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

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Two White papers submitted to CF6:

- ”Opportunities from Cross-survey Analyses of Static Probes”, Eric J. Baxter, Chihway Chang, Andrew Hearin, Jonathan Blazek, Lindsey E. Bleem, et al. arXiv:2203.06795.

- ”Multi-Experiment Probes for Dark Energy – Transients“, Alex G. Kim, Antonella Palmese, Maria E. S. Pereira, Greg Aldering, Felipe Andrade-Oliveira, et al. arXiv:2203.11226.

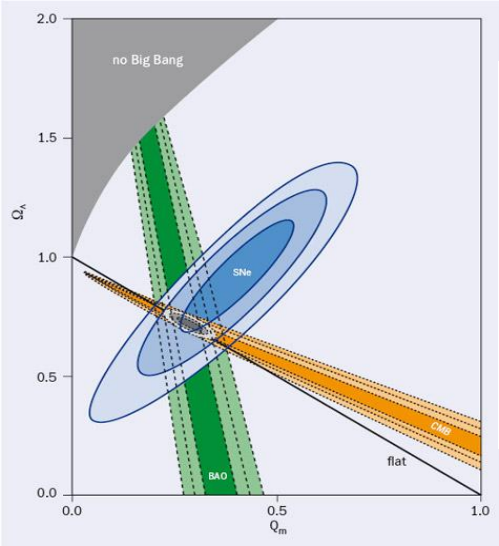
Many facilities motivated and discussed in CF1-7 white papers for example:

- “Observational Facilities to study Dark Matter” arXiv:2203.06200
- ”CMB-S4 White Paper” arXiv:2203.08024
- ”The Sanford Underground Research Facility”, arXiv:2203.08293
- ”A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics”, arXiv:2203.02309
- ”Rubin Observatory after LSST”, arXiv:2203.07220
- ”CMB-HD White Paper”, arXiv:2203.05728
- ”Future Gravitational-Wave Detector Facilities”, arXiv:2203.08228

Guidance is that Snowmass reports should focus on science motivation

**Old** way of thinking the infrastructure (**2203.06795**)

- Independent & Isolated Surveys
- In house analysis & simulations
- Proprietary data kept secret for years
- Uncoordinated choices in modeling syst.
- Duplication of effort (waste of $$)



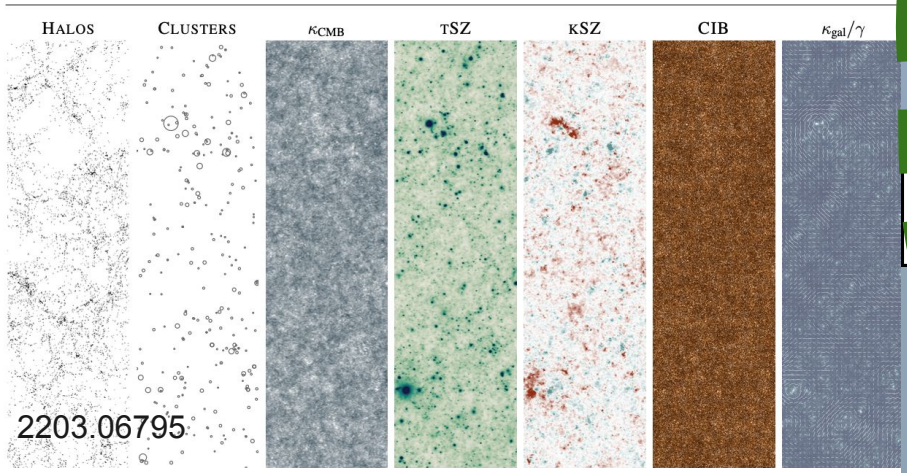

Joint analyses happen only in the cosmological parameter space (just stack likelihoods)

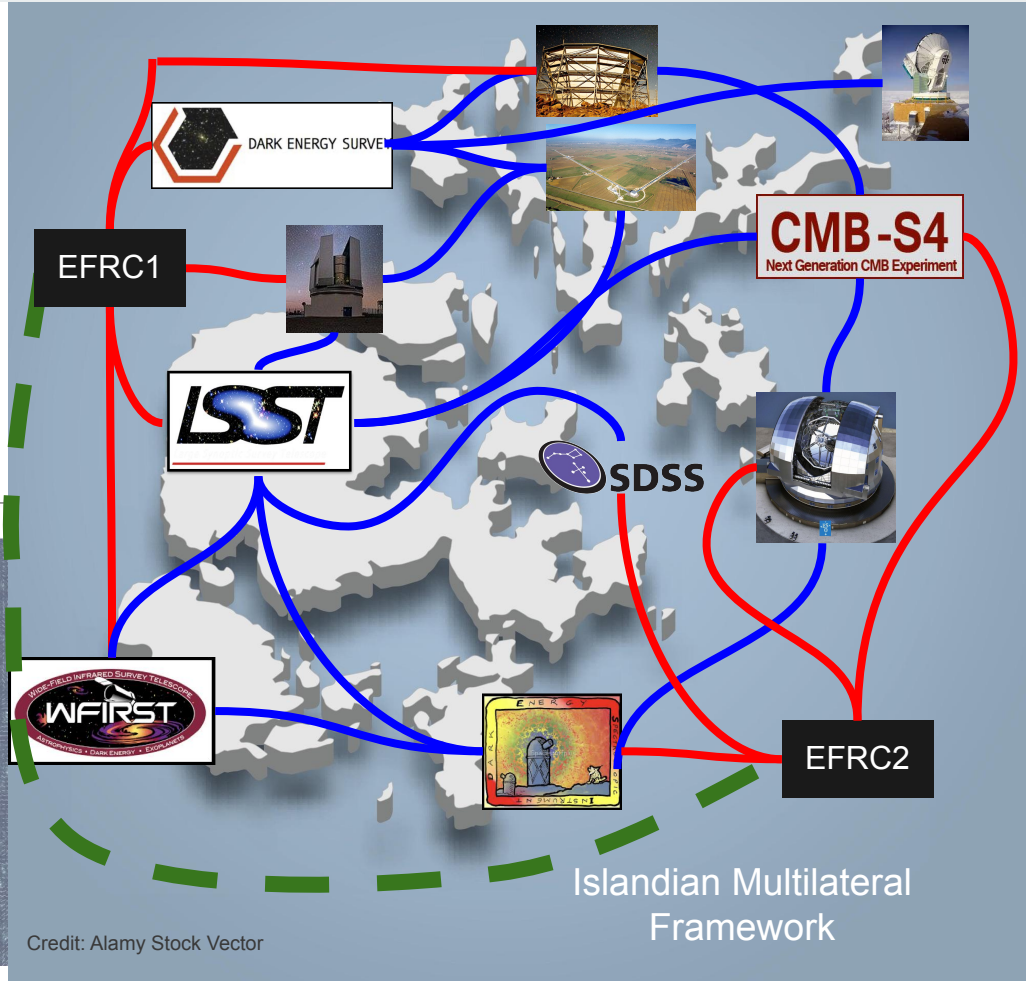

Credit: Alamy Stock Vector

Sovereignty isolated island model for our observatory infrastructure

**Future** way of thinking the infrastructure (**2203.06795**)

- Coordination of survey strategies
- Coordination of simulations
- Extensive data-sharing
- Coordinated choices in modeling syst.
- **Multilateral** agreements "handshakes"
- Centers that coordinate crosstalk



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

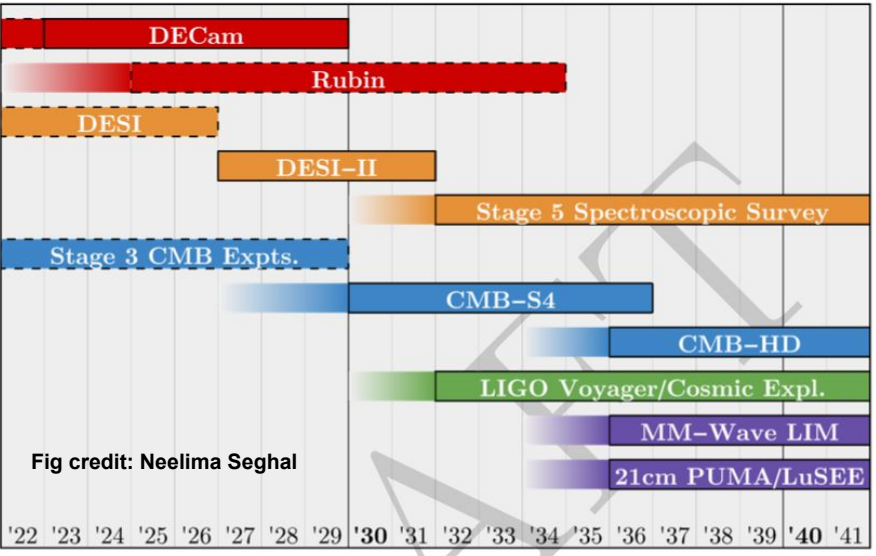
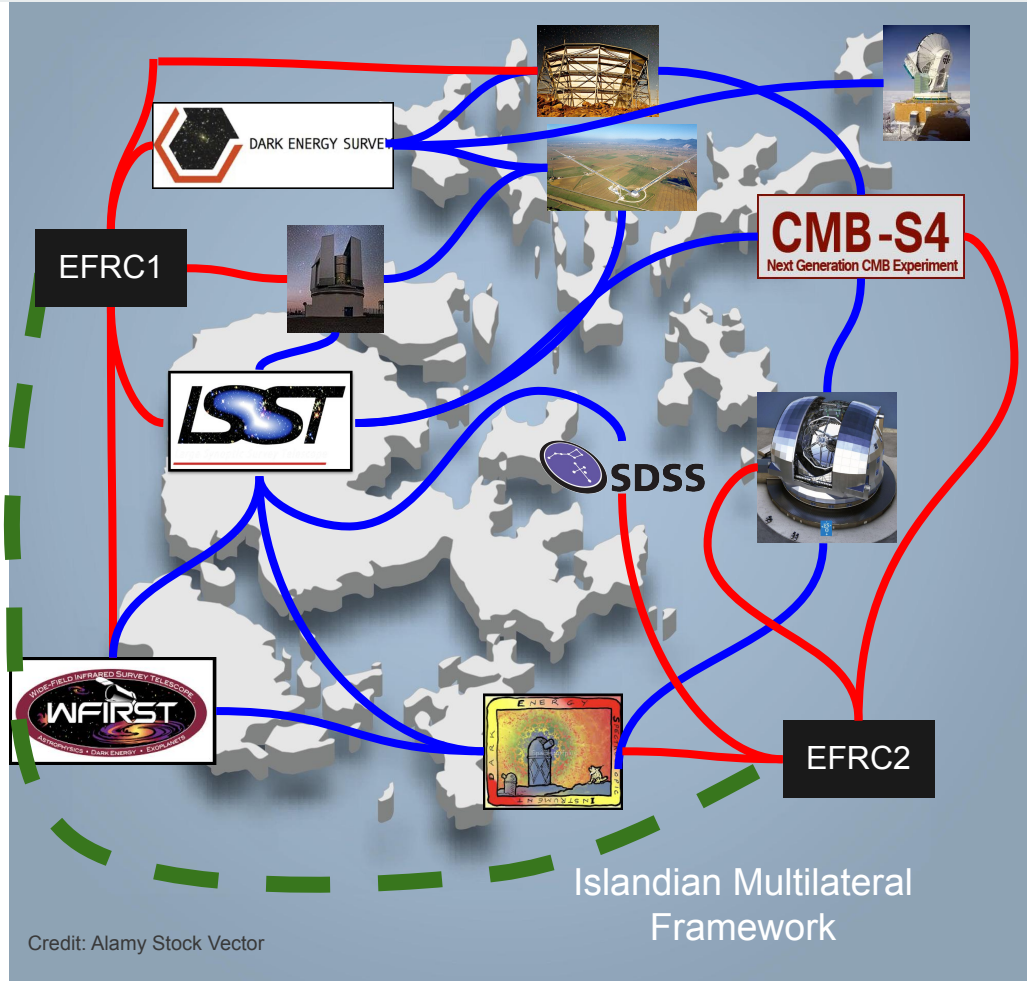


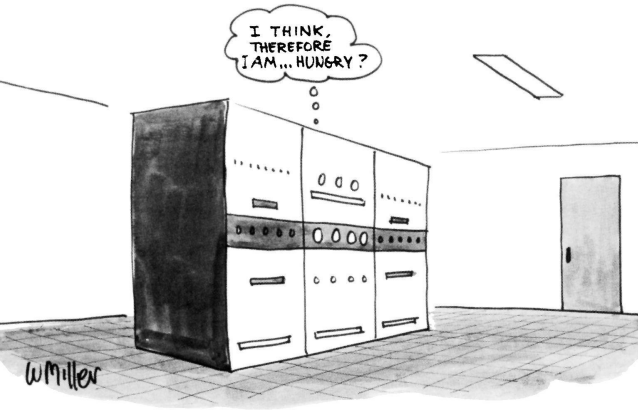

Fig credit: Neelima Seghal

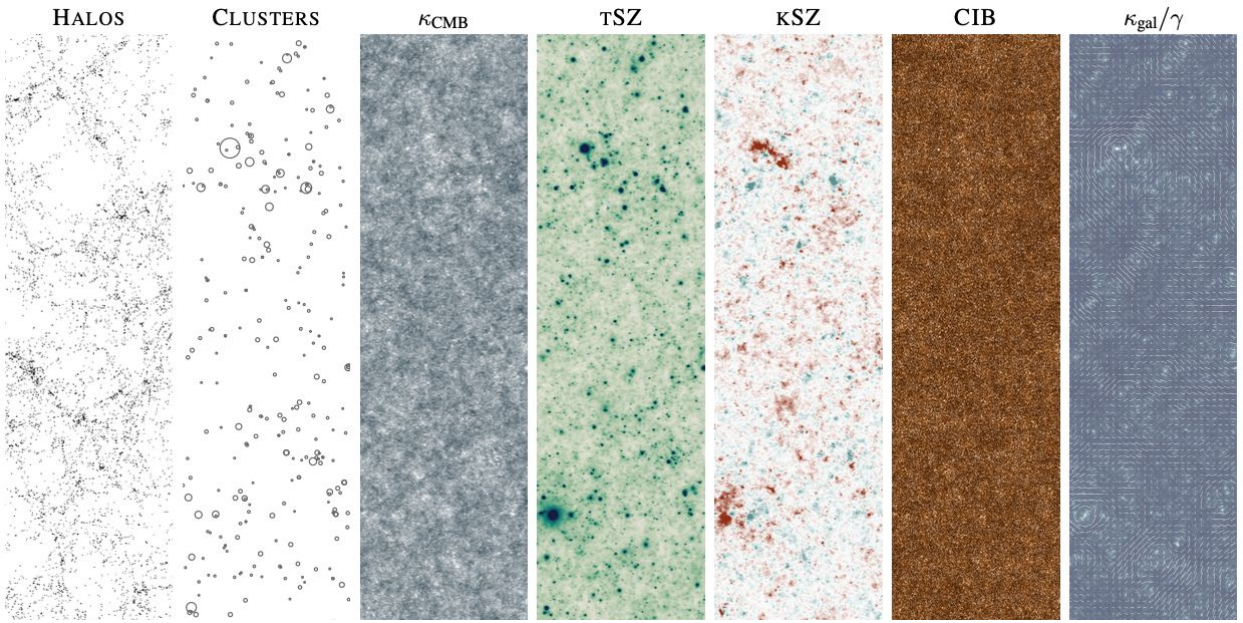
**Figure 6-1.** *Current and potential future facilities probing cosmic acceleration that are or may be supported by the HEP Cosmic Frontier. Dashed boxes indicate fully-funded facilities. Facilities in red are optical imaging, in orange are optical spectroscopy, in blue are CMB, in green are gravitational waves, and in purple are radio/mm spectroscopy. The fade-in regions indicate commissioning periods, while the solid boxes indicate full survey observations.*

**No single experiment can reveal the nature of dark energy.**



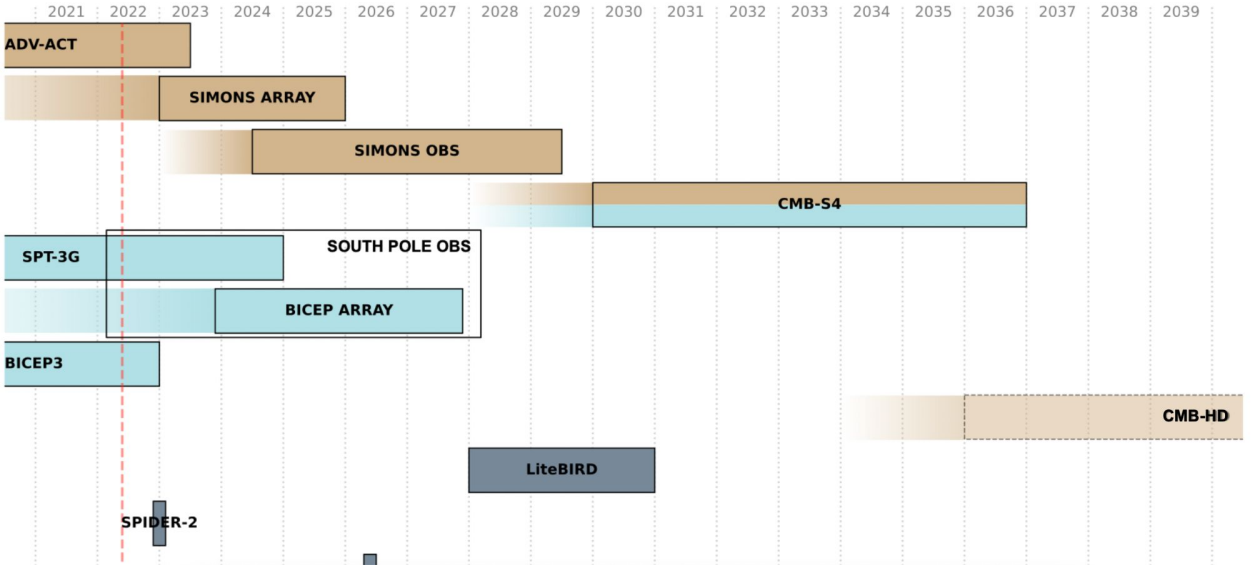
Based on this view what we need from theory?

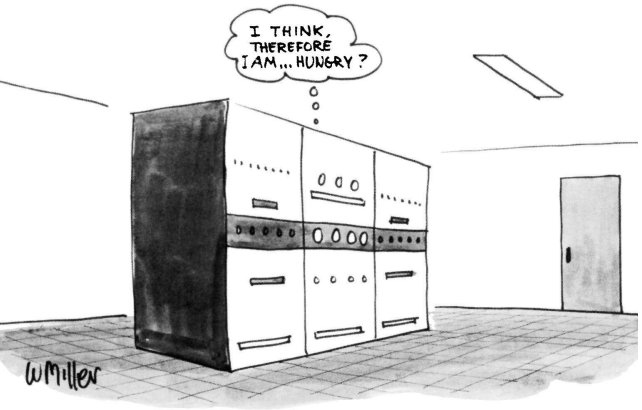



- Better simulations (or EFT methods given that baryons are important for k > 1 h/Mpc)
- Precise predictions in the context of exotic dark energy models (ex: modify gravity)
- Better understanding of astrophysics/systematics

Based on this view what we need from theory?




- Need for faster code - ex: Boltzmann code slow down a lot when forecasting CMB-S4/SO
- More ideas on how the CMB damping tail can probe weird/exciting physics pre-recombination

Based on this view what we need from theory?

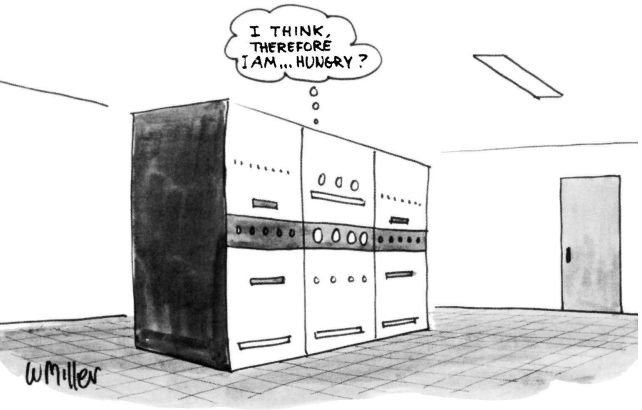
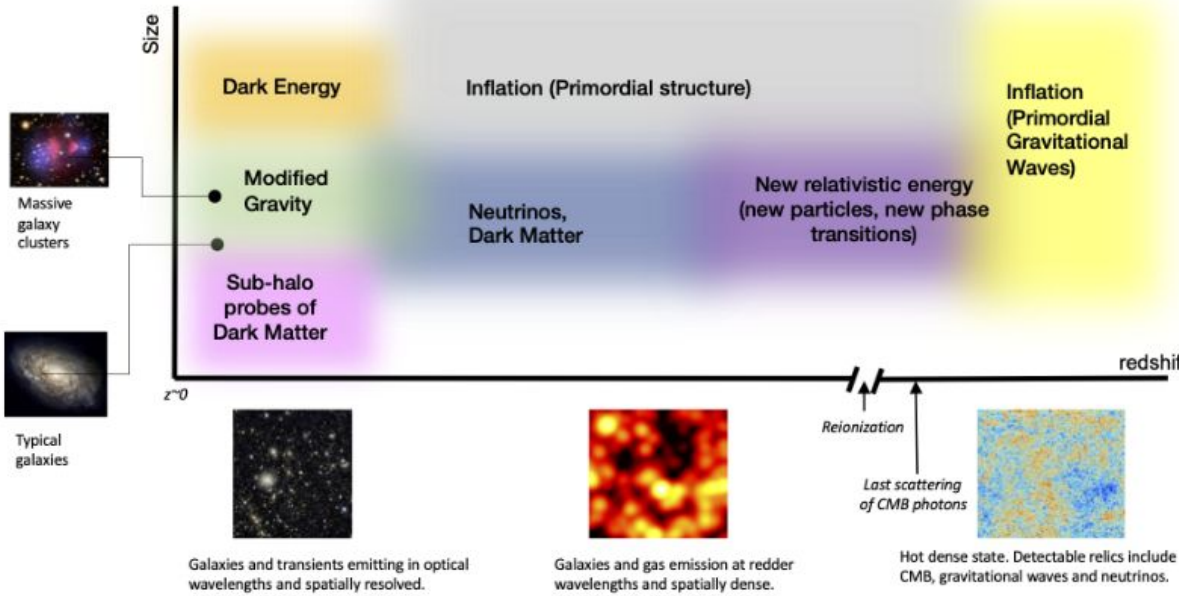



Fig credit: Clarence Chang




- Better predictions for dark matter
- Effective field theory/perturbation theory models in mildly **non-linear** scales
- More models to explain shift in the sound horizon

Based on this view what we need from theory?

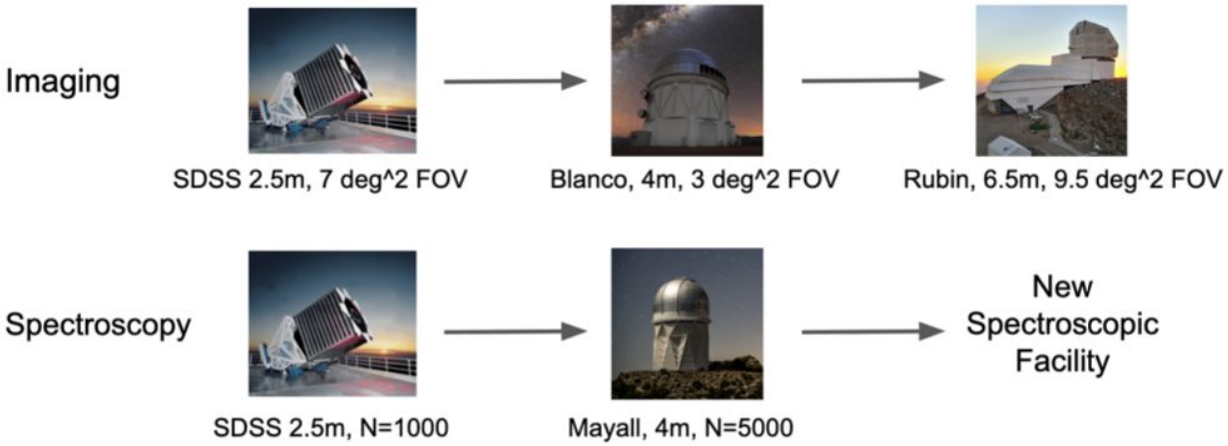
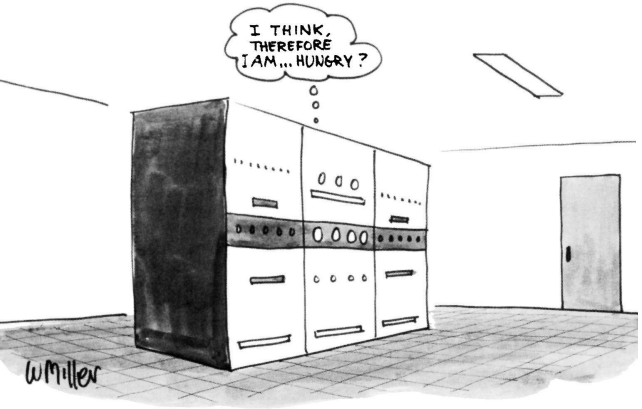



**Figure 6-4.** *Summary of imaging and spectroscopic surveys and facilities, ongoing and planned, that are supported by DOE/NSF partnerships. The international ground and space-based landscape of optical wide-field surveys, ongoing and planned, is very rich but for clarity is not represented here. SDSS had both imaging and spectroscopic capabilities, the Blanco telescope was used to carry out the DES, and the Mayall is currently used for DESI. In the near future, the Rubin Observatory will begin LSST. A new spectroscopic facility would open up new scientific opportunities.*

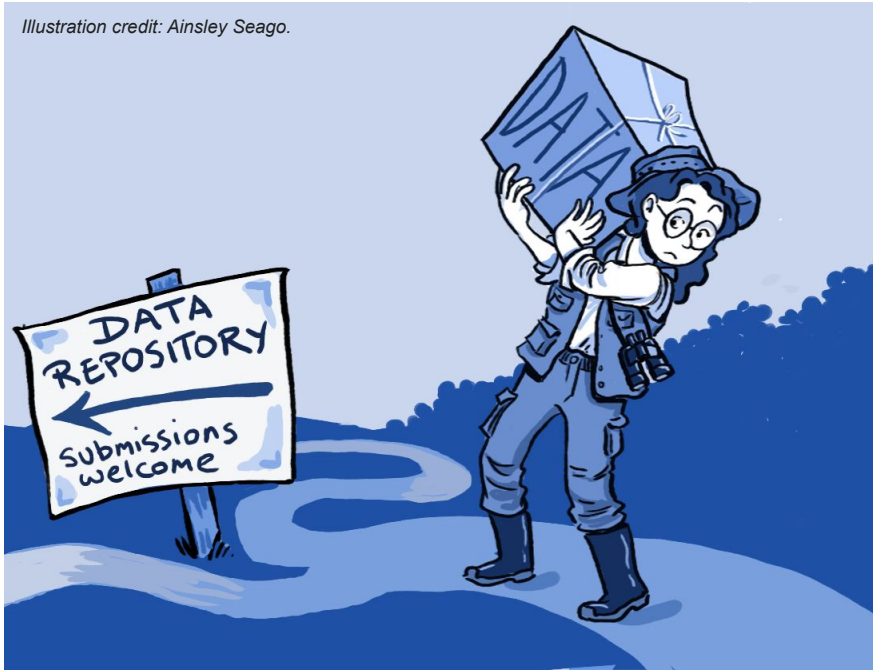



- Better understanding on how to combine 2D vs 3D (image vs spectroscopy surveys) to extract dark matter/dark energy/early universe behaviour

# DOE Archival data: critical infrastructure (multi-site archival network - **WP: 2203.08113**)

**Petabytes** of heterogeneous data worth billions of dollars

- How data can be efficiently accessed in various DOE supercomputers?
- Need homogeneous code infrastructure to access them (avoid chaos). (not the current model)
- Multi-site google model for robustness?
- Would we need fiber optic infrastructure to transmit data between archival sites and DOE supercomputers?
- In-site computation resources



## Repurposing expensive facilities (**WP: 2203.07220**)

We just built or are going to build expensive facilities & cameras

Strategic: $1-20M proposals that repurpose facilities (ex: DECam, DESI-II, Rubin…)

- New filters (narrow filters)
- Follow up for GW
- Microlensing continue searches (DM science)
- Higher cadence survey
- Larger Area (DECam)
- time-delay measurements of lensed quasars and SNe

# Transients

- Examples: new constraints on Hubble constant from detection of optical counterparts to GW detections and to strongly-lensed supernovae; follow-up Rubin SN detections;  follow-up IceCube Neutrino Events
- Advocate for development of a US-HEP multi-messenger program:
  - Infrastructure to coordinate multiple facilities and data transfer
  - Repurposing (and support) of smaller (3-4m) telescopes for high-efficiency follow-up, search and discovery of GW and other transients
  - Theory and modeling to improve cosmological constraints
  - Develop agreements for dedicated target of opportunity observing across multiple facilities, negotiate schedules, develop decision process for target follow-up
  - Computing resources, access to High Performance Computing

To checkmate LCDM in the 2020's (and 2030's), measurements of LSS & CMB must work harmoniously to expand our knowledge of the Universe at early, intermediate, and late times.

Like in chess, premature (single effort) attacks on the standard model will probably be unsuccessful


- CMB facilities: **critical** **(WP: 2203.08024, 2203.05728)**
- LSST: **critical** **(WP: 2203.07252)**
- 2D vs 3D (spectrography): **critical** **(WP: 2203.07506)**
- GW: **critical** **(WP: 2203.08228)**

Such facilities are multi-purpose discovery machines that will inform our understanding of dark energy, dark matter, and inflation.

# Thank You. Questions?