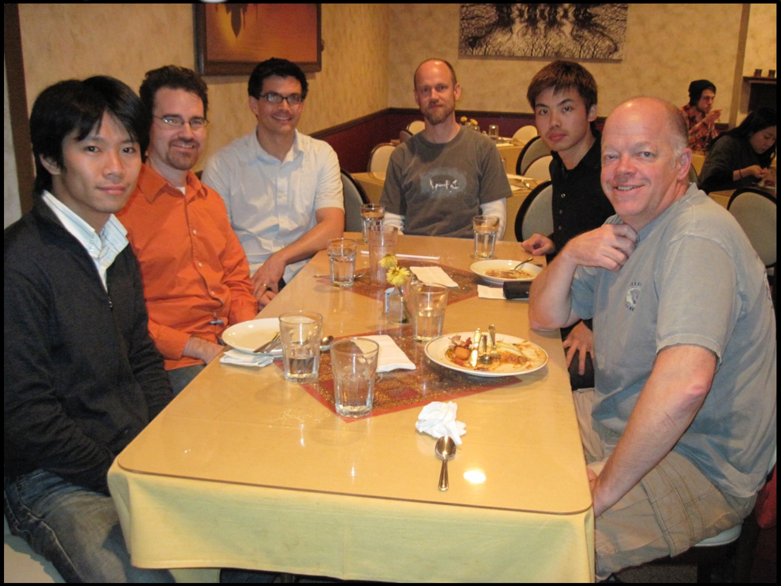
Dawn of High-Energy "Multimessenger" Astrophysics: Right Time, Right Place, and Right People



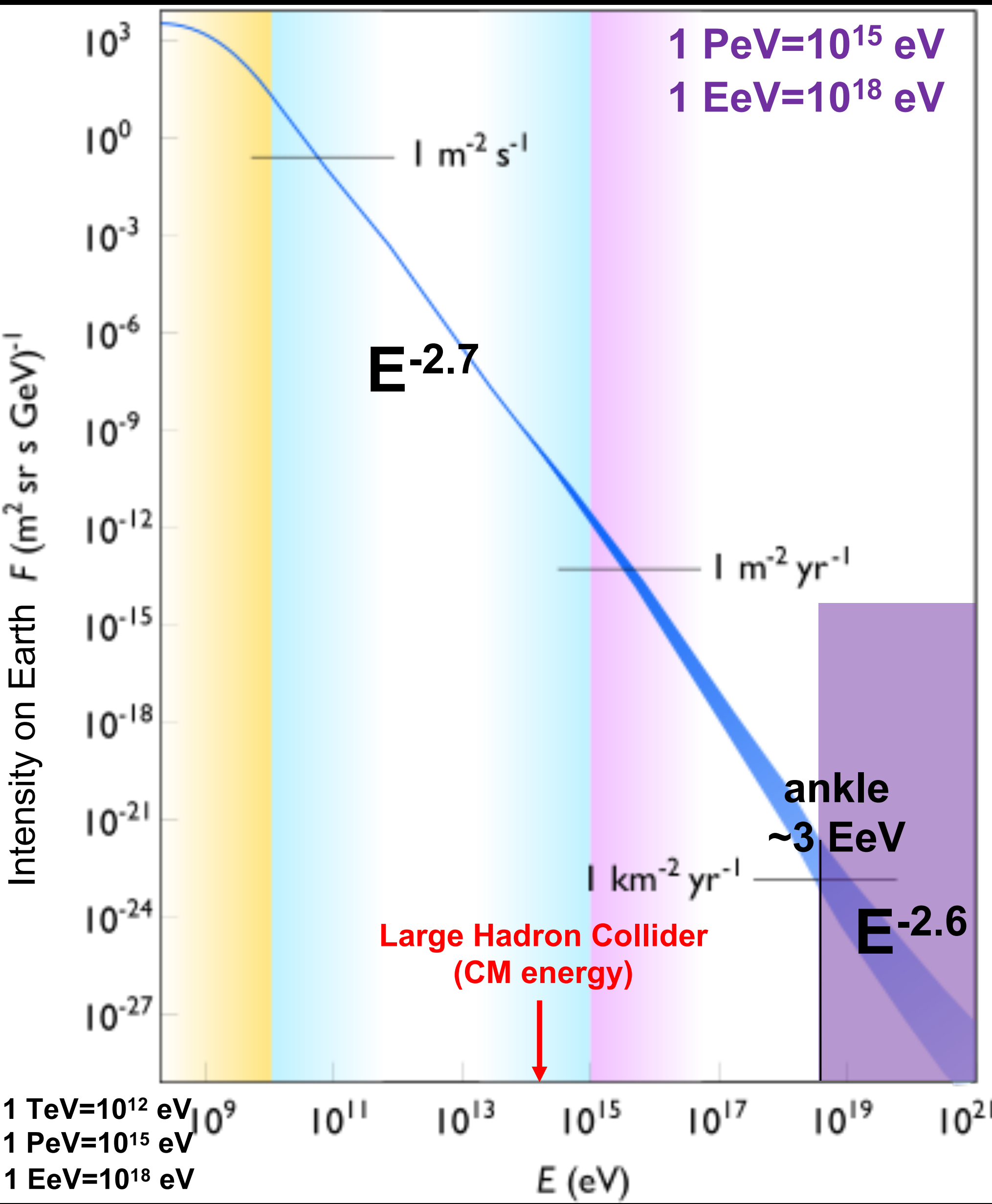
PENNSTATE 1855

Kohta Murase (PSU)
(CCAPP Fellow in 2010-2012)

June 10
CCAPP's 20th Anniversary Conference

NSF

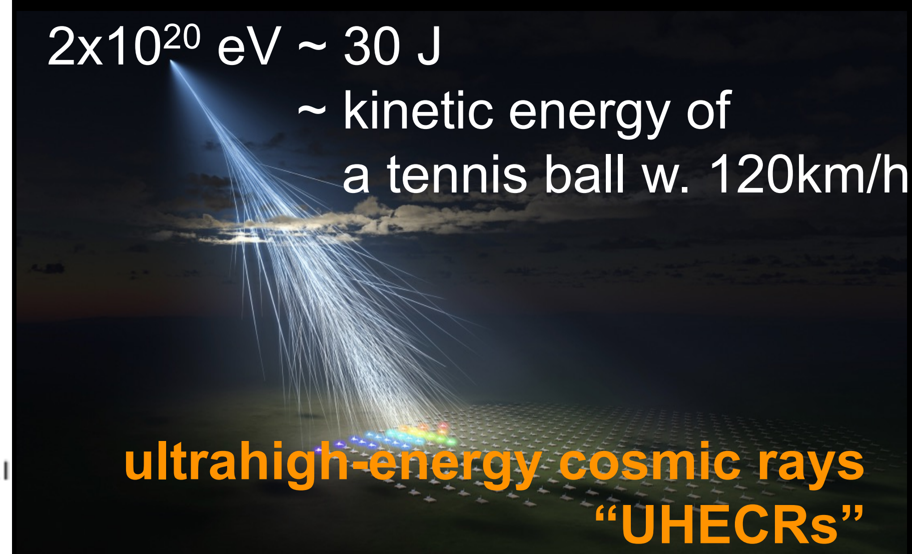
Cosmic-Ray Origin – A Century Old Puzzle



power-law spectrum

$$\frac{dN_{\rm CR}}{dE} \propto E^{-s_{\rm CR}}$$

acceleration mechanisms?
propagation processes?



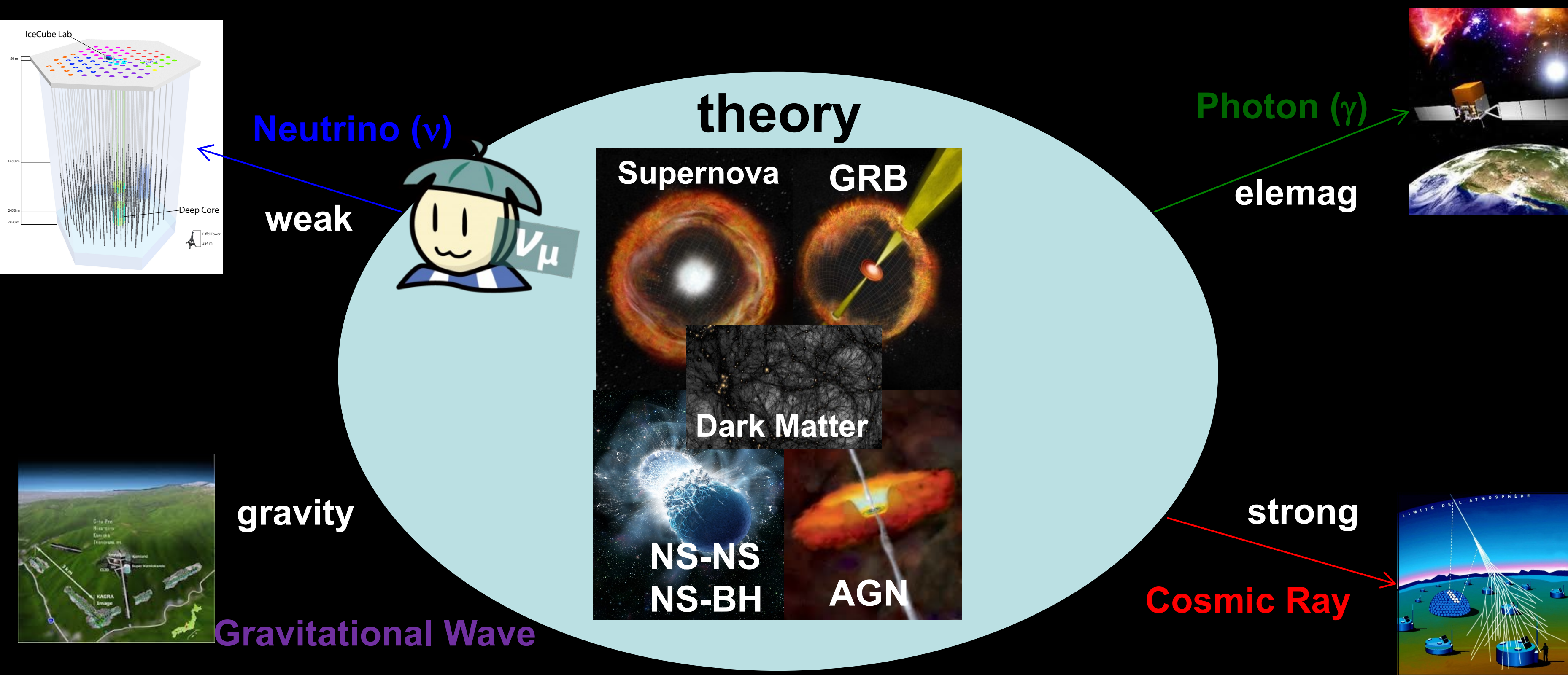
High-Energy Multimessenger Astrophysics

Extremely energetic particles need "extreme accelerators"

Our Universe is dynamic and full of nonthermal phenomena

ex.1 HE neutrinos and γ rays as a probe of cosmic-ray physics

ex.2 HE neutrinos and γ rays as a probe of dark matter annihilation/decay



Not just more data: theory-data synergy is essential

My Journey to CCAPP

HIGH-ENERGY NEUTRINOS AND COSMIC RAYS FROM LOW-LUMINOSITY GAMMA-RAY BURSTS?

KOHTA MURASE,[1] KUNIHITO IOKA,[2] SHIGEHIRO NAGATAKI,[1,3] AND TAKASHI NAKAMURA[2]

Received 2006 July 6; accepted 2006 September 15; published 2006 October 9

ABSTRACT

The recently discovered gamma-ray burst GRB 060218/SN 2006aj is classified as an X-ray flash with very long duration driven possibly by a neutron star. Since GRB 060218 is very near, ~140 Mpc, and very dim, the 1 yr observation by *Swift* suggests that the rate of GRB 060218–like events might be very high so that such low-luminosity (LL) GRBs might form a different population from the cosmological high-luminosity (HL) GRBs. We found that the high-energy neutrino background from LL GRBs could be comparable with that from HL GRBs. If each neutrino event is detected by IceCube, later optical-infrared follow-up observations such as those by Subaru and *HST* can possibly identify a Type Ibc supernova associated with LL GRBs, even if gamma rays and X-rays are not observed by *Swift*. This is in a sense a new window from neutrino astronomy, which might enable us to confirm the existence of LL GRBs and to obtain information about their rate and origin. We also suggest that LL GRBs are high-energy gamma-ray and cosmic-ray sources.

Protecting Life in the Milky Way: Metals Keep the GRBs Away

by

K.Z. Stanek[1], O.Y. Gnedin[1], J.F. Beacom[2,1], A.P. Gould[1], J.A. Johnson[1], J.A. Kollmeier[1], M. Modjaz[3], M.H. Pinsonneault[1], R. Pogge[1] and D.H. Weinberg[1]

[1] Dept. of Astronomy, The Ohio State University, Columbus, OH 43210
e-mail: (kstanek,ognedin,gould,jaj,jak,pinsono, pogge,dhw)@astronomy.ohio-state.edu
[2] Dept. of Physics, The Ohio State University, Columbus, OH 43210
e-mail: beacom@mps.ohio-state.edu
[3] Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138
e-mail: mmodjaz@cfa.harvard.edu

2006: John sent me comments via email

2007: I met Carsten (postdoc @ PSU)

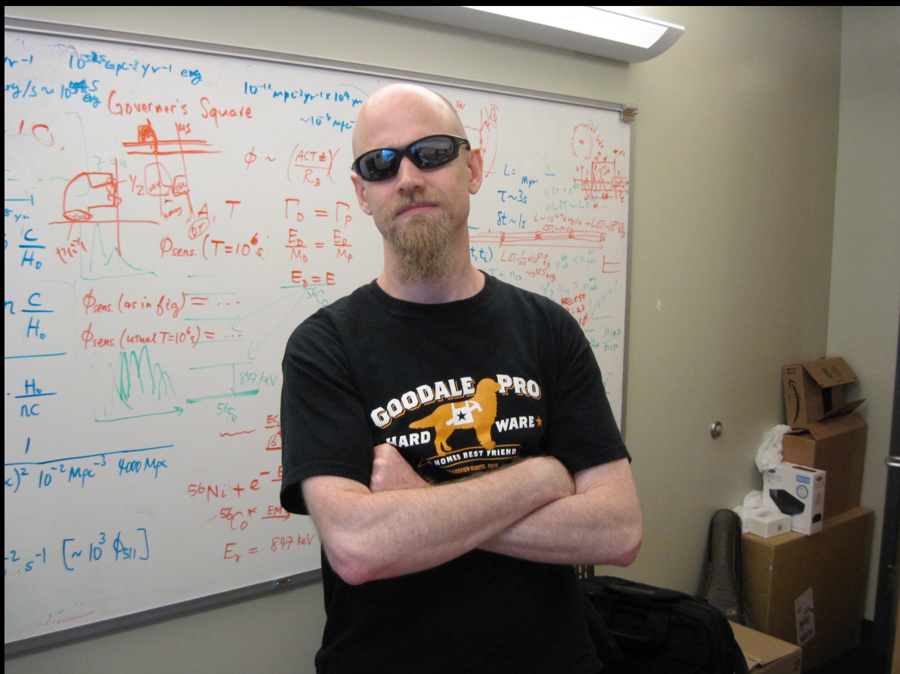
2008: I attended the CCAPP dark-matter workshop and met John in person

2009: I visited CCAPP for 1 month

In Japan, I was sometimes discouraged to work on HE ν astrophysics.
I found CCAPP scientifically attractive, supportive, and encouraging.

Coming to CCAPP

My life and career in the US began at CCAPP in Spring 2010.

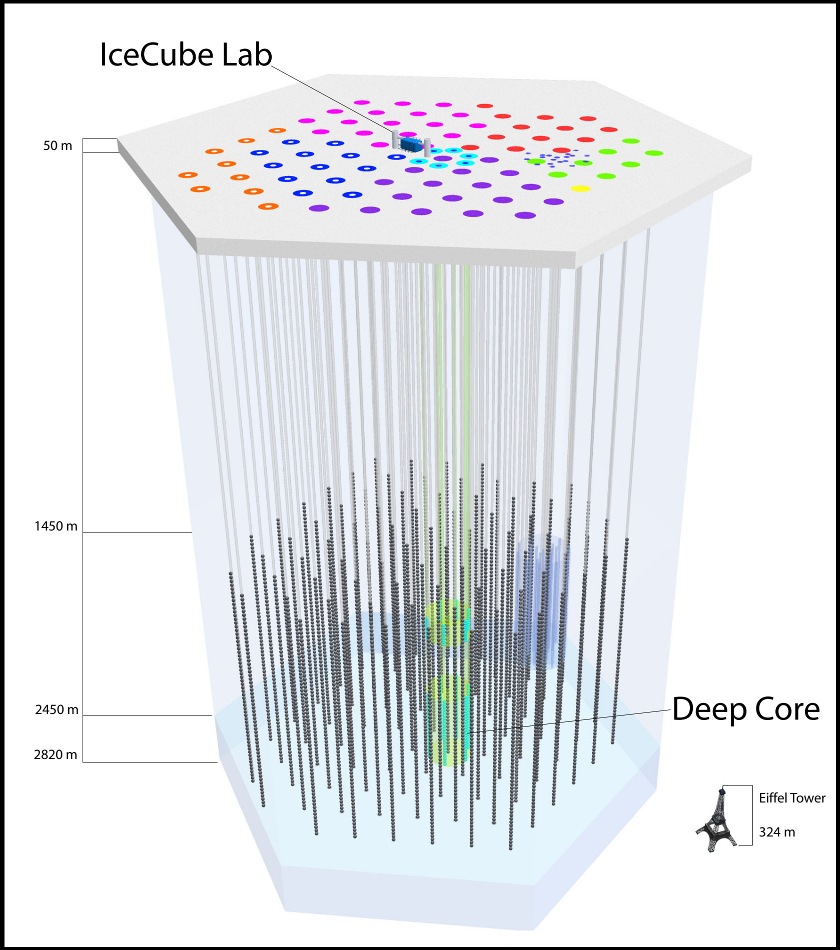


Outstanding colleagues, strong support from CCAPP

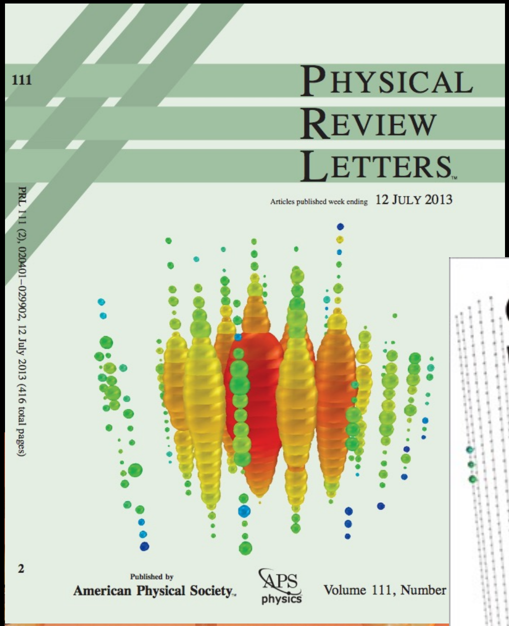
Exchange rate around that time 1 USD ~ 80 JPY (cf. 1 USD ~ 160 JPY now)

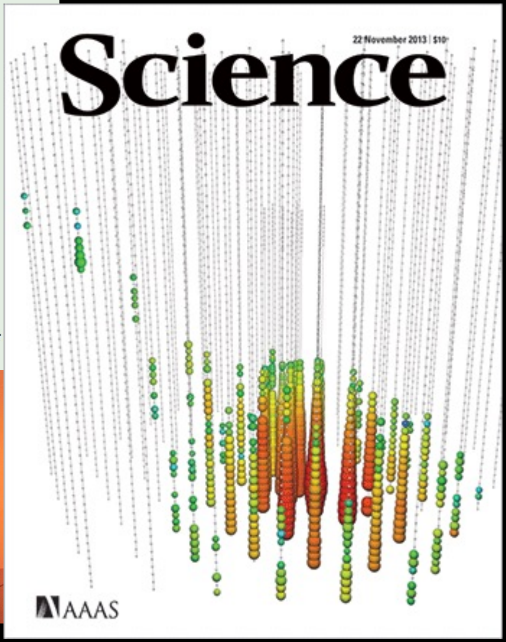
Discovery of High-Energy Cosmic Neutrinos

2010:
IceCube completion



2012-2013: evidence of high-energy cosmic ν

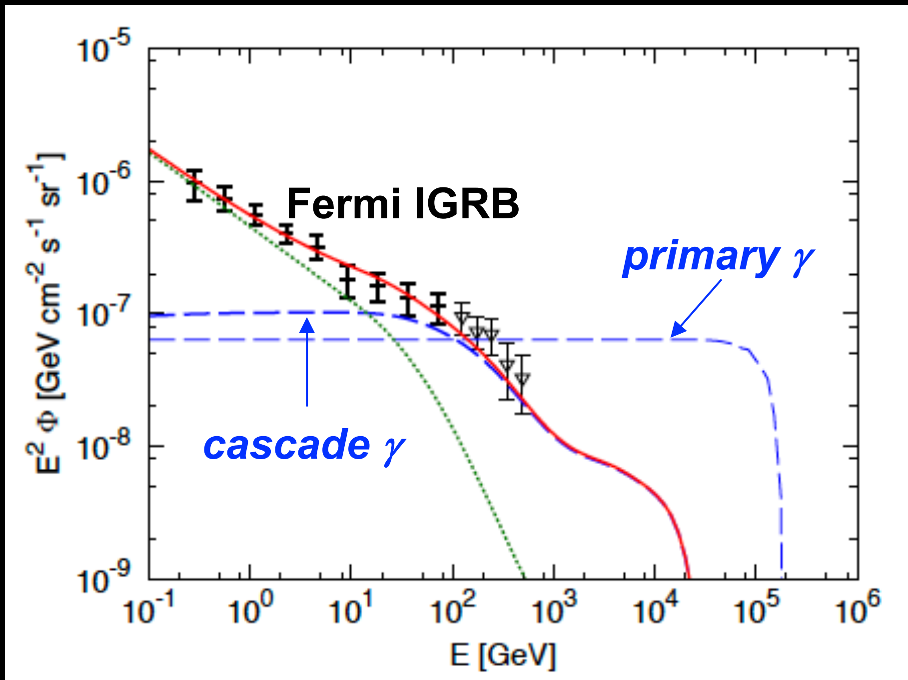




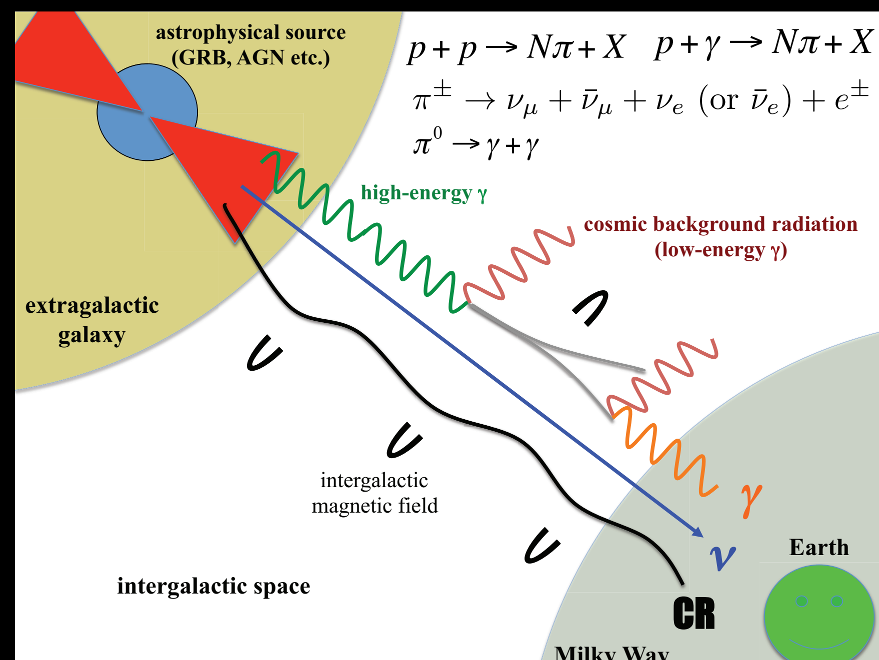
Neutrino 2012 @ Kyoto

Pre-Discovery of HE Cosmic Neutrinos

KM, Beacom & Takami 2012 JCAP

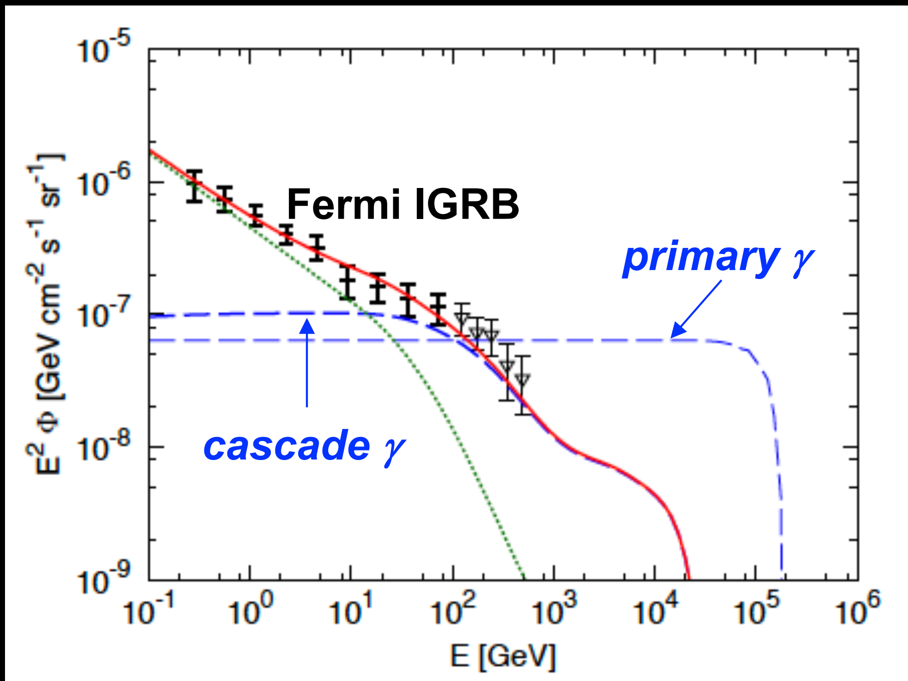


Constraining γ-ray and ν energy generation densities in the Universe using the isotropic γ-ray background and the upper limit on the ν background

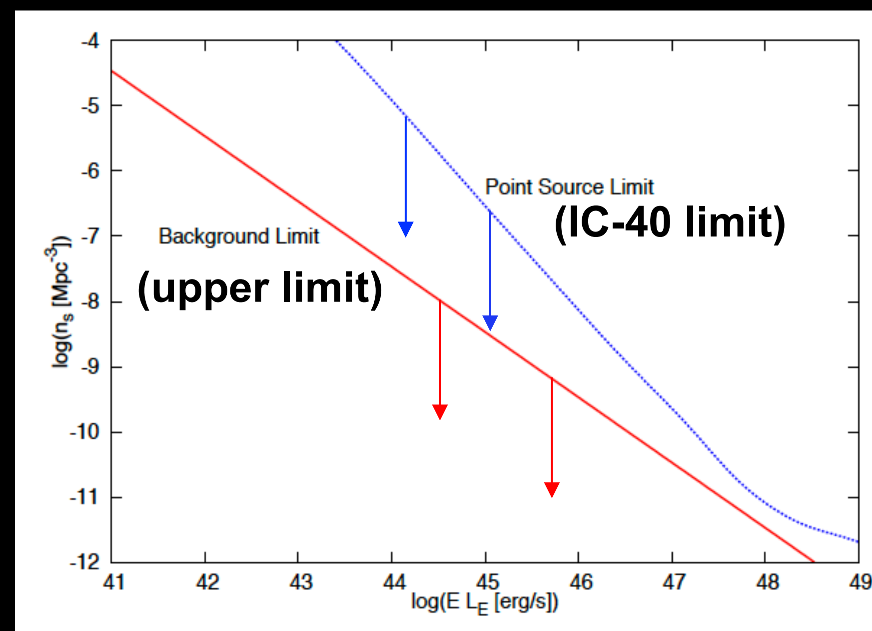


Pre-Discovery of HE Cosmic Neutrinos

KM, Beacom & Takami 2012 JCAP



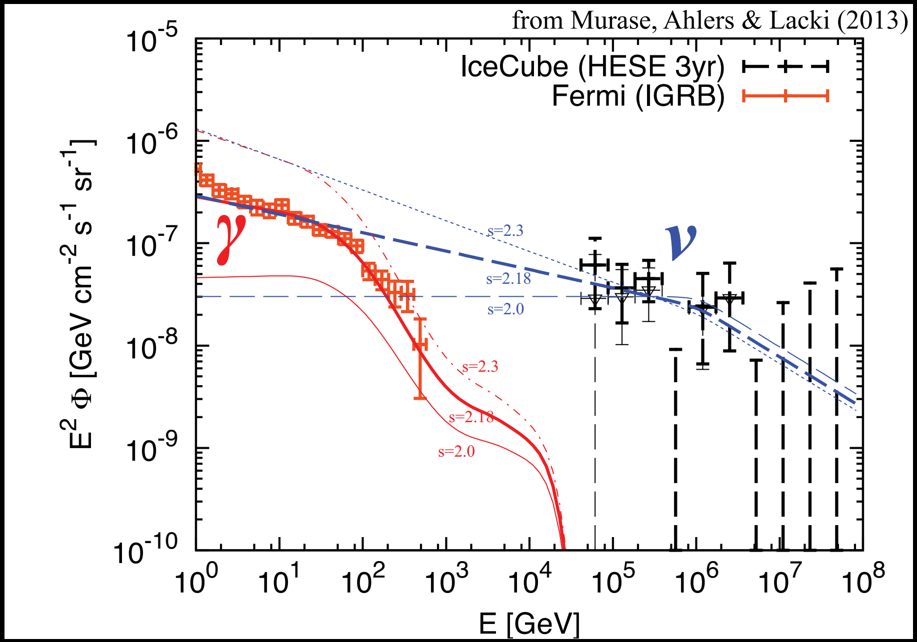
Constraining γ-ray and ν energy generation densities in the Universe using the isotropic γ-ray background and the upper limit on the ν background



How rare are the brightest ν sources?

→ (weak) constraints on the population of ν sources in the density-luminosity plane

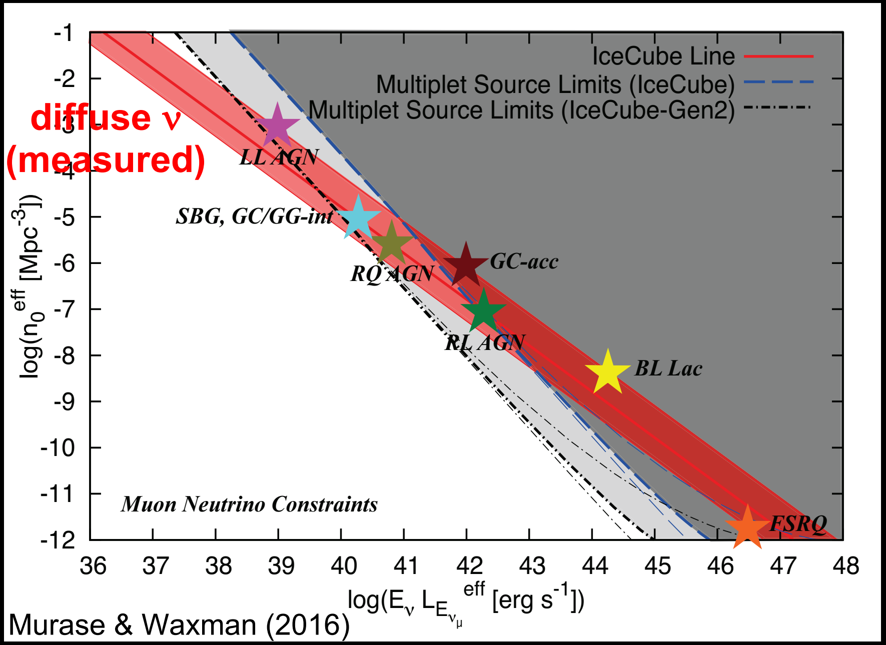
Post-Discovery of HE Cosmic Neutrinos
Power of Multimessenger Analyses



$$\varepsilon_\gamma Q_{\varepsilon_\gamma} \approx \frac{4}{3K}(\varepsilon_\nu Q_{\varepsilon_\nu})|_{\varepsilon_\nu=\varepsilon_\gamma/2}$$

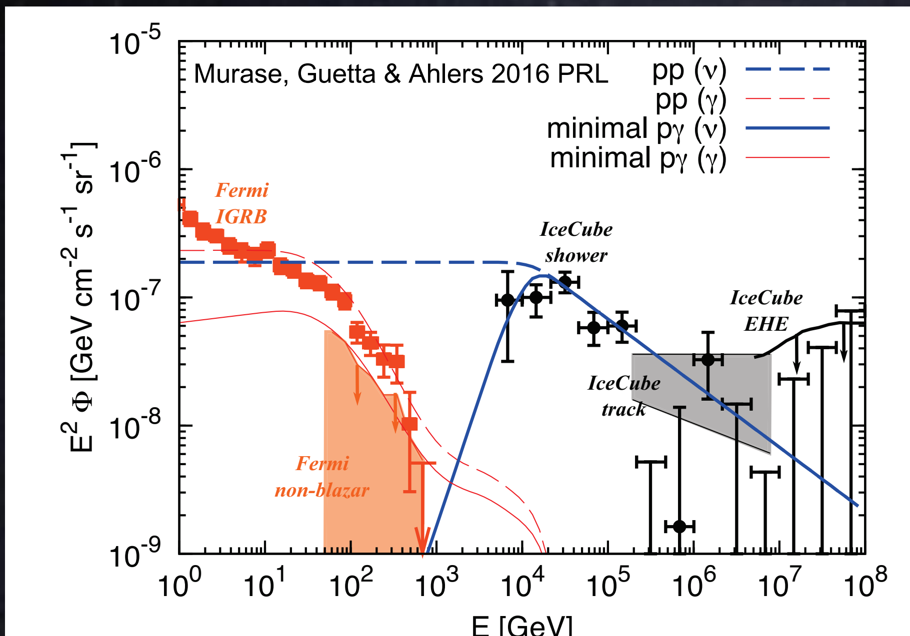
K=1 (pγ), K=2 (pp)

s<2.1-2.2 : stringent constraints on cosmic-ray reservoirs (ex. starbursts)



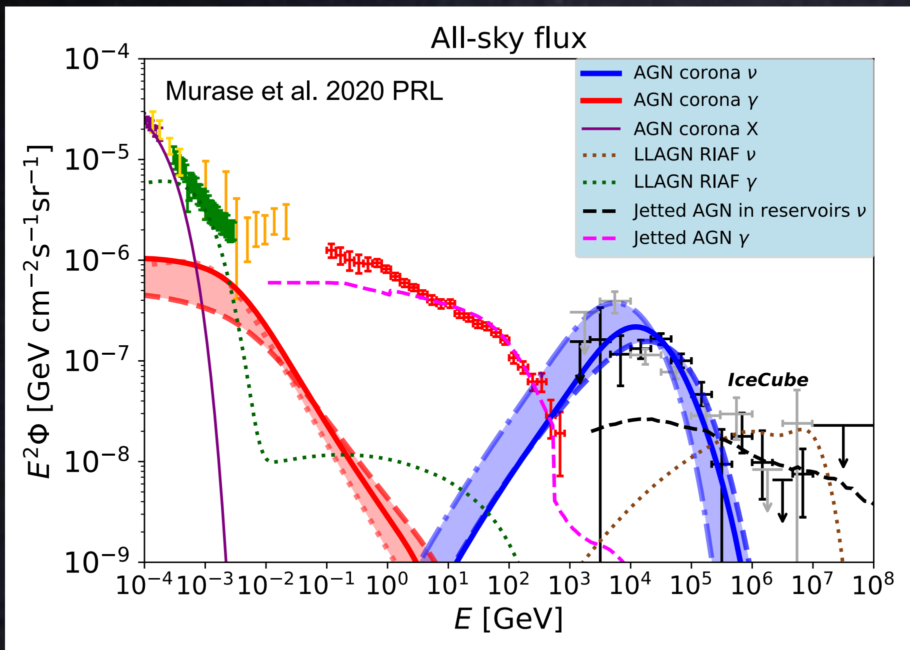
How rare are the brightest ν sources?
→ meaningful constraints from anisotropy
rare sources (ex. blazars): "subdominant"

Where Do HE Cosmic Neutrinos Come from? Multimessenger Clues



Necessity of γ-ray “hidden” ν source population

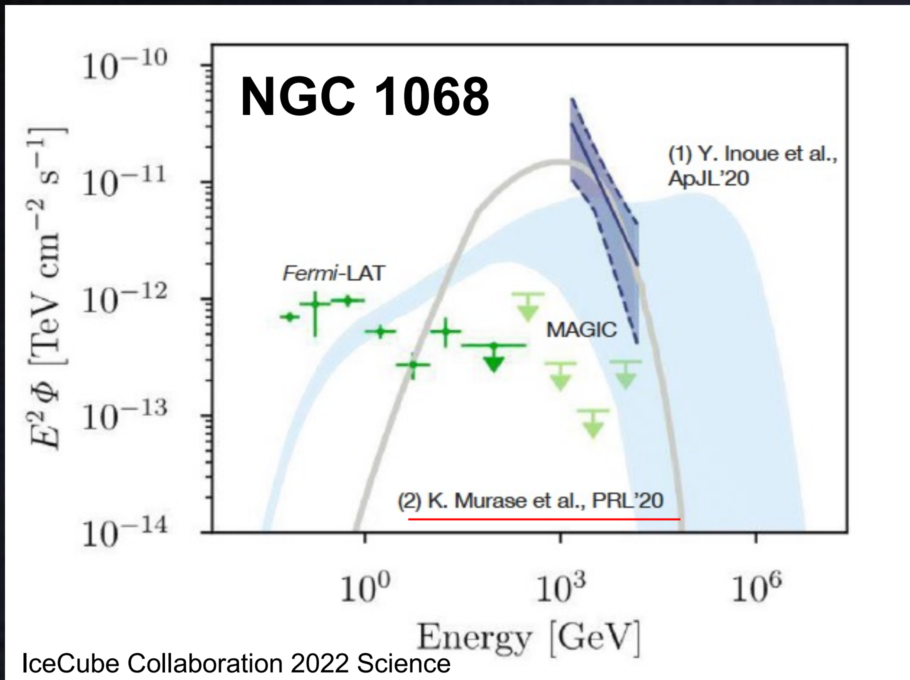
Where Do HE Cosmic Neutrinos Come from? Multimessenger Clues



Vicinity of massive black holes (AGN coronae)

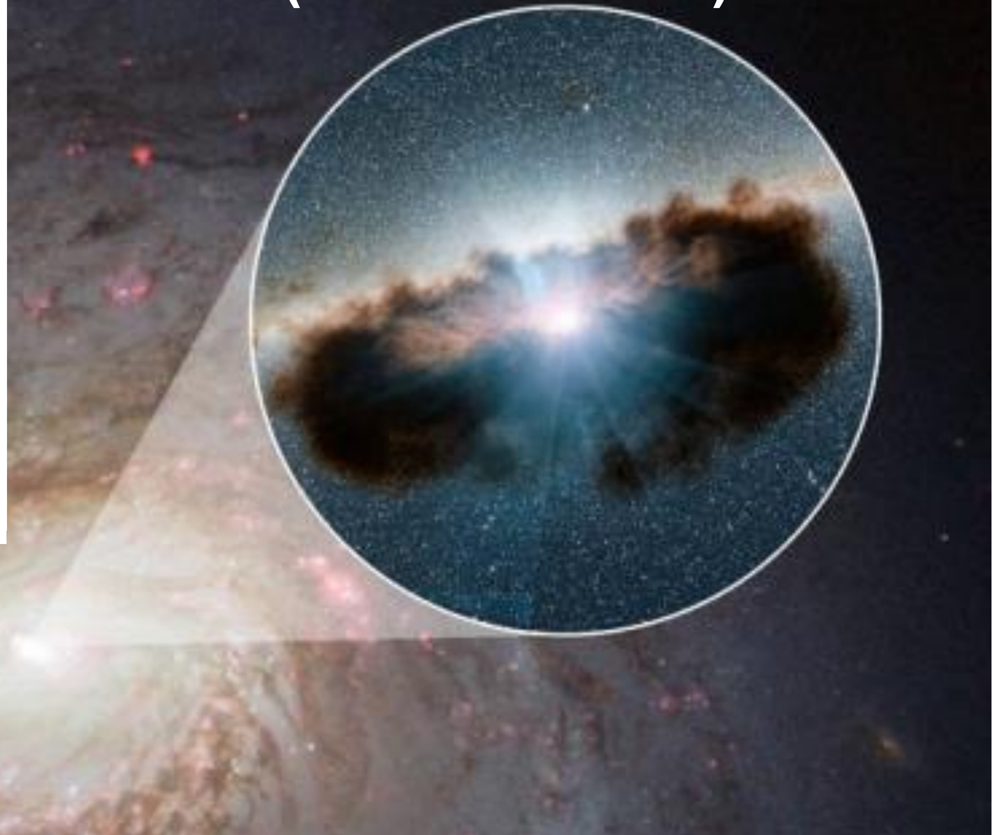
Necessity of γ-ray "hidden" ν source population

Where Do HE Cosmic Neutrinos Come from? Multimessenger Clues



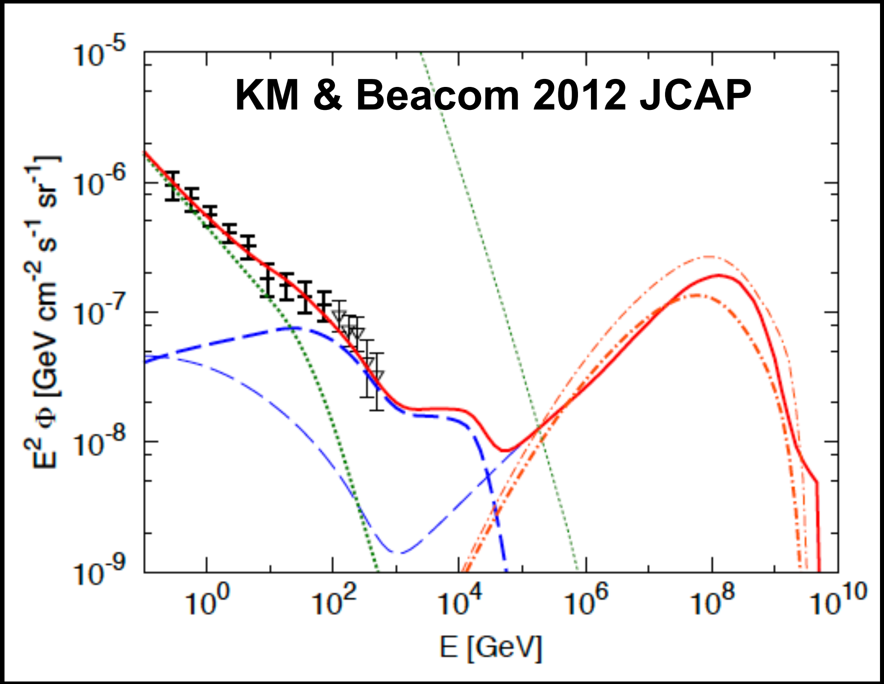
IceCube Collaboration 2022 Science

Vicinity of massive black holes (AGN coronae)



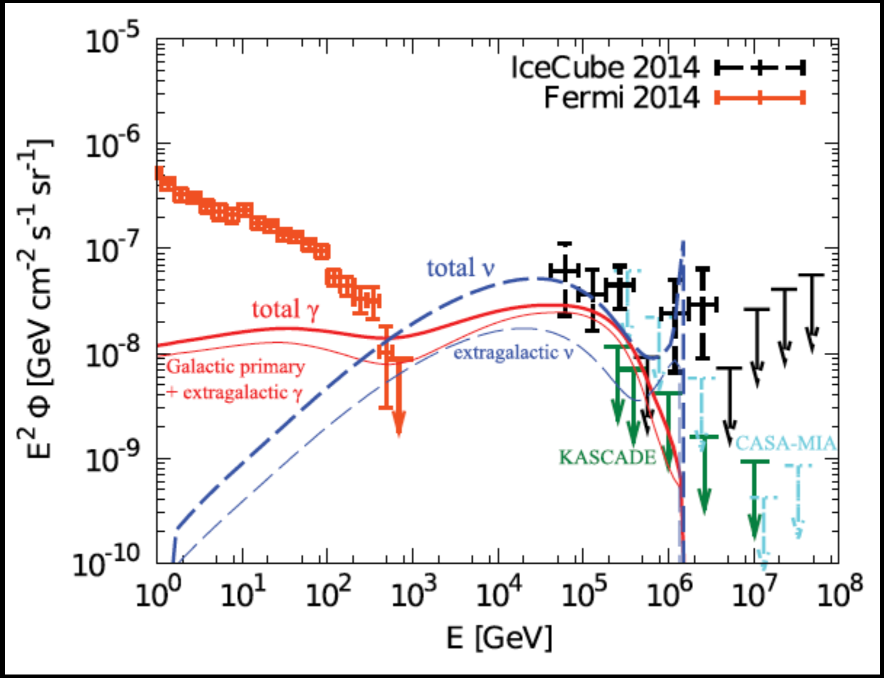
Necessity of γ-ray "hidden" ν source population
→ supported by evidence (4σ) for νs from a nearby AGN

Multimessenger Probes of Heavy Dark Matter



ν and cascade γ-ray constraints on heavy dark matter for masses above TeV (initiated at the 2008 CCAPP workshop)

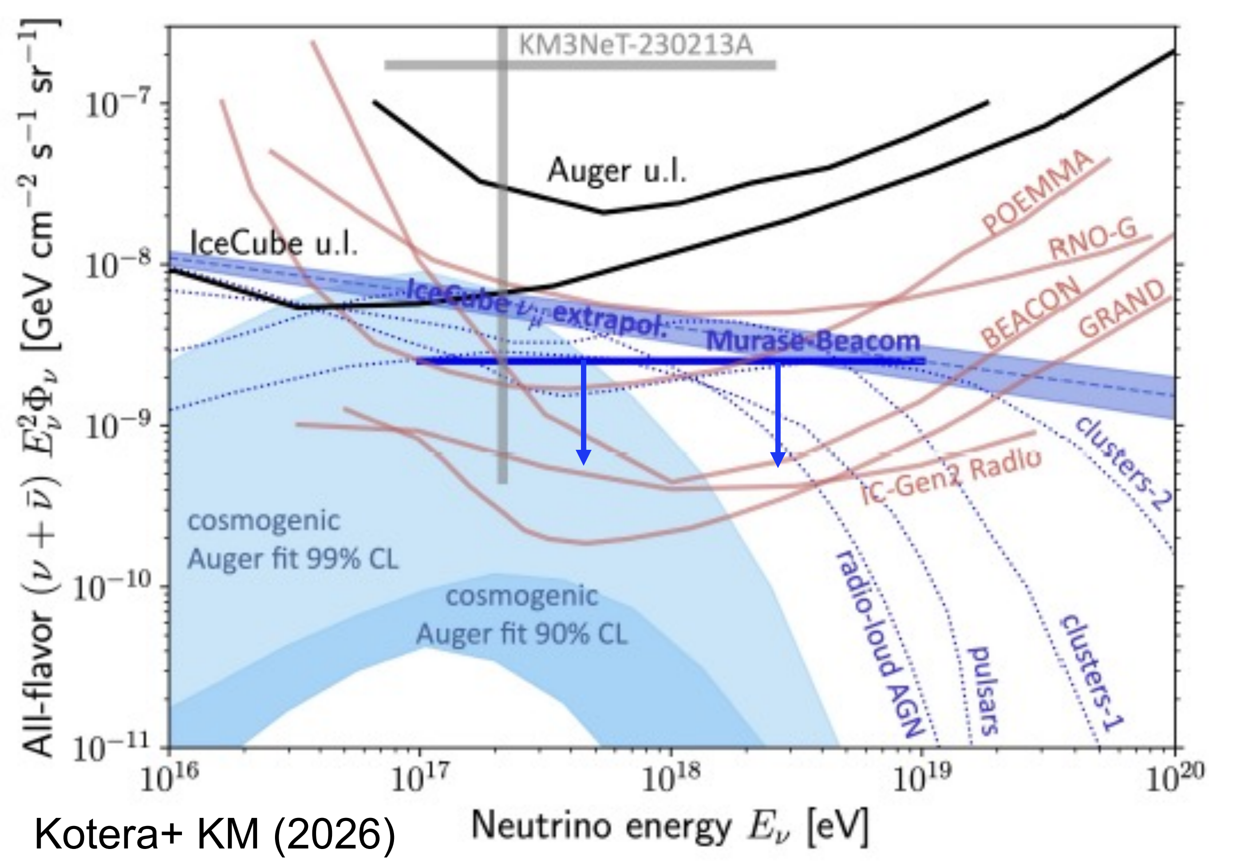
KM, Laha, Ando & Ahlers 2015 PRL



The dark matter origin of IceCube νs disfavored by cascade γ-ray constraints

Ultrahigh-Energy Cosmic-Ray Accelerators? Not Yet…

Auger data indicate that UHECRs are dominated by "nuclei"
→ associated UHE ν background: < a fewx10^{-9} GeV cm^{-2} s^{-1} sr^{-1}



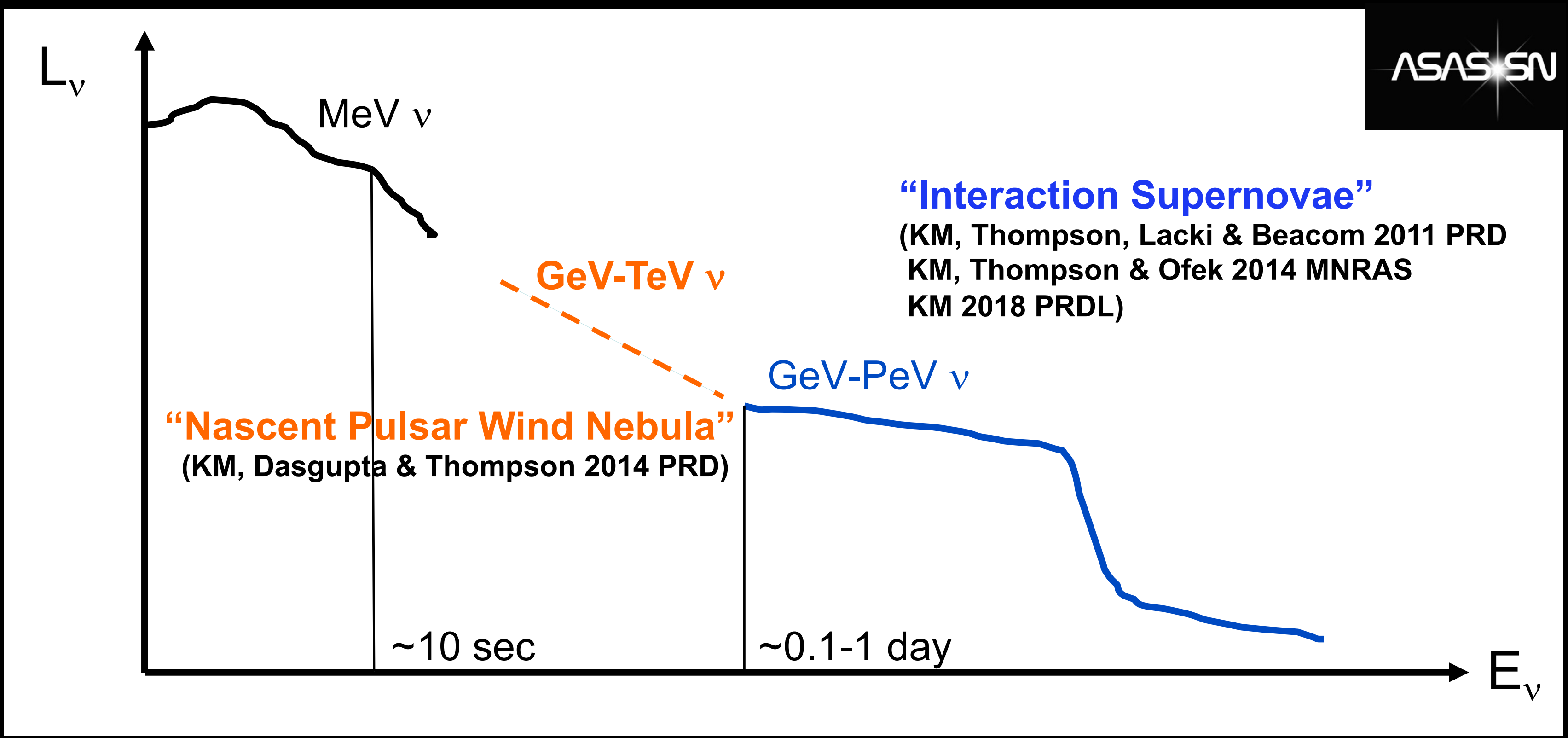
Murase & Beacom 2010 PRD

Useful benchmark flux for next-generation UHE ν detectors

Transients? High-Energy Supernova Neutrinos

Supernova: "multimessenger" & "multienergy" ν source

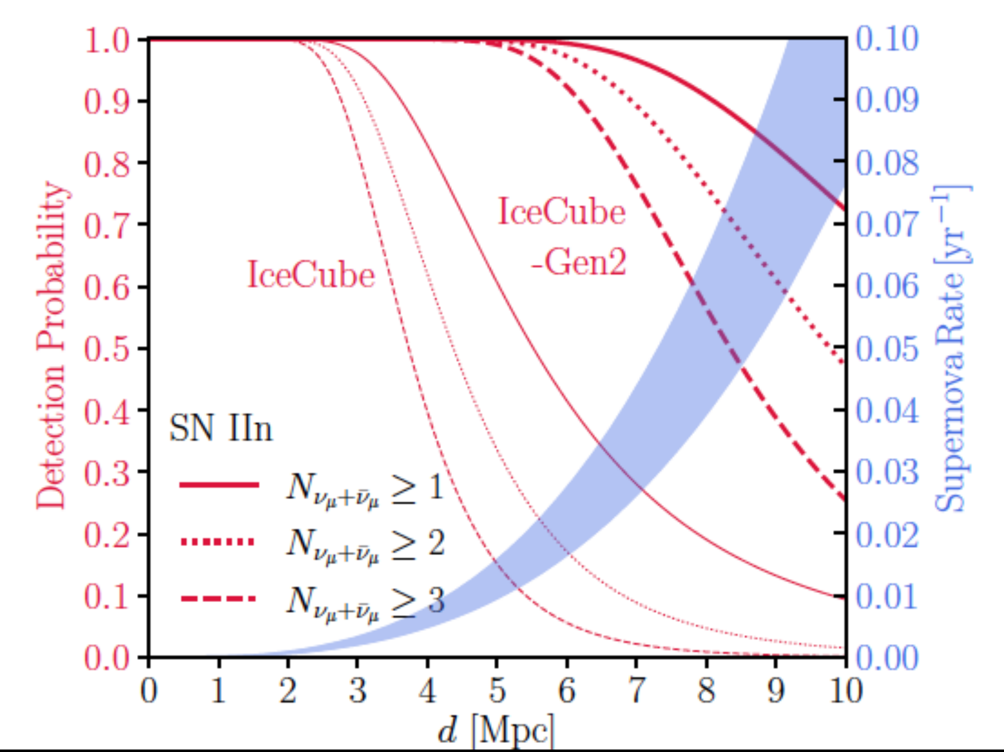
Progenitors commonly have "confined" circumstellar material

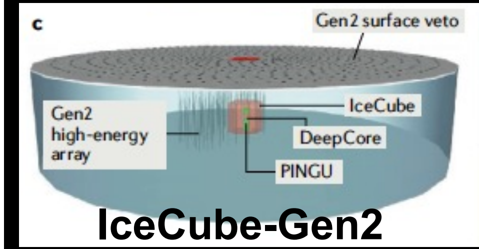


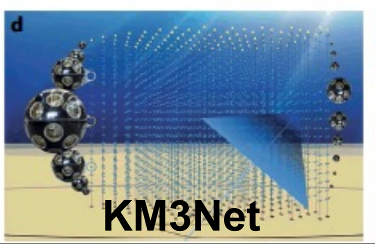
CCAPP mini-workshop in 2012: "Revealing Deaths of Massive Stars with GeV-TeV Neutrinos" → helped young researchers develop the network

New Era of HE Multimessenger Transient Search

Kheirandish & KM 2023 ApJL (see also KM 2024 PRD)







- Next Galactic SN: ~1000 events of TeV νs in IceCube
- More chances to detect "mini-bursts" in the Rubin era especially with the global ν detector network

Many Seeds, Many Discoveries – One Multimessenger Path

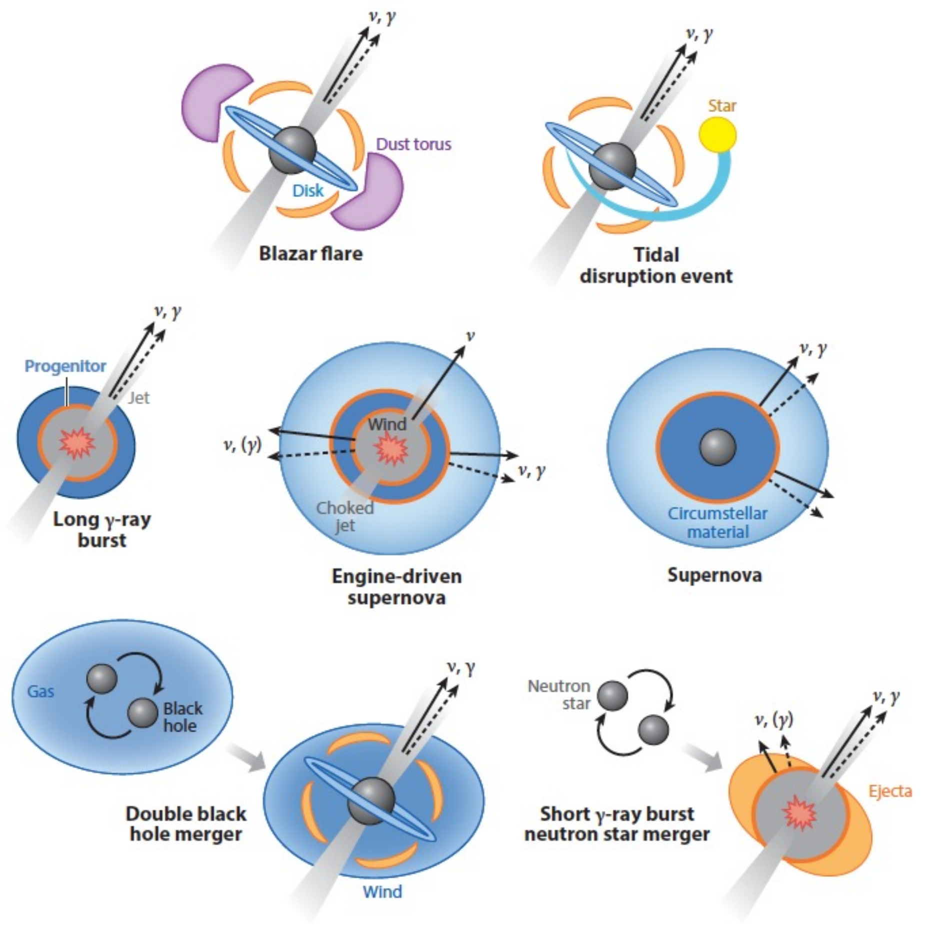
Right Time: IceCube completion & the discovery of HE cosmic neutrinos
Right Place: CCAPP where particle physics, astrophysics, and cosmology meet
Right People: John, Todd, Carsten, Shun, Basu, Ranjan, Kenny, Brian, and all the outstanding faculty, postdocs, students, and administrative staff

CCAPP helped me shape my academic career in the US.
Many ideas planted here became useful in the current multimessenger era.

Happy 20th Anniversary, CCAPP!

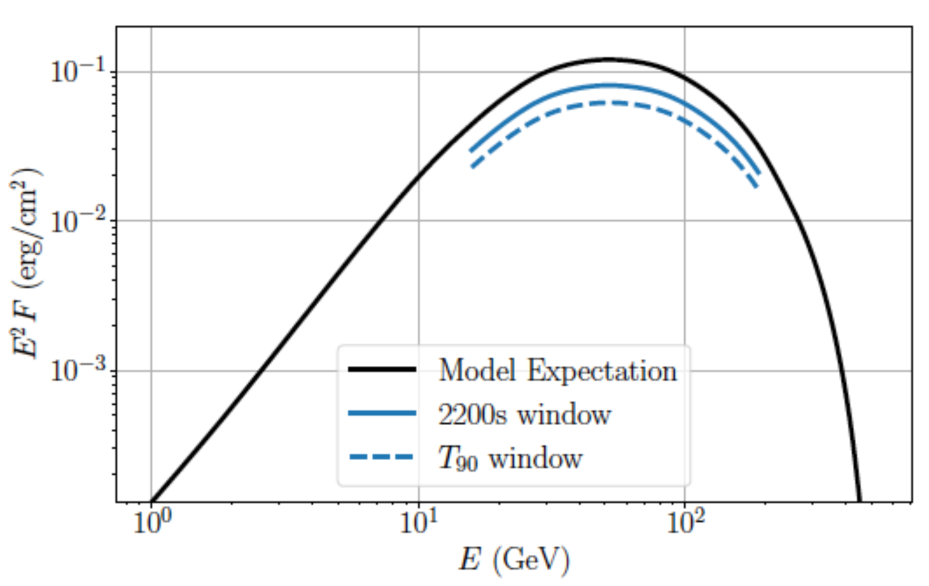
Thanks!

GeV-TeV Neutrino Astrophysics



KM & Bartos (2019)
Meszaros, Fox, Hanna & KM (2019)

- n-loaded relativistic outflows lead to "quasithermal" νs in the GeV-TeV range
  (KM, Kashiyama & Meszaros 13 PRL)
- Probes of jet composition and dissipation mechanism
- Meaningful constraints from the brightest GRB 221009A



IceCube Collaboration 2024 ApJ