Mass distribution model of nearby spirals: from 1D to 2D

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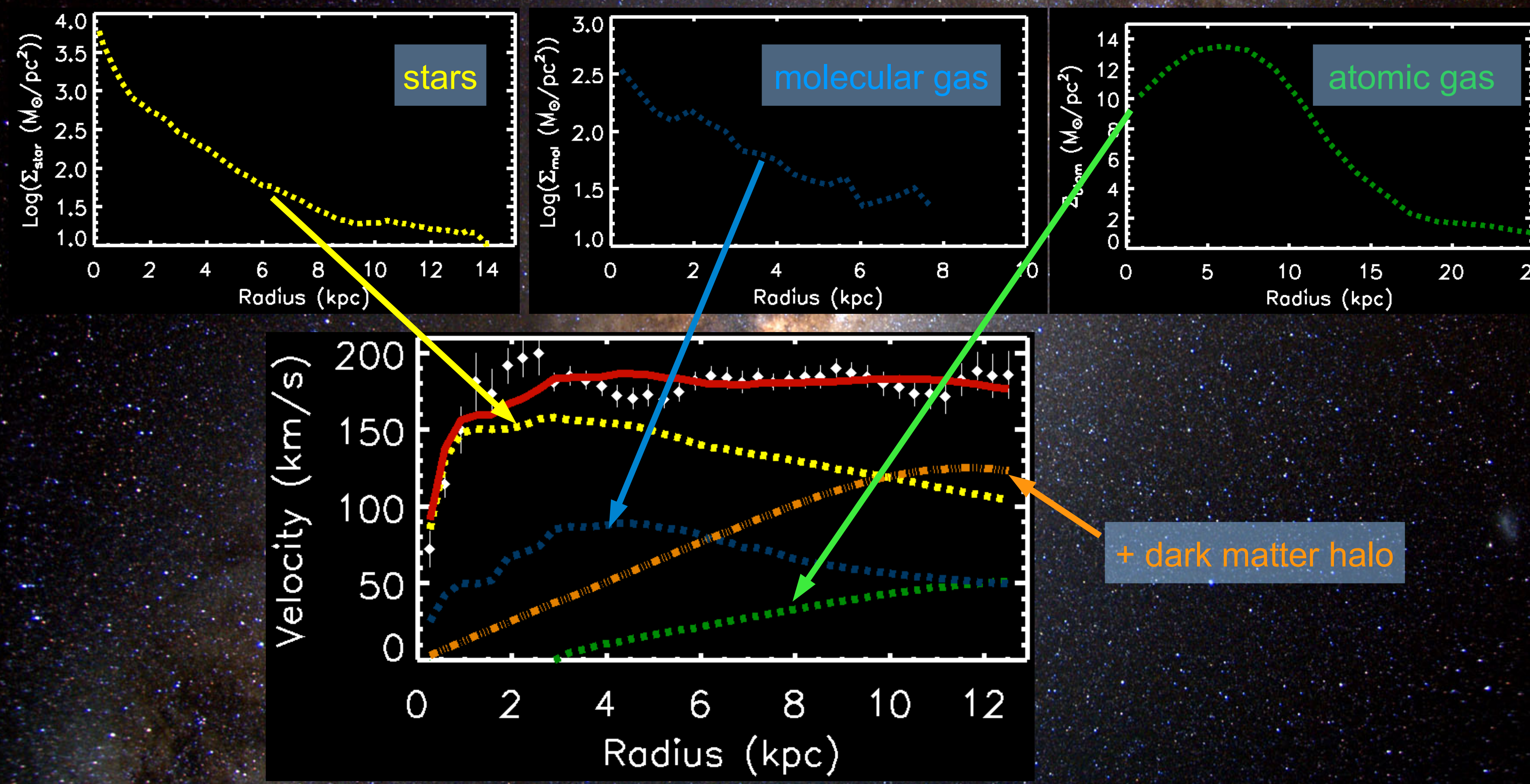
Mass distribution models from rotation curves (1D)



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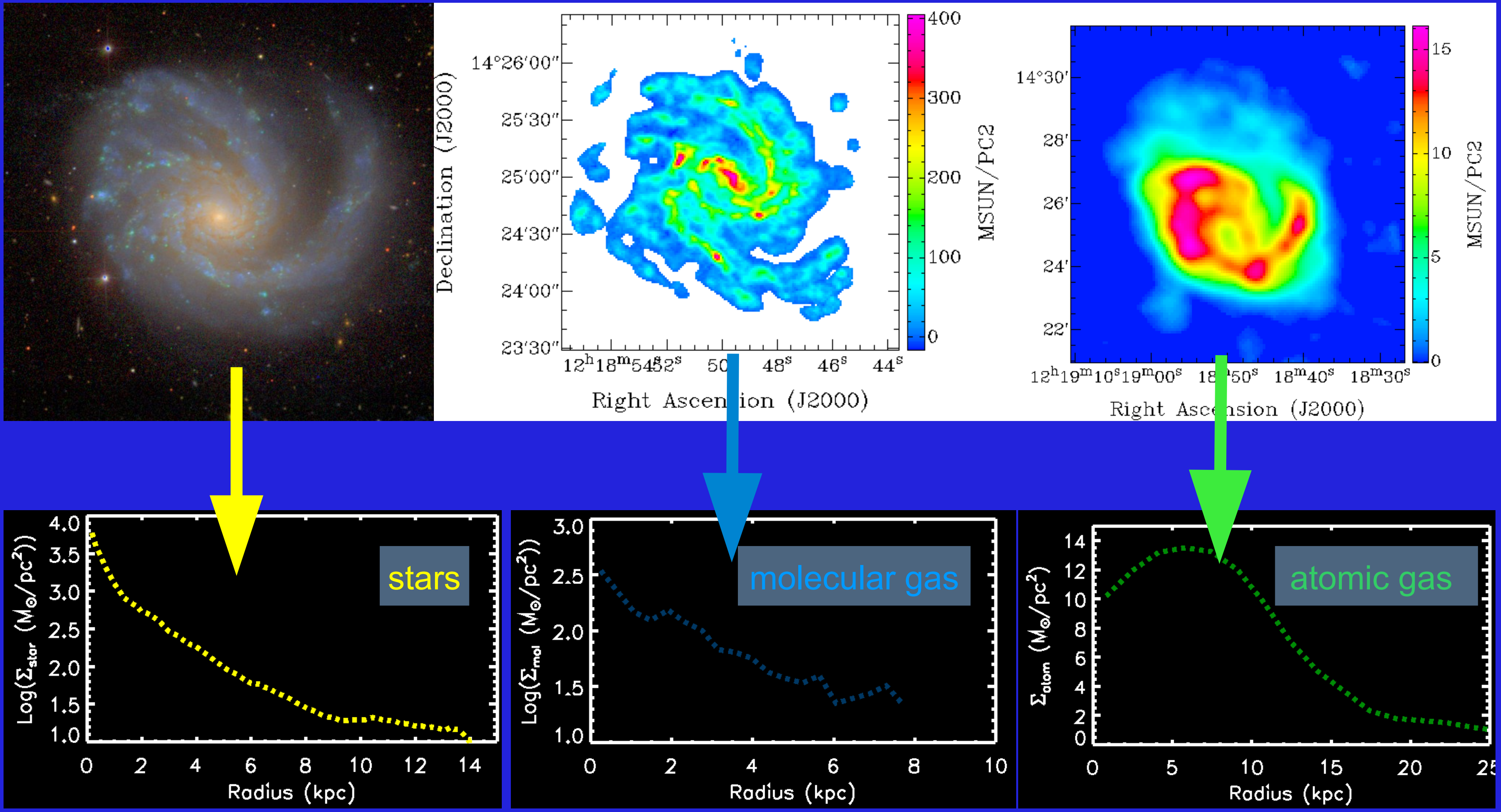
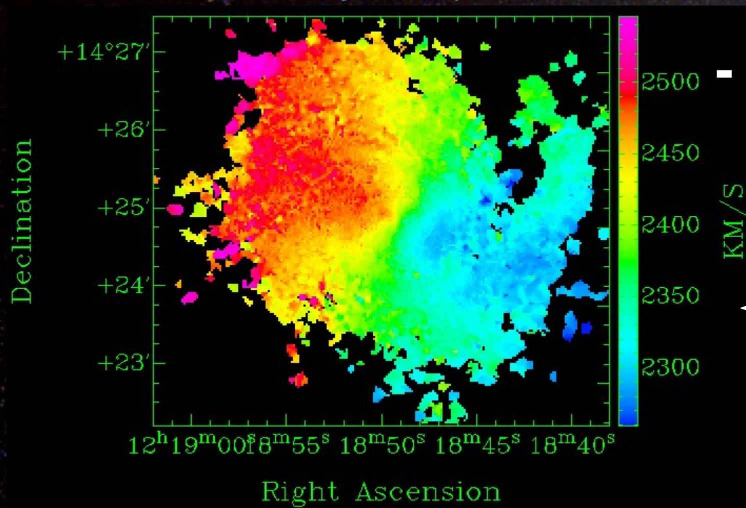
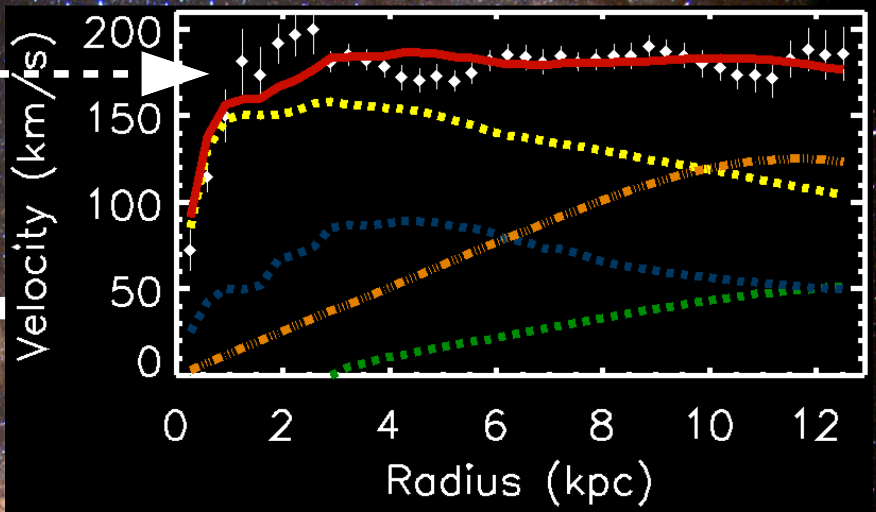


Spirals are asymmetric

Velocity field of Messier 99



Rotation curve of Messier 99



?

Can we extend the mass modelling from rotation curves (1D) to velocity fields (2D)?

Messier 99

- Grand design spiral
- Almost face-on disc
- Sc
- Virgo Cluster (~17 Mpc)
- Many high-quality spectro/photom. data

Methodology

- Deproject surface density maps
- Calculate 2D maps at z=0kpc (potential, acceleration, rotation velocity)
- Build total velocity map on a unique (x,y) grid
  - $V^2_{lum}(x,y) = V^2_{atom}(x,y) + V^2_{mol}(x,y) + V^2_{star}(x,y)$
- Fit the model $\left(V^2_{lum}(x,y)+V^2_{DM}(x,y)\right)^{1/2}$ (cosθ sin i) = (Vobs-Vsys)
  - $V_{DM}(x,y)$: dark matter contribution on the same (x,y) grid
  - Non-linear Levenberg-Marquardt least-squared fit

Gravitational potential of luminous mass in 3D (discs)

The "Hyperkernel" method (Huré 2013)

$$\psi(\boldsymbol{r}) = -\mathcal{G}\int \frac{\mathrm{d}m'}{|\boldsymbol{r}-\boldsymbol{r}'|} \quad \Longrightarrow \quad \psi(\boldsymbol{r}) = \frac{1}{f(\boldsymbol{r})}\partial^2_{q_1 q_2}\mathcal{H}(\boldsymbol{r})$$

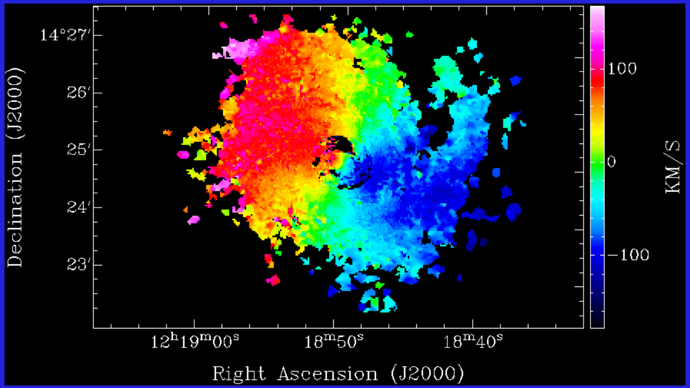
$$\mathcal{H}(x,y,z) = \iiint_{\Omega'} \rho(x',y',z') \times \kappa^{xy}(x-x',y-y',z-z')\mathrm{d}x'\mathrm{d}y'\mathrm{d}z'$$

$$\kappa^{xy} = -Z\,\mathrm{atan}\,\frac{XY}{Z|\boldsymbol{r}-\boldsymbol{r}'|} + Y\ln\frac{X+|\boldsymbol{r}-\boldsymbol{r}'|}{\sqrt{Y^2+Z^2}} + X\ln\frac{Y+|\boldsymbol{r}-\boldsymbol{r}'|}{\sqrt{X^2+Z^2}} \equiv \kappa^{xy}(X,Y,Z)$$

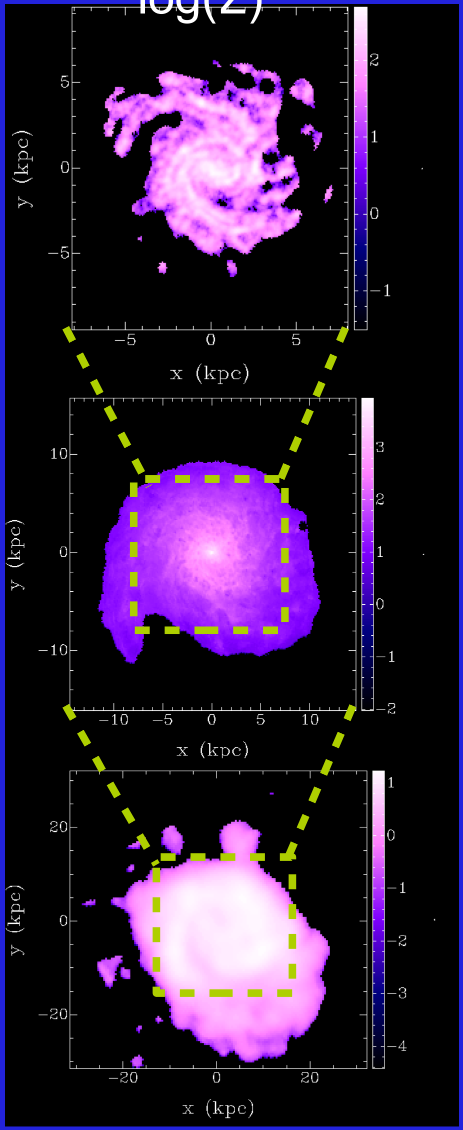
$\rho(R, z) = \Sigma(R)D(z)$ where $D(z) \sim \mathrm{sech}^2(z/z_0)$; $\mathrm{sech}(z/z_0)$; $\exp(-z/z_0)$ with $z_0 = h_0/5$

Data

- Molecular disc density
  - Rahman+11
  - CO1-0 CARMA
- Stellar disc density
  - Zibetti+09, NIR images
  - M/L = f(x,y)
- Atomic disc density
  - ViVA survey : Chung+09
  - VLA
- Hybrid CO+Hα velocity field
  - Chemin+06
  - Hα Fabry-Perot interferometry



log(Σ)



Mol. mass 7×10^9 $M_\odot$

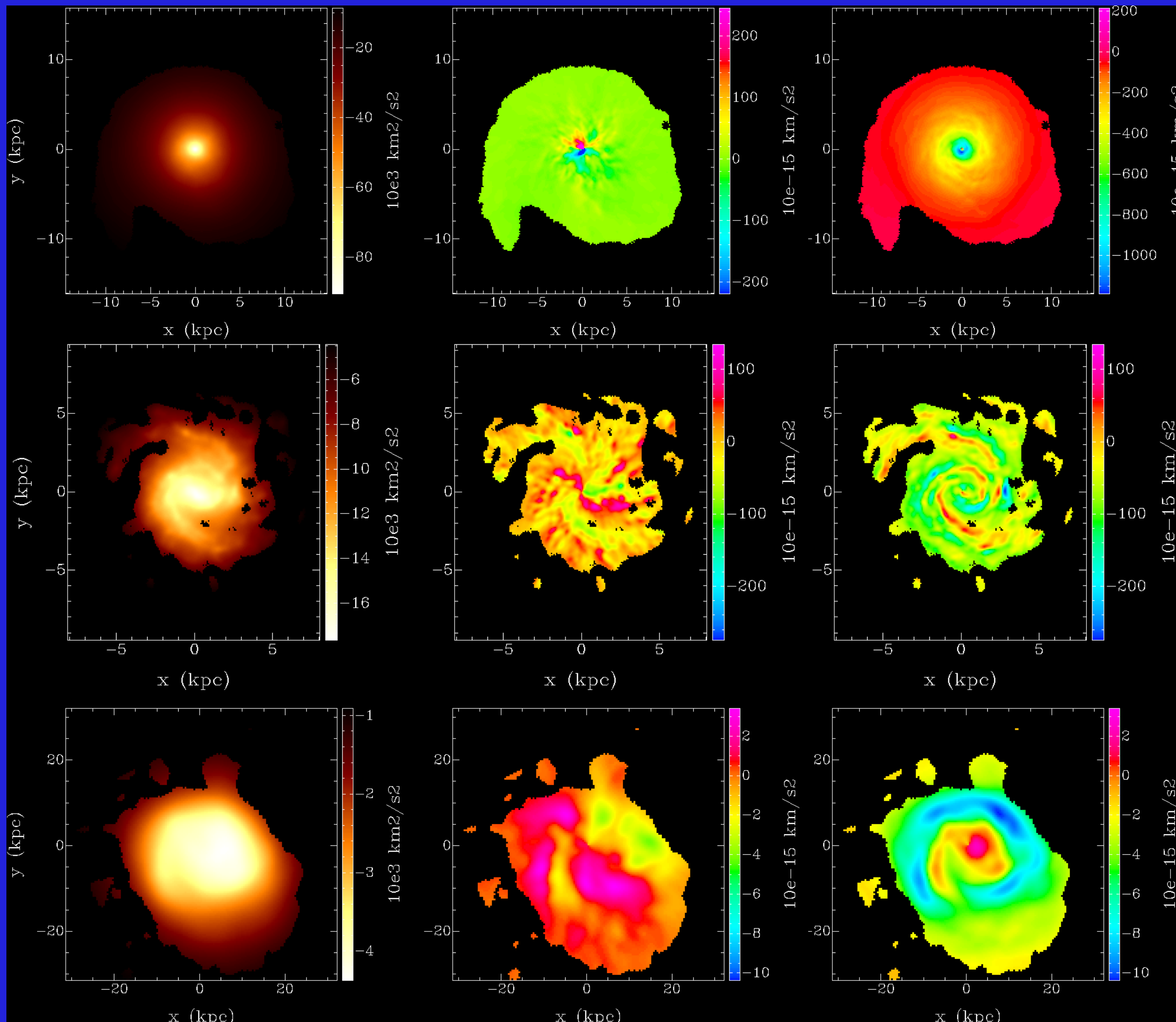
Stellar mass 3×10^{10} $M_\odot$

Atom. mass 7×10^9 $M_\odot$

Results

Amplitudes increase with mass density

Ψ	g_Φ	g_R



Stellar disc

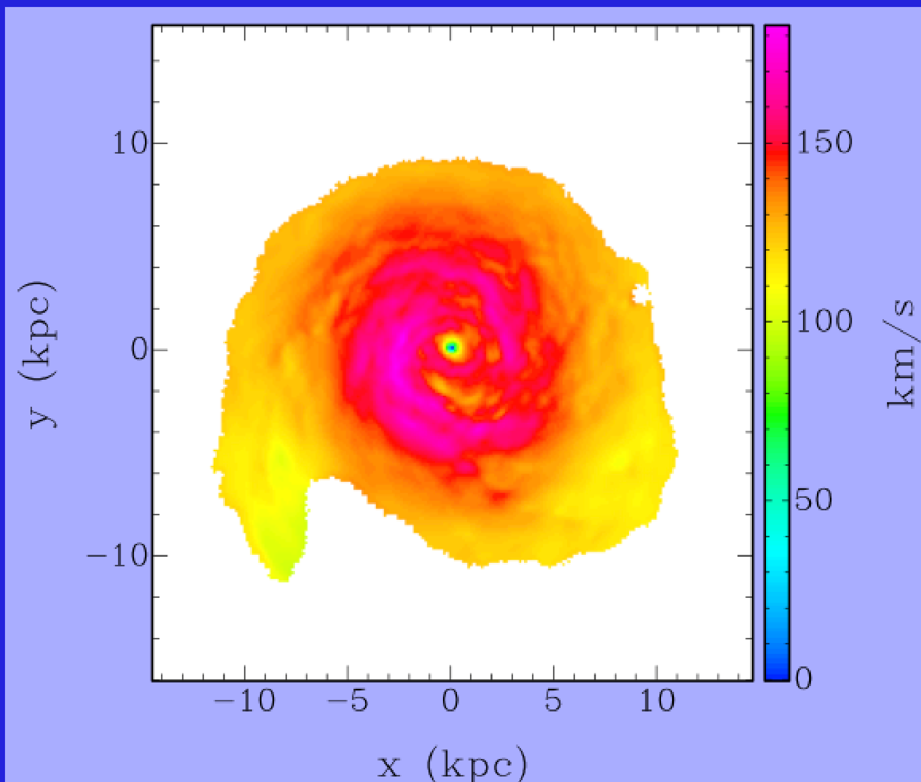
Molecular gas disc

Atomic gas disc

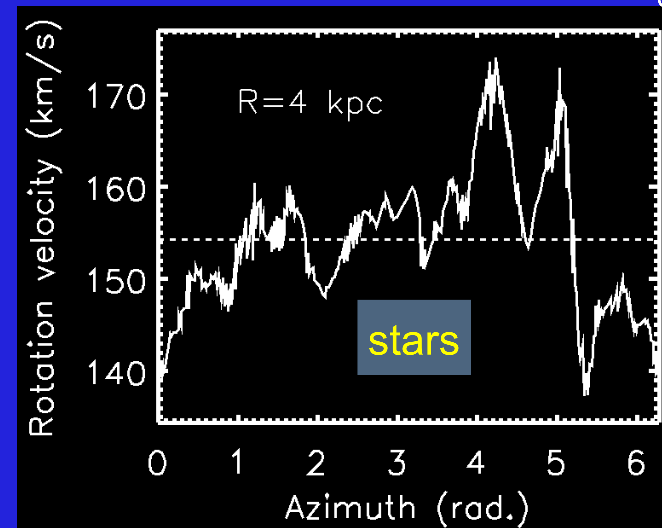
Results

Velocity strongly depends on azimuth

R = 4 kpc ~ 2.2 h_0



Map of the rotation velocity from the stellar disc component



Results

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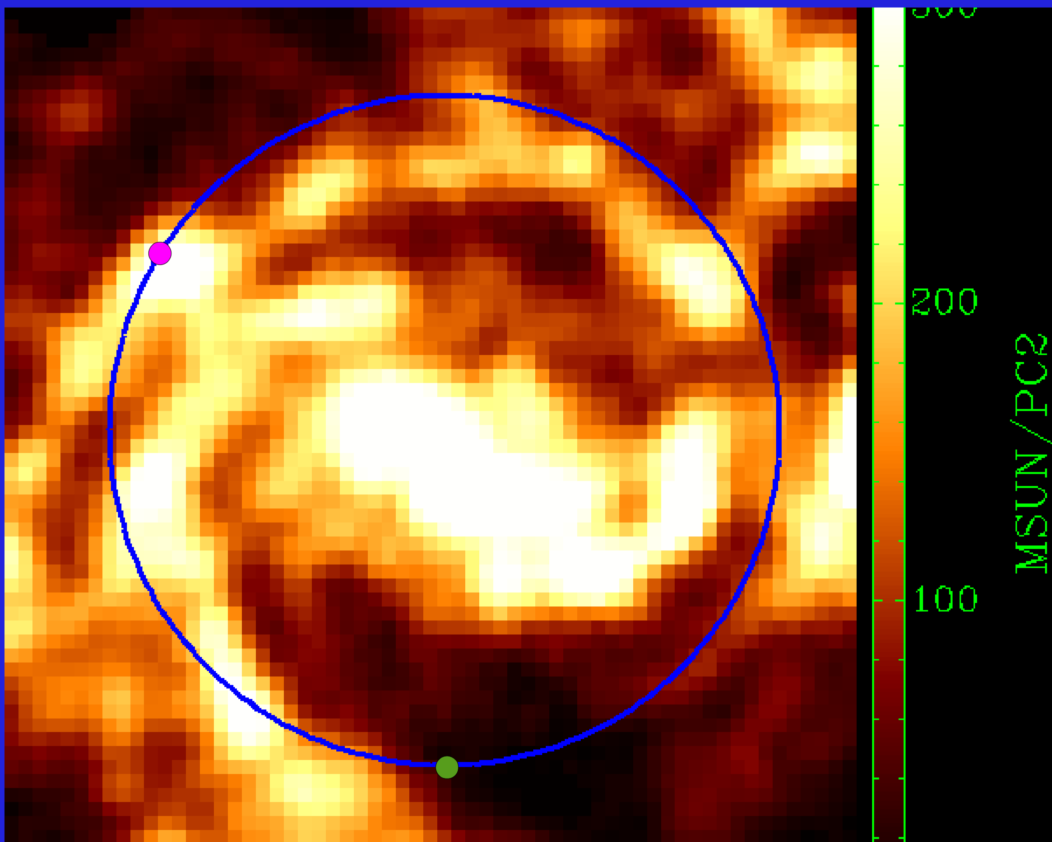
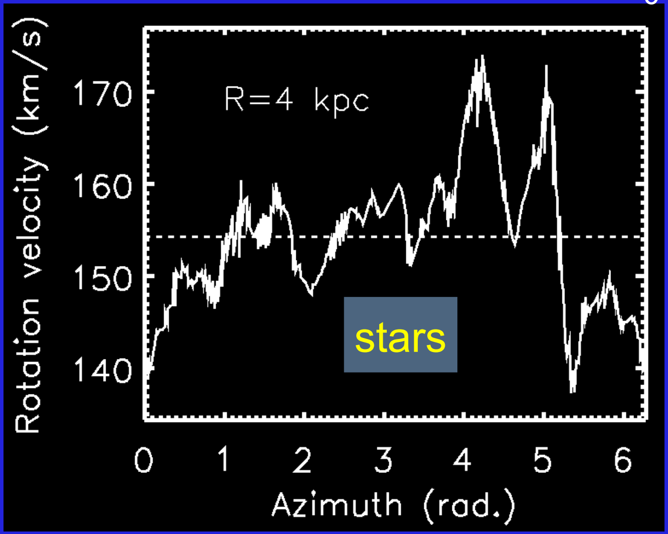
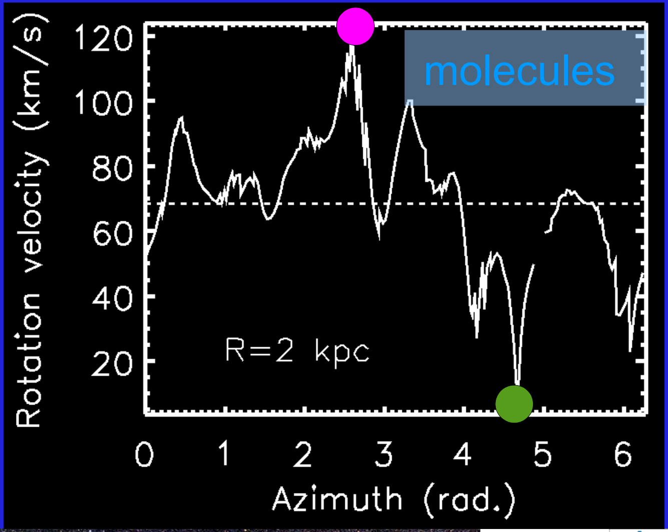


Molecular disc density map

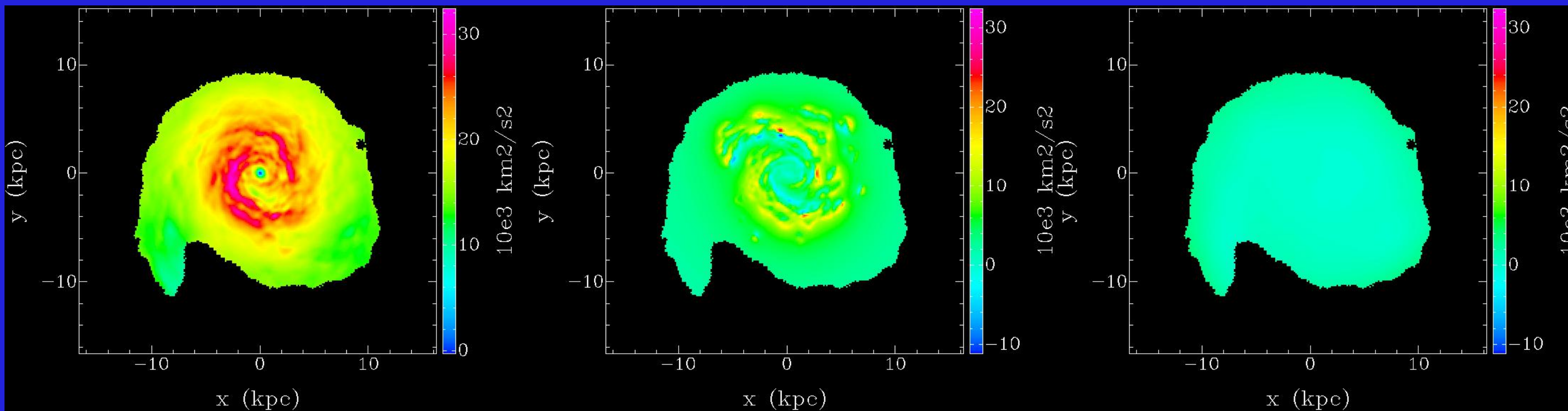
R = 4 kpc ~ 2.2 h_0





Results

V^2_{star} V^2_{mol} V^2_{atom}



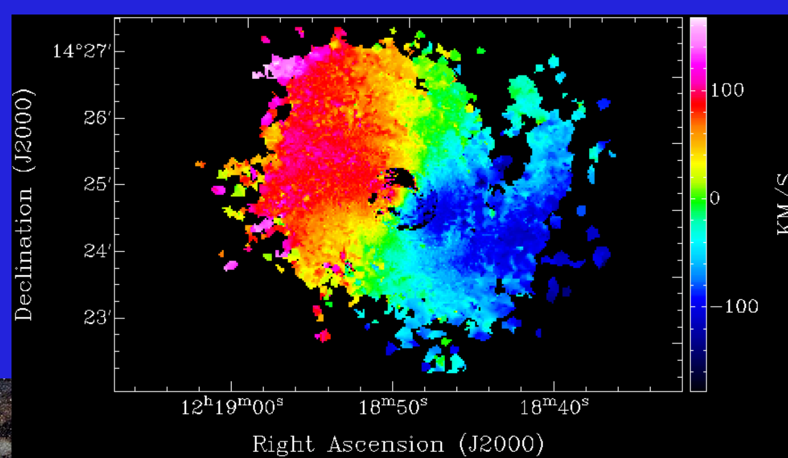
$$\rho_E(r) = \rho_{-2} \exp\left\{-2n\left[\left(\frac{r}{r_{-2}}\right)^{1/n} - 1\right]\right\}$$

Dark matter density profile: Einasto model

Navarro+04, Merritt+06

R < 12.6 kpc - 23211 d.o.f.

ρ_{-2} = 6.9 ± 0.9 10^{-3} M_o/pc^3
r_{-2} = 9.4 ± 0.5 kpc
n = 0.23 ± 0.10



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Results

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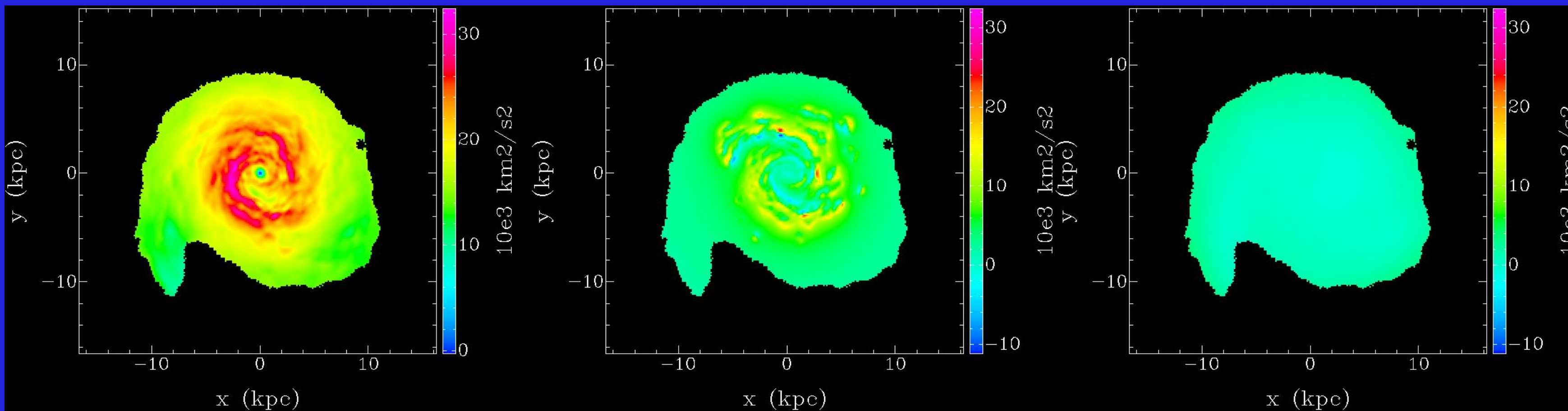

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$\rho_{-2} = 6.9 \pm 0.9\ 10^{-3}\ M_o/pc^3$
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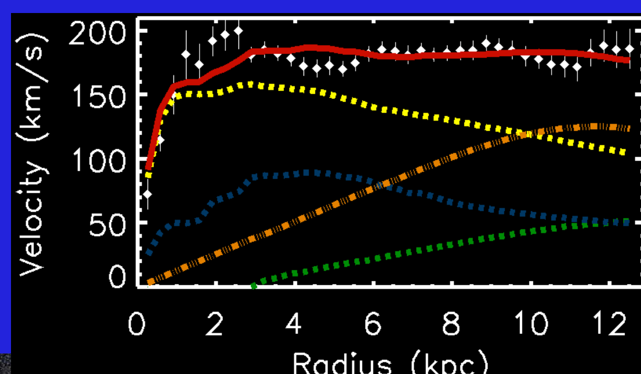
$n = 0.23 \pm 0.10$



$\rho_{-2} = 6.9 \pm 1.9\ 10^{-3}\ M_o/pc^3$
$r_{-2} = 9.2 \pm 0.8$ kpc
$n = 0.14 \pm 0.18$

35 d.o.f.

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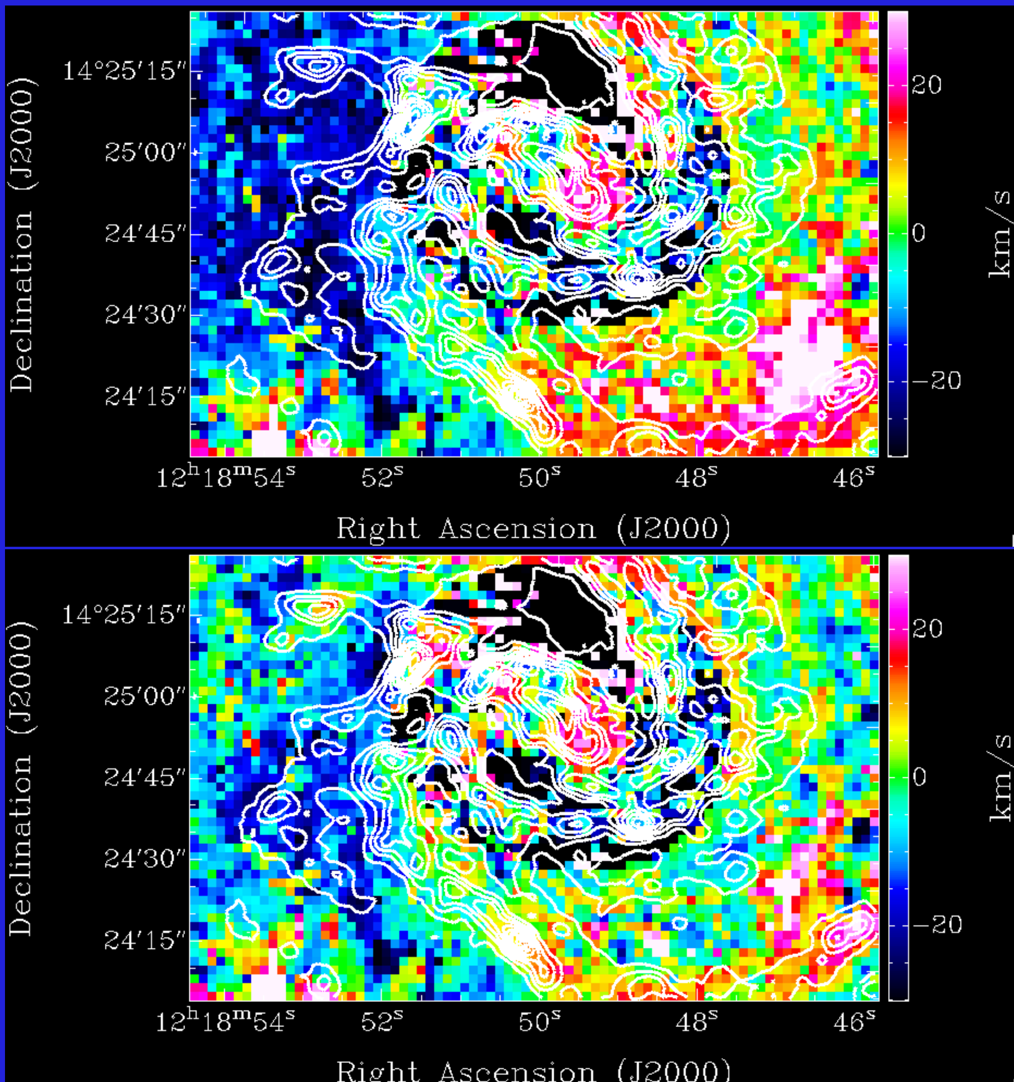
Results



Residual l.o.s. velocity fields

VFobs - VFmod1D

Contours = molecular gas emission

VFobs - VFmod2D

With a 2D modelling :
residuals are less scattered (2.2 kms)
residuals are lower (650 m/s)

Next steps

- Bulge contribution
- More complex density law for DM halo (spheroidal)
- Modified Newtonian Dynamics
- Larger sample of galaxies (SINGS/THINGS, etc)
- Further applications
  - Study the (impact of) perturbations of potential(s)
  - Orbit reconstruction/numerical simulations