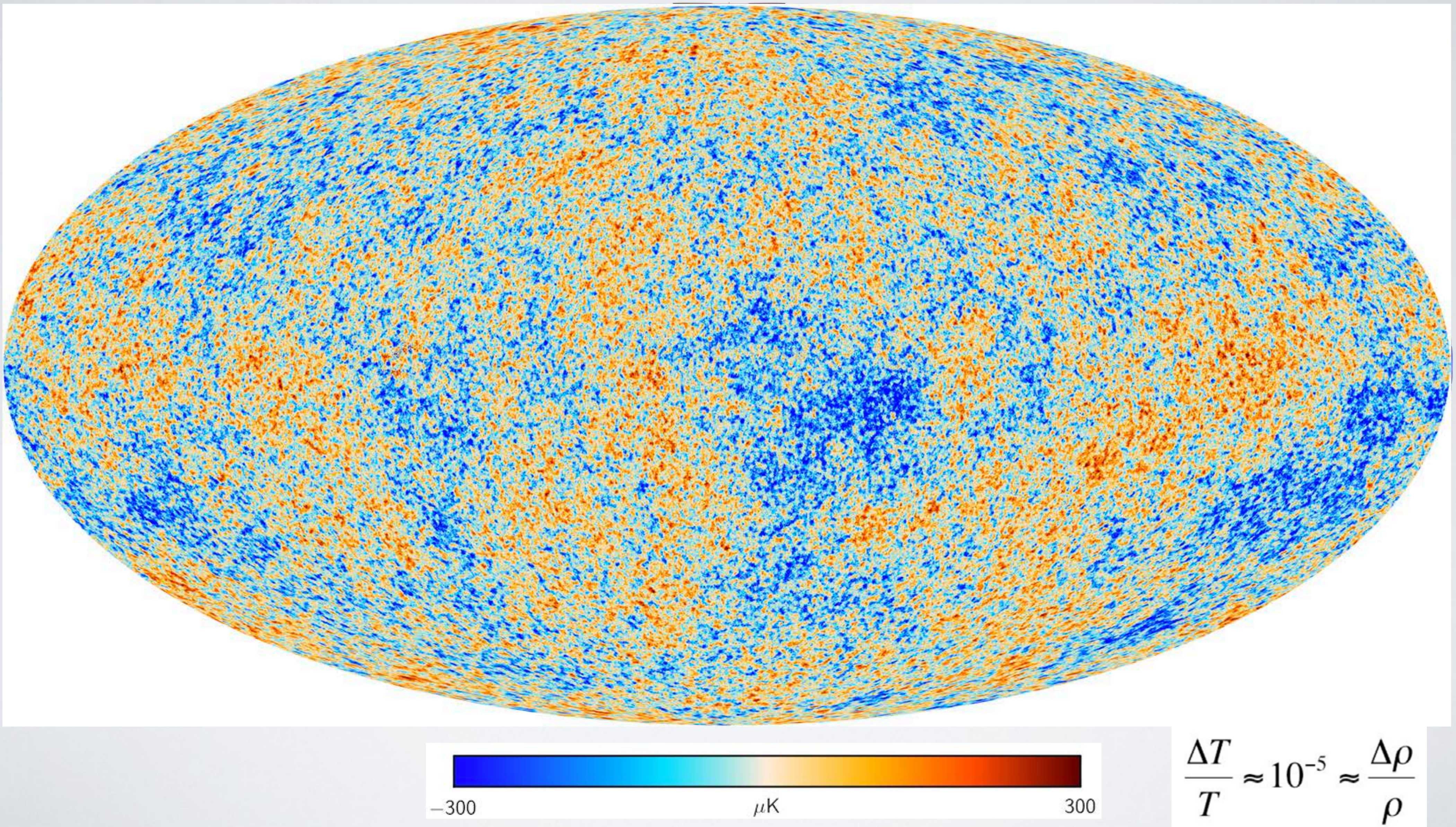
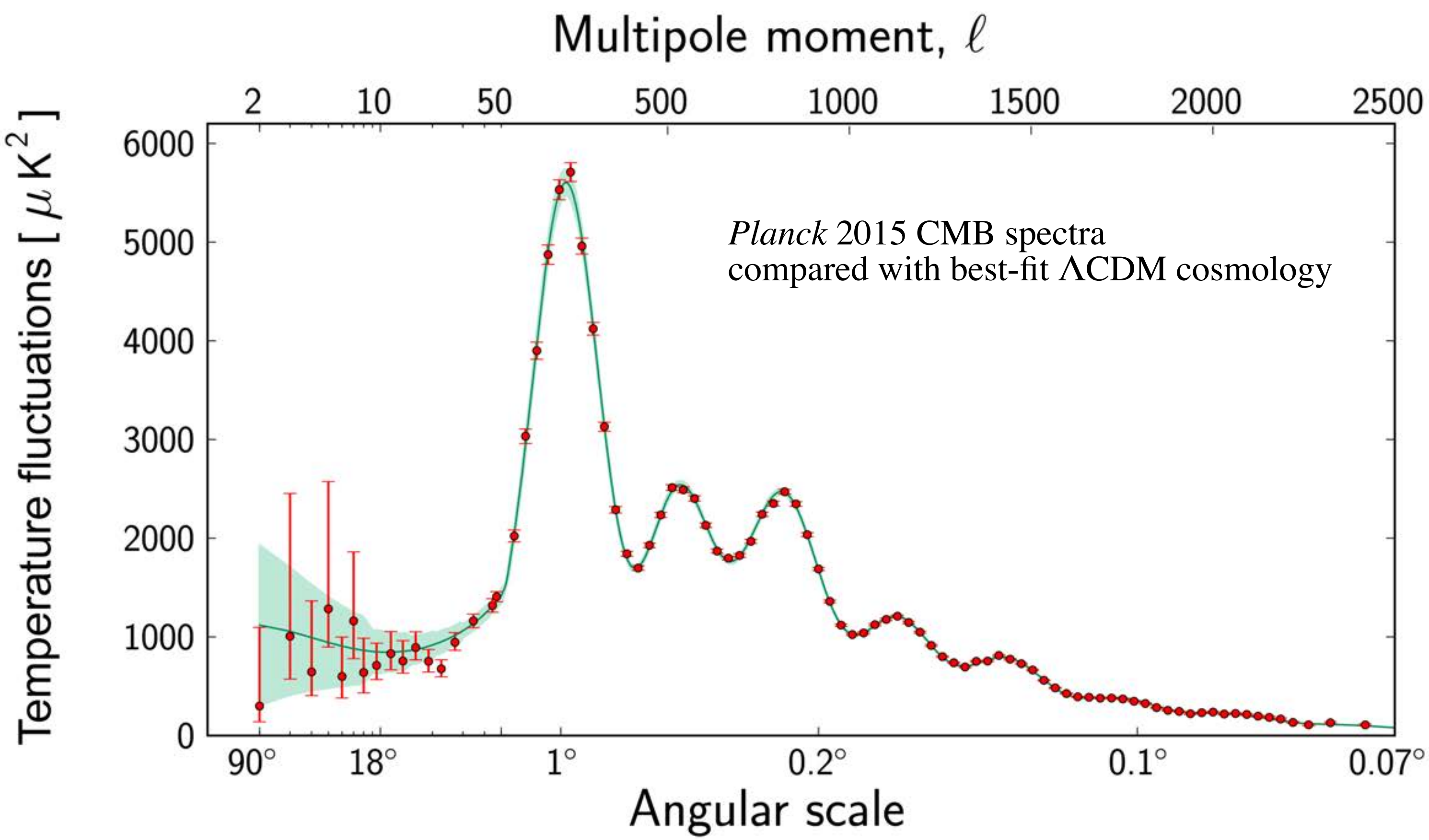
Francisco Prada
IAA-CSIC, Granada

“Dark Matter in the Sky”

Dark Matter in the Microwave Sky



$$\frac{\Delta T}{T} \approx 10^{-5} \approx \frac{\Delta \rho}{\rho}$$

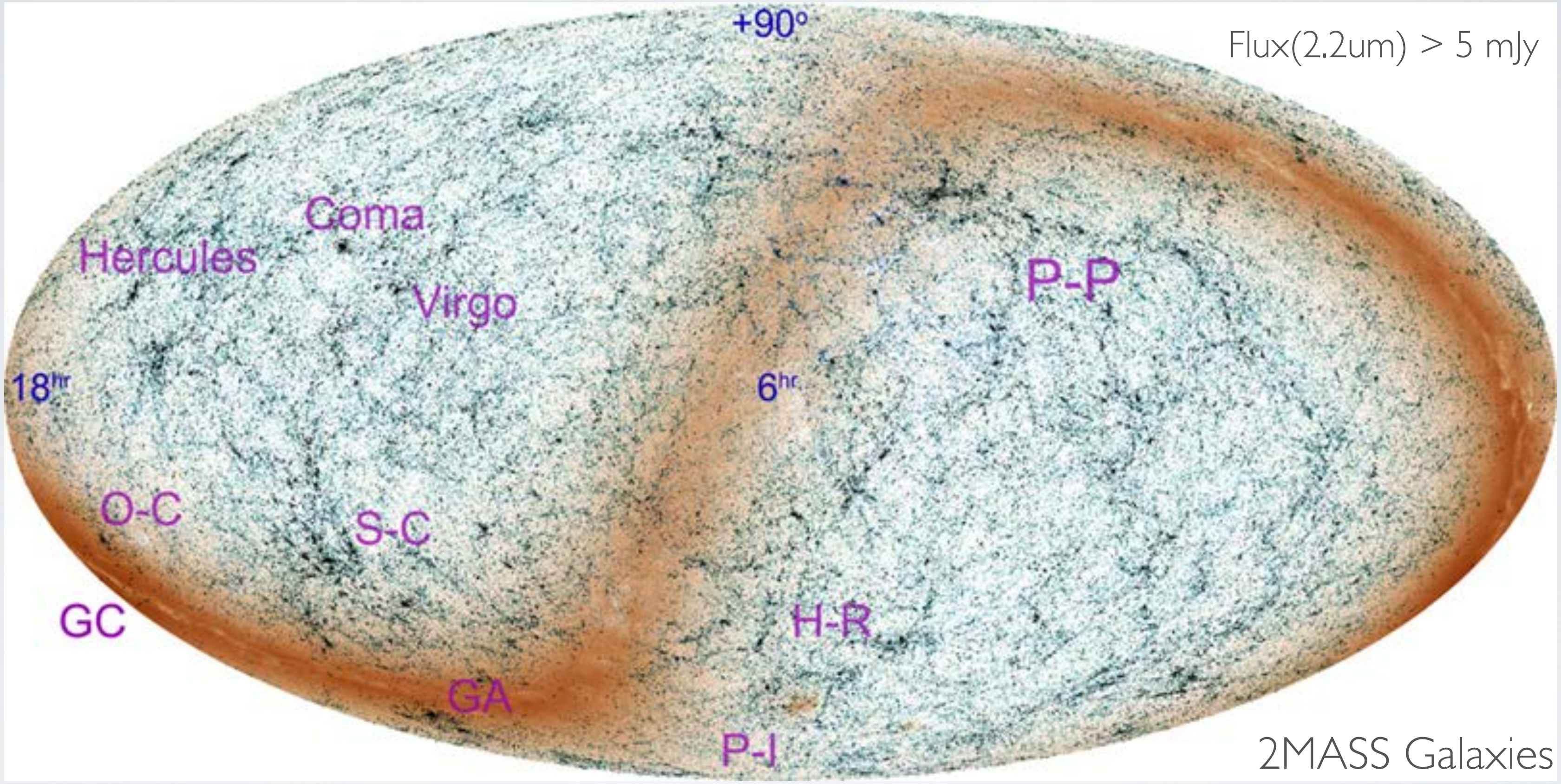


The peaks and troughs in the power spectra reflect their origin in oscillating sound waves. These features tell us that the Universe once contained a very hot, dense plasma, with the CMB anisotropies mostly originating from acoustic modes in the coupled photon-baryon fluid, driven by dark matter potential perturbations

Cold Dark Matter density

$$\Omega_c h^2 = 0.1198 \pm 0.0015$$

The Infrared Sky



Dark Matter as key ingredient to explain the large-scale structure of the universe

Large-Scale Structure
Galaxy Power Spectra

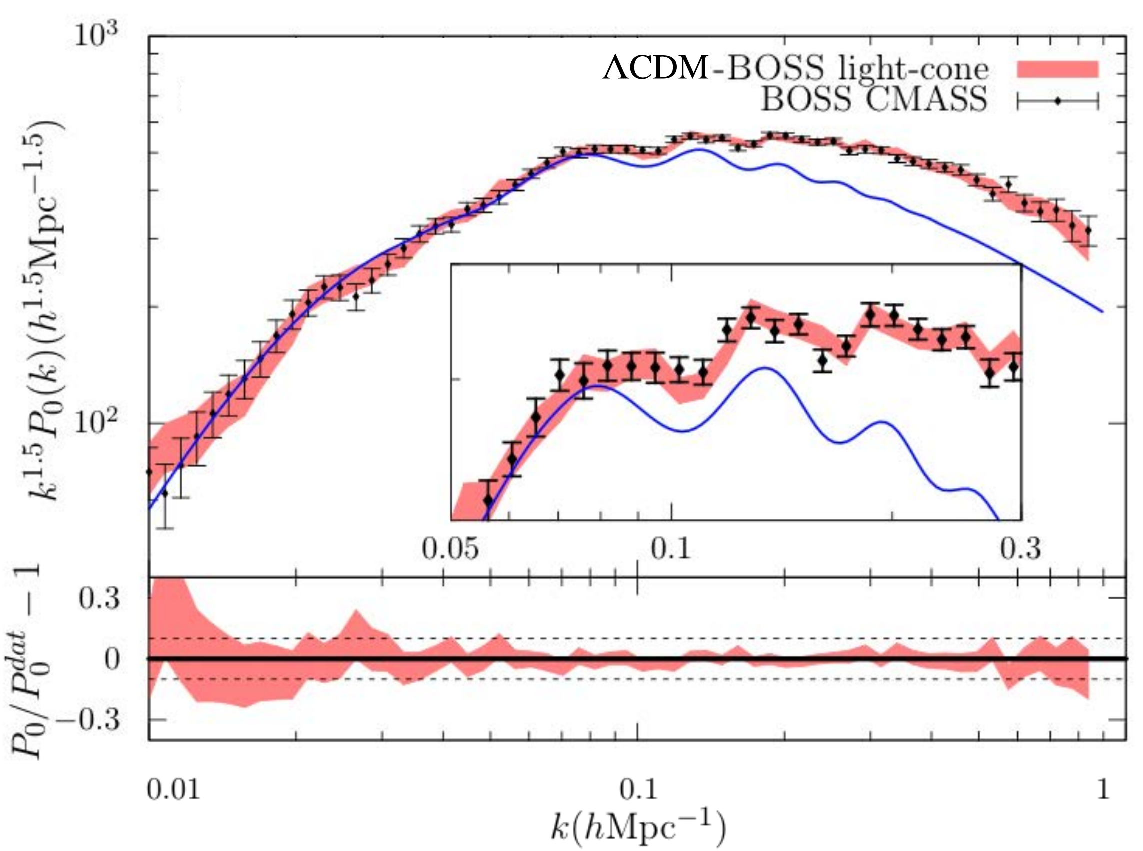
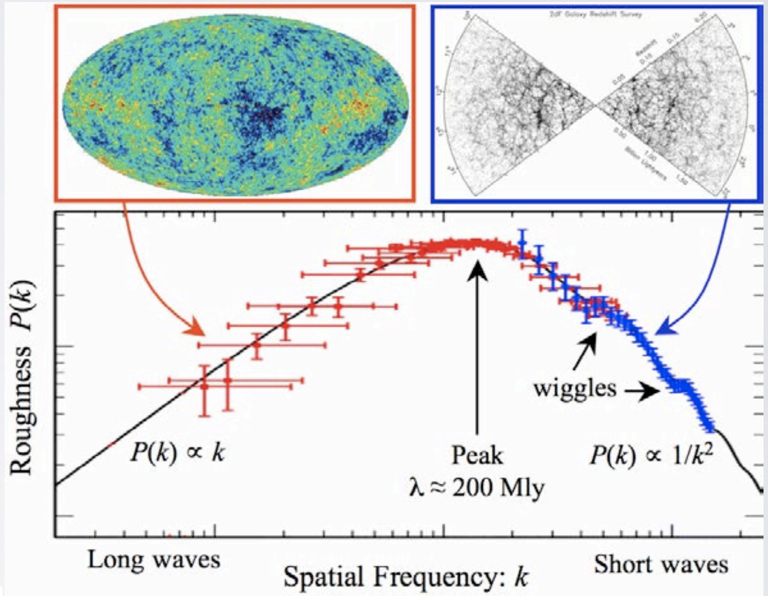


Figure 11. Monopole of power spectrum from the ΛCDM -BOSS light-cone and the CMASS DR12 sample. 7



$$k_{\mathrm{max}} \sim k_{\mathrm{eq}} = 0.104\,\omega_{\mathrm{m}}\,h\mathrm{Mpc}^{-1}$$

$$\omega_{\mathrm{m}} \equiv \Omega_{\mathrm{m}} h^2$$

e.g. Prada et al. 2011

Rodríguez-Tores, Chuang, Prada et al. 2016

SDSS III

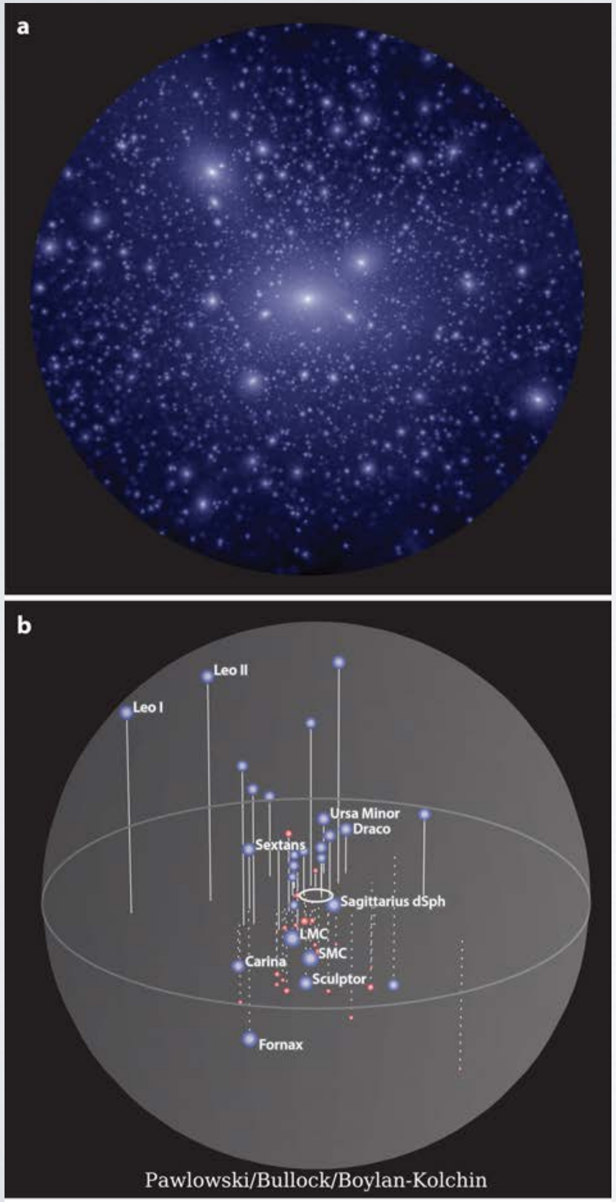
https://www.youtube.com/watch?v=nI3dvYcydCg

Small-Scale Structure

Hierarchical Galaxy Formation

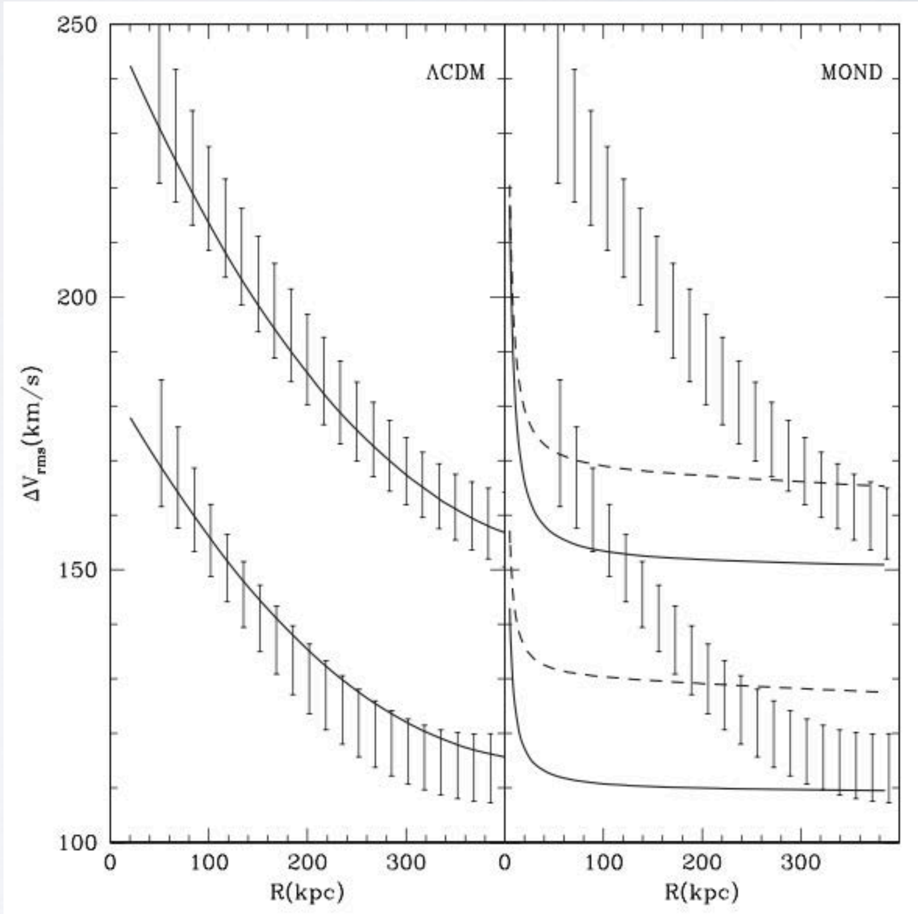
"Missing satellite problem"

Klypin, Kravtsov,Valenzuela & Prada 1999; Moore et al. 1999



Bullock JS, Boylan-Kolchin M. 2017.
Annu. Rev. Astron. Astrophys. 55:343–87

Testing gravity with motion of satellites around galaxies



Klypin & Prada 2009

"Dark Matter in the Sky"

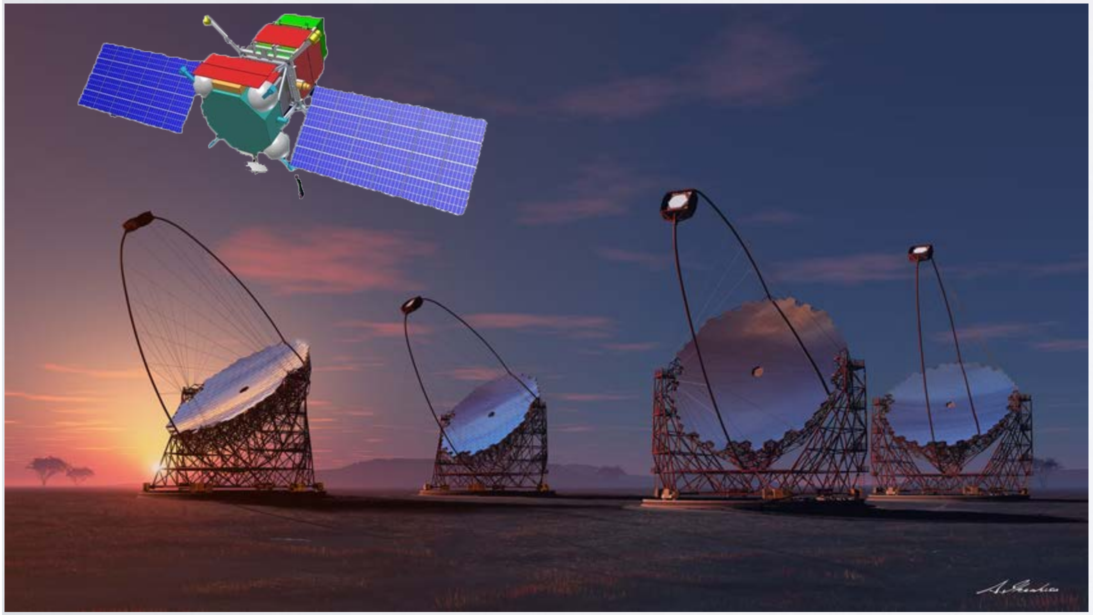
Future Prospects

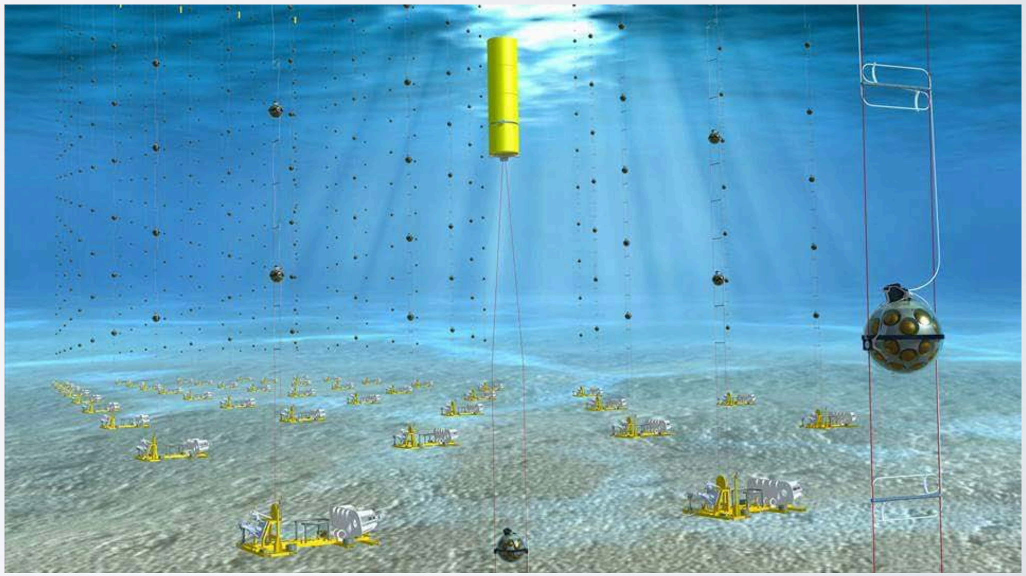
1. Satellite abundance, substructures and tidal disruption
2. Rotation curves: Low-density cores vs. high-density cusps
3. CMB spectral distortions
4. High-Energy observations

- High-Energy observations:

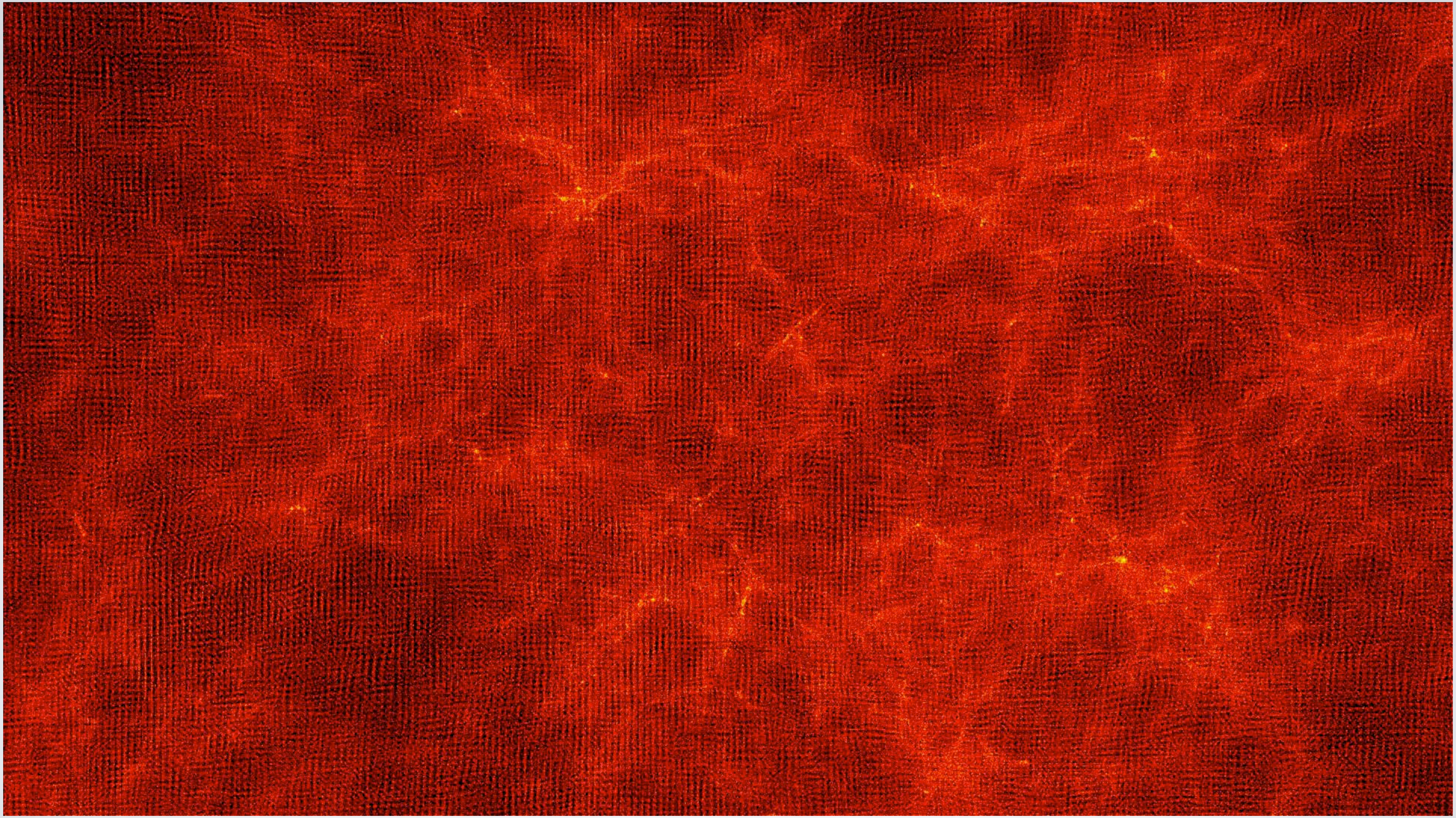
gamma and cosmic rays (e.g. unID Fermi sources)
diffuse TeV–PeV neutrino flux

{CTA, Fermi, GAMMA-400, Auger, Antares and KM3NeT, IceCube}



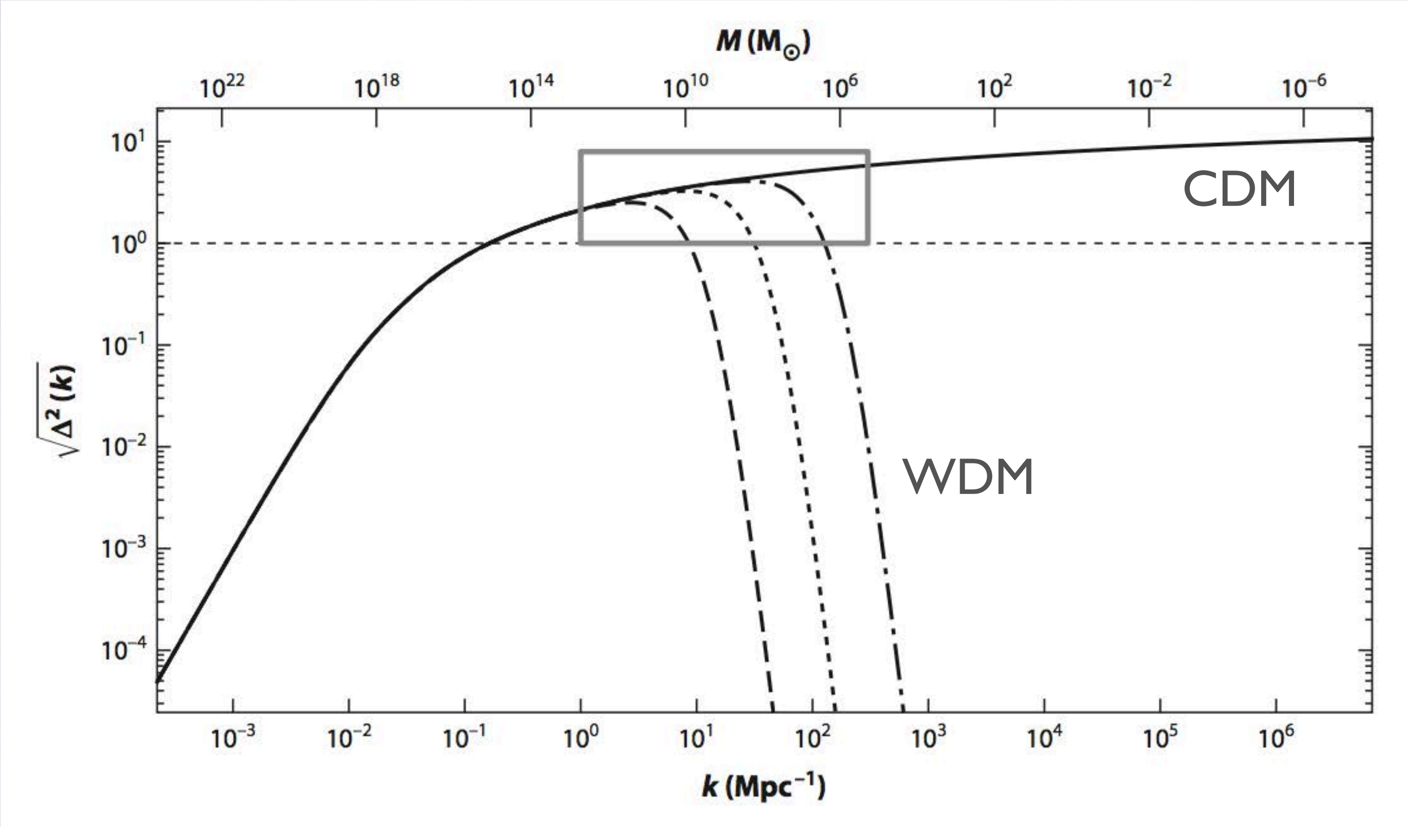


- Satellite abundance, substructures and tidal disruption



Credit: Sergey Pilipenko

Structure formation show a strong drop in the number of subhaloes with masses M < M1, where M1 is the Jeans mass scale associated with the free-streaming length of the DM particle model.

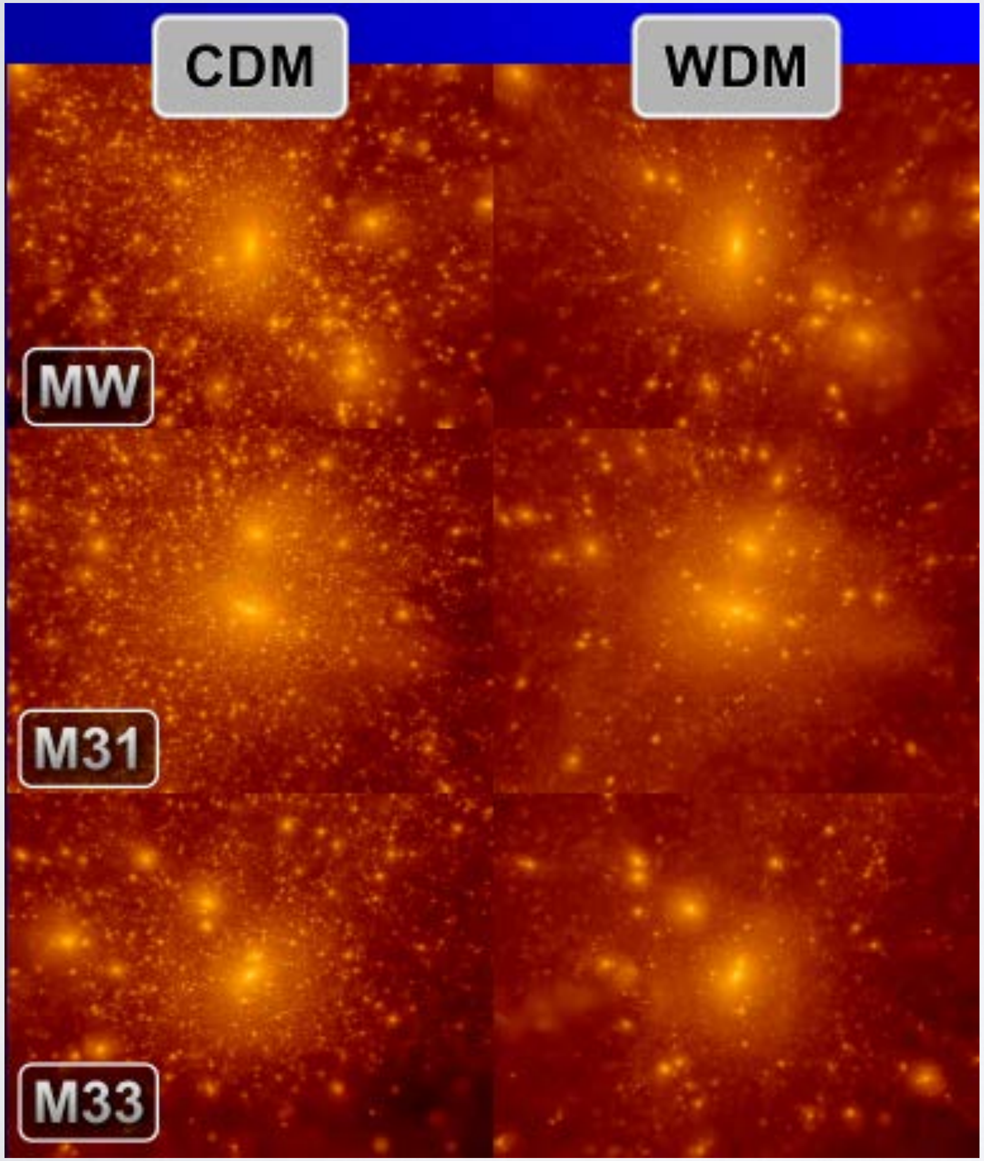


e.g. for CDM haloes made of neutralinos (mCDM ~ 100 GeV) the mass cut-off is expected at M1~10^{-6} M$_\odot$

WDM particles decouple later and have non-negligible thermal velocities, which leads to a lower cut-off (mWDM ≥ 3.3 keV), finding a lower mass cut-off at M1~3×10^{8} M$_\odot$

- Satellite abundance, substructures and tidal disruption

(1) Abundance of satellite dwarfs in the Milky Way ("Missing satellite Problem")



Credit: AIP

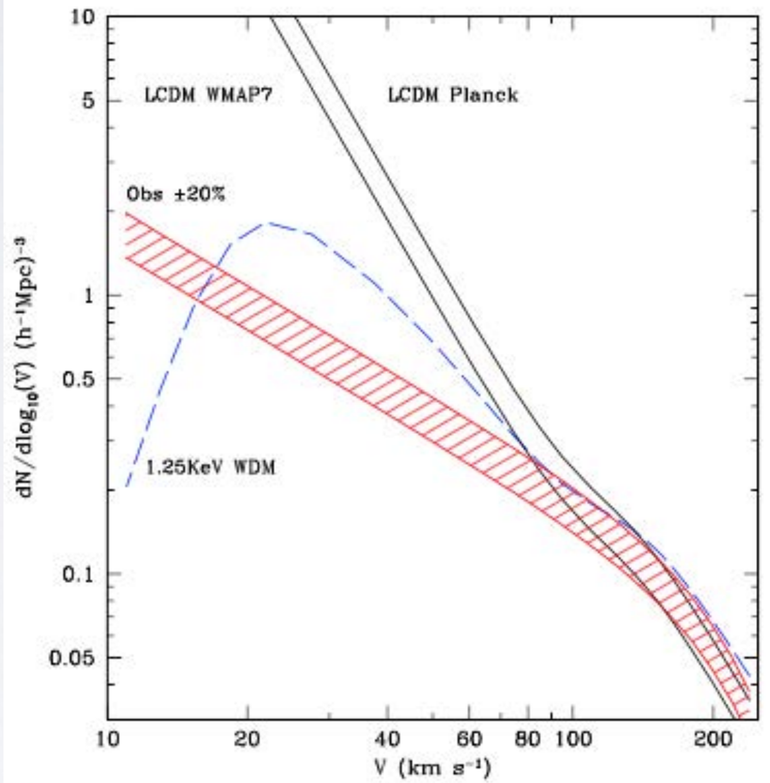
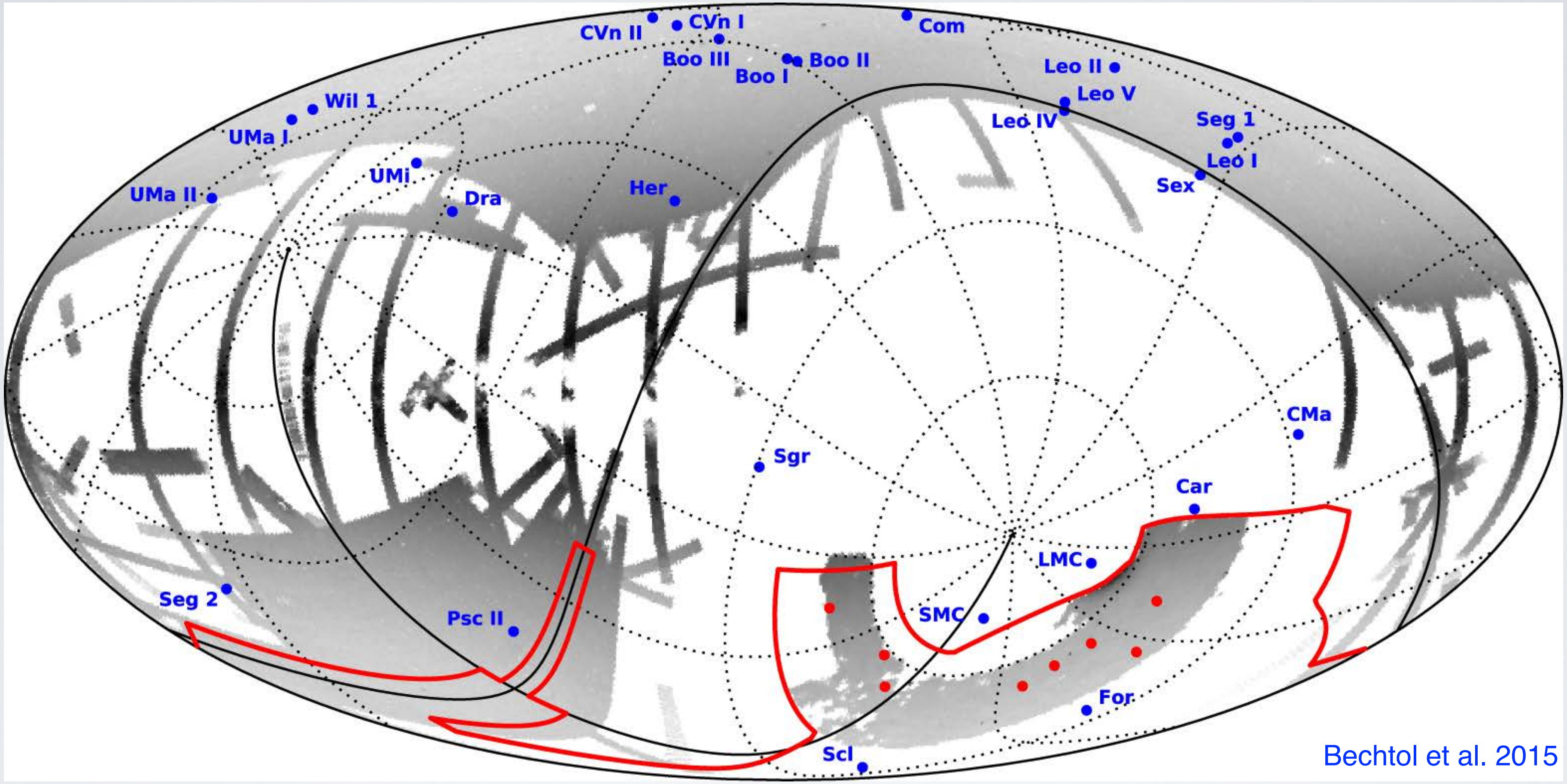
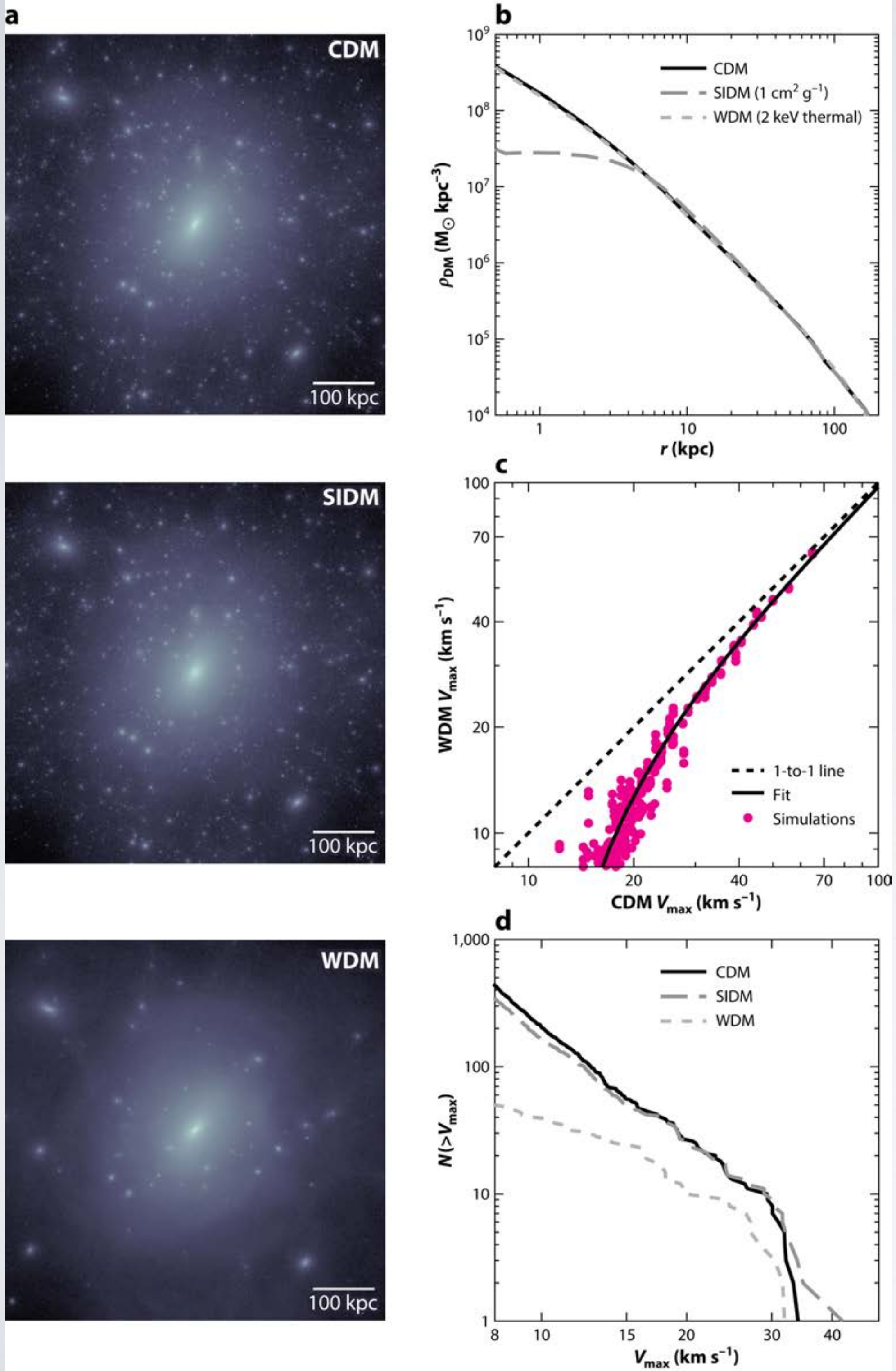


Figure 13. Comparison of the observed and theoretical estimates of the circular VF of galaxies. The shaded area shows the region of the observed VF – a strip of ±20 per cent around the reconstructed VF in the Local Volume as given by equation (12). The solid curves show the ΛCDM model predictions. The dashed curve shows the best prediction for the WDM model with thermal neutrino mass of $m_{\rm dwm} = 1.35$ keV. Both theoretical models have severe problems. The WDM model predicts a wrong shape for the VF; it fails by a factor of 2–3 at small velocities while still overpredicting the abundance of 30 km s^{-1} galaxies. The ΛCDM-*Planck* model overpredicts the abundance of dwarf galaxies with $V \lesssim 60$ km s^{-1}.

Klypin et al. 2015

EIGHT NEW MILKY WAY COMPANIONS DISCOVERED IN FIRST-YEAR DARK ENERGY SURVEY DATA

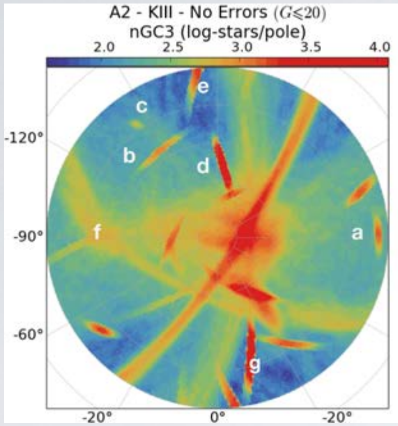




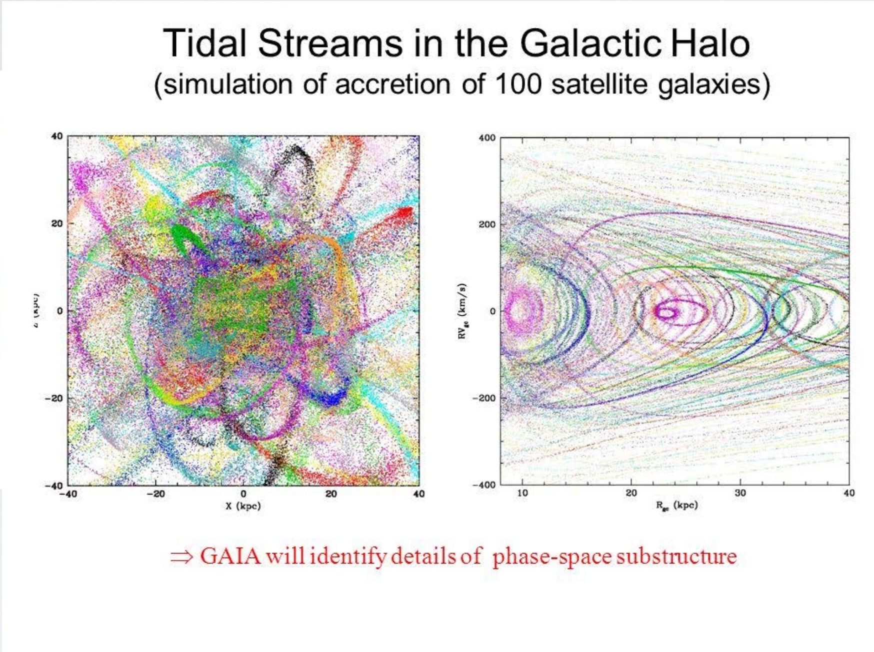
Bullock JS, Boylan-Kolchin M. 2017.
Annu. Rev. Astron. Astrophys. 55:343–87

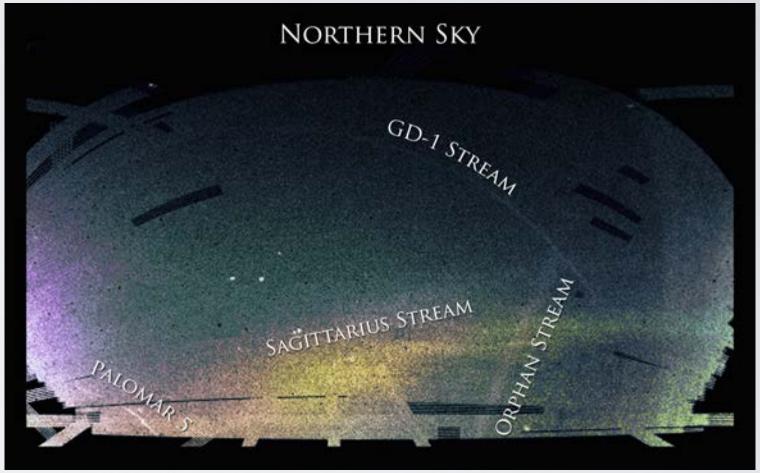
Nature of Dark Matter in the Milky Way

Predictions for the detection of tidal streams with Gaia



Mateu et al. 2017

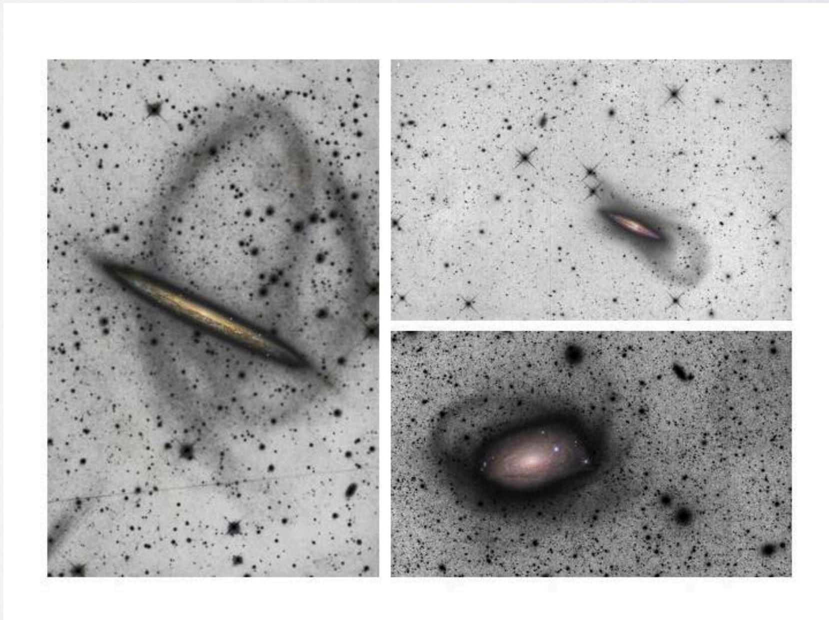




Credit: SDSS

Observed tidal streams in galaxies

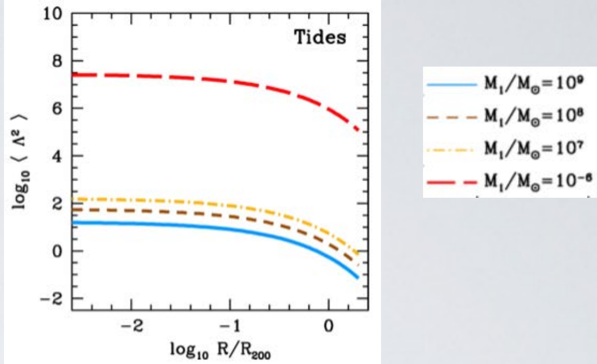
Credit: David Martínez-Delgado



(III) Fluctuations of the gravitational field generated by a random population of substructure microhalos

"The fluctuations of the *tidal* field are completely dominated by the smallest and most abundant subhaloes. Observational experiments may be sufficiently sensitive to Galactic tidal fluctuations to probe the 'dark' low end of the subhalo mass function and constrain the particle mass of warm and ultralight axion dark matter models."

Peñarrubia 2018



Observational tests with wide binaries: wide stellar binaries can be easily disrupted by the tidal field of the host galaxy, e. g.

For $M = 10^{-6}$ M$_\odot$, the binary separation at which one may expect to observe tidal perturbations varies from ≃0.6 pc (at the Galactic center) up to ≃1 pc (at the virial radius).

(IV) Detection of Earth-size dark matter clumps in our *"Da Hood"* vía Pulsar Time Array observations or evidences of gravitational perturbations

e.g.

Kashiyama & Oguri 2018
Sánchez-Conde, Prada et al. 2018, in prep

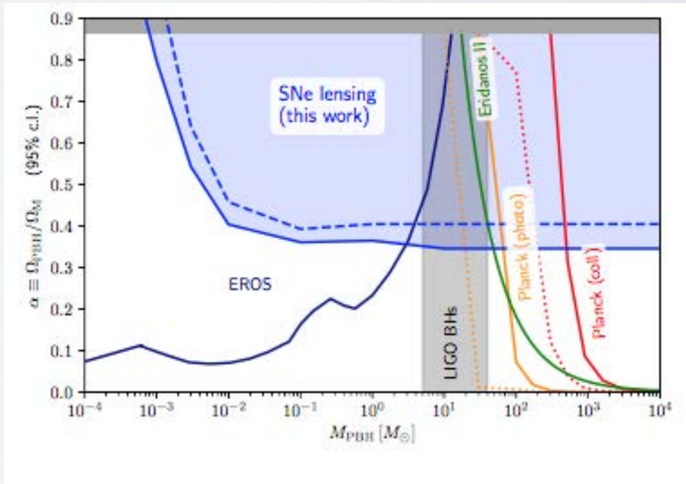
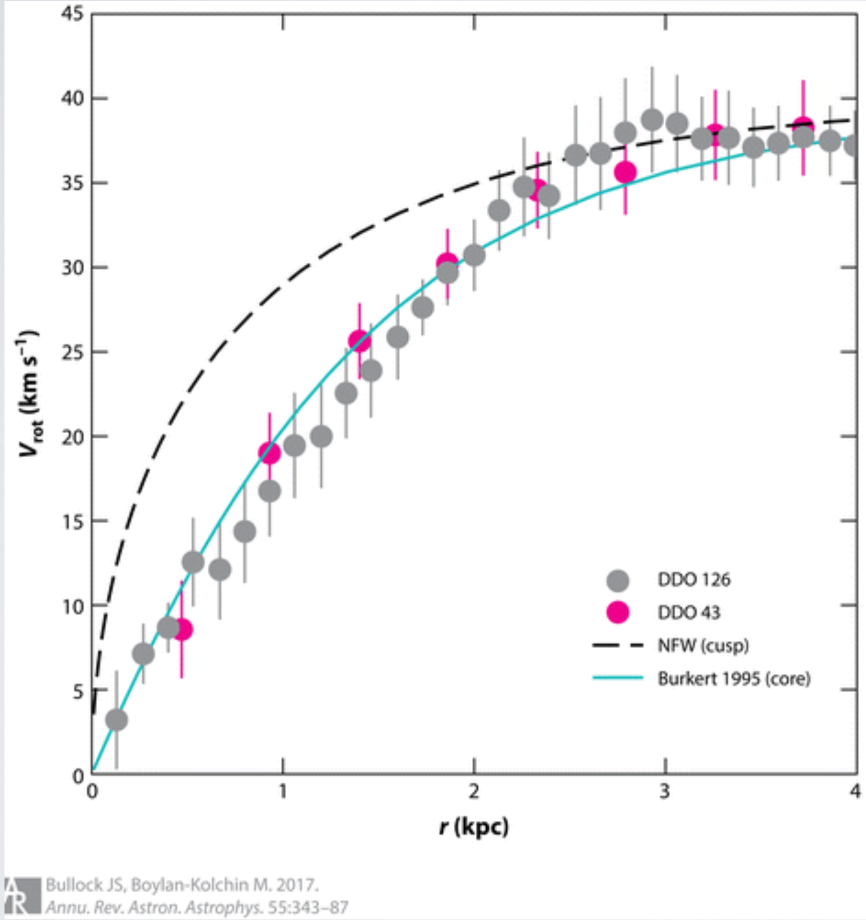


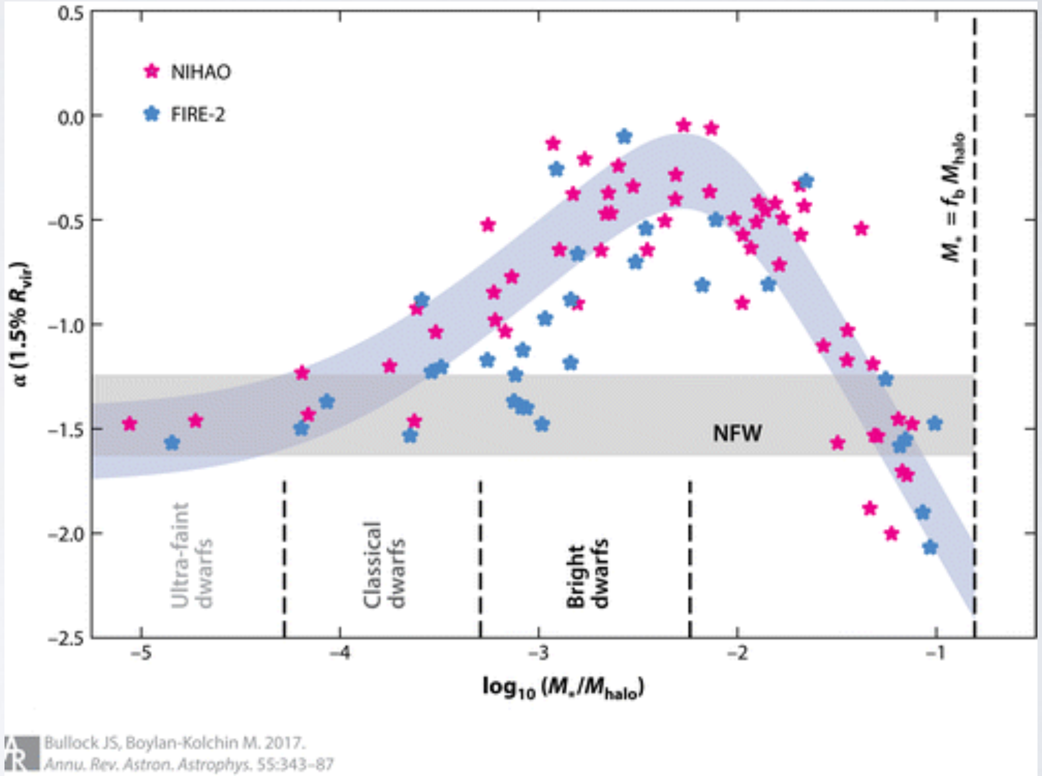
FIG. 1: Bounds on the abundance of PBHs as a function of the mass (95 % confidence level). The analysis of SNe lensing using the JLA (solid) and Union 2.1 compilations (dashed) constrain the PBH fraction in the range $M \gtrsim 0.01 M_\odot$.

Zumalacárregui & Seljak 2017

- Rotation curves: Low-density cores vs. high-density cusps



The cusp-core problem

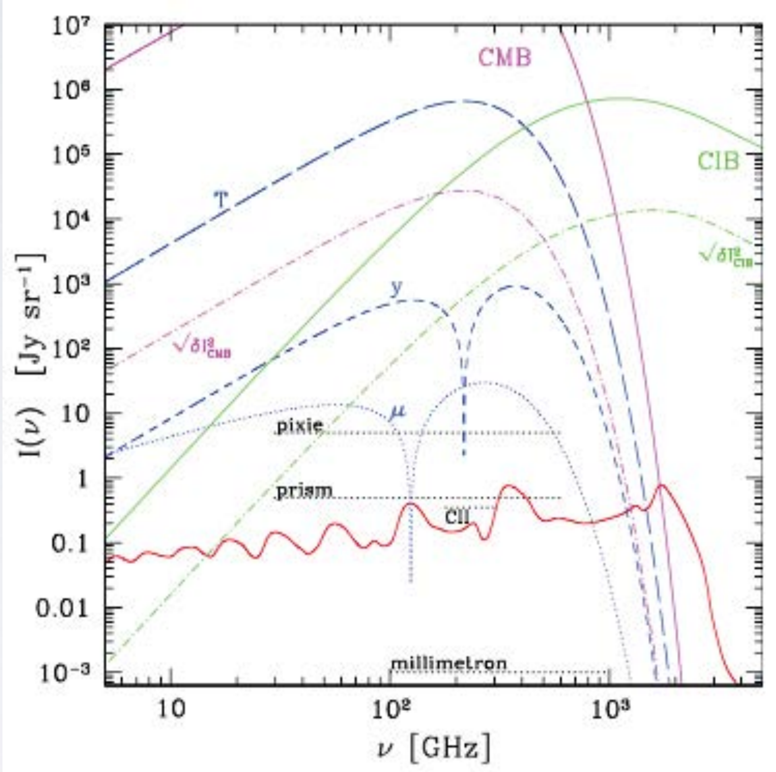


The impact of baryonic feedback on the inner profiles of dark matter halos

• CMB spectral distortions

Using CMB spectral distortions to distinguish between dark matter candidates

The dissipation of small-scale perturbations in the early universe produces a distortion ("**μ**-type" and "**y**-type") in the blackbody spectrum of cosmic microwave background photons.



Desjacques et al. 2015

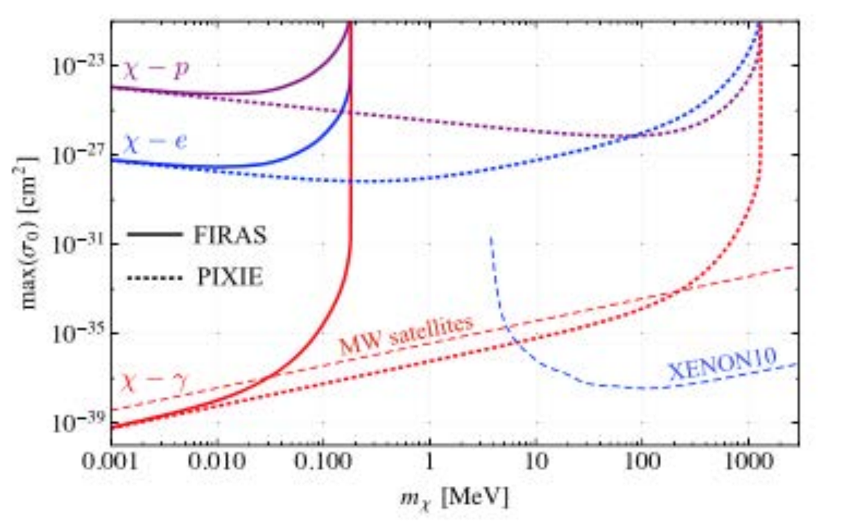


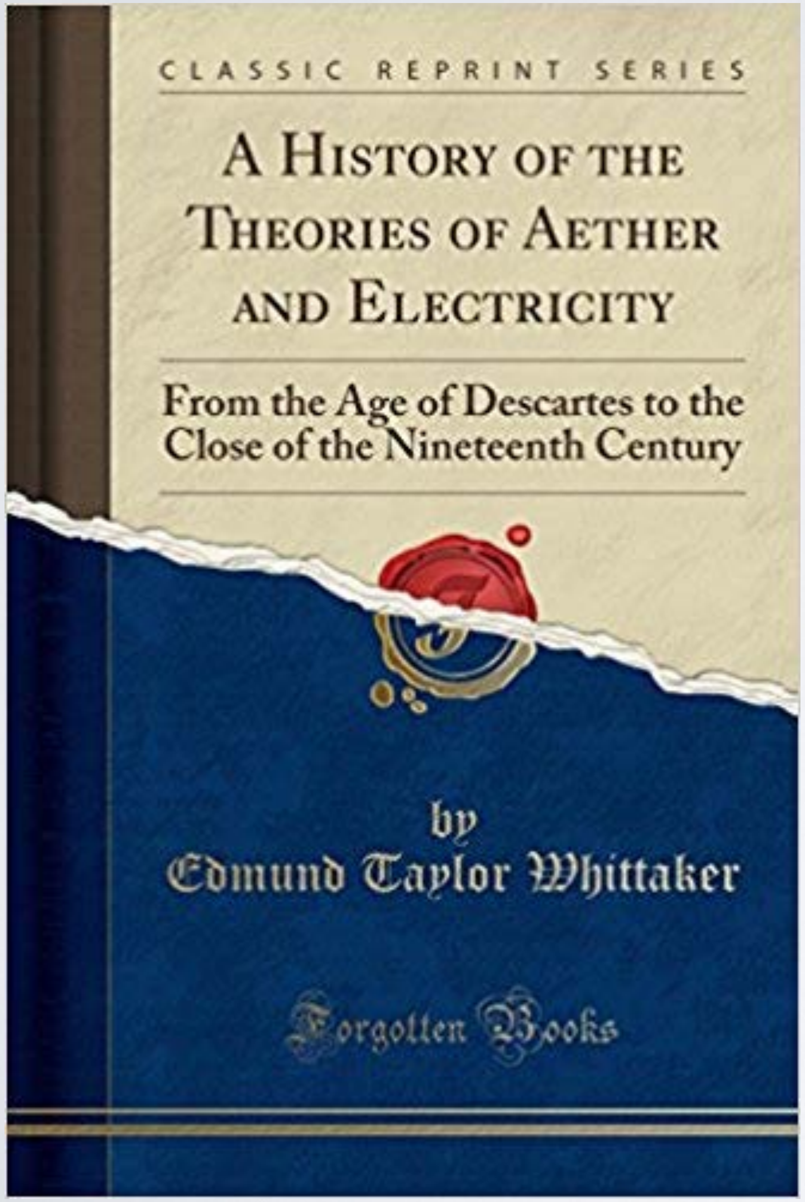
FIG. 2 (color online). Current upper bounds from FIRAS (solid) and forecasted detection thresholds from PIXIE (dotted) on the energy-independent DM-proton (purple), DM-electron (blue), and DM-photon (red) cross sections σ_0, as a function of the DM mass. Masses $m_\chi \geq 0.18$ MeV are unconstrained by FIRAS as the distortion can never reach $\Delta\rho_\gamma/\rho_\gamma = 5 \times 10^{-5}$, even for infinitely large cross section. PIXIE will extend the domain of constrainable masses by 4 orders of magnitude, up to $m_\chi \approx 1.3$ GeV. For comparison, we also show the constraints on DM-electron scattering from XENON10 data [6] and the limits on DM-photon scattering from Milky Way satellite counts [29]. No other probe currently constrains DM-proton scattering in the range of masses shown.

Ali-Haïmoud et al. 2015

e. g. Particular models in which the dark matter is kinetically coupled to either neutrinos or photons until shortly before recombination.
PIXIE (and PRISM) are new planned space missions

"Yo creo en la Providencia, que envía las cosas a su tiempo, aunque a nosotros a veces no nos lo parezca"

Vicente Ferrer



¡Gracias!