Dark Matter, Milky Way and CREDO

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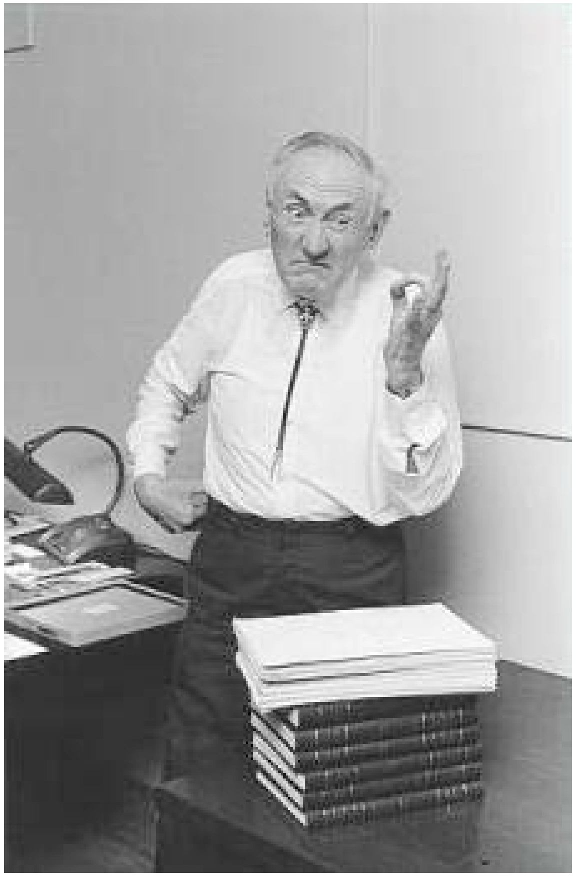
Fritz Zwicky



The beginnings of the dark matter.

The beginnings of the dark matter notion should be linked with the investigations of galaxies and with the person of Fritz Zwicky.

The proper motions of galaxies in galactic clusters had been pointing to higher masses of these clusters, than estimated based on their brightness.

Obviously, nobody had been using the nonbarionic dark matter notion at that time, and simply some matter difficult to detect, invisible in the spectrum band-width available to observations, had been understood under this notion.

Motivation – why is NDM important?

Nonbaryonic dark matter (NDM) is a basic notion in many branches of science, including astrophysics.

The NDM constitutes a predominating part of the galactic clusters' masses, and of separate spiral galaxies (also dwarf elliptical galaxies, which are especially abundant within it).

The presence of DM is also a factor stabilizing spiral galaxies, and enabling the formation of structures in the Universe.

Saying it shortly, NDM is currently one of the basic and indispensable notions and entities.

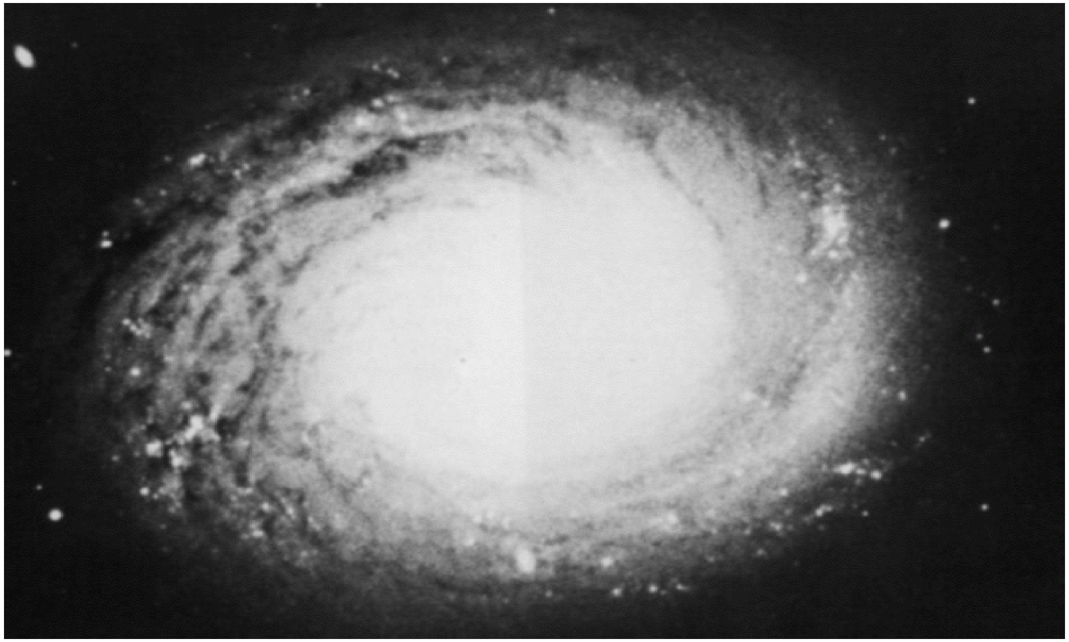
Intensive searches for NDM are conducted – its detection should be possible: either direct, or indirect, through observation of decay products. Until now there are no such experimental DM observations.

Large electromagnetic cascades can provide clues about the presence, or not, of DM, as well as its distribution.

CREDO results may alow testing some of the NDM scenarios.

Only a few years ago, both I and my collaborators, belonged to a group of persons convinced about the ubiquity of nonbaryonic dark matter, in general, and its indispensability in solving the problem of rotation of spiral galaxies, in particular. But these viewpoints underwent a complete change during the period of last few years. This change was prompted by our investigations.

The first galaxy, which upon an investigation appeared to have little CDM is the NGC 4736 galaxy (M94).

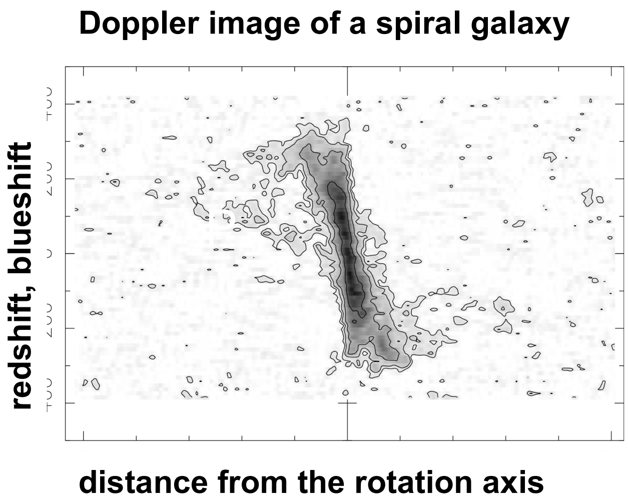


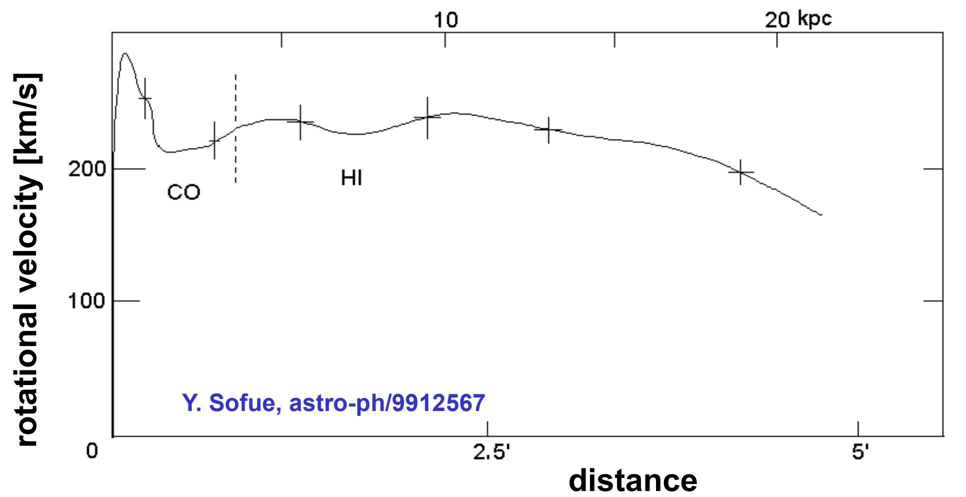
J. JaLocha, Ł. Bratek, M. Kutschera

Is dark matter present in NGC4736? An iterative spectral method for finding mass distribution in spiral galaxies

2008 ApJ 679 373J

Rotation curves of spiral galaxies and Dark Matter (DM)





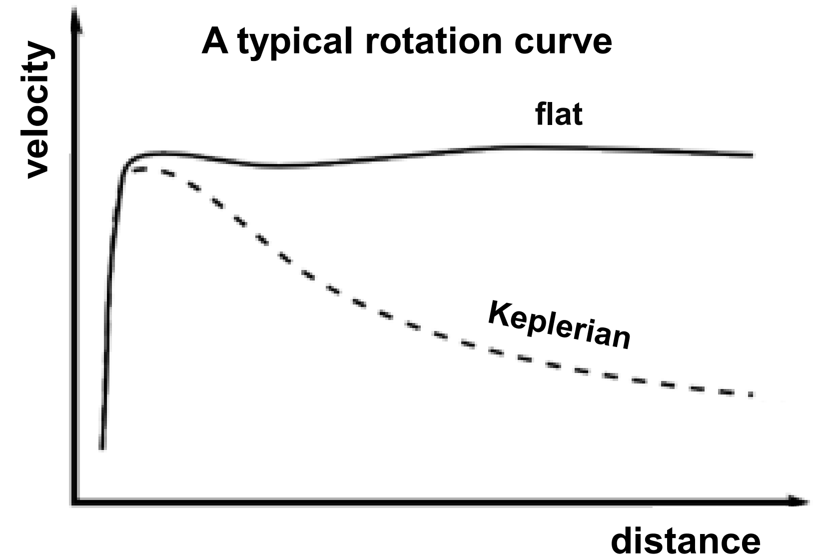
Problems:

flat rotation curves, not Keplerian

dynamical mass different from the mass of visible matter

the Infra Red band mass-to-light ratio M/L should be not greater than 2, otherwise dark matter is required

(M/L=1 for the Sun)



Standard modelling of rotation curves:

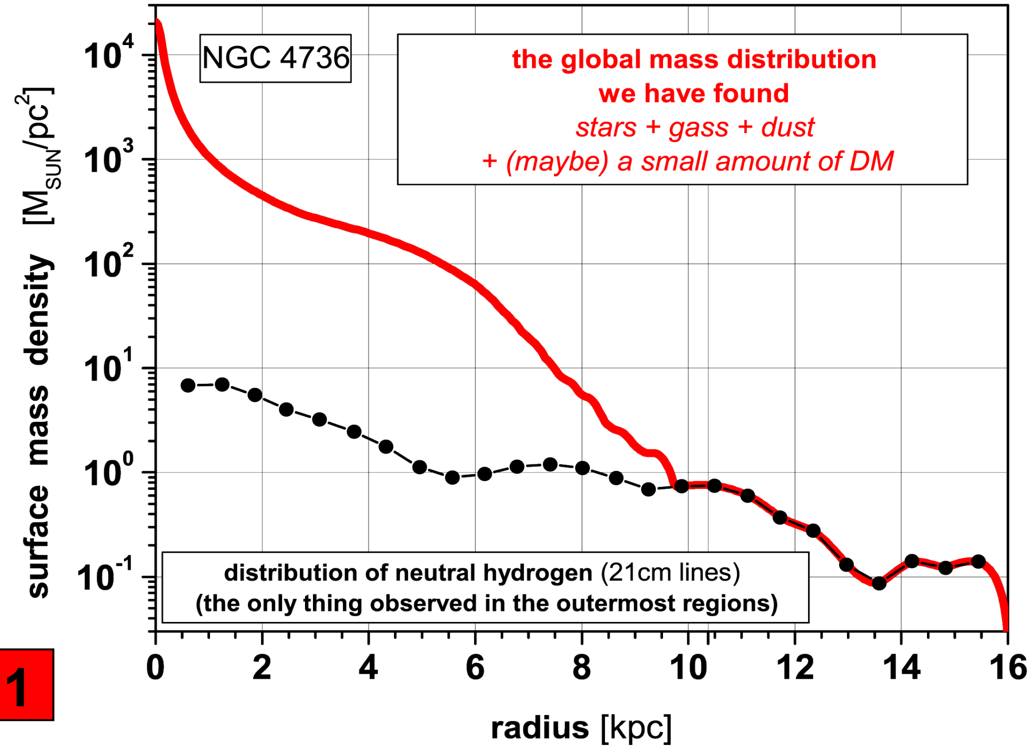
arbitrarily assumes a spherical halo of DM inside of which the luminous baryonic matter with a constant M/L is immersed

In the classical approach to modelling of spiral galaxies one proceeds based on the measured luminosity curve; a constant mass-to-light ratio is most often assumed (although, usually different ones for the central bulge and for the disk). Then, based on this, a density distribution is inferred.

If such a density distribution does not lead to predictions that agree with the galactic rotation, the missing dynamical mass is recovered by introducing a dark halo.

In contrast, I start with a rotation curve and then I obtain the mass-to-light ratio as the result of the modelling process and when the ratio is low I conclude that the disk model accounts for the galaxy properties very well.

A SAMPLE OF OUR RESULTS



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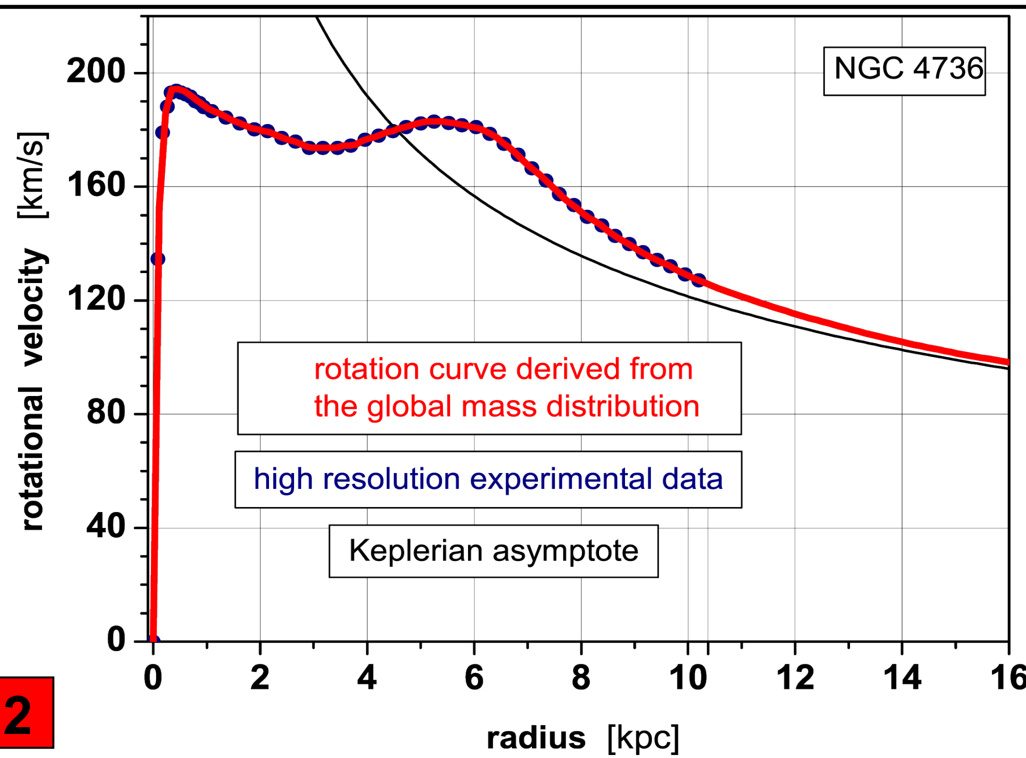

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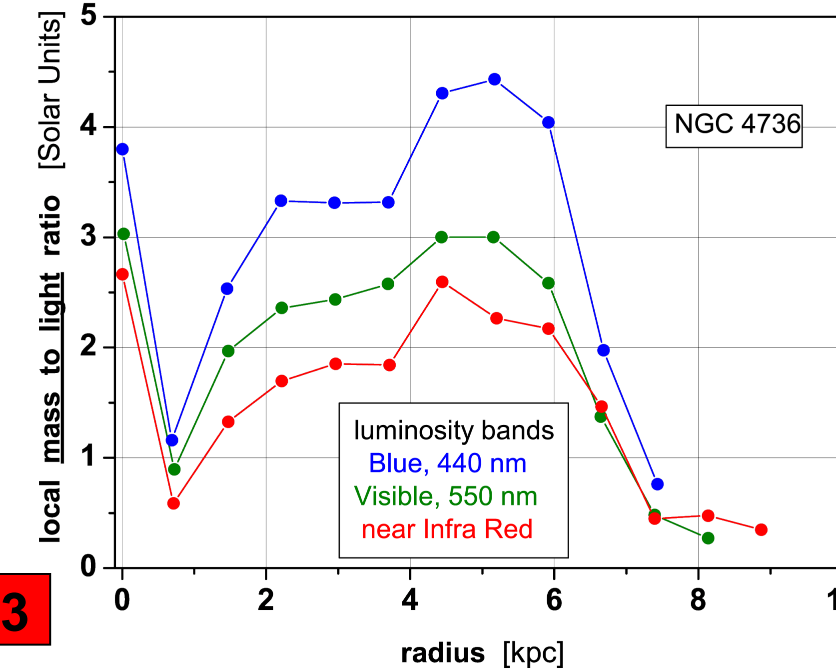


3

the total mass: 34 milliards of Solar masses
the global IR-band mass-to-light ratio: 1.2 in Solar units

Astronomers:

problems in fitting their model to observations
2/3 of total mass of the galaxy in the form of Dark Matter

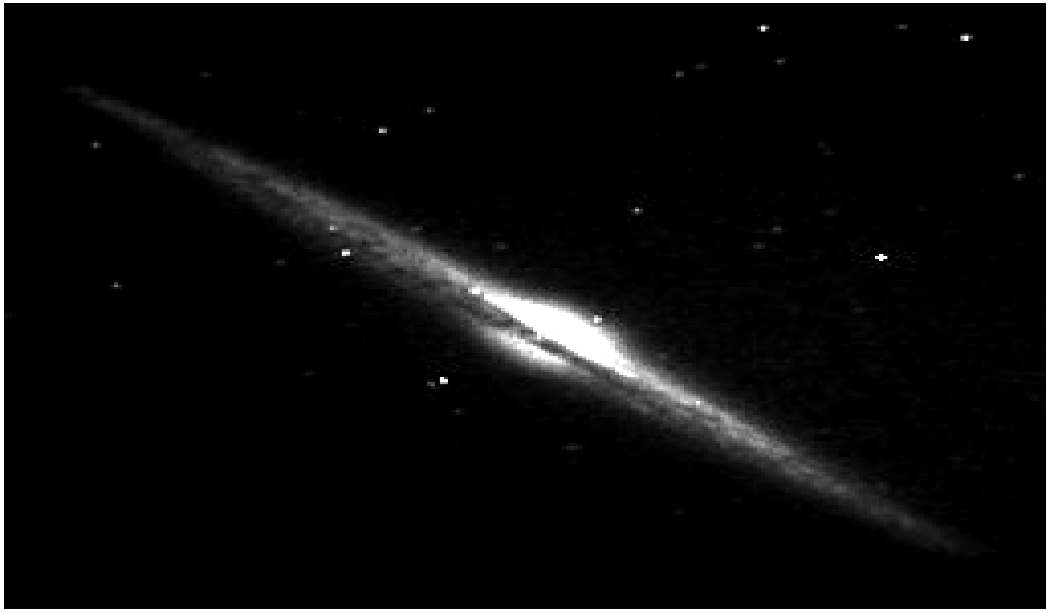
Our approach:

a consistent global mass distribution,
excellent reconstruction of rotation curve
Dark Matter?, maybe some

Rotation curves of some galaxies can not be explained under spherical symmetry, the Global Disk Model is thus more suitable

For a class of galaxies, mass-to-light ratios, and consequently, the amount of dark matter, can be reduced significantly

In particular, it can be done also for the Milky Way



Me and co-authors, were devoted to this topic and it concerned microlensing in a thin disk model of our Galaxy. A crucial notion we have to do with while considering microlensing, is the notion of an optical depth - it describes a probability of finding a gravitational lens in between an observer and an object.

What is very important, only a compact object (star, planet) can be a lens, and so, the microlensing is sensitive only to baryonic matter. Nonbaryonic dark matter is not detectable through this phenomenon.

The optical depth is being determined based on microlensing observations in the Milky Way (observed are changes in the brightness of objects due to lenses passing between us and those objects), but it can also be calculated theoretically if we assume that we know density of matter in the Galaxy at least for radii ranging from the Galactic center to the Sun.

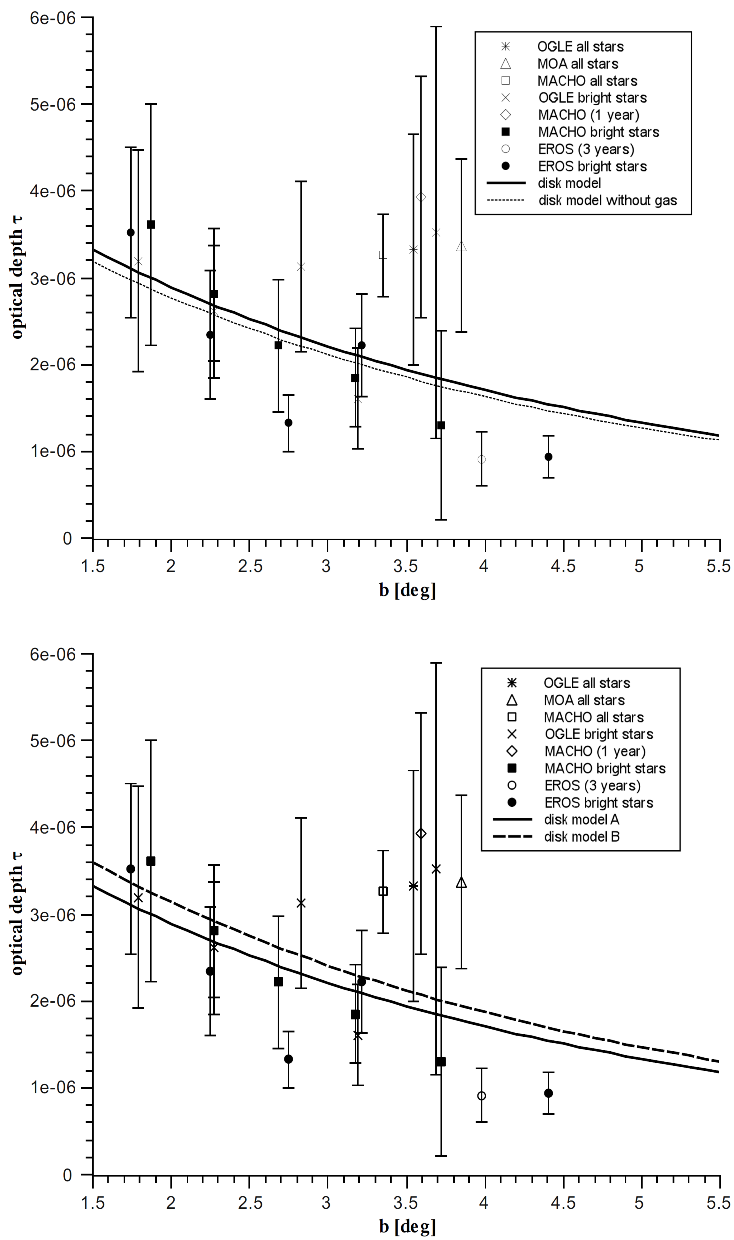


Figure 5. Optical depths in disk model with the disk scale height $h = 325\,\mathrm{pc}$. TOP PANEL: The result for rotation curve A [*thick line*] and after subtracting the gas contribution [*thin line*]. BOTTOM PANEL: Comparison of optical depths for two model rotation curves A [*solid line*] and B [*dashed line*] (both without gas subtraction).

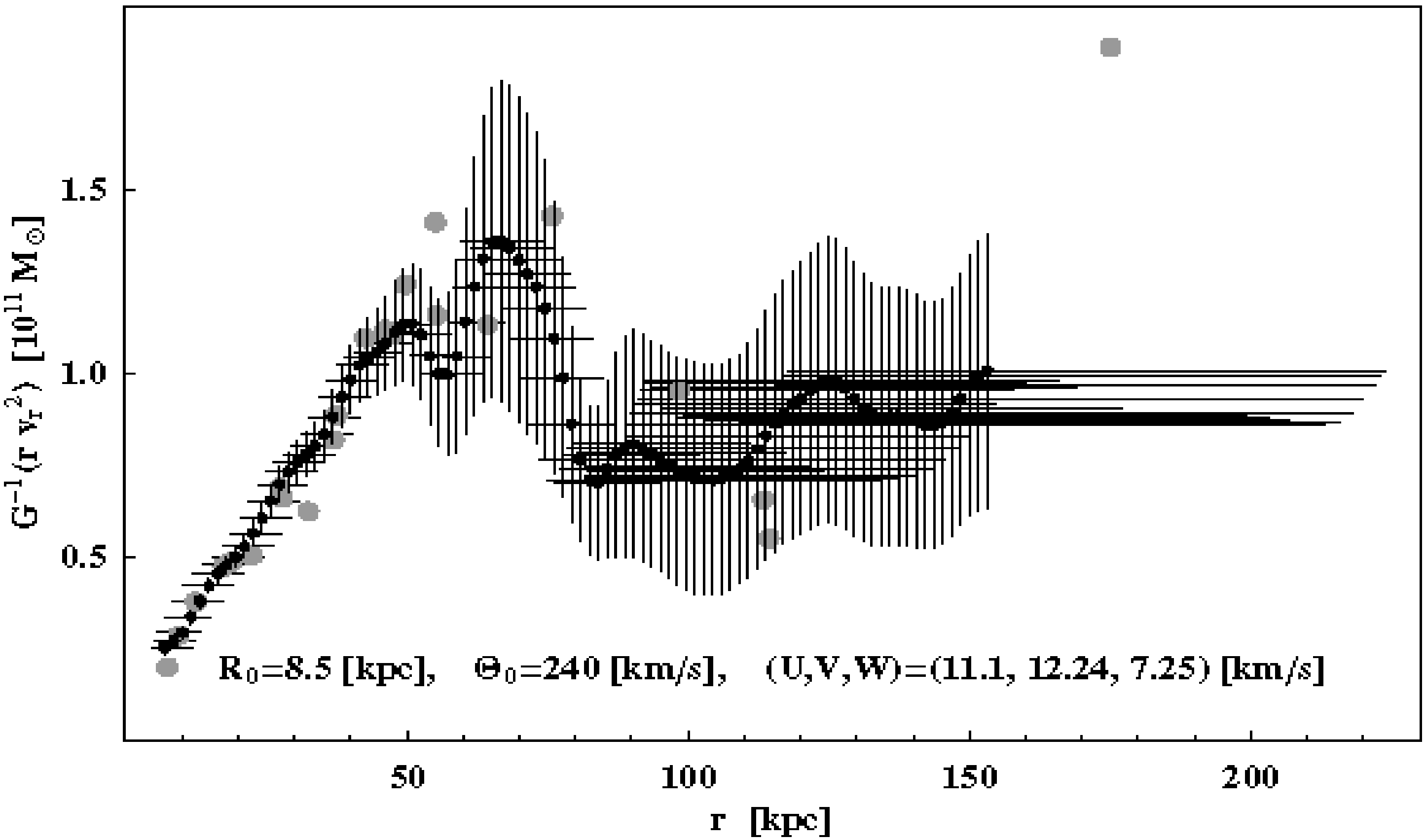
We compared the optical depth obtained as a result of observations, with that obtained in a theoretical way from the surface density obtained under the assumption, that our Galaxy has a disk-like geometry (and can be modelled as an infinitesimally thin disk), and we obtained an agreement between them. Putting this differently, we demonstrated that the whole matter needed to account for the Milky Way rotation within the Solar circle is seen through the gravitational microlensing, thus it is certainly a baryonic matter.

S. Sikora,Ł. Bratek, J. JaLocha, M. Kutschera
Gravitational microlensing as a test of a finite-width disk model of the Galaxy
2012, A&A, 546, A126

As one of the most important result concerning the problem of dark matter in galaxies I consider the paper, in which we deal with the motion of the baryonic halo objects around the Milky Way.
Objects which contribute to such a halo are, among other things, dwarf galaxies, globular clusters and isolated stars.

It was standard approach to analyze the motion of these objects in a dark matter potential, which was used many times for estimating the Galaxy mass.
But we applied a method different from that commonly used: its novelty was in releasing the constraints imposed on the phase space, and in considering a gravitational potential of a compact mass, thus corresponding to a Galaxy without dominating dark matter. Constraints arise by conditions imposed on in advance, by the assumed profiles of the secondary quantities, derived from the phase-space distribution function, such as the flattening of the velocity dispersion ellipsoid. It is standard to assume it in the form of an anisotropy parameter independent of the distance, which makes the models of motions of halo objects more stiff. In the case of a central mass potential, which should well approximate a compact mass potential for large distances, this means adopting a model of the phase space equivalent to a system of confocal elliptic orbits, with an arbitrary number density defined over the space of energies and ellipticity.

Following this, we are able to model the dispersion anisotropy as almost arbitrary function of the distance. In the result of this, the expected value for the ellipticity of orbits crossing a sphere of a given radius, can depend in a complicated way on the distance. Despite the formidability of this problem, we succeeded in developing a general procedure reconstructing the distribution function in the phase space, consistent with the observed profile of the radial velocity dispersion.



Finally, we showed that the observed motion of the halo objects is fully consistent with the assumption that our Galaxy mass is low (of the order of $2{,}4\times10^{11}\ M_\odot$), that is, such as one should expect based on the rotation curve of the Galactic disk, if the Galaxy mass is not dominated by nonbaryonic dark matter.

Ł. Bratek, S. Sikora, J. JaLocha, M. Kutschera
A lower bound on the Milky Way mass from general distribution function models,
2014 A&A 62A.134B

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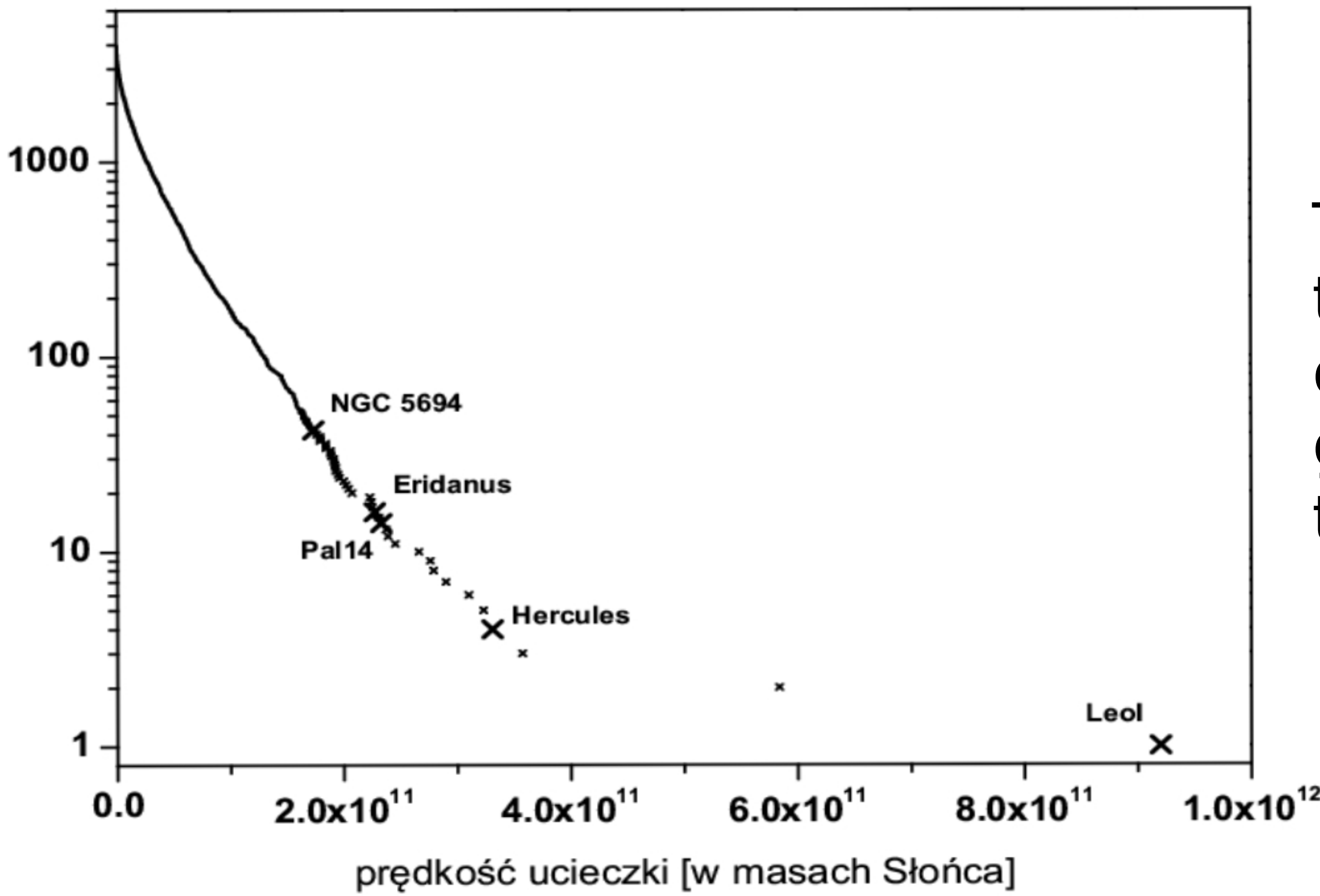

Then only a few of the observed halo objects would not be gravitationally linked to the Galaxy.

The radial dispersion profile of the motion of the baryonic halo objects alone does not give the upper bound on the Galaxy mass. However, this approach allows us to estimate the far more important lower bound for the Galaxy mass, consistent with the observed motion of halo objects

Summary:

It may be then, that in the Milky Way there is much less DM than commonly believed – this may be the cause of problems with experimental detection.

But observation of the signal from the decay of NDM by **CREDO** experiment, e.g. in the form of a large electromagnetic cascade, could falsify our model of the Galaxy as disk-like, lightweight object.