Multimessenger Study of Heavy Dark Matter
A02 Group Status Report

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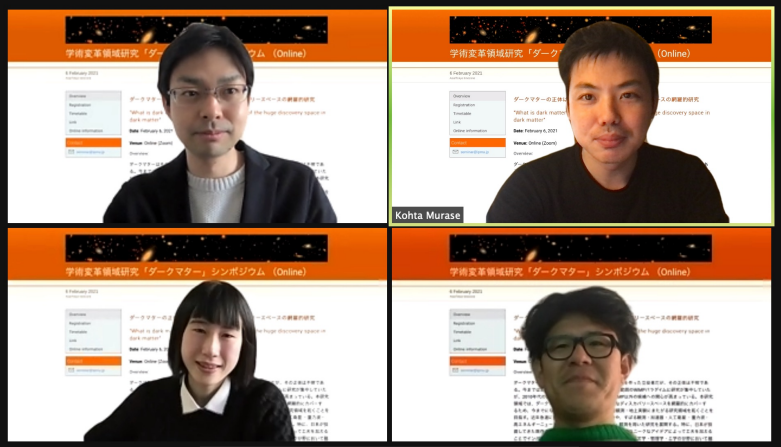


"What is Dark Matter?"

March 29 2022

科研費 KAKENHI

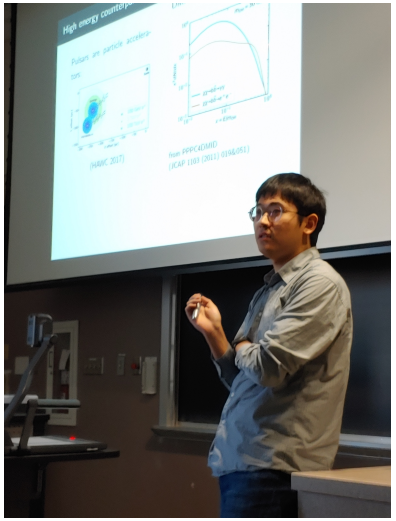
YITP YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

New Team Members

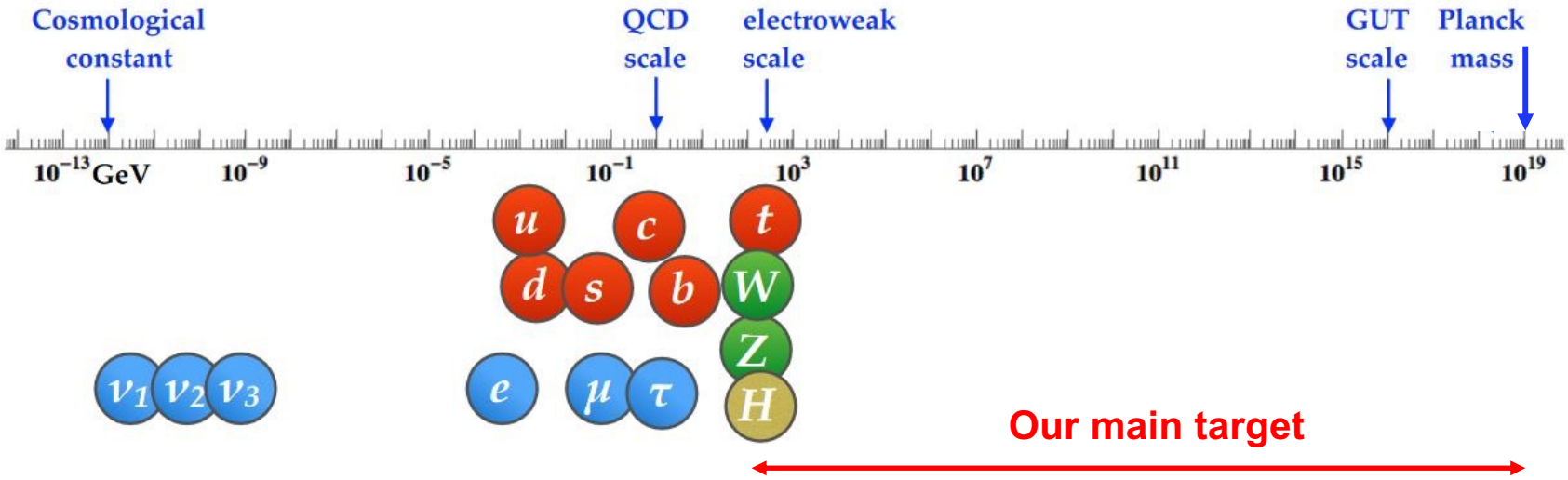
Unfortunately, COVID-19 led to many complications…
But 2 postdocs have almost joined the team!

Saikat Das – original plan: 2021 summer
→ started in 2021 fall
working on multimessenger emission at UHE energies

Deheng Song – original plan: 2021 winter
→ will start in 2022 spring
working on multimessenger emission at MeV-TeV energies and DM models

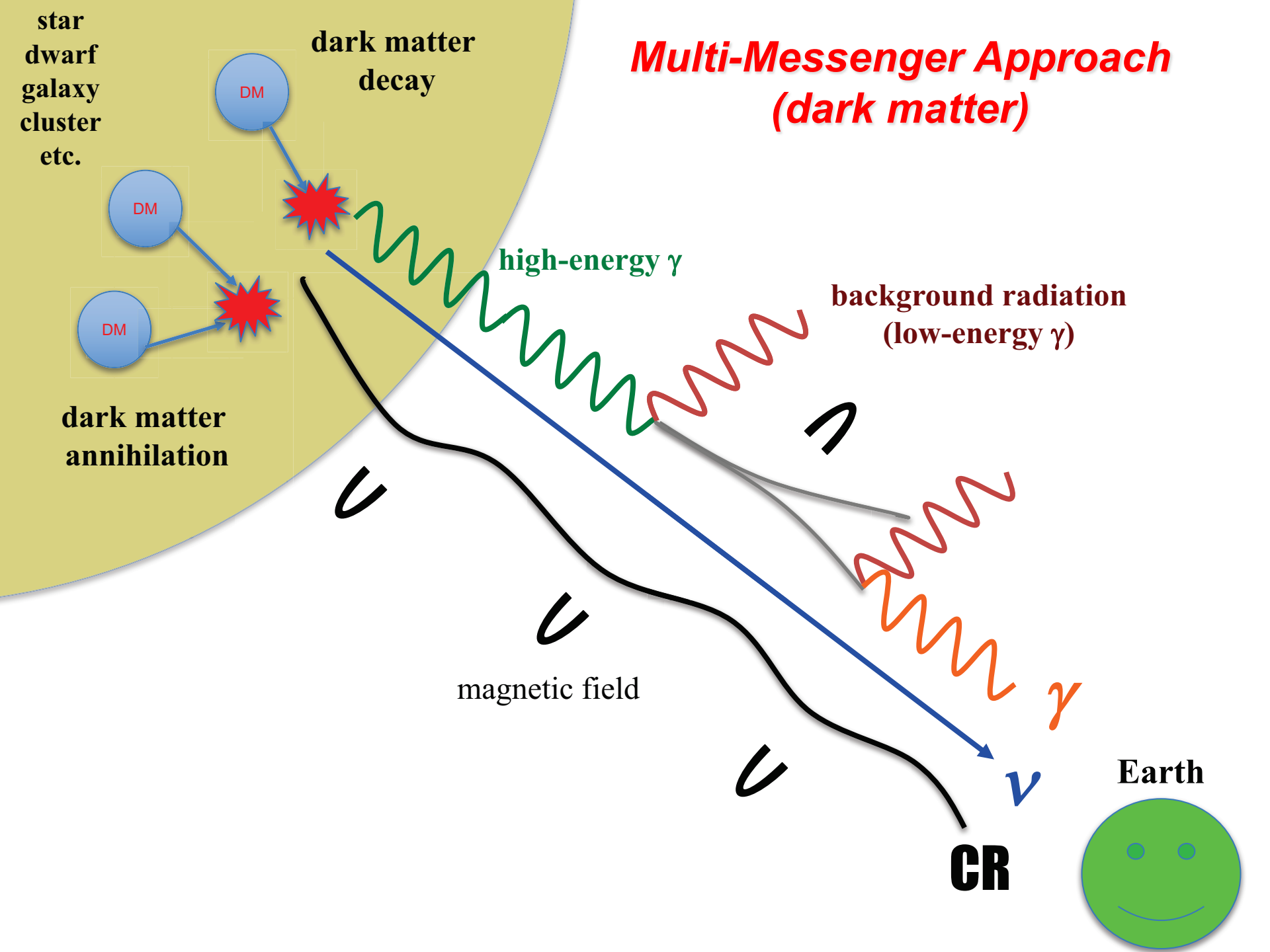


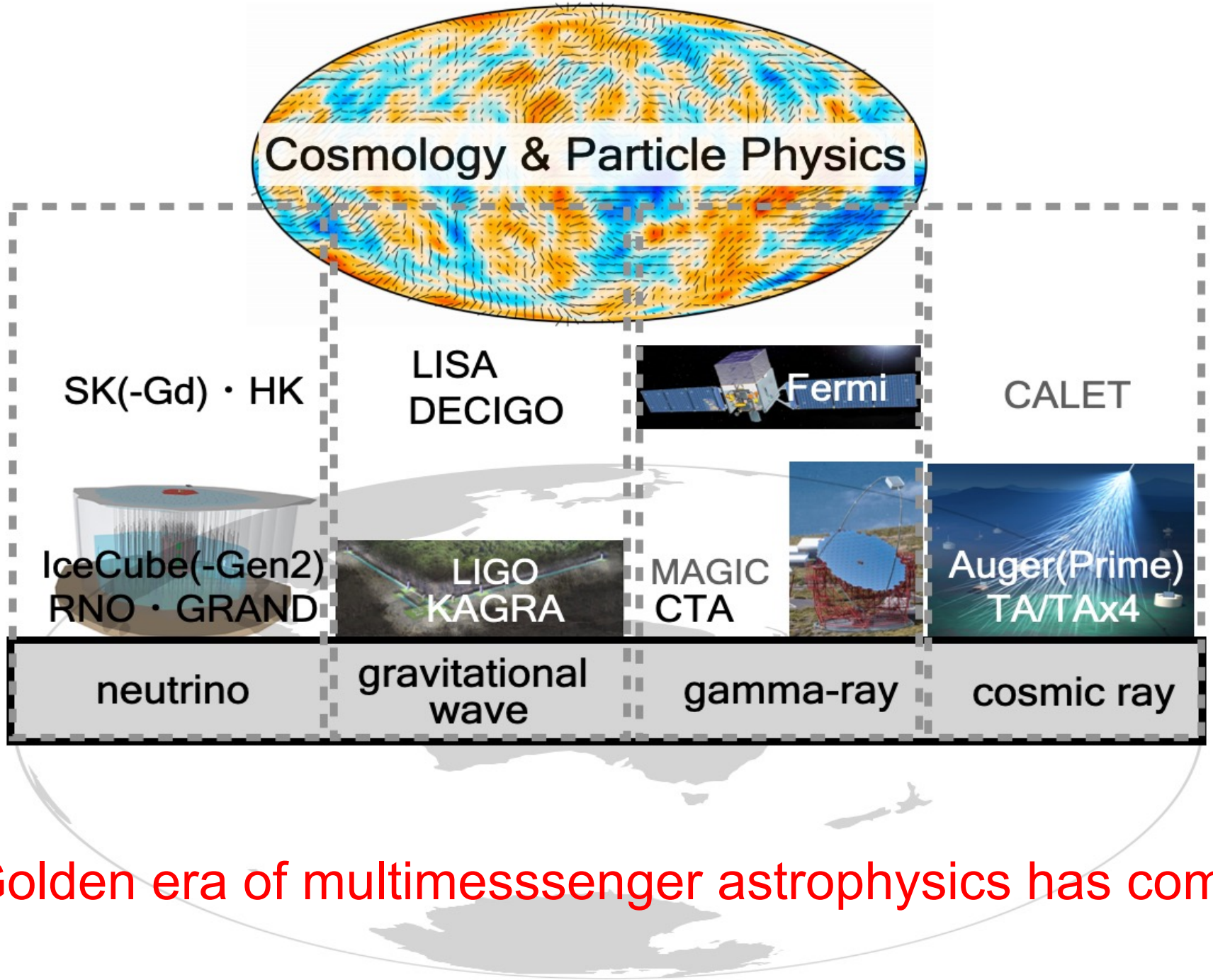
Focus of A02 Group



- >10 orders of magnitude in energy (above TeV)
  It may not be a desert
- Beyond LHC energies: “energy frontier"
- More challenging for direct detection
- Indirect searches are much more important

Multi-Messenger Approach (dark matter)

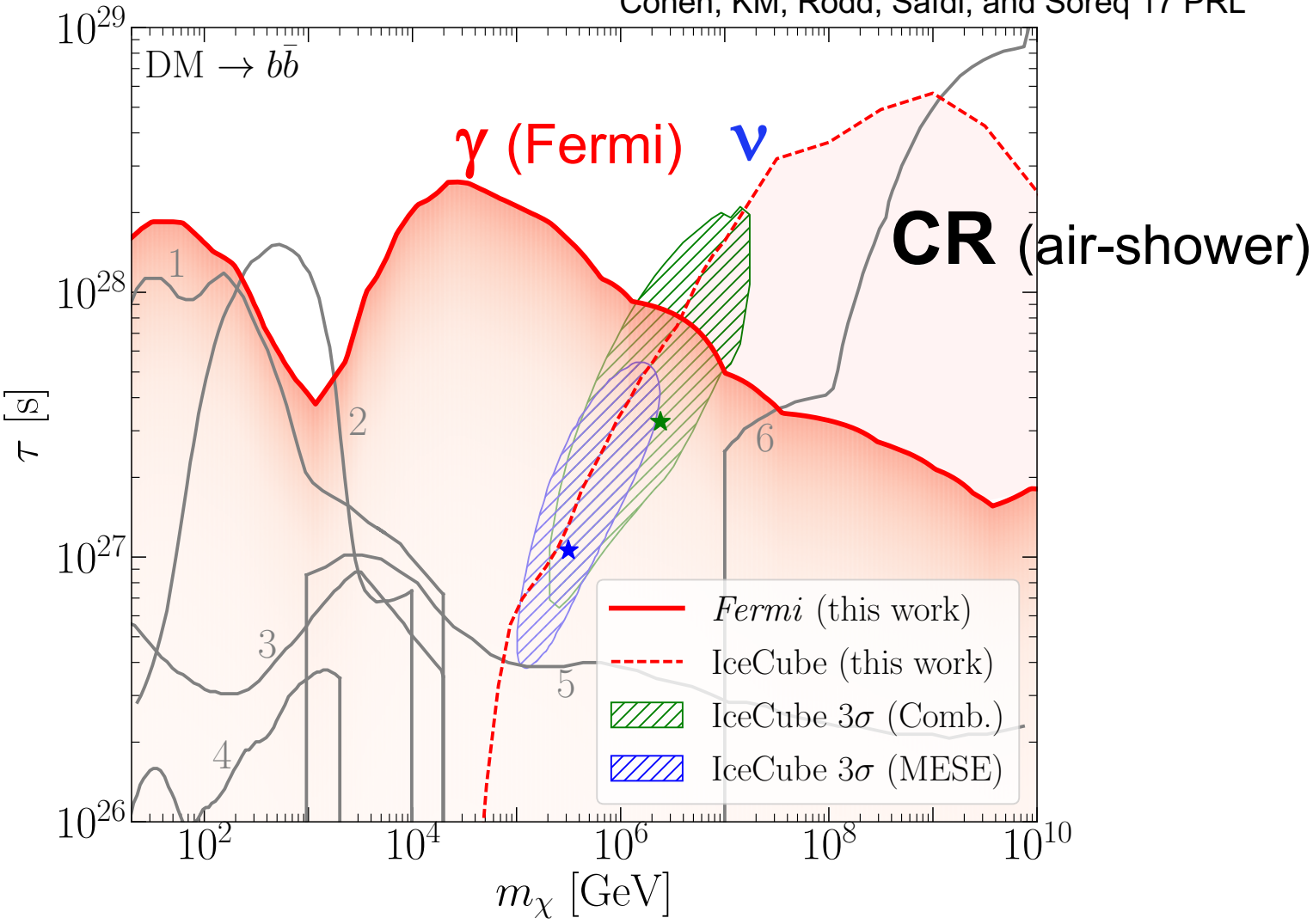




Golden era of multimesssenger astrophysics has come!

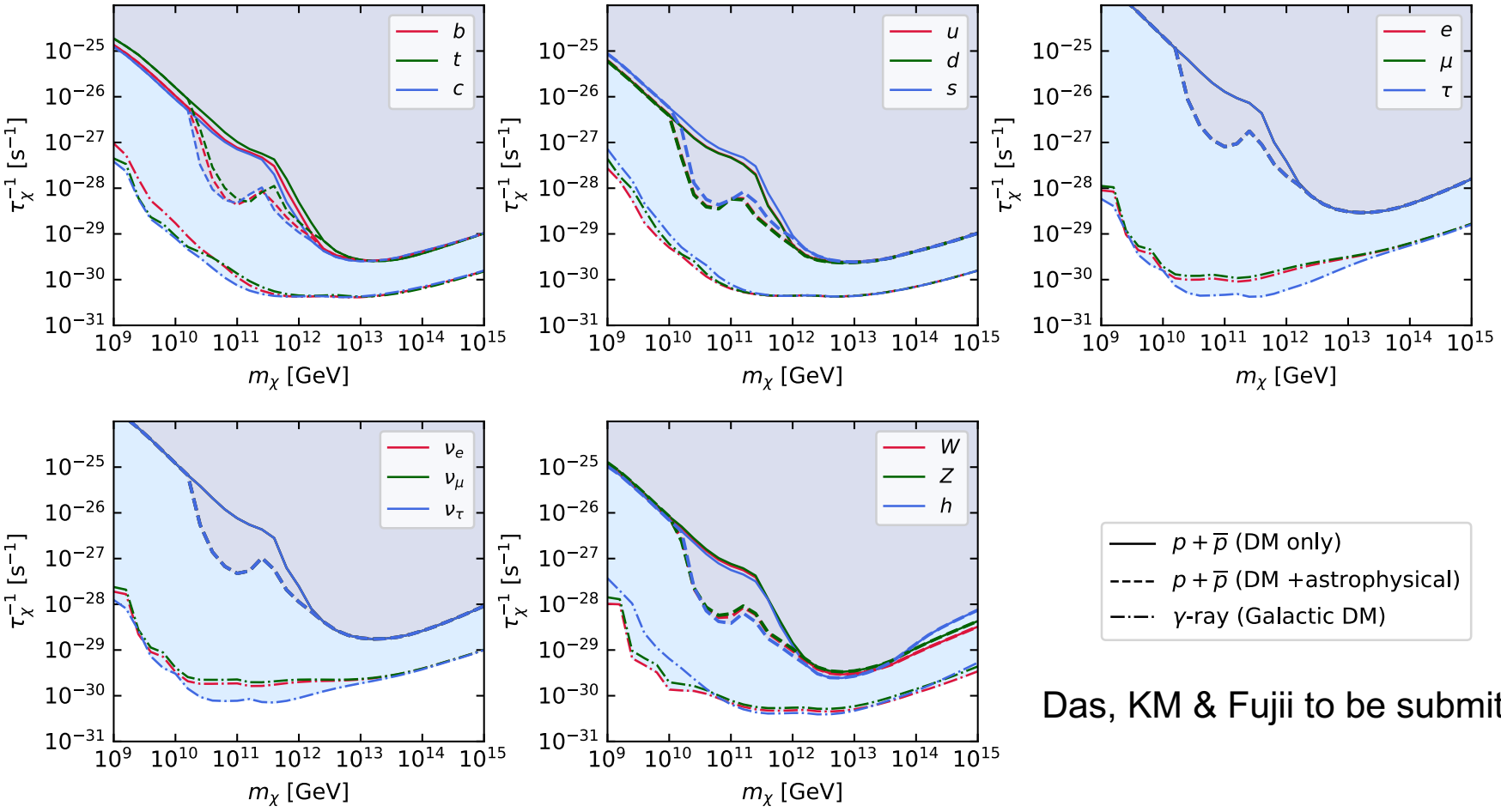
Diffuse Multi-Messenger Limits on Decaying DM

Cohen, KM, Rodd, Safdi, and Soreq 17 PRL



Beyond EeV energies? Other astrophysical probes?

UHECR Constraints



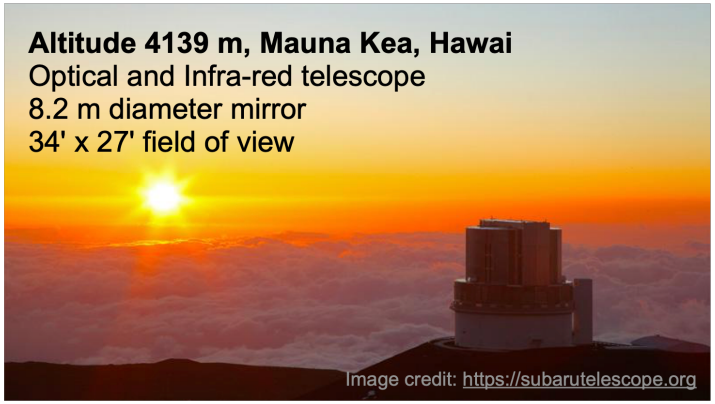
Das, KM & Fujii to be submitted

Updated constraints from the latest Auger data with composition
→ talk by Saikat Das

Seeing Cosmic-Ray Extensive Air Showers

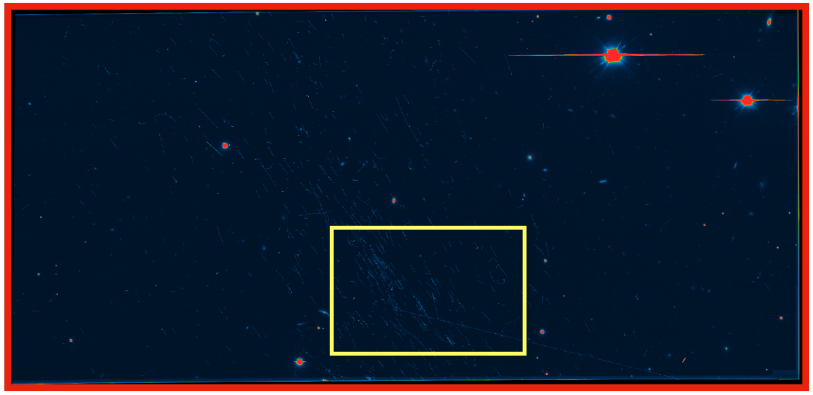
Direct detection of Subaru HSC CCDs

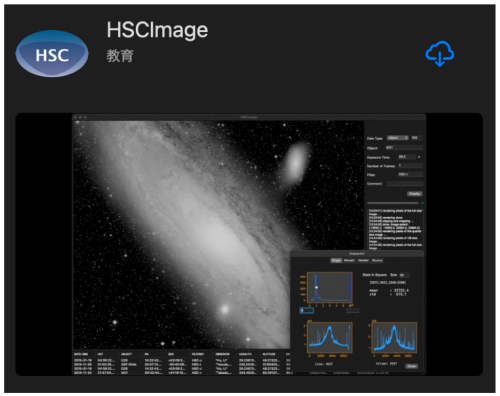
Koike, Kawanomoto, Miyazaki (NAOJ), Fujii (Kyoto) in prep. (HSC Project 433)



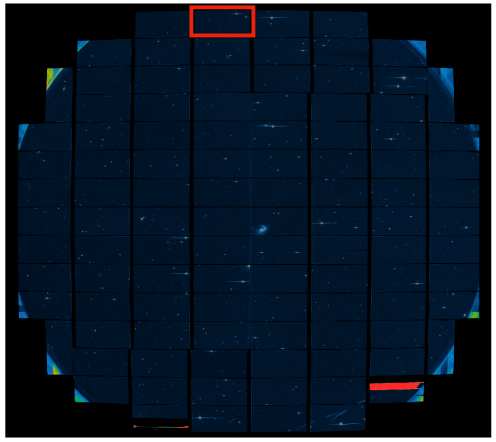
CCD size
30 mm x 60 mm
0.2 mm thickness
150 sec. exposure

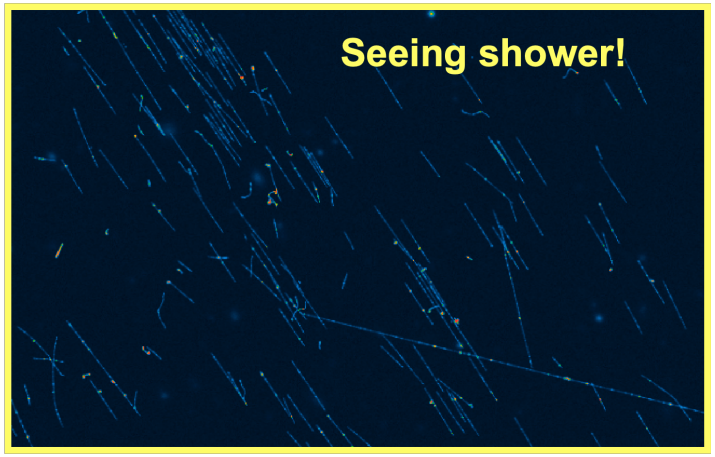
116 CCDs





App Store (Mac)





HSC CCDs can be used as cosmic-ray detectors
→ talk by Toshihiro Fujii

Search for Nearby DM Halos

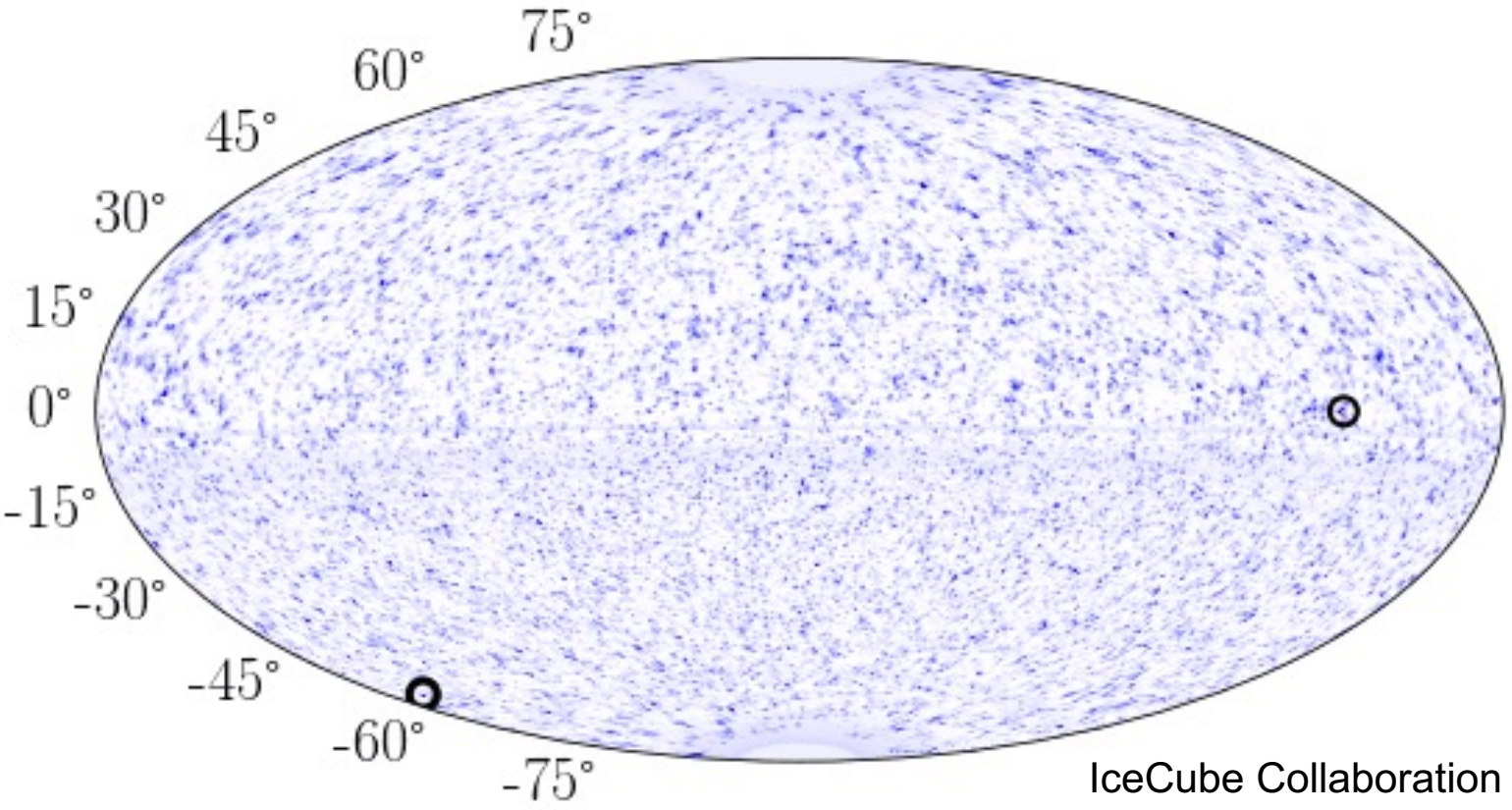
- Galactic DM halo (e.g., Bai+ 14 PRD)
- Nearby DM halos (clusters & galaxies)

"point/extended" sources

decaying DM: signal flux $\propto M_{dm}/\tau_{dm}/d^2$

stacking/cross-correlation

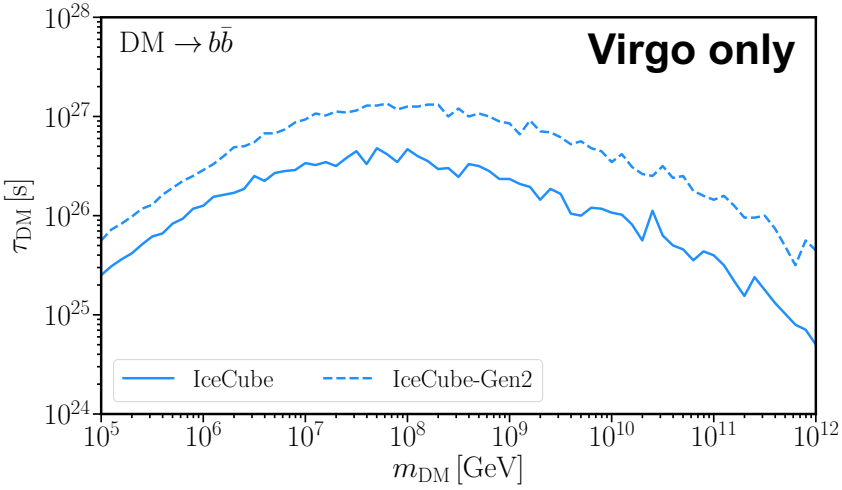
"independent" of γ–ray bounds

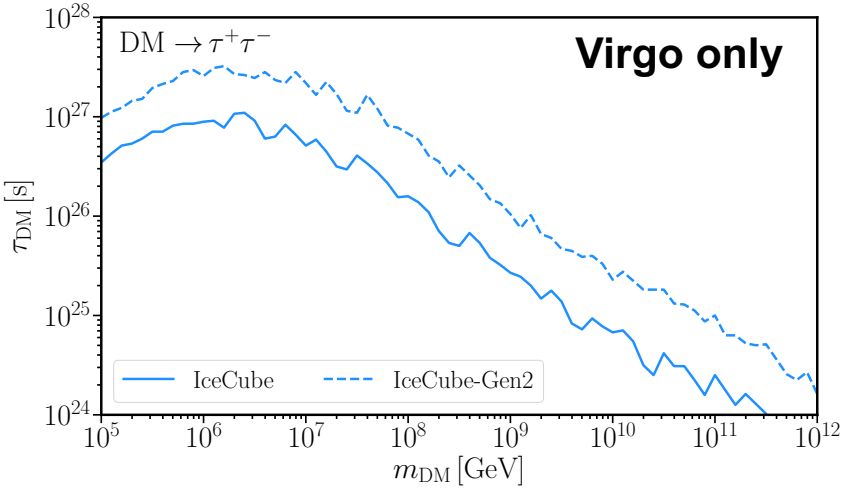


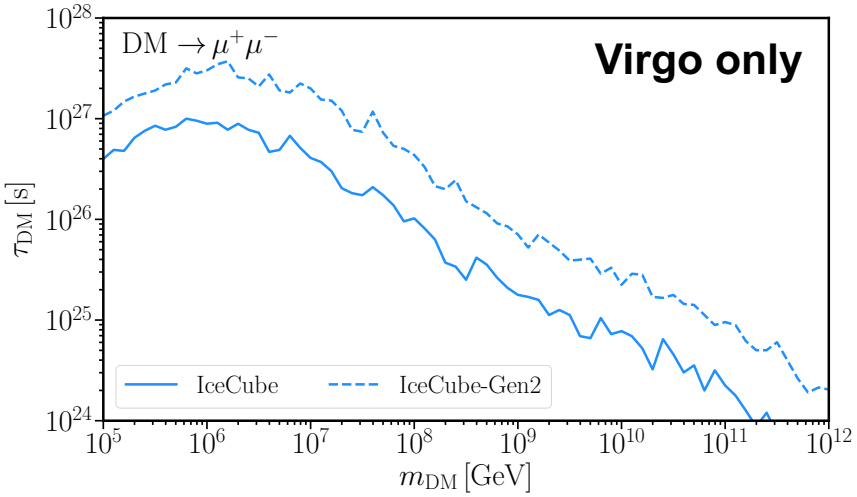
IceCube Collaboration 20 PRL

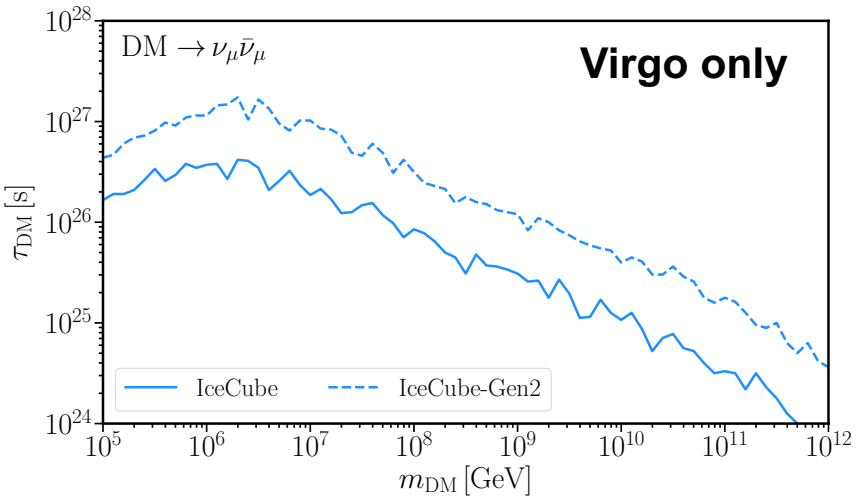
Sensitivities from Nearby DM Halo Searches

Chianese, Kheirandish & KM 22 in preparation







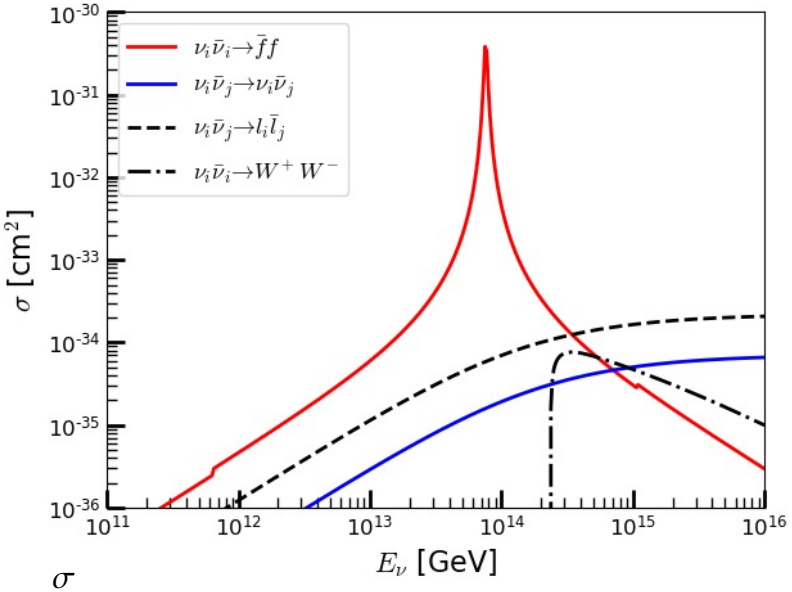


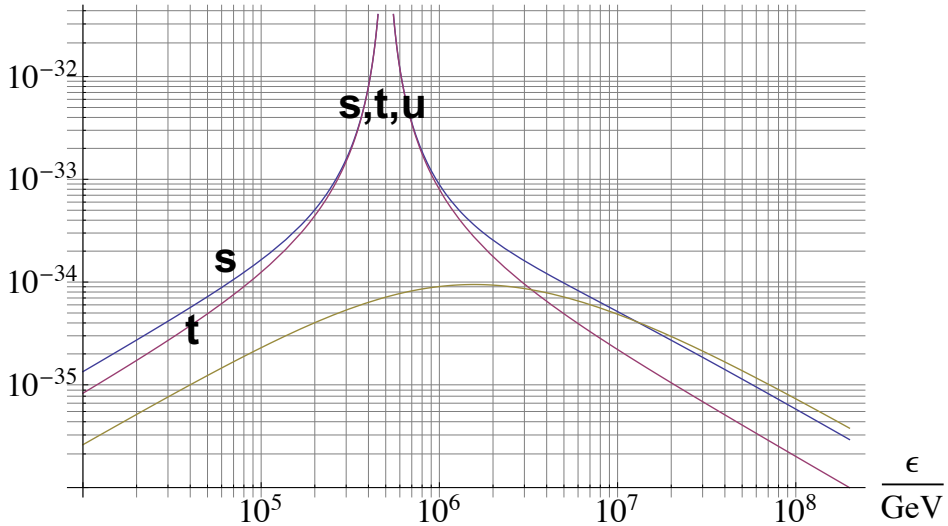
In future, stacking w. more clusters/galaxies can overwhelm diffuse ν searches

Astrophysical Effects

AMES – Astrophysical Multimessenger Emission Simulator
simulating high-energy nonthermal emission
computing EM and ν oscillation/cascades (w. BSM)

Neutrino Interactions En Route





Standard Model

$$\varepsilon_{\rm res} = \frac{m_Z^2}{2m_\nu} = 8.3 \times 10^{13}\ {\rm GeV} \left(\frac{m_Z}{91\ {\rm GeV}}\right)^2 \left(\frac{m_\nu}{0.05\ {\rm eV}}\right)^{-1}$$

not important for astrophysical ν

but can be for VHDM

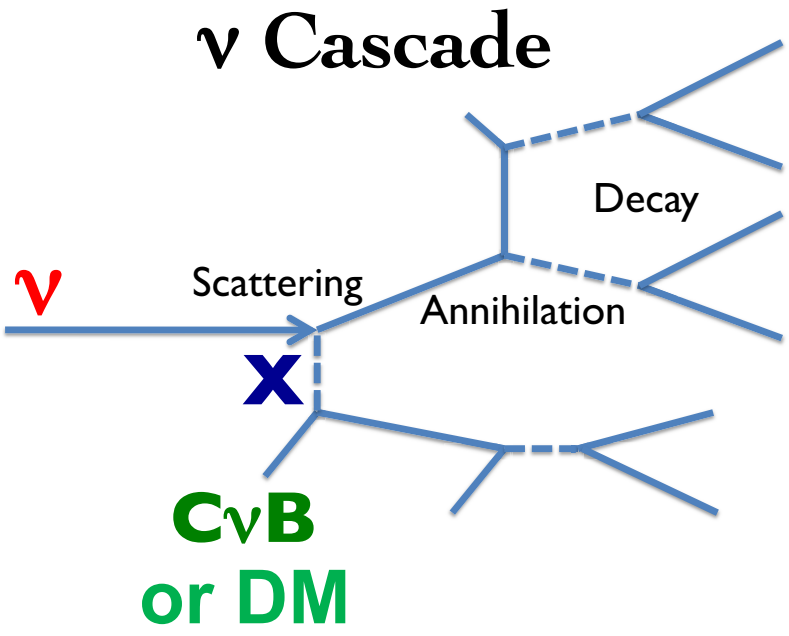
$$\mathcal{L} \supset g_{ij}\bar{\nu}_i\nu_j\phi$$

$$\mathcal{L} \supset gV_\mu\bar{\nu}\gamma^\mu\nu + gV_\mu\bar{X}\gamma^\mu X$$

motivated by cosmology & particle physics

$$\varepsilon_{\rm res} = \frac{m_{Z'}^2}{2m_\nu} = 10^6\ {\rm GeV} \left(\frac{m_{Z'}}{10\ {\rm MeV}}\right)^2 \left(\frac{m_\nu}{0.05\ {\rm eV}}\right)^{-1}$$

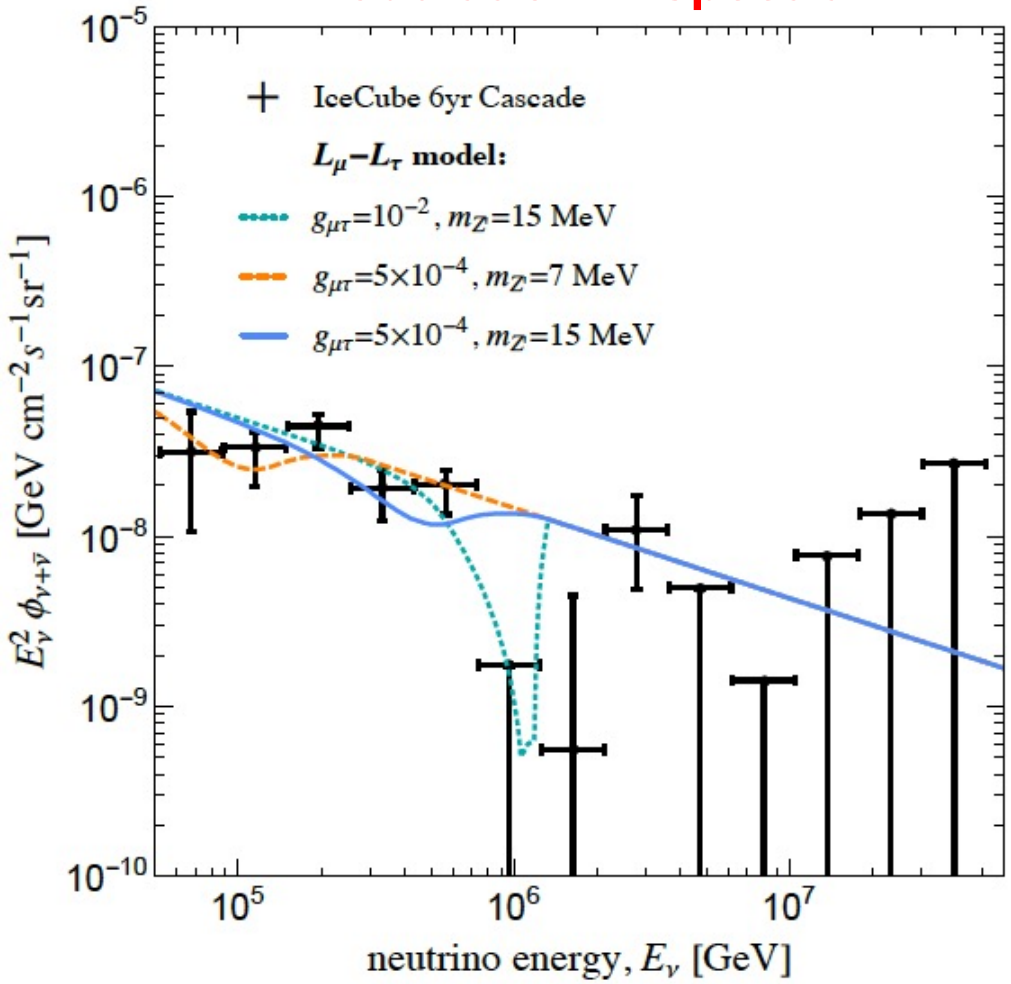
Neutrino Attenuation/Cascades as New Probes



modulation in time arrivals
(application to astro. transients)

KM & Shoemaker 19 PRL
Carpio & KM 22
Eskenasy, Kheirandish & KM 22
Carpio, Kheirandish & KM 22

modulation in spectra



Carpio, KM, Shoemaker & Tabrizi 21

Heavy Dark Matter Production

- Thermal production of CDM, freeze-out (e.g., WIMP) unitarity bound: $m_{DM} < 100$ TeV (Griest & Kamionkowski 90)

- VHDM production mechanisms?

Summary

- Updated constraints with the latest multimessenger data
  - Das & Fujii

- ν and γ-ray searches for nearby dark matter halos for VHDM (with EM cascades inside halos) – Song & Hiroshima

- Code development on astrophysical processes (bonus: neutrino-neutrino, neutrino-DM interactions)

- Cosmological probes - Yamanaka & Naruko
  - DM production mechanisms
  - quantum phase transition & topological defects

More results will come out in 2022