Kinematics of LSB and Dwarf Galaxies: Implications for LCDM Models

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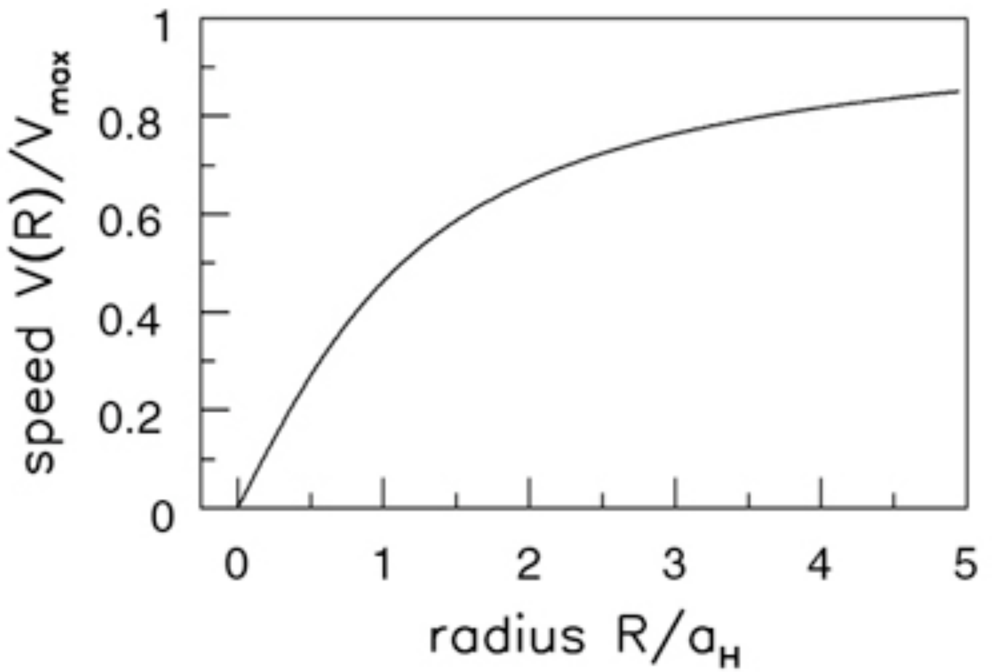
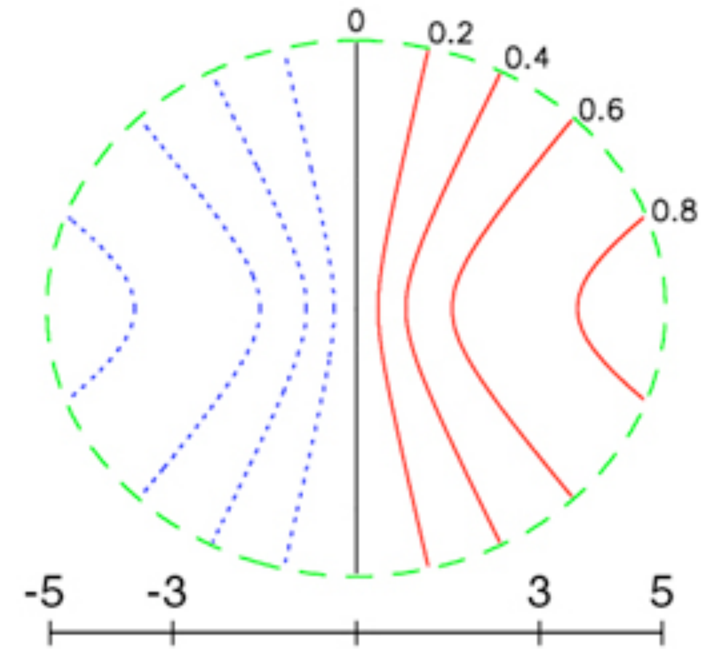
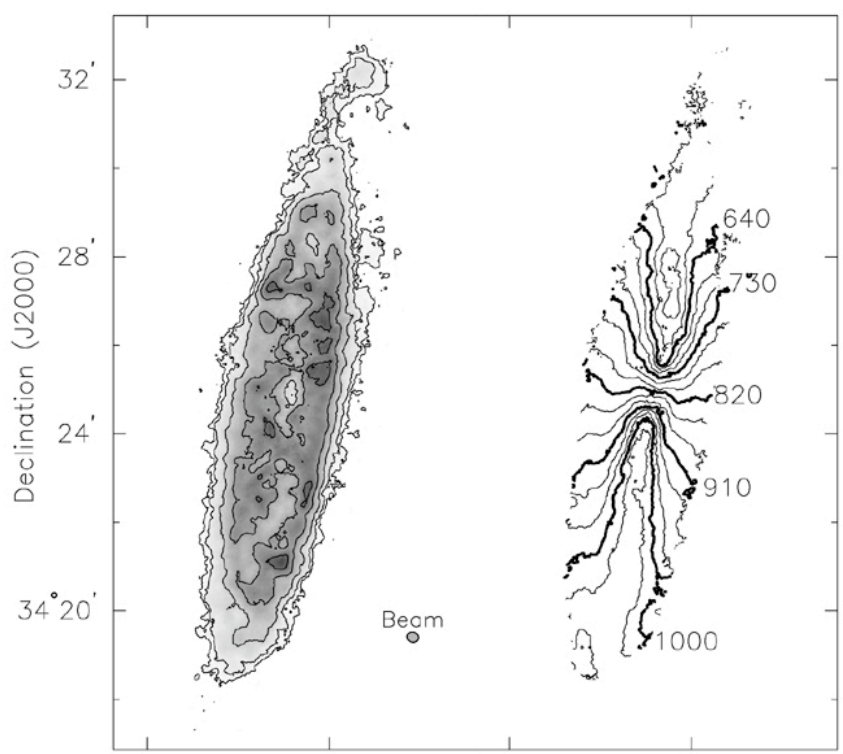
with Anatoly Klypin NMSU Octavio Valenzuela UNAM and Fabio Governato UW

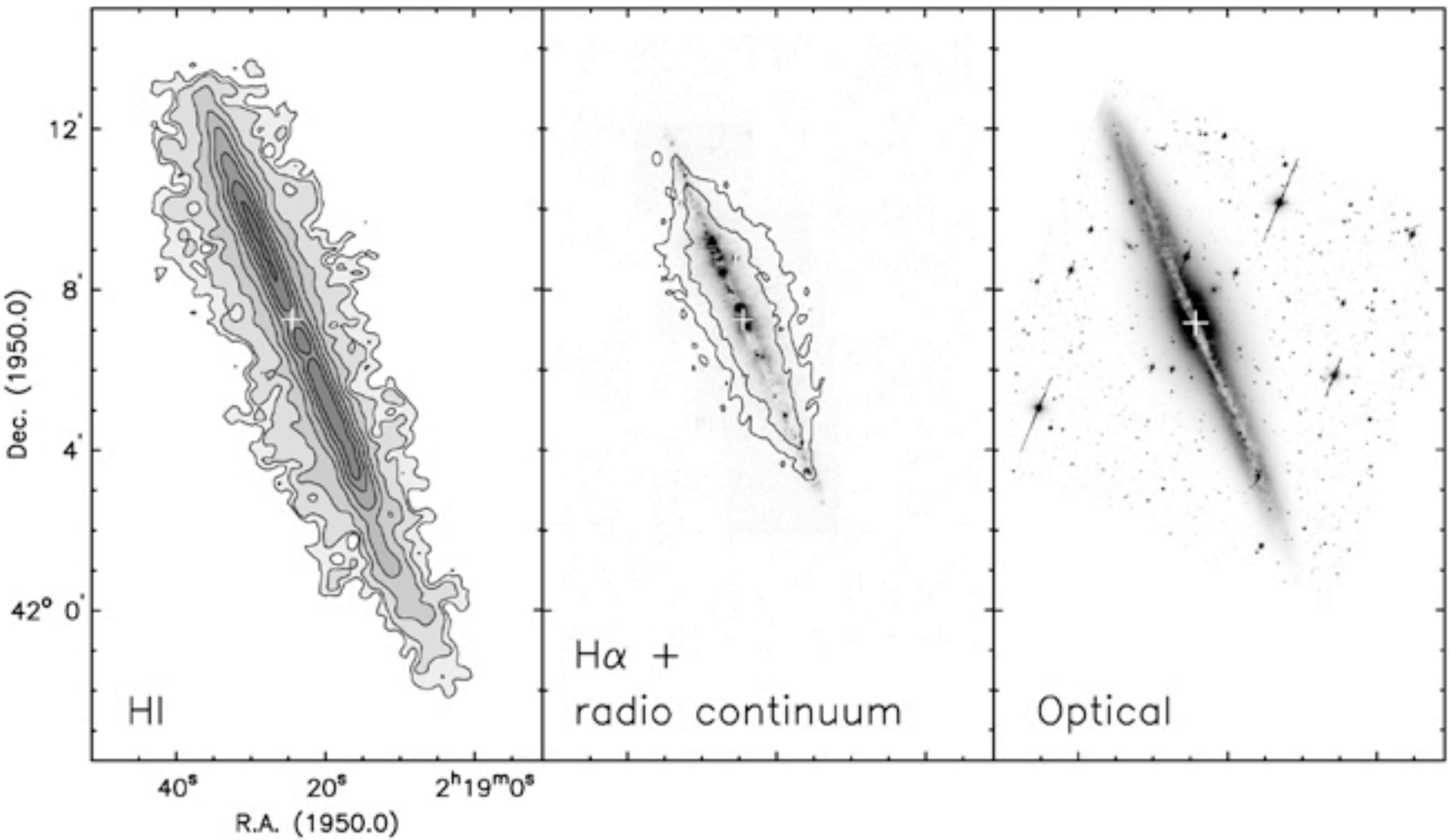
the rotation curve





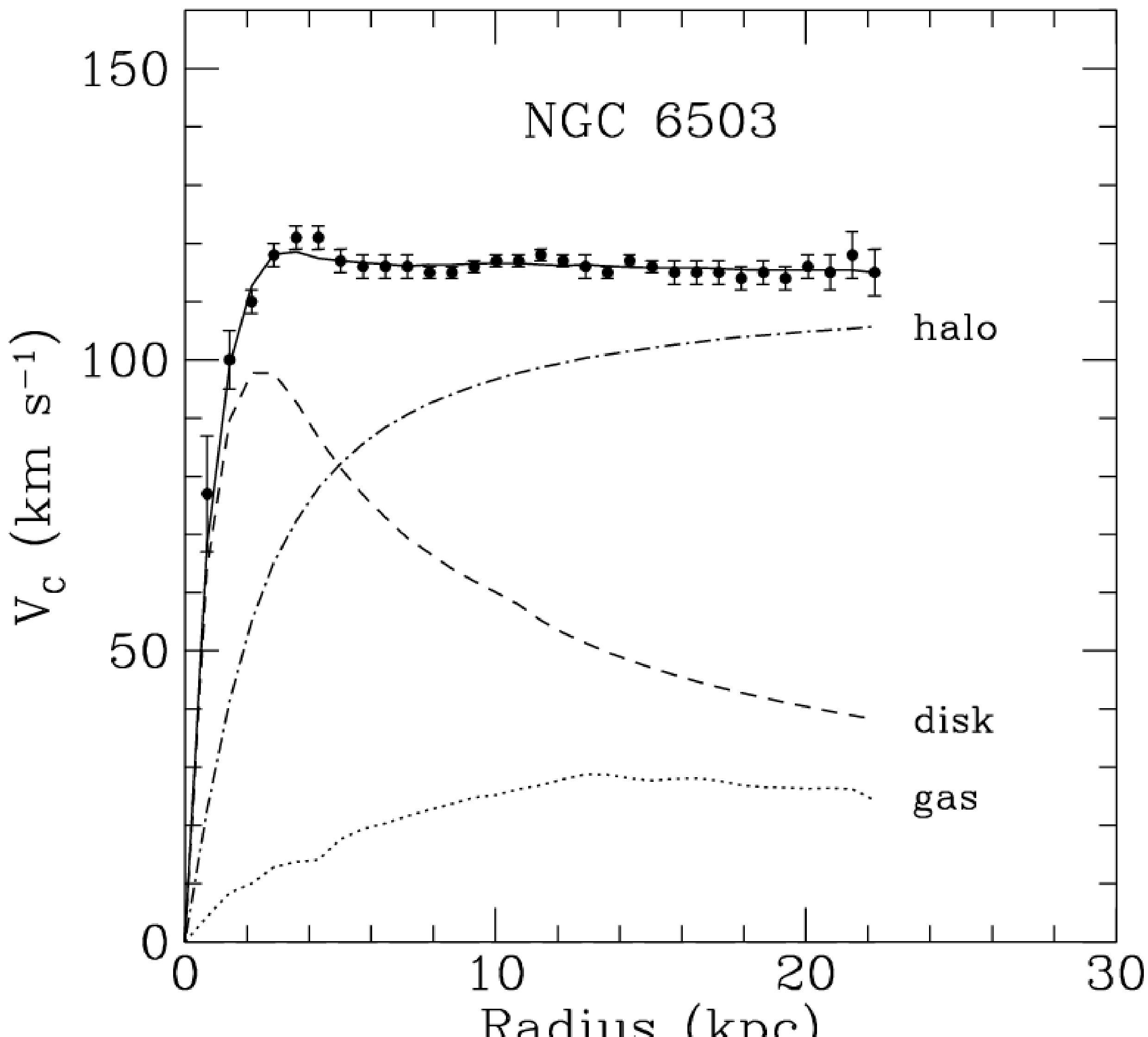


example of spiral galaxy data



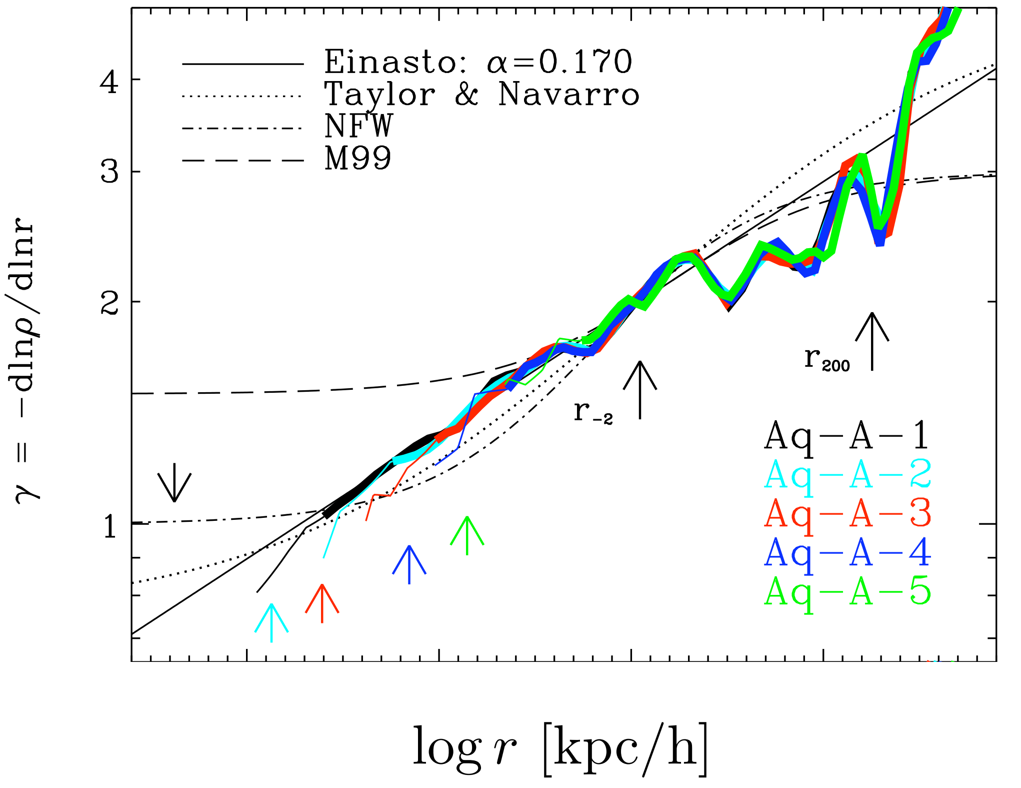
NGC 891

$$\frac{GM(<r)}{r^2} = \frac{v^2}{r}$$



Navarro et al 2008 astroph 0810.1522

4.4 billion particles per halo



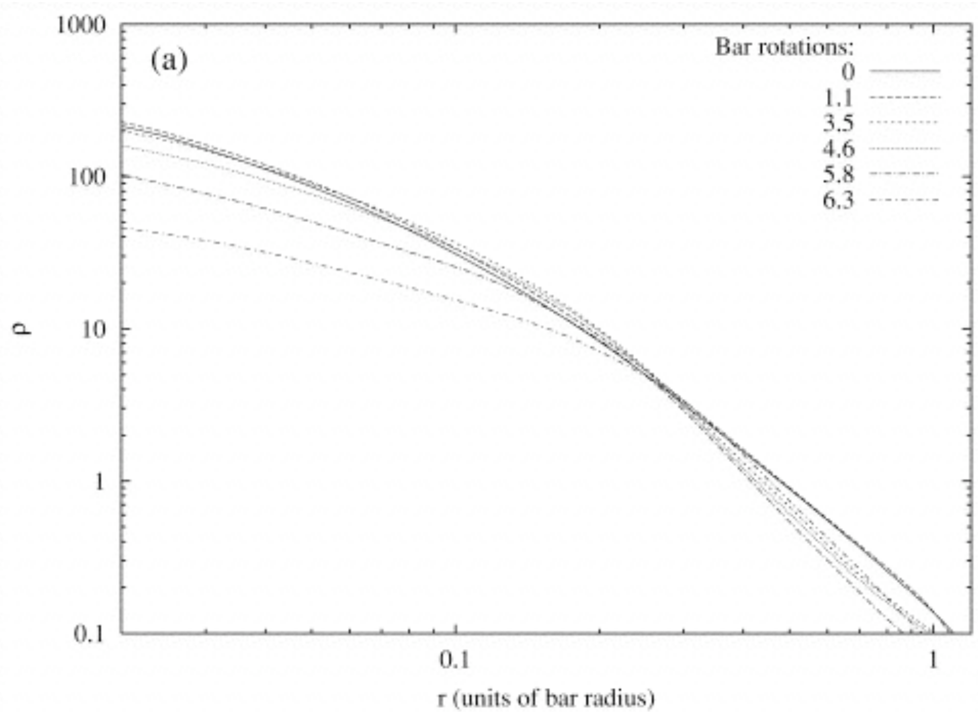
cusp is present between 0.2 and 1kpc with slope steeper than -1

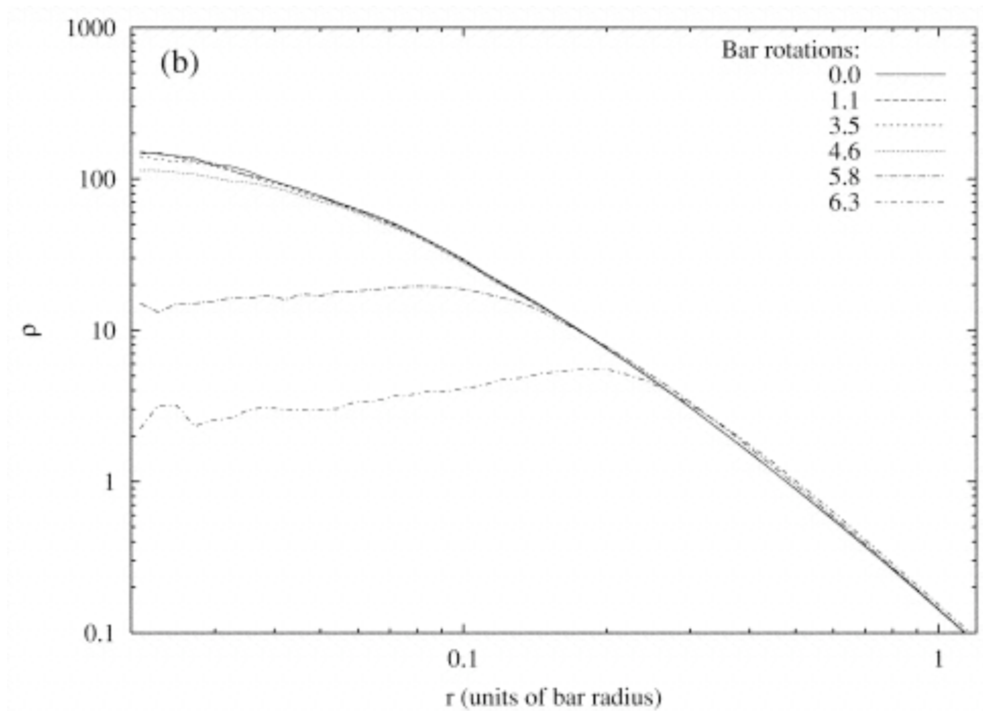
Bars can modify the structure of the halo

Katz and Weinberg ApJ (2002) 580, 627

linear theory

N-body

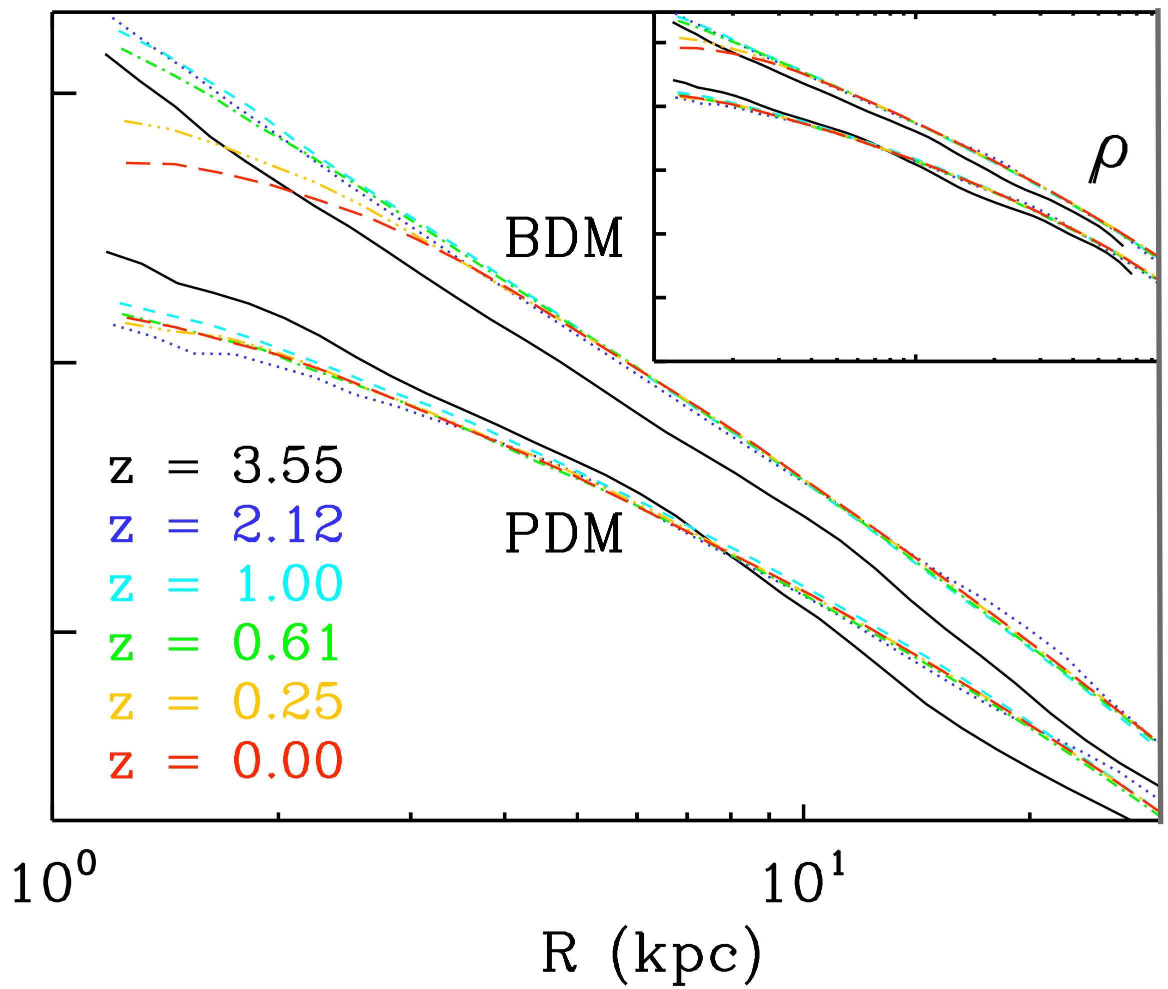




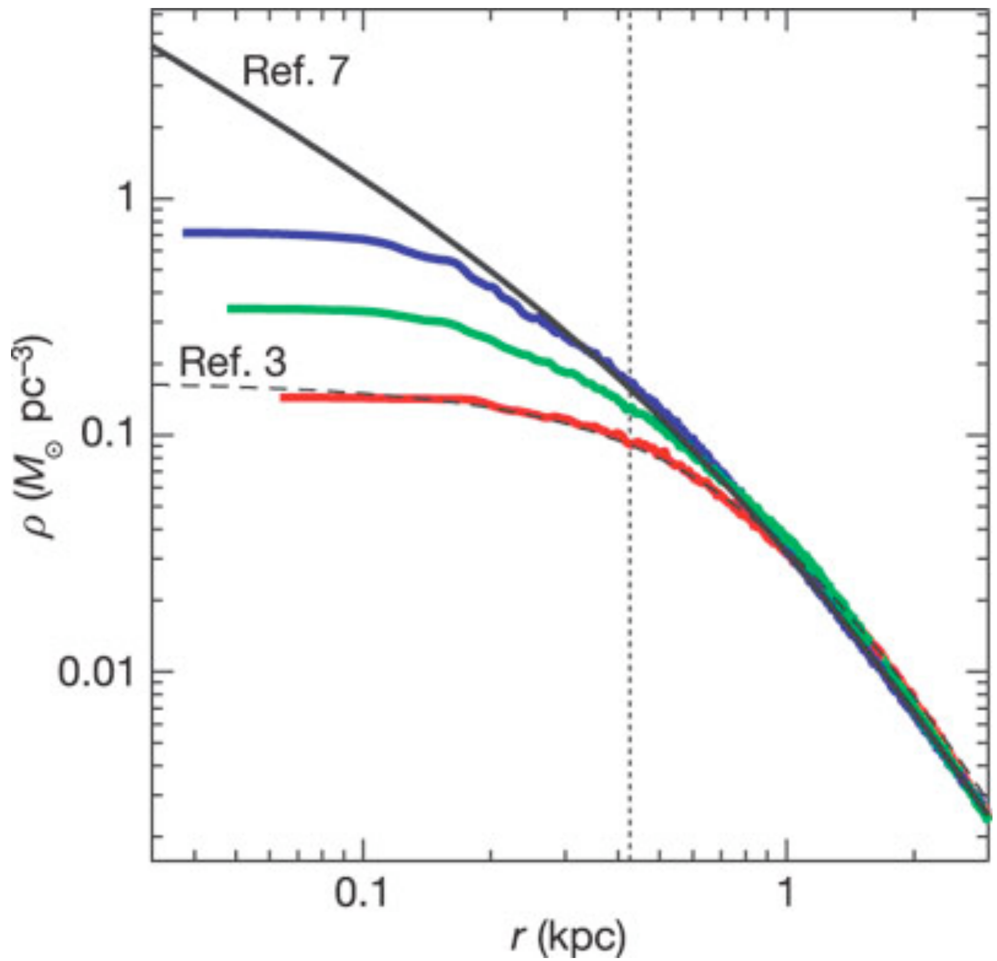
Dynamical friction of sub-clumps of baryons heats up halo overcomes adiabiatic contraction effect and creates a core

Romano-Diaz et al ApJL (2008)

El-Zant and Shlosman ApJ (2001)



Random bulk motions induced by stellar feedback can heat up the dark matter distribution removing the cusp



The blue, green and red lines simulated halo after 40, 80 and 140 Myr, dotted line marks the radius A = 400 pc (the amplitude of the oscillations)

Mashchenko, Couchman and James Wadsley Nature (2006)

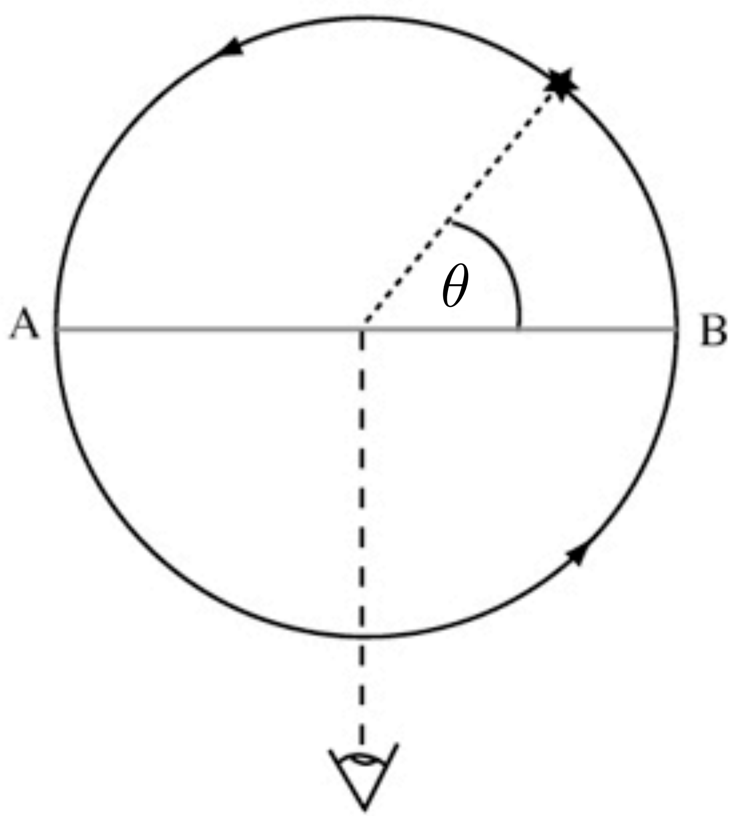
The efficiency of the various mechanisms outlined above (to remove the cusp) versus adiabatic contraction (to enhance the cusp) is still an open question...

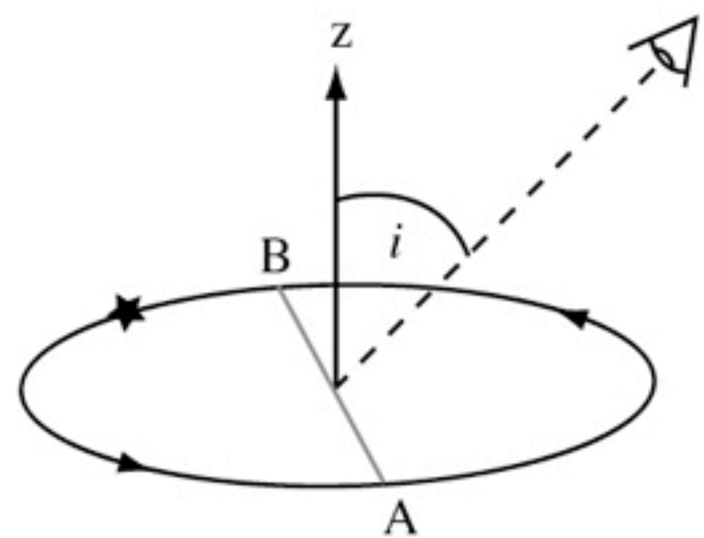
The real world

$$V_t(r,\theta) = \overline{V}_t(r) + \sum_{1}^{\infty} V_{m,t}(r)\cos[m\theta + \theta_{m,t}(r)]$$

$$V_r(r,\theta) = \overline{V}_r(r) + \sum_{1}^{\infty} V_{m,r}(r)\cos[m\theta + \theta_{m,t}(r)]$$

$$V_{\mathrm{obs}} = V_{\mathrm{sys}} + \sin i (V_t \cos\theta + V_r \sin\theta)$$

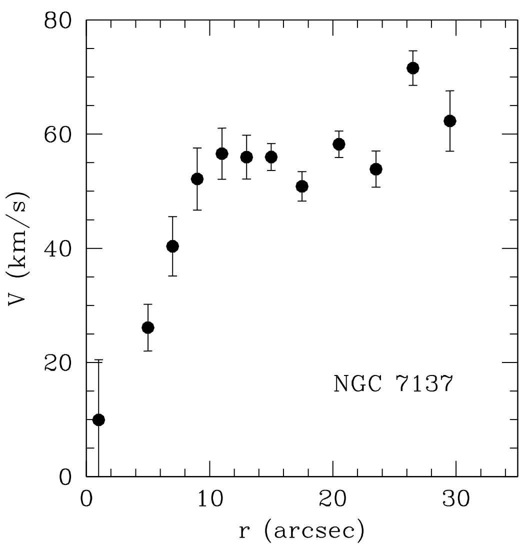


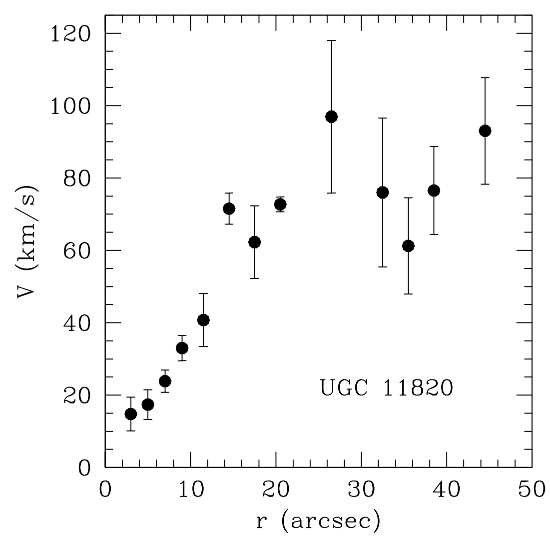


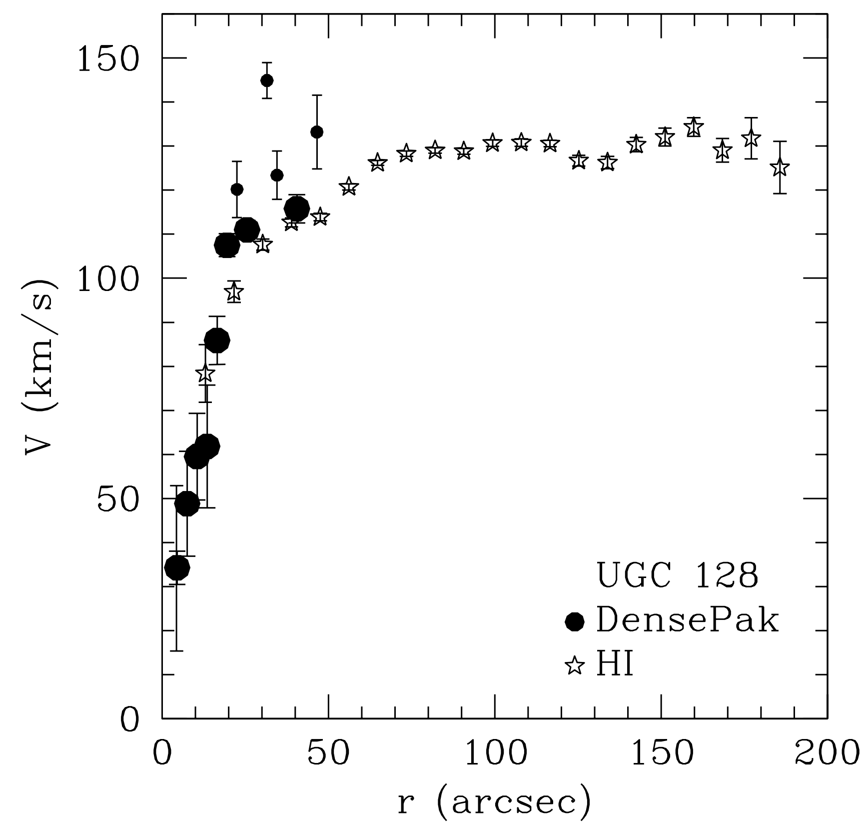
Modeling the line of sight velocity

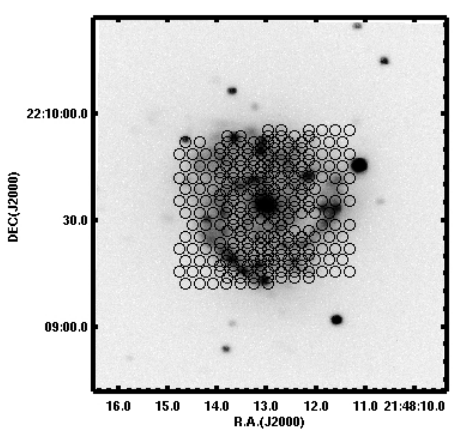
Is H-alpha gas a good tracer of the potential?

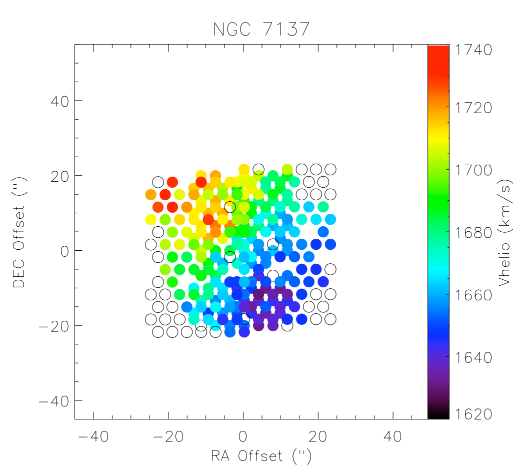
Kuzio de Naray et al. ApJ, 2008 Yes, no need for asymmetric drift correction





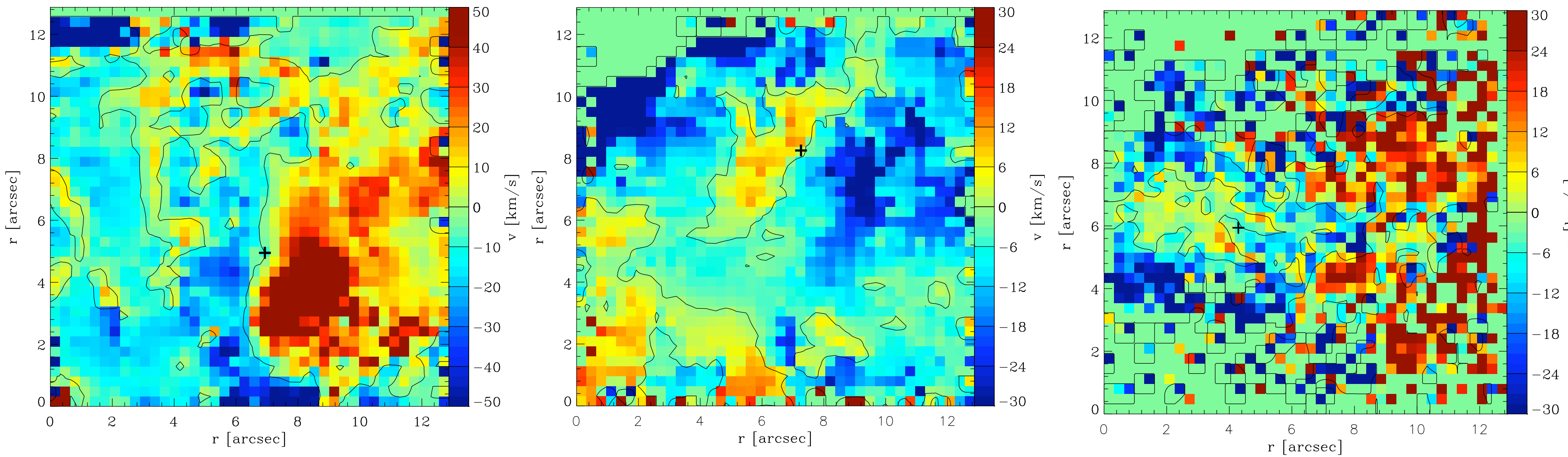






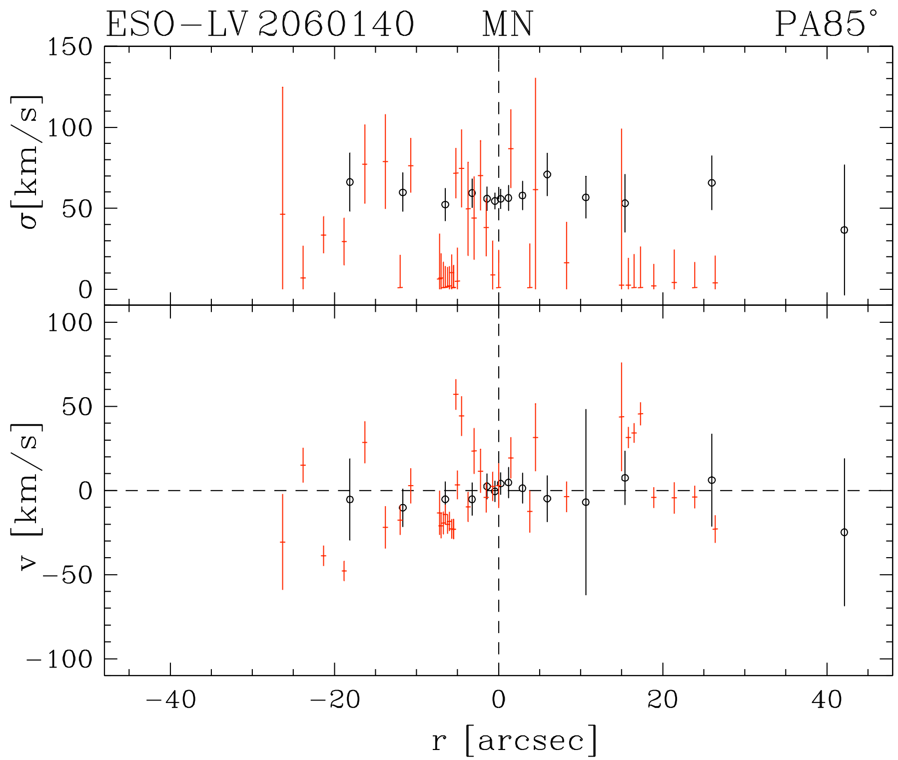
Is H-alpha gas a good tracer of the potential?

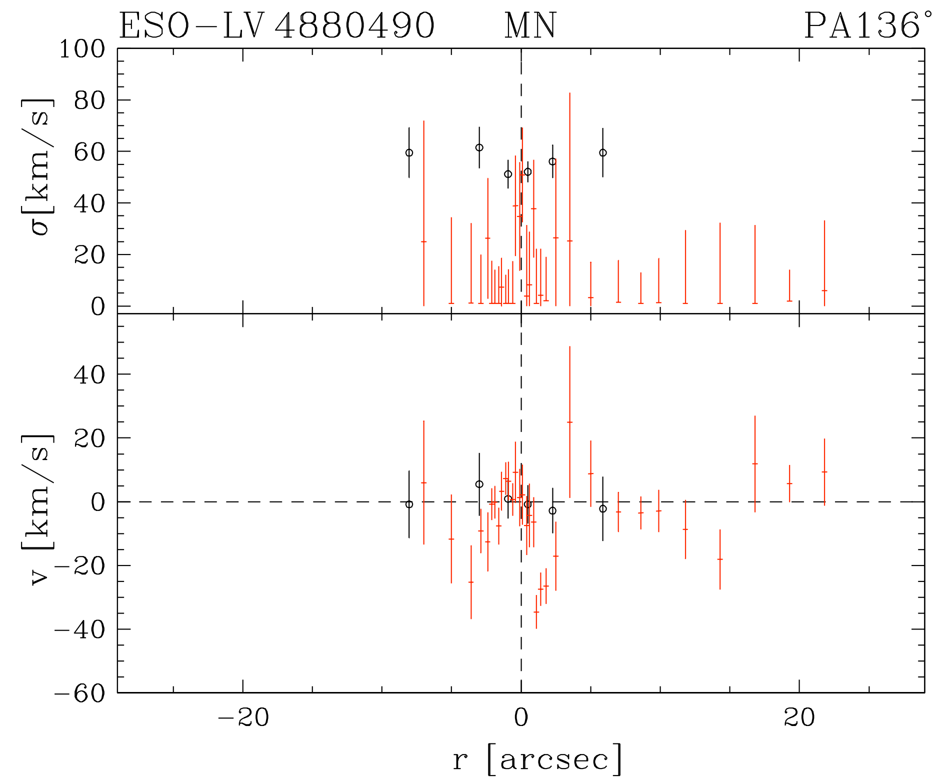
Pizzella et al integral field spectroscopy of 3 LSB galaxies with VMOS VLT



velocity residuals from rotation curve fit are substantial!

compare gas (red) vs stars (black) along LSB minor axis





can we quantify non-circular motions?

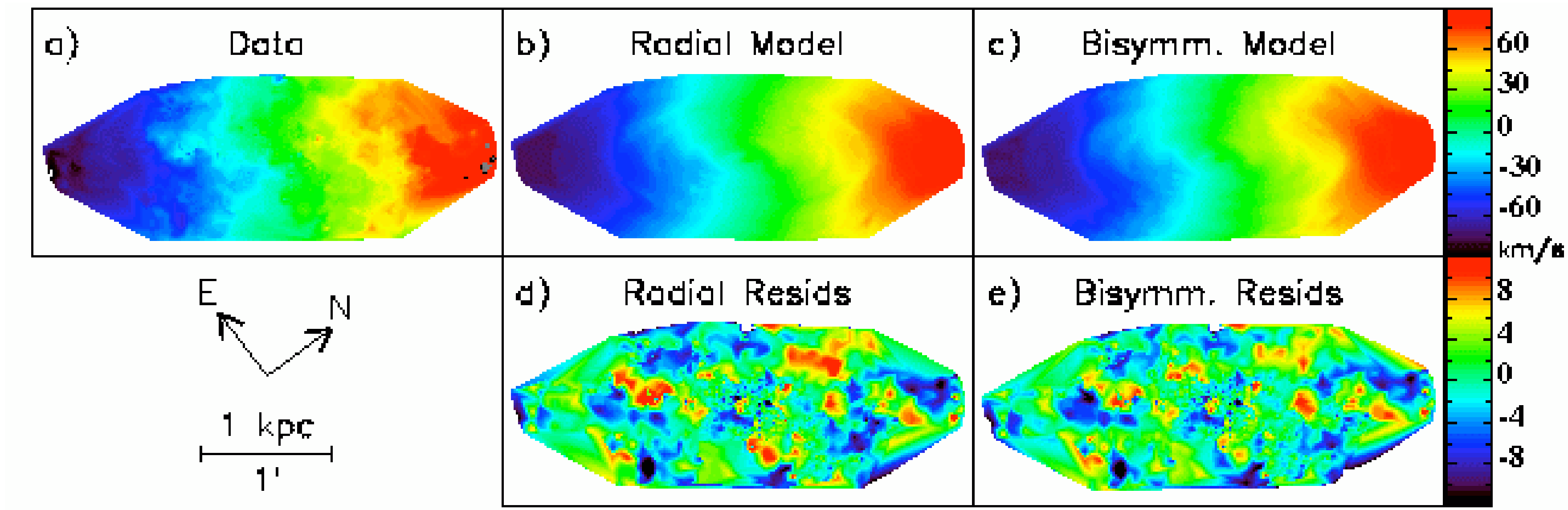
eg: for bar symmetry use m=2 terms

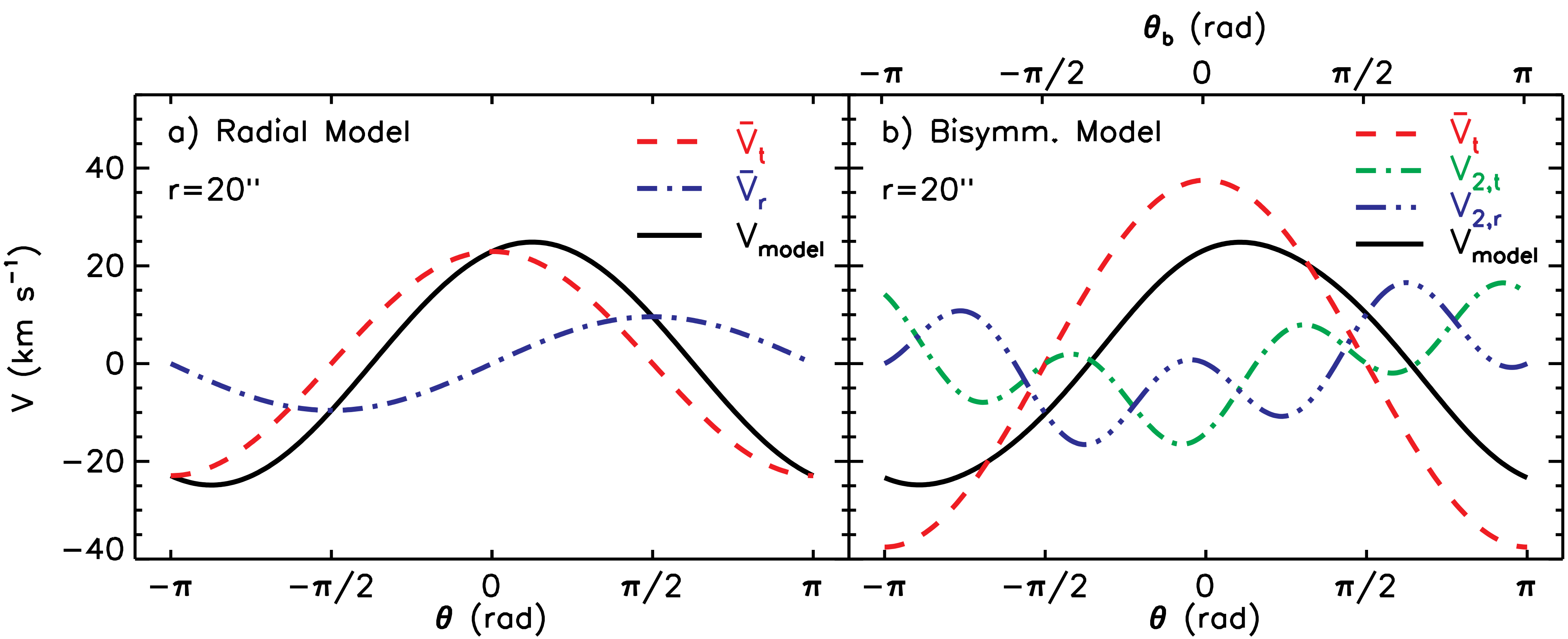
$$V_{\rm model} = V_{\rm sys} + \sin i[\overline{V}_t \cos\theta - V_{2,t}\cos(2\theta_b) - V_{2,r}\sin(2\theta_b)\sin(\theta)]$$

$\theta_b = \theta - \phi_b$ ϕ_b is the bar position angle

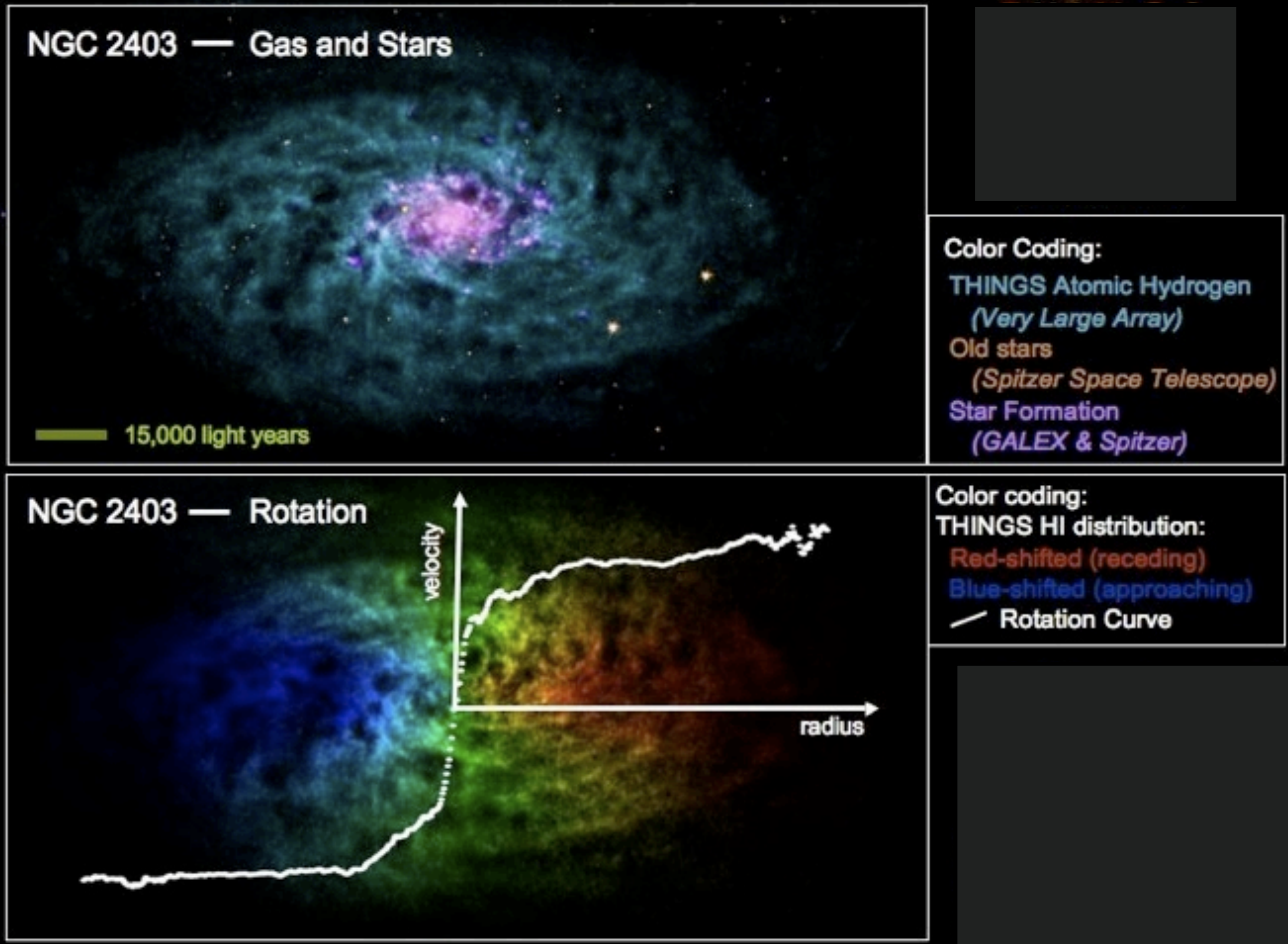
most spiral galaxies are barred

Apply to NGC 2976 Spekkens & Sellwod 2007





The HI Nearby Galaxy Survey



19 nearby 3< D < 15Mpc disk galaxies at high spatial and velocity resolution

THINGS approach to non-circular motions

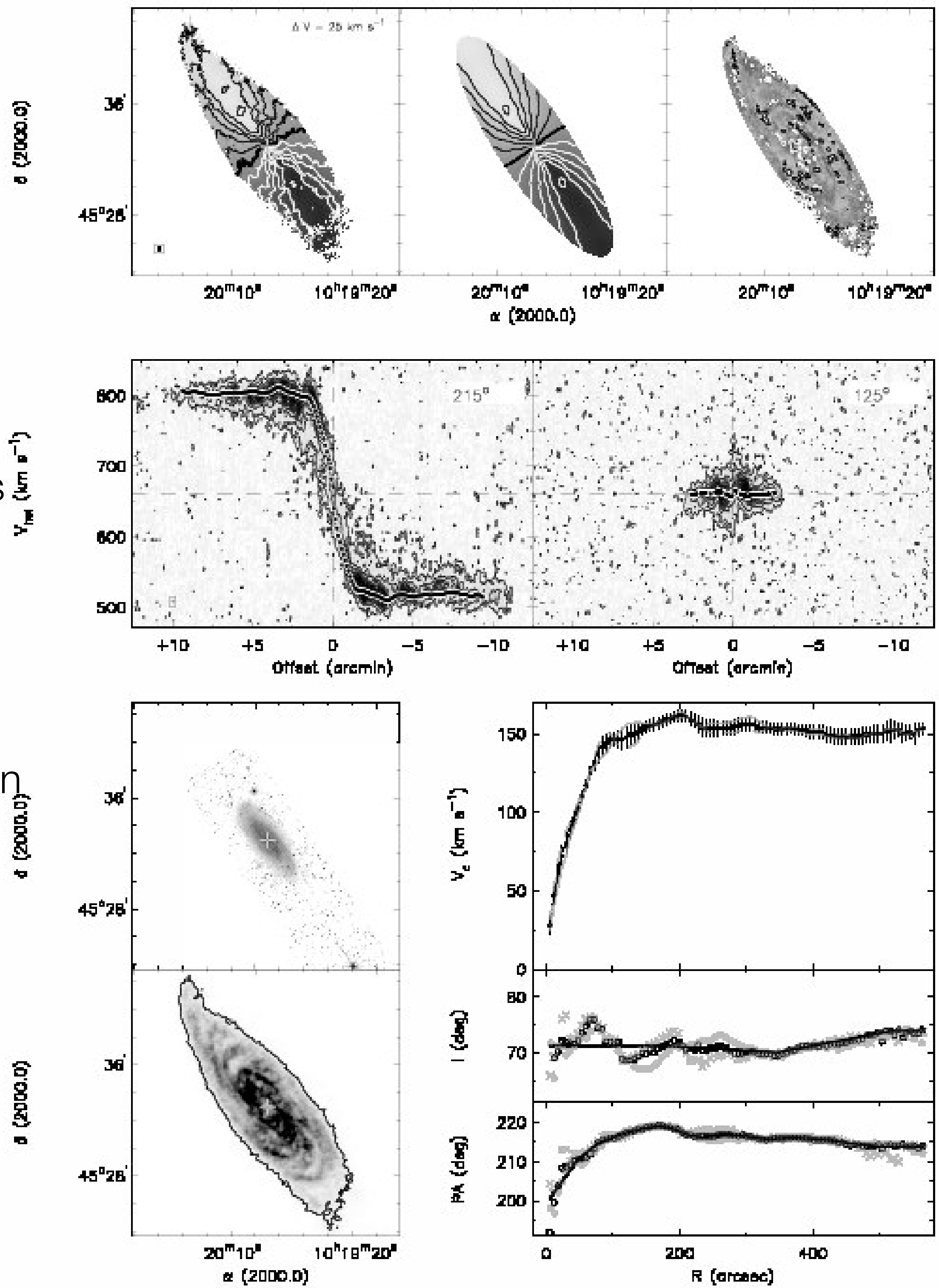
$$V_{\rm los}(r) = V_{\rm sys}(r) + \sum_{m=1}^{3} c_m(r)\cos m\theta + s_m(r)\sin m\theta$$

$$\epsilon_{\rm pot}\sin(2\varphi_2) = (s_3 - s_1)\frac{1 + 2q^2 + 5q^4}{c1(1 - q^4)} \qquad q = \cos(i)$$

φ_2 is the angle between the minor axis of the elongated ring and the observer

n.b. epicycle theory applies to gas on closed orbits and *small* distortions

NGC3198



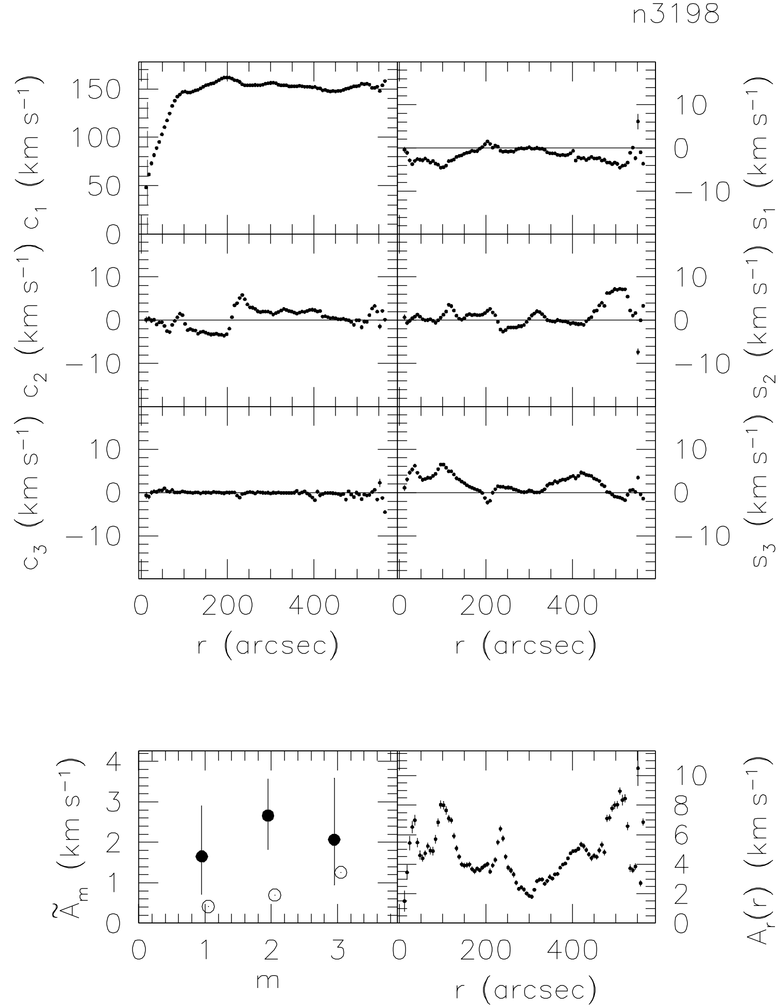
PV diagram major axis

PV diagram minor axis

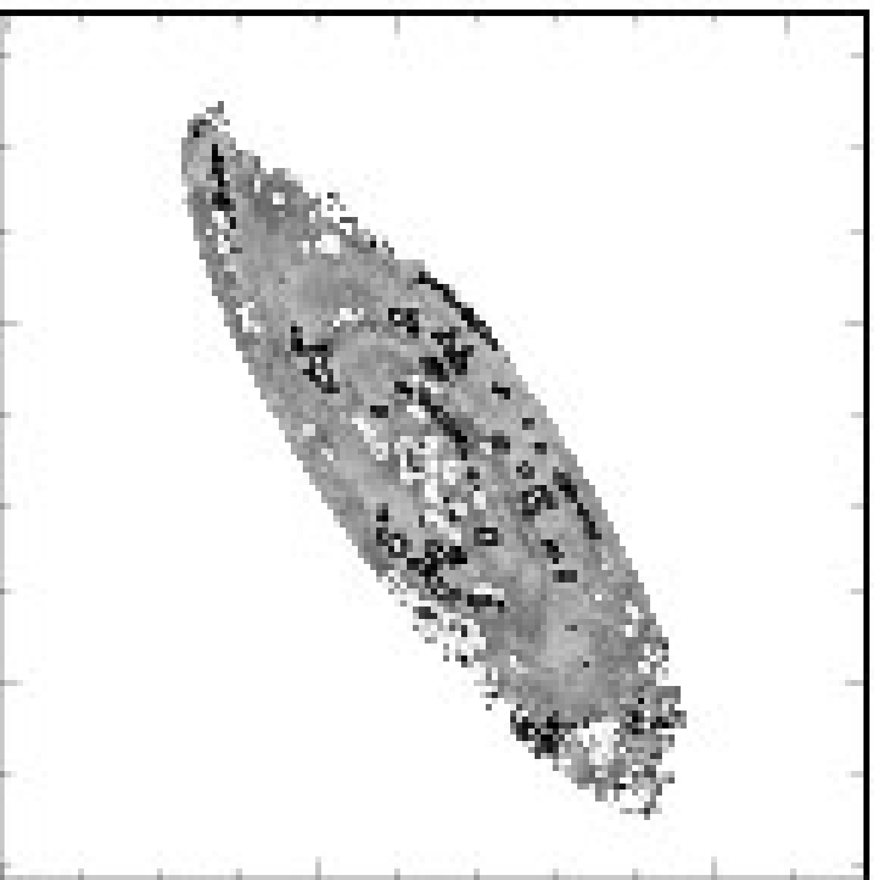
Spitzer irac 3.6 micron

HI map VLA

eg ngc 3198

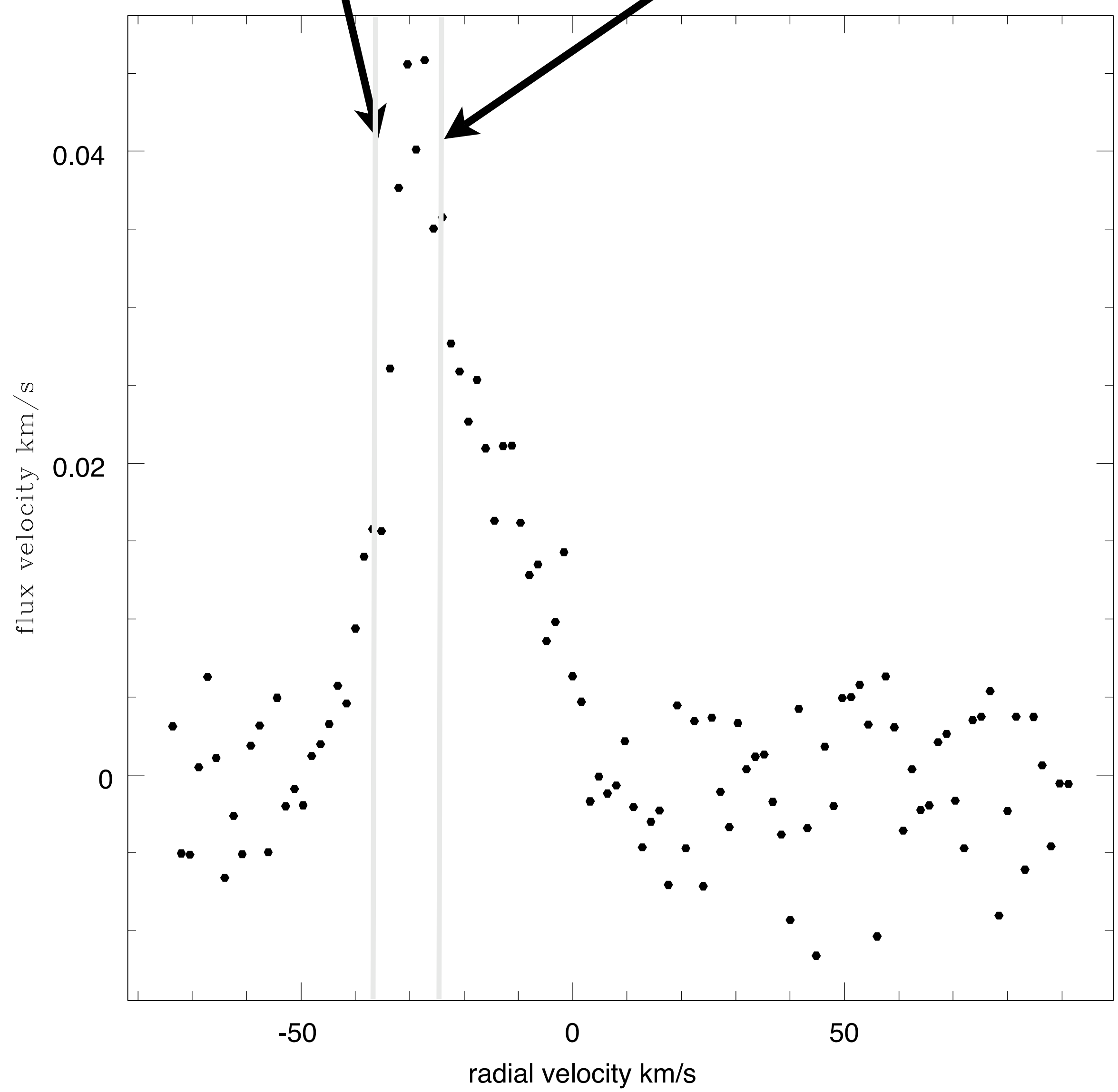


residuals to the tilted ring fit
white -30km/s to +30km/s black



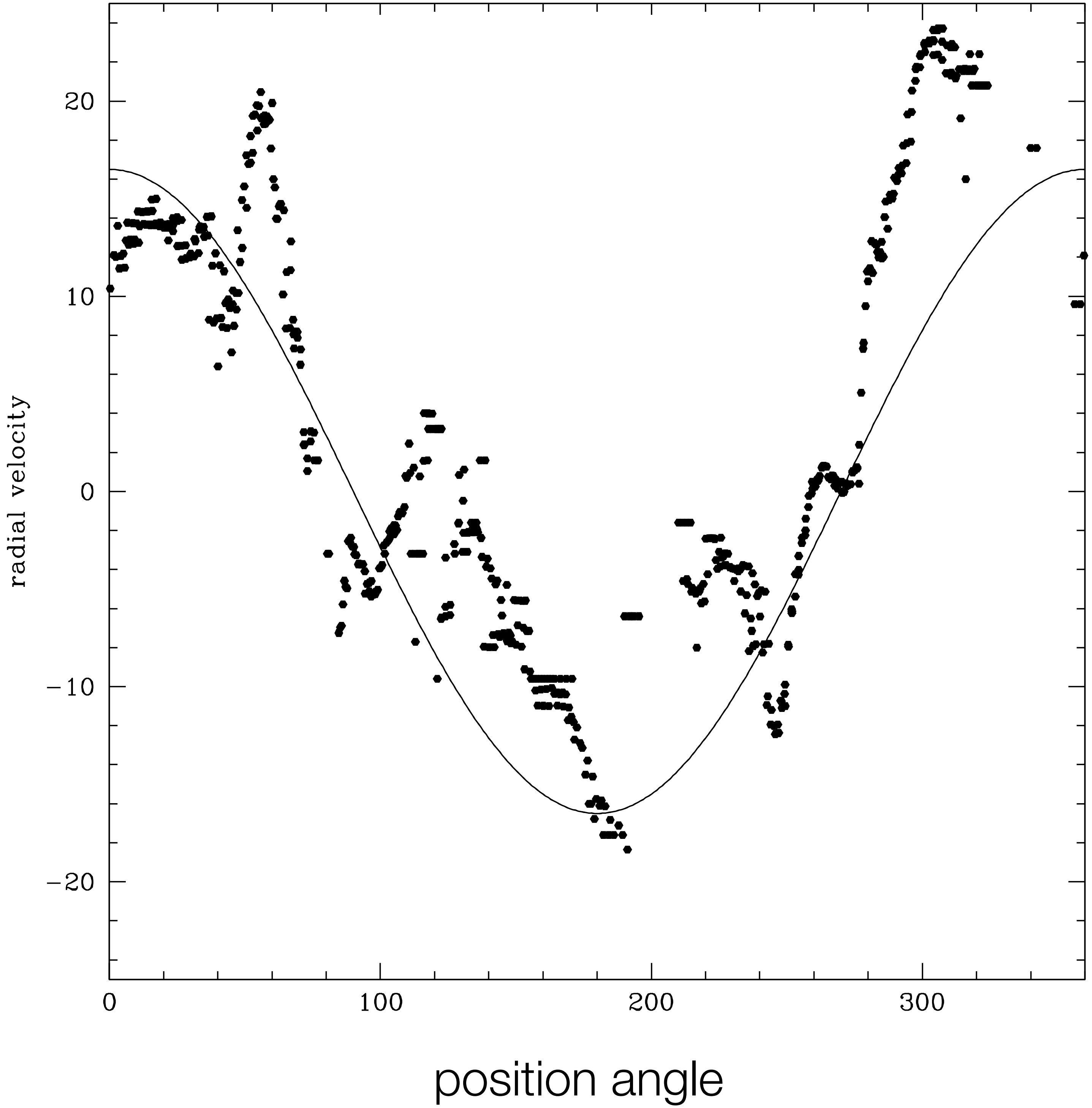
intensity weighted mean velocity -24.3km/s

maximum velocity -36.8 km/s

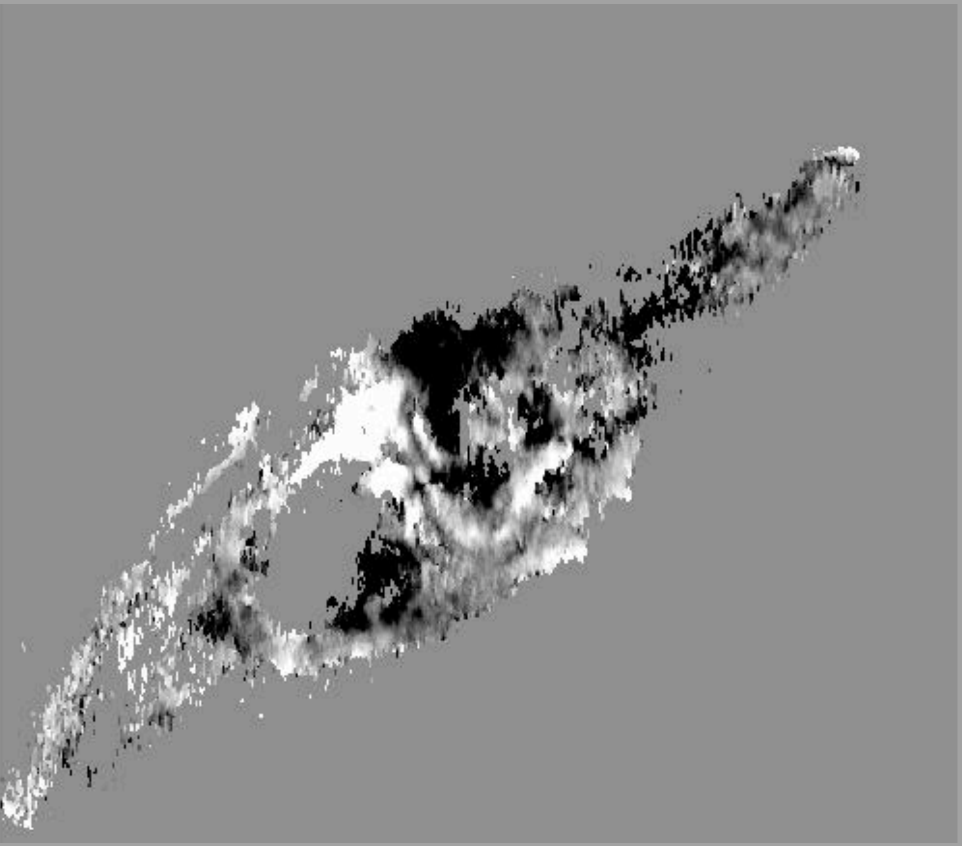


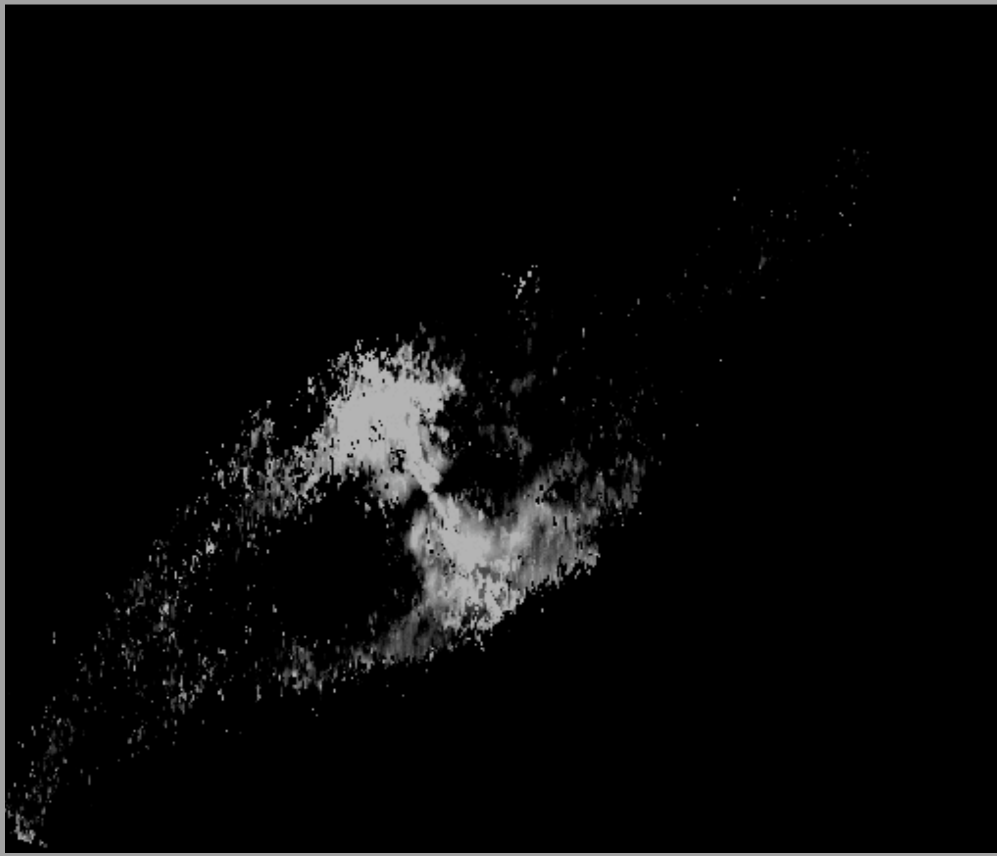
NGC 6822

NGC 6822 semi major axis 0.5kpc



ngc 6822 residuals from circular rotation fit





where do we go from here?

1. we need better theoretical predictions: DM simulations predict a cusp on the scale 0.1~1 kpc but what about the effects of baryons?

2. when comparing models to data try to use models that more closely match real galaxies (eg Governato's talk) rather than epicycle approximation which may not apply

3. As well as using different data sets, examine the same data sets eg NGC 6822 (Rhee et al in prep) so we can reach agreement on the amplitude of non-circular motions and how best to measure them

4. Given difficulties with gas, try to obtain rotation curves of galaxies using optical emission from the stars (difficult but worth the effort)