Title: Complex Dynamics of Stars and Nebular Gas in Active Galaxies Centred in Cooling X-ray Atmospheres

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Subject: Cosmology

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Abstract:

Active Galactic Nuclei (AGN) feedback is known to play a key role in galaxy evolution and in regulating star formation. Studying the interplay between the central AGN and the different gas phases permeating galaxies is crucial to further our understanding of this powerful mechanism. We have observed the central regions of four brightest cluster galaxies at optical wavelengths using the Keck Cosmic Web Imager. With the high-resolution integral field unit data obtained from these observations, we map the fluxes and velocities of both emission lines and stellar absorption lines. This allows for a detailed tracing of gas cooling in galaxy centres. These galaxies have extensive X-ray and radio observations, allowing us to compare the dynamics of different gas phases and to study their interactions. Nebular emission extends up to tens of kiloparsecs from the central cluster galaxies of Abell 1835, PKS 0745-191, Abell 262, and RX J0820.9+0752. With the stellar continua, we map the kinematics and ages of the stars, learning about the systems' star formation histories. Our findings highlight the complex stellar and gas dynamics which can be induced by radio-mechanical feedback. Surprisingly, three of the four systems have substantial (~ 150 km/s) velocity differences between their central galaxy and its associated nebular gas. This shows that the central galaxy is not at rest with respect to its surrounding nebula. In PKS 0745-191 and Abell 1835, nebular gas is churned up by buoyantly rising bubbles and jets. The churned gas is also surrounded by larger scale, lower velocity dispersion nebular emission. These complex motions will affect thermally unstable cooling, the interactions between the AGN and its atmosphere and how jet energy dissipates in its surroundings. These novel results highlight the deeply complex dynamics of AGN feedback and the multiphase gas in the centre of massive galaxies.

Complex Dynamics of Stars and Nebular Gas in Active Galaxies Centred in Cooling X-ray Atmospheres

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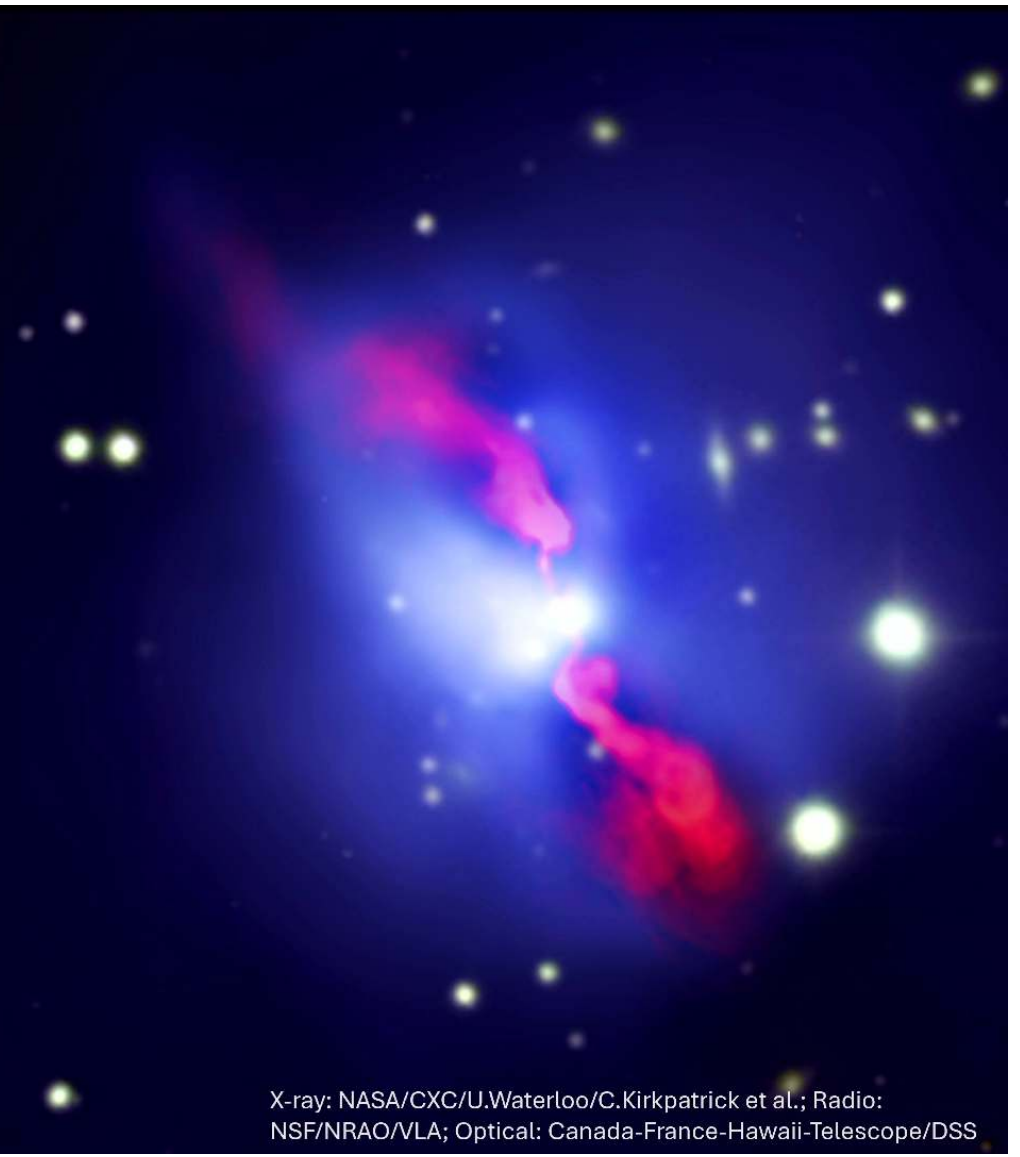


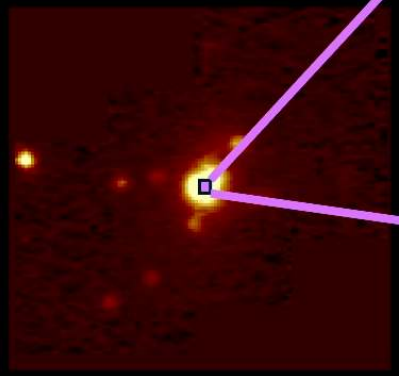
X-ray: NASA/CXC/U.Waterloo/C.Kirkpatrick et al.; Radio: NSF/NRAO/VLA; Optical: Canada-France-Hawaii-Telescope/DSS

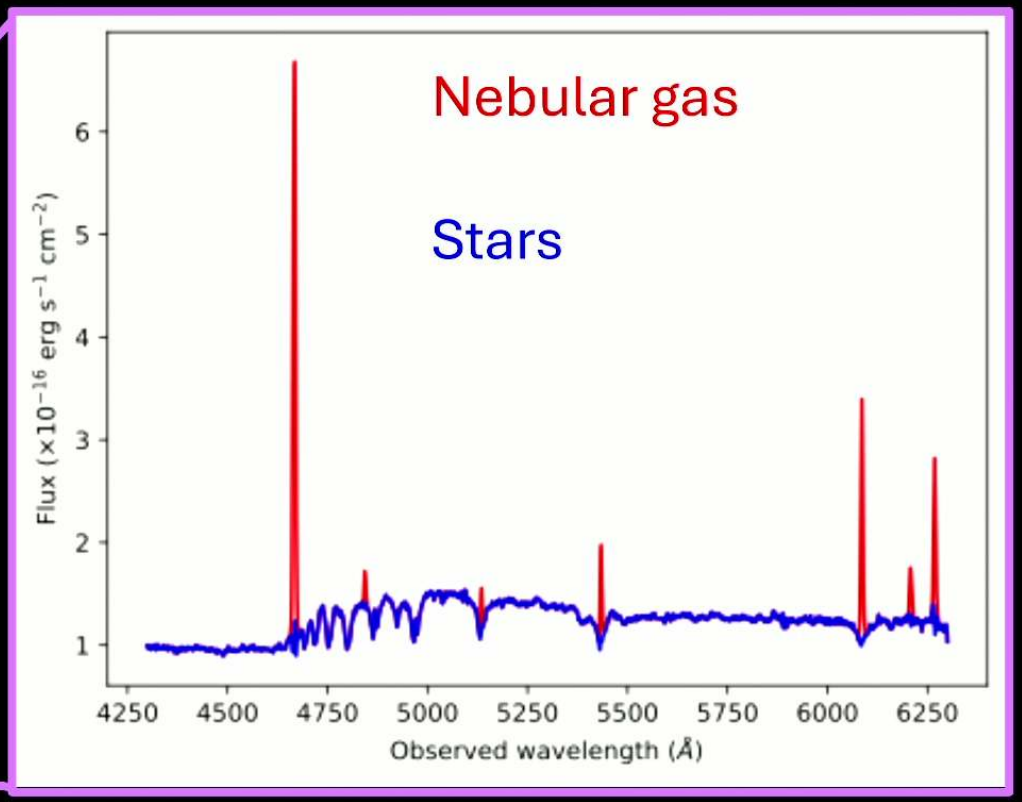
Observations

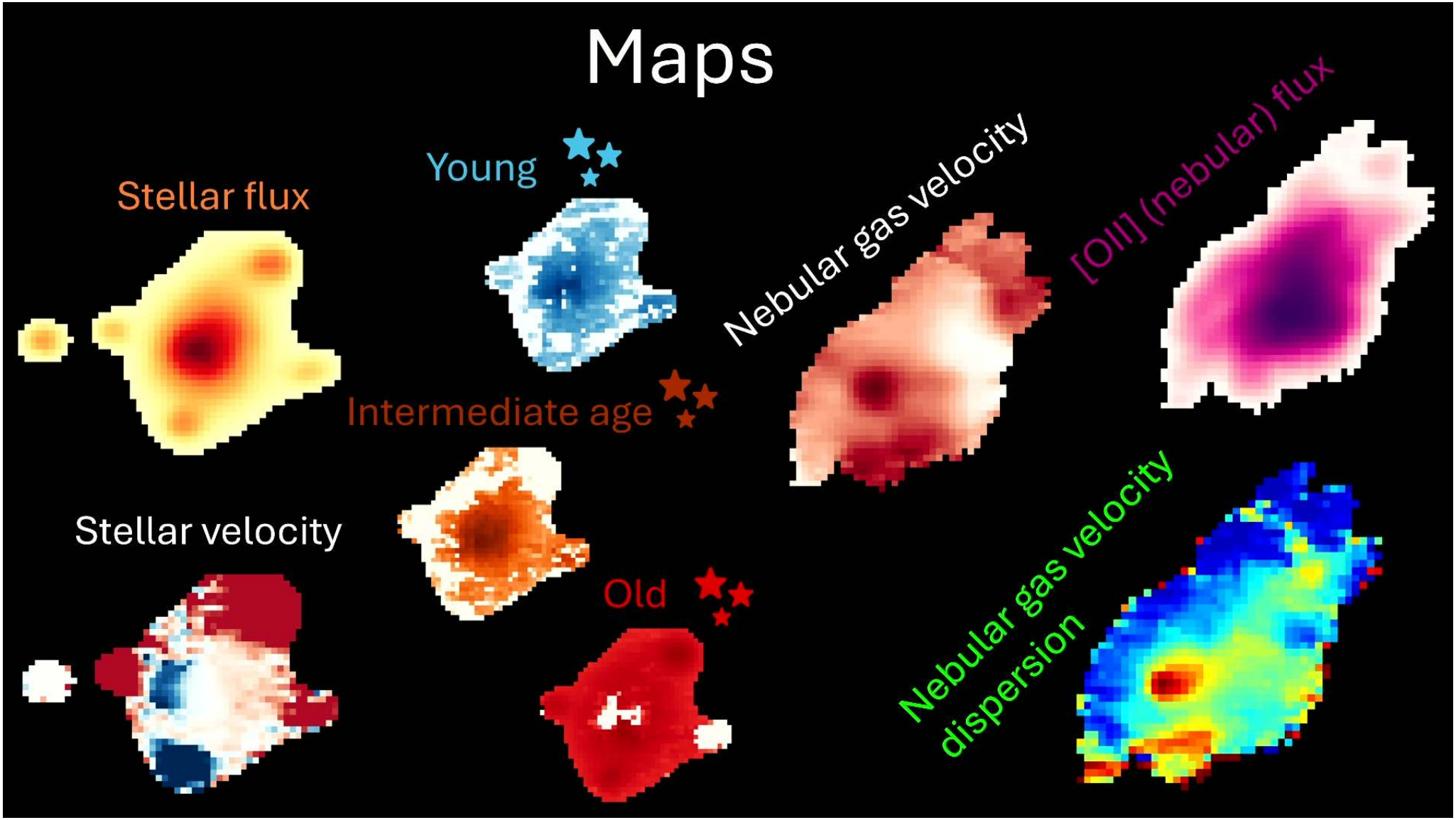
Using Keck Cosmic Web Imager (KCWI)
Integral field unit spectroscopy

3 (4) targets:

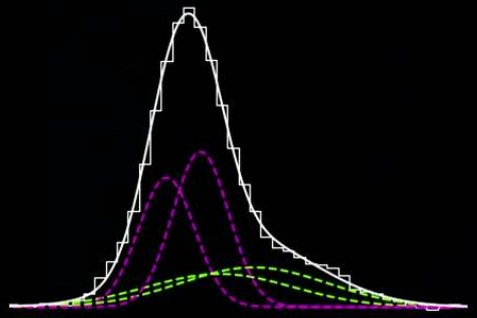
- Abell 1835
- PKS 0745-191
- RX J0820.9+0752
- (Abell 262)



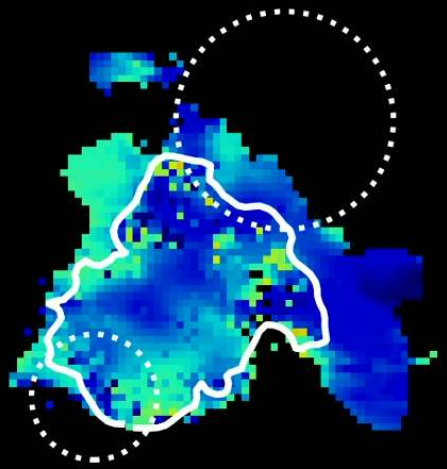



Maps
Stellar flux
Young
Nebular gas velocity
[OII] (nebular) flux
Intermediate age
Stellar velocity
Old
Nebular gas velocity dispersion

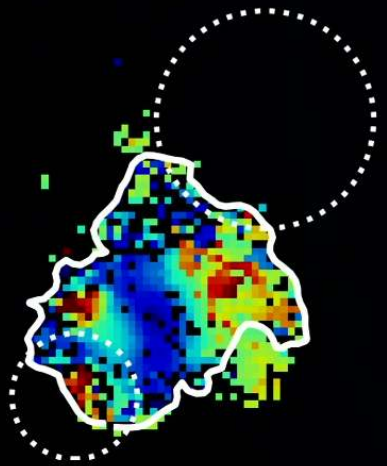
Distinct kinematic components in nebular emission

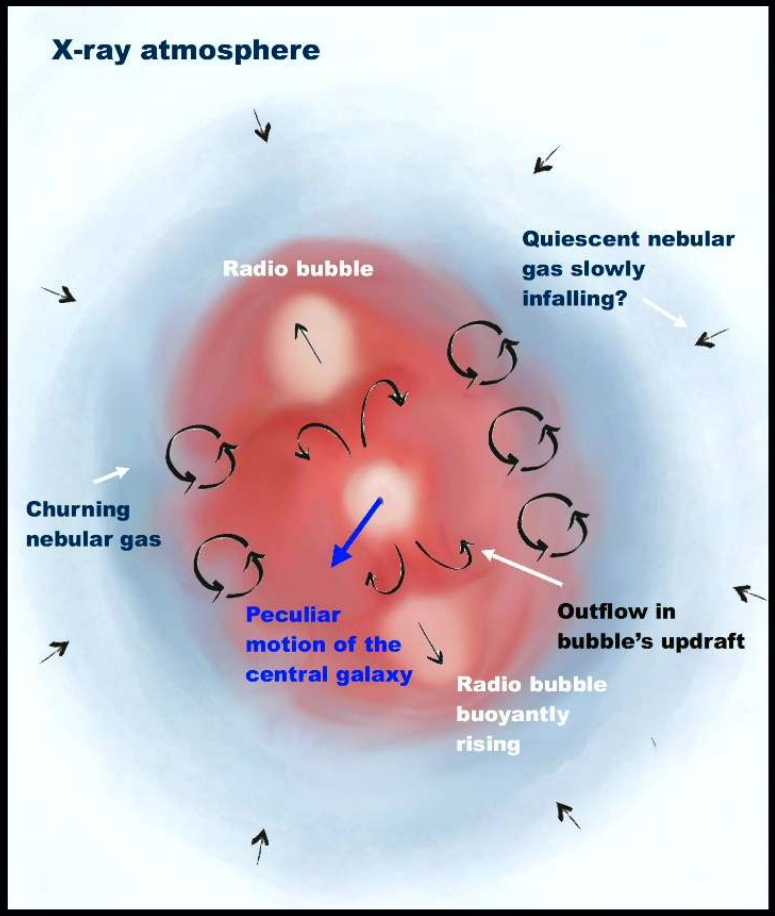


Quiescent



Churned-up

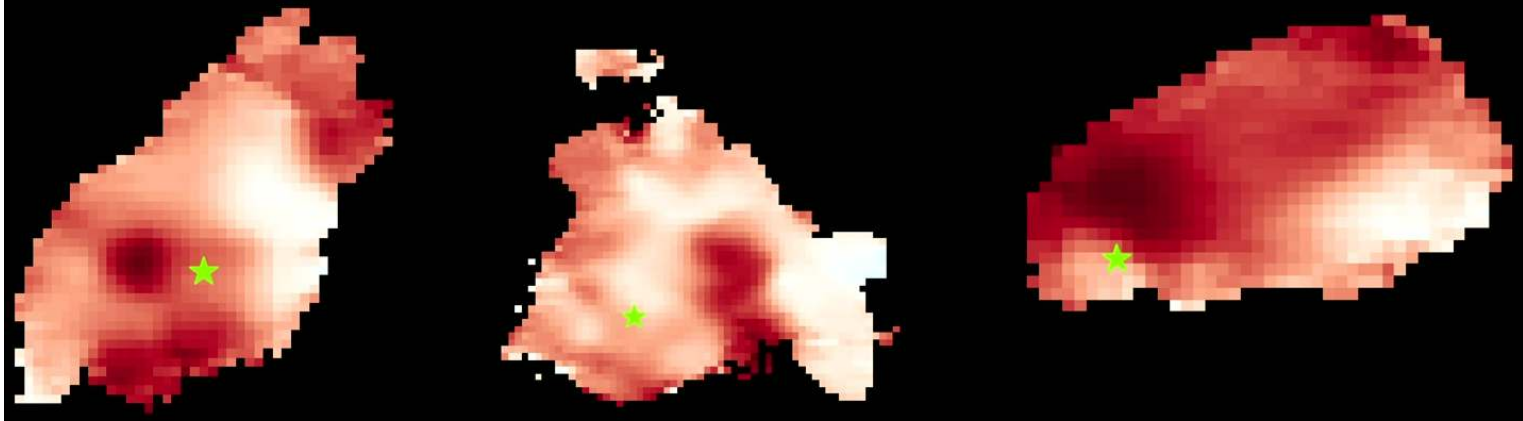


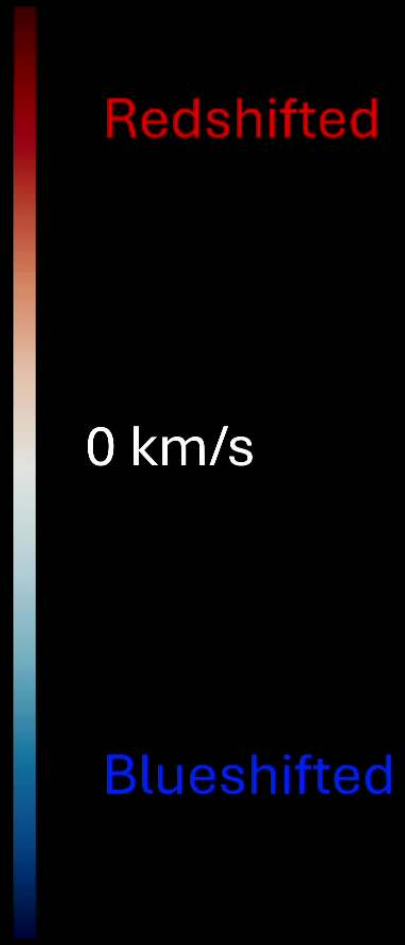


Gingras+2024

Peculiar motion of the central galaxy

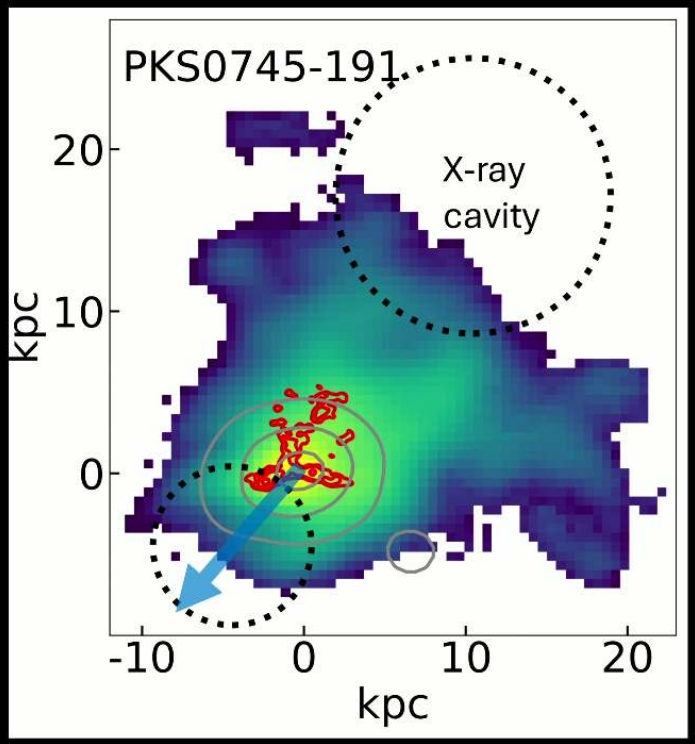
Nebular gas median velocity maps

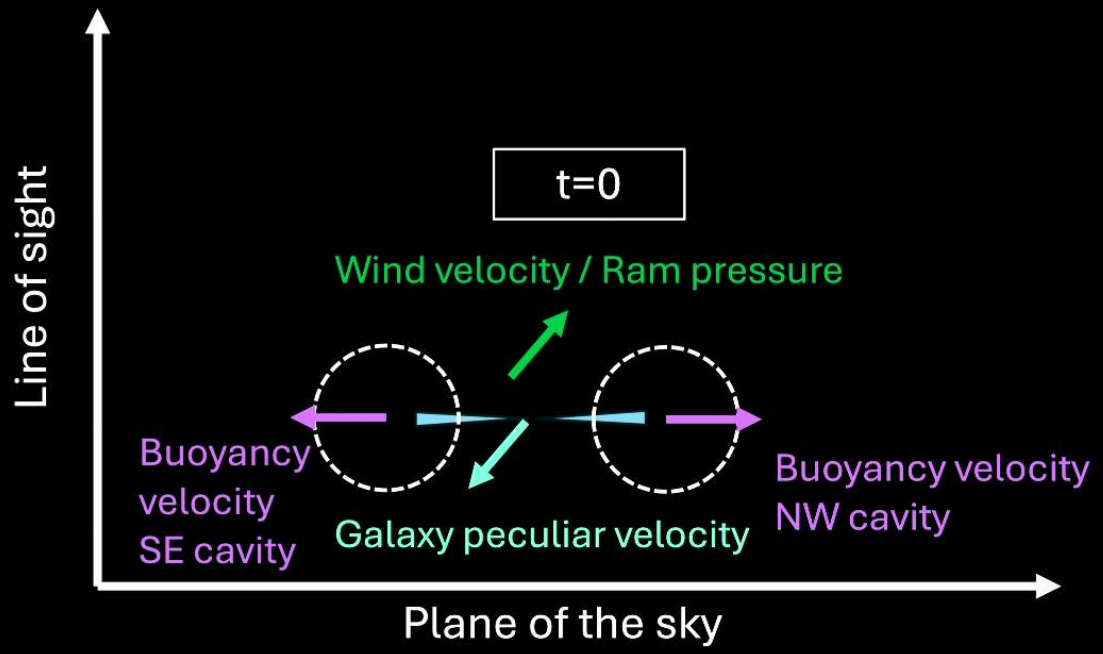




There is a systemic velocity difference between central galaxy and its nebular gas. The nebular gas is redshifted by ~ 150 km/s with respect to the galaxy in all three systems.

Peculiar motion of the central galaxy

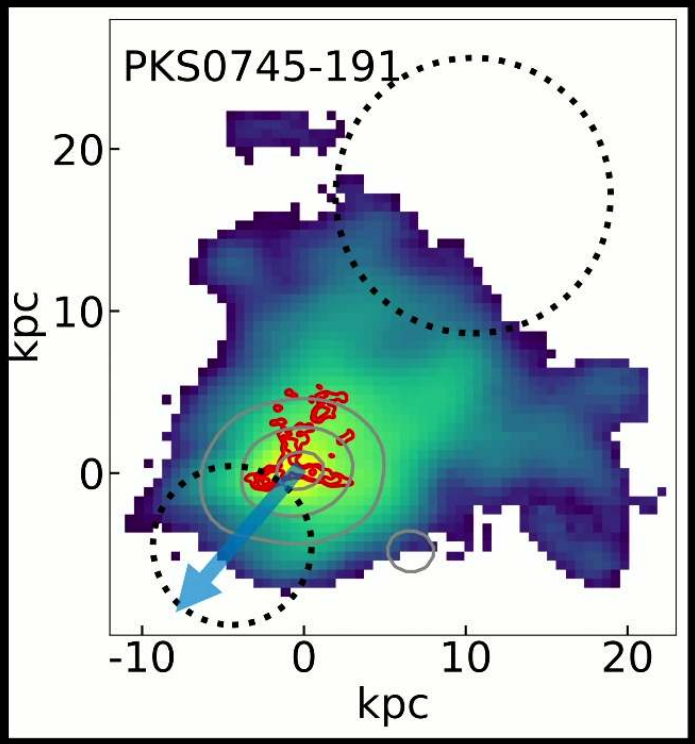


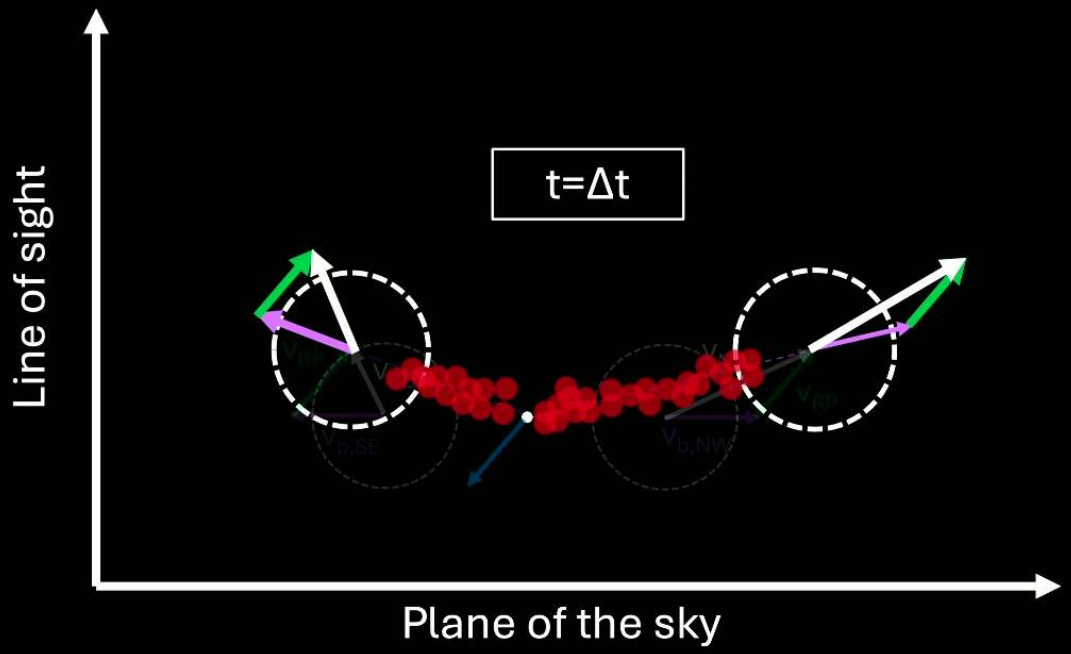


Sanders+2014, Russell+2016

PKS0745-191: Both cavities are behind the central galaxy

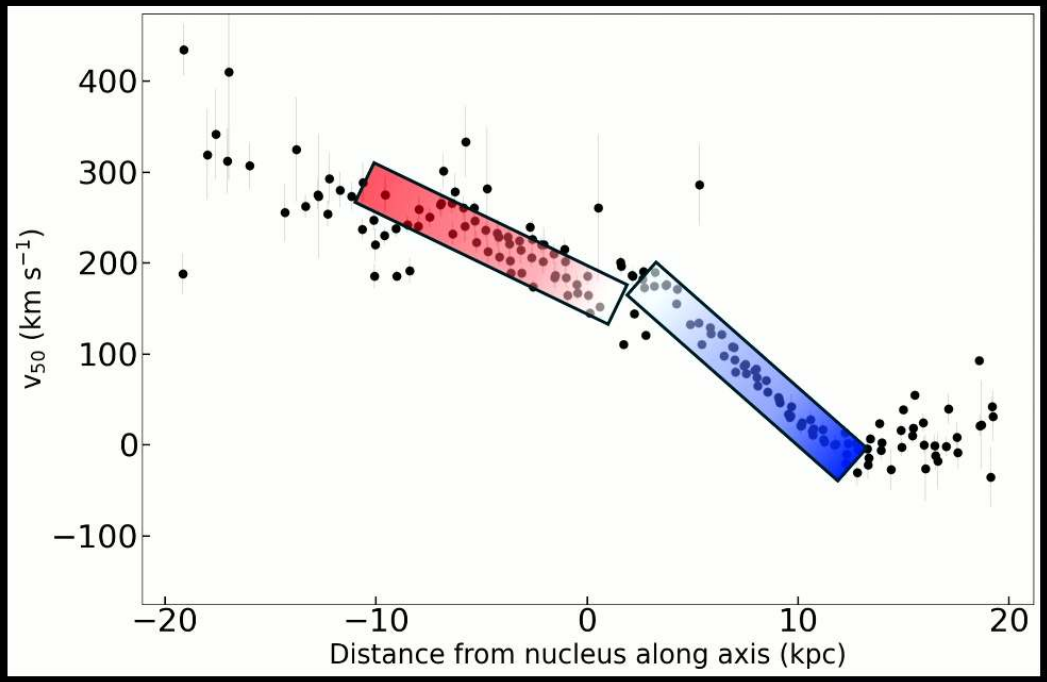
Peculiar motion of the central galaxy

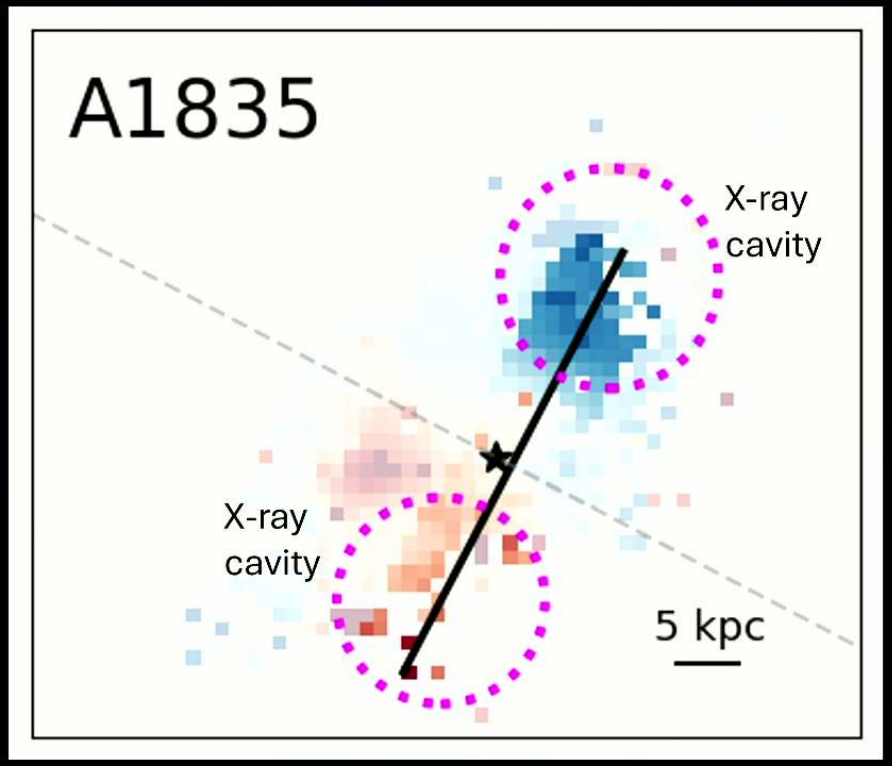




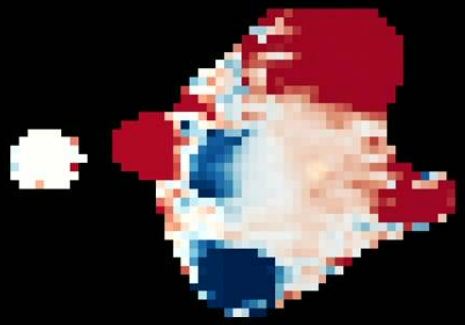
Nebular gas outflows

McNamara+2006, Gingras+2024

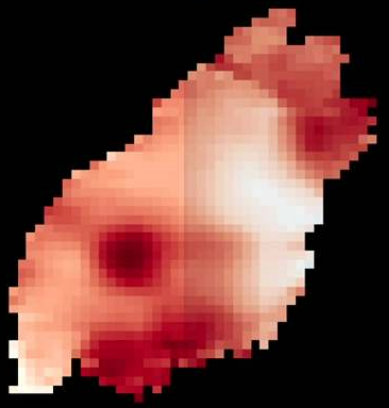




Stellar velocity

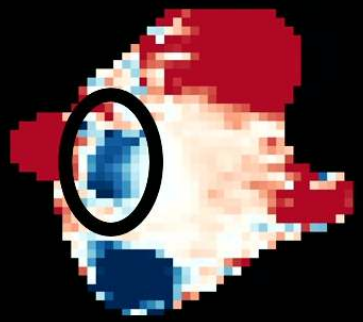


Gas velocity



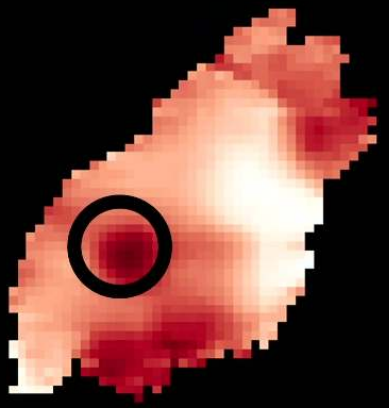
Comparison between nebular gas kinematics and star kinematics

Stellar velocity map



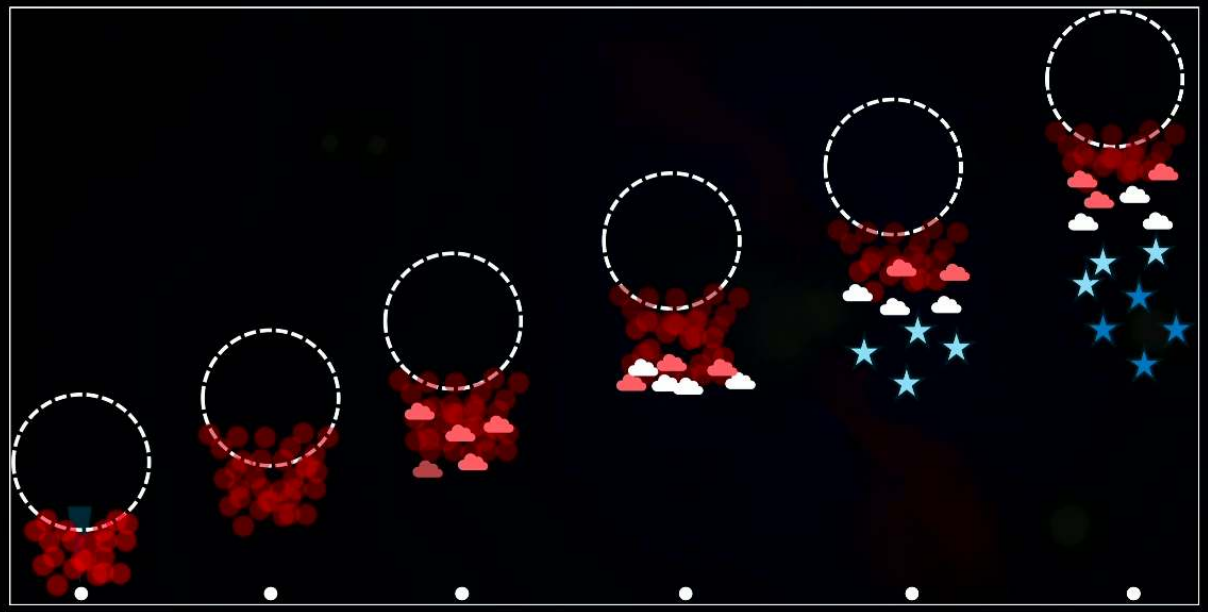
$V_{\star}$ ~ -300 km/s

Nebular gas velocity map



V_{gas} ~ +300 km/s

Comparison between nebular gas kinematics and star kinematics

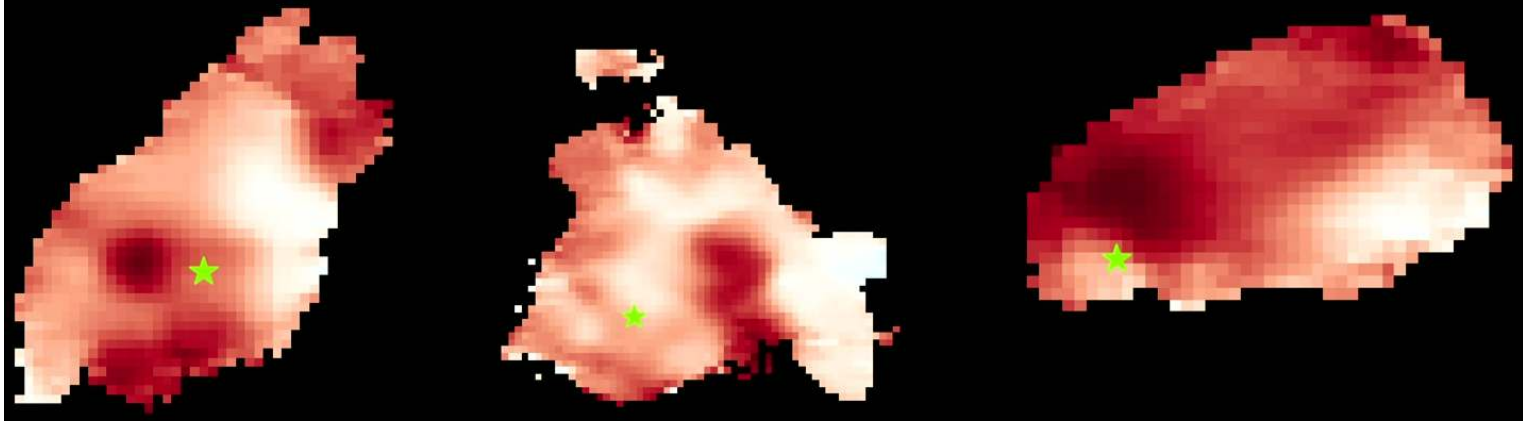


Summary

- **Peculiar velocity between the central galaxy and its associated nebular gas**
  - $|\Delta v| \sim 150$ km/s
  - Explains peculiar morphology and dynamics of RX J0820.9+0752 and PKS 0745-191
- **Multiple kinematic components in nebular emission**
  - **Innermost gas churned-up by central AGN**
  - **Surrounded by quiescent gas on larger scales**
- **Observations consistent with stimulated AGN feedback model**
  - Gas motions consistent with outflows trailing buoyant X-ray cavities
  - Dynamics of stars and nebular gas consistent with nebular outflow and subsequent infall of young stars in Abell 1835.

Peculiar motion of the central galaxy

Nebular gas median velocity maps



Redshifted

0 km/s

Blueshifted

There is a systemic velocity difference between central galaxy and its nebular gas. The nebular gas is redshifted by ~ 150 km/s with respect to the galaxy in all three systems.