# Introduction to Dark Matter

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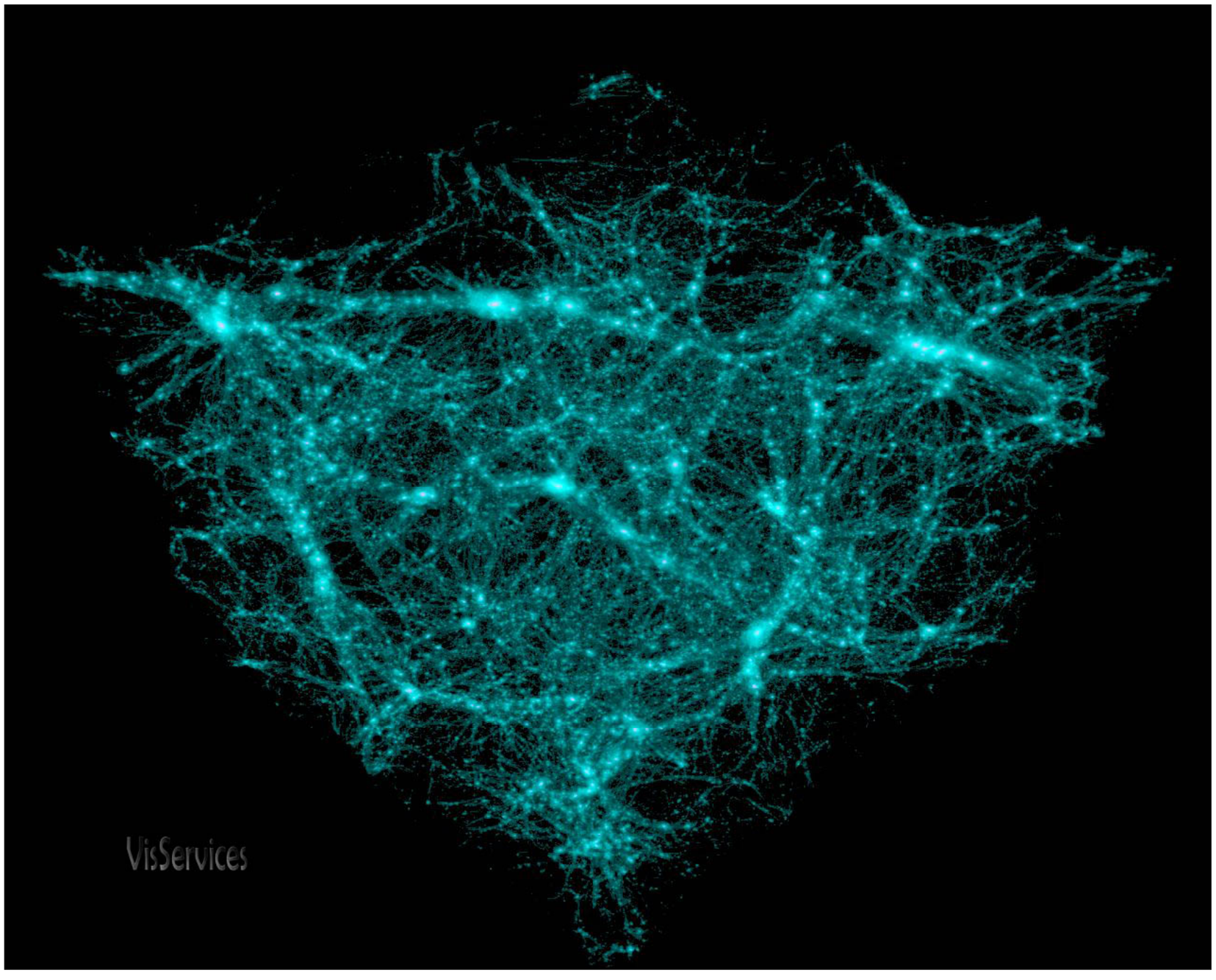
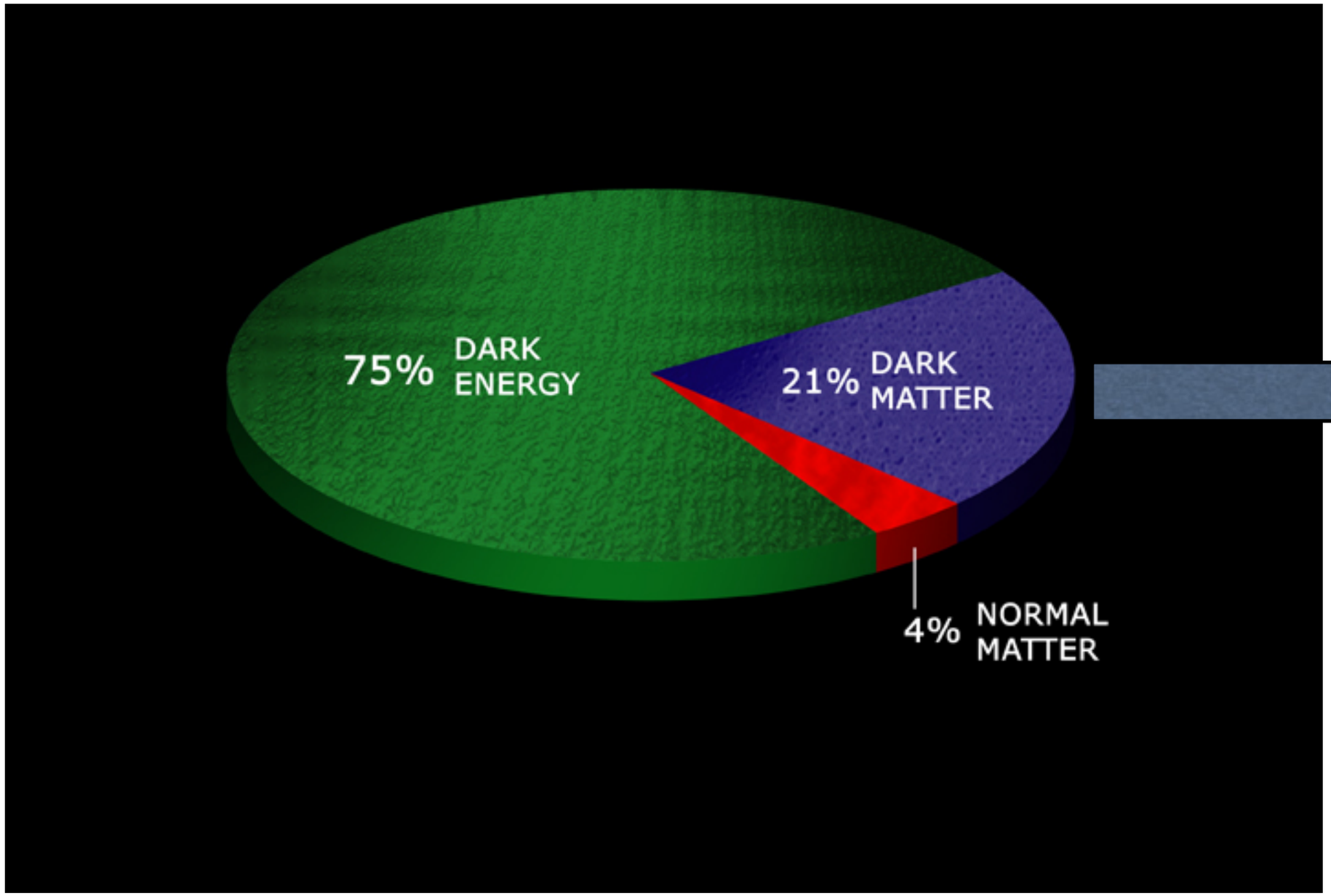
University of Notre Dame



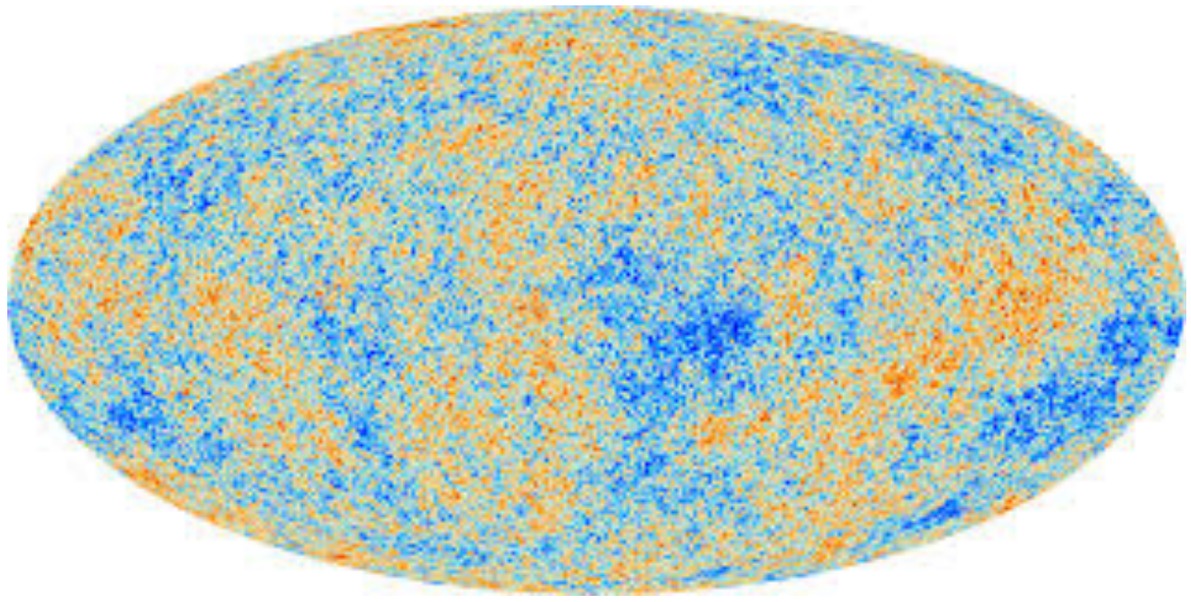
# Cosmic Cake

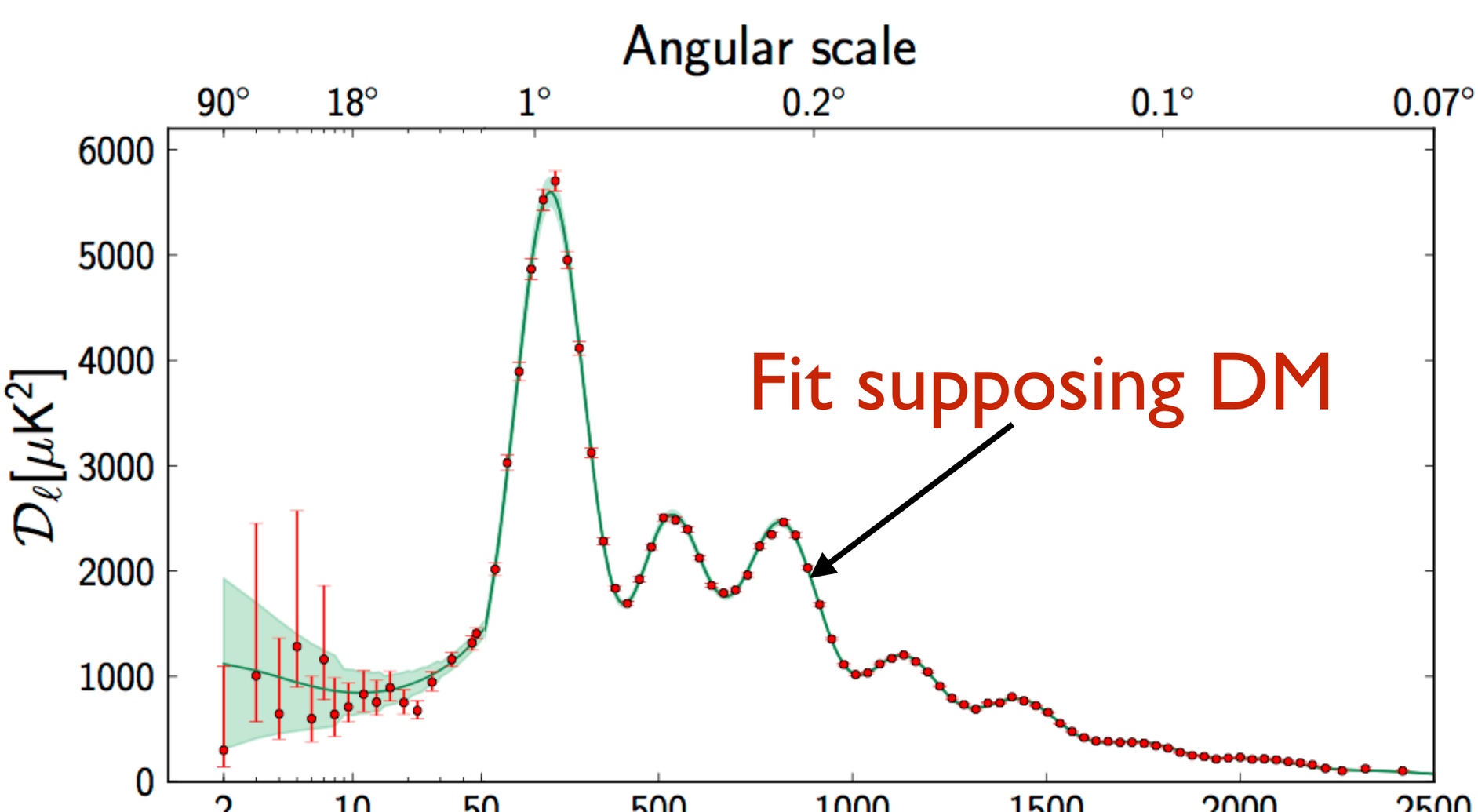



what is this?

Measure indirectly by Planck

# Angular analysis of the pertubations





- One expects in general grounds that the rotation velocity of galaxies should follow the following scaling:

$$v \sim \sqrt{\frac{G_N M(r)}{r}}$$

The further away from the center you are the slower you spin

- But.....

- But much before Planck.....

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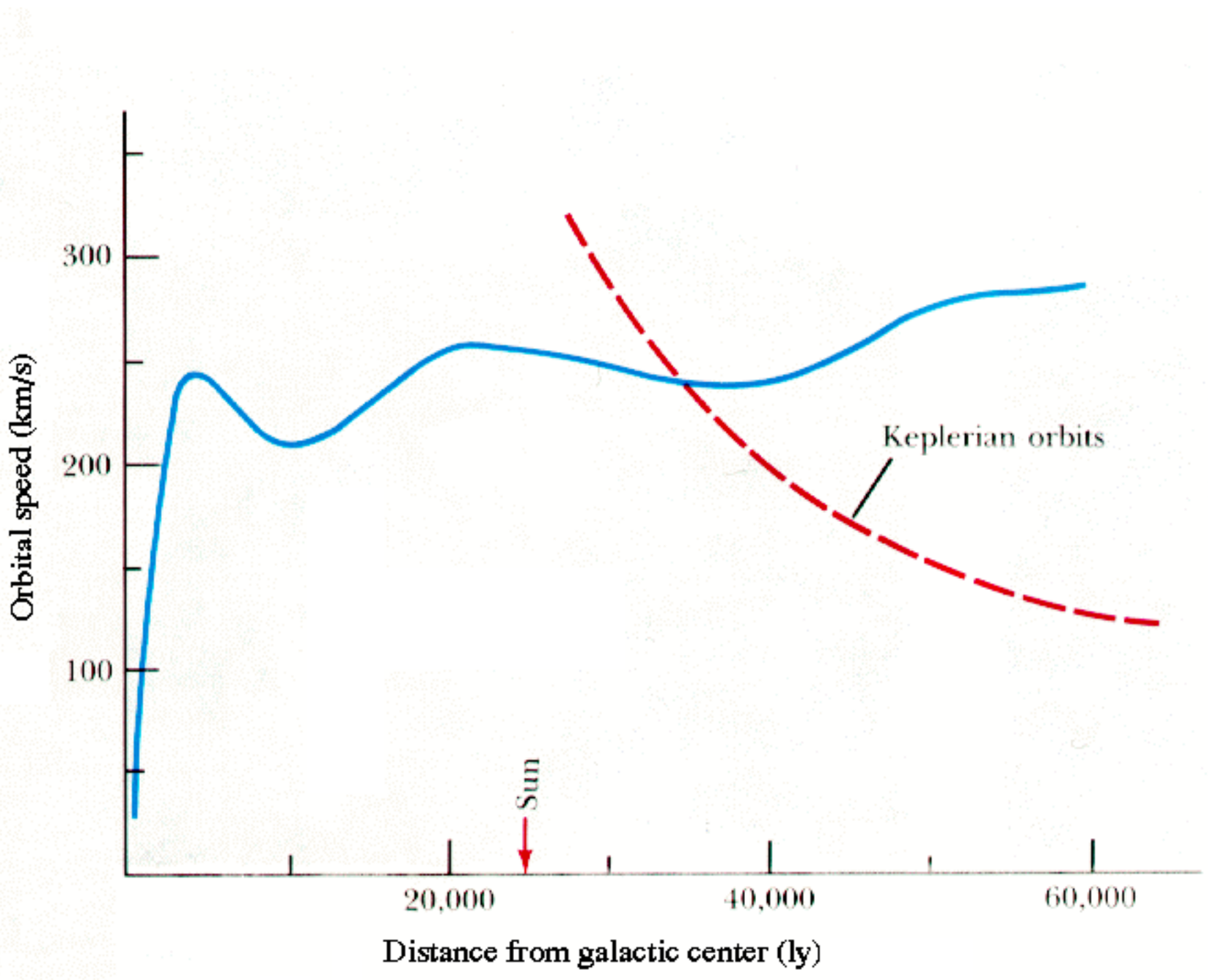

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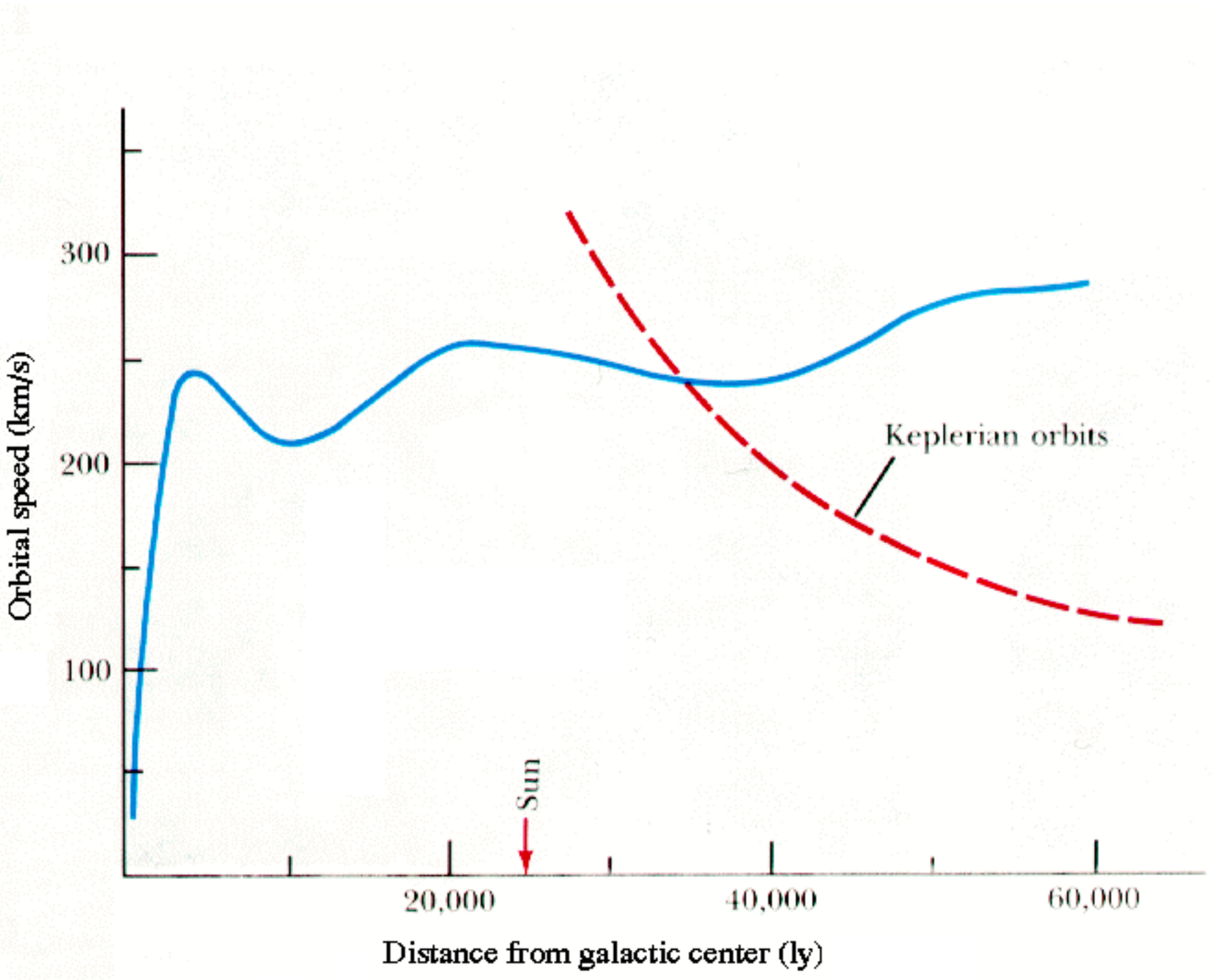


??????

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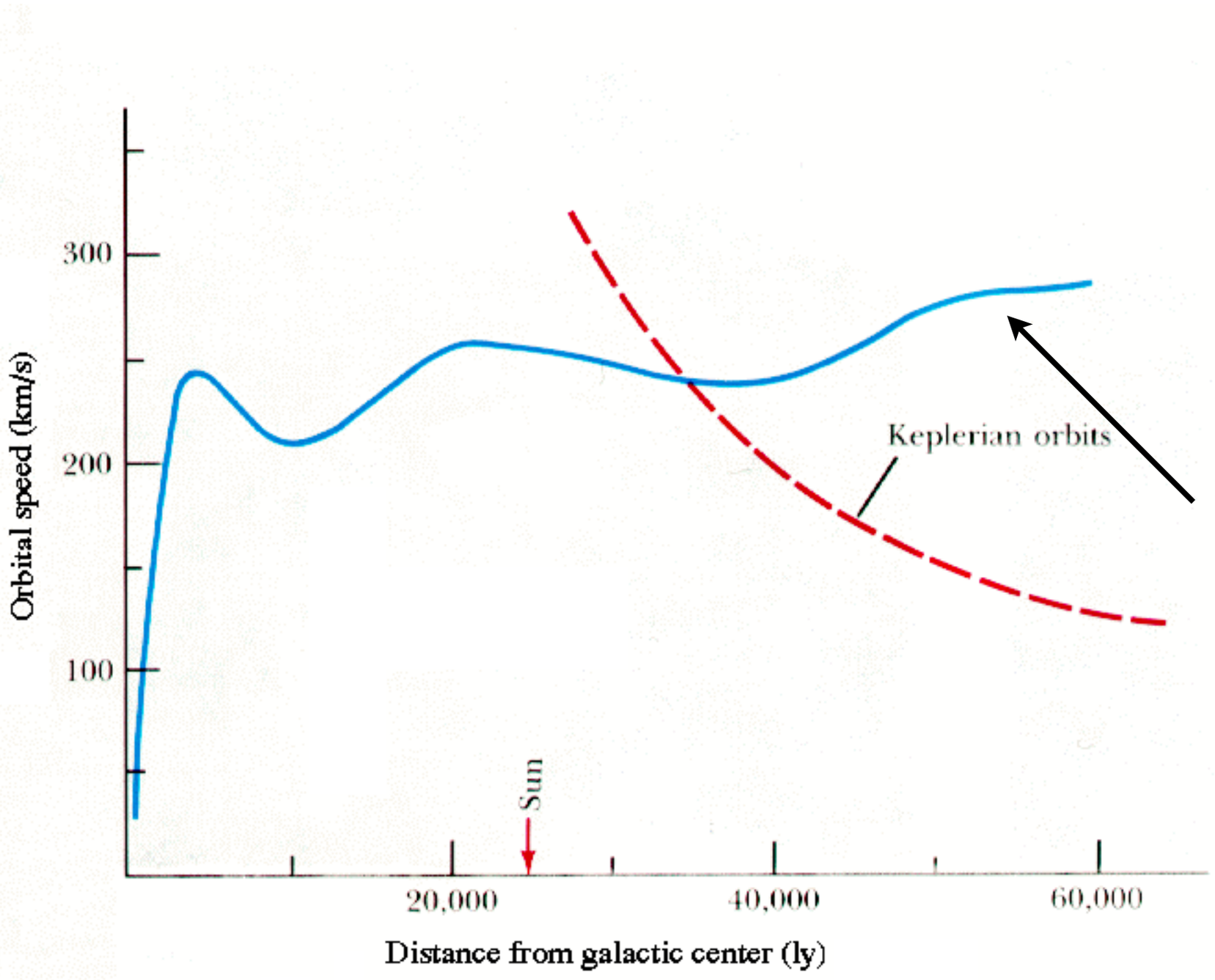

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- Changing the underlying theory of gravity to explain the problem with the rotation of galaxies has lead to a new theory:

Modification Of Newtonian Dynamics

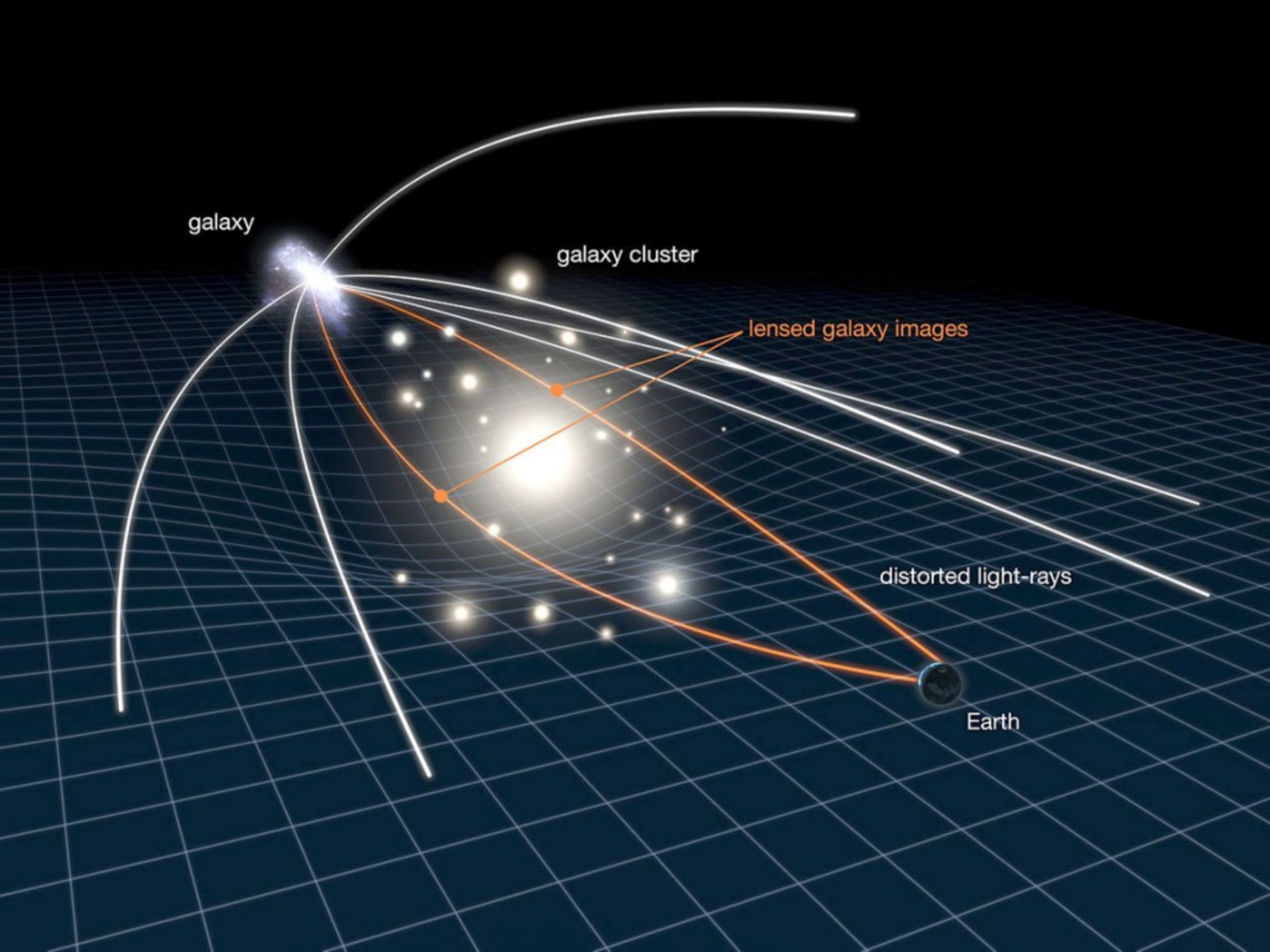
- In its minimal version it introduces a dependence of gravity on the acceleration of the body

- Tuning that value could explain the rotation‘s curve

- One can try to make a fully covariant theory whose low energy limit is MOND

- There has been some literature on the subject, specially by Bekenstein and his Tensor-Vector-Scalar gravity but it has some problems:
  - It does not explain as well the rotations of galaxies as DM
  - It has some inconsistencies
  - It is unclear if it can explain Planck
  - But it can not explain:

Bullet Cluster: the center of gravity (blue) differs from the center of gas (red)


galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth

- So then we are left with the possibility that the effect is due to matter than we don't see

- Could it be ordinary matter?

  - Cold gas, MACHOs, white dwarfs, black holes are not enough and are actually inconsistent with BBN

  - Neutrinos are hot (relativistic) and its density is constrained by structure formation

- We are left with candidates beyond the standard model

- We are looking for a particle which:

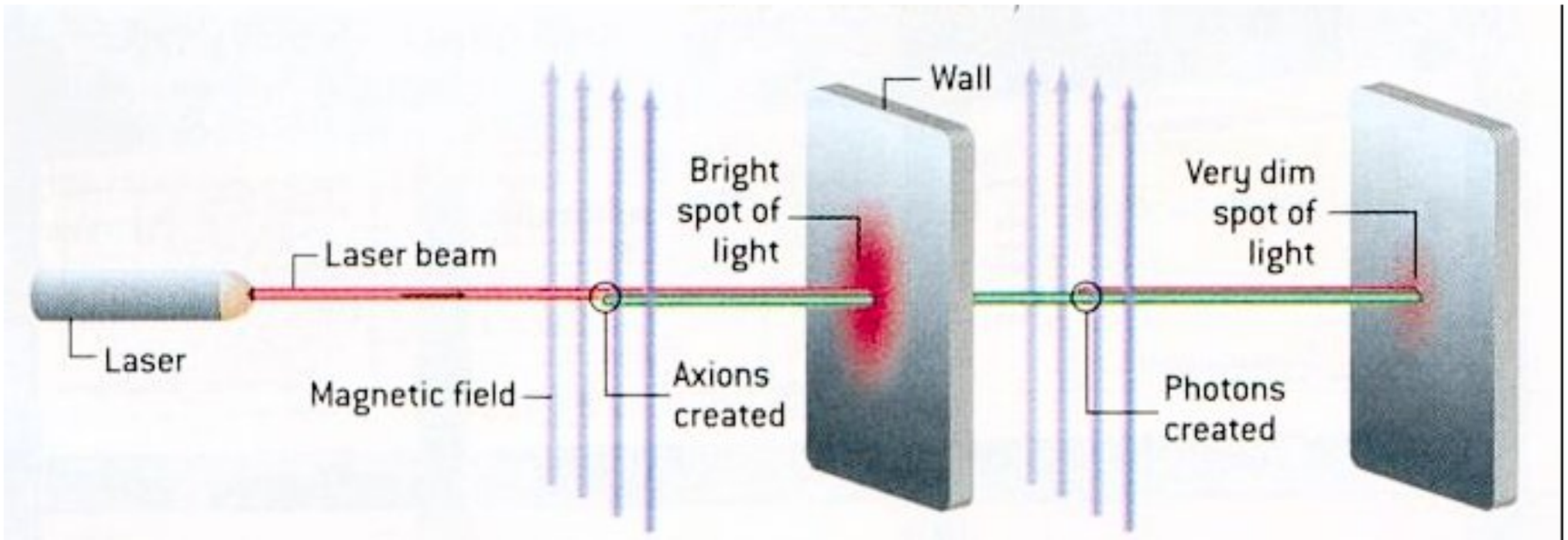
  - Is stable or metastable (in order to be able to explain DM now)

  - Neutral

  - Cold i.e. not relativistic (maybe warm)

  - Whose interactions are such that it leads to the observed density

- One of the first candidates proposes is the axion with a mass of around ~$10^{-5}$ eV (even lighter than neutrinos by 5 orders)




LIGHT BEAM experiment that would confirm the existence of axions passes a laser beam through a strong magnetic field, converting some photons to axions (*green beam*). The axions penetrate a wall before passing through another magnetic field that converts some of the particles back to photons, which form an extremely faint spot on the far wall.

- Another possibilities are WIMPS, particles with weak interactations and masses around 100 GeV

- The so-called WIMP miracle occurs because with masses and couplings testable right now you can reproduce the DM abundance thermaly.

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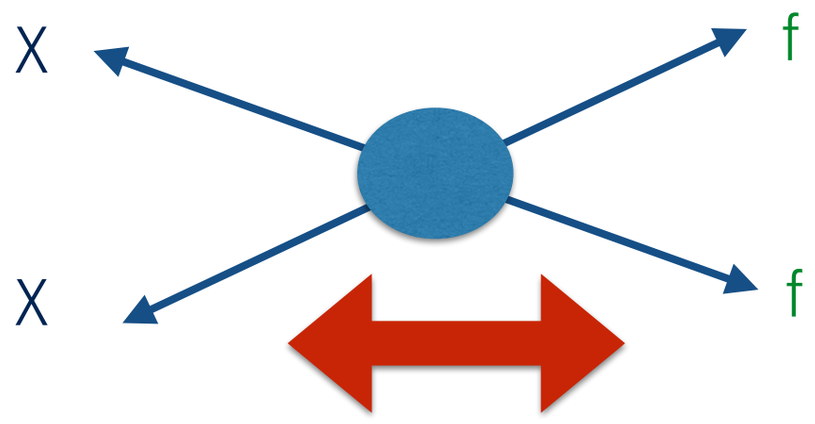

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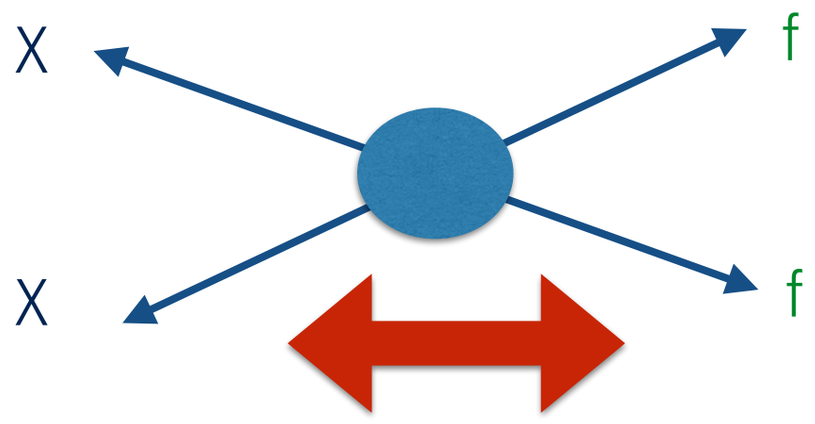

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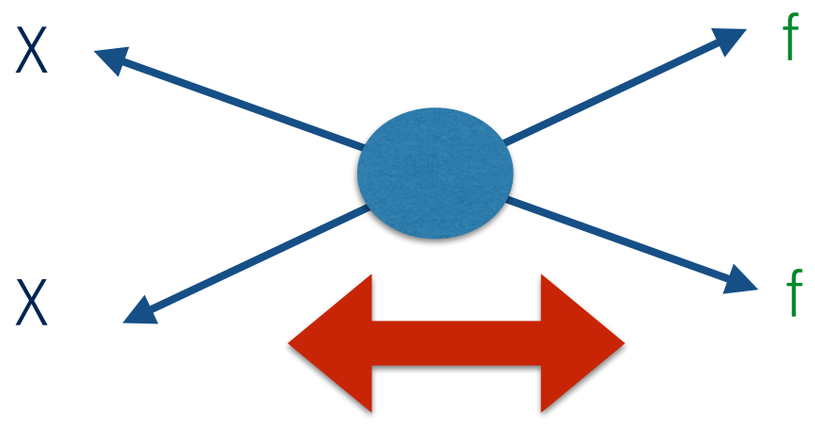

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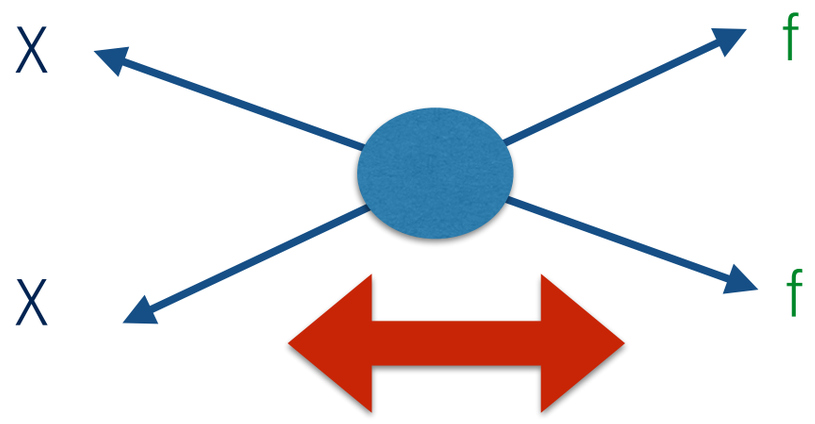


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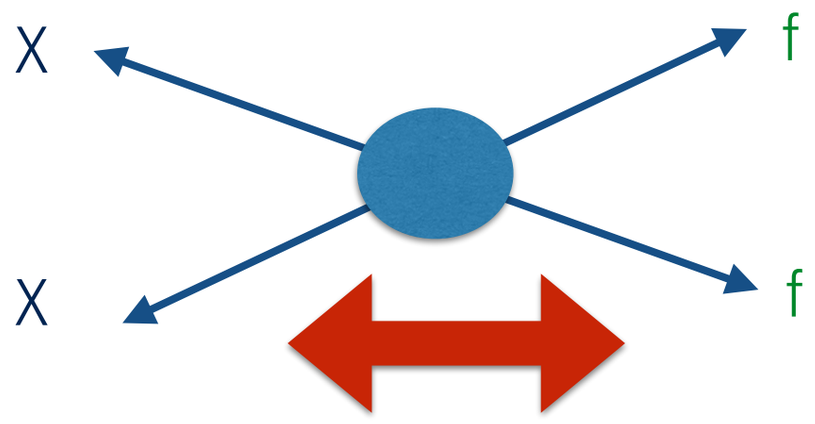


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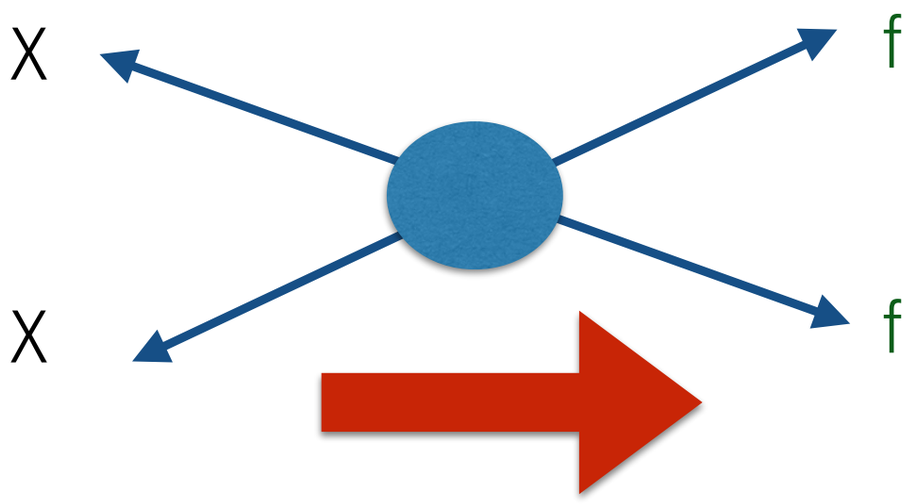
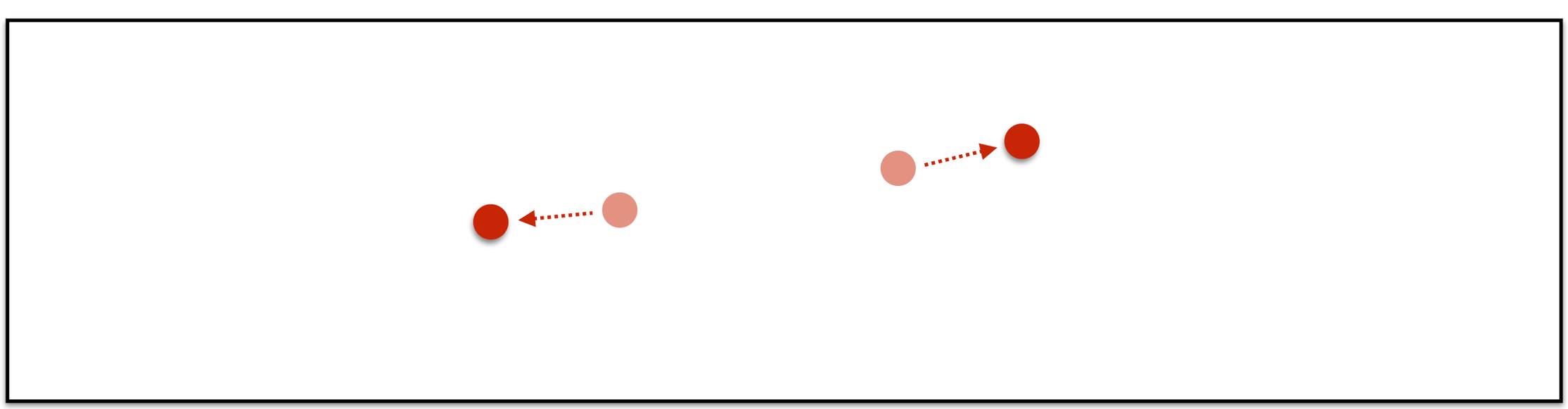


- In an static universe that would mean that DM will eventually desappear into us.

- But the universe is expanding so it leaves a relic density of DM that can not find another DM to annihilate.



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We love funny names

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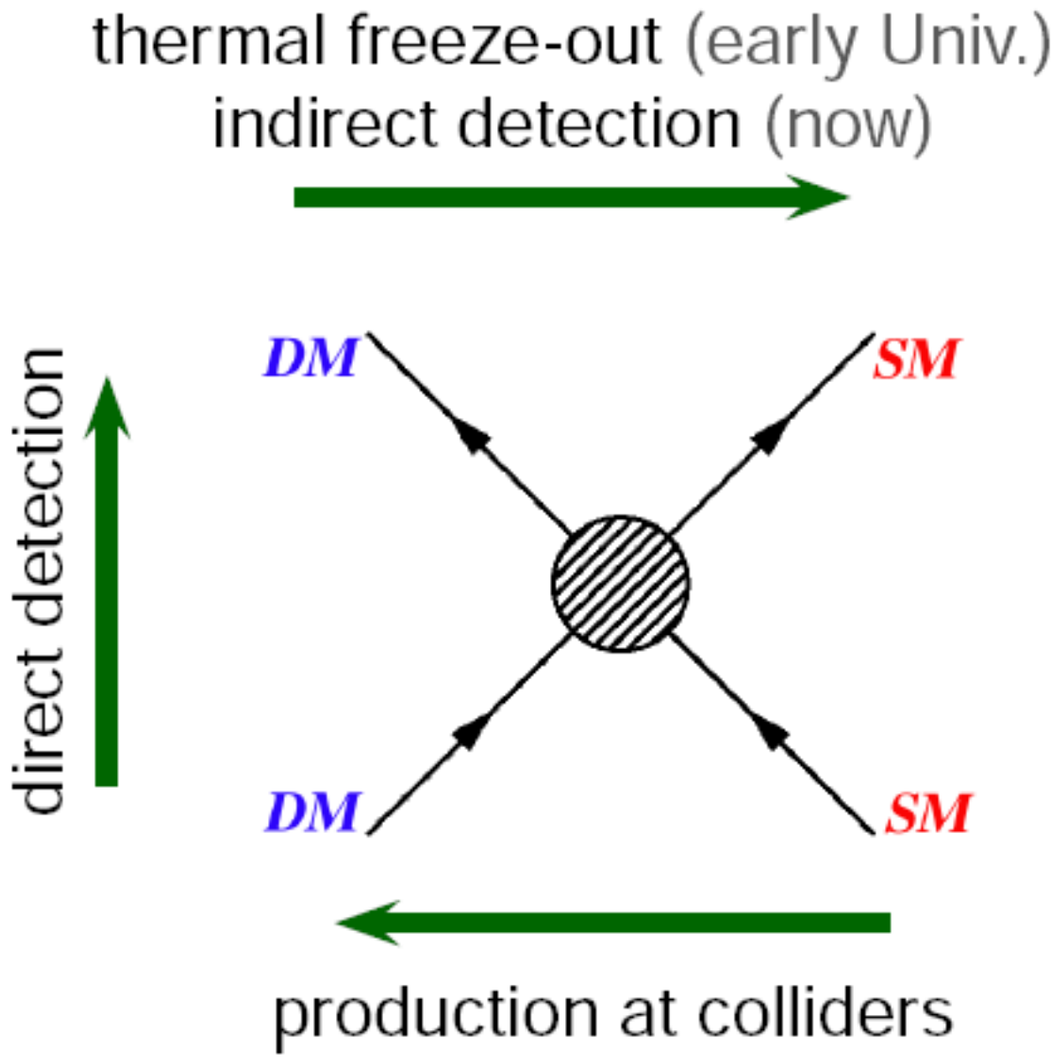
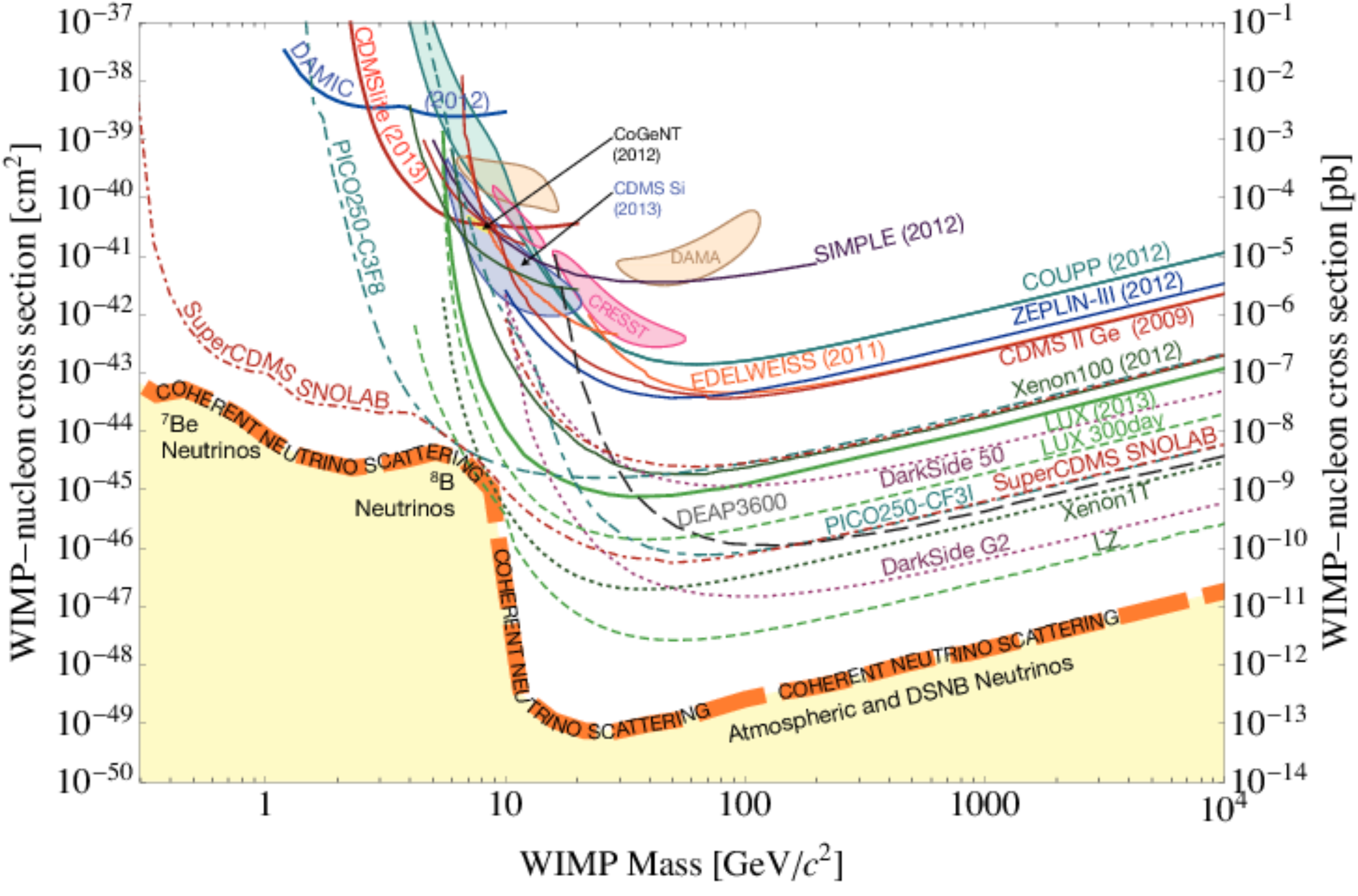



# Ways to detect DM


WIMP–nucleon cross section [cm$^2$]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/$c^2$]
$10^{-37}$
$10^{-38}$
$10^{-39}$
$10^{-40}$
$10^{-41}$
$10^{-42}$
$10^{-43}$
$10^{-44}$
$10^{-45}$
$10^{-46}$
$10^{-47}$
$10^{-48}$
$10^{-49}$
$10^{-50}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
1
10
100
1000
$10^4$
DAMIC
CDMSlite (2013)
(2012)
CoGeNT (2012)
CDMS Si (2013)
DAMA
CRESST
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
EDELWEISS (2011)
CDMS II Ge (2009)
Xenon100 (2012)
LUX (2013)
LUX 300day
DarkSide 50
SuperCDMS SNOLAB
PICO250-CF3I
Xenon1T
DEAP3600
DarkSide G2
LZ
PICO250-C3F8
SuperCDMS SNOLAB
COHERENT NEUTRINO SCATTERING
$^7$Be Neutrinos
$^8$B Neutrinos
COHERENT NEUTRINO SCATTERING
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Atmospheric and DSNB Neutrinos