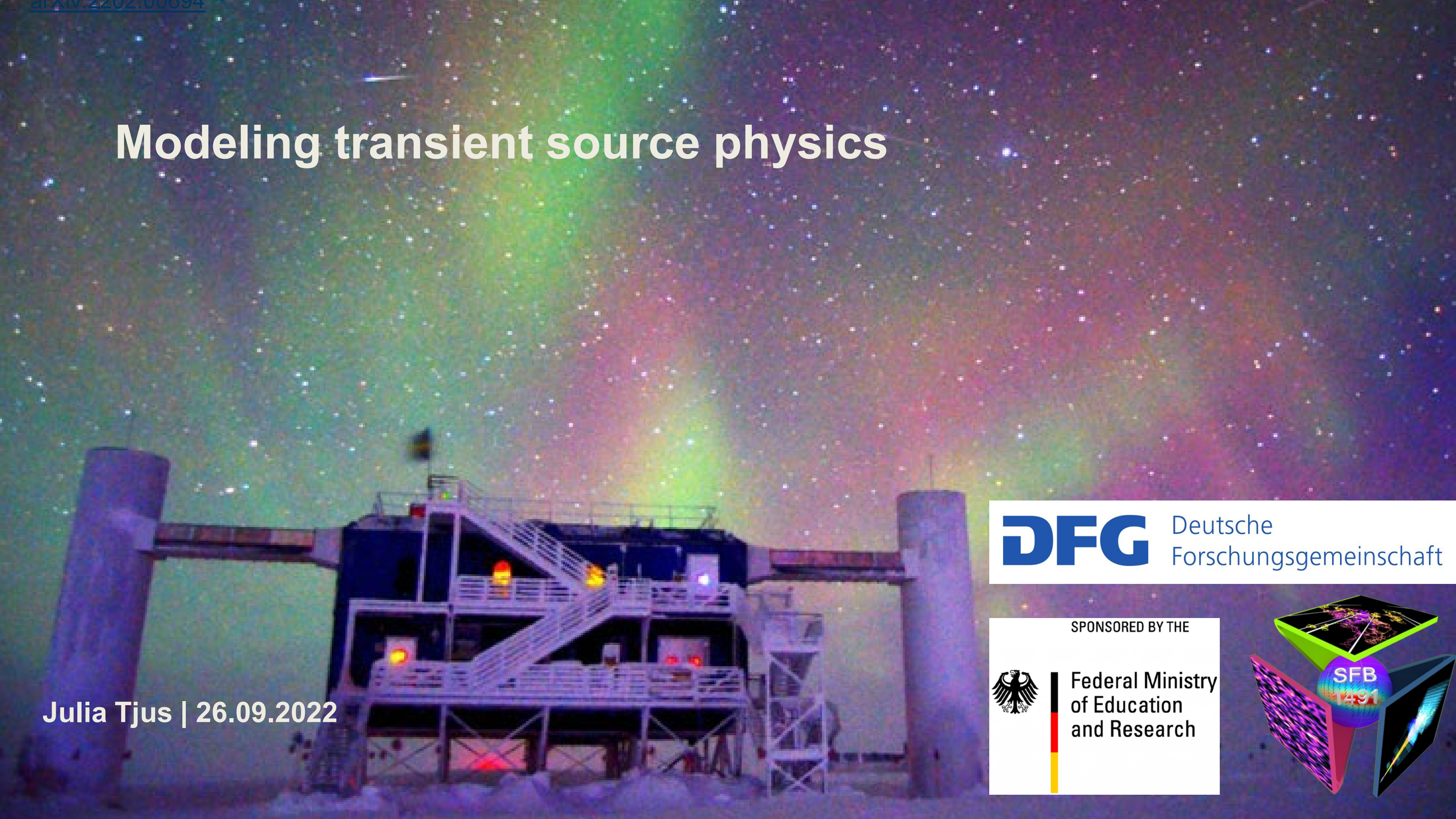
arXiv:2202.00694

Modeling transient source physics



Julia Tjus | 26.09.2022

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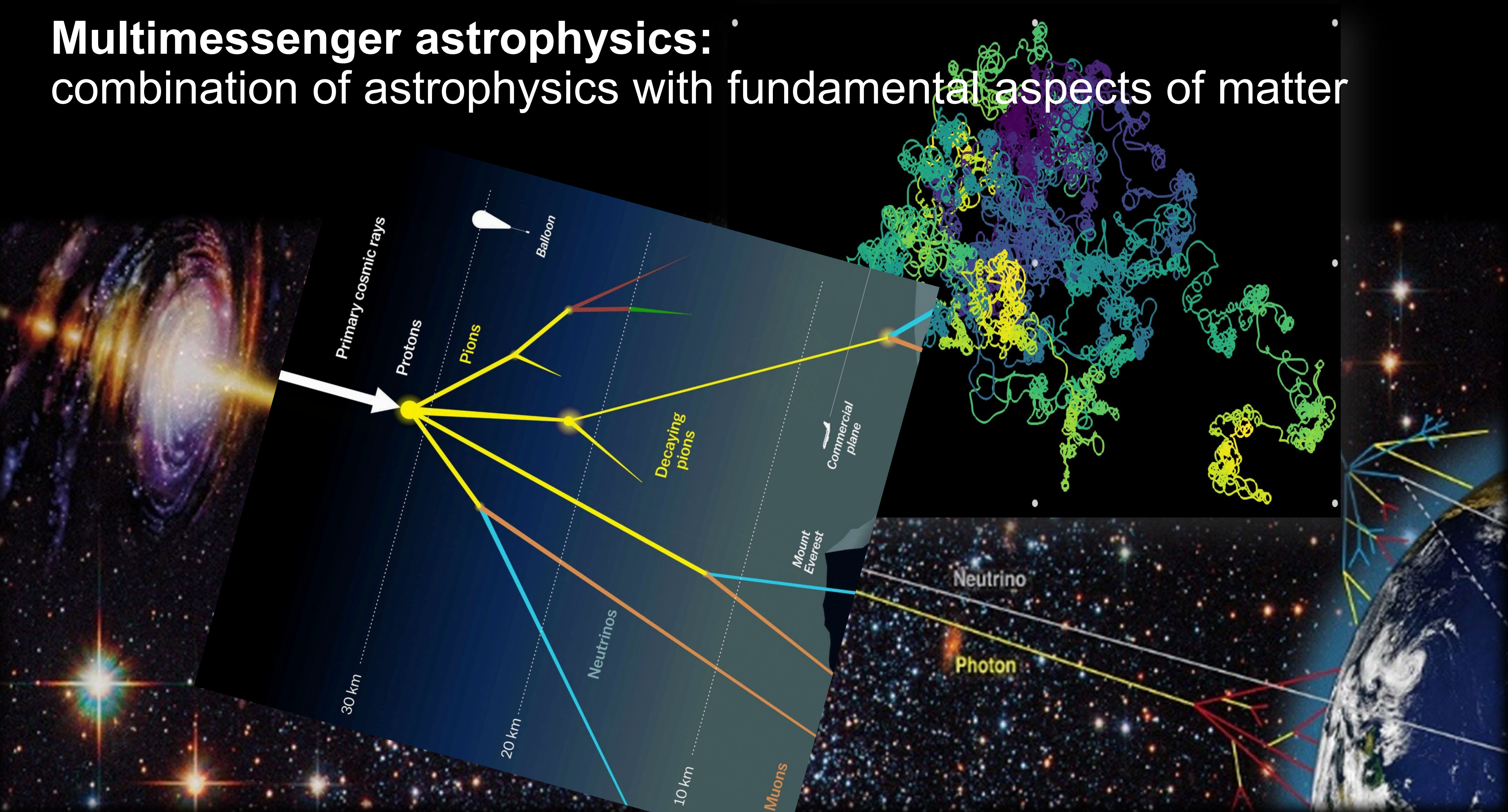
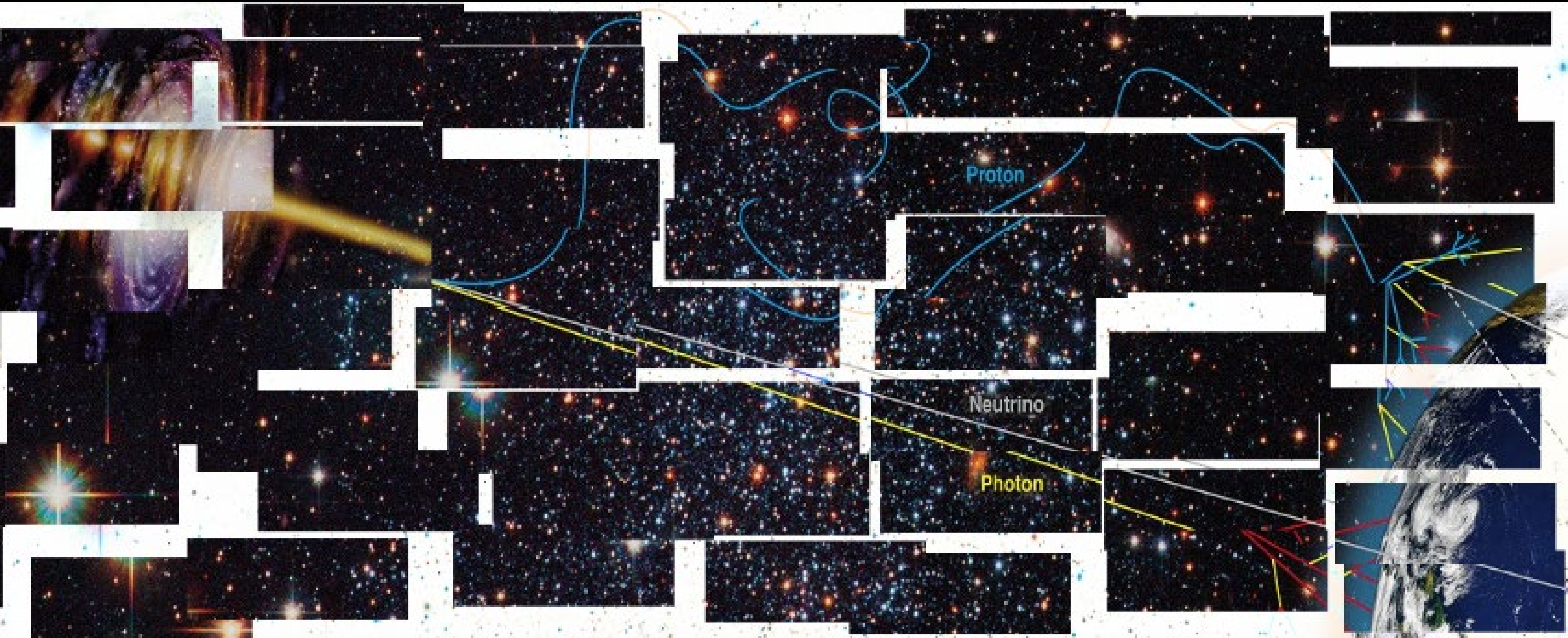
Multimessenger astrophysics:

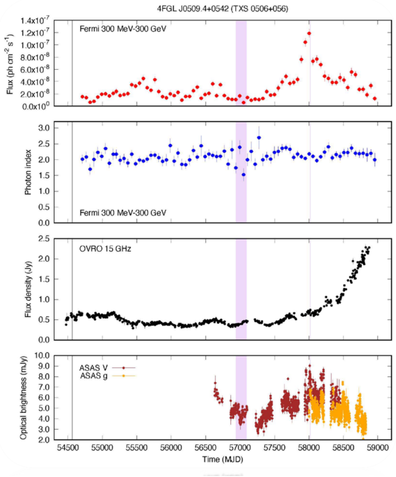
combination of astrophysics with fundamental aspects of matter



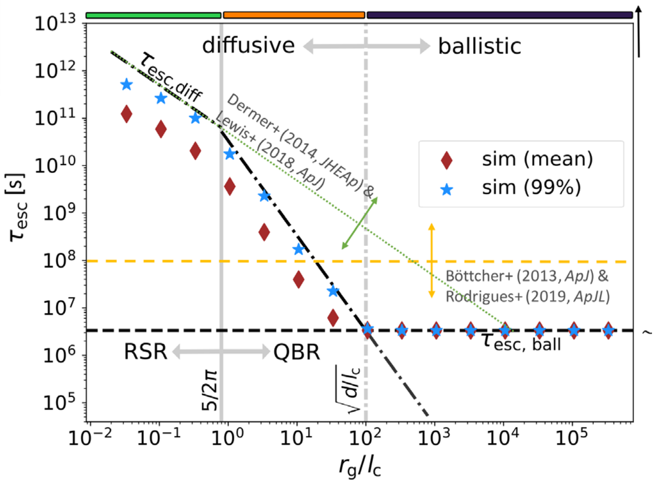
Multimessenger astrophysics:
a puzzle from low to high-energy and including γ, ν, and GWs



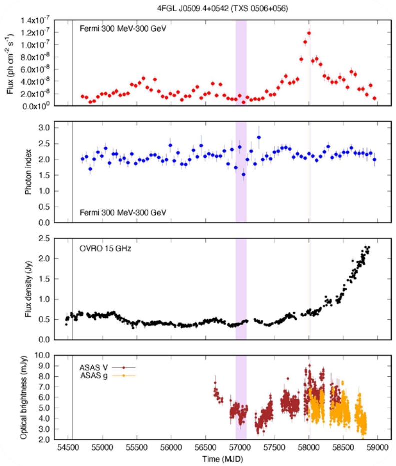
Talk today



- Multimessenger Astronomy: connecting γ- and ν-emission
- Multimessenger modeling: Theoretical concepts
- Outlook



Talk today



- Multimessenger Astronomy: connecting γ- and ν-emission

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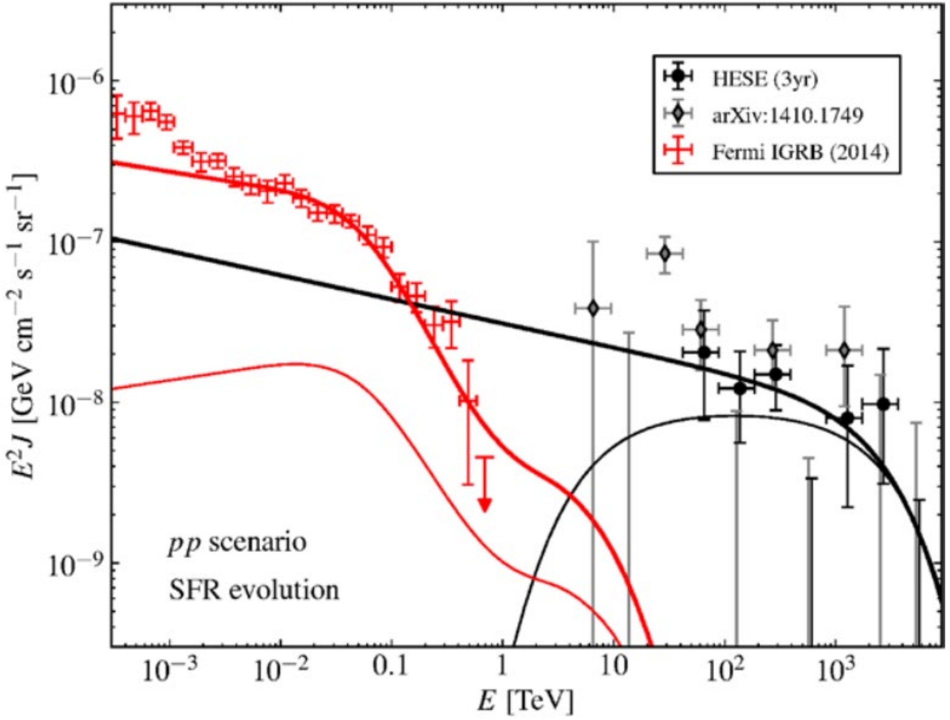
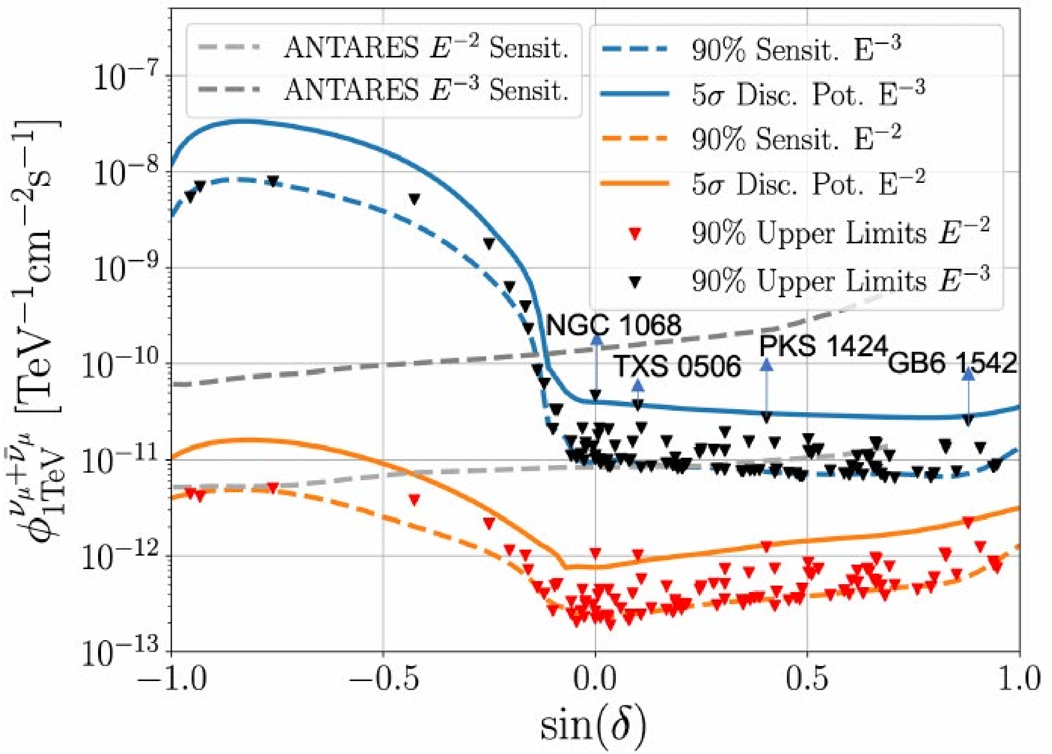
Multimessenger astrophysics: Co-production of gamma-rays and neutrinos, but…

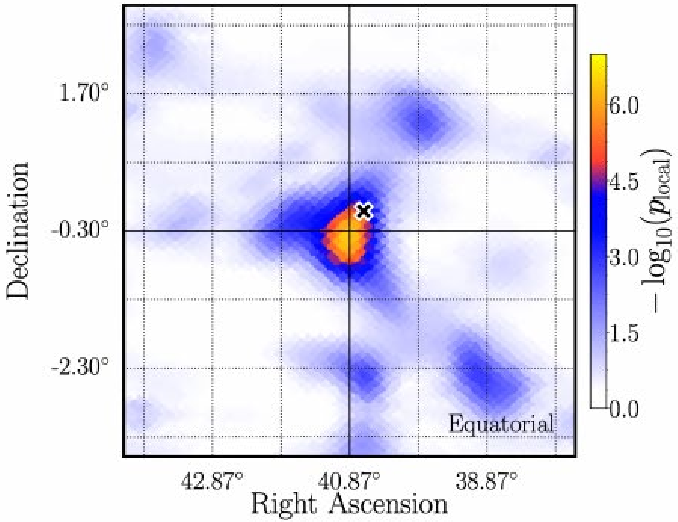
- Gamma-ray measurements as upper limits to neutrino production
- Spectra steeper than $E^{-2.2}$ quickly overproduce gamma-ray measurements (Fermi) when only considering intergalactic γ–γ
- Intrinsic γ–γ or γ-gas component needed?



Ahlers & Halzen, Rep. Prog. Phys. 78:126901 (2015)

10 years of point source searches in IceCube
First pieces of evidence for sources

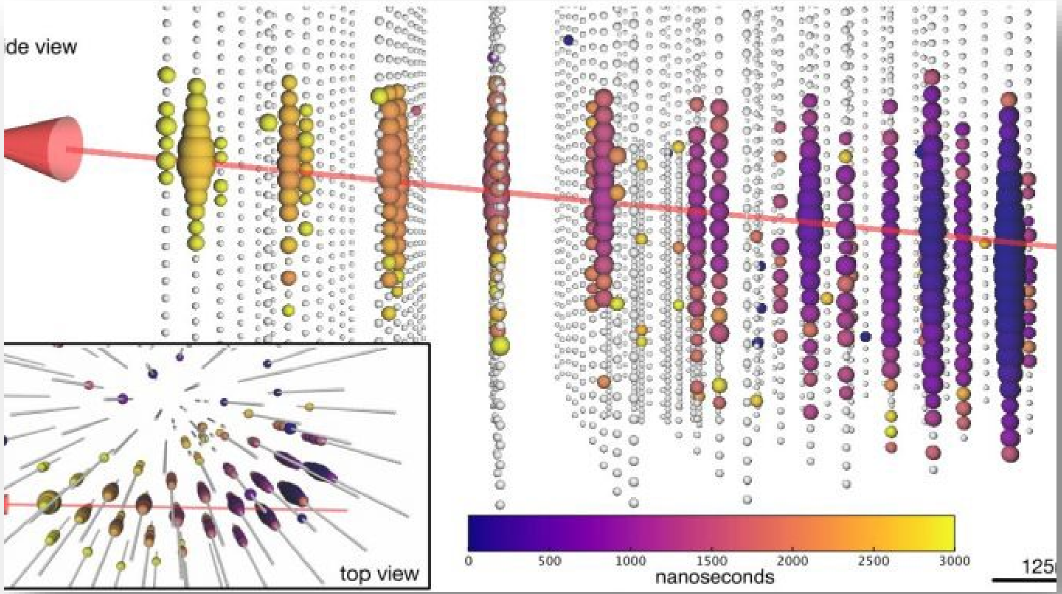


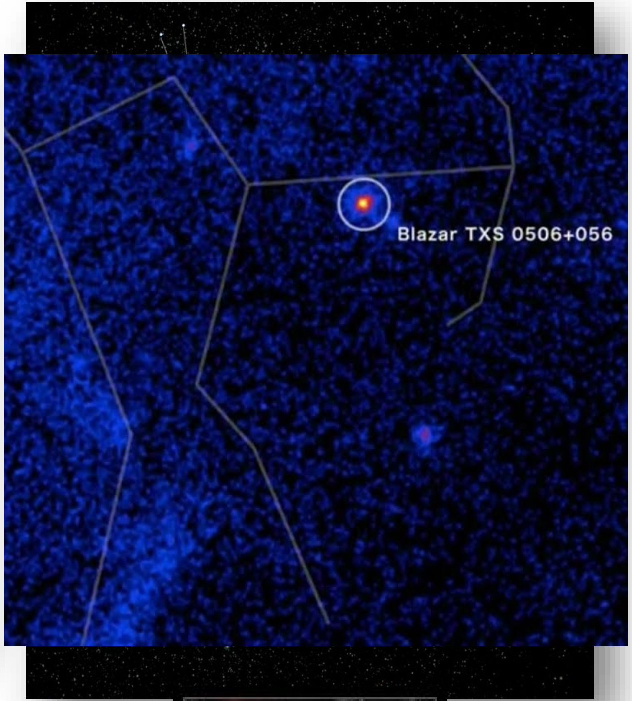


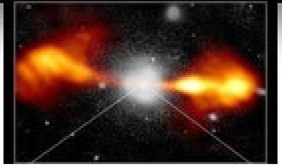
NGC1068 – evidence at 2.9σ level

Aartsen et al (IceCube Coll) Phys. Rev. Lett. 124, 051103 (2020)

A first possible neutrino source: TXS0506+056



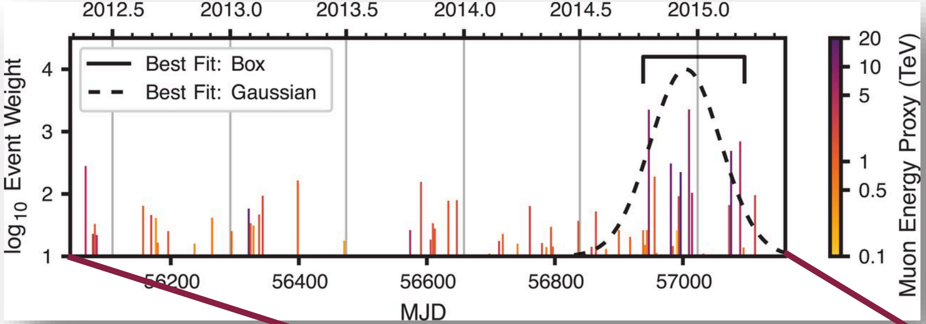




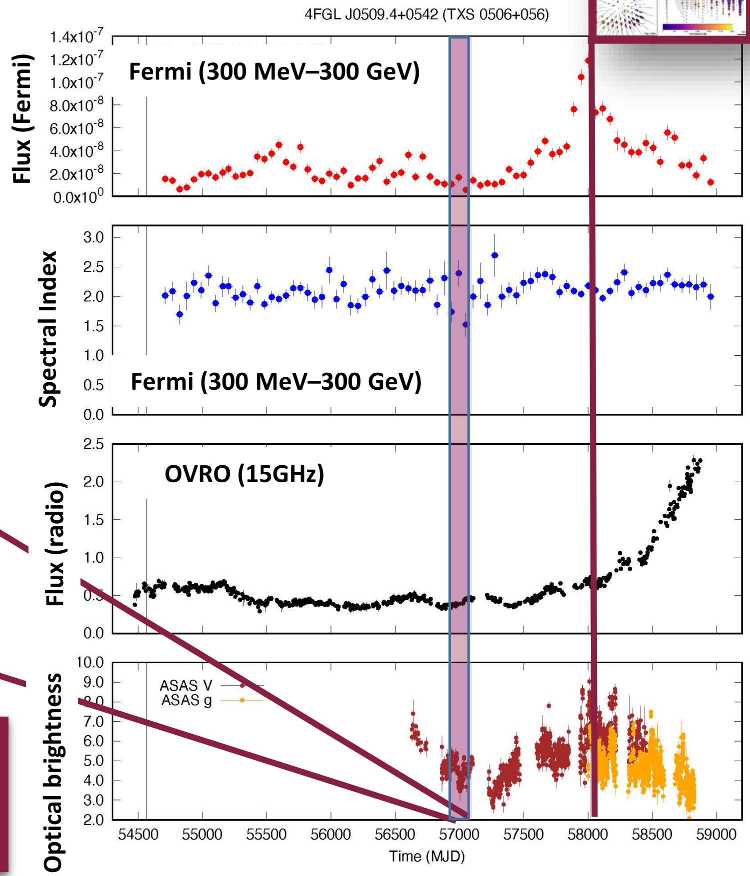
Aartsen et al (IceCube/Fermi/MAGIC Coll), Science (2018)

Multimessenger emission with TXS0506+056

Neutrino excess @ ~3σ in 2014/2015



Aartsen et al (IceCube Coll), Science (2018)



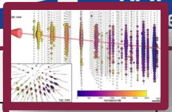


Fig: Emma Kun, Budapest

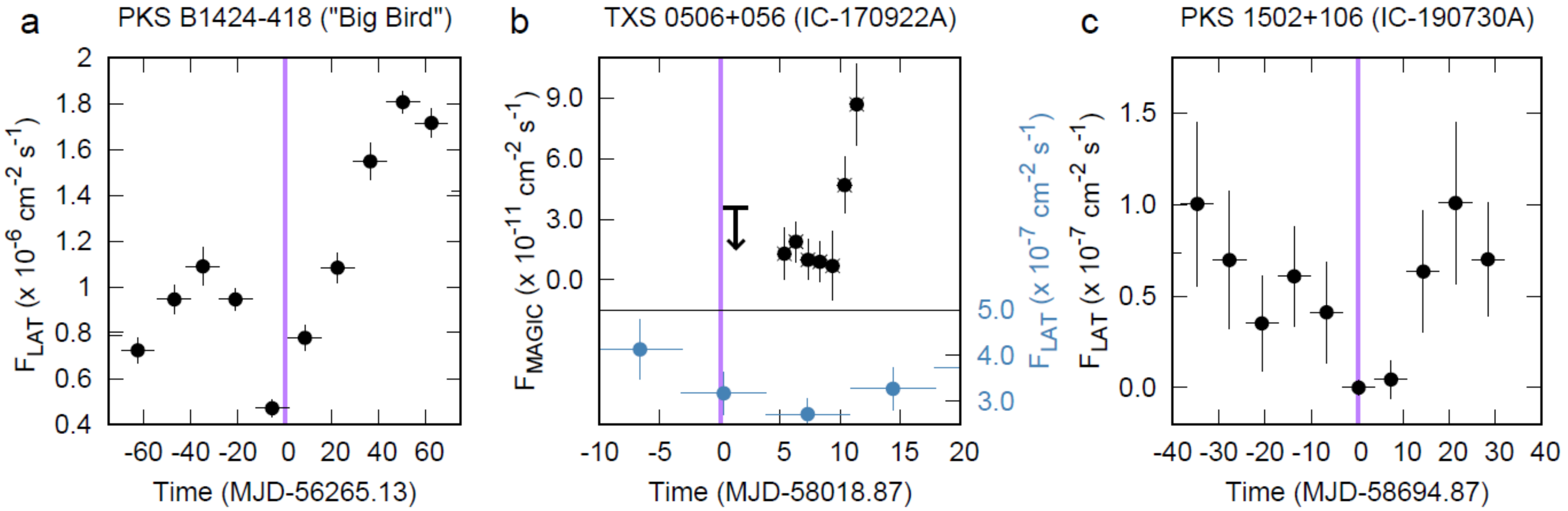
- ➔ Two potential neutrino flares of very different nature:
  - ➔ 2014/2015: ~100 days long, ~10TeV in energy, no MM activity
  - ➔ 2018: 1 neutrino with ~300TeV energy, coincident γ-ray flare

A new event from the direction of TXS

- Uncertainty ~3.5° (corner clipper)
- Energy ~160TeV
- Signalness 42%
- Almost exactly 5 years after the bright 290TeV event (IC170922A)

https://astro-colibri.com

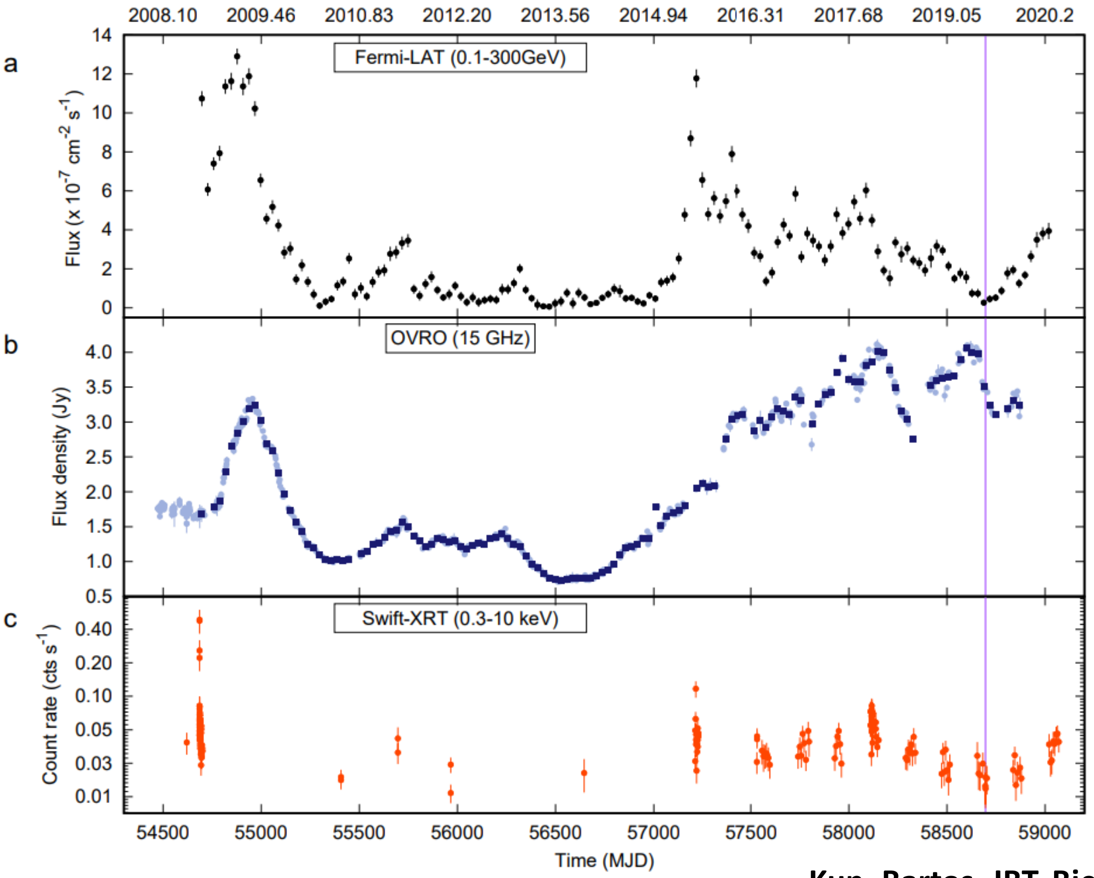
Time-domain of AGN



Kun, Bartos, JBT, Biermann, Halzen, Mez´´o ApJL (2021)

Neutrinos arrive in γ-minima? Possible if gas density extreme: photon absorption

PKS1502+106



Kun, Bartos, JBT, Biermann, Halzen, Mező, ApJL (2021)

Talk today

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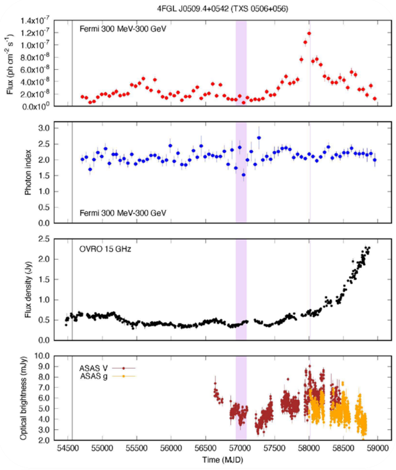
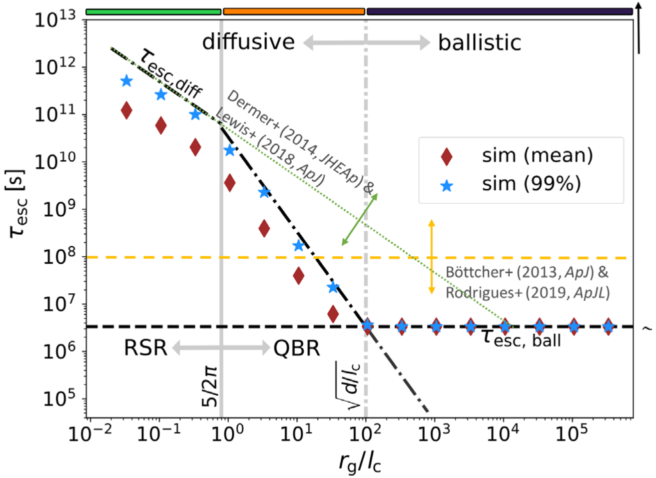
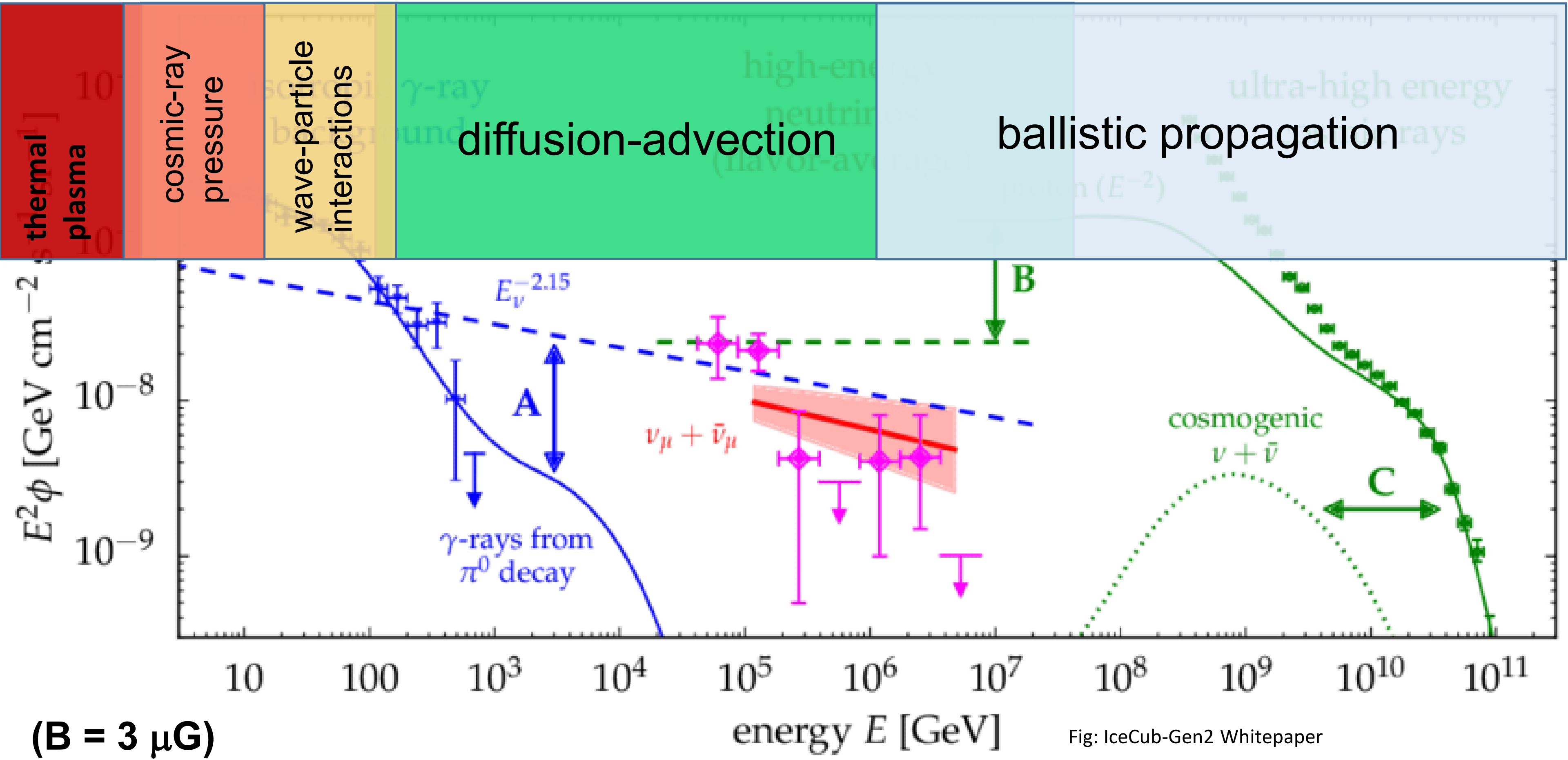




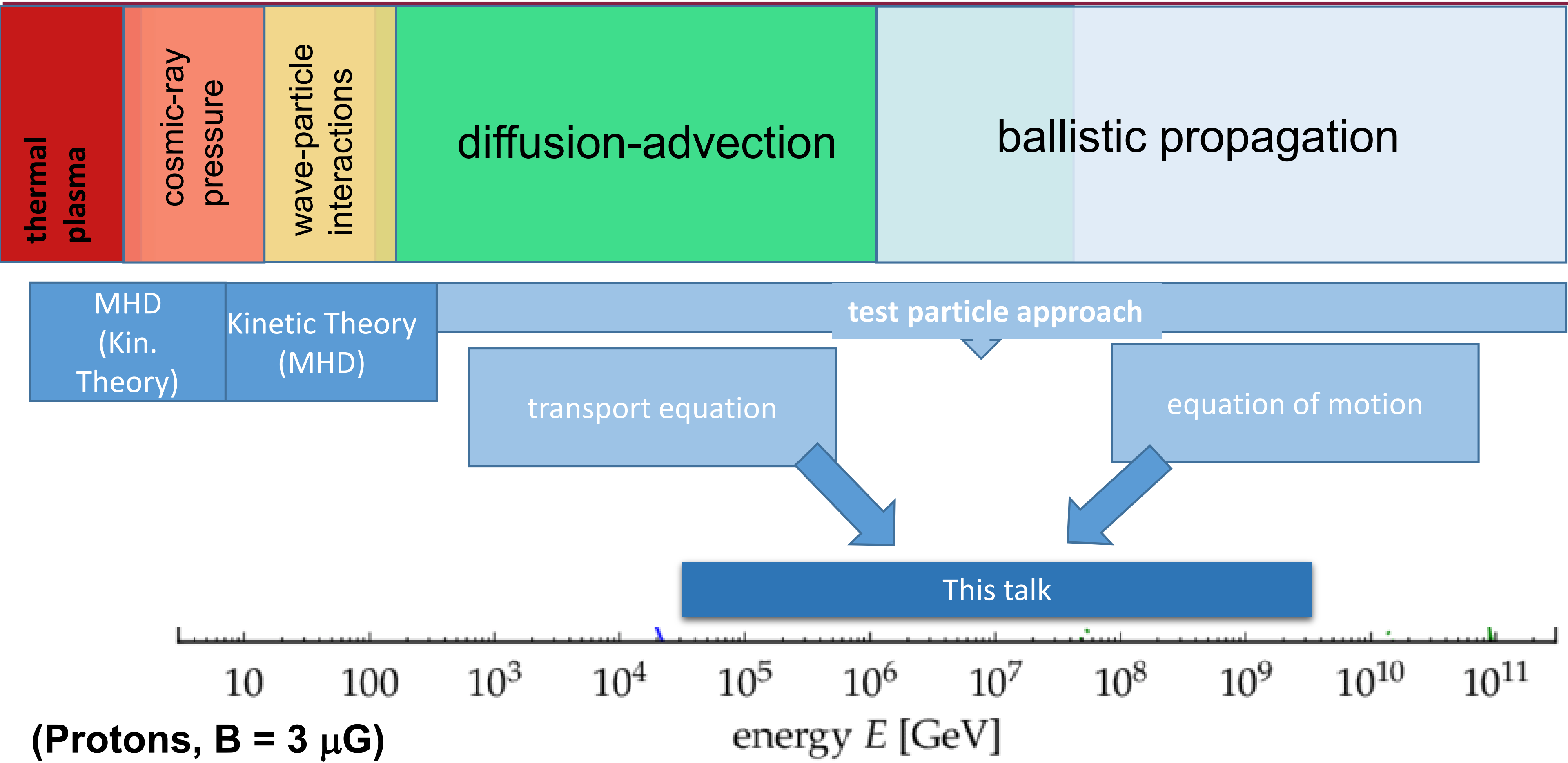
Cosmic-ray propagation regimes: physics



(B = 3 μG)

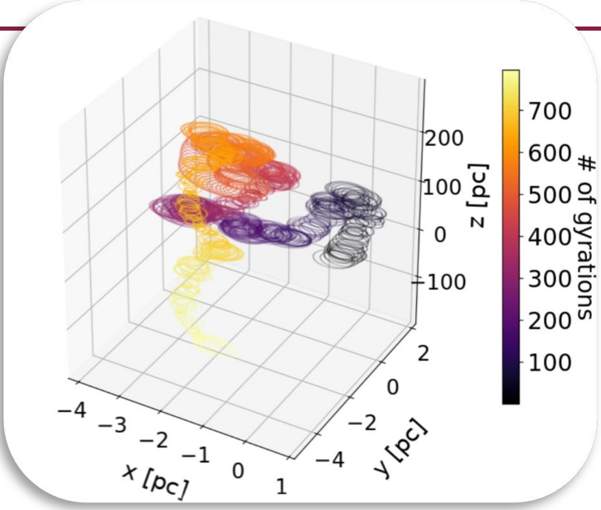
Fig: IceCube-Gen2 Whitepaper

Cosmic-ray propagation regimes: methods



Test particle approach: transport modeling

RAPP Center



Single Particle Picture:
Equation of motion

$$\frac{d\boldsymbol{p}}{dt} = q(\boldsymbol{v} \times \boldsymbol{B})$$

Multiple Particle Picture:
Transport equation

$$\frac{dn}{dt}(\vec{r}, t, E) = Q + \nabla(D_{xx}\nabla n) - \nabla(\vec{U} \cdot n) + \frac{\partial}{\partial p}\left[p^2 D_{pp} \frac{\partial}{\partial p} \frac{n}{p^2}\right] - \frac{\partial}{\partial p}\left(\frac{dp}{dt}\right) + \frac{\partial}{\partial p}\left[\left(-\frac{p}{3} \cdot \nabla\vec{U}\right) \cdot n\right]$$

Time dependence

Source term

Diffusion

Advection

Momentum diffusion

Energy loss/gain

Momentum advection

Simplifying approach: using time scales in the transport equation

$$\frac{dn}{dt}(\vec{r},t,E) = Q + \nabla(D_{xx}\nabla n) - \nabla(\vec{U}\cdot n) - \frac{\partial}{\partial\gamma}\left(\frac{d\gamma}{dt}\right)$$

Time dep. — Source term — Diffusion — Advection — Energy loss/gain

$$\frac{dn}{dt}(\vec{r},t,E) = Q - \frac{n}{\tau_{esc}} - \frac{n}{\tau_{adv}} - \frac{n}{\tau_{loss}}$$

- Scale analysis

$$\tau_{esc} = \frac{H^2}{D} \qquad \tau_{adv} = \frac{H}{U} \qquad \tau_{loss} = \left(\frac{d\gamma}{dt}\right)^{-1} d\gamma$$

Loss & escape timescales – example (blazars)

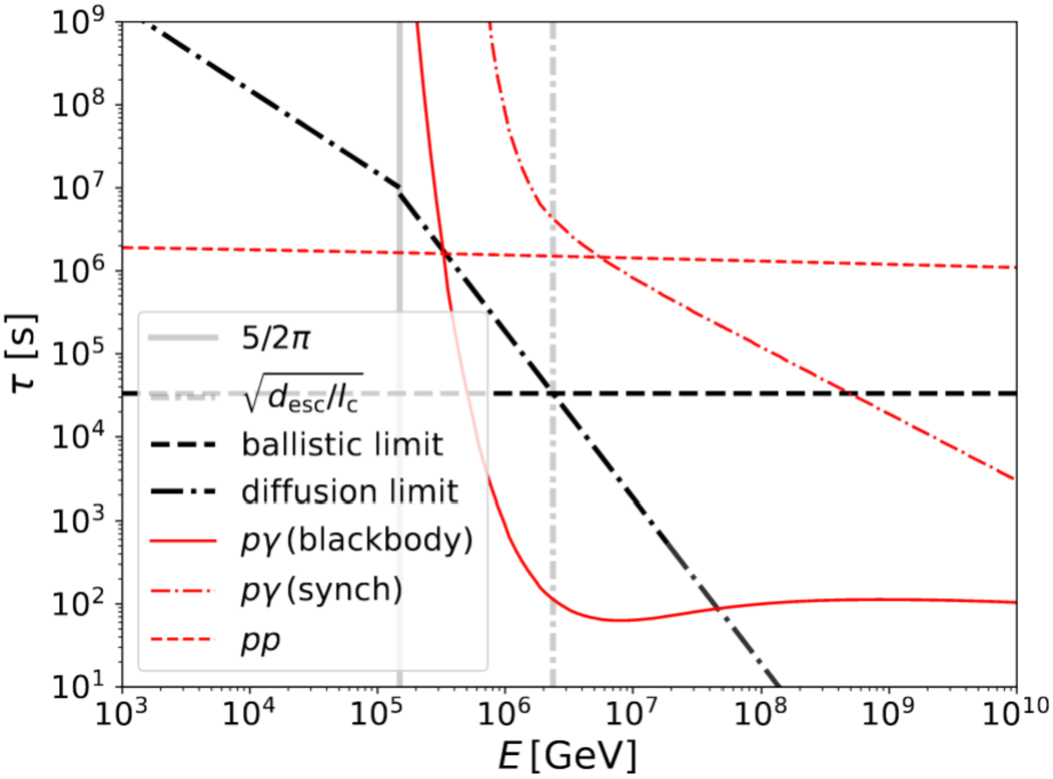
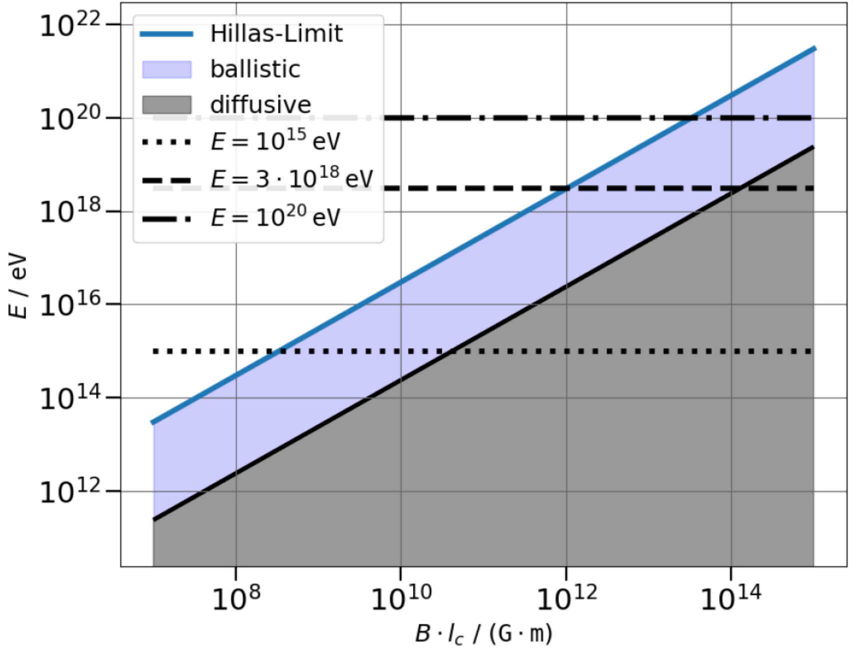


Fig: Vladimir Kiselev (RUB)

Escape timescale: diffusive VS ballistic



➔ Ballistic behavior at energies:

$$E \gtrsim Z \cdot \left(\frac{l_c}{10^{11}\,\mathrm{m}}\right) \cdot \left(\frac{B}{0.42\,\mathrm{G}}\right) \cdot 10^{15}\,\mathrm{eV}$$

➔ Consideration in transport equation: change from diffusive to ballistic timescale ➔

JBT et al, MDPI Physics (2022)

Code comparison – basic properties

- State-of-the-art codes so far: solution of transport equation with escape timescale

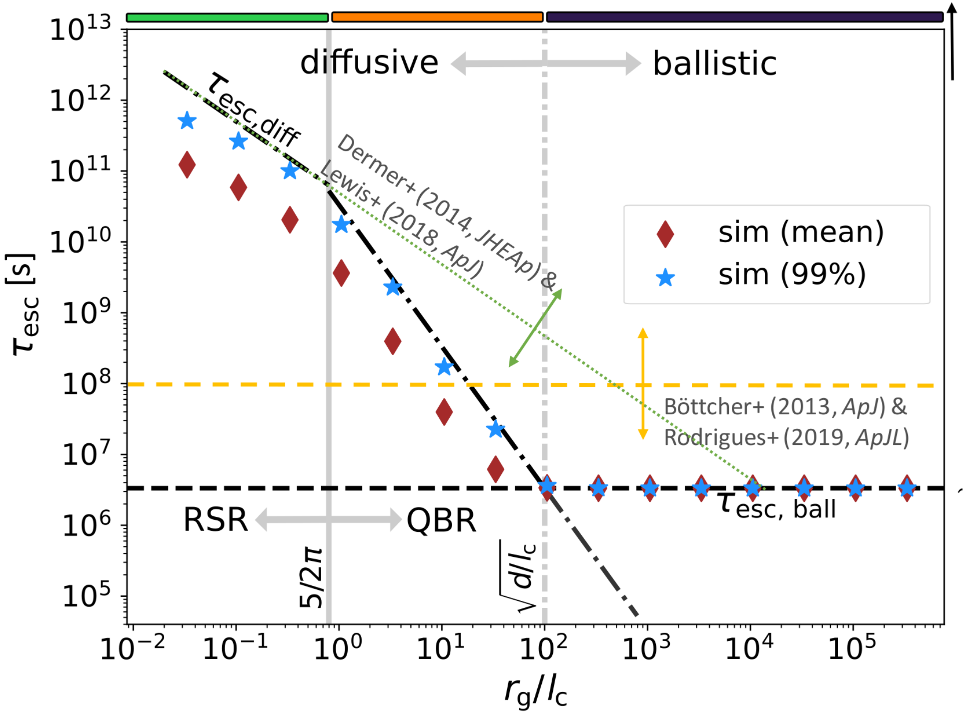
New code development (Hörbe et al 2020) AGNPropa:

- 3-dim (B-field, gas & diffusion)
- Transport equation & EoM

JBT et al, MDPI Physics (2022)

Code	AM^3	PARIS	ATHEνA	Böttcher
Reference	Gao et al. (2017)	Cerruti et al. (2015)	Dimitrakoudis et al. (2012)	Böttcher et al. (2013)
Transport equation	yes	yes	yes	yes
EoM	no	no	no	no
steady state	yes	yes	yes	yes
time dependent	yes	no	yes	no
B-field	1dim	1dim	1dim	1dim
Diffusion	1-dim	1-dim	1-dim	1-dim
Photohadron	yes	yes	yes	yes
Hadron-hadron	no	no	no	no

Timescales: diffusive VS ballistic



$$\tau_{esc} = \frac{R^2}{D} \sim E^{-\frac{1}{3}} \; (E < qBl_c)$$

$$\tau_{esc} = \frac{R^2}{D} \sim E^{-2} \; (E < qBl_c)$$

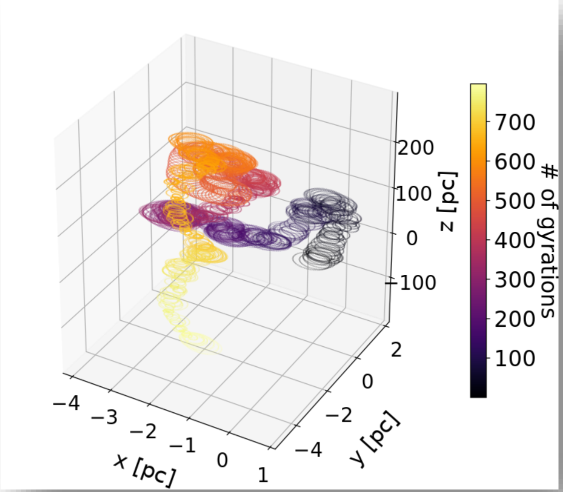
$$\tau_{esc} = \frac{R}{c} \sim \text{const} \; (E > 100qBl_c)$$

Reicherzer, PhD thesis, Bochum/Saclay (2022)

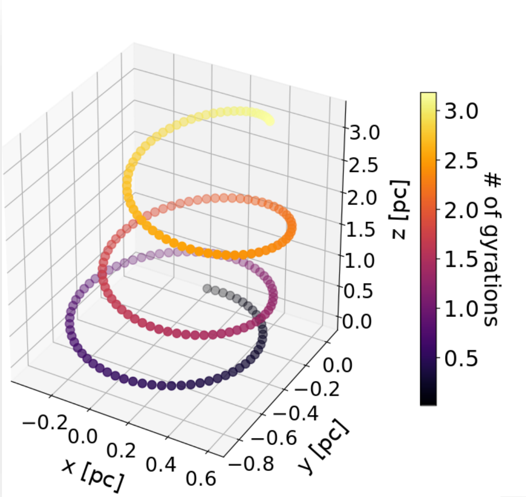
AGN Propa
Combinig the transport equation & the equation of motion

$$\frac{\delta n}{\delta t} = \nabla \cdot \left(\hat{D} \cdot \nabla n\right) - \vec{u} \cdot \nabla n + Q$$

$$\frac{d\boldsymbol{p}}{dt} = q(\boldsymbol{v} \times \boldsymbol{B})$$



$B = B_0 + \delta B$



conversion into Stochastic Differential Equation (SDE):

$$dr_\nu = A_\nu dt + D_{\nu\mu} d\omega^\mu$$

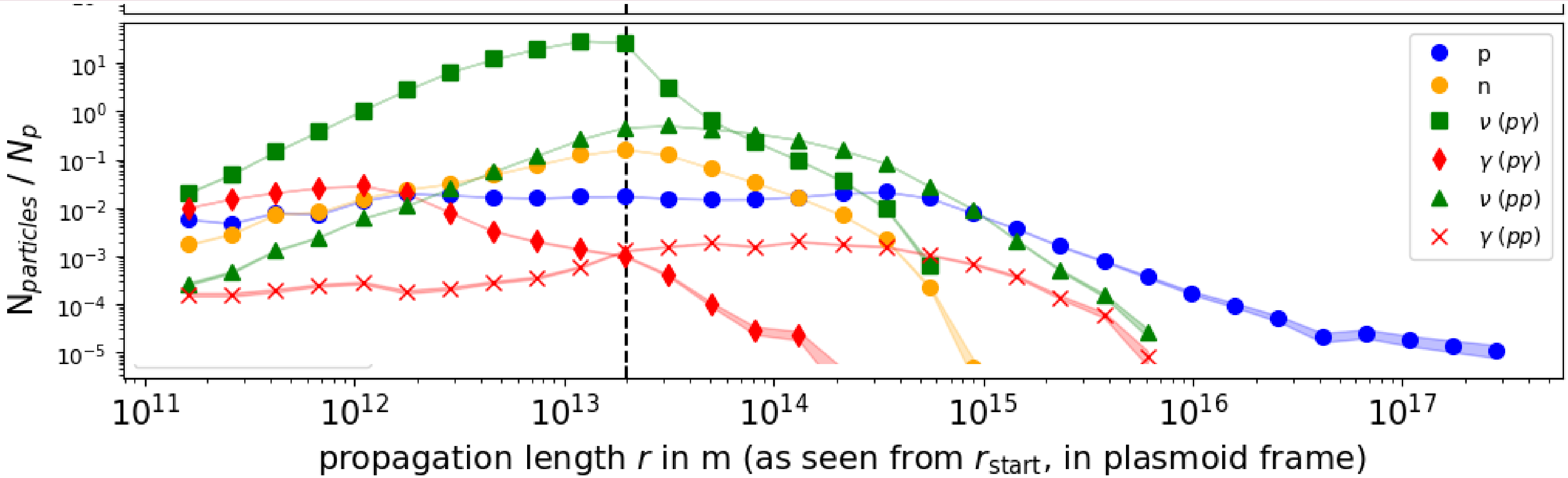
➔ treatment as quasi-particles

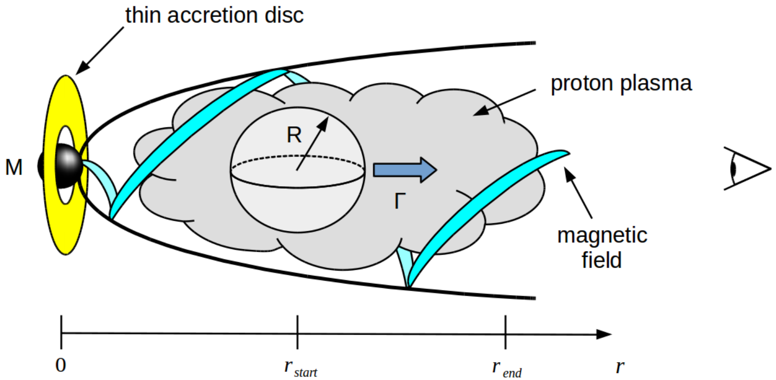
Numerical solution via Cash-Karb or Boris-Push

Treatment in one framework possible in this approach

CRPropa 3.1: Merten, JBT, Fichtner, Sigl, JCAP (2017)

First test results with AGNPropa



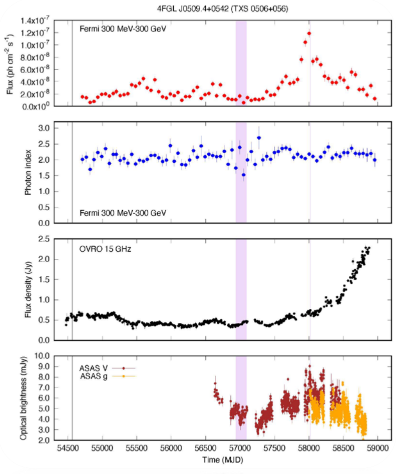


→ γ-absorption near disk with decreasing effect due to outward propagation

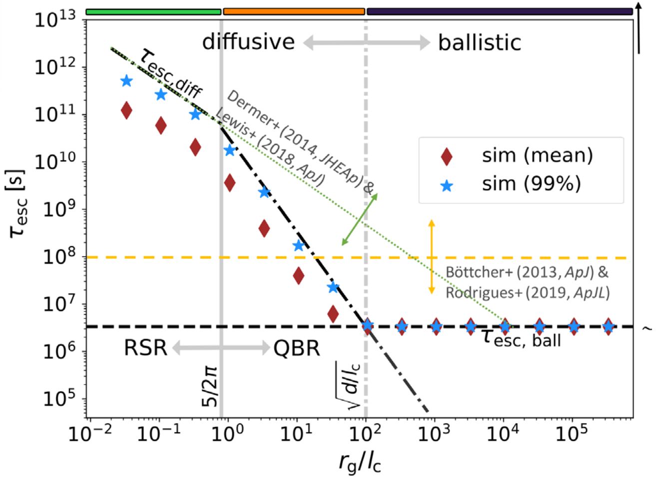
Hörbe, Morris, JBT, Cotter, MNRAS (2020)

Talk today

- Multimessenger Astronomy: connecting γ- and ν-emission



- Multimessenger modeling: Theoretical concepts



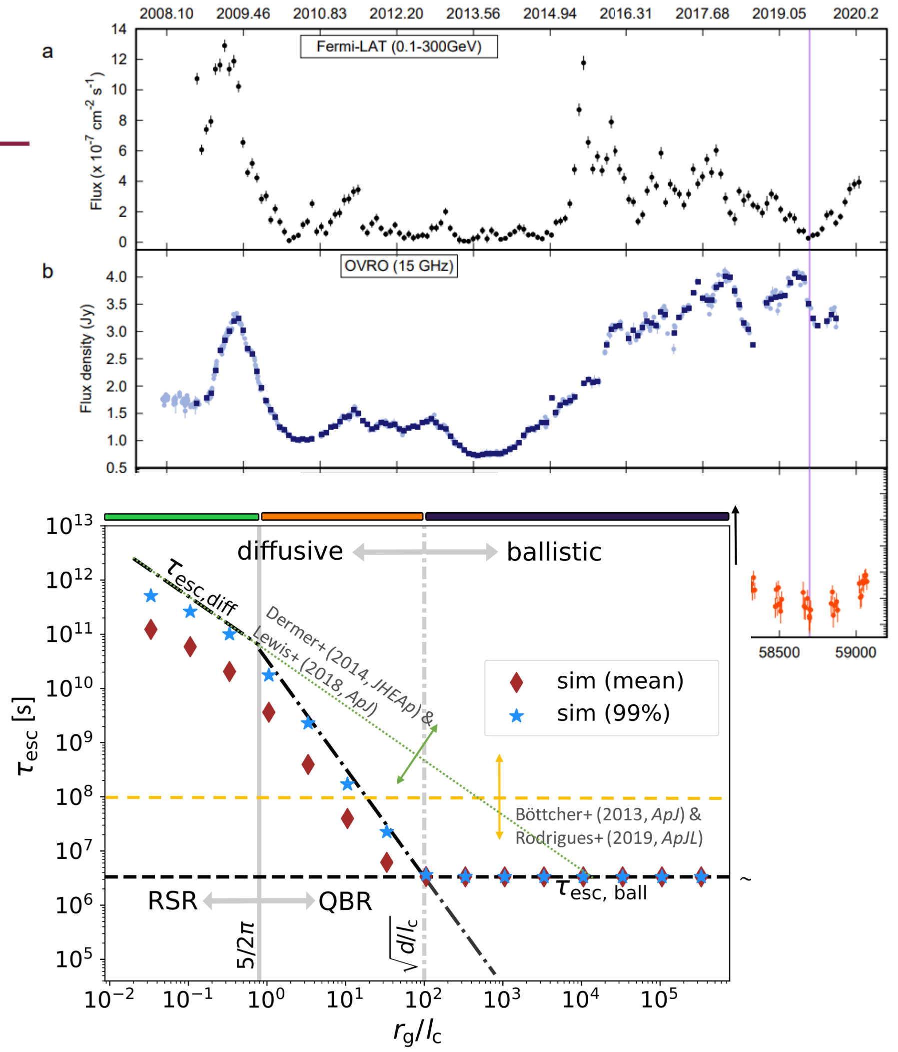
- Outlook

Summary

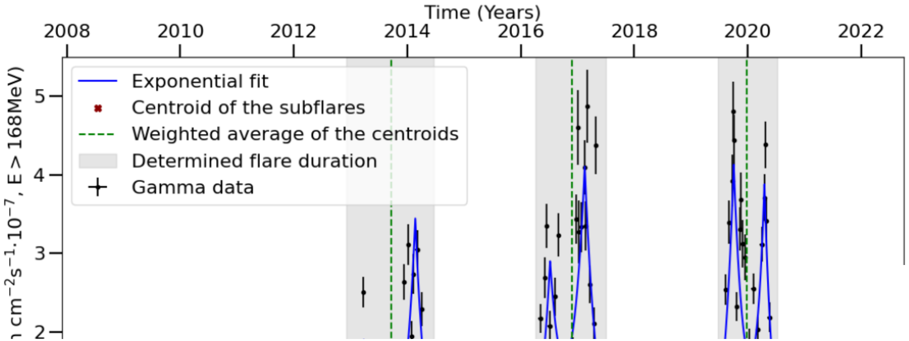
- Something is wrong with the γ-ν connection: are we looking at γ-absorbed sources?

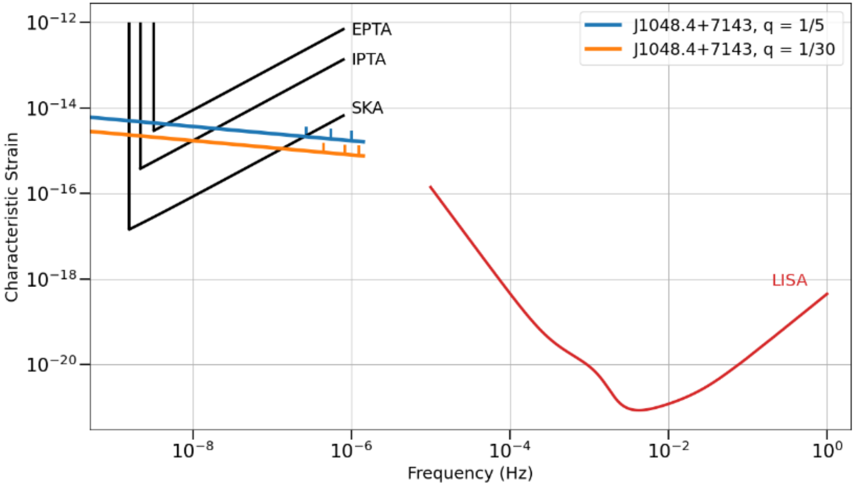
- Modeling via transport equation requires consideration of escape timescale (diffusive VS ballistic)

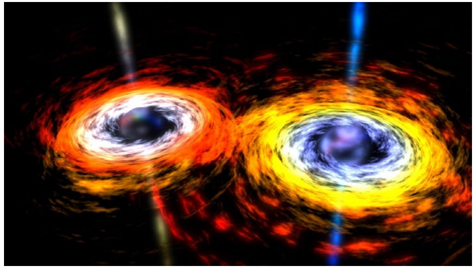
- 3dim modeling of structures to match time and energy domains at the same time

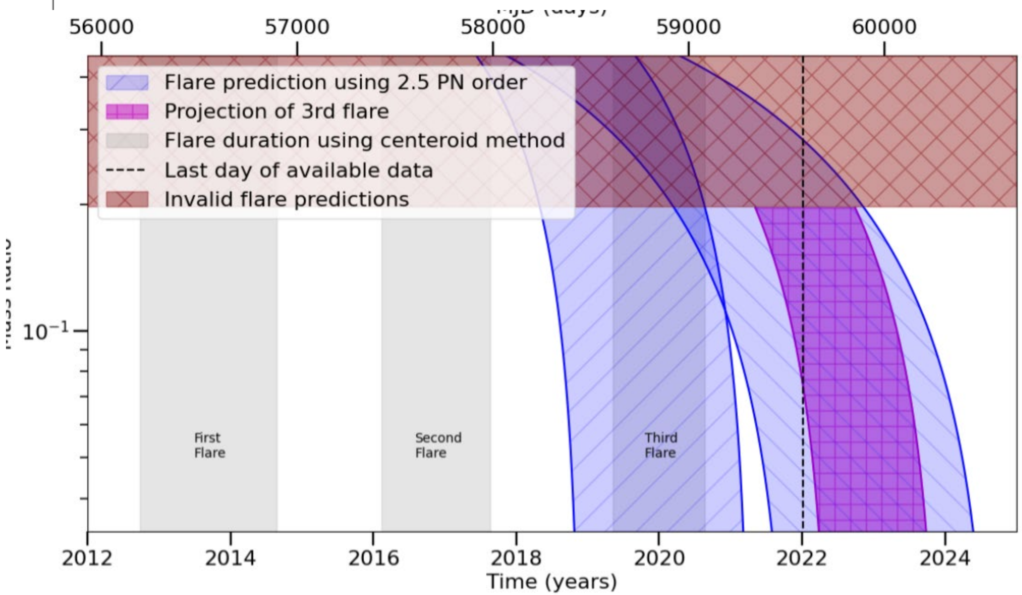


Outlook: ν-GW-connection for SMBBHs



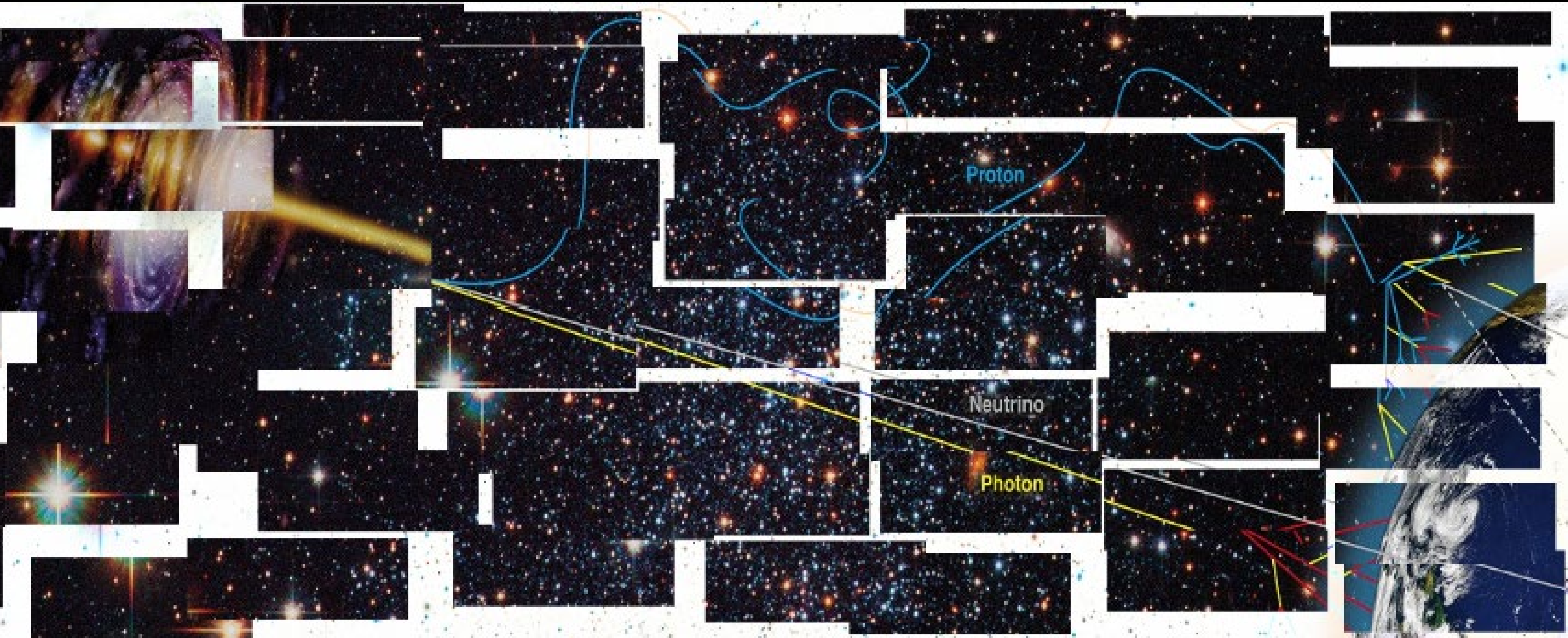


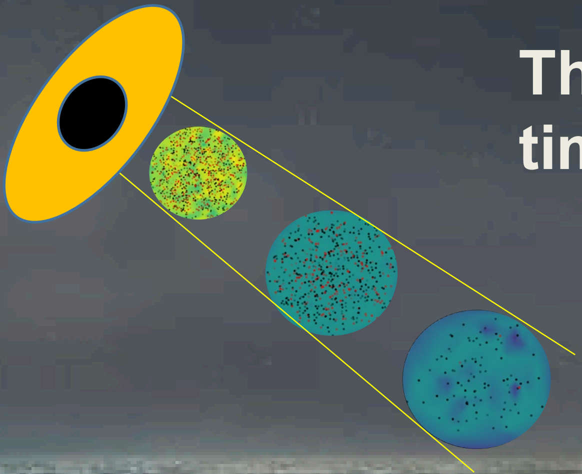




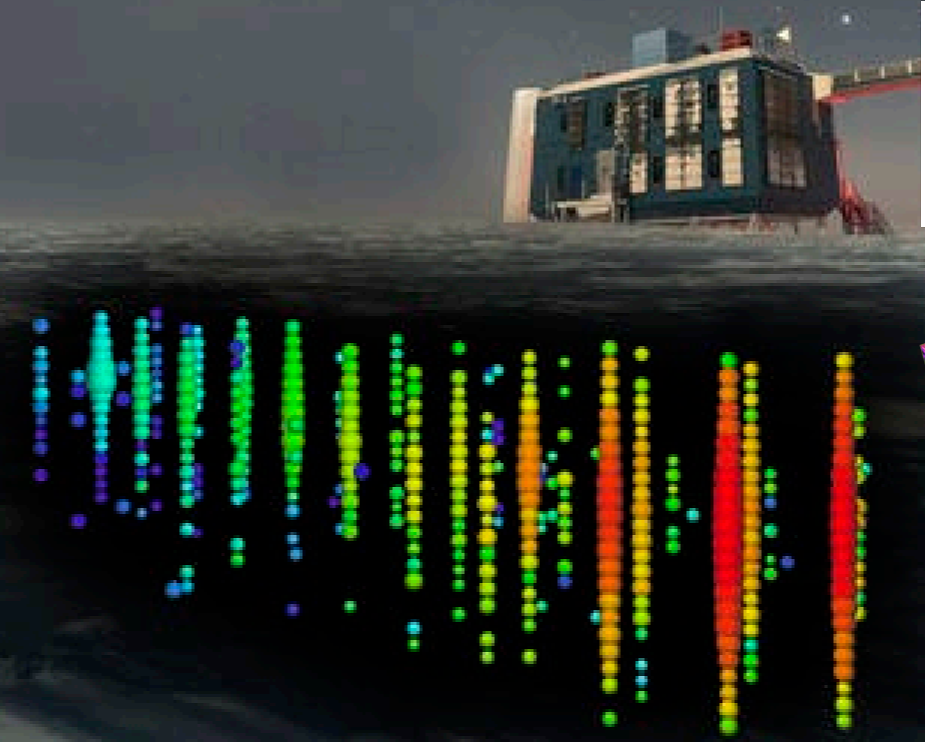
Kun, Jaroschewski, Ghorbanietemad, Frey, JBT, Britzen, Gabanyi, Kiselev, Schlegel, Schroller, Reichherzer, Cui, Wang & Shen, arXiv:2209.05107, submitted

Transient multimessenger astrophysics:
a (time-dependent) puzzle for physicists





Thank you for listening – time for questions ☺



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