

Cosmic Frontier

CPM Report



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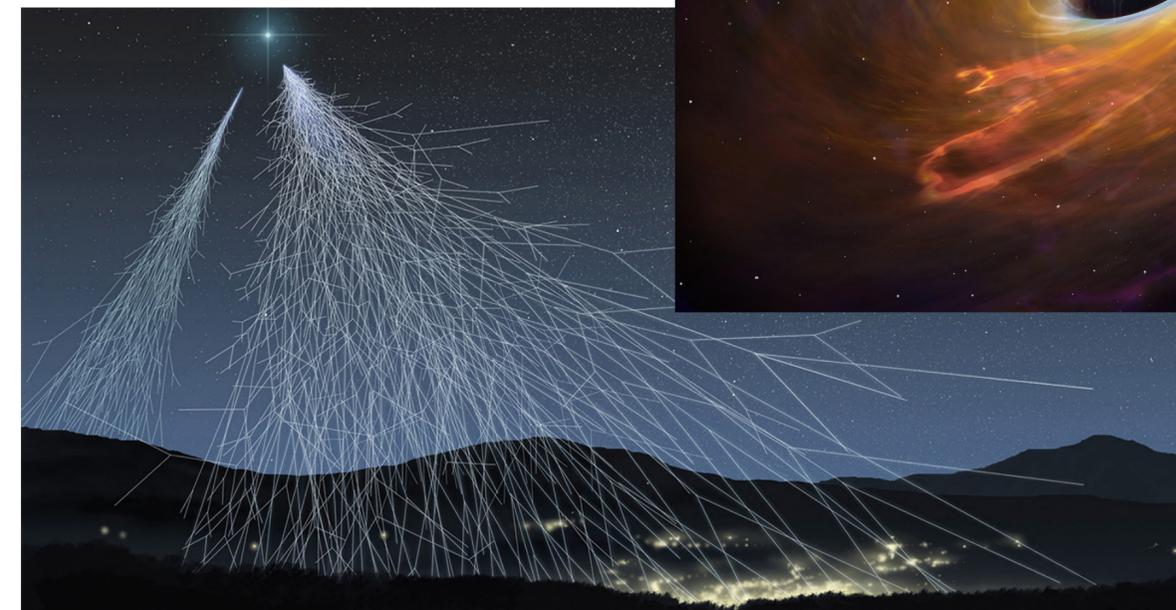
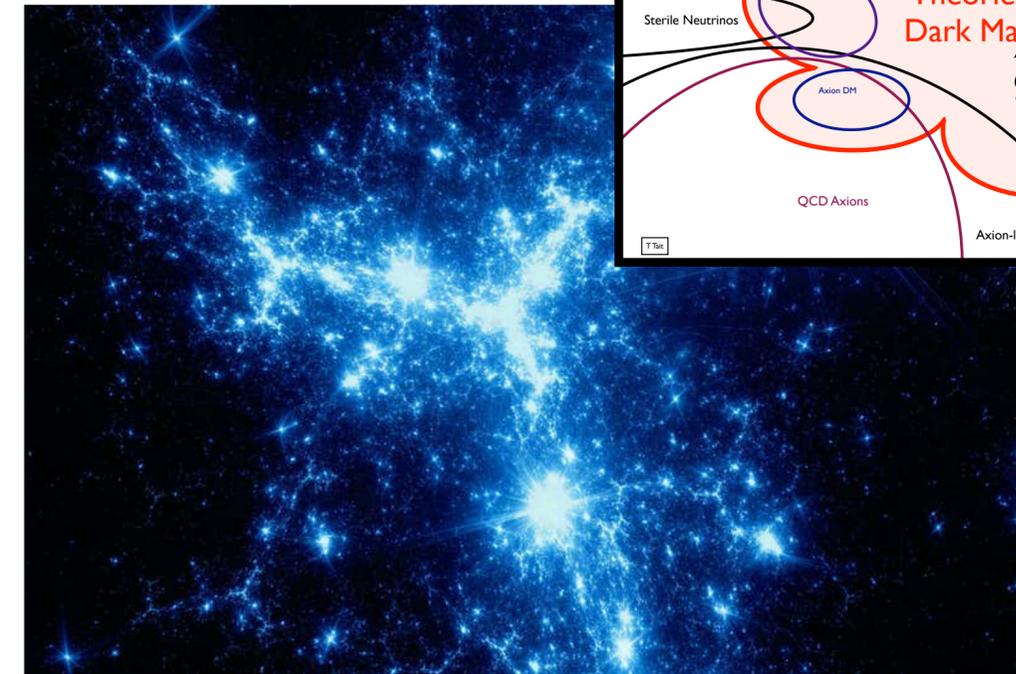
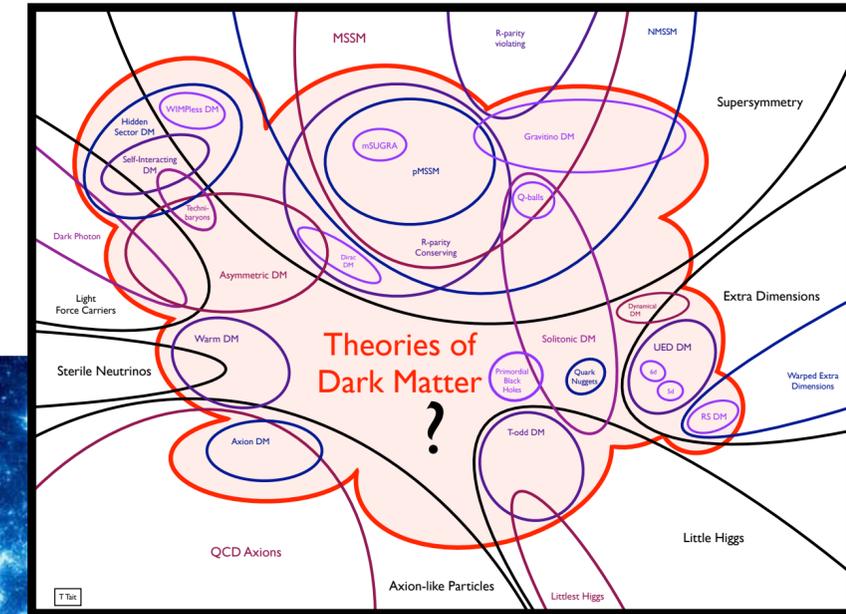
Snowmass CPM
October 8, 2020



Justice for Breonna Taylor
#SayHerName

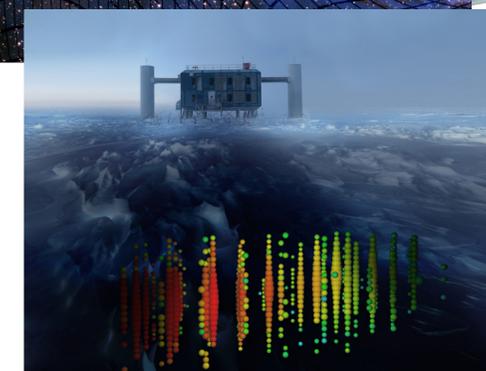
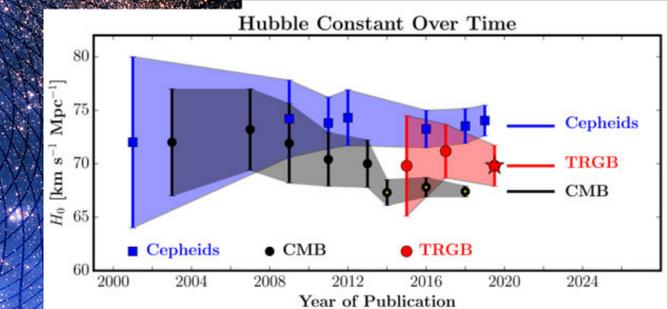
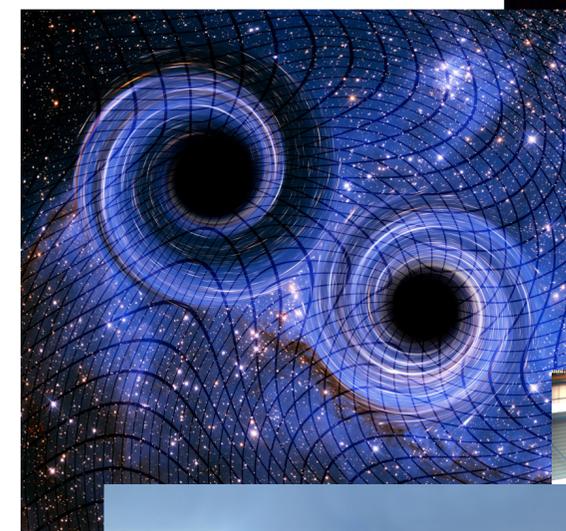
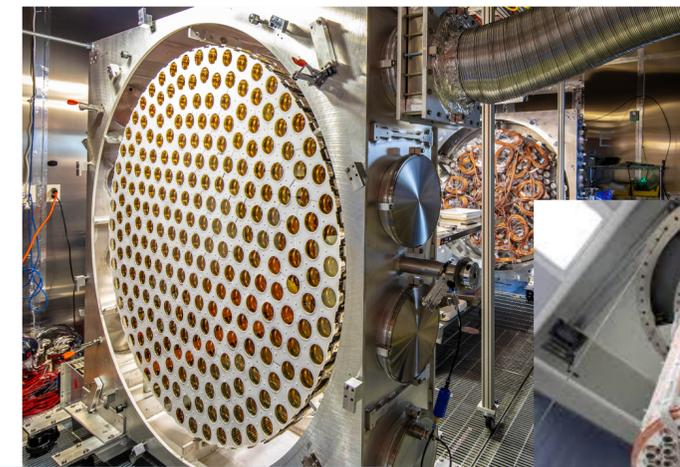
Big Questions

- **What is the fundamental nature of dark matter? How does it connect to the Standard Model?**
- **What is dark energy? Is it a dynamical quantity? How does cosmology reveal the fundamental dynamics governing the Universe?**
- **How can cosmic and astrophysical observations reveal new physics and provide new ways to explore new phenomena?**



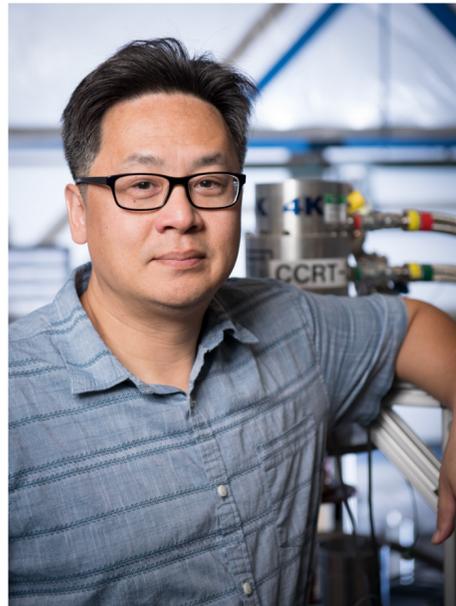
Vibrant Activity

- Since Snowmass 2013, the Cosmic Frontier has seen an explosion of exciting results and opportunities!
- Dark matter masses over 50 orders of magnitude are being seriously considered and we are finding new ways to probe them!
- Cosmological observations have entered the precision era, and tensions may hint at things to come!
- Astrophysical and astronomical probes have opened up new windows to learn about dark matter and dark energy!
- Gravitational waves and ultrahigh energy neutrinos have come online as a messenger with which we can study the Universe!
- New facilities are coming online, and offer unprecedented opportunities for new discoveries!



Cosmic Frontier: Organization

Conveners



Aaron Chou
Fermilab



Marcelle Soares-Santos
University of Michigan



Tim Tait
UC Irvine

Topical Subgroup & Conveners

Topical Group	Co-conveners			
CF1: Particle DM	Jodi Cooley SMU	Tongyan Lin UCSD	Hugh Lippincott UCSB	Tracy Slatyer MIT
CF2: Wavelike DM	Joerg Jackel Heidelberg	Gray Rybka UW	Lindley Winslow MIT	
CF3: DM Astro Probes	Alex Drlica-Wagner Fermilab	Chanda Prescod-Weinstein UNH	Haibo Yu UC Riverside	
CF4: DE & CA The Modern Universe	Jeff Newman Pittsburgh	Masao Sako U Penn	Anze Slosar BNL	
CF5: DE & CA Cosmic Dawn & Before	Clarence Chang ANL	Laura Newburgh Yale	Deirdre Shoemaker Georgia Tech	
CF6: Dark Energy Complimentarity	Chihway Chang Chicago	Brenna Flaugher Fermilab	David Schlegel LBNL	
CF7: Cosmic Probes	Rana Adhikari Caltech	Luis Anchordoqui CUNY	Ke Fang UW Madison	B.S. Sathyaprakash Penn State Kirsten Tollefson MSU

Liaisons with other Frontiers

- Community Engagement Frontier: Sijbrand de Jong
- Computational Frontier: Deborah Baird, Brian Yaney
- Energy Frontier: Caterina Doglioni
- Instrumentation Frontier: Kent Irwin, Hugh Lippincott
- Neutrino Frontier: Tali Figueroa-Feliciano, Yvonne Wong
- Rare & Precision Frontier: Susan Gardner
- Theory Frontier: Flip Tanedo
- Underground Facilities Frontier: Jodi Cooley, Hugh Lippincott
- Snowmass Early Career: Chelsea Bartram, Kristi Engel, Bibhushan Shakya

CF1: Dark Matter: Particle-Like

- Covers dark matter in the regime where it appears in experiments as individual quanta, rather than coherently via wave phenomena. Techniques to search for such particles include directly through its interactions with detector materials, indirectly from products of its annihilation, and via production at accelerators (primarily covered in other frontiers).
- **CF1 @ CPM**
 - 147 LOIs (the most of any topical group!)
- **Activities Going Forward**
 - Working group meetings will continue as necessary: <https://indico.fnal.gov/category/1193/>
 - Aim to convert the 147 LOIs into around 10 white papers.
 - Dedicated DM complementarity workshop early 2021.

CF2: Dark Matter: Wave-Like

- Covers low mass bosonic dark matter in the regime where it appears in experiments coherently via wave phenomena rather than as individual quanta. Examples include the QCD axion and more general axions, dark photons, and scalar dark matter. Current experimental techniques include broadband and resonant searches via cavities, circuit oscillators, NMR, utilizing low noise readout with quantum sensing and amplification technologies.
- **CF2 @ CPM**
 - More than 80 LOIs
- **Activities Going Forward**
 - Regularly scheduled working group meetings will continue.
 - Solicit white papers on specific topics based on the LOIs and discussion at the CPM, gathering further information/input in targeted discussions and town hall-style meetings as necessary.

CF3: Dark Matter: Cosmic Probes

- Covers properties of dark matter that can be uniquely probed by cosmological and astrophysical observations. Techniques include measurements of the cosmological distribution of dark matter, as well as studies of astrophysical objects in extreme environments. Examples of dark matter models probed through these techniques are warm dark matter, self-interacting dark matter, ultra-light axions, and primordial black holes.
- **CF3 @ CPM**
 - More than 70 LOIs
- **Activities Going Forward**
 - Monthly working group meetings with community will continue (cadence likely to increase after the CPM), as well as continuing biweekly mini-workshops.
 - Collect and digest community input from LOIs and CPM to build consensus on key questions and opportunities, work on contributed white papers, and work on CF3 report.
 - Participate in DM-focused meetings in January and beyond (complementarity). Also will use: Aspen Winter DM meeting organized by CPW.

CF4: Dark Energy and Cosmic Acceleration: Cosmic Probes

- Covers cosmic probes of cosmology in the Modern Universe, when galaxies are fully formed. These probes include galaxy clusters, galaxy clustering, redshift space distortions, gravitational lensing, baryonic acoustic oscillations, supernovae and more. Spectroscopic, broad-band and multi-wavelength surveys are examples of experiments that will be primarily discussed in this working group. Other examples include projects involving CMB, 21cm, and gravitational wave observations.
- **CF4 @ CPM**
 - 57 LOIs (many joint with CF6)
- **Activities Going Forward**
 - Continue biweekly discussions and presentations: https://snowmass21.org/cosmic/de_universe
 - Join efforts on common goals (post LSST of Rubin Observatory, GW standard siren modelling and follow up, redshift drift, intensity mapping, SN follow up, joint probes, massive spectroscopy, and others).
 - Condense community contributions into <57 white papers!

CF5: Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before

- Covers cosmic probes of cosmology in the early Universe from Inflation Era through the Cosmic Dawn. Subtopics include: growth of structure probes (e.g. 21cm power spectrum in the dark ages), probes of expansion history (e.g. BAO with black hole mergers, CMB), primordial non-gaussianity and inflation. High-z gravitational wave observatories, 21cm and CMB projects are examples of experiments expected to be primarily discussed here.
- **CF5 @ CPM**
 - More than 27 LOIs (many joint with other frontiers)
- **Activities Going Forward**
 - CF5 working group: R. Caldwell, C.L. Chang[†], D. Green, R. Hlozek, K. Huffenberger, D. Jacobs, A. Liu, M. Loverde, J. McMahon, L. Newburgh[†], M. Sakellariadou, D. Shoemaker[†]
 - Please contact working group members with questions.
 - Post-CPM, we will schedule a series of topical meetings between the CF5 working group and associated LOIs to discuss a roadmap forward.

CF6: Dark Energy and Cosmic Acceleration: Complementarity of Probes & New Facilities

- Covers the connections between probes across multiple axes including combined probes across the early/late time regimes, and plans for future observatories/facilities to maximize the science outputs for Dark Energy and Cosmic Acceleration physics. Discussions about multimessenger projects (including GW, and Neutrinos) and new physics opportunities not included in the early/late universe topics are also welcome here.
- **CF6 @ CPM**
 - More than 58 LOIs (directing GW and cosmic-ray focused ones to CF7)
- **Activities Going Forward**
 - Develop an overall picture of the landscape of proposed new facilities (in science goals, wavelength, scale of project etc.)
 - Connect LOI authors of similar interest, form smaller groups that could be in close contact going forward (white paper writing and/or responsible for subsections in the TG report).
 - Plans for future telecons/workshop (maybe with CF4/5/7).

CF7: Cosmic Probes of Fundamental Physics

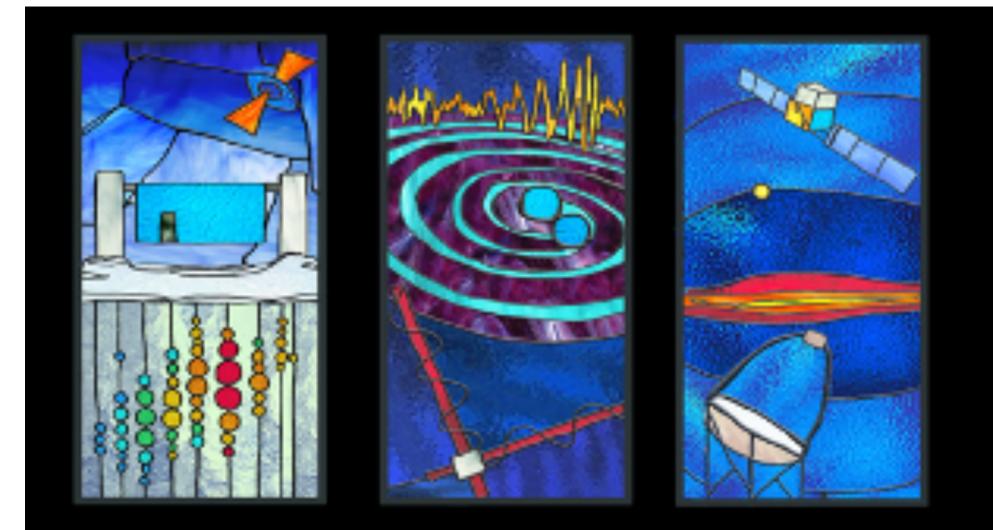
- Covers cosmic probes of fundamental physics topics beyond Dark Matter and Dark Energy using gravitational waves, cosmic rays, gamma rays, and neutrinos, as well as their combined studies to facilitate the multi-messenger science. This includes measurements of neutrino properties from cosmology (overlap with NF 5), tests of general relativity, emergent spacetime (overlap with CF2, 3, 5), black hole information with gravitational waves, the tension between local distance ladder measurements and cosmic microwave background estimates of the Hubble constant, equation of state of dense nuclear matter and hadron-quark gluon phase transitions, particle acceleration in astrophysical environments, bread-and-butter perturbative QCD and hadronic physics of extensive air showers, Lorentz Invariance Violation, search for evaporating primordial black holes, and exotic particles such as SUSY q-balls and axions.

- **CF7 @ CPM**

- 140 LOIs (spread across many messengers)

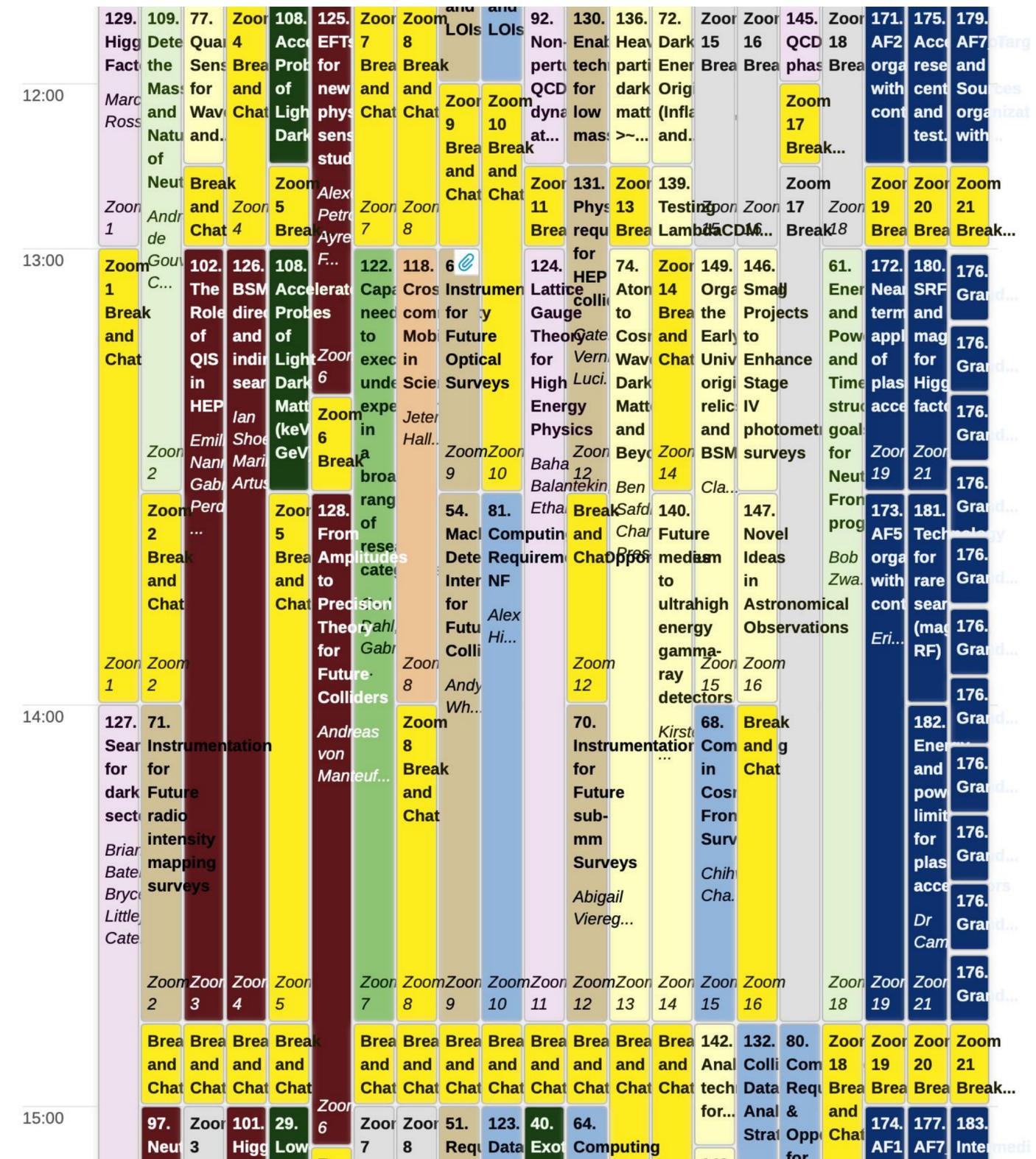
- **Activities Going Forward**

- Regularly scheduled working group meetings every week or two, including short talks; topic-focused meetings; and meetings to enable collaboration across experiments.
- Outline of topical group report in April 2021.



Cosmic Frontier at the CPM

- Great engagement with the Cosmic Frontier at the CPM!
- 30+ Joint sessions involving Cosmic Frontier topical working groups.
- Typically 100-200 attendees in each of the sessions with Cosmic Frontier participation.
- Thank you for this engagement — you are what will make CF activities at Snowmass 2021 into a success!



Cosmic Frontier plan (draft 0)

The plan for the Cosmic Frontier to prepare its report for Snowmass 2021 follows the general outline for the Snowmass process. **Topical working groups are now meeting biweekly or more frequently**, and there are weekly to biweekly meetings of the Cosmic Frontier conveners and liaisons to discuss issues as they arise. Each topical group will ultimately prepare a chapter of the final Cosmic Frontier report, aided by the relevant portions of the community according to the timeline:

- **October 2020:** The Community planning meeting will chart the overall direction for each working group, allow for planning with other frontiers concerns points of mutual interest.
- **October-January:** Topical groups will work with LOI authors to coordinate the studies needed to provide the input for their working group reports. **Each topical group will organize one-day zoom workshops as necessary.**
- **February to March 2021:** **Two Cosmic frontier-wide (virtual) meetings** will take place, to coordinate the material for the working group reports and harmonize topics across working groups.
- **May 2021:** Draft reports for each topical working group will be assembled, and discussed with the community via topical working group meetings.
- **July 2021:** The major findings will be presented at the Snowmass 2021 Summer Study meeting, and revised according to input from the community and updated results.
- **Fall 2021:** The final reports are due.

How to Get Involved

- All of the topical working groups are holding regular meetings to discuss their activities.
- Sign up for the email distribution lists, check out the relevant slack channels, and watch the google calendar for scheduled working group meetings.
- <https://snowmass21.org/cosmic/start>
- Even if you did not submit an LOI, you are welcome to join the discussion to participate in white papers, and to contribute to the topical working group reports.
- Taking part in the ongoing working group activities is the best way to contribute your thoughts to the final reports.