Neutrino Production by Heavy Nuclei in Gamma-ray bursts

The neutrino – cosmic ray connection

[D. Biehl, D. Boncioli, A. Fedynitch, W. Winter – in preparation]

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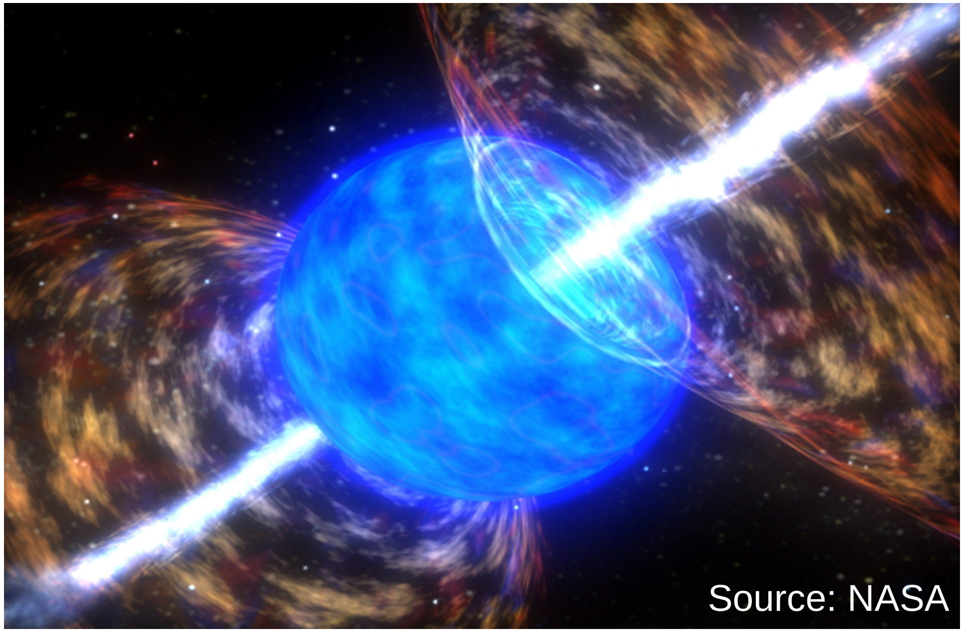
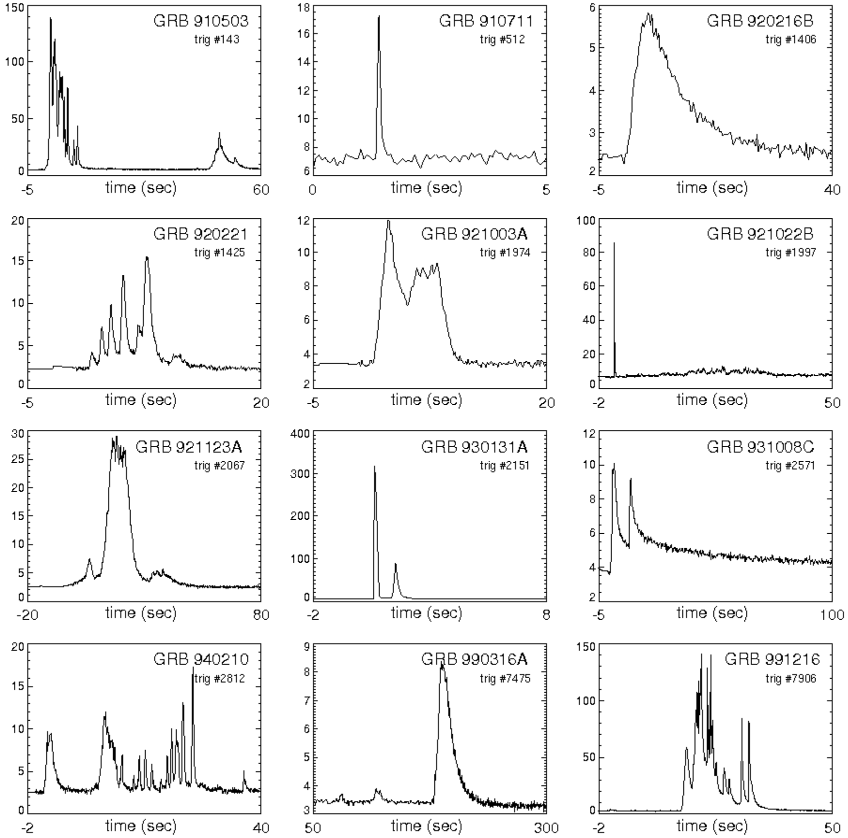
Gamma-ray bursts (GRBs)

- One of the most energetic phenomena in the universe
  - Long-duration bursts with duration ~ 10 – 100s collapse of massive stars?
  - Short-duration bursts with duration ~ 0.1 – 1s neutron star mergers?





[D. Perley, BATSE, NASA]

GRB light curves: Large variety!

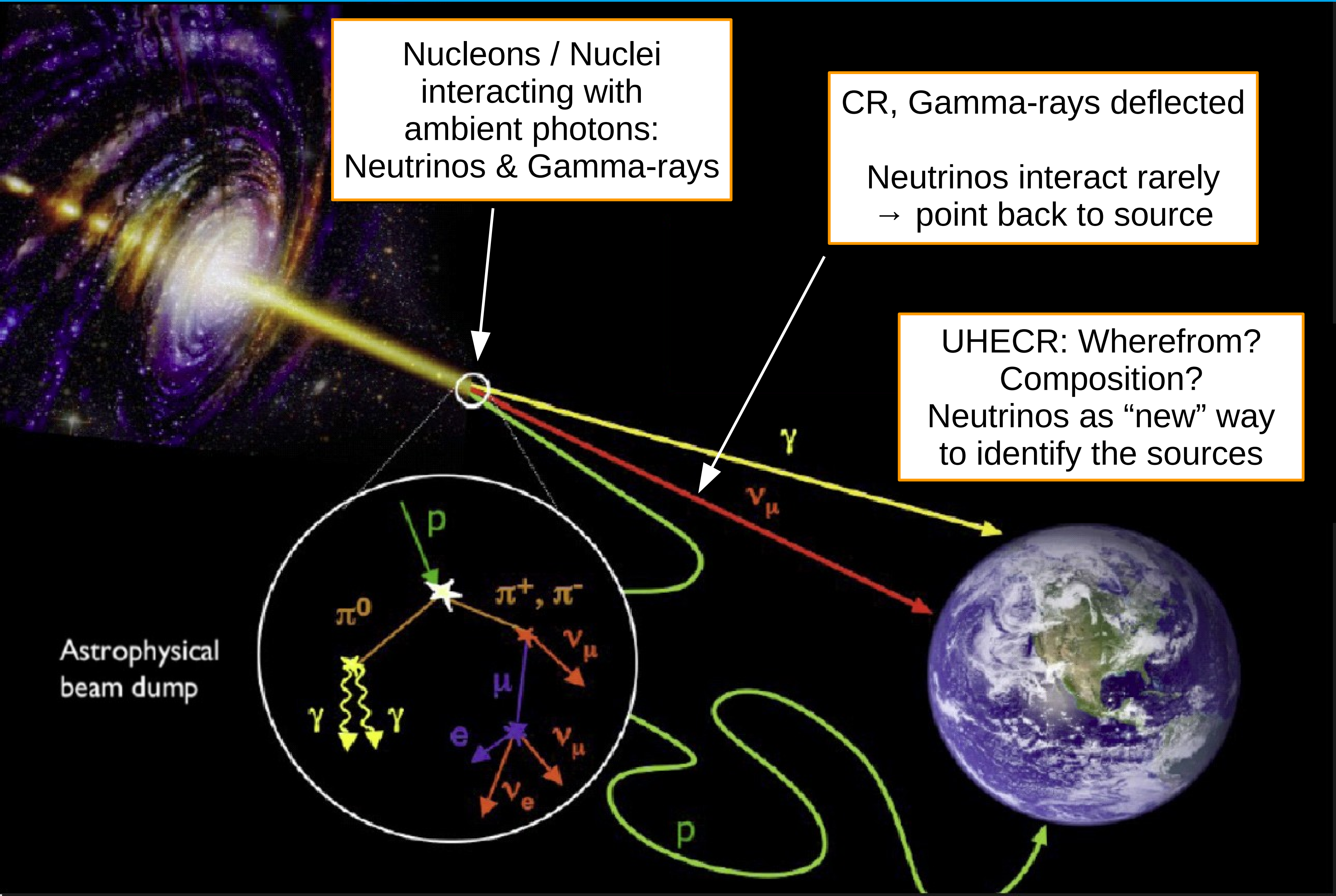
Neutrinos and the origin of cosmic rays (CR)

Nucleons / Nuclei interacting with ambient photons: Neutrinos & Gamma-rays

CR, Gamma-rays deflected

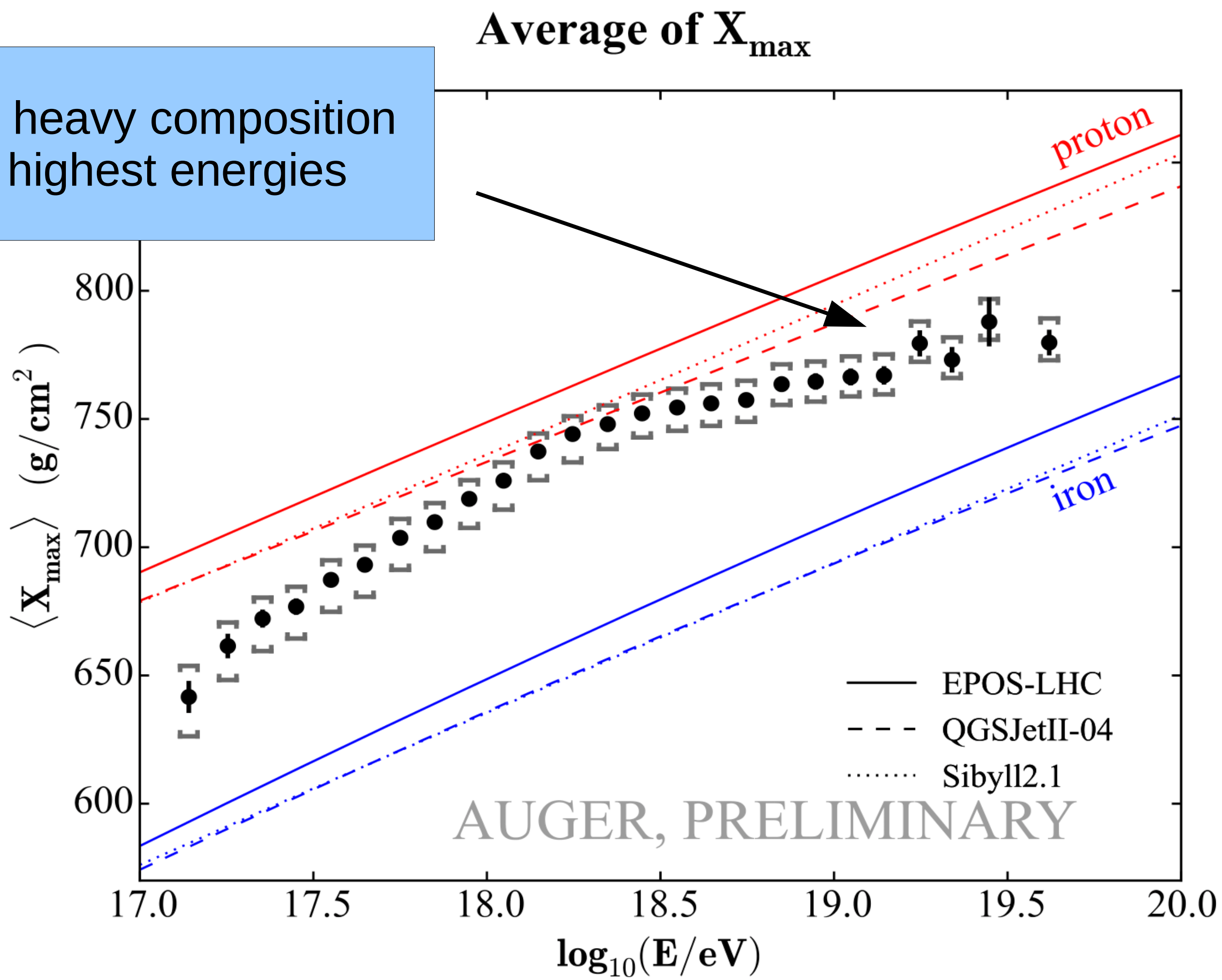
Neutrinos interact rarely → point back to source

UHECR: Wherefrom? Composition? Neutrinos as “new” way to identify the sources



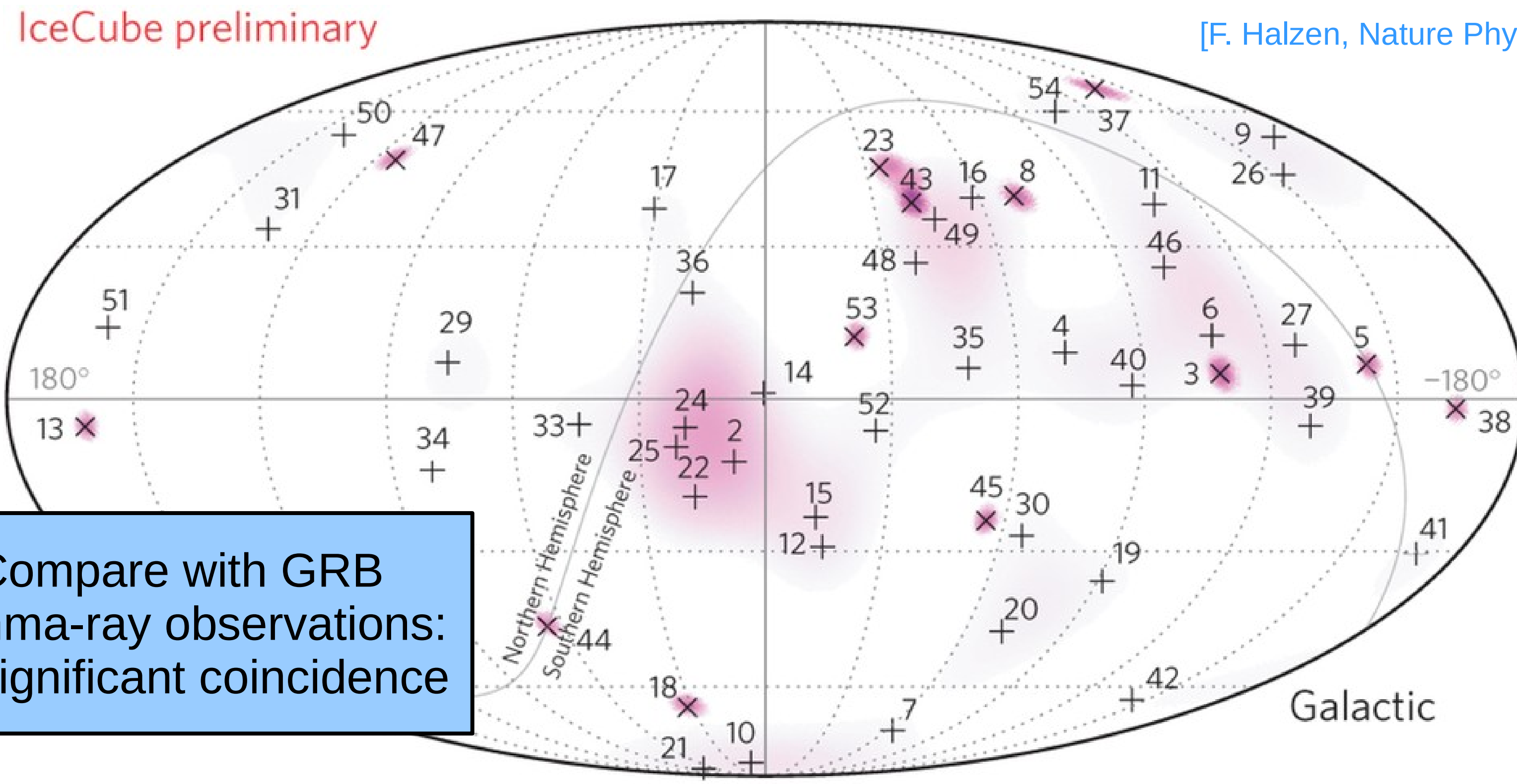
Hints on heavy UHECR composition

Trend to heavy composition
at the highest energies



[Auger Collaboration, ICRC 2015]

IceCube constraints on neutrino production from GRBs

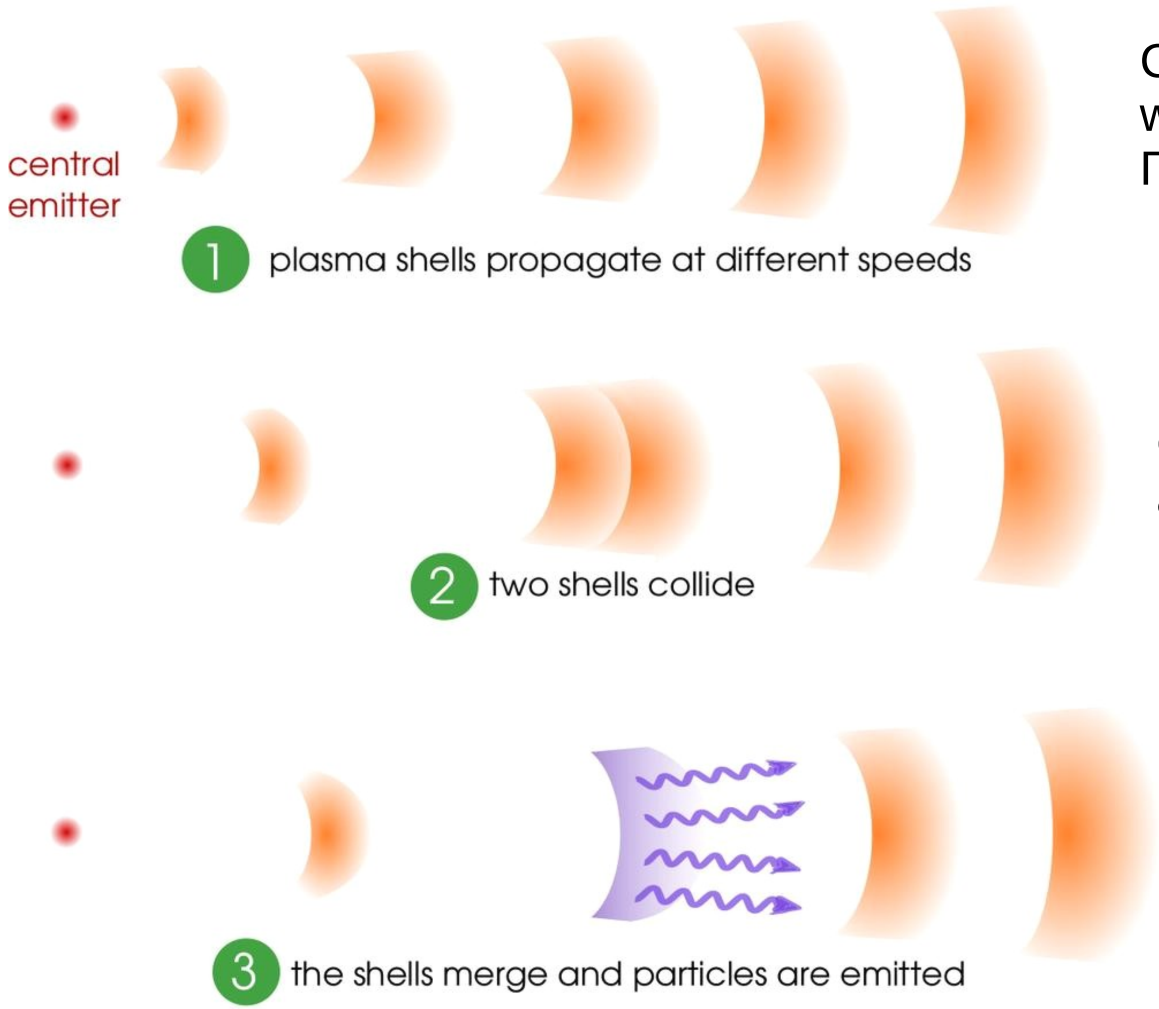


[F. Halzen, Nature Physics (2016)]

Compare with GRB gamma-ray observations: no significant coincidence

- Strong constraints on observed diffuse HE neutrino flux: only ~ 1% from GRBs
  [IceCube Collaboration – Nature 484, 351-354 (2012) and Astrophys. J. 805, L5 (2015)]
- But: neutrino production depends on CR escape mechanism (burst parameters)
  [S. Hümmer, P. Baerwald, W. Winter – PRL 108, 231101 (2012)]
  [P. Baerwald, M. Bustamante, W. Winter – ApJ 768, 186 (2013) and Astropart Phys. 62, 66 (2015)]

GRB internal shock model



Central engine ejects shells within a relativistic jet: $\Gamma \sim 10 – 1{,}000$

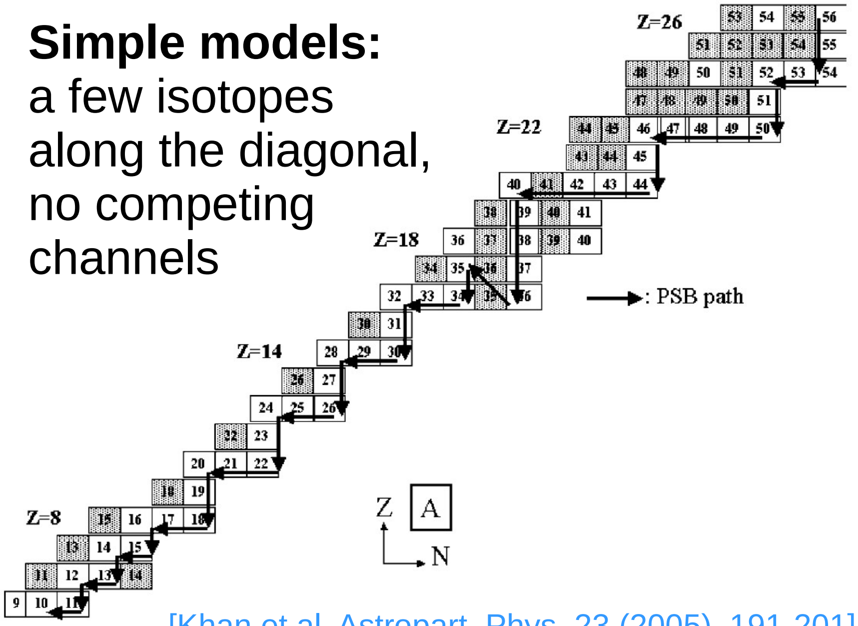
Colliding shells form shocks at radii: $R \sim 10^7 – 10^{10}$ km

Shocks produce and accelerate particles up to ultra-high energies

[Fig. from M. Bustamante, P. Baerwald, K. Murase, W. Winter, Nat. Commun. 6, 6783 (2015)]

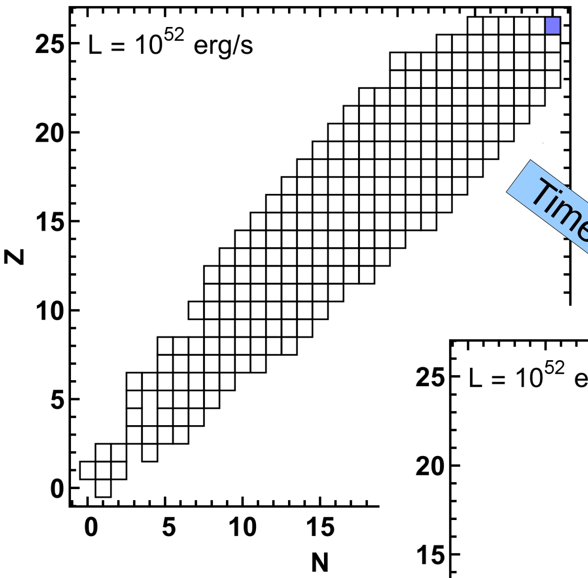
NeuCosmA – nuclear cascades

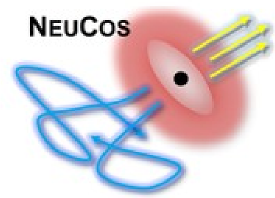
Simple models:
a few isotopes along the diagonal, no competing channels

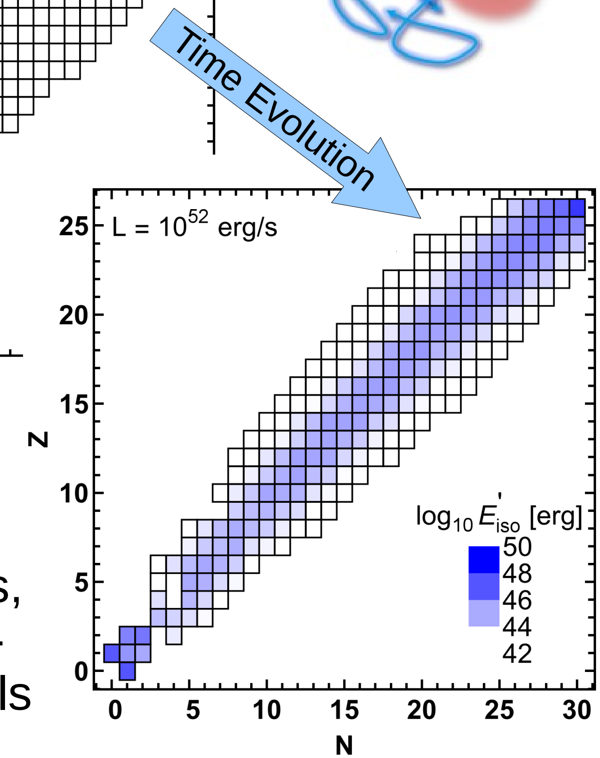


[Khan et al, Astropart. Phys. 23 (2005), 191-201]

- > Disintegrated nuclei and secondaries fed back to the system
- > Detailed information on interactions and densities in the source







NeuCosmA:
~ 500 isotopes,
~ 45,000 competing channels

[D. Boncioli, A. Fedynitch, W. Winter – arxiv:1607.07989]
[DB, D. Boncioli, A. Fedynitch, W. Winter – in preparation]

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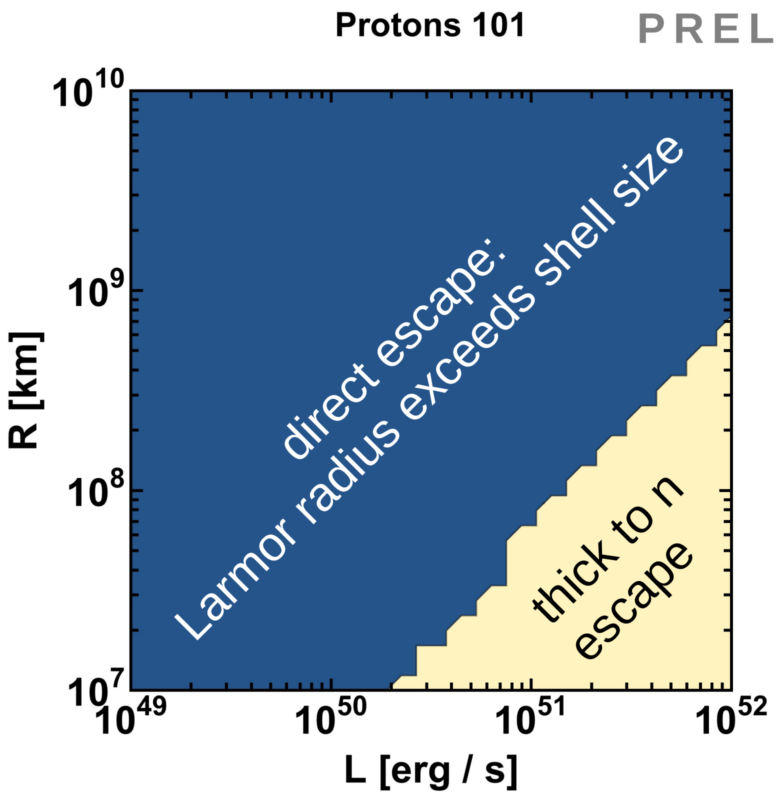
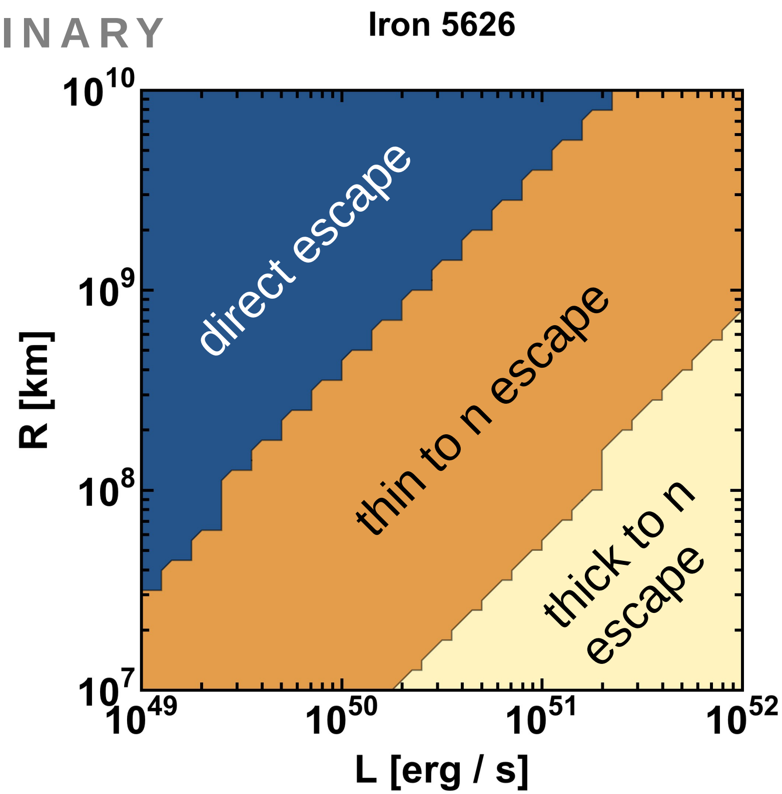
NeuCosmA: CR escape and neutrino production regimes

PRELIMINARY

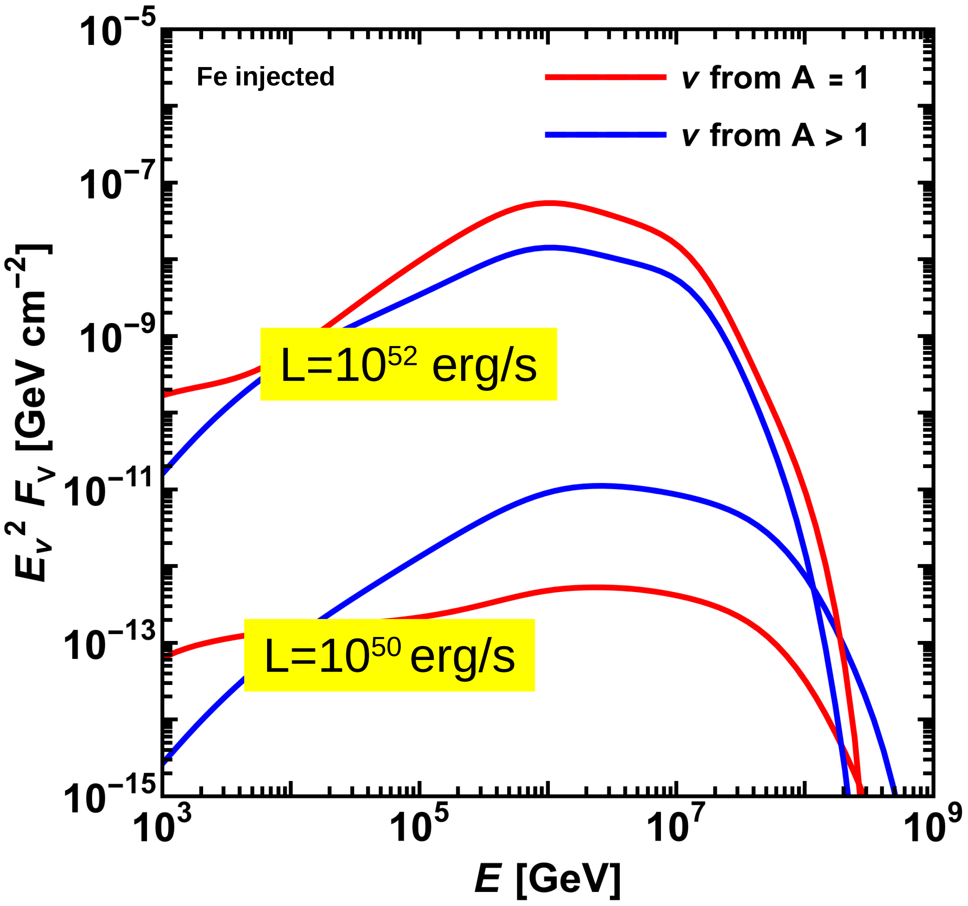




[DB, D. Boncioli, A. Fedynitch, W. Winter – in preparation]

- Direct escape: less neutrinos than CRs in agreement with IceCube, other regions: more neutrinos than CRs (excluded)
- Identify neutrino production regimes depending on burst parameters → neutrinos test UHECR escape mechanism!

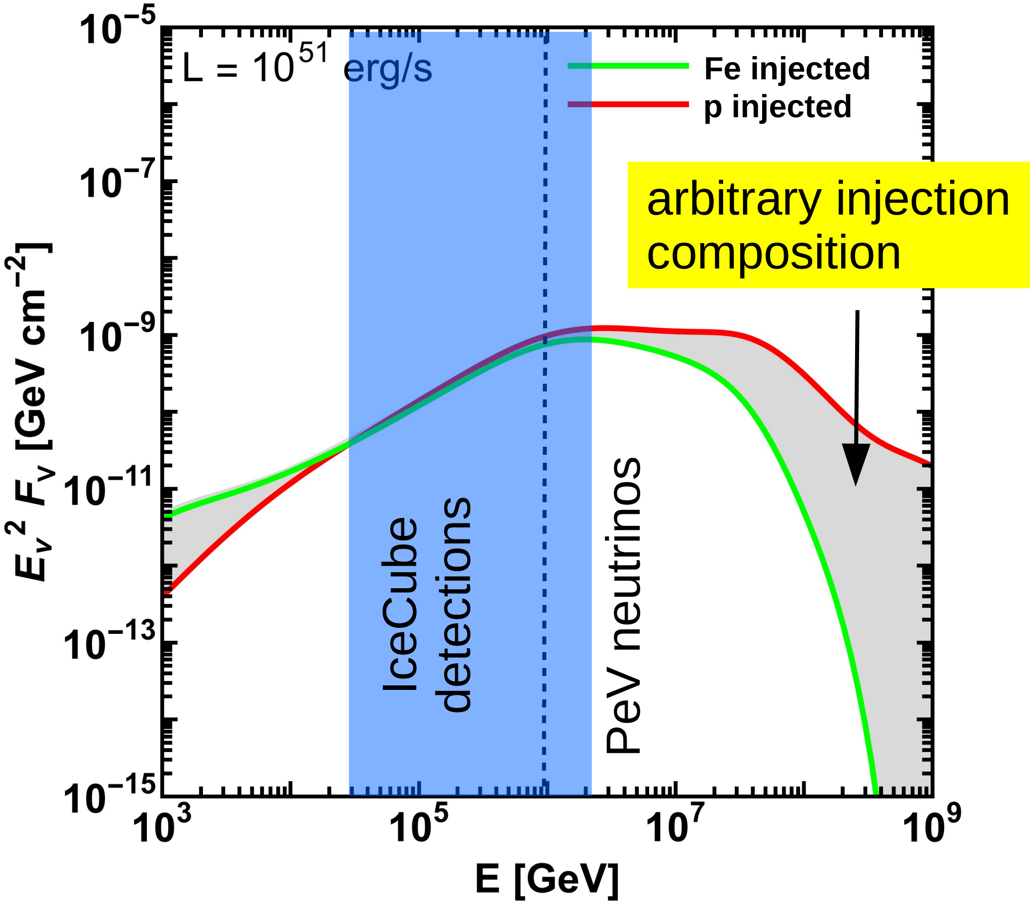
NeuCosmA – contributions to neutrino flux



[DB, D. Boncioli, A. Fedynitch, W. Winter – in preparation]

- Inject iron only
- Track the contribution of neutrons and protons (A = 1) and heavier isotopes up to iron (A > 1)
- Low luminosity leads to low disintegration rate
  - Much more heavy than light isotopes in the source
  - Photomeson production by nuclei dominates
- High luminosity leads to high disintegration rate
  - Light nuclei produced efficiently
  - Photohadronic interaction dominated by nucleons

NeuCosmA – dependence on injection composition



[DB, D. Boncioli, A. Fedynitch, W. Winter – in preparation]

- > Total neutrino flux for different injection composition
- > Between 10 TeV to 1 PeV almost same flux, no dependence on injected isotope
- > Not distinguishable by flux, although high energy cutoff favors heavy composition

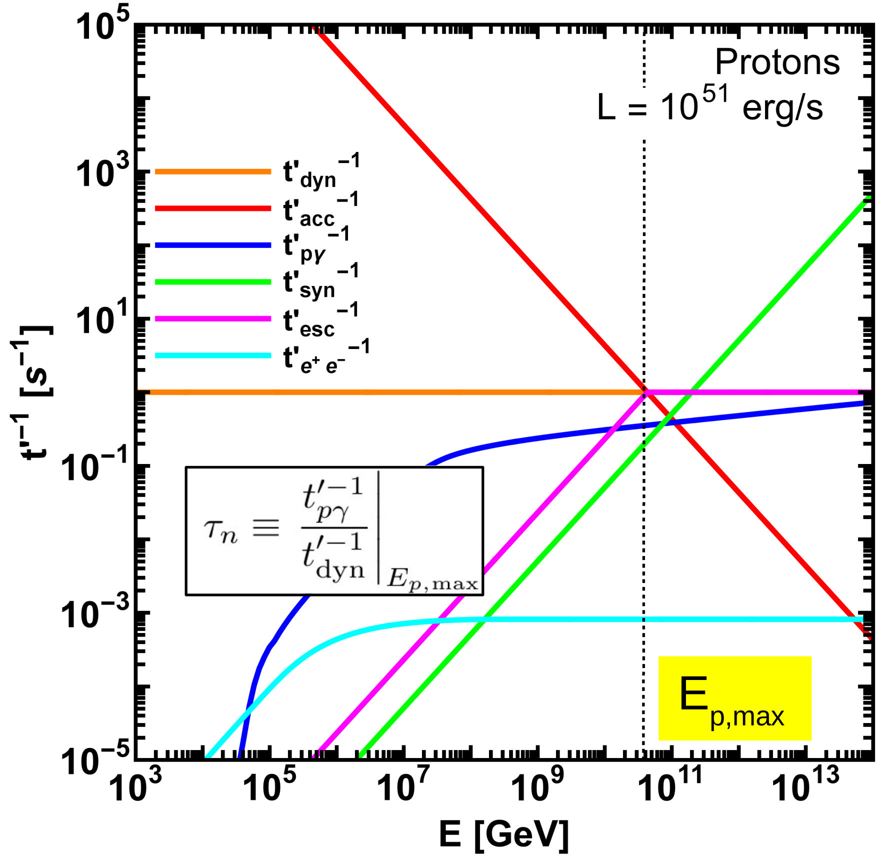
Conclusion

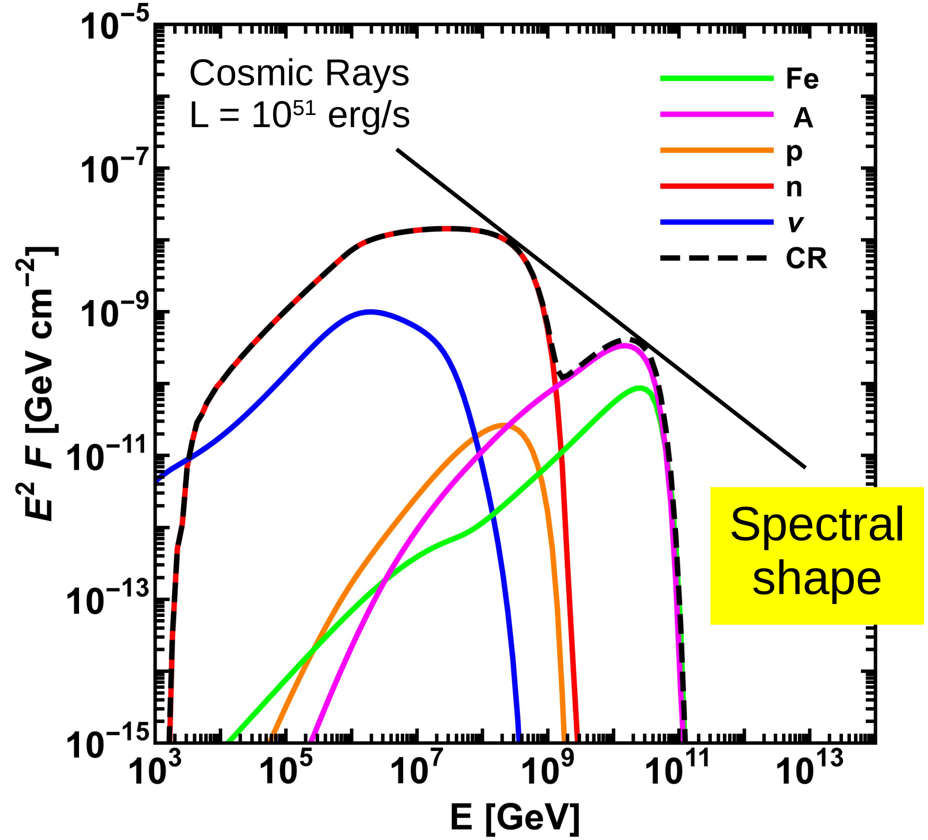
- GRBs can be the sources of high energy neutrinos, only the simplest models can be excluded
- GRBs can be the sources of the UHECR and are good candidates to observe a correlated event
- NeuCosmA allows us to study the connection between neutrinos and cosmic rays in astrophysical sources
- Parameter space studies will reveal the correlation between cosmic ray escape and neutrino production regimes
- Heavy nuclei can contribute efficiently to the neutrino flux when disintegration is suppressed and there is no strong dependence on the injection composition

BACKUP

NeuCosmA – interaction rates & particle escape

[DB, D. Boncioli, A. Fedynitch, W. Winter – in preparation]





- Optical thickness at maximum energy influences CR and neutrino spectra
- Photomeson- / Photodisintegration rates scale roughly ~A
- As luminosity increases linearly, fluxes increase quadratically
- Nucleons bound in nuclei carry only fraction E/A of total energy