Dark Matter and Multimessenger Physics

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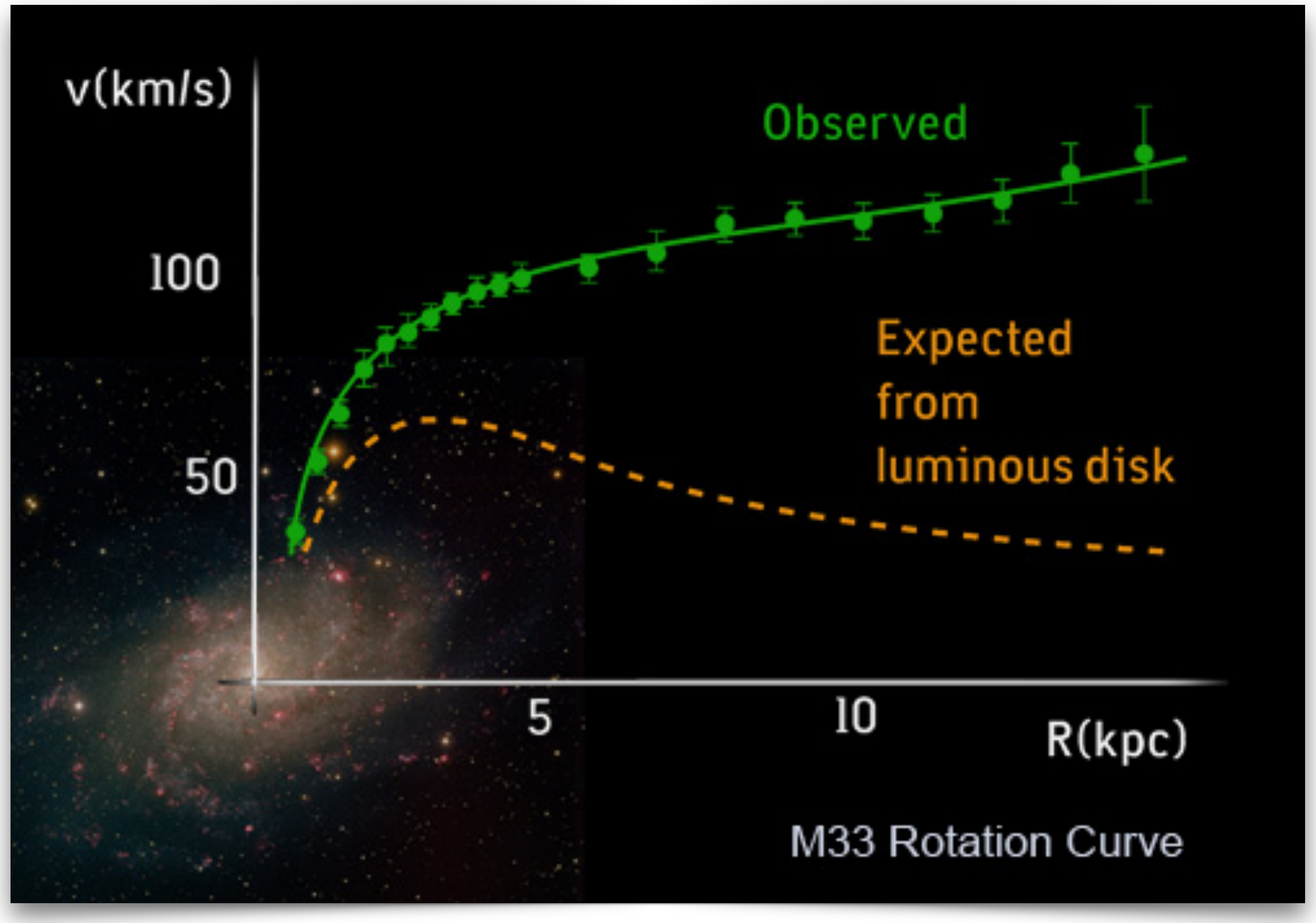
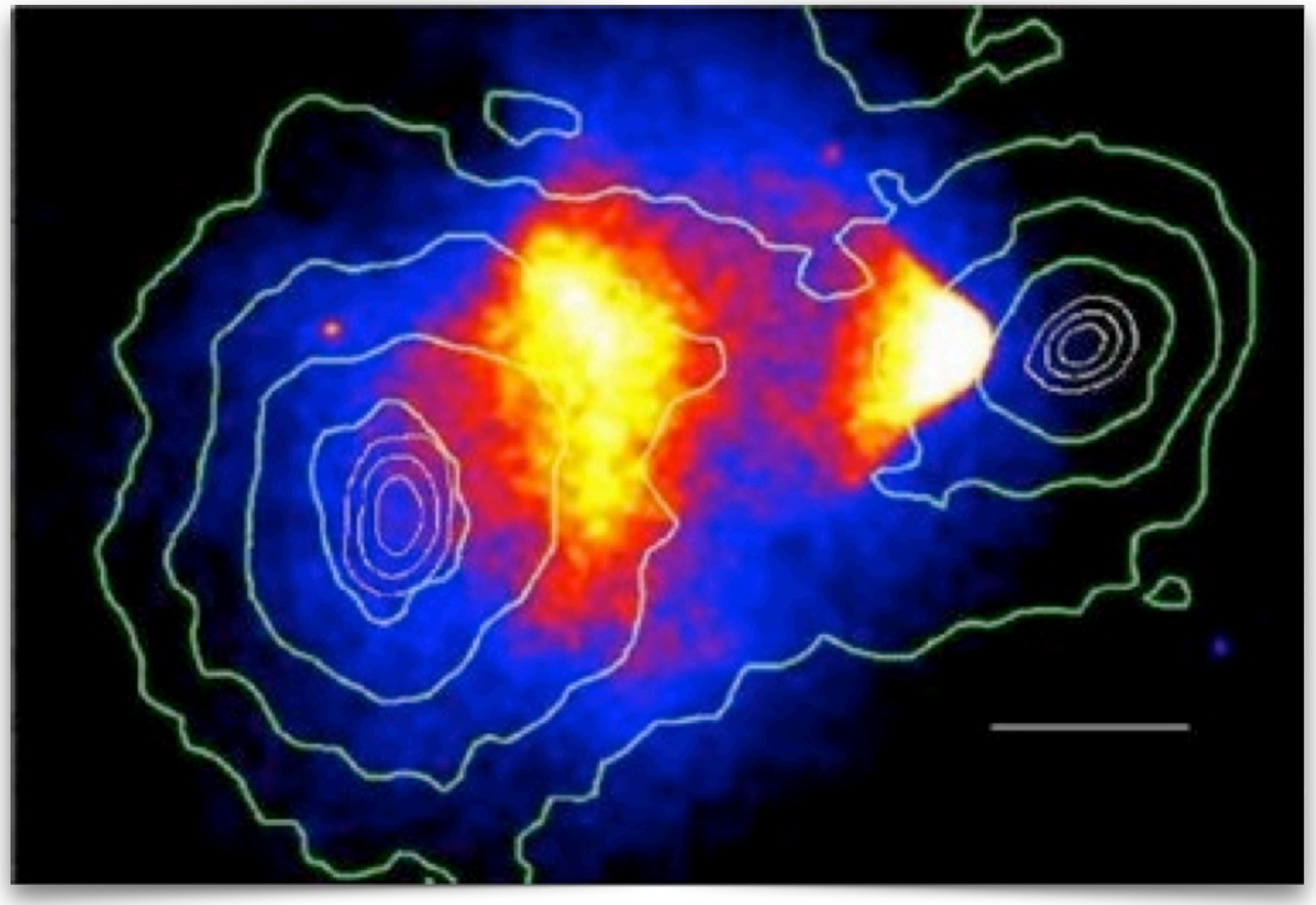
Dark matter: gravitational evidences

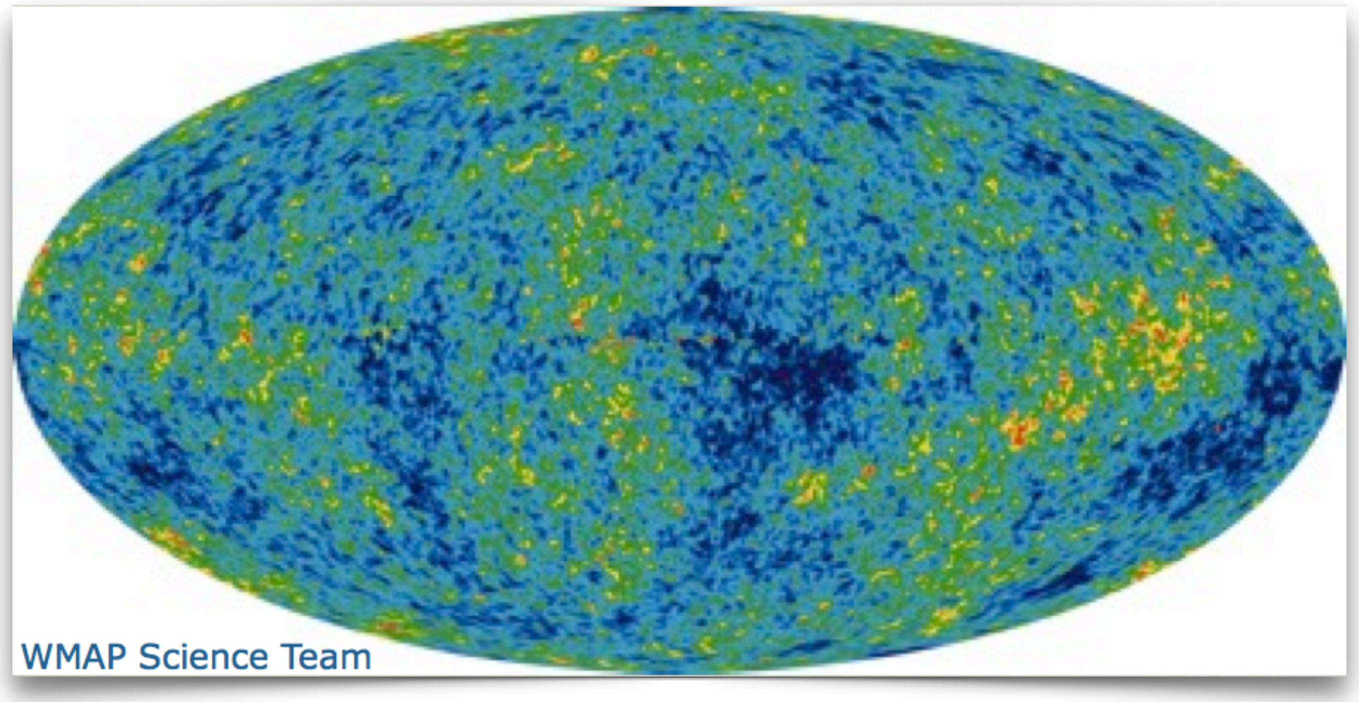
*Comprises **majority** of **mass** in Galaxies*
Missing mass on Galaxy Cluster scale
(Zwicky (1937))

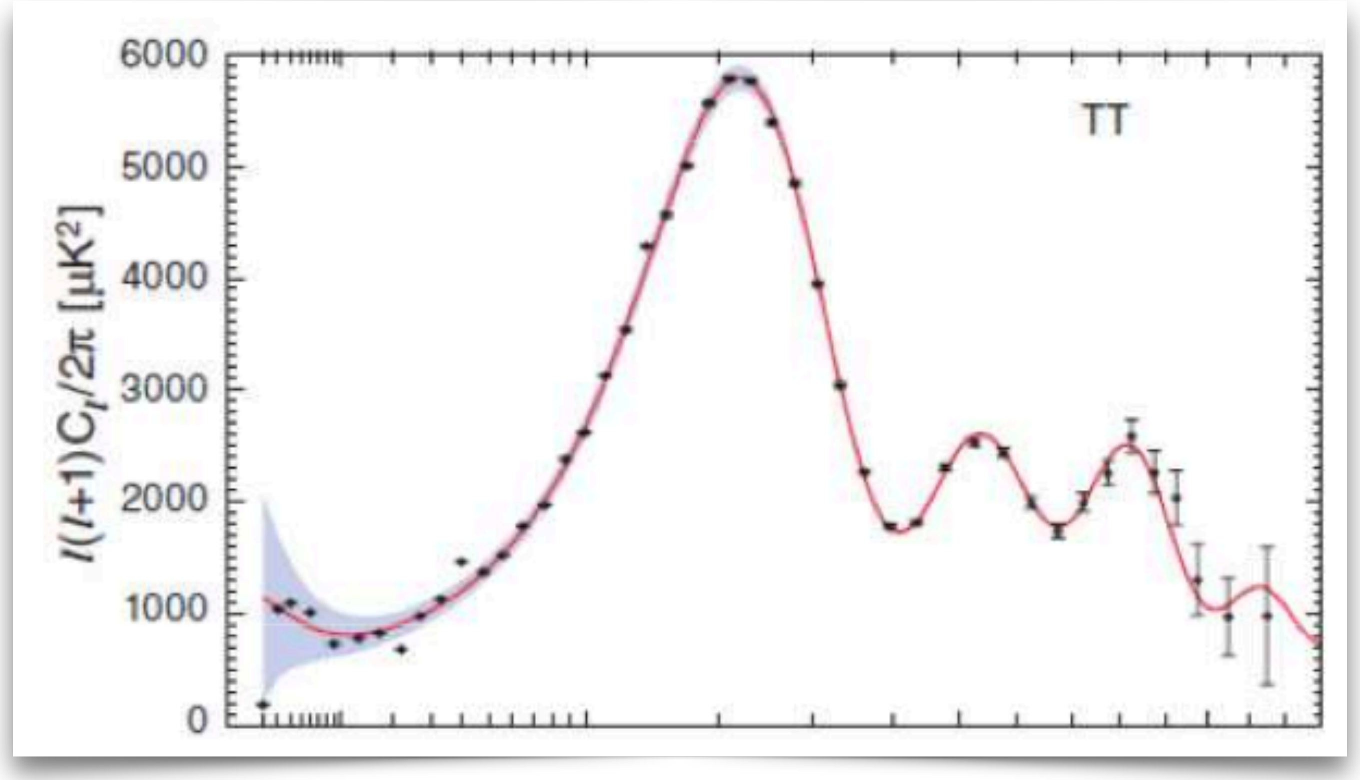
*Large **halos** around Galaxies*
Rotation Curves
Rubin+(1980)



*Almost **collisionless***
Bullet Cluster

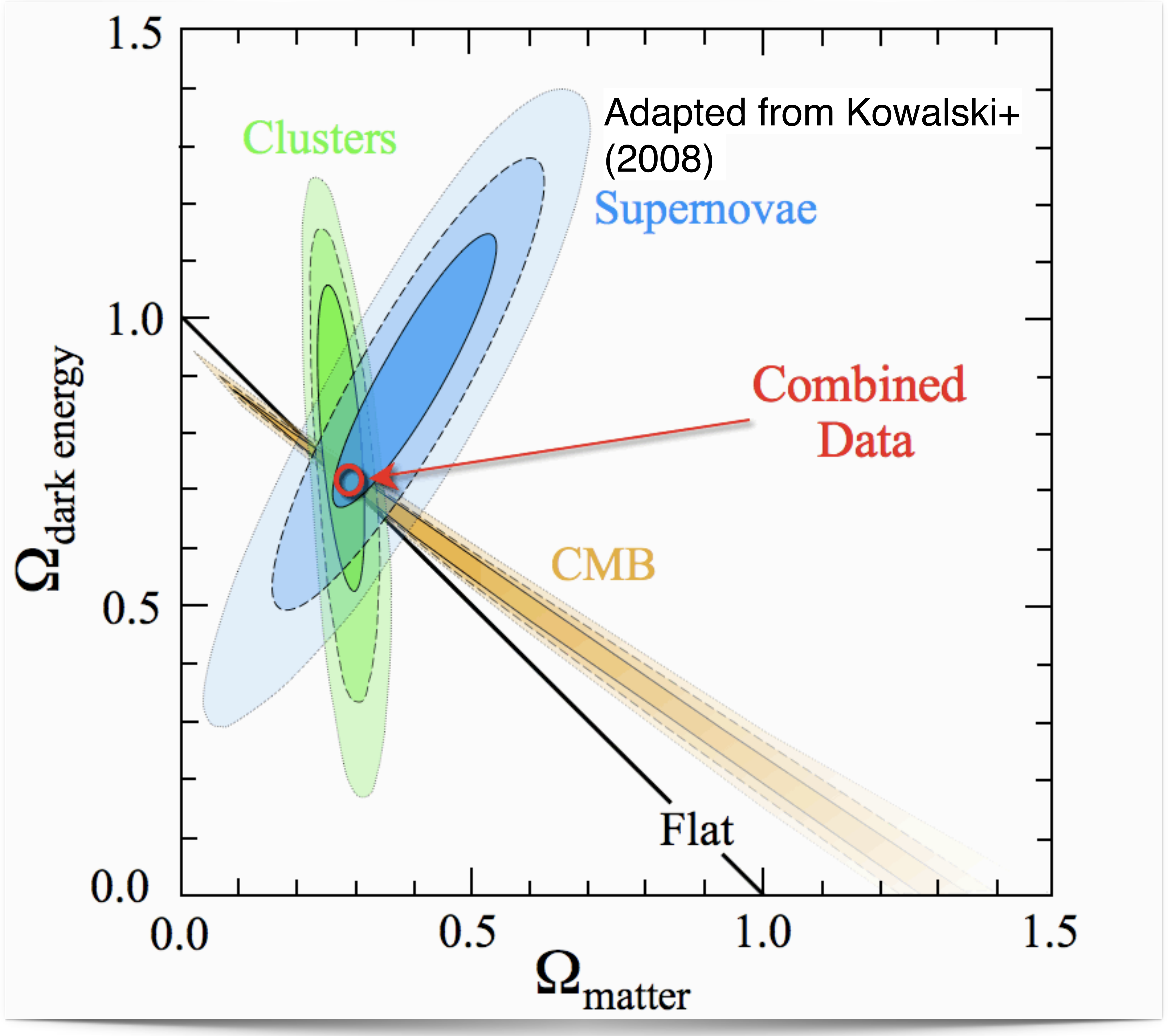


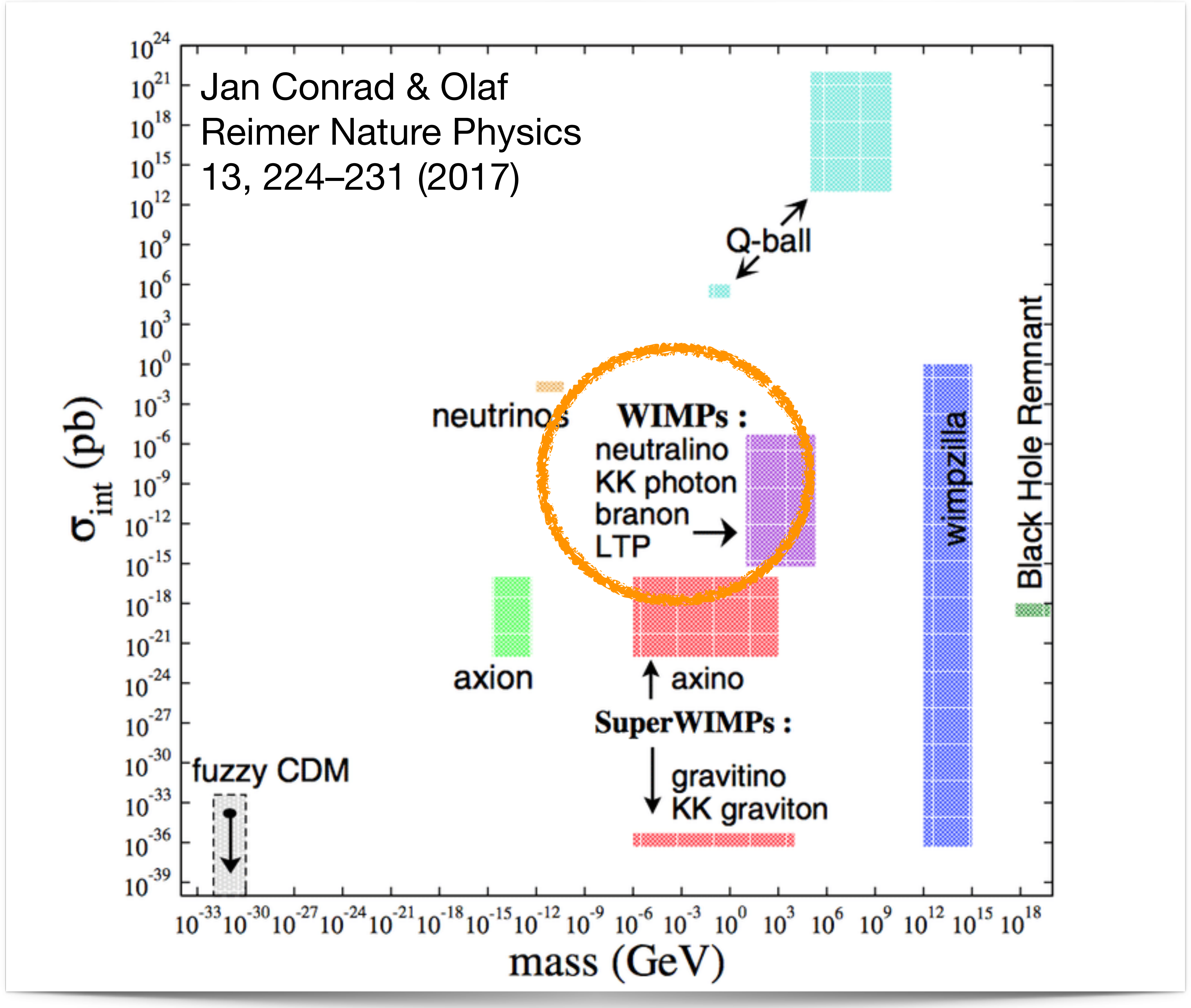




Non-Baryonic
Big-Bang Nucleosynthesis,
CMB Acoustic Oscillations
WMAP(2010), Planck(2015)

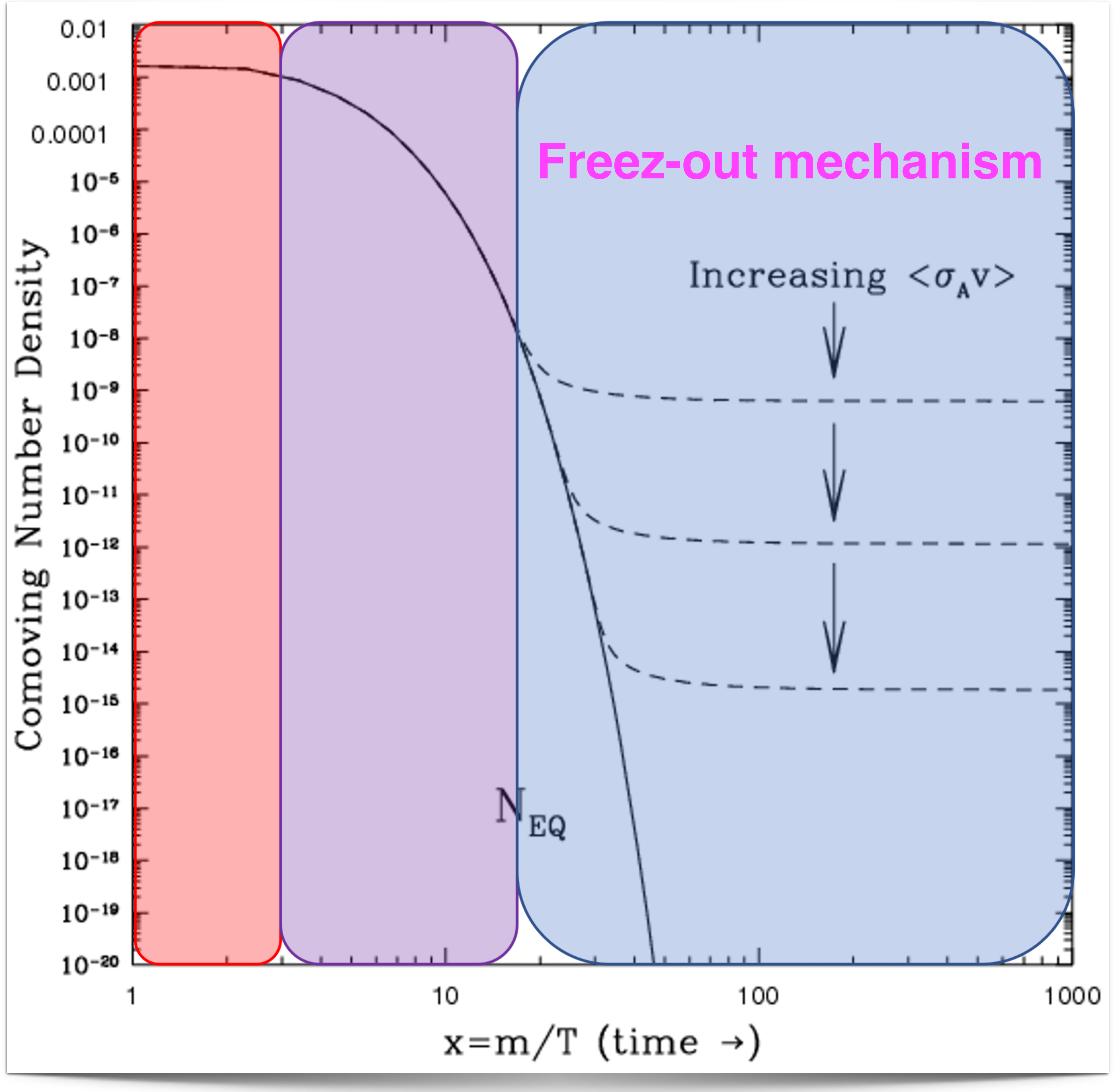
A plethora of dark matter candidates

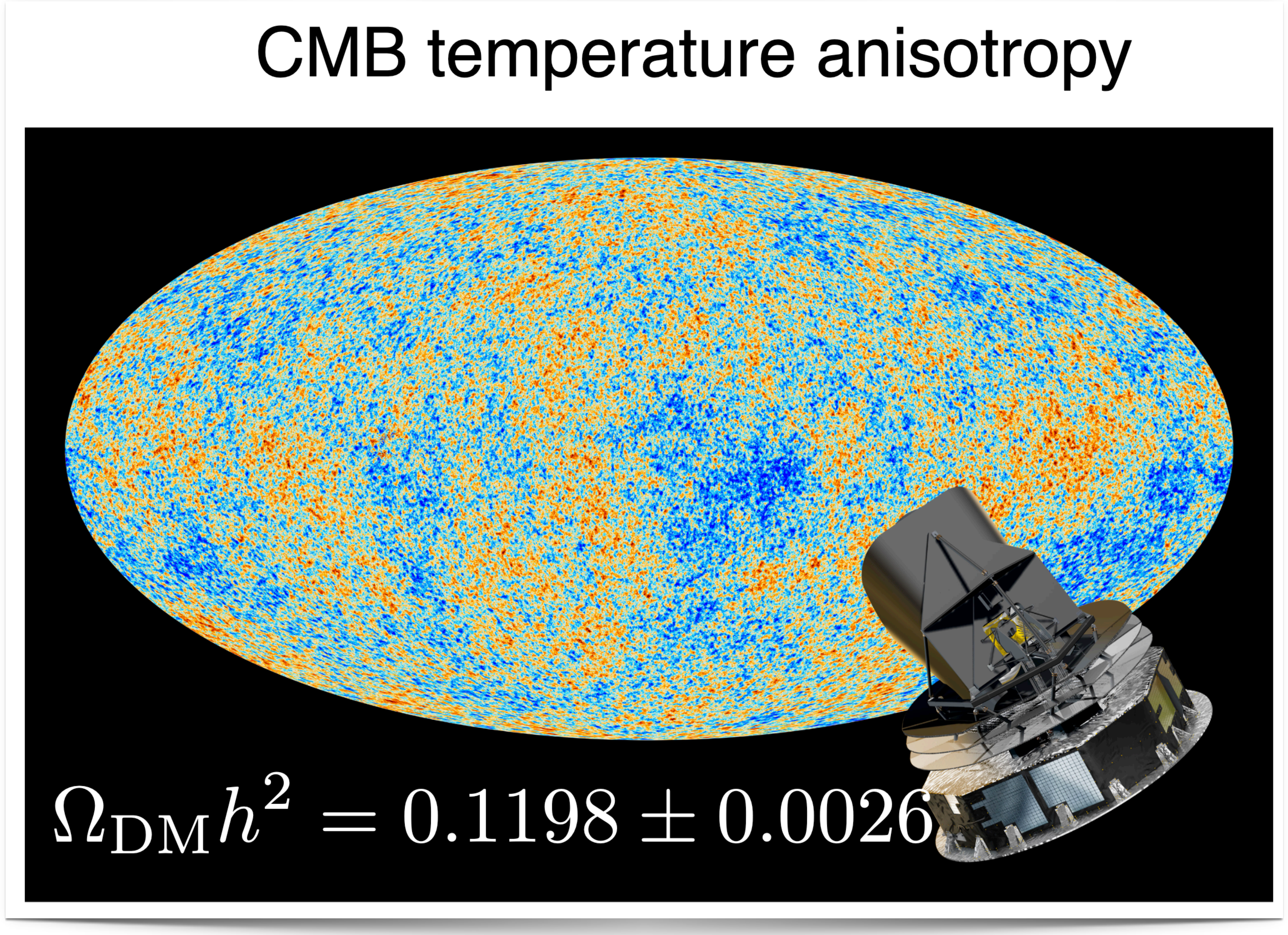




- No Standard Model particle matches the known properties of dark matter
- **One most popular candidate is a particle type that is weakly interacting, but much more massive than a neutrino (weakly interacting massive particle, or WIMP).**
- **Primordial black holes have gathered interest recently.**

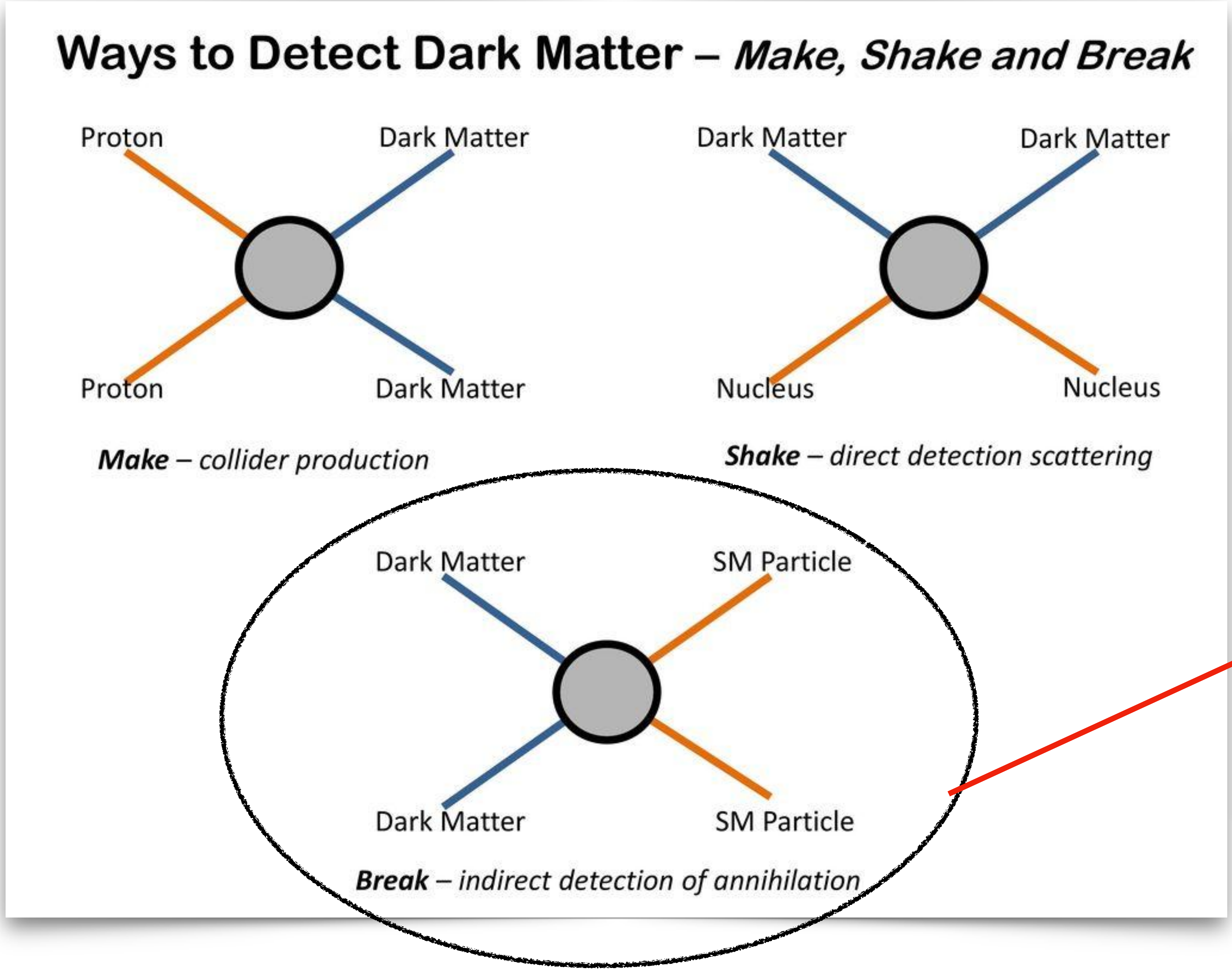
The WIMP 'miracle'

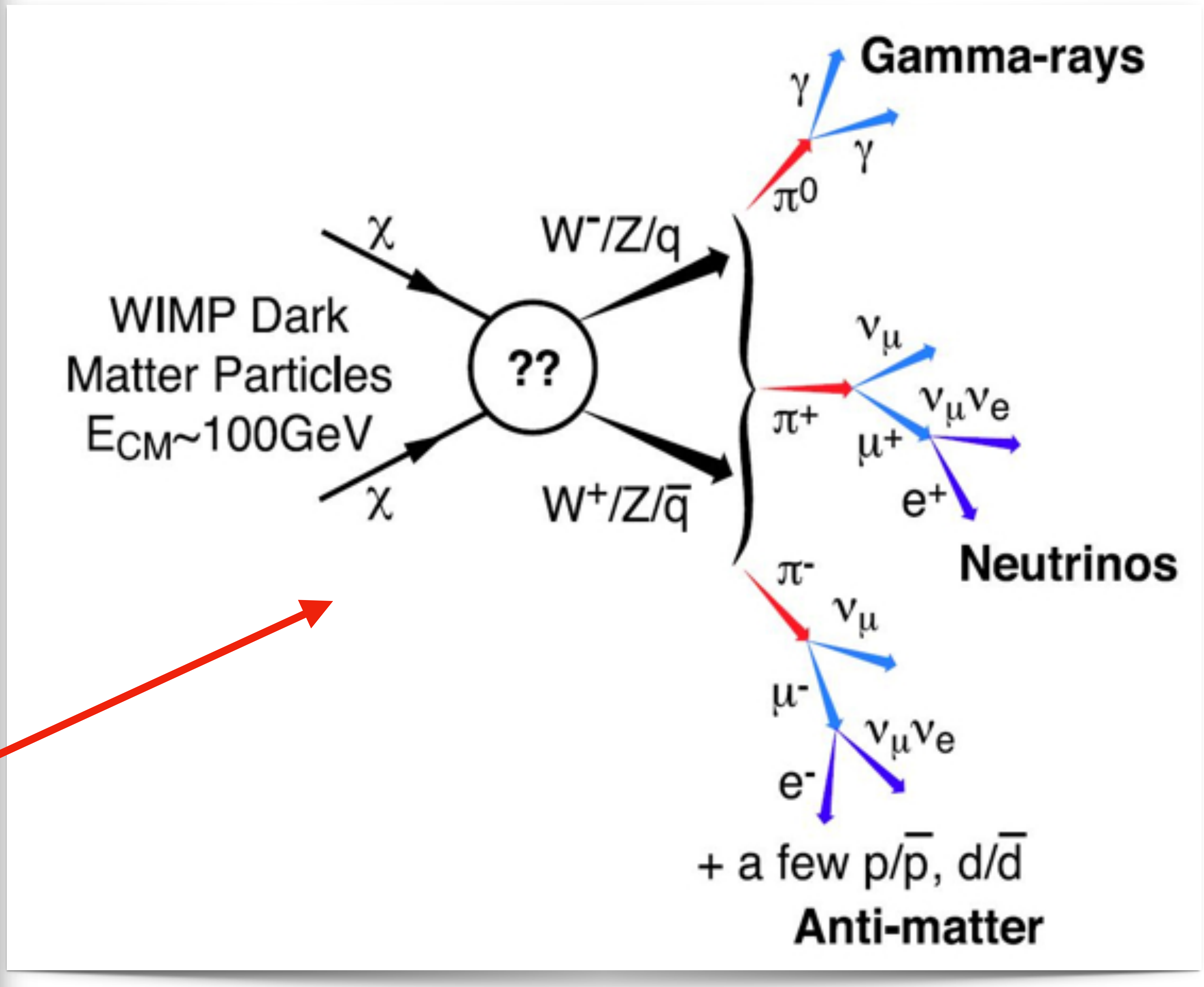




$$\Omega_{\rm DM}h^2 \sim \frac{10^{-27}{\rm cm}^3/{\rm s}}{\langle\sigma({\rm DM\,DM} \to {\rm SM\,SM}){\rm v}\rangle} \qquad \langle\sigma({\rm DM\,DM} \to {\rm SM\,SM}){\rm v}\rangle \sim 3\times 10^{-26}{\rm cm}^3/{\rm s}$$

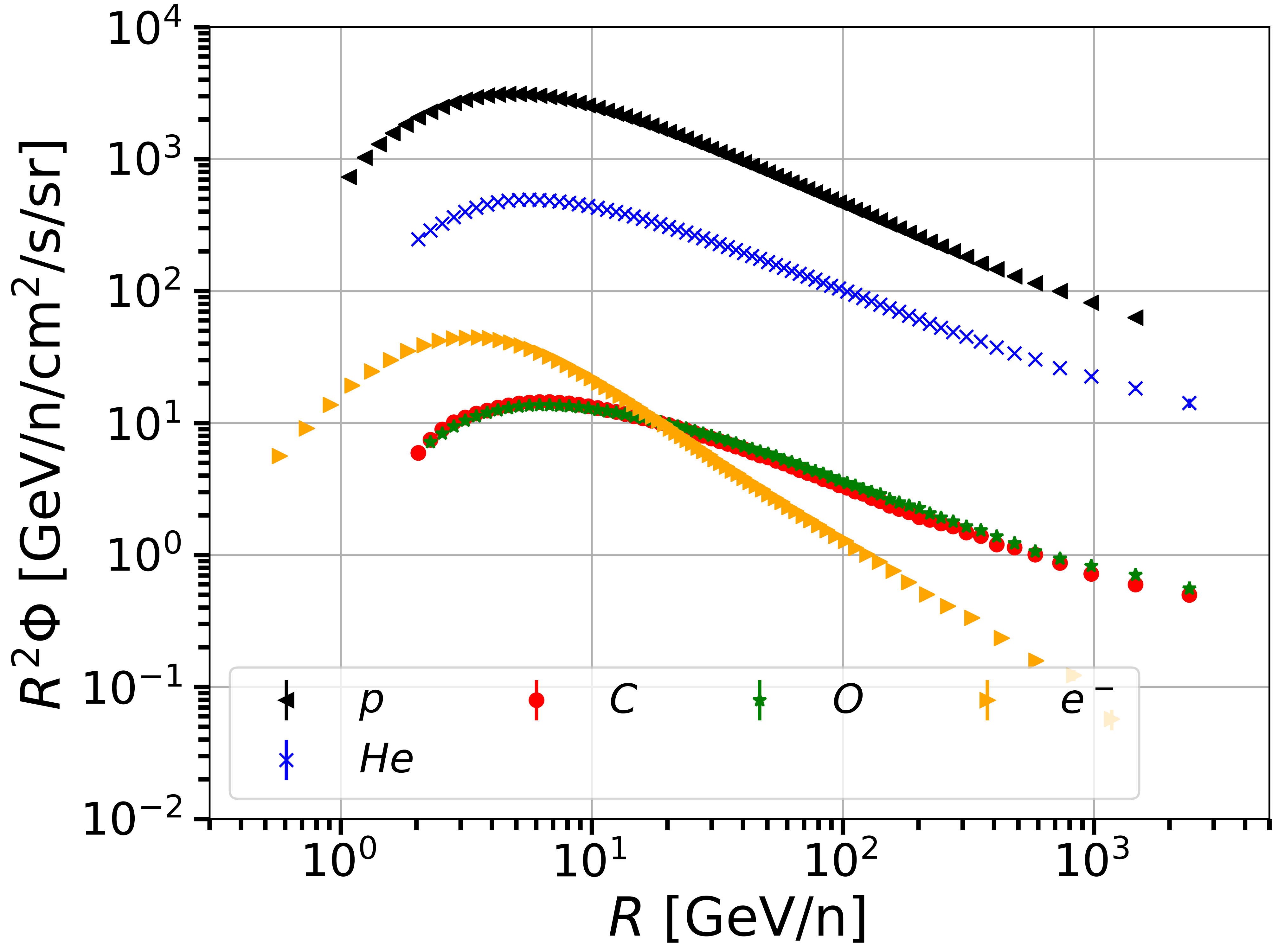
Dark matter searches

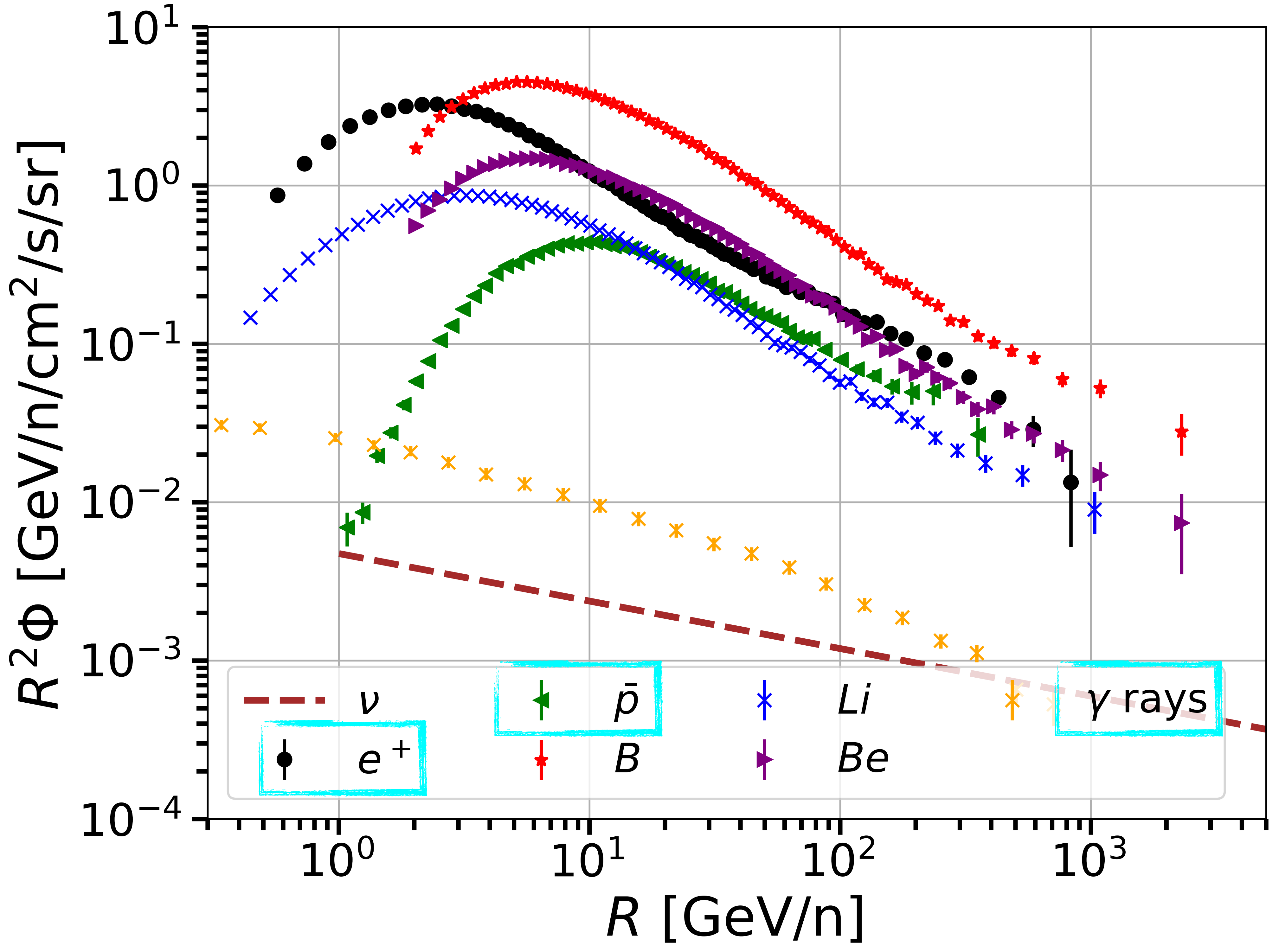




Multimessenger search for a DM signal in cosmic particles

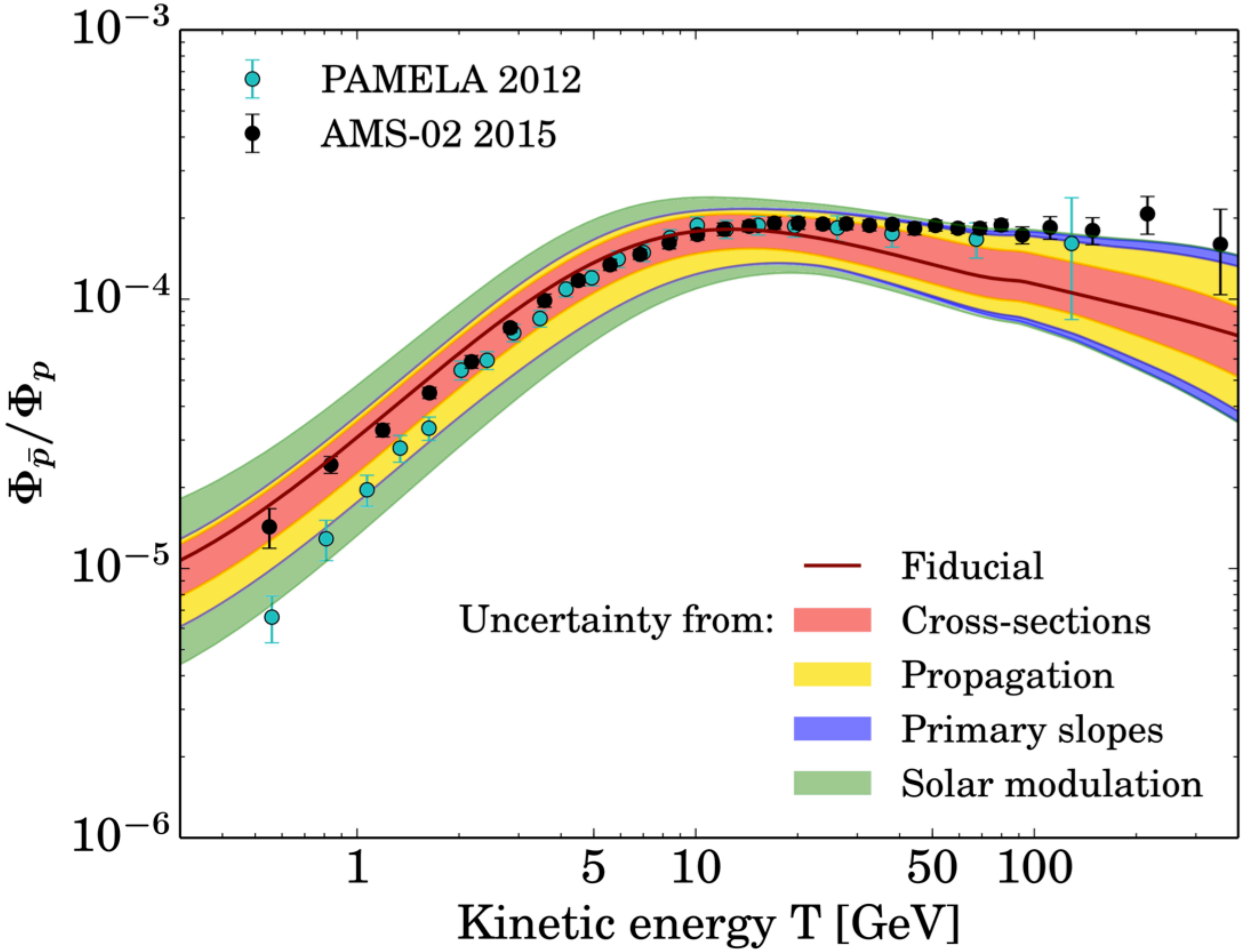
- Among all cosmic rays, secondaries are the most interesting for DM searches.
- In particular antiprotons, e+, gamma rays and neutrinos are the most studied.
- Antinuclei are also considered because the DM production should exceed the secondary one at low energy.



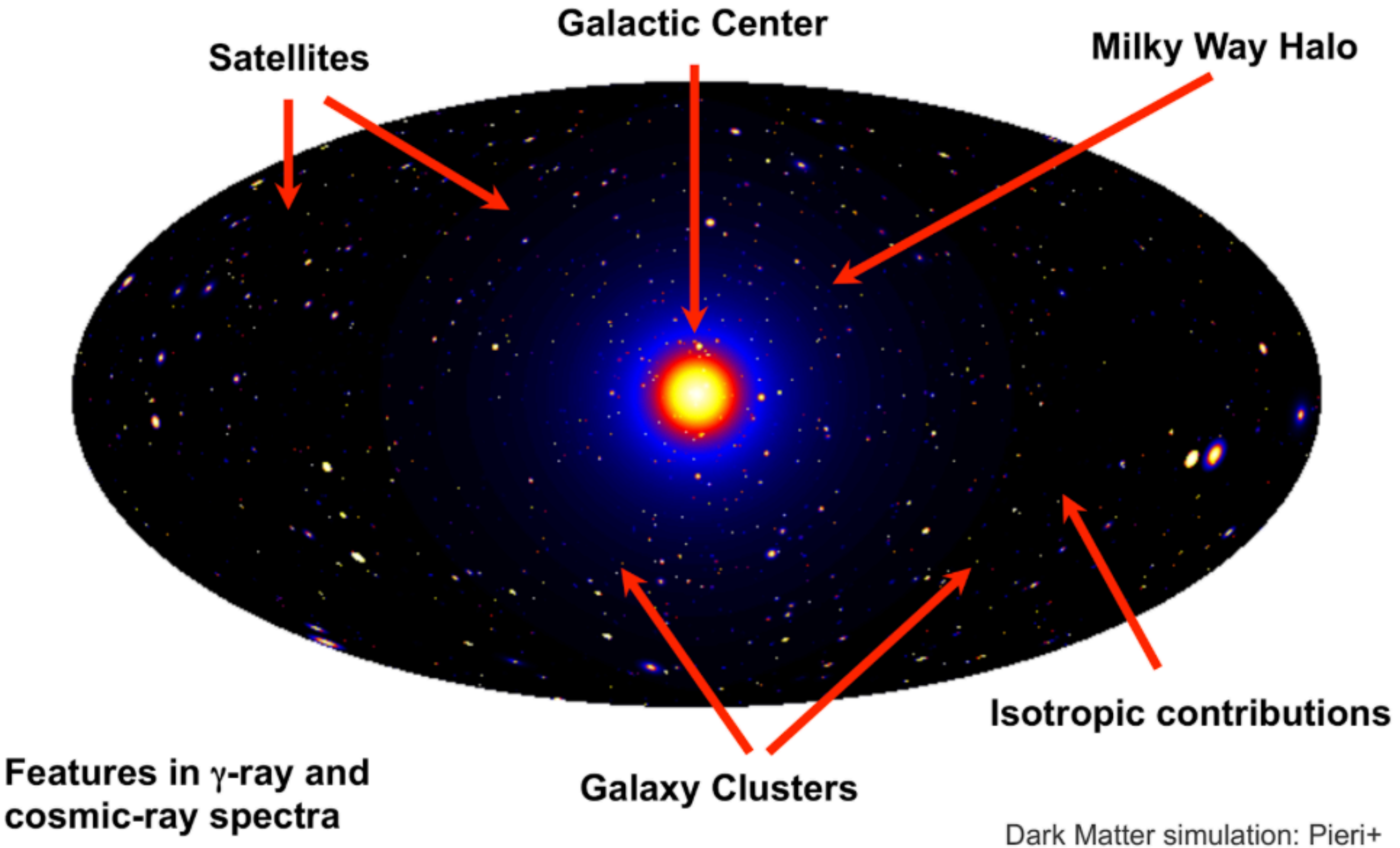


Dark Matter Search with cosmic rays

- Theoretical uncertainties for the astrophysical production of cosmic rays is dominated by systematic uncertainties



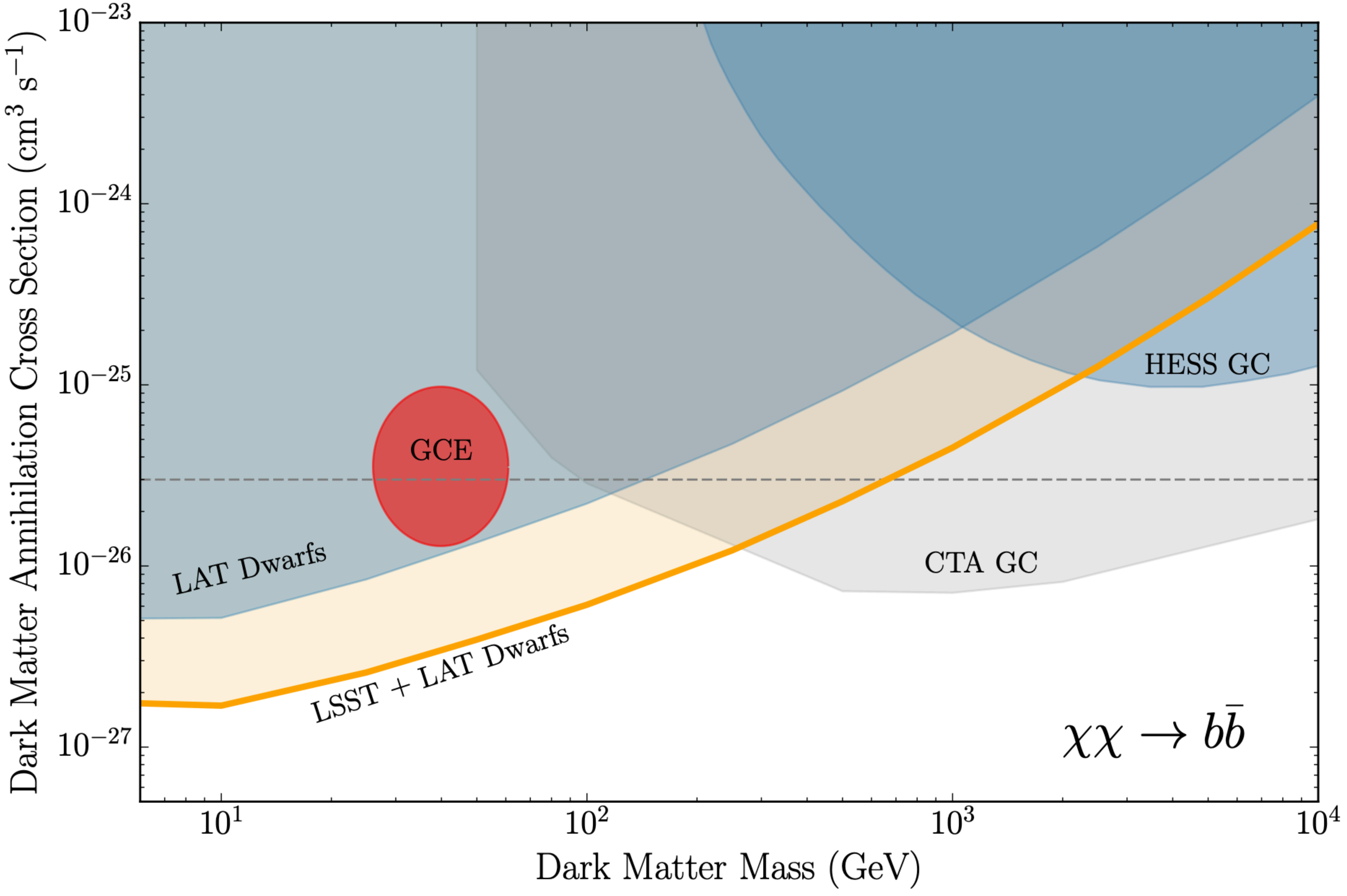
Gamma-ray map from dark matter annihilation



Dark Matter simulation: Pieri+
2011PhRvD..83b3518P

Multi-target search for DM in gamma rays

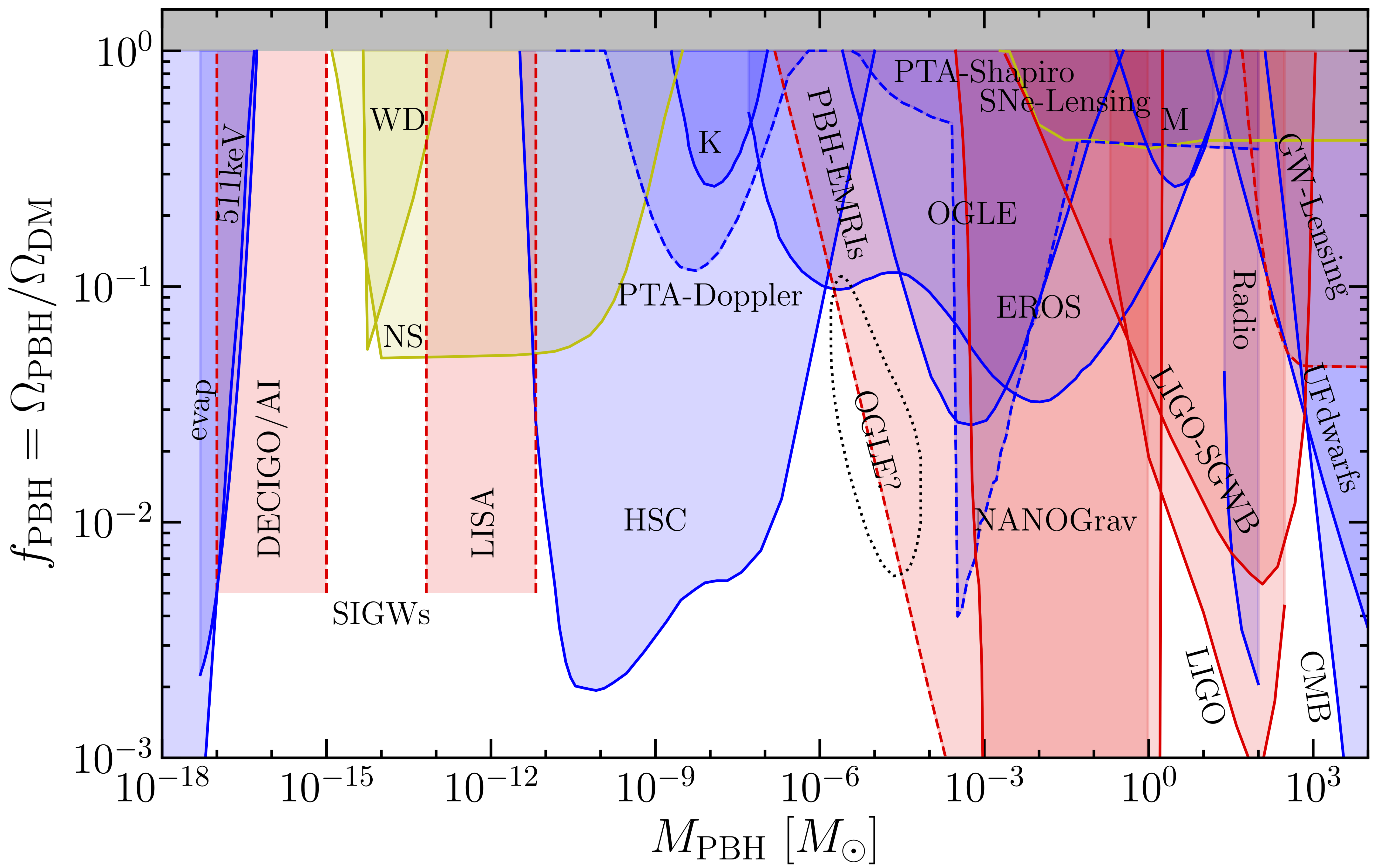
- The relic density is proven up to hundreds of GeV.



https://arxiv.org/pdf/1902.01055.pdf

Primordial Black Holes: Definition

- What are Primordial Black Holes (PBHs)?
  - Predicted by S. Hawking in 1971.
  - Black Holes that were originated in a radiation dominated era.
  - They do not count for the total baryonic mass of the Universe.
  - Their masses can range from the Planck scale up to supermassive BHs.
  - PBH search regained interest after the detection of Gravitational Waves, being proposed as **possible contributors for DM**



Neutron Stars as Gravitational Wave Sources

A. Coalescing Binary NS/BH systems

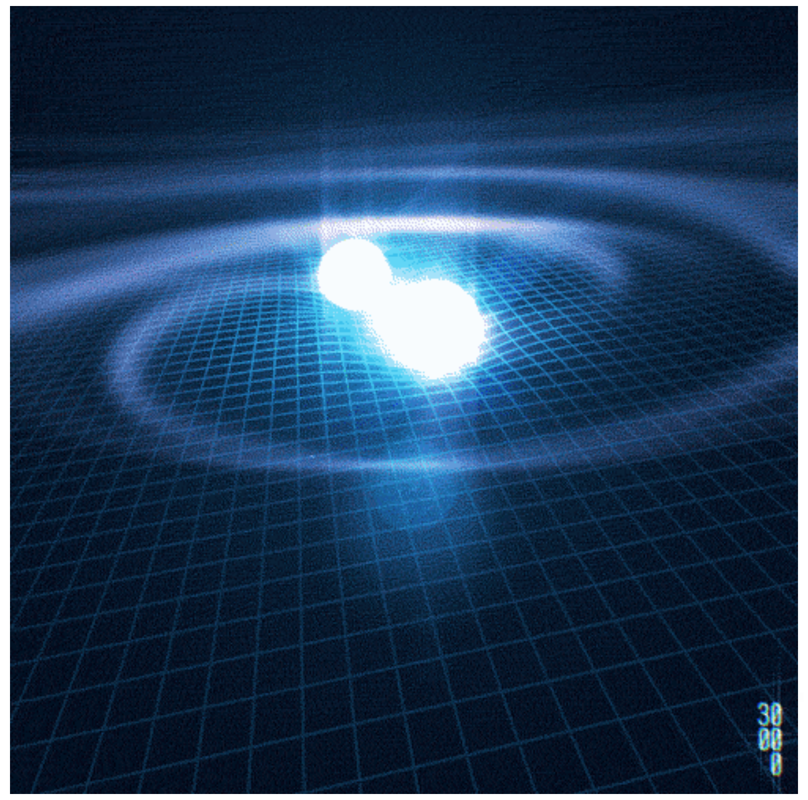
$$E_{kin} \sim \frac{1}{2} U_{grav} = \frac{1}{2} \frac{G M_1 M_2}{R_1 + R_2}$$

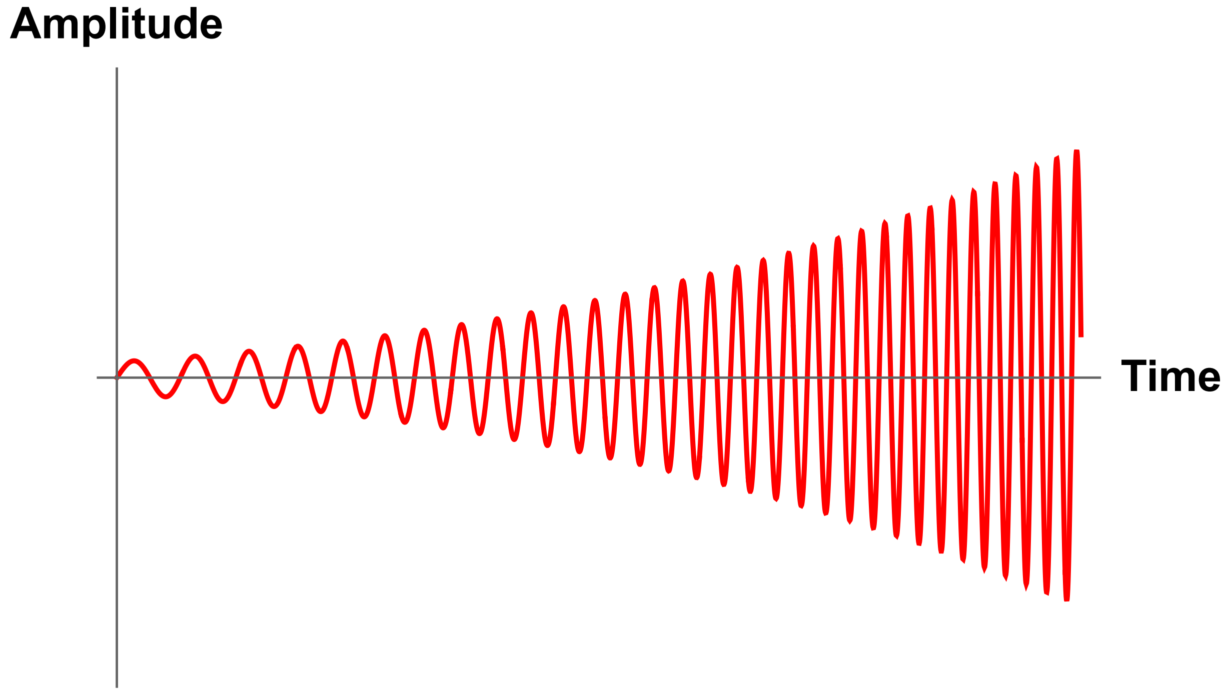
NS-NS: $\frac{1}{2} \frac{G M^2}{R} \sim 0.015\, M^2$

BH-BH: $\frac{1}{2} \frac{G M_1 M_2}{2G(M_1 + M_2)} \sim \frac{M_1}{8} \frac{q}{1+q}$

$$h \sim 10^{-20-23} \quad for \quad D \sim 1-200\, Mpc \quad - \quad \nu \quad 0.1-2\, kHz$$

Timescale ~ seconds



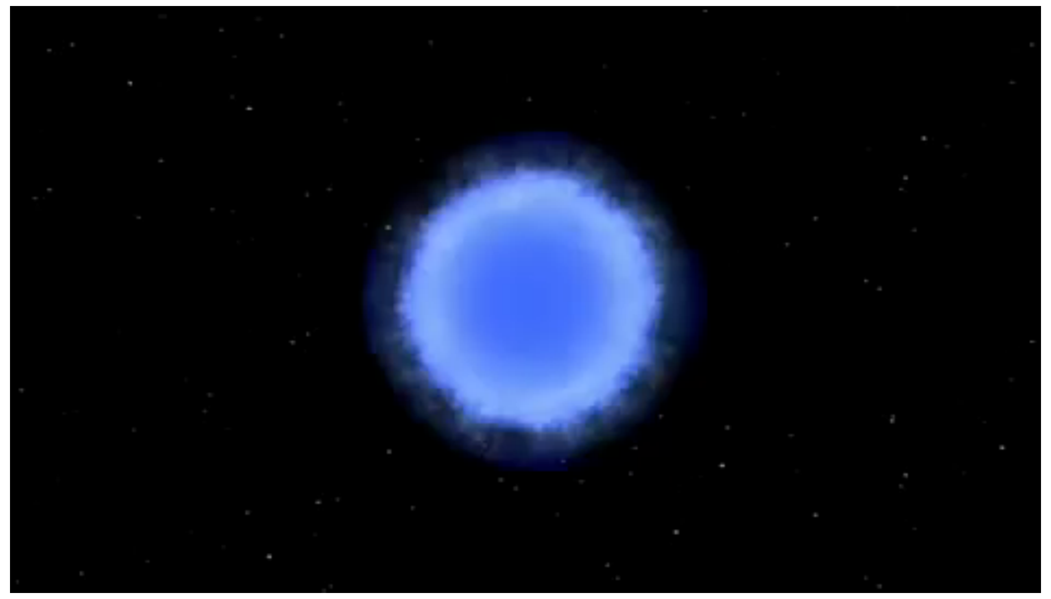


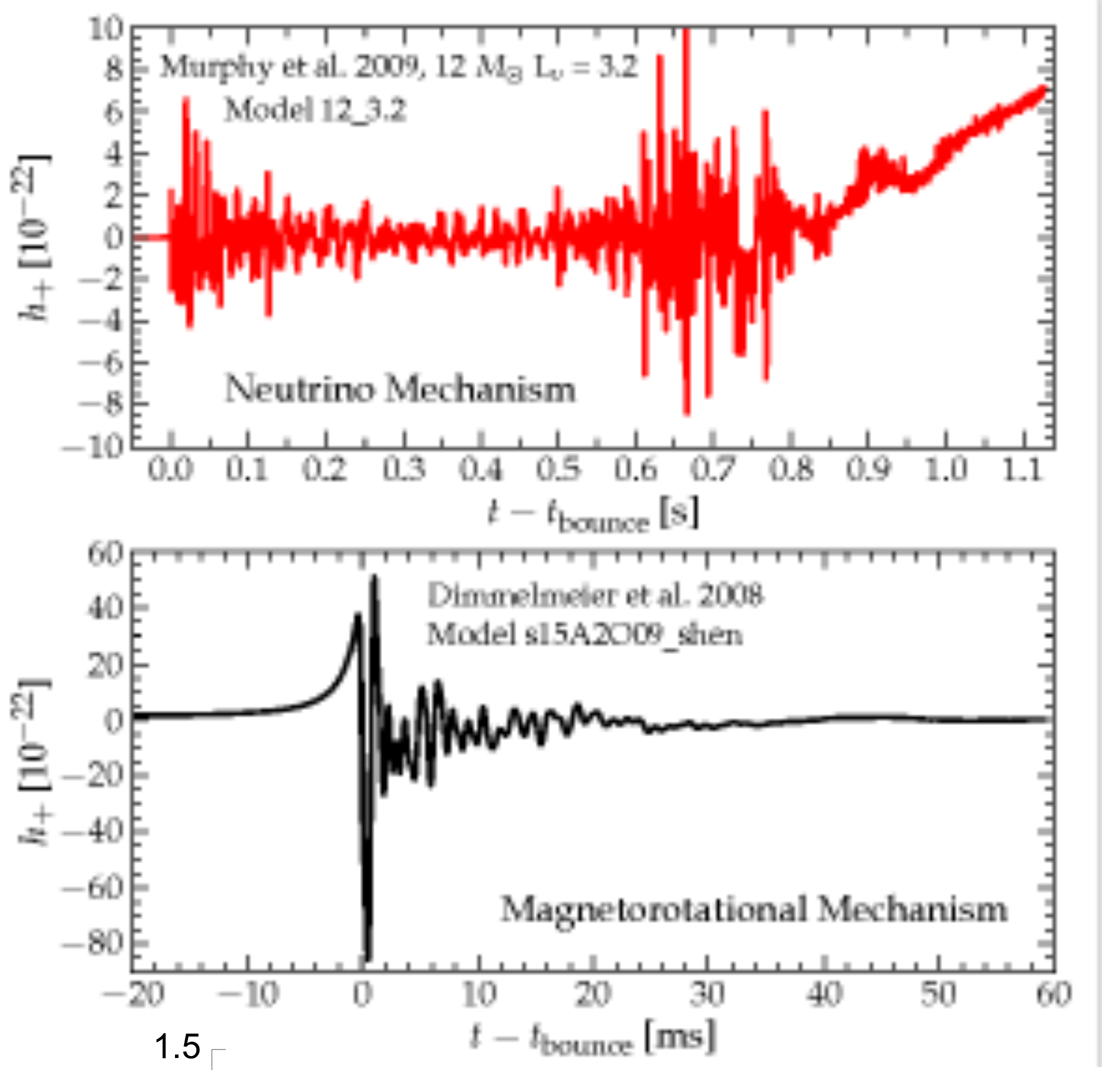
B. Core-Collapse Supernovae

$$E_{kin} \sim 10^{-4} - 10^{-8} M_{sun} c^2$$

$$h \sim 10^{-20 \div -26} \quad for \quad D \sim 10\, Kpc \quad - \quad \nu \quad 0.2-1\, kHz$$

Timescale ~ sub – second



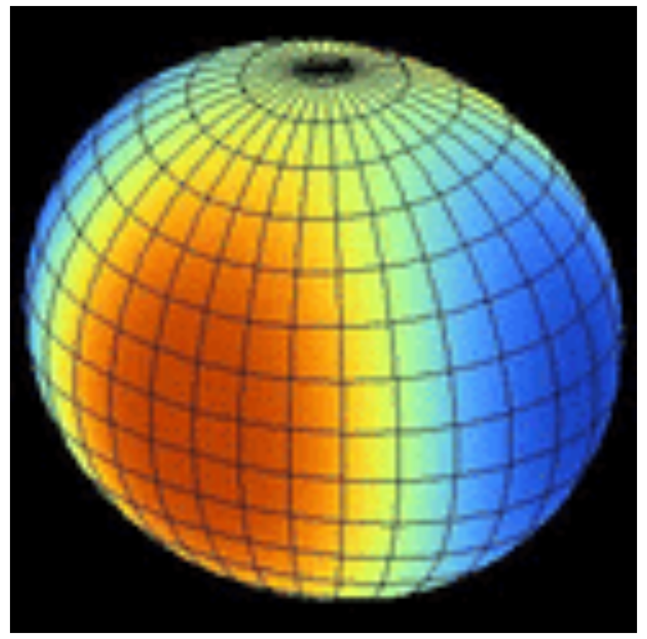


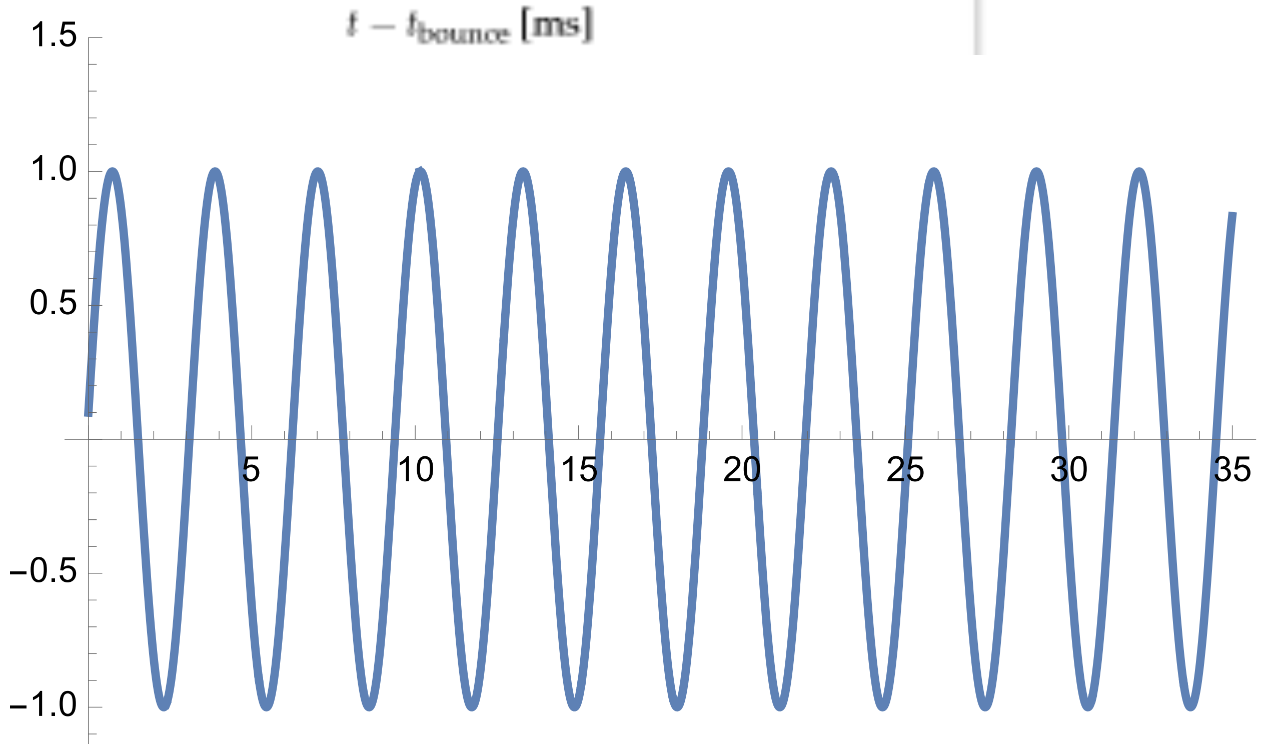
C. Fast spinning NS with "mountains"

$$E_{kin} < 10^{-10} M_{sun} c^2$$

$$h \; < \; 10^{-26} \quad for \quad D \sim 10\, Kpc \quad - \quad \nu \quad 10-600\, kHz$$

Timescale ~ detector lifetime





Neutron Stars as Gravitational Wave Sources

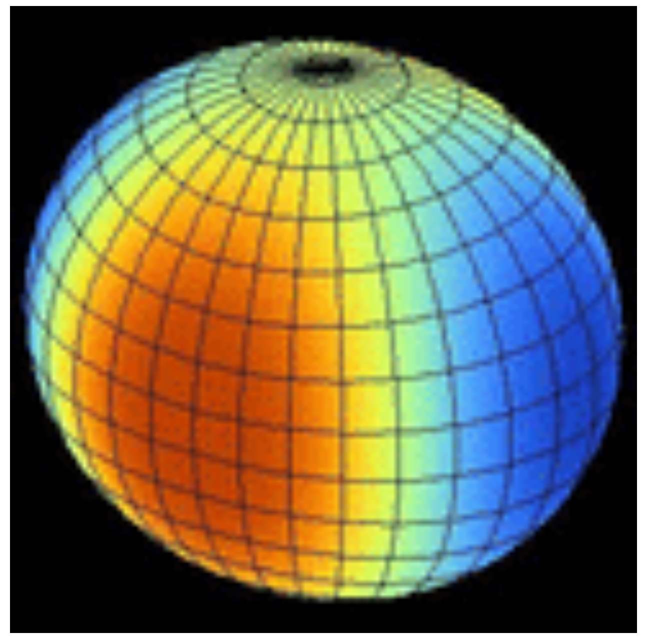
D. Long Transients

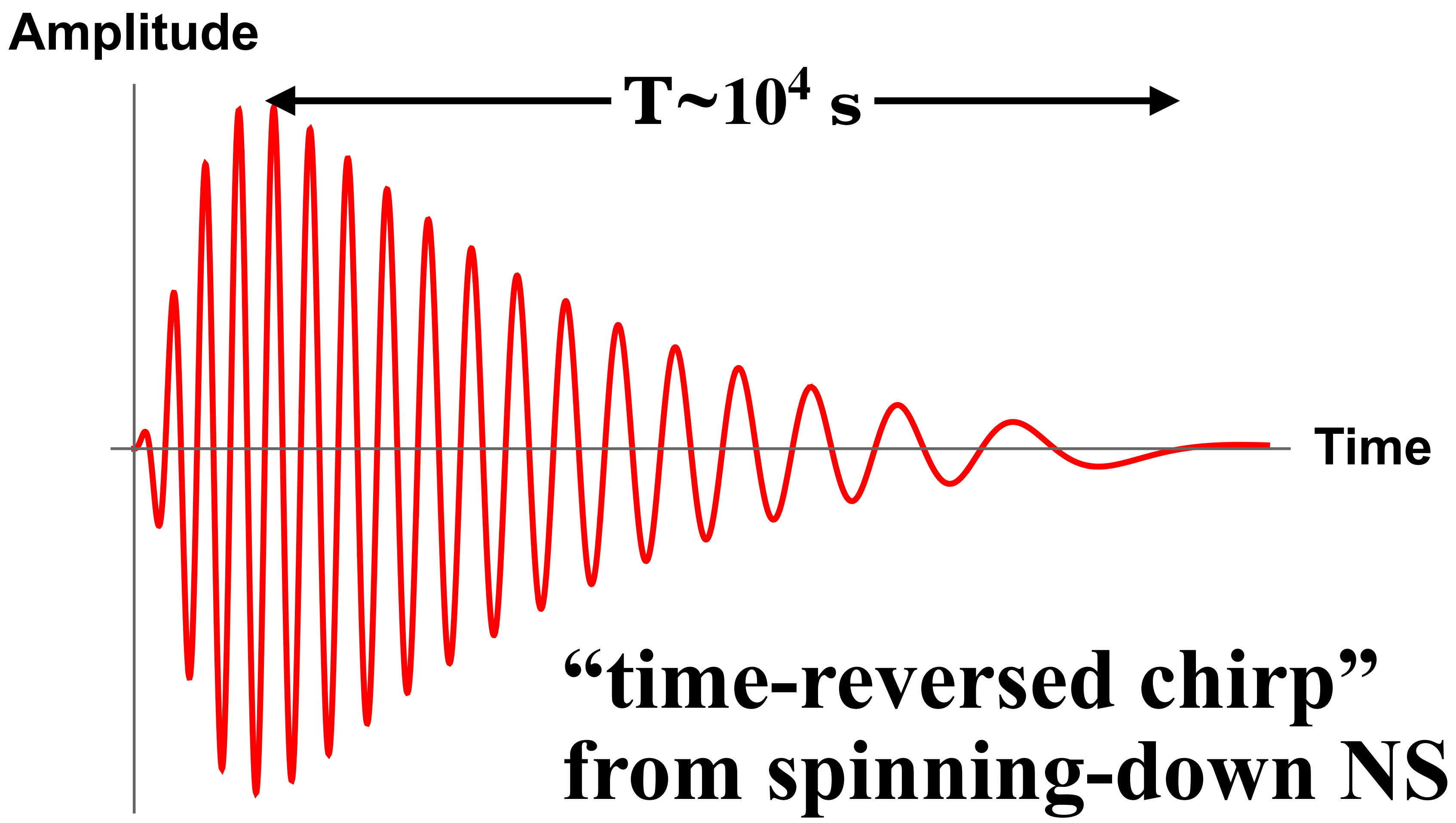
ms-spinning NS with "fast" spin down

$E_{\rm kin} \sim 10^{-3} M_\odot c^2 \qquad (\epsilon \sim Q_{22}/I \gtrsim 10^{-4})$

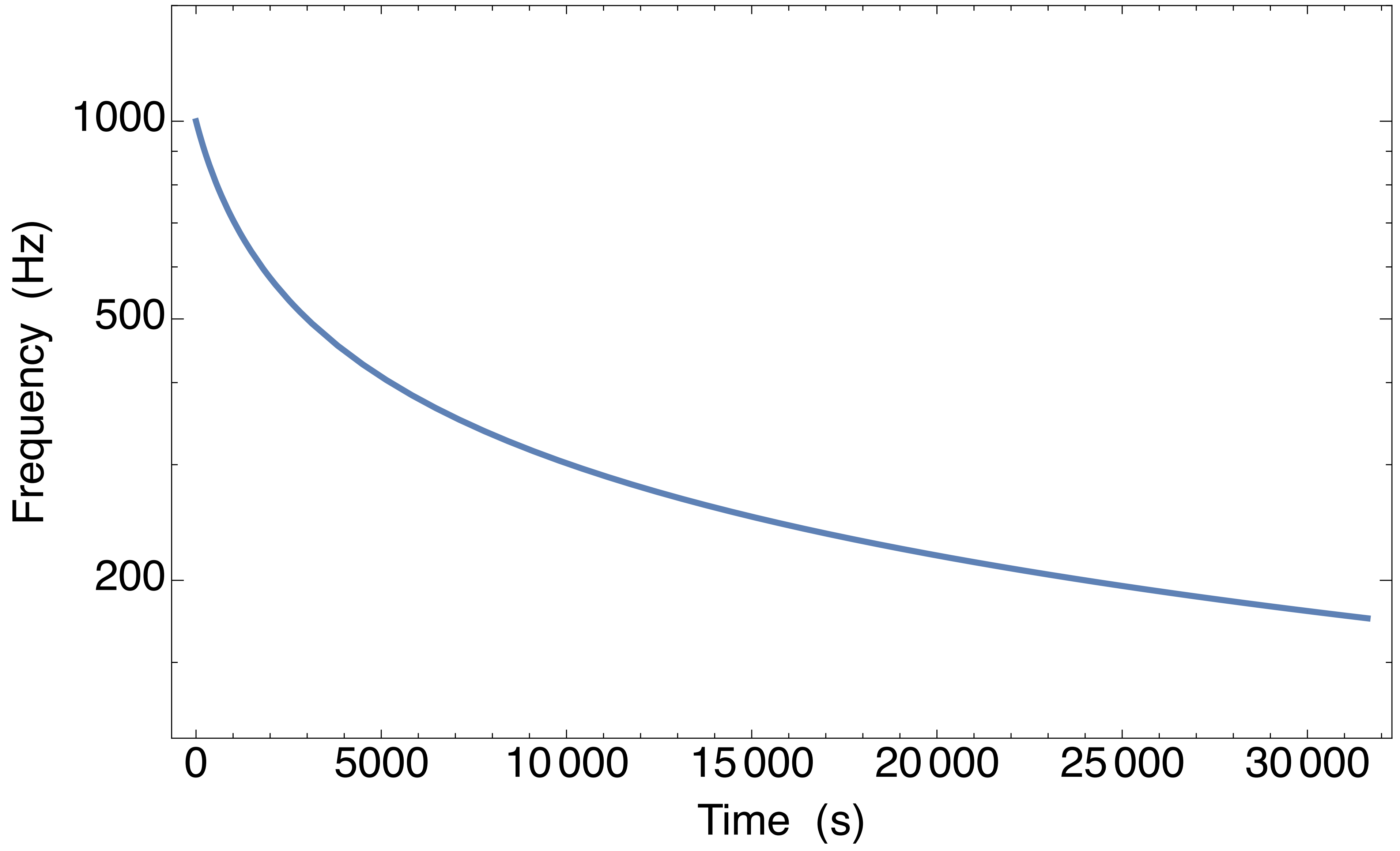
Timescale ~ hours

$h \sim 10^{-26} - 10^{-25} @ D \sim 1$ Mpc – $\nu \sim 0.5 - 2$kHz





"time-reversed chirp" from spinning-down NS



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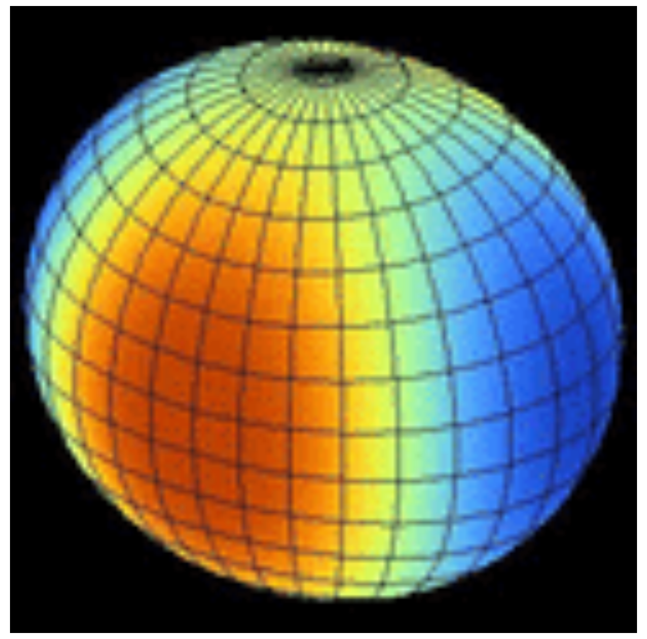

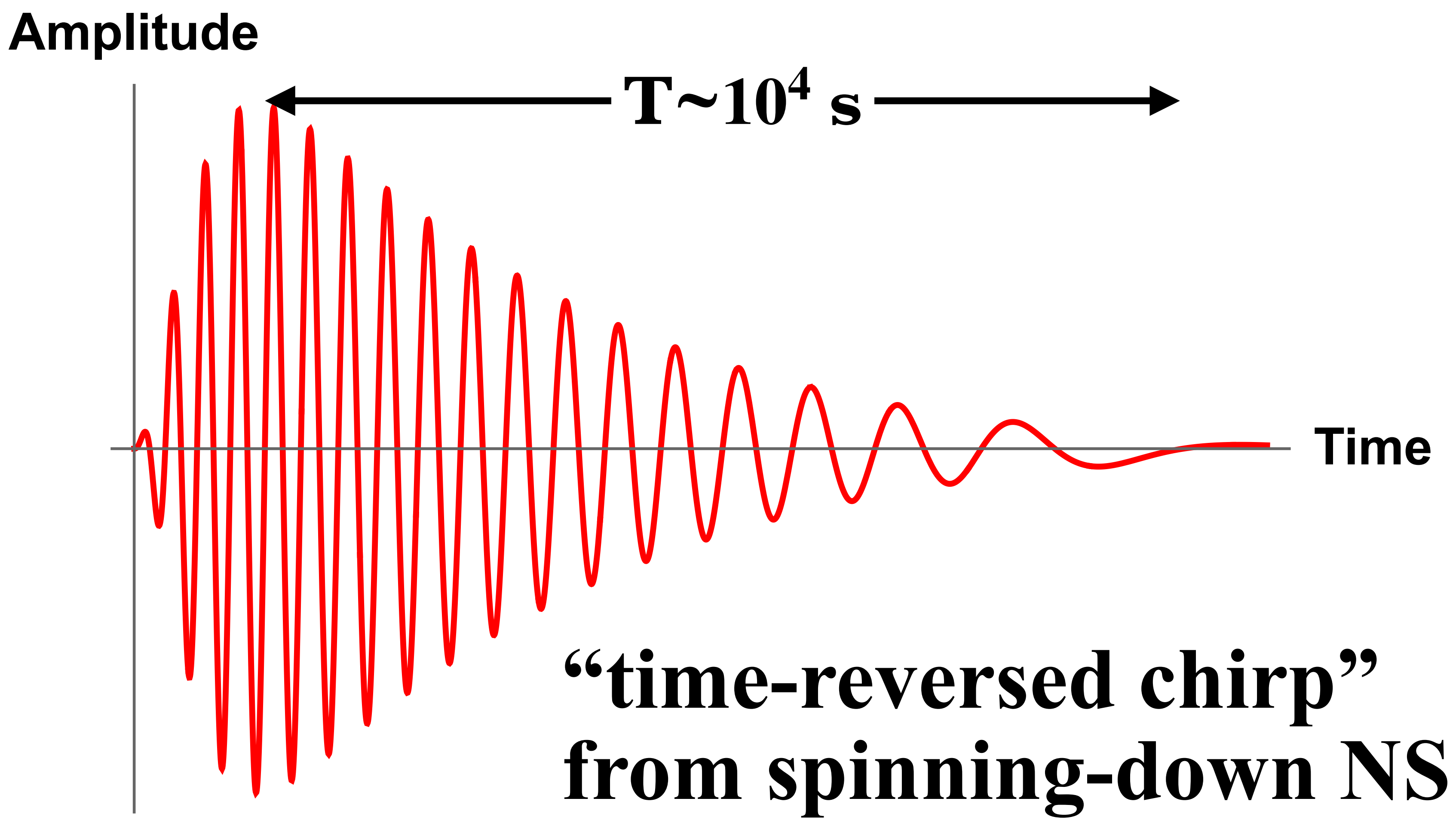

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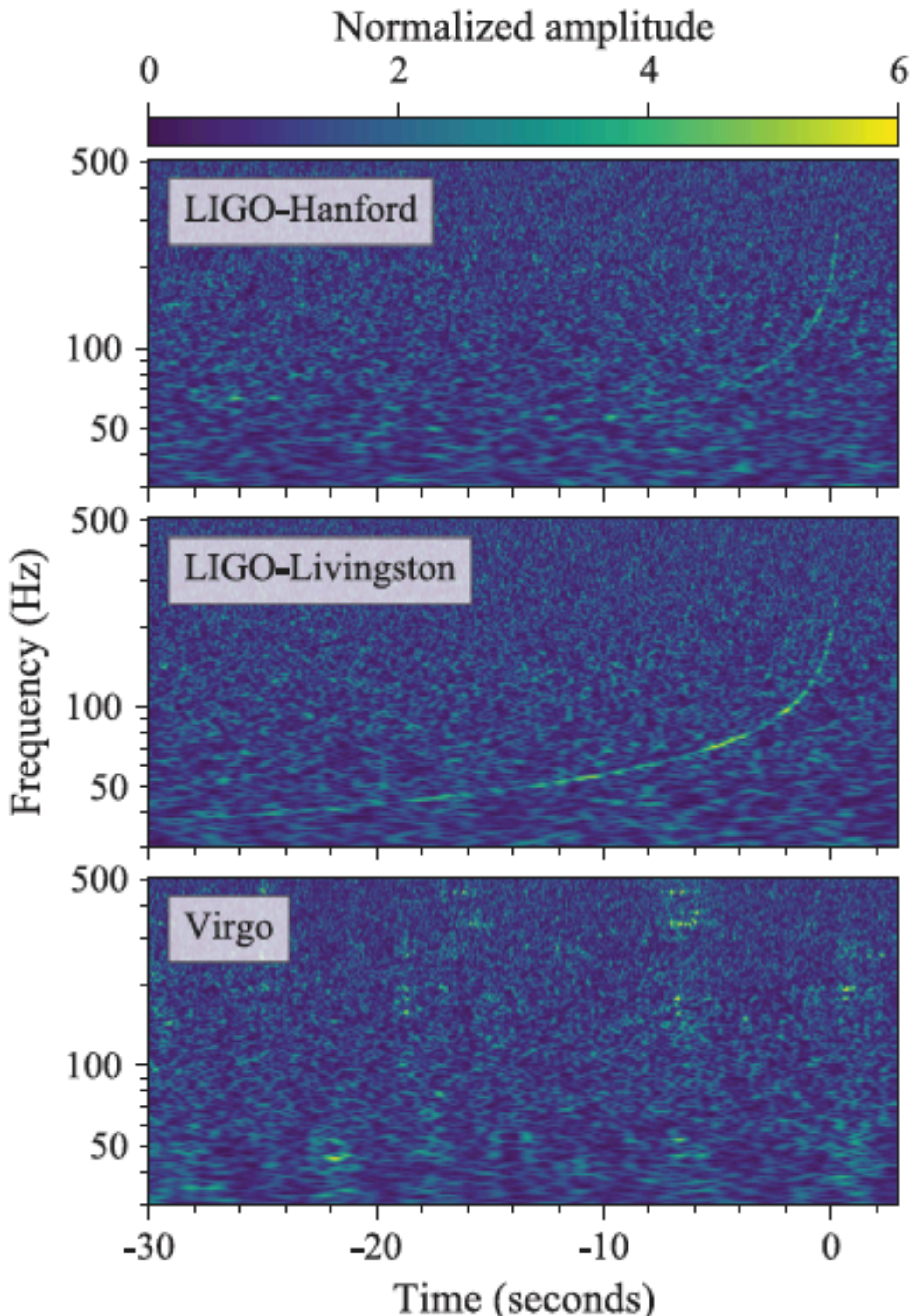
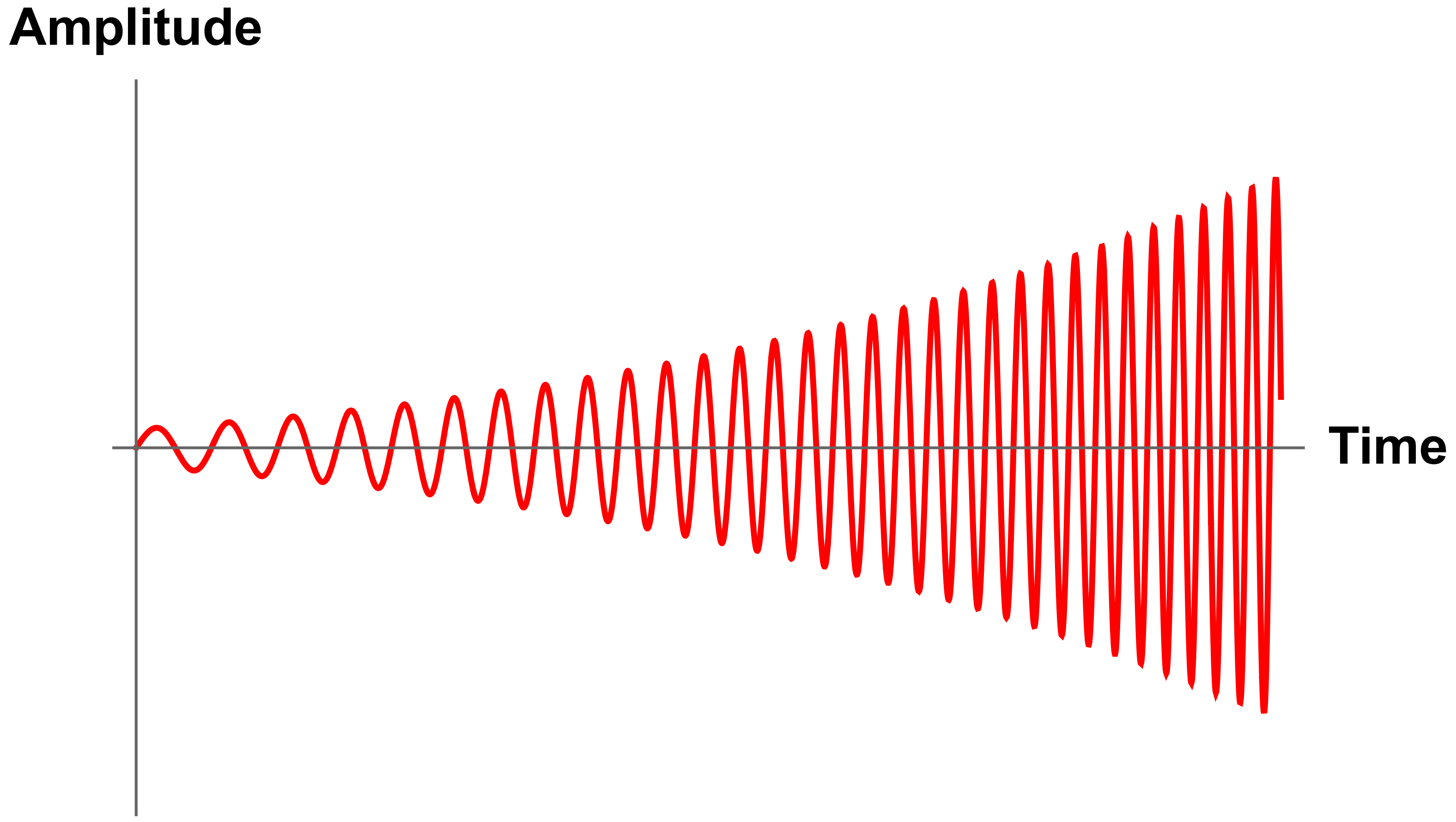
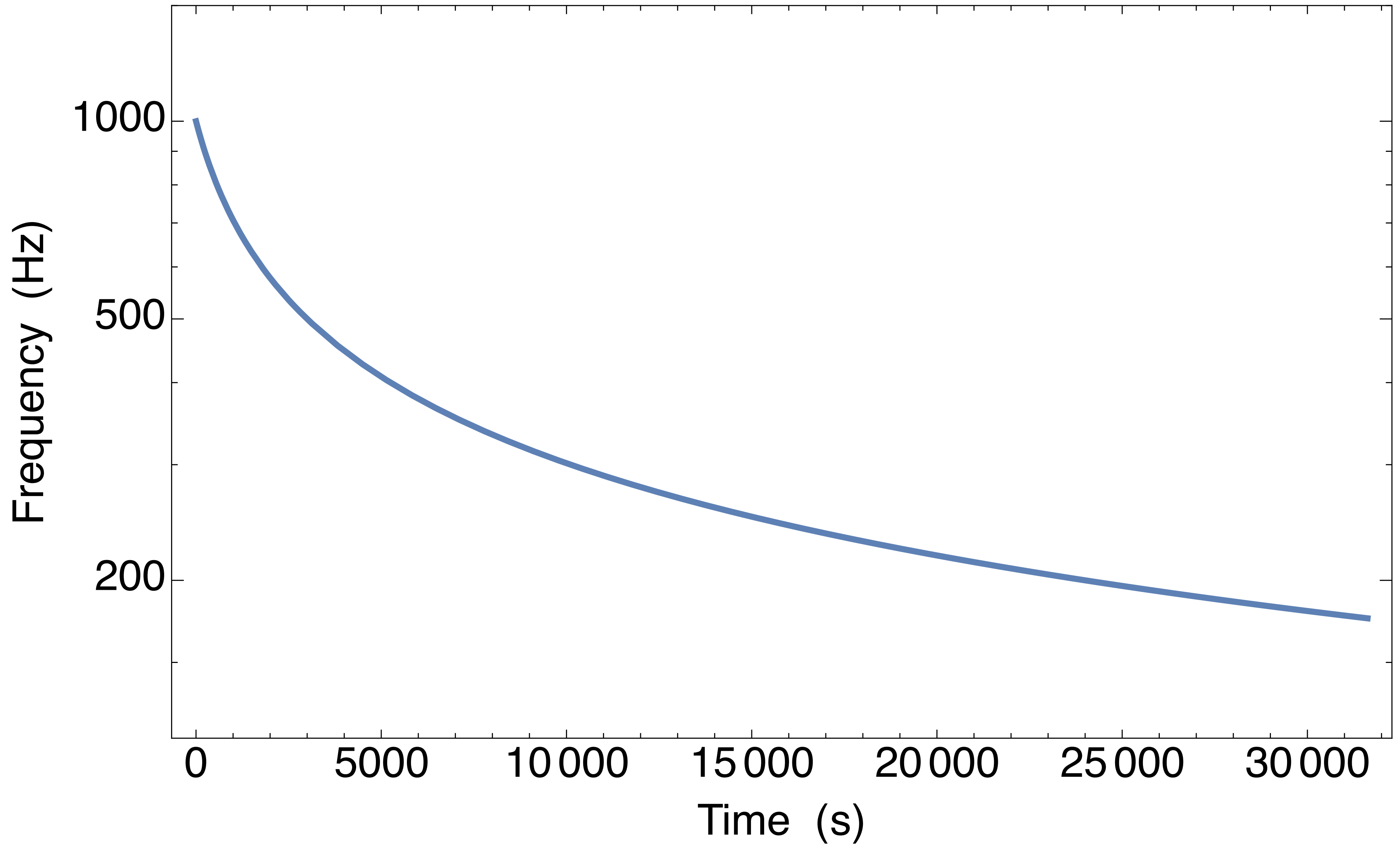




"chirp" from binary merger



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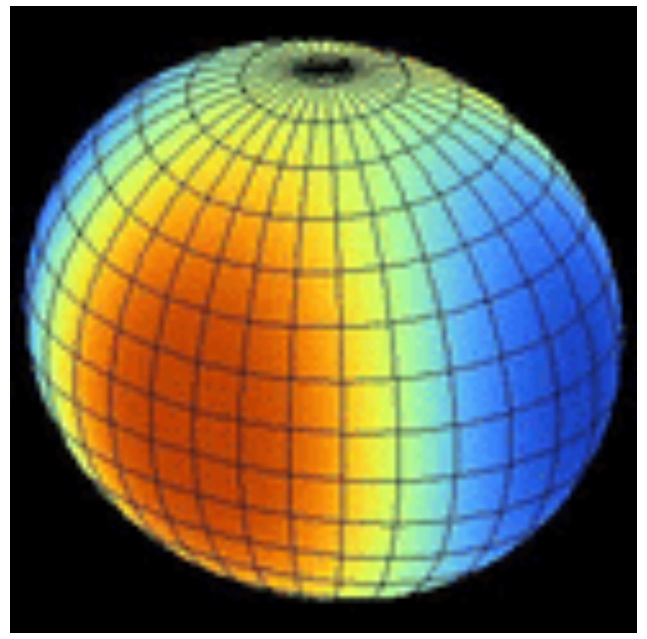

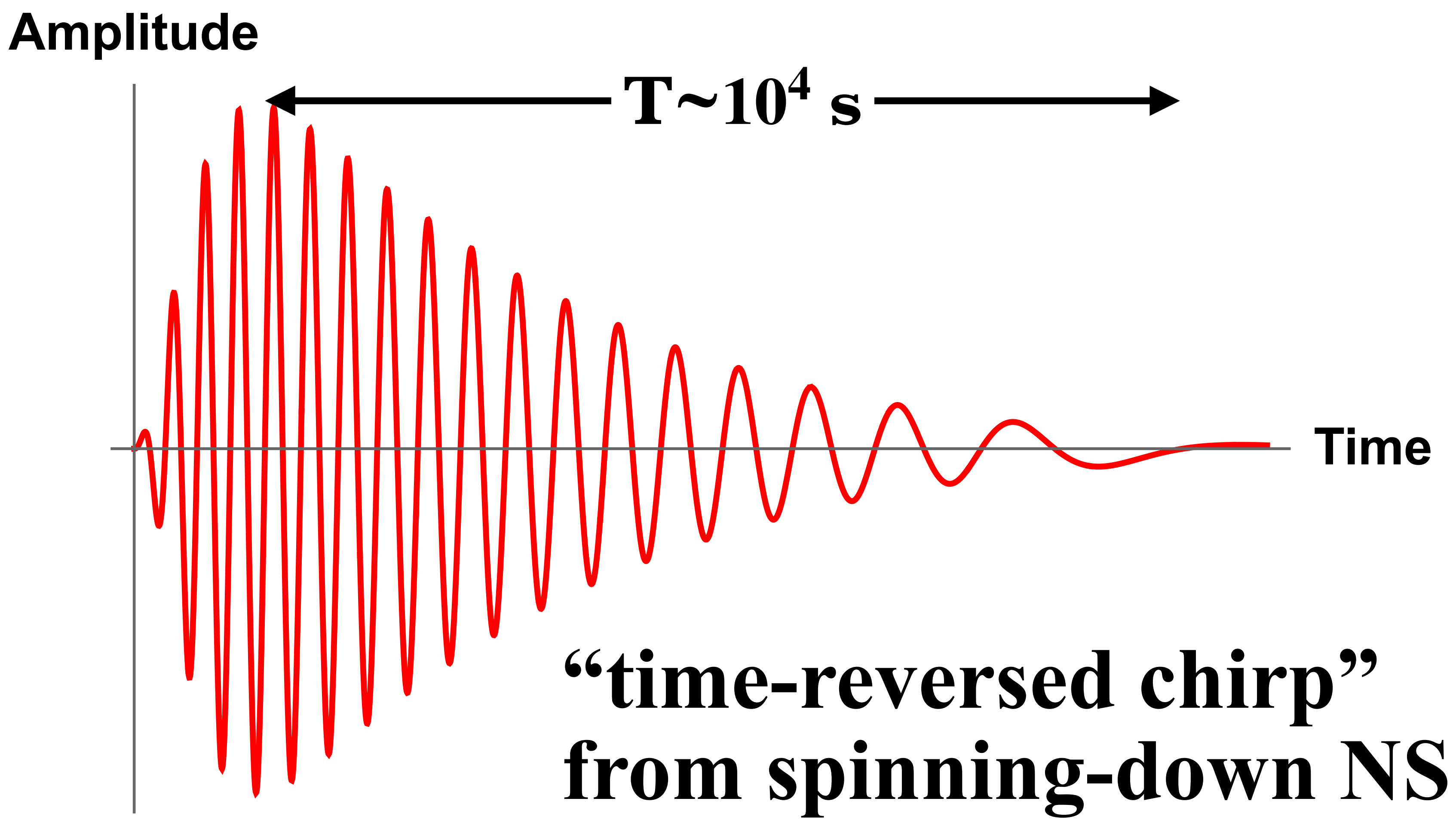

In particular, newborn magnetars are the best candidates for this class of possible signals

FORMATION SITE

core-collapse ($M > 30\ M_\odot$?)

Long GRBs
Zhang & Meszaros (2001)
Dall'Osso et al. (2011)
Metzger et al. (2011)

Super-Luminous SNe
Kasen & Bildsten (2010)
Mazzali et al. (2014)
Metzger et al. (2016)

binary NS merger
Giacomazzo & Perna (2013) - cf. Dall'Osso & Rossi (2013)

Short GRBs
Rowlinson et al. (2013)
Rezzolla & Kumar (2015)

Possible Electromagnetic Counterparts