Hidden imprints of minor merging in early-type galaxies: inner polar rings and inclined large-scale gaseous disks in S0s

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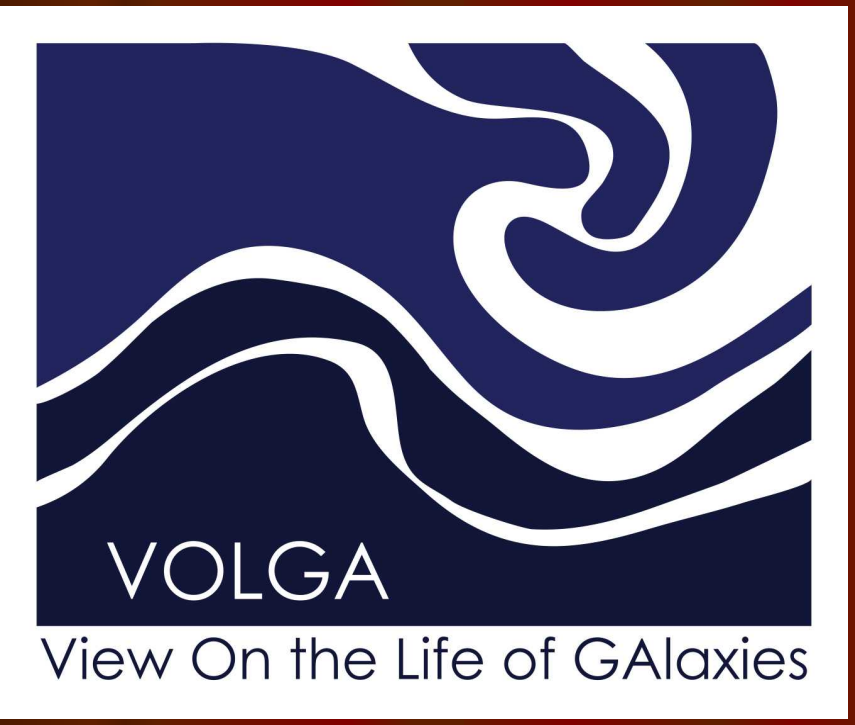
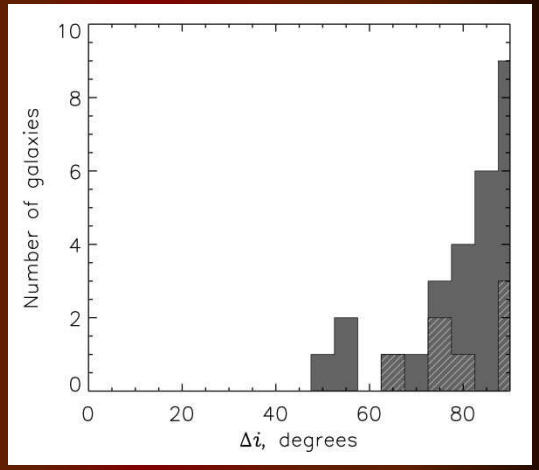
In collaboration with:

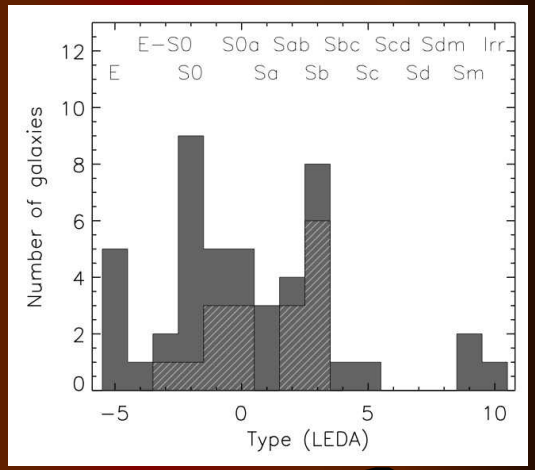


- Alexei Moiseev (SAO RAS)
- Victor Afanasiev (SAO RAS)

Inner polar disks, what is it?

- Gaseous (mostly ionized-gas), regularly rotating disks
- with radii of 0.2-2 kpc,
- highly inclined to the galactic planes – by 50-90 deg.
- Recently a totality of 47 objects are reviewed by Moiseev (2012) – see here histograms from this review.
- Mostly in S0-Sb, but there are some known cases in Es and very late-type galaxies



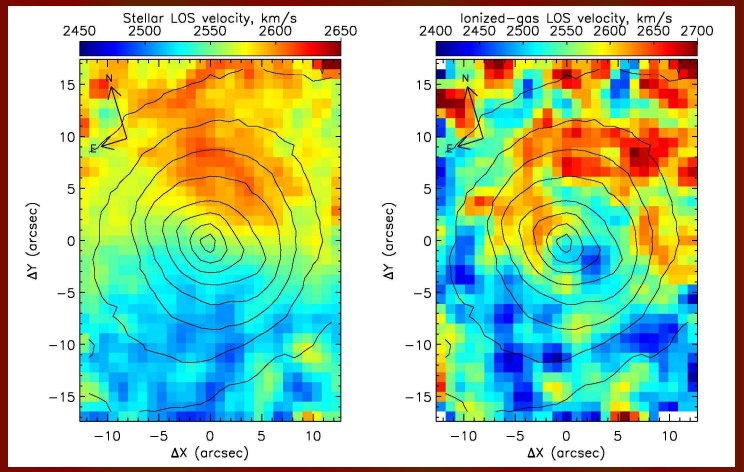


Moiseev 2012

3D-kinematical diagnostics

- By applying a tilted-ring analysis to the stellar and gaseous LOS velocity fields, we obtain the parameters of the spatial orientations of their rotation planes – inclinations i and line-of-nodes position angles PA.
- The mutual inclination angle is calculated as following:

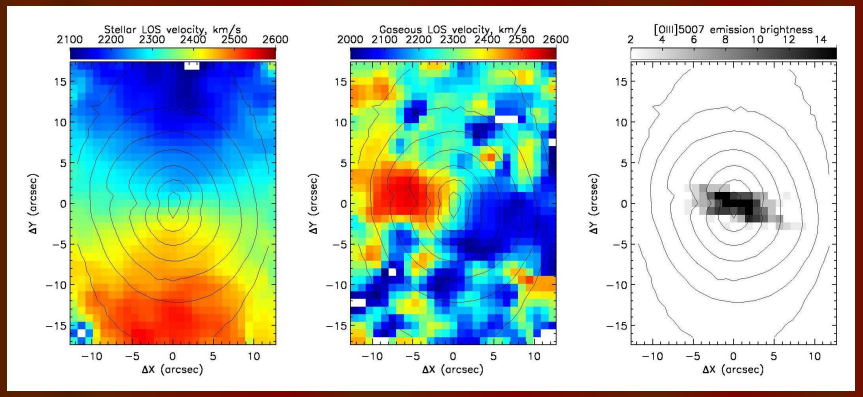
$$\cos \Delta i = +/- \cos(PA_{*} - PA_{gas}) \sin i_{*} \sin i_{gas} + \cos i_{*} \cos i_{gas}$$



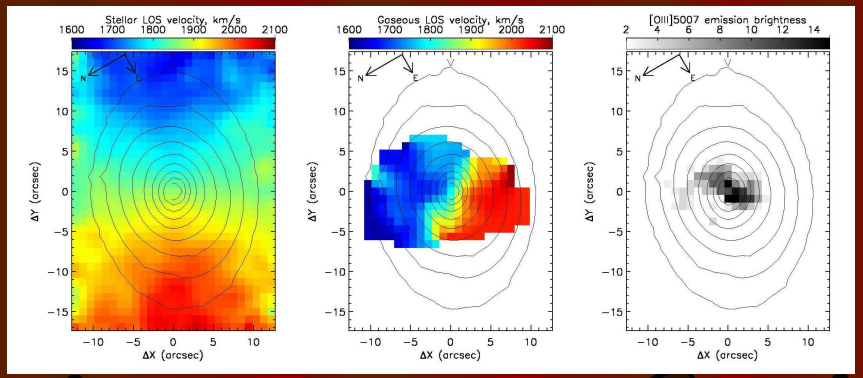
Δi =45 or 80 deg

NGC 5850: the inner polar disk was firstly found by Moiseev et al. (2004); now how as it is seen by the SAURON

Sometimes, if the polar gaseous disk is edge-on, it is seen `by eye'



NGC 4233

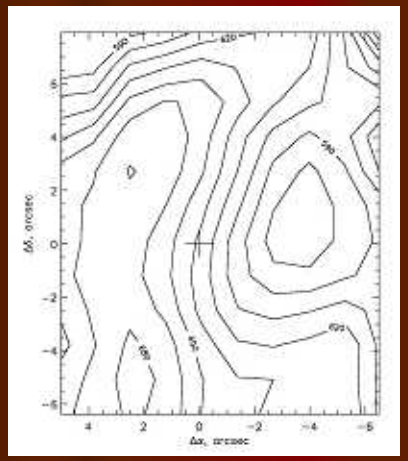


NGC 5507

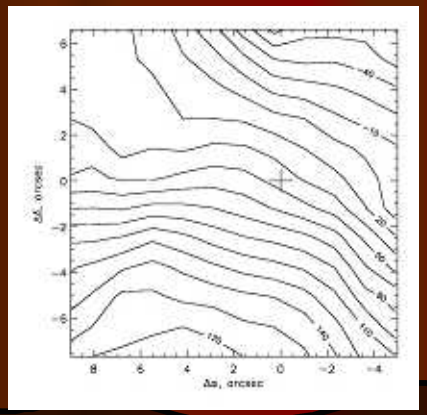
- Two S0 galaxies from the ATLAS-3D, where the distribution of the [OIII]5007 emission-line brightness gives a view of the edge-on polar disks.

Or even not strictly edge-on - when the dust related to the gas is projected onto the central part of a galaxy...

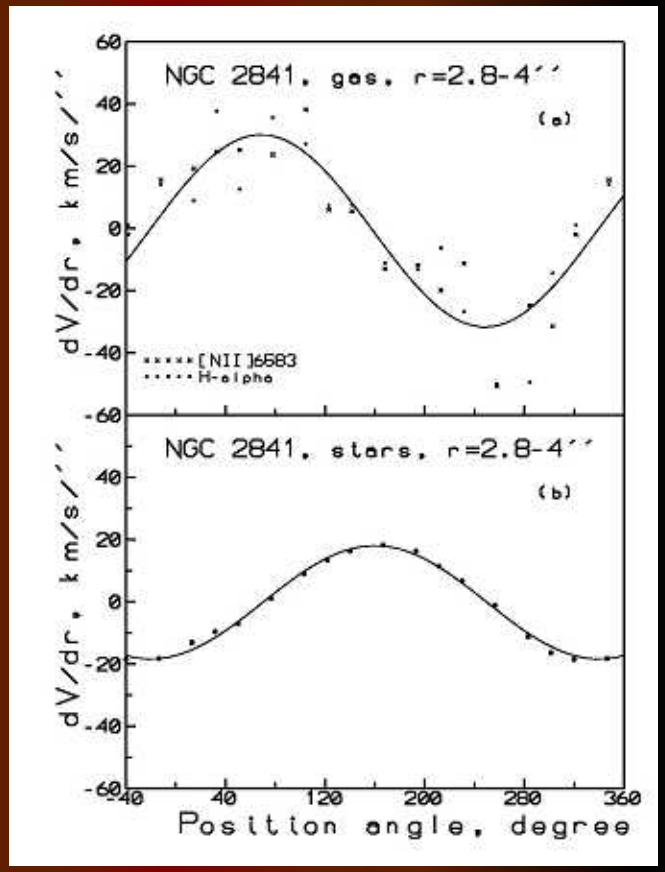
Our first finding with IFS MPFS/BTA - Sb NGC 2841, Sil'chenko et al. (1997)



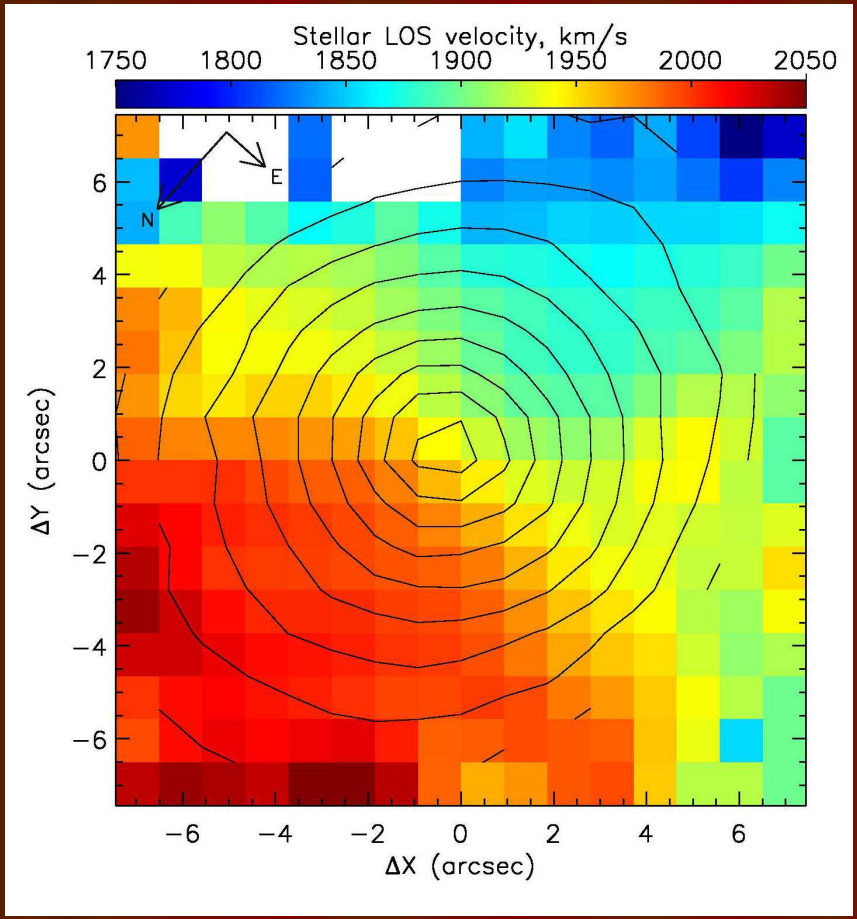
Ionized gas LOS velocity field

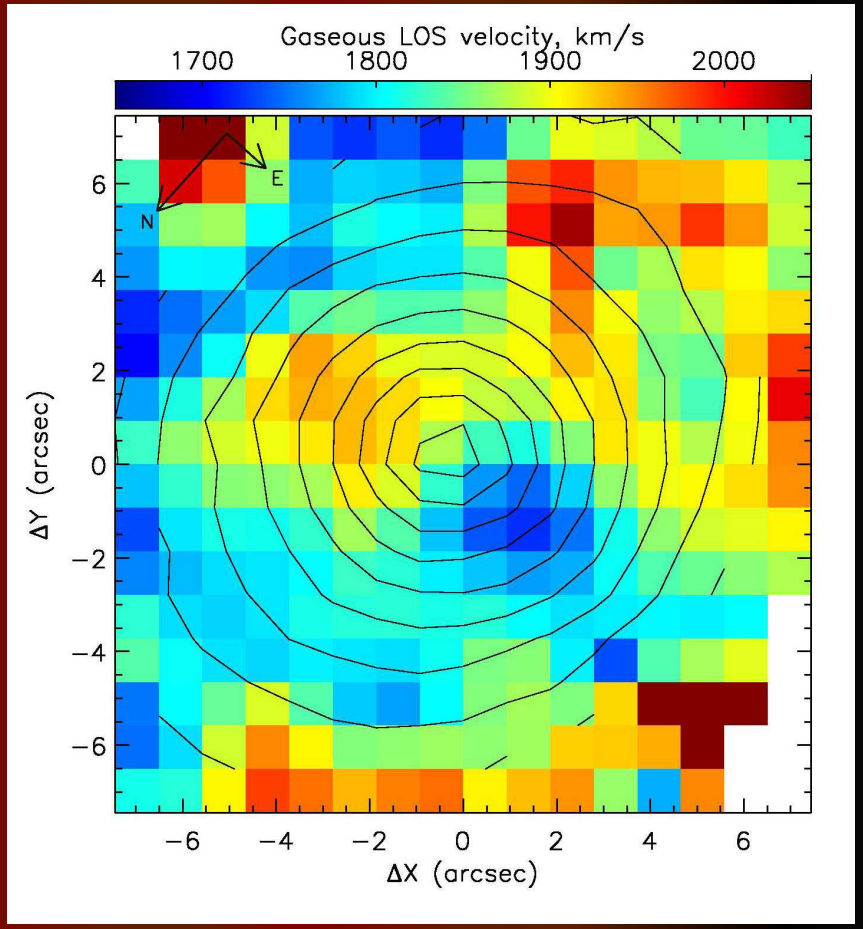


Stars, LOS velocity field



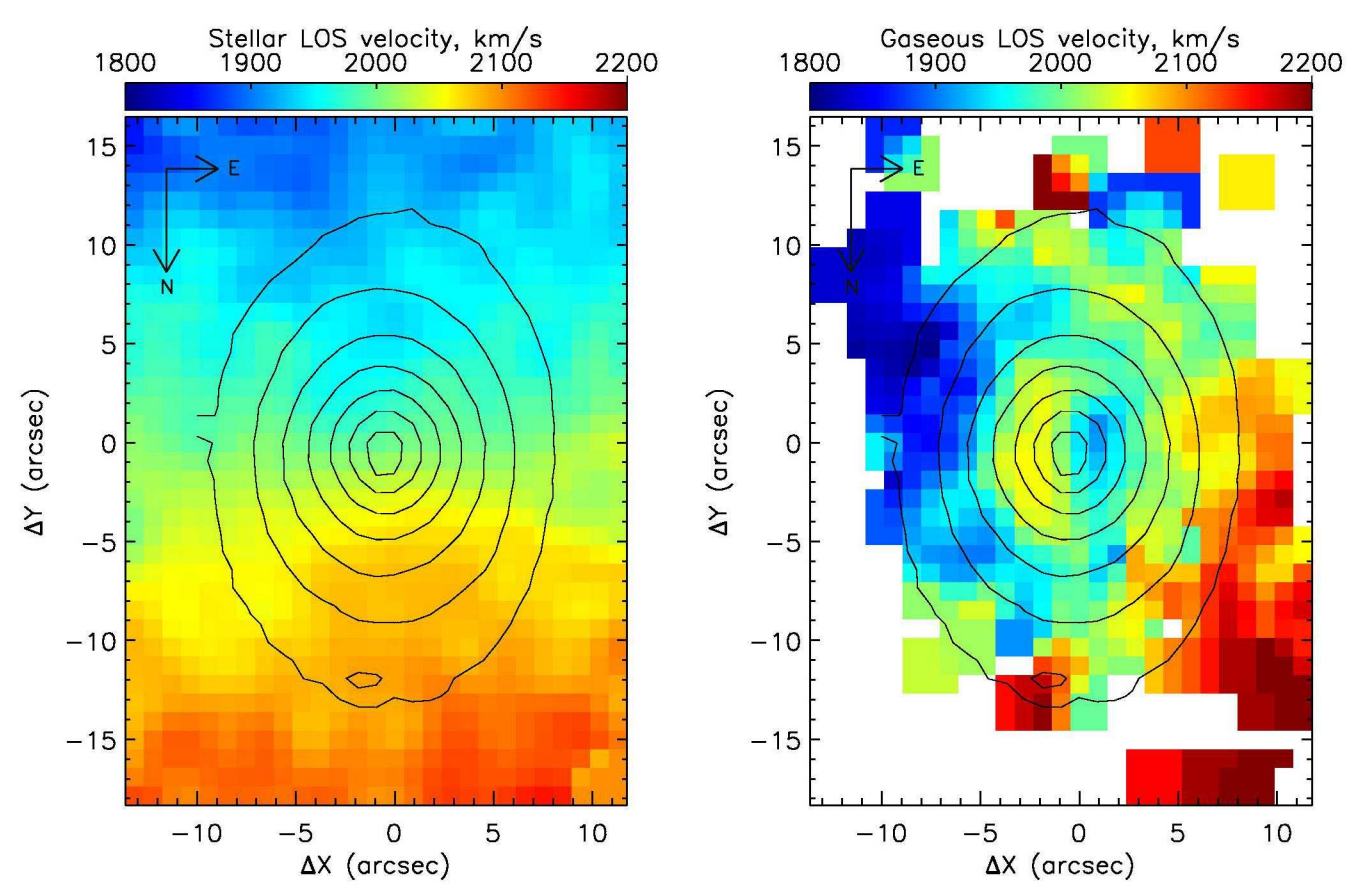
NGC 2962 with the MPFS/BTA





(unpublished up to now, observed by Alexei Moiseev in 2007)

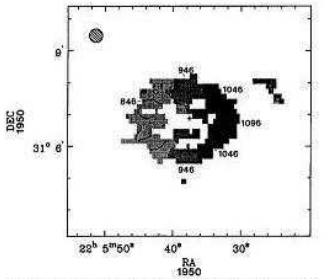
The same galaxy – NGC 2962 – observed at the SAURON within the ATLAS-3D survey



Incidence

- Among 149 S0s observed by the ATLAS-3D project in 2007-2008, 13 S0s have inner polar disks.
- Among the full number of 200 S0s observed by the SAURON from 1999 to present, 20 S0s have inner polar disks.
- So if we consider this sample as a volume-limited one, the frequency of inner polar disks is **10% of all nearby S0s.**

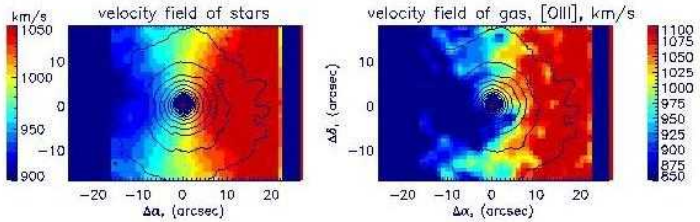
Outer gas accretion? NGC 7217, quite isolated!

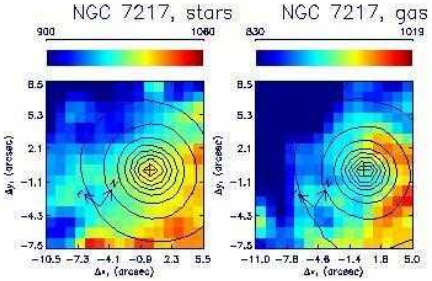


HI, Buta et al. 1995

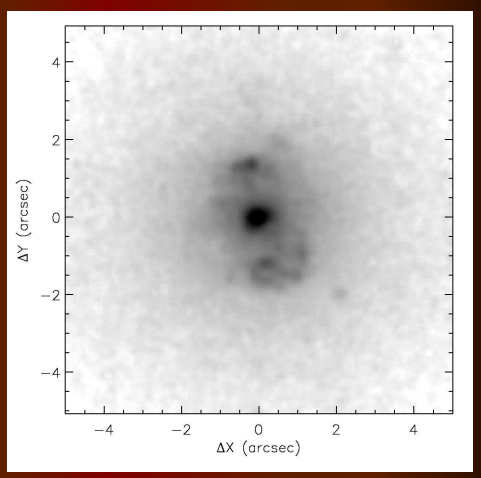
FIG. 17.—H I velocity field with a resolution of 25″ × 25″ (*hatched circle*), made as explained in the text. Isovelocity contours are 846 to 1096 in steps of 50 km s^{-1}. The cross indicates the center of the galaxy.

SAURON, Oct99:

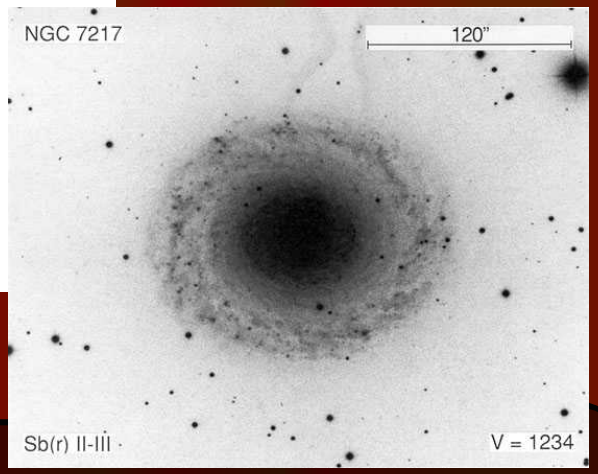


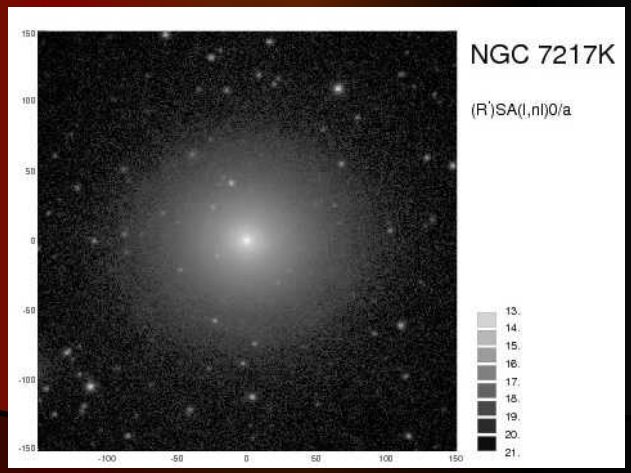


MPFS, Aug98



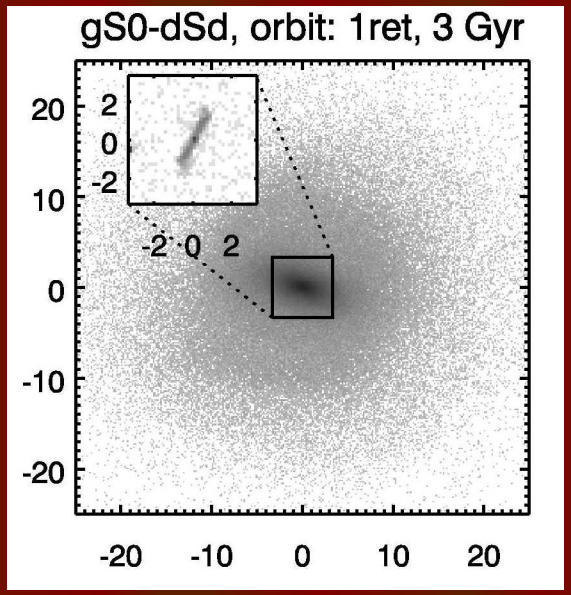
NGC 7217, HST/ACS, narrow filter centering on [NII]6583

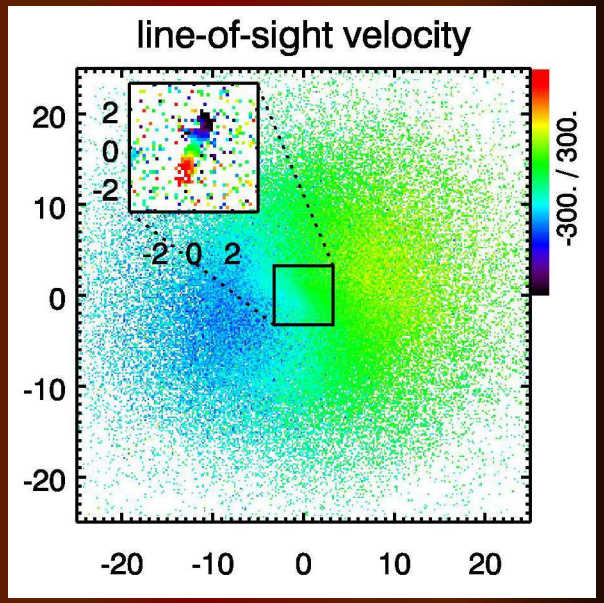




Blue photo (103ao)

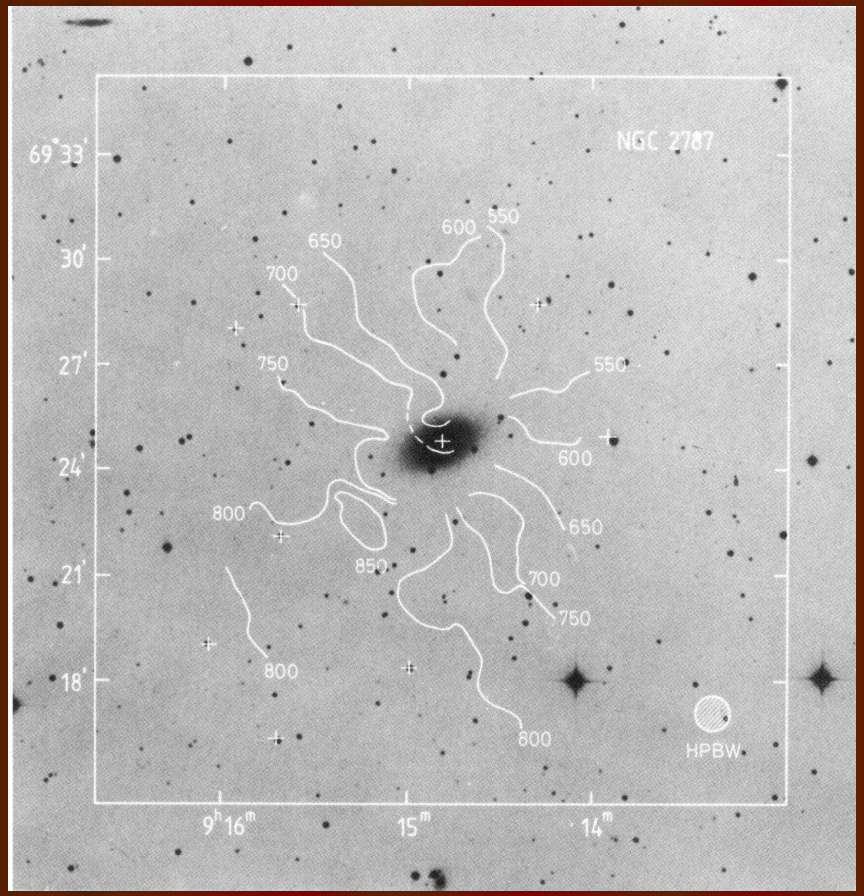
The scenario for the innermost part (GALMER): Merging a Sd-satellite from an inclined retrograde orbit may provide an inner quasi-polar disk



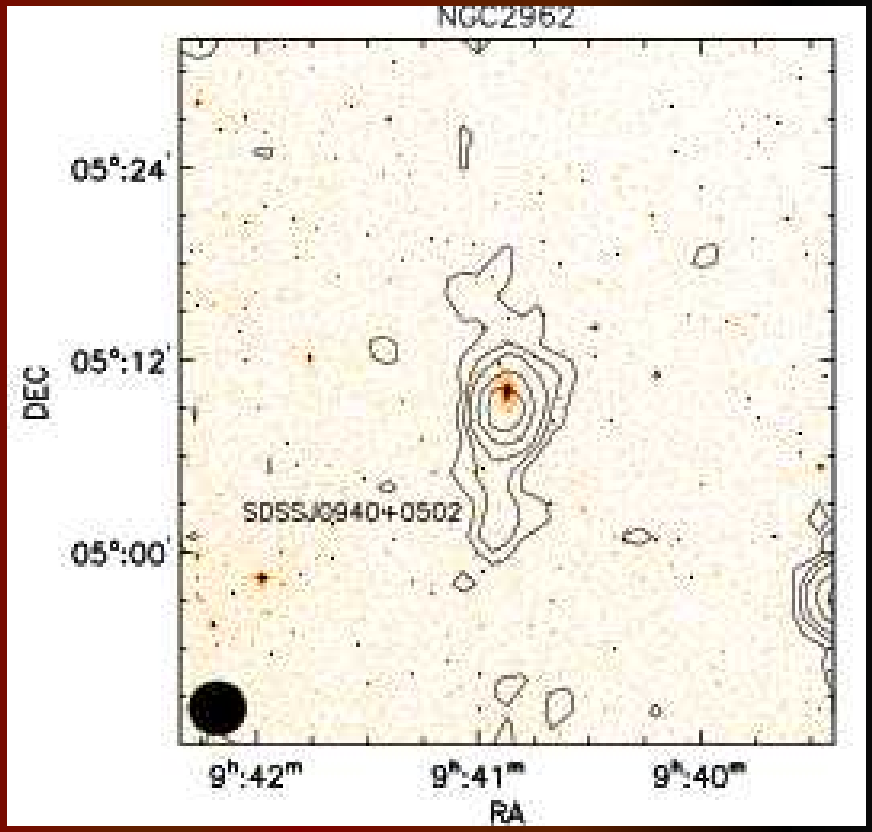


Sil'chenko, Chilingarian, Sotnikova, Afanasiev (2011)

Often the outer HI is quite regular and decoupled from the inner polar disk!



NGC 2787
Shostak 1987

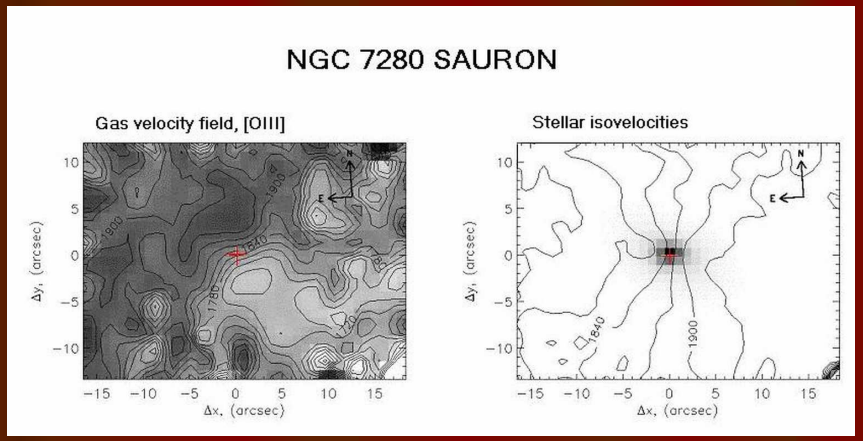


NGC 2962, Grossi et al. 2009

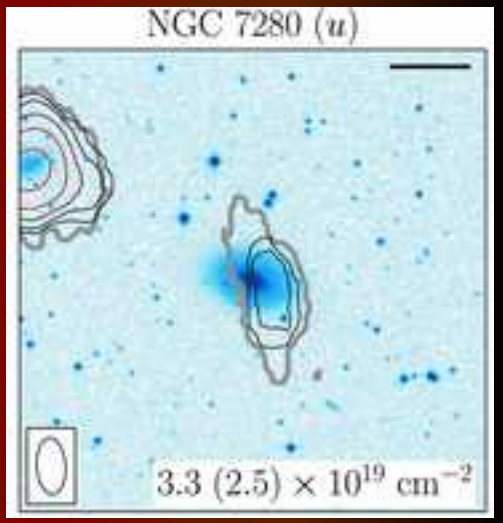
An intrinsic mechanism of aligning?

- Van Albada et al. (1982): if inner gas is polar inside a tumbling triaxial structure, the outer gaseous disk is forced to warp to be counterrotating with respect to the stars.
- Friedli and Benz (1993): if the outer gas is counterrotating, due to the momentum redistribution by a bar it may inflow and leave the galactic plane forming a stable quasi-polar disk within 1 kpc of the center

There are known cases of the outer polar HI and in-plane counterrotating warm gas…



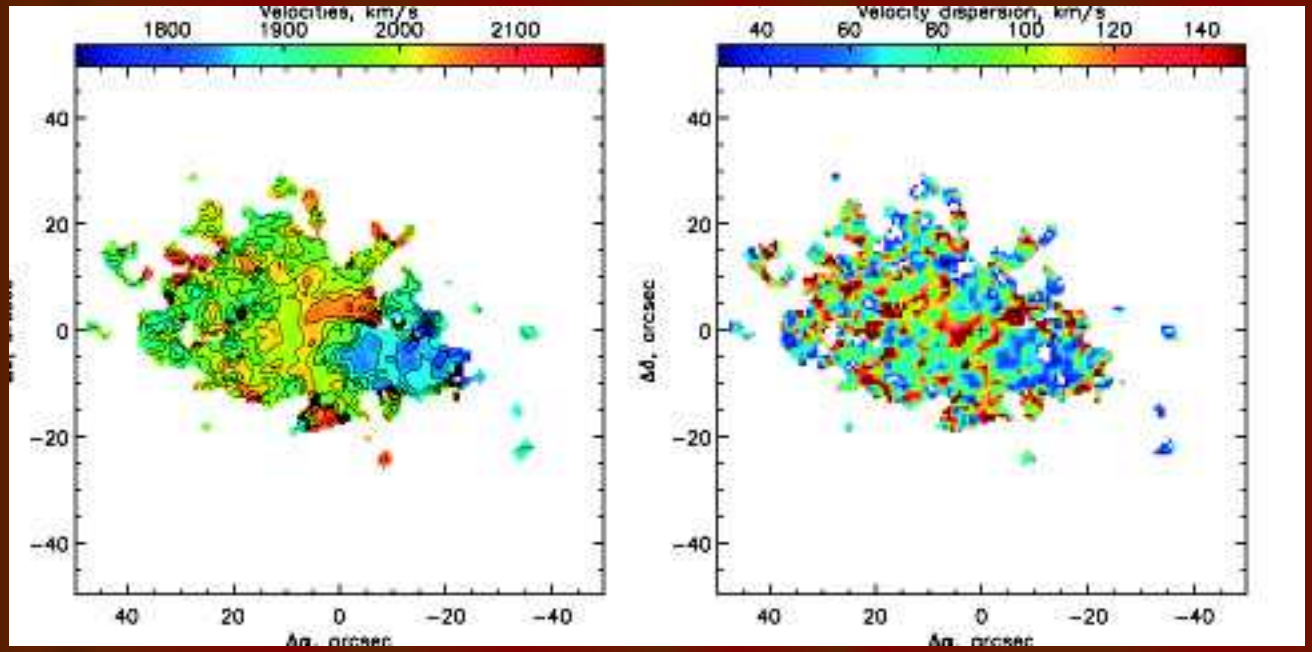
Sil'chenko 2005

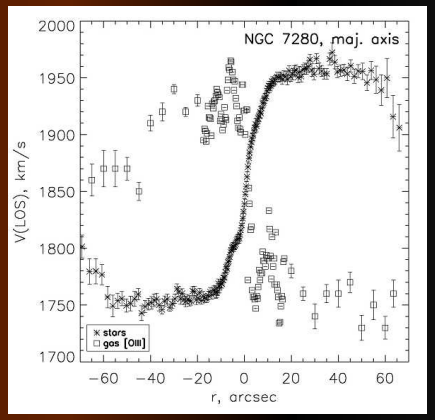


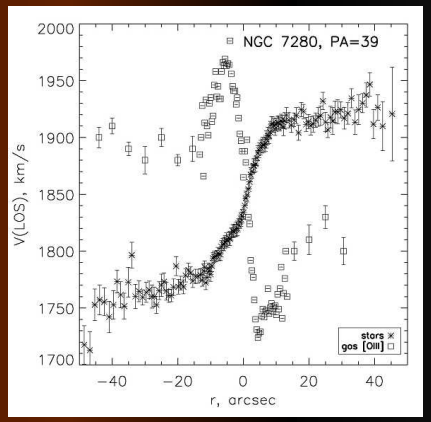
Serra et al. 2012

- E.g. SAURON data for NGC 7280 provide the velocity fields beyond the edges of the MPFS frame; so in addition to the inner gas polar disk found by us with the MPFS (Afanasiev & Sil'chenko 2000), here we see also star/gas counterrotation at R>7"

Our new observations of NGC 7280 with the SCORPIO-2 of the Russian 6m BTA







The scanning Fabry-Perot, [OIII]5007

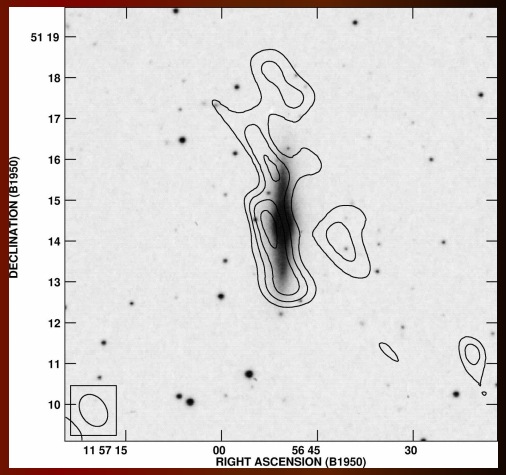
Gas disk warp: R<3″ Δ i =80, R=3″-5″ Δ i = 49, R=5″-9″ Δ i = 40, R=10″-20″ Δ i = 11

Van Albada et al.!!!

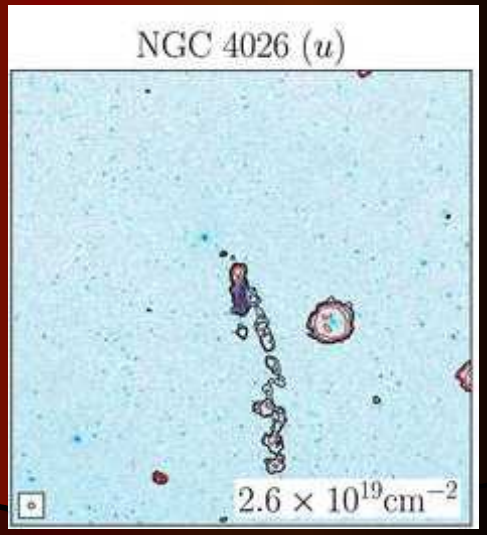
Long slit, SCORPIO-2

A visibly similar case – NGC 4026…

Megacam data (“MATLAS”)

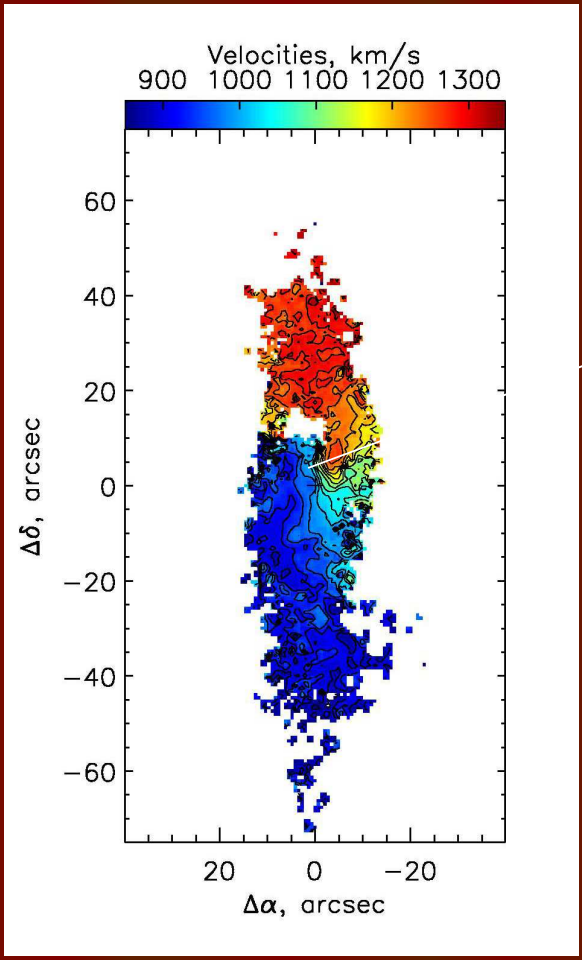


HI, Sage & Welch (2006)

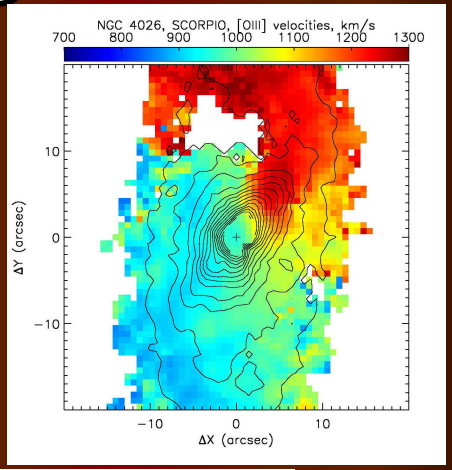


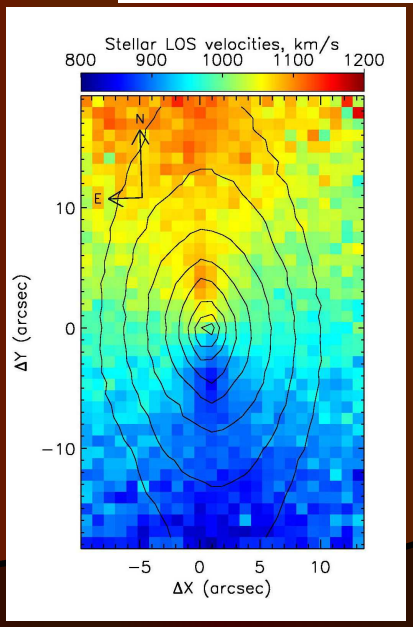
HI, Serra et al. (2012)

…NGC 4026 – but outer planar gas is co-rotating!



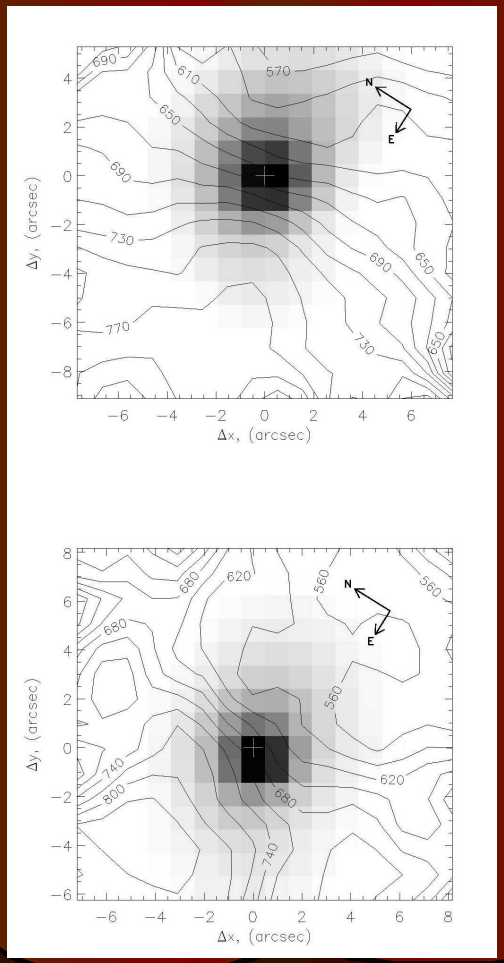
Fabry-Perot, BTA



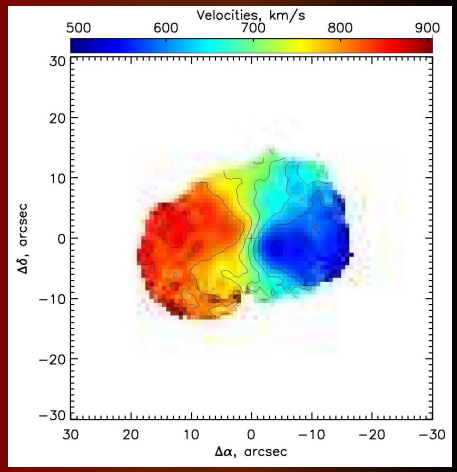


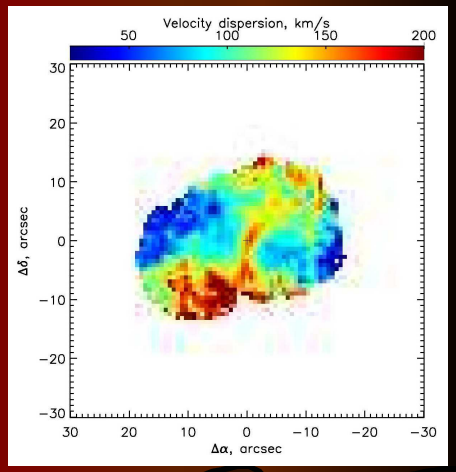
Stars, SAURON

In any environments! Isolated S0-S0/a galaxies NGC 7217 and NGC 2787:



NGC 2787

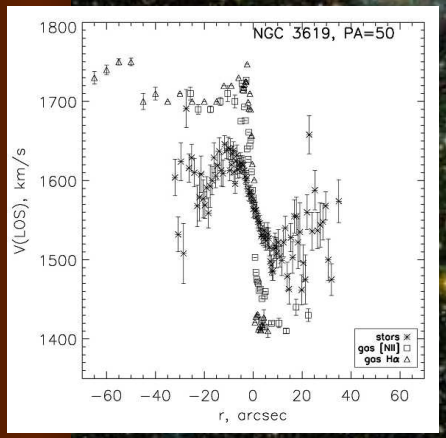




MPFS, BTA

Fabry-Perot, BTA

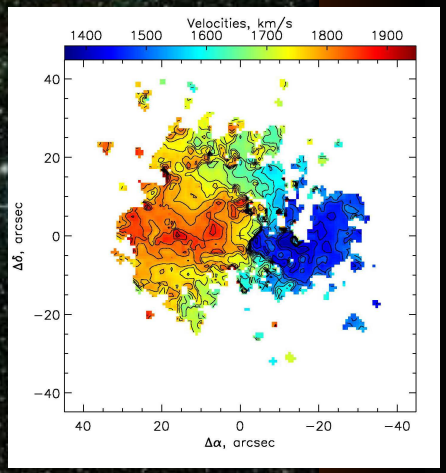
In any environments! In groups:



NGC 3619

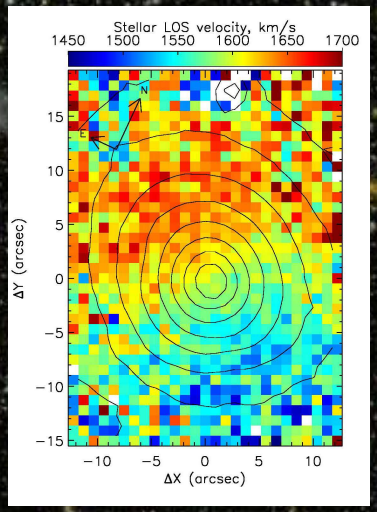
R=10”-25”: Δi=36 or 72 deg;

R=5”-9”: polar or EXPANSION!



Long slit, SCORPIO-2

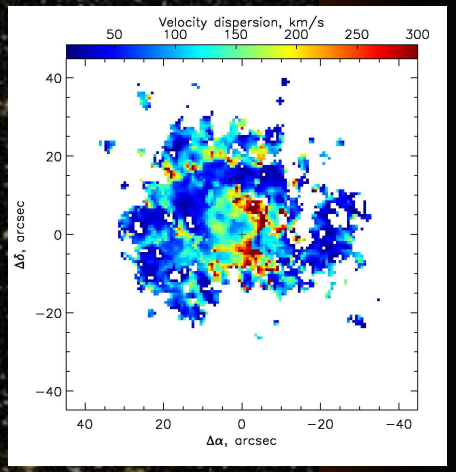
Megacam data (“MATLAS”)



SAURON:

PA_{kin} =44

i_{kin} = 21

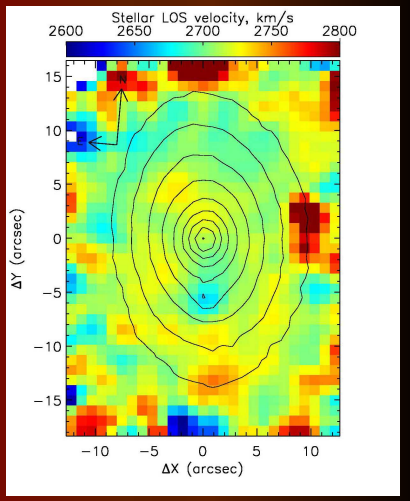


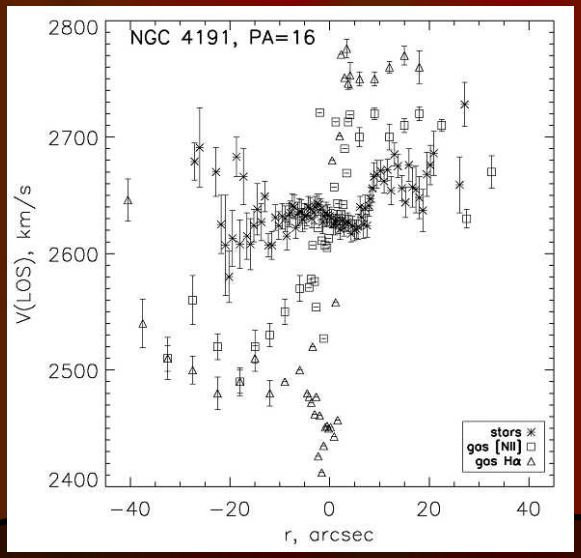
Fabry-Perot, BTA

In any environment! Even in Virgo:

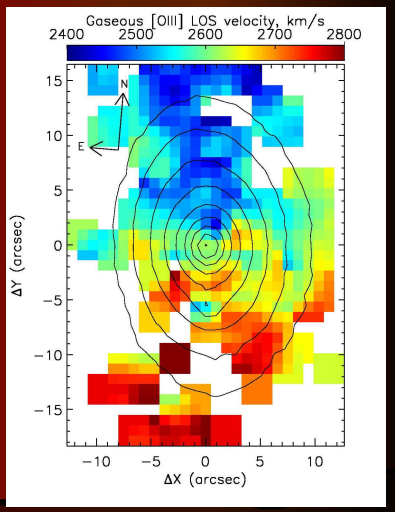
SDSS

NGC 4191





Long slit, SCORPIO-2



SAURON

About the S0s and spirals difference and shaping:

- Many S0s contain cold gas (40% in the field - ATLAS-3D, up to 78% in the field – Welch & Sage 2003, up to 72% in isolation – Katkov et al. 2015);
- But even gas-rich S0s do not form stars in the disks in the half of all cases (Pogge & Eskridge 1987, 1993);
- If there is any difference in gas surface density?

About the S0s and spirals difference and shaping:

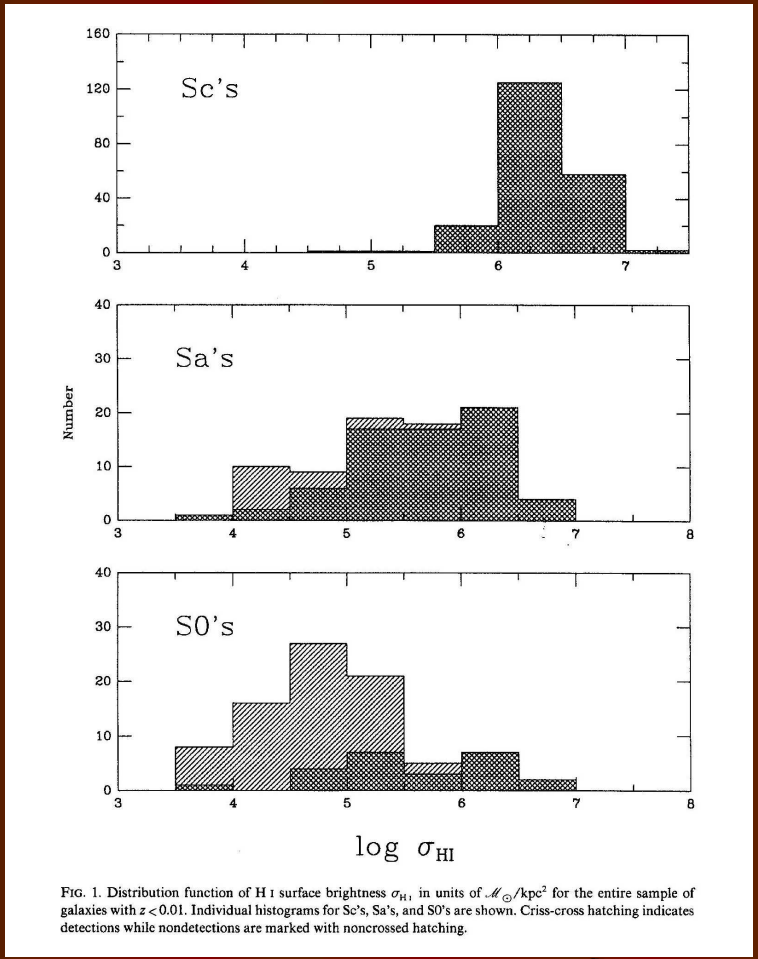


FIG. 1. Distribution function of H I surface brightness σ_{H_I}, in units of $\mathcal{M}_\odot$/kpc^2 for the entire sample of galaxies with $z < 0.01$. Individual histograms for Sc's, Sa's, and S0's are shown. Criss-cross hatching indicates detections while nondetections are marked with noncrossed hatching.

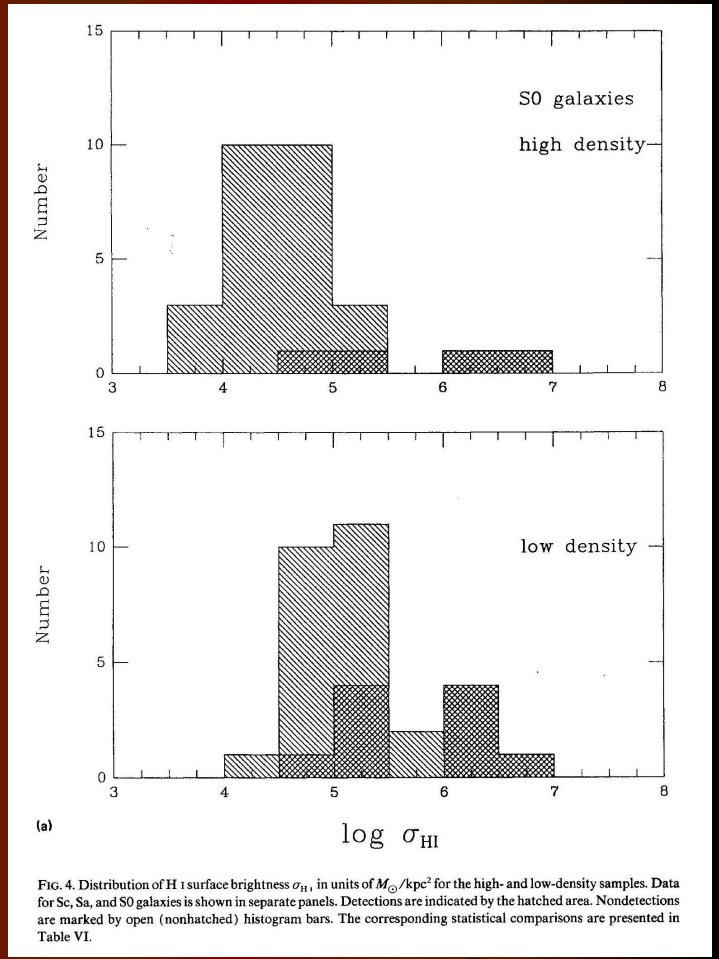


FIG. 4. Distribution of H I surface brightness σ_{H_I}, in units of $M_\odot$/kpc^2 for the high- and low-density samples. Data for Sc, Sa, and S0 galaxies is shown in separate panels. Detections are indicated by the hatched area. Nondetections are marked by open (nonhatched) histogram bars. The corresponding statistical comparisons are presented in Table VI.

Haynes et al. 1990

So, to the S0s and spirals difference:

- No difference in gas density between S0s and early-type spirals!
- Also, we believe that ALL DISK GALAXIES, both S0s and spirals, accrete cold gas from outside – with the rate similarly depending on the environment density.
- Why the latters form stars, and the formers do not?

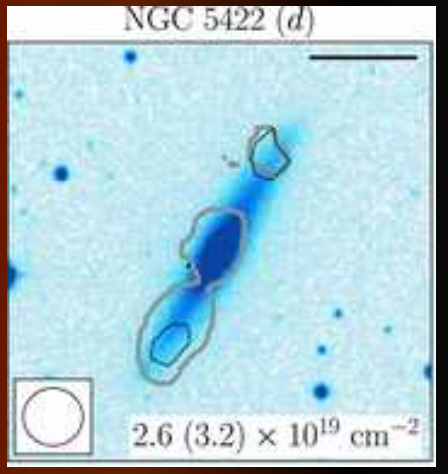
Perhaps, does the geometry play?

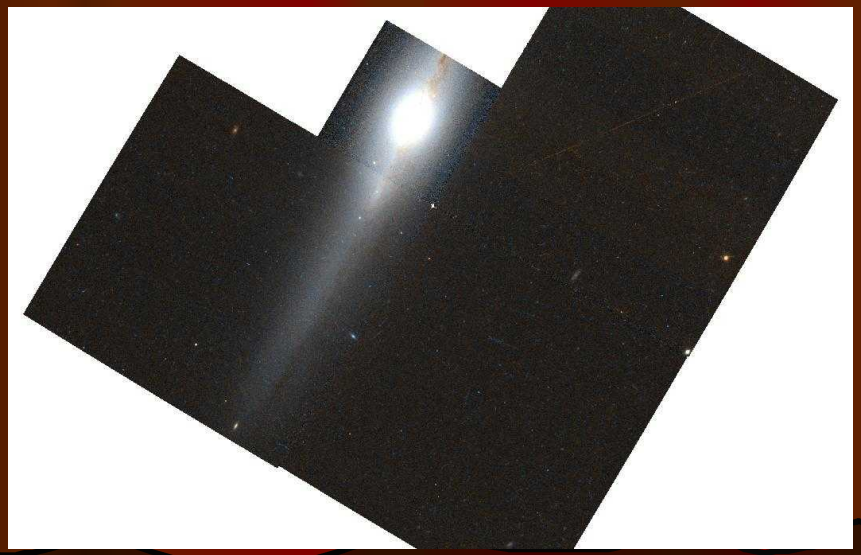
Megacam

NGC 5422

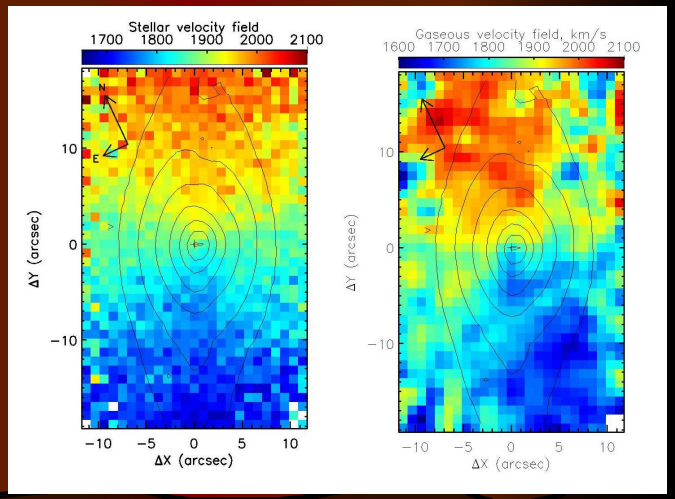
HI,

Serra et al. (2012)





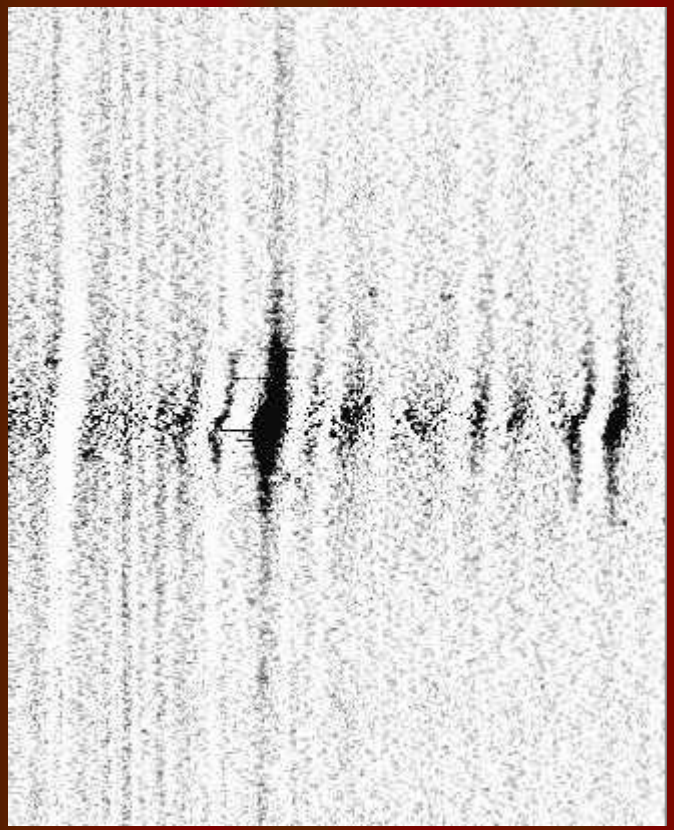
HST F814W/F450W (HLA)



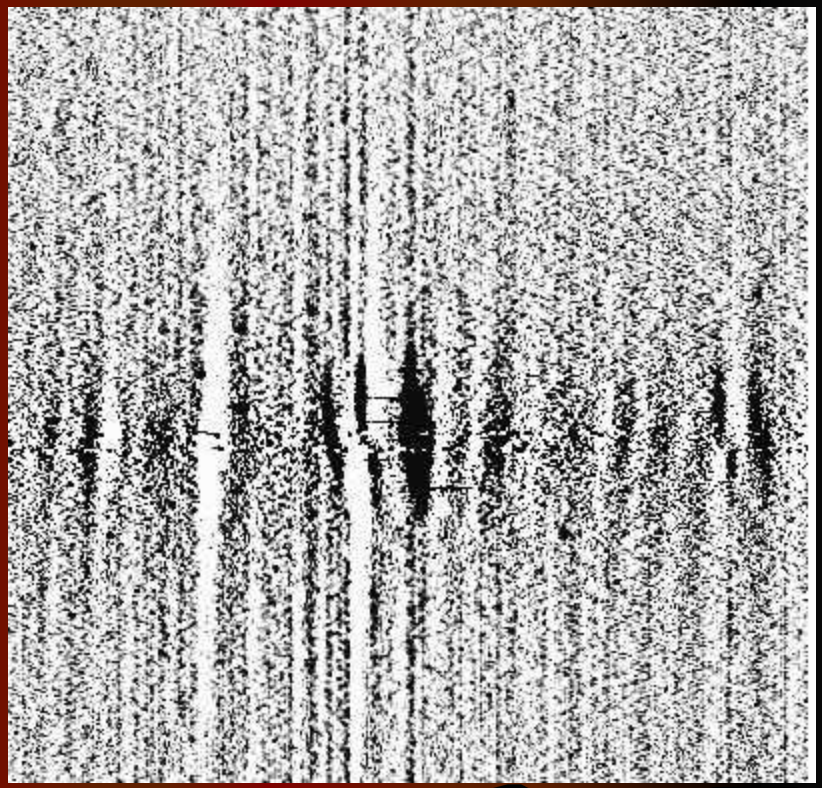
SAURON IFU data

NGC 5422 and other galaxies with inclined gaseous disks: No star formation in the disks!

NGC 5422



NGC 3941



Spectra from SCORPIO-2, BTA, long slit: continuum-subtracted H-alpha range

Conclusion-hypothesis:

- Perhaps, to fuel star formation in the accreted gas, it must be smoothly accreted in the galaxy plane… Or at least its momentum must be aligned.