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

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XI SCSLSA

3C 348. Credit: NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA)

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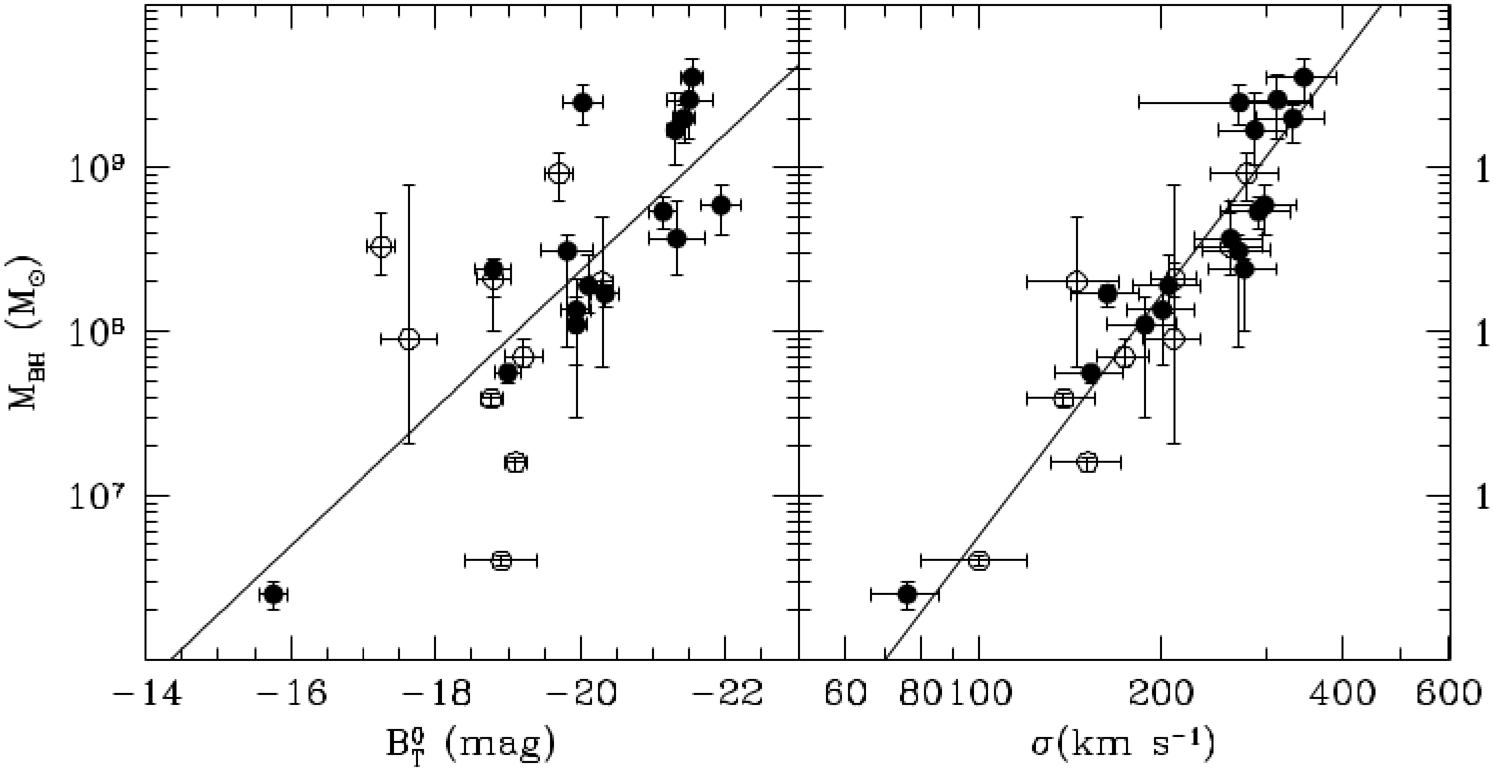
Outline

- 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● – *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.

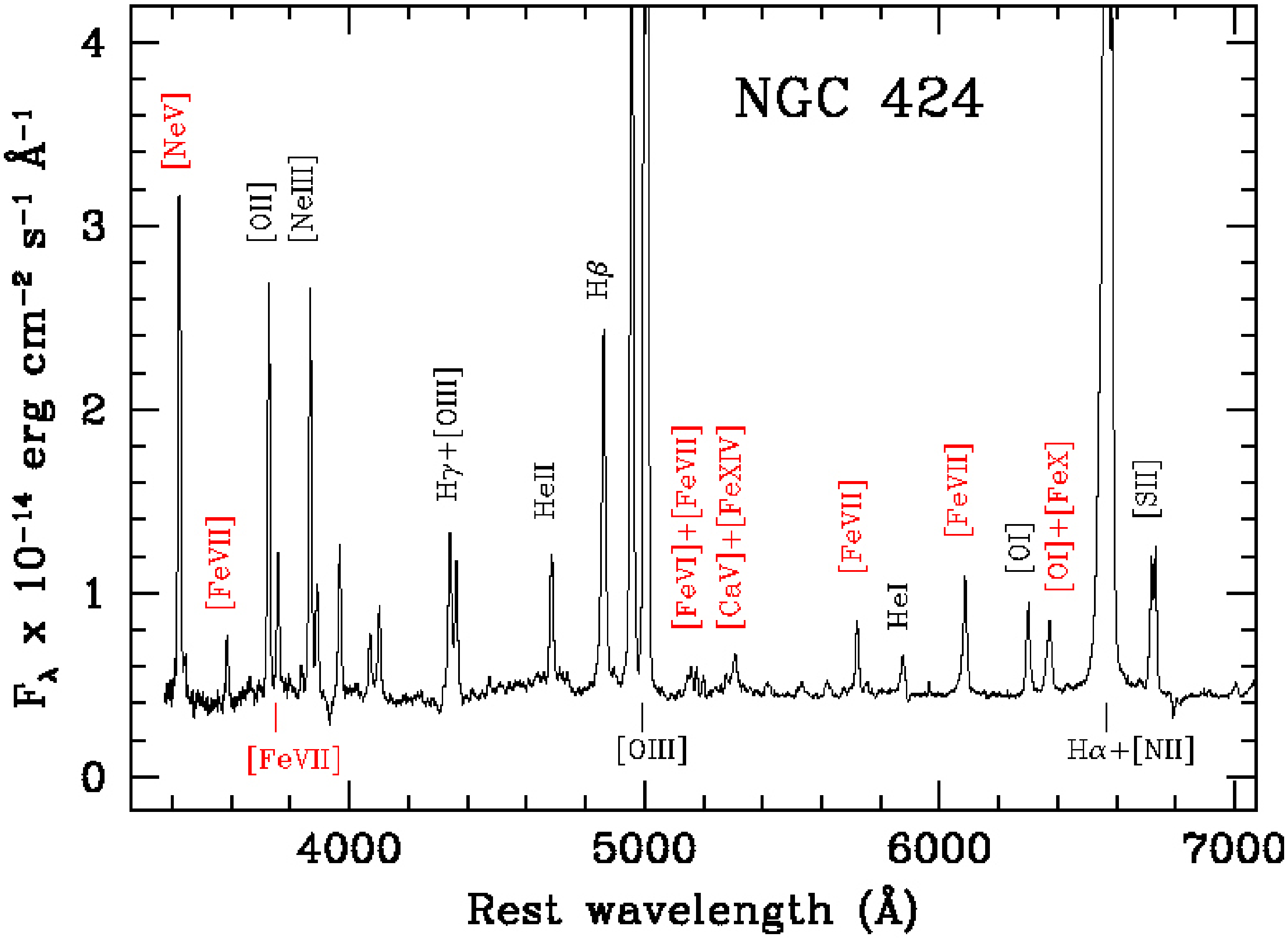
- Theoretical models suggest an origin of these outflows by fast AGN accretion disk winds (Zubovas & Nayakshin, 2014; Chan, C.-H., & Krolik, 2017).

- 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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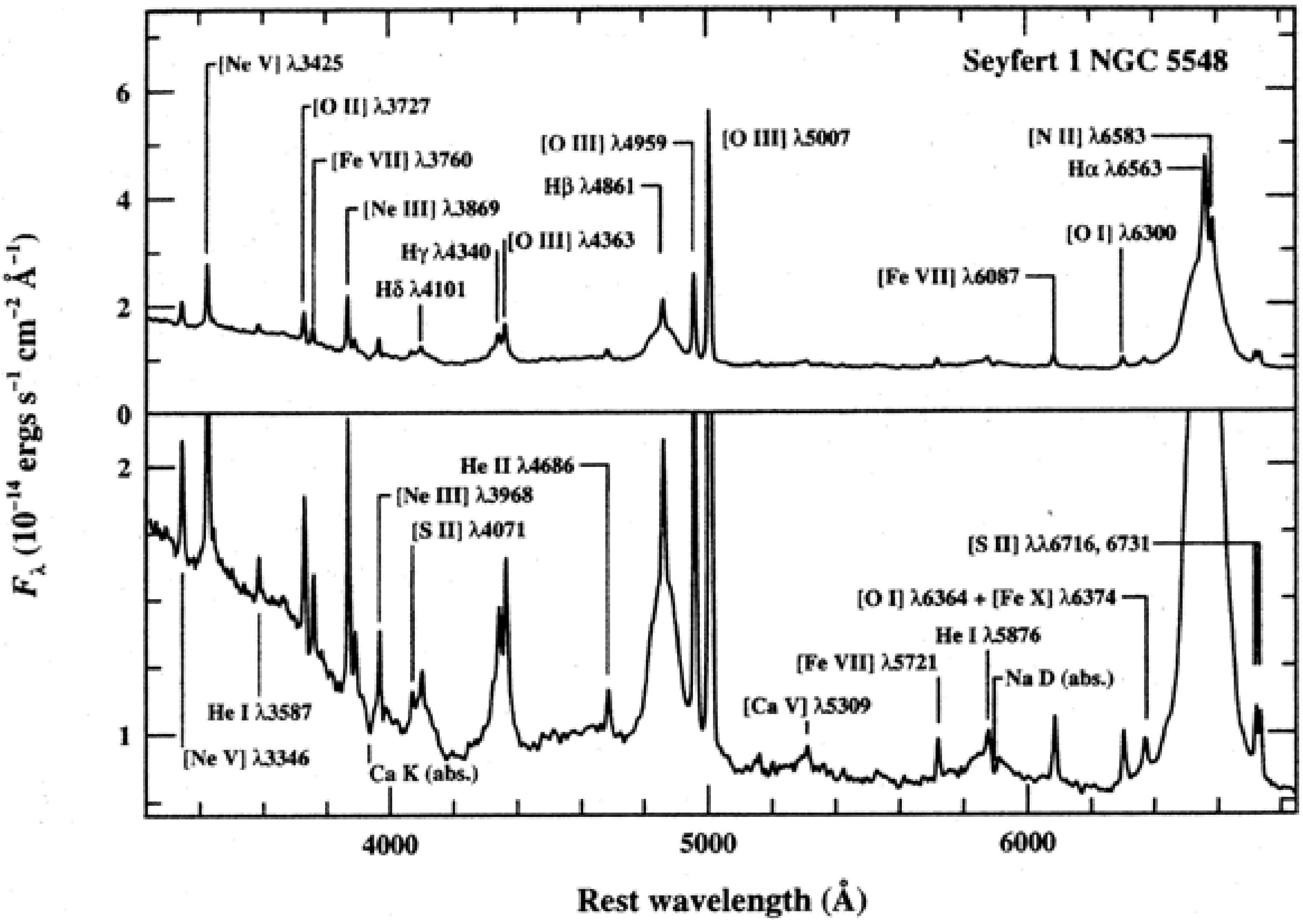

NGC 5548 – Peterson, 1997

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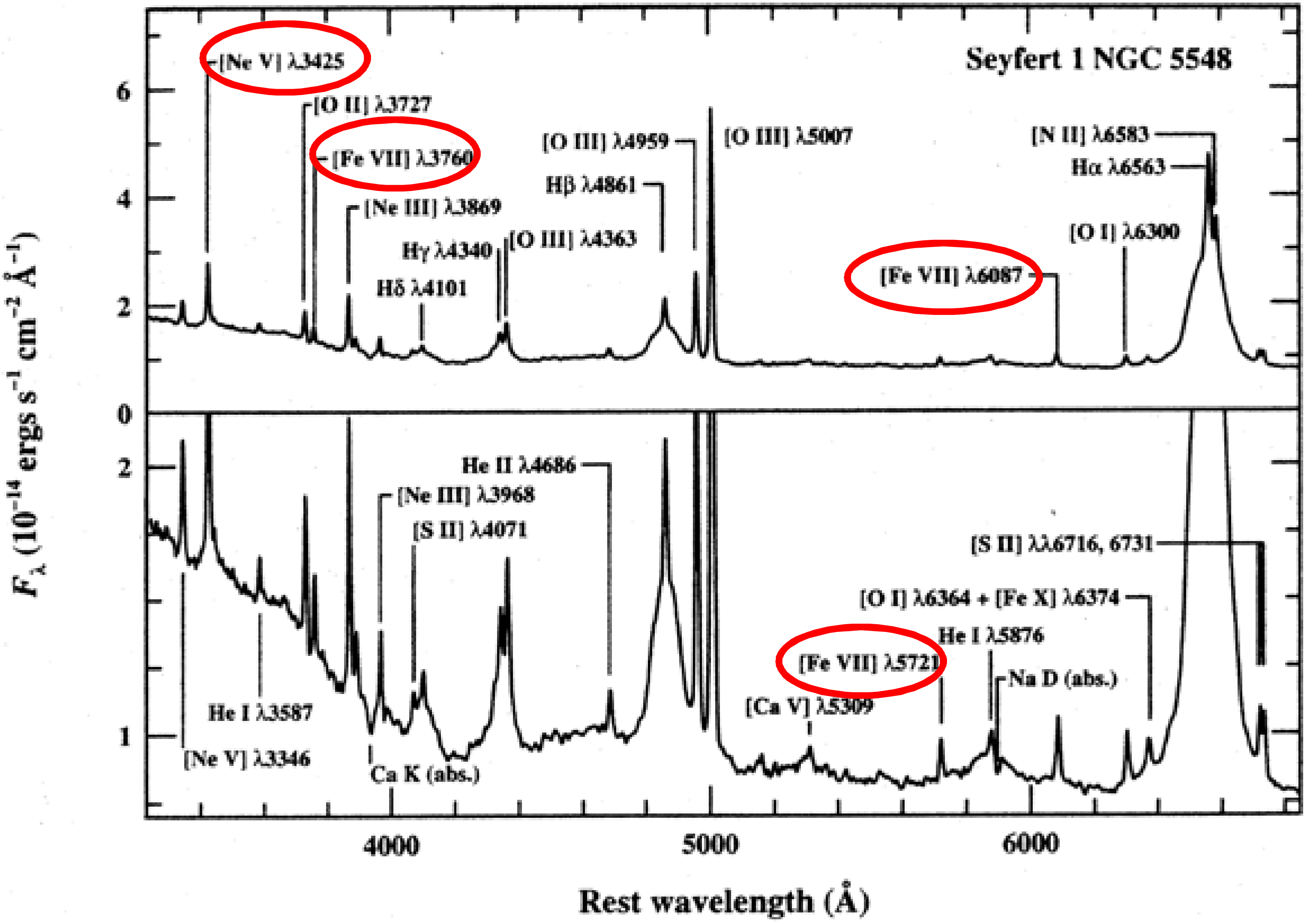

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Coronal Lines – Fact sheet

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

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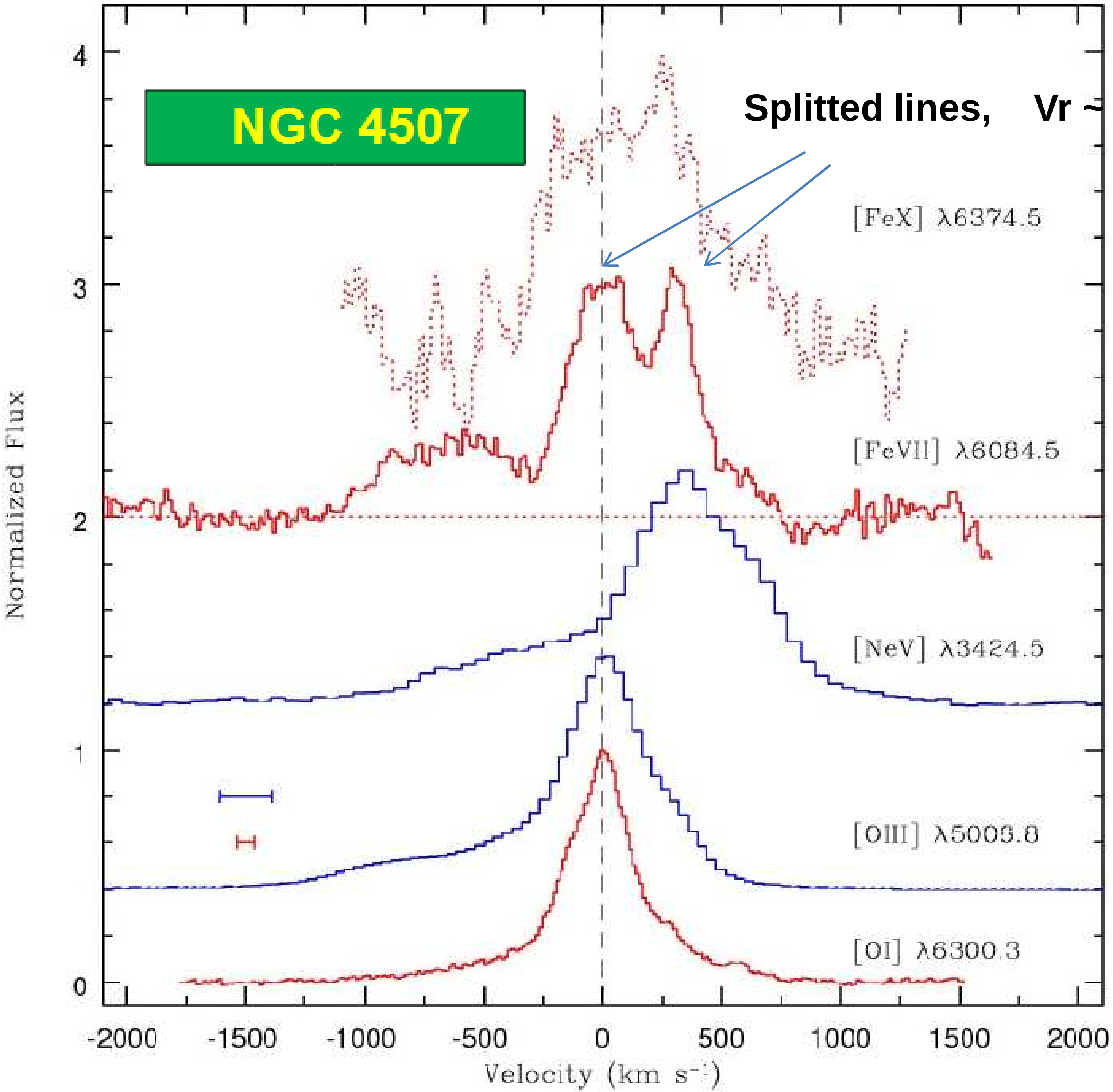

NGC 4507

Splitted lines, Vr ~ 250 km/s

- 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).

Rodriguez-Ardila et al. (2012)

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- Not observed in LINER AGNs.

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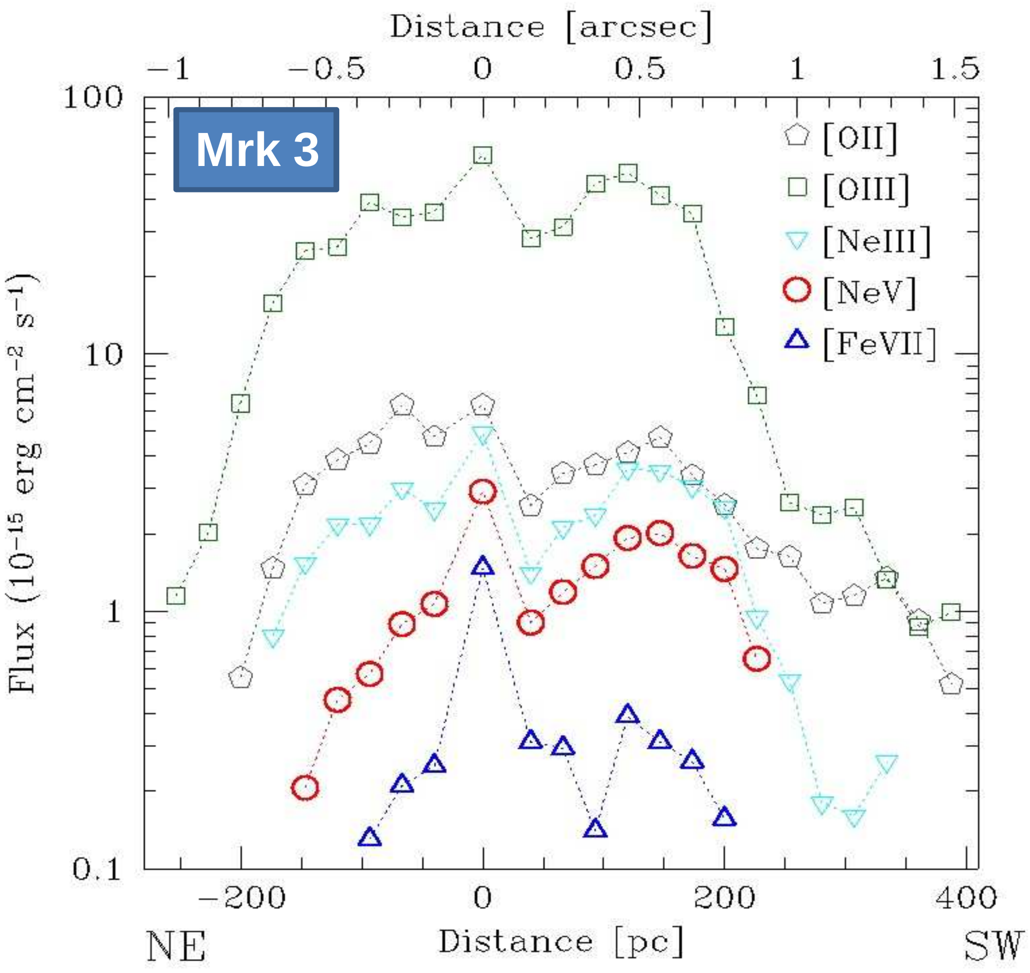
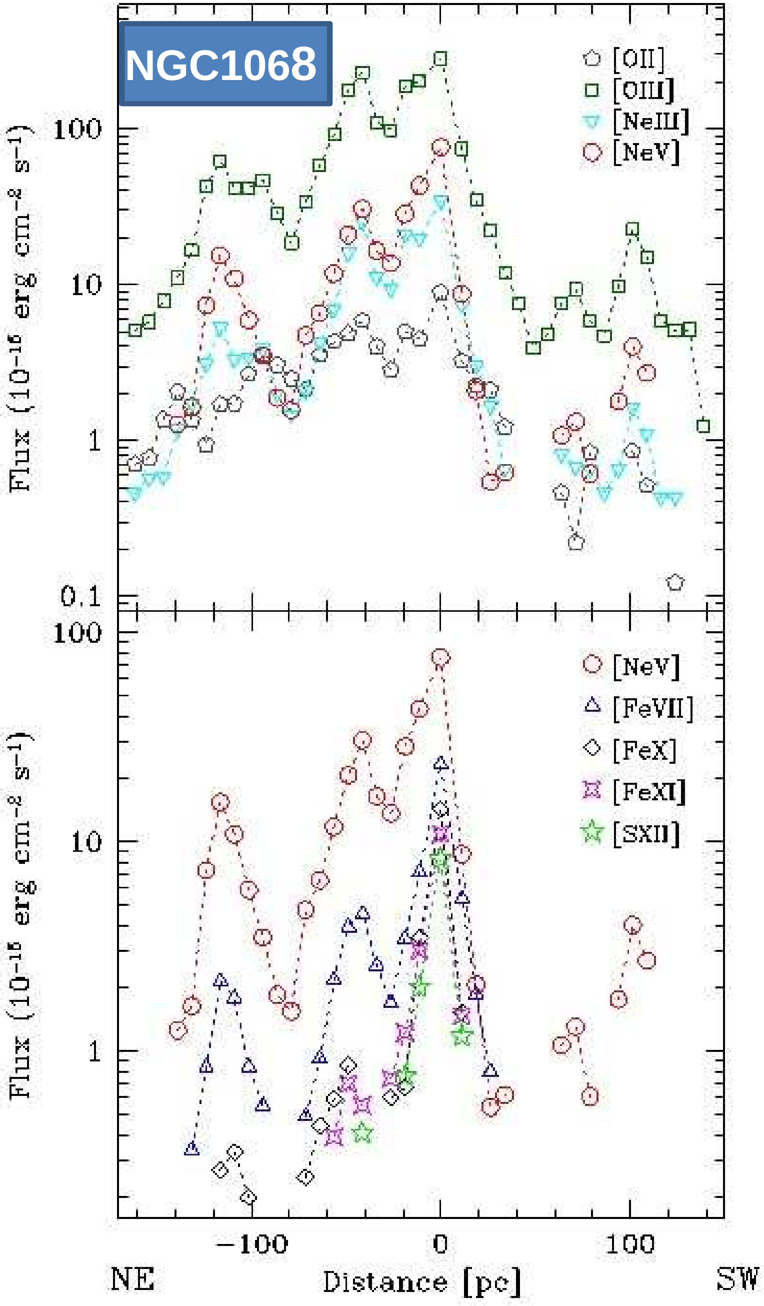
Distinguishing between these scenarios is tricky. Observations alone do not allow to discriminate between the different hypothesis.

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)

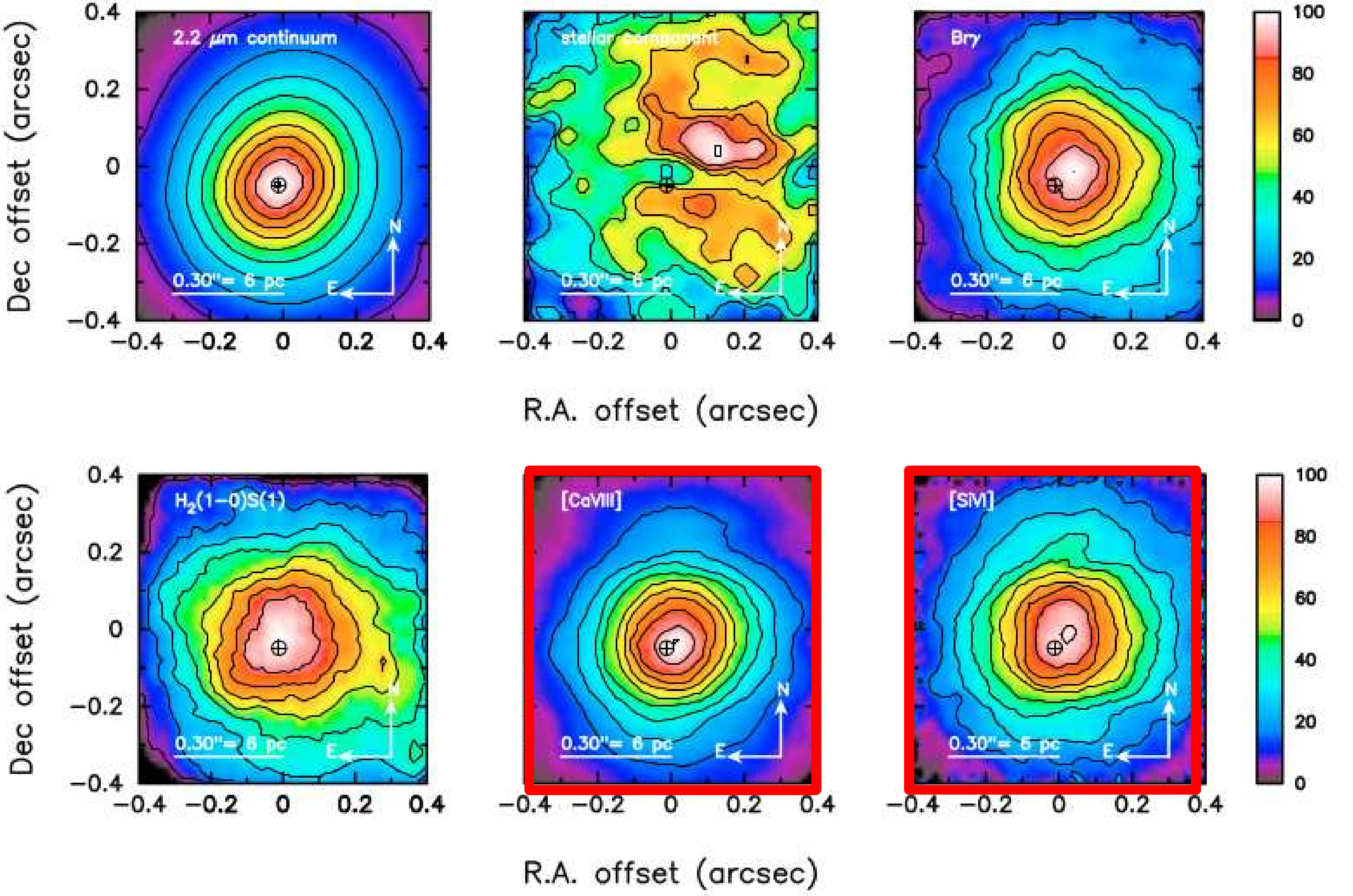
IFU & imaging studies of the CLR

- 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

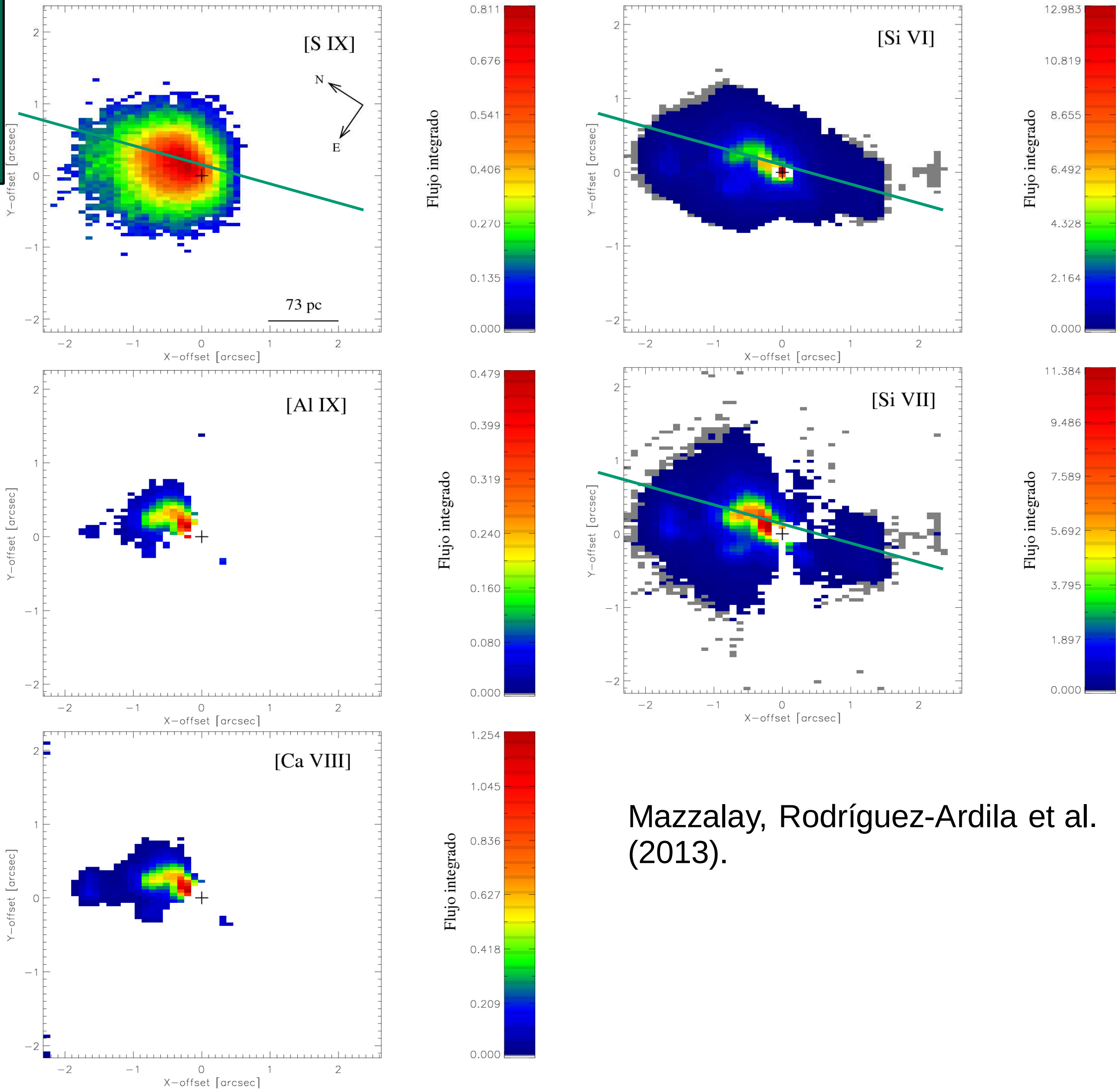
- Irregular morphology

- Brighter regions to N-NE from the nucleus. An arc that extends for ~0.8”.

- Towards SW, weaker emission (extinction).

- Extension:

  - NE: 2.3” ~170 pc
  - SW: [SiVI] & [SiVII]
    - have a secondary peak at ~2.2”
  - SW: [SIX] < 1”



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

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

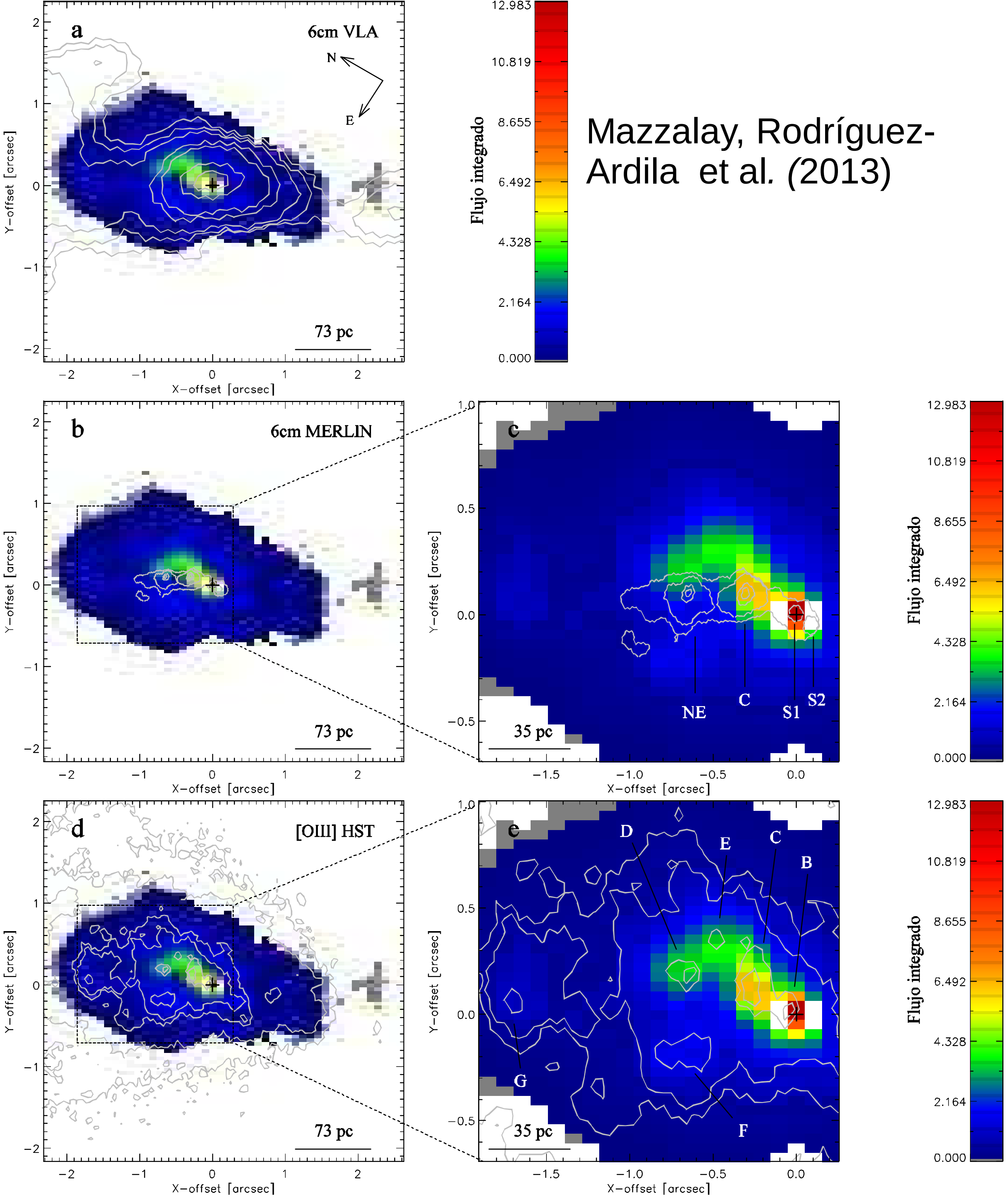
[SiVI], [OIII] and radio emission

- [SiVI] very similar to [OIII]

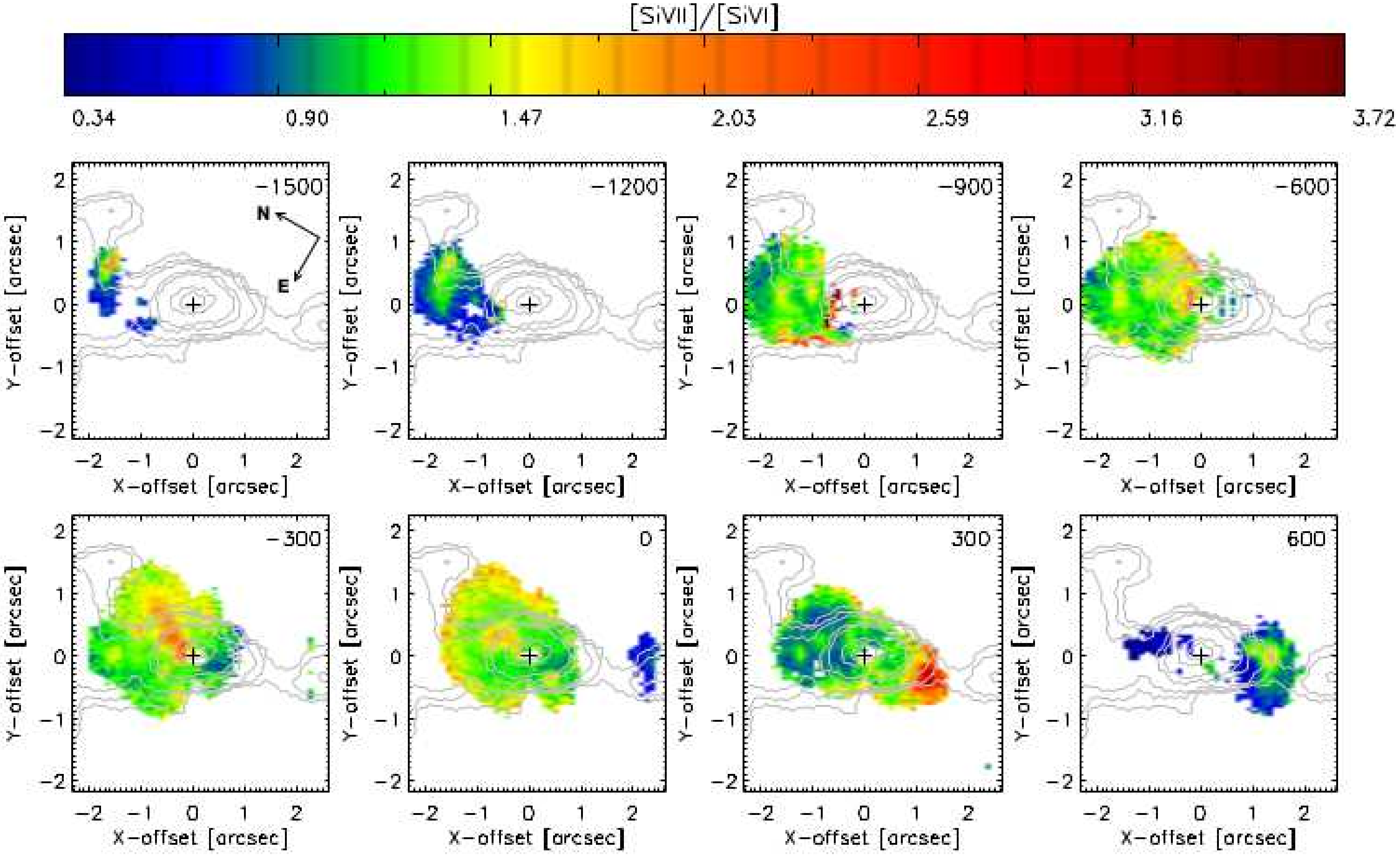
- [SiVI] elongated in the direction of the radio-jet

- At smaller scales (Merlin): the jet cleans up a channel, increasing the gas density (an 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)

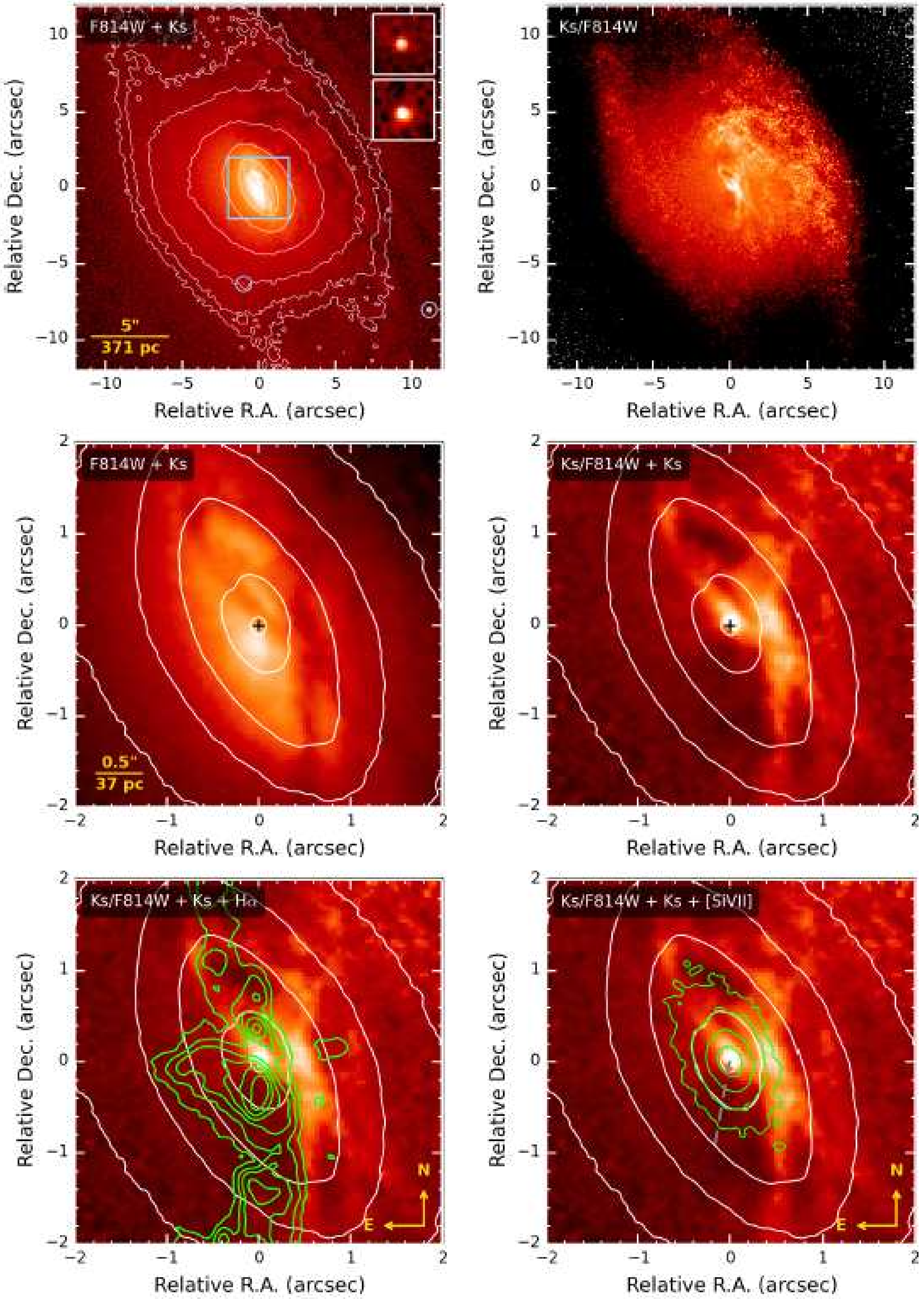


- Because of the difference in ionization potential between both lines (~40 eV), their flux ratio maps the ionization structure.

- 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, [Si VII]/[Si VI] ~3) from the centre.

- Pure photoionization models predict a peak of [Si VII]/[Si VI] of 1.5.

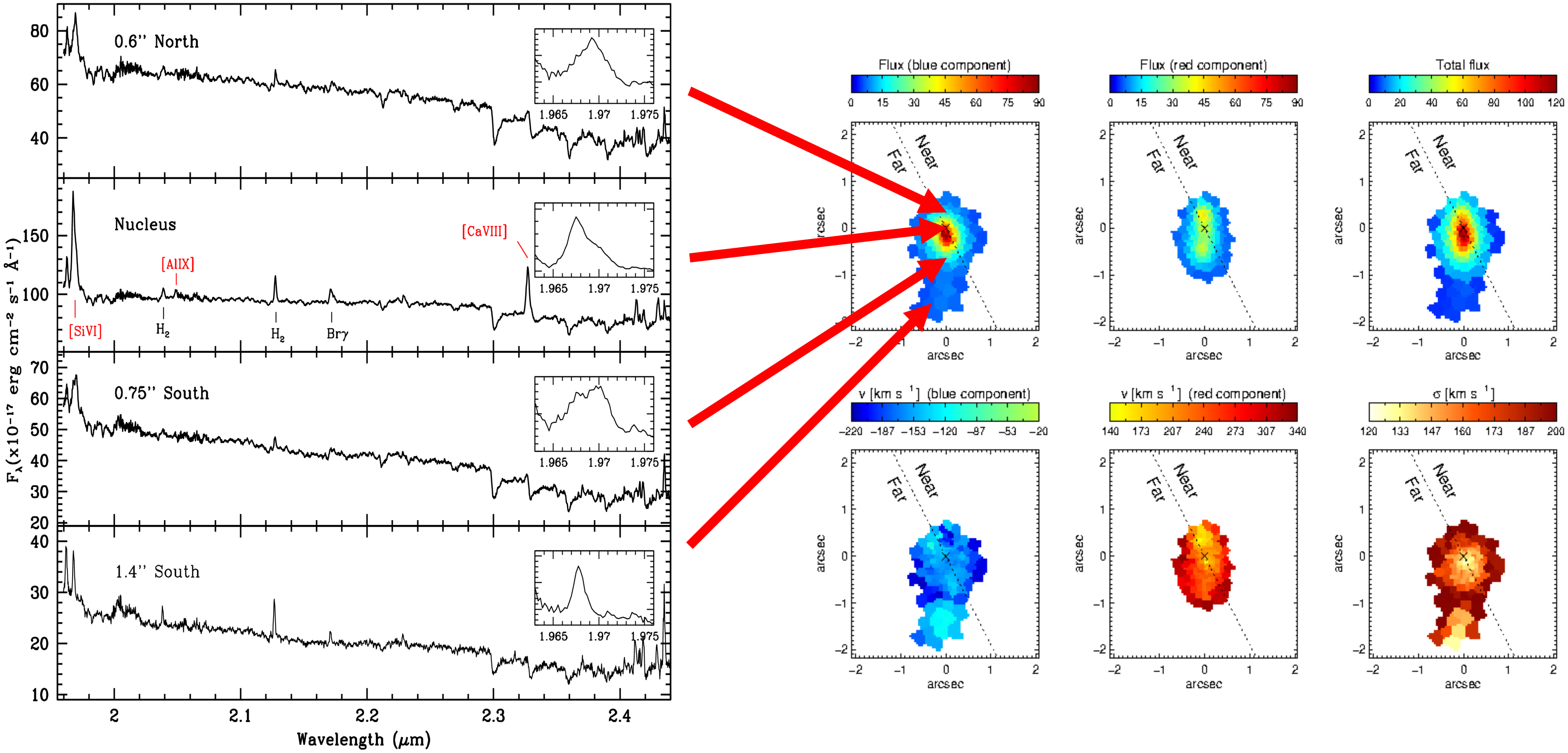
- Wang et al. (2012) suggest that spot ‘G’ and cloud ‘HST-H’ are strongly interacting with the jet. Shocks produce thermal X-ray emission, increasing the [Si VII]/[Si VI] ratio.



NGC 1386

- It is one of the nearest AGN at 15.3 Mpc, 1 ″ ~ 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} ~ 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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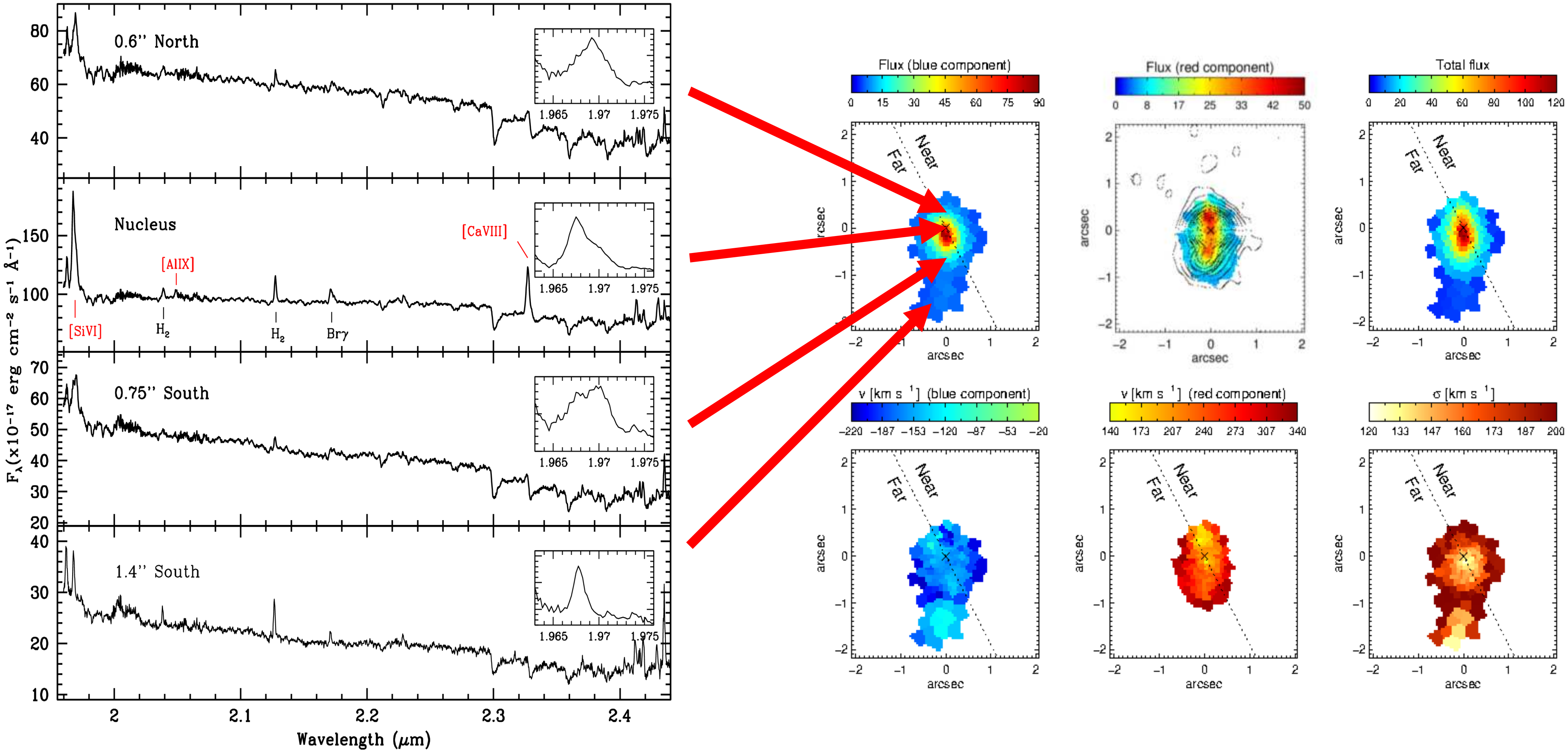
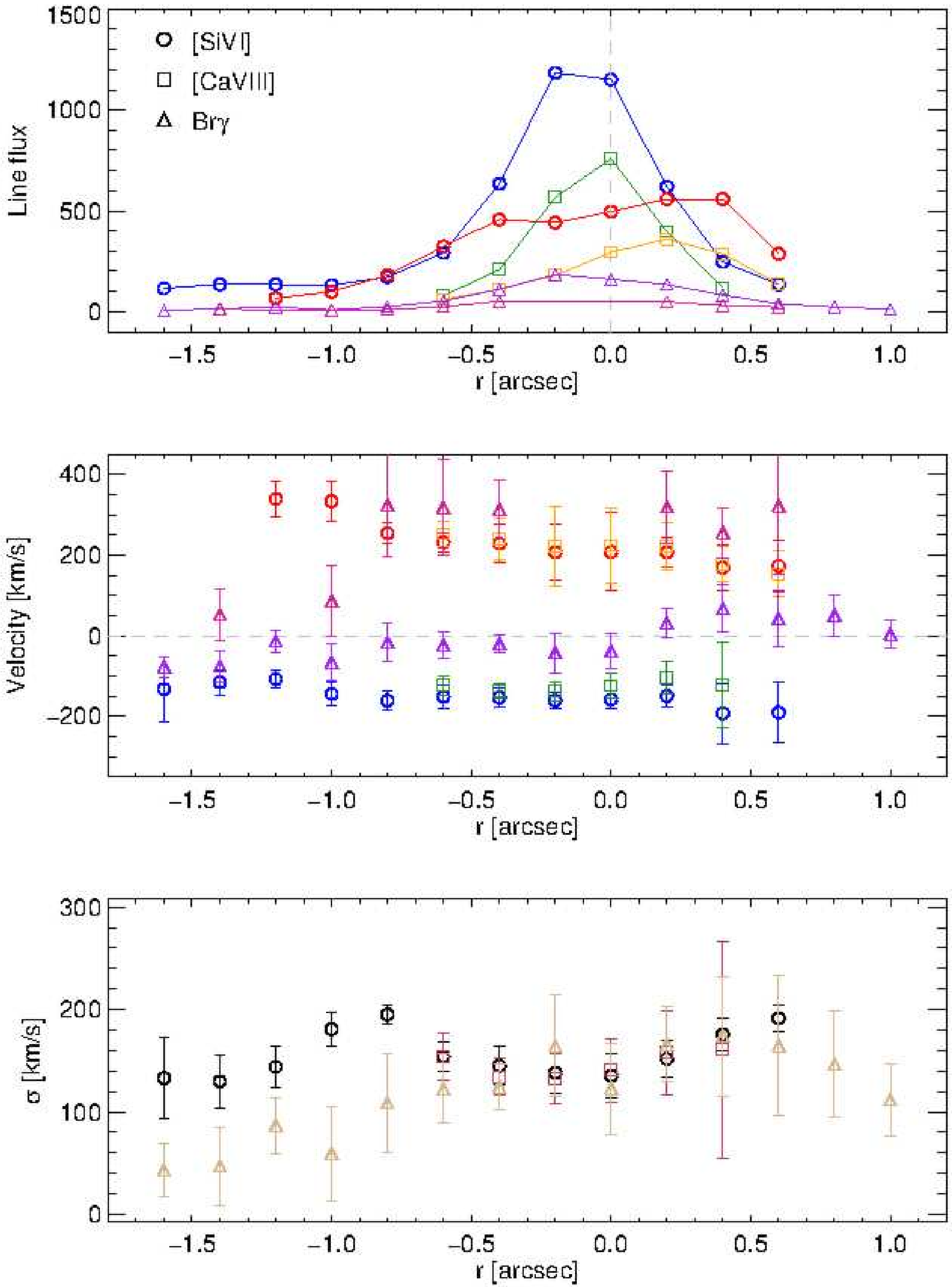


Rodríguez-Ardila et al. (2017)



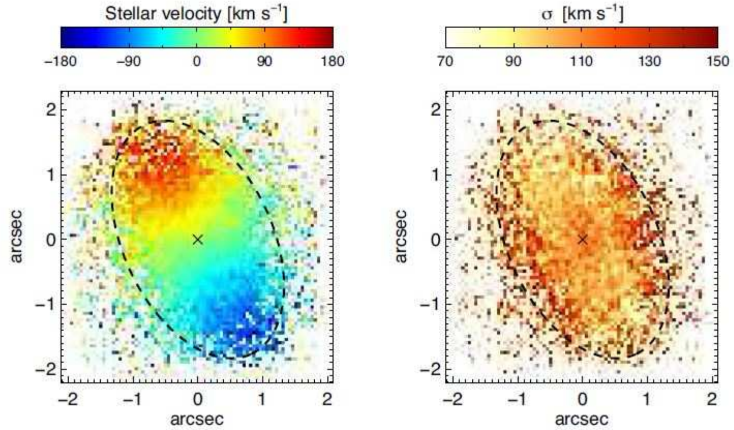
- Powerful mass outflows traced by the forbidden high-ionization gas.

- Two symmetrical expanding hot gas shells moving in opposite directions along the LOS.

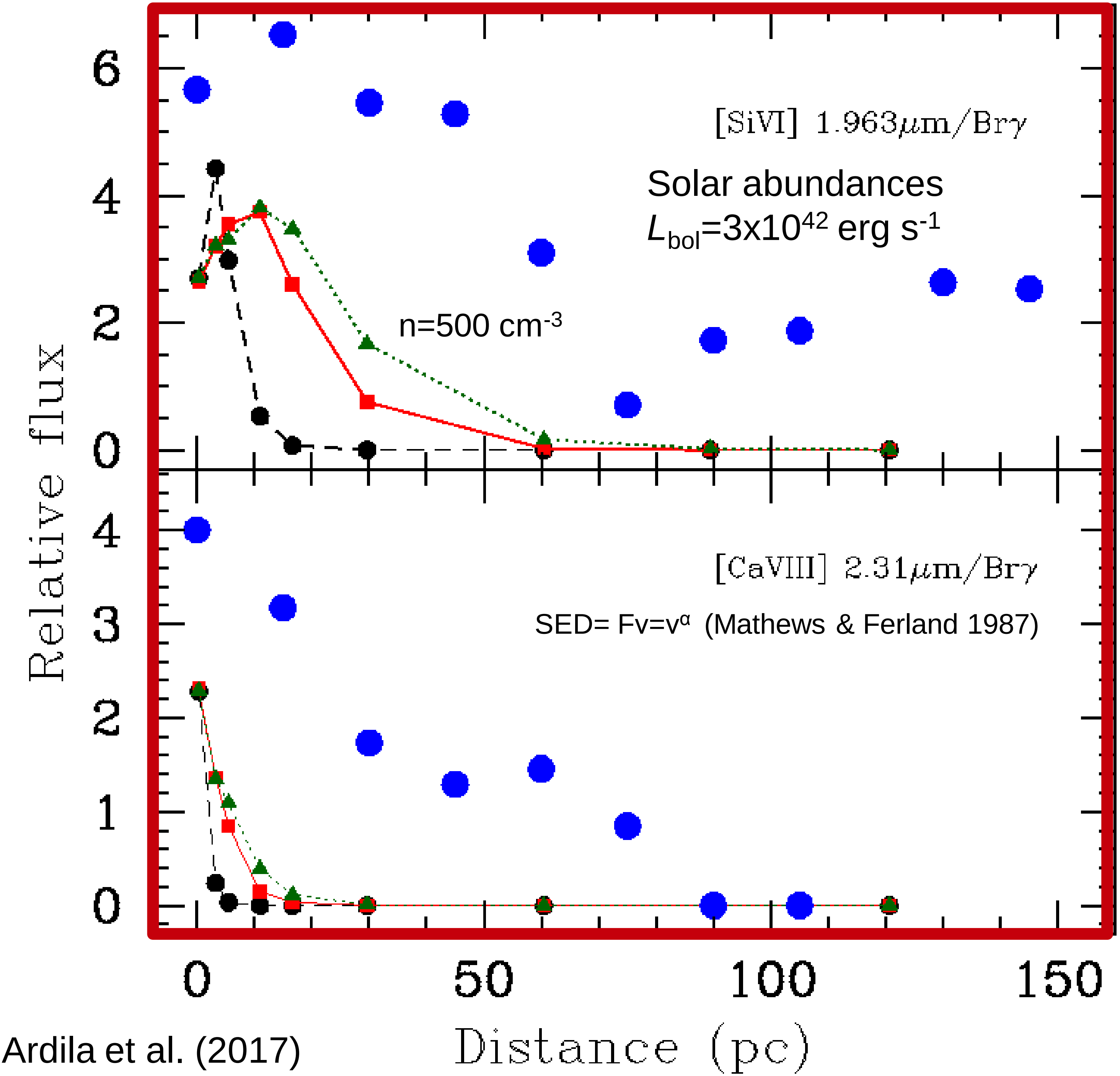
- Using:

$$\dot{M}_{\rm out} = 5.5\left(\frac{m_{\rm p}}{1.67\times10^{-24}\,{\rm g}}\right)\left(\frac{n_{\rm e}}{10^{2.97}\,{\rm cm^{-3}}}\right) \times\left(\frac{l}{111\,{\rm pc}}\right)\left(\frac{w}{37\,{\rm pc}}\right)\left(\frac{f}{0.1}\right)\left(\frac{v_{\rm out}}{225\,{\rm km\,s^{-1}}}\right)\,{\rm M_\odot\,yr^{-1}}$$

allows us to derive outflow rates of up to 11 M⊙/yr in NGC1386.



Photoionization model results for NGC 1386



Rodríguez-Ardila et al. (2017)

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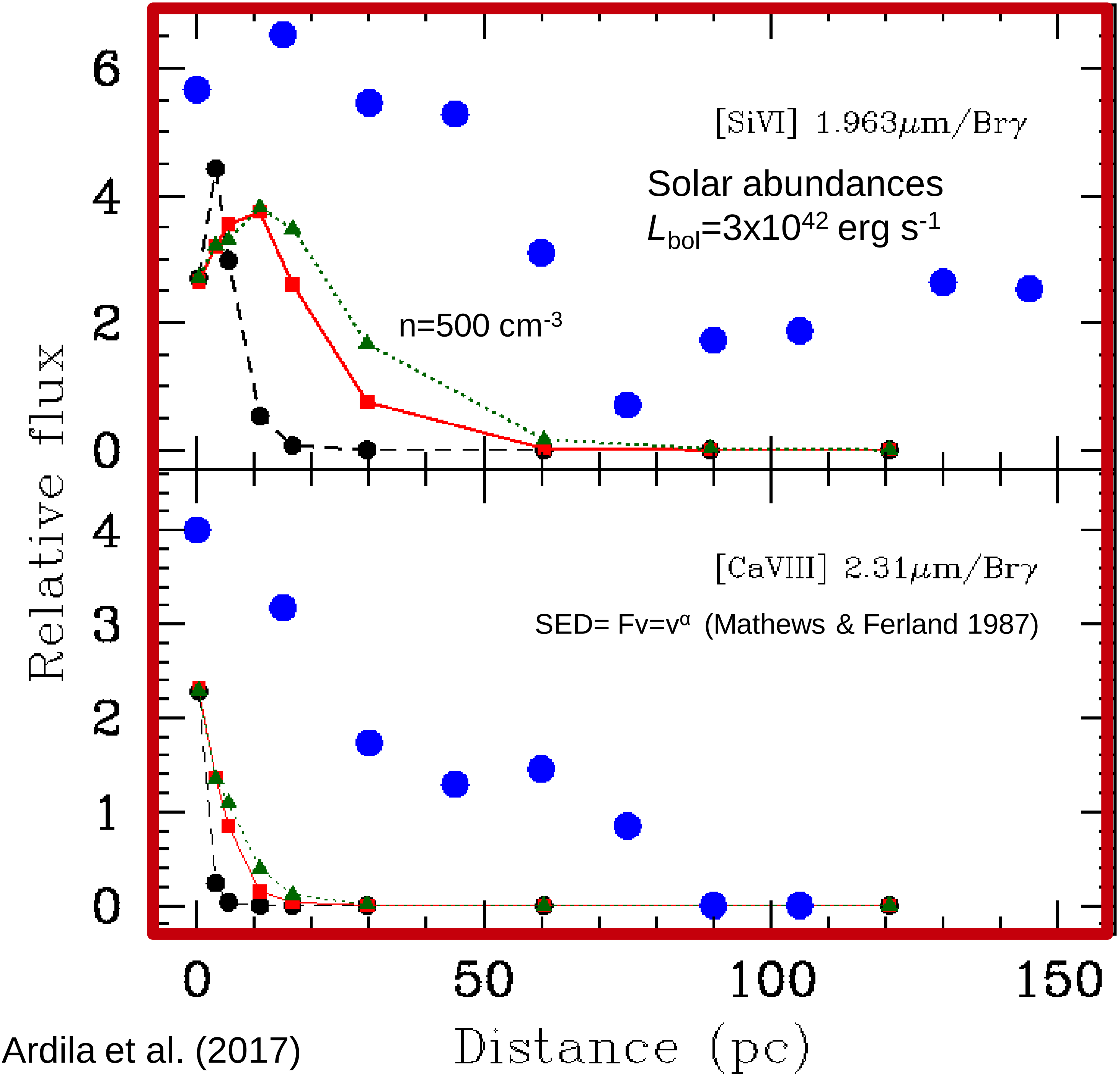
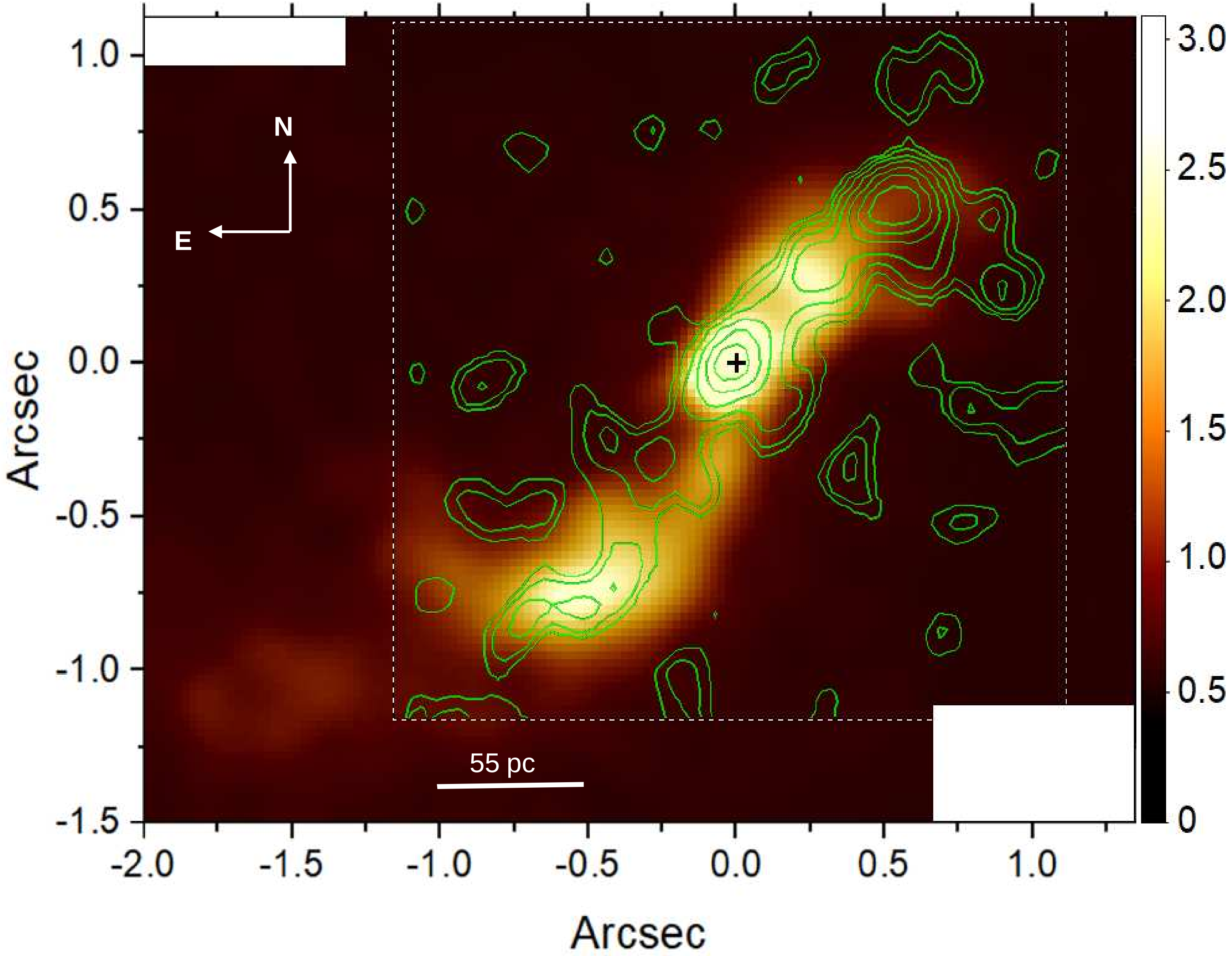


Shock-dominated clouds predict [SiVI] / Brγ between 13 and 2.1, for *V*s = 300 and 500 km/s, respectively (Contini & Viegas 2001).

Rodríguez-Ardila et al. (2017)

The case of ESO418-G14



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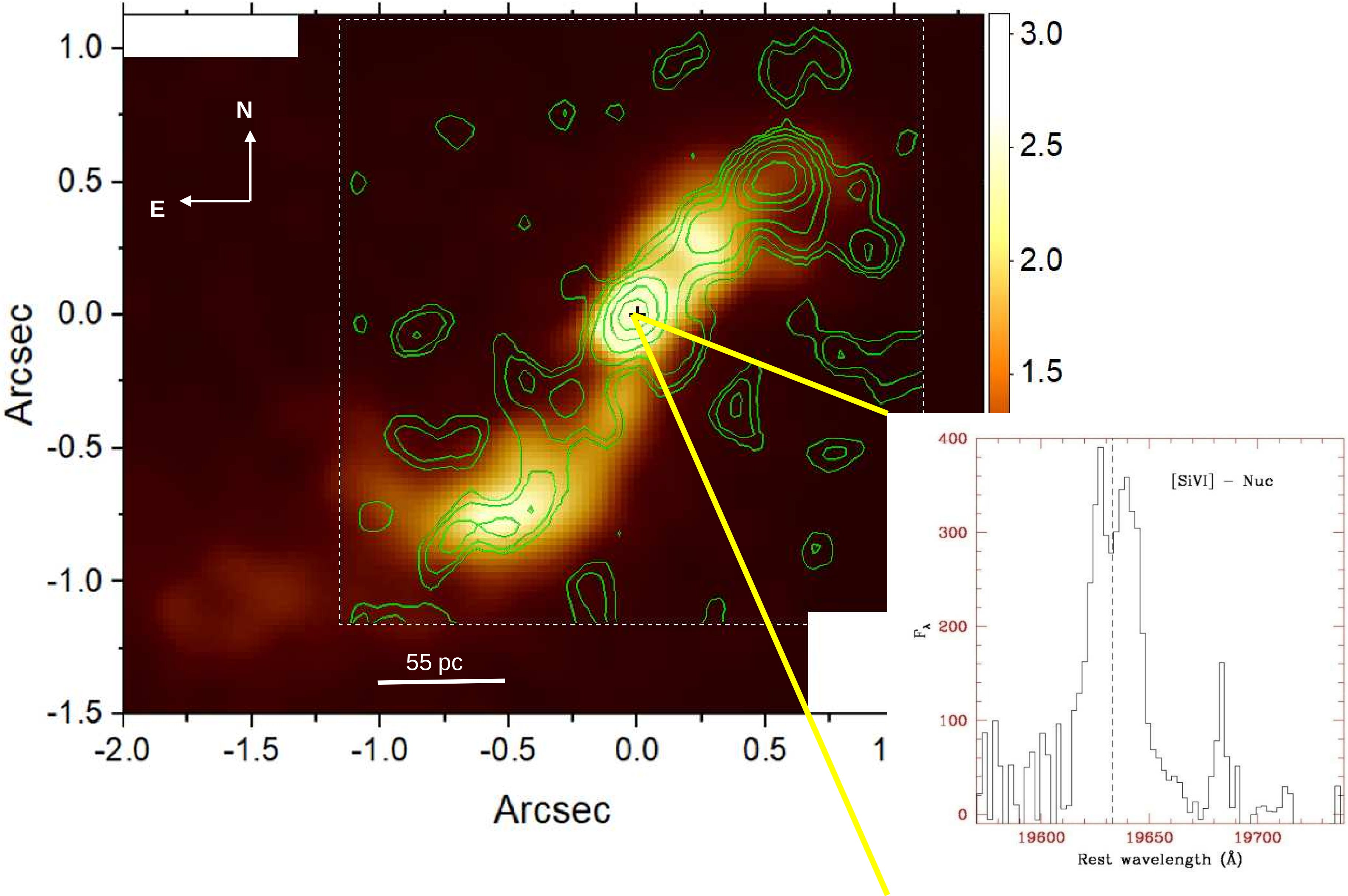

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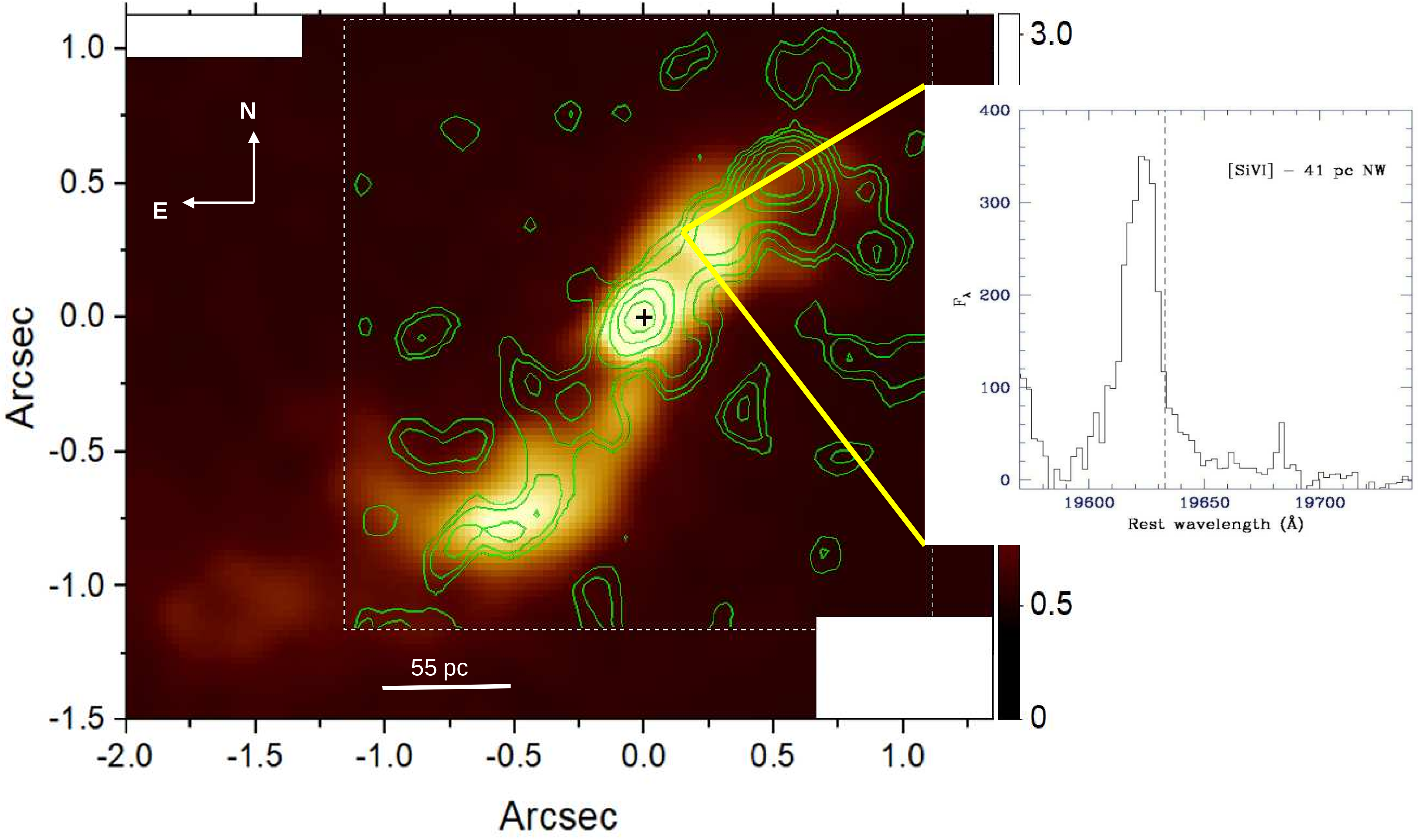

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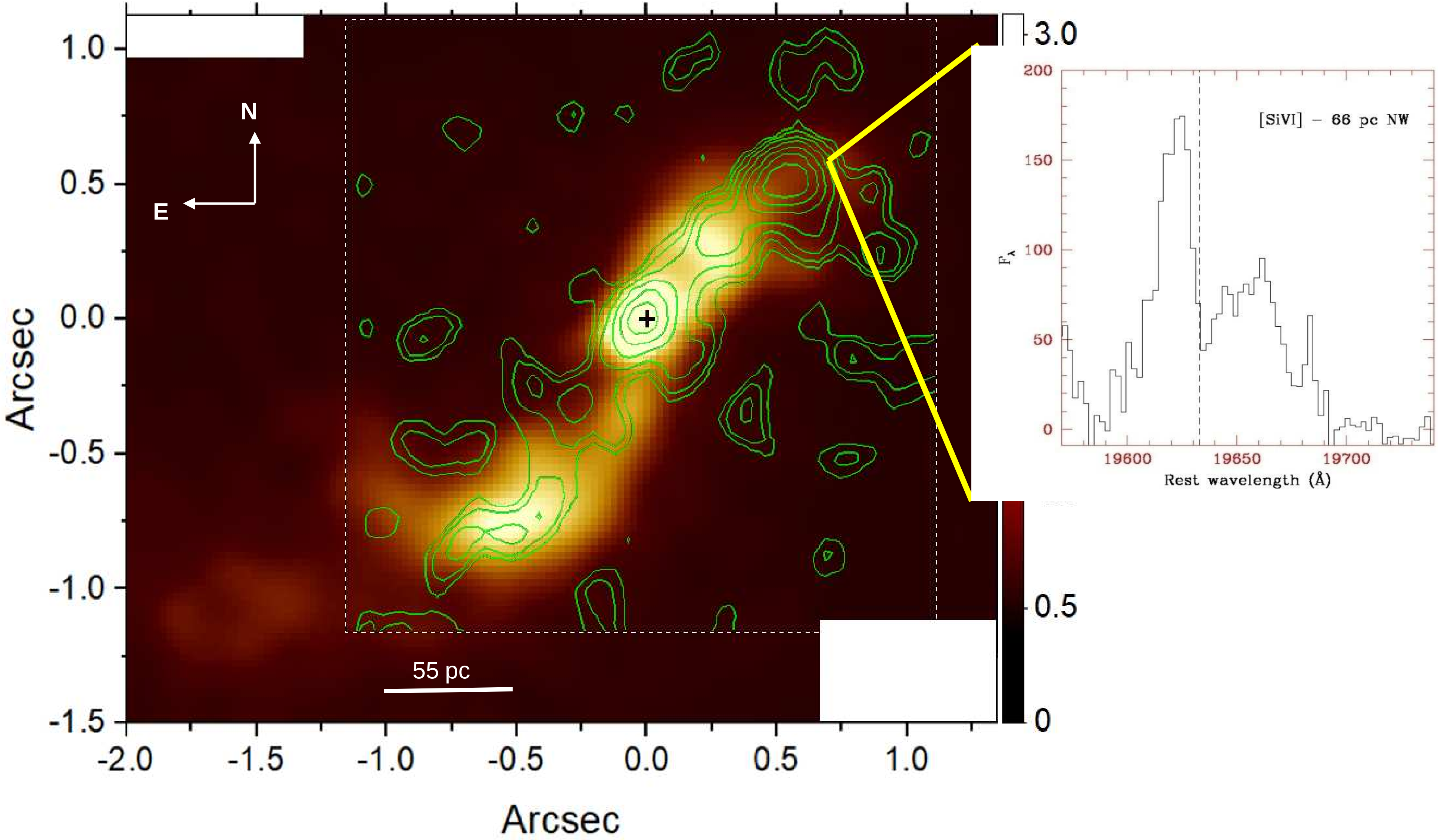

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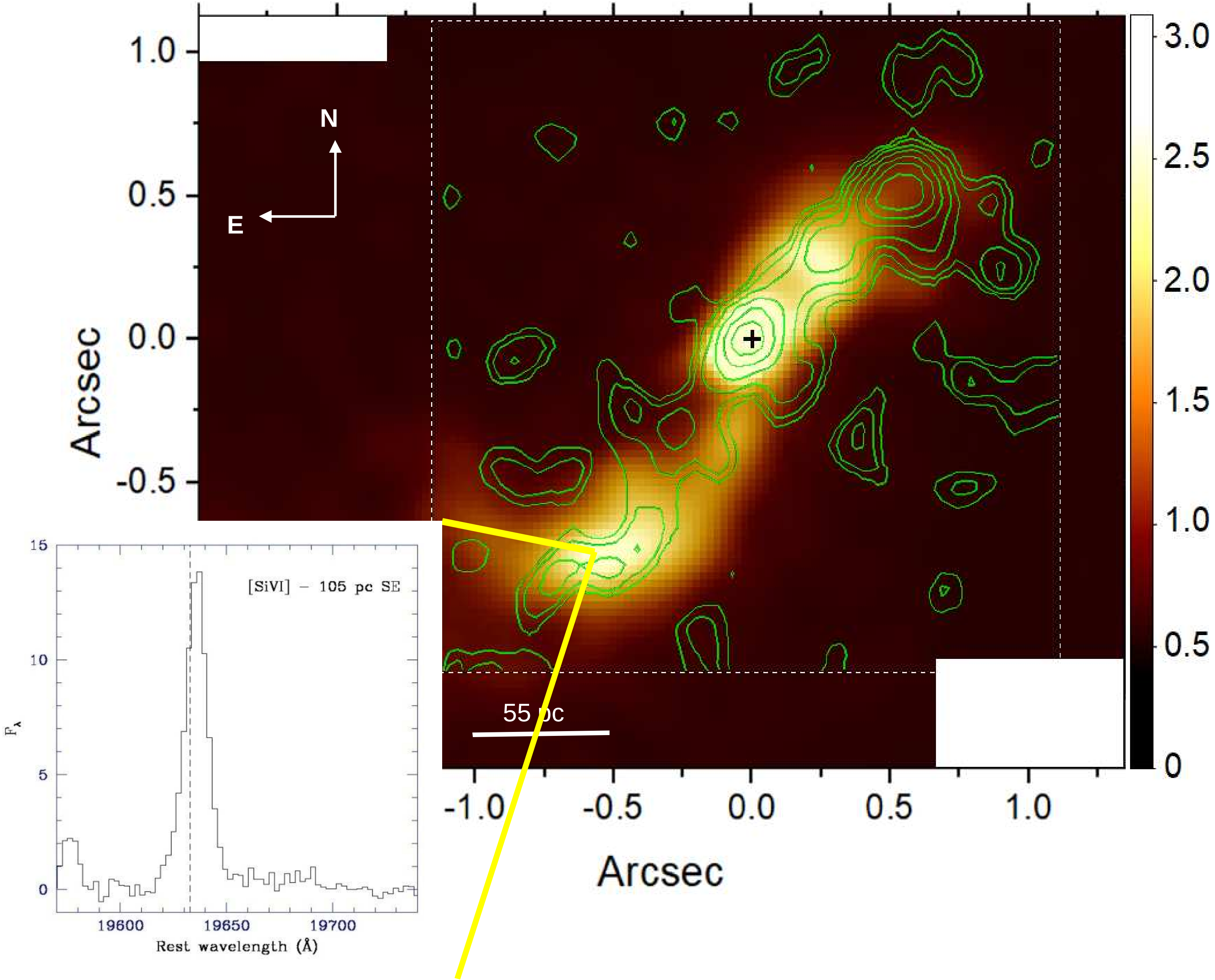
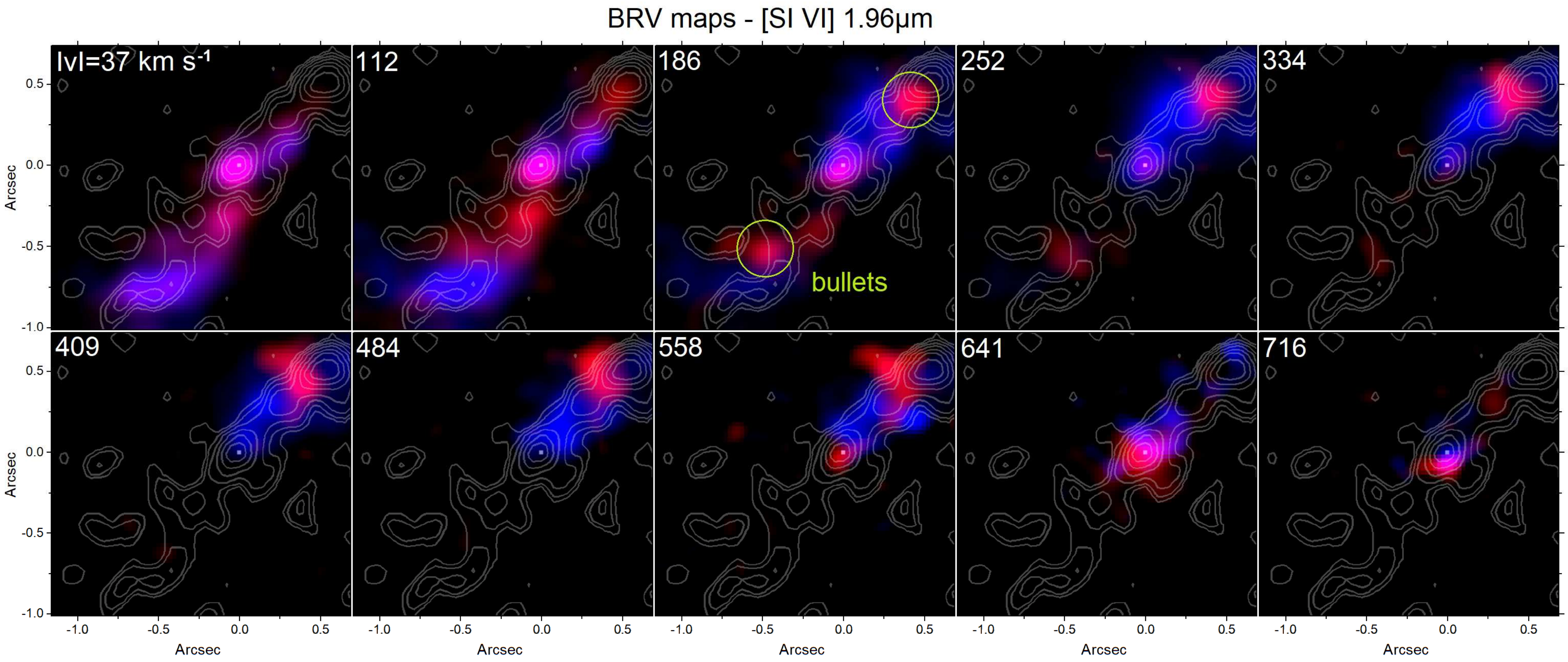
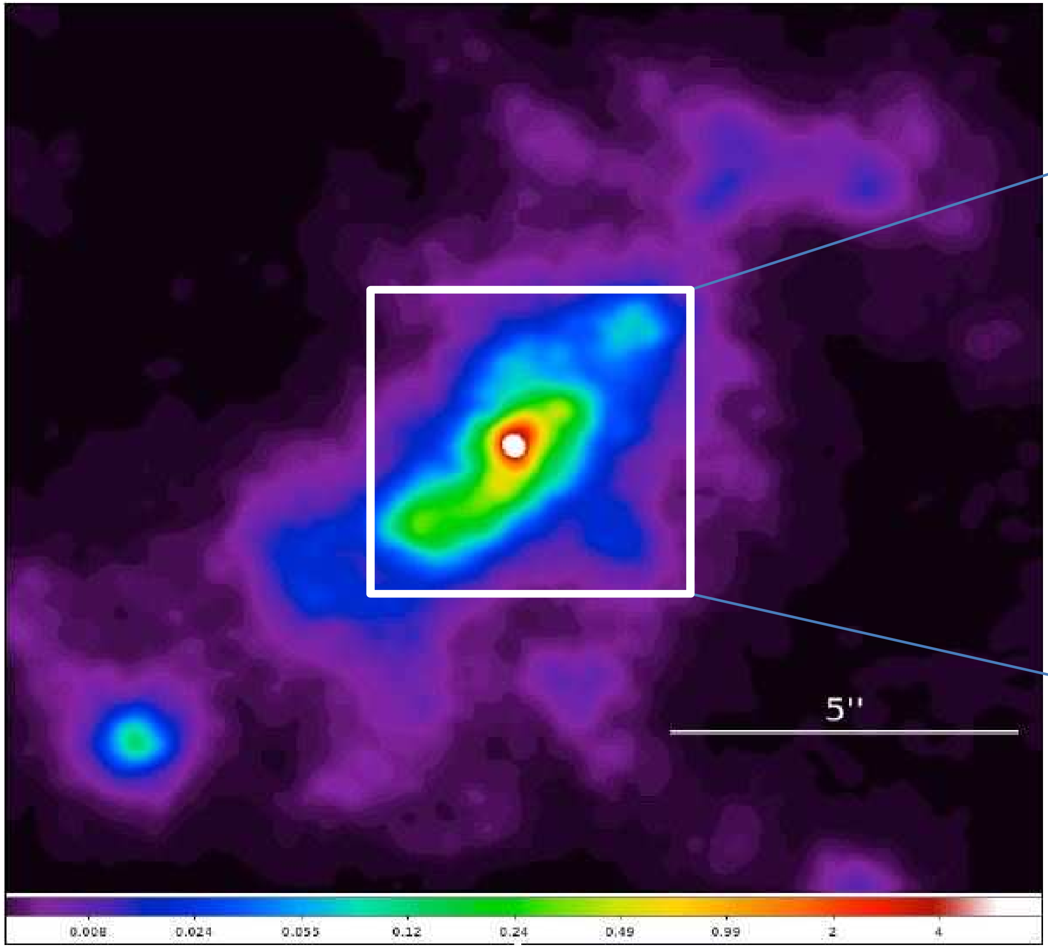


Channel maps of [SiVI] in ESO428-G14



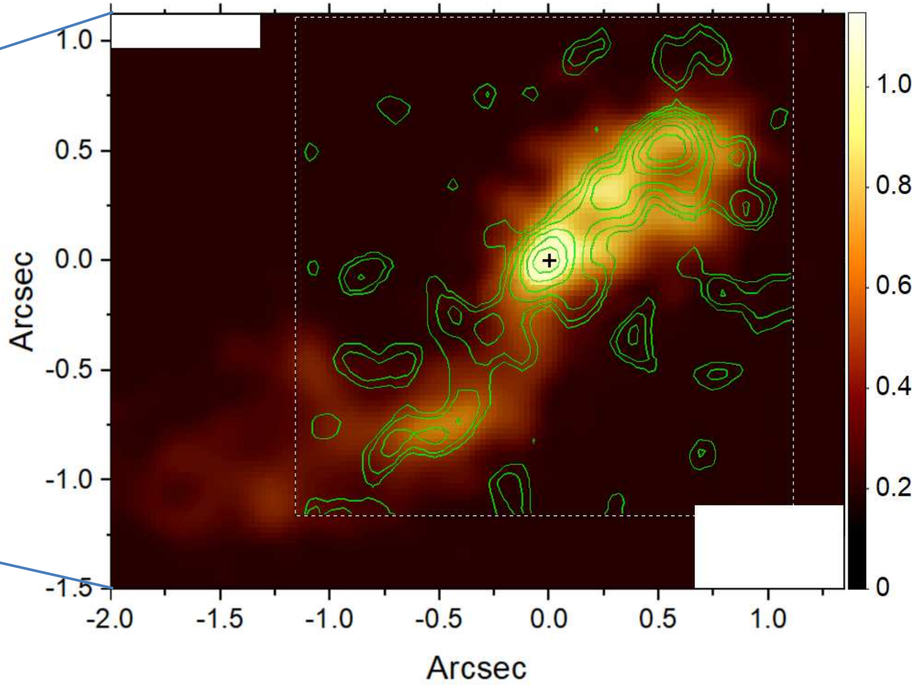
May, Rodríguez-Ardila, Prieto et al. (in prep.)

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 ~1000 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 ~11 $M_\odot$ /yr. Such a substantial outflow rate might have strong implications on the feeding and accreting processes in AGN.