Universidade Federal de Santa Maria
Grupo de Astrofísica

The emission structure and kinematics of the molecular and ionized gas in the inner kiloparsec of nearby active galaxies

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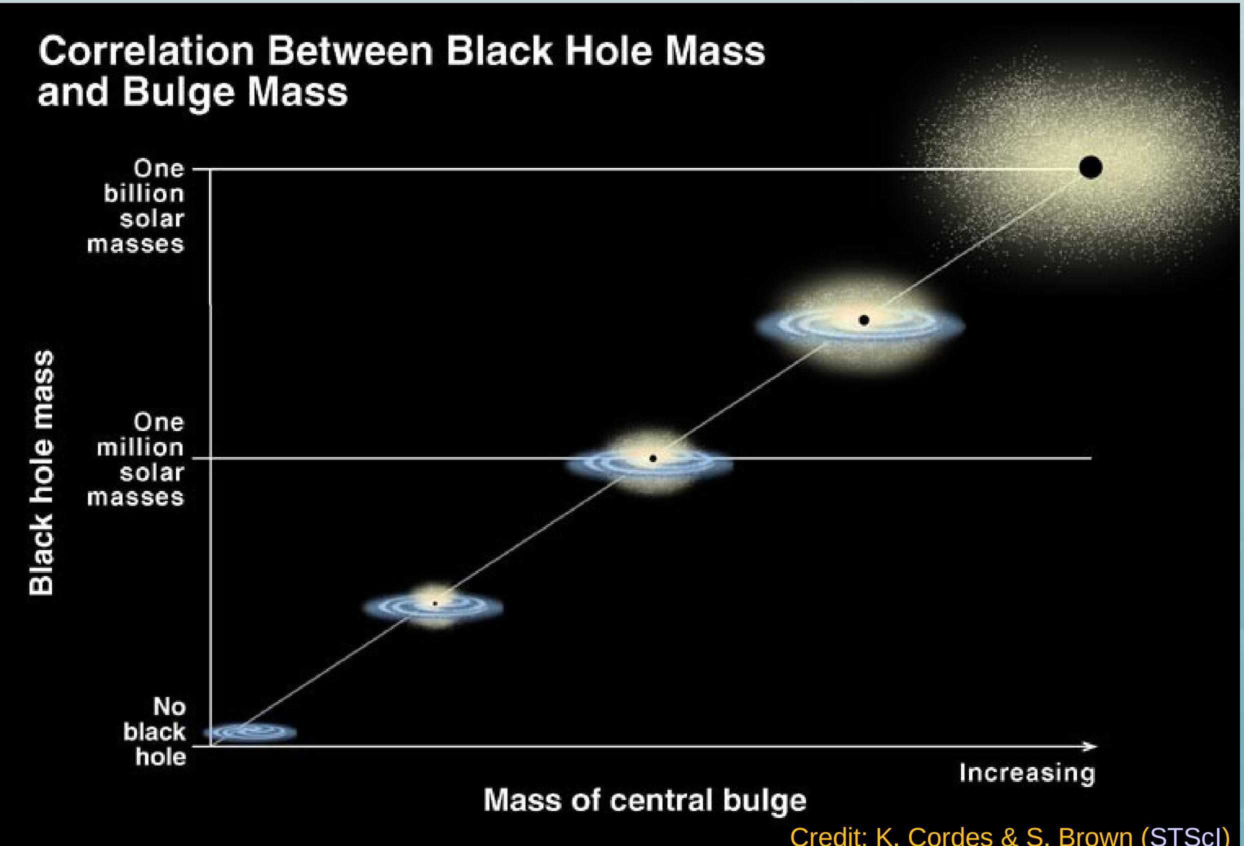
Outline

- ✓ Introduction and motivation
- ✓ Electron temperature distributions from GMOS-IFU observations
- ✓ Ionized outflows from GMOS-IFU observations
- ✓ Molecular and ionized gas emission from NIFS observations
- ✓ Conclusions

Introduction

The bulk of galaxy/star formation occurred in the **first 3 Gyr** of the Universe



Credit: K. Cordes & S. Brown (STScI)

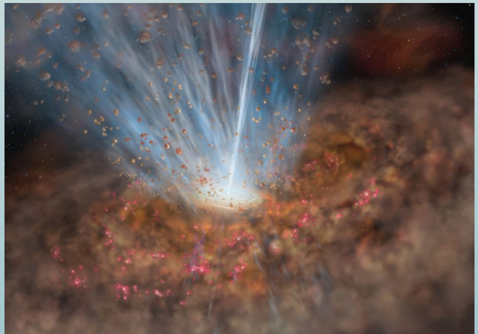
Co-evolution of SMBH and galaxies

- Observations of quasars at *z*>6: SMBHs form early, evolving together with the galaxies;
- $M_{SMBH} - \sigma$: (e.g. Magorrian et al, 1998; Ferrarese & Merrit, 2000; Gebhardt et al. 2000)
- Simulations: SMBHs form in the densest regions: the center of galaxies (e.g. Di Matteo et al. 2008)

AGN winds and shocks

- Identifying and characterizing the **processes that transform galaxies from star-forming to quiescent** is a fundamental goal of extragalactic astronomy

- AGN winds/jets can be effective in suppressing star formation



Credits: Gemini Observatory/Aura, art by Lynette Cook

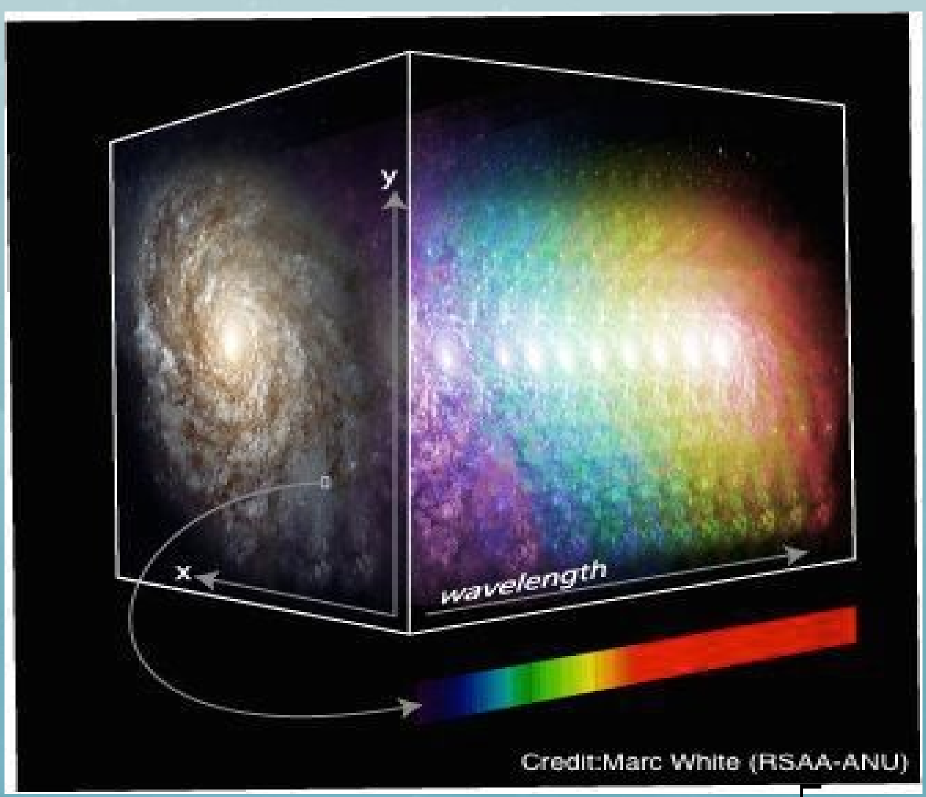
- AGN outflows occur in multiple gas phases, especially the most massive (molecular) phases can produce shocks and affect the star formation in their hosts.

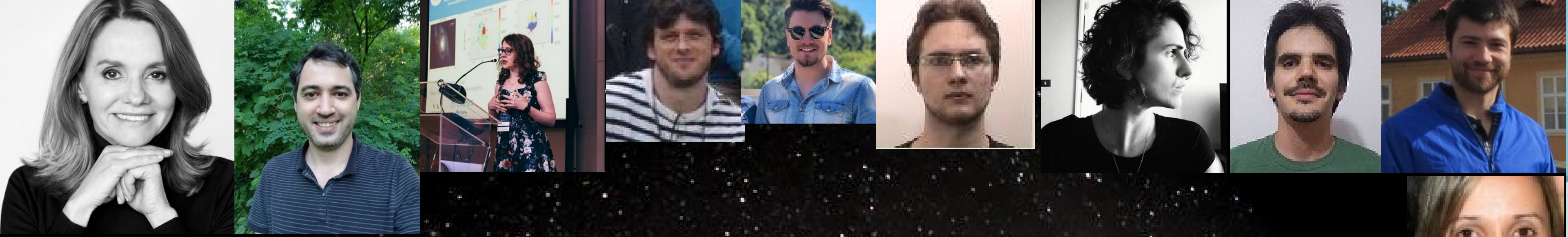
- The multiphase nature of AGN outflows is still not well understood. What are their geometries and kinetic powers?

AGN winds: observations

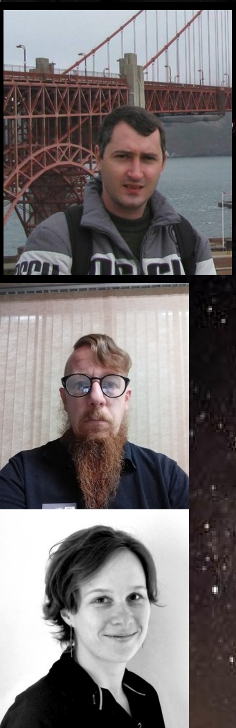
- AGN winds and shocks **are hardly resolved** by observations of distant galaxies (where the bulk of growth occurs)
- But they **can be resolved in nearby active galaxies** (in which the SMBH is accreting)
- Here, we look for outflows in the inner kpc of nearby active galaxies using IFS

Integral Field Spectroscopy





AGNIFS team: Storchi-Bergmann, T.; Riffel, R. A., Riffel, R.; Bianchin, M.; Ruschel-Dutra, D.; Freitas, I. C., Diniz, M. R., Schonell, A. J., Dametto, N. Z., Dahmer-Hahn, L. G., Schnorr-Muller, A., de Oliveira, B.



Collaborators: Dors, O. L., Zakamska, N. L., Armah, M., Burtscher, L., Bentz, M. C., Crenshaw, M., Davies, R., Fischer, T., Krabbe, A. C., Feltre, A., Rosario, D., Hägele, G. F., Cardaci, M. V., Esteban, C. , Robinson, A., Lena, D., Elvis, M. Rodriguez-Ardila, A.

Gemini Observatory/AURA image by Joy Pollard

- ✓ **Electron temperature distributions and shocked gas emission – GMOS**
  - Riffel et al., 2021a (MNRASL, 501, 54), 2021b (MNRASL, 506, 11)
- ✓ Ionized outflows in the optical – GMOS
  - Ruschel-Dutra et al. 2021 (MNRAS, 507, 74)
- ✓ Molecular and ionized gas distribution and kinematics – NIFS
  - Riffel et al., 2021c (MNRAS, 503, 5161), 2021d (MNRAS, 504, 3265)
  - Riffel et al., *in prep.*

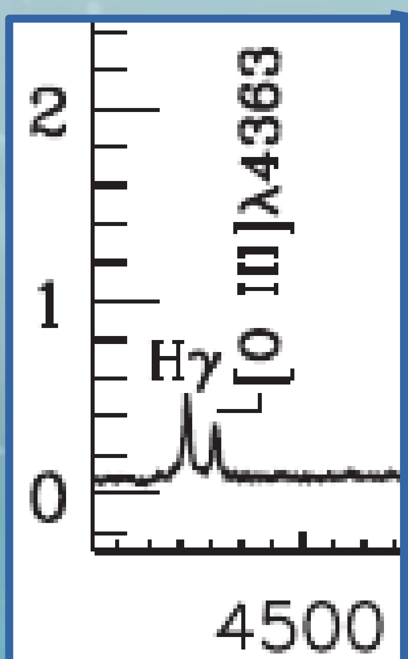
Electron temperature distributions and shocked emission

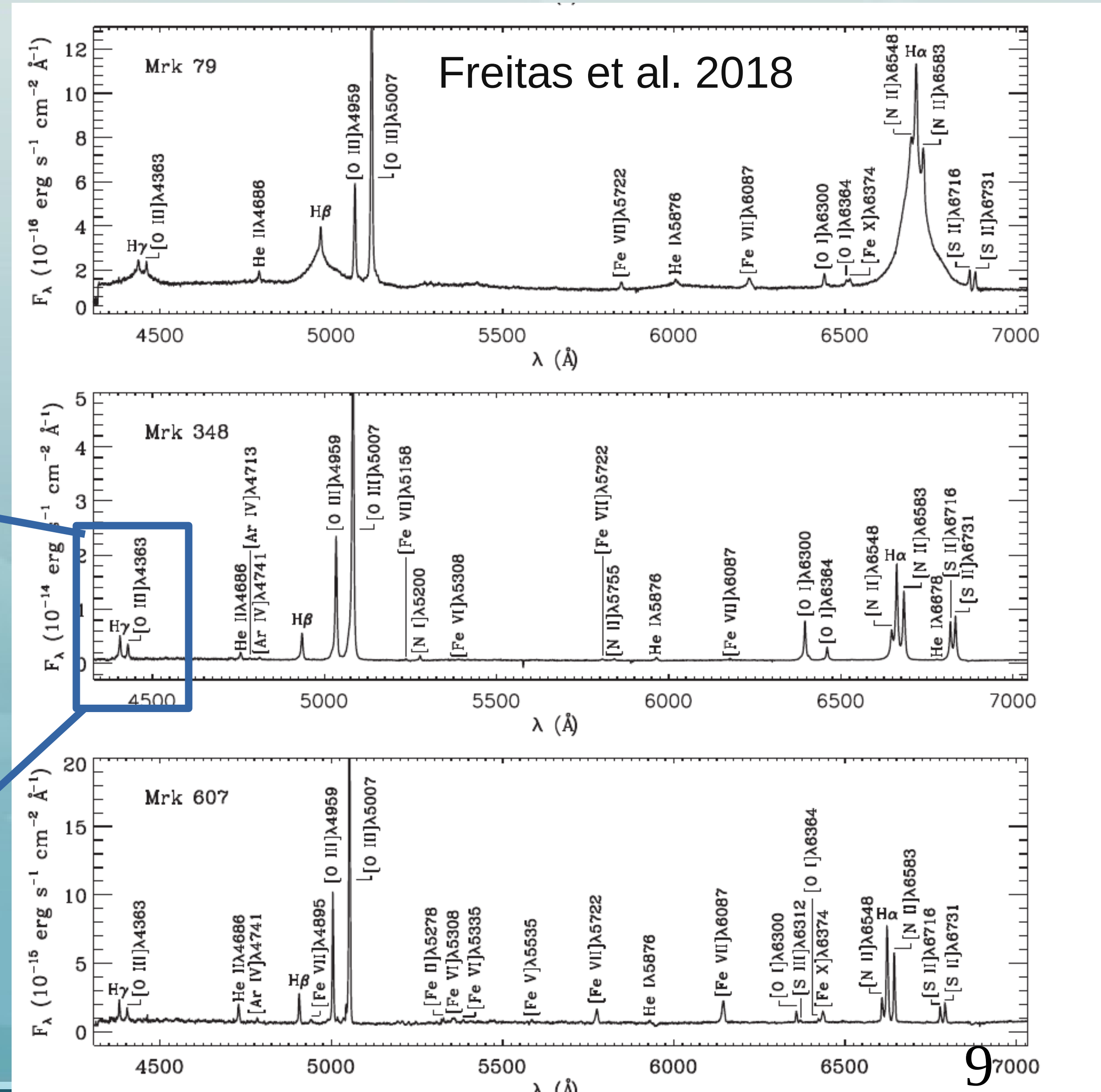
(Riffel et al. 2021a, 2021b)

- **Motivation: Shocks from AGN outflows may affect the ionization structure and *Te* distribution**, particularly in regions where the AGN ionizing photons are shielded by the nuclear obscuration (e.g. Zakamska & Greene, 2014)
- Lack of spatially resolved determinations of T_e in the NLR of AGNs
- High quality GMOS-IFU observations used to map the T_e distribution in the inner kpc of 3 luminous Seyferts

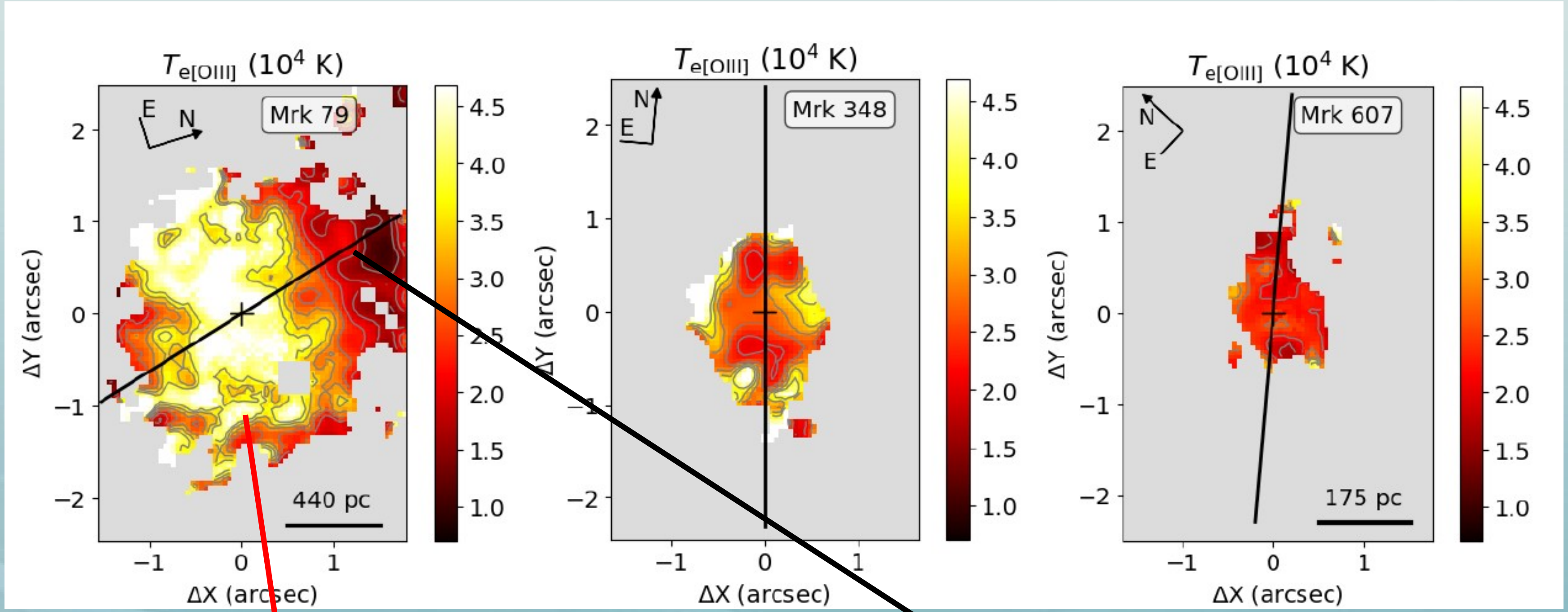
Electron temperature distributions and shocked emission in three nearby Seyferts (Riffel et al. 2021a, 2021b)

- Selected because the [OIII]4363 line is detected and spatially resolved, allowing the production of *Te* maps

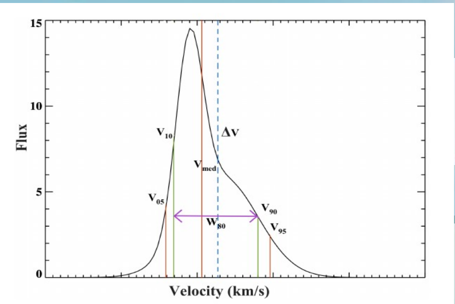




Electron temperature distributions and shocked emission in three nearby Seyferts (Riffel et al. 2021a, 2021b)

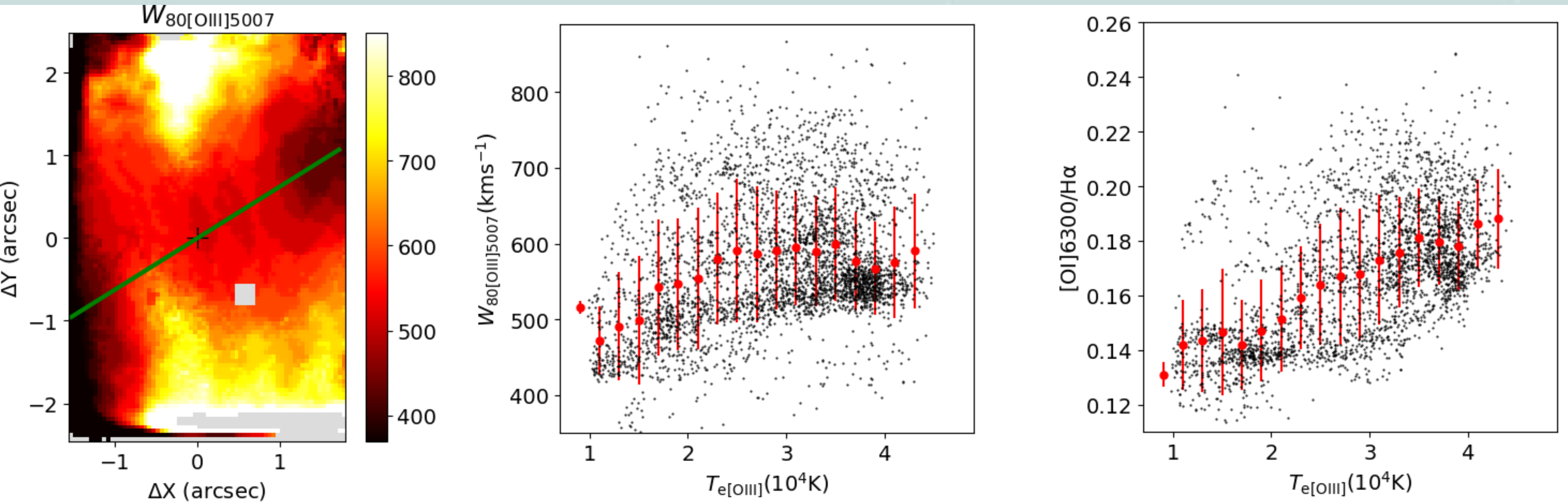


The **highest temperatures** are observed outside the **AGN ionization** axis



Electron temperature distributions and shocked emission in three nearby Seyferts (Riffel et al. 2021a, 2021b)

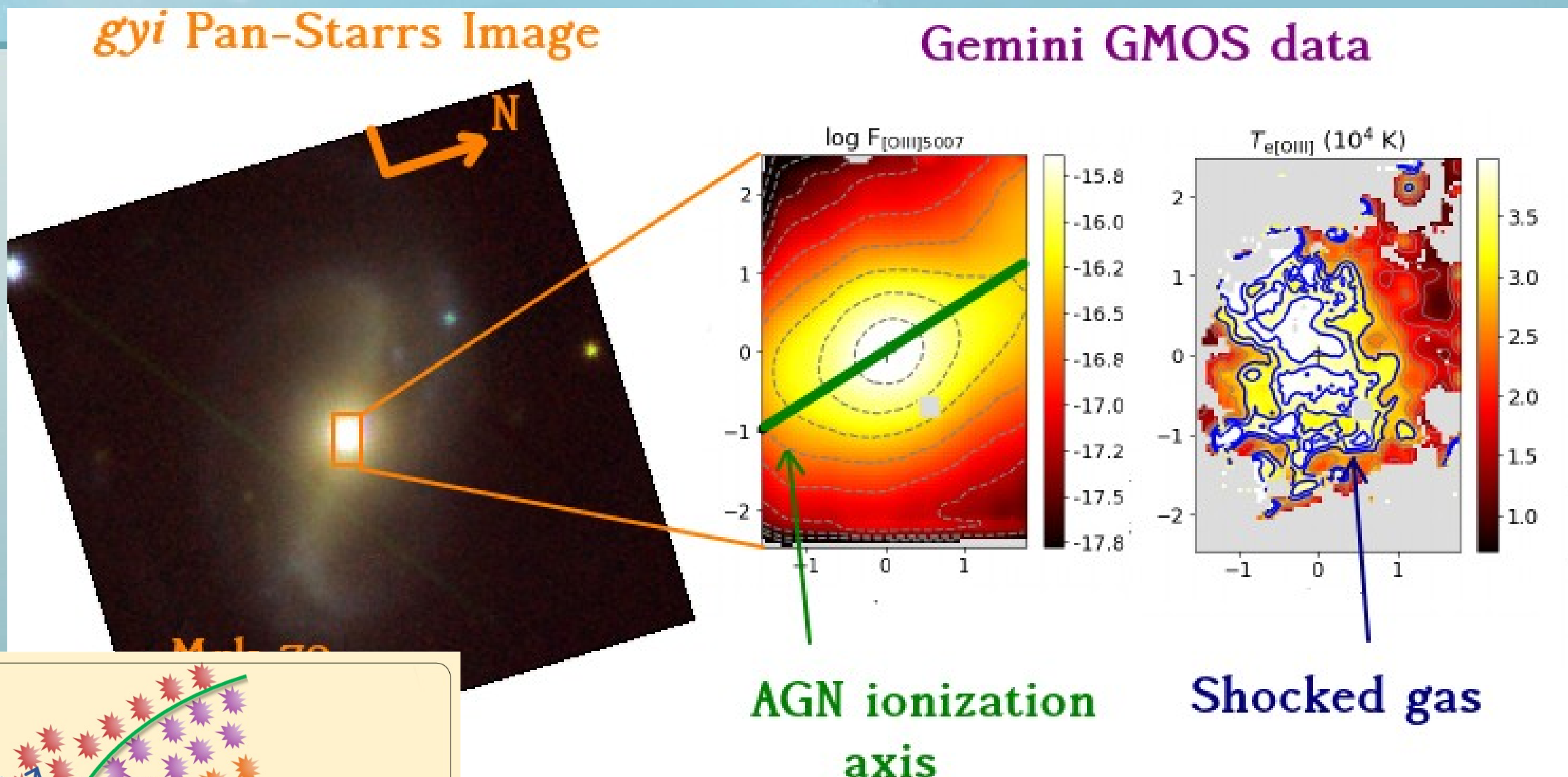
McElroy+ (2015, MNRAS, 446, 2186)

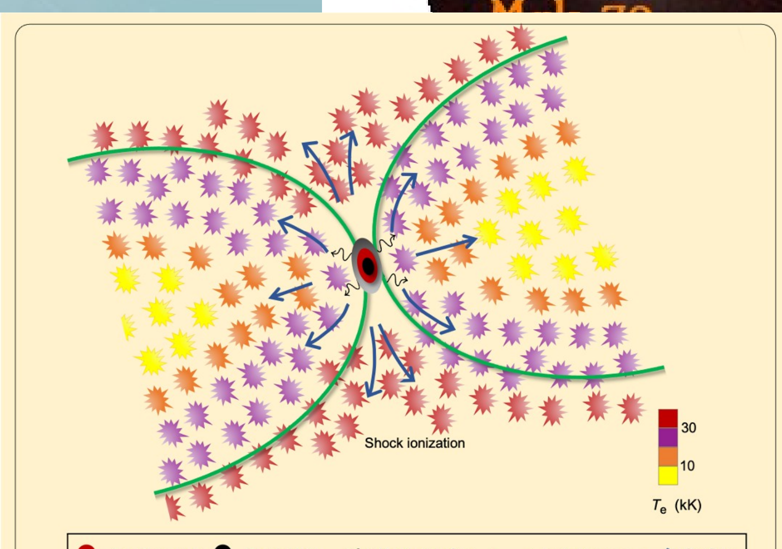


- The temperature increases with increasing line width and [OI]/Hα
- Standard AGN photoionization models can not reproduce the observed temperature distributions

- **Shocks** play an important role in the observed temperature distribution and ionization structure, at least in Mrk79 and Mrk348

Where are the shocks?





Credits: Saito, S & Dors, O.

Riffel et al. 2021a, 2021b

- ✓ Electron temperature distributions and shocked gas emission – GMOS
  - Riffel et al., 2021a (MNRASL, 501, 54), 2021b (MNRASL, 506, 11)

- ✓ **Ionized outflows in the optical – GMOS**
  - Ruschel-Dutra et al. 2021 (MNRAS, 507, 74)

- ✓ Molecular and ionized gas distribution and kinematics – NIFS
  - Riffel et al., 2021c (MNRAS, 503, 5161), 2021d (MNRAS, 504, 3265)
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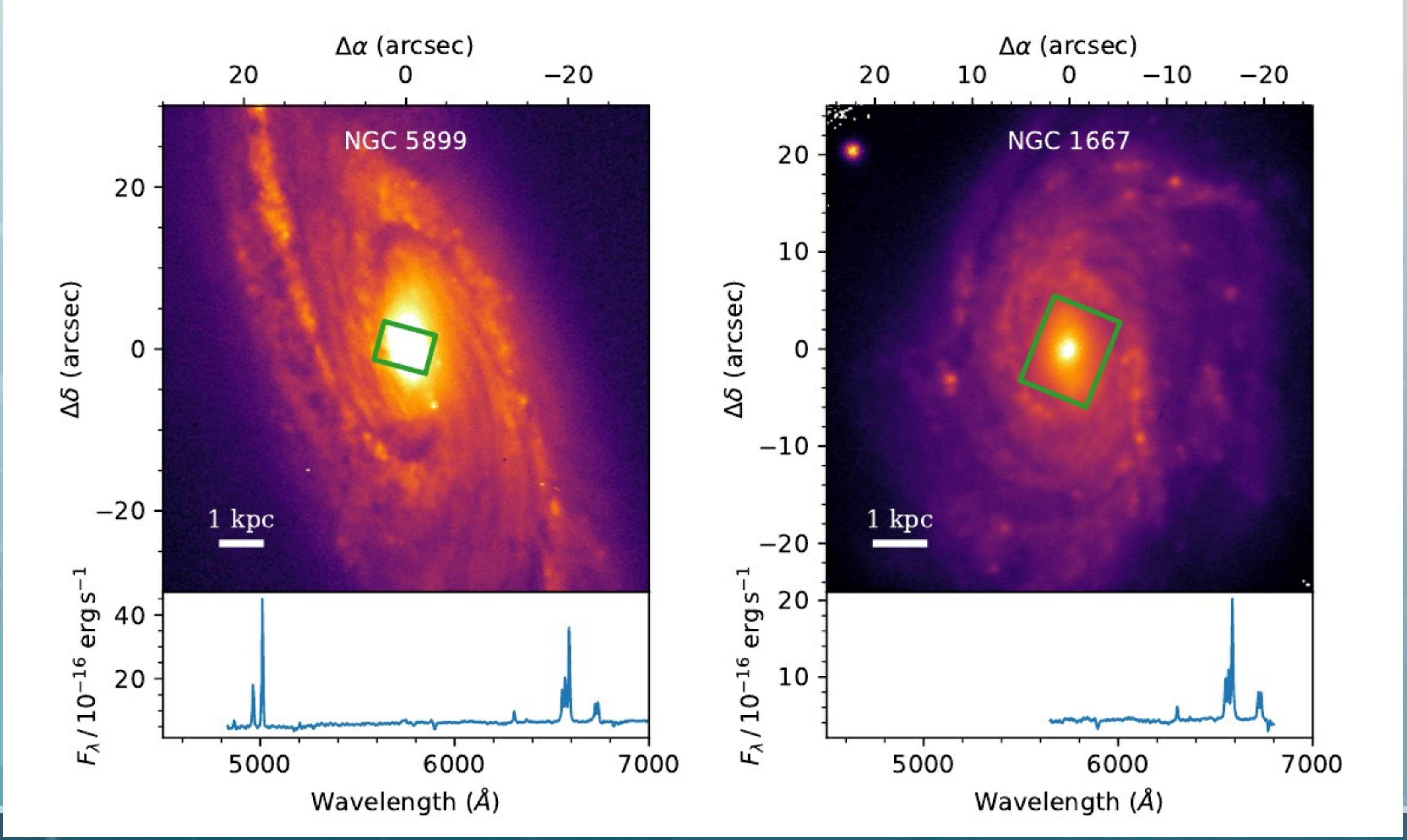
Ionized outflows observed with GMOS (Ruschel-Dutra et al. 2021)

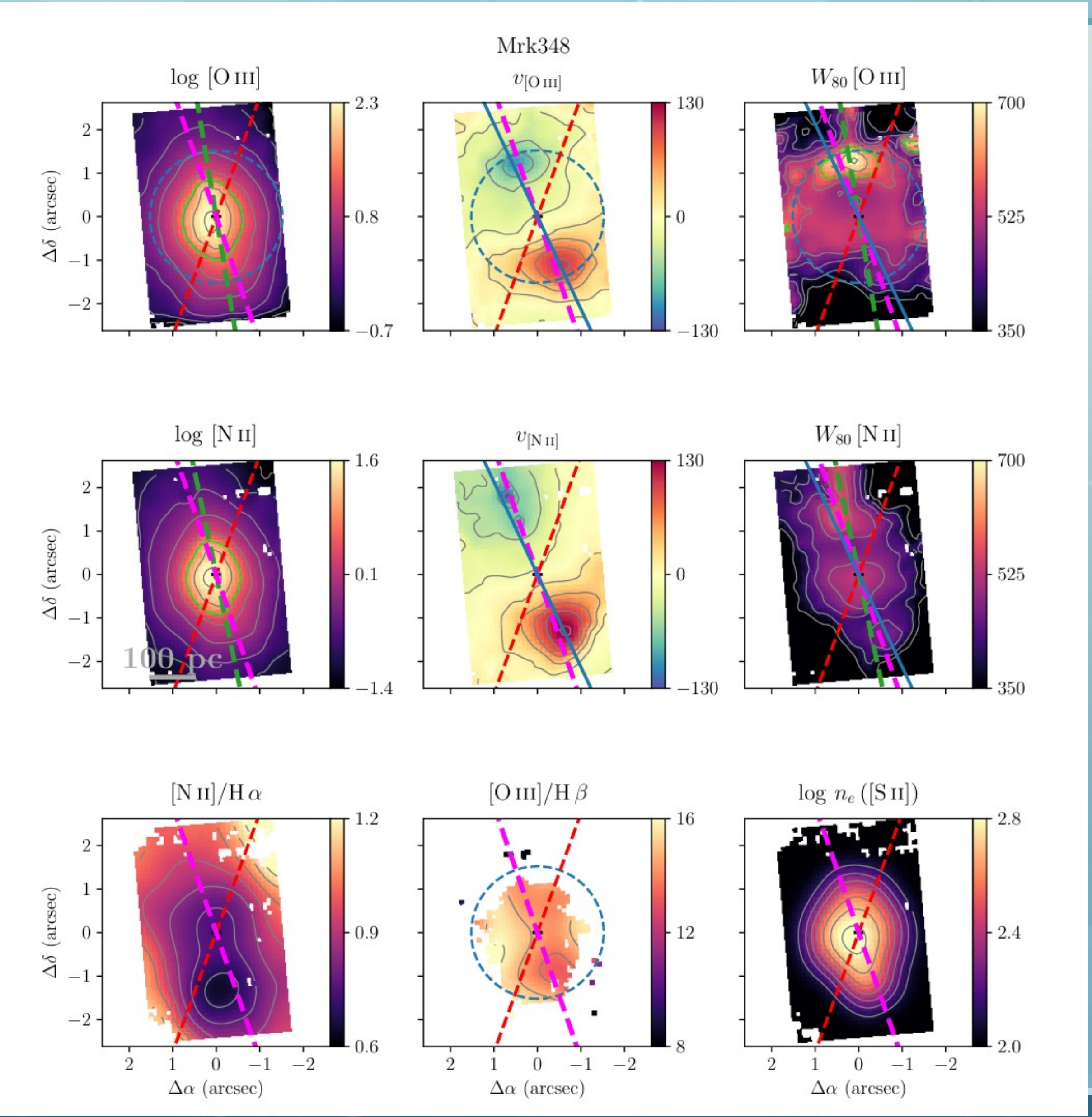
Sample: 30 local (z ≤ 0.02) AGN hosts that our group has collected over the past decade via observations with the GMOS-IFU

Single slit mode: 13 objects

Two slit mode: 17 objects



Ionized outflows observed with GMOS (Ruschel-Dutra et al. 2021)

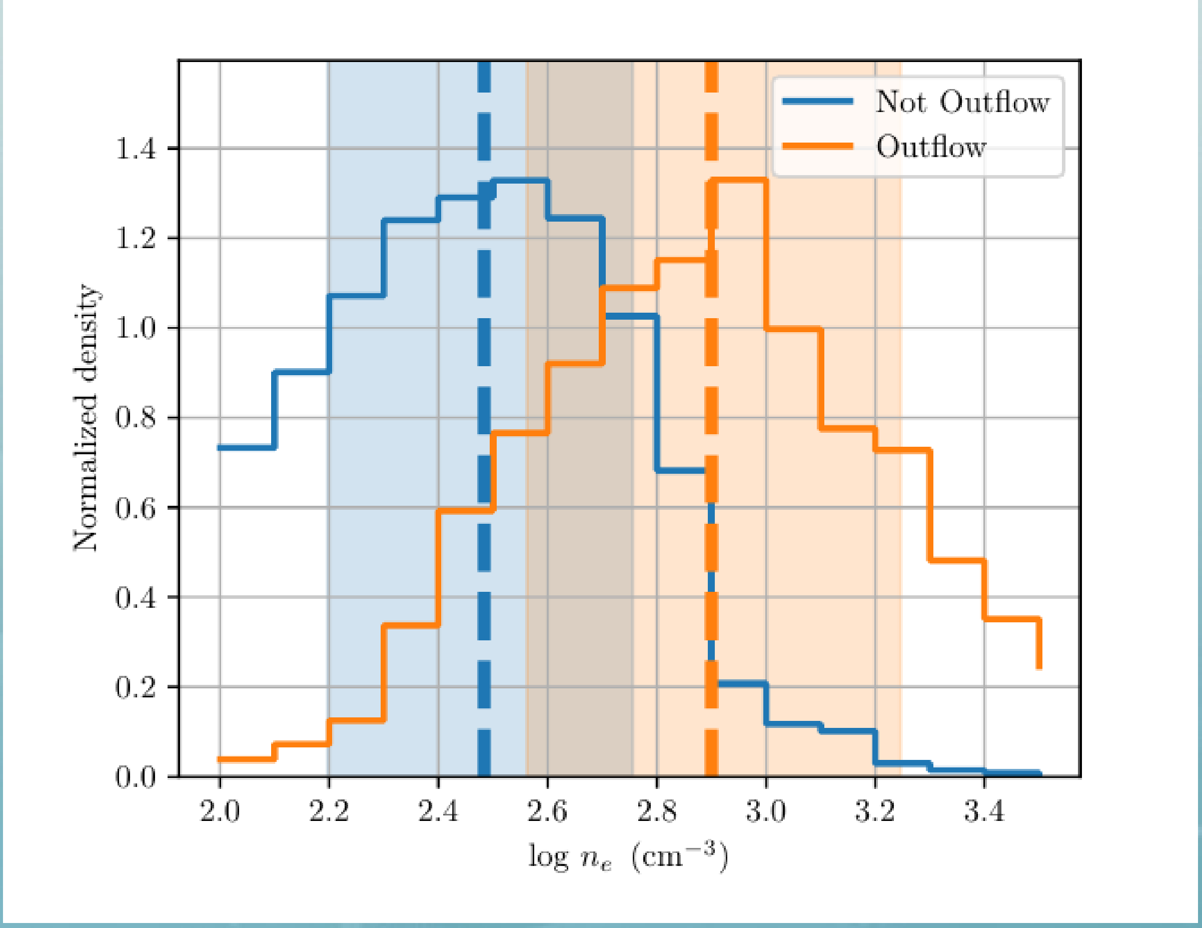


Ionized outflows observed with GMOS (Ruschel-Dutra et al. 2021)

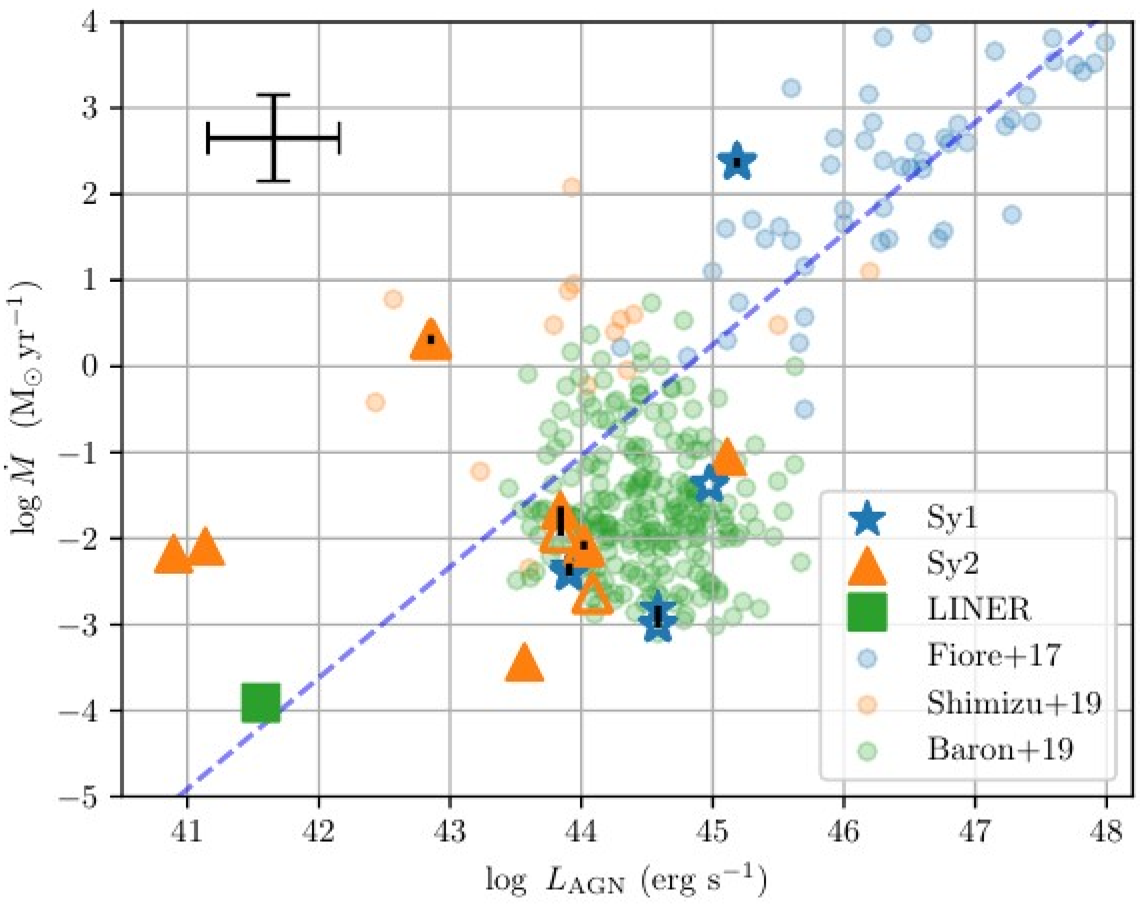
Outflows

- W80 > 600 km/s, excluding spaxels whose kinematics is dominated by gravitational motions

- EW (Hα) > 6Å, to ensure an accurate value for LHα



Ionized outflows observed with GMOS (Ruschel-Dutra et al. 2021)



Mass outflow rates

$$\dot{M} = M \frac{v}{R}$$

- the mass of the outflow is obtained from the LHα.

- adopting *W80*/2 for the velocity of the outflow and the maximum distance from the nucleus as the radius *R* of the outflow.

- ✓ Electron temperature distributions and shocked gas emission – GMOS
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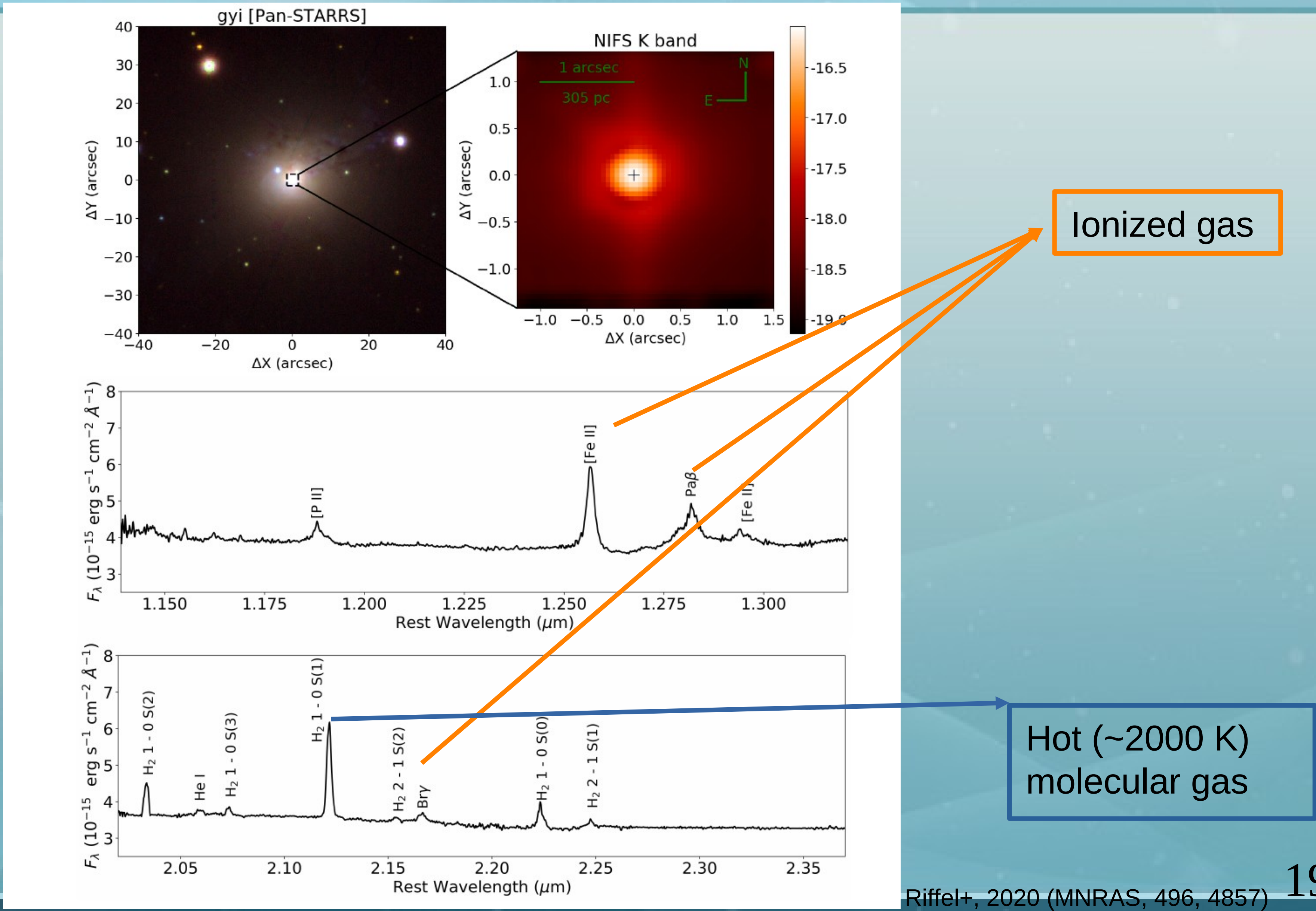
Molecular and ionized gas from NIFS observations

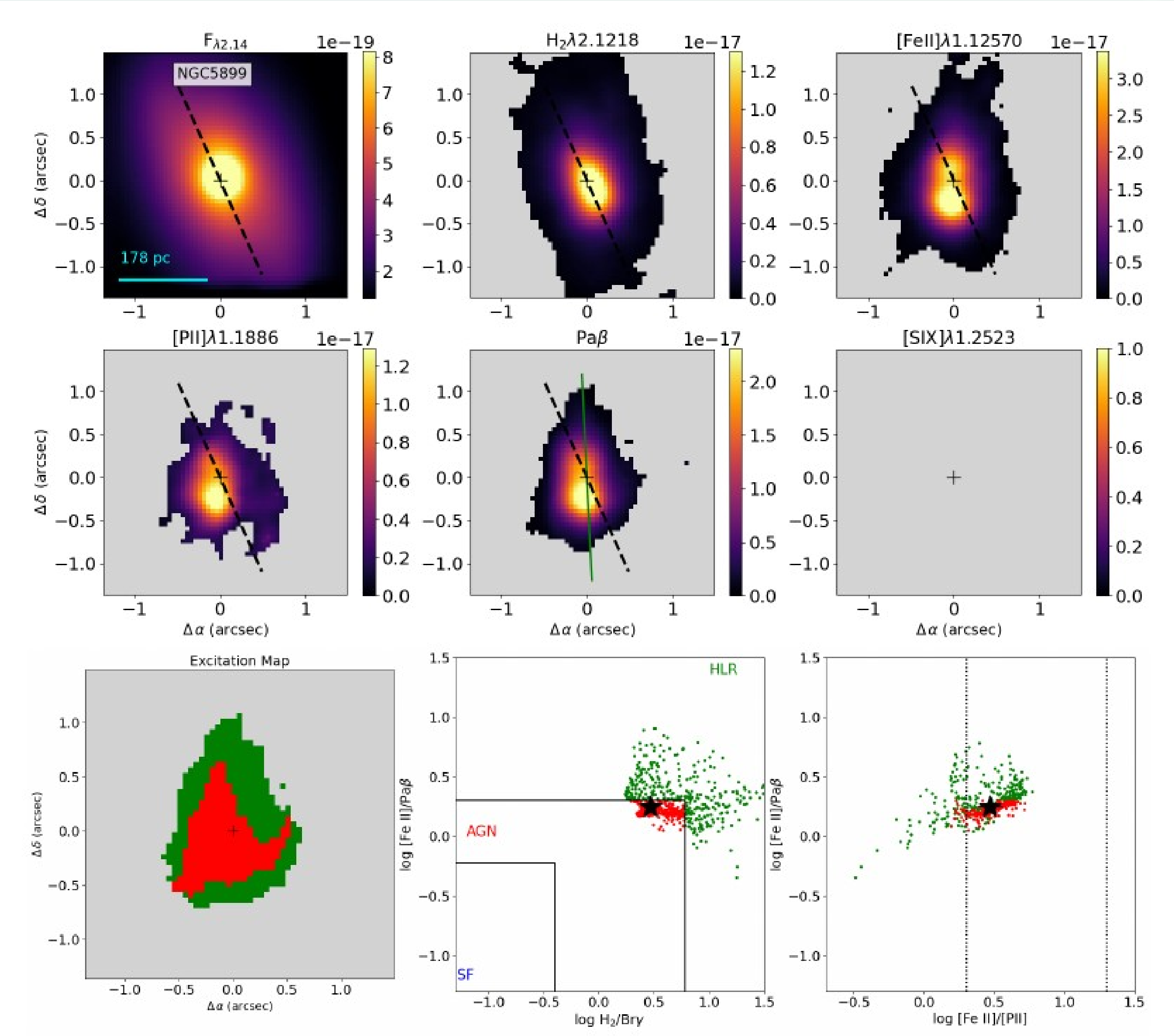
(Riffel et al. 2021c,2021d)



Riffel+, 2020 (MNRAS, 496, 4857)

Molecular and ionized gas from NIFS observations

(Riffel et al. 2021c,2021d)

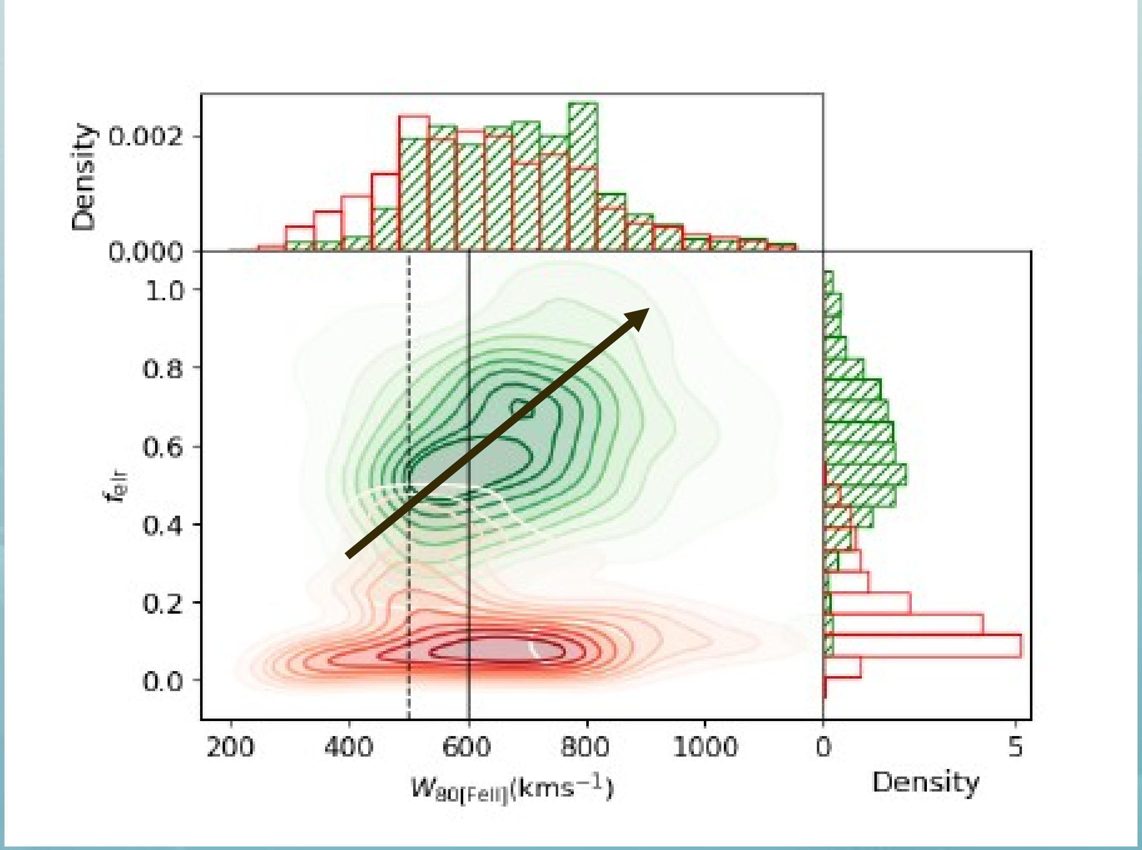


Riffel et al. 2021c: Gas excitation in 6 Seyferts (J and K-band data)

AGN radiation and shocks are the main excitation mechanisms of the H_2 and [Fe II] emission lines

Molecular and ionized gas from NIFS observations

(Riffel et al. 2021c,2021d)

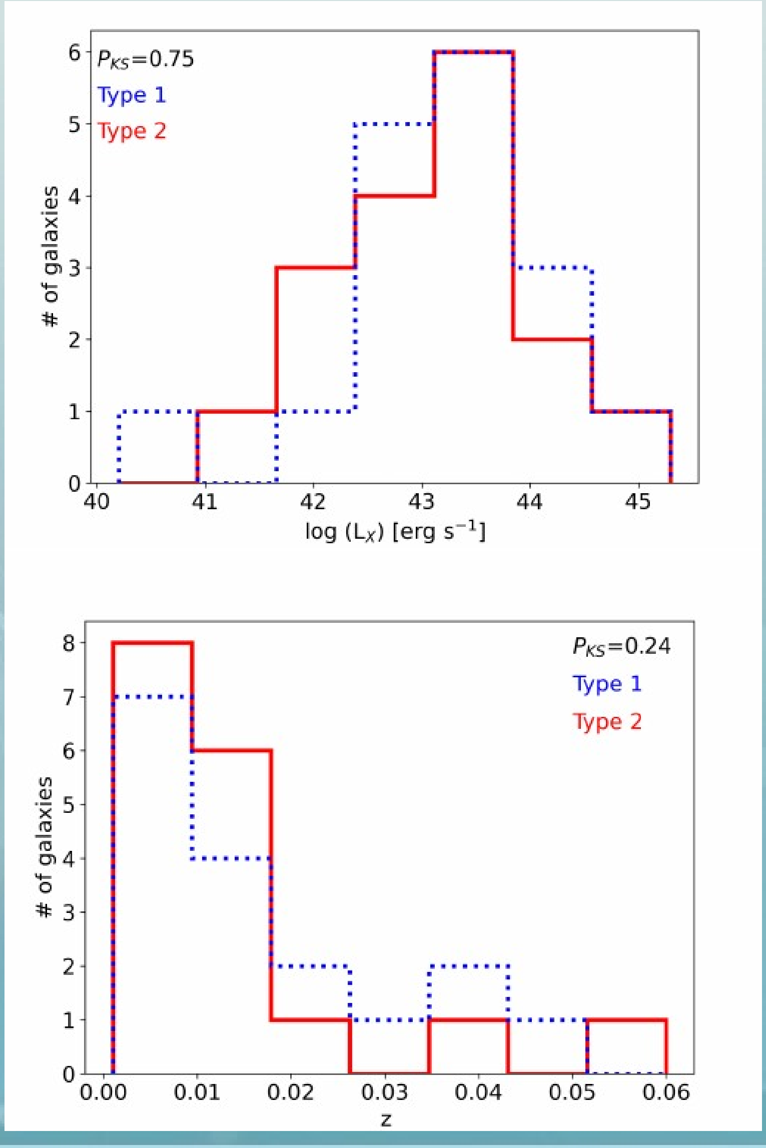


The HLR region is produced by shocks due to outflows.

This corresponds to 29% of the spaxels, usually located more distant from the galaxy nuclei.

Molecular and ionized gas from NIFS observations

(Riffel et al. 2021c,2021d)



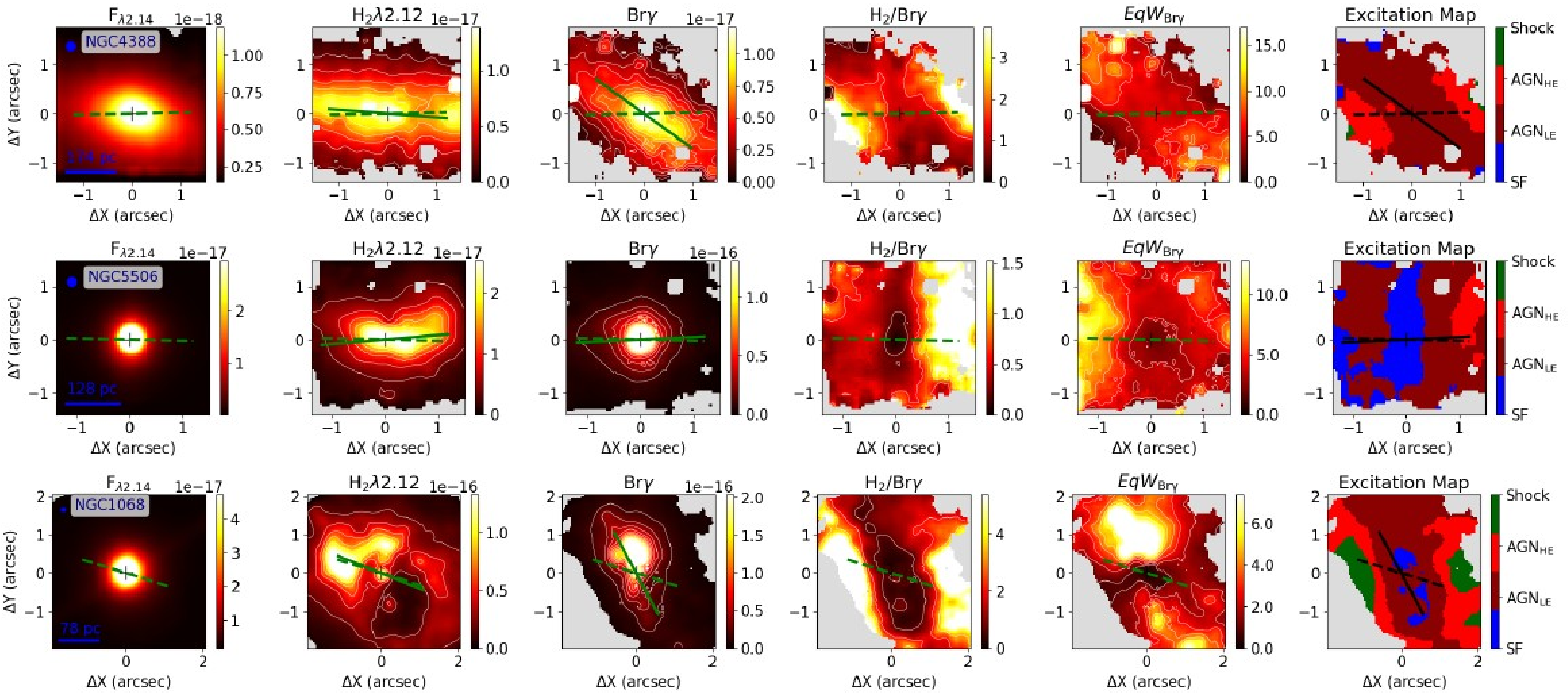
Riffel et al. 2021d: K-band data of 36 AGN

- All AGN from the Swift BAT 105 month catalog, at *z*<0.1, with archival NIFS data.

- Similar distributions in L_X and *z* for type 1 and type 2 AGN.

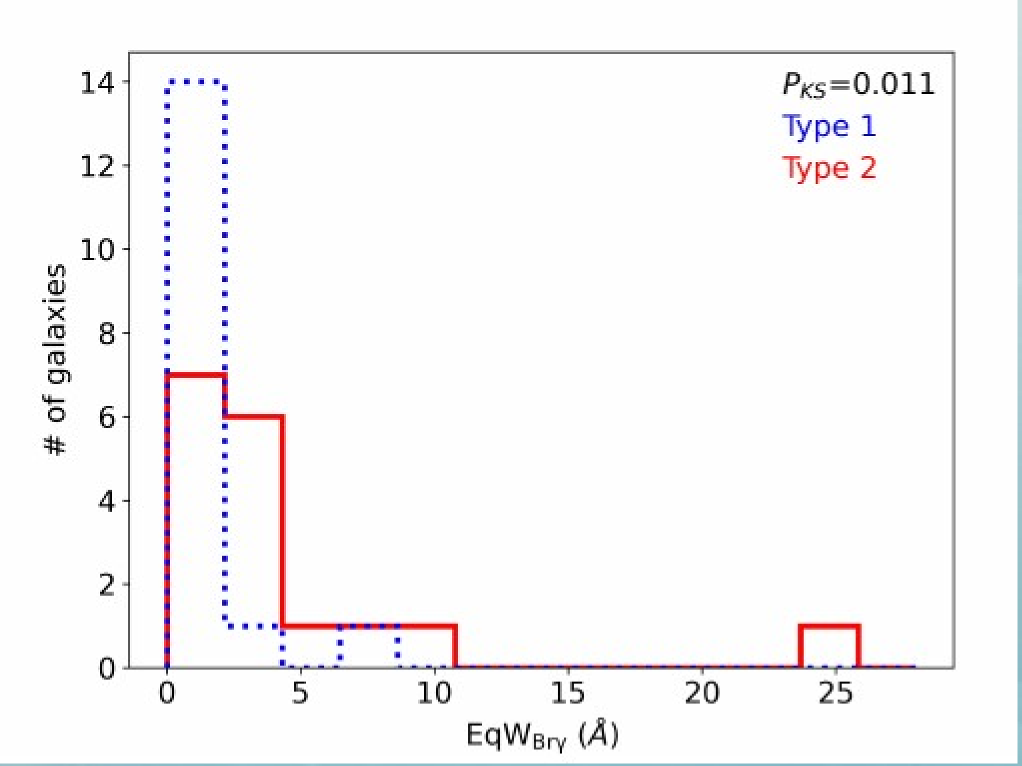
Molecular and ionized gas from NIFS observations

(Riffel et al. 2021c,2021d)



Molecular and ionized gas from NIFS observations

(Riffel et al. 2021c,2021d)

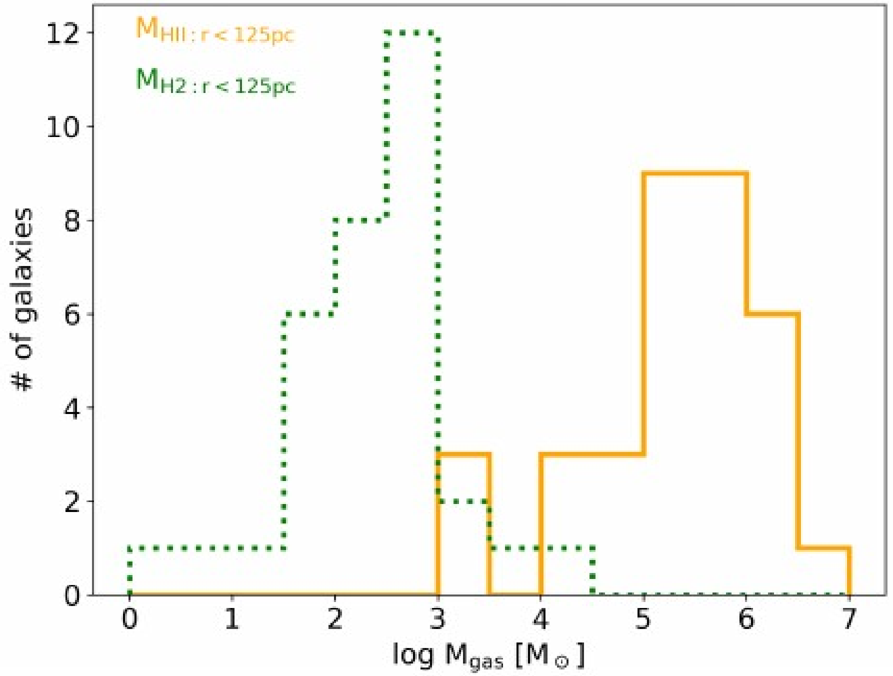


- Type 1 and type 2 AGN show similar emission-line flux distributions, ratios, H2 excitation temperatures and gas masses, supporting the AGN unification scenario.

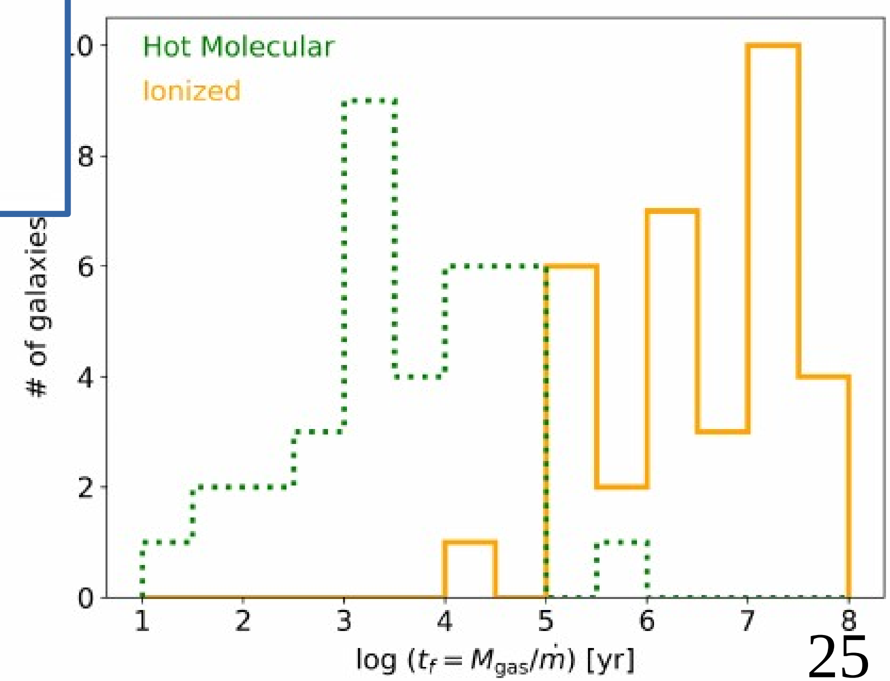
- Type 1 and type 2 differ only in their nuclear Brγ equivalent widths, which are smaller in type 1 AGN due to larger contributions of hot dust emission to the K-band continuum in type 1 nuclei.

Molecular and ionized gas from NIFS observations

(Riffel et al. 2021c,2021d)



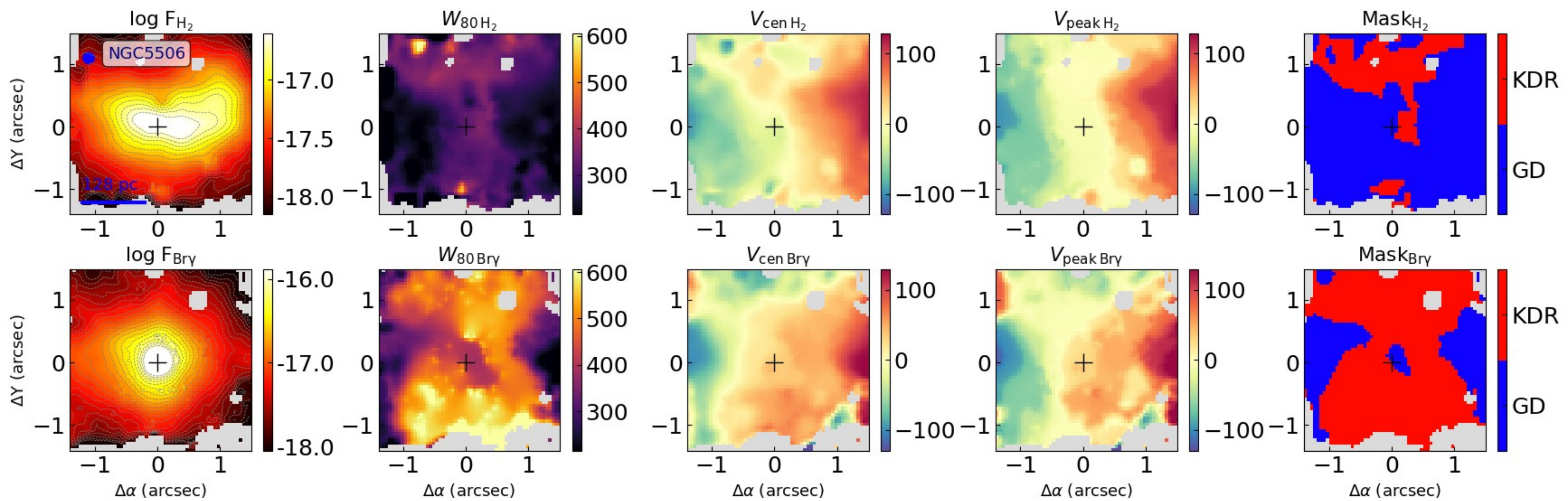
- The mass of hot molecular and ionised gas in the inner 125 pc radius are in the ranges $10^1 - 10^4$ M_{Sun} and $10^4 - 10^6$ M_{Sun}



- The mass of ionized gas within the inner 125 pc radius alone is more than enough to power the AGN in our sample for a duty cycle of 10^6 yr at their current accretion rates.

Molecular and ionized gas from NIFS observations

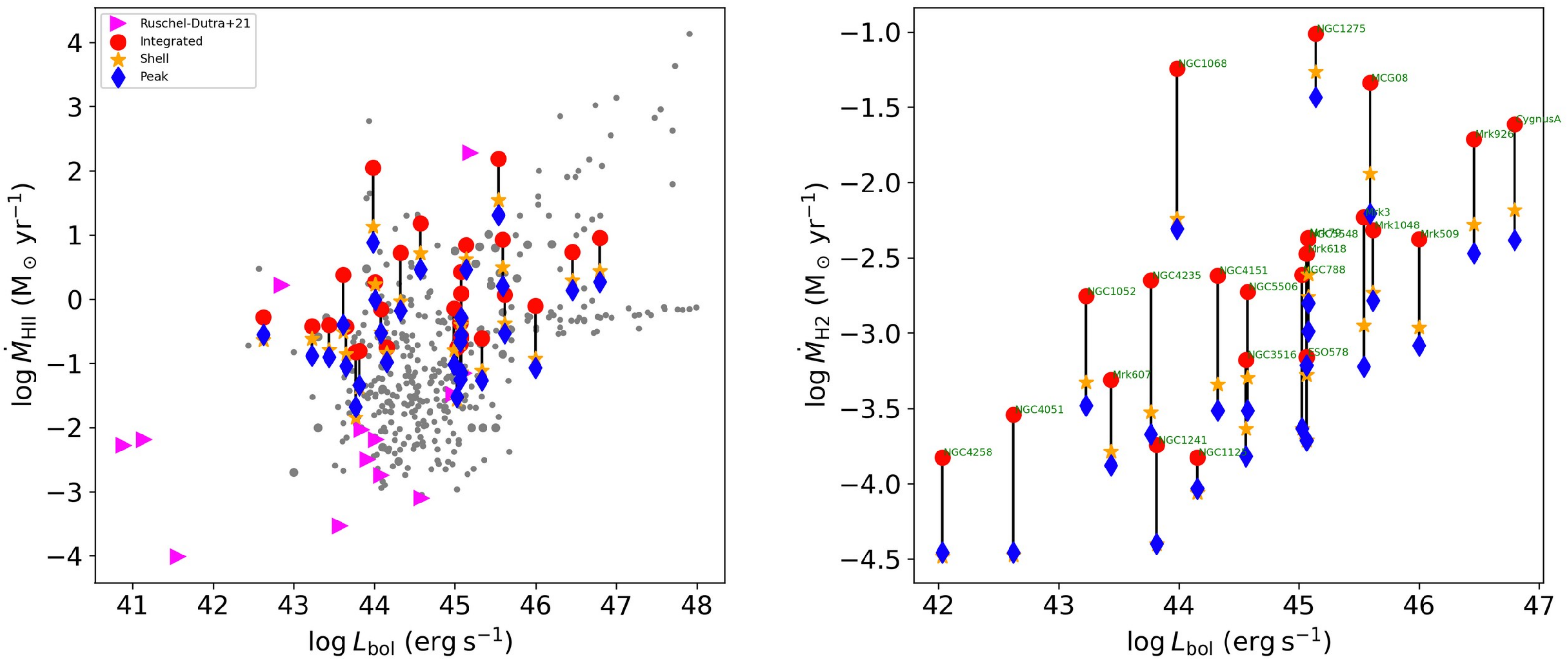
(Riffel et al., in preparation)



- For each galaxy we measure the H_2 and Brg flux distributions and kinematics
- We define a kinematically disturbed region (KDR)
  - W_{80Brg} > 400 km/s
  - W_{80H2} > 330 km/s

Molecular and ionized gas from NIFS observations

(Riffel et al., in preparation)



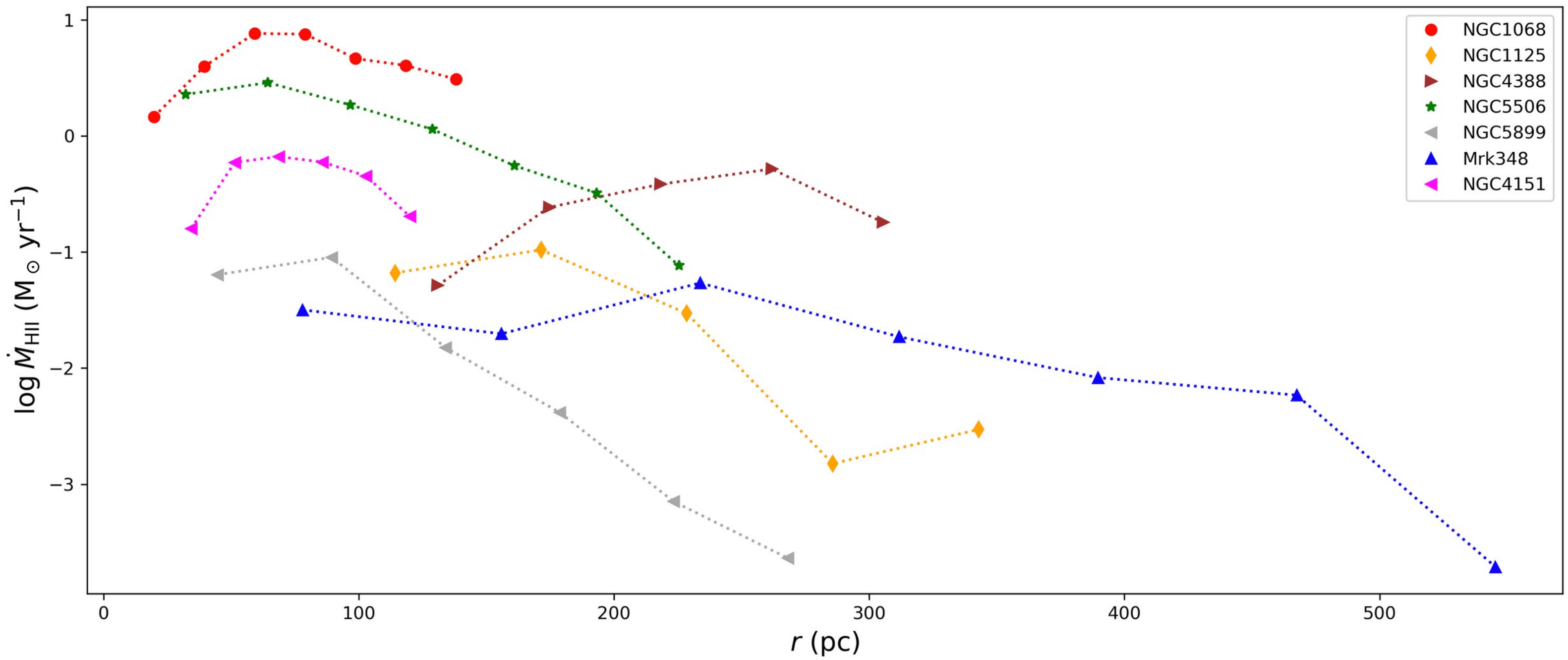
Mass outflow rates

Ionized gas: 10^{-2} – 100 M_{sun}/yr (27 objects)

Hot molecular gas: $10^{-4.5}$-10^{-1} M_{sun}/yr (20 objects)

Molecular and ionized gas from NIFS observations

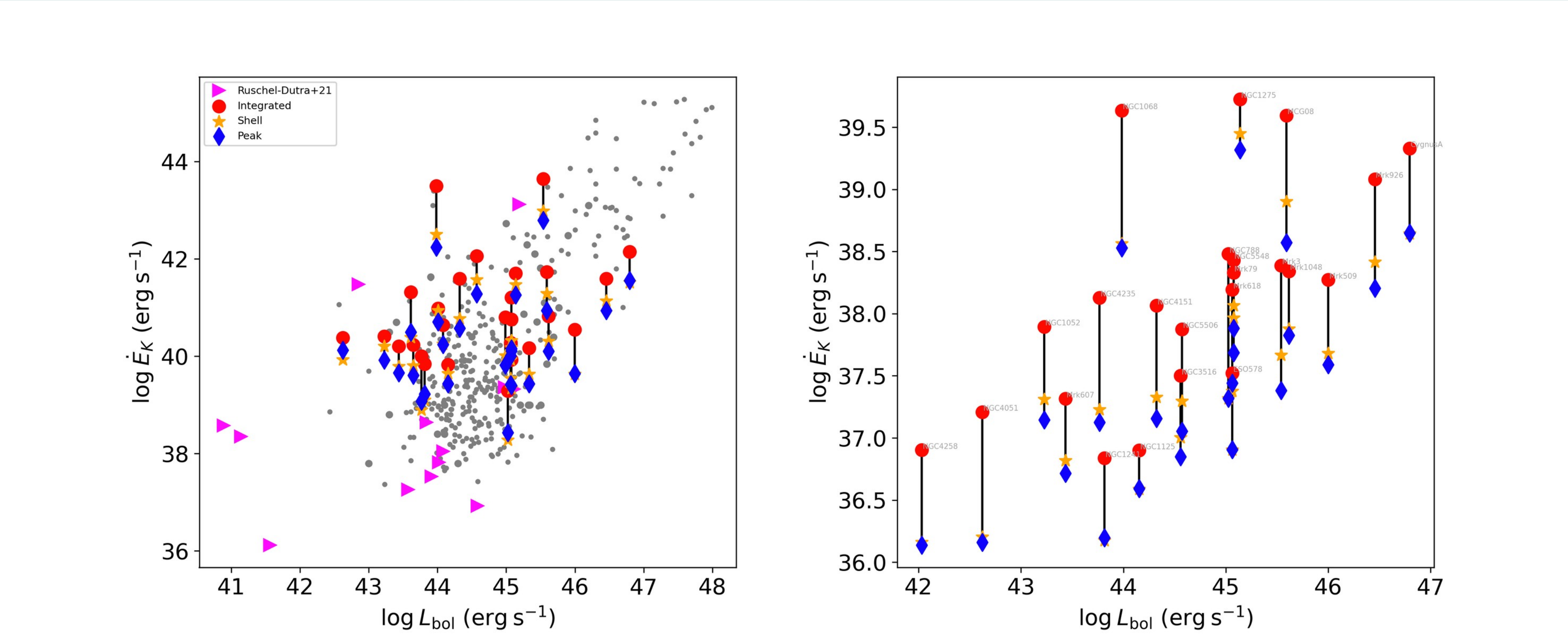
(Riffel et al., in preparation)



The mean radius for the peak of the outflow is 230 +/- 40 pc

Molecular and ionized gas from NIFS observations

(Riffel et al., in preparation)



• The kinetic powers of the ionized outflows correspond to 10^{-5} – 3% of the AGN bolometic luminosities, with a median value of 0.0025%.

• The outflows are usually not powerful enough to quench star formation in host galaxies (e.g. Hopkins & Elvis, 2010).

Conclusions

✓**Shocks play an important role in the observed electron temperature distributions**.

✓**Shocks are more important in regions away from the AGN ionization axis,** where they can be easily observed as the AGN radiation field is shielded by the nuclear dusty torus

✓ **Ionized outflows** are detected in most objects (80%) with velocities of ~100 – 1000 km/s at an outflow rate of **10^{-4}-10^{2} $M_{sun}yr^{-1}$**

✓**Hot H_2 outflows** are observed in ~55% of the galaxies with mass rates of **10^{-4}-10^{-1} $M_{sun}yr^{-1}$**

✓ The outflows are not powerful enough to supress star formation in the host galaxy.

✓ The observed outflow velocities and powers indicate a **"maintenance mode" feedback, where the outflows redistribute the gas within the galaxy,** but it still remains available for further star formation

Thank you!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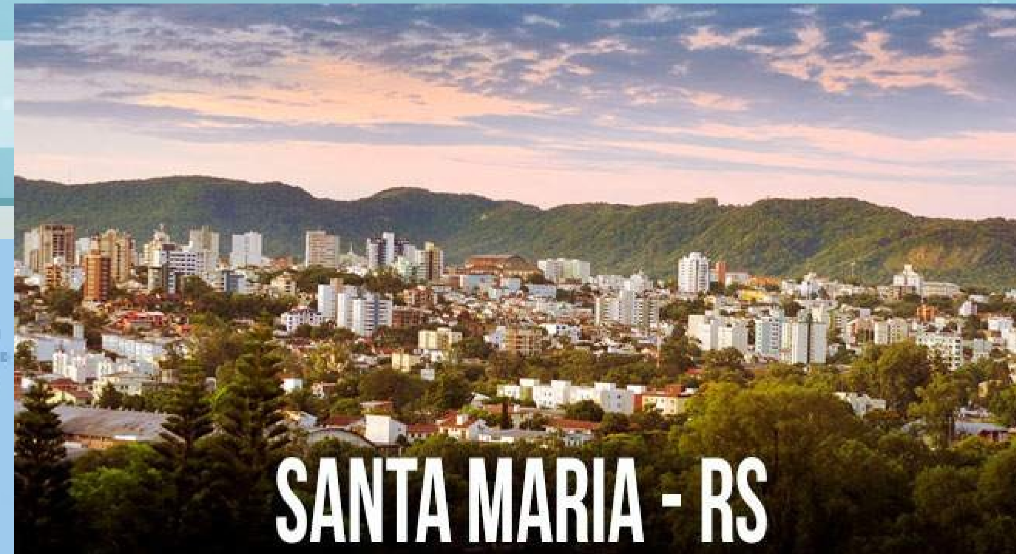
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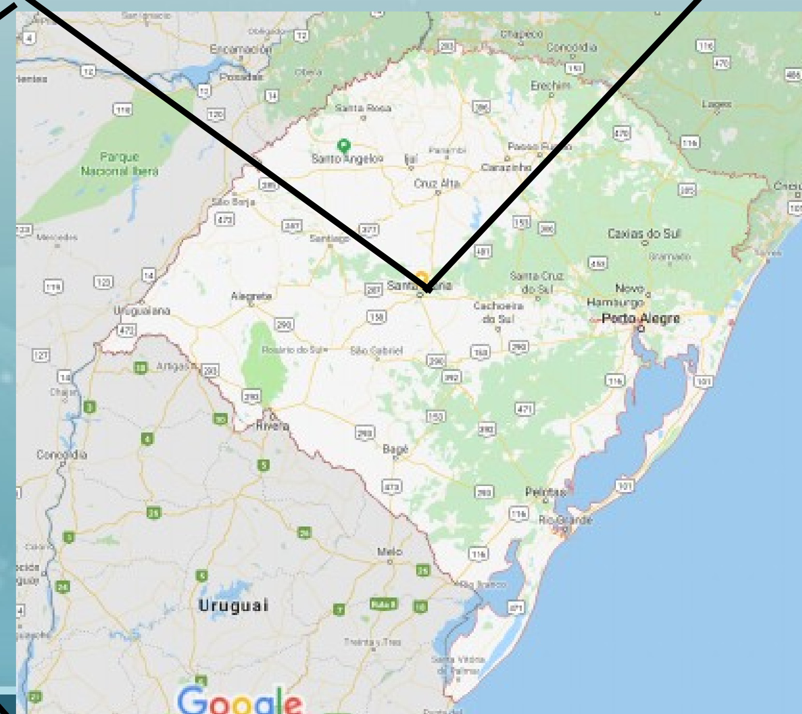
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