

Feedback in the central parsecs of active galactic nuclei mapped from high-ionisation lines

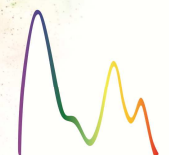
Alberto Rodríguez-Ardila, LNA/Brazil

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Ximena Mazzalay (MPE)
Daniel May (LNA)

11th Serbian Conference on Spectral Line Shapes in
Astrophysics
Šabac, Serbia, August 21-25, 2017

XI - Serbian Conference on Spectral Line
Shapes in Astrophysics
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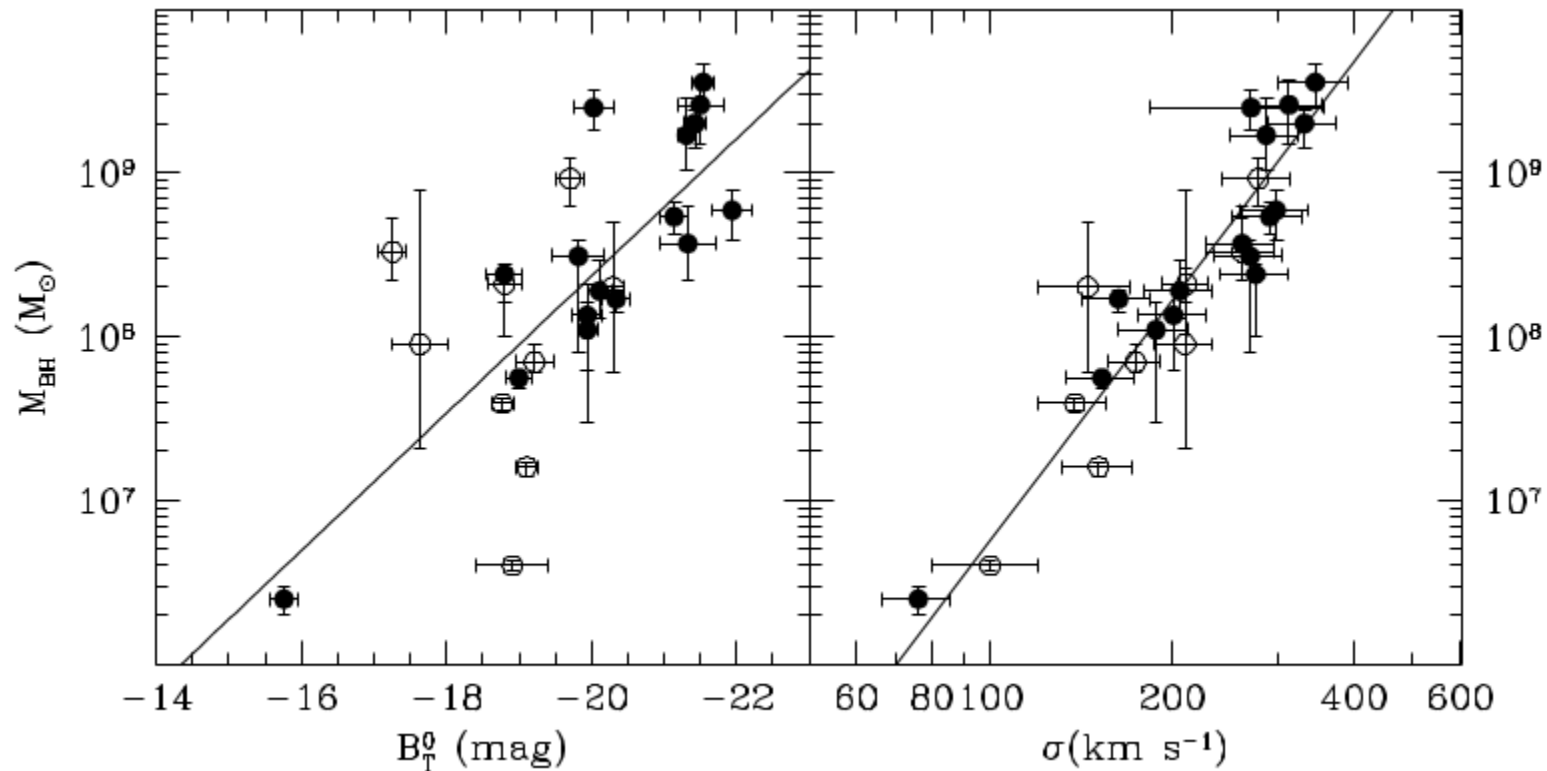
XI SCSLSA



Outline

- Feedback, AGNs and CLs – Overview
- Properties of the CL emission region
- The effect of the radio-jet on the CL emission
- Results from IFU spectroscopy
- Final remarks

The M_{\bullet} – L Relation



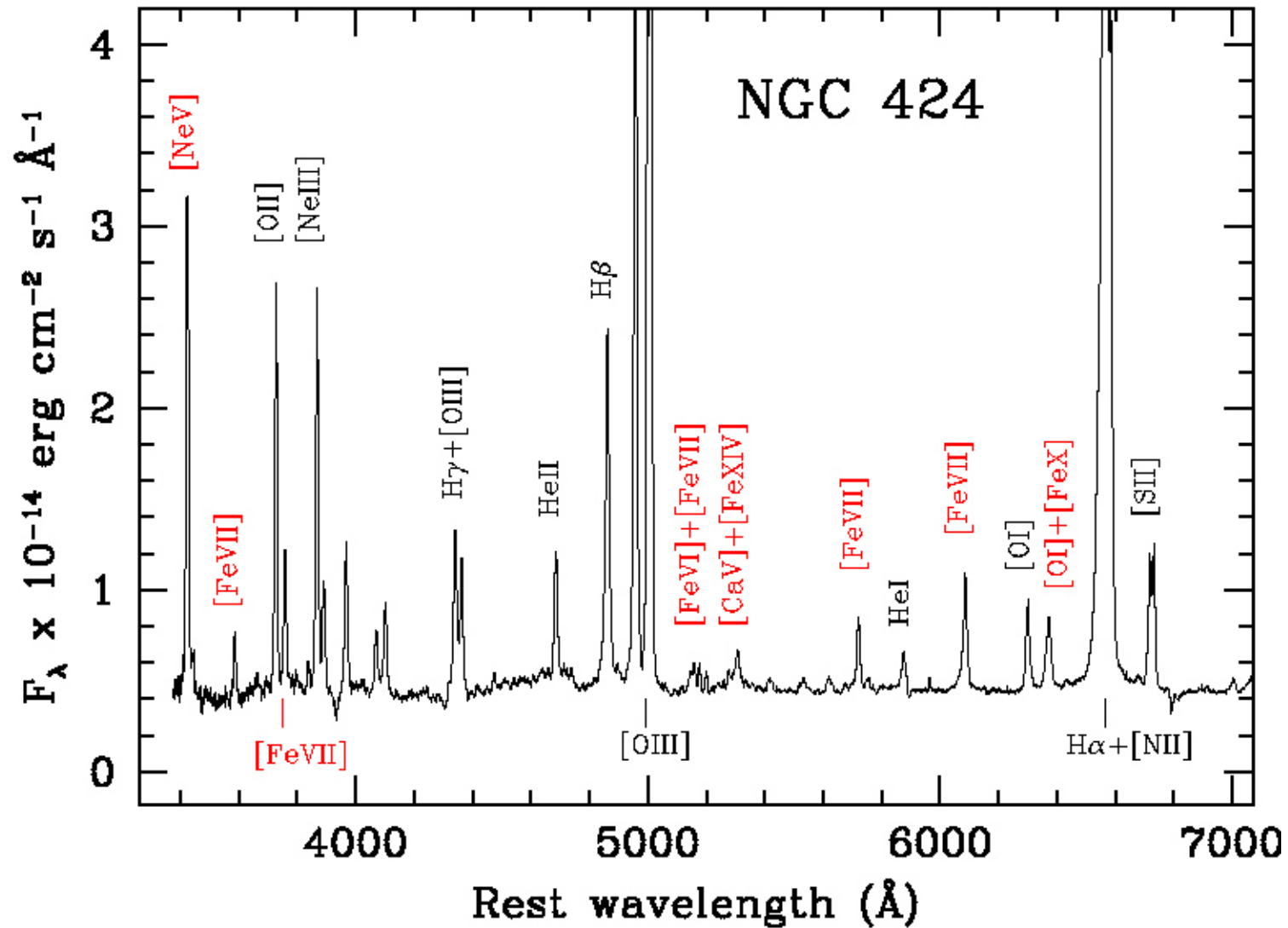
Ferrarese & Ford (2005)

- The growth of the SMBH is related to the evolution of the entire host galaxy, perhaps linked to the AGN phase.
- Holds essentially at three spatial scales: (i) on scale thousands of kpc; (ii) on hundred-parsec scale; (iii) on parsec scale, where lies the accretion disk, accompanied by both jets and outflows and the much thicker molecular torus.

The $M. - L$ Relation ...

- When the SMBH reaches a critical mass, it may be powerful enough to heat up and eject the gas, terminating the growth of both, galaxy and SHBH.
- Theoretical models suggest an origin of these outflows by fast AGN accretion disk winds (Zubovas & Nayakshin, 2014; Chan, C.-H., & Krolik, 2017).
- These outflows sometimes carry away mass at a rate comparable to the accretion rate (Laor & Davis, 2014; Fiore+ 2017).
- In radio galaxies, feedback is expected to operate through heat injection into the surrounding gas by a relativistic jet (Fabian, 2012).
- Even **small scale jets** in AGNs can transfer a large amount of mechanical energy into a very small region, producing strong shocks and bright emission from collisionally excited plasma (Rodríguez-Ardila et al. 2017).

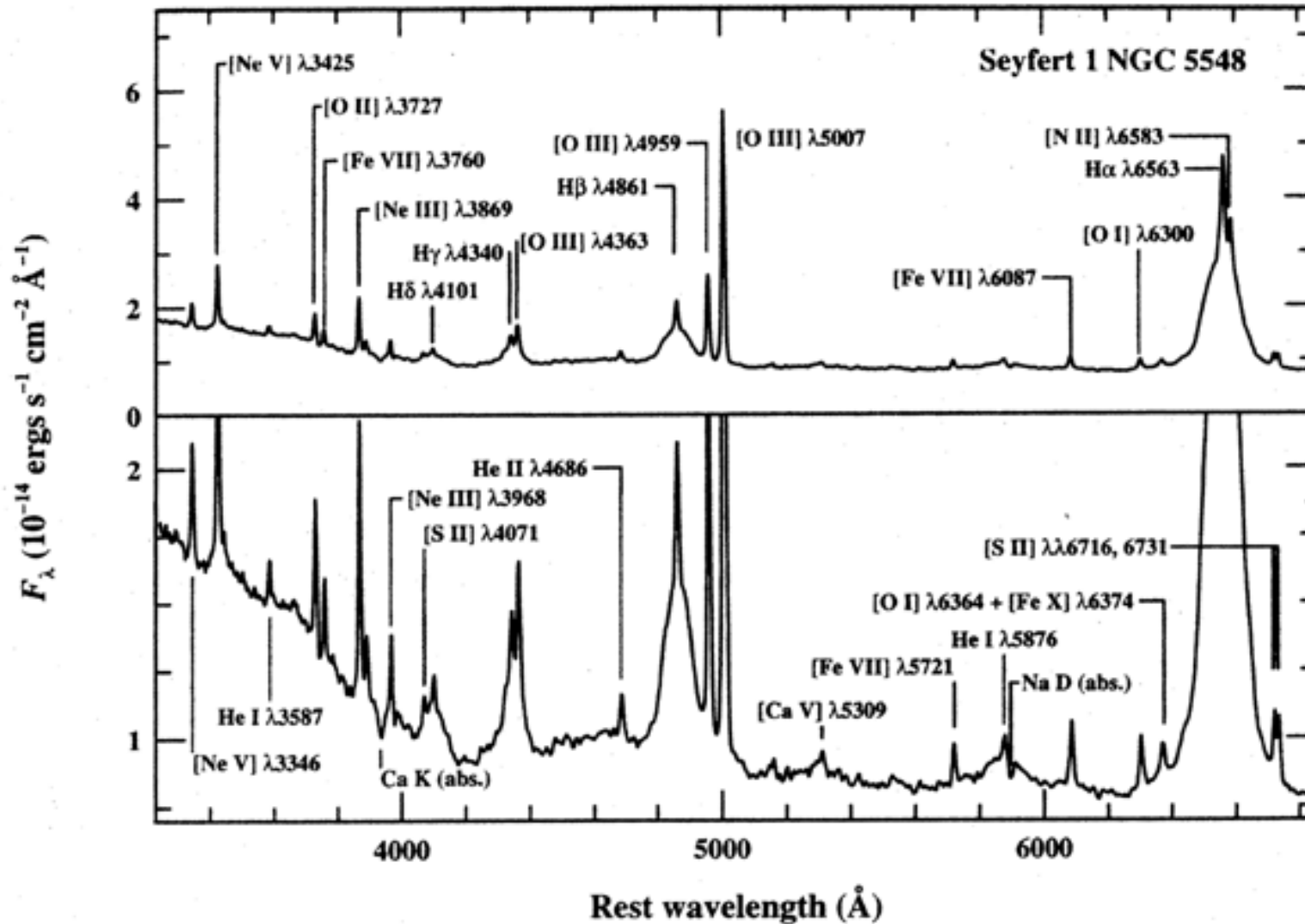
Coronal lines in AGNs



Rodríguez-Ardila et al. (*in prep.*)

They may be intrinsically faint. 4 m class telescopes or larger are necessary to study them!

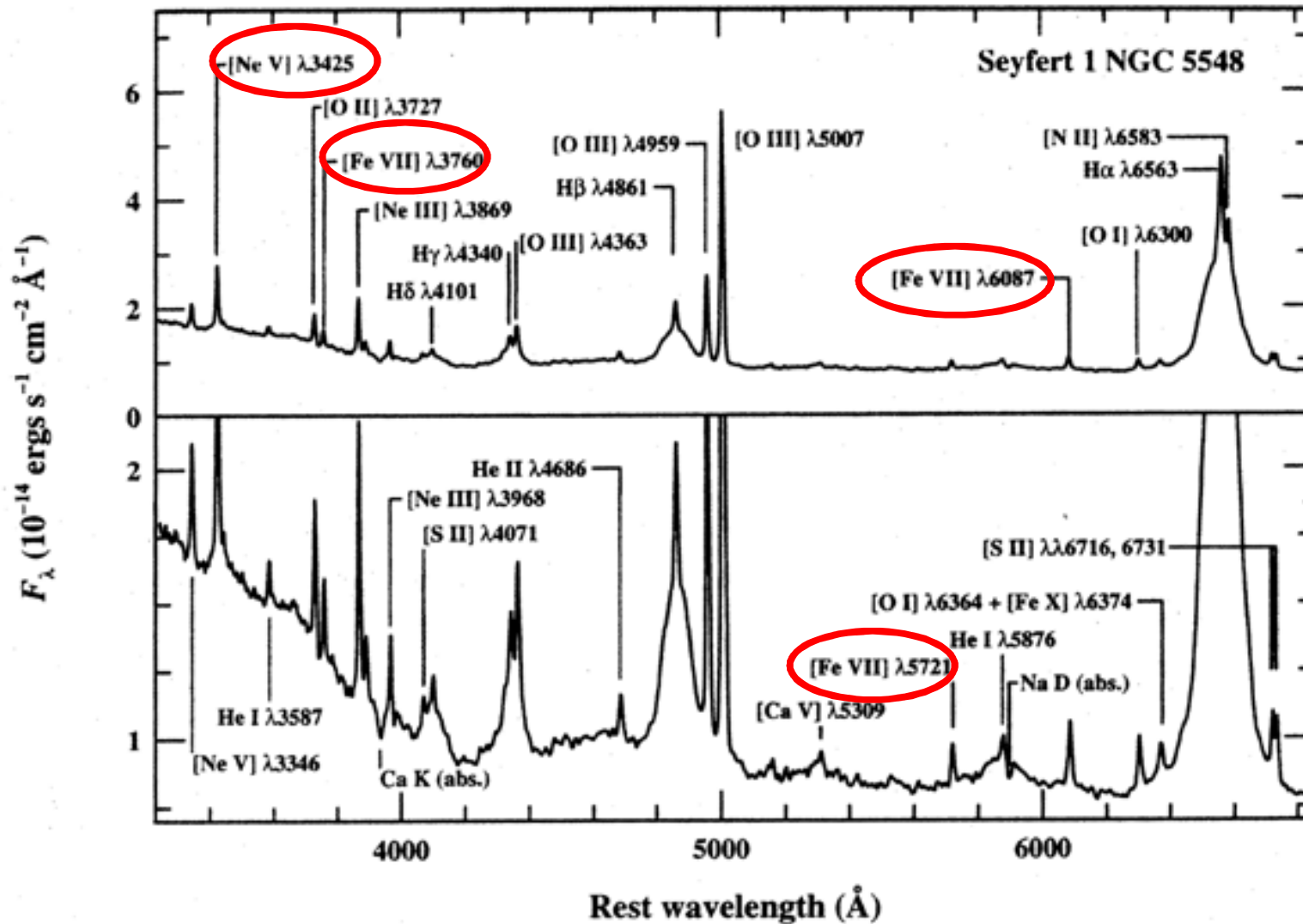
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NGC 5548 – Peterson, 1997

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Coronal Lines – Fact sheet

- Due to their high IP (>100 eV), free of potential contributions from star formation → provide direct look into the NLR and probe physical processes directly associated to the AGN.

Most important CLs in the optical & NIR

Ion	λ (Å)	IP (eV)
[NeV]	3425	100
[FeVII]	5721,6084	100
[FeX]	6374	235
[FeXI]	7892	262
[SXII]	7611	504
[SVIII]	9913	280.9
[SIX]	12521	328.2
[SiX]	14310	351.1
[SiVI]	19630	166.8
[CaVIII]	23212	127.7
[SiVII]	24840	205

First reported in an AGN (NGC 4151) by Oke & Sargent (1968)

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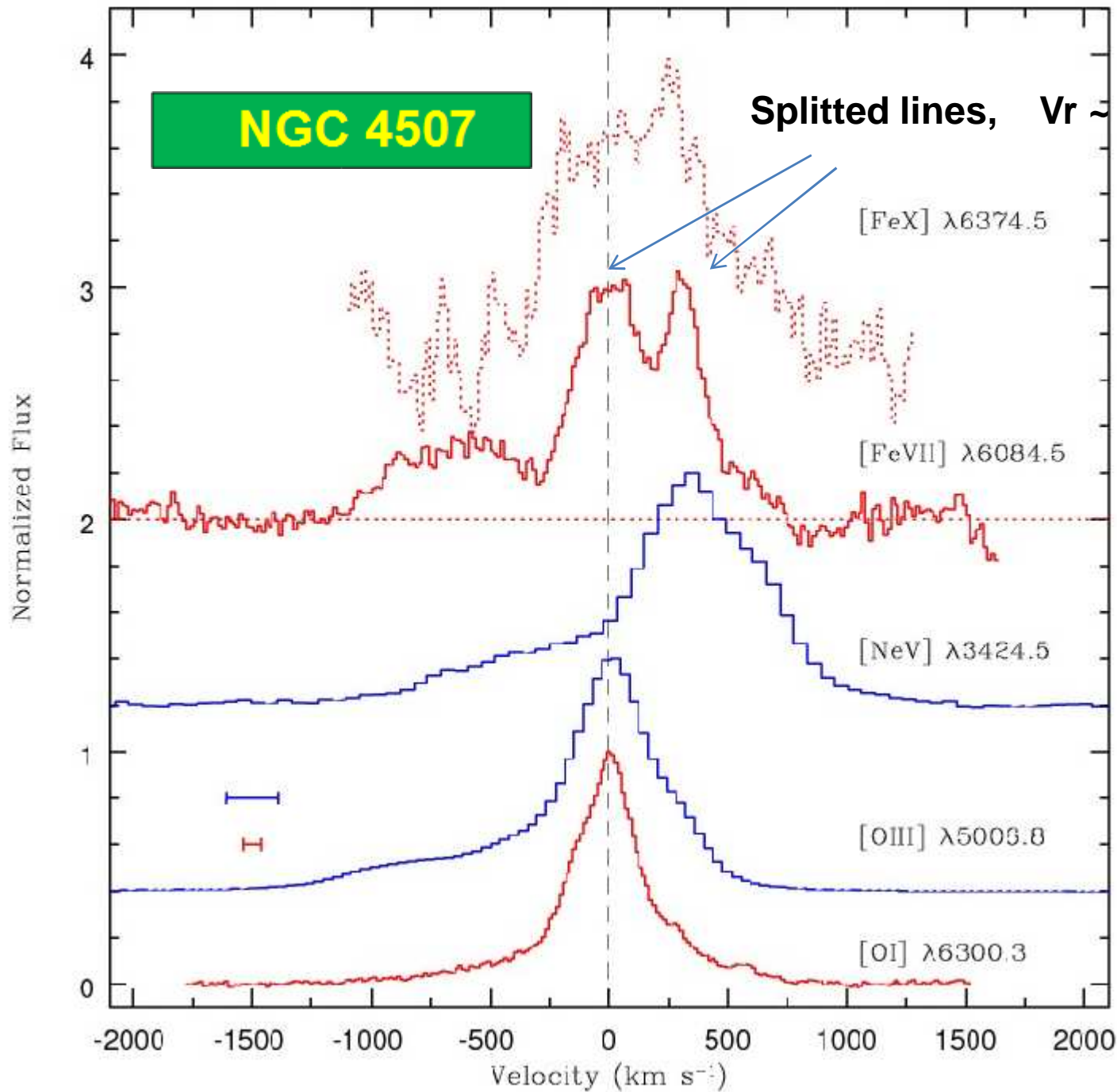
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- Tend to be broader than low-ionisation forbidden lines (Phillips & Osterbrock 1975; Erkens et al. 1997). Their centroid position is blueshifted / redshifted with respect to the systemic velocity of the galaxy (Penston et al. 1984, Rodríguez-Ardila et al. 2006, 2011).



- Gas is moving in radial direction in a nuclear collimated wind.
- [O I] is slower, mostly circular rotating gas.
- Ultra-fast outflow in X-rays (Tombesi et al. 2010).

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- ➡ It was suggested that the CLR should be located closer to the AGN than the classical NLR but outside the BLR.
- ➡ Not observed in LINER AGNs.

Several models have been proposed to explain the CLs:

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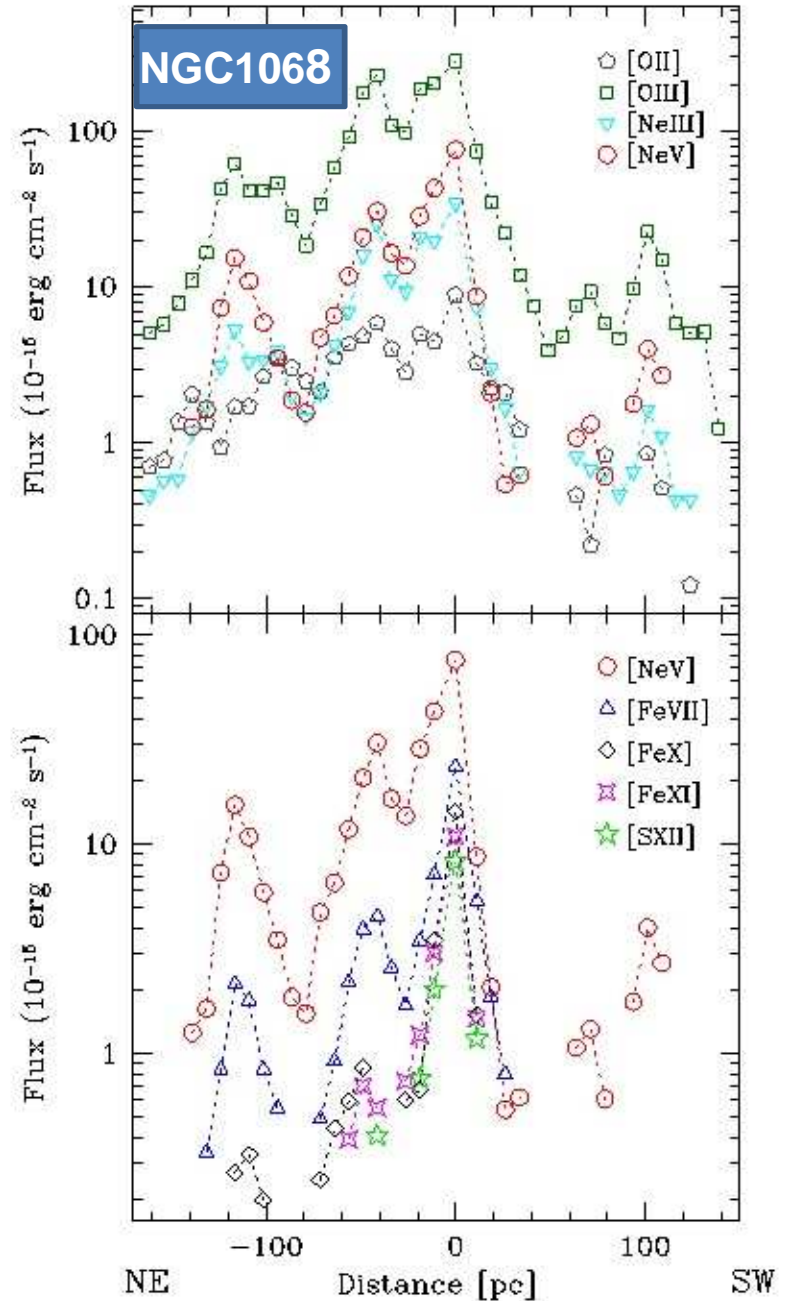
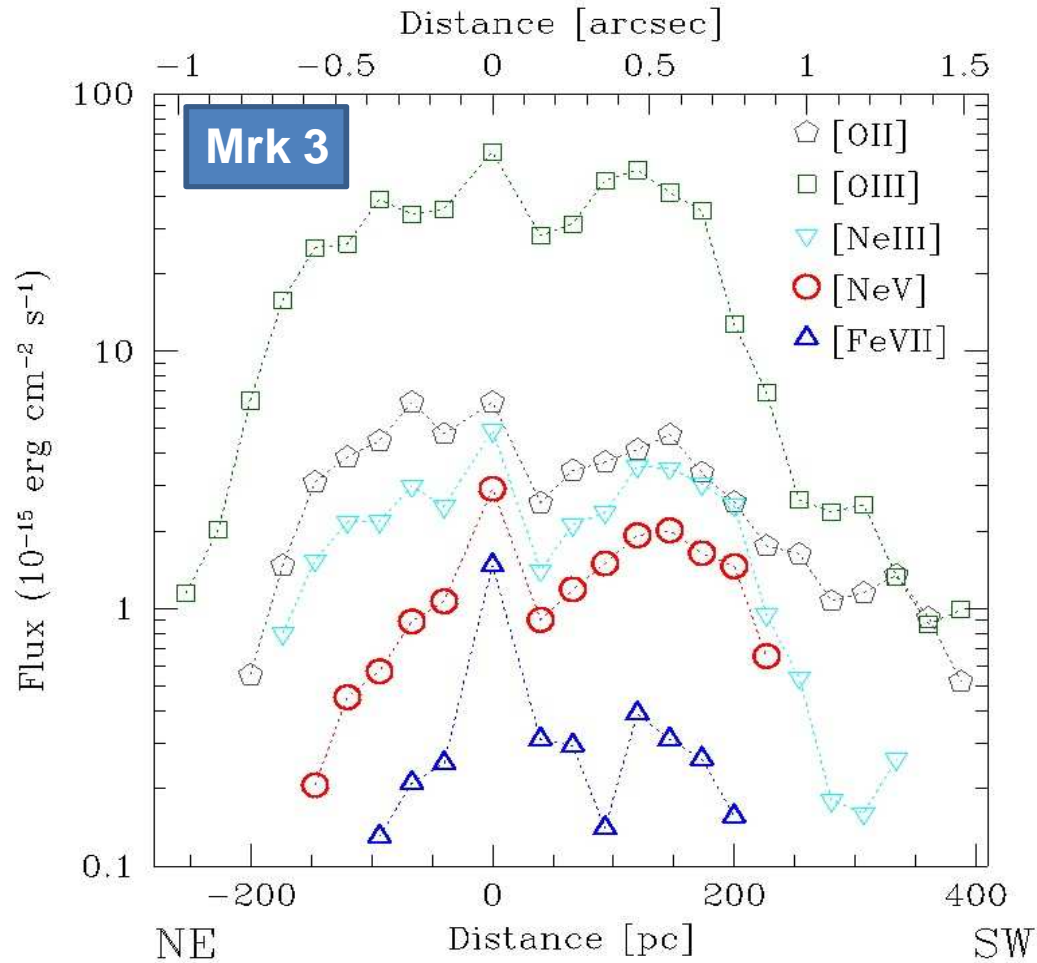
▶ **Shocks between the radio jet and the ISM** in addition to photoionization by the central source (Contini & Viegas 2002; Rodríguez-Ardila 2006, 2011, 2017).

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**Distinguishing between these scenarios is tricky.
Observations alone do not allow to discriminate between
the different hypothesis.**

Flux distribution of the NLR – Mrk 3 & NGC 1068



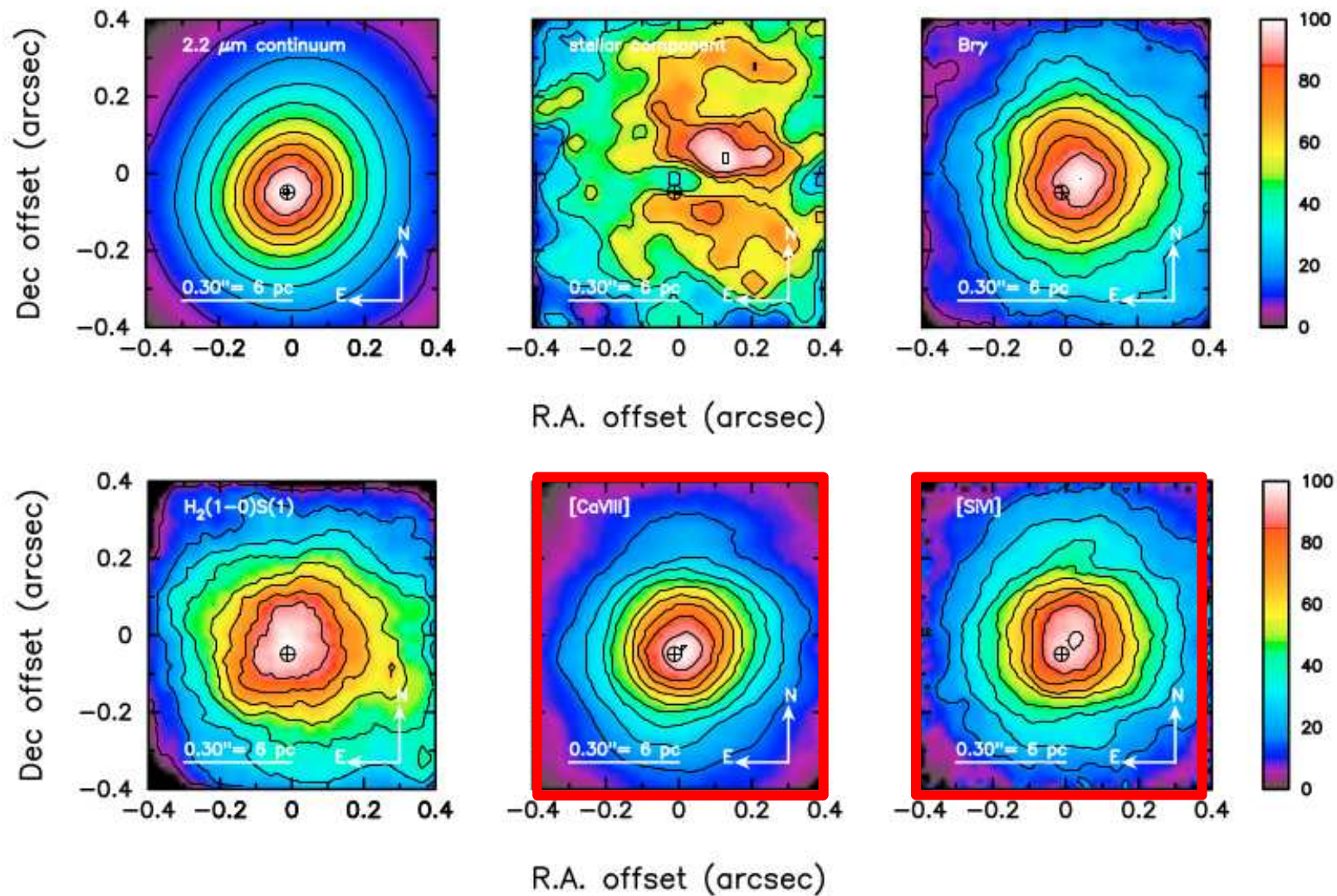
The CLs display a clumpy structure, similar to the one observed in low-ionization lines.

Mazzalay, Rodríguez-Ardila & Komossa, (2010)

IFU & imaging studies of the CLR

- Study the light distribution of [FeVII] in the optical; [SiVI], [SiVII], [SVIII], [SIX] in the NIR.
- Map the CLR kinematics and its relationship with the radio jet by means of AO observations (NIFS, SINFONI, OSIRIS)
- Compare the observed emission line ratios with models to infer the physical conditions of the coronal gas.

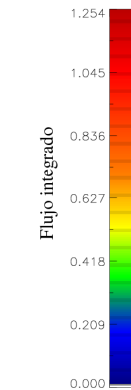
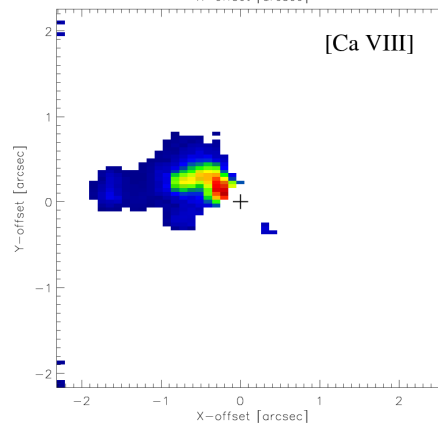
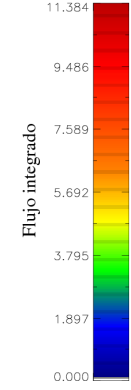
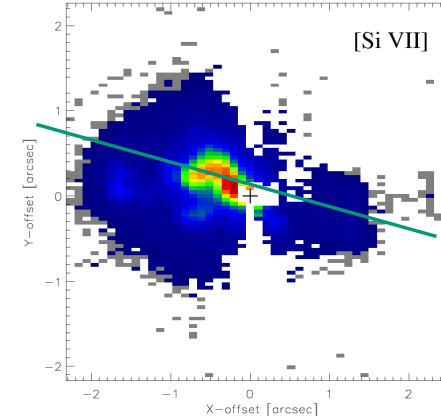
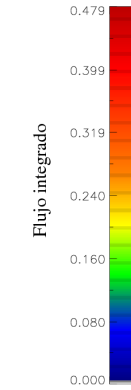
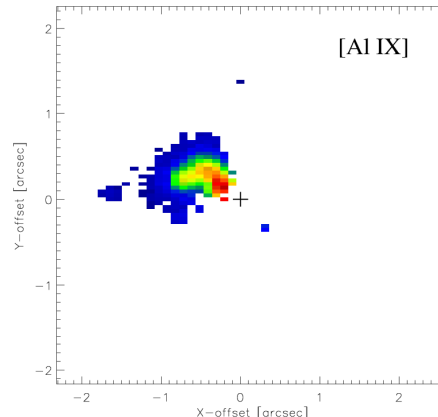
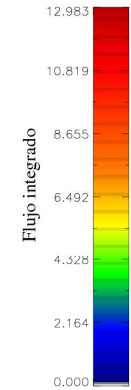
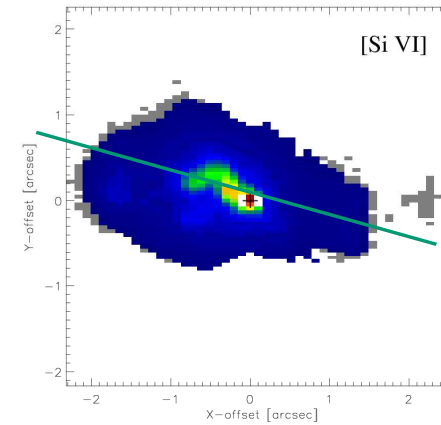
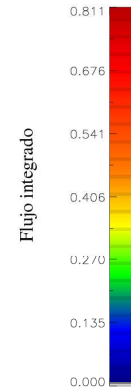
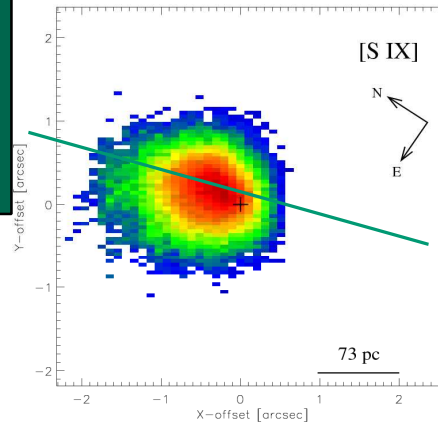
The case of the Circinus Galaxy



Müller-Sánchez et al. (2006)

Gemini / NIFS observations of NGC 1068 Morphology & Extension of the CLR gas

- Elongated in the NE-SW direction
- Irregular morphology
- Brighter regions to N-NE from the nucleus. An arc that extends for $\sim 0.8''$.
- Towards SW, weaker emission (extinction).
- Extension:
 - NE: $2.3'' \sim 170$ pc
 - SW: [SiVI] & [SiVII]
 - have a secondary peak at $\sim 2.2''$
 - SW: [SIX] $< 1''$



Mazzalay, Rodríguez-Ardila et al. (2013).

No similar data available in the optical region !!!!

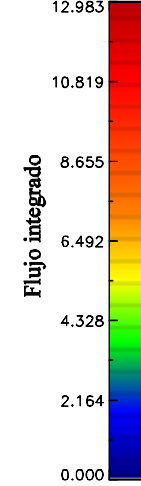
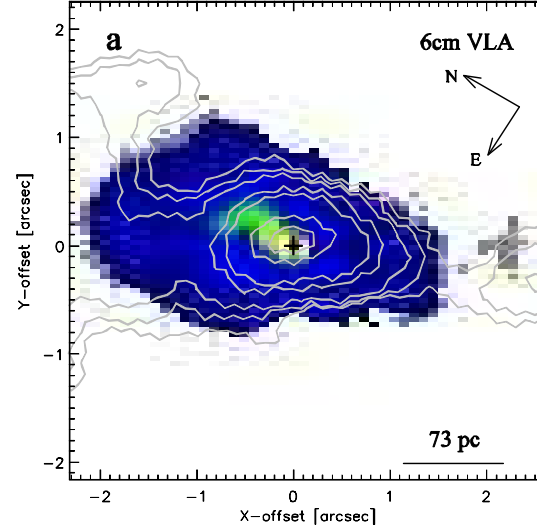
[SiVI], [OIII] and radio emission

➡ [SiVI] very similar to [OIII]

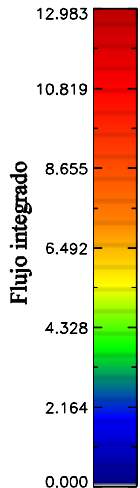
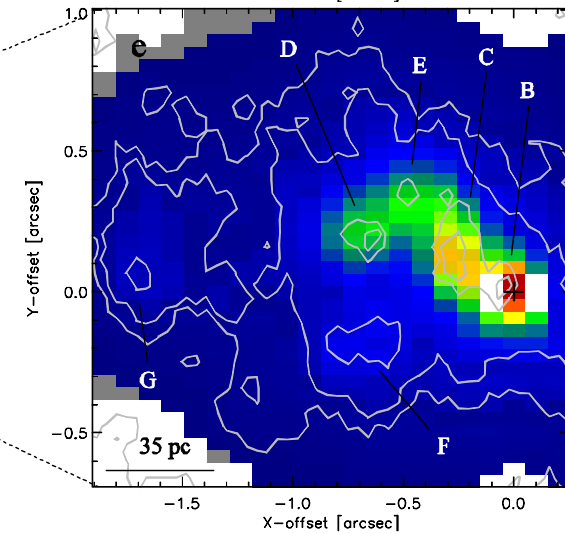
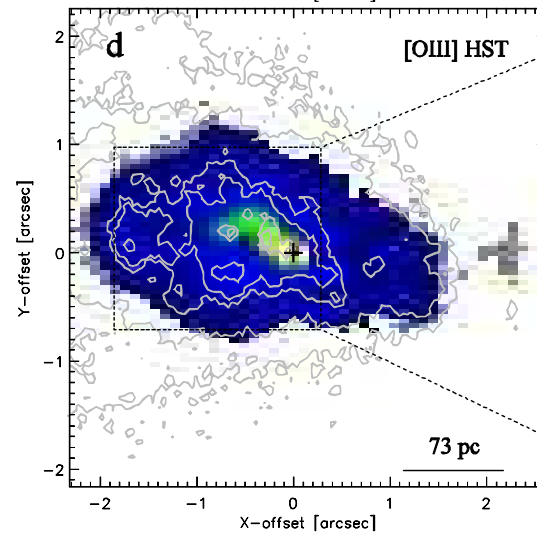
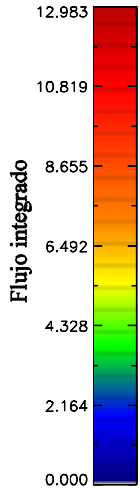
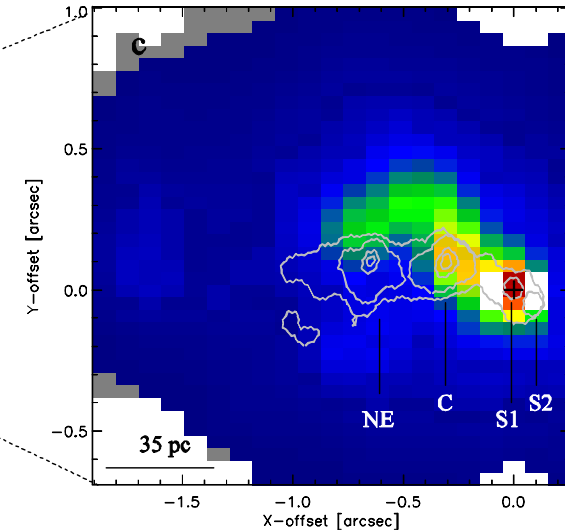
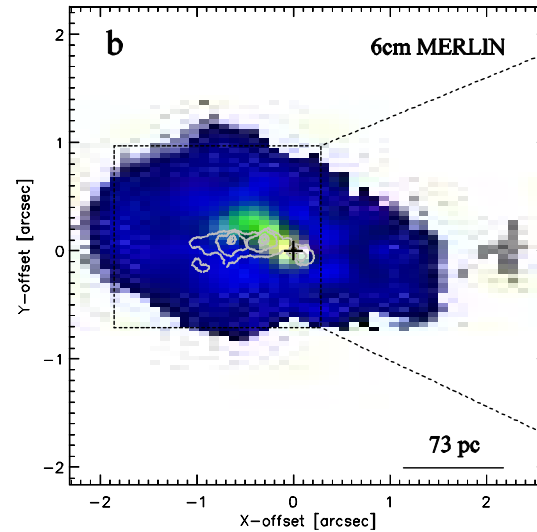
➡ [SiVI] elongated in the direction of the radio-jet

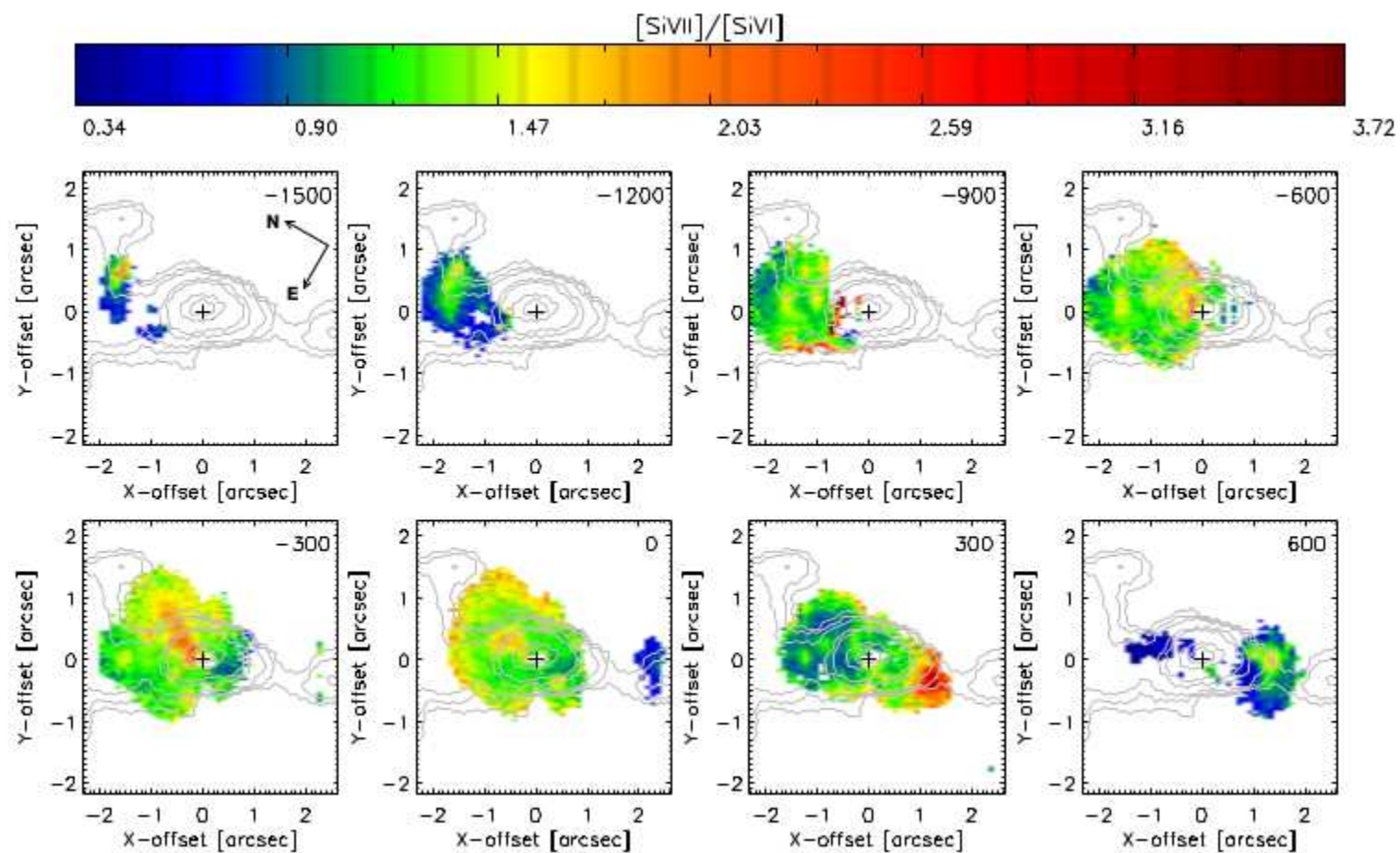
➡ At smaller scales (Merlin): the jet cleans up a channel, increasing the gas density (and its emission in the border).

➡ The jet plays a fundamental role in the morphology of the CLR gas in NGC1068



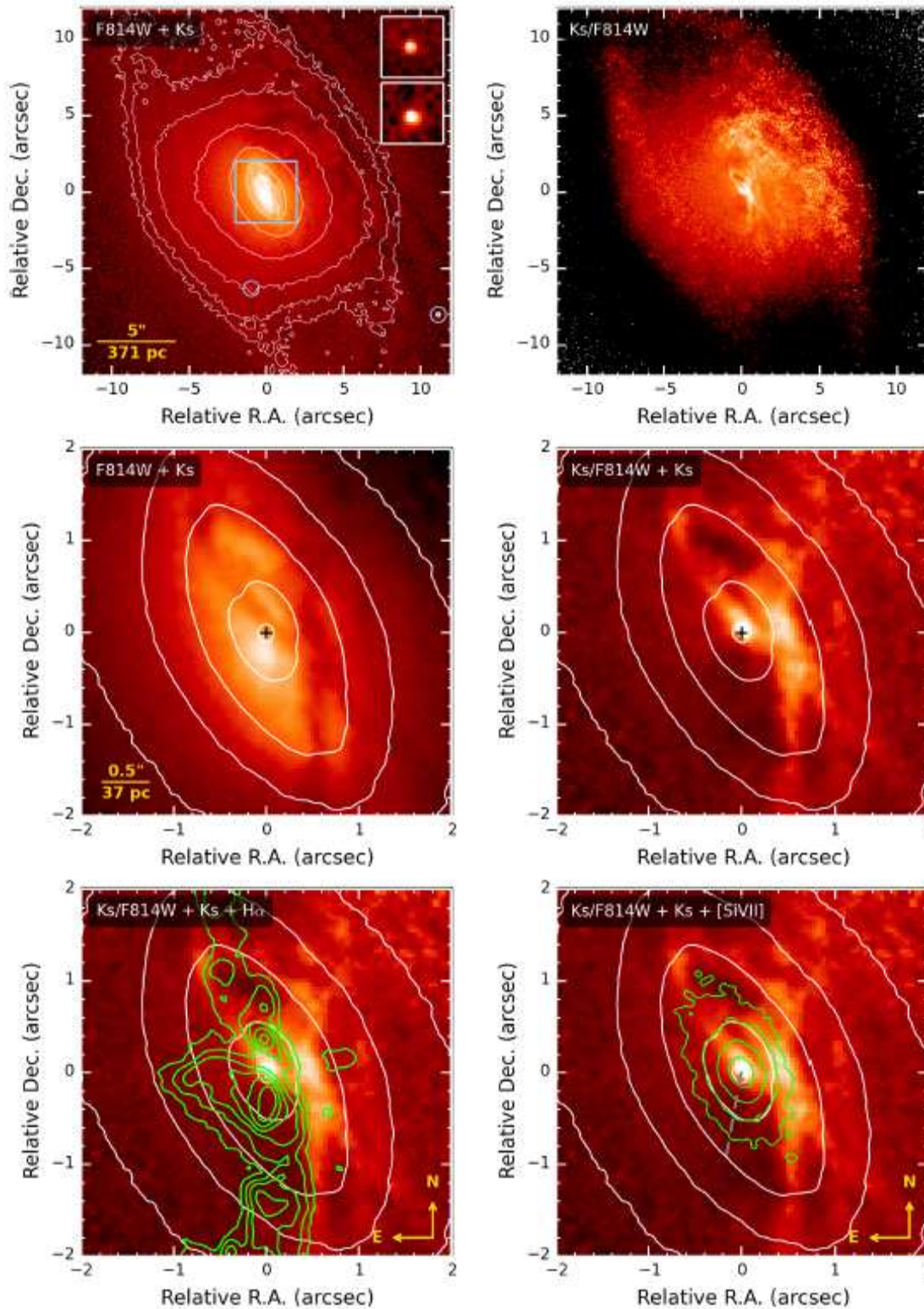
Mazzalay, Rodríguez-Ardila et al. (2013)





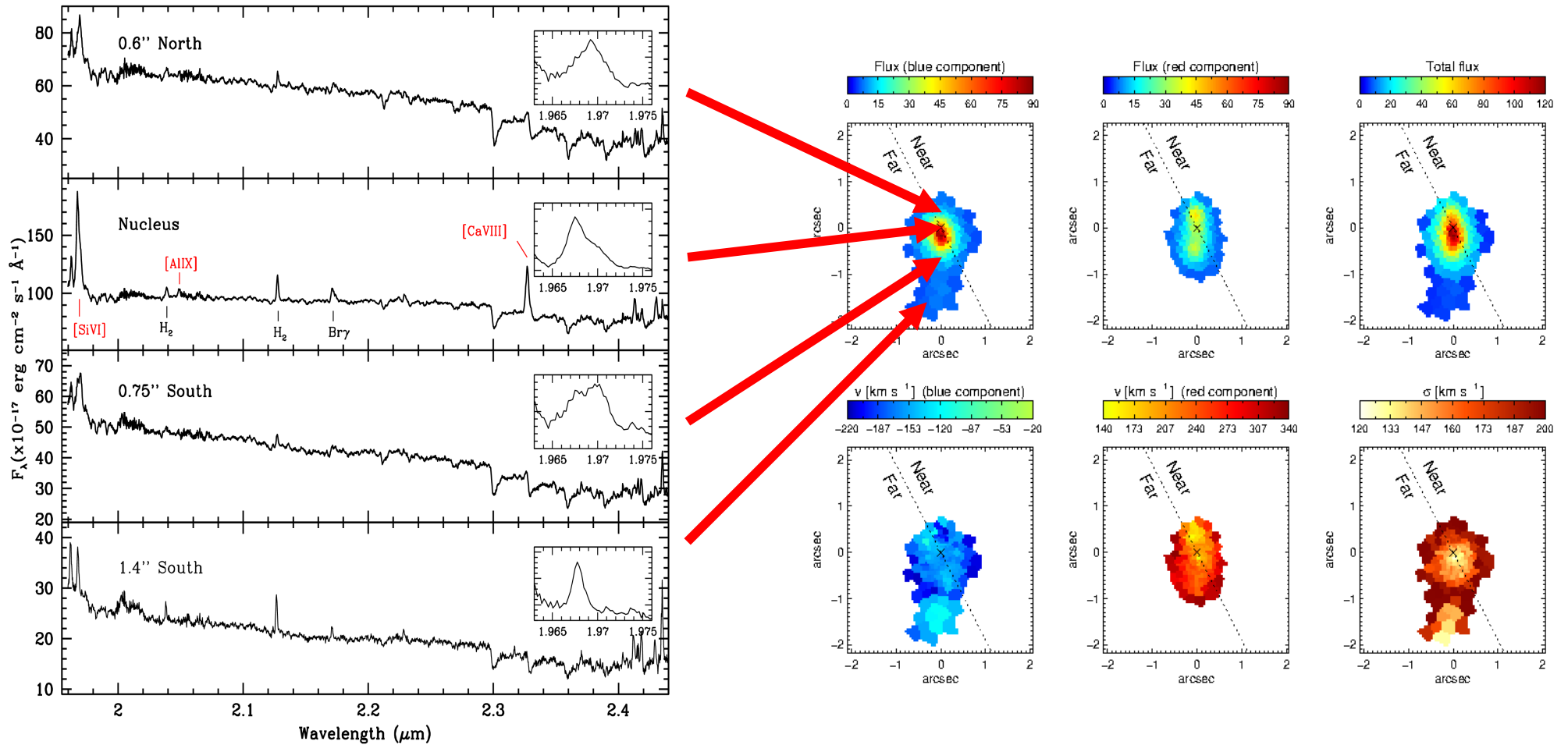
- ▶ Because of the difference in ionization potential between both lines (~ 40 eV), their flux ratio maps the ionization structure.
- ▶ The largest values in a region coincident with the inner portion of the jet before bending (S-N direction) and at about $1.3''$ SW (point H, $[\text{Si VII}]/[\text{Si VI}] \sim 3$) from the centre.
- ▶ Pure photoionization models predict a peak of $[\text{Si VII}]/[\text{Si VI}]$ of 1.5.
- ▶ Wang et al. (2012) suggest that spot 'G' and cloud 'HST-H' are strongly interacting with the jet. Shocks produce thermal X-ray emission, increasing the $[\text{Si VII}]/[\text{Si VI}]$ ratio.

NGC 1386



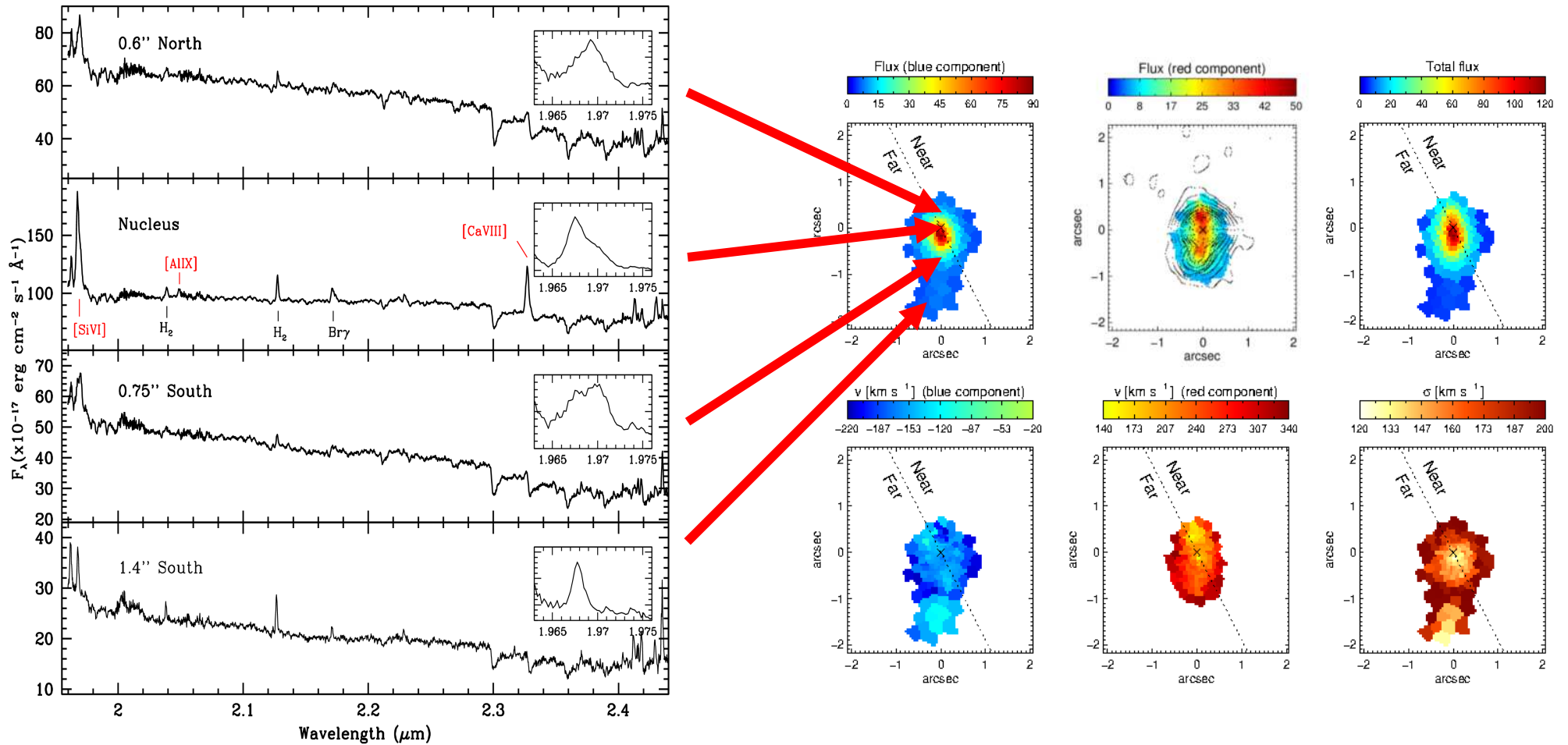
- It is one of the nearest AGN at 15.3 Mpc, 1 " \sim 75 pc.
- Dust filaments arising at this northwest side seen curving towards the centre.
- The true centre of the galaxy only unveiled at IR wavelengths in *K*-band.
- A low luminosity AGN ($\log L_{bol} \sim 42$ erg s $^{-1}$) but yet displays a very strong CL spectrum in the IR and optical.

NGC 1386 – SINFONI VLT

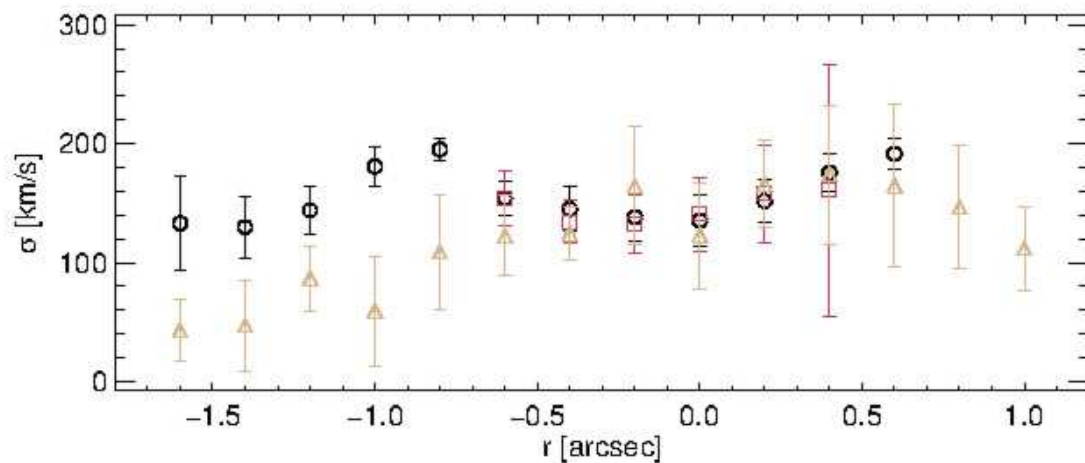
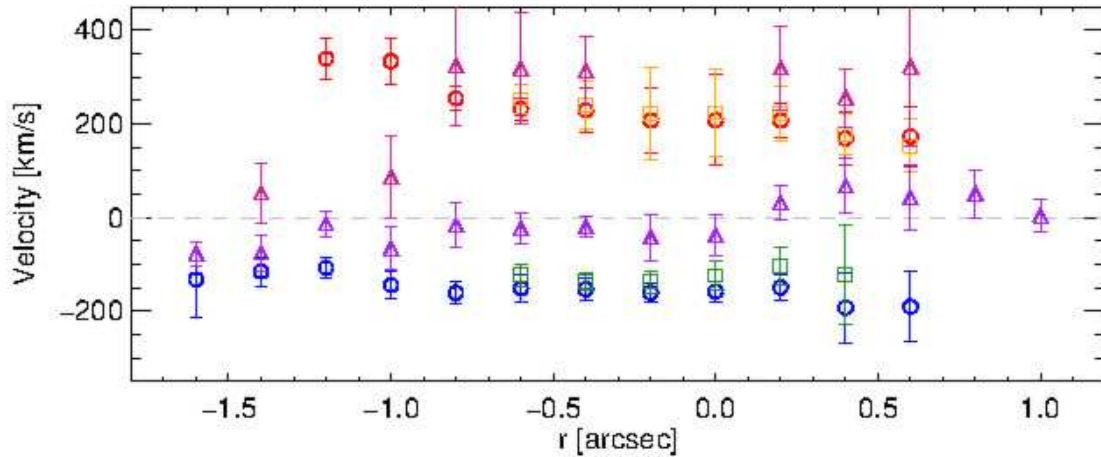
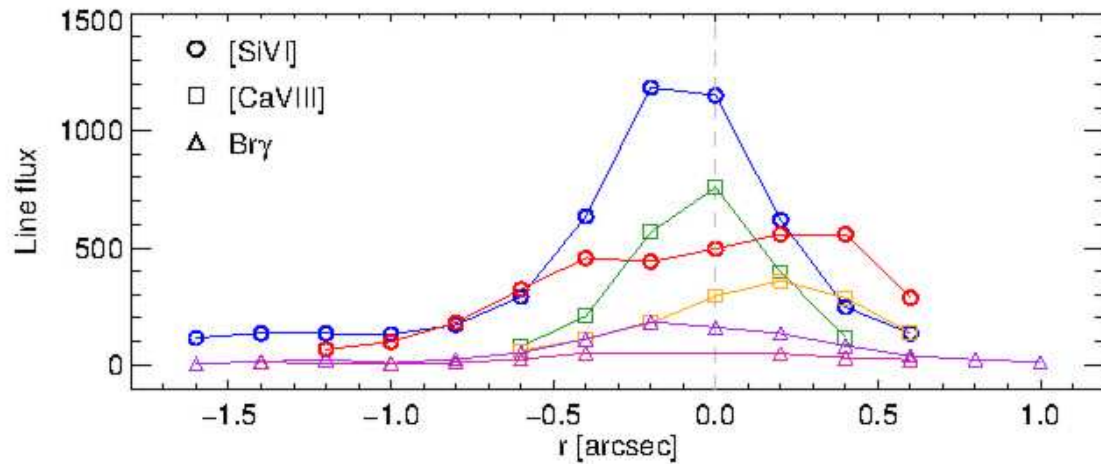


Rodríguez-Ardila et al. (2017)

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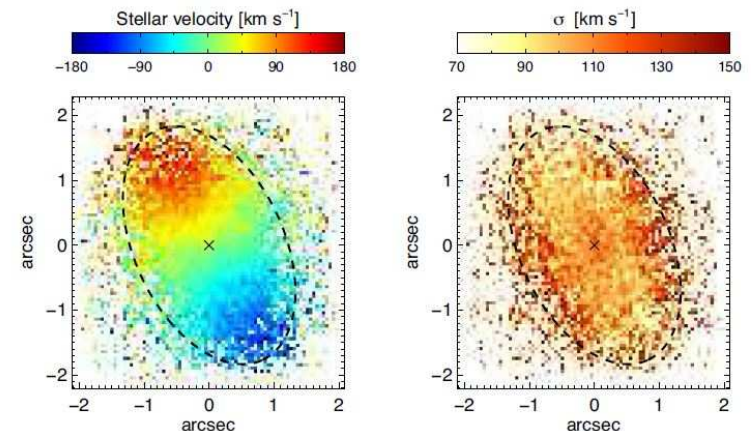
Rodríguez-Ardila et al. (2017)



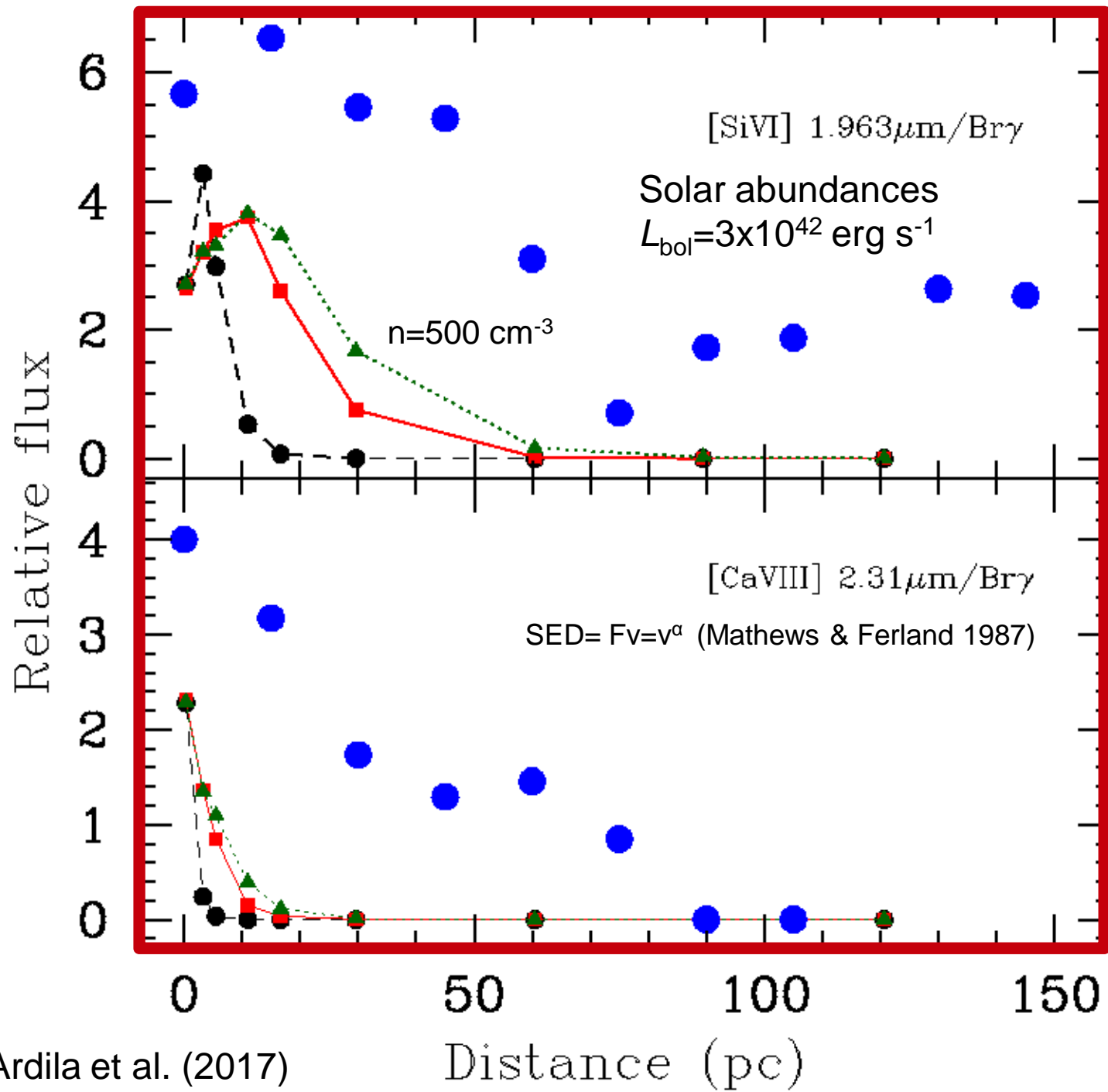
- Powerful mass outflows traced by the forbidden high-ionization gas.
- Two symmetrical expanding hot gas shells moving in opposite directions along the LOS.
- Using:

$$\dot{M}_{\text{out}} = 5.5 \left(\frac{m_p}{1.67 \times 10^{-24} \text{ g}} \right) \left(\frac{n_e}{10^{2.97} \text{ cm}^{-3}} \right) \times \left(\frac{l}{111 \text{ pc}} \right) \left(\frac{w}{37 \text{ pc}} \right) \left(\frac{f}{0.1} \right) \left(\frac{v_{\text{out}}}{225 \text{ km s}^{-1}} \right) M_{\odot} \text{ yr}^{-1}$$

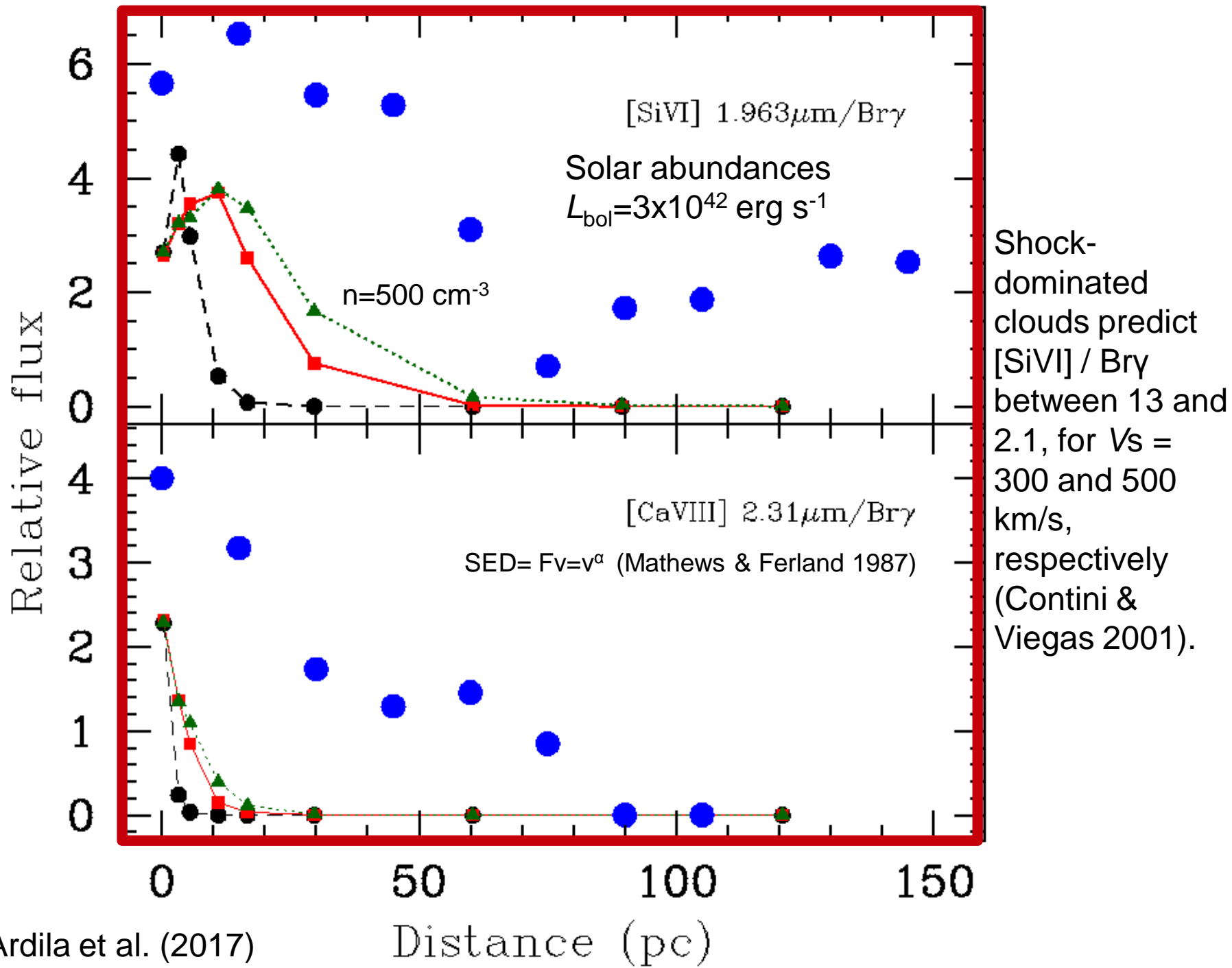
allows us to derive outflow rates of up to 11 M_{\odot}/yr in NGC1386.



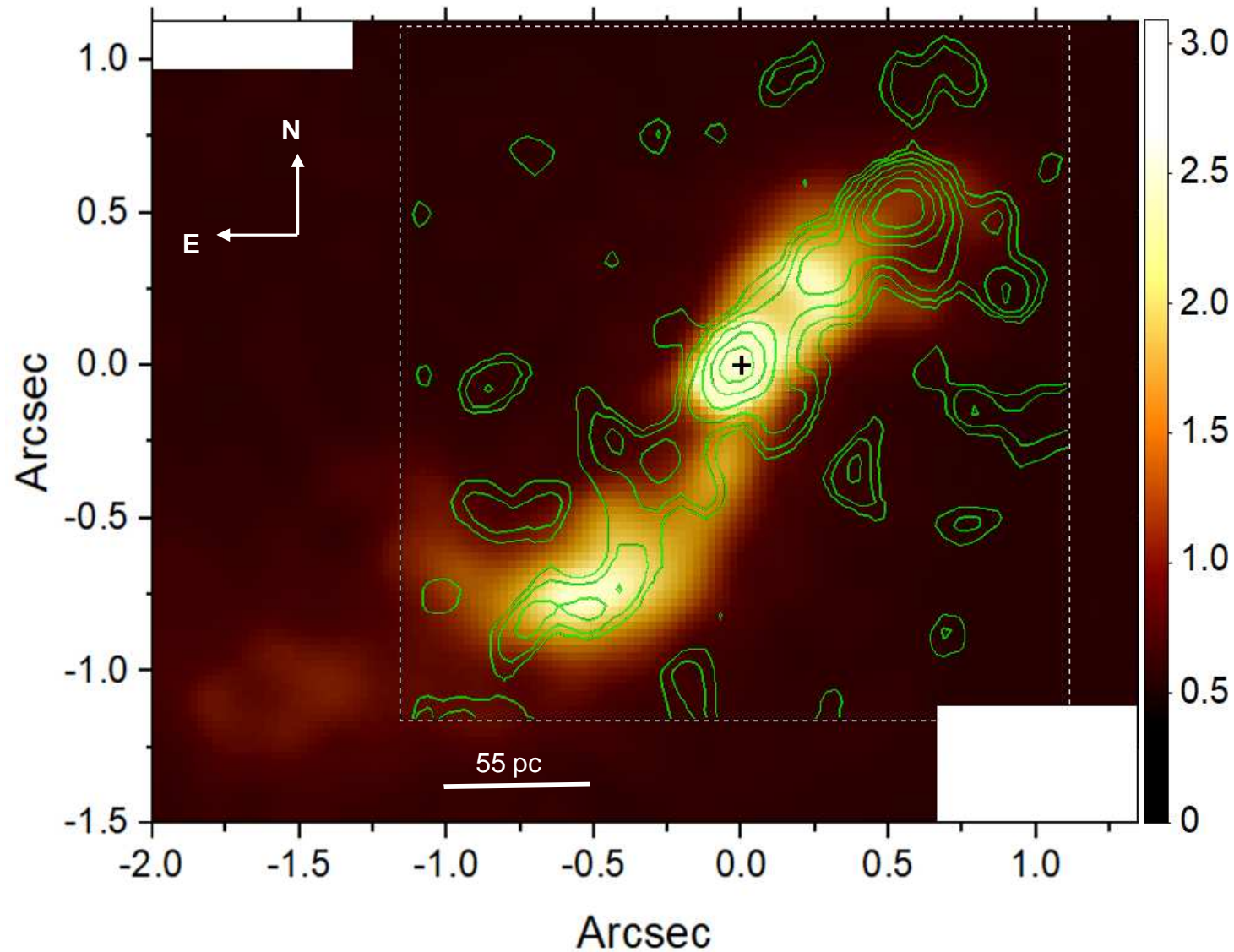
Photoionization model results for NGC 1386



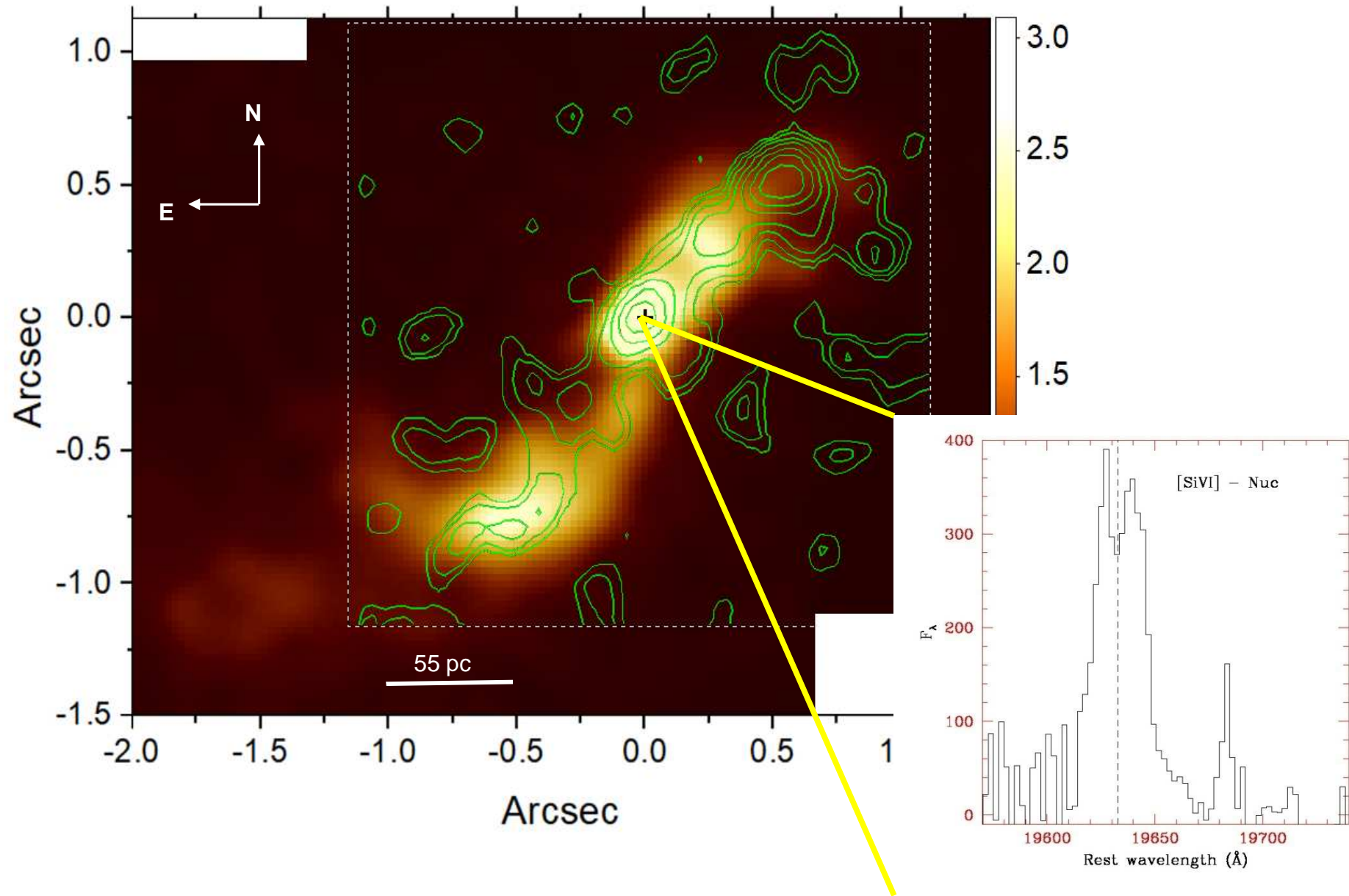
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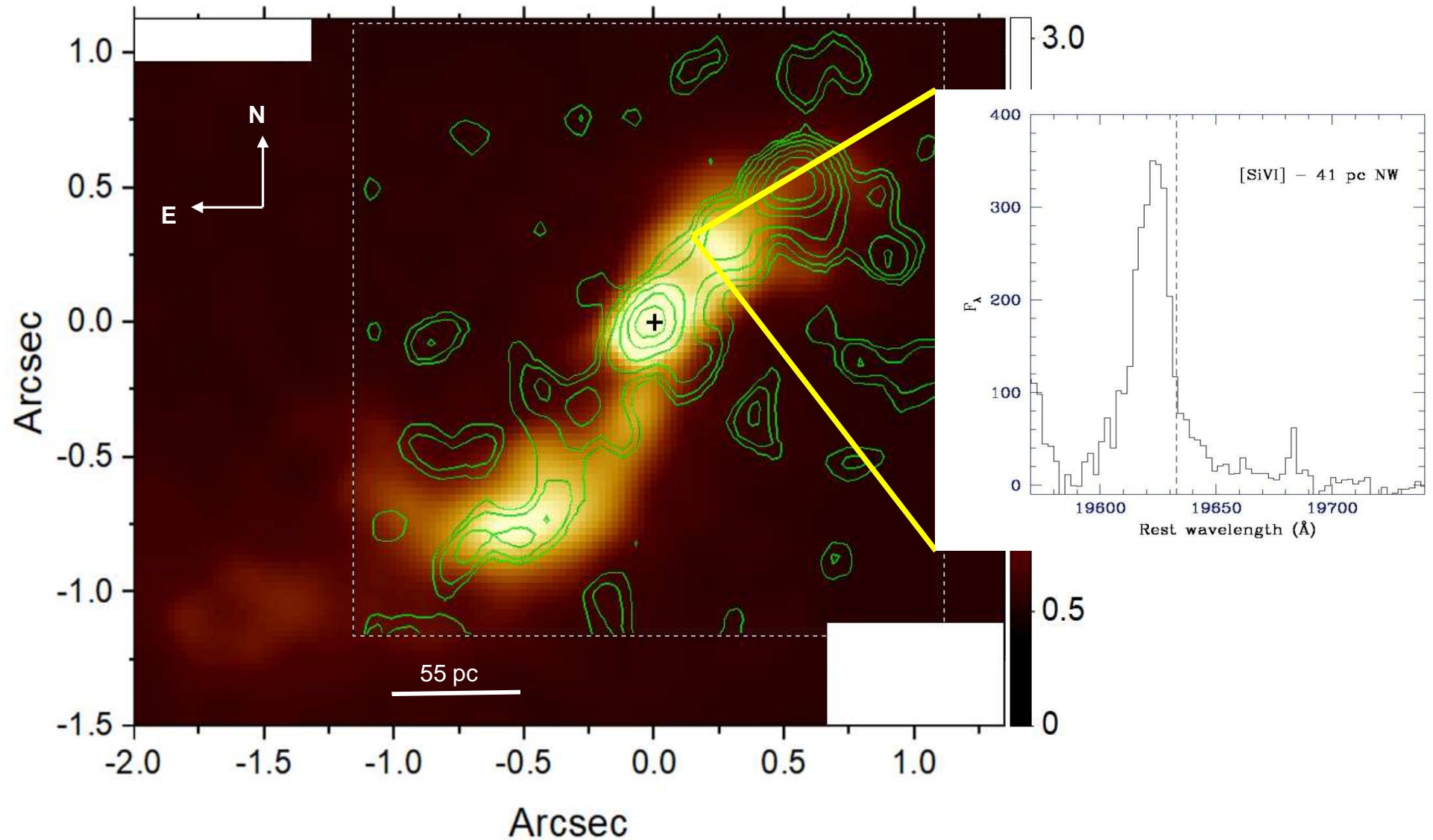
The case of ESO418-G14



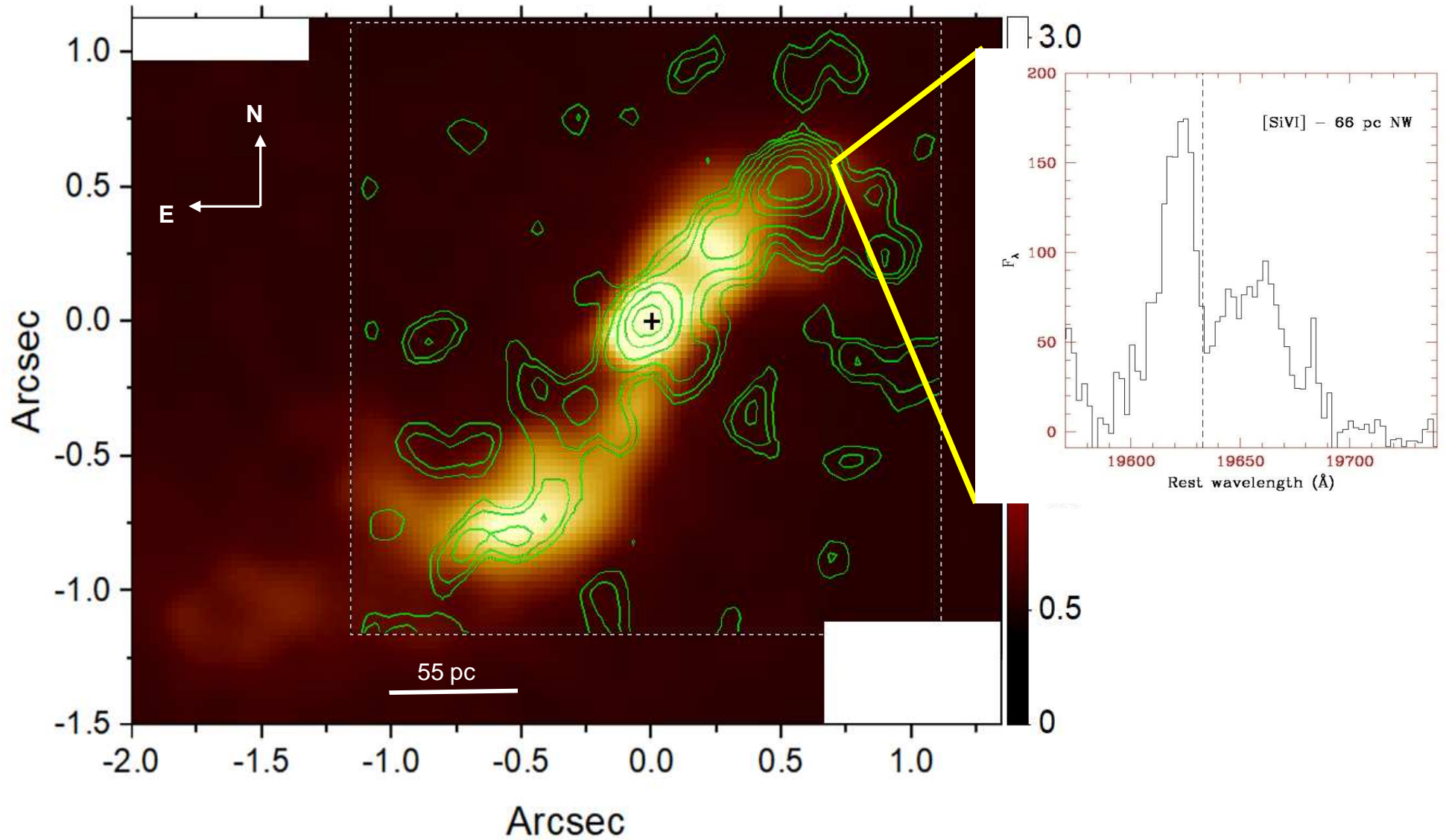
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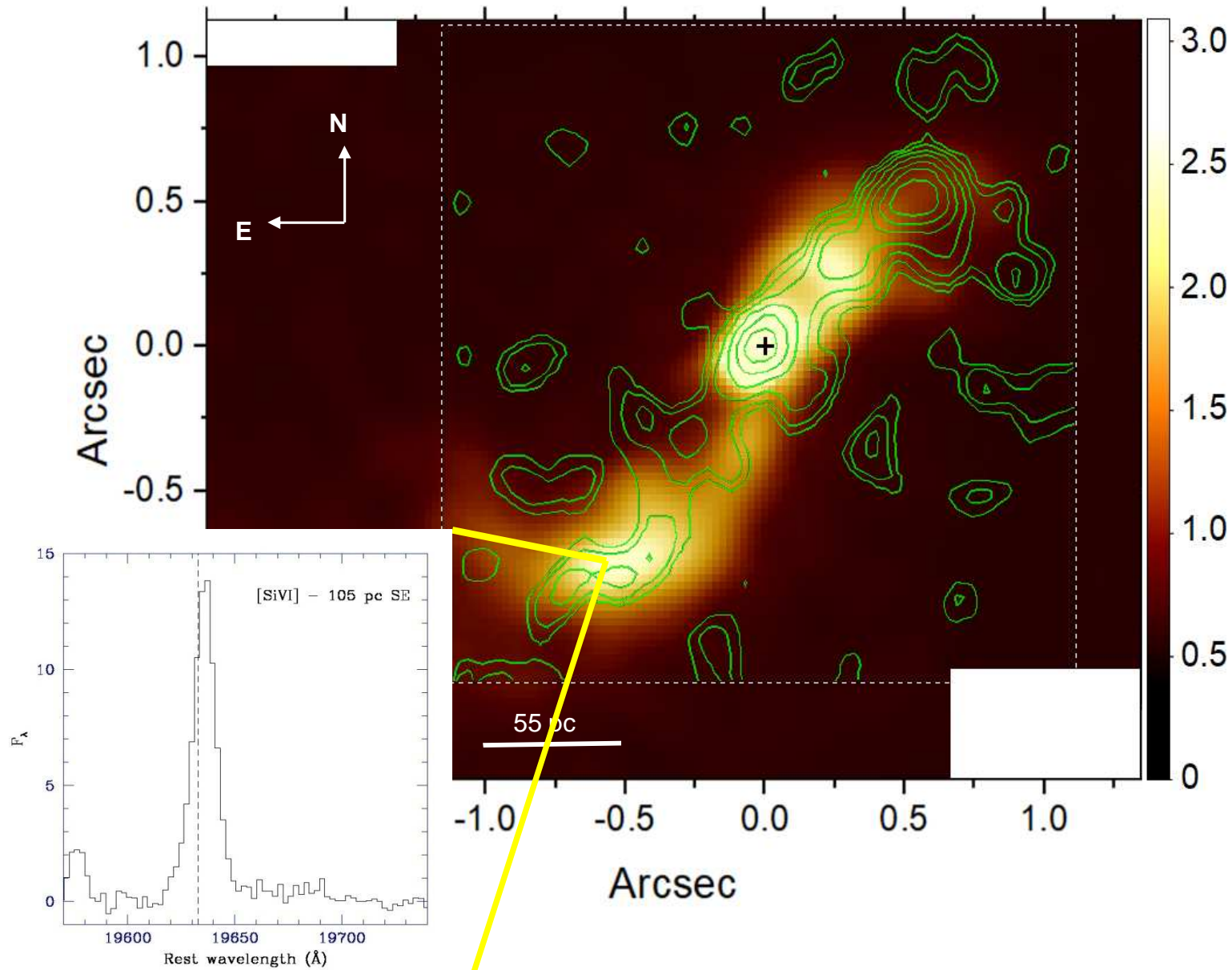
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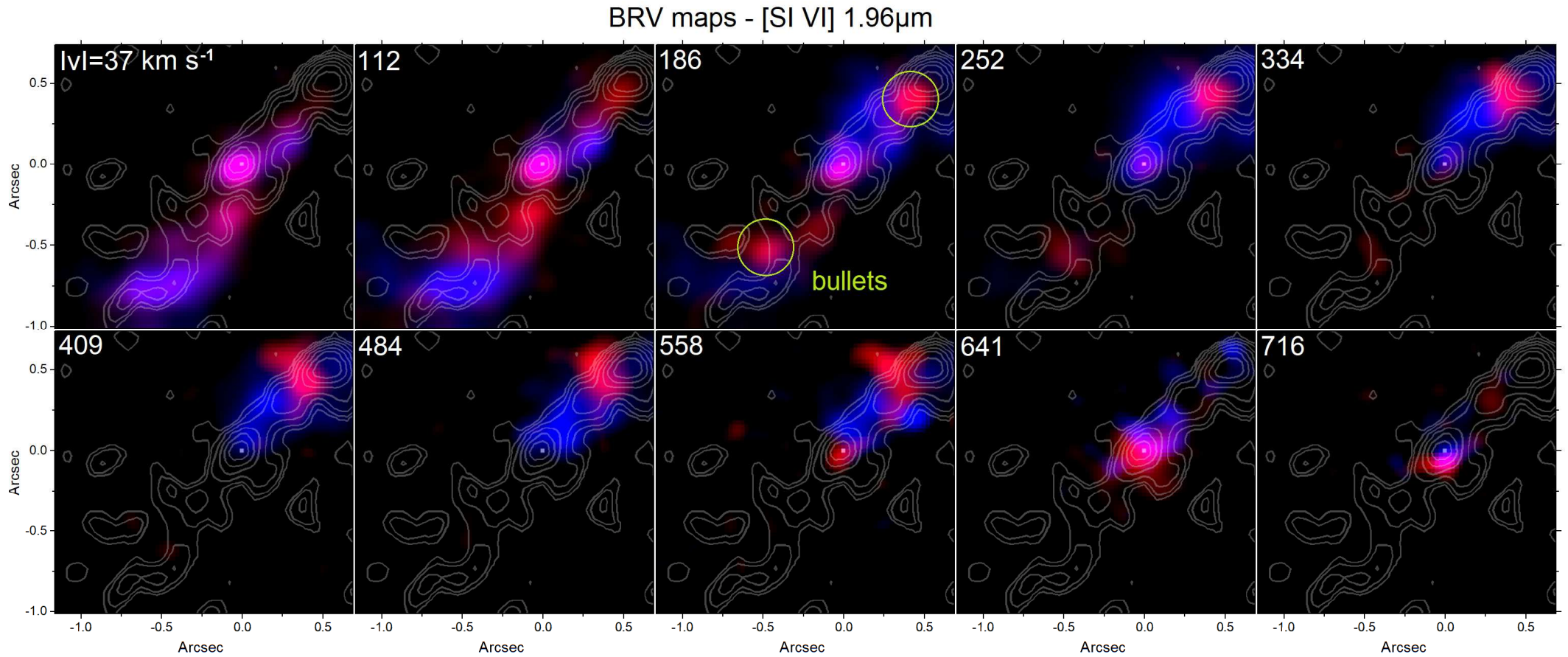
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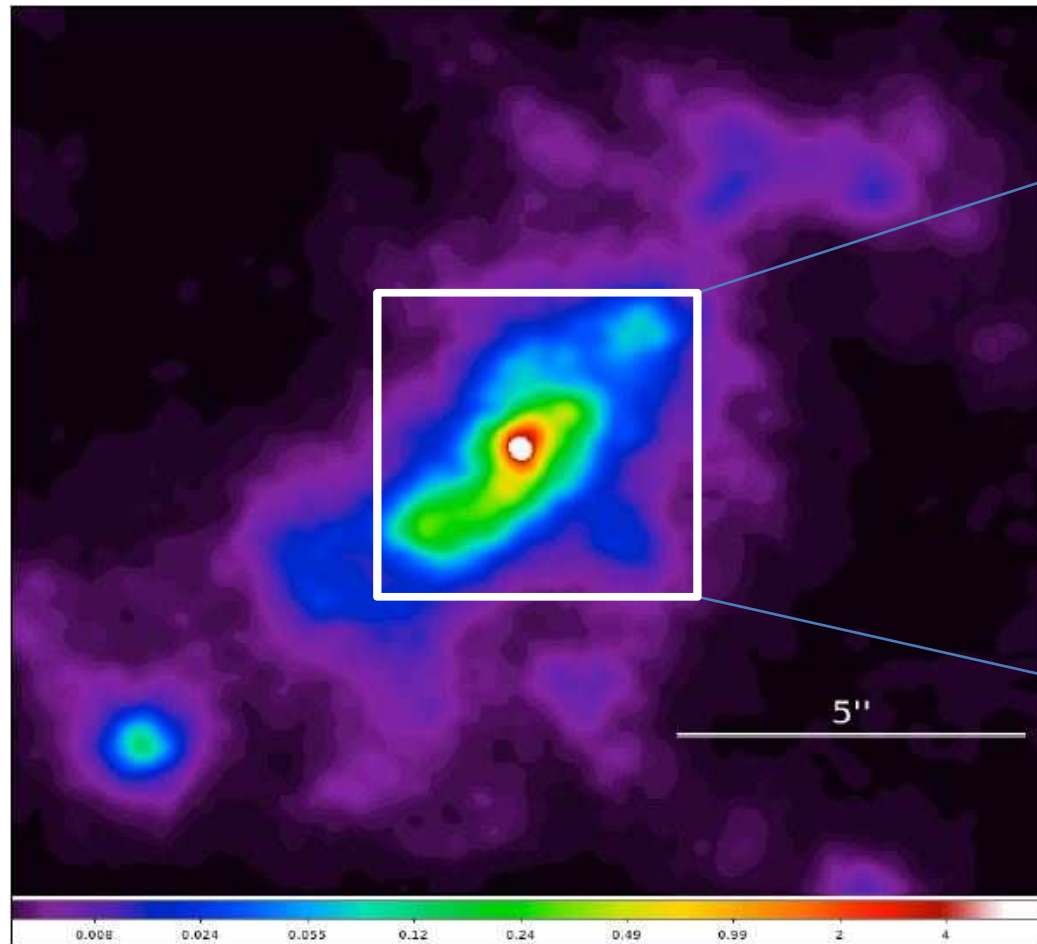


Channel maps of [SiVI] in ESO428-G14



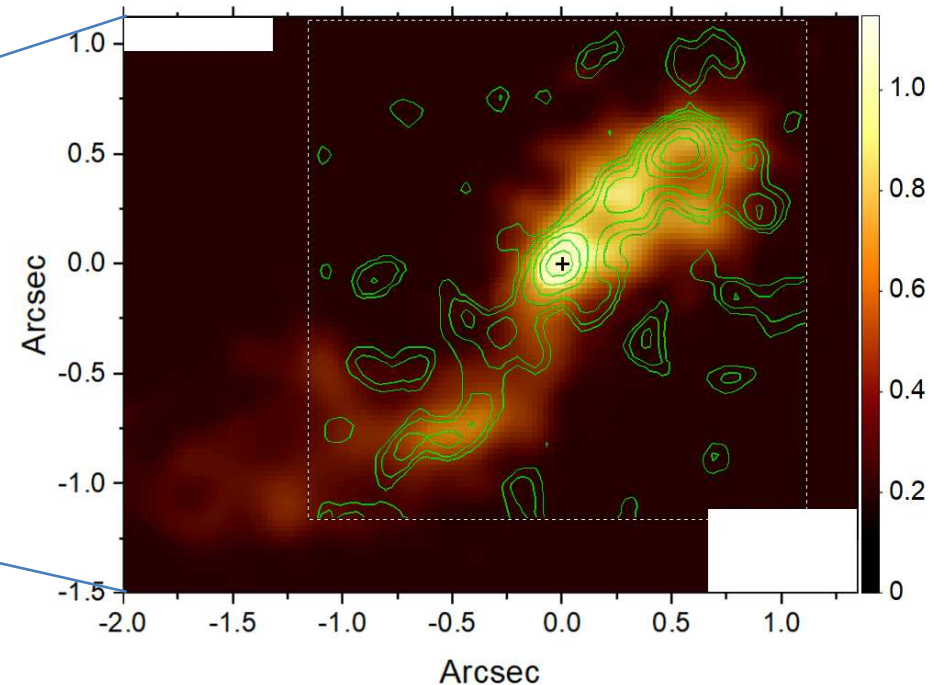
May, Rodríguez-Ardila, Prieto et al. (in prep.)

Evidence of radio-jet shocks induced emission?



3-6 keV Chandra image of ESO428-G14.
(Fabbiano et al. 2017).

May, Rodríguez-Ardila, Prieto et al. (in prep.)



- Radio jets may also produce collisional excitation of encountered clouds.
- In ESO428-G014, the X-ray surface brightness increases at the bend in the jet, suggesting an interaction.
- If the shock velocities are $\sim 1000 \text{ km s}^{-1}$, hard X-ray emission will result.

Take away message

- AO IFU observations reveal a compact but still extended CLR, with sizes that reaches from a few pc up to 250 pc from the AGN.
- The coronal lines usually displays highly complex profiles, not observed in lower-ionization lines. This suggests that at least part of this emission is originated from strong winds/outflows at the inner portion of the narrow line region ($r < 300$ pc).
- AO IFU spectroscopy shows coronal gas aligned with the radio jet and kinematically perturbed, with little evidence of disk-rotation (as suggested by the stellar component or H_2 , for instance), supporting the scenario where part of this emission is produced by shocks.
- We found evidence of massive gas ejections, likely associated to the AGN. The mass outflow rate derived from the high-ionization gas indicate $\sim 11 M_{\odot}$ /yr. Such a substantial outflow rate might have strong implications on the feeding and accreting processes in AGN.