
Cosmic frontier: Theory efforts & synergies

Laboratory activities

- Regular interactions between HEP theory, Astro-theory and cosmo/astro experiment
- Astrophysics seminar series
- Weekly MUNCH journal club
- Weekly “chalk talk”
- “Axion club” – an informal gathering of theorists and experimentalists
- 2014 Academic Lectures including four on dark matter and five on CMB

Community leadership

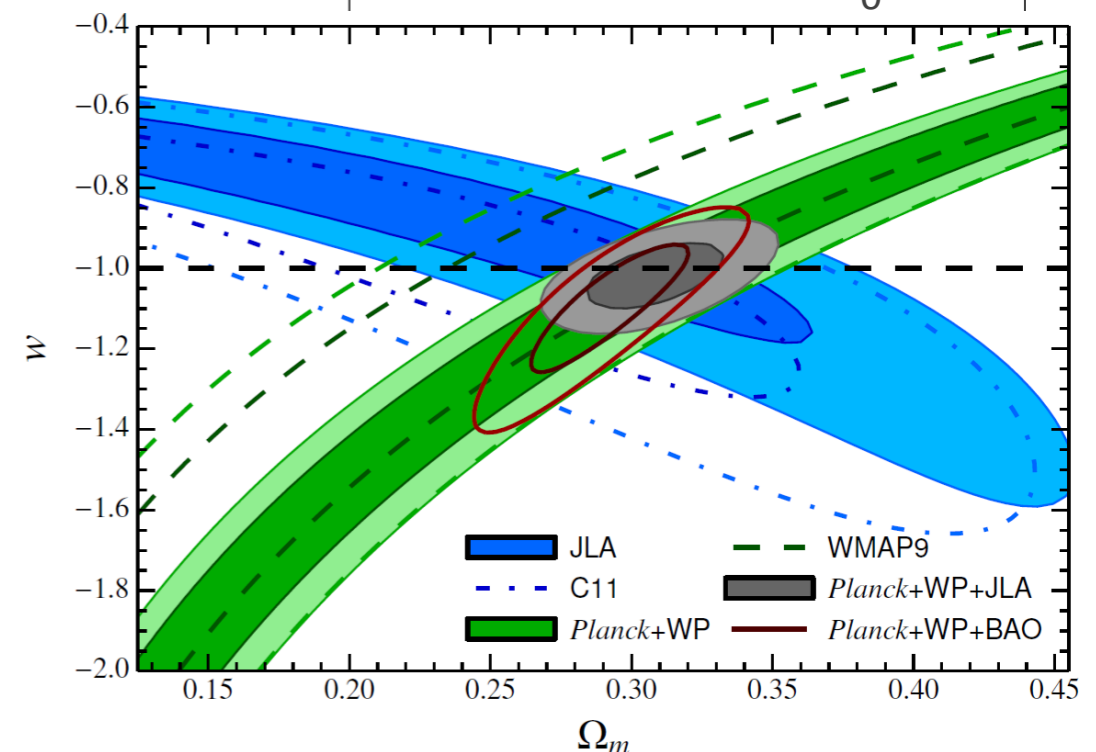
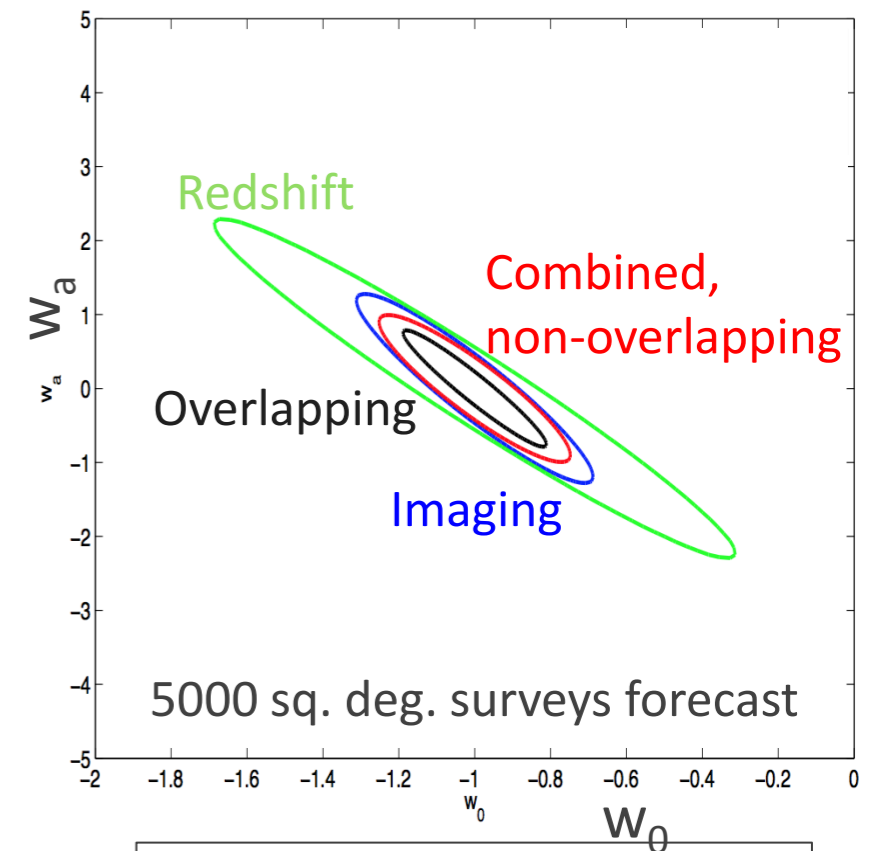
- Group represented on P5
- Several Snowmass co-conveners
- DOE Dark Energy Science Plan Task Force
- HEPAP Subpanel on Future DOE HEP Facilities
- Multiple advisory committees e.g. NAS Astronomy and Astrophysics, NAS Assessment of a Plan for US Participation in Euclid, NAS Future of the Optical/Infrared System, DOE/NSF/NASA
- International Advisory Committee: International Institute of Physics (Brazil)
- APS Division of Astrophysics (Dep. Secretary)
- Aspen Center for Physics (Vice President)

Workshops, schools, & mentoring

- > 20 students advised in period 2011–2014
- Organized international conferences and schools at Fermilab and elsewhere e.g.
 - Combining Probes in Cosmological Surveys,
 - Cosmological Survey Inference System,
 - DES–LSST Joint Workshop,
 - First Galaxies and Faint Dwarfs,
 - Cross–correlating Cosmic Fields,
 - Beijing 21cm Workshop,
 - Identification of Dark Matter,
 - New Perspectives on Dark Matter,
 - Combined Probes in DES,
 - Primordial Non–gaussianity,
 - Workshop on Laboratory Tests of Dark Energy....

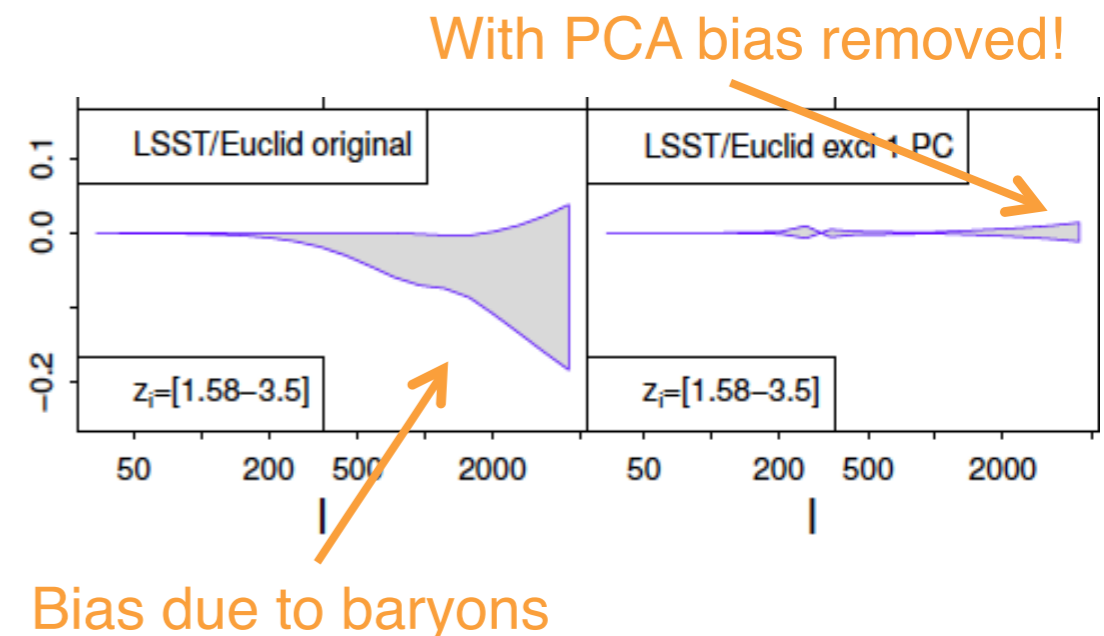
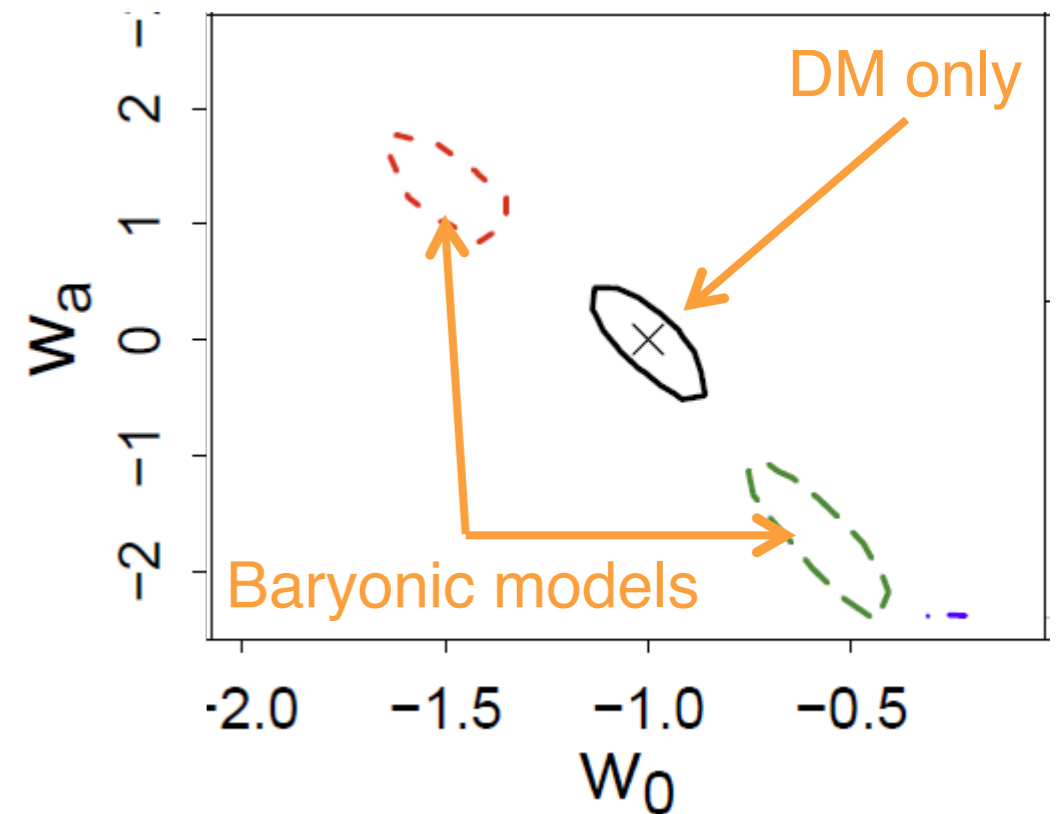
Dark Energy [Frieman, Gnedin]

- Constraining DM and modified gravity with combined surveys
 - overlapping 2D (imaging e.g. DES, LSST) and 3D (redshift e.g. BAO, eBOSS) surveys provide stronger constraints
- Results impact design of cosmic surveys
- Improving supernovae constraints on dark energy
 - control dominant SN distance systematics
 - results in tightest and robust DE constraints to date



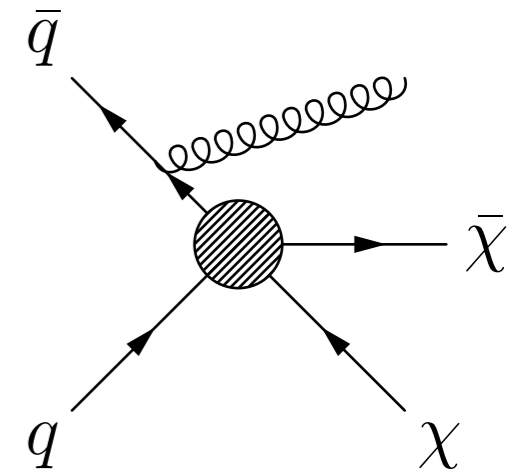
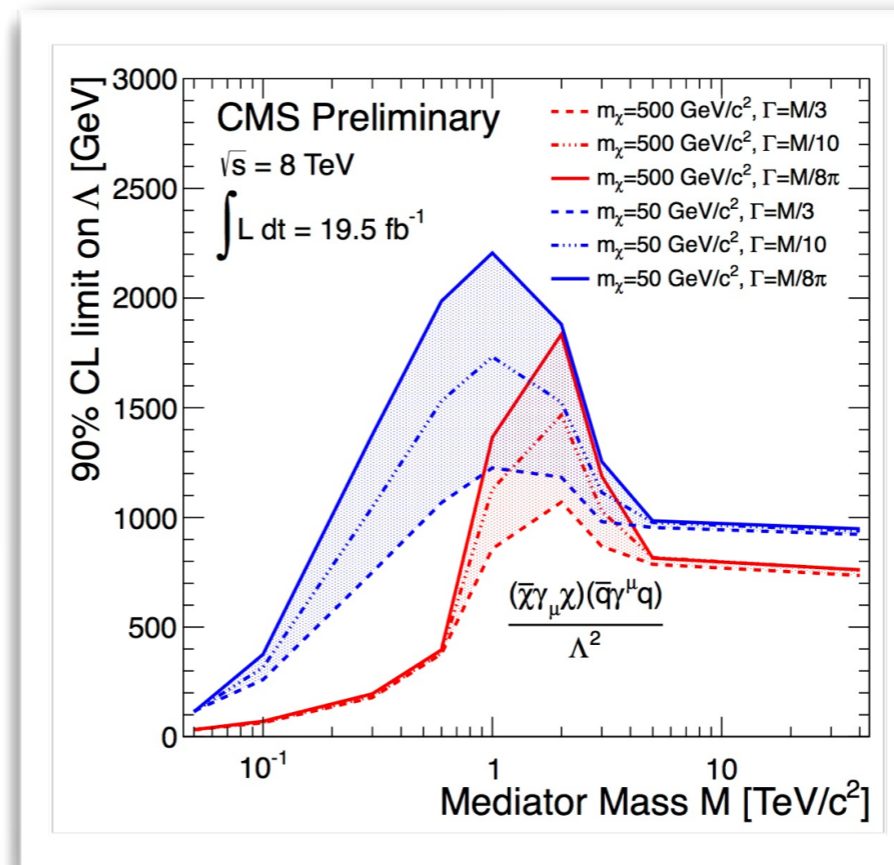
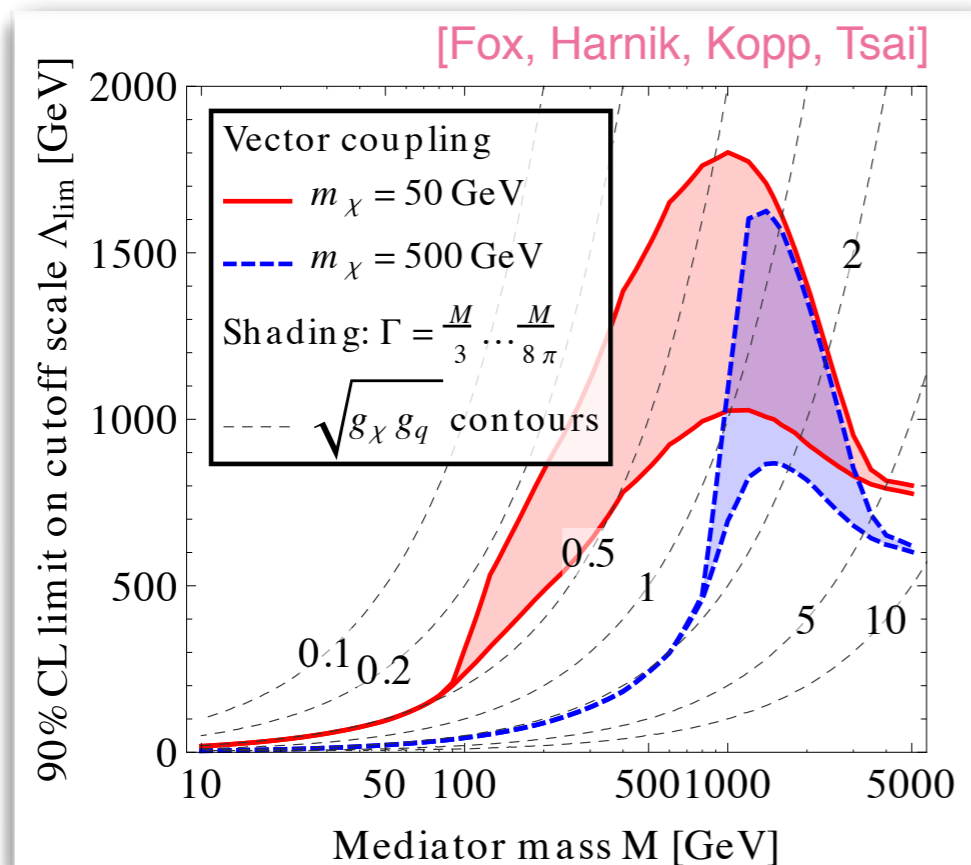
Cosmological Computing [Gnedin, Dodelson]

- Baryonic physics affects matter clustering in complex way and is major systematic effect in many Dark–Energy studies
 - Comparable to statistical errors for existing surveys (e.g. DES), but will be “killer” for LSST.
- Fermilab theorists using numerical simulations including baryons to develop and test approaches for mitigating bias from baryonic effects.
 - Developed a novel, Principal Component Analysis based method that removes most bias and improves significantly over previous approaches.
 - With Scientific Computing Division, building a general simulation suite for community use.



Mono-X: Dark matter @ the LHC [Fox, Harnik]

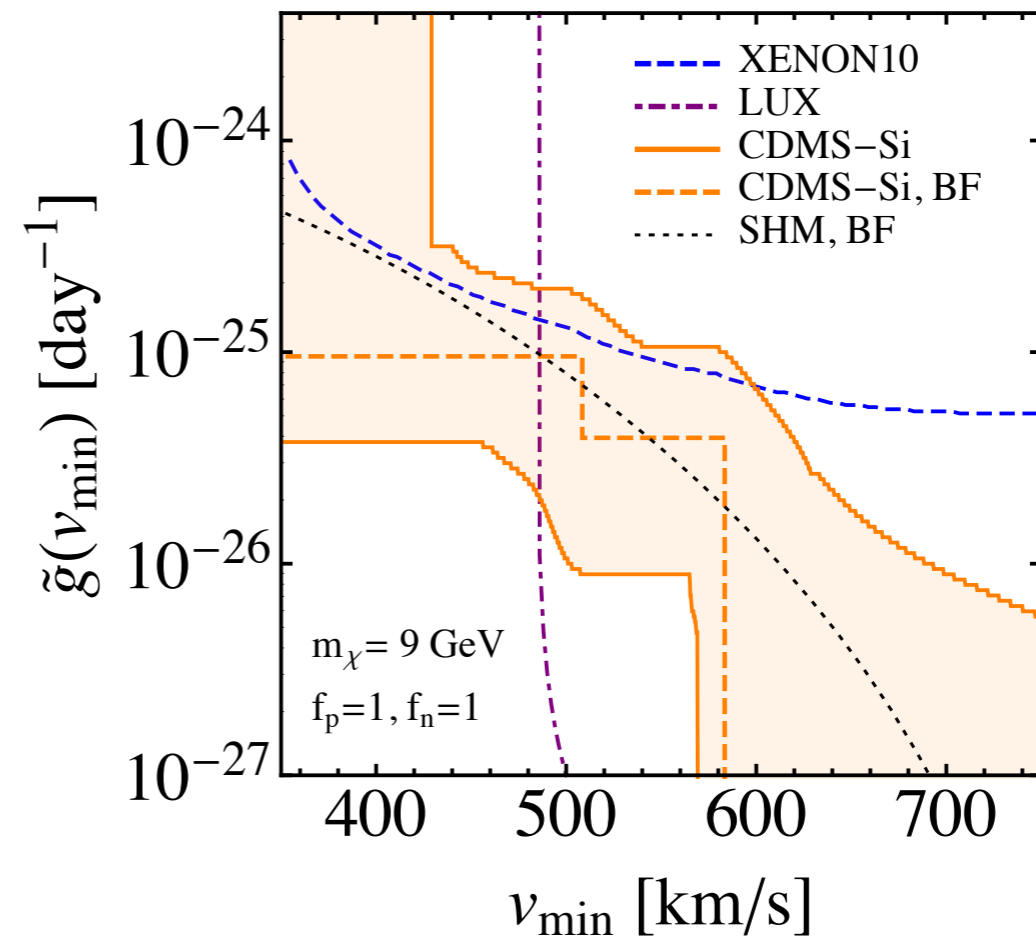
- Using “mono”-jet/photon/Z/W/X searches at colliders as a complement to direct and indirect DM searches
- Fermilab group one of the pioneers
- Now a standard search channel at LHC.
 - Regular interaction with CDF, CMS, and ATLAS



- Ongoing progression from EFT operators to simplified models
 - NLO implementation into MCFM [Fox, Williams]

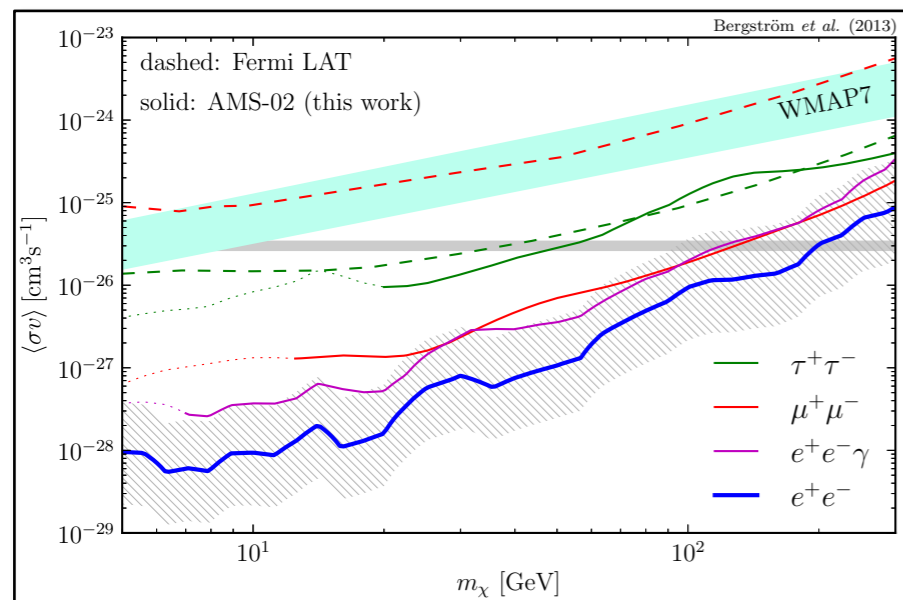
WIMP searches: traditional [\[Fox, Hooper\]](#)

- Particle and Astroparticle theory group members have regular contact with CDMS, LZ, PICO, CoGeNT, LUX,... to discuss signatures, searches and interpretations
- Developed a technique to enable analysis of direct detection results free of assumptions about astrophysics, applied to CoGeNT, LUX [\[Fox\]](#)
- Being adopted by experiments

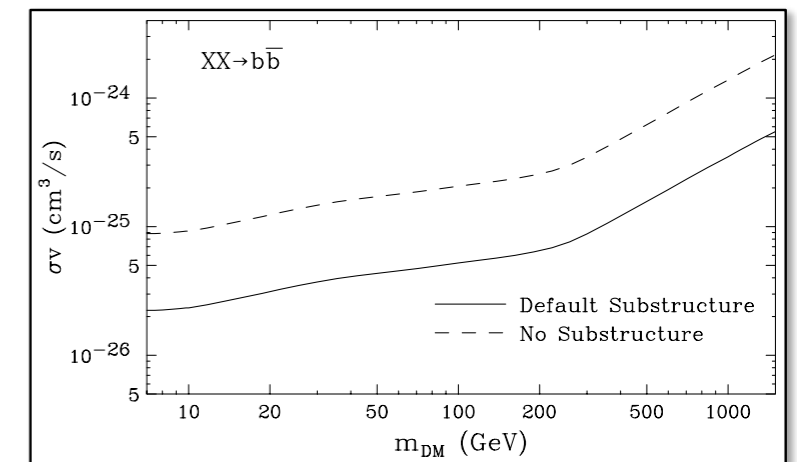
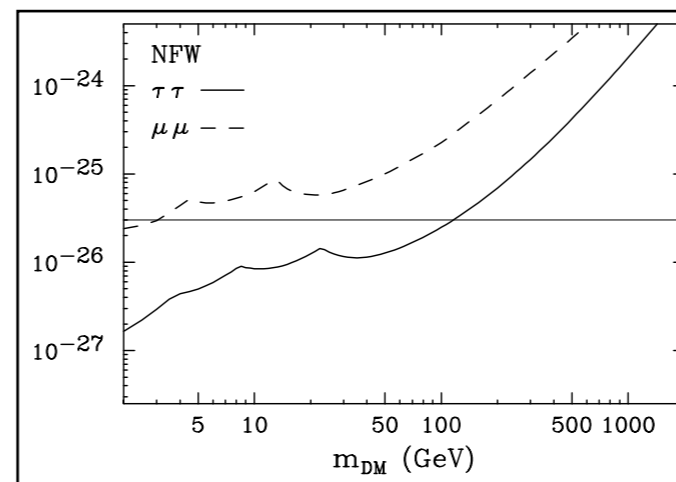


Indirect WIMP searches [Hooper]

- Fermilab has been at the forefront of indirect DM searches, including those utilizing gamma-ray, positron, antiproton, neutrino, and radio signals
- These studies have yielded some of the most stringent limits on the particle nature of DM:



AMS results yield very stringent constraints on leptophilic DM [Cholis, Hooper]

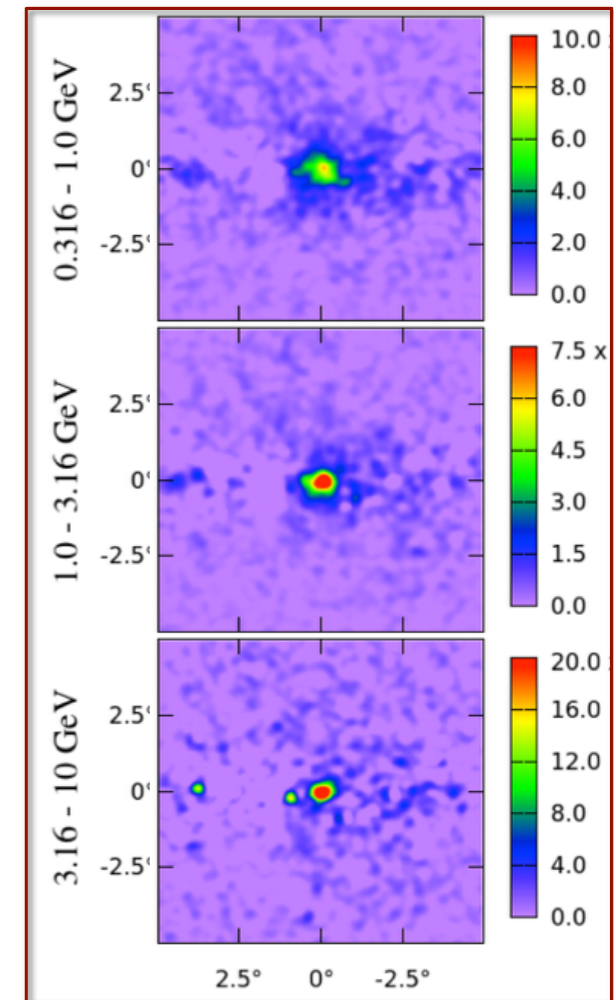
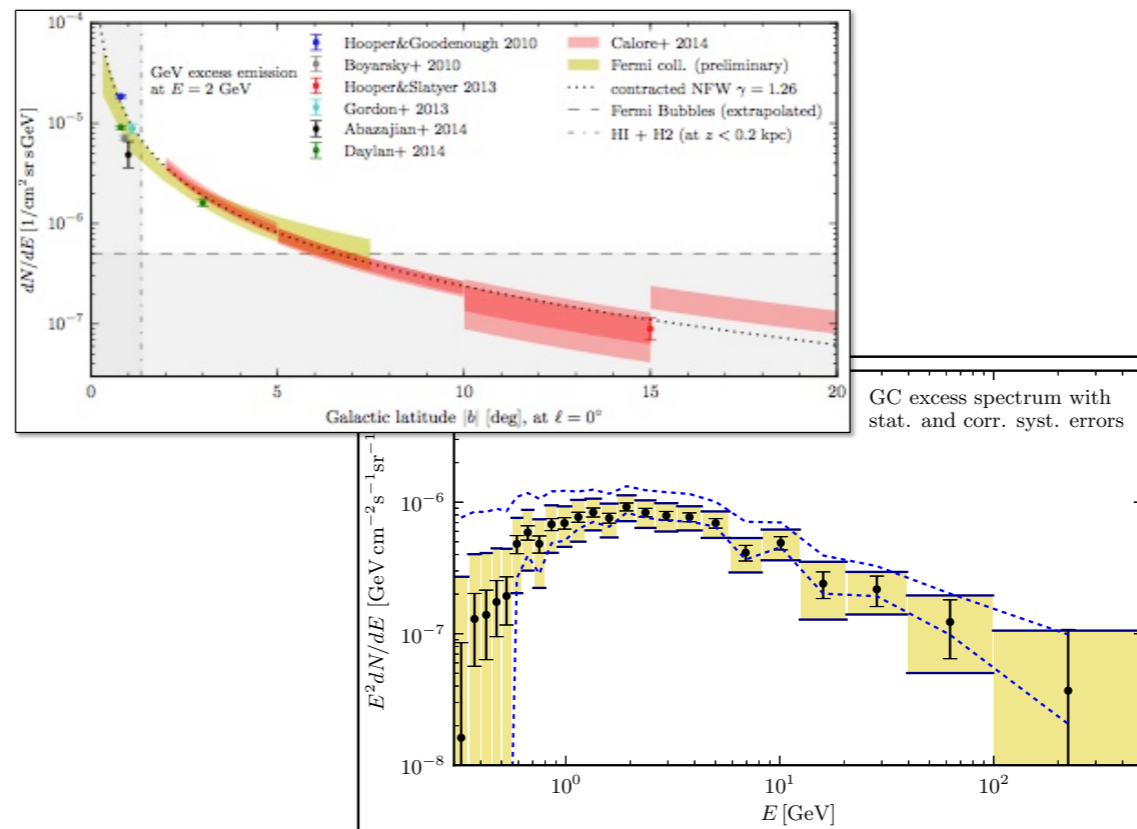
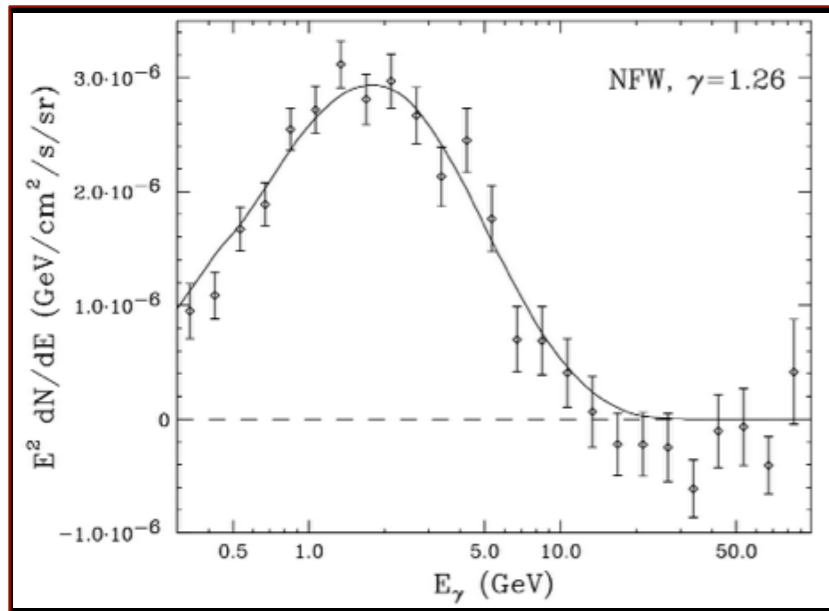


Stringent constraints from gamma-ray observations of the Galactic Center [Hooper, Kelso], the isotropic background [Cholis, Hooper, McDermott], subhalo searches [Berlin, Hooper]

- New cosmic ray antiproton measurements (anticipated soon) are expected to be particularly powerful probes of DM annihilation

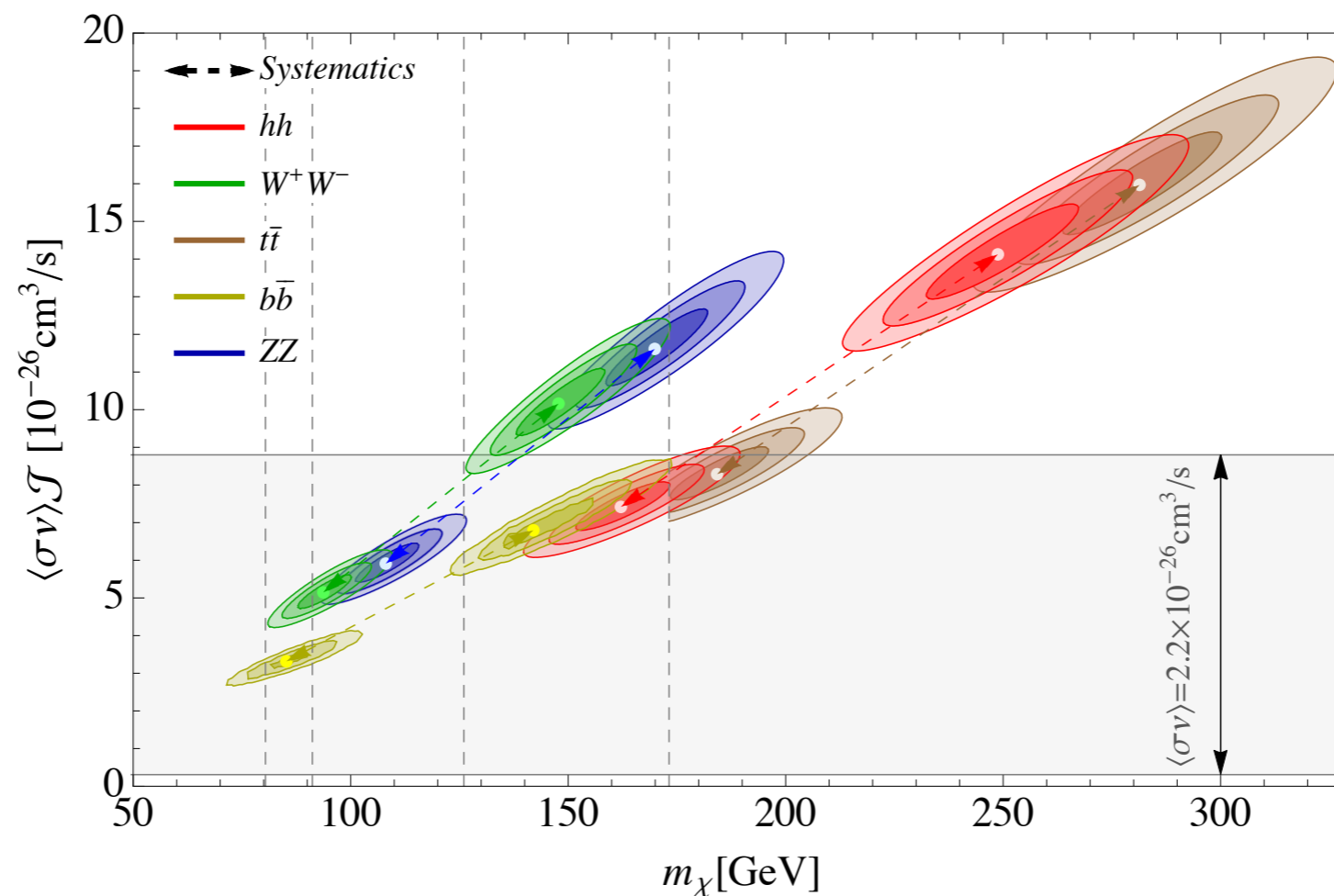
The galactic center γ -ray excess [Hooper]

- Over the past several years, an excess of \sim GeV scale photons from the inner several degrees of the Milky Way has become increasingly well measured
- Spectrum and morphology of this signal agree well with the predictions of annihilating DM; spatially extended, spherical, etc.
- Much interest and investigation has been directed at this observation (\sim 120 citations over the past 12 months)
- Original identification at Fermilab [Hooper, Goodenough], with important follow up work at Fermilab as well [Hooper, Linden, Cholis]



The galactic center γ -ray excess: particle-physics interpretations [Fox, Harnik, Hooper]

- Many of highest impact papers on DM phenomenology/model building related to the GC excess have come from FNAL:
 - First comprehensive study of simplified models [Berlin, Hooper, McDermott]
 - Hidden sector models [Berlin, Hooper, McDermott]
 - Higgs, gauge boson, top quark final states [Agrawal, Batell, Fox, Harnik; Cholis, et al.]
 - Z' mediated models [Hooper]
 - Connection with the 3.55 keV line? [Berlin, Hooper, McDermott]



Dark Matter, Neutrinos, and Inflation [Stebbins, Dodelson, Lykken, Frieman]

- FNAL Theoretical Astrophysics has a strong tradition of finding cosmic probes of BSM physics e.g.
 - Primordial gravity waves and vorticity [Stebbins]

VOLUME 78, NUMBER 11

PHYSICAL REVIEW LETTERS

17 MARCH 1997

A Probe of Primordial Gravity Waves and Vorticity

Marc Kamionkowski*

Department of Physics, Columbia University, 538 West 120th Street, New York, New York 10027

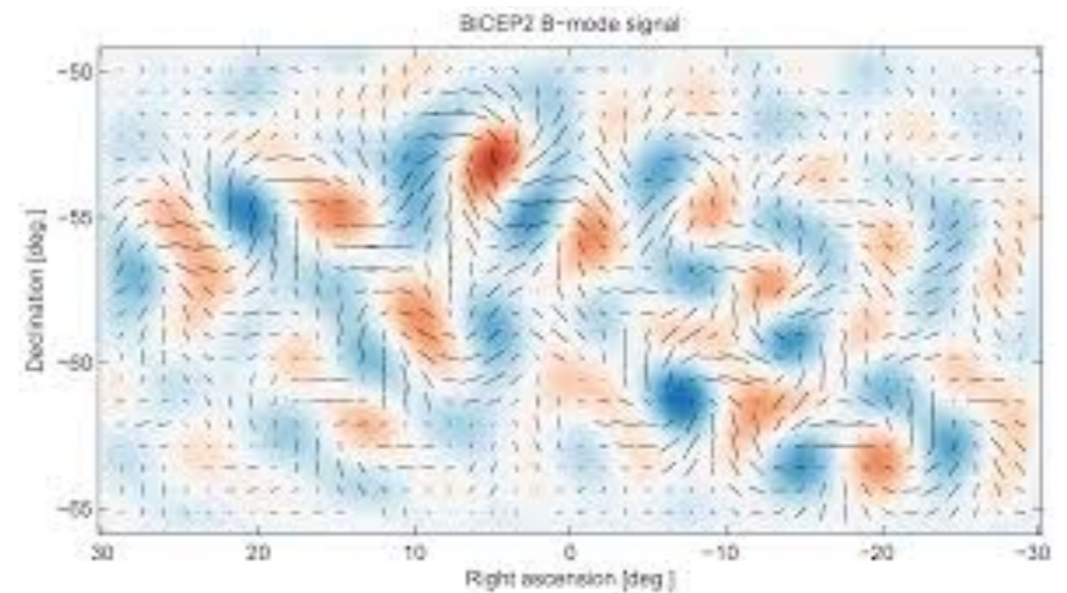
Arthur Kosowsky†

*Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02138
and Department of Physics, Lyman Laboratory, Harvard University, Cambridge, Massachusetts 02138*

Albert Stebbins‡

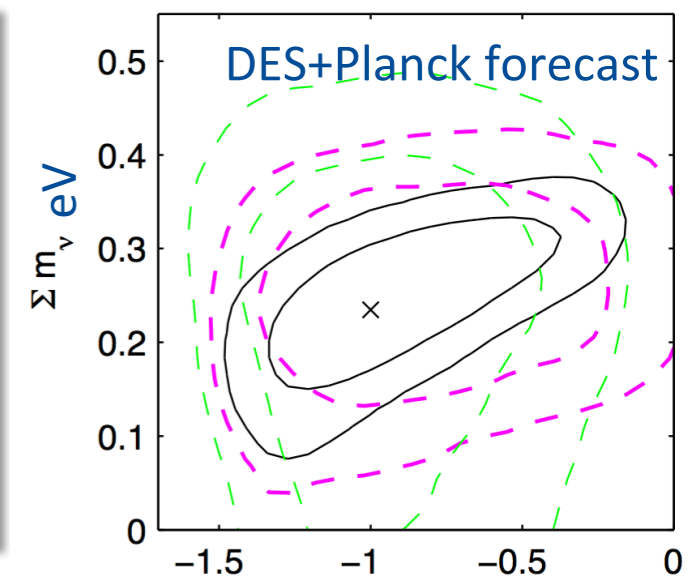
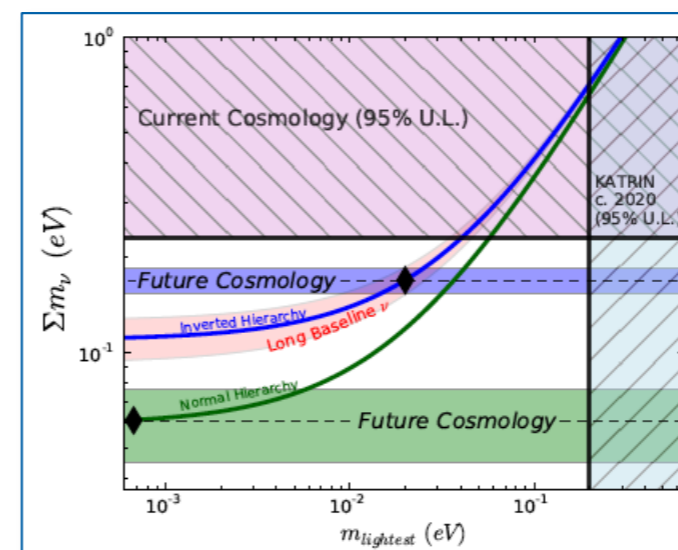
*NASA/Fermilab Astrophysics Center, Fermi National Accelerator Laboratory, Batavia, Illinois 60510-0500
(Received 19 September 1996)*

A formalism for describing an all-sky map of the polarization of the cosmic microwave background is presented. The polarization pattern on the sky can be decomposed into two geometrically distinct components. One of these components is not coupled to density inhomogeneities. A nonzero amplitude for this component of polarization can only be caused by tensor or vector metric perturbations. This allows unambiguous identification of long-wavelength gravity waves or large-scale vortical flows at the time of last scattering. [S0031-9007(97)02705-1]

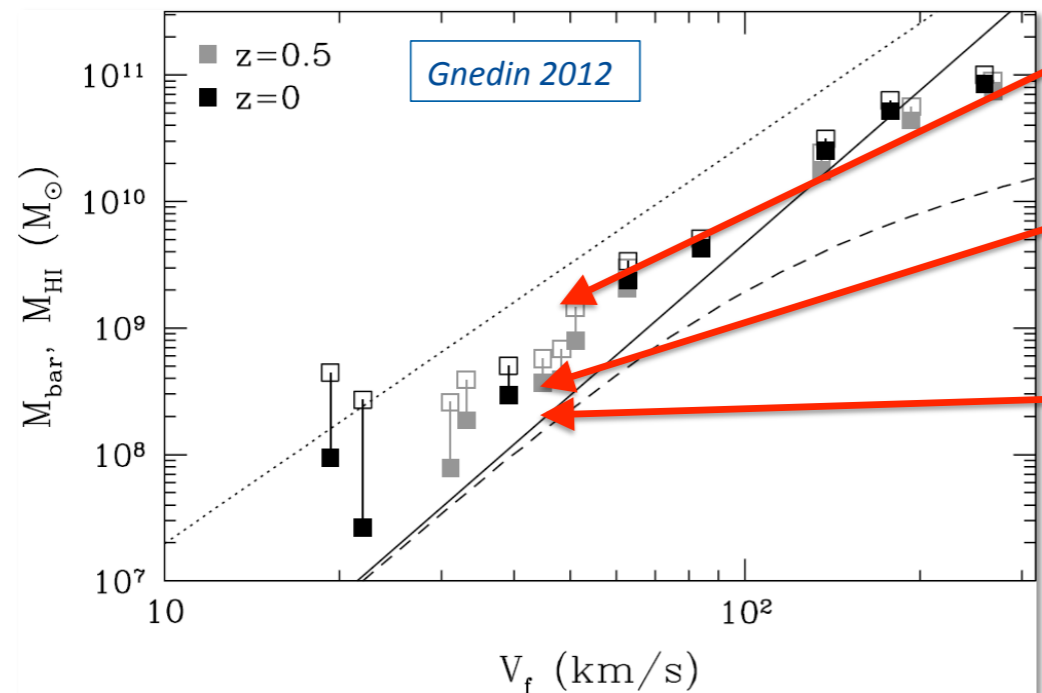


- DES Large-scale structure constrains neutrino mass
- Interpreting cosmic constraints on neutrino masses and hierarchy

[Dodelson, Lykken, Frieman]



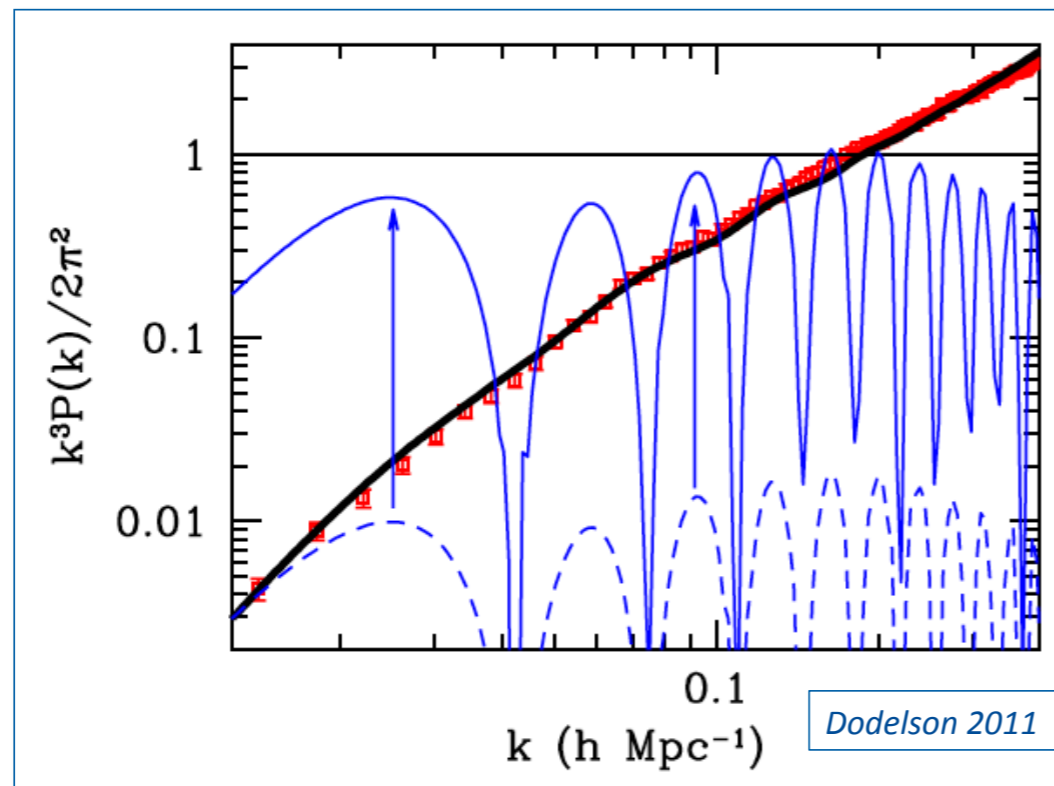
Dark Matter: the case against MOND [Gnedin, Dodelson]



Total gas

Neutral (= observable) gas

"MOND line"



- Claims of evidence for MOND arise from improper interpretation of observations

- TeVeS raises the amplitude of perturbations but with the wrong shape, a generic problem for modified gravity models

WIMP searches: non-traditional

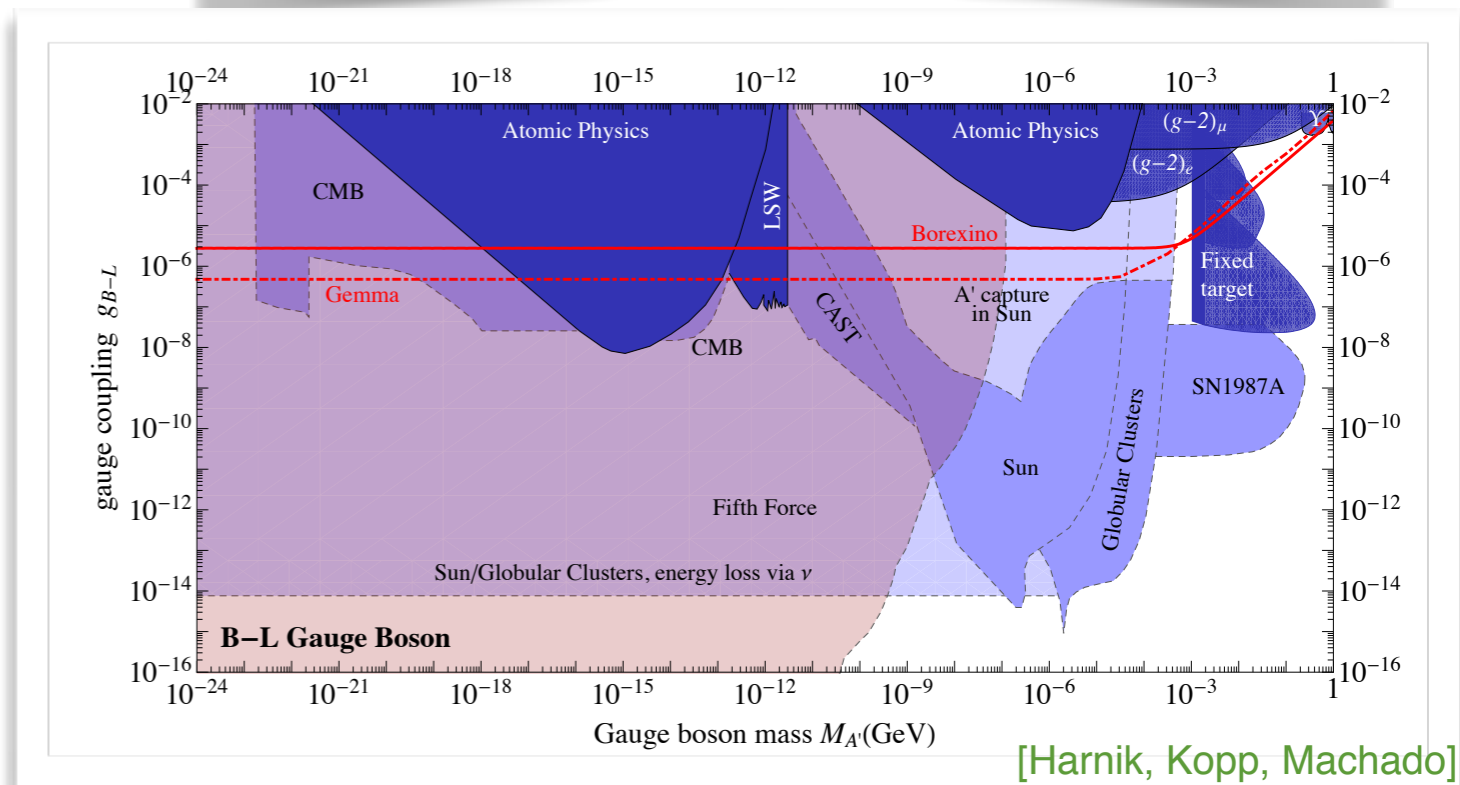
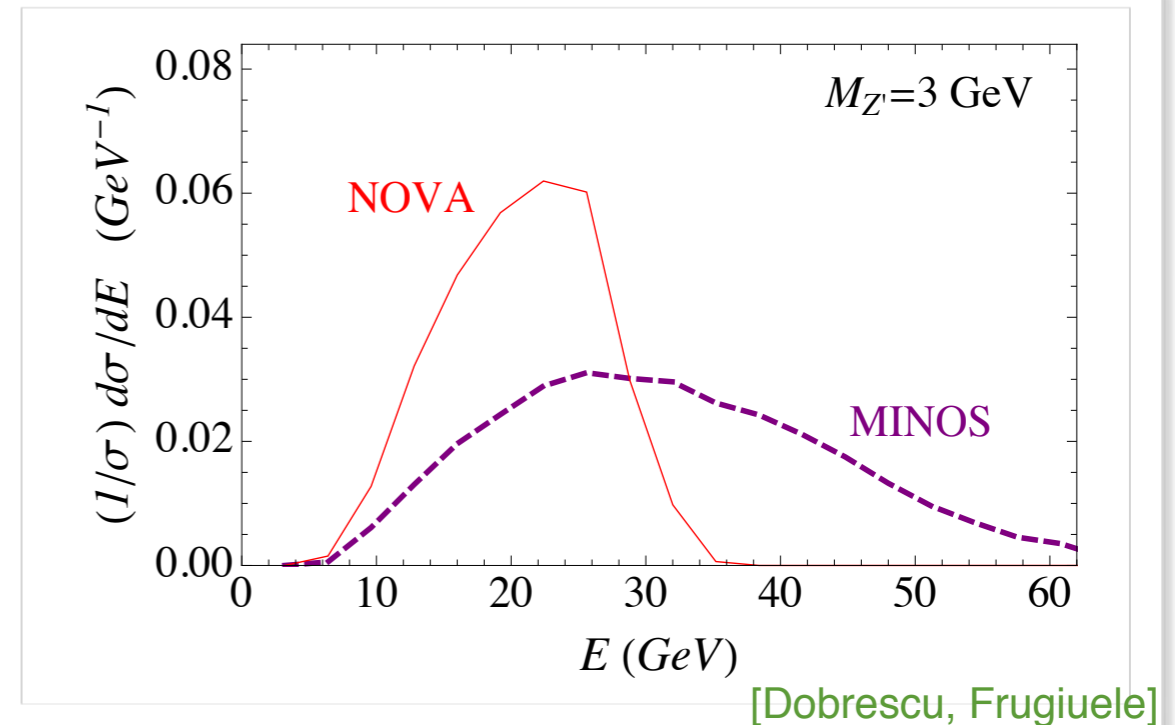
- Theory group leading effort to utilize FNAL neutrino experiments to search for dark sector particles...

[Dobrescu, Harnik]

- ..and to use DM detectors to probe neutrino properties [Harnik]

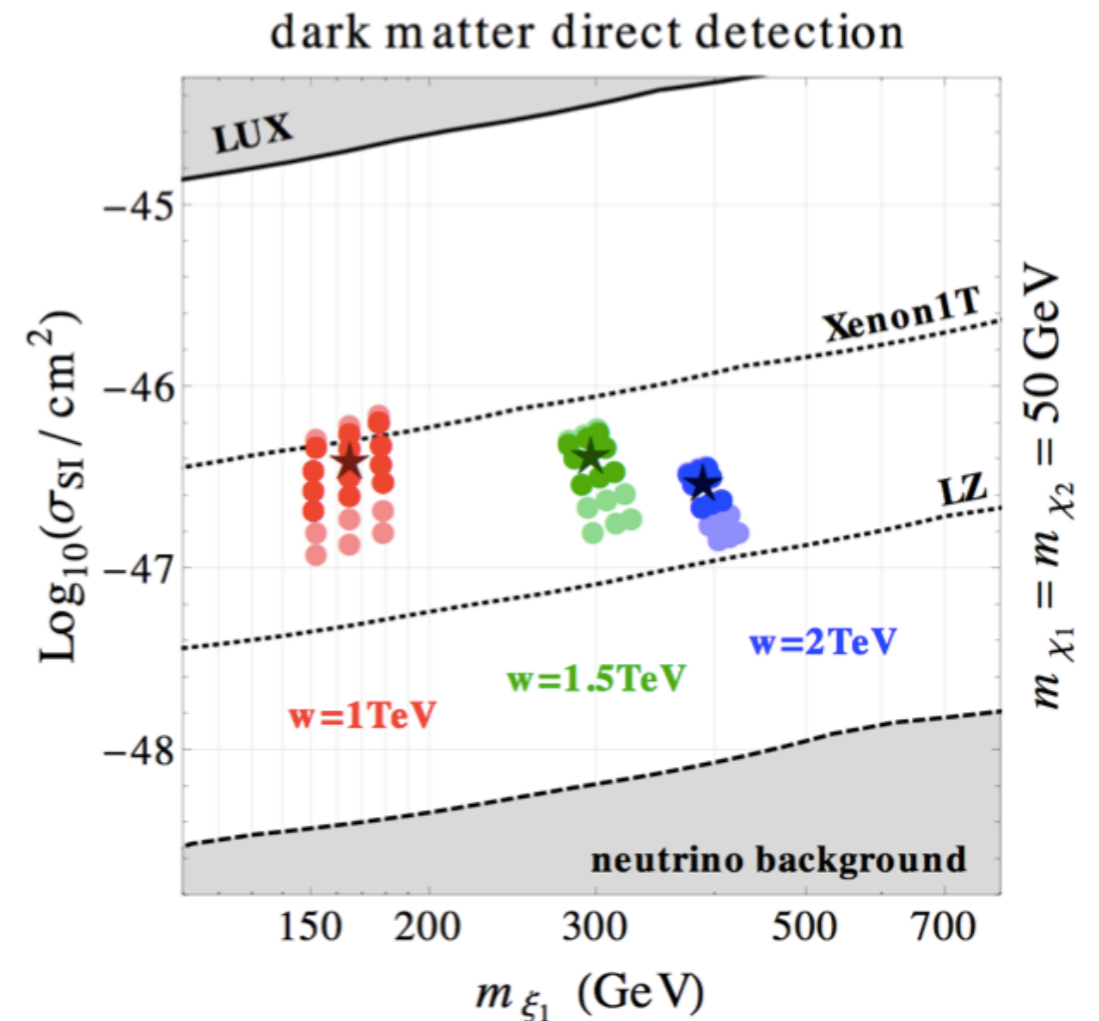
- Complementary collider probes of light dark sectors

- Theory organized, URA funded workshop–"New Perspectives on DM" [Fox, Harnik]



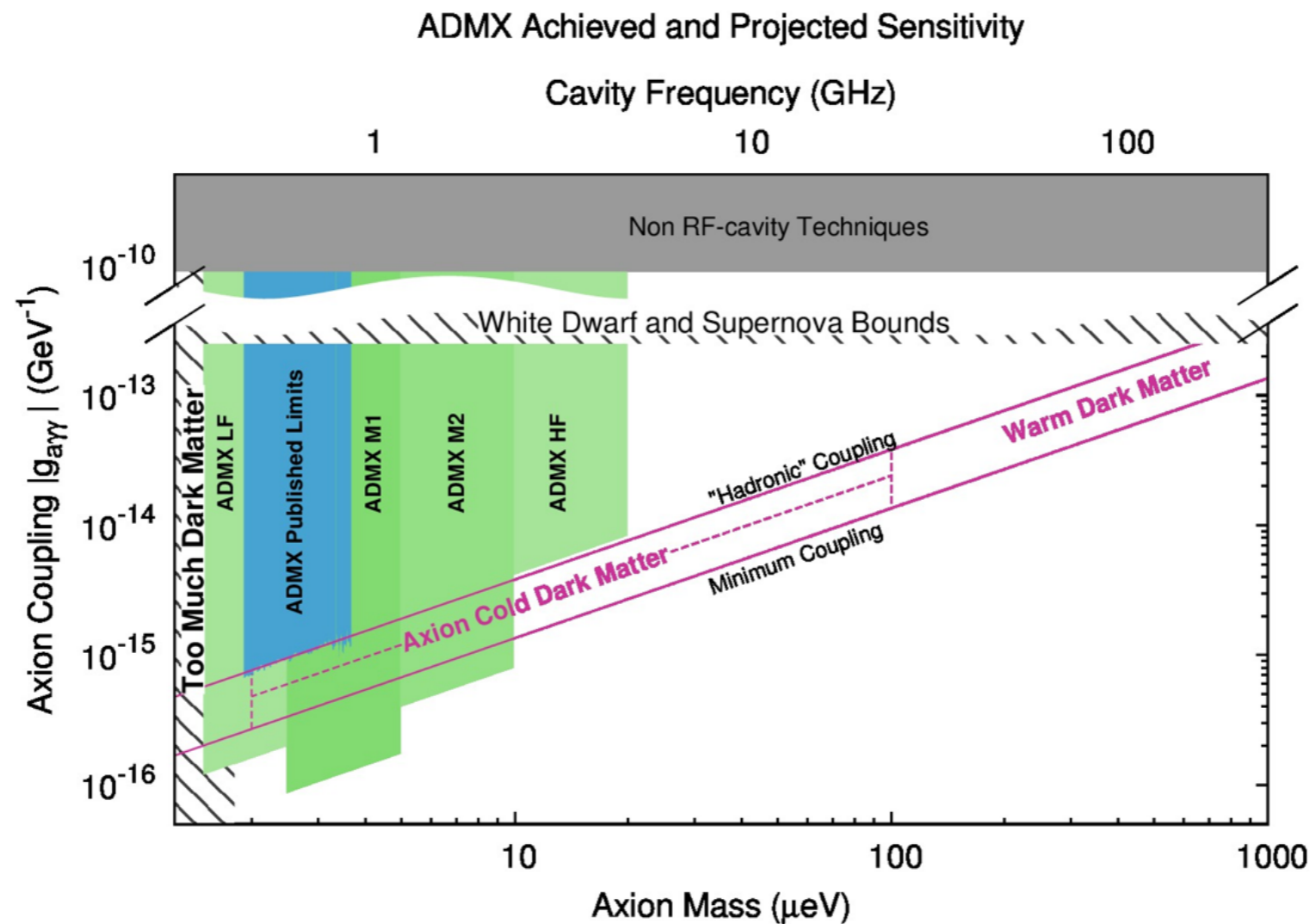
Higgs portal to the dark sector [Altmannshofer, Bardeen, Bauer, Carena, Lykken]

- Radiative breaking of the dark gauge group triggers EWSB through the Higgs portal coupling.
- $M_H \sim 125$ GeV + stability of the Higgs potential
→ radiative breaking of the dark gauge group @ TeV scale.
- Dark sector complex scalar and fermions are charged under the dark $SU(2) \times U(1)$ gauge interactions.
- Neutral dark fermions, with the correct thermal relic abundance.
- Lighter stable dark fermions charged under the dark force, with **observable effects on galactic-scale structure**.



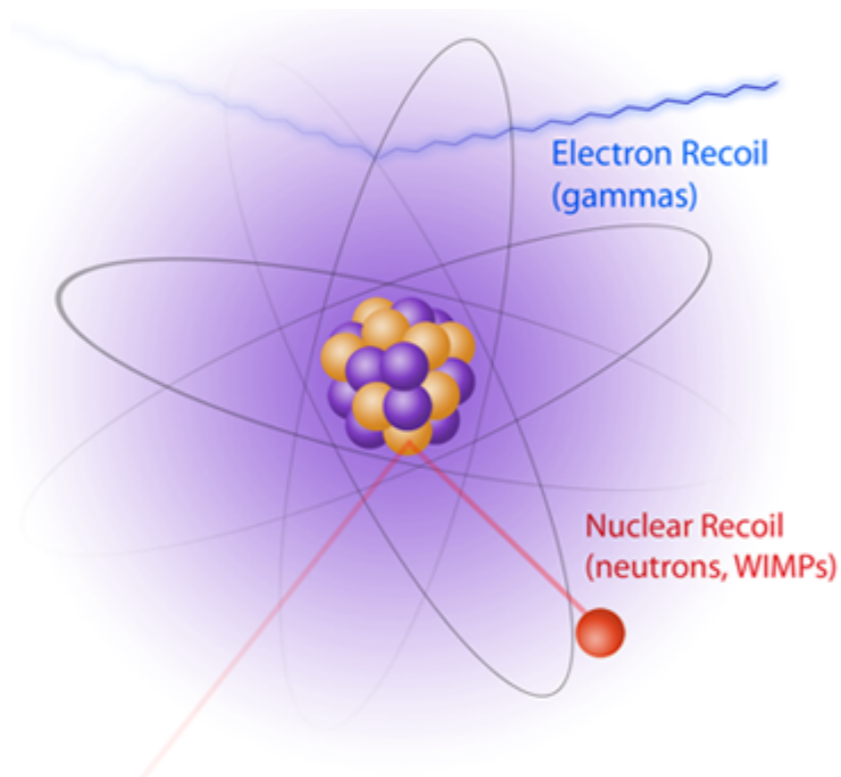
Axion dark-matter searches [Eichten, Hill]

- Axion “journal club”: astro- and particle- theory groups preparing for FNAL’s role on ADMX
- Helping experimentalists develop new search strategies and detector design concepts



Lattice QCD for dark-matter searches

- For spin-independent dark matter (e.g. mediated by Higgs exchange), **DM-nucleon scattering X-section depends upon nucleon light- & strange-quark contents**
 - LQCD calculations of already rule out large $\langle N|ss|N\rangle$ used in many phenomenology papers
 - Anticipate obtaining $\sim 10\text{--}20\%$ errors (which is sufficient) in the next five years [Van de Water with MILC Collaboration]



[Junnarkar & Walker-Loud. PRD87 (2013) 11. 114510 1

