Russian Academy of Sciences Institution
Special Astrophysical Observatory

Polar structures in different scales: «an observer's view»

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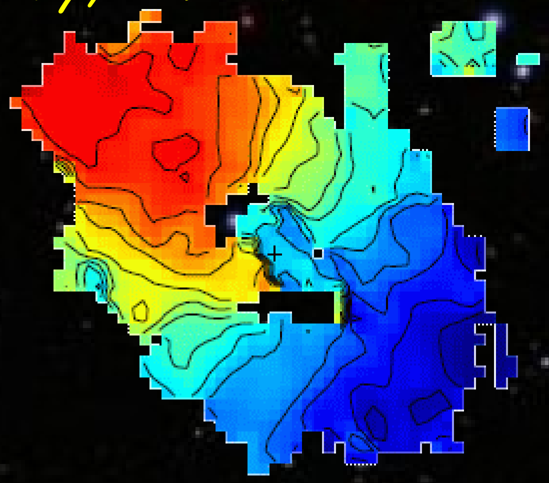
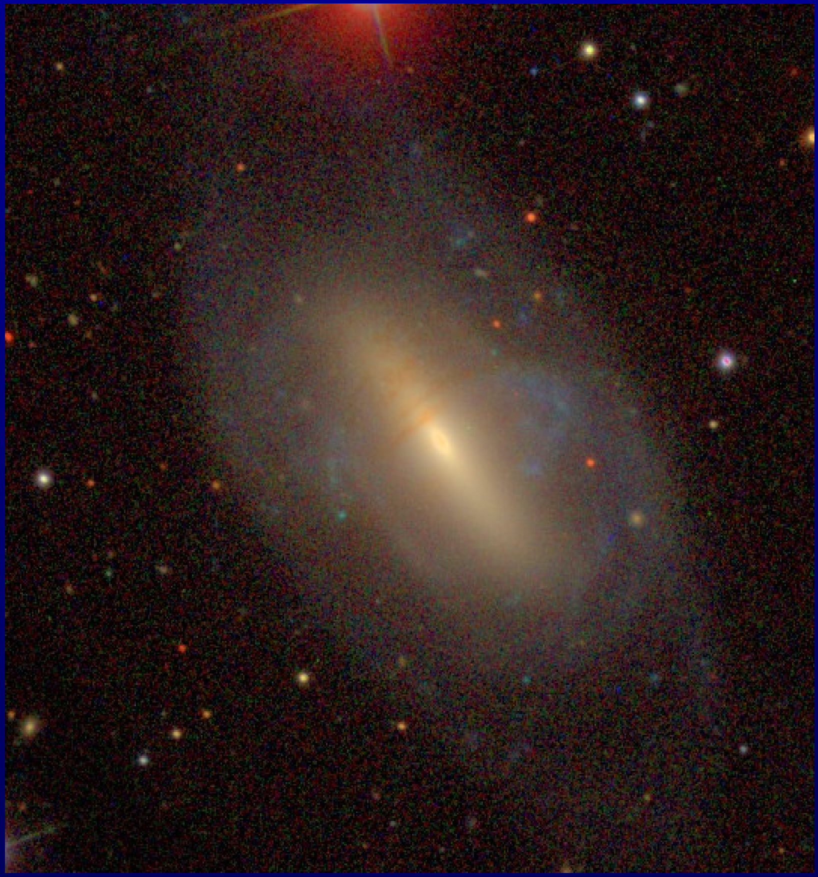


The beginning of history: NGC 2685 ('Spindle Galaxy')



Sandage (1961): *..is perhaps the most unusual galaxy in the Shapley-Ames catalogue. There are two axes of symmetry..*

Schechter & Gunn (1978): «NGC 2685: Spindel or Pancake?» *..the underlying stellar component is a S0 galaxy.. the peculiar rotation of the gas found by Ulrich (1975) are the result of the accretion of a galaxy or an instellar gas cloud..*

Laustsen & Wes (1982): NGC4650: a nearly edge-on ring galaxy?
Whitmore, Schweizer & Rubin (1982) A0136-080: A SO Galaxy with a Polar Disk
Steiman-Cameron & Durisen (1982): Stable polar gas disks in triaxial S0 galaxies

Why PRG interesting?

- Studying a role of mergings and interactions in galaxy evolution (disk and bulge formation, starformation, etc.)

- Implication for dark matter: M/L>20-50

- Probe to the shapes of dark matter halos, because we observe rotation in two different planes (if the polar ring is in equilibrium).

Formation of polar rings: simulations

1) The major merging scenario:

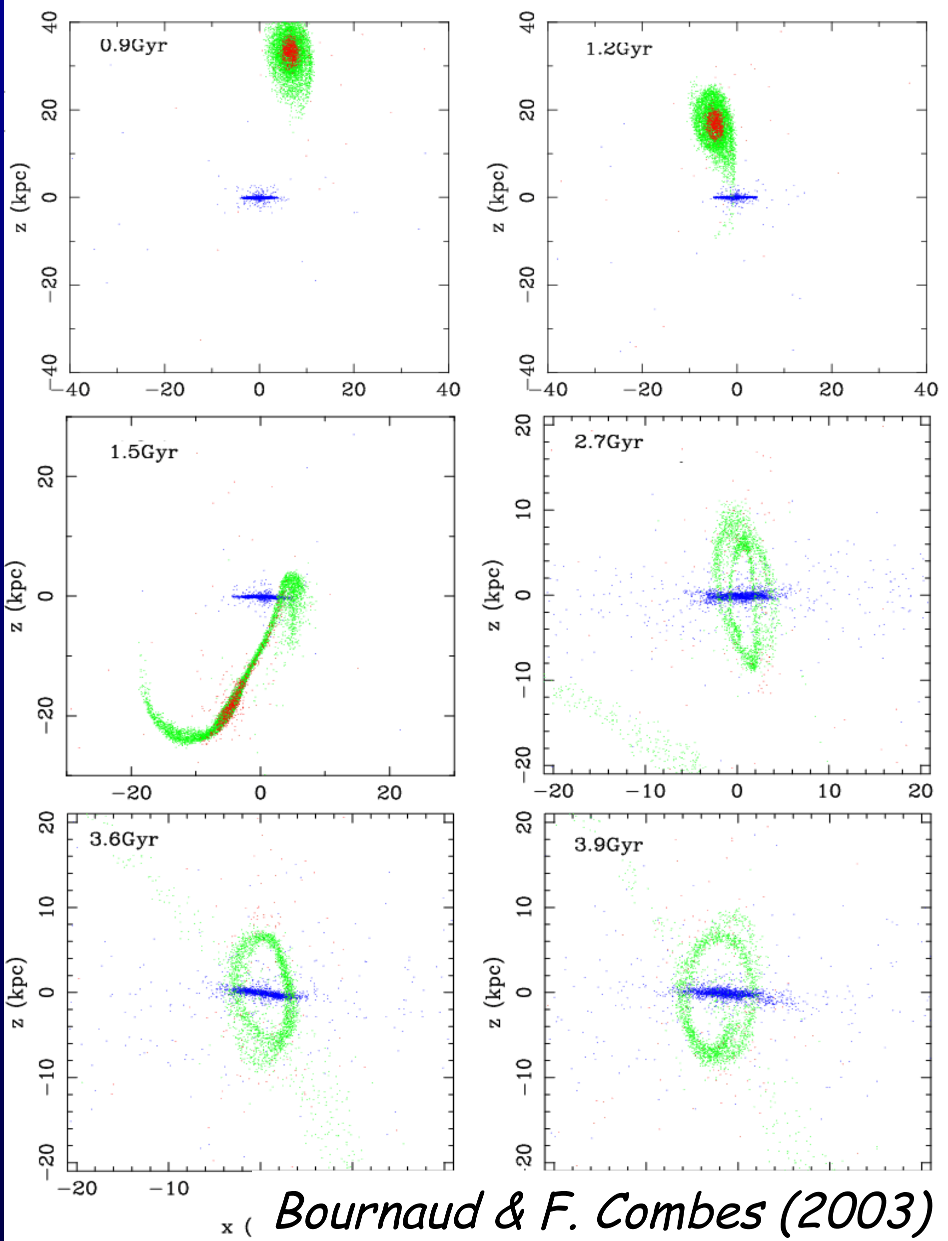
- A head-on collision between two orthogonal spiral galaxies (Bekki, 1998; Bournaud & Combes, 2003)

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)

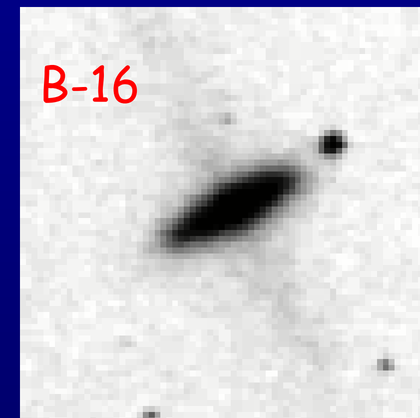


Bournaud & F. Combes (2003)

A photographic atas of 157 polar ring galaxies, Whitmore et al (1990): ~0.5% of local S0

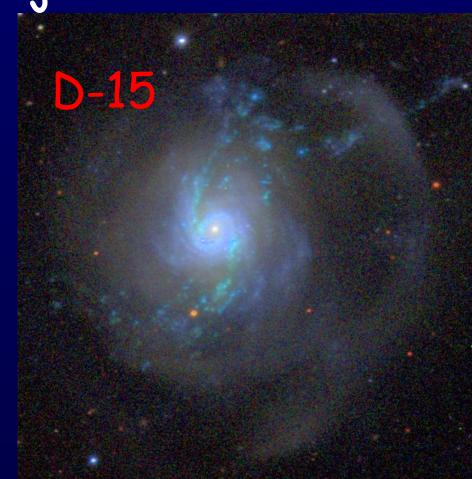
PRC-A (6 galaxies):
Kinematically confirmed

PRC-B (27 galaxies)
Good candidates



PRC-B (73 galaxies)
Possible candidates

PRC-D (51 galaxies)
Related objects



20 years looking in Polar Rings Catalogue...

see Combes (2005), Iodice et al. (2003), Sparke (2002)

- A host galaxy like S0 or E, the polar component is like spirals or irregular galaxies (gas-rich and bluer)
- Not only narrow annuli, but also extended disk-like rings
- Warped and inclined rings

Polar rings kinematics:

- Only 20 large-scale polar rings + 6 inner rings were kinematically confirmed from the Whitmore et al list:

  - HI maps (Cox et al; Sparke et al; Jozsa's talk)
  - optical-long slit spectroscopy (Reshetnikov et al)
  - optical 3D spectroscopy (Spalyapina et al, Merkulova's talk)

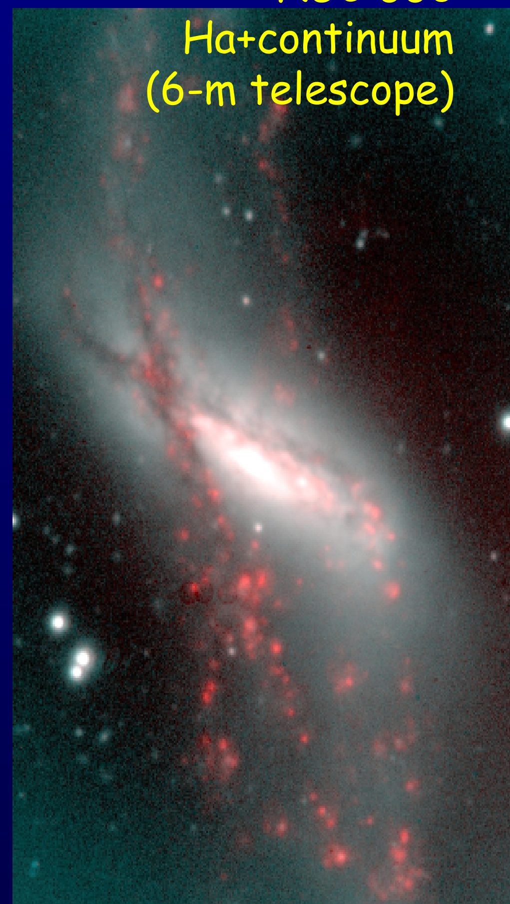
But for many candidates we have not any information about their inner kinematics.

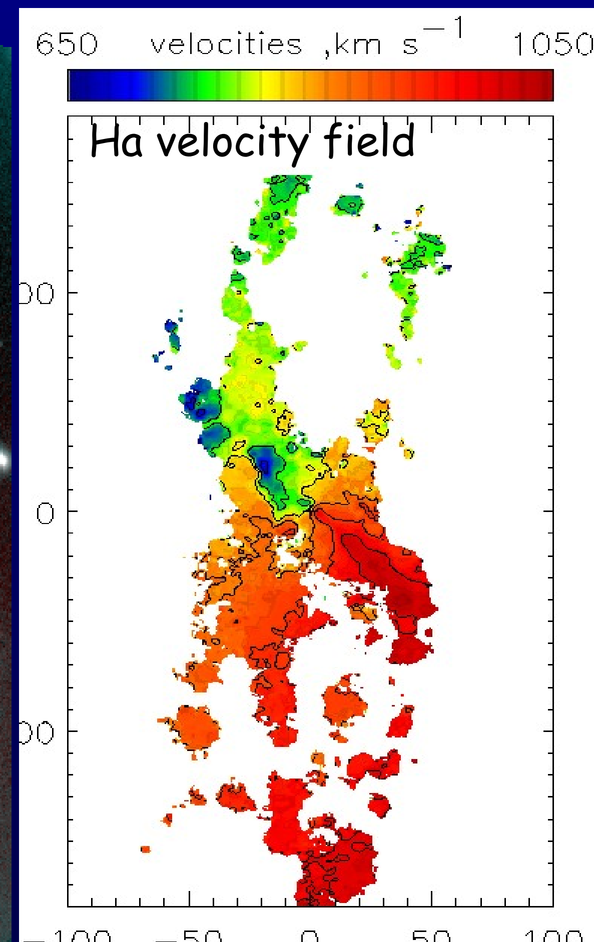
2D kinematics with 3D spectroscopy

- Integral-field spectrograph MPFS (Afanasiev et al., 2000)
- Focal reducer SCORPIO with scanning Fabry-Perot interferometer (Moiseev, 2002)

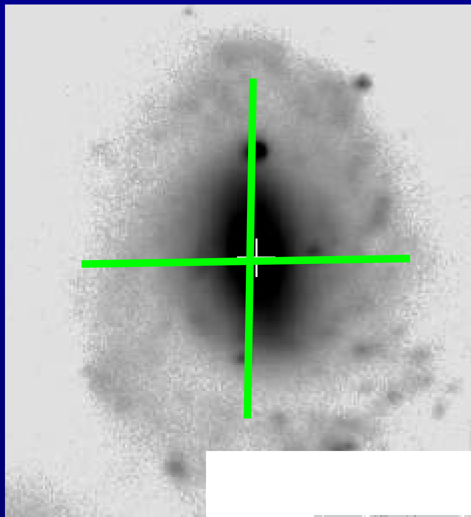
6-m telescope of the Special Astrophysical Observatory Russian Academy of Sciences (SAO RAS).

NGC 660
Ha+continuum
(6-m telescope)



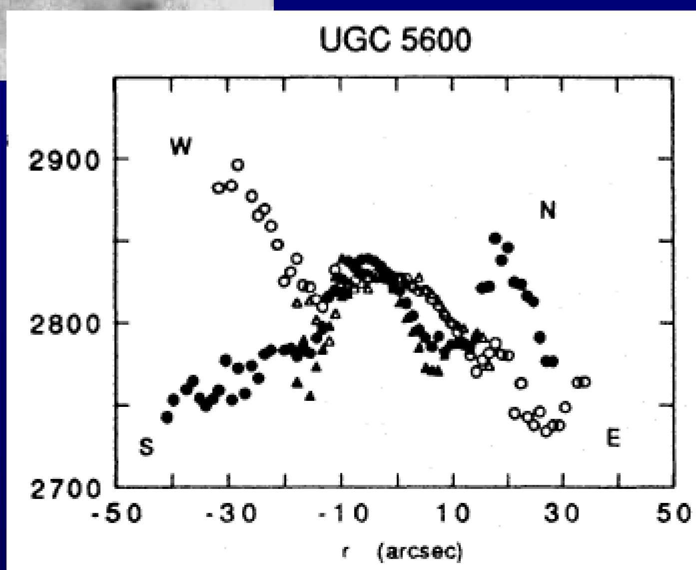


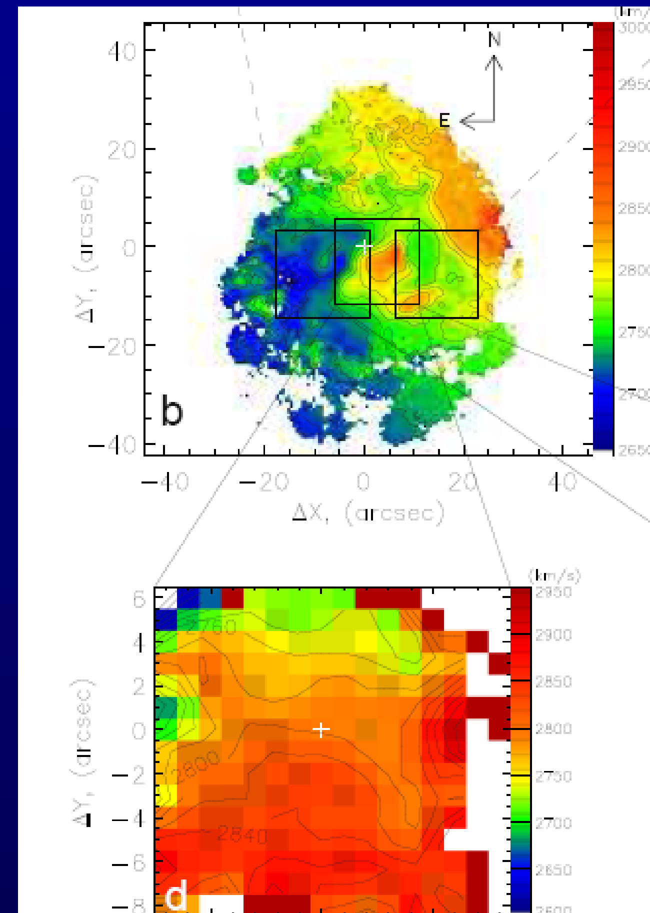
UGC 5600: an example of comlicated structure



Veocity fields:

Long-slit data:





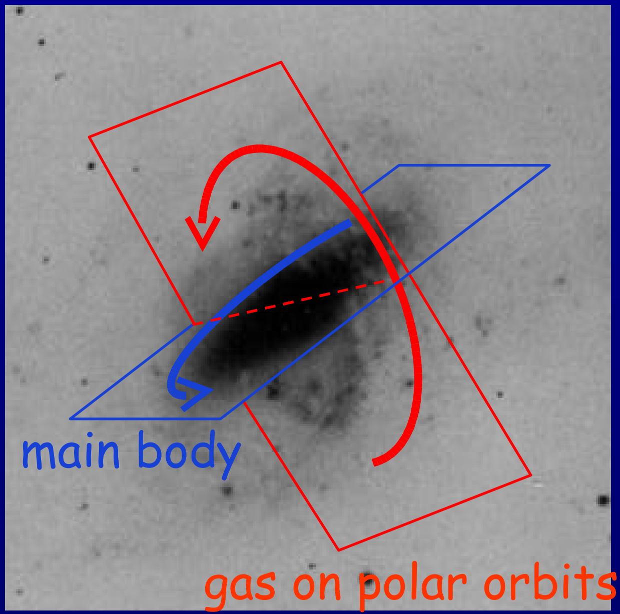
Reshetnikov & Combes (1994)

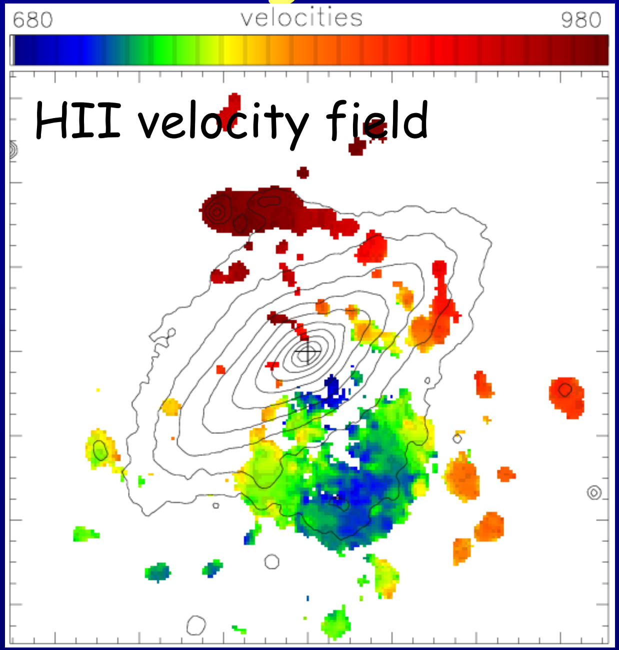
Central counter-rotation along major axis + regular rotation of the ring

Shalyapina et al(2002,2007)

Inner polar ring and warped external disk

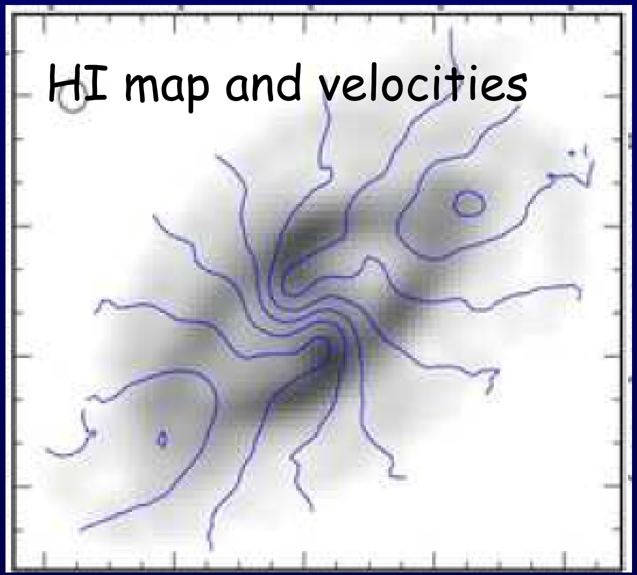
NGC 2685: ionized gas and HI kinematics

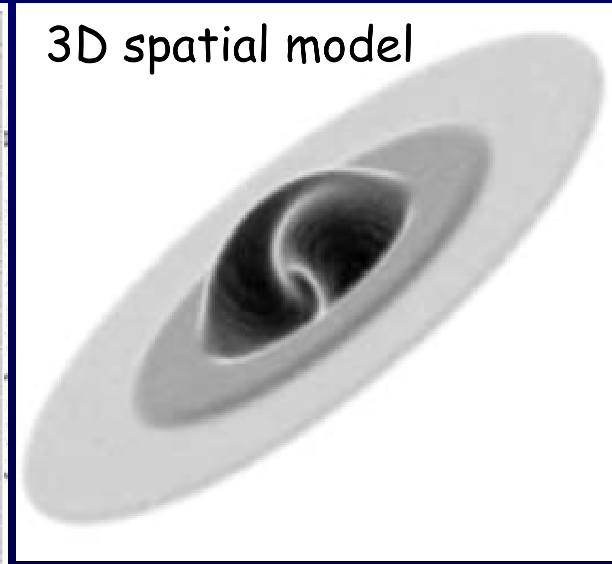




Fabry-Perot data:

Hagen-Thorn et al (2005): A polar disk of the ionized gas (Δi =87 deg)





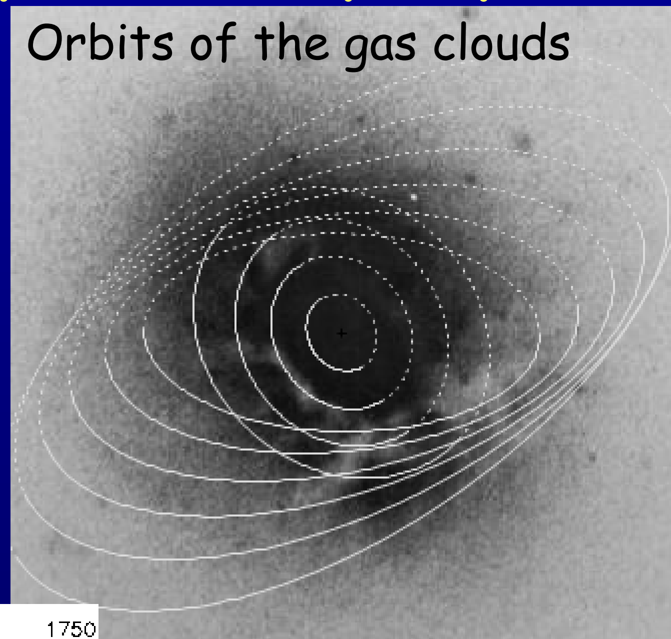
HI WSRT data :

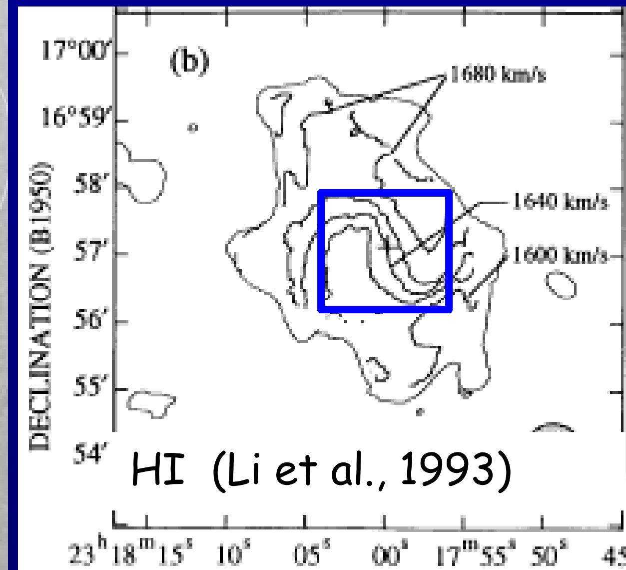
Jozsa et al (2008): Extremely warped disk. Inner part — strongly inclined (Δi~70 deg) but outer regions are coplanar with the central S0 stellar disk

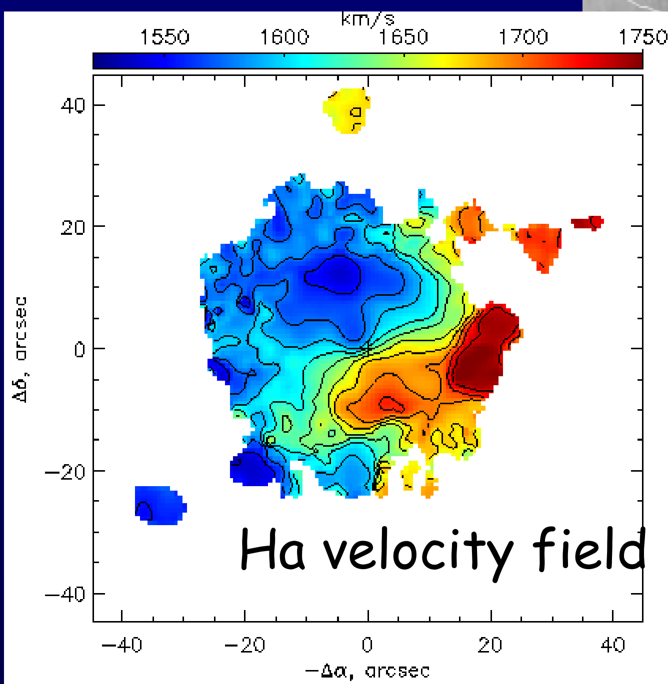
Arp 212: warped polar ring

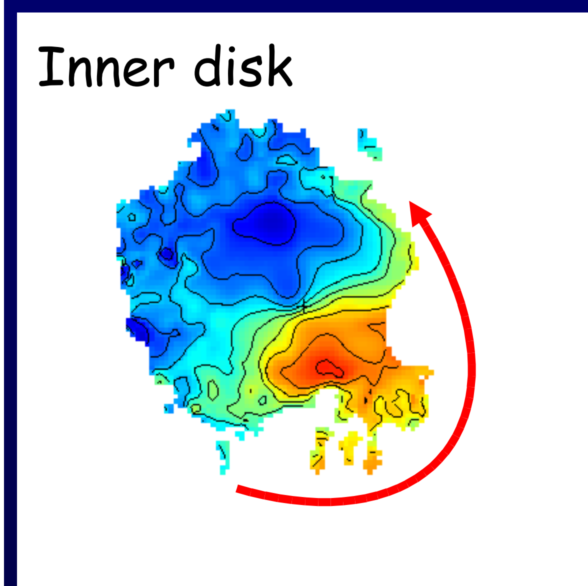
..Formation of the polar/warped gaseous disk after accretion from gas-rich dwarf galaxy UGC 12549..

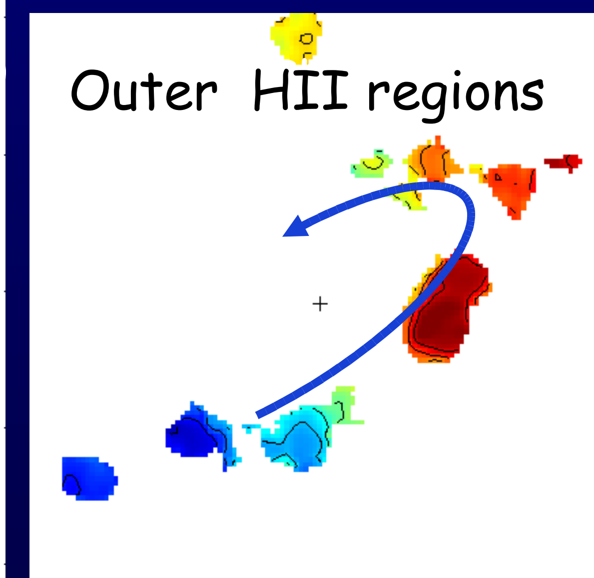
(Mosieev, 2008)



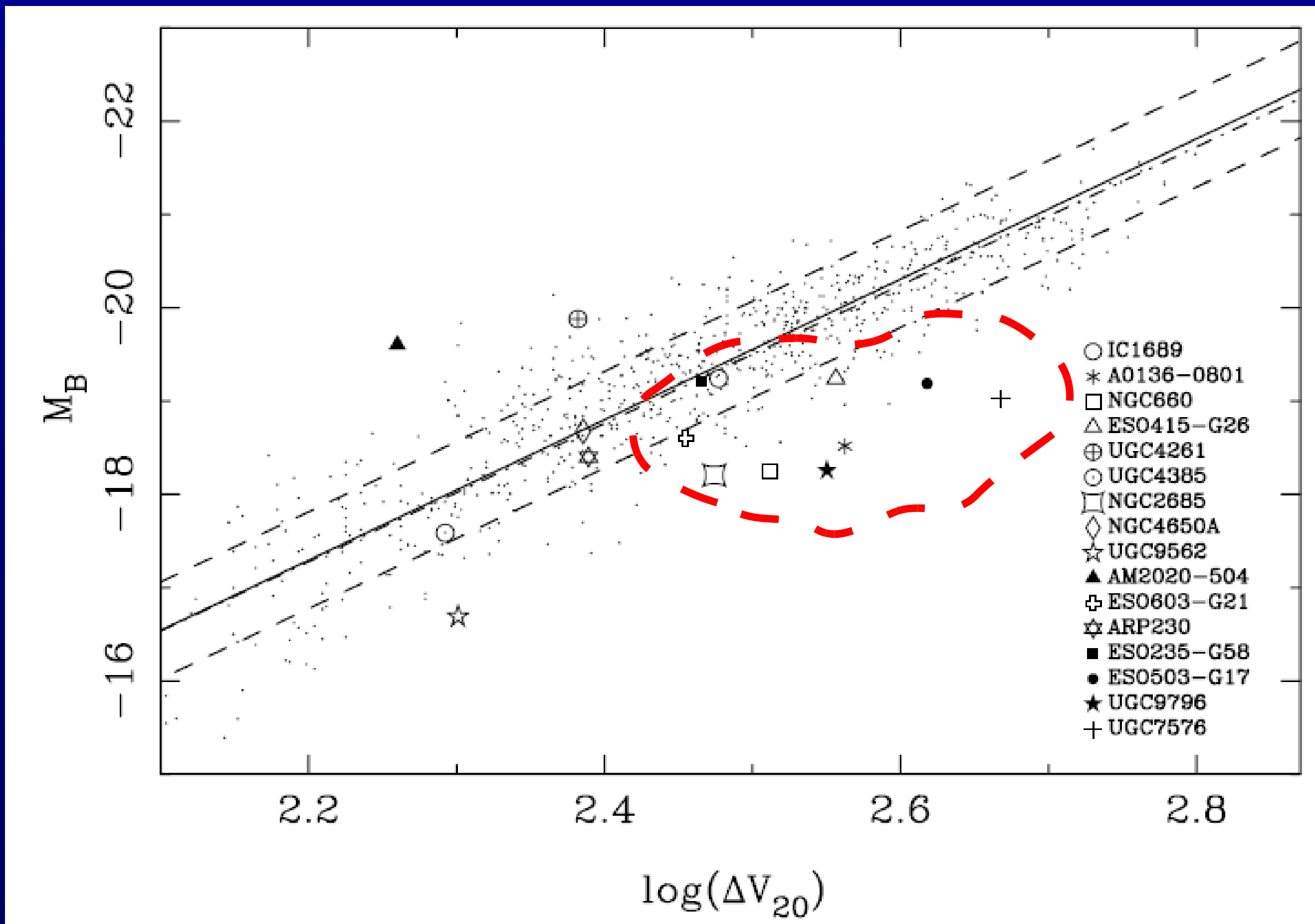


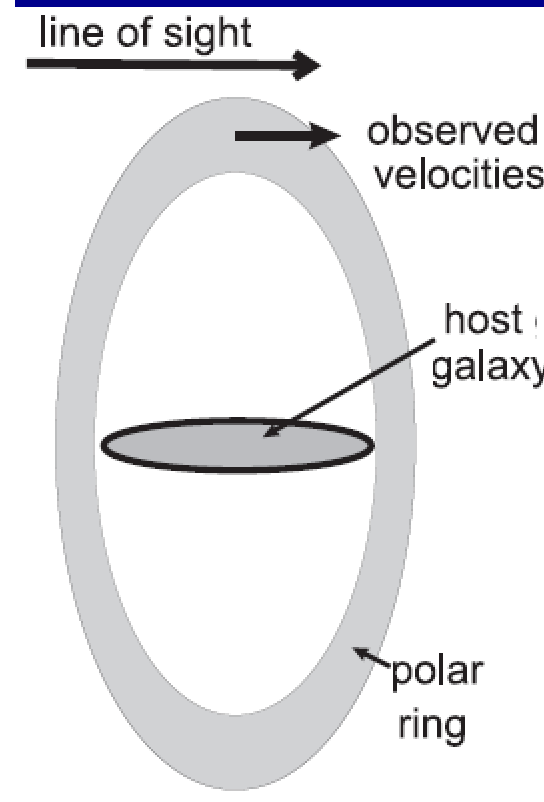






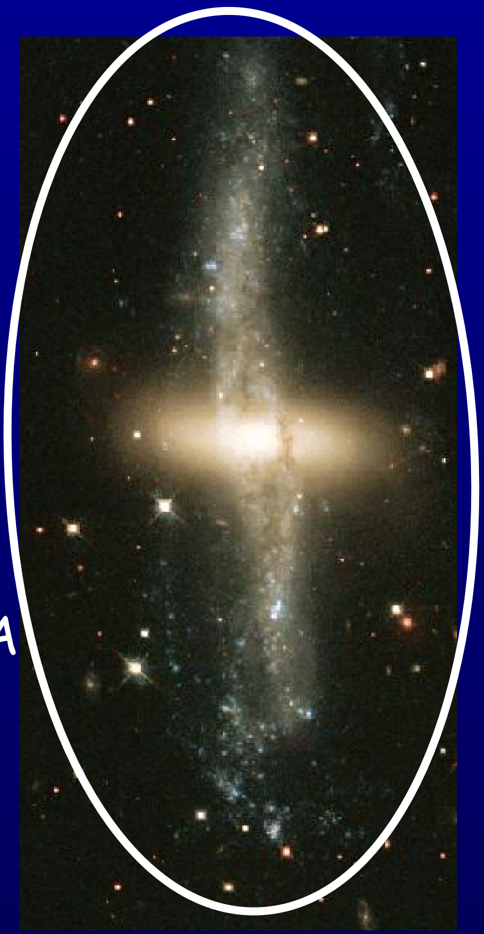
The Tully-Fisher relation for PRG





Iodice et al (2003), Reshetnikov (2004):
PRG showing larger rotation veocities than expected for the observed luminocity. It can be explained by a flattened polar halo, aligned with the polar ring

What is the true shape of dark matter halo?



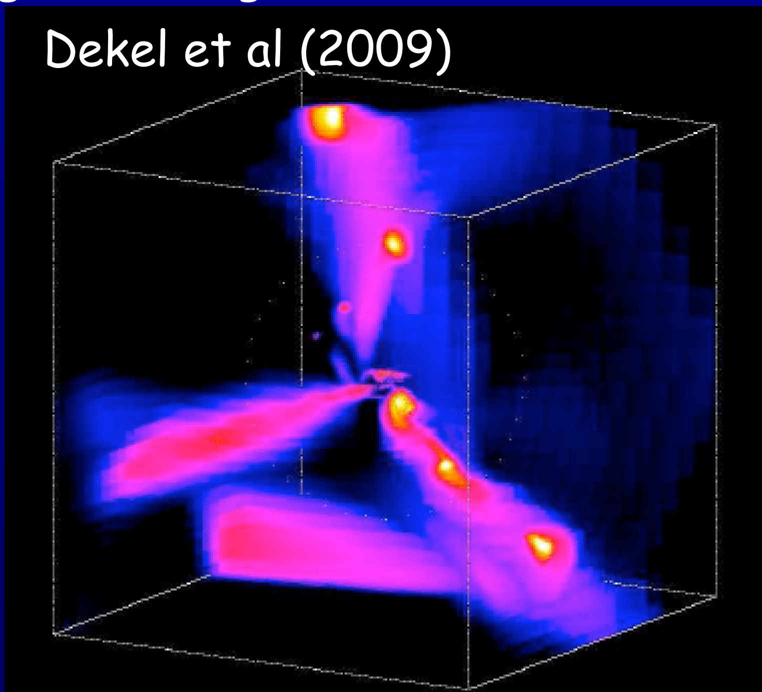
Theory and simulations (wait Debattista's talk!):
A flattening should be depend from the origin (Combes, 2005):
Accretion: c/a<1
Merging: c/a≈1
Triaxial CDM halo: c/a=0.5-0.7

Observations:
T-F relation: flattened halo along polar plane
Iodice et al (2009): new dynamical model for NGC4450A constrains very flat halo with c/a=0.3

Strongly tilted rings would survive preferentially in roundest halos:
NGC 2685 (Josza et a, 2008),
NGC 3718 (Sparke et al, 2009),
NGC 4753 (Steiman-Cameron, 1993)
We need more spatial resolved 2D kinematics + detailed modeling of the gravitational potential shape

Gas arretion from cosmic filaments?

Macci et al (2006):
gas infalling from cosmic filaments, with inclined angular momentum



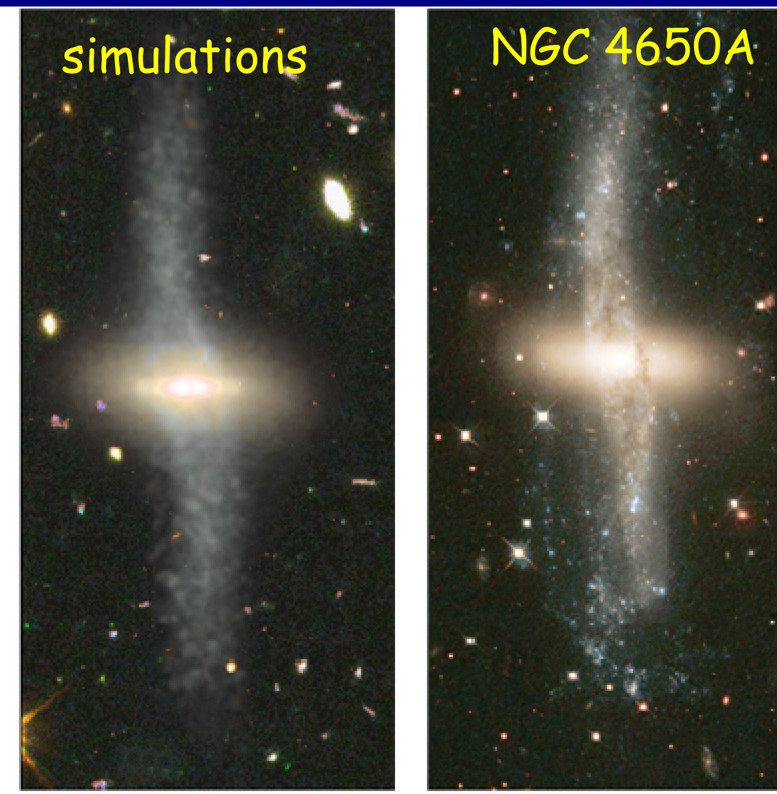


FIG. 3.— The simulated polar disk (left) is imaged by assigning

Brook et al (2008) :
Simulated object similar with NGC 4650A

Spavone et al (2010): low metallicity (Z=0.2 Zsun) in the polar disk of NGC 4650
implies a cold accretion scenario?

Chemical abundance in PRG

Ionized gas and stars metallicity: only few spectral measurements were published:

UGC 5600 (Shalyupina et al., 2002): 0.9 Zo
UGC 5119 (Merkulova et al., 2008): [Fe/H]=-0.33...-1.5 (stars)
II Zw71 (Perez-Montero et al., 2009): 0.1 Zo

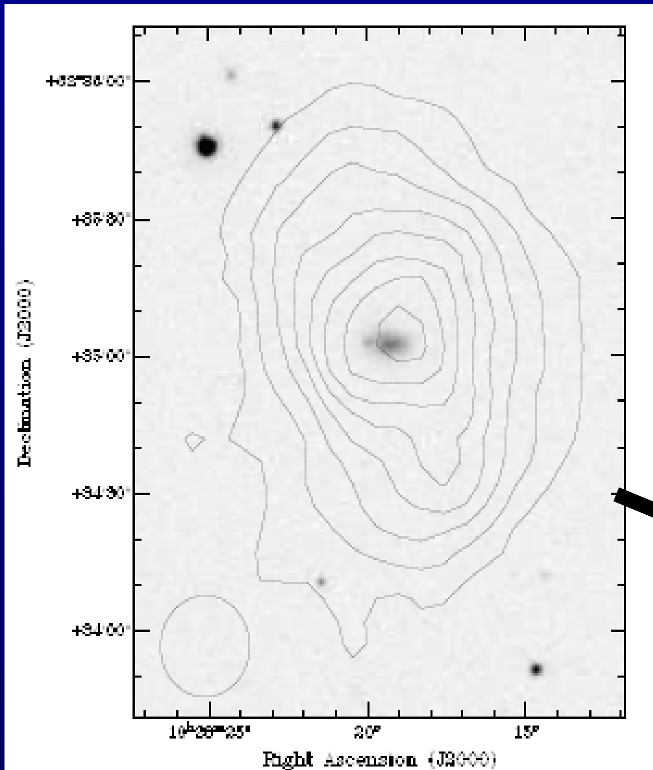
SDSS J075234+.. (Brosh et al.,2010): 0.4 Zo
NGC 4650A (Spavone et a., 2010): 0.2 Zo

Lower than that expected by metallicity-luminosity relation (if this relation can be accepted for PRG!)

Stellar color-magnitudes diagrams in rings:

NGC 660 (Karataeva et al., 2004): 0.4 Zo
NGC 2685, 4450A (Karataeva et al., 2004): 0.4 Zo
NGC 5128 (Karataeva et al., 2006): metal-rich red supergiants in the ring

Other implications for cold accretion scenario



SDSS J102819+623502
Stanonik et al (2009):
HI polar disk in wall between voids

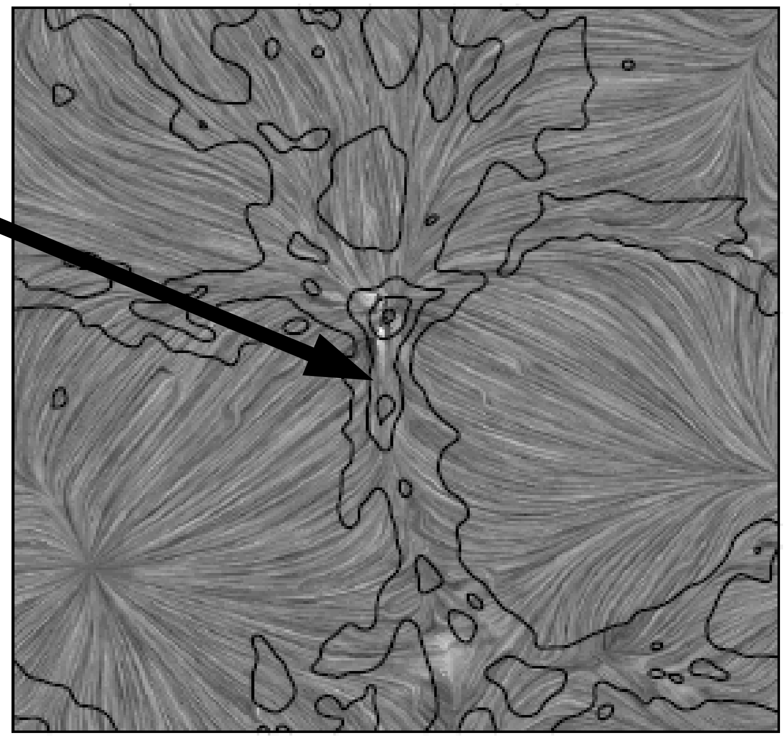
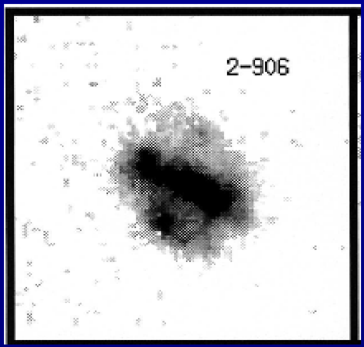
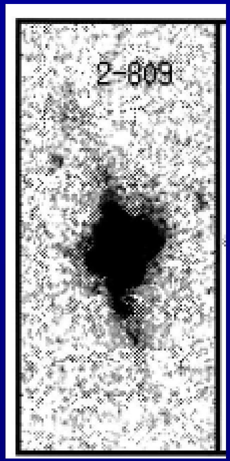


FIG. 5.— N-body simulation showing the flow lines of the cosmic elocity field, with density contours superimposed. Clearly visible

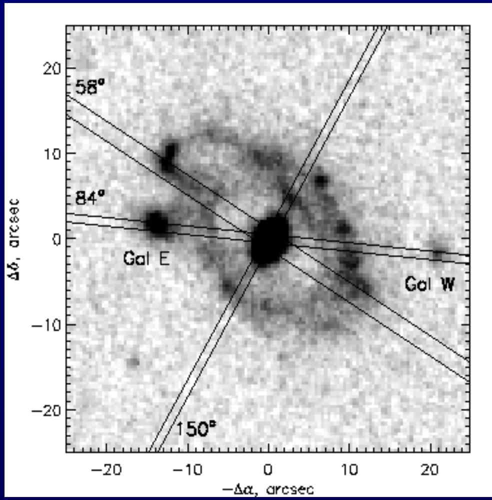




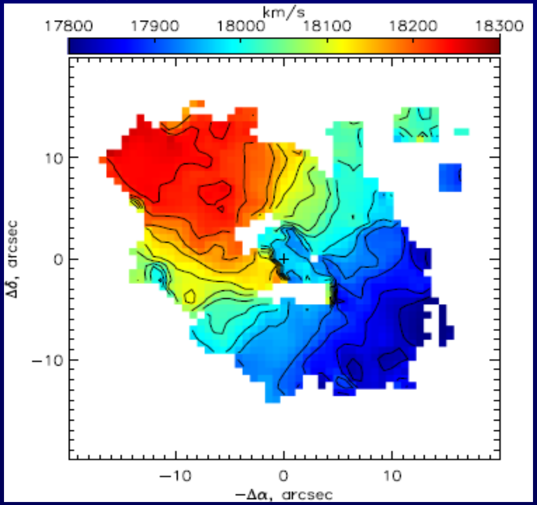
Distant polar rings

HST deep field and UDF candidates z=0.5-1.5
(Reshetnikov, 1997; Reshetnikov & Dettmar, 2007)

SDSS J075234.33+292049.8
kinematically confirmed polar ring at Z=0.06 (Brosh et al 2010)



SDSS image



Hβ velocity field
(6-m telescope)

A giant (D=50 kpc) stellar-gaseous disk inclined on Δi= 73±12° relative central S0-like host. M/L=20

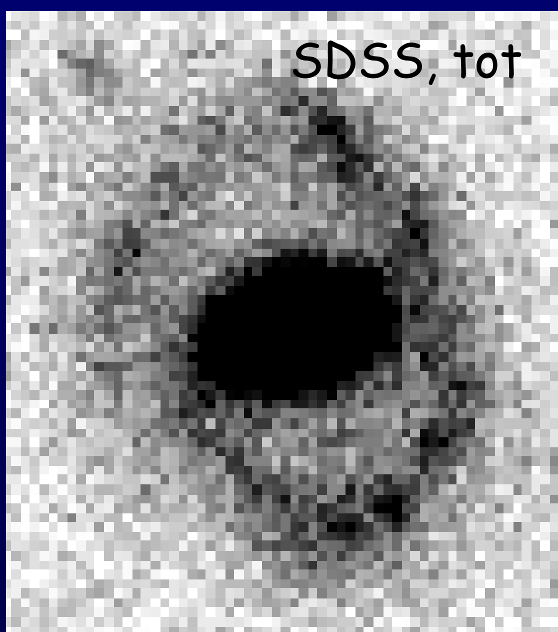
A large distant prototype for NGC4650?

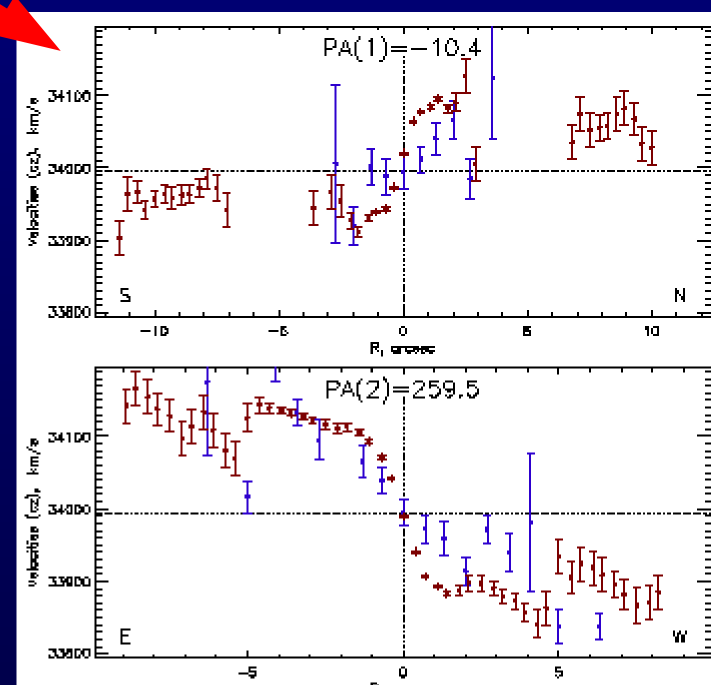
Moderate orientation of both components

New PRG candidates in SDSS

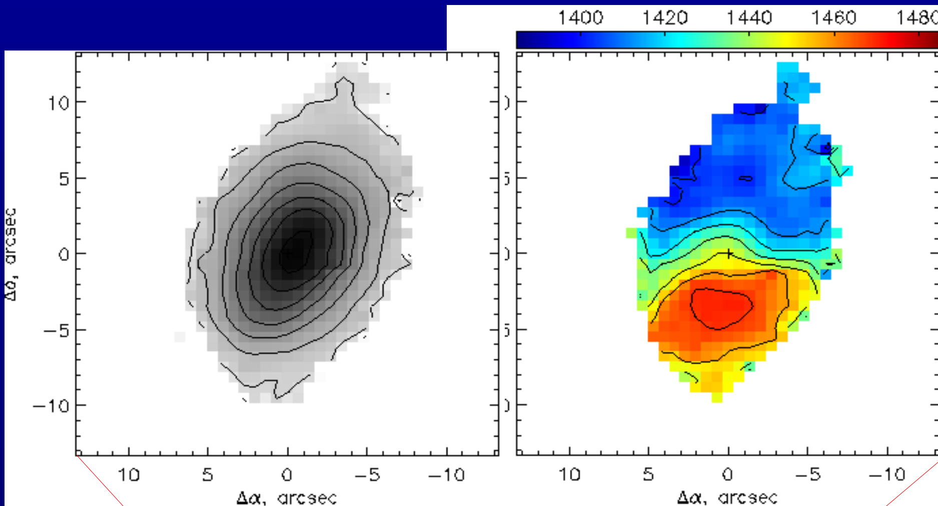
Long-slit spectroscopic observations at 6-m telescope (Moiseev, Reshetnikov & Belokurov)

Elongated polar ring at z=0.11: long-slit kinematics



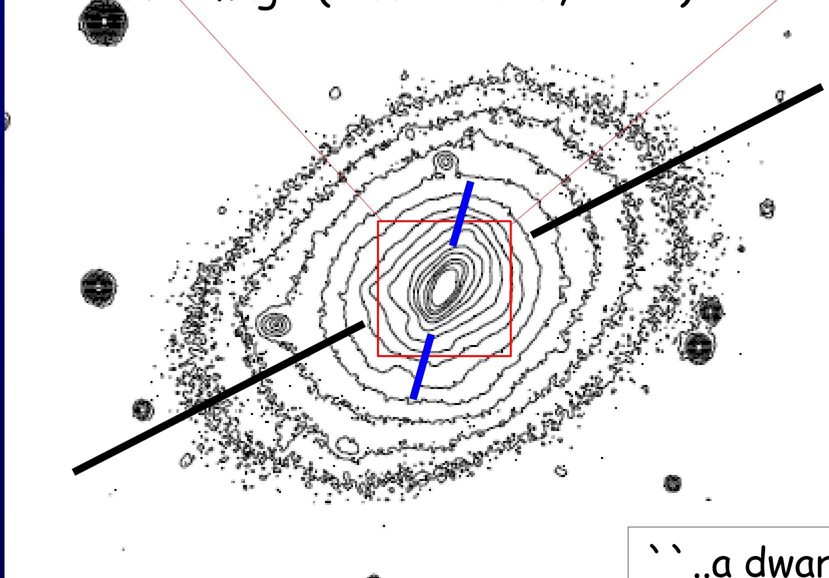


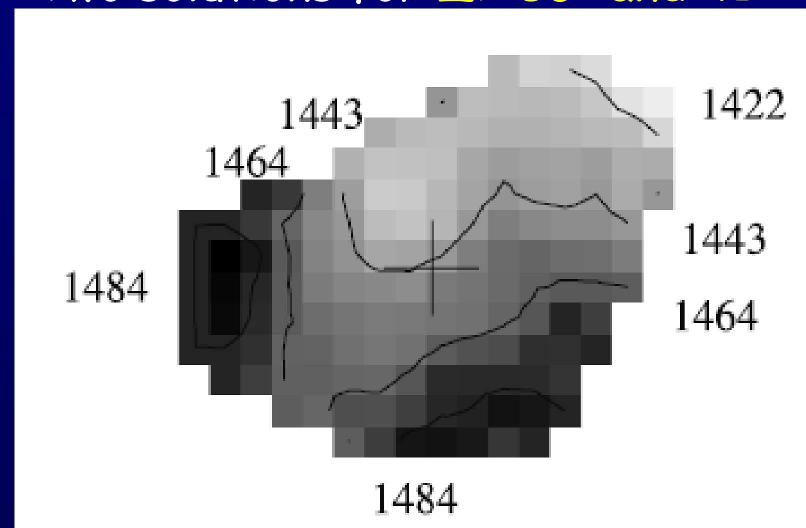
Blue compact dwarf galaxies: Mrk 33



Inner disk (kinematics): PA=171°, i=60°
Outer disk (isophotes) : PA=120°, i=48°
Two solutions for Δi: 86° and 41°

B-band image (Cairos et al, 2001)

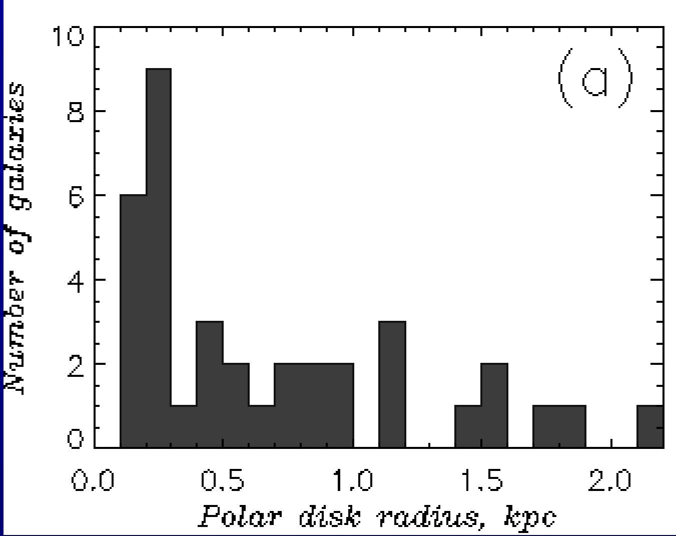




VLA 15'' beam, Bravo-Alfaro et al, 2004:

``..a dwarf elliptical that has recently captured gas in a close interaction or merger with an initially gas-rich companion.''

Circumnucelar polar/inclined disks



Outside of Whitmore et al. definition PRG: inner and outer components both comparable in size

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

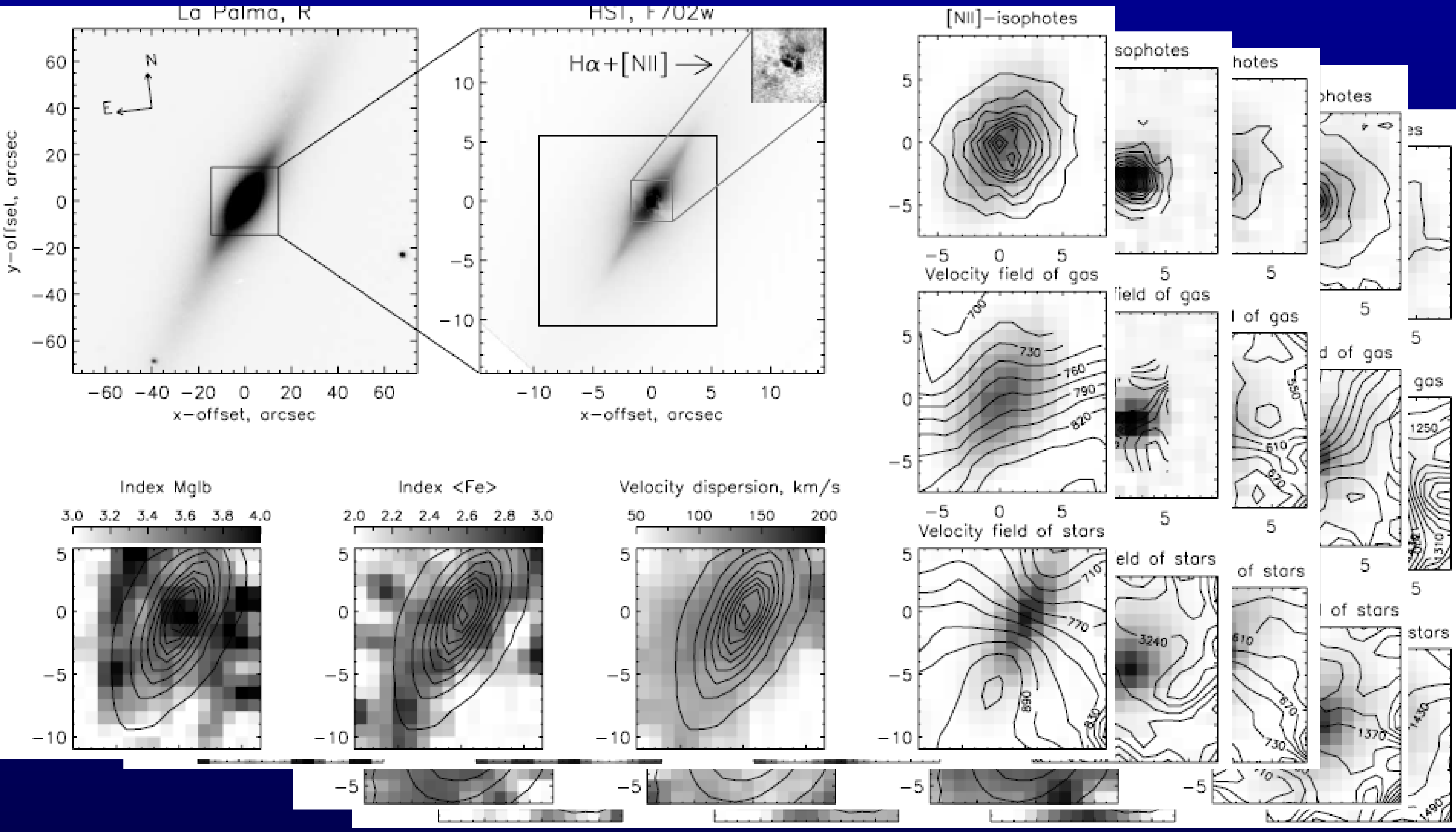
Moiseev, Silchenko & Katkov (2010, in prep):
list of 37 IPS with sizes 0.1 — 2 kpc

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

3D spectroscopy are an optimal technique to study of circumnuclear kinematics.

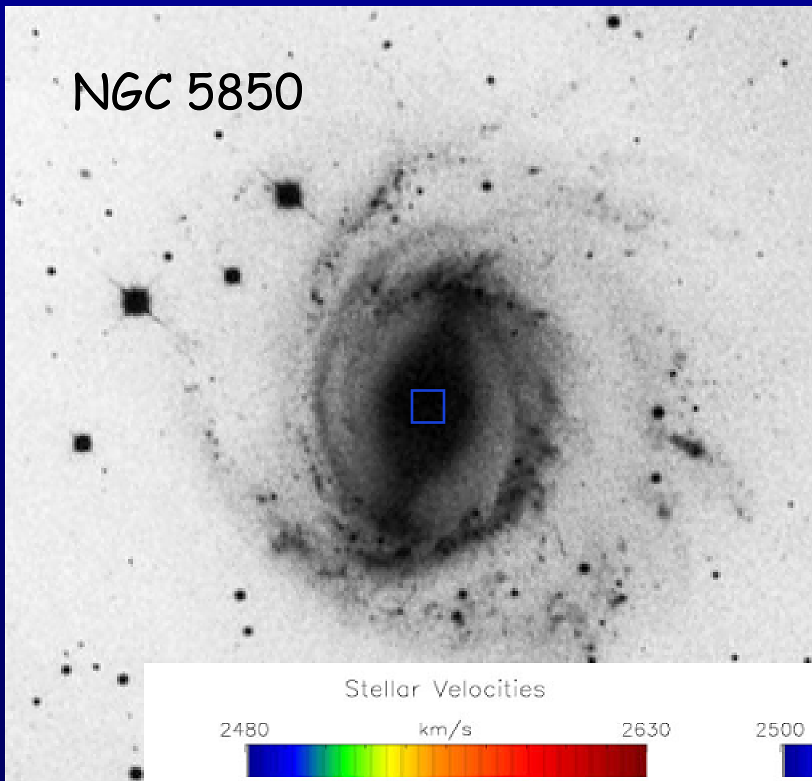
~70% of the listed IPS has been discovered or confirmed with the 3D facilities on the SAO RAS 6-m telescope

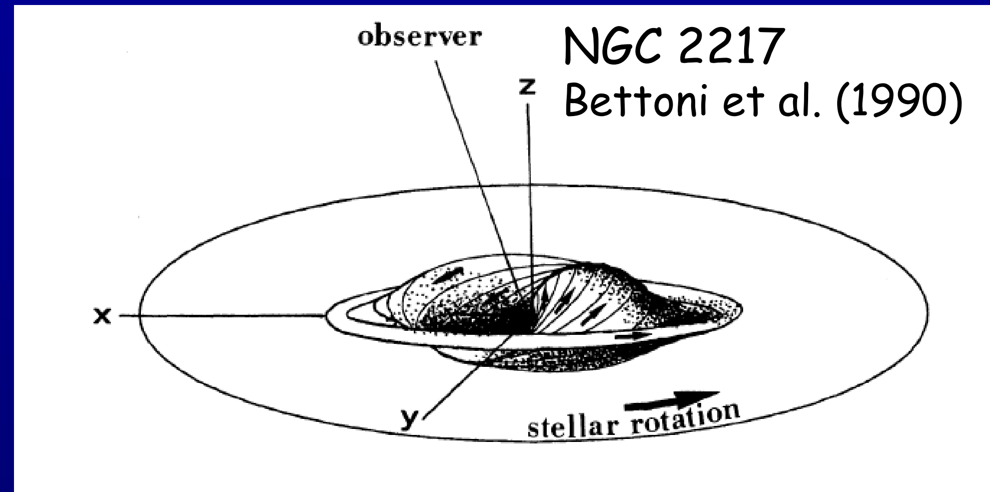
2D kinematics of S0 galaxies with circumnuclear dust lanes

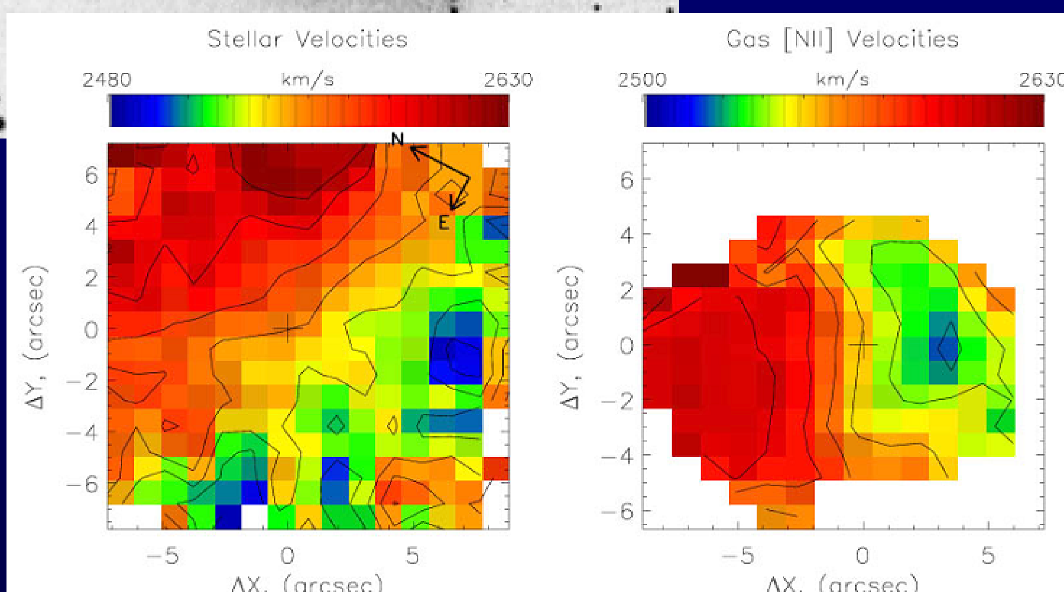


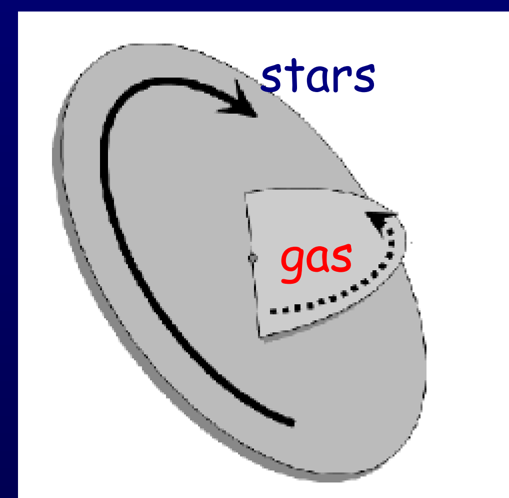
Sil'chenko & Afanasiev (2004): MPFS observations of stars and gas kinematics

Inner polar disks and bars



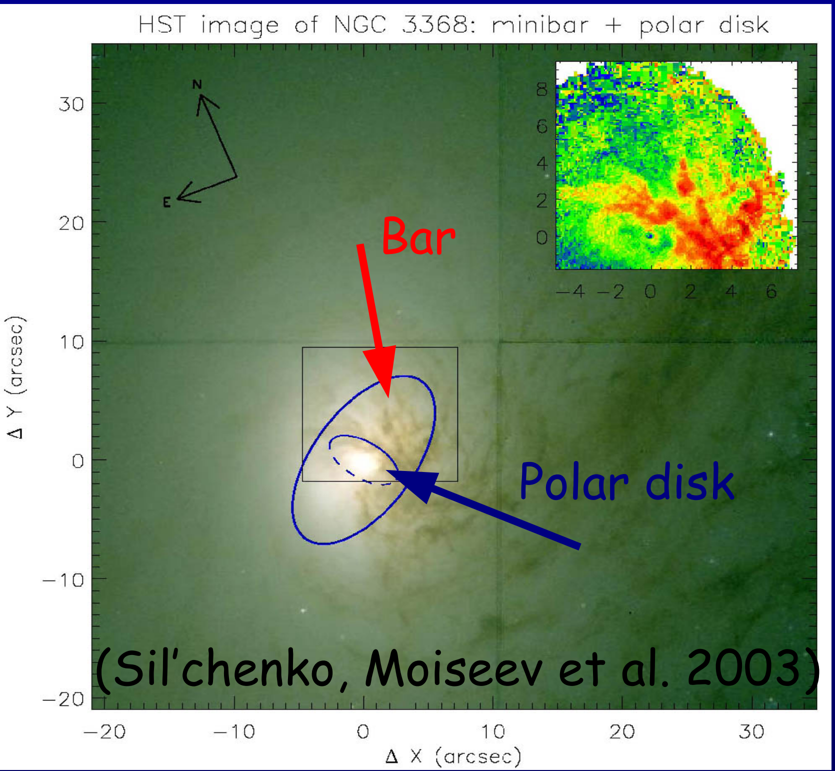


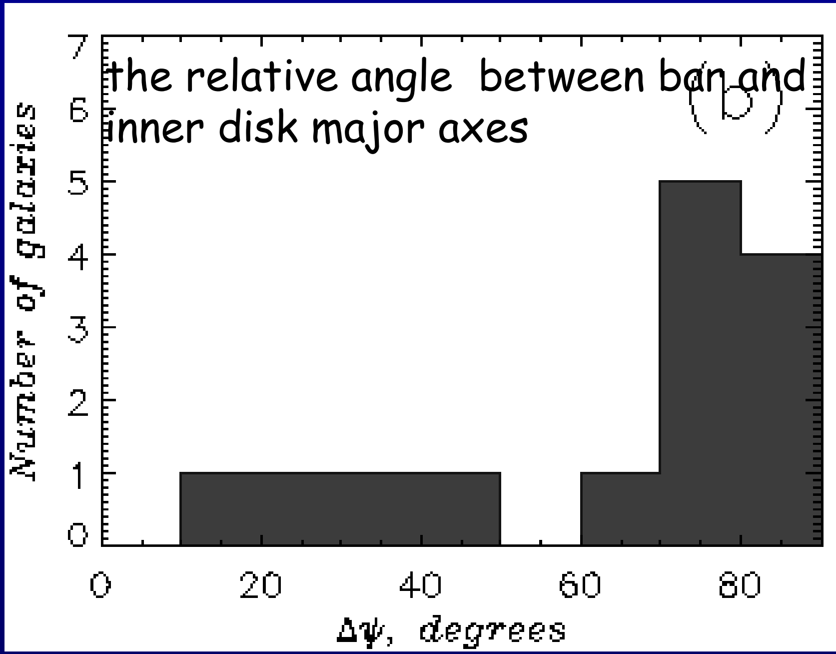




Moiseev et al (2004)

Inner disks observed in barred galaxies (43%)





Inner polar disks 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 counterrotating gas, belonging to the stellar-gaseous disk, finally occupies stable orbits strongly inclined to the disk plane under bar driving force.
A gas/stars counter-rotation is observed in 10 galaxies in the list.

External gas accretion?

- diffuse light stellar tidal arm and strongly warped external HI layer in NGC 2655 (Sparke et al., 2008);
- the external HI cloud traces the recent acquisition of cold gas in NGC 2768 (Crocer et al., 2008);
- two kinematical components detected on P-V diagram in HI data of NGC 3414 (Morganti et al., 2006);
- low-contrast shells/riples in NGC 6340 (Chilingarian et al., 2009).

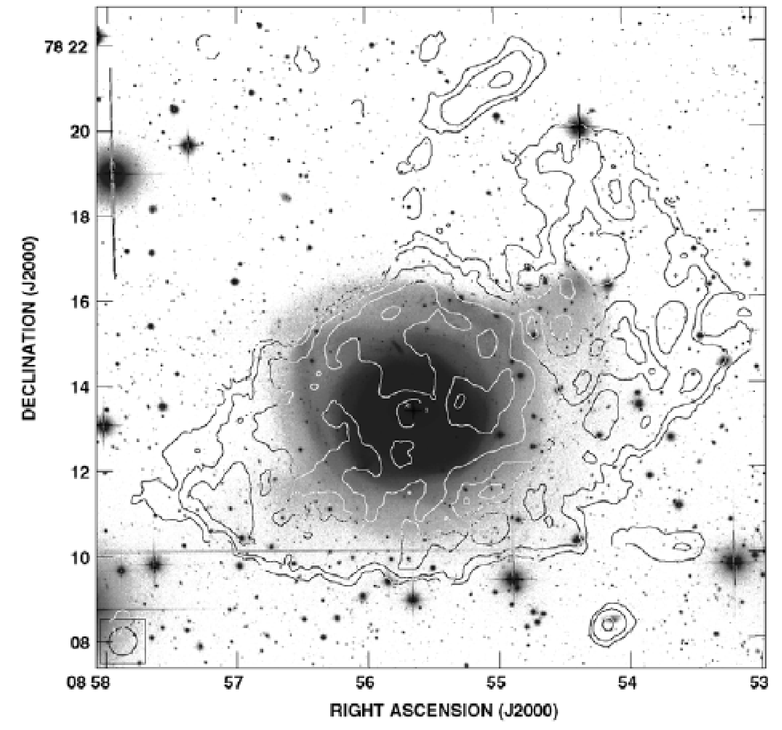
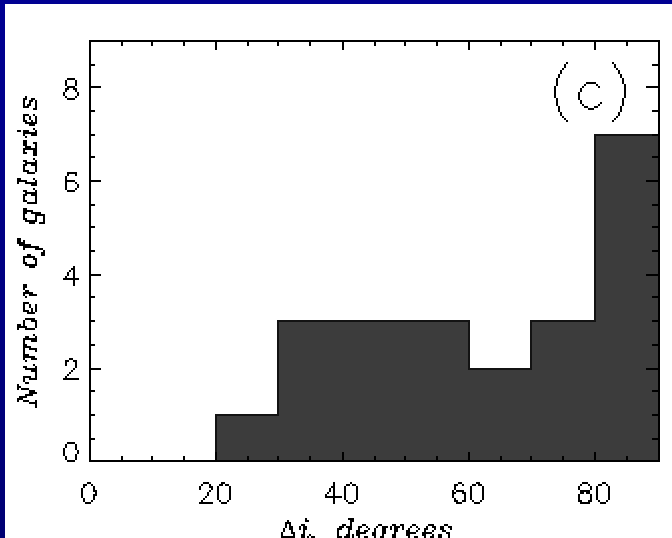


Figure 7. Total H I emission around NGC 2655 integrated over velocity,

Other cases:

Inner polar structures are only a fossil remainder of past minor merging events.

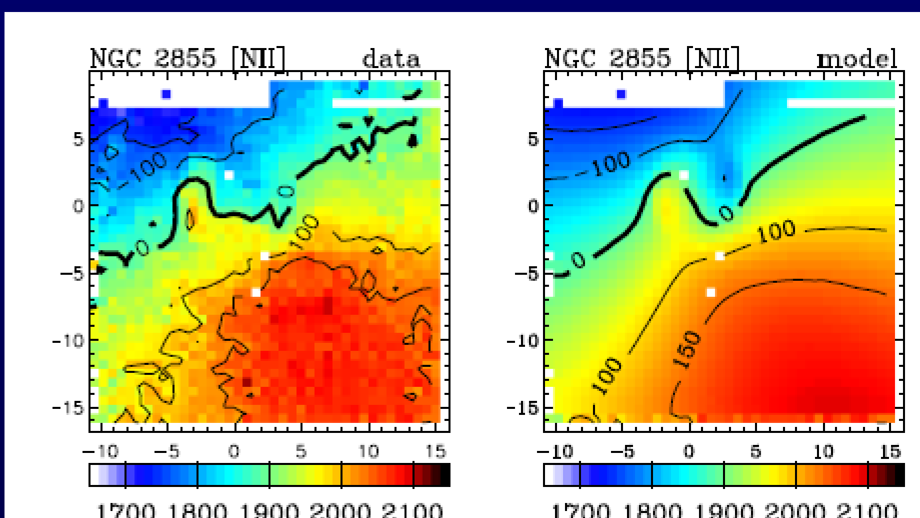
Polar or inclined?

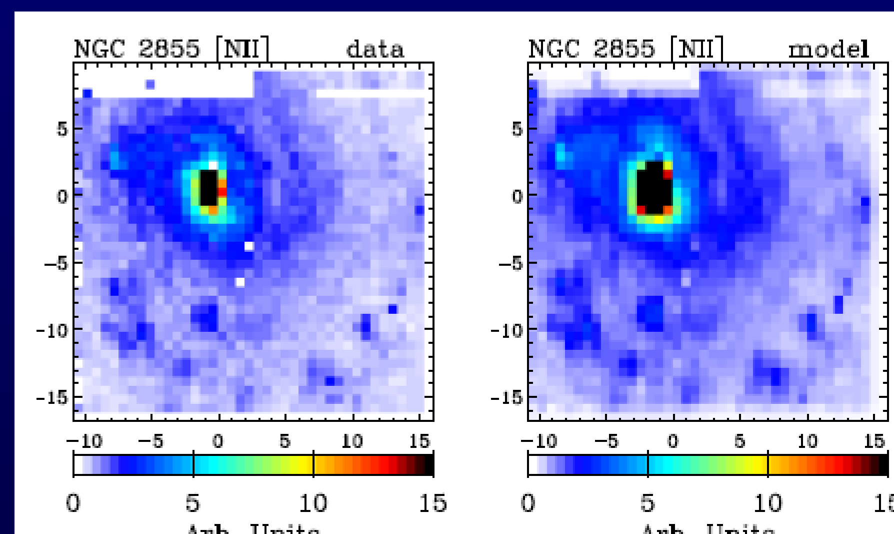


16 galaxies where the mutual inclination angle was estimated in original works

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

Coccato et al (2007): VIMOS/VLT kinematics of warped inner disk in NGC 2855





Conclusion

- Polar rings could provide clues on the 3D shape of DM halos, but detailed kinematic information is still absent (except only few objects).

- A good way is to combine 3D optical spectroscopy data with HI kinematics inferred from radio interferometric data.

- Age and chemical abundance measurements could be important to test possible scenario of polar ring formation from a cosmic filaments cold accretion

- 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.

Thank you!