A search of neutral gas outflows in nearby [U]LIRGs via optical IFS of the NaD feature

S. Cazzoli[1,2,3], S. Arribas[1], R. Maiolino[2,3] and L. Colina[1]

[1]CSIC - Departamento de Astrofisica - Centro de Astrobiologia (CSIC-INTA) Madrid
[2]Cavendish Laboratory, University of Cambridge, Cambridge, [3]Kavli Institute for Cosmology, University of Cambridge, Cambridge

Galactic Winds (GWs)

GWs have a central role in galaxy evolution regulating and quench both the star formation both the black hole activity. They are also primary contributors to the chemical and thermal evolution of the Universe by enriching and heating the IGM. Indeed, cosmological models of galaxy evolution require energetic outflows to reproduce the observed properties of galaxies[1]. The multiphase nature of GWs complicates the task of estimating the feedback. Of particular interest is to measure the mass of gas expelled by winds in the coldest phases (i.e., the reservoir available for the SF).

Cold Neutral GWs in [U]LIRGs

Roughly 80% of local luminous and ultra-luminous infrared galaxies ([U]LIRGs) show blueshifted absorption of neutral sodium (NaD$\lambda\lambda$5890, 5896), indicating that cold neutral winds are common in such objects. Local [U]LIRGs have a starburst activity and basic structural[2] and kinematic[3] properties similar to that found for "main-sequence" high-z star forming galaxies[4]. Recent works[5,6] have suggested that high-z [U]LIRGs are scaled-up versions of local LIRGs. Such population offer the opportunity to study the outflow phenomenon at environments similar to that observed at high-z, but with a much higher S/N and linear resolution.

The IFS [U]LIRGs survey[7]

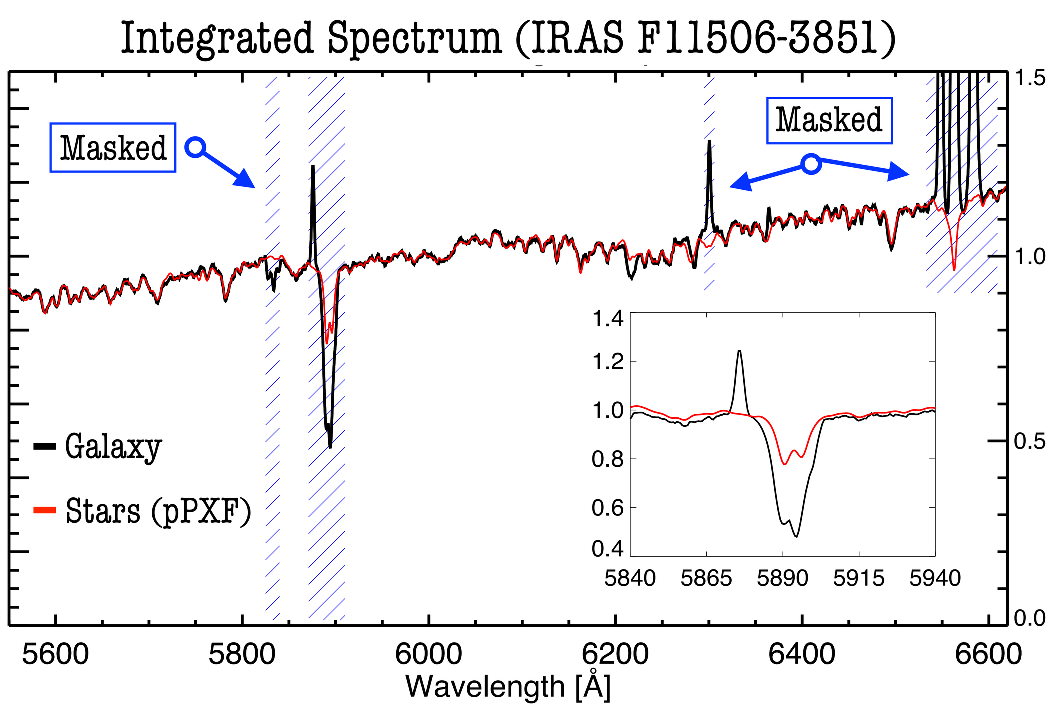
- 31 LIRGs + 8 [U]LIRGs (TOTAL = 51 individual galaxies)
- z ~ 0.009 - 0.09 (<0.024>)
- $L_{\rm IR} = (10^{11} - 10^{12.6})\ L_\odot$
- Isolated, interacting and post-merger galaxies
- HII, Seyfert and LINER ionization types

Observations:

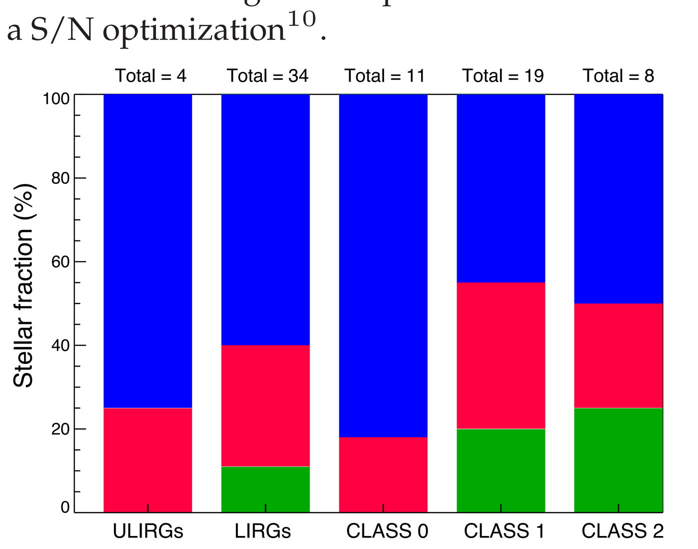
- IFU of VIMOS @ ESO-VLT
- HR orange grating (5250-7400 Å) R~3470
- FoV 29.5"x29.5"
- Spaxel Scale of 0.67" per fiber

Stellar NaD

The stellar NaD absorption originated in late-type stars (e.g., K-type giants) may contribute to the observed NaD feature. To evaluate the global "stellar contamination" to NaD we apply the Penalized Pixel Fitting method[8] (pPXF) to the integrated spectra of the galaxies. We produced a model stellar spectra that matches the observed line-free continuum (any ISM features, e.g., HeIλ5876 and the NaD, are blocked). The Indo-Us Coude library[9] has been used as a stellar template, providing wide spectral coverage (3460-9464 Å) at a resolution of 1.0 Å (FWHM) for 1273 spectra.



Top. An example of the integrated spectra and its best-fit stellar spectra obtained with the pPXF approach. The insert highlights the NaD region: the lack of good agreement in the doublet feature indicates that the NaD absorption is mainly interstellar in origin. The spectra is extracted from the 2D-IFS data cube based on a S/N optimization[10].

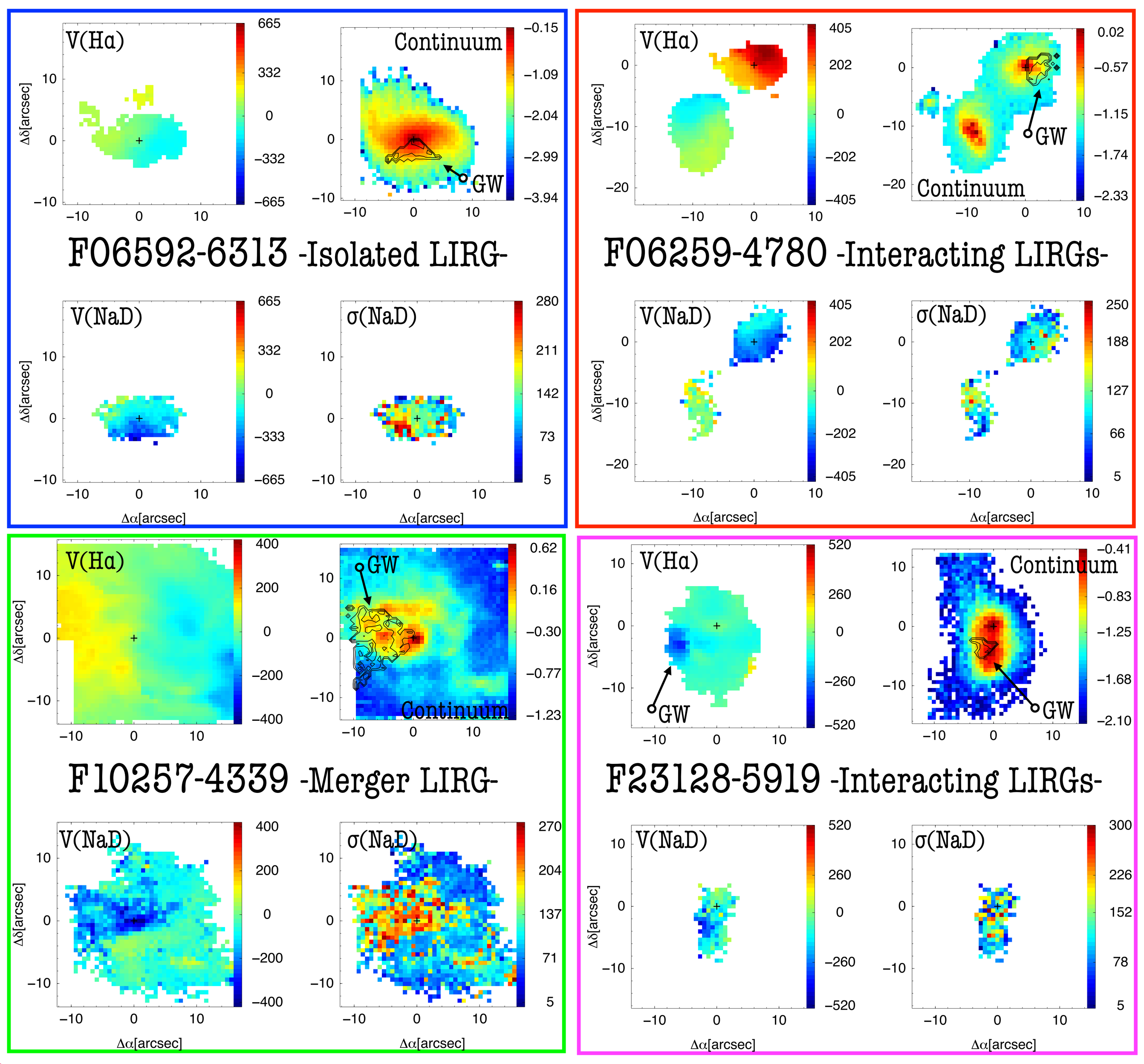


Left. The fraction of stellar contamination derived with pPXF for different luminosities and morphological types in the whole sample. Bars are color-coded by the amount of stellar fraction in individual integrated spectra, as follows:

- LOW: <50%
- MEDIUM: 50-80%
- HIGHT: >80%

NaD-Kinematic and GWs

Most of the NaD-absorption features show smooth and unblended line profiles. A Levenberg-Marquardt fitting routine in IDL (MPFITEXPR) is used to fit with one kinematic component the NaD feature for each spaxel. The output of the routine (line flux, central wavelength and intrinsic width) were used to generate spectral maps. In the following panels, we present examples of the 2D velocity field of the ionized gas (traced by H$\alpha\lambda$6563[4]) and the 2D neutral gas spectral maps (V(NaD), σ(NaD)) for four LIRGs with different morphologies. As reference, we also include the continuum image generated from the VIMOS-IFU data cube.



F06592-6313. Its ionized gas component is undergoing orderly rotation with amplitude of ~160 km/s while, along the galaxy semi-minor axis (towards the South), we observe broad and blue-shifted NaD lines with velocities up to 660 km/s. This is indicating strong radial motions, likely emerging from the nucleus, that are interpreted as a GW.

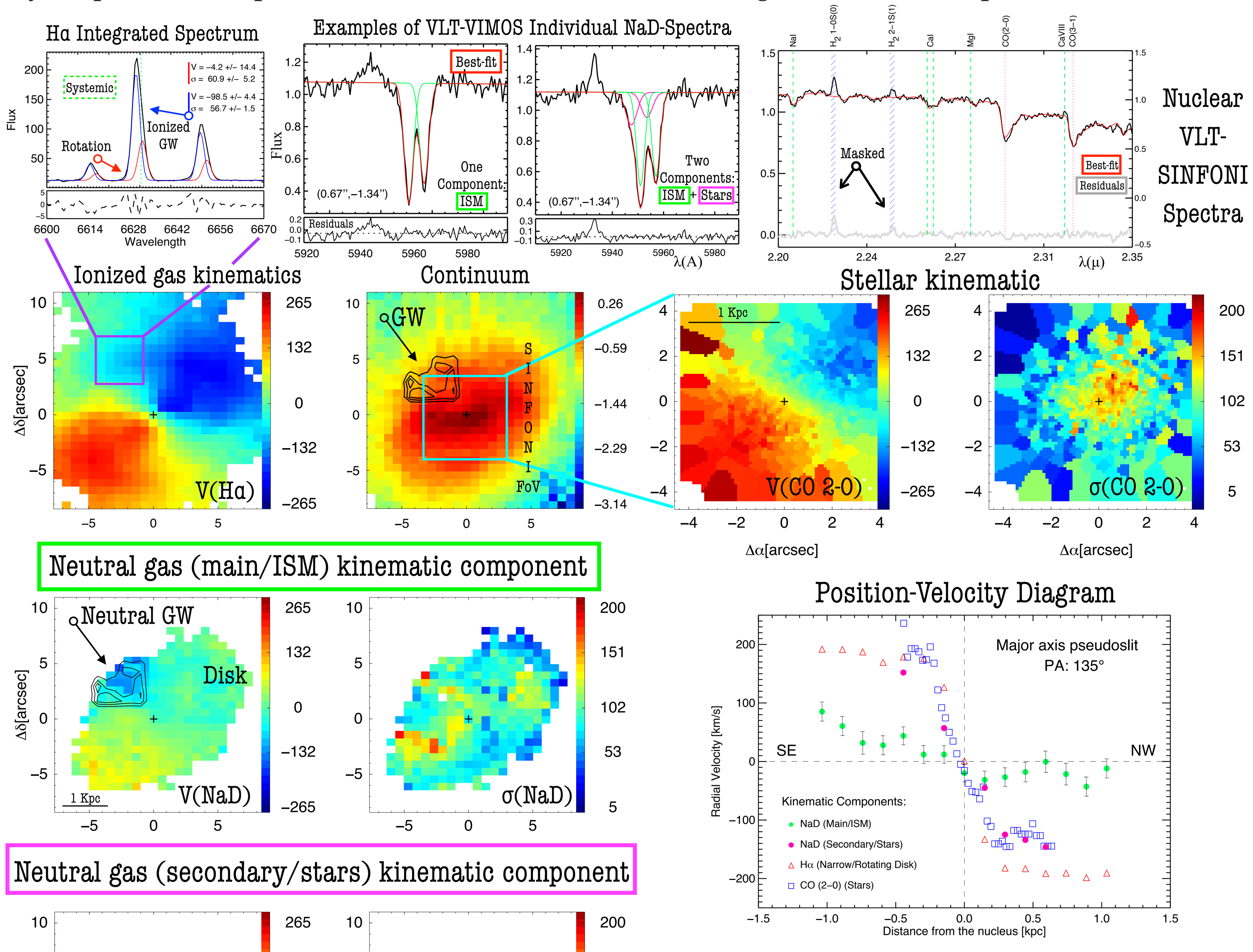
F06259-4780 North shows an asymmetric neutral gas velocity field revealing modest deviation from rotation toward the West. The spatial coincidence between non-circular motions and turbulence (as seen in the σ-map) is consistent with the presence of outflowing neutral gas. The outflow is likely powered by SF, since the absence of evidence of AGN or tidal features induced by merger shocks.

F10257-4339. Towards the East, the NaD line profiles are extremely broad and blue shifted. Velocities, reaching 400 km/s, are much larger than the ionized gas velocities and are too hight to be simply explained by NaD-rotation. The neutral gas is clearly outflowing and the GW is likely to be massive enough to provide a strong feedback on the host.

F23128-5919 is a system composed by two merging galaxies separated by ~4 kpc. Most of the neutral gas associated to the merger is outflowing reaching velocities up to 500 km/s. The bubble emerging from the region between the two nucleus (toward the East) is unique in our sample and represents a multiphase outflow powered by the merger.

Multi-λ description of the LIRG IRAS F11506-3851 ($L_{\rm IR} = 10^{11.3}\ L_\odot$)

In **Cazzoli et al. 2014 - arXiv1406.5154C** , the morphology and the 2D kinematics of the gaseous (neutral and ionized) and stellar components have been mapped for IRAS F11506-3851, via NaD, Hα and CO(2-0) λ2.293μm features. The kinematics of the ionized gas and the stars are dominated by rotation, with large observed velocity amplitudes and centrally peaked velocity dispersions maps. The 2D kinematics of the neutral gas shows a complex structure dominated by three main components.



Thick disk. The slowly rotating disk (supported by random motions) is lagging significantly as compared to the ionized gas and the stars, and it has an irregular and off-centered σ-map.

Kpc-scale GW. It is revealed by the large blueshifted velocities (up to 154 km/s) observed along the galaxy's semi-minor axis (likely perpendicular to the disk). On the basis of a simple free wind scenario, we derive an outflowing mass rate ($\dot{M}_{\rm w}$) in neutral gas of ~48 M$_\odot$yr^{-1}. Since the SFR is ~34, the GW is evacuating gas 1.4 (i.e., $\dot{M}_{\rm w}$/SFR) times faster than the SF. The GW is caught in act also in its ionised phase.

Stars. A secondary NaD component has properties fully consistent with a stellar origin, as evidenced by its kinematics. This result is also supported by the stellar-continuum modeling of the integrated spectrum, which indicates that ~2/3 of the NaD absorption is interstellar in origin, while only a small contribution is due to the stars.

SUMMARY: Main kinematic properties of the different constituents/phases in IRAS F11506-3851

Constituent or phase	Tracer	Component (Structure)	ΔV^a km/s	σ_c^b km/s	σ^c km/s
Stars	CO(2-0)	main (disk)	188 ± 11	136 ± 20	78 ± 16
	NaD	secondary (disk)	150 ± 15	152 ± 31	82 ± 31
Ionized Gas	Hα	main (disk)	203 (202) ± 4	95 ± 4	45 (44) ± 10
Neutral Gas	NaD	main (disk)	83 (80)± 12	127 ± 5	84 (83) ± 10
		main (outflow)	-64 ± 20	...	98 ± 10

– Notes. The FoV covered by the NaD absorption cover only the central region of the VIMOS FoV. The near-IR individual spectra has been modelled with the pPXF approach and the correspondent maps were binned using the adaptive Voronoi binning method[11]. PV Diagram: error bars are not displayed for the ionized gas, stars and the NaD secondary component speeds since they are, typically, less than 15 km/s, (smaller than the corresponding symbols).

Future developments

- The combination of IFS VIMOS + SINFONI data allowed us to address the issues of the GW-feedback in IRAS F11506-3851, as well as the kinematical and dynamical properties of its stellar and gaseous (ionised and neutral) components.
- Key questions such as the role (and properties) of neutral GWs in host galaxy evolution and the analogy of GWs in local and distant galaxies will better addressed in future papers of the series. We leave for the following paper of the series a detailed kinematical study of the neutral gas kinematics within our entire sample.
- **Cazzoli et al. 2014 - 014 arXiv1406.5154C** & **Cazzoli+2014 in prep. - - Stay tuned!**
- **CONTACTS:** scazzoli@cab.inta-csic.es — s.cazzoli@mrao.am.ac.uk

References

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