Corrugated velocity pattern in spiral galaxies: NGC 278, NGC 1058, NGC 2500 & UGC 3574

Mª Carmen Sánchez Gil, Emilio J. Alfaro & Enrique Pérez
Instituto de Astrofísica de Andalucia, CSIC. Granada

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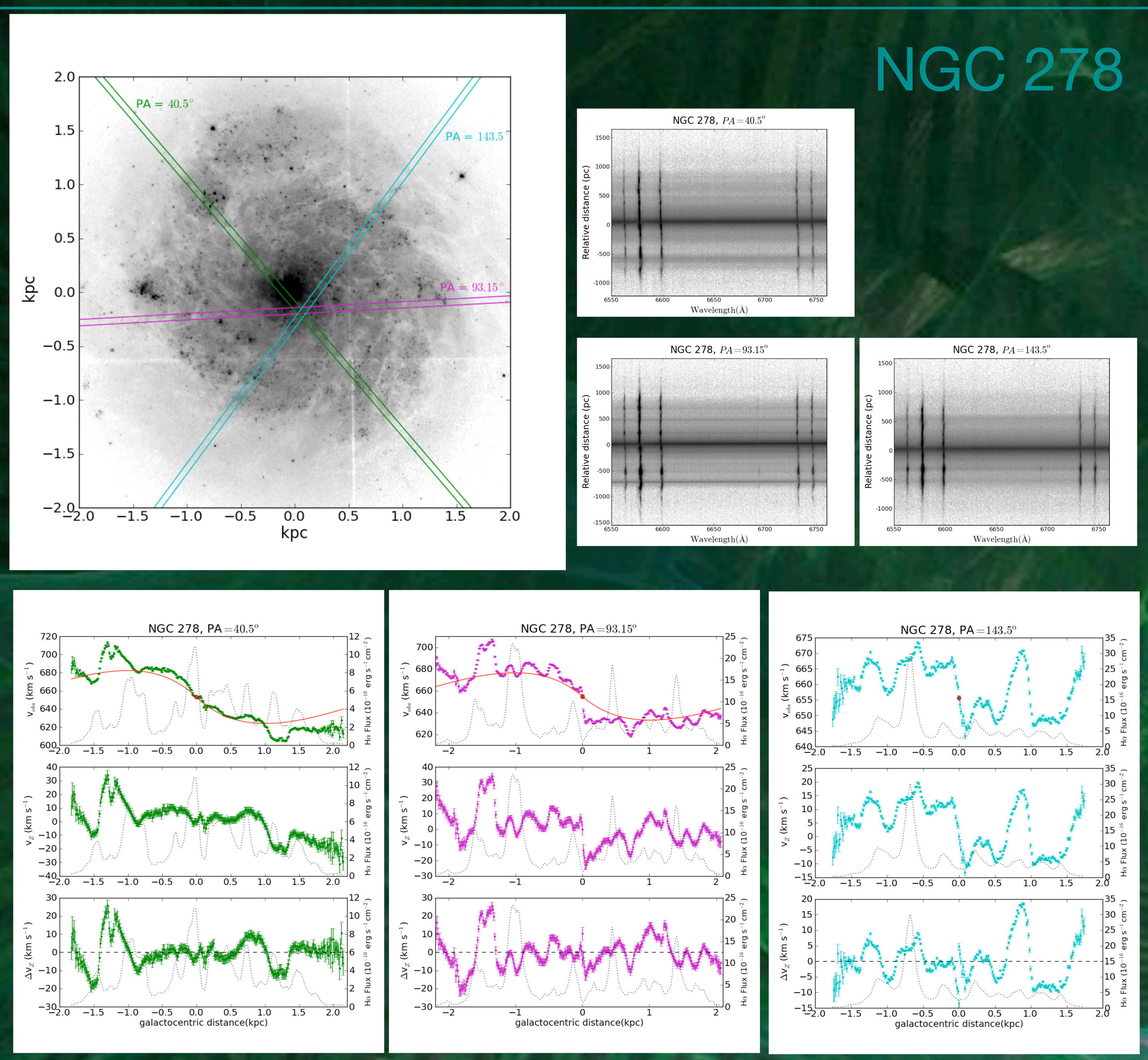
Detection of a corrugated velocity pattern:

- We report the detection in Hα of a radial corrugation in the vertical velocity field of a sample of nearby face-on, spiral galaxies.
- A corrugated velocity pattern was firstly detected in NGC 5427, Alfaro et al. (2001).
- Spatial corrugations are well known in the Milky Way since the sixties of the XX century (Kerr 1957; Gum, Kerr, & Westerhout 1960).
- The origin of the corrugations is still matter of debate. Several mechanisms driving these structures have been proposed:
  - A galactic bore generated by the interaction of a spiral density wave with a thick gaseous disk, as modeled by Martos & Cox (1998).
  - Collisions with high-velocity clouds and galactic interactions. Some authors also explored the possibility of undulations along spiral arms, induced by magneto-gravitational instabilities (Nelson 1985; Gómez de Castro & Pudrtiz 1992; Km, Hong & Ryu 1997; Franco et al. 2001).
- More recently, corrugations in the disk of the edge-on spiral galaxy IC 2233 has been discovered by Matthews & Uson (2008). At this case the authors point to global gravitational instabilities as the origin of this corrugation pattern. Although local perutbations may also be important.

DATA:

- We obtained long-slit spectroscopy with the double arm ISIS spectrograph, attached to the 4.2 m WHT, at the San Roque de los Muchachos Observatory (La Palma), during December (15-16) 2003.
- Two spectral ranges observed simultaneously: around Hβ (4861 Å) and Hα (6563 Å), with the gratings R600B and R1200R respectively, providing a dispersion of 0.45 and 0.23 Å/pixel.
- Slit width of 1 arsec, with a spatial sampling of 0.2 arsec/pixel.
- The slit was placed at two or three different position angles for each galaxy.

NGC 278



We analyse the perpendicular component of the velocity to the galactic disk, V_Z (usually ignored for being considered negligible in many kinematical studies), and its corrugated pattern.

We assume the observed velocity as the projection on the line of sight of all its components. So, it can be expressed in terms of:

$$V_{obs} = V_{sys} + V_{\parallel} \sin i + V_{\perp} \cos i = $$
$$= V_{sys} + V_{rot} \cos\theta \sin i + V_{\perp} \cos i$$

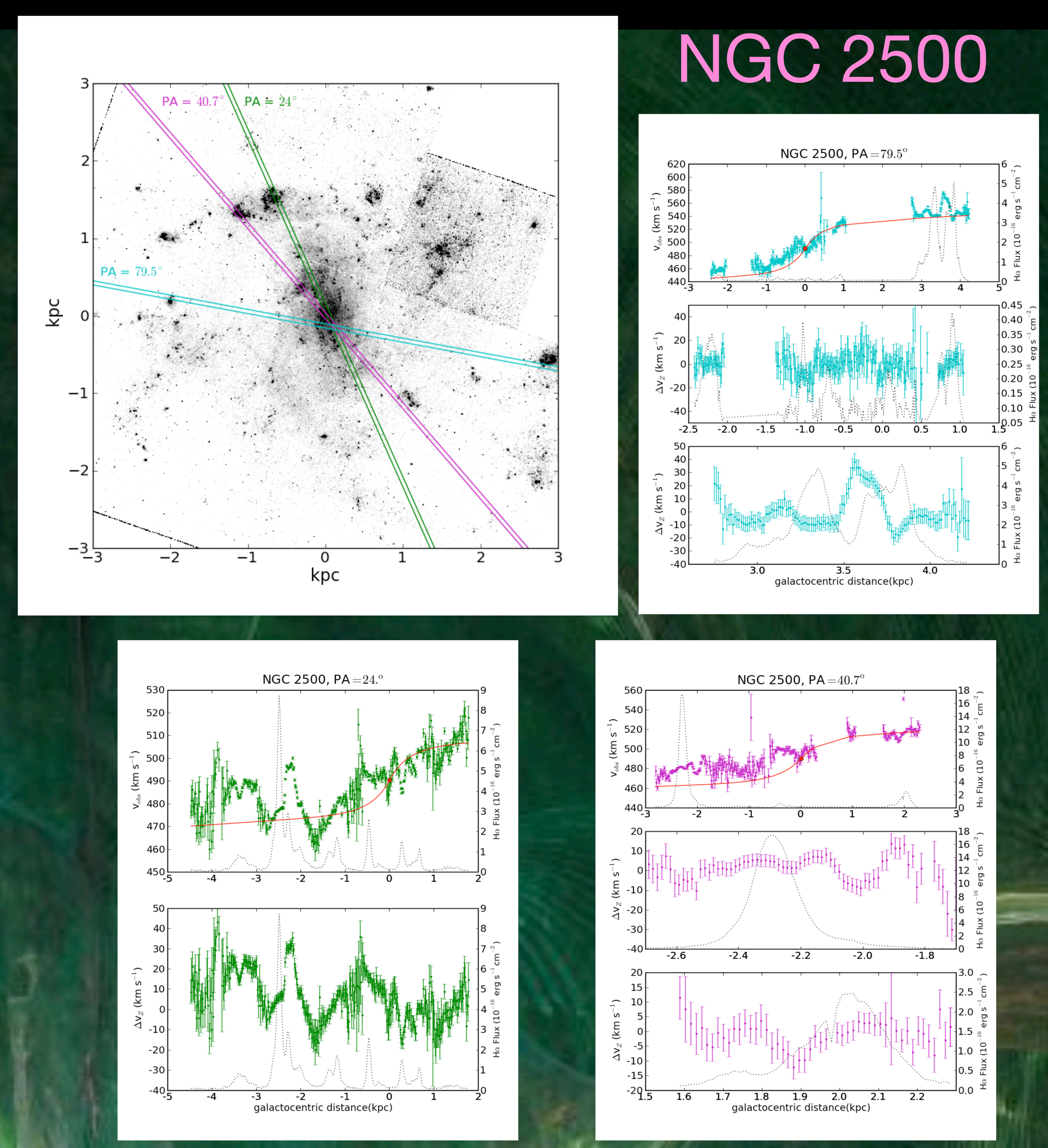
where V_{sys} (red dot in the plots) is the systemic velocity of the galaxy, $V_{\parallel}$ and $V_{\perp}$ (or V_Z) are the parallel and perpendicular velocity components to the disk, respectively.
i is the inclination angle of the galaxy disk, and θ is the angle in the plane of the disk, counter-clockwise from the major axis.

The rotation curves, V_{rot} (the red lines in the plots), as well as the PA and i for the galaxy sample were obtained from Epinat et al. (2008).

The vertical velocities were detrended, ΔV_Z, by fitting a linear component to the global residual trend as rotational residues and removing them. Remaining only the local oscillations of V_Z.

Our aim is to analyze the corrugated velocity pattern in term of the star formation processes. To do this we compare V_Z with the Hα emission along the slit.

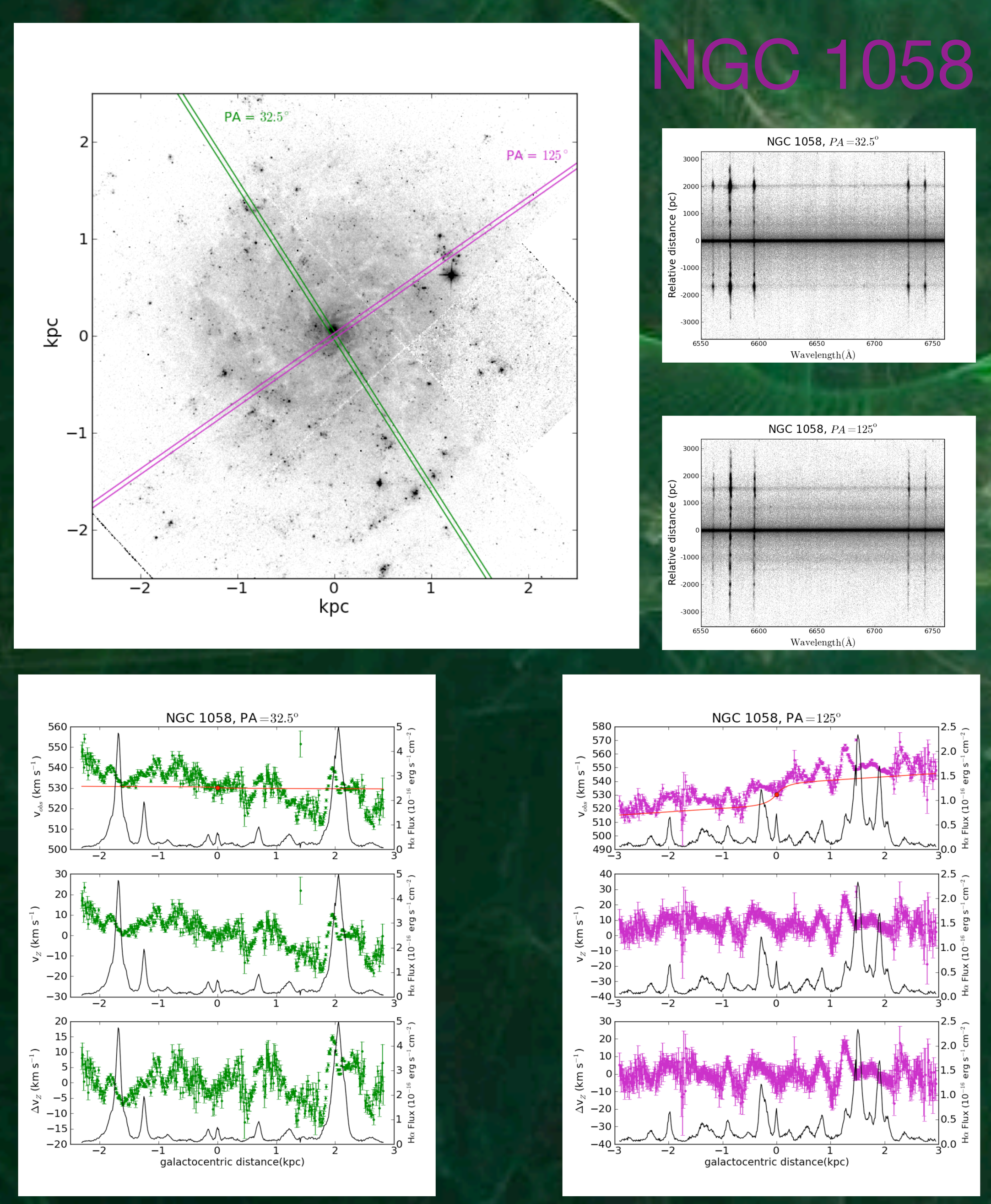
NGC 2500



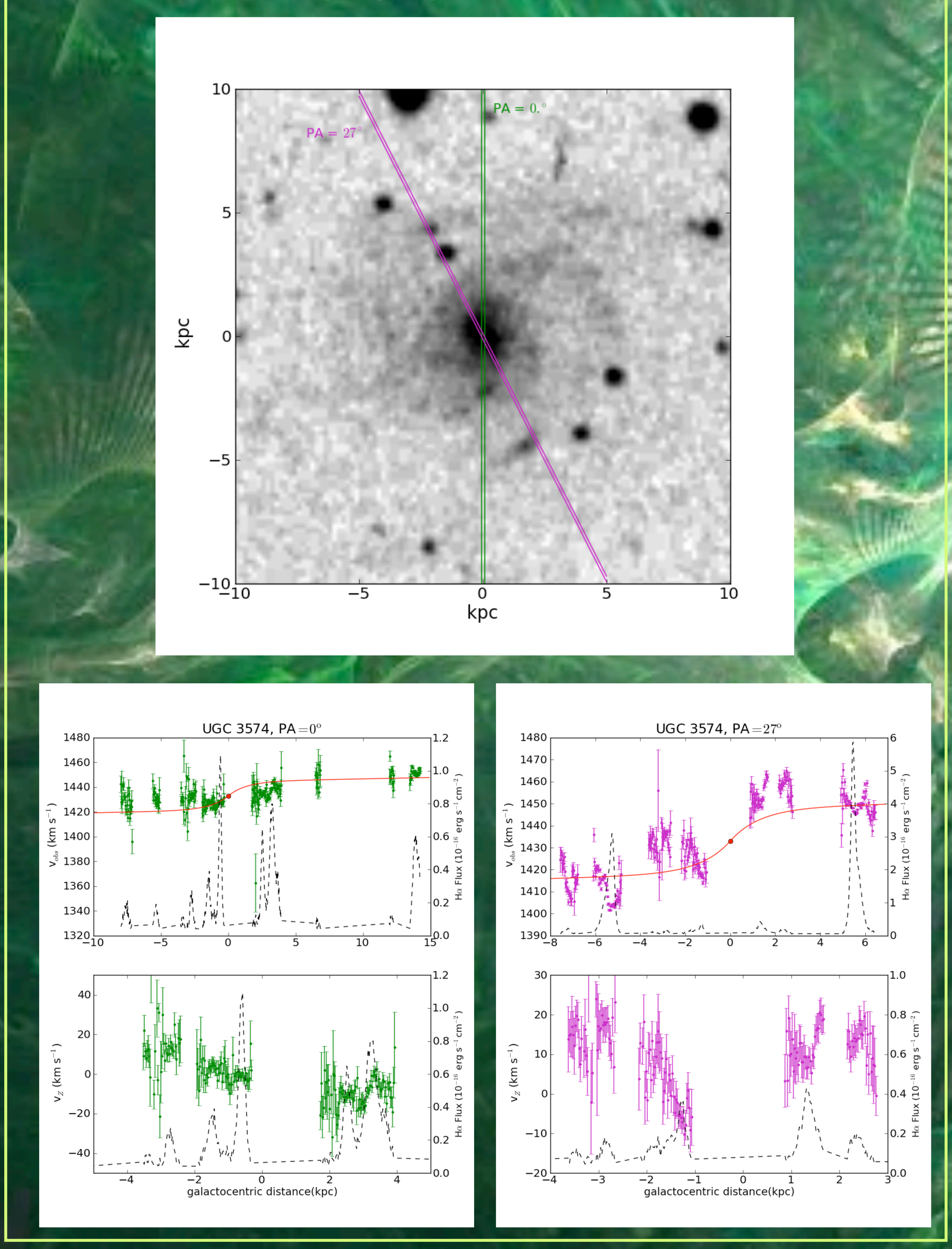
Diagnostic Diagrams:

- The ionization and excitation process can be determined by plotting [NII]/Hα versus [OIII]/Hβ, depending on its location in the diagram (Baldwin, Philips & Terlevich 1981).
- Diagnostic Diagrams (DD) show photoionization, from high energetic photons, as the main ionization mechanism.
- Only a small portion of the gas appears to be ionized by low-velocity shocks. Except for NGC 1058, where the slit with PA = 125º have a bigger portion of ionization by shocks.
- NGC 278 and NGC 1058 show all their different slits positions, represented with different colors, at the same location of the DD.
- Whereas at NGC 2500 and UGC 3574, each slit postion occupies a different location in the DD, as a metallicity gradient.

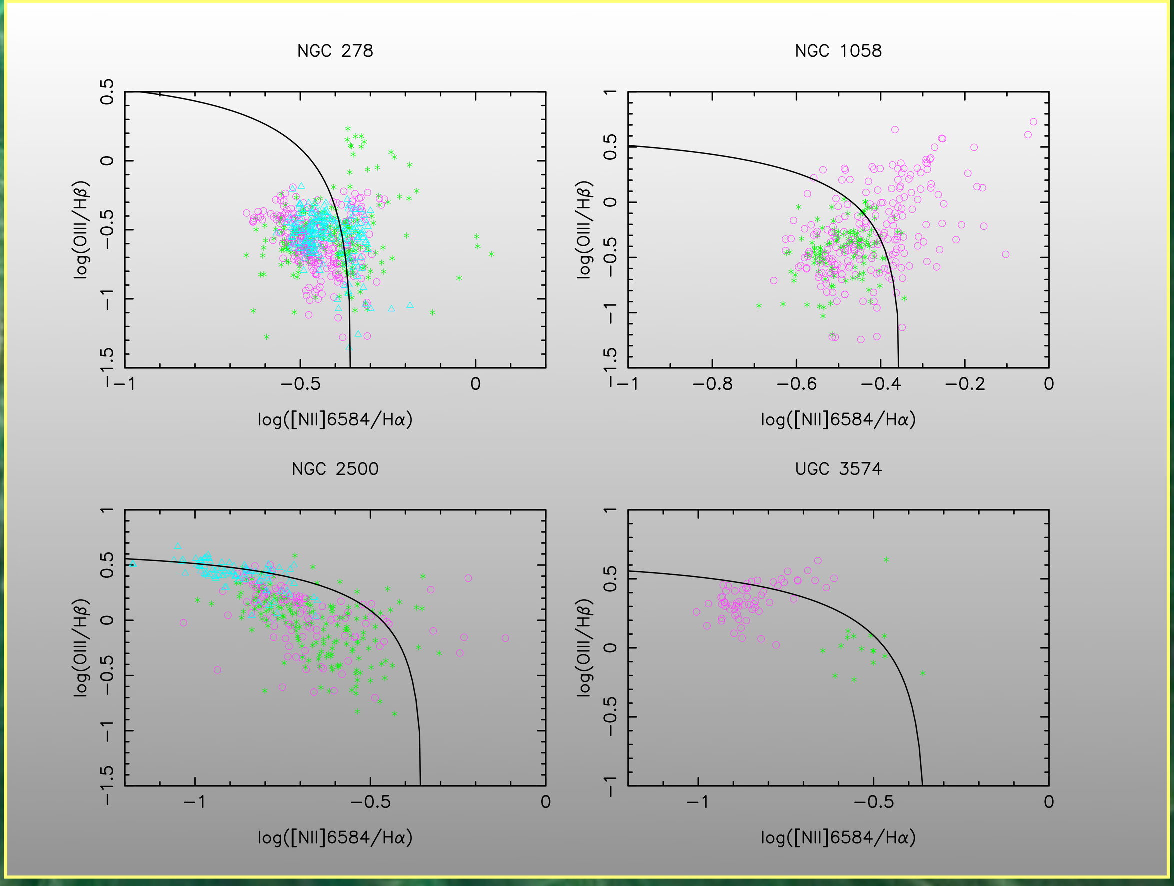
NGC 1058



UGC 3574



Diagnostic Diagrams



FIRST RESULTS:

- The existence of corrugations has been already reported, e.g. Alfaro et al. (2001), Matthews & Uson (2008). In this work not only the existence of radial and azimuthal corrugations is clearly observed, we report a first systematic study on velocity corrugations in a sample of nearly face-on spiral galaxies.
- Corrugations are closely link, as cause/effect, to the large scale star formation processes: density waves, tidal interactions, galactic bores, collisions of high velocity clouds with disk, etc. Which mechanism is the origin of disk corrigations is still an open problem.
- A first stage of the analysis of the data and their results are presented. Some first results are:
  - NGC 278 and NGC 1058 show a similar behavior to NGC 5427 (Alfaro et al. 2001), with a clear displacement between the velocities and emission line peaks. Where the approaching (negative values) peaks of ΔV_Z occur in the convex border of the arms, and the receding maxima (positive values) are located behind the Hα emission maxima, in the concave side. This kinematical behavior is similar to the one expected in a galactic bore generated by the interaction of a spiral density wave with a thick gaseous disk.
  - Whereas NGC 2500 and UGC 3574 do not show so clear the last relation between the velocities and emission line peaks. It should be due to a fainter Hα emission and discontinuous line fit.
  - We also get the same differenciation among the galaxies, NGC 278, NGC 1058 by one hand and NGC 2500, UGC 3574 in the other, in their ionization behavior in the DD.
  - In NGC 278, the PA=143.5º slit has a quite strong ΔV_Z peak in a weak Hα emission zone. This could be associated with the corrotation.