

# STRUCTURE AND DYNAMICS OF MALIN 1

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JENAM-2011 “Minor merging as a driver of galaxy evolution”

7 July 2011, St.Petersburg

## *Outline*

### **What was known before**

- Photometry and structural features of Malin 1
- Kinematics (HI rotation curve)

### **Our observations (Alexei Moiseev, SAO)**

- A stellar rotation curve and velocity dispersion profiles

### **Data analysis**

- The discovery of a satellite; an explanation of the structural features
- A “cold” rotation curve and the dark halo of Malin 1

# *Malin – a man and a galaxy*

THE ASTRONOMICAL JOURNAL

VOLUME 94, NUMBER 1

JULY 1987

## DISCOVERY OF A HUGE LOW-SURFACE-BRIGHTNESS GALAXY: A PROTODISK GALAXY AT LOW REDSHIFT?

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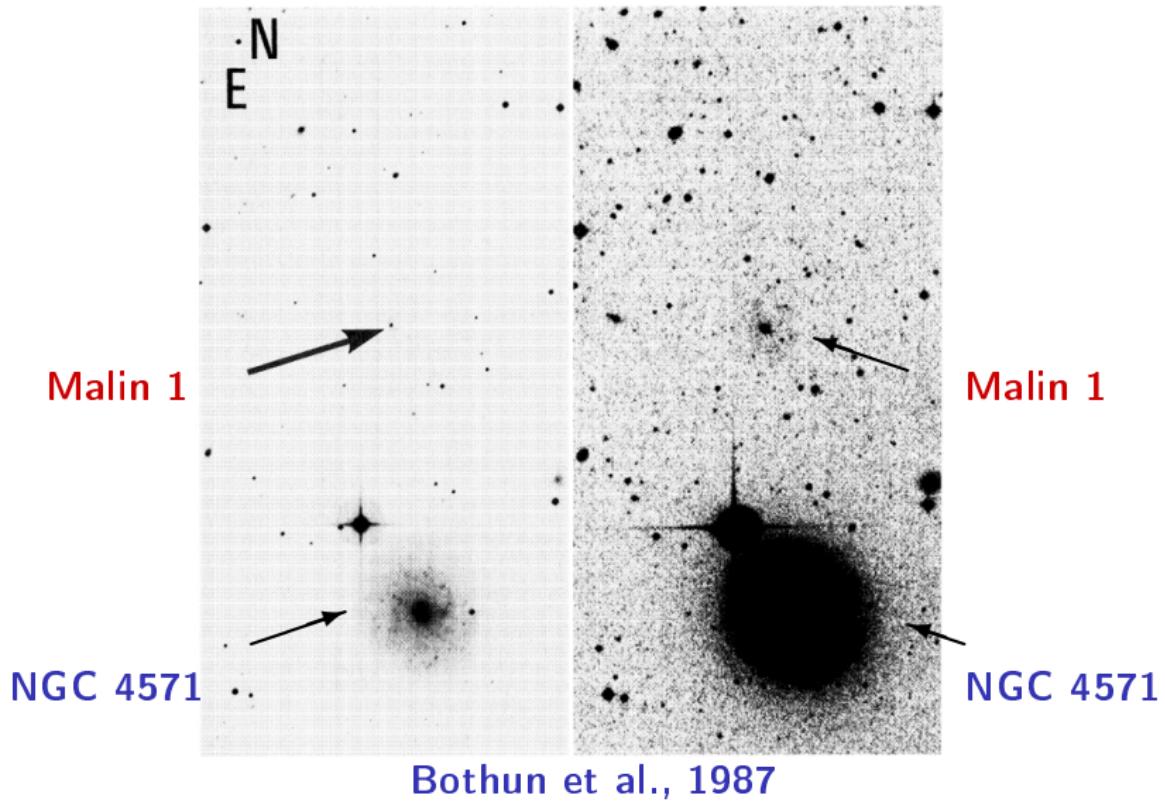
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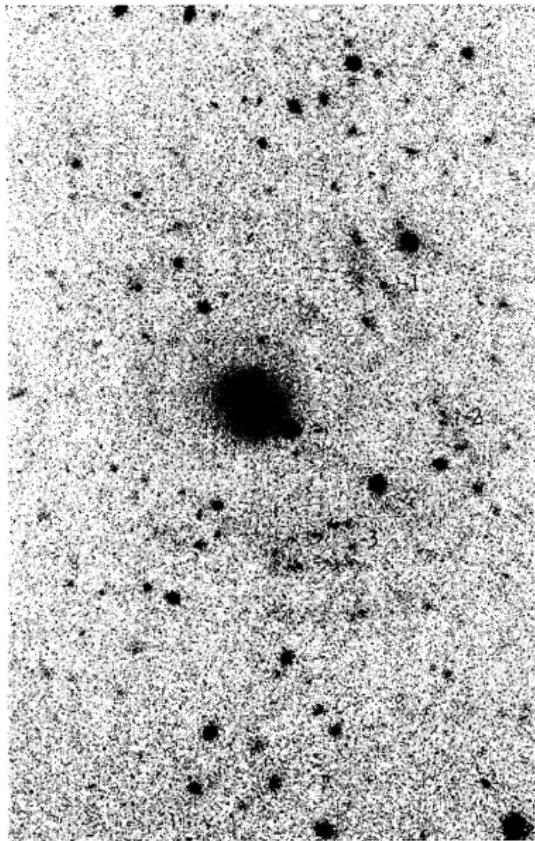
*Received 20 February 1987*

“The galaxy of interest which we **christen** **Malin 1**...”

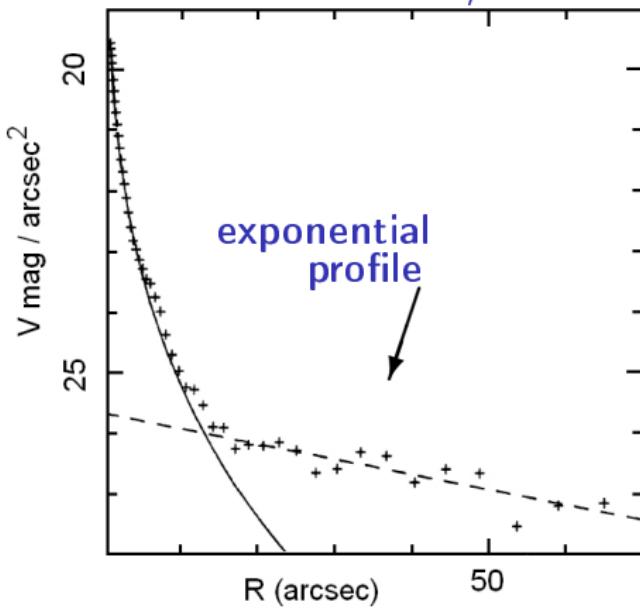
# Malin – a man and a galaxy



# *Ground-based data. Giant stellar disc – the V band*



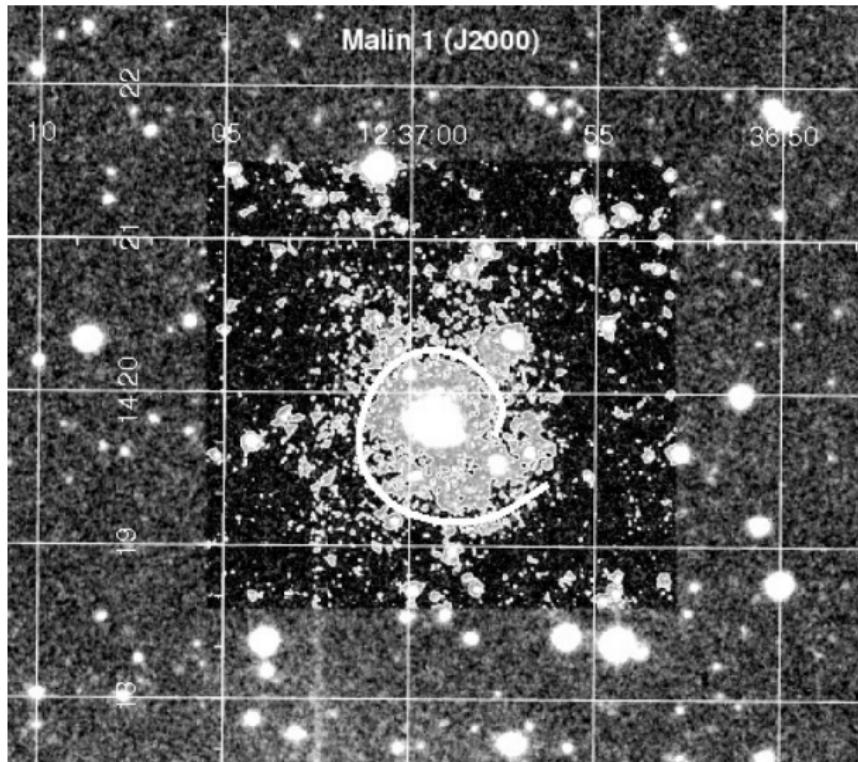
Bothun et al., 1987



**A surface brightness profile**

scale : 1.53 kpc/arcsec

# Outer one spiral arm – the R band



Moore and Parker, 2006

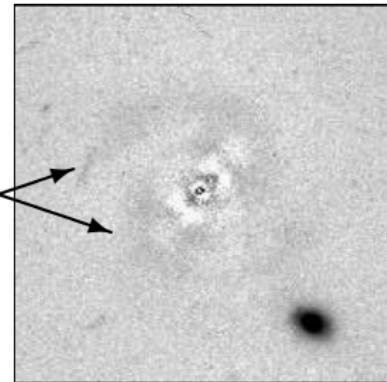
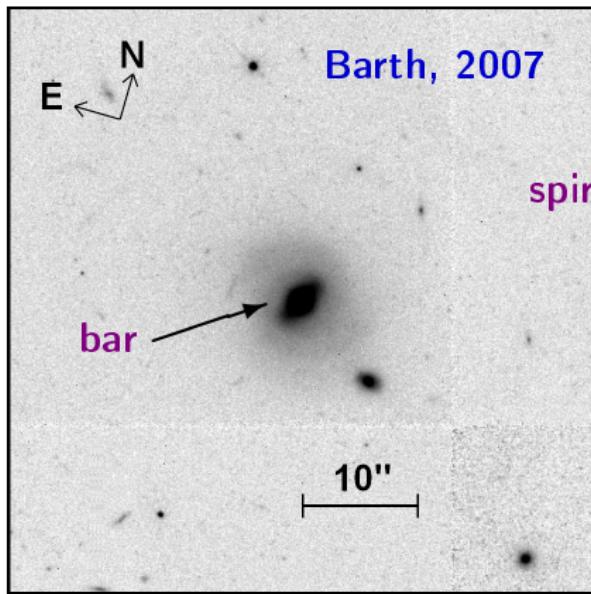
# Giant stellar disc – main parameters

- $D_L = 370$  Mpc; scale = 1.53 kpc/arcsec

The band	$V$	$R$
<u>Extension</u>	60'', or 90 kpc	80'', or 120 kpc
<u>Scale lenght</u> $h_{\text{outer}}$	45'', or 68 kpc	33'', or 50 kpc
<u>Central surface brightness</u> $\mu_{0,\text{outer}}$	$\approx 25^m.5/\square''$	$\approx 24^m.7/\square''$

- $M_V \approx -22^m.9$  – **Extremely bright!!!**

*HST data. Normal stellar disc in Malin 1 – the I band.  
Bar and two spiral arms*



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Bulge:	$r_{\mathrm{e,b}}$	0.6 kpc
	$n$	1.24
	$m_b(I)$	17 <sup>m</sup> .0

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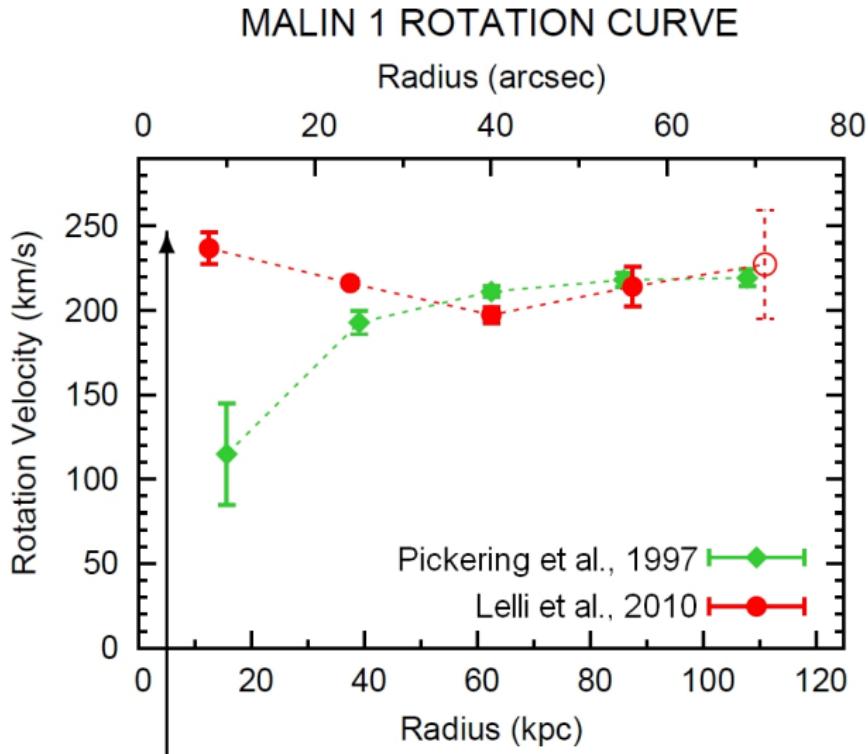
$$I_{\text{bulge}}(r) = I_{0,\text{b}} e^{-\nu_{\text{n}}[(r/r_{\mathrm{e,b}})^{1/n}]}$$

$$I_{\text{disc}}^{\text{inner}}(r) = I_{0,\text{d}}^{\text{inner}} e^{-r/h_{\text{inner}}}$$

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Disc:	$\mu_0^{\text{inner}}(I)$	20 <sup>m</sup> .1/ $\square''$
	$h_{\text{inner}}$	4.8 kpc

# HI rotation curve



$$\mathcal{M}(\text{HI}) \approx 6.7 \cdot 10^{10} \mathcal{M}_{\odot}$$

**Decomposition of  
the rotation curve:**

Pickering et al., 1997

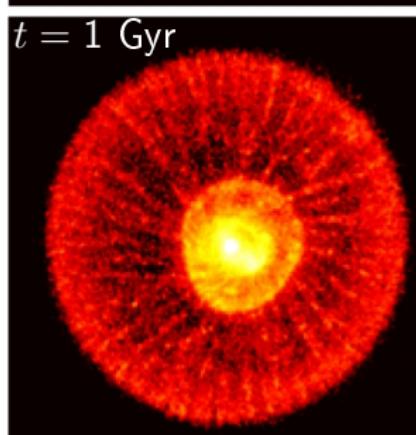
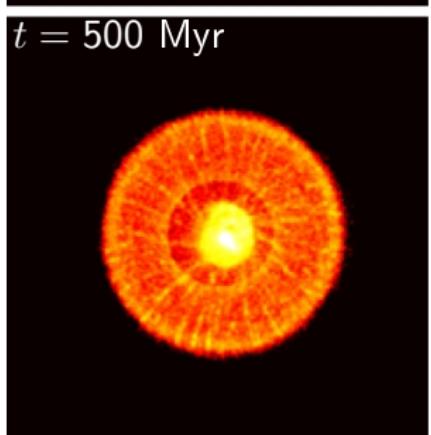
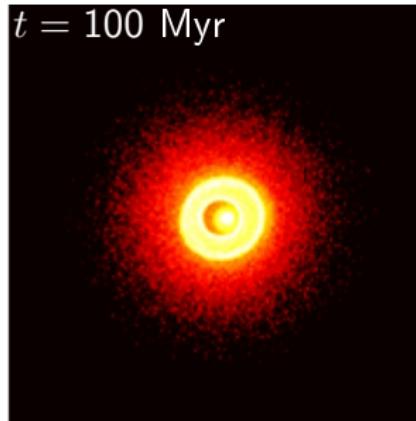
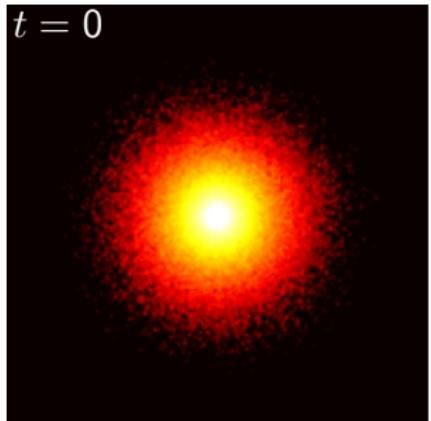
Sancisi & Fraternali, 2007

Seigar, 2008

Lelli et al., 2010

Inner disc, bar and bulge

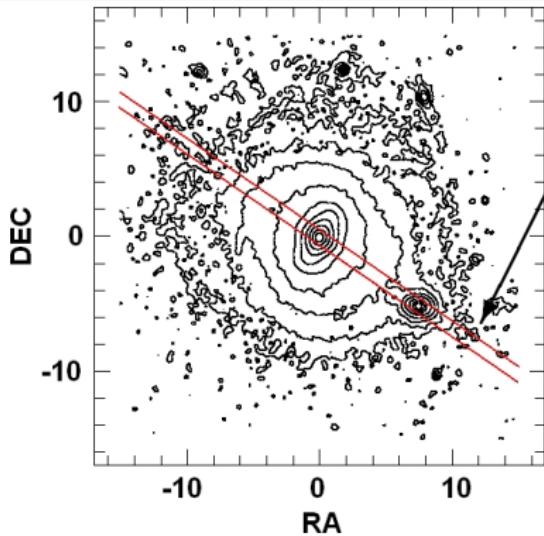
# *A collisional model. Where is a satellite?*



Mapelli et al., 2008

**A very massive satellite is needed!!!**

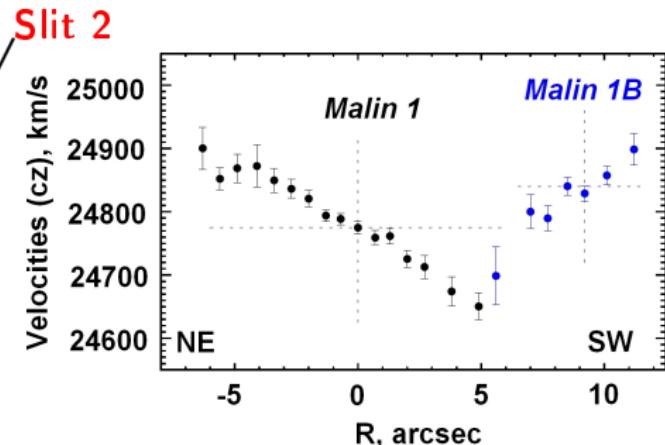
# *6-m telescope's data. A missing satellite?*



Slit 1 – PA = 200°

Slit 2 – PA = 235°

Slit 3 – PA = 333°



$$\Delta v \sim 65 \pm 16 \text{ km/s}$$

$$\Delta R_{\text{proj}} \sim 14 \text{ kpc}$$

$$L_{\text{satellite}}(I) \approx 0.1 L_{\text{Malin1}}(I)$$

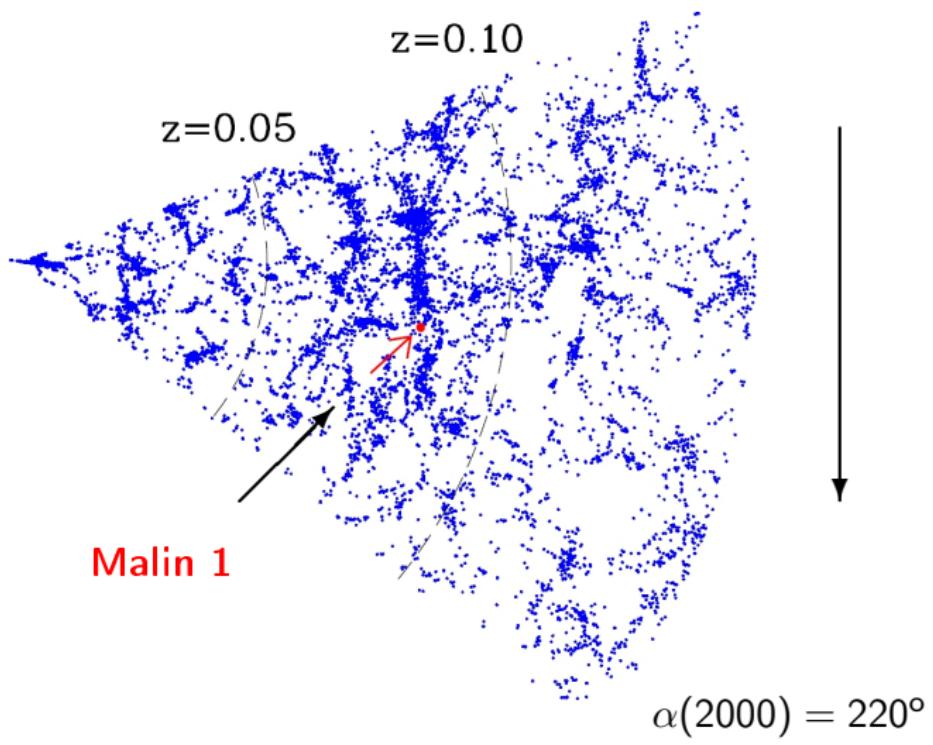
Too small

A close orbit rather than a flyby

# Formation in the voids?

A slice within  $13.1^\circ \leq \delta(2000) \leq 15.6^\circ$

$\alpha(2000) = 160^\circ$



# A missing satellite?

The nearest bright galaxy:

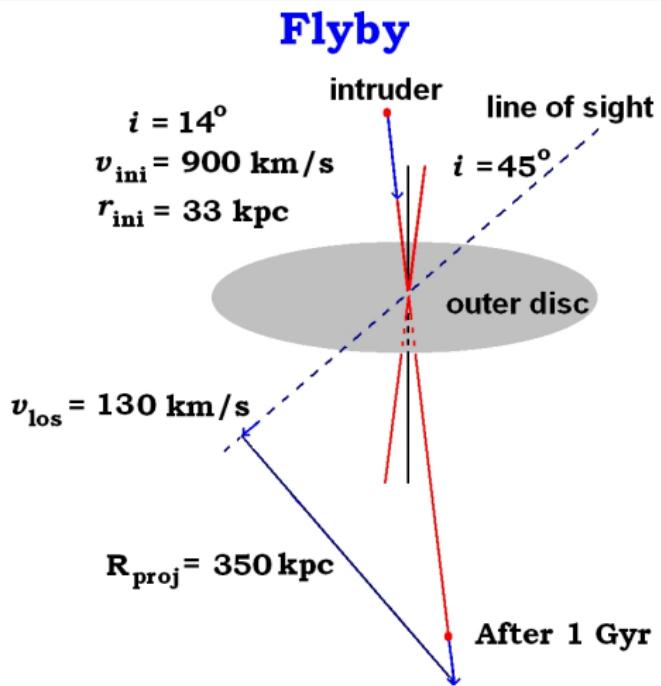
SDSS J123708.91+142253.2

$$\Delta R_{\text{proj}} \sim 350 \text{ kpc}$$

$$\Delta v \sim 132 \pm 29 \text{ km/s}$$

The *g*-band:

$$L_{\text{satellite}}/L_{\text{Malin1}} = 1/2.5$$

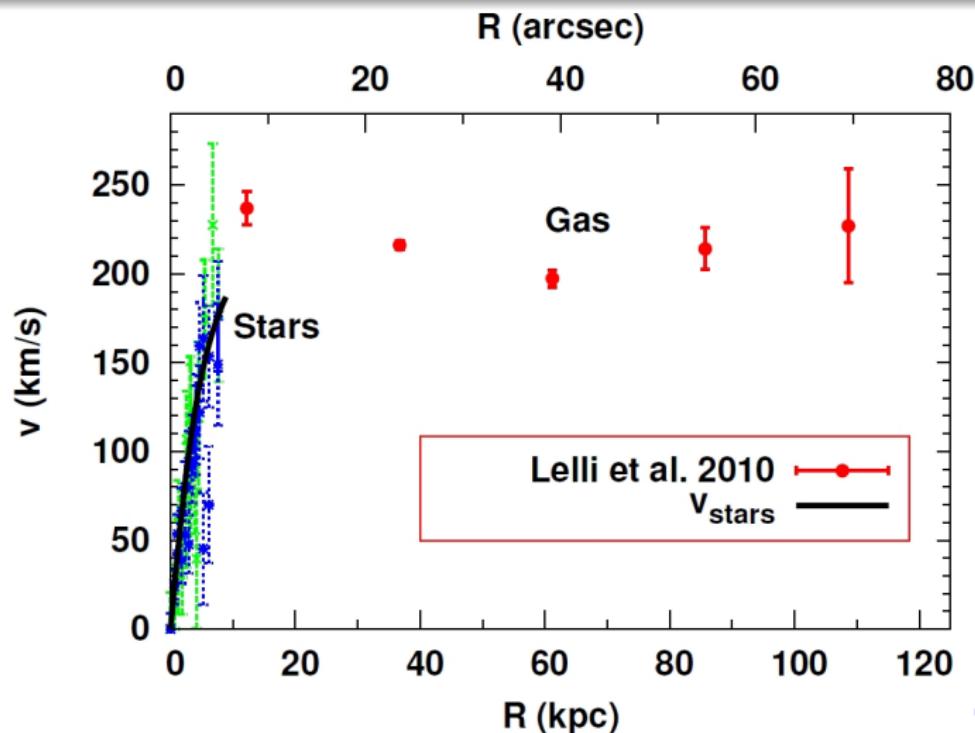


Can be reconciled with Mapelli's model!

## Stellar rotation curve (two slits)

PA = 200° – was not used; data are very noisy

PA = 235° and PA = 333°  $\implies i = 38^\circ, \text{PA}_{\text{maj}} = 1.7^\circ$



# Asymmetric drift

## Stellar and gaseous rotation curves

The asymmetric drift equation – the in-plane steady state

$$v_c^2 - \bar{v}_\varphi^2 = \sigma_\varphi^2 - \sigma_R^2 - R \frac{\partial \bar{v}_R \bar{v}_z}{\partial z} - \frac{R}{\Sigma_d} \frac{\partial \Sigma_d \sigma_R^2}{\partial R}$$

$$\Sigma_d(R) = \left( \frac{M}{L} \right) I_d(R)$$

$R \frac{\partial \bar{v}_R \bar{v}_z}{\partial z}$  – describes the tilting of the velocity ellipsoid;  
essential only in the centre

## *LOS velocity dispersion*

### Profiles along slits

$$\sigma_{\text{los}}^2(R') = [\sigma_R^2 \sin^2 \varphi + \sigma_\varphi^2 \cos^2 \varphi] \sin^2 i + \sigma_z^2 \cos^2 i$$

$$R' = \frac{R \cos i}{\sqrt{1 - \sin^2 i \cos^2 \varphi}}; \quad \varphi = PA - PA_{\text{maj}}$$

### Radial and azimuthal profiles

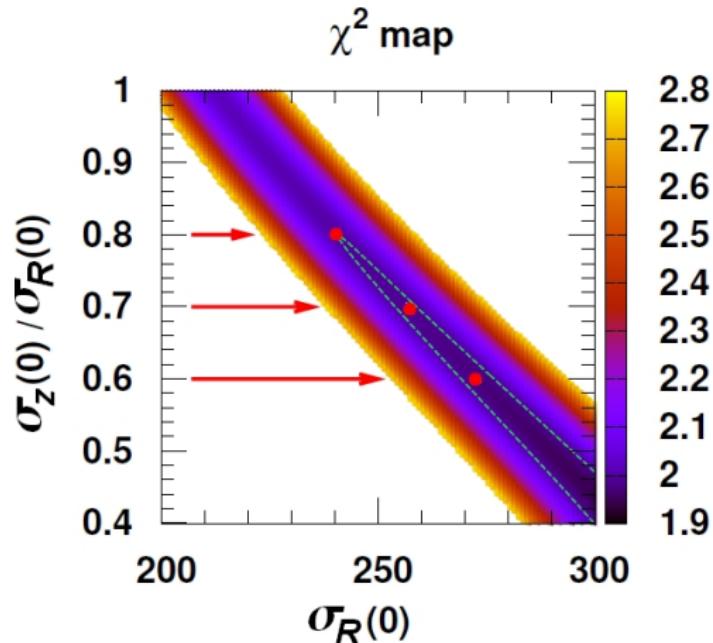
$$\frac{\sigma_\varphi^2}{\sigma_R^2} = \frac{1}{2} \left( 1 + \frac{\partial \ln \bar{v}_\varphi}{\partial \ln R} \right)$$

### Solid body rotation

$$\sigma_\varphi \approx \sigma_R$$

$\sigma_{\text{los}}(R)$  doesn't depend on PA!!!

# Velocity dispersion profiles. Degeneracy

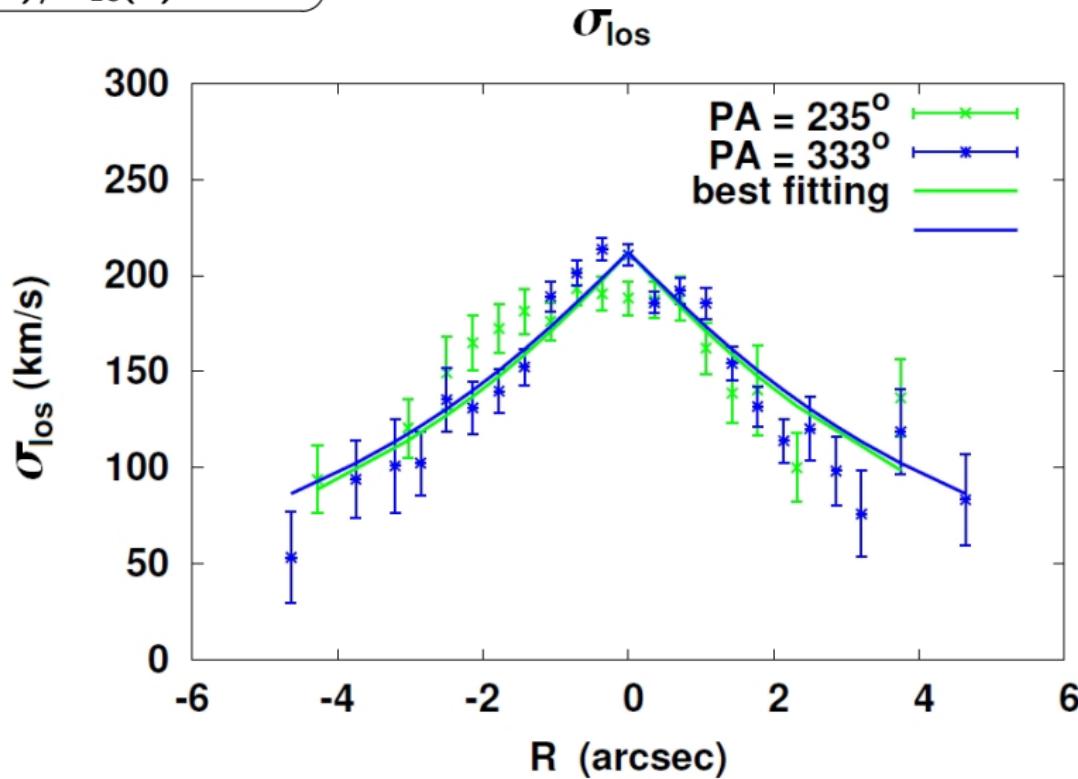


$$\sigma_{\text{los}}^2(R) \approx \sigma_R^2 \sin^2 i + \sigma_z^2 \cos^2 i$$

$$\sigma_z(R) \propto \sigma_R(R) = \sigma_{R,0} e^{-R/h_{\text{kin}}} ; \quad h_{\text{kin}} \approx 2 h$$

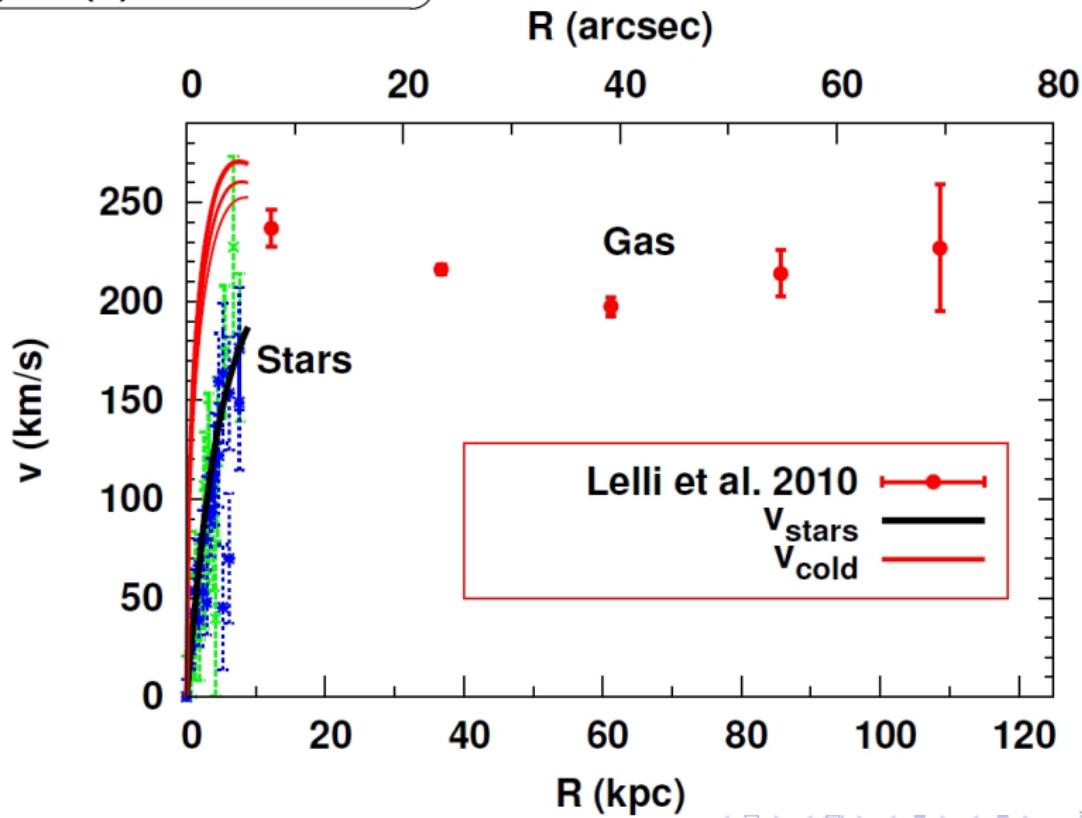
# Velocity dispersion profiles

$$\sigma_z(0)/\sigma_R(0) = 0.6$$



## Recovered “cold” rotation curve

$$\sigma_z(0)/\sigma_R(0) = 0.6, 0.7, 0.8$$



## *Decomposition of the rotation curve*

$(\mathcal{M}/L_{\text{band}})$  – Bell et al., 2003:  $\lg(\mathcal{M}/L_{\text{band}}) = a_{\text{band}} + b_{\text{band}} \times \text{Color}$

**Inner disc** – exponential profile;  $h_z/h_{\text{inner}} = 0.2$

**Bar** – Sersic profile

$$B - V = 0.9 \implies 1.7 < (\mathcal{M}/L_I) < 2.8 \text{ (up to 3.5)}$$

**Bulge** – Sersic profile

$$(\mathcal{M}/L_I) - \text{free}$$

**Outer disc** – exponential profile

$$(\mathcal{M}/L_R) \approx 0.9$$

+ HI

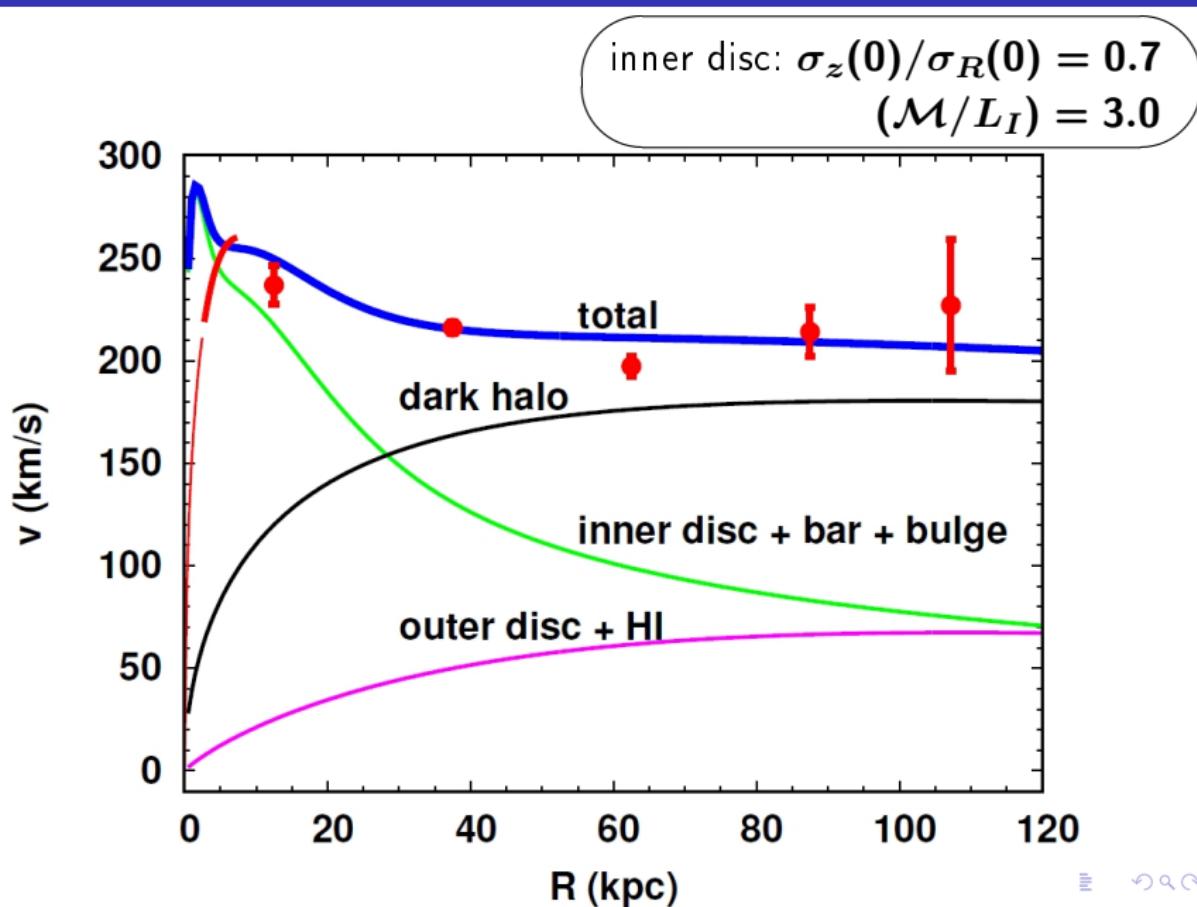
**Dark halo** – NFW model

Two parameters:

$$c = r_s/r_{200} - \text{concentration}$$

$v_{200}$  – the velocity at the virial radius

# “Maximal” disc, “minimal” bulge



## *Summary*

The discovery of a small satellite Malin 1B interacting with Malin 1

The location and the speed of the galaxy SDSS J123708.91+142253.2 can be reconciled with the collisional model of the outer disc

The “cold” rotation curve was recovered

If the inner disc is maximal dark matter begin to dominate only in the outermost regions