Astroparticle Physics

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Early Career Researchers in Particle Physics in Austria
HEPHY
May 23 2024

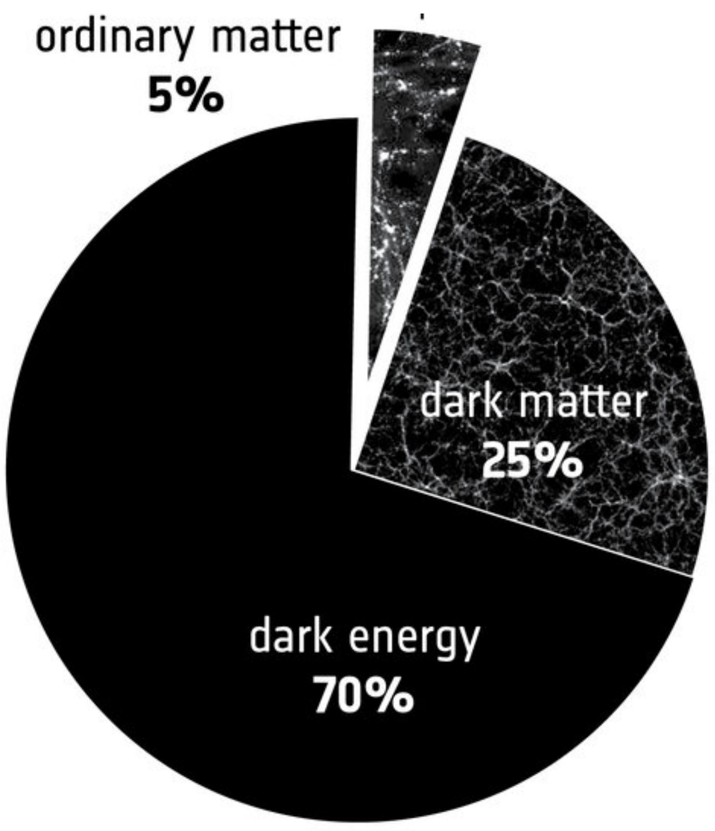
ÖAW AUSTRIAN ACADEMY OF SCIENCES
universität wien
European Research Council Established by the European Commission
FWF Der Wissenschaftsfonds.

Astro-particle Physics in Austria

In the broadest sense, astroparticle physics is the discipline concerning the study of “particles” arriving to Earth from outer space

Big science questions:

- origin of cosmic rays
- origin of neutrino masses
- origin of baryon asymmetry of the universe
- nature of dark matter
- nature of dark energy



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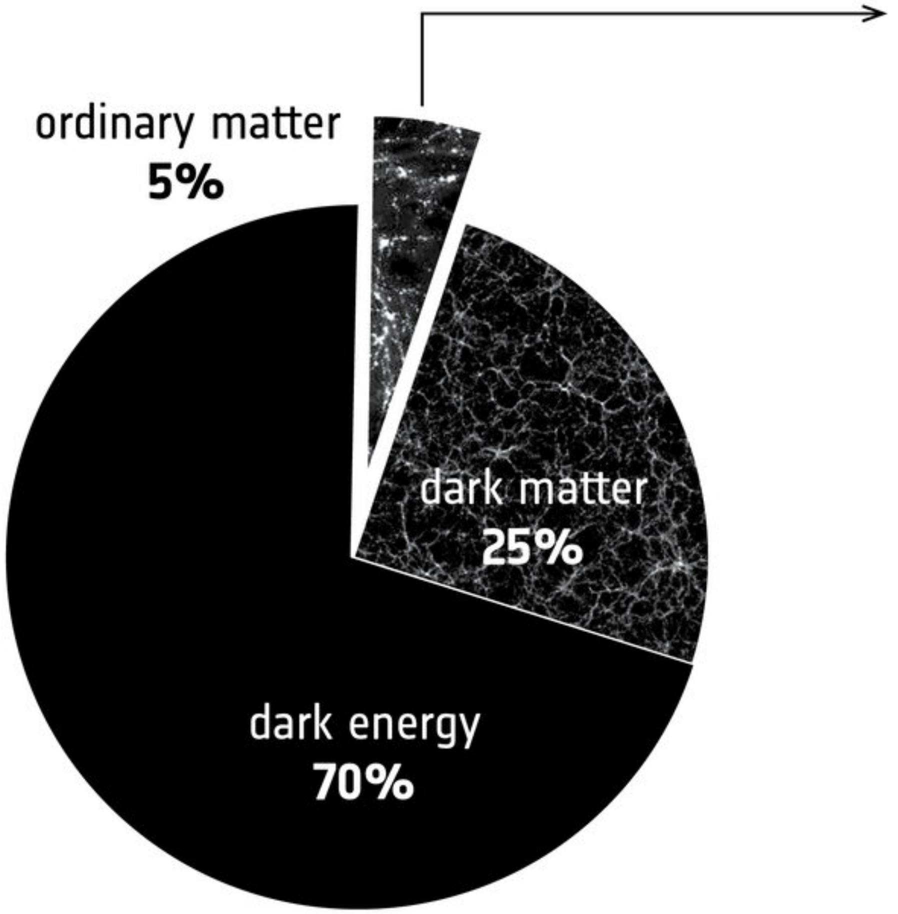

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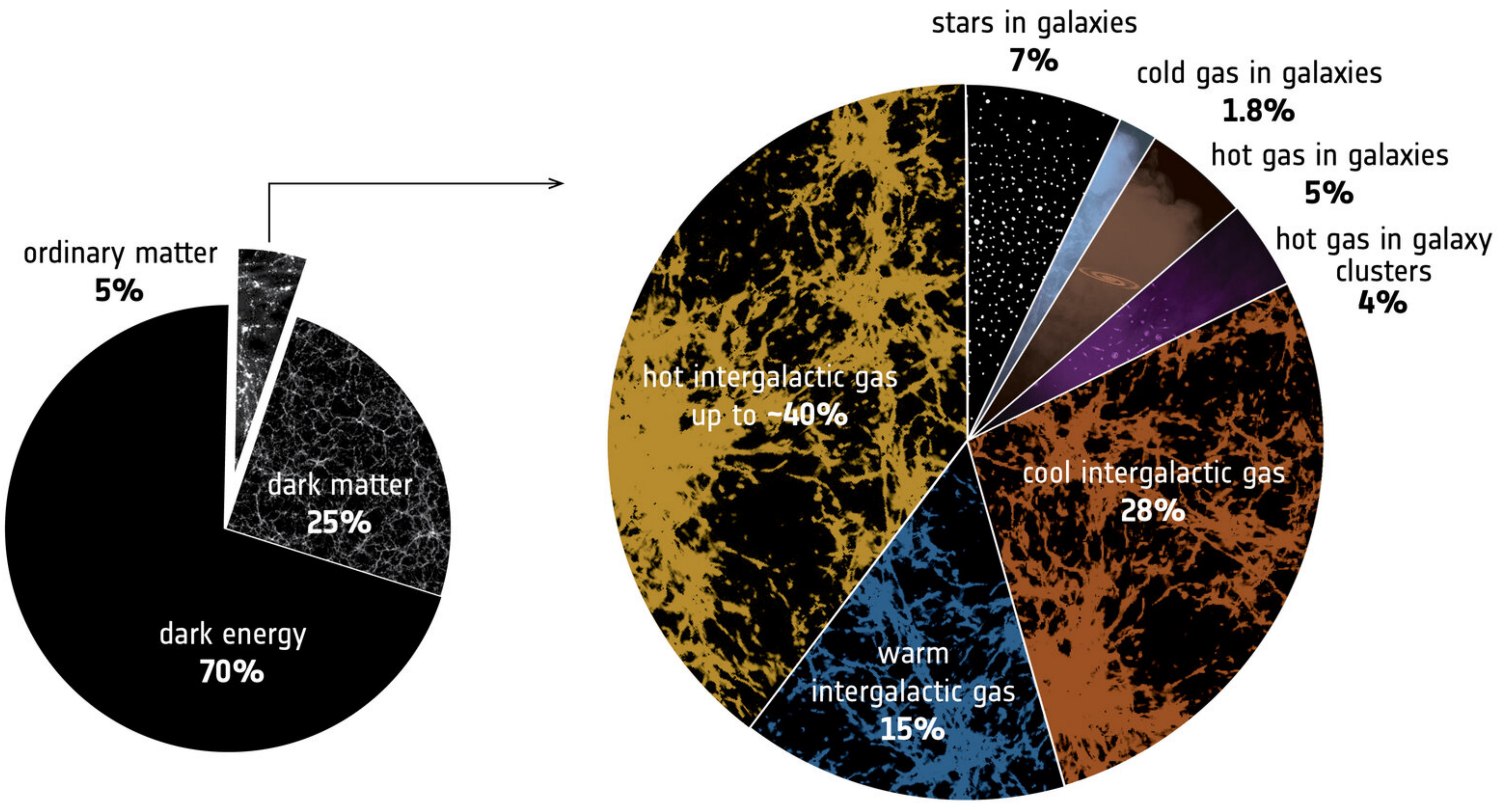
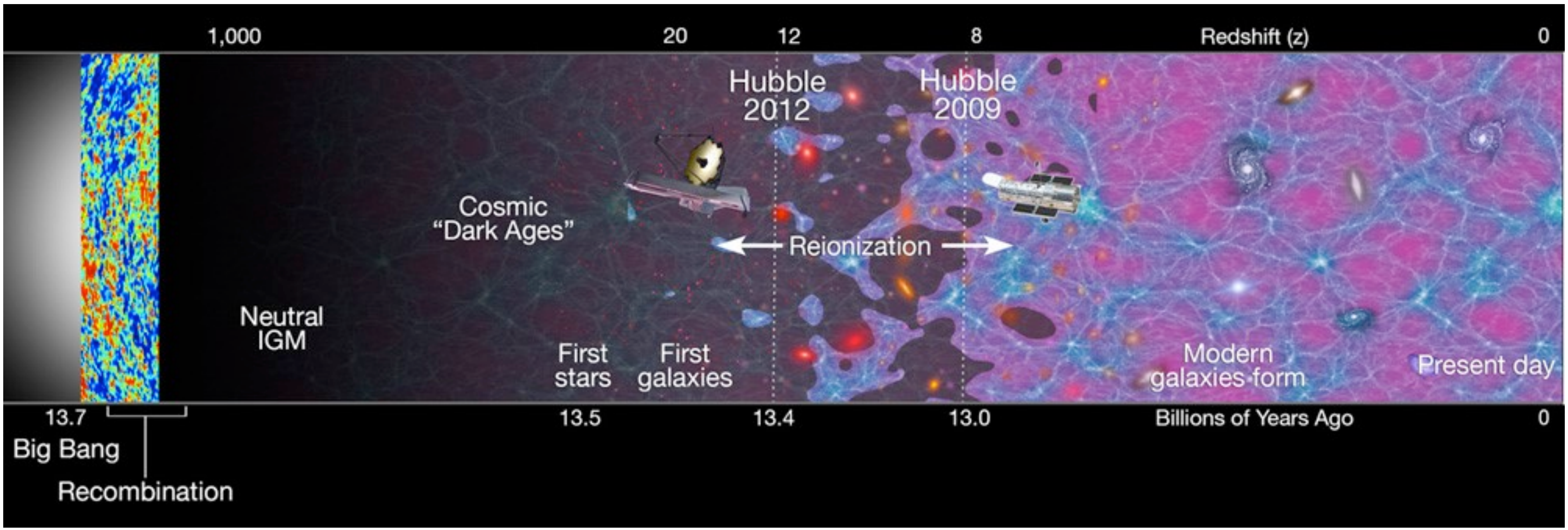


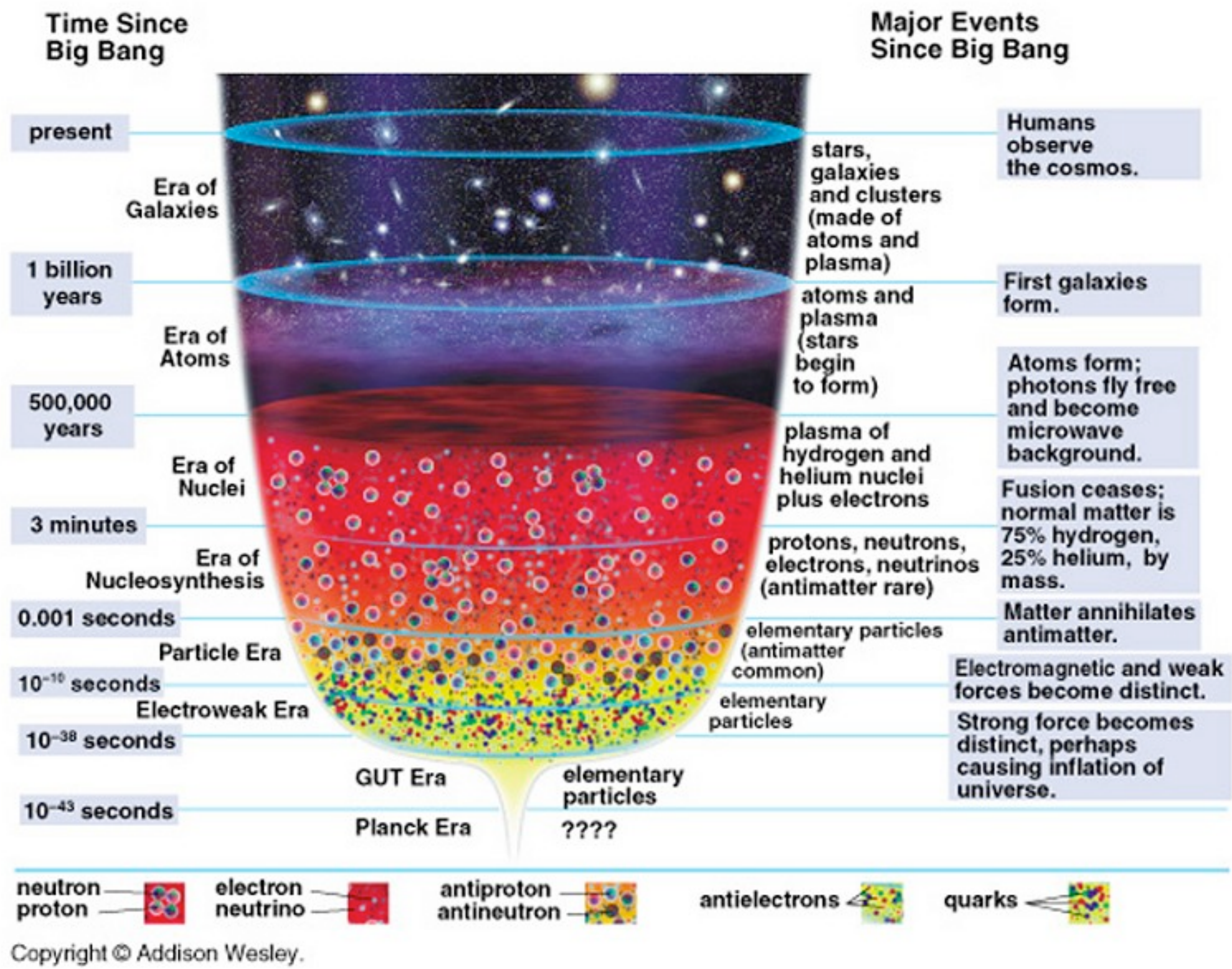
Cosmic history

An astronomer’s view:



Cosmic history

A particle physicist's view



Our "Laboratory"

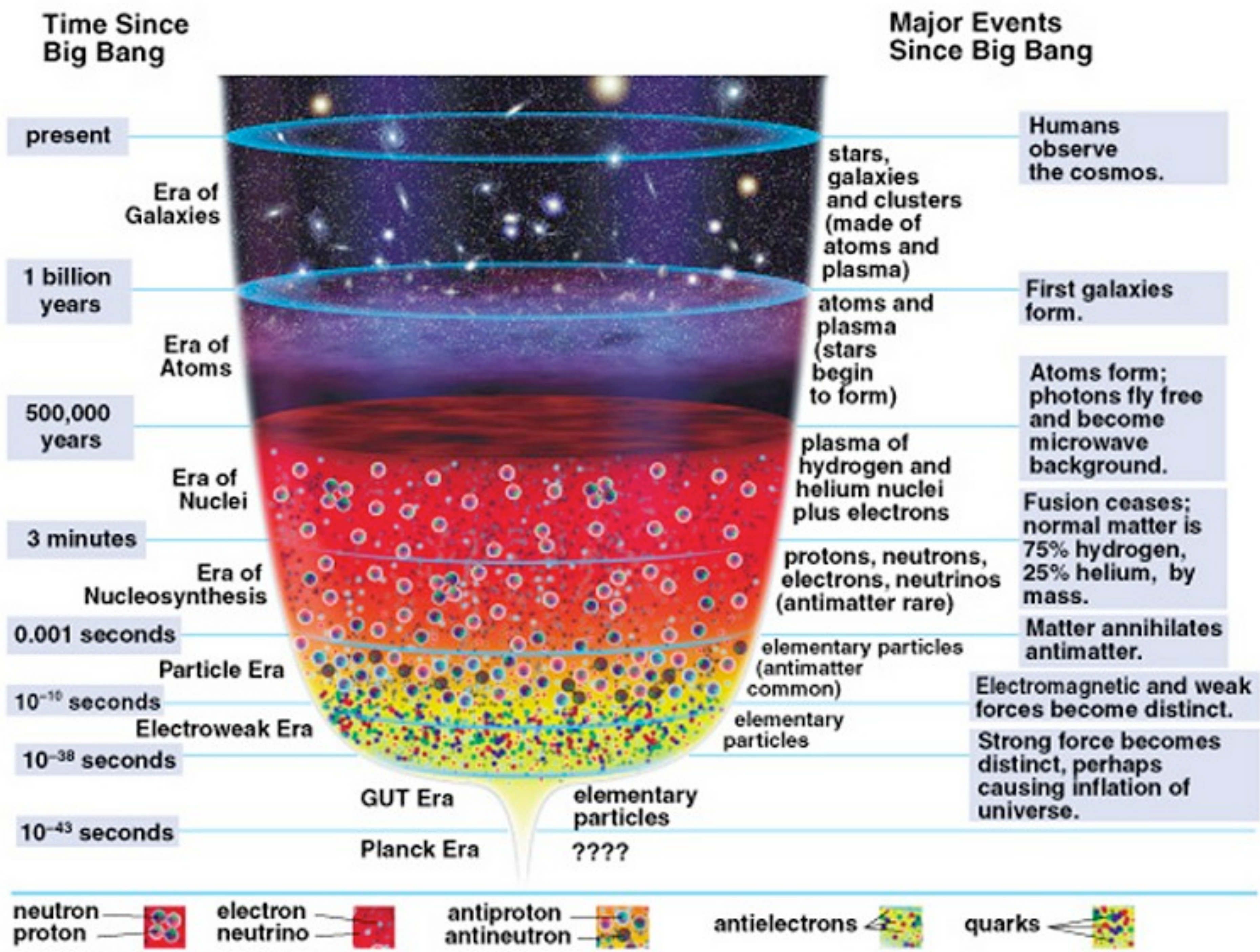
A particle physicist's view

z=0 experiments

z < few
astrophysics
(CRs, GWs)

z < 1100
cosmology
(CMB, large scale
structure)

z >1000
early Universe
DM, Baryogenesis



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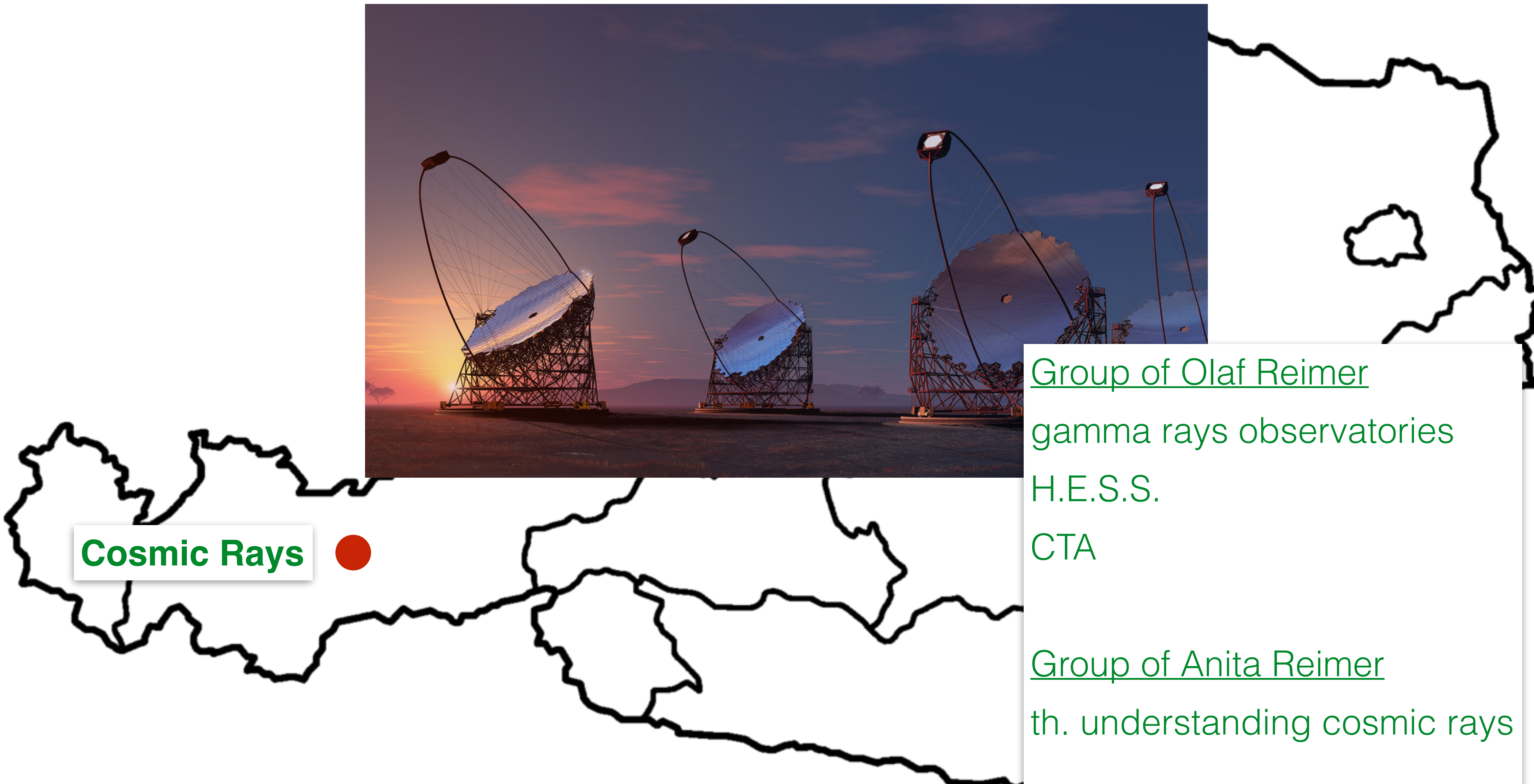

Group of Olaf Reimer

gamma rays observatories

H.E.S.S.

CTA

Group of Anita Reimer

th. understanding cosmic rays

+ other astro groups

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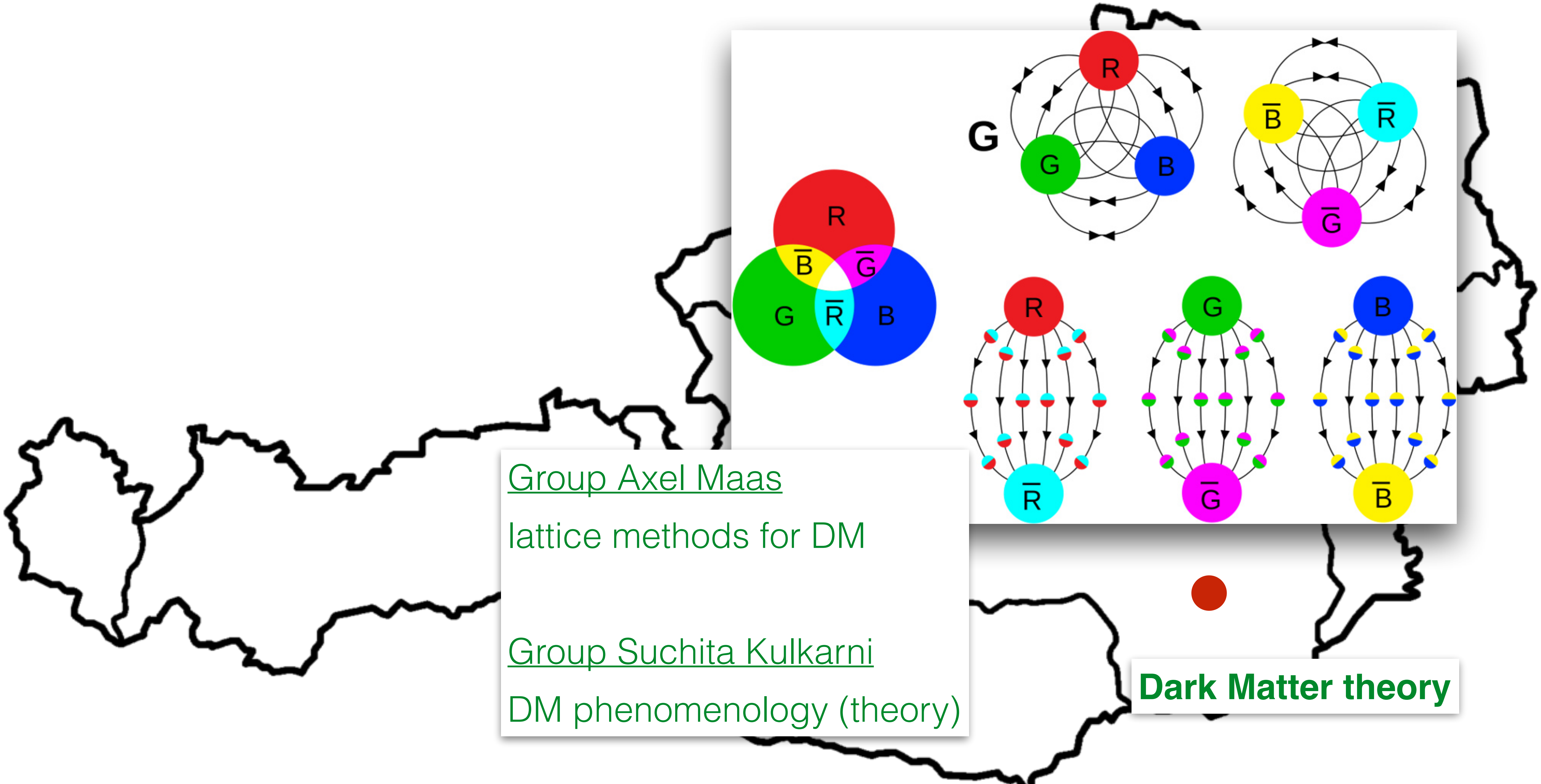

[Group Axel Maas]

lattice methods for DM

[Group Suchita Kulkarni]

DM phenomenology (theory)

Dark Matter theory

Astro-particle Physics in Austria

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Dark Matter

Cosmology / early Universe

Gravitational Waves

Groups of Jochen Schieck and Florian Reindl (HEPHY & TUM)

Dark Matter direct detection with CRESST and COSINUS

Group of Josef Pradler (HEPHY & UVIE)

DM phenomenology (theory)

Group of Oliver Hahn (UVIE)

cosmology; numerical simulations for structure formation

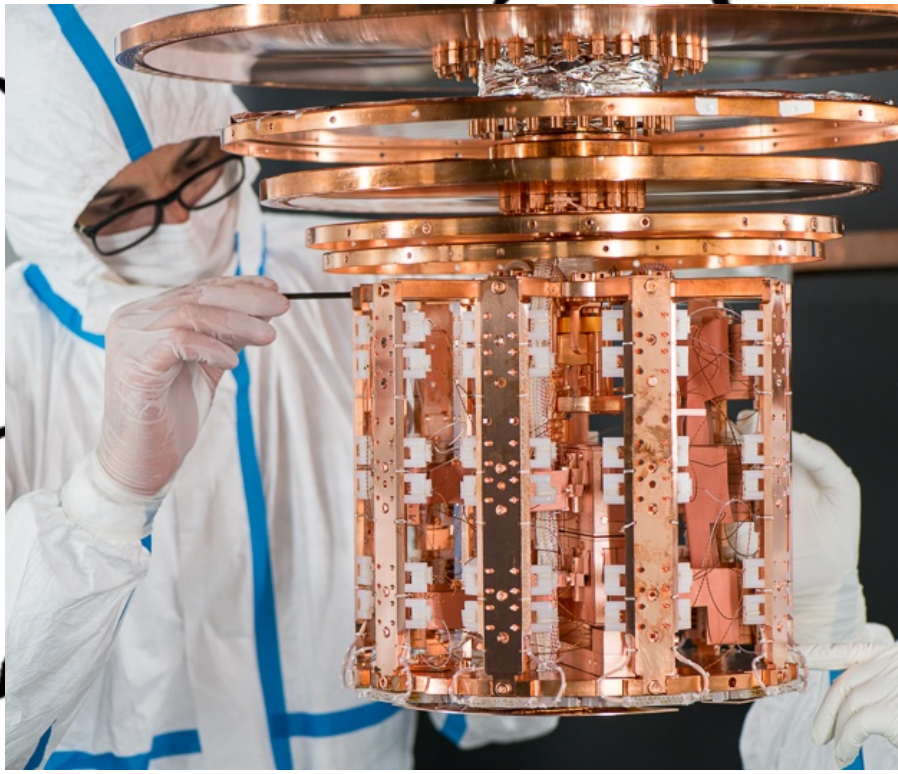
Group of Glenn van de Ven (UVIE)

dynamics of stellar systems / DM simulations

Gianluca Ingulia (HEPHY)

Gravitational waves / member of Einstein Telescope

+ other groups with New Physics overlap (e.g. Abele)



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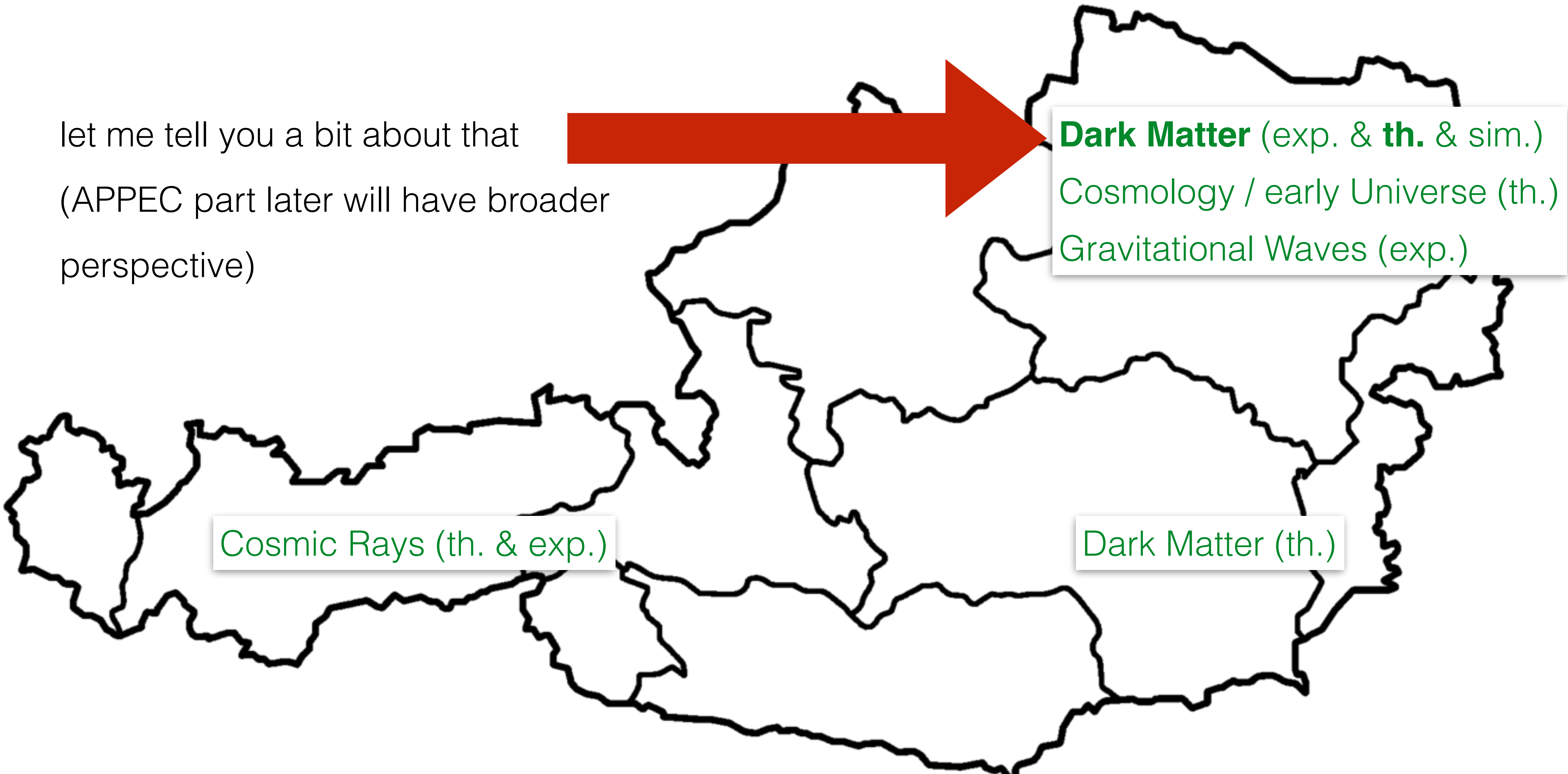
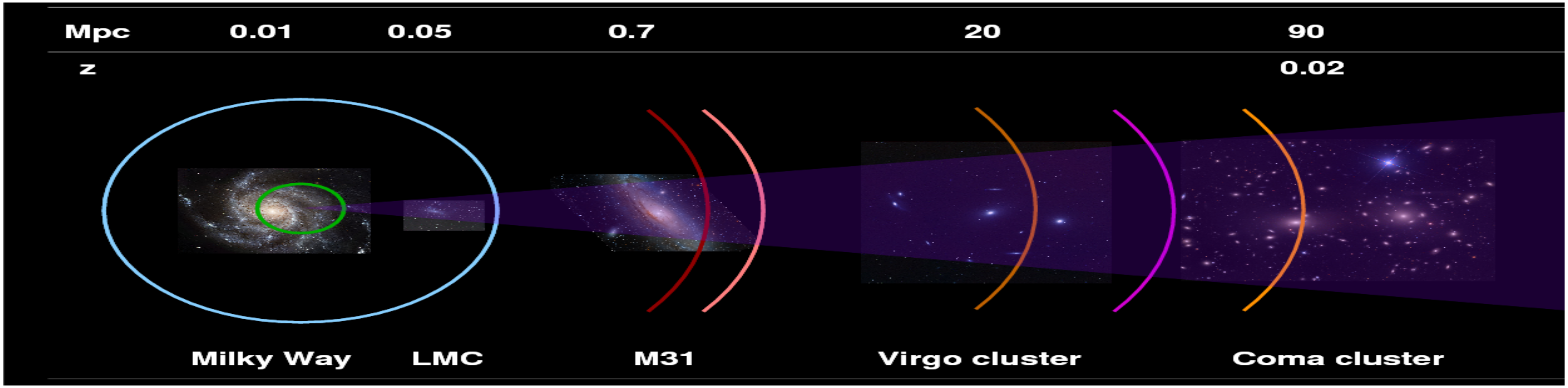
let me tell you a bit about that

(APPEC part later will have broader perspective)



Evidence for DM on any scale > kpc

Missing mass problem of the 20th (and 21st) century

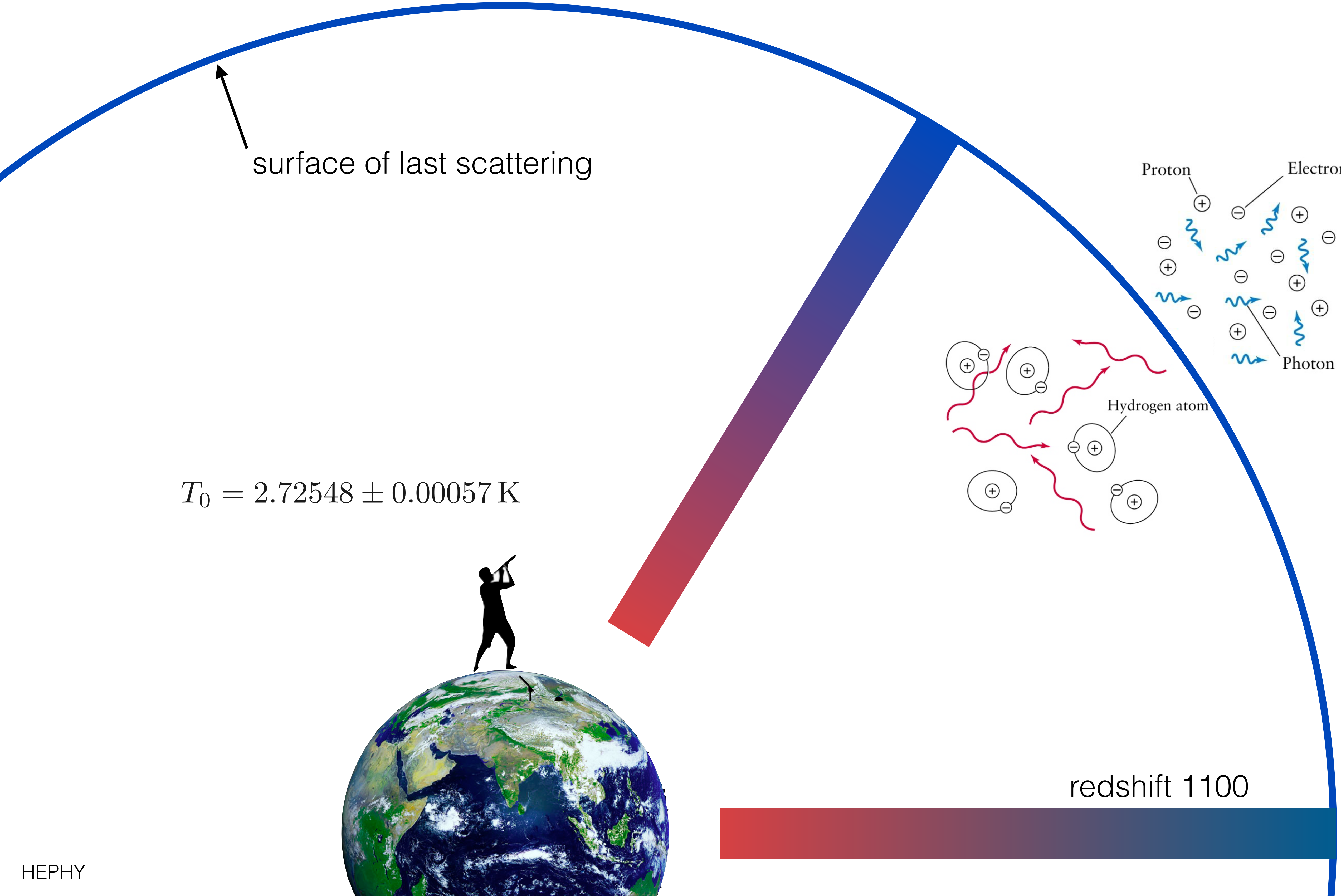


1939 H. Babcock
observing rotation
curve of Andromeda

1936 S. Smith
using 30 galaxies
of Virgo cluster

1933 F. Zwicky
using 8 galaxies
of Coma cluster

Cosmic Microwave Background (Gpc)

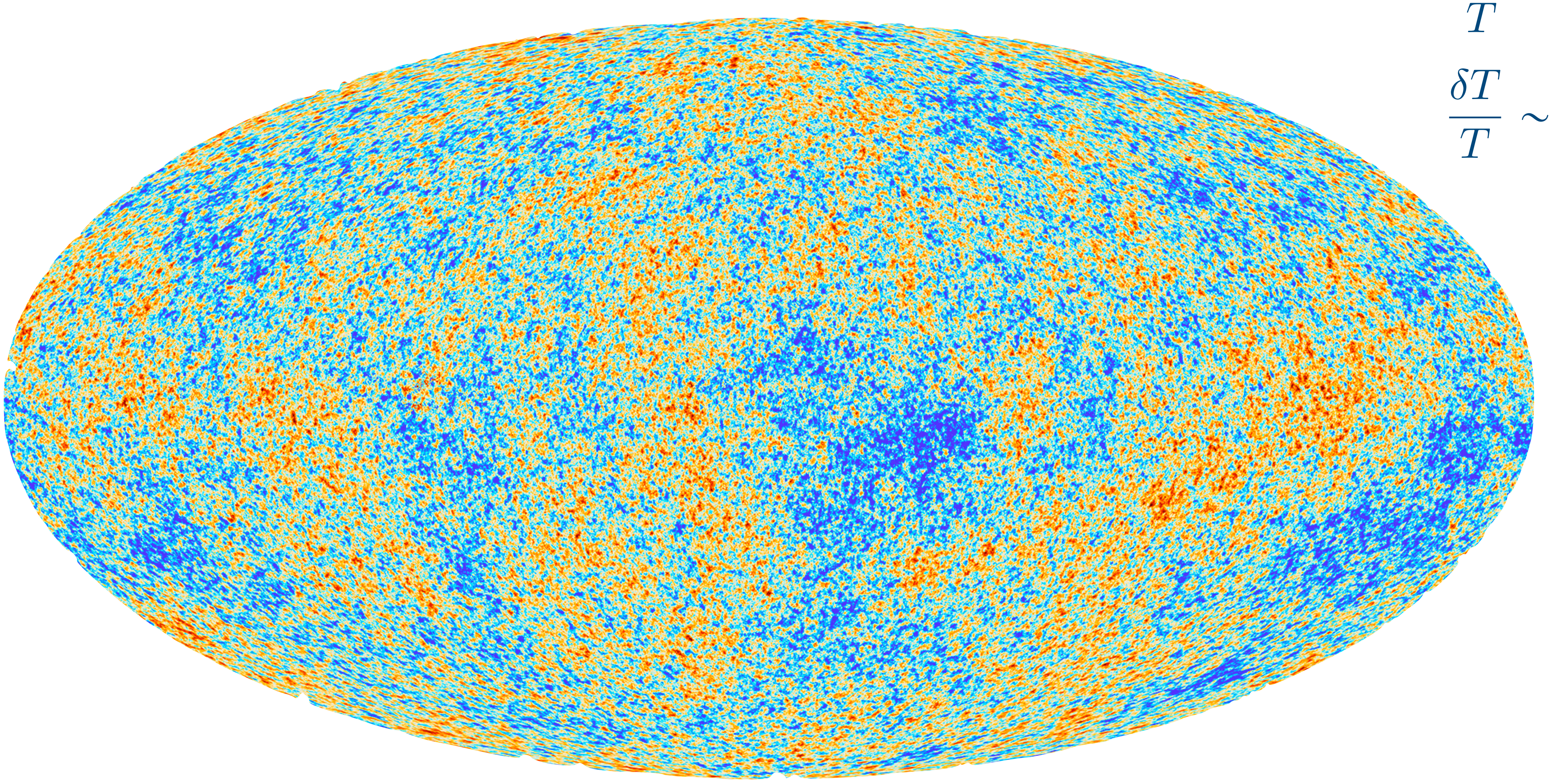


$$T_0 = 2.72548 \pm 0.00057\,\mathrm{K}$$

Cosmological scales

Cosmic Microwave Background

ESA Planck Satellite (2009-2013)



$$\frac{\delta T}{T} \sim 10^{-5}$$

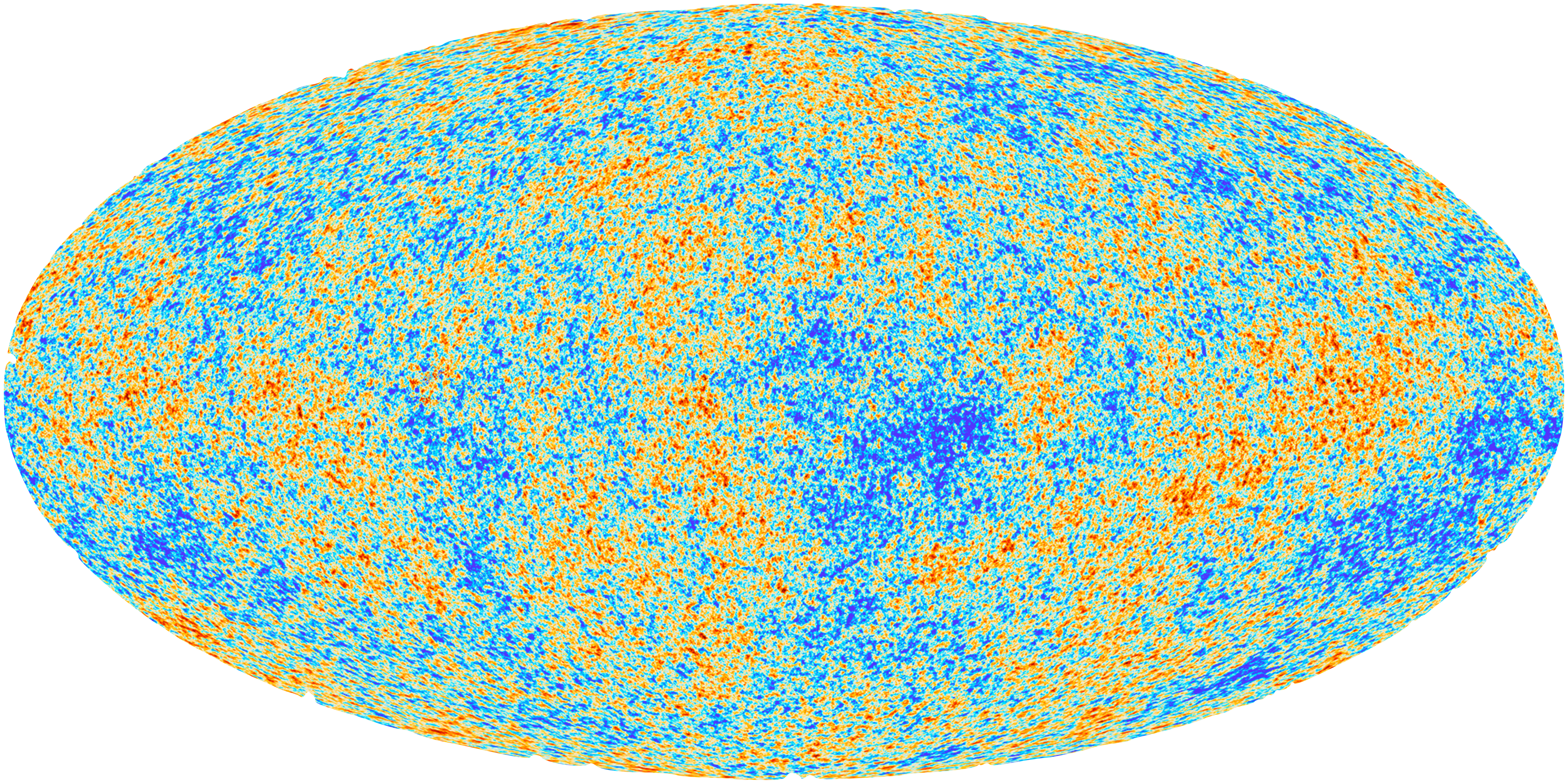
$$\frac{\delta T}{T} \sim \frac{\delta \rho_b}{\rho_b}$$

The CMB with an accuracy better then 1/100000.

Cosmological scales

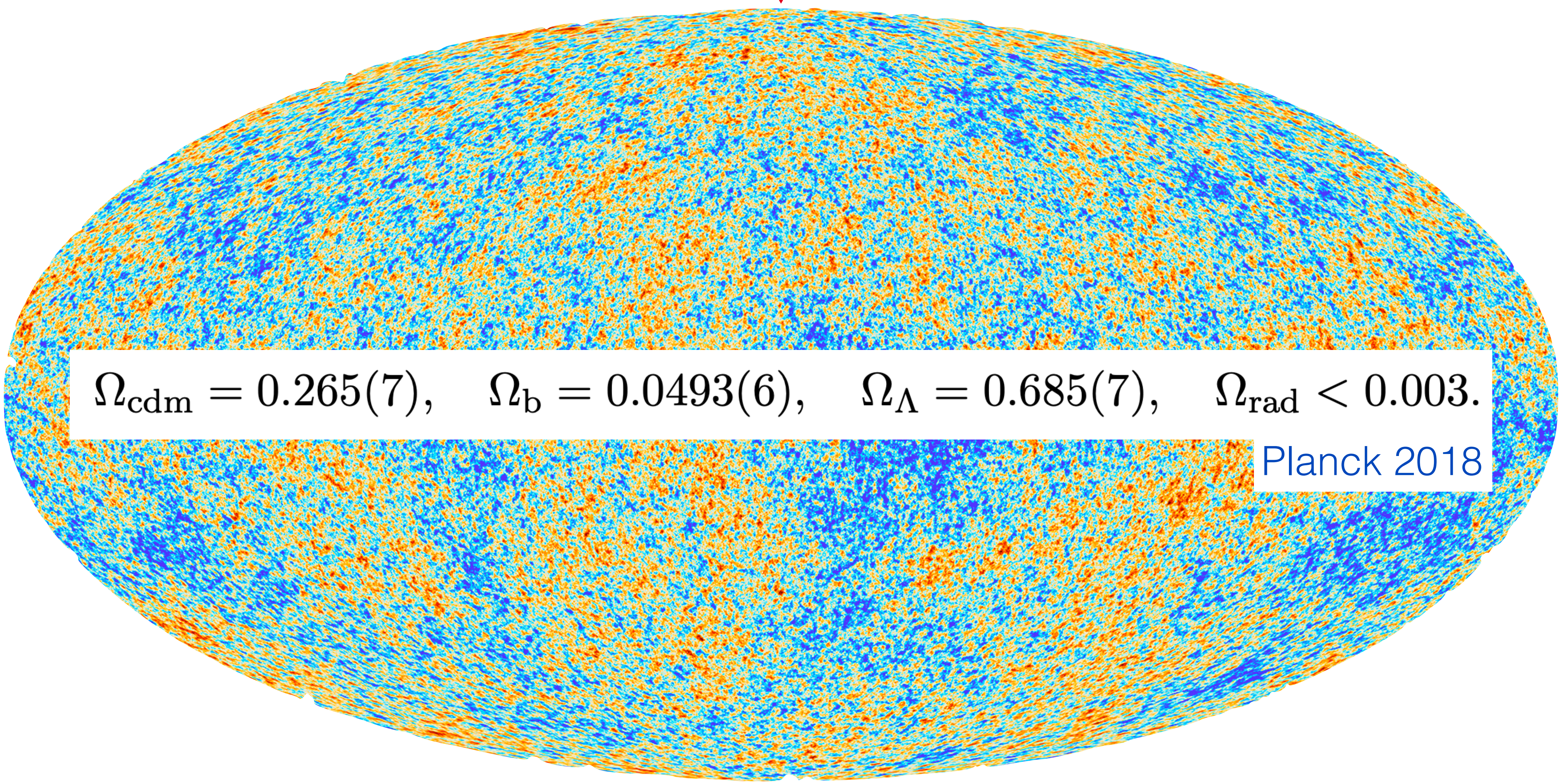
Cosmic Microwave Background

Dark Matter is the key ingredient to explain the CMB observations (linear theory)



Dark Matter is key…

… in explaining the observations of the CMB (linear theory)

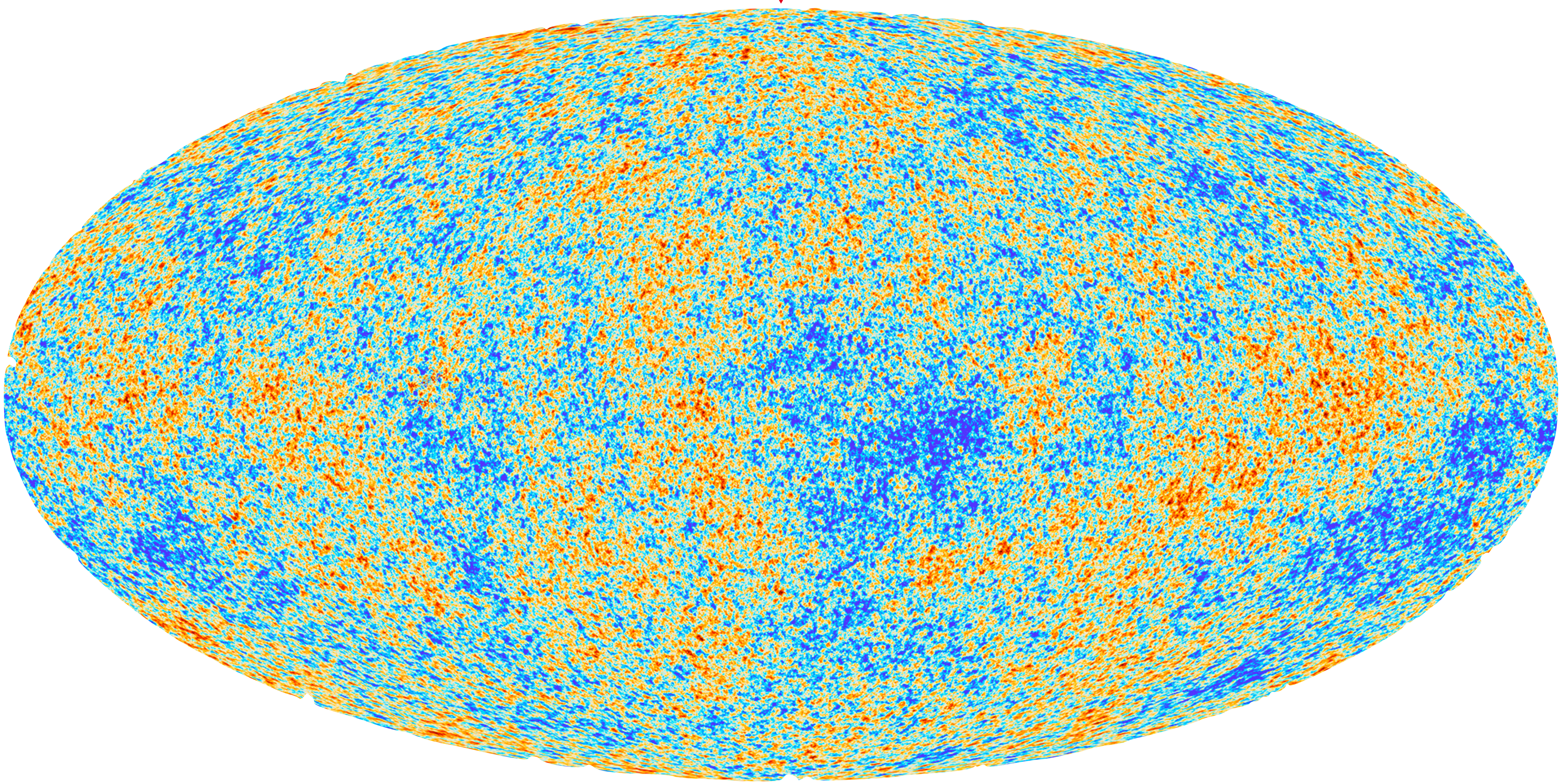


$$\Omega_{\mathrm{cdm}} = 0.265(7), \quad \Omega_{\mathrm{b}} = 0.0493(6), \quad \Omega_{\Lambda} = 0.685(7), \quad \Omega_{\mathrm{rad}} < 0.003.$$

Planck 2018

Dark Matter is key…

… in explaining the observations of the CMB (linear theory)



… in the formation of large scale structure such as galaxies and clusters of galaxies

What can Dark Matter be?

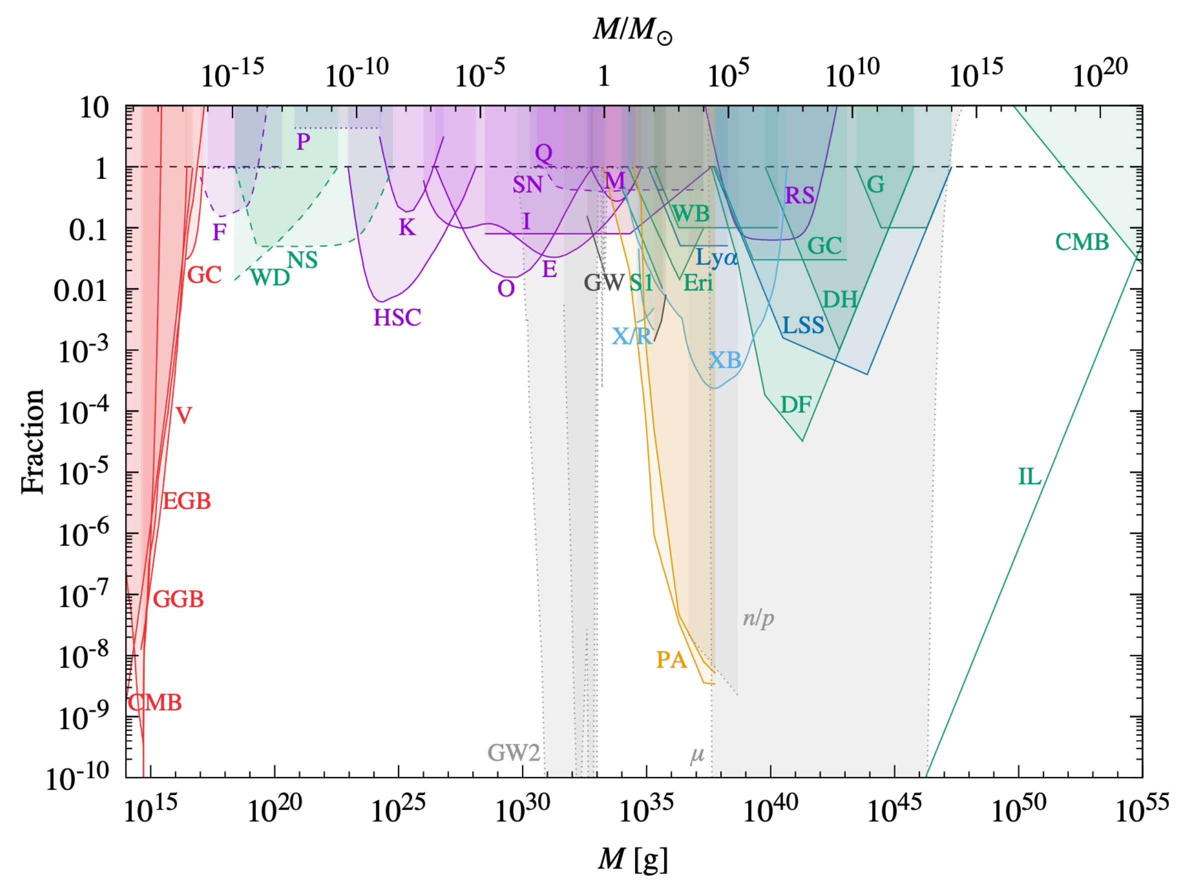
Modified Gravity?

successes on Galaxy scales,
but fails elsewhere

Primordial Black holes?

asteroid mass black holes may
still make up 100% of DM

New particle(s) of nature?



The missing mass - what is it?

New particle(s) of nature

electroweak scale WIMPs,

MeV and GeV-scale DM

axion, ALPs

keV sterile neutrinos

gravitinos

other super-WIMPs such as Dark Photons

A model beloved for its

inner beauty

$$
\begin{aligned}
\frac{1}{e}\mathscr{L}_{\text{sugra}} = &-\frac{M_P^2}{2}R + g_{ij^*}\tilde{\mathscr{D}}_\mu\phi^i\tilde{\mathscr{D}}^\mu\phi^{*j} - \frac{1}{2}g^2\left[(\mathrm{Re}f)^{-1}\right]^{ab}D_{(a)}D_{(b)} \\
&+ ig_{ij^*}\overline{\chi}_L^j\gamma^\mu\tilde{\mathscr{D}}_\mu\chi_L^i + \varepsilon^{\mu\nu\rho\sigma}\overline{\psi}_{L\mu}\gamma_\nu\tilde{\mathscr{D}}_\rho\psi_{L\sigma} \\
&- \frac{1}{4}\mathrm{Re}f_{ab}F_{\mu\nu}^{(a)}F^{\mu\nu(b)} + \frac{1}{8}\varepsilon^{\mu\nu\rho\sigma}\mathrm{Im}f_{ab}F_{\mu\nu}^{(a)}F_{\rho\sigma}^{(b)} \\
&+ \frac{i}{2}\mathrm{Re}f_{ab}\overline{\lambda}^a\gamma^\mu\tilde{\mathscr{D}}_\mu\lambda^b - e^{-1}\frac{1}{2}\mathrm{Im}f_{ab}\tilde{\mathscr{D}}_\mu\left[e\overline{\lambda}_R^a\gamma^\mu\lambda_R^b\right] \\
&+ \Bigg[-\sqrt{2}g\partial_i D_{(a)}\overline{\lambda}^a\chi_L^i + \frac{1}{4}\sqrt{2}g\left[(\mathrm{Re}f)^{-1}\right]^{ab}\partial_i f_{bc}D_{(a)}\overline{\lambda}^c\chi_L^i \\
&+ \frac{i}{16}\sqrt{2}\partial_i f_{ab}\overline{\lambda}^a[\gamma^\mu,\gamma^\nu]\chi_L^i F_{\mu\nu}^{(b)} - \frac{1}{2M_P}gD_{(a)}\overline{\lambda}_R^a\gamma^\mu\psi_\mu \\
&- \frac{i}{2M_P}\sqrt{2}g_{ij^*}\tilde{\mathscr{D}}_\mu\phi^{*j}\overline{\psi}_\nu\gamma^\mu\gamma^\nu\chi_L^i + \text{h.c.}\Bigg] \\
&- \frac{i}{8M_P}\mathrm{Re}f_{ab}\overline{\psi}_\mu[\gamma^m,\gamma^n]\gamma^\mu\lambda^a F_{mn}^{(b)} \\
&- e^{K/2M_P^2}\Bigg[\frac{1}{4M_P^2}W^*\overline{\psi}_{R\mu}[\gamma^\mu,\gamma^\nu]\psi_{L\nu} - \frac{1}{2M_P}\sqrt{2}D_iW\overline{\psi}_\mu\gamma^\mu\chi_L^i \\
&+ \frac{1}{2}\mathscr{D}_iD_jW\overline{\chi_L^c}^i\chi_L^j + \frac{1}{4}g^{ij^*}D_{j^*}W^*\partial_i f_{ab}\overline{\lambda}_R^a\lambda_L^b + \text{h.c.}\Bigg] \\
&- e^{K/M_P^2}\left[g^{ij^*}(D_iW)(D_{j^*}W^*) - 3\frac{|W|^2}{M_P^2}\right] + \mathcal{O}(M_P^{-2}),
\end{aligned}
$$

Supergravity

A model beloved for its
outer beauty

$$\mathcal{L} = \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2}m_S^2 S^2 - \lambda S^2 (H^\dagger H)$$

Higgs portal

A model beloved for its

outer beauty

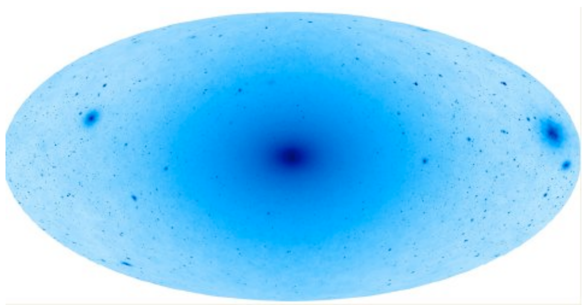
$$\mathcal{L} = \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2}m_S^2 S^2 - \lambda S^2 (H^\dagger H)$$

=> experiment decides!

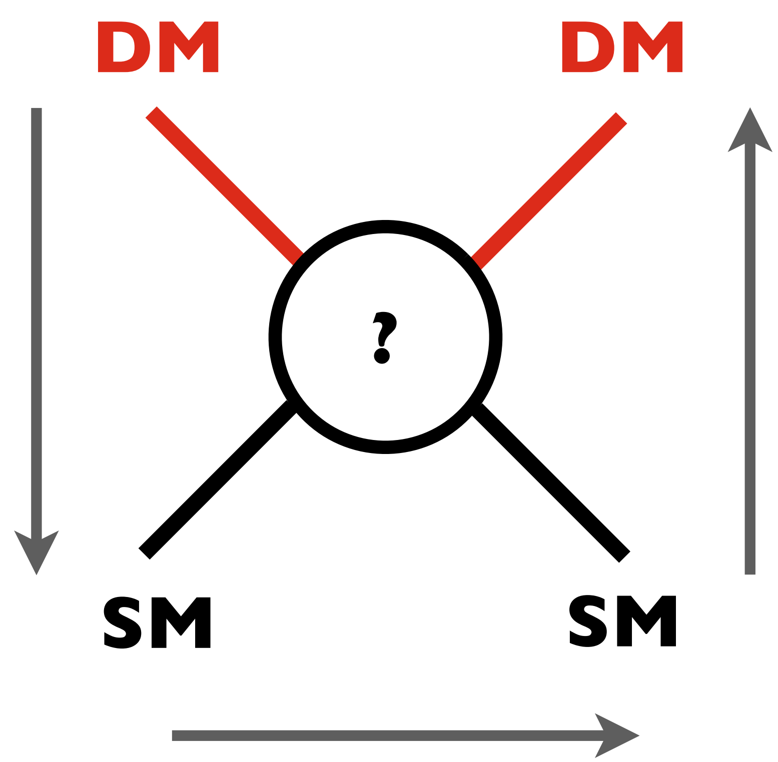
Higgs portal

Where to look for a signal?

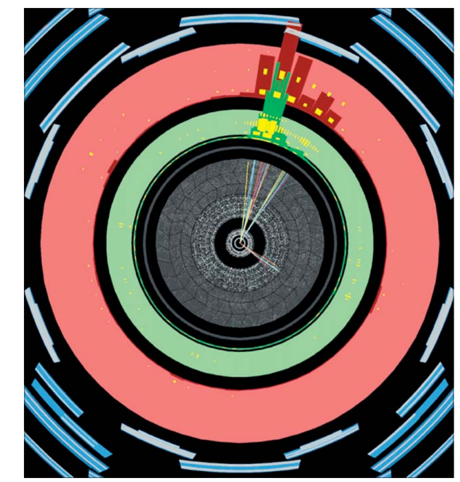
Look anywhere you can!



primordial
and galactic
annihilation



production
at colliders

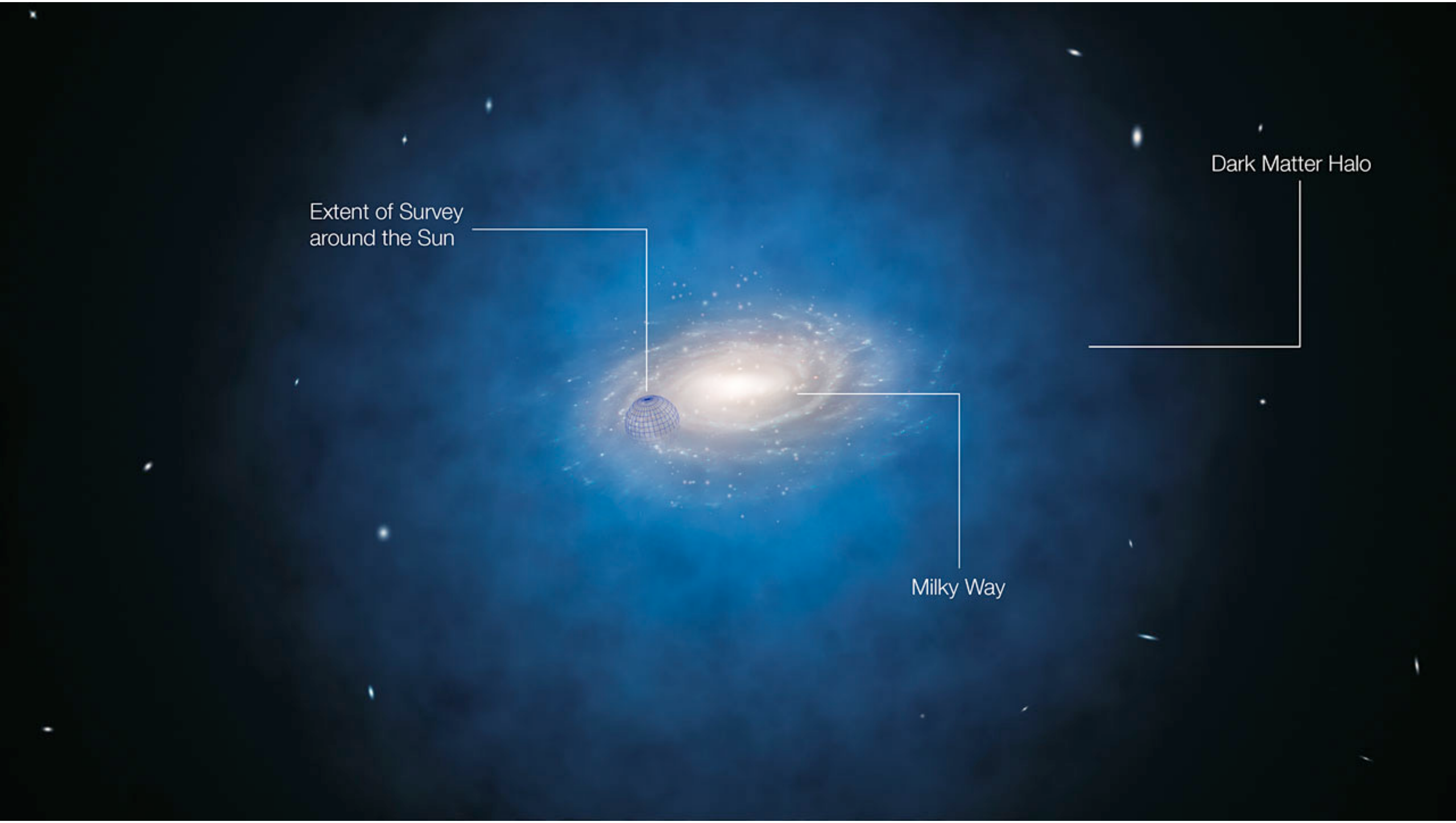


DM-nucleus or electron scattering

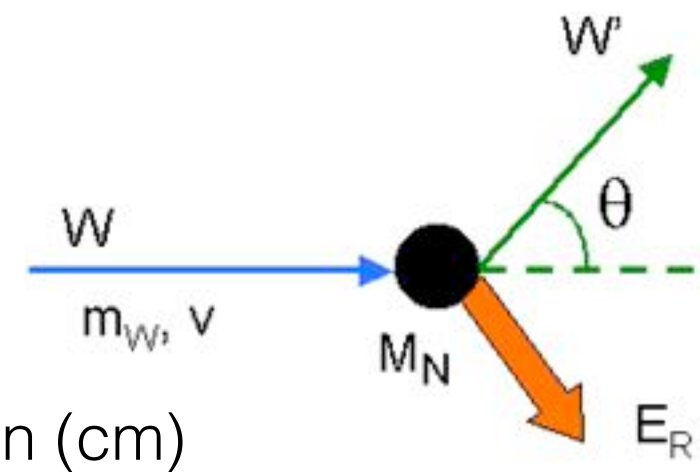
@ HEPHY:
experimental groups
CRESST / COSINUS

take this as an example

Detecting DM particles from the halo



DM Direct Detection



~ keV

Basic idea

Detection Rate = particle flux (1/cm²/sec) x cross section (cm)

$$\frac{dR(t)}{dE_R} = N_T \frac{\rho_0}{m_{\rm DM}} \int_{v \geqslant v_{\rm min}} d^3\mathbf{v}\, v\, f_{\rm LAB}(\mathbf{v}) \frac{d\sigma}{dE_R}$$

[cpd/kg/keV]

Astrophysics

local DM density

DM velocity distribution in the LAB frame

recoil cross section

Particle Physics

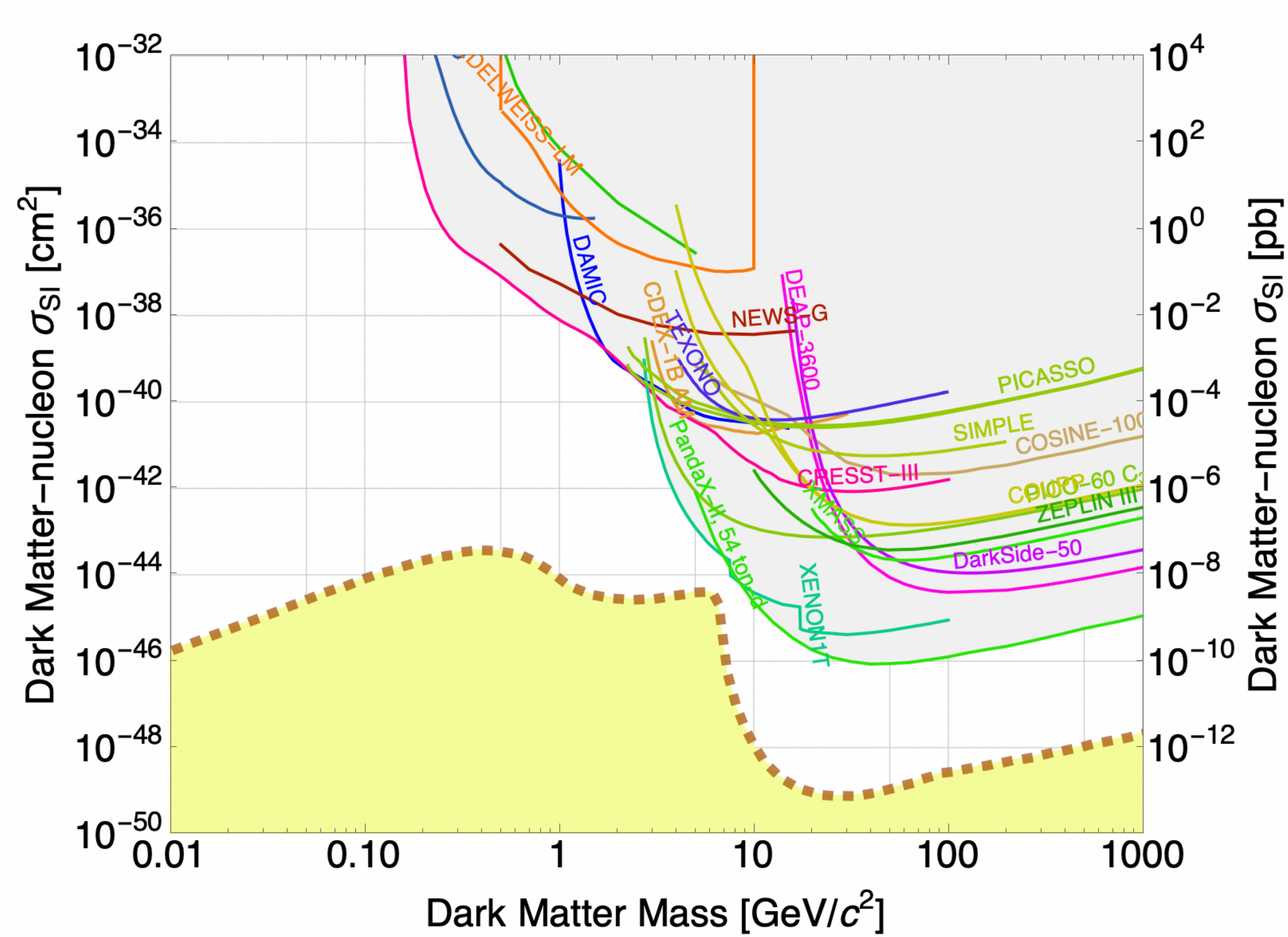
Contributions to f(v)

- virialized component
- substructure $(p < 10^{-4})$
- debris flow, streams

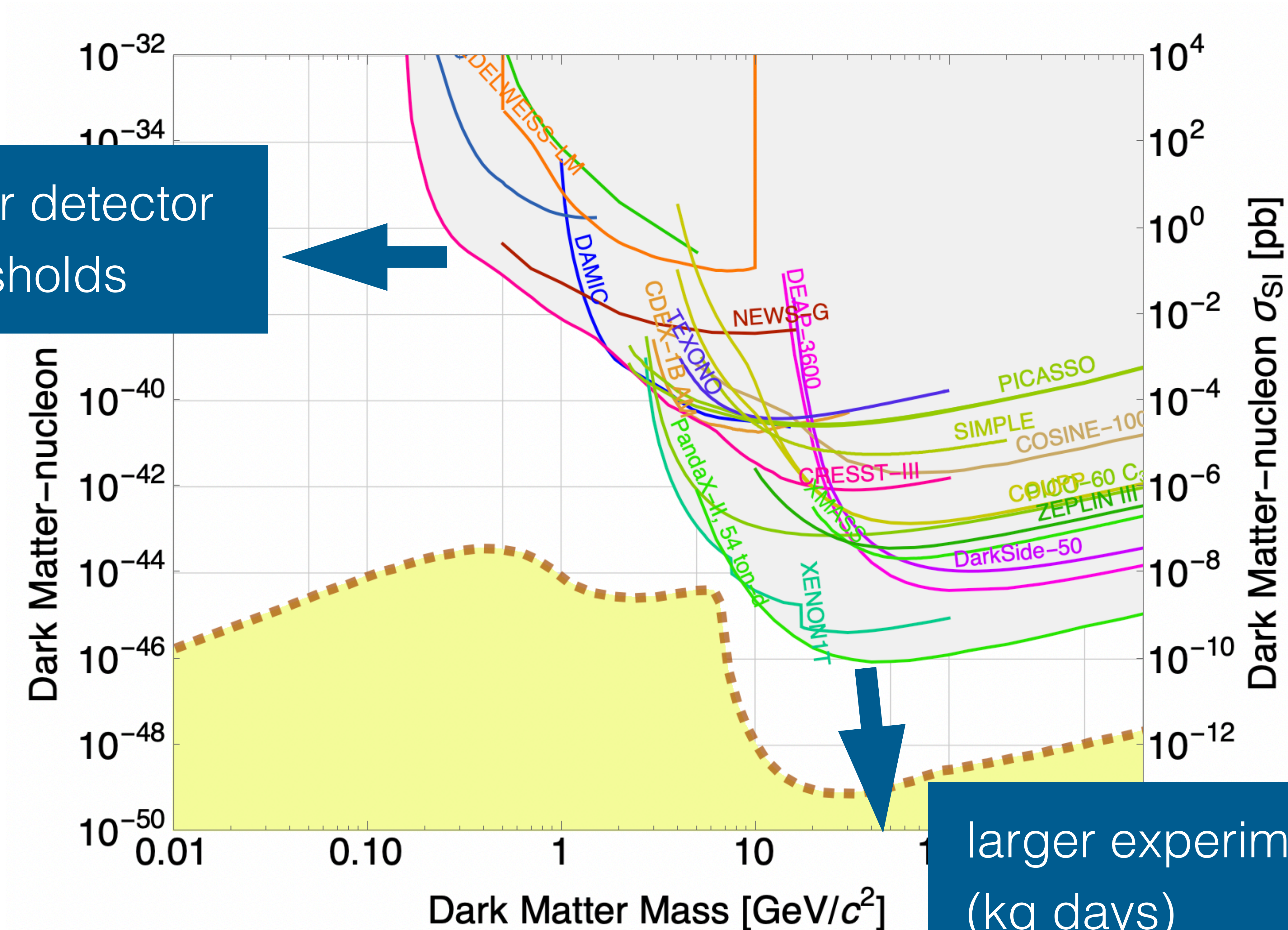
Very little is known

- largely dissipationless
- stable on cosmological timescales

Direct detection low-mass frontier



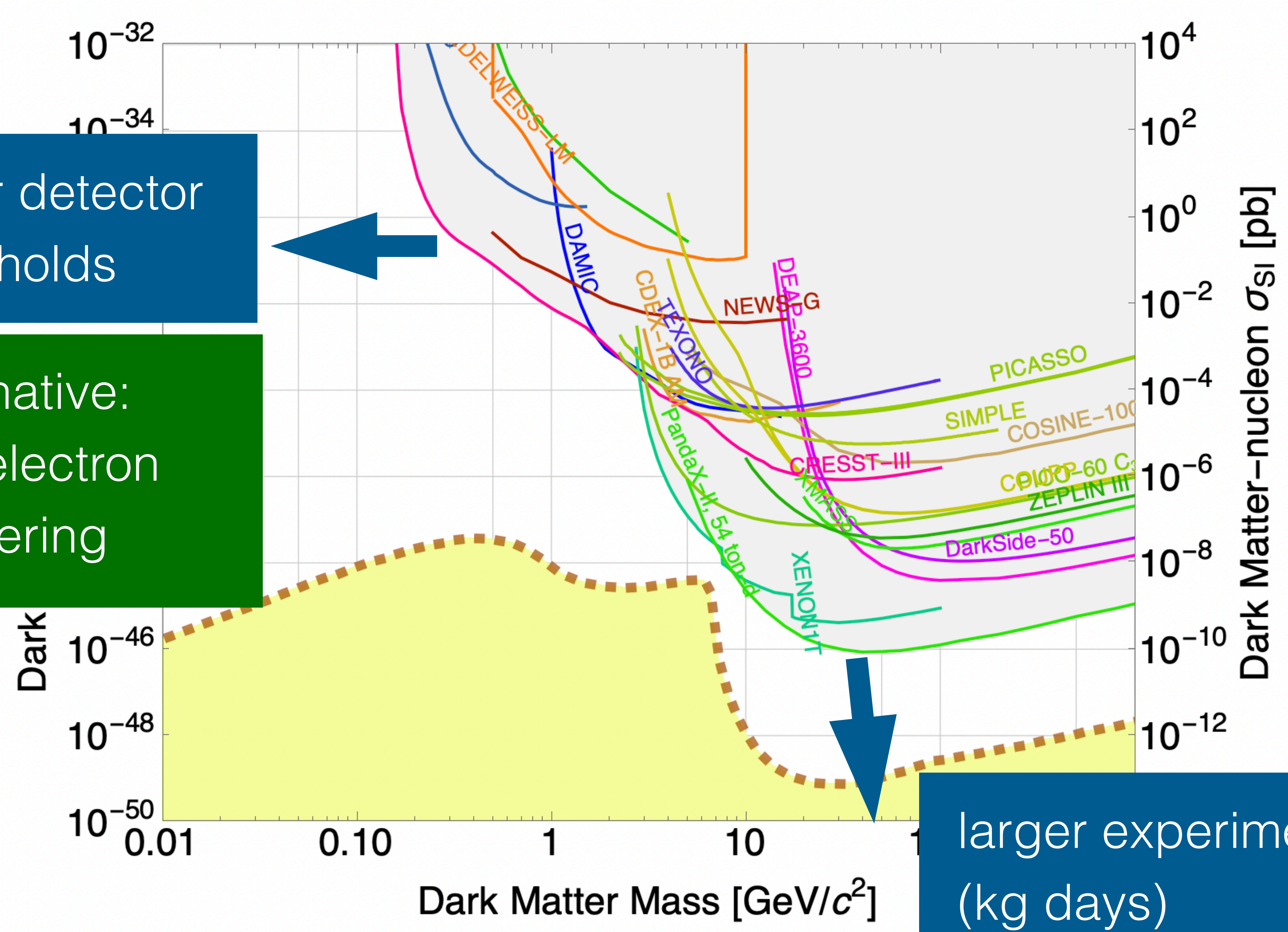
Direct detection low-mass frontier



lower detector thresholds

larger experiments (kg days)

Direct detection low-mass frontier



lower detector thresholds

alternative: DM-electron scattering

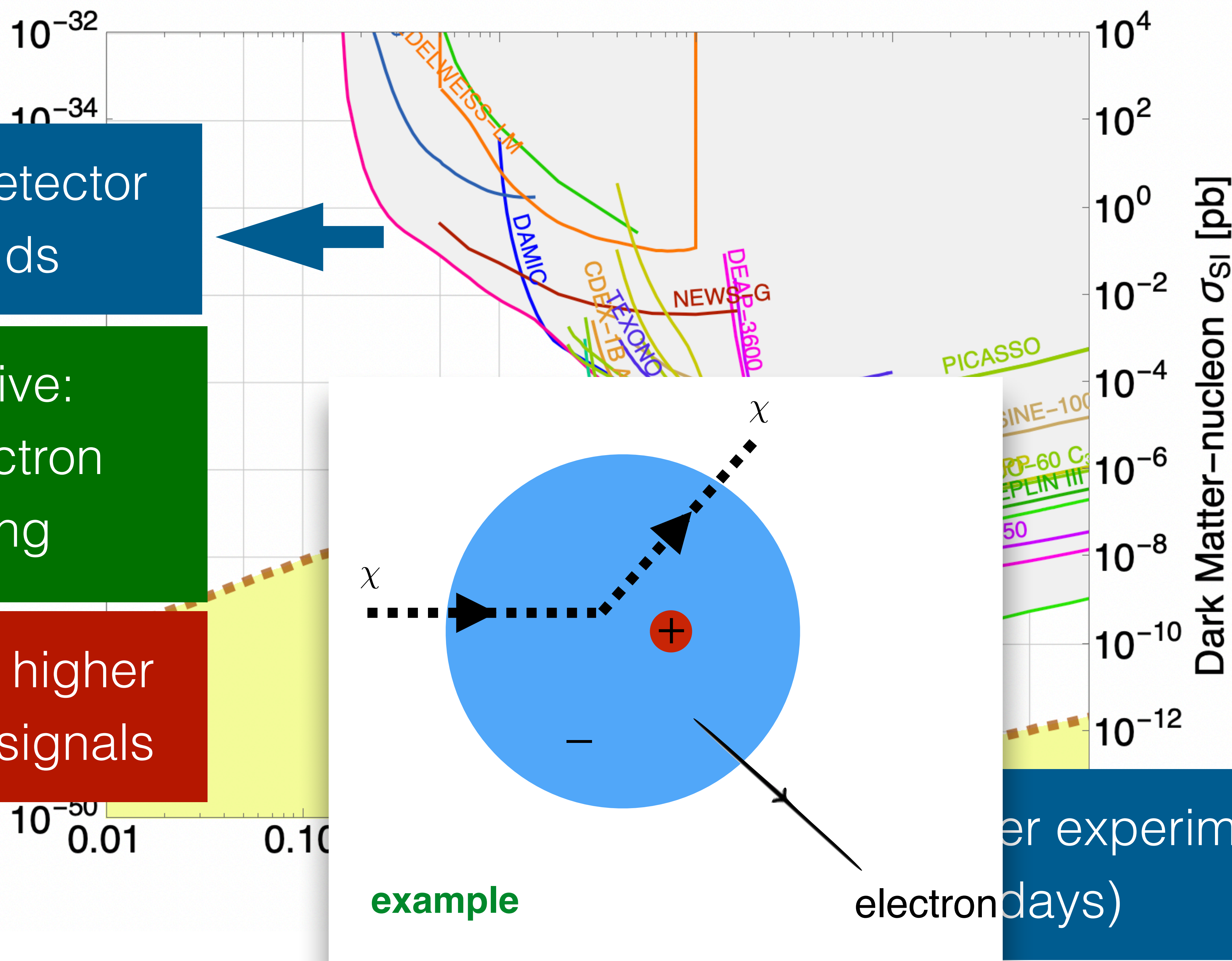
larger experiments (kg days)

Direct detection low-mass frontier

lower detector thresholds

alternative: DM-electron scattering

intrinsic higher energy signals



er experiments
days)

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