





### Neutrino Astrophysics Markus Ahlers, D. Jason Koskinen & Irene Tamborra *MSc Day, October 24, 2019*

### Who are we?







#### Irene Tamborra tamborra@nbi.ku.dk

#### D. Jason Koskinen koskinen@nbi.ku.dk

Markus Ahlers markus.ahlers@nbi.ku.dk

#### Neutrino Astrophysics

## The Elusive Neutrino

### three neutrino flavours

- very small masses (unknown origin)
- large mixing between flavour and mass states (unknown mechanism)
- 2nd most abundant particle in the Universe (impact on cosmology)
- unique probe of high-energy astrophysics

#### Standard Model of Particle Physics



(+ Higgs boson)

### Neutrinos in Astrophysics



### Unique abilities of **cosmic neutrinos**:

**no deflection** in magnetic fields (unlike cosmic rays)

**no absorption** in cosmic backgrounds (unlike gamma-rays)

**smoking-gun** of unknown sources of cosmic rays

**coincident** with photons and gravitational waves

**BUT,** very difficult to detect!

Markus Ahlers

# Neutrinos as Messengers

### Crab Nebula seen with Hubble in Photons

Markus Ahlers

### Neutrinos as Messengers

RADIO	MICROWAVE	INFRARED	OPTICAL
ULTRAVIOLET	X-RAYS	GAMMA-RAYS	NEUTRINOS

## Powerful Probes in Astrophysics

Neutrinos provide us with:



#### Neutrinos are copiously produced in astrophysical sources, e.g.



Markus Ahlers

### Neutrino Fluxes



### Neutrino Fluxes



Markus Ahlers

### Neutrino Flavor Oscillations



### Neutrinos in Supernovae and Mergers

### Neutrino Interactions

#### Understood phenomenon.



Neutrinos interact with neutrons, protons and electrons.

We still need to learn a lot about this process!



## Stellar Nucleosynthesis

#### Elements heavier than iron are born in supernovae and neutron-star mergers.



#### Synthesis of new elements could not happen without neutrinos.

$$n + \nu_e \rightarrow e^+ p$$

$$p + \overline{\nu_e} \rightarrow e^+ + n$$

# Neutrino Imprints on SN Dynamics



Tamborra, Walk et al., Phys.Rev. D98 (2018) no.12, 123001

Neutrinos **probe explosion mechanism of a supernova and its rotation.** Complementary information from detection of gravitational waves.

### Neutrinos In & From Cosmic Accelerators

## Multi-Messenger Astronomy



Acceleration of charged nuclei (**cosmic rays**) - especially in the aftermath of cataclysmic events, sometimes visible in **gravitational waves**.



Secondary **neutrinos** and **gamma-rays** from pion decays:

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu} \qquad \pi^{0} \rightarrow \gamma + \gamma$$
$$\downarrow e^{+} + \nu_{e} + \nu_{\mu}$$

Markus Ahlers

### The IceCube Observatory



#### Neutrino Astrophysics

# Breakthrough in 2013

#### First observation of high-energy astrophysical neutrinos by IceCube!

"track event" (from  $\nu_{\mu}$  scattering)

"cascade event" (from all flavours)



["Breakthrough of the Year" (Physics World), Science 2013] (neutrino event signature: early to late light detection)

Markus Ahlers

Neutrino Astrophysics

### Status of Neutrino Astronomy



-900

### Status of Neutrino Astronomy



Markus Ahlers

#### Neutrino Astrophysics

### Astrophysical Neutrinos & Particle Physics



Ahlers, Bustamante et al., Bull.Am.Astron.Soc. 51 (2019) 215

Markus Ahlers, NBI Copenhagen

### Astrophysical Neutrinos & Particle Physics



Ahlers, Bustamante et al., Bull.Am.Astron.Soc. 51 (2019) 215

### Summary

Neutrinos:

- Fundamental in most energetic phenomena in our Universe.
- Ideal messengers.
- Carry imprints of engine and population of extreme transients.
- Affect element formation in astrophysical sources.
- Their flavor conversions are crucial but yet to be fully grasped.

M.Sc. projects in Neutrino Astrophysics can cover various aspects:

- impact on stellar evolution
- potential to probe astrophysical environments
- fundamental neutrino properties
- direct probe of the origin of cosmic rays
- observation in neutrino telescopes or experiments

Thank you

for your attention!