

CF7. Cosmic Probes of Fundamental Physics

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Early Career Representatives: Kristi Engel and Tiffany Lewis

137 Letters of Intent; 12 white papers

Link to CF7 Report:

<https://www.dropbox.com/s/7aaxxImtcjvxyqb/CF7-report.pdf?dl=0>

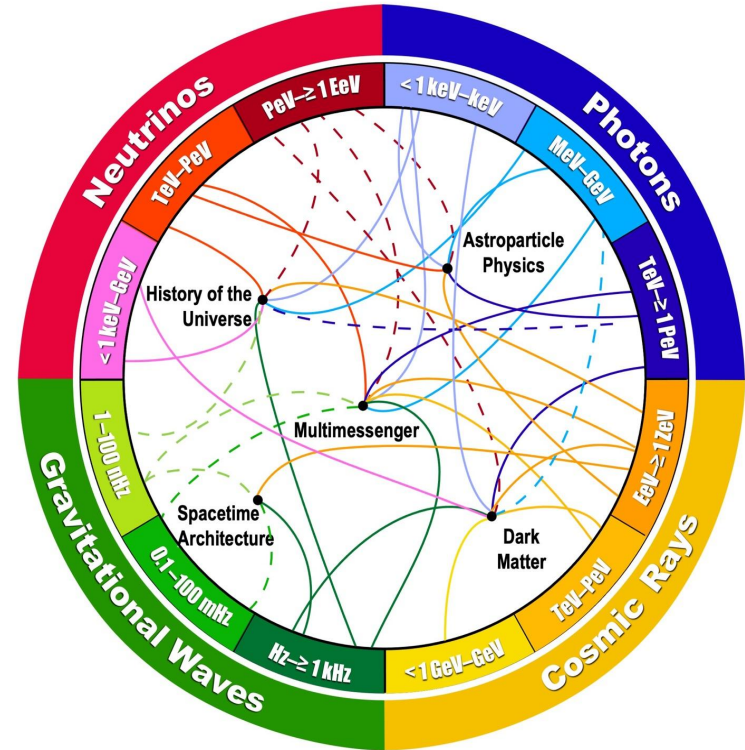
Feedback form:

<https://forms.gle/kKuWWPgRaohQ8YqN7>

Five main topical areas driven by big science questions with cosmic probes over the next decade:

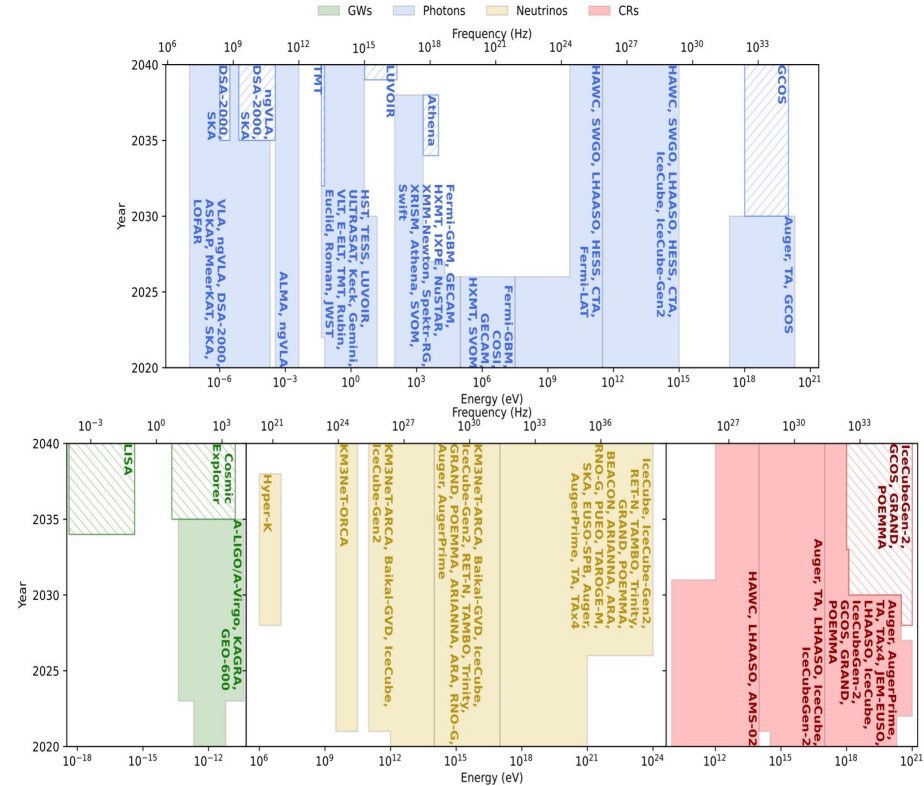
- History of Universe and Cosmology
- Cosmic Probes of Dark Matter
- Astroparticle Physics
- Multimessenger Synergies in Particle Astrophysics
- Architecture of Spacetime

Solid curve: current existing facilities
Dashed curve: future experiments



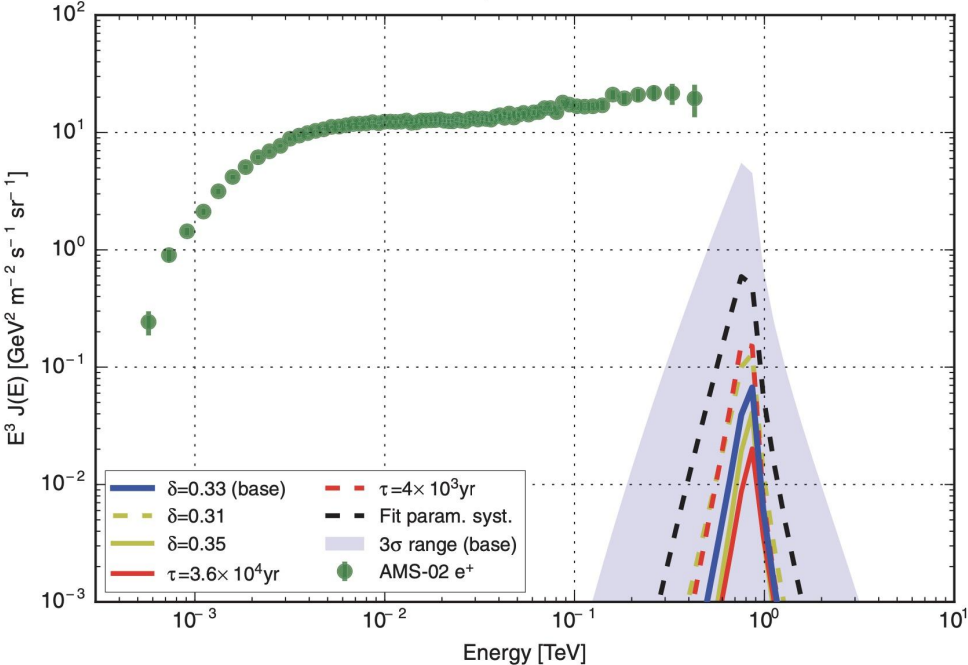
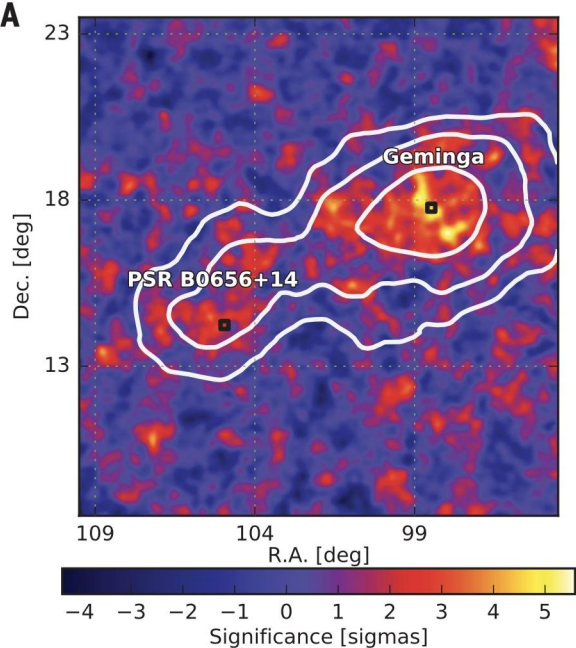
Multimessenger Synergies in Particle Astrophysics

- Sources of Cosmic Particles
- Extreme-energy particle acceleration and interaction
- Diffuse backgrounds: gamma-ray, supernova neutrino, astrophysical diffuse neutrino, cosmogenic neutrino backgrounds, and Galactic diffuse emission
- Galactic TeVatrons and PeVatrons
- Production of heavy elements



Particle Astrophysics example - TeV halos vs AMS-02 Positron Excess

HAWC Coll. *Science* (2017)

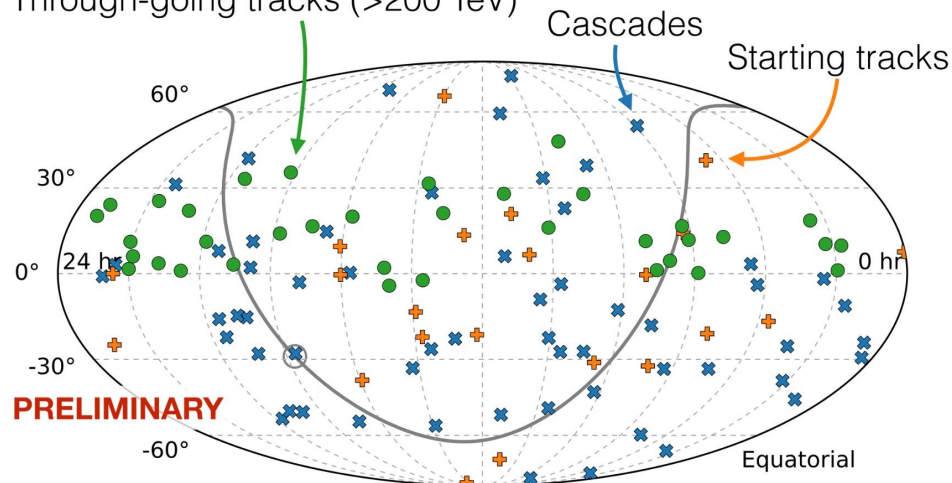


Understanding the astrophysical contribution is crucial to indirect dark matter searches

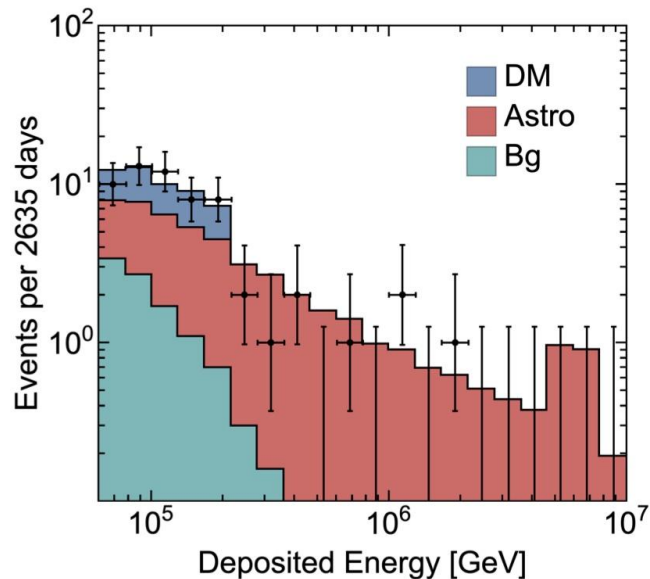
Particle Astrophysics example - Diffuse High-energy Neutrino Background

IceCube Coll. (2020, 2021, 2022); Reimann, *galaxies* (2017)

Through-going tracks (>200 TeV)

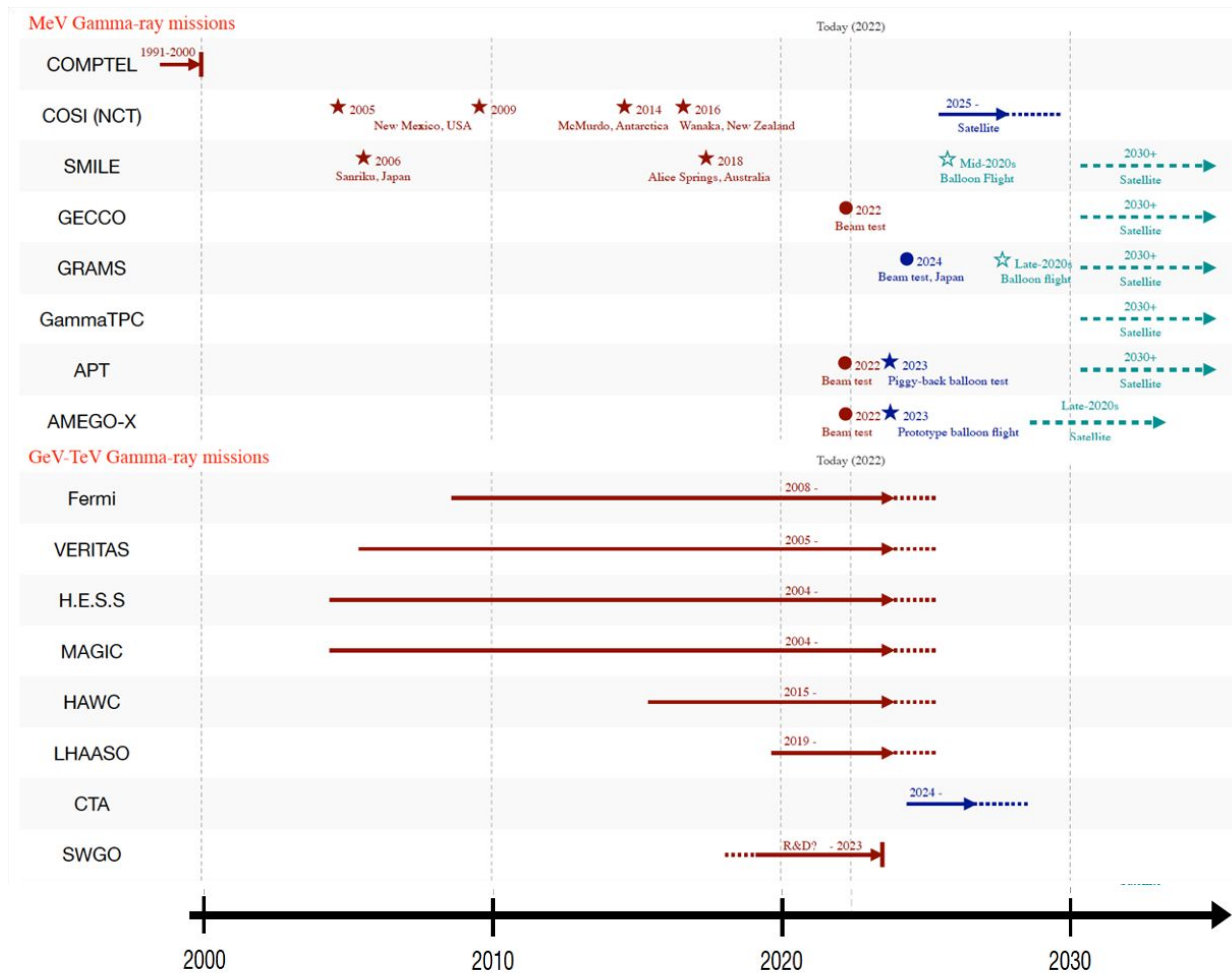


Chianes et al *JCAP* (2019)



Precise measurements of diffuse emission backgrounds are important to indirect searches

Gamma-Ray Instrumentation Roadmap



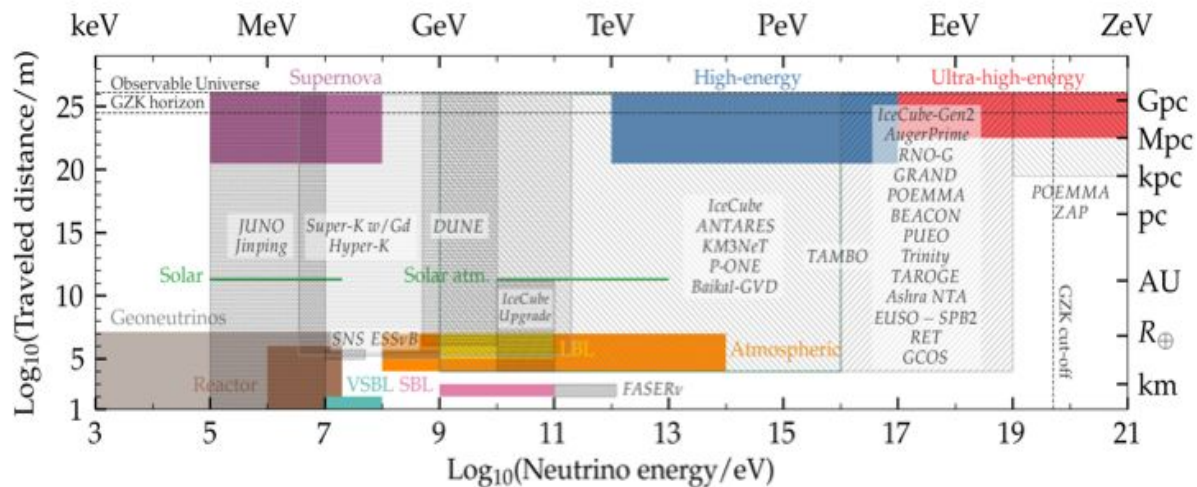
Current/previous, Near-term, Future

- → → Satellite: funded/proposed
- ★ ☆ Balloon: funded/proposed
- ○ Beam test: funded/proposed

Instrumentation Roadmap

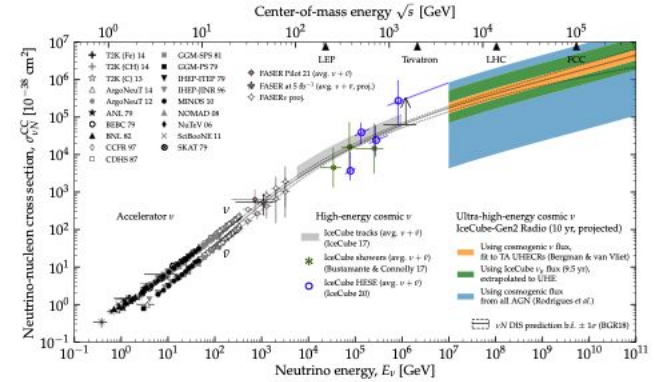
Experiment	Feature	Cosmic Ray Science	Timeline
Pierre Auger Observatory	Hybrid array: fluorescence, surface e/μ + radio, 3000 km ²	Hadronic interactions, search for BSM, UHECR source populations, σ_{p-Air}	AugerPrime upgrade
Telescope Array (TA)	Hybrid array: fluorescence, surface scintillators, up to 3000 km ²	UHECR source populations, σ_{p-Air}	TAx4 upgrade
IceCube / IceCube-Gen2	Hybrid array: surface + deep, up to 6 km ²	Hadronic interactions, prompt decays	Upgrade + surface enhancement IceCube-Gen2 deployment IceCube-Gen2 operation
GRAND	Radio array for inclined events, up to 200,000 km ²	UHECR sources via huge exposure, search for ZeV particles, σ_{p-Air}	GRANDProto-300 GRAND 10k GRAND 200k multiple sites, step by step
POEMMA	Space fluorescence and Cherenkov detector	UHECR sources via huge exposure, search for ZeV particles, σ_{p-Air}	EUSO program POEMMA
GCOS	Hybrid array with X_{max} + e/μ over 40,000 km ²	UHECR sources via event-by-event rigidity, forward particle physics, search for BSM, σ_{p-Air}	GCOS R&D + first site GCOS further sites

2025 2030 2035 2040

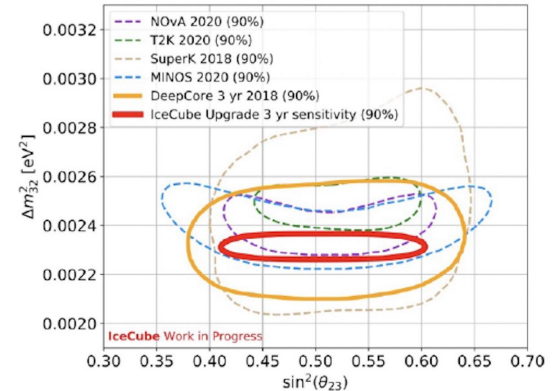


Astroparticle Physics

- **Standard Model particles and their interactions**
- **Beyond-Standard-Model (BSM) neutrino physics:** BSM neutrino interaction with DM, sterile neutrinos, secret neutrino interactions, neutrino flavors
- **Muon puzzle of UHECRs**
- **Nature of matter in neutron star interiors**
- **Test of Lorentz and CPT invariance**
- **Exotic particles in QED domain**



Ackermann et al., *HE and UHE neutrino whitepaper*
[2203.08096](https://arxiv.org/abs/2203.08096)

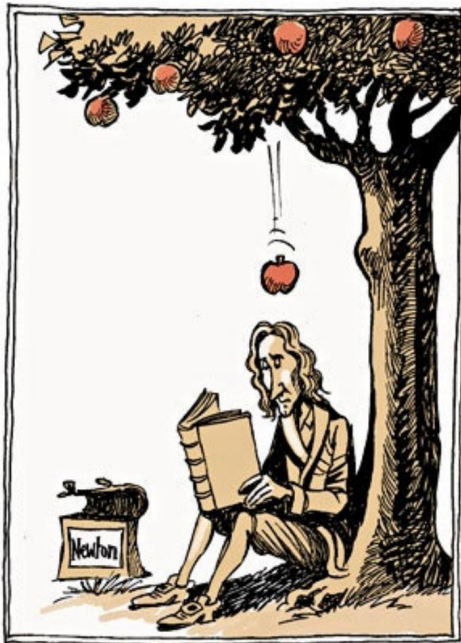


Updated from IceCube Coll. [1908.09441](https://arxiv.org/abs/1908.09441)

Astroparticle Physics

in synergy with Energy, Accelerator, and Computational Frontiers

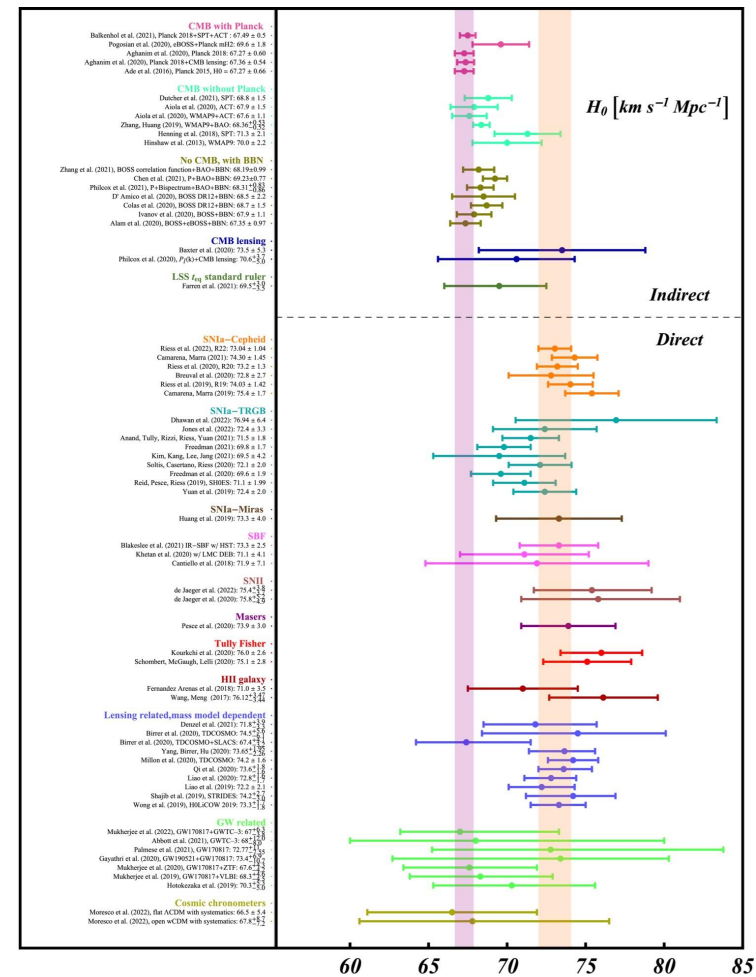
Collisions That Changed The World



Test of strangeness production: Solving the “muon puzzle” with AugerPrime + CERN’s FPF

History of the Universe and Cosmology

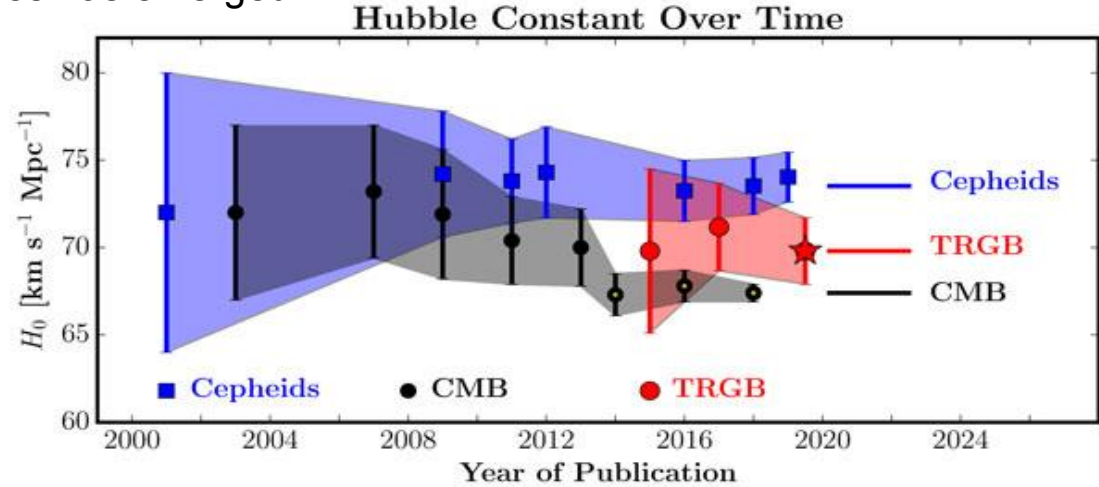
- **Hubble constant (H_0) tension**
(in synergy with CF4-6)
- **Imprints from early universe:**
cosmic strings, primordial GW from inflation, GW from phase transitions
- **Super-have dark matter particles produced at the end of inflation:**
ultrahigh-energy cosmic rays, photons, and neutrinos
- **Inferring the Neutrino Mass from Cosmological Probes**
NF5-CF7 cross-frontier discussion session in HUB 307 (July 22 8:00 to 12:00)



Hubble constant tension

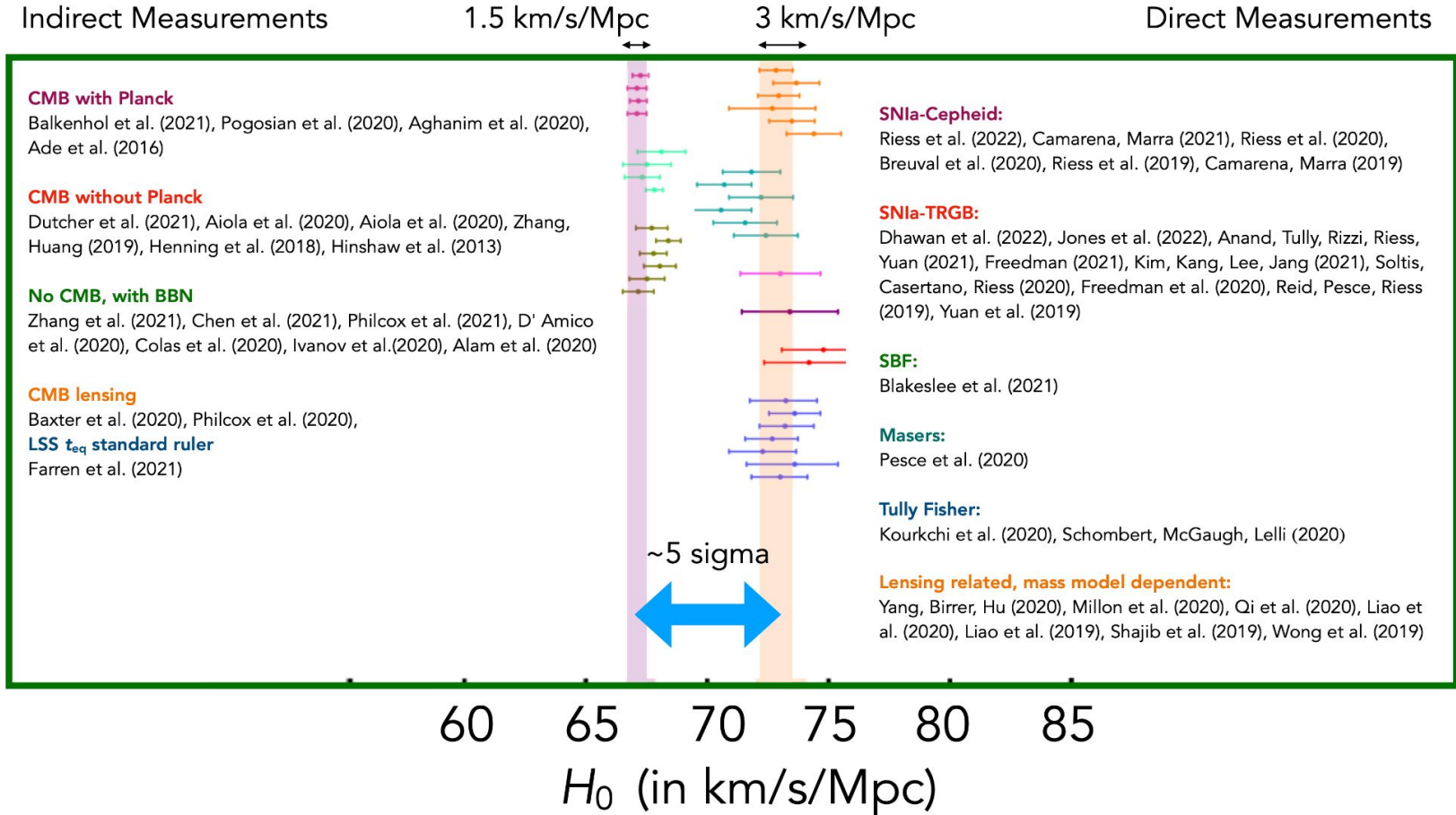
➤ After last Snowmass an intriguing inconsistency between measurements of the cosmic expansion rate based on early- and late-Universe probes has emerged

➤ This inconsistency shows up as a discrepancy in the value of H_0 as inferred from measurements of CMB anisotropies and as measured from a series of distance indicators in the local Universe

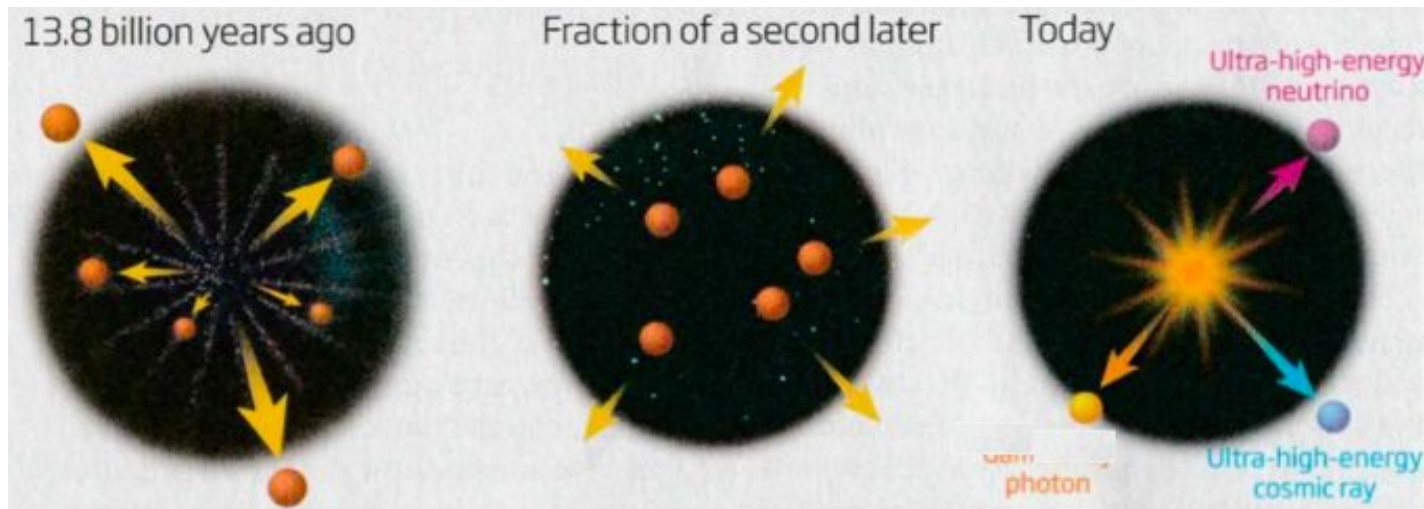


- Depending on which set of measurements one combines ➤ tension between model-dependent and independent estimates of H_0 sits between 4.5σ to 6.3σ
- The H_0 tension has become new cornerstone of modern cosmology and many new-physics setups are rising to the challenge
- Is the H_0 tension a footprint of BSM physics?
- Roughly 50 GWSS with EM counterparts would be needed to measure H_0 to 1% precision

High Precision Measurements of the Hubble Constant



Birth and death of superheavy X-particles



- Intense fluctuating gravitational fields gave birth to superheavy X-particles just after the big bang
- The expansion of space during inflation distributed the X-particles through the cosmos
- After billions of years the X-particles decay producing a range of detectable particles
 - particle physics factor (solving DGLAP numerically)
- To estimate the flux of detectable particles we need to evaluate:
 - astrophysical factor (with roughly 10% uncertainty)
- X-particle have GUT scale masses ➡ **background free** dark matter indirect detection experiments!
- **A clear detection of an extreme energy photon would be momentous discovery**

Quantum Gravity Constraints on Low Energy Dynamics in synergy with Theory Frontier

Swampland: IR consistent QFTs that cannot be embedded into a UV complete QGT

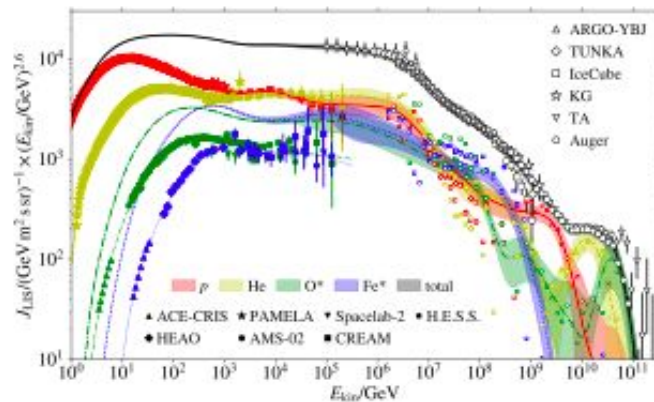
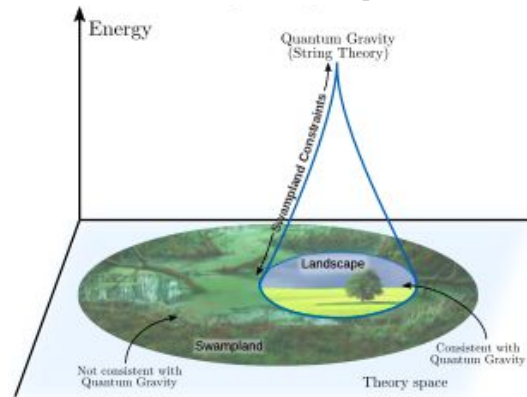
- This sorting of QFTs by their consistency with gravity has become an unexpectedly powerful theoretical tool offering potential solutions to the problems of fine-tuning
- E.g. Cosmological Hierarchy Problem $\Lambda \sim 10^{-122} M_{\text{Pl}}^4$
- Local EFT breakdown at higher-dim Planck scale:



$$M_{\text{UV}} \sim \lambda^{-1/3} \Lambda^{1/12} M_{\text{Pl}}^{2/3} \sim 10^{10} \text{ GeV}$$

- Is the cutoff of the CR spectrum driven by M_{UV} ?
- Connection to the H_0 tension?

See Montero-Vafa-Valenzuela arXiv:2205.12293



Cosmology of non-minimal dark sectors

➤ Dynamical Dark Matter (DDM) is a framework for non-minimal dark sectors which posits that the dark matter in the Universe comprises a vast ensemble of interacting fields with a variety of different masses, lifetimes, and cosmological abundances

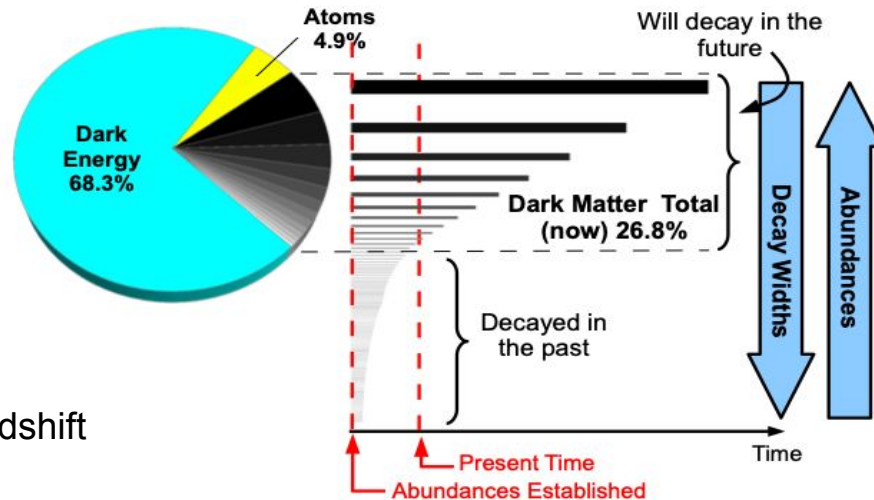
➤ Distinctive probe of secluded dark sectors

➤ Dark-to-dark decays modify the way in which the expansion rate of the Universe evolves with redshift

➤ E.g. dark-to-dark decays of a DDM ensemble alter the dependence of $H(z)$ on z and so DDM framework can potentially provide a way of addressing the H_0 tension

➤ 13 “take-away lessons” for Snowmass 2021

see Dienes and Thomas [arXiv2203.17258](https://arxiv.org/abs/2203.17258):



Gravitational Waves: Key Science Questions

- Black holes and neutron stars throughout the Universe

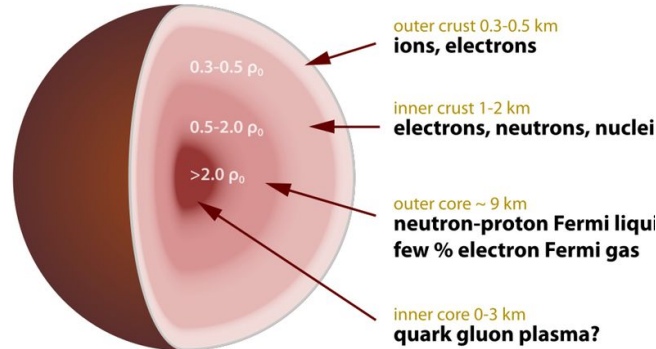
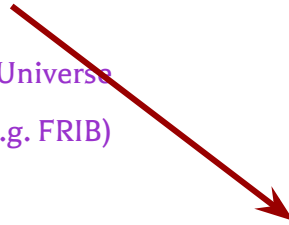
- Axion clouds around black holes
- Primordial black holes

- Dynamics of dense nuclear matter

- Equation of state ($p > 10^{17} \text{ kg/m}^3$)
- QCD phase diagram
- Synthesis of heavy elements in the Universe
- Synergies w Rare Isotope studies (e.g. FRIB)

- Physics beyond the standard model

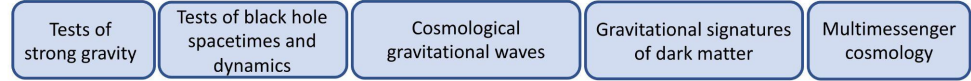
- Dark matter in neutron stars
- Modified gravity; spacetime structure
- What is the nature of BH Horizons?
- Boson stars and other exotic objects
- Precision cosmology for H_0 and dark energy



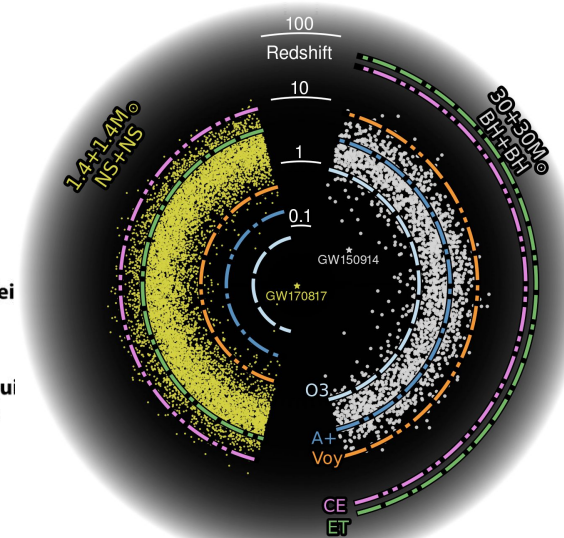
Experiments



Science investigations

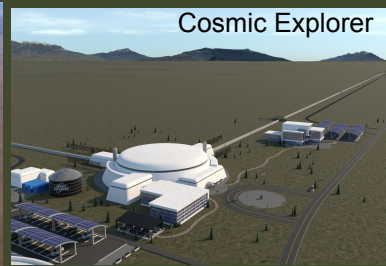
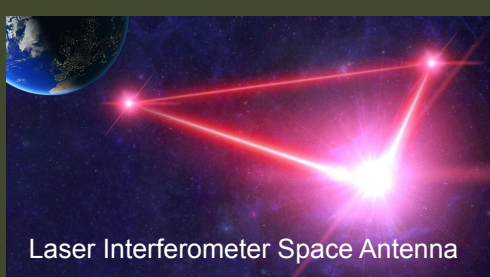
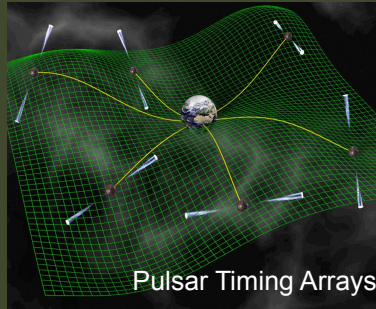
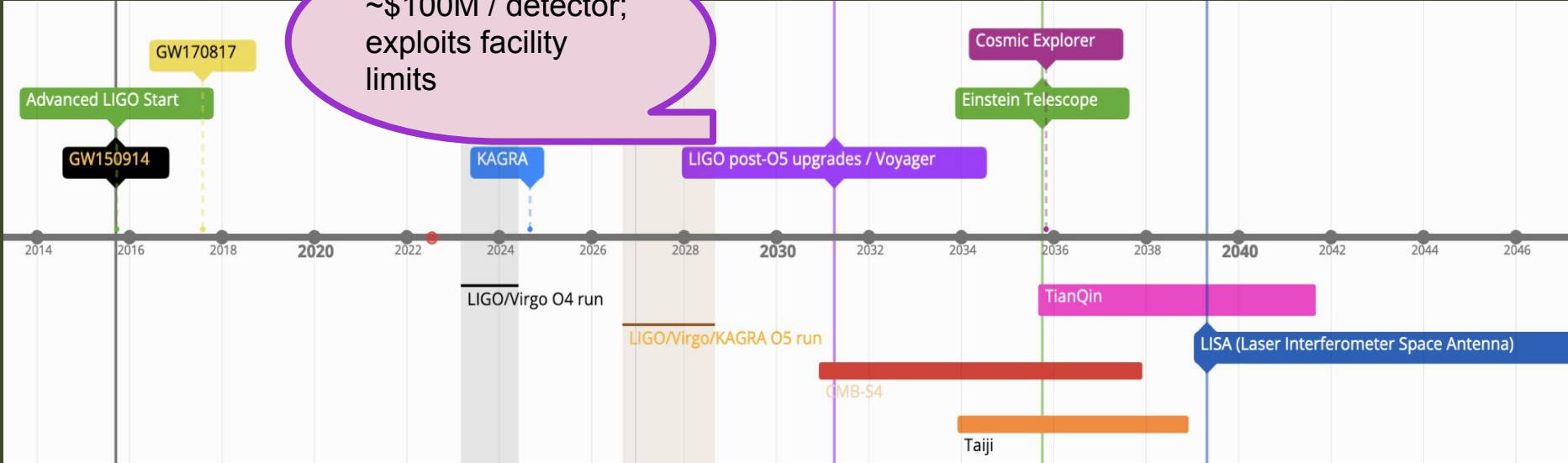


Fundamental physics



GRAVITATIONAL WAVES: FACILITIES AND TIMELINE

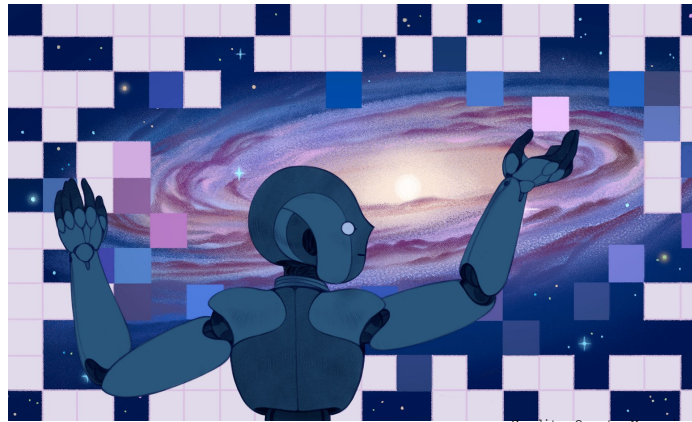
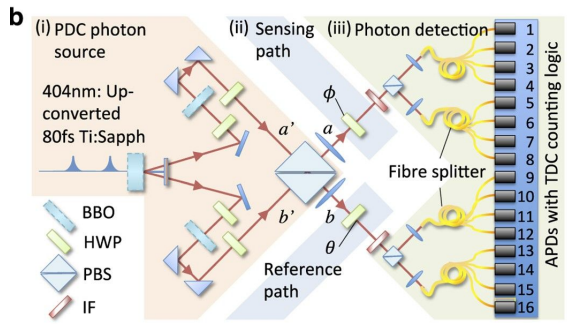
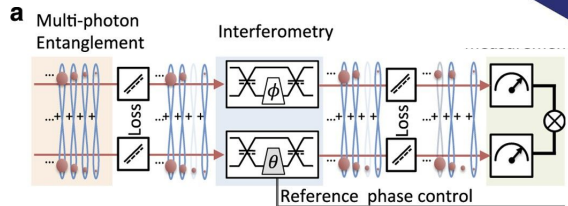
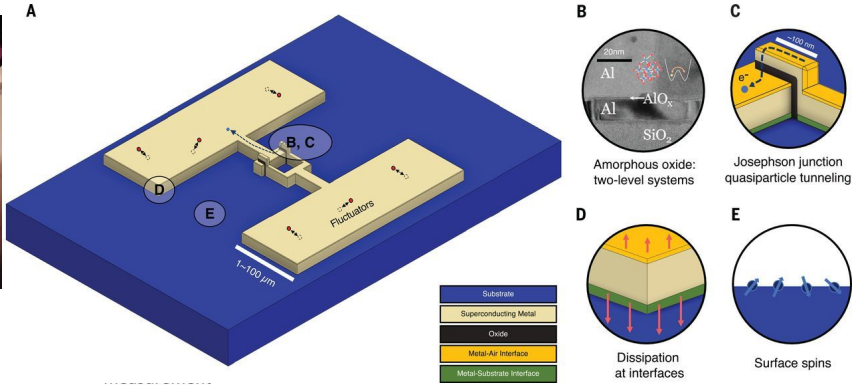
~\$100M / detector;
exploits facility
limits



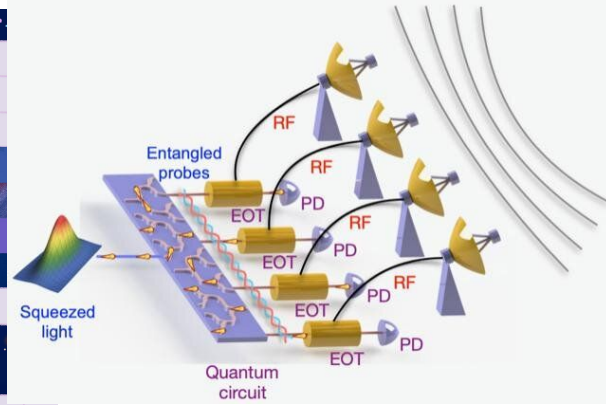
GW INSTRUMENTATION ROADMAP*



UHV tubes ~ 10-40 km



ML: RL CONTROL SYSTEMS



*MANY SYNERGIES WITH EXISTING HEP EXPERTISE/GOALS

CONCLUSION:

GREAT OPPORTUNITIES FOR DISCOVERIES

- Several Science Objectives from Multi-Messenger Probes (EM, UHECR, GW, ν)
- Cosmic Probes of Dark Matter: Particle, wave, or modified gravity