-The Cosmic Frontier -An Overview for RPF

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https://snowmass21.org/cosmic/start

A. Chou, M. Soaros-Santos, T. Tait



Possible dark matter (DM) candidates vary by **many** decades in mass!

All evidence for DM comes from astrophysics, assuming gravity is understood.

Dark energy is utterly mysterious. It is more prominent today than in the cosmic past.

What broader questions can we study and how?

E.g., the possible co-genesis of baryons and dark matter is a multi-frontier (CF/RF/NF/Theory) issue....



— THE COSMIC FRONTIER

★ Many Fronts, Different Technologies ★

Terrestrial or Space-Based Studies

- CFI: Dark Matter: Particle-Like [J. Cooley, T. -T. Yu, H. Lippincott, T. Slatyer]
- CF2: Dark Matter: Wave-Like [J. Jaeckel, G. Rybka, L. Winslow]
- CF3: Dark Matter: Cosmic Probes [A. Drlica-Wagner,
- C. Prescod-Weinstein, H.-b.Yu]
- CF4: Dark Energy and Cosmic Acceleration: The Modern Universe [J. Annis, J. Newman, A. Slosar]
- CF5: Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before [C. Chang, L. Newburgh, D. Shoemaker]
- CF6: Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities [V. Miranda, B. Flaugher, D. Schlegel]
- CF7: Cosmic Probes of Fundamental Physics [R. Adhikari, L. Anchordoqui, K. Fang, B.S. Sathyaprakash, K. Tollefson]

- THE COSMIC FRONTIER -TODAY

- Overview of physics & driving questions in CF1 - CF7 in turn
 - These subgroups have subgroups! Hundreds of white papers have been submitted to CF!
 - Thus our discussion will be incomplete!
- Note topics that complement work in RPF
 Here, too, our discussion will be incomplete!
 My apologies if your favorite topics are not represented!





Particle-like Dark Matter DM Direct Detection to the v Fog

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Note arXiv:2203.8084

The v "floor" is really a "fog"!

Great strides with LXe technology!

New mechanisms of detection!

Particle-like Dark Matter



spin dependent

Note arXiv:2203.8084



Also gravitational direct detection of ultra-heavy DM is under R&D

Wave-like Dark Matter Enter the axion* A. Berlin and others





Newly attained sensitivity to the QCD band! *Vacuum misalignment can produce scalars and vectors also...

Wave-like Dark Matter

Broad strides to QCD band via γ & nucleon couplings



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Wave-like Dark Matter DM Direct Detection Boot-Strapped by the Quantum Toolbox!



Quantum toolbox & future of quantum sensors for dark matter detection



Measurements beyond the standard quantum limit



Quantum logic spectroscopy

Image credits: MIT Vuletic group, Piet Schmidt, Nature 517, 592, Nature Physics 14, 198



Dedicated quantum sensors for dark matter detection



Entanglement: Heisenberg-limited spectroscopy

Note arXiv:2203.14915, 2203.14923



Dark Mater. Cost of robes Towards the small scale frontier!*



Cosmic small-scale structure is washed out if DM is too light *N.B. a single DM candidate is assumed!

Dark Matter: Cosmic Probes Extreme Astrophysical Environments





Outcomes sensitive to dynamical details....



Dark Energy and Cosmic Acceleration (CF. Key Questions

- Is ΛCDM the best model?
- Is GR correct on large scales, or not?
- How did large scale structure arise $from_{2w_0}$ the event of inflation?

Test: the Dark Energy EoS



Dark Energy and Cosmic Acceleration Massively Multiplexed Spectroscopy

Precision Measurements of the Matter Power Spectrum



Dark Energy and Cosmic Acceleration (CF5) Multimessenger Observations Now with Gravitational Waves!



Dark Energy and Cosmic Acceleration Physics Probed with Redshift CF6





Dark Energy and Cosmic Acceleration Complementarity! New Facilities! New Probes!



Probing Cosmic Concordance









Cosmic Probes Enter the Hubble Tension



Is it a physics effect or an observational systematic effect or effects? Or?

Broader Complementarities



Indirect Dark Matter Detection MeV Mission Futures



– **THE COSMIC FRONTIER** – Summary

The existence of dark matter and of dark energy are established through astrophysical observations.

Discovering their physical origin — and more — appears to be within our future grasp

A veritable explosion of white papers can be found in CF! Let a thousand flowers bloom....

The identification of DM (and more) will ultimately be a multi-frontier effort (& w/ RPF!)! Note <u>Dark Matter Small Projects New Initiatives</u> as an example (RPF: LDMX, CCM, M³....)

"The Future Ain't What It Used to Be." — Yogi Berra

Backup Slides





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Cosmic Probes





