#144
New Facilities for Dark Energy

LOIs covered in this session:
https://docs.google.com/document/d/1VwgCFtTMq8FYzGXEuABXNbHVxhzUXfOTK6YP_XKnqdc/edit

Introduction

Ultimate Goal (by July 2021):

- The **Cosmic Frontier** produces a report, including a frontier summary and chapters from the different topical groups (next bullet point)
- The topical group **CF6** (Dark Energy and Cosmic Acceleration: Complementary of Probes and New Facilities) produces a 20-50 page chapter
- These reports are accompanied by **contributed white papers** from the community (Snowmass 2013 had 27)
- Sufficient **communication/consolidations** should happen during the process so that the CF6 summary report reflects the view of the community
- LOI groups on similar topics are encouraged to collaborate on contributed white papers
- Link to 2013 Snowmass shows likely overall structure of reports and papers, check out the cosmic frontier page for the scale of the number of papers, and hierarchy of summary reports
- Comments from Chris Quigg provides some historical perspective

Snowmass 2013 Cosmic Frontier page (partial)

Chapter 4: Cosmic Frontier
Conveners: J. L. Feng and S. Ritz

Working Group Summary (arXiv:1401.6085)

Subgroup Reports:

24.	WIMP Dark Matter Direct Detection	1310.8327
25.	WIMP Dark Matter Indirect Detection	1310.7040
26.	Non-WIMP Dark Matter	1310.8642
27.	Dark Matter Complementarity	1310.8621
28.	Dark Energy and CMB	1309.5386
29.	Cosmic Probes of Fundamental Physics	1310.5662

Contributed Papers:

General:

023	M.W. Cahill-Rowley, *et al.*	pMSSM Benchmark Models for Snowmass 2013	1305.2419 (PDF)
040	Pierre Auger Collaboration	The Next Frontier in UHECR Research with an Upgraded Pierre Auger Observatory	1307.0226 (PDF)
093	L.A. Anchordoqui, *et al.*	Roadmap for Ultra-High Energy Cosmic Ray Physics and Astronomy	1307.5312 (PDF)

Cosmic Probes of Physics:

004	S. R. Klein, *et al.*	Neutrino Absorption in the Earth, Neutrino Cross-Sections, and New Physics	1304.4891 (PDF)
007	VERITAS Collaboration	VERITAS contributions to CF6-A: Cosmic Rays, Gamma Rays and Neutrinos	1304.6764 (PDF)
009	F. Krennrich, *et al.*	The Extragalactic Background Light (EBL): A Probe of Fundamental Physics and a Record of Structure Formation in the Universe	1304.8057 (PDF)

27 contributed papers total

- 2 Direct Wimp detection
- 5 Indirect DM detection
- 3 Non-Wimp DM
- 3 DM Complementarity
- 3 DE and CMB
- 8 Fundamental

List continues

Preliminary Snowmass Timeline / Process

Starting point for discussion with the community during CPM

Meetings & Workshops (10 Frontiers & 80 Topical Groups) + Contributed Papers

Nov. 2020	Dec. 2020	Jan. 2021	Feb. 2021	Mar. 2021	Apr. 2021	May 2021	Jun. 2021	Jul. 2021	Aug. 2021	Sep. 2021	Oct. 2021
					Community Meeting (APS April Meeting)		Community Summer Study (CSS) July 11-20, 2021 + DPF 2021 (UW Seattle)				Snowmass Report

TGs: effort on consolidation, coordination & solicitation, leading to studies & Contributed Papers

TGs develop their key questions and opportunities

TGs produce outlines of their reports

(TGs: communication with authors of Contributed Papers)

Frontiers/TGs produce Preliminary Frontier Reports
Community feedback on Preliminary Frontier Reports

CSS

Build consensus on key questions / opportunities of particle physics,
enabling technologies, community engagement;
Formulate the content of Executive Summary

Frontiers/TGs produce Final Frontier Reports
Steering Group produces Preliminary Executive Summary
Community feedback on Prelim. Exec. Summary
Snowmass Draft Report and Review
Snowmass Final Report

Topical group CF6 covers Dark Energy and Cosmic Acceleration: Complementary of Probes and New Facilities

In this session we will have a brief review of the proposed new facilities that submitted LOIs and develop a plan for future meetings and preparation of a summary report. Sessions #142/143 covered Complementary Probes.

To get started we asked each submitter to prepare slides describing new facilities:

-- Overall science goal

-- Collaboration model

-- Scale of investment for US agencies, international partnerships, other investments

-- Desired support from the DOE laboratory system

-- Timescale

-- R&D plan

Session #144: New facilities for dark energy

Science cases covered in other sessions

Minimal output: Table of possible future facilities

Maximal output: Roadmap of future facility capabilities, and required R&D to get there

This should be an easy case!

-- Building on successful roadmap: (e)BOSS, DES, DESI, Rubin/DESC, CMB-S4

-- Actual measurements, not just null results

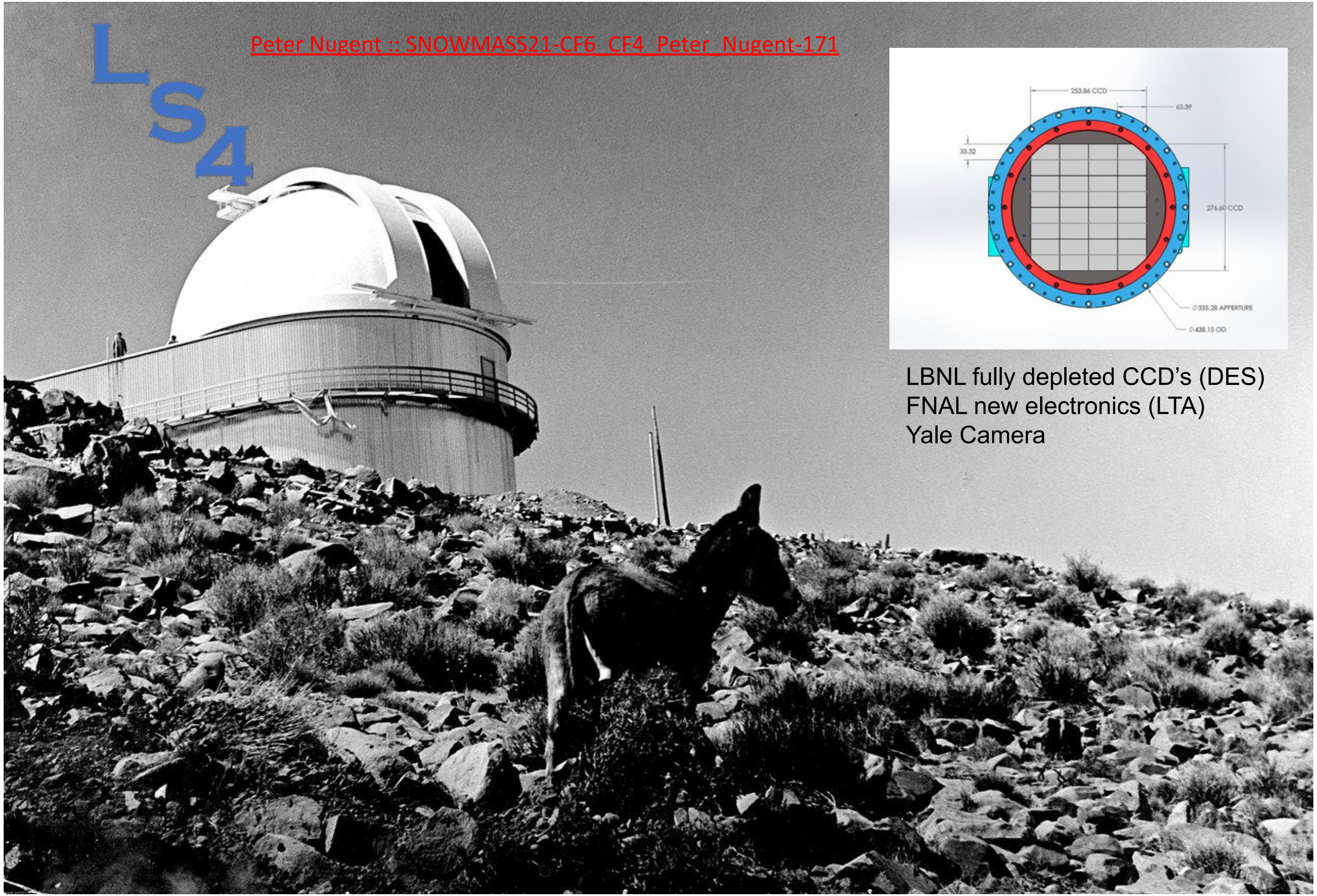
-- Specifically we're building on expected outcomes of Rubin, CMB-S4

What we would like to decide at the end of this session

Our initial thoughts were to group the new facilities by size/cost/scale: Small, medium, large investments required by NSF or DOE.

Does this grouping make sense? Alternatives? These groups would work together to e.g. make the case for agency investment and write white papers. Does anyone want to serve as a group contact?

- Weekly/bi-weekly meetings in CF6? Does the Wed 3pm CDT time still work?
- Communication:
  - Slack channel?
  - CF6 mailing list?



Peter Nugent :: SNOWMASS21-CF6_CF4_Peter_Nugent-171

LBNL fully depleted CCD’s (DES)
FNAL new electronics (LTA)
Yale Camera

La Silla Schmidt Southern Survey

Quick facts:

- 20 sq. deg. fov
- 2 fixed filters (g+z)
- 45s exp; 15s read+slew
- g-band: 21.0+/- 0.5
- z-band: 20.0
- 2k-4k sq.deg./night
- 90% Survey mode
- 10% MMA ToO’s
- Real-time public data

LS4 Considerations

Peter Nugent :: SNOWMASS21-CF6_CF4_Peter_Nugent-171

Overall science goal: Fill in the Rubin Observatory's LSST cadence to increase the scientific potential of nearby/fast evolving transients with a particular focus on SN Ia / SN II-P cosmology & peculiar velocities, and standard sirens with NS - NS/BH mergers.

Collaboration model: Collaboration (partners with cash, ccd's, software) determines cadence and fields, data is streamed to public in near real time, save for 10% for ToO's (1 month hold).

Scale of investment (roughly): $500k for camera upgrade (private funding), $75k/yr for observatory operations (ESO), $300k for follow-up Opt. spectroscopy & IR imaging.

Desired support from the DOE laboratory system: 2-4 FTE to handle nightly operations and maximize cosmology specific science goals - can be partially shared with other programs.

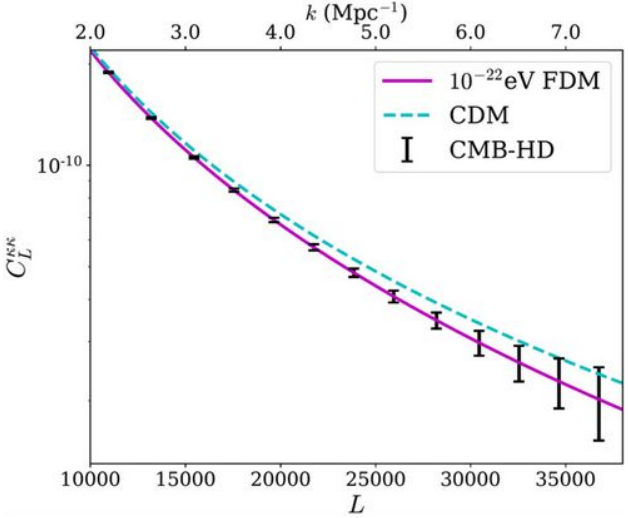
Timescale: Given ESO approval in late Nov. 2020, first light Jan. 2022 (modulo covid).

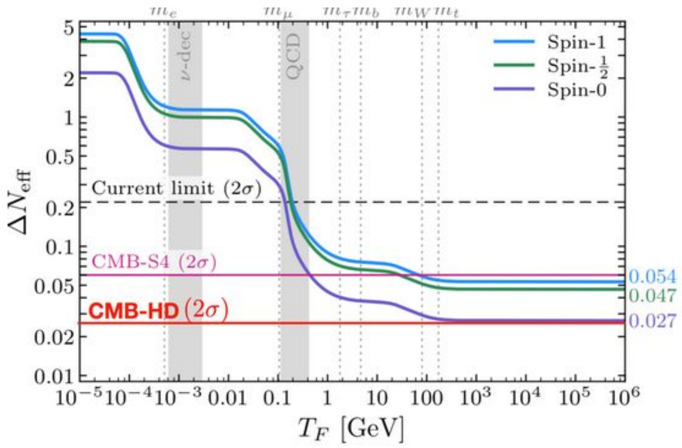
R&D plan: Some engineering (similar to MzLS) for camera, the rest is pipeline work based on PTF/iPTF/ZTF real-time pipelines and SkyPortal. All of which are already funded through 2022.

CMB-HD

Overall science goals

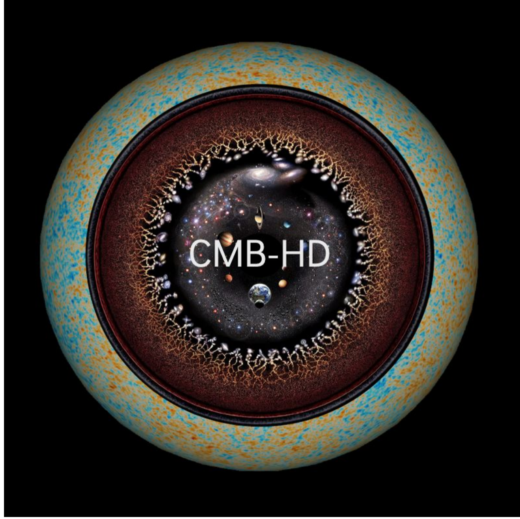
- Dark matter & Other New Particles via i) CMB lensing measurement of matter power spectrum on small scales, ii) Neff constraint, and iii) axion constraints
- Inflation via i) primordial non-Gaussianity ($\sigma(f_{NL})$=0.26), ii) primordial magnetic field measurements, and iii) primordial gravitational waves (in conjunction with external small-aperture CMB experiments)
- Dark Energy via mapping structure with i) high-res CMB lensing, and the ii) tSZ and kSZ effects
- Neutrinos via i) Neff and ii) neutrino mass constraints
- Astrophysics: i) planets, ii) transients, iii) gastrophysics





For details see Astro2020 Decadal reports in 1903.03263, 1906.10134, and 2002.12714, as well as https://cmb-hd.org

CMB-HD



Instrument and Survey

- Two 30-meter off-axis crossed Dragone telescopes
- Each with 800,000 detectors (200,000 pixels)
- Location: Cerro Toco in the Atacama Desert
- Survey: 50% of sky, 7.5 years, 0.5 uK-arcmin noise in temp, 15 arcsecond resolution (5 times better resolution and 3 times deeper than the CMB-S4 wide survey)

CMB-HD Collaboration

- 55 people currently; open collaboration roughly following model of Rubin Observatory

Scale of Investment

- 1 billion dollar project; joint NSF and DOE investment needed

DOE laboratory system instrumental for detector and instrumentation delivery

Timescale

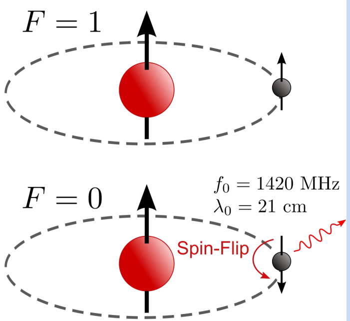
- 2 years design + 2 years construction; 7.5 years of survey operations

R+D Plan

- Several enabling technologies being developed and advanced by current experiments (e.g. GBT, SO, CCAT-prime, BLAST-TNG, TolTEC -- see 2002.12714 for details)

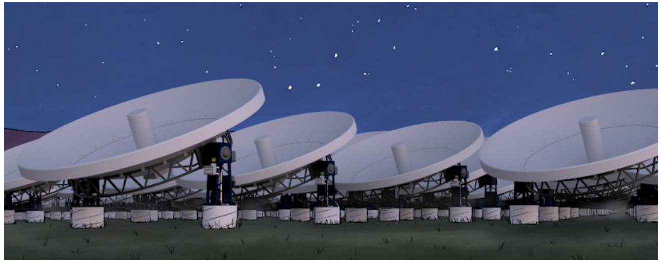
Neelima Sehgal, Stony Brook University

Packed Ultra-Wideband Mapping Array (PUMA)



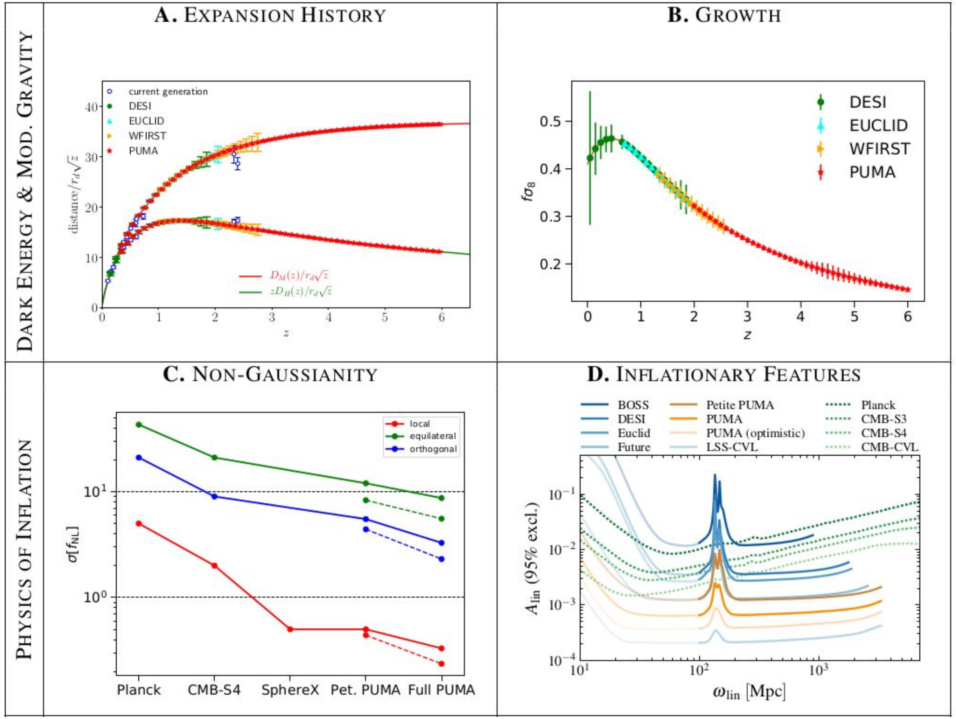
Intensity mapping relies on the redshifted 21cm line:

- Emitted by self-shielded neutral hydrogen in galaxies,
- Spectroscopic galaxy survey in radio,
- Does not require a targeting survey, but also does not detect individual objects.



PUMA is

- **Packed**: Dishes close together for maximum sensitivity at scales of interest,
- **Ultra wide-band:** Employing latest in RF technology advances driven by telecom industry,
- **Mapping:** Maps large-scale structure in the Universe,
- **Array:** A software/hardware radio telescope.



4 exciting science goals relevant to DOE HEP

PUMA

Instrumentation BRN report envisions start of observations in 2030.

PUMA Proto-collaboration:

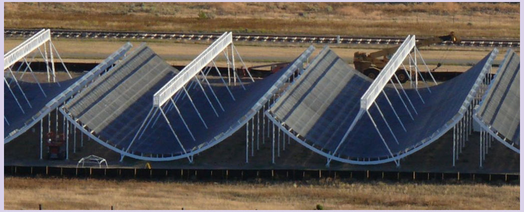
- Tremendous Arrays Workshop (2018)
- Cosmic Visions 21cm Working group report (2018),
- Astro 2020 Decadal Survey Submissions (2019),
- Snowmass 2021 Letters of Interest,
- First (remote) collaboration meeting in Summer 2020,
- Will continue operating in semi-formal mode for the foreseeable future.

Want to know more?

- [1810.09572]
- [1907.12559]
- [2002.05072]

R&D plan:

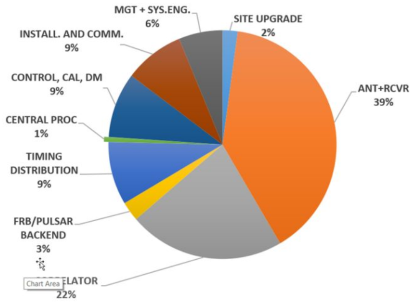
- PUMA is not shovel ready.
- Technical problems associated with calibration, stability and cost-effective manufacturing of reflectors need to be developed.
- PUMA will benefit enormously from commoditization of RF and compute technology.
- Decadal 2020 RFI developed a clear R&D path.
- We are working towards establishing seed funding from agencies to follow this plan.



Precursor instruments:

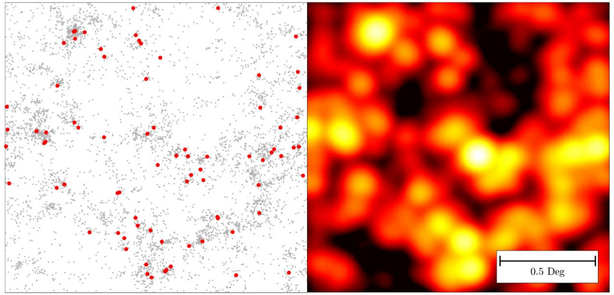
- CHIME and Tianlai, currently taking data
- HIRAX, PUMA-like array with 1024 dishes

Full PUMA cost is in the few hundreds of million $ range and will require inter-agency collaboration.



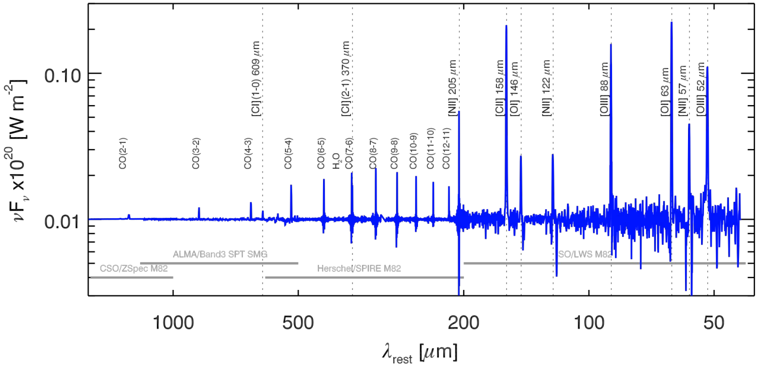
Mm-wave Line Intensity Mapping

- Spectroscopic mm-wave detectors can measure large-scale, integrated emission from redshifted far-IR lines (CO, [CII]). No source detection threshold, so large volumes are surveyed quickly. A single 80-300 GHz instrument can detect LSS from 0 < z < 10!
- Science goals:
  - **Inflation** - primordial non-Gaussianity in power spectrum and bispectrum
  - **Dark Energy** - expansion history at z > 3, growth of structure
  - **Neutrinos and Light Relics** - sum of neutrino masses, N_eff
  - **Astrophysics** - high-z star formation, Epoch of Reionization
- Individual pathfinder experiments are now funded/operating (TIME, CONCERTO, CCAT-p), which will demonstrate the basic technique.
  Not expected to return cosmological constraints - we need much more sensitive instruments!

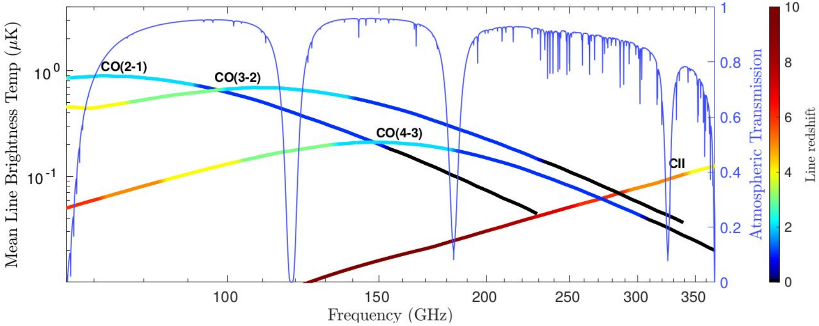


LIM Status Report
1709.09066

FIR and submm lines



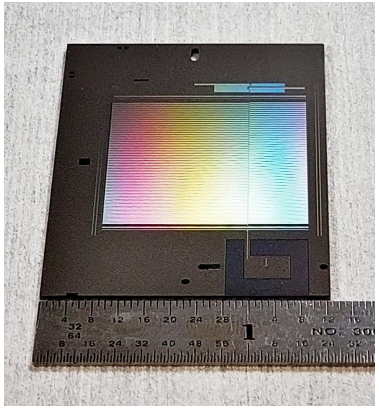
Joaquin
Vieira



Karto
Keating

Mm-wave Line Intensity Mapping

- Key technological advance needed is the development of **large-format, on-chip mm-wave spectrometers**. Individual spectrometers demonstrated now (e.g., SuperSpec). Scaling up to densely-packed wafers will build on CMB heritage.
- Multiple instrument concepts for various science goals: SPT/SO LAT-like for arcminute scales and foreground removal, BICEP-like for degree scales and larger
- Rough cost to build: ~$10M for small-scale, ~$50M for large-scale (using existing facilities)
- DOE support for detector fabrication/testing would enable the aggressive timeline below
- R&D Plan: now proposing to demonstrate LIM with moderate-sized on-chip spectrometer wafers



SuperSpec R=300 filter-bank spectrometer (Erik Shirokoff)

Stage	**Time**	**Spec. Count**	**Example**	**Science Threshold**
Detection	Now	10–50	TIME[9], CONCERTO[10], CCAT-p[11]	Clustering power spectrum
Small-scale	2-4 yr	100–500	SPT-like, 1 tube × 400 spec. BICEP-like, 400 spec.	$\sigma(\alpha_{\rm BAO}) < 0.01$ at $z \sim 3$ $\sigma(f_{\rm NL}^{\rm loc}) < 3$
Large-scale	4-8 yr	1000–5000 10000–50000	Filled SPT/ACT, 7 tubes × 400 spec. BICEP Array-like, 7 tubes × 400 spec. SO/CMB-S4 LAT, 85 tubes × 400 spec.	$\sigma(\Sigma m_\nu) < 0.036$ (+ Planck) $\sigma(f_{\rm NL}^{\rm loc}) < 1$ $\sigma(N_{\rm eff}) < 0.07$ (+ Planck)

Table 2: Stages of future mm-wave LIM experiments. Note that "Small-scale" and "Large-scale" refer to spectrometer count and not angular scales. "Time" indicates rough time to start of operations given sufficient investment. The science thresholds are approximate and conservative—they are single-tracer, ignore cross-correlations, and only consider up to $k_{\rm max} = 0.2$ (smaller scales are accessible with the anticipated angular and spectral resolution).

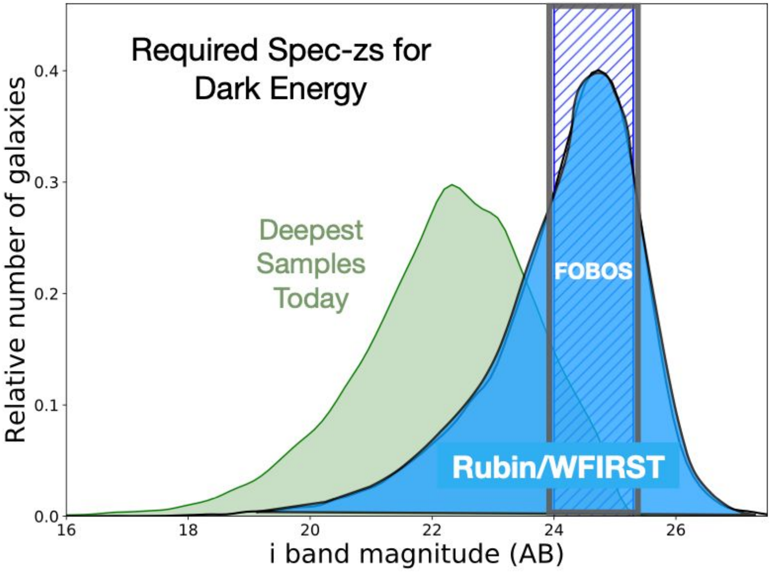
Mm-wave LIM Facilities LOI

The Keck Fiber-optic Broadband Optical Spectrograph (FOBOS): Building a deep spec-z sample for Stage IV Dark Energy Missions

Dan Masters (LOI 192)
On behalf of the FOBOS team (PI Kevin Bundy, PS Kyle Westfall)
With input from Rachel Mandelbaum, Jeff Newman, Jason Rhodes
https://fobos.ucolick.org/
dmasters@ipac.caltech.edu

The FOBOS Cosmology Program

- Current deep spectroscopic samples are incomplete & biased at depths relevant to Rubin/Roman
- The FOBOS cosmology program would build up ultradeep 50h integrations on ~15k carefully selected galaxies
  - Spanning the bulk of the parameter space for Rubin/Roman shear cosmology samples
- FOBOS would build a *representative* spectroscopic training sample with a host of scientific benefits in addition to dark energy FoM improvement through photo-z training
- Notional program would target 12 independent fields, with redshifts to i=25.3 AB
- An existing ground-based 10m telescope equipped with a highly multiplexed, blue-sensitive spectrograph is a practical, cost-effective solution to obtain the required deep spec-z samples
- The envisioned FOBOS cosmology program would provide science-ready data products to the community on a rapid cadence
- Potential for a 40% improvement in the dark energy FoM for LSST



Why FOBOS?

- Suited to the upcoming era of deep imaging surveys
- Facility instrument with a broad range of scientific uses
- With high target densities of ~6 arcmin^{-2}, FOBOS is well-matched to the faint samples from upcoming photometric surveys
- FOBOS has no redshift desert
  - ➢ Blue sensitivity to 0.3 micron yields Lyα redshifts for sources at $z \gtrsim 1.5$
- FOBOS achieves this on a time-scale that is relevant for these missions (first light 2028)
- Keck telescope is already built and highly productive
- FOBOS is WMKO's top-ranked instrument priority
- Currently in conceptual design phase, which will be completed in early 2021
- Exploring collaboration and funding models
  - ➢ Considering non-traditional models including large programs for which the data would be immediately available to the community

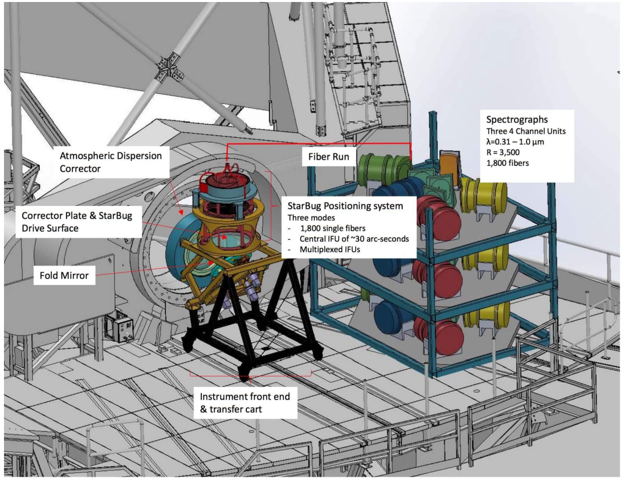


TABLE 1. Summary of FOBOS Specifications

Telescope	10-m Keck II
Patrol Field	$D = 20'$
Total Number of Fibers	1800 (Table 3)
Single-Fiber (MOS) Aperture	$D = 0.8''$
Multi-IFU FOV (37 fibers)	$D = 5.6''$
Large IFU FOV (1657 fibers)	$D = 37.6''$
Spectral Range	0.31–1μm
Spectral Resolution	3500
Throughput	$\gtrsim$30%
Limiting Magnitude†	r(AB)$\sim$24.5

†To reach S/N$\sim$1 in a 1hr integration.

fobos.ucolick.org

LOI: [SNOWMASS21-CF6_CF3_Dickinson-257.pdf]

The US Extremely Large Telescope Program

- **Extremely Large Telescopes** (ELTs, > 20m primary apertures, optical-infrared (OIR))
  - **Angular resolution** $\theta \approx \lambda/D \approx$ 7 mas (λ/1μm) (30m/D) with adaptive optics at infrared wavelengths
  - **Unprecedented sensitivity** $\propto$ D^4 for diffraction-limited point source observations
- US-ELTP important for **Cosmic Frontiers science** including
  - **Cosmic Expansion:** Precision measurement of H_0 via standard candles (TRGB), standard clocks (gravitational lensing time-delay cosmography), standard sirens (gravitational wave source distance precision via OIR counterpart inclination measurement) [CF4_CF6_Treu-030; CF4_CF6-Beaton-181]
  - **Dark Energy:** Ultra-deep multi-object spectroscopy to enhance LSST Dark Energy science; "Cosmological parallax" tests [CF4_CF6_Newman-171; CF5_CF6_Pierce-042]
  - **Dark Matter:** Testing small-scale deviations from ΛCDM via dwarf galaxy 3D stellar kinematics (halo core density profile) and gravitational lensing (sub-halo mass function) [CF3_CF0_Simon-038; CF3_CF7-Birrer-037]
  - **Gravitational Wave / Multi-messenger Astrophysics:** Spectroscopy of faint OIR GW counterparts, physics of compact object mergers [CF4_CF6_Chornock-158]
  - **Supermassive Black Holes & General Relativity:** Precision stellar orbits close to the **Galactic Center's supermassive black hole**
- US-ELTP envisions that ≥ 50% of open access observing time would be dedicated to large, peer-reviewed **collaborative Key Science Programs (KSPs)**
  - Systematic approach to addressing **fundamental problems** that require large amounts of TMT+GMT observing time
  - KSP teams would be organized following **open collaboration models** TBD with the science community
  - **Broaden research participation** by scientists and students at small and underserved institutions & departments
  - **Promote widespread benefit** from federal investment in the US-ELTP

LOI: SNOWMASS21-CF6_CF3_Dickinson-257.pdf

The US Extremely Large Telescope Program

- **US-ELTP is a partnership:** NSF's NOIRLab, Giant Magellan Telescope (GMT) and Thirty Meter Telescope (TMT)
  - Provide US open access to an all-sky ELT system via ≥ 25% national share of observing time on TMT and GMT
  - Ensure construction completion for both observatories
  - Public / private partnership; US / international partnership
- Cost & scale of **US federal investment** is TBD
  - Plausible NSF MREFC scale $850M x 2 telescopes (NY Times, March 2020) + non-federal US + international partners
  - NSF's NOIRLab user & data services construction probably ≤ $100M
- **Timescale**
  - Subject to Astro2020 recommendation, NSF review, federal appropriations process
  - With suitable funding and site access now, telescopes could be operational well before 2030
- **R & D**
  - GMT & TMT are shovel-ready with critical components under construction or under contract now
  - NOIRLab user support & data services are low-risk and build on decades of precursors at NOAO, Gemini and Rubin/LSST
  - Recent NSF development award to AURA for user services and technical risk reduction
- **Potential role for DOE contributions** to future instrumentation for Cosmic Frontier science, e.g.,
  - Wide-field adaptive optics and precision astrometry
  - Wide-field high-multiplex spectroscopy
  - Wide-band optical+infrared spectroscopy & spectropolarimetry (e.g., for GW counterpart follow-up)

Maunakea Spectroscopic Explorer Conceptual Design

Maunakea Spectroscopic Explorer

Jen Marshall, MSE Project Scientist

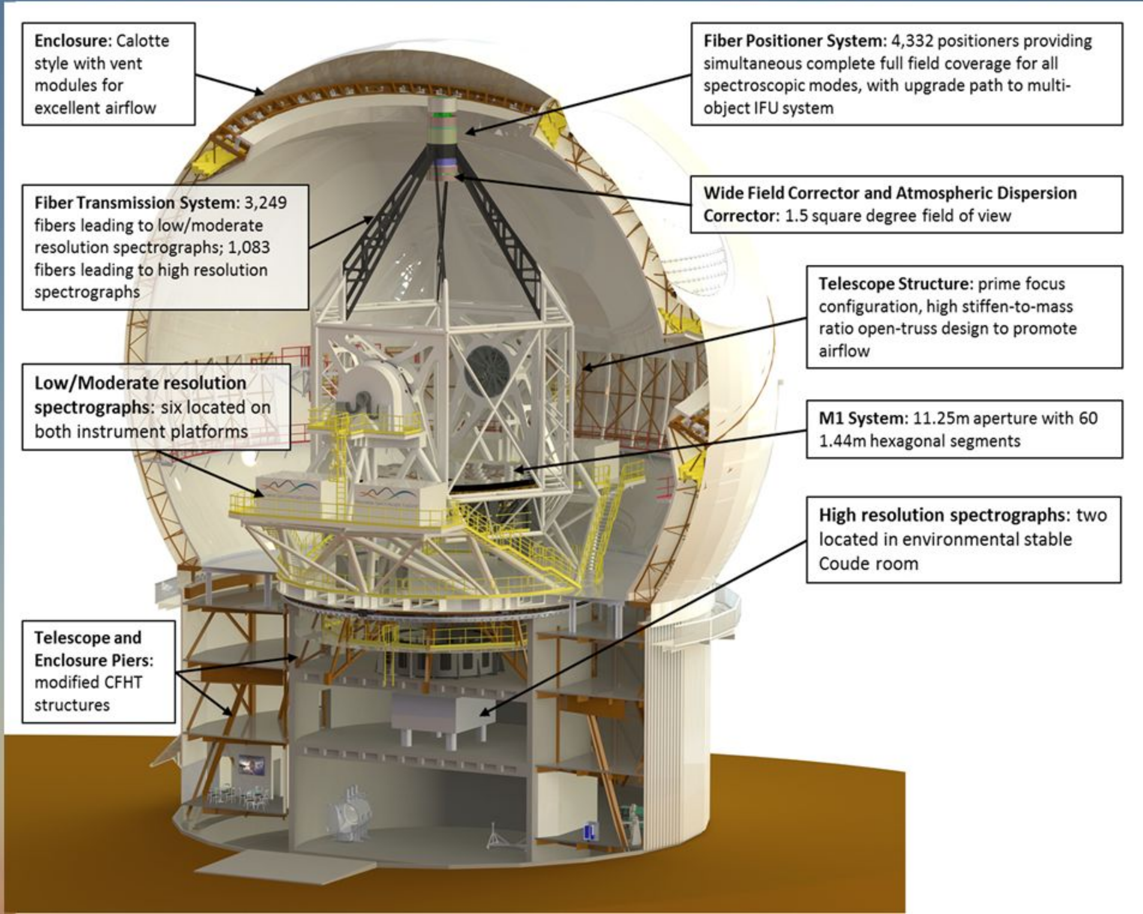
Upgrade existing Canada-France-Hawaii Telescope on Maunakea, Hawaii to a **completely dedicated** spectroscopic survey facility:

- 11.25m diameter telescope
- 1.5 square degree field of view
- 4,332 fiber positioner feeds two sets of spectrographs:
  - *Low/moderate resolution:*
    - R~3,000 or R~6,000
    - UV to H band
    - 3249 fibers
  - *High resolution:*
    - R~40,000
    - Three windows in optical
    - 1083 fibers

Conceptual design complete in 2018; First Light ~2030

More details: mse.cfht.hawaii.edu

https://www.snowmass21.org/docs/files/summaries/CF/SNOWMASS21-CF6_CF4-IF2_IF0_Jennifer_Marshall-141.pdf



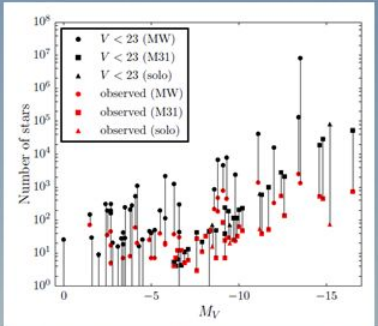
Maunakea Spectroscopic Explorer

MSE Science Case

Dark Matter

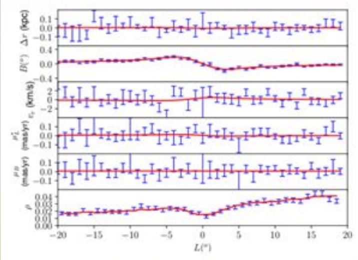
https://www.snowmass21.org/docs/files/summaries/CF/SNOWMASS21-CF3_CF7_Ting_Li-153.pdf

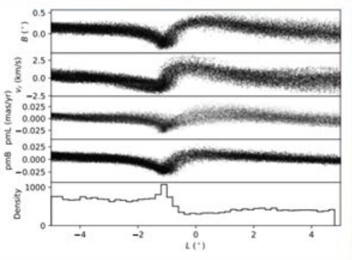
MSE's astrophysical tests of dark matter science case:
Li, Kaplinghat, et al. arXiv: 1903.03155



Left: Spectroscopic sample sizes for known dwarf galaxies. Red points are confirmed member stars; black points indicate number of stars observable with MSE. Rubin/LSST should find ~100 more dwarfs.

Below, left: Simulated observations of a $10^7 M_\odot$ subhalo impact adapted from Erkal & Belokurov 2015; these observations are possible with existing facilities. Below, right: Gap in a simulated GD-1-like stream from a $10^6 M_\odot$ subhalo. Both are readily detectable by MSE.





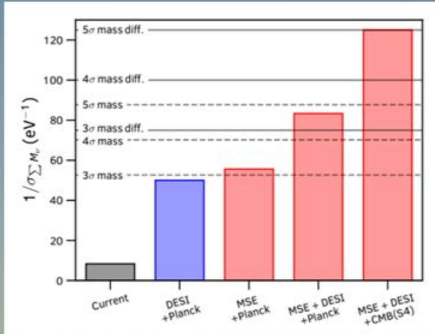
Dark Energy

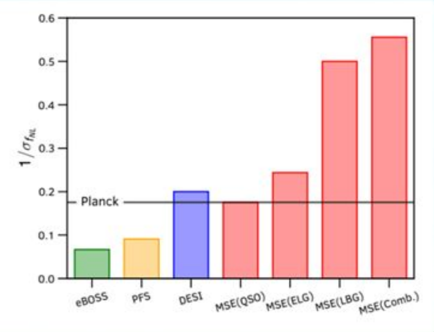
https://www.snowmass21.org/docs/files/summaries/CF/SNOWMASS21-CF4_CF6_MSE-086.pdf

Cosmology with MSE: **Percival, Yeche, et al. arXiv: 1903.03158**

MSE will enable one of the largest and highest redshift galaxy surveys possible, by number and by volume

5.4 M ELGs with 1.6<z<2.4
7.0M LBGs with 2.4<z<4.0
1.5M Lyα forest LOSs





Neutrino mass: MSE's cosmological large-volume survey will measure the combined mass of the neutrino better than any other project; when combined with DESI+CMB(S4), a 5-σ measurement can be made

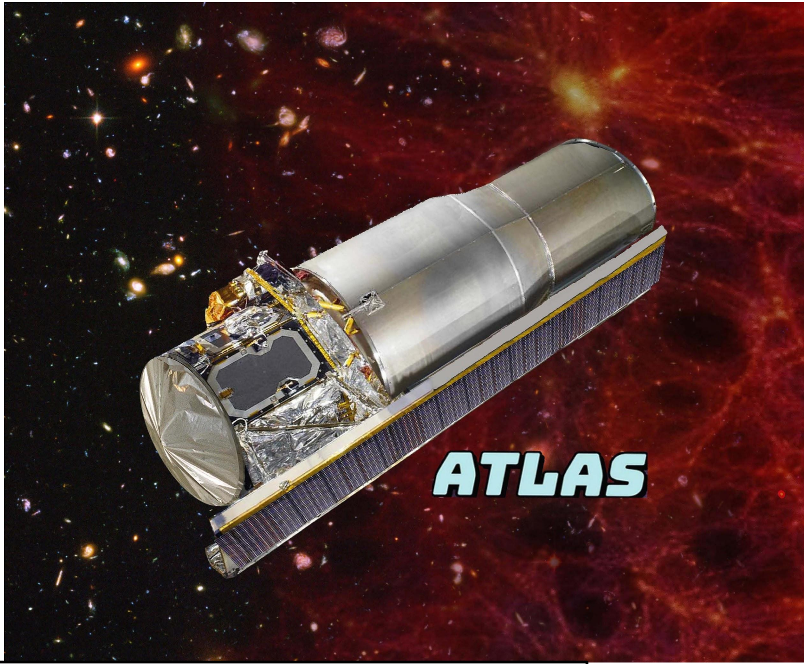
Primordial non-Gaussianity: Exquisite constraints to probe physics of inflation in the early Universe, ruling out a number of inflationary models

MSE Detailed Science Case, arXiv: 1904.04907; MSE Astro2020 APC white paper, arXiv: 1907.07192

Yun Wang LOI: SNOWMASS21-CF4_CF6-108.pdf

ATLAS Probe: Astrophysics Telescope for Large Area Spectroscopy

- **1.5m aperture telescope with 0.4 deg^2 FoV**
- **R = 1000 multi-slit spectroscopy over 1-4μm**
- **6,000 spectra simultaneously**
- **200M galaxy spectra over 2000 deg^2**
- **3 tiered survey from *z* = 0.5 to *z* = 7 and beyond**
- **Slit selectors: Digital Micromirror Devices**
- **Launch Ready Date: < 2030**
- **Cost within NASA probe-class envelope**



- **Map the cosmic web to shed light on the physics of galaxy evolution.**
- **Trace large scale structure densely to illuminate the nature of dark energy.**
- **Probe the Milky Way's dust-shrouded regions, reaching the far side of the Galaxy.**
- **Explore Kuiper Belt Objects in the outer Solar System.**

PI: Yun Wang (Caltech/IPAC) **Primary Partner:** JPL **Instrument Lead:** M. Robberto (STScI & JHU)

Ref: Wang et al. (2019), PASA, 36, e015, arXiv:1802.01539; http://atlas-probe.ipac.caltech.edu

ATLAS Probe & Snowmass 2021 New Facilities for Dark Energy

- **Overall Science Goal:** ATLAS will obtain definitive measurements of dark energy & tests of General Relativity, to address the fundamental question, "What is driving the accelerated expansion of the Universe?"
- **Collaboration model:** Open collaboration. Interested scientists may contact the PI with a proposal to join, describing their qualifications and intended contributions, to be evaluated by the PI and subject leads, in consultation with the core team.
- **Scale of investment for US agencies, international partnerships, other investments:** ATLAS will be proposed as a NASA Probe class space mission, with international partners including ESA and Australia. JPL has funded the ATLAS mission study. Australian Astronomical Optics at Macquarie University has funded the ATLAS optical design.
- **Desired support from the DOE laboratory system:** Funding for scientists to contribute to ATLAS dark energy science, technology, and instrumentation.
- **Timescale:** ATLAS will be launch ready before 2030.
- **R&D plan:** Develop ATLAS science, technology, and instrumentation utilizing all available resources, in preparation for developing the ATLAS Probe mission proposal once NASA issues the AO for probe missions.

Transient (SN Ia) Follow-up Network

- **Overall science goal:** Enable the study of Dark Energy, Gravity, and other HEP science using transients discovered by Rubin and other public searches, through supplemental optical/NIR spectral/imaging follow-up
- **Collaboration model:** Complicated. Use Snowmass to figure this out,
  - DESC has intellectual investment and scientific stake in transient and non-transient spectroscopy
  - Rubin Observatory soliciting International In-Kind Contributions, several responses to which include transient follow-up that could be part of the Network
  - Private facilities will be used for follow-up
  - Private data supplement public transient searches, e.g., ZTF-II in the north
  - Other LSST Science Collaborations want similar network elements though driven by different science goals and requirements
- **Timescale:**
  - Now and later. 2-3 sigma PV results possible current and soon-to-be-online facilities if made available.. Precision 4-5 sigma PV science would require re-instrumentation of larger telescopes.
  - Doubt transient searches will stop after 10 years of Rubin

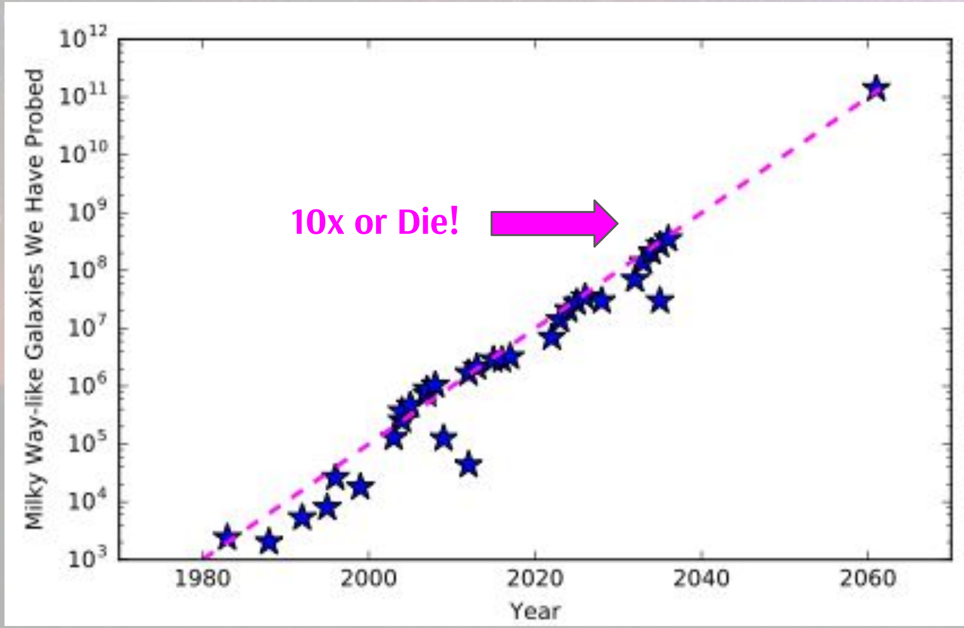
Transient (SN Ia) Follow-up Network

- **Scale of investment for US agencies, international partnerships, other investments:** Tiered by science case
  - Peculiar velocity / low redshift: one 2-m -- eight 4-m facilities
  - Expansion history / high redshift: one 4-m telescope -- one 10-m facilities
  - Refurbish older instruments, commitment of telescope resources; instrument R&D
  - Leverage planned/existing resources: older telescopes seeking work;, 4MOST, DESI, SNIFS
  - *Importance of science and risk mitigation should have us move away from current model of regularly applying for telescope time*
- **Desired support from the DOE laboratory system:** Collaboration building, interagency liason, MOUs with partner institutions, instrument R&D; detectors; remote/automated observing; data management
- **R&D plan:** IFU spectroscopy; Germanium CCDs

Intersection with 146. Small Projects to Enhance Stage IV photometric surveys

The MegaMapper: Framework

Juna Kollmeier on behalf of the MegaMapper Team : LOI



1. **Ambitious**: 10/10 → 10x improvement in mapping capability per decade to continue pace for LSS cosmology

   STAY ON THE LINE!

2. **Achievable**: No obvious technical or analytic show-stoppers. Multi-decade experience and proven techniques

   Guaranteed Success!

3. **Mid-scale**; Synergies with DOE workforce and current investments (DESI/Rubin) with opportunities for participation at all scales

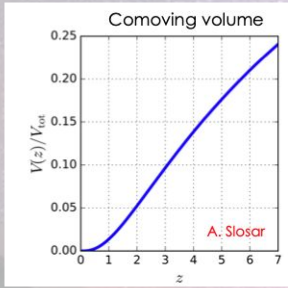
The MegaMapper: Overview

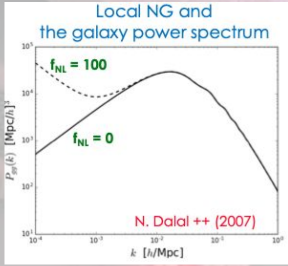
Juna Kollmeier on behalf of the MegaMapper Team : LOI

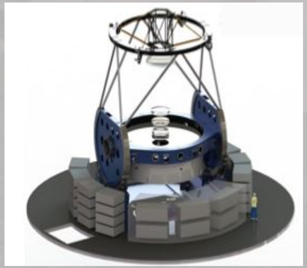
Focal Plane: 20,000 fibers with robotic positioners. • 32 petals, each feeding 625 fibers to a single spectrograph. • Close-packing at 6.2 mm pitch

Instruments: Fibers feed DESI spectrographs. Option to re-use 10 DESI spectrographs + 6 identical SDSS-V spectrographs **REDUCE COST/REUSE SUCCESSFUL DESIGNS/HARDWARE!**

Telescope: **6.5m telescope in Chile (maximal Rubin overlap!)**; A near copy of (or modification to) existing Magellan 1 & 2 telescopes. **7 square degree field of view**. Revised optical design and larger central hole; 2.5 m secondary mirror + 4/5-lens corrector including ADC







Probing High-z Dark Energy: Spectroscopic information content of the universe has barely been touched. Current DEFoM is woefully “compressed” w.r.t information content of the z=0-->6 universe. ***VOLUME, VOLUME, VOLUME!*** MORE MODES NOW! (See White & Wilson 2019). Enable reach into matter dominated era. (probe “tracking”)

Inflation via Non-Gaussianity: MegaMapper aims to probe interesting regime in primordial non-Gaussianity. The plan is to reach a precision where non-standard inflation models can be accessed. [$\sigma(f_{NL}^{local}) \approx 0.7$] **Ferraro et al.**

Probing Dark Matter: Vastly more powerful facility for probing small-scale structure of the Milky Way and effects of dark matter substructure.   **Simon et al.**

Support & Planning

Scale of Investment: MM is meant to be a **mid-scale experiment** at approximately ~$160M USD. Cost study and analysis underway. Various cost-saving mechanisms built in at the outset vis a vis re-used telescope and instrument designs/hardware

Collaboration Model: Similar to SDSS/DESI; Combination of Institutional support, private philanthropic foundations, and NSF/DOE. Anticipated NSF/DOE contributions total $50M/each with remainder raised via other avenues.

Desired Support from DOE Lab System: *Hardware development*: Focal plane and instrument from labs and DOE PIs (builds on HEP capability and workforce)

Timescale: First light in 2030; (possibly earlier depending on telescope system adopted)

R&D Plans: ***Some, but not all, of the required technology has been developed and deployed already***! New R&D involves robots, electronics, cooling, and optical studies. Early feasibility studies getting going now. *R&D investment done early saves $$$ down the line!*