White Paper 3: Fundamental physics and beyond the Standard Model

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JOHNS HOPKINS
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White Paper 3: Fundamental physics and beyond the Standard Model

Topics: **Tests of general relativity**
Nature of black holes and exotic compact objects (gravastars, boson stars, fuzzballs, etc.)
Dark matter: ultra-light bosons, dark photons, axions (overlap with WP6*)

This White Paper will combine 5 Letters of Interest (LOIs):

Emanuele Berti <berti@jhu.edu>
Fundamental Physics with Gravitational Wave Detectors [CF#044]
Suvodip Mukherjee <smukherjee1@perimeterinstitute.ca>
Multi-messenger Probes of Cosmology and Fundamental Physics using Gravitational Waves [CF#143]
Xavier Siemens <xavier.siemens@oregonstate.edu>
Fundamental Physics with Pulsar Timing Arrays [CF#149]
Craig Hogan <craighogan@uchicago.edu>
Physical Effects of Nonlocally Coherent Quantum Gravity [CF#032]
Emil Mottola <emil@lanl.gov>
Searching for Scalar Gravitational Waves in Neutron Star Binary Mergers [CF#166]

*** WP6: Early Universe Phase Transitions: Correlating SGWB with EM Observations**

Michael Ramsey-Musolf <mjrm@sjtu.edu.cn>, Yue Zhao <zhaoyue@physics.utah.edu>, Vuk Mandic <vuk@umn.edu>, Robert Caldwell <robert.r.caldwell@dartmouth.edu>, Haipeng An <anhp@mail.tsinghua.edu.cn>

White Paper 3: Fundamental physics and beyond the Standard Model

Topics: **Tests of general relativity**
Nature of black holes and exotic compact objects (gravastars, boson stars, fuzzballs, etc.)
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Partially overlapping White Papers (that I am aware of):

Masha Baryakhtar+ [CF03]
Dark Matter In Extreme Environments

Vuk Mandic+
Detection of Early-Universe Gravitational Wave Signatures and Fundamental Physics

Sukanya Chakrabarti+
Cosmic Probes of Fundamental Physics (Beyond the Standard Model and Dark Matter)

Fundamental physics with gravitational wave detectors

LIGO/Virgo: black holes and neutron stars are nature-given fundamental physics laboratories

Upcoming experiments:

High-f: KAGRA, LIGO India, Cosmic Explorer, Einstein Telescope, NEMO (Neutron-star Merger Observatory)

Mid-band: MAGIS, AION, AEDGE, DECIGO

Low-f: LISA, Tianqin, PTAs

Black hole horizons, quantum gravity, information paradox

- Black hole spectroscopy
- Multipolar structure
- Quantum modifications at horizon scales?

Corrections to general relativity

- Additional fields, modifications of inspiral radiation
- Black hole uniqueness theorems violated: exotic compact objects?

Probing dark matter

- Primordial black holes?
- Minicharged dark matter
- Ultralight boson clouds, bosenovas, EM signatures?

Gravitational-wave propagation and graviton mass

- GW170817: constraints on Lorentz violation in the gravitational sector
- Dispersion: graviton mass, extra dimensions, parity violation

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Cosmology and fundamental physics with multimessenger observations

Hubble constant measurement

Hubble tension: discrepancy between Cepheids + Sne Ia and Planck observations of CMB

GW standard sirens with EM counterparts: identify host galaxy ($z<0.1$) or
LISA MBHs out to $z\sim10$

Dark energy and cosmological parameters

GWs at $z>0.1$ allow us to measure D_L and z, hence the dark energy EOS w(z)

Cross-correlate with galaxy distribution, peculiar velocities…

[Dark matter]

Dynamical friction in IMRIs

Ultralight boson clouds, bosenovas, EM signatures?

[Modified gravity]

GW170817: constraints on Lorentz violation in the gravitational sector

Dispersion: graviton mass, extra dimensions, parity violation

Time delays between photons and gravitons

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Fundamental physics with PTAs

Cosmic strings / superstrings

Phase transitions in the early Universe / string theory strings “stretched” due to expansion
Can produce SGWB or bursts; PTAs most sensitive to these sources until LISA launches (2034)

Primordial GWs from inflation

Broad-band; probably fainter than SMBH background, but depends on models
In some models spectrum rises with frequency, can be constrained

[Dark matter]

Periodic oscillations in gravitational potential from scalar fields with mass $\sim 10^{-23}$
CDM clumps near the Earth or a pulsar

[Modified gravity]

In general, up to six polarizations
Each line of sight to a pulsar gives an independent projection of the polarizations
Tens of pulsars: polarization constraints
Also enhanced response to longitudinal polarizations

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Summary

Obvious overlap in themes. November 2021 plan for possible sections:

Black hole horizons, quantum gravity, information paradox
Modified gravity
Hubble constant measurement
Dark matter
Dark energy and cosmological parameters
Cosmic strings / superstrings
Primordial GWs from inflation

Will coordinate with corresponding authors and start assigning section captains

Timeline:

- ✓ **White Paper outline in November 2021**

White Paper 3 status: sections reorganized, mostly written - almost there

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

Snowmass2021 Cosmic Frontier White Paper: Fundamental Physics and Beyond the Standard Model

Emanuele Berti[1], Vitor Cardoso[2,3], Zoltán Haiman[4], Emil Mottola[5,6], Suvodip Mukherjee[7], Bangalore Sathyaprakash[8,9,10], Xavier Siemens[11,12], and Nicolás Yunes[13]

Contents

Summary

Obvious overlap in themes. February 2022 outline:

Test of strong field gravity
Black hole horizons, quantum gravity, information paradox
Gravitational signatures of dark matter
Expansion history of the Universe using multimessenger observations
Cosmological gravitational waves

Most of the sections are already written but need polishing
Comparing notes with other WPs with similar topics

Timeline:

- ✓ **White Paper outline in November 2021**
- ✓ **First draft by March 2022: almost there**
  https://www.overleaf.com/read/dswqzmdrprjw

Final draft by July 2022