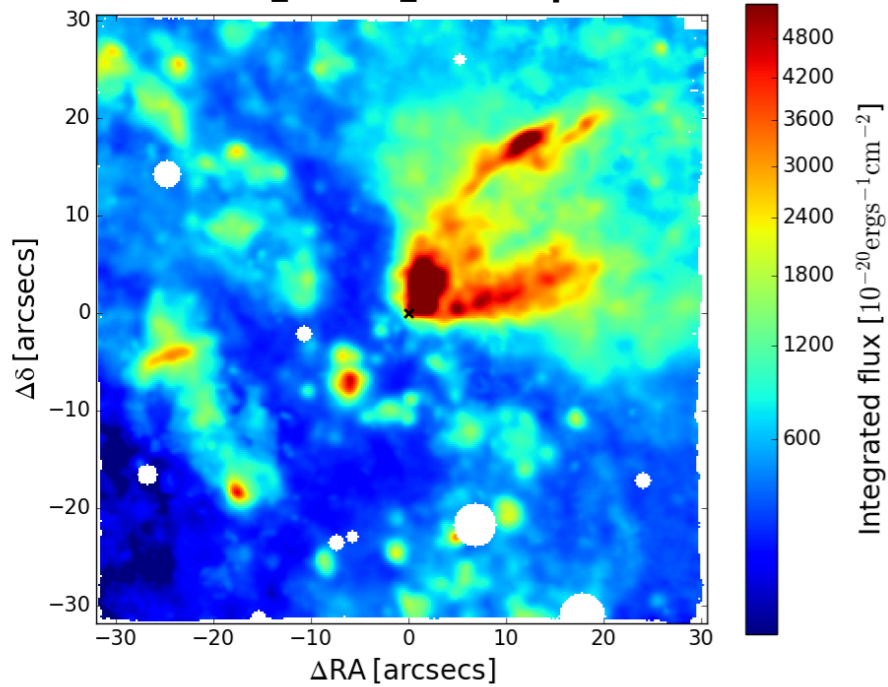
[NII] W70



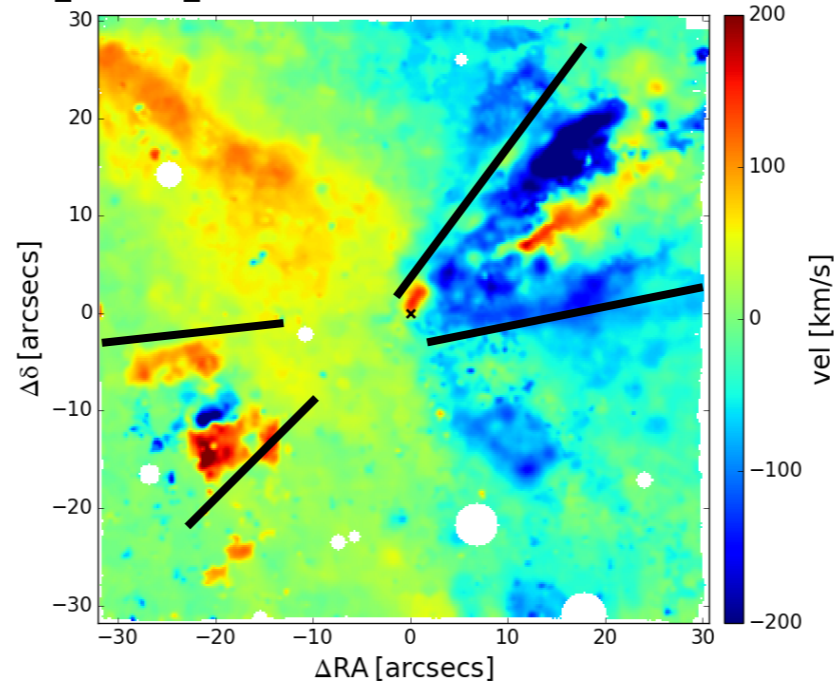
MAGNUM survey: outflow structure

NGC 4945

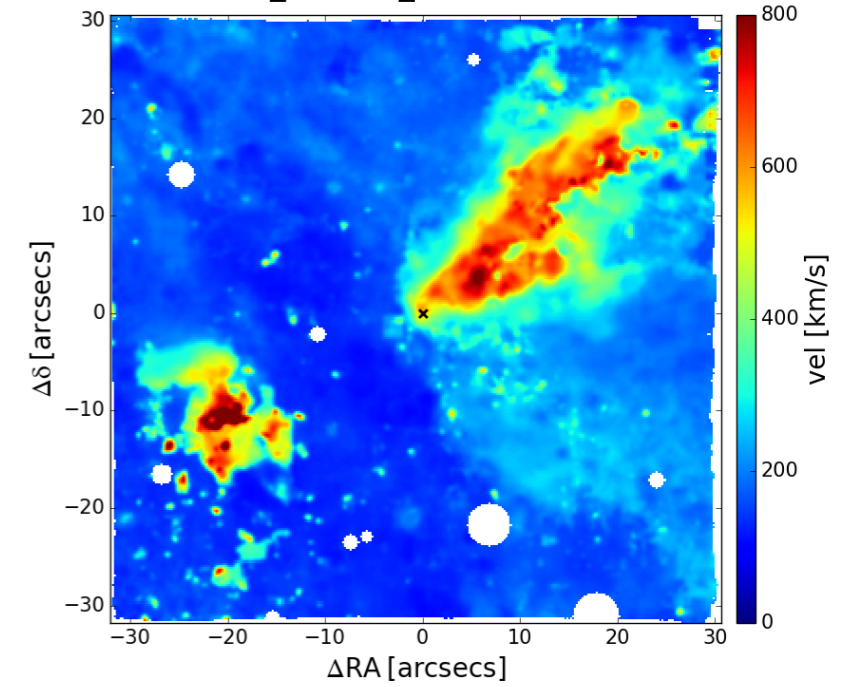
[NII] map



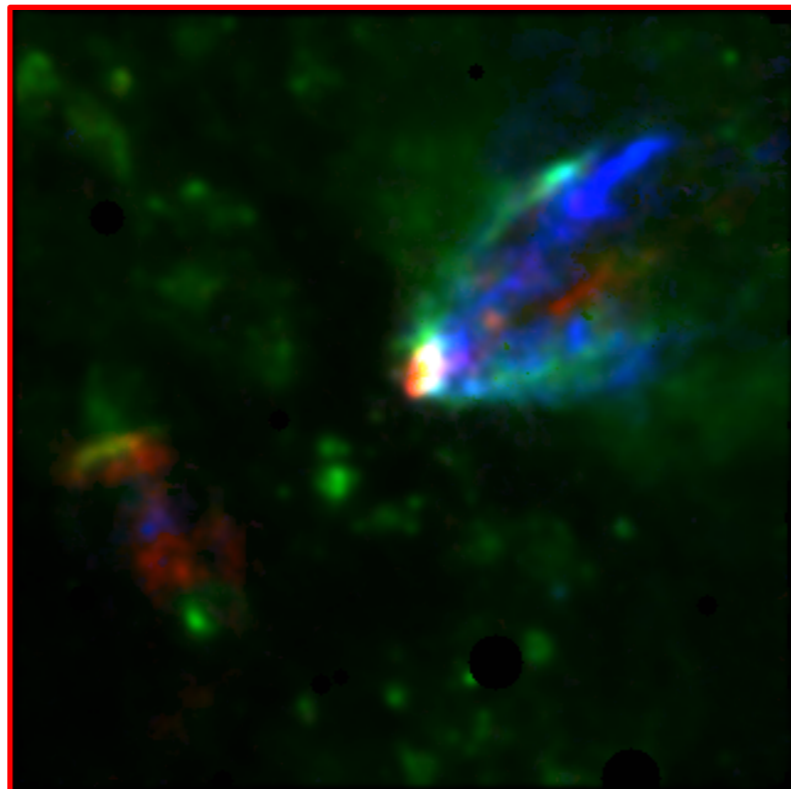
[NII] vel. - Stellar vel.



[NII] W70



Double conical outflow
with complex structure

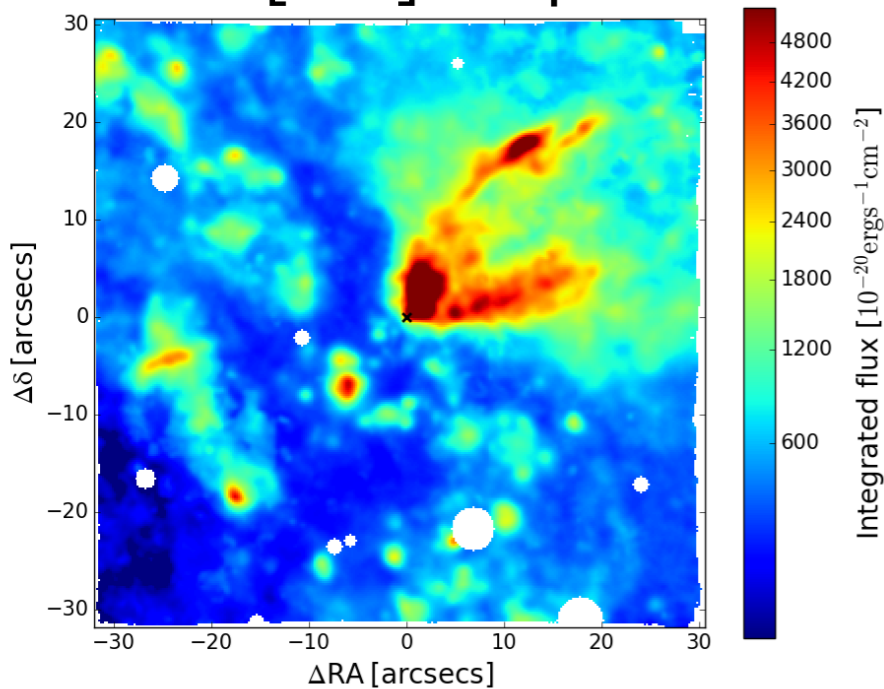


Blue: $\text{Flux}_{[\text{NII}]} < -300 \text{ km/s}$
Green: $-300 \text{ km/s} < \text{Flux}_{[\text{NII}]} < 300 \text{ km/s}$
Red: $\text{Flux}_{[\text{NII}]} > 300 \text{ km/s}$

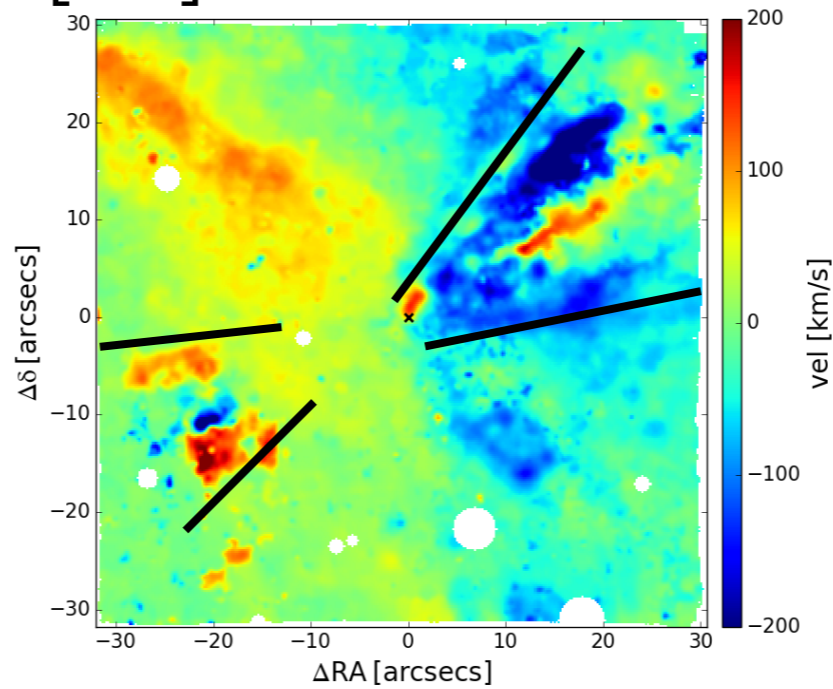
MAGNUM survey: outflow structure

NGC 4945

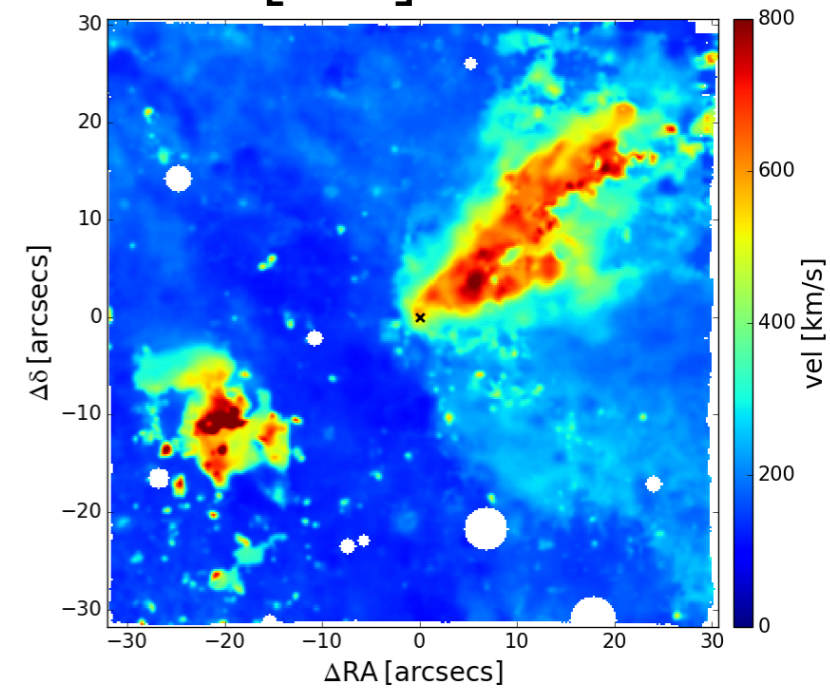
[NII] map



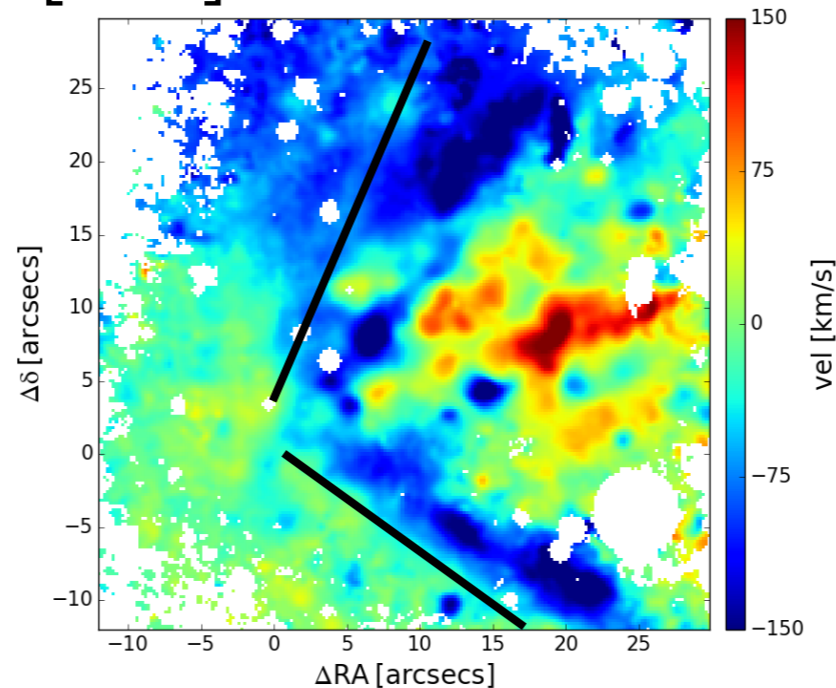
[NII] vel. - Stellar vel.



[NII] W70



[OIII] vel. - Stellar vel.



Circinus

FOV ~ 850 pc

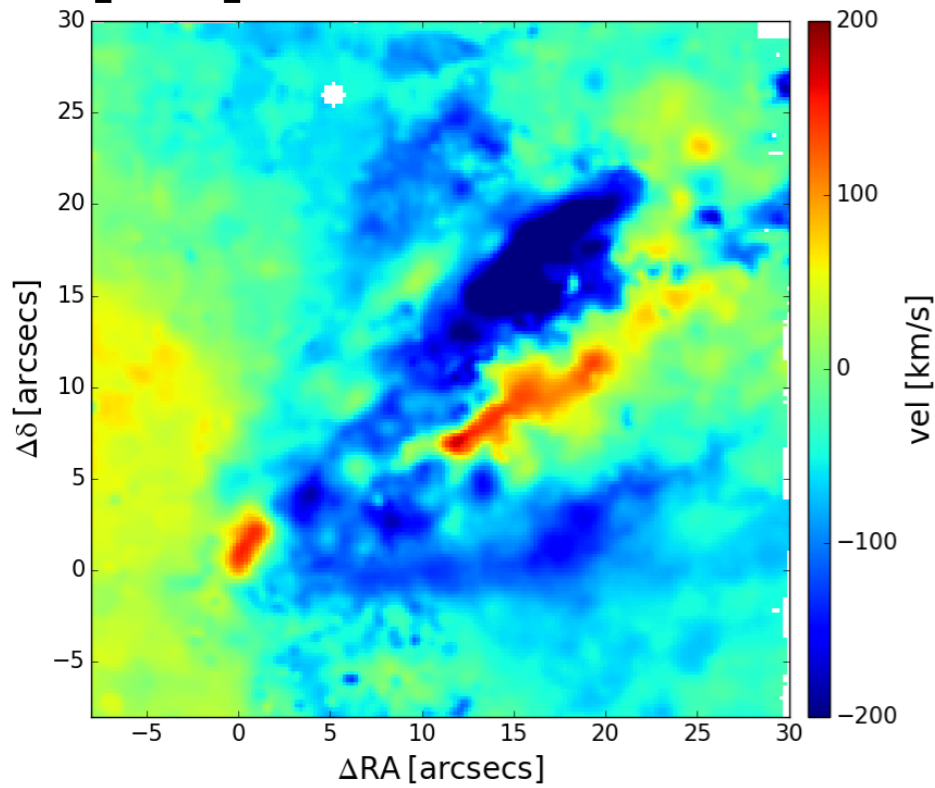
Zoom on the cone:
same velocity structure
of the outflow

Edges → approaching
Axis → receding

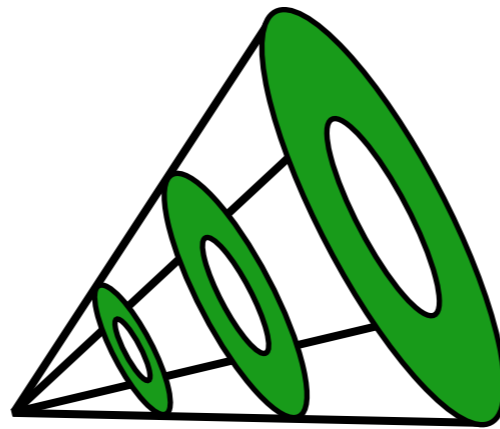
MAGNUM survey: outflow structure

NGC 4945

[NII] vel. - Stellar vel.

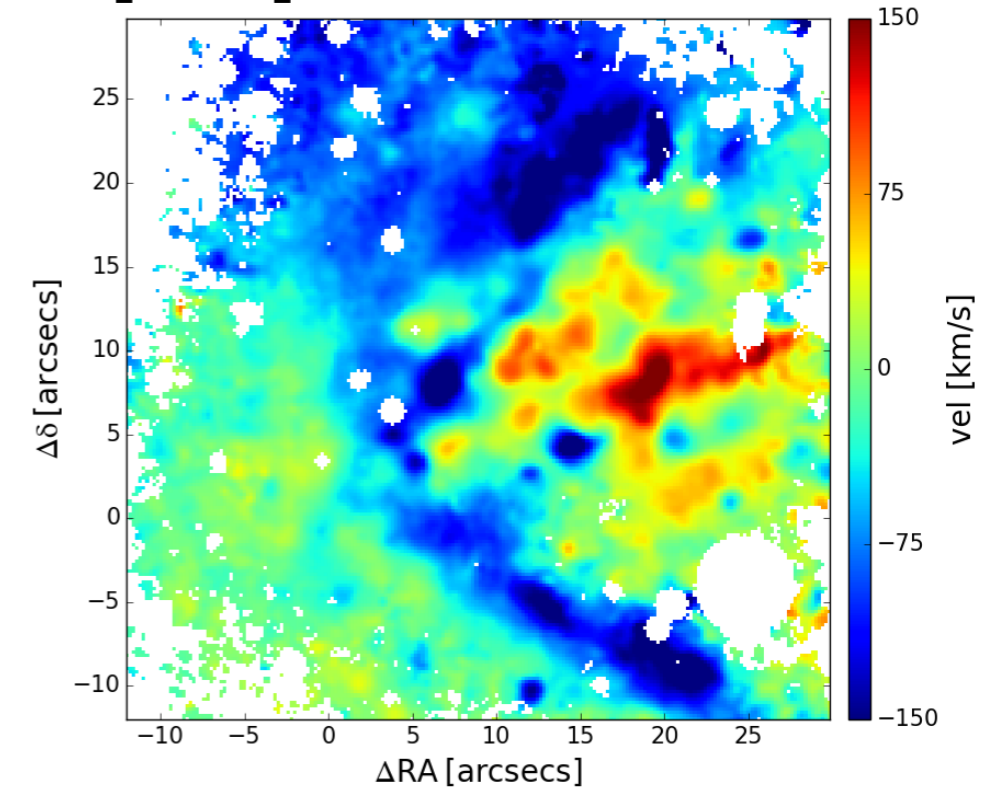


A hollow conical outflow?



Circinus

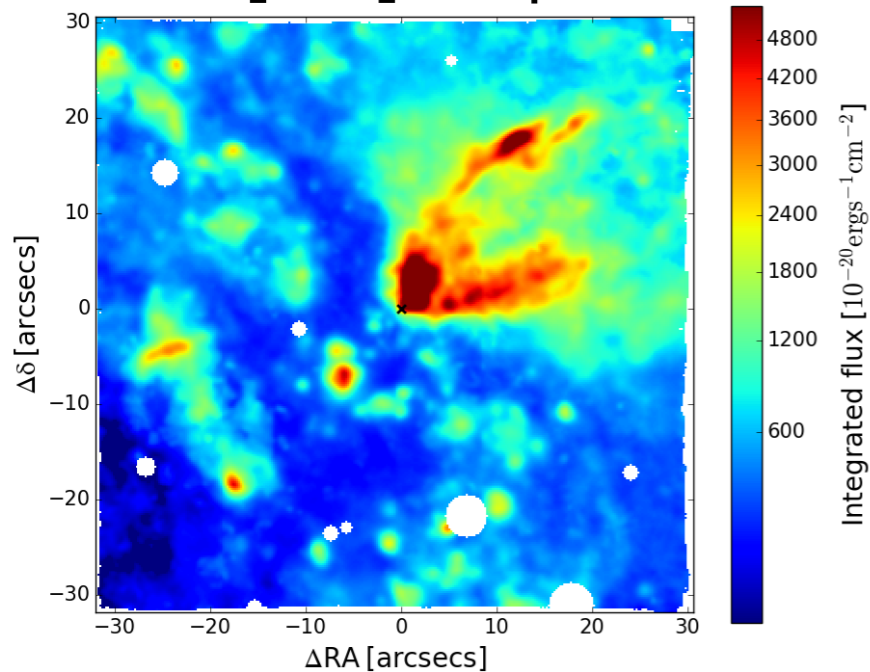
[OIII] vel. - Stellar vel.



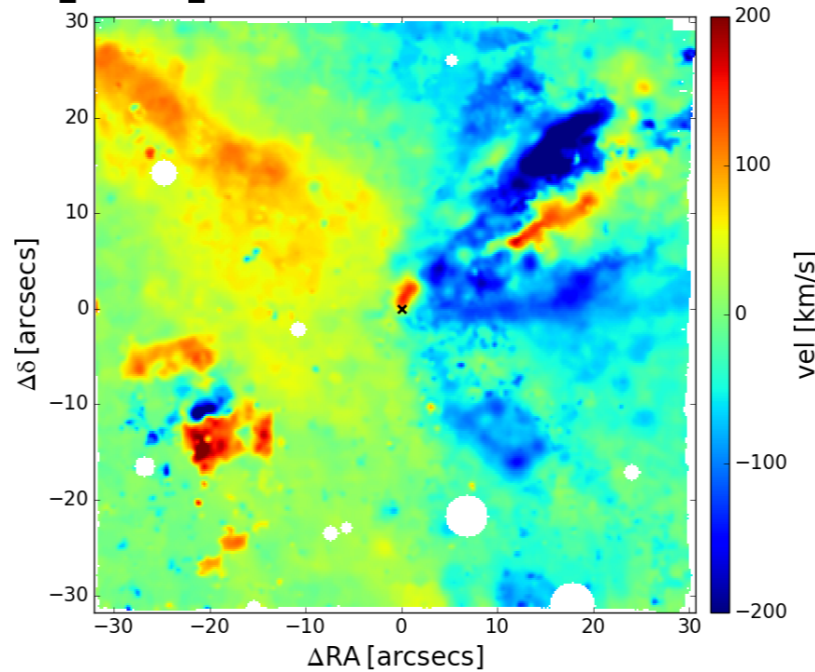
MAGNUM survey: outflow structure

NGC 4945

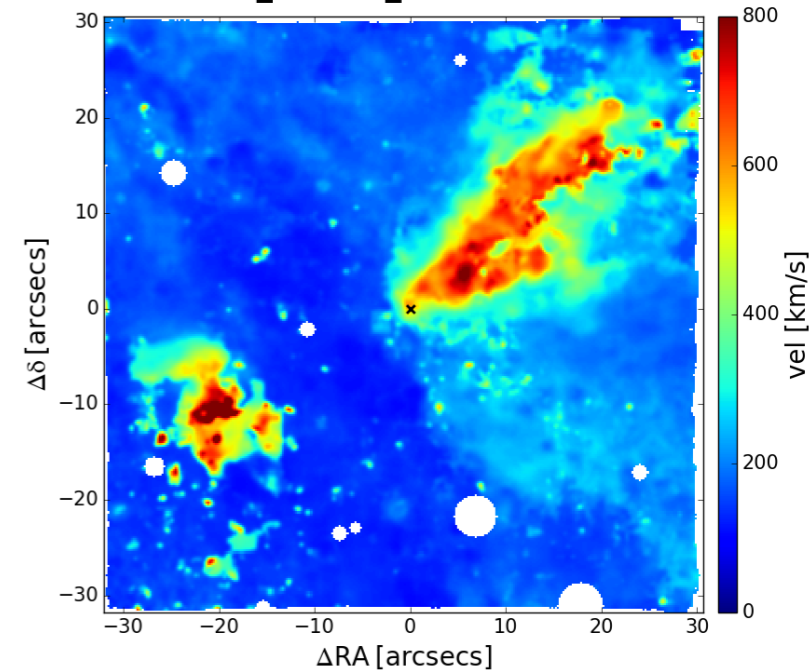
[NII] map



[NII] vel. - Stellar vel.

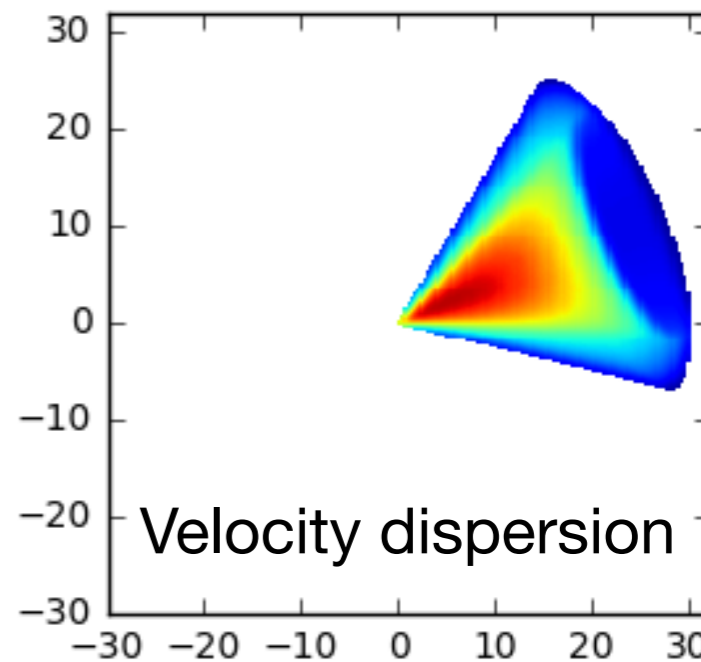
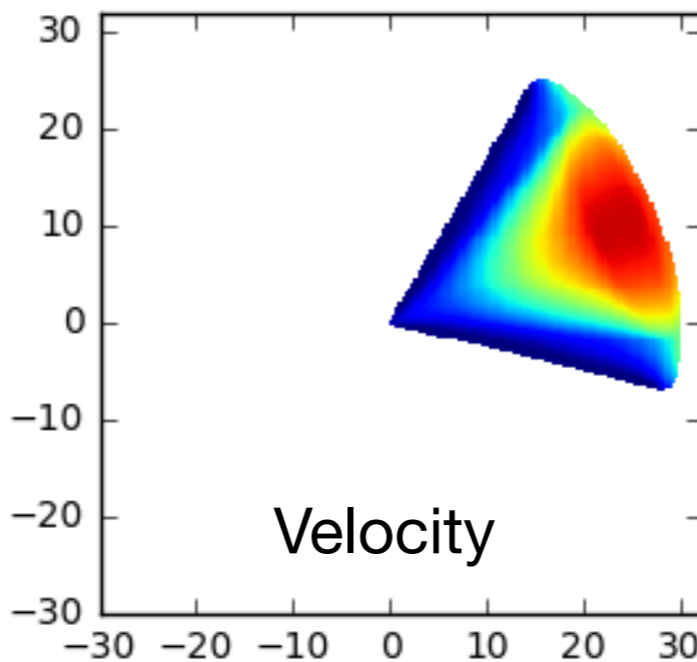
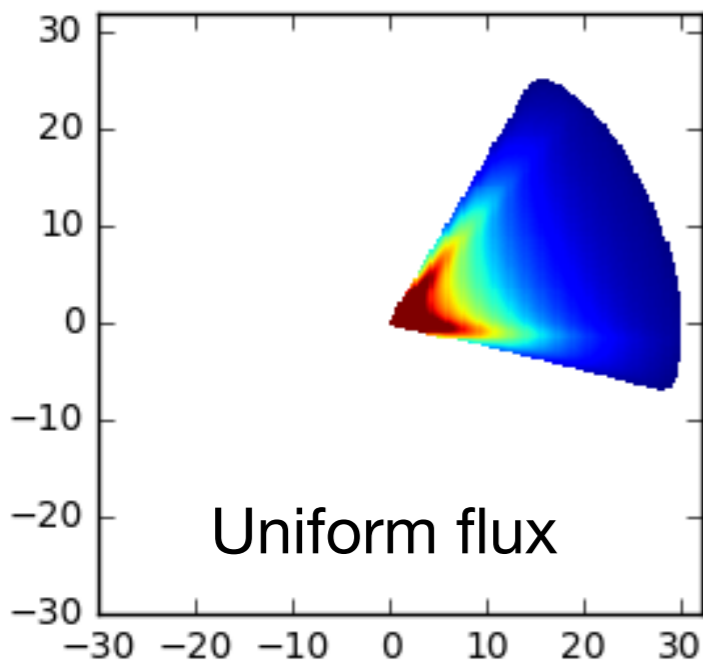


[NII] W70



Venturi et al. 2017

A simple kinematic model: hollow cone



Summary

- **MAGNUM** survey: **ionized gas kinematics and ionization, outflows and feedback** in nearby AGN **down to ~ 10 pc** with **VLT/MUSE**
- **NGC 1365** (Venturi et al. 2018)
 - ✦ **H α** \rightarrow **star formation** in **disk/bar**; **[OIII]** \rightarrow **AGN-ionized double-conical kpc-scale outflow** \rightarrow outflow **not broad wing** like at low-resolution in more powerful objects
 - ✦ **Radial profiles** of outflow **velocity, mass outflow, kinetic** and **momentum rate** \rightarrow decrease at larger distance: AGN more powerful recently? mass loading?
 - ✦ **Extended vs nuclear X-ray wind** \rightarrow energy- and momentum-driven scenarios unlikely, radiation pressure-driven feasible. Neutral atomic + molecular gas needed!