The very extended rotation curve of NGC 3741

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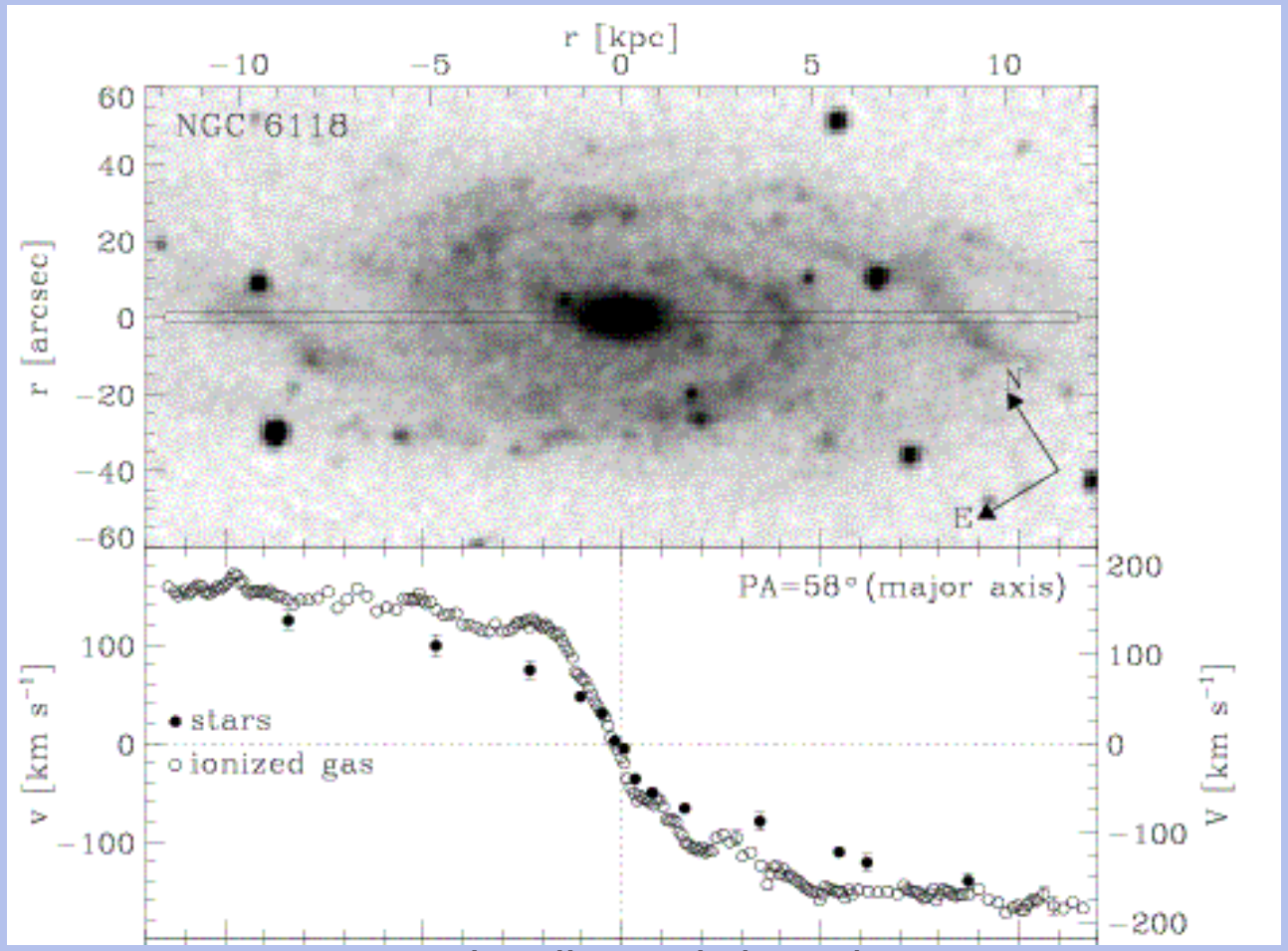
Part 1

Introduction

Part 1: What are rotation curves?



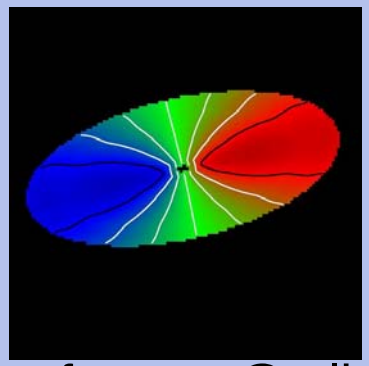
Pizzella et al. (2004)

Rotation velocity of gas and/or stars as a function of radius

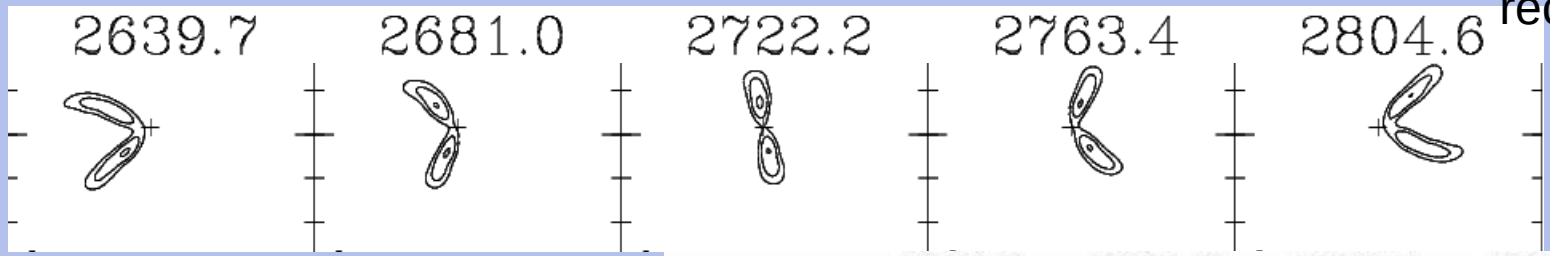
$V_{rot}(r)$: traced via different lines: Hα, HI, CO, …

Part 1: rotation curves from HI data

Rotating disk:



Data cube (series of maps @ slightly different freq.) should look like this:

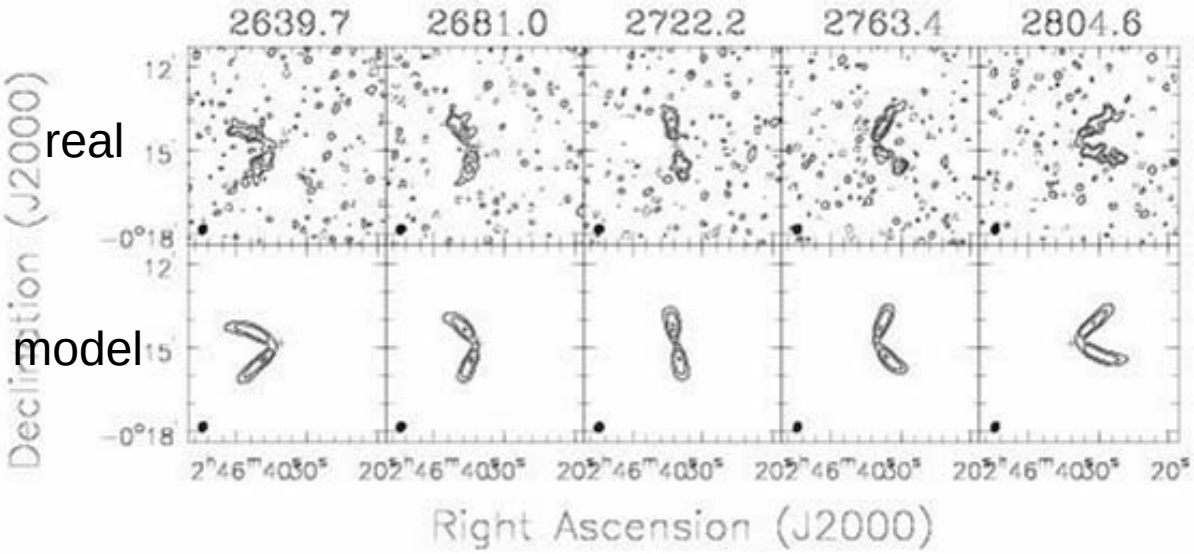


receding velocity (km/s)

What about real observations?

real

model

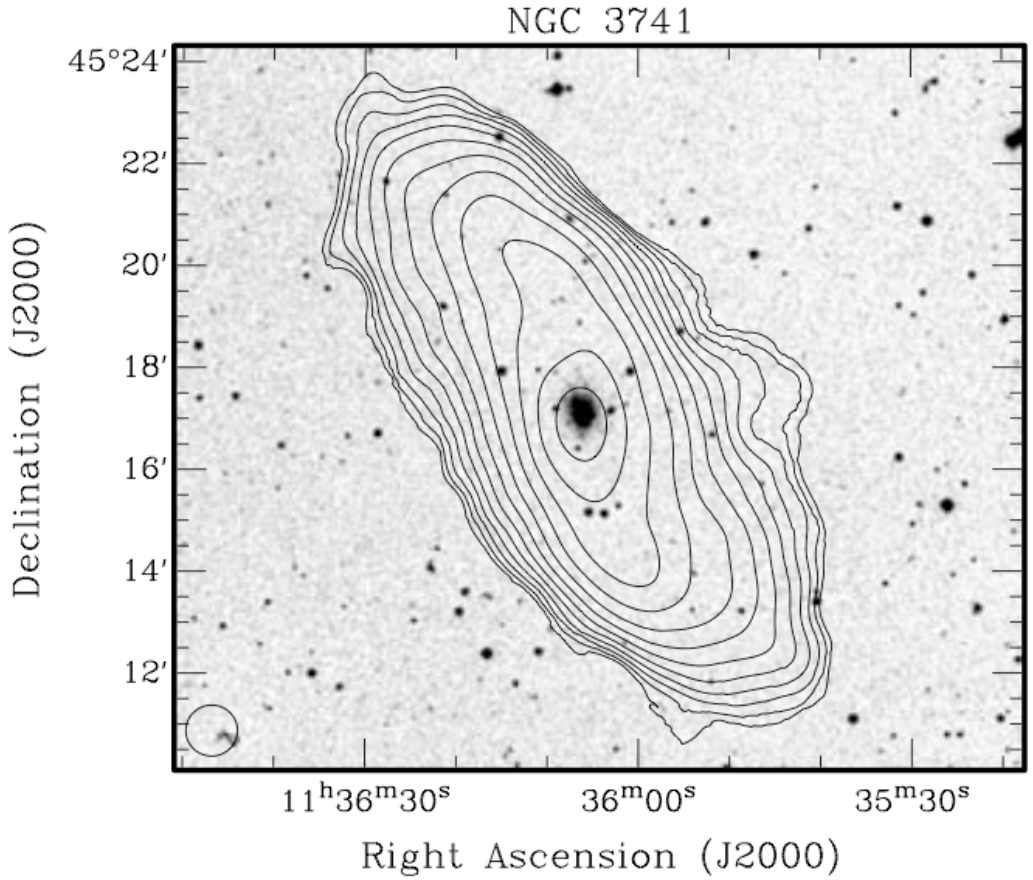


Part 2

NGC 3741:
The most extended rotation curve ever

Part 2: NGC 3741

(Gentile, Salucci, Klein, Granato, 2007, MNRAS, 375, 199)



greyscale: optical

contours: total HI (neutral hydrogen)

2 x 12h WSRT observations

NGC 3741: dwarf irregular galaxy

HI disk extends out to 42 exponential scale lengths (largest ever!)

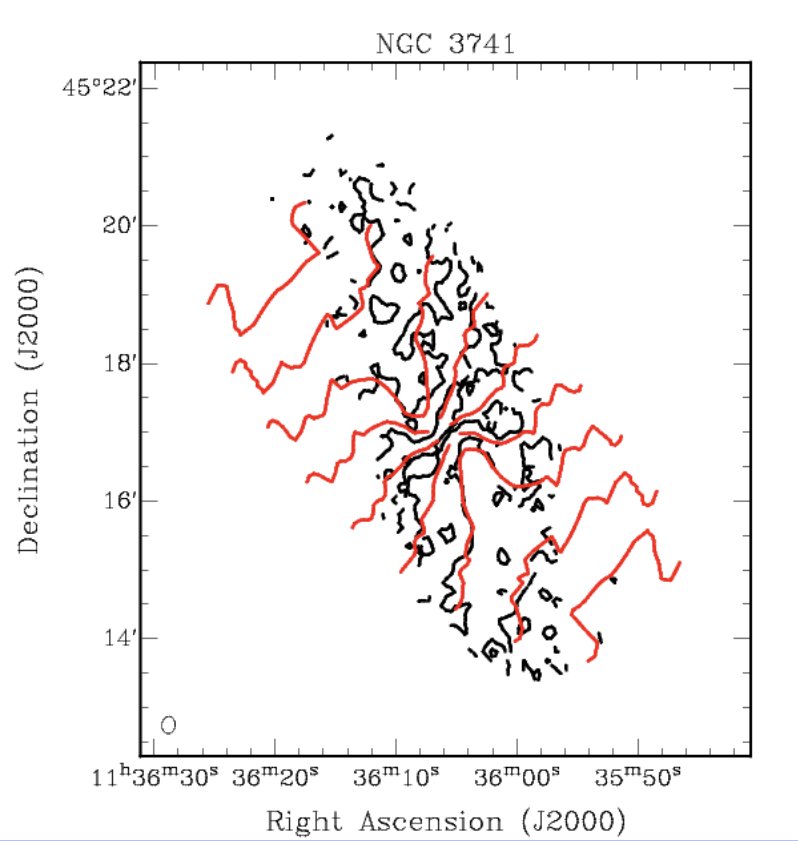
Very regular/symmetric distribution and kinematics

Part 2: NGC 3741: kinematics

- First attempt to understand the kinematics:
  tilted-ring fit on the velocity field:

red: model

black: obs



velocity field

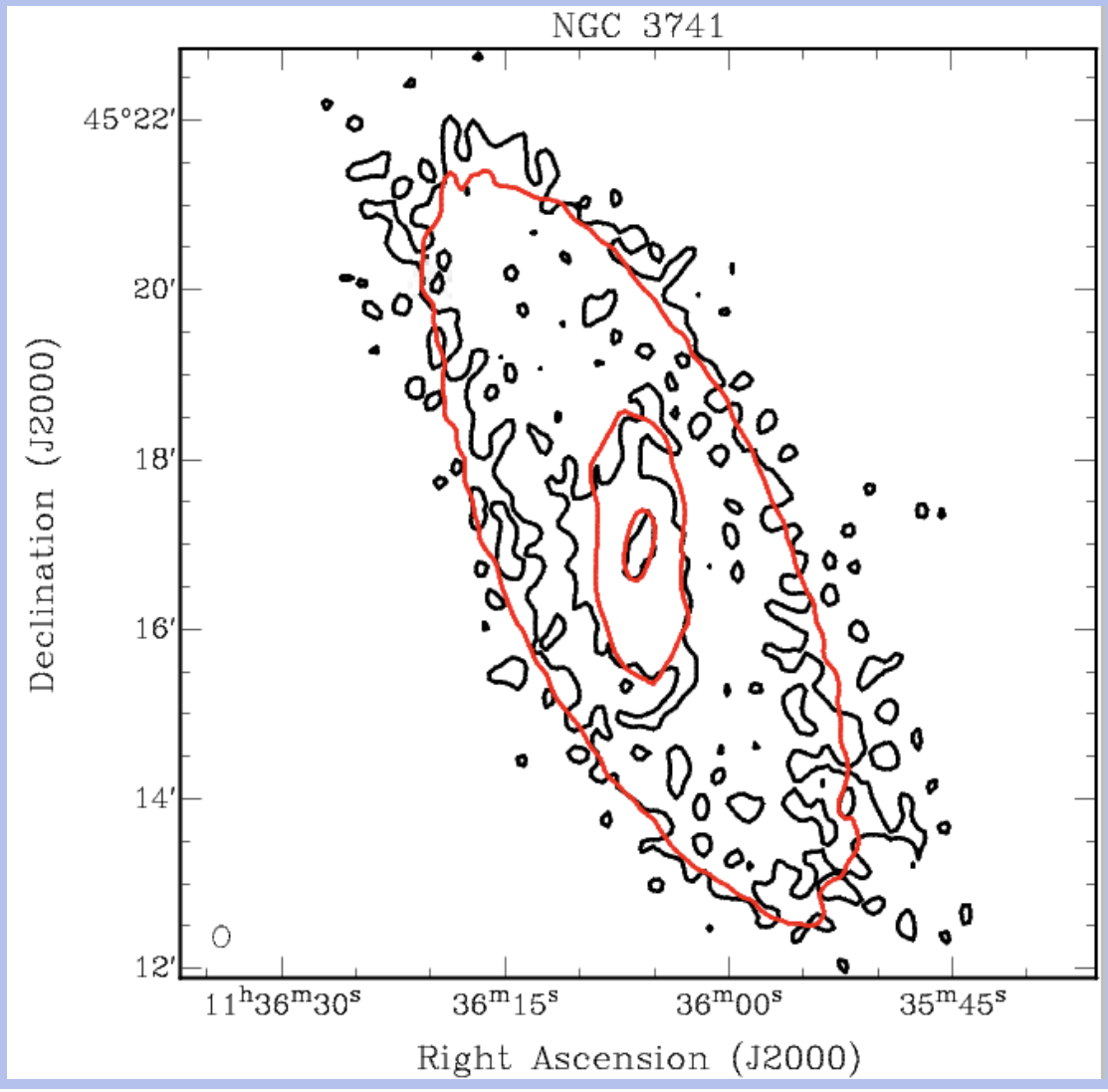
Kinematical and morphological orientations are different!

Part 2: NGC 3741: kinematics

- First we fixed geometrical parameters to match total HI:

red: model

black: obs



Part 2: Non-circular motions

- Then, to determine kinematical parameters: harmonic decomposition of the velocity field

  (Schoenmakers et al. 1997, Wong, Blitz and Bosma 2004, Gentile et al. 2005)

$$V_{los} = c_0 + \sum_{j=1}^{n} [c_j \cos(j\psi) + s_j \sin(j\psi)]$$

where ψ=azimuthal angle and $c_0=v_{sys}$

n=1 → tilted ring model

→ Look at $c_j(r)$ and $s_j(r)$ terms up to j=3

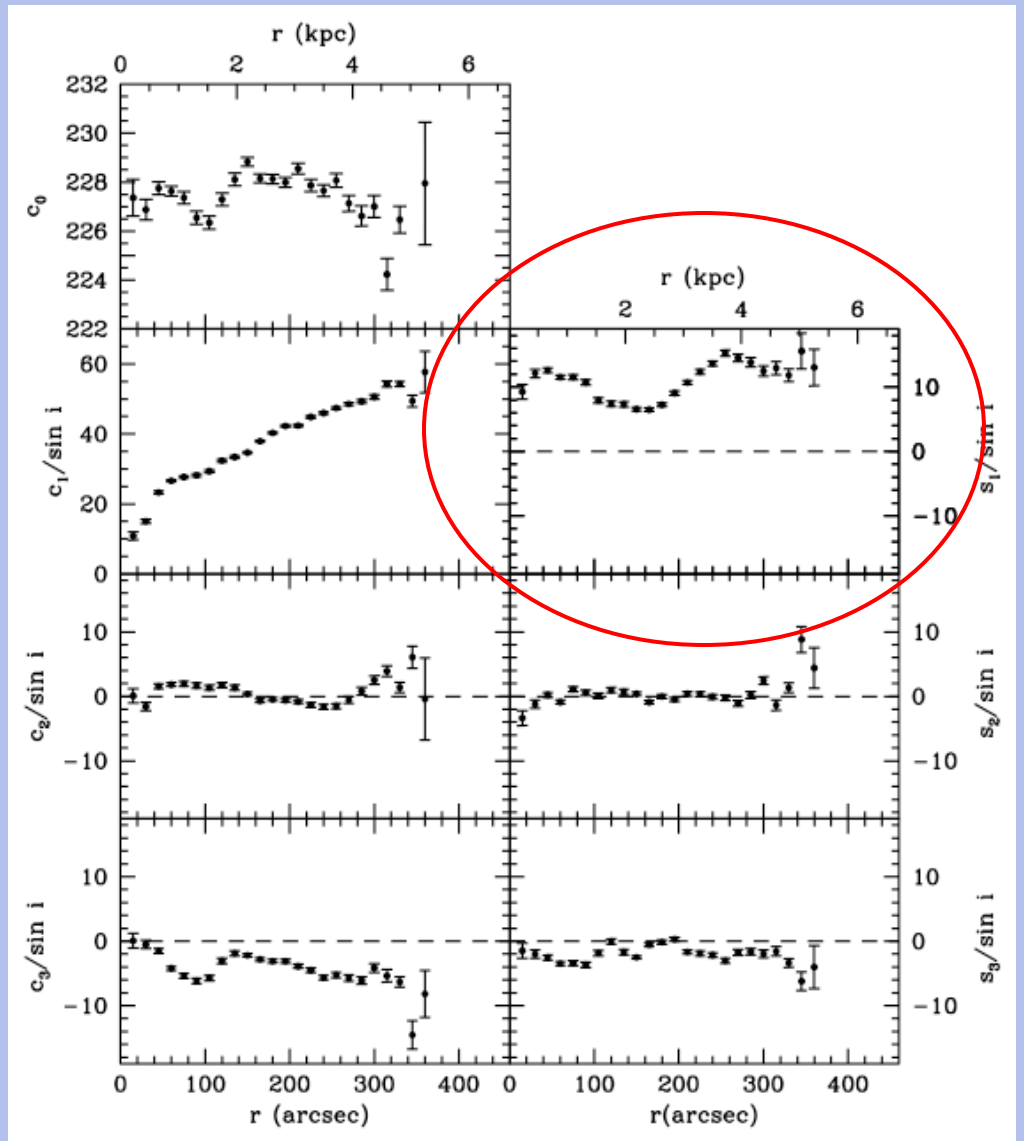
Part 2: NGC 3741: kinematics

c_0

$c_1/\sin i$

$c_2/\sin i$

$c_3/\sin i$



$s_1/\sin i$

$s_2/\sin i$

$s_3/\sin i$

Part 2: NGC 3741: kinematics

- Then we built model data cubes, based on physical and geometrical parameters:

  centre, $V_{rot}(r)$,$V_{rad}(r)$, incl(r), PA(r), etc.

some are refined iteratively.

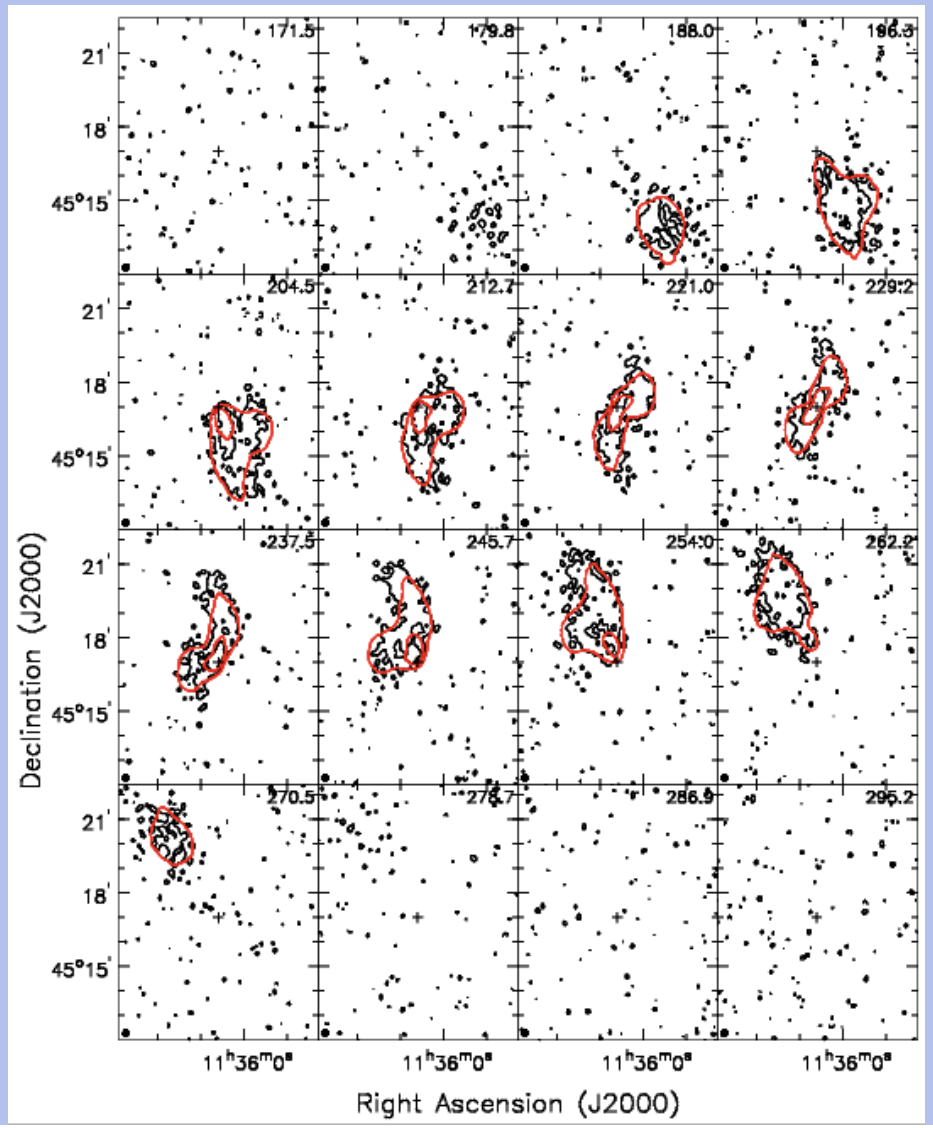
Automatic fitting: work in progress by our group (Józsa et al. 2007)

Part 2: NGC 3741: kinematics

- Very good match of observed and model data cubes:

red: model

black: obs

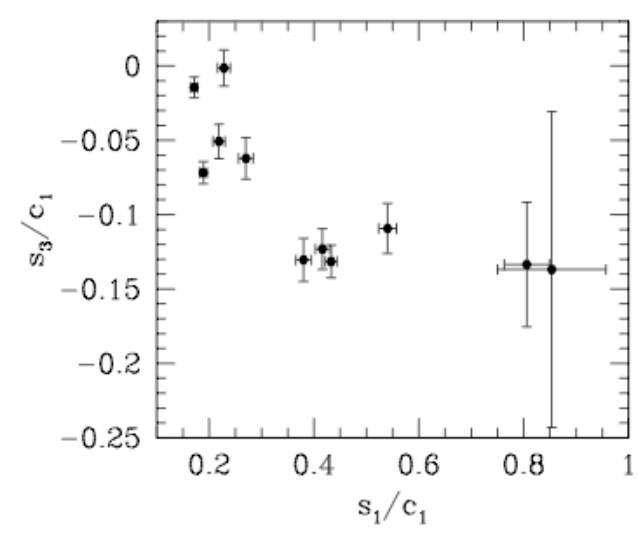


Part 2: NGC 3741: kinematics

- How do we interpret these non-circular motions?

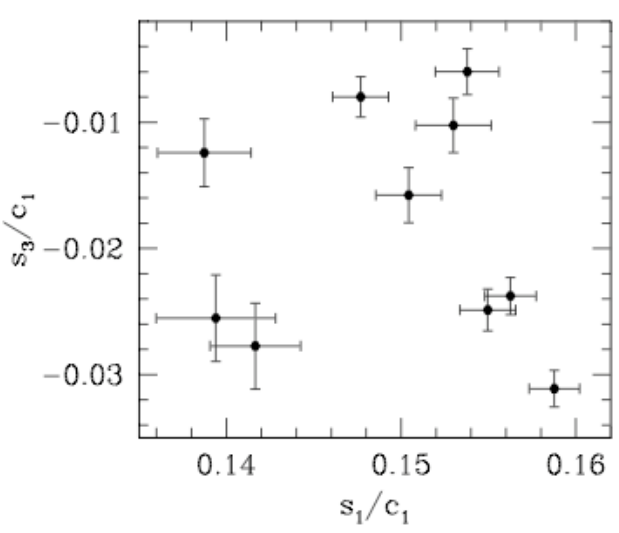
  s_3 vs. s_1 from harmonic decomposition:

inner parts



~anti-correlation

outer parts



no anti-correl.

Speculation: inner bar and outer ongoing accretion?

Part 2: NGC 3741: mass models

- Burkert halo (central constant density core)

- NFW halo (“cuspy”, ΛCDM prediction) using c-M_{vir} relation

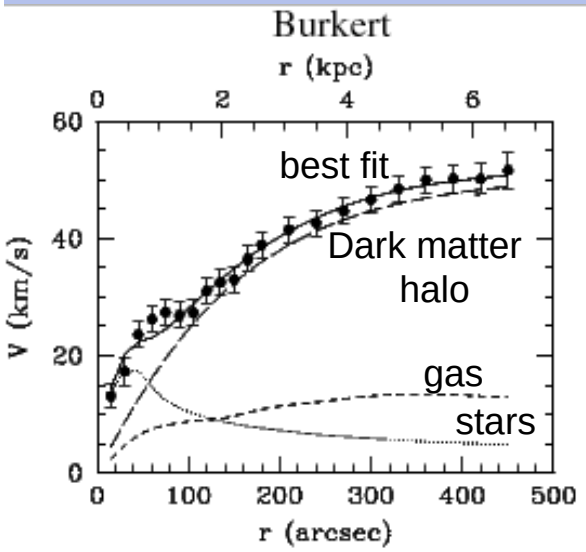
- NFW halo with c and M_{vir} independent parameters

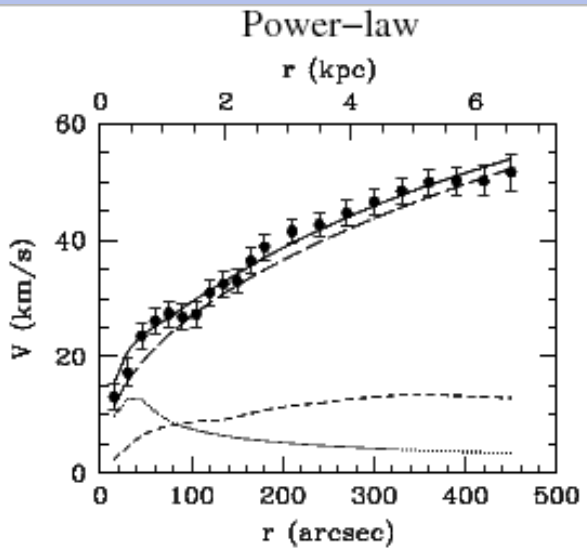
- Power law ($\rho \sim r^{-\alpha}$): ~ average slope over observed radial range

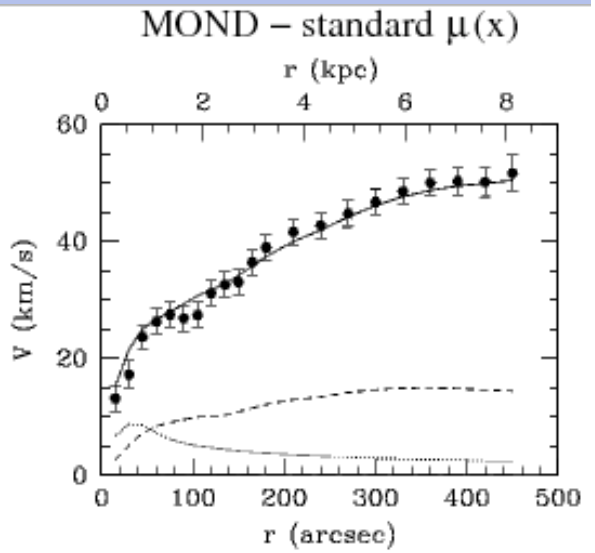
- MOND (Modified Newtonian Dynamics)
  with ”standard" interpolation function $\mu(g/a_0)$

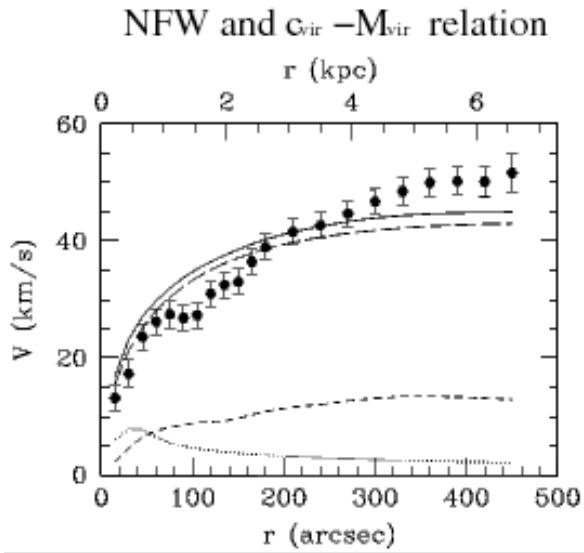
- MOND with new $\mu(g/a_0)$ by Famaey & Binney (2005)

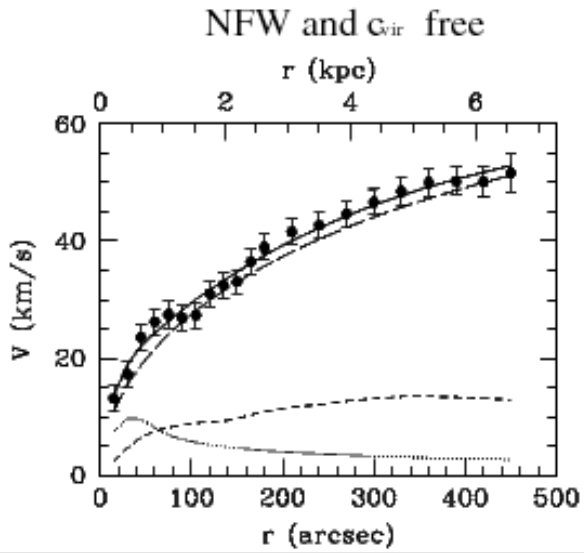
Part 2: NGC 3741: mass models

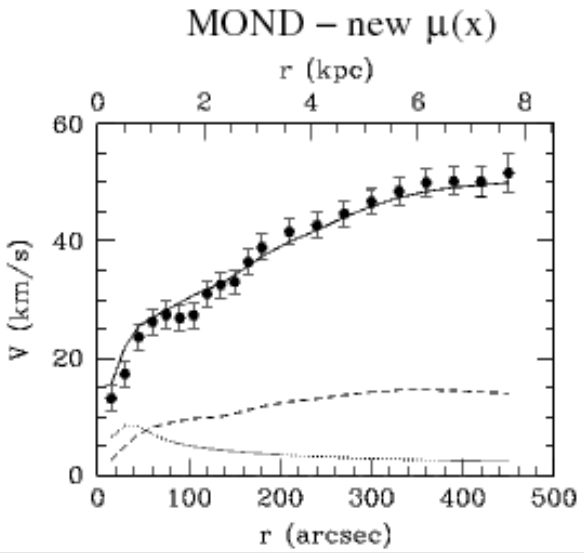




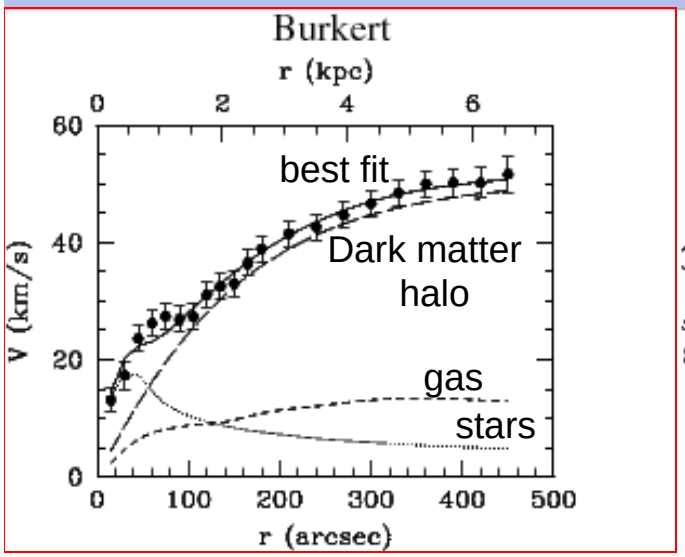


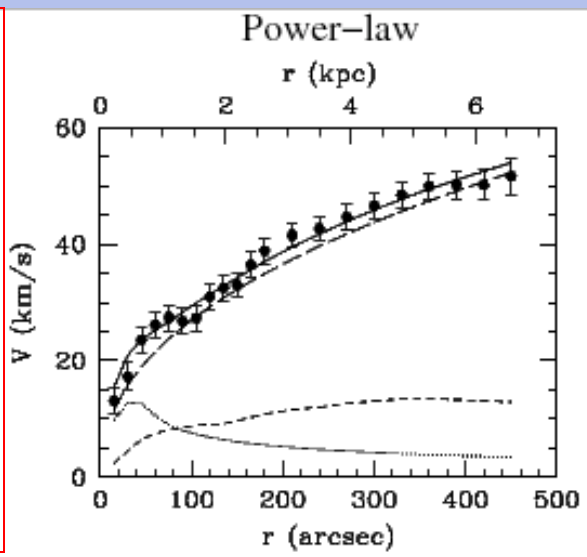


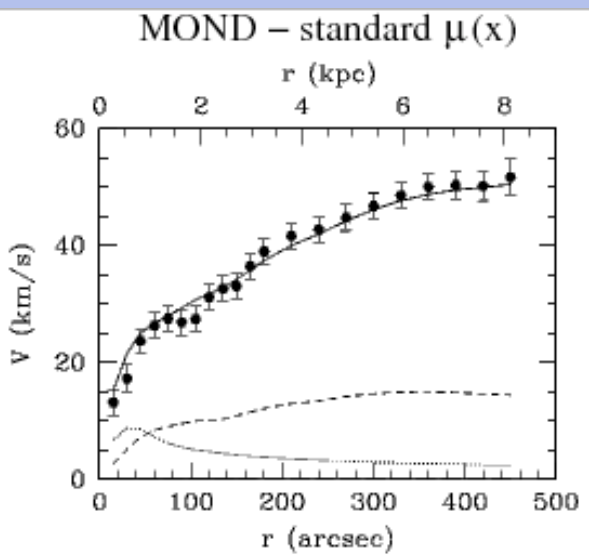


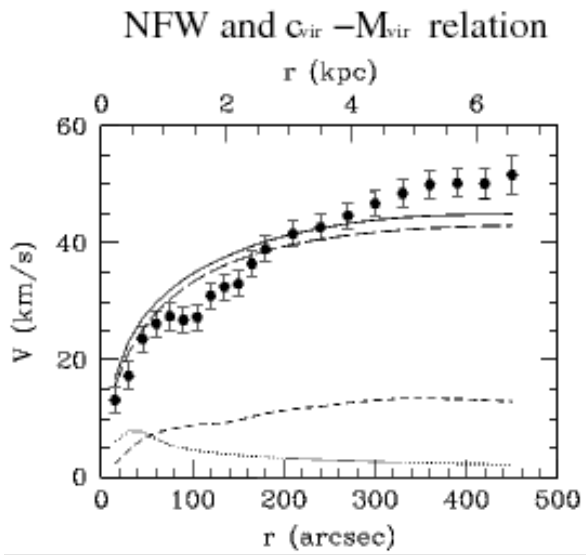


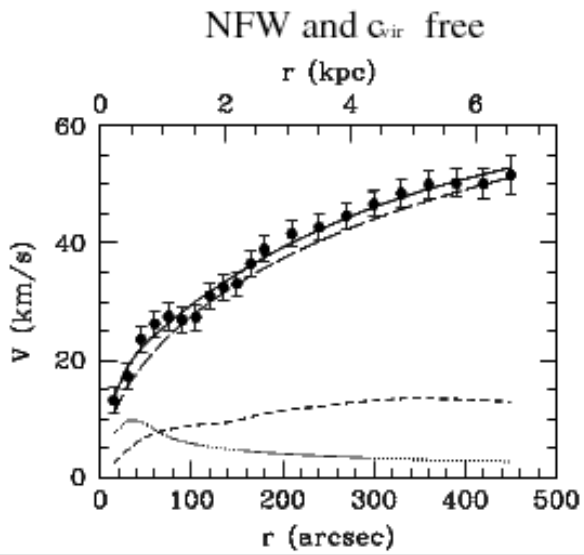
Part 2: NGC 3741: mass models

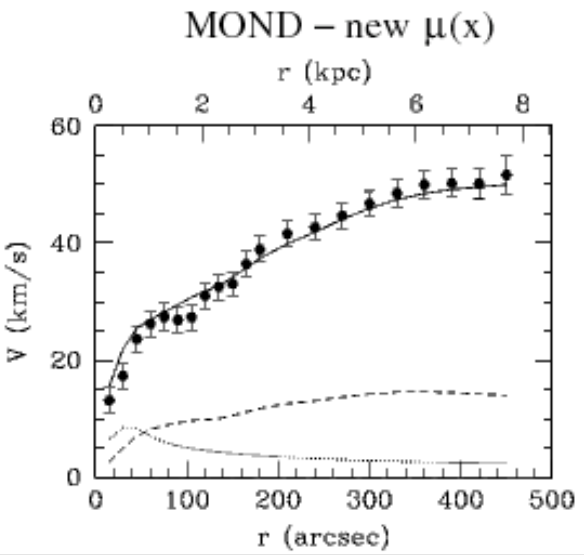






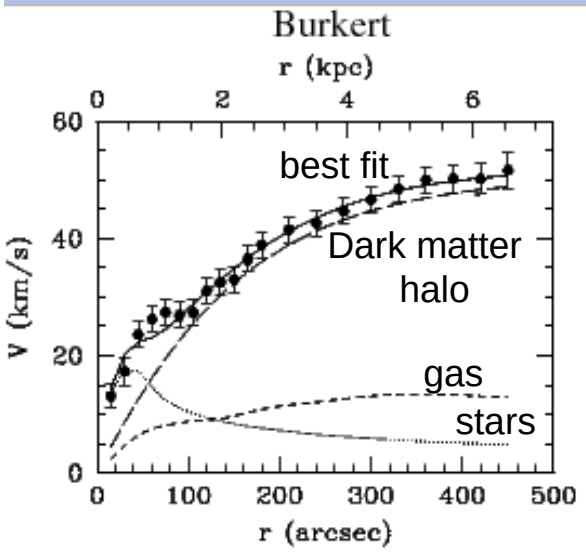


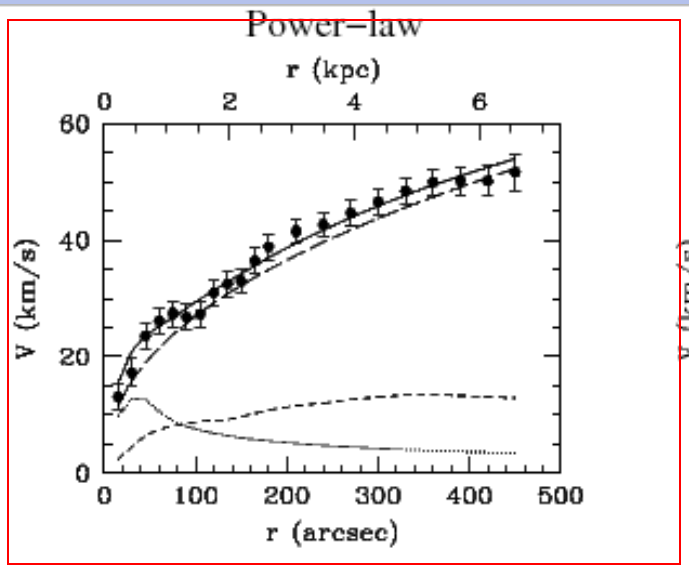


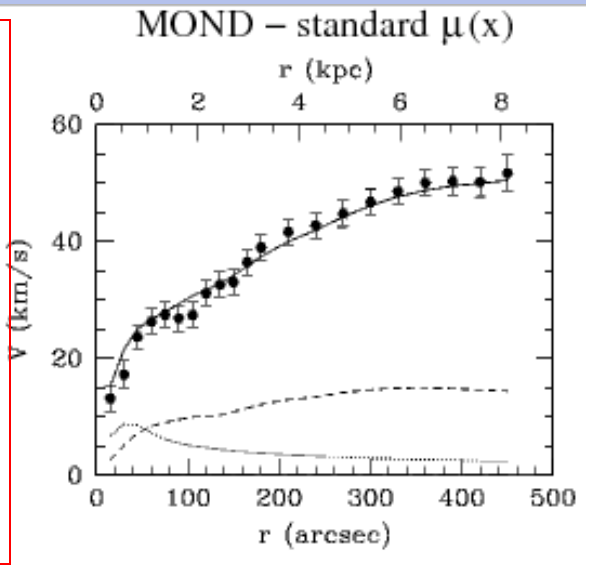


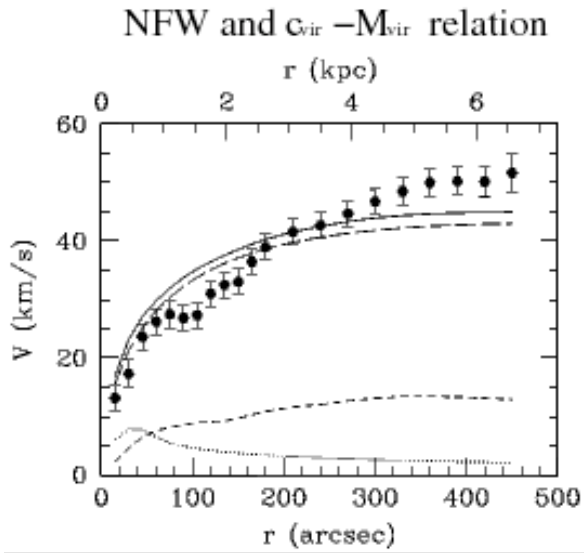
Dark matter halo with core fits well

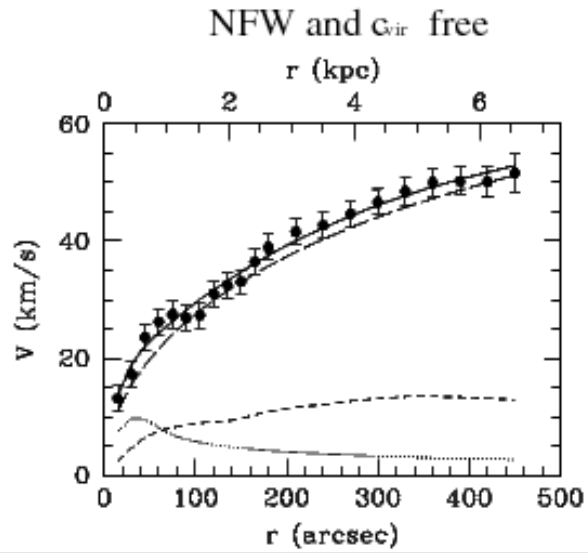
Part 2: NGC 3741: mass models

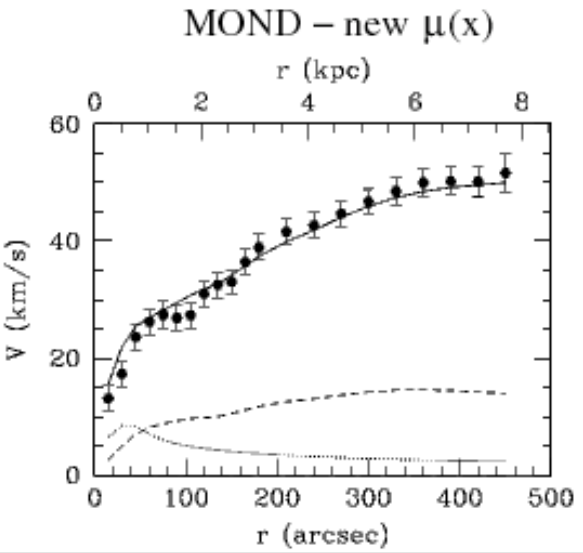






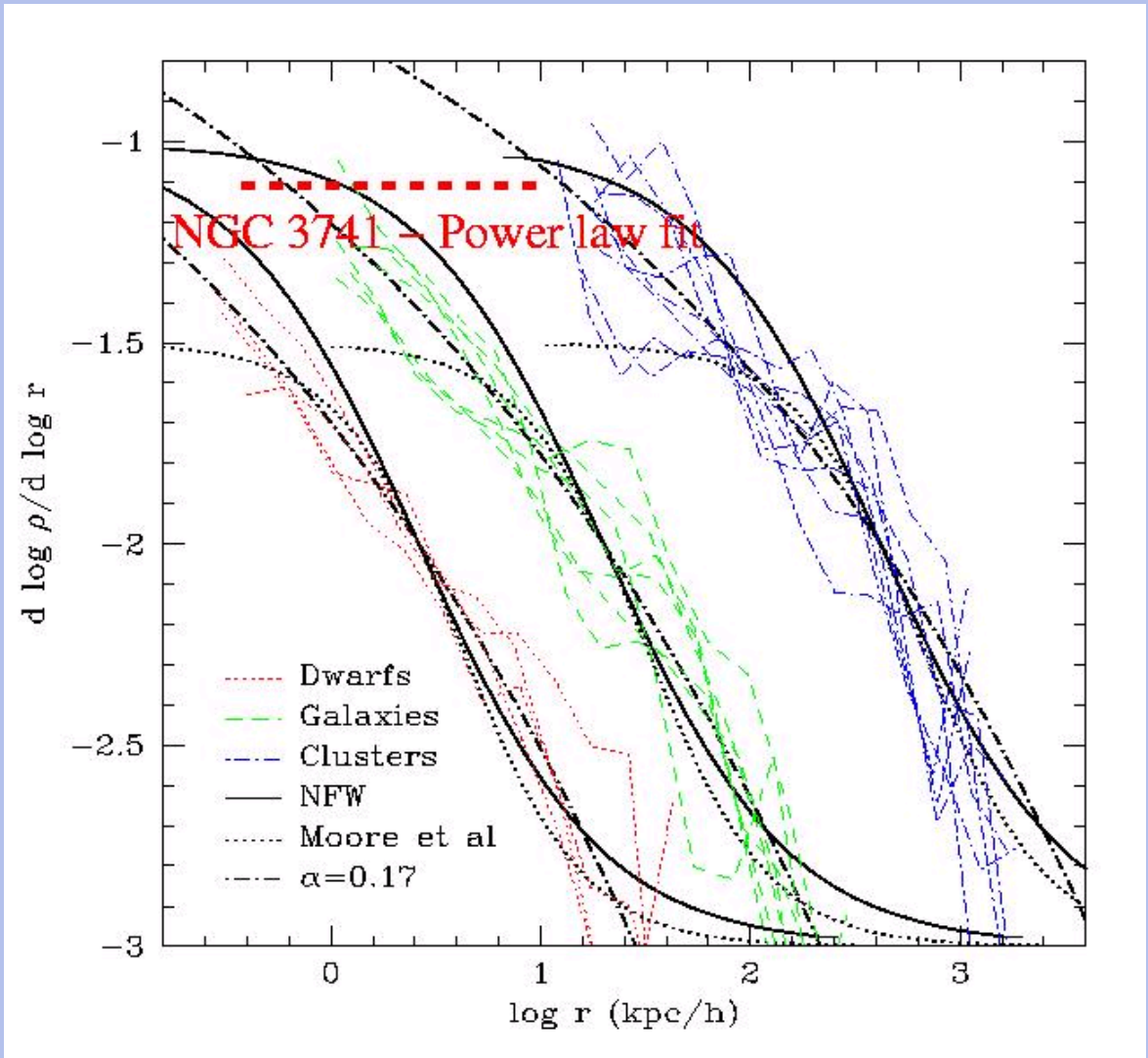






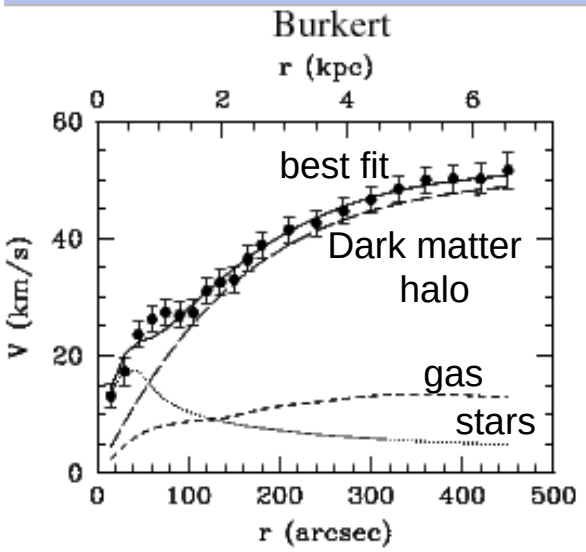
Power-law: $\rho \sim r^{-\alpha}$: $\alpha = 1.1 \pm 0.1 \rightarrow$ Inconsistent with ΛCDM

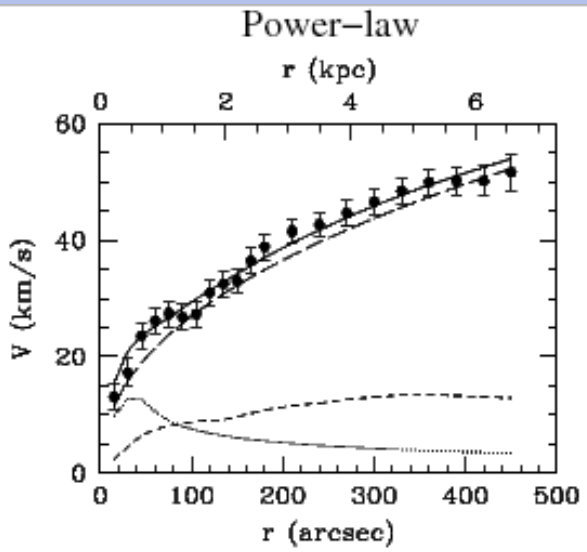
Part 2: NGC 3741: mass models

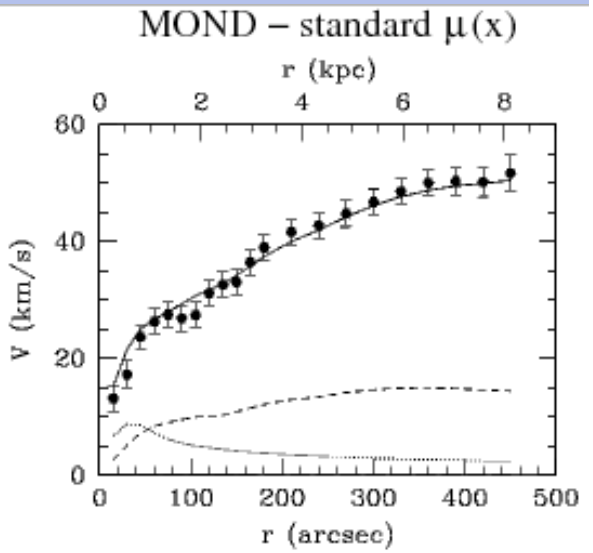


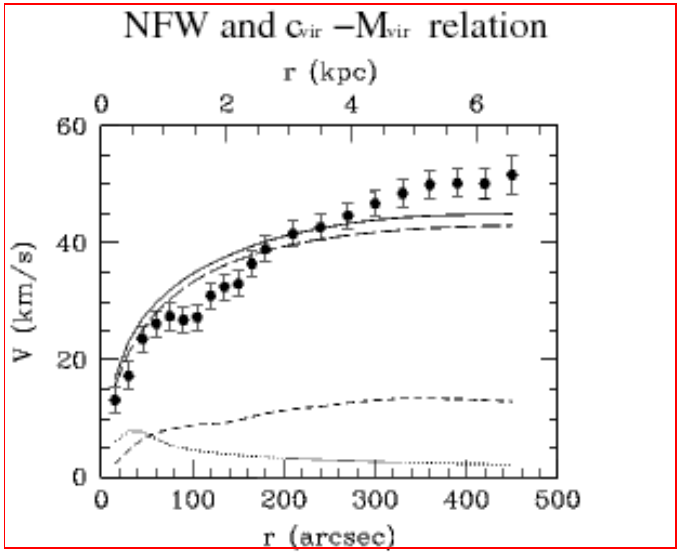
Navarro et al. (2004)

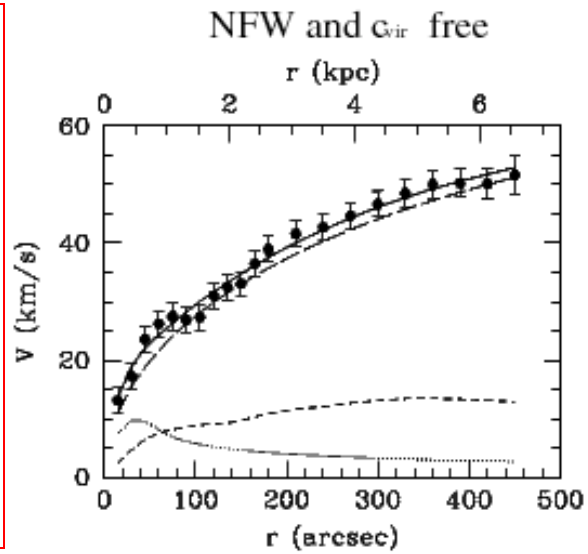
Part 2: NGC 3741: mass models

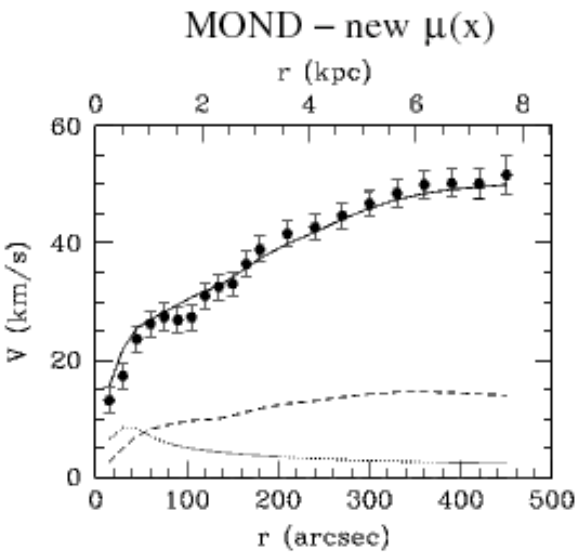






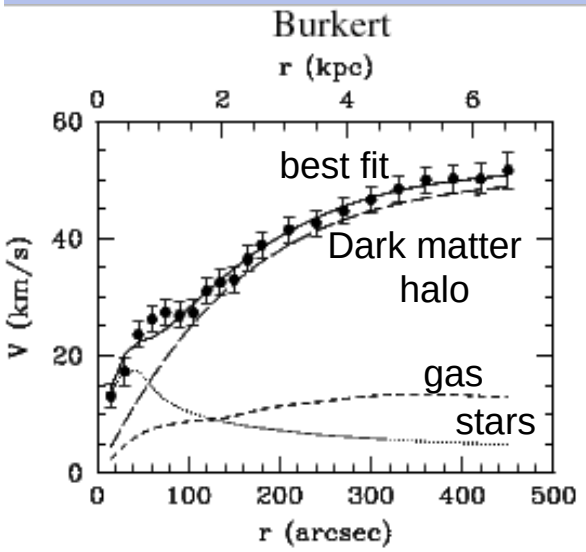


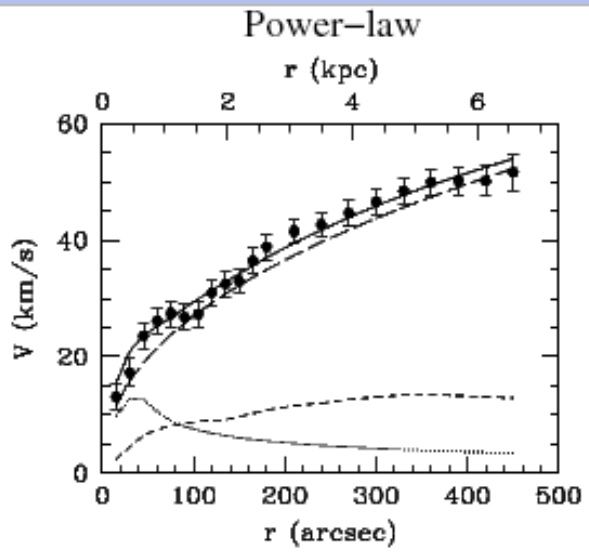


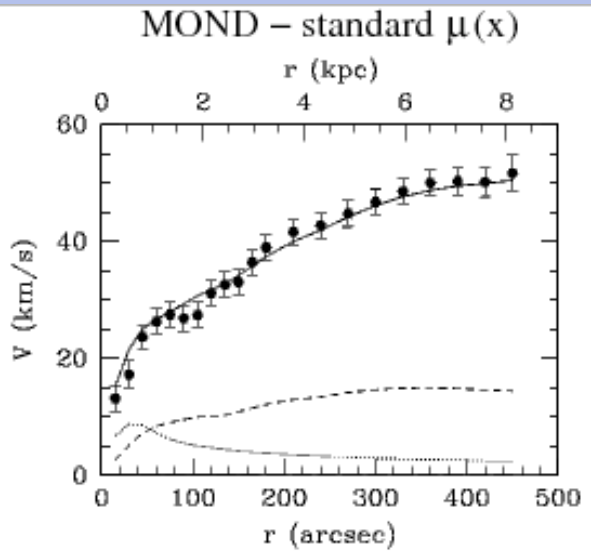


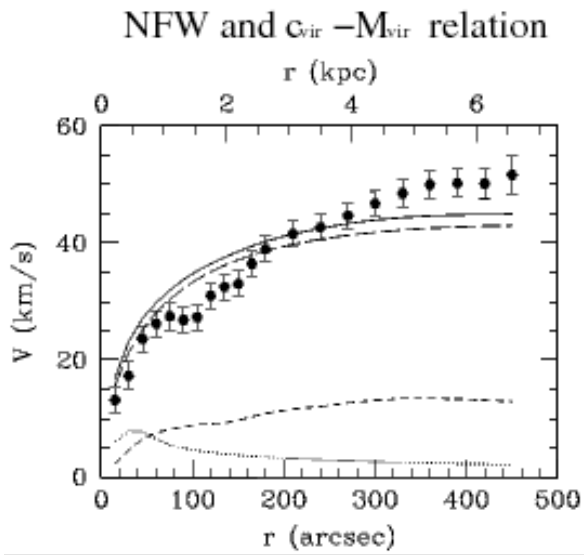
NFW using c_{vir}-M_{vir} relation fits badly

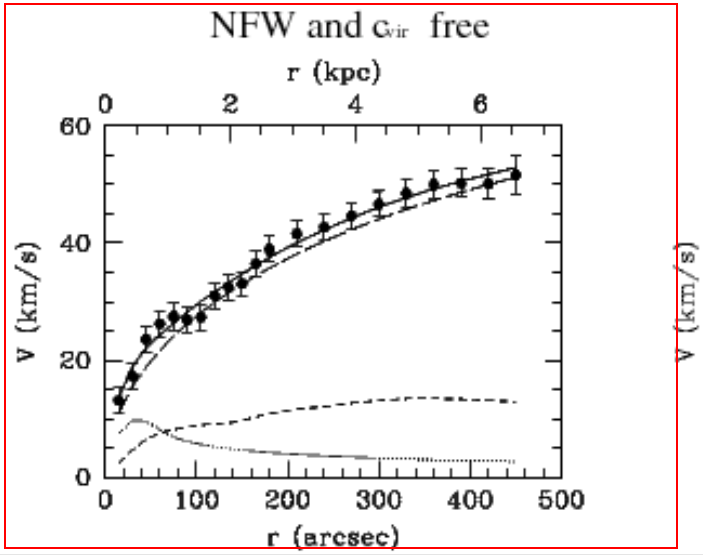
Part 2: NGC 3741: mass models

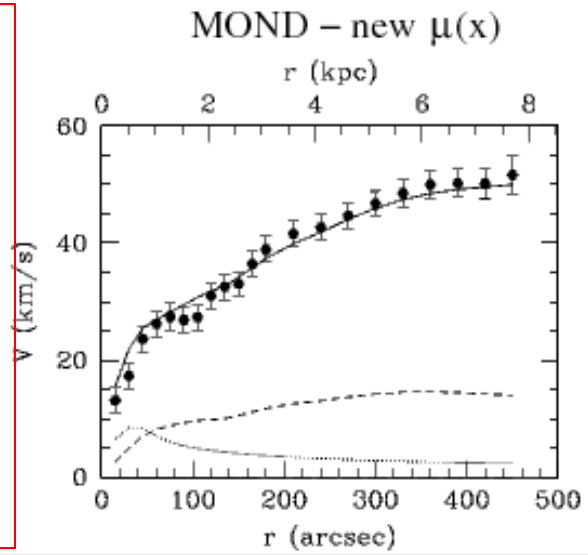






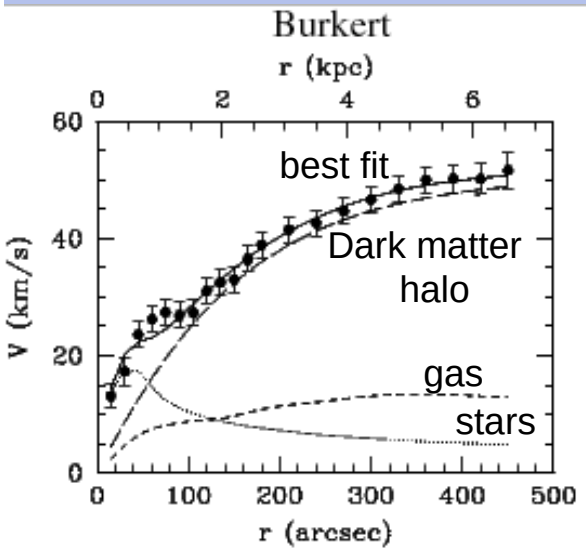


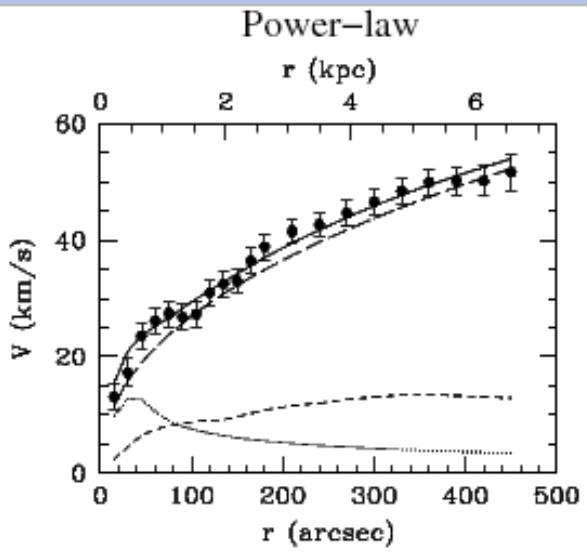


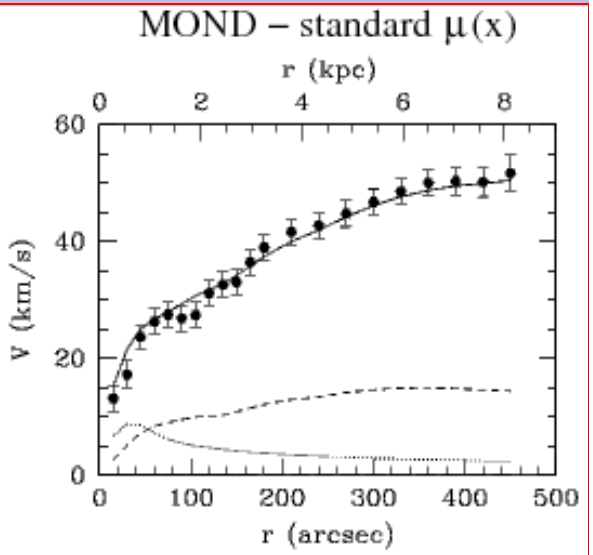


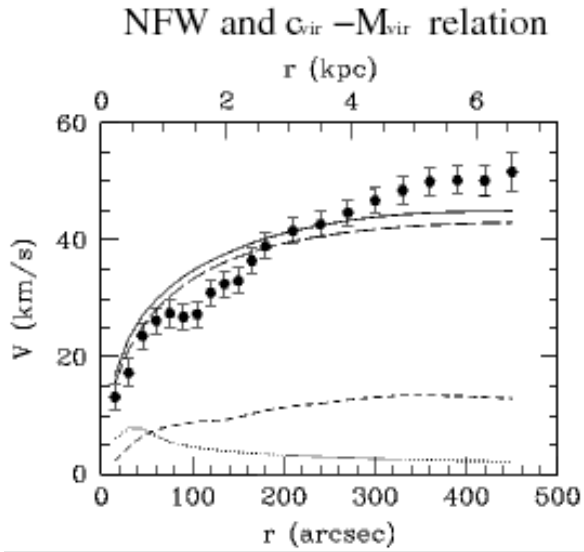
$M_{vir}=10^{11}\ M_{sol}$, c_{vir} at 2.5σ from predicted c-M_{vir} relation

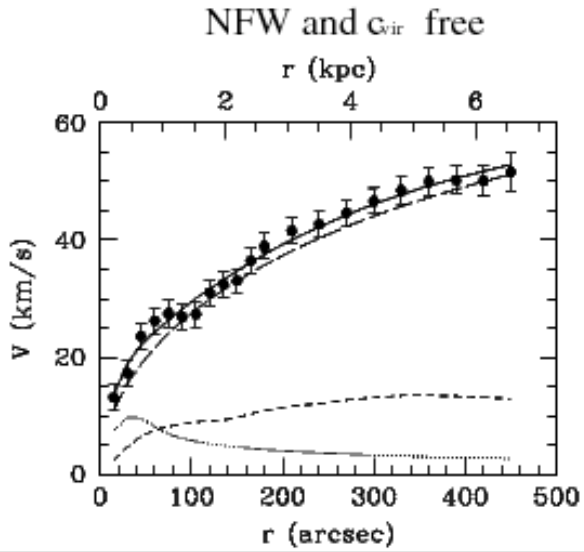
Part 2: NGC 3741: mass models

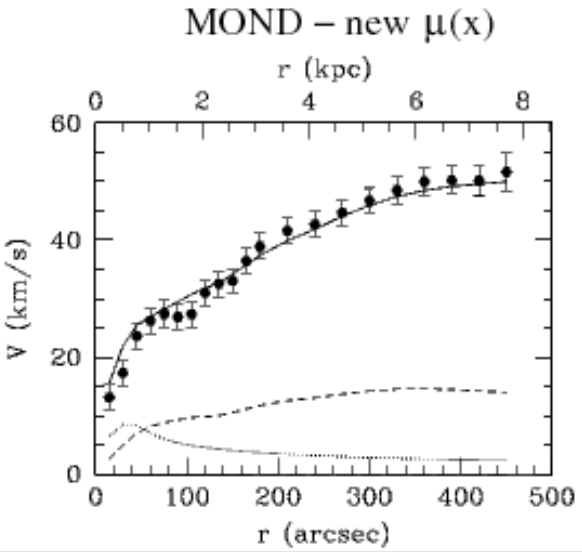












Both MOND fits are very good

Part 3

Ongoing work

Gas-rich dwarf galaxies

Sample selection: $M_{HI} / L_B > 2.0$

+ other criteria to have good data

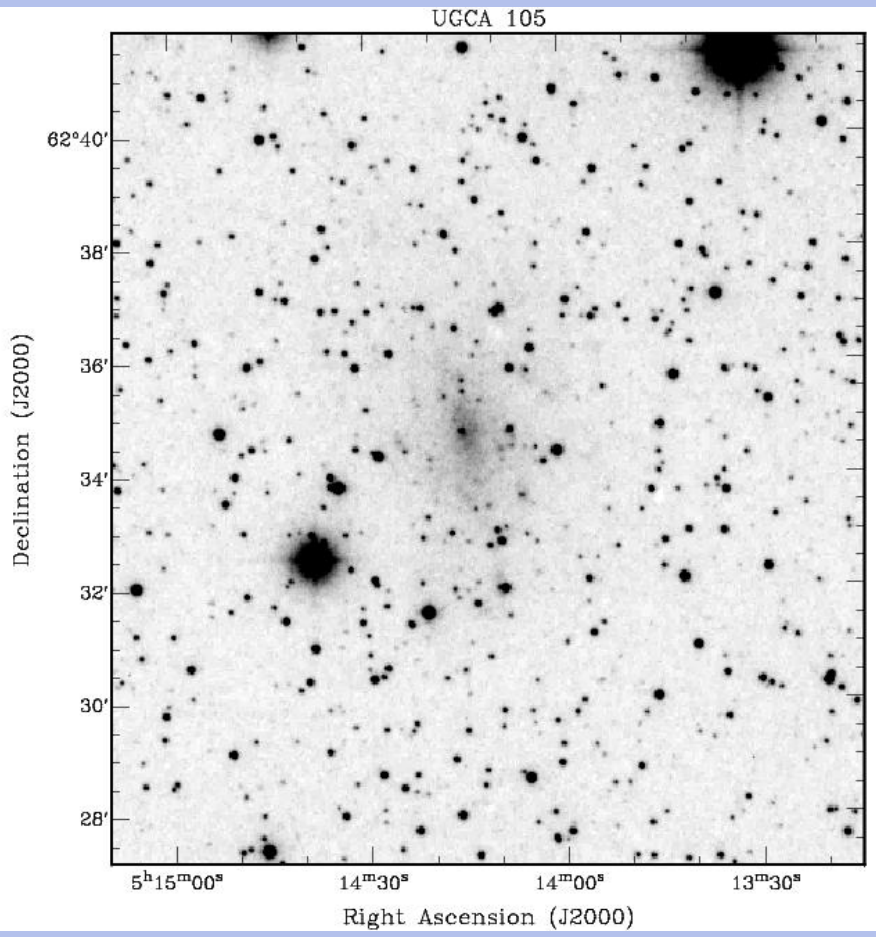
(distance, HI flux, dec, inclination, etc.)

Accepted HI proposals:

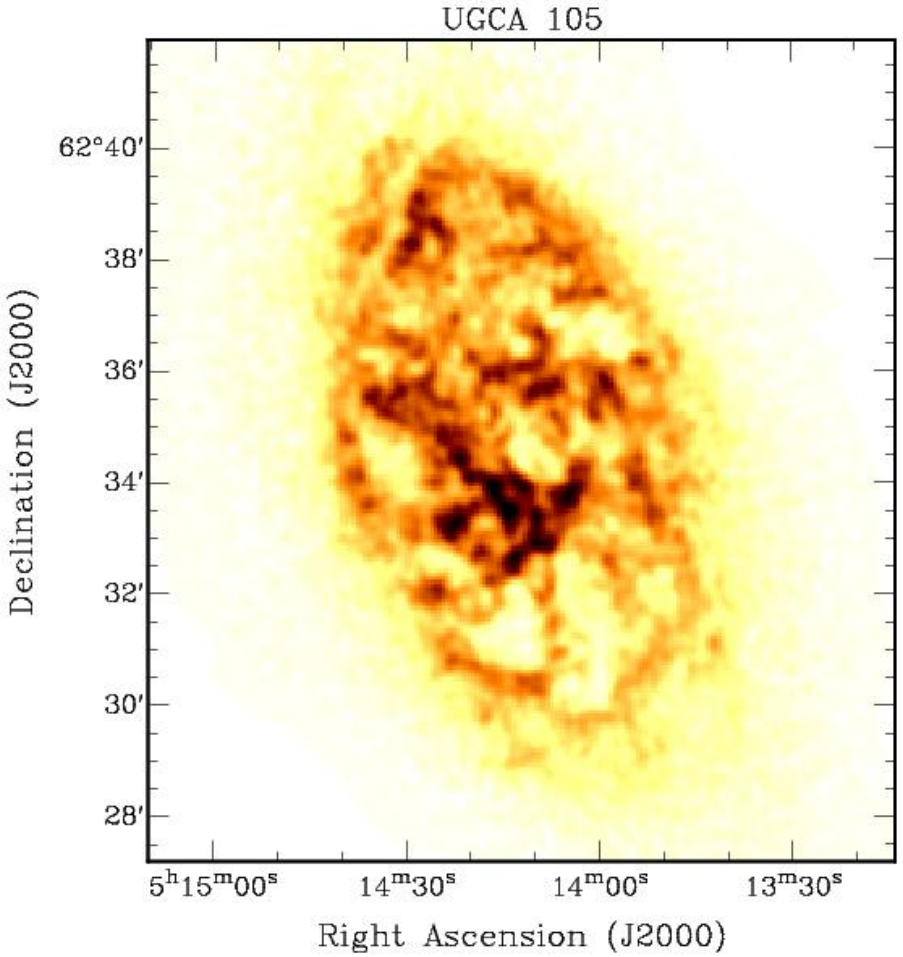
WSRT: 4 galaxies, each 2 x 12 h - observed in the last few months

VLA: 2 galaxies, 8 h each - observed in March

UGCA 105



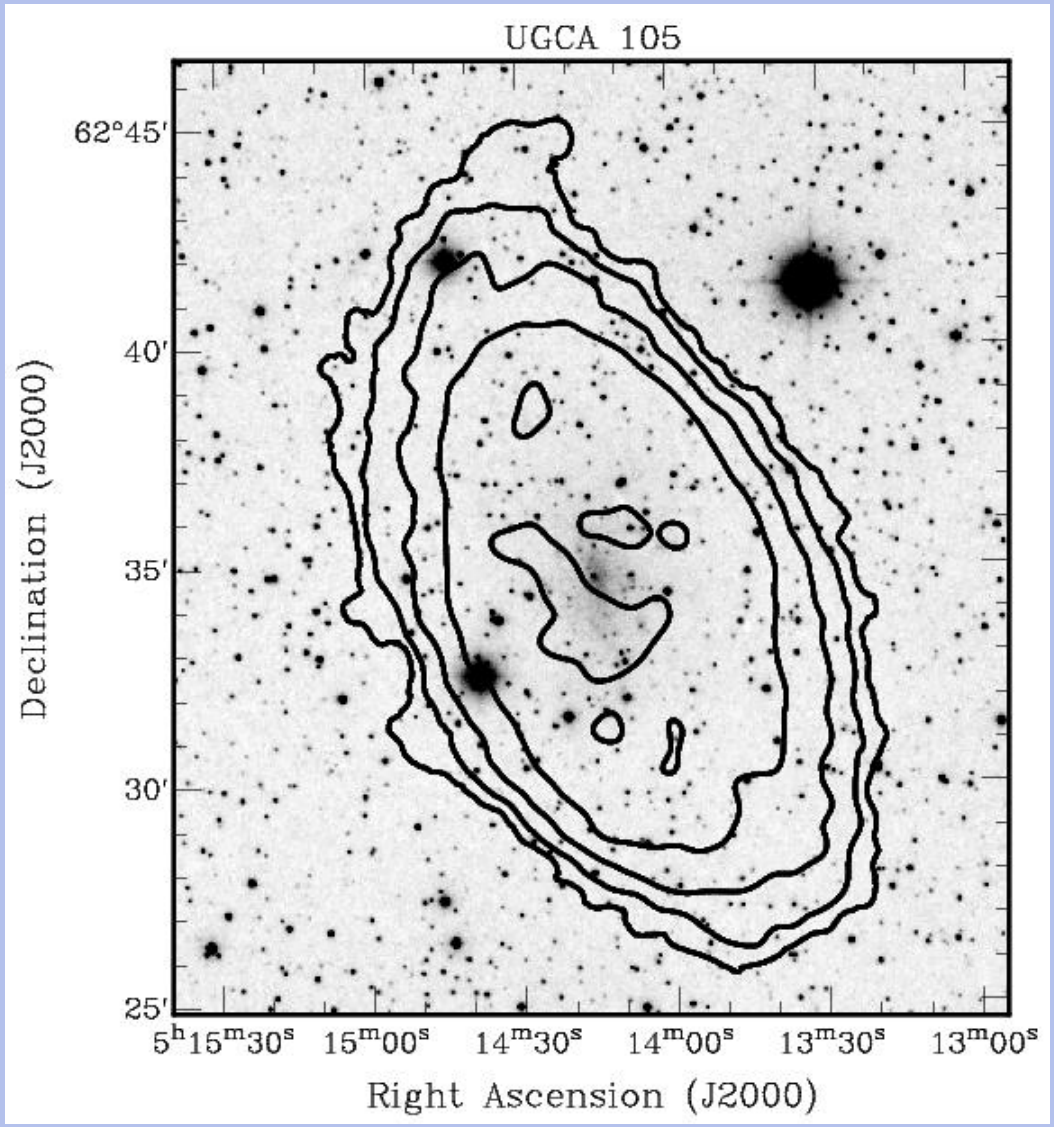
Optical



HI (beam: 15" x 13")

HI data from WSRT

UGCA 105



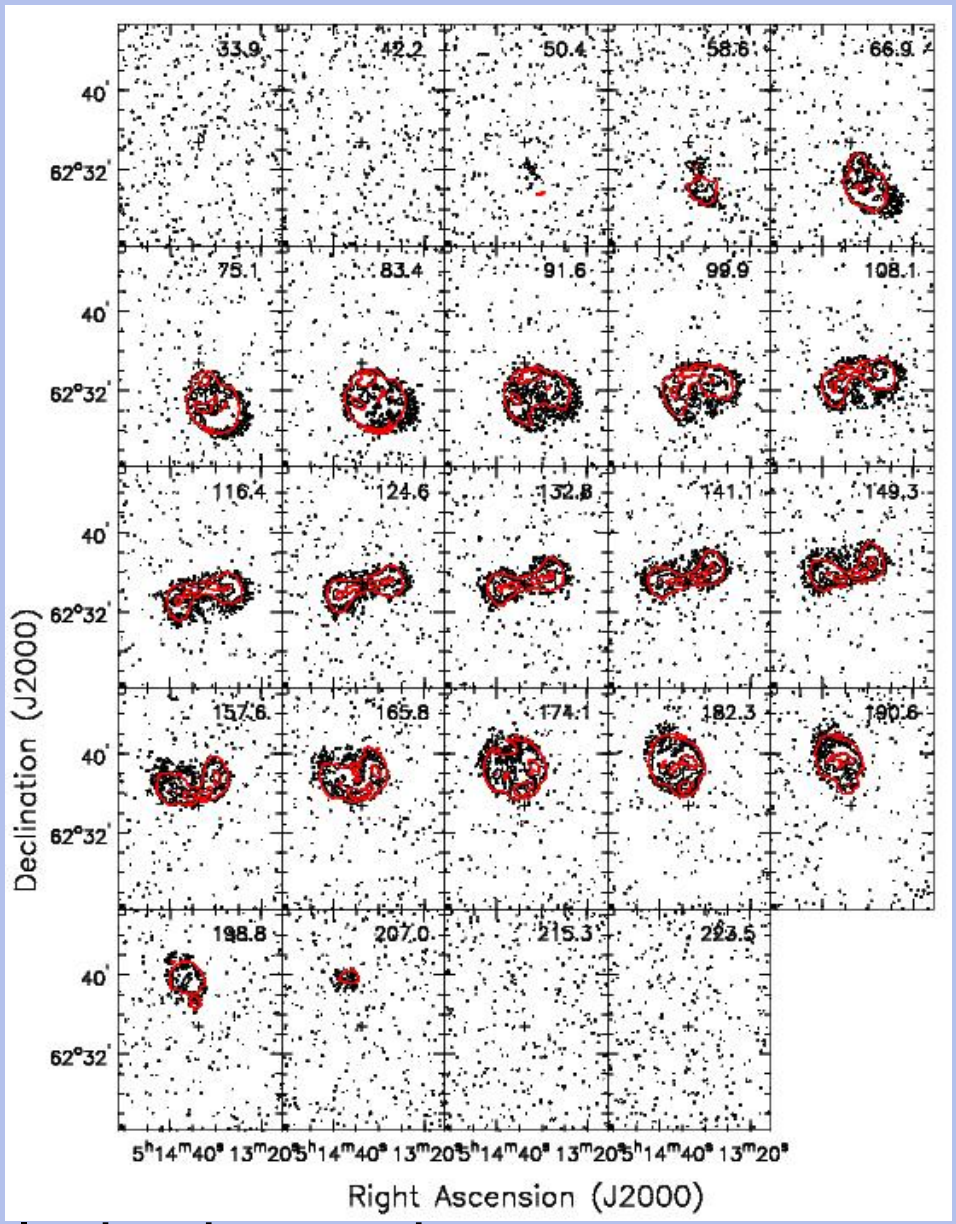
Greyscale: optical - Contours: low-res HI (40"x40")

UGCA 105 - model data cubes

High resolution

Model data cubes
using Tirific (Józsa et al. 2007)

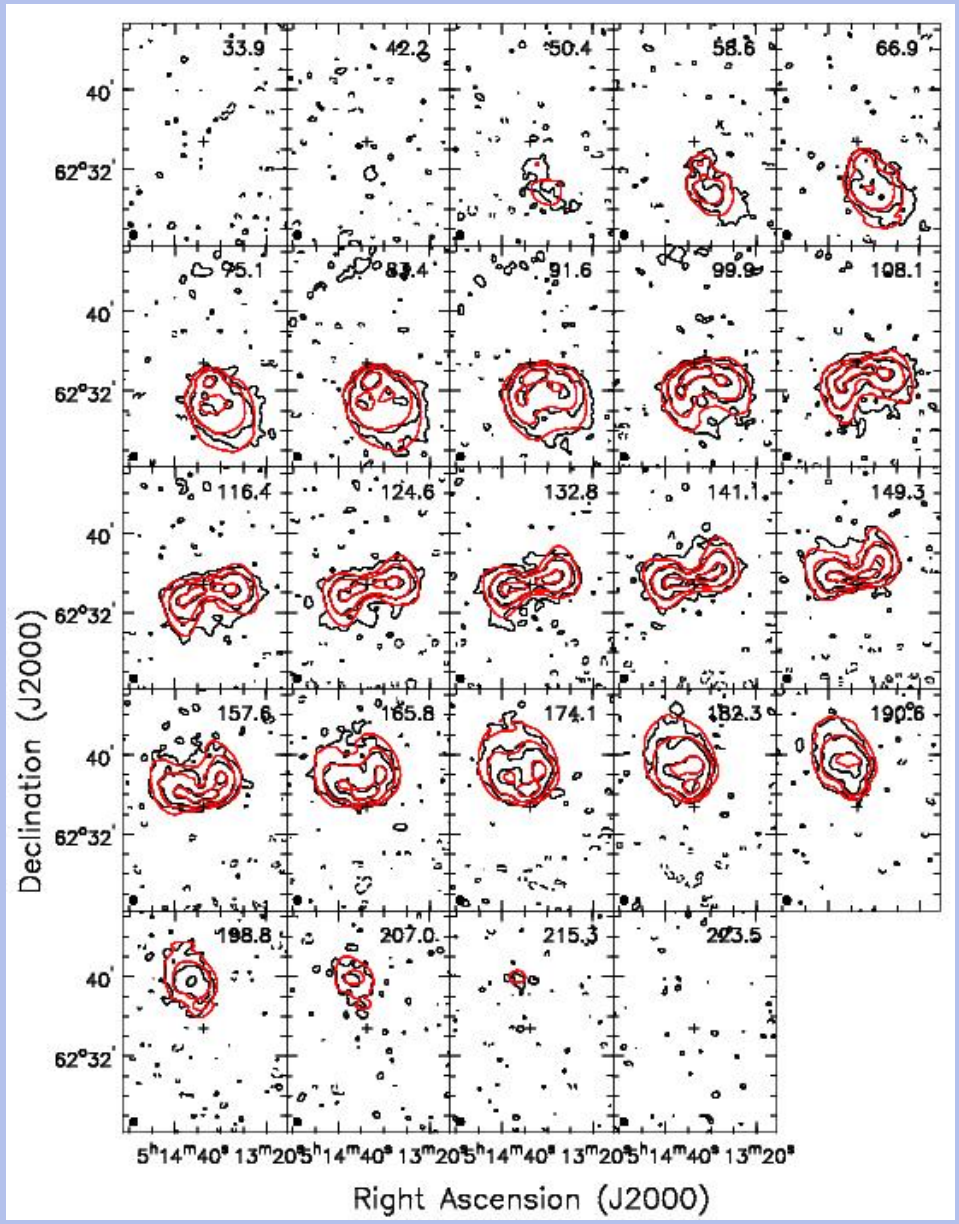
http://www.astro.uni-bonn.de/~gjozsa/tirific.html



Red: model - Black: observations

UGCA 105 - model data cubes

Low resolution

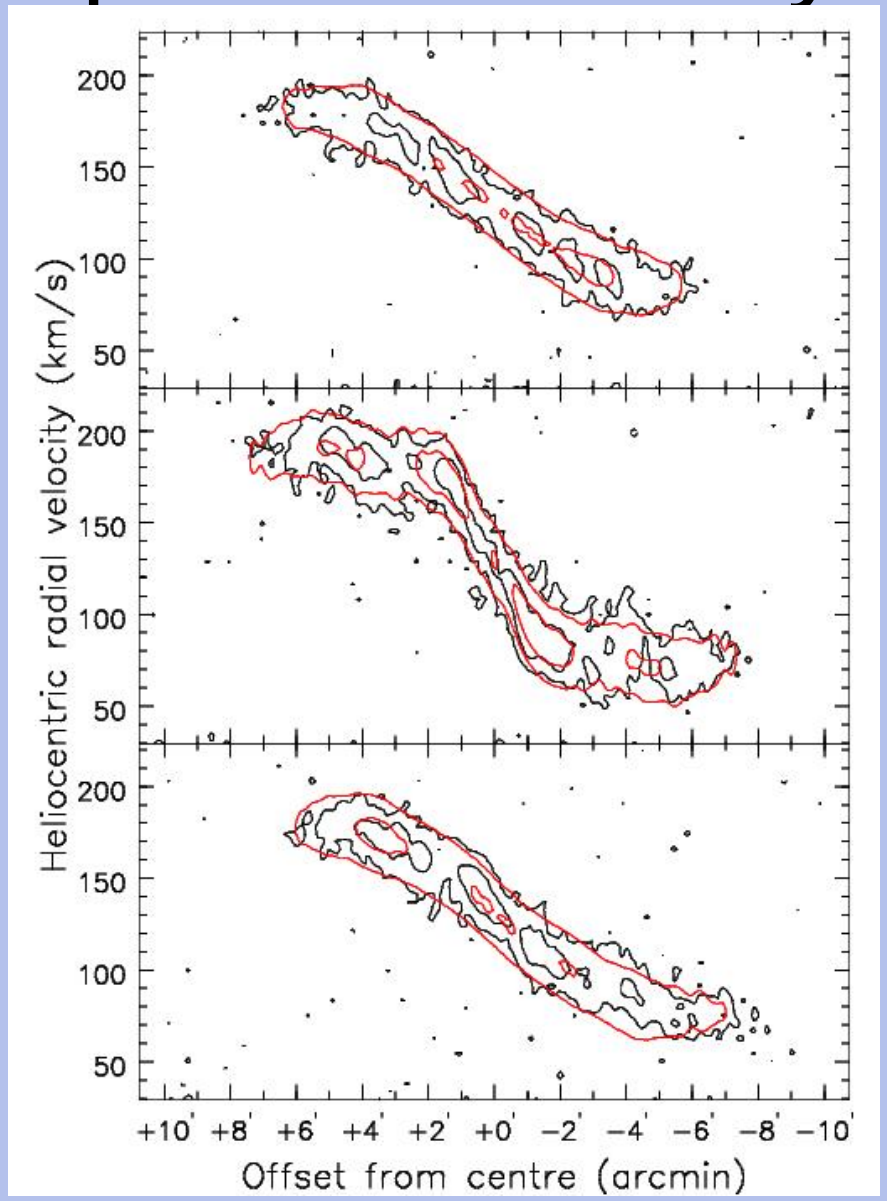


Red: model - Black: observations

UGCA 105: position-velocity diagrams

High resolution

PVDs parallel
to major axis

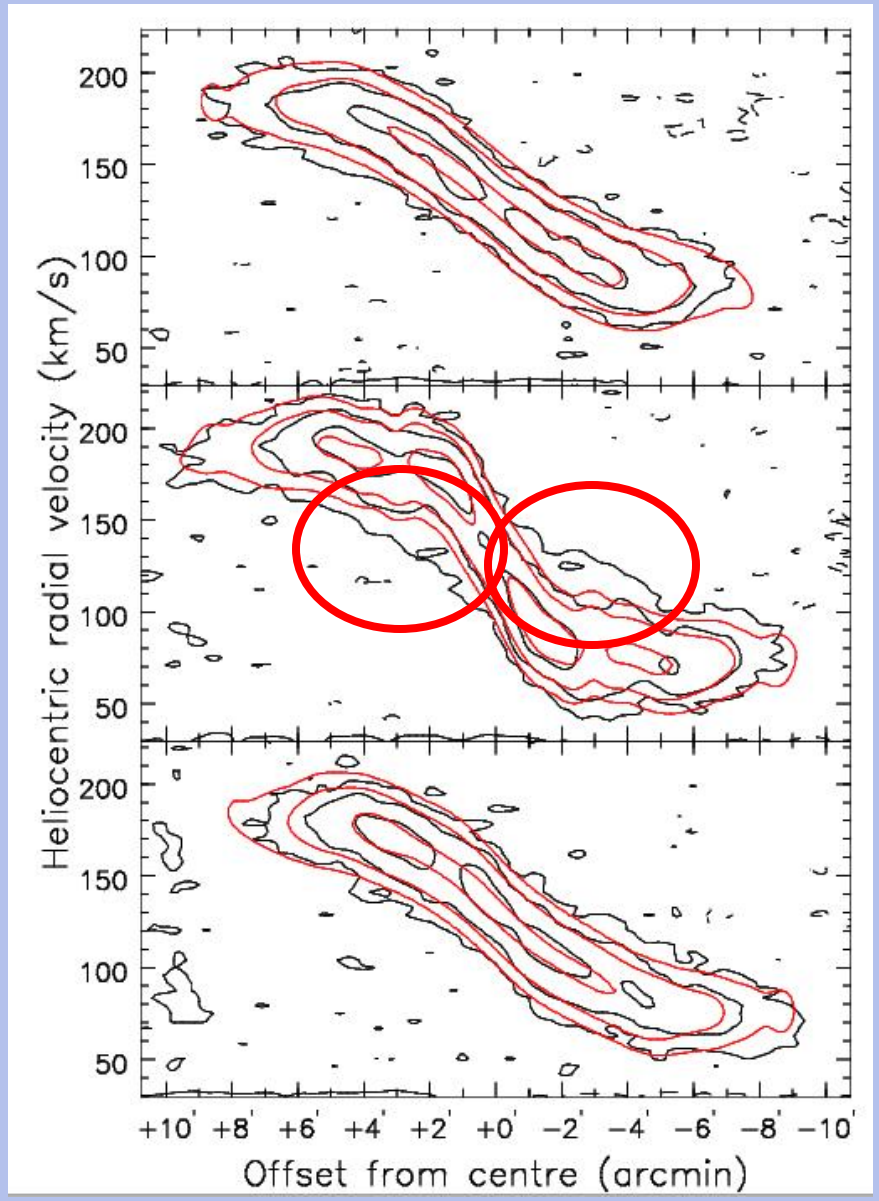


Red: model - Black: observations

UGCA 105: position-velocity diagrams

Low resolution

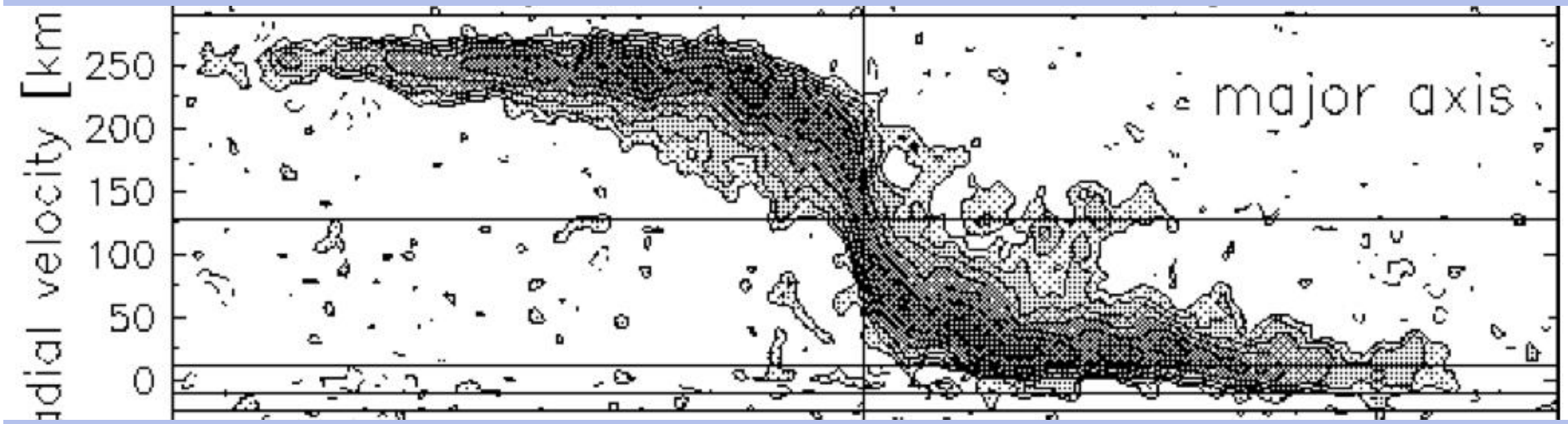
PVD parallel
to major axis



Red: model - Black: observations

UGCA 105: position-velocity diagrams

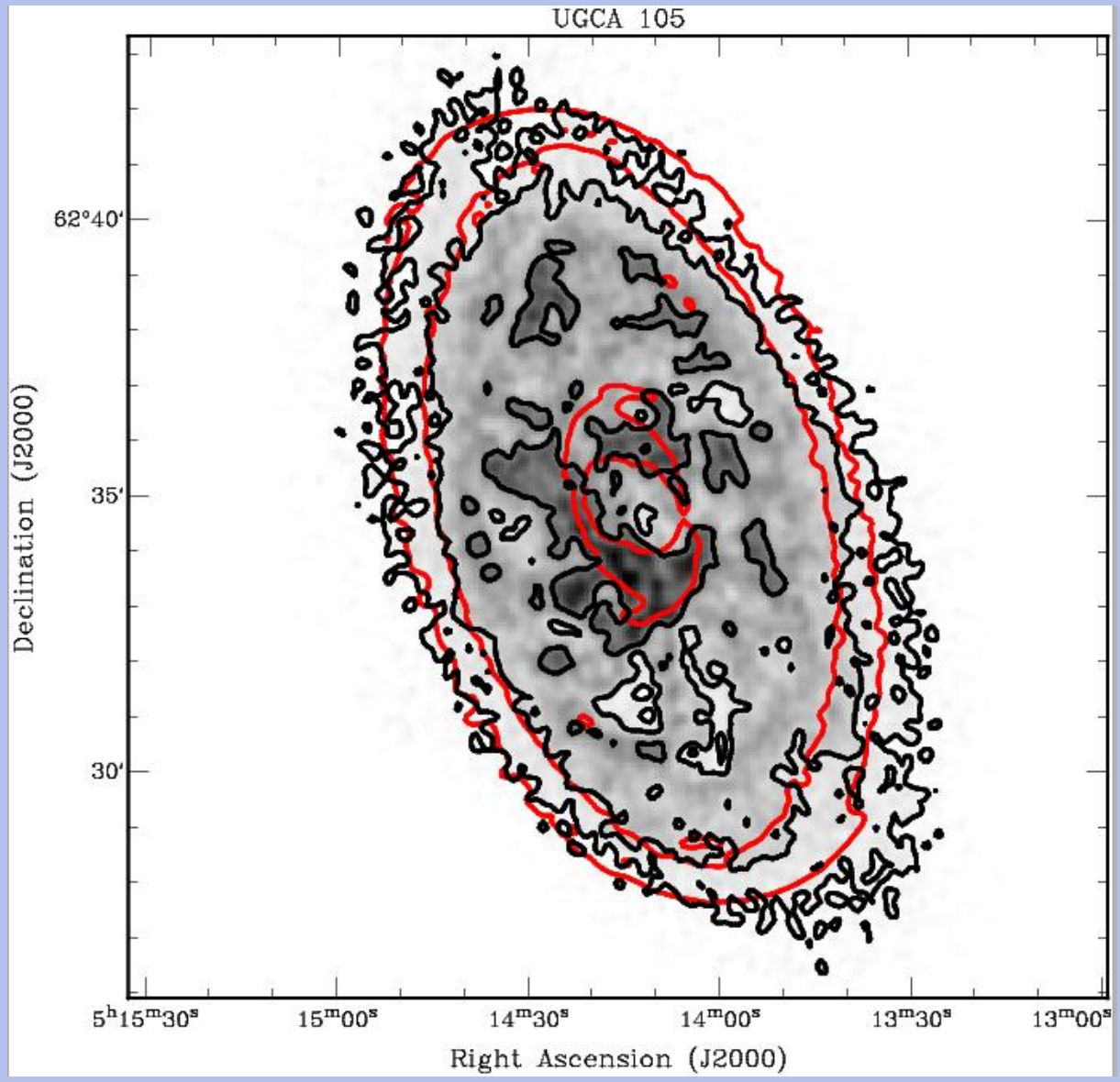
Anomalous gas: same signature as in NGC 2403 (Fraternali et al.)



See also works by Heald et al.

UGCA 105: total HI map

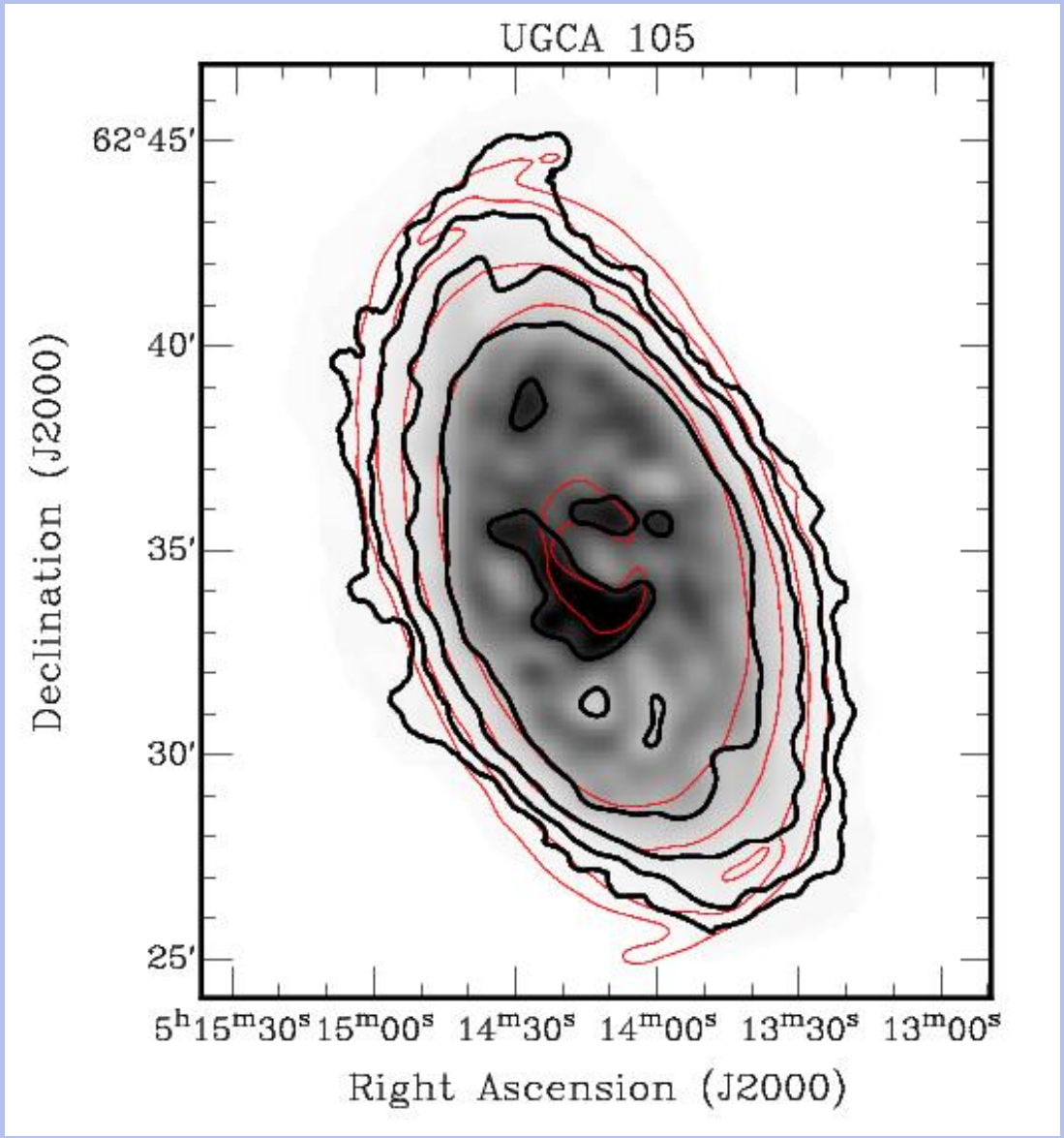
High resolution



Red: model - Black: observations

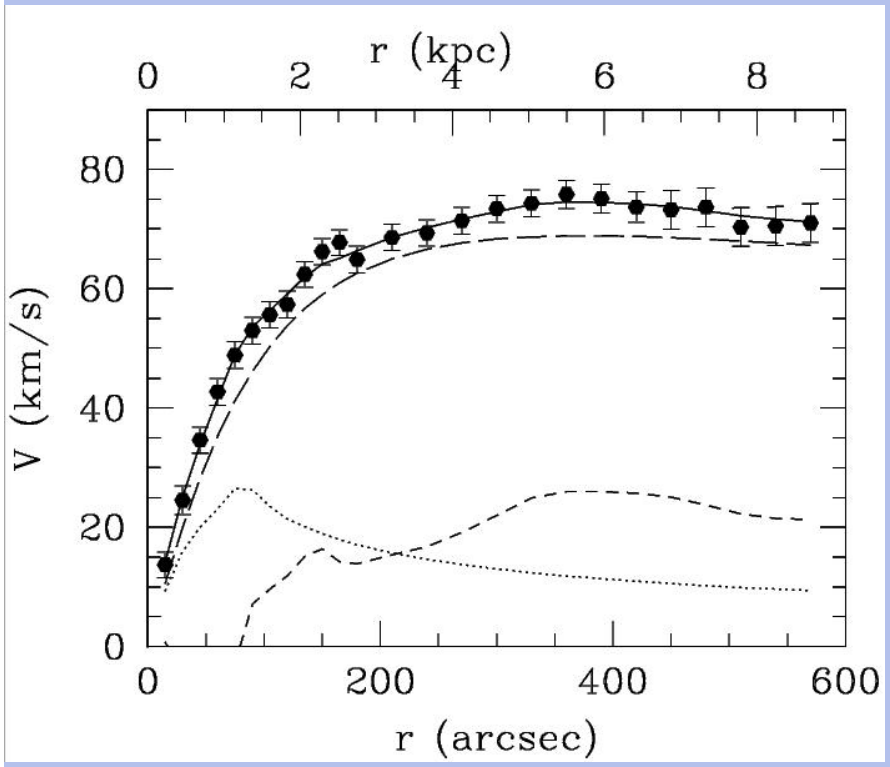
UGCA 105: total HI map

Low resolution

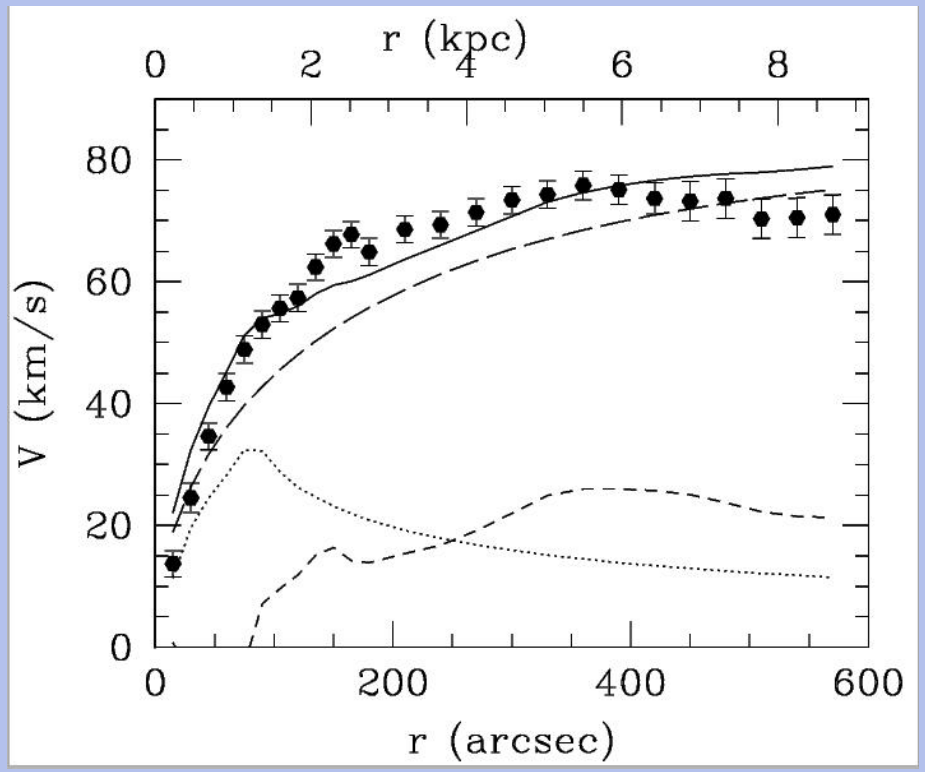


Red: model - Black: observations

UGCA 105: preliminary mass models



Mass model with dark halo with constant density core



Mass model with halo predicted by ΛCDM

Part 4: Conclusions

- NGC 3741: - the most extended rotation curve ever
  - HI data: reproduced with model data cubes
  - Cored halo and MOND fit very well
  - NFW fits badly for realistic parameters

- Ongoing work: - sample of NGC 3741-like galaxies
  (very gas-rich, very large HI disk)
  - currently: UGCA 105, ongoing modelling
  of WSRT data