Mass Distribution in Hickson Compact Groups

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Problems and Issues

- Since Zwicky 1933
  the Universe has a weight problem it is too slim …

- Since then, a question arises:
  Are commercial diets effective or the Universe has succeeded to hide more than 80 % of its mass ….

Problems and Issues

To tackle this heavy problem – two approaches

* Actually try to find what the DM stuff is made of – particle physics – new physics ..

* Take for granted the DM and try to find out its effects, limits on galaxies, clusters, groups etc ..

How to study DM haloes

- N body simulations – Galaxies formation
  Cosmological Simulations – Millennium I -II

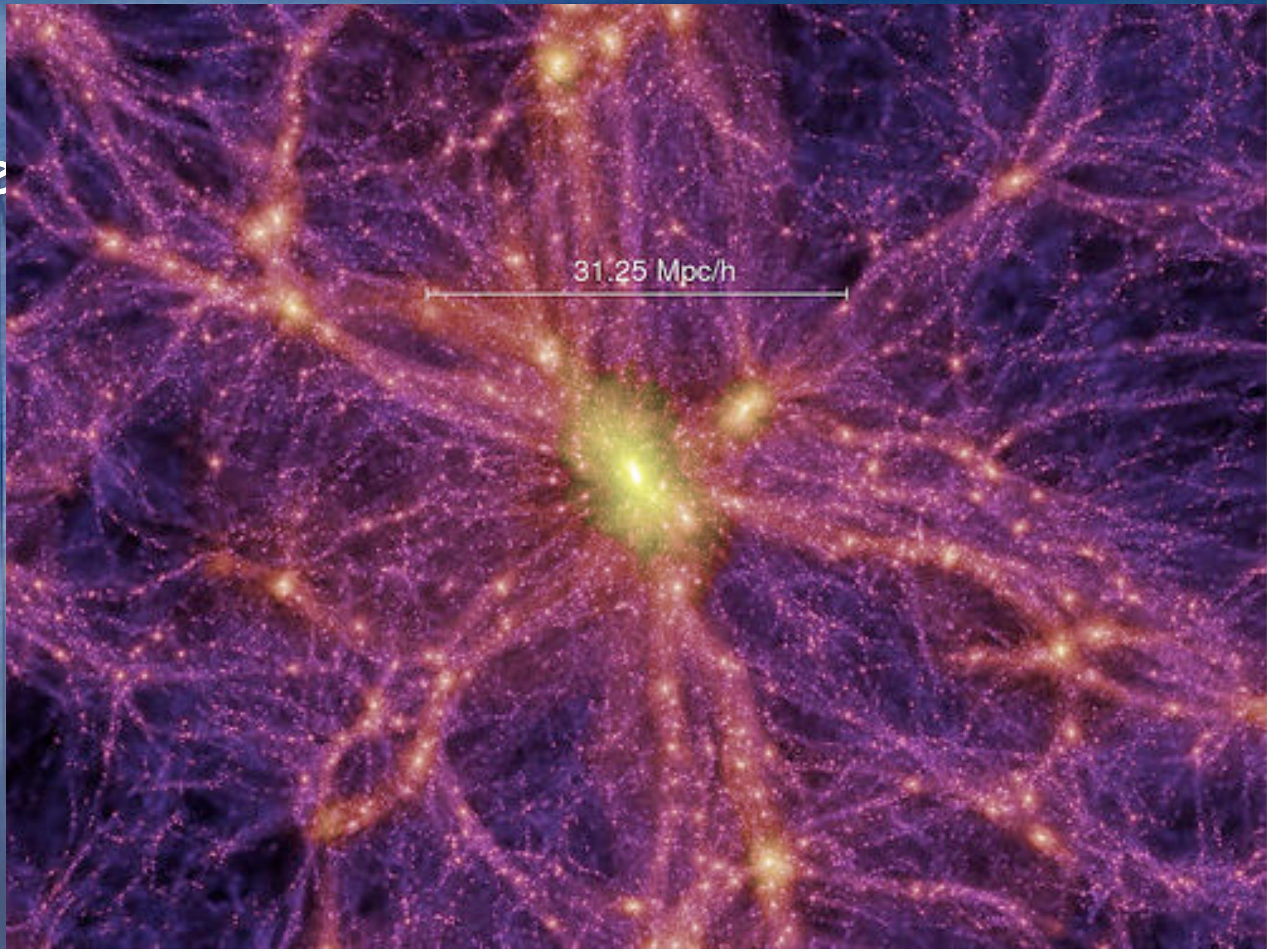
- Models of halos – Core – Cusp - Triaxial

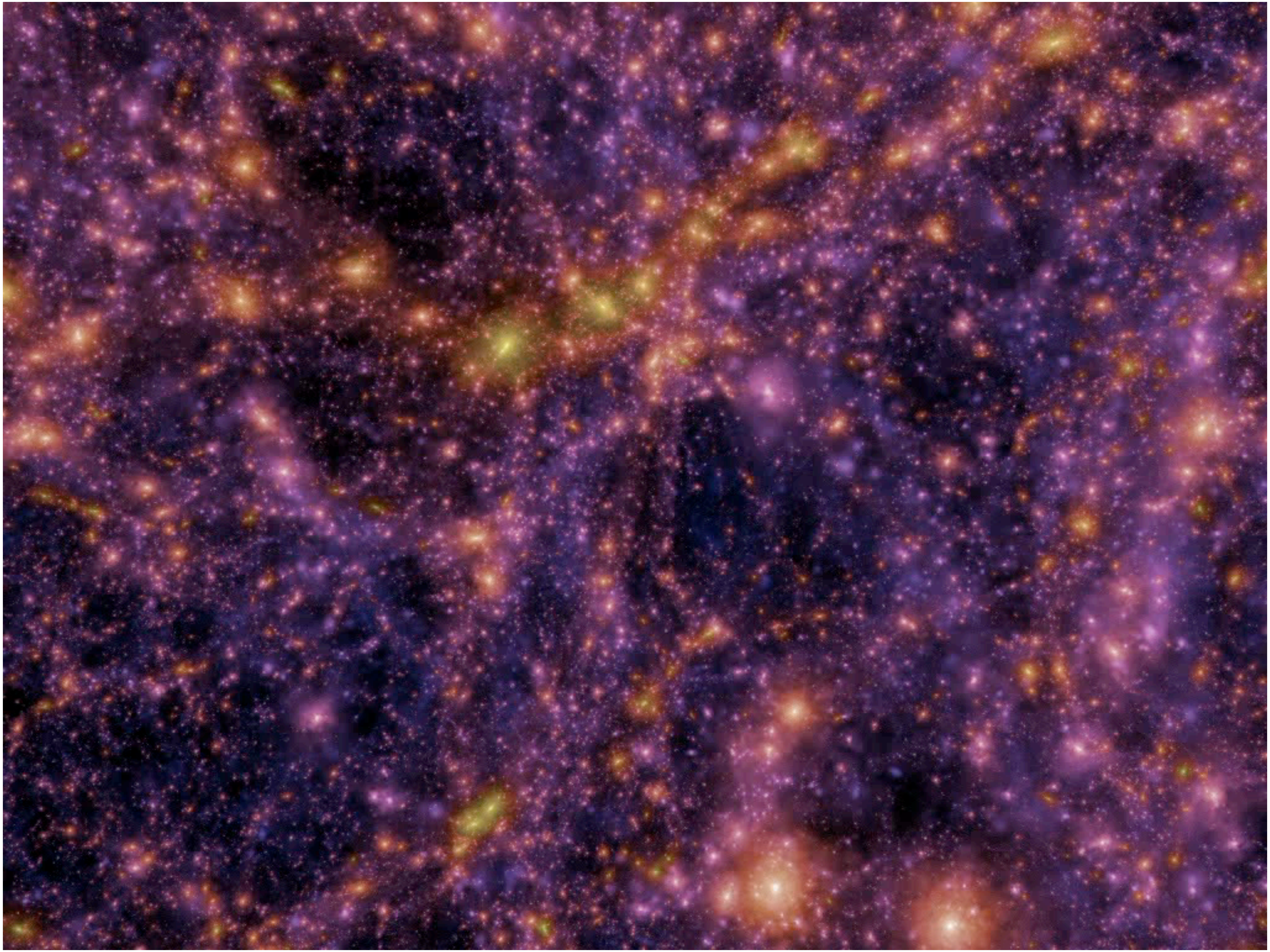
- Observations
  Clusters of galaxies
  Individuals RCs

N body simulations - Galaxies formation

Cosmological Simulations - Millennium 2005

- $N = 2160^3 \cong 10^{10}$ particles (each one 8.6×10^8 **h**$^{-1}$ M_{sun})
- **z** = 127 to present
- Cubic region 500**h**$^{-1}$Mpc

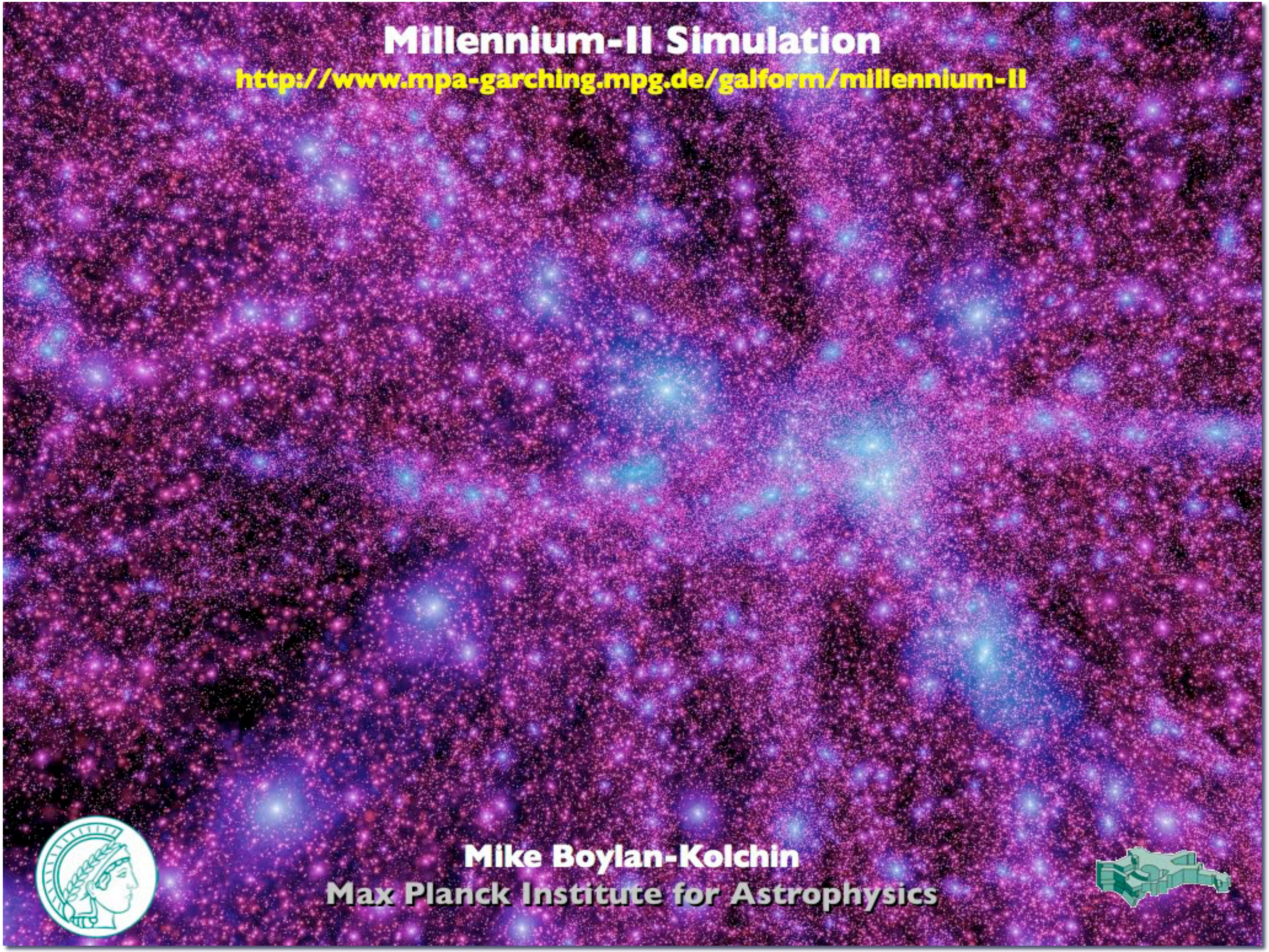




N body simulations – Galaxies formation

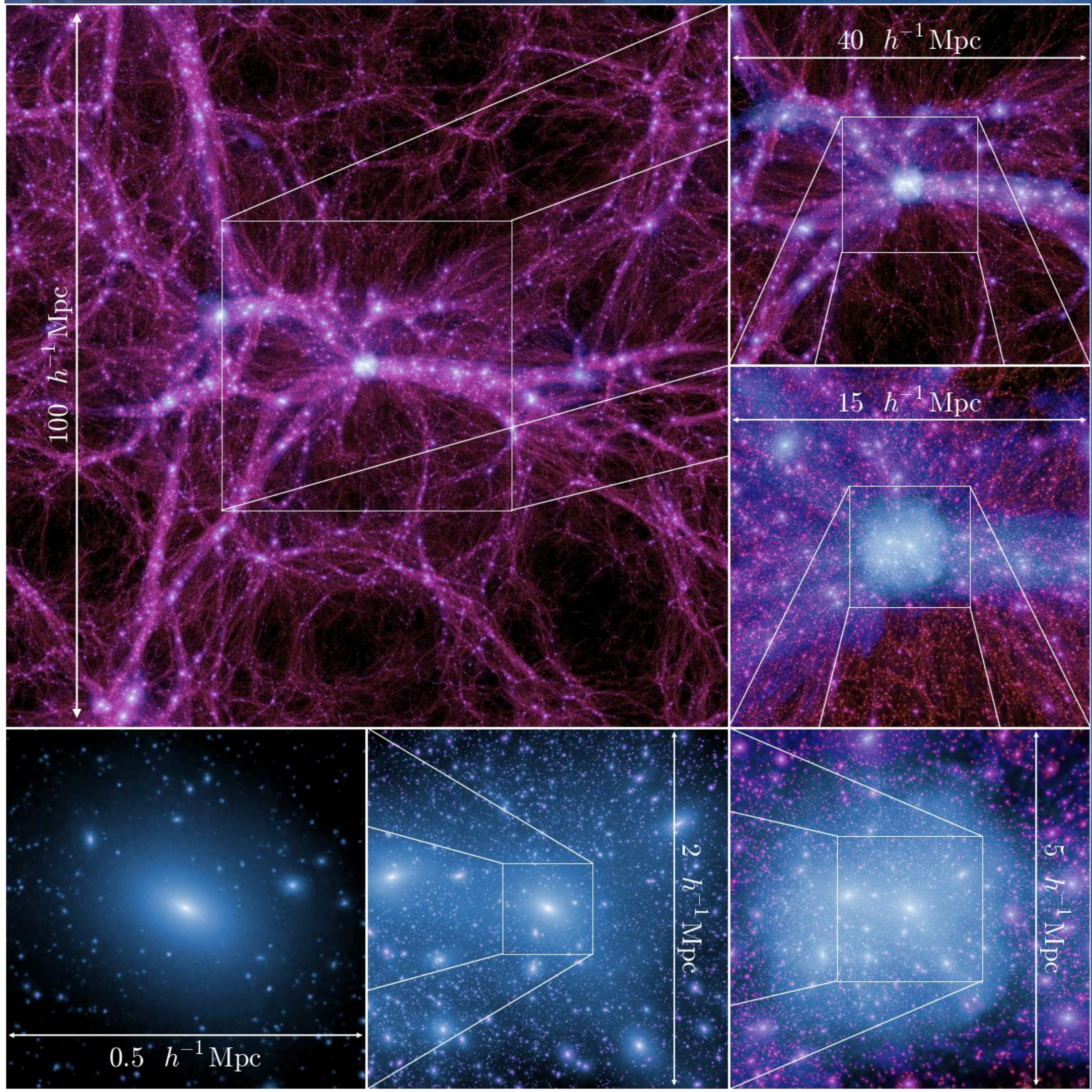
Cosmological Simulations – Millennium II

- Simulations probe structure of galaxy-scale dark matter haloes with high mass resolution
- The MS-II has five times the spatial resolution (DM particle mass - $6.9\times10^{6}\ \mathbf{h}^{-1}M_{sun}$)
- High clustering leads to very long merger trees (the longest contains over 90 million subhaloes, compared to only 500 thousands in the largest MS tree)


Millennium-II Simulation
http://www.mpa-garching.mpg.de/galform/millennium-II
Mike Boylan-Kolchin
Max Planck Institute for Astrophysics

N body simulations - Galaxies formation

Cosmological Simulations - Millennium II



Zoom sequence from 100 to 0.5 Mpc/h into the most massive halo in the simulation at redshift zero

Boylan-Kolchin et al. 09

N body simulations - Galaxies formation

Cosmological Simulations - Millennium II

5 Mpc/h Boylan-Kolchin et al. (2009) 0.5 Mpc/h

Dark Halo Models

- Spherical core halo – isosphere

- Spherical cusp halo – spherical
  - triaxial Halo Models

Dark Halo Models

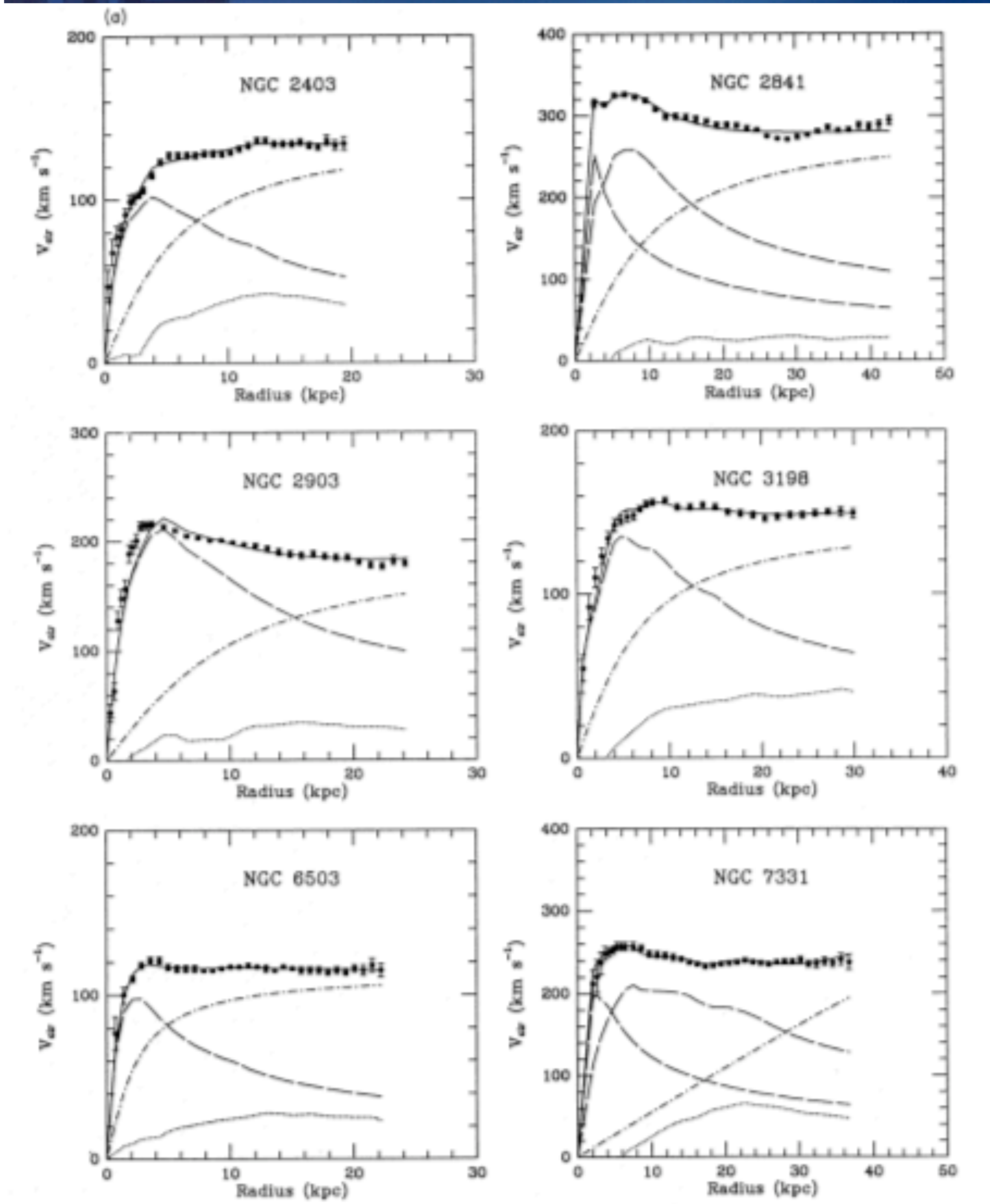
The cusp/core discrepancy

* The small-scale crisis in cosmology

- Core DH (spherical / pseudo iso-sphere) describes well RCs – late 80s (Begeman 91, Broeils 92, Carignan 85)

Solid body RCs in the inner parts

Begeman et al. 91



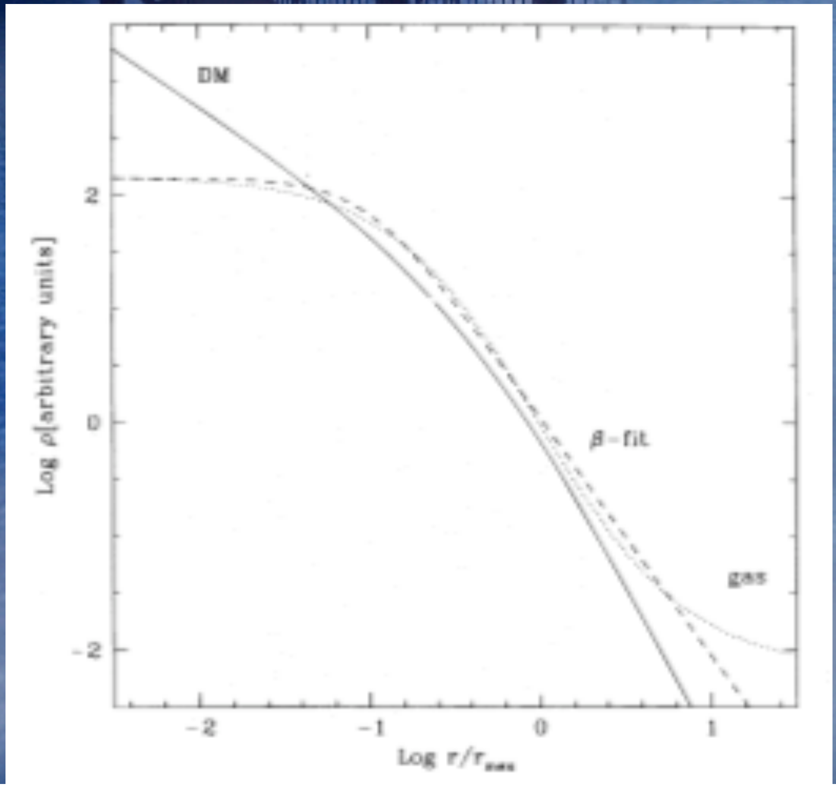
Disk / Spherical Halo Decomposition of RCs

HI Rotation curves

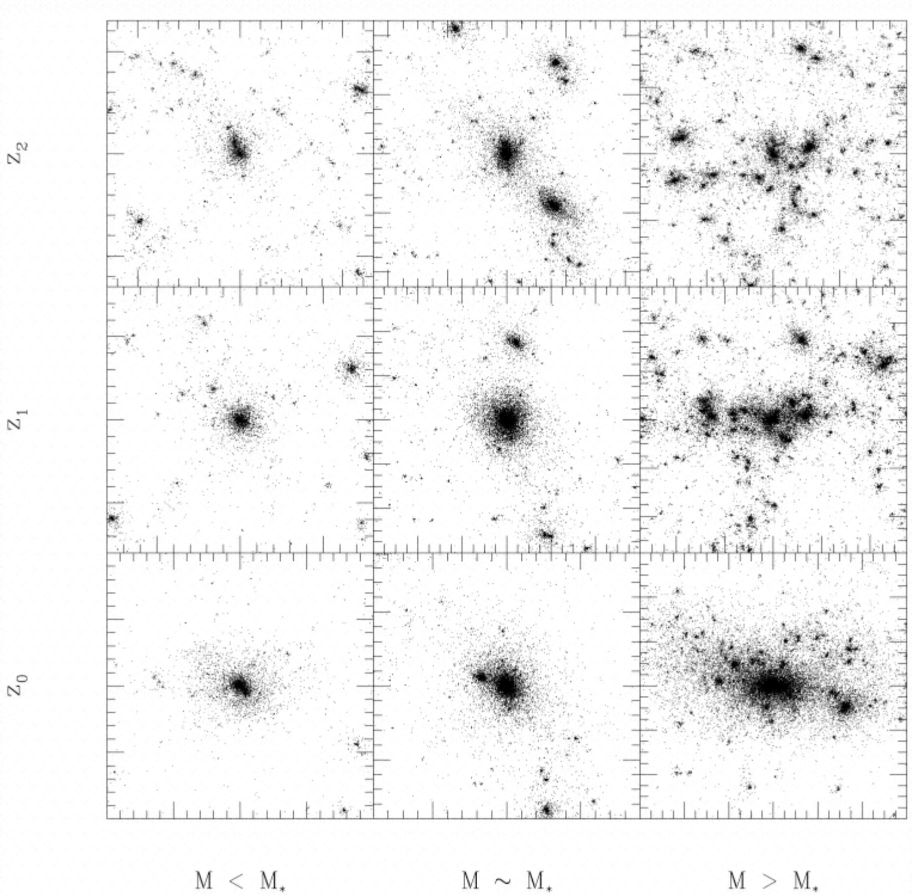
Dark Halo Models

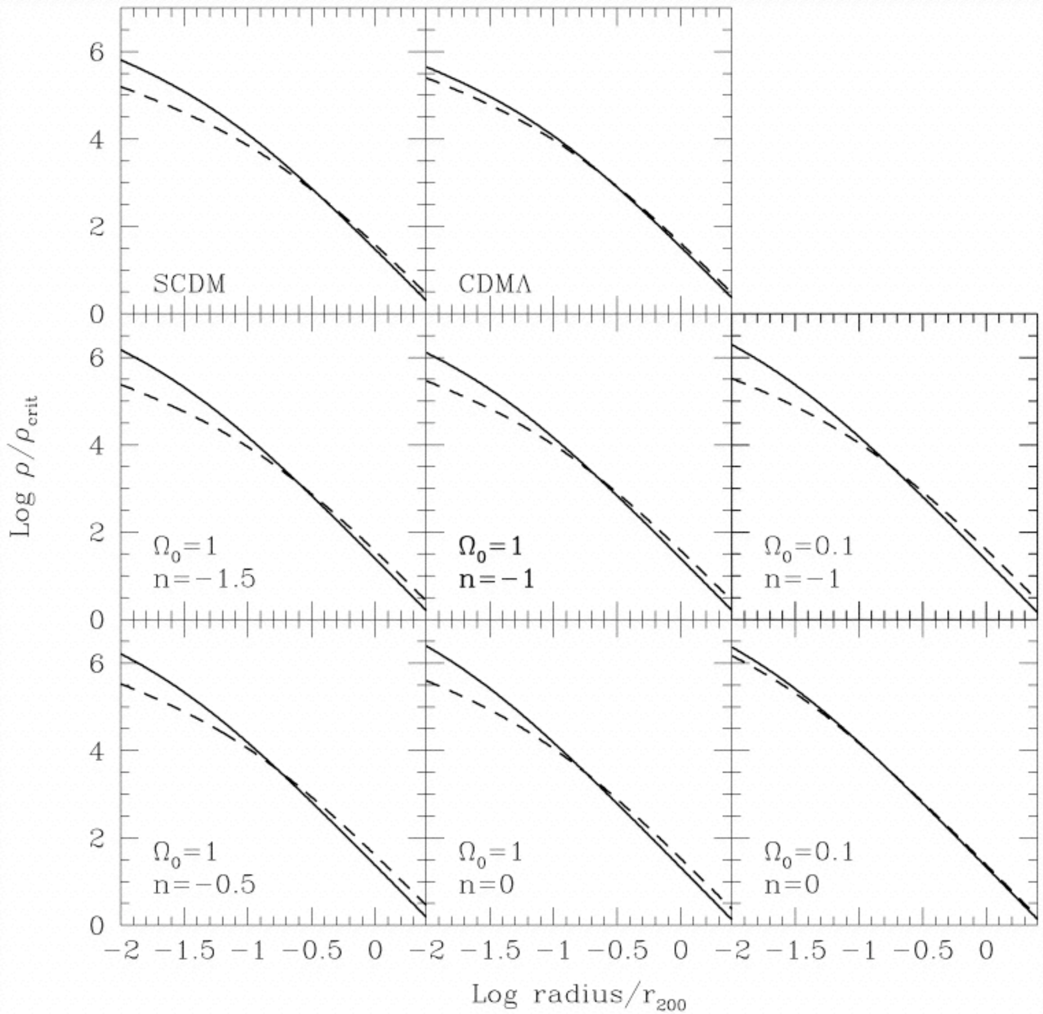
The cusp/core discrepancy

- Cusp DH – from CDM simulations – 90's (Dubinski 91, Navarro 96,97)



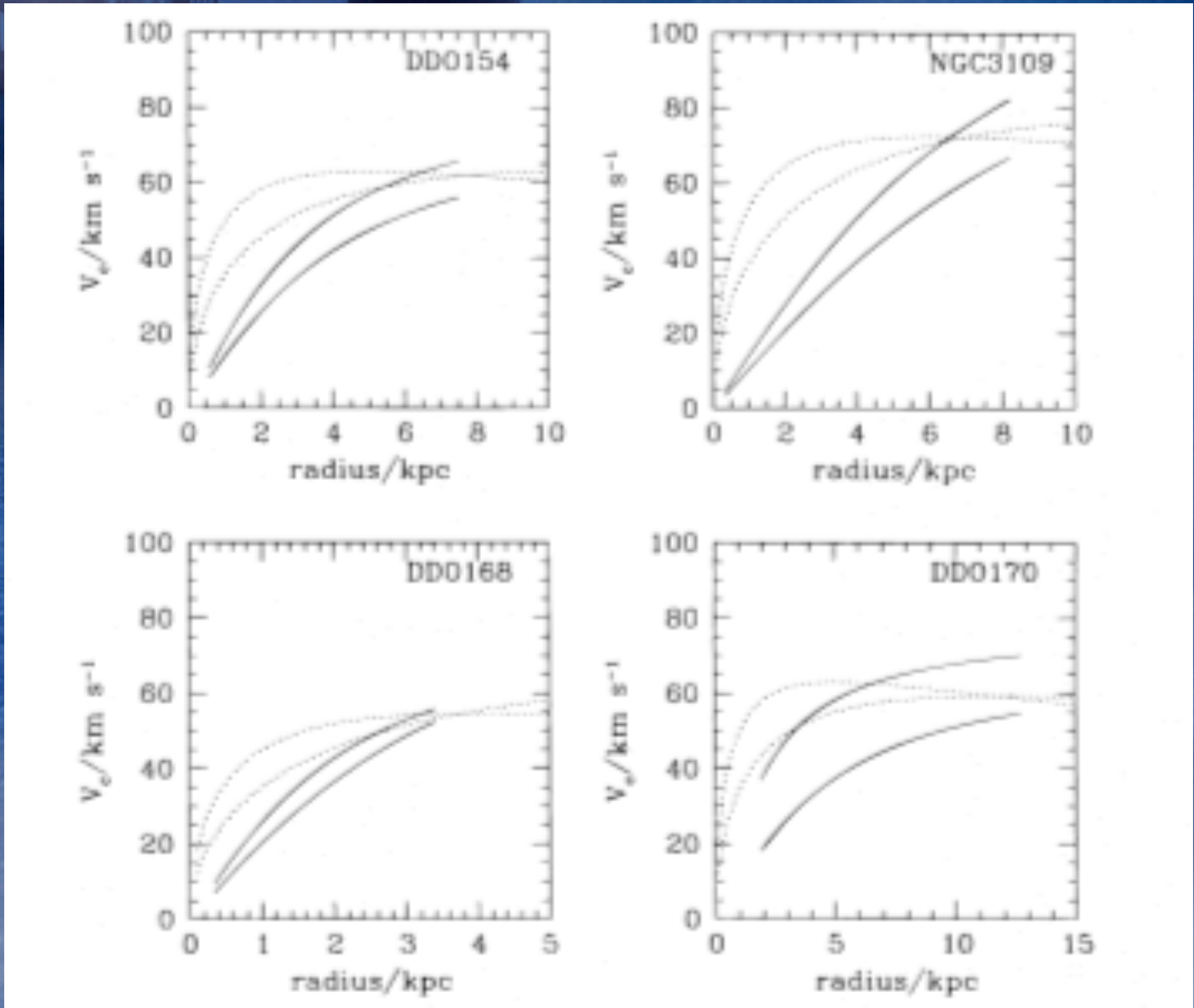
Navarro et al. 1997





Fits to the density profiles

Navarro et al. 1996



Dark Halo Models

Possible Systematical Effects

* Pointing problems
  - Slit observations – See later
* Non circular motions
  - Gas motion disturbed -> underestimate the slope

These effects are too small to explain the discrepancy

Dark Halo Models

Causes for the presence of a cored DH

* Feedback & Mergers – removal of cusp DH by:
  - Bars rotation transfering angular momentum to DM – Weinberg 02
  - Merging cusp halos ? cusp+ cusp = cusp
* Dynamical friction – Core created at high z
* Triaxiality Hayashi 07 – Navarro 03

  Elliptical disturbance in NFW halo

  → systematic non circular motions misinterpreted as core halo

Difficult to mistake spherical or triaxial halos with core DH

Schematics representations of different halos signatures in velocity fields (LSB)

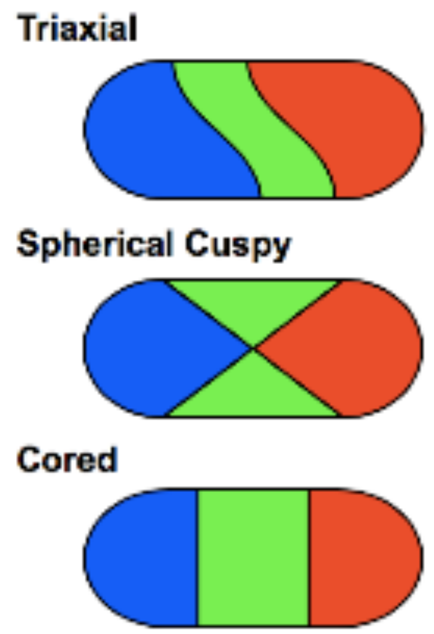


Figure 8. Schematic representations of the distinguishing features of the triaxial cuspy, spherical cuspy, and spherical cored mock velocity fields.

Mock VF

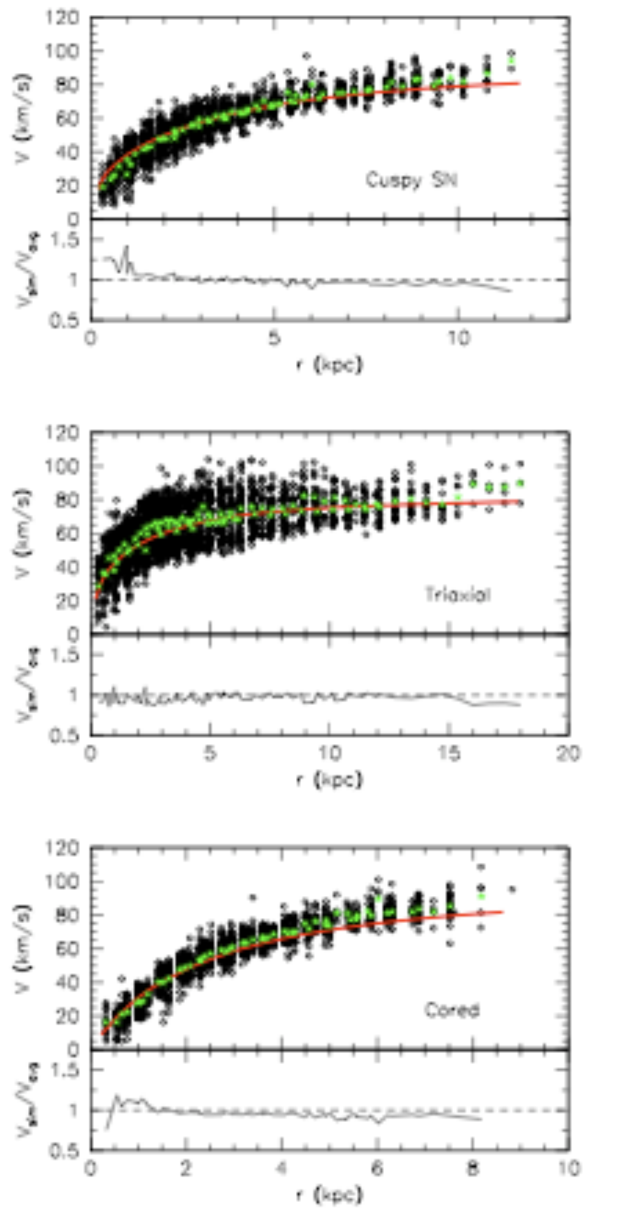


Figure 11. Comparison of the recovered mock rotation curves (black open circles) to the rotation curve derived from the simulation (red line) using $V^2 = GM/r$. The green stars are the average mock rotation curve. The bottom panels plot the ratio of the simulation rotation curve to the average mock rotation curve.

Kuzio de Naray 11

The Observation of Rotation Curves

- The first proof of a mass discrepancy for individual galaxy

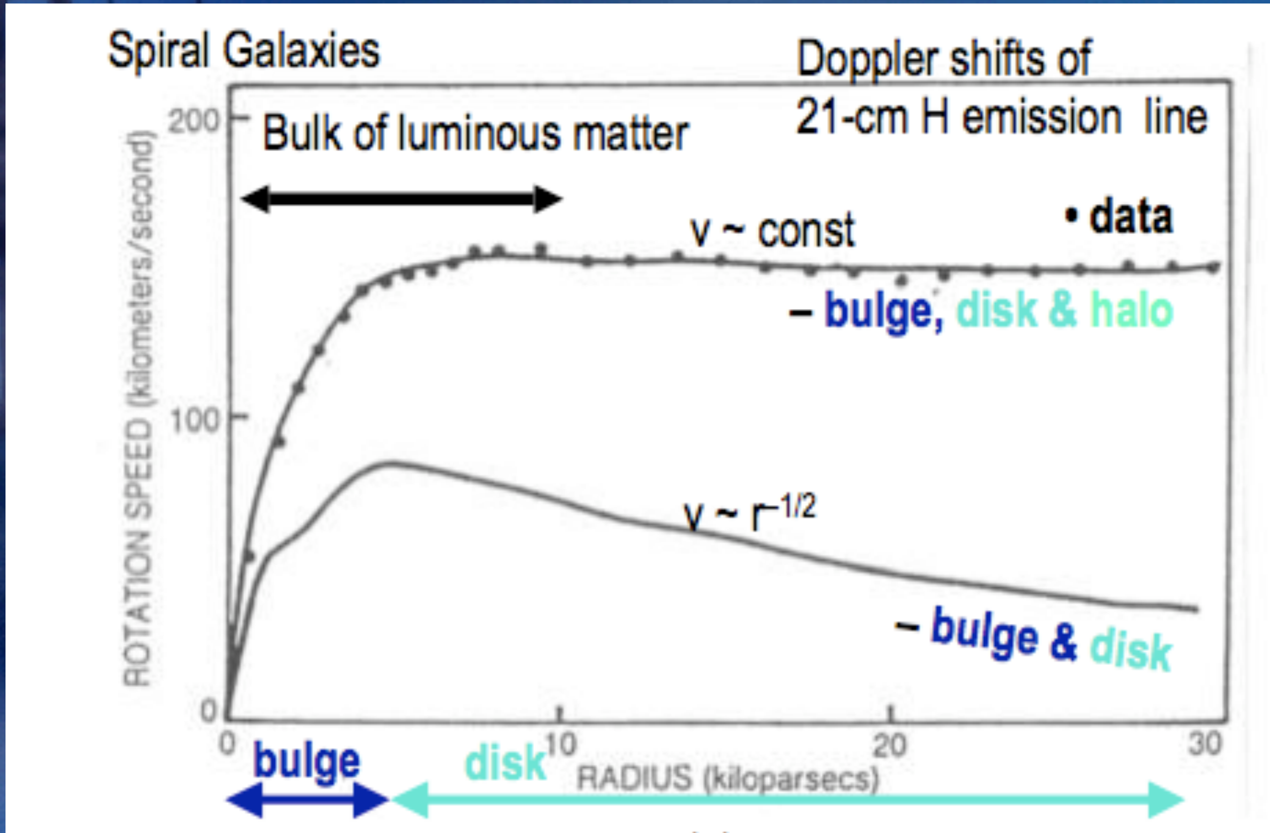
- Physics 1.01 - Newton Second law

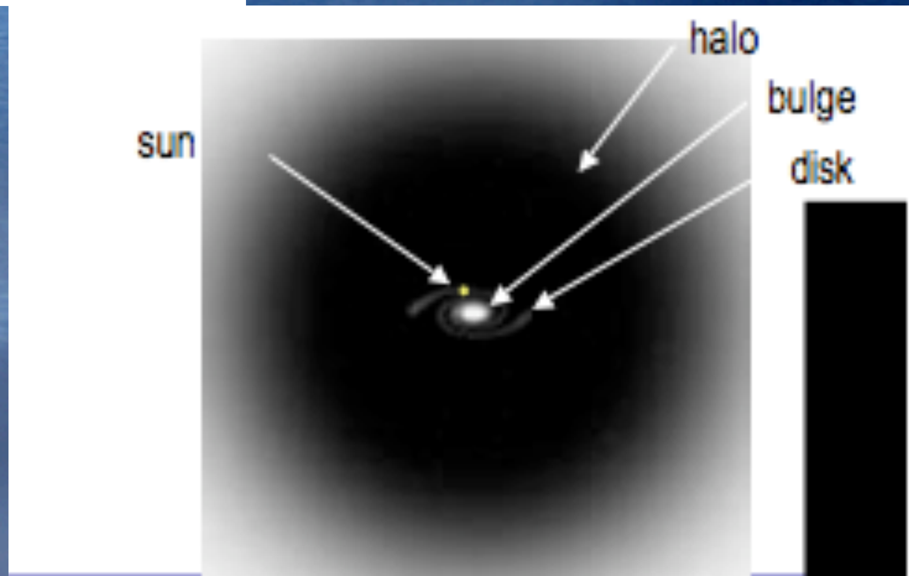
$$F_{\text{centripetal}} = F_{\text{gravity}}$$

$$\frac{mv_r^2}{r} = \frac{GmM_{\text{total}}(r)}{r^2}$$

$$v_r = \sqrt{\frac{GM_{\text{total}}(r)}{r}}$$

$$\frac{M(r)}{r} \rightarrow \text{const} \quad (r >> r_{core})$$





Thanks Rick Gaitskell Brown University

The Observation of Rotation Curves

Some studies for the last 40 years

* Roberts & Rots 1973 – HI
* Bosma 1981 – van Albada 1985 – HI
* Rubin et al. 1988 – $H\alpha$
* Amram et al. 1992 – $H\alpha$
* Epinat et al. 2008 - $H\alpha$

The Observation of Rotation Curves

- The What ?
  * What lines to observe ?
- The Who ?
  * What kind of galaxies ?
- The Where ?
  * What kind of environment
- The How ?
  * How to do it ?

The Observation of Rotation Curves

Which lines used for RC ?

- Emission lines – $H\alpha$, [OIII], [NII]

  Easy to observe – Gas tracer – quick response to gravitational perturbation

- Absorption lines – CaII – NaD

  More difficult to observe – Stars tracer Potential well tracer

The Observation of Rotation Curves

Which lines used for RC ?

Emission lines, Hα, HI, CO have low dispersion velocity compared to rotational velocity

- Atomic Hydrogen HI
  Large Extension Disk

- Molecular Gas - ^{12}CO (J=1-0) – (J=2-1)
  Inner disk and central regions of spirals (extinction)
  ALMA – 0.01" – dv < 1 km/s

NGC 4303

Sofue et al. 03

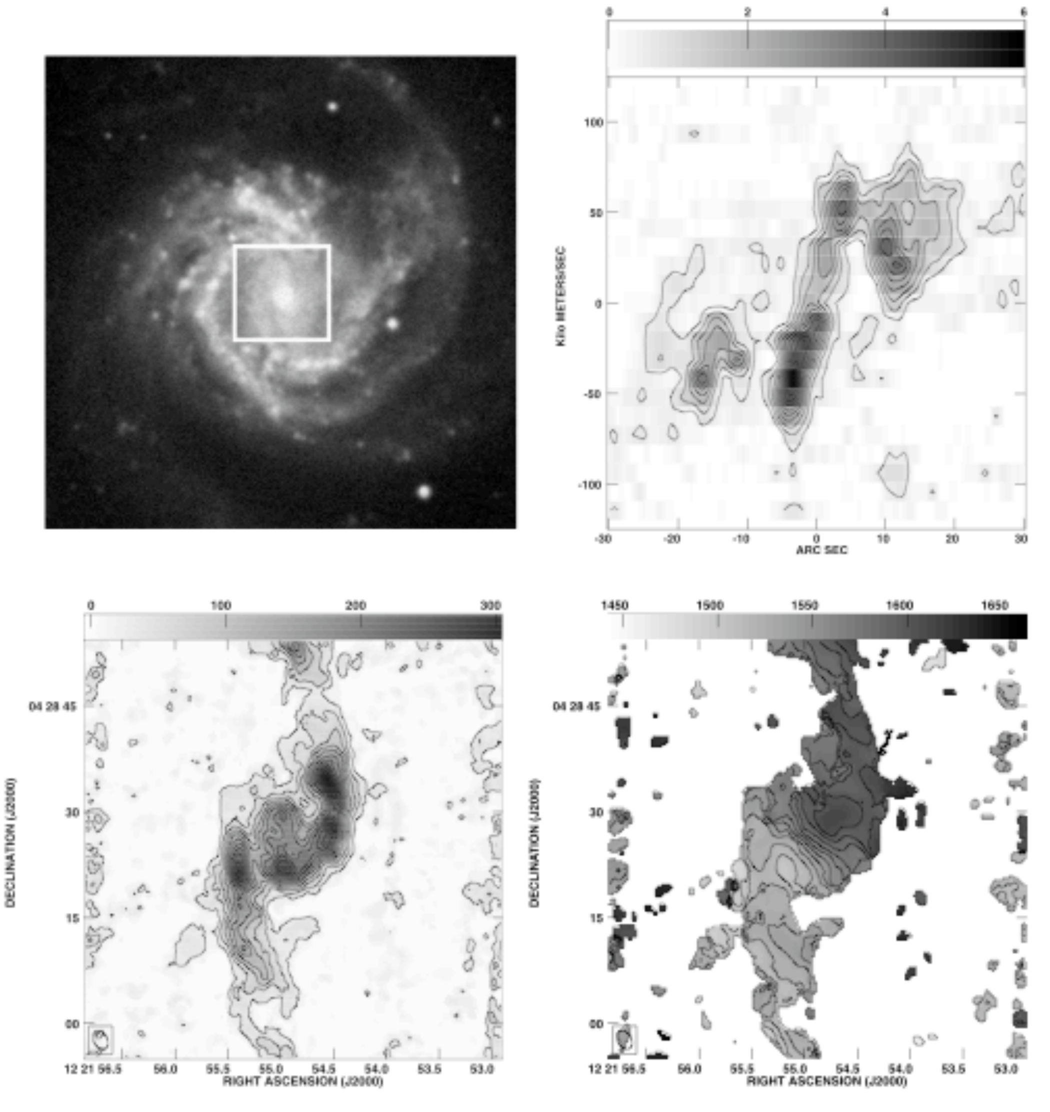
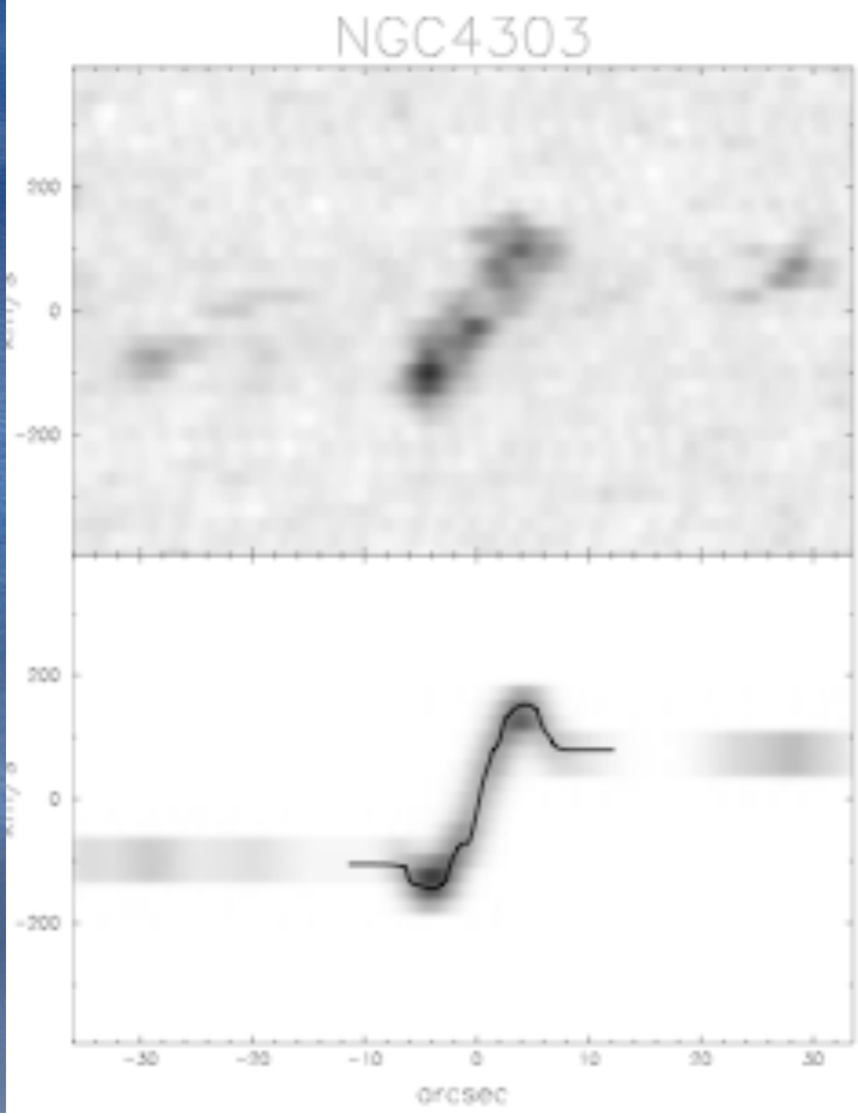


Fig. 1. (Continued.) (d) **NGC 4303**: (tl) DSS *b*-band 5′ × 5′, $i = 25°$, PA = 0°. (bl) Ico: 1′ × 1′; Beam 2″80 × 1″90; cl = 25 × (1, 2, …, 12) K km s^{-1}. (tr) PVD: 1′ × 3″, PA = 340°; cl = 0.5 × (1, 2, …, 12) K. (br) V-field: 1′ × 1′; cl = 1500 to 1600, every 10 km s^{-1}.

Sofue et al. 03



The Observation of Rotation Curves

What kind of galaxie ?

Almost all kinds over the years

- Spirals - HII regions - diffuse gas - disk
  * Mass distribution - DM
- Ellipticals - small gas disks - slow rotator
  * Viewing angles of Triaxial shape - Plana 96
  * Planetary nebulae - DM - Arnaboldi 98
- Low Surface Brightness and Dwarf galaxies

  Swaters 99

The Observation of Rotation Curves

Where are the galaxies to observe?

Environment is important

- No declining RC for galaxies in clusters (Rubin et al. 88 vs Amram et al. 92)

- TF relation for galaxies in clusters and field galaxies Epinat et al. 08 – Torres-Flores et al. 11

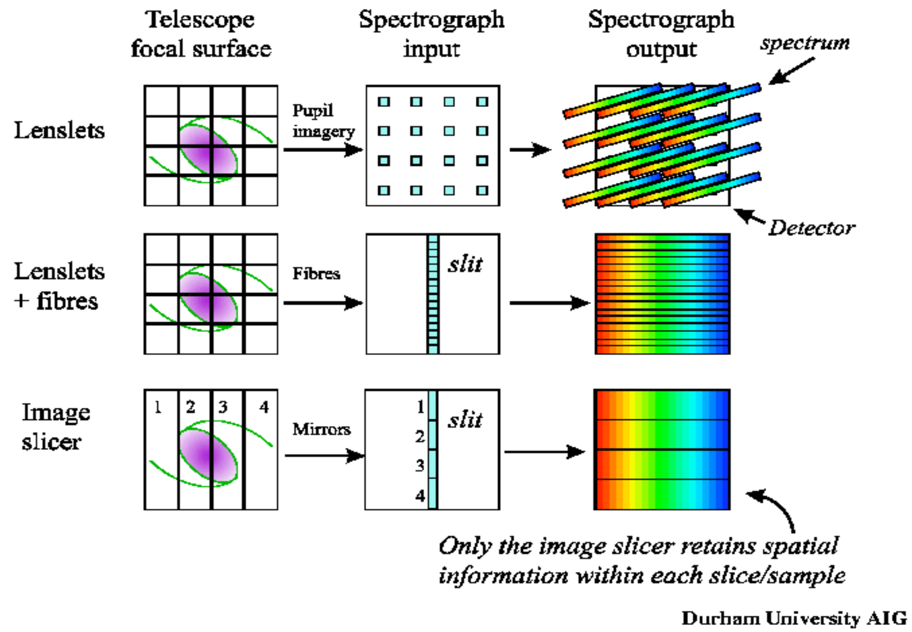
The Observation of Rotation Curves

How to build RC ?

- HI velocity fields – extended – resolution

- For years – 1D long Slit spectra
  Simple but 1D only -> Prb for Major Axis and Vmax

- Since 90's – 2D velocity maps are taking over
  * Fabry-Perot – large field – small λ range
  * IFUs – small field – large λ range


Telescope focal surface
Spectrograph input
Spectrograph output
spectrum
Lenslets
Pupil imagery
Detector
Lenslets + fibres
Fibres
slit
Image slicer
Mirrors
slit
1
2
3
4
Only the image slicer retains spatial information within each slice/sample
Durham University AIG

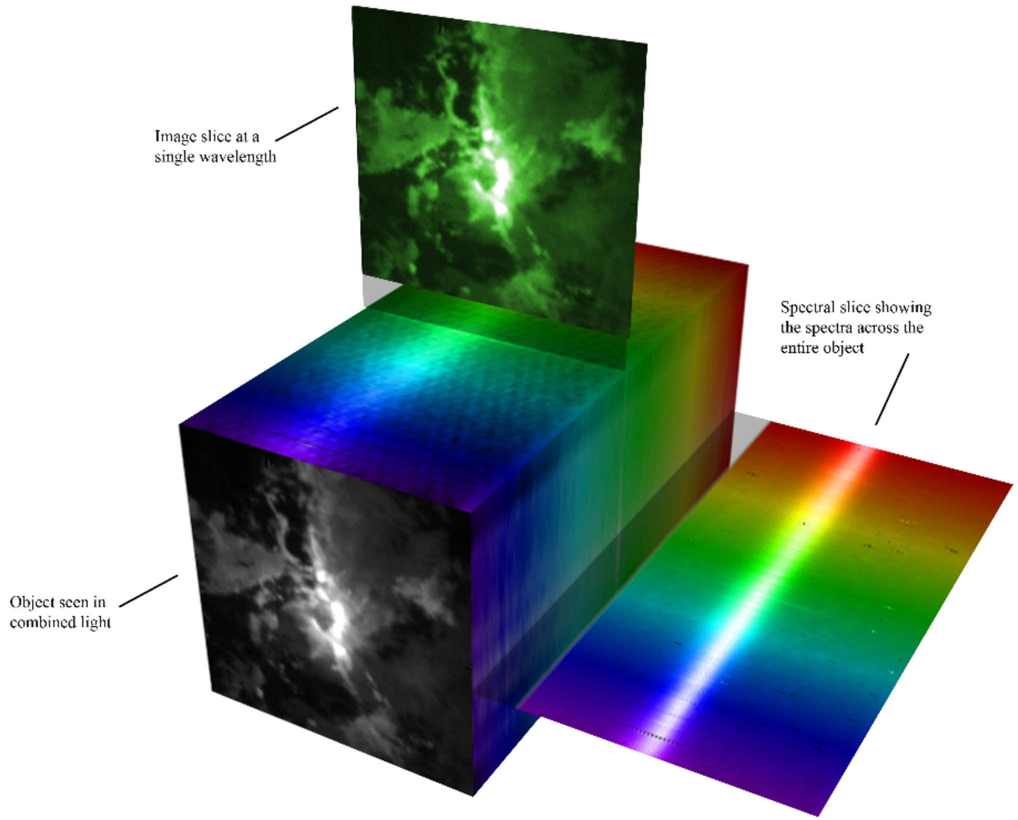


Image slice at a single wavelength
Spectral slice showing the spectra across the entire object
Object seen in combined light

The Observation of Rotation Curves

The art of Rotation Curves

* Position Velocity Diagrams - PVDs - Long Slit
  - -> Intensity Weigthed Velocity
  - -> Peak Intensity - Centroid
  - -> Iteraction method

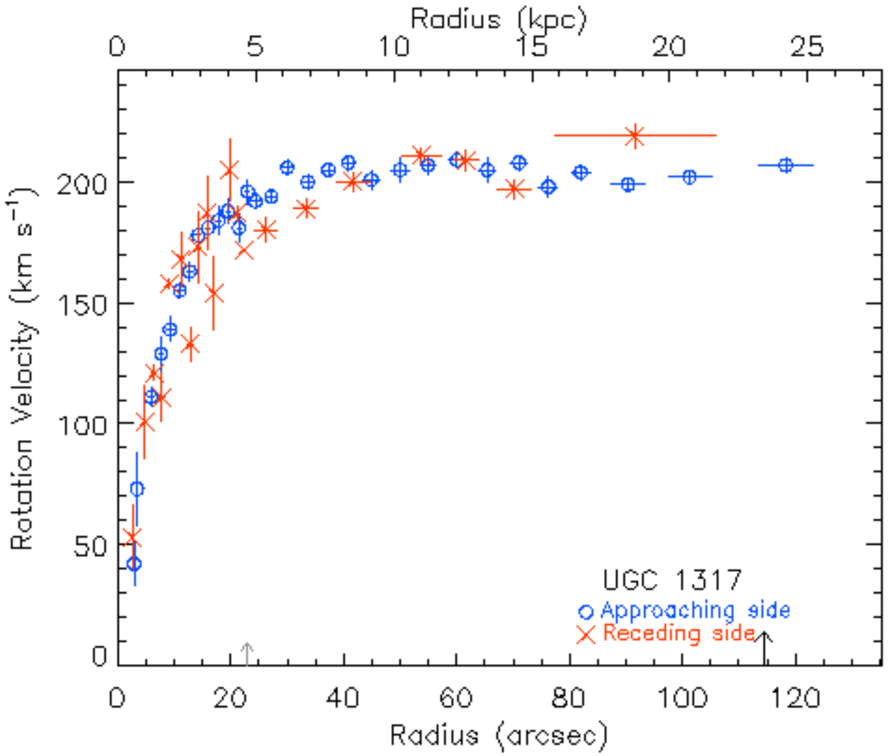
Drawbacks - Major Axis confusion

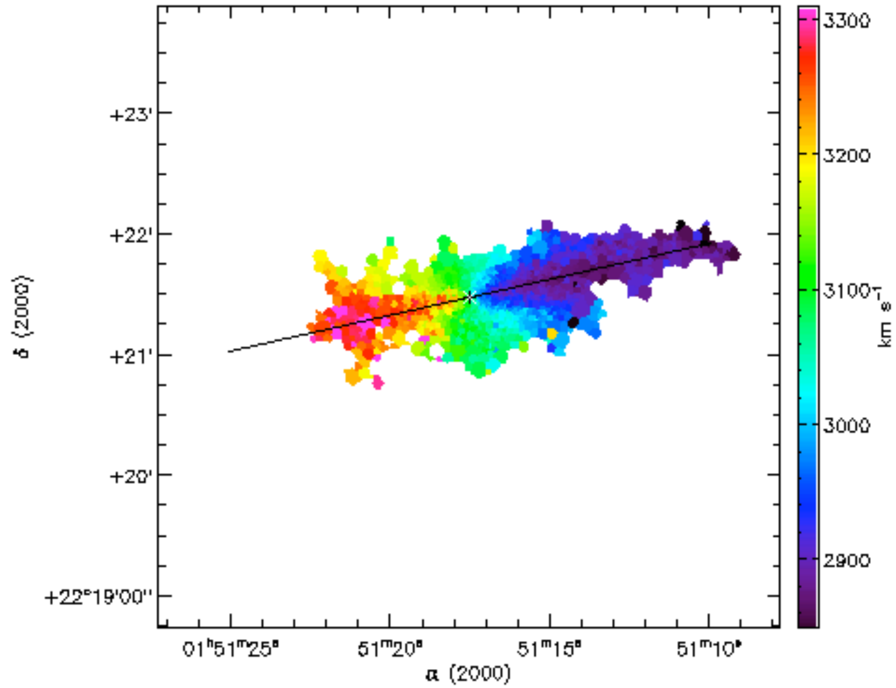
- Beam smearing

The Observation of Rotation Curves

The art of Rotation Curves

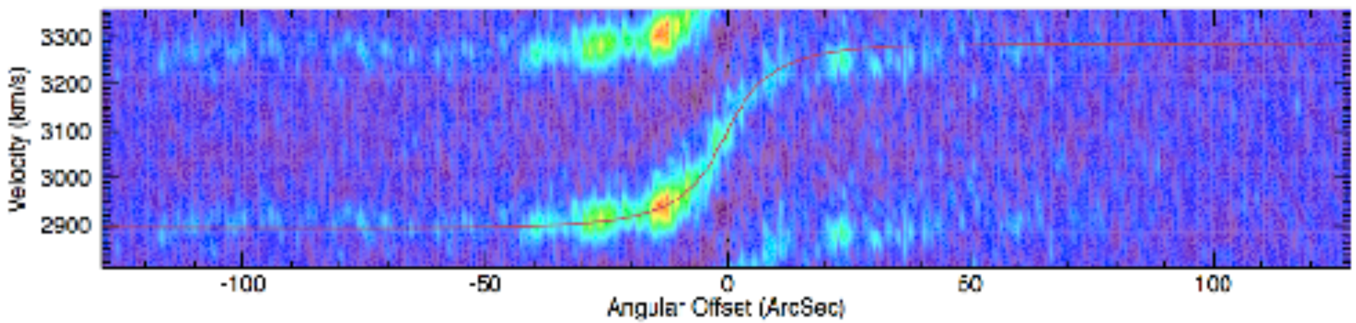
* Velocity Fields – Kinematical Parameters
  - HI – Tilted rings – warp HI disk
    PA & Inclination variations
  - Hα – Use of residual VF to estimate
    dispersion induced by non circular
    motions – Epinat 08
    Better estimation of errors





Epinat et al. 2008

fabryperot.oamp.fr/FabryPerot



The Observation of Rotation Curves

The art of Rotation Curves

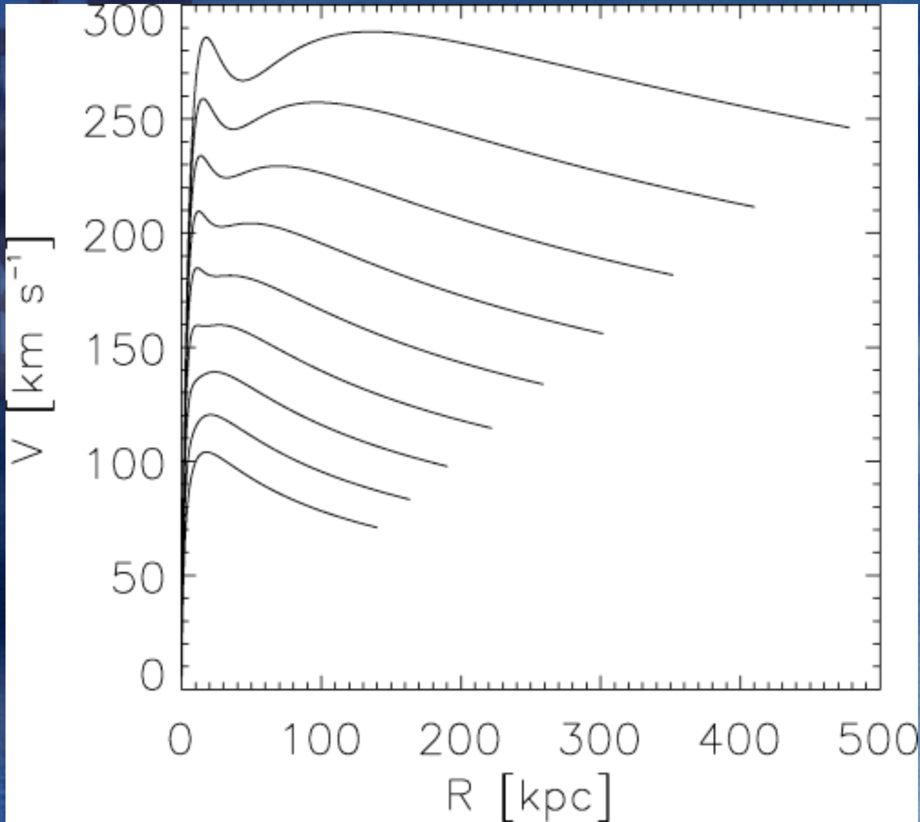
The Universal Rotation Curve

- Kinematical properties of Sb - Irr -> URC

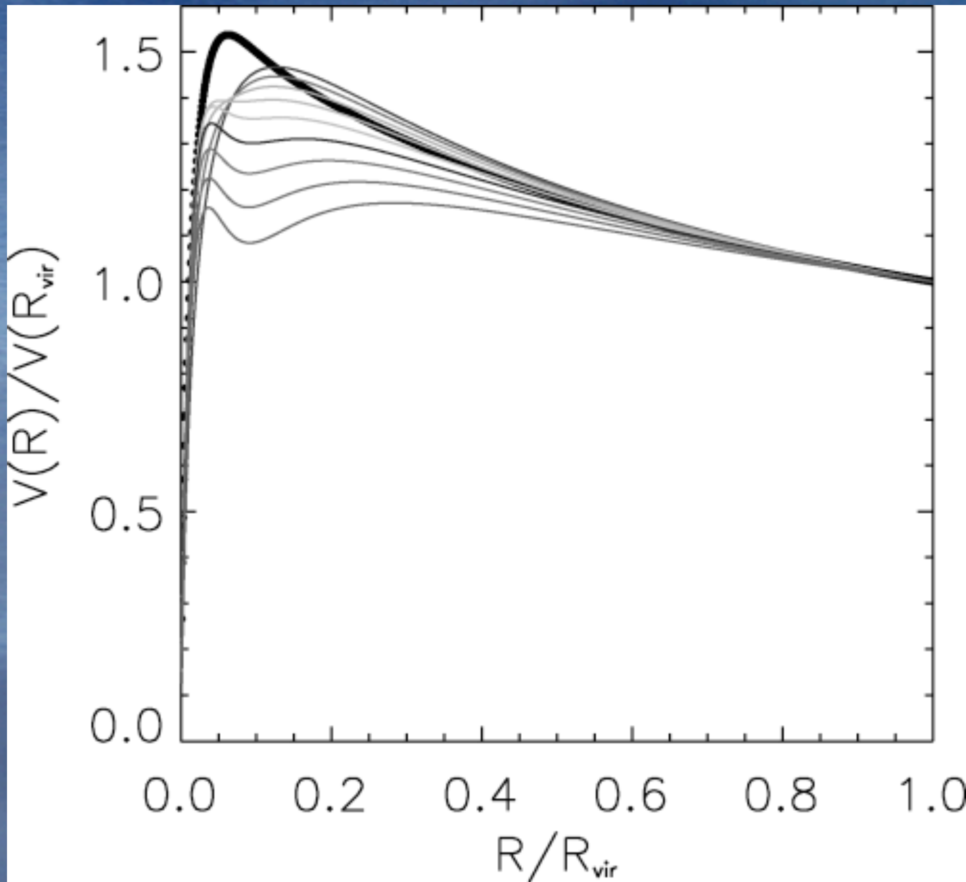
  Persic & Salucci 91 - Salucci 07

  RCs that can fit data tuned by galaxy property (luminosity - Vopt - mass...).

  URC meant to be observational counter part of the NFW RC from cosmological simulations.


300
250
200
150
100
50
0
V [km s⁻¹]
0
100
200
300
400
500
R [kpc]

Salucci 07

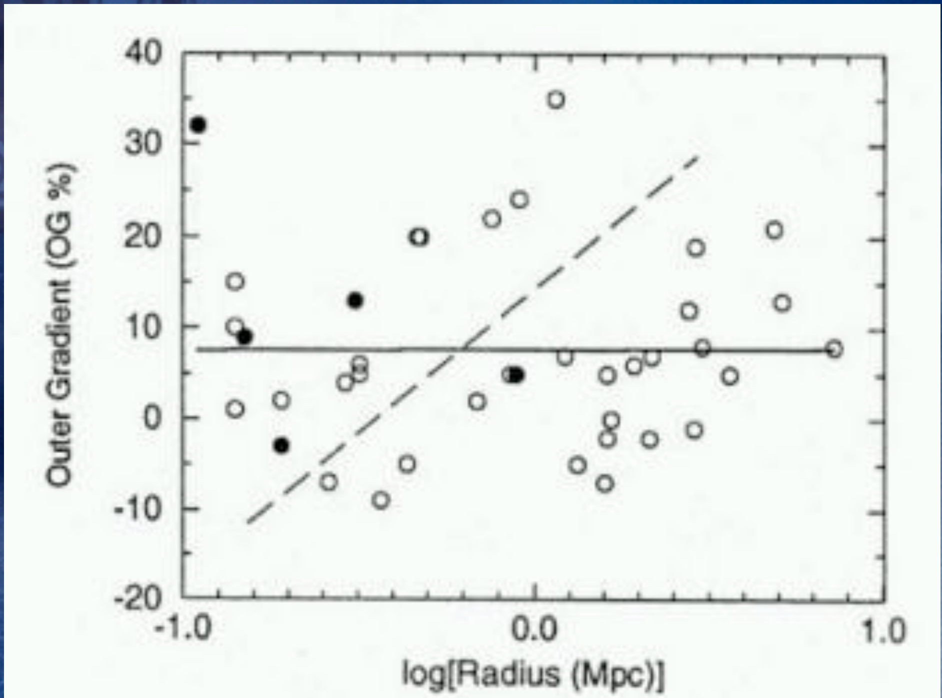

1.5
1.0
0.5
0.0
V(R)/V(R_vir)
0.0
0.2
0.4
0.6
0.8
1.0
R/R_vir

Influence of Environment

Importance of interactions

- Galaxies formation – importance of initial conditions – (large fluctuations)
- Faster evolution of galaxies in clusters & CGs
    * Density/nature of interactions
    * Galaxy/Galaxy – pairs – CGs
    * Clusters galaxies interactions
        - Dynamic pressure from hot gas
        - Galaxy/Galaxy interactions
    * Fusions and accretions

Influence of Environment



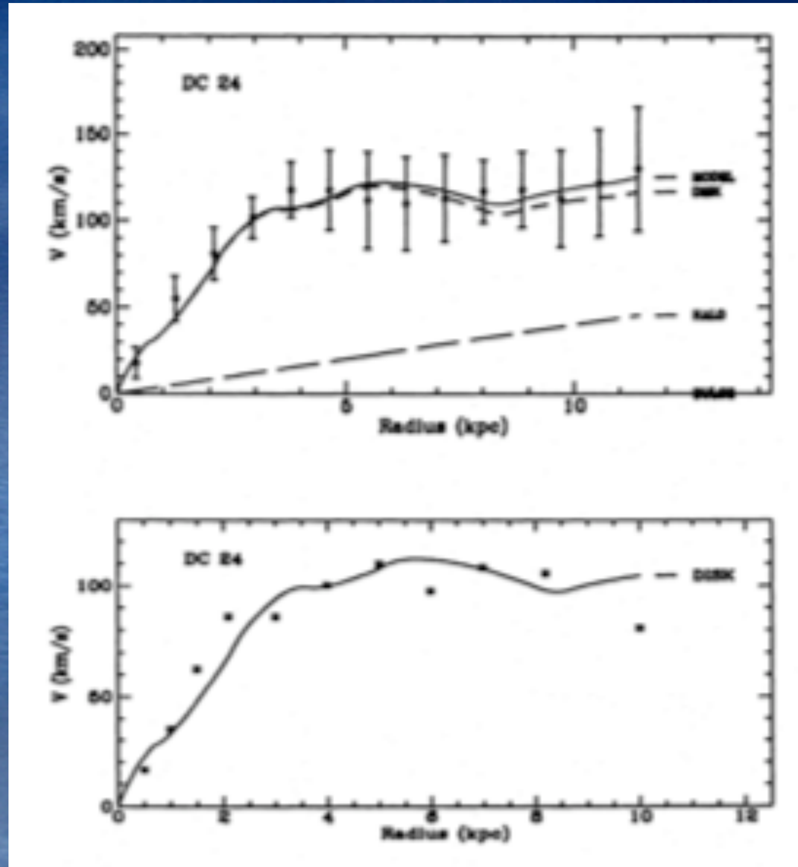


Fig. 11. Two-component (luminous and dark) mass models. (line=model, dash=disk, long dash=halo, zero bulge component). (Upper) Using O-profile and our spline-function fitted rotation curve. (Lower) Using O-profile and RWF's rotation curve.

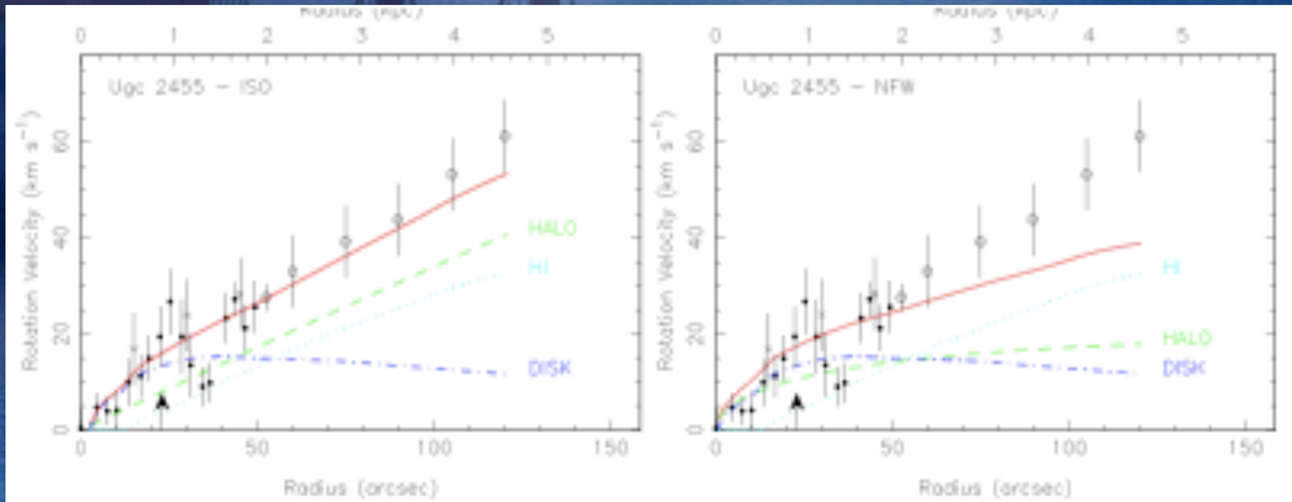
Amram et al. 96

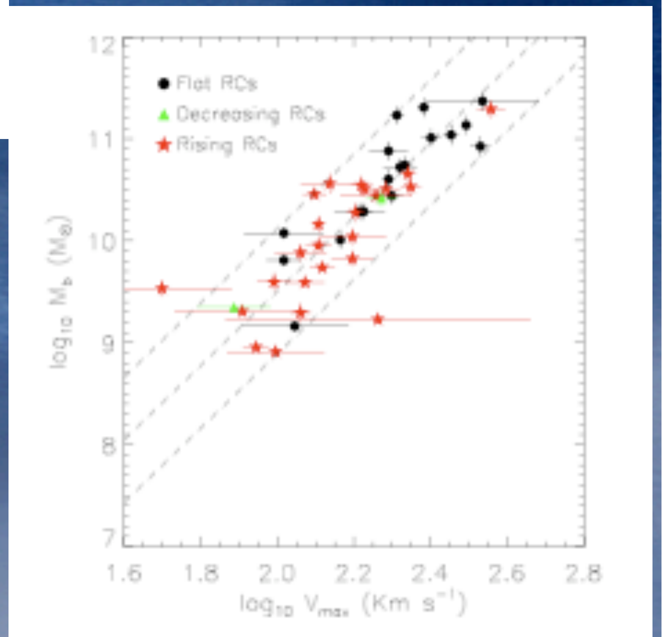
Cluster's galaxies

Influence of Environment

GHASP Survey - Gassendi Ha SPiral

Garrido 05 - Epinat 08a,b - Spano 08 - Torres-Flores 11





Influence of Environment

SINGs Survey

Daigle 06 - Dicaire 08

* Non circular motions + bars affect kinematical parameters

* Incorrect DM contribution in the mass model derived from RCs.

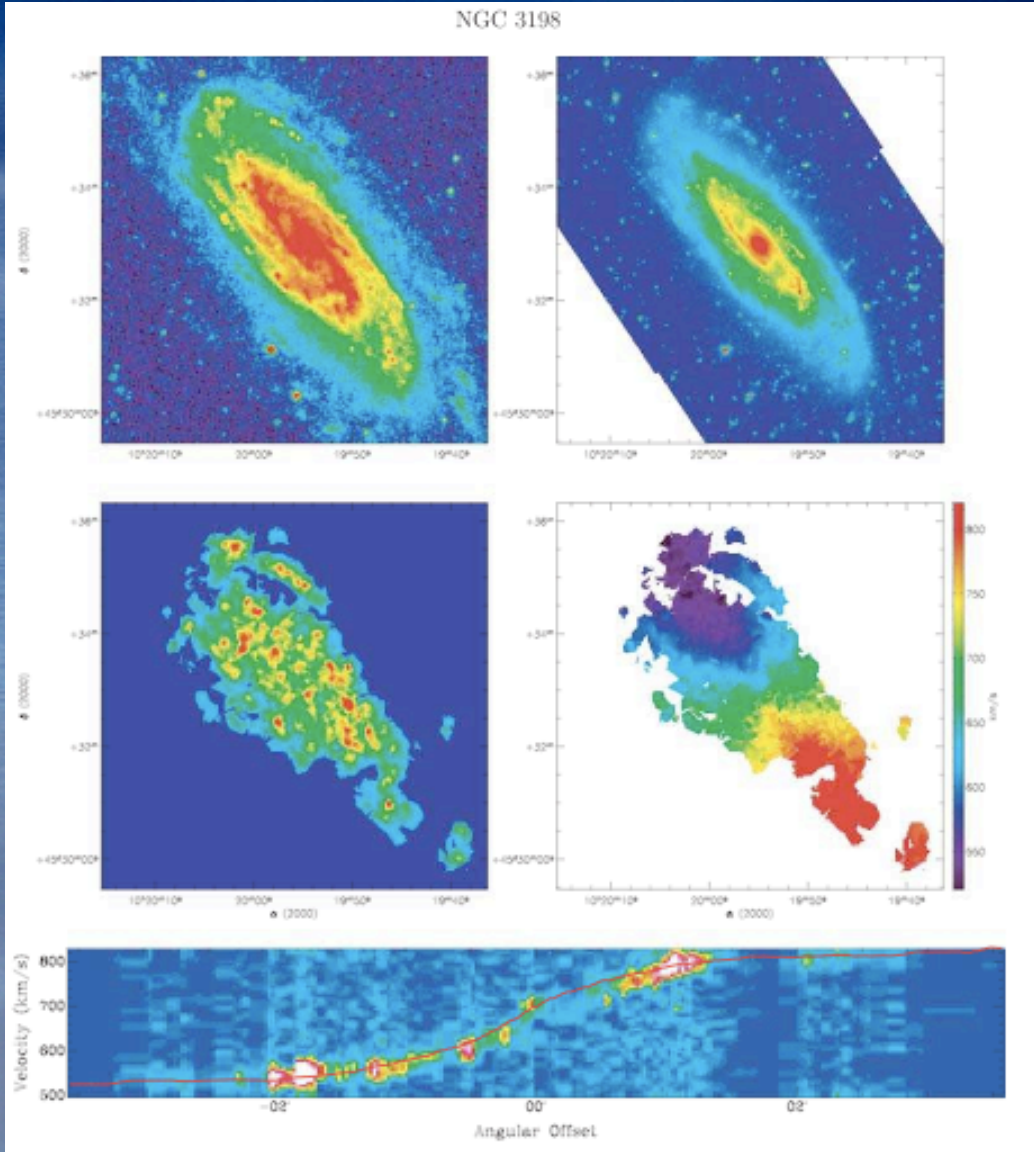
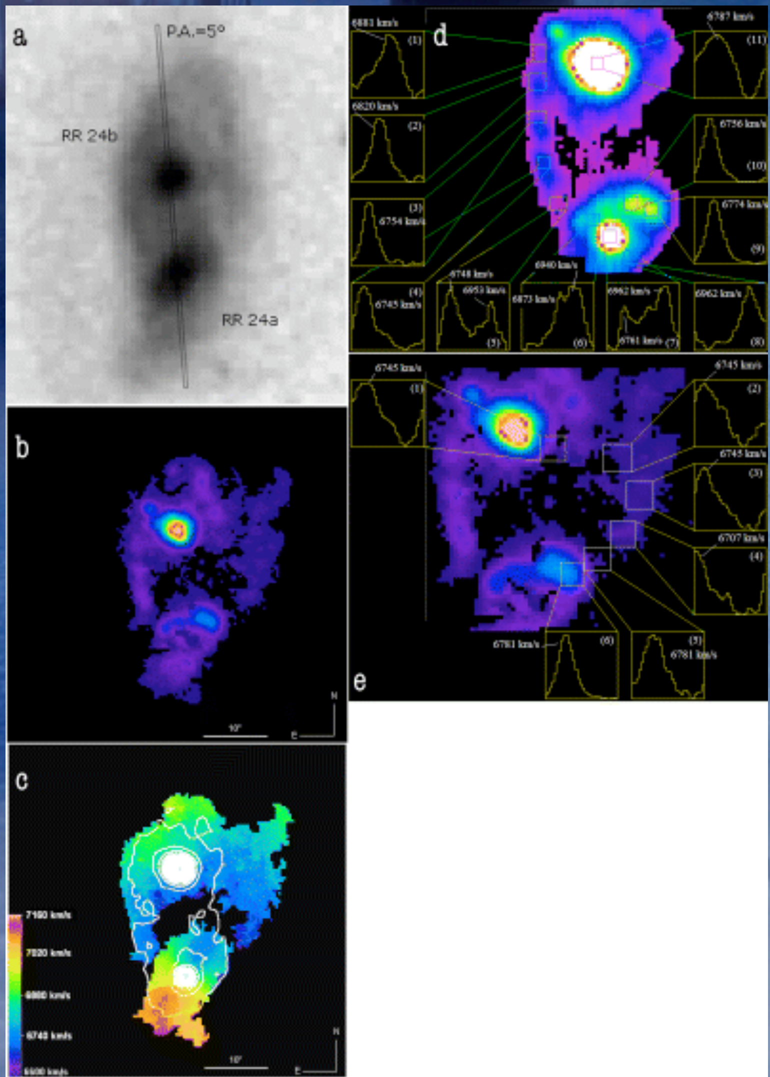
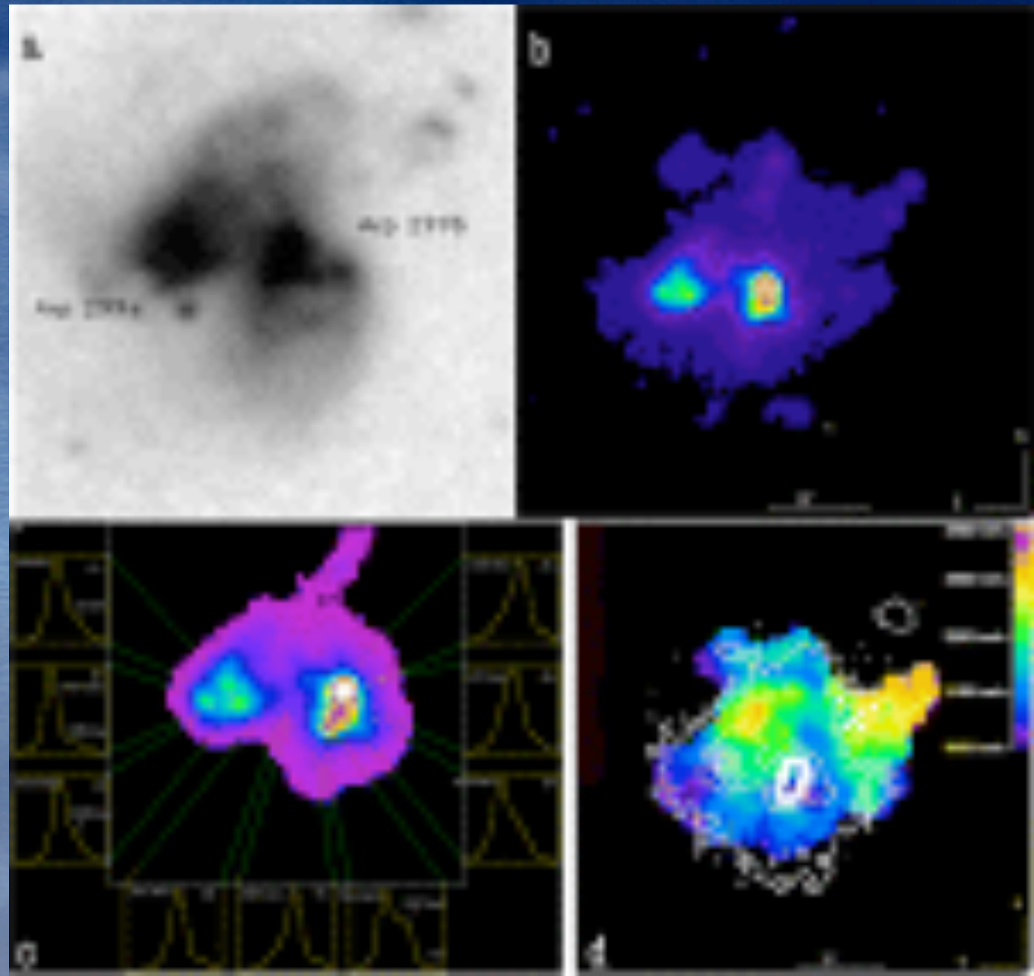


Figure B11. NGC 3198. Top left: XDSS Blue Band image. Top right: *Spitzer* IRAC 3.6-μm image. Middle left: Hα monochromatic image. Middle right: Hα velocity field. Bottom: PV diagram.

Influence of Environment

Galaxy Pairs





Rampazzo 05

Dark Halo in Compact Groups

Efficiency of interaction in different environments

- From accretions to fusions
- Impact on starburst
- Dark Halo fate

Summary

- Introduction on Hickson Compact Groups
- Kinematical study
- The mass model
- Results
- Conclusion and Perspectives

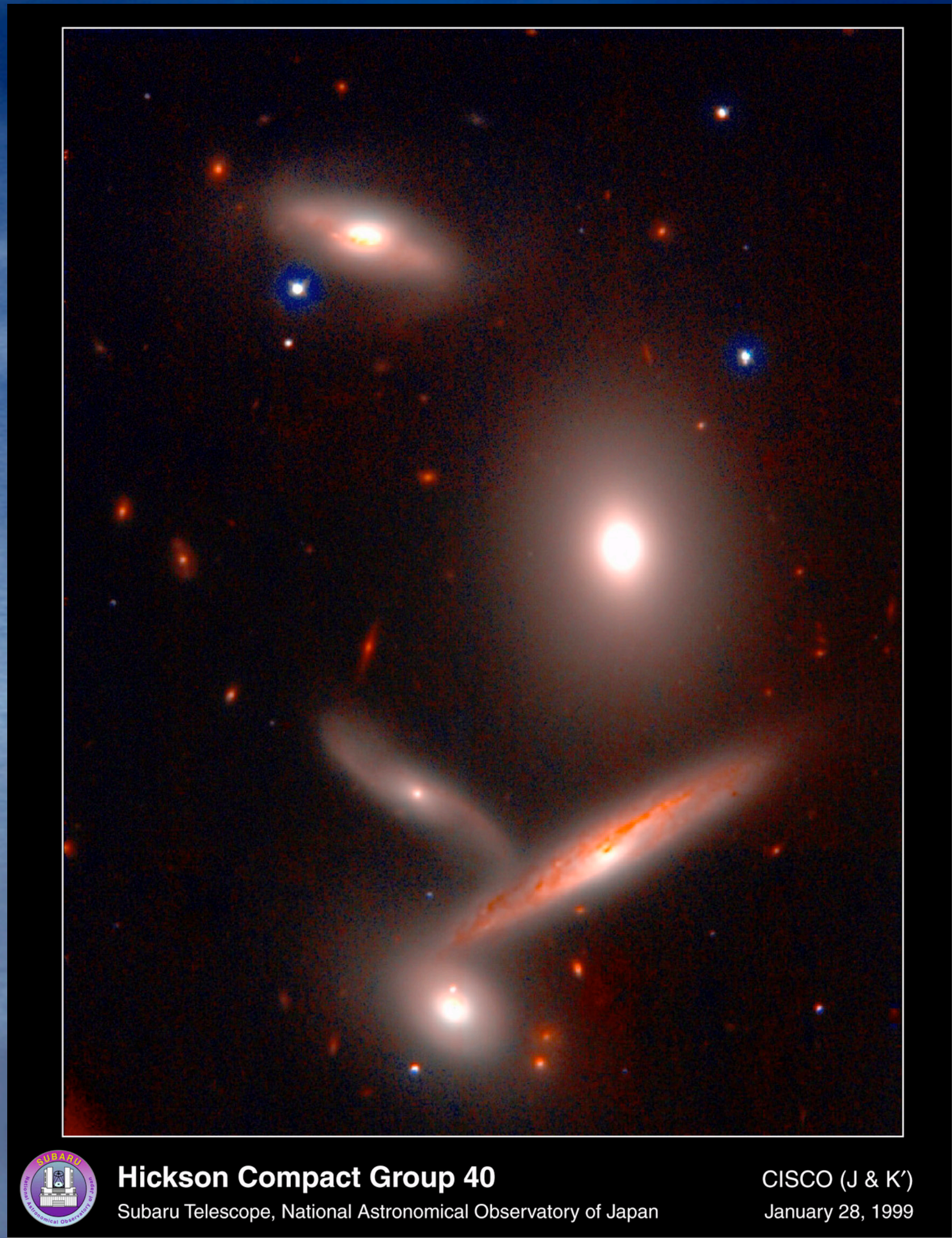
Description

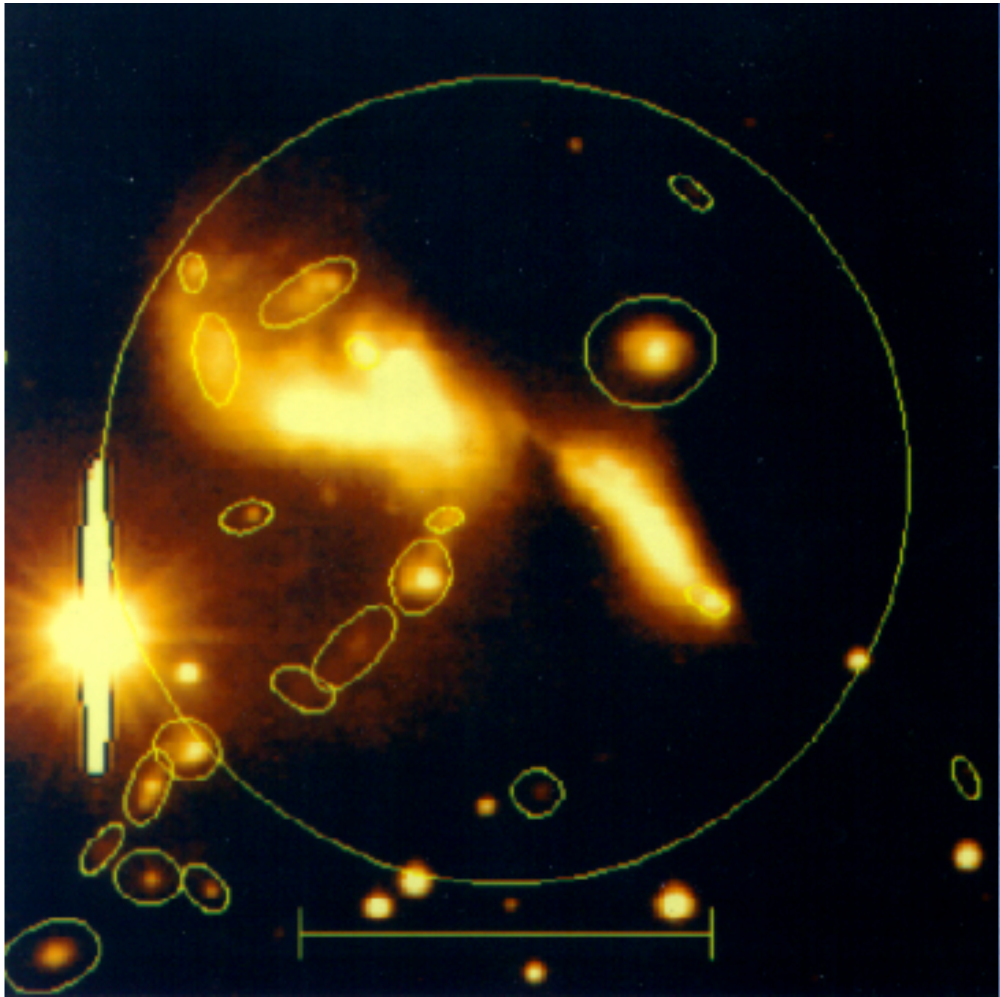
* Definition
  - Groups of 3 to 7 bright galaxies
  - Three magnitudes interval (B band)
  - Small separation on the sky

Hickson found 100 groups

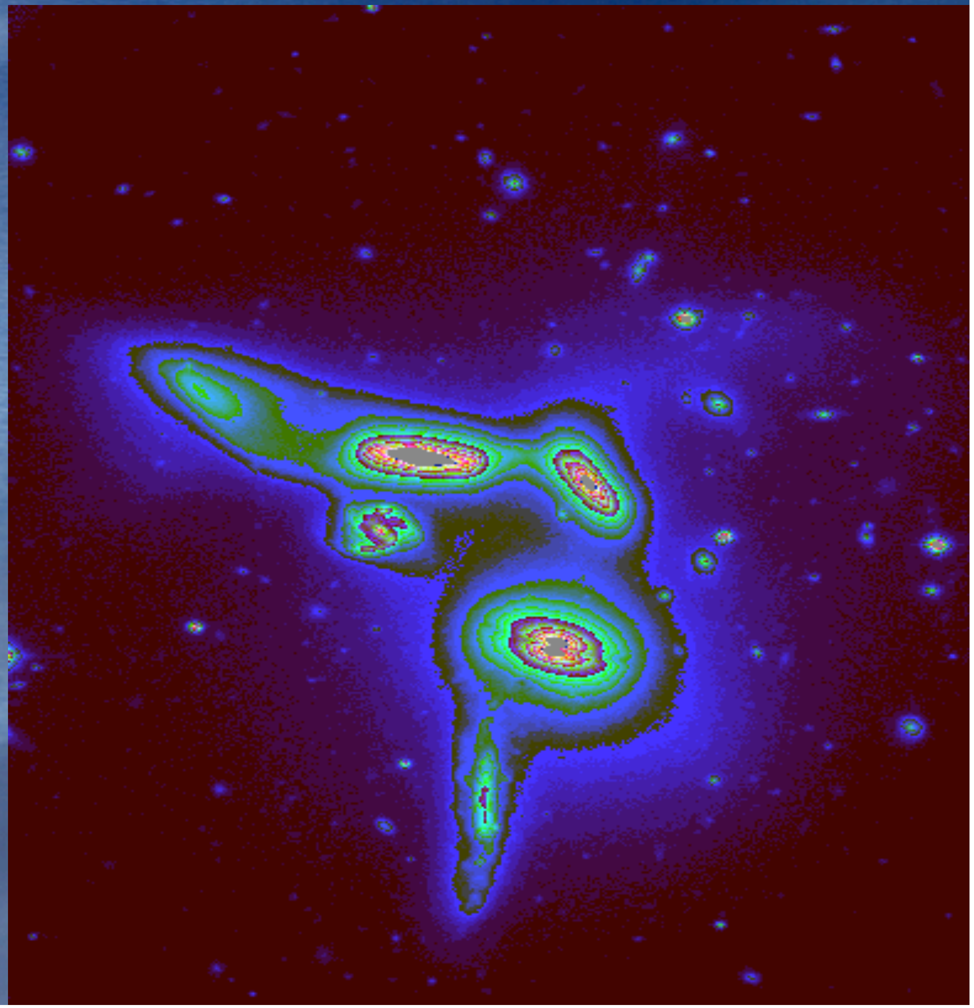
And 92 physically bound


Hickson Compact Group 87
Hubble Heritage
PRC99-31 • Space Telescope Science Institute • Hubble Heritage Team (AURA/STScI/NASA)


SUBARU
Hickson Compact Group 40
Subaru Telescope, National Astronomical Observatory of Japan
CISCO (J & K′)
January 28, 1999



HCG 31



HCG 79
Seyfert's Sextet

Consequence

Hickson study → low velocity dispersion

+

Hickson study → high density

↓

Favours Interactions

HCG are good labs to study interactions

Several signs

* Different ISM phases
  - -> X rays - Potential well - Ponman 96
  - -> HI - Deficit - Verdes-Montenegro 01
  - -> NIR - MIR - FIR - Bitsakis 10
  - -> UV - GALEX - Torres-Flores 09
  - -> Molecular CO
  - -> Warm gas - $H\alpha$
* Star formation history - Enhanced SFR due to interactions (Verdes-Montenegro 01)

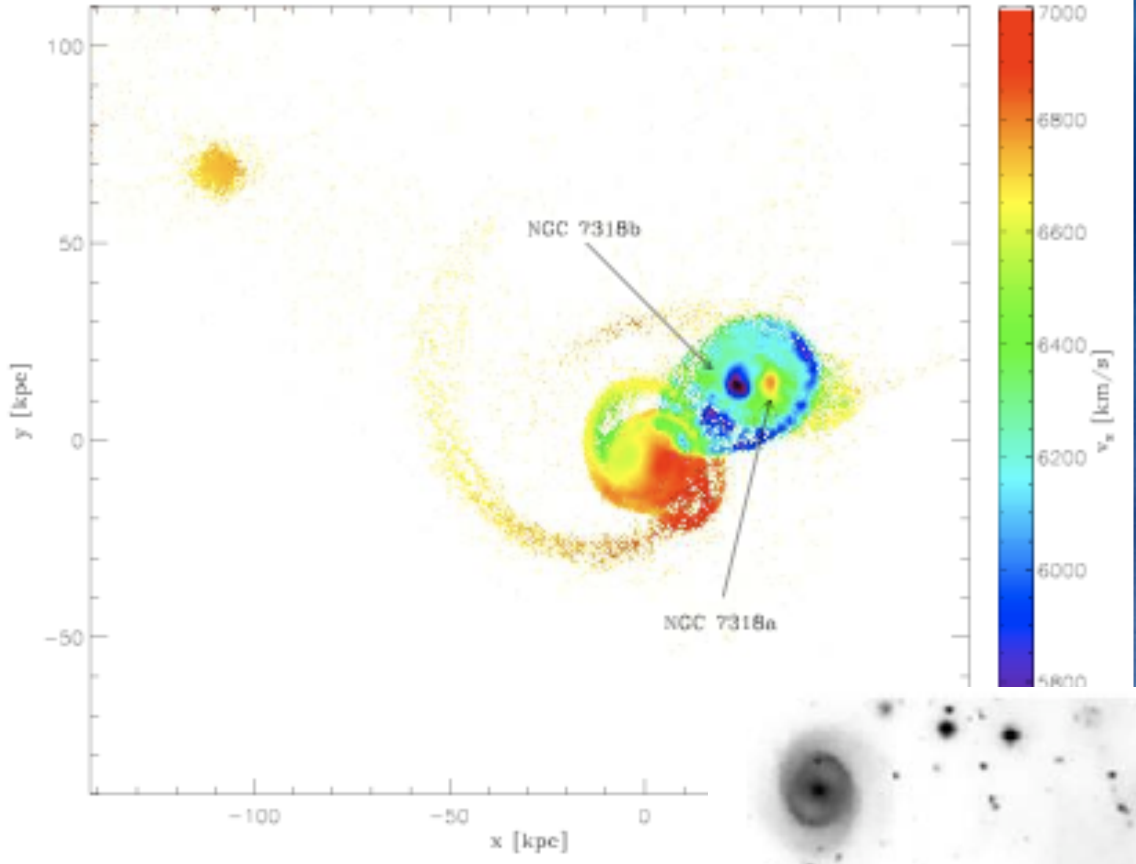
HCGs simulations

- An handfull of N bodies simulations

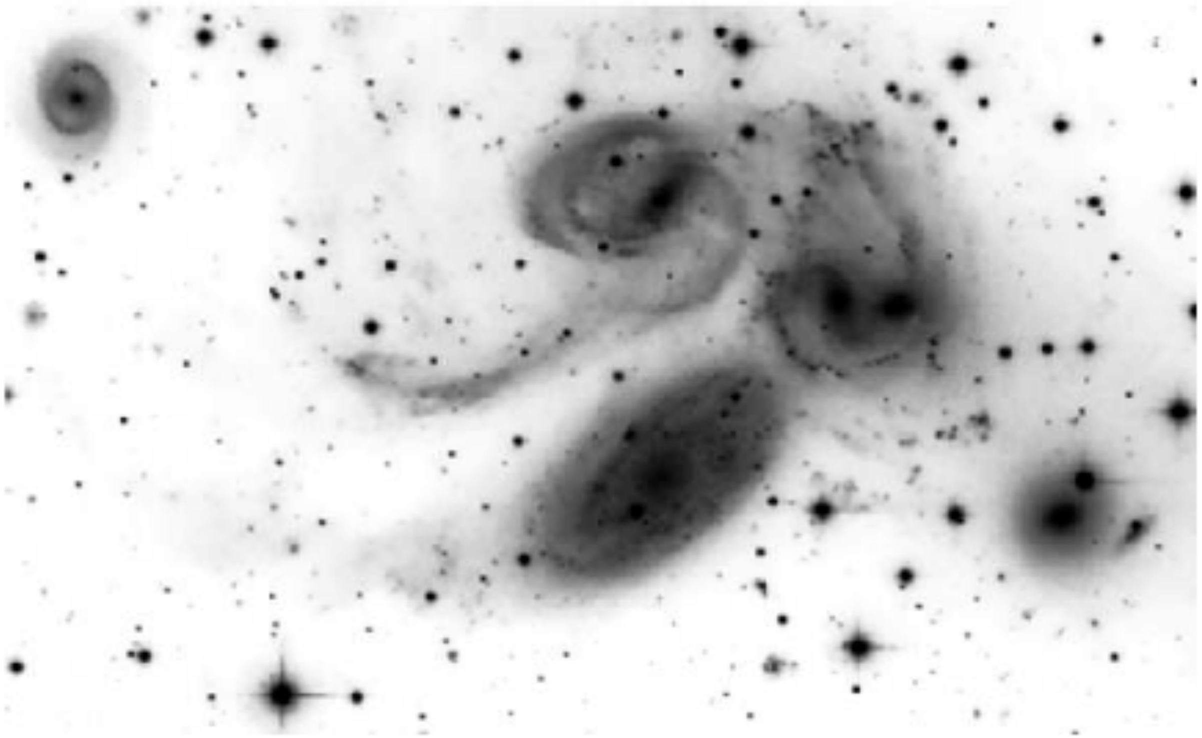
  * Athanassoula 97 – Fine tuned initial conditions to survive Hubble time

  * Aceves 01 – Karachentsev's compact triplets most advanced stage of gravitational clustering of initially diffuse triplets

  * Renaud 10 – Stephan Quintet simulation


NGC 7318b
NGC 7318a
y [kpc]
x [kpc]
v_r [km/s]
100
50
0
-50
-100
7000
6800
6600
6400
6200
6000
5800


Renaud 10

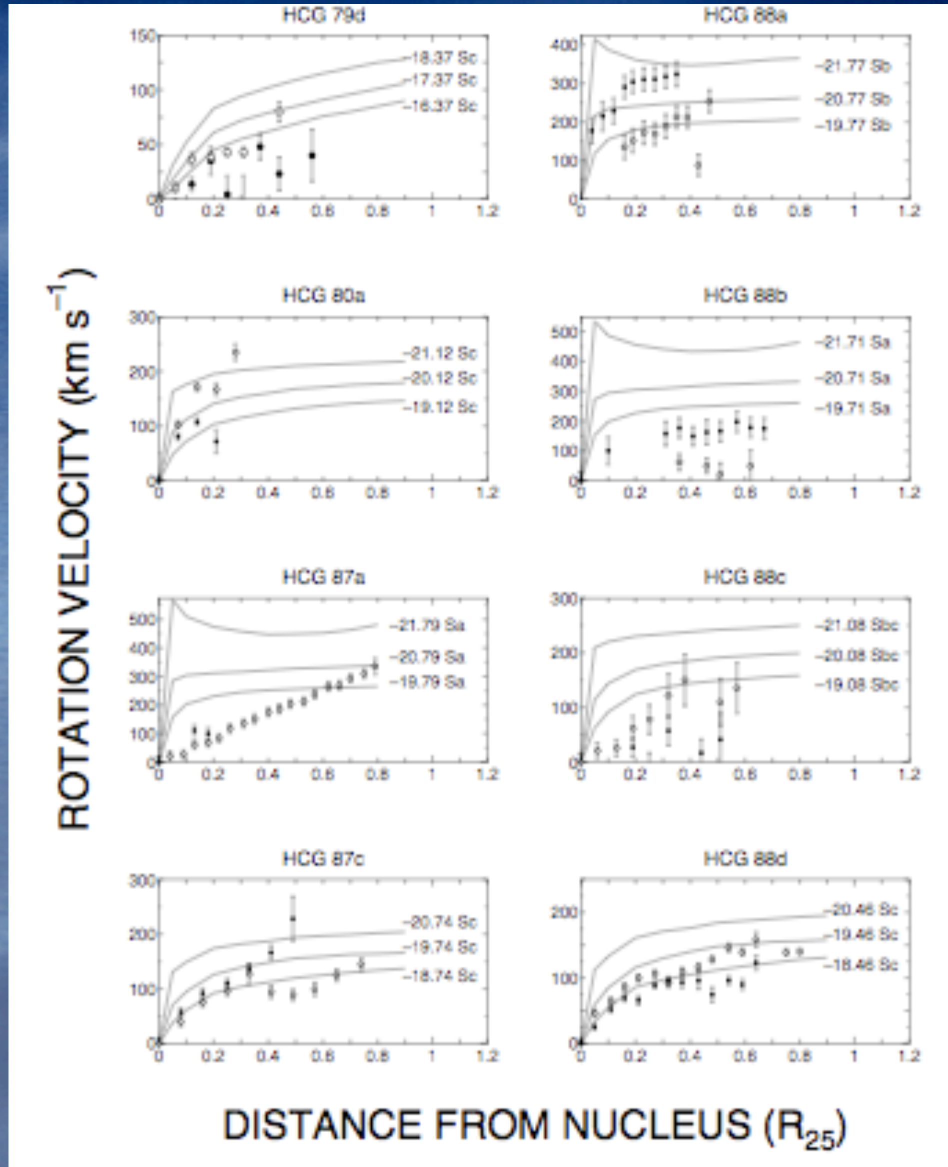


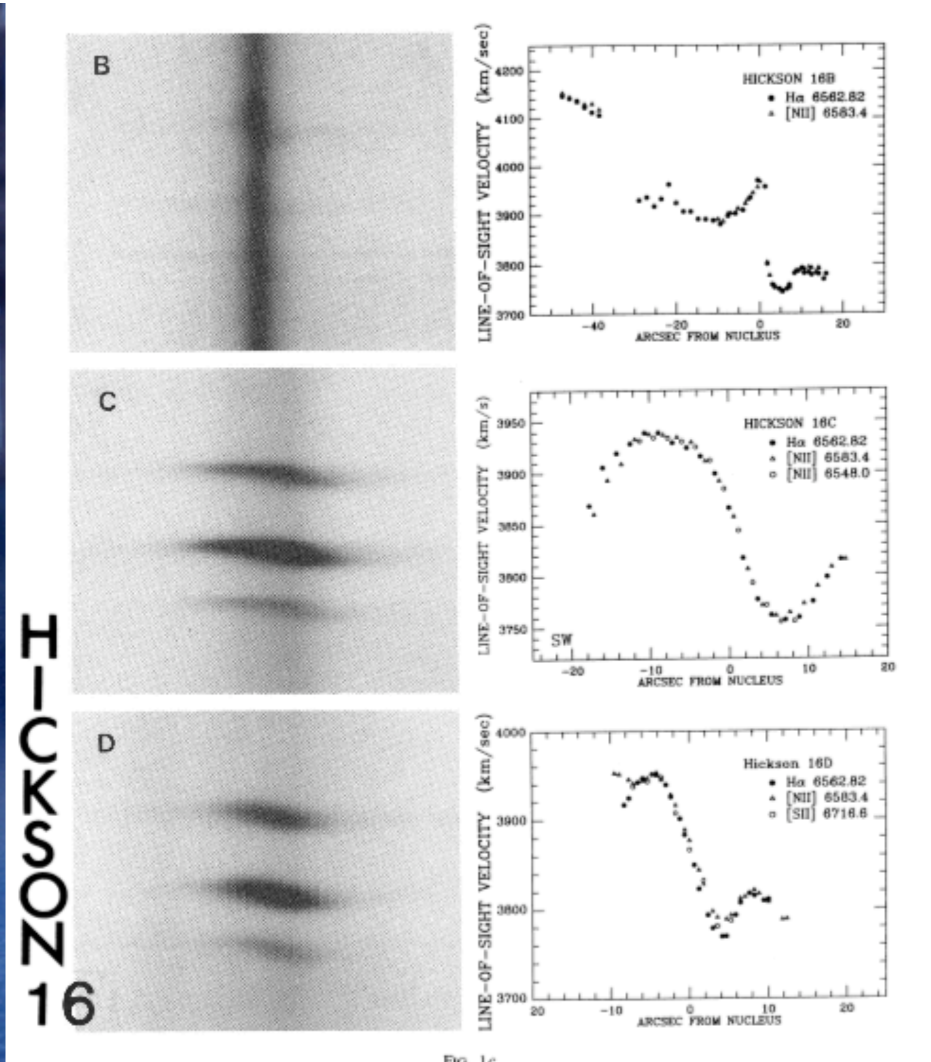
HCG Kinematics

- Rubin et al. 1991 – first study – long slit 25 RCs
  Spirals show high degree of disturbance
  B – band Tully – Fisher relation

- Nishiura et al. 2000 – long slit 30 RCs
  Asymmetry and peculiar RCs more frequent
  No correlation between dynamical prop. & activity

Nishiura 00



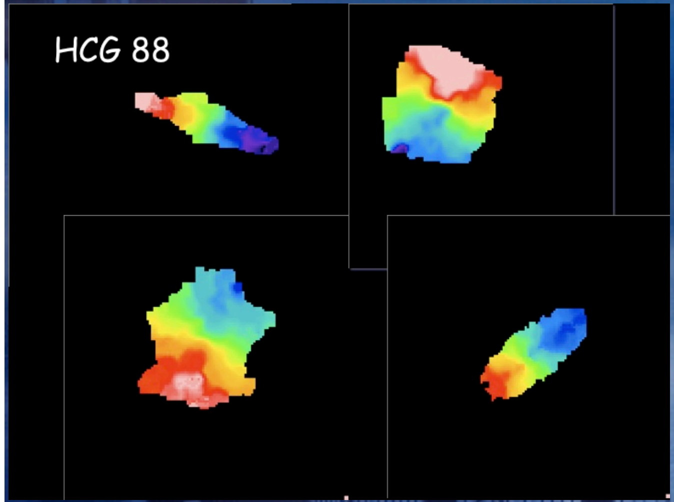


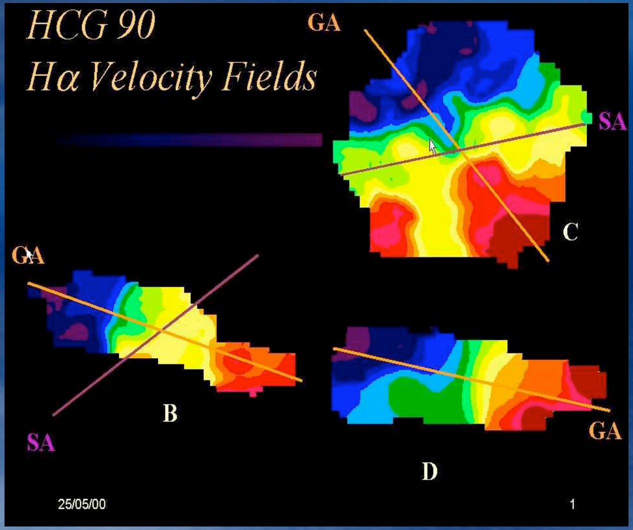
Rubin 91

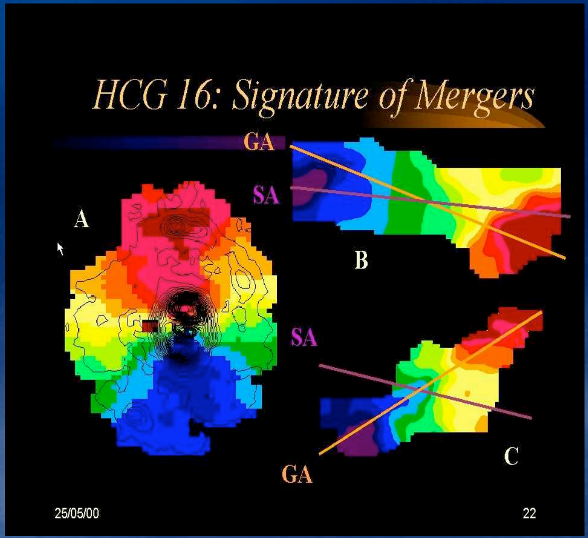
2D Kinematical Study

- Use of scanning Fabry-Perot for 2D maps
  * 55 velocity fields - 41 RCs
- Individual group study
  * Sequence of evolution
  * Tidal dwarf galaxies candidates
- Study of the sample
  * Tully Fisher
  * Mass Distribution

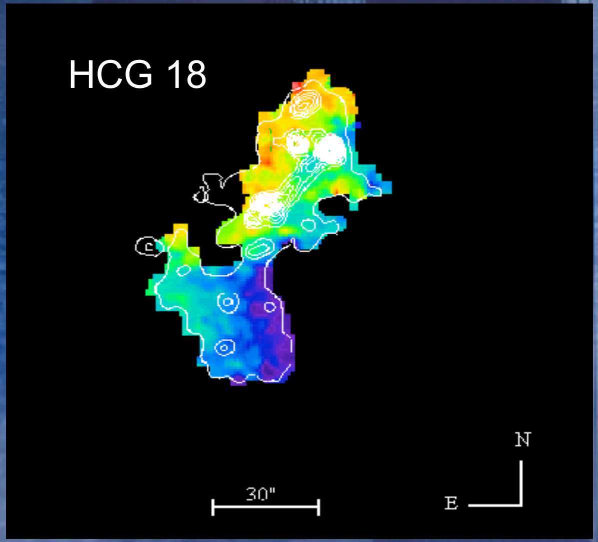
http://fabryperot.oamp.fr/FabryPerot

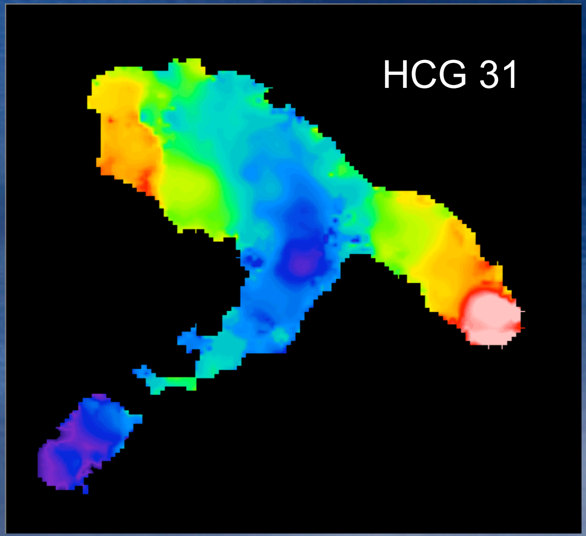






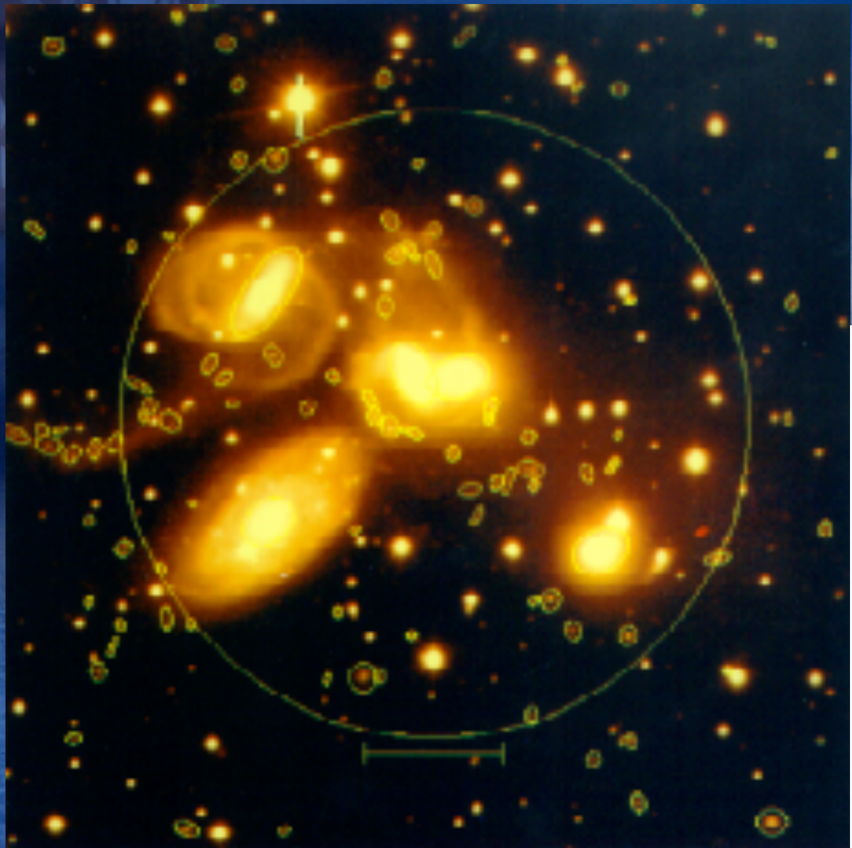
Velocity maps





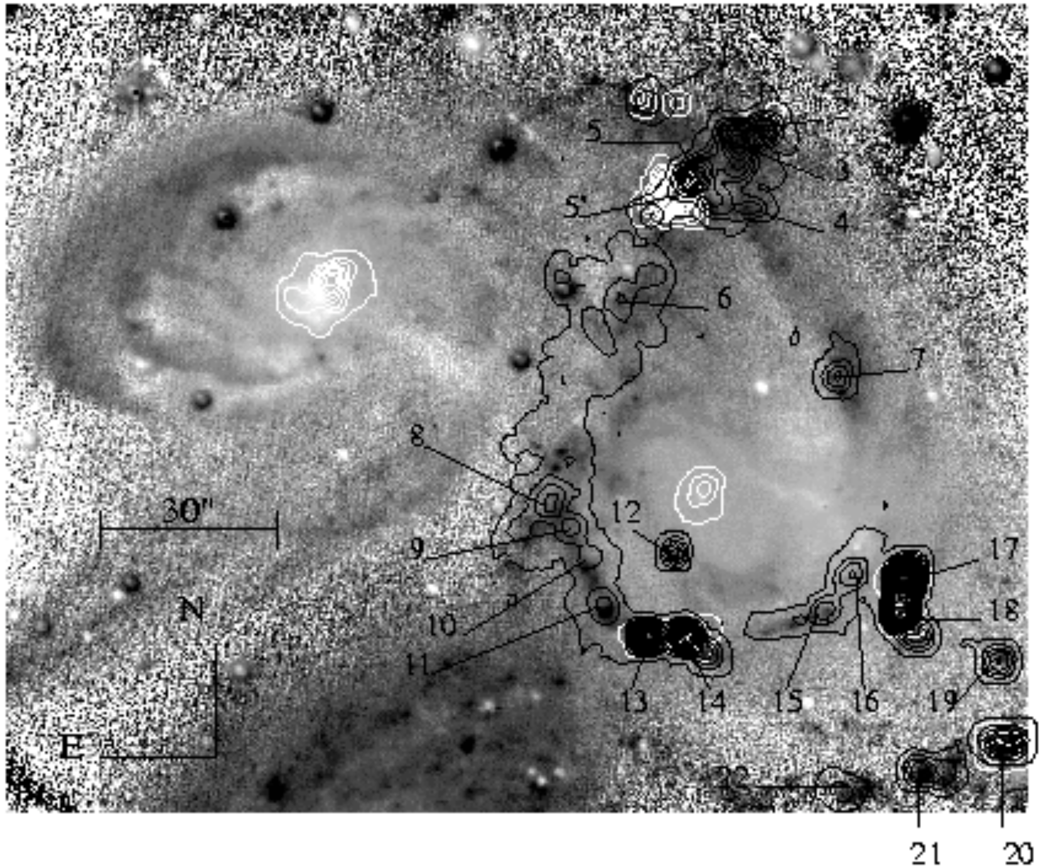
Plana et al. 1998, 2000, 2003
MdO et al. 1998
Amram et al. 2003, 2004, 2007
Torres-Flores et al. 2009

Tidal dwarf galaxies candidates



Hunsberger et al. 1996

Plana et al. 1999



Mendes de Oliveira et al. 2001

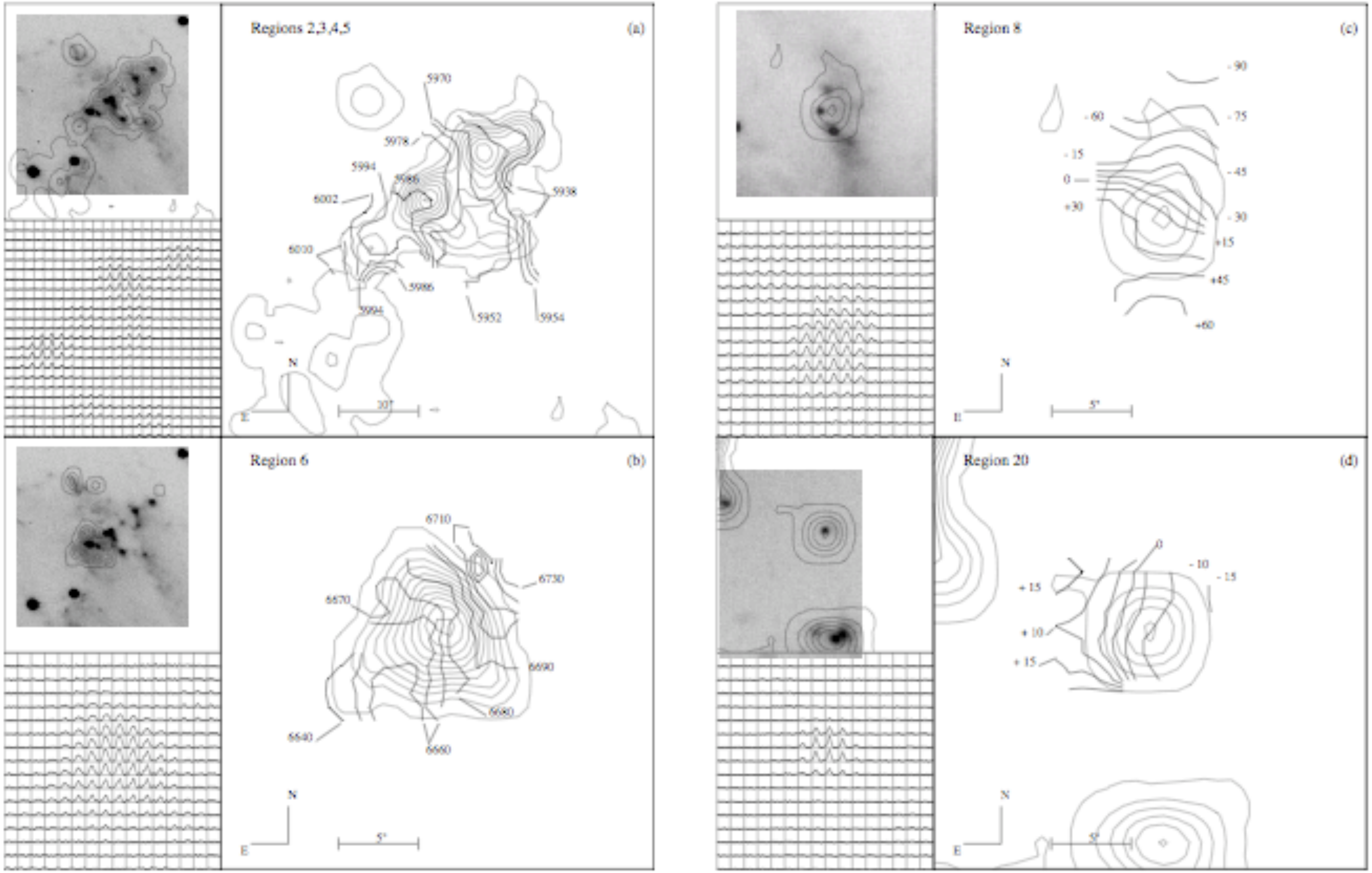
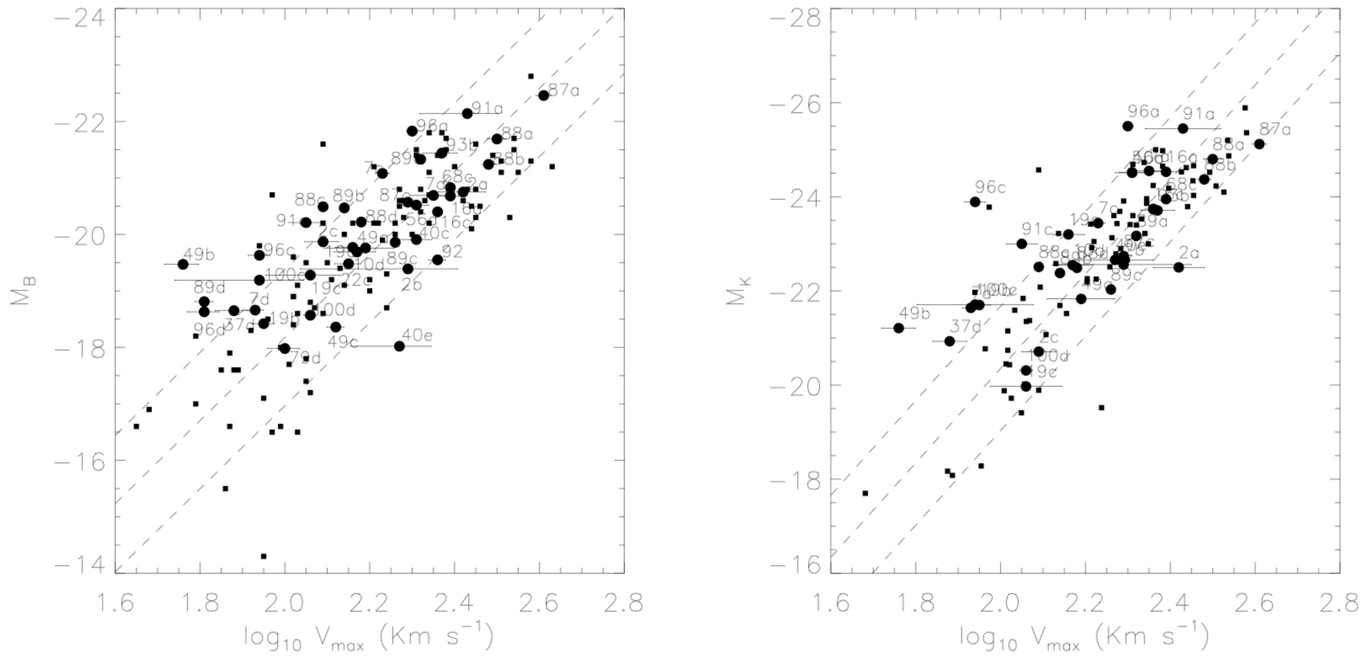


FIG. 3.—(*a–g*) *Top left*, *B*-band image superposed on the monochromatic map, with the isocontours the same as those presented in Fig. 1*a*; *bottom left*, profiles from the Fabry-Pérot data cube—the pixel size is 0″.86; *right*, the velocity field superposed on the monochromatic image. The field size for the right panel is the same as that for the top left panel.

The Tully-Fisher in NIR

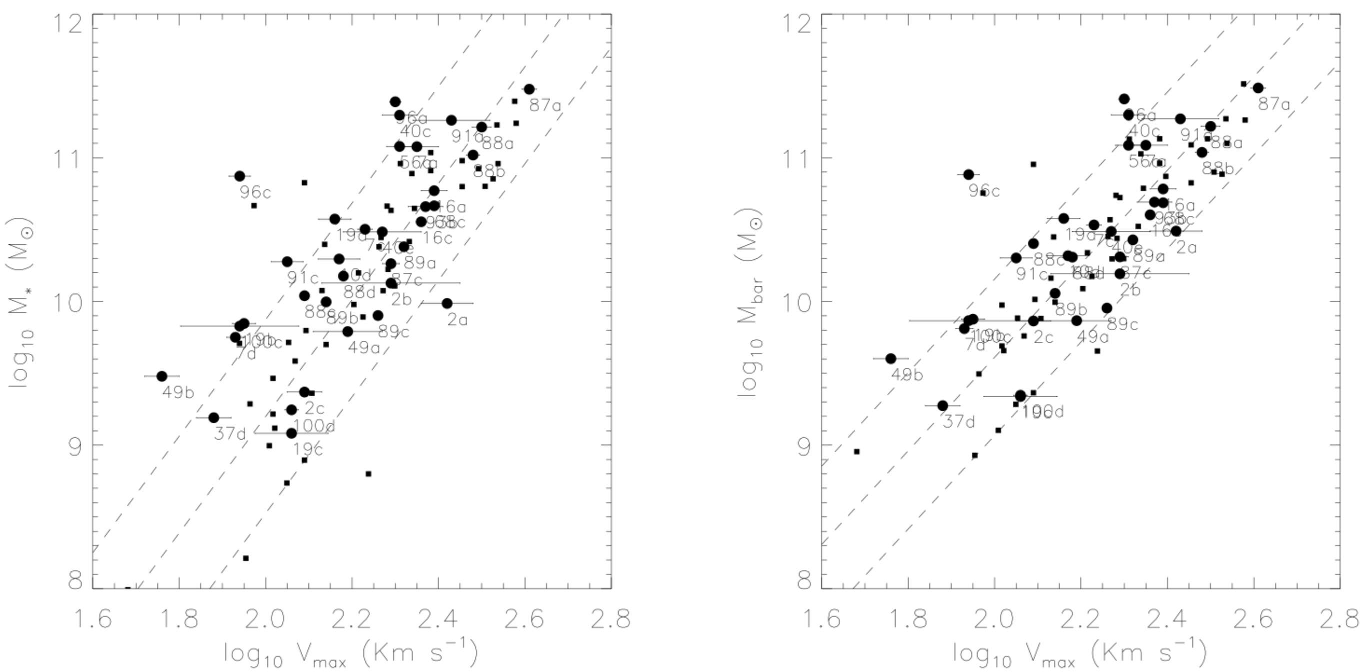
- Problem of B-band -> not an old pop. tracer + dust extinction
- Do TF relation using NIR band
  * K band photometry from 2mass survey
  * Comparison with GHASP survey – 200 field galaxies.
- 36 galaxies – m_{K20} from 2mass corrected from internal and external extinction

TF relation
B and K bands



Torres-Flores et al. 2011 submitted

Baryonic TF

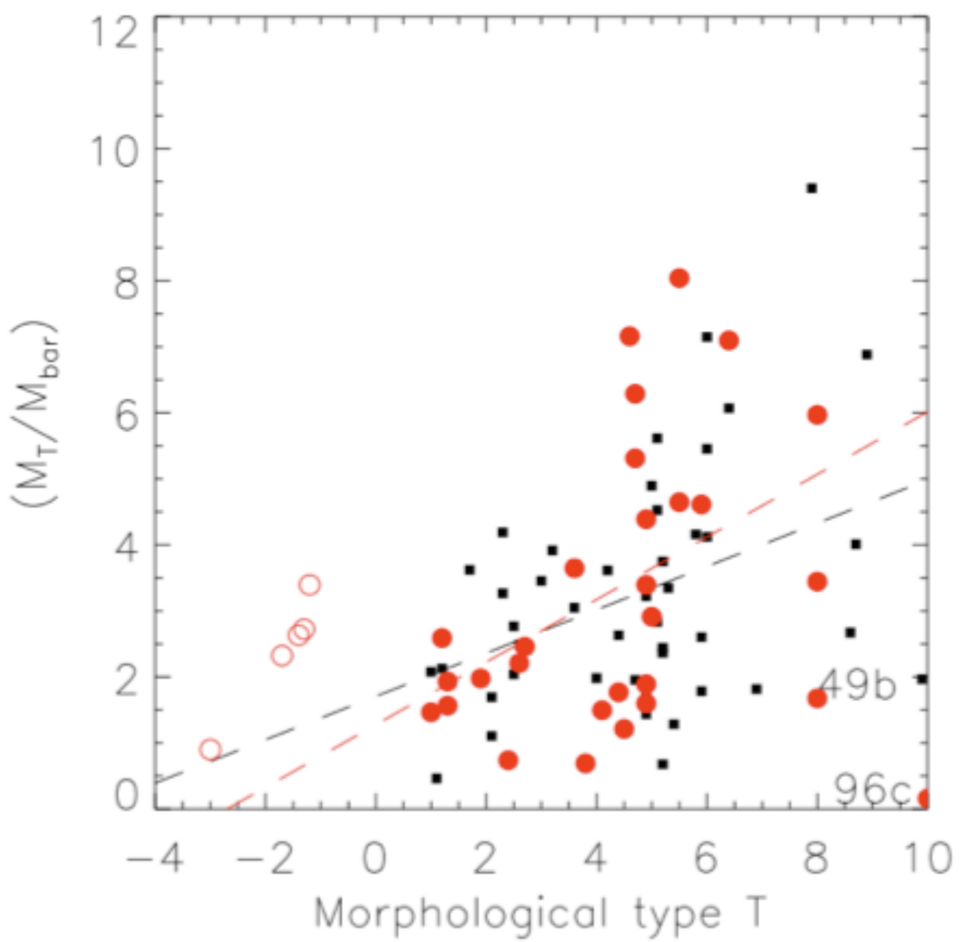


The baryonic TF relation for HCG

- Important for M/L parameters
- Baryonic mass = stellar + gas masses
  * Stellar mass = $10^{-0.776+0.452(B-R)} L_K$
    (from Bell & de Jong 2001)

  * HI masses Haynes & Giovanelli 84
    corrected with Verdes-Montenegro 2001
  * H_2 masses - estimation

The baryonic TF relation for HCG



* Late type galaxies more DM dominated than early type

* Little differences between HCG and field galaxies

Torres-Flores et al. 2011 submitted

Mass Distribution in HCG

- Next step is to estimate DH shape
- And compare with others environment
  => Differences of DH due to interactions

- Sample of 19 HCG galaxies with RCs
  * RCs in Amram et al. 03, Plana et al 03
  * Surface photometry: J-band in 2mass
  * Mass model to fit RCs

Mass Distribution in HCG

- Mass model: Stellar mass from surf. bright.
  Dark Halo from spherical distr.

  * Isosphere:

$$\rho(r) = \rho_o / [1 + (r/R_o)^2]^{3/2}$$

  * NFW:

$$\rho(r) = \rho_c / [(r/ R_c) (1 + r/R_c)^2]$$

Mass Distribution in HCG

- Stellar mass: surf. bright. profile in J-band

2 components:

Exponential Disk: $$\mu = \mu_o + 1.0857\,\frac{r}{r_o}$$

$r^{1/4}$ bulge: $$\mu = \mu_e + 8.3268\left[\left(\frac{r}{r_e}\right)^{1/4} + \left(\frac{r}{r_t}\right)^{4}\right]$$

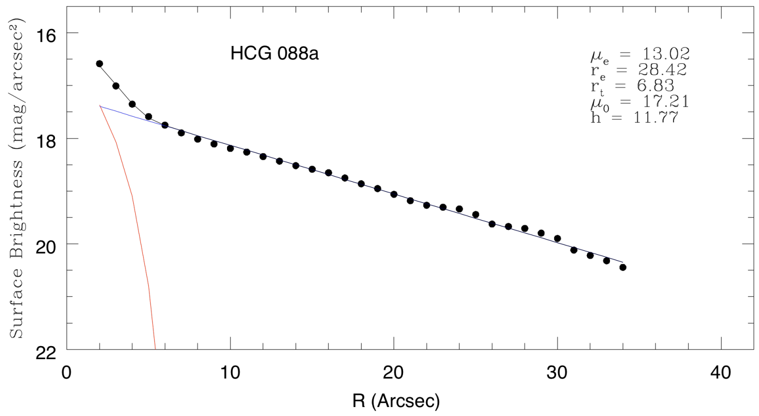
5 parameters: μ_0, r_0, μ_e, r_e and r_t

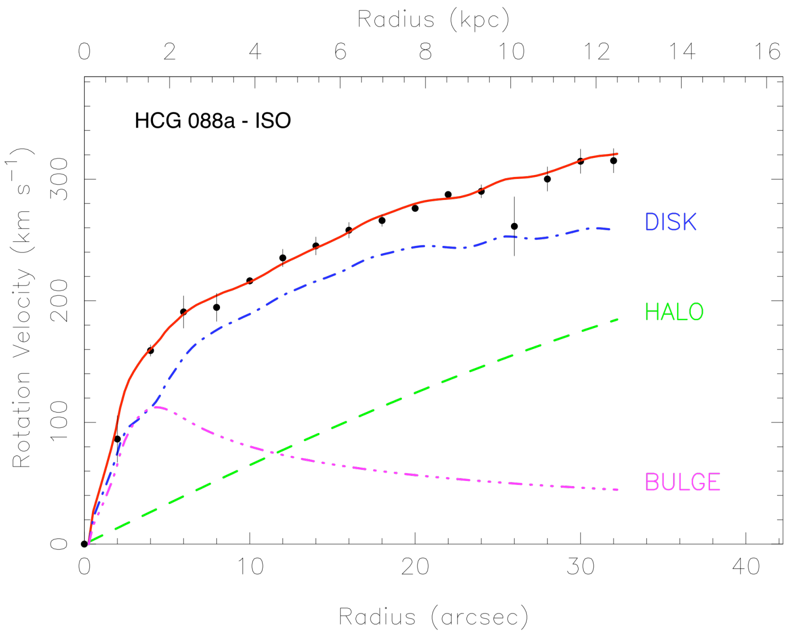
Mass Distribution in HCG

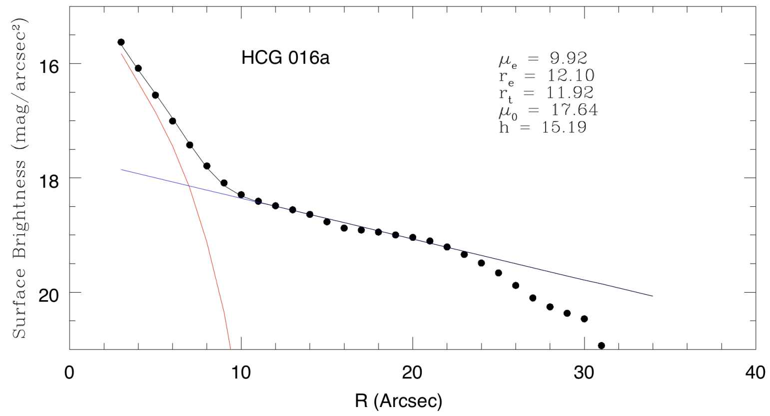
- Mass model from Carignan & Freeman 85 revised Blais-Ouellette 00 – Best Fit Model

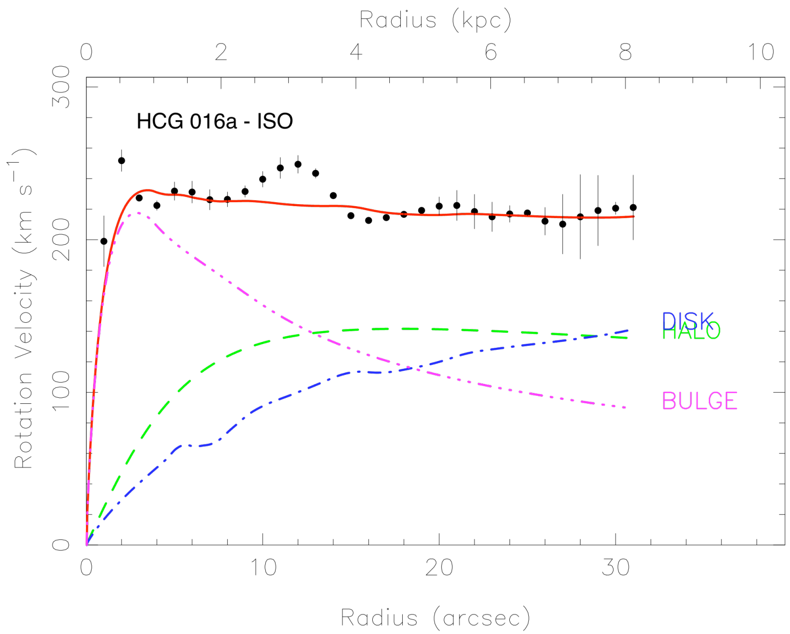
    * Quadratic sum of velocity contribution for disk, bulge and halo
    * RC fit by minimizing the χ^2 in a 4D space $(M/L)_{disk}$, $(M/L)_{bulge}$, ρ_0 and R_0

- Maximum Disk Model to get the upper limit of the disk contribution


HCG 088a
μ_e = 13.02
r_e = 28.42
r_t = 6.83
μ_0 = 17.21
h = 11.77
Surface Brightness (mag/arcsec²)
R (Arcsec)

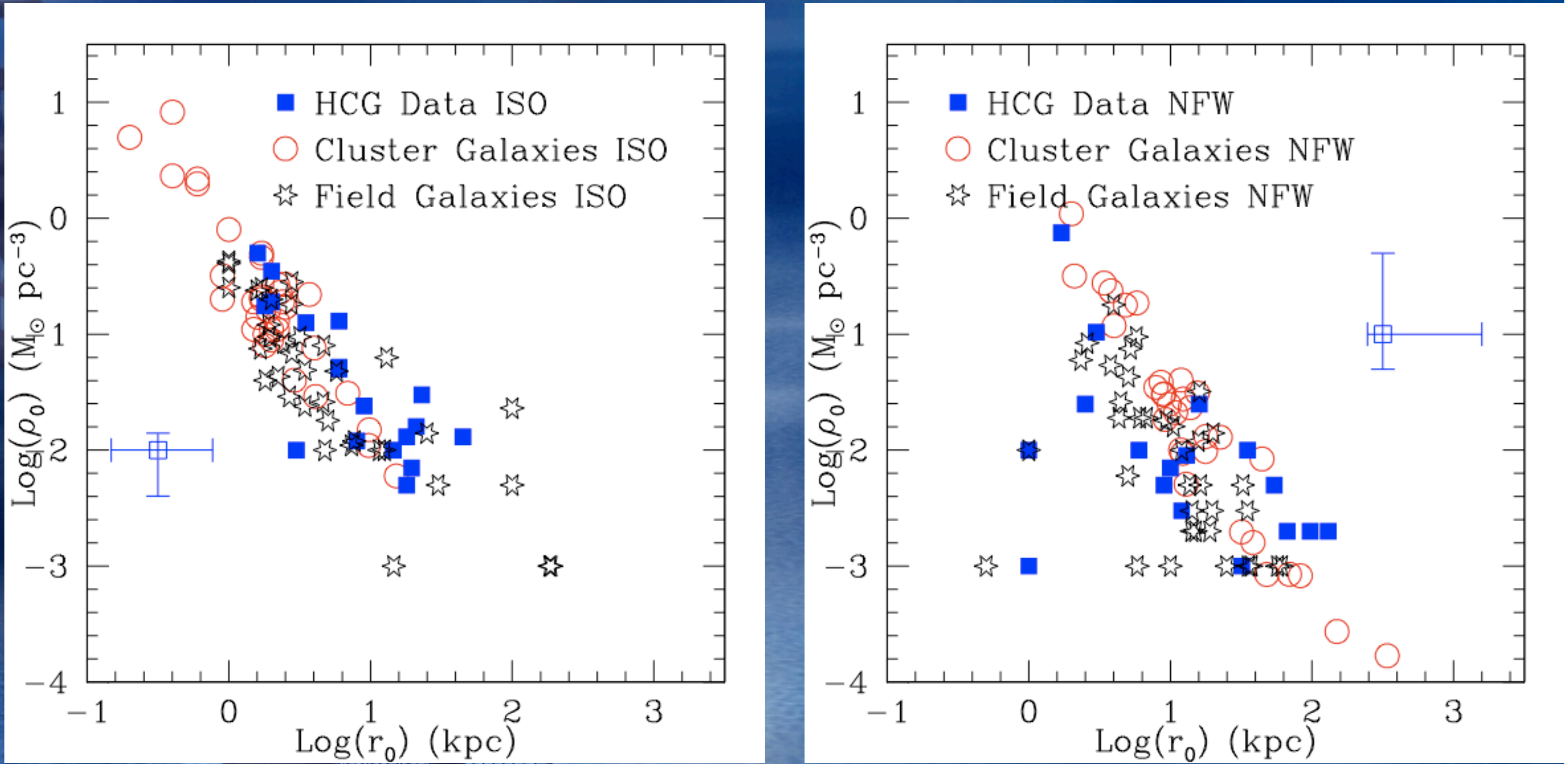

HCG 088a - ISO
Radius (kpc)
Rotation Velocity (km s⁻¹)
DISK
HALO
BULGE
Radius (arcsec)


HCG 016a
μ_e = 9.92
r_e = 12.10
r_t = 11.92
μ_0 = 17.64
h = 15.19
Surface Brightness (mag/arcsec²)
R (Arcsec)


HCG 016a - ISO
Radius (kpc)
Rotation Velocity (km s⁻¹)
DISK
HALO
BULGE
Radius (arcsec)

Mass Distribution in HCG

- Comparison between halo parameters:
  - ρ_0 vs r_0 – tighter relation with ISO than NFW
  - $\rho_0 * r_0$ vs M_B – constant
- Disk scale length/r_0 vs M_B almost constant
- Comparison disk M/L using ISO or NFW
- Comparison of halo parameters and M/L between HCG and field galaxies (GHASP)



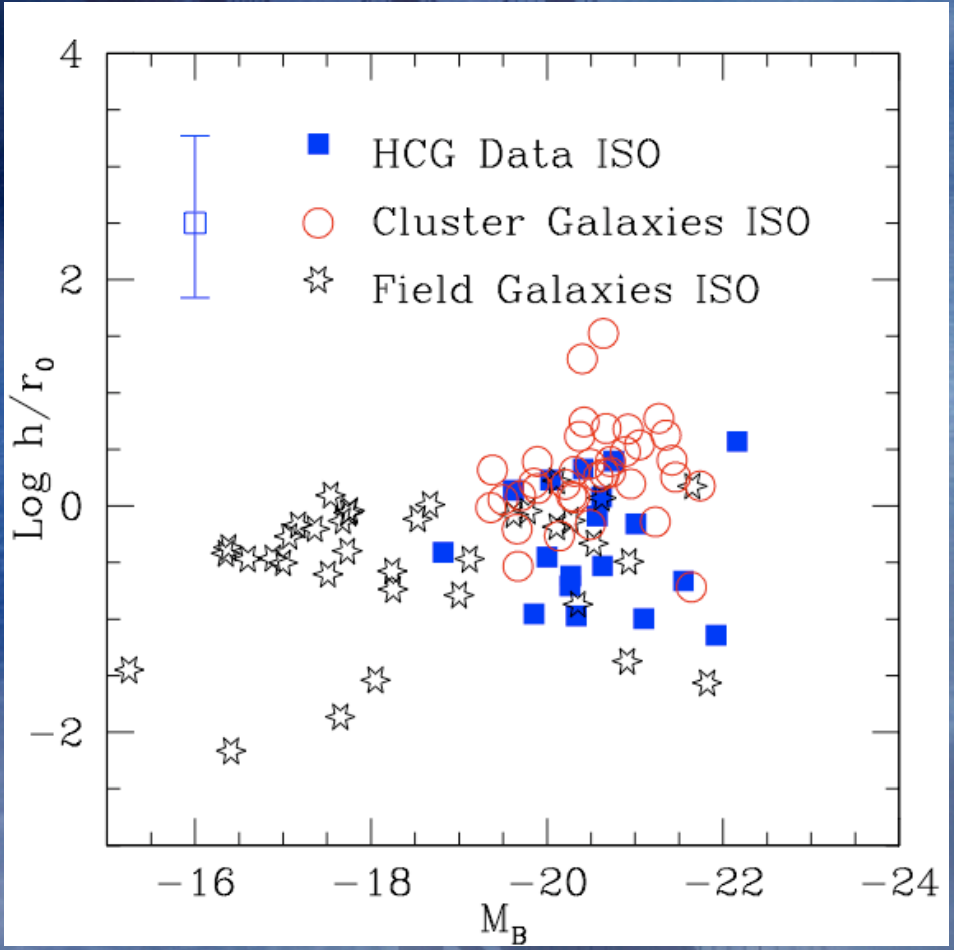
Plana et al. 2010

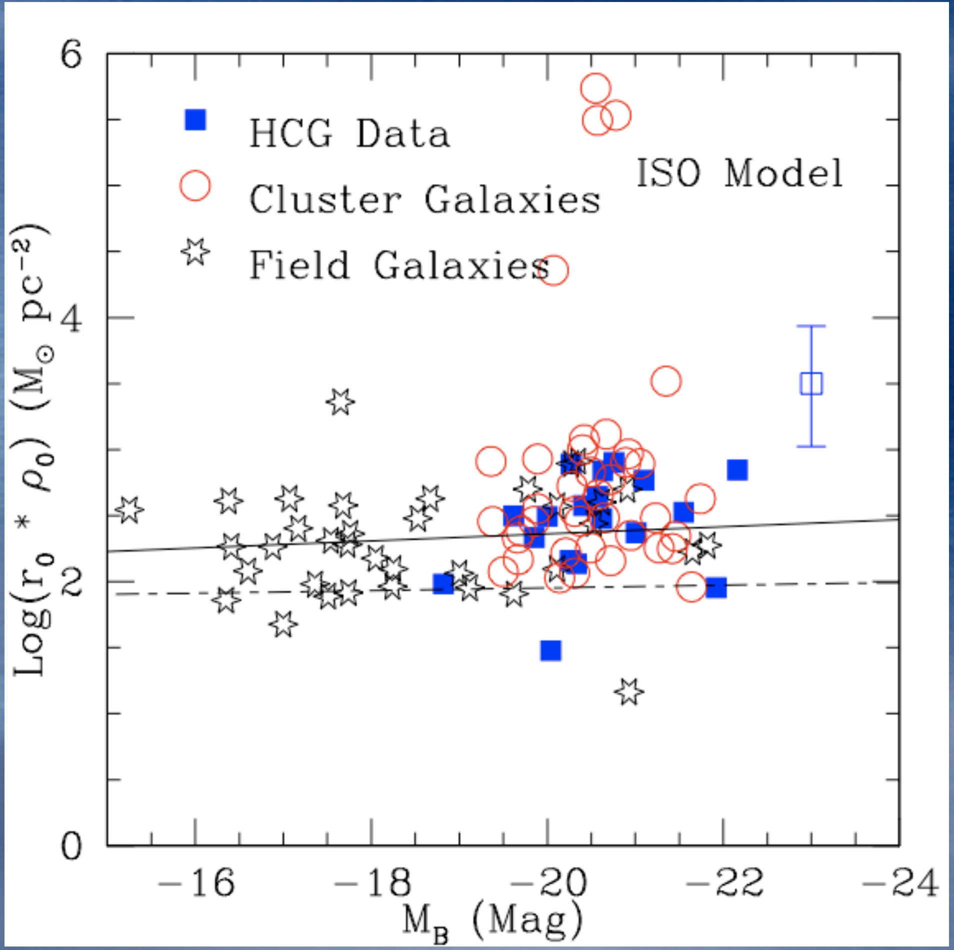
Correlation ρ_0 vs r_0 – Comparison with Spano 08 (field galaxies) and Barnes 04 (Cluster galaxies)

ISO Correlation: 0.80 – NFW Correlation: 0.48

h and r_0 connected

$\rho_{0*} r_0$ - projected DH density - Faint field galaxies show more concentrated DH

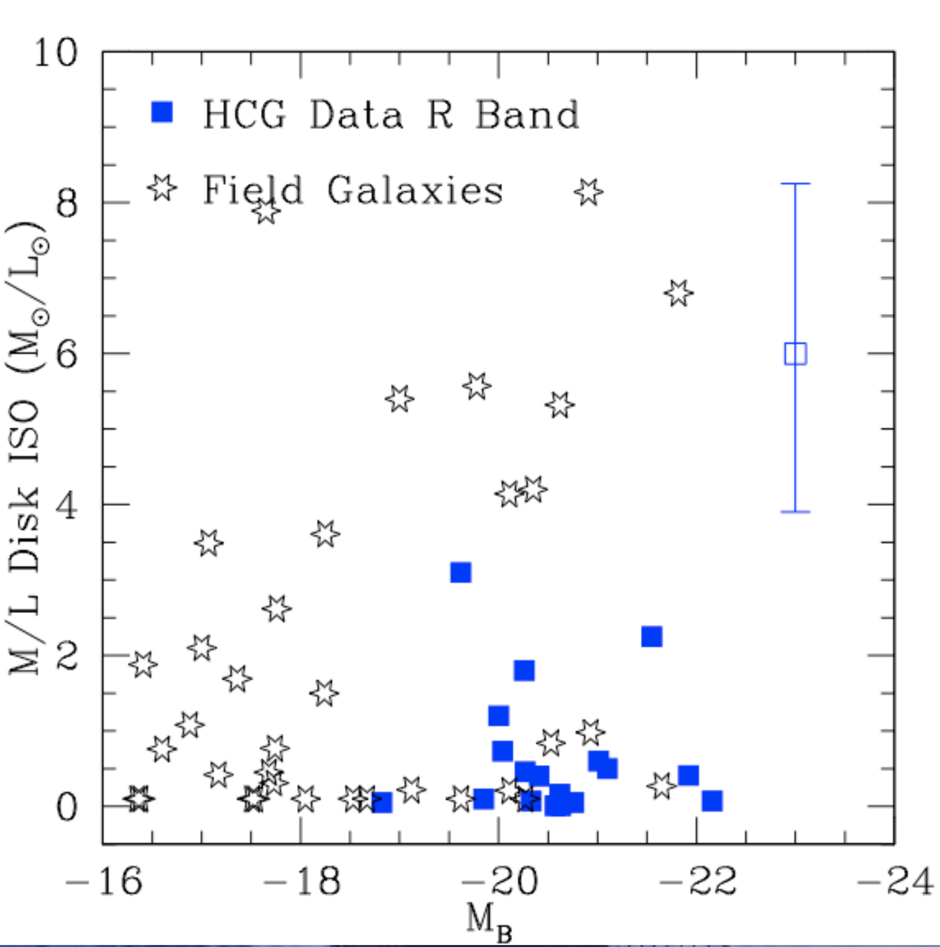




Mass Distribution in HCG

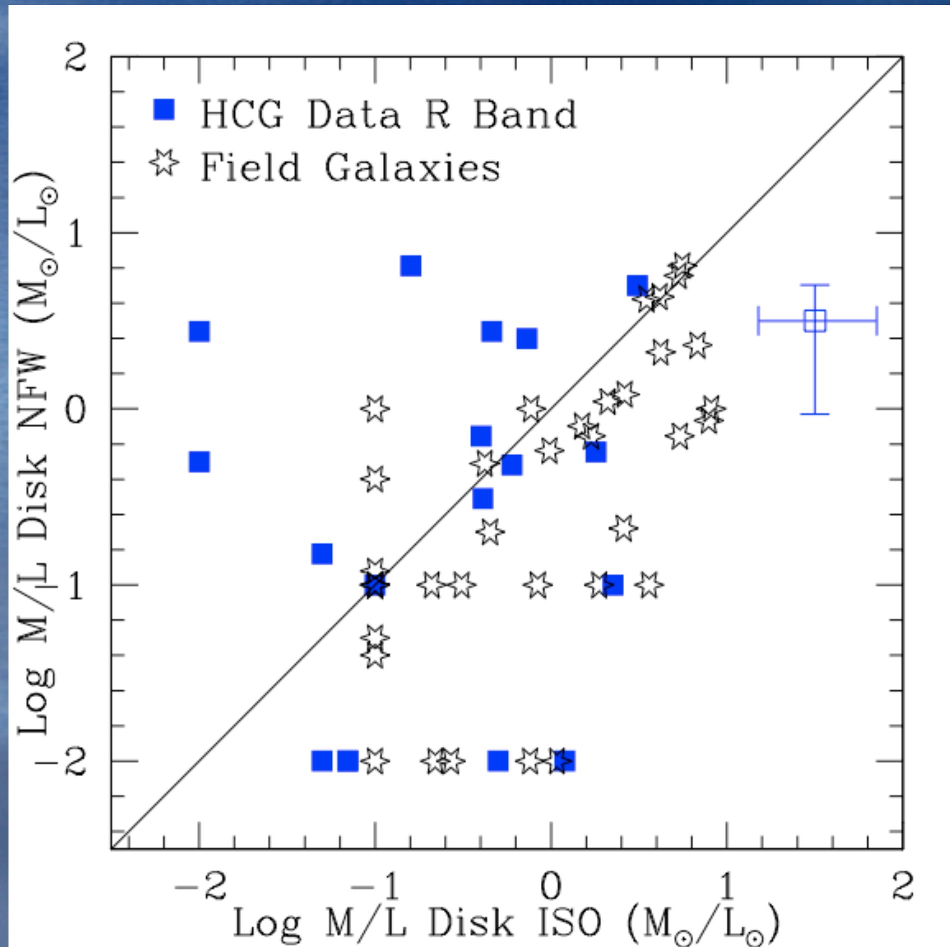
- No obvious differences with halo param. between different environments
  * Strong correlation: ρ_0 vs r_0 for field, cluster and HCG galaxies (consistent with Kormendy 04)
- NFW halo less satisfactory than ISO
- High halo mass in HCG galaxies
- No clear relation between M/L vs M_B

Plana et al 2010



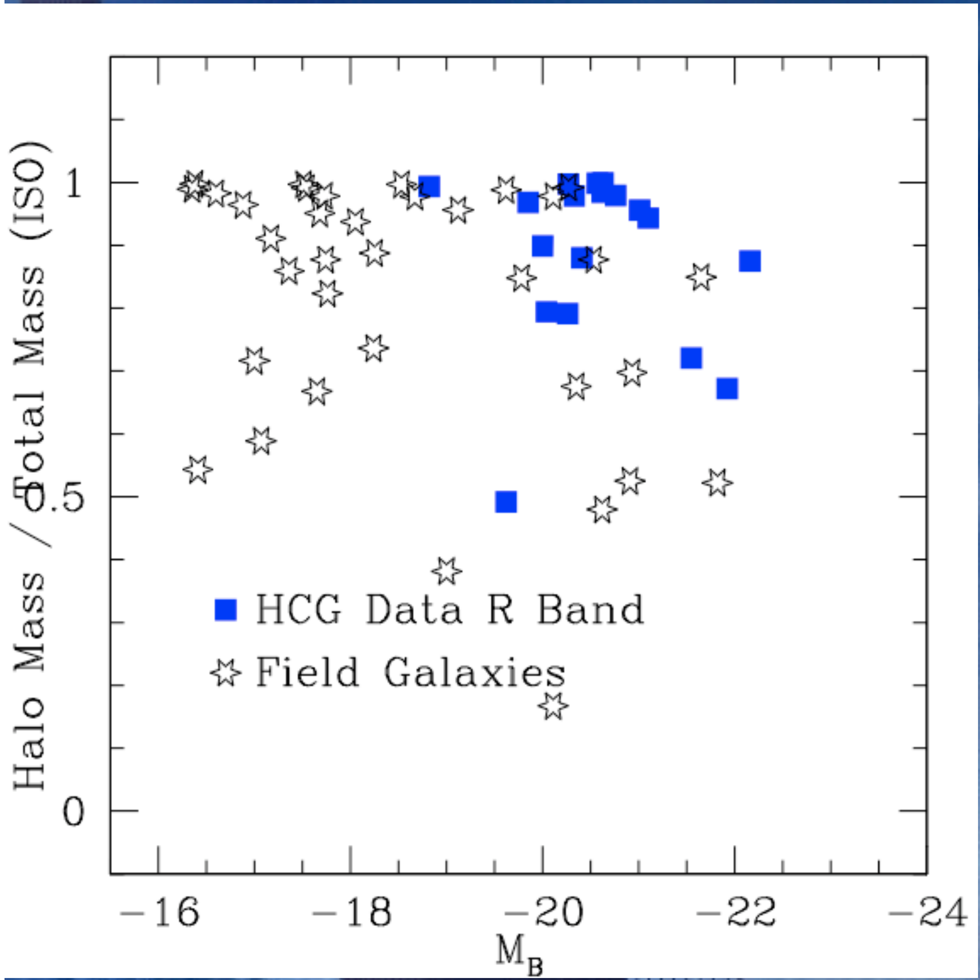
Field galaxies M/L much higher than HCG

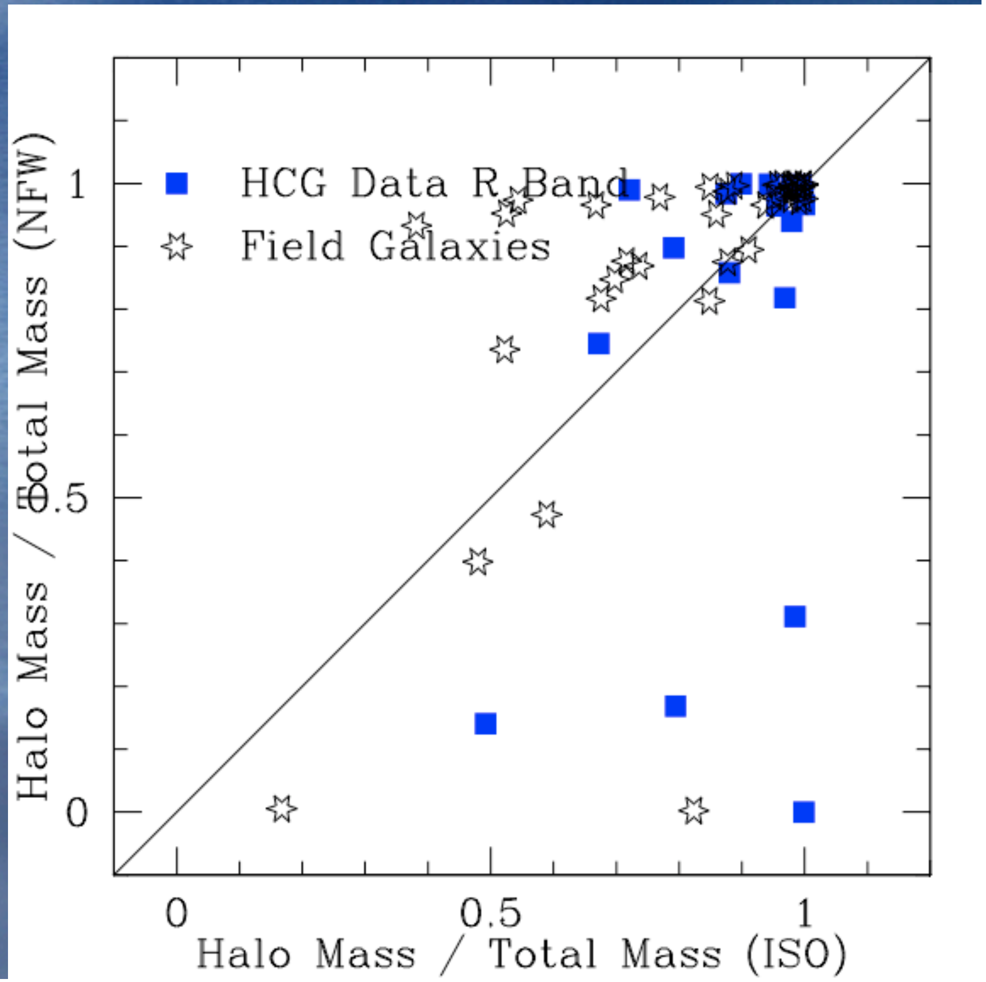
ISO gives higher disk M/L



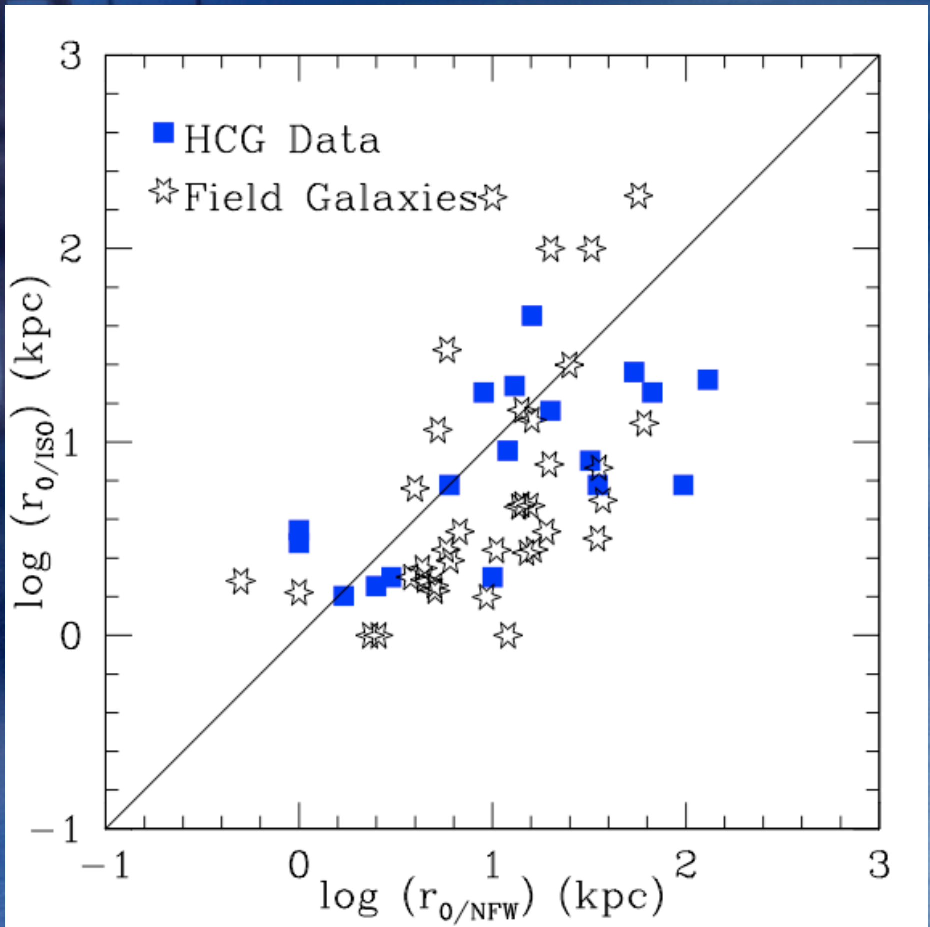
Dark Halo dominated HCG and field galaxies

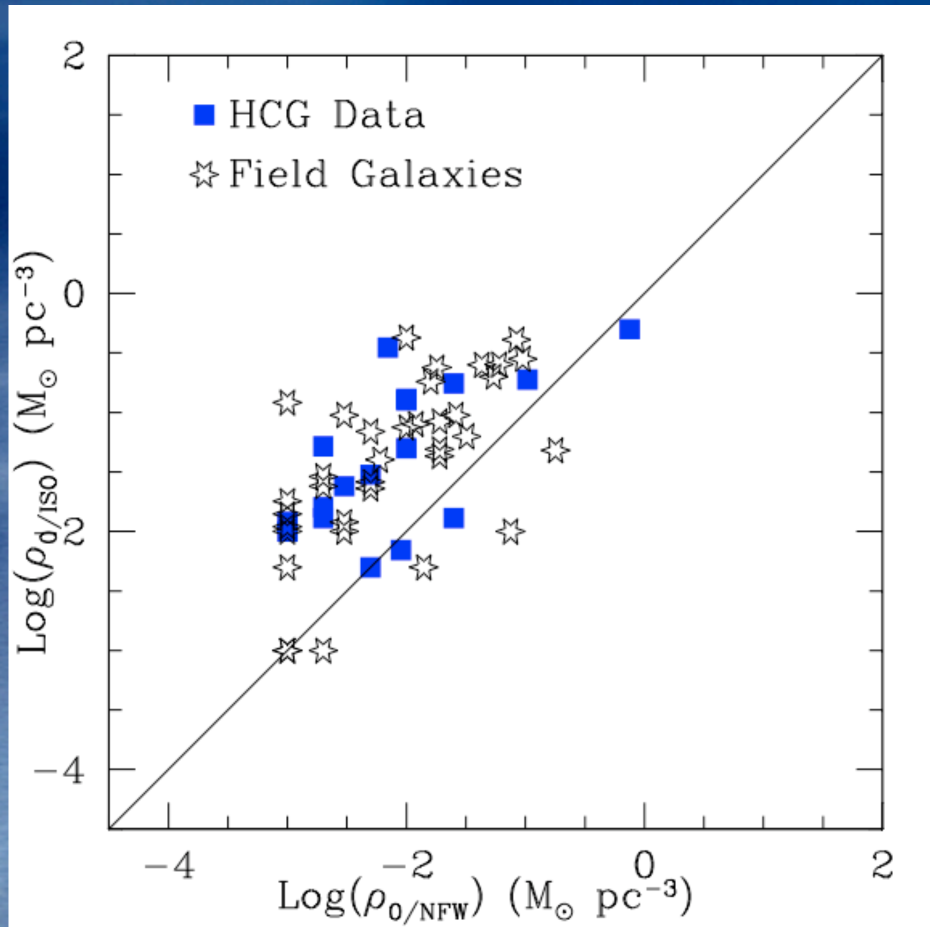
Independent of M_B



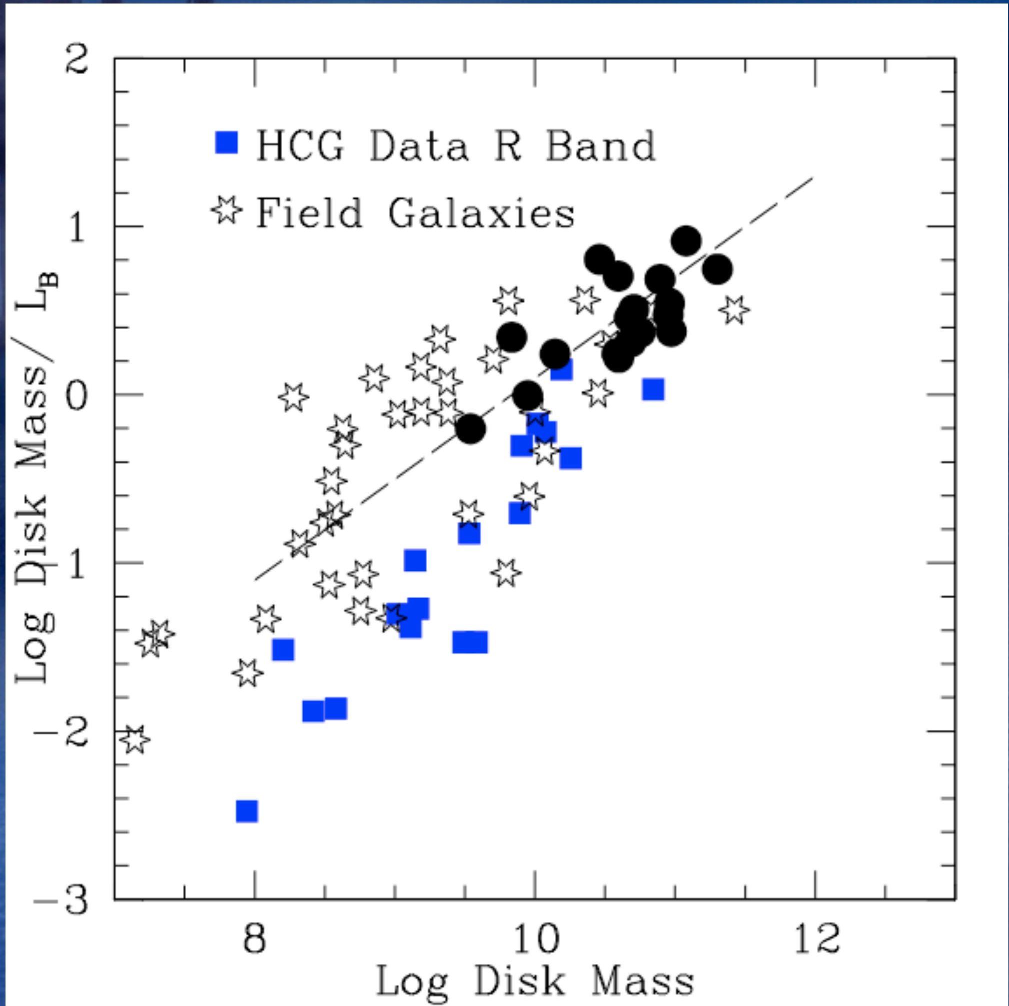


Using NFW or ISO





- ISO gives apparent more peaked halo than NFW
- NFW can not fit RCs slope (not high enough) -> favors disk over halo
- ISO minimize the disk vs halo



Disk Mass to Light ratio correlates with Disk Mass see Salucci 08

-> 18 Spirals Disk masses from RC and SPS

-> Our slope is steeper

-> Larger disk mass range

Conclusion - Perspectives

- Mass distribution in HCG not as different as we thought with field galaxies
- Difficulties to estimate disk M/L
- Move to SSP mass disk estimation
- Move to 2D dynamical mass distribution
    * Broad band images
    * 2D Velocity fields
- Projection to high z