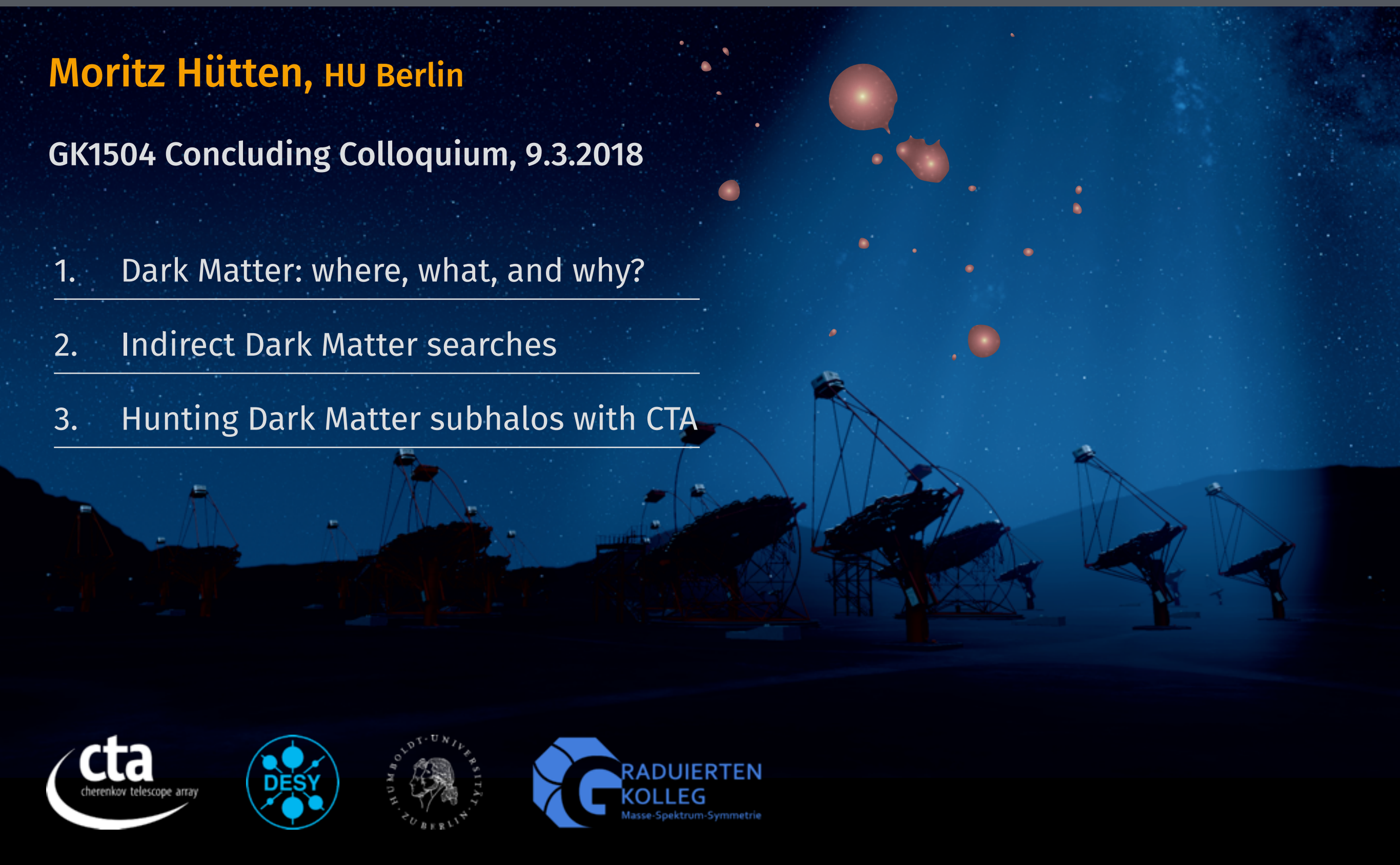
Search for dark matter annihilation with astroparticles

Moritz Hütten, HU Berlin

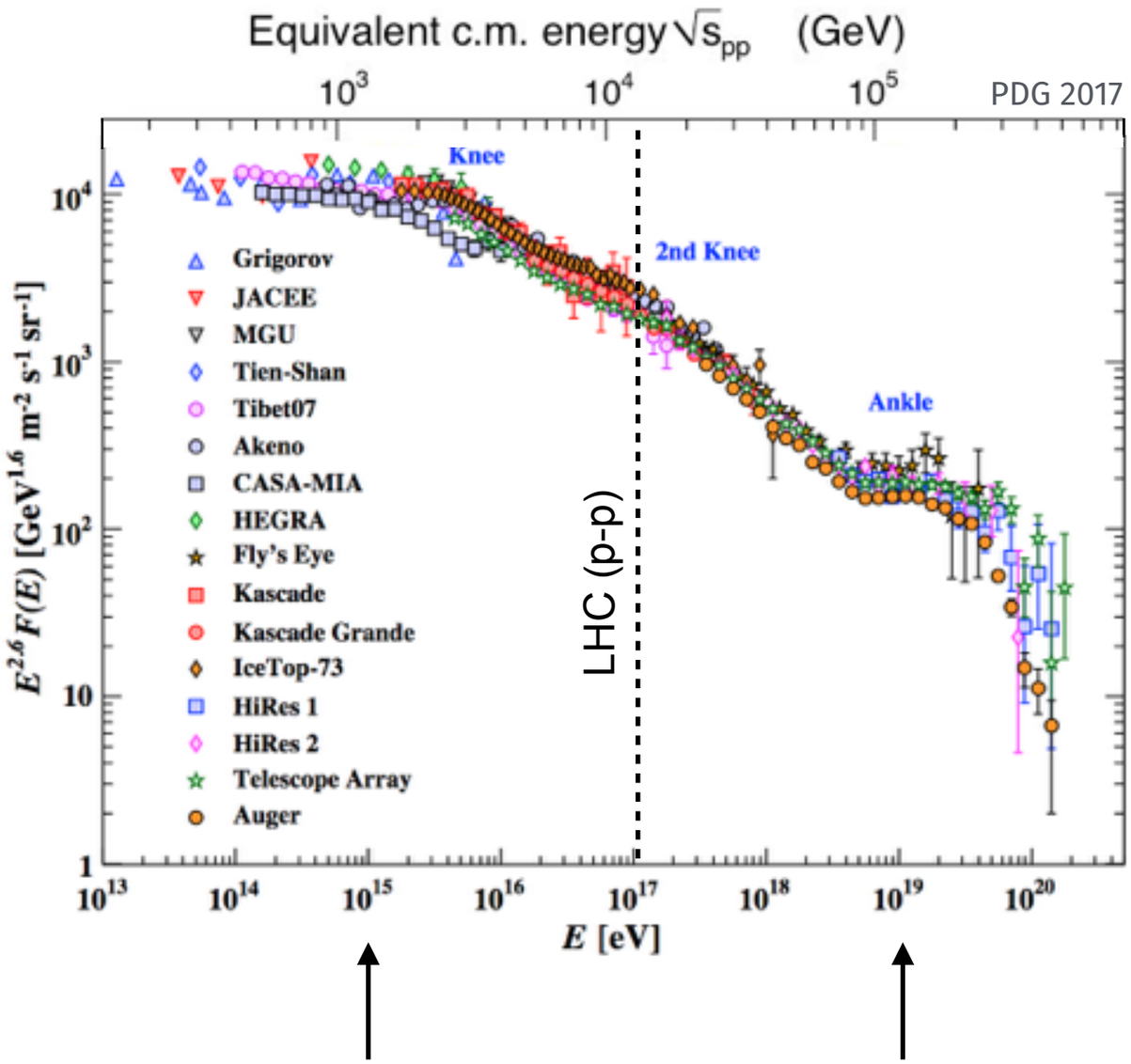
GK1504 Concluding Colloquium, 9.3.2018

1. Dark Matter: where, what, and why?
2. Indirect Dark Matter searches
3. Hunting Dark Matter subhalos with CTA



Intro: Observing the violent Universe

- Each m^2 of the atmosphere hit by one $E \geq 100\ \mathrm{GeV}$ particle **per second:**

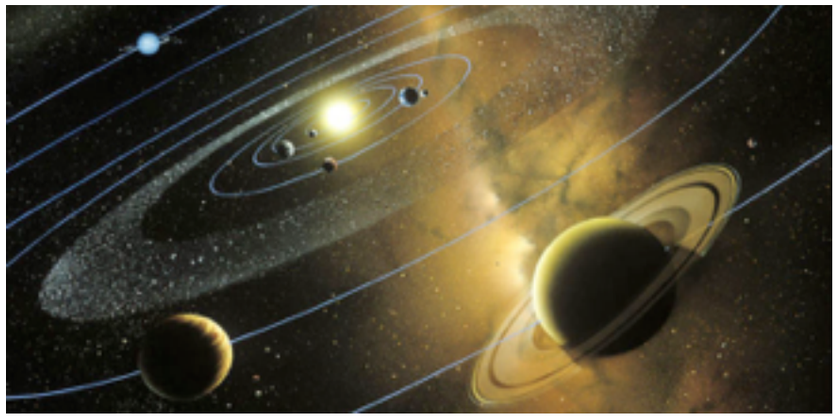


1 particle per m^2 and year

1 particle per km^2 and year

Hillas (1984):

$$E_{\mathrm{max}} \sim 10^{20}\,\mathrm{eV} \cdot Z \cdot \frac{B}{\mathrm{T}} \cdot \frac{R}{\mathrm{AU}}$$

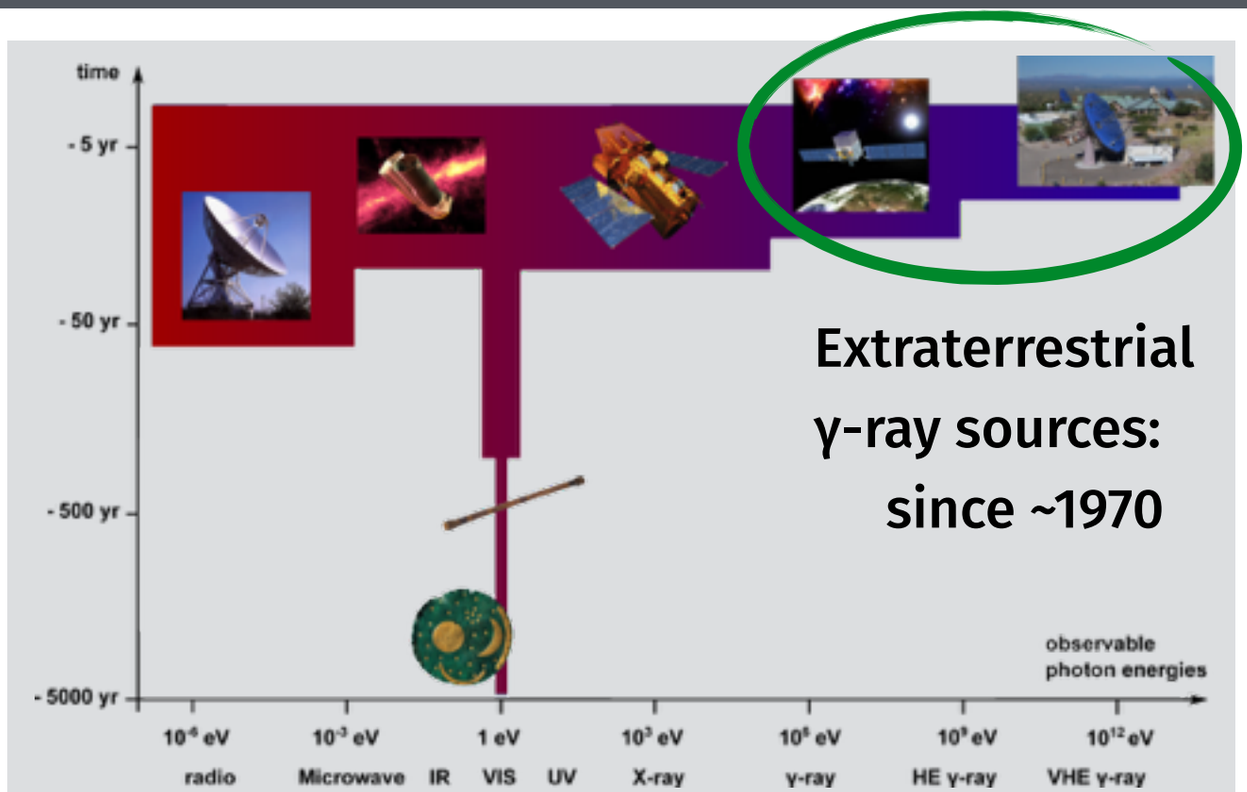


Need a solar-system LHC

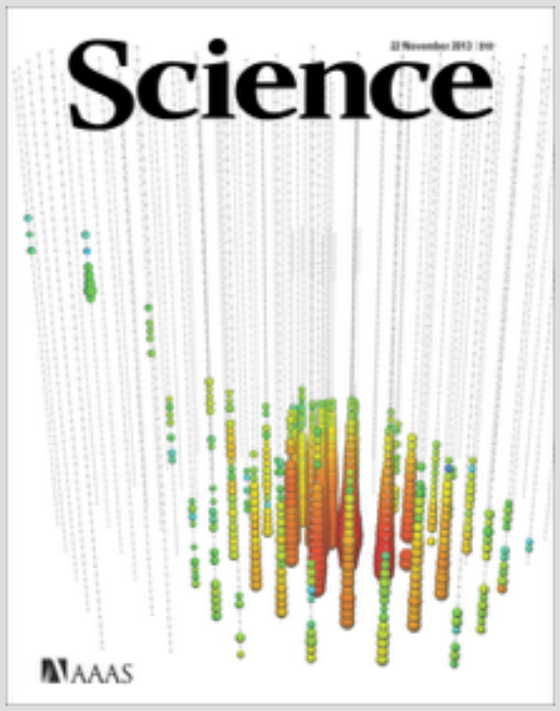
- **Where do these violent particles come from?**
- **How are they accelerated?**
- **Do particle physics (x-sections, new physics,...) with these particles?**

Intro: Observing the violent Universe

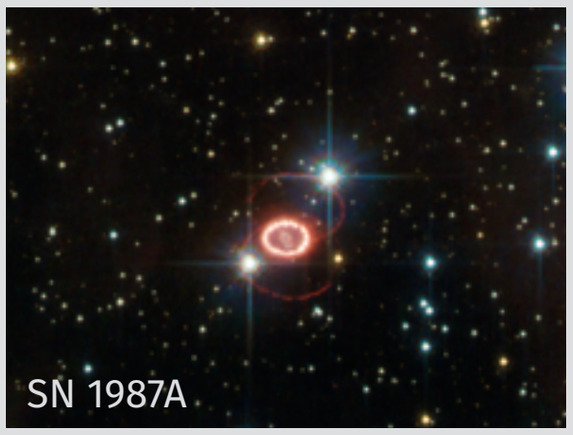
Charged cosmic particles: since 1912

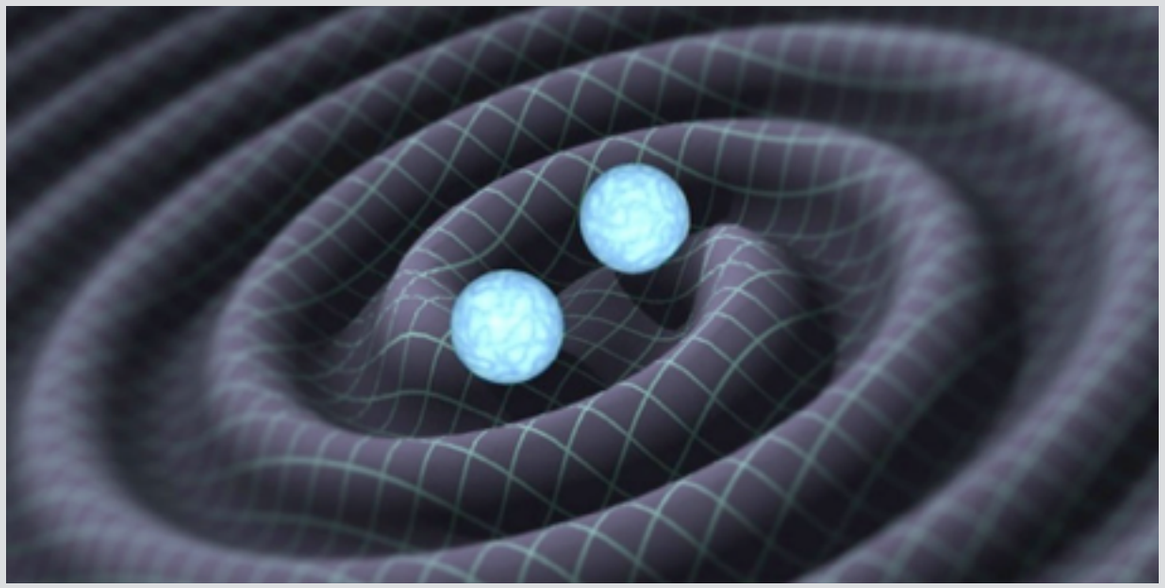


Extraterrestrial γ-ray sources: since ~1970



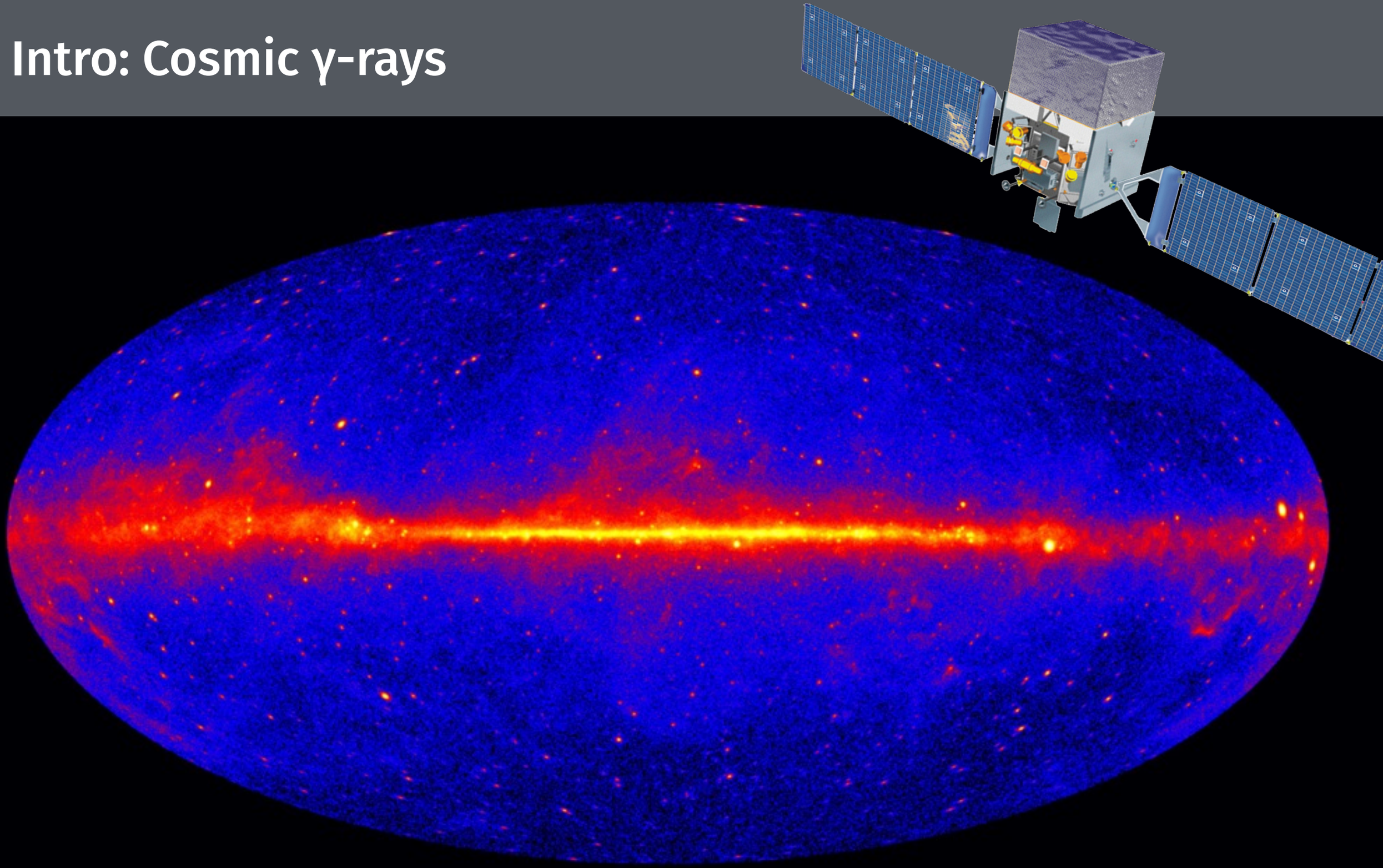
Astrophysical neutrinos: since 1987/2013





Gravitational waves: since 2015

Intro: Cosmic γ-rays



Fermi LAT satellite:

Since 2008: $3000+$ Galactic and extragalactic sources emitting $E > 100\ \mathrm{MeV}$ photons

Intro: Observing the violent Universe

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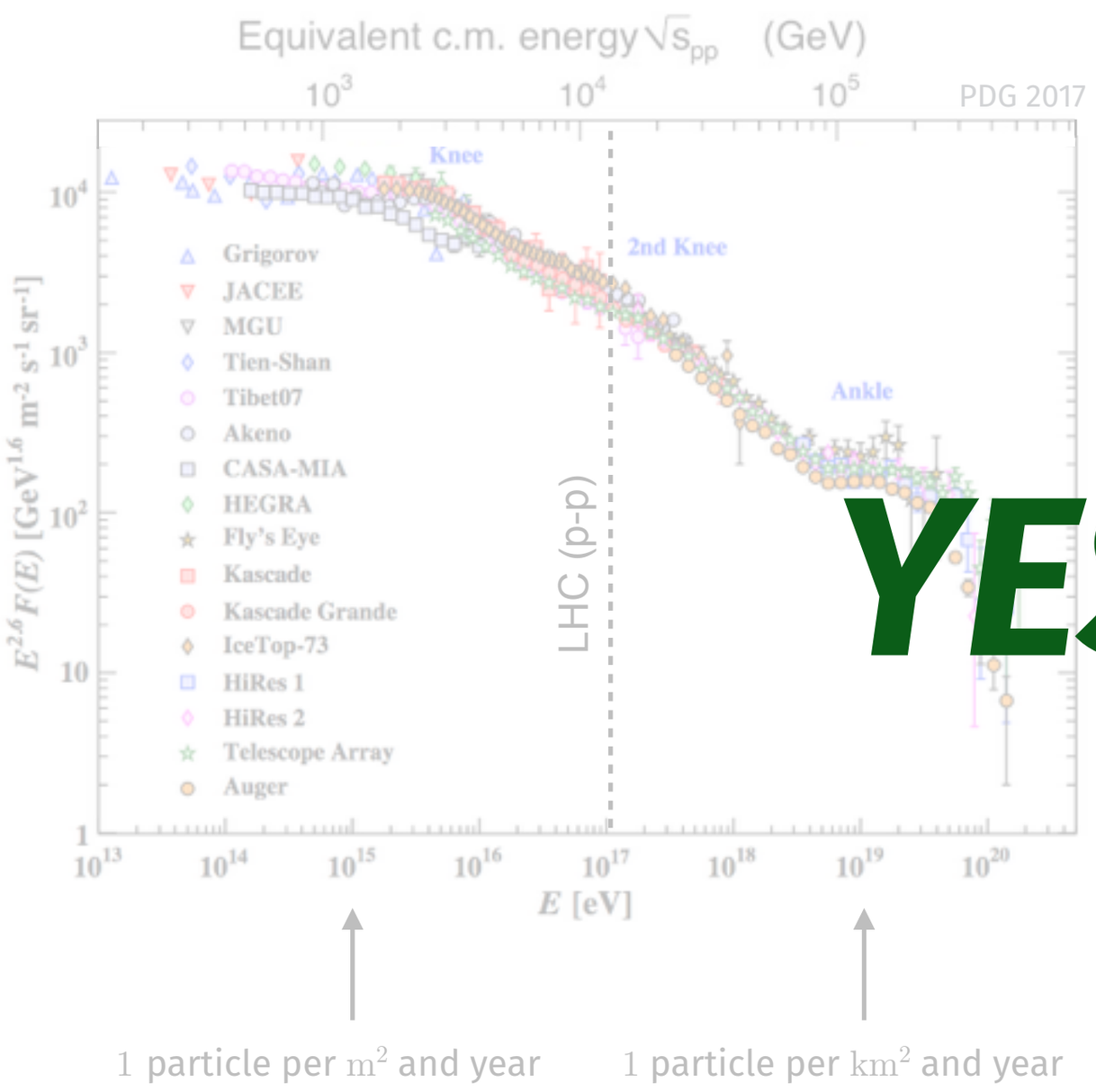

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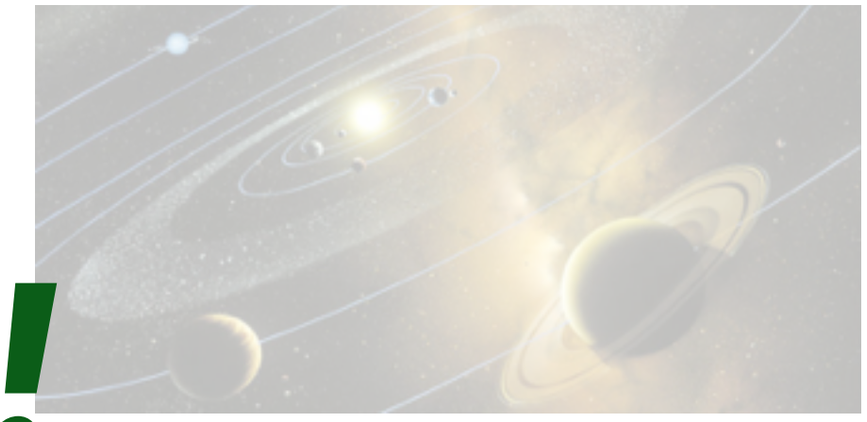


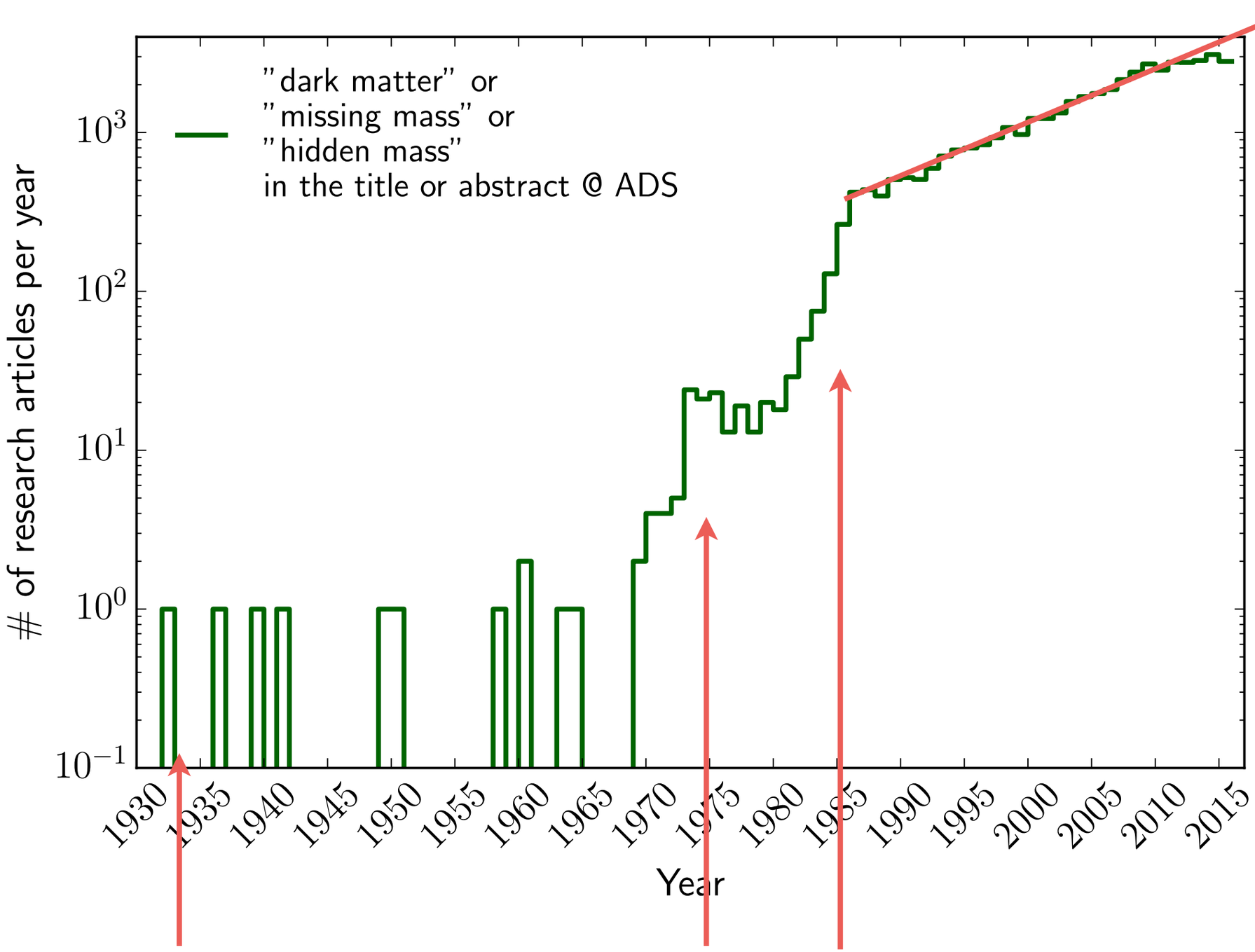
YES ! Need a solar-system LHC

- Where do these violent particles come from?
- How are they accelerated?
- **Do particle physics (x-sections, new physics,...) with these particles?**

1. Dark Matter: where, what, and why?

picture by R. Sanders (2010)

What's the (dark) matter?



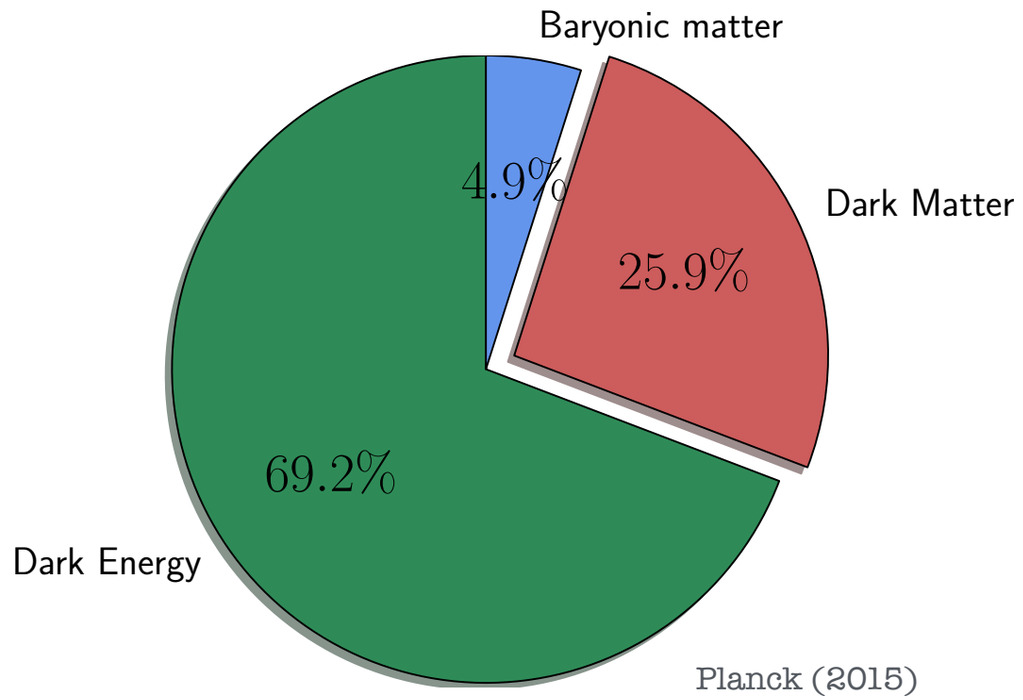
2020:
30 articles on dark matter per day?

1933: Fritz Zwicky "discovers" dark matter

~1975: Vera Rubin et al. study Galaxy rotation curves

~1985: Particle physicists become excited

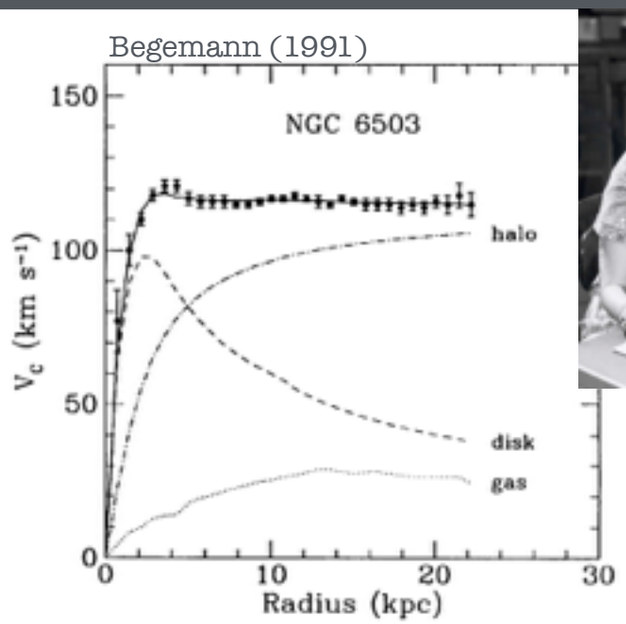
What's the (dark) matter?



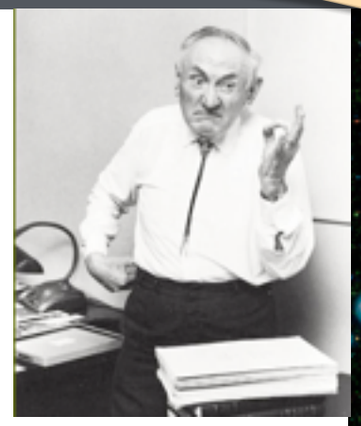
Planck (2015)

What's the (dark) matter?

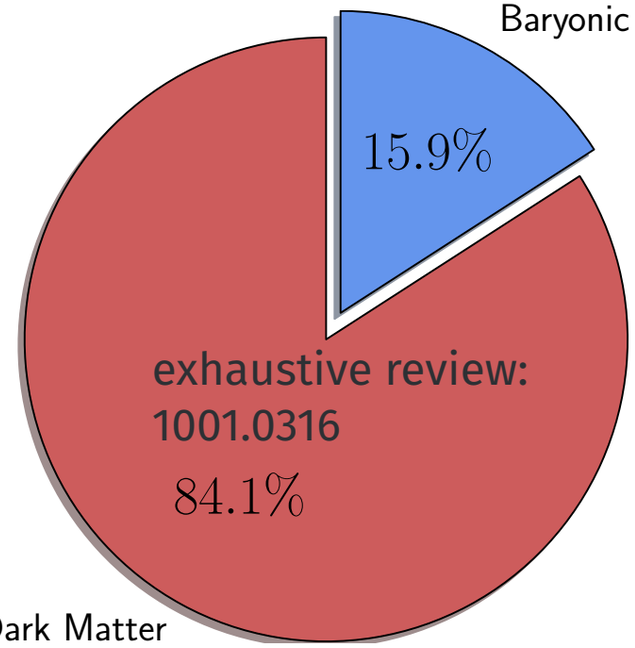
All evidence is gravitational only



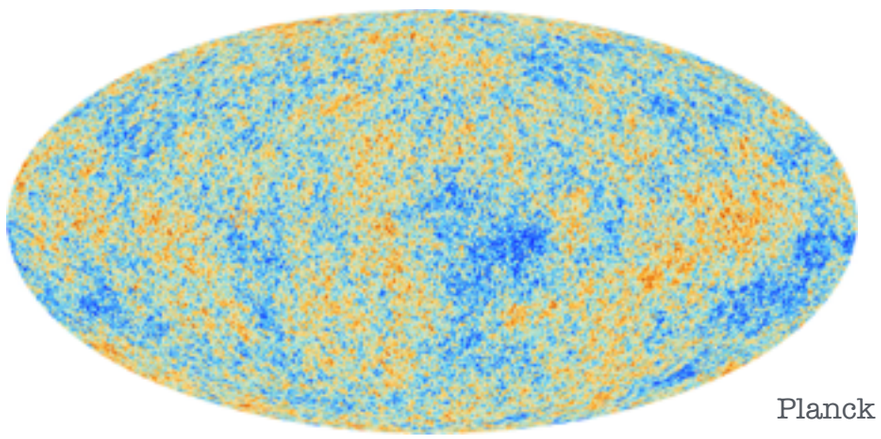
Spiral galaxies



Galaxy clusters

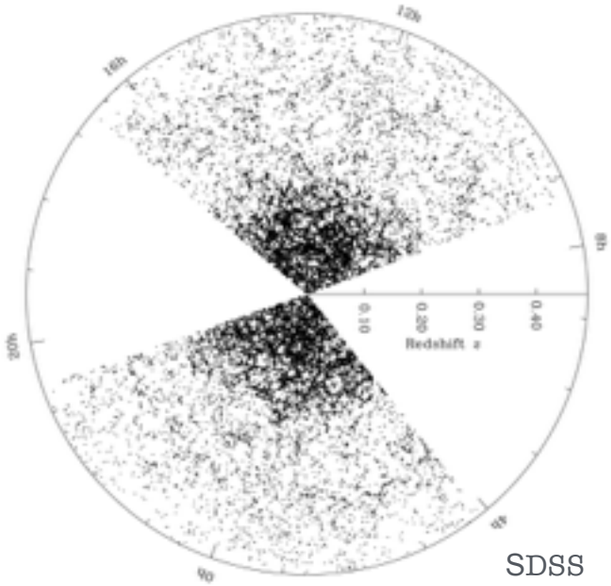


Cosmic Microwave Background



Planck

Large Scale Structure



SDSS

What's the (dark) matter?

- Most of the dark matter is already excluded to be:
  - black holes, brown dwarfs, Jupiter-sized bodies (e.g., astro-ph/0607207)
  - interstellar or intergalactic gas or dust (e.g, Wilson & Mauersberger, 1994)
  - the cosmic neutrino background (e.g., White et al., 1983)

- Dark matter is maybe:
  - ? a proxy for in[sufficient understanding of Gravity] (e.g., Milgrom, 1983, ..)

- Most physicists (s[trongly believe the dark matter is]:
  - + **indicating new p[article(s) beyond the Standard Model:]**

    - electromagnetically neutral
    - stable
    - massive (GeV - TeV)
    - freeze-out annihilation cross section of *O*(weak interaction)

"Cold particle dark matter" paradigm:

Weakly Interacting Massive Particles (WIMPs)

What's the (dark) matter?


Nuclear Physics B238 (1984) 453–476
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SUPERSYMMETRIC RELICS FROM THE BIG BANG*

John ELLIS and J. S. HAGELIN
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305, USA

D. V. NANOPOULOS, K. OLIVE†, and M. SREDNICKI‡
CERN, CH-1211 Geneva 23, Switzerland

- Ellis, Hagelin et al. (1984+):

  supersymmetric Dark Matter

  DM = lightest + stable particle in MSSM (Minimal supersymmetric SM)

- ~~Sneutrinos~~ or **neutralinos**:

$$\chi_1^0 = N_{11}\,\widetilde{B} + N_{12}\,\widetilde{W}_i + N_{13}\,\widetilde{H}_1^{\,0} + +N_{14}\,\widetilde{H}_2^0$$

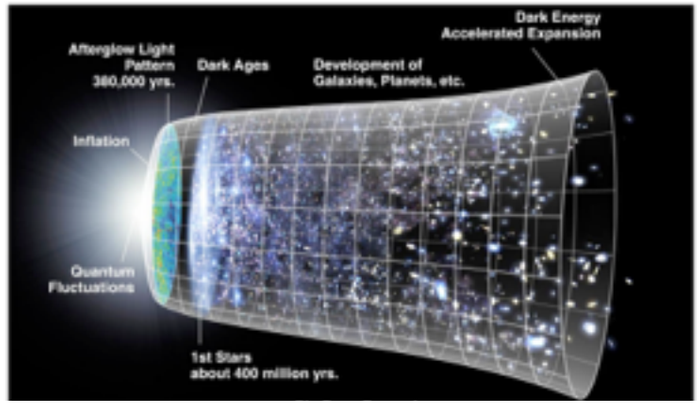
  - Neutralino: spin $1/2$ = Fermion
  - Majorana fermion favored: $\chi = \overline{\chi}$

- Weak annihilation into heavy SM fermions favored:

$$\chi\bar{\chi} \to t\bar{t},\ b\bar{b},\ \tau^+\tau^-,\ c\bar{c},\ \mu^+\mu^-$$

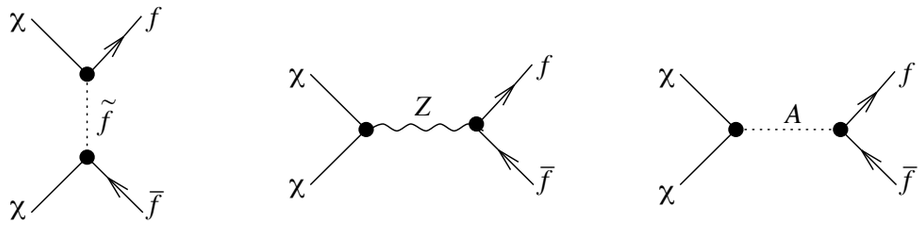
What's the (dark) matter?

WIMPs can explain their gravitational evidence, nicely fitting into Cosmological Standard Model:



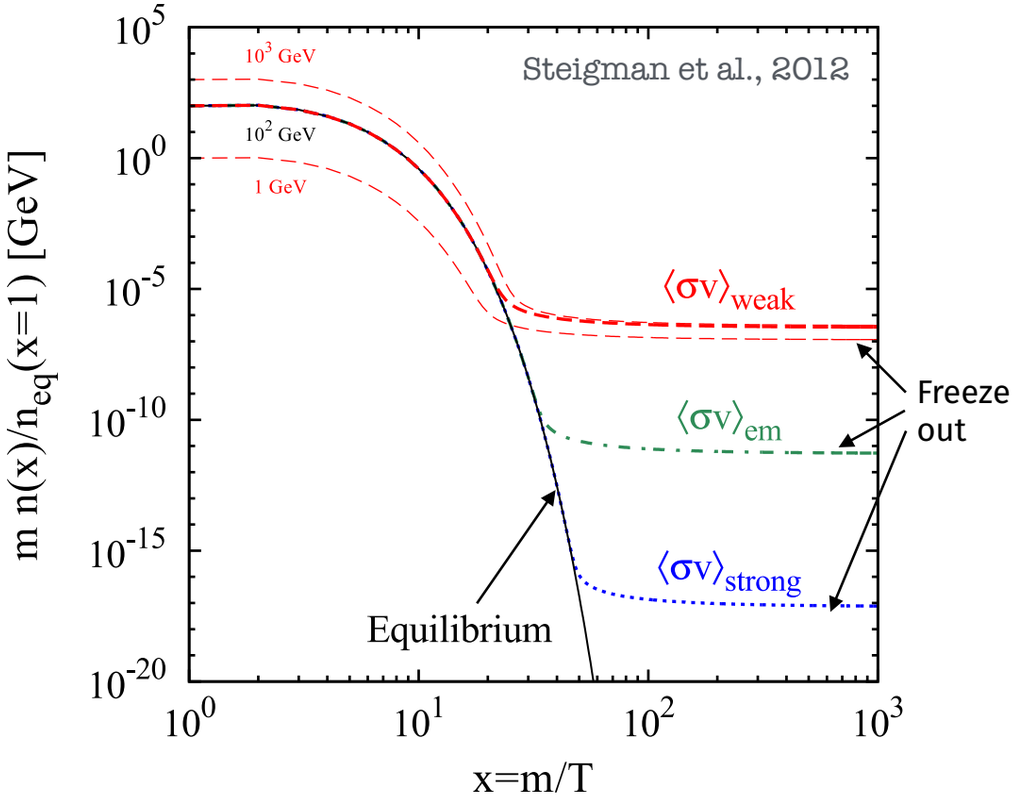
1. Lots of beyond-SM particles in thermal early Universe particle soup

2. Universe cools down: WIMPS annihilated away into lighter SM particles



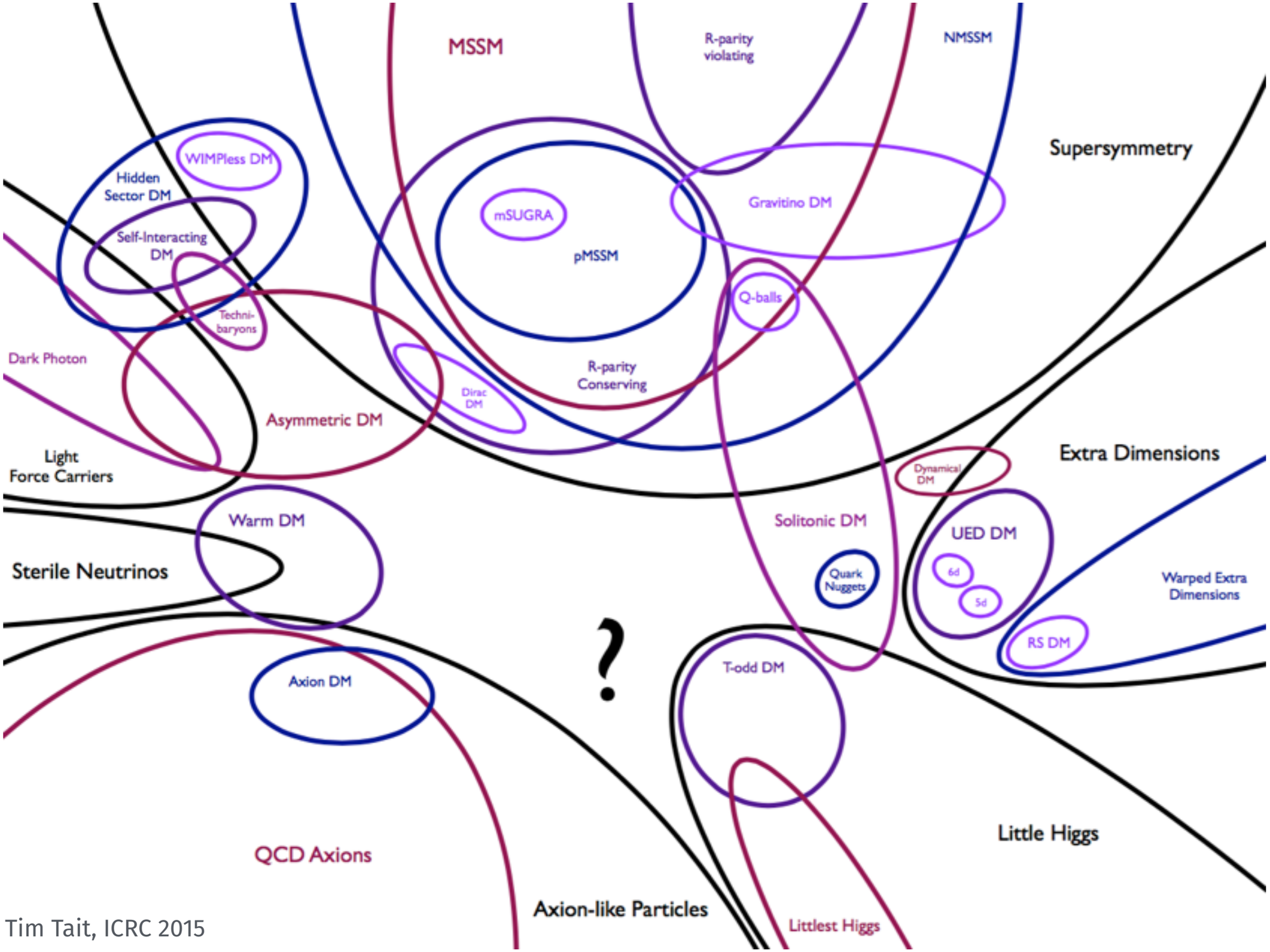
3. WIMP annihilation frozen out when Universe's density became too low

Need exactly weak scale!
A miracle?



$$\frac{h^2\,\Omega_\chi^0}{0.1} \approx \left(\frac{\langle\sigma v\rangle_f}{3\times 10^{-26}\ \frac{\mathrm{cm}^3}{\mathrm{s}}}\right)^{-1}$$

MSSM neutralinos not the only DM candidates...



Tim Tait, ICRC 2015

Searching for particle DM

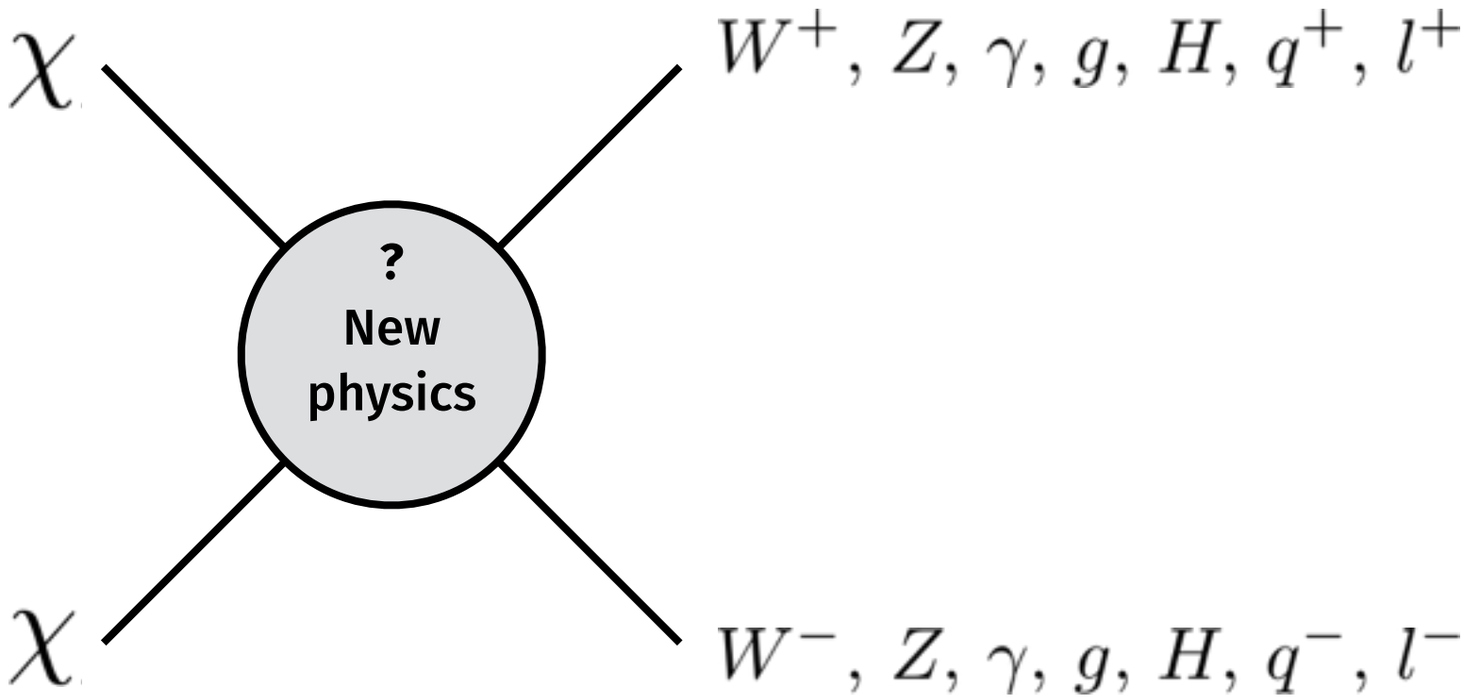
Relic annihilation (and decay?):

Indirect detection

Nuclear and electron recoils:

Direct detection

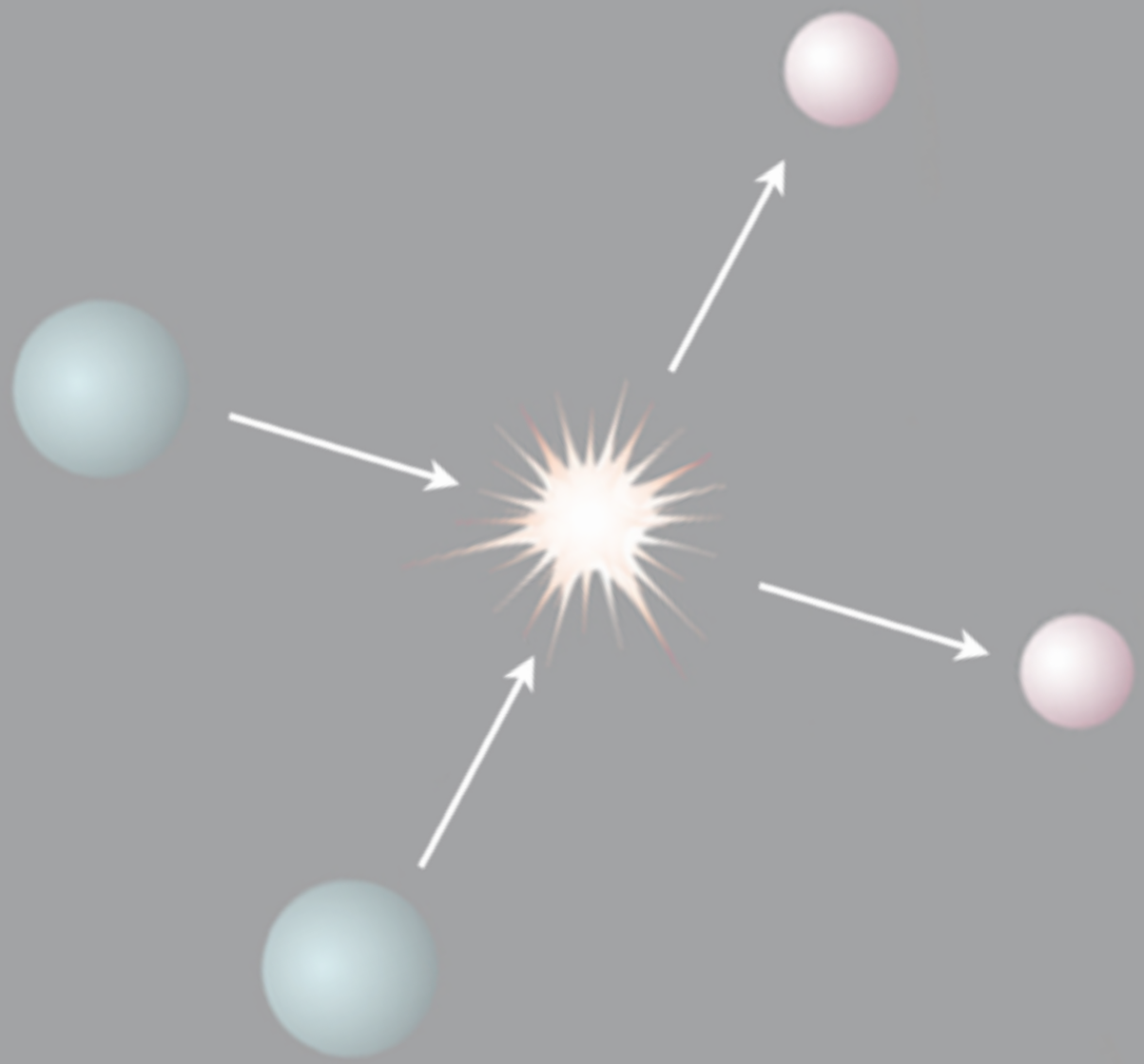
Xenon1T, Lux-Zeplin, SuperCDMS,...



Produce DM particles in the lab:

Collider searches

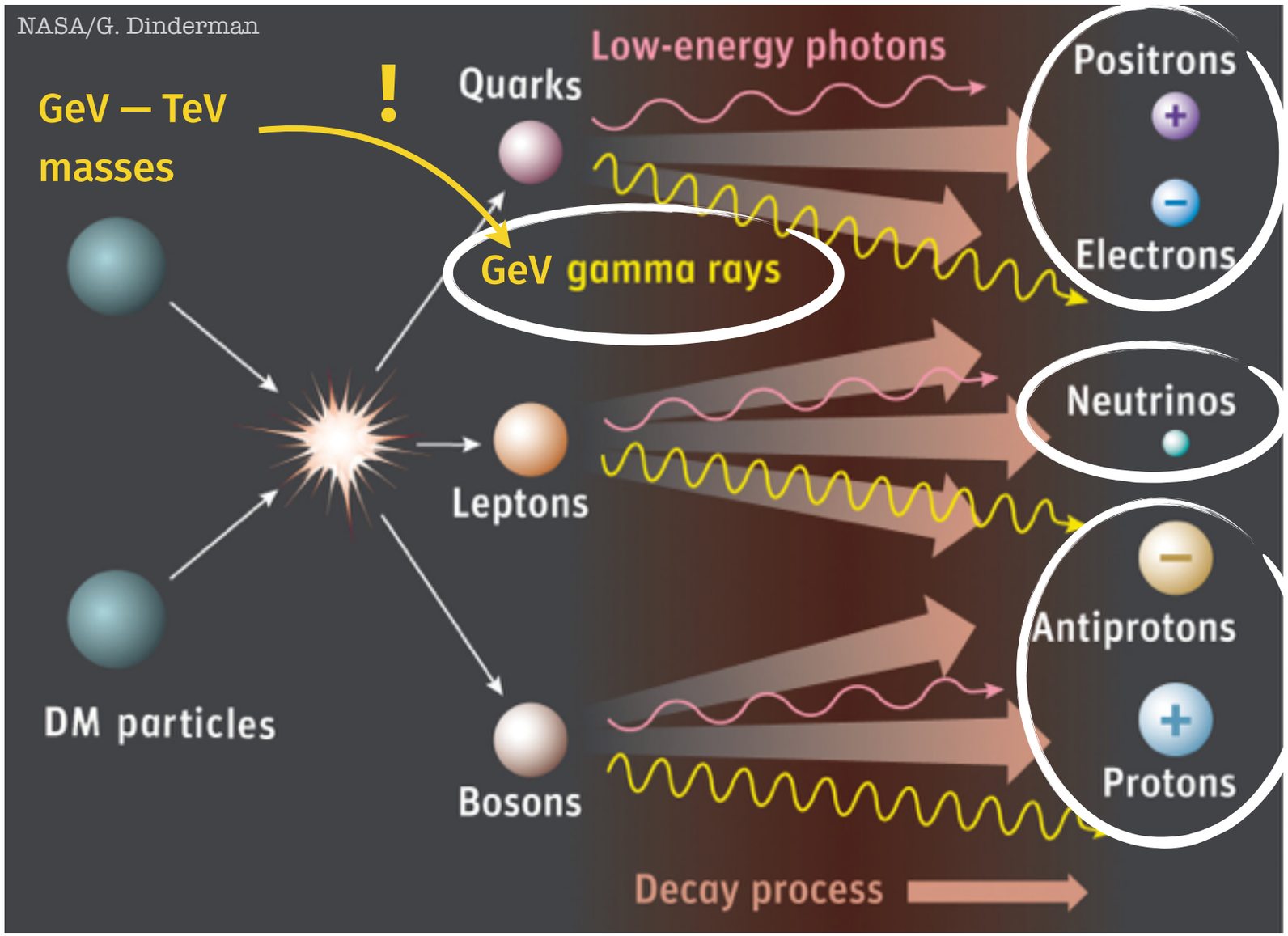
2. Indirect Dark Matter searches



Dark matter indirect detection

- DM annihilations still occasionally happening: **“Relic annihilation”**
- On Earth: 1 annihilation per km^3 and 1000 years

➡ **Look for astrophysical signatures: Astroparticles!**



Charged particles:

- \- diffusion
  (lost info about origin)
- \+ rare antiparticles
  (➔ PAMELA, AMS)

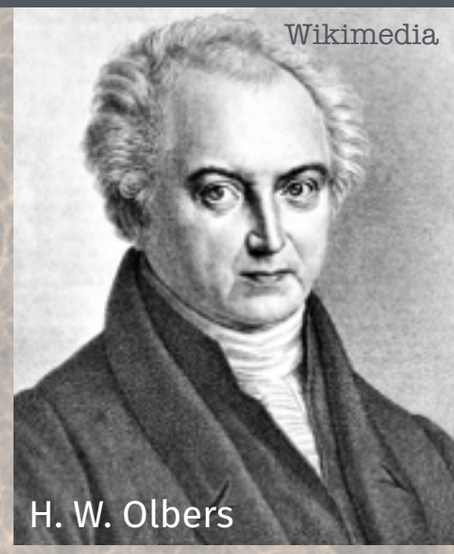
Neutrinos:

- \+ straight to observer
- \+ no absorption
- \- difficult to detect

γ-rays:

- \+ straight to observer
- \+ no absorption in MW
- \- astrophysical background

A faint γ-ray glow from all DM in the cosmos?



- Heinrich Wilhelm Olbers (* 1758, † 1840):

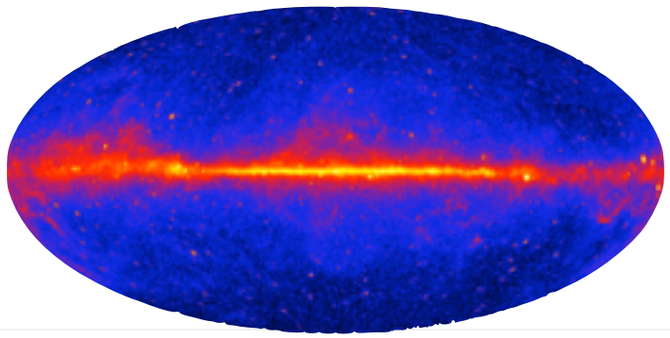
  If you look towards a star in any direction, the night-sky sky should be quite bright.

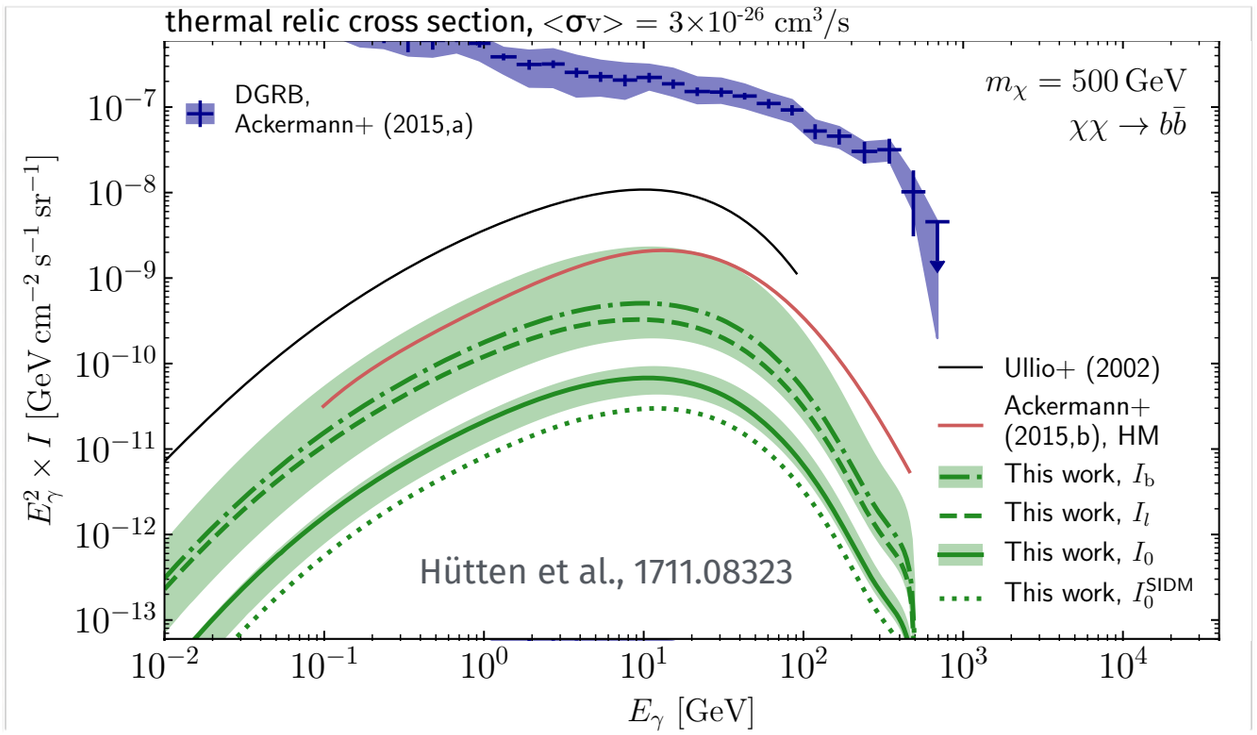
  Well, not really... Universe has finite age and decreasing energy density.

- **What about the γ-ray glow from DM relic annihilation in a finite, expanding Universe?**

- Gunn, Steigman et al. (1978) → Hütten et al. (2018):

Expect **rather low** isotropic γ-ray intensity from extragalactic annihilating DM



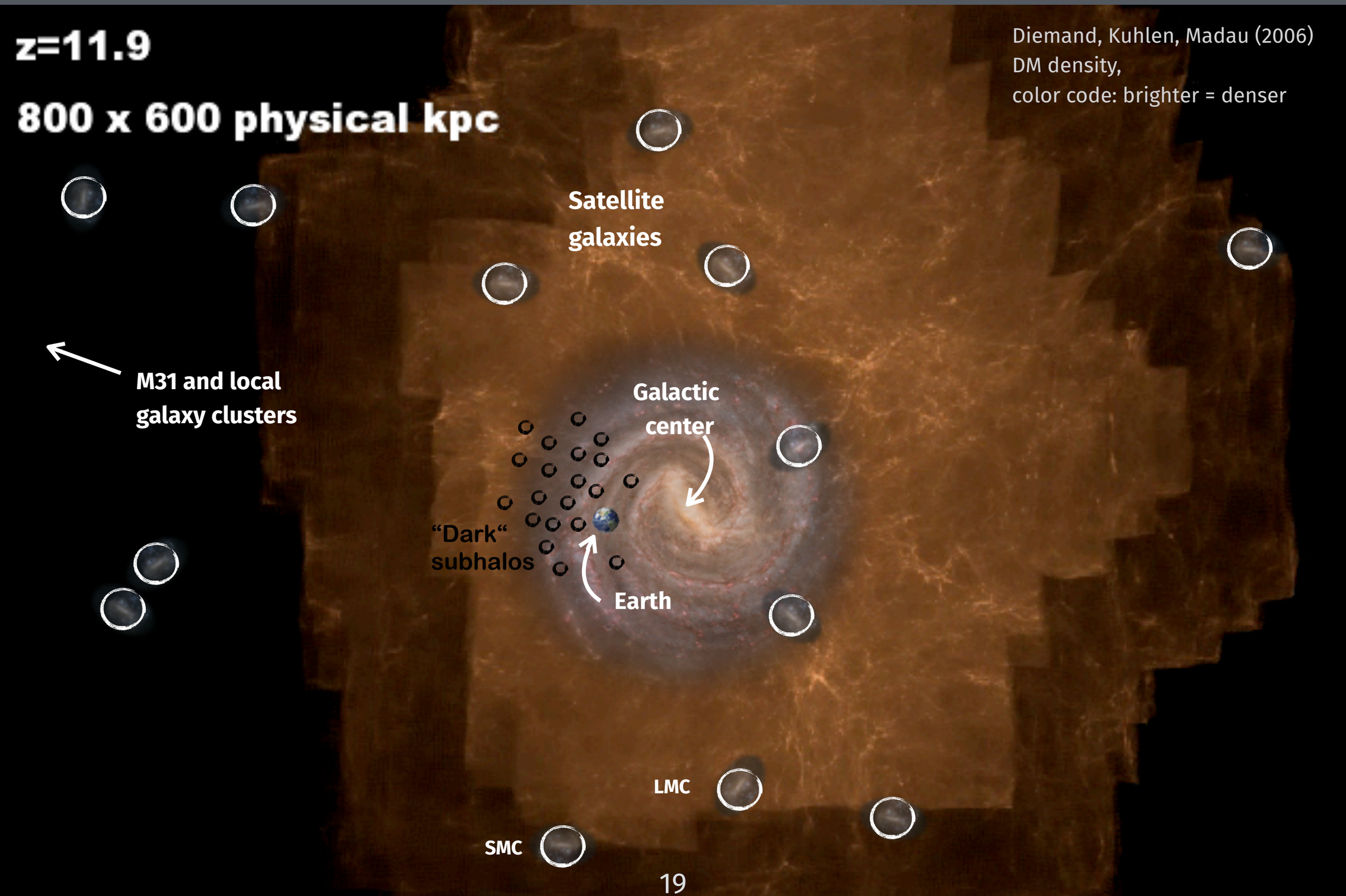


Hunting for dark matter clumps

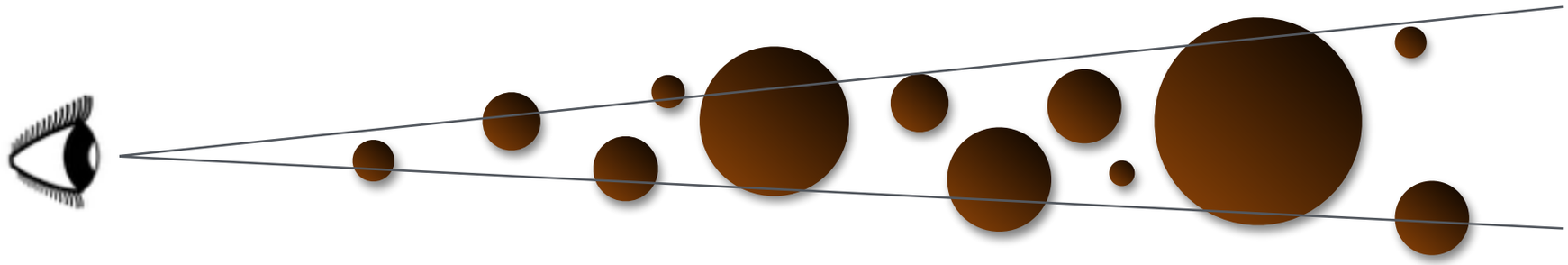
All ist not lost, however...

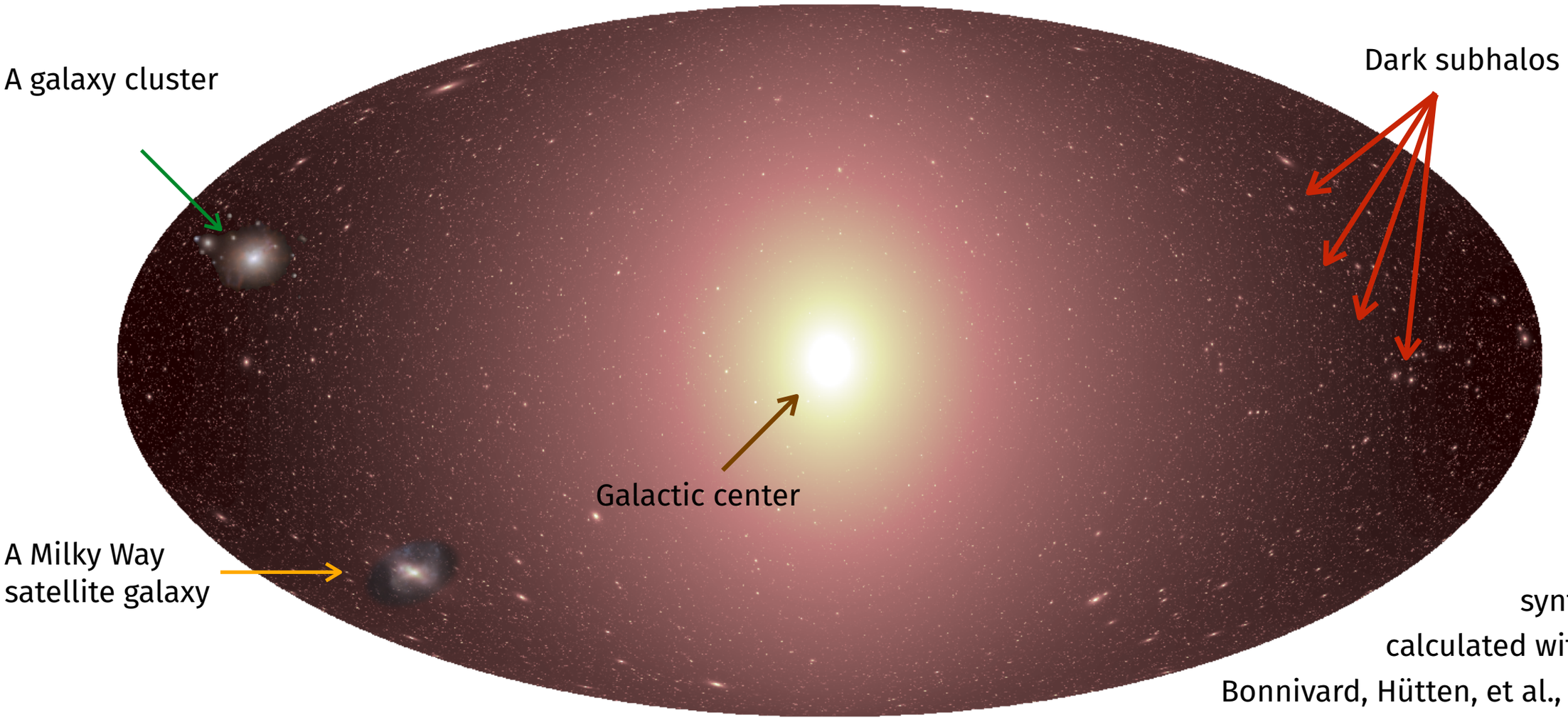
Dark matter likes to concentrate in localized clumps

Dark matter in the Galaxy



The Galactic Dark matter sky from Earth





synthetic map
calculated with **clumpy**
Bonnivard, Hütten, et al., 1506.07628

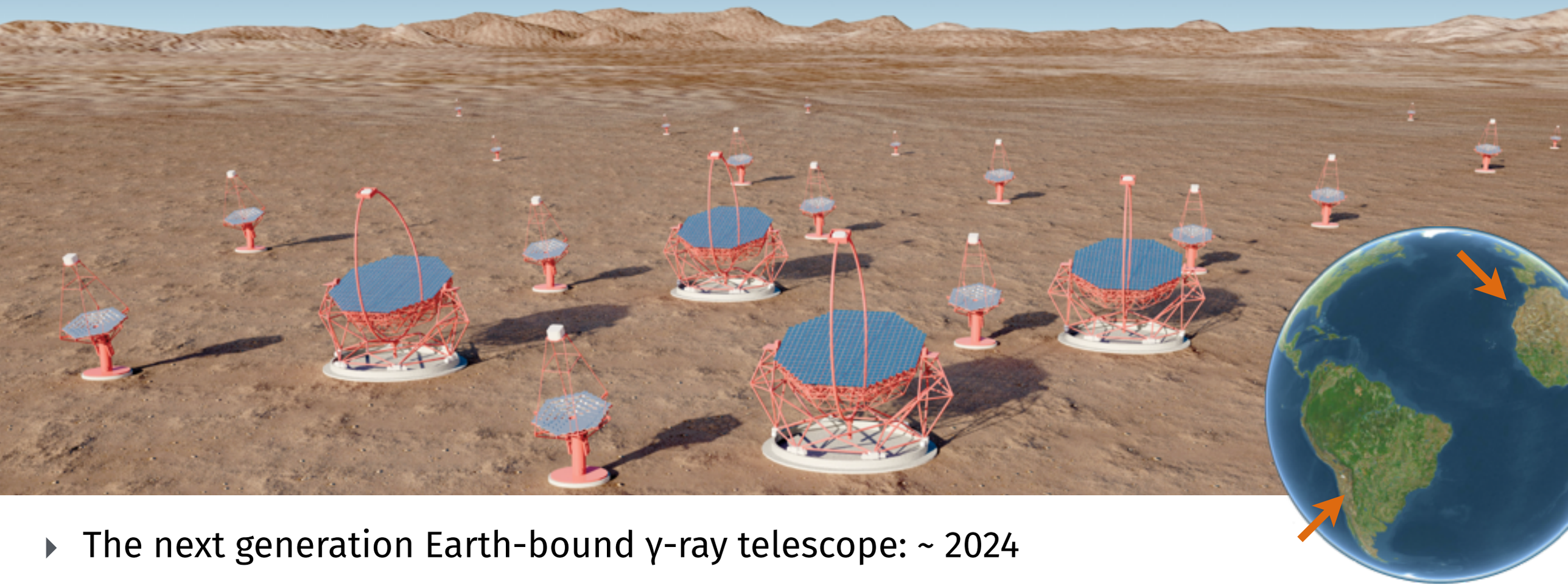
log (γ-ray intensity from DM annihilation), Galactic coordinates

3. Hunting Dark Matter subhalos with CTA

The Cherenkov Telescope Array (CTA)

CTA concept and performance: Acharya et al. (AP, 2013), Bernlöhr et al. (AP, 2013)

CTA, G. Pérez, IAC, SMM



- The next generation Earth-bound γ-ray telescope: ~ 2024
- Two arrays of 99 / 19 Cherenkov telescopes in Chile / La Palma
- γ-ray energy range: $20\ \mathrm{GeV} - 300\ \mathrm{TeV}$
- Angular resolution: $< 0.1°$
- Field of view diameter: $\sim 7°$: Large enough for large-sky surveys

The Cherenkov Telescope Array (CTA)

La Palma, December 2017:
The 1st LST's dish mounted!

Earth-bound γ-ray astronomy: Cherenkov technique

very high-energy γ-ray ($E >$ some 10 GeV)

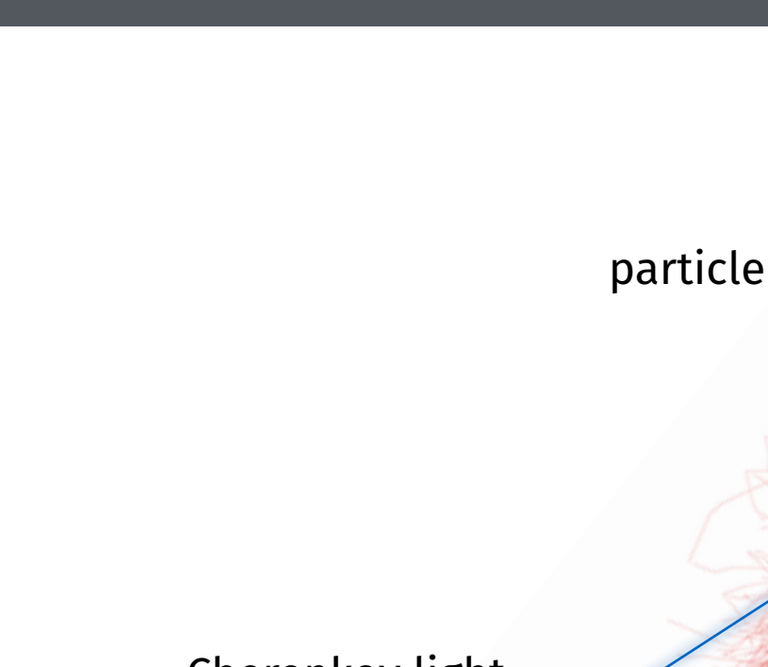
particle shower

atmosphere, h ≈ 25 km

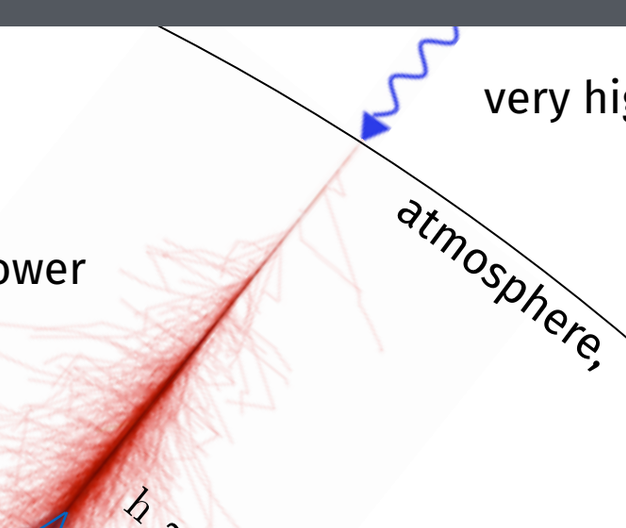
h ≈ 10 km

1°

Cherenkov light



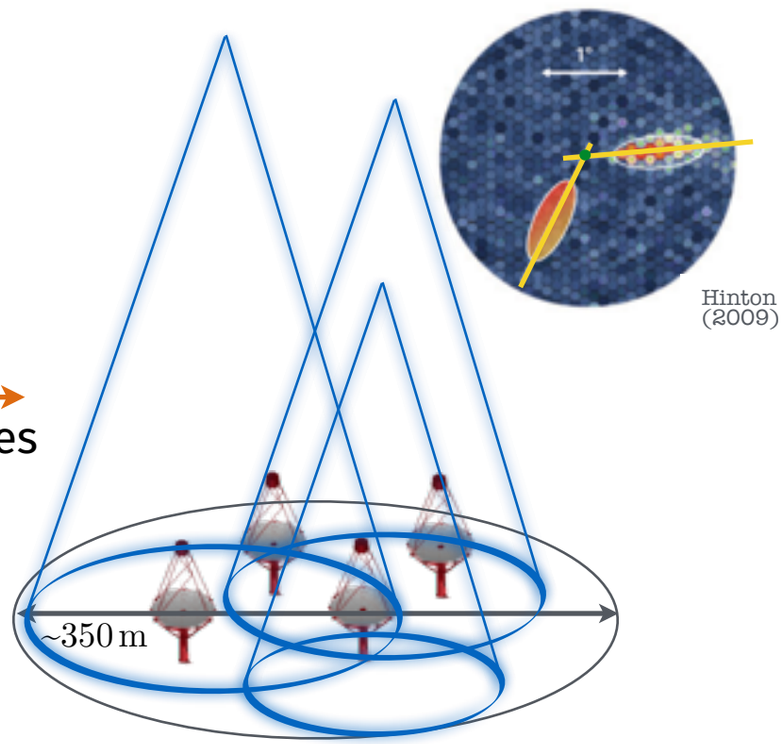
Shower image in the camera



- direction of primary γ-ray
- Energy of primary γ-ray

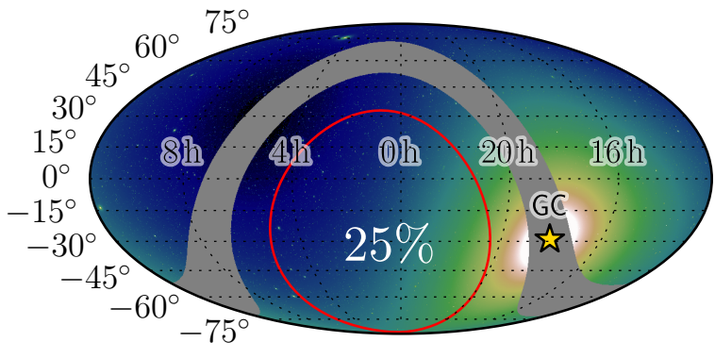
Multiple telescopes

- Stereoscopic reconstruction



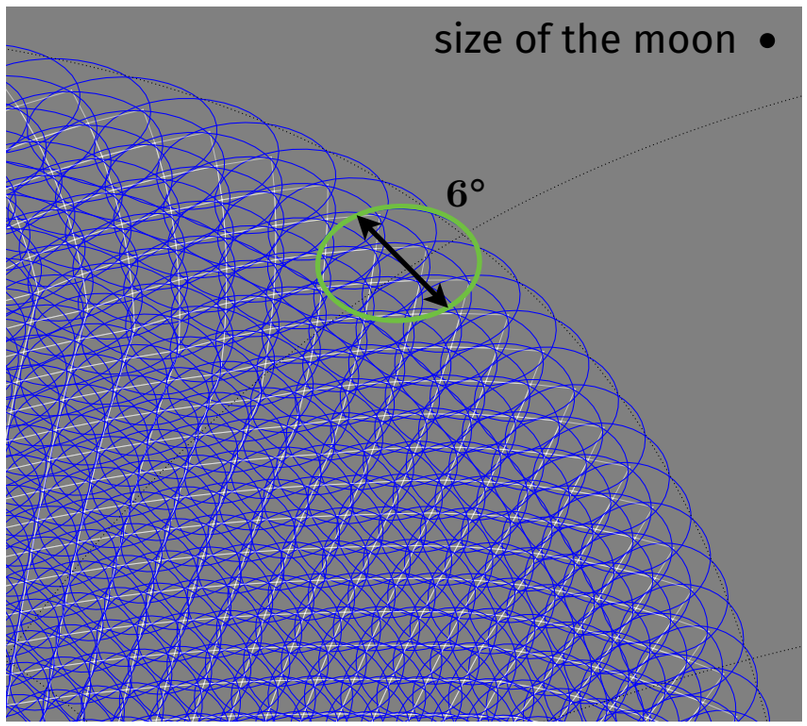
- Effective detector area $> 0.1\ \mathrm{km}^2$

A model for the CTA extragalactic survey



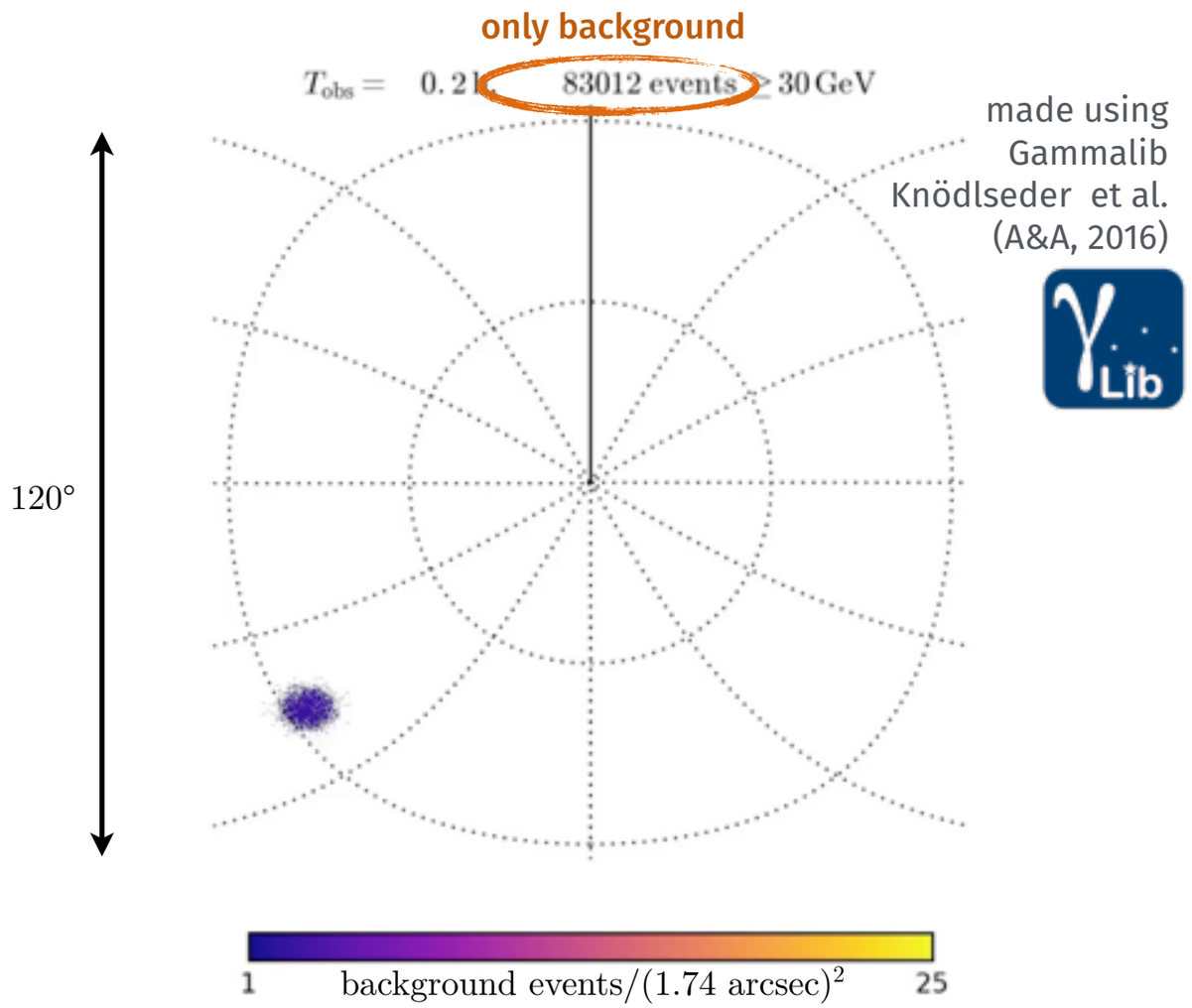
The CTA *extragalactic survey key science project*: Acharya et al. (1709.07997)

- $T > 300$ h to raster $\sim 25\%$ of the sky outside the Galactic plane
- Goal: Complete within < first 10 years of operation



Example: 3000 observations à 10 min

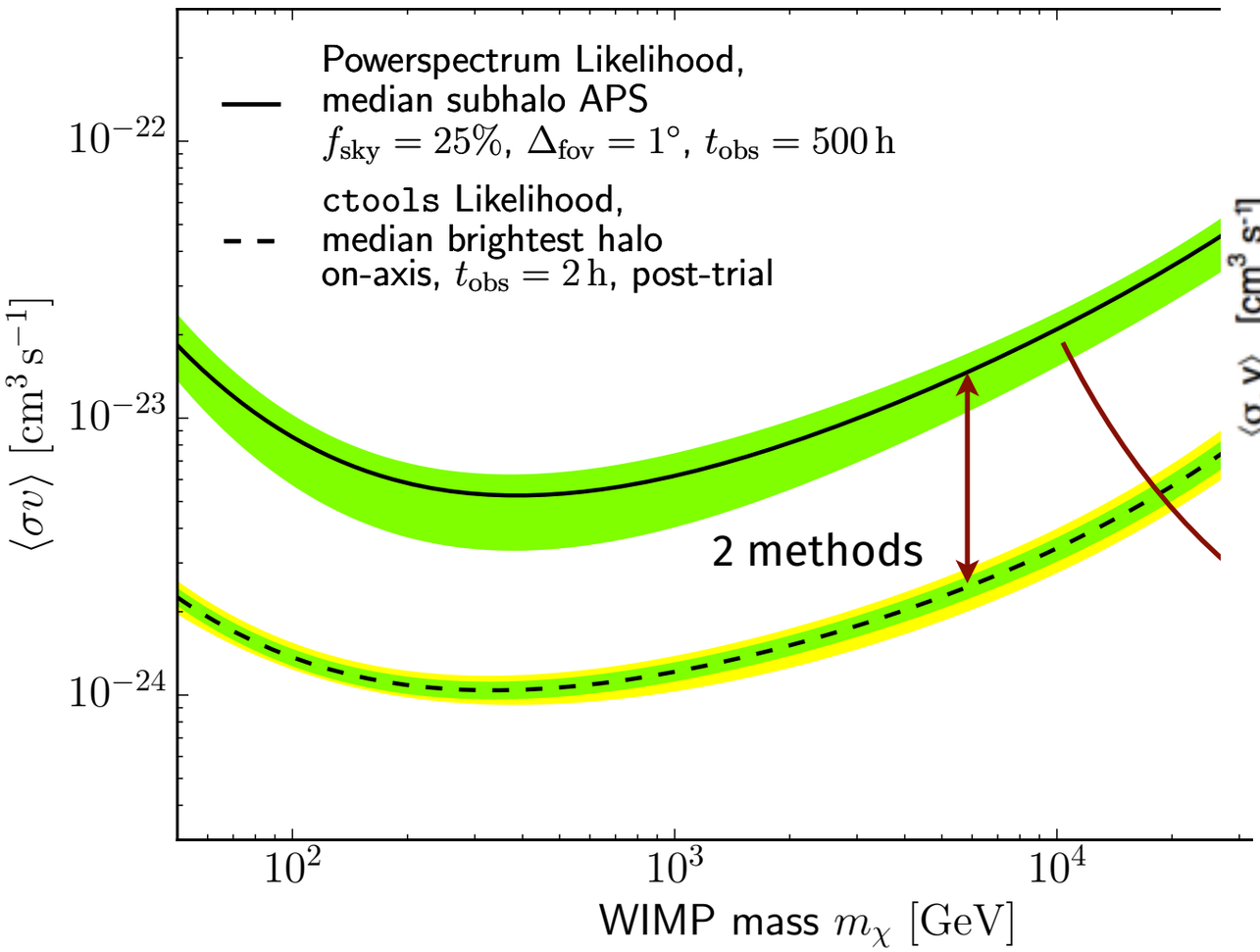
- Spacing $\Delta_{\mathrm{fov}} = 2°$



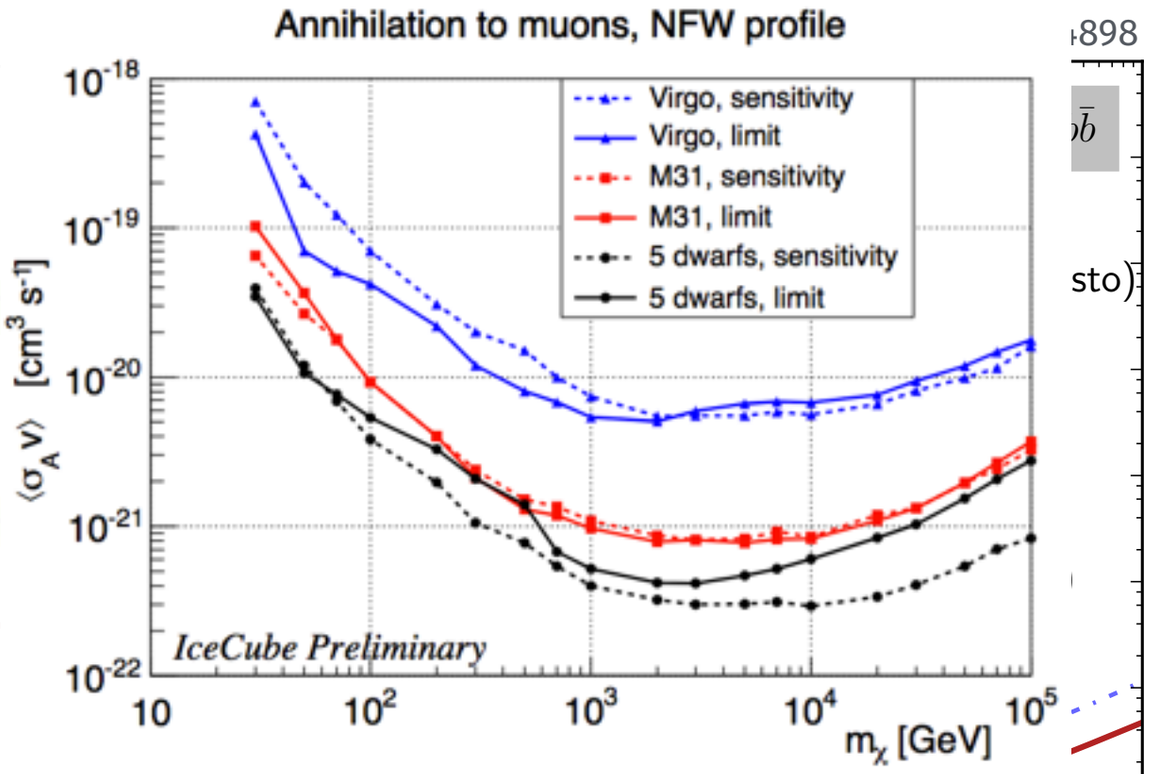
made using Gammalib Knödlseder et al. (A&A, 2016)

CTA sensitivity to Galactic dark matter subhalos: Summary

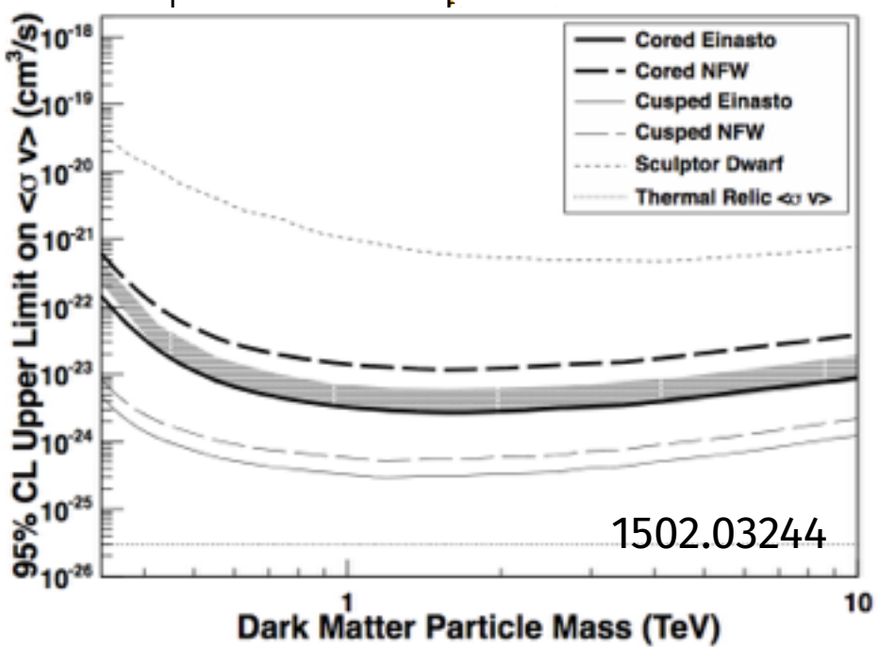
500 h CTA survey, 95% C.L.



M. de With, ICRC 2015, IceCube/neutrinos:



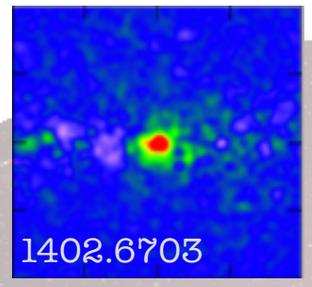
G. Spengler, H.E.S.S. γ-rays from Galactic center:



Summary: Ranking of the various targets (after H. Zechlin)

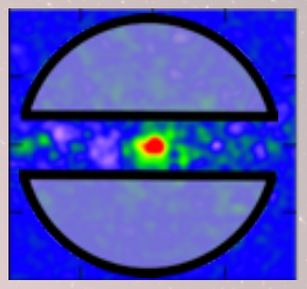
Signal strength $\propto \frac{1}{d^2}\frac{M^2}{V}$

Galactic center
$d = 8$ kpc



Galaxy clusters

Meike de With
@GK1504



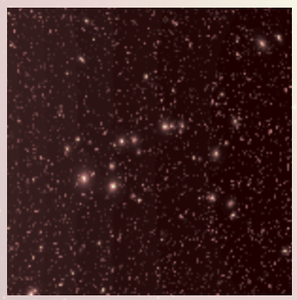
Galactic center vicinity

Gerrit Spengler
@GK1504

Robust constraints

Dark Galactic
subhalos

Moritz Hütten
@GK1504



Milky Way
satellite galaxies

Meike de With @GK1504

What's next with dark matter?

Thanks for your attention!
More comments/questions?