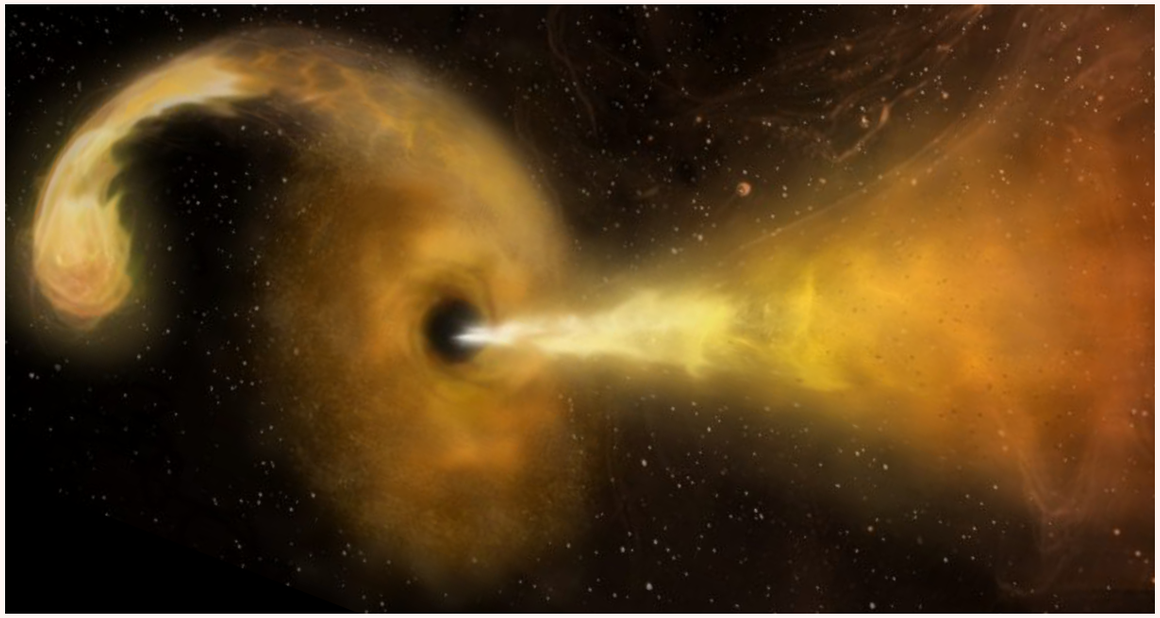
CHASING THE COSMIC ACCELERATORS WITH HIGH ENERGY ASTROPARTICLES



CLAIRE GUÉPIN

Neil Gehrels fellow, University of Maryland, College Park

& NASA Goddard Space Flight Center, Greenbelt

Rencontres des Jeunes Physicien·ne·s 2021

RJP 2021

Adapted from *GRAND collaboration (2018)*

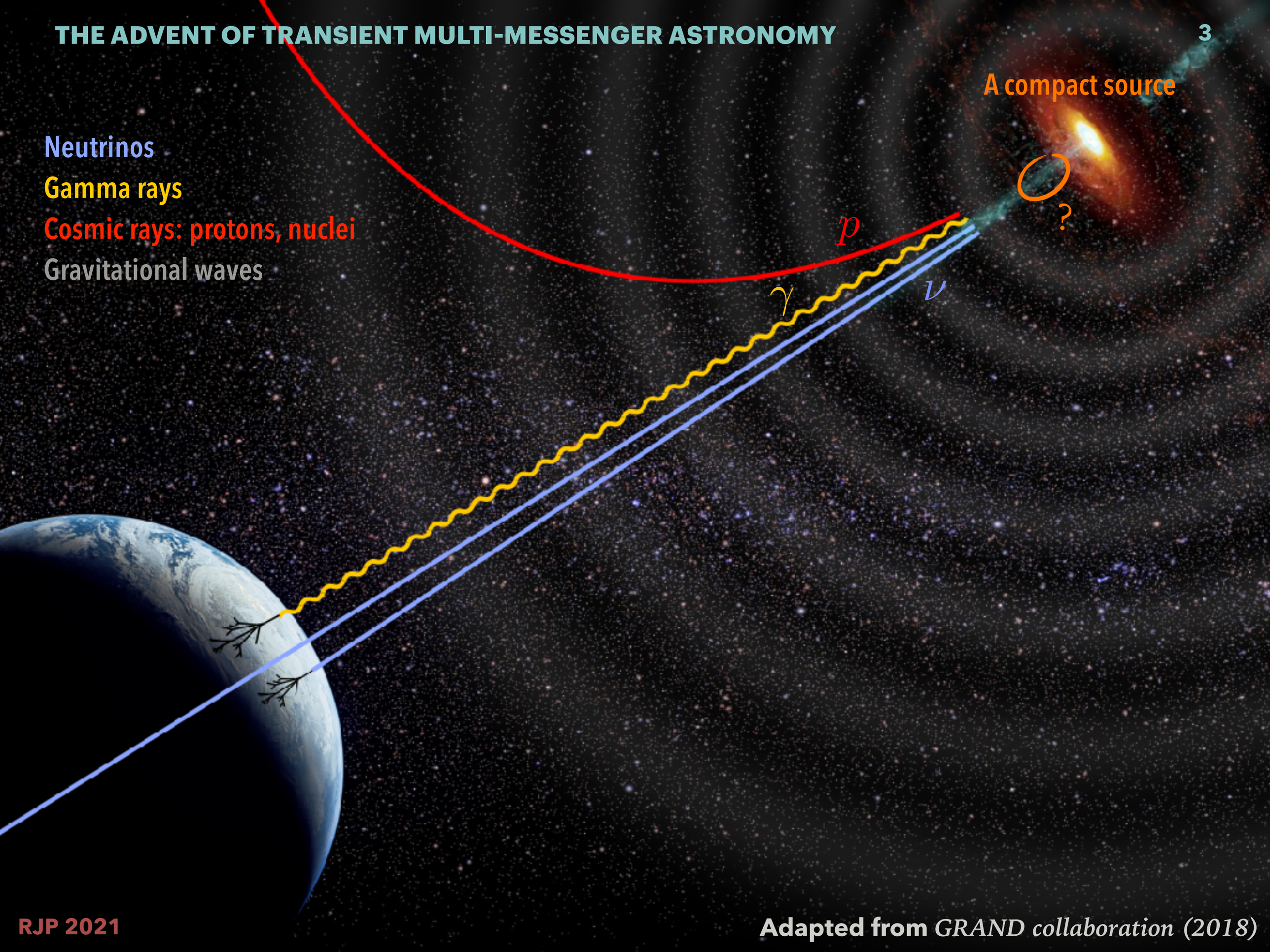
Neutrinos

Gamma rays

Cosmic rays: protons, nuclei

Gravitational waves

A compact source



RJP 2021

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Neutrinos

Gamma rays

Cosmic rays: protons, nuclei

Gravitational waves

Photopion production

Pair production

A compact source

?

p

γ

ν

e^+

e^-

p

$\bar{\nu}_\mu$ ν_μ π^+ $\gamma_{\rm CMB}$

μ^+ n

ν_e e^+

γ π^0 p

γ $\gamma_{\rm CMB}$

p

RJP 2021

Adapted from *GRAND collaboration (2018)*

Number of observed sources, resolutions

ex. observatories LSST, TAP, WFIRST, SKA, CTA

LSST : $\sim 10^6$ sources / night in 2023

Photons, **cosmic rays** (nucleons and charged nuclei), **neutrinos** et **gravitational waves**

ex. H.E.S.S. | ex. Auger | ex. IceCube | ex. Virgo

Multi-messenger observations of transient sources

ex. GW170817, ex. IC170922A & TXS 0506+056

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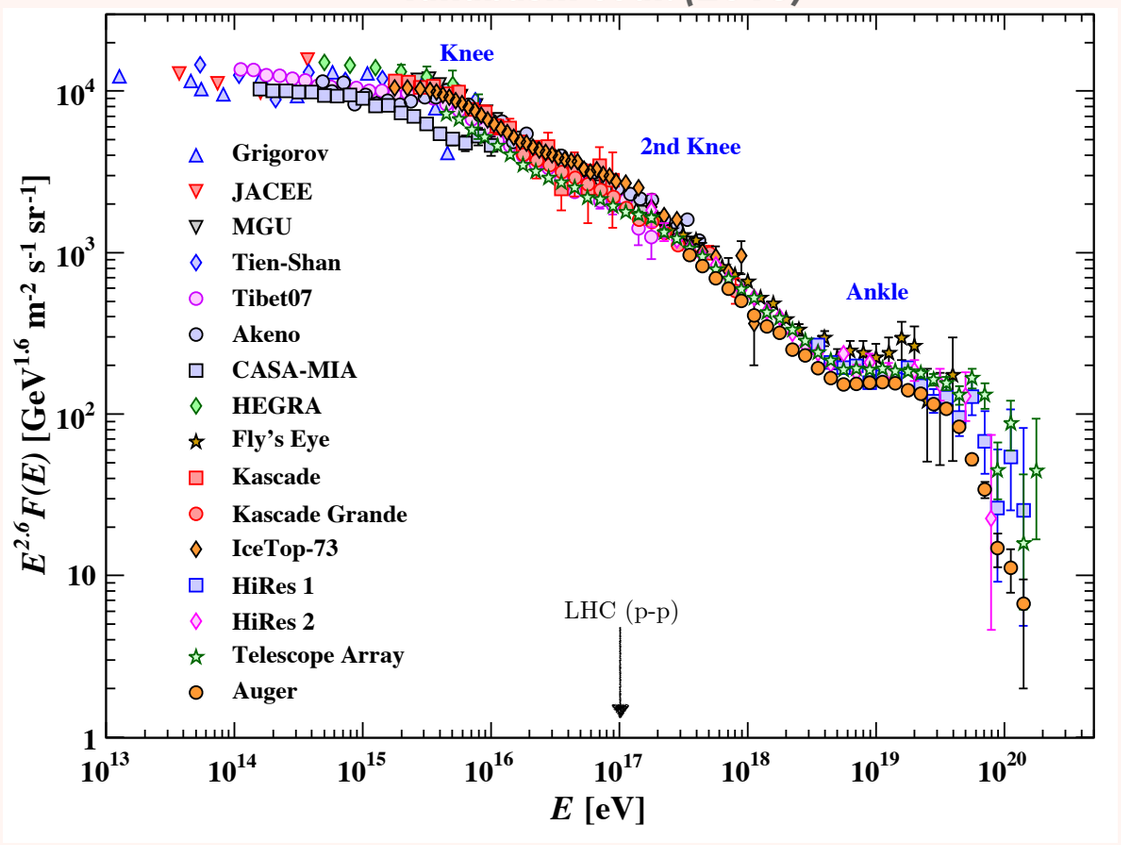
Unprecedented information about the high-energy universe

Sources of high-energy cosmic rays and neutrinos?

For instance: high to ultra-high energy cosmic-ray spectrum

Tanabashi et al. (2018)



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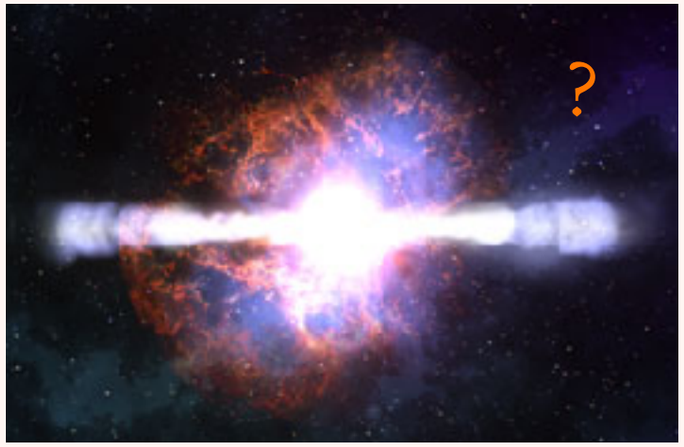
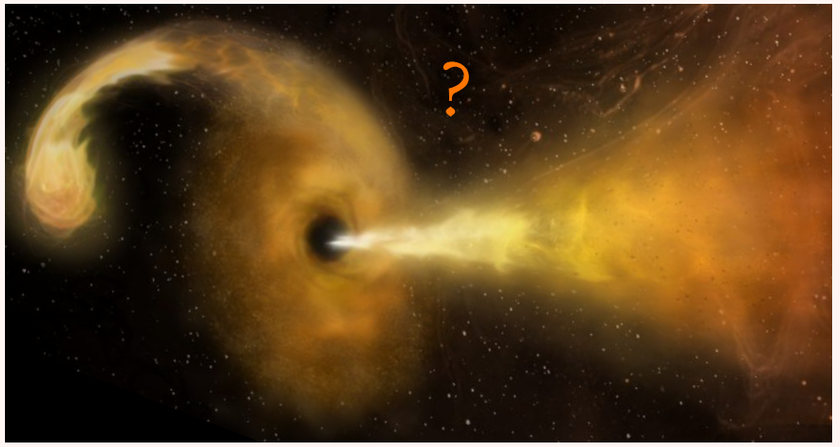
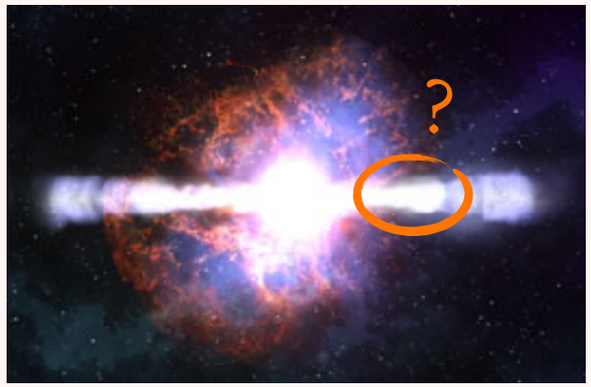
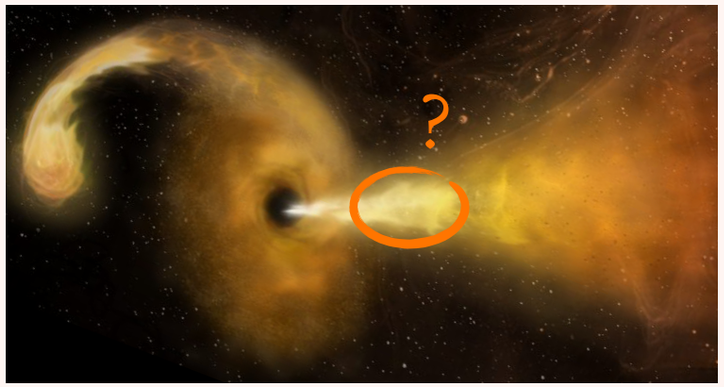




Supernovae? Tidal disruptions by massive black holes? …

Observable characteristics → general macroscopic model & description of micro-physic processes





Source:

- distance d_{L}
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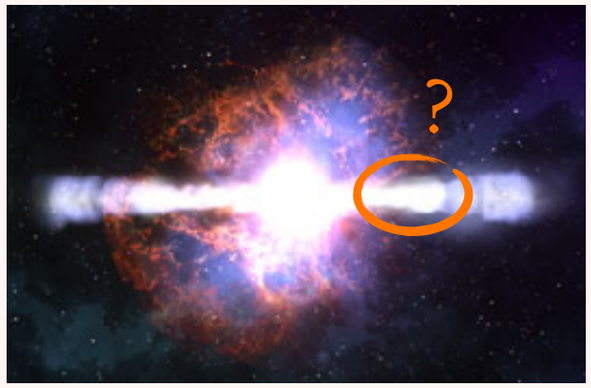
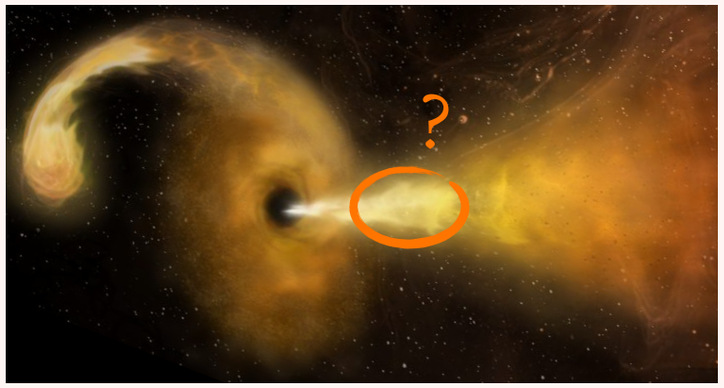
- bulk Lorentz factor Γ

Observable characteristics → general macroscopic model & description of micro-physic processes





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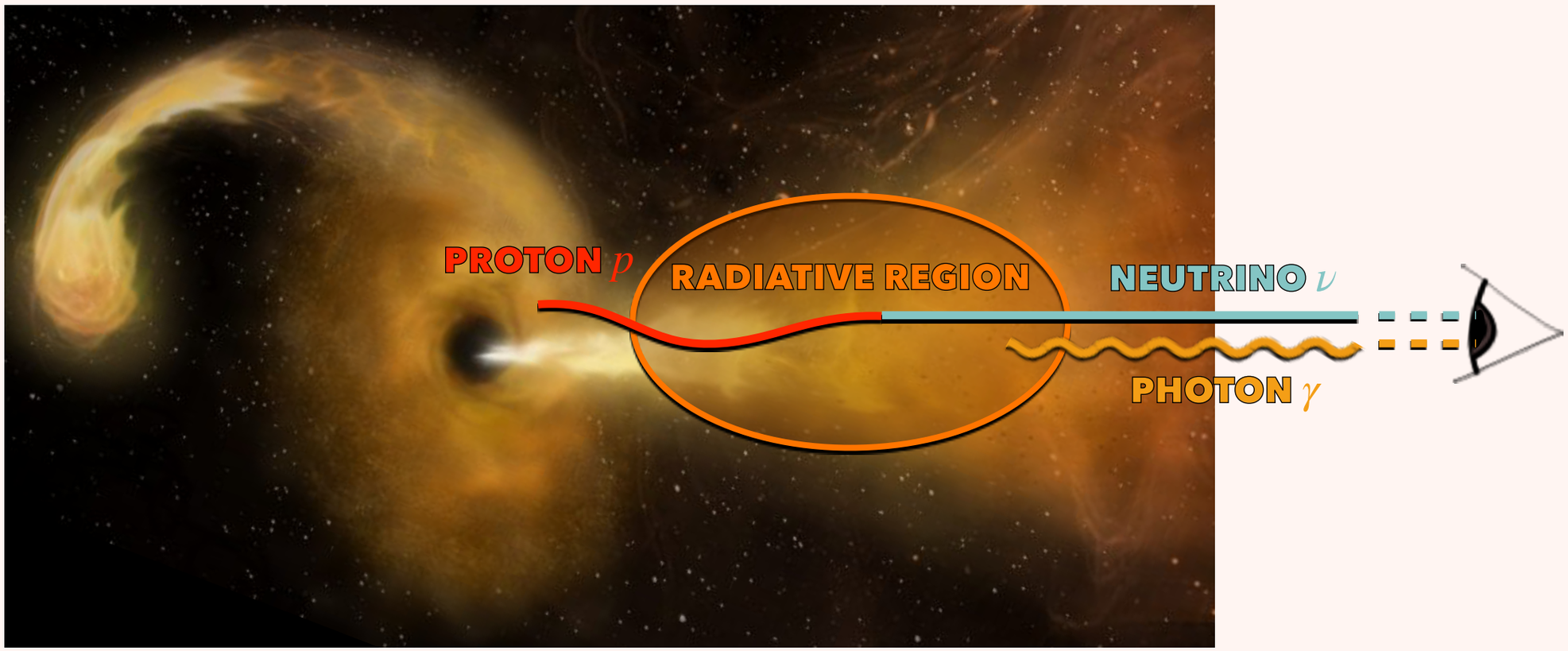
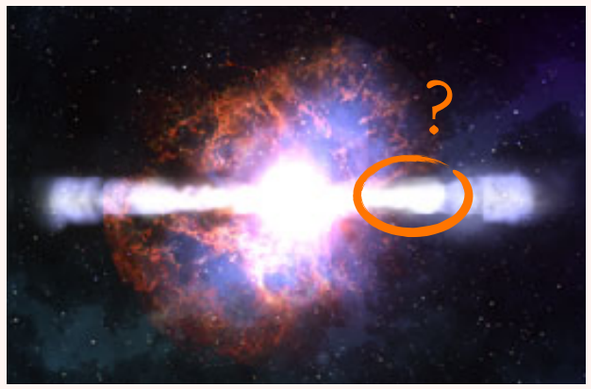
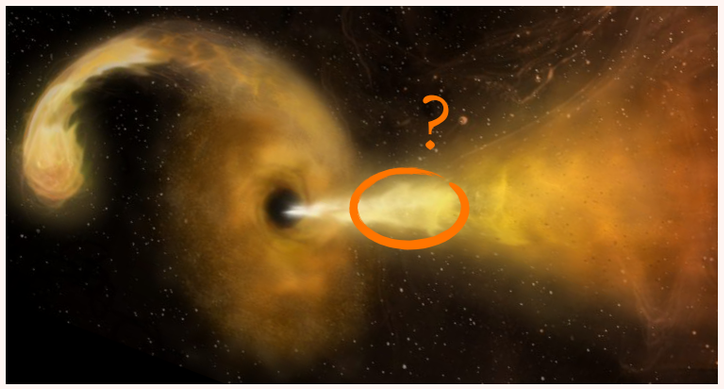


Transient sources	**Micro-physic processes**	**Future UHE observatories**
High-energy emissions? Populations?	Particle acceleration? Interactions?	Coincident observations?

Observable characteristics → general macroscopic model & description of micro-physic processes





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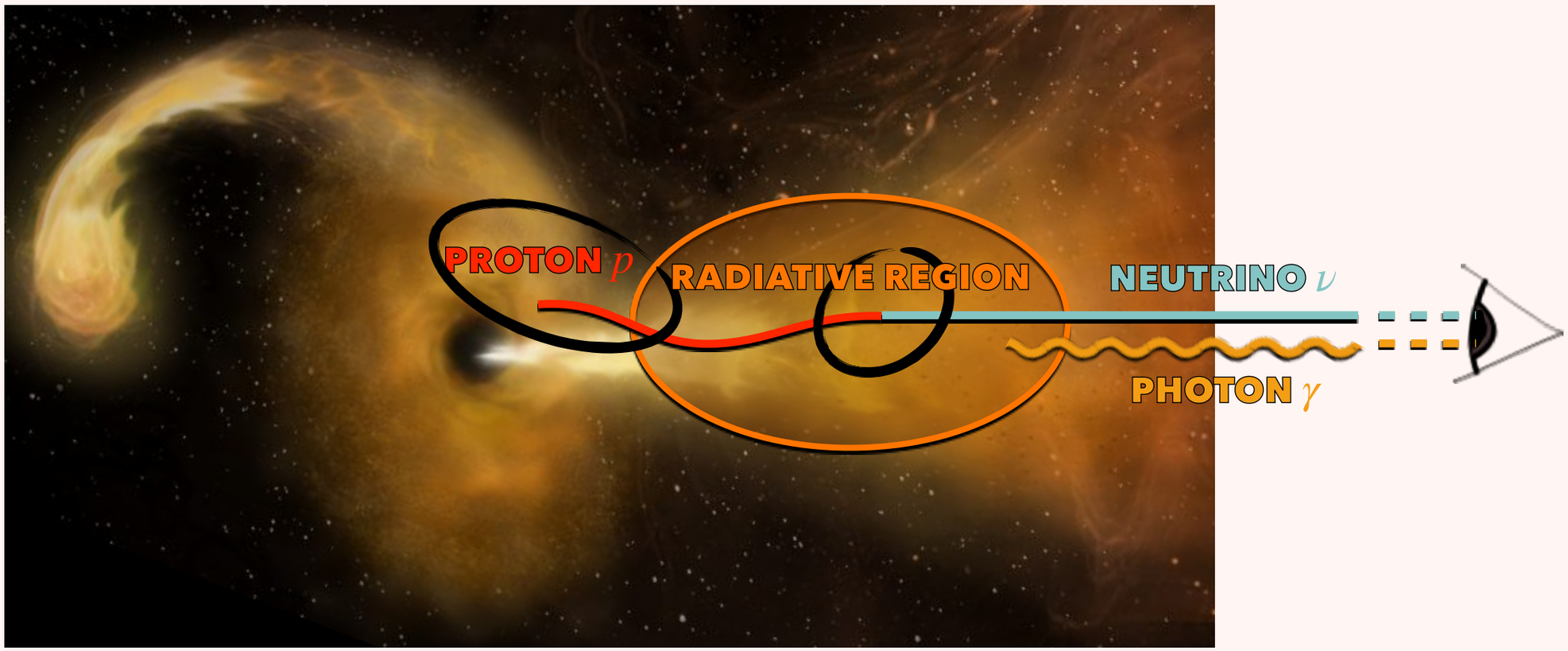

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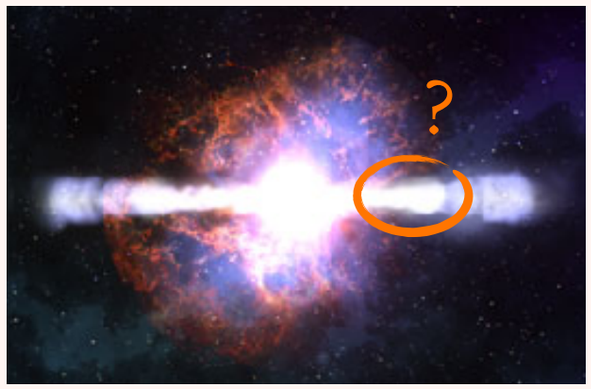

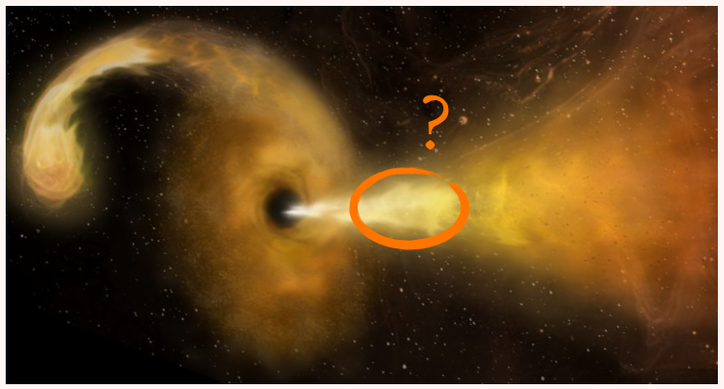

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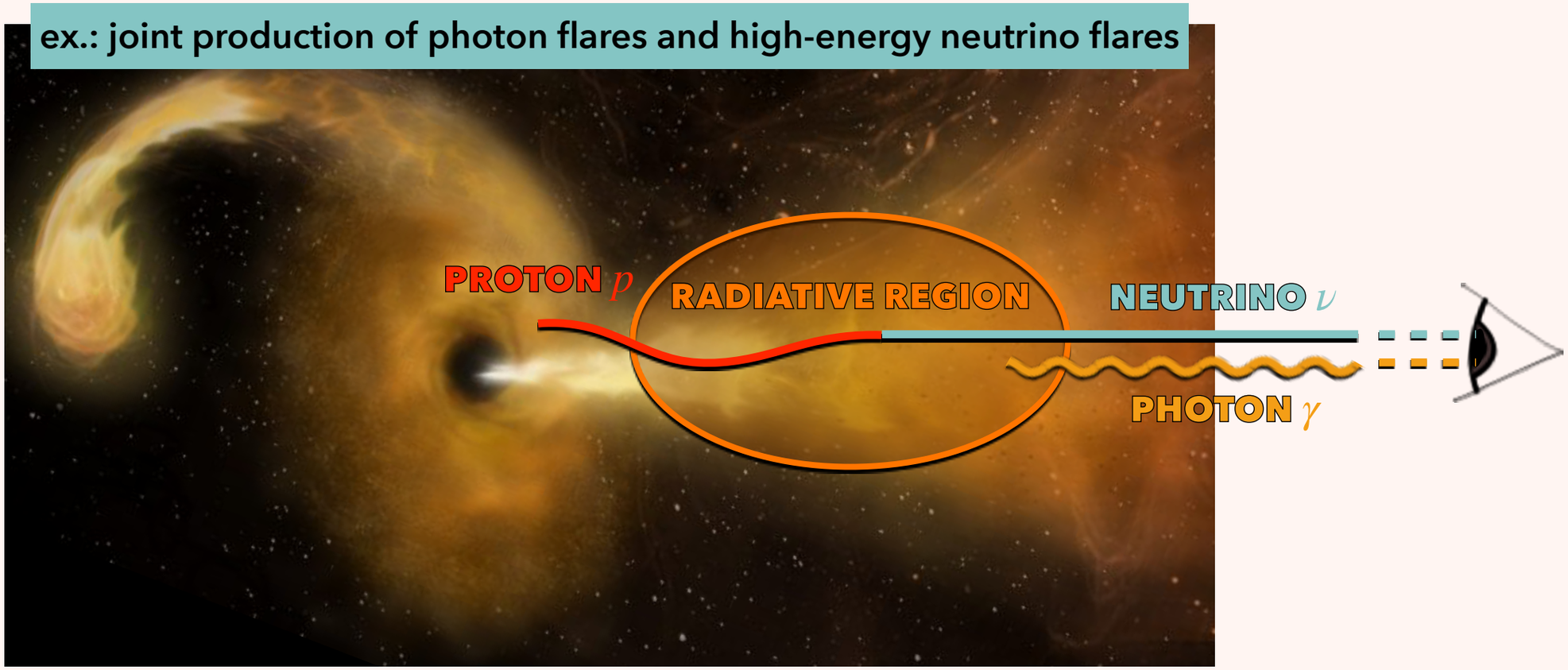
ex.: joint production of photon flares and high-energy neutrino flares



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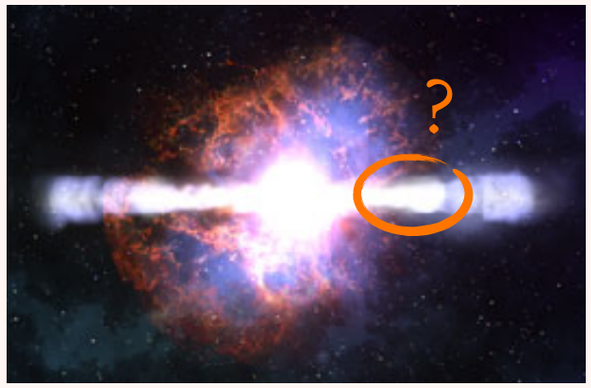

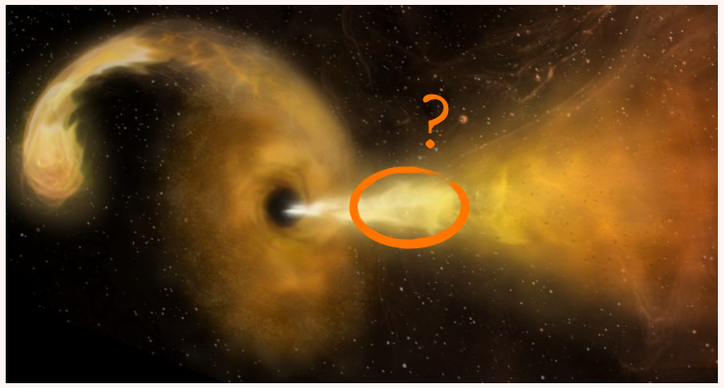

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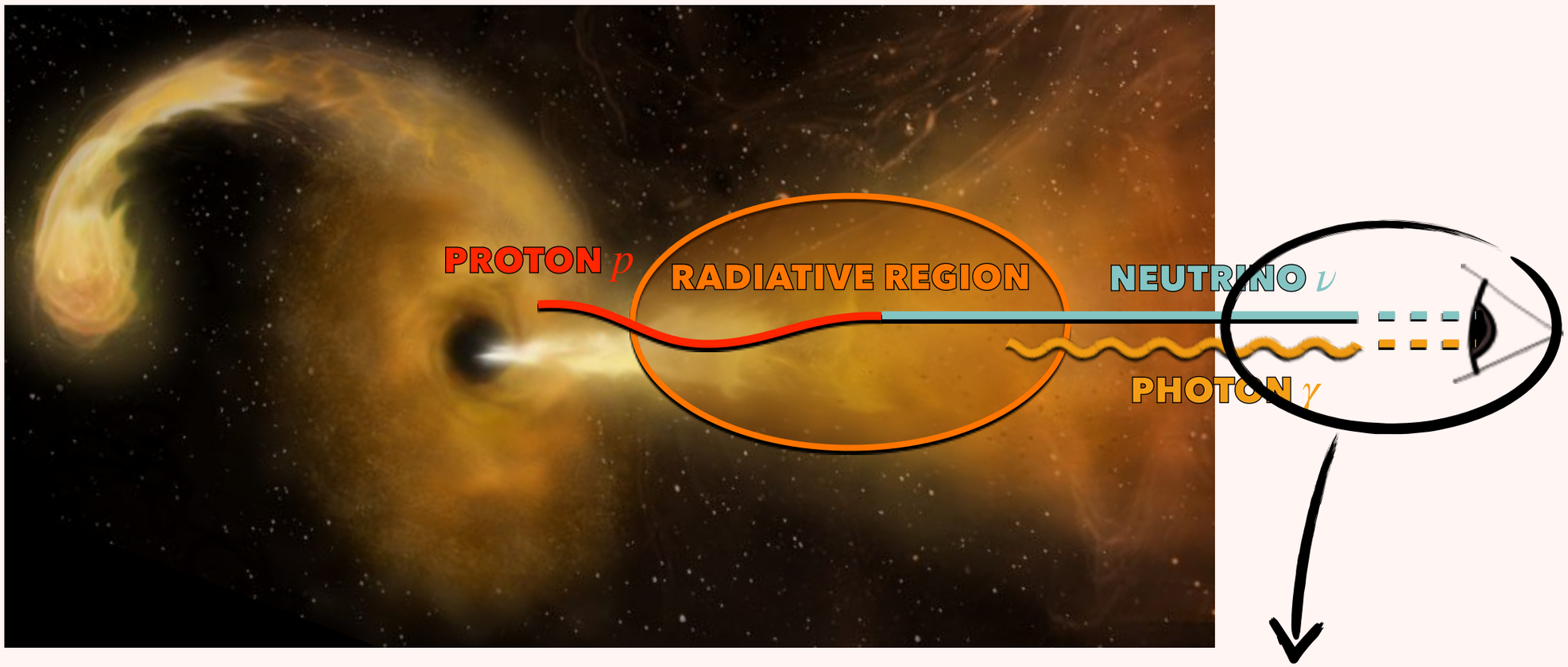

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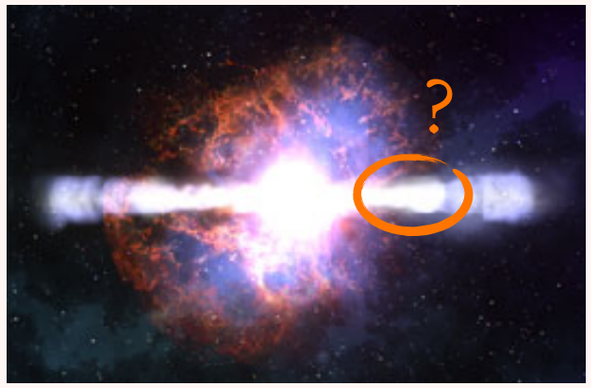
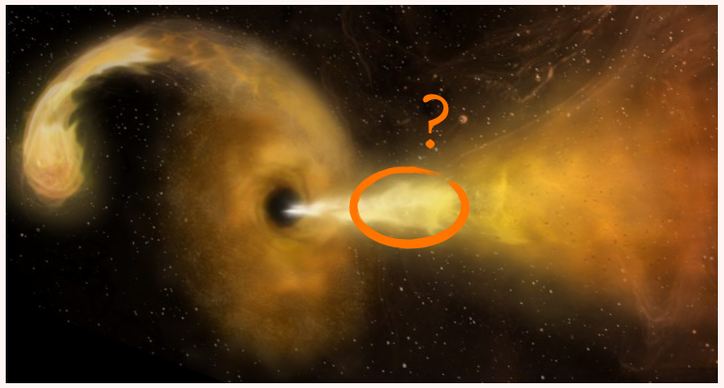
RJP 2021

General macroscopic models: explore the parameter space of transient sources





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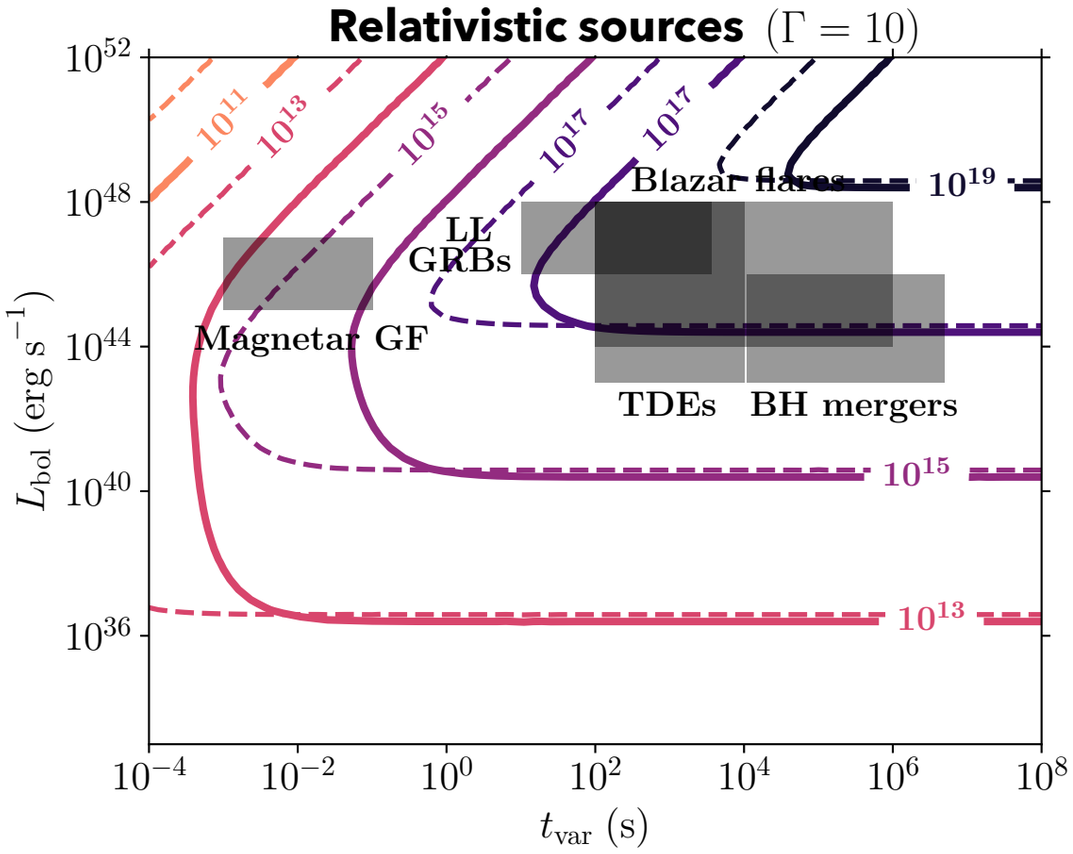
High-energy **neutrinos** coincident with photon flares: $E_{\nu,\rm max}$ (eV), **Guépin** *& Kotera (2017)*



$p\gamma \to N\pi$

dashed: pion +/- decay

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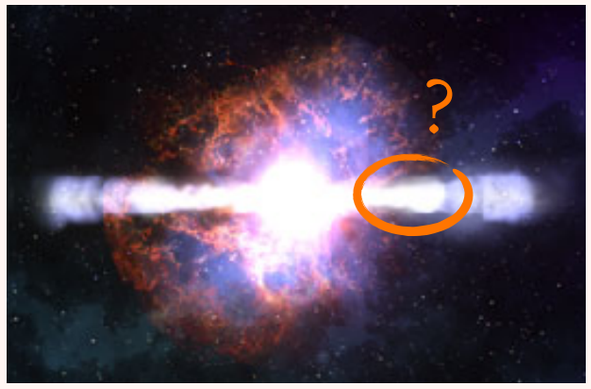

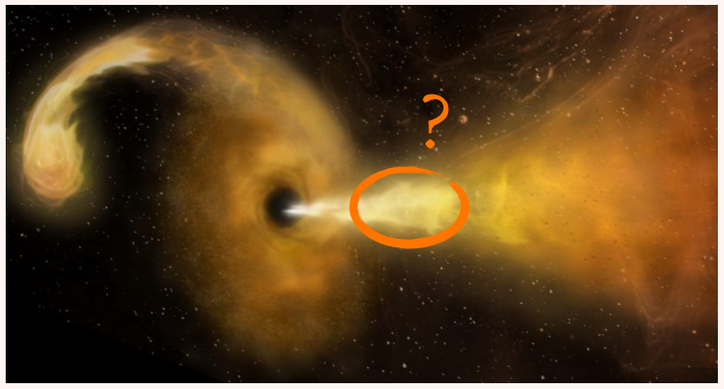

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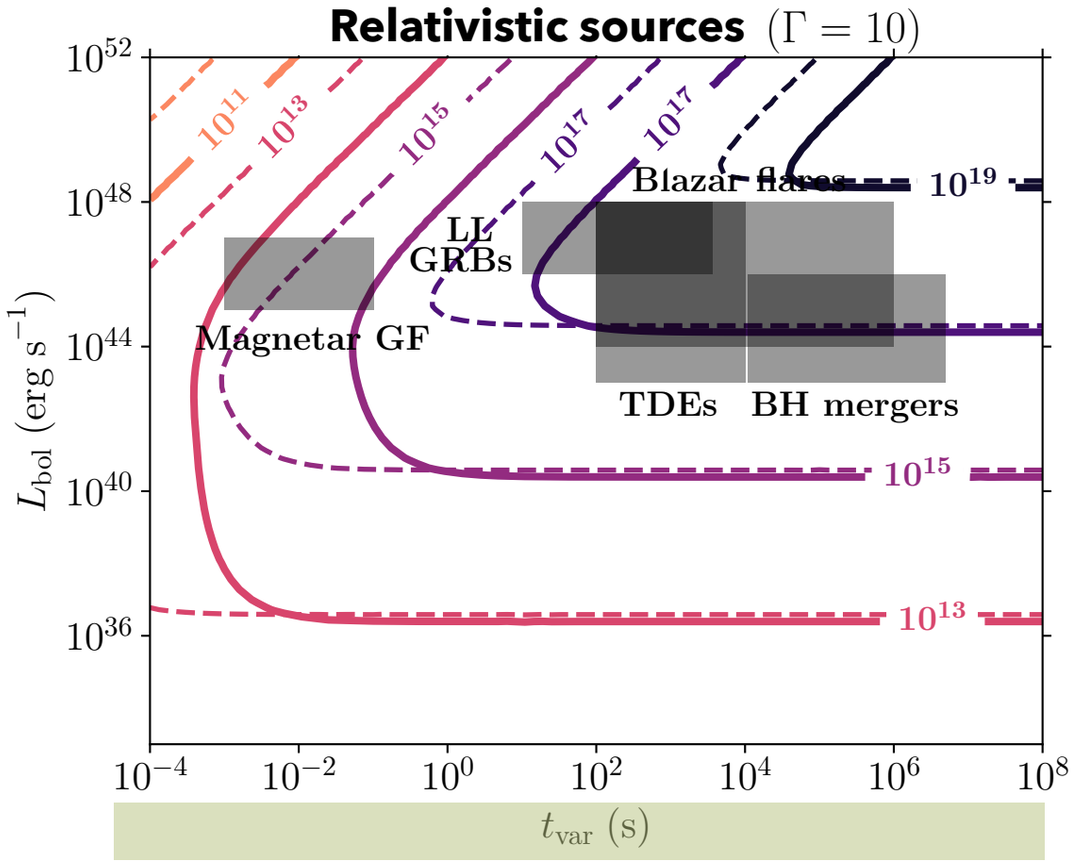

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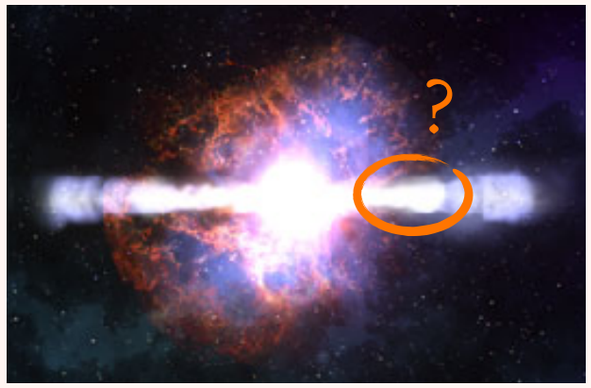

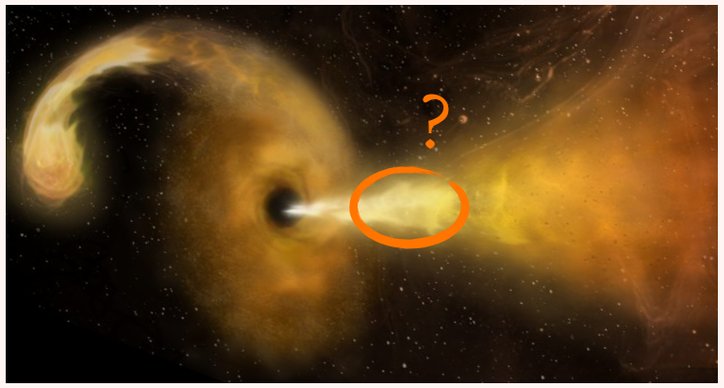

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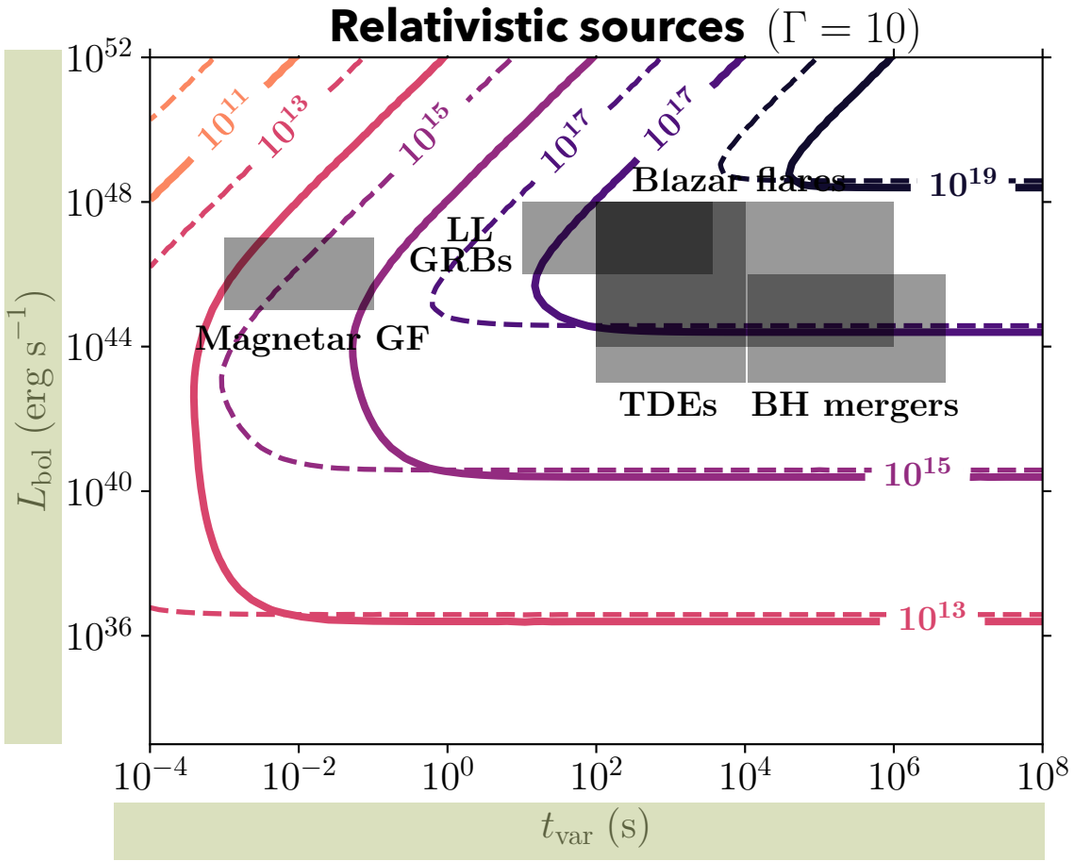

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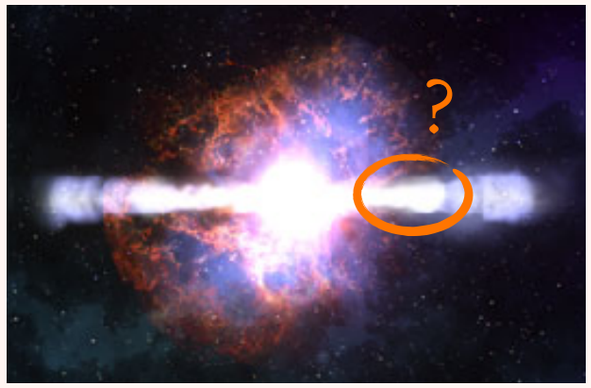

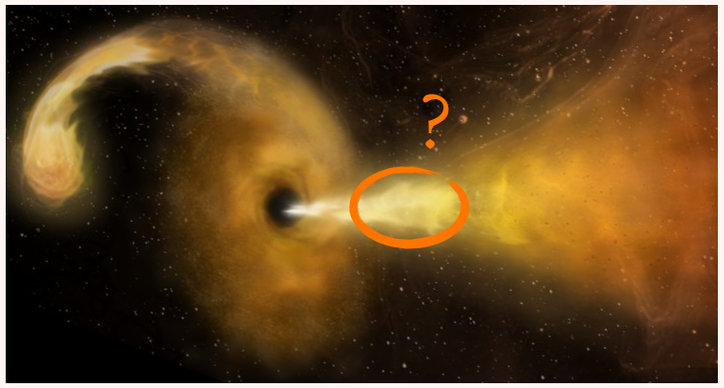

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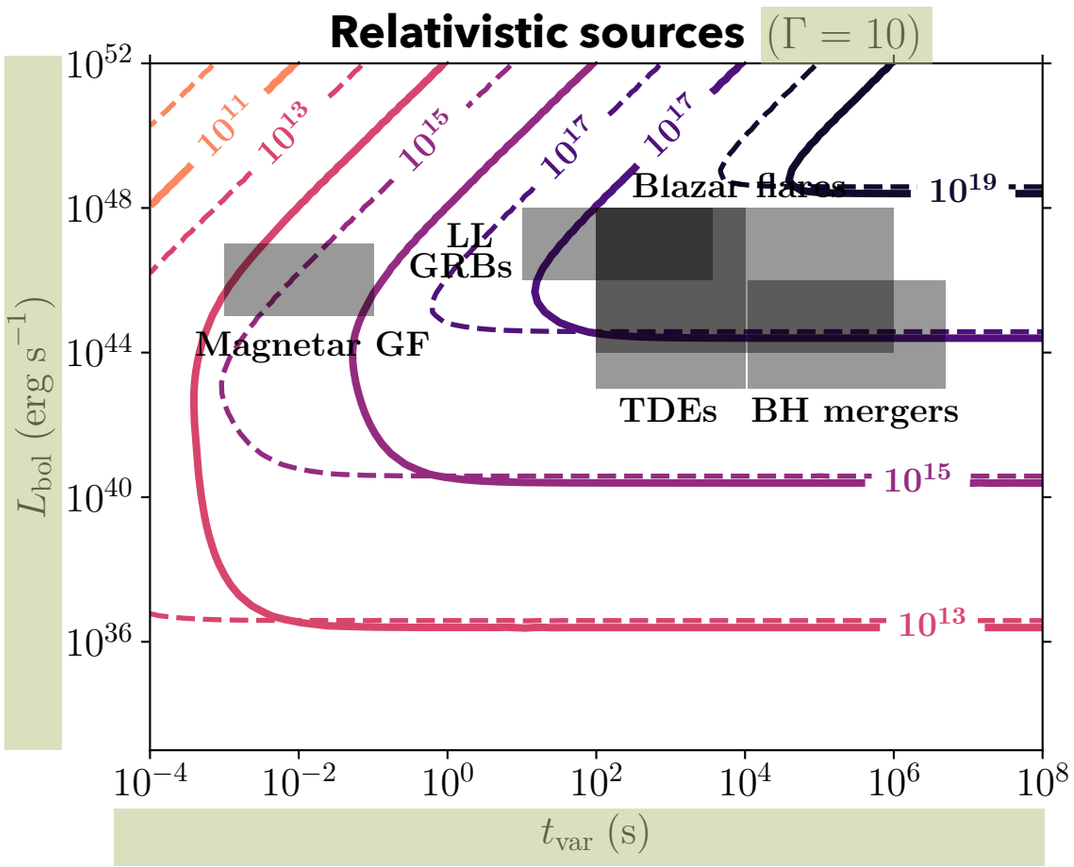

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General macroscopic models: explore the parameter space of transient sources

- identify important physical processes for emissions of transient sources
  - energy losses of secondary particles $\pi^{\pm}$, $\mu^{\pm}$ **Guépin** *& Kotera (2017)*

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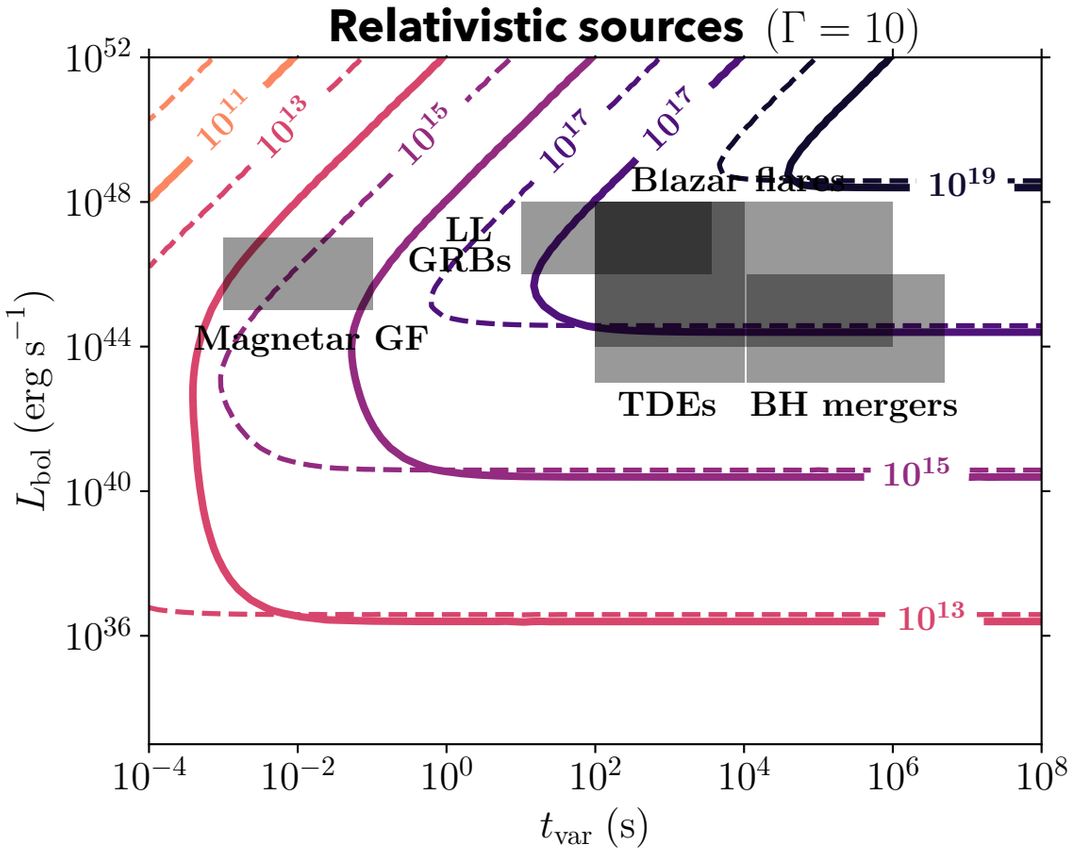

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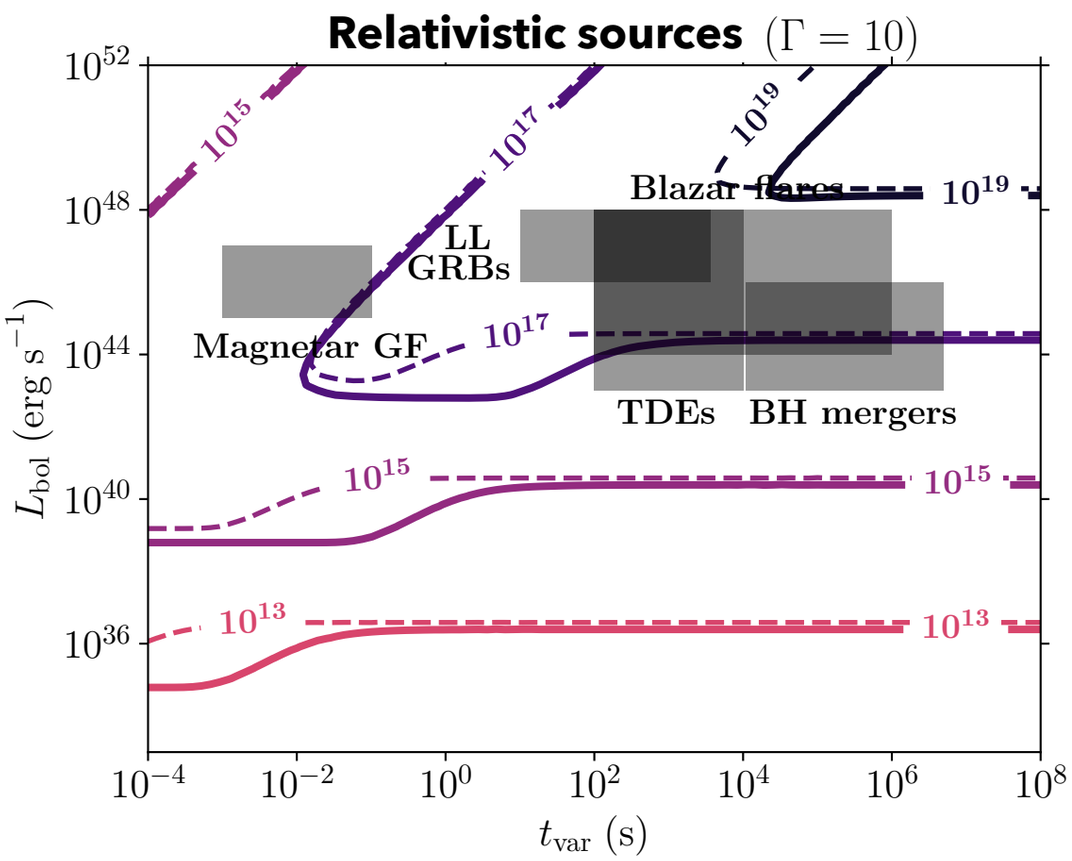
  - acceleration of secondary particles $\pi^{\pm}, \mu^{\pm}$ **Guépin** *(2020)*

Impact of secondary particle acceleration on $E_{\nu,\max}$ (eV), **Guépin** *(2020)*



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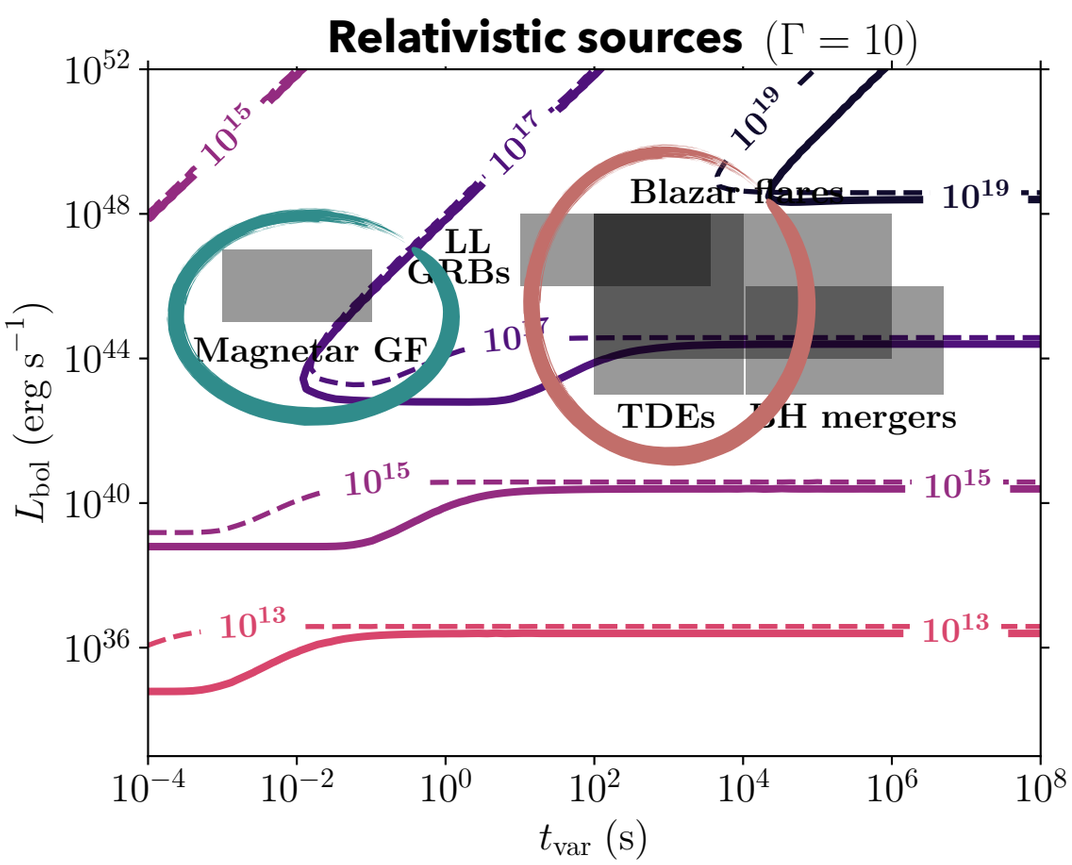
Impact of secondary particle acceleration on $E_{\nu,\max}$ (eV), **Guépin** *(2020)*



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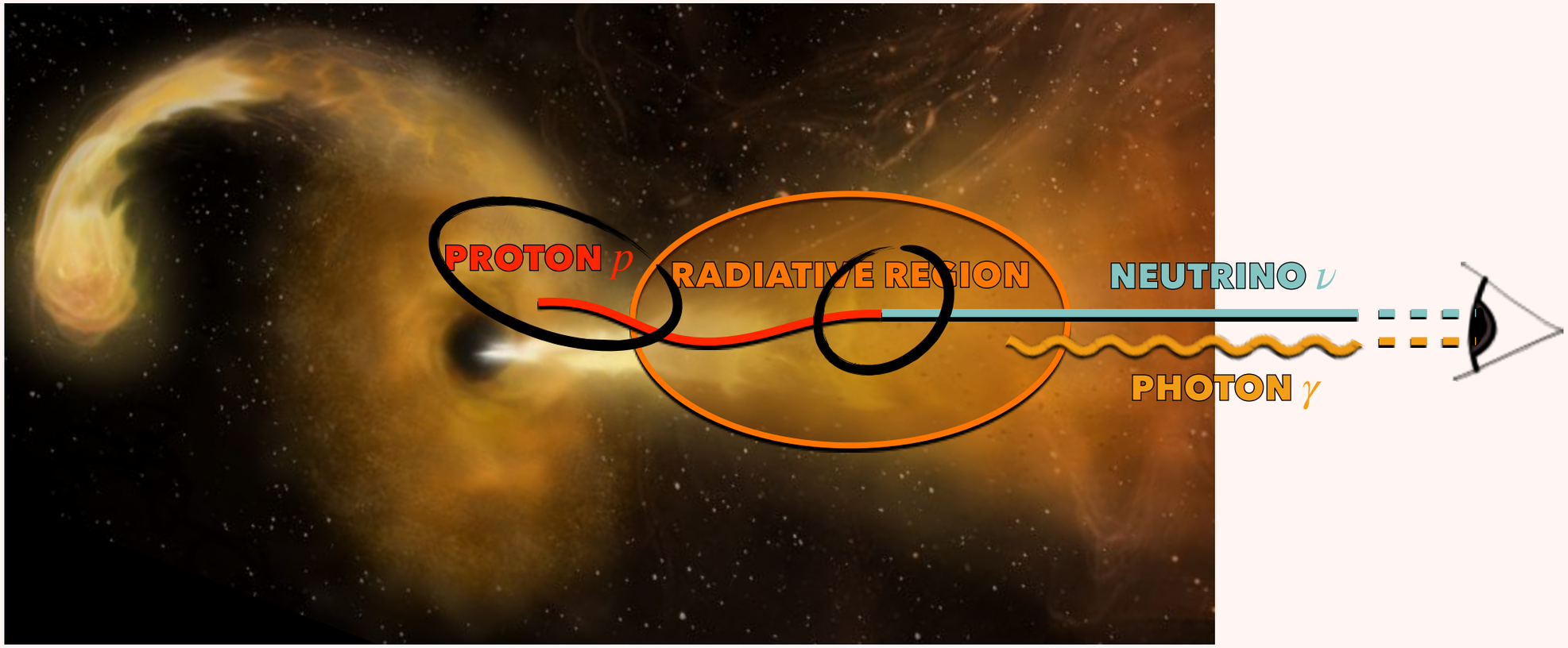

Transient sources	**Micro-physic processes**	**Future UHE observatories**
High-energy emissions? Populations?	Particle acceleration? Interactions?	Coincident observations?

MONTE-CARLO CODE: INTERACTIONS OF ULTRA-HIGH ENERGY COSMIC RAYS

PIC (PARTICLE IN CELL) SIMULATIONS: ACCELERATION OF COSMIC RAYS

Armengaud et al. (2007), Kotera et al. (2009), Alves Batista et al. (2016)

Implement new modules, specific for study of transient sources

+ temporal variations of photon/hadron backgrounds → **Guépin**, *Kotera, Barausse, Fang, Murase (2018)*
+ energy losses of charged pions and muons → **Guépin**, *Kotera, Barausse, Fang, Murase (2018)*
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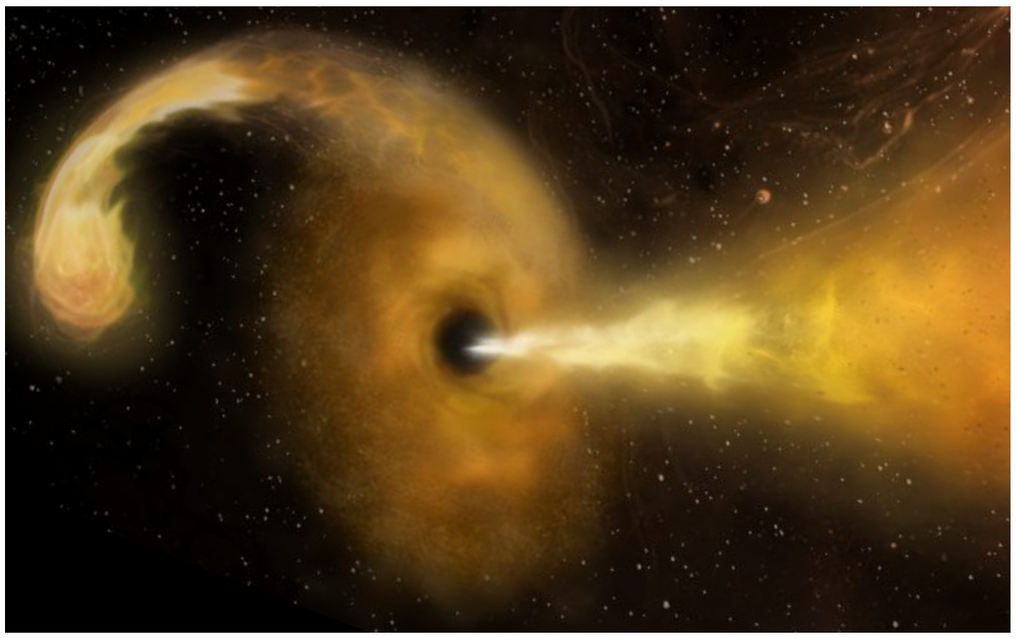
Tidal disruption of a star by a massive black hole



Merger of two neutron stars

Armengaud et al. (2007), Kotera et al. (2009), Alves Batista et al. (2016)

Implement new modules, specific for study of transient sources

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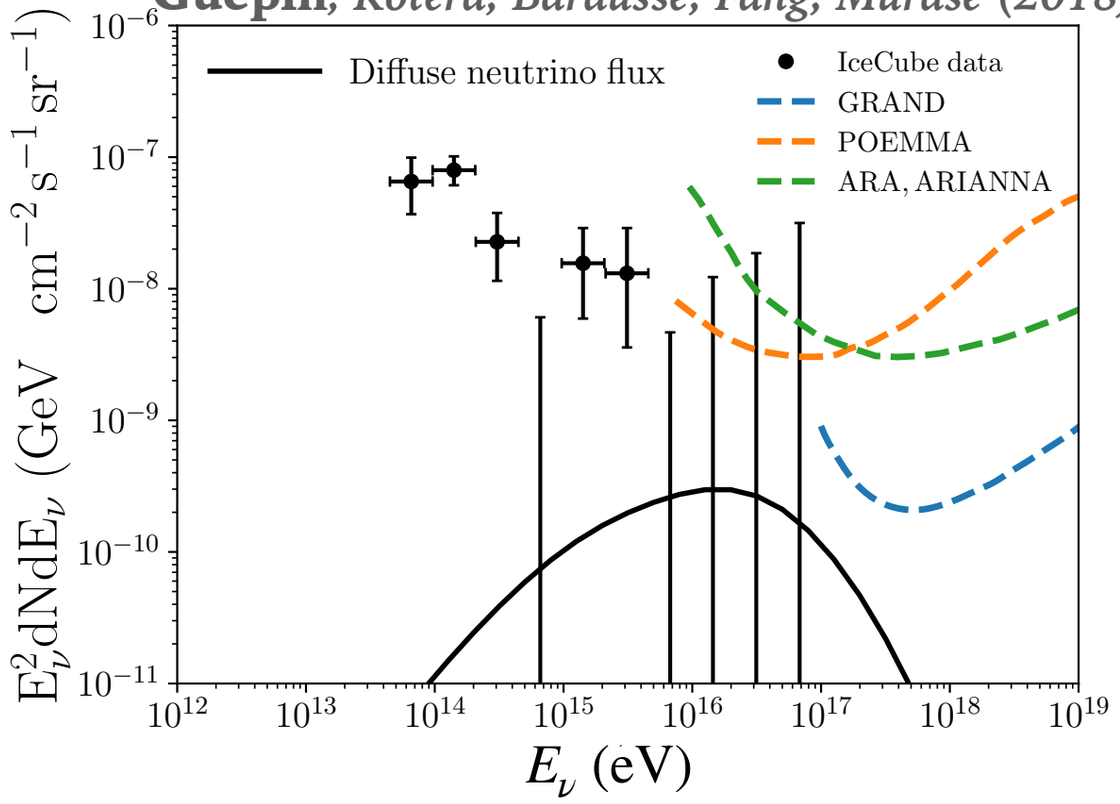
Predict diffuse spectra of high-energy neutrinos

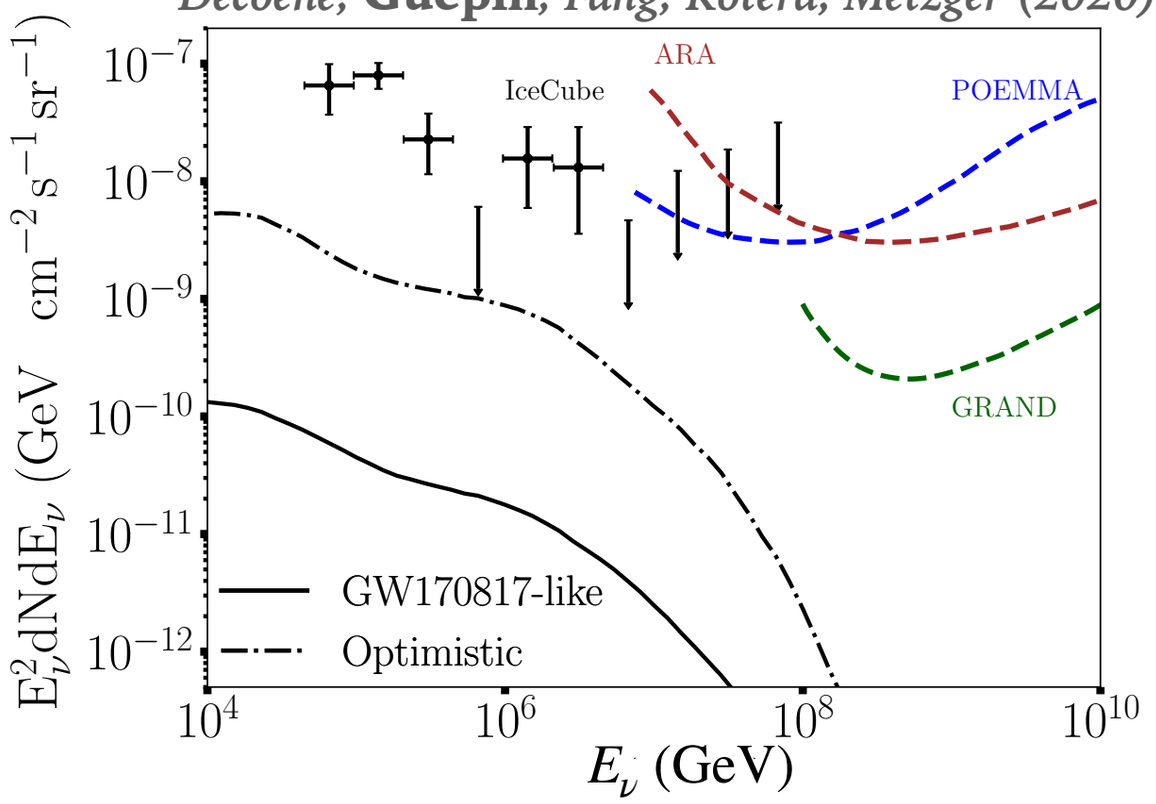
Tidal disruption of a star by a massive black hole

Guépin, *Kotera, Barausse, Fang, Murase (2018)*



Merger of two neutron stars

Decoene, **Guépin**, *Fang, Kotera, Metzger (2020)*

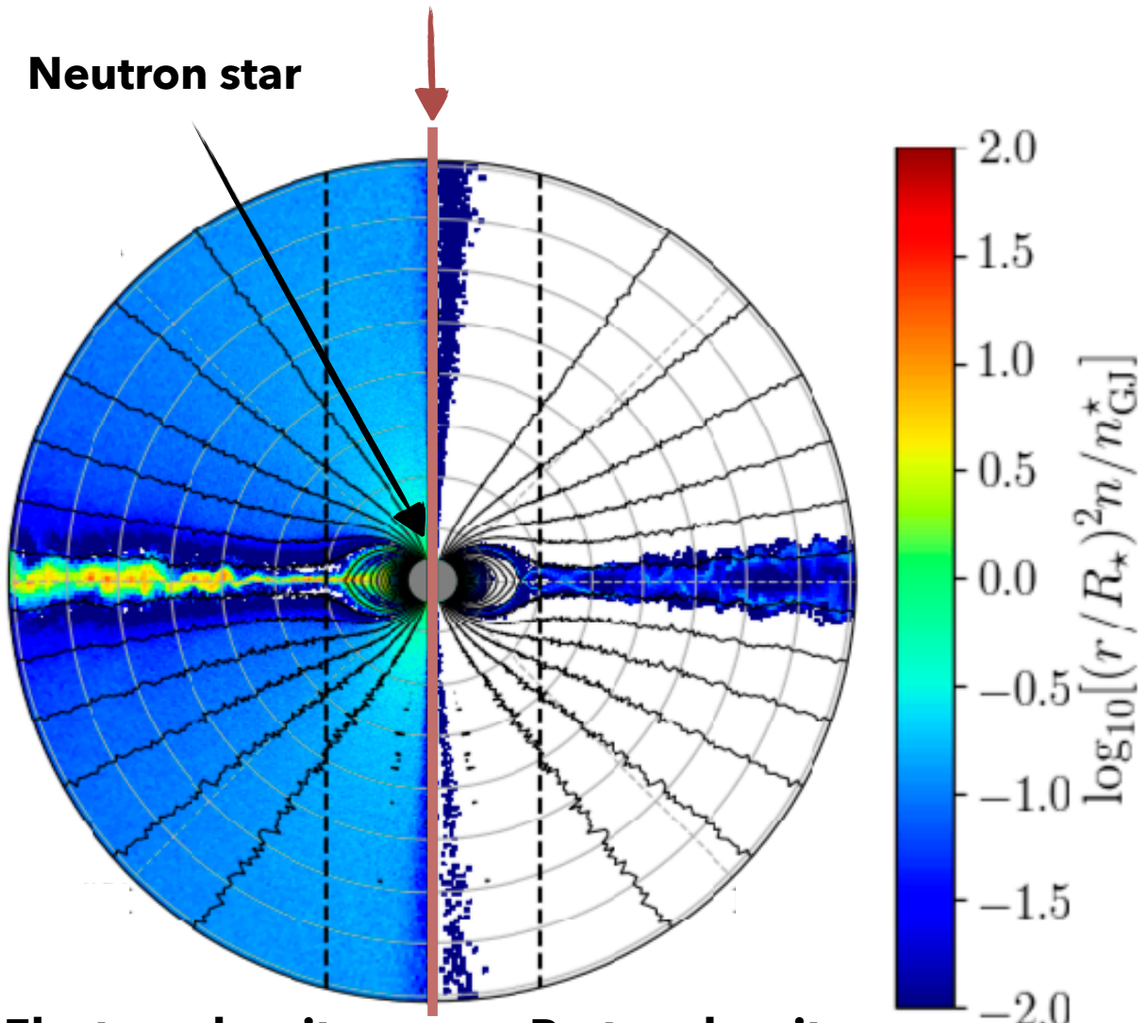


Code: Zeltron, 2D, axi-symmetric, *Cerutti et al. (2013)*

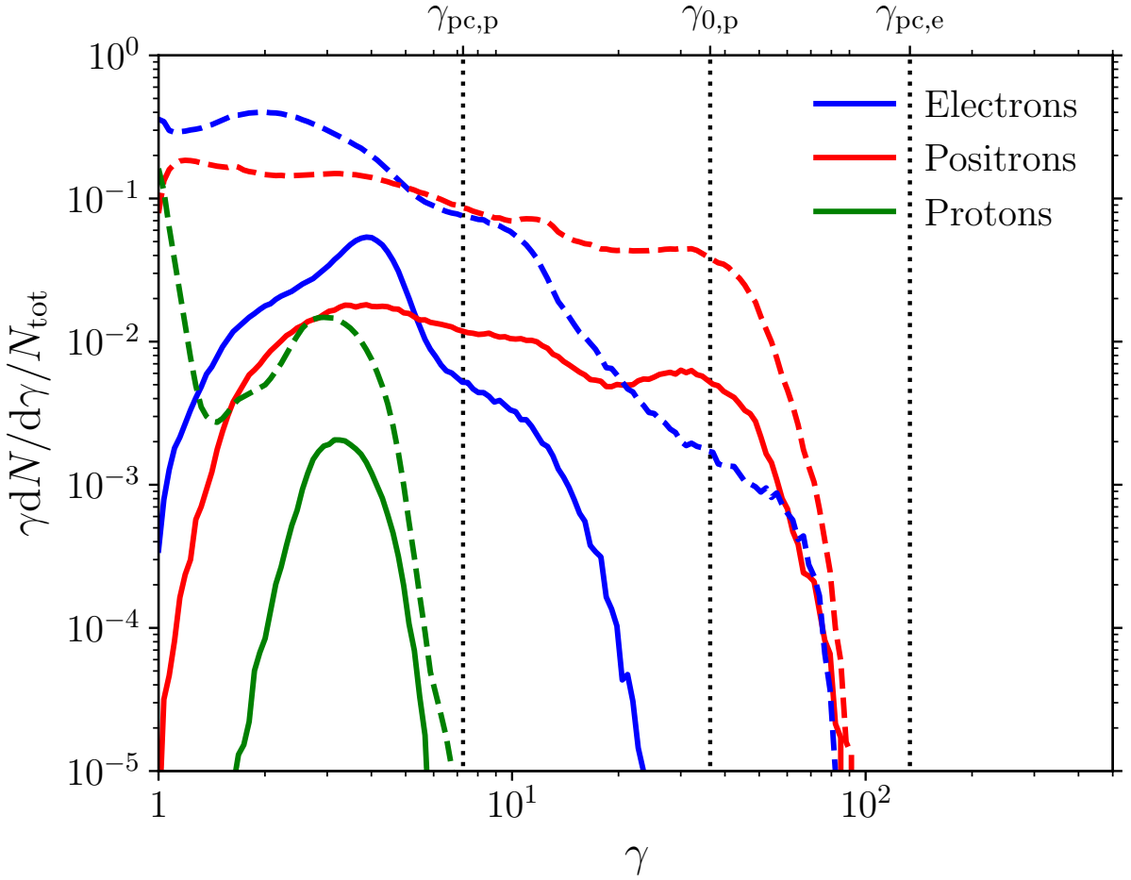
First study of proton acceleration in pulsar magnetospheres

Guépin, *Cerutti, Kotera (2020)*

rotation axis = initial magnetic dipole axis



Simulated spectra: electrons, positrons and protons



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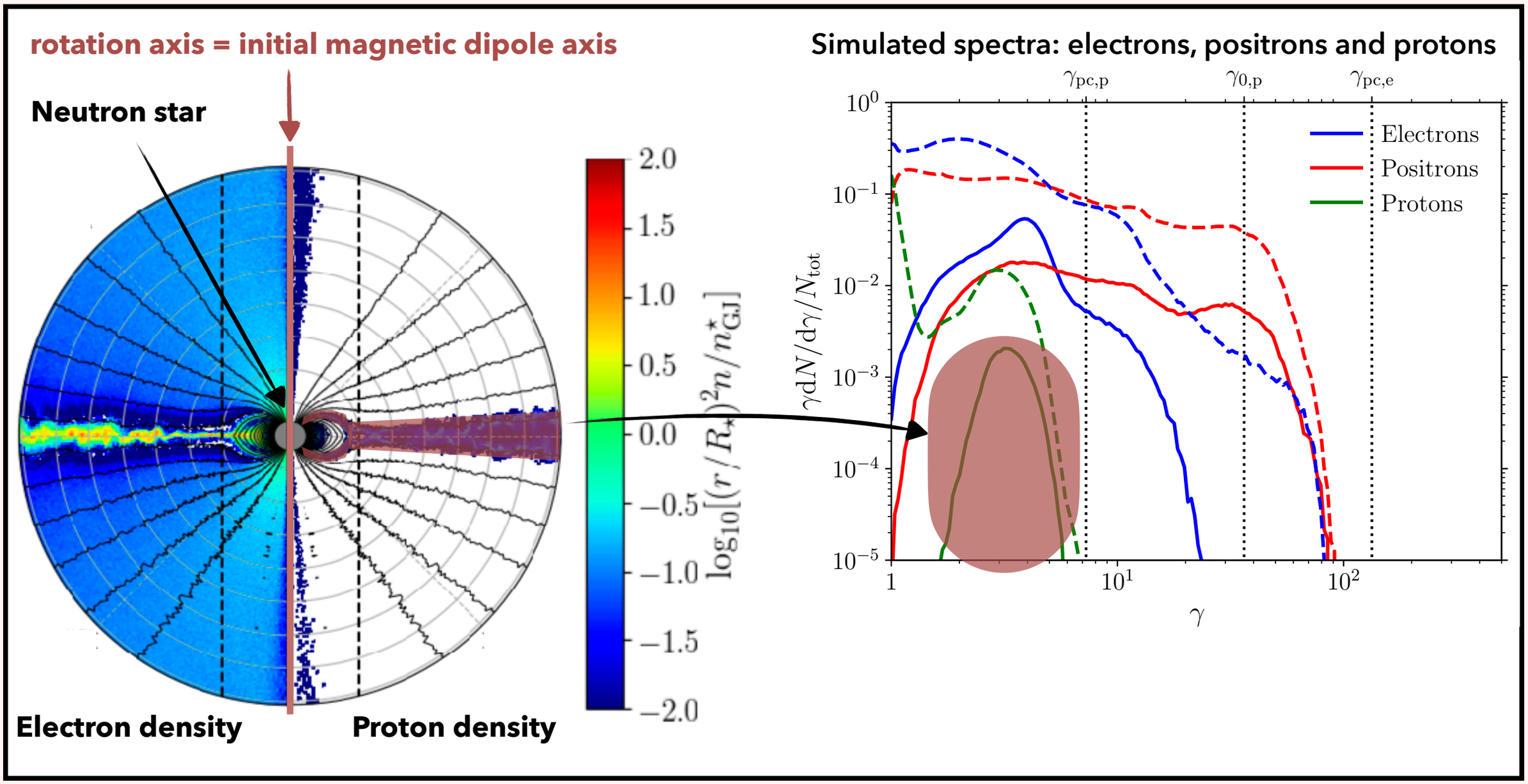

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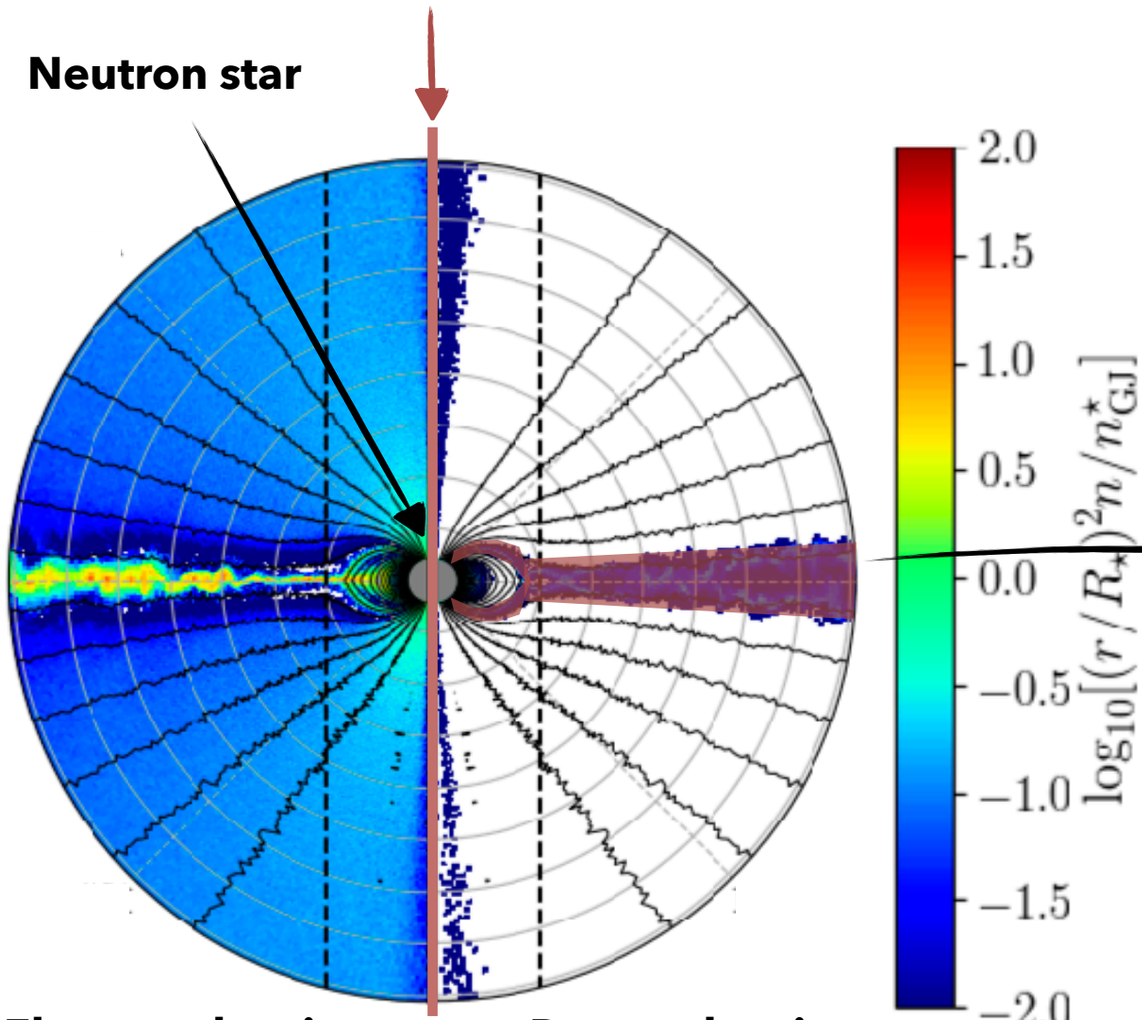

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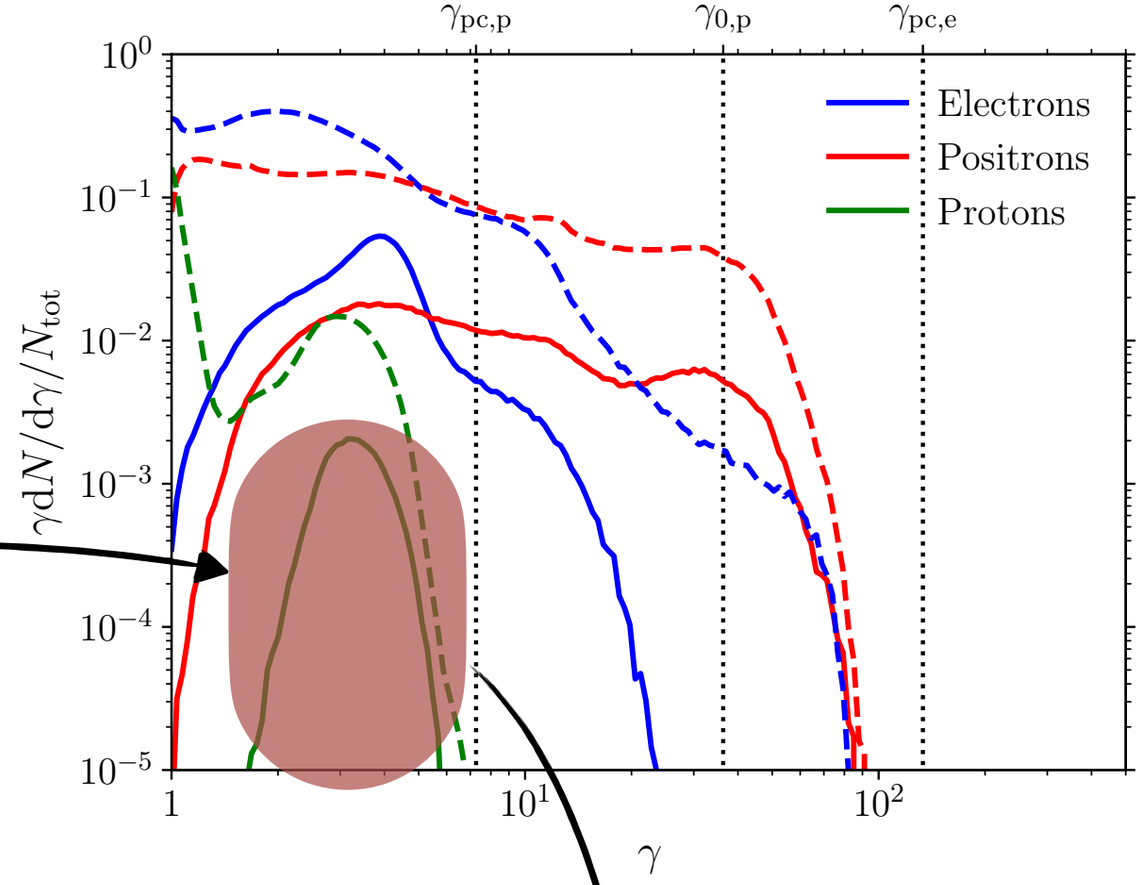

Millisecond pulsars, $E_{\rm p,max}$:

$$E_{\rm p} \simeq 5\times10^{15} - 2\times10^{16}\,{\rm eV}\; B_{\star,9} R^2_{\star,6} P^{-1}_{-3}$$

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Code: Zeltron, 2D, axi-symmetric, *Cerutti et al. (2013)*

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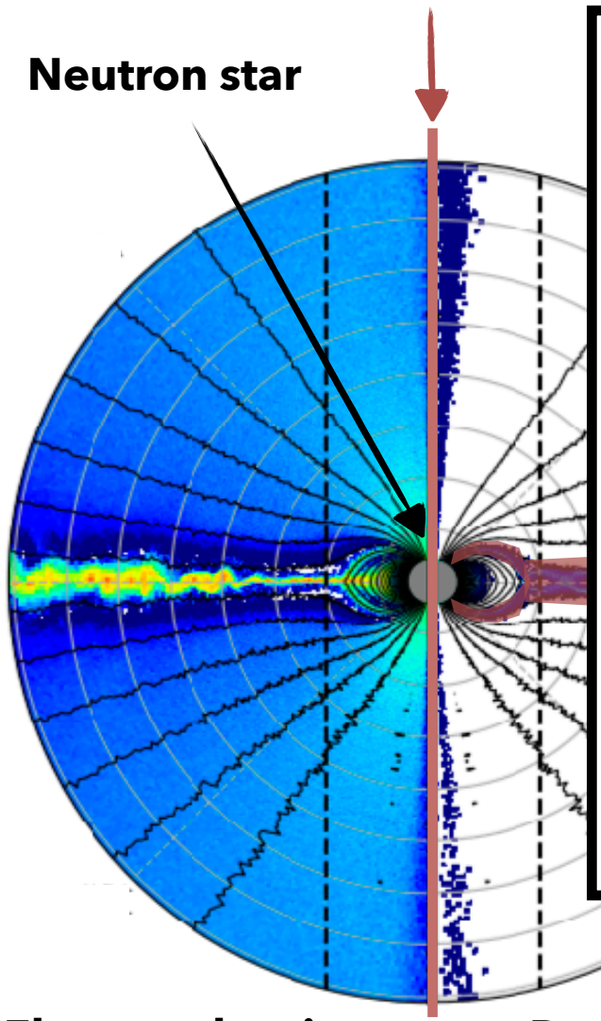
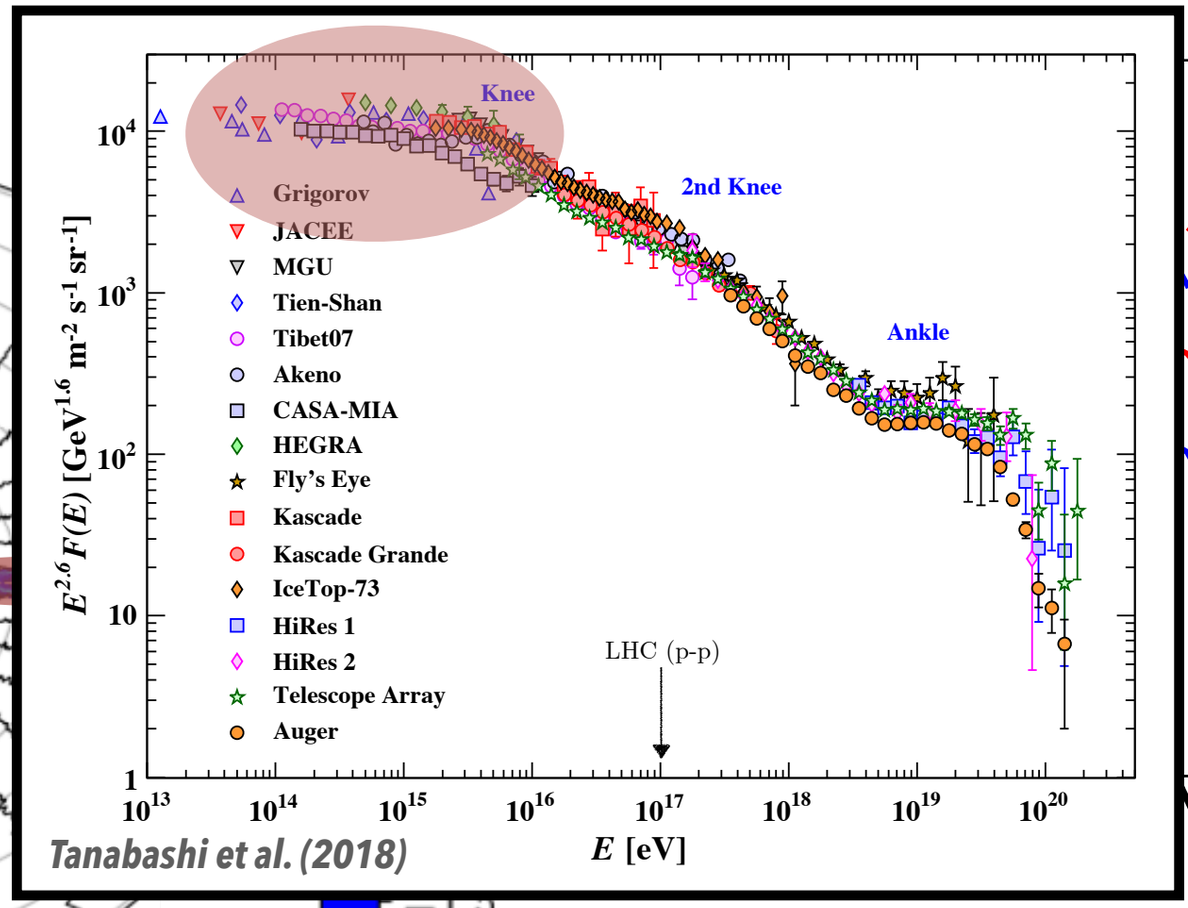
Neutron star



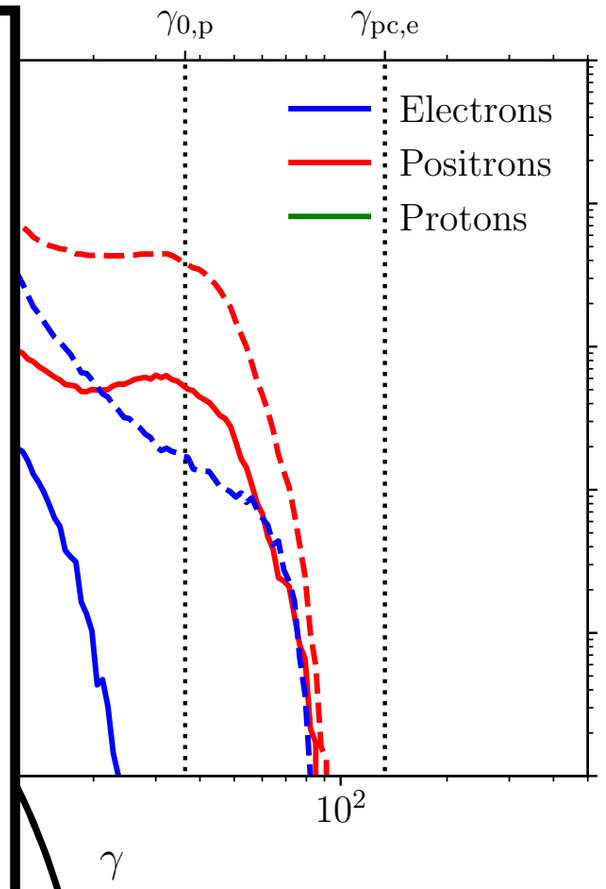
Electron density

Proton density

Simulated spectra: electrons, positrons and protons



Tanabashi et al. (2018)



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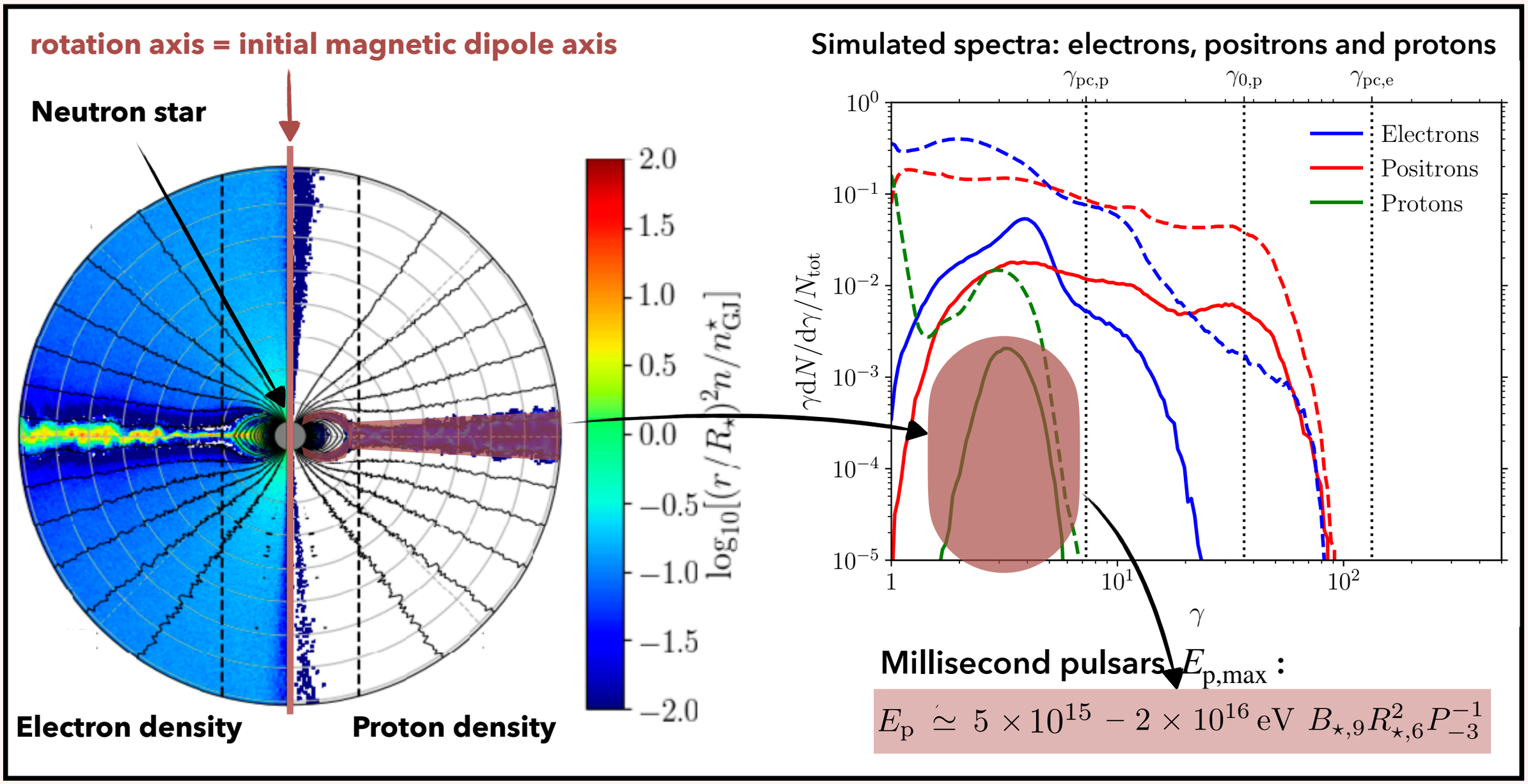

+ Emission of HE photons in Galactic center region, population of millisecond pulsars (analytique)

Guépin, *Rinchiuso, Kotera, Moulin, Pierog, Silk (2018)*

Code: Zeltron, 2D, axi-symmetric, *Cerutti et al. (2013)*

First study of proton acceleration in pulsar magnetospheres

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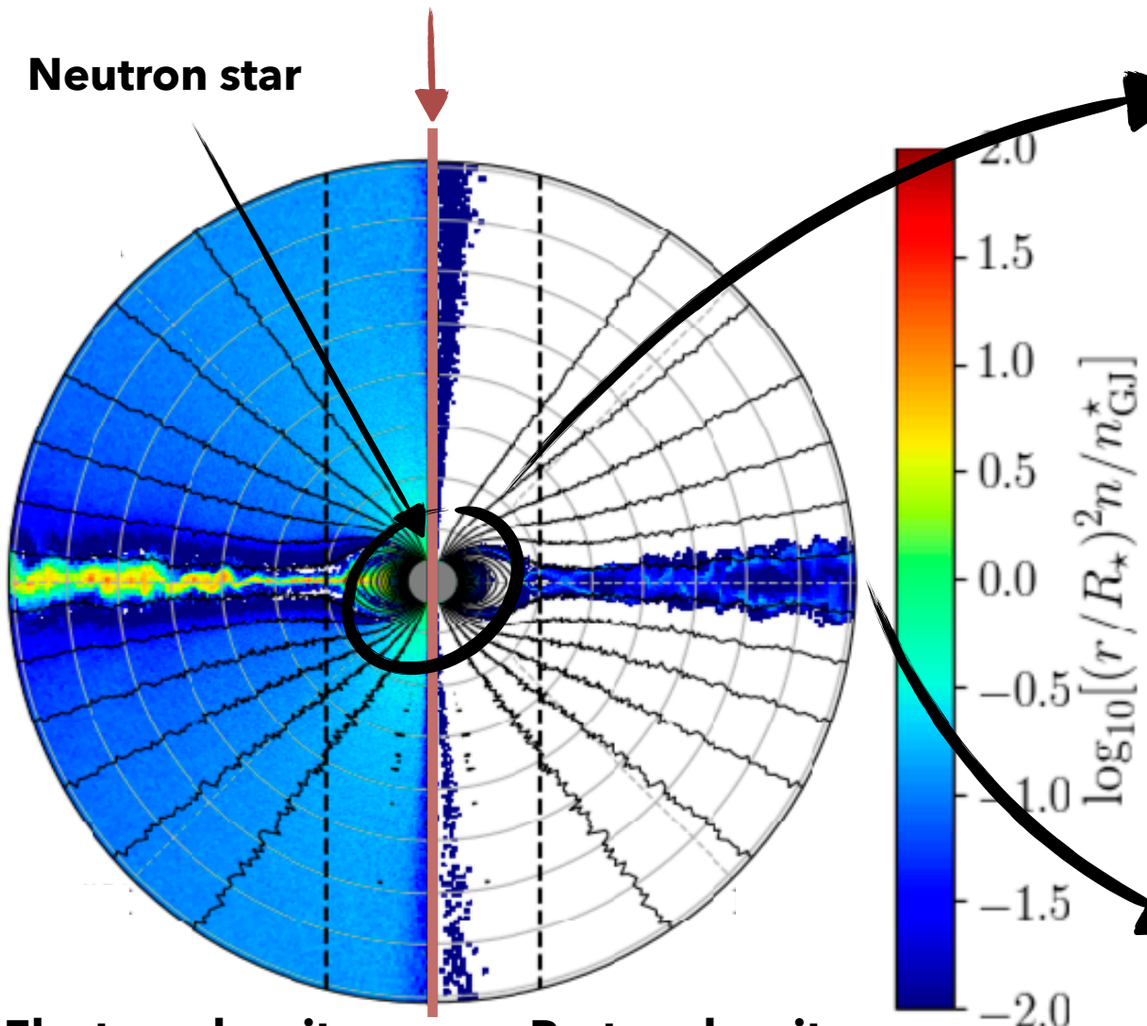
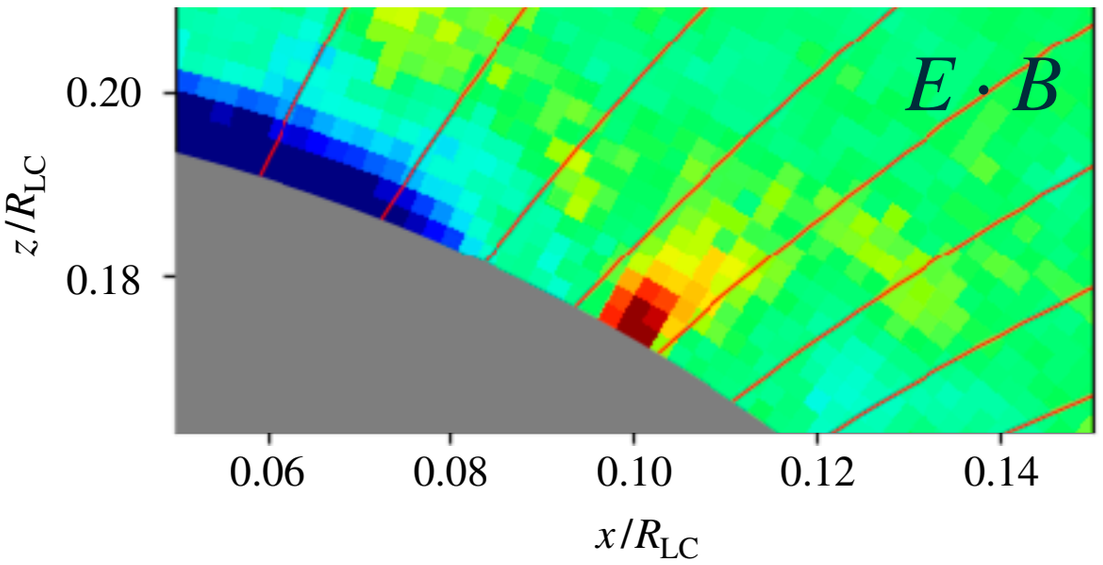


Ongoing work

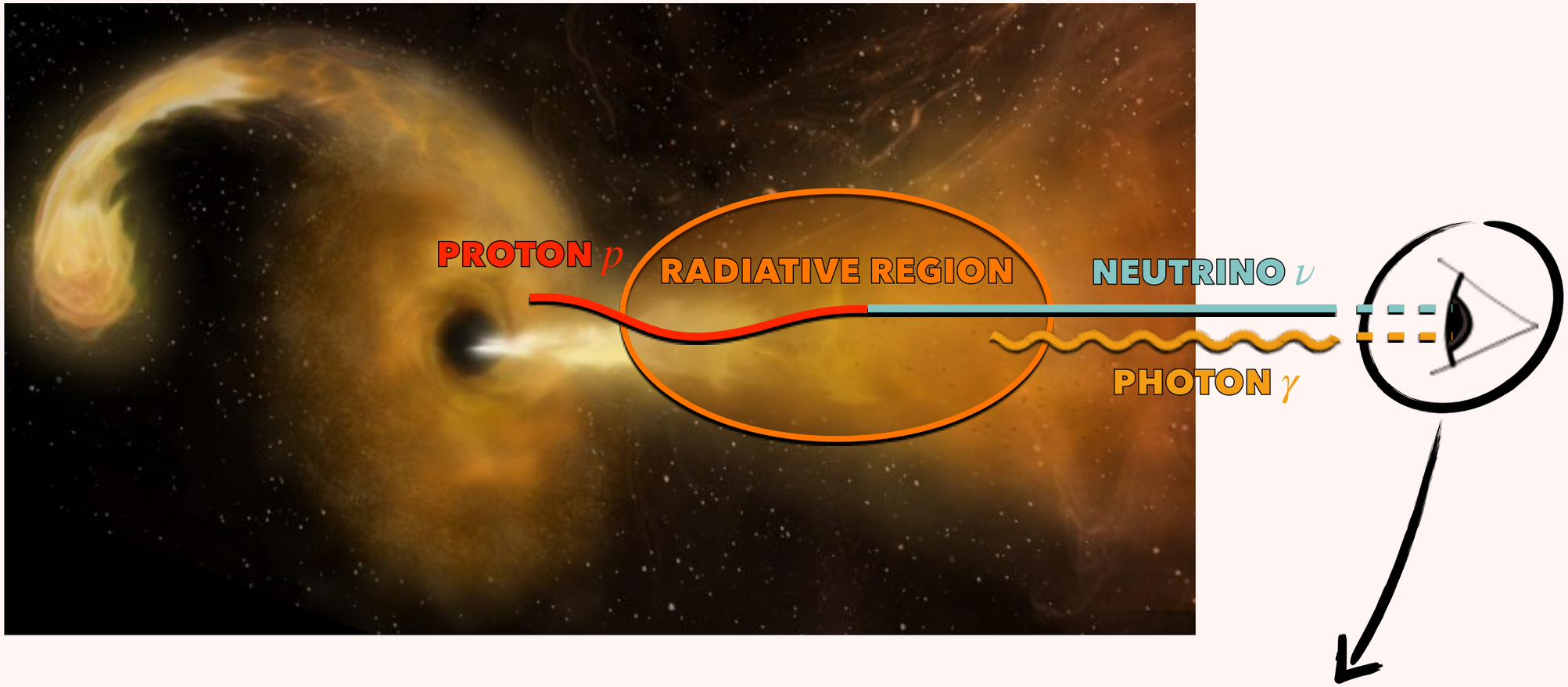
Injection: return current and pair cascades
Large-scale and local PIC simulations
Collaboration : Kalapotharakos, Harding (NASA Goddard)



Propagation in wind and termination shock:
instabilities and gamma-ray halos (ex. Geminga)
Collaboration : Marcowith (LUPM), projet ANR GAMALO

+ Emission of HE photons in Galactic center region, population of millisecond pulsars (analytique)
Guépin, *Rinchiuso, Kotera, Moulin, Pierog, Silk (2018)*

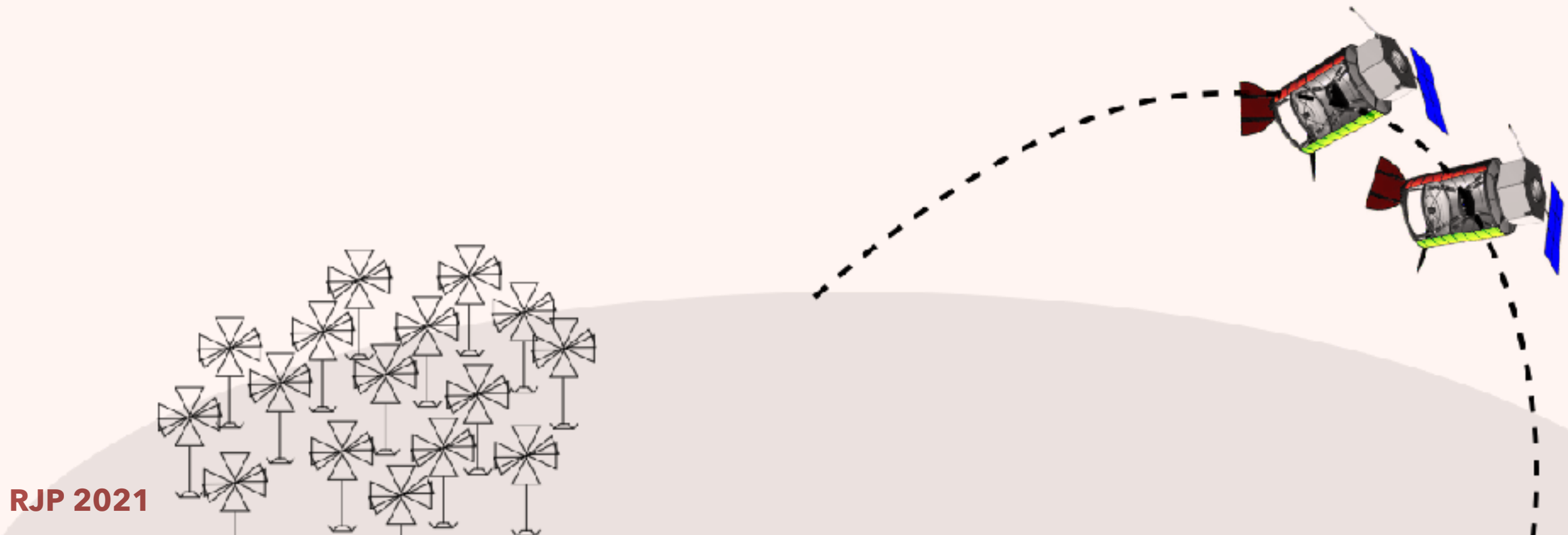
Observable characteristics → general macroscopic model & description of micro-physic processes



Transient sources	**Micro-physic processes**	**Future UHE observatories**
High-energy emissions? Populations?	Particle acceleration? Interactions?	Coincident observations?

Collaboration GRAND incl. **Guépin** *(2019)*

Collaboration POEMMA incl. **Guépin** *(2020)*



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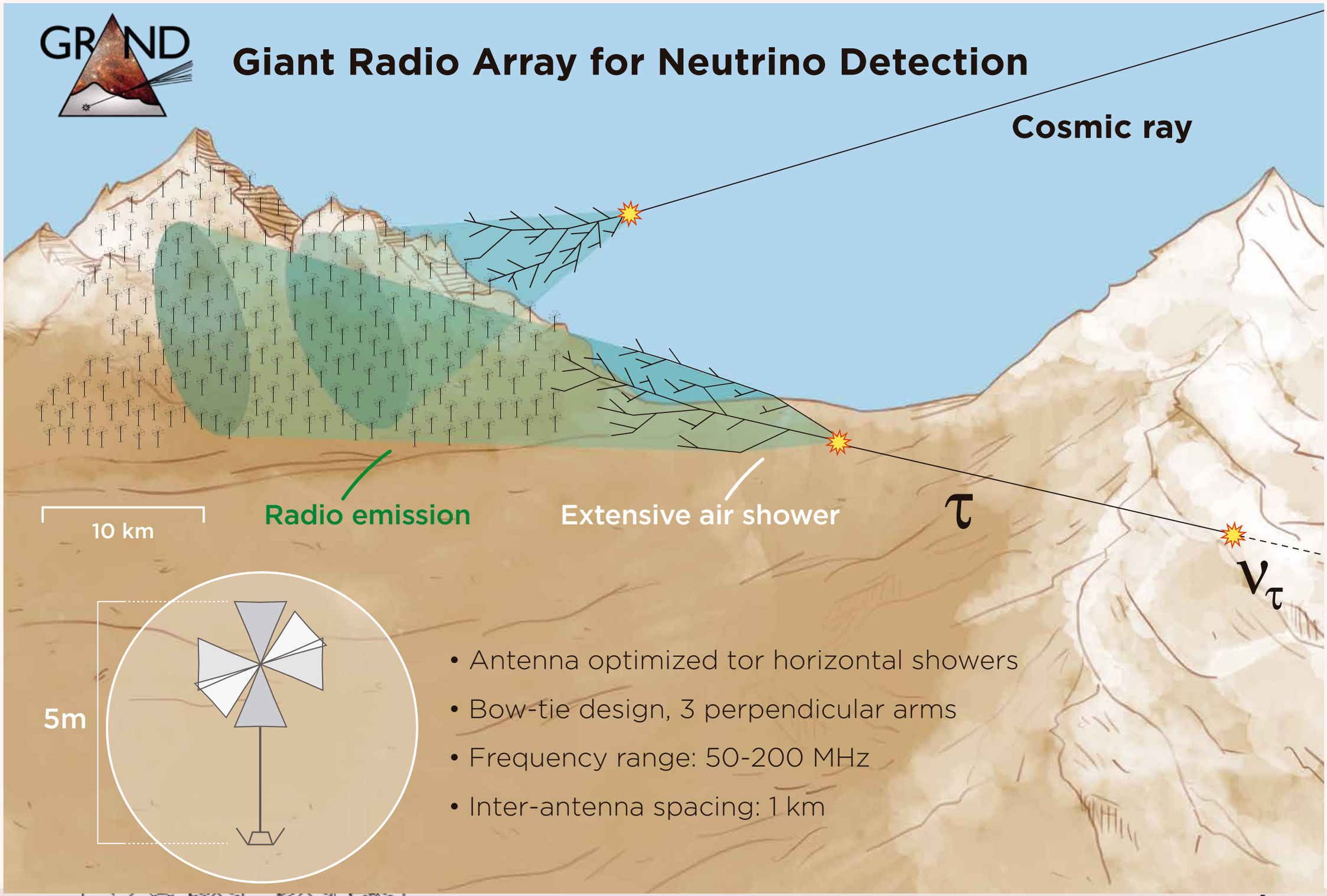
Collaboration GRAND incl. **Guépin** *(2019)*

Collaboration POEMMA incl. **Guépin** *(2020)*



Collaboration GRAND incl. **Guépin** *(2019)*

Simulations ZHAireS

- **Reconstruction nature cosmic ray (proton, iron)**

Least mean square algorithm
Zilles, Tueros

- **Machine learning for reconstruction**

Machine learning group, graph convolutional networks
de Errico, Torres de Mello Neto, Koirala, Tueros, Martineau…

Collaboration POEMMA incl. **Guépin** *(2020)*

- **Sky coverage, observation strategy**

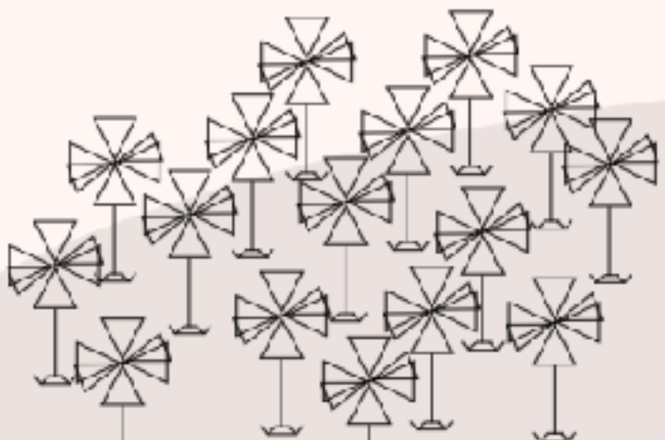
Guépin, *Sarazin, Krizmanic, Loerincs, Olinto, Piccone (2019)*

- **Observation of transient sources**

Venters, Reno, Krizmanic, Anchordoqui, **Guépin**, *Olinto (2020)*

- **Dark matter detection**

Guépin, *Aloisio, Anchordoqui, et al. in prep.*



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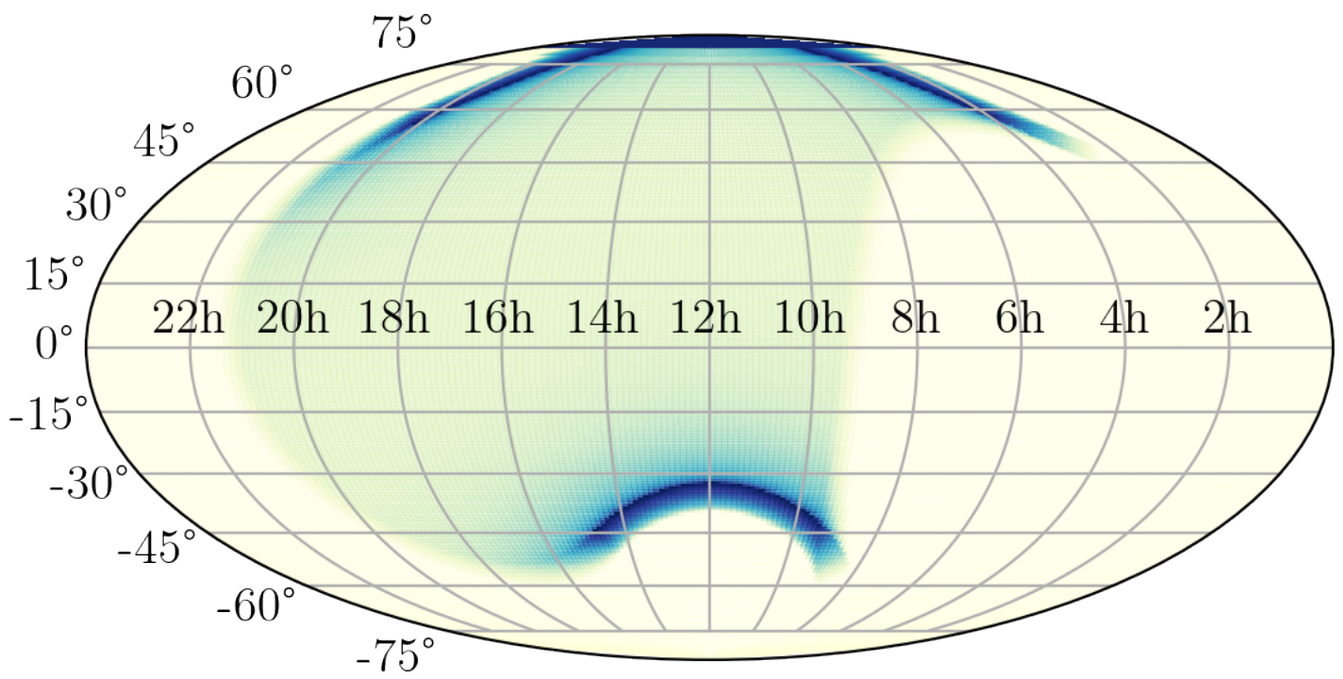
POEMMA, sky coverage, Observation of transient sources



CG, *Sarazin, Krizmanic, Loerincs, Olinto, Piccone (2019)*

Unprecedented information about the high-energy universe

Sources of high-energy cosmic rays and neutrinos?

Transient sources	**Micro-physic processes**	**Future UHE observatories**
High-energy emissions? Populations?	Particle acceleration? Interactions?	Coincident observations?
models for transient sources and compact sources radiation backgrounds, magnetic fields, temporal variability, populations	**model propagation, acceleration, interaction of cosmic rays** analytic, Monte-Carlo code and Particle-In-Cell simulations	**ground observation (radio)** reconstruction cosmic-ray properties **space observation (optical)** sky coverage, observation strategies, e.g. for transient sources

Unprecedented information about the high-energy universe

Sources of high-energy cosmic rays and neutrinos?

Theory | Numeric | Experimental

Transient sources
High-energy emissions? Populations?

Micro-physic processes
Particle acceleration? Interactions?

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models for transient sources and compact sources
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ground observation (radio)
reconstruction cosmic-ray properties

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Perspectives

Self-consistent and time-dependent models for radiation backgrounds

Marry micro-physic scales and macroscopic source models

New observations: treatment and observation strategies

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