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# Superconducting DM

arXiv: 1712.10311

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Alexander Vikman

CEICO, Institute of Physics,  
Czech Academy of Sciences



29.05.2018

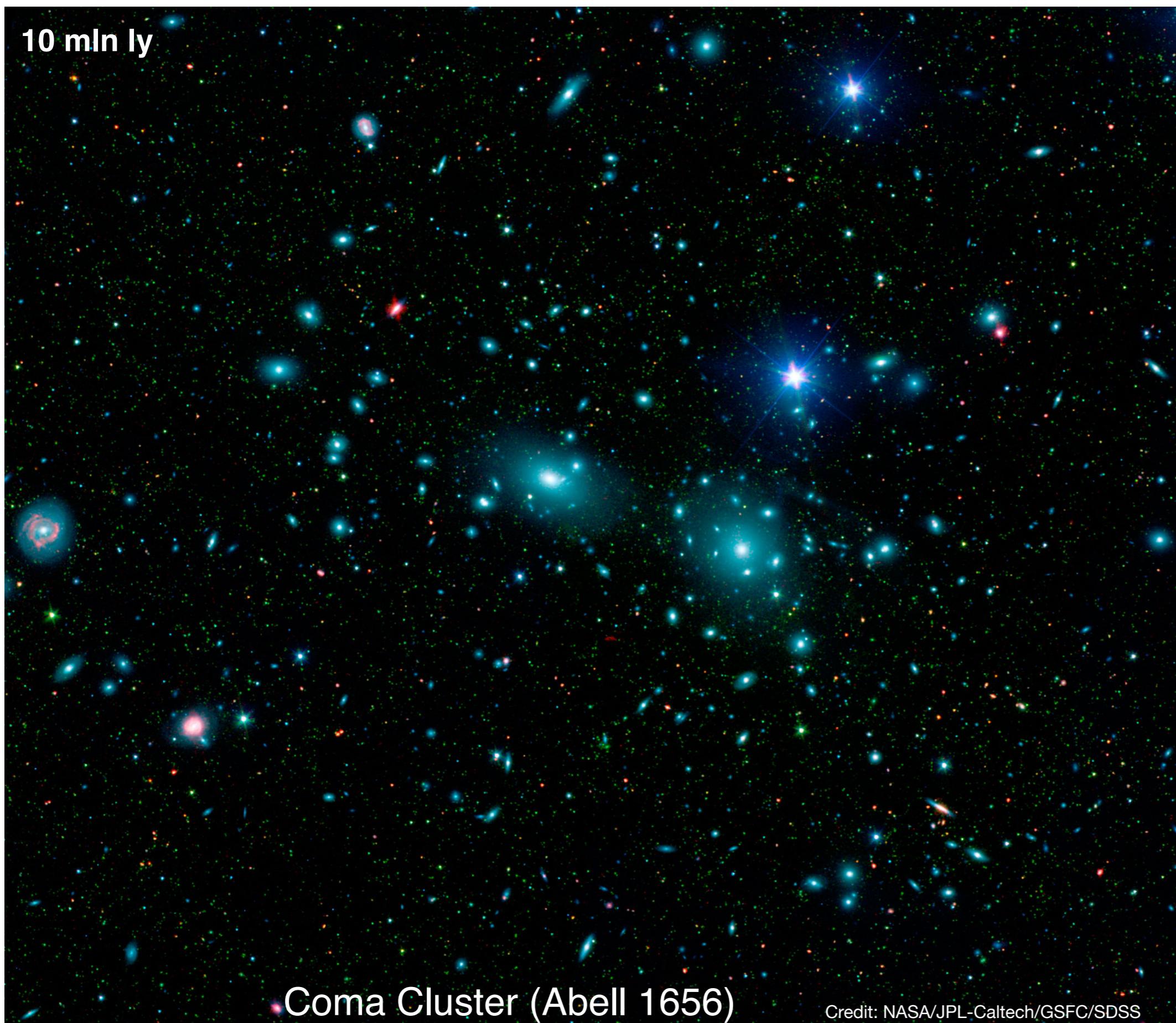


EUROPEAN UNION  
European Structural and Investment Funds  
Operational Programme Research,  
Development and Education



# *Dark Matter on “Small” Scales*

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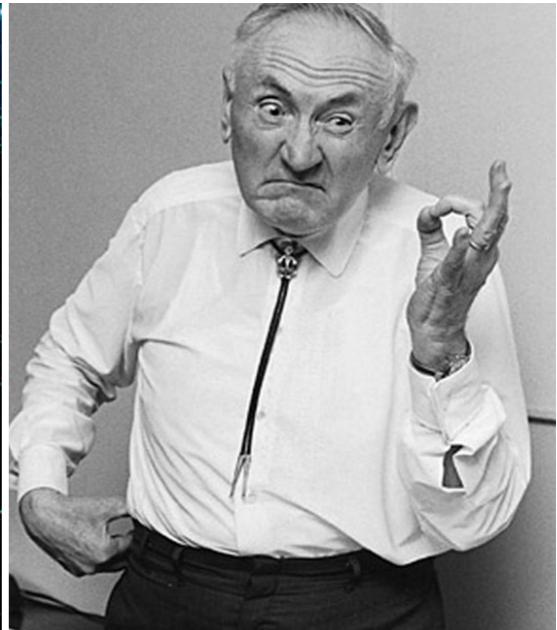
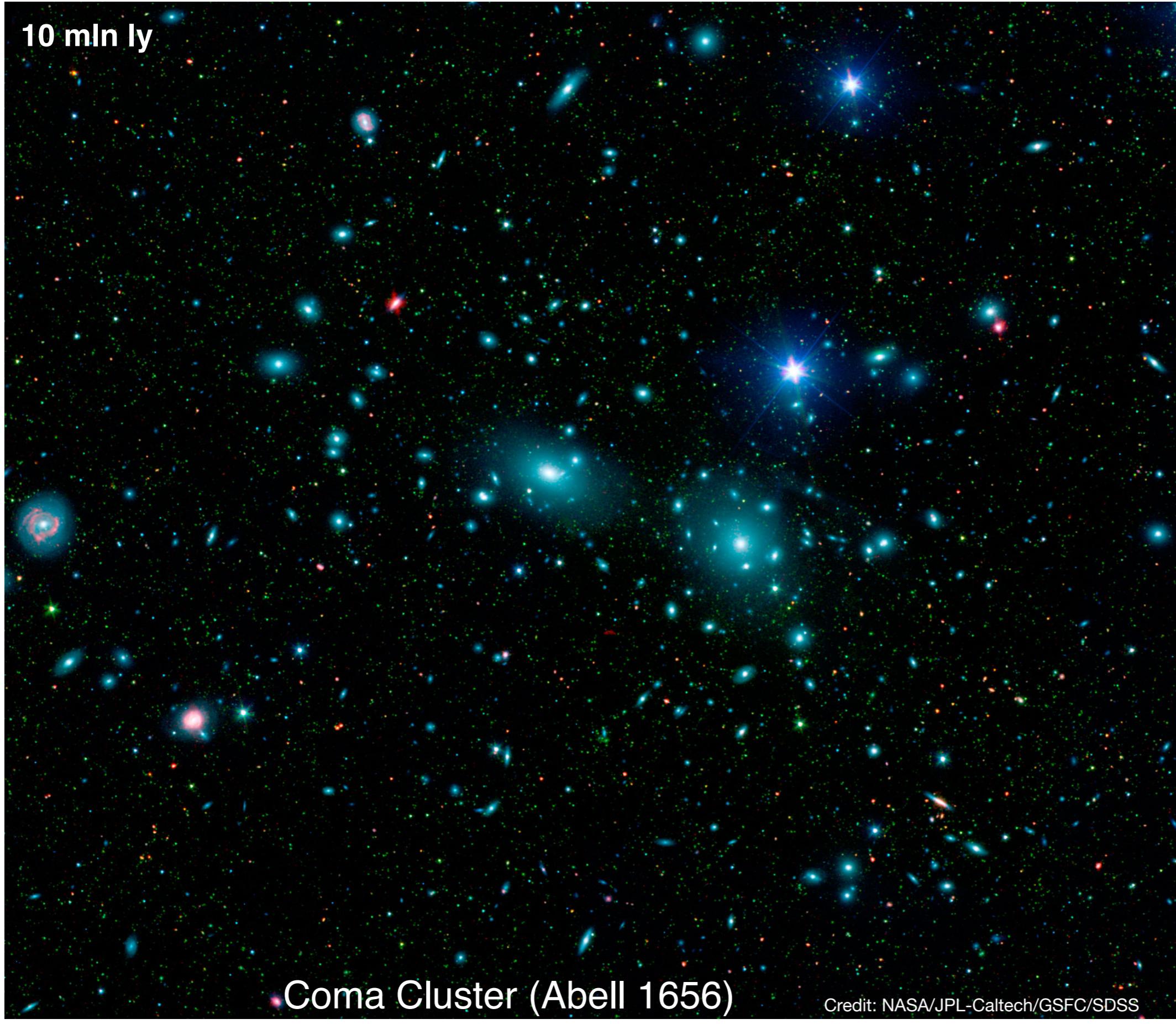


Coma Cluster (Abell 1656)

Credit: NASA/JPL-Caltech/GSFC/SDSS

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10 mln ly



*Fritz Zwicky, 1933*

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Credit: NASA/JPL-Caltech/GSFC/SDSS

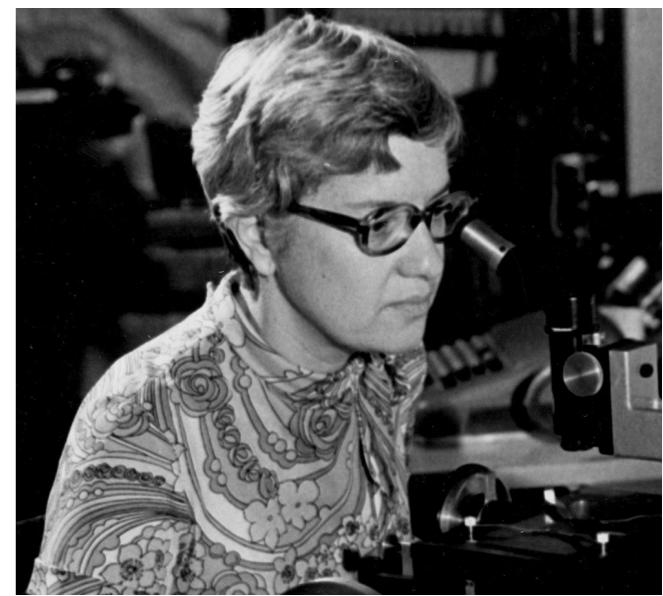
*Dark Matter  
on “Small” Scales*



*Vera Rubin, 1970-80*



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*Vera Rubin, 1970-80*

Andromeda Galaxy (M31)

*Galaxy Evolution Explorer image*



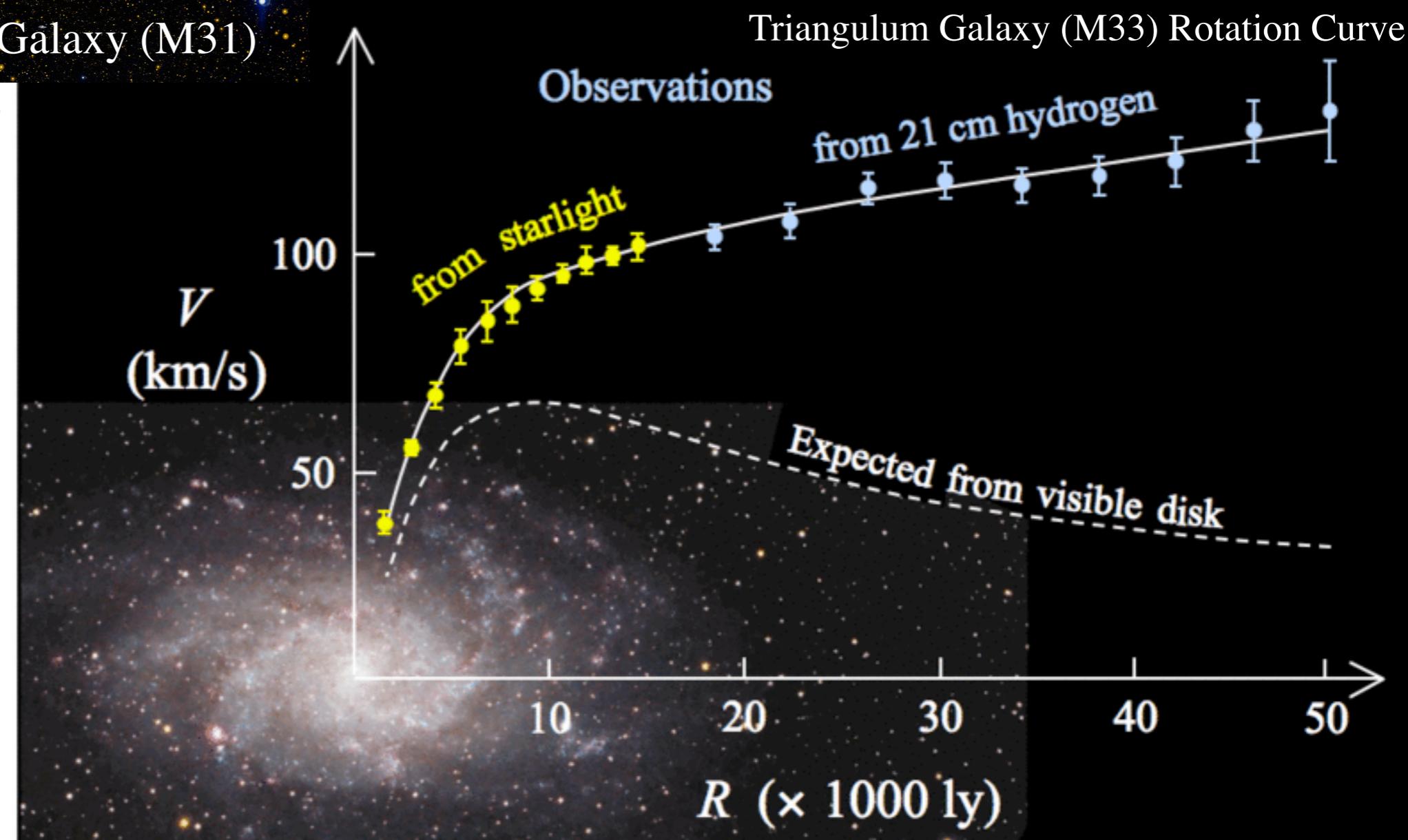
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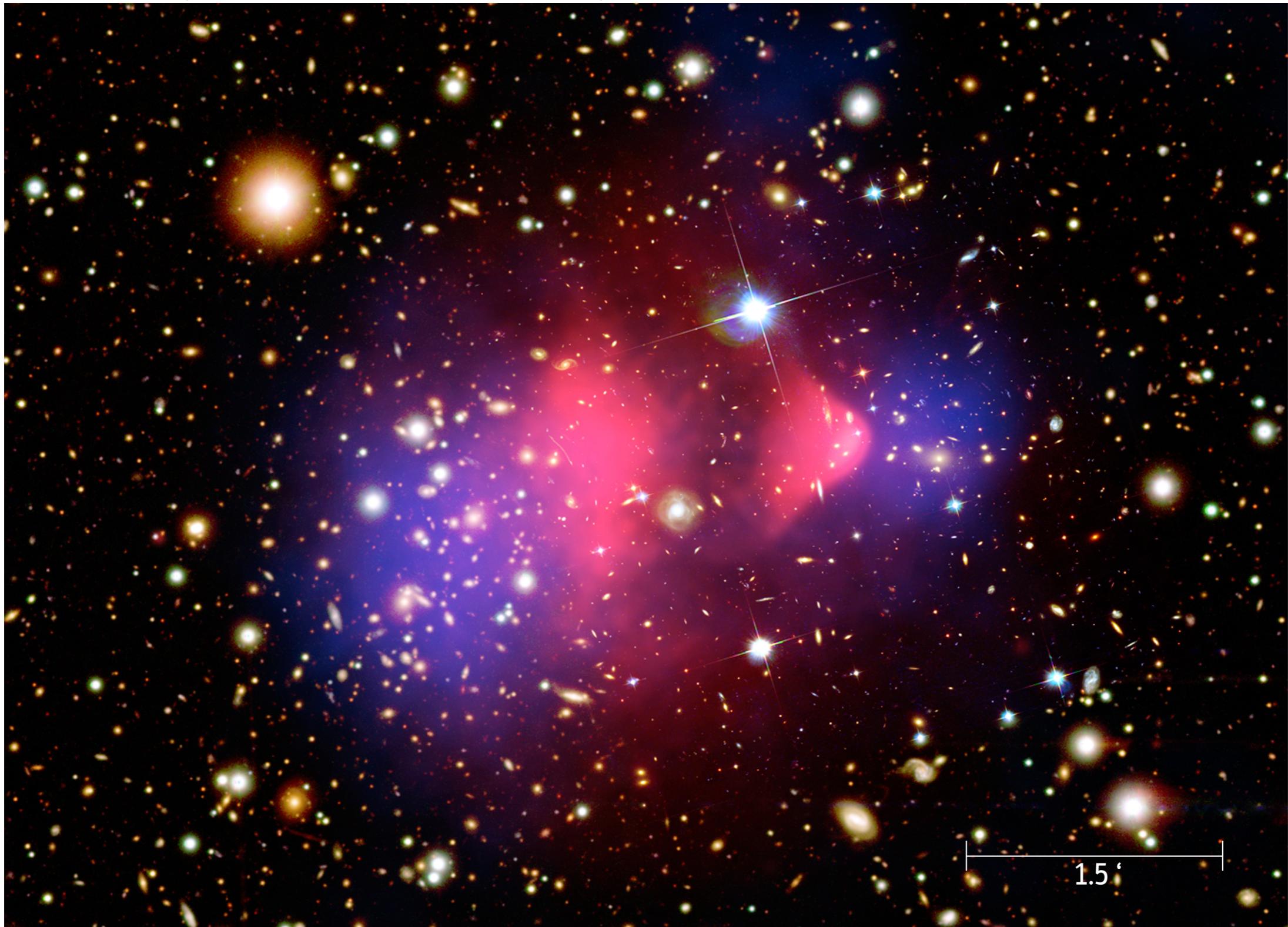
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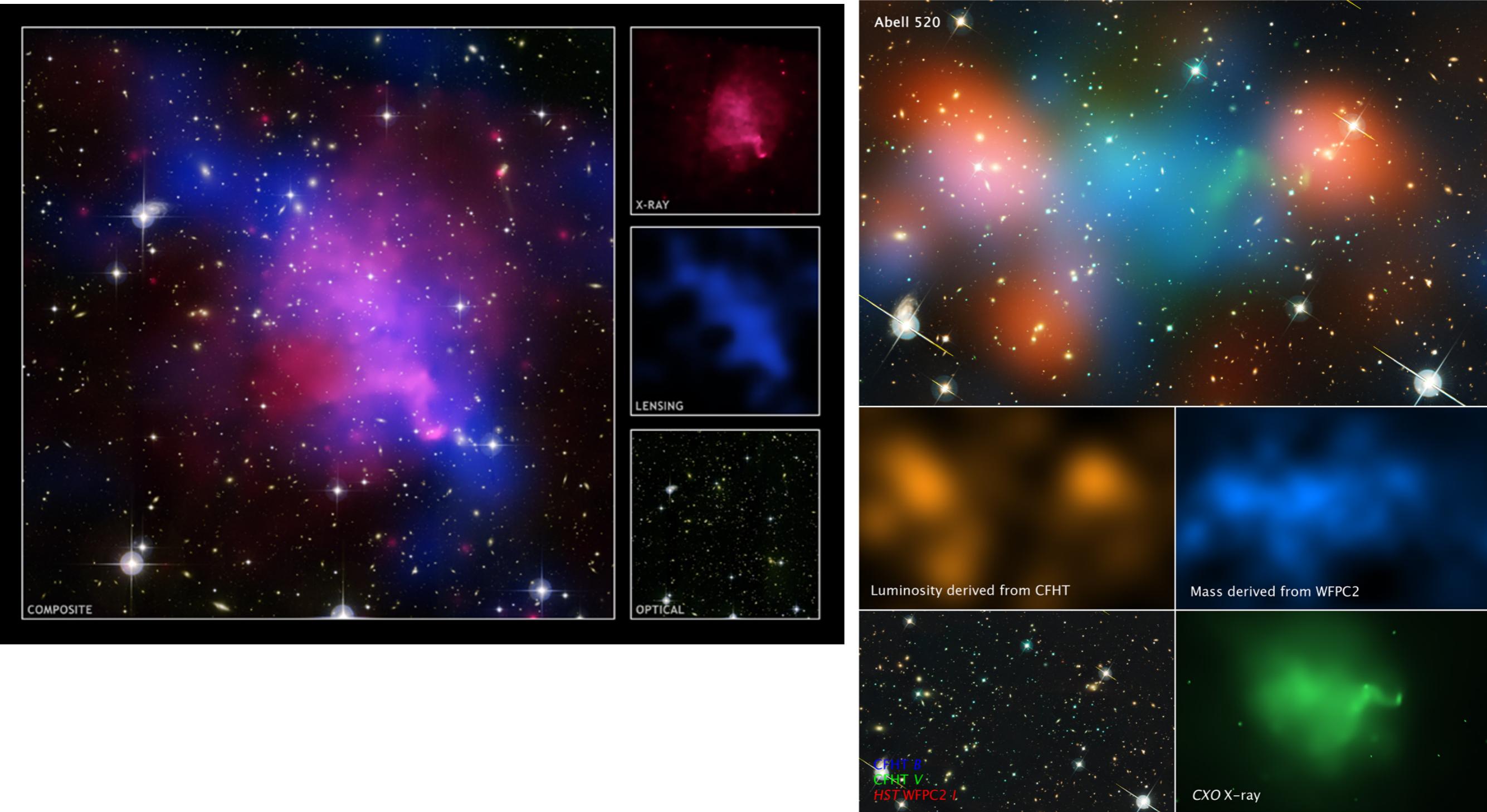
# *Bullet Cluster: Dark Matter passes by “without” interactions*

It is at a comoving radial distance of 1.141 Gpc (3.7 billion light-years)

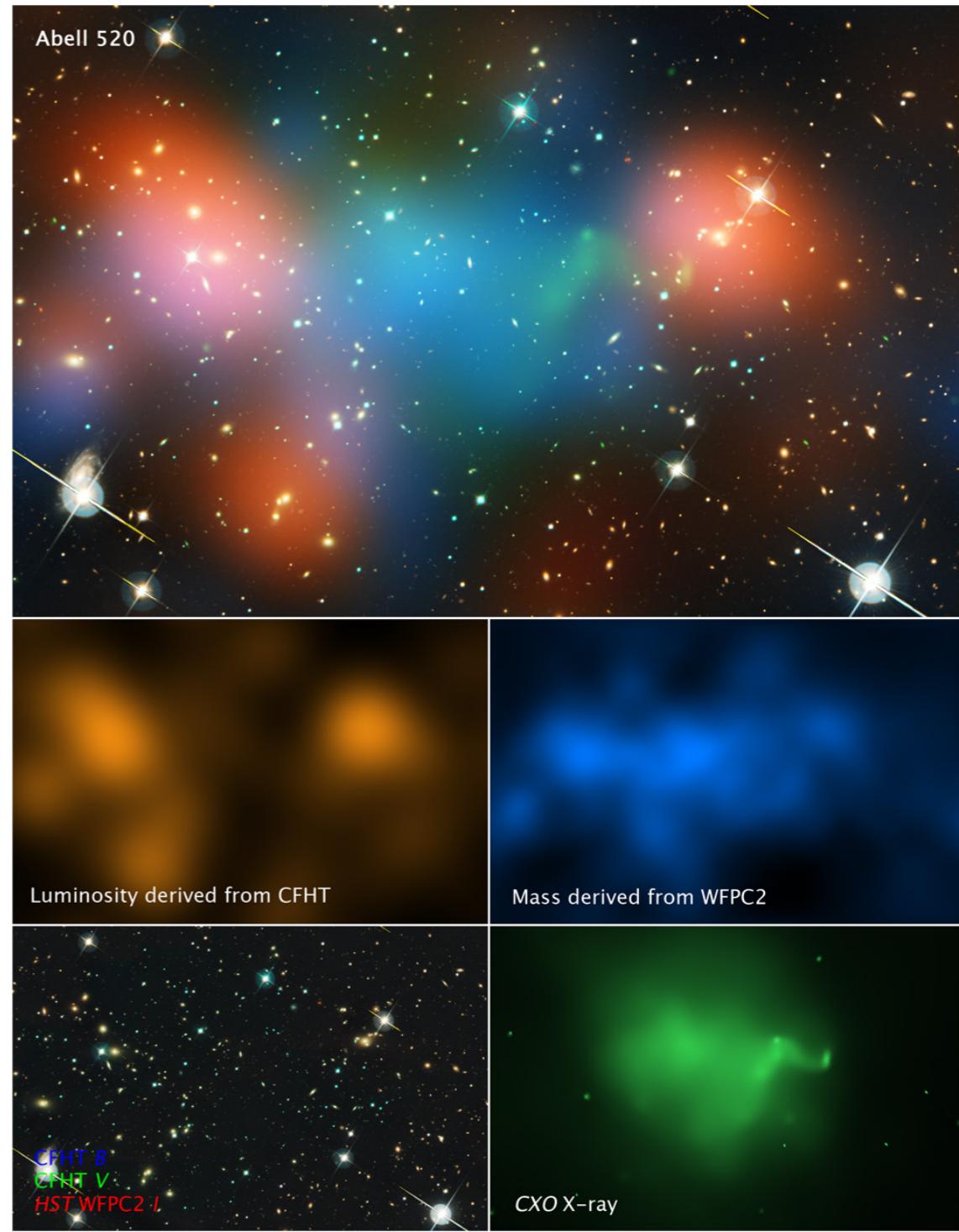
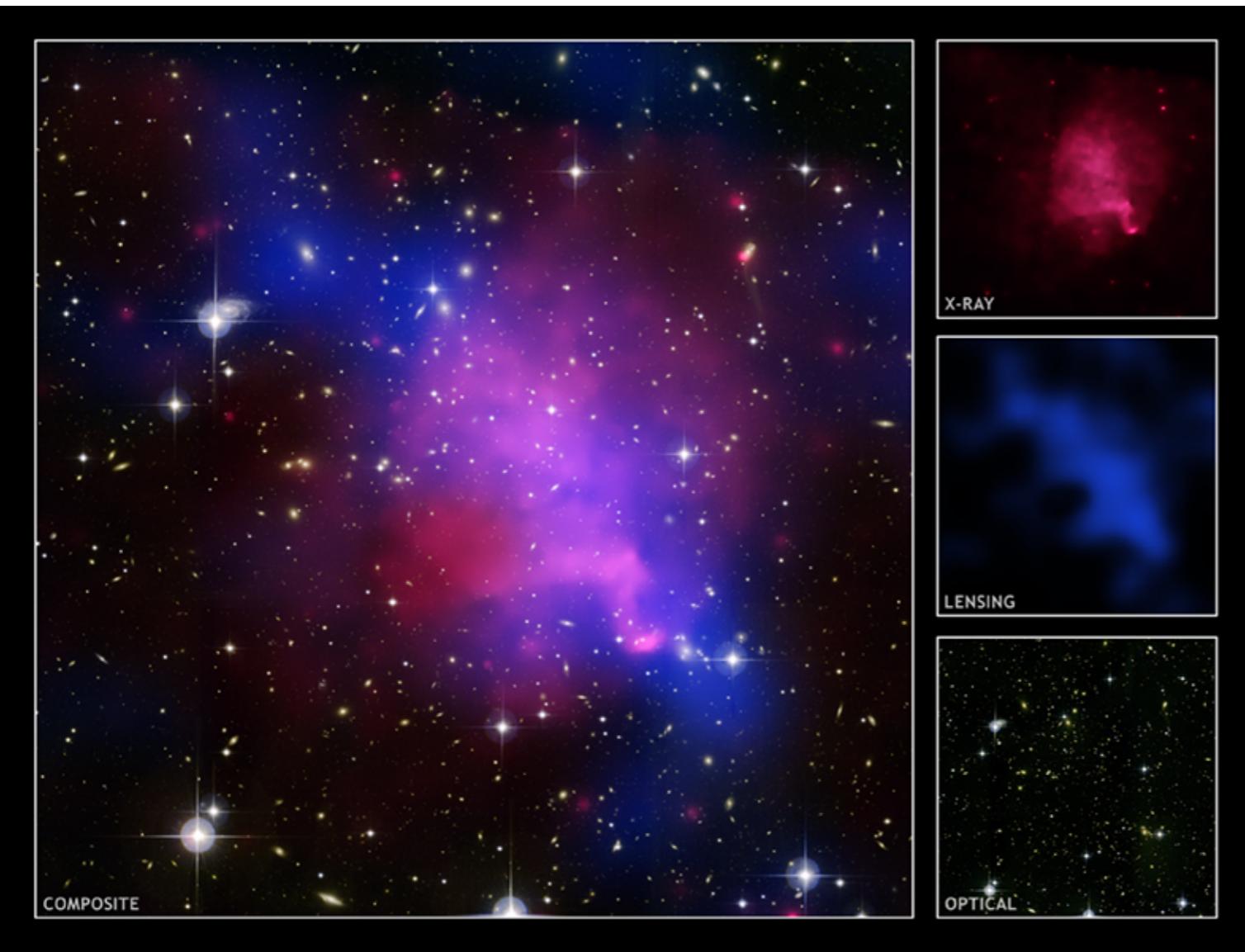
NASA/CXC/M. Weiss - Chandra X-Ray Observatory: 1E 0657-56



# *Abell 520, Train Wreck Cluster*



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## *Dark Core?!*

# But is DM dust-like in Galaxies?

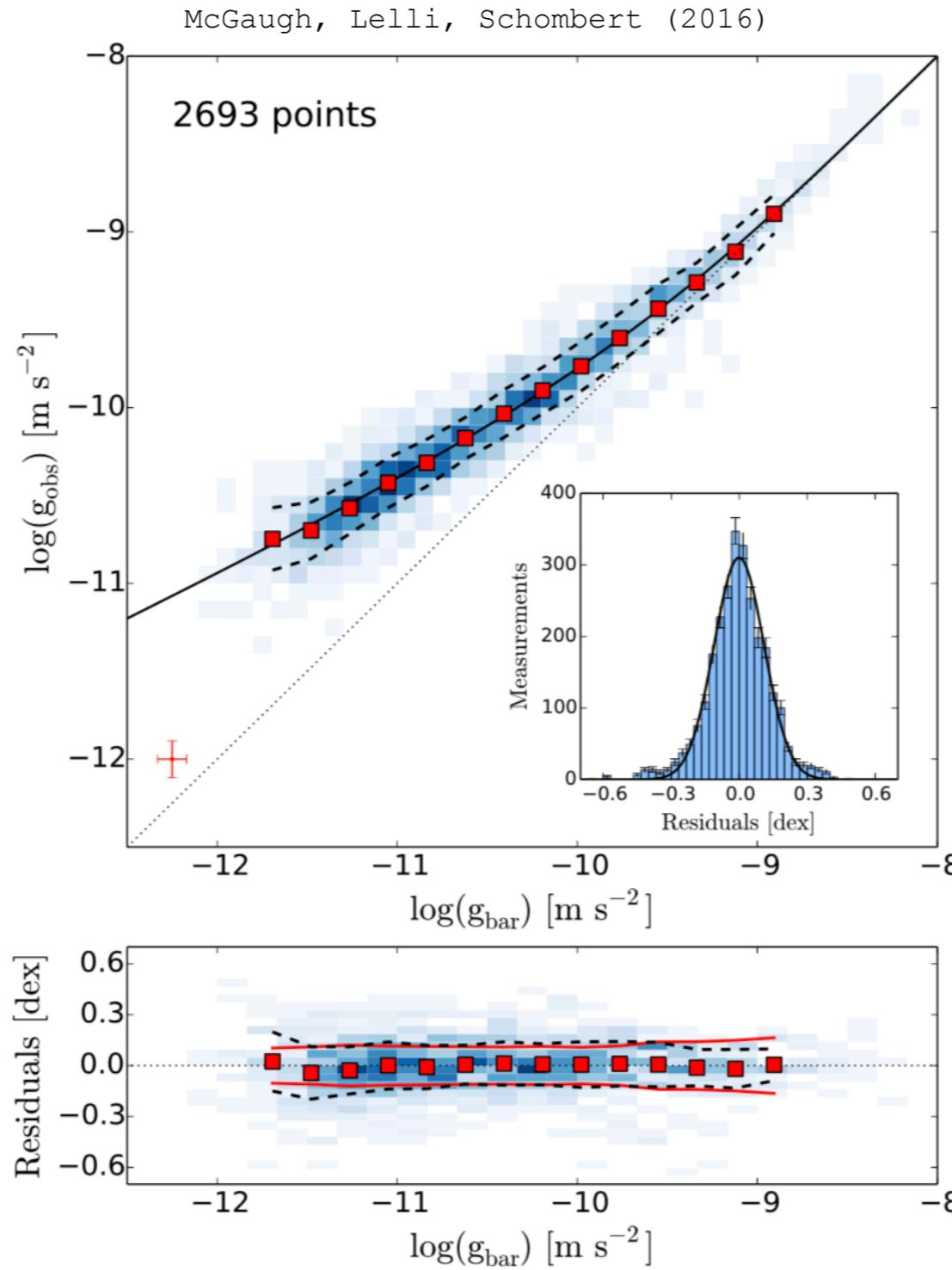


FIG. 3. The centripetal acceleration observed in rotation curves,  $g_{\text{obs}} = V^2/R$ , is plotted against that predicted for the observed distribution of baryons,  $g_{\text{bar}} = |\partial\Phi_{\text{bar}}/\partial R|$  in the upper panel. Nearly 2700 individual data points for 153 SPARC galaxies are shown in grayscale.

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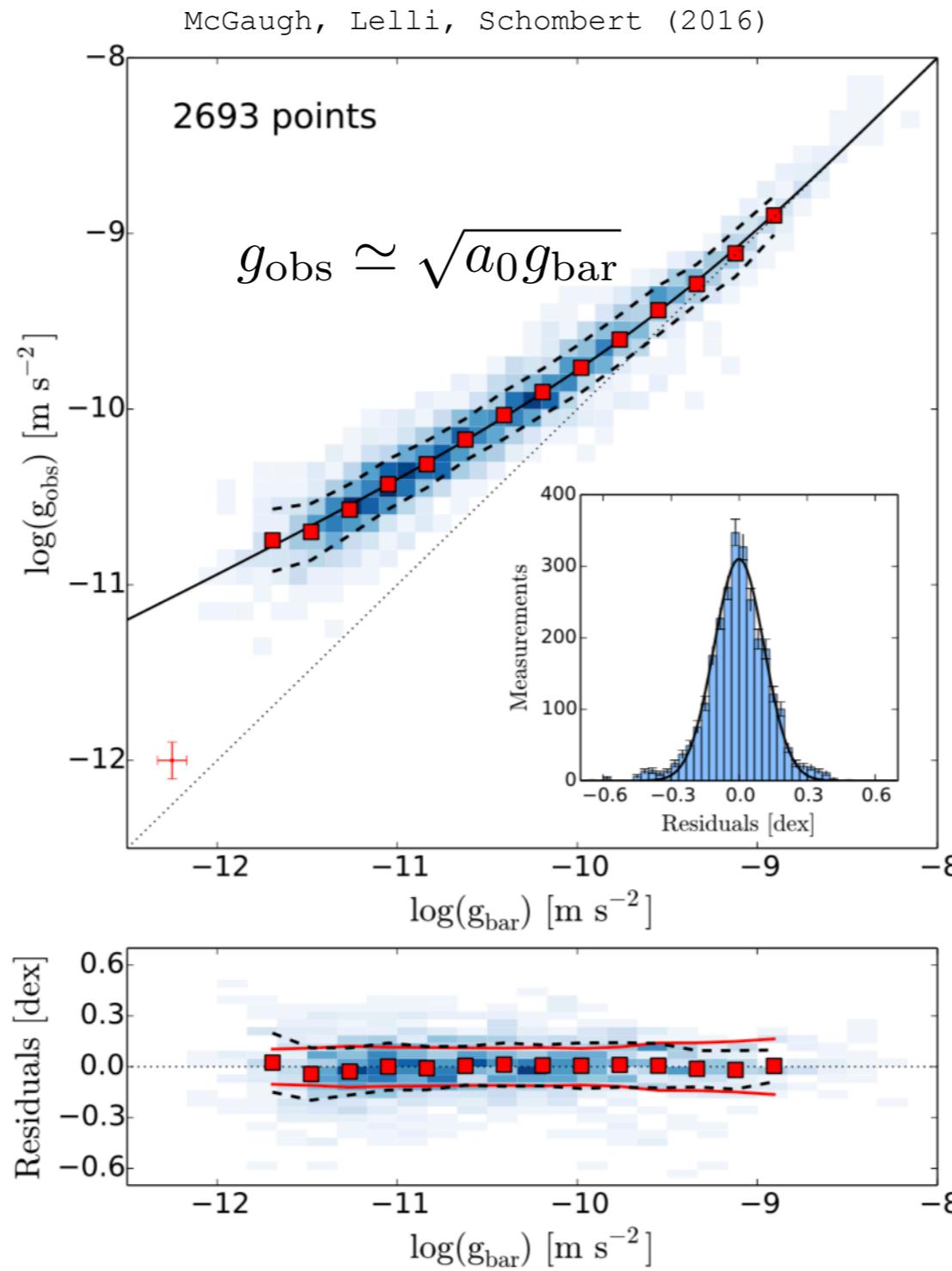


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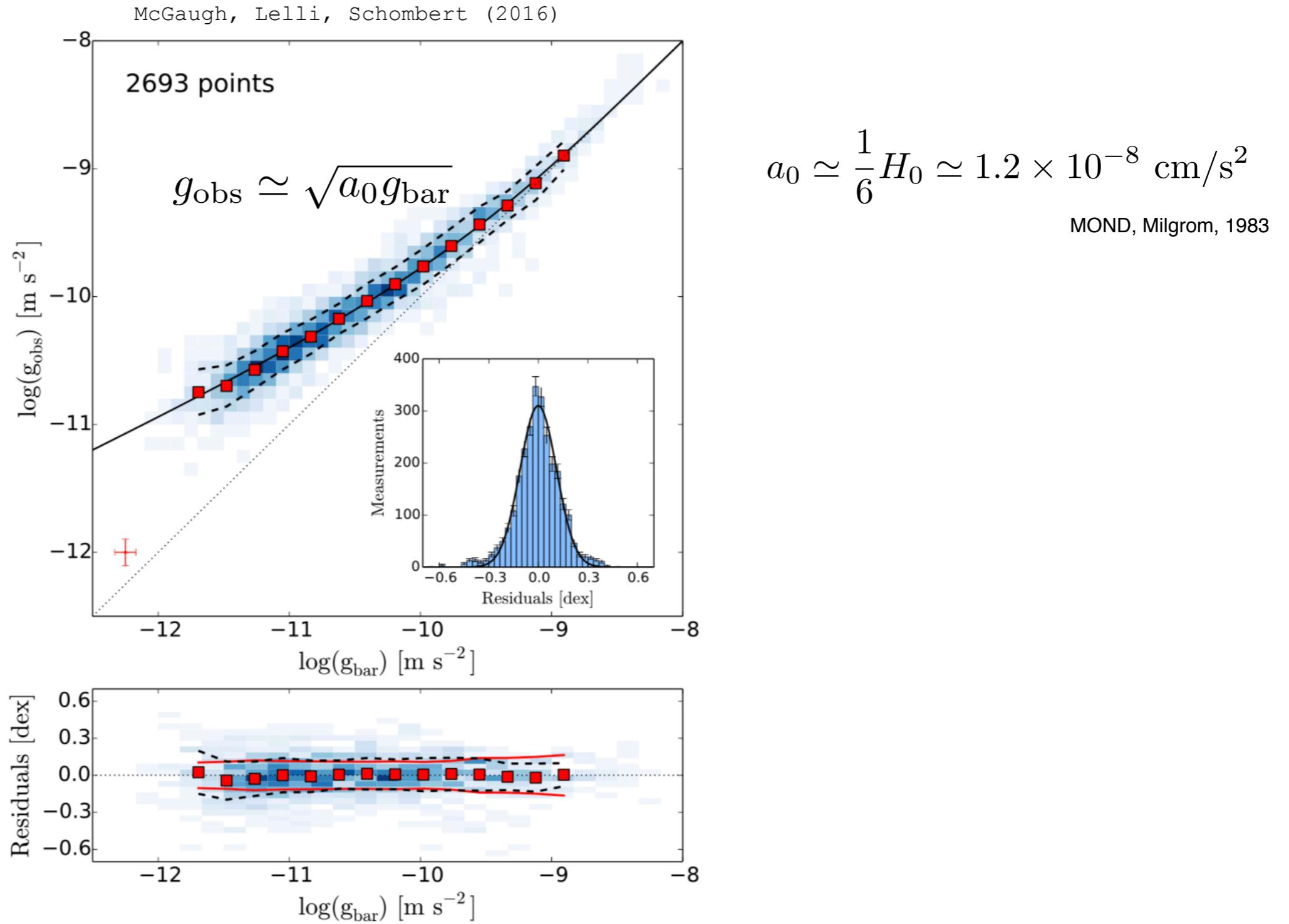
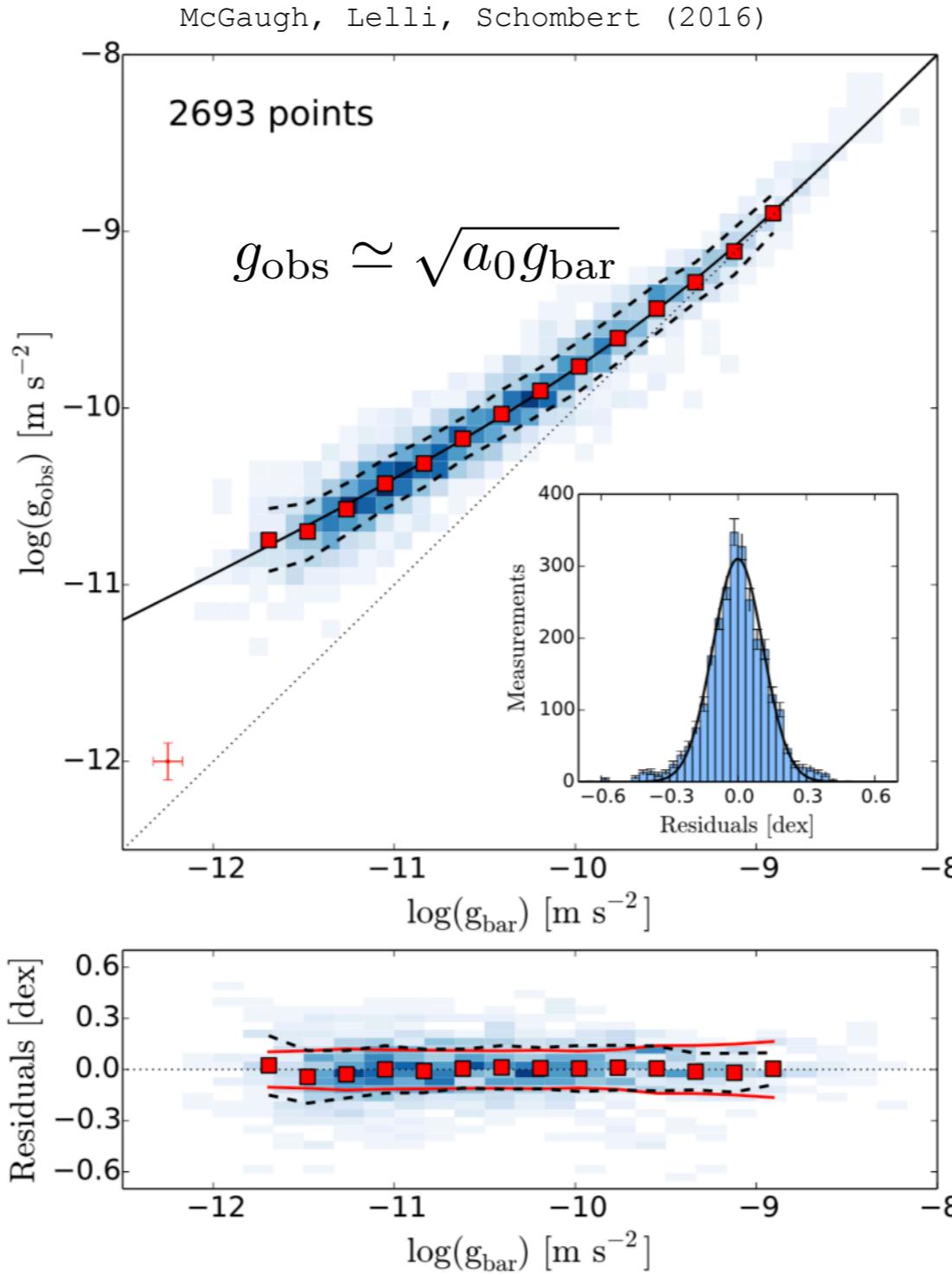


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$$a_0 \simeq \frac{1}{6} H_0 \simeq 1.2 \times 10^{-8} \text{ cm/s}^2$$

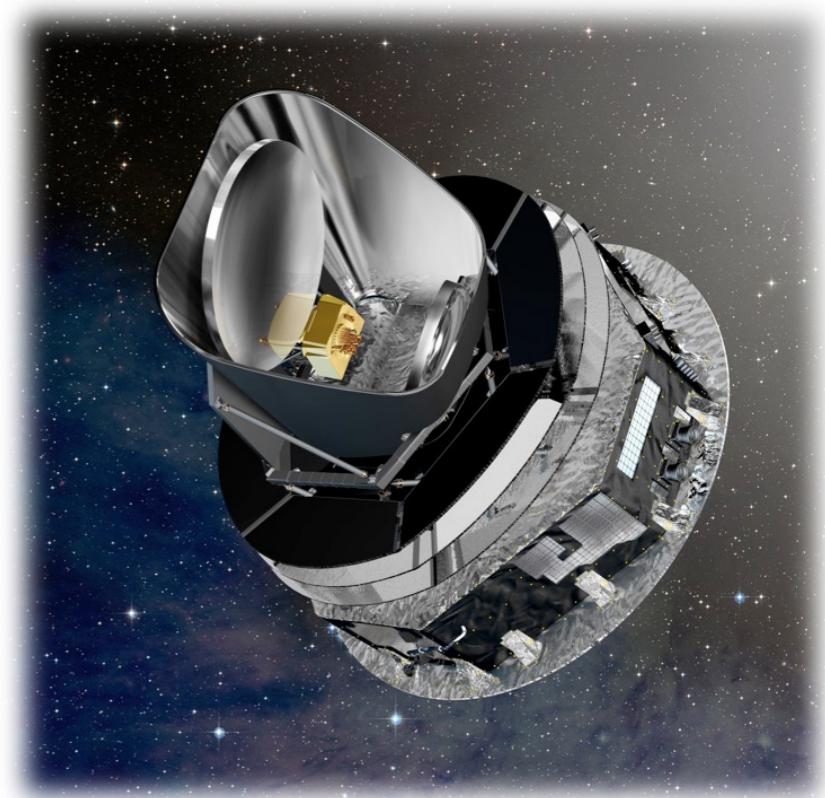
MOND, Milgrom, 1983



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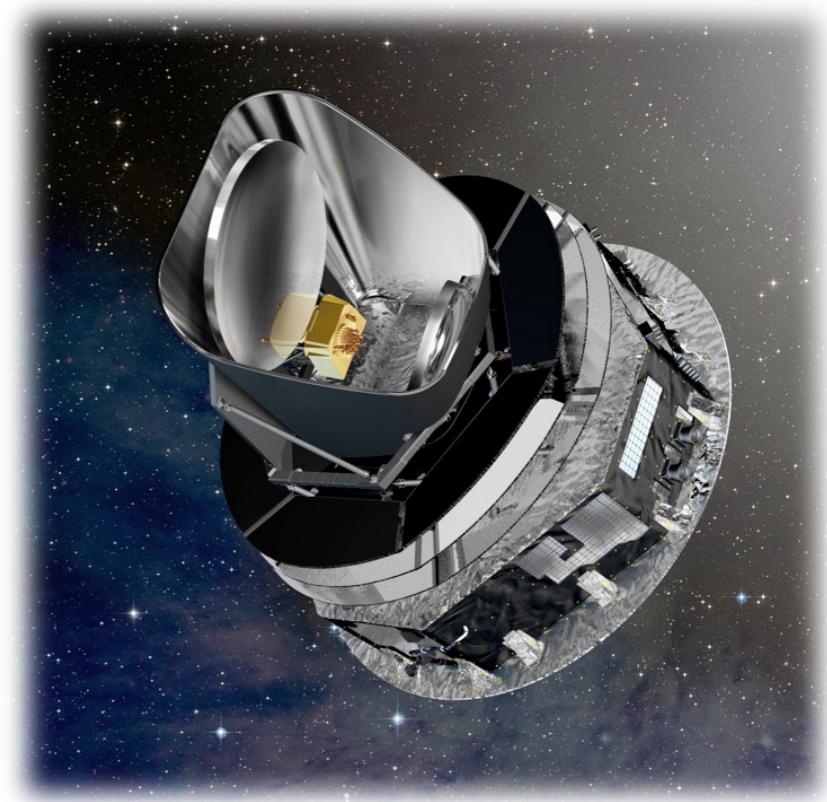
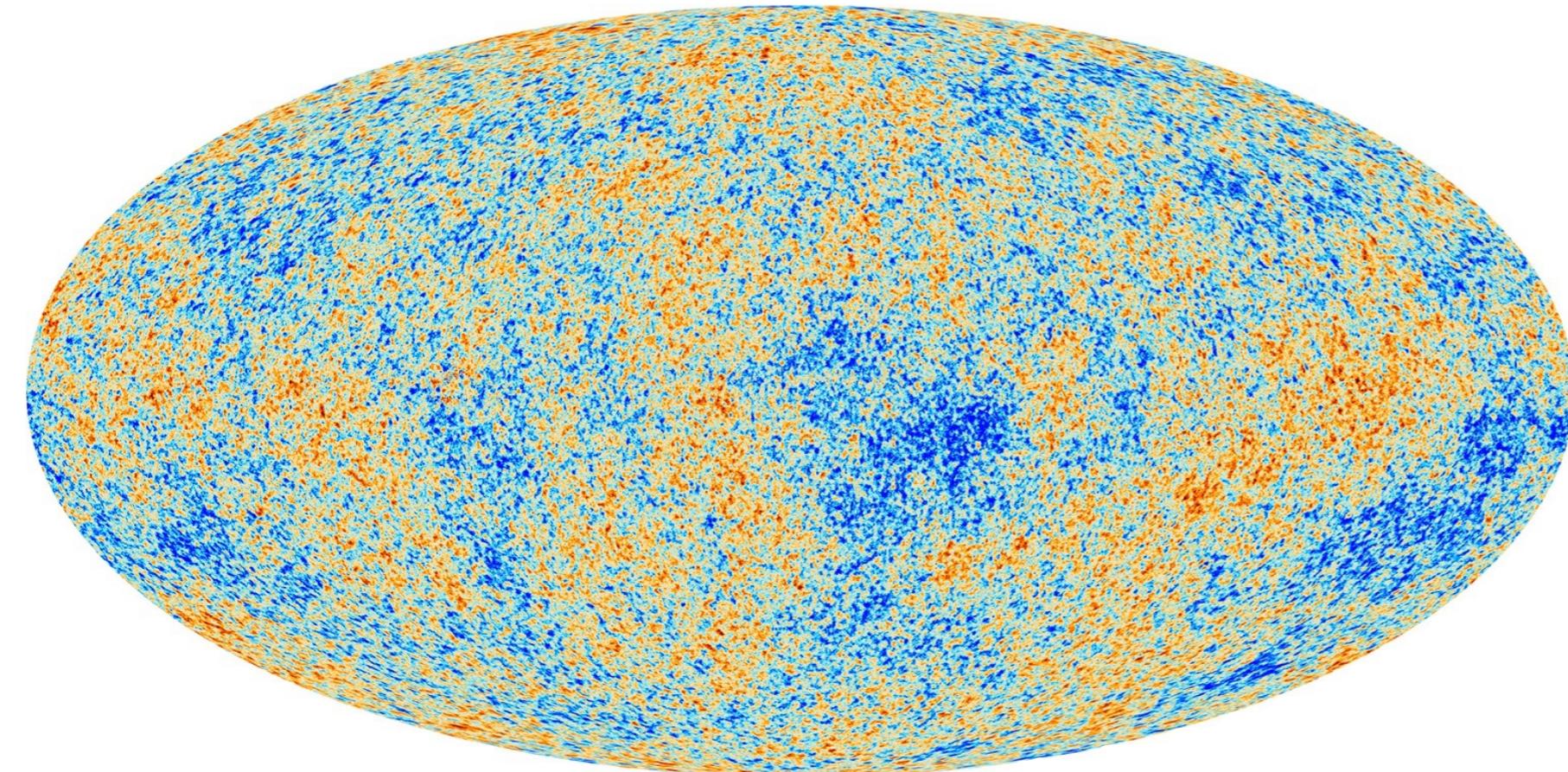
# *Dark Matter in Cosmology, CMB*

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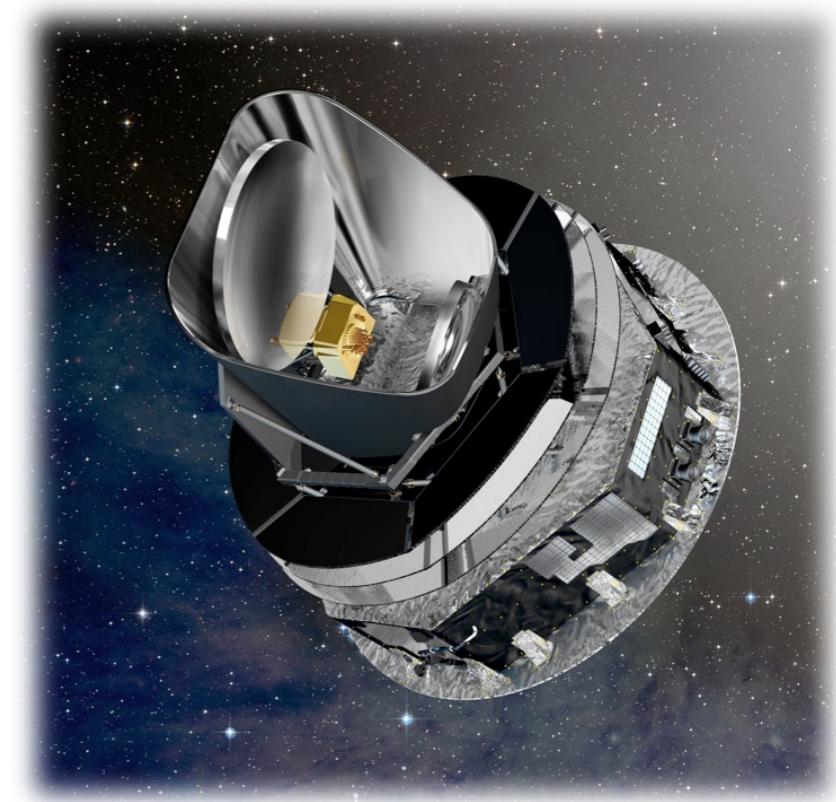
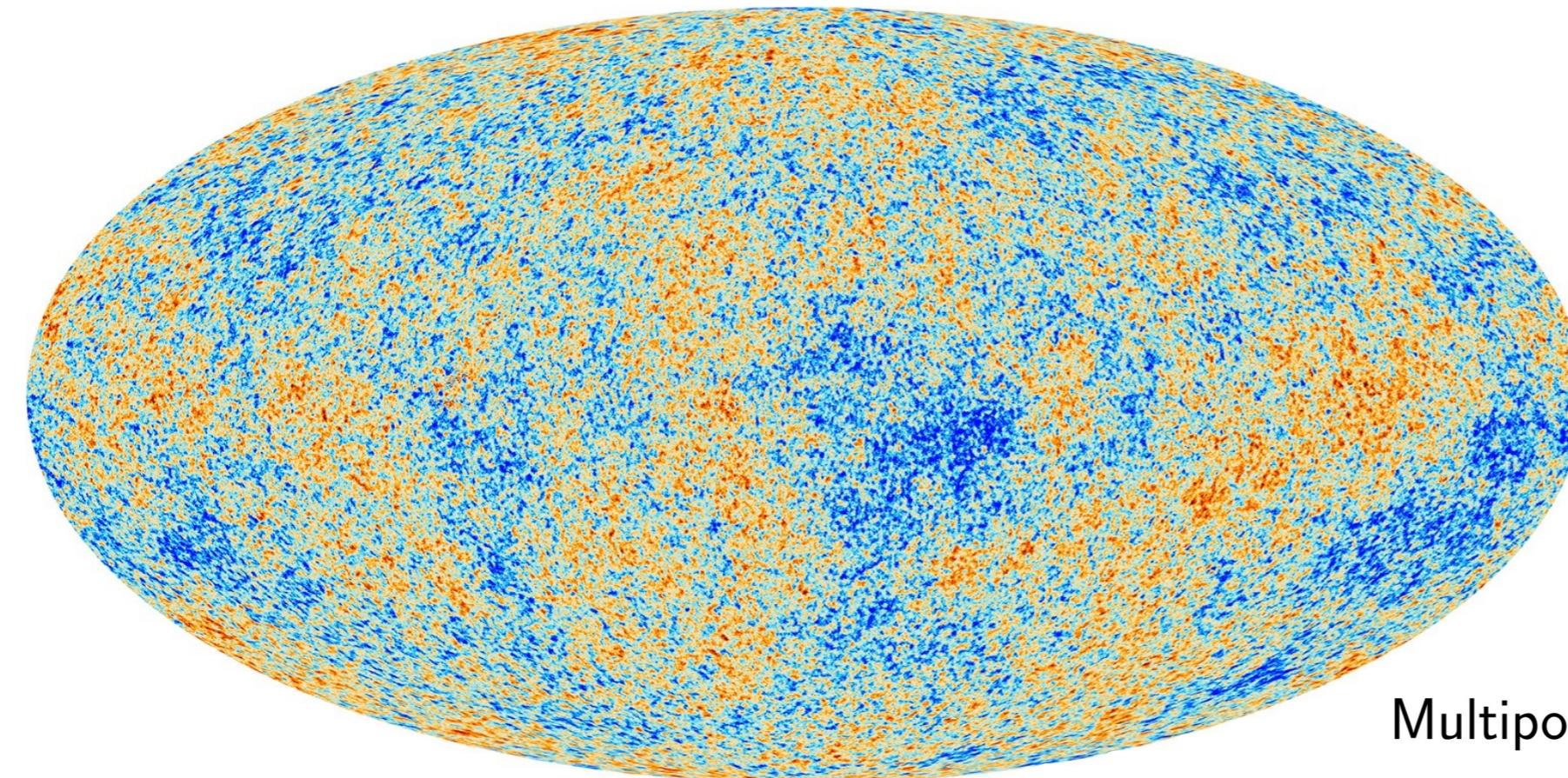
PLANCK 2013

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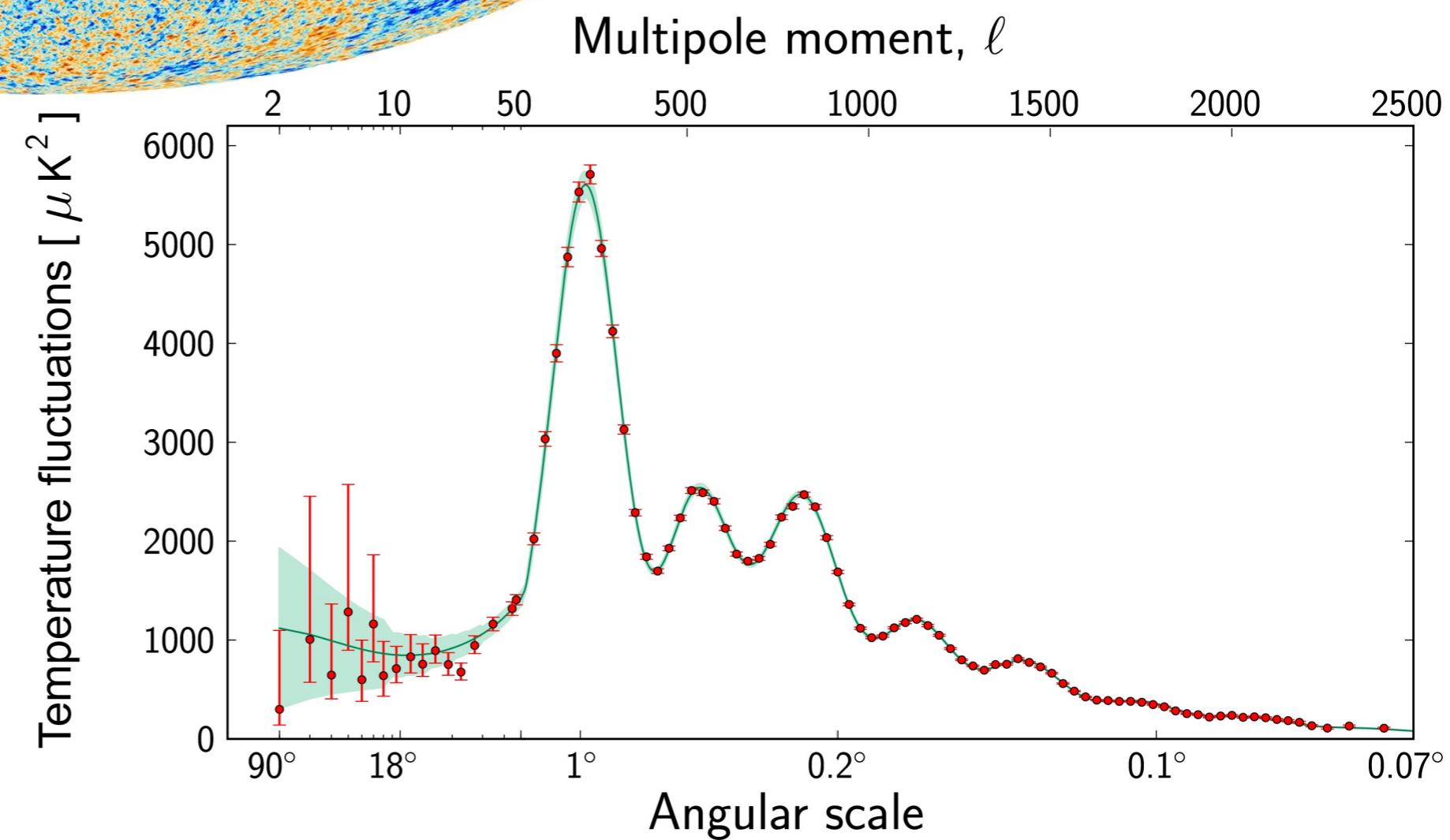


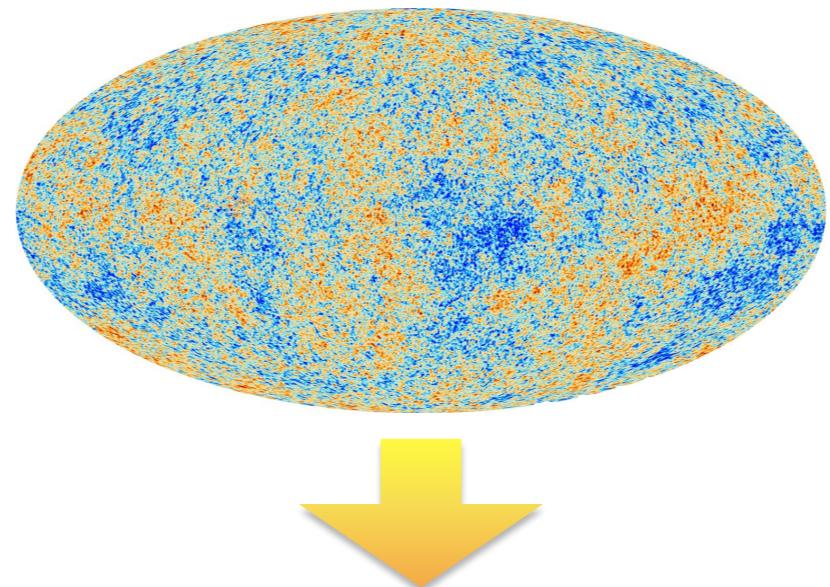
PLANCK 2013

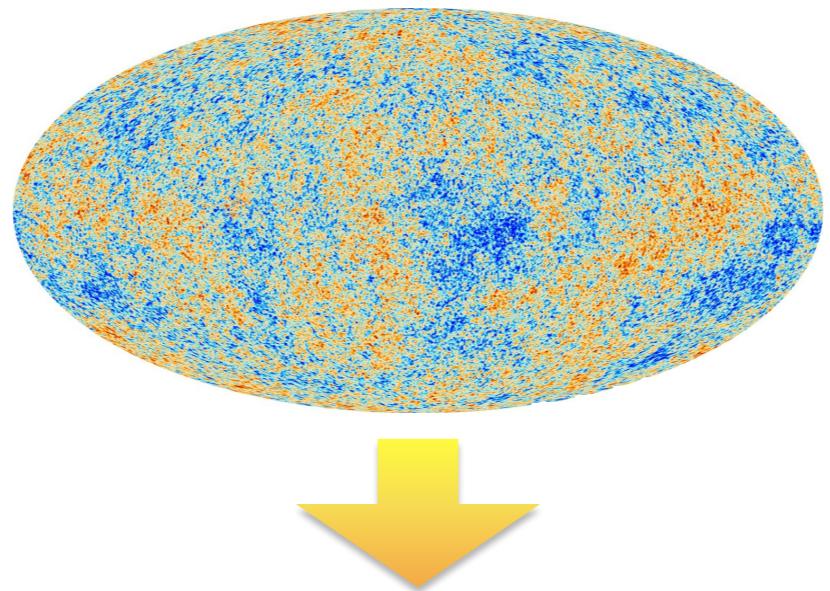
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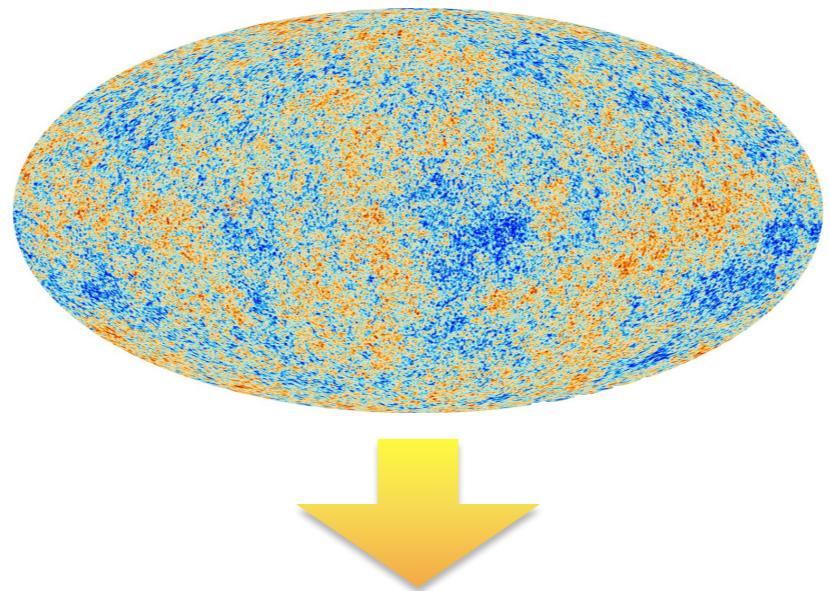
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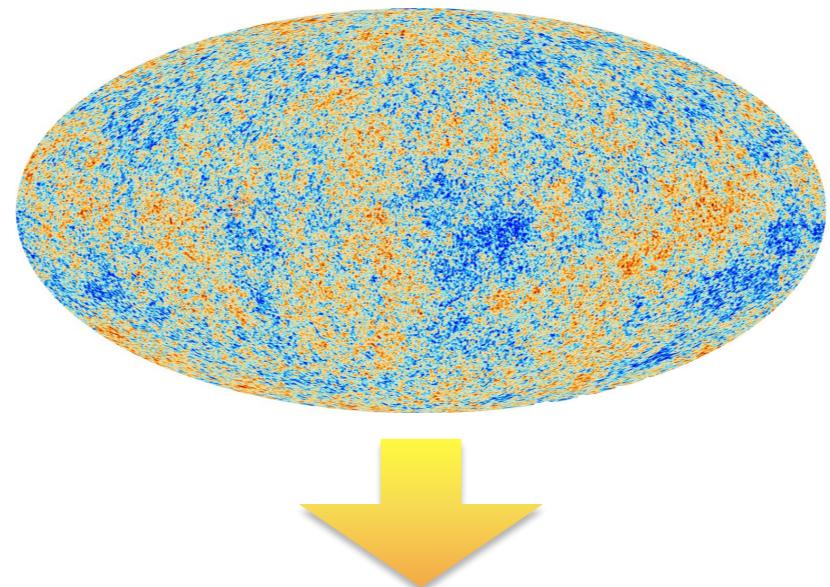


$$T_{\mu\nu}^{\text{DM}} = (\rho + p) u_\mu u_\nu - p g_{\mu\nu}$$



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$$w_{\text{DM}} = p/\rho$$

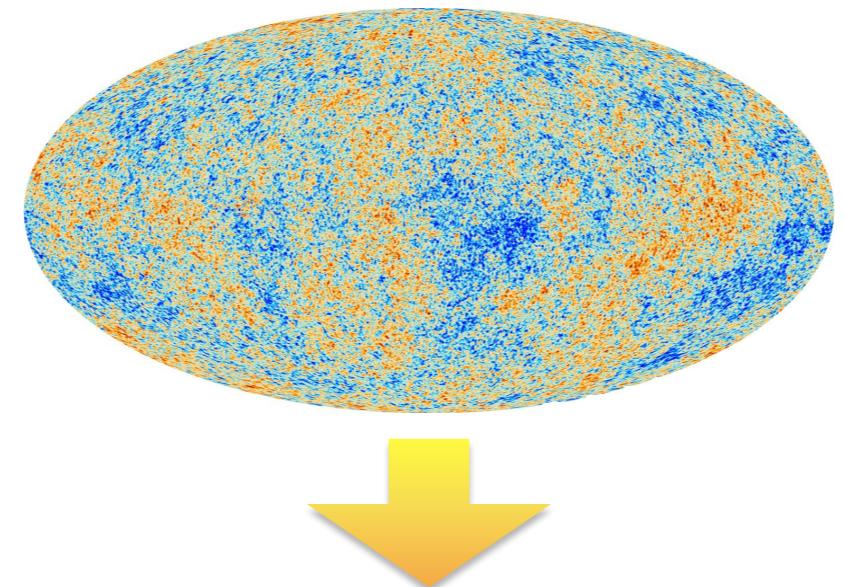


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$$-0.000896 < w_{\text{DM}} < 0.00238$$

Kopp, Skordis, Thomas, (2016)

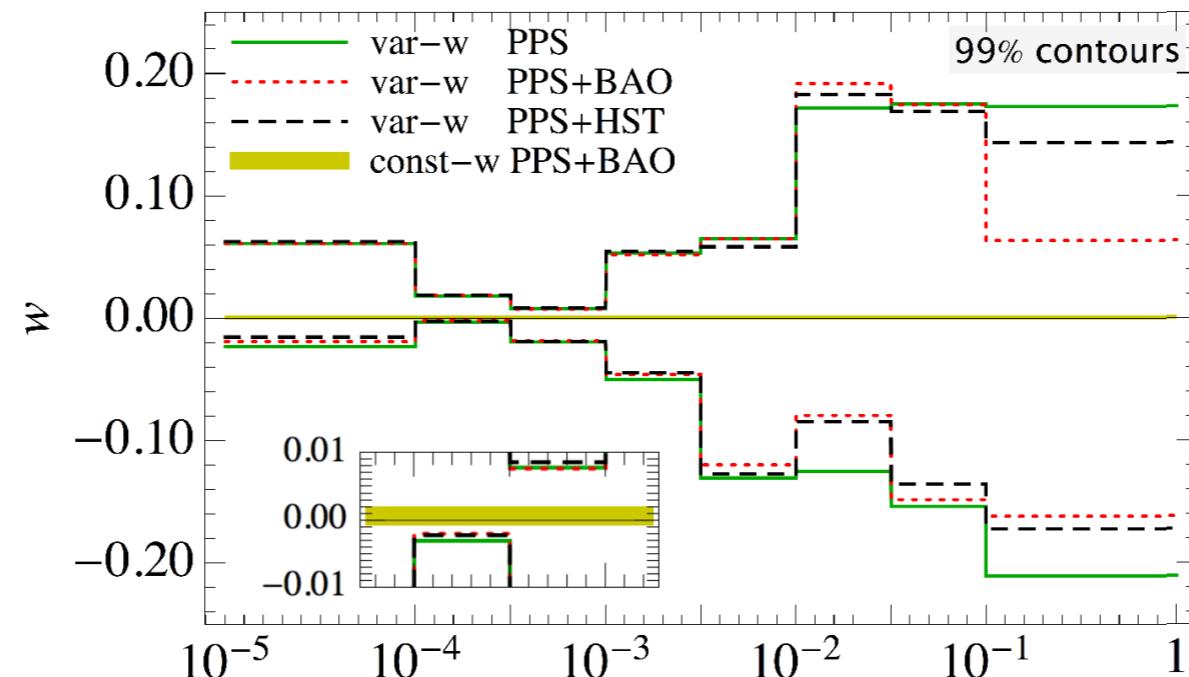


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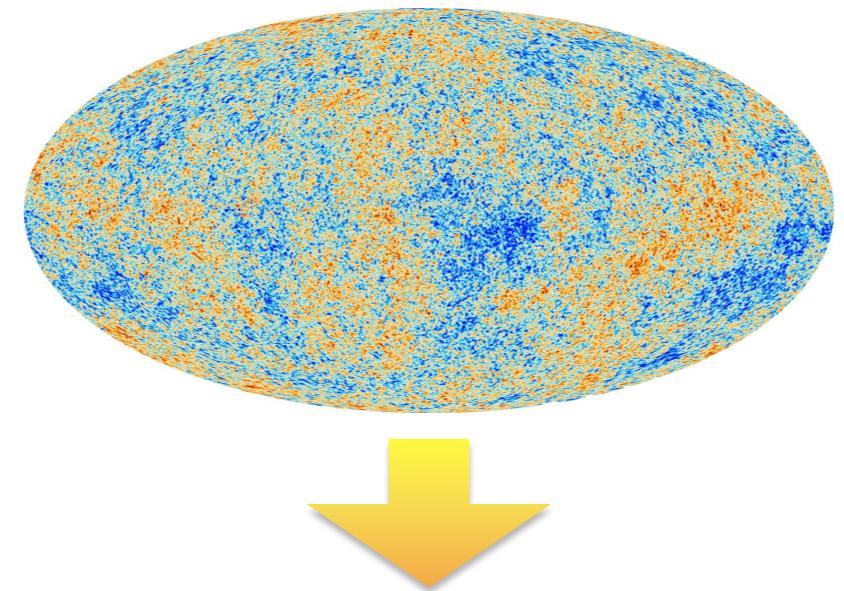
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Kopp, Skordis, Thomas, Ilic (2018)

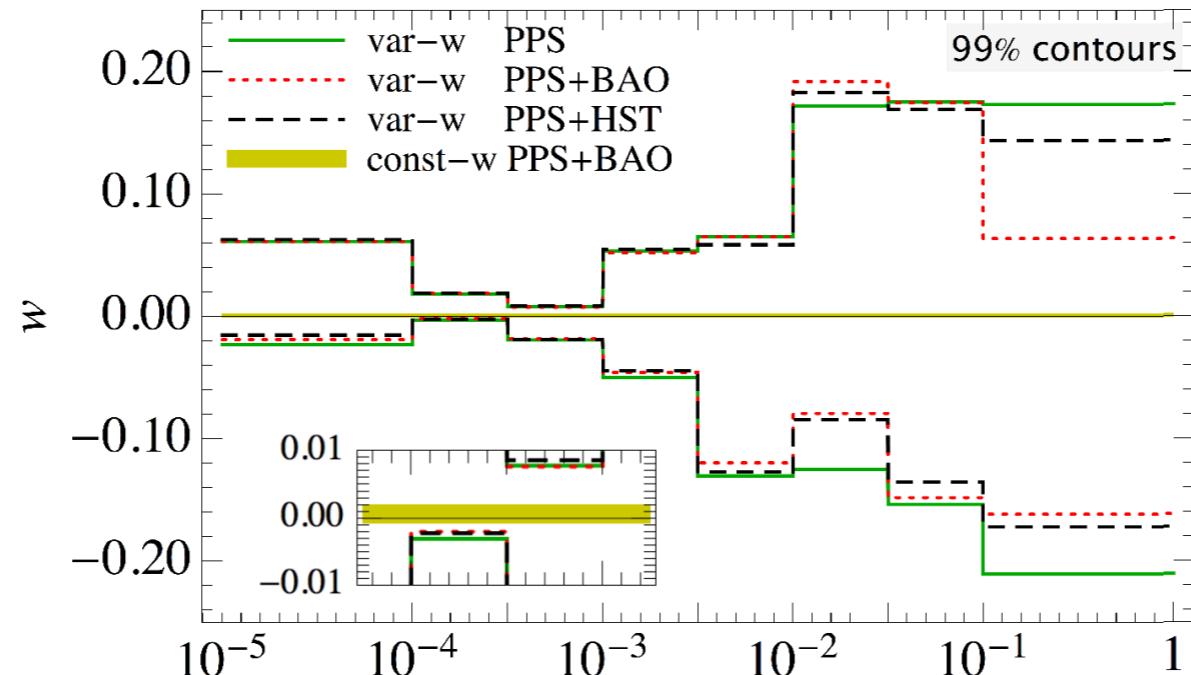


$$T_{\mu\nu}^{\text{DM}} = (\rho + p) u_\mu u_\nu - p g_{\mu\nu} \rightarrow T_{\mu\nu}^{\text{DM}} \simeq \rho u_\mu u_\nu$$

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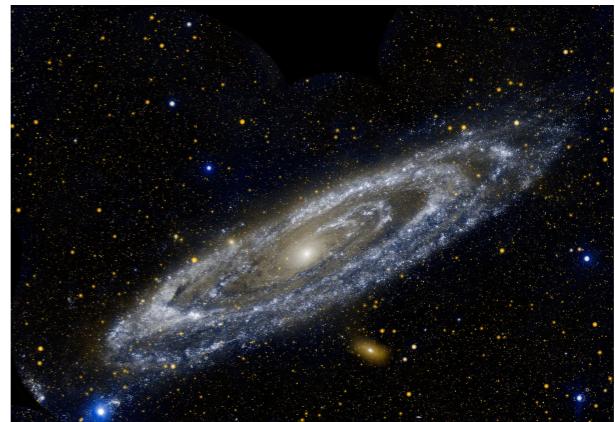
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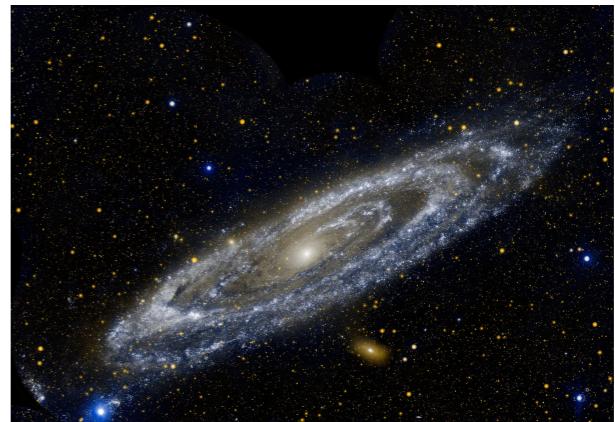
# Cosmological Magnetic Fields

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*Galaxy Evolution Explorer image*

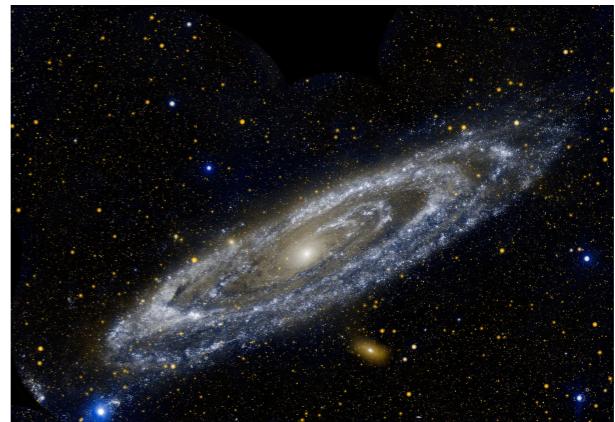
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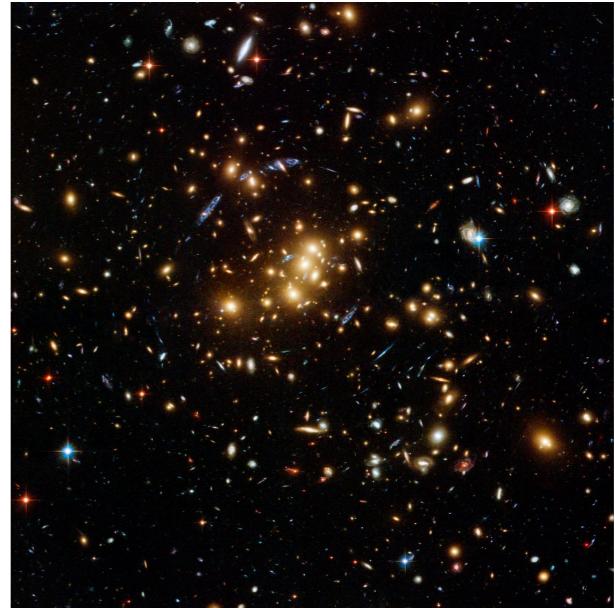
$$B \simeq 10^{-6} \text{ G}$$

# Cosmological Magnetic Fields



*Galaxy Evolution Explorer image*

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*Hubble Space Telescope*

# Cosmological Magnetic Fields

Neronov, Vovk (2010)

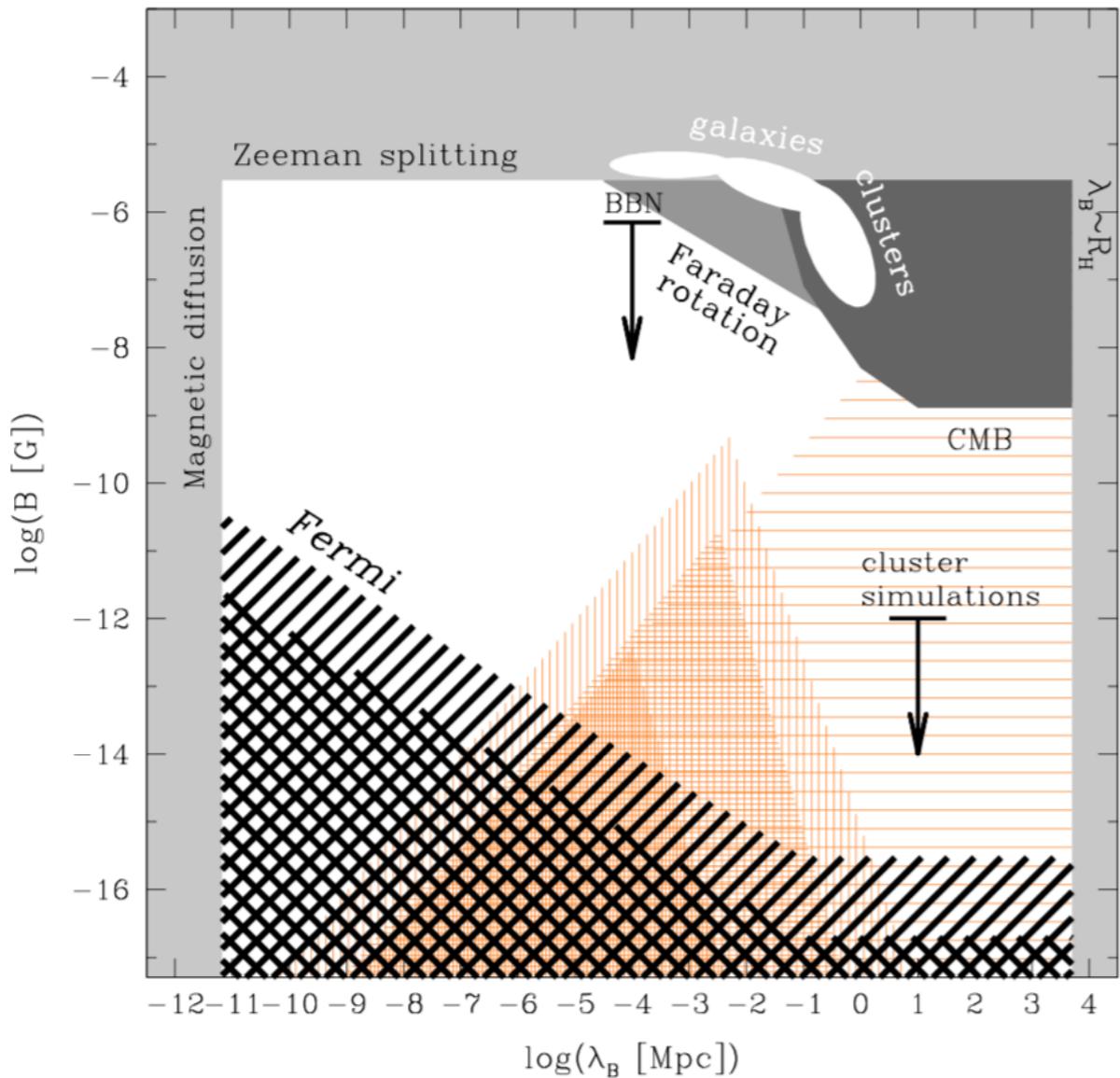
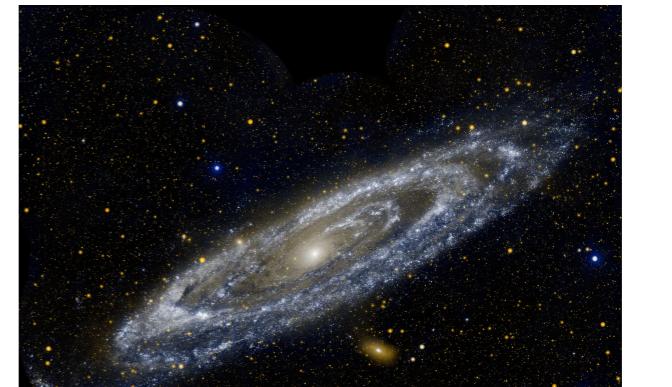
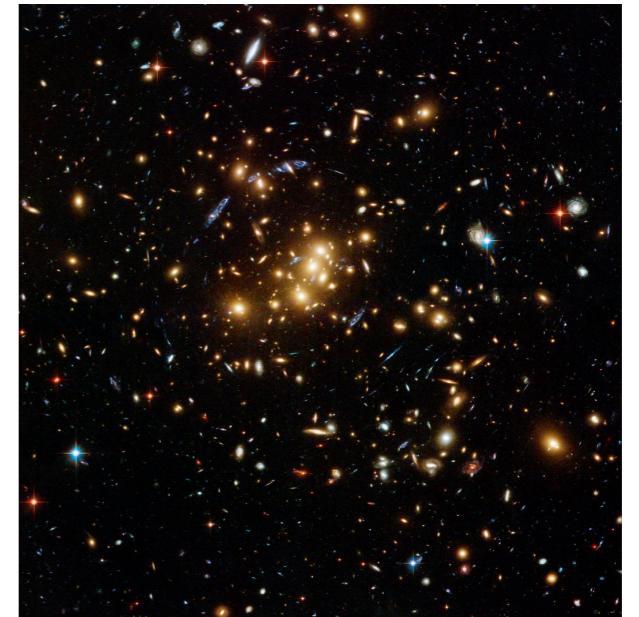


Fig. 2: Light, medium and dark grey: known observational bounds on the strength and correlation length of EGMF, summarized in the Ref. (25). The bound from Big Bang Nucleosynthesis marked “BBN” is from the Ref. (2). The black hatched region shows the lower bound on the EGMF derived in this paper. Orange hatched regions show the allowed ranges of  $B, \lambda_B$  for magnetic fields generated at the epoch of Inflation (horizontal hatching) the electroweak phase transition (dense vertical hatching), QCD phase transition (medium vertical hatching), epoch of recombination (rear vertical hatching) (25). White ellipses show the range of measured magnetic field strengths and correlation lengths in galaxies and galaxy clusters.



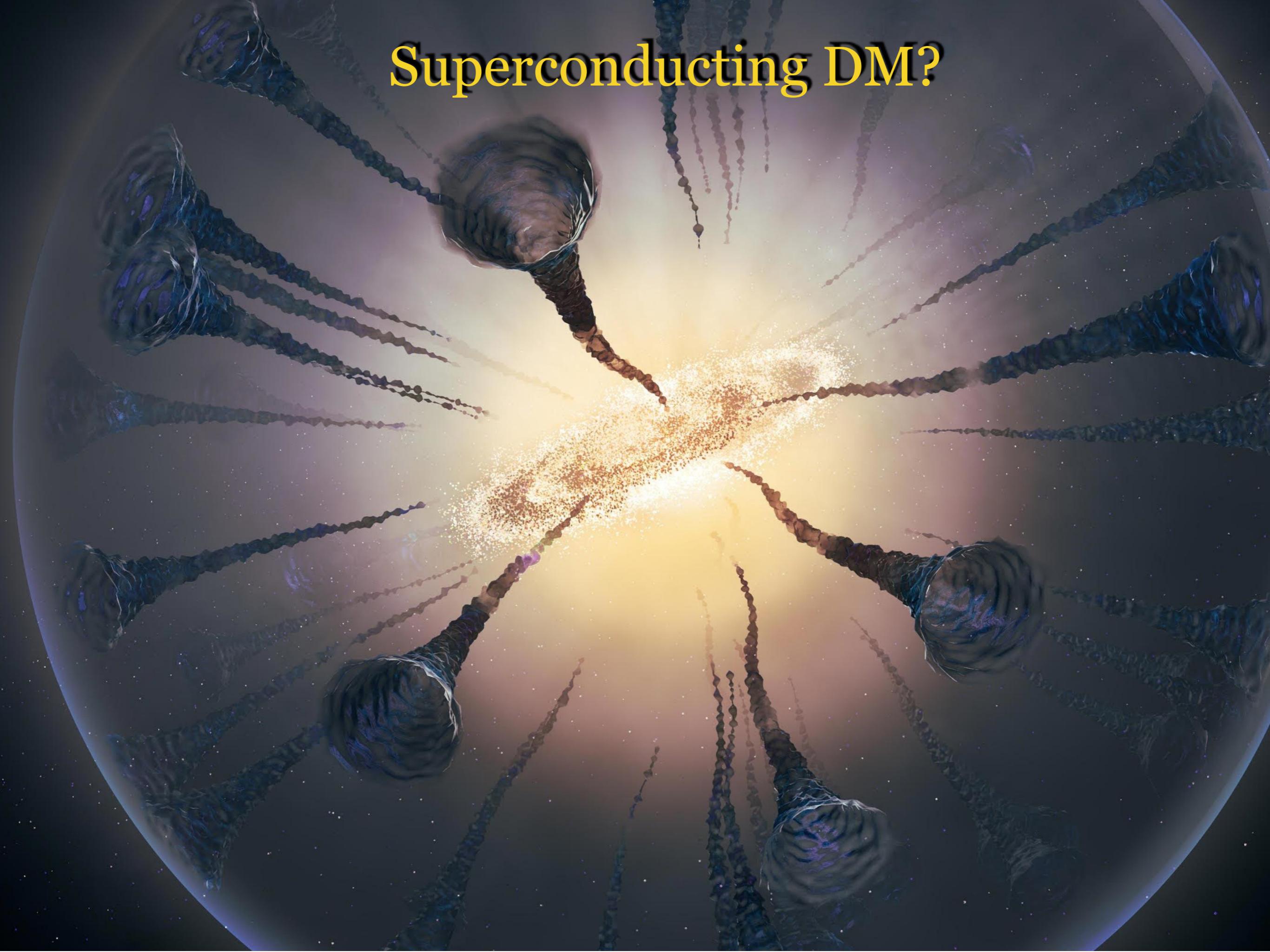
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# Superconducting DM?



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- Observed cosmological magnetic fields

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Neronov, Vovk (2010)

- Can some cosmological medium support these magnetic fields?
- Type II superconductor can be the medium
- DM (or its part) can be the cosmological medium accommodating magnetic fields in form of the Abrikosov vortices / strings

# Main Idea and Motivation II

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# Irrotational Dust, linear DM

$$S\left[\rho,\varphi,g\right]=\int d^4x\sqrt{-g}\,\frac{\rho}{2}\left(\frac{\left(\partial\varphi\right)^2}{M^4}-1\right)\,,$$

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$$u_\mu = \frac{\partial_\mu \varphi}{M^2}$$

# Velocity Potential Redefinition

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$$\varphi \rightarrow \phi \qquad M\left(\varphi\right) \rightarrow \mu$$

$$d\phi = \frac{d\varphi}{f^2\left(\varphi/\mu\right)}$$

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No shift-symmetry



Different mass functions

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# Mimetic Substitution

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new degenerate higher derivative and  
Weyl-invariant, U(1) charged, gauge-invariant  
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new degenerate higher derivative and  
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Scalar-Vector-Tensor theory.

Not covered by Horndeski (1980) and (2018), or Heisenberg (2014) constructions!

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# Gauge invariant variables

$$(\varphi, \bar{\varphi}, A_\mu) \rightarrow (\chi, \theta, G_\mu)$$

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# Higgs Phase without potential

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c.f. Chameleon screening for scalars, Khoury, Weltman (2003)

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$$a_\mu = u^\lambda \nabla_\lambda u_\mu \simeq -\frac{q^2}{2\mu^2} \nabla_\mu^\perp (G^\lambda G_\lambda)$$

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Compare with a charged particle:

$$ma_\mu = eF^{\mu\nu}u_\nu$$

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# Dark Photon mass bounds

$$10^{-13} \text{ eV} \lesssim m_{D\gamma} \lesssim 3 \times 10^{-12} \text{ eV}$$

Cardoso et al. (2018)

the Proca mass, super radiance, observed stability of the inner disk of stellar-mass black holes

$$m_\gamma = q \sqrt{\frac{3\Omega_{SDM}}{8\pi}}~\frac{HM_{Pl}}{\mu}$$

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$$\mu = q \sqrt{\frac{3\Omega_{SDM}}{8\pi}} \frac{HM_{Pl}}{m_\gamma} \gtrsim q \sqrt{\frac{3\Omega_{SDM}}{8\pi}} 1 \text{ GeV}$$

# Decay of perturbations

$$\left(\frac{q^2\chi^2}{M^4}\right) \delta\rho G^\mu G_\mu$$

$$q^2\rho\left(\frac{\chi^2}{M^4}\right)' \delta\chi G^\mu G_\mu$$

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*Thanks a lot for attention!*