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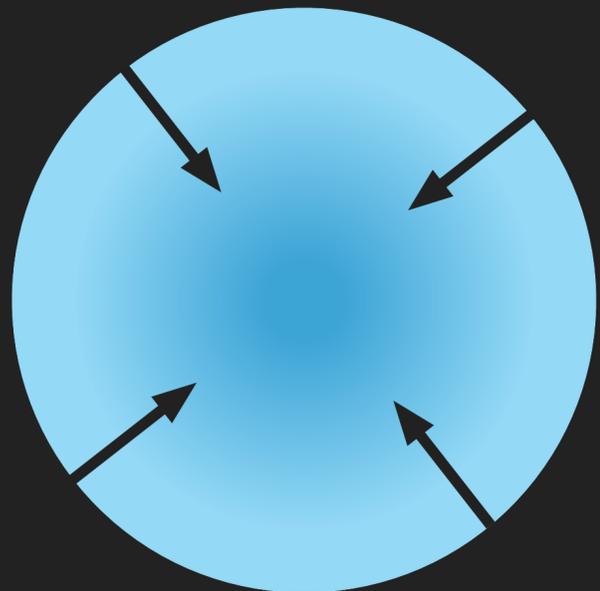
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**NEUTRINO PHYSICS WITH CORE-COLLAPSE  
SUPERNOVAE**

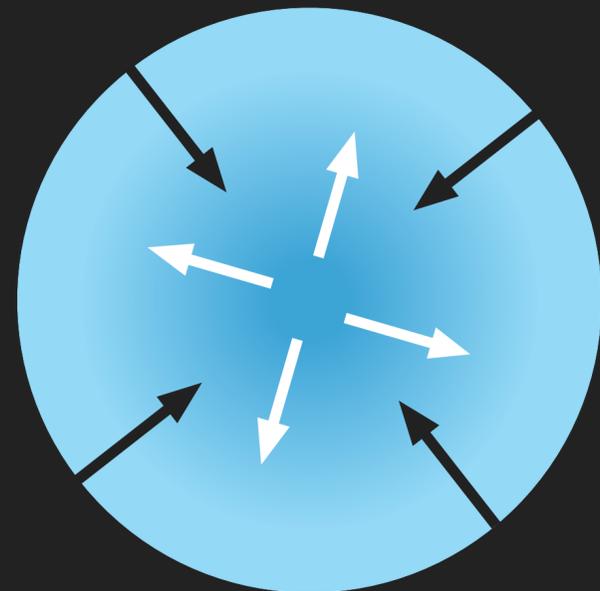
# Core-Collapse Supernovae

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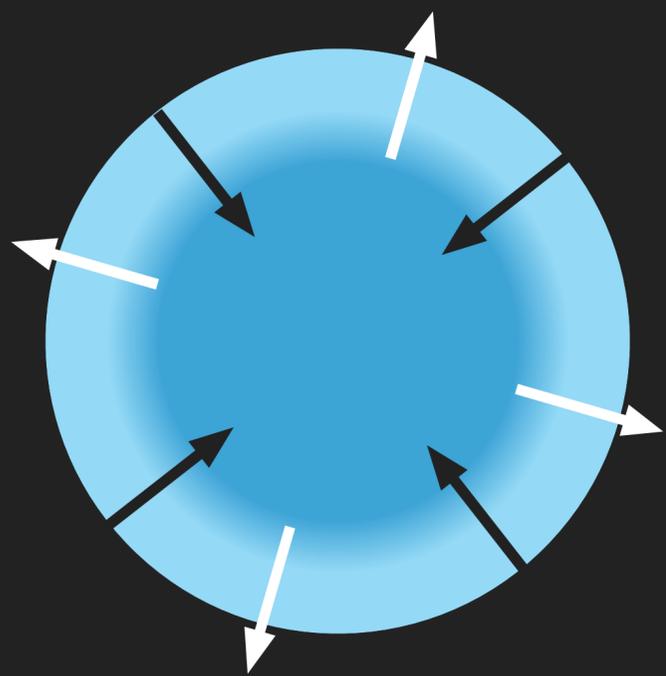
## What?



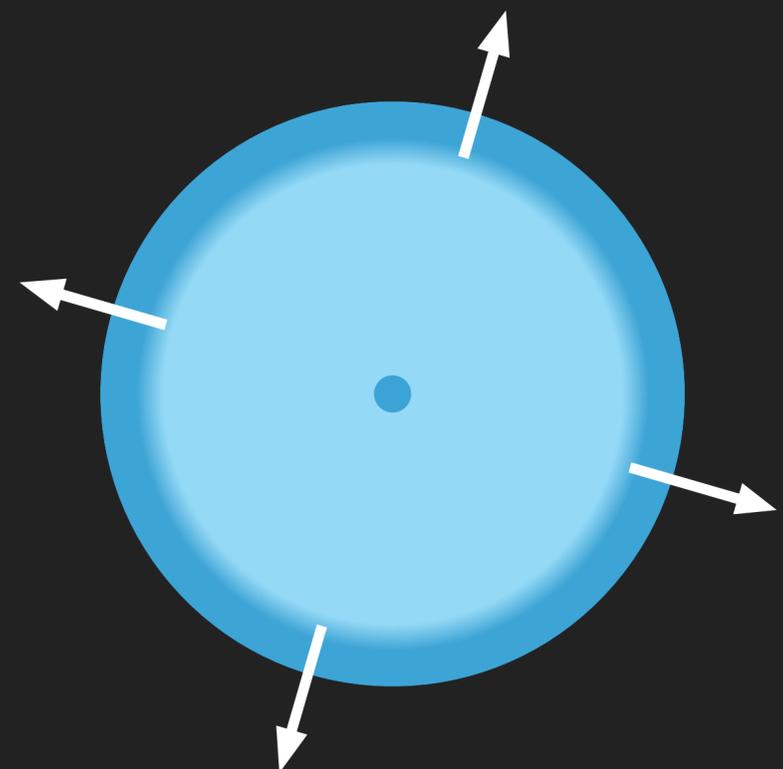
Collapse of the Iron core.  
Neutronization of the nucleus  
via photo-disintegration and  
inverse beta-decays.



Neutron degeneracy stops  
the collapse.  
Nuclear density is in the core.  
Proto-neutron star forms.  
Rebounce of the infalling  
material triggers shock  
waves.



Shock waves fed by  
neutrino radiation from  
the cooling neutron star.



Shock waves move  
outside ejecting the  
material surrounding  
the core.

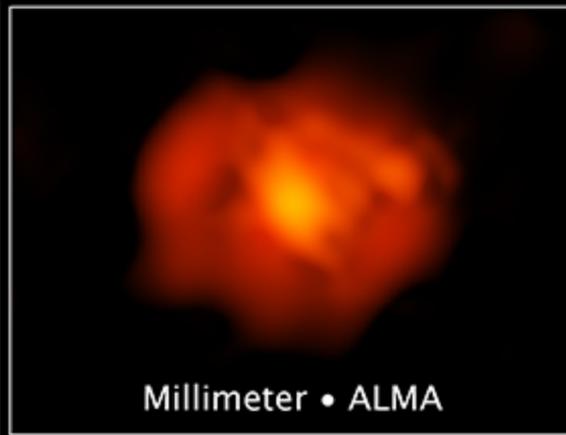
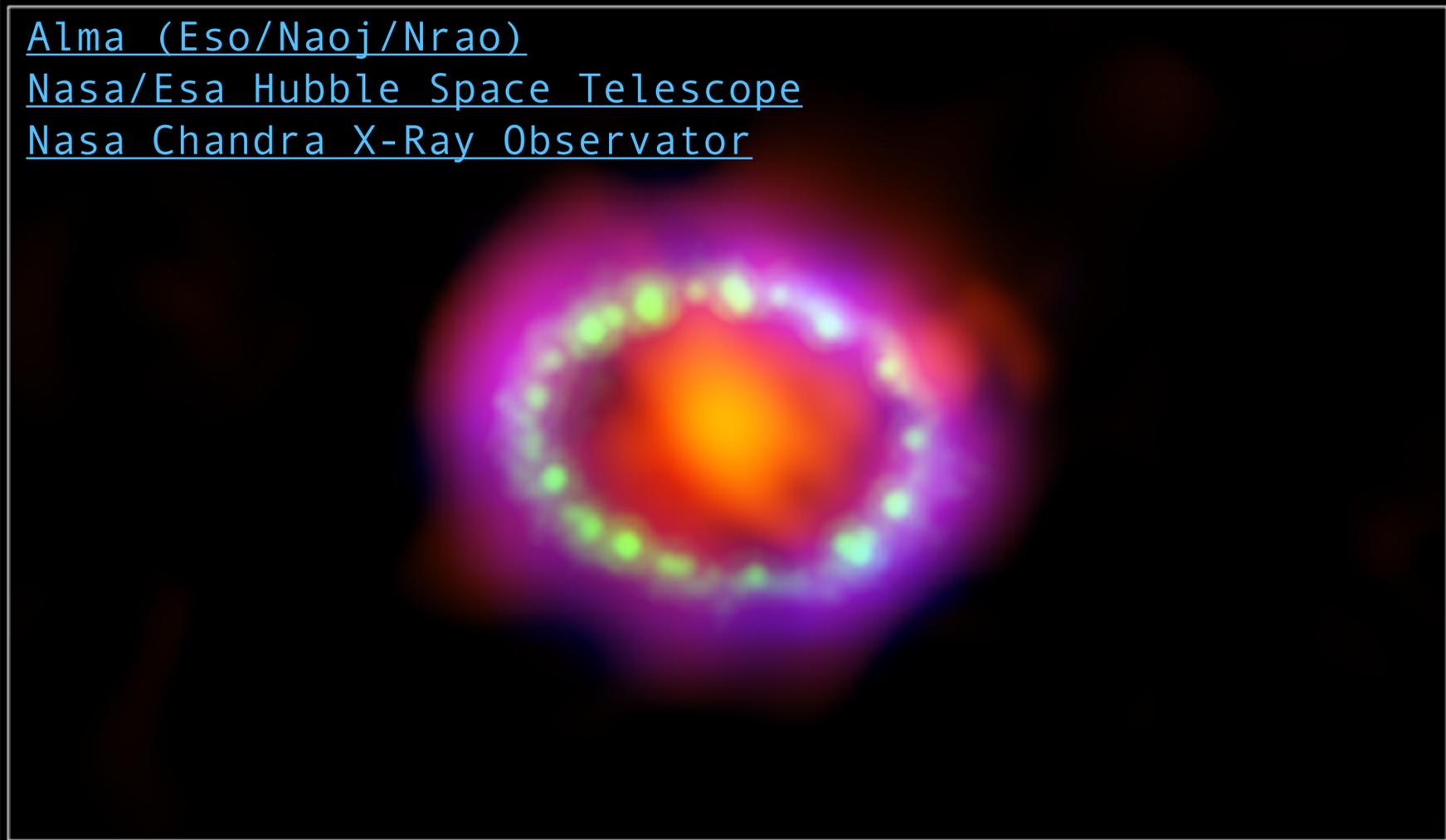
# Core-Collapse Supernovae

## Why?

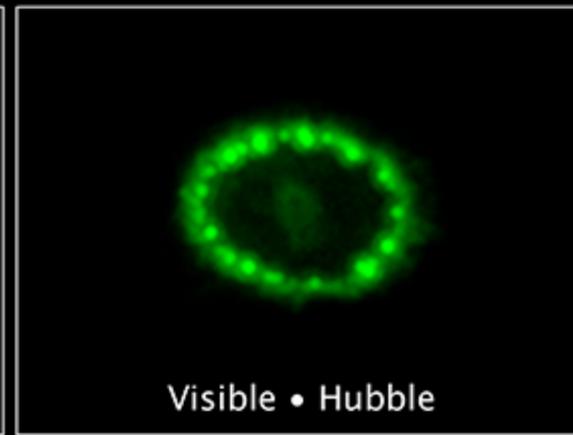
## 1 Already observed!

Neutrino signal from SN1987A  
Giulia Pagliaroli (LNGS) & Matteo Ballelli (GSSI)

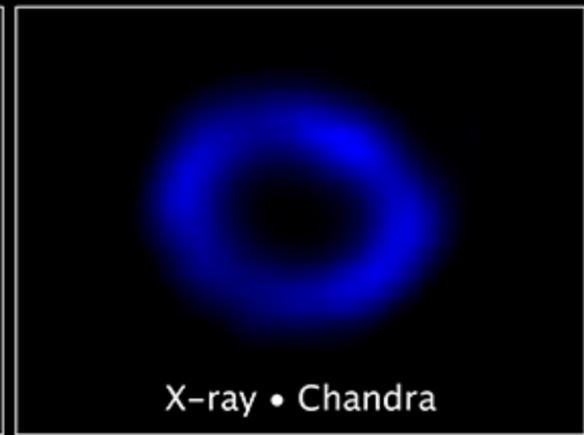
Alma (Eso/Naoj/Nrao)  
Nasa/Esa Hubble Space Telescope  
Nasa Chandra X-Ray Observator



Millimeter • ALMA



Visible • Hubble



X-ray • Chandra

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## 2 Neutrinos factories...

~99% energy released through neutrinos fluxes



Large emission of  $\mathcal{O}(10 \text{ MeV})$   
neutrinos within  $\mathcal{O}(10 \text{ s})!$



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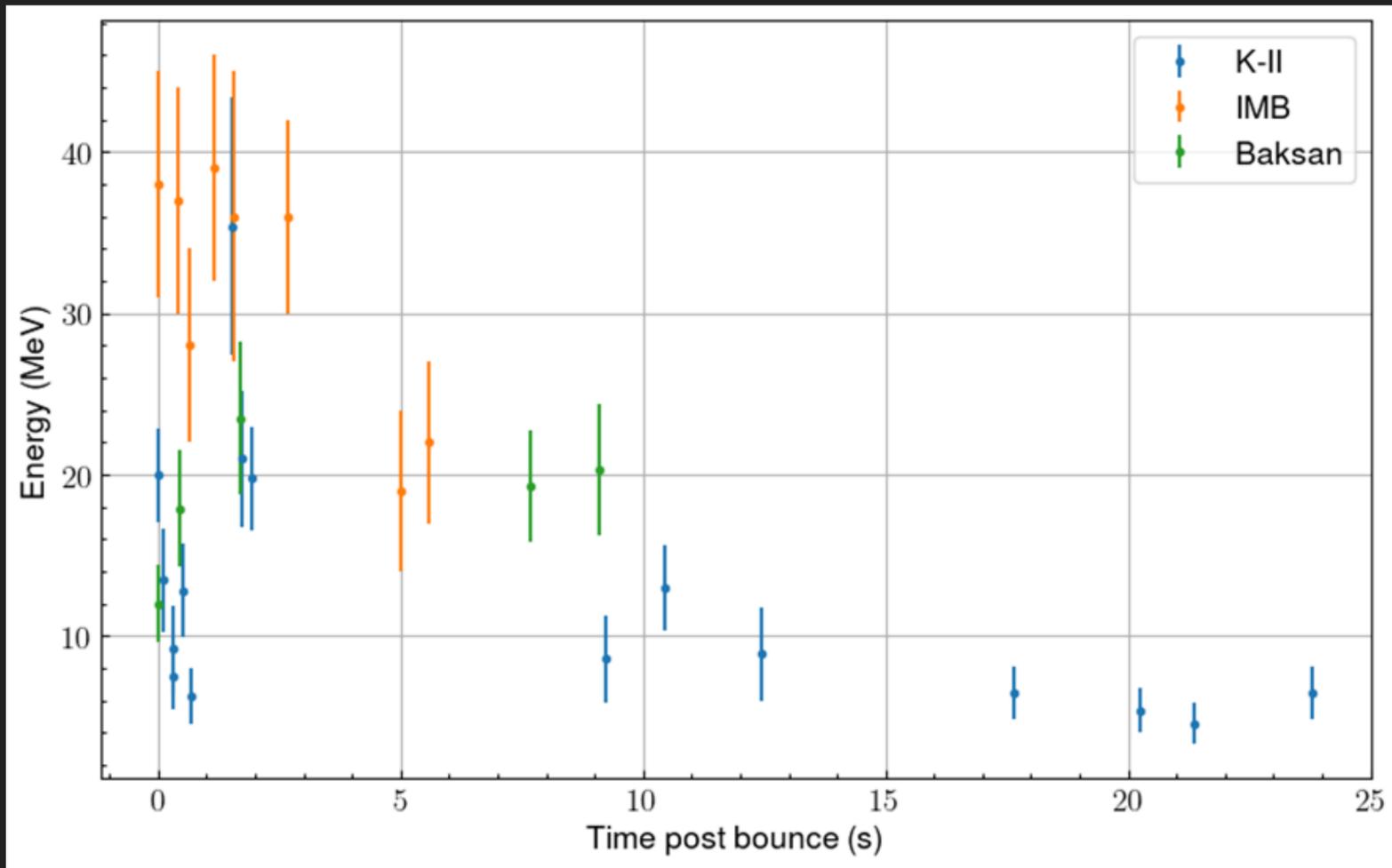
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## 3 Multimessenger Cosmic Laboratories

Unique opportunity to study interactions of elementary particles under extreme condition within a multimessenger context



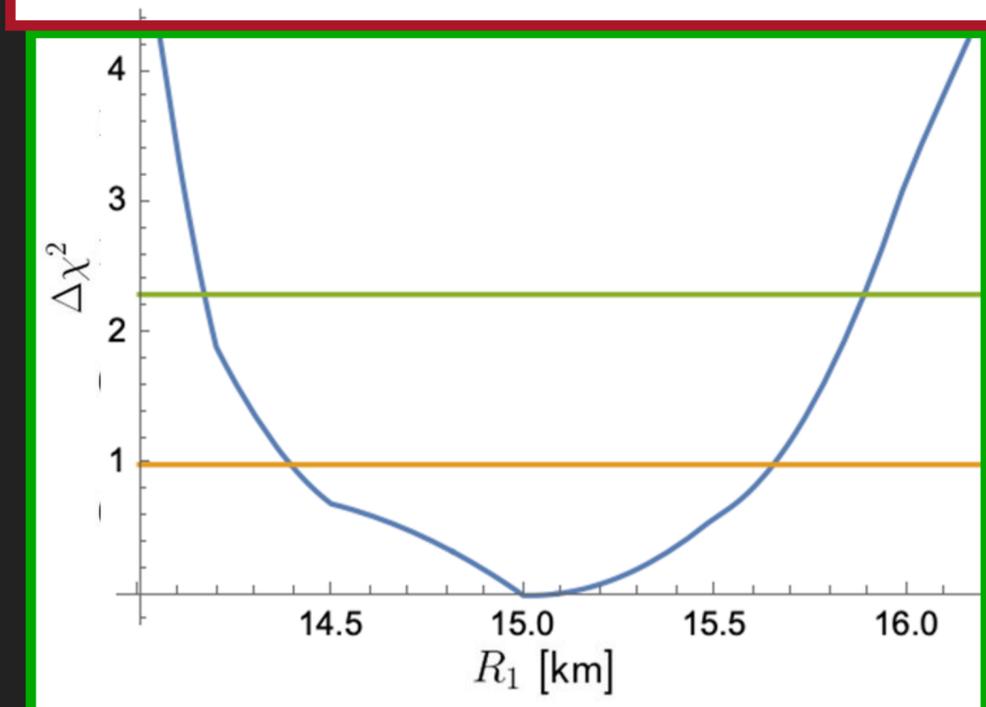
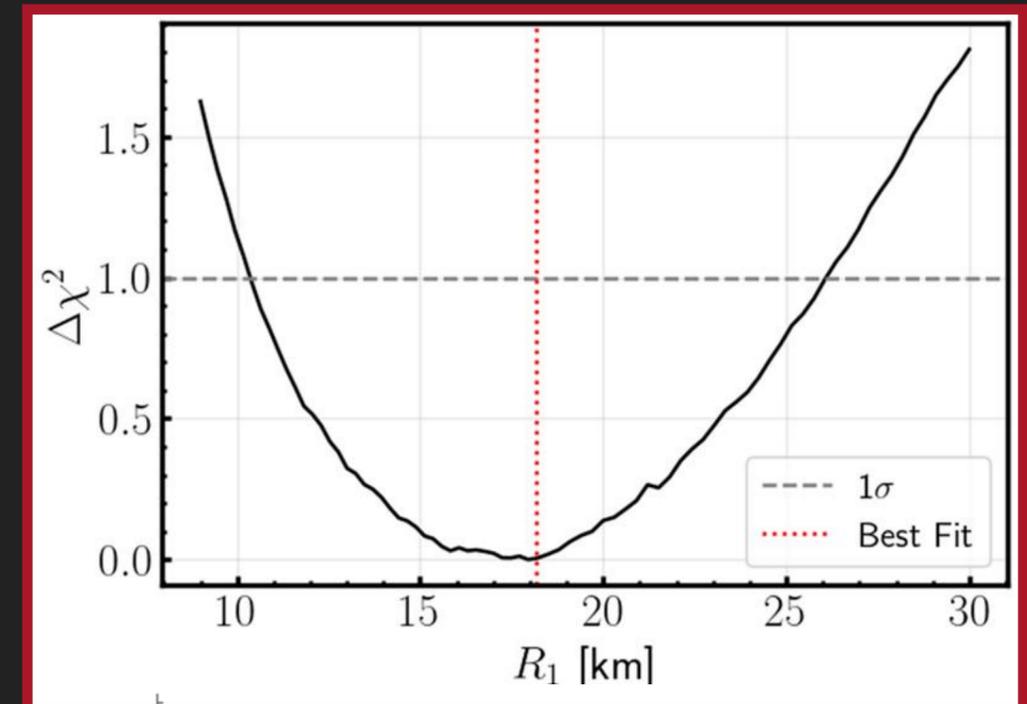
## Hints for **MODELING** and **SIMULATIONS**



Giulia Pagliaroli (LNGS) & Matteo Ballelli (GSSI)

## Interesting observables in the multimessenger era

Proton-neutron-star radius



## SN@LNGS

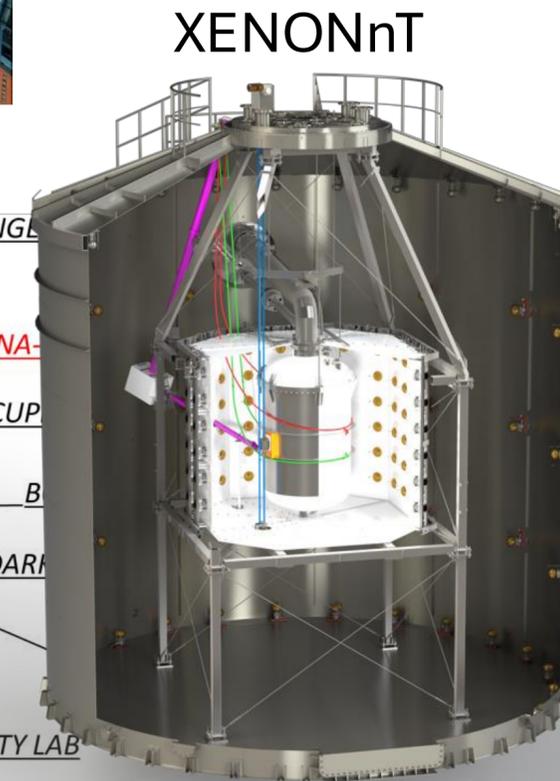
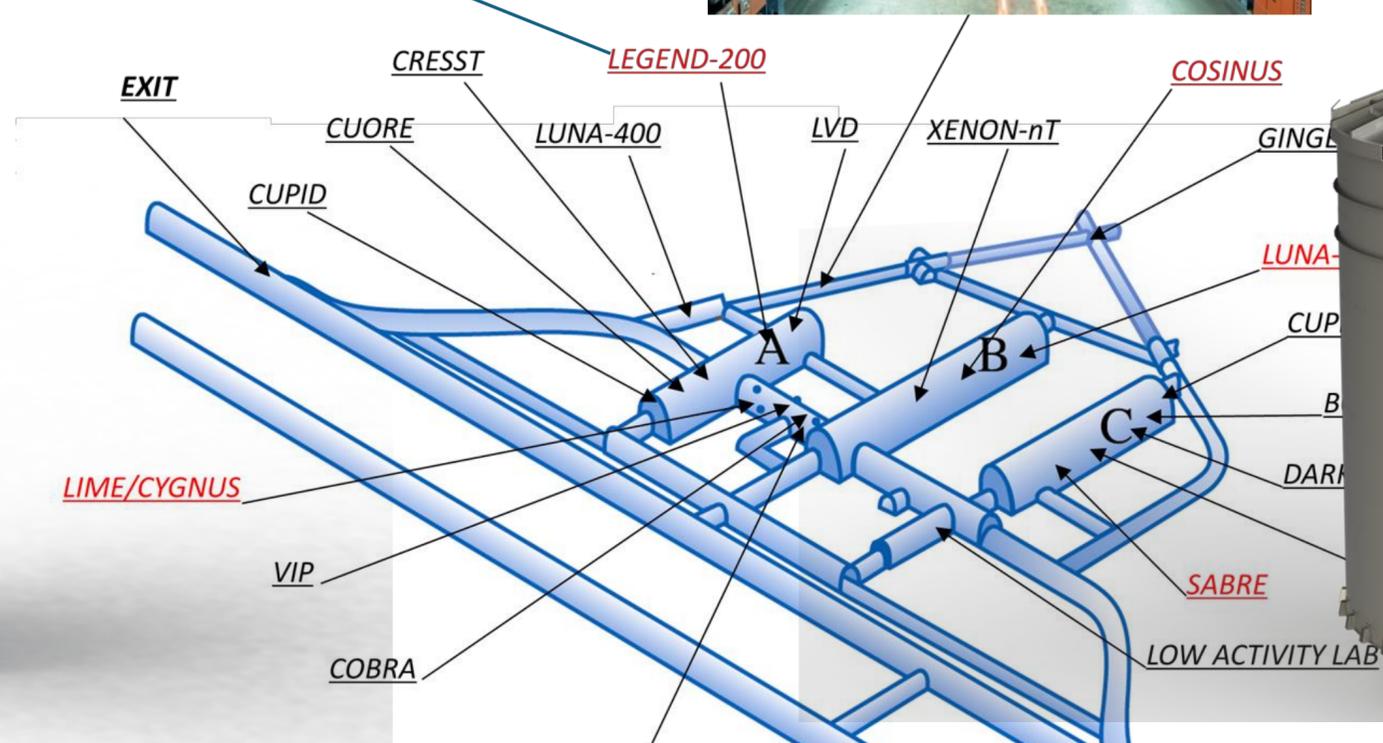
LVD (293 events)



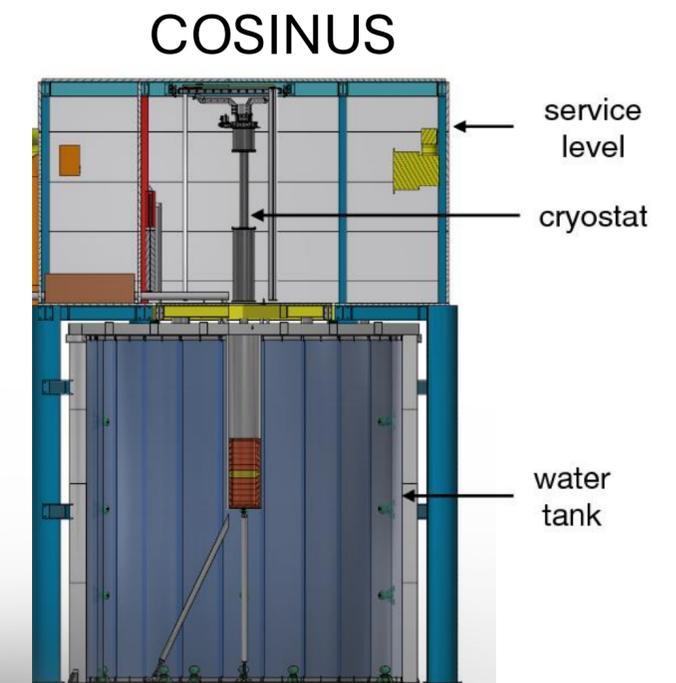
SN@10 kpc -> H2O IBD and NO  
 XENONnT (700 ton) = 167  
 LEGEND 200 (590 ton) = 140  
 COSINUS (270 ton) = 64



LEGEND-200



XENONnT

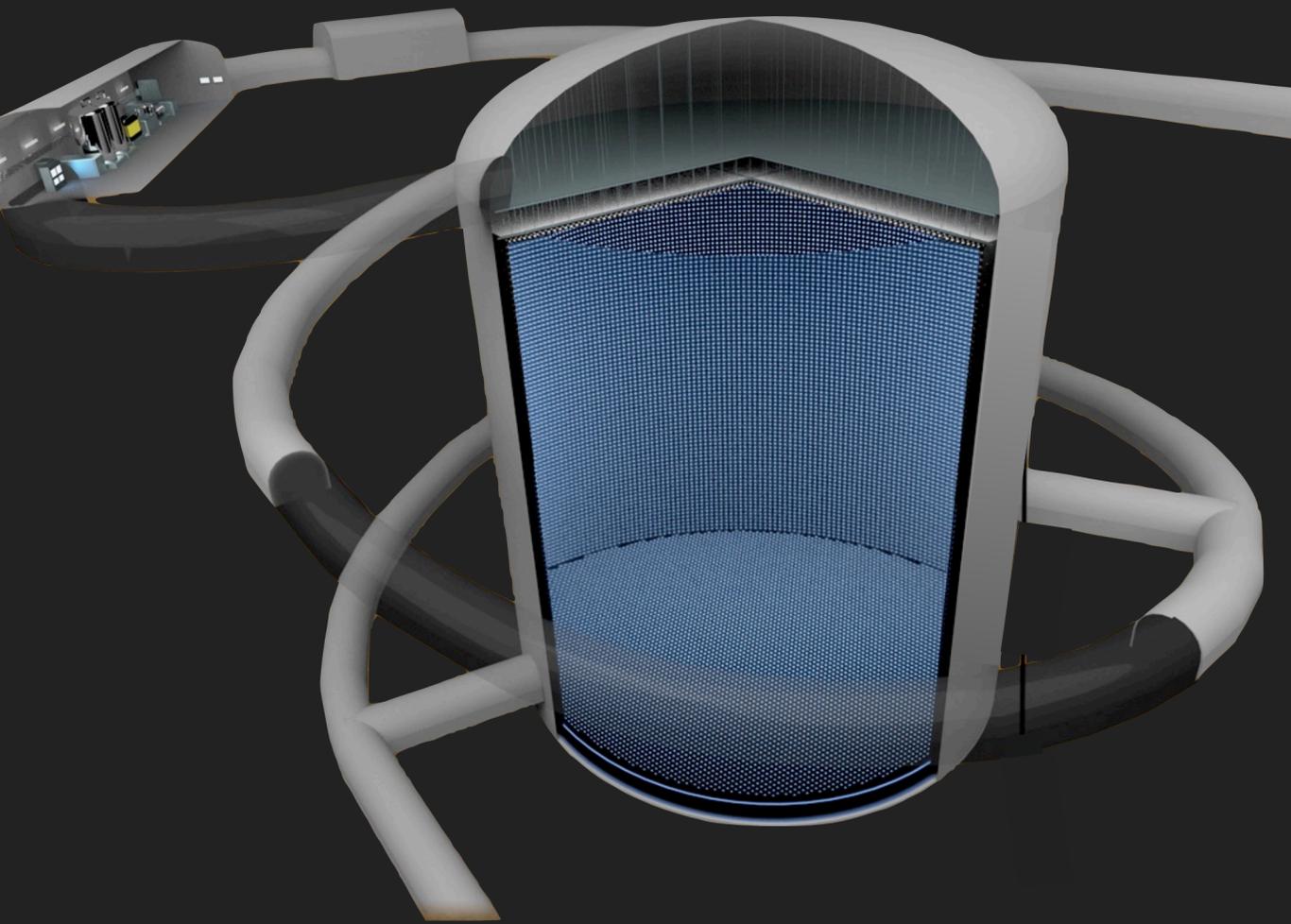


COSINUS

An infrastructure with several detectors sensitive to SN neutrinos: an interesting network of different detectors located in the same place. Combined Horizon: LMC. Very high duty cycle and fast coincidence in time (ms).

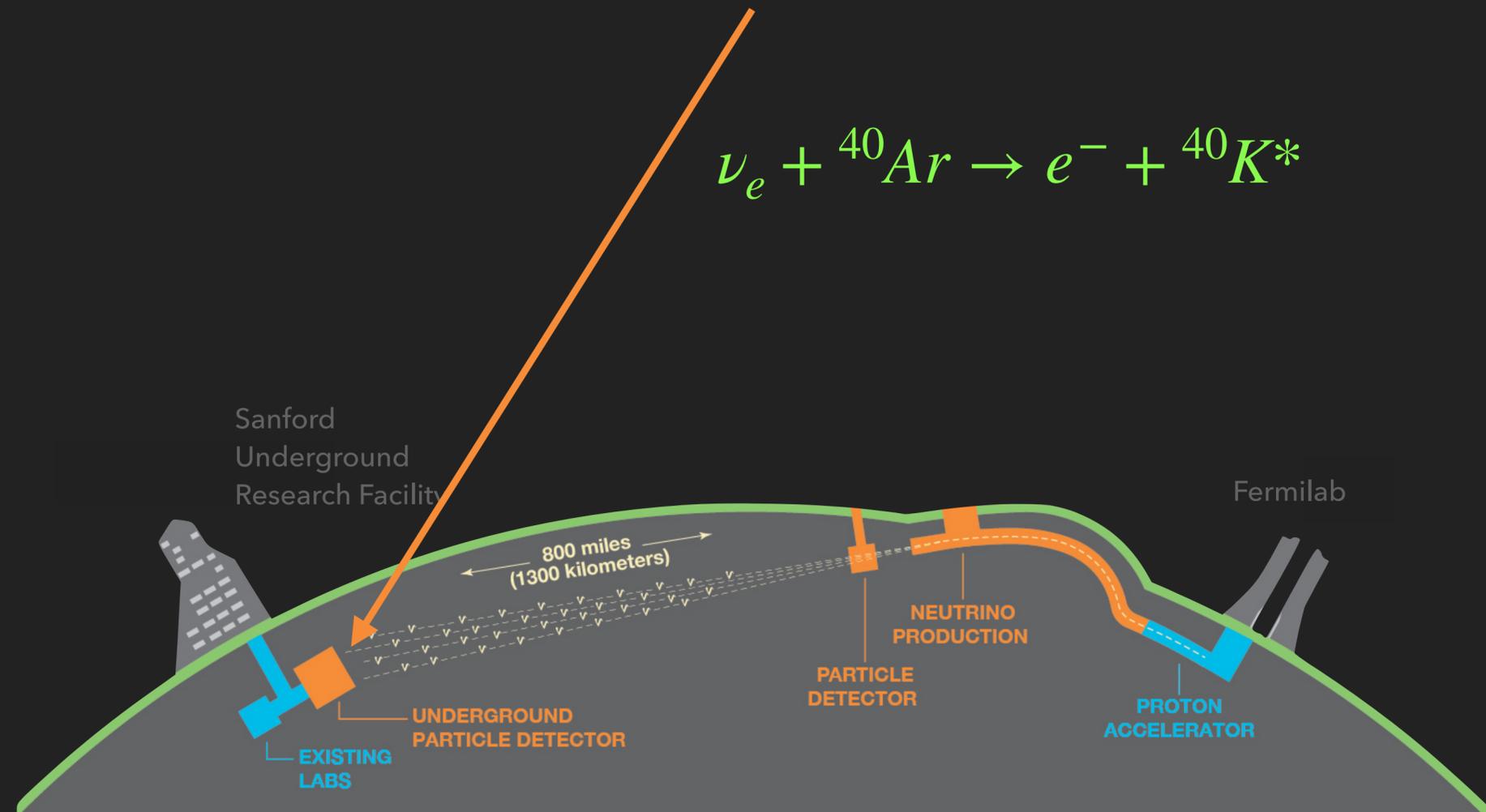
## HYPER-KAMIOKANDE (HYPER-K)

Water Cherenkov detector



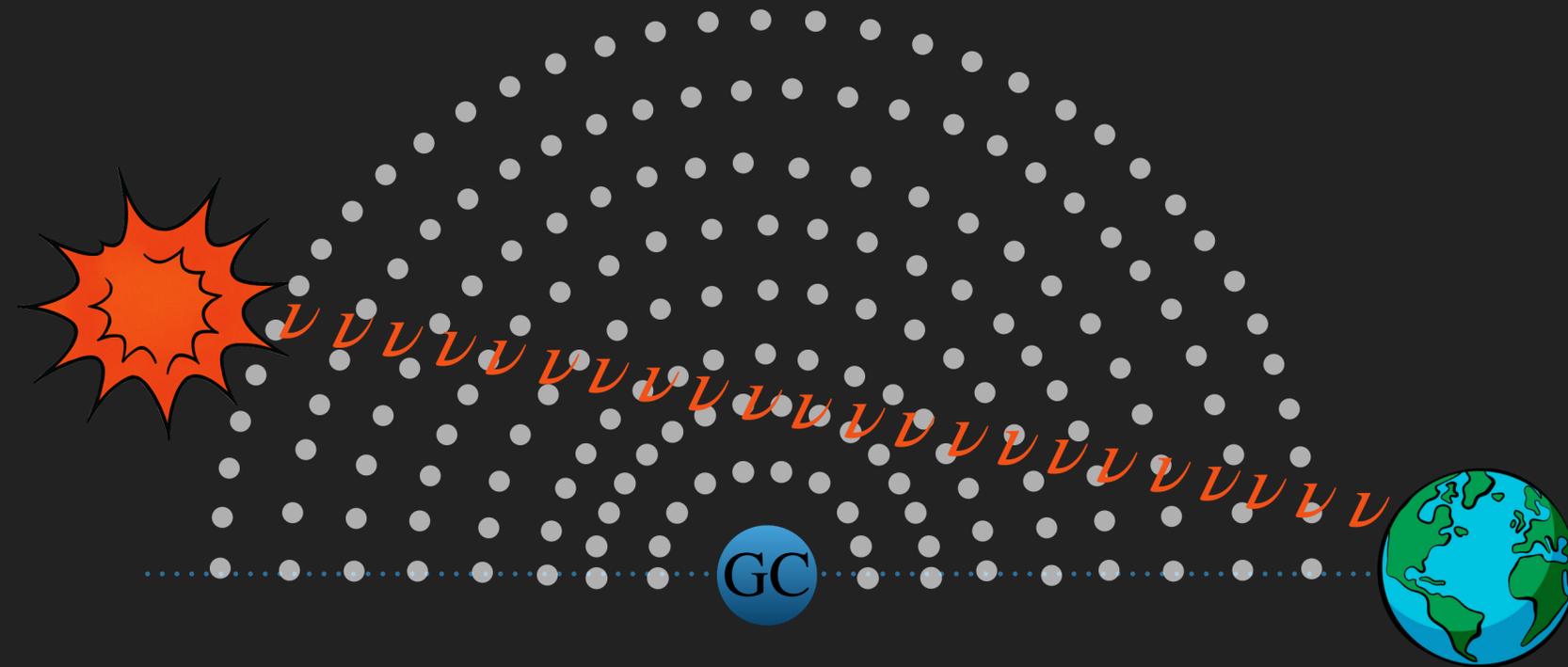
## DEEP UNDERGROUND NEUTRINO EXPERIMENT (DUNE)

Far detector: Liquid-Argon Time-Projection Chamber

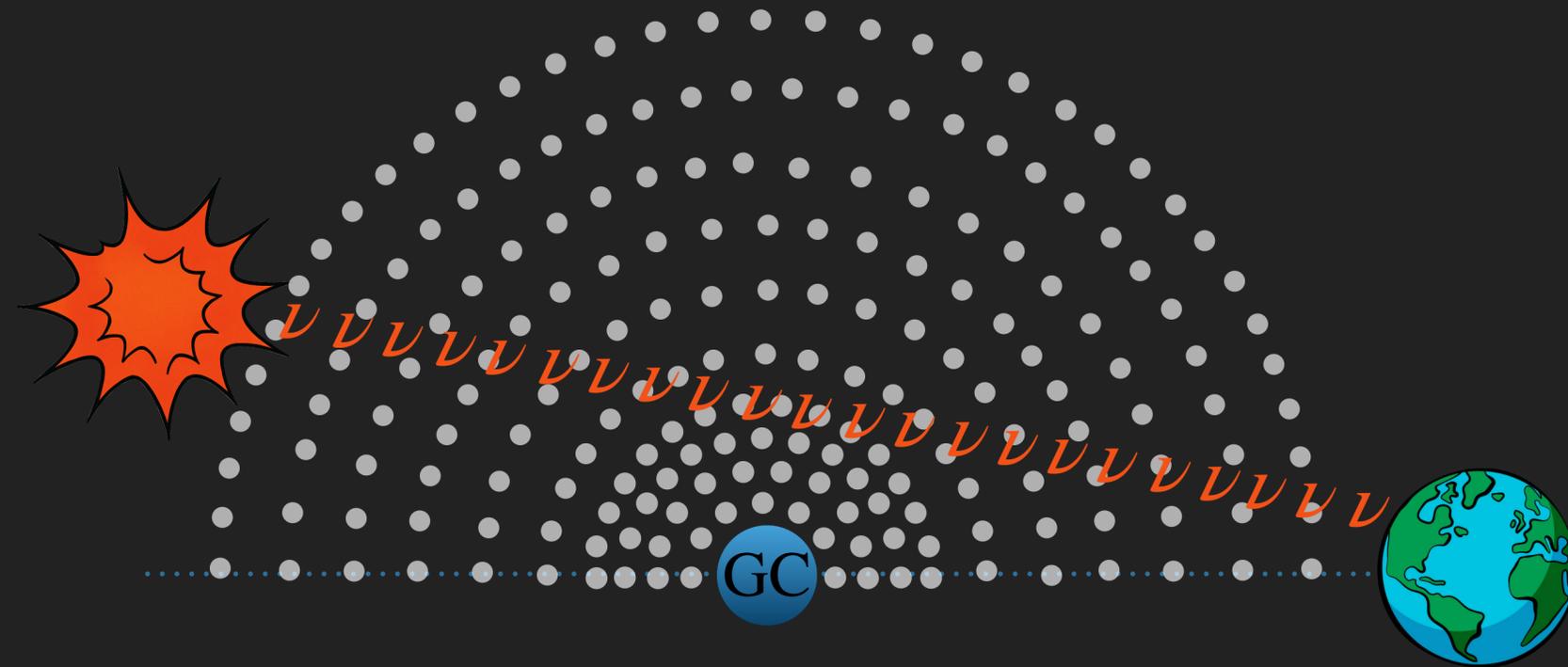




$$\Delta t_{\text{vac}} = \frac{D}{2} \left( \frac{m_\nu}{E_\nu} \right)^2$$



$$\Delta t_{\text{dark}} = \frac{D}{2} \left( \frac{m_\nu}{E_\nu} \right)^2 \frac{\overline{\rho_\phi}(r, \varphi, \gamma)}{\rho_\phi(r_\odot)}$$



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