Astrophysics Theory

Snowmass UHECR Workshop II
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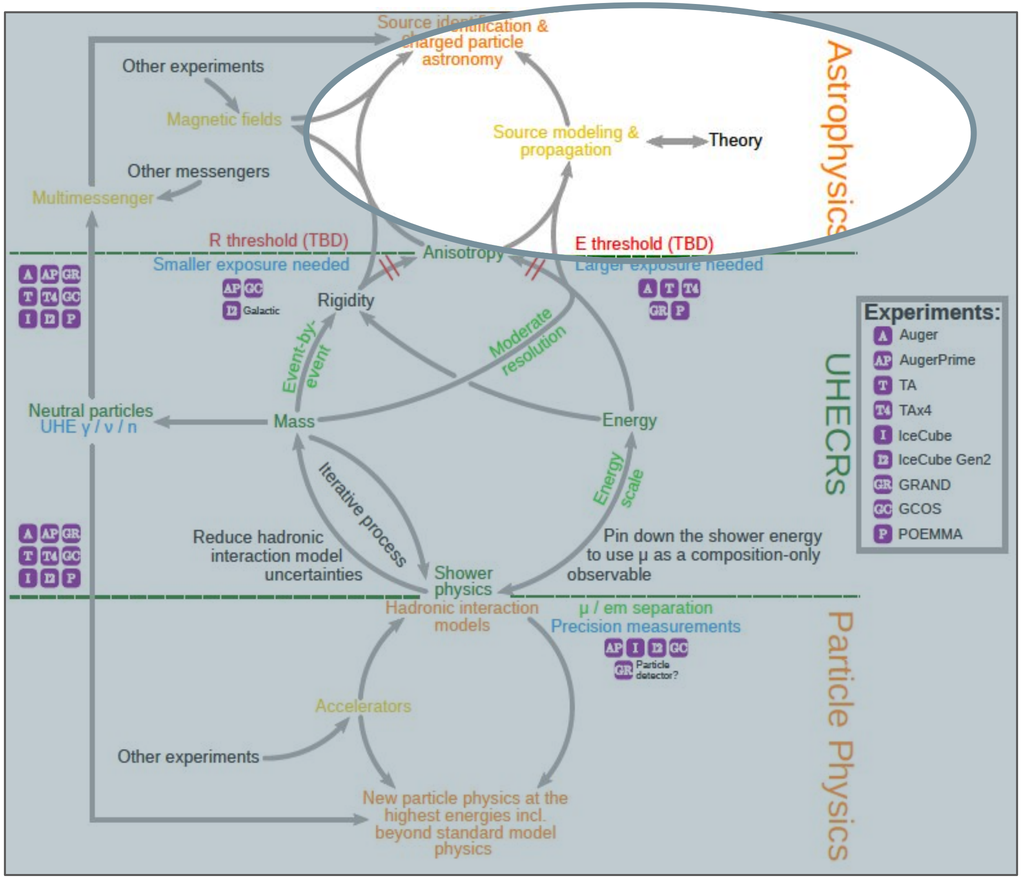
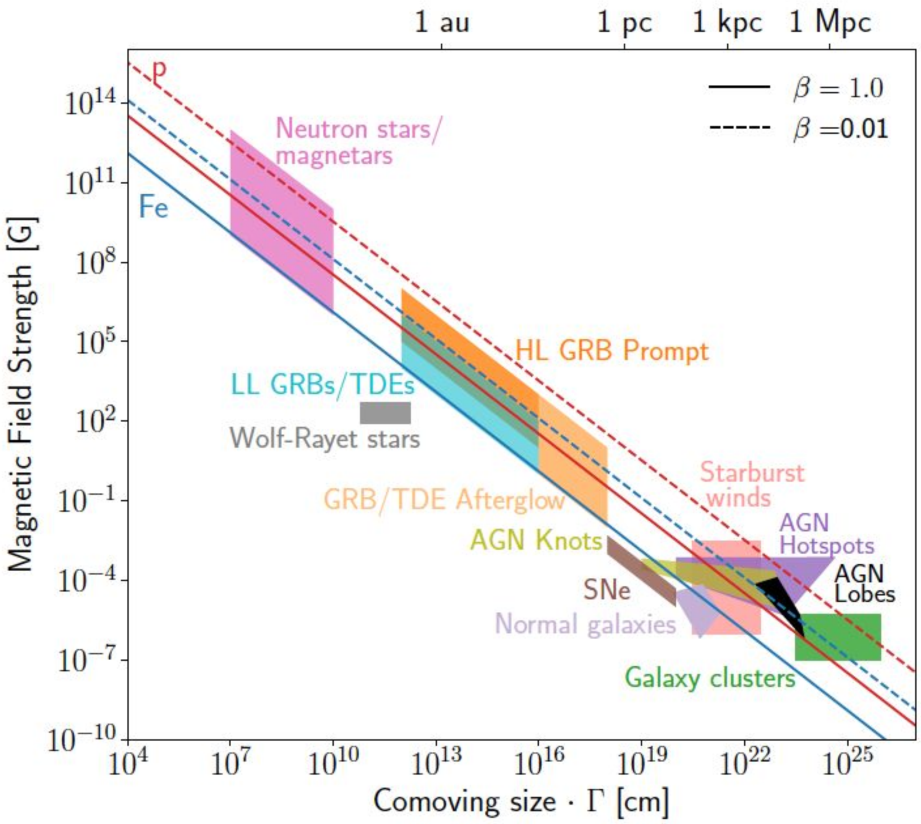


Conveners: F. Oikonomou, T. Venters
Contributors: R. Aloisio, K. Murase

What are the sources of UHECRs?

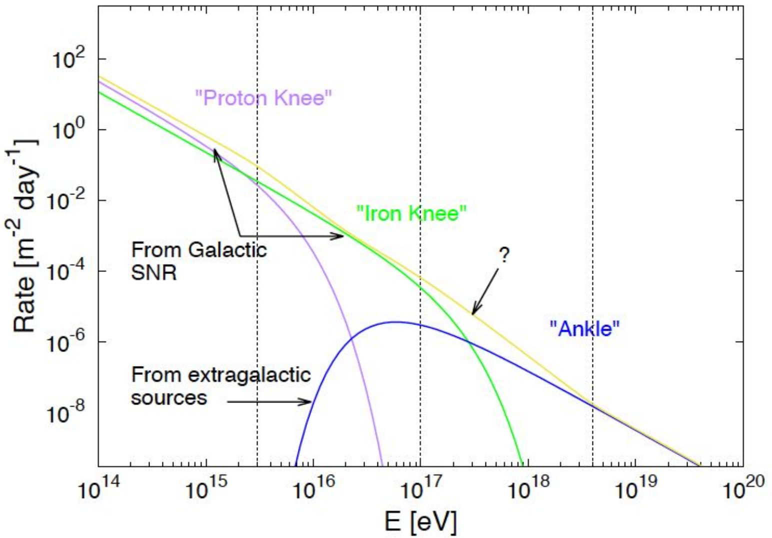
- Several source classes have characteristics required to accelerate UHECRs
  - Which and how many contribute to obs. UHECR flux?
- Many candidates are known cosmic accelerators
  - Do they accelerate hadrons?
  - To what energies?
  - What are the implications for particle acceleration in astrophysics?
  - How does hadronic acceleration impact these sources?
- Which hadronic accelerators produce CRs and which produce gamma rays and neutrinos?

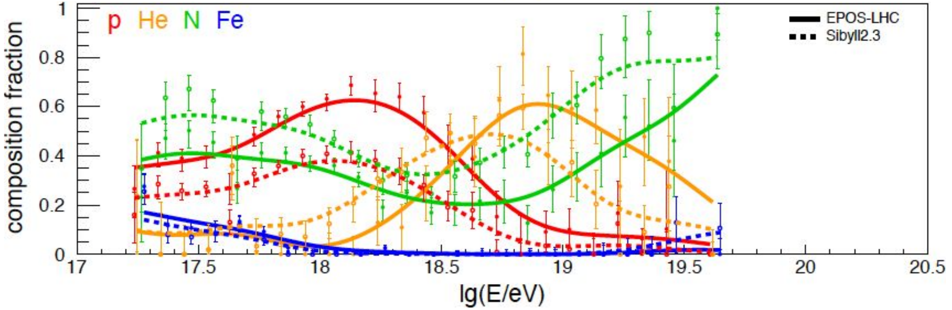


MIAPP Report 2019

Where is the Transition from Gal. to Extragal.?

- Dipolar modulation → UHECRs above 8 EeV are extragalactic.
- At ~10^{18} eV, lighter composition and no detectable anisotropy imply UHECRs at these energies are extragalactic.
- Below 10^{18} eV, the composition gets heavier, consistent with a transition to GCRs with rigidity-dependent spectrum.
- Two issues:
  - Difficult for candidate galactic sources to reach hundreds of PeV.
  - Composition heavier below 10^{18} eV due to N-group elements (G or EG unknown) → *Need experiments capable of distinguishing CNO at these energies*

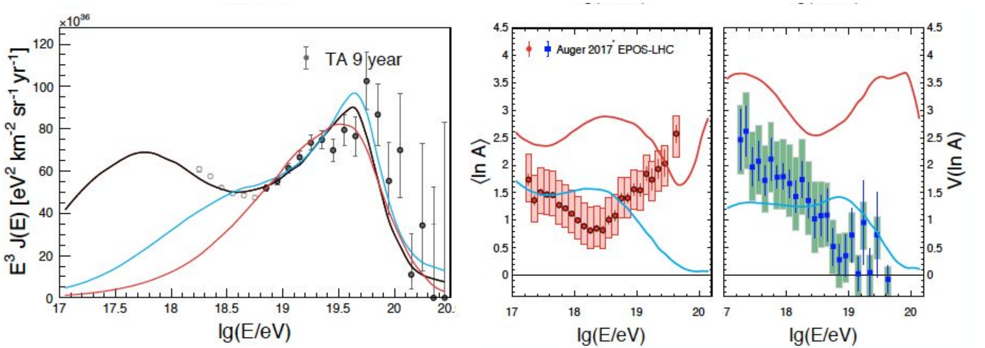




MIAPP Report 2019

What Determines the End of the CR Spectrum?

- “Pure GZK” scenarios have difficulty fitting measurements at the highest energies.
- Mixed-composition source spectra can fit, but at a price:
    - Need extra component to reproduce the “ankle.”
    - Source spectra are hard (γ ~ 1.6) or source evolution is strong and negative.
- Including spallation effects near the source successfully reproduces measurements.
    - Need extra soft component dominated by iron (presumed galactic here).
    - Injection spectrum is hard (γ ~ 1) or source evolution is negative.



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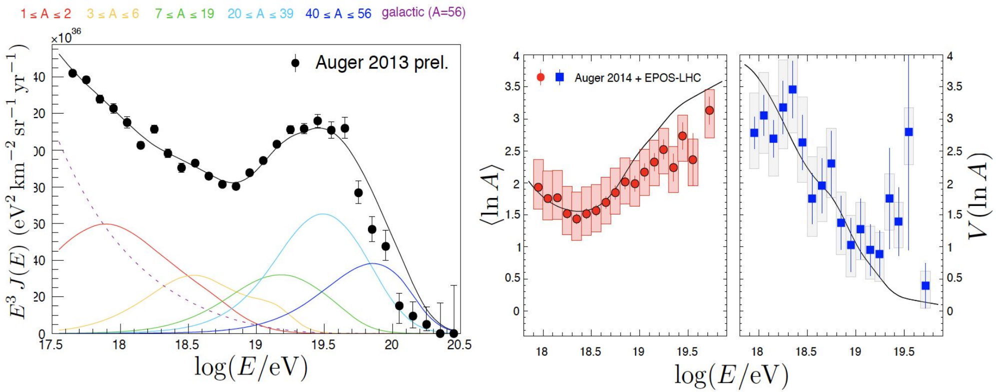
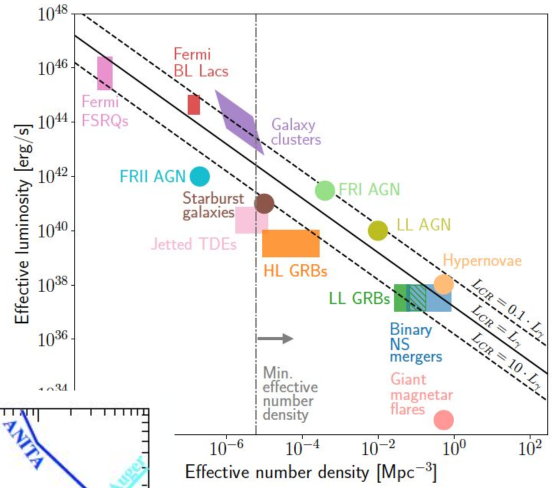


Unger, Farrar, & Anchordoqui 2015

How are UHECR Sources Distributed in the Universe?

- Current UHECR measurements provide only limited constraints on the source density.
- Lack of significant clustering in UHECR arrival directions → minimum effective number density.
- Otherwise, constraints on separation between sources derived from propagation:
  - “GZK horizon” at high energies
  - “Magnetic horizon” at low energies
- Future measurements/analyses needed:
  - *Source identification!*
  - Multipoles as a function of energy
  - Cosmogenic neutrino flux



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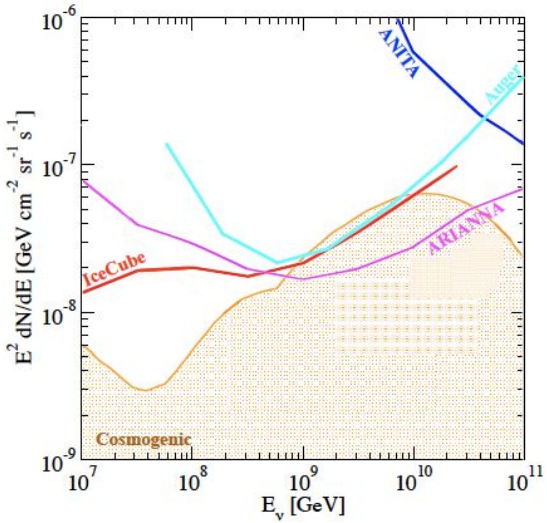
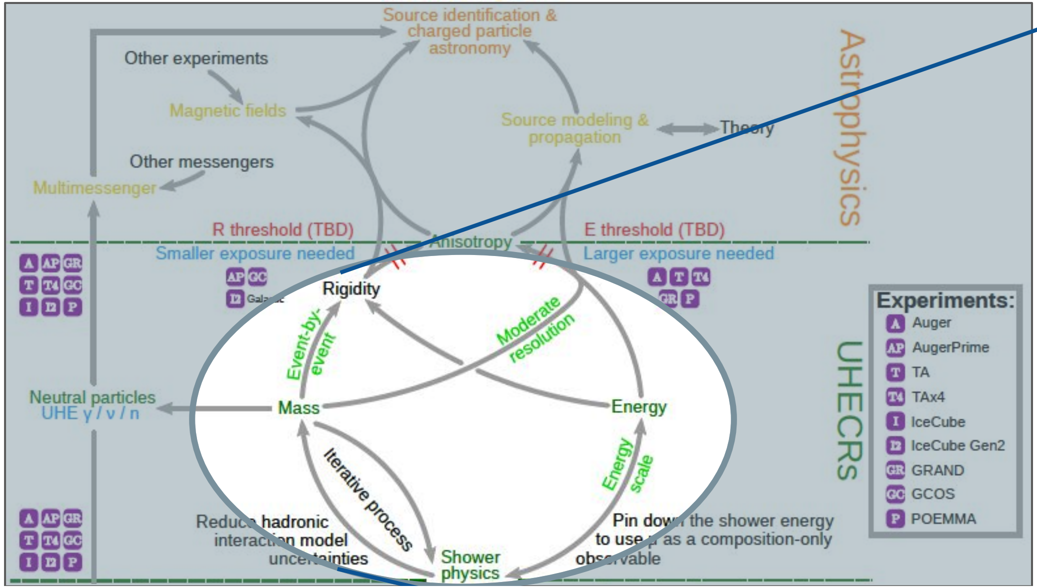
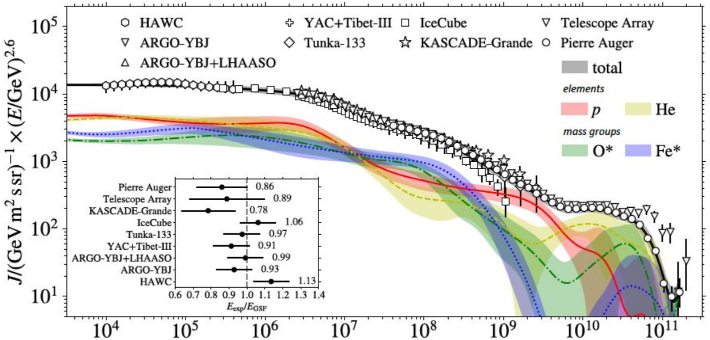
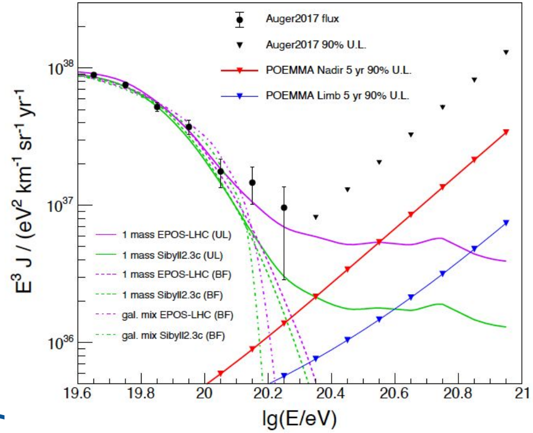


Roadmap to Charged Particle Astronomy I





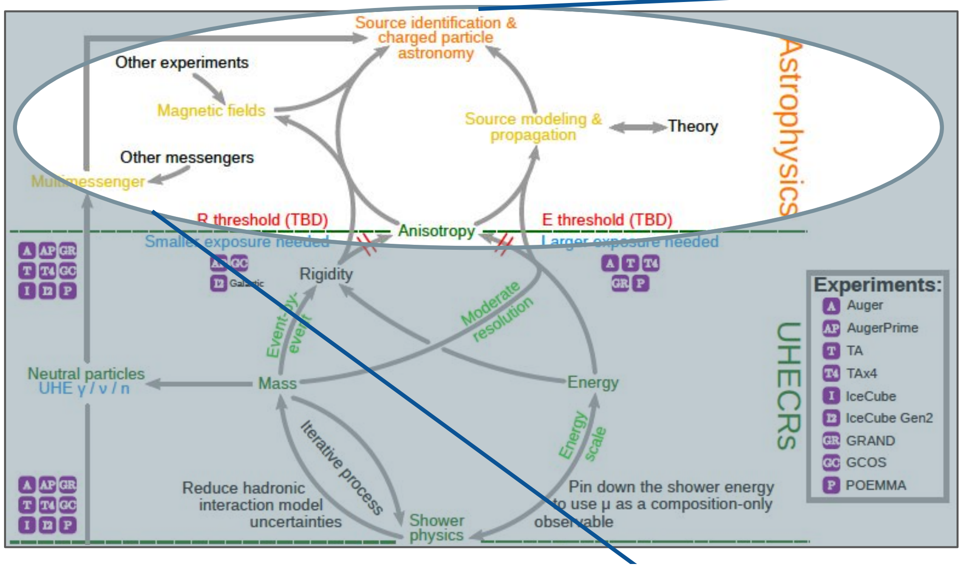
Schröder 2019

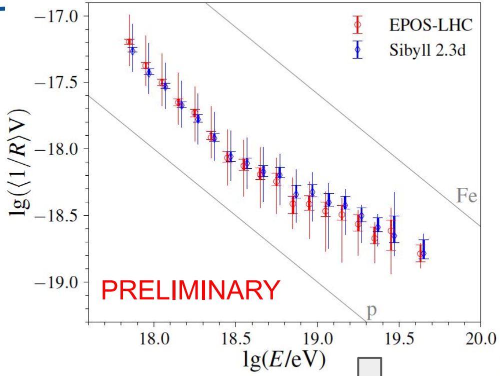


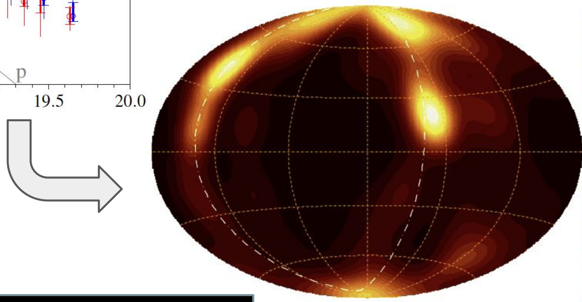
POEMMA Collab. 2020

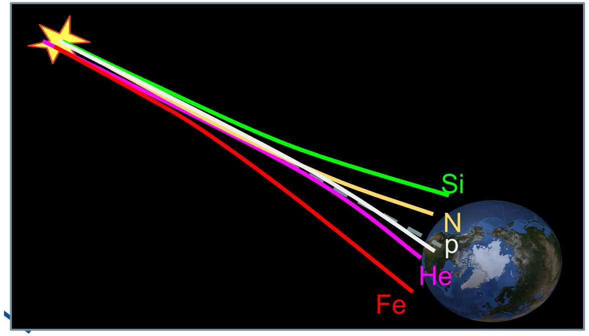
- Higher mass resolution → mass-resolved spectra → distinguish spallation processes from rigidity dependence.
- A “recovery” in the CR spectrum would be a signature of a GZK scenario.

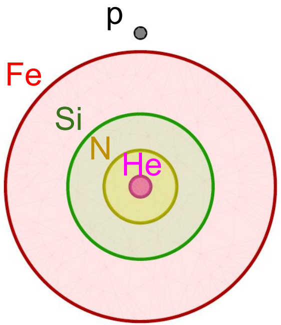
Roadmap to Charged Particle Astronomy II











- High-rigidity measurements will allow for source identification.
- Composition- and energy-dependent source tomography to determine source characteristics (i.e., distance, injection spectra, composition).

Thank you!

Synopsis

The evolving observational picture motivates new theoretical frameworks for understanding the origins of UHECRs and their journey through the cosmos. Answering the outstanding questions of the UHECR picture will require the enhanced capabilities of a new generation of UHECR experiments, as well as leveraging insights brought about by continued progress in supporting areas of astrophysics and the emerging multimessenger landscape.

Outline

- **Outstanding and New Questions in UHECRs** – How have measurements from the current generation of experiments shifted theoretical/interpretive frameworks for understanding UHECRs?
- **Near-term Outlook for the Emerging UHECR Picture** – How will advancements and progress made in the <u>next decade</u> mold our understanding of UHECRs?
  - Advancements in UHECR experiments – planned upgrades and addition of new facilities and capabilities within the next decade
  - Progress from supporting areas of astrophysics – the nature of candidate astrophysical sources (e.g., acceleration mechanisms, evolution of particle populations, etc.); cosmological matter distribution; mapping the GMF and constraining EGMFs (see the beginning of charged particle astronomy?); leveraging multimessenger observations
- **Building a New UHECR Paradigm** – What further advancements will we need in the <u>next two decades</u> in order to answer the outstanding questions of UHECRs?

Contributing Science Tasks

- **Astrophysics Theory** – T. Venters, F. Oikonomou, K. Murase, R. Aloisio, R. Alves-Batista
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- **Dark Matter/BSM** – O. Deligny, R. Aloisio
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- **Magnetic Fields** – T. Jaffe, M. Unger
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- **Multimessenger** – J. Eser, J. Alvarez-Muniz, L. Lu
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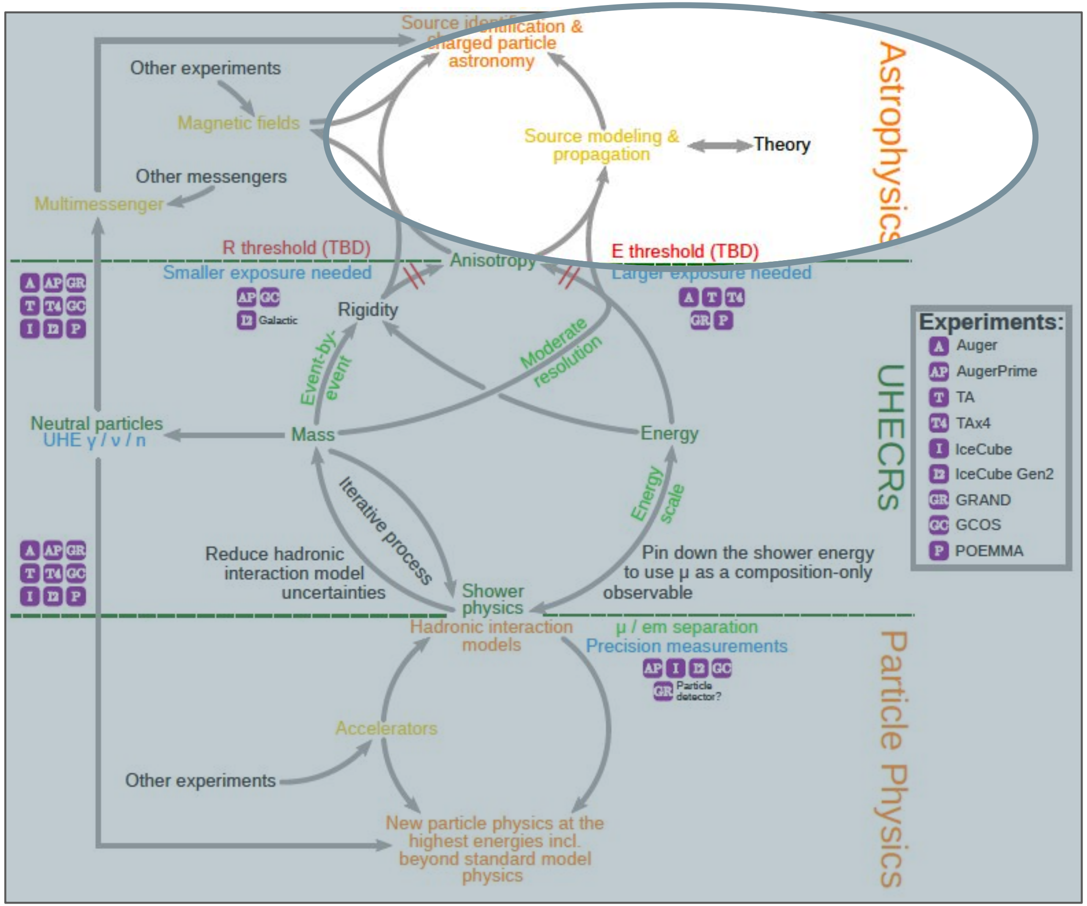
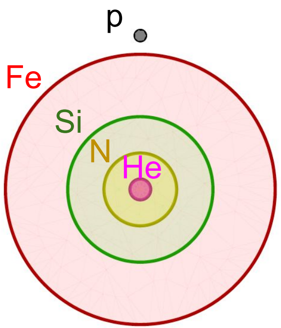
More volunteers welcome!

Roadmap to Charged Particle Astronomy

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Si
N
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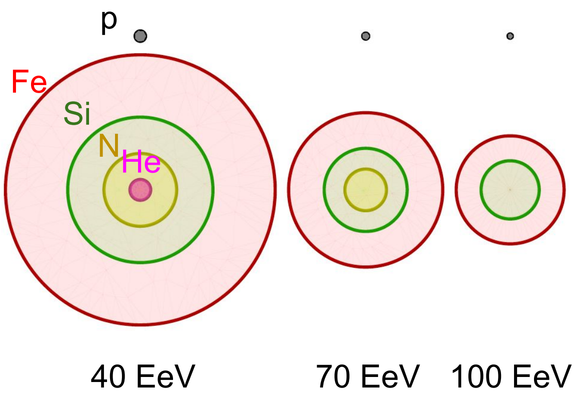
p
Fe
Si
N
He
40 EeV
70 EeV
100 EeV