Hadronic And Leptonic Processes in Extragalactic Sources:

a multi-messenger, multi-source approach to unveil the origin of γ-ray radiation and neutrinos

— Lara Nava —
INAF

Annual report

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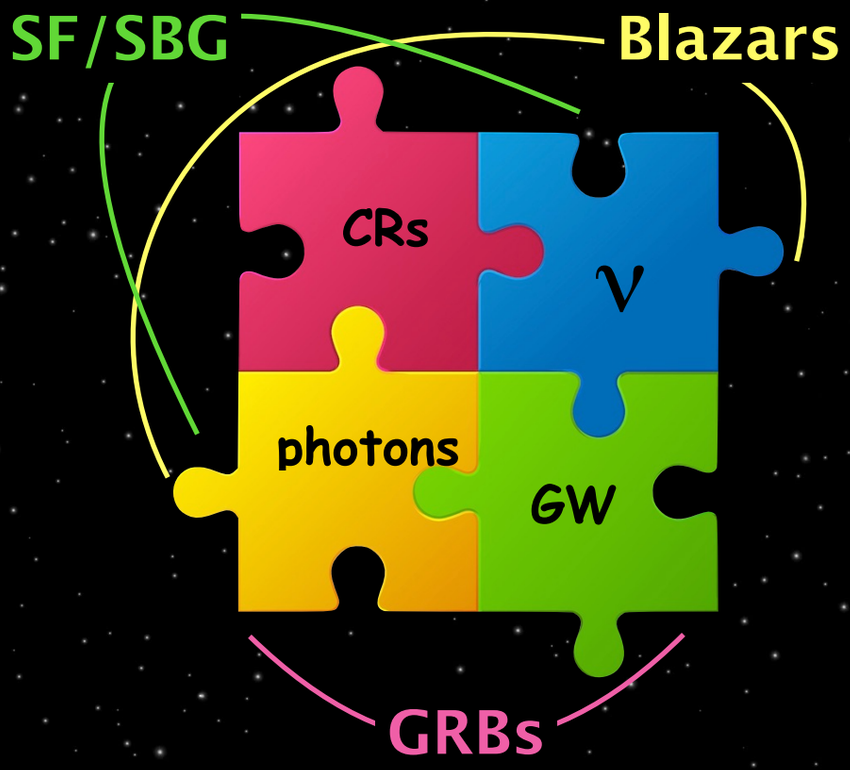
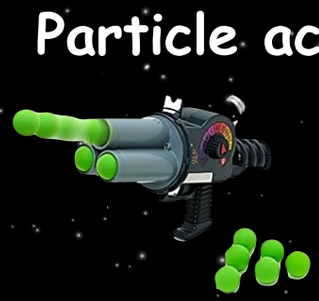
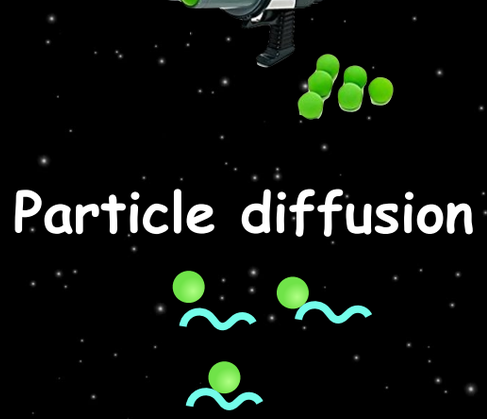
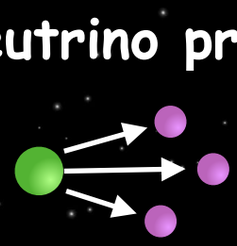
Hadronic And Leptonic Processes in Extragalactic Sources:





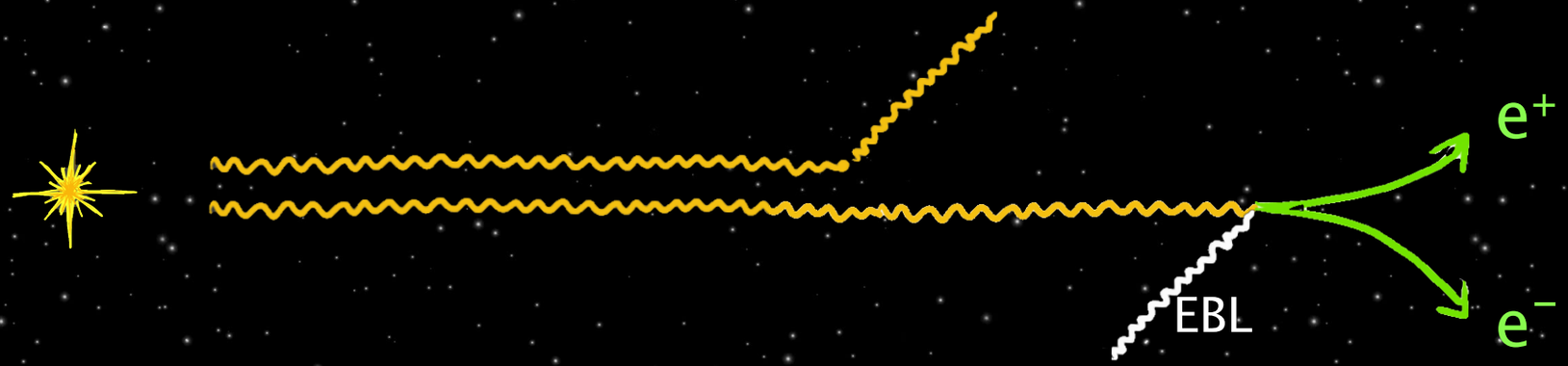


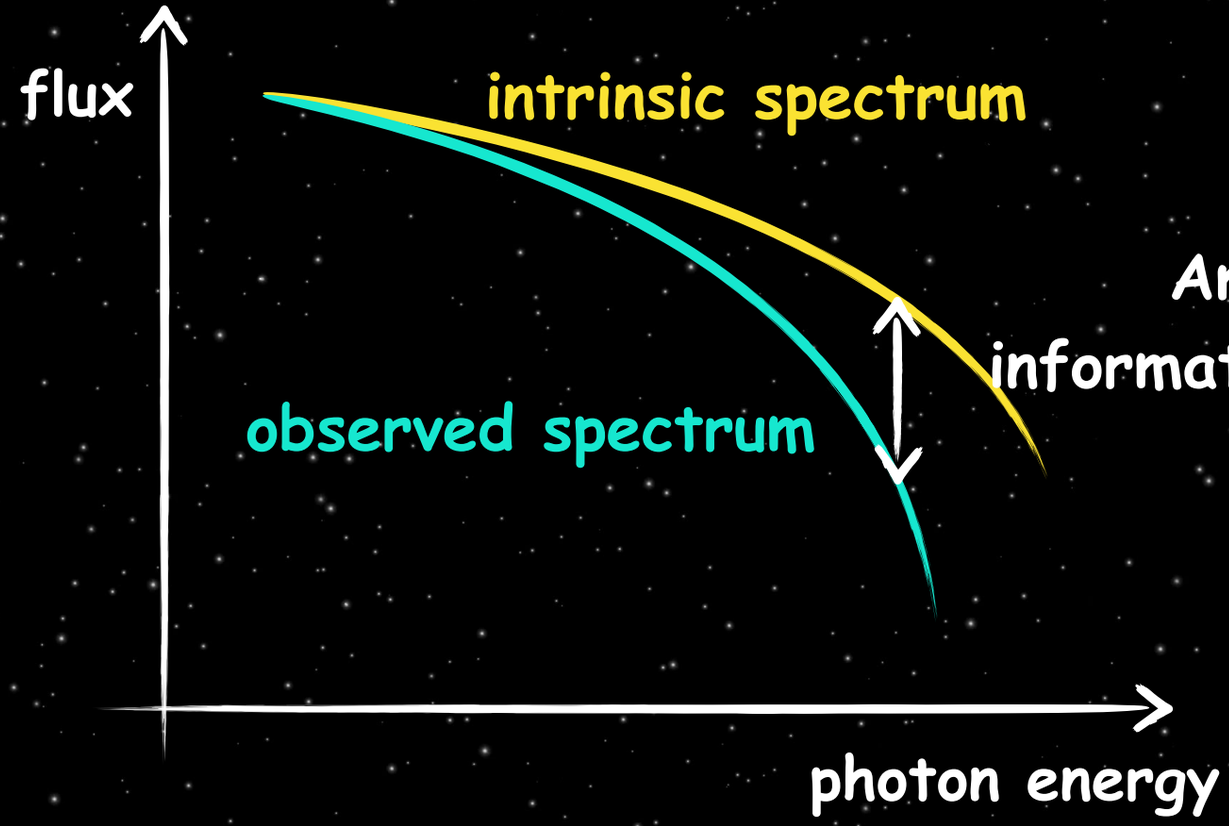


a multi-messenger, multi-source approach to unveil the origin of γ-ray radiation and neutrinos

Photons

the Universe is not completely transparent to photons



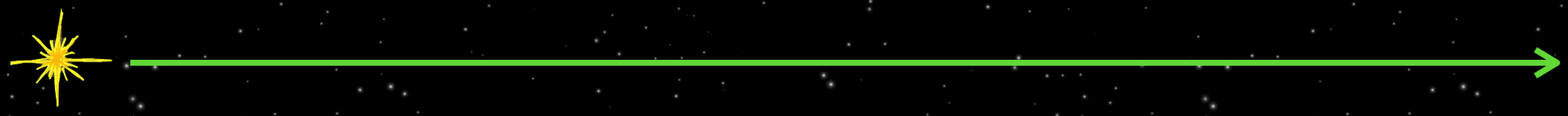


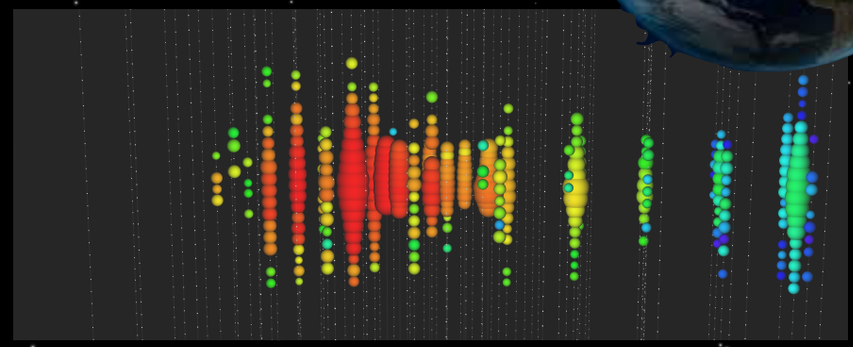
Amount of attenuation holds the information about absorbers/magnetic field/ background radiation fields…

…but we need to know the intrinsic spectrum first

Neutrinos

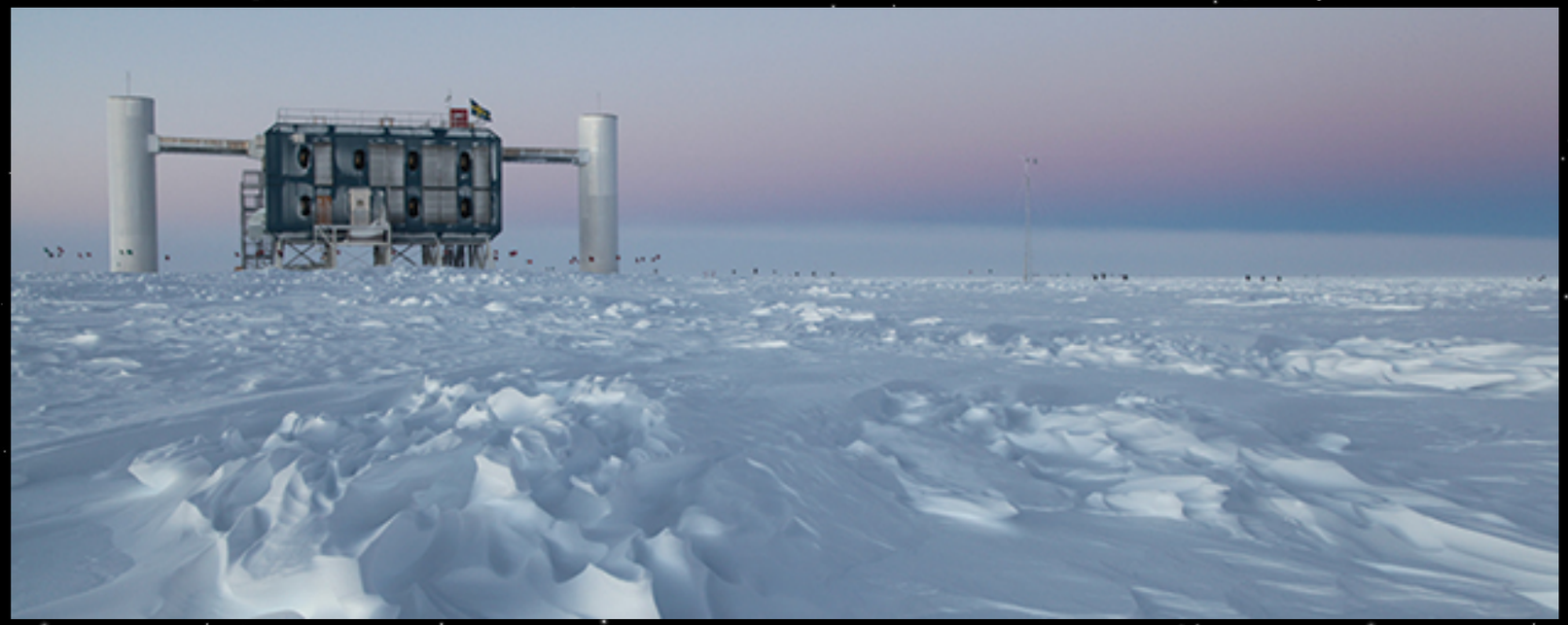
the Universe is transparent to neutrinos…but so are our detectors…





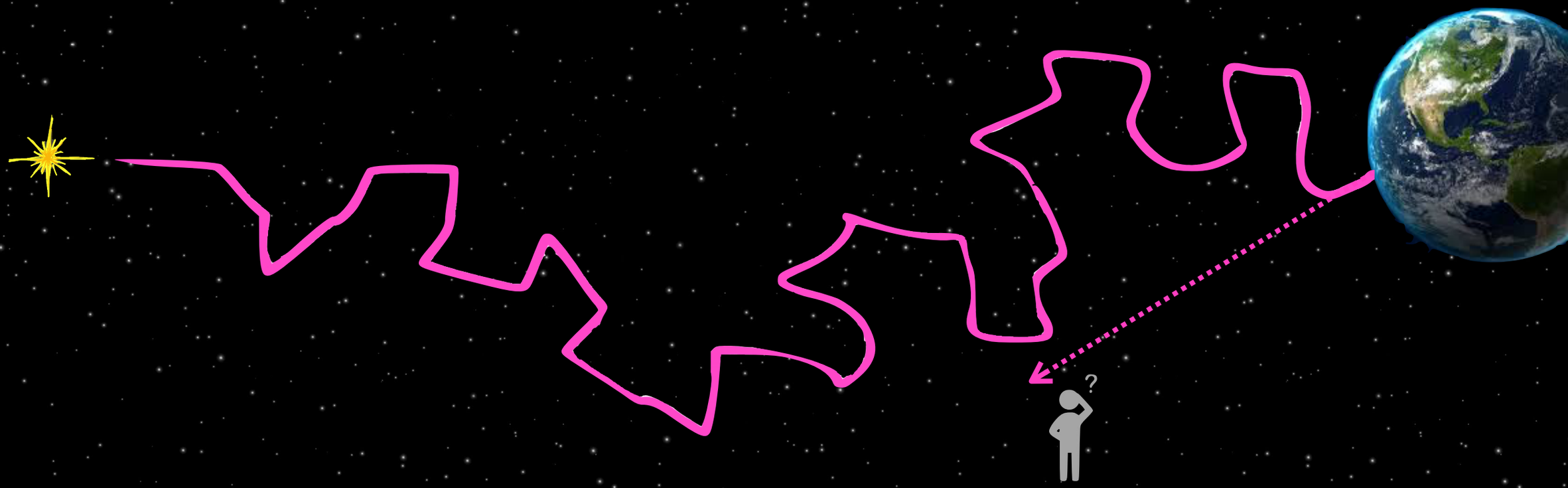
71TeV neutrino detected by IceCube

IceCube Lab at the South Pole — cubic km of ice



Cosmic Rays

charged particles, deflected by the magnetic field



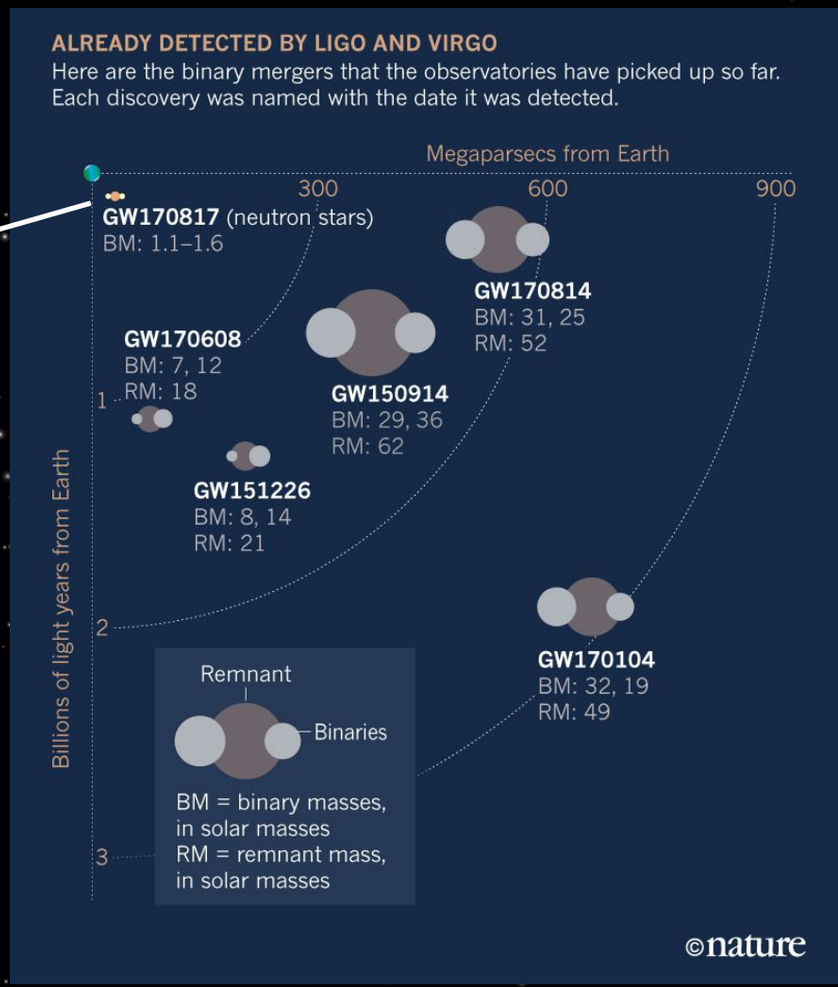
Sources of CRs have not been identified yet!
γ-ray and ν output from CR production is unknown

Gravitational Waves

must be very close to the Earth

40 Mpc

no e.m. signal expected from
BH–BH mergers



Gamma-Rays from Gamma-Ray Bursts and their connection to Gravitational waves

GeV-TeV observations of GRBs: the state-of-the-art

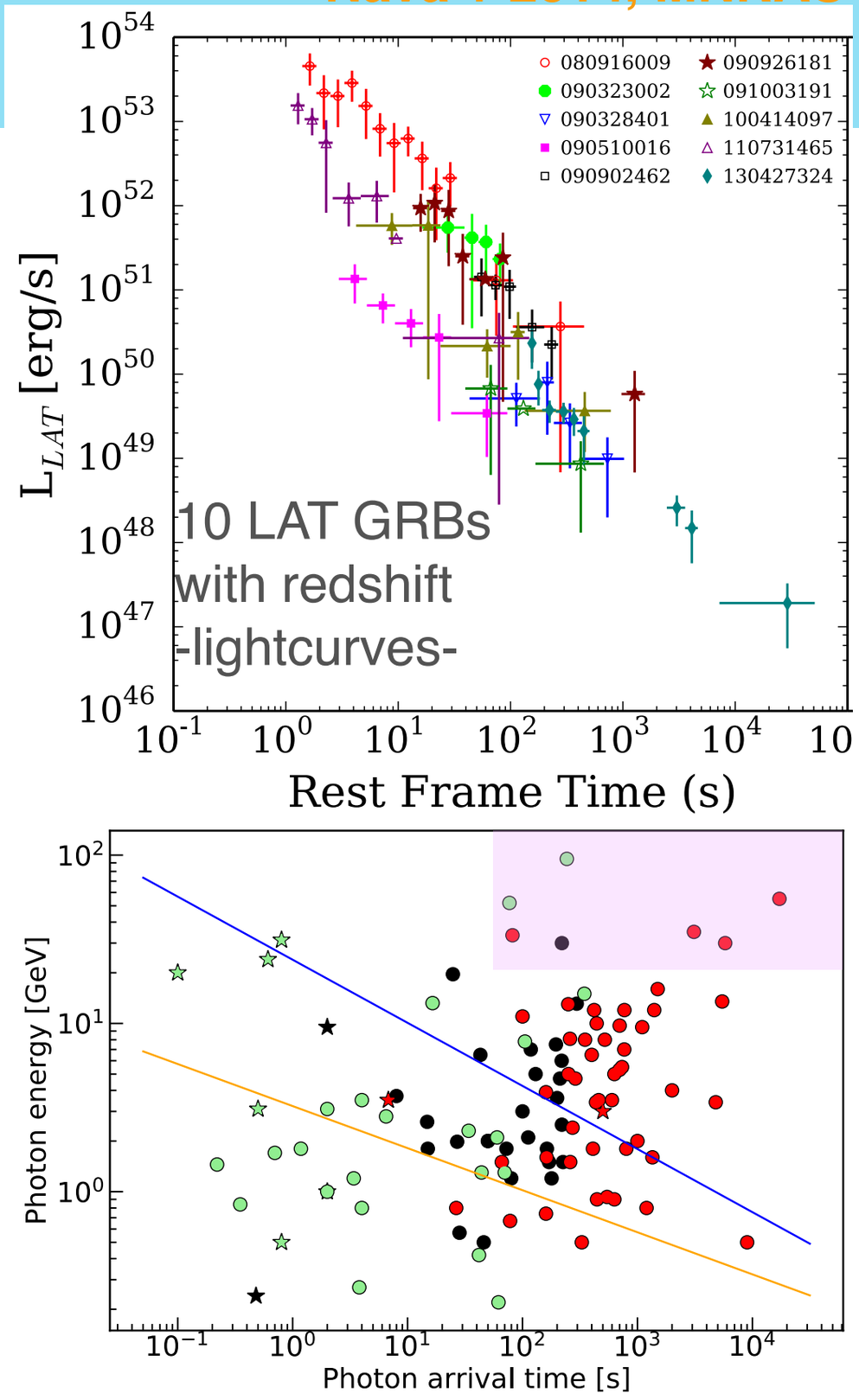
Space Missions:

- CGRO-EGRET (20 MeV - 30 GeV)
  - 6 GRBs
  - 18 GeV photon 75 minutes after prompt

- AGILE-GRID (30 MeV - 50 GeV)
  - 9 GRBs (one short)
  - confirm long-lasting emission, PL decay

- Fermi-LAT (20 MeV - 300 GeV)
  - 143 GRBs (130 Long + 13 Short)
    - 12% of GBM bursts within FoV
    - 30 with redshift (0.145 - 4.35)
    - 11 between 20 GeV - 95 GeV
  - up to 10^4 seconds after prompt

Nava + 2014, MNRAS



Nava 2018, review *HE emission from GRBs*, 2018, IJMPD, 2742003, arXiv:1804.01524

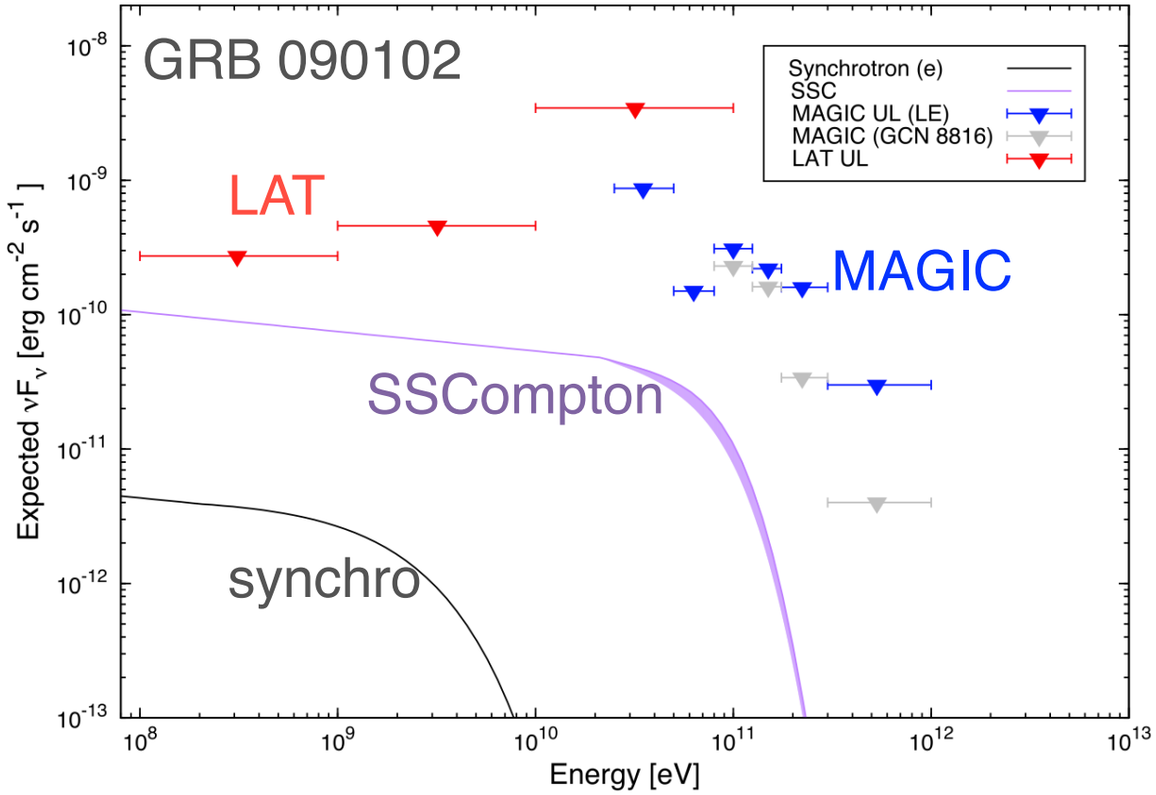
GeV-TeV observations of GRBs: the state-of-the-art

Ground Observations (IACT - EAS)

- MAGIC / HESS / VERITAS
  - number of observed GRBs:
    - hundred / several tens
  - low energy threshold:
    - 50 / 50 / 100 GeV
  - time delay:
    - < 100 s / 100-1000 s

- HAWC
  - > 50 GeV, no time delay, 100 GRBs observed so far

Aleksic + 2014



— No detections, only upper limits —

Nava 2018, review *HE emission from GRBs*, 2018, IJMPD, 2742003, arXiv:1804.01524

Relevance of GeV-TeV GRB studies

- In GRB physics
  - reveal the presence of an inverse Compton component
  - understand the nature of the radiative processes
  - place constraints on the magnetic field strength

- In other fields of astrophysics/ fundamental physics
  - EBL: GRBs are complementary to AGNs
  - LIV: Lorentz Invariance Violation tests
  - Physics of relativistic shocks

CTA collaboration and GRBs:
- ongoing project -

The PoSyTIVE project

Population **Sy**nthesis **T**heory **I**ntegrated code for **V**ery high-energy **E**mission

PoSyTIVE project: theory-based models for estimates of GRB detection rate

Population **Sy**nthesis

(Long and Short)

Theory **I**ntegrated code for **V**ery high energy **E**mission

(prompt and afterglow)

Instrument response & observing conditions

CTA detections rates:

- for prompt and afterglow emission
- for Long and Short GRBs
- as a functions of physical parameters
- as a function of the external GRB alert (Swift, Fermi, SVOM, THESEUS, HERMES)

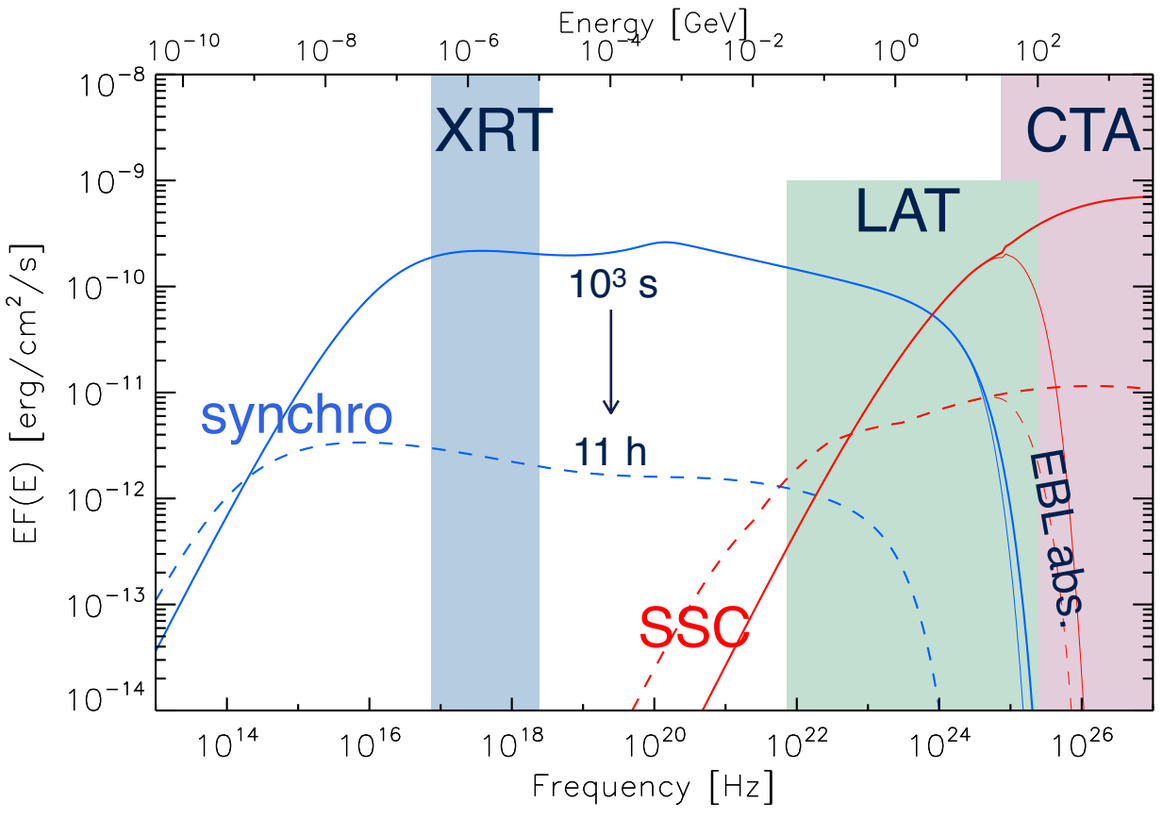
GRB consortium paper !!!

Modeling of afterglow emission

Dynamics:
external shocks in coasting and during deceleration

Radiation:
synchrotron and SynchroSelf Compton radiation. Corrections for KN regime included. Correction for off-axis configuration!!!!

Code output:
light curves and spectra from beginning of afterglow to 10^4 - 10^5 seconds



CTA/GRB F2F meeting

- AIM: draft the GRB consortium paper
- PLACE: INAF - OABrera
- DATE: 16 - 18 January
- pre-meeting on CTA and GW?

CTA and Gravitational Waves

ONGOING PROJECT by the CTA/GW team

✓ Simulation of BNSs and their GW emission and detection

✓ Short GRB 090510 as a prototype, on-axis

⇒ 0.08–0.5 GW+CTA detection per year

Patricelli + 2018

FUTURE PROJECT and my involvement

✓ Theoretical modeling of GRB HE emission from short GRBs

✓ Consider off-axis configuration

Gamma-Rays

and their connection to

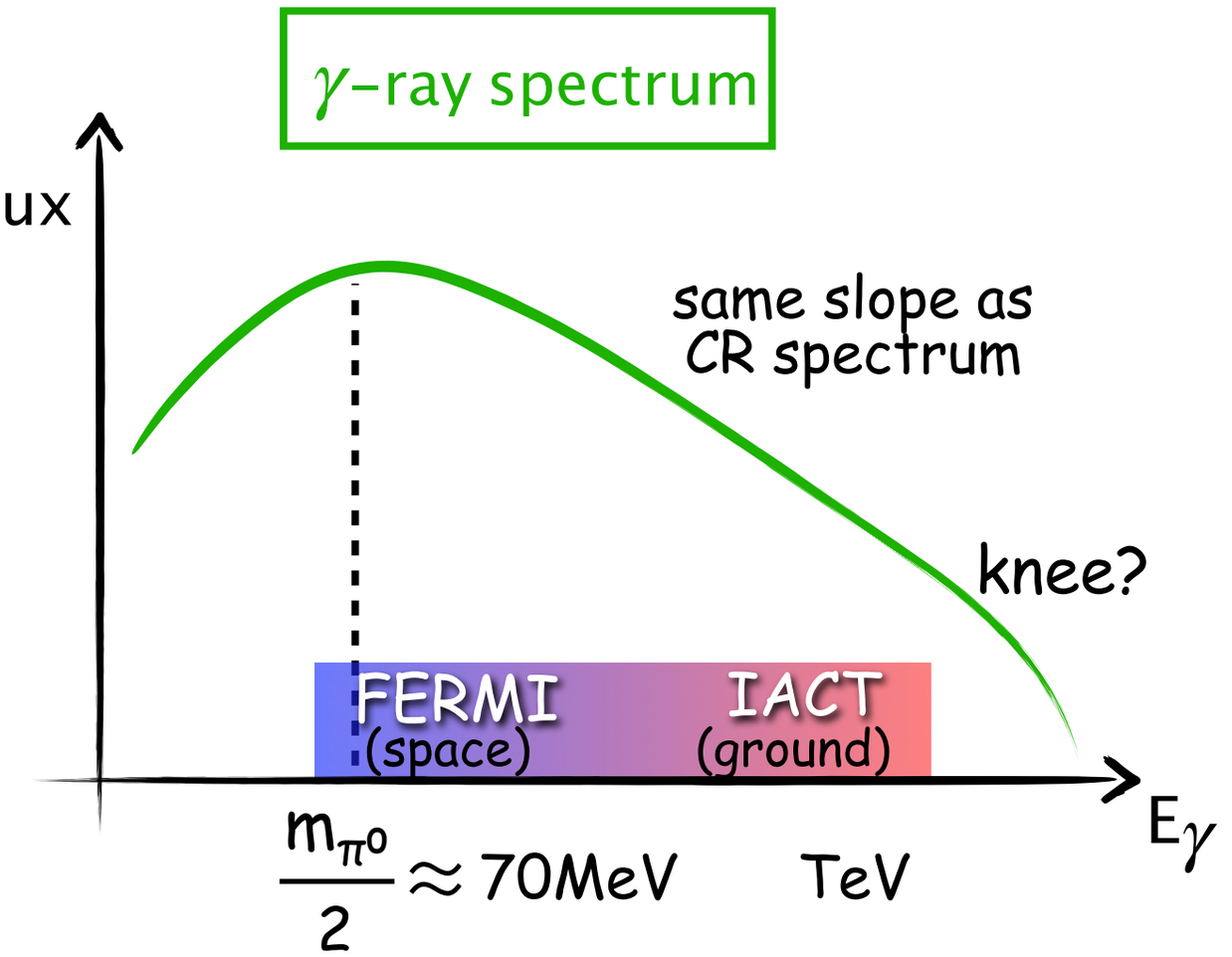
Cosmic-Rays and neutrinos

in Star Forming Galaxies

SuperNova Remnants as particle accelerators

CR → p + p → p + p + π^0 → $\gamma + \gamma$; ISM

$\langle E_\gamma \rangle \simeq E_{CR}/10$

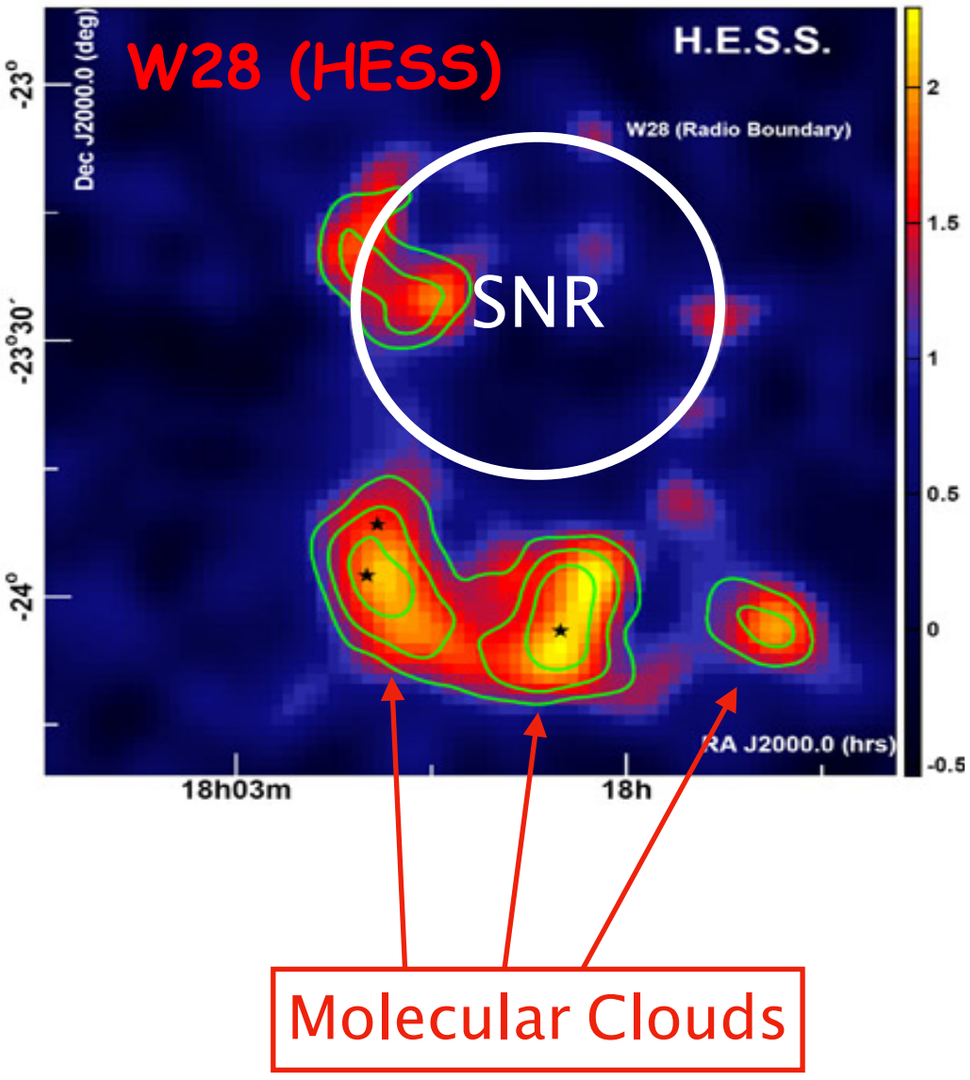


p + p → p + p + $\pi^\pm$ → $\mu^\pm$ + ν_μ ($\bar{\nu}_\mu$) → $e^\pm$ + $\bar{\nu}_\mu$ (ν_μ) + ν_e ($\bar{\nu}_e$)

$\langle E_\nu \rangle \simeq E_{CR}/20$

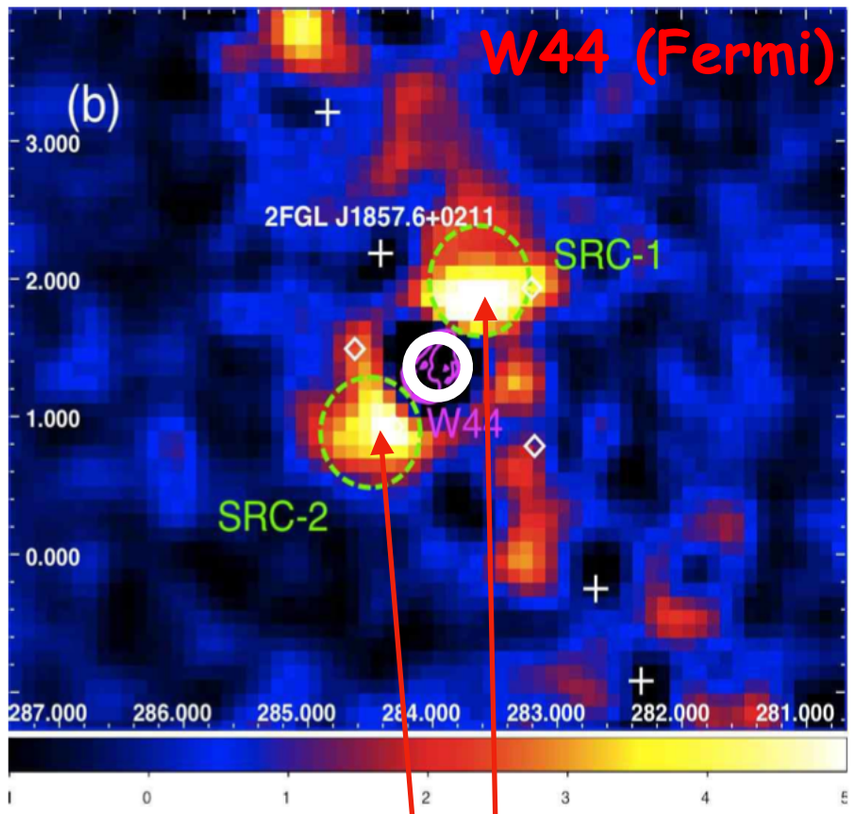
SuperNova Remnants as particle accelerators

Aharonian et al, 2008



Molecular Clouds

Uchiyama et al, 2012



Molecular Clouds

SuperNova Remnants as particle accelerators

Diffusion coefficient

Nava et al. 2016
Nava et al. 2018 (submitted)

CR are usually treated as 'test particles' passively scatter on the inhomogeneities of the magnetic field.

BUT if their energy density is > $B^2/8\pi$ they trigger the growth of the magnetic turbulence (streaming instabilities)

⇒ **CR self-confinement**

SuperNova Remnants as particle accelerators

Diffusion coefficient

Nava et al. 2018 (submitted)

diffusion

CR pressure

$$\frac{\partial P_{\rm CR}}{\partial t} + V_{\rm A}\frac{\partial P_{\rm CR}}{\partial z} = \frac{\partial}{\partial z}\left(\frac{D_{\rm B}}{I}\frac{\partial P_{\rm CR}}{\partial z}\right),$$

Alfven waves

$$\frac{\partial I}{\partial t} + V_{\rm A}\frac{\partial I}{\partial z} = -V_{\rm A}\frac{\partial P_{\rm CR}}{\partial z} - 2\Gamma_{\rm d} I + Q\,,$$

growth rate

damping rate

relevant only if CR pressure is higher than B energy density:
the size of the SNR at the time when CR are released is fundamental!

the nature of damping mechanisms strongly depends on the ISM phase

Galactic-scale properties of diffusion

Boron/Carbon ratio (B/C): Boron = secondary product of the nuclear collisions of Carbon (and heavier) nuclei; C = mainly primary

⇩

grammage:

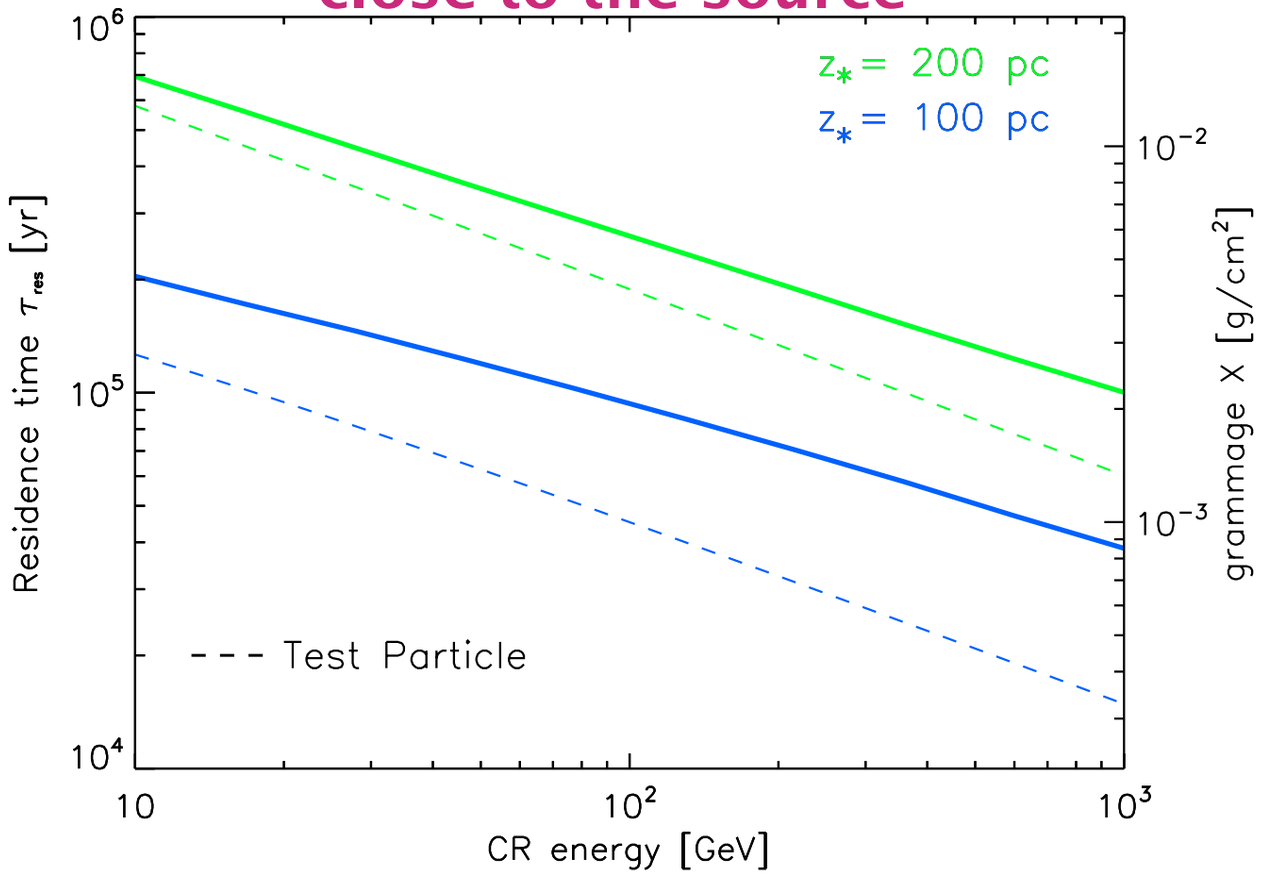
$$X(p) \approx 1.4\, m_p\, n_d\, (h/H)\, v(p)\, \tau_d$$

⇩ residence time

galactic diffusion coefficient

$$D_{gal} \propto 1/\tau_d$$

residence time and grammage close to the source



Nava et al. 2018 (submitted)

Summary: project status and results

Present (work in progress)

- Afterglow modeling of HE and VHE radiation, off-axis ✓
    1. GW electromagnetic counterpart ✓ **but more in the future**
    2. CTA and origin of HE emission in GRB ✓
    3. GW/CTA connection ✓
- Diffusion of CRs ✓

Future

- Neutrinos: estimate of different source contributions and temporal correlation gamma-neutrino