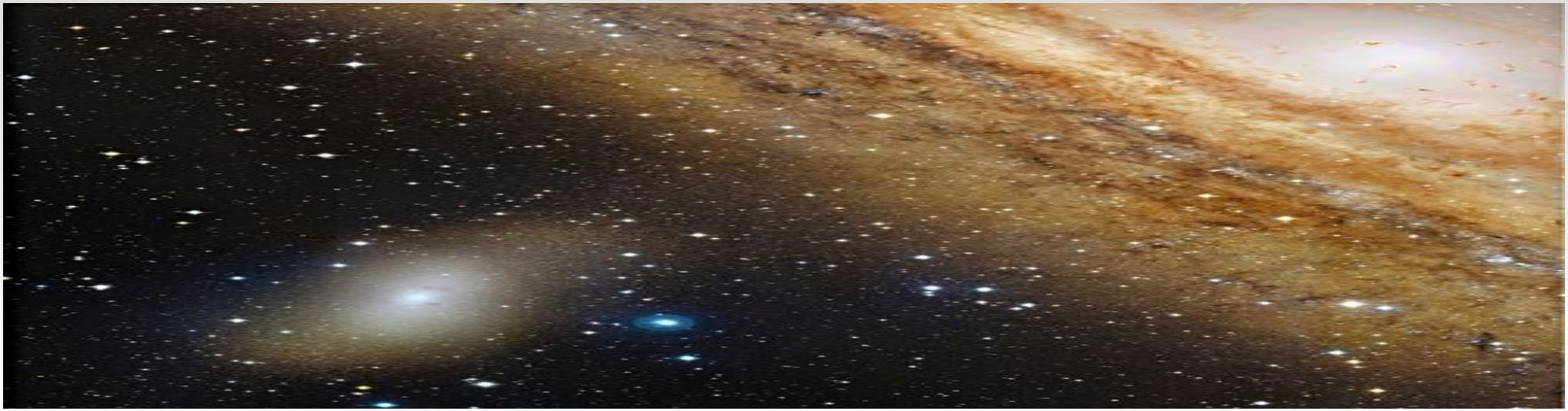
Testing the dark matter equation of state



Cosmology on the Beach

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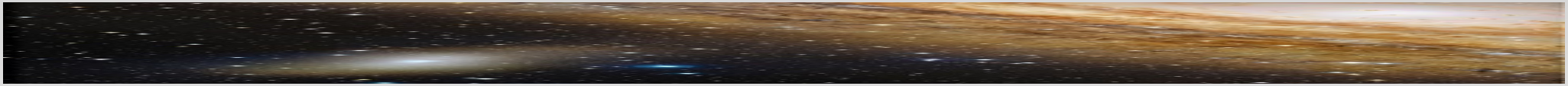
The goal



To put constraints on the dark matter equation of state using observations at galactic scales, more specifically using galactic rotation curves

The motivation

Since the nature of the dark matter is not yeat clear, it makes sense to use observations in order to investigate the possible dark matter equation of state and in particular if dark matter could be diferent to a presureless fluid.

To compare our results with previous bounds on the dark matter equation of state using cosmological observations

The hypotheses

We assume that

- galactic halos are spherically symmetric
- with a static space-time
- and that the dark matter is an isotropic perfect fluid

$$ds^2 = -e^{2\Phi/c^2}\, c^2\, dt^2 + \frac{dr^2}{1 - \frac{2\,G\,m}{c^2\,r}} + r^2\, d\Omega^2$$

$$T_{\mu\nu} = (\rho + p/c^2) u_\mu u_\nu + p g_{\mu\nu}$$

We also consider that the halo is a Newtonian system

$$\nabla_x{}^2\ \Phi \ = \ 3\, q\, \bar{\rho},$$

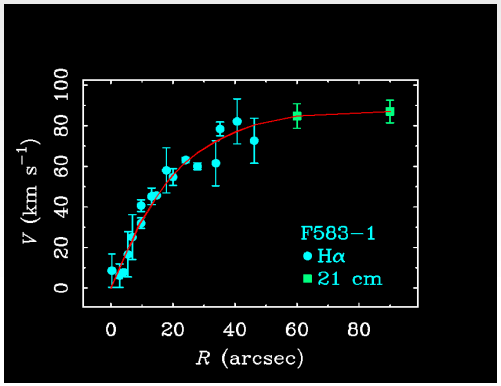
$$\bar{p}' \ = \ -\bar{\rho}\ \ \Phi'$$

where $q = M_0\, G / c^2\, R_0$ is a dimensionless quantity that appears when the system is written without dimenssions

Let's proceed

It can be obtained an expression relating the tangential velocities of test particles, v_t, following stable circular orbits in the space time, with the gravitational potential Φ, by means of solving the geodesic equations for test particles in circular stable orbits

$$\frac{\Phi'}{c^2} = \frac{\beta^2}{r},$$



with $\beta^2 = \frac{{v_t}^2}{c^2}$.

The dark matter equation of state is directly computed from previous equations once the velocity profile $\beta^2(x)$ is given.
We consider an observational velocity profile proposed by Salucci et. al., which was obtained by fitting 1023 galaxies

$$\beta^2 = {\beta_0}^2 \frac{x^2}{x^2 + a^2},$$

β_0 stands for the ratio of the terminal velocity to the speed of light, and a determines how fast the velocity reaches a terminal value.

The obtained dark matter equation of state

Given the functional form of $\beta^2(x)$, we obtain an analytical expression for the equation of state of the dark matter in the halo

$$\bar{p} = \frac{\beta_0^2 \bar{\rho} \left(\beta_0^2 + 6a^2 q\rho + \beta_0 \sqrt{\beta_0^2 + 24a^2 q\rho} \right)}{\left(\beta_0 + \sqrt{\beta_0^2 + 24a^2 q\rho} \right)^2}$$

The functional form of the equation of state is the same for all the galaxies but depends on the parameters β_0 and a that are different for each galaxy.

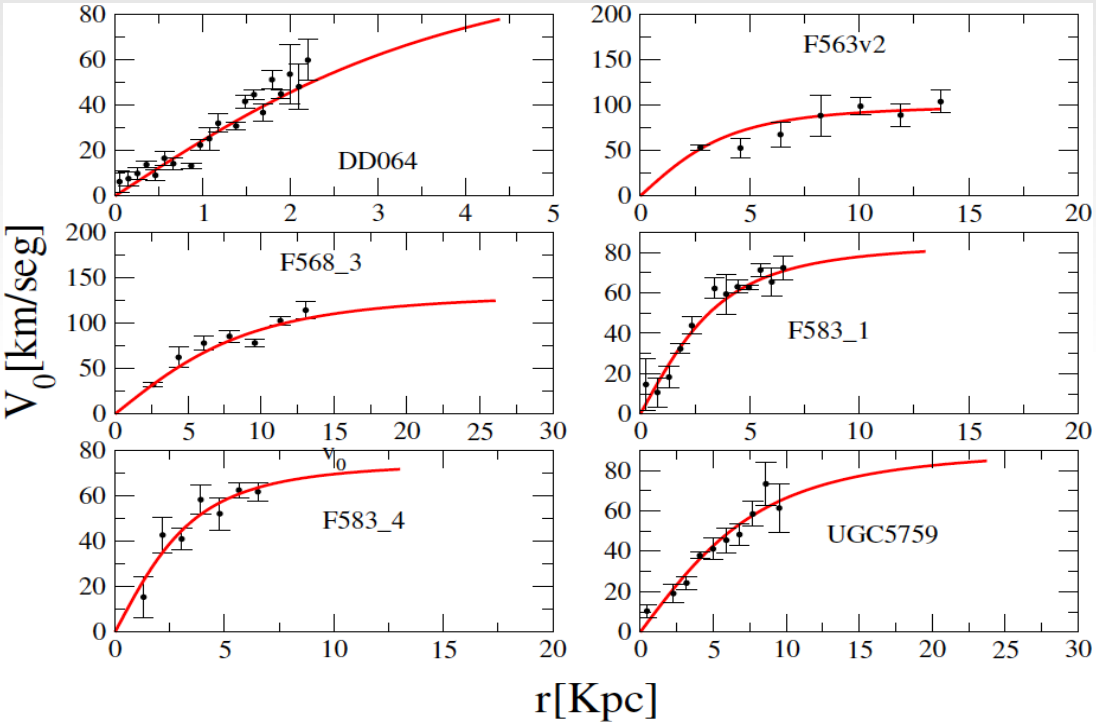
In fact, it is possible to write β_0 and a in terms of the central density and the central pressure for each galaxy, those quantities could be thought as dependent on the initial conditions of the formation of the galaxy

$$\rho_0 = \frac{\beta_0^2}{qa^2}$$

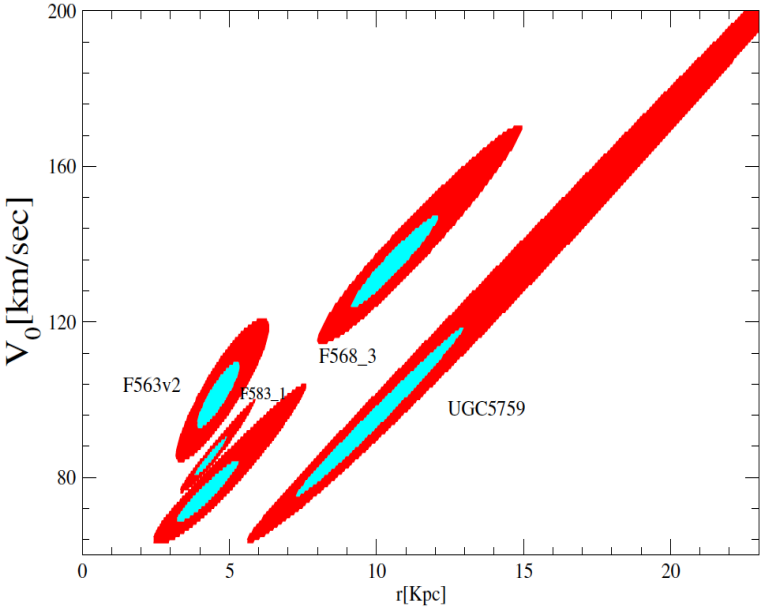
$$p_0 = \frac{\beta_0^4}{3qa^2}$$

Results

Fits of Rotation Curves for some LSB galaxies

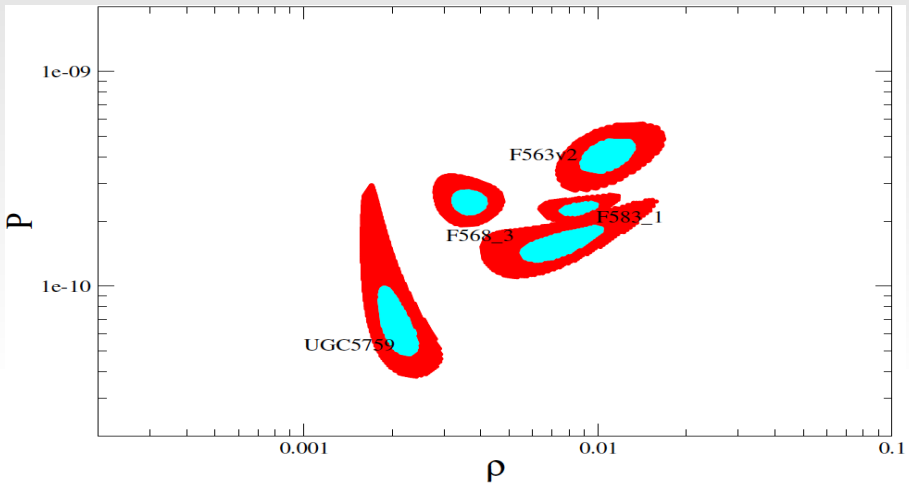


β_0 and a best fits



Results

Values of the central pressure and the central density for the corresponding LSB galaxies



$$\rho_0 = \frac{\beta_0^2}{qa^2}$$

$$p_0 = \frac{\beta_0^4}{3qa^2}$$

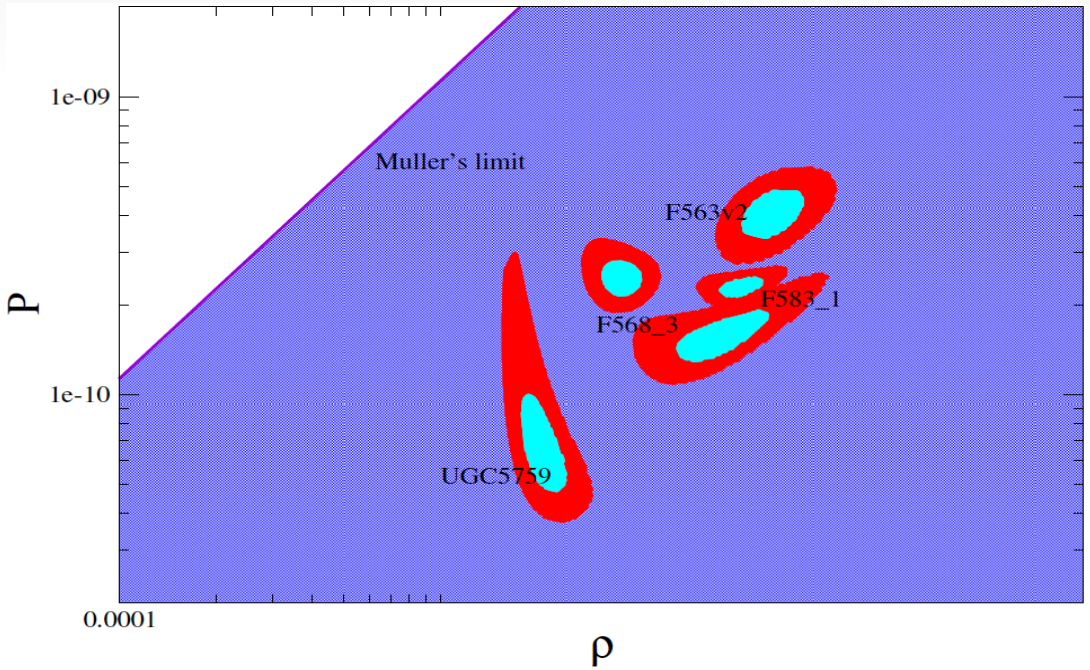
$$\bar{p} = \frac{\beta_0^2 \bar{\rho} \left(\beta_0^2 + 6a^2 q\rho + \beta_0 \sqrt{\beta_0^2 + 24a^2 q\rho} \right)}{\left(\beta_0 + \sqrt{\beta_0^2 + 24a^2 q\rho} \right)^2}$$

Central values of the density and pressure are the maximum values that density and pressure take.

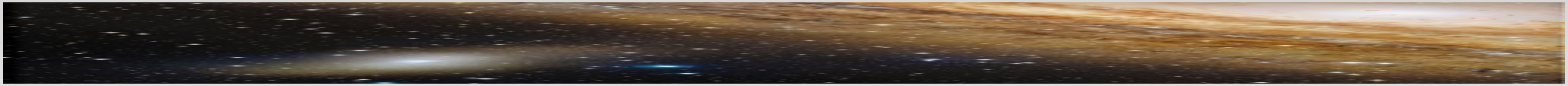
Comparison with cosmological constraints

Using CMB, supernovae Ia and large structure data Müller found constraints on the equation of state in a modified LCDM cosmology. Assuming a barotropic equation (p = w rho) of state for the dark matter he found -1.5 x 10^-6 < w < 1.13 x 10^-6 if the dark matter produces no entropy

Our constraints ”are consistent” with those of Müller.



Conclusions



- Our obtained dark matter equation of state is not barotropic

- Within our hypotheses, local observations allow that the dark matter could be different of a presurless fluid

- The functional form of the obtained equation of state is the same for different galaxies however it depends on central pressure and density of each galaxy. Those quantities depend on the initial conditions of the galaxy formation

- Although cosmological constraints on the dak matter equation of state are setting considering a barotropic fluid, our constraints ”are compatible” with them.