Multimessenger Study of Heavy Dark Matter

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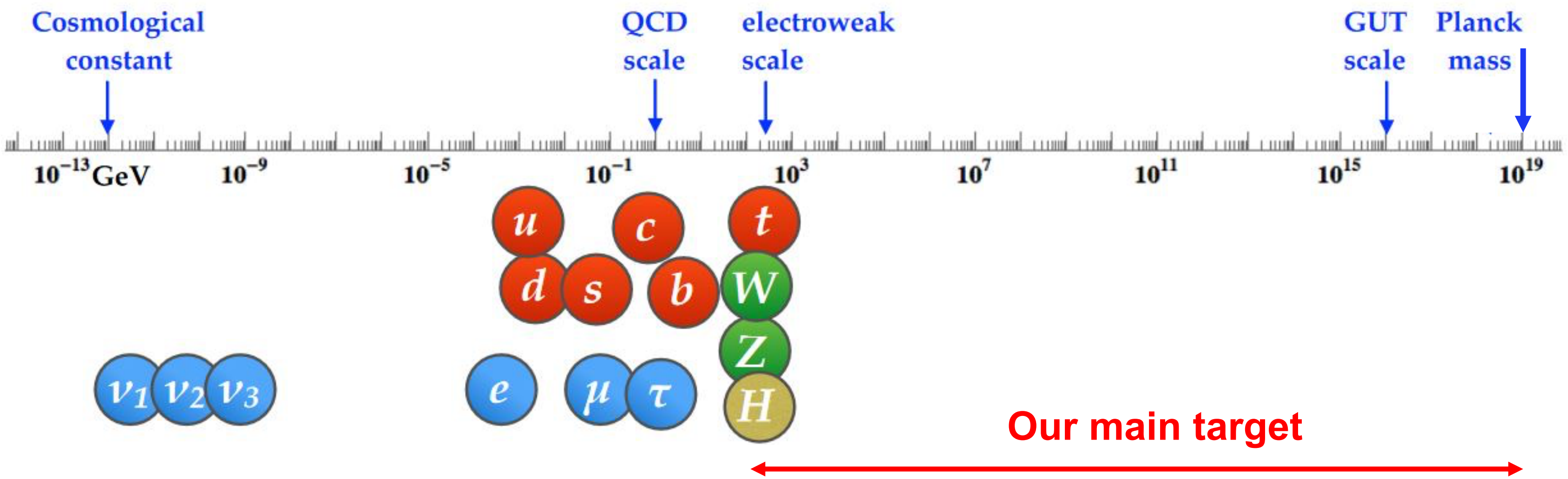
"What is Dark Matter?"

February 6 2021

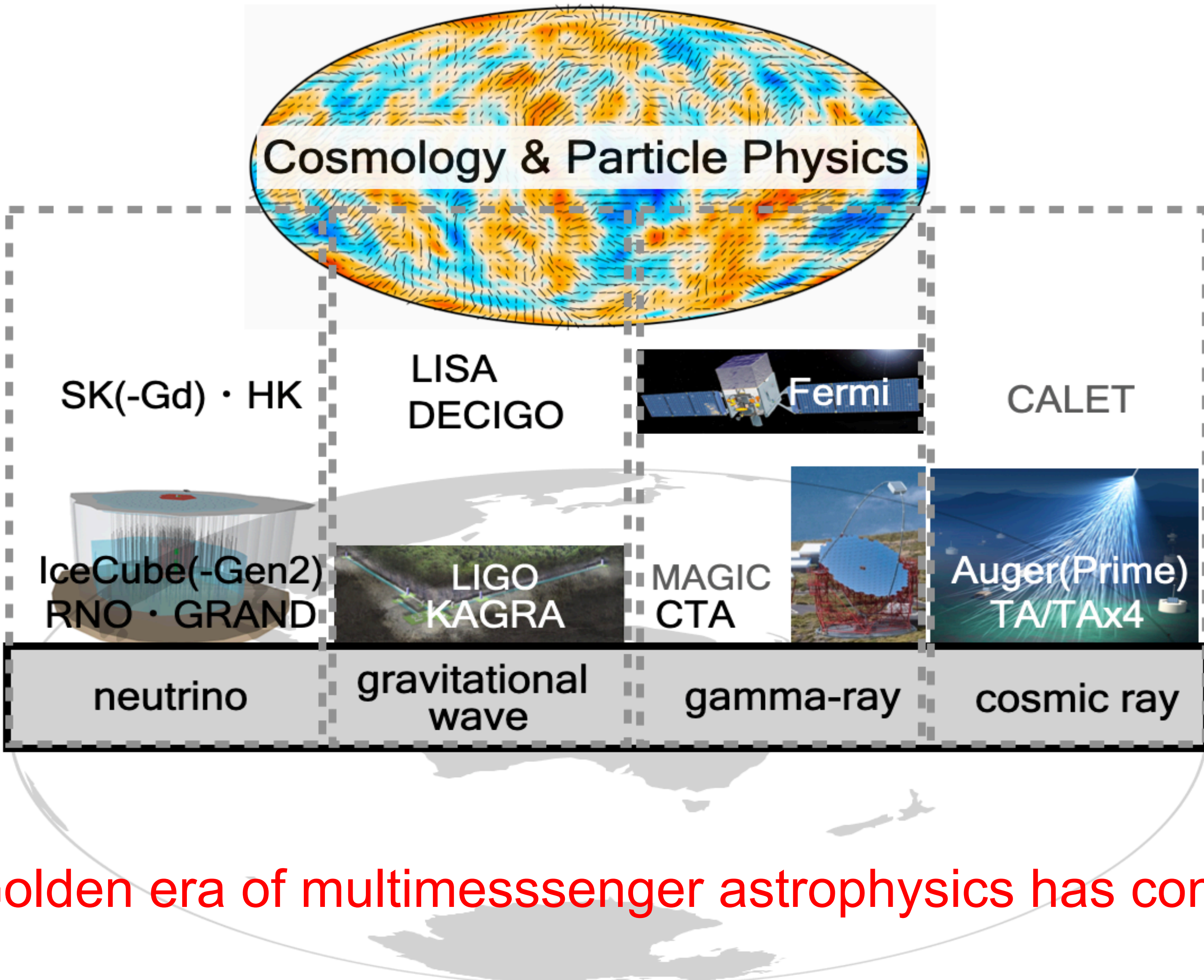
科研費
KAKENHI

YITP
YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

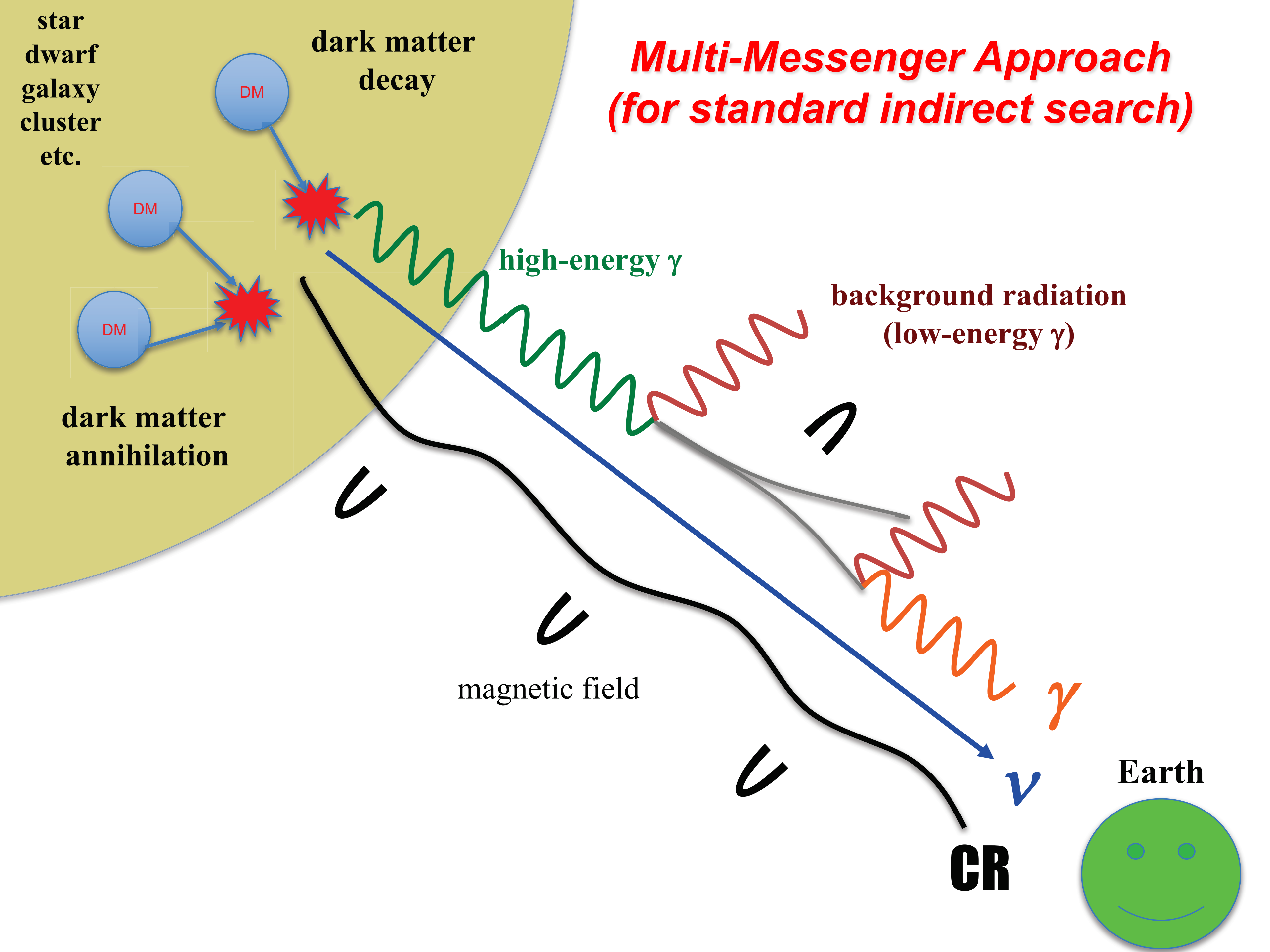
Focus of A02 Group



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

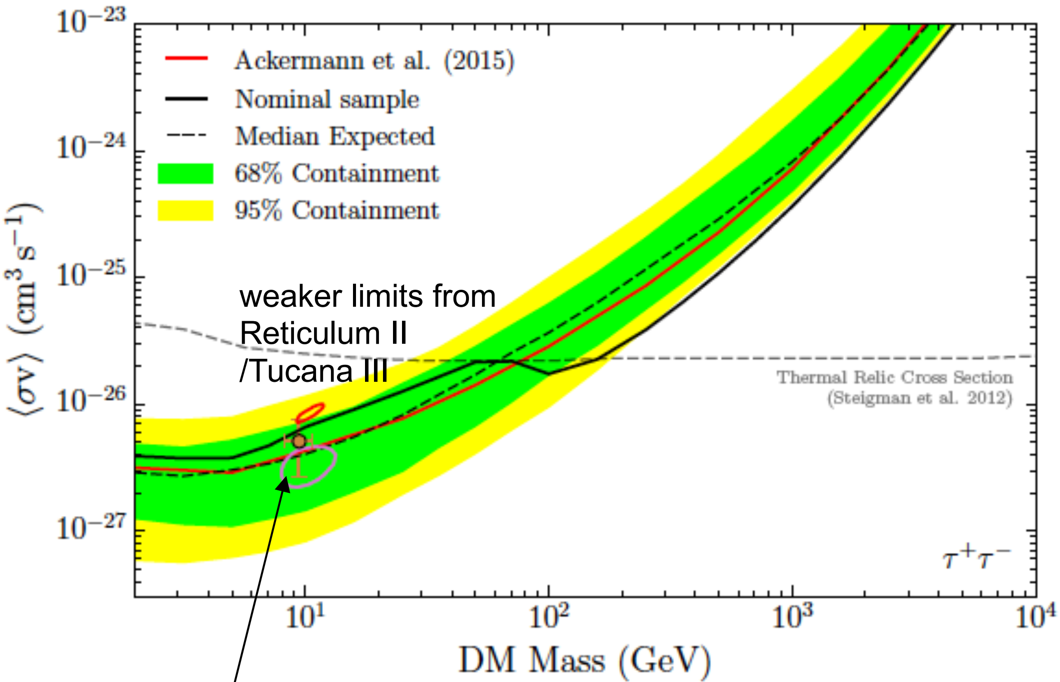


Golden era of multimesssenger astrophysics has come!



Multi-Messenger Approach
(for standard indirect search)
star
dwarf
galaxy
cluster
etc.
dark matter
decay
DM
DM
DM
dark matter
annihilation
high-energy γ
background radiation
(low-energy γ)
magnetic field
γ
ν
Earth
CR

Gamma-Ray Limits on Annihilating Dark Matter

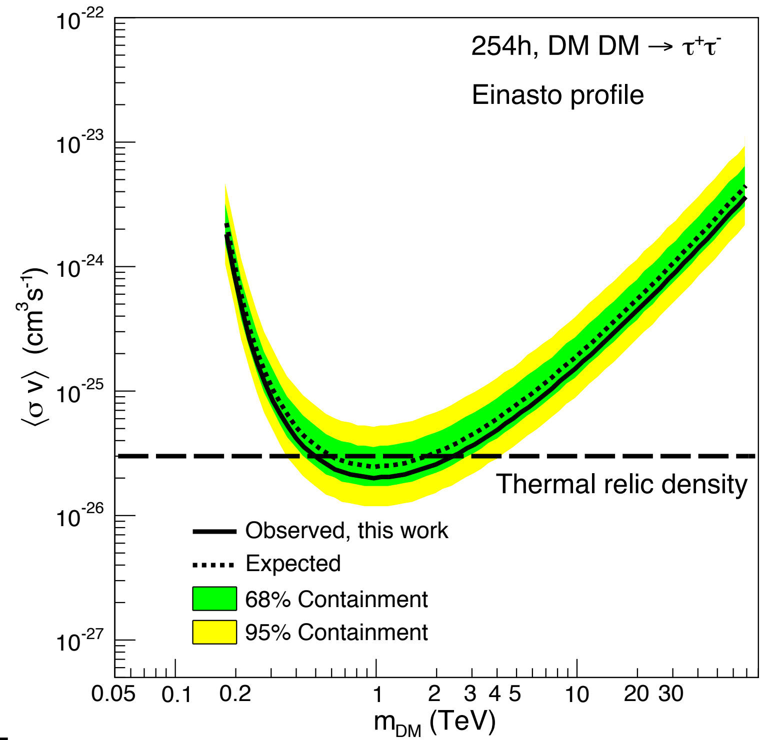


2σ best-fit regions for
Galactic center excess
(not excluded by dwarf analyses)

Dwarf & dwarf candidates

45 sources w. 6 year LAT data

Fermi Collaboration 17 ApJ
see also e.g., Ando+ 20 PRDR

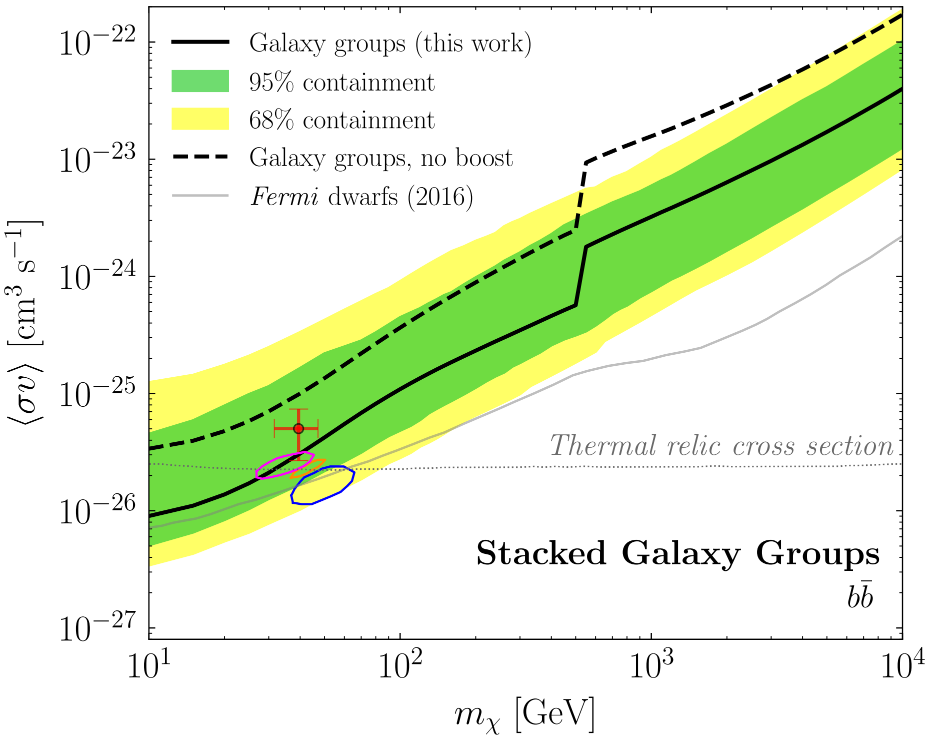


Galactic center region

inner 300 pc w. 10 year data

HESS Collaboration 16 PRL

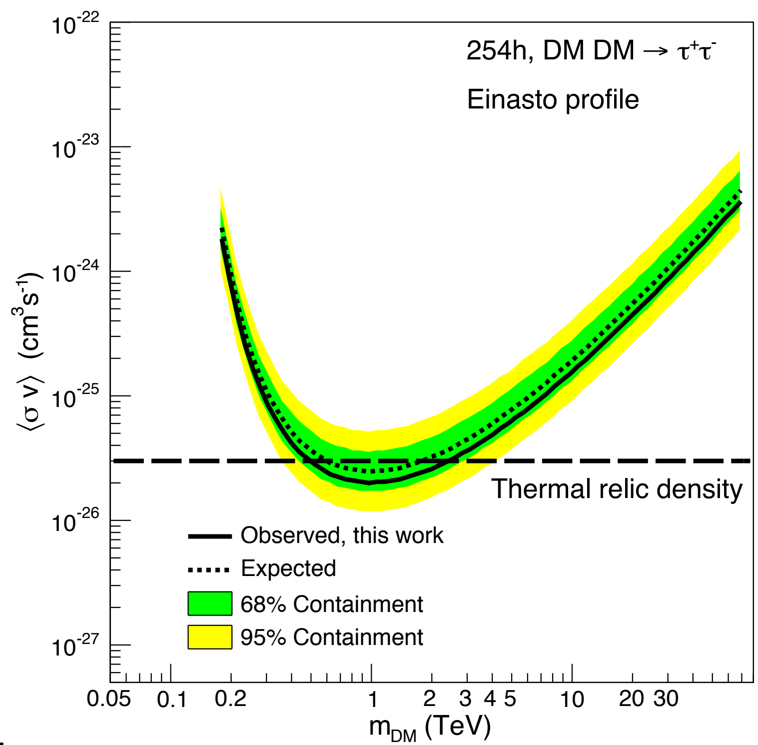
Gamma-Ray Limits on Annihilating Dark Matter



Galaxy groups & clusters

~500 sources out to z~0.03

Lisanti+ 18 PRL



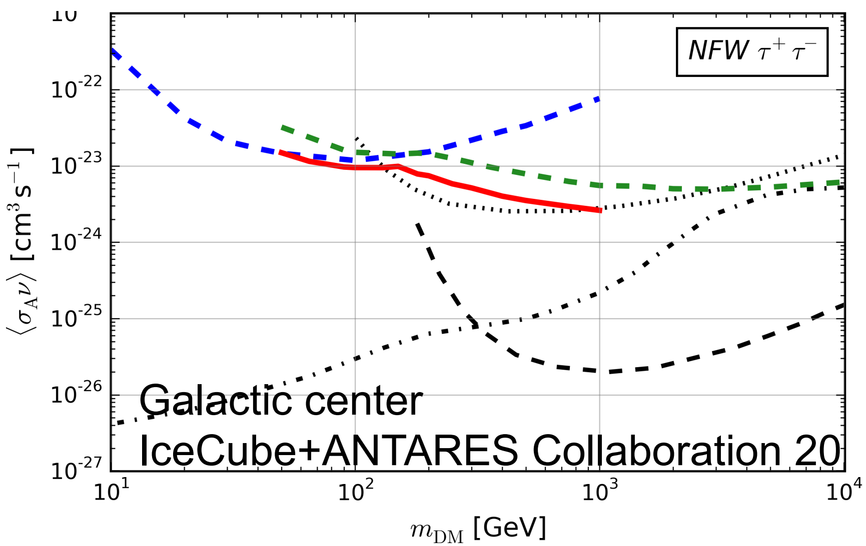
Galactic center region

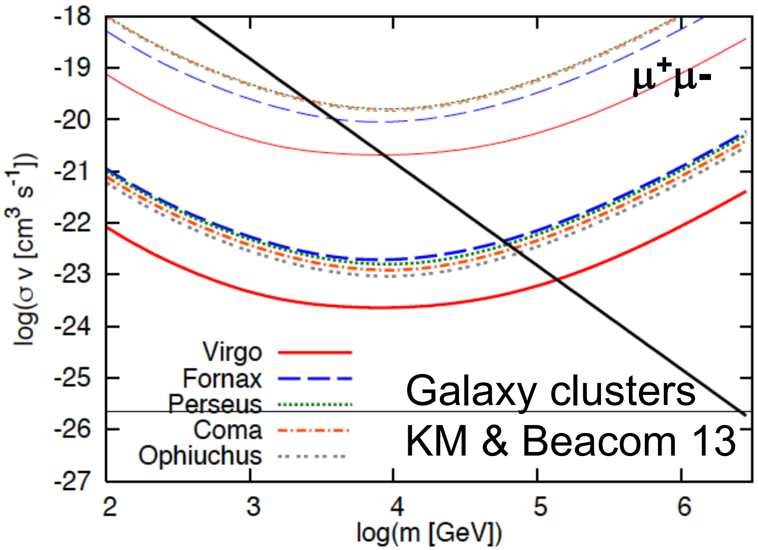
inner 300 pc w. 10 year data

HESS Collaboration 16 PRL

CR & ν Limits on Annihilating Dark Matter

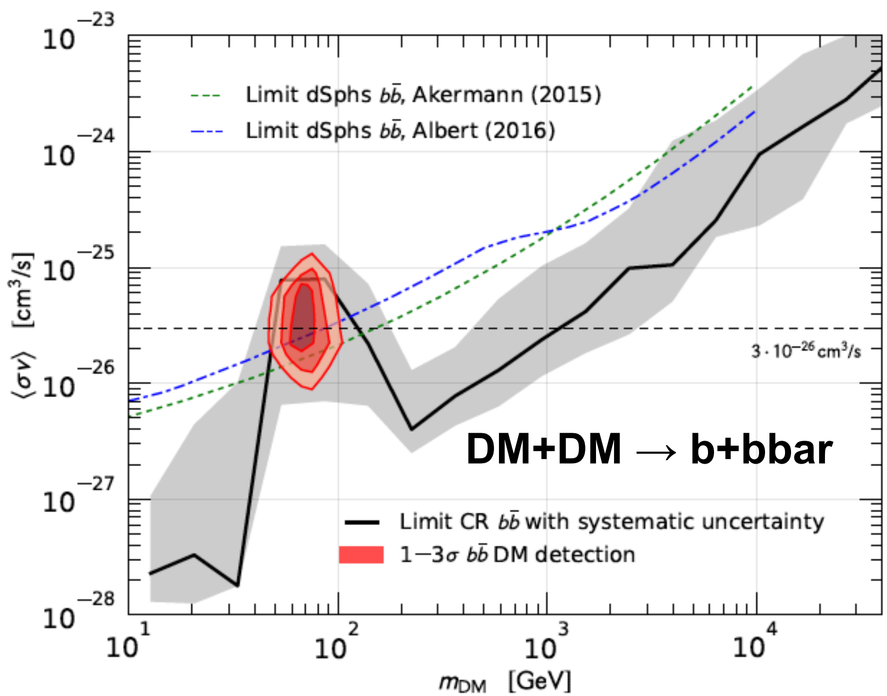
ν w. IceCube/ANTARES data





anti-proton w. AMS-02 data

Cuoco et al. PRL 17
Cui et al. PRL 17



Heavy Dark Matter?

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

- Nonthermal production (e.g., Wimpzilla)

gravitational production

(e.g., Chung et al. 98)

$$\Omega_X h^2 \approx \frac{T_R}{10^8\,\mathrm{GeV}} \begin{cases} (m_X/H_I)^2\,, & m_X \ll H_I \\ \exp(-m_X/H_I)\,, & m_X \gg H_I \end{cases}$$

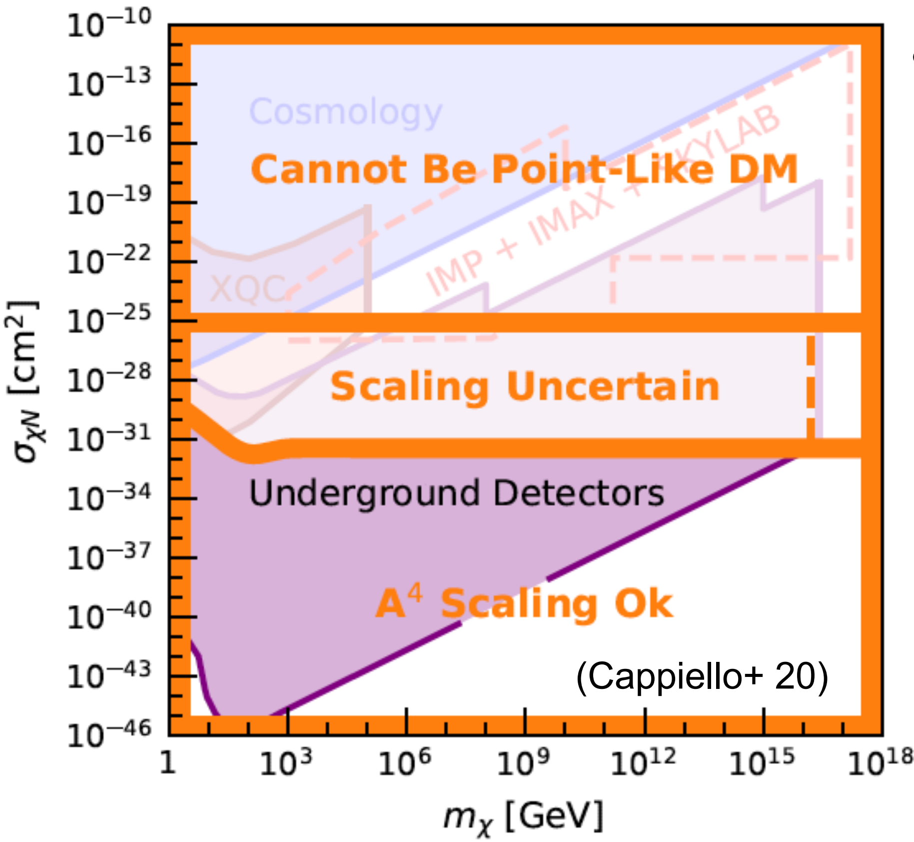
More Mechanisms

Many recent ideas…

- Thermal production via combination of co-scattering and decay (Kim & Kuflik 19)
- Freeze-in through Higgs portal (Kolb & Long 19)
- Freeze-out in the hidden sector (e.g., Berlin+ 16)
- During the phase transition (e.g., Baker+ 20, Chway+ 20)
- Hawking radiation from primordial black holes (e.g., Lennon+ 18, Mmorrison+ 19)
- Decay of cosmic string

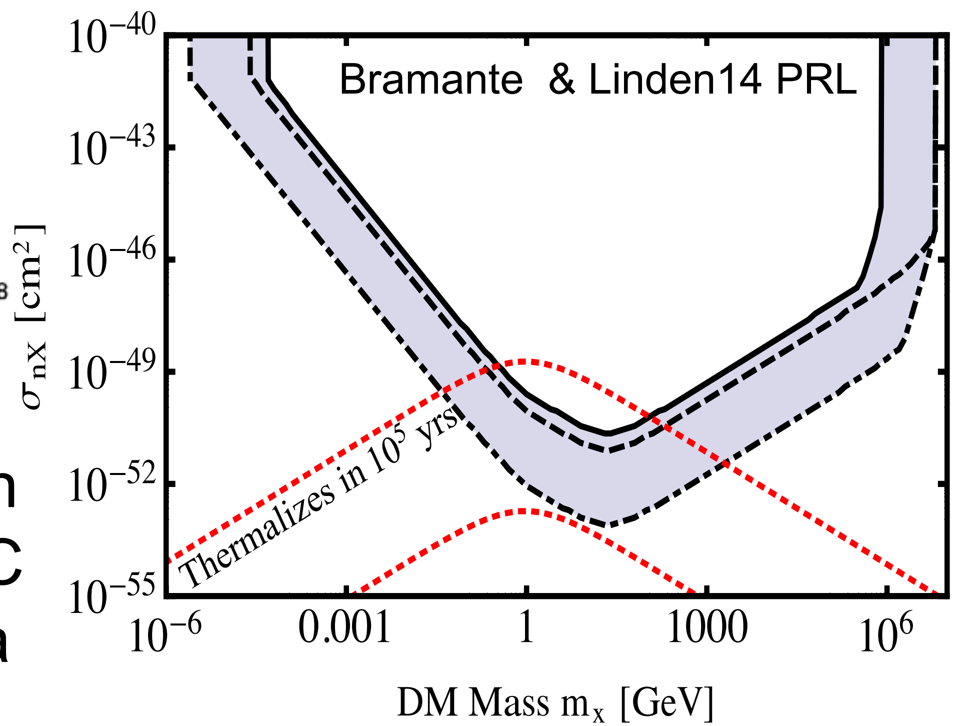
…

Largely Unexplored but Can be Relevant

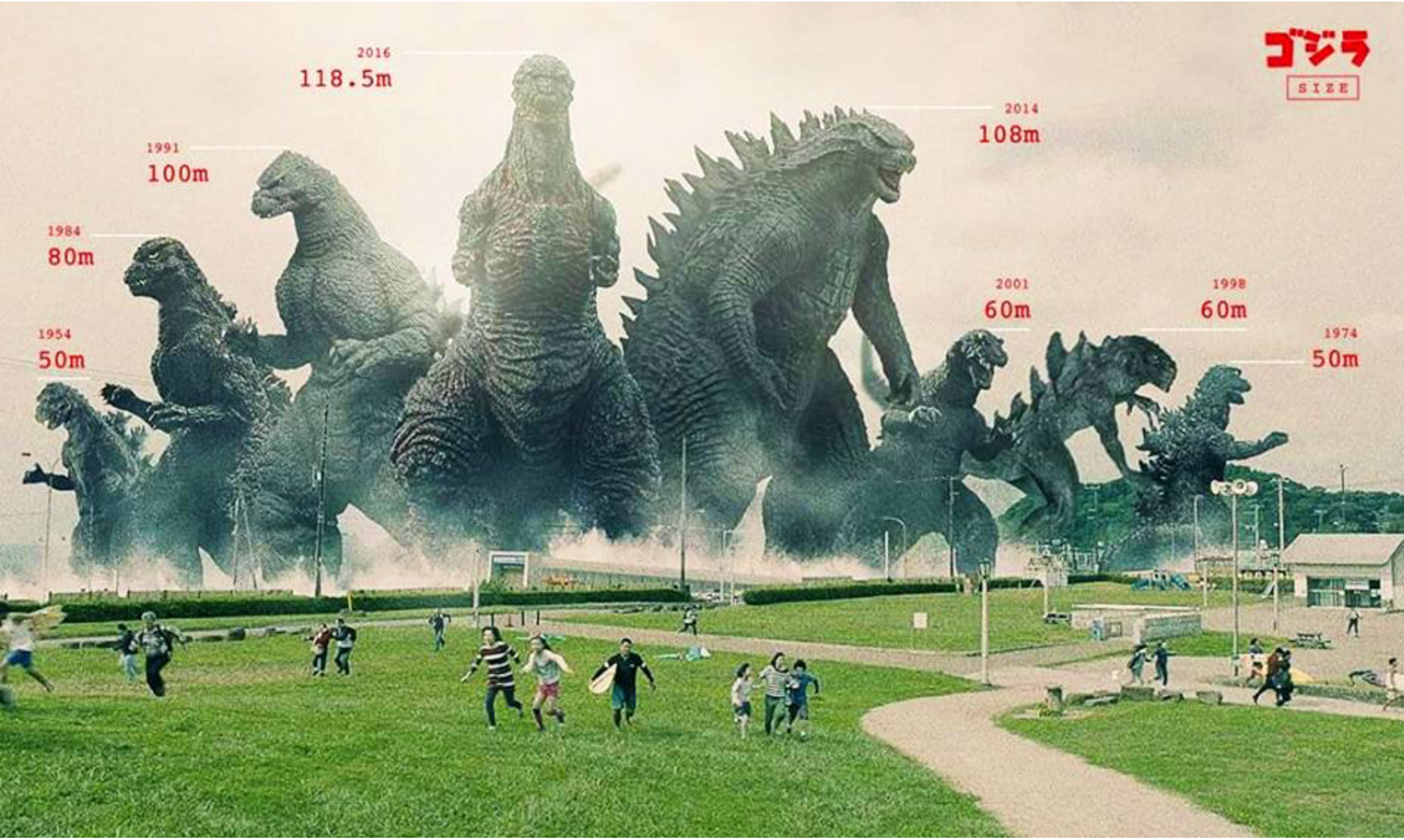


- Direct/indirect detection limits large parameter space allowed especially if DM is composite
(e.g., Harigaya+ 16, Digman+ 19)

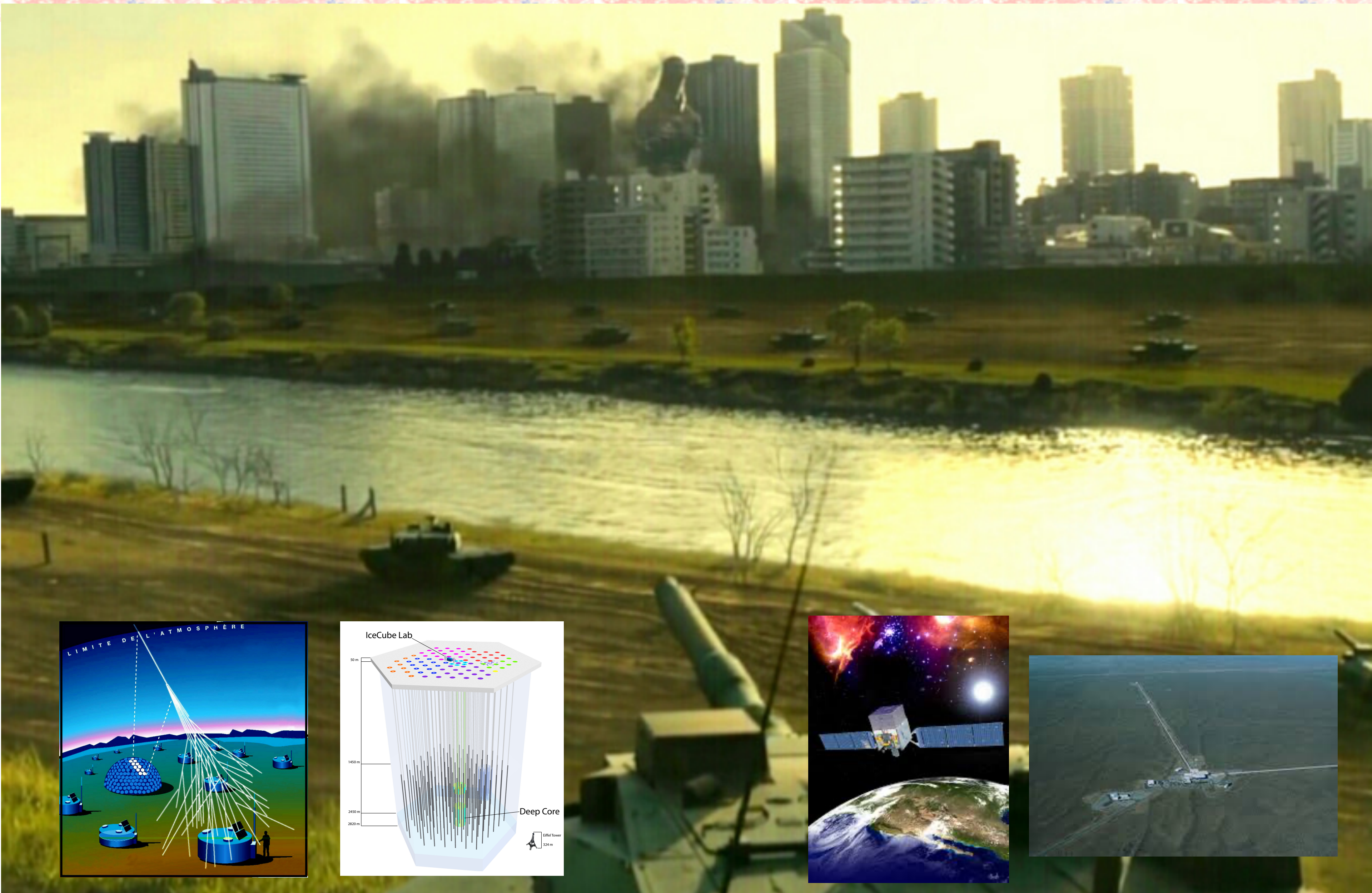
- DM
  - DM implosion could explain the paucity of pulsars at GC
  - 1-100 PeV DM help SNe Ia
  (Bramante 16 PRL)



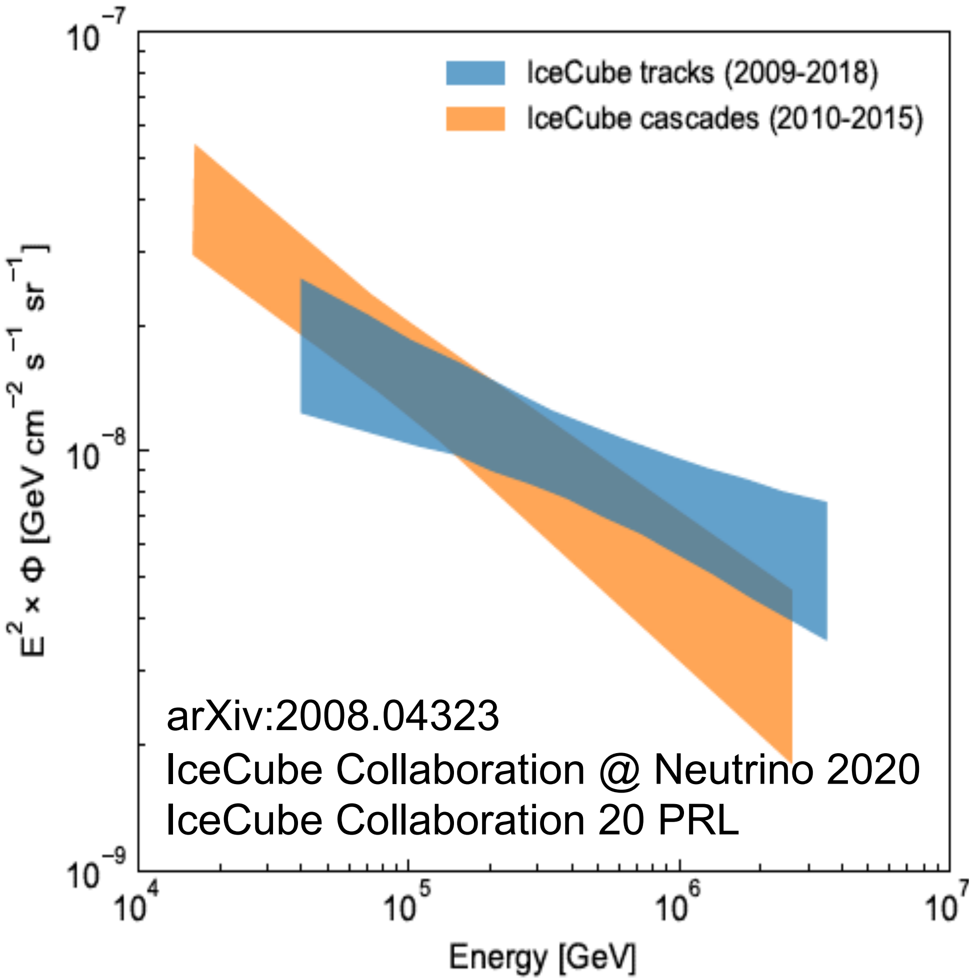
Many Motivations to Give Birth to Heavy Guys

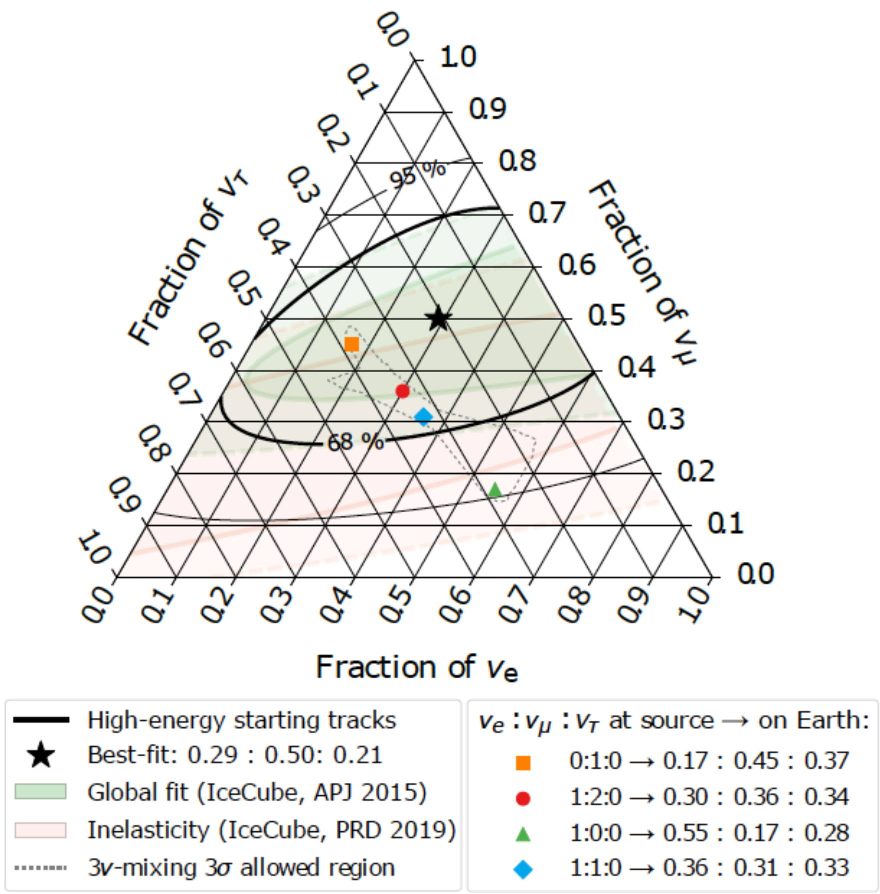


Multimessenger Power



IceCube Neutrinos

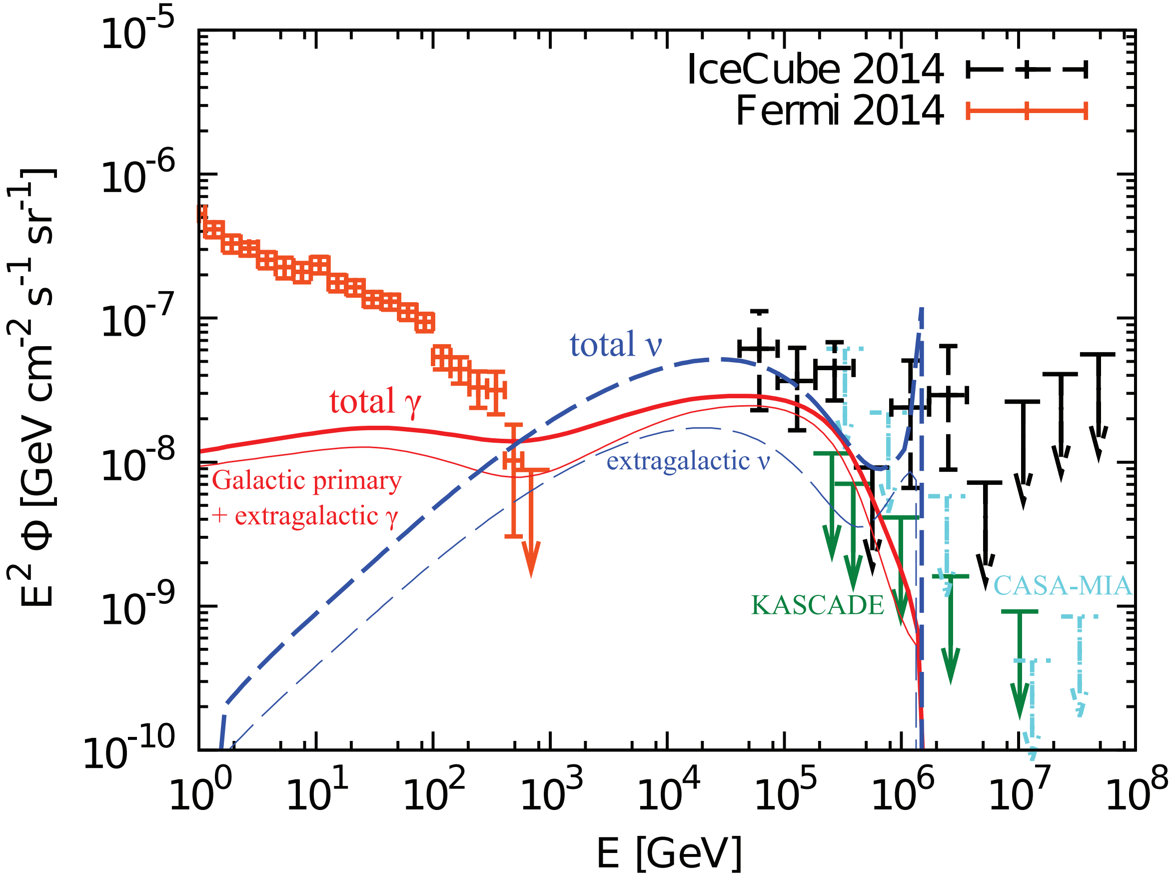




Decaying dark matter as the origin of IceCube neutrinos?

Feldstein+ 13, Esmaili & Serpico 14, Bhattacharya+ 14, Higaki+ 14, Rott+ 15…

Multi-Messenger Emission of Decaying Dark Matter



KM, Laha, Ando & Ahlers 15 PRL

see also:
KM & Beacom 12
Esmaili & Serpico 15

DM → ν_e+ν_e (12%)
DM → b+bbar (88%)

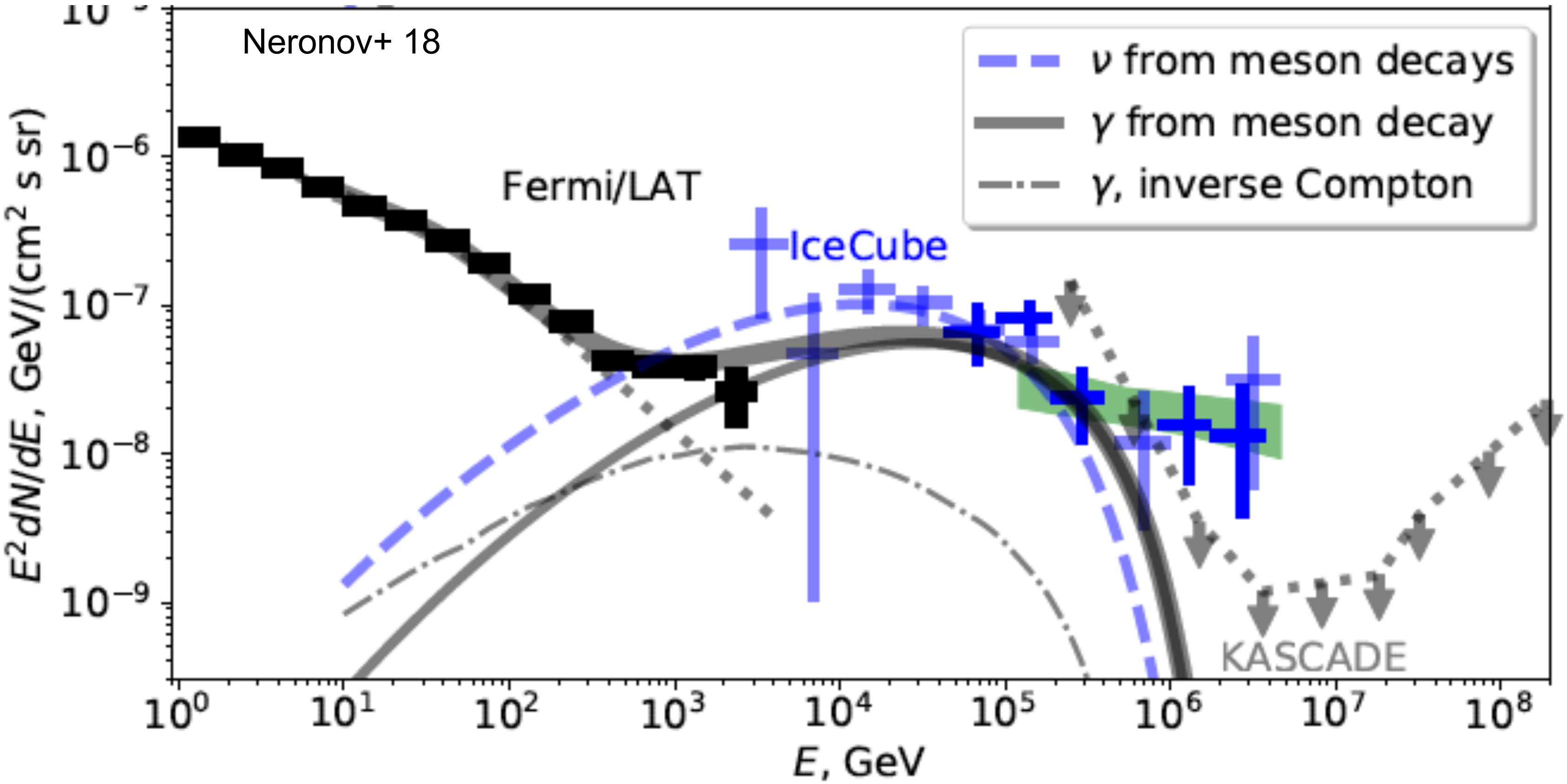
(similar results in other models that are proposed)

- Galactic: γ → direct (w. some attenuation), $e^{\pm}$ → sync. + inv. Compton
- Extragalactic → EM cascades during cosmological propagation

Testable with existing Fermi (sub-TeV γ) and air-shower (sub-PeV γ) data

Gamma-Ray Excess?

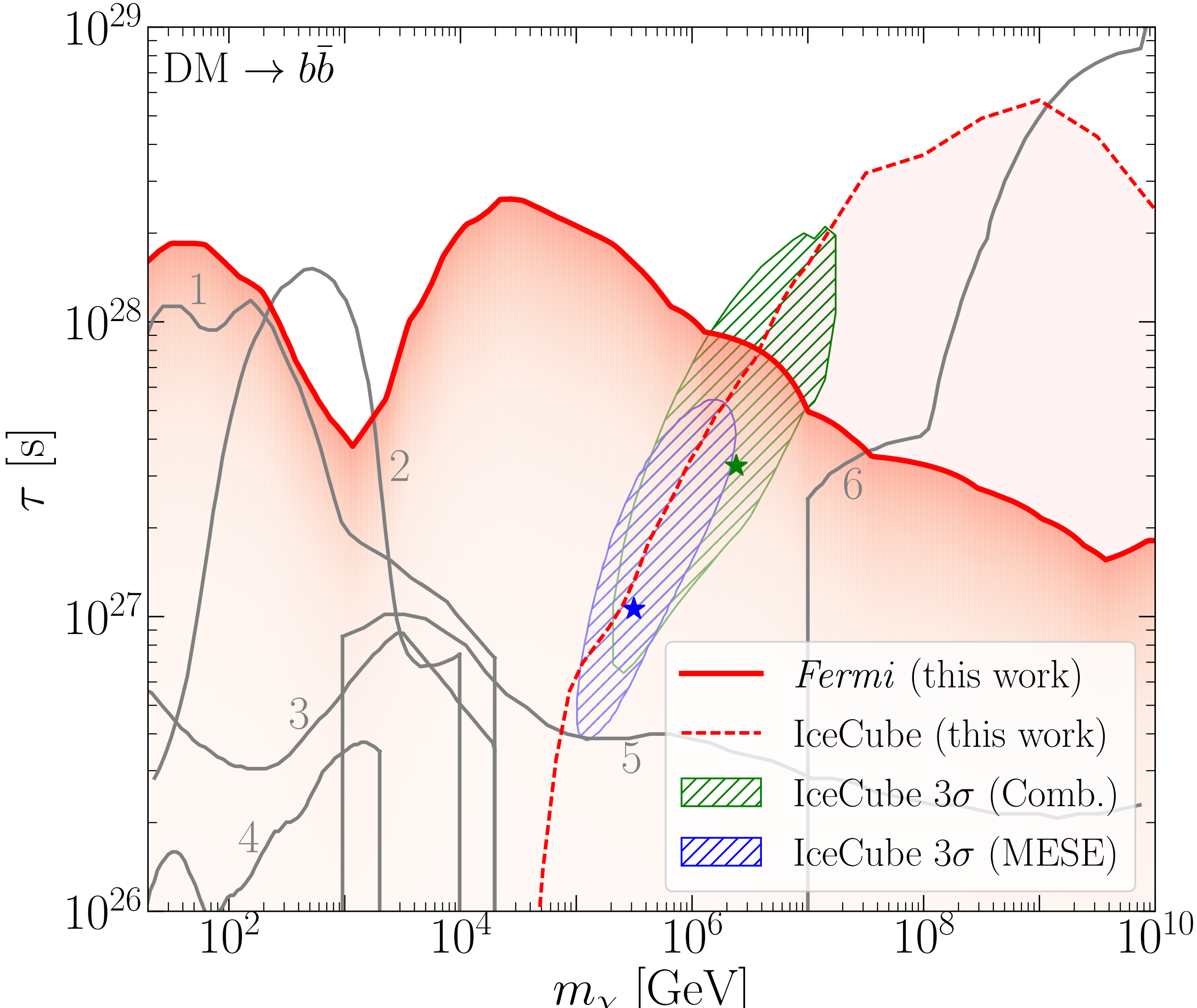
Excessive γ rays at high Galactic latitudes?



Upcoming diffuse TeV-PeV γ-ray searches are crucial & promising
Tibet AS+MD, HAWC, LHAASO, ALPACA…

Multi-Messenger Constraints on Decaying DM

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



Pass 8, eight-year Fermi data w. non-Poissonian template fitting method

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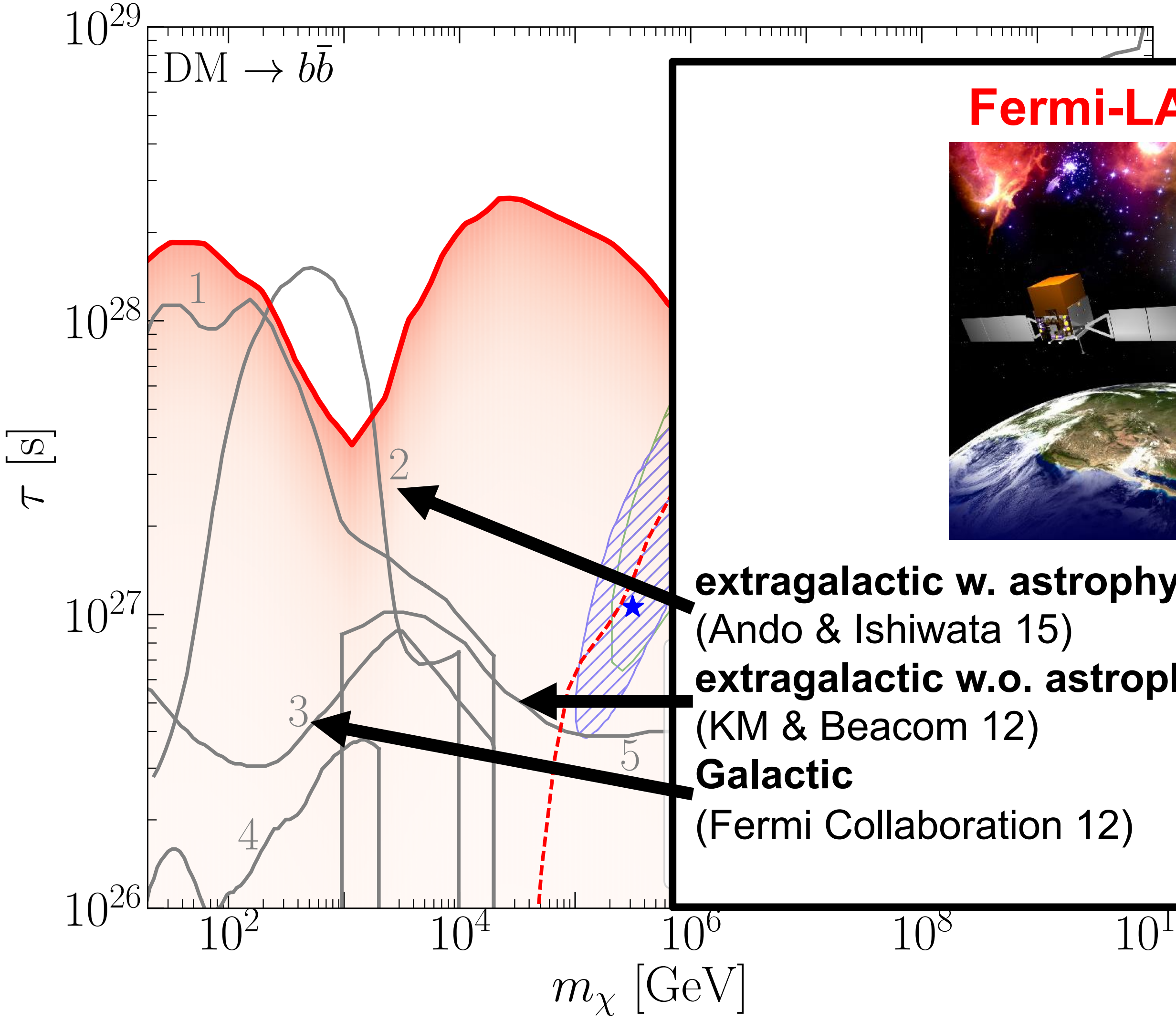

Fermi-LAT

extragalactic w. astrophysical models
(Ando & Ishiwata 15)

extragalactic w.o. astrophysical models
(KM & Beacom 12)

Galactic
(Fermi Collaboration 12)

Gamma-ray limits are improved independently of astrophysical modeling

Multi-Messenger Constraints on Decaying DM

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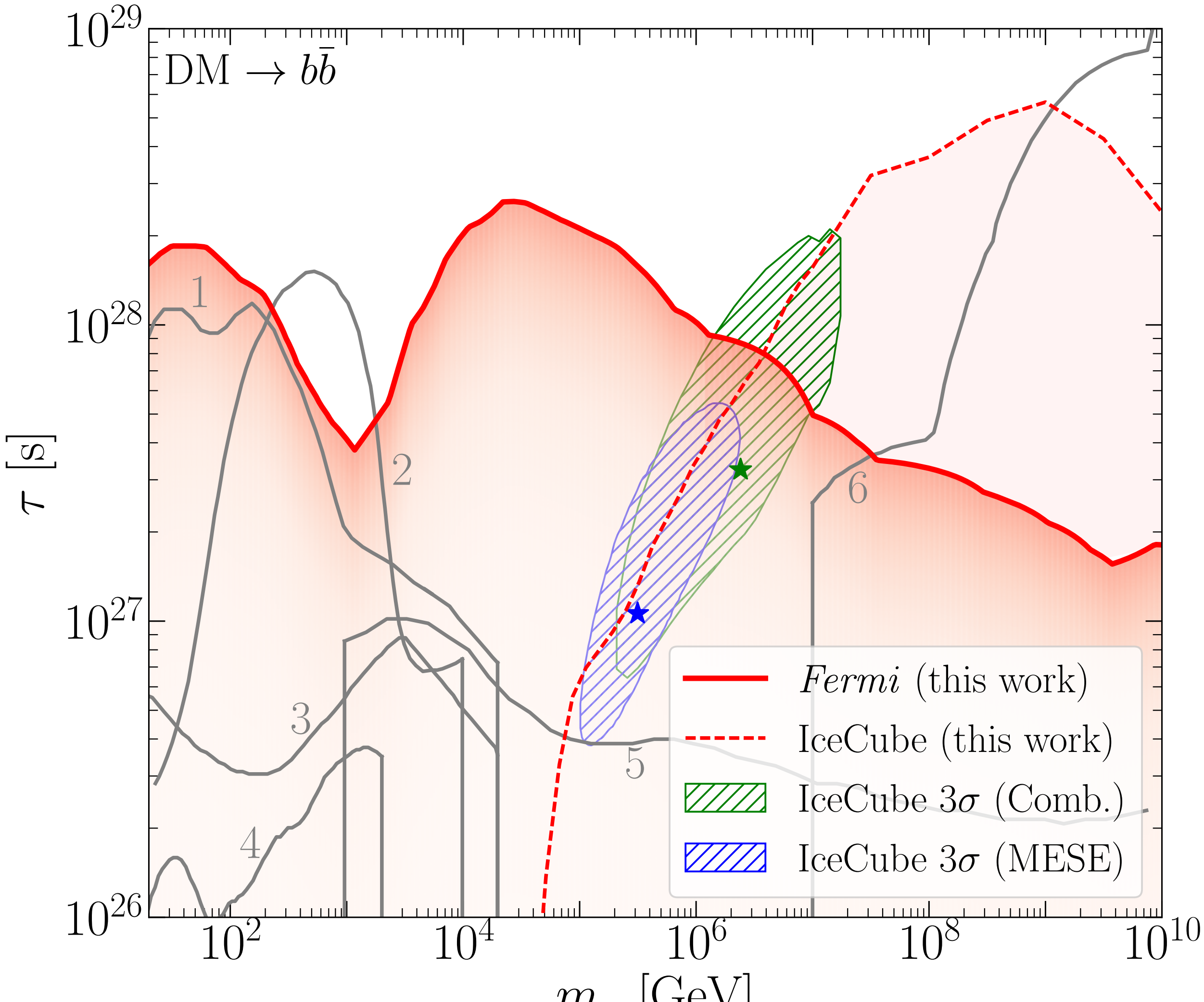

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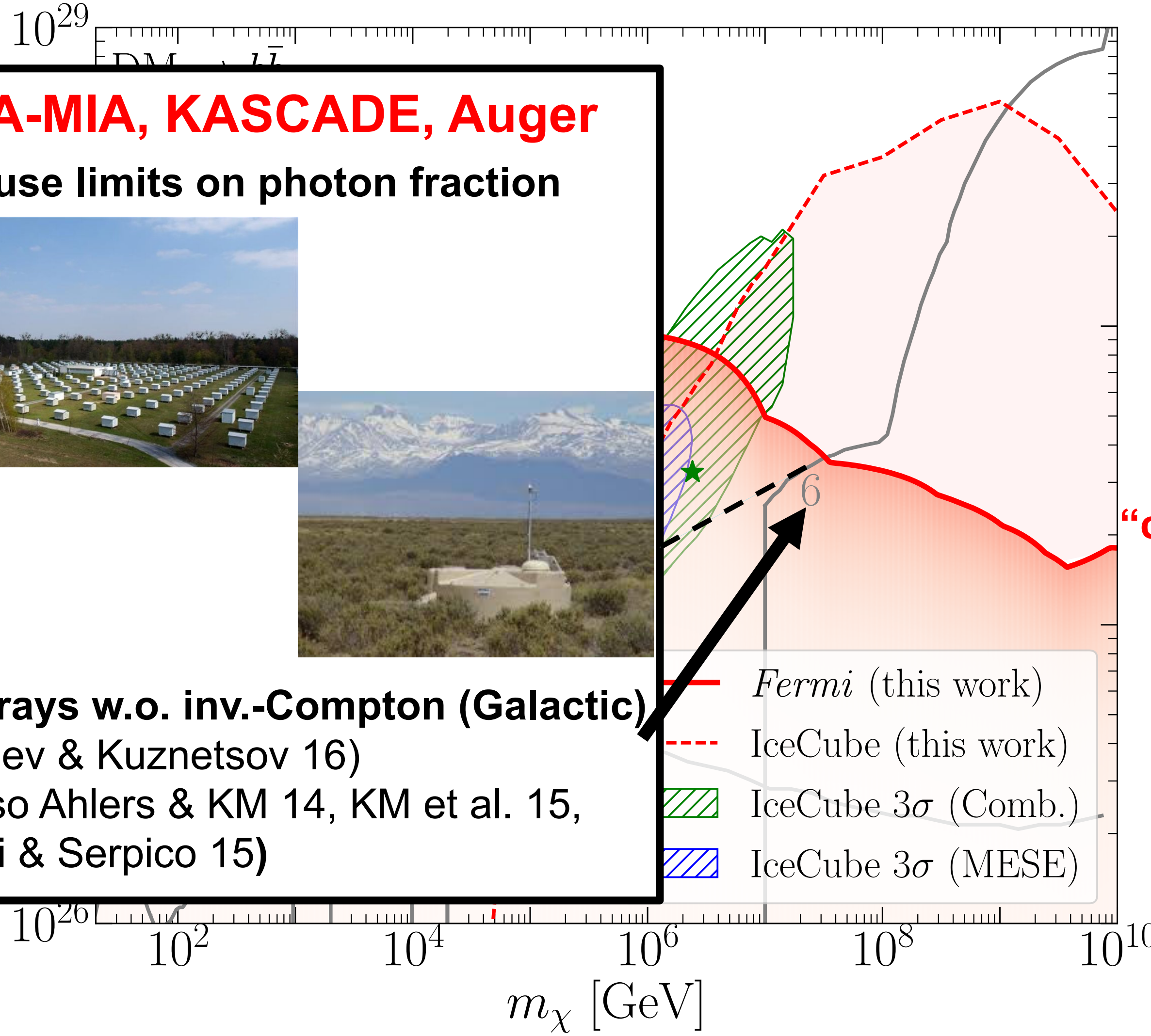


CASA-MIA, KASCADE, Auger

diffuse limits on photon fraction

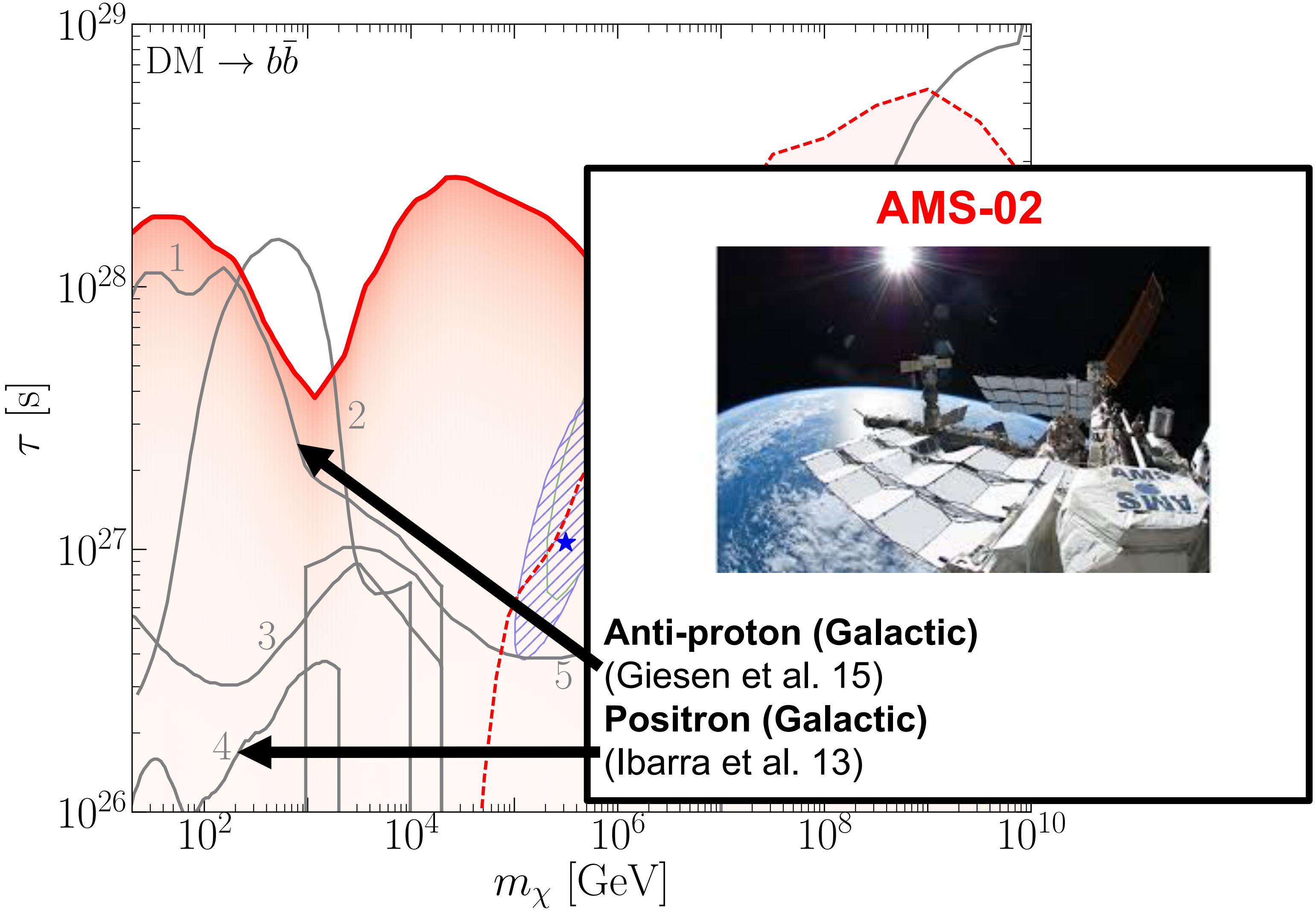
VHE g rays w.o. inv.-Compton (Galactic)
(Kalashev & Kuznetsov 16)
(see also Ahlers & KM 14, KM et al. 15,
Esmaili & Serpico 15)

"cascade" bound (extragalactic)

tension w. diffuse VHE γ-ray limits that are important at ultrahigh energies

Multi-Messenger Constraints on Decaying DM

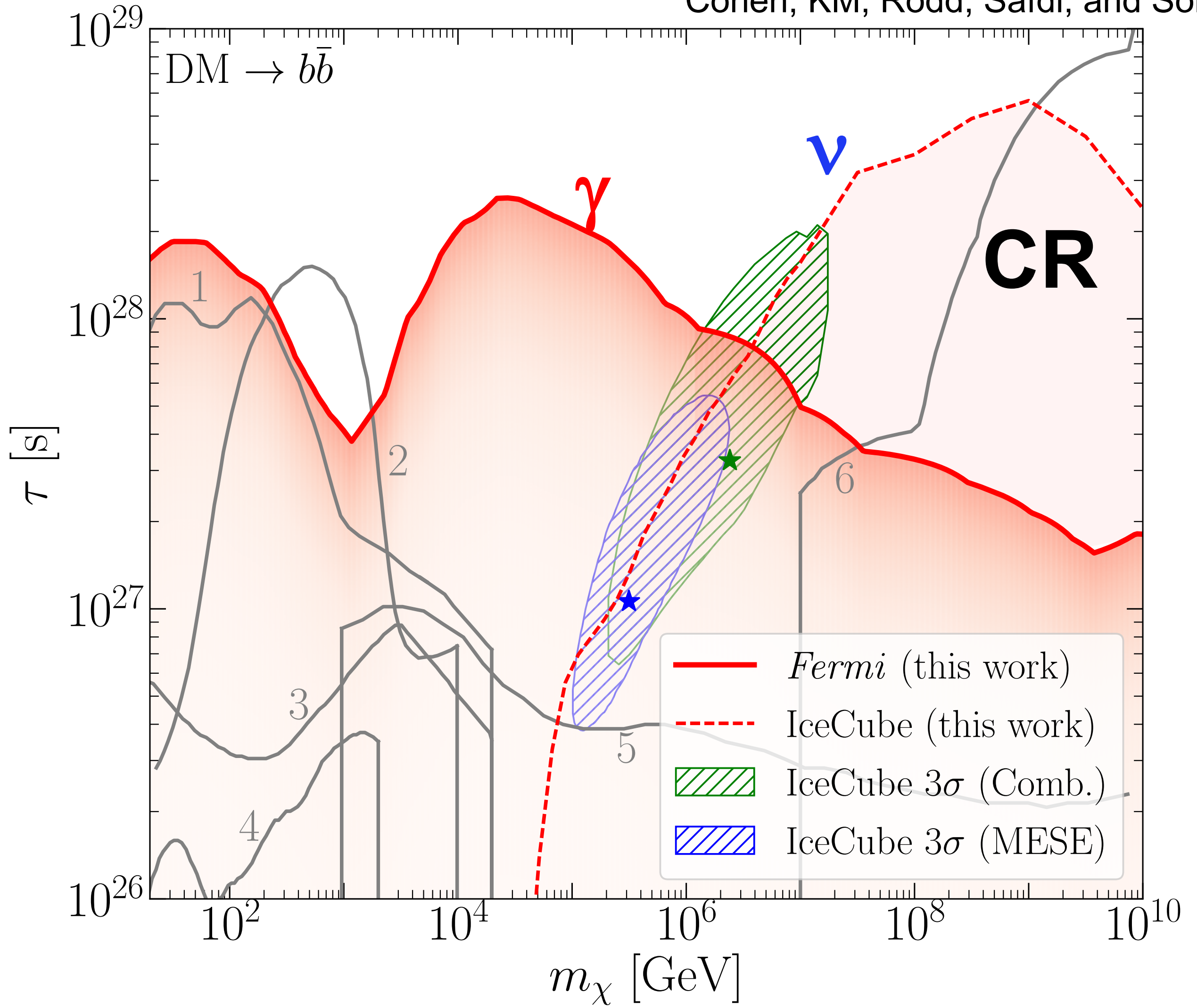
Cohen, KM, Rodd, Safdi, and Soreq 17 PRL



Anti-proton constraints are competing for soft channels such as DM→bb

Multi-Messenger Constraints on Decaying DM

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

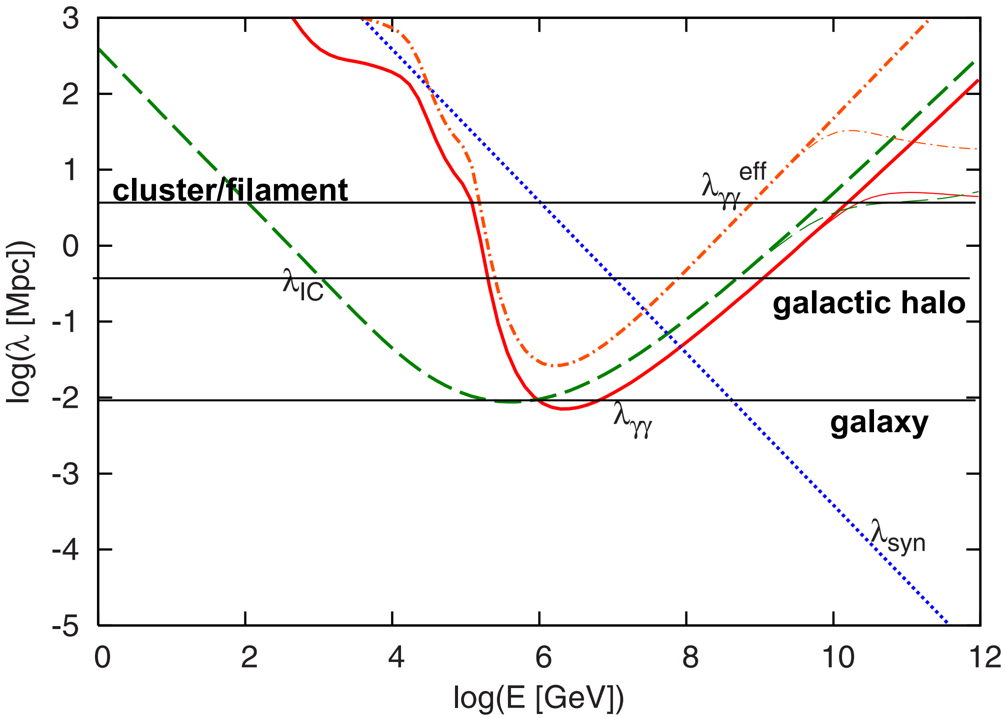


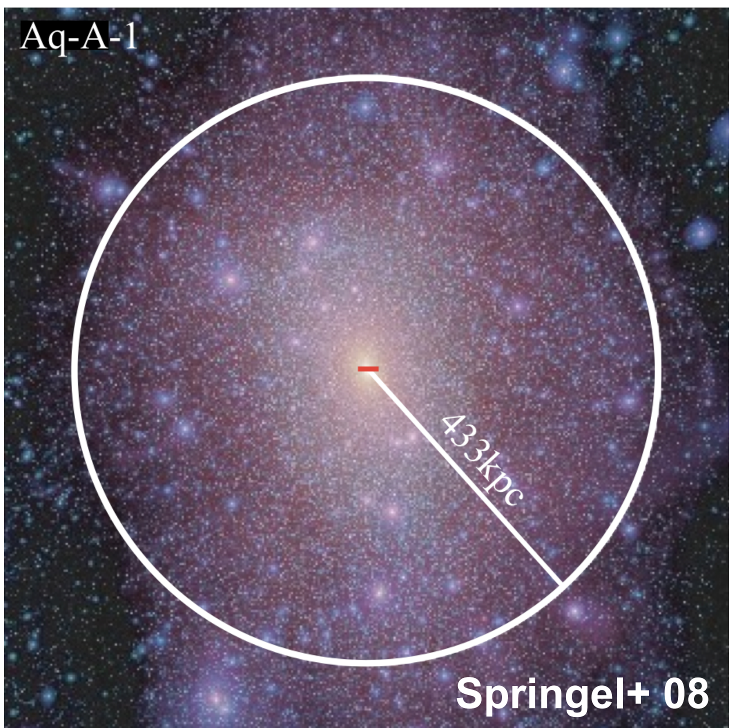
Three messengers give complementary constraints on heavy DM

Theoretical Issues

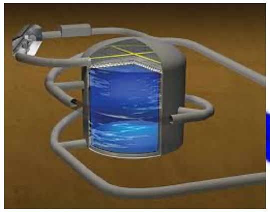
- Energy frontier
  (ex. EW symmetry restoration, possible large Higgs multiplicity)
- Astrophysical information matters for the fate of SM particles
  - EM cascades occur inside objects ("smeared density profile")
  - CR propagation depends on halo properties (e.g., outflows)

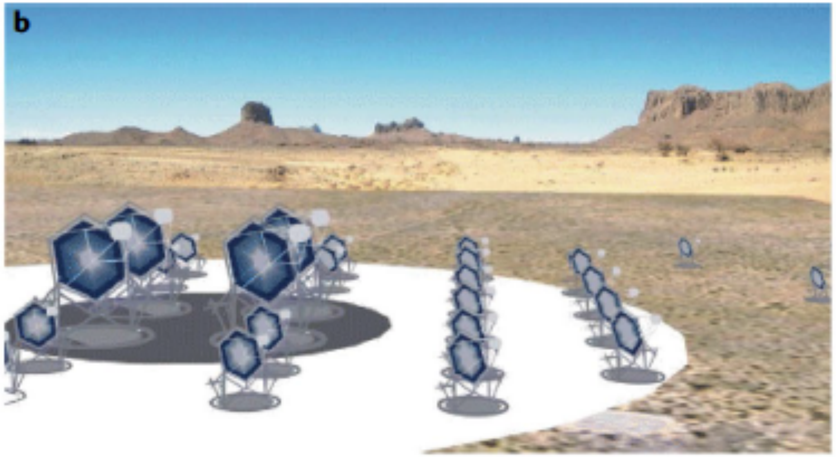
  Not taken into account in most studies

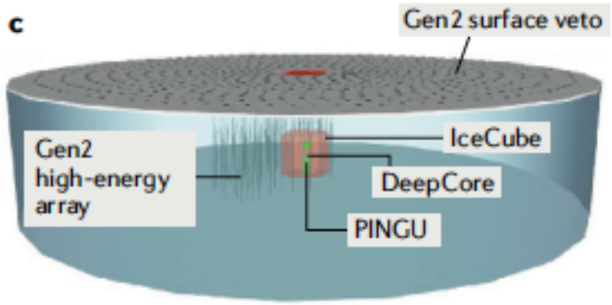


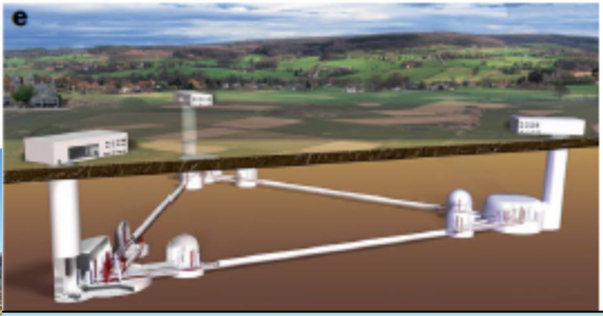


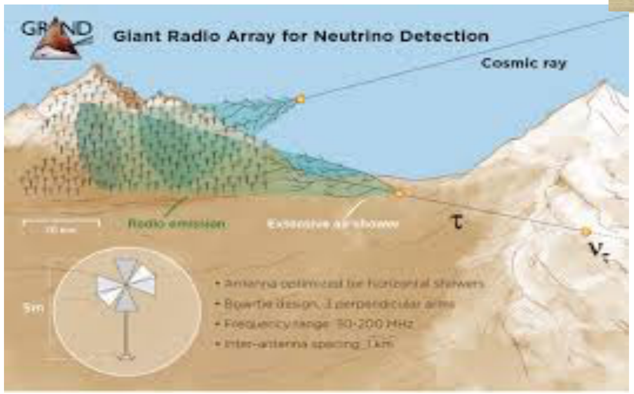
From Dark to Bright in Future









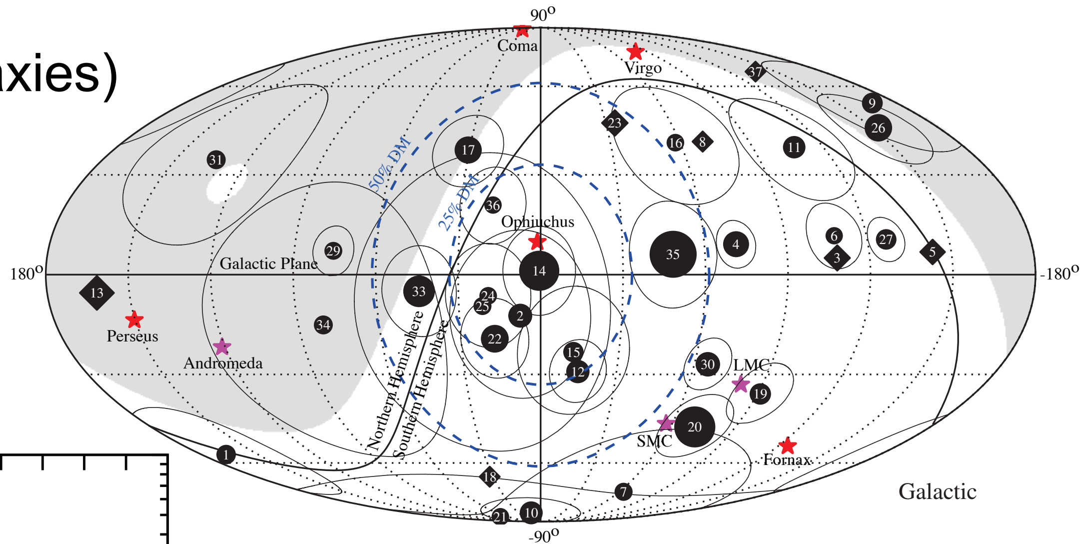


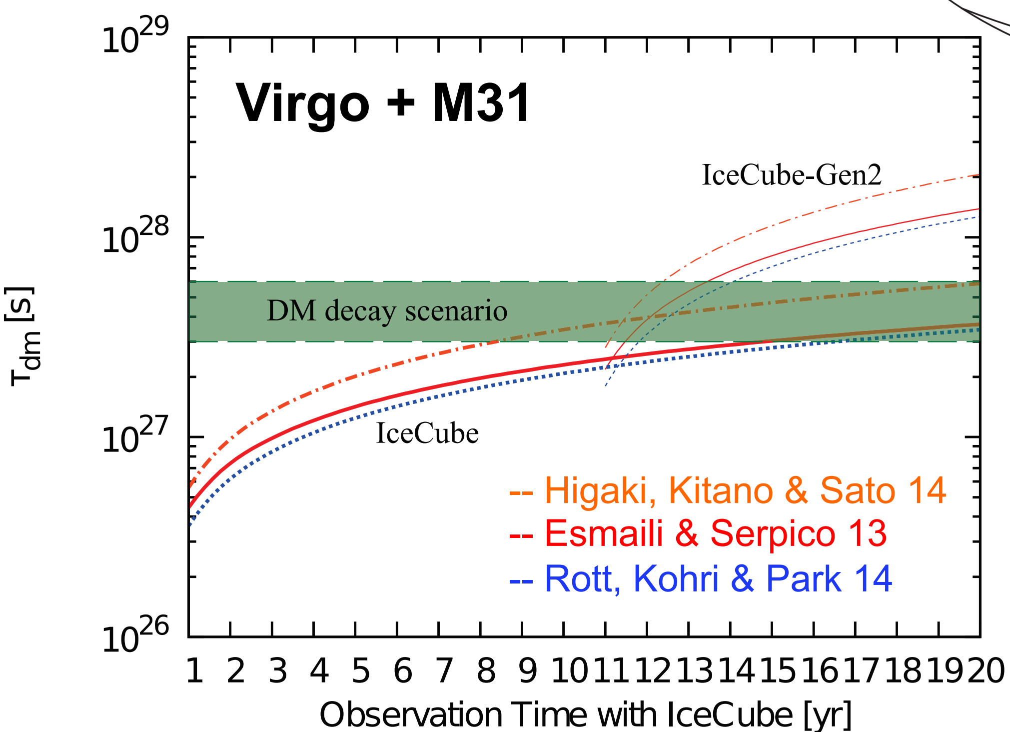
Multi-messenger data in the next decade will enable us to probe more discovery space even in the PeV-ZeV range

Relevance of Search for Nearby DM Halos

Nearby DM halos (clusters & galaxies)
“point/extended” sources

source flux $\propto M_{dm}/\tau_{dm}/d^2$





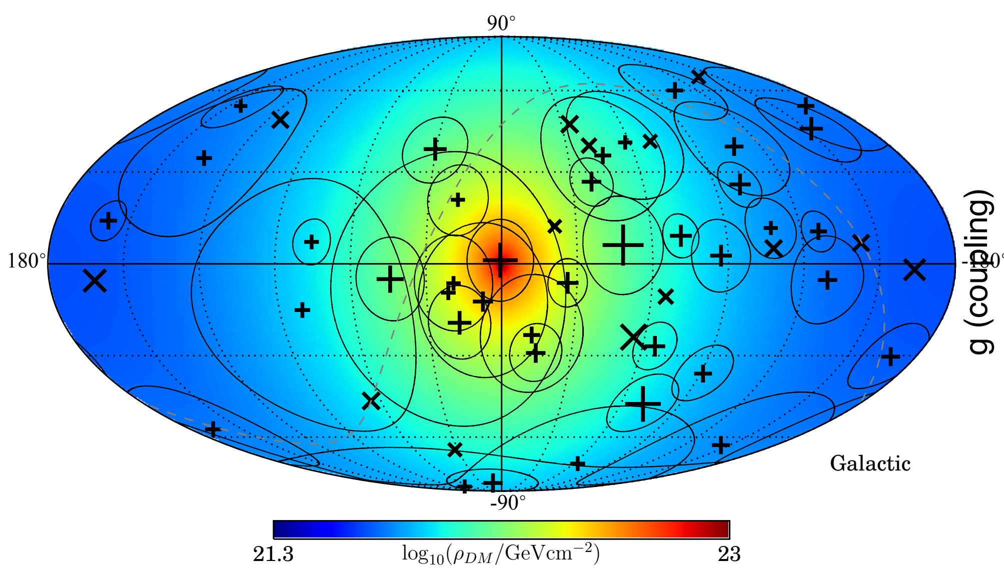
stacking/cross-correlation

very powerful independent of γ–ray searches

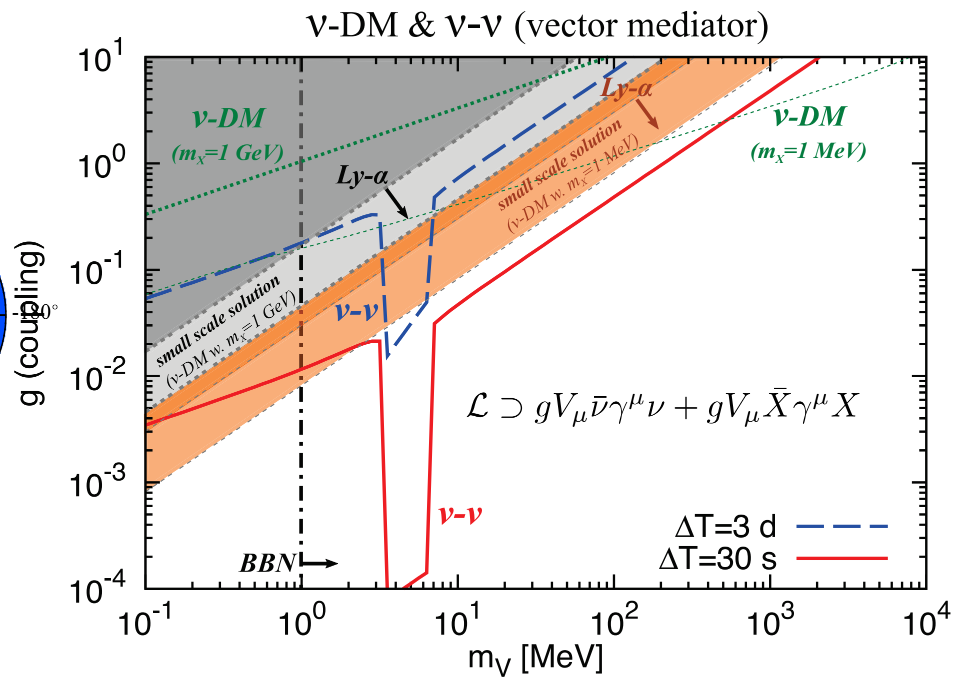
KM, Laha, Ando & Ahlers 15 PRL

High-Energy Particles as a Probe of Dark Matter

- ν-DM scatterings induce deflection or time delays
  -> limits complementary to laboratory constraints
  (often providing the best constraints)
- Probing models invoked to alleviate substructure problems and/or the Hubble tension (e.g., Z' model with a MeV mediator)



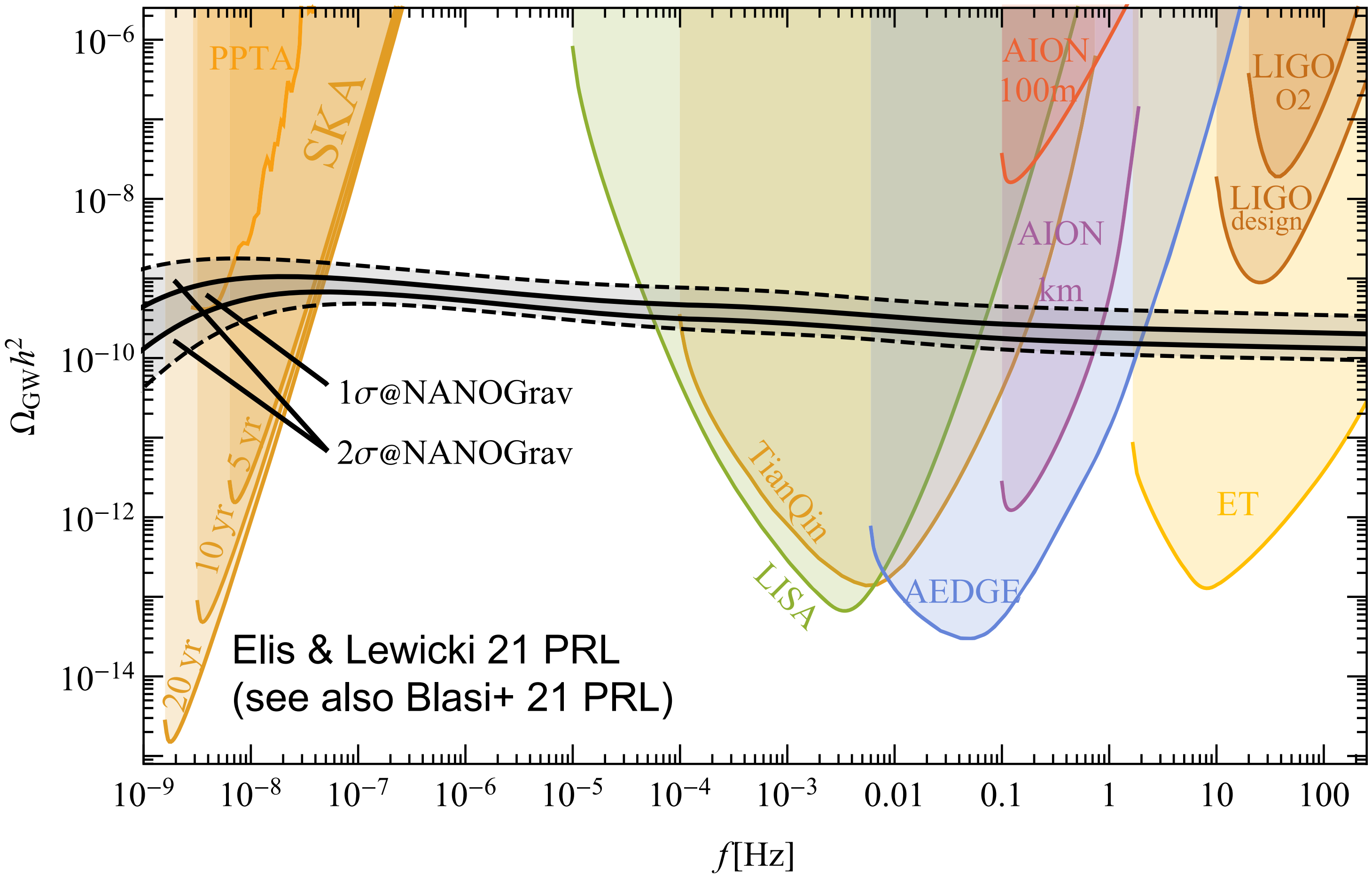
Arguelles et al. 17 PRL



KM & Shoemaker 19 PRL

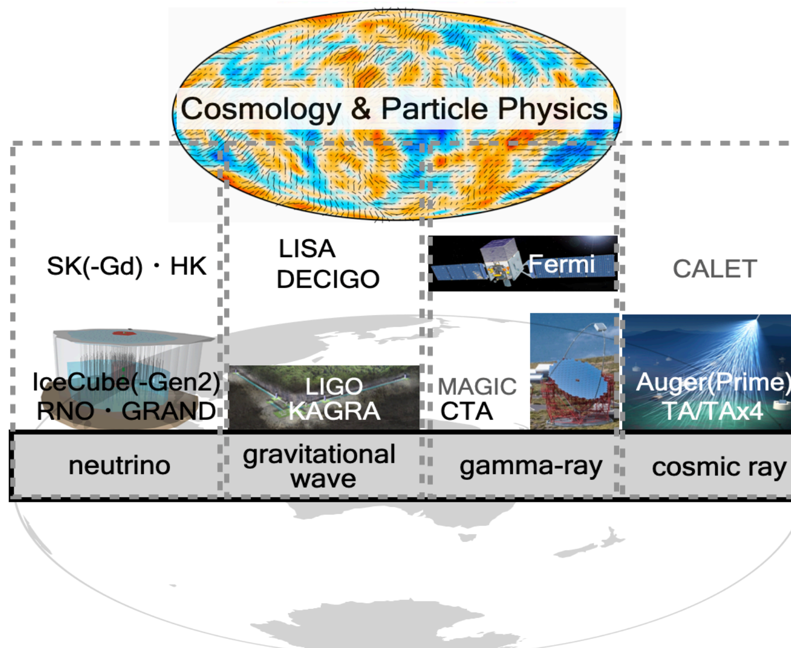
Gravitational Waves & New Physics

- cosmic strings (e.g., Dror+ 20 PRL)
- first-order phase transition (e.g., Schwaller 15 PRL)



Summary

- Many motivations for heavy dark matter
- Multi-messenger approaches are powerful
- Connection to various astrophysical problems
  → Great synergies with other groups
- Two postdocs will join the A02 group in 2021




学術変革領域研究「ダークマター」シンポジウム（Online）
6 February 2021
Overview
Registration
Timetable
Link
Online information
Contact
seminar@ipmu.jp
"What is dark matter
dark matter"
Date: February 6, 2021
Venue: Online (Zoom)
Overview:
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