OVERVIEW OF COSMIC PROBES:
GRAVITATIONAL WAVES

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#127: SEARCHES FOR DARK SECTORS:  
TUESDAY 1400, ZOOM 1

**Early Universe Phase Transitions**
- Gravitational Wave as a probe of phase transitions during inflation Haipeng An, Lian-Tao Wang
- Complementarity between collider and gravitational wave signatures of a first-order electroweak phase transition Michael Ramsey-Musolf, Ashutosh Kotwal
- Probing the Electroweak Phase Transition with Exotic Higgs Decays Marcela Carena
- Phase Transitions: Precision Calculations of Gravitational Wave Spectrum and Thermal Parameters Huai-Ke Guo
- Composite Higgs: Collider Signals and Electroweak Phase Transition Da Liu
- Gravitational Waves from Low Energy Supersymmetry Breaking Nathaniel Craig

**Primordial Black Holes**
- Gravitational waves from primordial black holes Sebastien Clesse
- Electromagnetic Probes of Ultralight Primordial Black Holes Ranjan Laha
Stochastic Backgrounds
- The Stochastic Gravitational Wave Background as a Probe of New Physics from the Early Universe Robert Caldwell
- Correlating Stochastic Gravitational Wave Background with Electromagnetic Observations Light Fields Vuk Mandic

Fundamental Physics
- Fundamental physics with gravitational wave detectors Emanuele Berti
- Probing Fundamental Physics using the Stochastic Gravitational Wave Background from the Early Universe Yue Zhao
- Fundamental Physics with Pulsar Timing Arrays Xavier Siemens
- Gravitational Wave Propagation as a Probe of Fundamental Physics Jay Tasson
- Search for gravitational waves from ultralight boson clouds around black holes Ling Sun
LIGO/Virgo: black holes and neutron stars are fundamental physics laboratories

- upgrades: A+, Voyager, KAGRA, LIGO-India (2025)

Future Observatories

- **High-f**: NEMO, Einstein Telescope, Cosmic Explorer (2030+)
- **Mid-f**: MAGIS, AION, AEDGE, DECIGO
- **Low-f**: LISA, Tianqin (mid-2030s)
- **Ultra-low-f**: Pulsar Timing Arrays, Nanograv, PPTA, EPTA, SKA (ongoing)

**Future colliders**: High Luminosity LHC (mid 2020s)
FUTURE GRAVITATIONAL-WAVE OBSERVATORIES

Credit: Evan Hall
bubble collisions during phase transitions could produce observable gravitational waves
- energy scale determines the frequency at which they might appear
- beyond standard model physics
  - mass-gap between BSM particles and EW scale
    - e.g. SUSY phase transitions
  - is the Universe natural?
  - what order is the EW phase transition?
  - first order phase transitions in the Higgs condensate
    - presence of new physics could alter the thermal history of the EW symmetry breaking
    - to what extent do future GW observatories probe EW phase transitions?
- slow roll inflation produces primordial stochastic background
  - observable in CMB B-modes
PRIMORDIAL BLACK HOLES

- masses of companion black holes in the first GW discovery was far greater than what most astrophysical models predicted
- however, some models with low metallicity do accommodate the existence of such ‘heavy’ black holes
- recent discoveries are challenging stellar formation scenarios
  - light companion of GW190814, primary companion of GW190521
  - some of LIGO-Virgo black holes might well be primordial in origin
- how can we ascertain that black holes are not of stellar origin or merger products?
  - detection of sub-solar mass black holes
  - black holes spins that are essentially zero
STOCHASTIC GRAVITATIONAL-WAVE BACKGROUND

- CMB
- SKA
- Indirect
- LIGO and Virgo
- PTA
- LISA
- aLIGO
- Blue Tilt
- Phase Transition
- Slow Roll Inflation
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?, mini-charged 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