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Fellowship for Innovation at INFN
H2020 MSCA COFUND
G.A. 754496
Istituto Nazionale di Fisica Nucleare

Astroparticle Physics & Cosmology: Overview

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MEMBERS (in speaking order today):

Luca Visinelli (Frascati)

Michael Leyton (Napoli)

Mattia di Mauro (Torino)

Rubén López-Coto (Padova)

Francesco Puosi (Pisa)

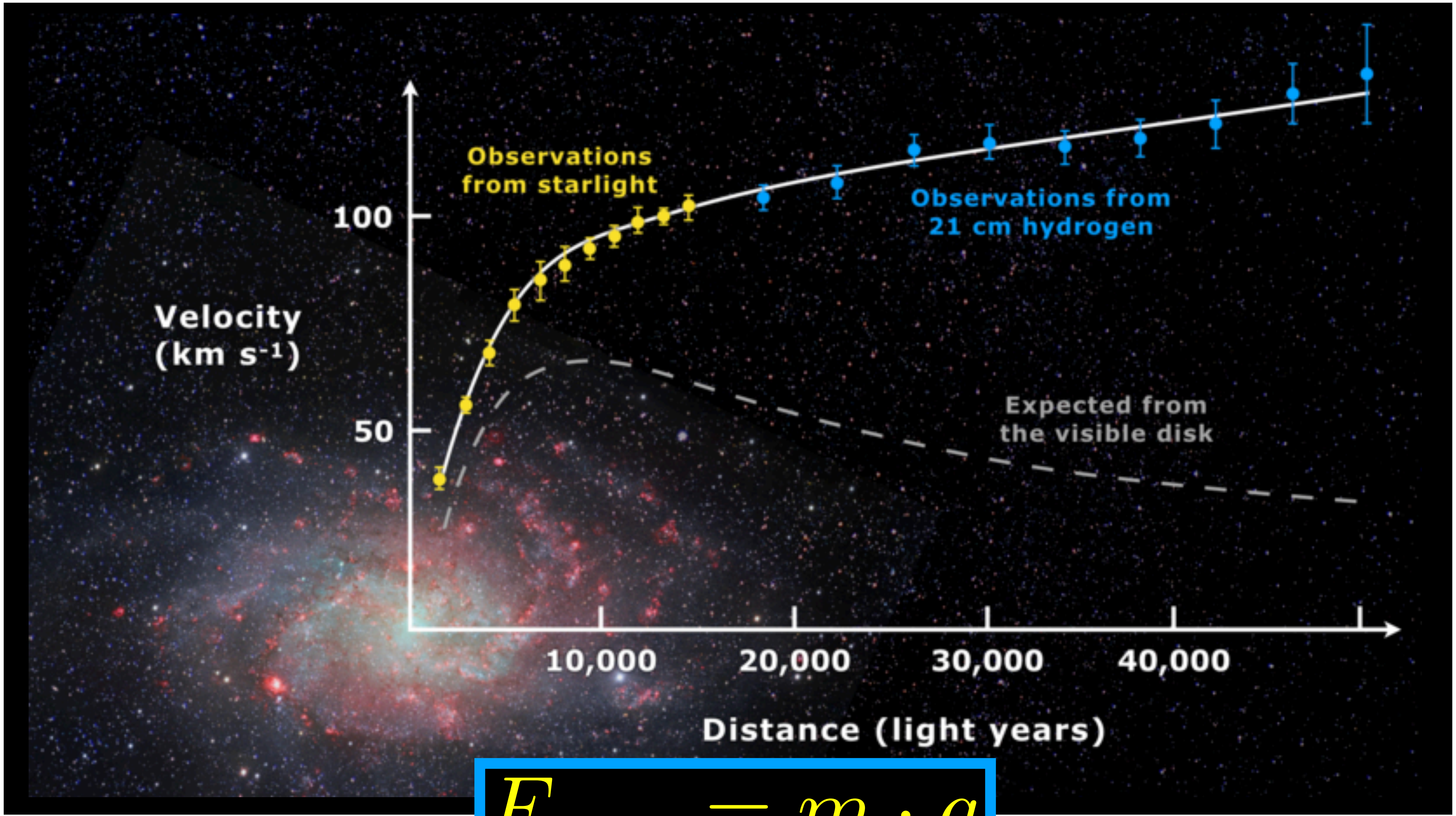
Guillerm Dòmenech (Padova)

Constantinos Constantinou (Trento)

Evidences for dark matter

Rotational velocity curve of M33

According to Newton's Law: $v = \sqrt{\frac{G_N M_{\rm encl}(r)}{r}}$

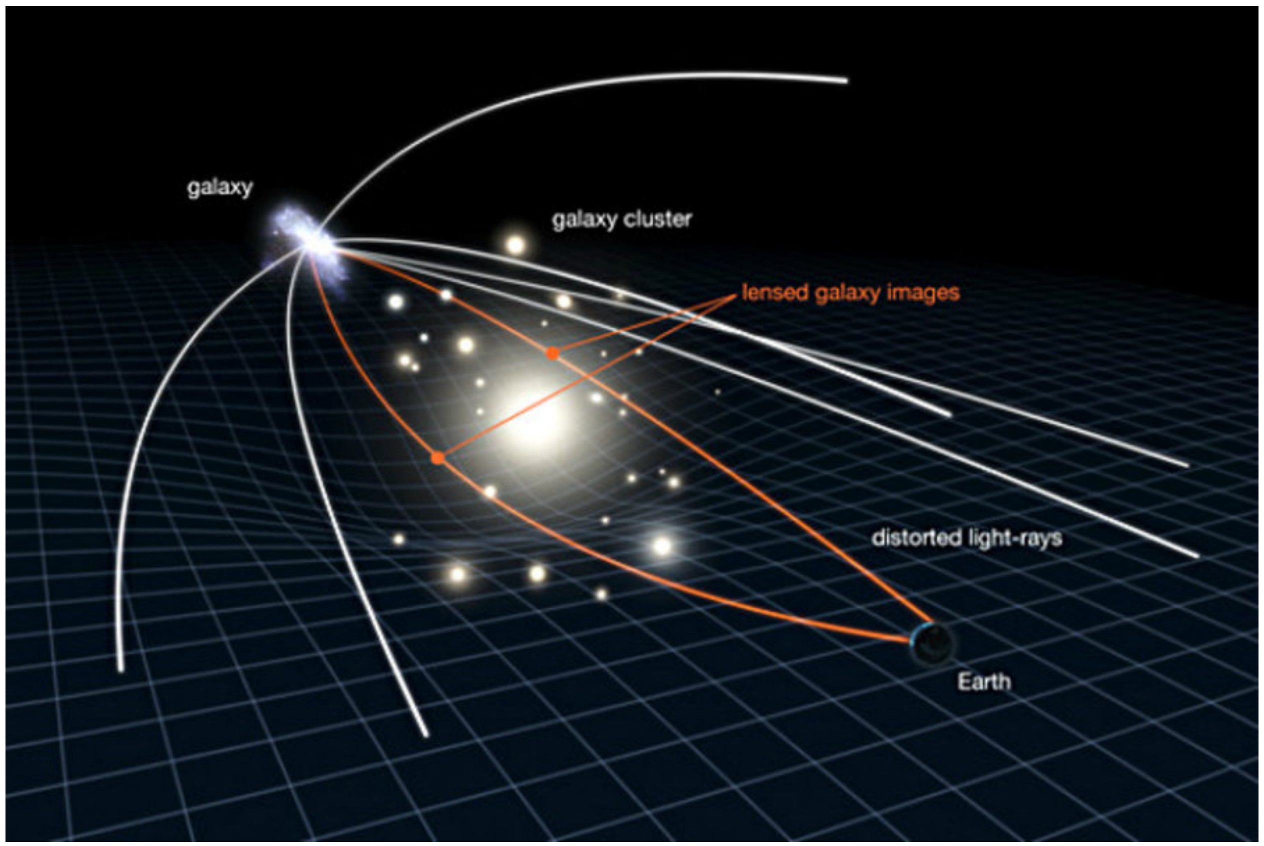


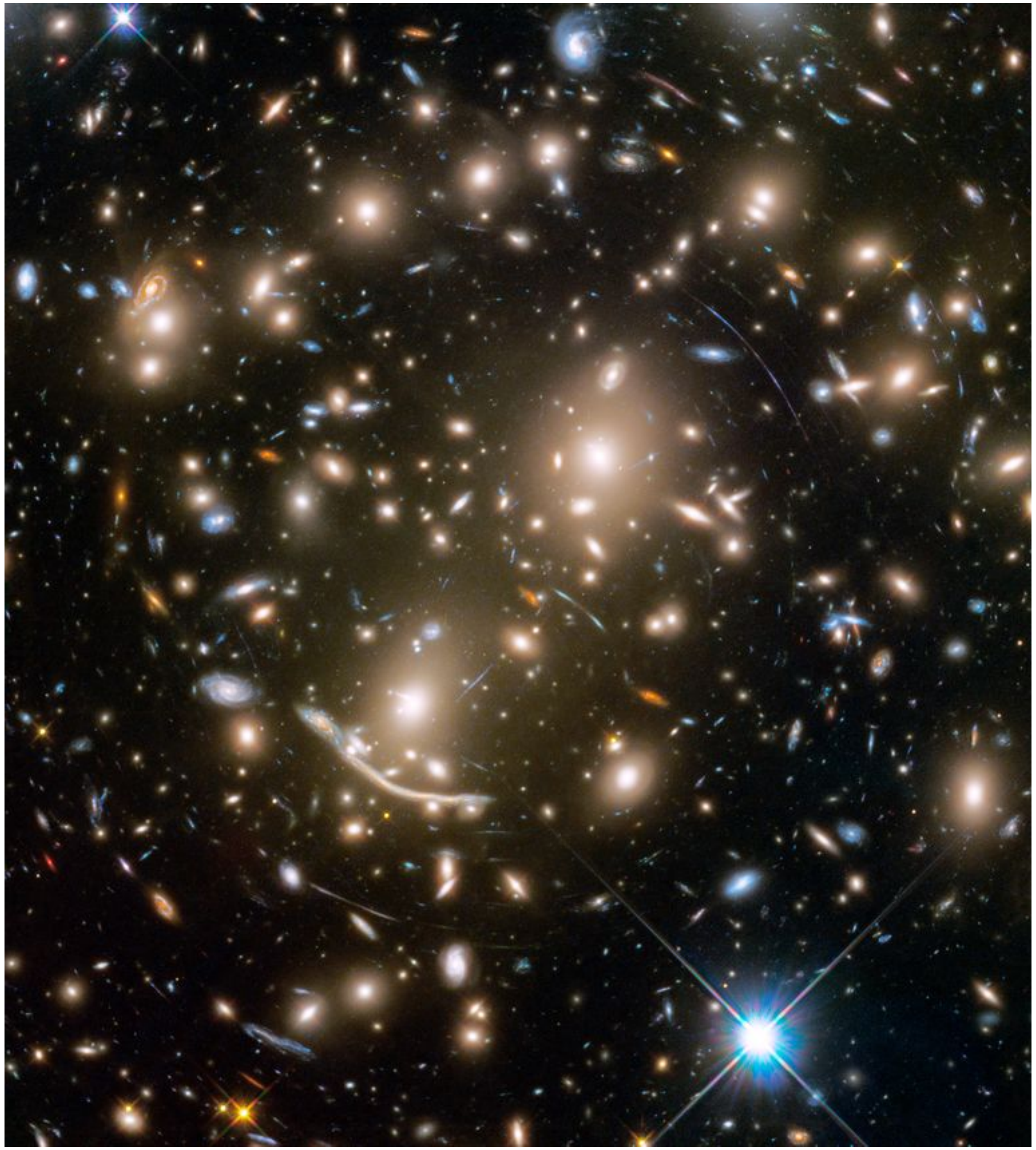
$$F_{\rm grav} = m \cdot a$$

Modify this side:
dark matter

Modify this side:
MOND (modified gravity)

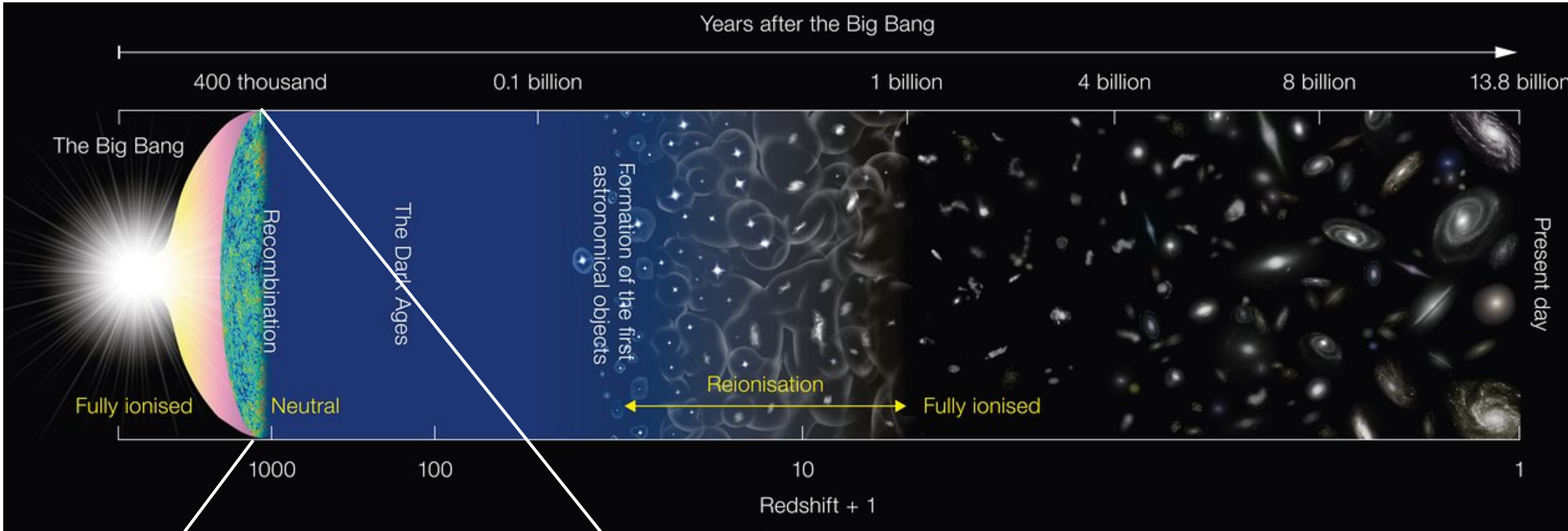
Gravitational lensing by galaxy clusters

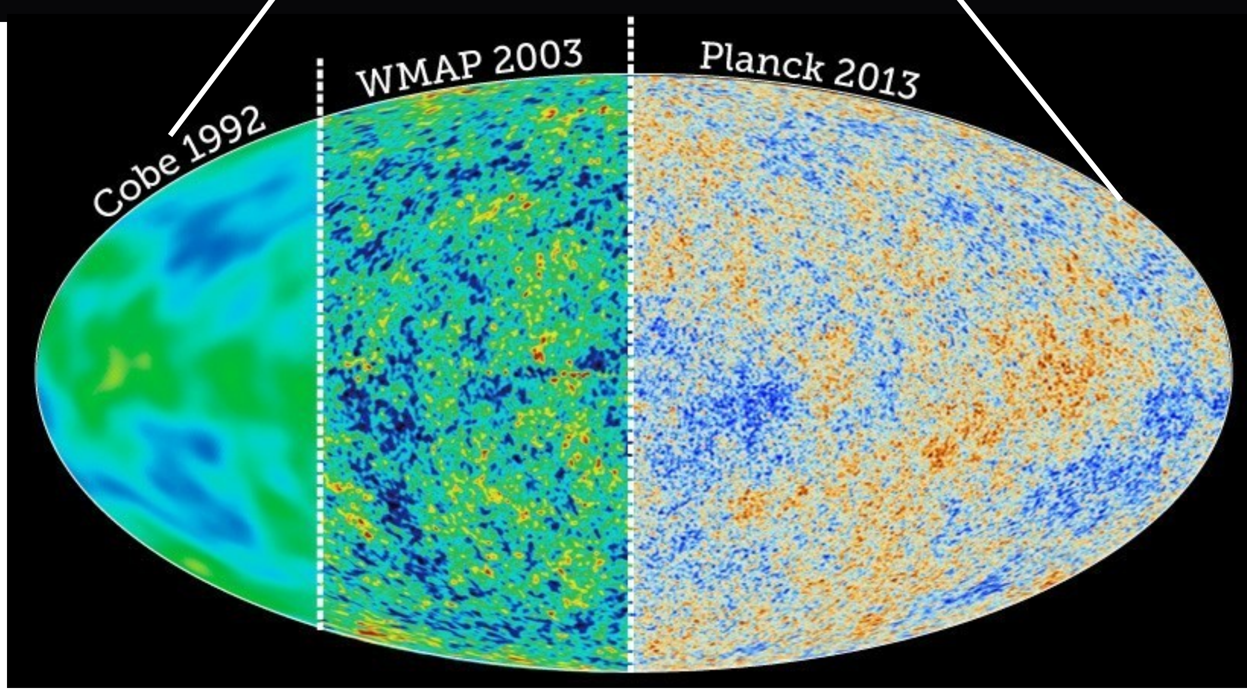




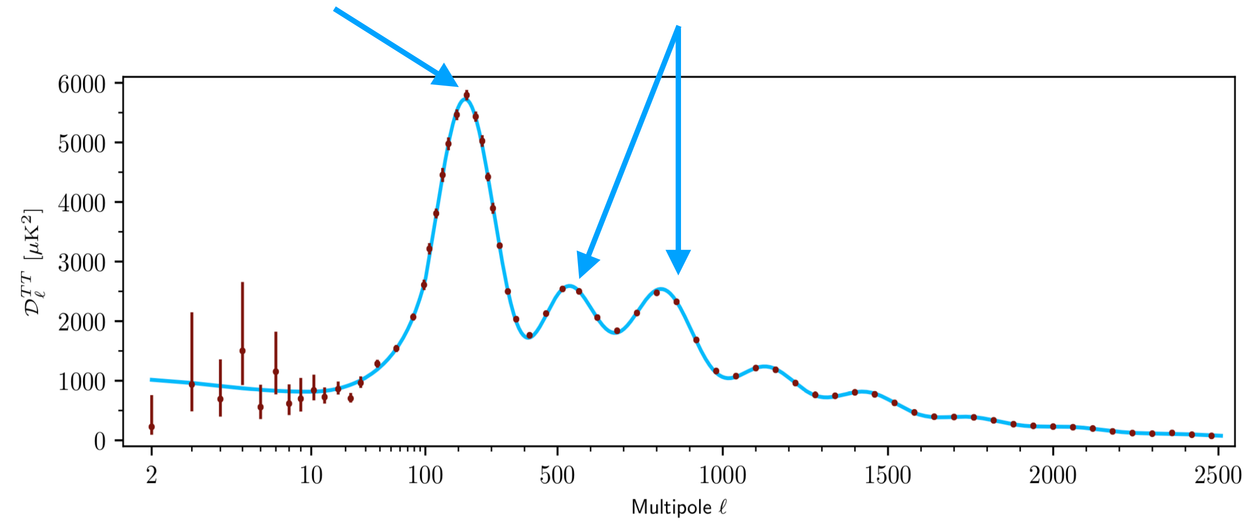
Additional evidence for the existence of dark matter comes from lensing

Cosmology





Position and relative size of peaks tell us about flatness & matter content



Evidences for dark energy

SNIa distance and luminosity

Luminosity distance of a SN $D_L \equiv \sqrt{\dfrac{\mathcal{L}}{4\pi\mathcal{F}}}$

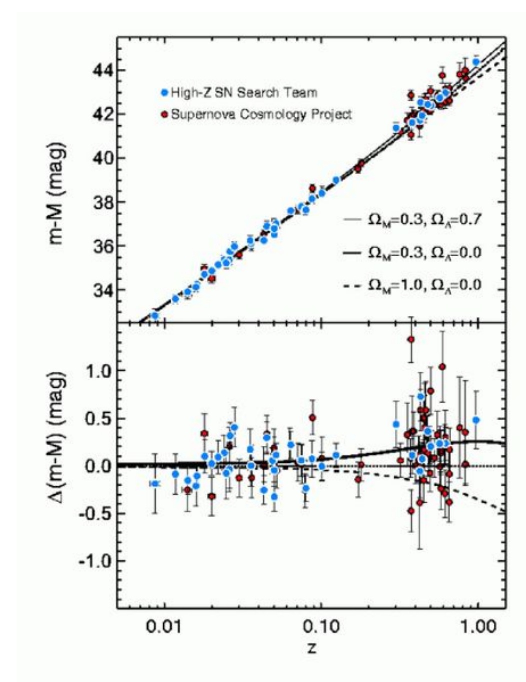
$\mathcal{L}$ Intrinsinc luminosity

$\mathcal{F}$ Observed flux

Fit observations at redshift z against the expression

$$D_L(z) = (1+z)\frac{c}{H_0}\int_0^z \frac{\mathrm{d}z'}{\sqrt{\Omega_m(1+z')^3 + \Omega_k(1+z')^2 + \Omega_\Lambda}}$$

c	speed of light
H_0	Hubble constant
$\Omega_m, \Omega_k, \Omega_\Lambda$	fractional energy density in matter, curvature, cosmological constant



Nobel Prize 2011

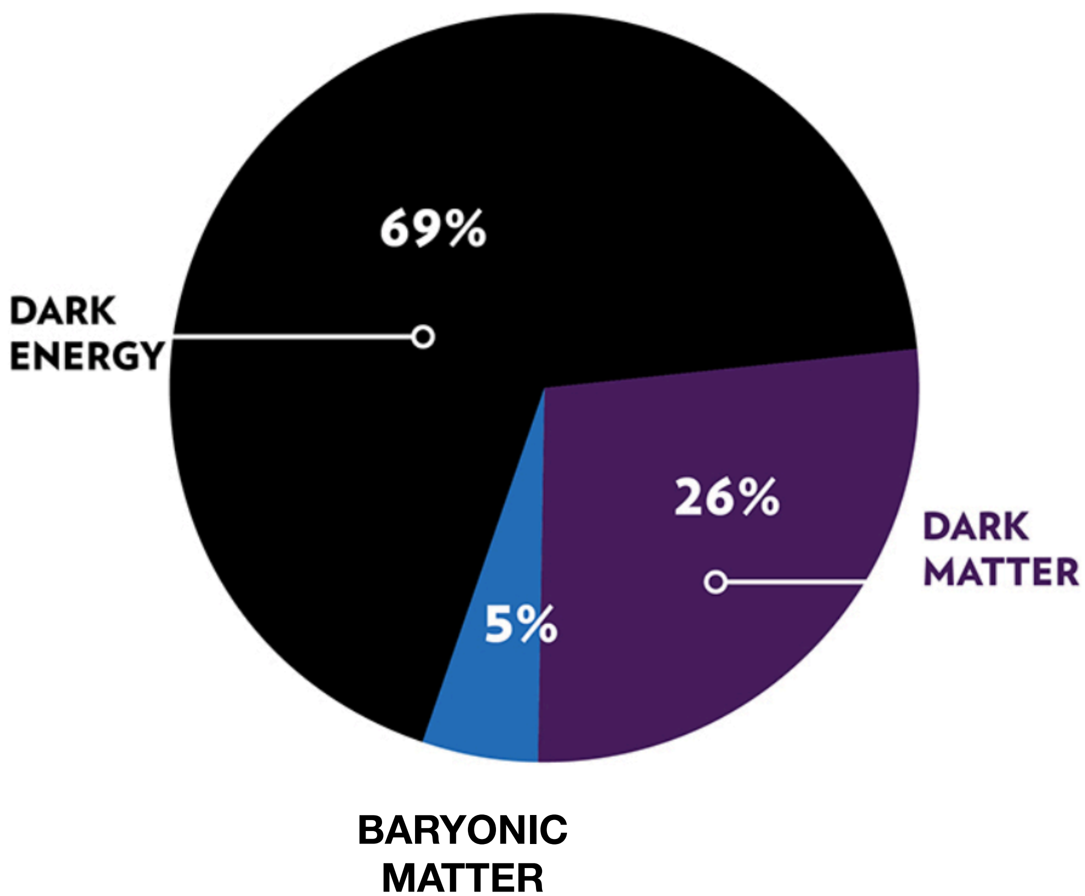
Saul Perlmutter

Brian Schmidt

Adam Reiss

Concordance cosmological model

Energy distribution today



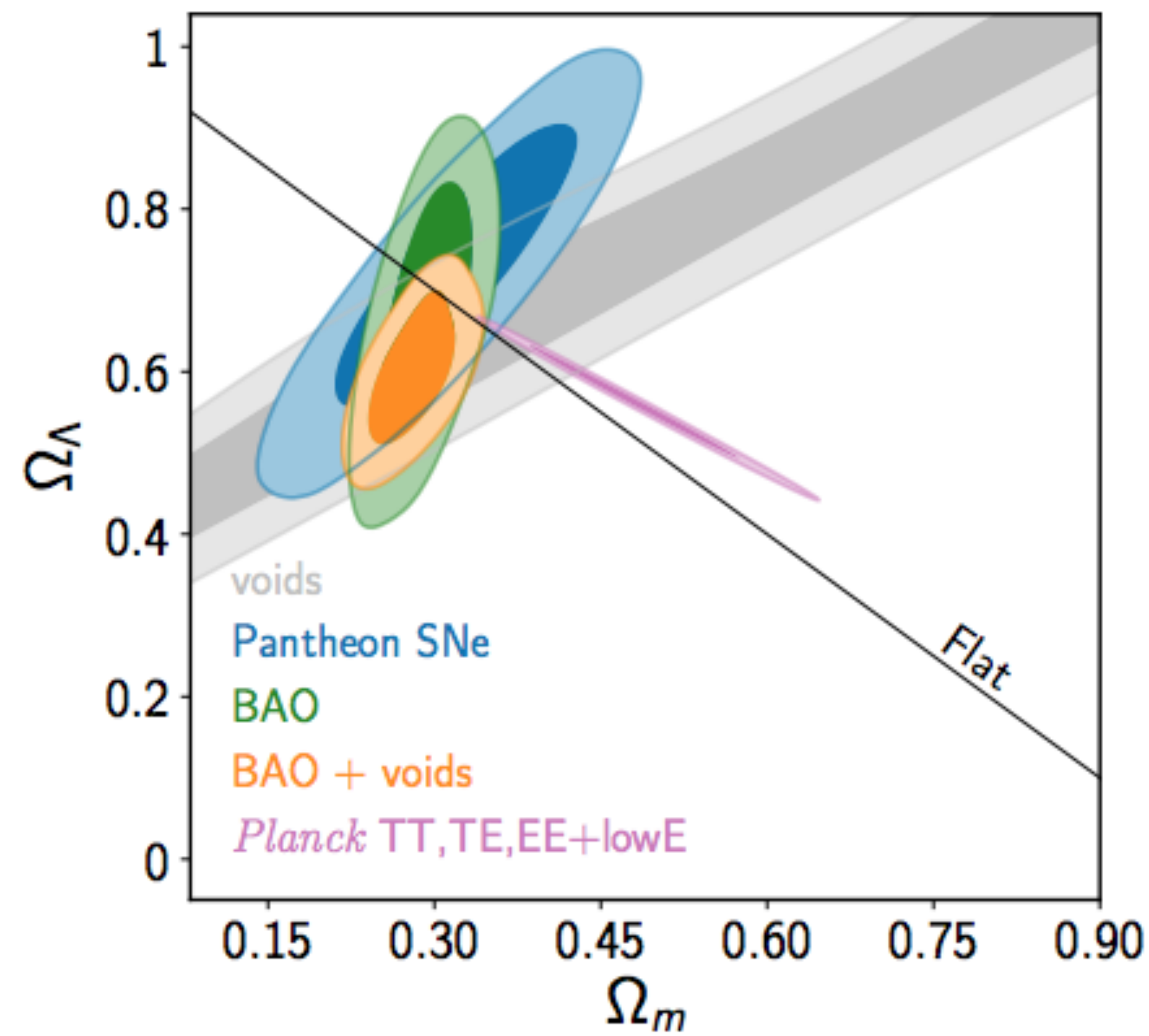
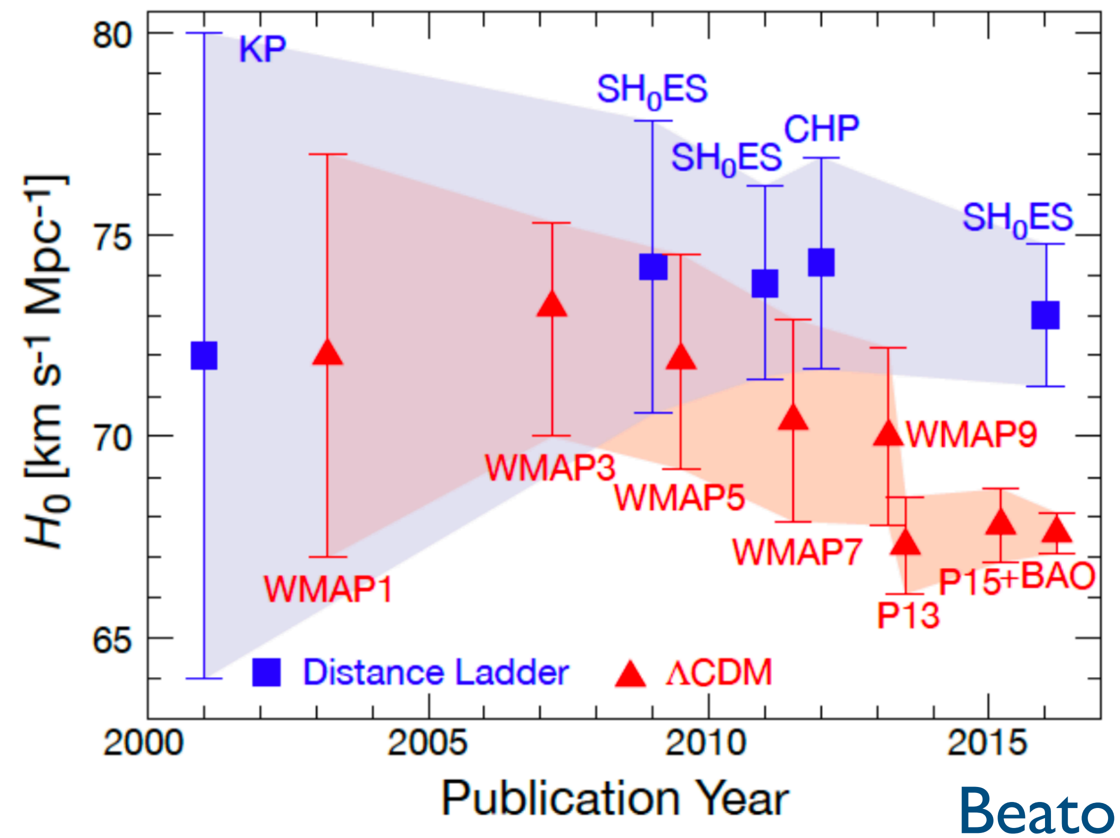


FIG. 4. Marginalised constraints on Ω_m and Ω_Λ obtained from BOSS voids, Pantheon SNe, BAO and *Planck* CMB, assuming $w = -1$. The line indicates spatially flat models. BAO+voids give $\Omega_\Lambda = 0.600 \pm 0.058$, a $> 10\sigma$ detection of acceleration.

Concordance cosmological model



Beaton+16, Freedman+17

See the very recent review on 2103.01183

In the Realm of the Hubble tension − a Review of Solutions †

Eleonora Di Valentino[1*], Olga Mena[2], Supriya Pan[3], Luca Visinelli[4], Weiqiang Yang[5], Alessandro Melchiorri[6], David F. Mota[7], Adam G. Riess[8,9], Joseph Silk[8,10,11]

Concordance cosmological model

The $\Lambda\mathrm{CDM}$ (Lambda-Cold Dark Matter) model is a concordance model that attempts to capture the key observations about both “early” and “late” Universe.

Key ingredients:

- Standard Model (SM) content: “baryons”, radiation, neutrinos;
- (Cold) dark matter;
- Dark energy in the form of a cosmological constant;
- Zero curvature, Friedmann-Robertson-Walker metric

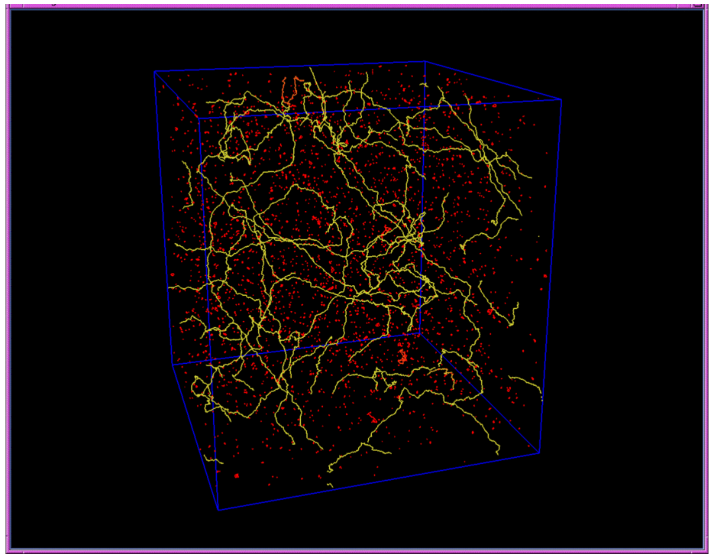
One more ingredient: inflation

Concordance cosmological model

Inflation is a very early epoch in which the expansion of the Universe accelerated

Inflation solves several problems of the standard Big-Bang picture:

- Flatness:
  $|1-\Omega_{\rm tot}| \lesssim 10^{-3}$ today means $|1-\Omega_{\rm tot}| \lesssim 10^{-5}$ at CMB
- Horizon:
  CMB patches are causally disconnected, yet temperature fluctuations only arise at the level of $\Delta T/T_0 \sim 10^{-5}$
- Absence of topological defects:



See talk by Guillem Domènech

The nature of dark matter

Is dark matter a particle?

Macroscopic object
es. (Primordial) black hole

Did LIGO detect dark matter?

Simeon Bird,* Ilias Cholis, Julian B. Muñoz, Yacine Ali-Haïmoud, Marc Kamionkowski, Ely D. Kovetz, Alvise Raccanelli, and Adam G. Riess[1]

see e.g. 1603.00464

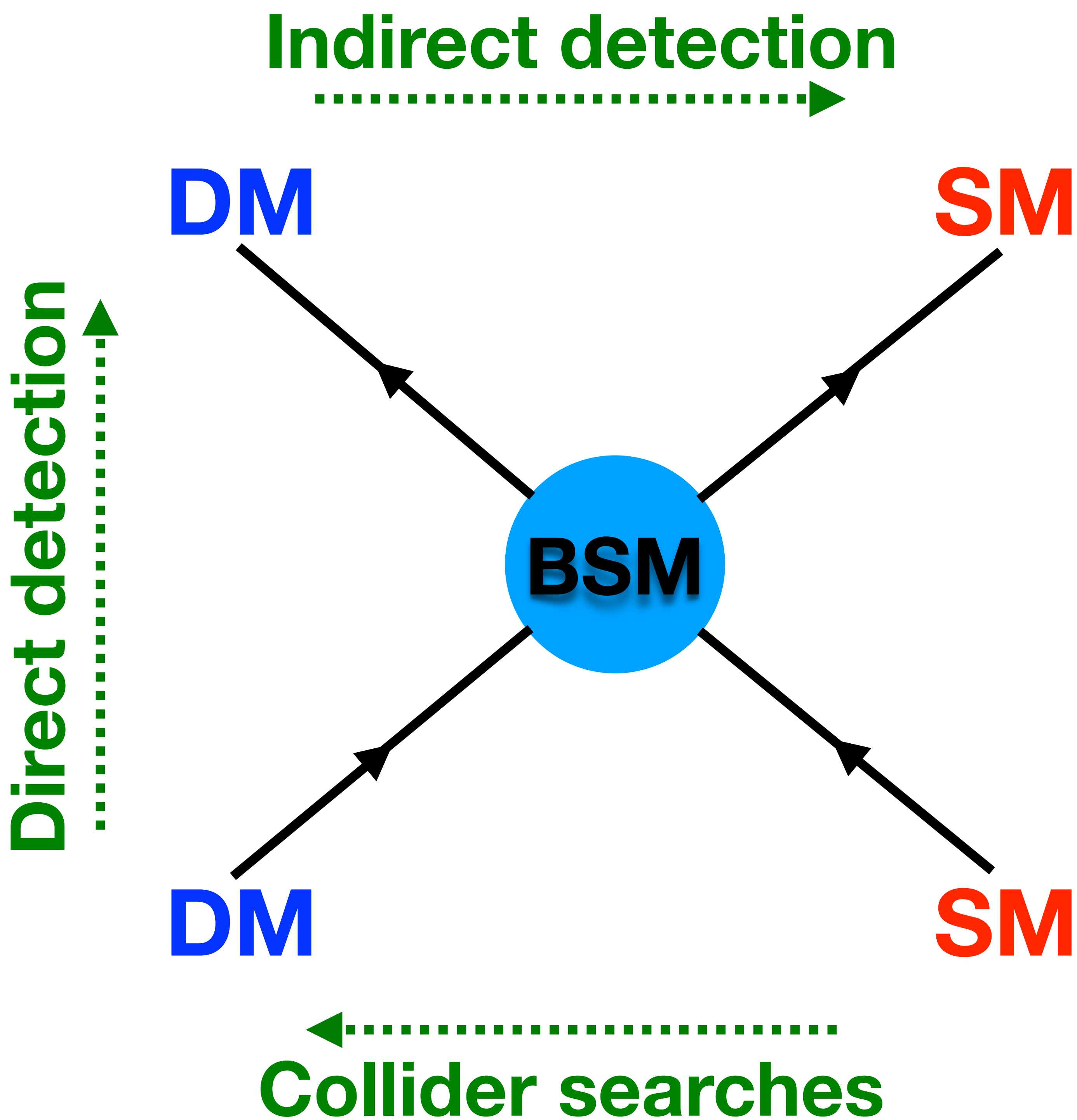
See talks by Guillem Domènech and Francesco Puosi on BHs

See also the talk by Constantinos Constantinou on dense environments

New particle not in the SM

- From supersymmetry (es. WIMP)
- From fixing QCD issues (es. axion)
- From a dark sector (mediated by Higgs or dark photon)
- Feebly-interacting light boson
- ….

New massive particle (WIMP)



See talk by Michael Leyton for direct detection searches

See talks by Mattia di Mauro and Rubén López-Coto for indirect detection searches

New massive particle (WIMP)

Black holes can possess a halo of gravitationally bound WIMPs around

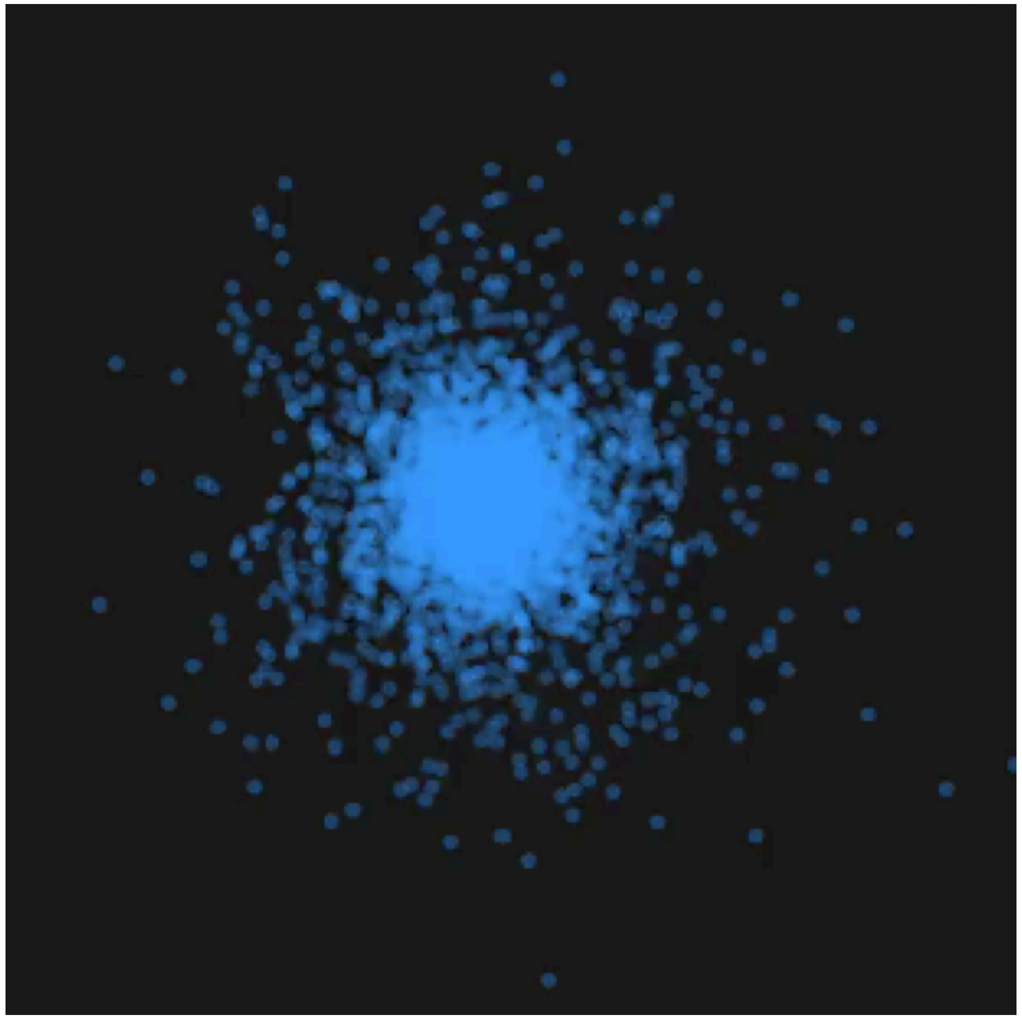
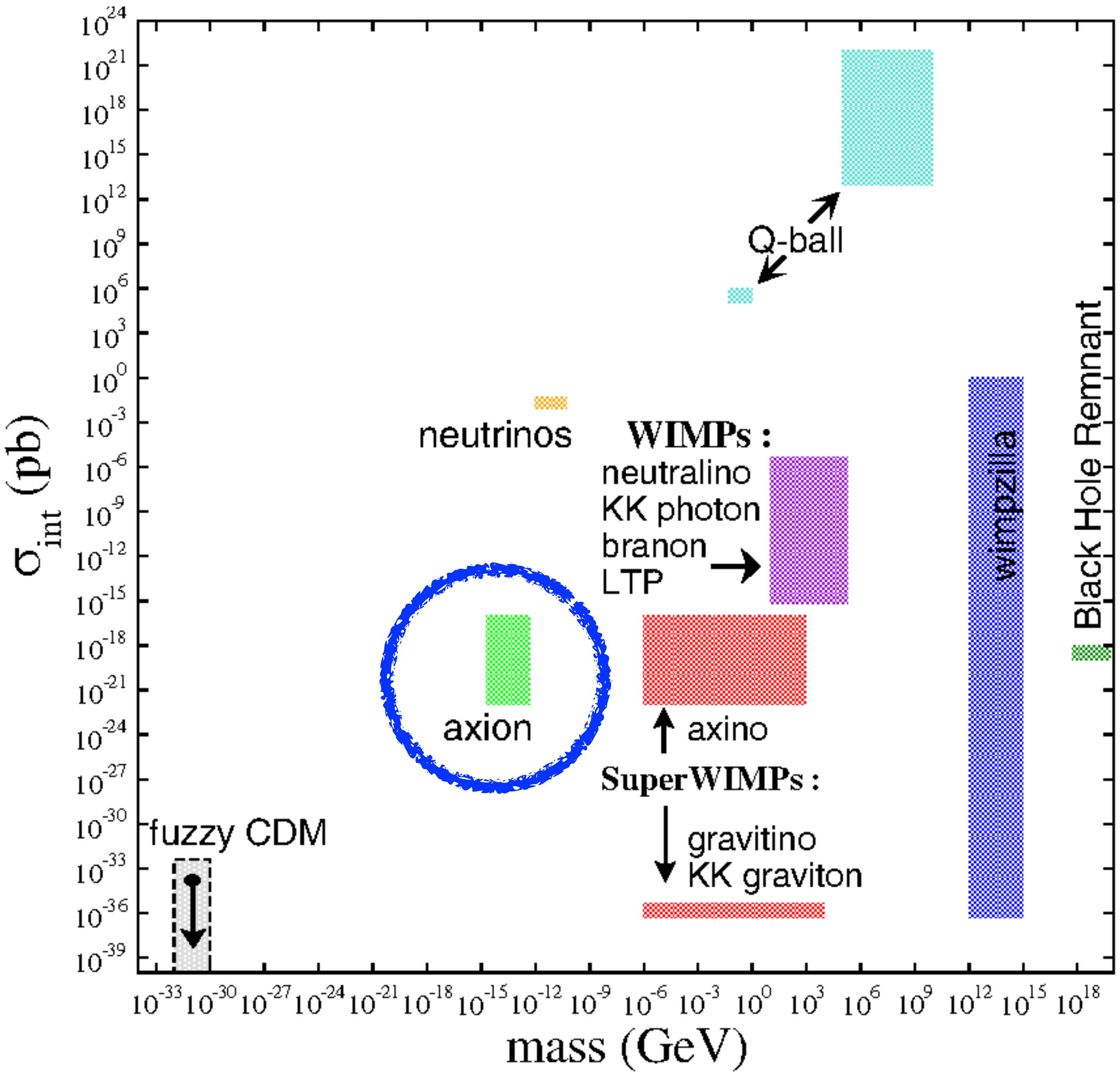


Figure from Kavanagh 1805.09034

Looking for WIMP annihilation signatures from these structures

See e.g. Carr, Kühnel, **LV** 2008.08077, 2011.01930

Axion



The axion is a light ($m_a \lesssim 10^{-2}\,\mathrm{eV}$) pseudoscalar predicted within QCD

Axion

ELSEVIER

Physics Reports
Volume 870, 25 July 2020, Pages 1-117

The landscape of QCD axion models

Luca Di Luzio [a], Maurizio Giannotti [b], Enrico Nardi [c], Luca Visinelli [d]

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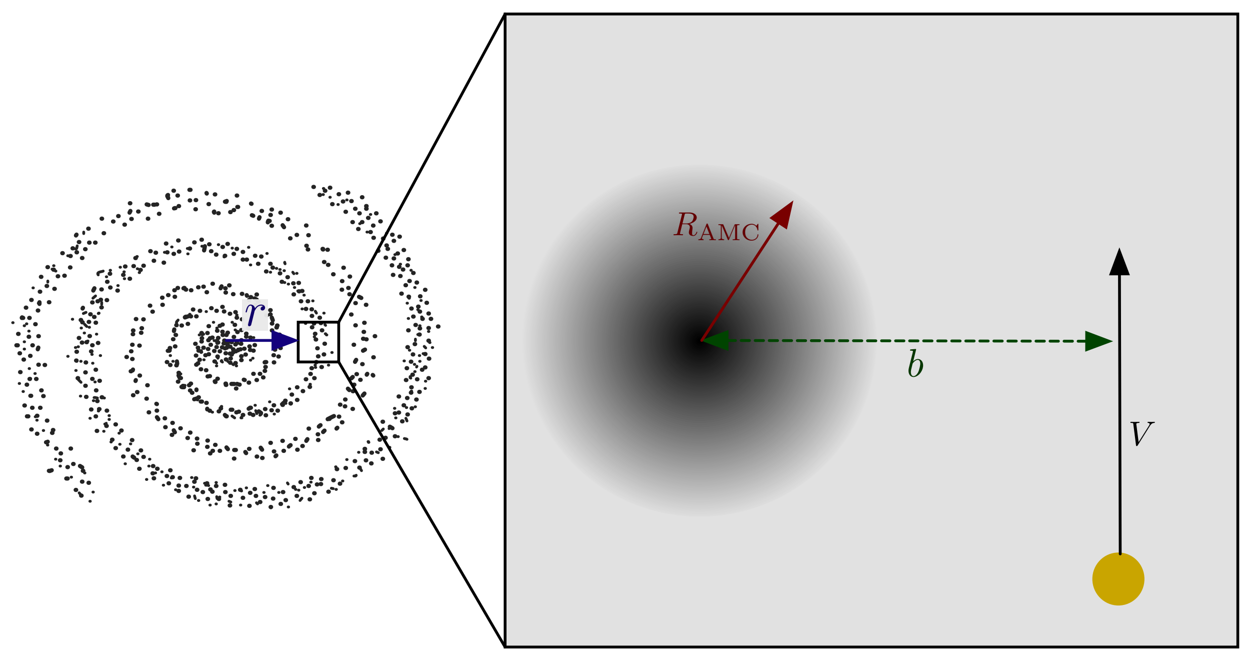
https://doi.org/10.1016/j.physrep.2020.06.002

Axion

Axions form distinct substructures: axion miniclusters and axion stars

Axion minicluster: clump of virialized, self-gravitating axions
Axion star: Condensate of axions kept in equilibrium by quantum pressure

Both objects form in the early Universe and can suffer tidal disruption



Edwards, Kavanagh, **LV**, Weniger, 2011.05377, 2011.05378

Axion

Future work:

Improve current simulations;

Interplay of axion miniclusters and axion stars;

Detection strategies away from direct detection for the QCD axion;

Extend to other light bosons