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High-Energy Astrophysical Neutrinos

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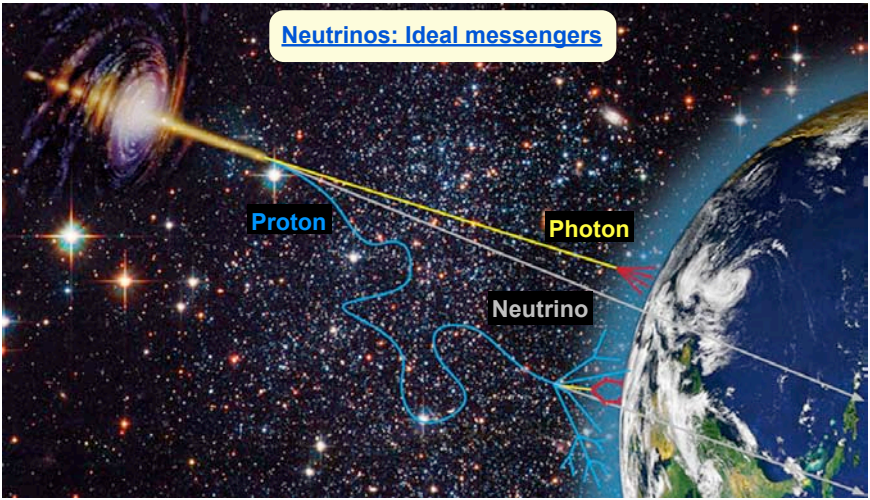
Neutrinos: New Frontier in Astrophysics

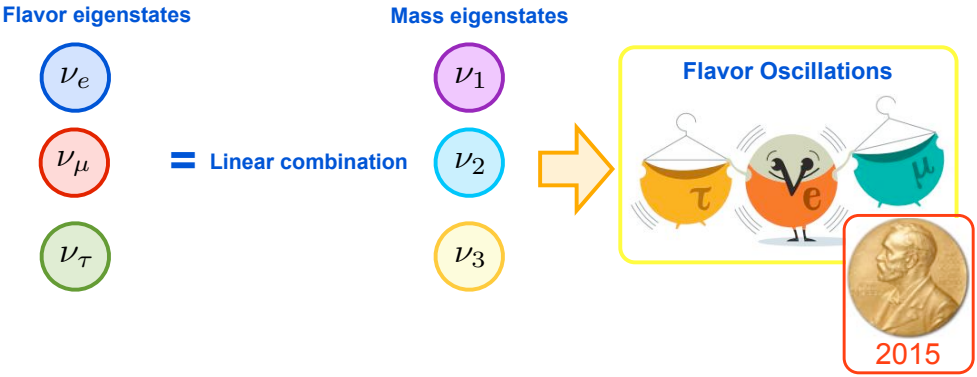
Neutrinos are **weakly interacting** elementary particles.

Escaping unimpeded, neutrinos carry information about sources not otherwise accessible.



Truly Novel Property of Neutrinos

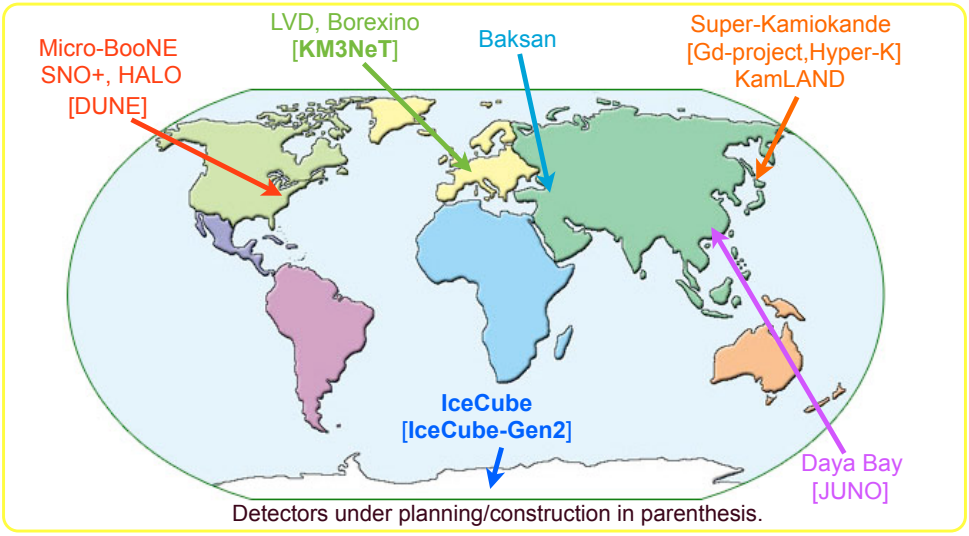
Neutrinos **oscillate** into each other by flavor mixing, because of their tiny non-vanishing mass.



- Neutrino flavor ratio give us information about **neutrino properties**.
- Flavor oscillations are affected by source matter distribution.
- In turn, flavor oscillations strongly affect source dynamics.
  ⇨ Study of flavor evolution allows us to learn about **source properties**.

Neutrino Astronomy

Several detectors are (or will be soon) sensitive to astrophysical neutrinos.



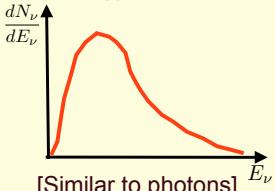
Detectors under planning/construction in parenthesis.

What could we learn by adopting neutrinos as messengers?

Neutrinos: Powerful Probes in Astrophysics

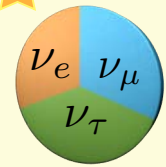
Neutrinos provide us with:

1. Energy distribution



[Similar to photons]

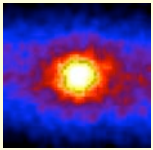
2. Flavor ratio



[Neutrinos only]

Neutrinos are copiously produced in astrophysical sources:

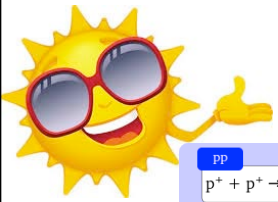
Sun



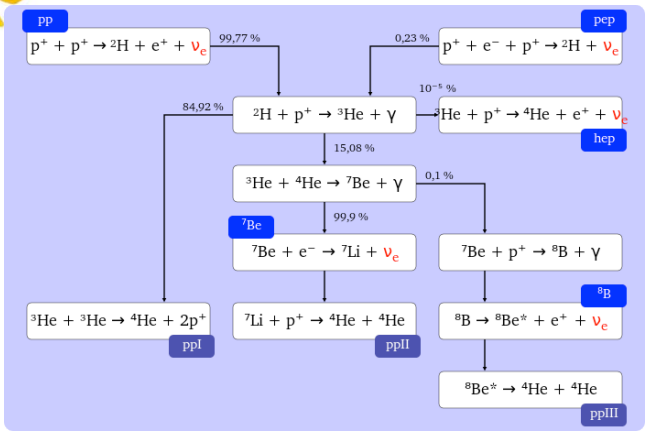
Supernovae

Gamma-ray bursts, ...

How Did We Learn About the Sun? Neutrinos!



Standard Solar Model

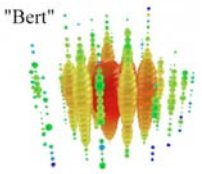


- Deficit of measured solar neutrino flux. ⇨ **Discovery of neutrino oscillations**.
- Neutrino flux strongly dependent from Sun core structure. ⇨ **Standard Solar Model Test**.

The high-energy neutrino astronomy era has begun!

2013 **Detection of neutrinos with the highest energy ever observed.**

2016 ~ 60 neutrino events.



Clear evidence for an astrophysical flux

We can learn about highly energetic phenomena in our Universe through neutrinos!

* IceCube Collaboration, Science (2013); PRL (2014); ApJ (2015); PRL (2015).

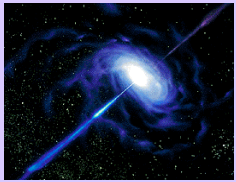
Where are these neutrinos coming from?

- ★ New physics?
- ★ Galactic origin [sub-dominant contribution]
- ★ **Extragalactic origin**

Star-forming galaxies

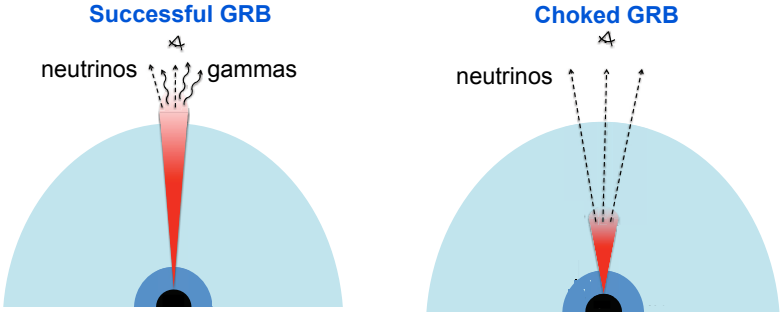
Gamma-ray bursts

Blazars



* Anchordoqui et al., JHEAp 1-2 (2014) 1. Meszaros, arXiv: 1511.01396. Waxman, arXiv: 1511.00815. Murase, arXiv: 1511.01590. Credits for images: ESA, Hubble, NASA web-sites.

Neutrinos from Gamma-Ray Bursts



Photon luminosity: 10^{52} erg/s 10^{48} erg/s 0 erg/s

GRB type: **High luminosity** **Low luminosity** **Choked**

GRBs have rich phenomenology. Still many uncertainties on their physics.

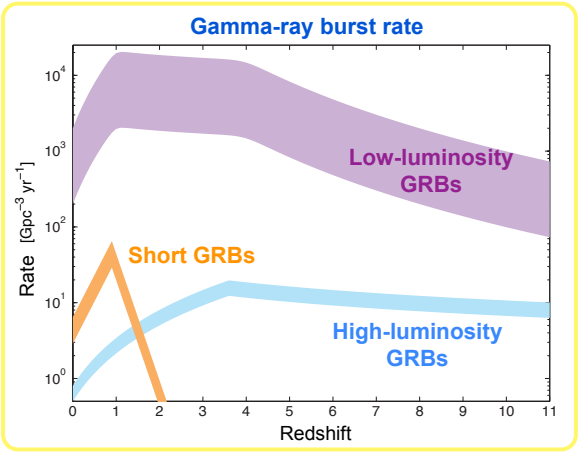
Dark GRBs are especially poorly understood because scarcely (or not) visible in photons.

* Meszaros, Astropart. Phys. (2013). Waxman & Bahcall, PRL (1997). Meszaros & Waxman, PRL (2001). Senno et al. (2016).

Neutrinos from Dark Gamma-Ray Bursts

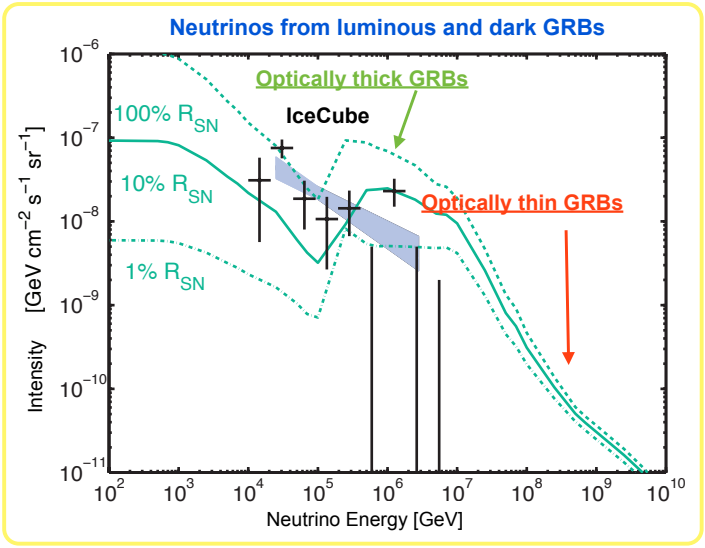
Dark GRBs expected to be more abundant than visible ones, but poorly detectable in photons.

Neutrinos could be the only way to study dark GRBs.



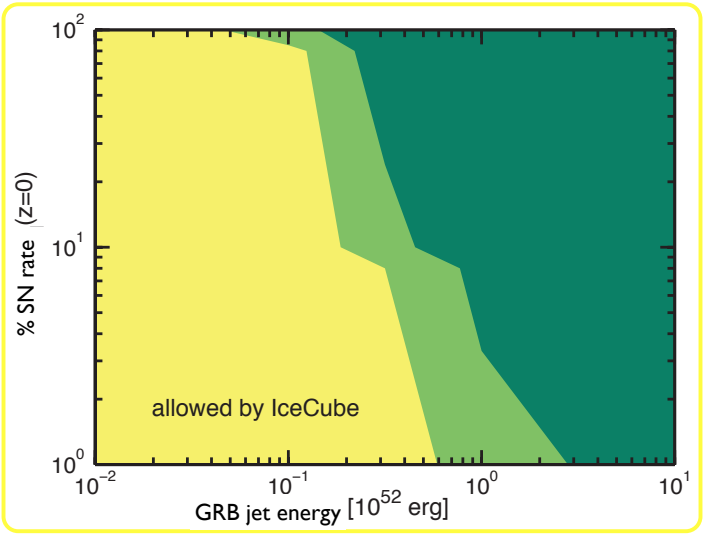
* Tamborra & Ando, JCAP (2015). Tamborra & Ando, PRD (2016).

Neutrinos Production in Dark GRBs: Methods



* Tamborra & Ando, PRD (2016). Senno et al. (2016). Meszaros & Waxman, PRL (2001).

Constraints on the SN-GRB connection



The IceCube flux can already put indirect constraints on the fraction of SNe evolving in choked bursts and their jet energy.

* Tamborra & Ando, PRD 93 (2016) 053010. IceCube and ROTSE Collaborations, A&A 539 (2012) A60.

Conclusions

- ★ Origin of the IceCube high-energy neutrino flux not yet clear.
- ★ Diffuse emission from optically thick jets is one natural possibility.
- ★ IceCube high-energy neutrino data indirectly constrain the choked GRB rate to be lower than 10% of the local SN rate.

Thank you for your attention!