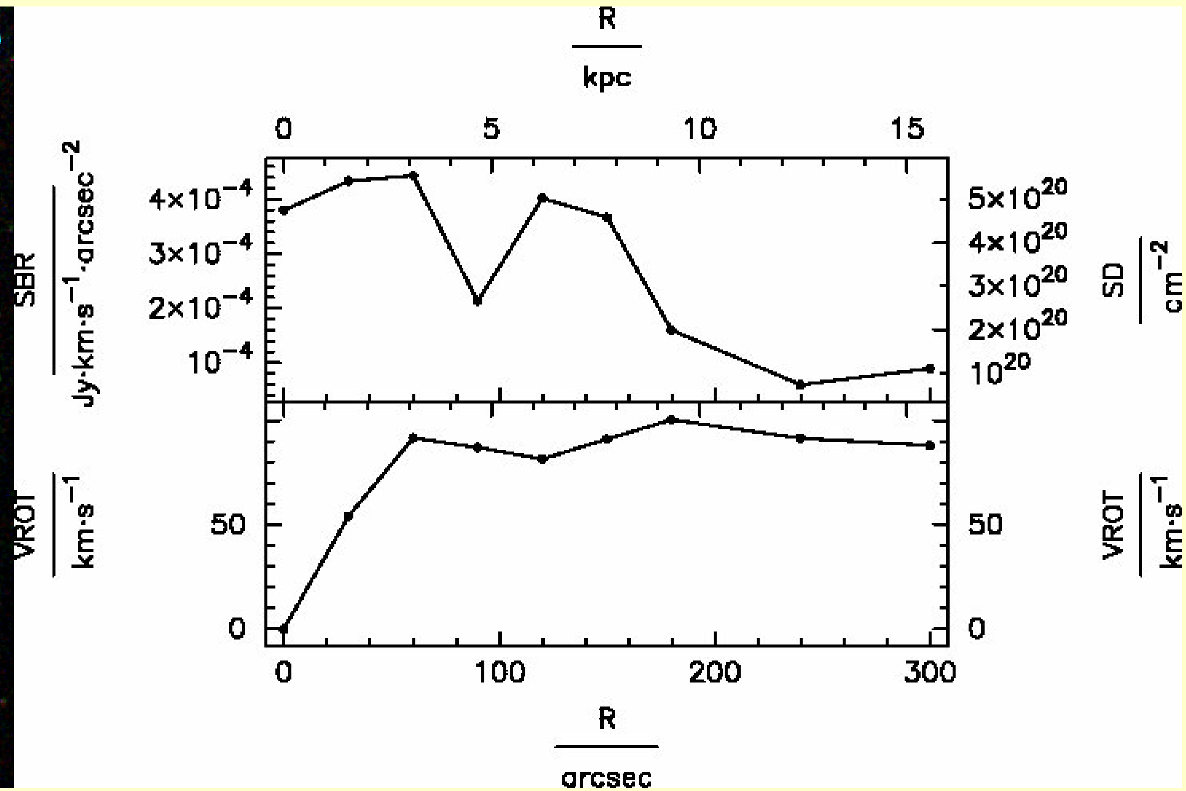
ASTRON

Netherlands Institute for Radio Astronomy

Parametrising spatially resolved HI disks

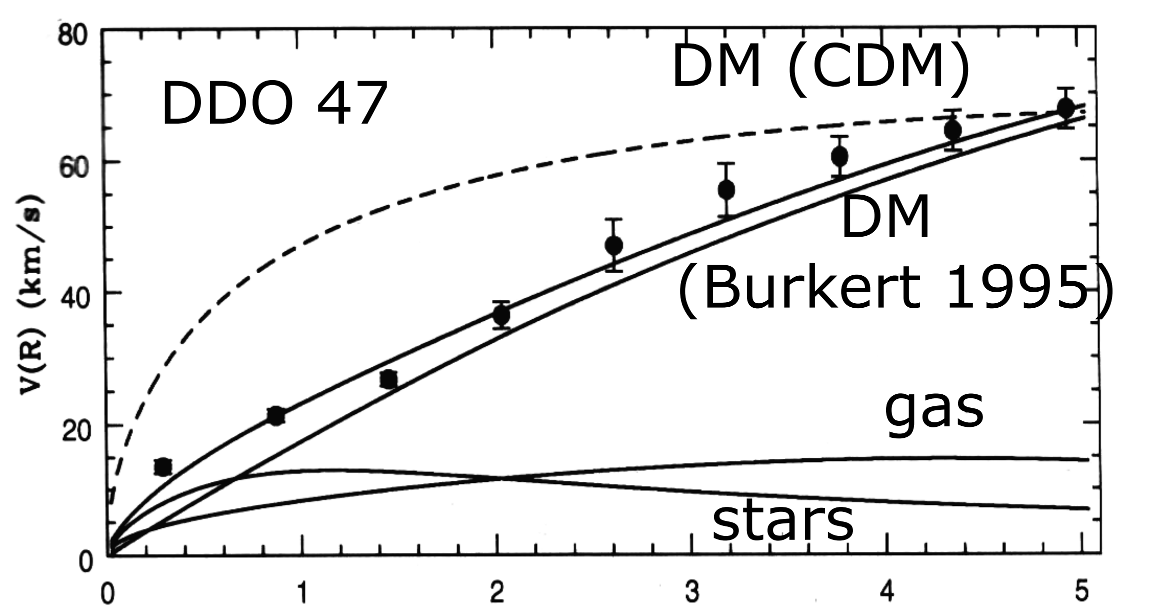


Gyula I. G. Józsa

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

Rotation curves

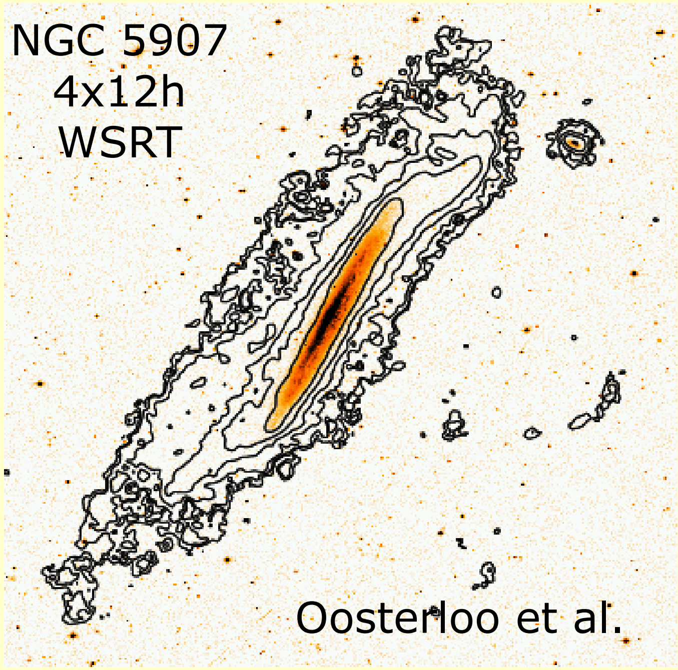
- CDM makes predictions for ρ_{DM} ("cusps", Navarro et al. 1996, Moore et al. 1998, Navarro et al. 2004, ...)
- Rotation curve analyses show a discrepancy (e.g. de Blok et al. 2001, de Blok & Bosma 2002, Gentile et al. 2004, 2005, 2007, McGaugh et al. 2007, de Blok et al. 2008)
- Indications for a **Universal Rotation Curve** (Persic, Salucci & Stel 1996, Salucci and Persic 1997, but see also Verheijen 1997, Bosma 1998), a two-parameter (luminosity, surface brightness) family of rotation curves (from optical data)
- Large-scale HI surveys will provide the **extension towards larger radii** for a much larger number of galaxies (albeit at lower resolution)

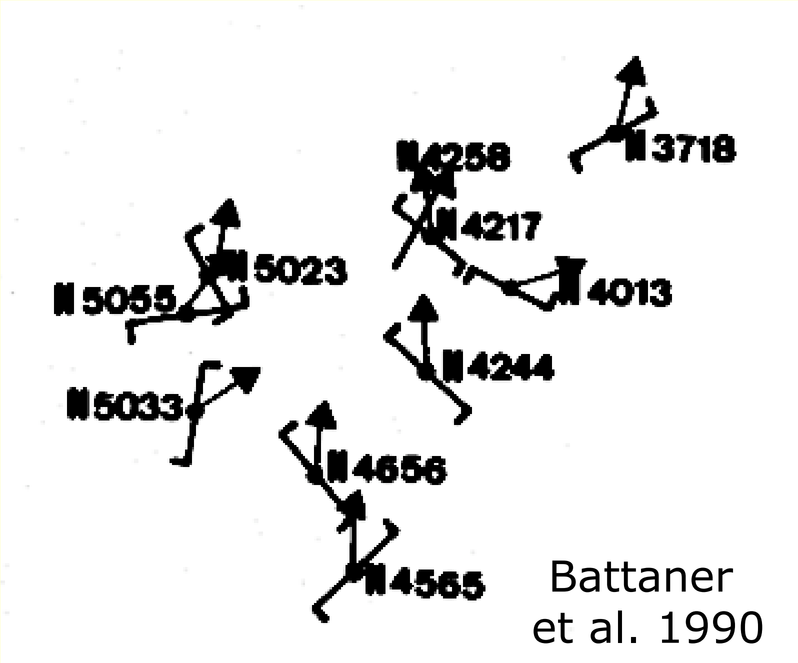


Salucci et al. 2003

Warps

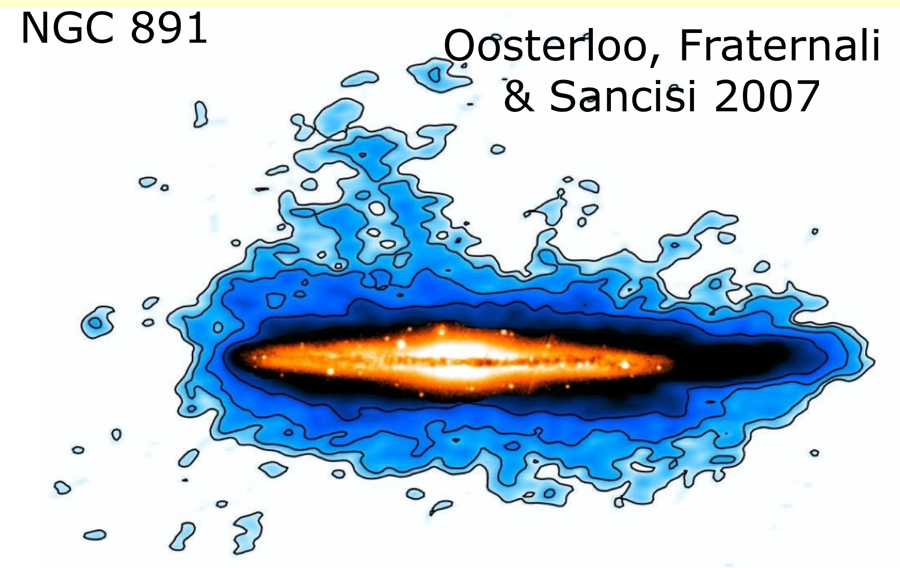
- Warps state an excitation from a dynamical ground state of the disk/DM halo system → **parametrisation constrains the dynamics of the DM/disk system** (e.g. Saha & Jog 2006)
- Large optical samples but **HI studies are rare** (e.g. Sánchez-Saavedra et al. 1990, **Briggs 1990**, **García-Ruiz 2002**, Ann & Park 2006, **Józsa 2007, Kalberla et al. 2007**)
- **Cosmic infall** (Ostriker & Binney 1989, ... , López-Corredoira et al. 2002, Shen & Sellwood 2006, Van der Kruit 2007)

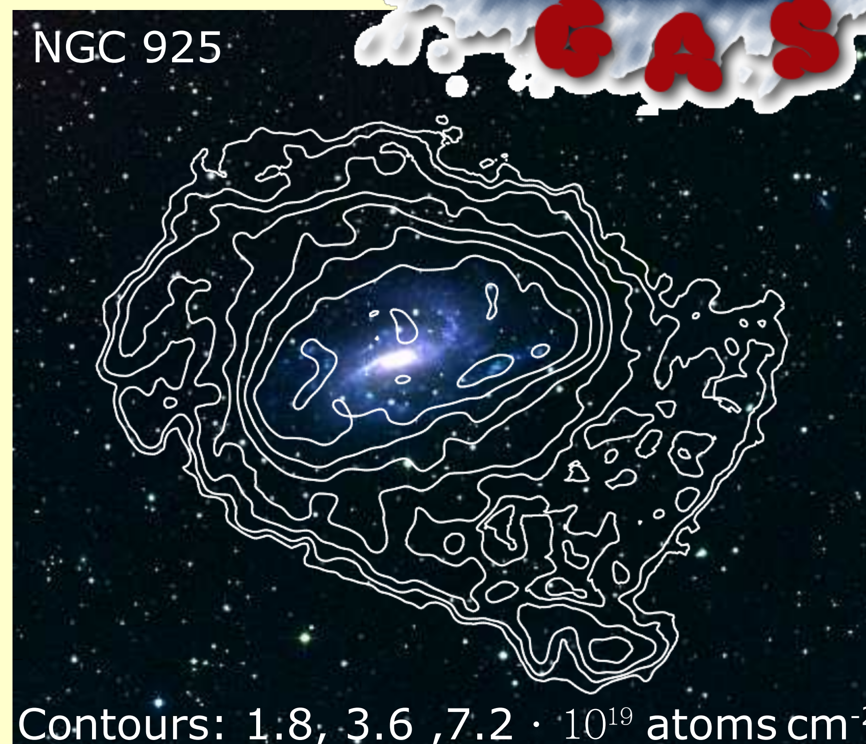




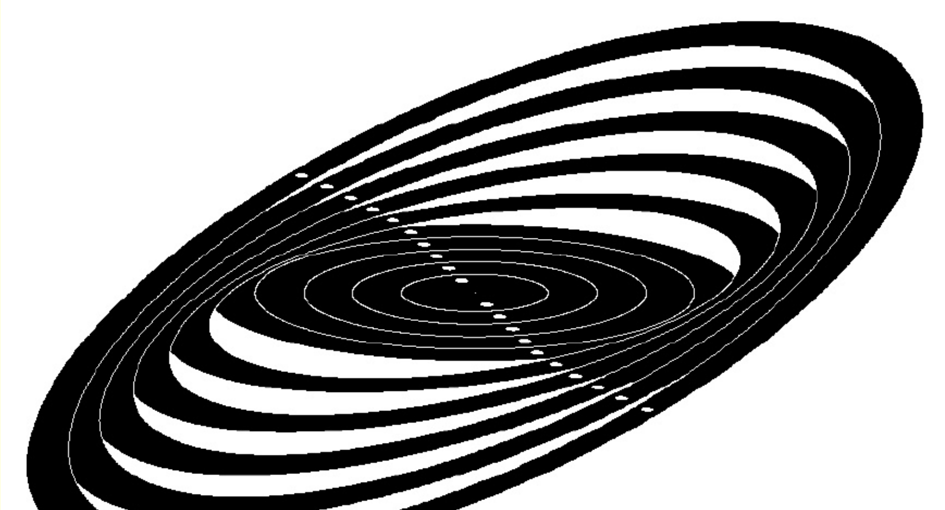
Anomalous gas

- **Accretion of satellites and/or gas from the IGM** is necessary to maintain star formation in spiral galaxies (Pagel 1997)
- **"Cold accretion"** is expected (Kereš et al. 2005)
- **Observations of neutral gas halos** (Fraternali et al. 2002, Heald et al. 2006, Oosterloo et al. 2007, Boomsma et al. 2008, Fraternali & Binney 2008)
- Only a **few cases** observed
- **HALOGAS** survey (Heald et al.)

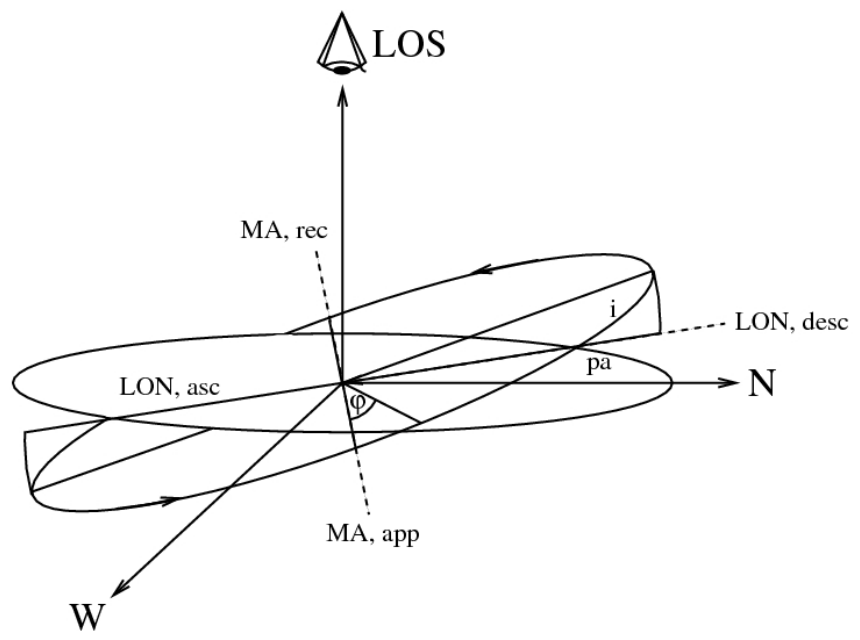




The tilted-ring model



García-Ruiz 2001



- Tilted-Ring-Model (Rogstad et al. 1974):

parametrise rings at different radii by

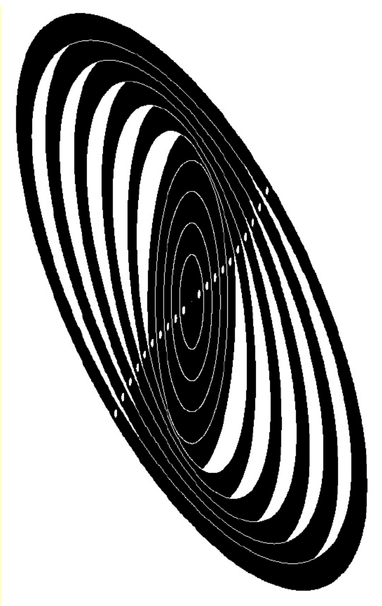
- two orientation parameters (inclination, position angle)
- central position
- surface brightness
- rotation velocity

tackling asymmetries by introducing azimuthal variations (Franx, van Gorkom & de Zeeuw 1994, Schoenmakers et al. 1999)

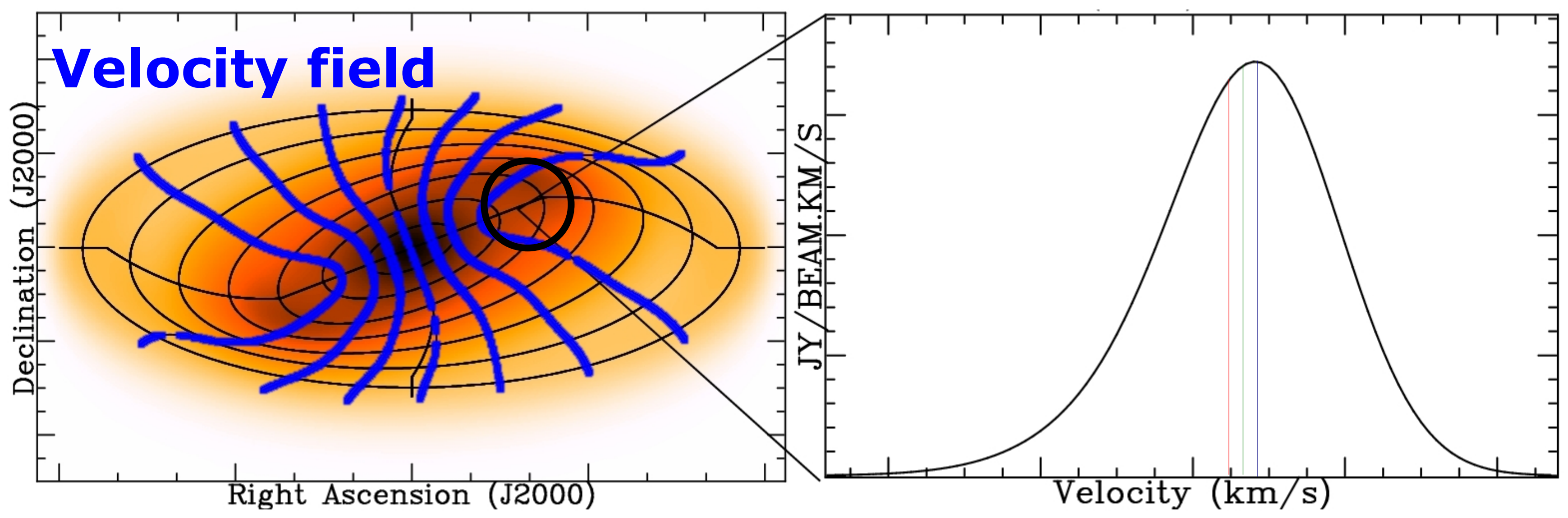
Fitting: velocity field

HI data cube: I(ξ,η,λ), via Doppler Shift I(ξ,η,v)
Rotcur: Fit to a "velocity-field" (Begeman 1987)

$$v_{obs}(x,y) = v_{sys} + v_{rot} cos(\theta(x,y,pa)) sin(i)$$

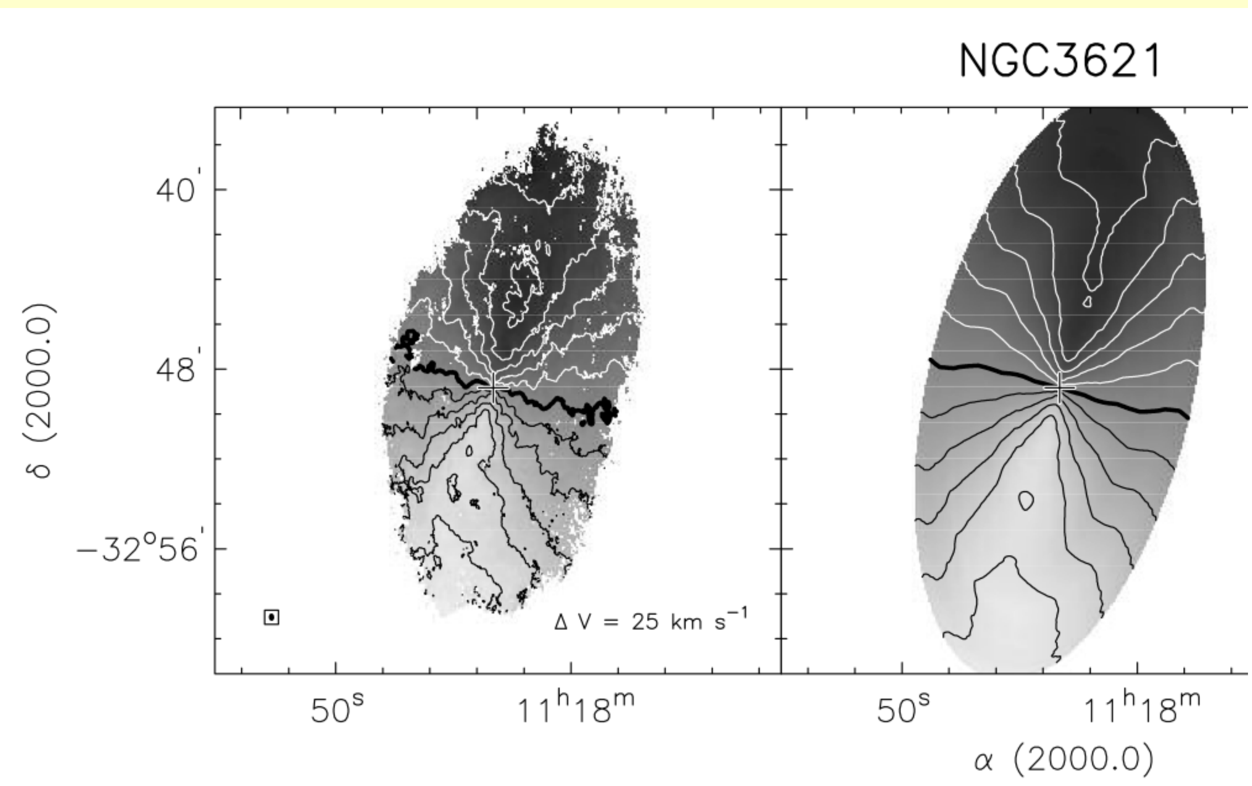


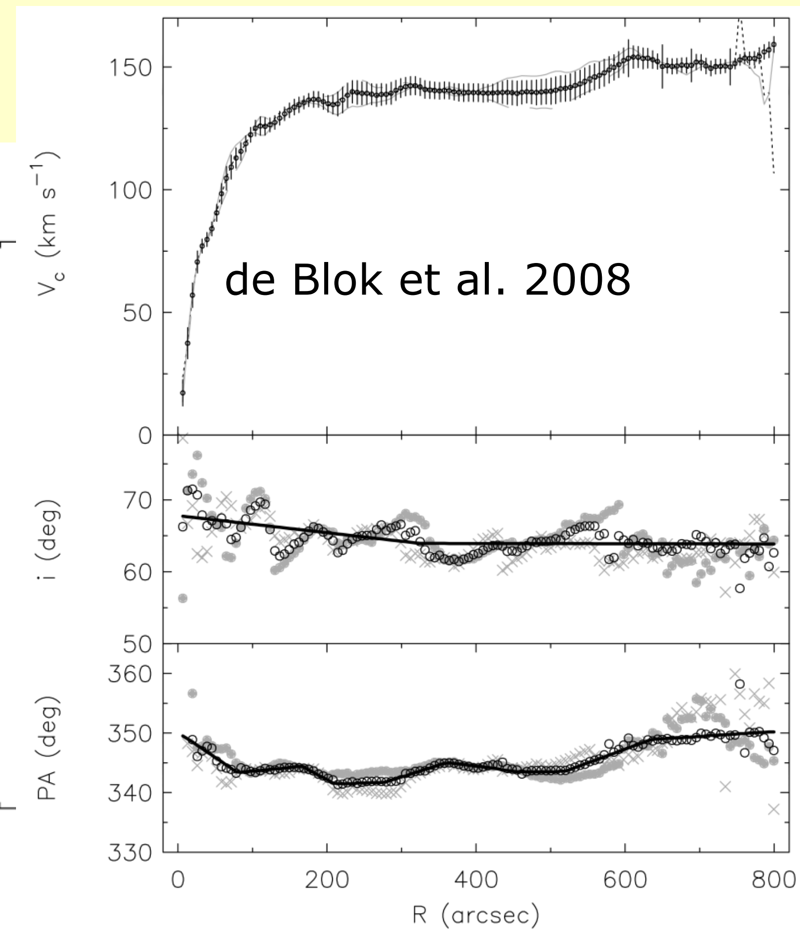
- **Main task: finding the appropriate velocity field**
  - Intensity-weighted mean
  - Velocity of the intensity-peak
  - (Multi-) Gaussian fit (Begeman 1987)
  - Gauss-Hermite polynomial fit (Noordermeer et al. 2007, de Blok et al 2008)



Fitting: velocity field

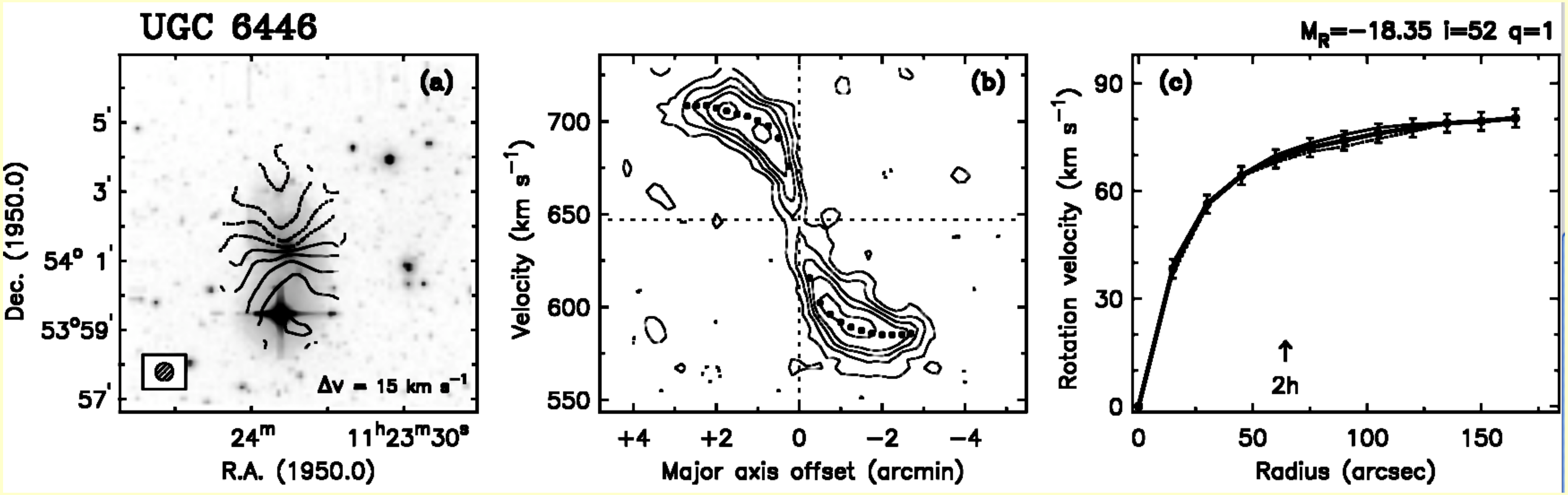
- Works very well for data cubes with **high spatial resolution** (de Blok et al. 2008)
- Fast





Fitting: velocity field

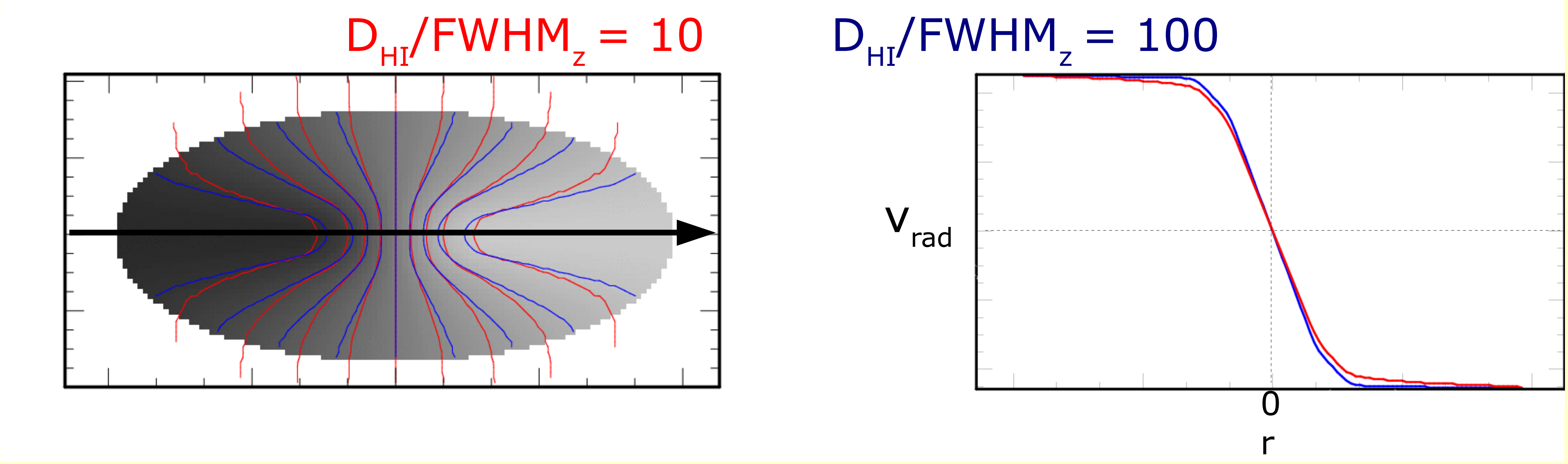
- Works very well for data cubes with **high spatial resolution** (de Blok et al. 2008)
- Fast
- For lower resolution (compared to the extent of the disk) "**beam smearing**" becomes an issue.



Swaters 1999

Fitting: velocity field

- Works very well for data cubes with **high spatial resolution** (de Blok et al. 2008)
- Fast
- For lower resolution (compared to the extent of the disk) "**beam smearing**" becomes an issue.
- Structural parameters are "missing":
  - **Surface brightness**
  - **Disk thickness**
- Fits to **edge-on and (highly) warped galaxies** impossible



Fitting data cubes

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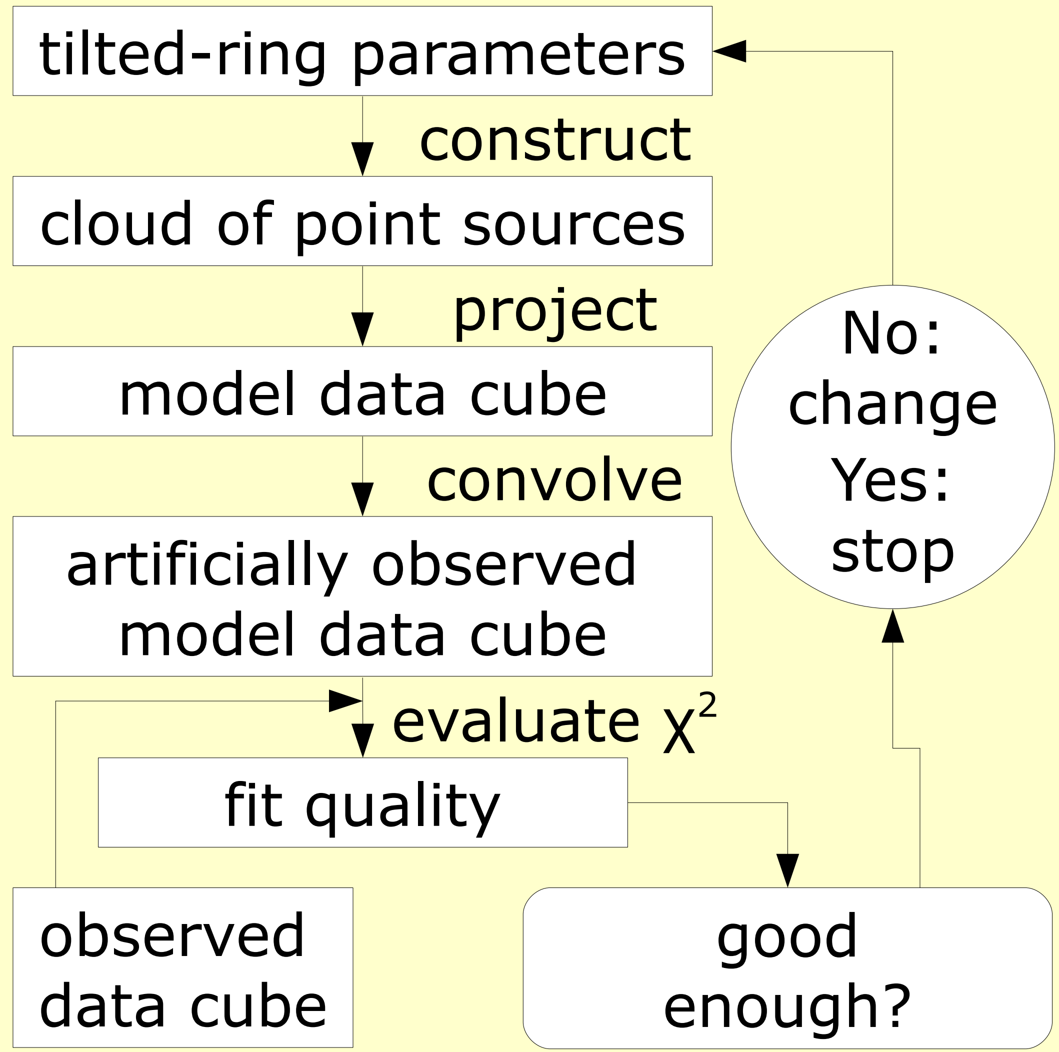
- Method has been applied by:
  Irvin (1991), Corbelli & Schneider (1997), Józsa et al. (2007), Fiege et al.



- Fit of orientational parameters, centre, rotation velocity, **surface brightness, scale height, dispersion**

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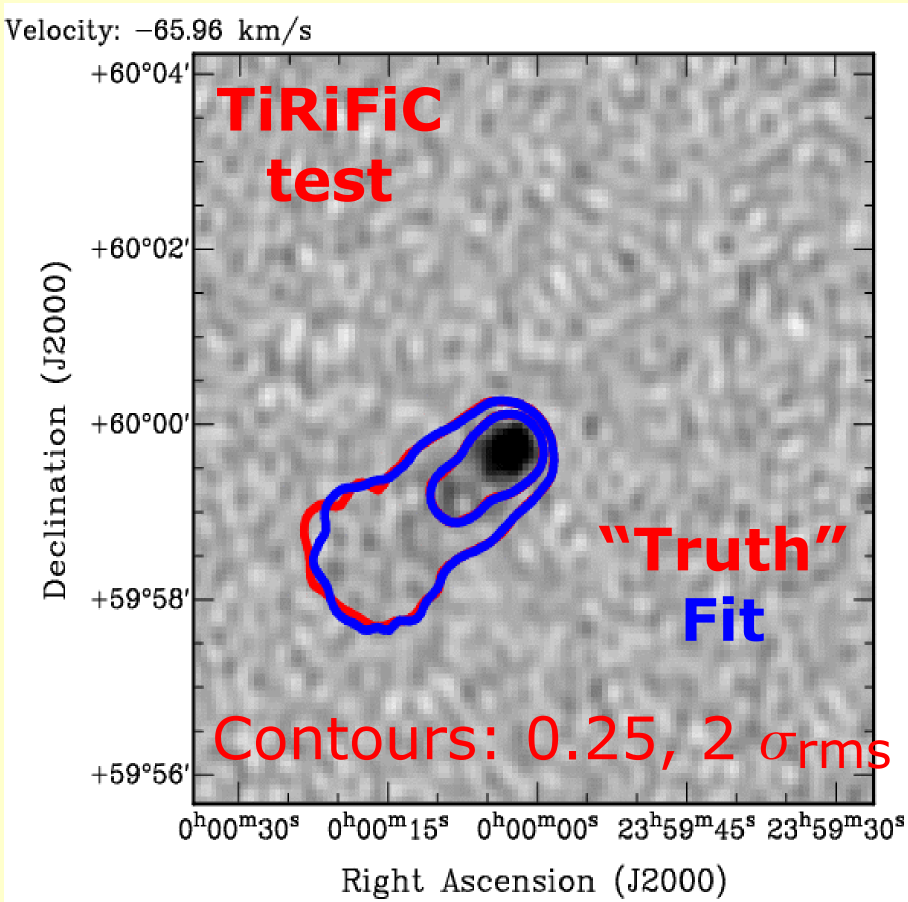
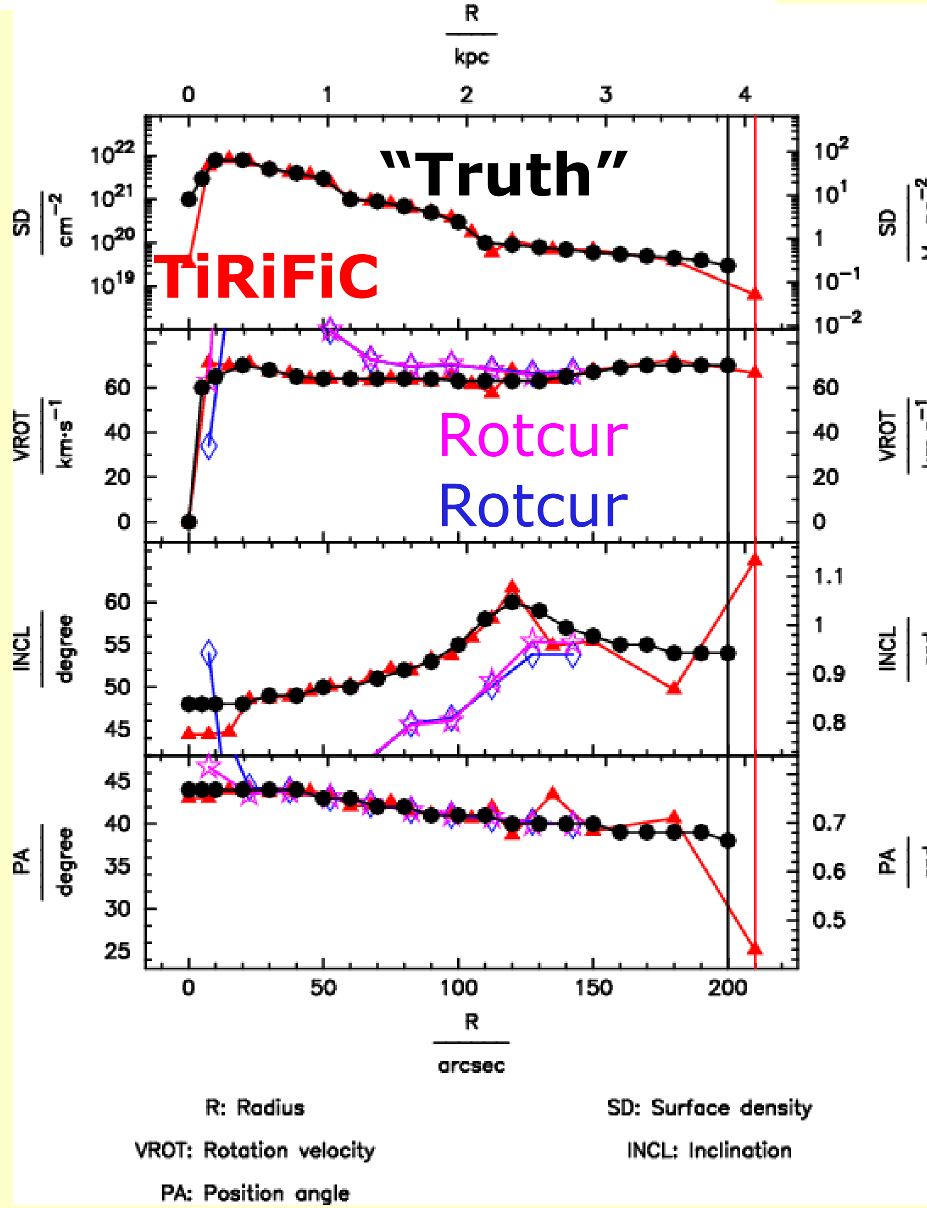
TiRiFiC tests

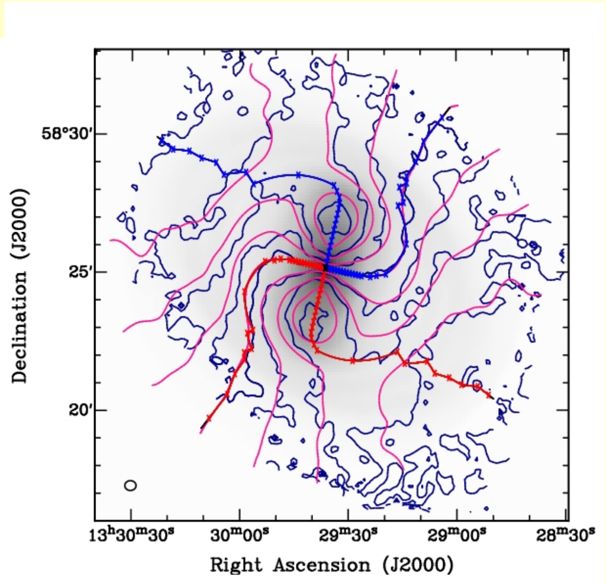


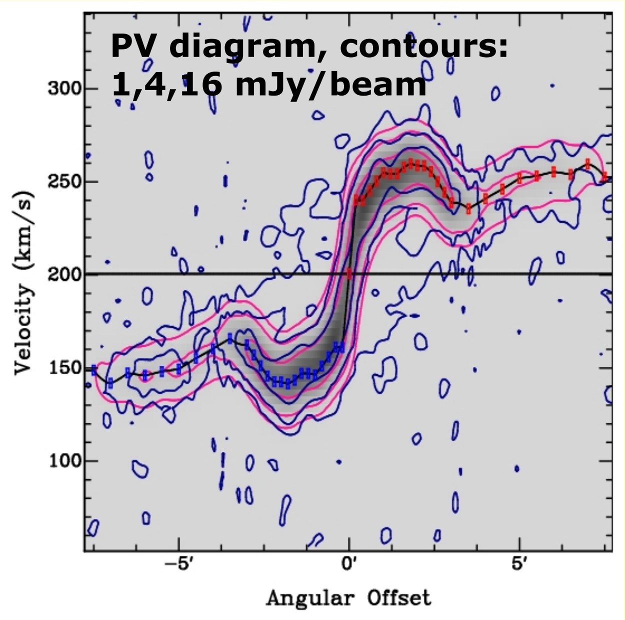
- Tests on artificial data (Józsa et al. 2007)
- **Enhanced sensitivity** through integral approach (depends on symmetry)



Fitting data cubes

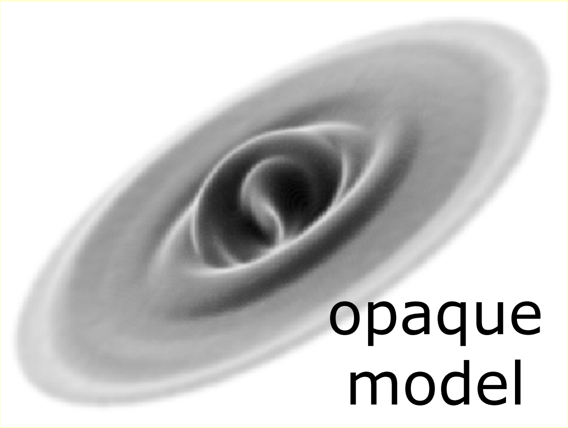
Velocity field, contours:
$v_{sys}\pm0,15,30,45,60$ km s $^{-1}$



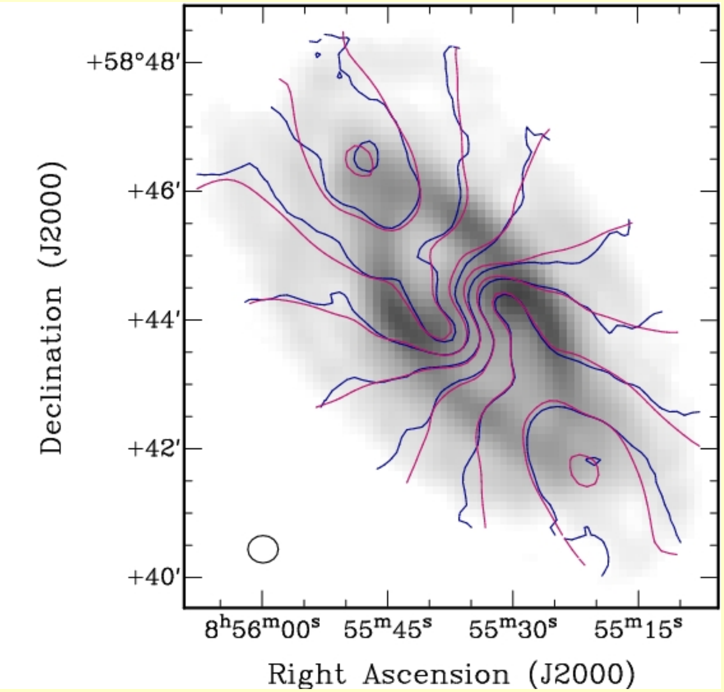


NGC 5204
(Józsa 2007)

NGC 2685
(Józsa et al. 2009)



opaque
model

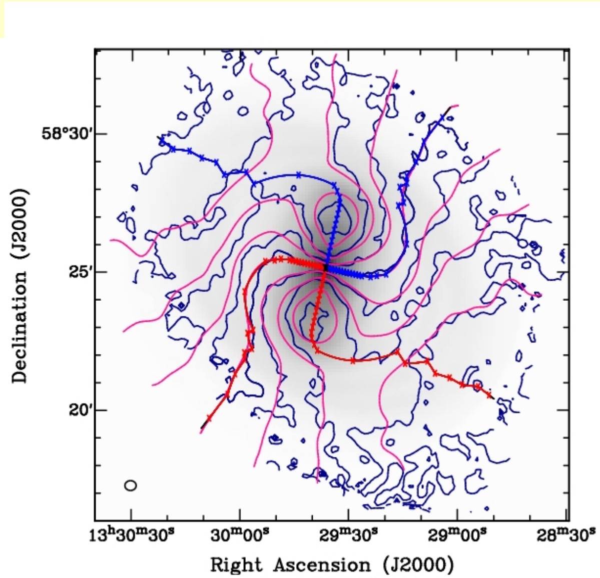


Velocity field,
contours: $v_{sys}\pm0,15,30,45,60$ km s $^{-1}$

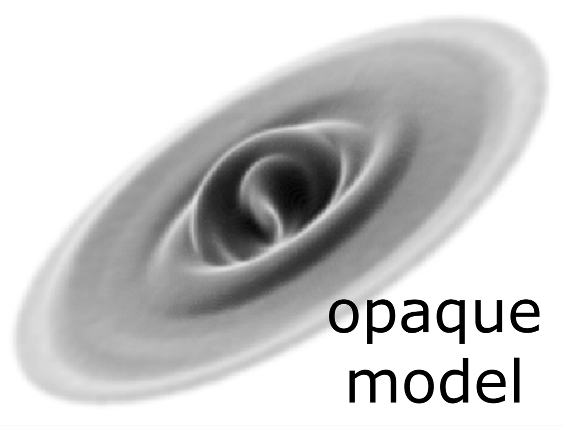
pink: model
blue: observation

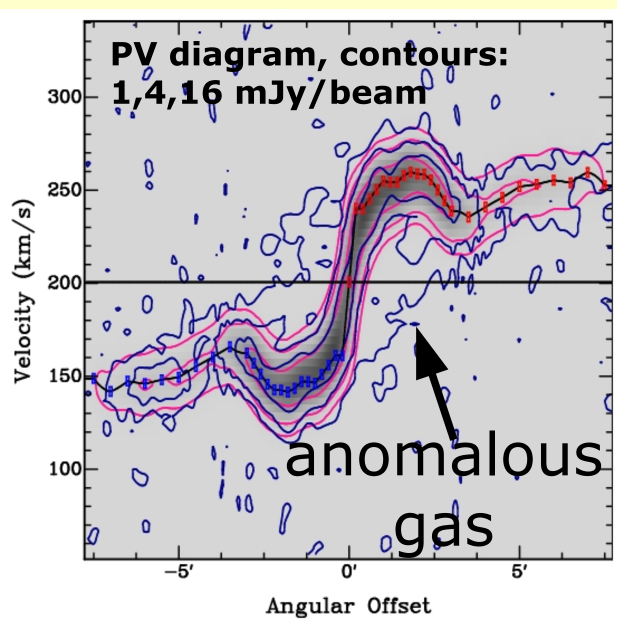
TiRiFiC: practice

Velocity field, contours: $v_{sys}\pm0,15,30,45,60$ km s $^{-1}$



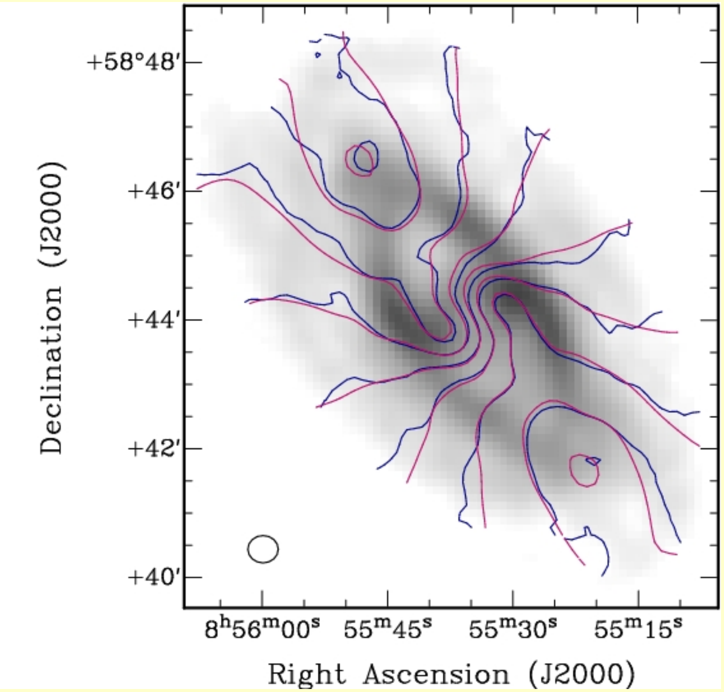
NGC 2685
(Józsa et al. 2009)





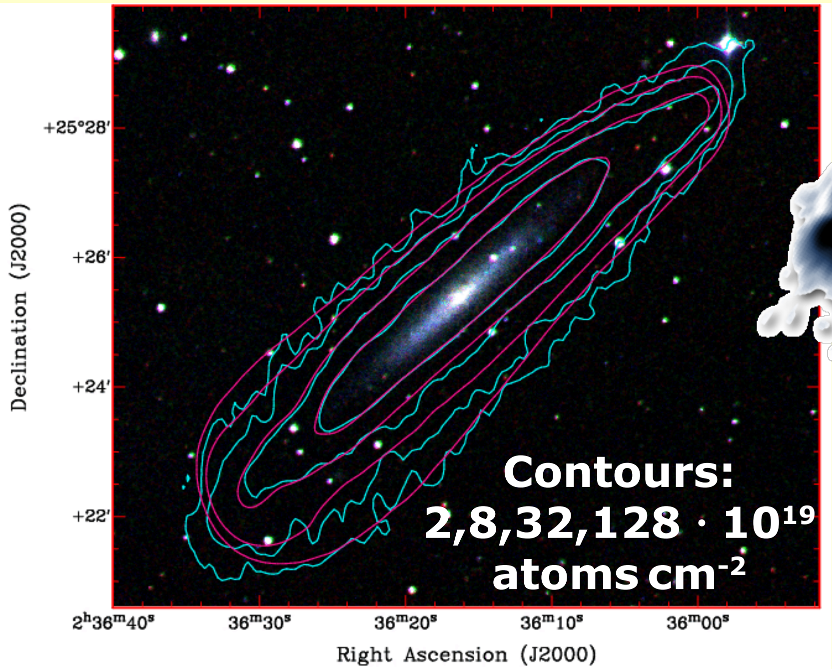
NGC 5204
(Józsa 2007)

pink: model
blue: observation

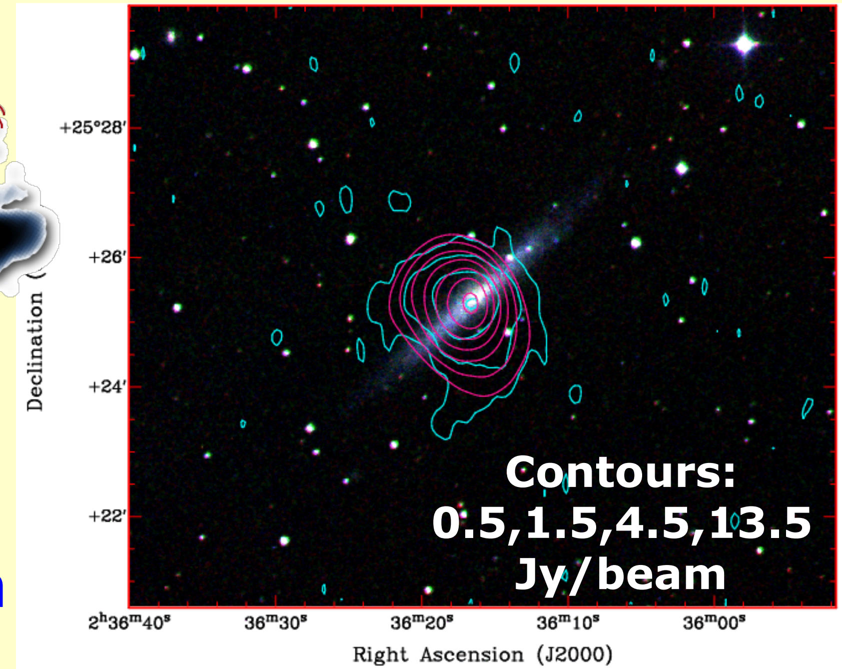


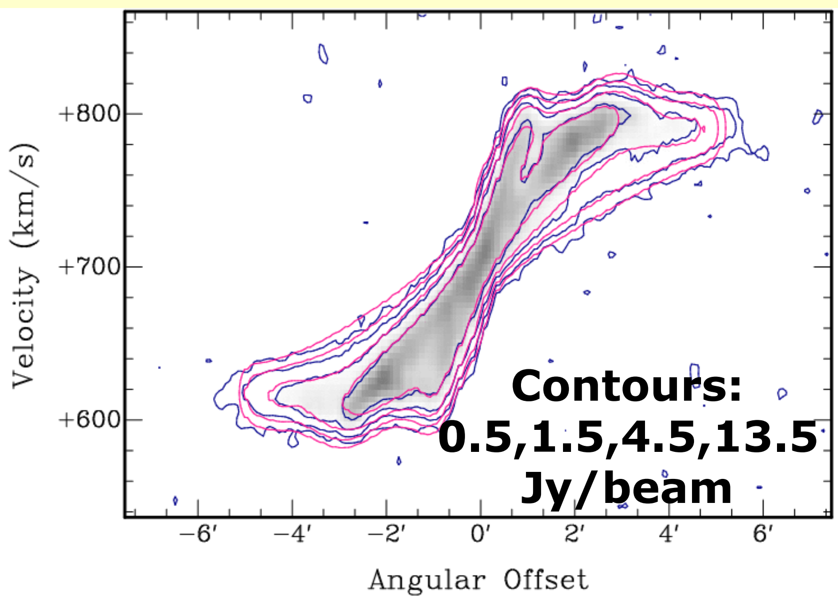
**Velocity field,
contours: $v_{sys}\pm0,15,30,45,60$ km s $^{-1}$**

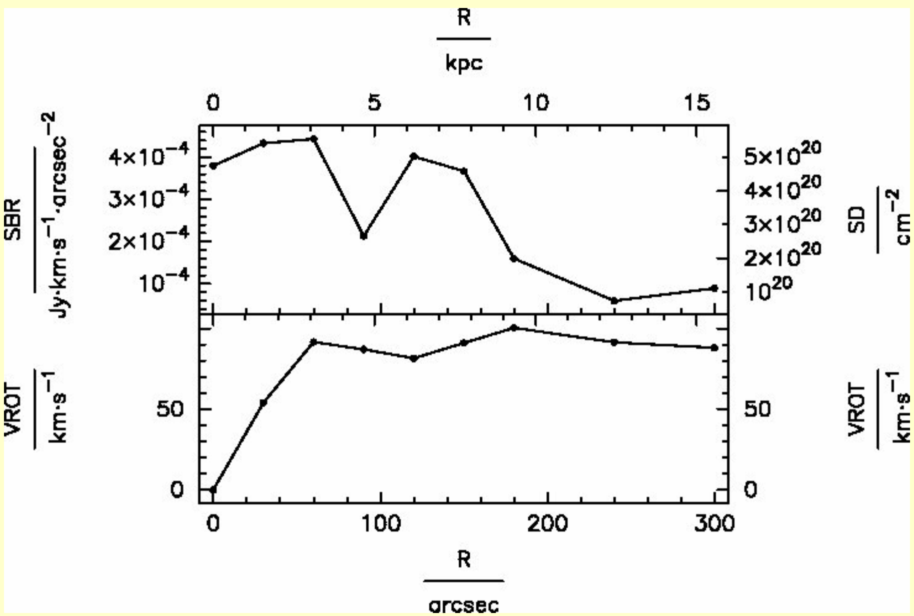
TiRiFiC: practice



UGC 2082
blue: observation
pink: model







Fitting data cubes

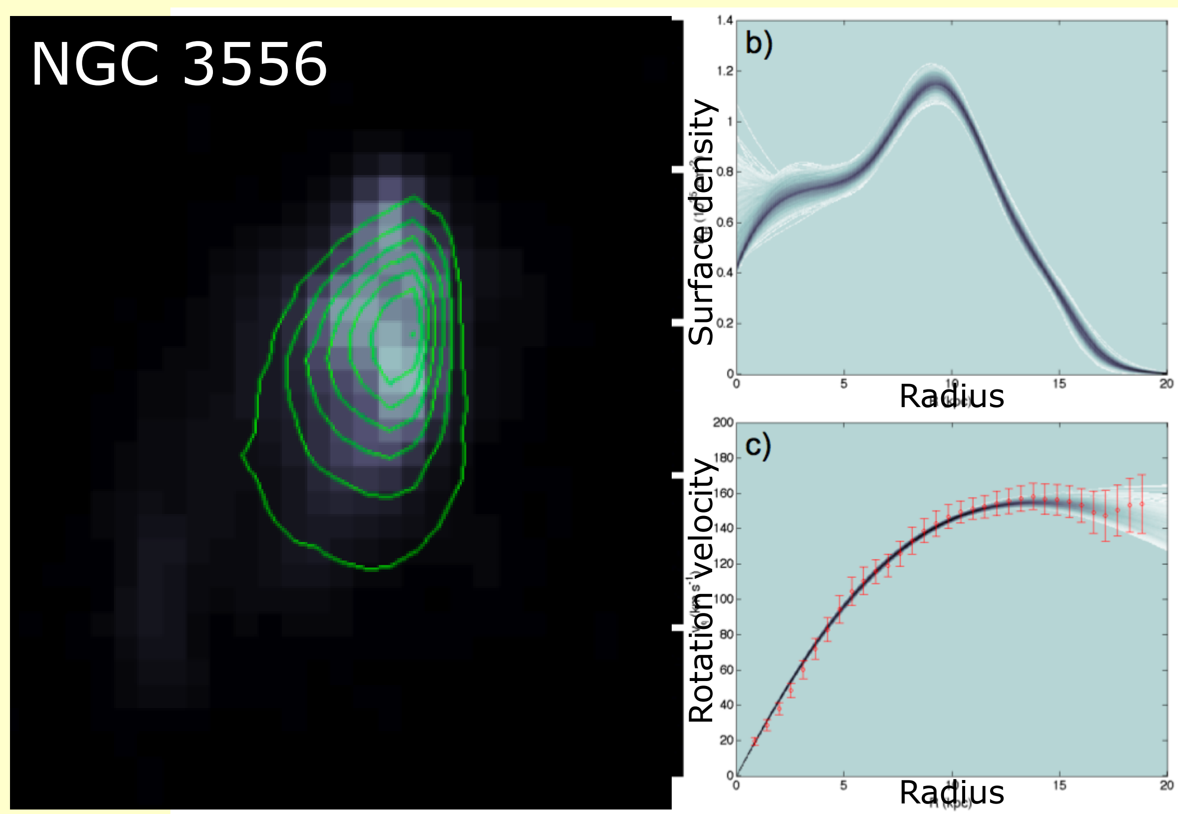
- Successful tests with TiRiFiC
- Fits to a larger class of objects possible (warped, edge-on disks)
- Slow
- Due to inefficient minimising algorithm:
  - Local χ^2-minima in parameter-space make repeated fits necessary
  - Occasionally "bumpy" fit results
- Sensitive to morphological asymmetries

- Future development of TiRiFiC:
  - include asymmetries in velocity and morphology (some implemented)
  - tests of efficient minimisers
  - multiple components
  - full automatisation

GaLAPAGOS

- **Gal**axy **A**strophysical **P**arameter **A**cquisition by **G**enetic **O**ptimization **S**oftware (Fiege, Wiegert, English)
- Parametric fits (currently 23-parameter empirical model)
- Stable genetic fitting algorithm for global minimum search ("Ferret", Fiege et al. 2004)
- Computing-time scales with number of parameters

r_{out}	outer radius
v_0	max rotational velocity
$r_{0,v}$	turnover radius
σ	velocity dispersion
a_v	rotation curve slope parameter
$N_{H,0}$	number density of disk
$D_{r,out}$	width of disk outer edge
H	disk scale height
T_{spin}	spin temperature
i_{warp}	maximum warp inclination
ϕ_{warp}	warp angle offset
$\phi_{twist,max}$	maximum twist angle
k_D	distance multiplier
v_{sys}	systemic velocity
i	inclination
pa	position angle
Δx	model centre offset in x
Δy	model centre offset in y
$a_1 \ldots a_{N_{fit}}$	surface density modulation



Summary

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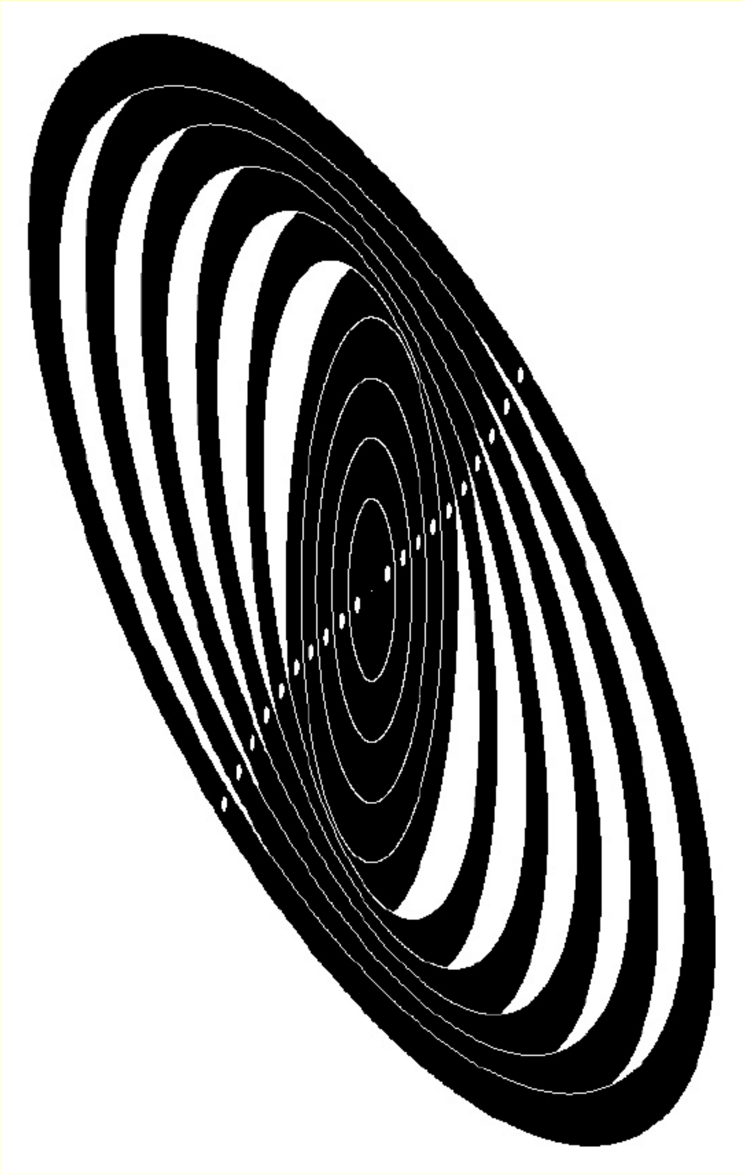
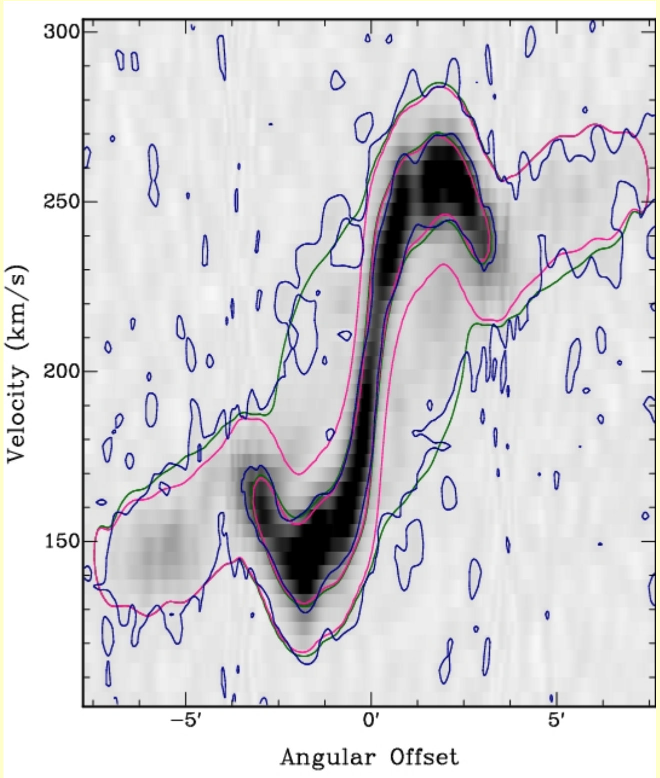
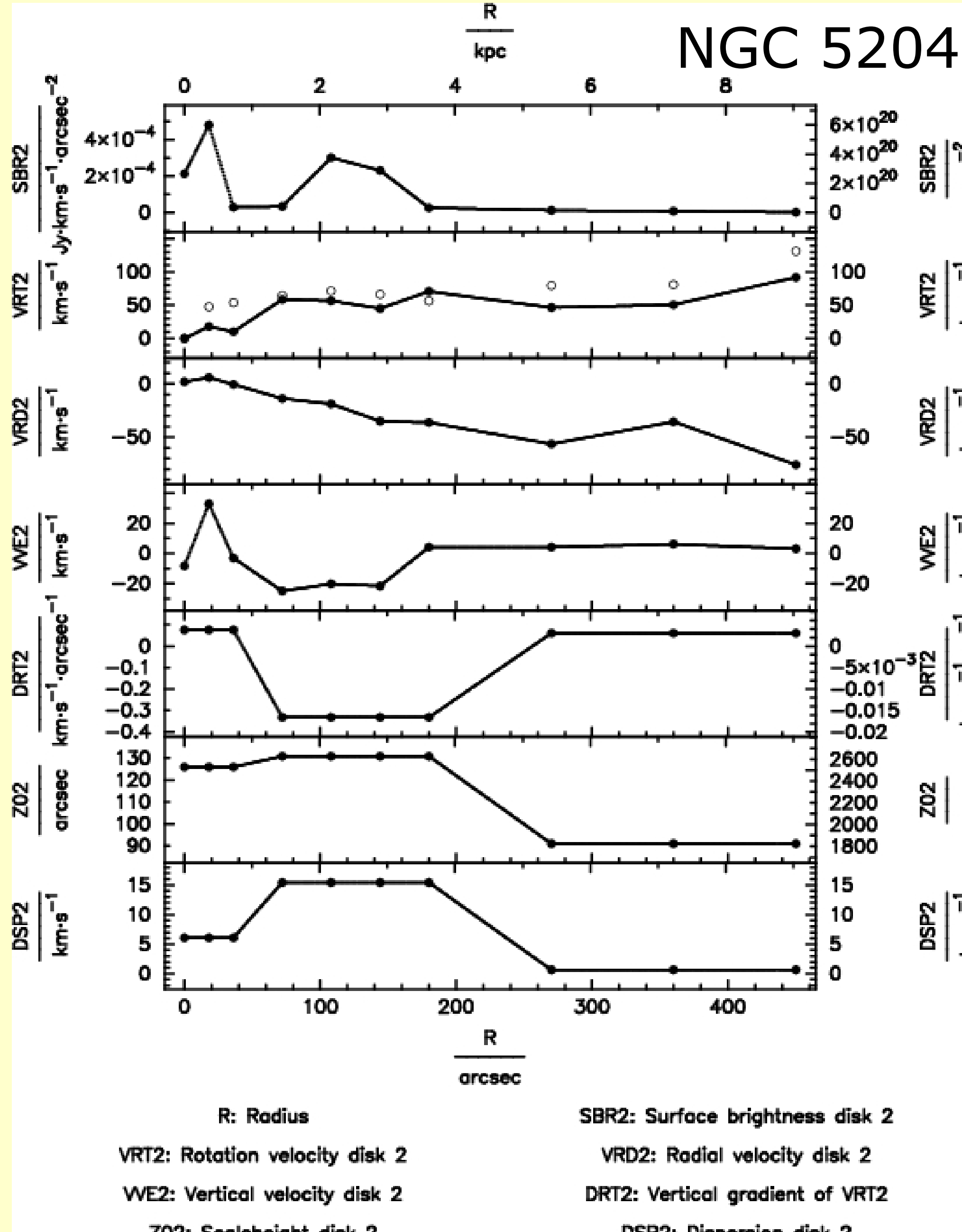
- Automated parametrisations of the kinematics and the morphology of resolved HI disks are desirable to fully exploit upcoming HI surveys
- The tilted-ring model is the most frequently used model and well suited (but may be substituded by models using less parameters for certain applications)
- Analyses of velocity fields work very well for spatially highly resolved disks, but are restricted to a sub-class of objects (inclination, warp geometry)
- Direct fitting of data cubes is highly complex, but it helps to overcome some of the problems when fitting velocity fields and has the best prospect of becoming a universal tool.



Complex models





Neutral gaseous halos cannot be explained by the fountain model (Shapiro & Field 1976) alone (Fraternali & Binney 2006) -> low angular momentum gas from an accretion event?