# SNOWMASS COSMIC FRONTIER

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Conveners

# P5 QUESTIONS FOR THIS TALK

1. What are the main messages? This should not be just a list of projects, nor should it be a repeat of the Snowmass and HEPAP presentations (you can assume the panel is already quite familiar with all those). Instead, in just a few slides, please summarize the primary goals for this area, and, to the extent possible, the emerging strategy and vision of how the pieces fit together, within this area, as well as across particle physics, over time.

2. What, if anything, did Snowmass miss (from this area or any area), e.g., a physics case, project, opportunity, strategy...?

3. What do you see as the main issues and decisions emerging from Snowmass that you anticipate P5 addressing? Please try to be specific about the issues and the options
    A. Do you have any suggestions how P5 might proceed to resolve these issues?
    B. What, if any, additional information do you think would be necessary for resolving each of these issues?

4. Anything else that should be conveyed?

# PROGRESS SINCE SNOWMASS AND HEPAP

**All working group summaries are now complete and publicly available**

- Cosmic Frontier Summary (with links to all the rest)
  http://www-public.slac.stanford.edu/snowmass2013/SnowmassWorkingGroupReports.html

- CF1: WIMP Dark Matter Direct Detection (Priscilla Cushman, Cristian Galbiati, Dan McKinsey, Hamish Robertson, Tim Tait) 1310.8327 [hep-ex]
  - A: Status and Science Case (Dan Bauer)
  - B: Defining the Parameter Space (Tim Tait)
  - C: Enabling Technology and Infrastucture (Bob Jacobsen)

- CF2: WIMP Dark Matter Indirect Detection (Jim Buckley, Doug Cowen, Stefano Profumo) 1310.7040 [astro-ph.HE]

- CF3: Non-WIMP Dark Matter (Alex Kusenko, Leslie Rosenberg) 1310.8642 [hep-ph]

- CF4: Dark Matter Complementarity (Dan Hooper, Manoj Kaplinghat, Konstantin Matchev) 1310.8621 [hep-ph]

# PROGRESS SINCE SNOWMASS AND HEPAP

- CF5: Dark Energy and CMB (Scott Dodelson, Klaus Honscheid) 1309.5386 [astro-ph.CO]
  - A: Distances (Alex Kim, Nikhil Padmanabhan) 1309.5382 [astro-ph.CO]
  - B: Growth of Cosmic Structure (Dragan Huterer, David Kirkby) 1309.5385 [astro-ph.CO]
  - C: Cross-Correlations (Jason Rhodes, David Weinberg) 1309.5388 [astro-ph.CO]
  - D: Novel Probes of Gravity and Dark Energy (Bhuvnesh Jain) 1309.5389 [astro-ph.CO]
  - E: Inflation Physics from CMB and Large Scale Structure (John Carlstrom, Adrian Lee) 1309.5381 [astro-ph.CO]
  - F: Neutrino Physics from CMB and Large Scale Structure (Kev Abazajian, John Carlstrom, Adrian Lee) 1309.5383 [astro-ph.CO]
  - G: Dark Energy Facilities (David Weinberg) 1309.5380 [astro-ph.CO]

- CF6: Cosmic Particles and Fundamental Physics (Jim Beatty, Ann Nelson, Angela Olinto, Gus Sinnis) 1310.5662 [hep-ph]
  - A: Cosmic Rays, Gamma Rays and Neutrinos (Gus Sinnis, Tom Weiler)
  - B: The Matter of the Cosmological Asymmetry (Ann Nelson)
  - C: Exploring the Basic Nature of Space and Time (Aaron Chou, Craig Hogan)

# WHAT ARE THE MAIN MESSAGES?

- Experiments at the Cosmic Frontier provide clear evidence of physics beyond the Standard Model, and there is great promise for continued, fast-paced progress on key questions for our field
  - What is dark matter?
  - What is dark energy?
  - What are the properties of neutrinos?
  - What is the physics of inflation?
  - Why is there more matter than antimatter?
  - What is the physics of the Universe at the highest energies?

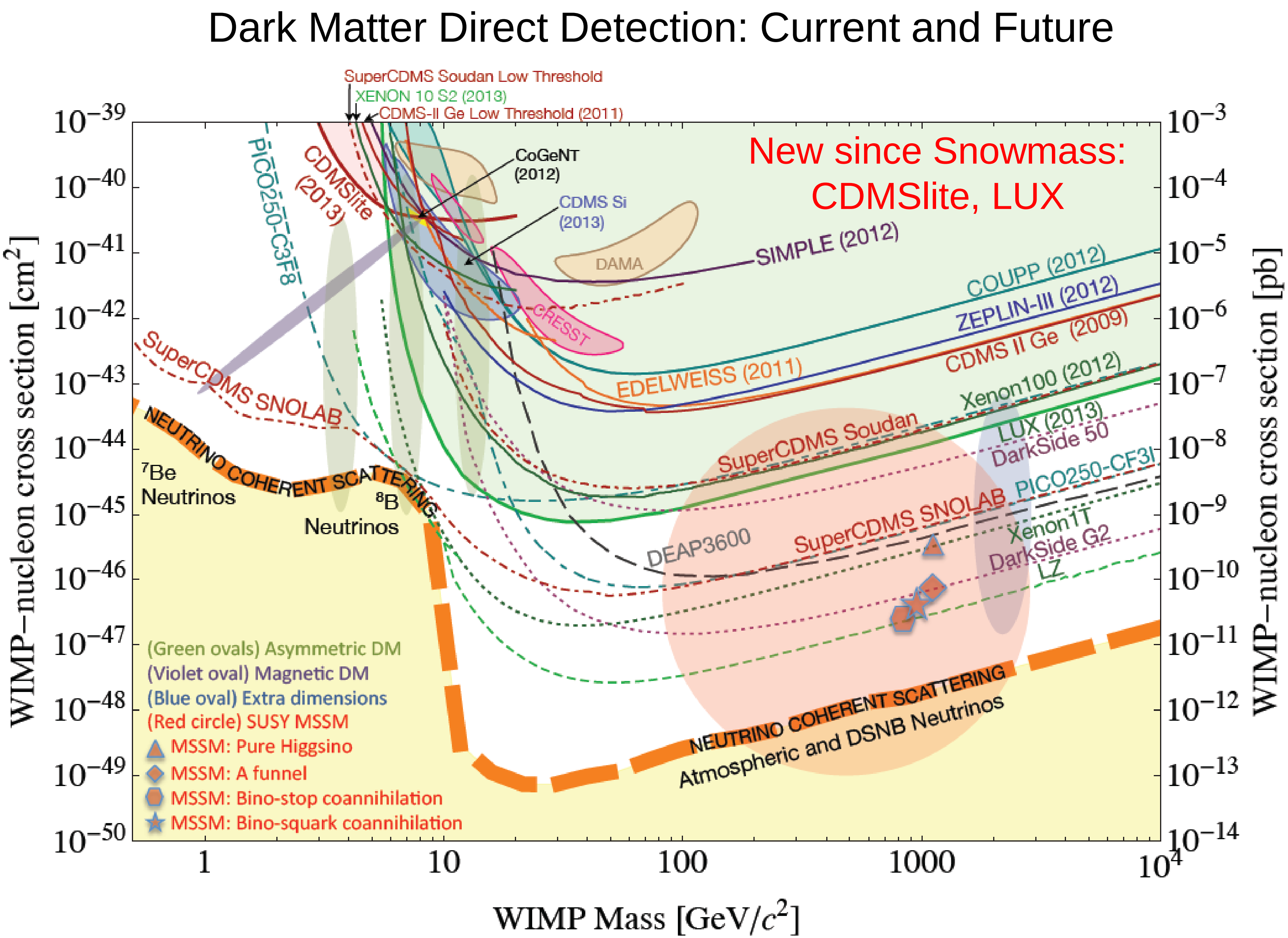
- In most cases, projects address more than one of these key topics.  Many topics cross Frontiers (dark matter, neutrinos, baryon asymmetry, ultrahigh-energy cosmic rays,…).

# WHAT ARE THE MAIN MESSAGES?

| Exp/Question | DM | DE | ν | Inflation | Highest Energies |
|---|---|---|---|---|---|
| Direct G2/G3 | ✔ | | | | |
| Non-WIMP (Axion,…) | ✔ | | | | |
| CTA | ✔ | | | | ✔ |
| PINGU | ✔ | | ✔ | | |
| ARIANNA/ARA | | | | | ✔ |
| GAPS | ✔ | | | | |
| CMB G3/G4 | ✓ | ✓ | ✔ | ✔ | |
| DESI | ✓ | ✔ | ✔ | ✓ | |
| LSST | ✓ | ✔ | ✔ | ✓ | |
| UHECR Experiments | | | | | ✔ |
| Theory | ✔ | ✔ | ✔ | ✔ | ✔ |

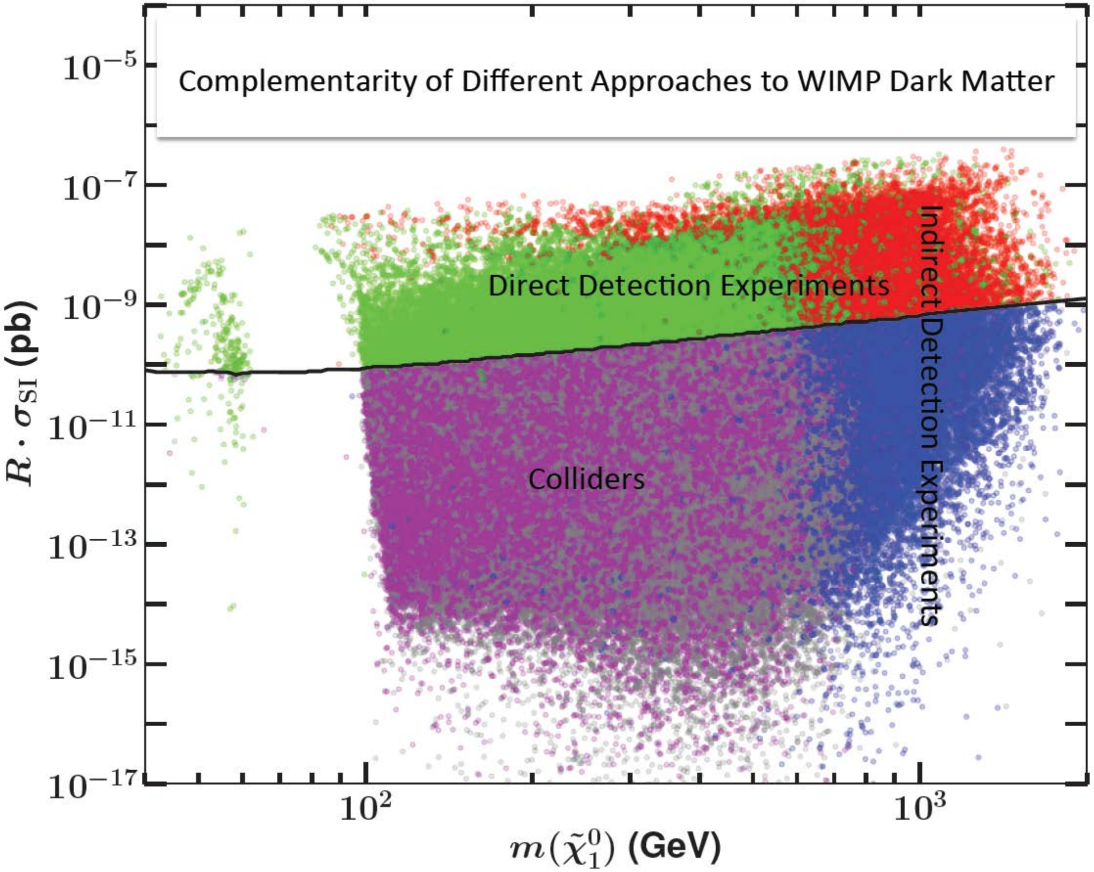
…and understanding the baryon asymmetry is a long-term research goal, involving detailed interplay among all the frontiers and theory.

# A VERY SMALL SAMPLE OF RESULTS FROM THESE SUMMARIES



# DARK MATTER COMPLEMENTARITY

pMSSM 19-parameter scan of SUSY parameter space

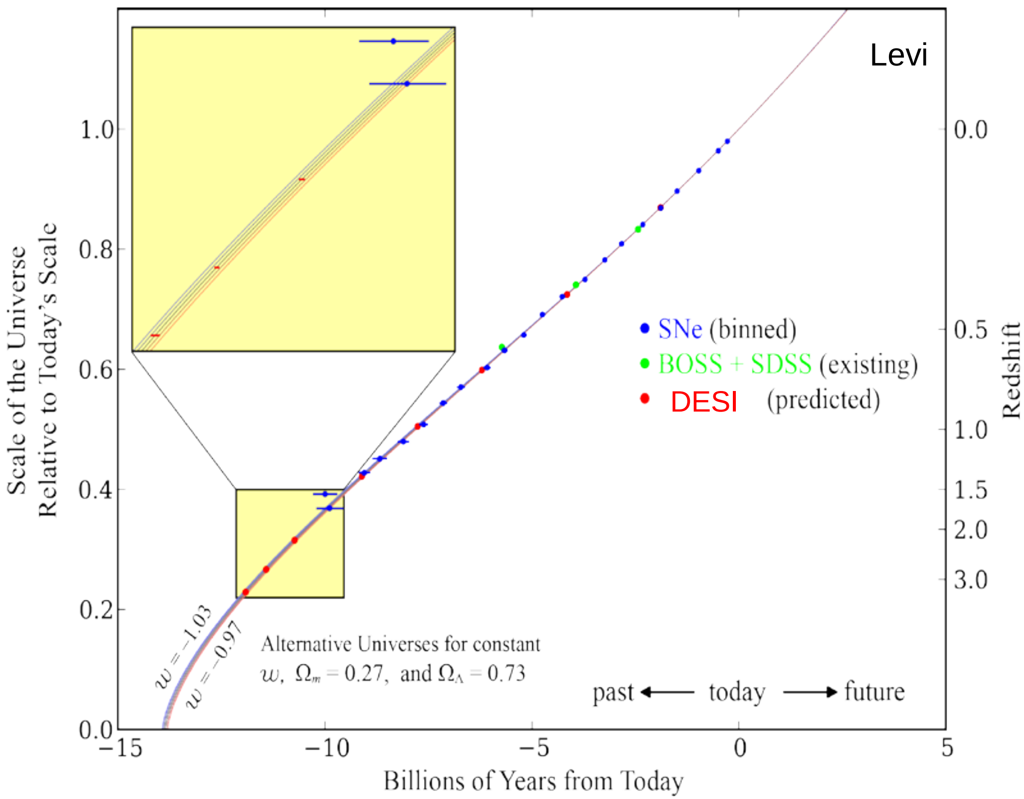


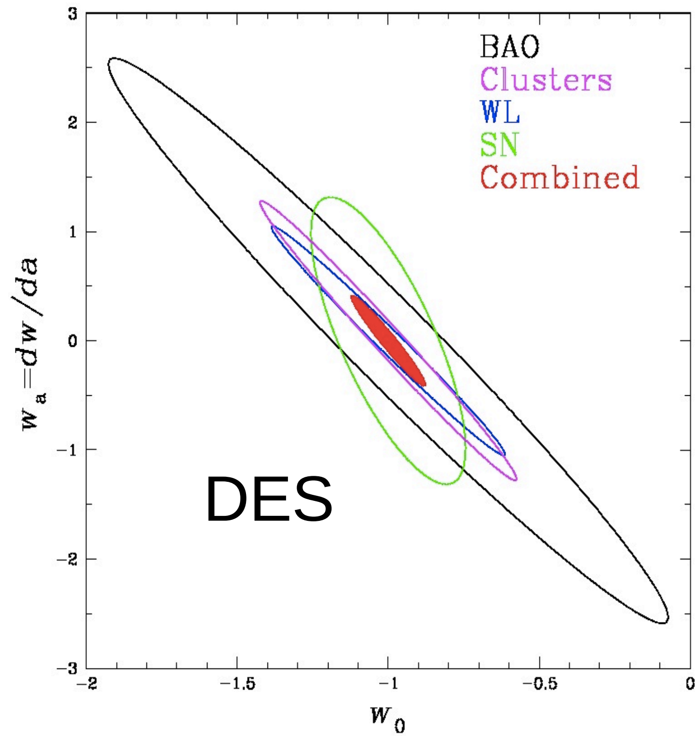

Cahill-Rowley et al. (2013)

- Complementarity for SUSY models; also for DM effective theories
- Many promising approaches to dark matter, and any compelling signal will have far-reaching implications

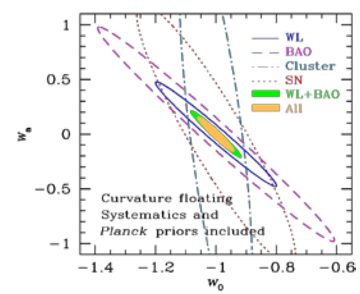
# PRECISION DARK ENERGY

- Stage III and Stage IV will take us into the era of precision dark energy, with stringent constraints on $w_0$, $w_a$



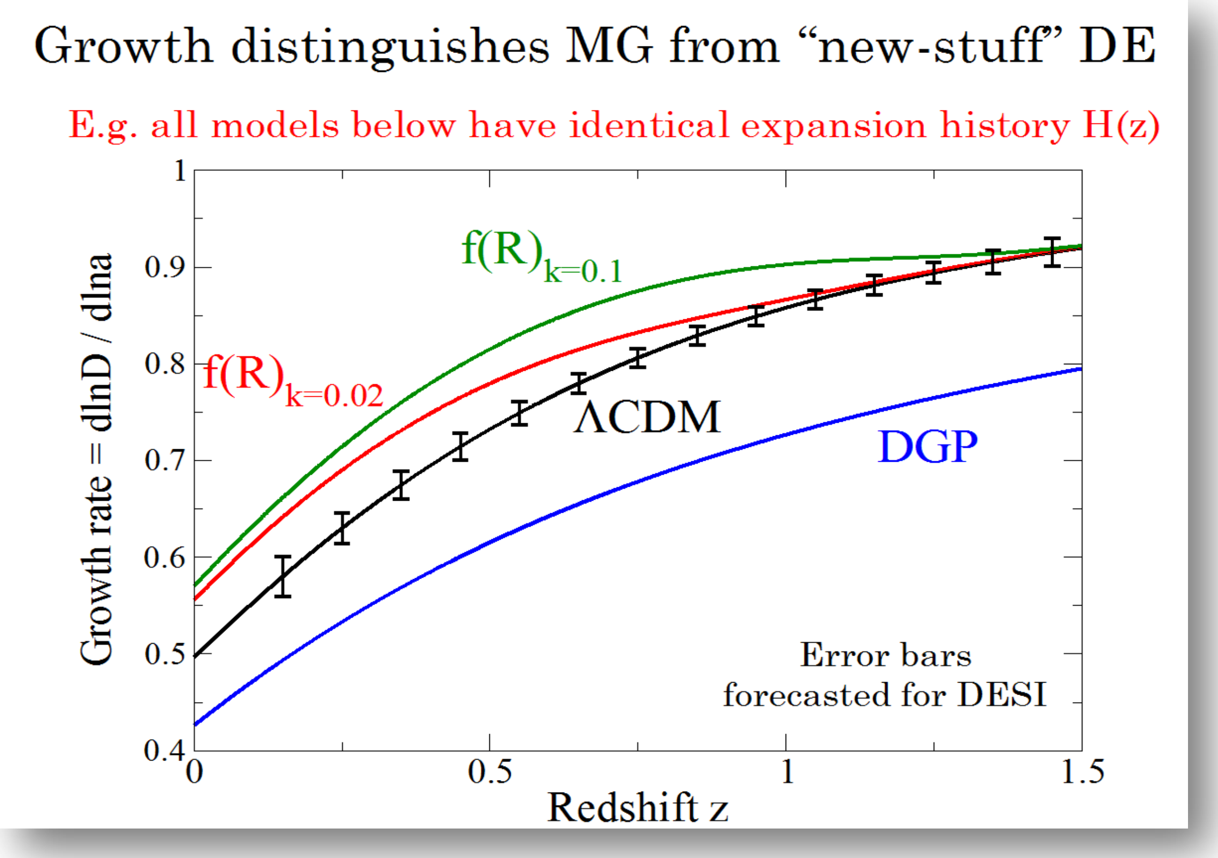




LSST

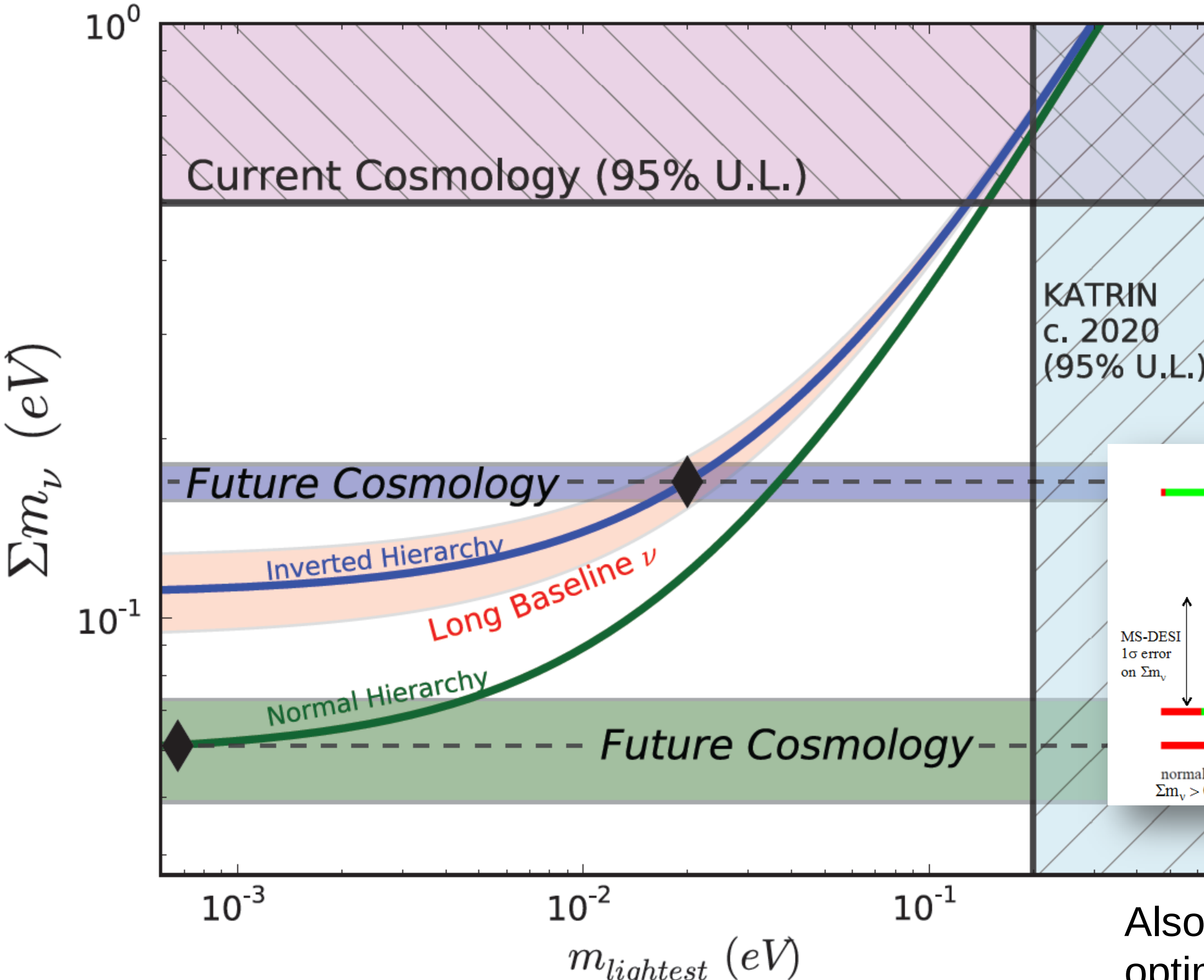


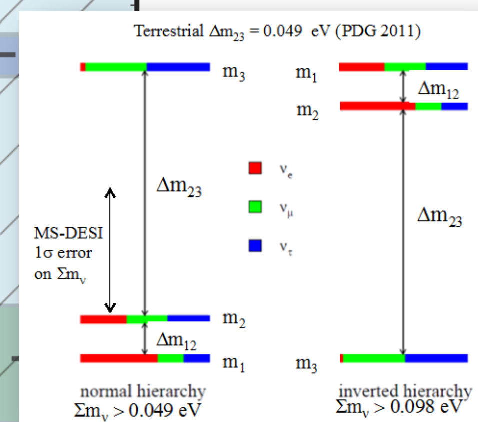
# BEYOND ($w_0$, $w_a$): TESTING GENERAL RELATIVITY

Modified gravity can be distinguished from dark energy: tests over a large range of distances and cosmic time using both spectroscopic and imaging surveys.



# NEUTRINO COSMOLOGY PROSPECTS




Cosmic Surveys

CMB with imaging and spectroscopic surveys

Also PINGU design is optimized to resolve the mass hierarchy

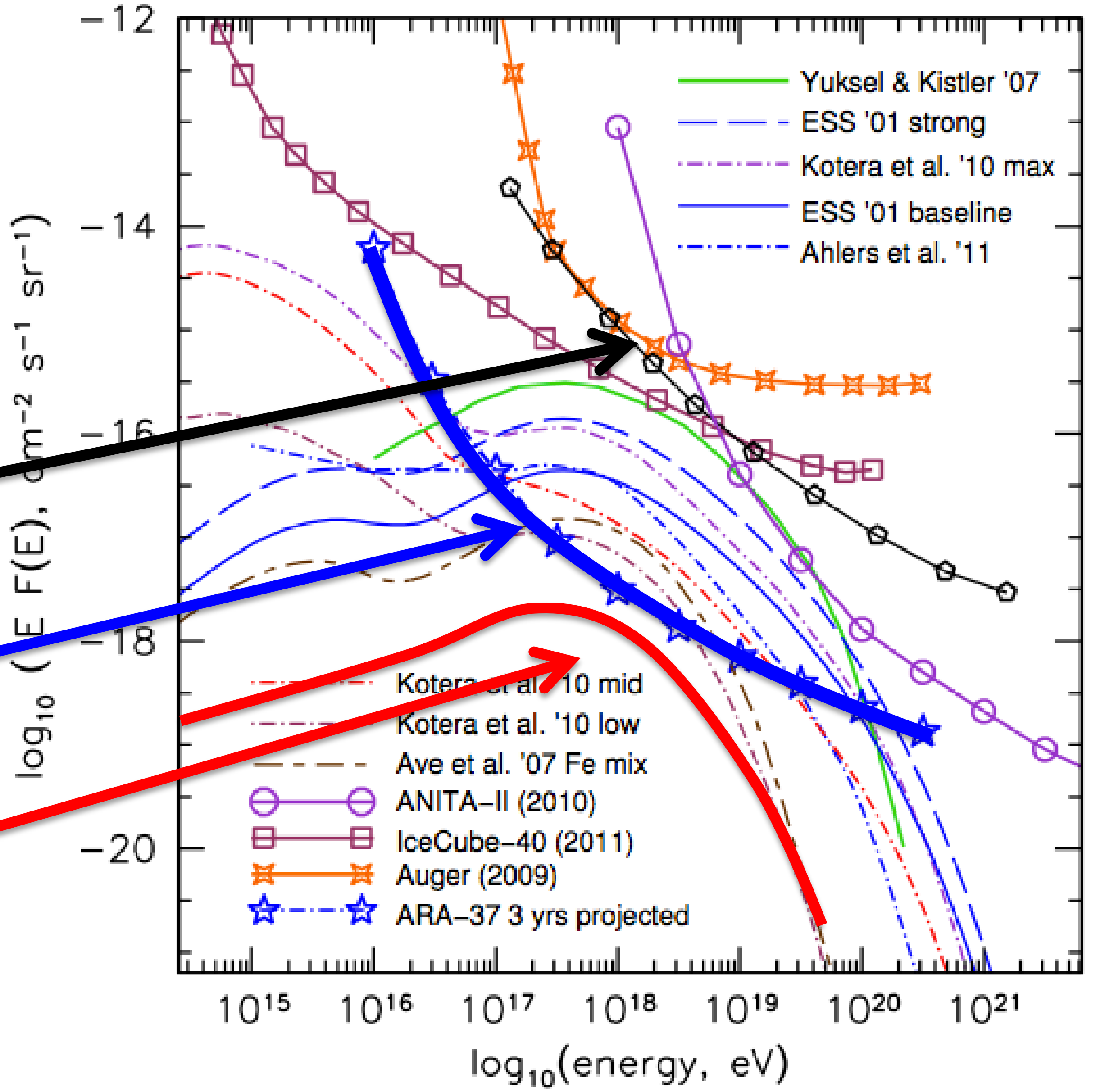
# GZK NEUTRINO PROSPECTS: ARIANNA, ARA

$$p + \gamma_{cmb} \rightarrow \Delta^+$$
$$\rightarrow n + \pi^+$$
$$\rightarrow \mu^+ + \boxed{\nu_\mu}$$
$$\rightarrow e^+ + \boxed{\bar{\nu_\mu} + \nu_e}$$

**Current Limits**

**Next Generation**

**Flux Lower Limit**



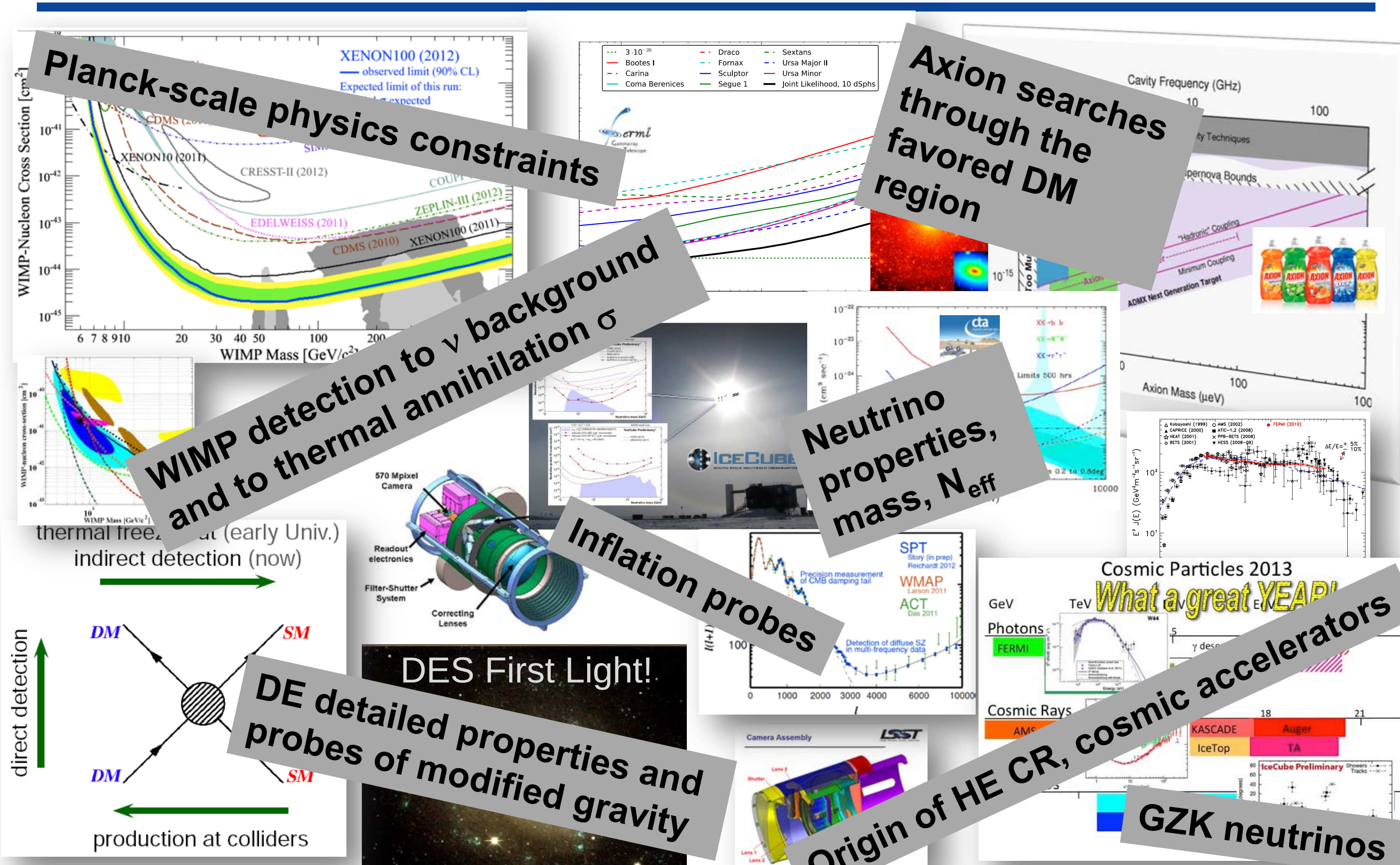
# WHAT DID SNOWMASS MISS?

- Snowmass did not address all potential Cosmic Frontier topics, such as gravitational waves
- Snowmass fostered many inter-Frontier and cross-Frontier conversations, but, as always, more would have been better (for example, on the topic of neutrino properties)
- Coherent international planning was considered, but not emphasized
- Prioritization (by design!)

# MAIN EMERGING ISSUES FOR P5 TO ADDRESS

- Dark Matter
  - Direct Detection: A discovery could occur at any time. Important to press forward with G2 implementation and G3 planning.
  - Indirect Detection: Next large-scale project is Cerenkov Telescope Array (CTA). Leadership has moved from the U.S. to Europe, and the project addresses topics in both astronomy and particle physics. Must determine U.S. scope and U.S. particle physics scope.
- CMB
  - Generations 3 and 4 have great relevance to particle physics. Progress requires significant particle physics program involvement, changing the paradigm.
- Overall
  - The list of excellent projects exceeds the available budget.

# THE COSMIC FRONTIER MENU




Activities at the Cosmic Frontier are marked by rapid, surprising, and exciting developments

# ANYTHING ELSE TO CONVEY?

- **Together with the other Frontier areas**, the Cosmic Frontier provides to particle physics
  - Clear evidence for physics beyond the Standard Model
  - Profound questions of popular interest
  - Frequent new results, surprises, with broad impacts
  - Large discovery space with unique probes
  - Important cross-frontier topics
  - Full range of project scales, providing flexible programmatic options
  - U.S. leadership