Illuminating the dark: searches for dark matter in the Milky Way

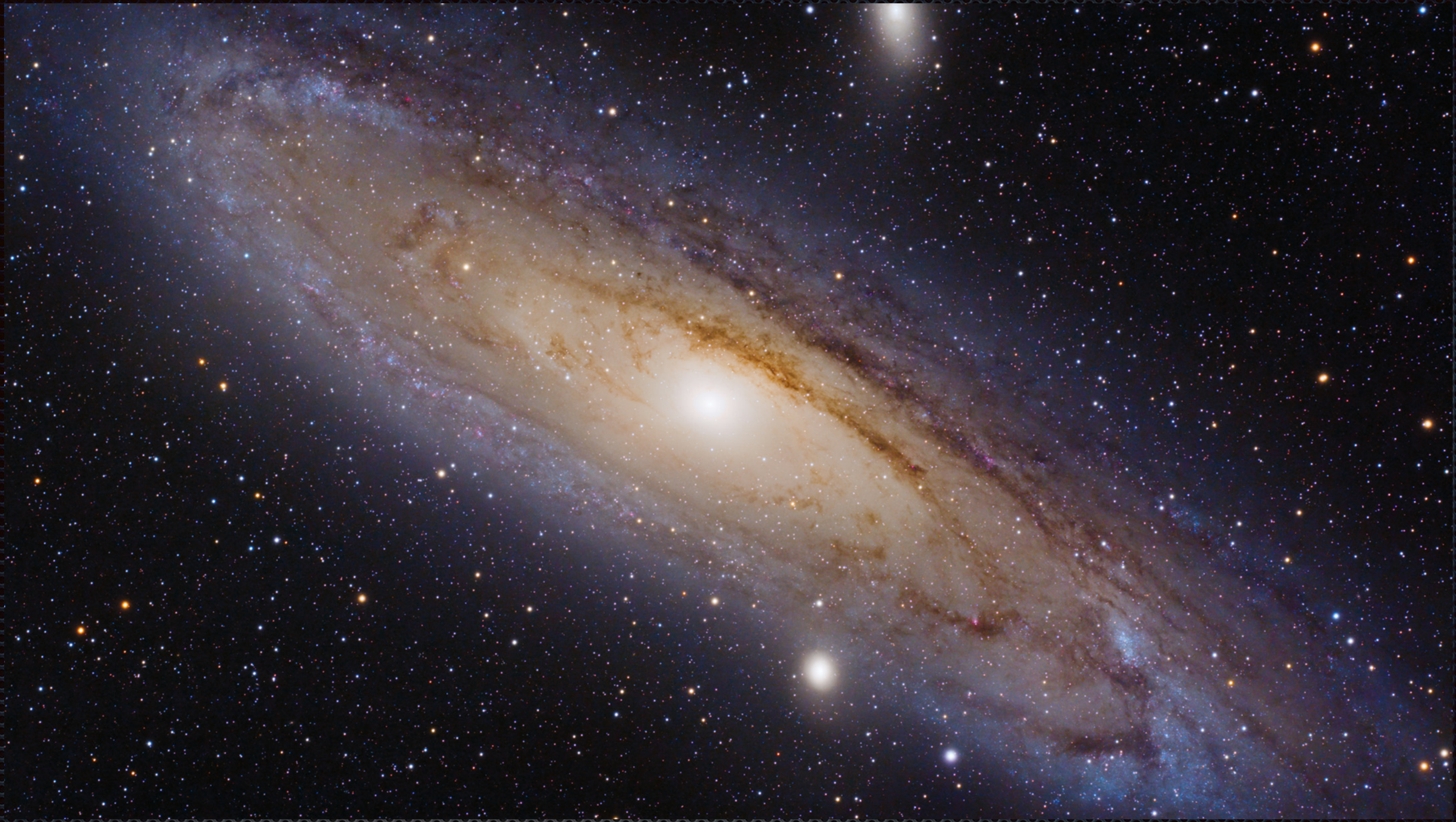
Laura Baudis
University of Zurich

European Research Council
Established by the European Commission

University of Zurich

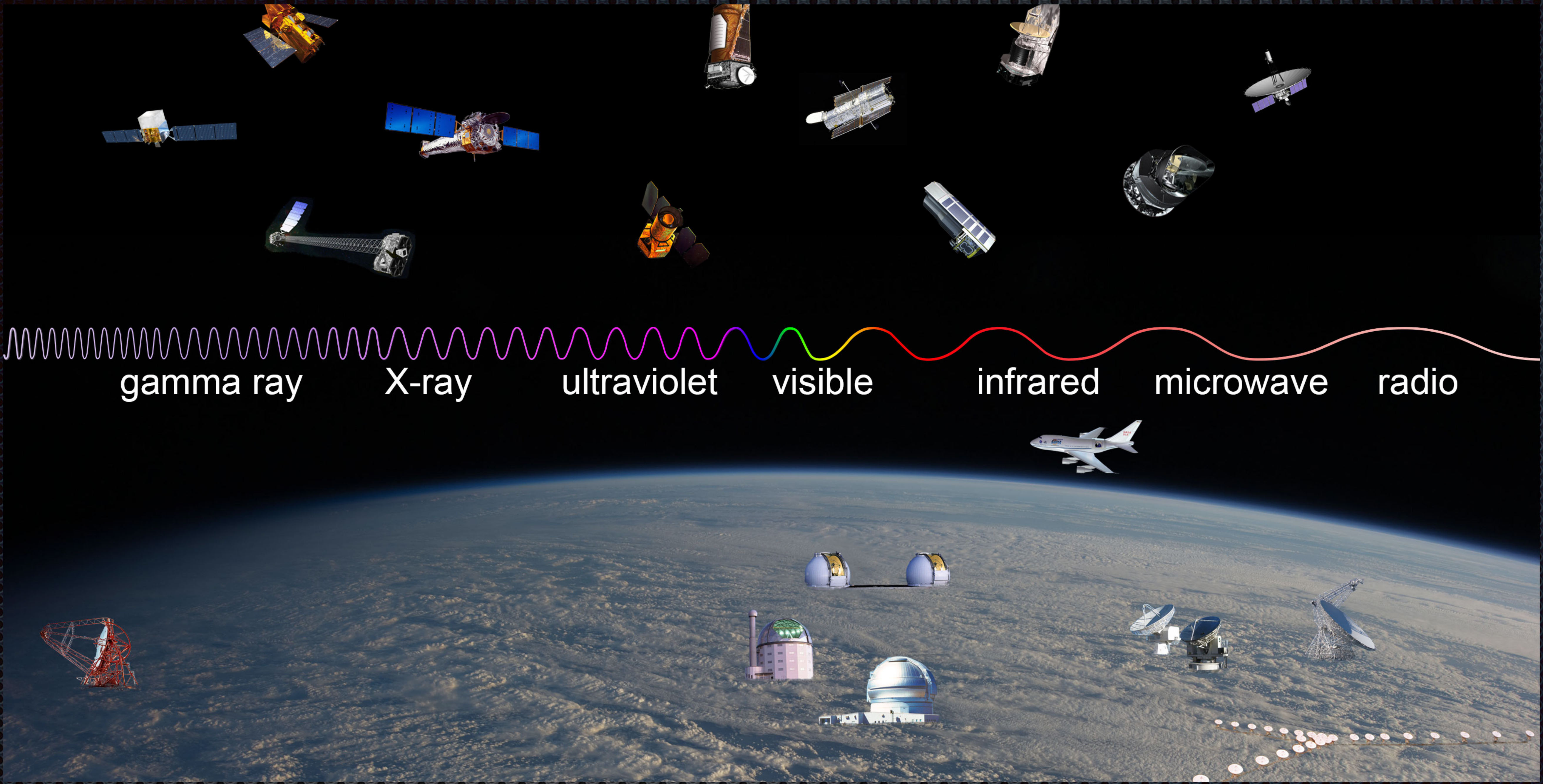

NASA and ESA image

When you look at the sky in a dark, clear night…



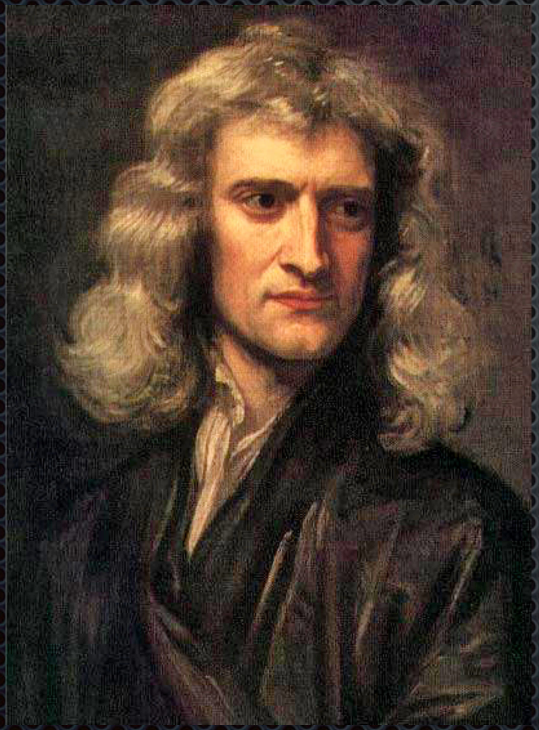
1 light year = 9.5 trillion kilometres

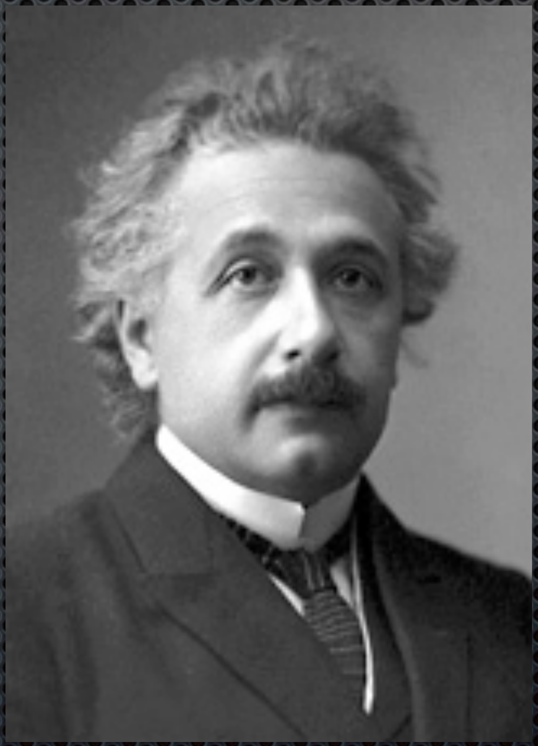
Andromeda, our neighbour, 2 million light years away



Mapping the visible Universe

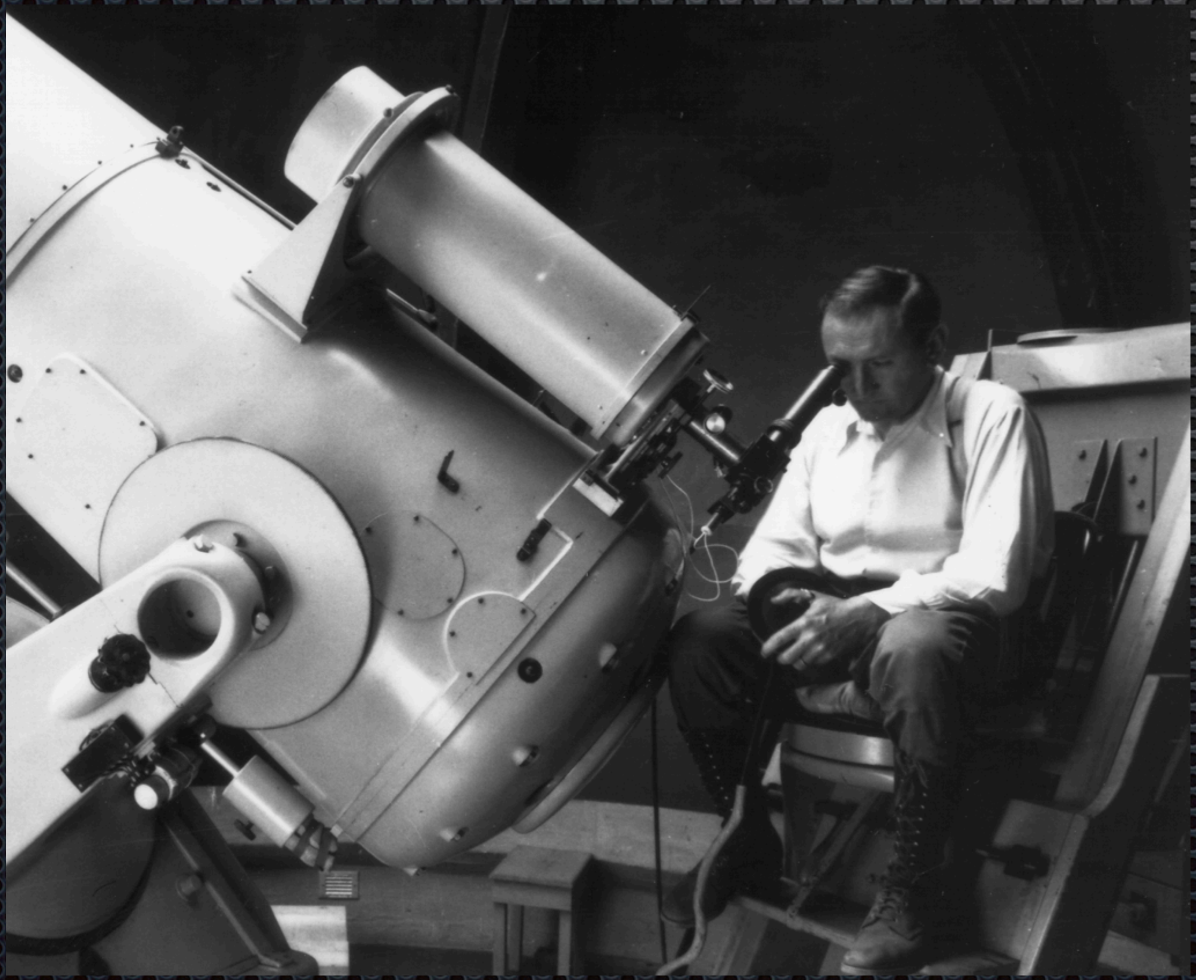
Most of the matter (85%) is *invisible or dark*

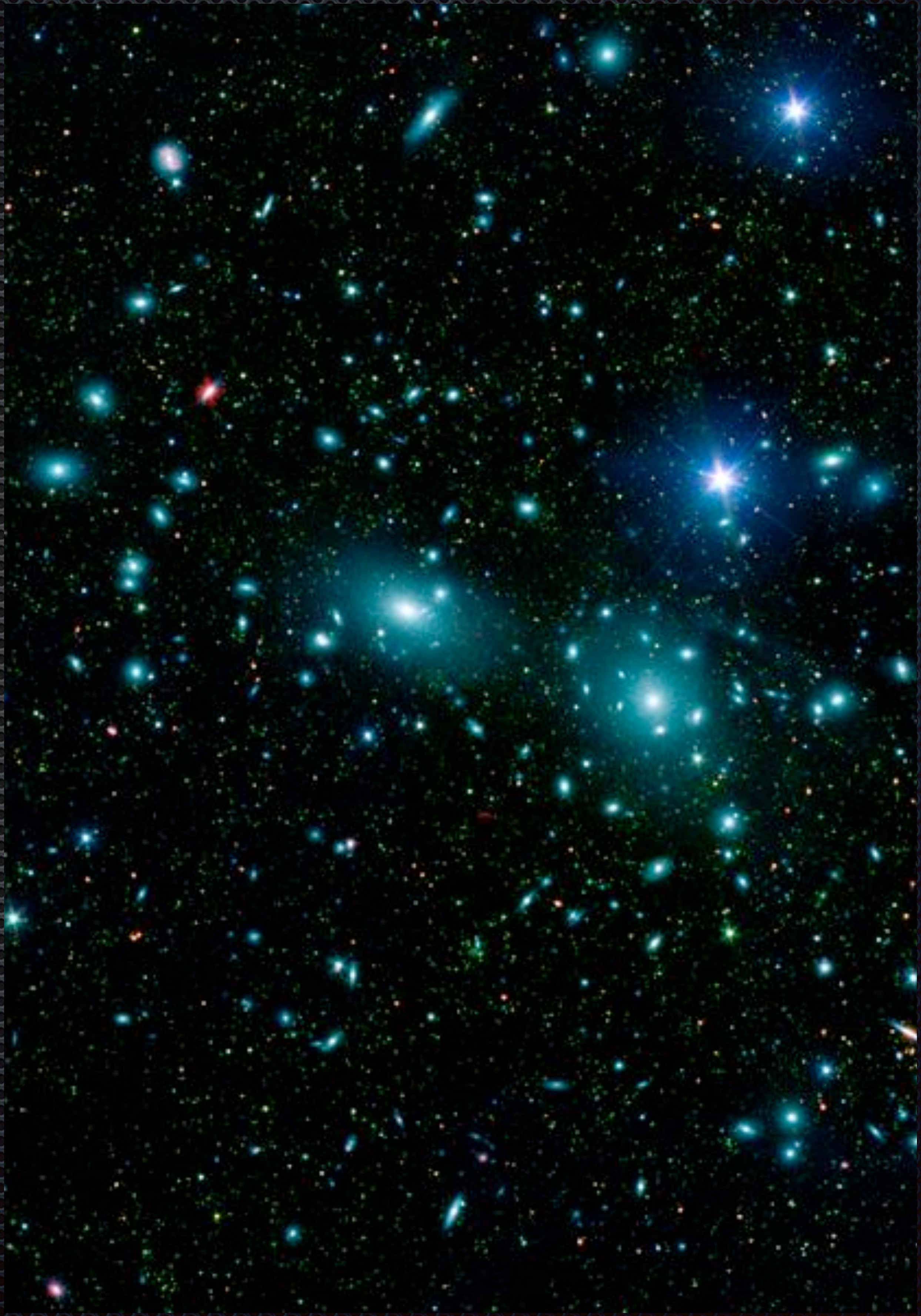




Dark Matter Map in Galaxy Cluster Abell 1689
Hubble Space Telescope ACS/WFC
NASA, ESA, and D. Coe (JPL/Caltech and STScI)

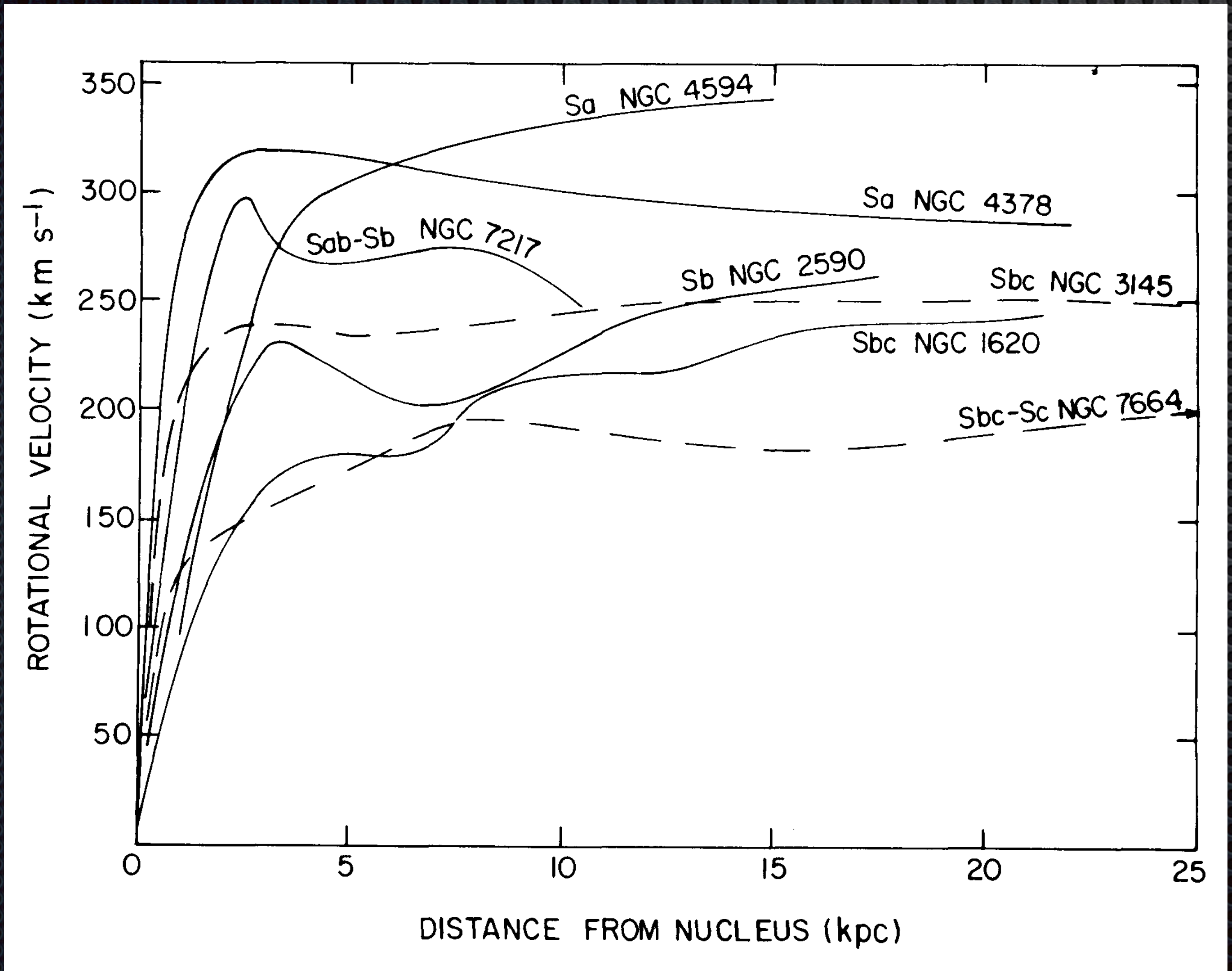
Fritz Zwicky: Coma cluster





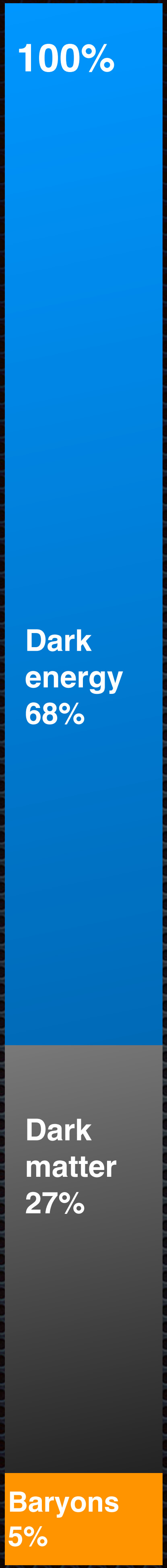
Dark matter in galaxies

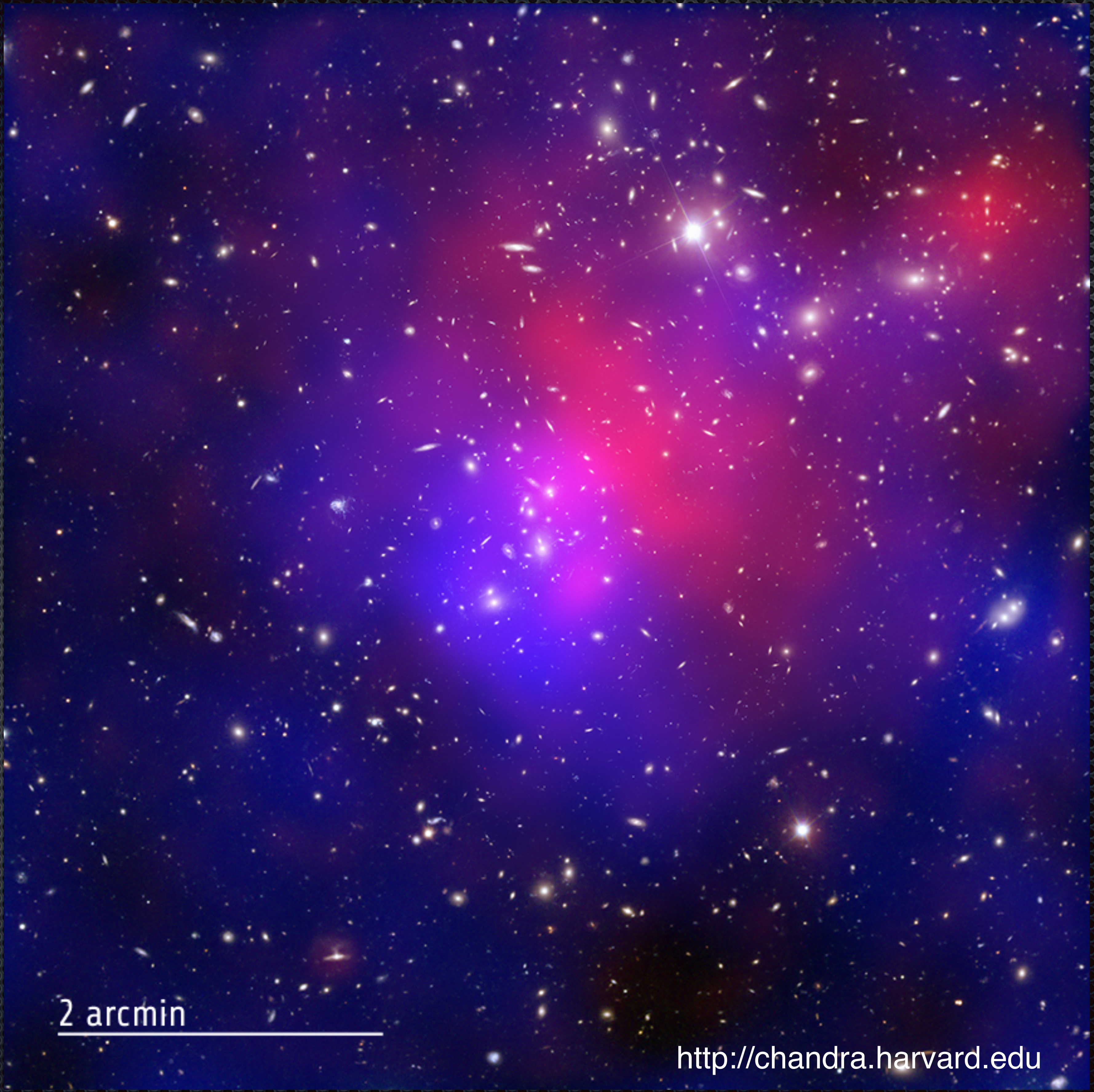
Vera Rubin: "In a spiral galaxy, *the ratio of dark-to-light matter is about a factor of 10*. That's probably a good number for the ratio of our ignorance-to-knowledge. *We're out of kindergarten, but only in about third grade.*"



Vera Rubin, Kent Ford, Norbert Thonnard, The Astrophysical Journal 1978

Dark matter in clusters of galaxies





Pandora's cluster of galaxies

3.5 billion light years

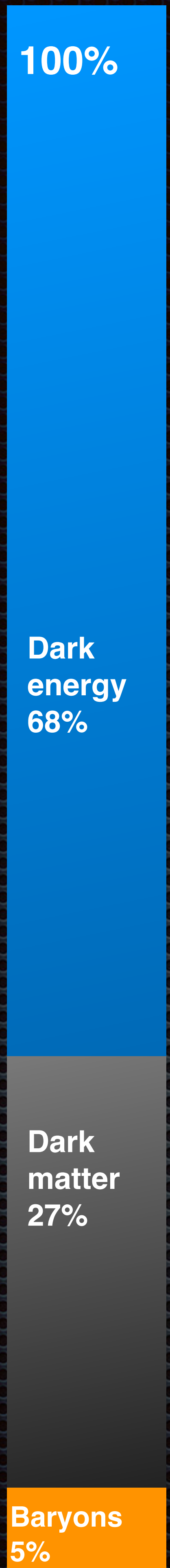
Blue: dark matter

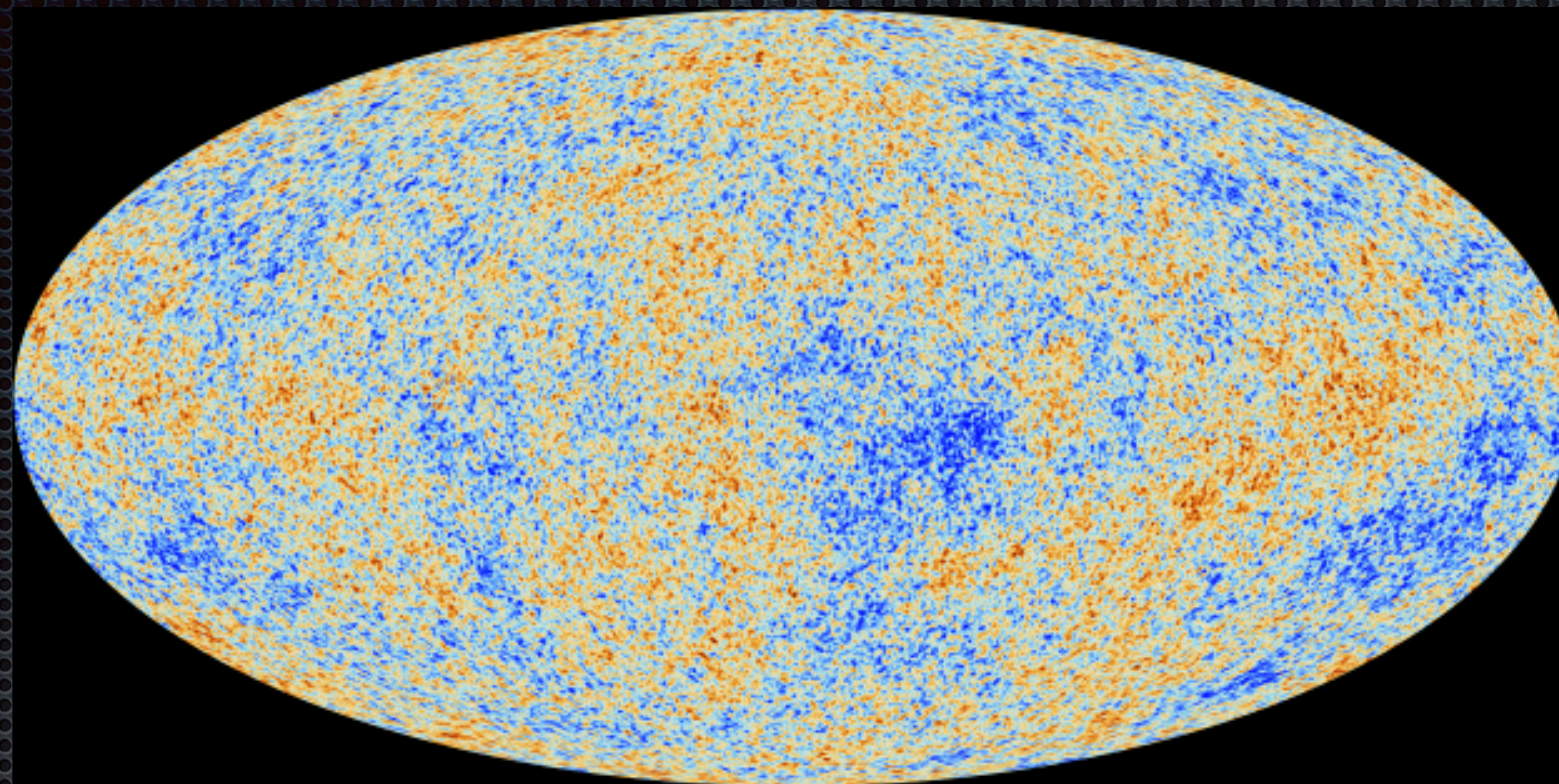
Red: hot X-ray gas

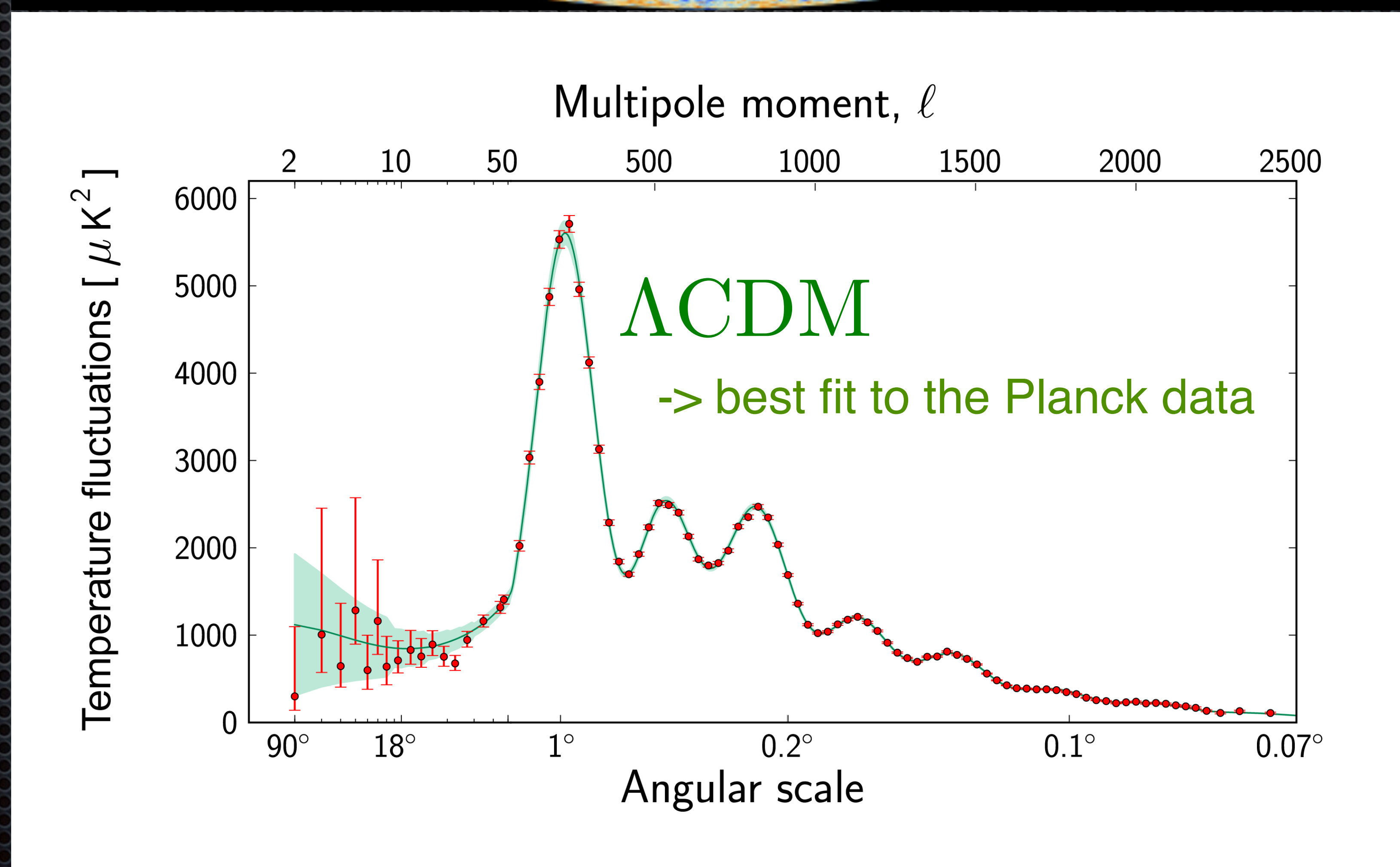
Optical: galaxies

4 clusters involved in the collision

Standard model of cosmology



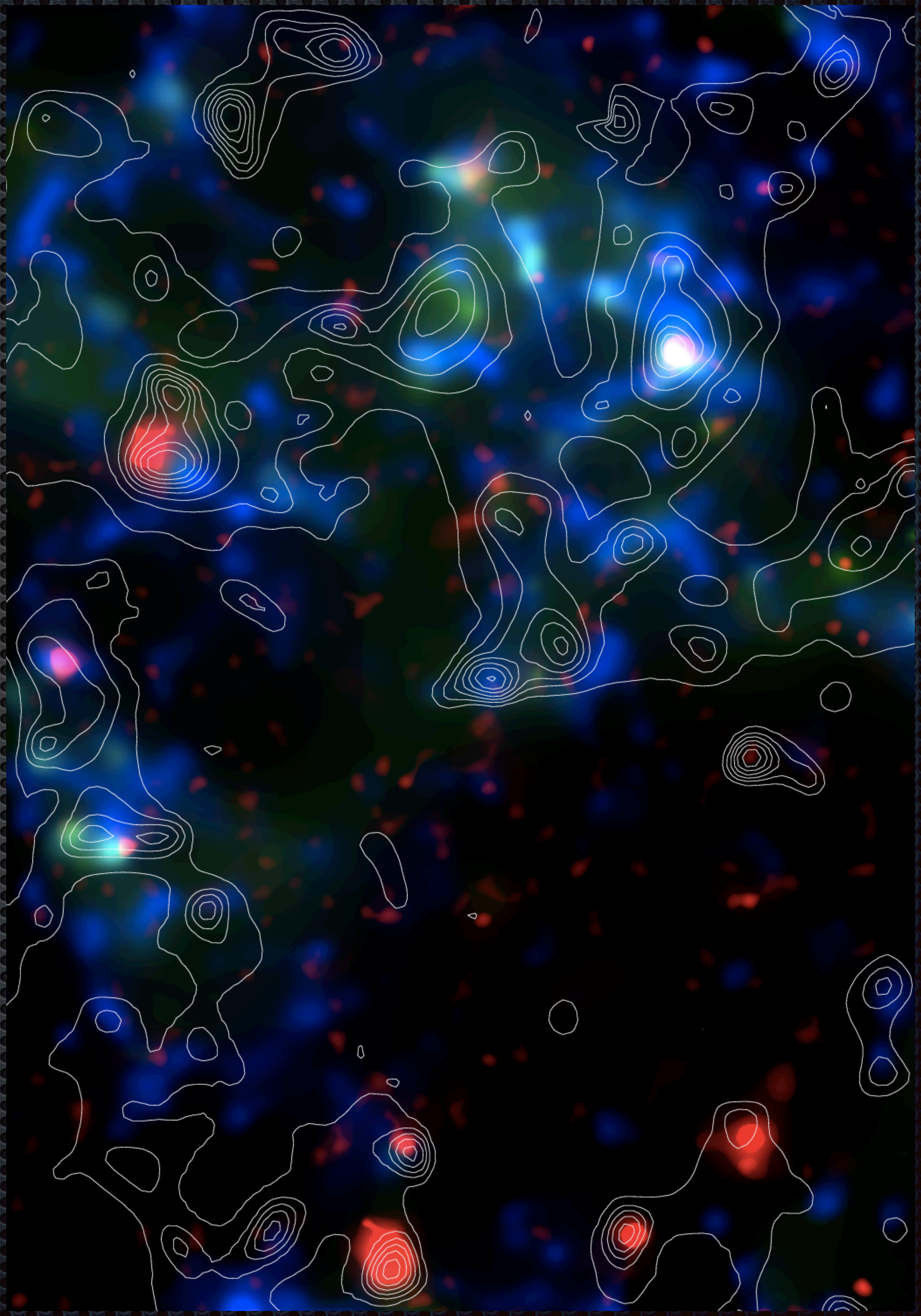




The cosmic microwave background

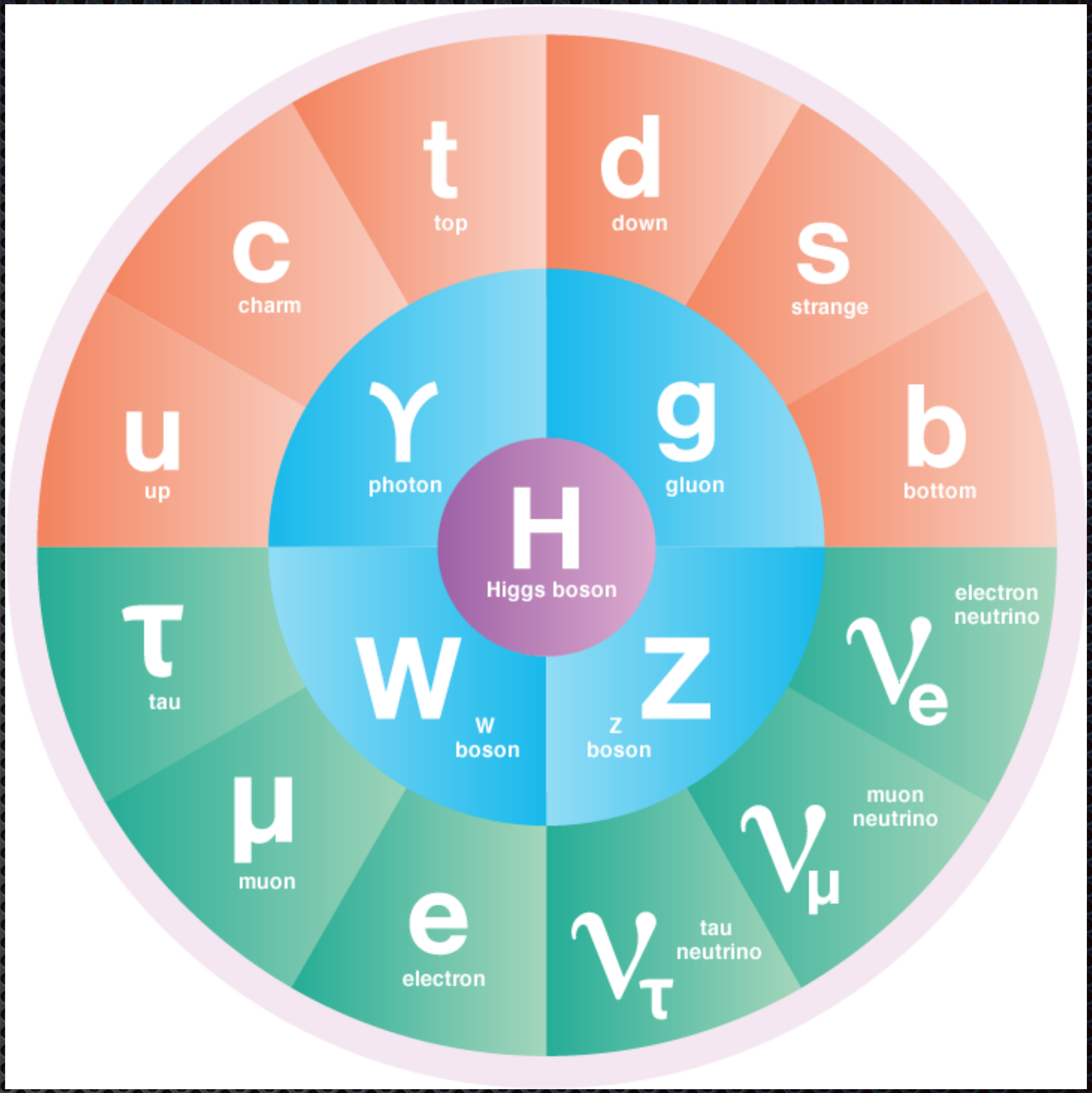
Dark matter forms structures and galaxies

But:
what is it made of?



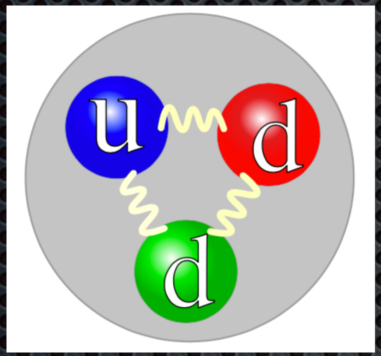
HST COSMOS survey; Nature 445 (2007), 268

The Standard Model of Particle Physics

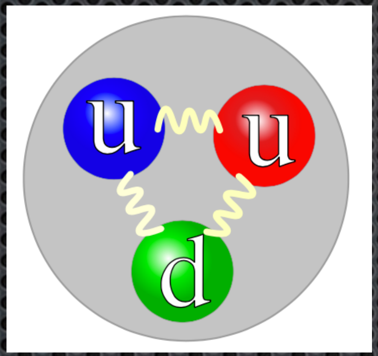


http://www.symmetrymagazine.org

Neutron



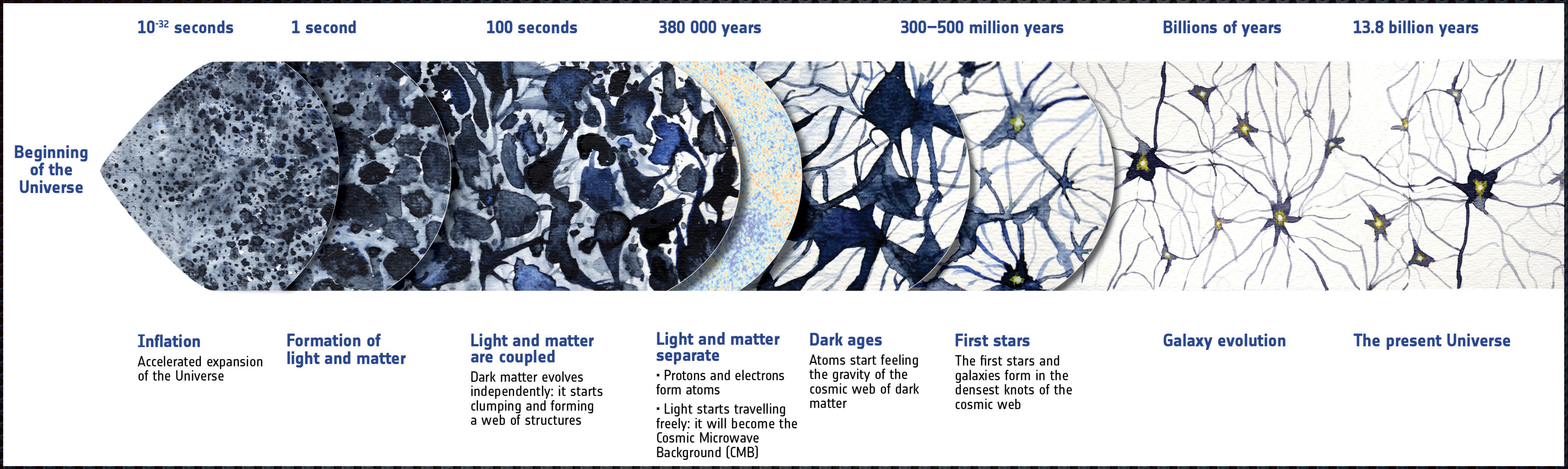
Proton



Elektron

galaxies, stars, planets, people,…

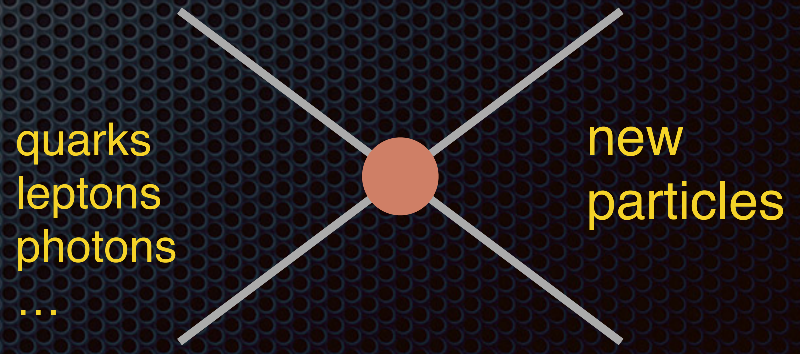
Particles from a *very early phase* of our Universe



- **A 'thermal relic' from an early period in our Universe**

  when the average temperature was $T \sim 10^{15}$ K ~ 100 GeV

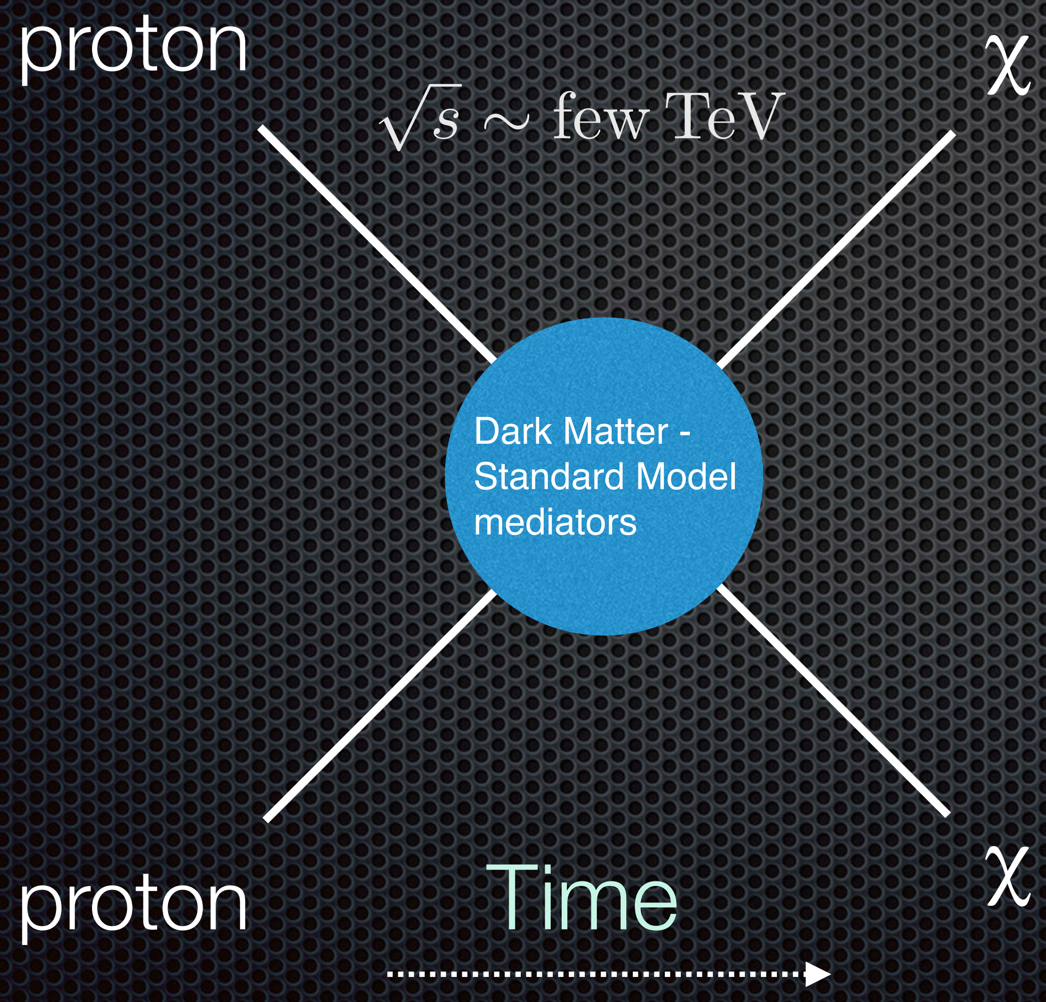
- No particle in the Standard Model is a viable candidate
- **Our young Universe was hot enough to create new, massive particles**

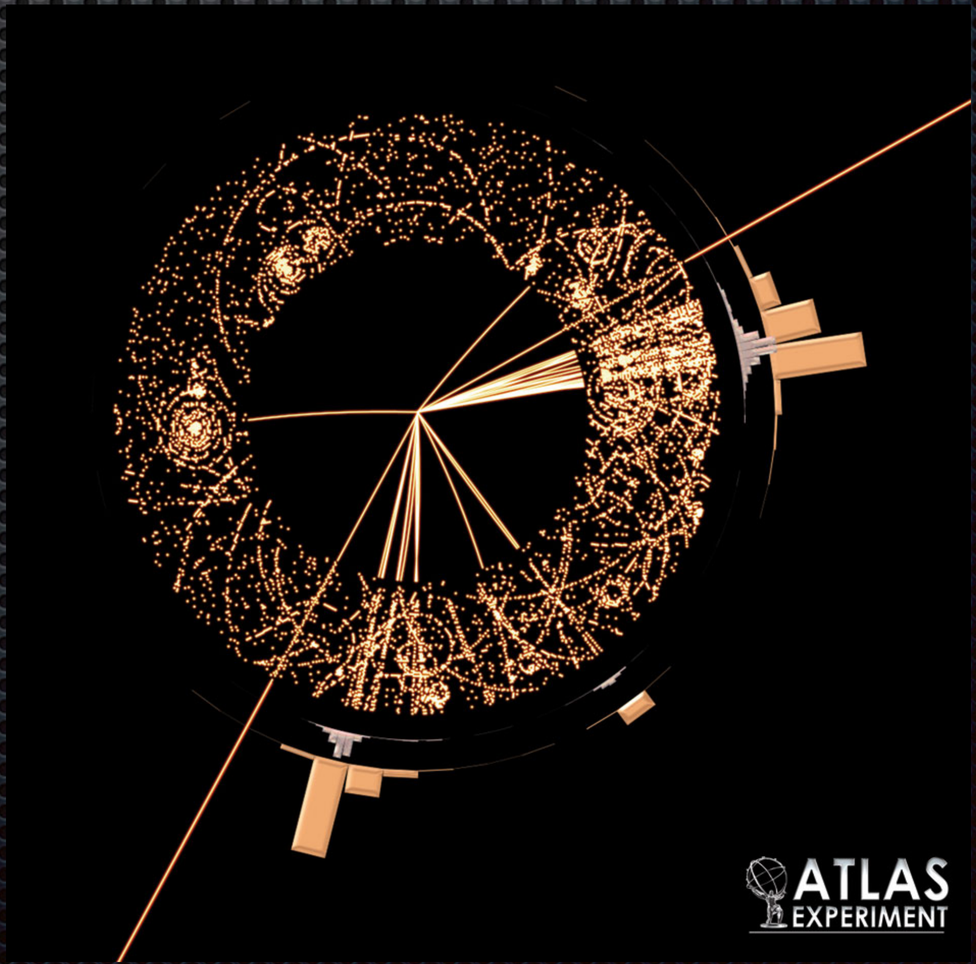


These *dark matter particles* make up the halo of our Milky Way

How to make them visible?

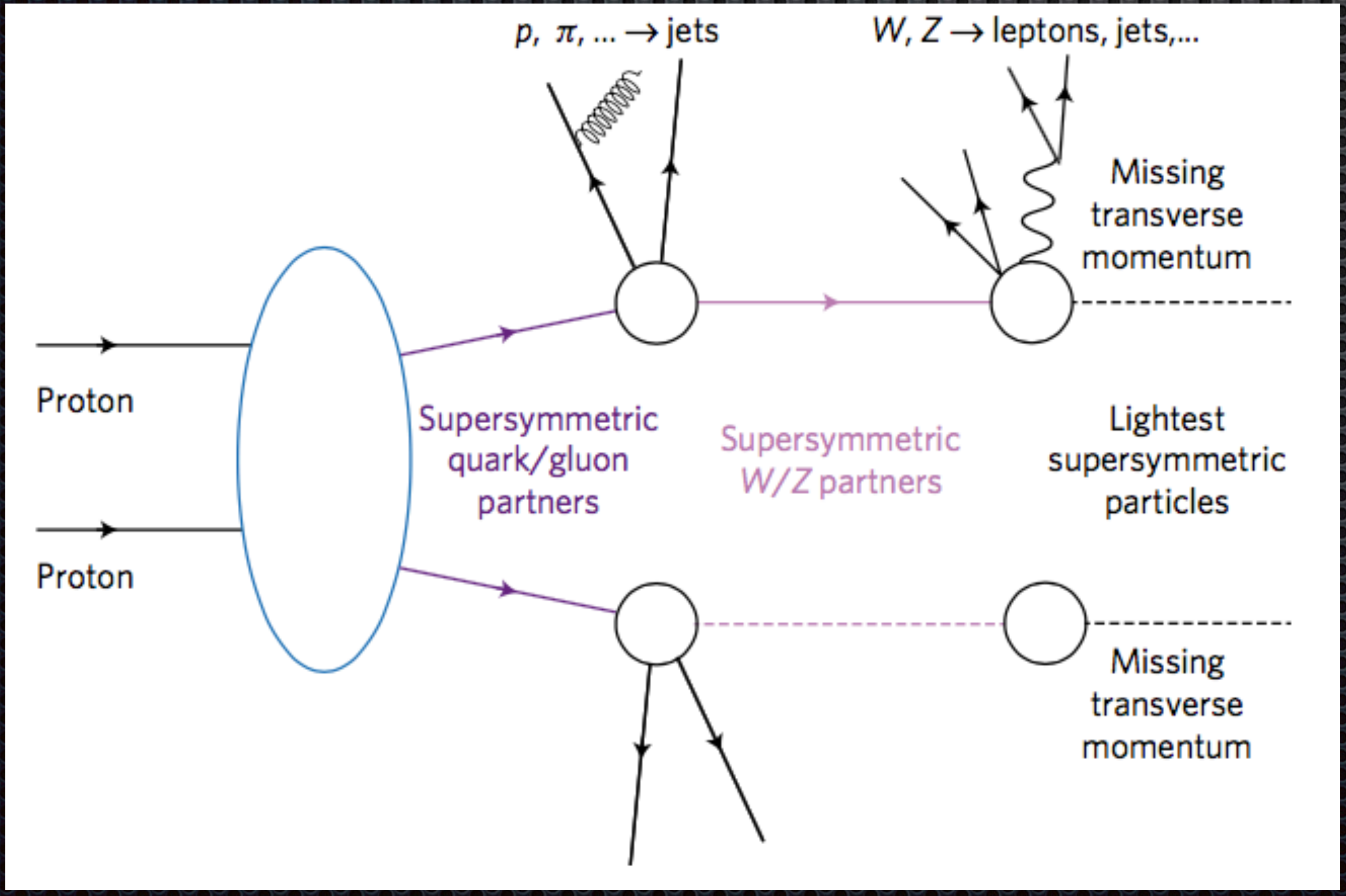
Produce such new particles at the LHC, in p-p collisions

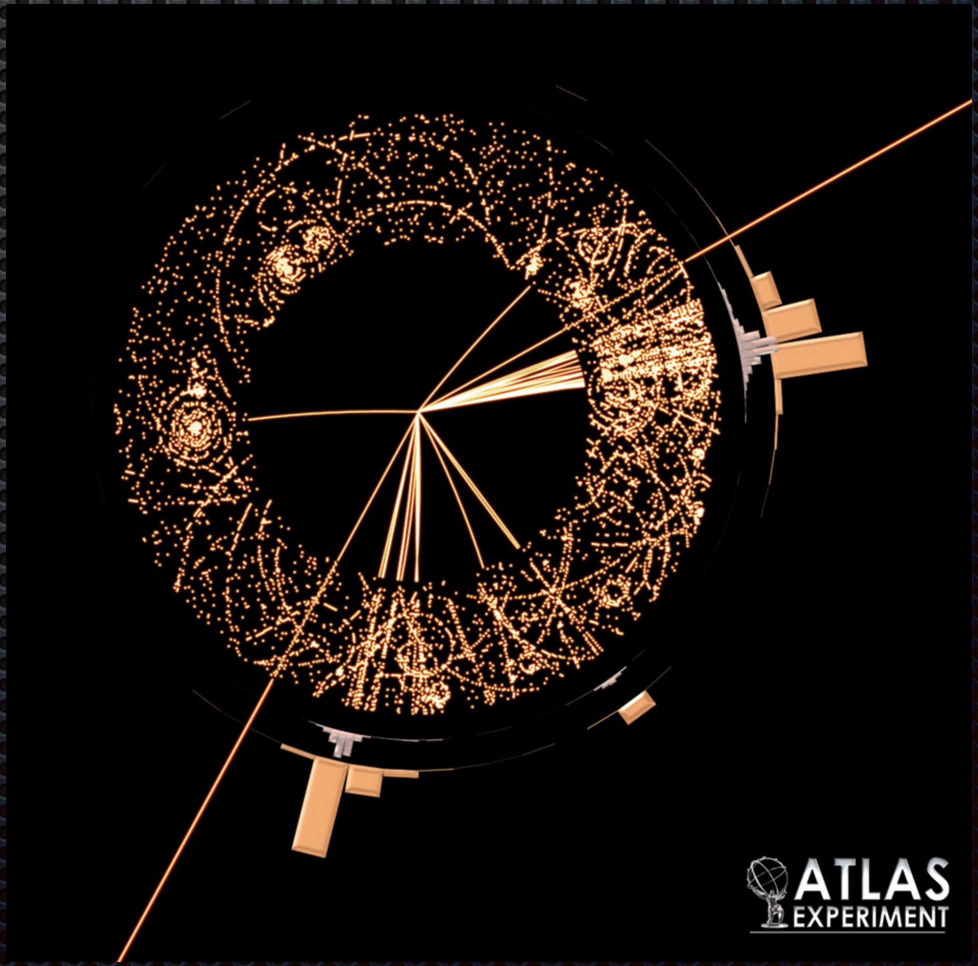




How to make them visible?

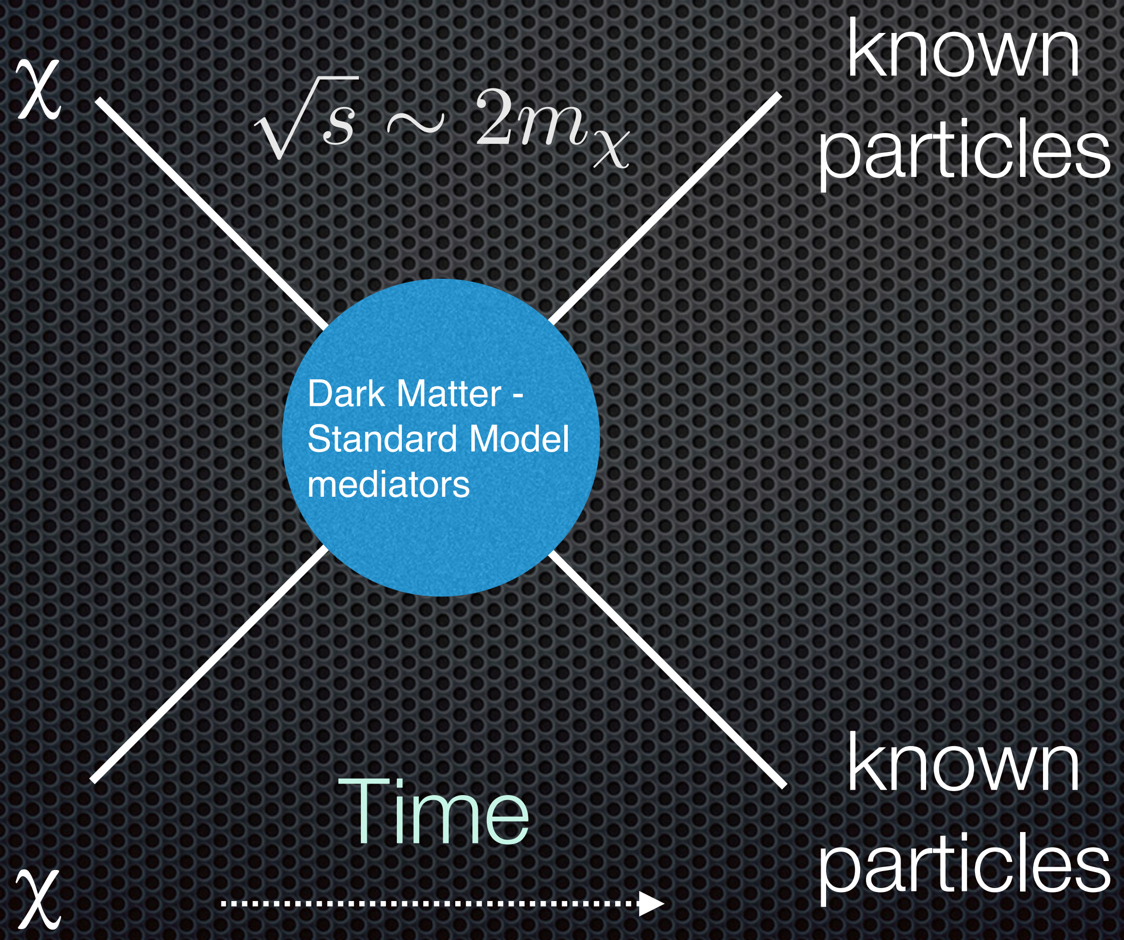
Produce such new particles at the LHC, in p-p collisions



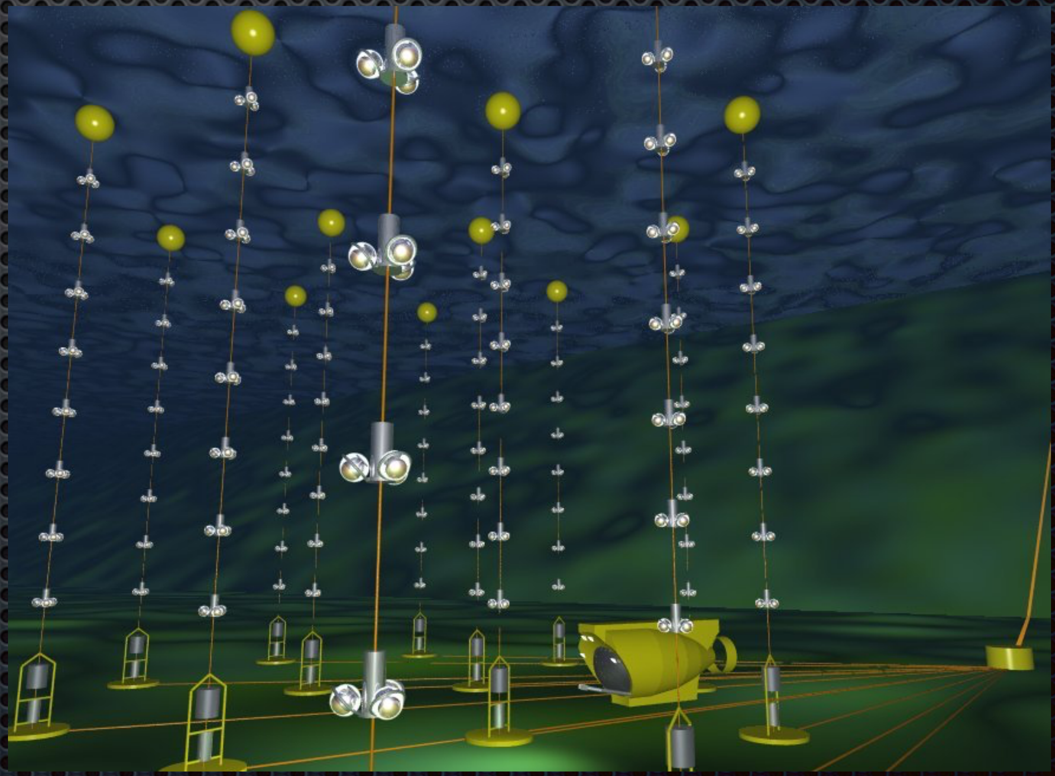


How to make them visible?

Look for their *annihilation products* in the Galactic Halo, Galactic Centre or in the Sun

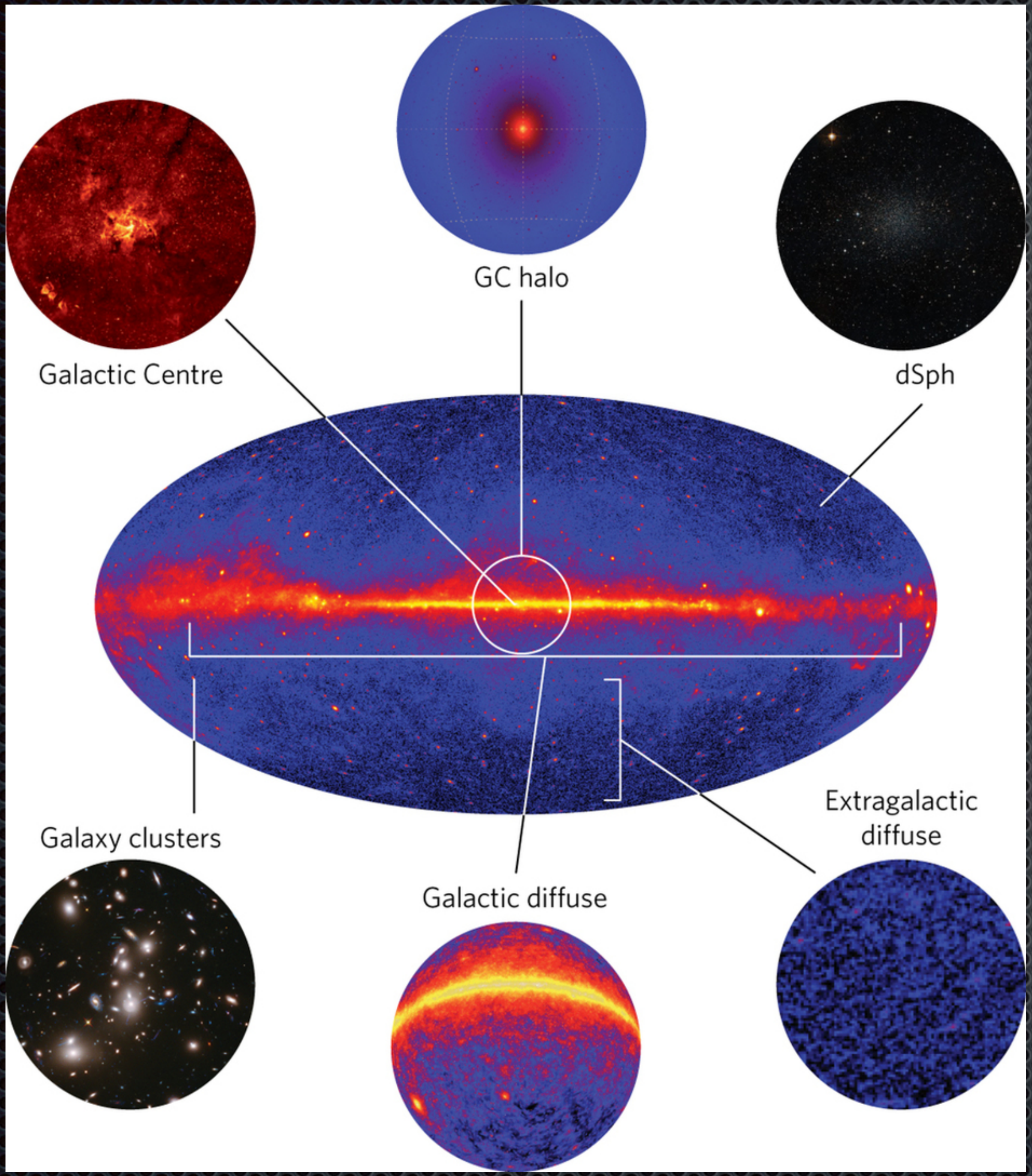


The AMS experiment on the ISS



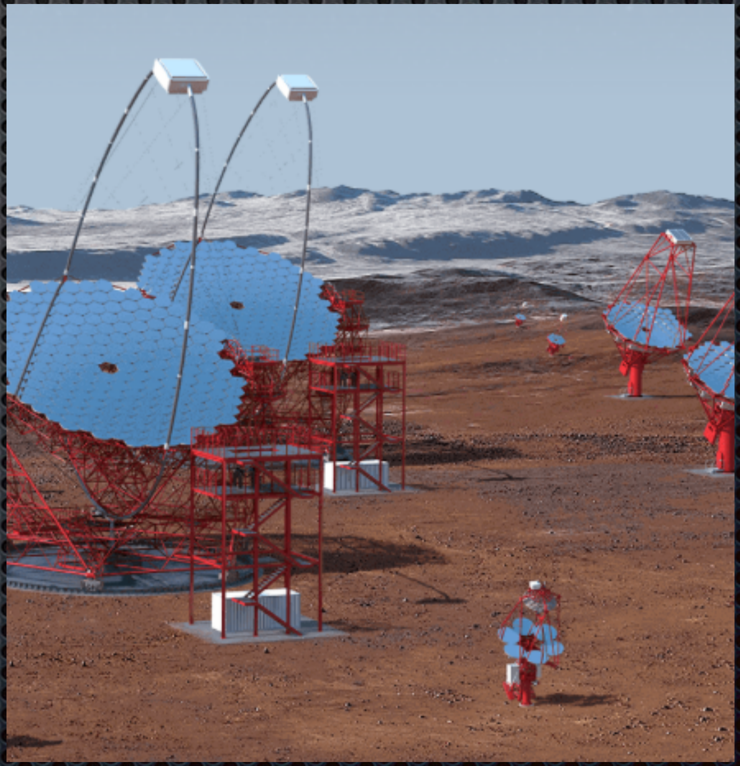
The Antares experiment in the Mediterranean sea

Indirect detection



Nature physics, March 2017

The Fermi-LAT instrument

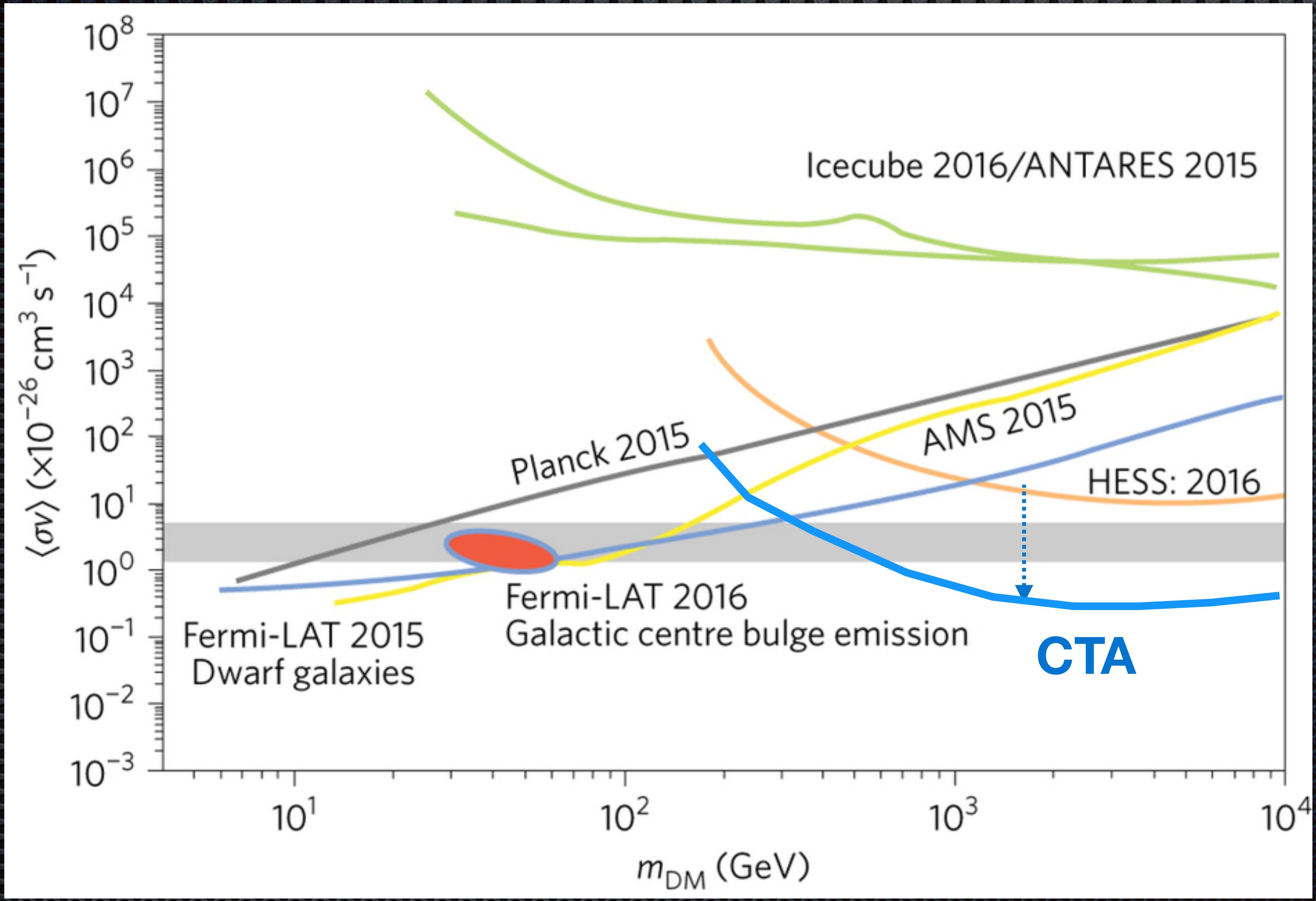


The Cherenkov Telescope Array

Constraints on the annihilation cross section

Indirect detection

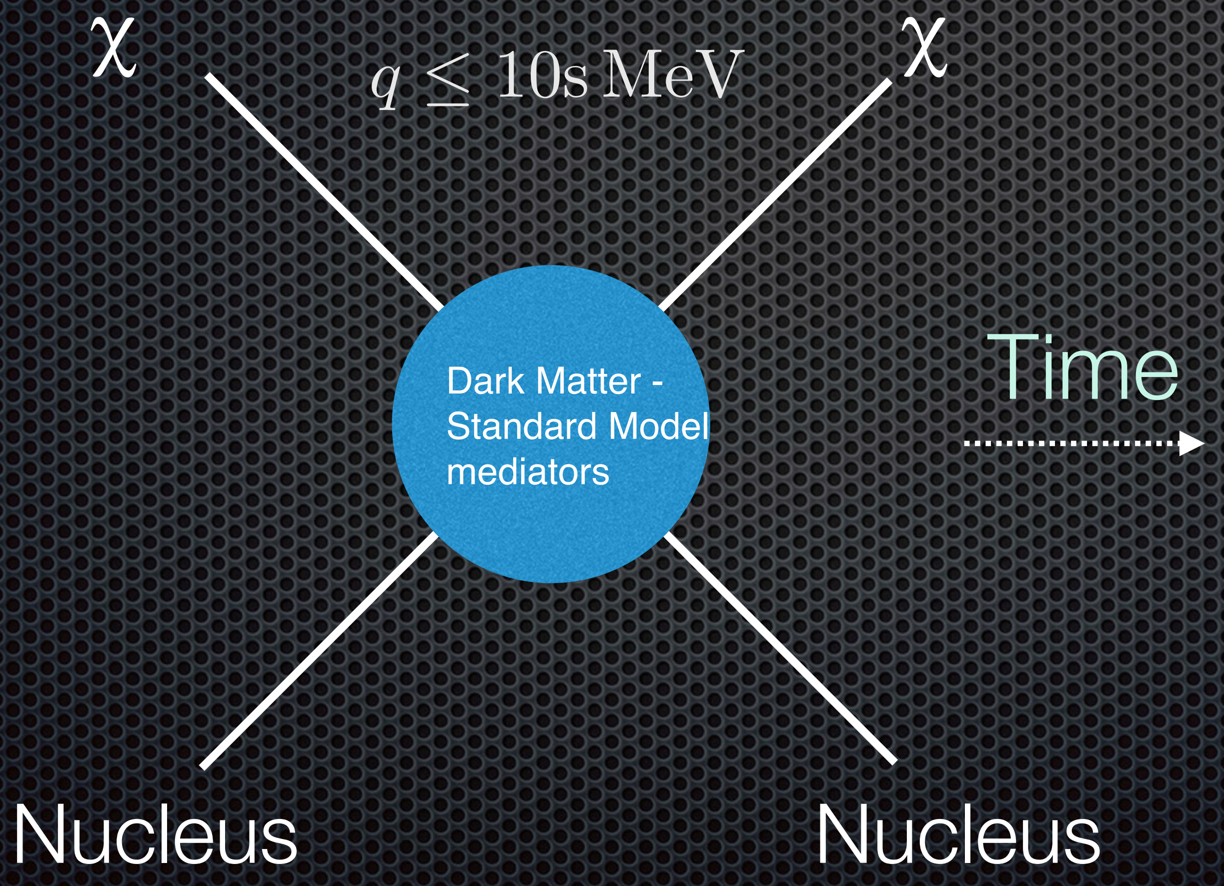
After Nature physics, March 2017

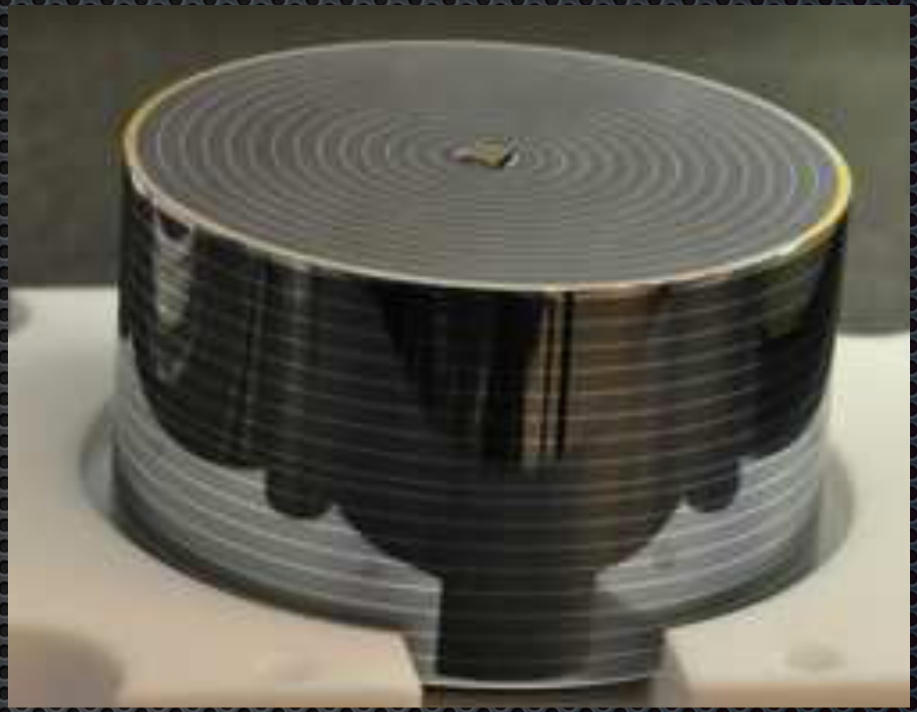


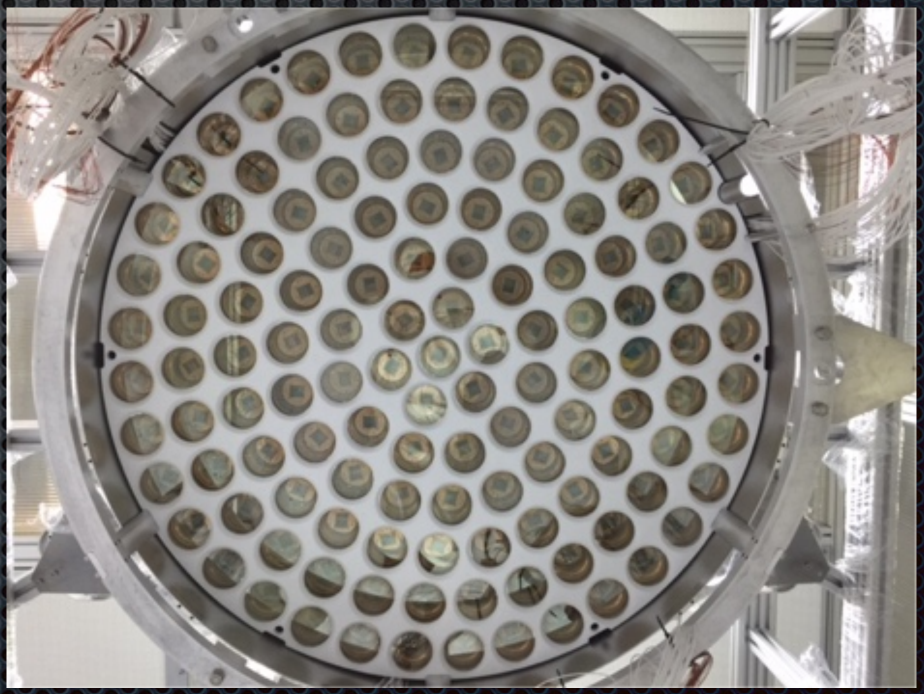
Constraints on the annihilation cross section

How to make them visible?

Look for very rare collisions of such particles with atomic nuclei

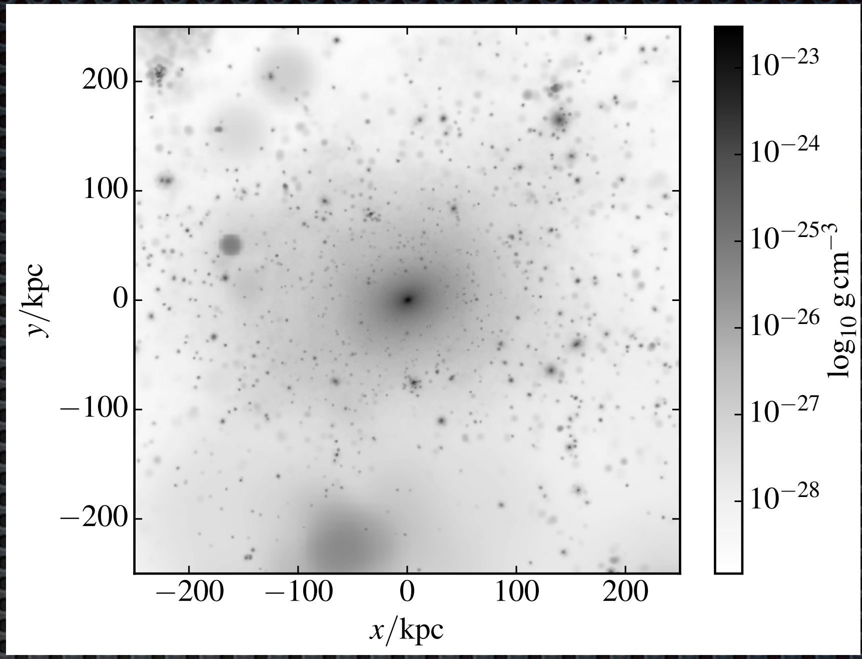


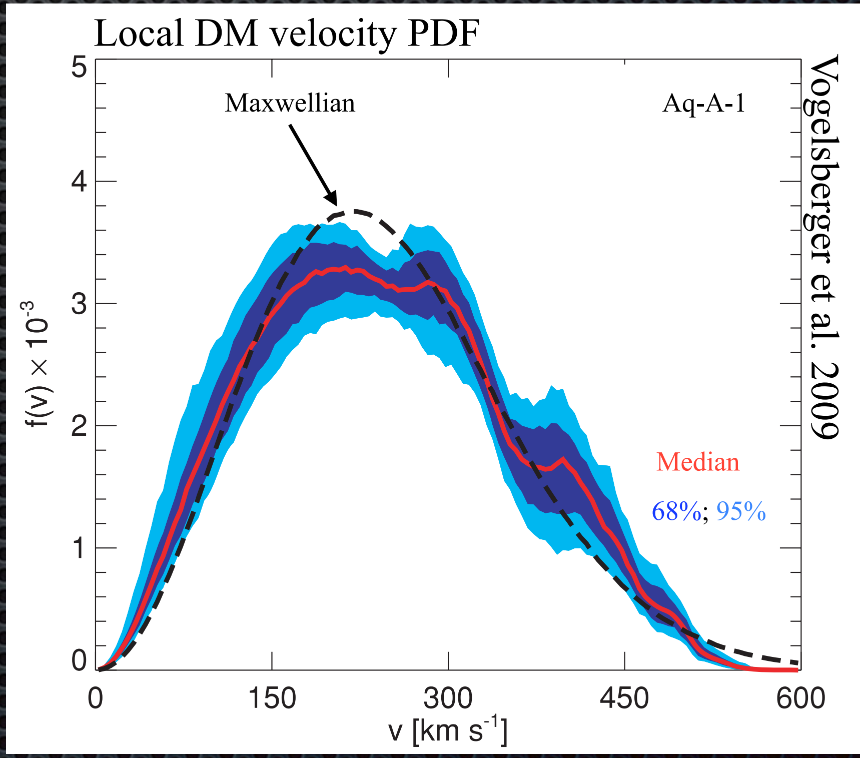




Flux of dark matter particles:

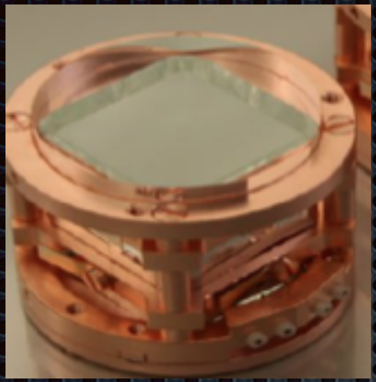
$$\phi = \frac{\rho_{dm}}{m_{dm}} \times \langle v \rangle$$

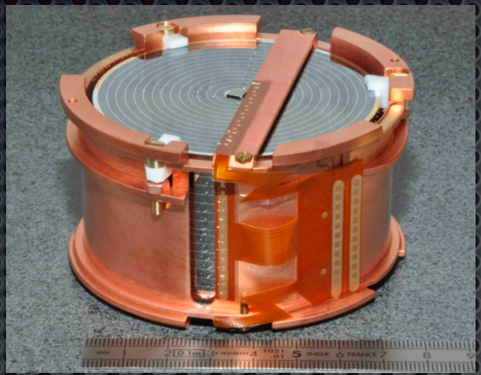


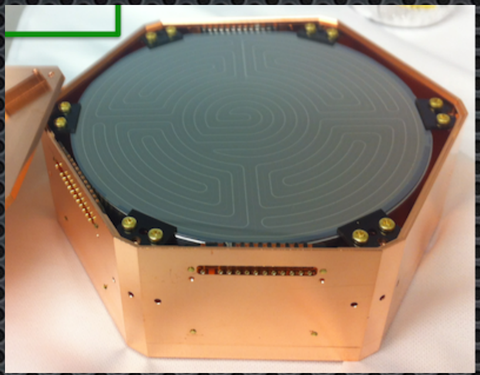


~ 10 millions through your hand, every second

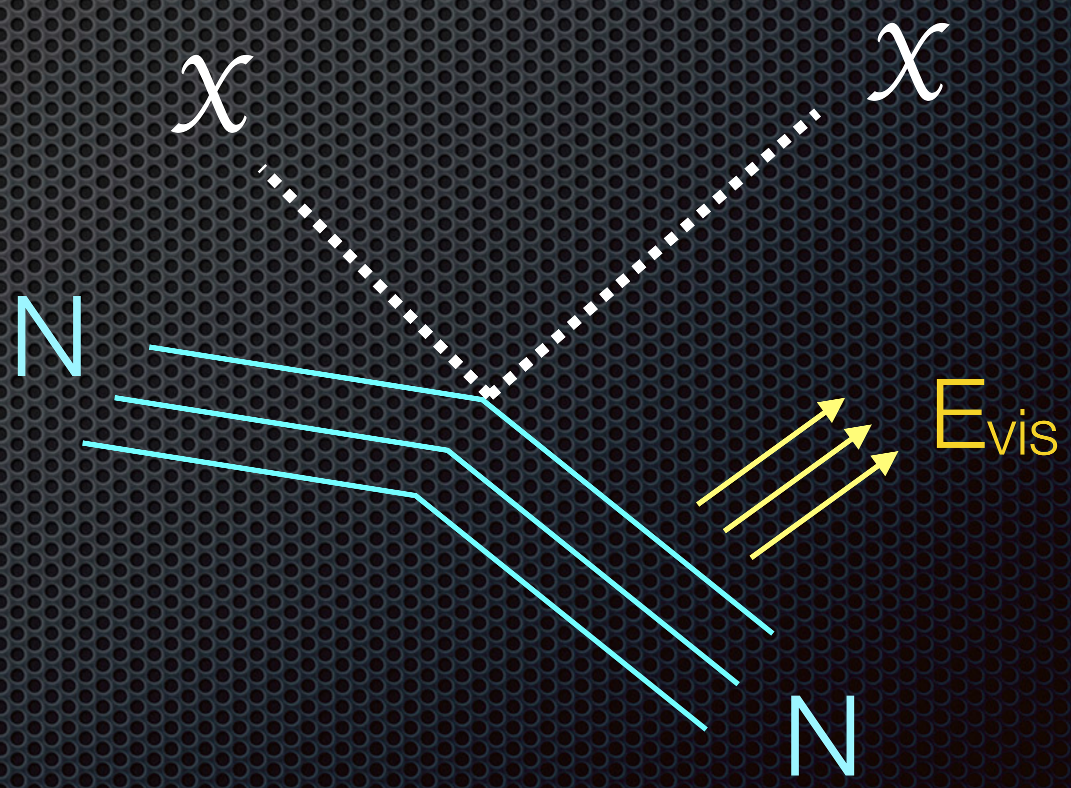
Direct detection experiments

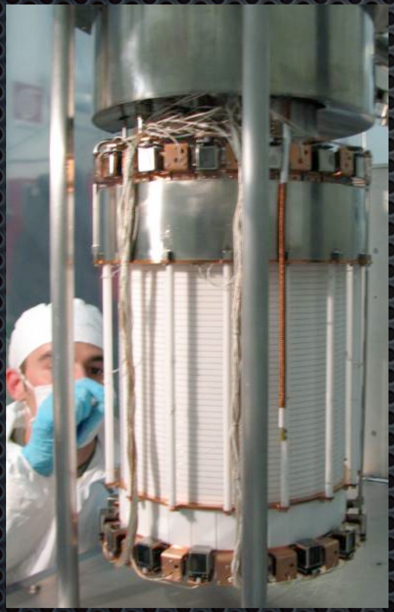






v/c ~10^{-3}





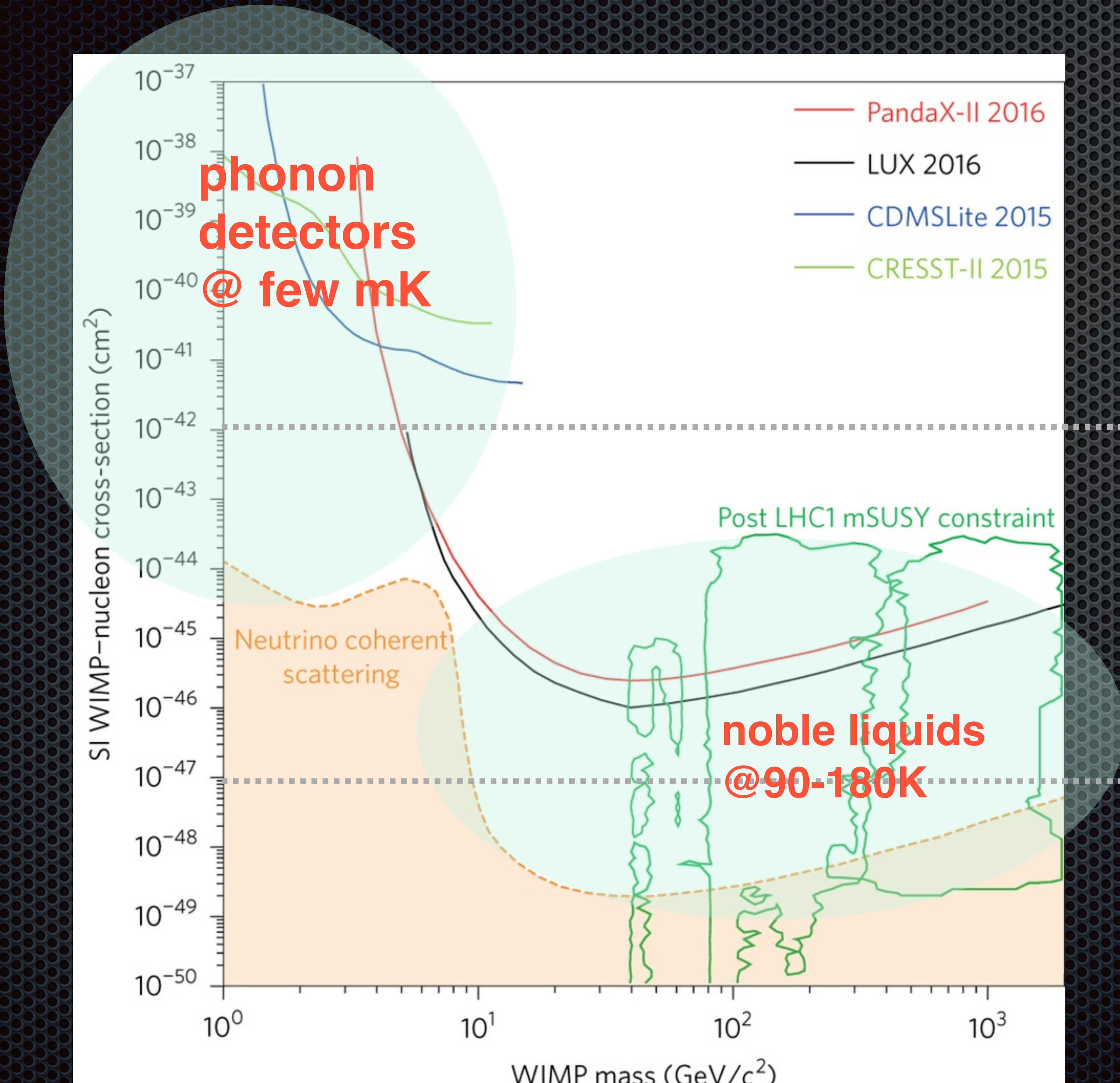
XENON100

LUX

DarkSide-50

$$E_R = \frac{q^2}{2m_N} < 100\,\mathrm{keV}$$

The WIMP landscape (before May 18, 2017)

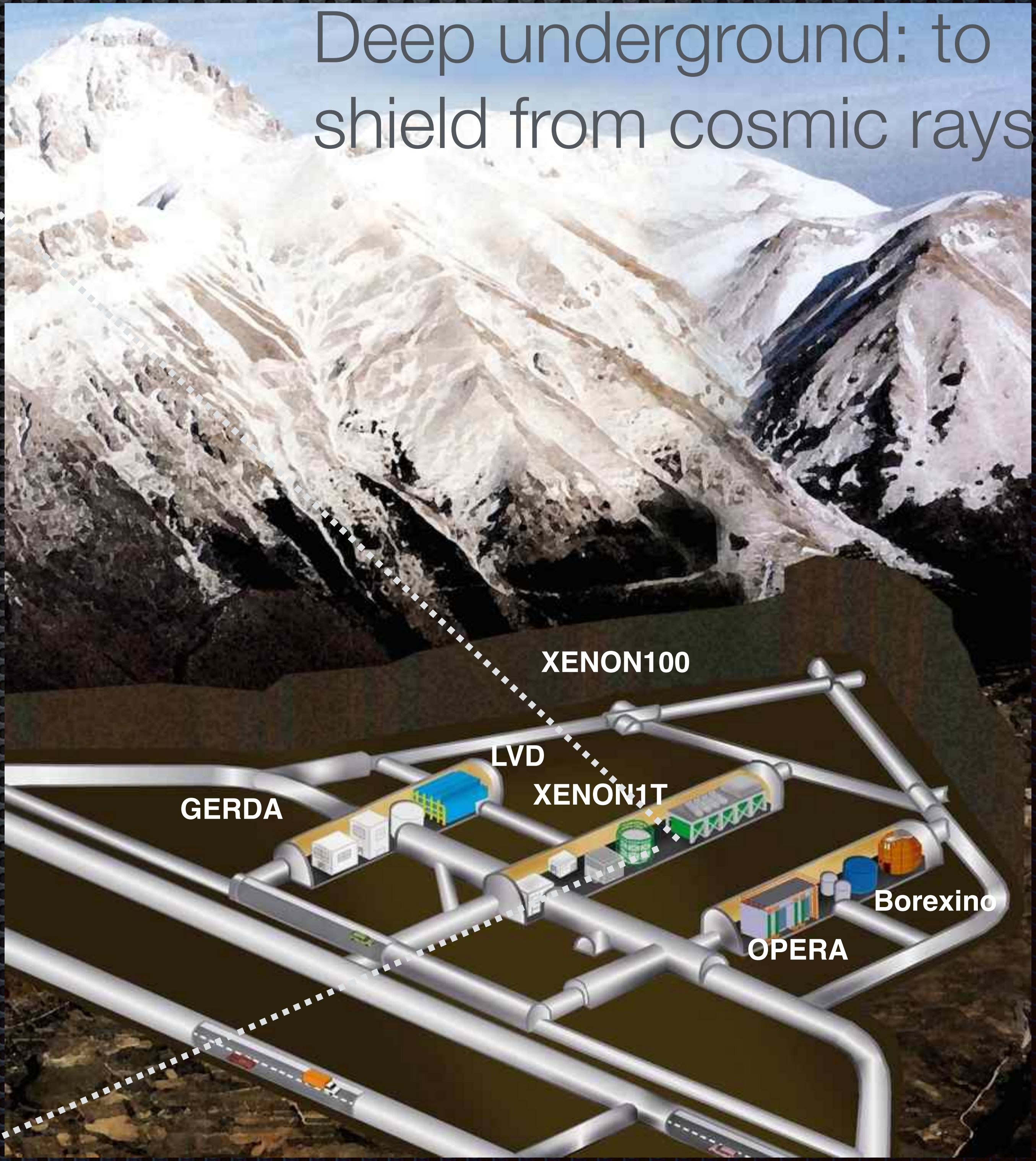


~ 1 event/ kg-day

~ 1 event/ tonne-year

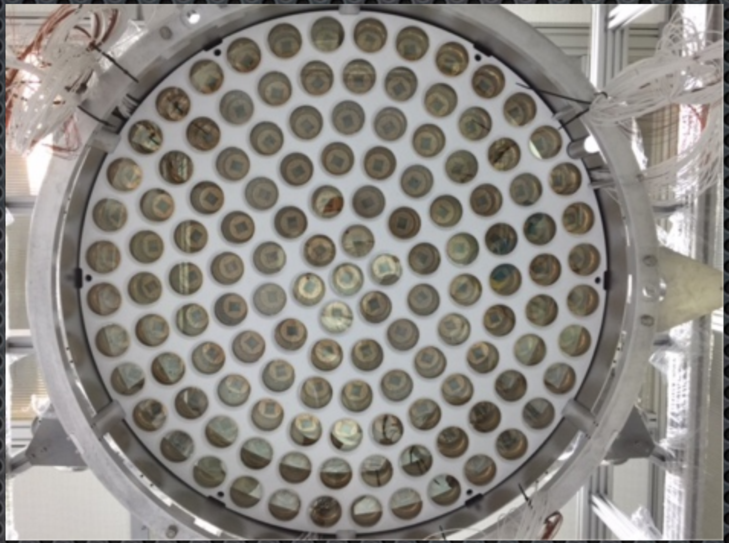
Nature physics, March 2017

XENON1T at LNGS



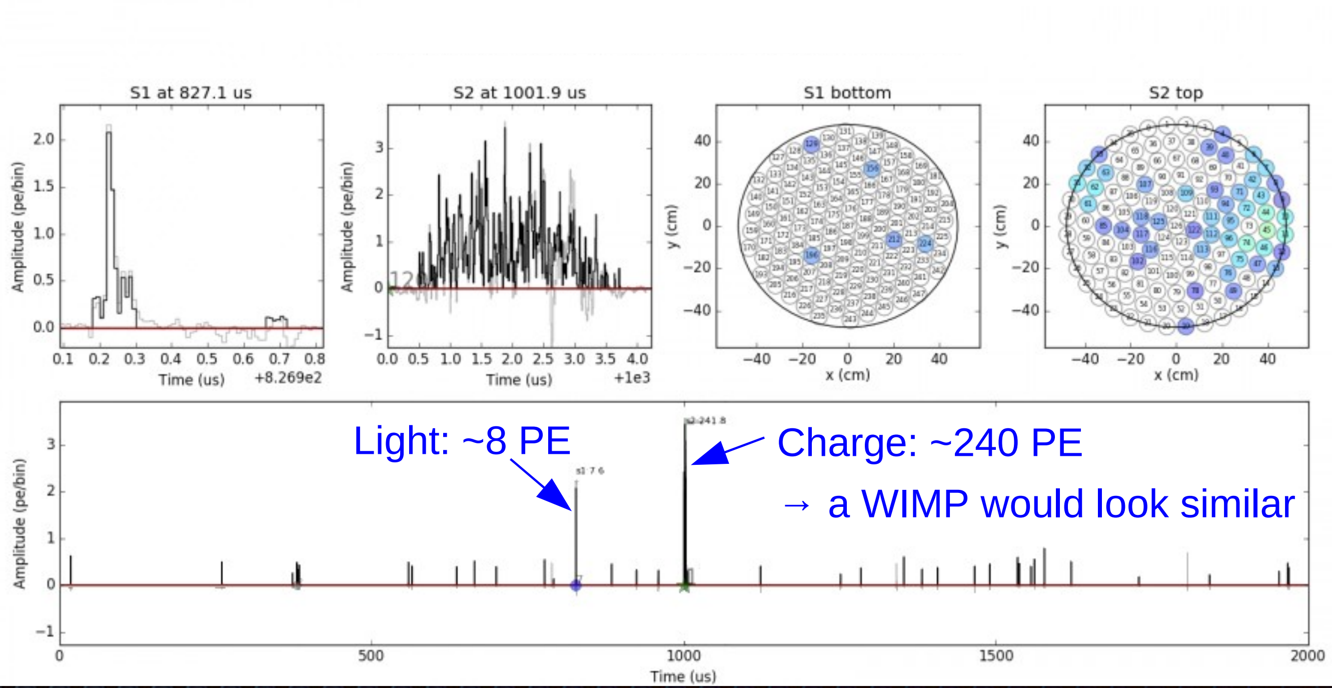
The XENON1T TPC

3.2 t LXe @180 K

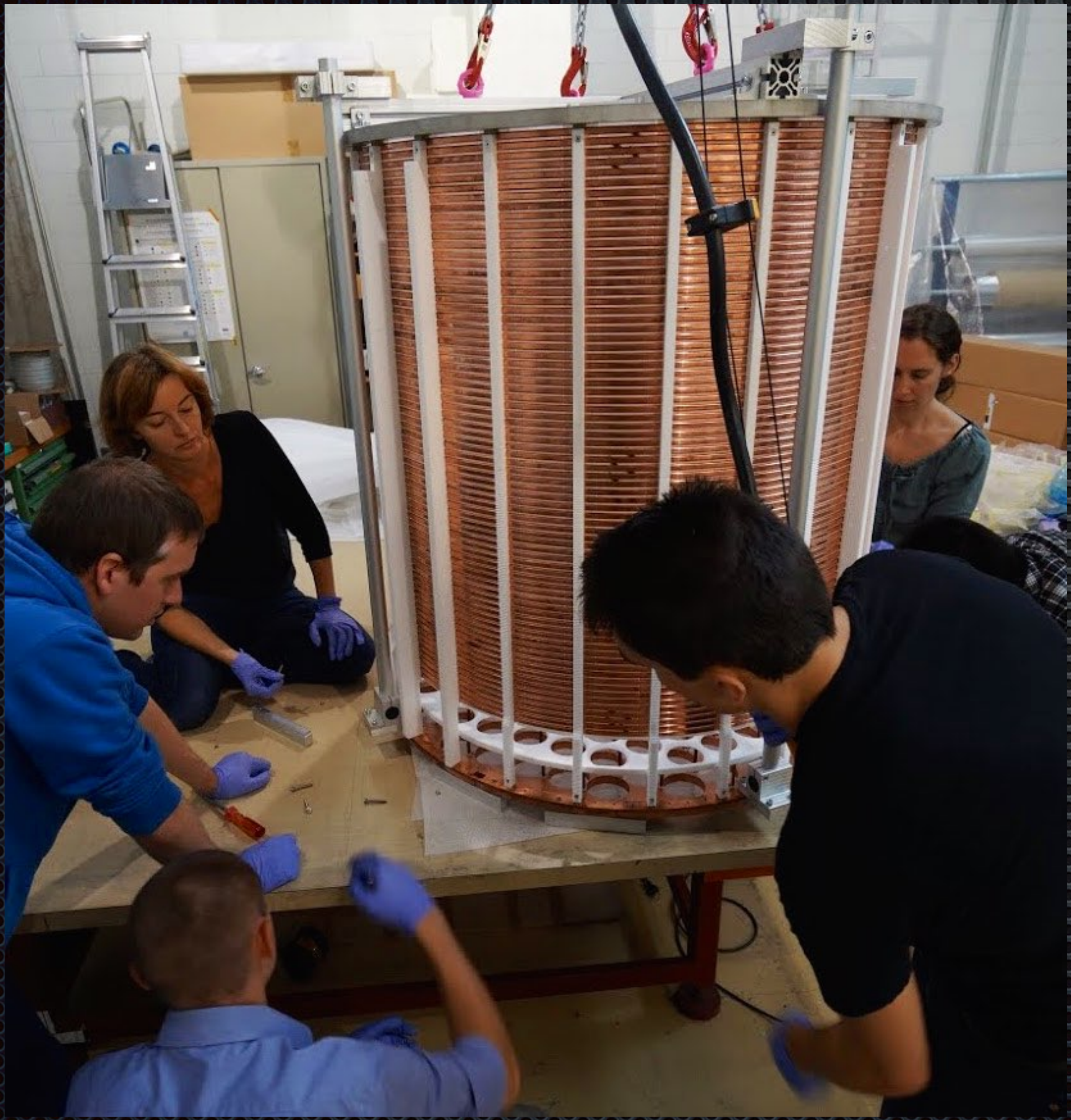


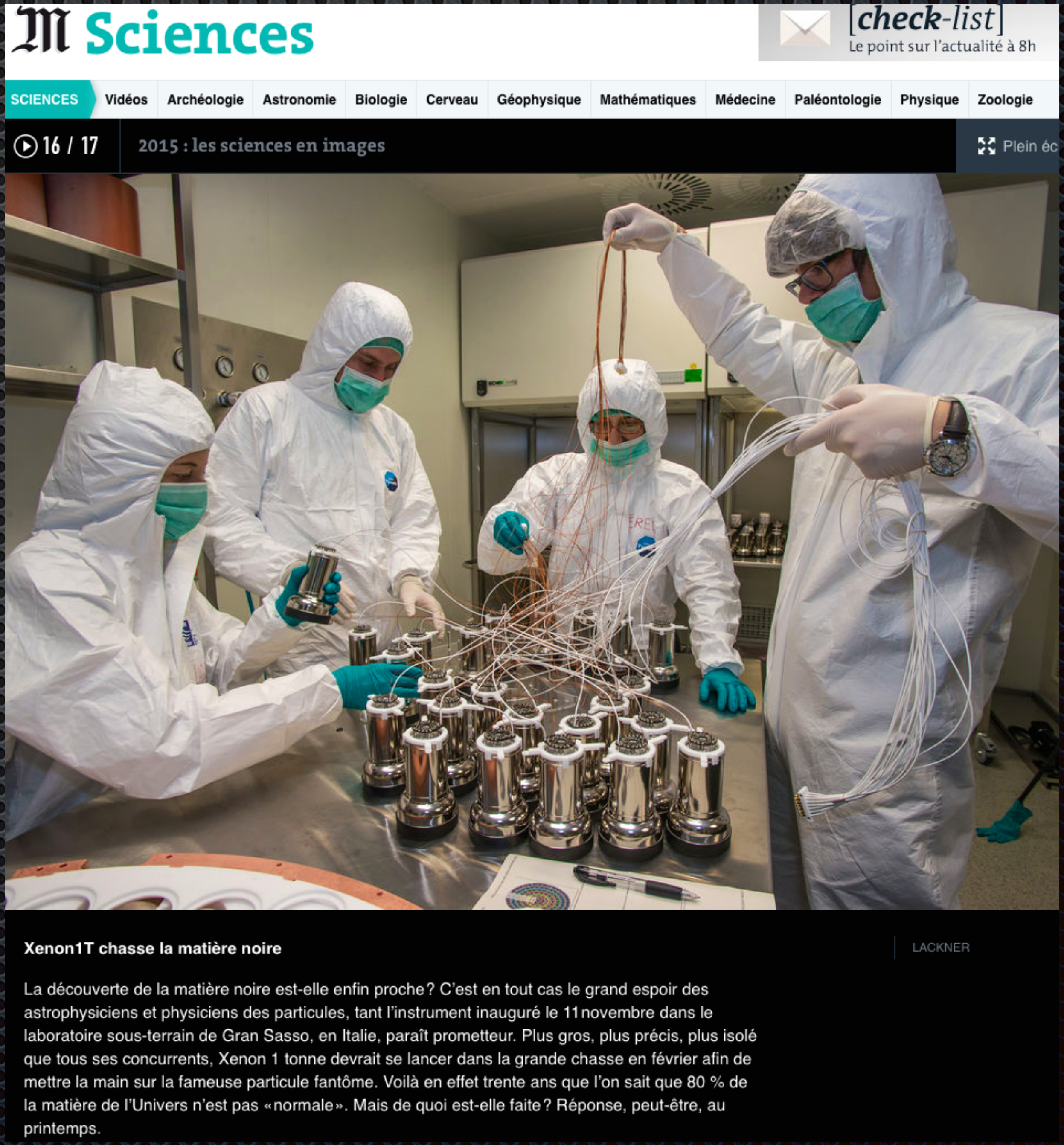
127 PMTs in the top array

121 PMTs in the bottom array



The XENON1T TPC: first assembly





Sciences

[check-list]
Le point sur l'actualité à 8h

SCIENCES | Vidéos | Archéologie | Astronomie | Biologie | Cerveau | Géophysique | Mathématiques | Médecine | Paléontologie | Physique | Zoologie

16 / 17 2015 : les sciences en images

Plein éc

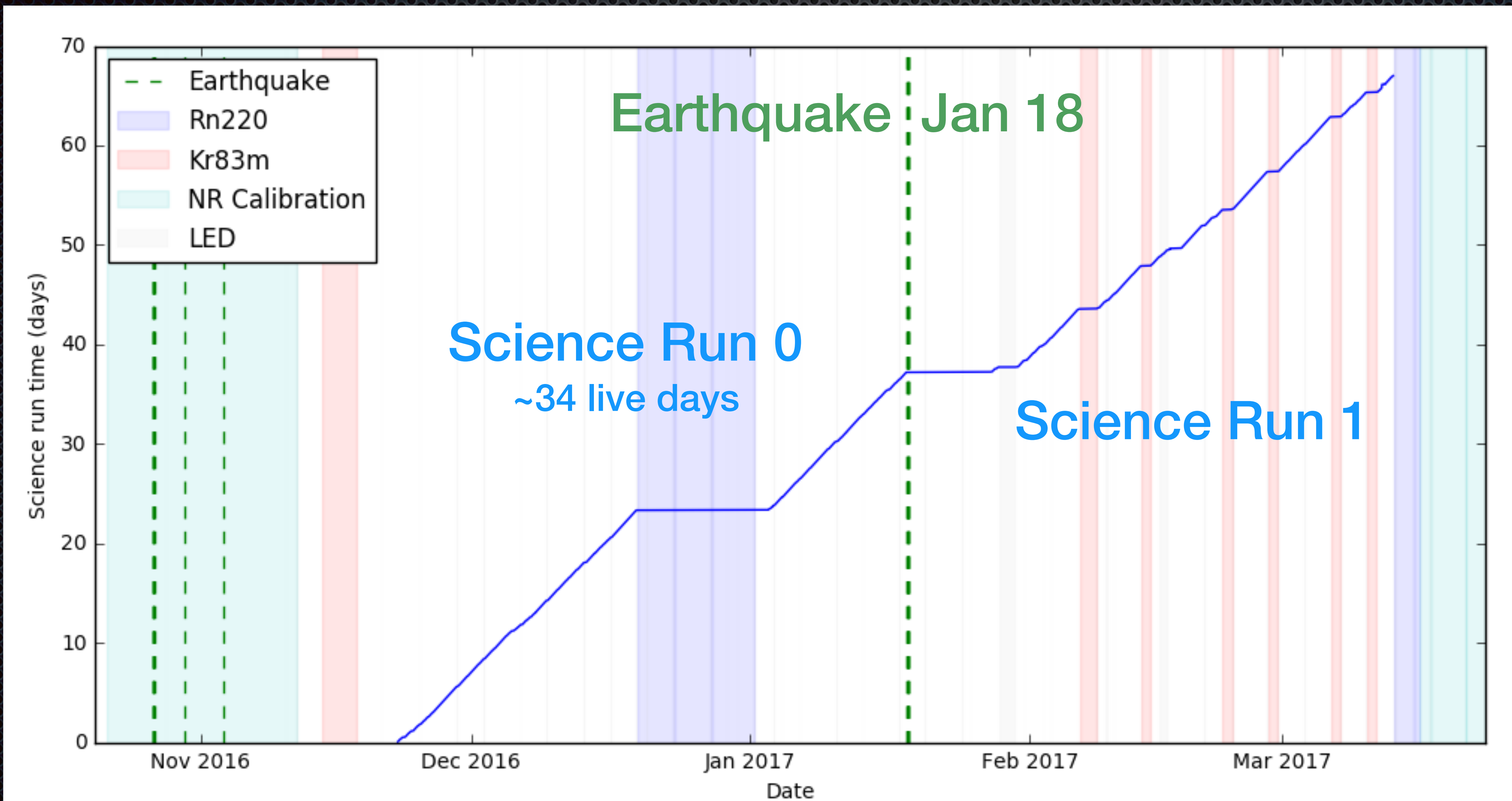
Xenon1T chasse la matière noire

LACKNER

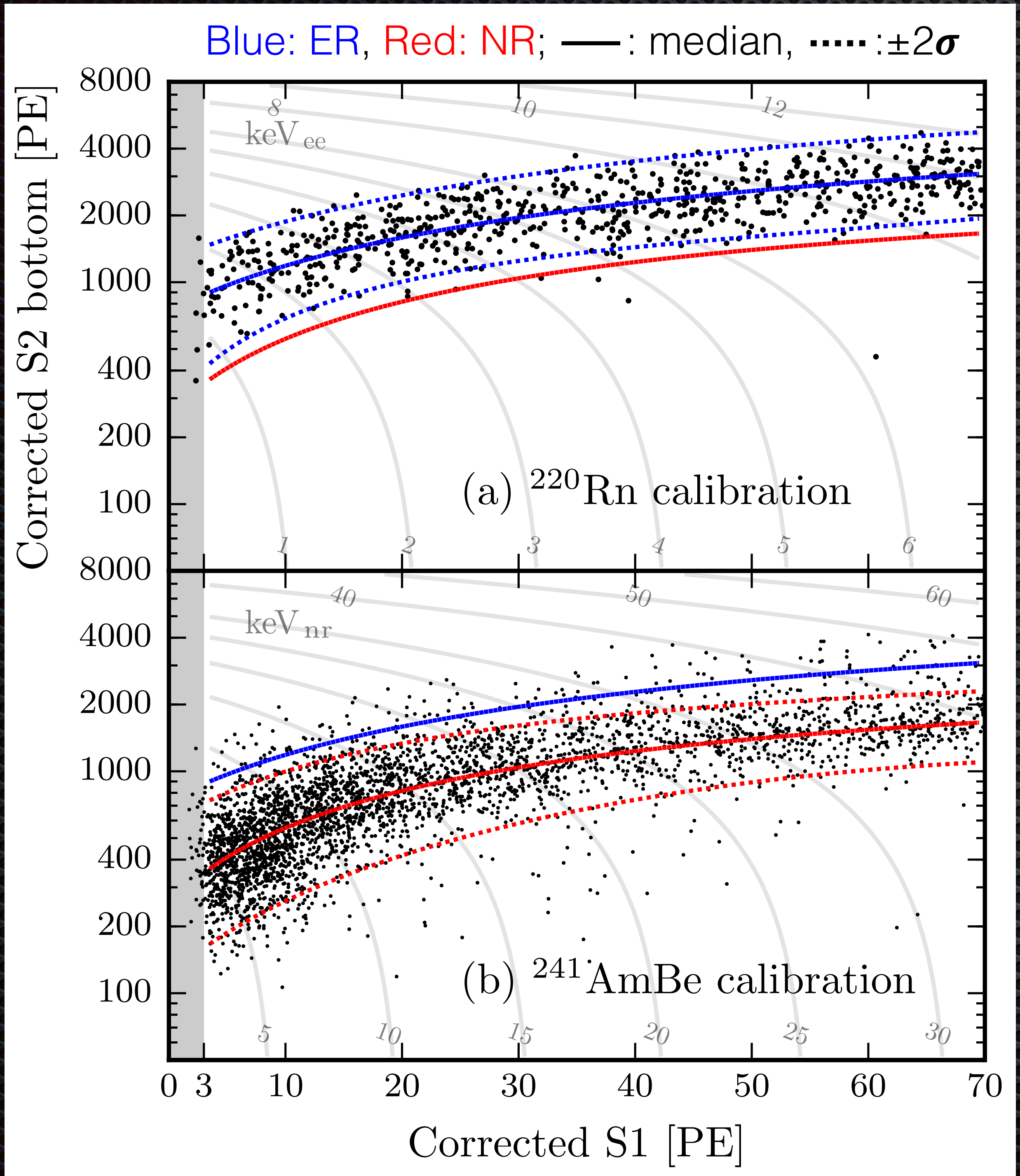
La découverte de la matière noire est-elle enfin proche? C'est en tout cas le grand espoir des astrophysiciens et physiciens des particules, tant l'instrument inauguré le 11novembre dans le laboratoire sous-terrain de Gran Sasso, en Italie, paraît prometteur. Plus gros, plus précis, plus isolé que tous ses concurrents, Xenon 1 tonne devrait se lancer dans la grande chasse en février afin de mettre la main sur la fameuse particule fantôme. Voilà en effet trente ans que l'on sait que 80 % de la matière de l'Univers n'est pas «normale». Mais de quoi est-elle faite? Réponse, peut-être, au printemps.

xenon1t.org

XENON1T: first results arXiv:1705.06655 (Science Run 0)

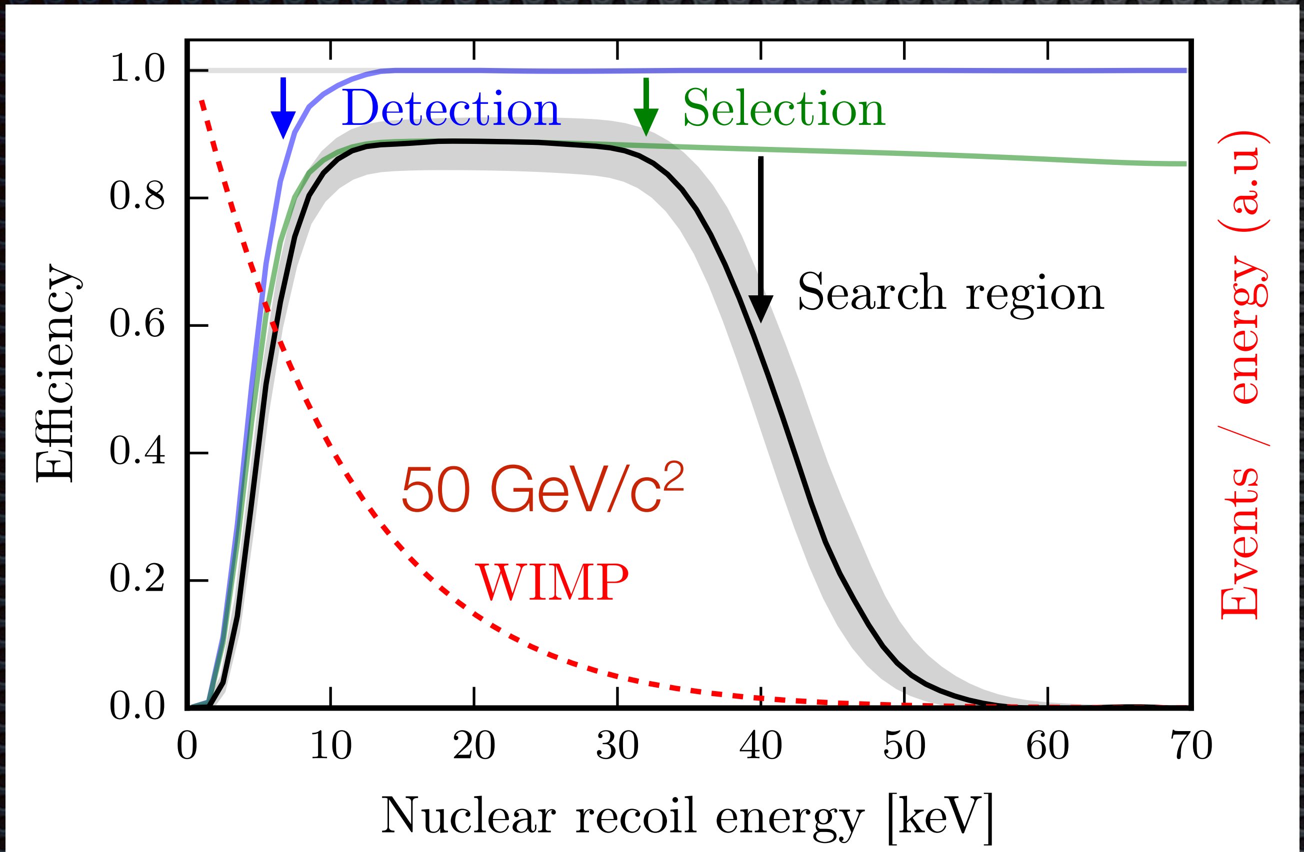


XENON1T: calibration



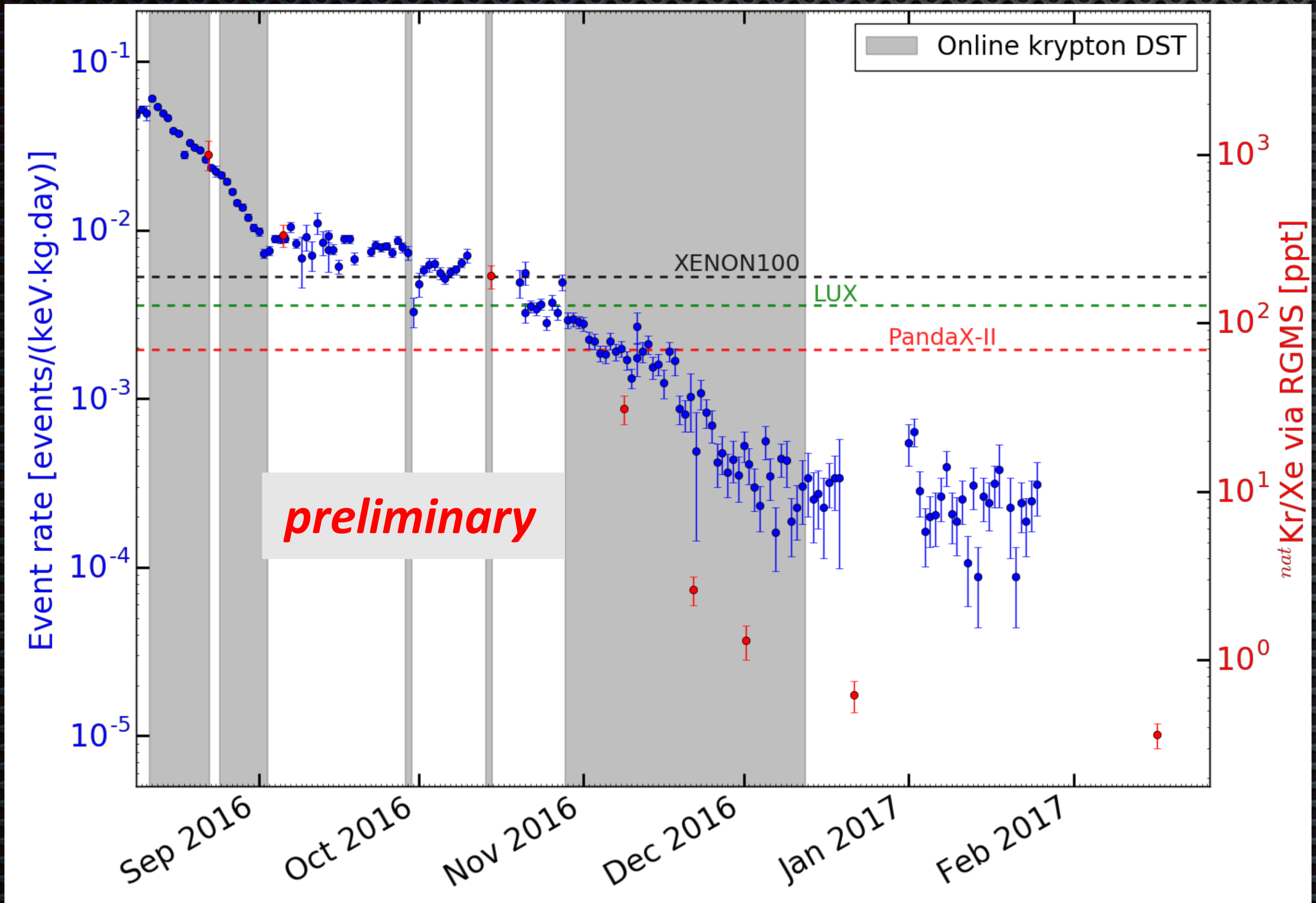
- Electronic recoils (^{220}Rn calibration)
- Nuclear recoils (^{241}AmBe calibration, currently also D-D fusion generator)

XENON1T: data selection



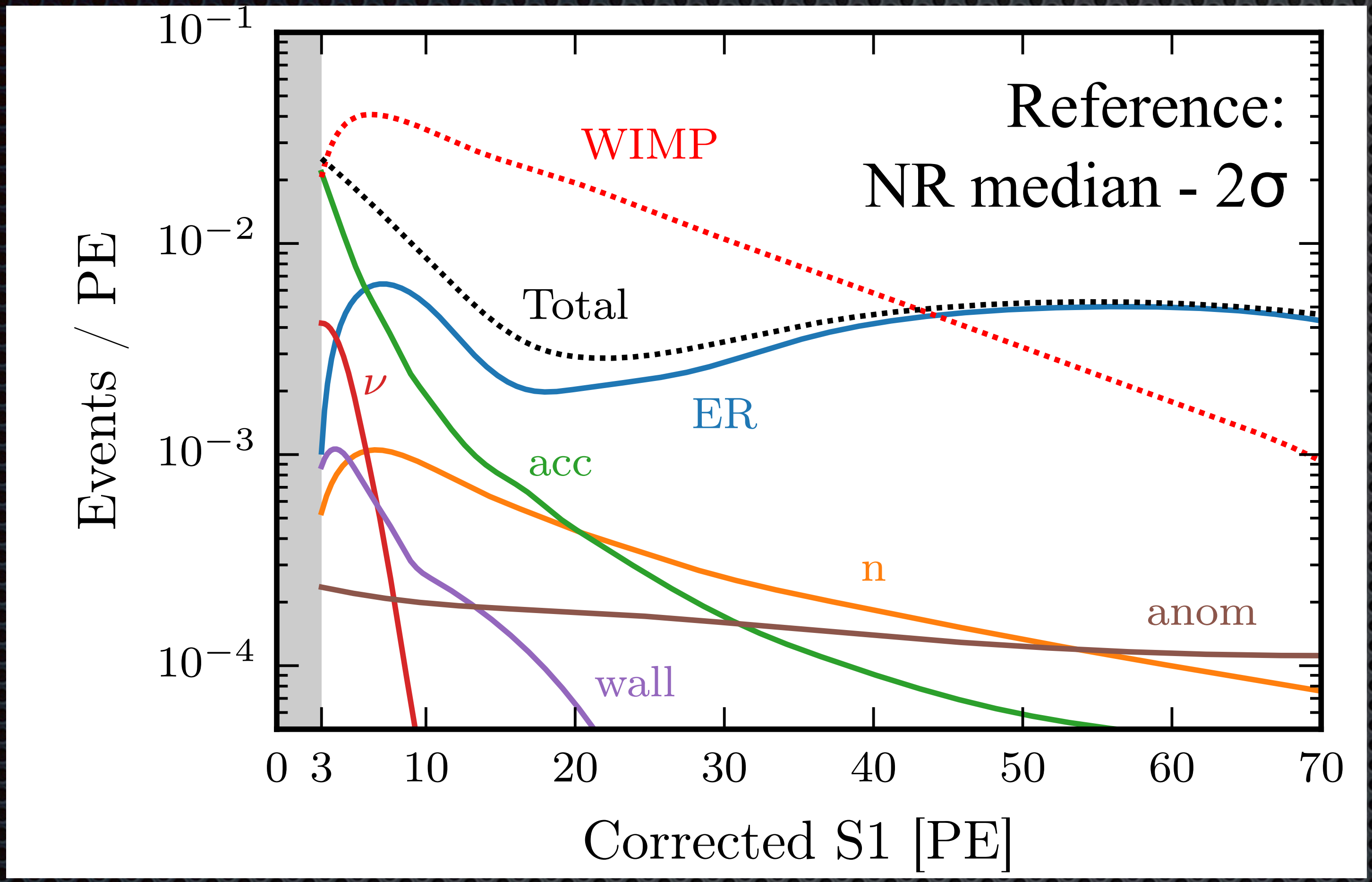
- Signal region blinded until selection fixed
- Single-scatter, event quality, peak quality, fiducial volume (1042 kg)

XENON1T: backgrounds



- ER rate prediction: 0.2 events/(ton y keV)
- reduced to predicted level
- ^{nat}Kr concentration reduced from 2.6 ppt to 0.36 ppt

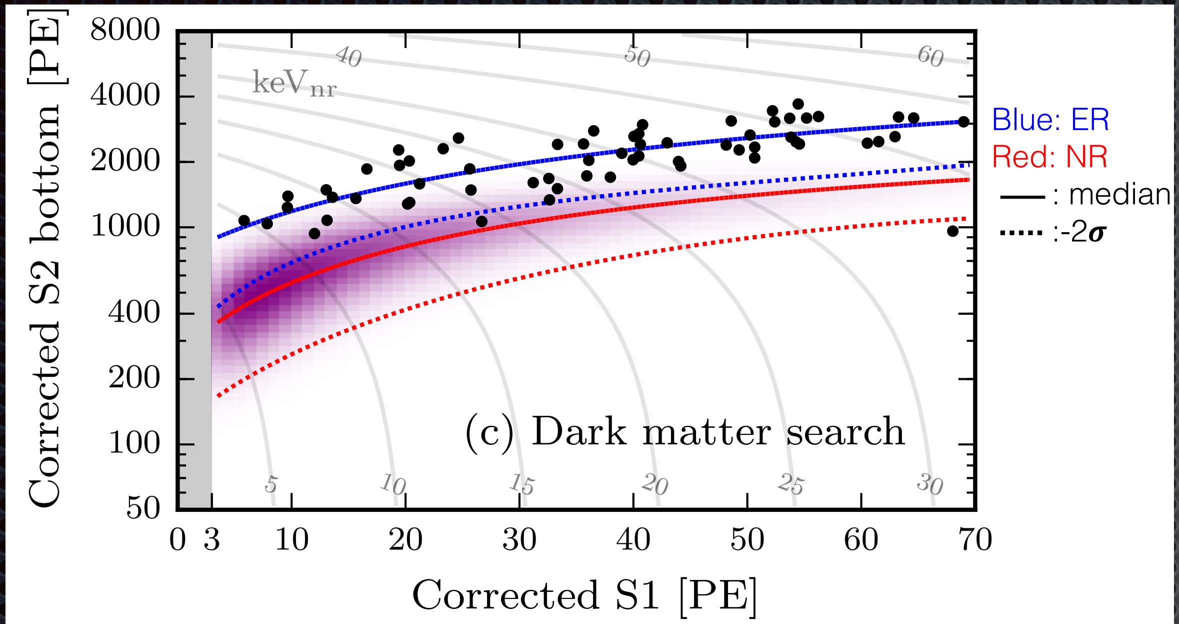
XENON1T: signal & backgrounds

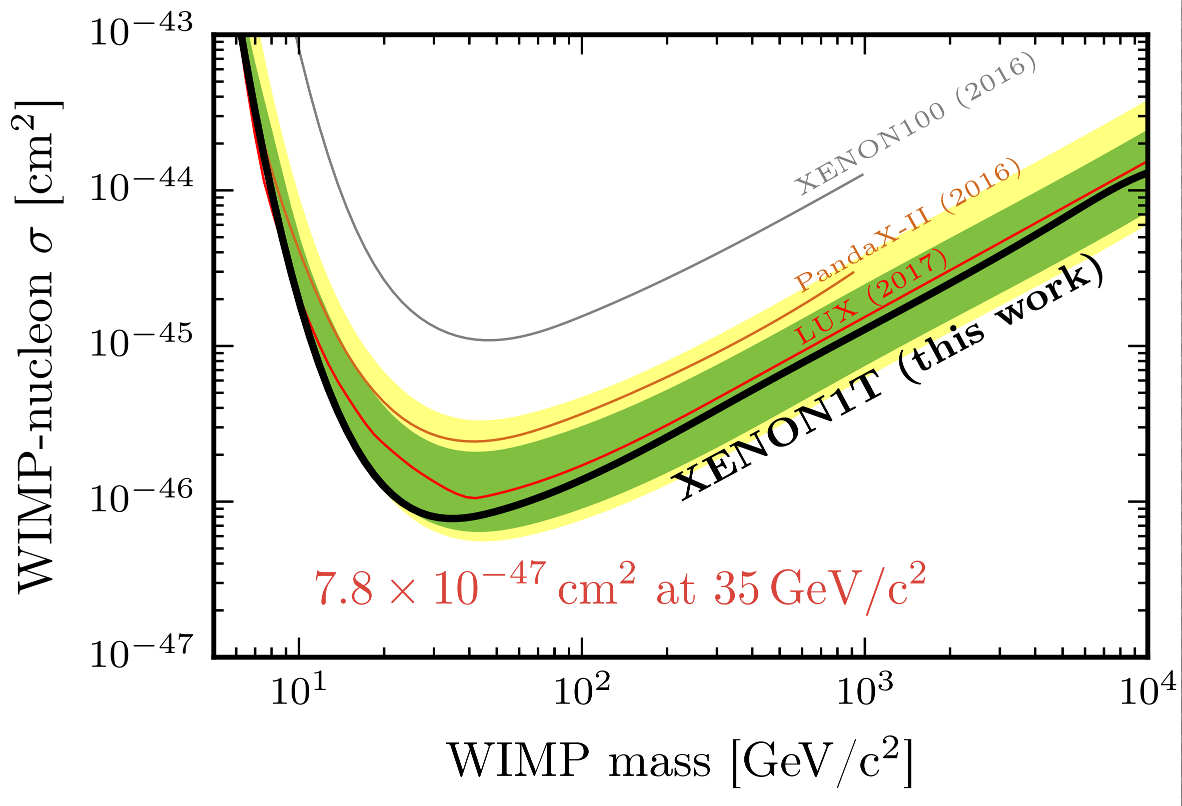


- 50 GeV/c^2, 10^{-46} cm^2 WIMP
- background dominated by radon
- ^{222}Rn reduced to 10 μBq/kg, further reduction possible

XENON, Eur. Phys. J. C (2017) 77: 358

XENON1T: first results

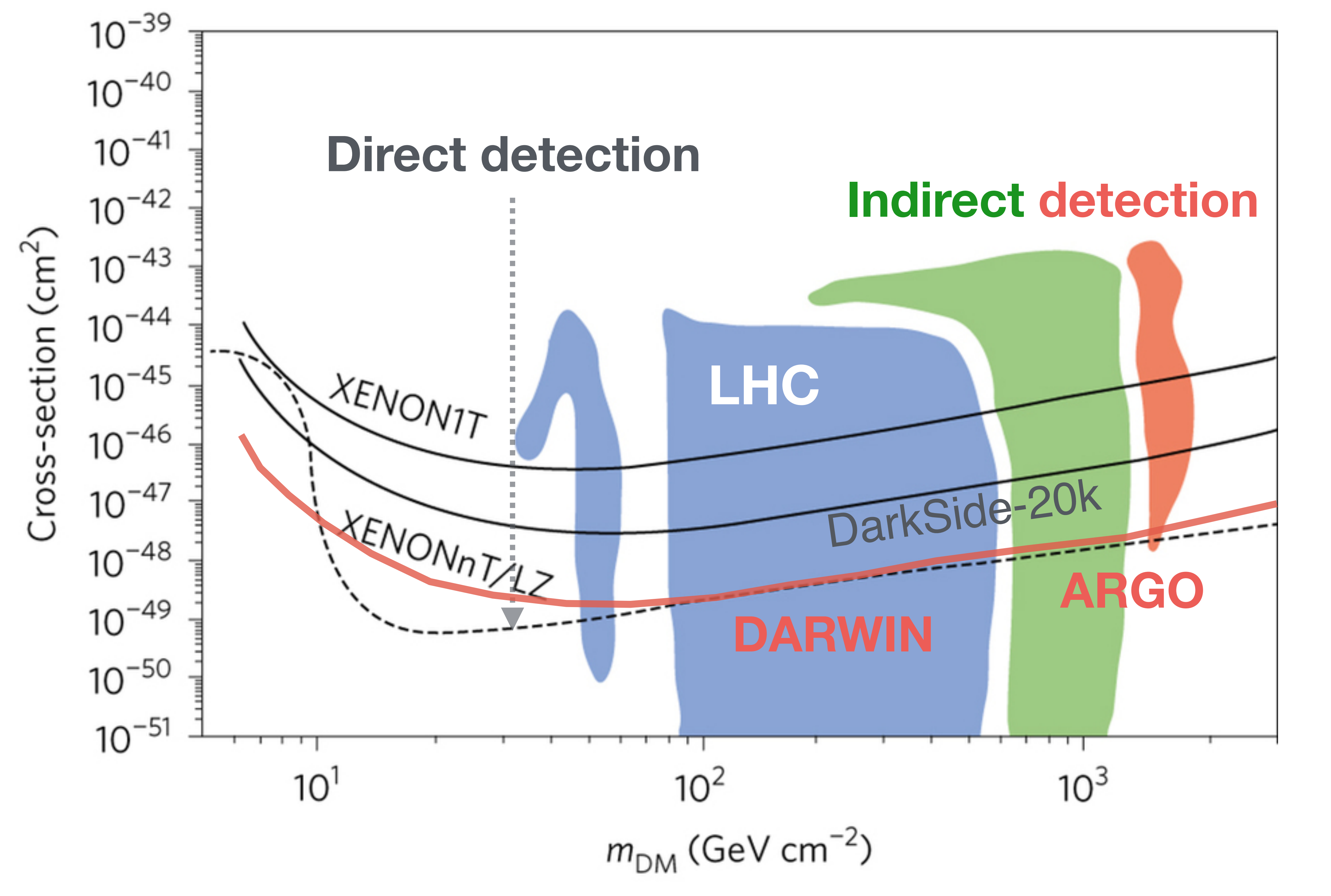




- Unbinned profile likelihood analysis
- no post-unblinding changes to event selection
- ER/NR shape determined from calibration fits

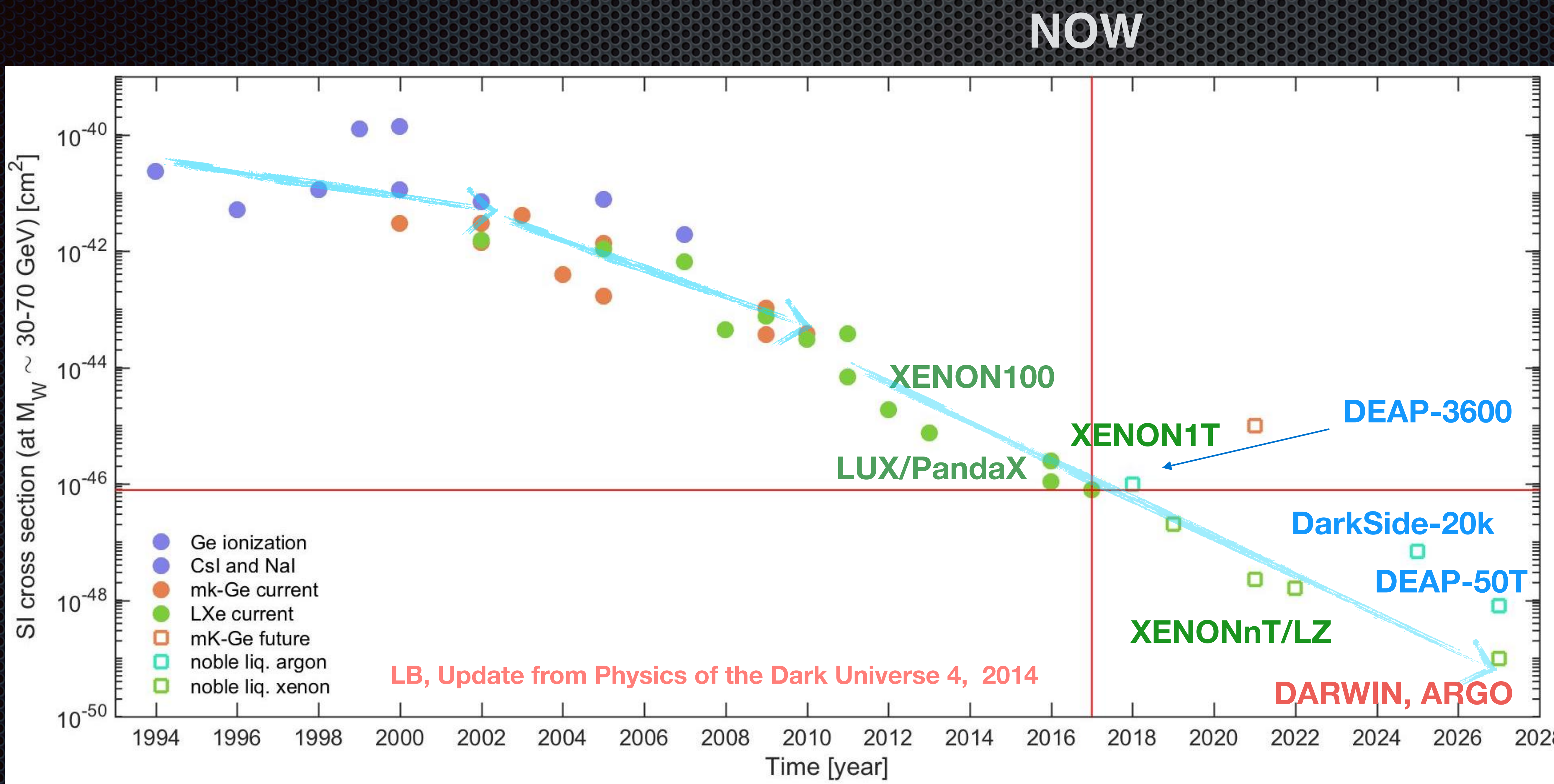
XENON, arXiv:1705.06655

Direct, indirect & LHC



Adapted after Nature physics, March 2017

Direct detection evolution

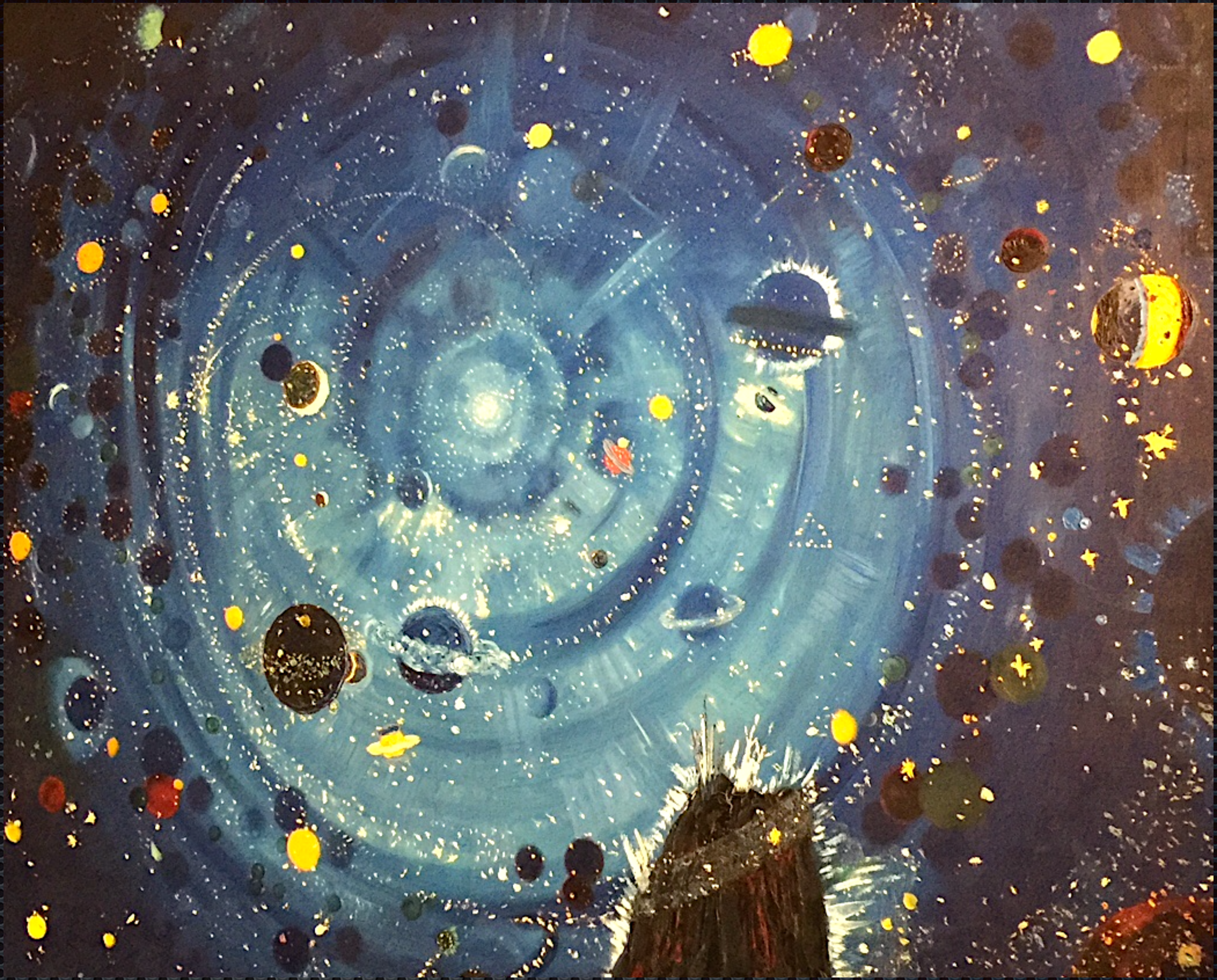


Constraints on the scattering cross section on nucleons

Summary & Outlook

- Cold dark matter is (still) a viable paradigm that explains all cosmological & astrophysical observations
  - It could be made WIMPs - thermal relics from an early phase of our Universe
  - - this hypothesis is testable: direct detection, indirect detection, accelerators
  - - so far, no convincing detection of a dark matter particle in the laboratory
- But: direct detection experiments offer excellent prospects for discovery
  - increase in WIMP sensitivity by 2 orders of magnitude in the next few years
  - reach neutrino background *(measure neutrino-nucleus coherent scattering from solar/atm/SN neutrinos!)* this & next decade
  - high complementarity with indirect searches (AMS, IceCube, CTA, Fermi...) & with the HL-LHC

W. Hablick, Sternenhimmel



- Of course, “the probability of success is difficult to estimate, but if we never search, the chance of success is zero”

G. Cocconi & P. Morrison, Nature, 1959

The End