A New Tool to Study Warped Galaxies

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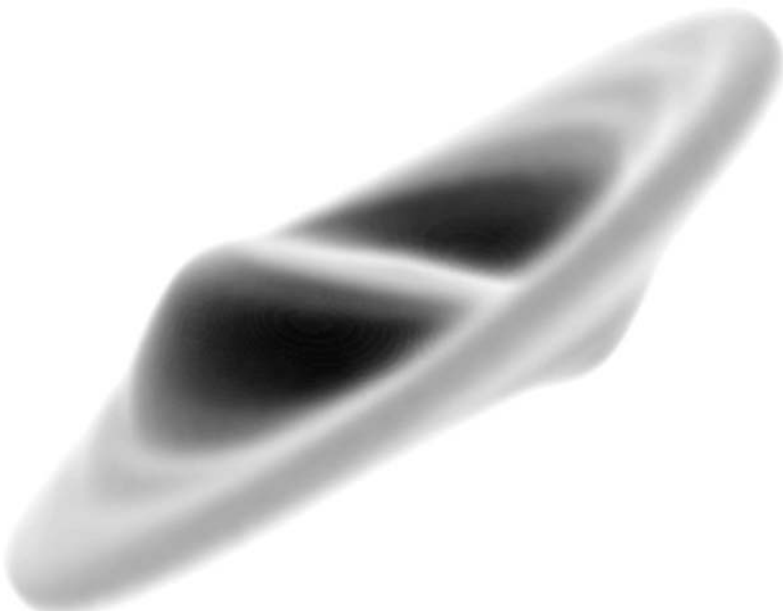
universitätbonn



Warps in galaxies: a frequent phenomenon!

- gaseous warps: pronounced in edge-on galaxies (Sancisi 1976; 1983)

- Reshetnikov & Combes (1998; 1999):

  - about 40% of late-type galaxies exhibit $\int$-shaped warps
  - tidal interaction a likely cause

- García-Ruiz (2001):

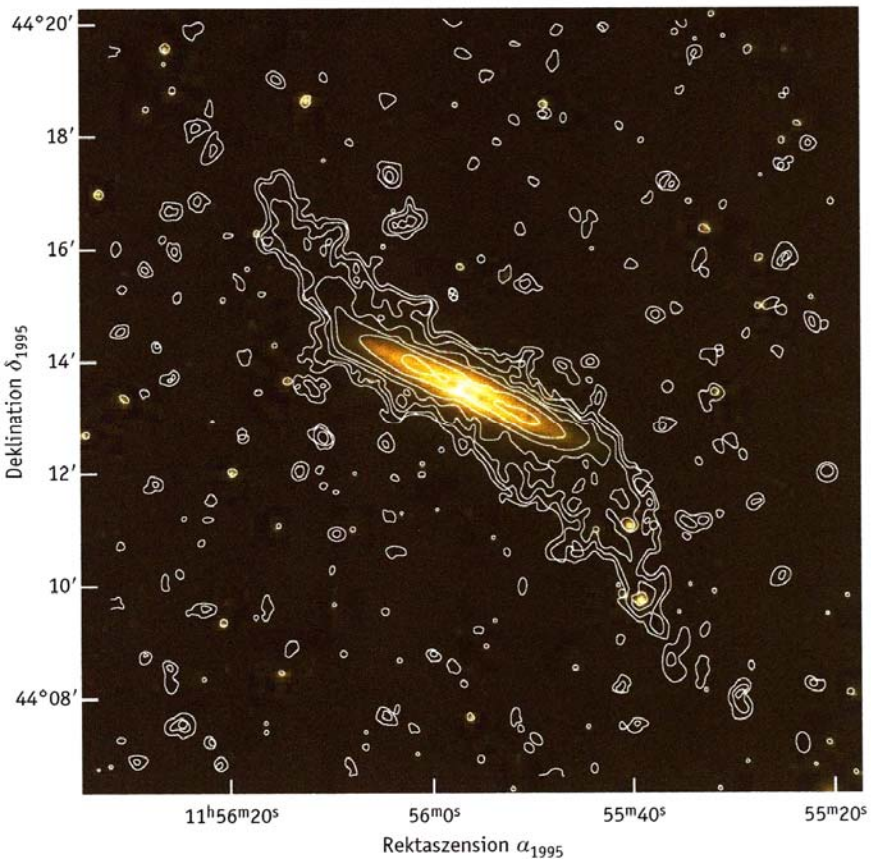
  - all galaxies with an HI disk more extended than the optical are warped (corollary: all disk galaxies are warped)
  - stronger and more asymmetric warps in more rich environments
  - but: also warps in isolated galaxies $\Rightarrow$ also other mechanisms

- origin of warps:

  - tidal forces
  - IGM (gas / DM infall)
  - (non-spherical) DM halos

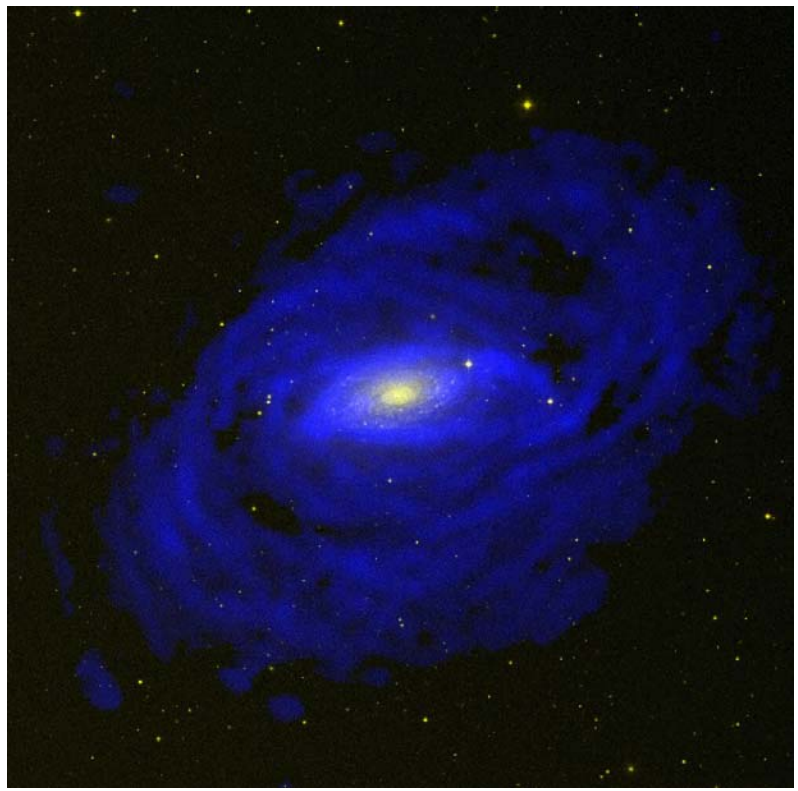
most pronounced in the HI line!

NGC 4013



Bottema et al. (1996)

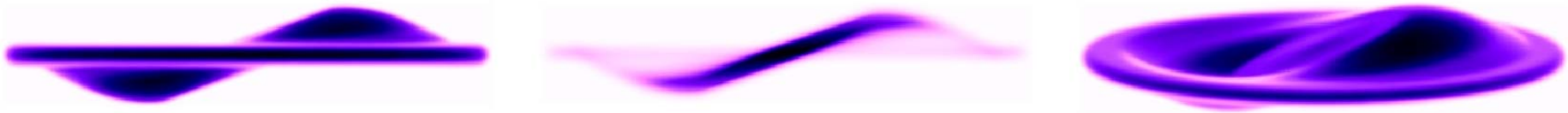
NGC 5055



Battaglia et al. (2006)

Warp shapes

edge-on, opaque | edge-on, translucent | inclined, opaque



S-shaped (antisymmetric, integral-signed) warp

U-shaped (symmetric, bowl-shaped) warp

L-shaped (asymmetric) warp

Most warps are grand-design S-shaped warps
(García-Ruiz et al. 2002, Sánchez-Saavedra et al. 2003)

Why study warps?

- information about evolution of galaxies
  - misalignment of disks in flattened halos (Sparke & Casertano 1988; Kuijken 1991)

- galaxy rotation curves
  - proper deprojection of galaxy kinematics required (Corbelli & Schneider 1997)
  - crucial to study (DM) potentials in galaxies

- growing number of related cosmological simulations
  - misalignment of angular momenta of baryonic disk and (non-spherical) DM halo (van den Bosch et al. 2002; Sharma & Steinmetz 2005; Bailin et al. 2005)
  - cosmic infall (Shen & Sellwood 2006)

Automated tool: “Tilted-Ring Fitting Code” (G. Józsa, Ph.D. thesis 2006)

http://www.astro.unibonn.de/~gjozsa/tirific.html

measured (HI) data cube
$I(\xi, \eta, v)$

simple initial model with constant
$\xi_0, \eta_0, \Sigma, v_{sys}, v_{rot}, i, p.a.$

grid points $r_1, r_2, \ldots r_n$

model cube

⇓

project onto data cube

⇓

convolution (ξ, η, v)

⇓

check χ^2 → better / worse?

new parameters, each ring
($\xi_0, \eta_0, \Sigma, v_{sys}, v_{rot}, i, p.a.$)

TiRiFiC has been tested extensively using artificial galaxies (Józsa et al. 2007, A&A, in press)

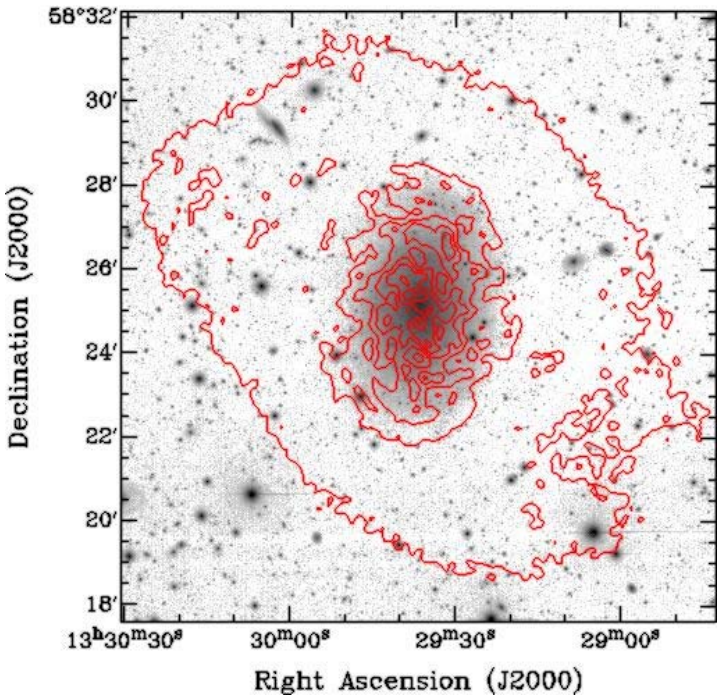
Kinematics and morphology of 3 warped disk galaxies (Józsa 2007, A&A, in press)

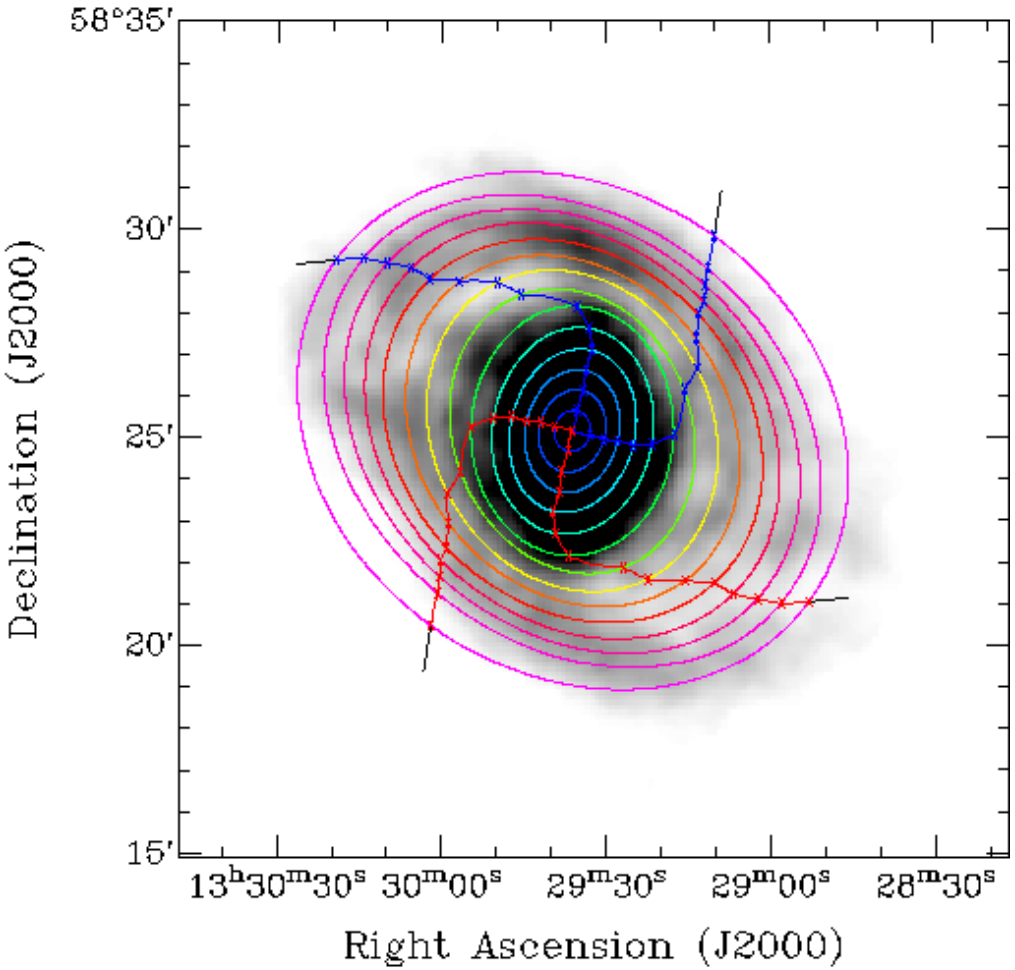
	D [Mpc]	L_B [10^9 $L_\odot$]	M_{dyn} [10^{10} $L_\odot$]
NGC 2541	11	4.5	> 12.1
UGC 3580	15	1.6	> 9.4
NGC 5204	4	0.8	> 2.2

application to M 33 (Braun et al., this conference)

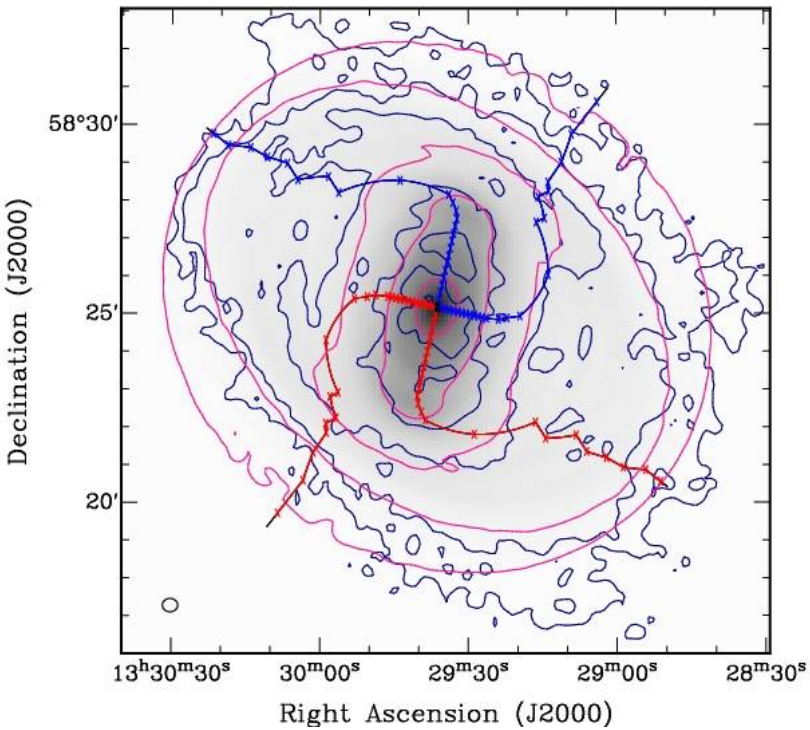
- isolated galaxies with strong symmetric HI warps
- no bars
- HI observations with WSRT
- optical photometry with INT

e.g. NGC 5204


58°32′
30′
28′
26′
24′
22′
20′
18′
Declination (J2000)
13h30m30s
30m00s
29m30s
29m00s
Right Ascension (J2000)

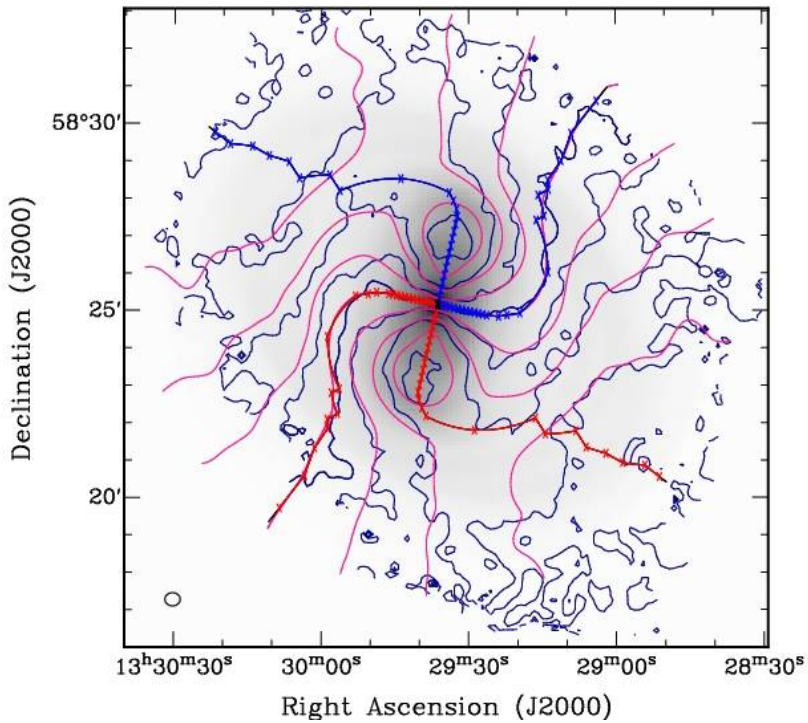

58°35′
30′
25′
20′
15′
Declination (J2000)
13h30m30s
30m00s
29m30s
29m00s
28m30s
Right Ascension (J2000)

column density



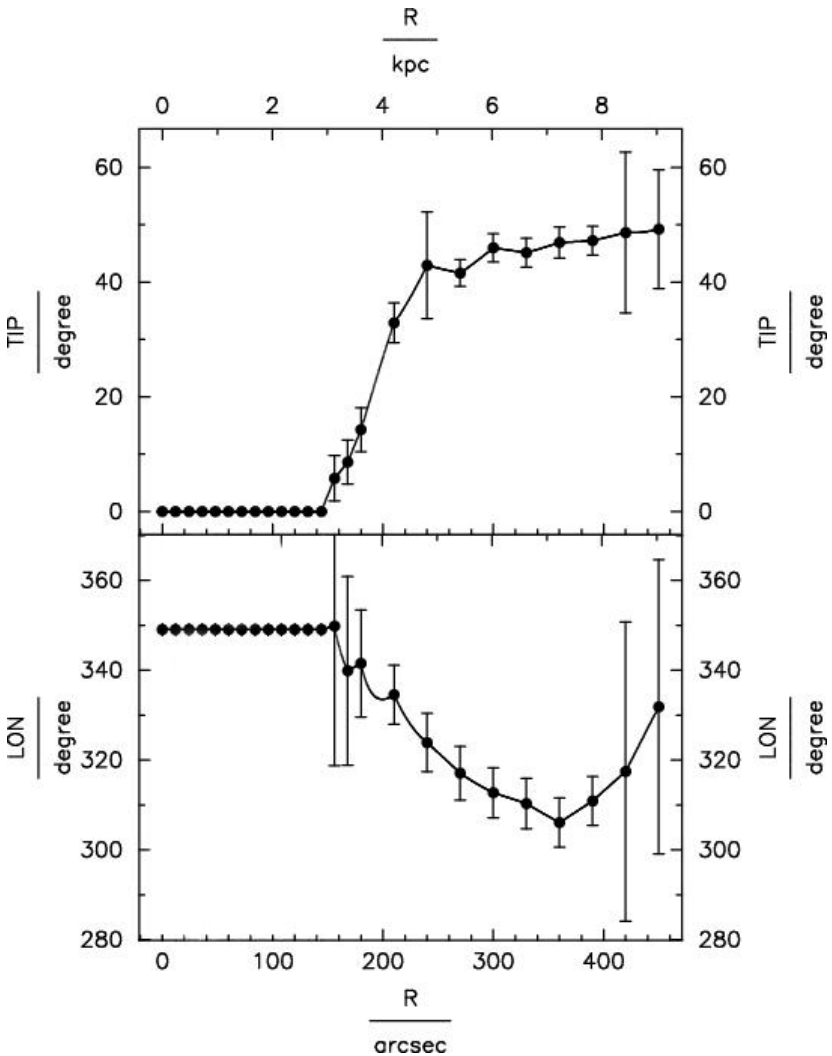
blue contours:
moment-0 column density
pink contours and grey-scale :
modeled column density

velocity field

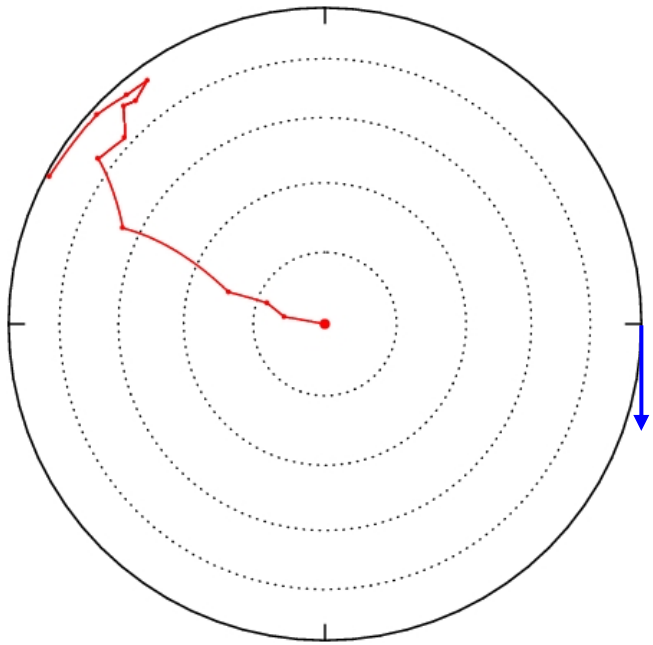


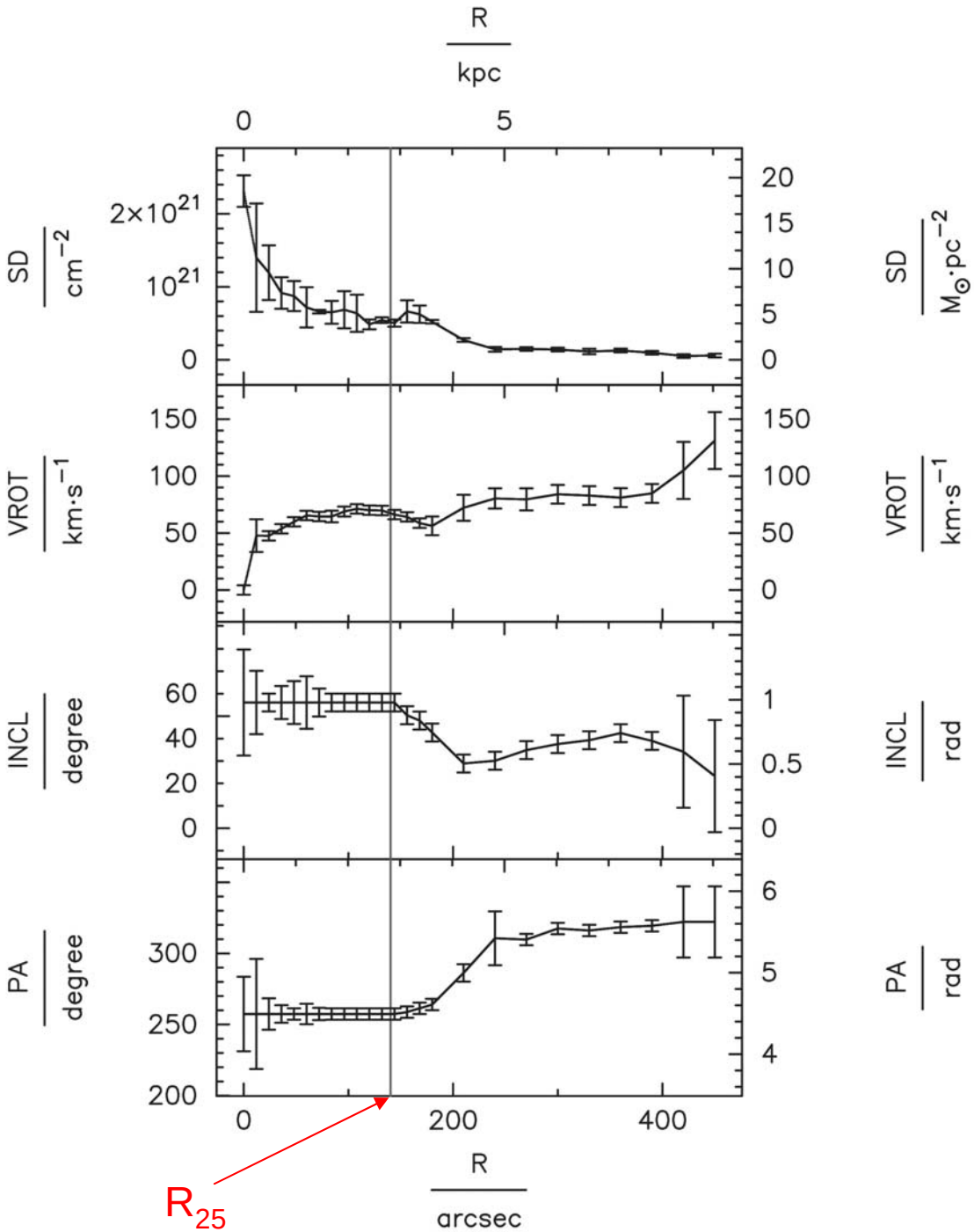
blue contours and grey-scale:
moment-1 velocity field
pink contours:
modelled velocity field
grey-scale: modeled column density

line of nodes

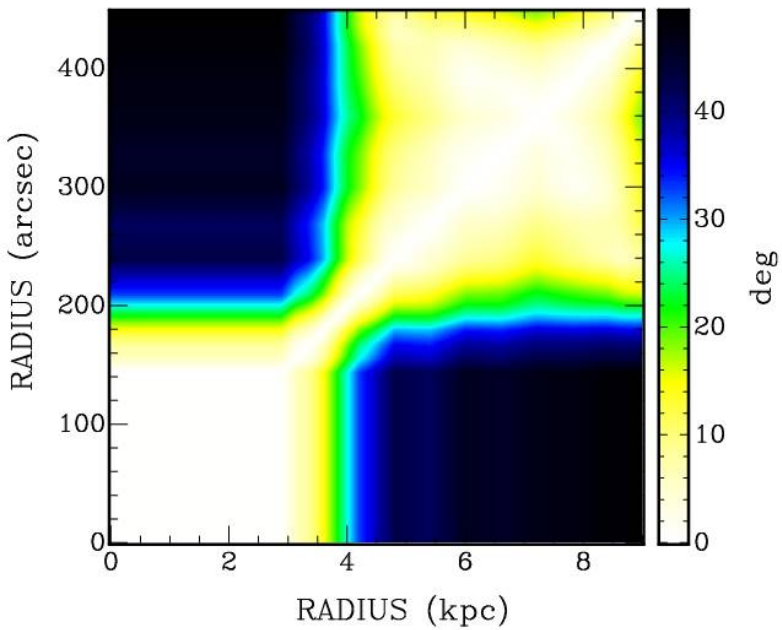


“Briggs plot”

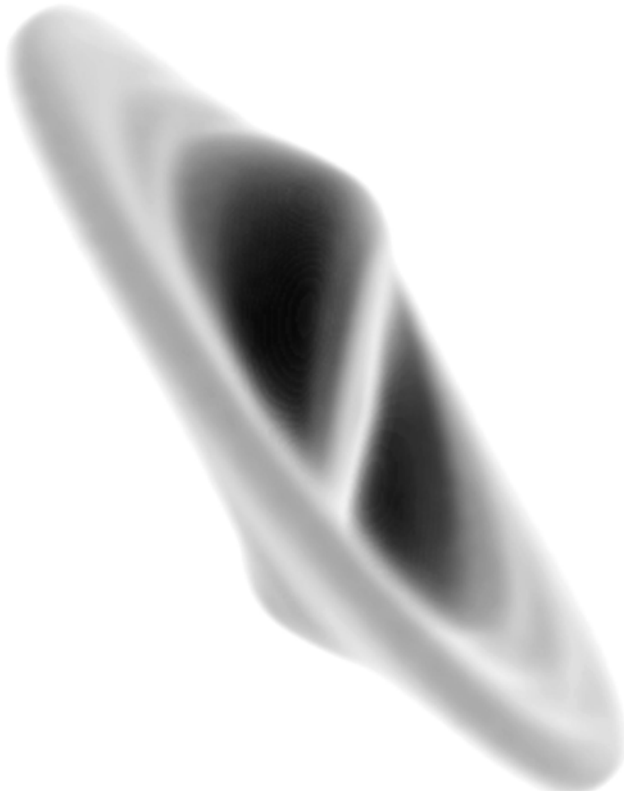



R
kpc
0
5
SD
cm^{-2}
2×10^{21}
10^{21}
0
SD
$M_\odot \cdot pc^{-2}$
20
15
10
5
0
VROT
km·s^{-1}
150
100
50
0
INCL
degree
60
40
20
0
INCL
rad
1
0.5
0
PA
degree
300
250
200
PA
rad
6
5
4
0
200
400
R
arcsec
R_{25}

“tiltogram”



“opaque”
3-D model of HI disk



Results:

- inner and outer flat disk
- transition at termination of stellar disk
- with drop of Σ_{HI}, shallow decrease beyond
- and slight increase in rotation velocity
- tip of the LON forms “leading spiral”

	v_{rot} [km s^{-1}]	r_t [kpc]	Δi	δi
NGC 2541	127	32	18º	4º
UGC 3580	121	28	14º	3º
NGC 5204	105	8.4	41º	6º

Outer disks have come into focus (this conference):

Braun et al.	: M 33
Briggs et al.	: giant LSBs
Braine & Gardan	: molecular gas & SF
Thilker et al.	: SF thresholds & LSB zones
Hunter & Elmegreen	: outer disks of dwarf galaxies

Conclusions:

- TiRiFiC works ok

- warped galaxies possess flat inner and flat outer disk

- warps start where
  optical disk has faded away
  Σ_{HI} drops to low level

- Σ_{HI} has shallow gradient beyond

- rotation velocity changes with orientation of the disk
  non-spherical DM halo?
  precession?

- two distinct kinematic regimes, each with constant line of nodes

- line of nodes advances in direction of rotation

Briggs' rules (1990) confirmed!
(see also van der Kruit 2007)


Grazie per organizzare un evento eccezionale!