Theory & the Cosmic Frontier

CF/TF9 Liaison Update

Flip Tanedo

UC RIVERSIDE
PHYSICS & ASTRONOMY

Snowmass 2021

THEORY FRONTIER

SNOWMASS

COMMUNITY PLANNING 2021

Selection of examples reflect my own limited familiarity. Please excuse many topics not explicitly mentioned and the rich literature not explicitly cited.

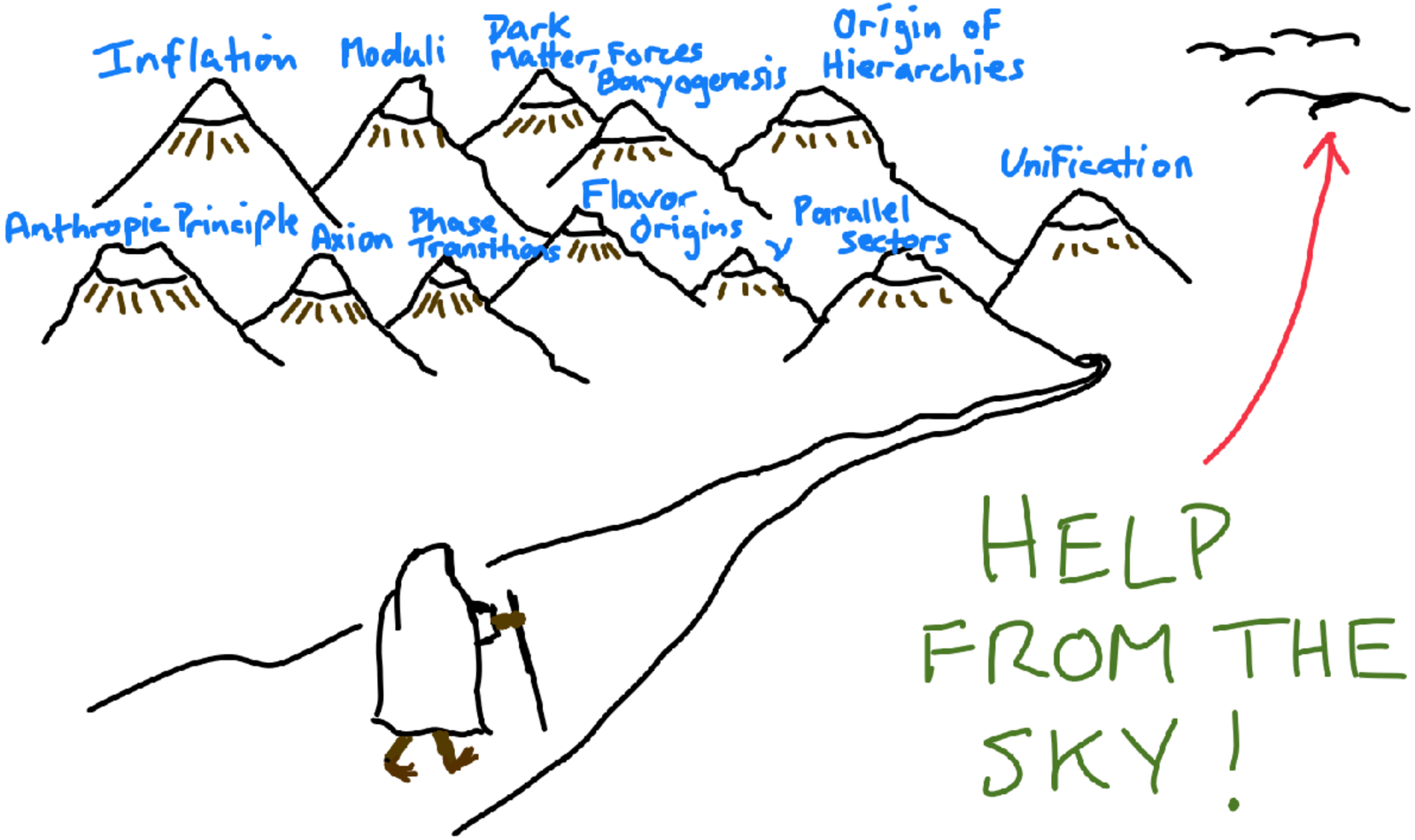
Feb 25, 2022

Theory Frontier Conference

UC SANTA BARBARA
Kavli Institute for Theoretical Physics

Theory Frontier / Cosmic Frontier relationship

A slogan for the CF as viewed by TF (via Raman)



Raman Sundrum's talk (pheno overview)

Take away message

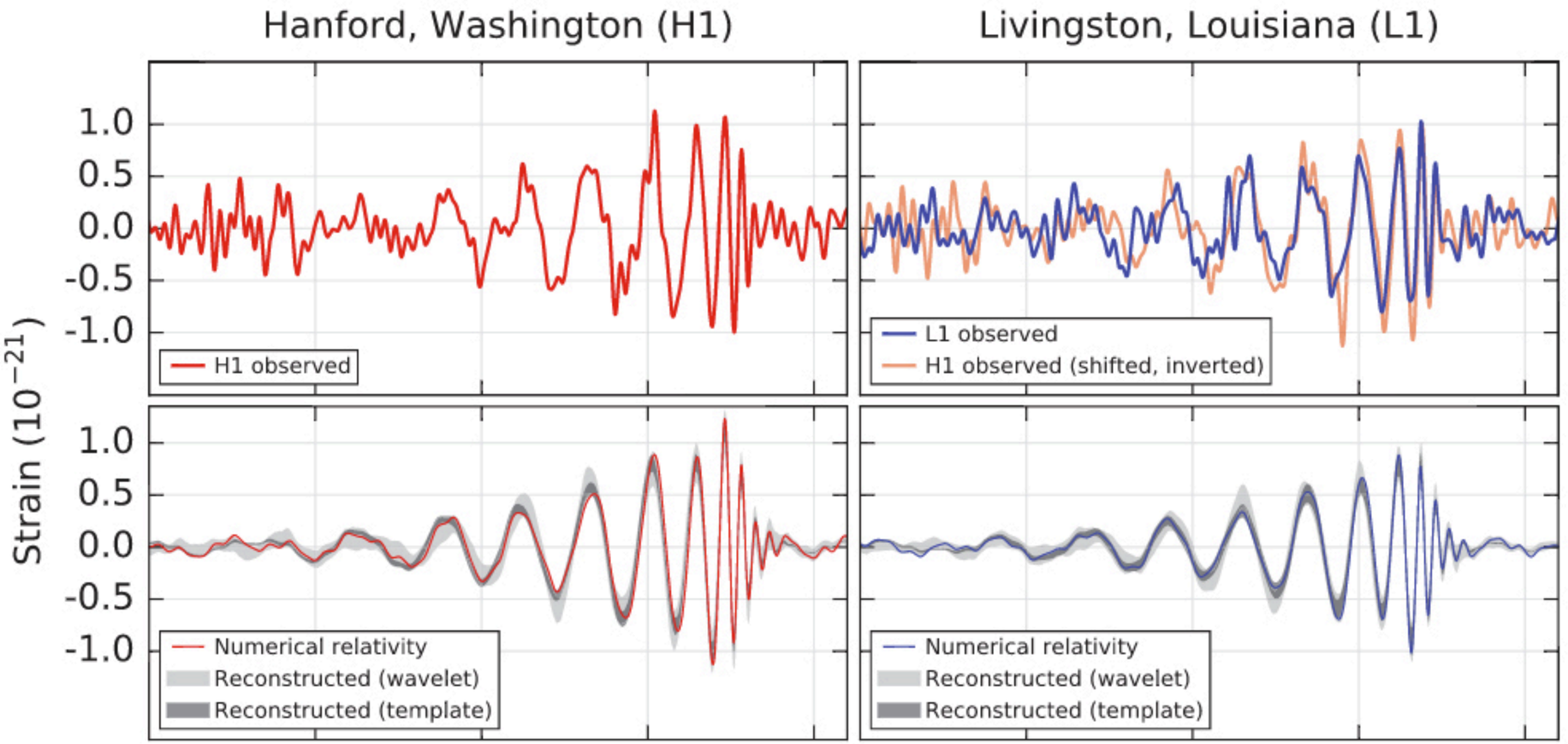
The cosmic frontier embodies the vibrancy of theory

and the *many ways* in which
theory is inextricable from discovery science.

Cosmic frontier is rapidly growing.
Theory & theorists are an essential part of this growth.

Since the last Snowmass...

Some highlights



H_0

σ_8

- New telescopes, experiments, facilities…
- Discrepancies that *may* be hints of new physics
- Big umbrella for “cosmic frontier”

Outputs from previous P5:
Dark Matter New Initiatives Program

B. P. Abbott et al., Observation of Gravitational Waves from a Binary Black Hole Merger, Phys. Rev. Lett. 116, 061102

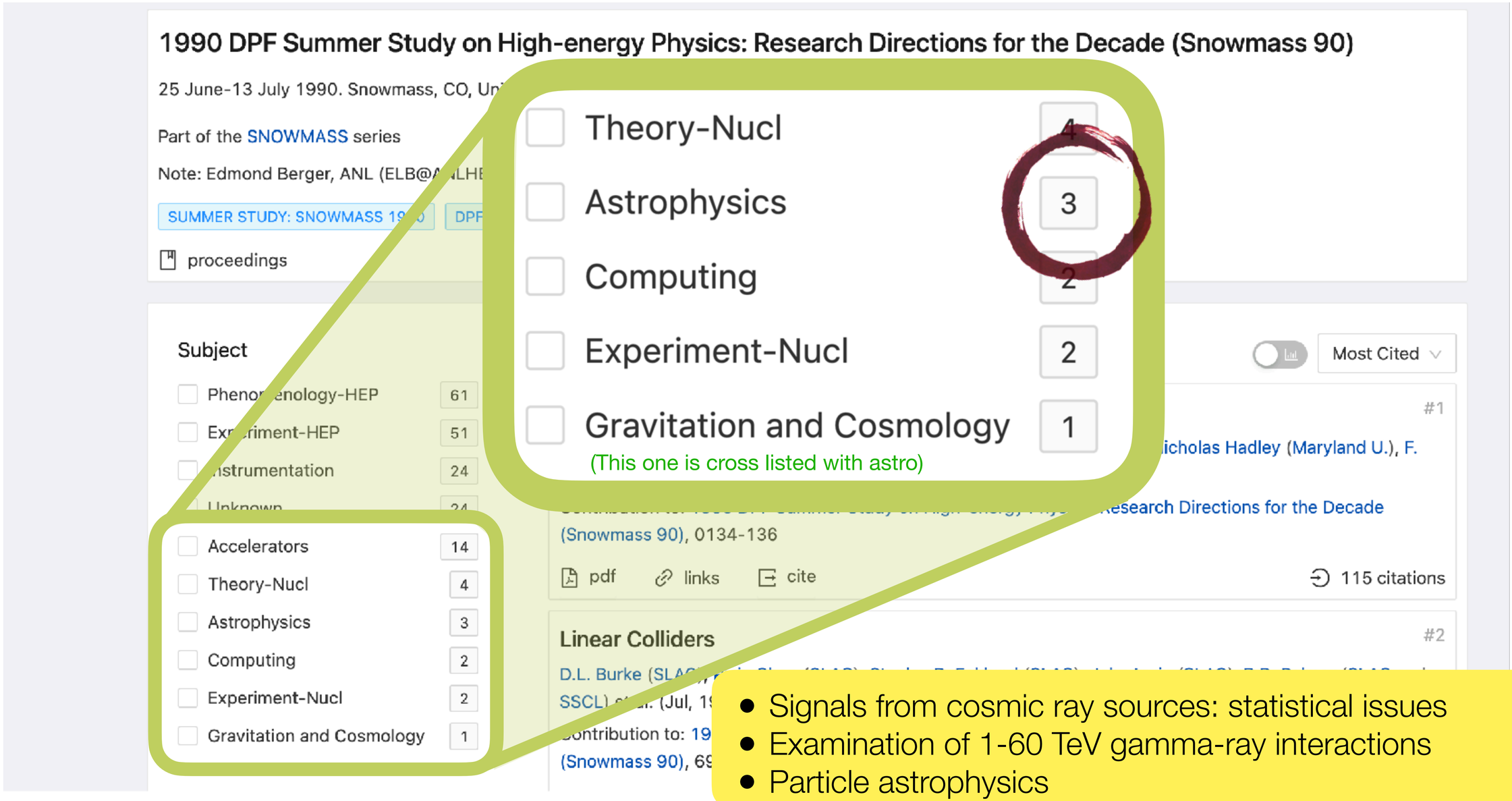
On the rapid development of the TF/CF connection

Until recently, string cosmology was the union of a field with no data and one with no predictions.

Shamit Kachru, ~2005

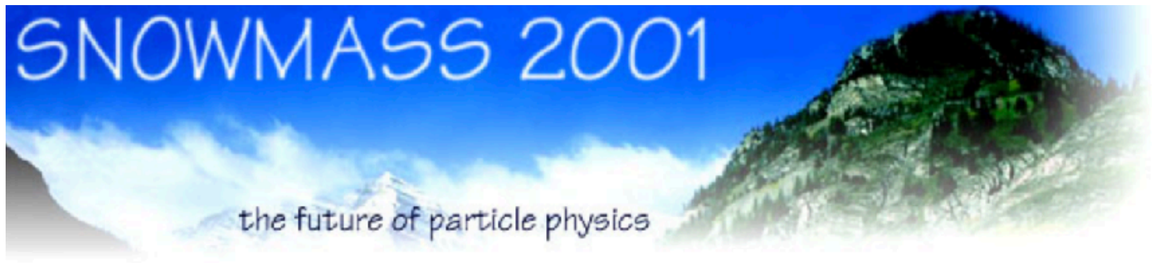
Contrast with the talks during this workshop!

Cosmic Frontier: Snowmass 1990



- Signals from cosmic ray sources: statistical issues
- Examination of 1-60 TeV gamma-ray interactions
- Particle astrophysics

Cosmic Frontier: Snowmass 2001



overview
@snowmass
schedule
bulletin
practical info
people/groups
NPSS technology
education outreach
media
young physicists
communication workshops
sponsors

P4: Working Group on Astro/Cosmo/Particle Physics

Working Group Convenors: Dan Akerib (Case-Western Reserve), Sean Carroll (Chicago), Marc Kamionkowski (Caltech), Steve Ritz (Goddard)

The Astro/Cosmo/Particle Physics Working Group encompasses a broad range of scientific topics that border on particle physics, cosmology, and astronomy. This area of research has been delineated more by historical accident than by calculated design. One of the goals of this group will be to explore what constitutes astro/cosmo/particle physics. For the purposes of this working group, we will consider research done in the following areas as at least being pertinent:

- Cosmology and the early Universe
- Dark matter and dark energy
- High-energy particle astronomy (using gamma-rays, cosmic rays, and neutrinos)

How many people in this room were in Snomass Young in 2001?

Group activities overview

- **Accelerators** (M1-M6)
- **Accelerator Physics / Technology** (T1-T9)
- **Experimental Approaches** (E1-E7)
- **Physics Issues** (P1-P5)

- Cosmology and the early Universe
- Dark matter and dark energy
- High-energy particle astronomy
- **Gravitational waves**
- The search for nucleon instability and the problem of why the Universe is made of matter

snowmass2001.org

Cosmic Frontier: Snowmass 2013

Cosmic Frontier

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
25. WIMP Dark Matter Indirect Detection
26. Non-WIMP Dark Matter
27. Dark Matter Complementarity
28. Dark Energy and CMB
29. Cosmic Probes of Fundamental Physics

+ 27 contributed papers classified by

- General
- Cosmic probes of new physics
- Dark energy and CMB
- Dark matter complementarity
- non-WIMP dark matter
- WIMP direct detection
- WIMP indirect detection

slac.stanford.edu/econf/C1307292

Cosmic Frontier: Snowmass 2021

dark matter

dark energy

beyond

Neutrinos, relativity, emergent spacetime,
Black hole information, Hubble tension,
Nuclear matter, extreme environments, …

- **CF1 particle-like**
- **CF2 wave-like**
- **CF3 cosmic probes**
- **CF4 modern universe**
- **CF4 (pre-) cosmic dawn**
- **CF6 complementarity**
- **CF7 fundamental physics**
- **dark matter complementarity**

Convenors: theory


TIM TAIT (CF CONVENER)


JOERG JAECKEL


TONGYAN LIN


TRACY SLATYER


HAI-BO YU


CHANDA PRESCOD-WEINSTEIN


ANŽE SLOSAR


DEIRDRE SHOEMAKER


VIVIAN MIRANDA


KE FANG


B.S. SATHYAPRAKASH

Photos from public webpages

CF1 particle-like

CF2 wave-like

CF3 cosmic probes

CF4 modern universe

CF4 (pre-) cosmic dawn

CF6 complementarity

CF7 fundamental physics

Liaison: **Flip Tanedo**, contact me to facilitate cross-frontier coordination

MAD LIBS (Cosmic/Theory Frontier edition)

World's Greatest Word Game

Theory _____ experiment.

(& simulation) (VERB) (& observation)

Image: Logopedia

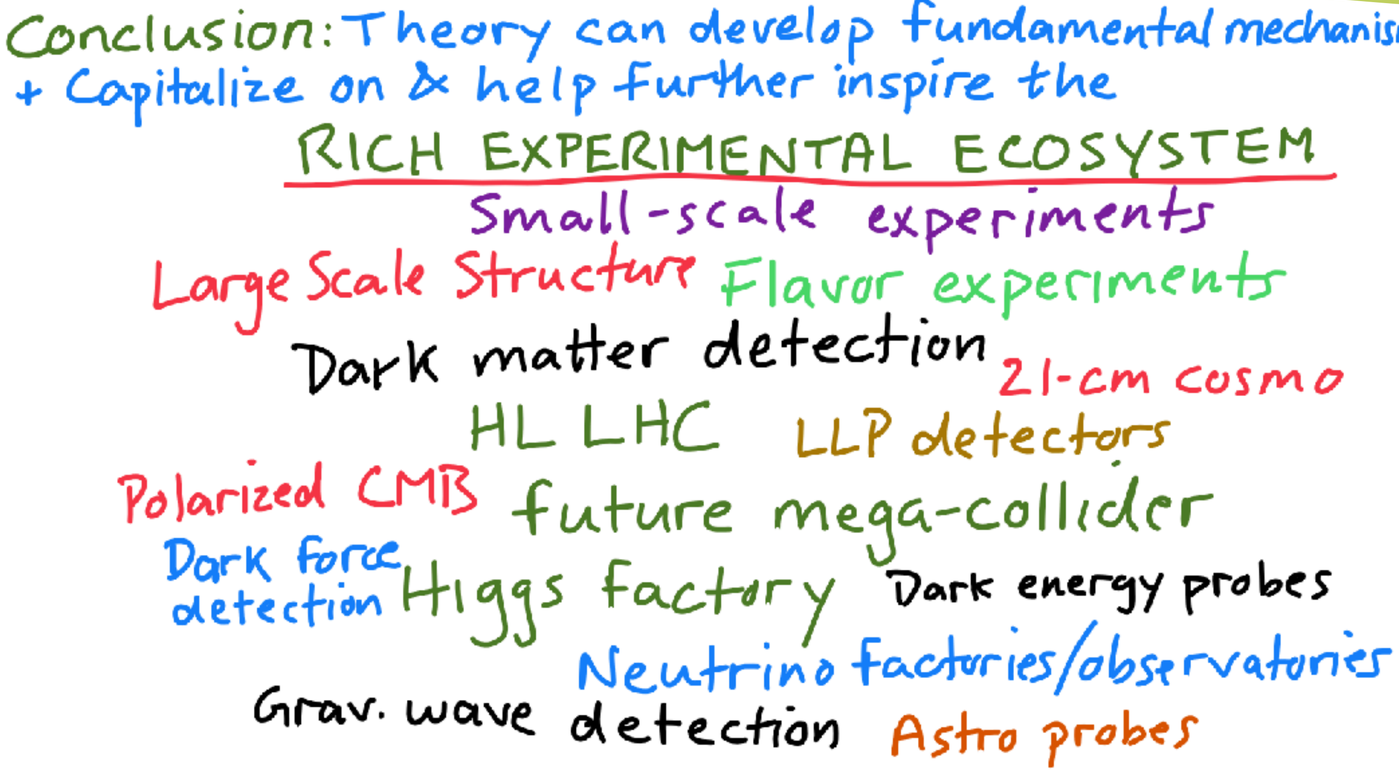
MAD LIBS (Cosmic/Theory Frontier edition)

World's Greatest Word Game

Theory _____ experiment.

DEVELOP
CAPITALIZE ON
INSPIRE

Raman:
(pheno
overview)



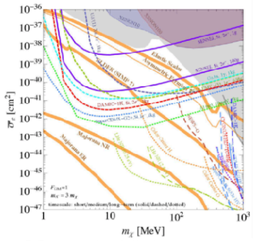
Raman Sundrum's talk

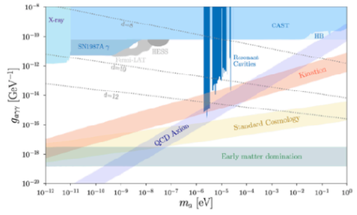
MAD LIBS (Cosmic/Theory Frontier edition)

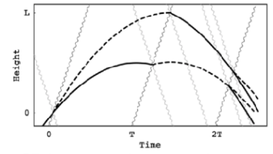
World's Greatest Word Game

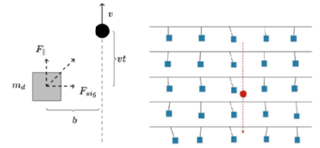
Theory _____ experiment.

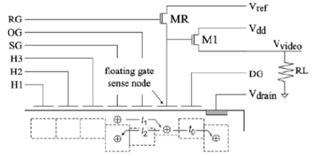
- Define theory targets
- Invent new uses for existing sensors
- Spur development of new sensors
- Help interpret new data (CM connections!)

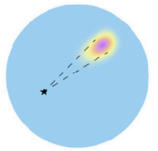

[Cosmic Visions 2018]

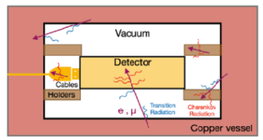

[Blinov et al 2019]

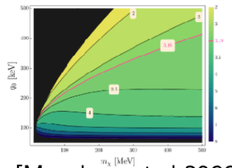

[Dimopoulos et al 2007]


[Carney et al 2019]


[Essig et al 2017]


[Baym et al 2020]


[Du et al 2021]


[Mandava et al 2022]

Yoni Kahn's talk (quantum sensors)

MAD LIBS (Cosmic/Theory Frontier edition)

World's Greatest Word Game

Theory _____ experiment.

(VERB)

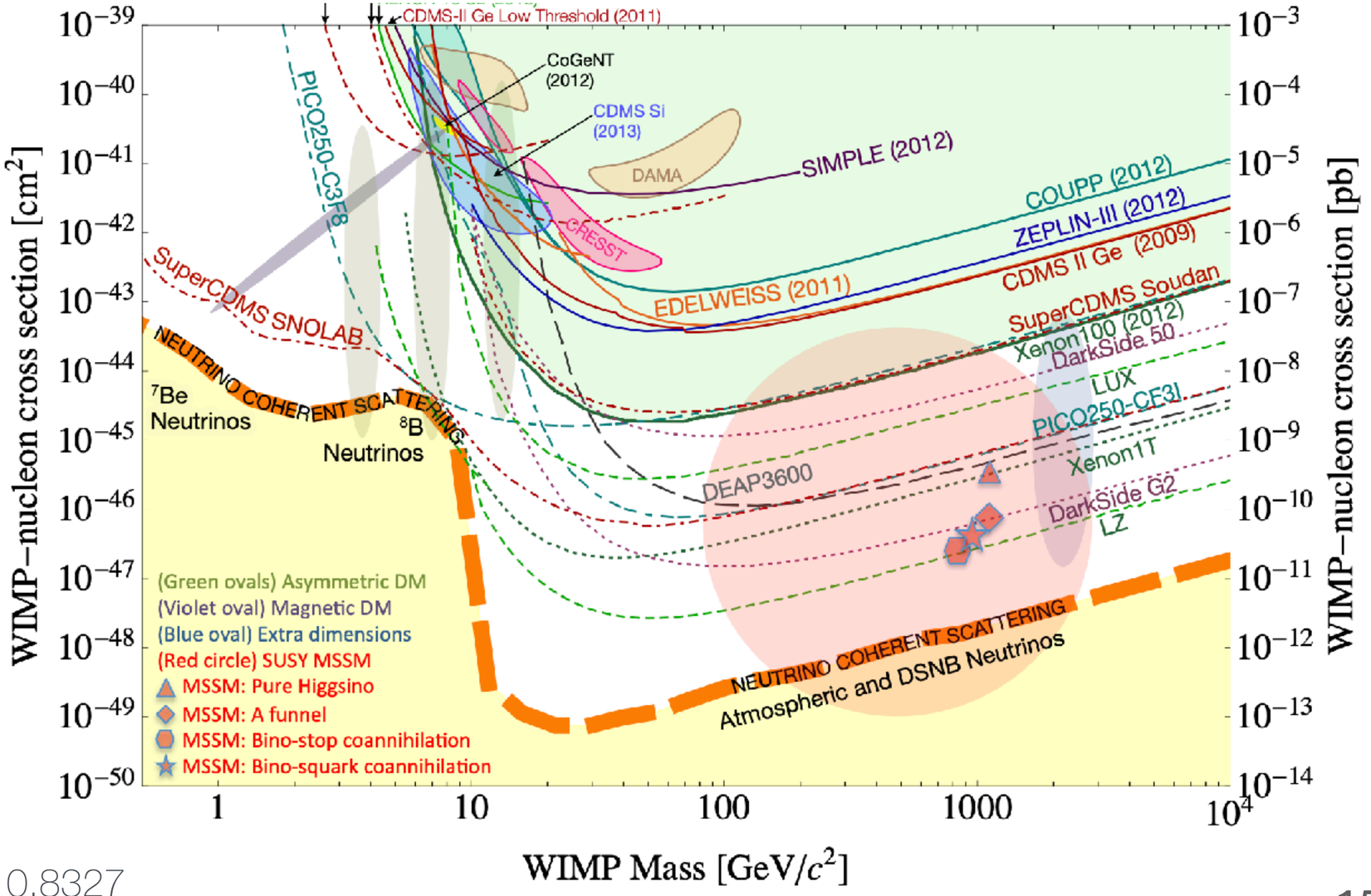
motivates | interprets | contextualizes | instigates | empowers

Theory motivates experiment.

2013

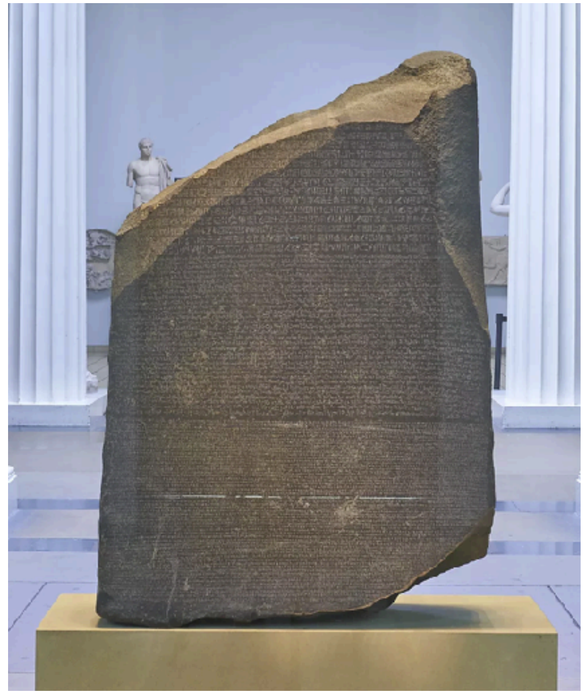
Going beyond theory = models to test

Nothing wrong with this, especially when our priors favor those models. But the role theory is more than a target on a plot.

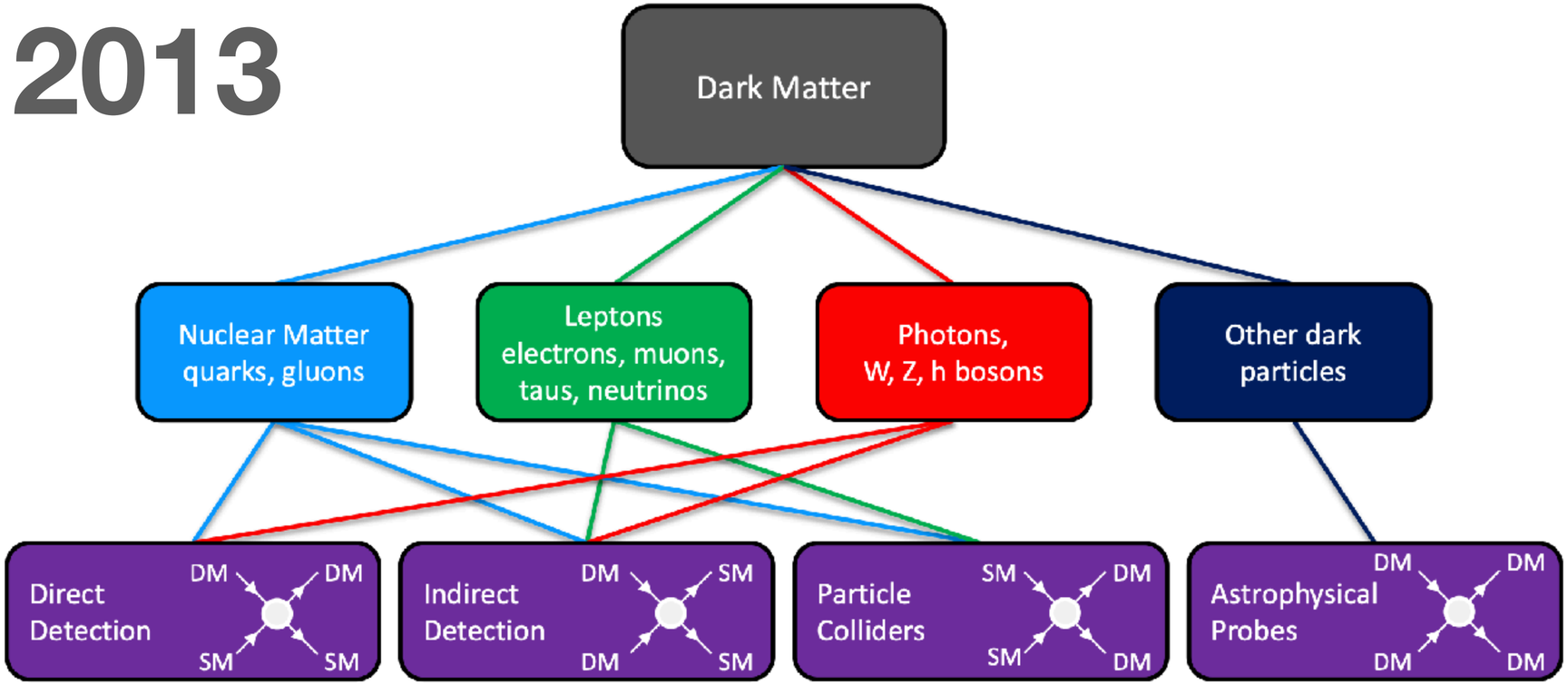


Snowmass 2013 CF1 report (Fig. 26) 1310.8327

Theory interprets experiment.



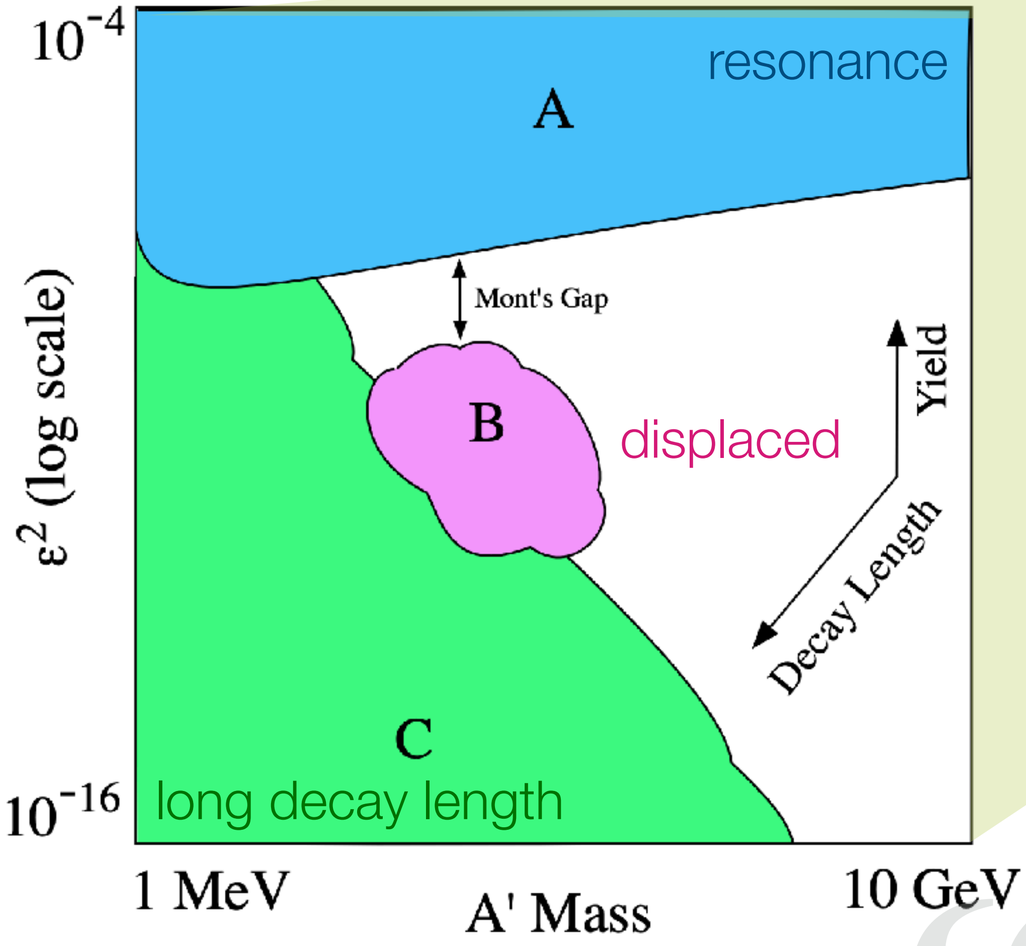
2013



Snowmass 2013, Cosmic Frontier: “Complementarity” report 1310.8621

Image: Rosetta Stone, *The British Museum* blog

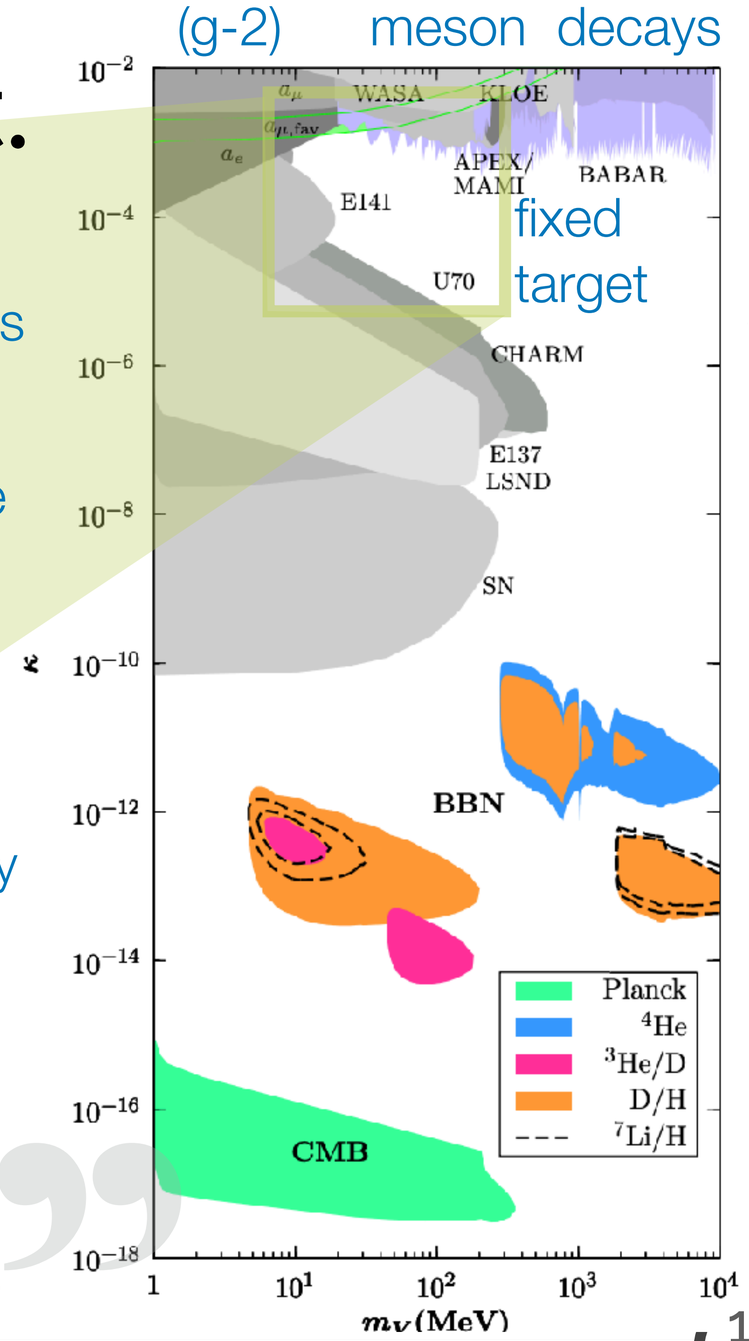
Theory contextualizes experiment.



beam dumps

supernovae

cosmology



Fradette, Pospelov, Pradler, Ritz 1407.0993

> Astro/cosmo/particle
> **multimessenger**
> **multiwavelength**

Images: Natalia Toro, Dark Sectors 2016 (1608.08632)

Theory instigates experiment.

The Forward Physics Facility at the High-Luminosity LHC

FASER: ForwArd Search ExpeRiment at the LHC

Editors: Jonathan Feng & Felix Kling (**BSM** and **DM**), Halsey Reno (**neutrinos**), Juan Rojo (**QCD**), and Dennis Soldin (**astroparticle**).

CERN Physicists Detect Collider Neutrinos for First Time

Nov 26, 2021 by News Staff / Source « Previous | Next »

Published in Physics

Tagged as CERN

Physicists from the Forward Search Experiment (FASER) Collaboration have observed six neutrino interactions during a pilot run of FASERν, a compact emulsion detector installed at CERN's Large Hadron Collider (LHC) in 2018.

See talk by Felix Kling; CF07 "Far Forward Physics" white paper; image: sci-news.com

Theory instigates experiment.

Direct Detection of Sub-GeV Dark Matter

Rouven Essig (SLAC), Jeremy Mardon (UC, Berkeley and LBL, Berkeley and Stanford U., ITP), Tomer Volansky (UC, Berkeley and LBL, Berkeley) (Aug, 2011)

Published in: *Phys.Rev.D* 85 (2012) 076007 • e-Print: 1108.5383 [hep-ph]

Direct Detection of sub-GeV Dark Matter with Semiconductor Targets

Rouven Essig (YITP, Stony Brook), Marivi Fernandez-Serra (Stony Brook U.), Jeremy Mardon (Stanford U., ITP and Stanford U., Phys. Dept.), Adrian Soto (Stony Brook U.), Tomer Volansky (Tel Aviv U.), Tien-Tien Yu (YITP, Stony Brook)

Published in: *JHEP* 05 (2016) 046 • e-Print: 1509.01598 [hep-ph]

SENSEI: Direct-Detection Constraints on Sub-GeV Dark Matter from a Shallow Underground Run Using a Prototype Skipper-CCD

SENSEI Collaboration • Orr Abramoff (Tel Aviv U.) et al. (Jan 29, 2019)

2021 New Horizons in Physics Prize

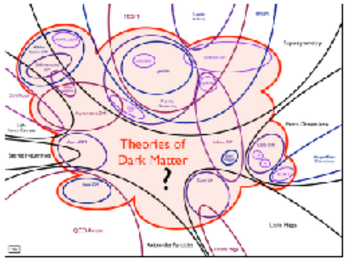
For advances in the detection of sub-GeV dark matter especially in regards to the SENSEI experiment

See Yoni Kahn's talk; White Paper: "Theory Meets the Lab" (TF09). See also work by Natalia Toro, Philip Schuster, and Rouven started (APEX); Yoni Kahn, Gordan Krnjaic, e tal. (M3 muon beam dump proposal, quantum sensing); Masha Baryakhtar, Robert Lasenby, and Junwu Huang (dark photon haloscopes); Mina Arvanitaki, Ken van Tilburg, Marianna Safranova et a. (ultralight scalar DM using atomic probes)

Theory empowers experiment.

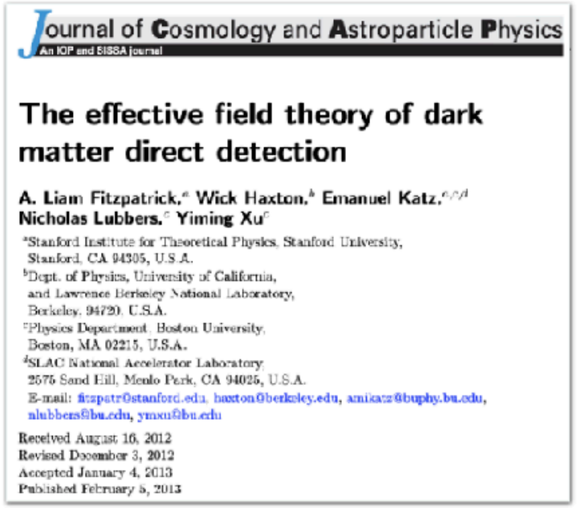
EFT of DM direct detection w/ phonons & magnons

Trickle. ZZ. Zurek. 2009.13534.



Similar situation in nuclear recoil calculations.

- At first, just spin-independent (SI) and spin-dependent (SD) benchmarks.
- Later on, extended to EFT.
- UV model ⇒ EFT ⇒ nuclear responses ⇒ rates.


Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

The effective field theory of dark matter direct detection

A. Liam Fitzpatrick,[a] Wick Haxton,[b] Emanuel Katz,[c,d,A] Nicholas Lubbers,[c] Yiming Xu[c]

[a]Stanford Institute for Theoretical Physics, Stanford University, Stanford, CA 94305, U.S.A.
[b]Dept. of Physics, University of California, and Lawrence Berkeley National Laboratory, Berkeley, 94720, U.S.A.
[c]Physics Department, Boston University, Boston, MA 02215, U.S.A.
[d]SLAC National Accelerator Laboratory, 2575 Sand Hill, Menlo Park, CA 94025, U.S.A.
E-mail: fitzpatr@stanford.edu, haxton@berkeley.edu, amkatz@buphy.bu.edu, nlubbers@bu.edu, ymxu@bu.edu

Received August 16, 2012
Revised December 3, 2012
Accepted January 4, 2013
Published February 5, 2013

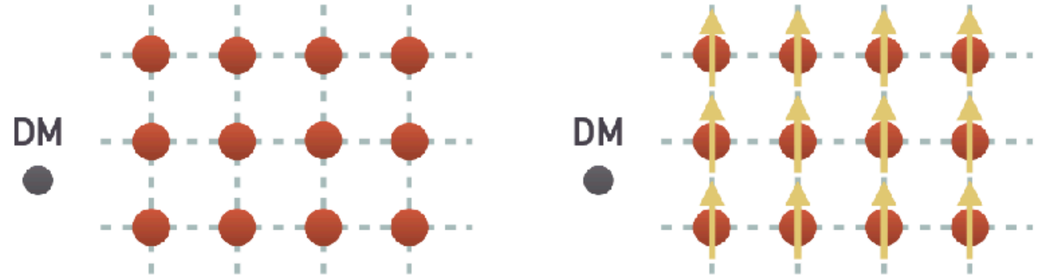
Crystal responses

Nonrelativistic (NR) EFT of DM-SM interactions

See also:
Cirelli, Del Nobile, Panci, 1307.5955.
Anand, Fitzpatrick, Haxton, 1308.6288 + 1405.6690.
Gresham, Zurek. 1401.3739.
Del Nobile, 1806.01291.

Similar calculation for electron excitations in atoms:
Catena, Emken, Spaldin, Tarantino, 1912.08204.

Phonon & magnon excitation rates



Killer app:
light dark matter

"EFT of crystal responses"

Slide from Kevin Zhang, HKUST IAS HEP program (2021); Review: Yoni Kahn & Tongyan Lin (2108.03239)

MAD LIBS (Cosmic/Theory Frontier edition)

World's Greatest Word Game

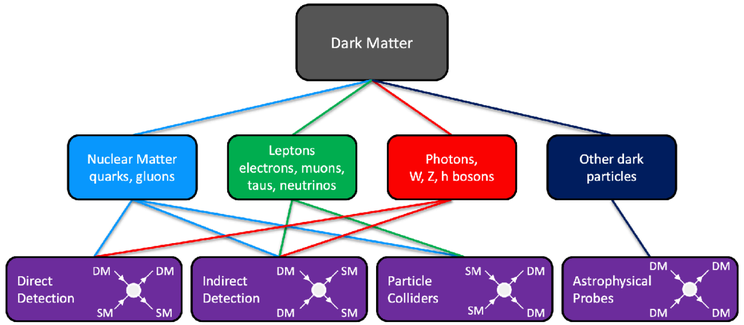
Theory _____ experiment.

(VERB)

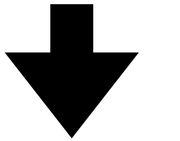
motivates | interprets | contextualizes | instigates | empowers

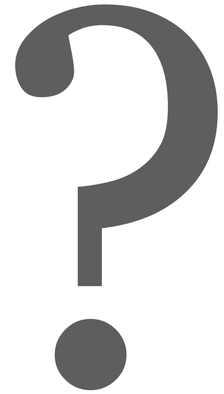
Dark Matter Complementarity 2021

A call to action: Cosmic Frontier complementarity group



- Need a **simple message**. e.g. *we've made progress and have clear goals for the decade*
- Need a **simple picture** that works across frontiers.
  - NO EXCLUSION PLOTS :)
  - Qualitative plots okay, something for colloquia.
- High level summary of the field vs. technical details
- #dark_matter_complementarity_discussions





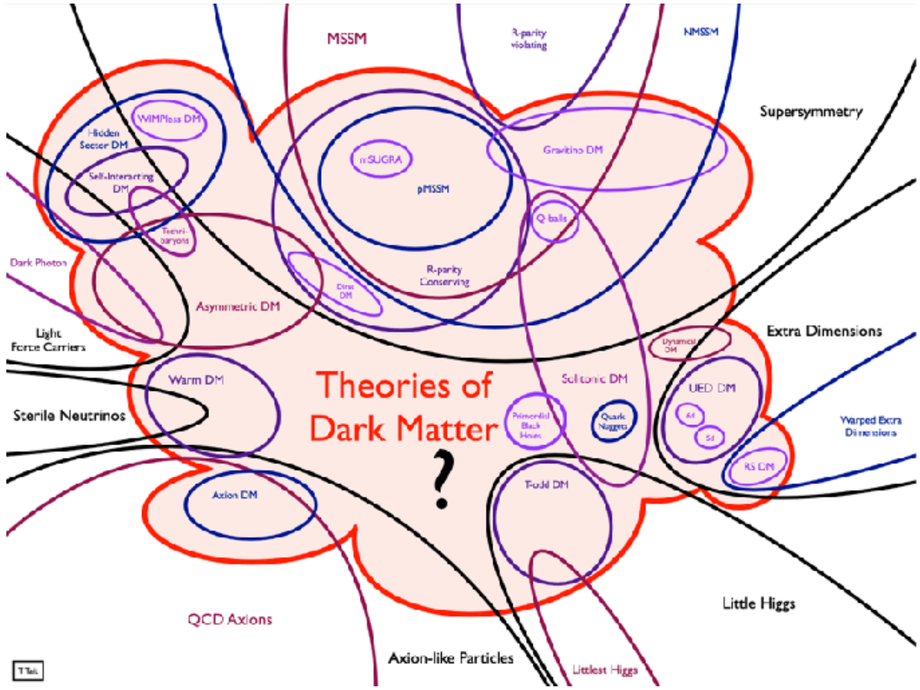
Slide courtesy of Lindley Winslow (adapted by Flip, with apologies for trimming)

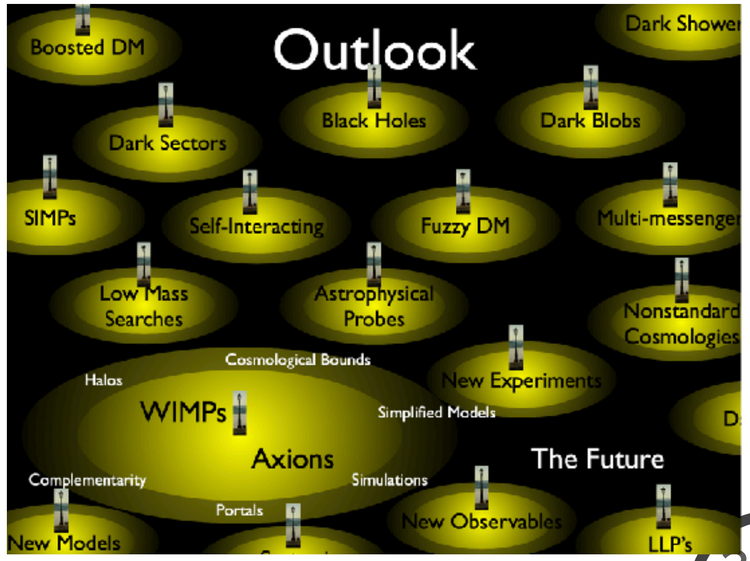
Dark Matter Complementarity 2021

Goal: concrete requests

- How do we maximize data from different souces?
- Continue Dark Matter New Initiatives process
- Support for new demonstrations
- R&D towards transformative technologies
- Progress on targets, detector response, …
- Vision: **every** frontier intersects with dark matter. Can be one of the unifying questions across Snowmass.

- #dark_matter_complementarity_discussions





Tim Tait's talk

Slide courtesy of Lindley Winslow (adapted by Flip, with apologies for trimming)

MAD LIBS (Cosmic/Theory Frontier edition)

World's Greatest Word Game

Theory YOUR VERB HERE _____ experiment.

motivates | interprets | contextualizes | instigates | empowers

The cosmic frontier embodies the
vibrancy of theory
and the *many ways* in which
theory is inextricable from discovery science.