MULTIPHASE OUTFLOWS IN LOCAL TYPE-2 QUASARS

Giovanna Speranza
Supervisors: Cristina Ramos Almeida & José A. Acosta with the QSOFEED team

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MULTIPHASE OUTFLOWS
IN LOCAL TYPE-2 QUASARS

quasar feedback project

QSOFEED

THE QSOFEED TEAM (IAC)

High-luminosity AGN (L_{bol}~$10^{45.5}$ erg/s) → to increase the probability of powerful outflows;

Nearby (z<0.14) → to resolve outflows;

Type-2 AGN → broad AGN and continuum naturally obscured by dust;

Diverse radio & optical morphologies → impact on outflows?

48 QSO2s from the SDSS catalogue of Reyes+08

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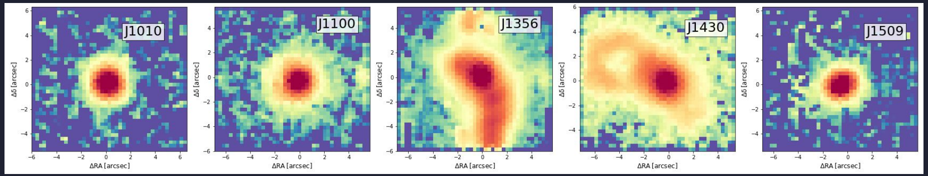
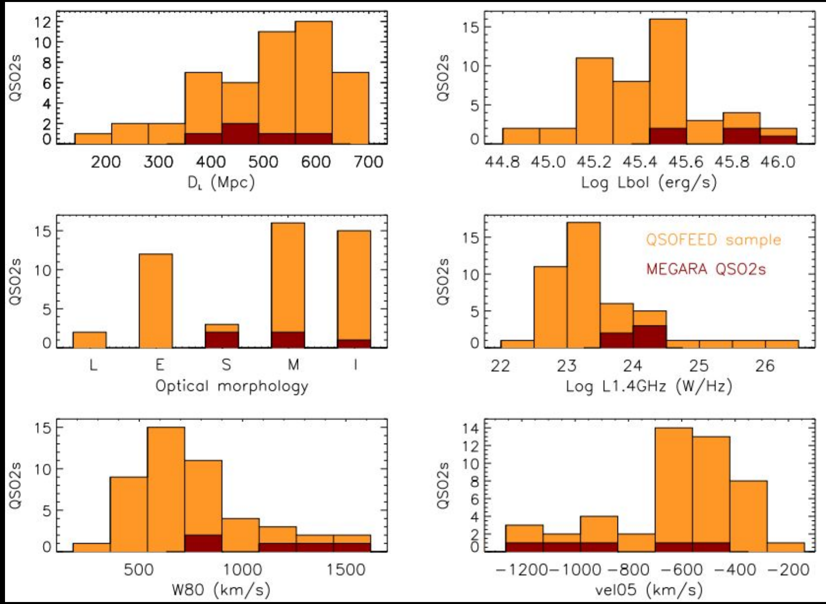
SOURCE CHARACTERISTICS



- All sources are Type-2 Quasars (QSO2s, $L_{[O\,III]} > 10^{8.5}\,L_{\odot}$ **Zakamska+03, Reyes+08**) located in the local Universe (0.08 < z < 0.12);
- They are radio-quiet according to their $L_{1.4GHz}/L_{[O\,III]}$ ratios (**Xu+1999**);
- The SFRs varies from 12 $M_{\odot}\,yr^{-1}$ to 69 $M_{\odot}\,yr^{-1}$ (**Ramos Almeida+22**);
- Their morphologies are diverse: barred spirals and early type mergers/interacting galaxies (**Ramos Almeida+22, Pierse+23**).



Speranza+24

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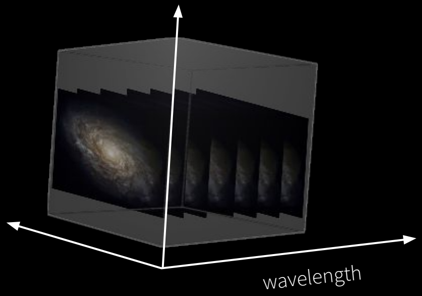
DATA & INSTRUMENTS



MEGARA

multi-espectrógrafo en GTC de Alta
Resolución para Astronomía

Location: **Gran Telescopio de Canarias (La Palma)**
Wavelength range: **5143.74-6168.19 Å (optical)**
Spectral resolution: **5850 (~ 54 km/s)**
Field of view: **12.5” x 11.3”**

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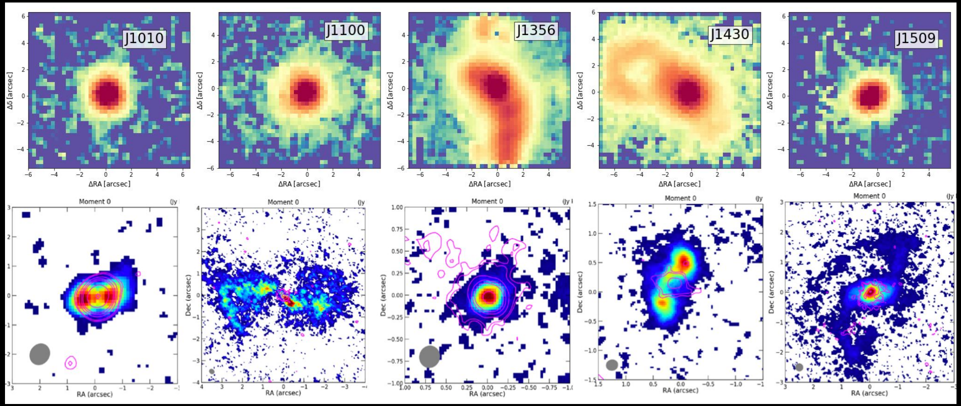
OBSERVATIONS

MEGARA (see **Speranza et al. 2024**)

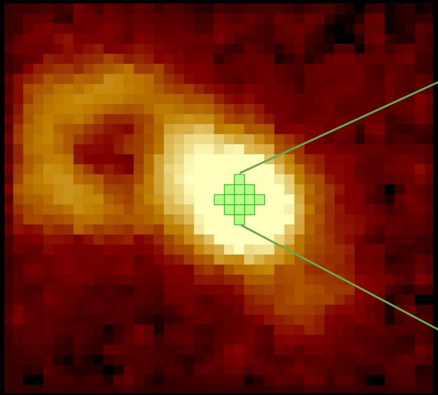


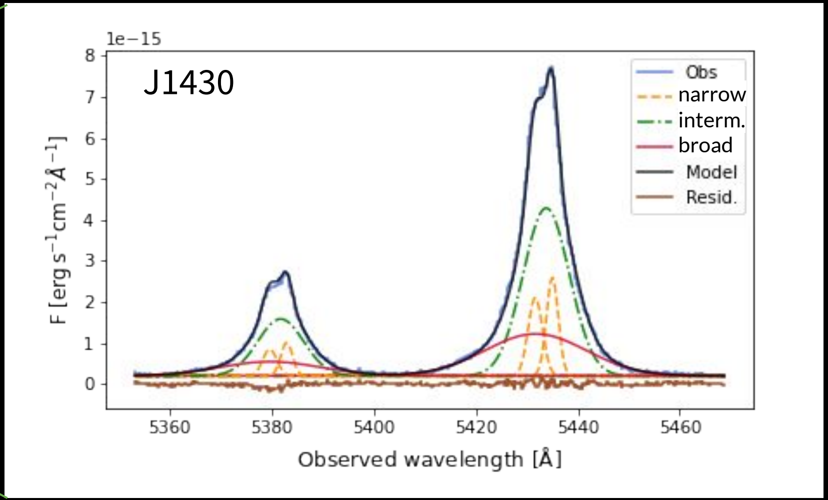
+

ALMA (see **Ramos Almeida et al. 2022**)

AGN OUTFLOWS IN 5 LOCAL TYPE-2 QUASARS:
EXPLORING THE NUCLEAR [O III] EMISSION

Extracted with an aperture of 1.2” (seeing = 1.1”)





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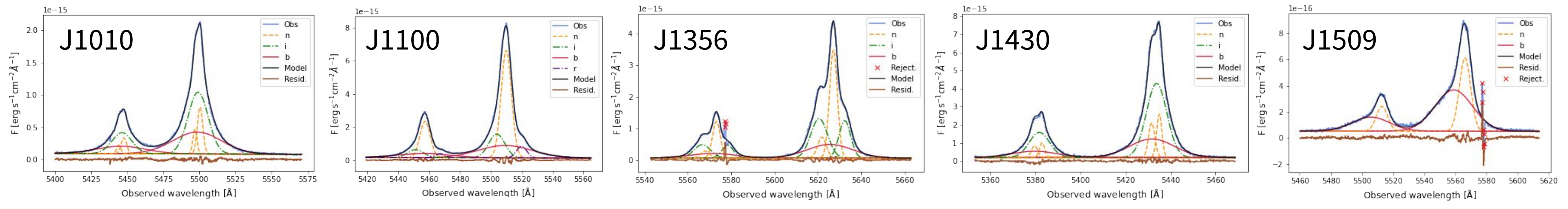

We measure blueshifted velocities up to -430 km s^{-1} and FWHM up to 2240 km s^{-1};

The profiles suggest complex kinematics due to AGN feedback and to galaxy interactions.

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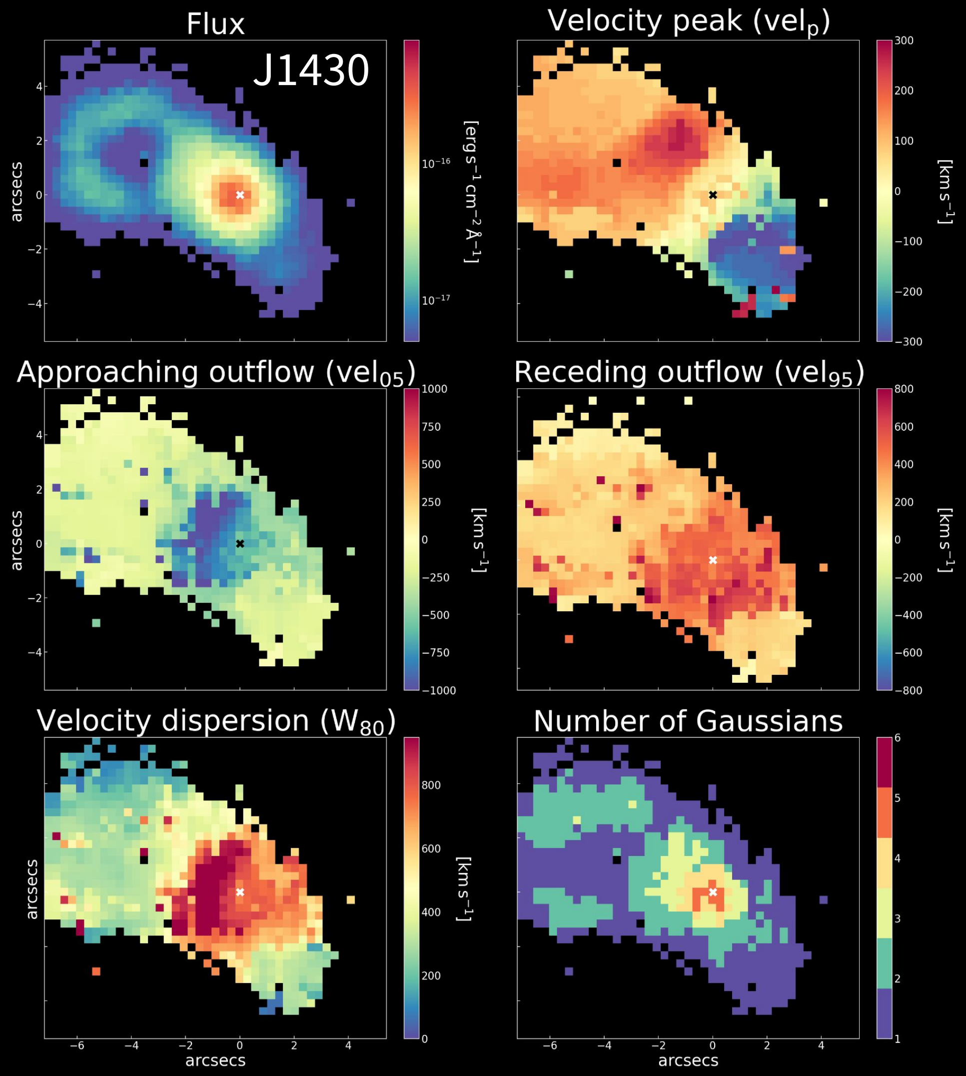
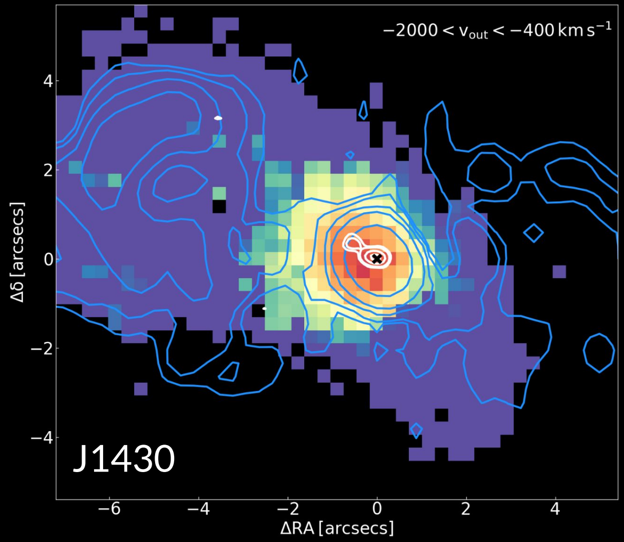
AGN OUTFLOWS IN 5 LOCAL TYPE-2 QUASARS:
THE EXTENDED EMISSION

4 out of the 5 QSO2s have spatially resolved [O III] emission



AGN OUTFLOWS IN 5 LOCAL TYPE-2 QUASARS:
EXTENDED RADIO EMISSION

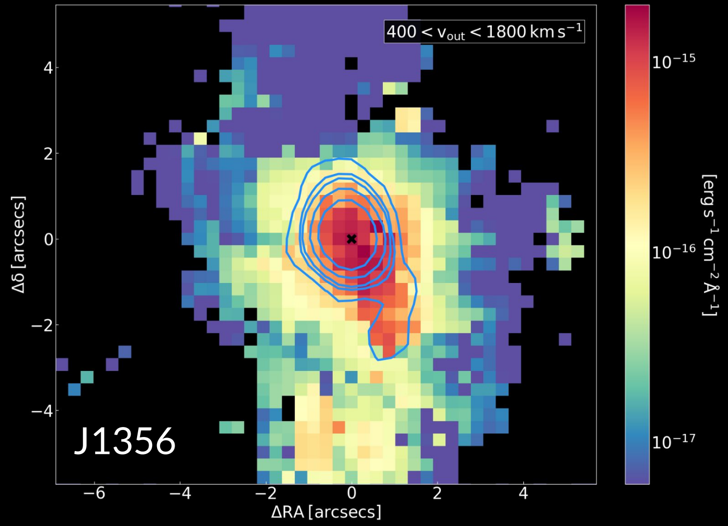


Radio contours from the VLA image at low (~ 1 arcsec beam) and high resolution (~ 0.25 arcsec beam)

Some sources present outflows cospatial with the radio jets.

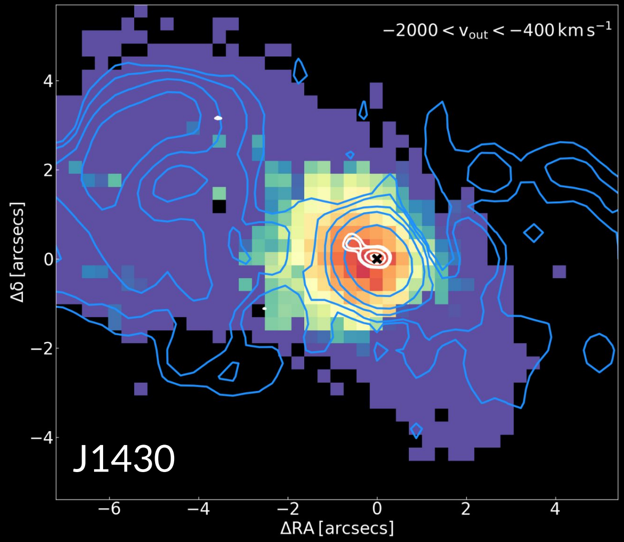
↓

Jets might be driving outflows even in radio-quiet AGNs.

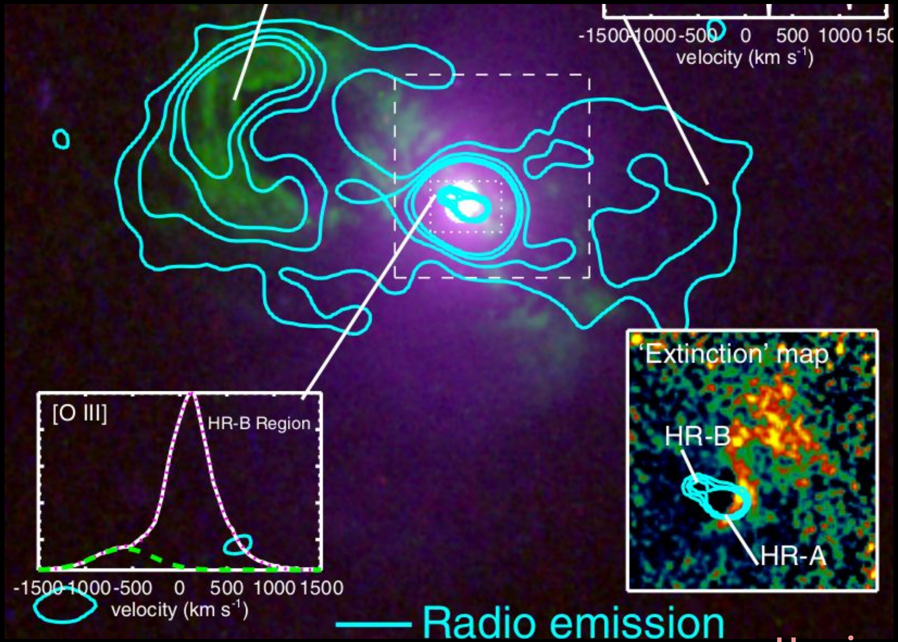


Radio contours from the VLA image at low resolution (~ 1 arcsec beam)

AGN OUTFLOWS IN 5 LOCAL TYPE-2 QUASARS:
EXTENDED RADIO EMISSION

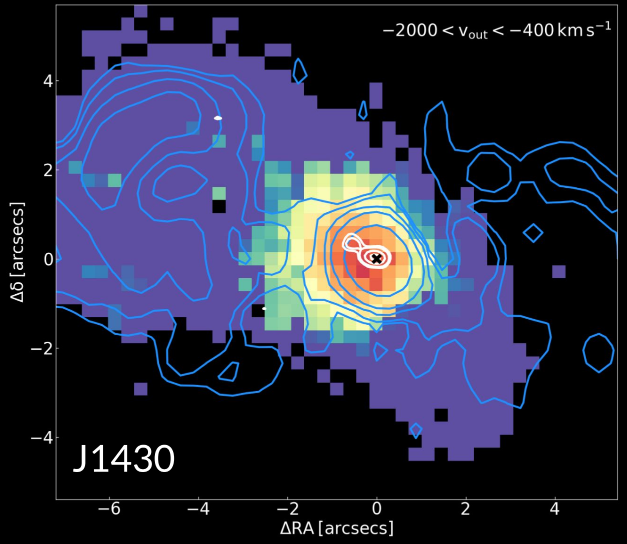


Radio contours from the VLA image at low (~ 1 arcsec beam) and high resolution (~ 0.25 arcsec beam)

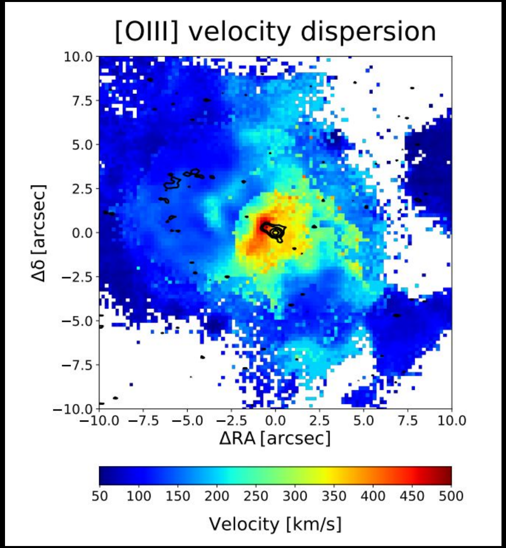


Harrison+15

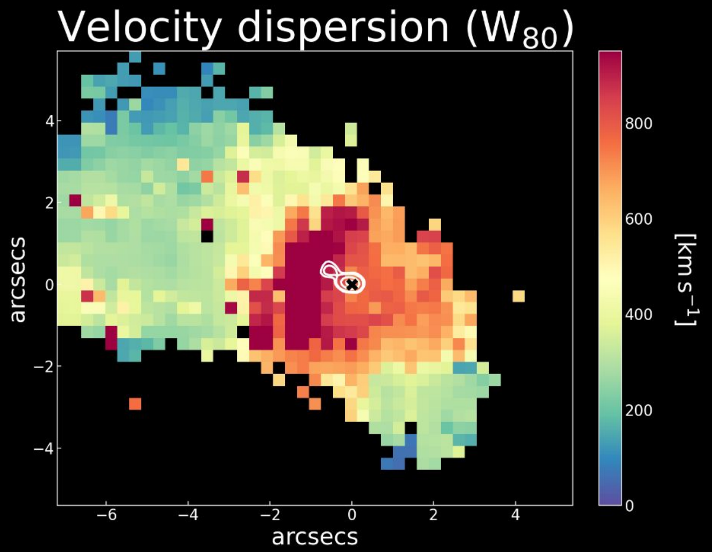
AGN OUTFLOWS IN 5 LOCAL TYPE-2 QUASARS:
EXTENDED RADIO EMISSION



Radio contours from the VLA image at low (~ 1 arcsec beam) and high resolution (~ 0.25 arcsec beam)



Venturi+23



Speranza+24

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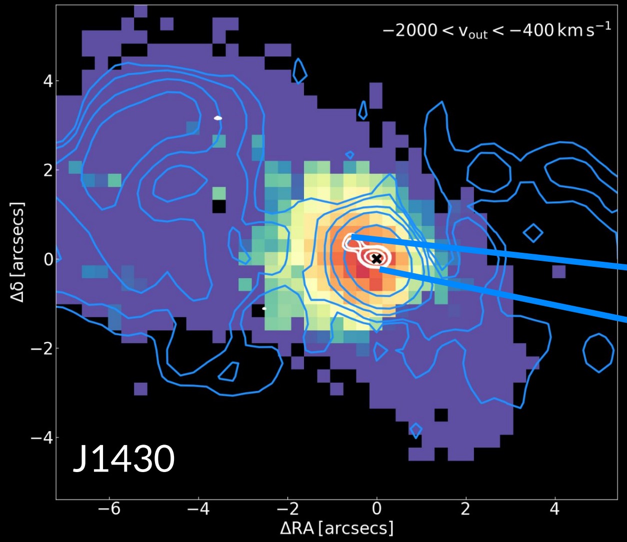
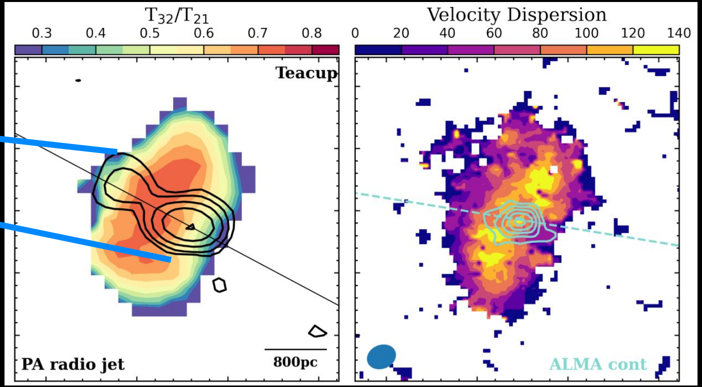
AGN OUTFLOWS IN 5 LOCAL TYPE-2 QUASARS:
EXTENDED RADIO EMISSION



Radio contours from the VLA image at low (~ 1 arcsec beam) and high resolution (~ 0.25 arcsec beam)

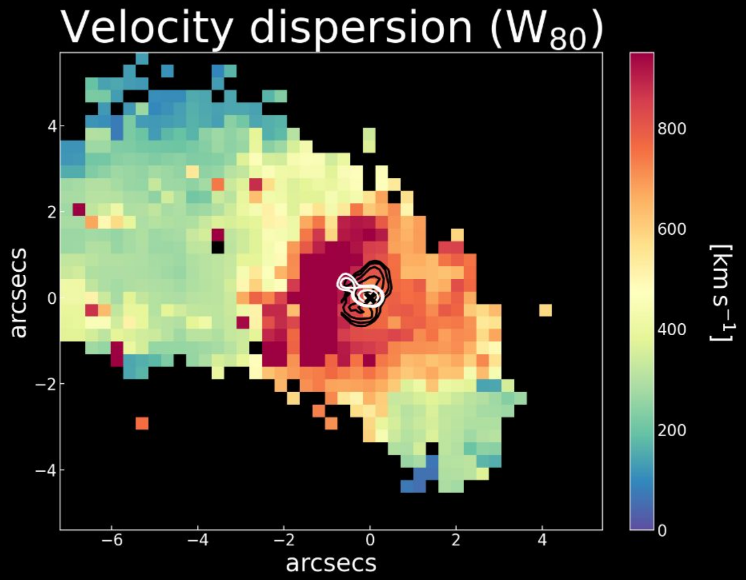
Higher gas excitation and velocity dispersion perpendicular to the jet in the CO(3-2)/CO(2-1) line ratio



Audibert+23

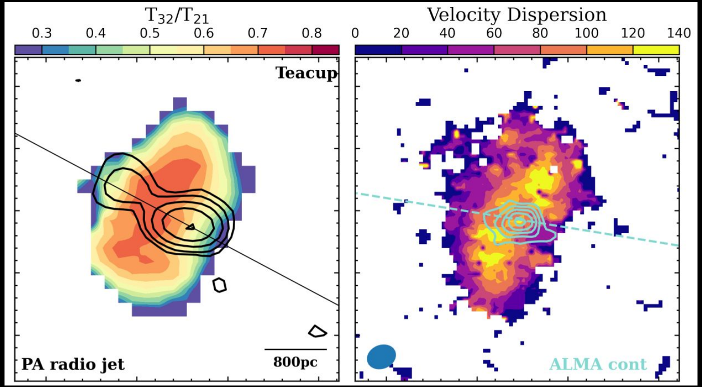
AGN OUTFLOWS IN 5 LOCAL TYPE-2 QUASARS:

EXTENDED RADIO EMISSION



Radio contours from the VLA image at high resolution (~ 0.25 arcsec beam) in white and T_{32} /T_{21} contours in black

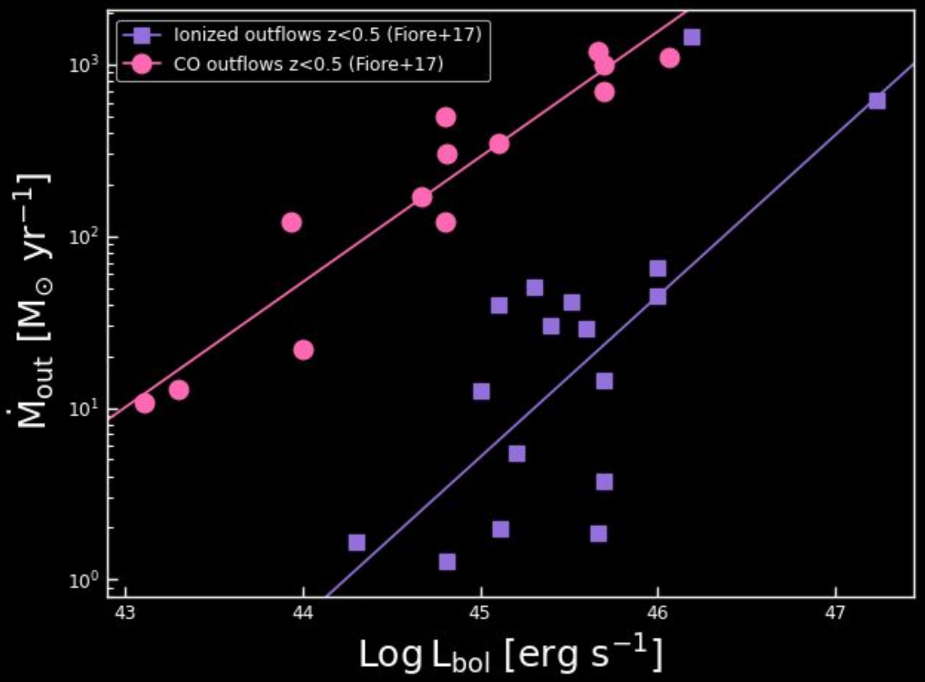
Higher gas excitation and velocity dispersion perpendicular to the jet in the CO(3-2)/CO(2-1) line ratio



Audibert+23

AGN OUTFLOWS IN 5 LOCAL TYPE-2 QUASARS:
A COMPARISON WITH ALMA IN SCALING RELATIONS

$$\dot{M}_{out} \propto \frac{v_{out}}{n_e R_{out}}$$



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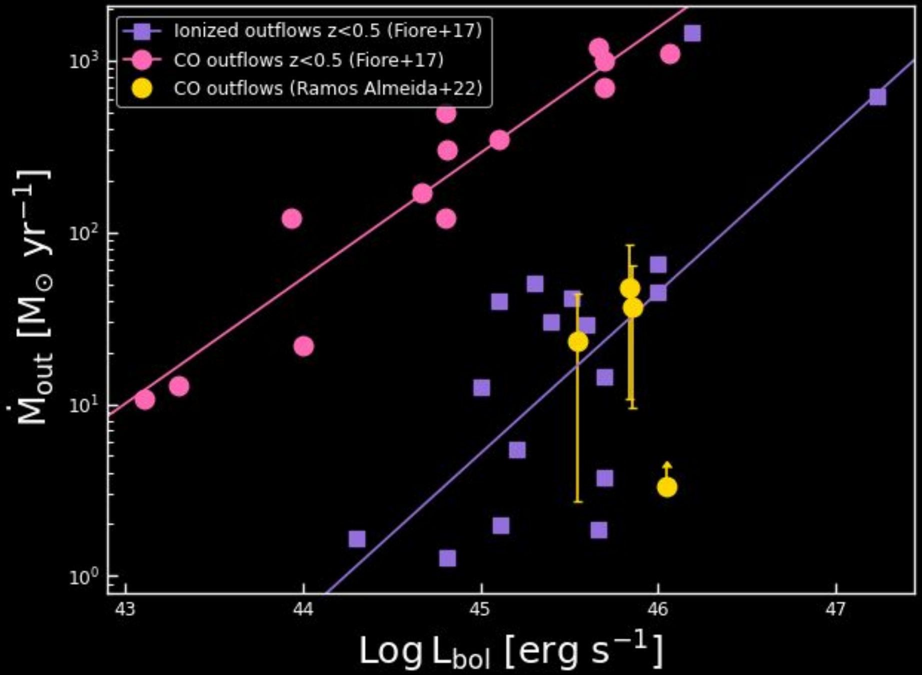

Ramos Almeida et al. 2022

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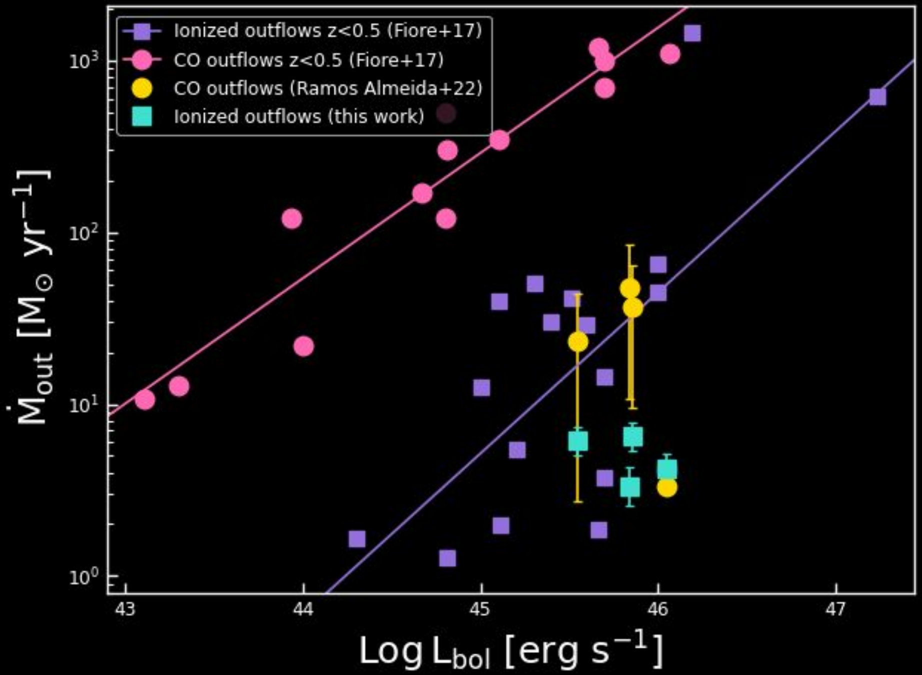

Ramos Almeida et al. 2022
+
Speranza et al. 2024

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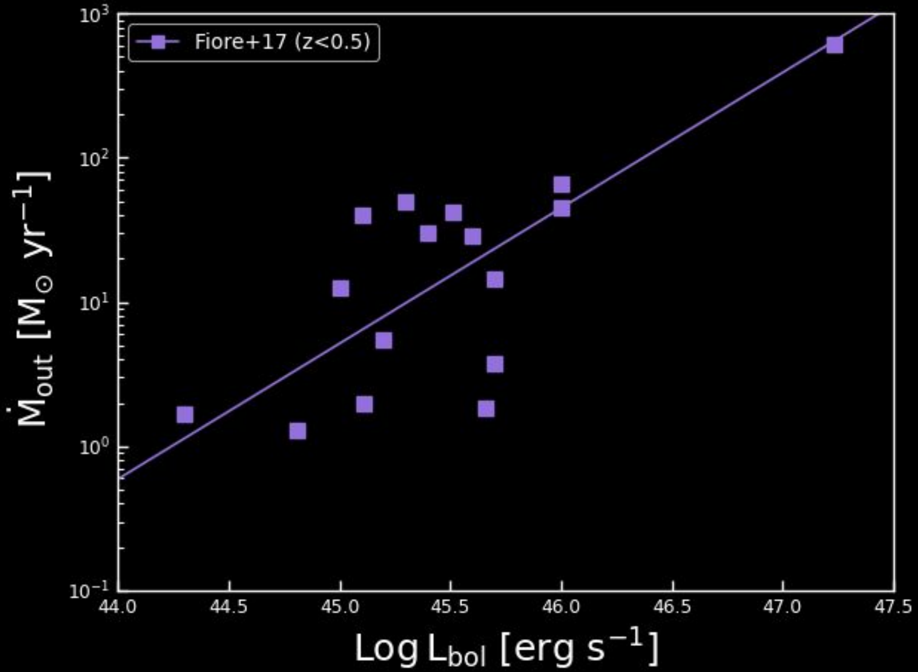
AGN OUTFLOWS IN 5 LOCAL TYPE-2 QUASARS:
IMPORTANCE OF THE ELECTRON DENSITY

$$\dot{M}_{out} \propto \frac{v_{out}}{n_e R_{out}}$$



Speranza et al. 2024

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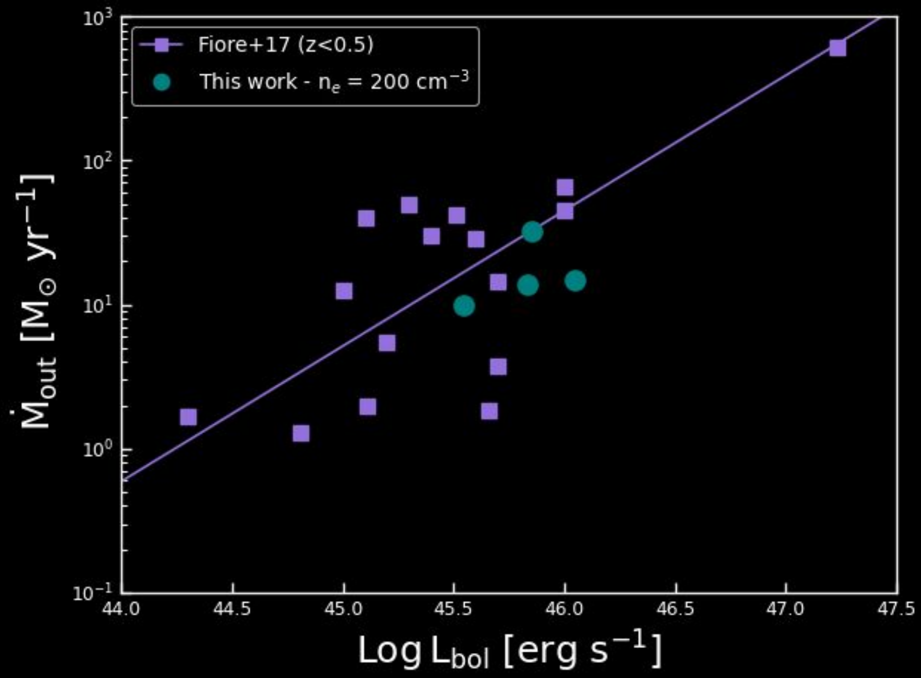

Speranza et al. 2024

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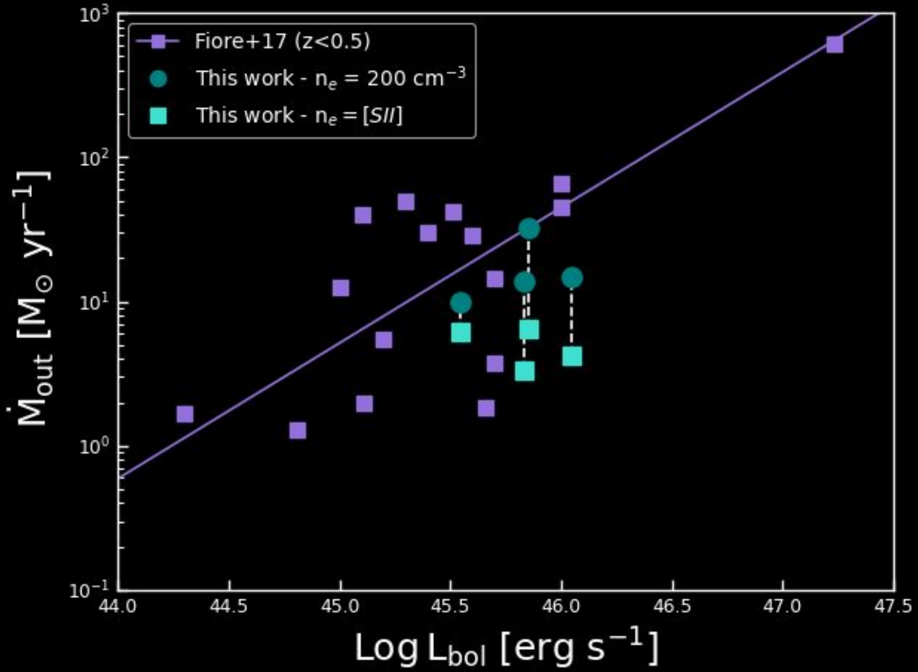

Speranza et al. 2024

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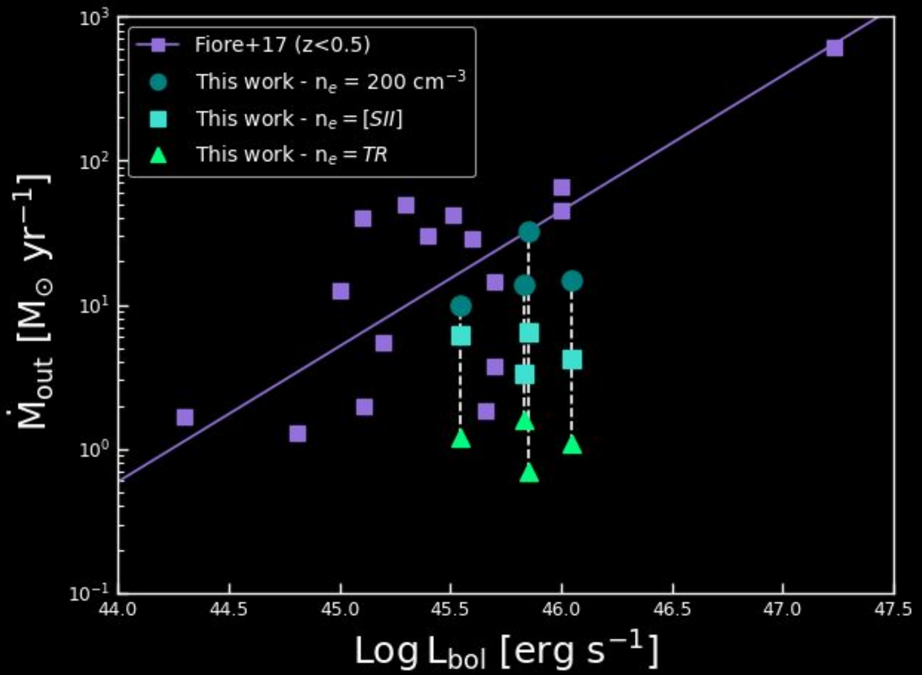

Speranza et al. 2024

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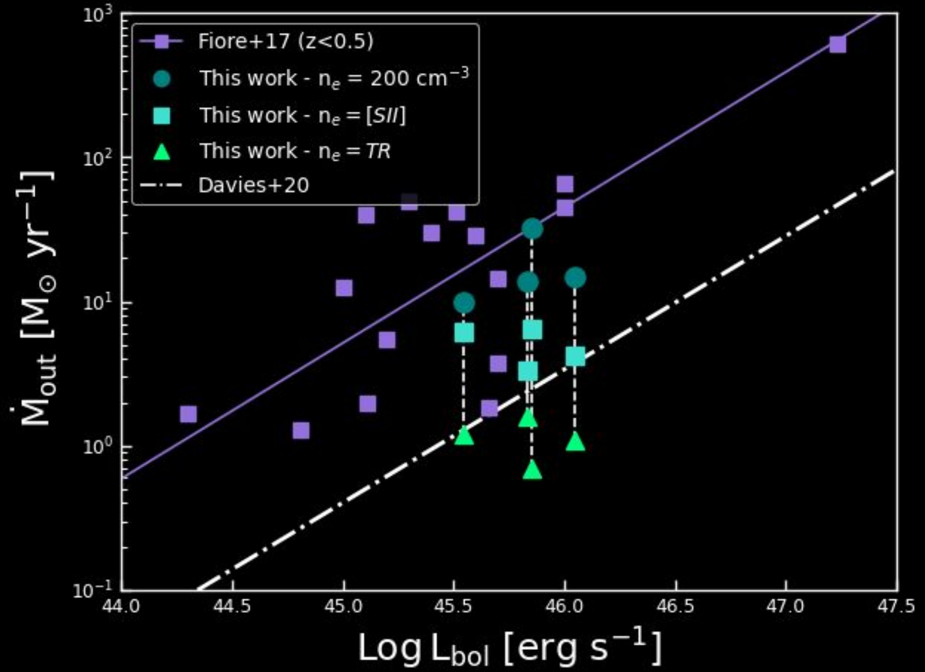
AGN OUTFLOWS IN 5 LOCAL TYPE-2 QUASARS:
IMPORTANCE OF THE ELECTRON DENSITY

$$\dot{M}_{out} \, \alpha \, \frac{v_{out}}{n_e \, R_{out}}$$



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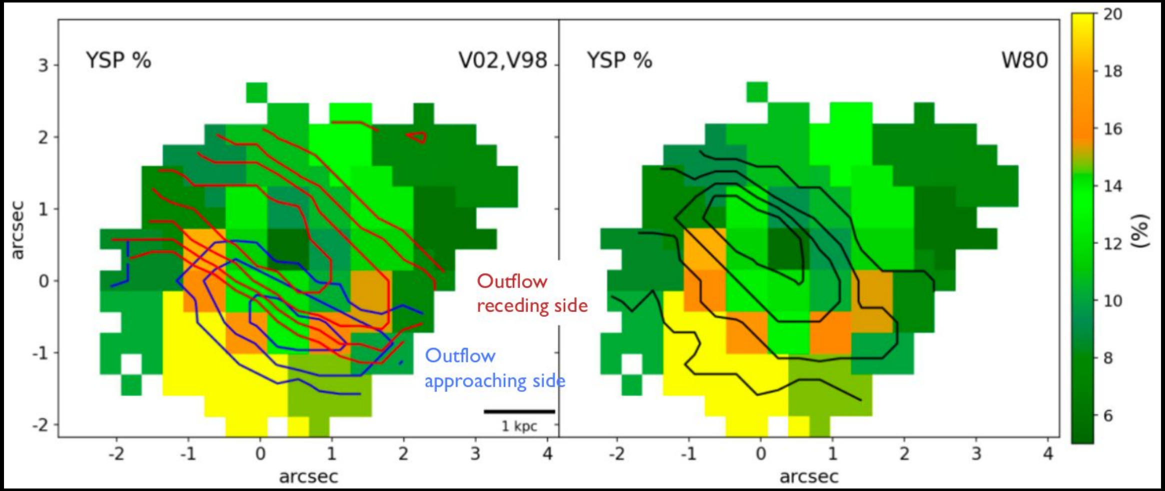
THE AGN FEEDBACK: RECENT RESULTS

Positive and negative feedback observed simultaneously on the young stellar population (YSP)



Bessiere & Ramos Almeida 2022

YSP ages 1 < Myr < 2 found to rise at ~0.9 kpc from the center.

Outflow dynamical timescale: ~1 Myr.

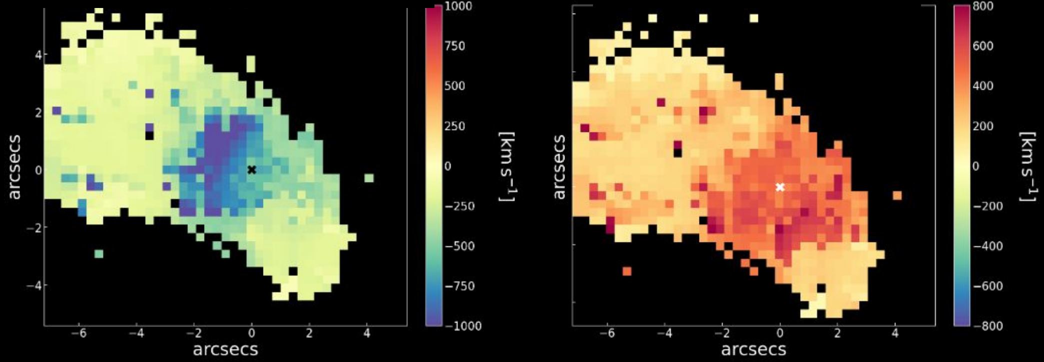
THE AGN FEEDBACK: NEW PERSPECTIVE

JWST proposal accepted (PI: **Ramos Almeida**)
Keck/KCWI proposal accepted (PI: **Canalizo**)

Studying the YSP distribution respect with the outflowing maps

APPROACHING OUTFLOW

RECEDING OUTFLOW



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MAIN CONCLUSIONS

Speranza et al. 2024

We spatially resolve 4 of the 5 outflows detected, measuring radii between 3.1 kpc and 12.6 kpc;

Using the [S II] lines we measure densities between 300 cm^{-3} and 1000 cm^{-3}, and between 1600 cm^{-3} and 9800 cm^{-3} using the trans-auroral lines;

In the QSO2 with extended radio emission detected in VLA data, this emission is aligned with the ionized outflows.

Combining ALMA (Ramos Almeida+22) and MEGARA observations we find lower outflow mass rates for the ionized and cold molecular outflows than those predicted from observational scaling relations (e.g. Fiore+17).

Scenario 1 → Mass outflow rate does not depend only on the Bolometric luminosity (coupling with the jets and outflow orientation may be considered).
Scenario 2 → The scaling relation is real but should be re-scaled.
Scenario 3 → Scenario 1 + Scenario 2.

TIMELINE

1st year

- Two observation runs at the Isaac Newton Telescope
- 1st paper published (**Speranza+21**)

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TIMELINE

1st year | 2nd year

- Two observation runs at the Isaac Newton Telescope
- 1st paper published (**Speranza+21**)

- Two months secondment at UNIBO working on Chandra observations
- 2nd paper published (**Speranza+22**)
- Three months of Prewarp secondment with Iván L.

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TIMELINE

1st year	2nd year	3rd year

1st year

- Two observation runs at the Isaac Newton Telescope
- 1st paper published (**Speranza+21**)

2nd year

- Two months secondment at UNIBO working on Chandra observations
- 2nd paper published (**Speranza+22**)
- Three months of Prewarp secondment with Iván L.

3rd year

- Accepted NIFS/Gemini proposal
- One month Nature astronomy secondment with Luca
- One month ULEI + one month UNIBO secondments working with Blessing & Evgenii
- 3rd paper published (**Speranza+24**)

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TIMELINE

1st year	2nd year	3rd year
• Two observation runs at the Isaac Newton Telescope • 1st paper published (Speranza+21)	• Two months secondment at UNIBO working on Chandra observations • 2nd paper published (Speranza+22) • Three months of Prewarp secondment with Iván L.	• Accepted NIFS/Gemini proposal • One month Nature astronomy secondment with Luca • One month Leiden + one month Bologna secondments working with Blessing & Evgenii • 3rd paper published (Speranza+24)

-17 DAYS TO THE THESIS DEFENSE

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BACKUP SLIDES

Image generated using VQGAN

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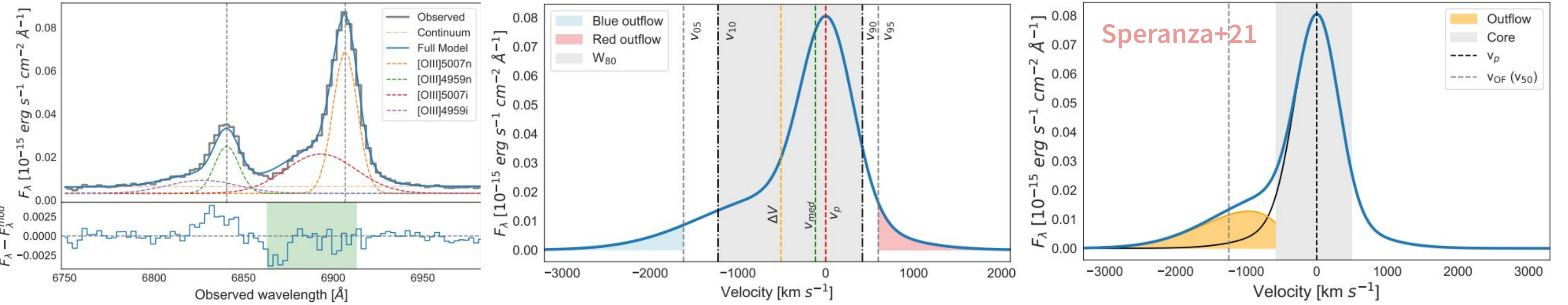
EMISSION LINE ANALYSIS

Parametric analysis

Non-parametric analysis



Hervella Seoane+23

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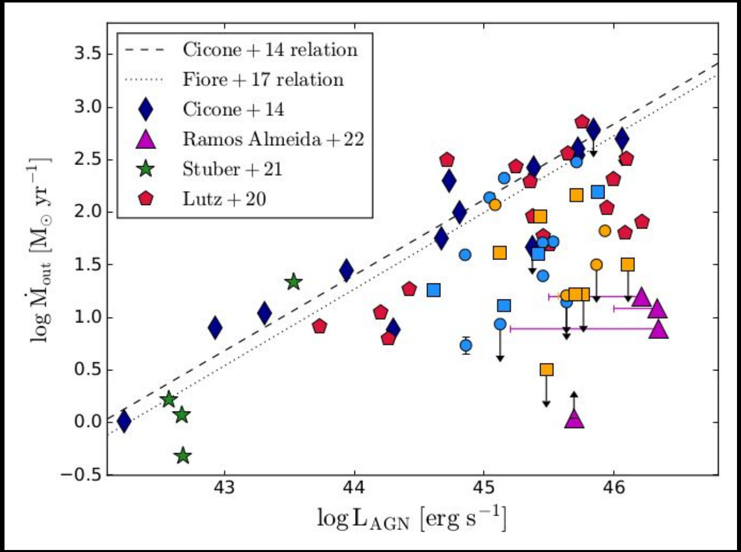
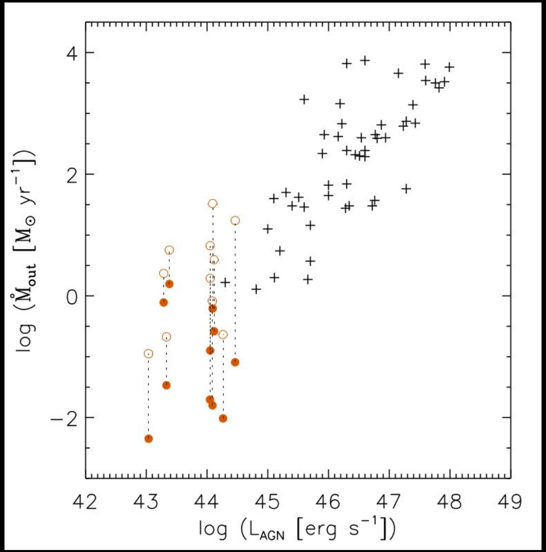
RECENT WORKS

Local ultraluminous infrared galaxies (ULIRGs)



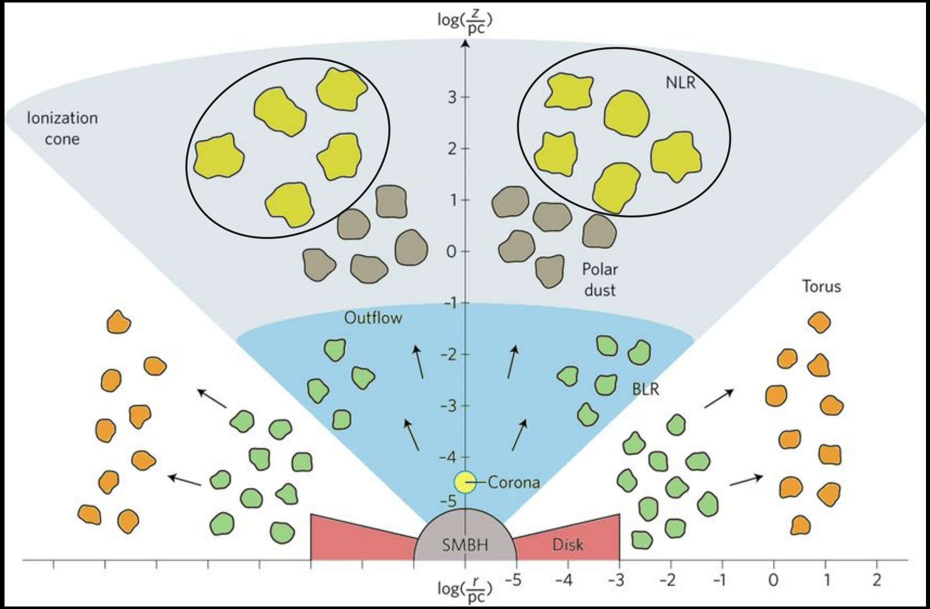
Lamperti+22

Local type 2 Seyferts



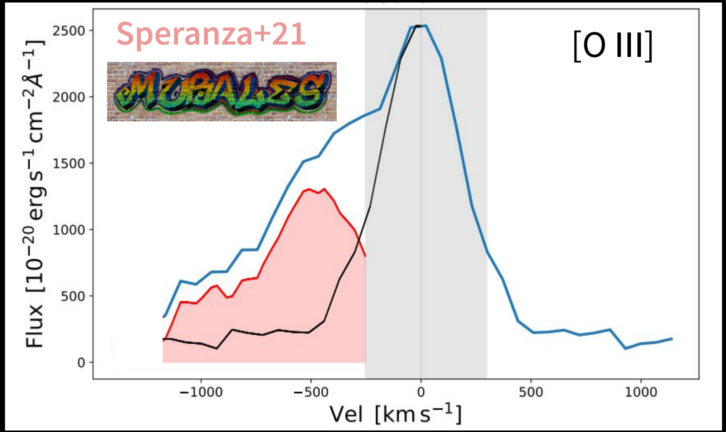
Davies+20

THE AGN FEEDBACK: OBSERVATIONAL EVIDENCES



Ramos Almeida & Ricci 2017

Detect outflowing gas to study the feedback



- In the optical band (ionized emission);
- In the near infrared band (ionized and warm molecular emission).

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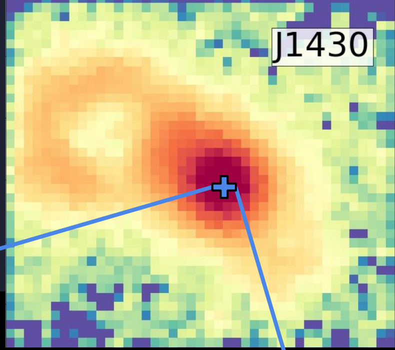
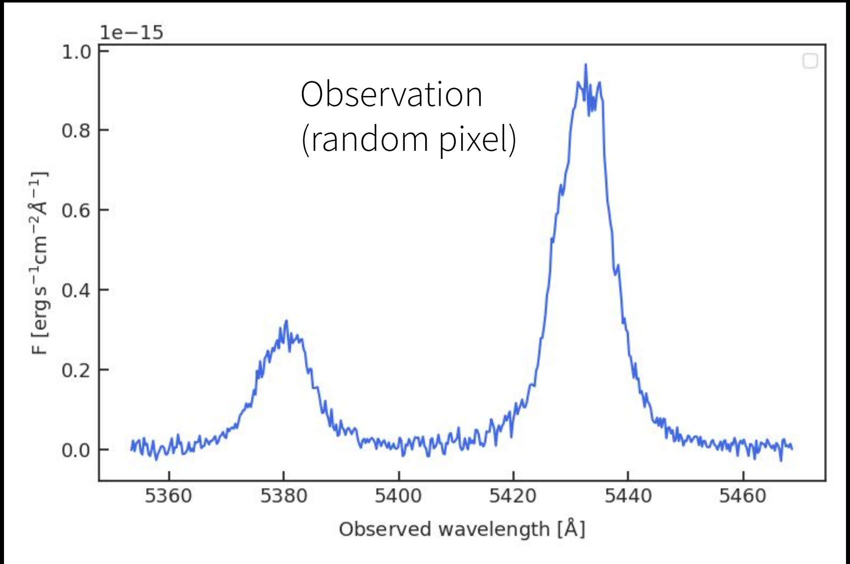
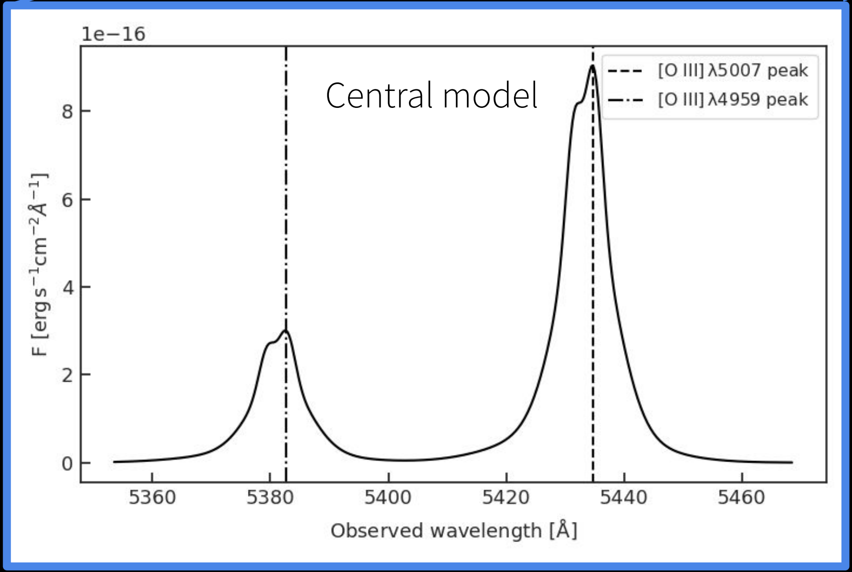
AGN WINDS IN 5 LOCAL TYPE-2 QUASARS:
RESIDUAL INSPECTION



We tested whether the ionized outflows are spatially resolved





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RESIDUAL INSPECTION

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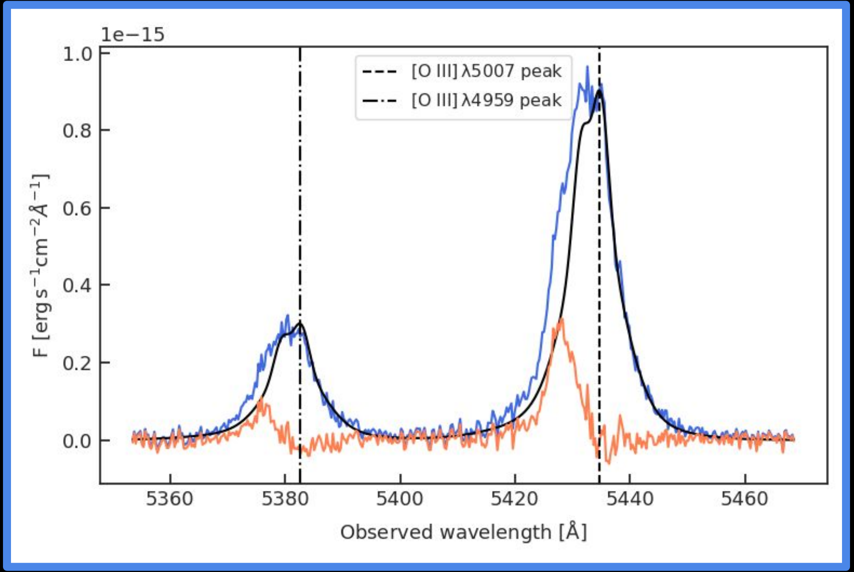

Residual excess = RESOLVED [O III] emission

Same method as Carniani et al. 2013

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AGN WINDS IN 5 LOCAL TYPE-2 QUASARS:
RESIDUAL INSPECTION

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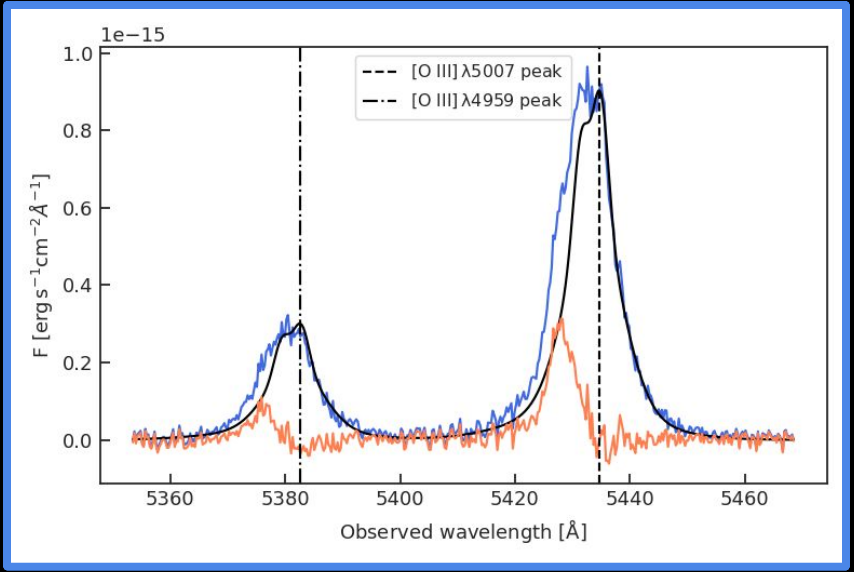

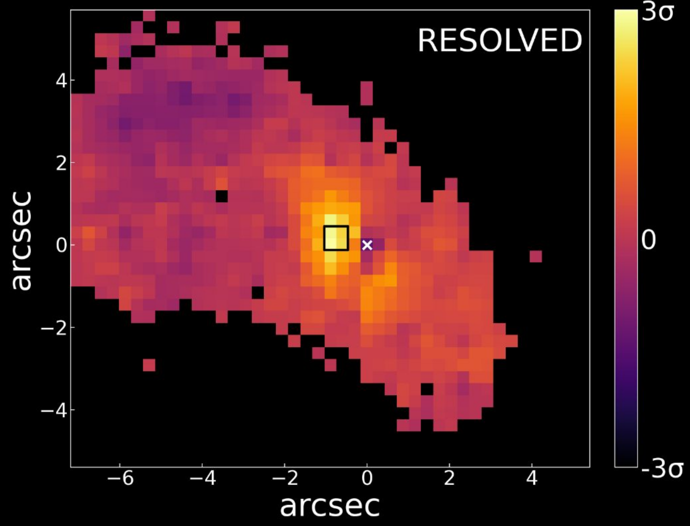

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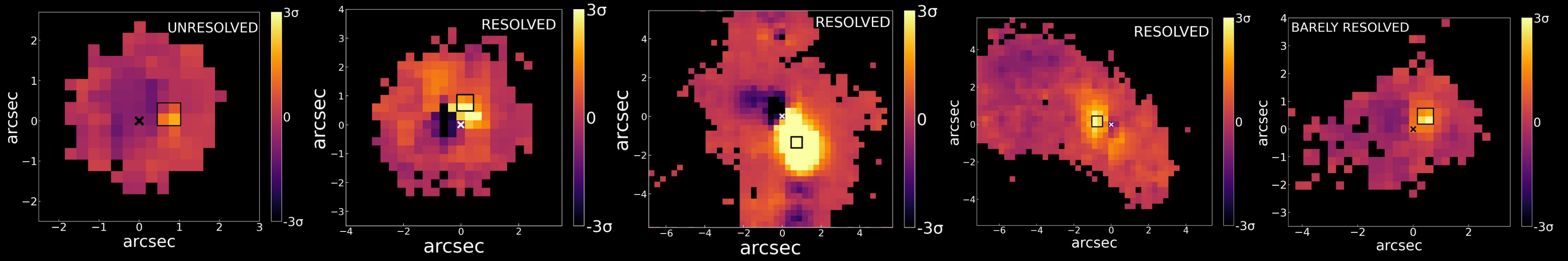
AGN WINDS IN 5 LOCAL TYPE-2 QUASARS:
RESIDUAL INSPECTION

Same method as **Carniani+13**



J1010

J1100

J1356

J1430

J1509

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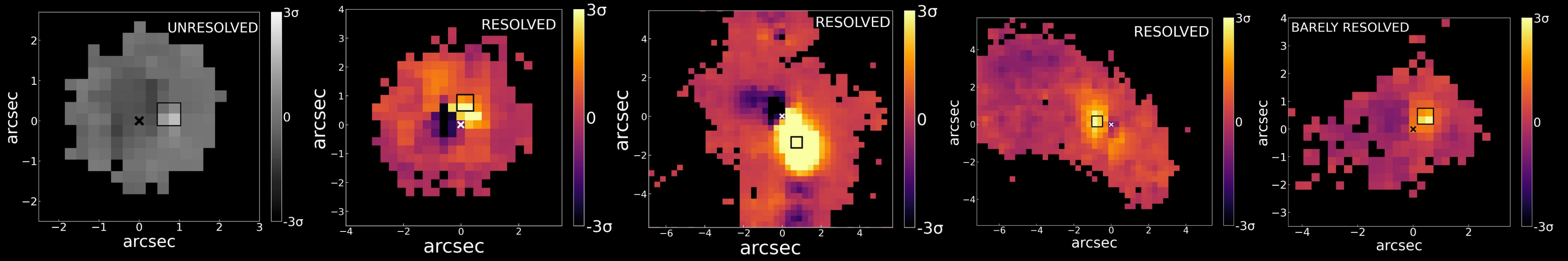
AGN WINDS IN 5 LOCAL TYPE-2 QUASARS:
RESIDUAL INSPECTION

Same method as **Carniani+13**

Same 4 QSO2s for which **Ramos Almeida+22** characterized cold molecular outflows from CO(2-1) measurements



J1010 | J1100 | J1356 | J1430 | J1509

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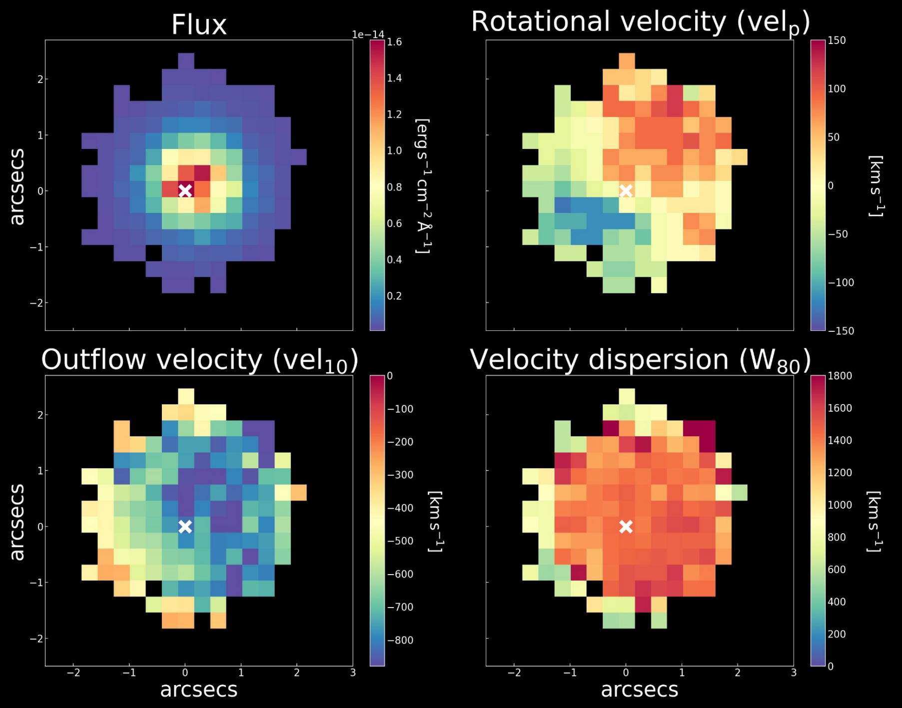
AGN WINDS IN 5 LOCAL TYPE-2 QUASARS:
THE EXTENDED EMISSION



J1010: spatially unresolved

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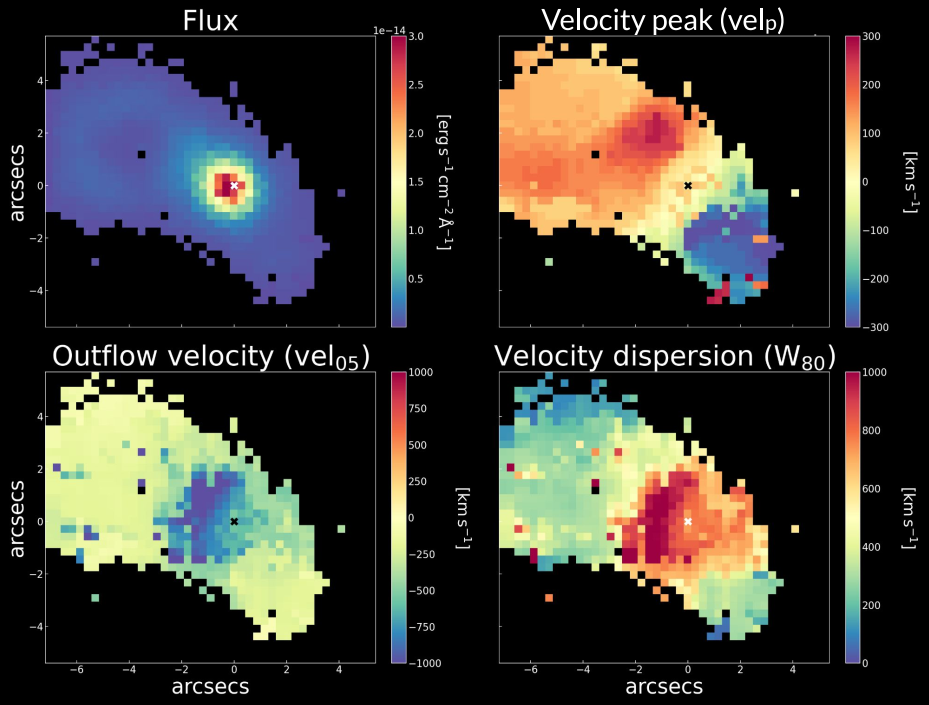
AGN WINDS IN 5 LOCAL TYPE-2 QUASARS:
THE EXTENDED EMISSION



J1430: spatially resolved

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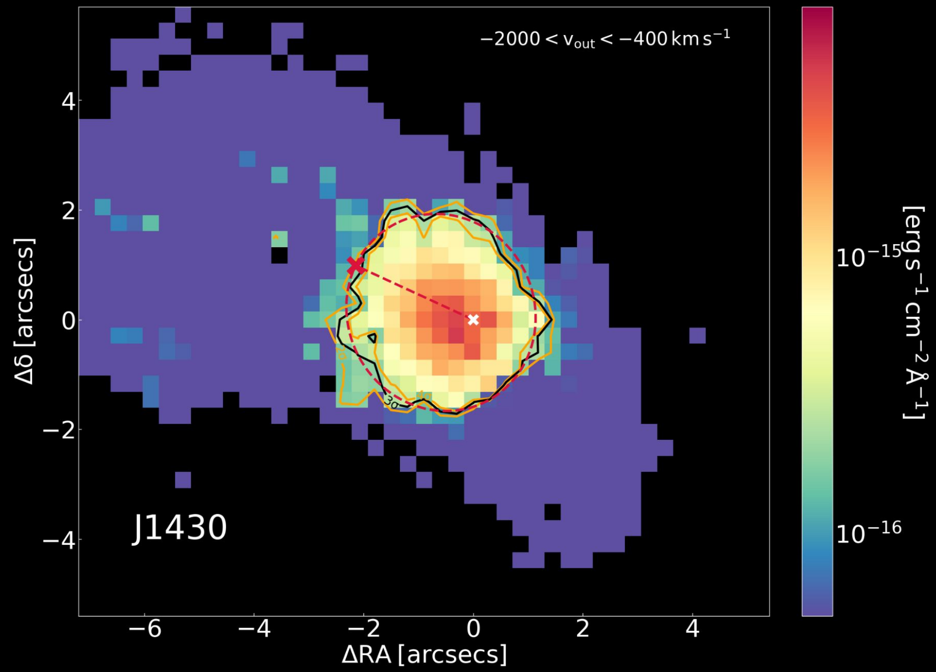
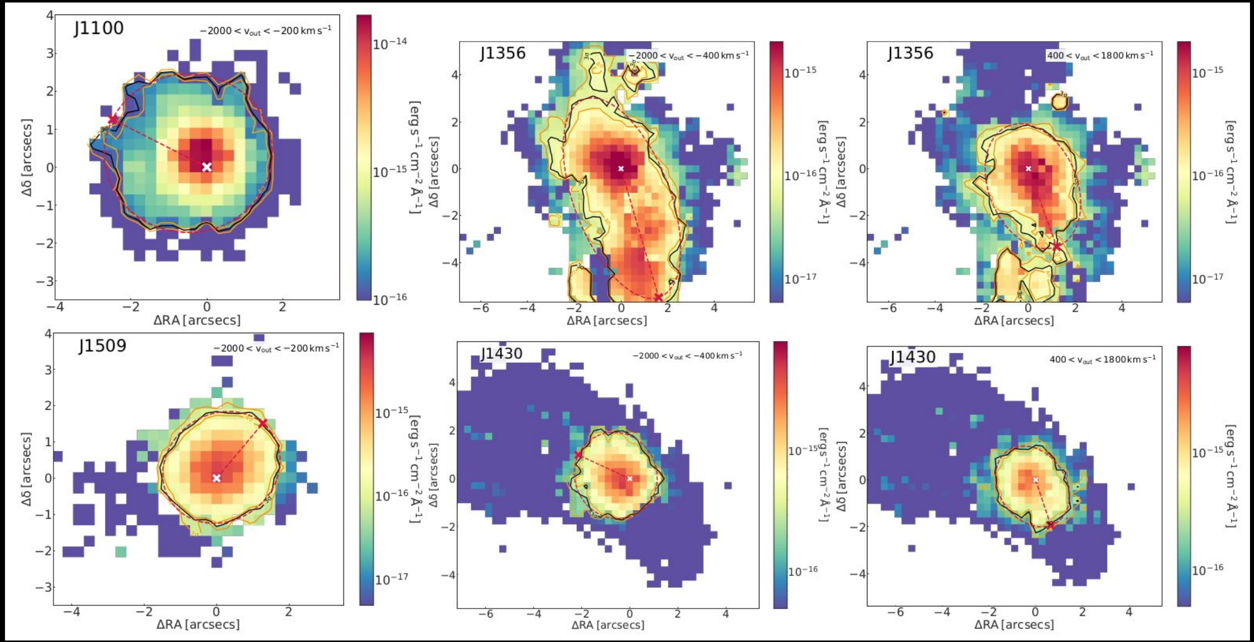
OUTFLOW EXTENSION



SDSS ID	z SDSS	Scale [kpc arcsec^{-1}]	R_{out} [kpc]
J101043.36+061201.4	0.0977	1.807	$5.1^{+0.2}_{-0.3}$
J110012.39+084616.3	0.1004	1.851	$12.6^{+0.1}_{-0.5} \mid 6.8^{+3.7}_{-1.8}$
J135646.10+102609.0	0.1232	2.213	$3.7^{+0.4}_{-0.2} \mid 3.1^{+0.3}_{-0.3}$
J143029.88+133912.0	0.0851	1.597	
J150904.22+043441.8	0.1115	2.028	$3.8^{+0.3}_{-0.2}$

OUTFLOW EXTENSION



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OUTFLOW PROPERTIES

ID	log n_e*	$M_{out} \times 10^6$	R_{out}	PA	v_{out}	$\dot{M}_{out}$
	[cm^{-3}]	[$M_\odot$]	[kpc]	[°]	[$km\ s^{-1}$]	[$M_\odot\ yr^{-1}$]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
J1100	$(3.0^{+0.09}_{-0.09})_{[S\ II]}$	$8.72^{+2.00}_{-1.63}$	$5.1^{+0.2}_{-0.3}$	63	-1236^{+358}_{-441}	$6.5^{+1.5}_{-1.2}$
J1356	$(2.51^{+0.1}_{-0.1})_{[S\ II]}$	$35.01^{+6.82}_{-5.40}$	$12.6^{+0.1}_{-0.5}\,\vert\,6.8^{+3.7}_{-1.8}$	197 | 200	$-631^{+145}_{-190}\,\vert\,483^{+178}_{-135}$	$6.1^{+1.1}_{-0.9}$
J1430	$(3.01^{+0.18}_{-0.18})_{[S\ II]}$	$4.64^{+1.73}_{-1.14}$	$3.7^{+0.4}_{-0.2}\,\vert\,3.1^{+0.3}_{-0.3}$	65 | 198	$-760^{+226}_{-254}\,\vert\,529^{+217}_{-159}$	$3.3^{+1.0}_{-0.7}$
J1509	$(2.85^{+0.1}_{-0.1})_{[S\ II]}$	$4.00^{+1.04}_{-0.83}$	$3.8^{+0.3}_{-0.2}$	320	-1289^{+274}_{-317}	$4.2^{+1.0}_{-0.8}$
ID	log n_e**	$M_{out} \times 10^6$	R_{out}	PA	v_{out}	$\dot{M}_{out}$
	[cm^{-3}]	[$M_\odot$]	[kpc]	[°]	[$km\ s^{-1}$]	[$M_\odot\ yr^{-1}$]
J1100	$(3.99^{+0.07}_{-0.08})_{TA}$	$0.89^{+0.16}_{-0.15}$	$5.1^{+0.2}_{-0.3}$	63	-1236^{+358}_{-441}	$0.7^{+0.1}_{-0.1}$
J1356	$(3.21^{+0.00}_{-0.15})_{TA}$	$6.99^{+0.23}_{-1.52}$	$12.6^{+0.1}_{-0.5}\,\vert\,6.8^{+3.7}_{-1.8}$	197 | 200	$-631^{+145}_{-190}\,\vert\,483^{+178}_{-135}$	$1.2^{+0.1}_{-0.2}$
J1430	$(3.24^{+0.05}_{-0.3})_{TA}$	$2.73^{+0.25}_{-0.99}$	$3.7^{+0.4}_{-0.2}\,\vert\,3.1^{+0.3}_{-0.3}$	65 | 198	$-760^{+226}_{-254}\,\vert\,529^{+217}_{-159}$	$1.6^{+0.1}_{-0.6}$
J1509	$(3.41^{+0.11}_{-0.21})_{TA}$	$1.10^{+0.32}_{-0.42}$	$3.8^{+0.3}_{-0.2}$	320	-1289^{+274}_{-317}	$1.1^{+0.3}_{-0.4}$

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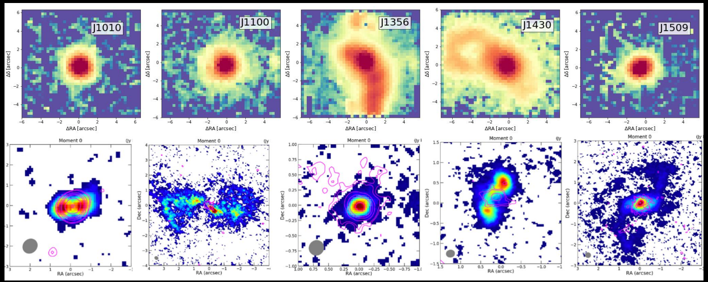
Giovanna Speranza[1,2], Cristina Ramos Almeida[1,2], Jose A. Acosta[1,2] & Bid4BEST team

[1] Instituto de Astrofísica de Canarias [2] Departamento de Astrofísica Universidad de La Laguna

THE ROLE OF AGN FEEDBACK IN SIX LOCALS TYPE-2 QUASARS

5 Quasars observed with:

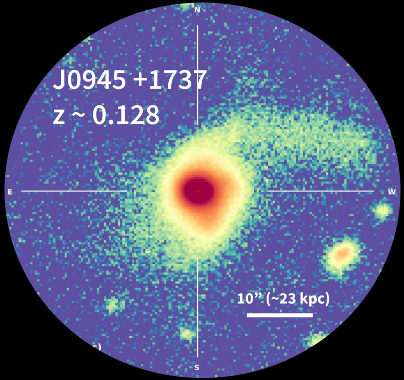
GTC/MEGARA



+

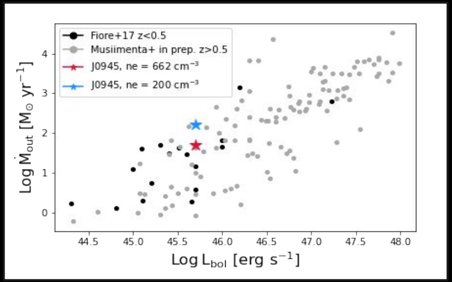
ALMA (see **Ramos Almeida et al. 2022**)

1 Quasar observed with: **Gemini/NIFS**



Isaac Newton Telescope image

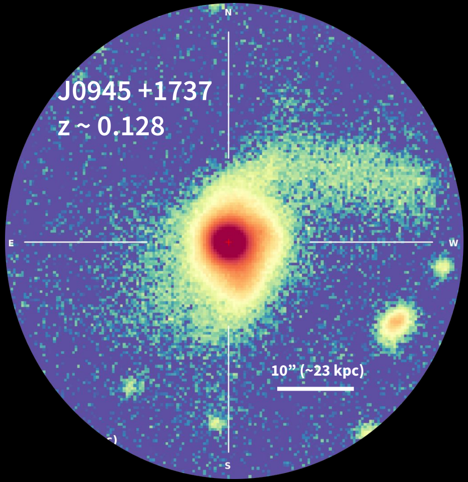
A powerful ionized outflow of **51 $M_{\odot}$ yr^{-1}**



Outflow properties? Ongoing interactions? Connection with the radio jets? → visit my poster (n. 410)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sktodowska-Curie grant agreement No 860744

A DETAILED STUDY ON J0945:
SOURCE CHARACTERISTICS



Isaac Newton Telescope image

- J0945 is a Type-2 Quasar (QSO2, i.e., L [O III] > $10^{8.5}$ $L_{\odot}$, Reyes+2008) located in the local Universe (z = 0.128);

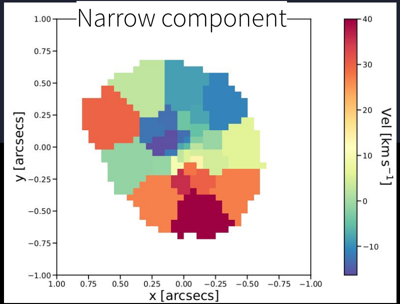
- It is a radio-quiet source according to Lal & Ho 2010;

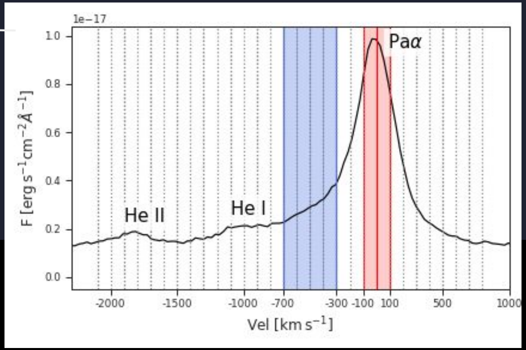
- Its stellar mass is 1.2 x 10^{10} $M_{\odot}$ with a SFR of 73 $M_{\odot}$ yr^{-1} (Jarvis+2020);

- The bolometric luminosity measured by Harrison+2014 is $L_{bol} = 10^{45.5}$ $L_{\odot}$ while Jarvis+2021 measured $L_{1.4GHz} = 10^{24.3}$ W Hz^{-1} ;

- J0945 has an irregular morphology and the observation of a tidal tail is a signature of a galaxy merger/interaction.

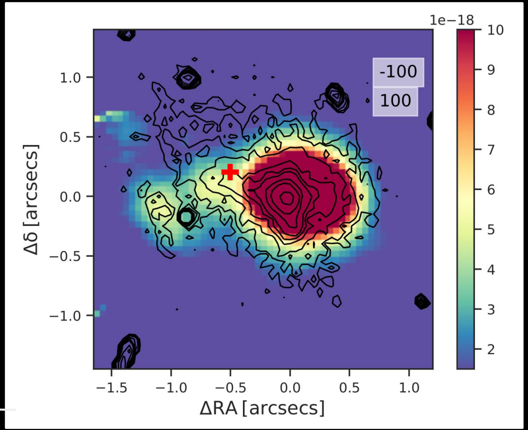
A DETAILED STUDY ON J0945:
WHAT WE FOUND





1. Signature of a recent interaction also confirmed in the recent work by Pierce+2022 (submitted);
2. An outflow extension of R_{out} ~ 3.4 kpc with a mass outflow rate of $\dot{M}_{out}$ = 51 $M_{\odot}\,yr^{-1}$, following the formula proposed in Rose+2018;
3. A radio emission co-spatial to the innermost outflow emission;
4. An agreement with powerful sources collected in Fiore+2017;

All details in Speranza et al. 2022



Paα flux mapemission between the central range of velocity (-100 & +100 km s^{-1}) with the σ contours of the HST image superimposed

THE 5 QSO2 OBSERVED WITH MEGARA:
CONCLUSIONS

To investigate the mechanisms driving the outflows and their impact we have to measure the mass and energy outflow rates ($\dot{M}_{out}$ and $\dot{E}_{kin}$).

Following Rose+2018: $\dot{M}_{out} \propto \frac{V_{out}}{n_e R_{out}}$

Velocity shift measured from the narrow component of the nuclear spectrum. $v_{out, max} = v_{out}$ - FWHM/2 (Fluestch et al., 2019)

According to Harrison+2014 & Ramos Almeida+2019: $\dot{E}_{kin} = ½\, \dot{M}_{out}\, (v^2_{out} + 3\sigma^2)$

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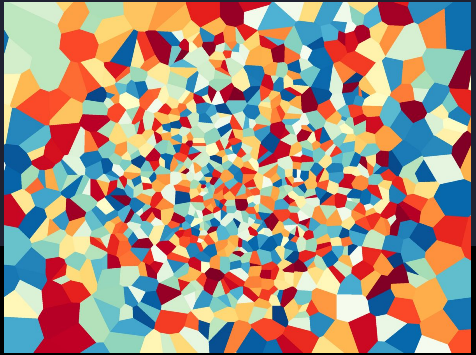
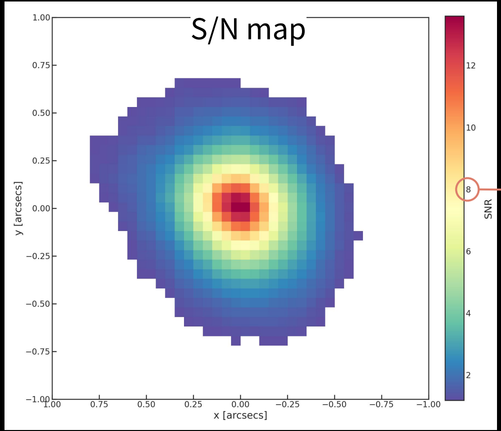
A DETAILED STUDY ON J0945:
THE EXTENDED EMISSION



VORONOI TESSELLATION



Median value S/N = 8

Signal-to-noise higher than the original following the procedure described by Cappellari & Copin (2003).

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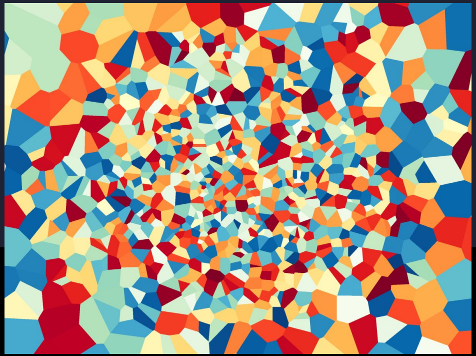
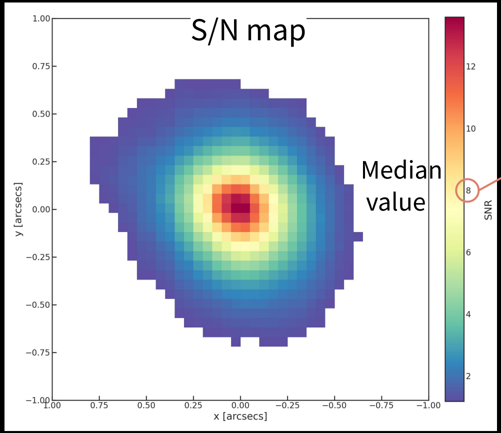
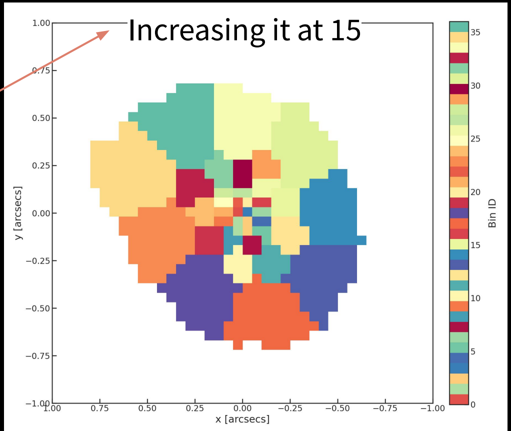
A DETAILED STUDY ON J0945:
THE EXTENDED EMISSION



VORONOI TESSELLATION





Signal-to-noise higher than the original following the procedure described by Cappellari & Copin (2003).

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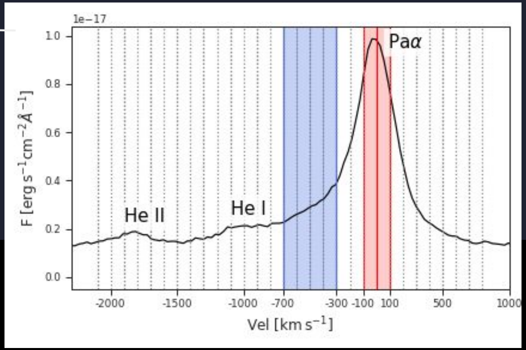
A DETAILED STUDY ON J0945:
WHAT WE FOUND



1. An outflow extension of R_{out} ~ 3.4 kpc with a mass outflow rate of $\dot{M}_{out} = 51\ M_{\odot}\,yr^{-1}$, following the formula proposed in Rose+2018;
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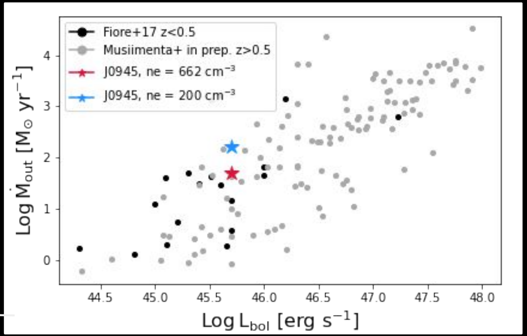

All details in **Speranza et al. 2022**

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A DETAILED STUDY ON J0945:
THE EXTENDED EMISSION

OUTFLOW PROPERTIES

To investigate the mechanisms driving the outflows and their impact we have to measure the mass and energy outflow rates ($\dot{M}_{out}$ and $\dot{E}_{kin}$).

Following Rose+2018: $\dot{M}_{out} \propto \dfrac{v_{out}}{n_e R_{out}}$

According to Harrison+2014 & Ramos Almeida+2019: $\dot{E}_{kin} = \frac{1}{2} \dot{M}_{out} (v^2_{out} + 3\sigma^2)$

THE 5 QSO2 OBSERVED WITH MEGARA: **CONCLUSIONS**

To investigate the mechanisms driving the outflows and their impact we have to measure the mass and energy outflow rates ($\dot{M}_{out}$ and $\dot{E}_{kin}$).

Following Rose+2018: $$\dot{M}_{out} \propto \frac{v_{out}}{n_e R_{out}}$$

Two estimation:

1. classical technique of the density-sensitive optical doublet ratio of [S II] λλ 6716,6731 (Osterbrock & Ferland, 2006);

2. the flux ratios of the trans-auroral lines (Holt et al., 2011).

According to Harrison+2014 & Ramos Almeida+2019: $\dot{E}_{kin} = \frac{1}{2} \dot{M}_{out} (v^2_{out} + 3\sigma^2)$

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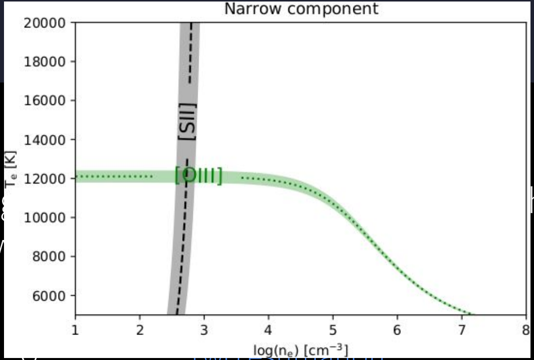
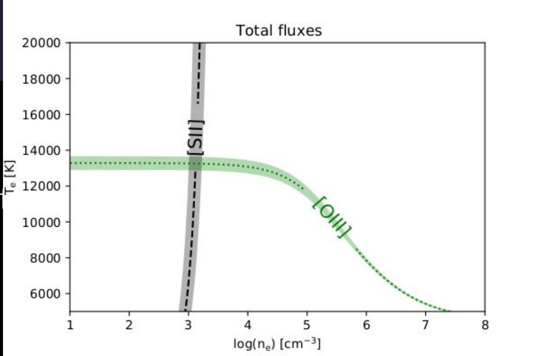
THE 5 QSO2 OBSERVED WITH MEGARA: **CONCLUSIONS**





To investigate the mechanisms drivin… have … measure the mass and energy outflow…

Two estimation:

Following Rose+2018: $\dot{M}_{out} \propto \frac{V_{out}}{n_e R_{out}}$

1. classical technique of the density-sensitive optical doublet ratio of [S II] λλ 6716,6731 (Osterbrock & Ferland, 2006);

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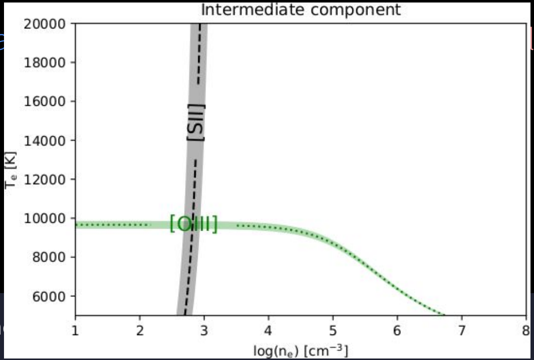
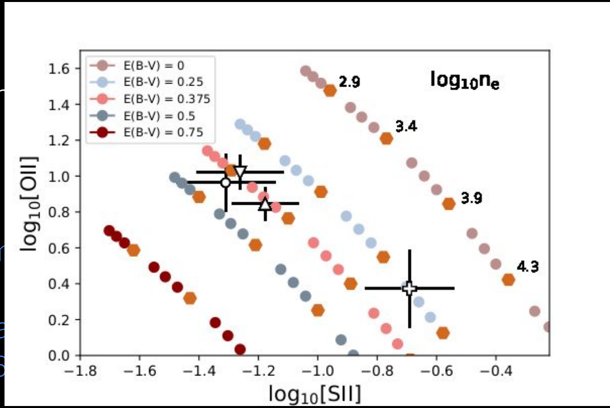


According to Harrison+2014 & Ramos Almeida+2019: $\dot{E}_{kin} =$

THE 5 QSO2 OBSERVED WITH MEGARA:
CONCLUSIONS

To investigate the mechanisms driving the outflows and th
measure the mass and energy outflow rates ($\dot{M}_{out}$ and $\dot{E}_{kin}$)



$\log n_n = 2.9 \pm 0.3$
$\log n_i = 2.9 \pm 0.2$
$\log n_b = 4.1 \pm 0.2$
$\log n_{tot} = 3.2 \pm 0.15$

Following Rose+2018: $\dot{M}_{out} \propto \frac{v_{out}}{n_e R_{out}}$

Two estim

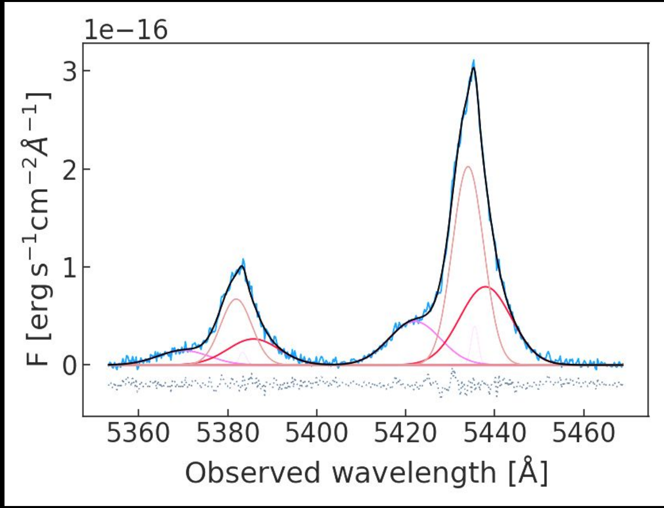
1. classica … blet ratio of [S II] λλ 6716

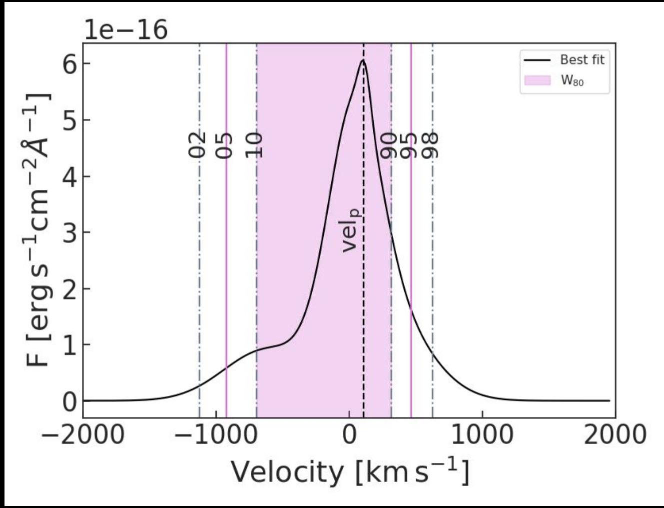
2. the flux ratios of the trans-auroral lines (Holt et al., 2011).

According to Harrison+2014 & Ramos Almeida+2019: $\dot{E}_{kin} = ½ \dot{M}_{out} (v^2_{out} + 3\sigma^2)$

THE AGN FEEDBACK

Parameter definitions for a random pixel of J1430





vel_p = gas rotation

$vel_{05/95}$ = outflow velocity

W_{80} = velocity dispersion

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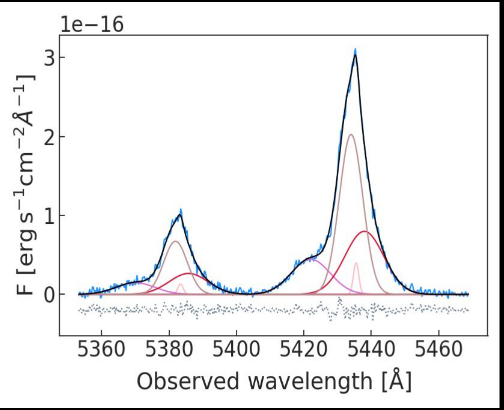
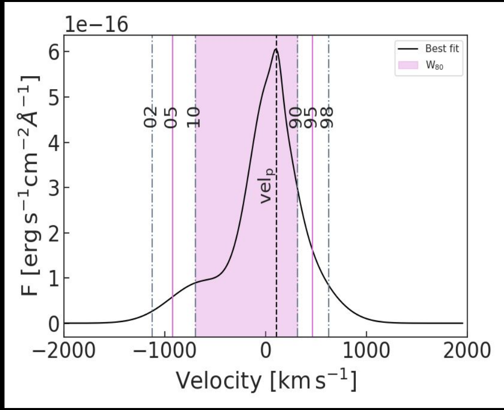
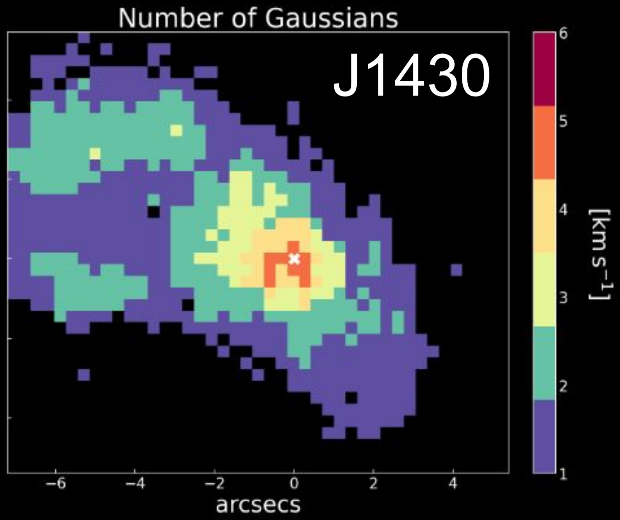
THE ROLE OF AGN FEEDBACK IN 5 LOCAL TYPE-2 QUASARS:
THE EXTENDED EMISSION

A NON-PARAMETRIC ANALYSIS







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