Conveners: Clarence Chang & Scott Dodelson

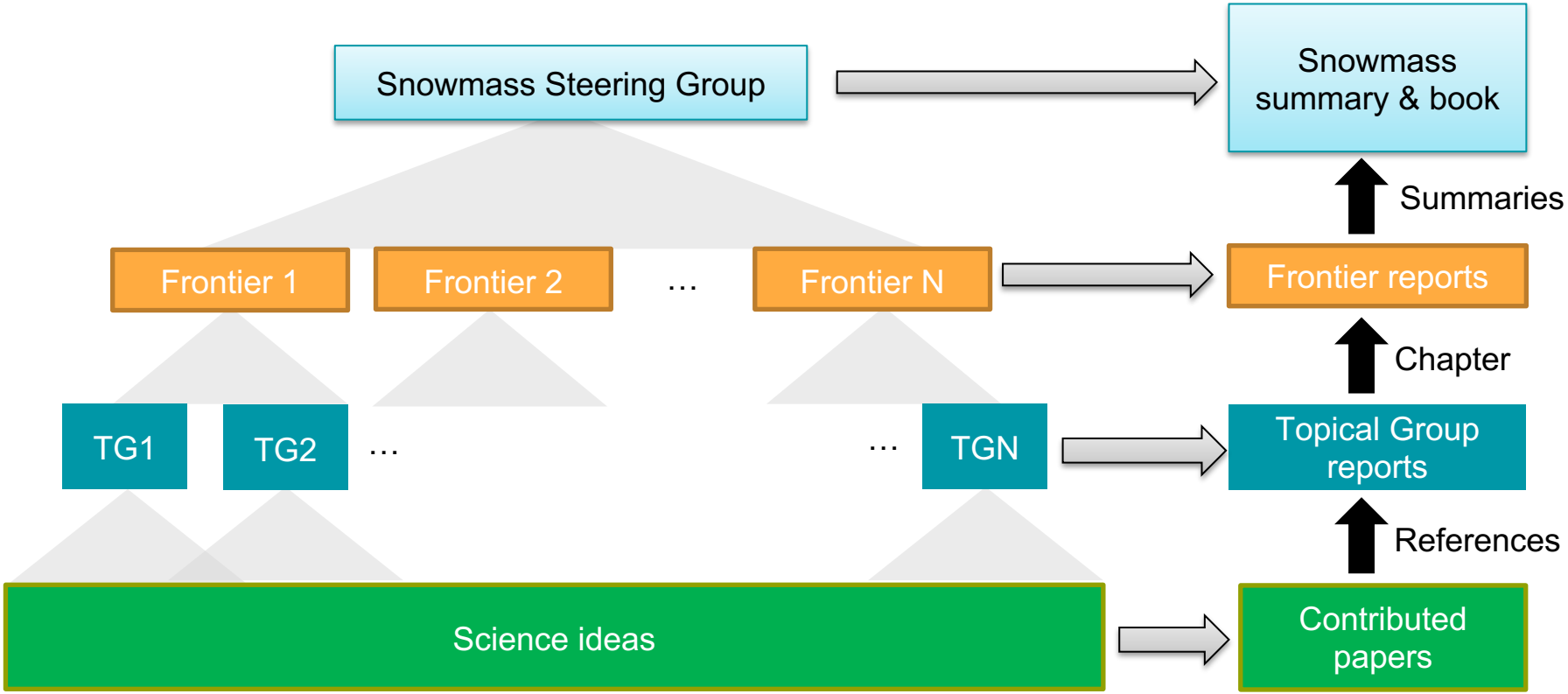
Snowmass leads into P5: Particle Physics Project Prioritization Process

- The equivalent of the Decadal Survey (i.e., P5's recommendations get translated into what gets funded and what does not) for all DOE High Energy Physics (LHC, LHC+, Fermilab, muons, theory, cosmic). So, there will be intense competition for funding.

- P5 in 2014 wrote: " Support CMB experiments as part of the core particle physics program. The multidisciplinary nature of the science warrants continued multiagency support." (This was new for DOE.) However, CMB-S4 is at the earliest stages (in the DOE process) of any project recommended by P5 in 2014.

- Very, very likely that the 2022-3 P5 will recommend CMB-S4 … but physics/cosmology has changed, and – in any event – it is important to articulate an updated science case for CMB-S4.

Snowmass21 organization: connecting science to reports



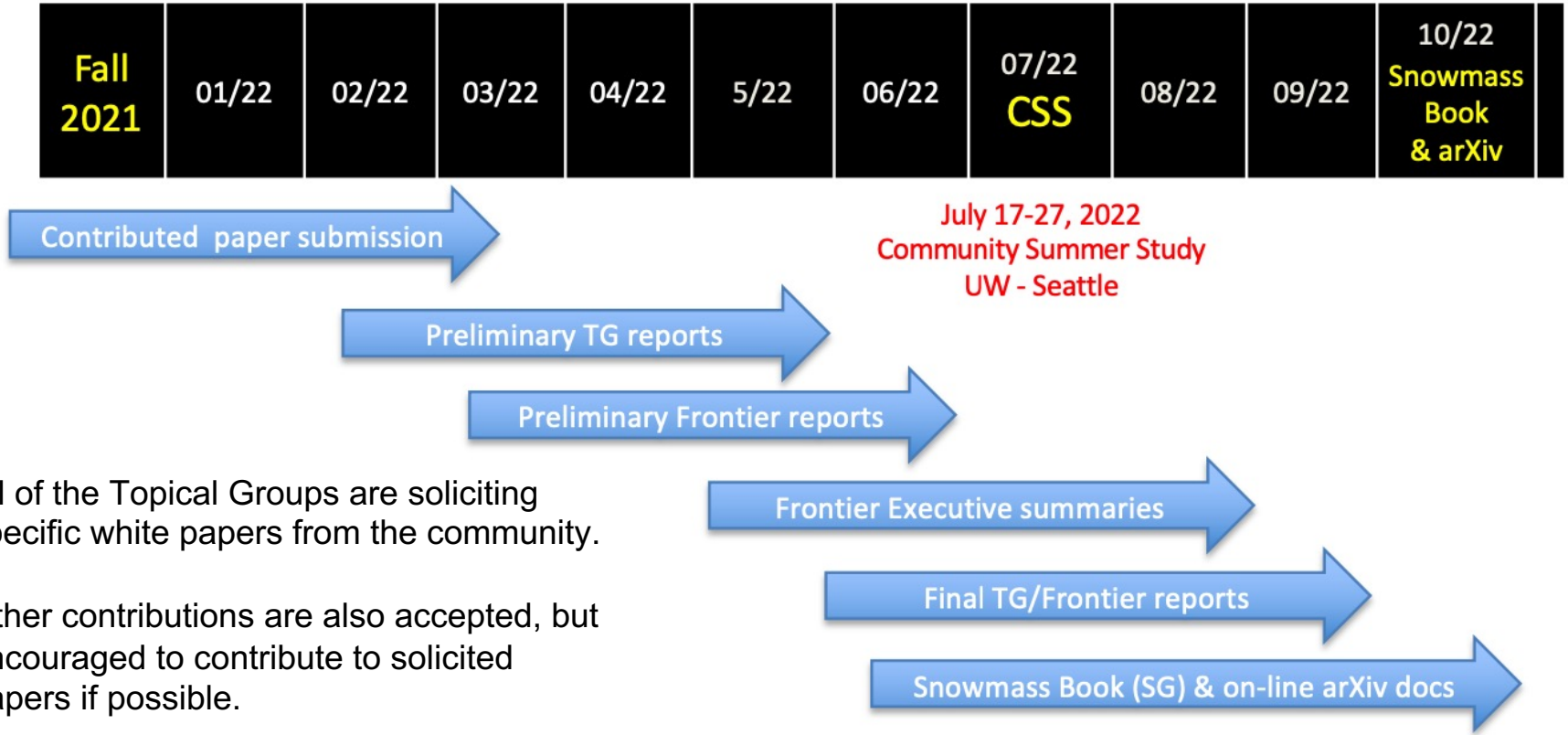
Overall Snowmass Structure

- Snowmass Frontiers
  - Energy Frontier
  - Neutrino Physics Frontier
  - Rare Processes and Precision
  - **Cosmic Frontier** →
  - **Theory Frontier**
  - Accelerator Frontier
  - Instrumentation Frontier
  - Computational Frontier
  - Underground Facilities
  - Community Engagement Frontier

- Each Frontier has subgroups (7 on average)

- CF1. Dark Matter: Particle-like
- CF2. Dark Matter: Wave-like
- **CF3. Dark Matter: Cosmic Probes**
- **CF4. Dark Energy and Cosmic Acceleration: The Modern Universe**
- **CF5. Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before**
- **CF6. Dark Energy and Cosmic Acceleration: Complementary Probes and New Facilities**
- **CF7. Cosmic Probes of Fundamental Physics**

Snowmass21 Timeline



All of the Topical Groups are soliciting specific white papers from the community.

Other contributions are also accepted, but encouraged to contribute to solicited papers if possible.

CF03 "Solicited" White Paper Topics

- **Dark matter physics from halo measurements** [#wp-cf03-dark_matter_halos]
  Dark matter physics from dark matter halos ranging from large-scale structure to sub-galactic scales.
  Facilitators: **Keith Bechtol, Simon Birrer, Francis-Yan Cyr-Racine, Katelin Schutz**
- **Primordial Black Holes & Gravitational Waves** [#wp-cf03-dark_matter_pbh_gw]
  Primordial black holes as dark matter and probes of inflation (joint with CF7?)
  Facilitators: **Andrea Albert, Simeon Bird, Will Dawson**
- **Numerical simulations and systematics** [#wp-cf03-dark_matter_sims]
  Importance of numerical simulations for extracting dark matter physics (joint with CompF2?)
  Facilitators: **Arka Banerjee, Annika Peter, Ferah Munshi**
- **Connecting dark matter to early universe physics** [#wp-cf03-dark_matter_early_universe]
  Light relics, 21cm (EDGES), etc. (joint with CF5 & TF9?)
  Facilitators: **Kim Boddy, Cora Dvorkin, Vera Gluscevic, Julian Muñoz**
- **Dark matter physics in extreme astrophysical environments** [#wp-cf03-dark_matter_xtreme]
  Includes stellar interiors, neutron stars, non-primordial black holes (joint with TF9?)
  Facilitators: **Masha Baryakhtar, Regina Caputo, Djuna Croon, Kerstin Perez**
- **Facilities for cosmic probes of dark matter physics** [#wp-cf03-dark_matter_facilities]
  Proposed facilities for cosmic probes of dark matter including MSE, MegaMapper, CMB-HD, etc.
  Facilitators: **Ting Li, Josh Simon, Sukanya Chakrabarti, Neelima Sehgal**

Large N_{linear}: [Anze, Martin, Simone] -- overlap with static sky of "joint analysis WP"

- Implies large volume, high z
- Target Science (e.g. Martin White + Simone Ferraro Paper z>2 paper):
  - Inflation
  - Parameters
  - Neutrinos
  - Expansion history, Early Dark Energy
- DESI-2, MegaMapper, MSE
- Later: PUMA, CO Line Intensity Mapping

Large nP: [K Dawson, Heitmann, Hearin]

- Implies low-z, smaller sky area
- Target Science:
  - Dark Matter Physics
  - Modified Gravity
  - Small Scale primordial power spectrum?
  - Primordial field recovery (?)
  - Unknown physics from a very rich dataset
- DESI-2, MegaMapper, MSE with a different strategy
- Later: ATLAS

High precision in Astrophysics [A Gonzalez, S Chakrabarti, M Pierce]

- Large spectroscopic precision
- Large astrometric precision
- Target Science:
  - Direct expansion measurements
  - Dark Matter Physics
  - Modified Gravity
  - GW, multi-messenger
- … list expts

Enabling flagship experiments to reach their potential: [Jeff, Peter N, Alex K, Dickinson M (ELT)] -- overlap with transient sky of "joint analysis WP"

- Many needs: spare fibers + smaller facilities for bright targets; small-area programs with next gen telescopes/instruments; deep high-multiplex spectroscopy
- Target Science:
  - Supernova follow-up + peculiar velocities
  - Strong lens follow-up
  - Photometric Redshift training and calibration
  - Intrinsic Alignment constraints
  - Galaxy cluster studies

Theory

- Inflationary science through non-gaussianity, primordial features & B-modes with Dan Green, Marilena Loverde
- Light relics with Dan Green, Marilena Loverde, Renee Hlozek
- BSM Cosmology (e.g. early universe phase transitions) with Robert Caldwell
- Beyond Standard Cosmology (e.g. cosmological low/high-z cosmology) with Robert Caldwell, Renee

Measurement

- Stochastic GW Background with Robert Caldwell, Deirdre Shoemaker
- 21cm (PUMA, “Cosmic Dawn Array”) with Adrian Liu, Danny Jacobs, Laura Newburgh
- Mm-wave LIM with Clarence Chang, Adrian Liu, Jeff McMahon
- CMB (e.g. CMB-HD, CMB from ground & space) with Kevin Huffenberger, Clarence Chang
- Optical Survey (e.g. Megamapper) with Laura Newburgh & Clarence Chang

Community volunteers

CF6 “Solicited” White Paper Topics

- **Joint-analysis of Static Probes** [overleaf] [notes] [#wp-cf06-static-probes]
  Importance of joint analysis in static (large-scale structure) probes.
  Facilitators: Andrew Hearin, Eric Baxter, Chihway Chang

- **Joint-analysis of Transient Probes** [overleaf] [notes] [#wp-cf06-transient-probes]
  Importance of joint analysis in transient (time-domain) probes.
  Facilitators: Maria Elidaiana, Alex Kim, Antonella Palmese

- **Collaboration Structure for Joint Analysis** [overleaf] [notes] [#wp-cf06-collaboration]
  Importance of substantial change in funding and collaboration model for joint analysis.
  Facilitators: Jason Rhodes, Brenna Flaugher

- **New Facilities:** Currently we do not plan to have an overall white paper for new facilities, but rather to summarize facility white papers across CF in the report
  - CF3 has solicited a paper on new facilities [#wp-cf03-dark_matter_facilities]
  - CF7 has a GW facility paper

Proposed Community White Papers

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** - led by CF7

3. **Fundamental physics and beyond the Standard Model**: Tests of general relativity, the nature of black holes, exotic objects (gravastars, boson stars, fuzz balls, etc.), Scalar GWs

4. Cosmology: (joint with CF3, CF1 & ?) - 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.

   (C) Paper 3 - Phase transitions in the early Universe

      I. Complementarity between collider and GW signatures of first order electroweak phase transitions

      II. Probing Fundamental Physics using the Stochastic Gravitational Wave Background from the Early Universe

      III. Correlating Stochastic Gravitational Wave Background with Electromagnetic Observations

Solicited White Papers:

Inflation and Connections to Formal Theory (with TF01): Liam McAllister and Eva Silverstein

Data Driven Cosmology: Raphael Flauger, Marilena LoVerde, Annika Peter, Mark Vogelsberger, and Risa Wechsler

Early Universe Model-Building (with TF08): David Curtin, Eric Kuflik, Yonit Hochberg, Neal Weiner, and Keisuke Harigaya

Indirect Detection: Mariangela Lisanti, Georg Raffelt, Kim Boddy, Christoph Weniger, Nick Rodd, and Sam McDermott

Theory Meets the Lab: Rouven Essig, Yoni Kahn, Simon Knapen, Peter Graham, Andreas Ringwald, and Natalia Toro

Effective Field Theories for Cosmology (with TF02): Mehrdad Mirbabayi and Marko Simonovic

Cosmological Bootstrap (with TF03/04): TBD

Physics & cosmology have changed, and – in any event – it is important to articulate an updated science case for CMB-S4.

Context: There is now a Fiducial Model of cosmology (LCDM) as well as a Standard Model of particle physics. Many scientists feel that neither is complete or even correct, but it has proven very difficult to disprove either of these or to find new physics.

- Hints of Tension: g-2, H_0, ..
- Dark Energy: w = -1 within a few percent. There remain many precision tests of LCDM (e.g., P(k,z)); this is similar to precision tests of the SM
- Dark Matter: The WIMP paradigm is being squeezed, opening up a vast landscape of possibilities. Depending on your tastes, this may be very exciting or sound similar to particle physicists advocating for larger collider to find new particles with N theories, each of which predicts something different.
- Theoretical developments in the importance of N_{eff}
- New exciting cosmic messengers (GW, HE neutrinos, multi-messenger)
- Second Quantum Revolution
- AI

SD's personal opinions, formed in part by the discussion yesterday

Physics & cosmology have changed, and – in any event – it is important to articulate an **updated science case** for CMB-S4.

Context: There is now a Fiducial Model of cosmology (LCDM) as well as a Standard Model of particle physics. Many scientists feel that neither is complete or even correct, but it has proven very difficult to disprove either of these or to find new physics. ***Much of the exciting science that will emerge from CMB-S4 is clearly outside the scope of DOE.***

1. Hints of Tension: g-2, H_0, ..
2. Dark Energy: w = -1 within a few percent. There remain many precision tests of LCDM (e.g., P(k,z)); this is similar to precision tests of the SM
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4. Theoretical developments in the importance of N_{eff}
5. New exciting cosmic messengers (GW, HE neutrinos, multi-messenger)
6. Second Quantum Revolution
7. AI

Clearly, inflation still a key science driver.

Make a strong case for N_{eff} . (4)

How much should the case emphasize looking for cracks in the LCDM egg (1,2)?

How much of the case rests on DM (3)?

Do you want to advocate for 5,6,7 becoming more of a part of the DOE program?

SD's personal opinions, formed in part by the discussion yesterday

Theory ←→ Cosmic Frontier

- Sense that 2014 P5 report not strong enough
- Also, theorists work on CMB-S4 (and get dinged for it)
- Dan Green is co-convening one of the TF09 – Astroparticle physics and cosmology -- in Snowmass

An Opportunity to Make Your Individual Voice Heard

Take the Survey HERE

- Encourage full HEPA community to participate in survey
- Deadline of **August 15th (~1 week left)**!
- Collects opinions & experiences across
  - Careers
  - Physics Outlook
  - Workplace Culture
  - Harassment/Racism
  - Visa Policies
  - COVID-19
  - Demographics
- Fermilab News Article
- Any questions? Suggestions? Ping us at SNOWMASS21-SURVEY@fnal.gov

Snowmass Day: September 24, 2021
CSS@UW-Seattle: July 17-27, 2022

Visit the Snowmass 2021 webpage to learn about Frontiers, white papers, and SEC!

We hope to see you on the #welcome-to-snowmass Slack channel!