IFU Search For Coherent Kinematic Structures Indicating Gas Inflow In Centres Of Galaxies

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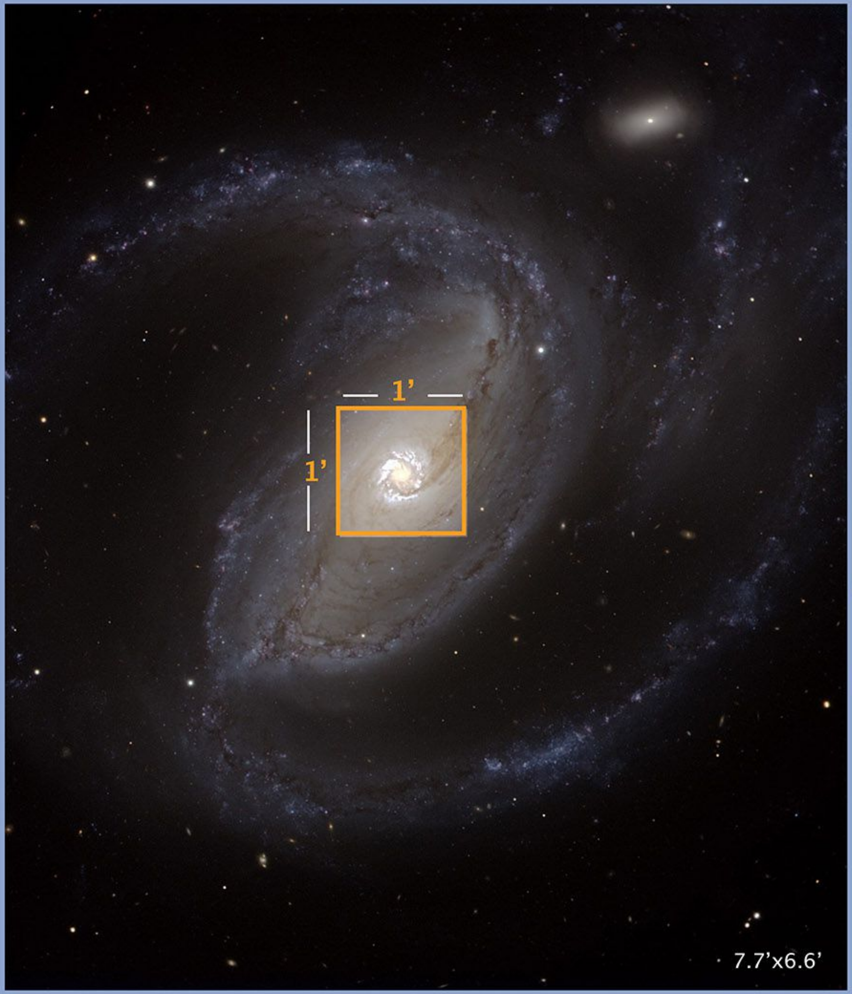
Overview

Gas inflows have a significant contribution to galaxy evolution. Commonly, gas inflows are associated with the presence of non-axisymmetric central stellar structures (bars) which are hosted by **65-70%** of disc galaxies in the local universe. Despite the consensus of inflow in these central structures on large scales, it is still not clear how does gas flow to the innermost nuclear regions of galaxies.

Theories and models indicate that gas inflow to the nucleus occurs as **coherent kinematic structures (shocks, kinematic spirals)** that form in response to the stellar gravitational potential. Thus far, instrumental limitations prevented detecting these structures in centres of galaxies.

In this work, we use data from next-generation **integral-field units (IFUs),** particularly from **MUSE**. We present our strategy of finding coherent structures in kinematic maps and our up to date findings.



Barred spiral (SBb) NGC 1097 (z=0.042). It hosts a bright AGN and has a nuclear ring in its inner 8” region. MUSE coverage of 1’x1’ is highlighted on the image.
Credits: VLT/ESO

Not familiar to gas inflows?

The torque induced by the bar puts gas clouds on intersecting trajectories. Such clouds collide along the bar, and the gas and the dust compressed in shocks give rise to the dust lanes. The shocked gas loses angular momentum and funnels to the inner regions of the galaxy, which is called gas inflows.

Gas inflows can **change the morphology of the central regions, enhance nuclear star formation, cause nuclear feeding, AGN feedback and quenching.**

Data sample

From AGN to inactive and early to late types, our diverse sample consists of 23 nearby galaxies from **the Composite Bulges Survey**[1] for which we gathered data from various instruments (MUSE, SINFONI spectrographs, HST imaging). The central stellar structures of the sample are extracted by well-defined criteria.

Strategy 1: Studying residuals after the direct subtraction of tracer velocity fields

Using this method, we aim to highlight coherent kinematic structures in gas velocity residuals without involving any models. The difference between the line of sight velocity of two emission lines indicates the regions of gas with different physical conditions that are moving with respect to one another.

Subtracting NII and Hα velocity fields revealed a strong coherent structure in the form of a blue spiral arm that extends from the centre towards the nuclear ring (see Figure 1 bottom). The feature is consistent with J Band NACO imaging residuals of Prieto et al. 2005[2] (i.e. once the radial intensity gradient has been removed).

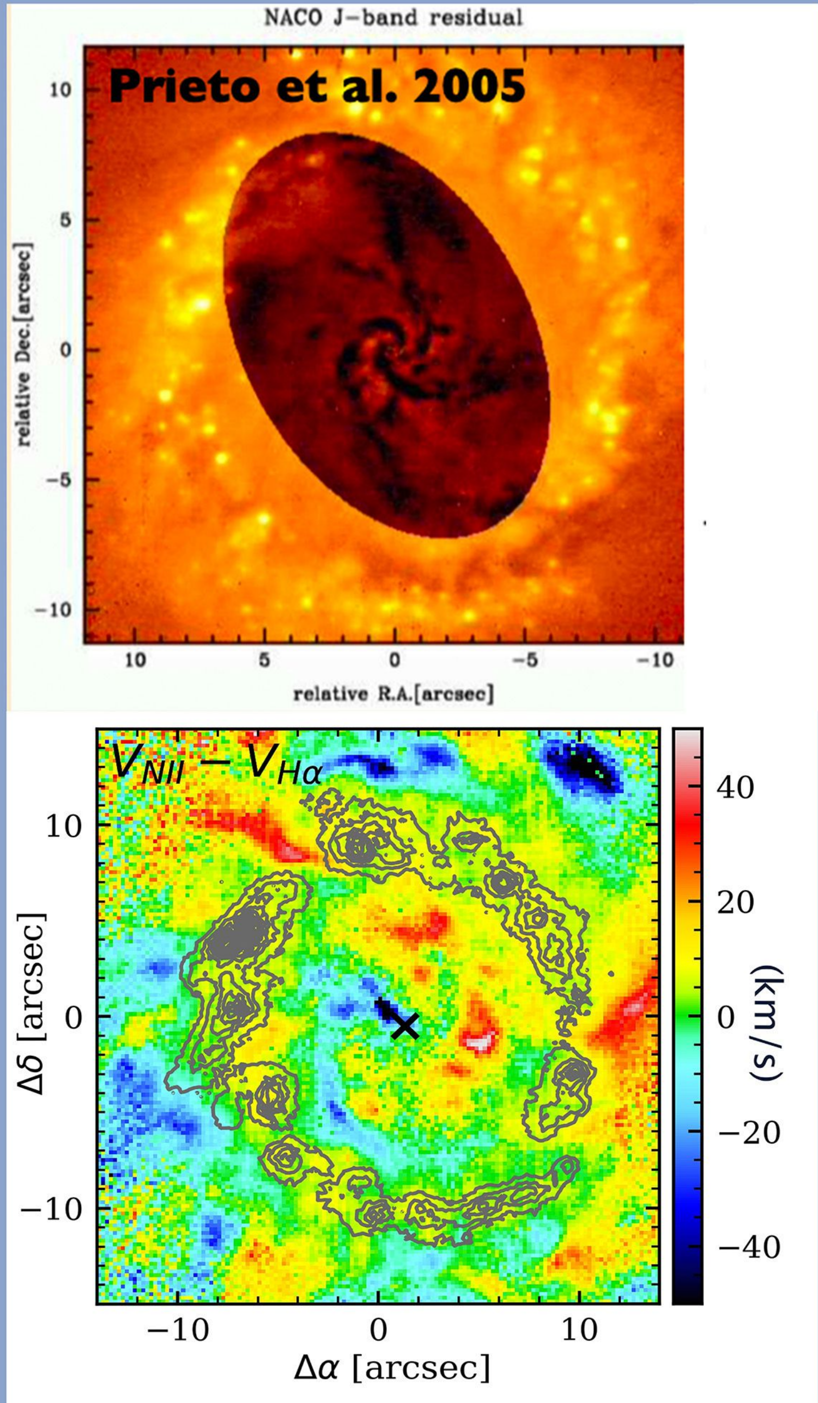


Figure 1: *top:* NACO J Band residual of NGC 1097 nucleus from Prieto et al. 2005. *bottom:* The residuals after NII and Hα velocity map subtraction. Contours represent Hα emission from the nuclear ring. The black cross indicates the centre.

What is the cause of NII−Hα spiral?

Since NII and Hα have very similar wavelengths, the difference in line of sight velocities is unlikely to be caused by obscuration.

We hypothesise that, if the spiral feature is the shock in gas similar to the large scale shocks along the bar, then NII should be preferably produced in the post-shock region which has a different velocity than the pre-shock region where Hα emission dominates. We expect that the nuclear spirals form as a wave response to non-axisymmetry in galactic potential[3].

Strategy 2: Coherent kinematic structures in residuals between data and model.

In this method, we fit the rotating disc model to our velocity fields. For this purpose, we employed the Kinemetry[4] software which performs harmonic expansion along best-fitting ellipses of optimal major axis' PA and of optimal ellipticity (plotted in Figure 2). For a thin circular disc, we interpret the major axis as the line of nodes and ellipticity as the effect of inclination.

We determine the best disk orientation parameters by choosing representative values of PA of line of nodes and q based on Figure 2. Then, we perform Kinemetry once more for a fixed PA and q. Kinemetry returns the rotating disc model and we subtract it from the original field. Residuals will reveal a non-circular flow of gas which should allow us to see coherent kinematic structures.

As shown in Figure 2, the parameters are not well constrained inside the nuclear ring. For both radial distributions values have a clear **"dip"** at 3"-6".

Constraining disc orientation carefully is crucial for our study. Subtracting a wrongly fitted disc model creates artefacts in residuals and obscures the physical features in the innermost regions (see Figure 3).

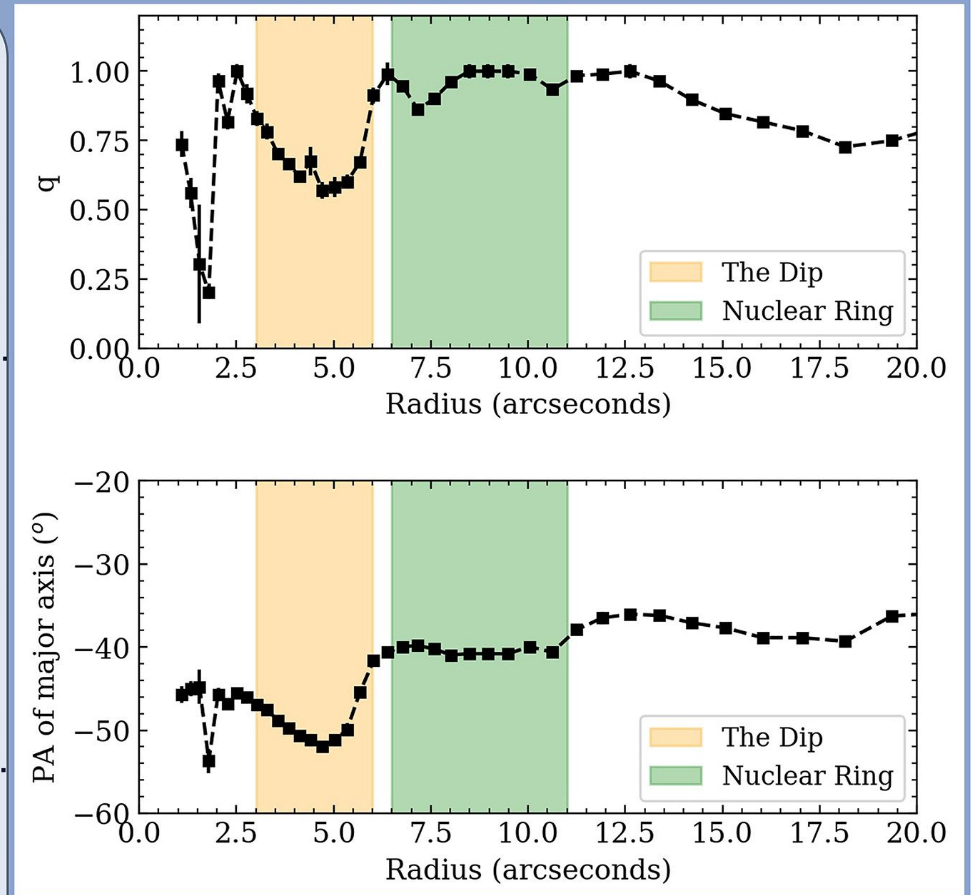


Figure 2: Radial distributions of q = cos(i) where i is the inclination (top), and of major axis' PA of the ellipse (bottom) derived by Kinemetry. The green shaded region represents the nuclear ring. The orange shaded region shows the range where the **dip** is present.

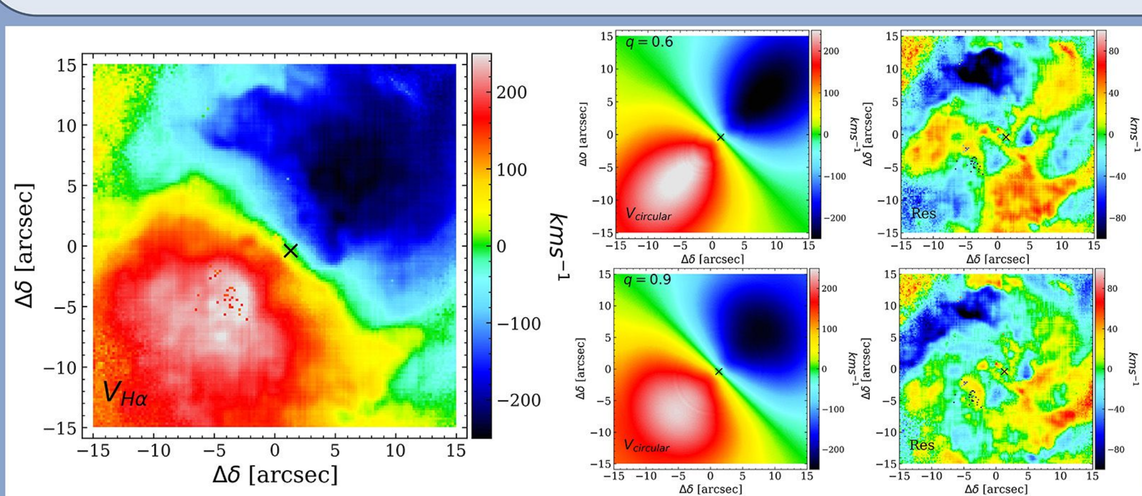


Figure 3: Example of artefacts caused by fitting a disc with wrong disc orientation parameters. Original Hα velocity field (left) rotating disc model (middle) residuals after subtracting the model from the original velocity field (right). PA of major axis is fixed at -46°. Top row is for q=0.6, bottom row is for q=0.9. The three arm fan structure in residuals indicates wrongly fitted inclination in the model.

Non-circular motion inside nuclear ring

Kinemetry, when applied to a thin disc, assumes circular motion, and then the ellipticity parameter arises from the inclination of the disc. However, ellipticity can also be caused by intrinsic non-circular motions in the disc inside the nuclear ring.

For non-circular motion, the line of nodes is not perpendicular to the zero velocity line, while it has to be perpendicular for circular motion. So, to check whether non-circular motions present, we can compare the PA of zero velocity line to the PA of line of nodes.

Figure 4 shows the radial distributions of PAs of zero velocity line after subtracting 90° and of line of nodes for both Hα and stellar velocity fields. For stellar velocity fields, the distributions are roughly aligned, while for gas, the difference in PA is~15° at 3”-6”. This strongly indicates the presence of non-circular motions inside the nuclear ring, corresponding to the “dip” where Kinemetry fails constraining parameter values (orange shaded regions of Figures 2 and 4).

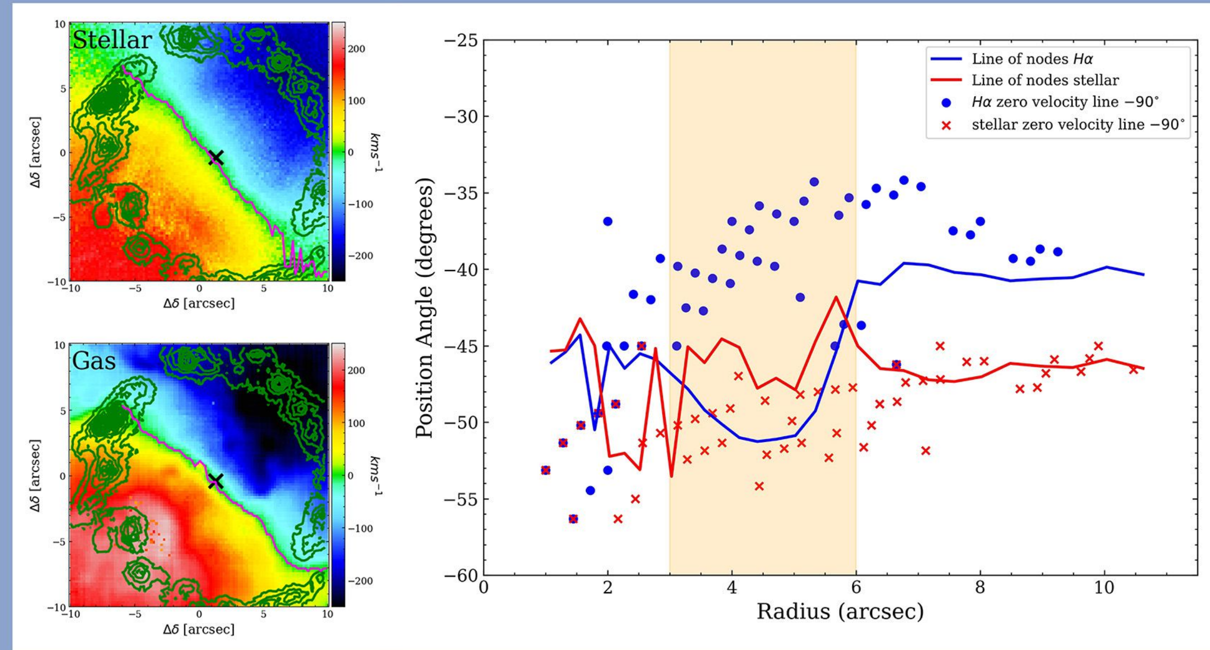


Figure 4: *left:* stellar (top) and Hα gas (bottom) velocity fields. The purple line shows the zero velocity line. Green contours represent Hα emission from the nuclear ring. The black cross represents the galaxy centre. *right:* the comparison between PAs of zero velocity line (points) and PAs of line of nodes (solid lines) from Kinemetry. The shaded region shows where the dip is present in Figure 2.

References
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