ASTRON

Netherlands Institute for Radio Astronomy

Warps and accretion in disk galaxies

(prospects for Apertif)

Gyula I. G. Józsa

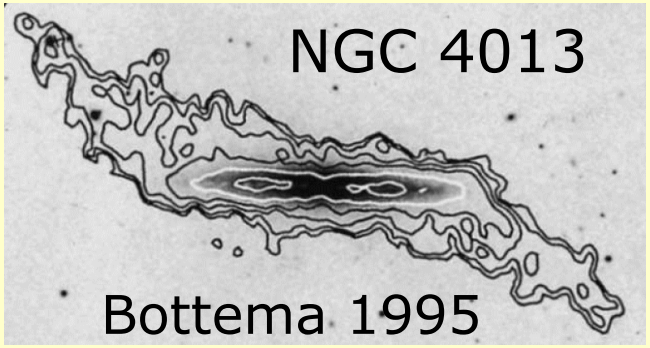
ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

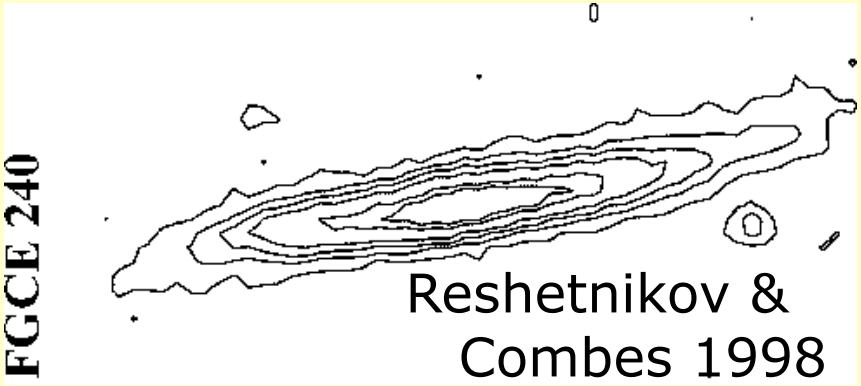
Outline

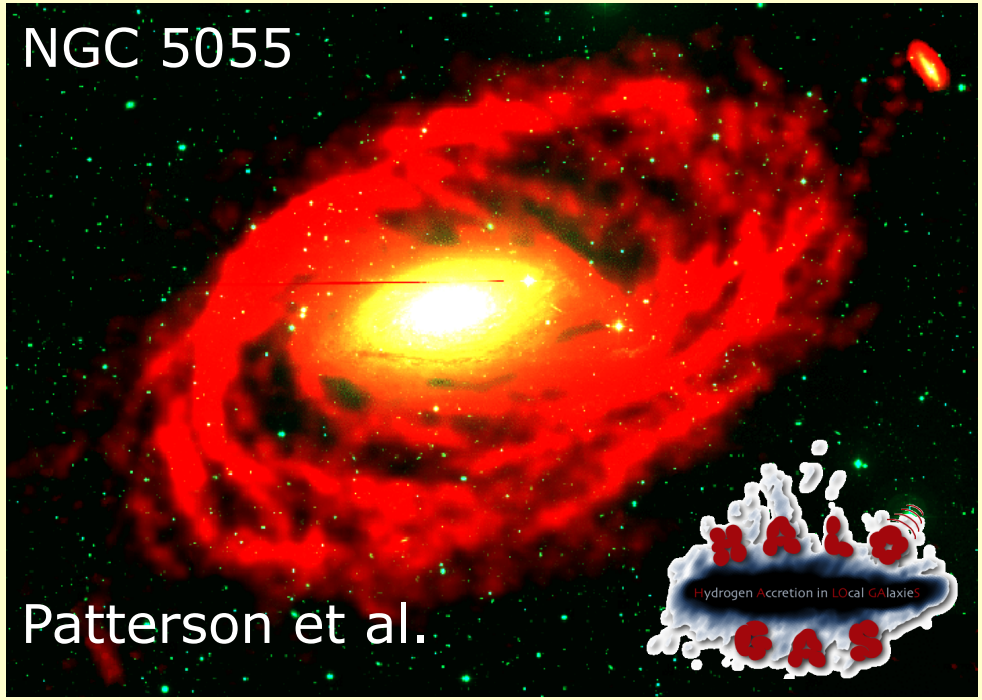
- Properties of warps
- Formation scenarios and observations
- Evidence for accretion in warped galaxies (?)
- HI environment at high sensitivity: NGC 4013
- Apertif: towards statistical samples
- Summary

Warps: Properties

- Warps are **ubiquitous**
- Warps usually **start where the optical disk fades** (→ **HI best tracer)**
- Most warps are dominated by an **m=1** vertical displacement (they are S-shaped)
- Warps tend to **higher asymmetry** (mixing with m=0, m=2, ...) and amplitude **in denser environments**

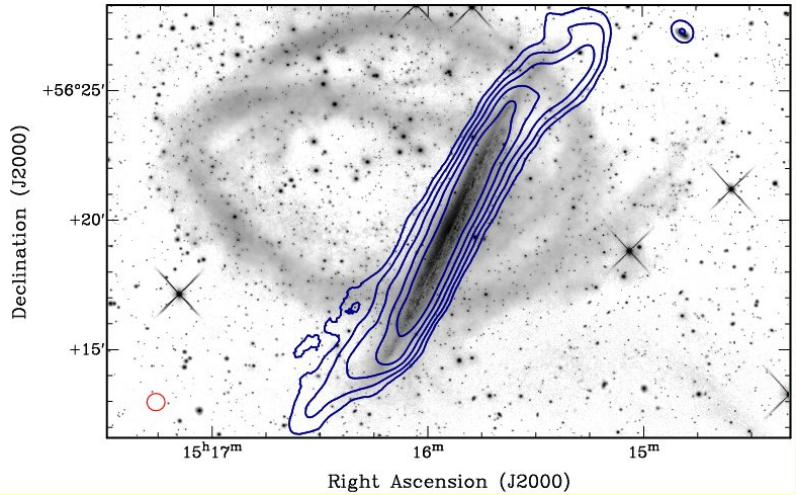




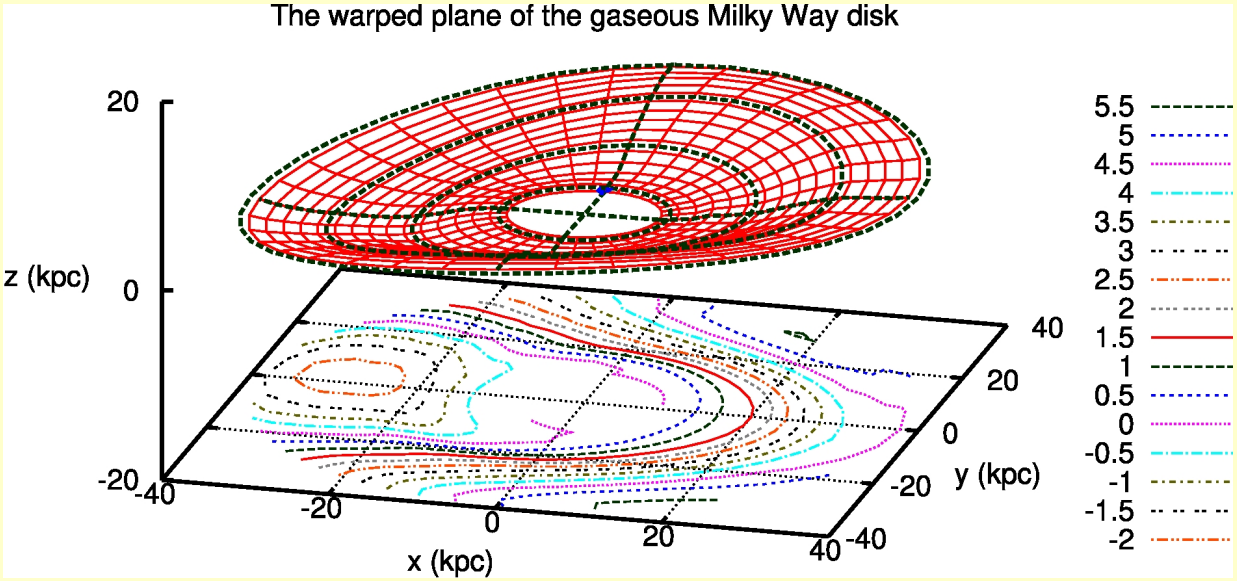


Warps: generation I

- Satellite interaction (excitation in existing disk) → Need of **close-by passages of massive companions** or **wakes in DM halo** or **MOND**
- Extragalactic winds → require high gas densities > $6 \cdot 10^5$ atoms cm^{-3}, produce **asymmetric warps**
- Magnetic fields → scenario requires high energy density of the intergalactic magnetic field



NGC 5907
WSRT HI (Józsa et al.)
and
Martínez-Delgado et al. 2008



Milky Way HI, Kalberla et al.

Rules for the behaviour of (HI-) warps

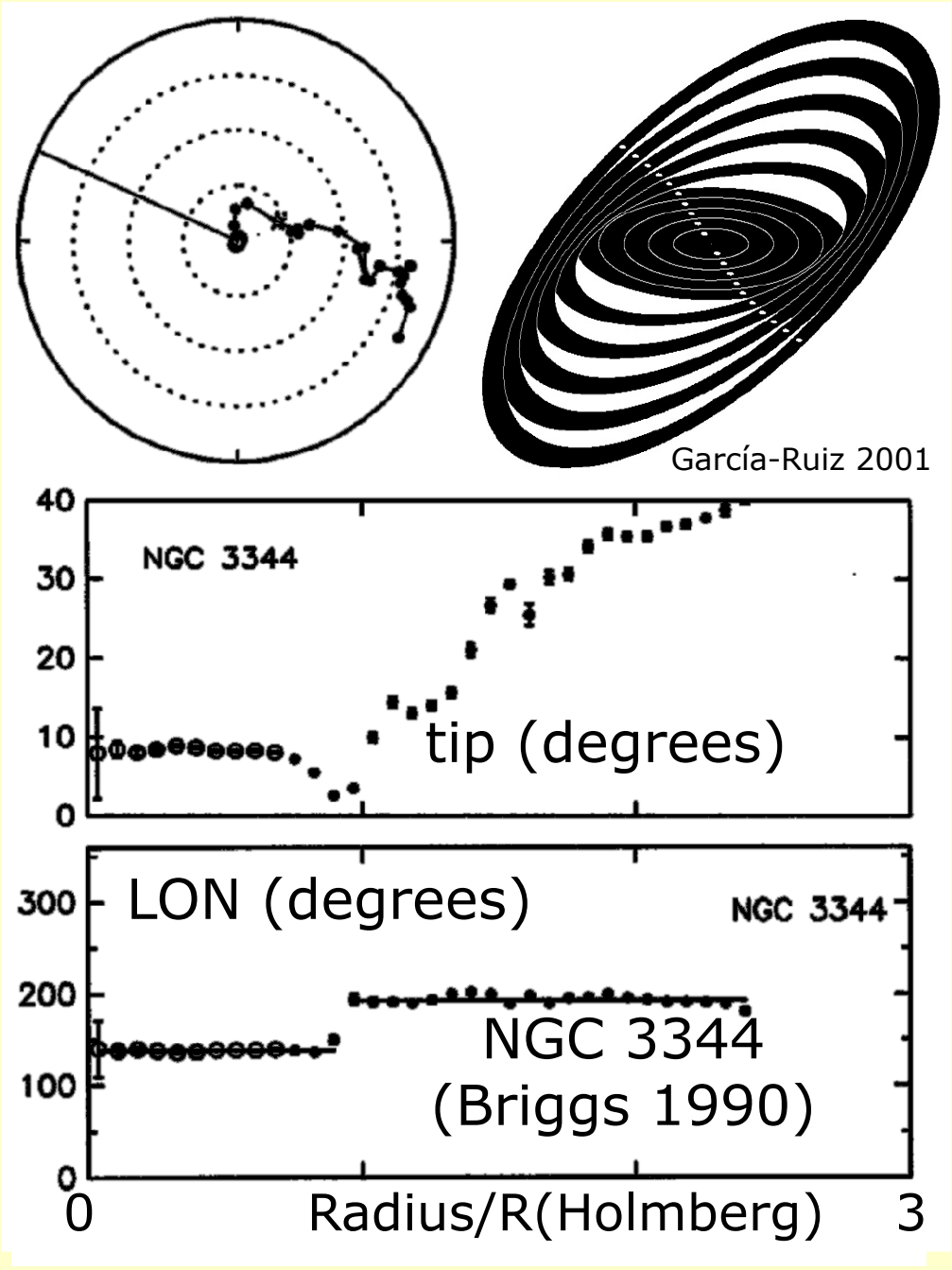
ASTRON

Briggs (1990) rules:

- The HI layer is **planar within R_{25},** but warping becomes detectable within R_{25}
- **Co-precession** inside a radius $R_{tr} \approx R_{Ho}$

→ **self-gravity** of the disk is important

- **Differential precession** beyond R_{tr} (probably retrograde decreasing precession rate)
- Indication for **co-precession** at large radii?



Warps: generation II

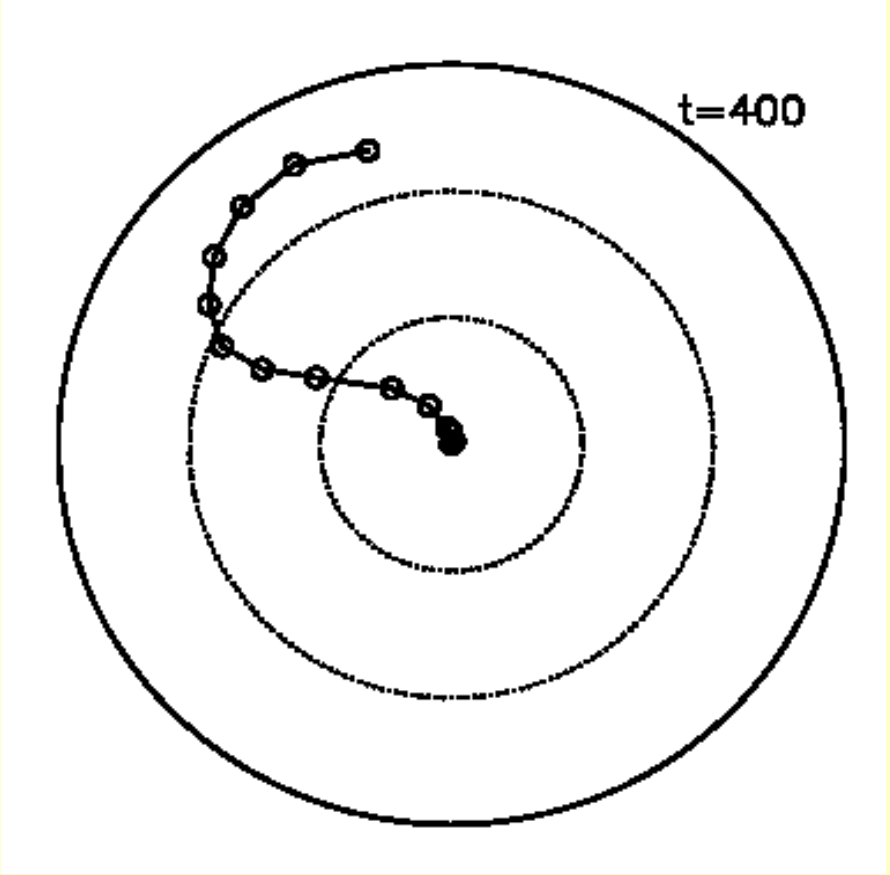
ASTRON

- **(Modified-) tilt modes and bending instabilities in conflict with Briggs' (1990) rules**
  (e.g. Sparke & Casertano 1988, Revaz & Pfenninger 2004, Saha & Jog 2006)

- **Disk-halo interactions: Dynamical friction** plays an important role

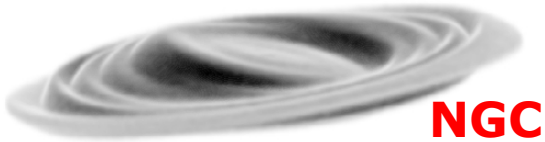
  → rapid alignment of disk and halo
  → **damping or wind-up of warp**
  (Nelson & Tremaine 1995, Dubinski & Kuijken 1995)

- **Late cosmic infall seems to do good job**
  (Ostriker & Binney 1989, Shen & Sellwood 2006)

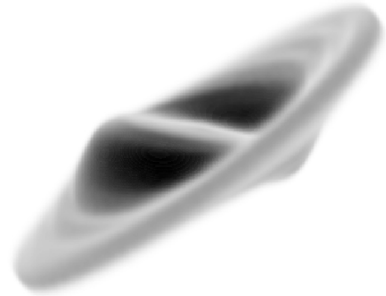


Shen & Sellwood 2006

More findings



NGC 2541



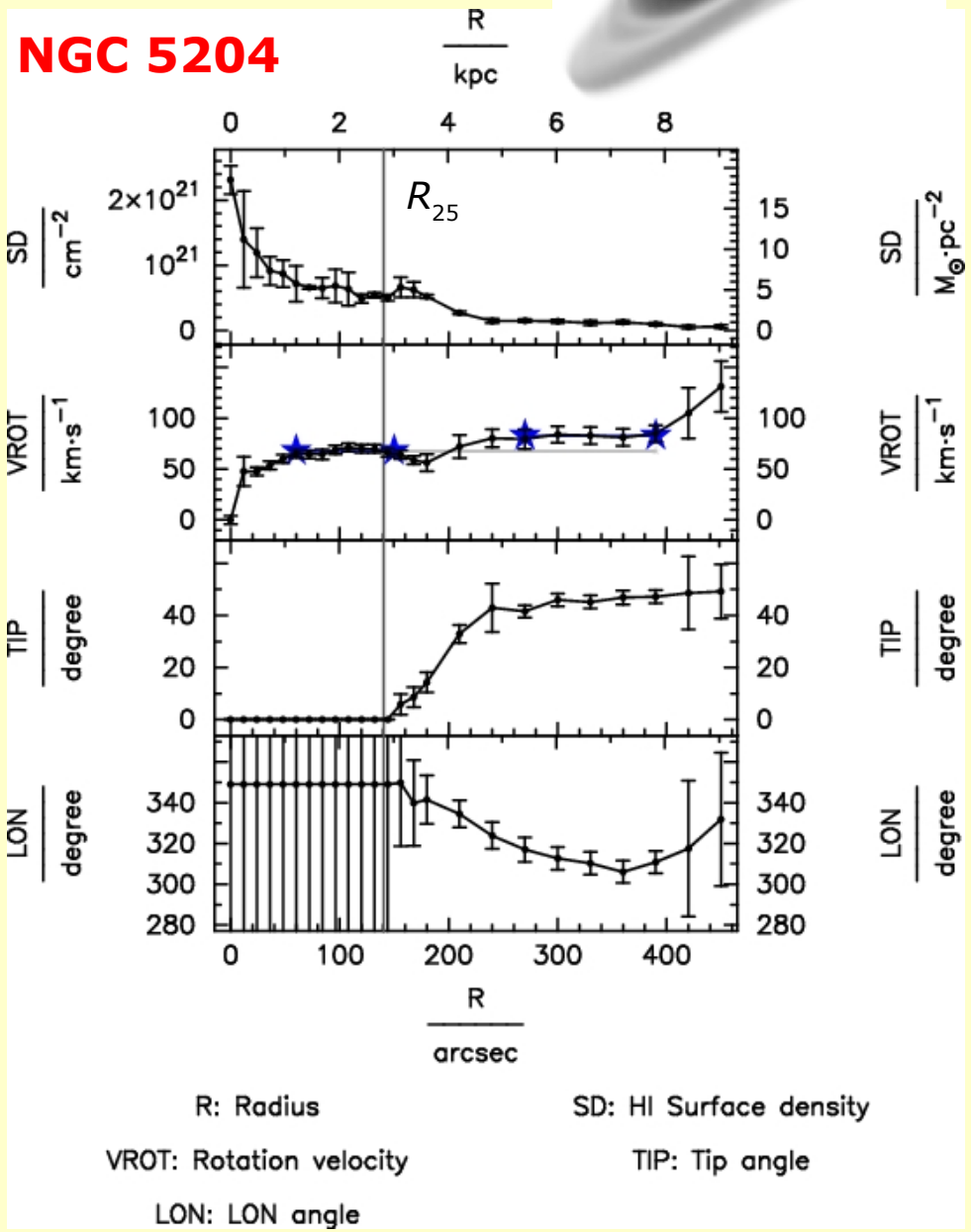
- **Two-disk structure in the HI disk**, the warp being a transition from one orientation to the other (Kuijken 1991, Corbelli & Schneider 1997, Józsa 2007)

- At the commencement of the warp in a few cases

i) the **HI surface density profile drops** (García-Ruiz 2002, van der Kruit 2007, Józsa 2007)

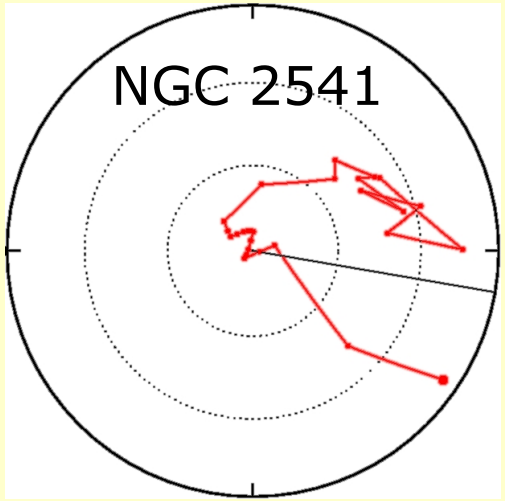
ii) the modelled **rotation velocity changes** (Corbelli & Schneider 1997, van der Kruit 2007, Józsa 2007)

NGC 5204

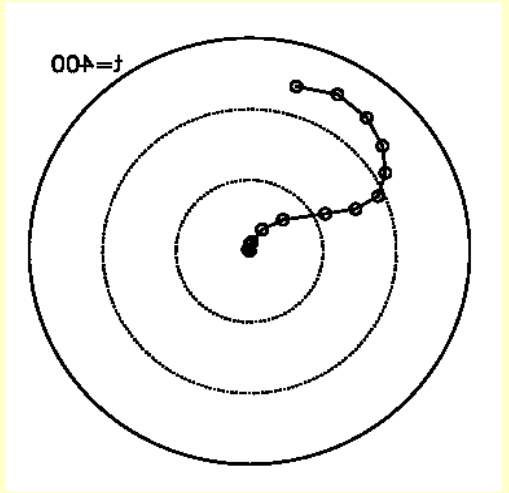


Warps: generation III

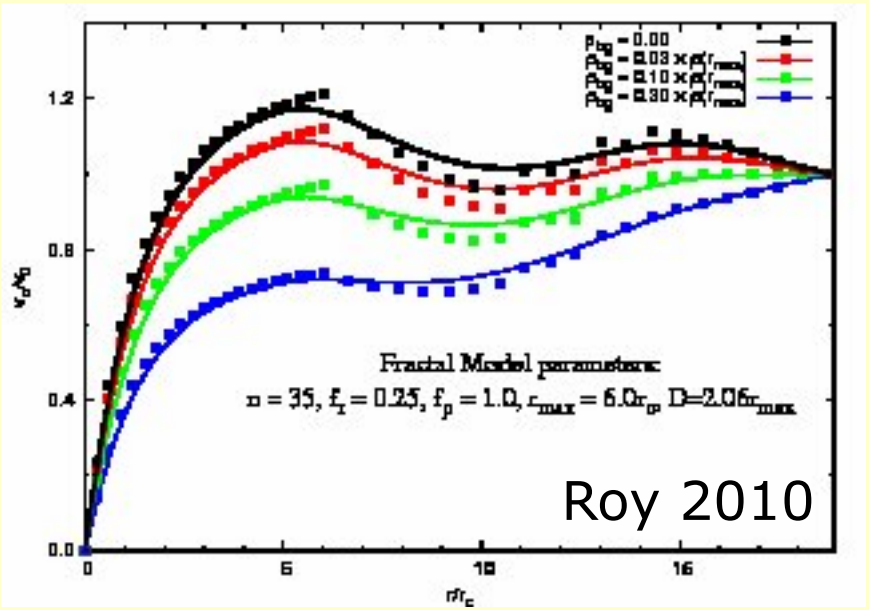
- **Common bending modes** of disk and DM halo? (Dubinski & Kuijken 1995)
- Late cosmic infall: **(dark) rings/substructure** (Shen & Sellwood 2006)
- **DM-substructure** (Bailin et al. 2005): the **DM halo** rapidly **aligns with the disk** in the reach of the disk, but maintains its orientation beyond 0.1 r_{vir}
- **Effect of DM sub-structure** on rotation velocity (Roy 2010)
  → intrinsic misalignment of the substructure may maintain warping



Józsa 2007

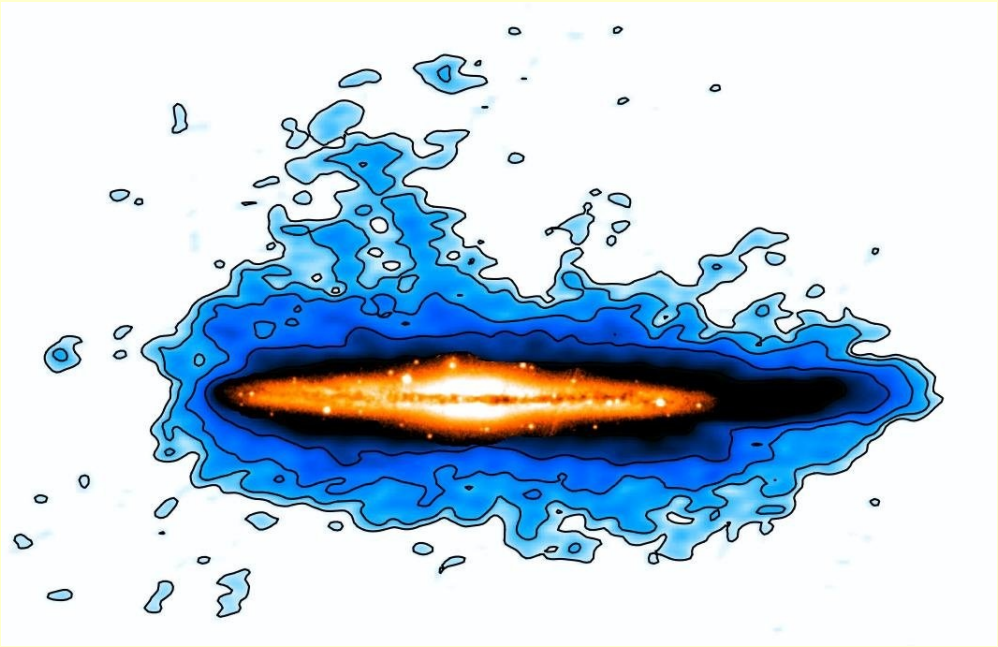


Shen & Sellwood 2006

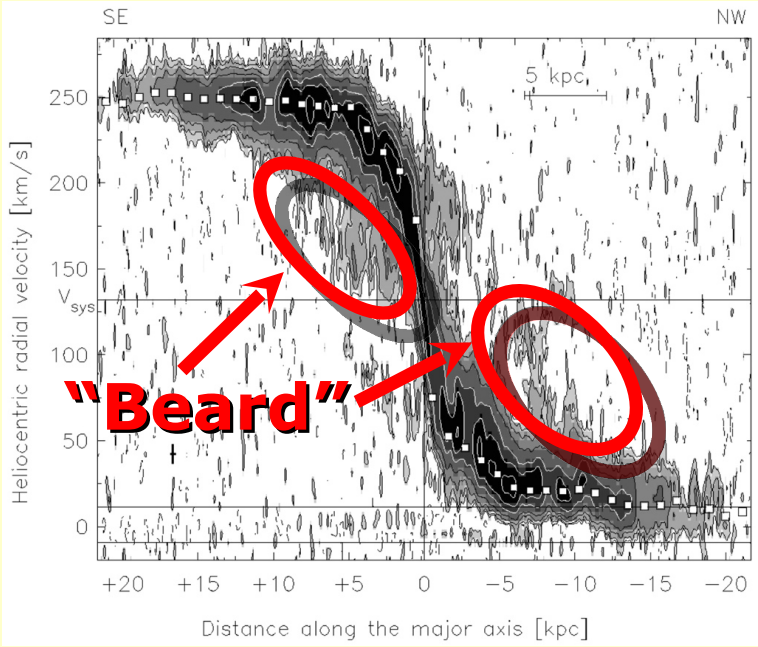


Gas accretion

- **Extraplanar gas** traces (partly) accretion
- Needed to **replenish star forming material**: 1 $M_\odot$/yr (e.g. Lacey & Fall 1985)
- Infall of **low-metallicity gas** (0.1 solar) needed to explain stellar metallicity abundances (e.g. "G-dwarf problem", Wakker et al. 1999)
- **Observed: ≥ 0.2 $M_\odot$/yr** (HVCs, minor mergers, Sancisi et al. 2008)
- Could be much more if an unseen, **cold accretion** takes place (Kereš et al. 2005)

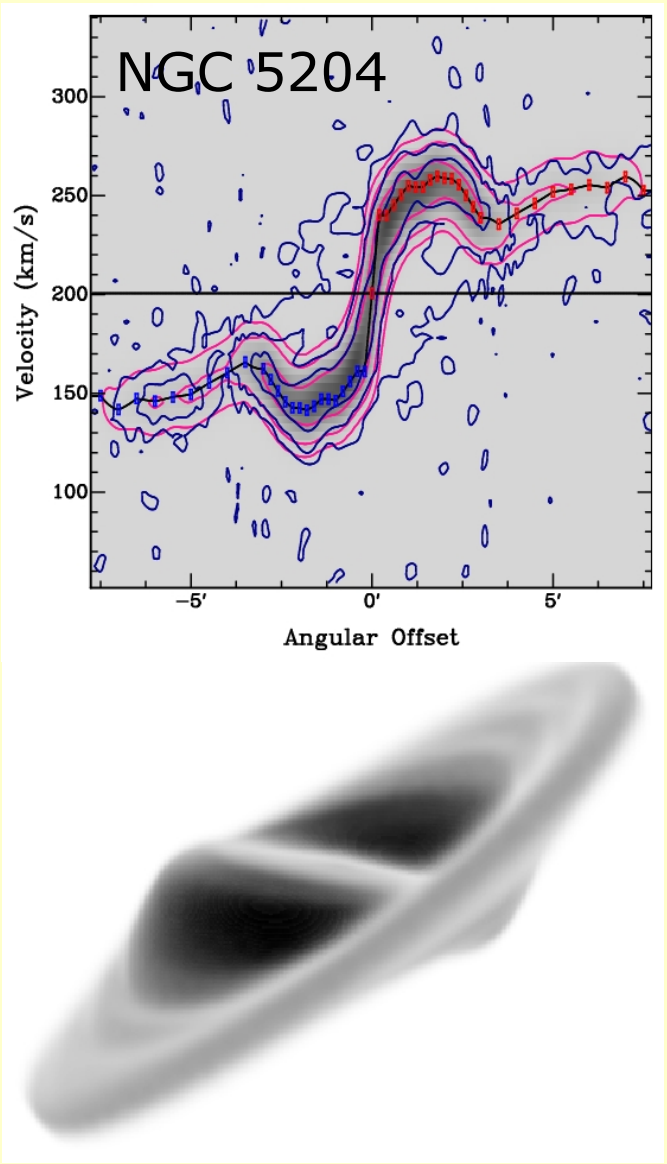


NGC 891 (Oosterloo et al. 2007)

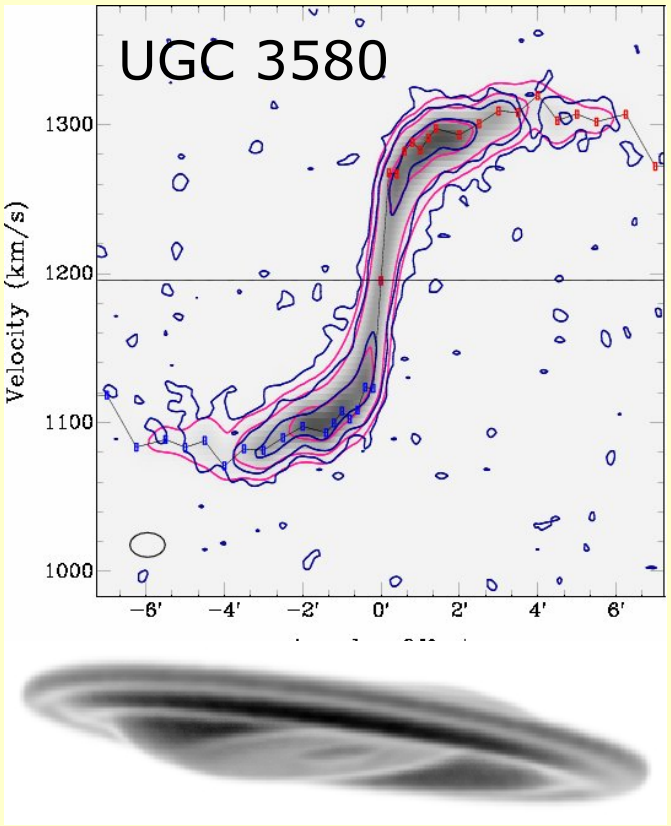


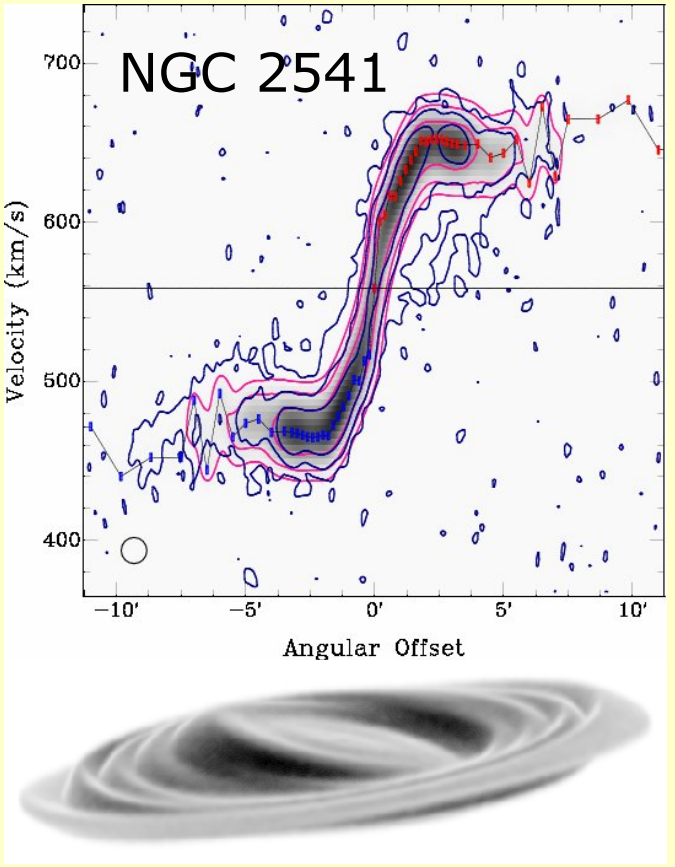
NGC 2403 (Fraternali et al. 2002)

Warps and anomalous gas



Contours:
1,4,16 mJy/beam





Józsa 2007

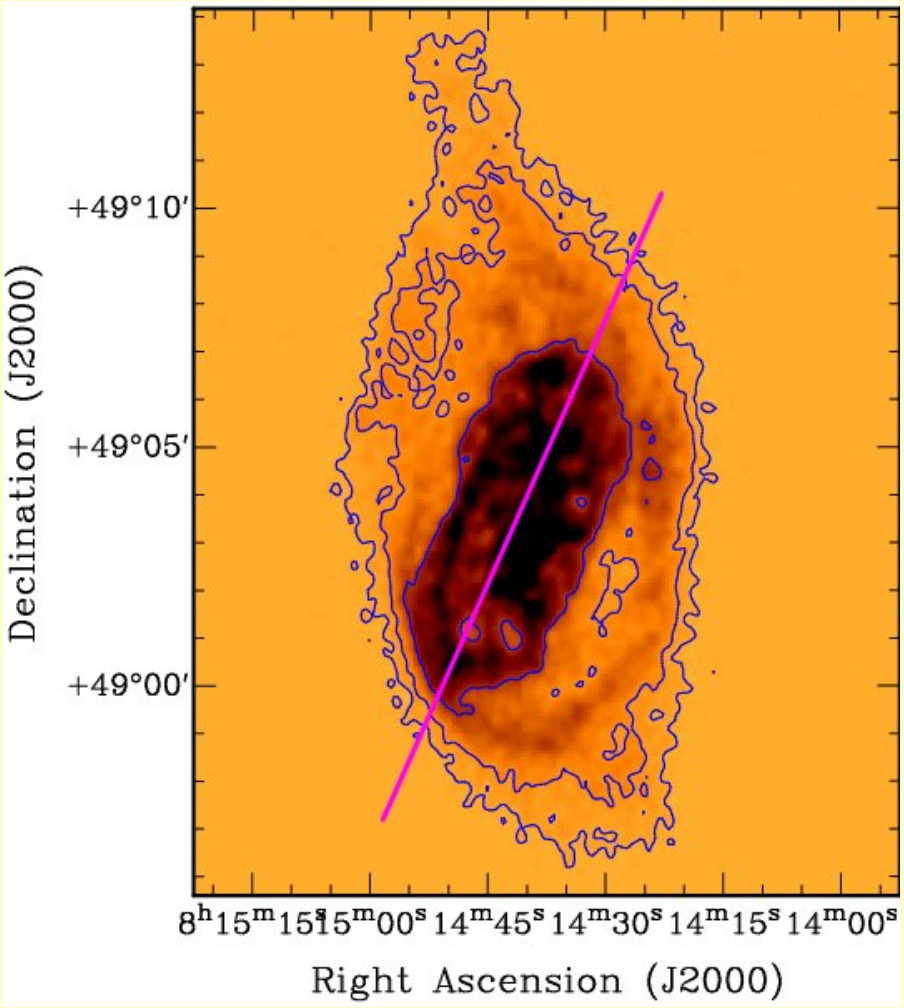
Warps and anomalous gas

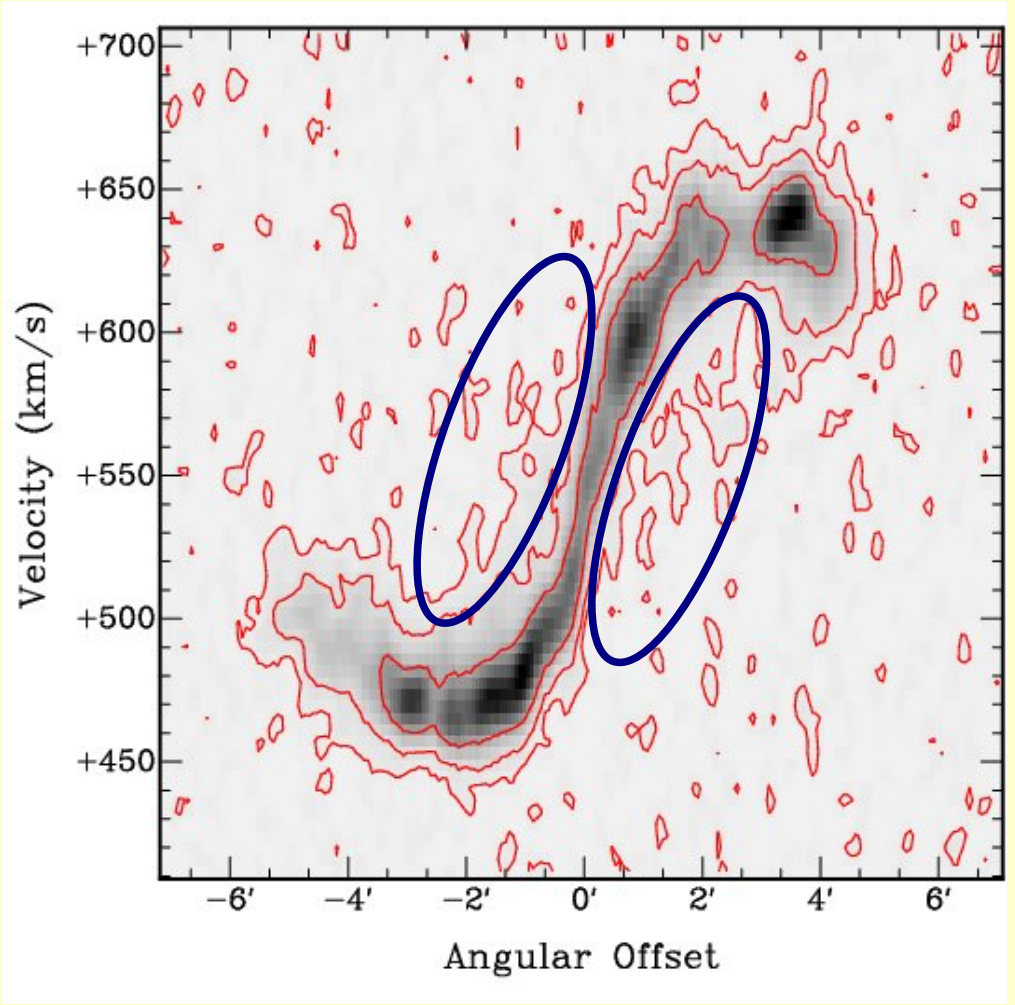
ASTRON

HALO GAS
Hydrogen Accretion in LOcal GAlaxieS

HALOGAS: WSRT search for faint HI in galaxies, see contributions by:
Laura Zschaechner,
Maria Patterson,
Peter Kamphuis

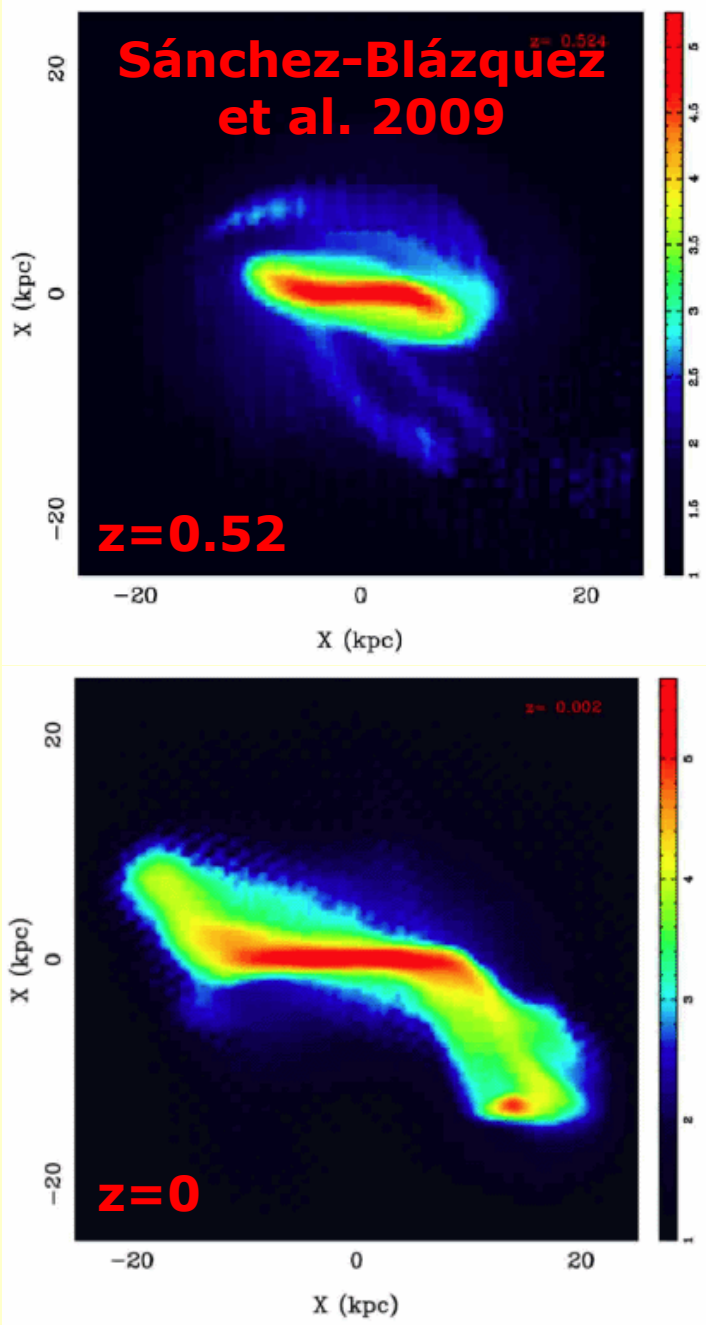
NGC 2541





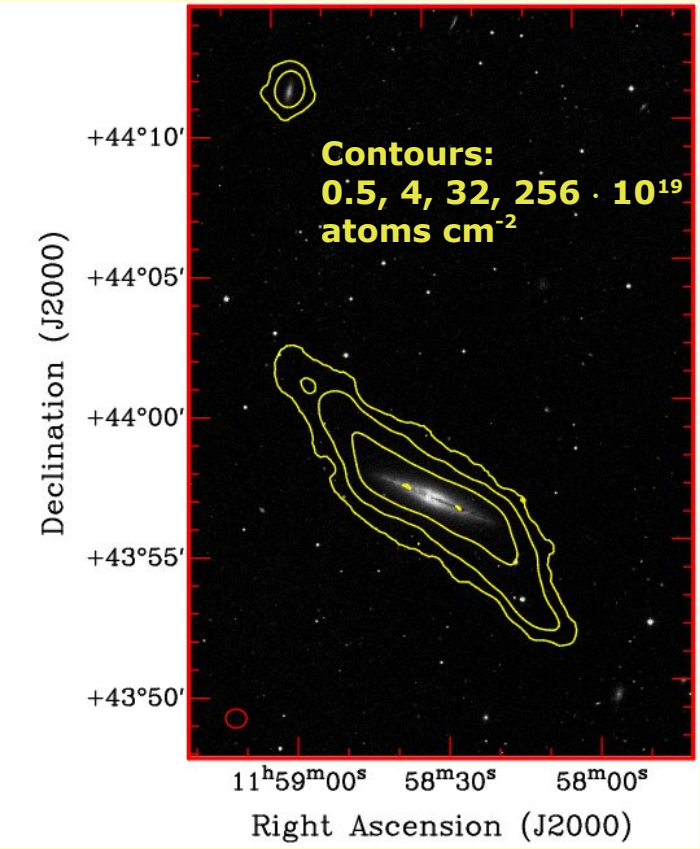
Warp generation IV

- **Satellite interaction** → gas accretion (Weinberg & Blitz 2006)
- **Gas capture** → gas accretion (Bournaud & Combes 2003)
- **Late cosmic infall** and accretion → Gas reservoir for star formation? (Sancisi et al. 2008)
- Connection of **warps and extraplanar gas** (Ostriker & Binney 1989, Binney 1992, Jiang & Binney 1999, Debattista & Sellwood 1999, Shen & Sellwood 2006, Sánchez-Blázquez et al. 2009, Roškar et al. 2010)
- If a **warp** is not (quasi-) permanent, it **could act as a steady gas supply** to the inner disk

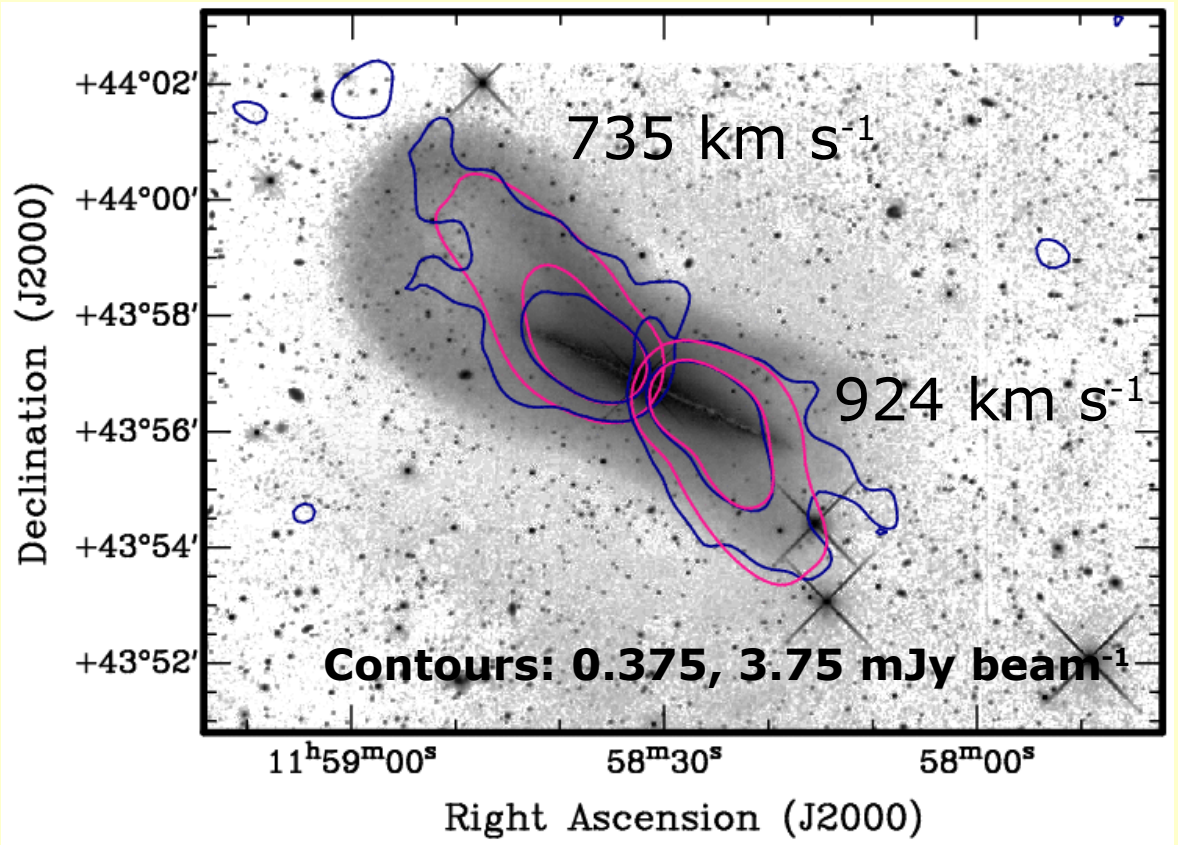


NGC 4013

- HI 17x12h WSRT
- $5\sigma_{rms} \triangleq 5 \cdot 10^{18}$ atoms cm^{-2} (FWHM = 16 km s^{-1})
- $5\sigma_{rms} \triangleq 1.2 \cdot 10^{5}$ M$_{\odot}$ (FWHM = 16 km s^{-1})
- Indication for neutral gas (deployment) at the position of stellar stream
- companion (CGCG 215-013)



DSS/WSRT HI



Martínez-Delgado et al. 2009/WSRT HI

Status

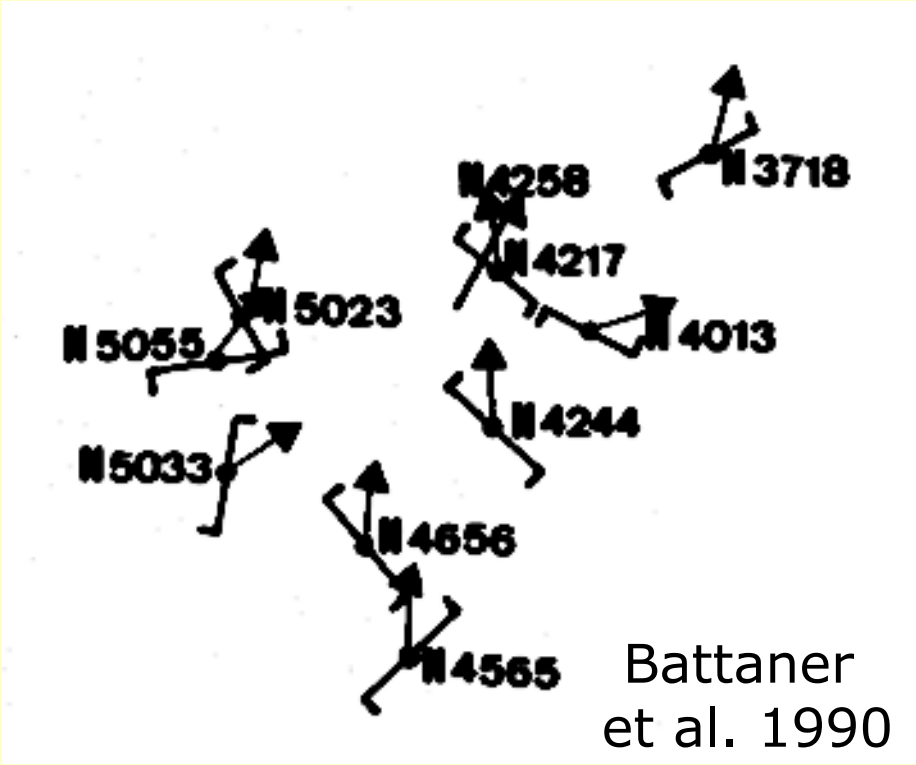
- Models invoking late infall work well to reproduce the kinematics and the morphology of (symmetrically) warped galaxies
- Indication of characteristic kinematic signatures for DM sub-structure (at the commencement of the warp)
- Large amounts of extraplanar gas observed in galaxies with regular warps (indication of inwards motion: NGC 5204)
- Extended low-column density gaseous disks
  → deployment of high angular-momentum gas in warps?
- Indication of connections of stellar- and gaseous debris in high-sensitivity HI observations
  → deployment of gas in minor mergers, at the same time generation of warp?

Want statistics...

- Current detailed observational **HI warp studies rely on observations of less than ~80 galaxies** (Bosma 1978, Briggs 1990, García-Ruiz 2002, Józsa 2007, Bae, Kim & Chung et al. (on VIVA), and a few other singular studies)

But we want a **statistical sample** to investigate

- **Environmental effects** on warp properties (amplitude, symmetry)
- The **connection of warps and HI halos**
- The **connection of galaxy- and warp properties** (mass, type)
- Relative **spin orientation** of inner and outer disk **with respect to the large-scale structure**



Battaner et al. 1990

Want statistics...

- Current detailed observational **HI warp studies rely on observations of less than ~80 galaxies** (Bosma 1978, Briggs 1990, García-Ruiz 2002, Józsa 2007, Bae, Kim & Chung et al. (on VIVA), and a few other singular studies)

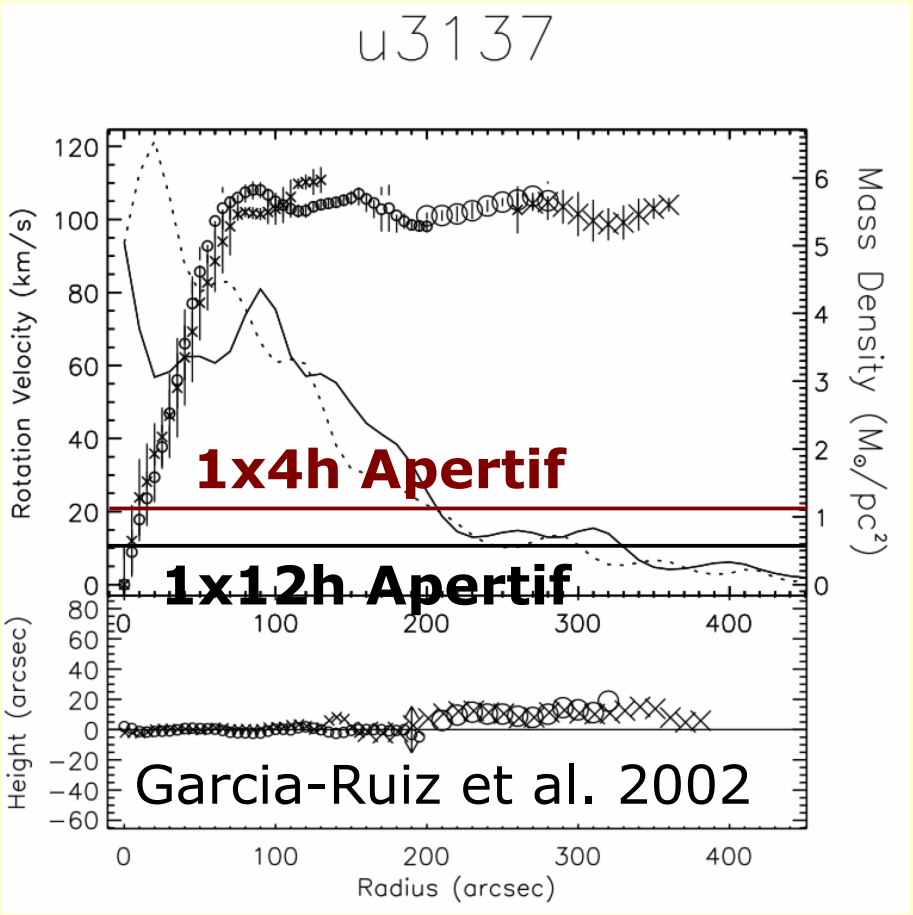
But we want a **statistical sample** to investigate

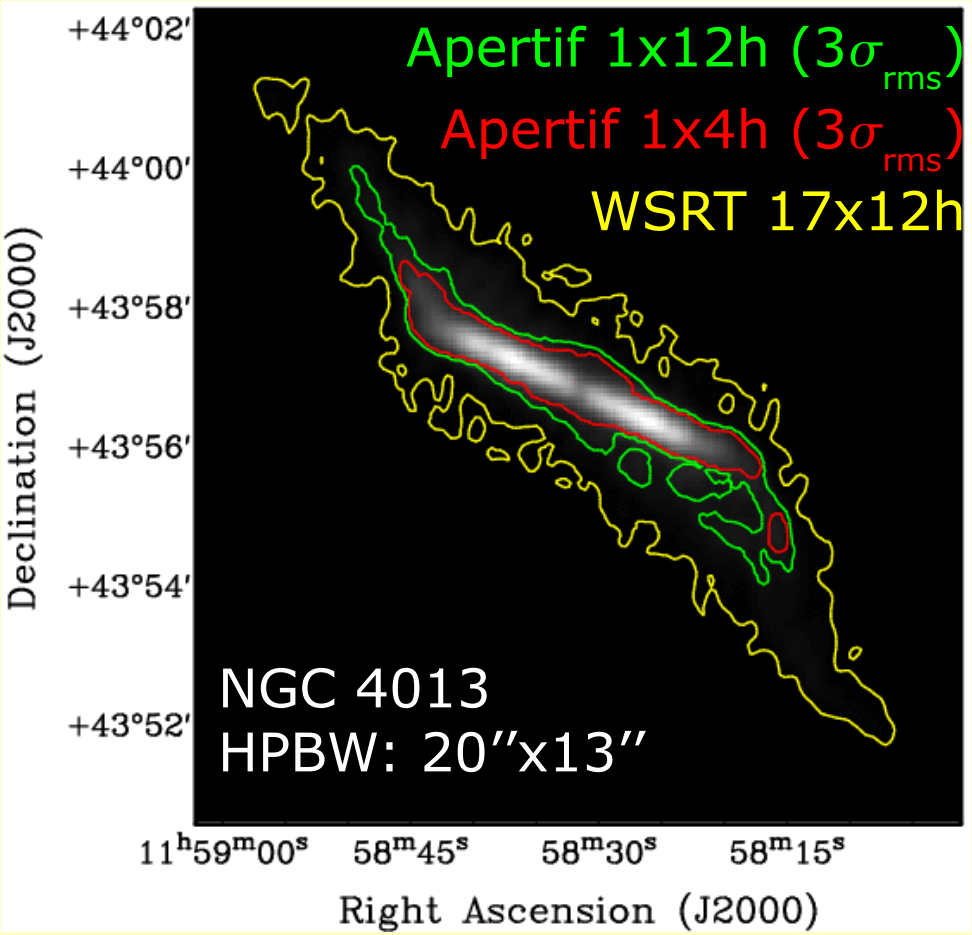
- **Environmental effects** on warp properties (amplitude, symmetry)
- The **connection of warps and HI halos**
- The **connection of galaxy- and warp properties** (mass, type)
- Relative **spin orientation** of inner and outer disk **with respect to the large-scale structure**

Apertif (ASKAP)

Sensitivity

- Need for large volumes → Wide-field capacity
- Sufficient sensitivity → Apertif with ≥ 12h per pointing



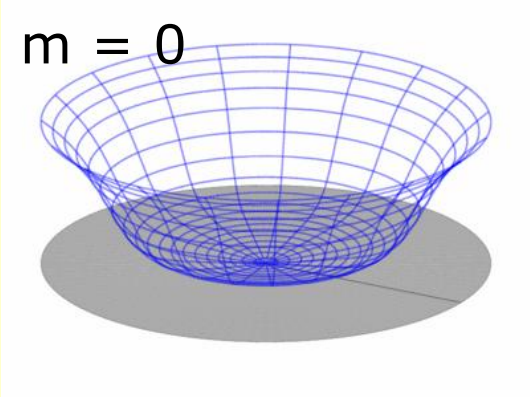


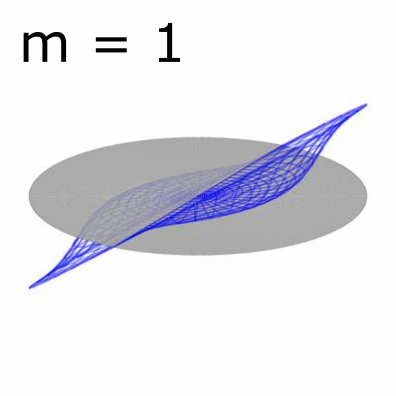
12h Apertif → $5\sigma_{rms}$=8·10^{19} atoms cm^{-2} (FWHM = 20 km s^{-1}, HPBW = 30'')

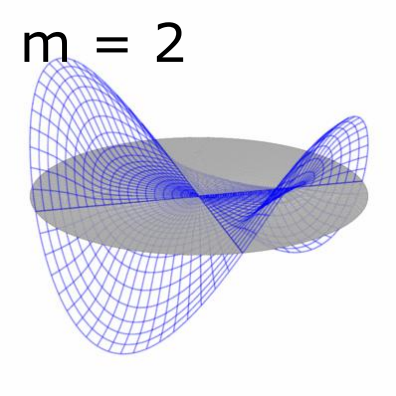
4h Apertif (WALLABY) → $5\sigma_{rms}$=1.4·10^{20} atoms cm^{-2} (FWHM = 20 km s^{-1})

Automated quantification

- Need for **automated software to characterise** warps and **galaxy kinematics** in general → currently being investigated in the scope of WALLABY/WNSHS







Heald et al.

Summary

- **Warps** are a probably **long-lived** (but not stationary) peripheral feature of disk galaxies in the **interface region between galaxy disk and the IGM**.

- (HI-) **Warps** might be **connected to** (cold) **accretion** and can possibly serve as a reservoir of (and a buffer for) star forming material.

- **A statistical investigation of warps with a wide-field survey instrument is highly desirable** to understand warps and the interface region between the bright HI disk and the IGM in general.

- A **minimum requirement** for such a study is a sensitivity as reached after **12h integration with Apertif**.

WNSHS

***W**esterbork **N**orthern **S**ky **HI** **S**urvey*

http://www.astron.nl/~jozsa/wnshs/

Summary

ASTRON

- **Warps** are a probably **long-lived** (but not stationary) peripheral feature of disk galaxies in the **interface region between galaxy disk and the IGM**.

- (HI-) **Warps** might be **connected to** (cold) **accretion** and can possibly serve as a reservoir of (and a buffer for) star forming material.

- **A statistical investigation of warps with a wide-field survey instrument is highly desirable** to understand warps and the interface region between the bright HI disk and the IGM in general.

- A **minimum requirement** for such a study is a sensitivity as reached after **12h integration with Apertif**.

20:30 Beer(!!!) cellar:

HI survey meeting