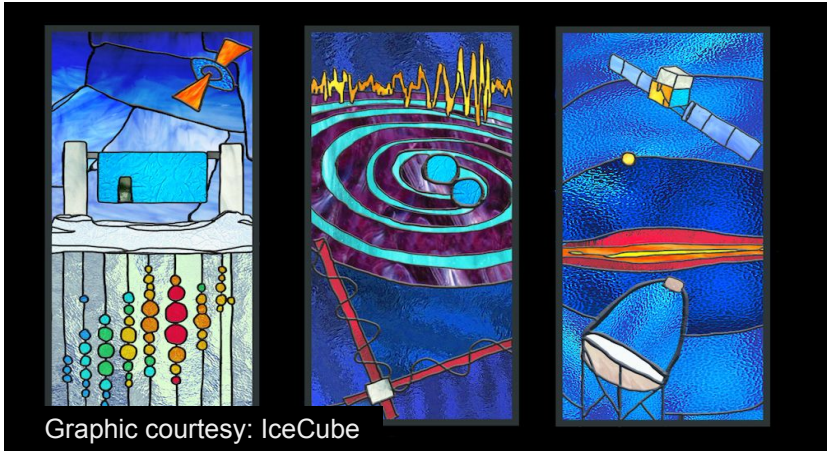
Cosmic Probes of Fundamental Physics: CF7

Snowmass 2021

Using the windows on the universe to learn about fundamental particles and high energy physics

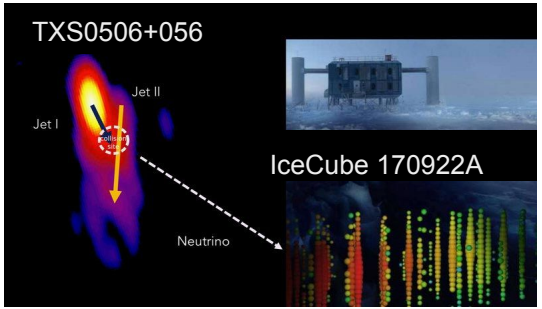
- **Science goals**: CF7 covers cosmic probes of fundamental physics topics beyond Dark Matter and Dark Energy using gravitational waves, cosmic rays, gamma rays, and neutrinos, as well as their combined studies to facilitate the multi-messenger science. It also covers various tests of ΛCDM using high and low redshift observations and the potential of standard candle/siren cosmology to address existing tensions in the data.

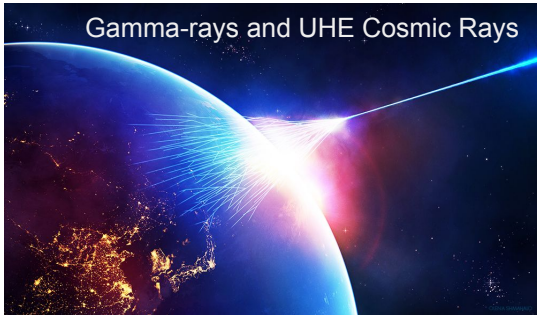
- **Conveners**:
  - Rana X Adhikari (Caltech)
  - Luis Anchordoqui (CUNY)
  - Ke Fang (UW-Madison)
  - B.S. Sathyaprakash (Penn State)
  - Kirsten Tollefson (MSU)



Graphic courtesy: IceCube

- **New for Snowmass 2021:**
  - *Major Science Accomplishments since the last Snowmass:* discovered astrophysical neutrinos and gravitational waves, their electromagnetic counterparts, a large scale anisotropy in ultrahigh energy cosmic ray sky, evidence for a tension between inferred and measured values of Hubble constant
- **LOIs:** received 140 LOIs in total, 71 with CF7 as a main topic
  - *By messengers*: 30, 22, 35, 45 on Gravitational waves, Cosmic rays, Neutrinos, Photons (including ~15 on cosmology, ~25 on gamma-rays)
  - *By type of work*: 32 focusing on theory, the rest on experiments and detectors
- **Plans for future activities**
  - After CPM we propose to meet once every week or two
    - Format: short talk(s), discussion
    - Topic-focused meetings
    - Meetings to enable collaboration across experiments
  - Outline of topical group report in April 2021





CF7: Proposed Community White Papers, 13

1. Multi-messenger facilities and experiments - umbrella paper that incorporates the GW, gamma-ray, cosmic rays and neutrino white papers; joint analysis; multi-messenger follow-up
2. Equation of state of high-density matter and QCD phase transitions
3. Fundamental physics and beyond the Standard Model:
    a. Tests of general relativity, the nature of black holes, exotic objects (gravastars, boson stars, fuzz balls, etc.)
    b. Dark matter, ultra-light bosons, dark photons, axions.
4. Cosmology – 3 papers
    a. Paper 1 - probing the dark sector multi-messengers: dark matter, dark energy
    b. Paper 2 - beyond the standard model: dark photons, ultra-light bosons, axions, primordial black holes, sterile neutrinos, etc.

CF7: Proposed Community White Papers

   c. Paper 3 - Phase transitions in the early Universe: Correlating Stochastic Gravitational Wave Background with Electromagnetic Observations
5. Gamma-ray experiments …
6. High-energy and ultrahigh energy neutrinos …
7. GW facilities paper - umbrella paper across all techniques - benchmarks
   a. Organize some meetings in November/December to exchange information on how to analyze different experiments.
8. UHECR - umbrella paper
9. Synergy between astroparticle and collider physics (led by EF)
10. Modelling gravitational wave sources (jointly with TF4)

Proposed Timeline for White Paper Writing

Here is a **suggested** timeline for writing “solicited” white papers. These dates are earlier than the July 31, 2021 submission deadline to ensure there is sufficient time for the conveners to include their findings into the CF7 summary report which will be written in parallel.

- Now - Dec 2020: Identify “solicited” white papers and “captains” for each
- ~~Jan. 2021:~~ Oct 2021: Have outlines showing what will be covered in the paper
- ~~March 2021:~~ March 2022: Have a first draft of white paper to CF7 conveners
- ~~April-June 2021:~~ March-May 2022: CF7 conveners write draft of their summary report to be discussed at the July 2022 Community Summer Study Snowmass meeting

1. Multi-messenger facilities and experiments

- Cross-messenger studies
- Joint analysis of multi-wavelength, multi-messenger data
- Coordinated/follow-up observations
- Topics not covered in umbrella papers on GWs, high-energy and UHE neutrinos, gamma rays, and UHE cosmic rays

(#wp-cf07-multi-messenger; Overleaf; Doc)

Kristi Engel (kristi.engel23@gmail.com), Toni Venters (tonia.m.venters@nasa.gov), Marcos Santander (jmsantander@ua.edu), Marco Muzio (msm659@nyu.edu)

2. Equation of state of high-density matter and QCD phase transitions

- Discovering quark-matter cores in massive neutron stars (CF#132)
  - Aleksi Kurkela, a.k@cern.ch
- Probing nuclear astrophysics and gravitation with neutron stars (CF#066)
  - Emmanuel Fonseca efonseca@physics.mcgill.ca
- Compact binaries as probes of dense matter and QCD phase transitions (CF#195)
  - J. Read jread@fullerton.edu
- Equation of state of cold, dense matter with EM observations of neutron stars (CF#087)
  - Slavko Bogdanov slavko@astro.columbia.edu
- Illuminating the dark sector in neutron star mergers (CF#213)
  - Kuver Sinha kuver.sinha@ou.edu
- Cold QCD matter at high densities (CF#225)
  - Or Hen hen@mit.edu

3. Fundamental physics and Beyond the Standard Model

- GW probe of fundamental physics (CF#143)
  - Suvodip Mukherjee s.mukherjee@uva.nl
- Fundamental physics with GW detectors (CF#044)
  - Emanuele Berti (Johns Hopkins) berti@jhu.edu
- Searching for scalar GWs in binary neutron star mergers (CF#166)
  - Emil Mottola emil@lanl.gov
- Physical Effects of Nonlocally Coherent Quantum Gravity (CF#032)
  - Craig Hogan (University of Chicago and Fermilab) craighogan@uchicago.edu
- Fundamental Physics with Pulsar Timing Arrays (CF#149)
  - Xavier Siemens xavier.siemens@oregonstate.edu

4a. Cosmology: probing the dark sector 1

- Probing the expansion history of the Universe with Gravitational Waves (CF#116)
  - Hsin-Yu Chen himjiu@mit.edu
- Multimessenger probes of cosmology and fundamental physics using GWs (CF#143)
  - Suvodip Mukherjee s.mukherjee@uva.nl
- Dark Energy Science with Multimessenger Probes and the Vera Rubin Observatory (CF#111)
  - Marcelle Soares-Santos mssantos@umich.edu
- Cosmology Intertwined I: Perspectives for the Next Decade (CF#019)
- Cosmology Intertwined II: The Hubble Constant Tension (CF#020)
- Cosmology Intertwined III: fσ8 and S8 (CF#021)
- Cosmology Intertwined IV: The Age of the Universe and its Curvature (CF#022)
  - arXiv:2008.11283, 2008.11284, 2008.11285, 2008.11286
  - Eleonora Di Valentino, eleonora.divalentino@manchester.ac.uk
- Effort is underway to write the WP, others are encouraged to join:
  - Team meeting Mondays 6am and Fridays at 12pm (eastern time) alternating every other week. This Monday we'll have a meeting at 6am. Proposed meetings 12/11/20 and 1/22/21 (4pm EST)
  - Whitepaper coordinator: Eleonora Di Valentino, eleonora.divalentino@manchester.ac.uk
  - UPDATE: monthly meetings since April 2021. Doodle poll has been circulated to decide on new meeting days. Idea is to switch again into weekly meetings. Dates will be decided on meeting of Sep. 21. Dedicated workshop planned for mid November.

4b. Cosmology: probing the dark sector 2

- Novel dynamical probes of DM on small scales (CF#014)
  - Sukanya Chakrabarti, (RIT) chakrabarti@astro.rit.edu
- Using GW interferometers as particle detectors to directly probe dark matter (CF#072)
  - Andrew Miller andrew.miller@uclouvain.be
- Gravitational waves from primordial black holes (CF#091)
  - Sebastien Clesse sebastien.clesse@uclouvain.be
- Search for gravitational waves from ultralight boson clouds around black holes (CF#136)
  - Ling Sun ling.sun@anu.edu.au
- Insights for Fundamental Physics and Cosmology with Light Relic (CF#147)
  - Joel Meyers jrmeyers@smu.edu
- Gravitational Wave Observations as a Probe of Dissipative Dark matter (CF#228)
  - Sarah Shandera ses47@psu.edu

Talk to CF1 and see if there are any linkages

4c. Cosmology: Probes of the Early Universe

- Complementarity between collider and GW signatures of first order electroweak phase transitions
  - Michael Ramsey-Musolf mjrm@sjtu.edu.cn
- Probing Fundamental Physics using the Stochastic GW Background
  - Yue Zhao (University of Utah) zhaoyue@physics.utah.edu
- Background from the Early Universe
  - Yue Zhao (University of Utah) zhaoyue@physics.utah.edu
- Correlating Stochastic GW Background with EM Observations
  - **Vuk Mandic**vuk@umn.edu
- The Stochastic GW Background as a Probe of New Physics from the Early Universe
  - **Robert Caldwell** robert.r.caldwell@dartmouth.edu
- GWs as a probe of phase transitions during inflation

  Haipeng An anhp@mail.tsinghua.edu.cn
- UDATE: See comments 1 and 4 in https://docs.google.com/document/d/187BrLqhBjAL6TapbHGz6Wn-gK2lZ9znI1HUK_y49kh4/edit

  We should probably add GW as probes of magnetic fields, matter asymmetry, and inflations

5. Gamma-ray experiments (#wp-cf07-gamma-ray-exp; Overleaf; Doc)

- **MeV experiments:** AMEGO (100(??), 121, 122, 176), GRAMS (170), GammaTPC (224) -- suggestions: Liz Hays, Julie McEnery, Carolyn Kierans, Regina Caputo
- **TeV experiments:** CTA (185), SWGO (186, 187, 190, 191, 192, 193, 196, 227, 229, 231, 232, 233, 234, 235) Kristi Engel, David Williams, Marcos Santander
- **EeV experiments:** Auger (140, 203), POEMMA (31) -- John F. Krizmanic

6. High-energy and ultrahigh energy neutrinos

- **25 LOIs in total**: Link to LOIs
  - 16 focus on current and future experiments
  - 5 on observational opportunities and strategies
  - 4 on theory developments

  Nepomuk Otte, Mauricio Bustamante, Steph Wissel, Hallsie Reno

- Session at the Snowmass Community Planning Meeting: https://indico.fnal.gov/event/44870/sessions/16261/#20201007
- UPDATE: Dedicated discussions are planned during the Workshop on Tau Neutrinos from GeV to EeV 2021 (9-28/10-1). https://www.bnl.gov/nutau2021/

7. Ultra High Energy Cosmic Rays

- **Experiments**: Auger (70, 140, 203, 265), TA (70, 265), POEMMA (31), GRAND (195), ZAP (24), SWGO (191, 226)
- **Science:** muon excess in cosmic ray air showers (58, 83), highest-energy Galactic cosmic ray physics (94) , mass composition (130), energy spectrum (265), anisotropy (70)
- **Detection techniques:** radio detection (118, 195), Cherenkov + radio (117), space (24, 31)

Frank Schroeder, Jörg Hörandel

UPDATE: White paper under discussion. Coordinators: Fred Sarazin, Frank Schroeder, Tonia Venters. Topical conveners: Alan Coleman, Johannes Eser, Eric Mayotte, Denis Soldin. Senior representatives from future experiments: Jörg Hörandel (GCOS), Angela Olinto (POEMMA), others will be contacted… Dedicated workshop planned for October.

8. GW facilities

- LIGO Voyager (CF#063)
  - Rana X Adhikari (Caltech) rana {at} caltech.edu
- Cosmic Explorer: The Next-Generation U.S. Gravitational-Wave Detector (CF#010)
  - Stefan Ballmer (Syracuse University) sballmer@syr.edu
- The Atom Interferometric Observatory and Network (AION) for DM exploration (CF#018)
  - L. Badurina (King's College London) (email address)
- The Matter-wave Atomic Gradiometer Interferometric Sensor (MAGIS-100) experiment (IF#136)
  - S. Chattopadhyay swapan@fnal.gov
- Long-baseline Atomic Sensors for Fundamental Physics (CF#164)
  - Jason Hogan hogan@stanford.edu
- Opportunities in gravitational physics (IF#134)
  - Jason Hogan hogan@stanford.edu
- Update: Cosmic Explorer project has completed the NSF Horizon Study
  - Visit https://cosmicexplorer.org/ to download the study document and join the CE consortium

9. Synergy between astroparticle and collider physics

- Author coordinator: Hallsie Reno, mary-hall-reno@uiowa.edu
- Addressing the muon problem in cosmic ray showers with new facilities at the LHC
- Determination of the contribution of charm-production to the IceCube background
- LoI doi:10.5281/zenodo.4009451
- https://zenodo.org/record/4009452#.X67HPy9h2u0

Hallsie Reno also somebody from Auger

UPDATE: FPF paper on synergy between accelerator-energ- neutrino-cosmic frontiers coming out this week. I'll provide the arXiv number before Friday meeting..

10. Modelling gravitational wave sources

- From scattering amplitudes to relativistic two-body problem (TF#067)
  - Alessandra Buonanno alessandra.buonanno@aei.mpg.de
- Numerical relativity for next generation GW probes of fundamental physics (CompF#080)
  - Pablo Laguna pablo.laguna@austin.utexas.edu
- Large effort to model binary neutron stars although there are no LOIs
  - Possibly approach interested folks