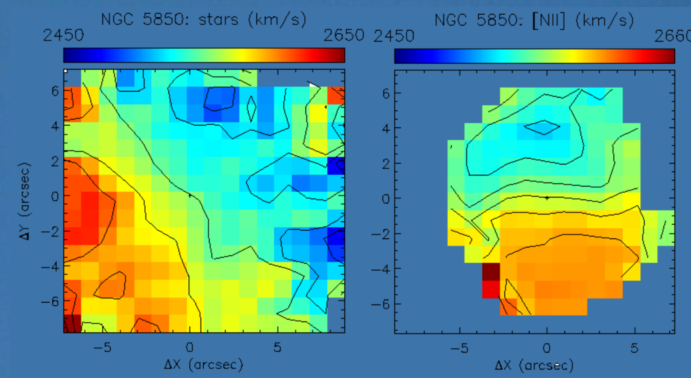
Inner polar discs and rings: observational properties.

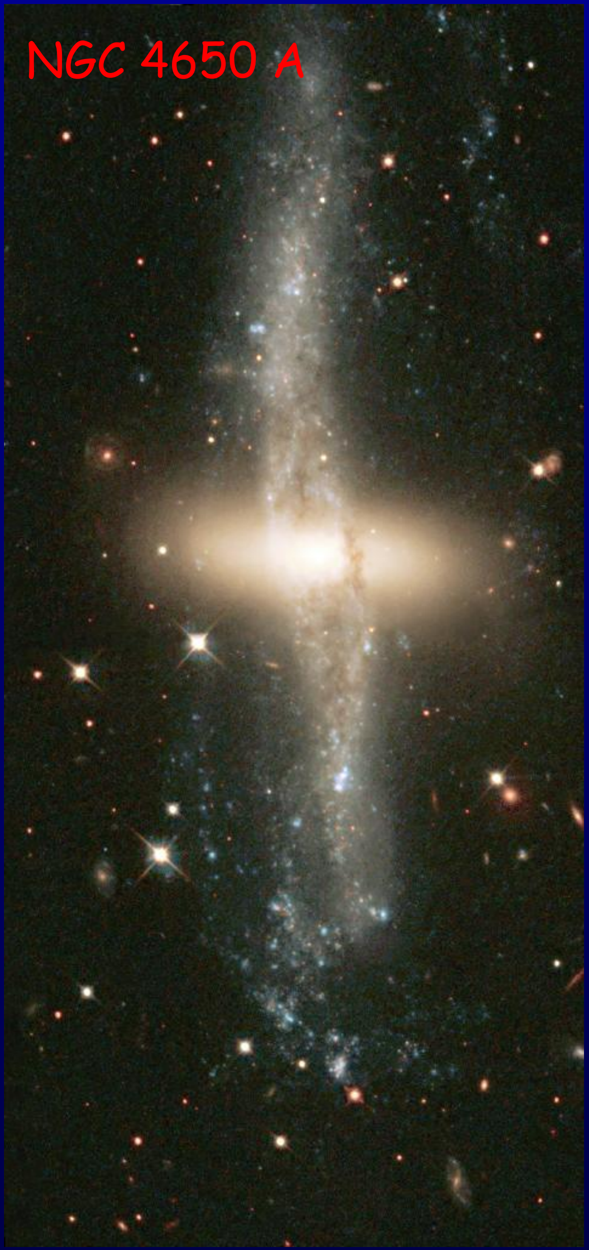


Alexei Moiseev

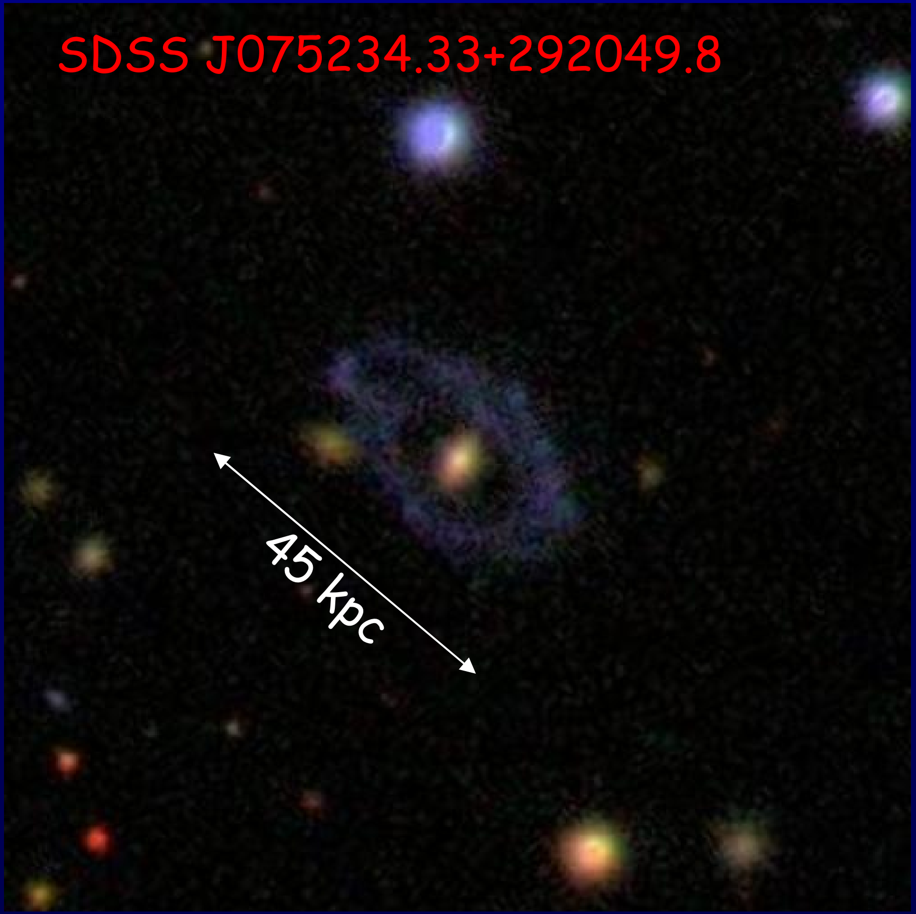
Special Astrophysical Observatory RAS,

N. Arkhyz, Russia

Large-scale polar rings: stable structures!



22 kpc



(Brosch et al, 2010)

Formation of polar rings: simulations

1) The major merging scenario:

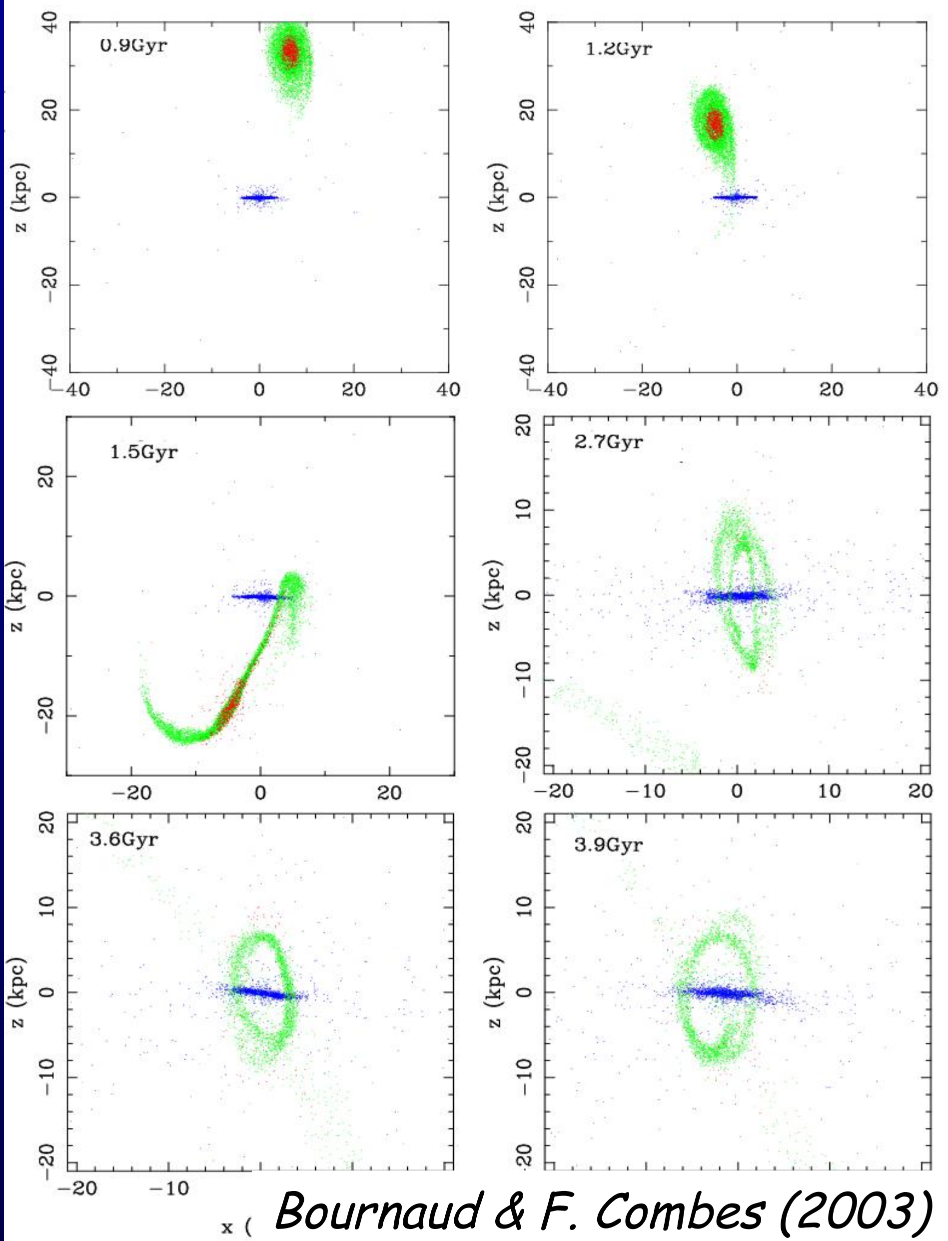
- A head-on collision between two orthogonal spiral galaxies (Bekki, 1998; Bournaud & Combes, 2003)

2) The accretion scenario:

-Tidal accretion of the polar material from a gas-rich donor galaxy (Schweizer et al. 1983; Reshetnikov & Sotnikova 1997)

- the disruption of a small companion on a polar orbit

- accretion of gas infalling from extragalactic cosmic filaments (Maccio et al., 2006)

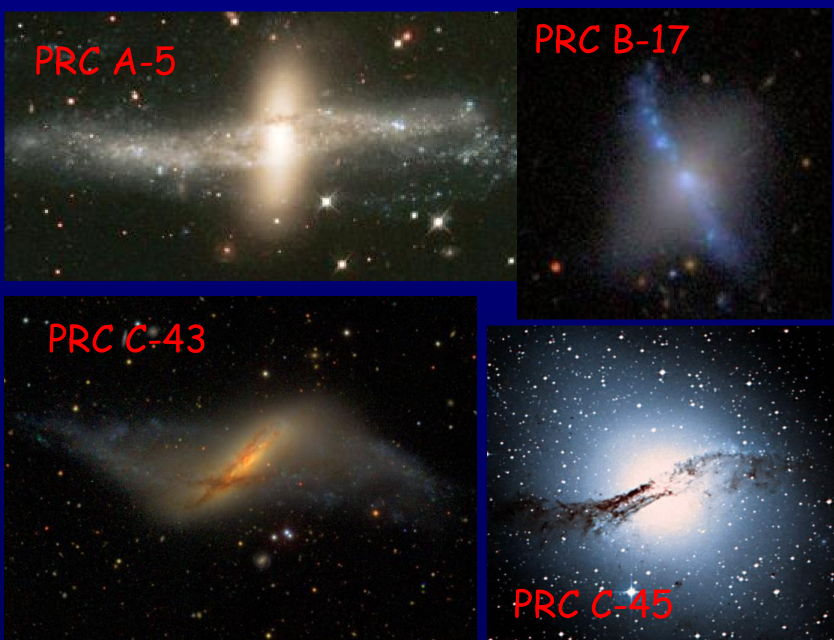


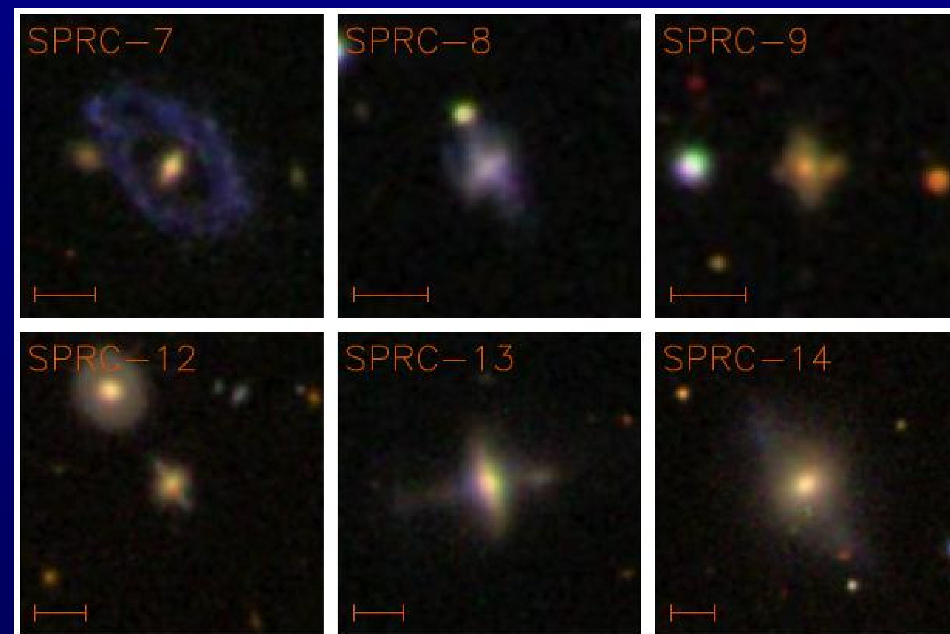
Bournaud & F. Combes (2003)

How many polar rings we know?

Whitmore et al (1990):
157 candidates (33 "best+good")
~25 kinematically confirmed

Moiseev et al (MNRAS, arXiv:1107.1966):
275 candidates (185 "best +good")
10 kinematically confirmed

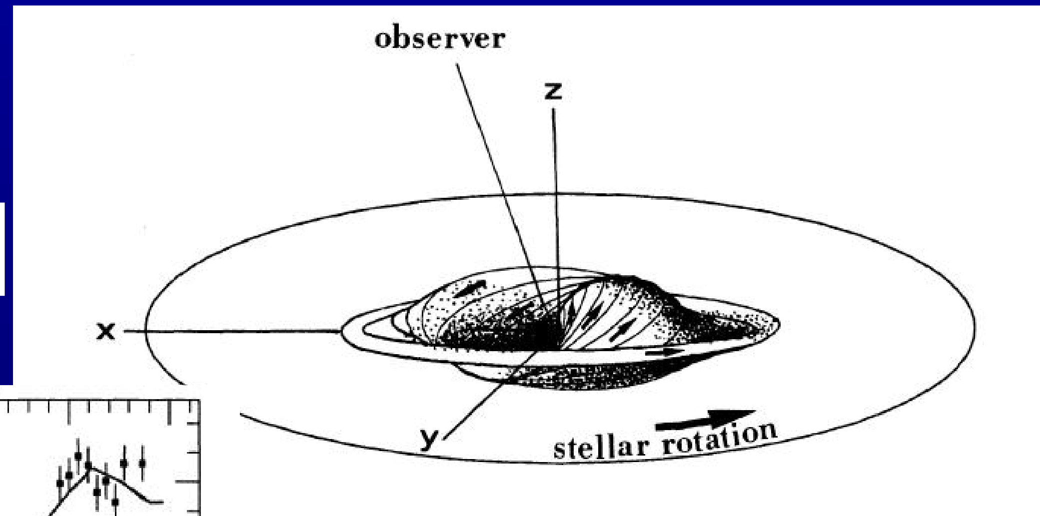




Kinematically confirmed inner polar structures (rings and discs) are already found in 44 galaxies!

NGC 2217

Bettoni, Fasano & Galetta (1990)



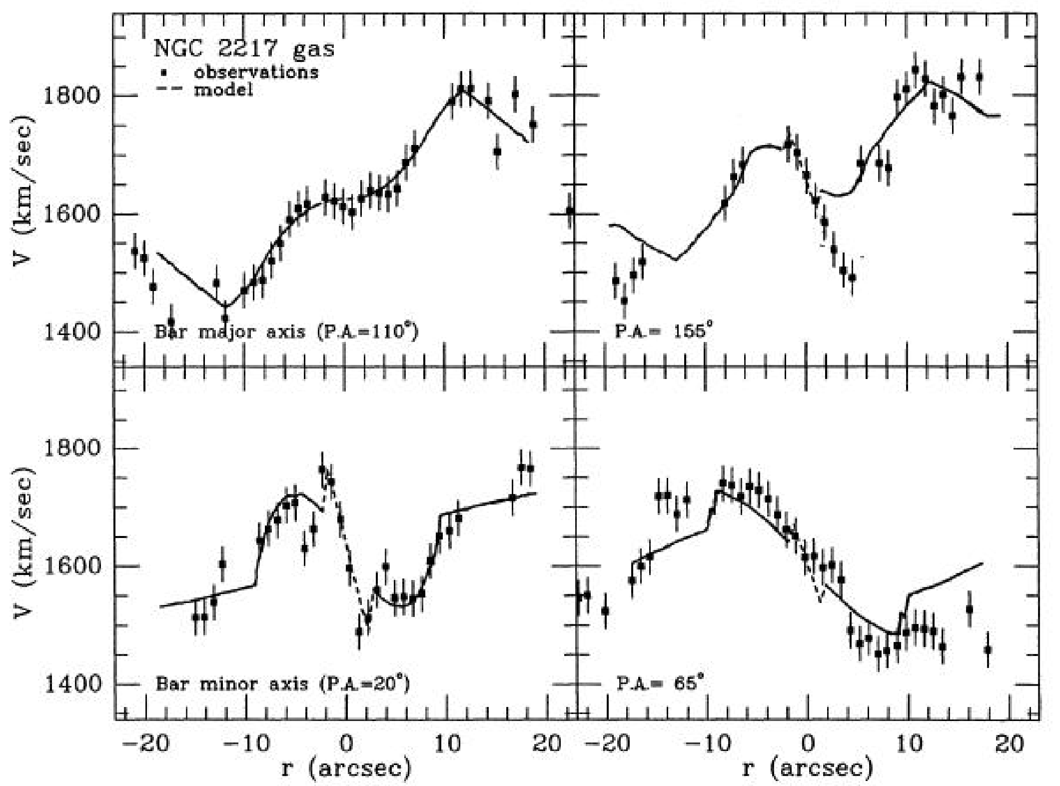
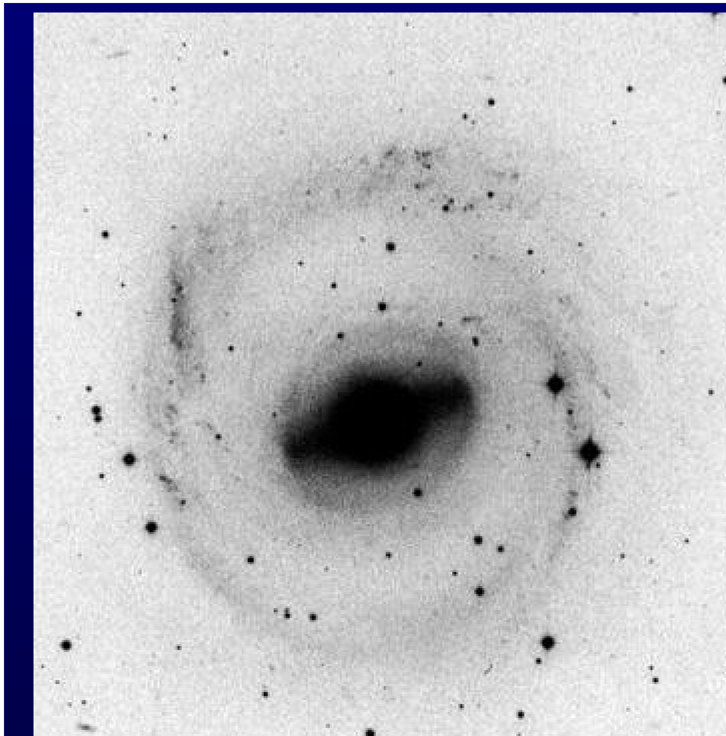


FIG. 7. Comparison between the observed rotation curves of the gas and our model of a warped and twisted gas disk. The dashed portion of the curves corresponds to that shown in Fig. 6.



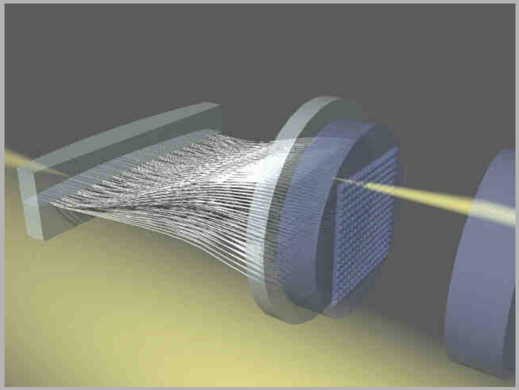
How we can detect them?

Low contrast structures (except circumnuclear dust lanes)
Kinematic measurements:

- Long-slit spectroscopy
- 2D velocity fields:
  - CO radio interferometric data
  - Integral-field (3D) spectroscopy (MPFS, SAURON, SCORPIO/FPI)


6-m telescope of the Special Astrophysical Observatory

~60% of the known inner polar structures has been discovered or confirmed with the 3D facilities on the SAO RAS 6-m telescope:



- Integral-field spectrograph MPFS (Afanasiev et al., 2000)

- Focal reducer SCORPIO with scanning Fabry-Perot interferometer (Moiseev, 2002)

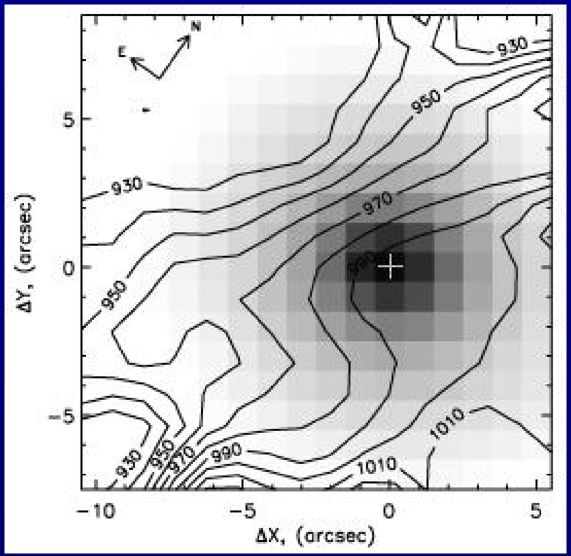
NGC 7217

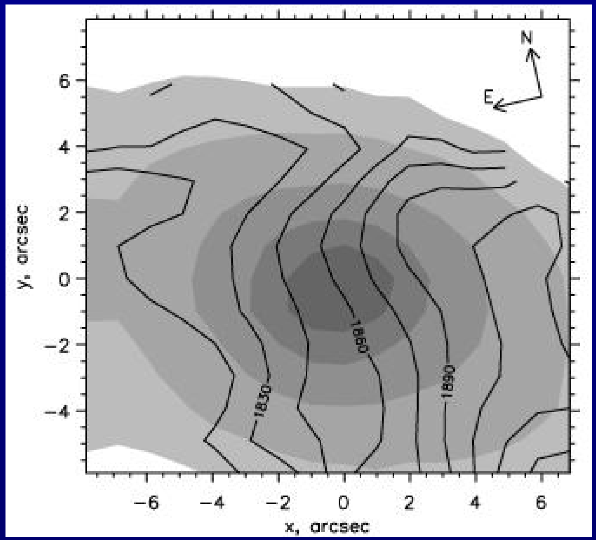
Silchenko & Afanasiev (2000)

NGC 7280

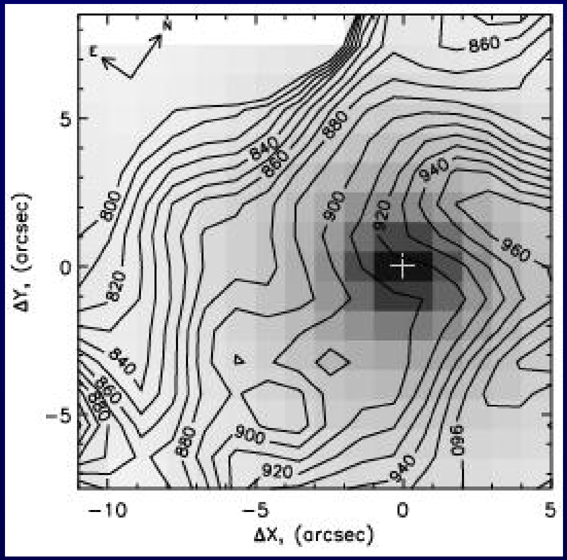
Afanasiev & Silchenko (2000)

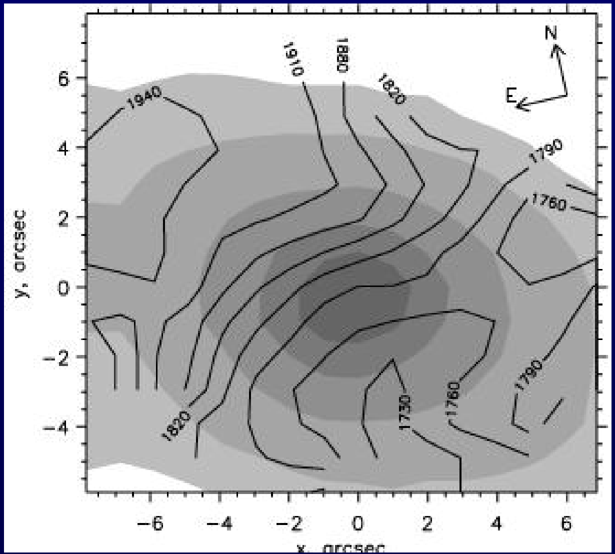
Stars:

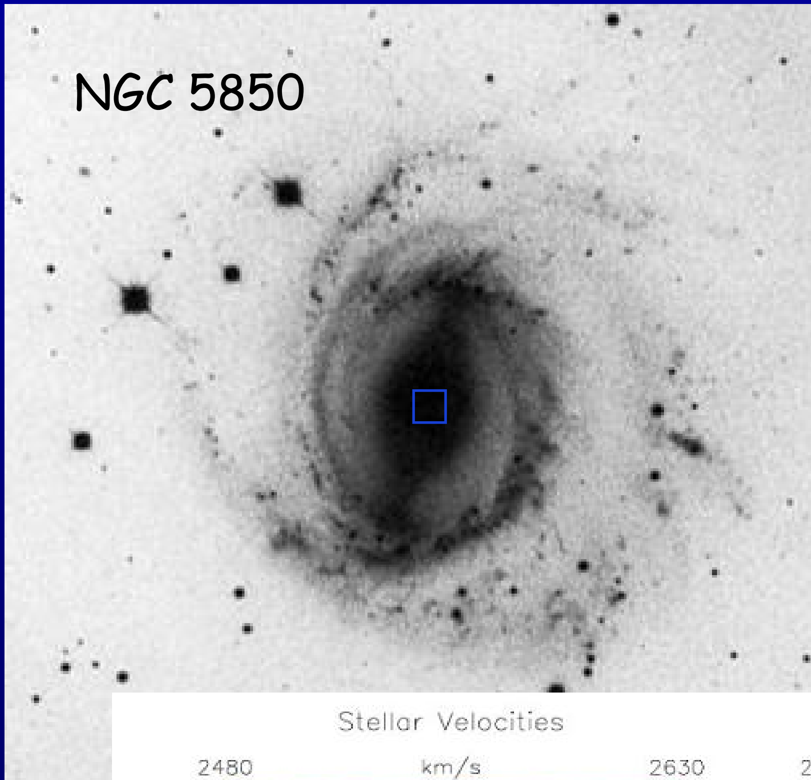


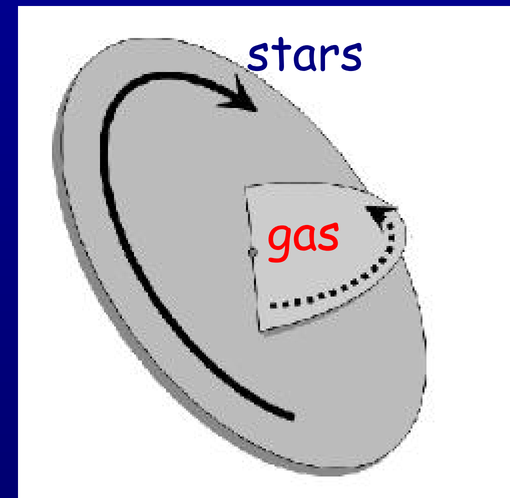


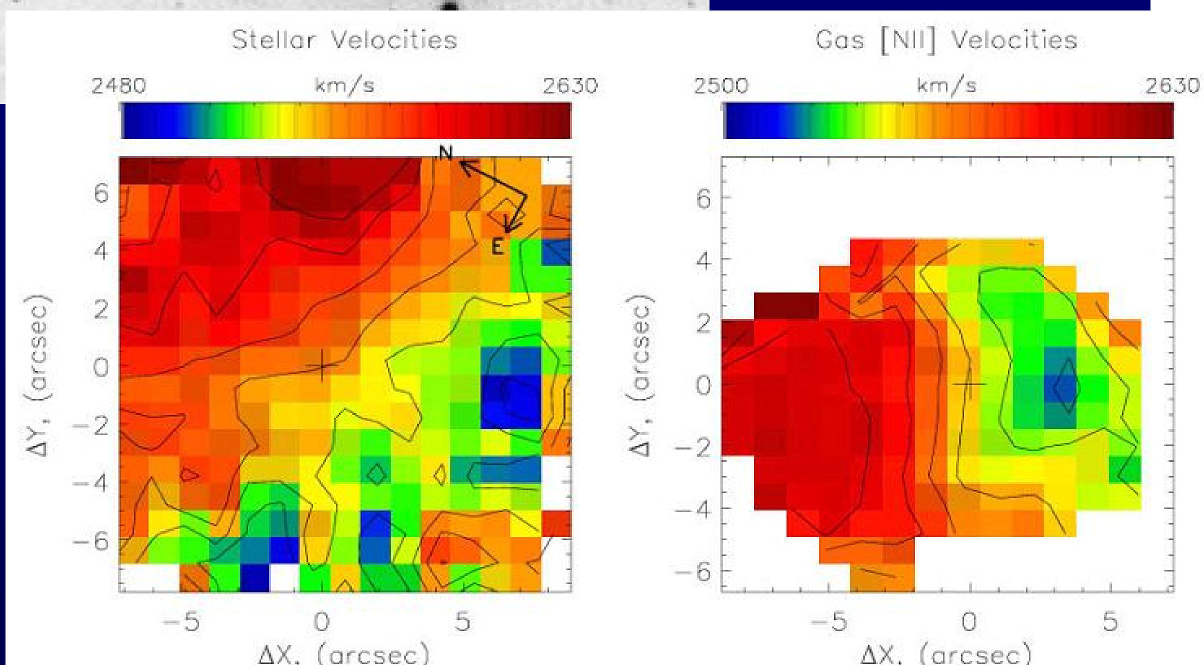
Ionized gas:







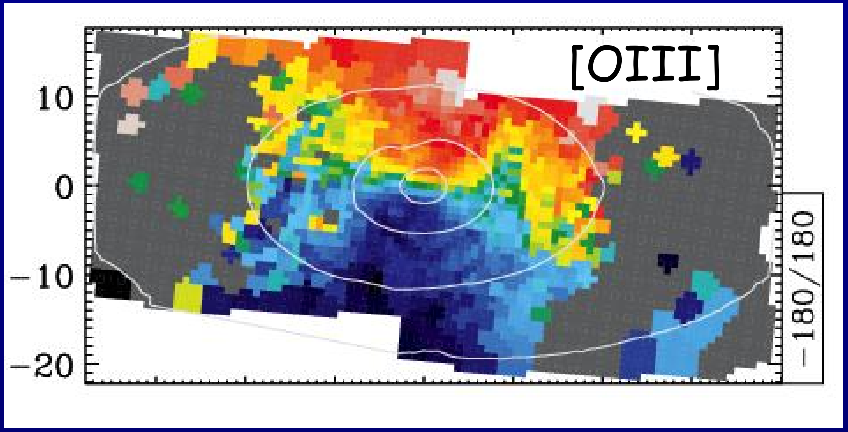


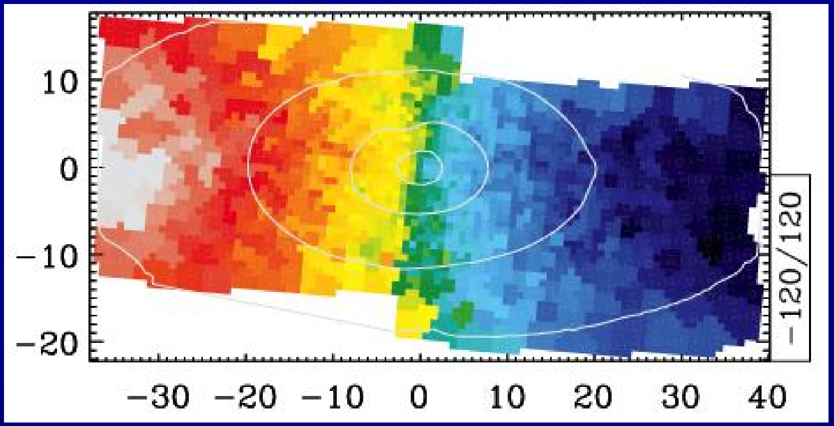


Moiseev et al (2004)

SAURON: kinematically decoupled cores

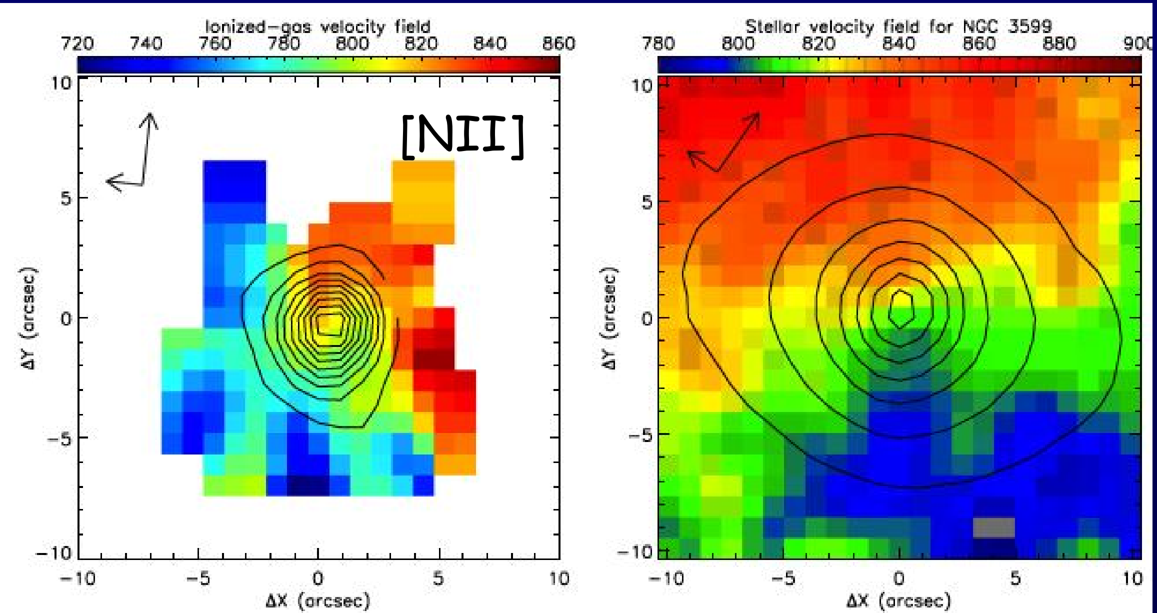
NGC 2768 (Sarzi et al 2006)





Ionized gas:

Stars:



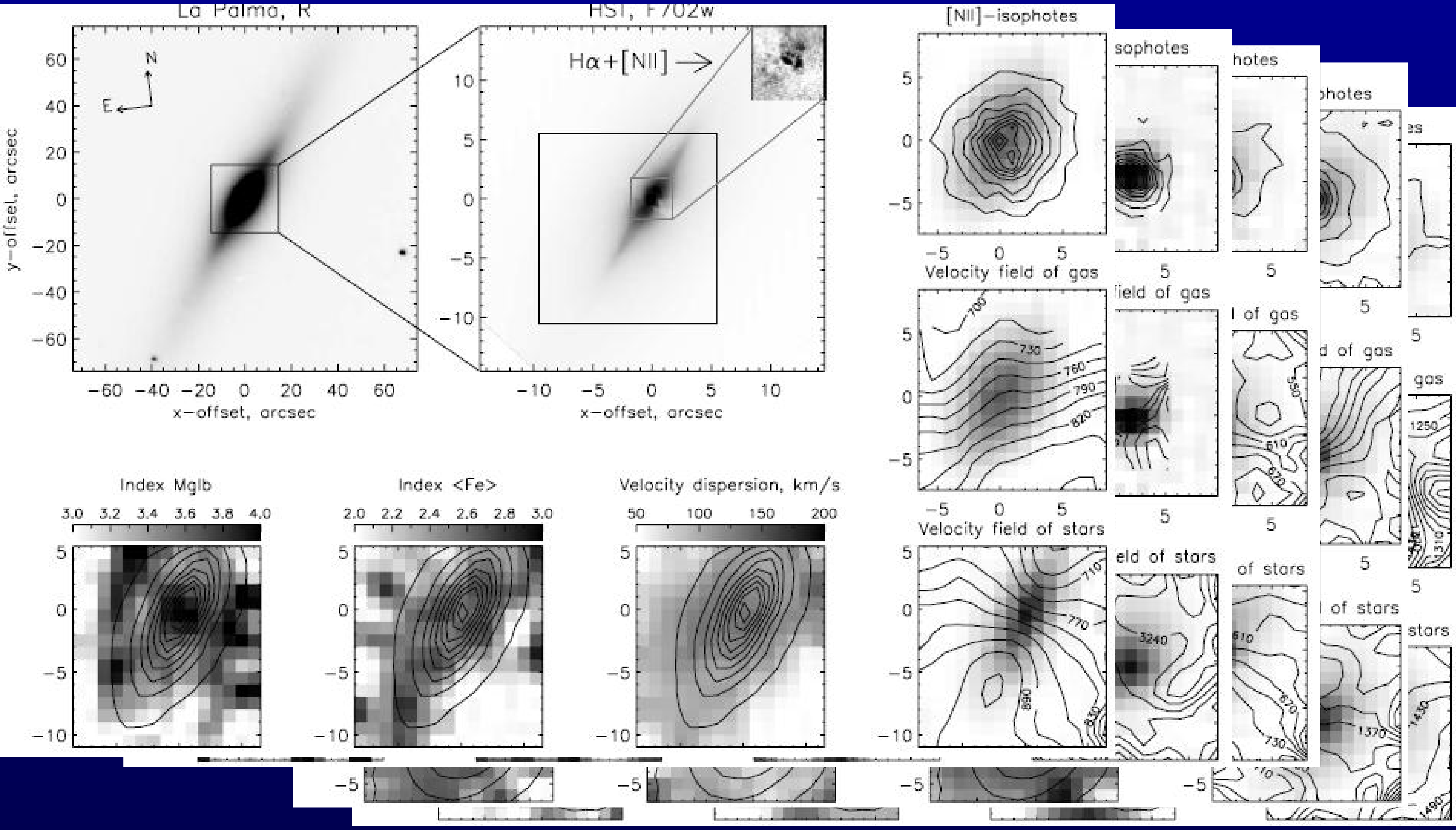
NGC 3599

MPFS – gas

SAURON - stars

Sil'chenko, Moiseev & Shulga (2010)

2D kinematics of S0 galaxies with circumnuclear dust lanes



Sil'chenko & Afanasiev (2004): MPFS observations of stars and gas kinematics

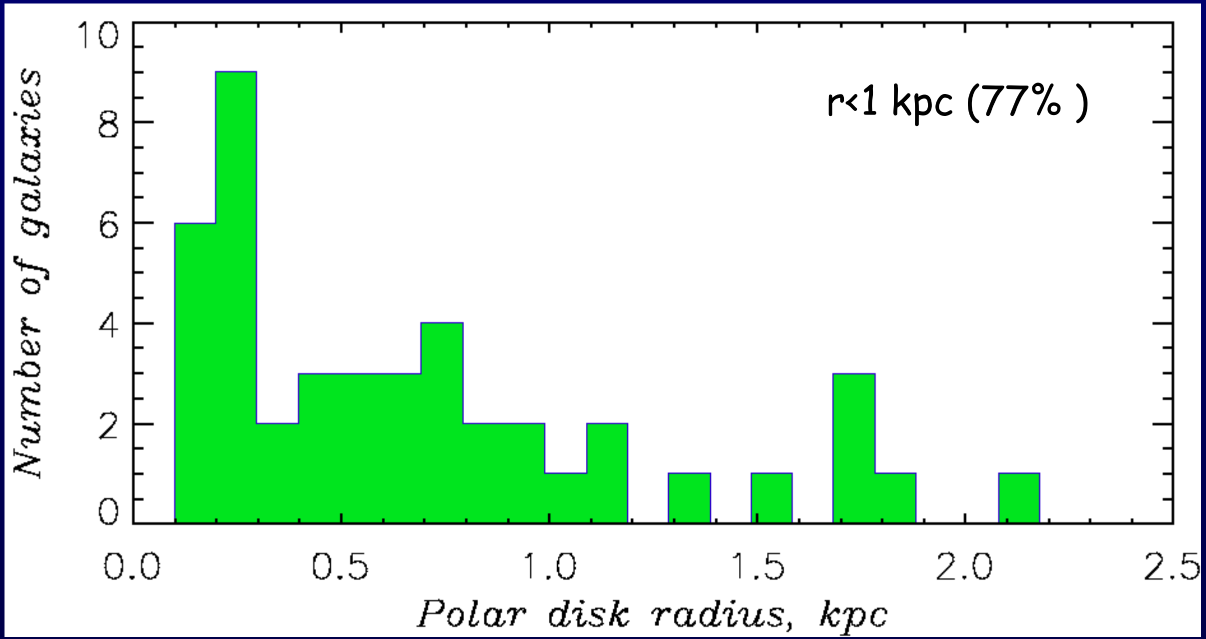
Inner polar structures: sizes

Corsini et al. (2003) listed 17 galaxies where inner polar structures (IPS) were found
Sil'chenko & Afanasiev (2004): + 8 galaxies

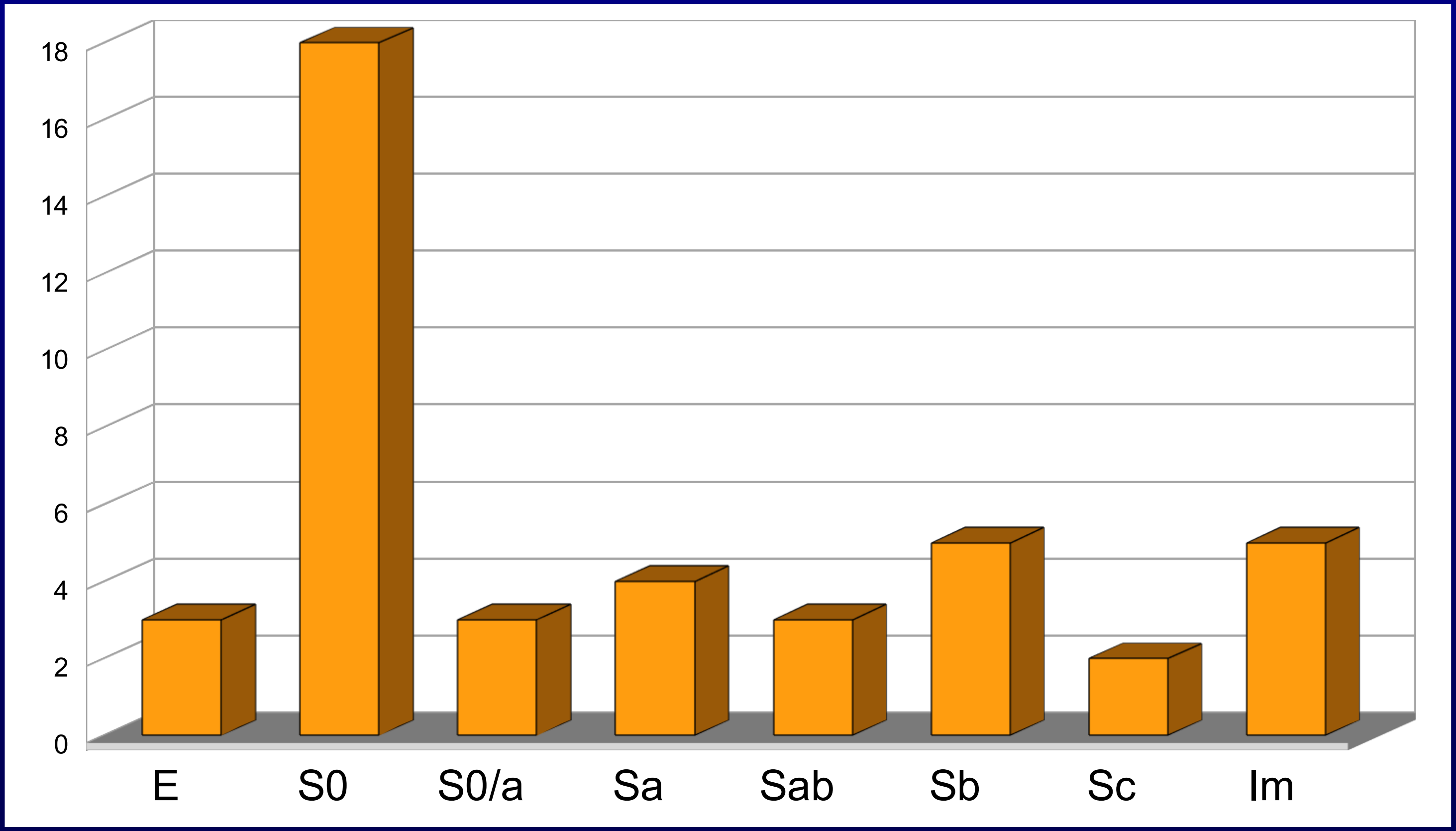
Moiseev, Silchenko & Katkov (2010): list of 37 galaxies

Our current list: 44 galaxies with confirmed IPS

Most of these structures were detected only from their kinematical tracers being hard to be noticed against the high-brightness bulges.



Inner polar structures: host galaxies

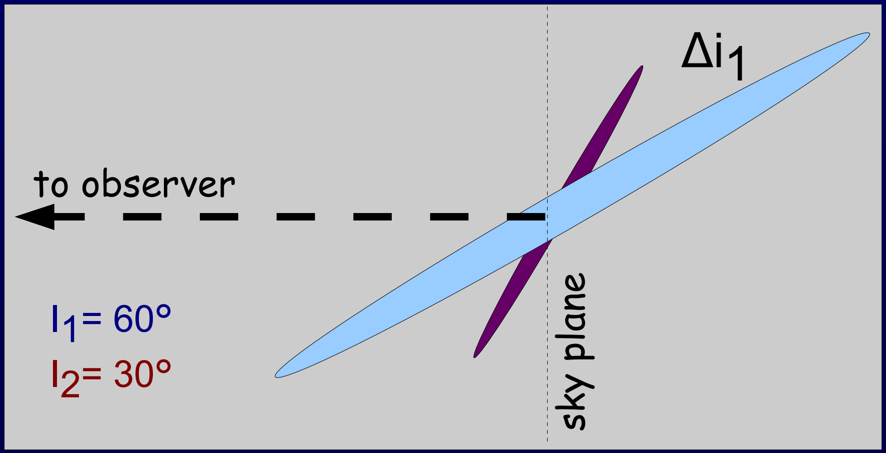


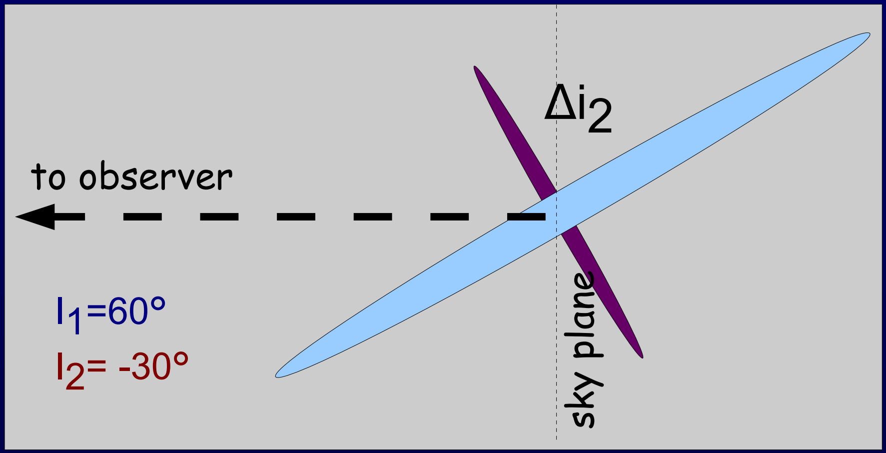
Inner polar structures: what is a real geometry?

Line-of-nodes position:
Inner structure: i_1, PA_1 from kinematics
Outer disk: i_2, PA_2 from morphology and/or kinematics

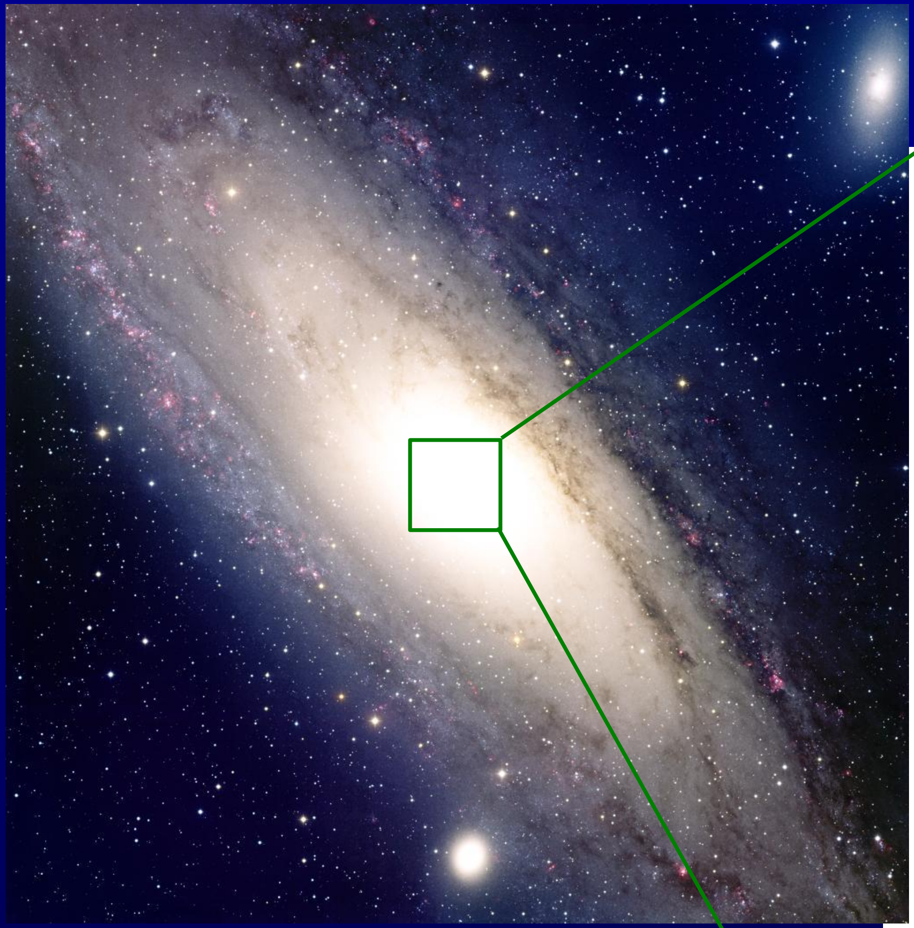
The restrictions
- model of regular circular rotation
  (alternative explanations: AGN outflow, radial gas motions in the bar)
- number of pixels
- two solutions - depends on their mutual orientation:

$$\cos(\Delta i) = \pm\cos(PA_1 - PA_2)\sin i_1 \sin i_2 + \cos i_1 \cos i_2$$





Messier 31: nolecular gas in the inner ring (r<0.7 kpc)



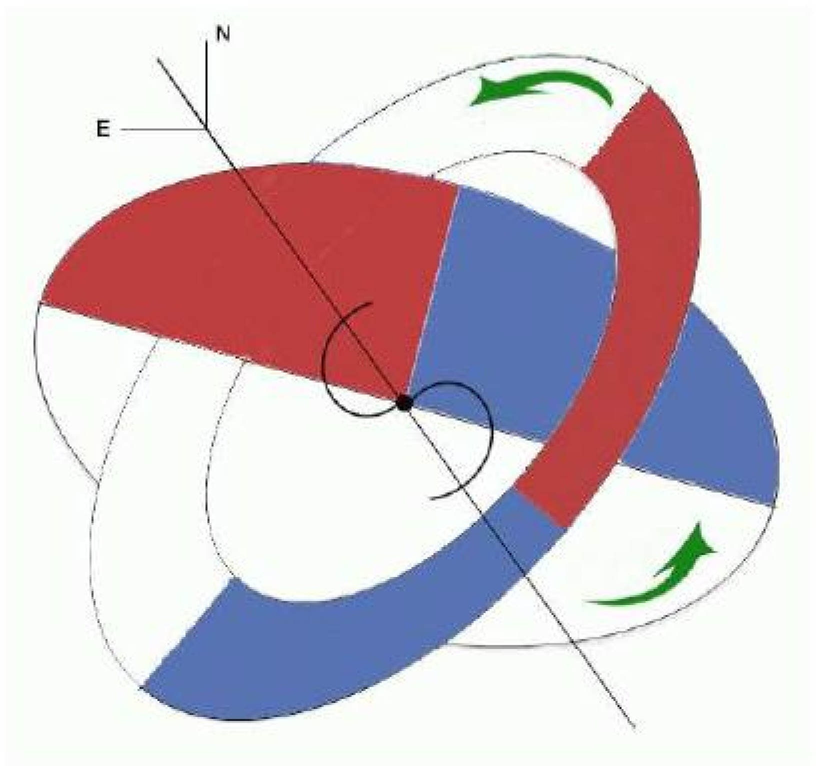
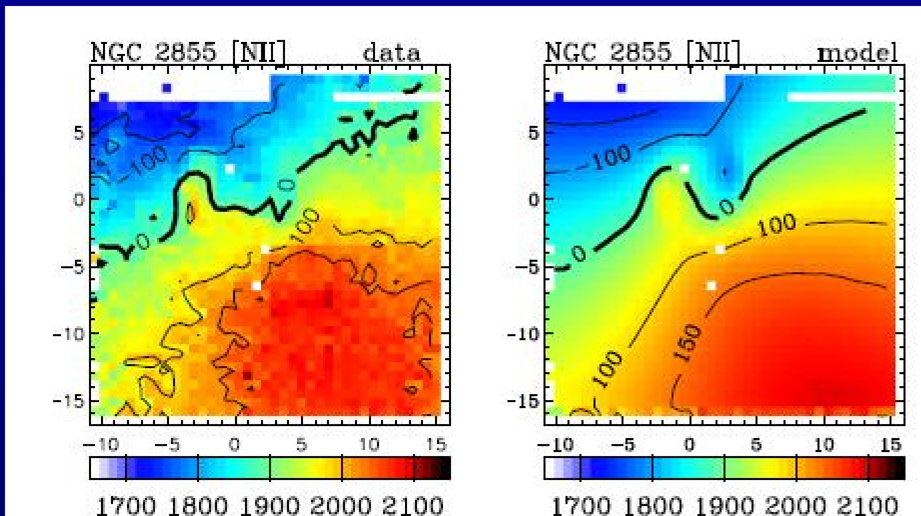


Fig. 16. Schematic view of the interpretation proposed for the CO velocities observed. The inner disc is presented with a PA of 60deg and an inclination of 43deg. The inner ring is superimposed with a similar inclination but a position angle of -35deg. The straight line indicates the position of the major axis of the main disc inclined by 77deg with a PA of 35deg.

Melchior & Combes (2011)

VIMOS kinematics of warped inner disc in NGC 2855



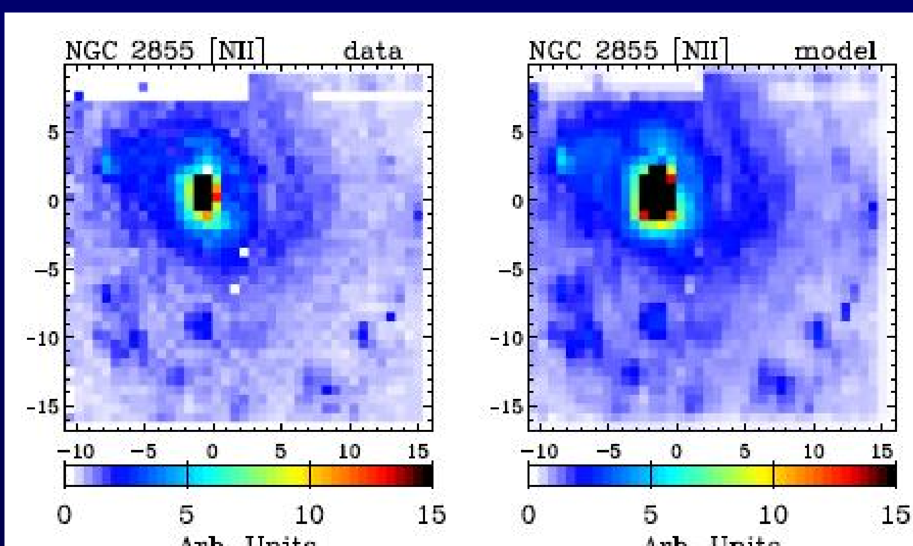


Table 5. Model with a warped disk for NGC 2885

Parameter	
V_{max} [km s^{-1}]	-373 ± 16
R_h [″]	4.3 ± 0.6
k_0 [″]	3.4 ± 0.1
k_1 [″]	0.82 ± 0.03
k_2 [deg]	-79.0 ± 2
c_0 [deg]	85.7 ± 0.7
c_1 [deg/″]	-10.11 ± 0.07
V_{sys} [km s^{-1}]	1885 ± 3

We evaluated the warping and twisting of the gaseous component from the radial profiles of ellipticity and position angle obtained from the isophotal analysis of the surface-brightness map of the [N II] $\lambda6583$ line in Sect. 3.1. We found that the following empirical functions

$$\delta_n(R''_n) = \frac{-k_2}{\pi} \arctan\left(\frac{R''_n - k_0}{k_1}\right) + \frac{k_2}{2} \qquad (29)$$

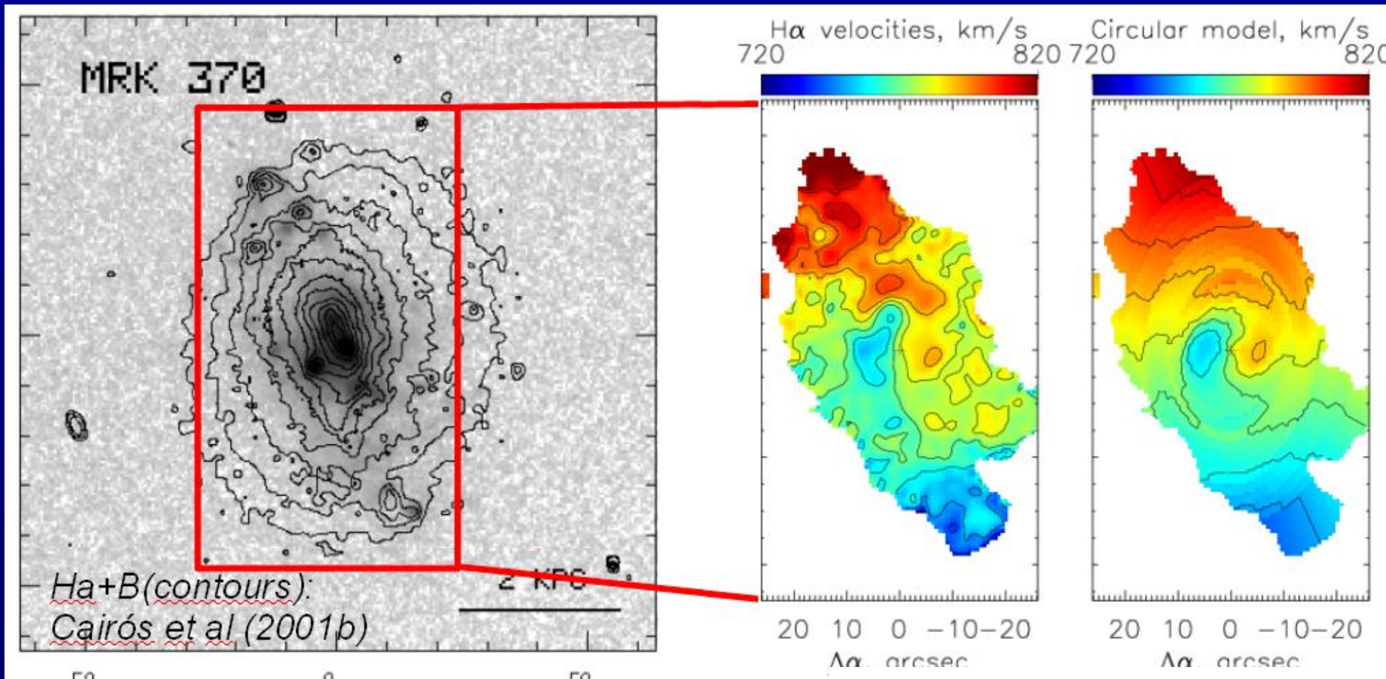
and

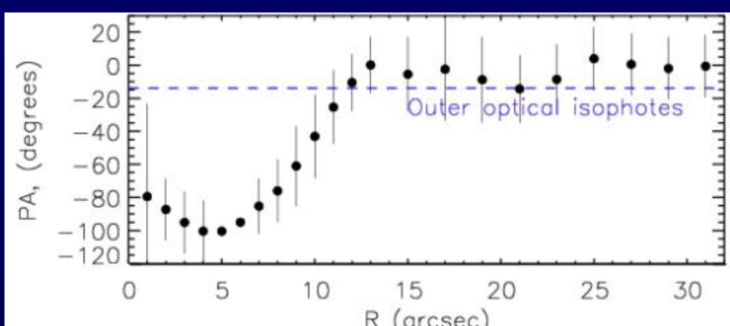
$$\gamma_n(R''_n) = c_0 + c_1 R''_n \qquad (30)$$

Coccato et al (2007):

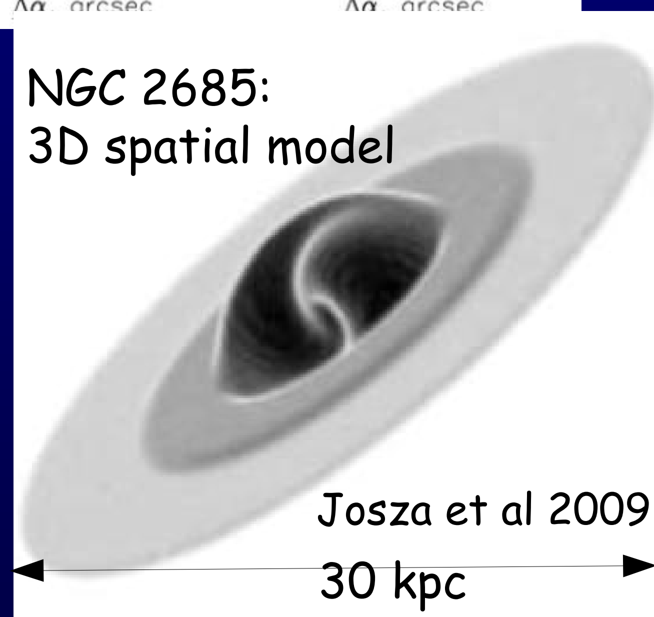
Mrk 370: warped gaseous disc

(Moiseev, 2010)





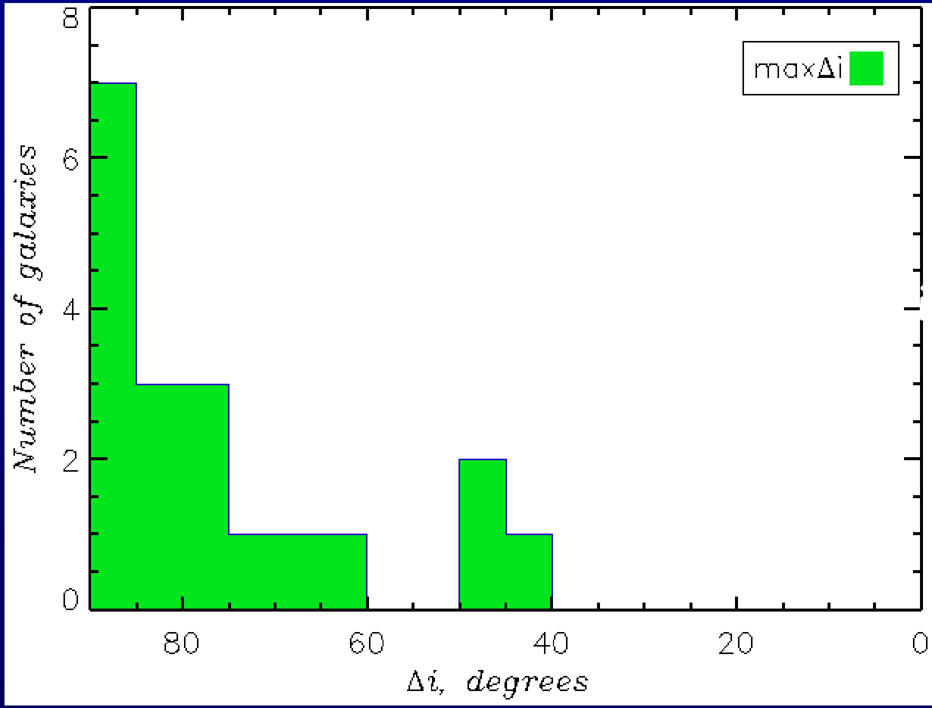
At r < 800 pc, the intrinsic orientation of the ionzed gas disc changes through Δi = 55 - 70 deg



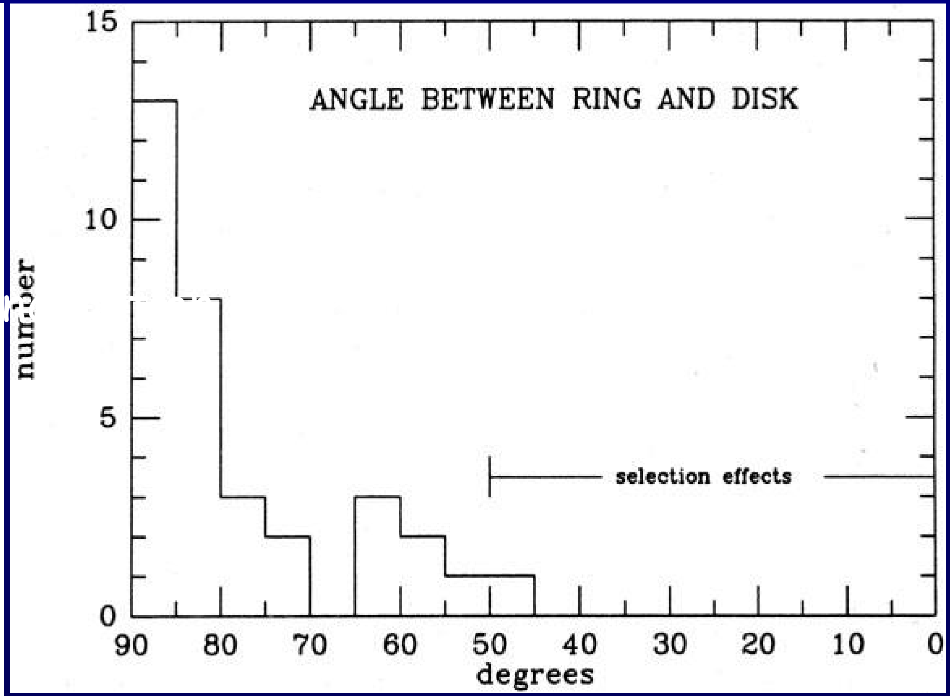
A small- scale analogue of strongly twisted HI disc in NGC 2685 ?

Inner polar structures: polar or inclined?

Inner structures in 19 galaxies where the mutual inclination angle was estimated:

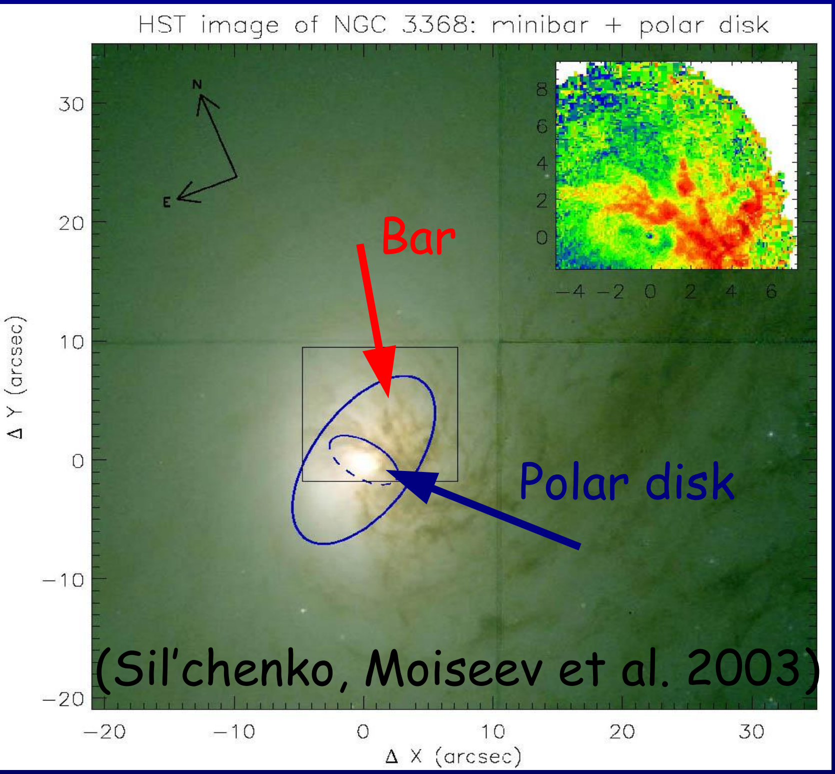


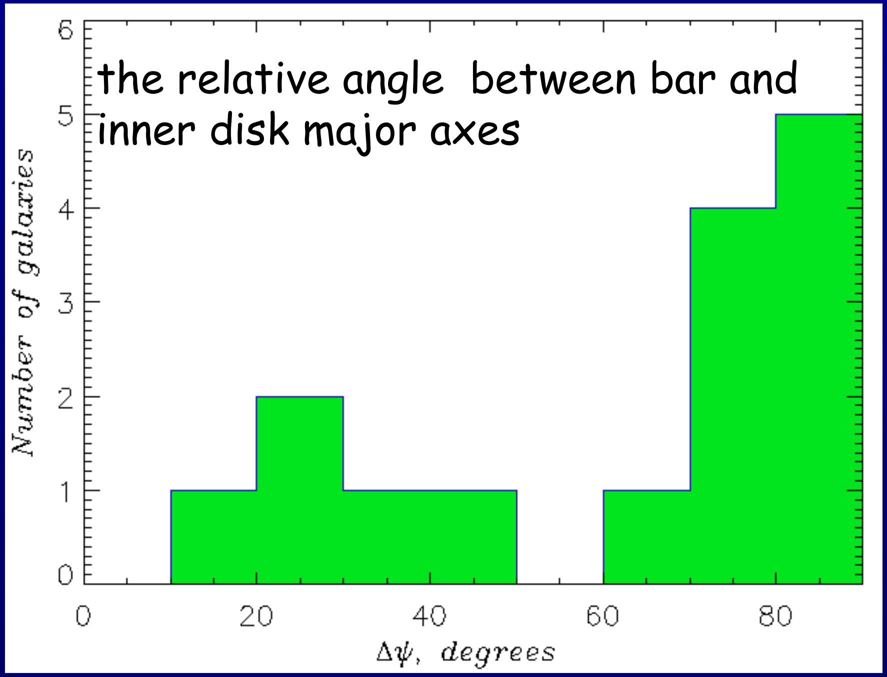
Classical polar rings (Whitmore, 1991):



The stability and living time of the inclined systems is still under debates.

Inner polar structures in barred galaxies (39%)





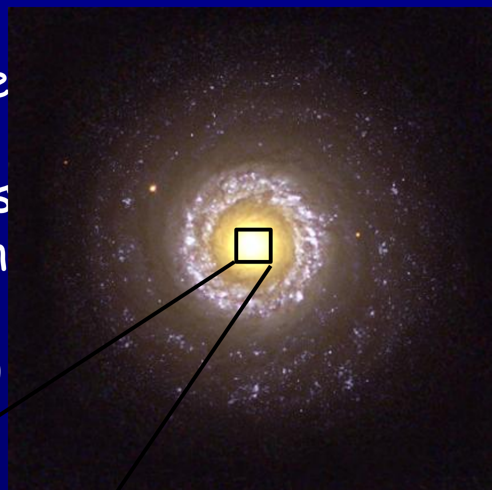
Inner polar discs prefer to be orthogonal to a bar major axis, i.e. lie in the one of principal plane of triaxial potential

Friedli & Benz (1993) predicted that counter-rotating gas, belonging to the stellar-gaseous disk, finally occupies stable orbits strongly inclined to the disk plane under bar driving force.

However only 17/44=39% of IPS hosts have bar or triaxial

Inner polar structures: gas/stars counter-rotation

NGC 7742: inner polar disc and global gas-stars conter-rotation (Sil'chenko & Moiseev, 2006)



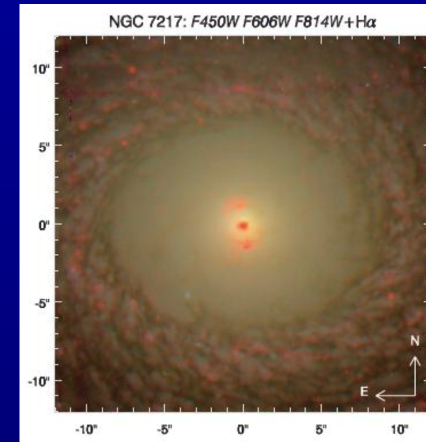


Figure 9. Inner polar disc in NGC 7217 as seen with the *HST*. This false colour composite is made of *F450W*, *F606W* and *F814W* WFPC2 images

NGC 7217:

GalMer simulations of retrograde orbits minor merging (Sil'chenko et al. 2011; Chilingarian's talk)

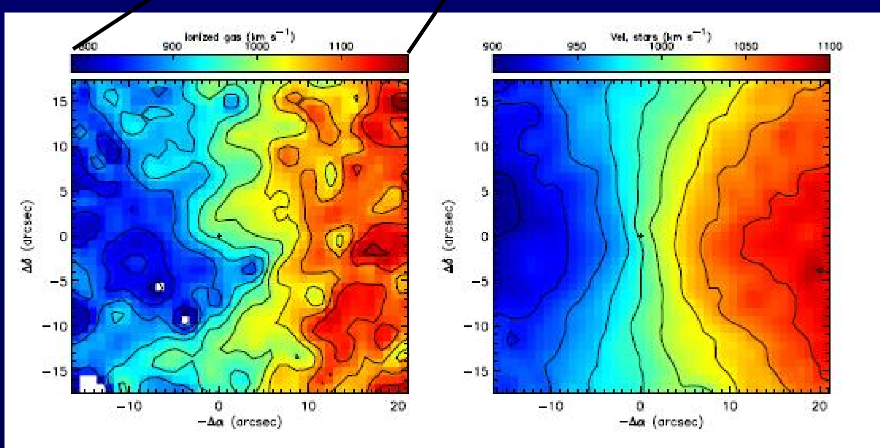


Fig. 7.— NGC 7217: line-of-sight velocity fields for the ionized gas (left) and for the stars (right) according to the SAURON data; maps represent a combination of two different point-

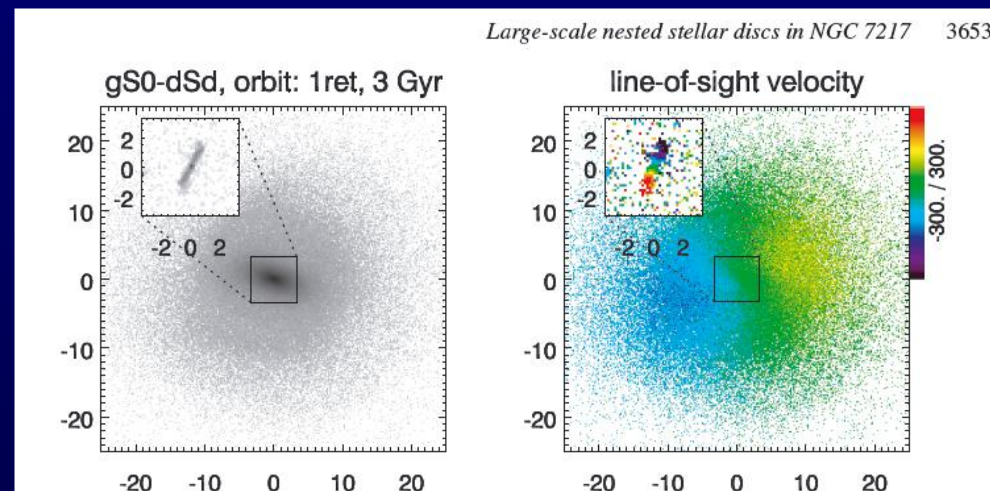
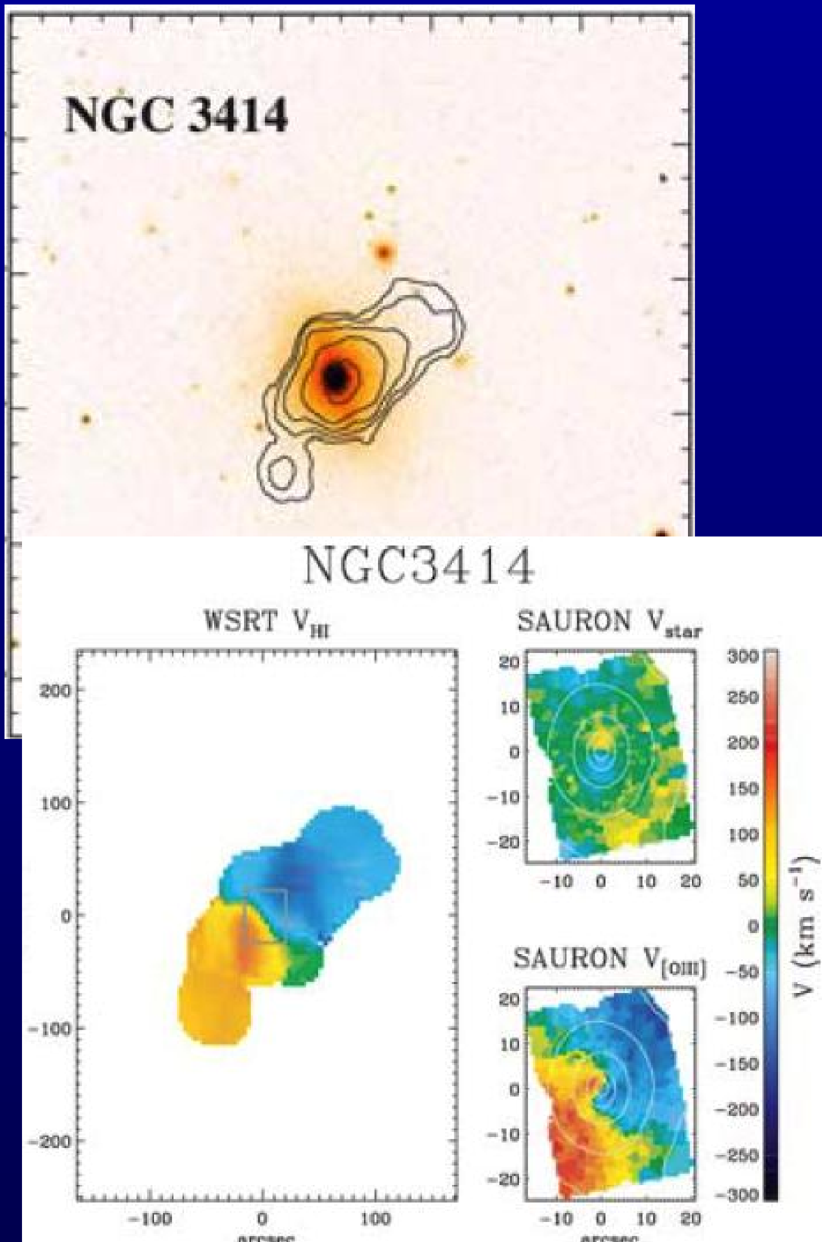


Figure 10. Left-hand panel: surface density of stars and the gas (inset) for a minor wet merger of gS0 and dSd galaxies (mass ratio 10:1) on a retrograde orbit. Right-hand panel: line-of-sight velocities of stars and the gas (inset) for the same merger. The signature of the inner polar ring seen edge-on is clearly visible. The orientation of the galaxy disc is chosen to match that of NGC 7217 ($i = 30°$). The axes are in kpc.

External HI clouds



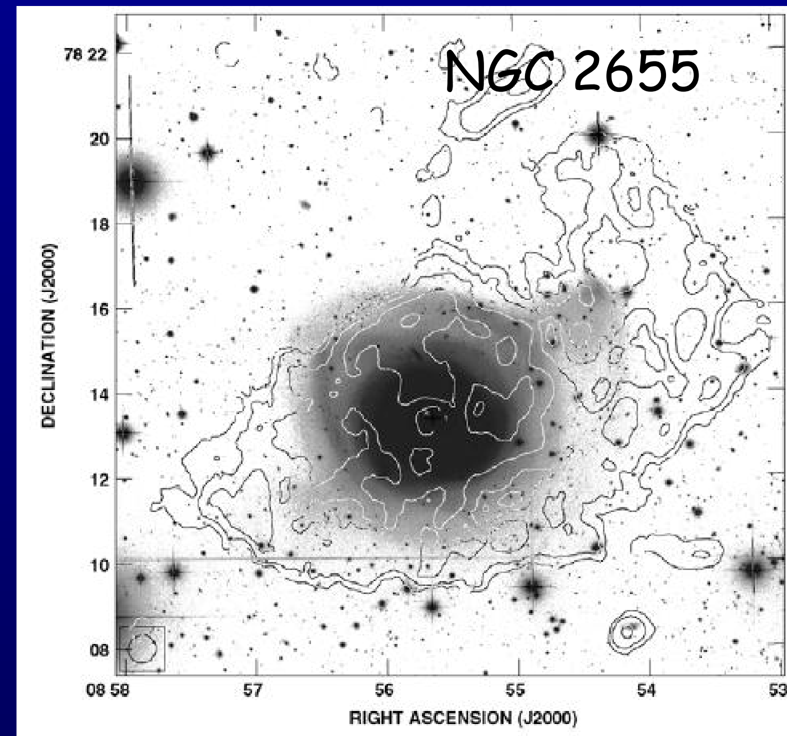
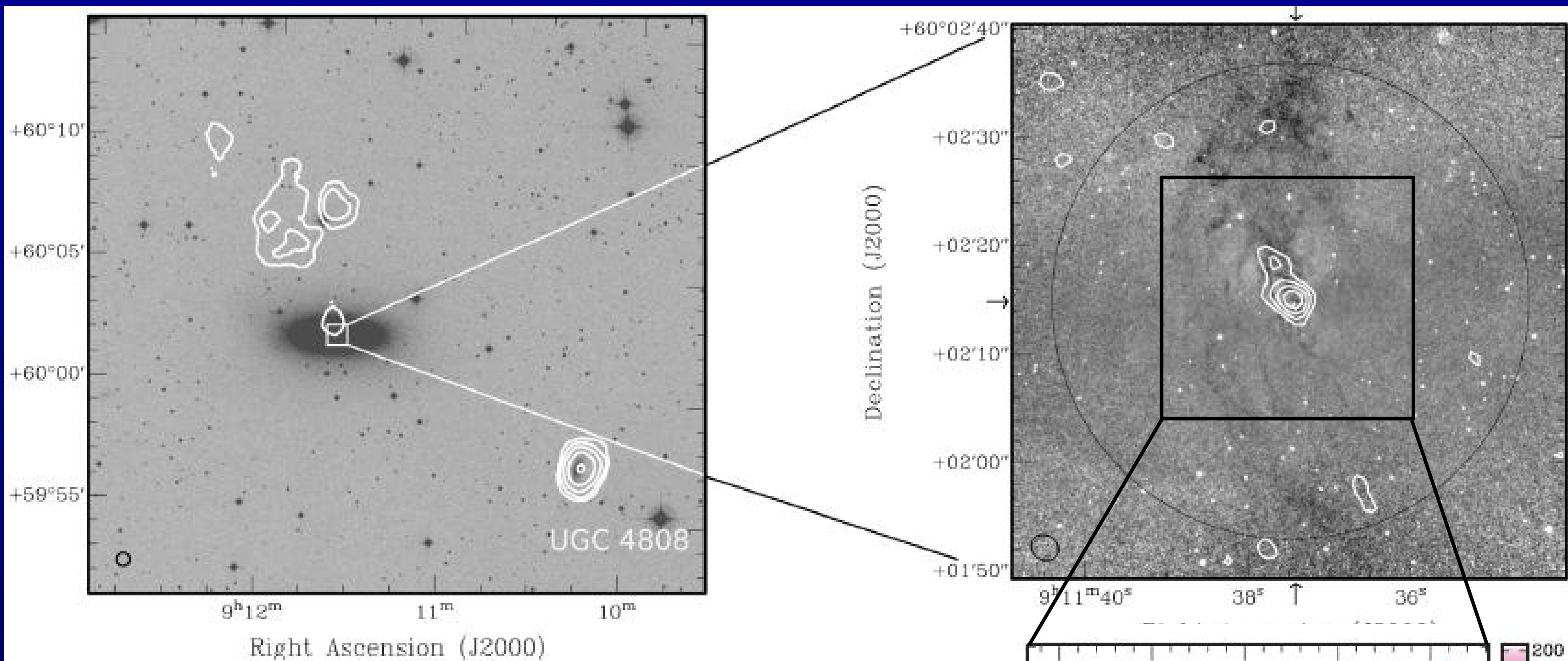


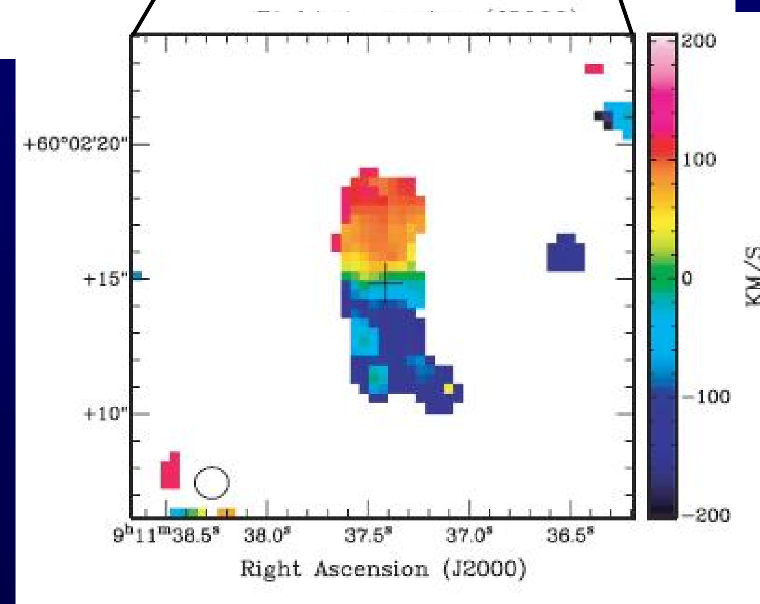
Figure 7. Total H I emission around NGC 2655 integrated over velocity,

Diffuse light stellar tidal arm and strongly warped external HI layer (Sparke et al., 2008);

Tho HI kinematical components (Morganti et al., 2006)

Molecular polar disc in NGC 2768

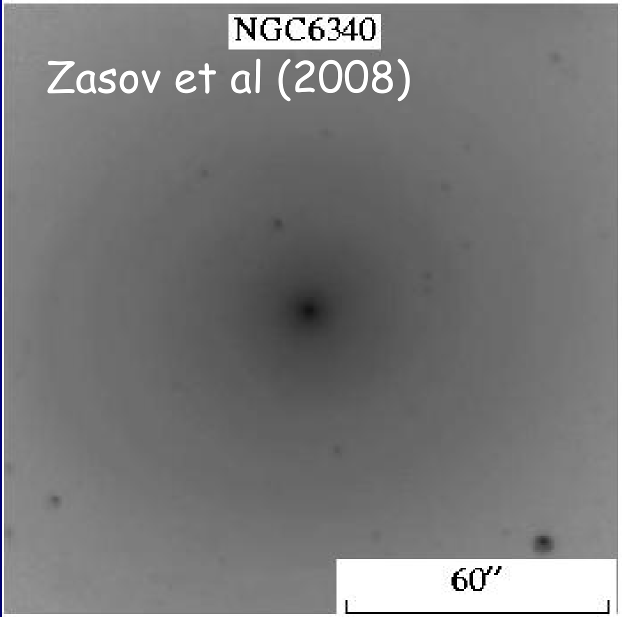


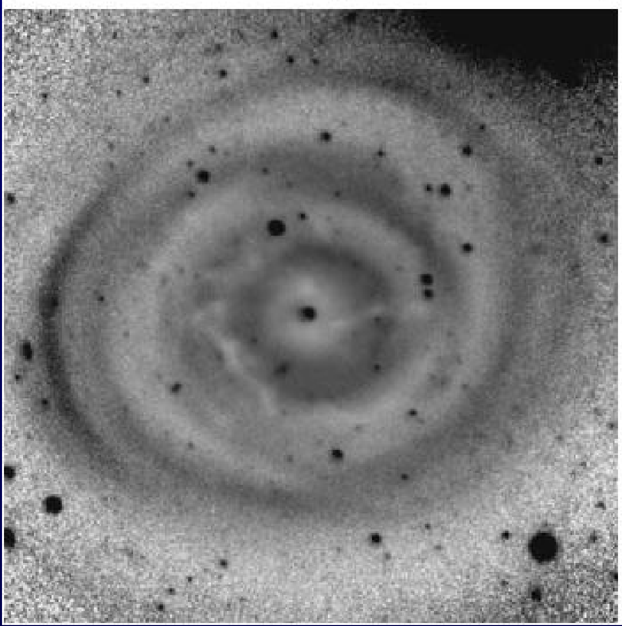


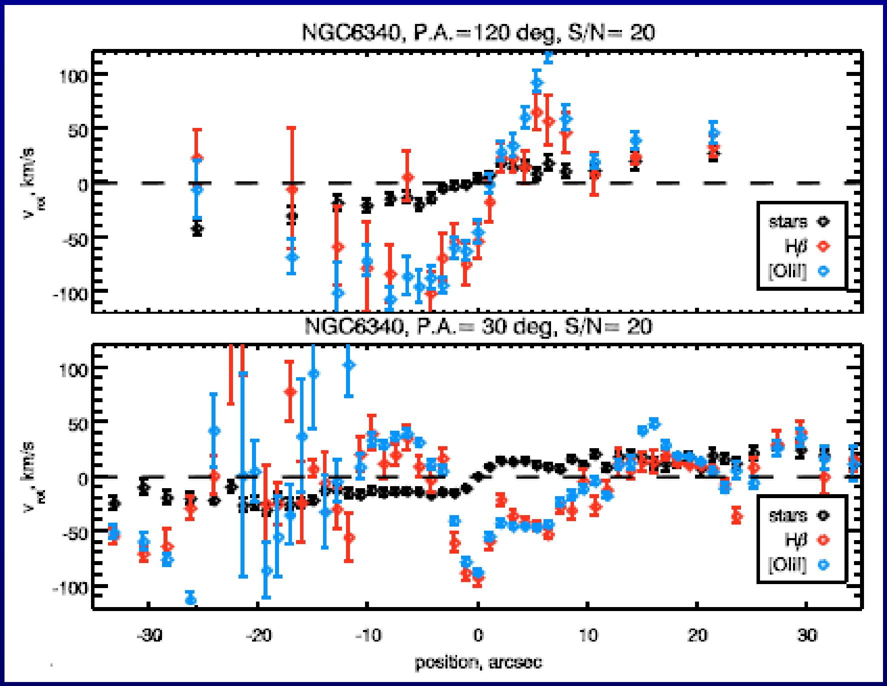
`..the molecular gas in NGC 2768 was recently accreted and is possibly still being accreted, in agreement with the much more extended but disturbed HI distribution..'

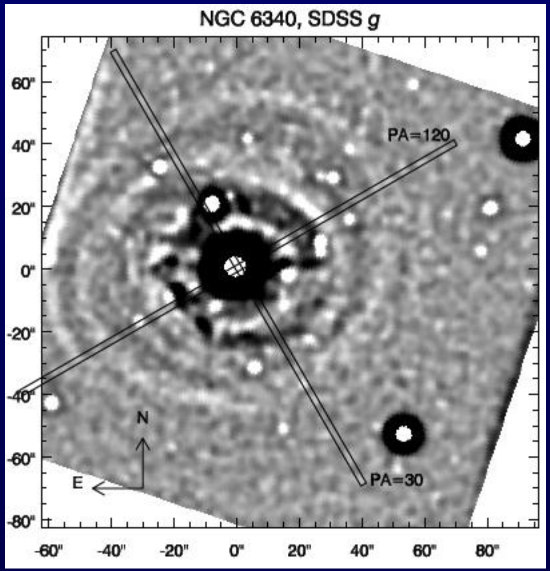
(Crocer et al., 2008)

NGC 6340: tidal shells/ripples









`inner polar disc ... inclined by 40–65 deg with respect to the large-scale stellar disc..'
(Chilingarian et al., 2009)

Inner polar structures: environmental effect

Gas-stars counter-rotation: 11

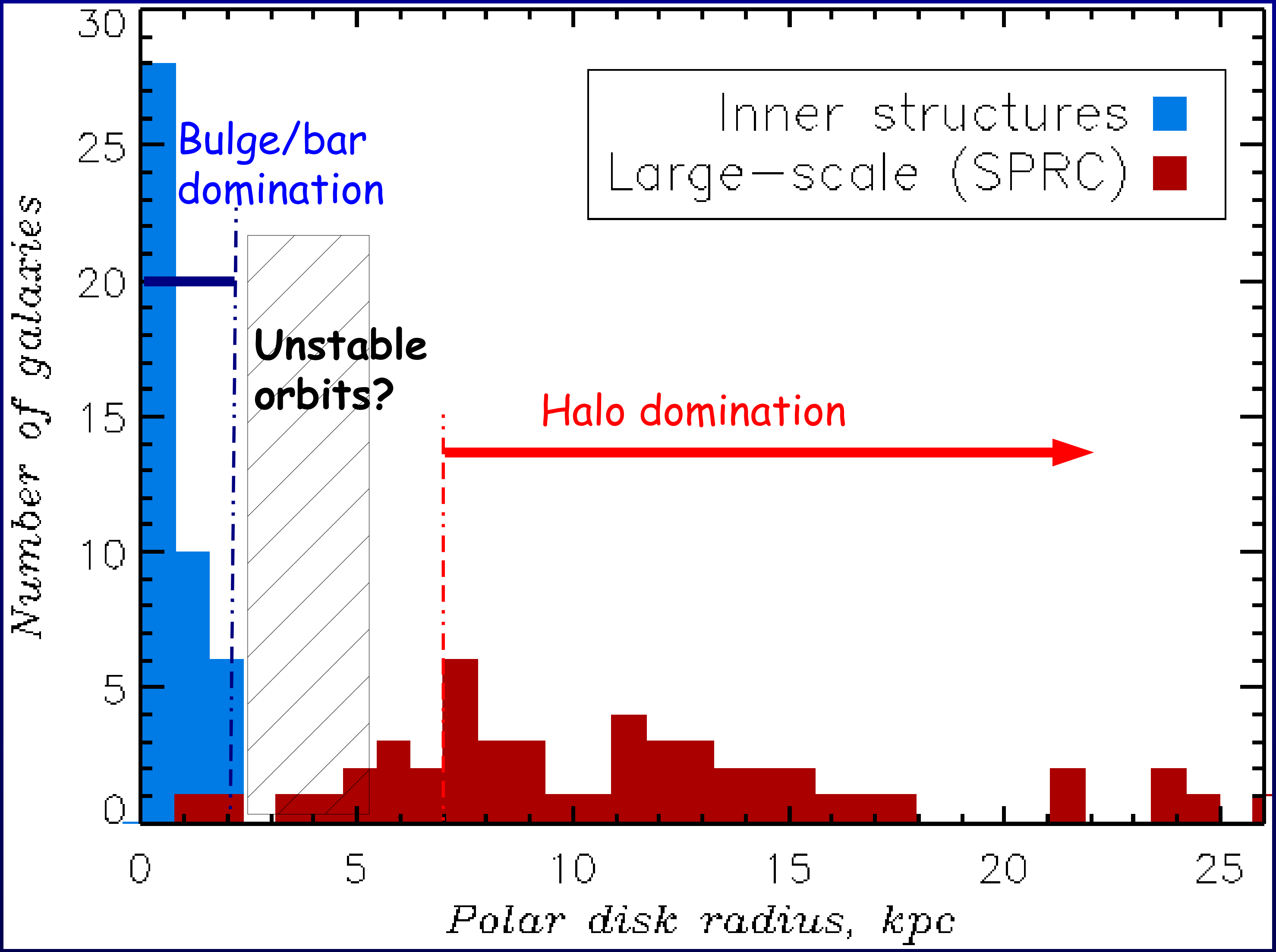
Filaments, tidal tails, interaction, cluster members, etc. : 19

HI external clouds: 9

80% of inner polar structures are related with recent interactions or minor merging

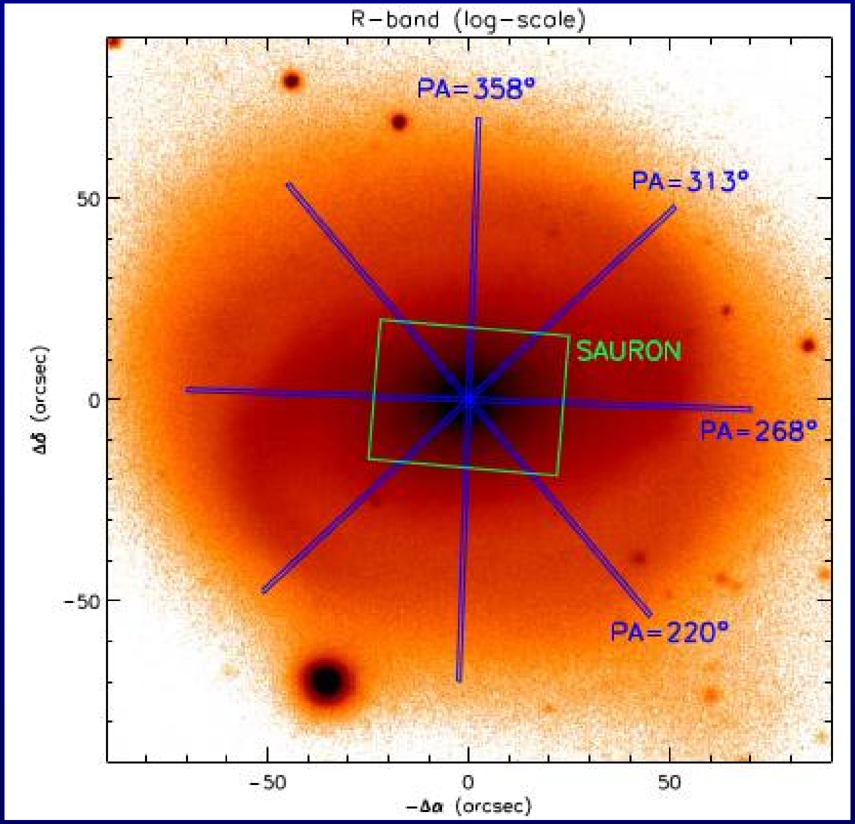
No any evidences of interactions: 9 galaxies (20%)
A fossil remainder of past minor merging/accretion events?

Where are intermediate-size structures?



Intermidiate-size structures: are they stable?

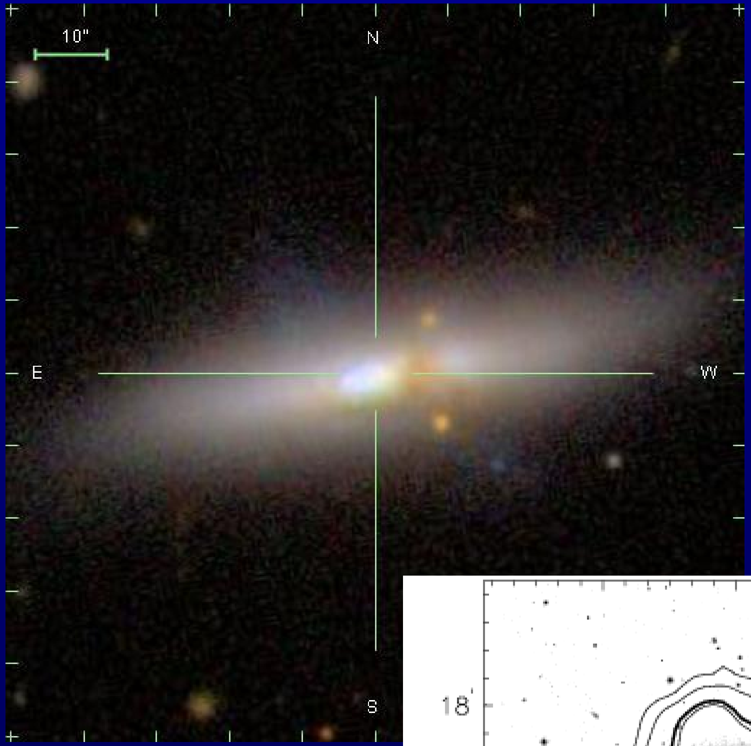
NGC 7743



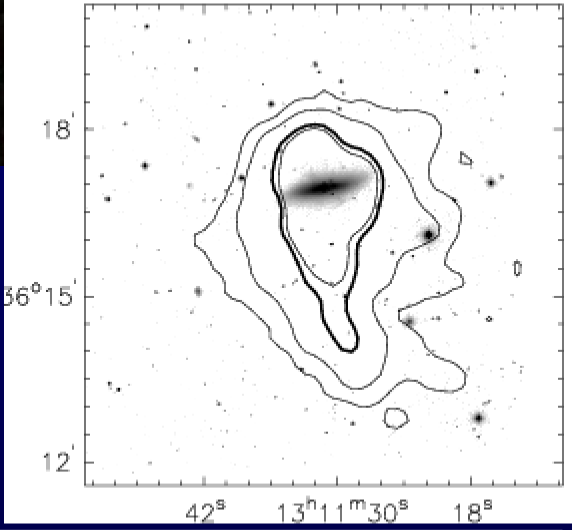
Inclined ionized-gas disc:
r=5.5 kpc
Δi=34±9, 77±9 deg

Katkov et al (2011, ApJ, accepted)

NGC 5014



SDSS image:
Blue ring r=3 kpc



HI (Noordermeer et al., 2005)

Conclusion

- The number of confirmed inner polar structures is larger than that of the 'classical' polar ring galaxies, but their origin and evolution is not well understood yet.

- The majority (80%) of inner polar structures are related with recent interactions, minor merging or accretion events

- Detailed simulations of their formation and evolution will help to better understand galactic merging history


Thank you for your attention!