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Highlights from Snowmass (with some Swedish bias)

CATERINA DOGLIONI - UNIVERSITY OF MANCHESTER & LUND UNIVERSITY

@CATDOGLUND, SHE/HER HTTP://WWW.HEP.LU.SE/STAFF/DOGLIONI/

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What is Snowmass?

SnowMass2021

- Organised by the Division of Particles and Fields (DPF) of the American Physical Society
  - involving the **particle physics community**
    e.g. high energy, intensity and cosmic communities
- Snowmass goals:
  - to work on / collect **new scientific studies**, mostly concerning future directions for the field
  - to **engage** the community and junior scientists
  - to prepare a **vision** for the **future of US particle physics**

- The vision is taken by the Particle Physics Project Prioritization Panel (P5) as **input to a 10-year strategic plan**

The P5 website: https://www.usparticlephysics.org/p5/

The P5 process, slides by chair H. Murayama

P5 science drivers from Snowmass 2013

- Use the **Higgs boson** as a new tool for discovery
- Pursue the physics associated with **neutrino mass**
- Identify the new physics of **dark matter**
- Understand cosmic acceleration: **dark energy and inflation**
- Explore the unknown: **new particles, interactions, and physical principles"**

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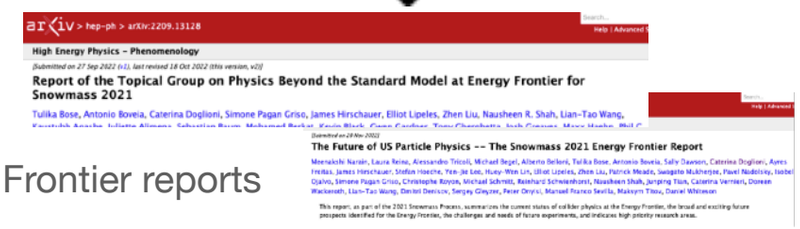
Organisation and process

see https://snowmass21.org

- Huge field and huge number of people! Also a multi-year effort, end of 2020 - end of 2022
- Organised in 10 *Frontiers*
  - Accelerator, Cosmic, Community Engagement, Computing, Energy, Instrumentation, Neutrino, Rare Processes and Precision Measurements, Theory, Underground + Snowmass Young (for early career input)
- Each Frontier has 5-10 Topical Groups
  - Example for Energy Frontier: *Higgs properties and coupling, BSM Higgs, Heavy Flavor and top physics, EW precision physics, Precision QCD, Hadronic structure and forward QCD, Heavy ions, Model-specific BSM, General BSM explorations, dark matter at colliders*
- Frontier and Topical Group conveners tasked with asking for and summarising **community input:**
  - >1500 letters of intent → 450 **whitepapers**
    - Summarised in **Topical Group reports**
      - Summarised in **Frontier reports**
        - Summarised in **Snowmass summary**
          - Summarised in **Snowmass executive summary**

Everything is available in the Snowmass Book: https://www.slac.stanford.edu/econf/C210711/

Some papers Lund Master's students have worked on (there are more!)



Final Topical Group and Frontier reports

Overall summary of high-level recommendations

All recommendations in the Snowmass summary, this is a summary of the summary of J. Butler's talk at Pheno2023

- Continue seeking answers to questions identified in the 2013 science drivers
  - Adding a possible new driver: *flavor as a tool for discovery*
- Support project portfolio w/**breadth and balance of physics topics, experiment sizes** and **timescales**
- Critical to support **completion** of existing experiments and operations (**DUNE, HL-LHC**)
- Support all research programs and what is connected to its entire lifecycle
  - from **blue-sky R&D** to **directed R&D** (in accelerator, detectors and computing) to **tools**
- Support **formal theory/phenomenology** and connect to experiment
- **Engage** with external but related communities (policy makers, broader society, educators)
- Support **career development** to retain the diverse talent pool needed for our success
- Promote **diversity, equity and inclusion** and improve **outreach & engagement**

- *The next few slides: brief highlights from the executive summary of each Frontier that could be interesting to researchers presenting at Fysikdagarna2023 (but also a personal choice given the time…)*

Survey of large future projects endorsed by the Frontiers

Decadal Overview of Future Large-Scale Projects		
Frontier/Decade	2025 - 2035	2035 -2045
Energy Frontier	U.S. Initiative for the Targeted Development of Future Colliders and their Detectors	
		Higgs Factory
Neutrino Frontier	LBNF/DUNE Phase I & PIP- II	DUNE Phase II (incl. proton injector)
Cosmic Frontier	Cosmic Microwave Background - S4 Spectroscopic Survey - S5*	Next Gen. Grav. Wave Observatory* Line Intensity Mapping*
	Multi-Scale Dark Matter Program (incl. Gen-3 WIMP searches)	
Rare Process Frontier		Advanced Muon Facility

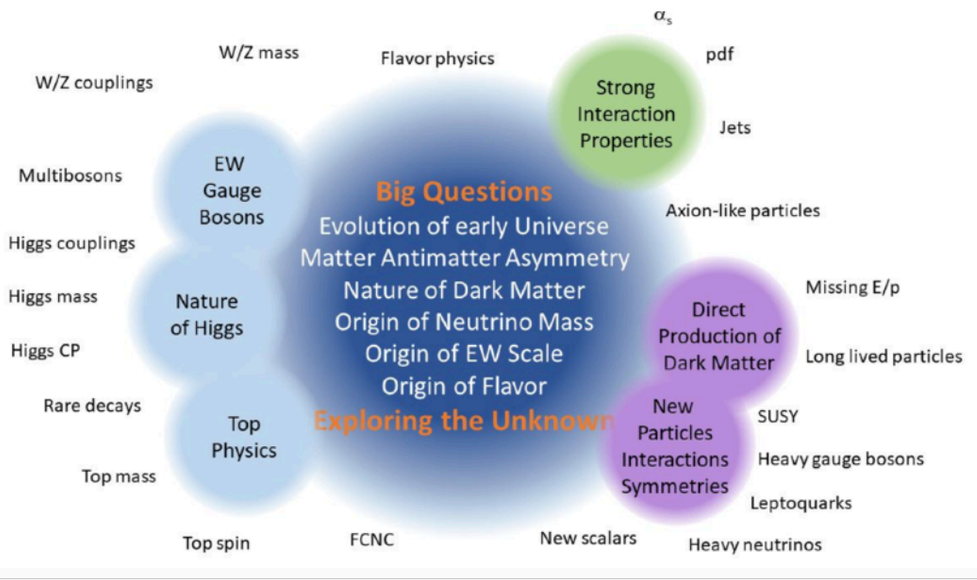
Table 1-1. *An overview, binned by decade, of future large-scale projects or programs (total projected costs of $500M or larger) endorsed by one or more of the Snowmass Frontiers to address the essential scientific goals of the next two decades. This table is not a timeline, rather large projects are listed by the decade in which the preponderance of their activity is projected to occur. Projects may start sooner than indicated or may take longer to complete, as described in the frontier reports. Projects were not prioritized, nor examined in the context of budgetary scenarios. In the observational Cosmic program, project funding may come from sources other than HEP, as denoted by an asterisk.*

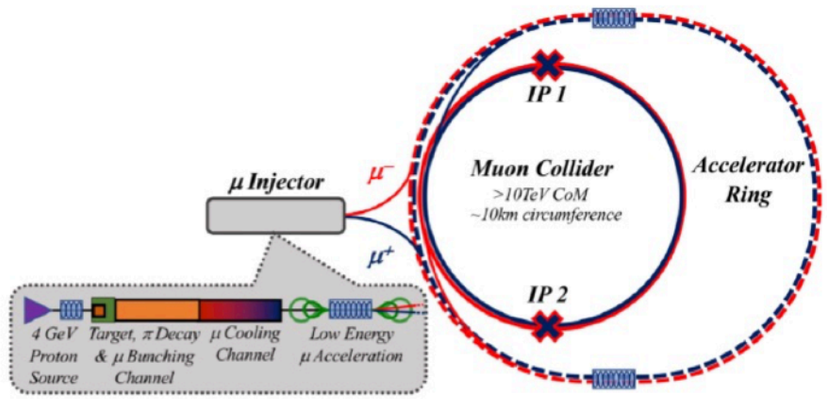
Examples of some of the projects prioritized in the Snowmass 2013/P5 2014 process: LBNF/DUNE, Muon g-2, ATLAS Upgrade, CMS Upgrade, Vera Rubin Observatory (plus other projects, big and small)

Highlights from the accelerator/energy frontier

L. Reina, Energy Frontier highlights @ CSS

- The next big project after HL-LHC (fully supported) should be a Higgs factory
  - J. Butler: many technologies acceptable - e.g. **FCC-ee,** ILC, CLIC, or new US-located Cool Copper Collider (C3)
  - must resolve hosting and funding issues around 2028 to get construction start before 2030
- On a longer timescale, build/host a multi-TeV scale collider for broader SM/BSM explorations
  - **FCC-hh** to be developed after Higgs factory
  - New: US-located **muon collider, 6-8 TeV CoM**
  - Both require significant R&D / feasibility studies, including more refined physics cases towards detectors
    - Personal take: one significant feasibility driver will be: "*can we make the energy needs of physics programs at a future collider as energy efficient as possible*"?





Highlight from ~~the cosmic/theory~~ all frontiers: dark matter

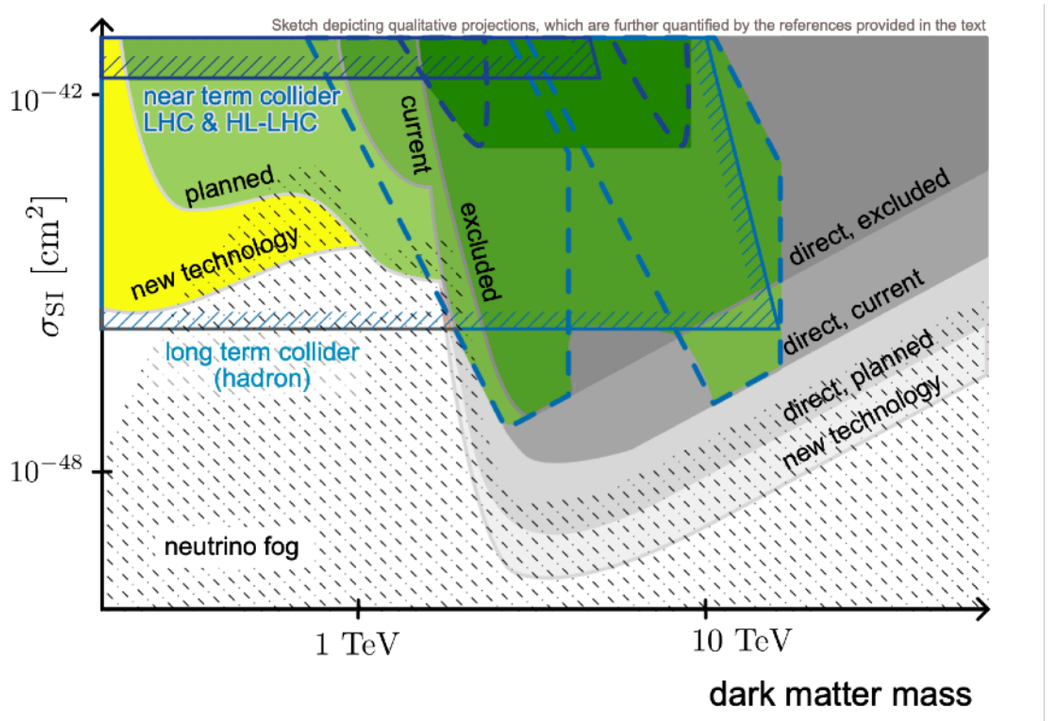
- Fundamental shift in how we think about DM searches: many more experiments and theories!

- Dark matter crosses **every** frontier
  - Also, the most used word in LOIs
    https://gordonwatts.github.io/snowmass-loi-words

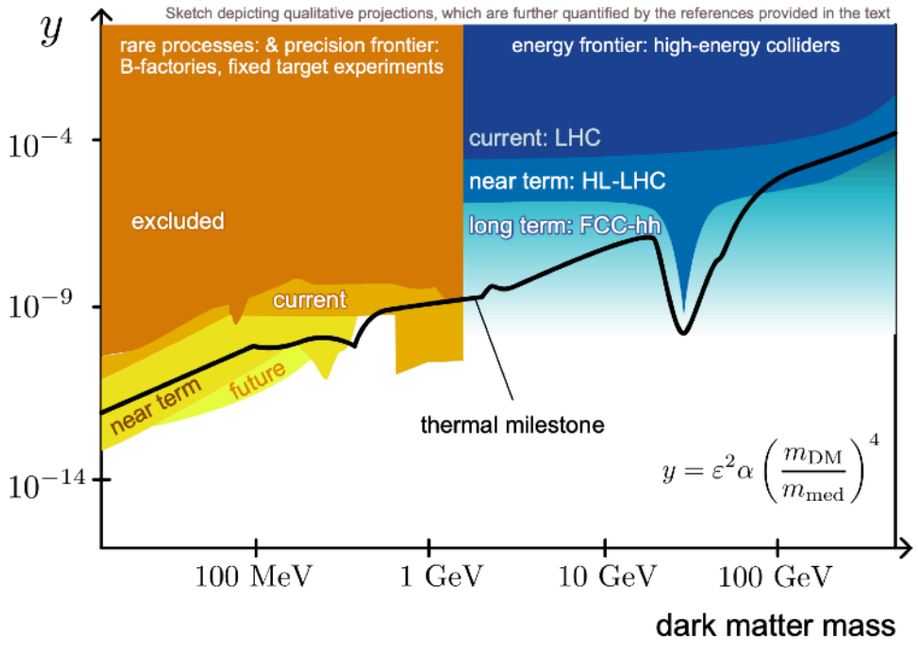
- **exciting exploratory phase** with new ideas implemented on short timescales alongside **deployment of large-scale projects** with increased sensitivity precision
  - *this includes many experiments with Swedish leadership and contributions*

- These considerations led to writing the **Snowmass dark matter complementarity report: https://arxiv.org/abs/2210.01770**
  - advocating support for theory and multiple experiments (rather than competition on who has better sensitivity)

WIMP DM: y axis is nucleon-DM cross section

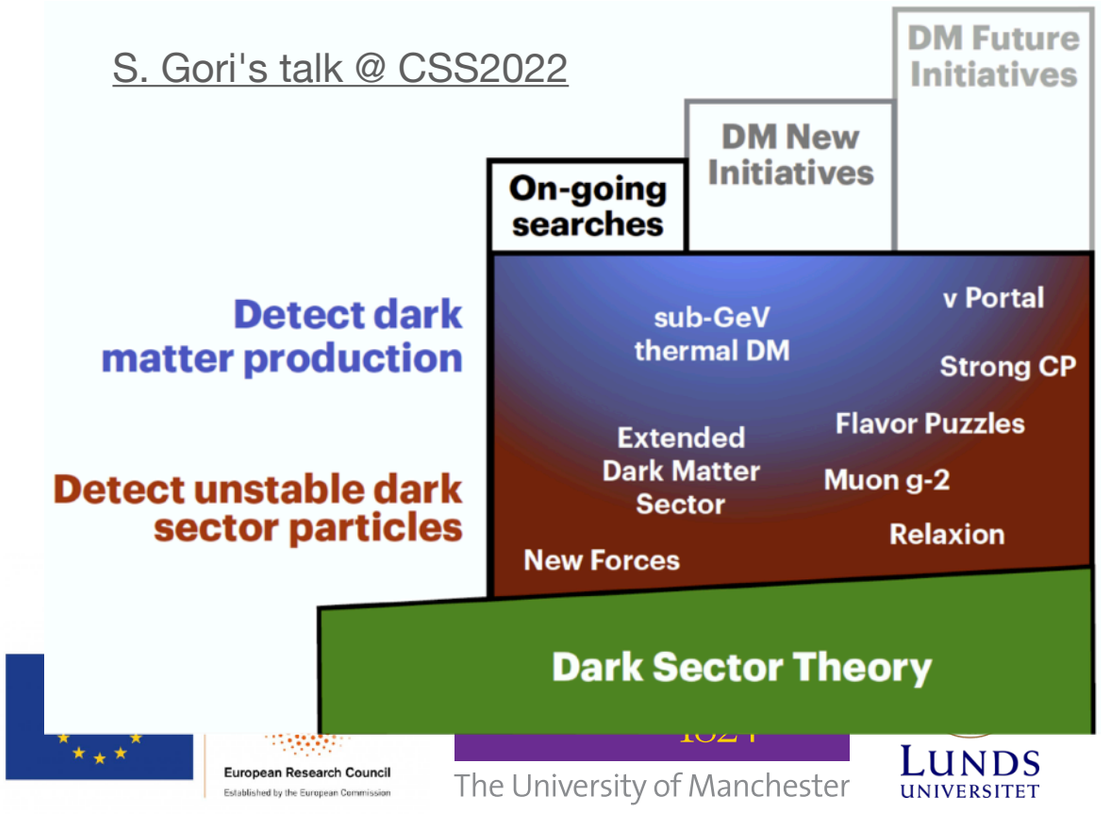


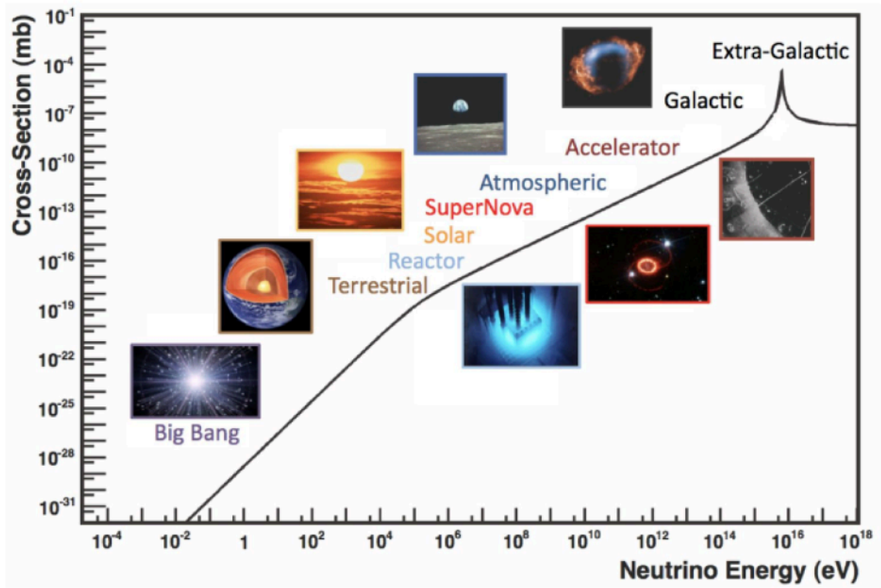
Dark photon mediated DM: y axis is proportional to interaction strength



Highlights from the rare&precision / neutrino frontiers

- Rare Processes and Precision Frontier
  - Identified science drivers/experiments: flavour (e.g. **LHCb upgrades**), precision tests of properties and symmetries (e.g.) dark sectors (e.g. **LDMX**)
  - new: proposal for a “muon campus” (muon facility) at Fermilab, synergistic with muon collider development



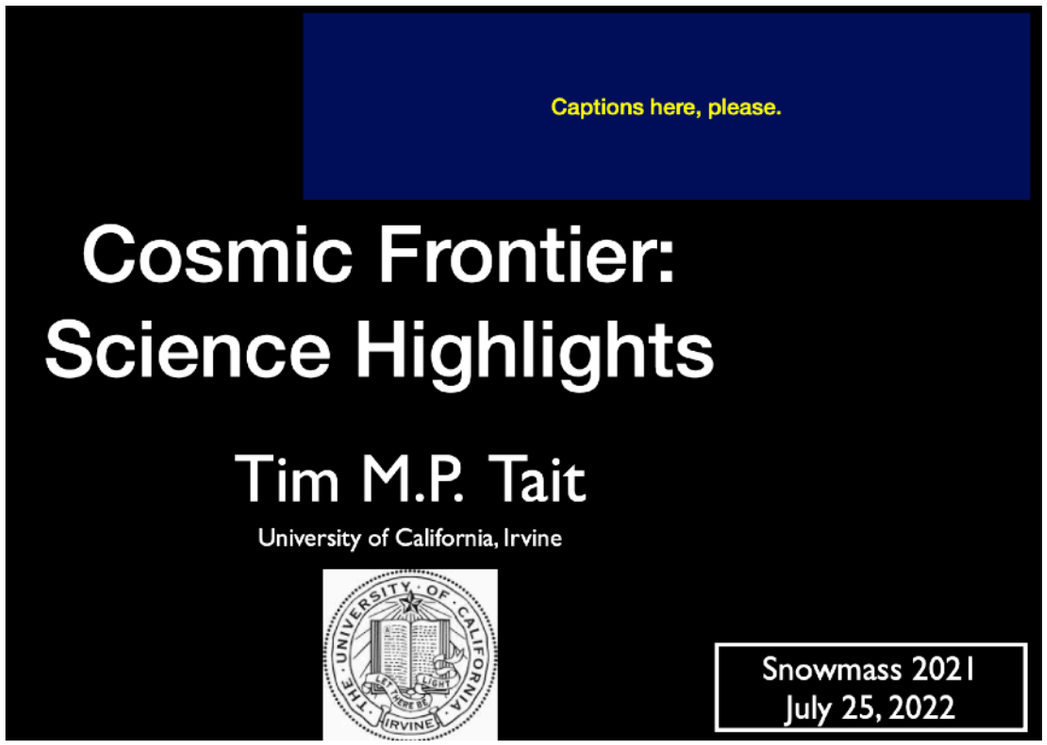


- Neutrino Frontier: Neutrino Frontier Summary Report
  - Identified science drivers/experiments: Measurements of neutrino properties (e.g. DUNE) alongside neutrinos as discovery tools and messengers (e.g. **IceCube**)
  - Strong synergies in beams and instrumentation (underground and overground) - e.g. **ESSvSB**, Forward Physics Facility

Highlights from Community Engagement Frontier

- Community Engagement Frontier (with many contributions from Early Career / diverse members of the community)
  - We must take a **cohesive and strategic approach** towards diversity, equity in collaboration with funding agencies and universities → specific suggestions in 11.4.8 of report
  - This is of strategic importance: enabling a better work environment means better talent attracted/retained in the field and in turn better results!

Small steps: make sure everyone *can* follow your talk



An example recommendation (personal experience: Sweden is already better than other countries regarding this point…)

- All community affiliates should reject harmful rhetoric and behavior related to work-life balance. This includes "ideas around 'lone geniuses', the need for unhealthy work schedules, and the idea that sacrifice of personal wellness demonstrates your commitment to science" [18]. Senior scientists are responsible to ensure that they are managing their time and the time of those in their group properly to respect work-life balance (including reducing meetings outside of working hours, or rotating meetings to accommodate varying time zones) [18].

Going forward after Snowmass

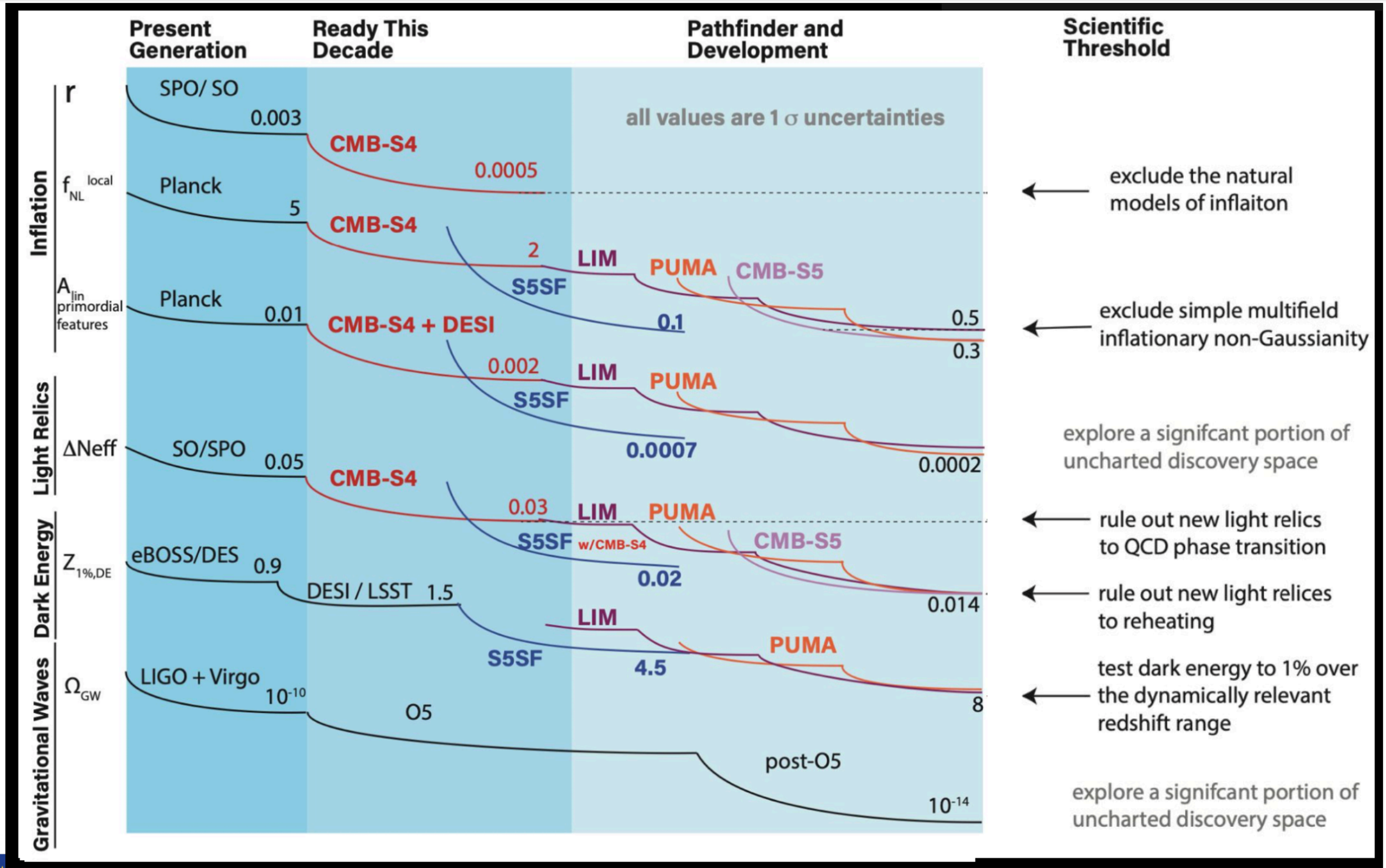
- 2023: Town Halls (in person/virtual) organised by P5
  - discussions on inputs from Snowmass
  - “open mic” sessions (anyone can contribute)
  - Next virtual Town Hall, June 26th, focused on small experimentsacross frontiers
- As a community, we need to take stock of diversity & inclusion recommendations to build for a healthy future
  - it starts with us (as allies if not personally affected) and propagates up!
- Work is ramping up on future projects
  - Physics studies, but also educating future particle & astroparticle physicists
  - Suggestion: work on the future with your Master’s students!

Thank you for your attention!

Snowmass participants at the Community Summer Study in Seattle, summer 2022

T. Tait, Cosmic Frontier science highlights

More highlights from the cosmic frontier: cosmological probes



A. Al Khadri, Theory Frontier highlights

More highlights from the theory frontier

HEP Theory

unifies the frontiers of particle physics

lays the foundations for future experiments

connects to gravity, cosmology, astrophysics nuclear physics, condensed matter, AMO, computer science, statistics, data science, mathematics

Fundamental Theory

Phenomenology

interconnected scientific ecosystem closely aligned with experiment

Computational Theory

central to the motivation, analysis, and interpretation of experiments

advances our understanding of Nature in regimes that experiment cannot (yet) reach

responsive:
propose new directions based on data
propose/guide new experiments
develop new analysis tools

incorporates new perspectives (QI, ML) and computational technologies to extend the boundaries of our knowledge