TEVPA 2025 –
CONFERENCE SUMMARY

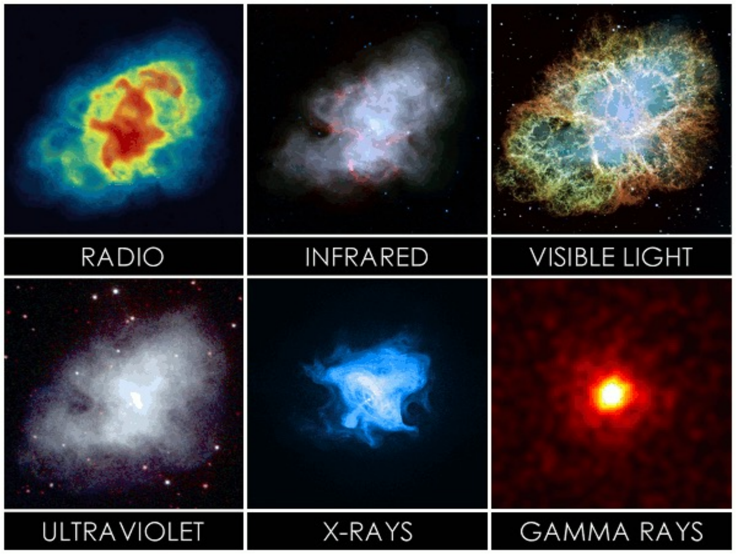
Dan Hooper – WIPAC, University of Wisconsin-Madison

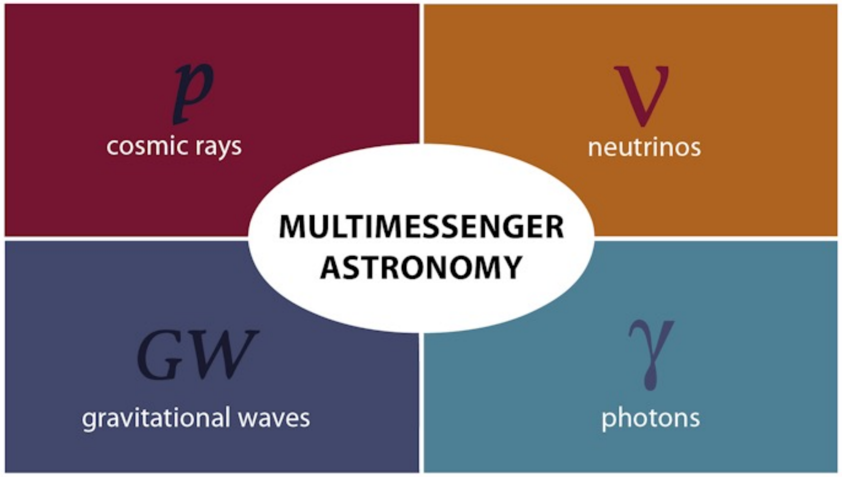
TeV Particle Astrophysics 2025, Valencia

November 7, 2025

Multi-Messenger Astrophysics

- Until the middle of the 20th century, essentially all of astronomy was conducted using visible light; these photons carry only a tiny fraction of the total information that reaches us from throughout the universe
- Astronomers have since developed ways of detecting and studying light at IR/UV/radio/X-ray/gamma-ray wavelengths
- Modern astronomy makes use not only of light, but other cosmic messengers – cosmic rays, neutrinos, gravitational waves – each of which provides us with different kinds of complementary information





Gamma Rays

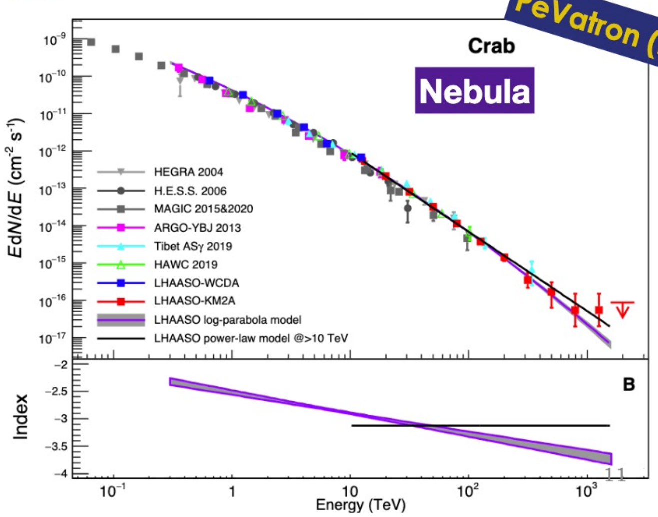
(Alicia Lopez Oramas, Michela Negro, Gabrijela Zaharijas, Anita Reimer, Christina Spingola)

Many (and many types of) Galactic Sources!

- Galactic Center, pulsars/PWN/TeV halos, SNRs, Microquasars, and more
- Connection with cosmic rays?
- Many VHE/UHE gamma-ray sources (LHAASO, HAWC, HESS, etc.)
- Might any of these sources be the long sought after hadronic Pevatrons?

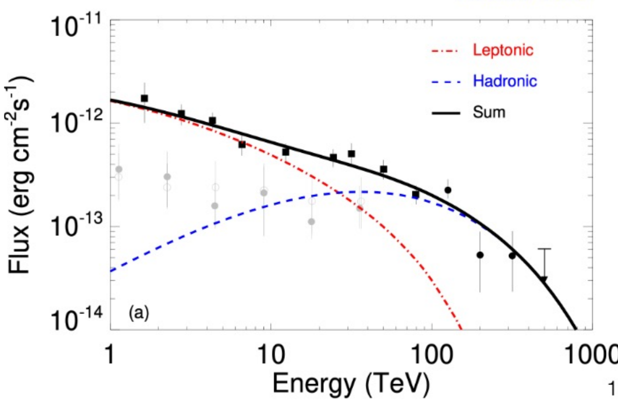
2016)

PeVatron (leptonic)



microquasar
SS433

LHAASO 2024



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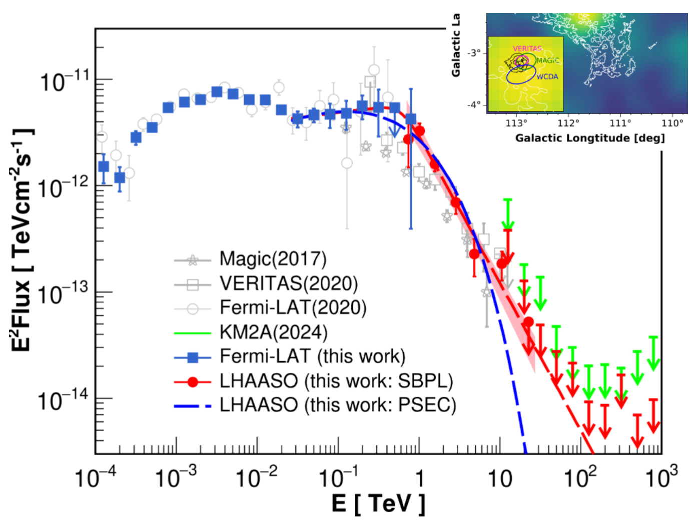
Sub-PeV: Cassiopeia A

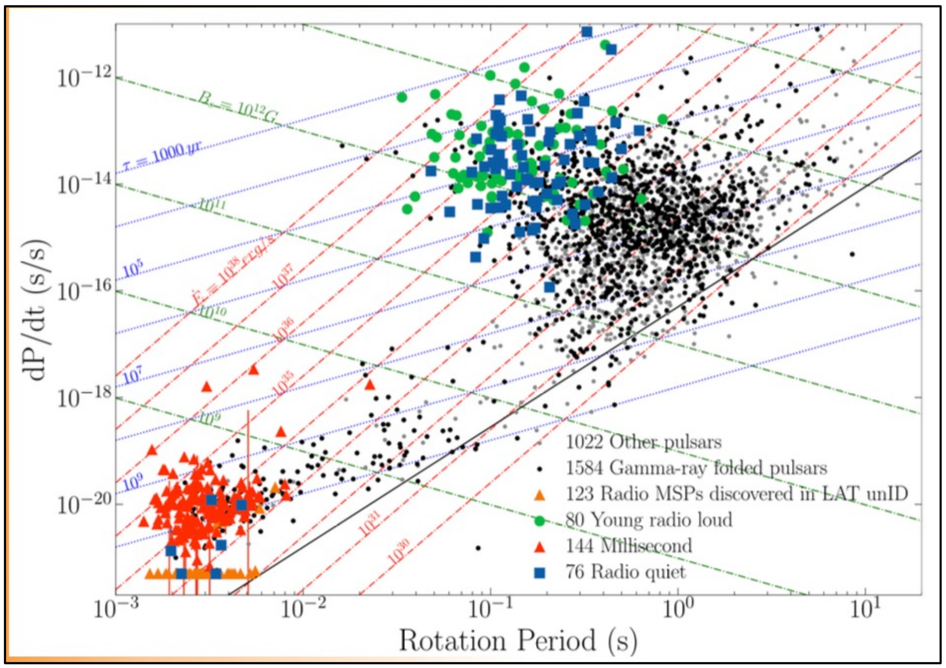


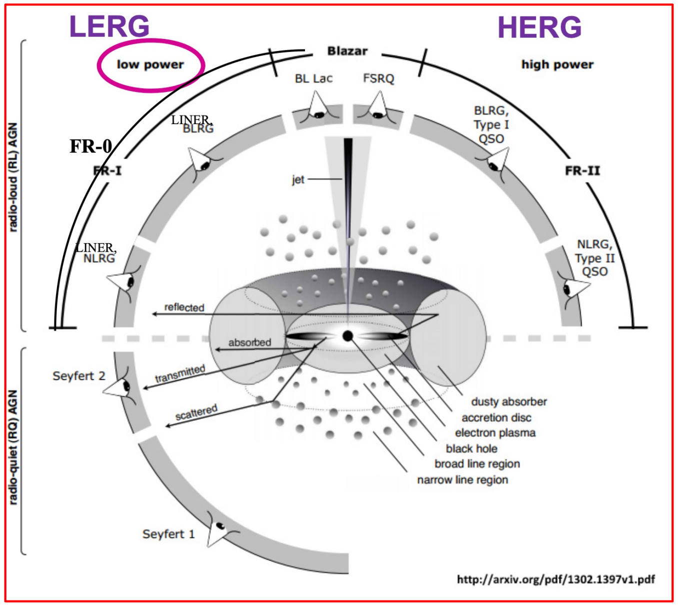
Evidence of proton acceleration

Gamma Rays

(Alicia Lopez Oramas, Michela Negro, Gabrijela Zaharijas, Anita Reimer, Christina Spingola)

- Thousands of gamma-ray AGN, and hundreds of gamma-ray pulsars (many radio quiet)
- Many exciting opportunities for gamma-ray transients (GRBs, magnetar flares, NS mergers)
- Origin of the diffuse gamma-ray background? Various classes of AGN must contribute, but gamma-ray-bright AGN do not seem to correlate with observed neutrinos; star-forming galaxies must also contribute

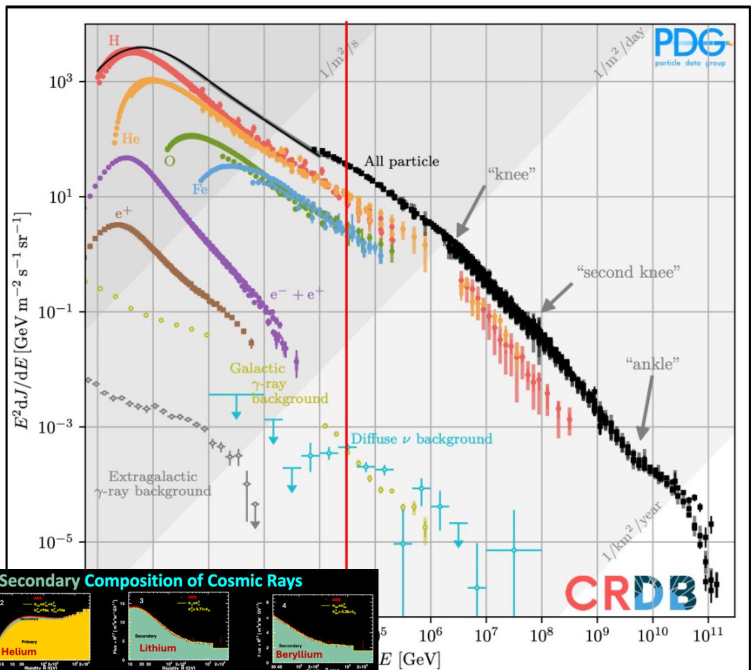


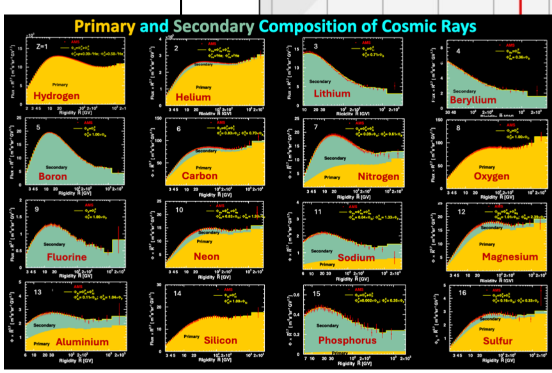


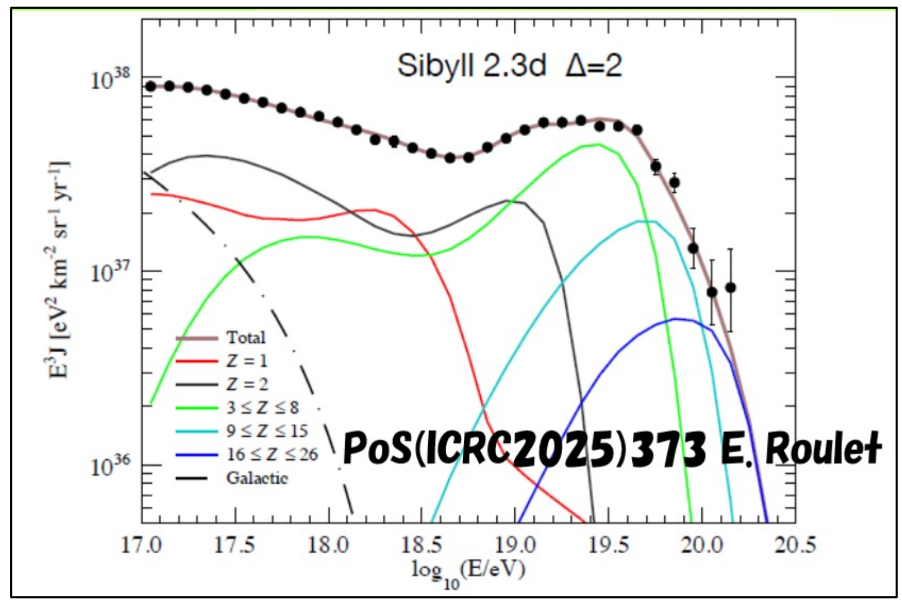
Cosmic Rays

(Katsuaki Asano, Weiwei Xu, Jaime Alvarez-Muniz, Brian Reville)

- Steady progress in understanding the spectrum and composition of the cosmic ray spectrum, but many open question remain; especially about their origin





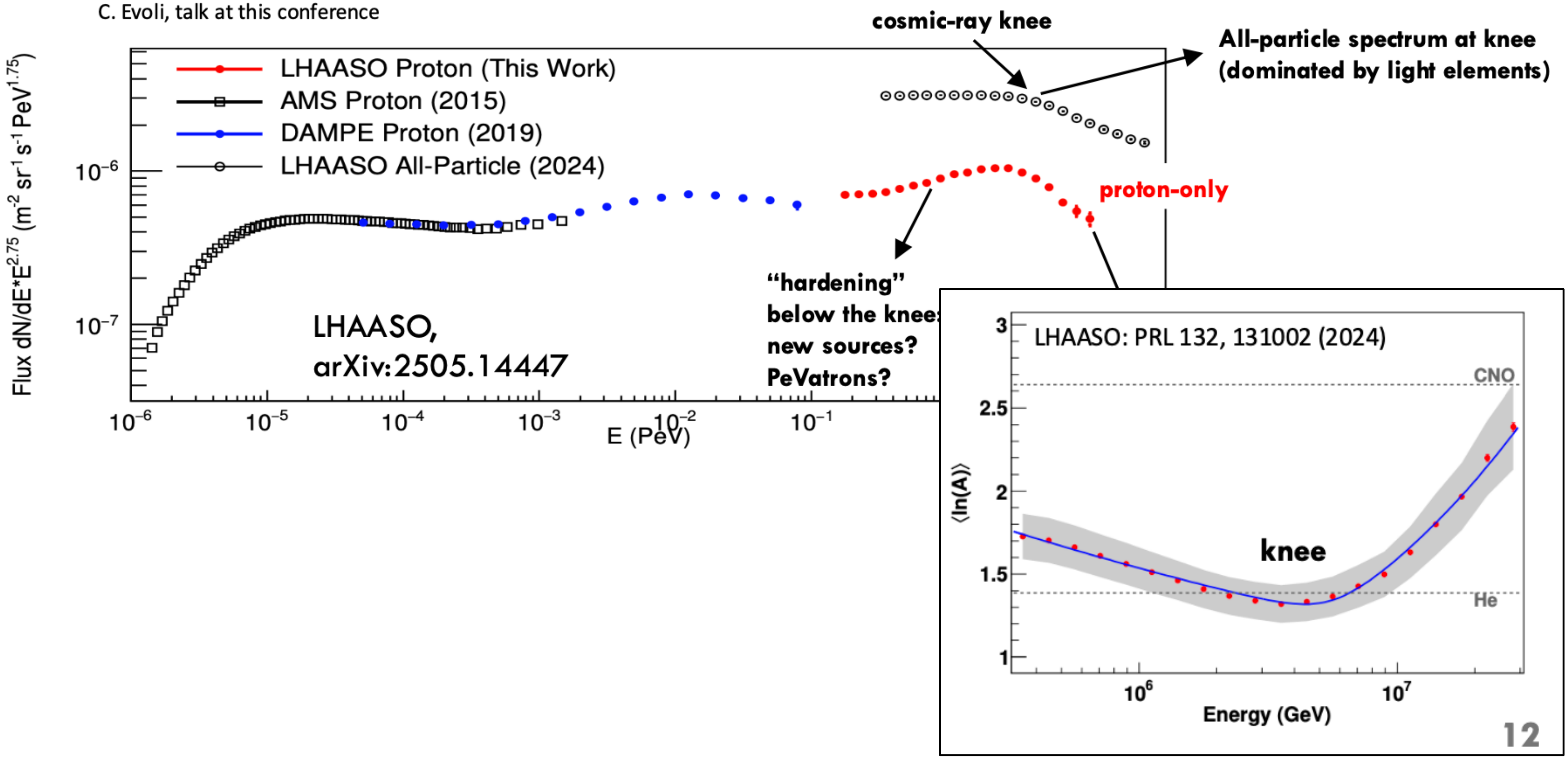


Cosmic Rays

(Katsuaki Asano, Weiwei Xu, Jaime Alvarez-Muniz, Brian Reville)

- LHAASO has measured the all-particle spectrum at the knee
- The knee appears to be dominated by light elements!
  → relatively shocking! A major challenge to the traditional view

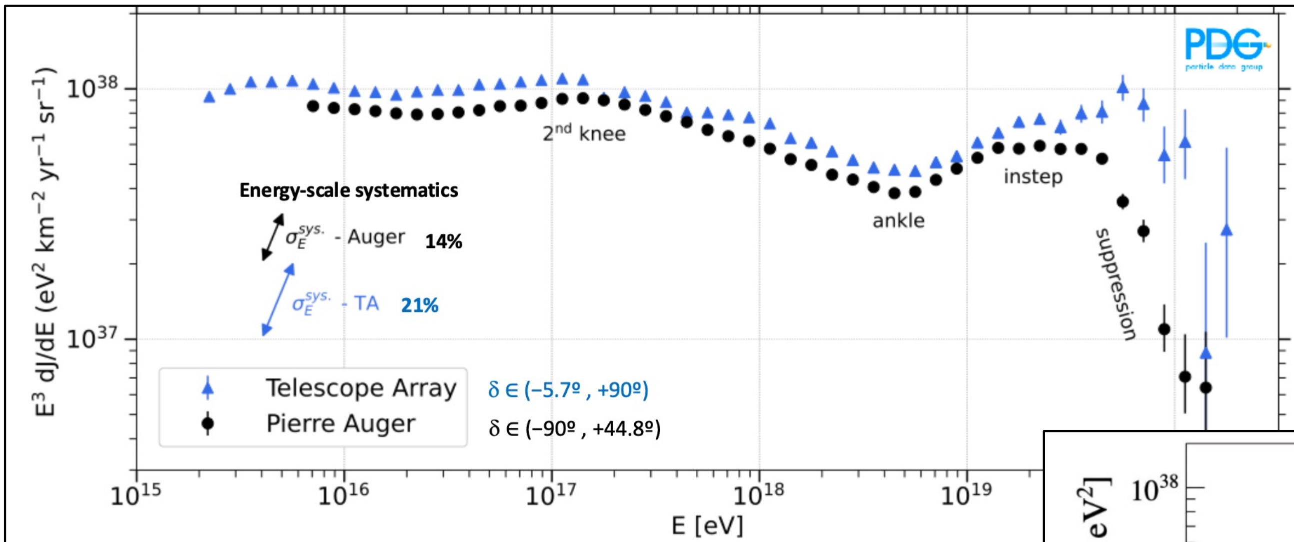
LHAASO: arXiv:2505.14447
C. Evoli, talk at this conference

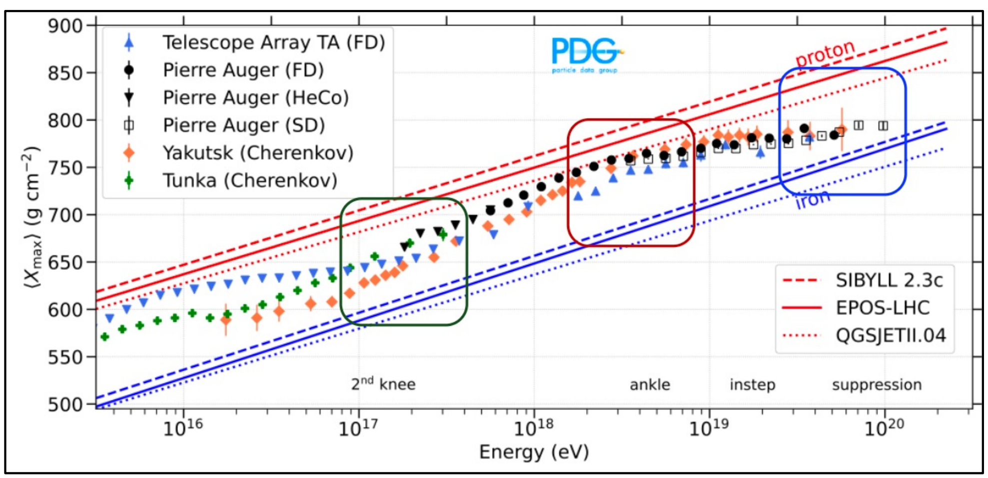


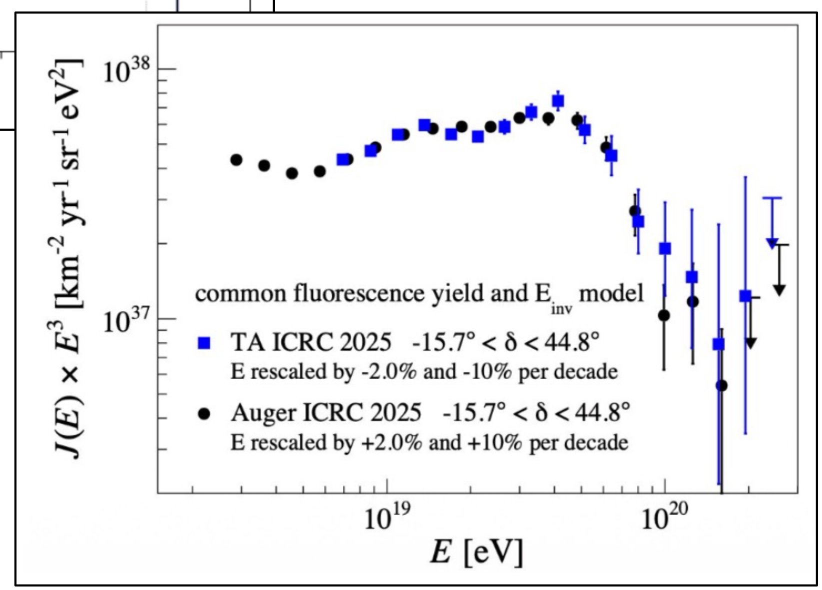
Cosmic Rays

(Katsuaki Asano, Weiwei Xu, Jaime Alvarez-Muniz, Brian Reville)

- A consensus seems to be forming around the spectrum and composition of UHECRs (pesmisstic news for cosmogenic neutrinos?)



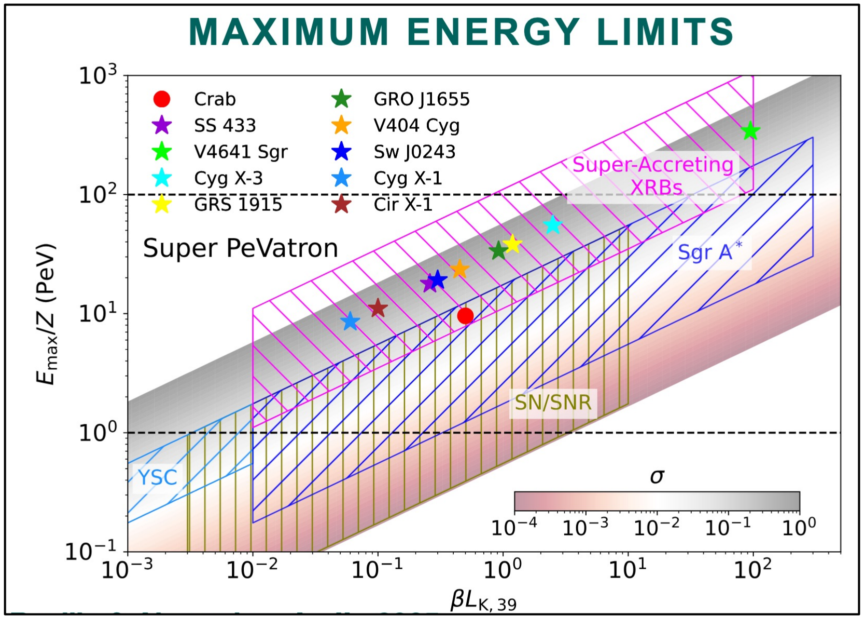




Cosmic Rays

(Katsuaki Asano, Weiwei Xu, Jaime Alvarez-Muniz, Brian Reville)

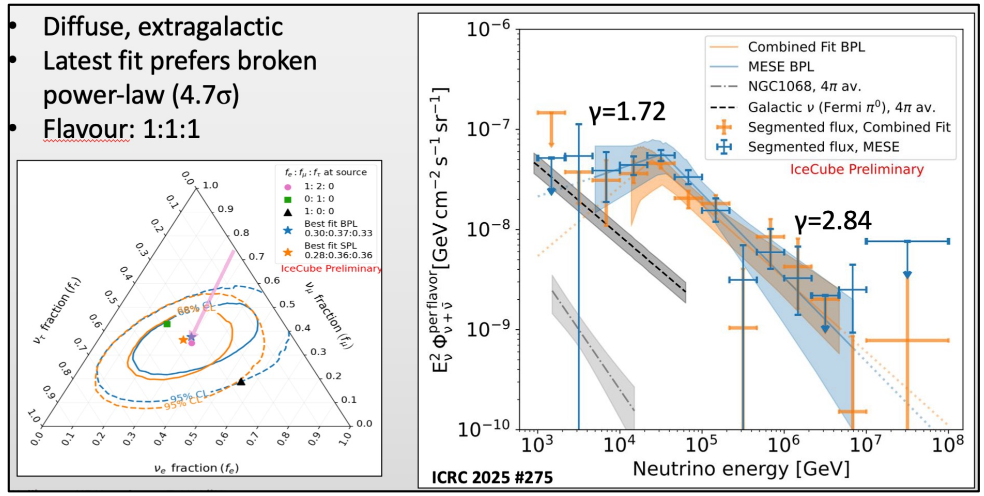
- The conventional wisdom has long been that Galactic cosmic rays are accelerated predominantly by SNRs, but this view has been challenged in recent years
- Most SNRs seem to be inefficient accelerators of PeV-scale cosmic rays, but young SNRs (featuring fast shocks in dense environments) could plausibly accelerate cosmic rays up to the knee
- Might microquasars or young massive star clusters play a role in accelerating the Galactic cosmic-ray spectrum?

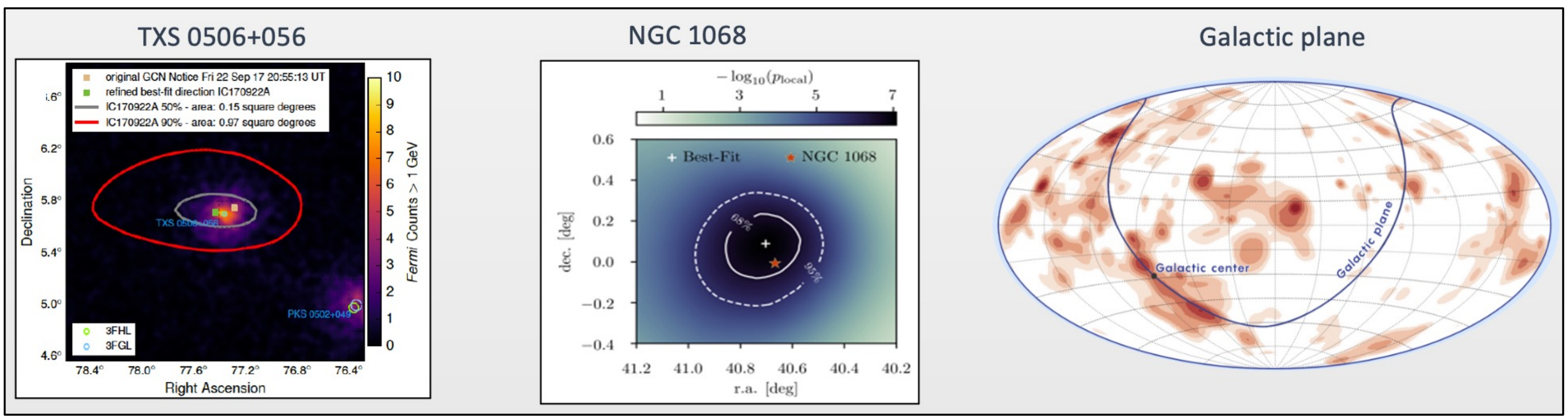


High-Energy Neutrinos

(Aart Heijboer, Irene Tamborra, Simona Toscano)

- Diffuse flux first detected by IceCube in 2013, now with spectrum and flavor ratios
- First identified sources:
  - -TXS 0506+056
  - -NGC 1068
  - -Galactic Plane
- Clear connections with the origin of cosmic rays

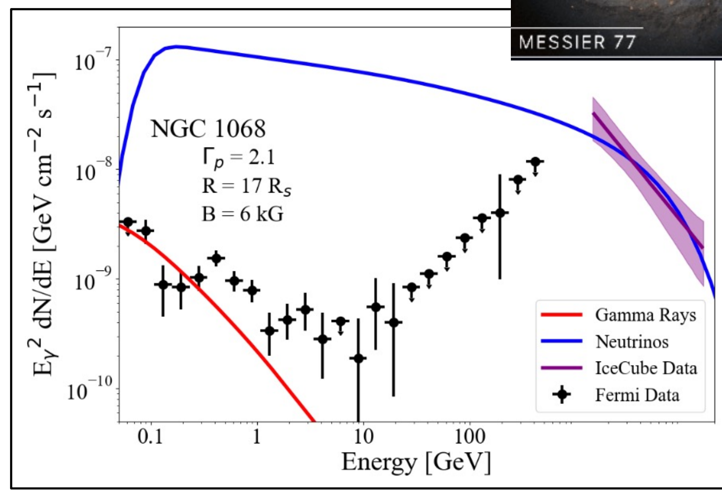




We also heard about progress with atmospheric neutrinos (see talk by Anatoli Fedynitch)

High-Energy Neutrinos

(Aart Heijboer, Irene Tamborra, Simona Toscano)



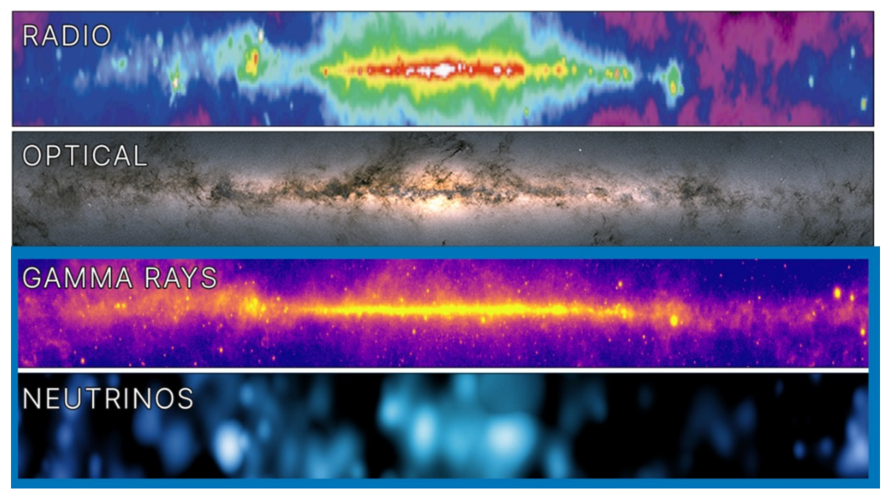
Blanco, DH, Linden, Pinetti, arXiv:2307.03259

NGC 1068 (see also Asano's talk)

- The lack of TeV-scale gamma-rays from NGC 1068 indicates that this is a "hidden source," opaque to gamma-rays
- Are gamma-ray obscured AGN the dominant source of high-energy neutrinos?
  NGC 4151? Tip of the cosmic Iceberg?
- It is increasingly clear that many of IceCube's neutrinos do *not* come from gamma-ray bright sources!

The Galactic Plane

- Some of the neutrinos from the Galactic Plane surely come from cosmic-ray interaction in the ISM, but individual cosmic ray accelerators are also likely to contribute!



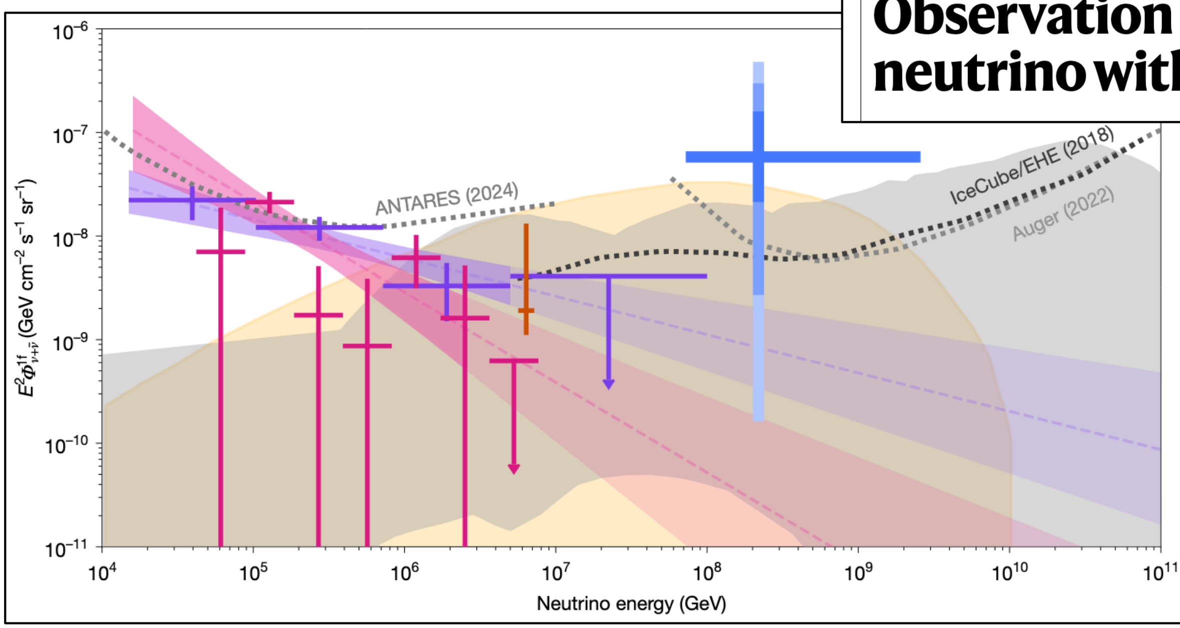
High-Energy Neutrinos

(Aart Heijboer, Irene Tamborra, Simona Toscano)

- An incredible ~220 PeV neutrino event was detected by KM3Net!
- Given IceCube's much larger effective area and operating time, it should see >100 such events for each one detected by KM3NeT
- This suggests the KM3NeT event was a lucky upward fluctuation
- That said, it still demonstrates that the astrophysical neutrino spectrum extends up to at least ~100 PeV! → Further motivation for radio-based UHE neutrino telescopes

Article

Observation of an ultra-high-energy cosmic neutrino with KM3NeT

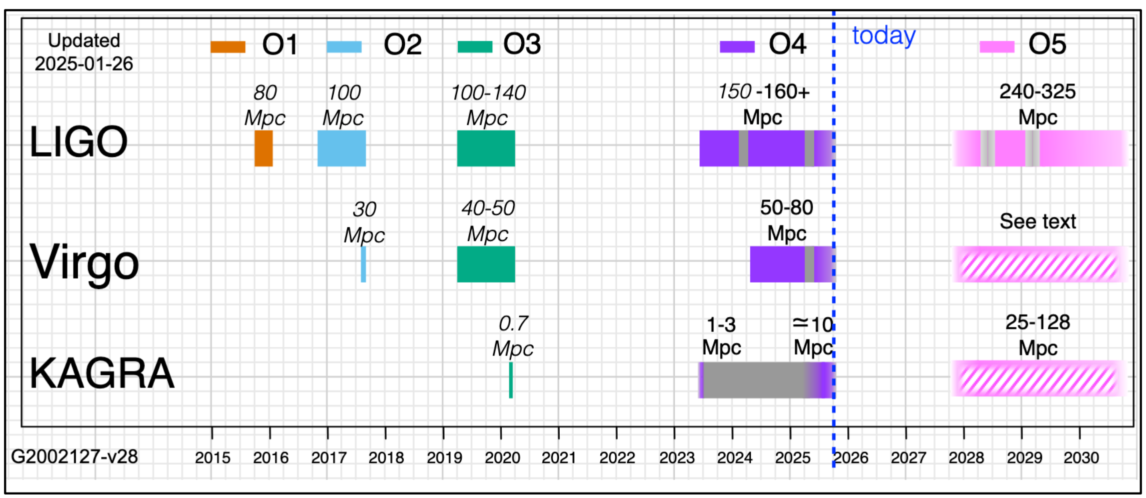


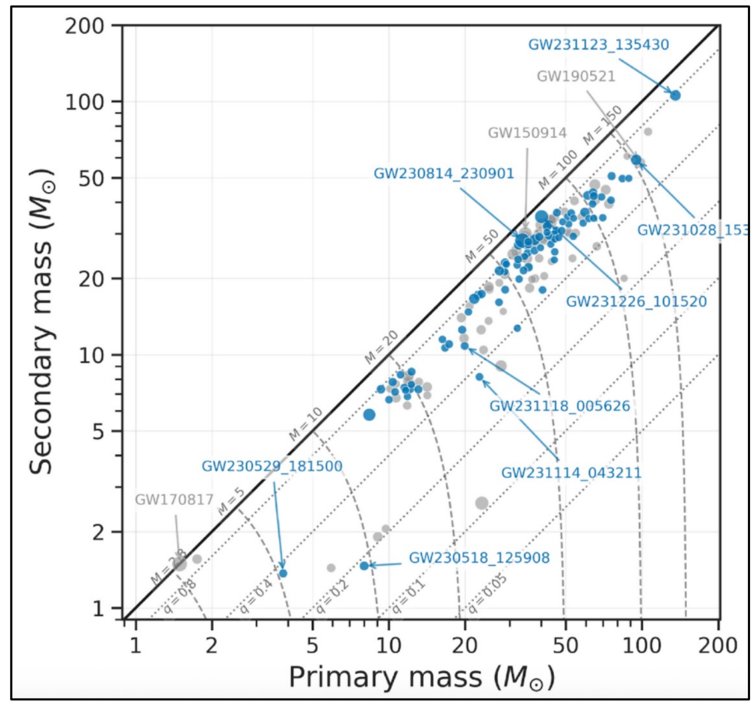
KM3NeT, Nature (2025)
Li et al, 2502.04508

Gravitational Waves

(Chiara Caprini, Jose Antonio Font, Alicia Sintes)

- Gravitational wave astronomy has come a long way since the first detection of a black hole binary merger a decade ago (GW150914)
- The latest gravitational wave transient catalog (GWTC-4.0) contains 128 new sources!
- This field has progressed from the first sources to *population studies*, measuring the distributions of BH masses, spins
- Neutron star mergers are more rare, but these events are accumulating too!

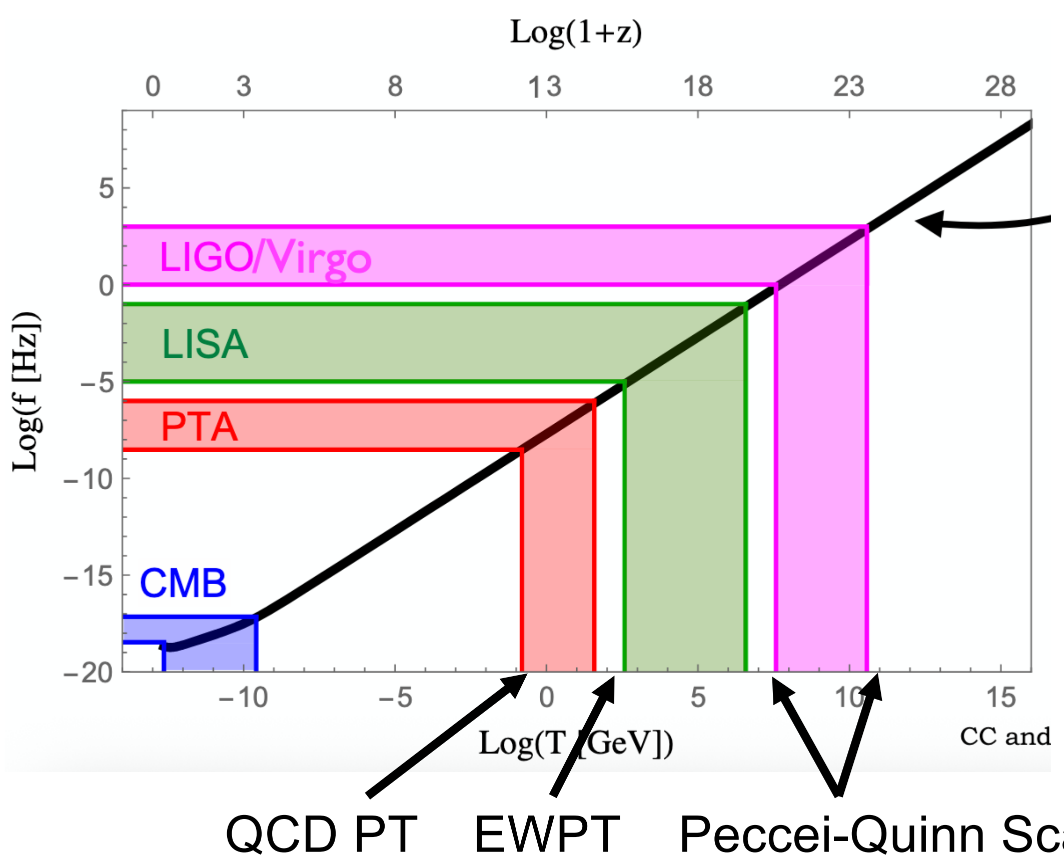


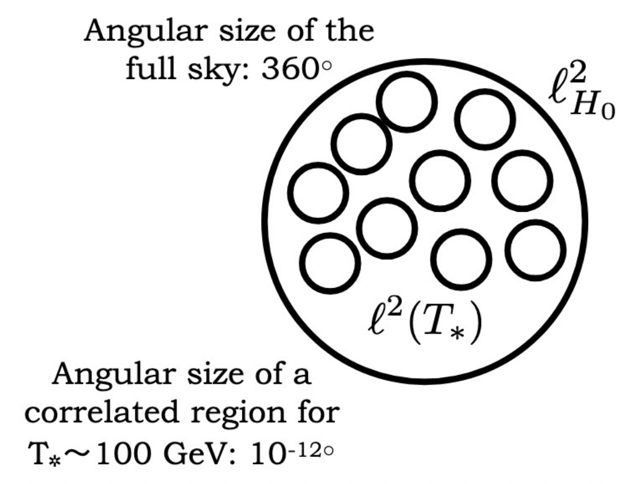


Gravitational Waves

(Chiara Caprini, Jose Antonio Font, Alicia Sintes)

- Gravitational waves produced in the early universe have a correlation scale that is too small to be resolved → only the statistical properties of these signals can be accessed (a stochastic background)

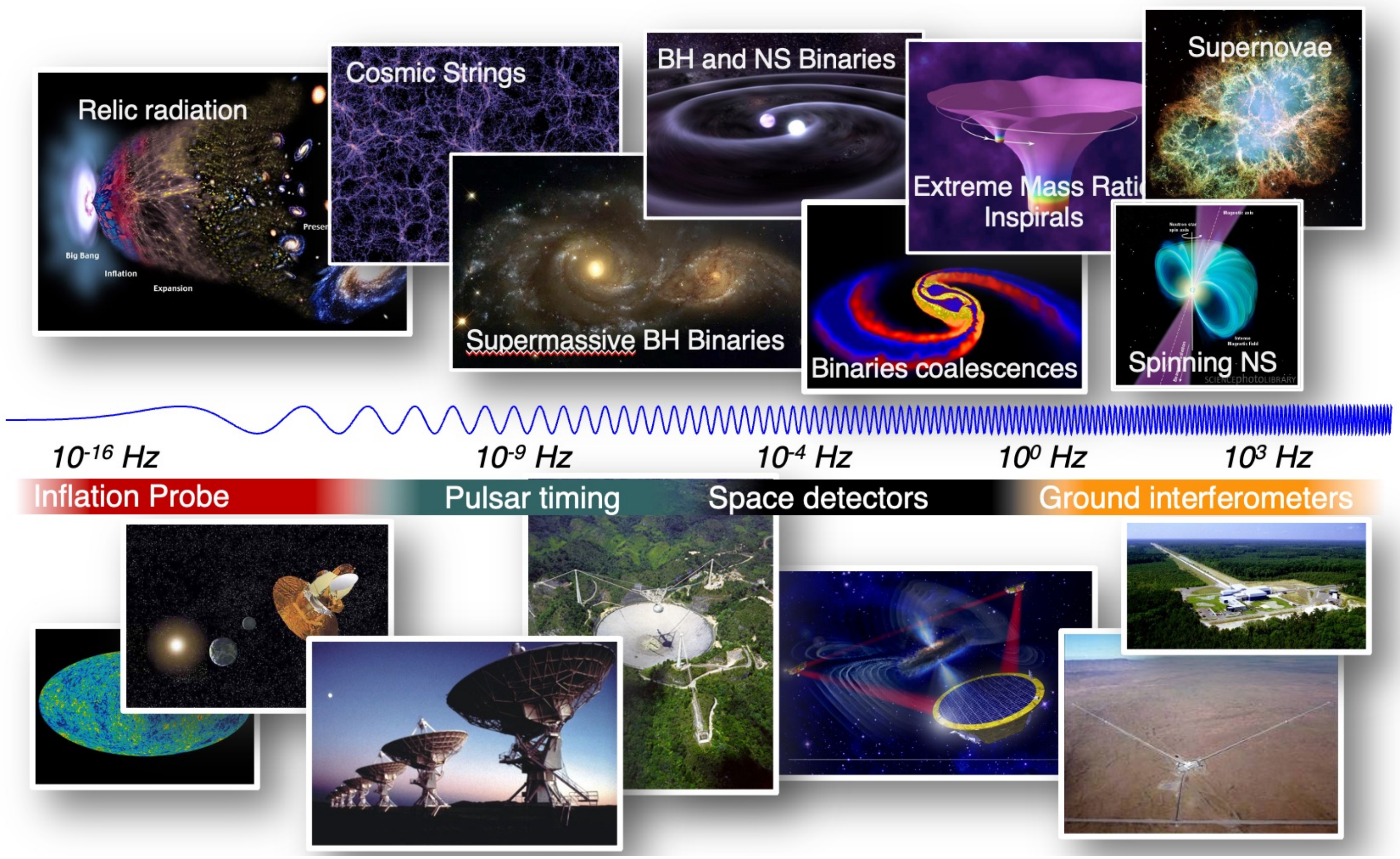




Gravitational Waves

(Chiara Caprini, Jose Antonio Font, Alicia Sintes)

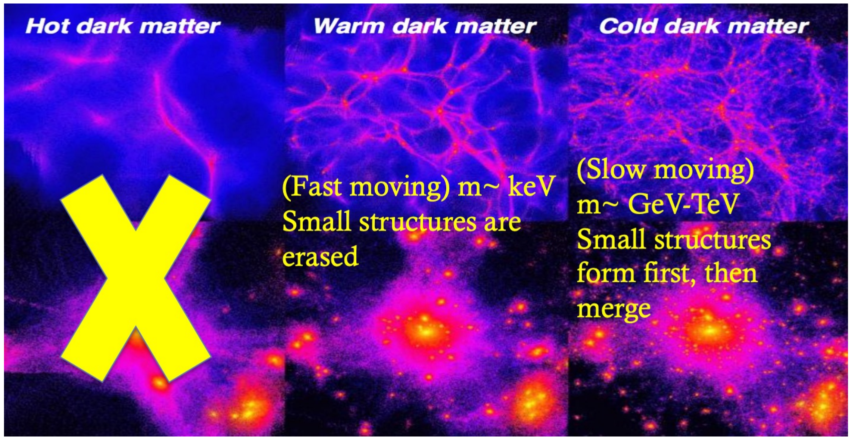
- A huge range of scientific goals!

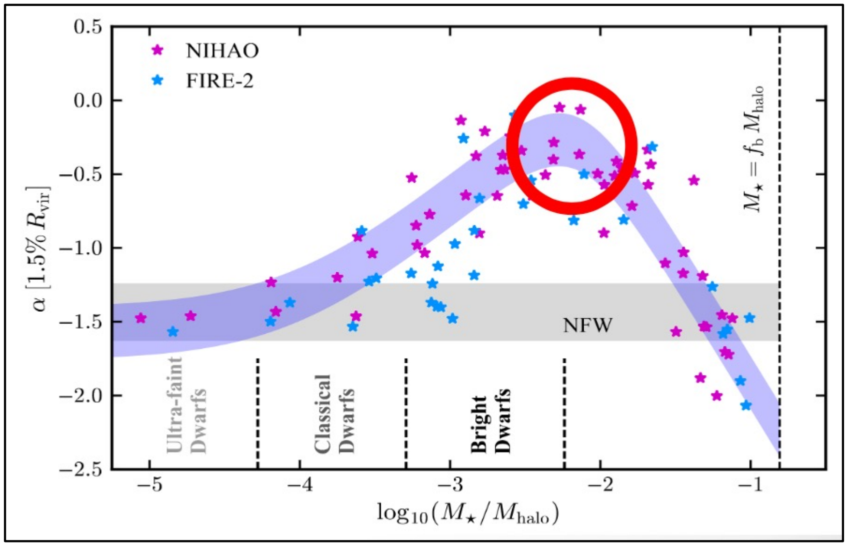


Dark Matter

(A. Di Cinto, D. Cerdeno, M. Taoso, L. Lopez-Honorez, C, Byrnes, S. Lowette, C. Gao, G. Krnjaic)

- Despite many claims of evidence for warm or self-interacting DM, when baryonic processes (stellar feedback, winds, SN injection, cooling,...) are correctly accounted for, this evidence goes away → ***cold, collisionless dark matter is alive and well!***
- Ultra-diffuse galaxies have been reproduced in cold, collisionless DM simulations → ***no need for alternative DM models!***
- Dark galaxies are not a surprise; dozens are predicted within 2.5 Mpc
- For appropriate initial conditions, the Local Group can be reproduced in great detail
- Inner slopes of DM halos depend on the total and baryonic mass





Dark Matter

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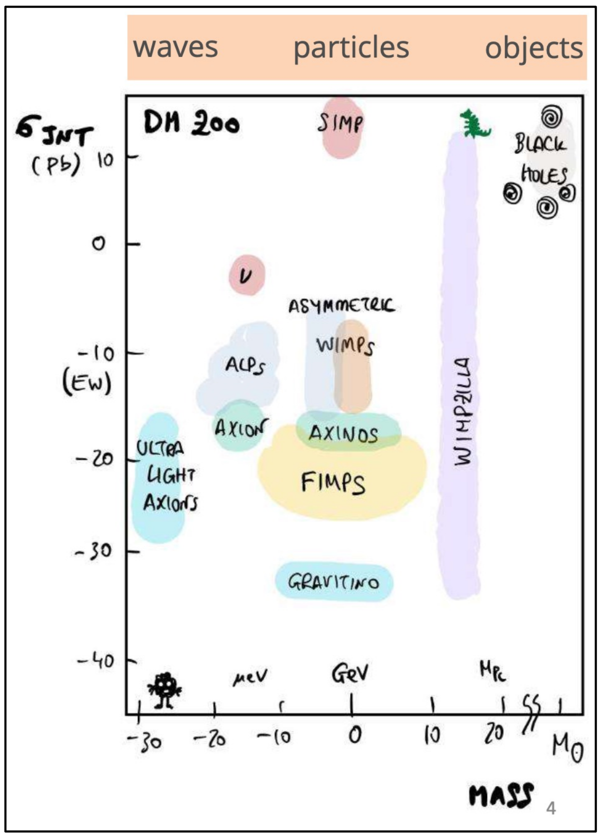
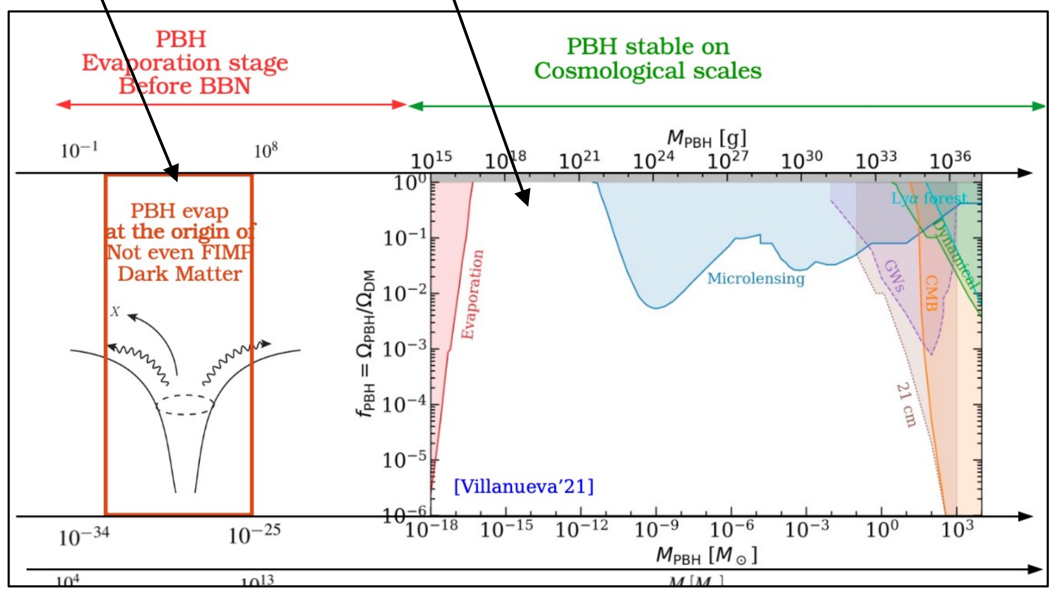
- Many forms of dark matter are being investigated:
  WIMPs, FIMPs, axions/ALPs, ultra-light DM, PBHs,…
- And many production mechanisms:
  Freeze-out, freeze-in, misalignment, gravitational production, late-time decays, out-of-equilibrium production, Hawking evaporation…

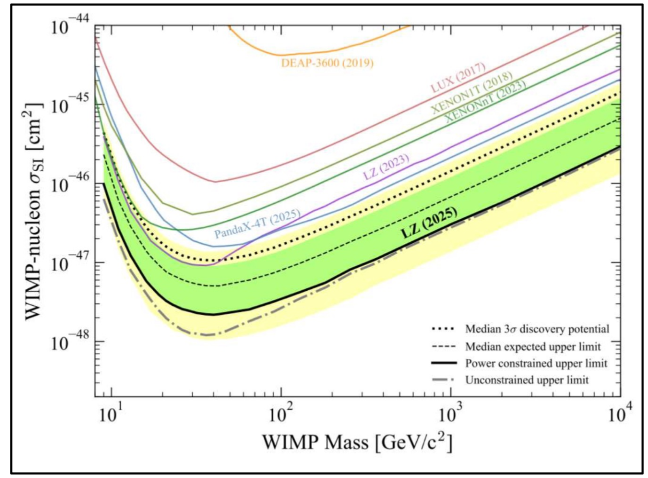


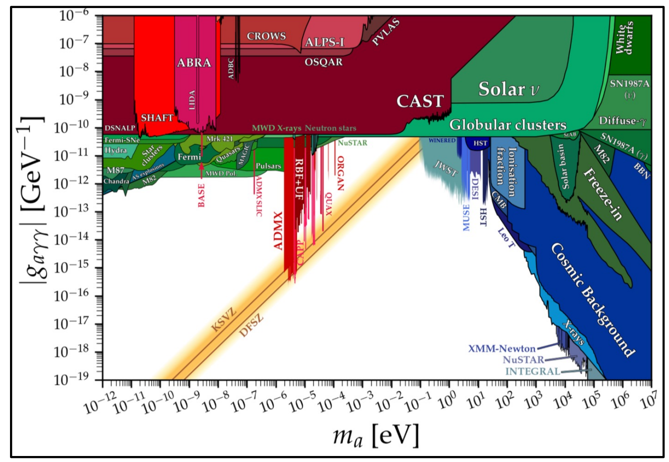


Dark Matter

(A. Di Cinto, D. Cerdeno, M. Taoso, L. Lopez-Honorez, C, Byrnes, S. Lowette, C. Gao, G. Krnjaic)

- Direct DM searches have ruled out many (but not nearly all) WIMP models
- Axions remain broadly untested
- There is no (and never was a) 3.5 keV line! (see parallel talk by Chris Dessert)
- The LHC continues to make progress in constraining the nature of DM – often statistically limited; improvement expected with greater luminosity; most sensitive to DM models with light mediators, which can be produced on-shell
- Many promising approaches are being pursued to search for axions and axion-like-particles

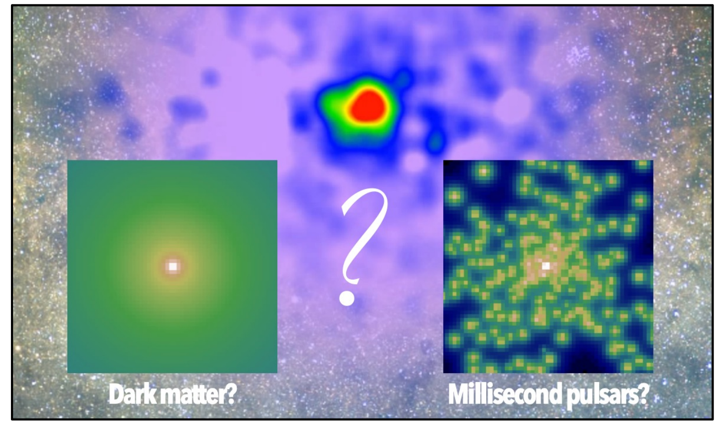


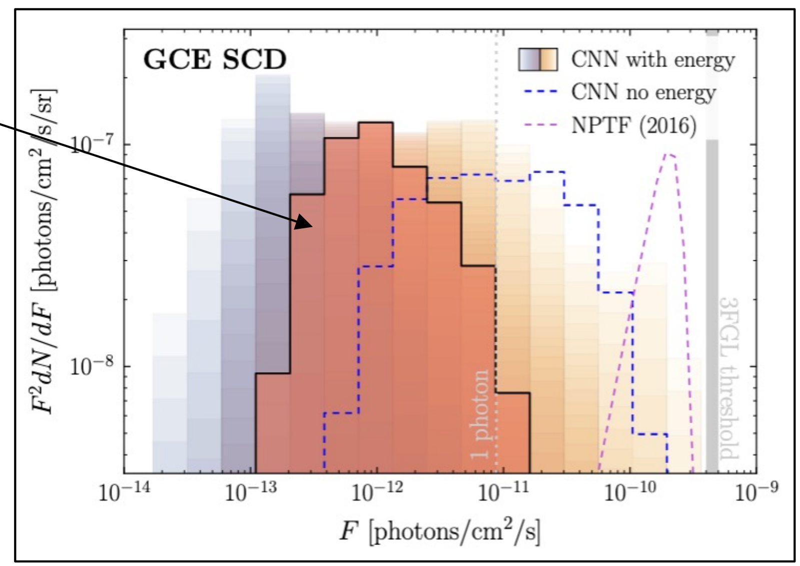


Dark Matter

(A. Di Cinto, D. Cerdeno, M. Taoso, L. Lopez-Honorez, C, Byrnes, S. Lowette, C. Gao, G. Krnjaic)

- The Galactic Center Gamma-Ray Excess persists and could be generated by annihilating DM or by a very large population of low-luminosity pulsars
- Earlier studies claimed to find evidence that unresolved point sources contribute to the gamma-ray excess, but these results have not held up to scrutiny
- More recent work finds no evidence of point sources → this signal is remarkably smooth, demonstrating that it cannot be generated by fewer than ~10^5 sources
- This result is *not* consistent with conventional pulsar explanations



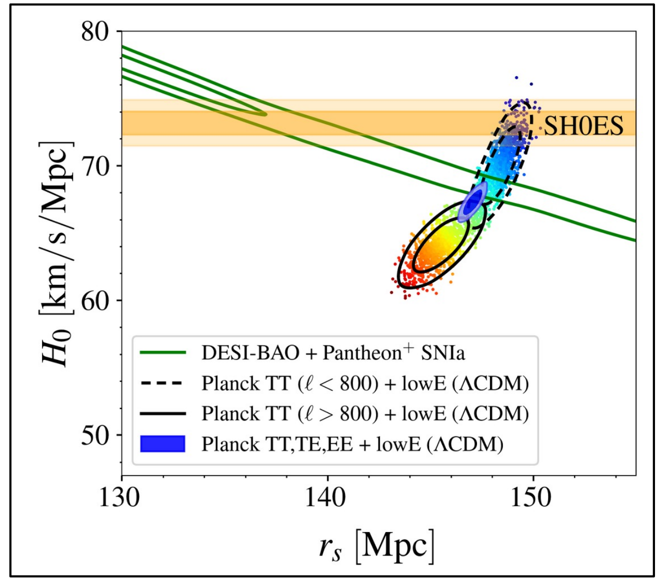


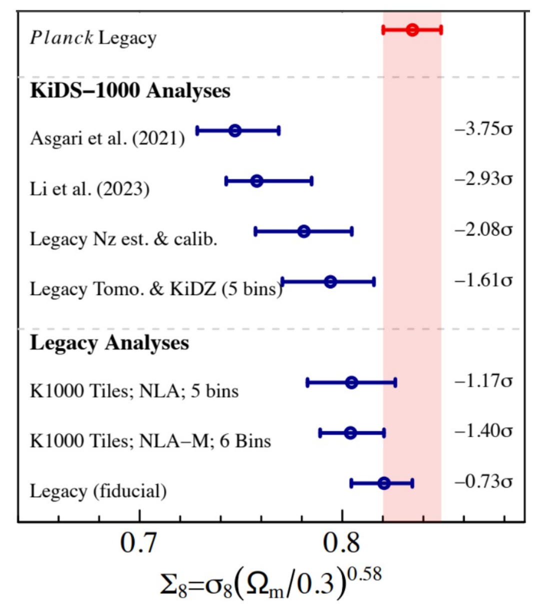
List, Park, Rodd, Schoen, Wolf, 2507.17804

Cosmology

(Ali Rida Khalife, Andrei Mesinger)

- The Hubble tension persists, and (in my opinion) has become only more compelling
- Possible solutions involve new pre-recombination physics (beyond-ΛCDM): new light relics, primordial magnetic fields, modified recombination, modified gravity, varying electron mass+curvature, early dark energy
- The idea here is to reduce the sound horizon in order to increase H_0, while keeping $\theta = r_s/D_A$ fixed
- Improved modeling by the KiDS collaboration has eliminated the S_8/σ_8 tension
- A new ~2-3.7σ tension has emerged between BAO measurements from DESI and the CMB



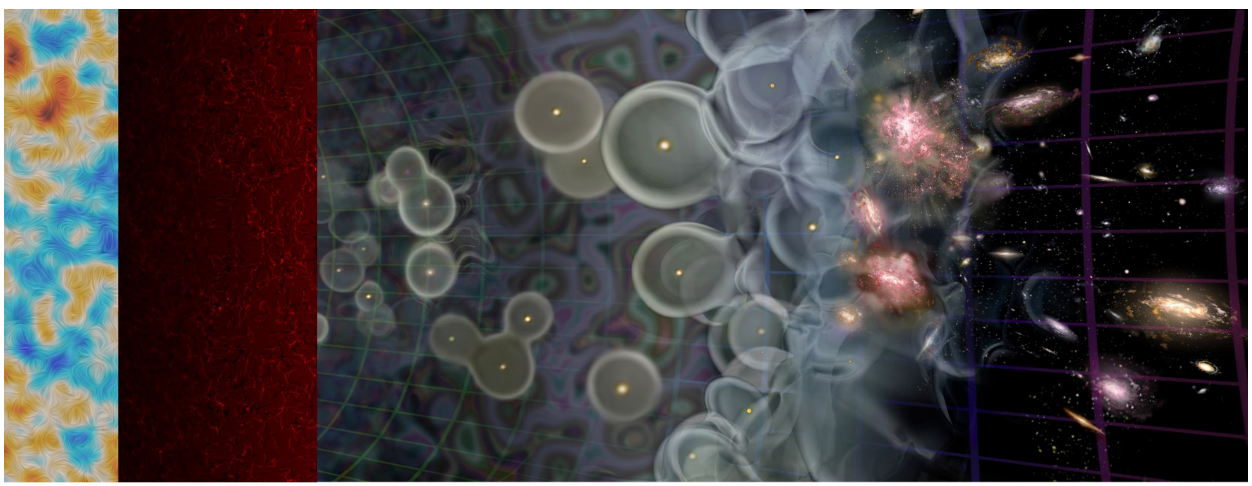


Cosmology

(Ali Rida Khalife, Andrei Mesinger)

21-cm cosmology has begun!

- Probe of the ionization and thermal history of the IGM (limits from HERA already suggest that some heating occurred at $z > 10$)
- Probe of the formation of the first galaxies
- Galaxy clustering + stellar properties provide a probe of the evolution of large-scale structure and other aspects of physical cosmology



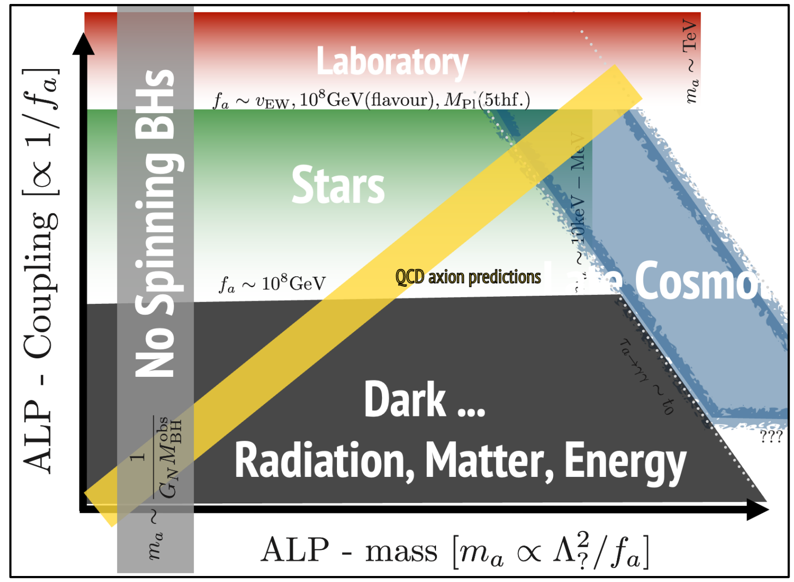
$z \approx 10^3$ $z \approx 30$ $z \approx 5$ $z = 0$

Connections With Particle Physics

(Javier Redondo, Gordan Krnjaic)

- Dark matter, baryogenesis, inflation, axions and axion-like particles, neutrino masses, dark energy, physics at extremely high energies, physics over extremely long baselines,…
- There remain many open questions in fundamental physics → these provide us with motivation and guidance

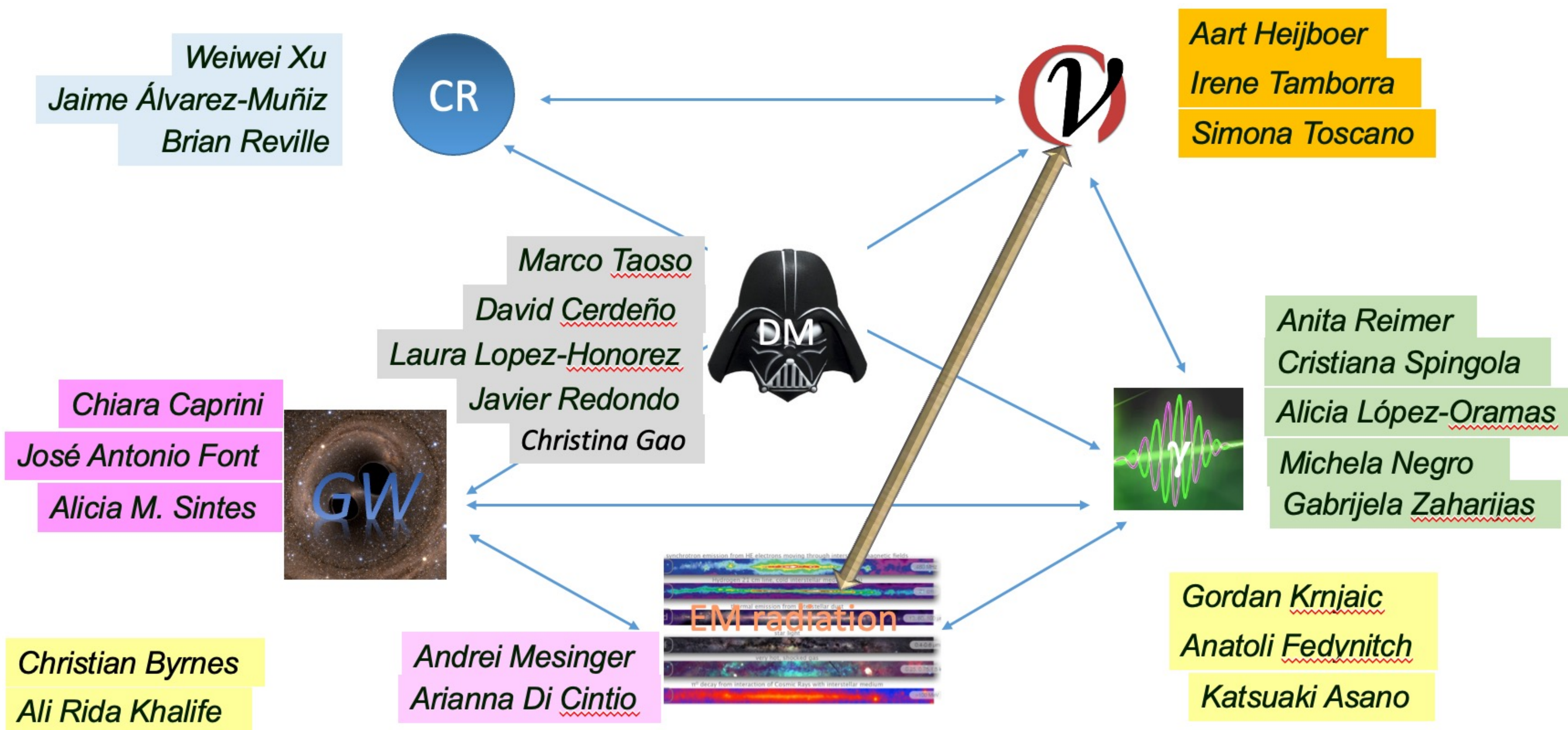
Neutrino Masses	Strong CP Problem
Dark Matter	Hierarchy Problem
Baryogenesis	Flavor Puzzle
Dark Energy	Cosmological Constant
Initial Conditions	Inflation



- These open questions *all* have potential connections with astrophysics and cosmology!

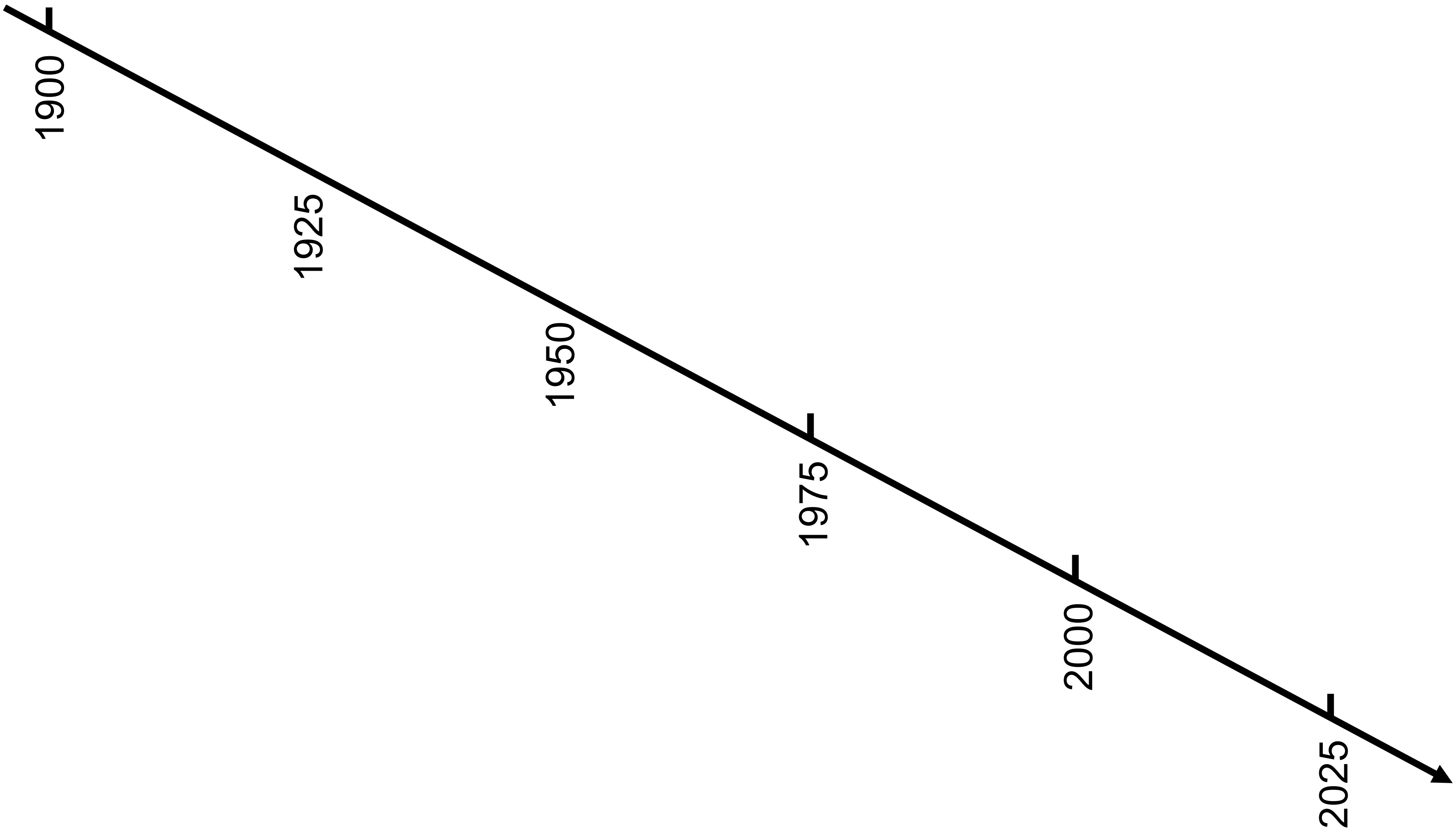
Multimessenger Astrophysics

(Maurizio Spurio +…)



M. Spurio: Multimessenger astrophysics - TeVPA 25 5

Timeline of High-Energy Particle-Astrophysics



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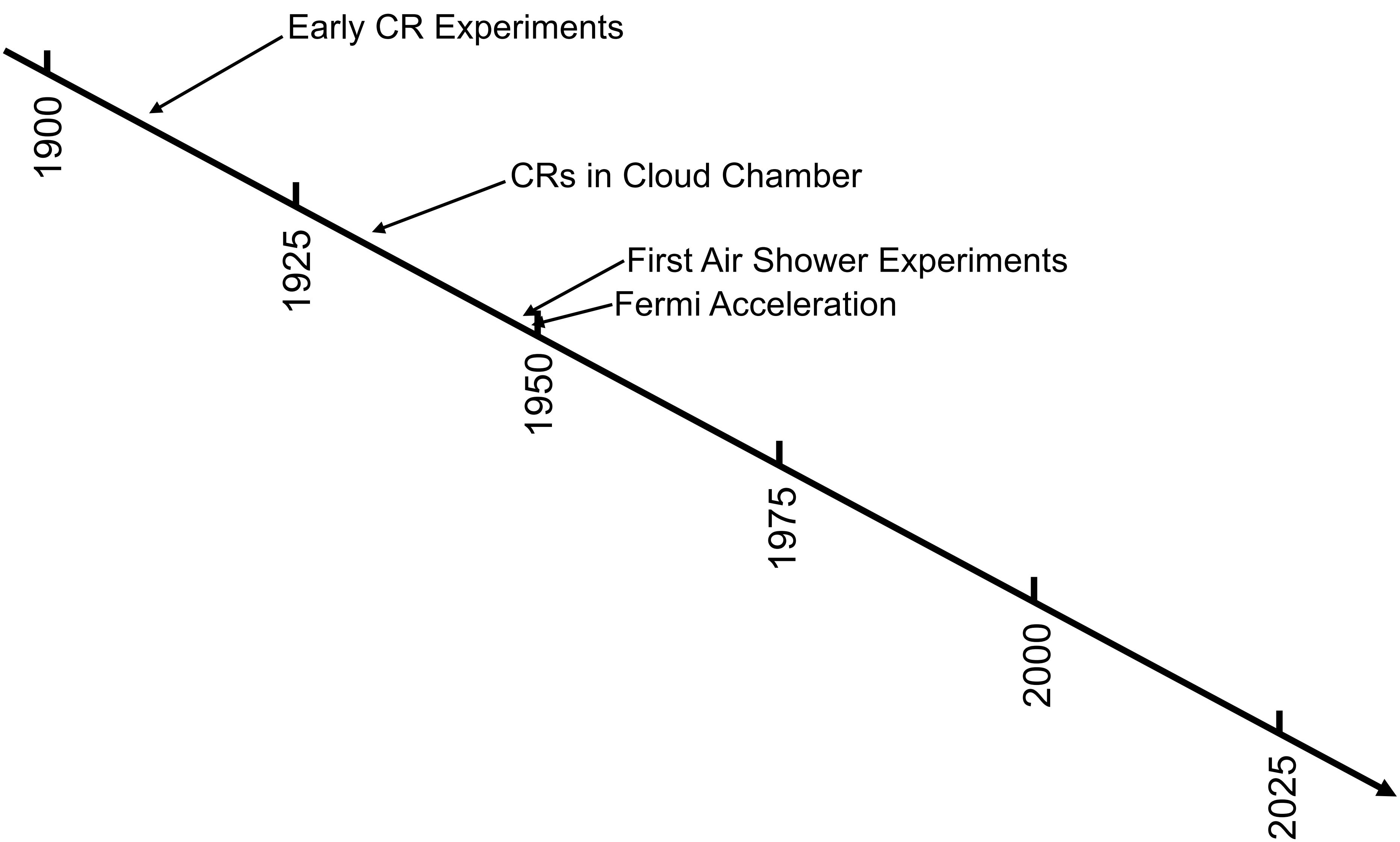

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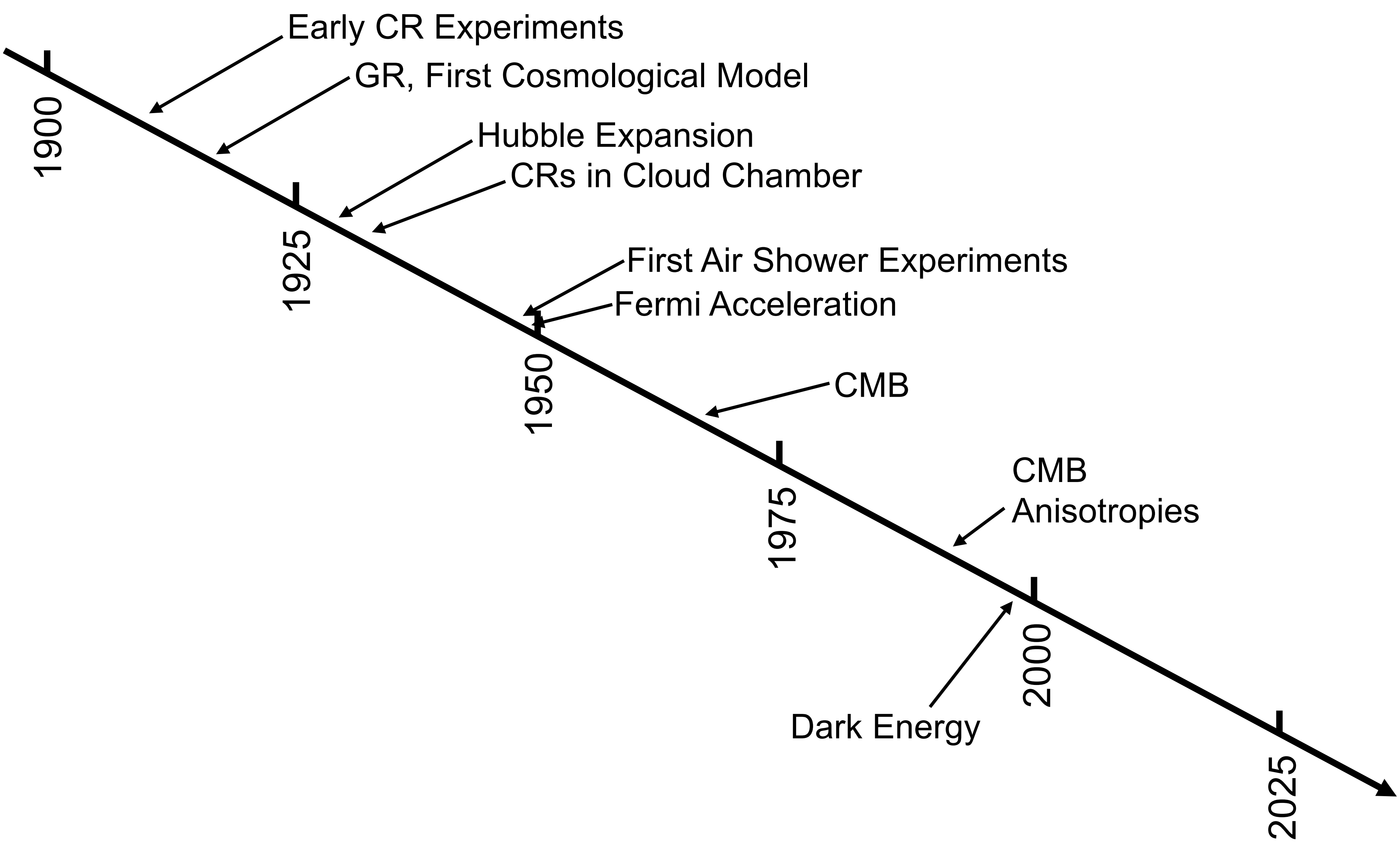

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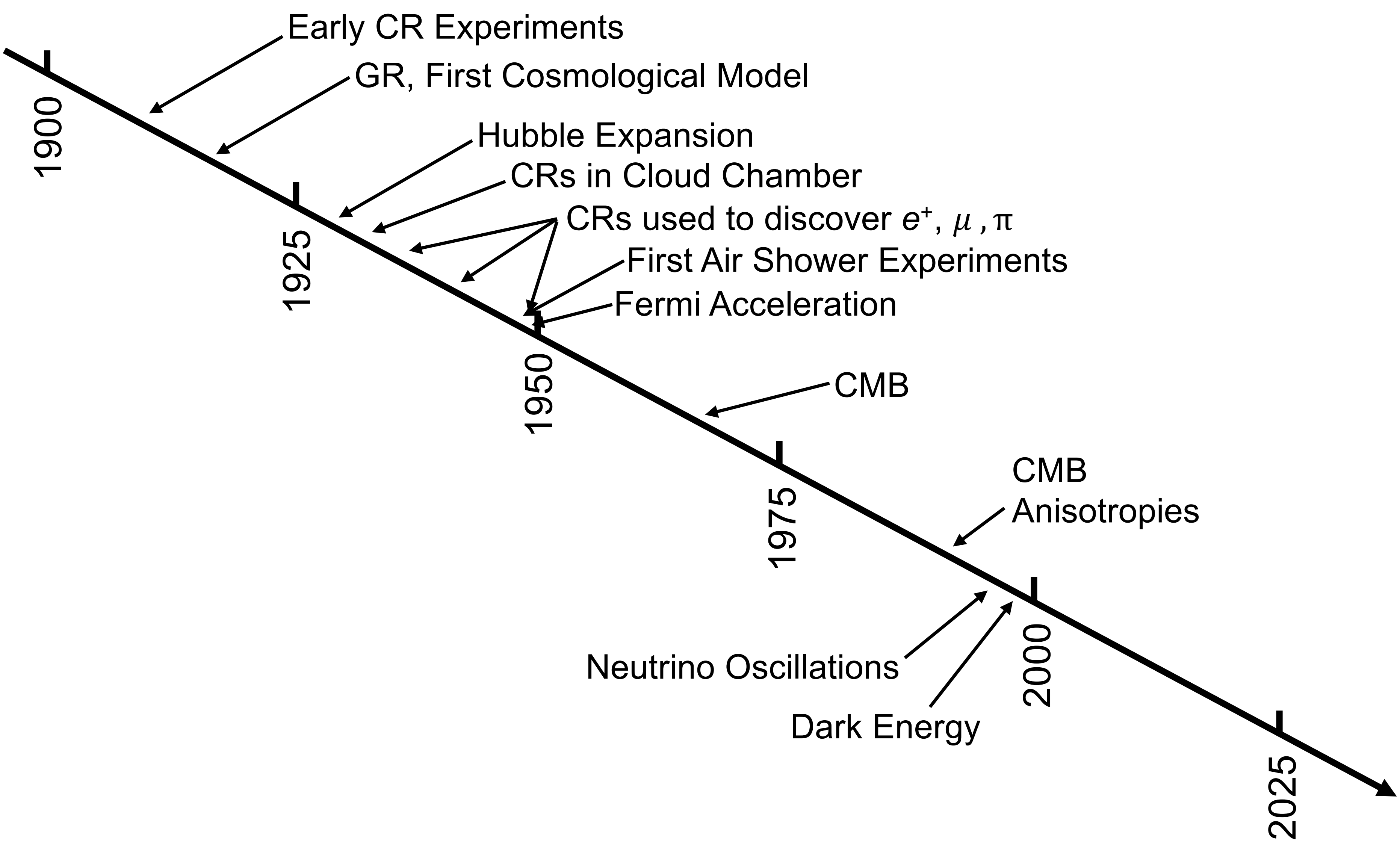

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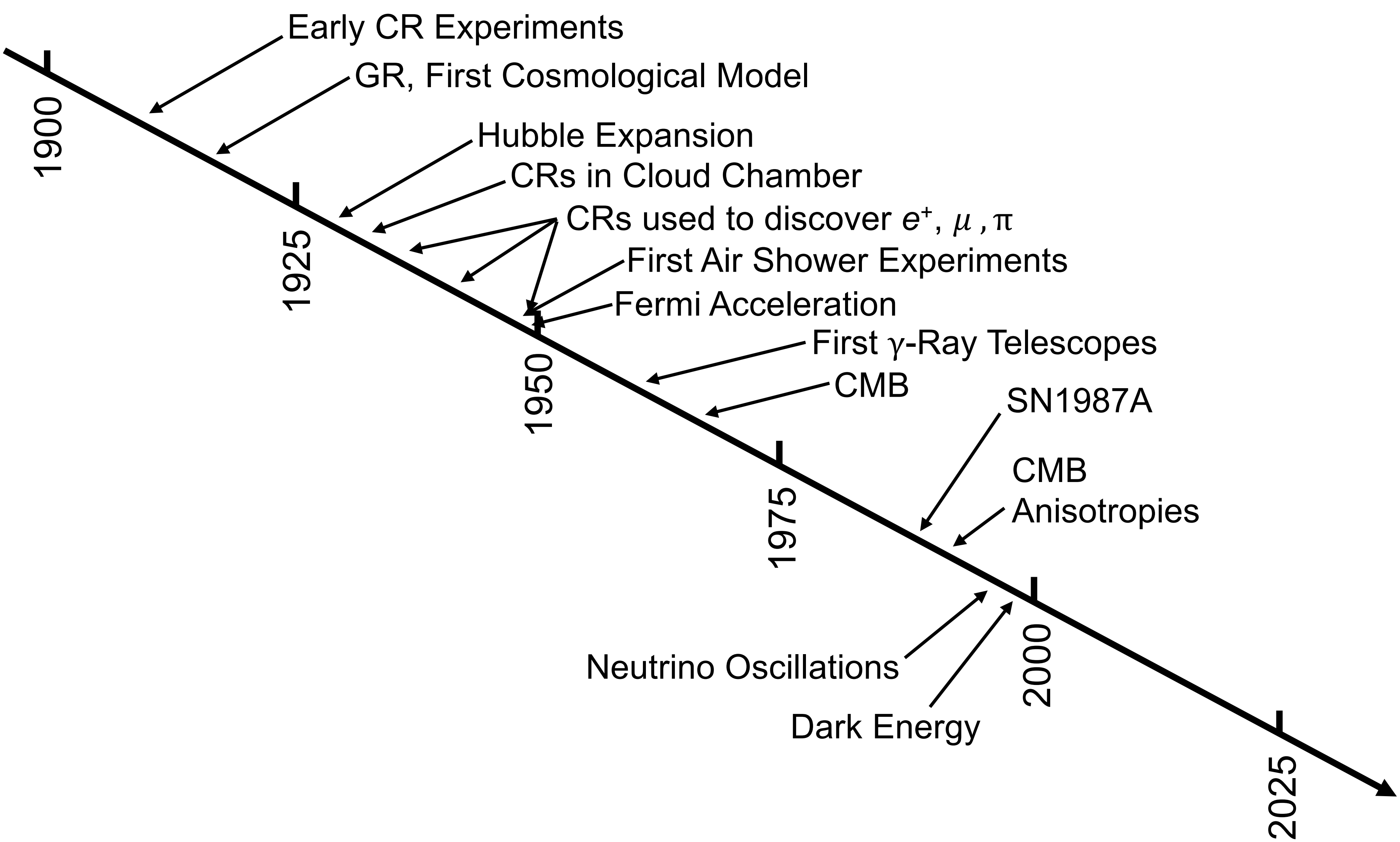

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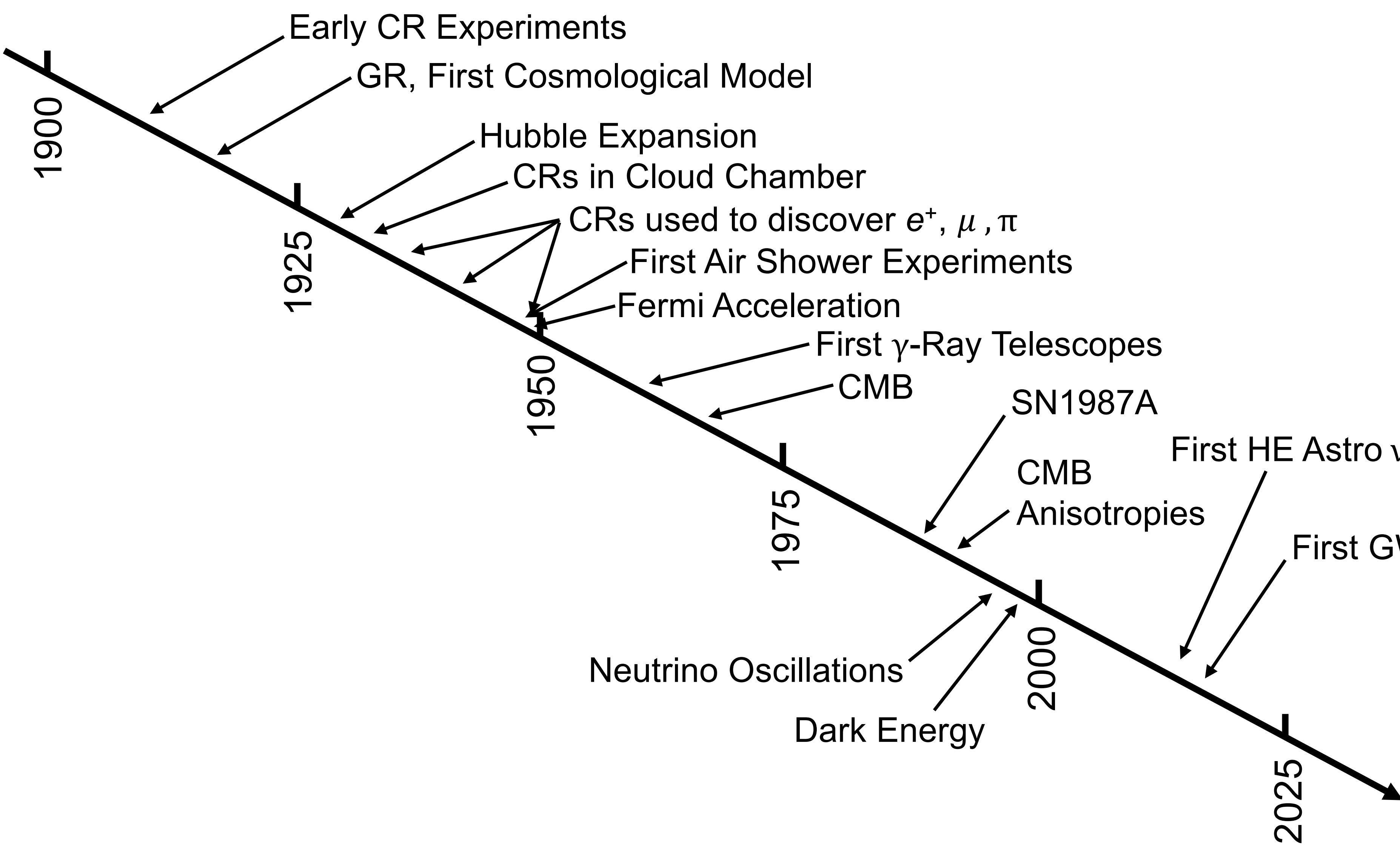
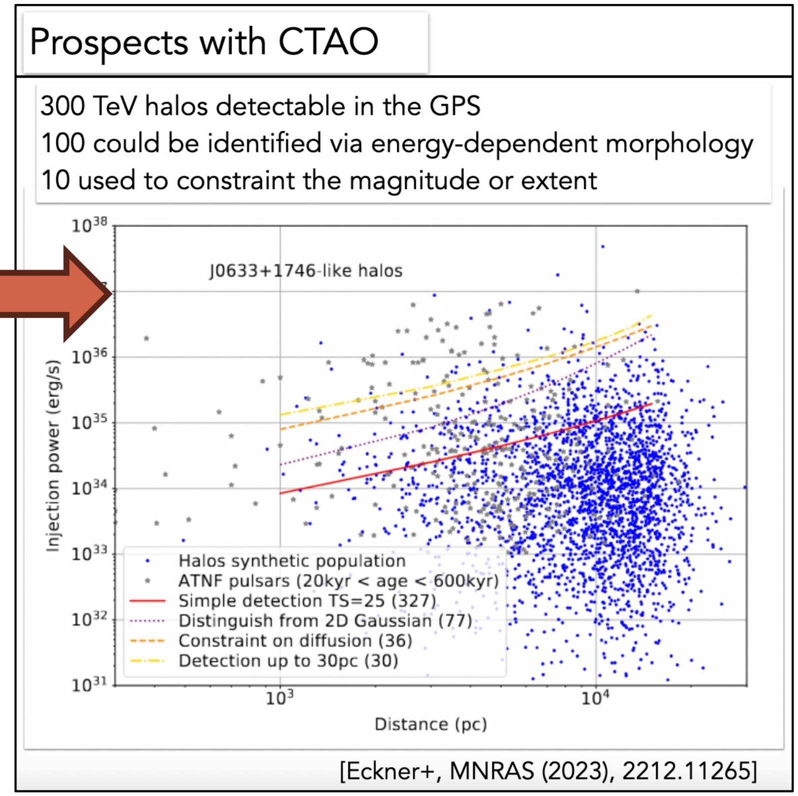
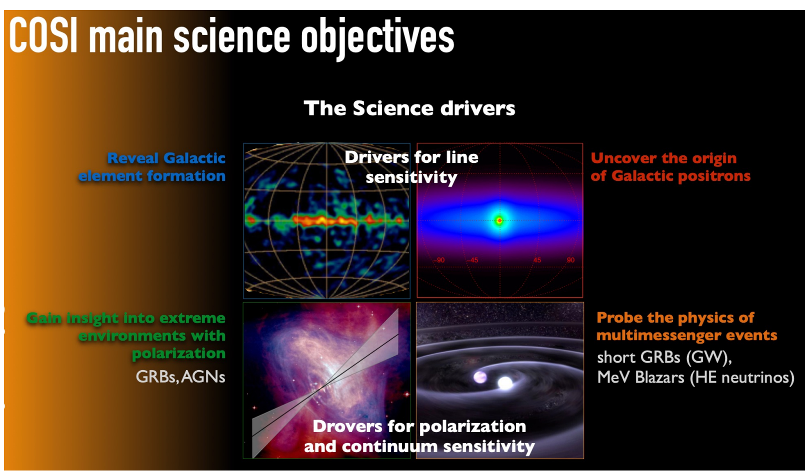


An Exciting Future for Particle Astrophysics!





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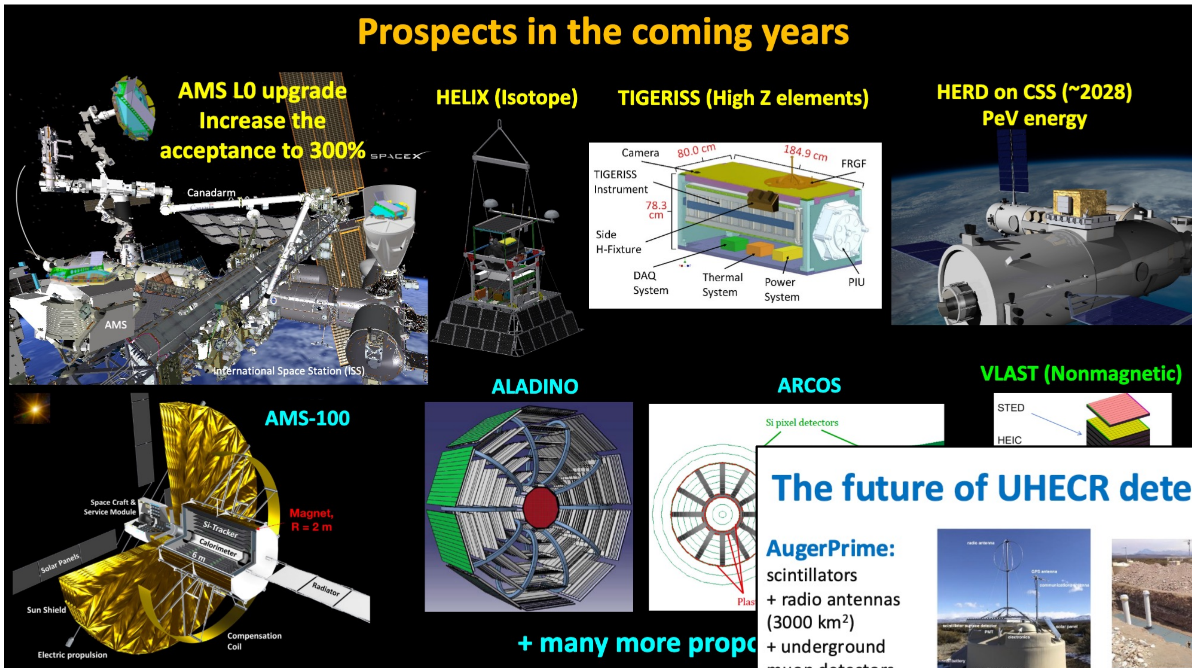

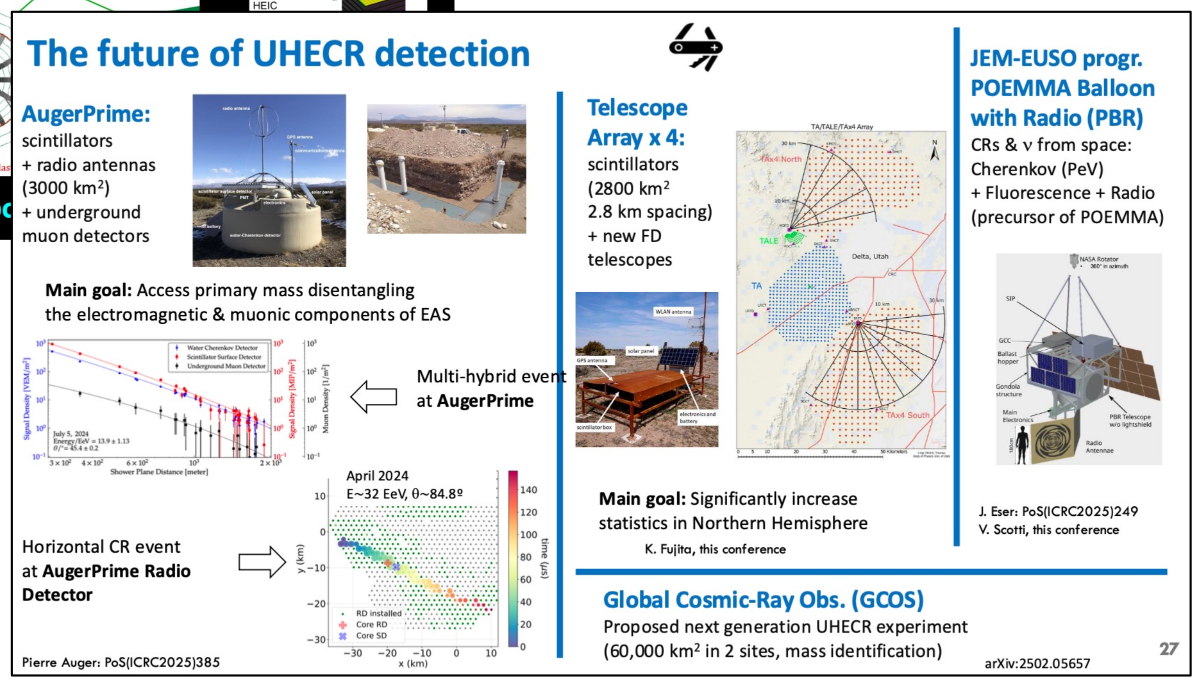

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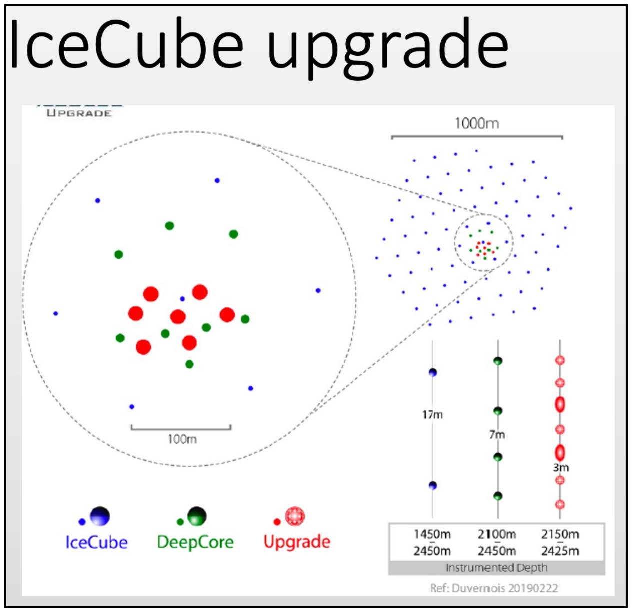
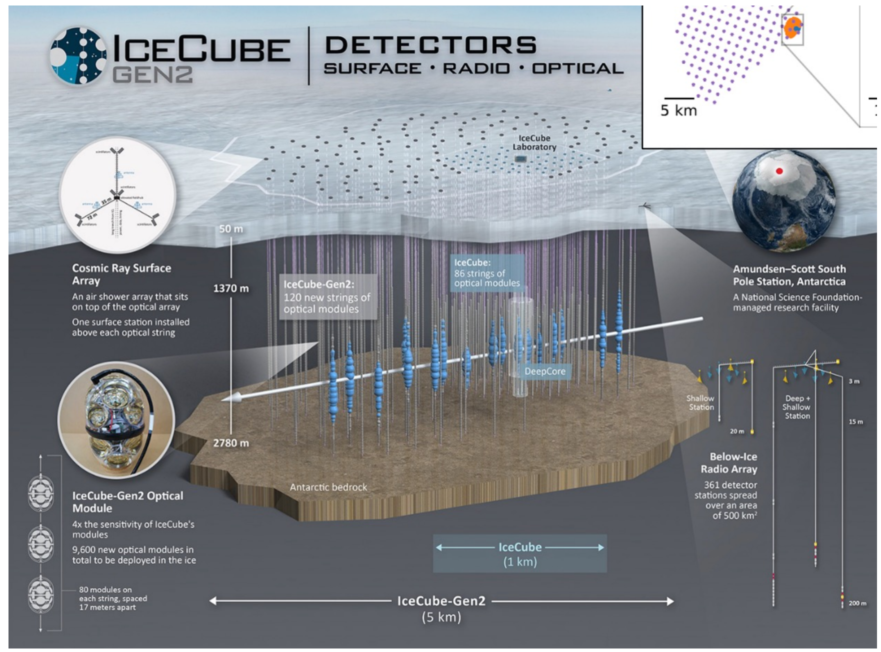


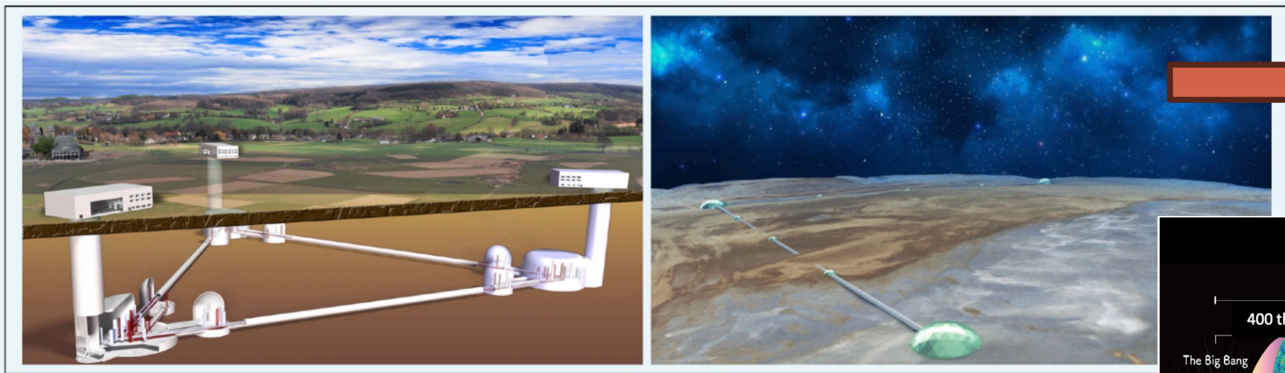


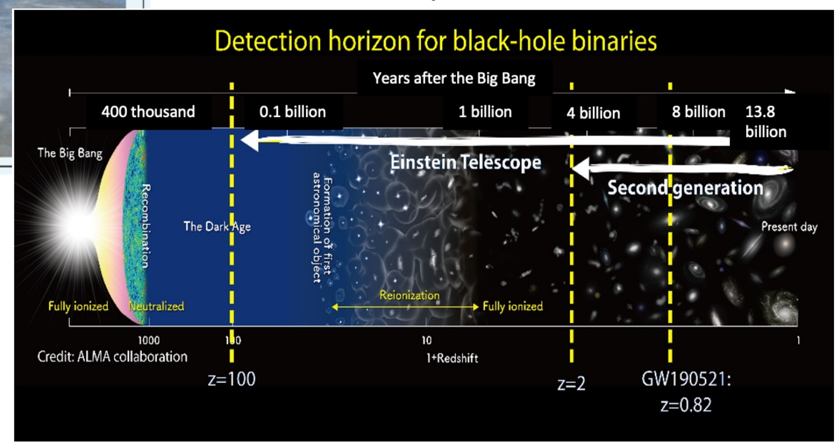
KM3NeT BAIKAL-GVD P-ONE TRIDENT 海铃计划

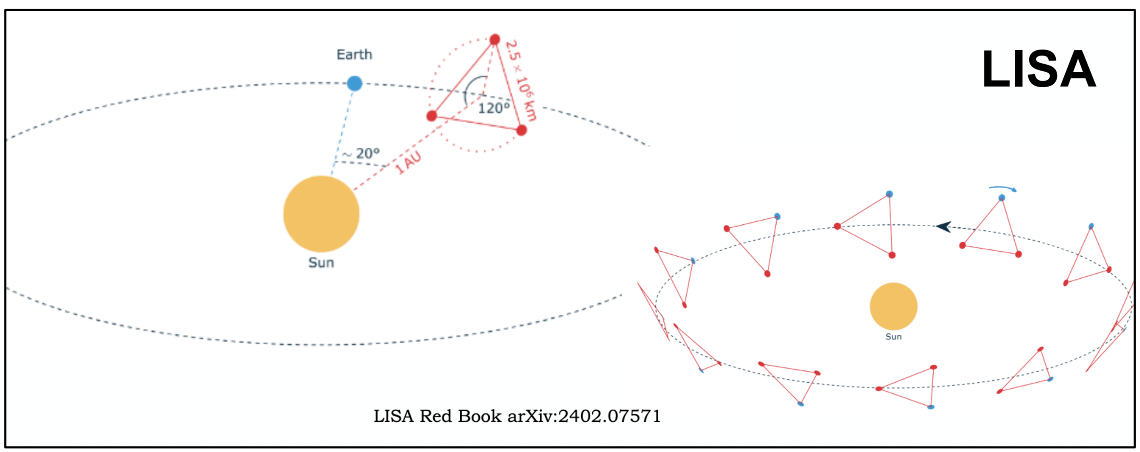
+UHE ν Telescopes:
ARA, RNO-G (ice),
BEACON, GRAND,
Trinity, TAMBO (ground),
PUEO, POEMMA (balloon),
JEM-EUSO (space)

An Exciting Future for Particle Astrophysics!

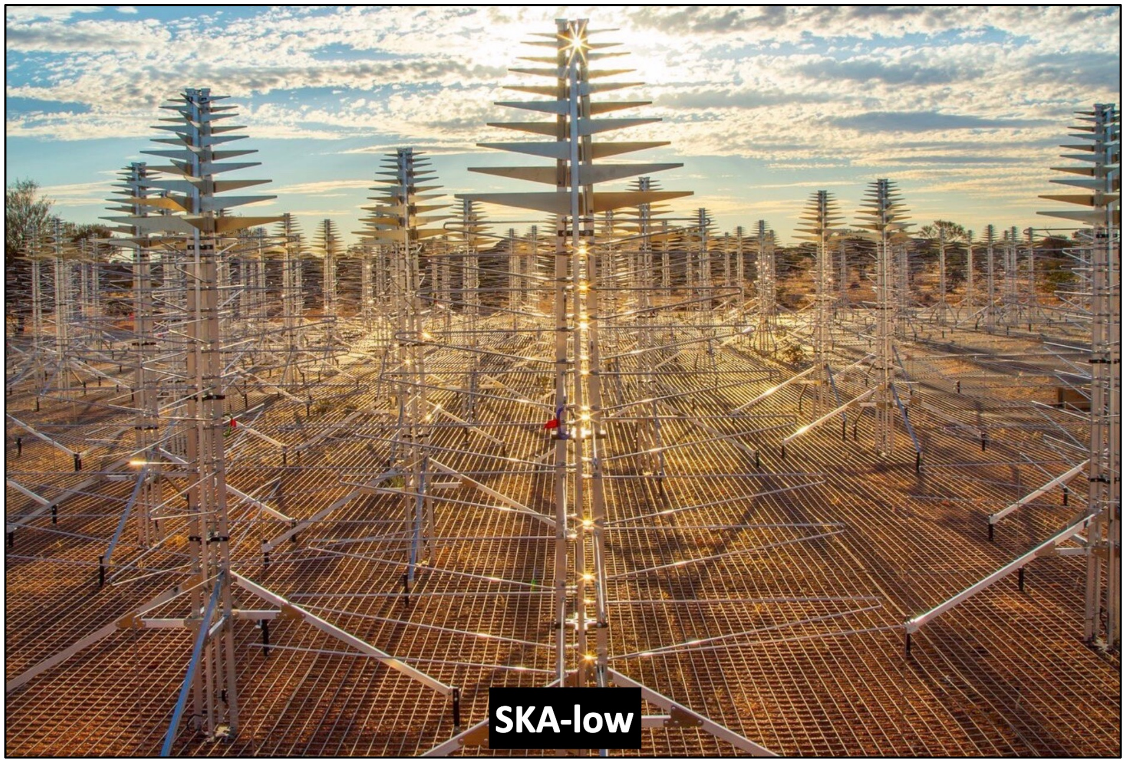
Einstein Telescope   Cosmic Explorer



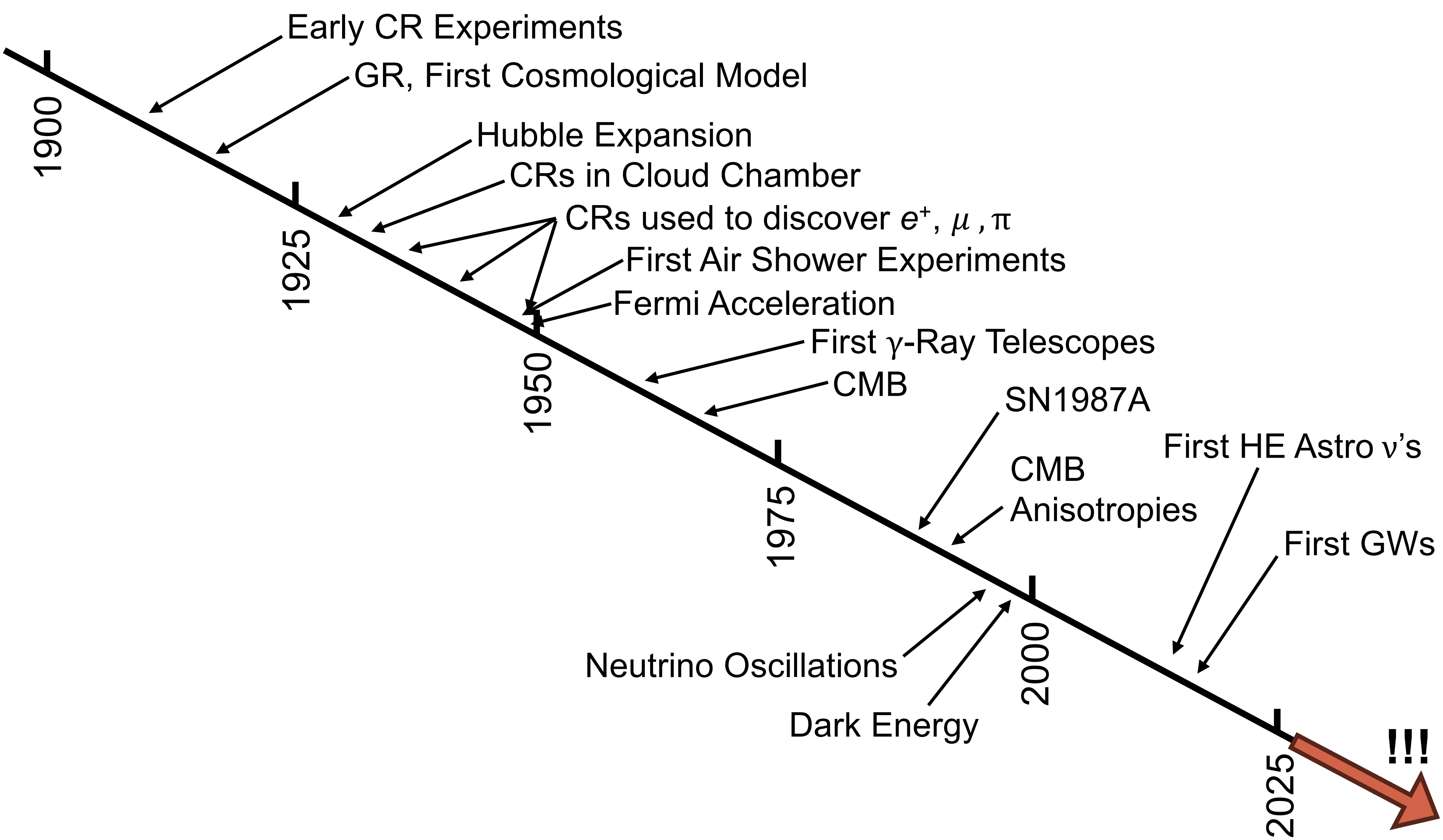




An Exciting Future for Particle Astrophysics!



Timeline of High-Energy Particle-Astrophysics



TeV Particle Astrophysics
TeVPA
Valencia 2025

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