The mass distribution in spiral galaxies

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Outline:

- The disk mass of spiral galaxies
- Radial Tully-Fisher relation (RTF)
- Satellites of spiral galaxies

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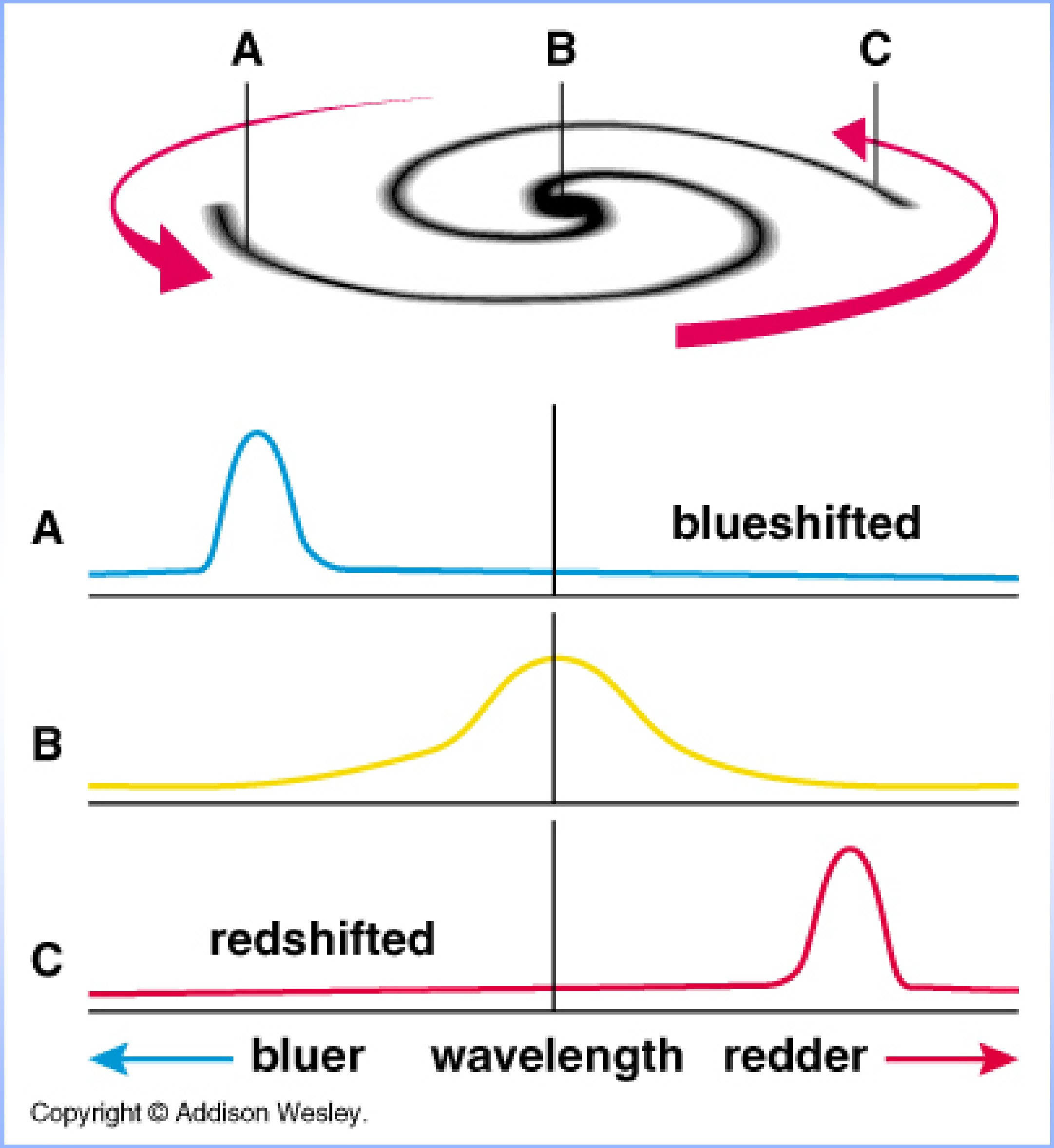
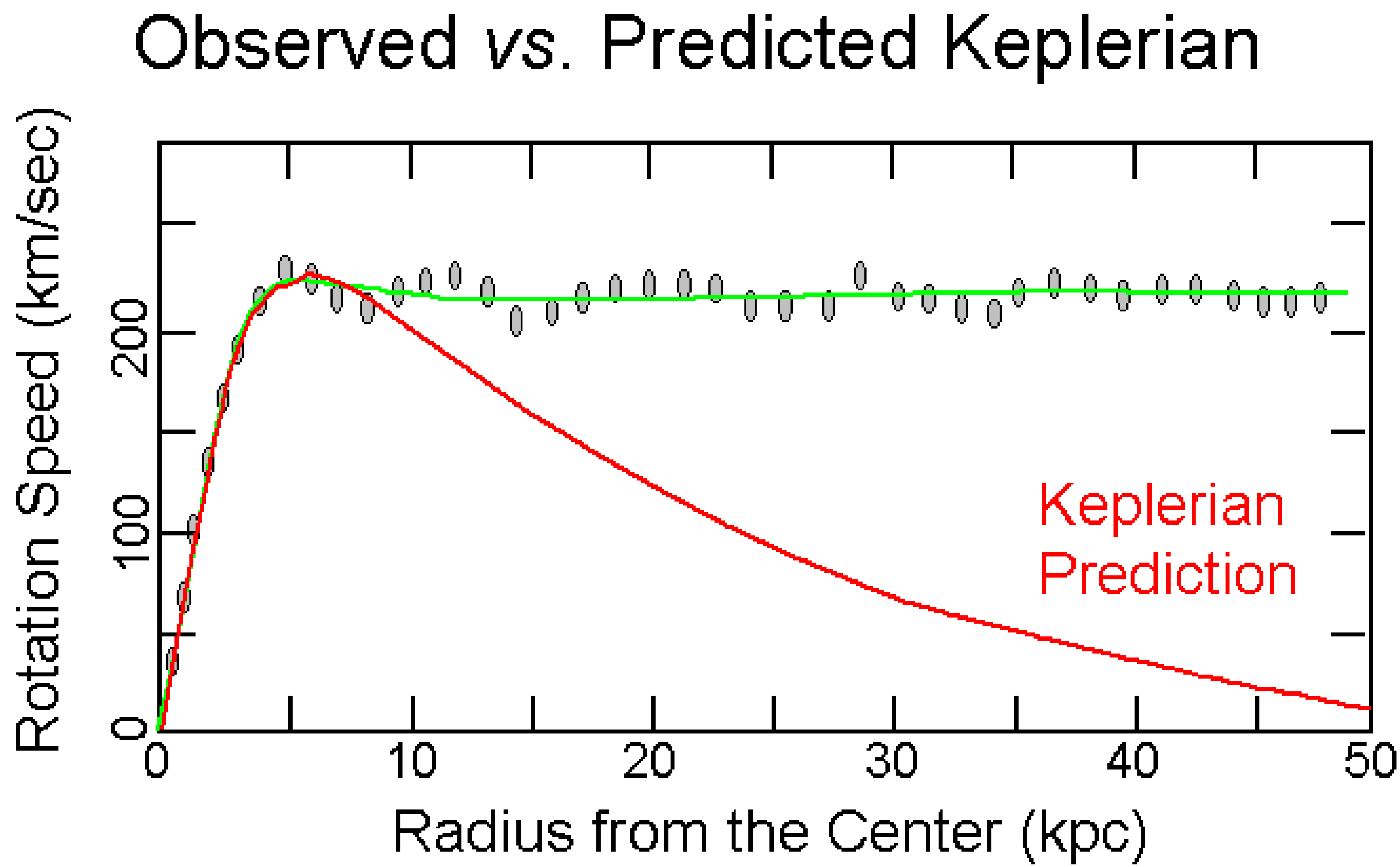


$$M(R) = \frac{V_{rot}^{2}\, R}{G}$$


Observed vs. Predicted Keplerian
Rotation Speed (km/sec)
0
100
200
0
10
20
30
40
50
Radius from the Center (kpc)
Keplerian
Prediction

Two different methods to determine the masses of spiral galaxies

1. Using kinematical data

$$V = [V_d^2 + V_h^2]^{1/2}$$

$$V_d^2(x) = V^2(R_{opt})\,\beta\,\frac{1.97x^{1.22}}{(x^2+0.78^2)^{1.43}}$$

$$V_h^2(x) = V^2(R_{opt})\,(1-\beta)\,(1+a^2)\,\frac{x^2}{(x^2+\alpha^2)}$$

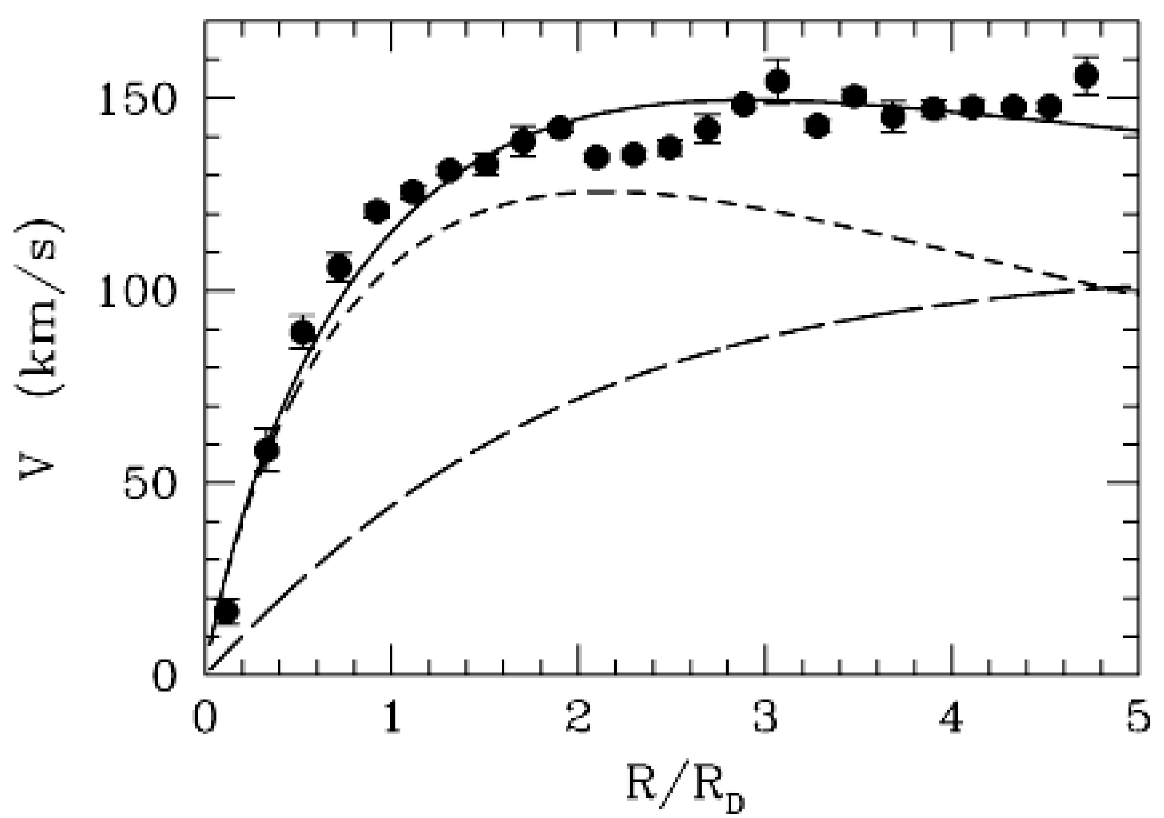
$$x = R/R_{opt}$$

$$\beta \equiv [V_d(R_{opt})/V(R_{opt})]^2$$

$$R_{opt} = 3.2R_d$$

$$M = 2V_d^2 R_d$$

UGC 8460



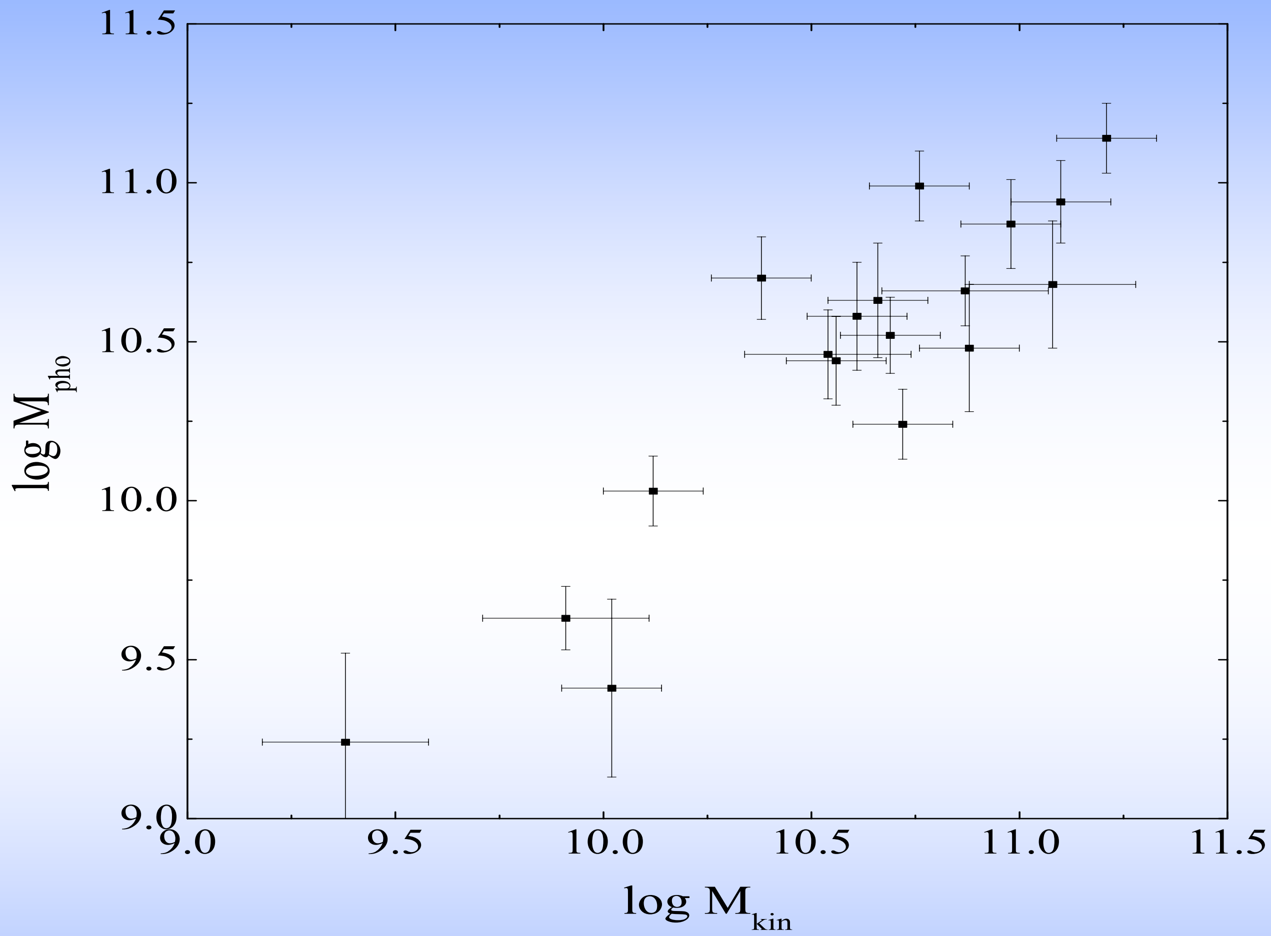
2. Using photometrical data

The method is based on the comparison of multicolor photometry from SDSS to a grid of stellar population synthesis models
(Niv Drory, Max-Planck, Garching)

The data:

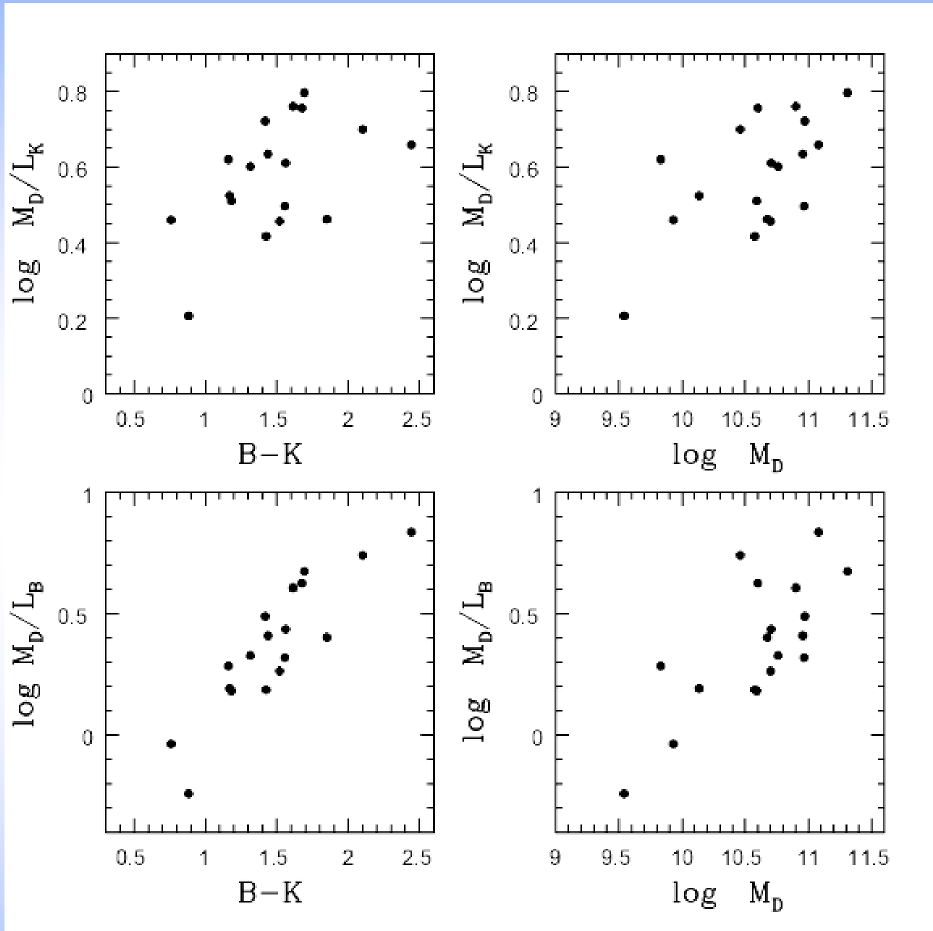
ugriz bands from the Sloan Digital Sky Survey (SDSS)
(Data Release 4)

JHK bands from the 2 Micron All Sky Survey



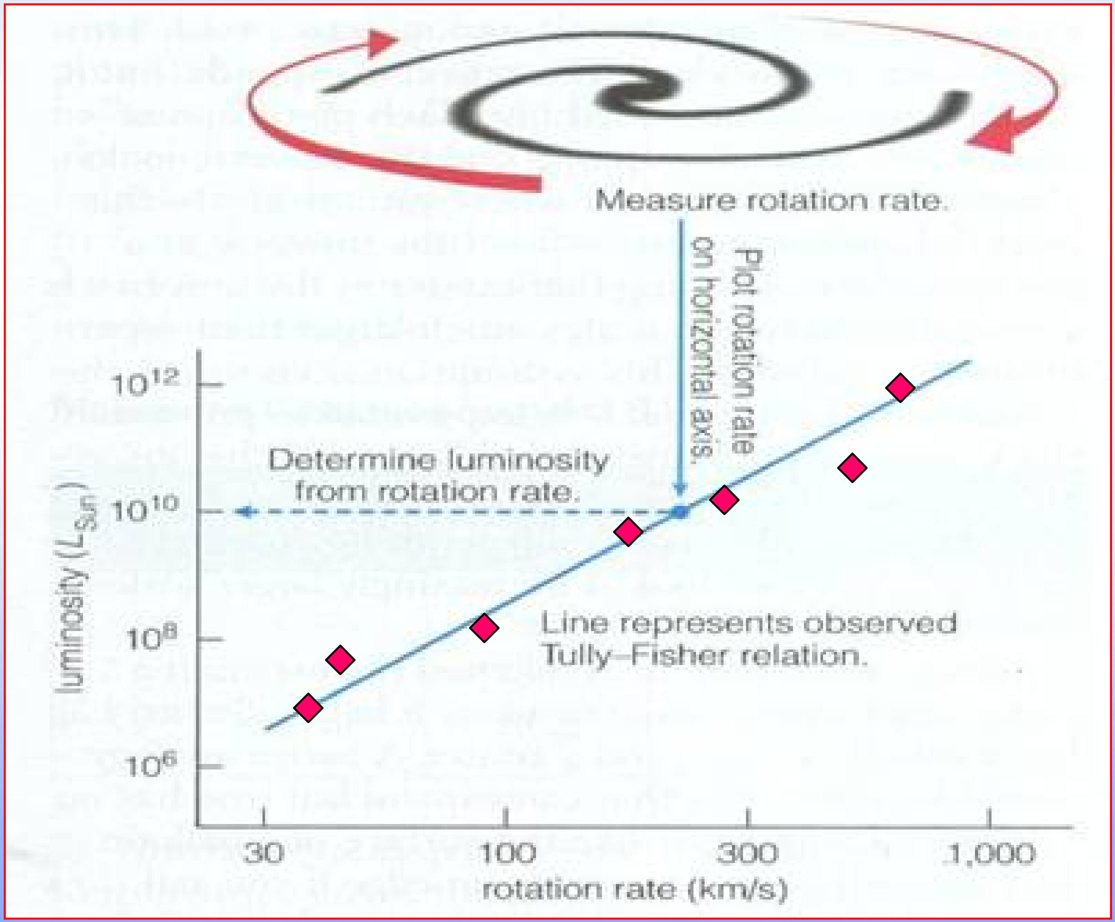
$$\log M_{pho} = (-0.4 \pm 1.27) + (1.02 \pm 0.12) \log M_{kin}$$

Mass-to-light ratio vs color and luminosity



$$\log M_D \cong \frac{1}{2}(\log M_{pho} + \log M_{kin})$$

The Tully-Fisher (TF) relation is an empirically established correlation between the luminosity (L) of a spiral galaxy and its rotational velocity (V) (Tully-Fisher, 1977)



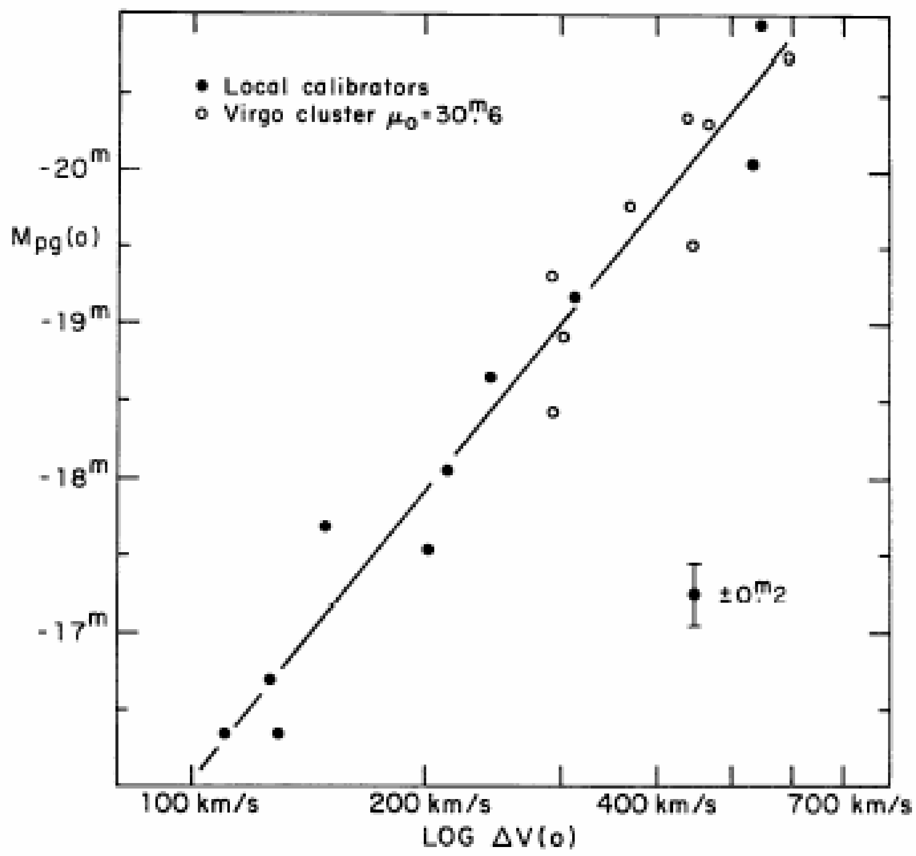


Fig. 5 (a) Absolute magnitude – global profile width relation produced by overlaying Figure 3 on Figure 1, adjusting Figure 3 vertically to arrive at a best visual fit with a distance modulus of $\mu_0 = 30^m.6 \pm 0^m.2$

New method of determining Distances to galaxies

R.B.Tully and J.R.Fisher, A&A, 54. 661-673, 1977

TF-relation has two important applications:

1. It is used to obtain cosmological distances

$$M = \mathrm{m} - 5\log\mathbf{D} - 25$$

2. It can be used for studying the dynamical properties and the evolution of galaxies

Physical basis of the TF-relation

From the equation of centrifugal equilibrium we get:

$$V_0^2 = \gamma \frac{GM}{R_c}$$

V_0 – representative velocity, M - total mass,
R_c – characteristic radius of luminous matter
γ - structural parameter depending on the shape of the mass distribution

total mass $M = M_{dark} + M_{lum}$

dark matter prameter

$$\alpha = \frac{M_{dark}}{M_{lum}}$$

surface density parameter

$$\mu_0 = \frac{M_{lum}}{R_c^2}$$

The first equation can be written in this form:

$$M_{lum} = V_0^4 [\gamma^2 (1+\alpha)^2 G^2 \mu_0]^{-1}$$

This equation can be written in the form of the Tully-Fisher relation:

$$L = V_0^4 [\gamma^2 (1+\alpha)^2 G^2 \mu_0 (M_{lum} / L)]^{-1}$$

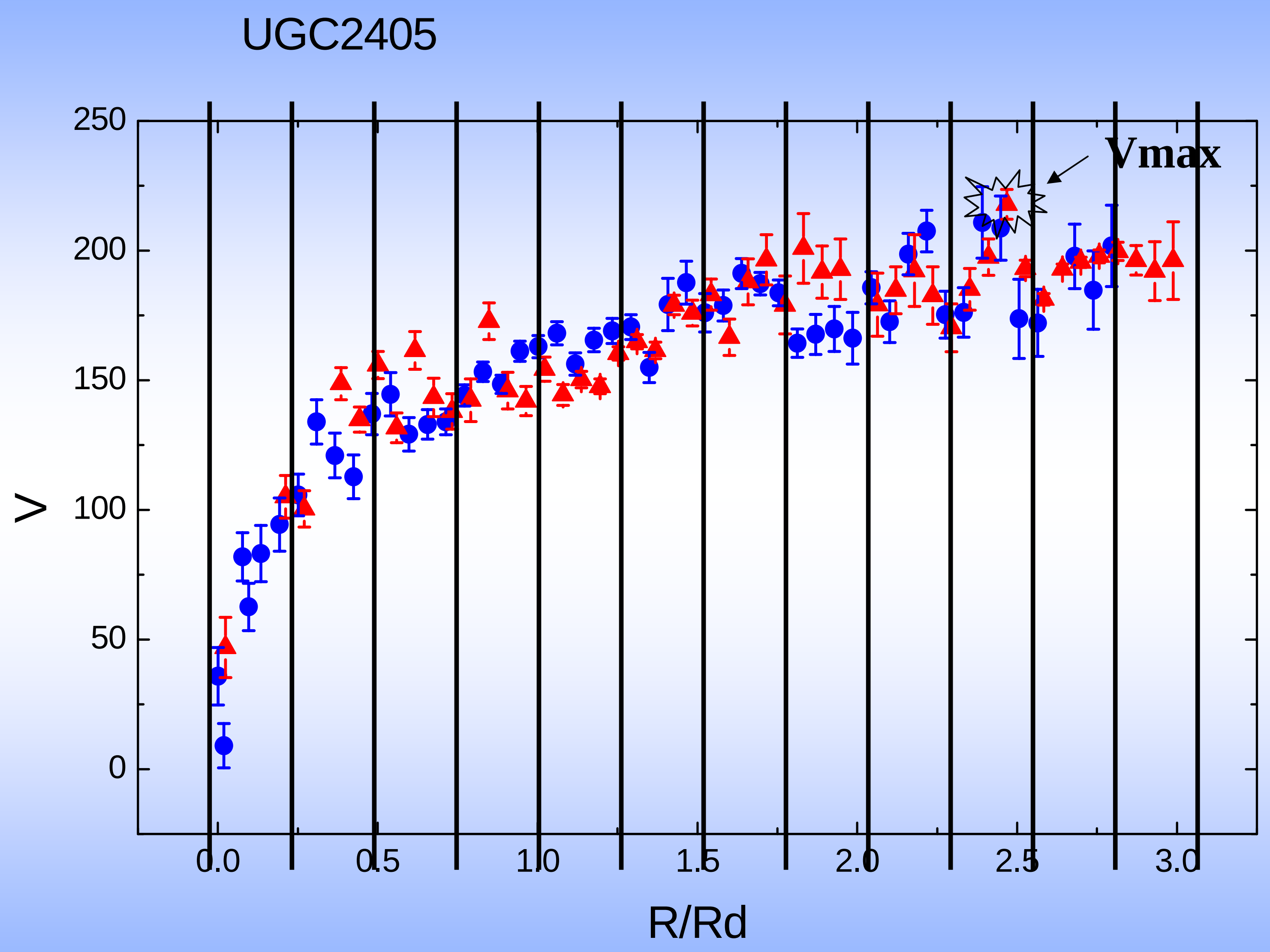
$$M = M_{sun} - 2.5 \log(L / L_{sun})$$

Samples:

1st sample: **967** spiral galaxies Mathewson (1992)

2nd sample: 304 spiral galaxies Courteau (1997)
86 galaxies selected for analysis

3 sample: 329 spiral galaxies Vogt (2004)
81 galaxies selected for analysis


UGC2405
Vmax
V
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
R/Rd

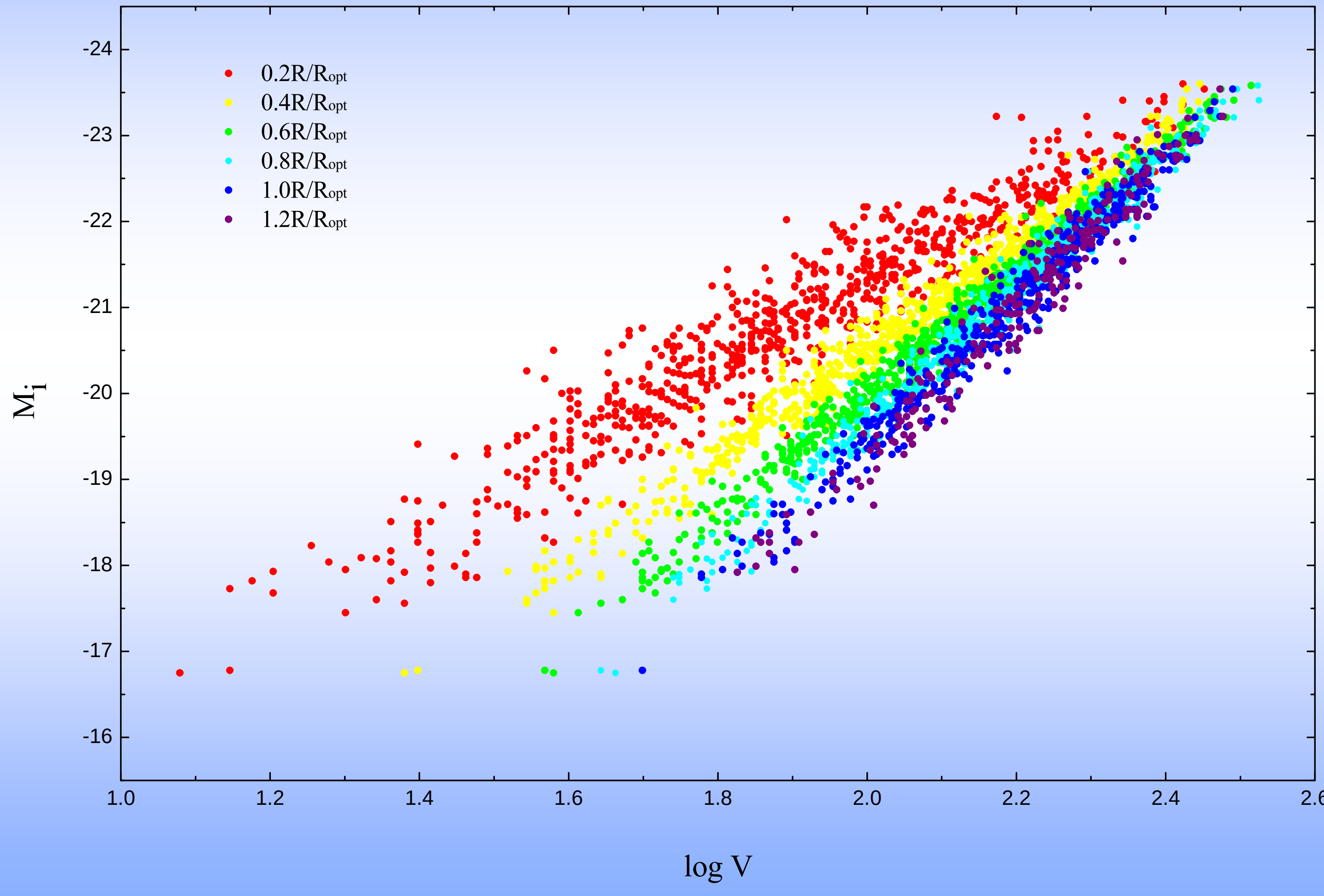
1. Mathewson sample: R $\longrightarrow$ R/R_{opt}; bin=0.2

2. Courteau sample: R $\longrightarrow$ R/R_d; bin=0.2

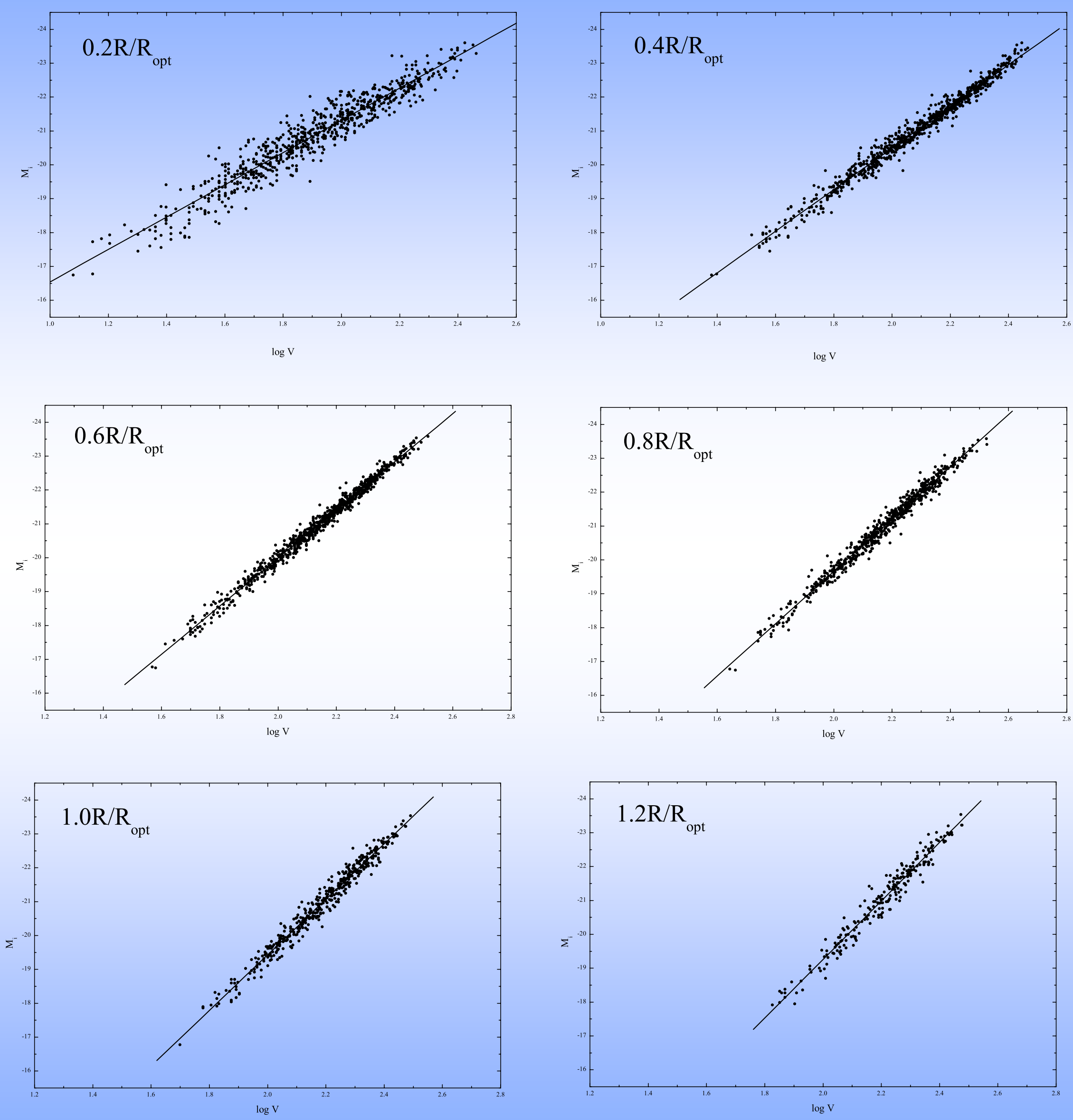
3. Vogt sample: R $\longrightarrow$ R/R_d; bin=0.2

$R_{opt}=3.2R_d$, where R_d is the disk exponential length-scale, for Freeman (exponential) disk this corresponds to the 25 B-mag/arcsec^2 photometric radius.

1st sample: TF-relation for 967 galaxies

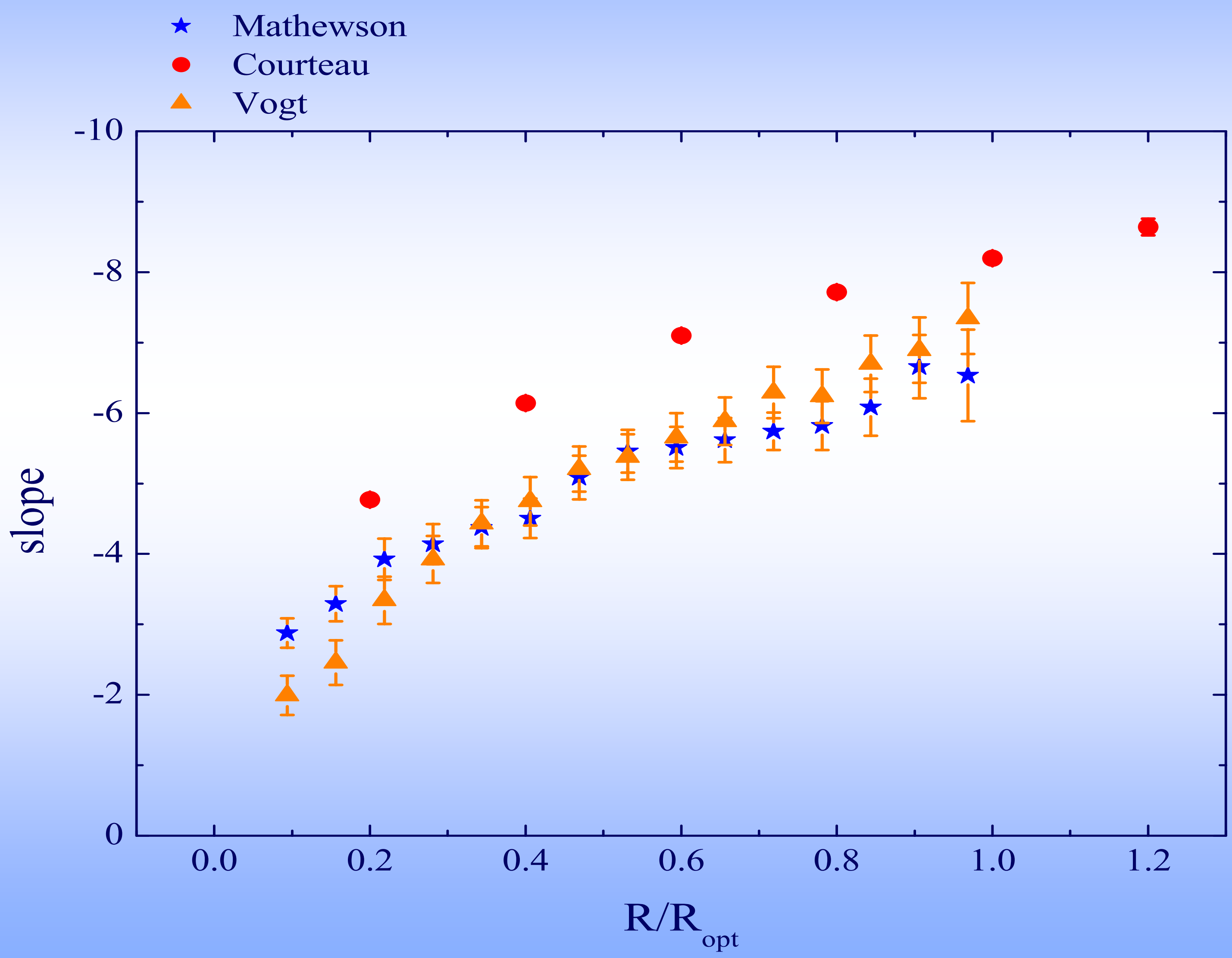


1st sample: TF-relation for 967 galaxies



Slope of the TF-relation

$$M_B = a_i + b_i \log V(R_i)$$



Gap in the slopes of 2 samples:

$$L = V_0^4 [\gamma^2 (1+\alpha)^2 G^2 \mu_0 (\mathrm{M}_{lum} / L)]^{-1}$$

No dark matter $L_x^{1+k} = V^4$

$$M_x = -2.5\left(\frac{4}{1+k}\right)\log V; \qquad \frac{\mathrm{M}_{\mathrm{lum}}}{\mathrm{L}} \sim \mathrm{L}^{\mathrm{k}}$$

k=0.1 for I band
k=0.3 for R band ⟵ function of the band

The slope of TF-relation is related to k

Physical meaning of the slope

The slope of the TF-relation steadily rises with distance due to the fact that the fractional amount of the dark matter in galaxies changes with the radius.

$$L \sim V_0^{\,4}\left(1+\alpha(R,L)\right)^{-2}$$

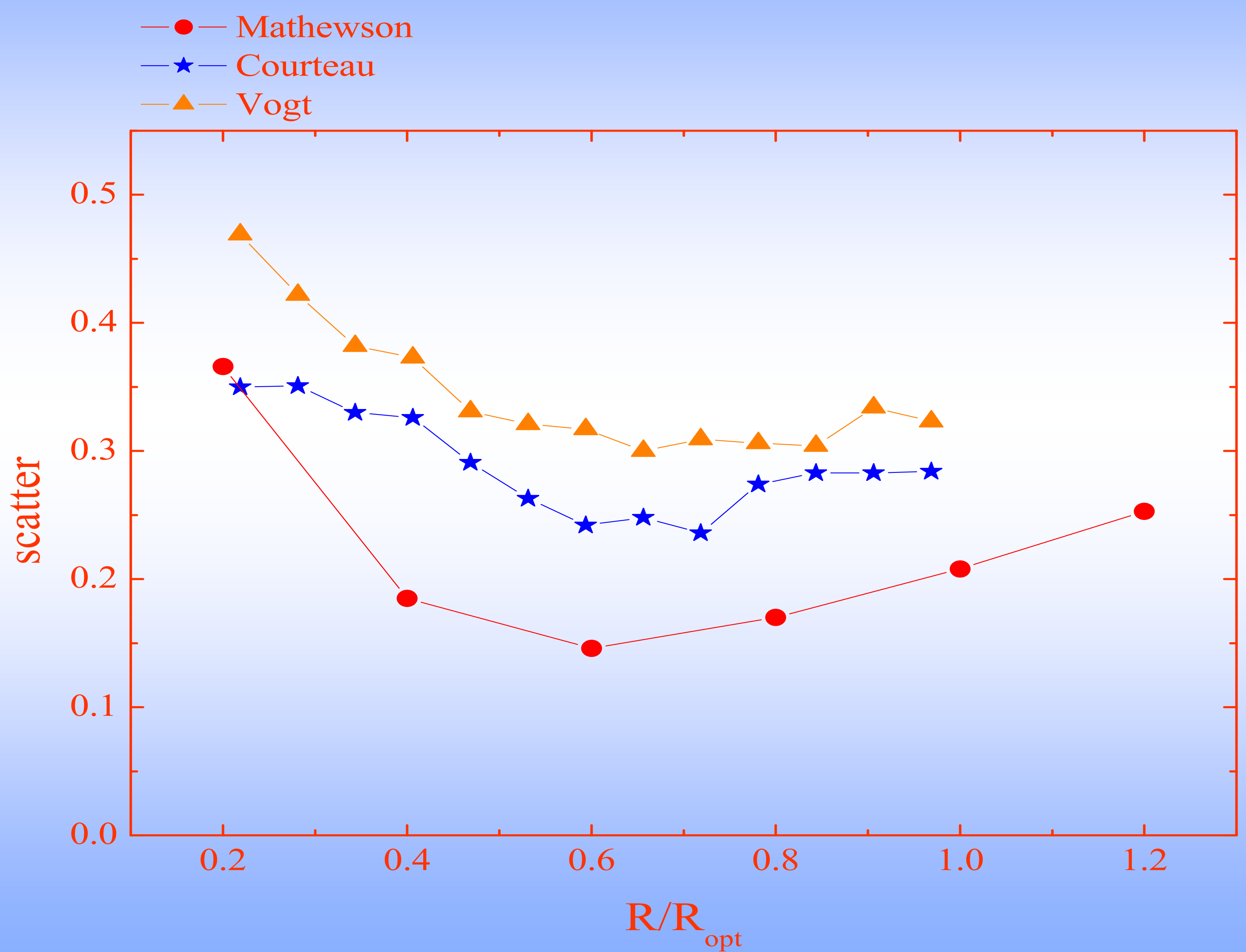
$$\frac{M_{dark}}{M_{lum}} = \alpha$$ ← dark matter parmeter

α decreases with L

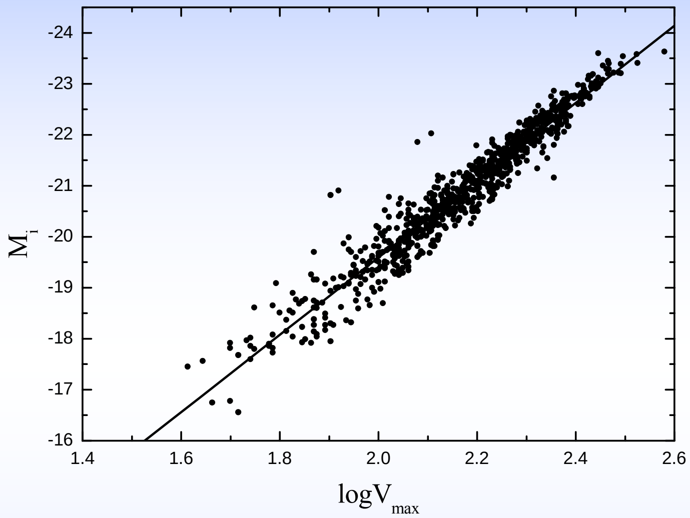
α increases with R

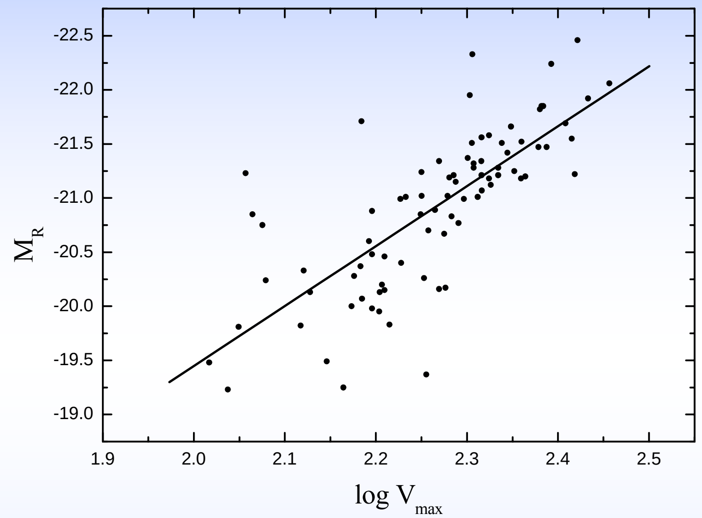
→ this has influence on the slope

Scatter of the TF-relation



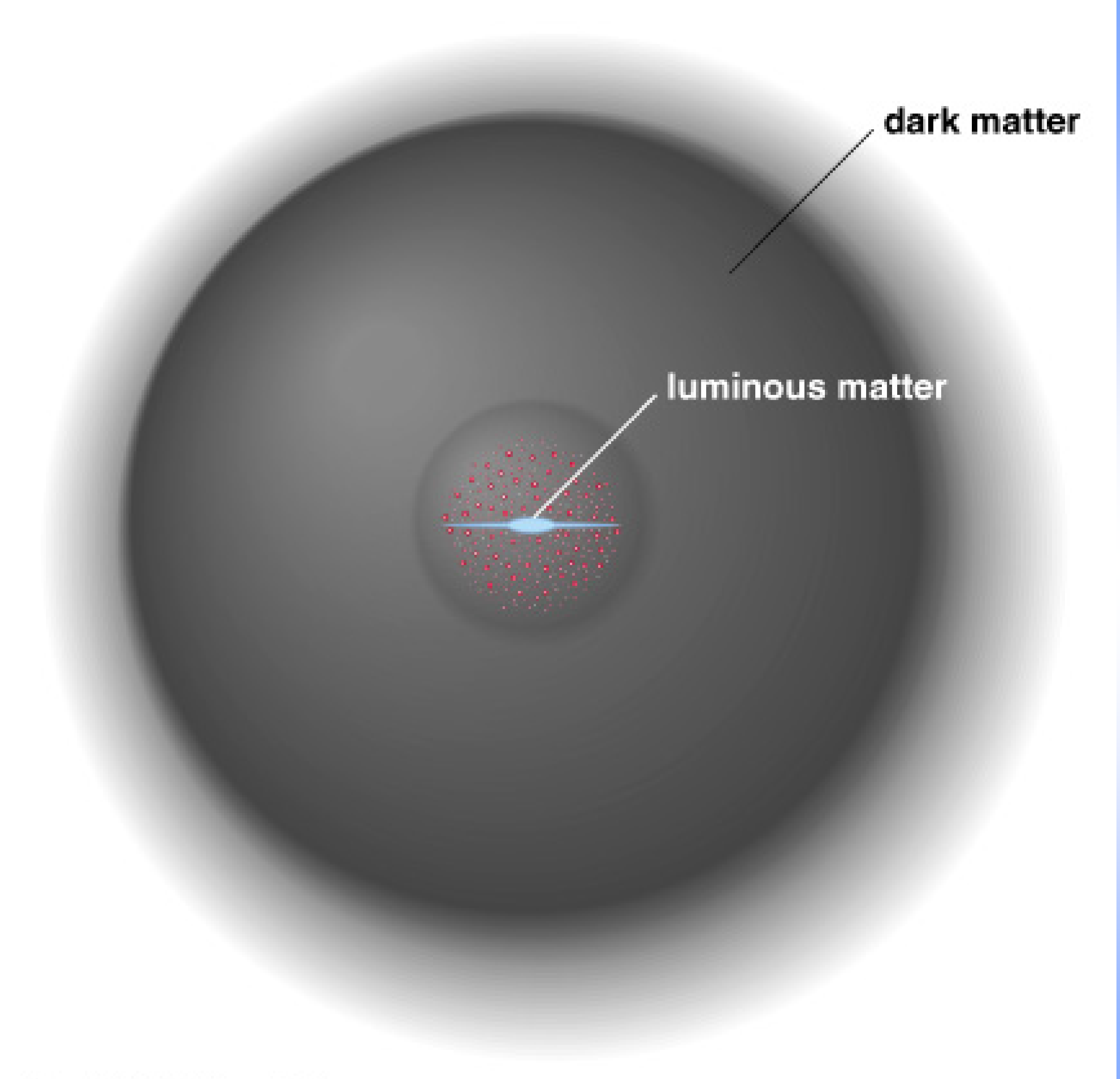
TF-relation using Vmax





slope=-7,579; scatter=0,328;
number of galaxies=843

slope=-5.54; scatter=0.49;
number of galaxies=83


dark matter
luminous matter

Probing dark matter halos of spiral galaxies with their satellites

1.5 - 2 satellites per host galaxy

- Zaritsky (1993): 45 primaries – 69 satellites

  Kitt Peak 2.3 m

- Sales & Lambas (2004): 1498 primaries – 3079 satellites

  2dFGRS 3.9 m

- T. Breinerd (2004) 3 samples: 1351 primaries – 2084 satellites,
  948 primaries – 1294 satellites,
  400 primaries – 658 satellites

  SDSS 2.5 m

We are studying 7 isolated spiral galaxies at z = 0.03 - 0.09

\+

= 58 h

Satellites + Rotation curves

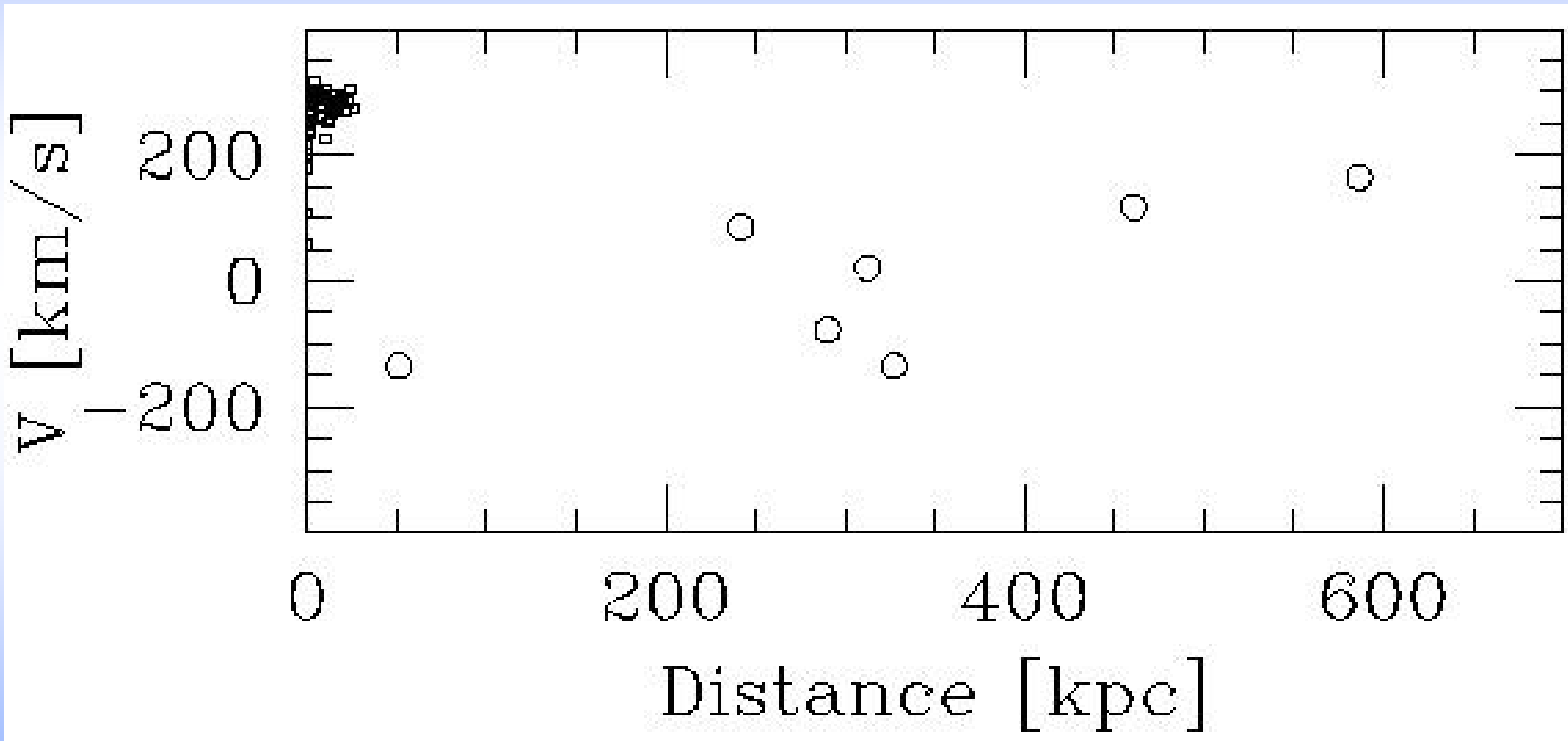
SDSS J154040.56-000933.5

z=0.078

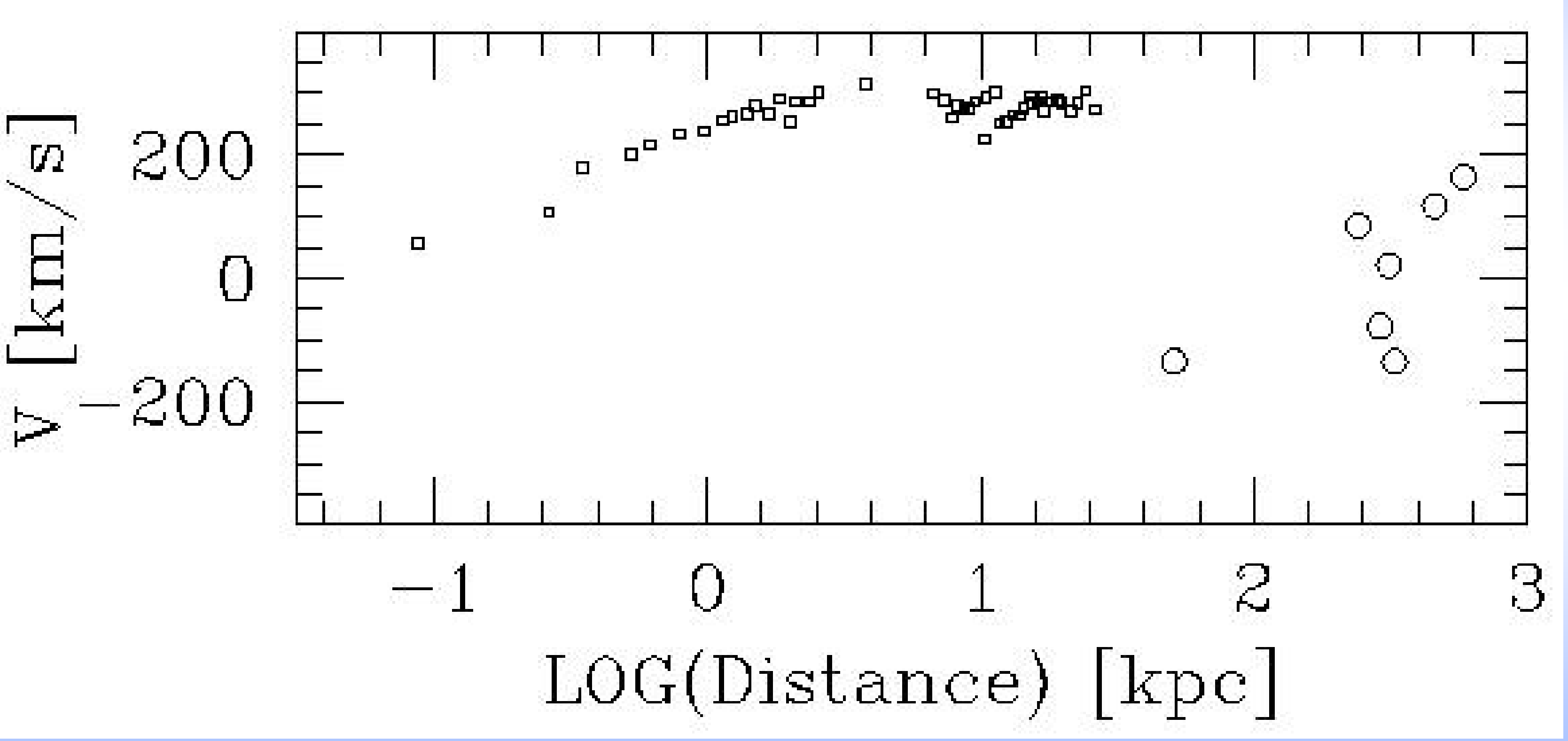
7 primaries 77 satellites identified

Primary galaxy	z	N of sat. (SDSS)	N of sat. (found)
SDSSJ134215.02	0.029	4	8
SDSSJ145211.01	0.046	4	7
SDSSJ152621.67	0.083	4	17
SDSSJ153221.6	0.085	5	19
SDSSJ154040.5	0.075	7	11
SDSSJ154904.29	0.077	2	8
SDSSJ221957.2	0.038	4	7

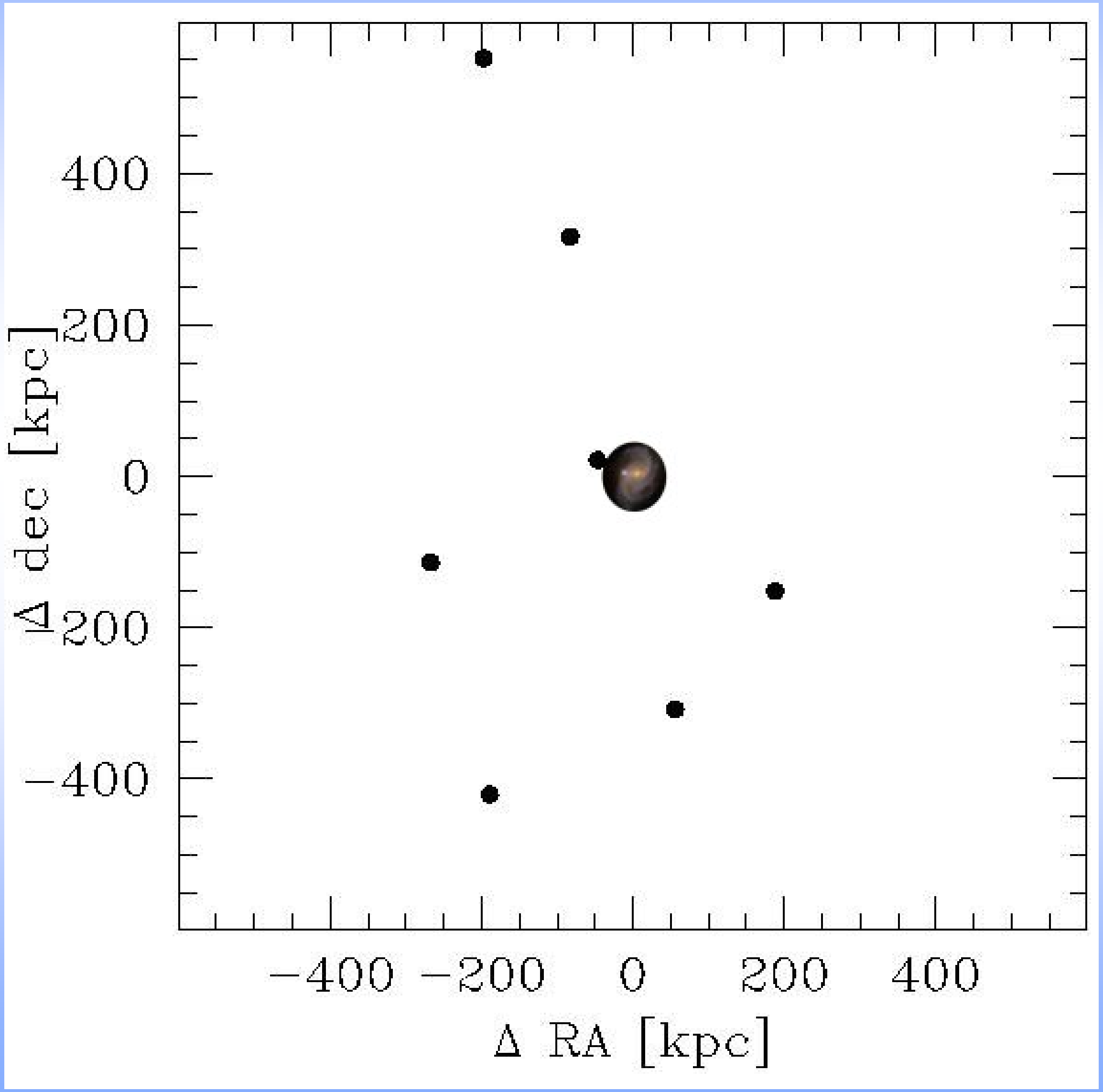
SDSS J145211.01+044053.6



SDSS J145211.01+044053.6



SDSS J145211.01+044053.6



Main results:

- The kinematical and spectro-photometrical methods coincides

- We found a Radial Tully-Fisher (RTF):

The slope decreases monotonically with the distance, while the scatter increases with distance. This implies the presence of a non luminous mass component (DM) whose dynamical importance, with respect to the stellar disk (baryonic matter) increases with radius.

The small scatter in the RTF-relation. This implies that galaxies have similar physical characteristics.

- Satellites seems a good tracer of matter distribution in spirals