Report from the Cosmic Frontier

(Workshop at SLAC, April 5-8, 2013)

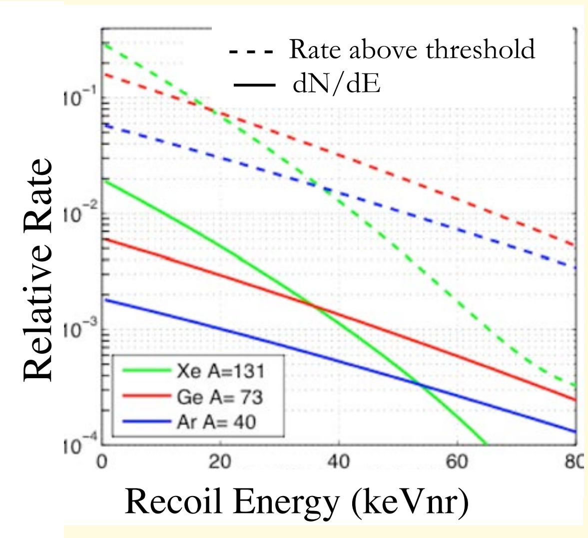
T. Shutt

Case Western Reserve University

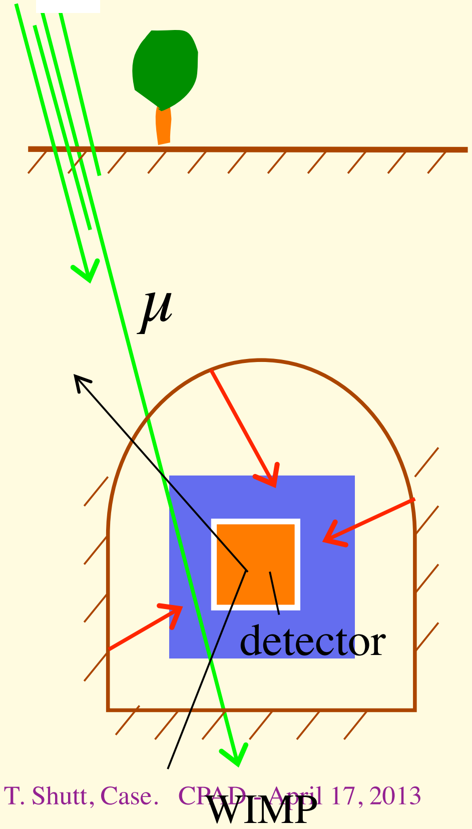
The Cosmic Frontier

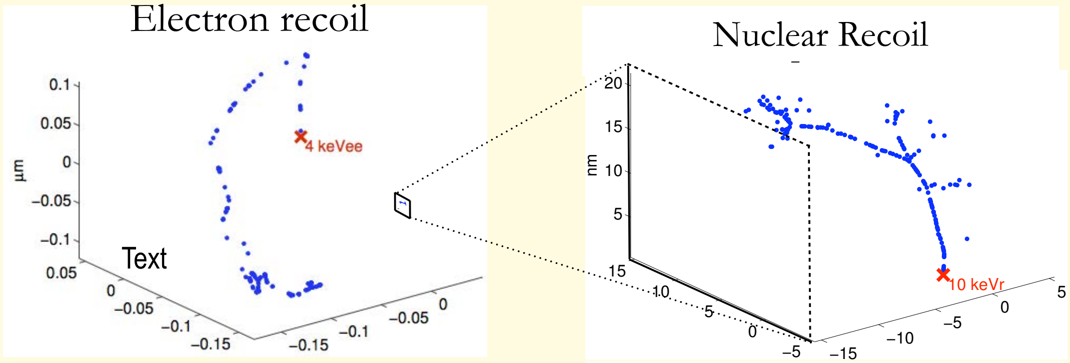
- CF1 - Direct detection of (WIMP) dark matter
- CF2 - Indirect detection of (WIMP) dark matter
- CF3 - Non-WIMP dark matter
- CF4 - Dark Matter complementarity
- CF5 - Dark Energy and CMB
- CF6 - Cosmic Particles and Fundamental Physics

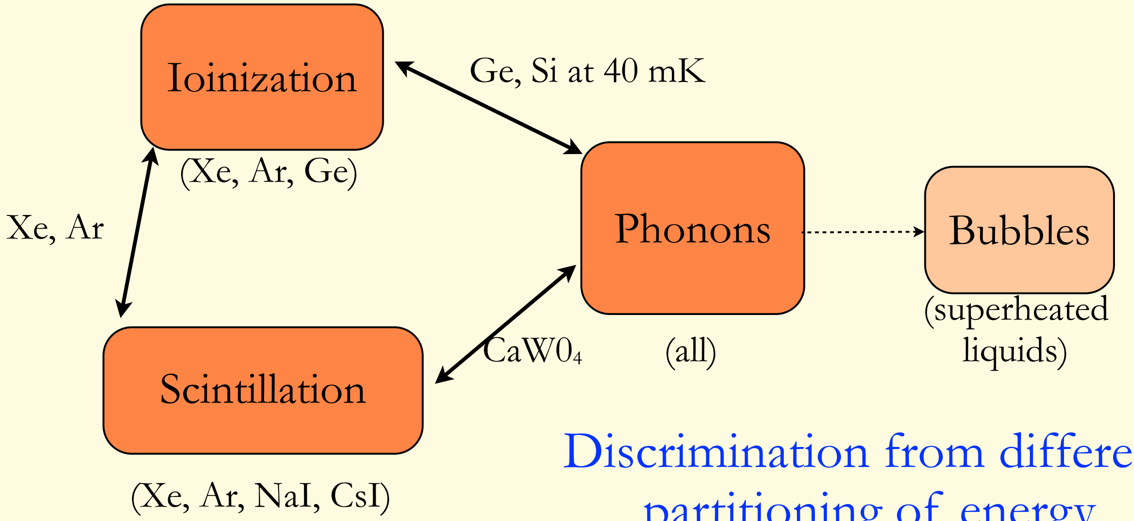
WIMP Detection



- Low-radioactivity materials + shielding
- Discrimination of electron-recoil backgrounds
  - – Nuclear tracks much denser
  - – Nuclear recoils create heat (Linhdardt)



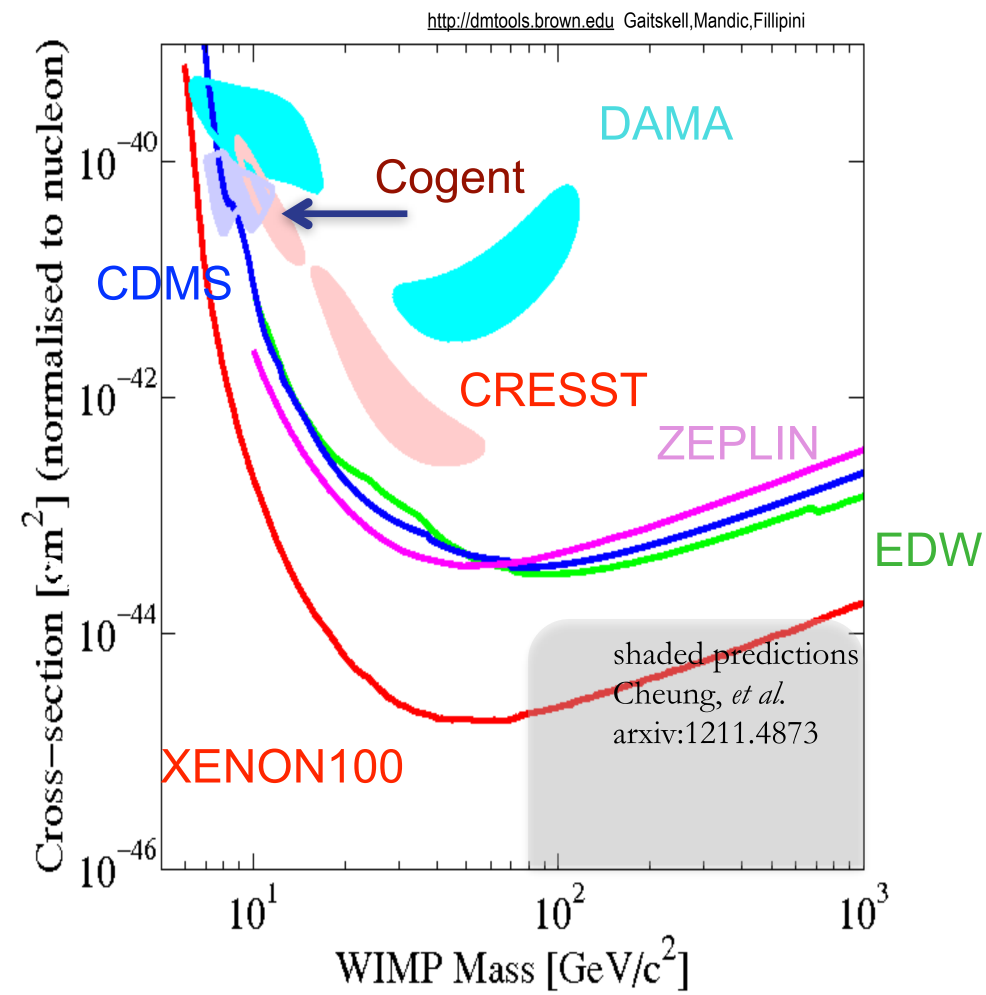




Discrimination from different partitioning of energy

Spin independent limits

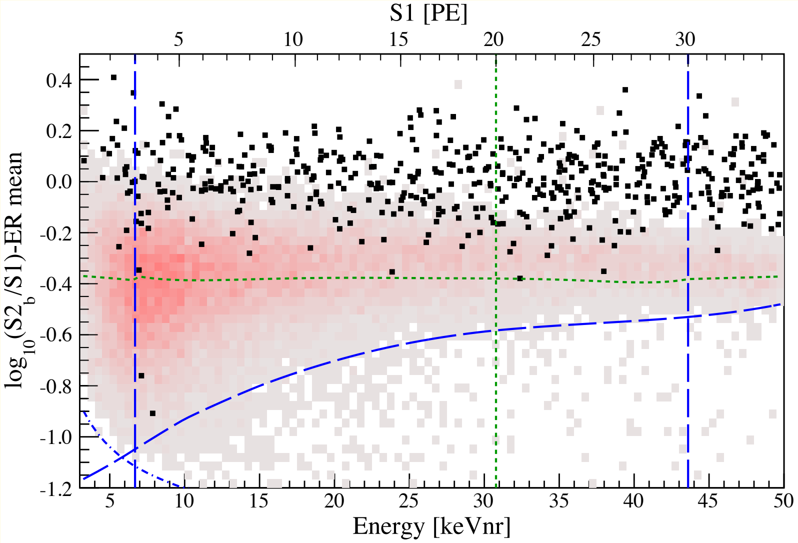
- Limits
  - Lowest limits from XENON100: $2\text{x}10^{-45}$ cm^2 at 50 GeV.
  - CDMS II, Edelweiss II, Zeplin III limits are around 2×10^{-44} cm^2.
- 25 years of extraordinary advances in technology and backgrounds
  - First results 1987: $\sim1\text{x}10^{-40}$ cm^2
- "Ovals" are claimed WIMP detections (DAMA), or signals above known backgrounds (Cogent, CRESST)



http://dmtools.brown.edu Gaitskell,Mandic,Fillipini

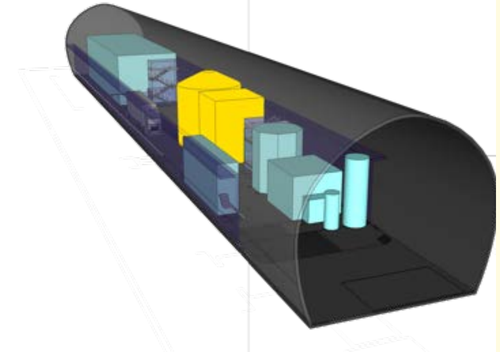
shaded predictions Cheung, *et al.* arxiv:1211.4873

XENON100 / 1T



- 225 live days x 34 kg fiducial mass
- Good position reconstruction leads to clean fiducialization
- 2 events, expected background of 1±0.2

XENON1T
- fully funded
- construction starting this month!
- in 10m diameter water tank
- at Gran Sasso
- 1 ton fiducial xenon target
- 3.5 ton total
- external backgrounds reduced to neutrino-induced signal level

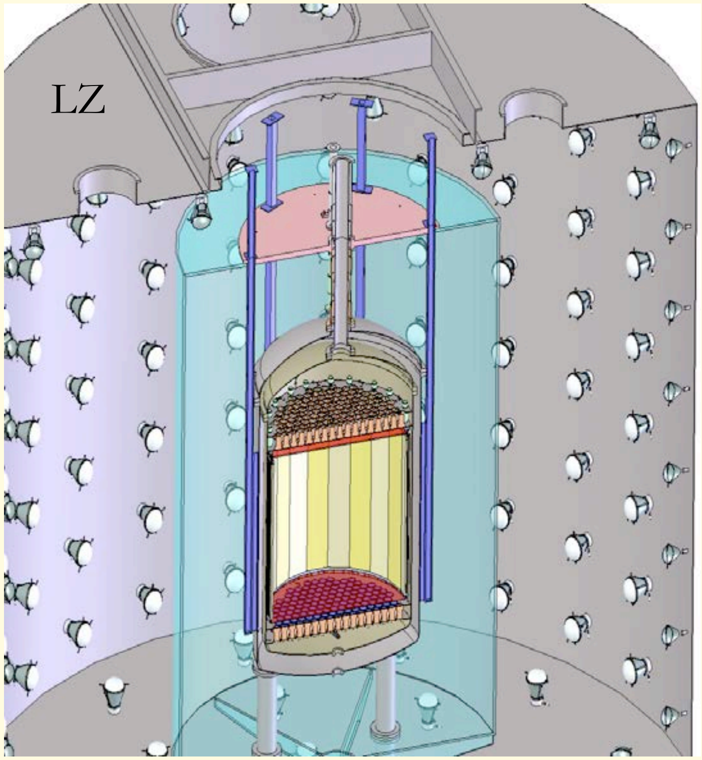


(location between ICARUS and WARP)

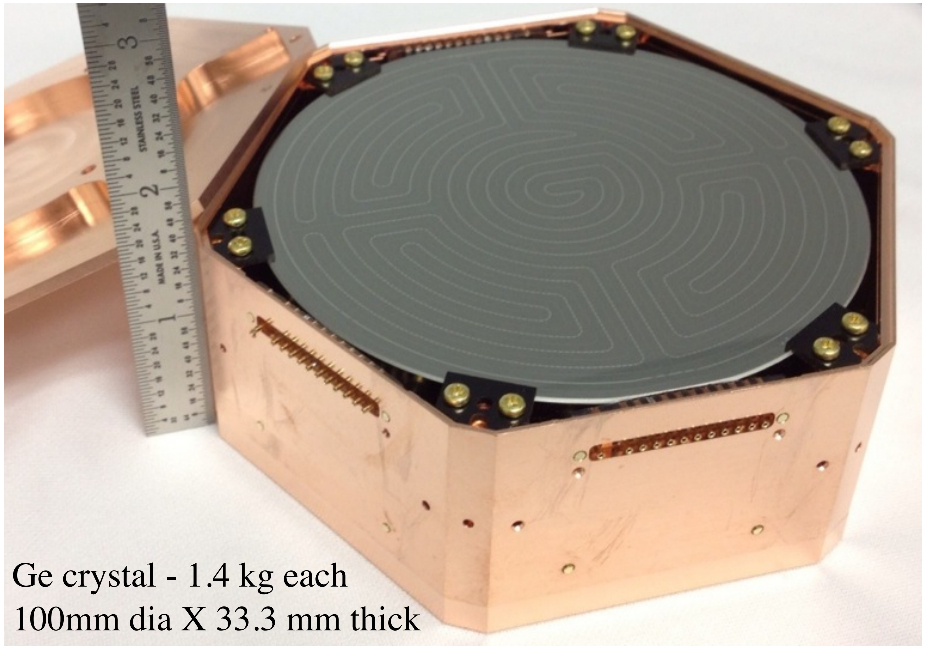
LUX / LZ

- Largest Xe TPC: 300 kg fully active
- High light yield
  - –8 pe/keV light yield (zero field, 662 keV).
- Science run 2013

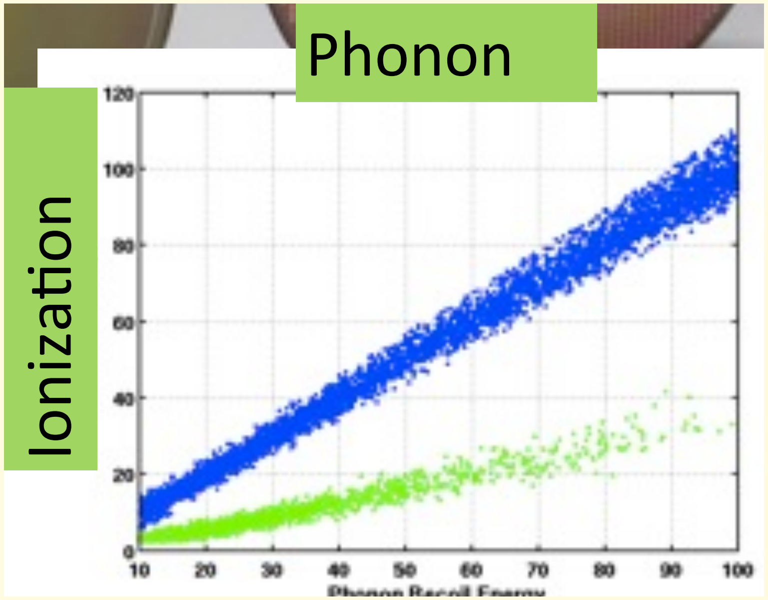
- 7 ton total, 6 ton fiducial
  - –Existing Davis Campus water shield
  - –SDSTA commitment to procure Xe.
- Outer detector: veto + measure background
- Dominant backgrounds: astrophysical neutrinos



CDMS / SuperCDMS

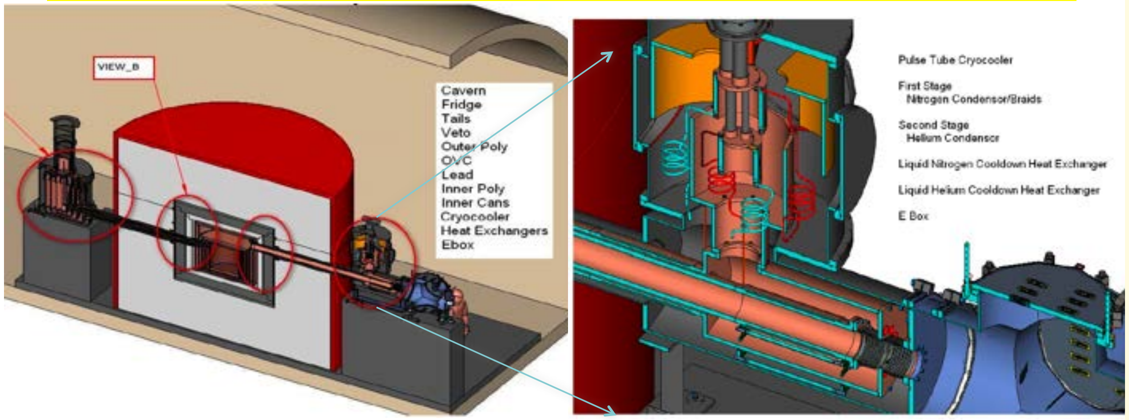


Ge crystal - 1.4 kg each
100mm dia X 33.3 mm thick

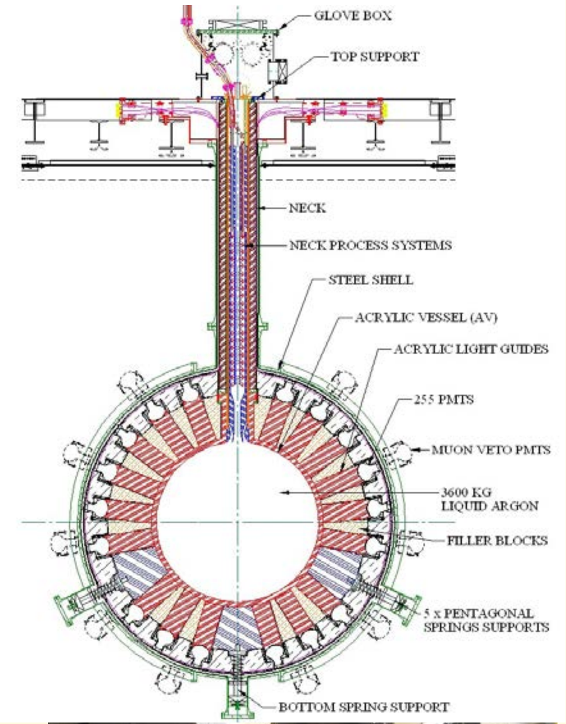


- Streamlined production - several locations
- New, interdigitated charge readout: no dead-layer
- Studying very low threshold designs: light WIMPS

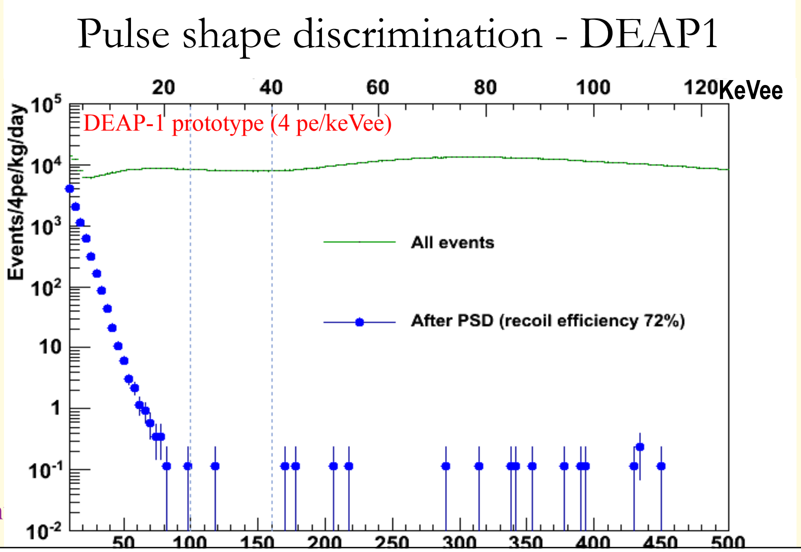
SuperCDMS SNOLAB (200 kg Ge in 400 kg Cryostat)



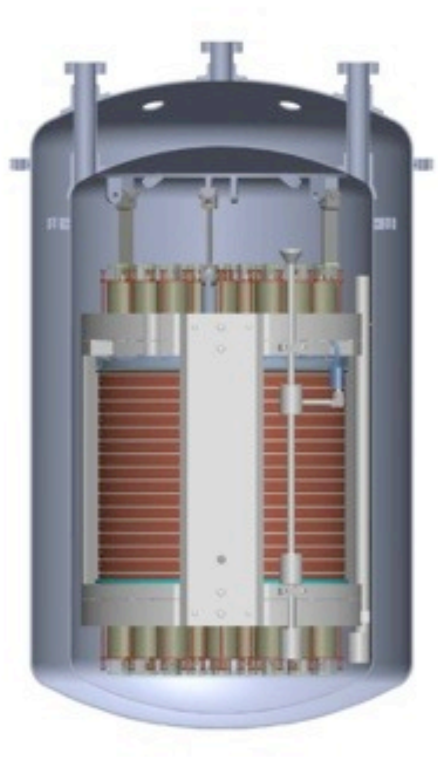
Liquid Argon - DEAP3600

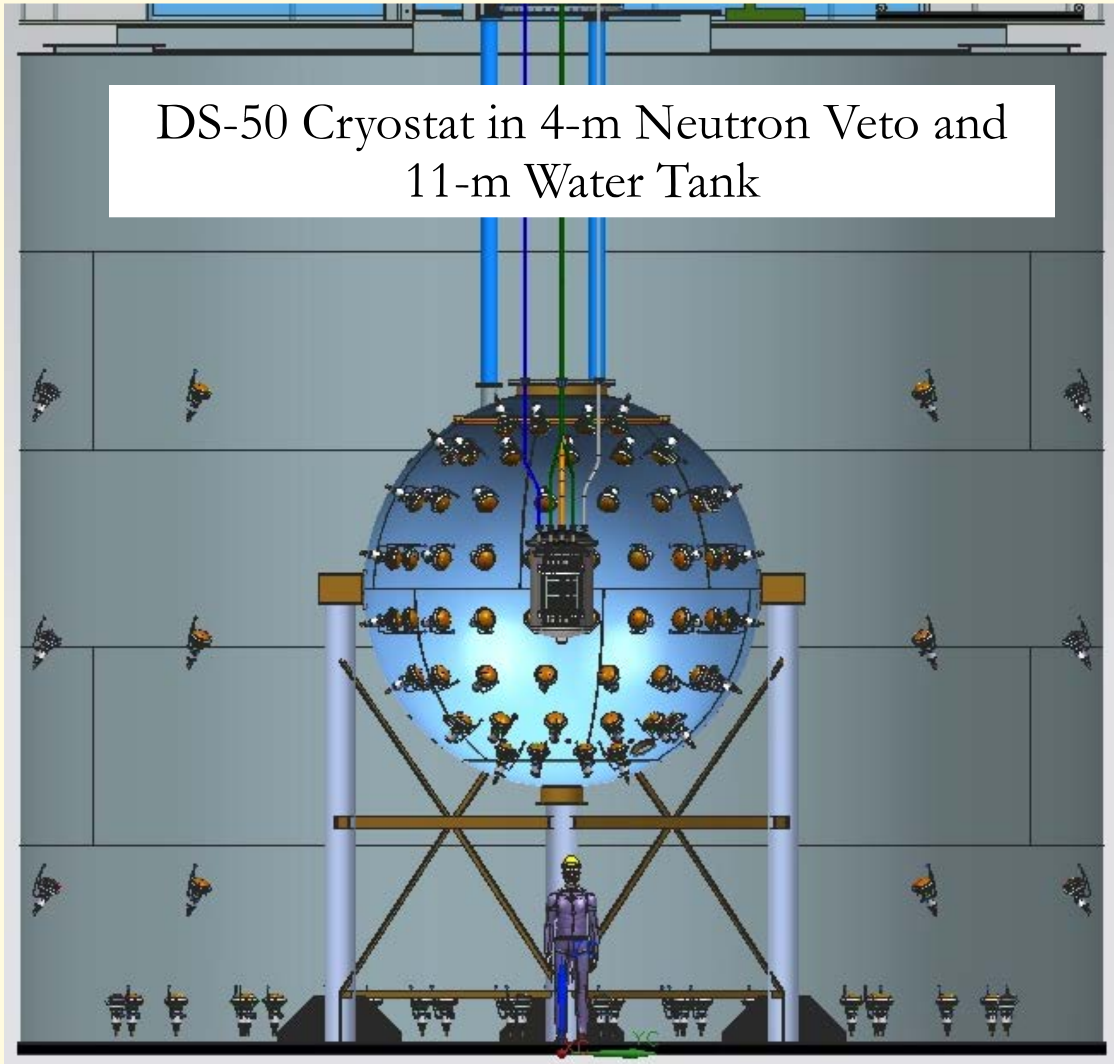


- Liquid Ar
  - Similar to Xe - less sensitive/mass, but cheaper
  - ^{39}Ar: beta decay, ~1 Bq/kg. 10^7 times pp neutrino background
  - Pulse shape discrimination: at 10^8 level or better, at high energy.
- DEAP 3600 - 3.6 tons of liquid Ar, 1 ton fiducial.
- SNOLAB. Begins running 2014
- In-situ refinishing of surface to remove Rn daughters


Pulse shape discrimination - DEAP1

DarkSide



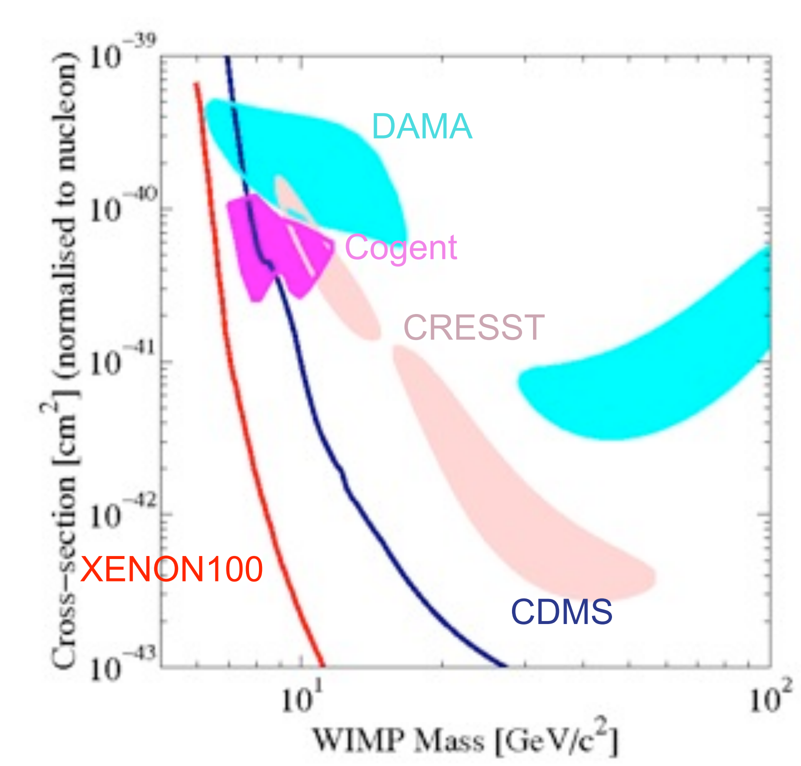


DS-50 Cryostat in 4-m Neutron Veto and 11-m Water Tank

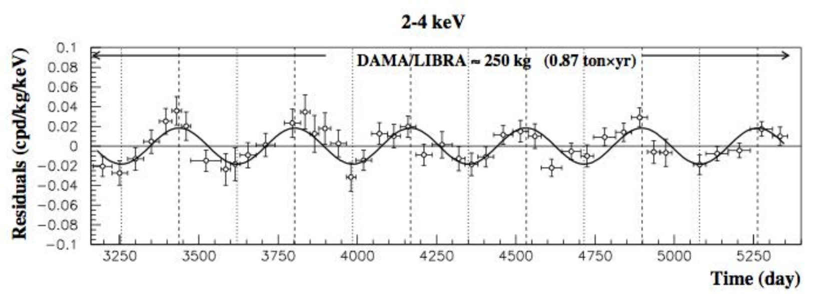
- TPC: S2/S1 and PSD discrimination
- DarkSide50: 50 kg target
- B-loaded scintillator shield
- Reduced ^{39}Ar content

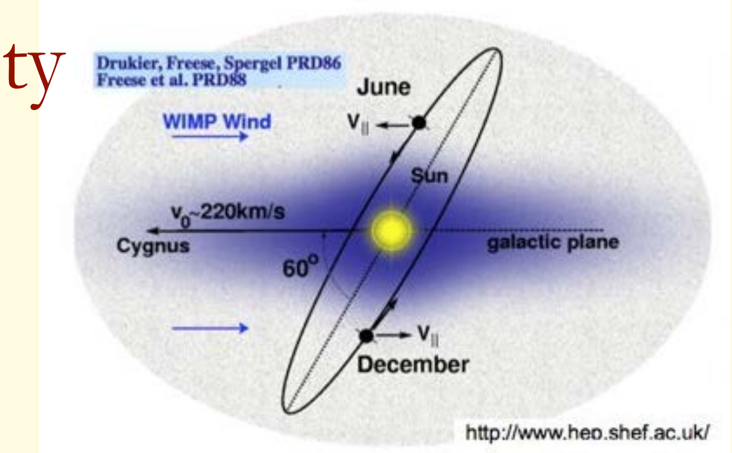
Low mass WIMPs

- WIMP particle physics paradigm is mass at the electroweak scale.
  - LHC rules out mass below about 80 GeV (with caveats)
- But still useful to search as low in mass as possible.
  - Signal hints in 10 GeV region.
  - New CDMS events
- Experiments are pushing thresholds lower.
  - S2-only TPC, cryodetectors
  - Robust neutron calibrations needed
  - Electron recoil channel - MeV mass, but poor sensitivity



Annual modulation + directionality

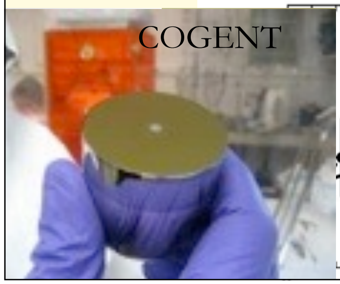


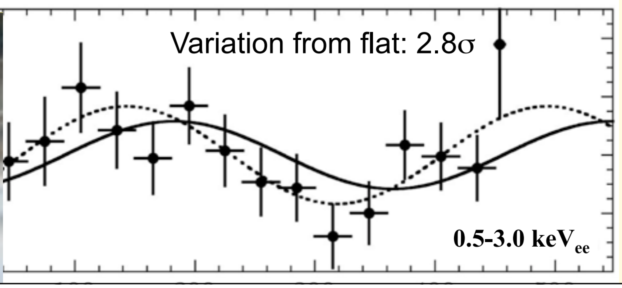


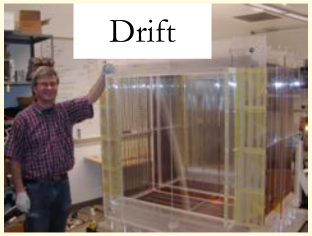
- DAMA/LIBRA: 250 kg of NaI.
  - few % modulation at threshold, right phase for DM
- Possible modulation in COGENT
- DM-ICE: NaI at South Pole

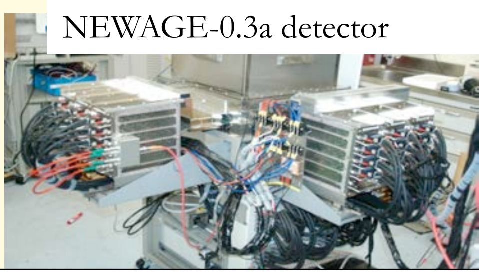
- WIMP wind modulates over day
- Track image: unambiguous galactic origin
- Low pressure gas: expand 50 tracks
- Challenge: Cost prior to WIMP signal
- Dark horse: recombination signal (Nygren)

Drill & Deployment Towers
IceCube Drill - 3/4/2013 *Blaise Kuo Tiong*









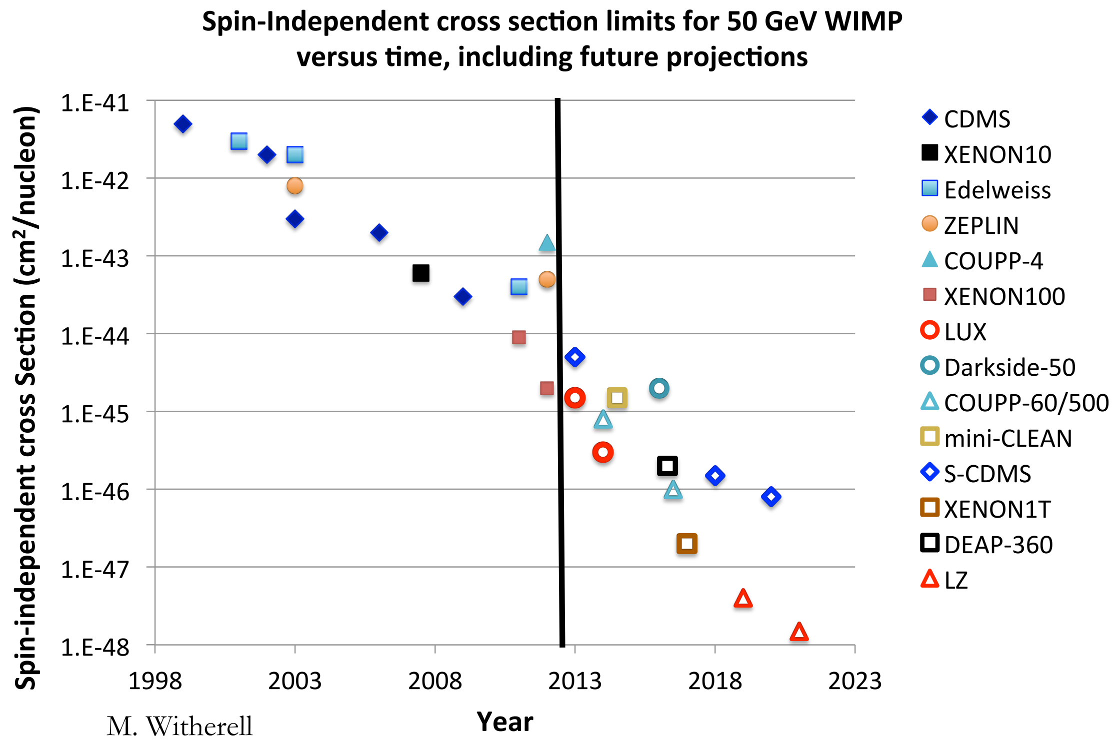
COUPP: A Bubble Chamber search for Dark Matter

J. Collar, Chicago

- 4 kg chamber taking data again at SNOLAB after removal of (α,n) sources.
- World's best spin-dependent (SD) WIMP-nucleus coupling sensitivity, and very near CDMS' spin-independent (SI) sensitivity.
- 60 kg chamber to be commissioned at SNOLAB January 2013. We expect world's best sensitivity for both SD & SI couplings from this device.
- 500 kg design in progress (NSF funded, DOE pending). Planned start of construction 2013, installation at SNOlab during 2015.

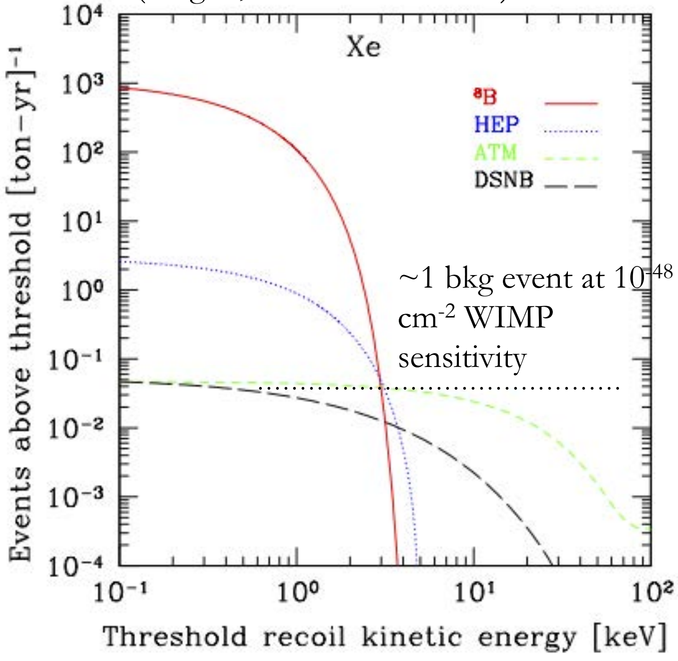
The future

- Part rapid progress in detector sensitivity will continue
- Experiments with 10^{-48} cm^2 sensitivity now being planned


Spin-Independent cross section limits for 50 GeV WIMP versus time, including future projections

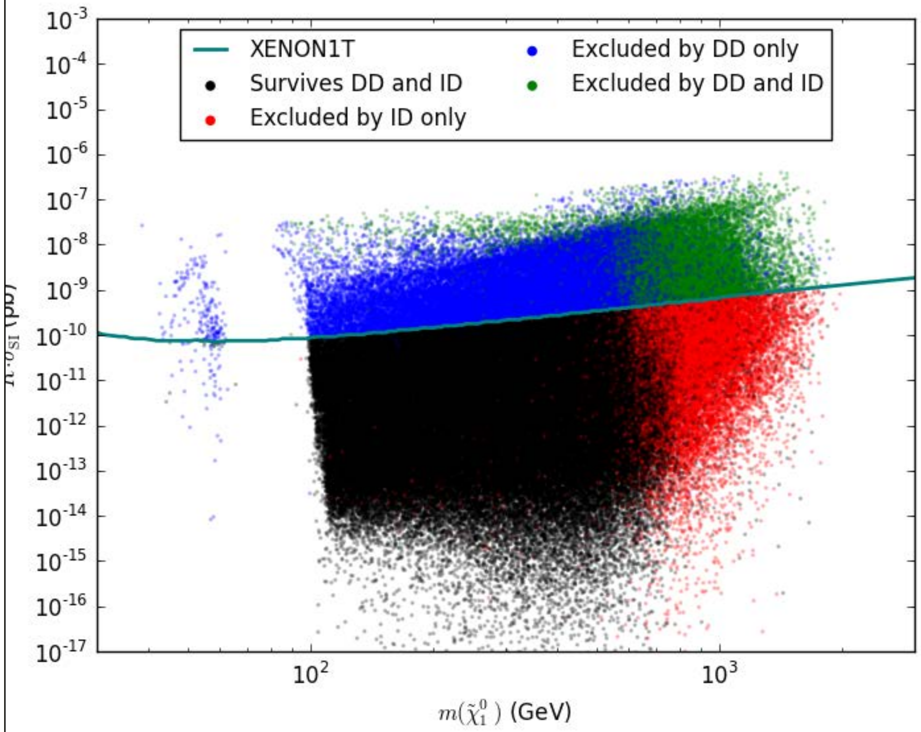
M. Witherell

(Strigari, arXiv:0903.3630v2)

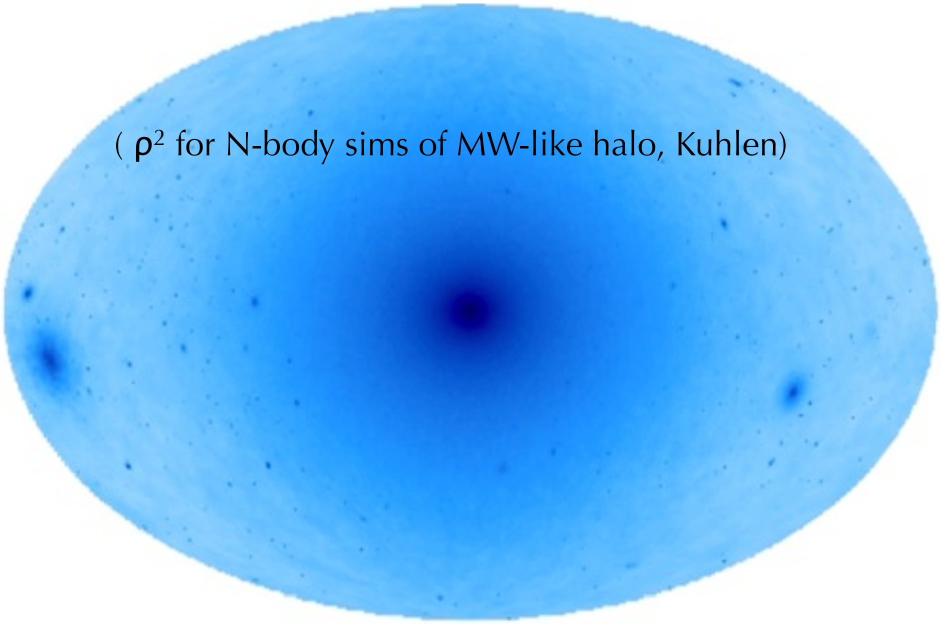

~1 bkg event at 10^{-48} cm^{-2} WIMP sensitivity

- Nuclear recoil background around the corner: Coherent neutrino scattering of astrophysical neutrinos.
  - Neutrino / WIMP rate mostly target independent
  - Spectrum similar to dark matter
  - Low masses more severely limited by ^8B signal

CF2: Indirect Detection Summary



(pMSSM scans, Cotta, Cahill-Rowley, Drlica-Wagner, Funk, Hewett, Ismail, Rizzo, Wood)



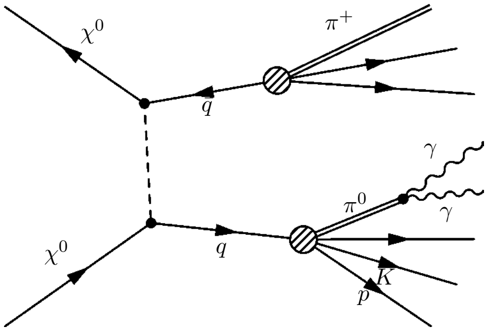
(ρ^2 for N-body sims of MW-like halo, Kuhlen)

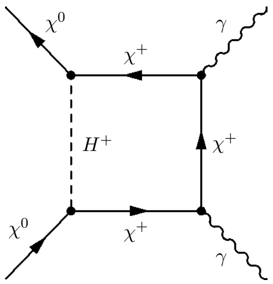
Jim Buckley

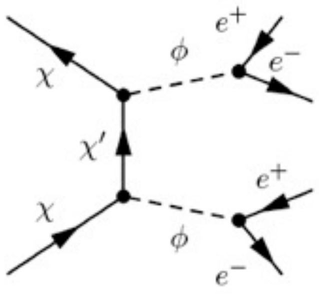
Washington University in St. Louis

for CF2: Doug Cowen, Stefano Profumo, JB conveners

Annihilation Channels

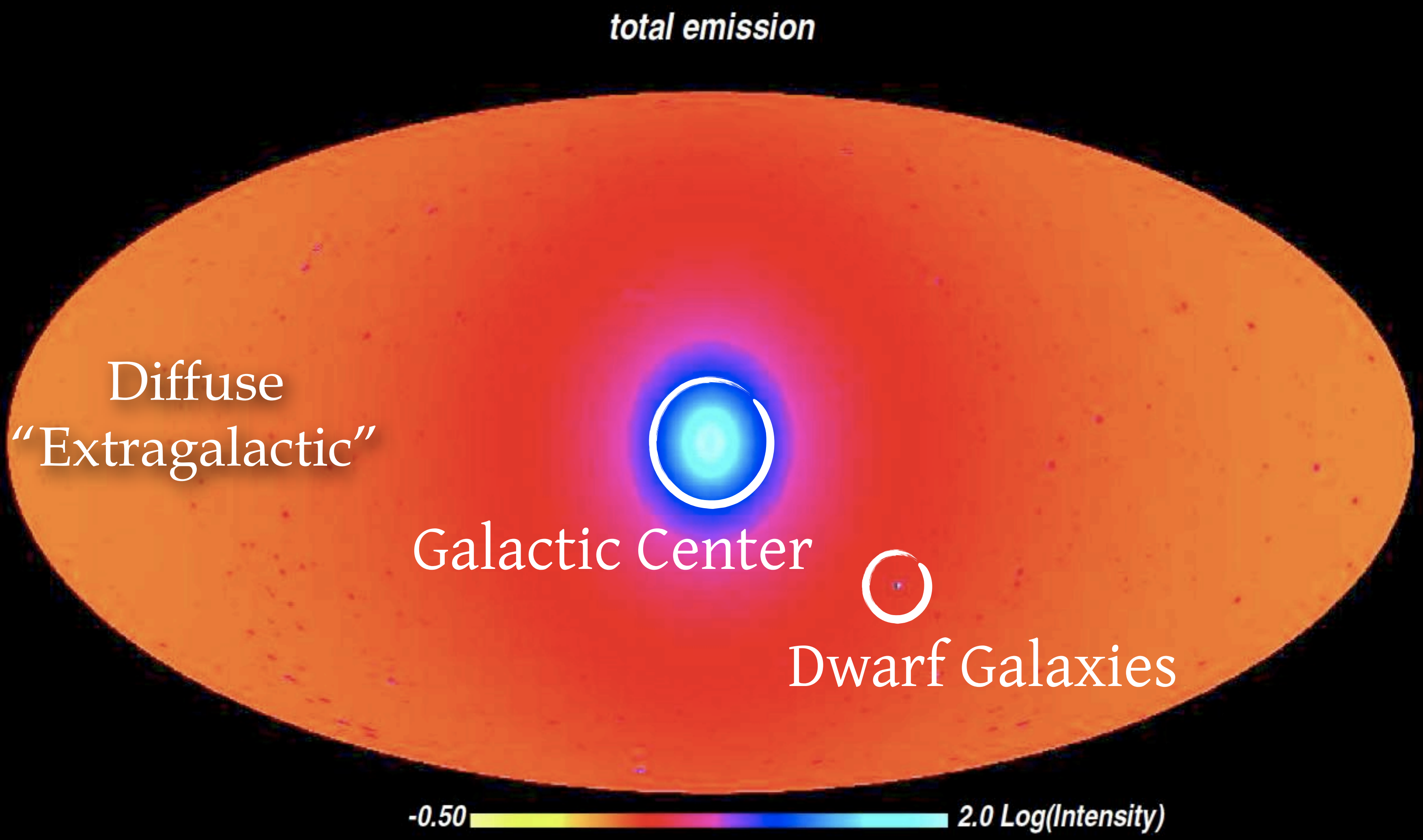






Annihilation Channel	Secondary Processes	Signals	Notes
$\chi\chi \to q\bar{q},\ gg$	$p, \bar{p}, \pi^{\pm}, \pi^0$	p, e, ν, γ	
$\chi\chi \to W^+W^-$	$W^{\pm} \to l^{\pm}\nu_l,\ W^{\pm} \to u\bar{d} \to \pi^{\pm},\ \pi^0$	p, e, ν, γ	
$\chi\chi \to Z^0Z^0$	$Z^0 \to l\bar{l},\ \nu\bar{\nu},\ q\bar{q} \to$ pions	p, e, γ, ν	
$\chi\chi \to \tau^{\pm}$	$\tau^{\pm} \to \nu_{\tau}e^{\pm}\nu_e,\ \tau \to \nu_{\tau}W^{\pm} \to p, \bar{p},$ pions		e, γ, ν
$\chi\chi \to \mu^+\mu^-$		e, γ	Rapid energy loss of μs in sun before decay results in sub-threshold νs
$\chi\chi \to \gamma\gamma$ $\chi\chi \to Z^0\gamma$	 Z^0 decay	γ γ	Loop suppressed Loop suppressed
$\chi\chi \to e^+e^-$		e, γ	Helicity suppressed
$\chi\chi \to \nu\bar{\nu}$		ν	Helicity suppressed (important for non-Majorana WIMPs?)
$\chi\chi \to \phi\bar{\phi}$	$\phi \to e^+e^-$	$e^{\pm}$	New scalar field with $m_{\chi} < m_q$ to explain large electron signal and avoid overproduction of p, γ

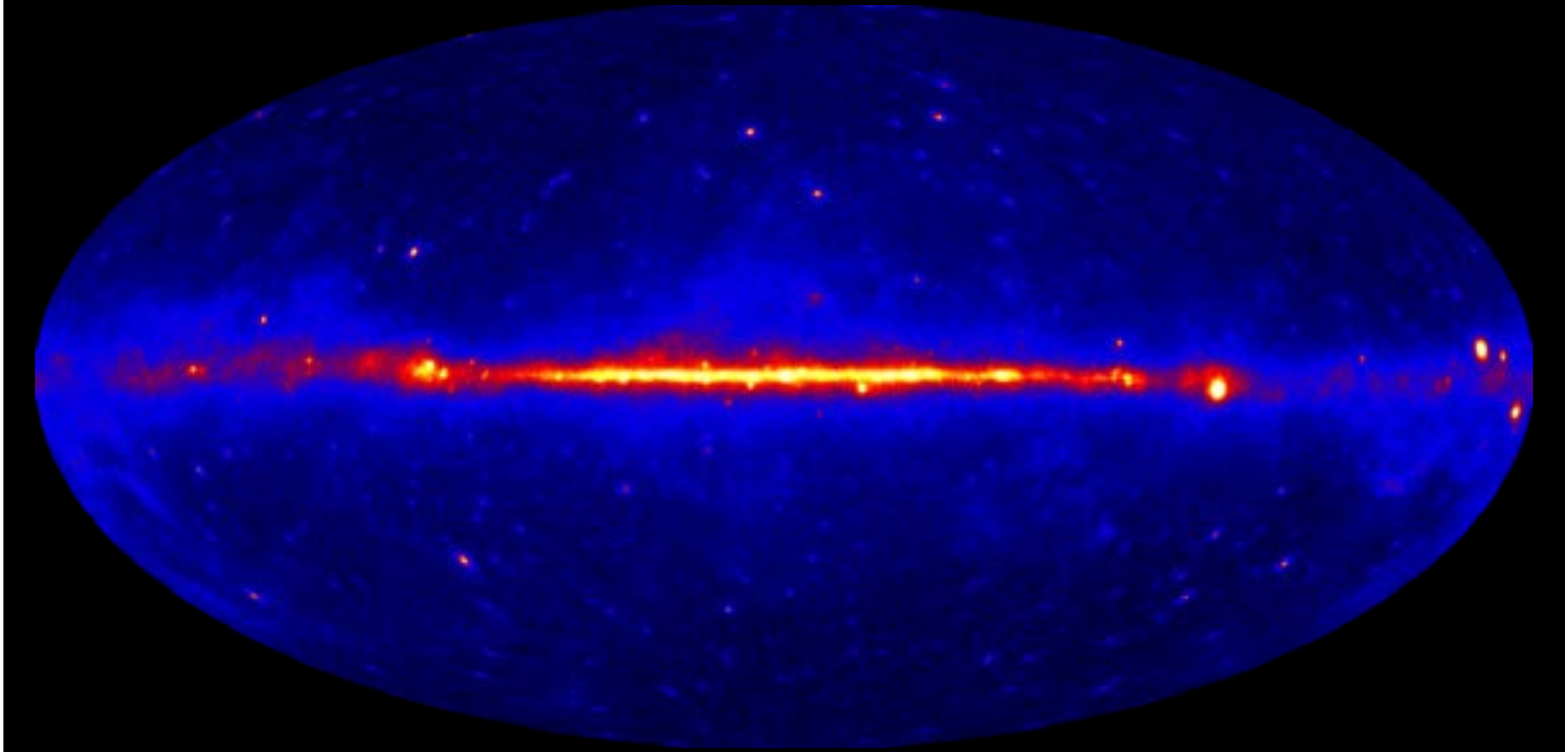
Galactic Contribution Over All-sky



Springel et al 2008

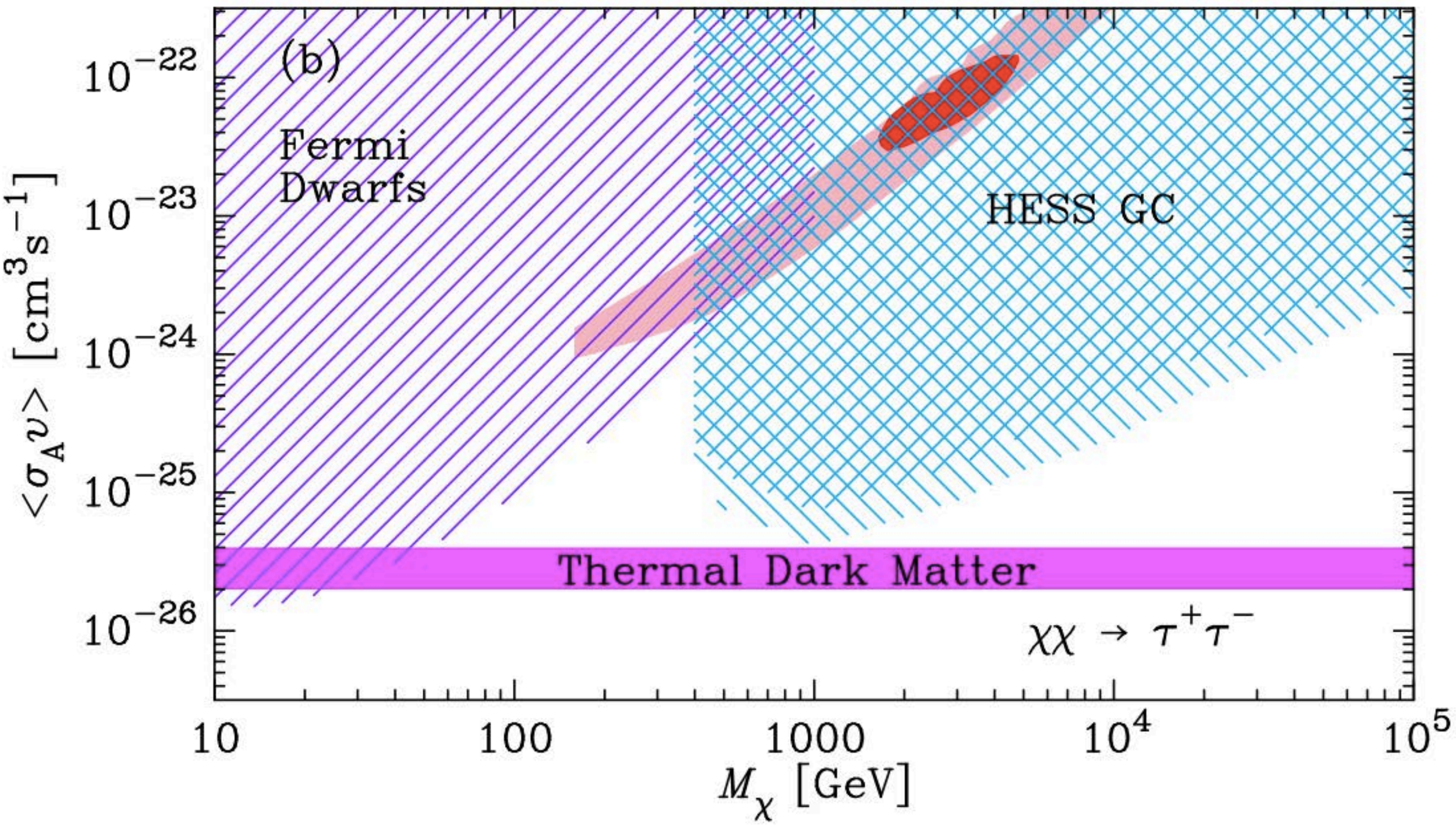
(Kevork Abazajian)

The Observed Fermi-LAT Gamma-Ray Sky



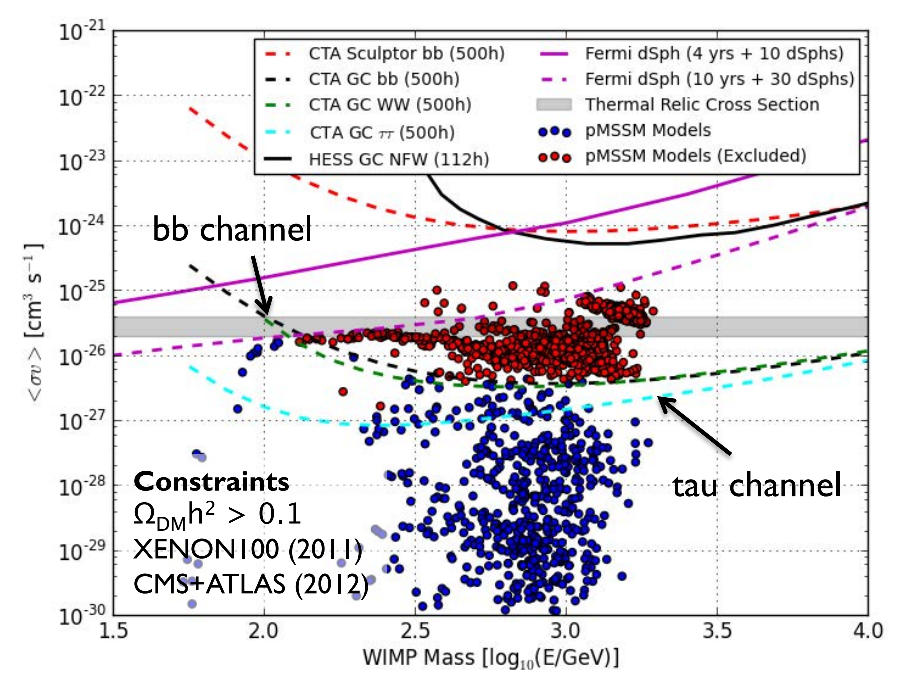
(Kevork Abazajian)

The Best Current Constraints: Fermi-LAT Dwarf Stacking & HESS GC



(Kevork Abazajian)

CTA



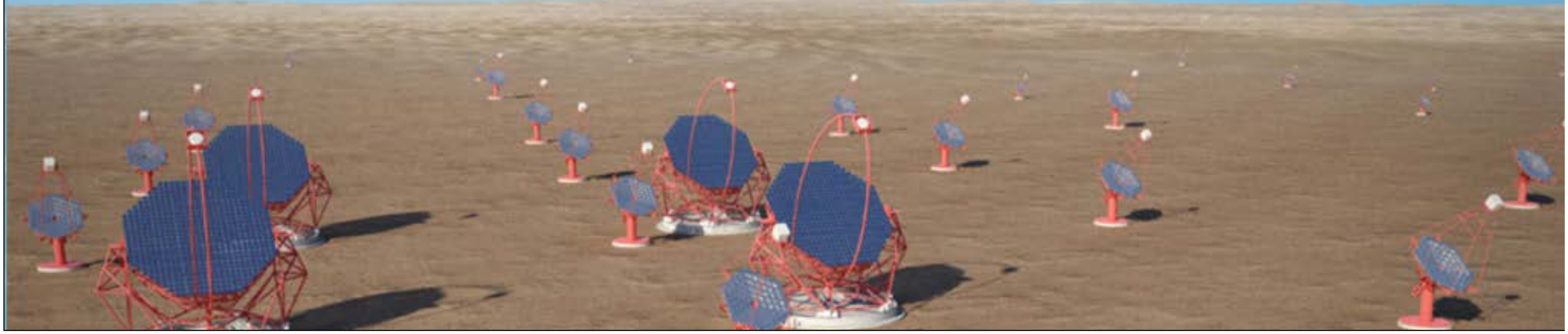
bb channel

tau channel

Constraints
$\Omega_{DM}h^2 > 0.1$
XENON100 (2011)
CMS+ATLAS (2012)

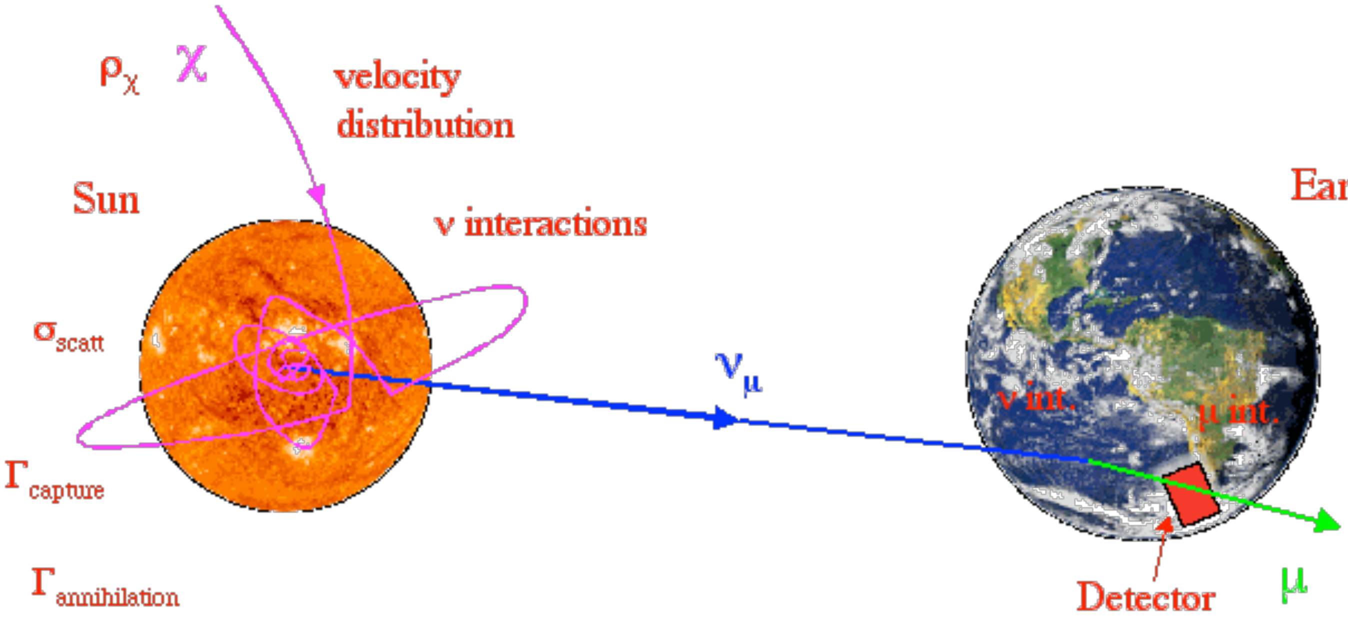
(M.Wood and A. Drlica-Wagner)

(JB)

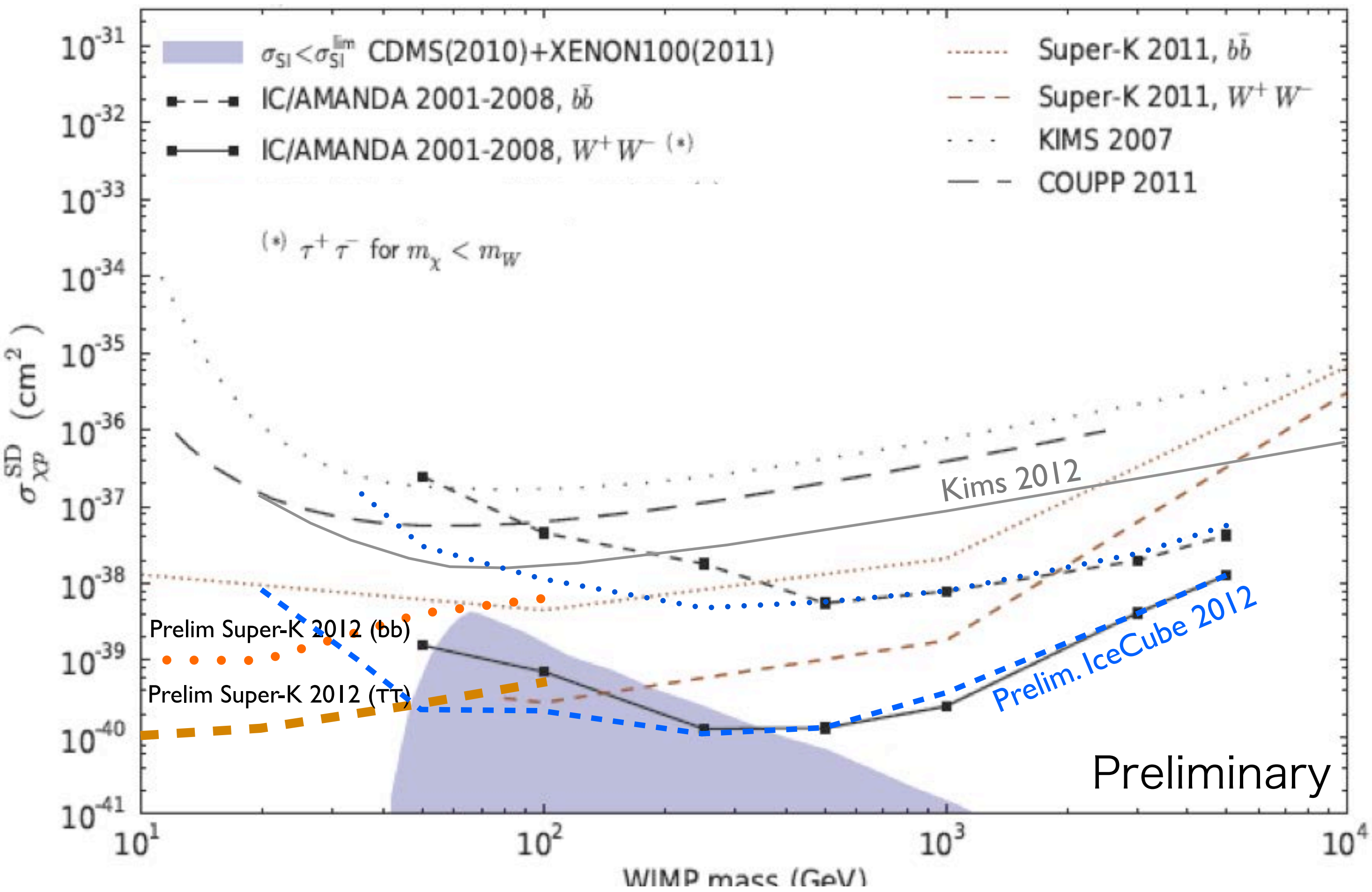


Neutrino Capture by Sun

- The sun is a big proton target that can accumulate WIMPs as they scatter off of the nuclei, are captured, and annihilate giving high energy neutrinos that can be detected at the earth

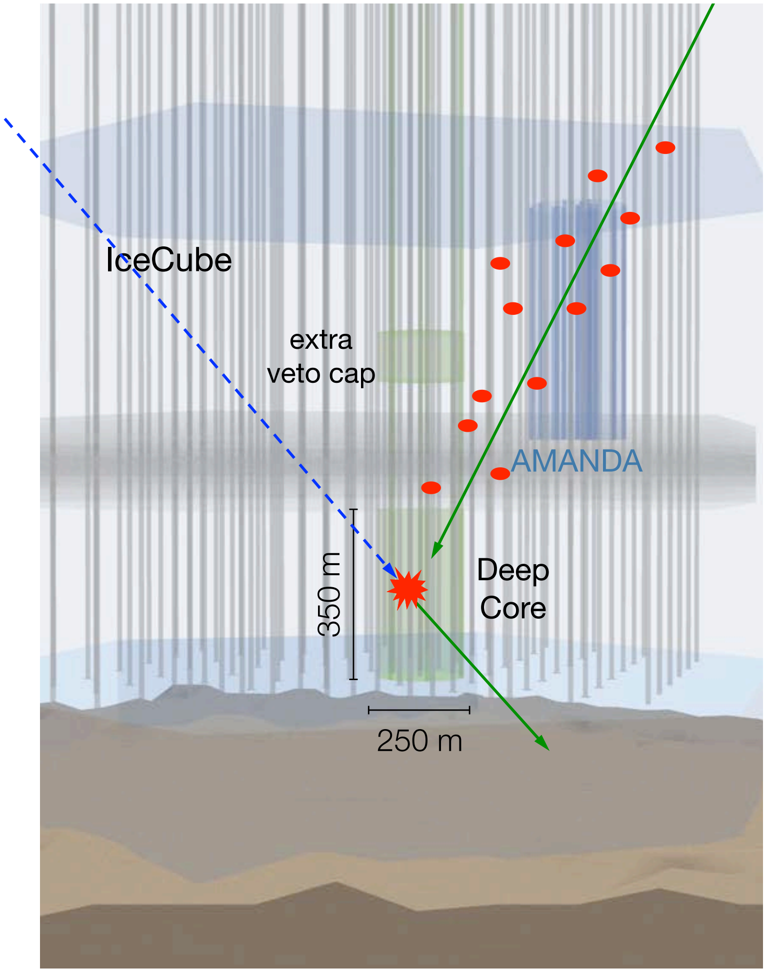


Neutrino SD Limits

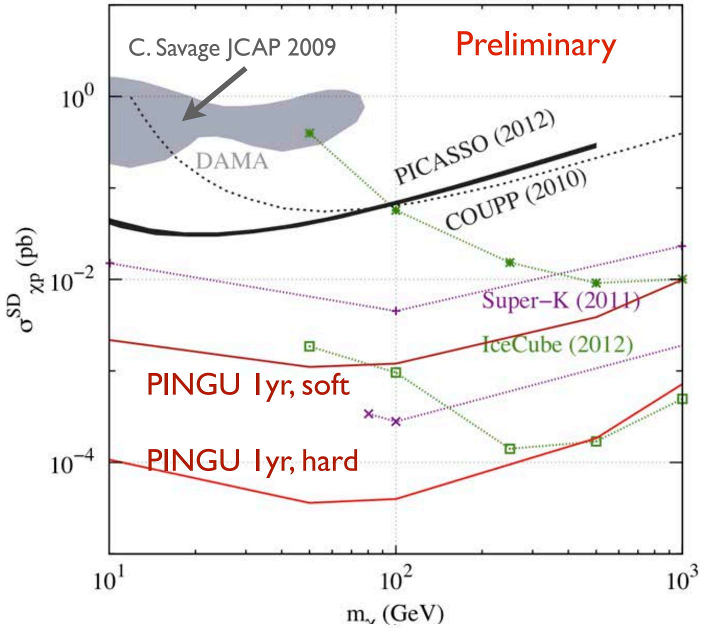


- Super-K and IceCube updated using contained events - lower threshold.

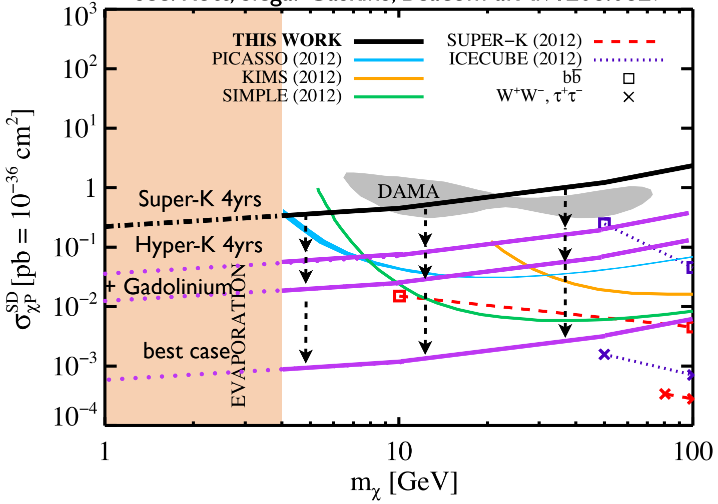
Future Neutrino Detectors



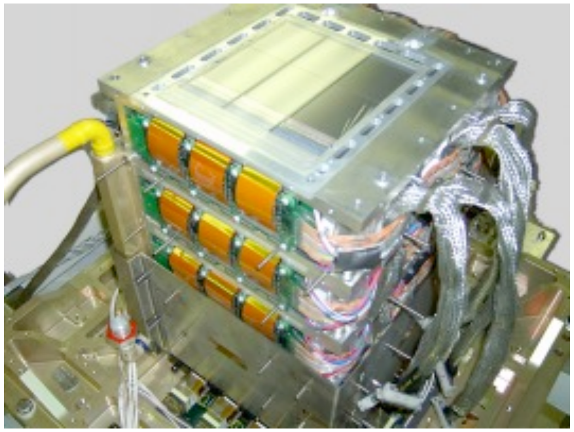
Adapted Rott, Tanaka, Itow JCAP09(2011)029 to



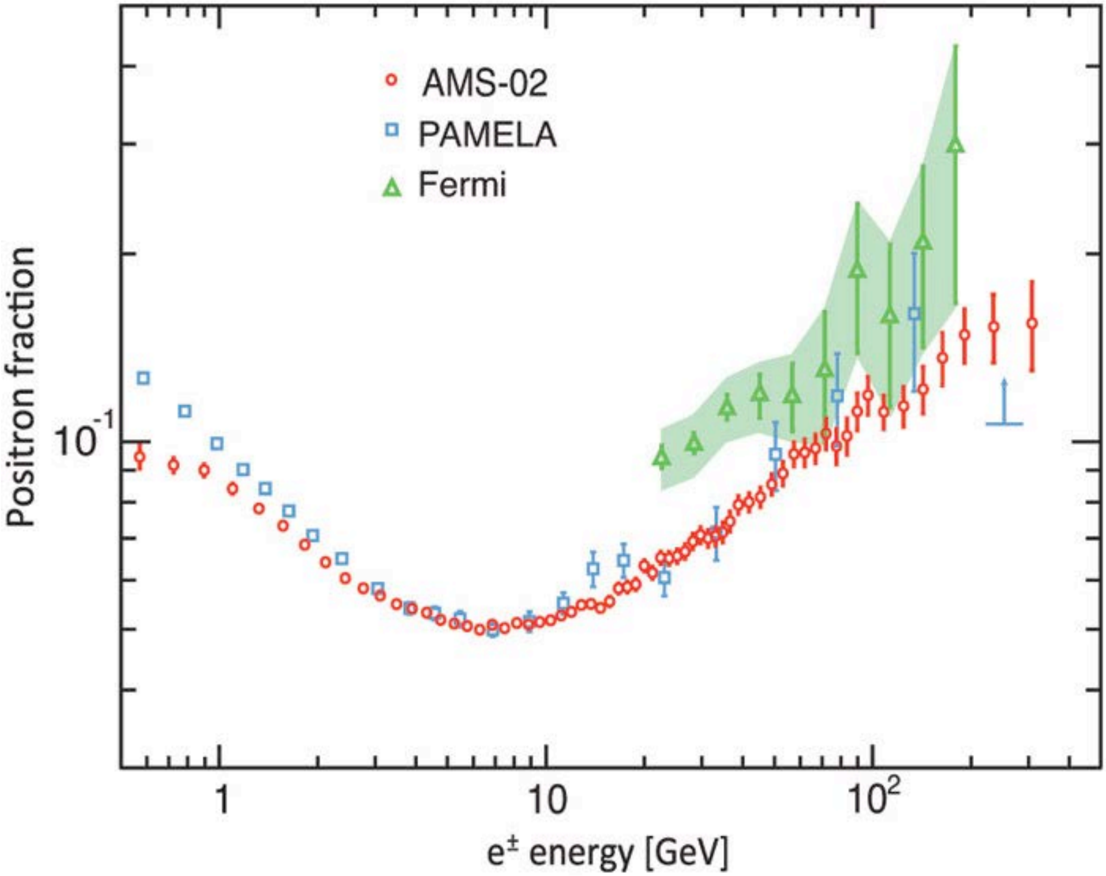
see: Rott, Siegal-Gaskins, Beacom arXiv1208.0827



Positron Results



Positron to Electron Fraction

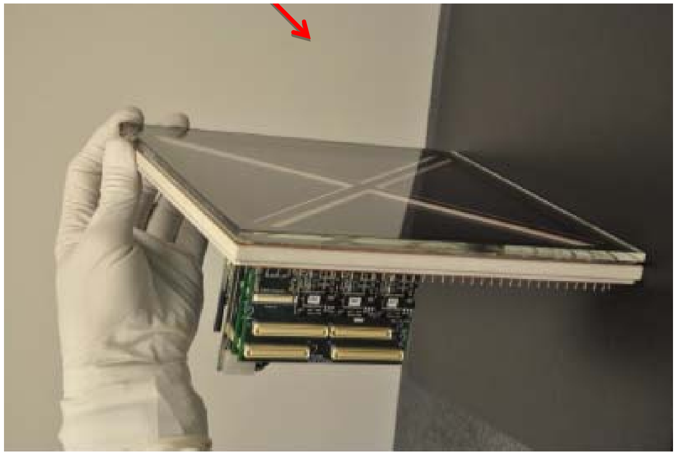


uction
Strong 98

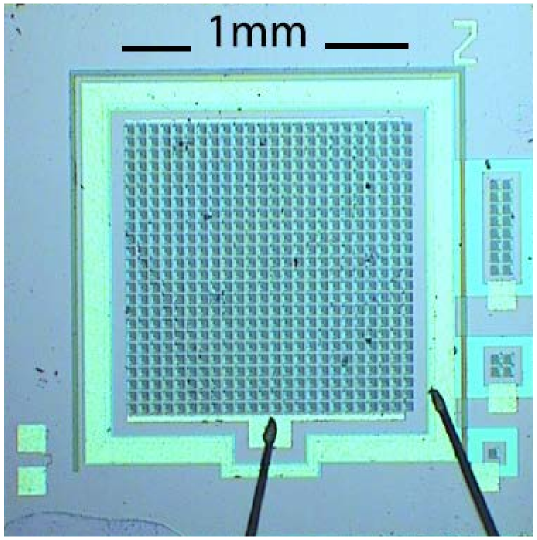
- Refinements in Pamela results, confirmation by Fermi using geomagnetic field, AMS results coming soon!

Technical Developments

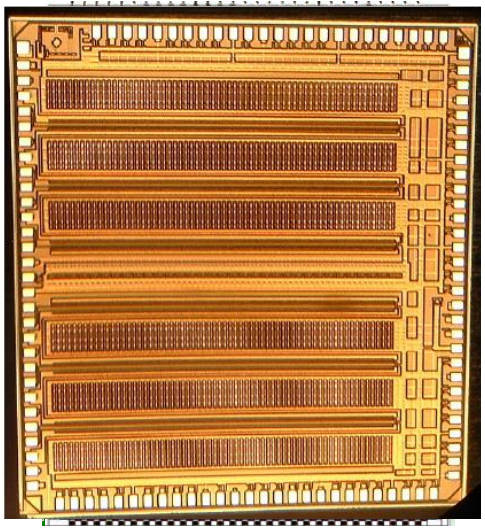
Large-Area HPMT (Masahi Yokoyama)



LAPPD psec timing, 8″ square photodetector, (K. Byrum)



SiPMs, (N. Otte)



- Analog pipeline ASICs (K. Nishimura)

Key Findings

Disclaimer: Not an exhaustive list of key Indirect DM science initiatives!
(10 minutes can't do justice to amazing breadth of work)

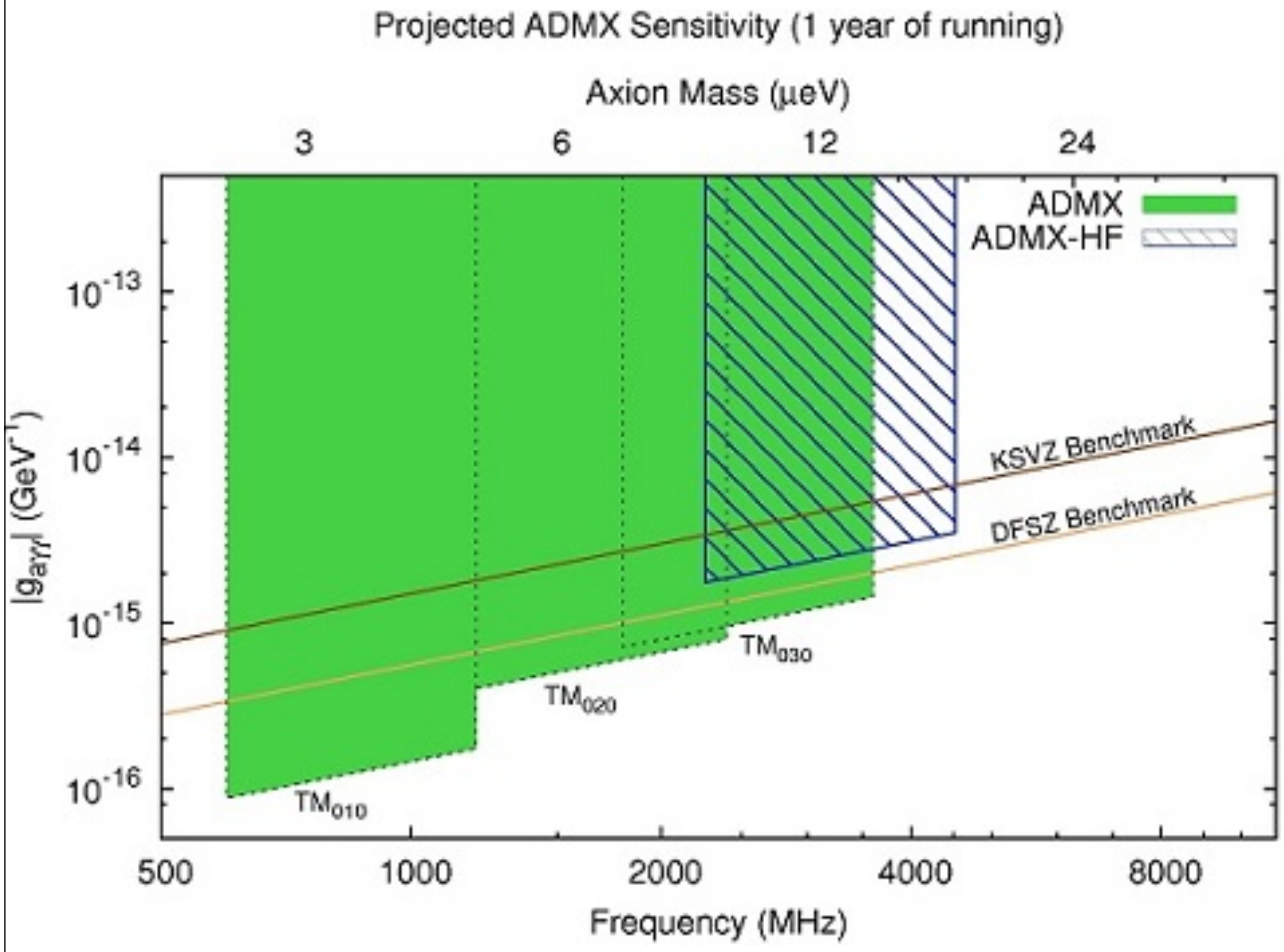
- CTA, with the U.S. enhancement would provide a powerful new tool for searching for WIMP dark matter, and would complement other methods
- Future Neutrino experiments like the PINGU enhancement to IceCube/DeepCore offer the possibility of a smoking-gun signal (high energy neutrinos from the sun), and may provide some of the best constraints on spin dependent cross sections.
- Other astrophysical constraints such as low-frequency radio (synchrotron from electrons) or X-rays (inverse Compton scattering by electrons) can provide very powerful tests for Dark matter annihilation for certain annihilation channels, competitive with existing bounds.
- Detailed theoretical studies with PMSSM, contact operators, realistic halo models are resulting in quantitative estimates of sensitivity
- Key technology developments overlap with Direct Detection and Collider experiments.

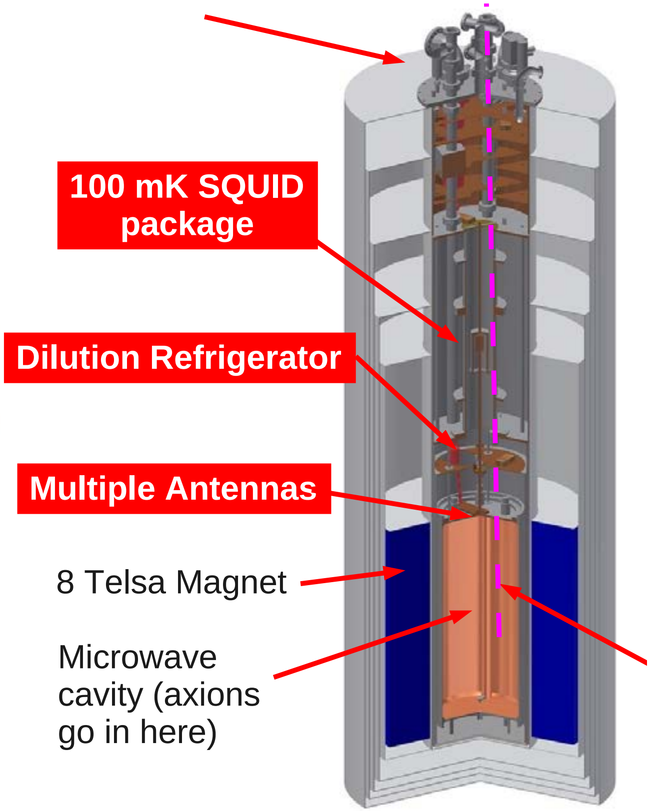
CF3 Summary
Non-WIMP Dark Matter

Alex Kusenko
Leslie Rosenberg

Cosmic Frontier Meeting, SLAC 06-08 March 2013

Gray Rybka: ADMX RF-Cavity Axion Search

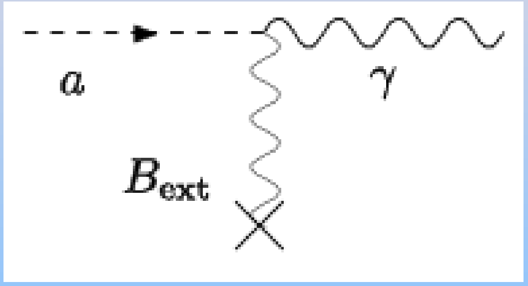




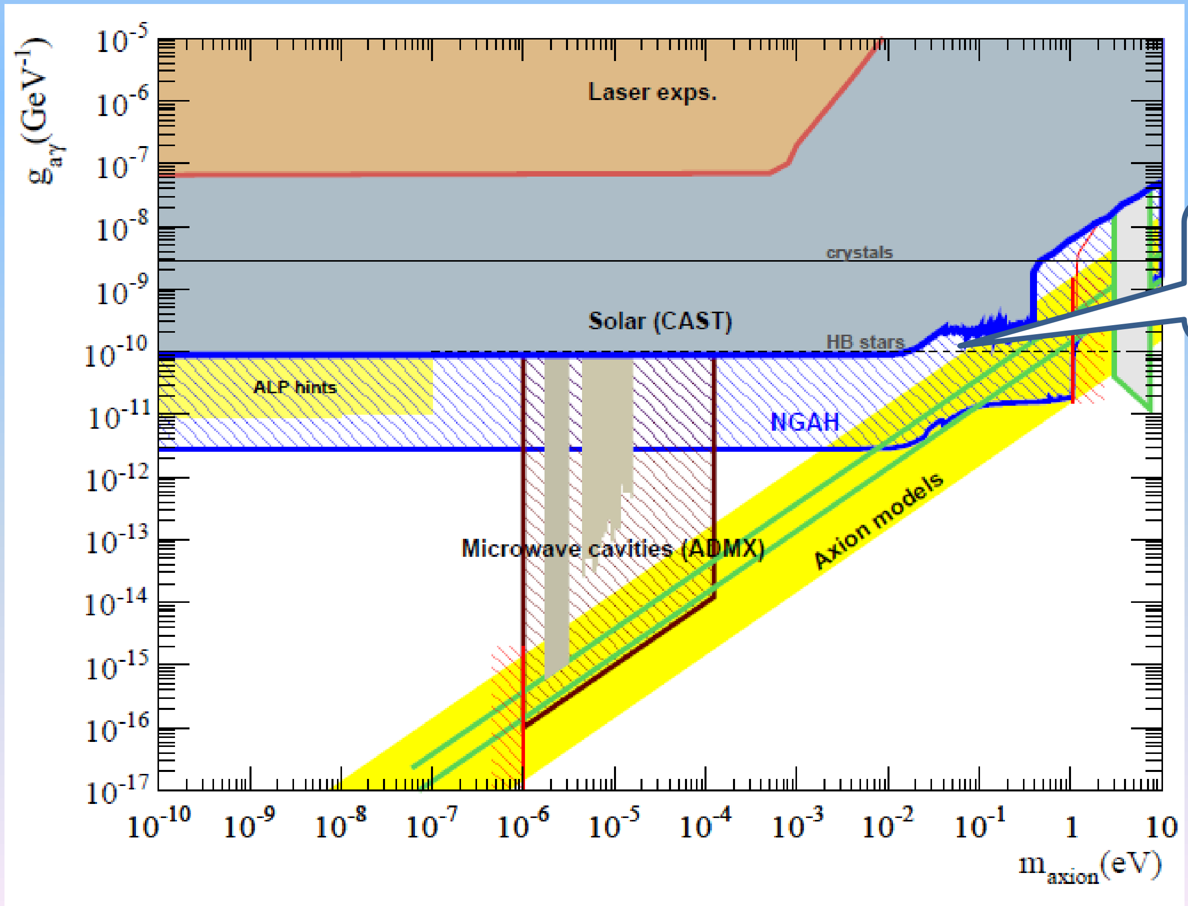
Able to detect the QCD axion or
reject the hypothesis at high confidence.

Experimental Axion (and ALPs) Search

Among the major axion experiments is the Cern Axion Solar Telescope (**CAST**), which is looking for axions from the sun. The Next Generation Axion Helioscopes (NGAH) are expected to improve the bounds by over an order of magnitude.



Axion-photon vertex

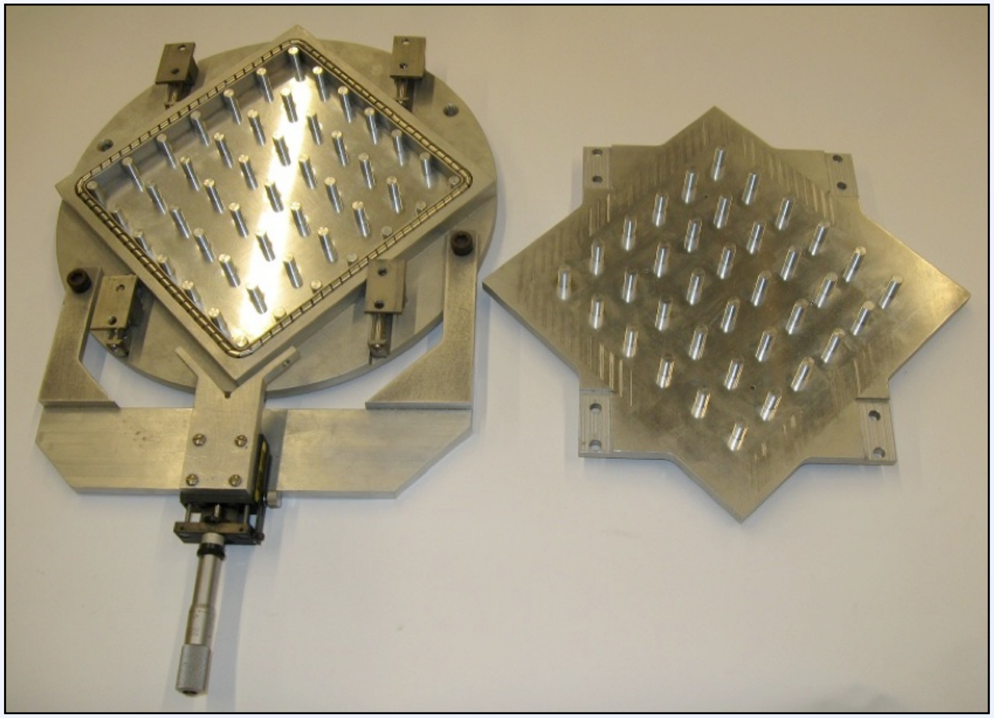


HB-bound, g_{10}=1.
Raffelt and Dearborn (1987)

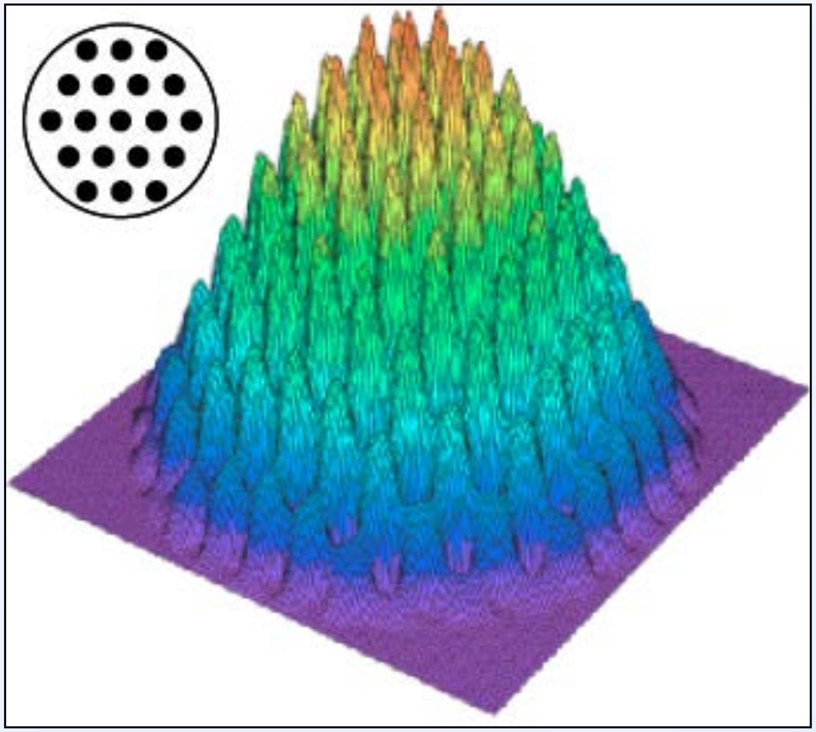
from I. G. Irastorza et al., *Latest results and prospects of the CERN Axion Solar Telescope*, Journal of Physics: Conference Series **309 (2011) 012001**

Carosi: RF-Cavity R&D

Cavities for RF-cavity axion searches: High Q, tunable, good “form factor”.

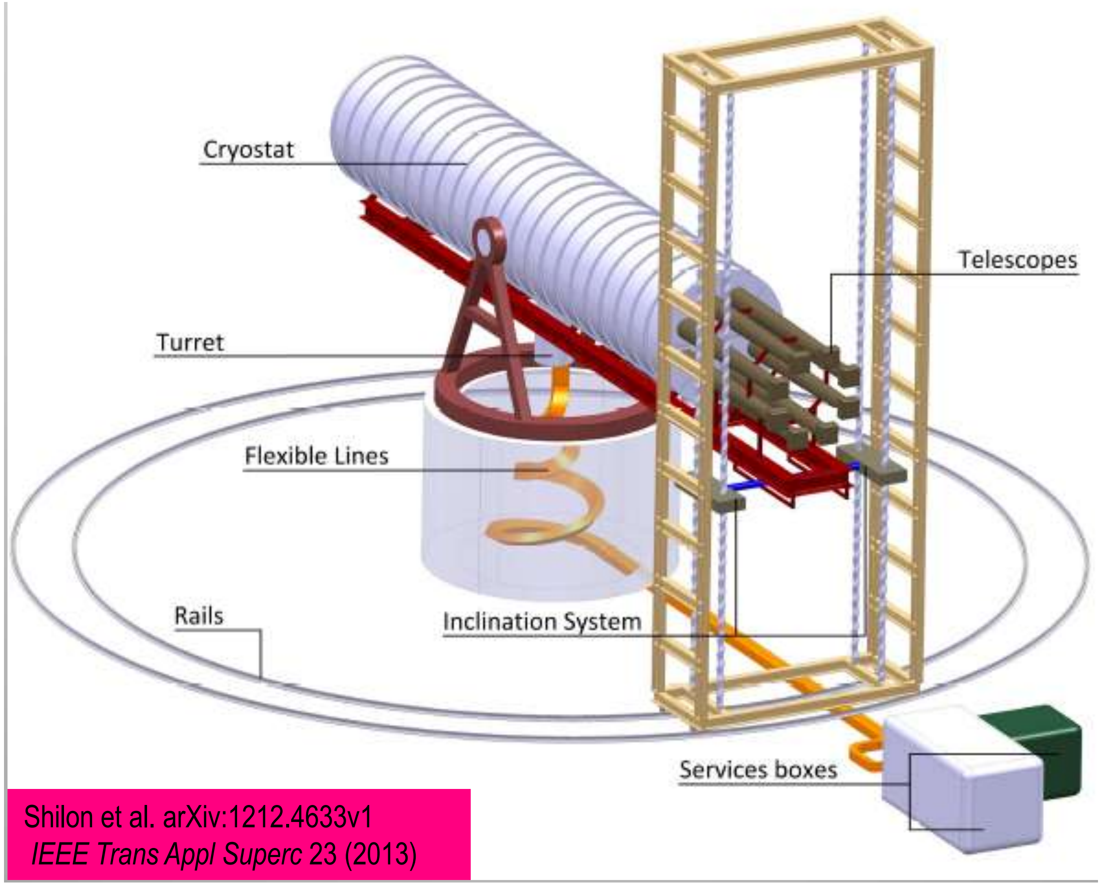


Prototype multipost cavity



***C. Hagmann simulation**

Pivovarov: IAXO



Shilon et al. arXiv:1212.4633v1
IEEE Trans Appl Superc 23 (2013)

International Axion Observatory:4th Generation Helioscope. Powerfully explores region of astrophysical hints of axions plus ...

Wide-Ranging, Lively Discussion

Wednesday:

Pierre Sikivie “An Argument that the Dark-Matter is Axions”
Maurizio Gionnotti “Astrophysical Constraints on Axion-Photon Coupling”
Kyu Junk Bae “Cosmology of SUSY Axion Models”
Gray Rybka “ADMX Current Status”
Karl van Bibber “ADMX-HF”
Gianpaolo Carosi “Microwave Cavity R&D for Axion Cavity Searches”
Michael Pivovarov “IAXO: International Axion Observatory”
Ariel Zhitnitsky “Dark Matter & Baryogenesis as Two Sides of the Same Coin”
Kyle Lawson “Ground-Based Quark Nugget Search”
Javier Redondo “IAXO and the Science Case”
Agnieszka Ciepiak “Contraining Primordial Black Hole Dark Matter Using Microlensing”
Jeremy Mardon “Direct Detection Beyond the WINP Paradigm”

Wide-Ranging Discussion (continued)

Thursday:

Takeo Moroi “Non-WIMP Dark Matter in SUSY Models
Yasunori Nomura “A Theoretical Perspective on Dark Matter”
Clifford Cheung “Non-WIMP Zoology”
Jiji “Double-Disk Dark Matter” (joint CF6)
Kris Sigurdson “Dark Matter Antibaryons and Induced Nucleon Decay” (joint CF6)
George Fuller “Dark Matter and Supernovae”
Kevork Abazajian “The Status of Sterile Neutrino Dark Matter”
Oleg Ruchaiskiy “Sterile Neutrinos as Dark Matter”
David Cline “The Search for Low-Mass WIMPs”
Leonidas Moustakis “Shedding Light”
Jenniver Seigel-Gaskins “Constraints on Sterile Neutrinos DM From Fermi …”

Friday (with CF4):

Louis Strigari “Is there observed tension between small-scale structure and CDM?”
Hector de Vega “Fermionic WDM Reproduces Galaxy Observations because of Q.M.”
Dodelson “Current and Future Cosmological Constraints on Neutrinos”

CF5: Dark Energy, Inflation and Neutrinos

Dark Energy Summary K. Honscheid

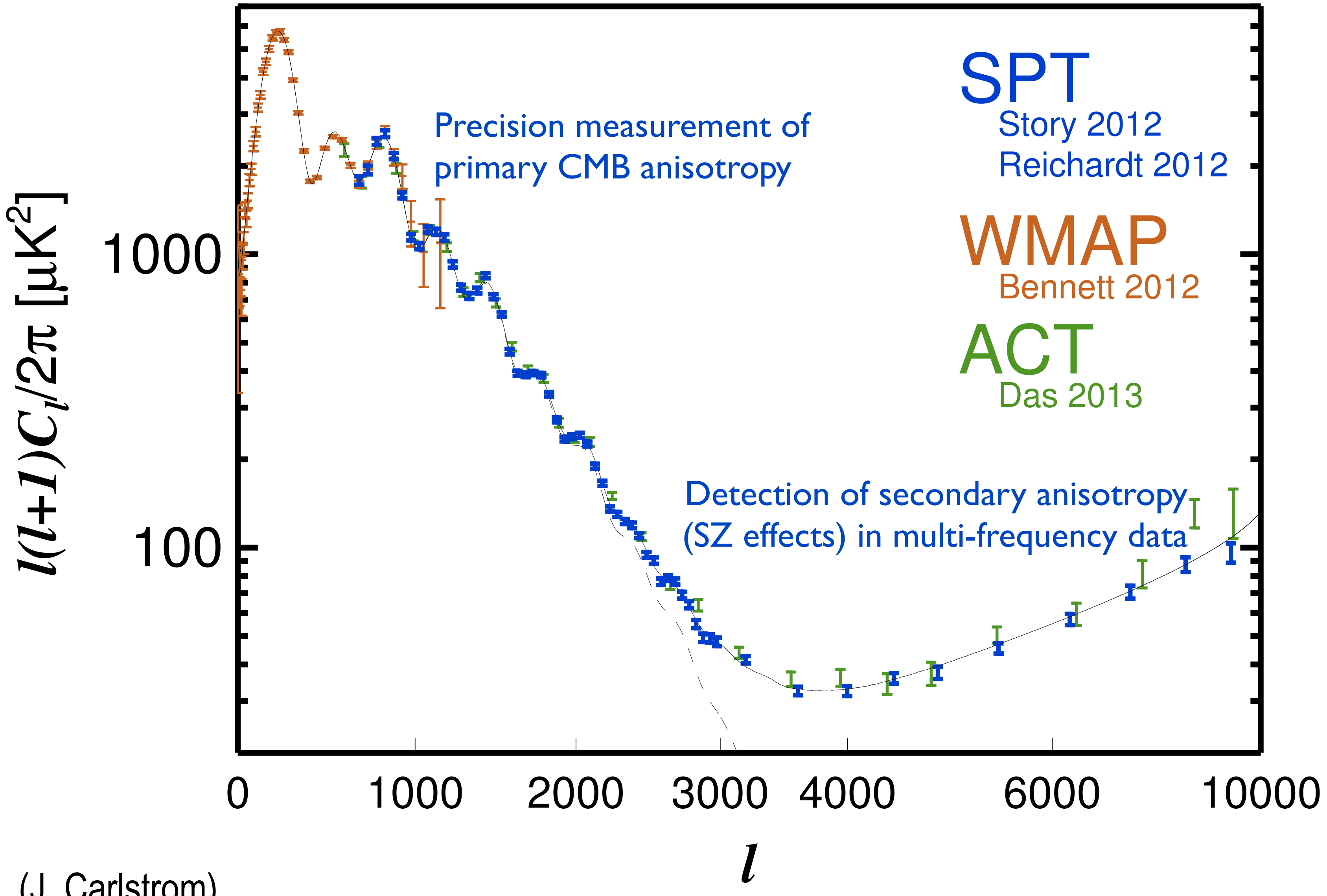
Part II: Projects

Dark Energy and the CMB

(Sarah Church, SD, Klaus Honscheid)

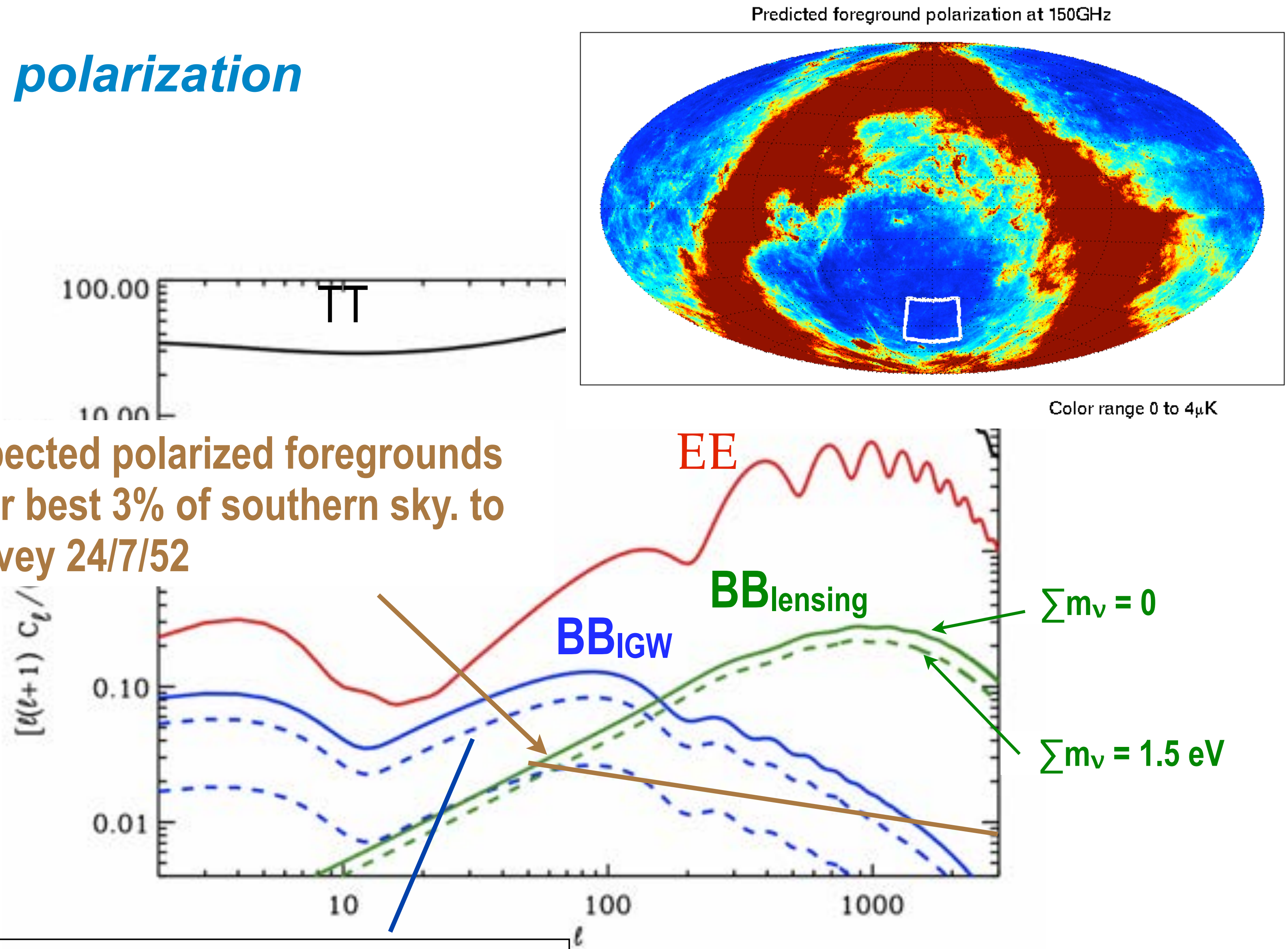
Anisotropy angular power spectrum

CMB - J. Carlstrom



(J. Carlstrom)

CMB polarization



Predicted foreground polarization at 150GHz

Color range 0 to 4μK

Expected polarized foregrounds over best 3% of southern sky. to survey 24/7/52

BB_{IGW}

$BB_{lensing}$

$\sum m_\nu = 0$

$\sum m_\nu = 1.5$ eV

Inflationary gravitation waves

(J. Carlstrom)

B-modes timeline

- 2009: $r < 0.7$ (BICEP) Chiang et al, 0906.1181
- 2012: no detections of inflationary or lensing B-modes

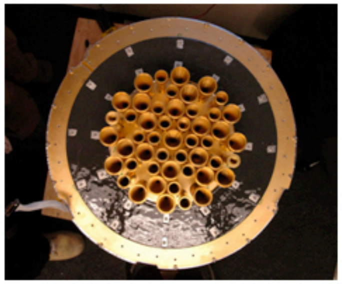
- 2013: $r \lesssim 0.1$ from Inflationary B-modes (BICEP II) ?
- 2013: Stage II experiments detect lensing B-modes
- 2013+ Stage II experiments $\sigma(r) \lesssim 0.03$
  and $\sigma(\Sigma m_\nu) \sim 0.1$ eV from lensing B-modes
- 2016+: Stage III achieve $\sigma(r) \lesssim 0.01$ & $\sigma(\Sigma m_\nu) \sim 0.05$ eV; measure lensing B-modes to $L \sim 800$ with $s/n > 1$; allow "delensing" of inflation B-modes

---

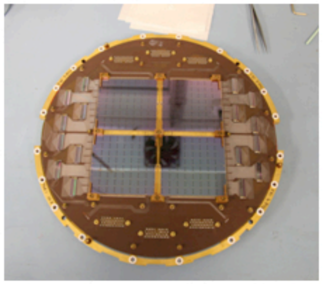
- 2020+: **Stage IV goal to reach $r \sim 0.001$ (or better?)**
  and $\sigma(\Sigma m_\nu) \sim 0.01$ eV

(J. Carlstrom)

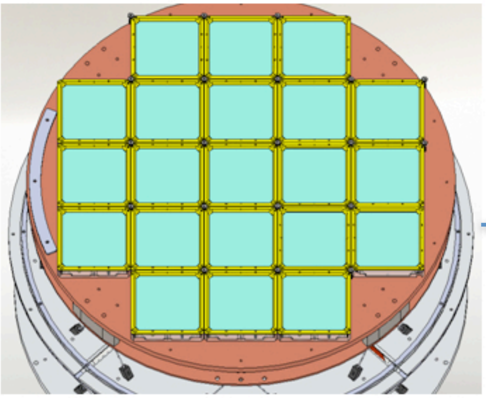
CMB Instrumentation I



98 NTDs (95/150 GHz)



512 TESs (150 GHz) per F.P.



>4,000 TESs (150GHz) per F.P.

Stage-IV CMB
Duplicate (>10x)
Focal planes
(physical size limited by
IR loading, size of
vacuum window, lenses)

- Stage II (~1000 elements) already observing
- Stage III (> 10K detector elements, e.g. TES)
  - 10x increase in mapping speed
  - Preparing for deployment
- Stage IV
  - 10x increase in mapping speed over stage III
  - Deploy ~2020?

See Clarence Chang, Chao-Lin Kuo talks, SLAC Cosmic Frontier Workshop, March 2013

(S. Church)

Summary

CMB measurements are at the heart of cosmology and fundamental physics.

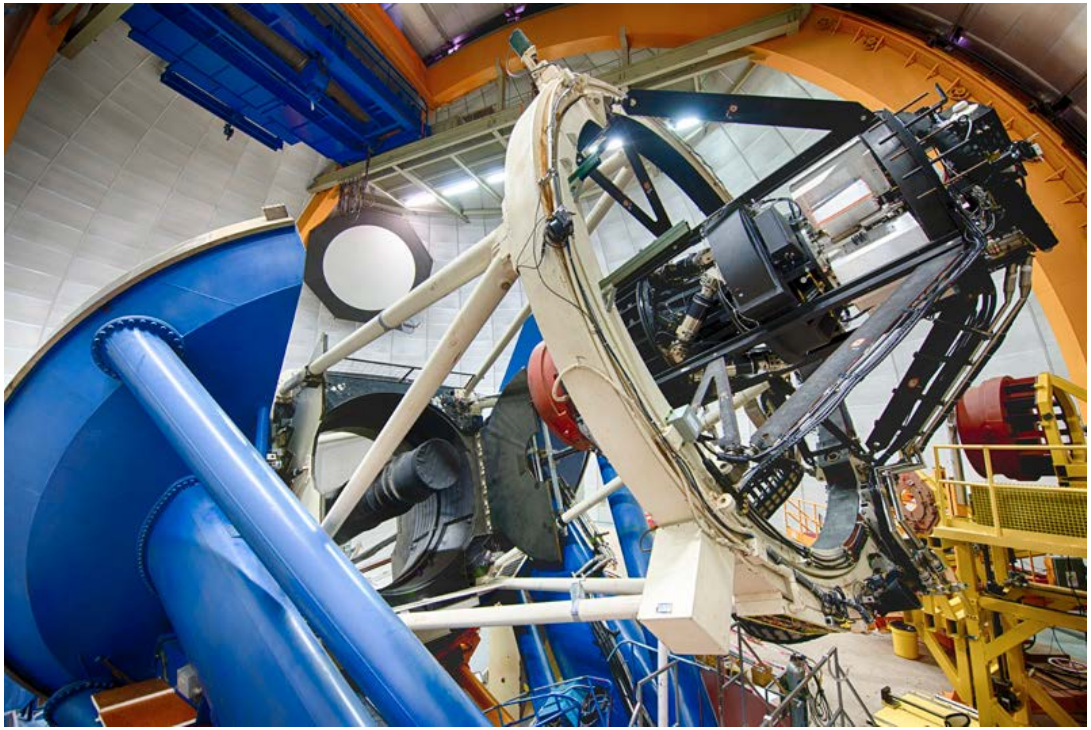
Stage IV CMB experiment is needed.

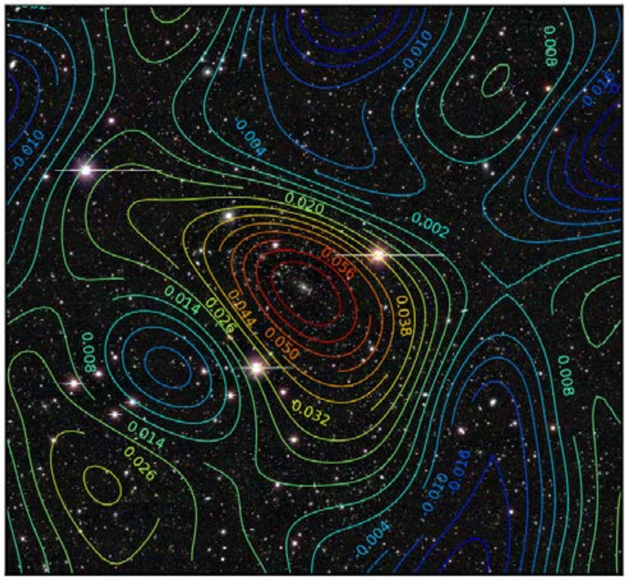
It will be extremely challenging, but achievable, with 100x or more increase in detectors from current Stage II, incredible attention to systematics, and commensurate increase in computing.

It is a HEP multilab-scale project!

(J. Carlstrom)

Dark Energy Survey – First Light September 12, 2012





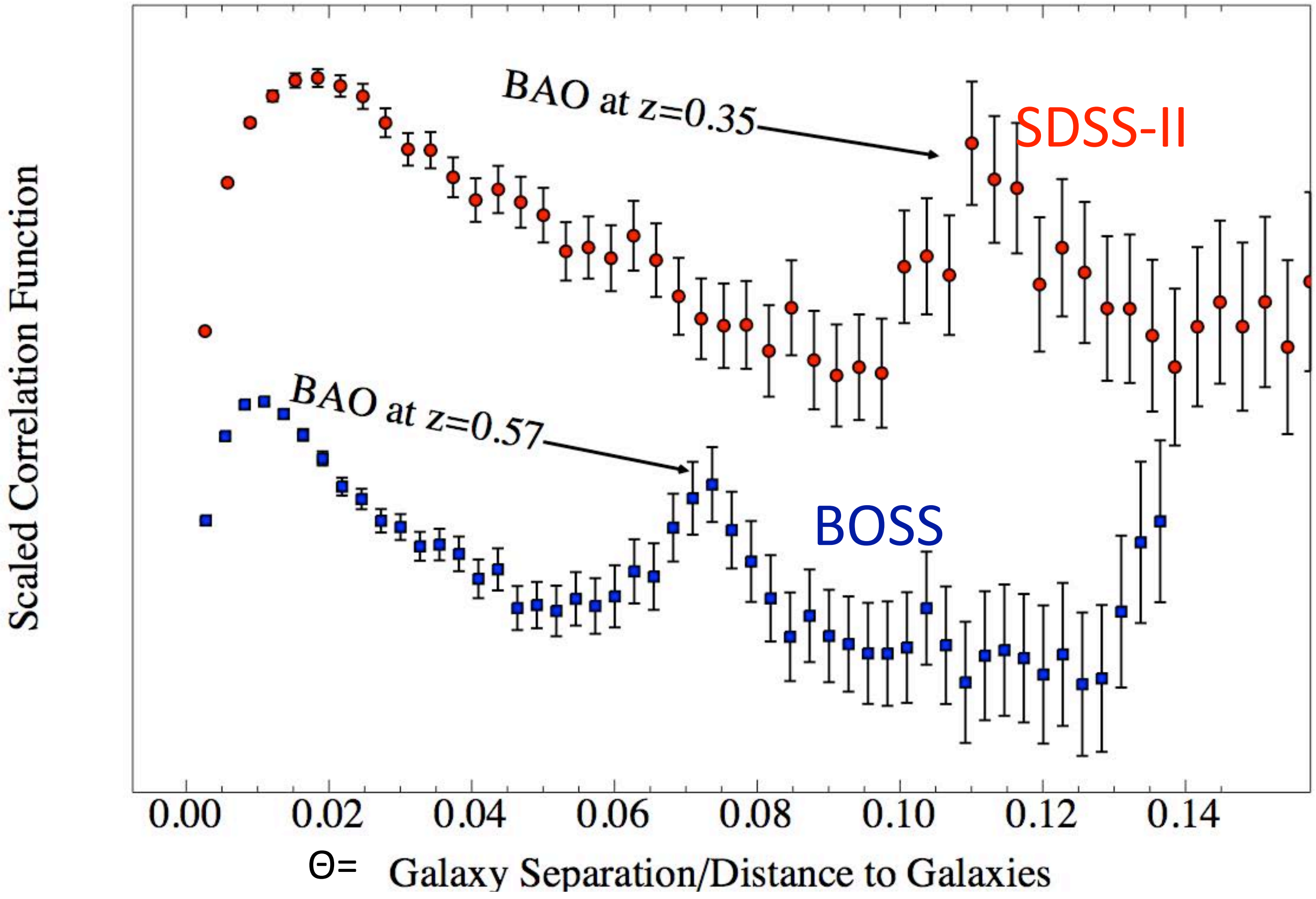
DES Weak Lensing Mass Map

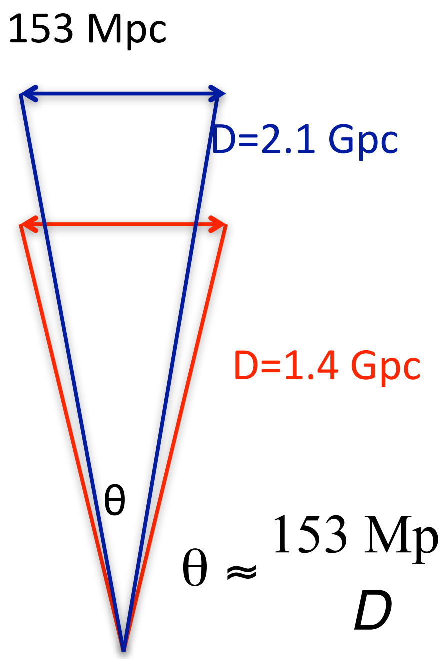
Cluster observed during SV

Michael Levi

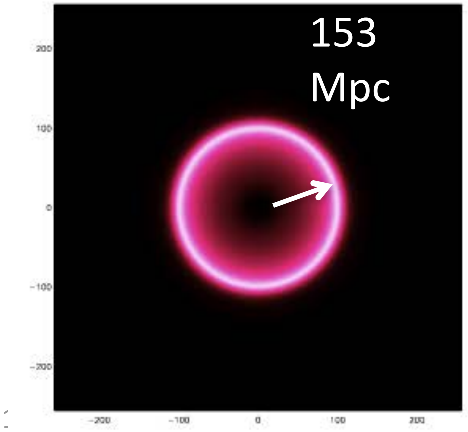
SDSS/BOSS has established BAO and RSD techniques

Measure angle θ, do trigonometry to get D(z).



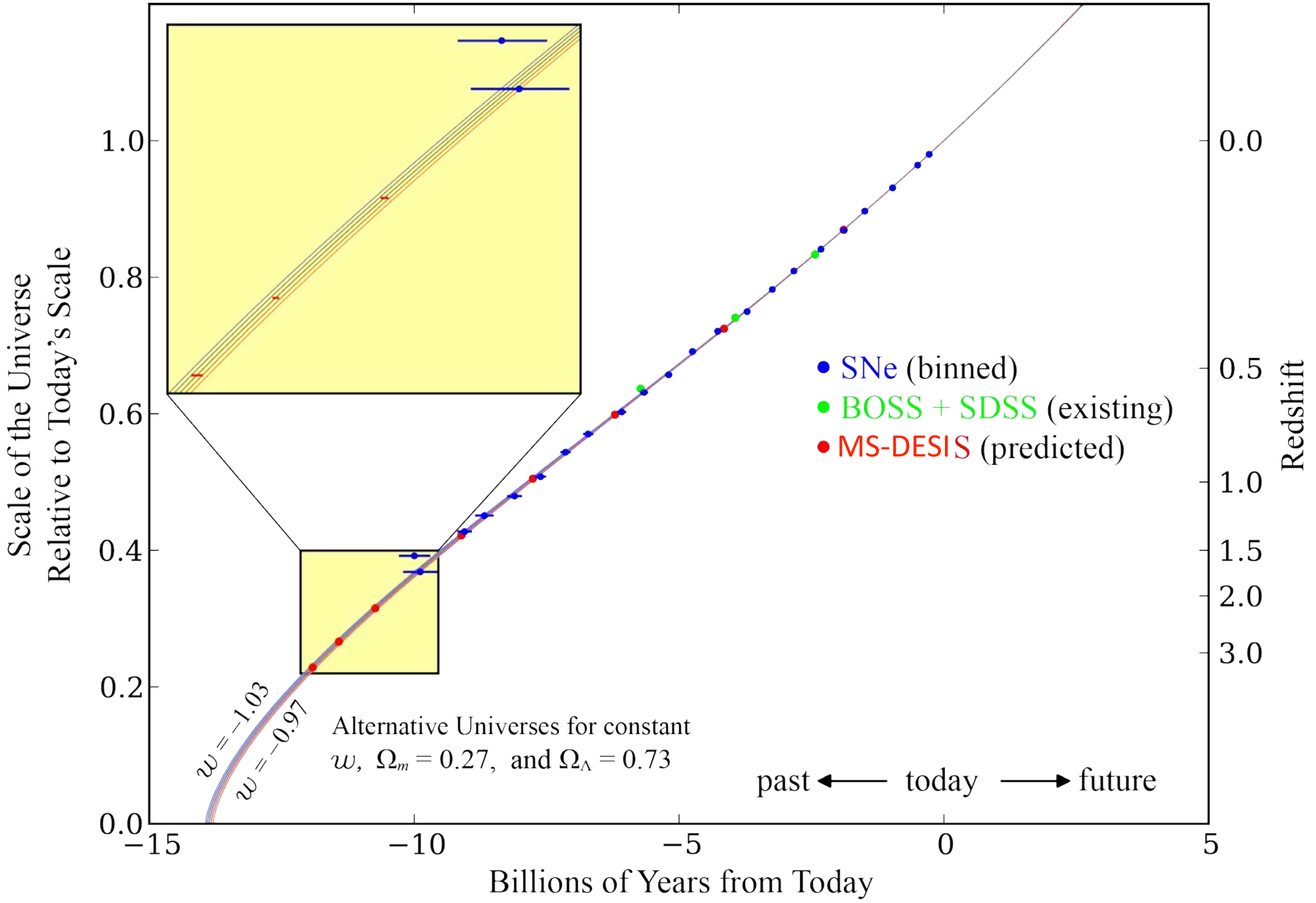


$$\theta \approx \frac{153\ \mathrm{Mpc}}{D}$$

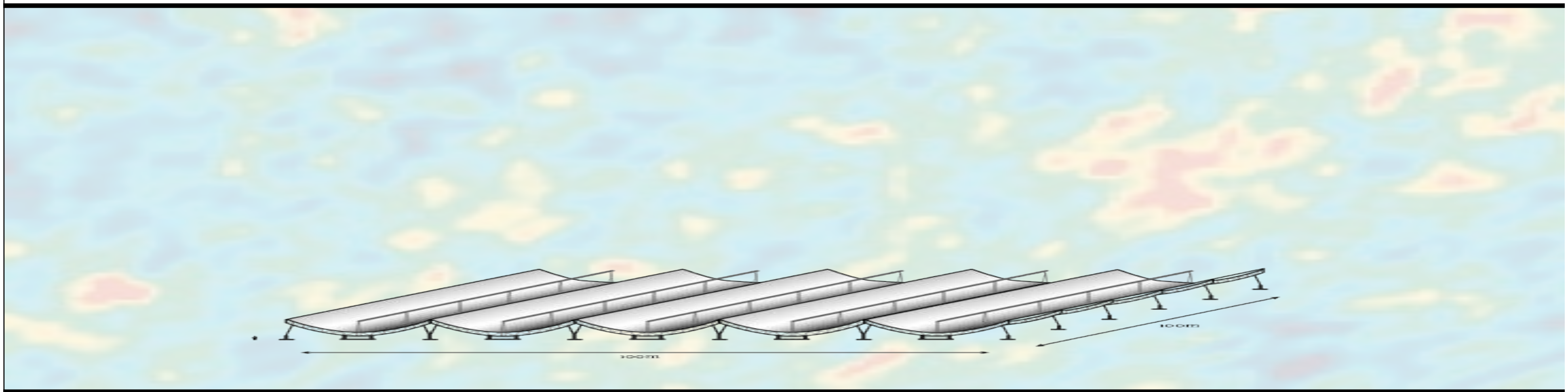


Michael Levi

MS-DESI Will Discriminate Between Dark Energy Models



21 cm Intensity Mapping for BAO and CHIME



UBC THE UNIVERSITY OF BRITISH COLUMBIA

DRAO
NRC · CNRC

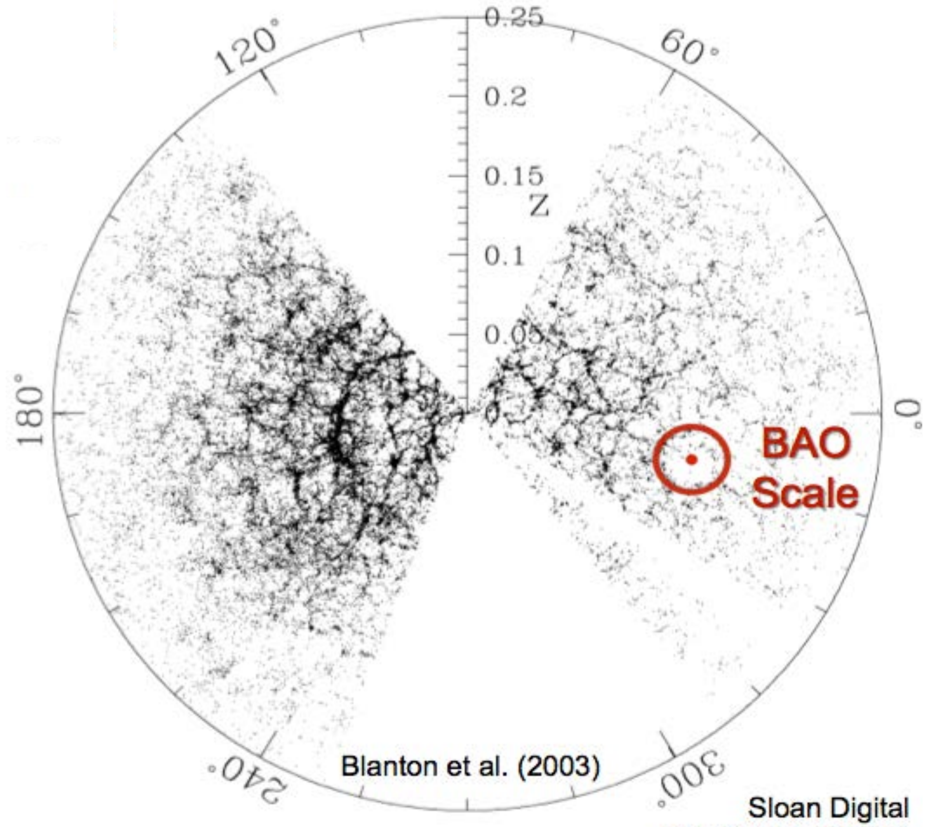
UNIVERSITY OF TORONTO

McGill

G. Hinschaw

G. Hinschaw

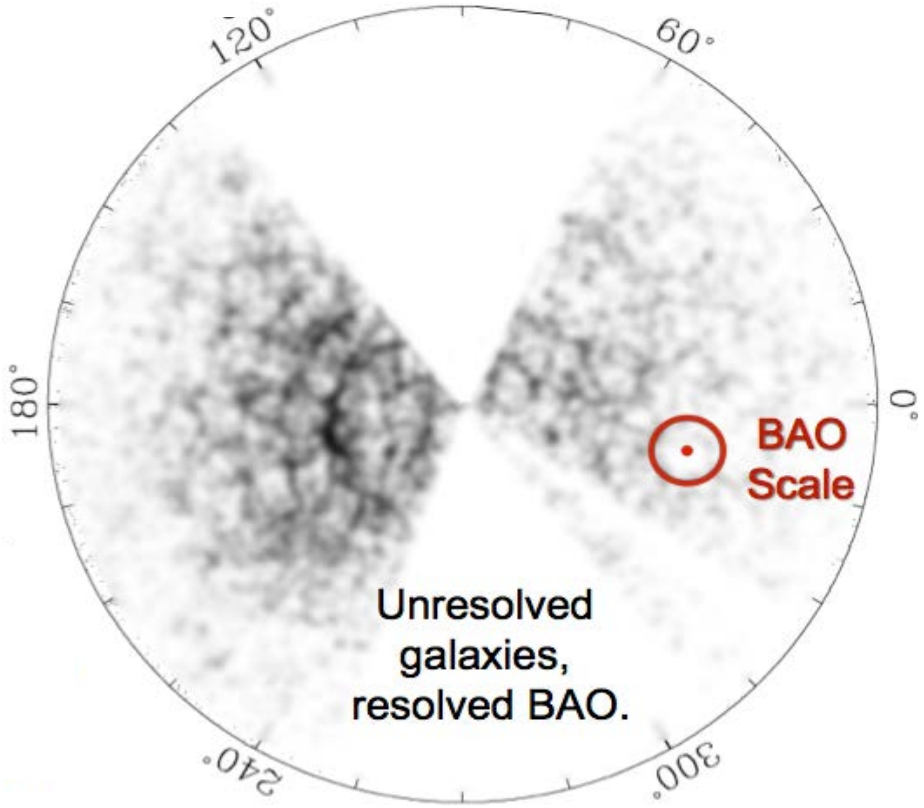
(Eisenstein et al., ApJ, 2005)



Blanton et al. (2003)

Sloan Digital
Sky Survey (SDSS)

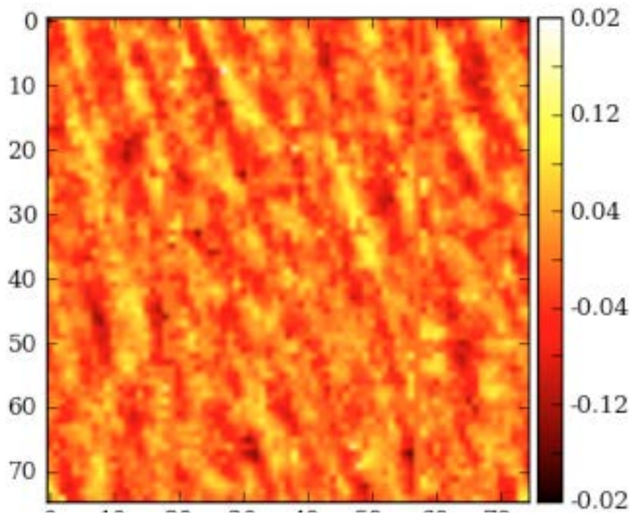
Simulated at 21 cm



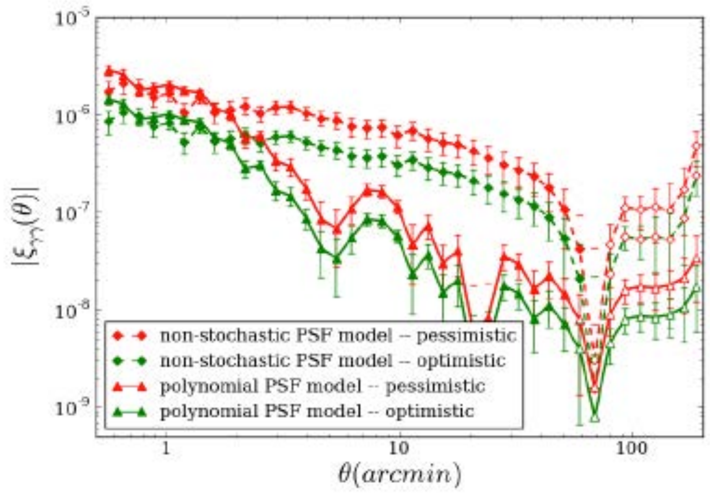
Unresolved
galaxies,
resolved BAO.

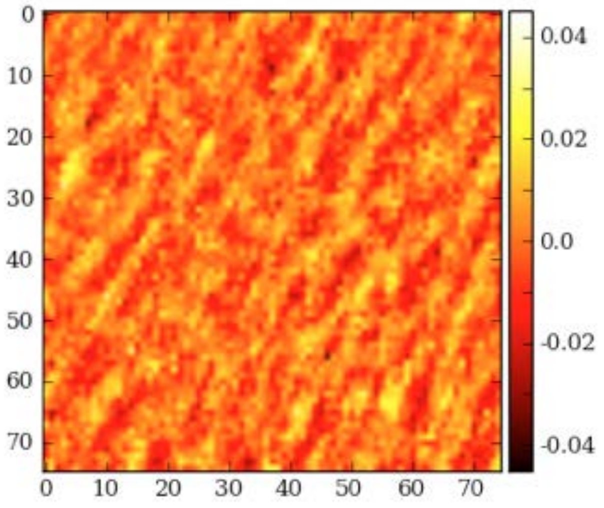
Steve Kahn

CHFT Residuals

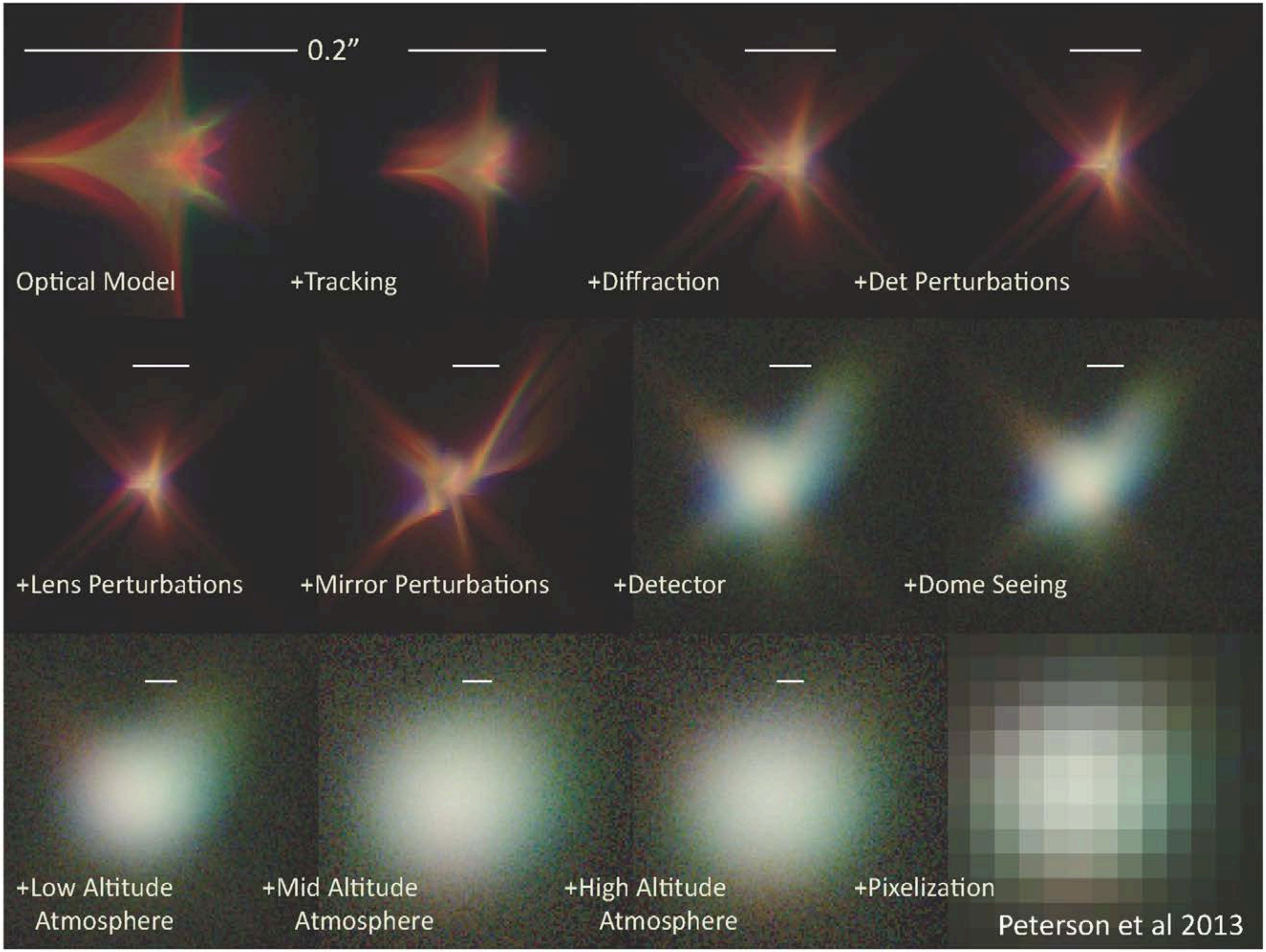


Weak Lensing Shear Systematics

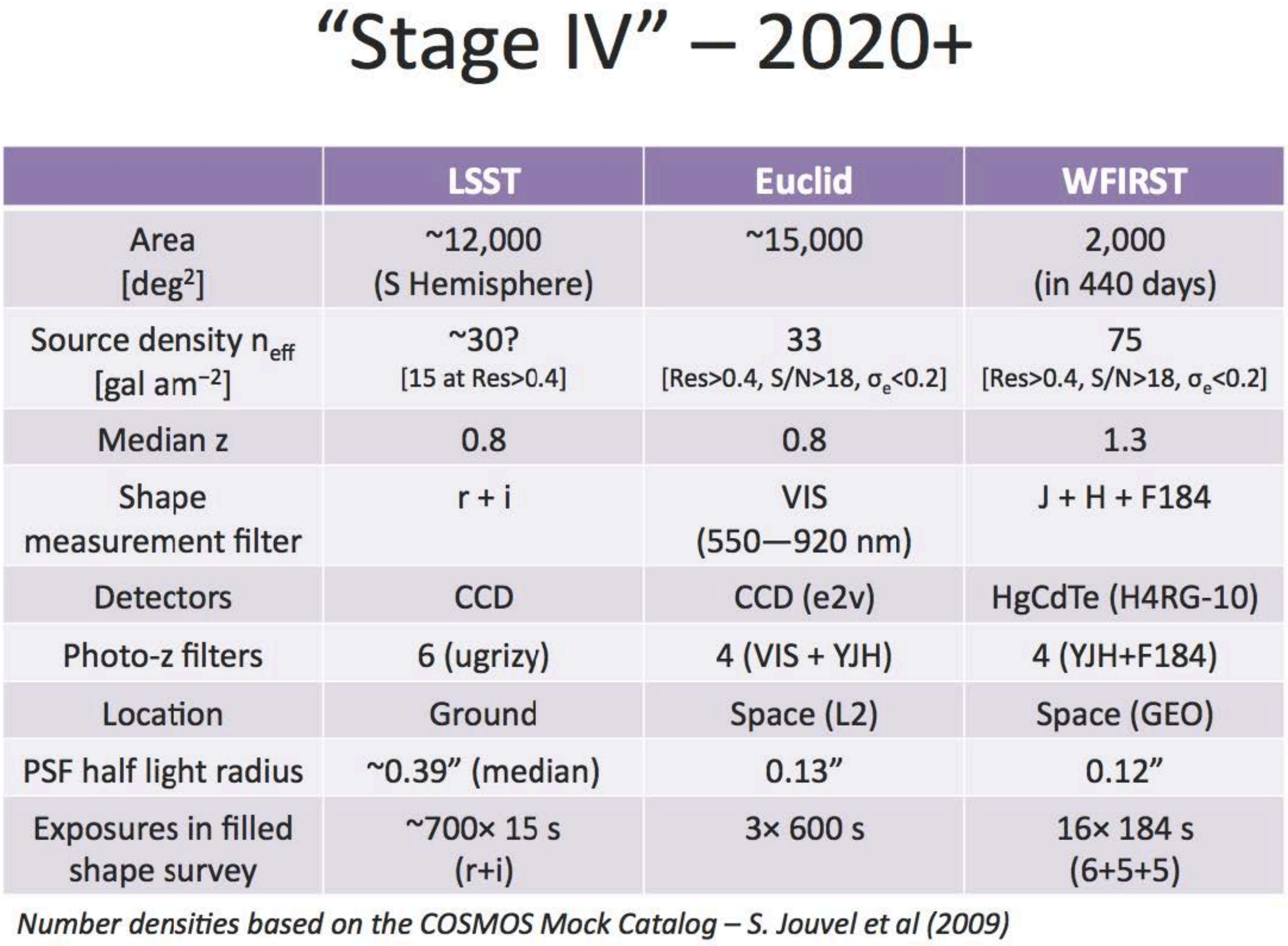




Simulation


0.2"
Optical Model
+Tracking
+Diffraction
+Det Perturbations
+Lens Perturbations
+Mirror Perturbations
+Detector
+Dome Seeing
+Low Altitude Atmosphere
+Mid Altitude Atmosphere
+High Altitude Atmosphere
+Pixelization
Peterson et al 2013

Space Missions (J. Rhodes, N. Gehrels)



“Stage IV” – 2020+

	LSST	Euclid	WFIRST
Area [deg^2]	~12,000 (S Hemisphere)	~15,000	2,000 (in 440 days)
Source density n_{eff} [gal am^{-2}]	~30? [15 at Res>0.4]	33 [Res>0.4, S/N>18, σ_e<0.2]	75 [Res>0.4, S/N>18, σ_e<0.2]
Median z	0.8	0.8	1.3
Shape measurement filter	r + i	VIS (550—920 nm)	J + H + F184
Detectors	CCD	CCD (e2v)	HgCdTe (H4RG-10)
Photo-z filters	6 (ugrizy)	4 (VIS + YJH)	4 (YJH+F184)
Location	Ground	Space (L2)	Space (GEO)
PSF half light radius	~0.39” (median)	0.13”	0.12”
Exposures in filled shape survey	~700× 15 s (r+i)	3× 600 s	16× 184 s (6+5+5)

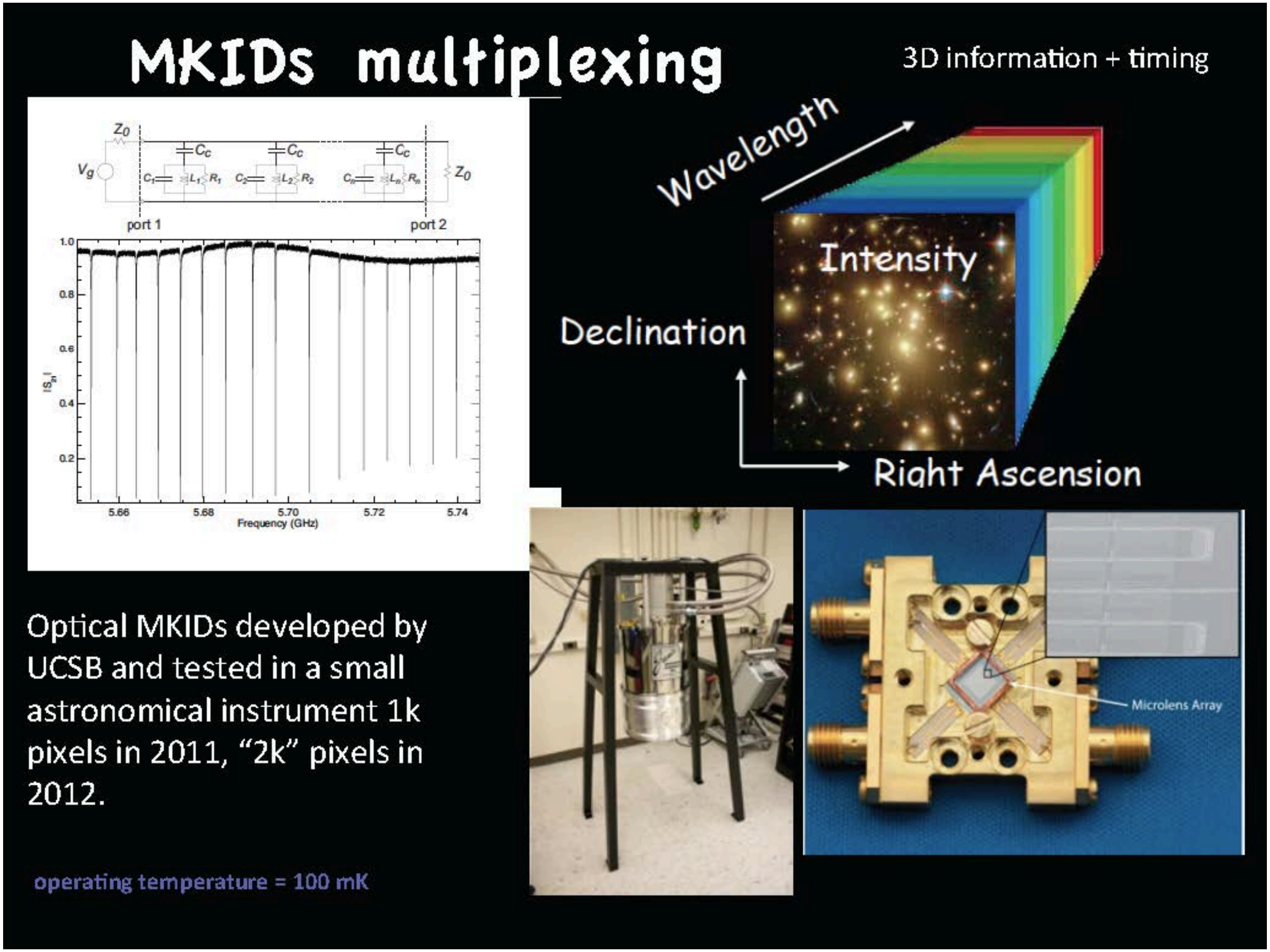
Number densities based on the COSMOS Mock Catalog – S. Jouvel et al (2009)

Dark Energy Technology

- MS-DESI (near future), LSST (a little further out)
- Desirable development for future experiments
  - Pixels with spectral sensitivity – spectroscopic information for each object significantly enhanced figure of merit of DE experiments
  - timing capability – can correct for atmospheric effects
- Examples of new technologies
  - MKIDs (kinetic inductance detectors)
  - SiPMs (Silicon Photomultipliers)
  - 50,000 fiber spectrograph

See talk by Juan Estrada, SLAC Cosmic Frontier Workshop, March 2013

Looking Ahead – New Ideas (J. Estrada)



MKIDs multiplexing

3D information + timing

Optical MKIDs developed by UCSB and tested in a small astronomical instrument 1k pixels in 2011, “2k” pixels in 2012.

operating temperature = 100 mK

What is driving the acceleration of the Universe?

Quintessence: New dynamical field with small mass

Test this by measuring the equation of state of dark energy (w,w') with four probes:

Supernovae

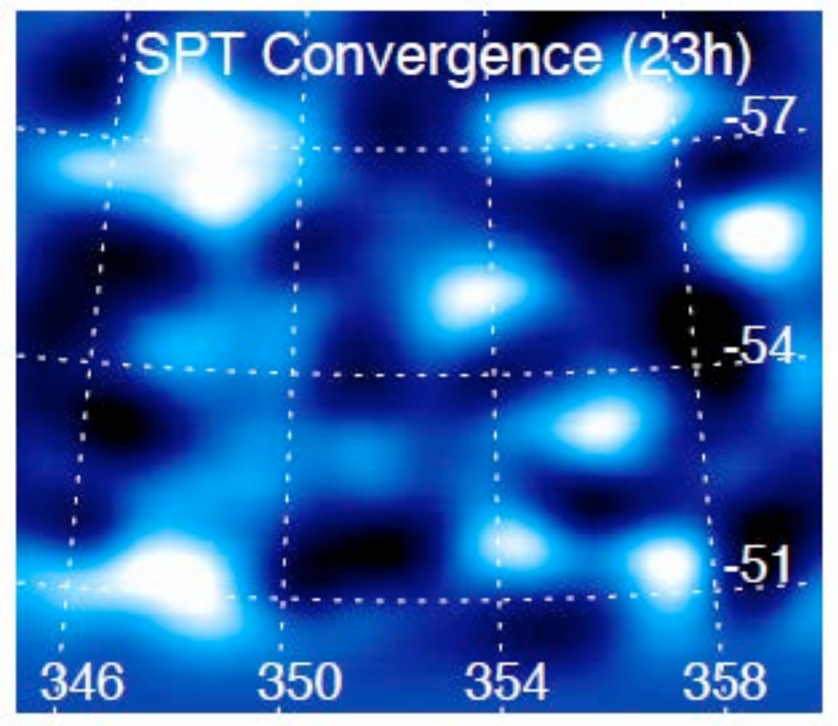
Baryon Acoustic Oscillations

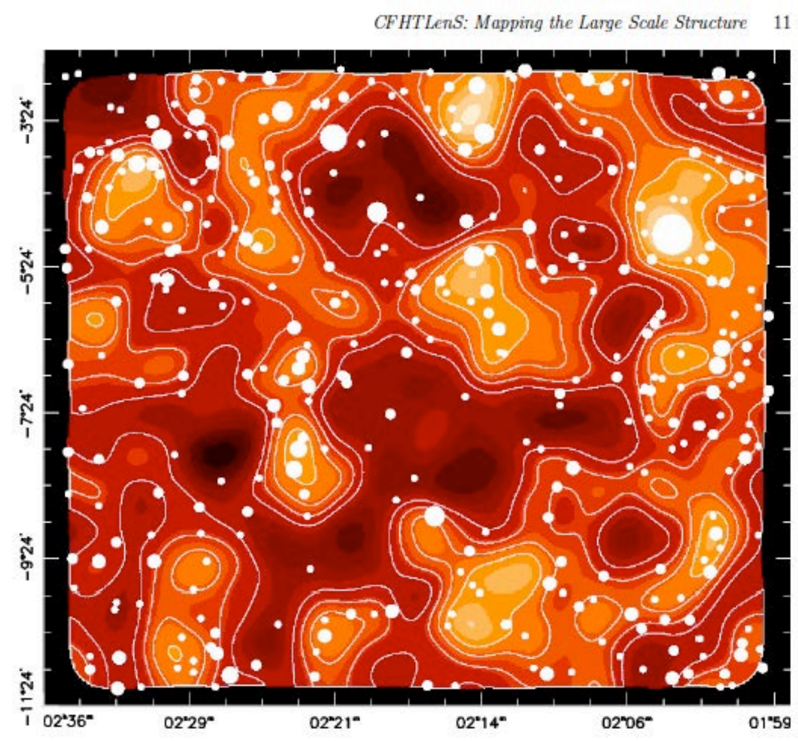
Galaxy Clusters

Gravitational Lensing

(Dodelson)

Test early dark energy by combining CMB Lensing and Galaxy Lensing

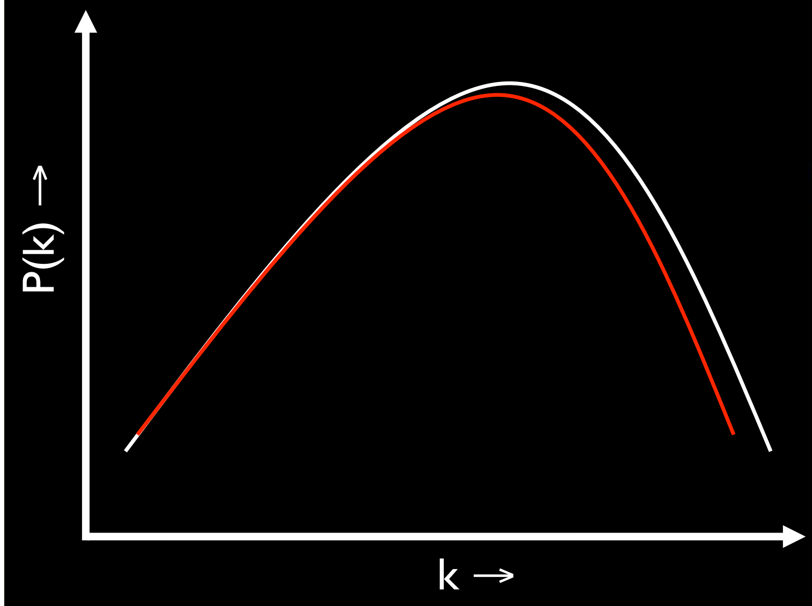


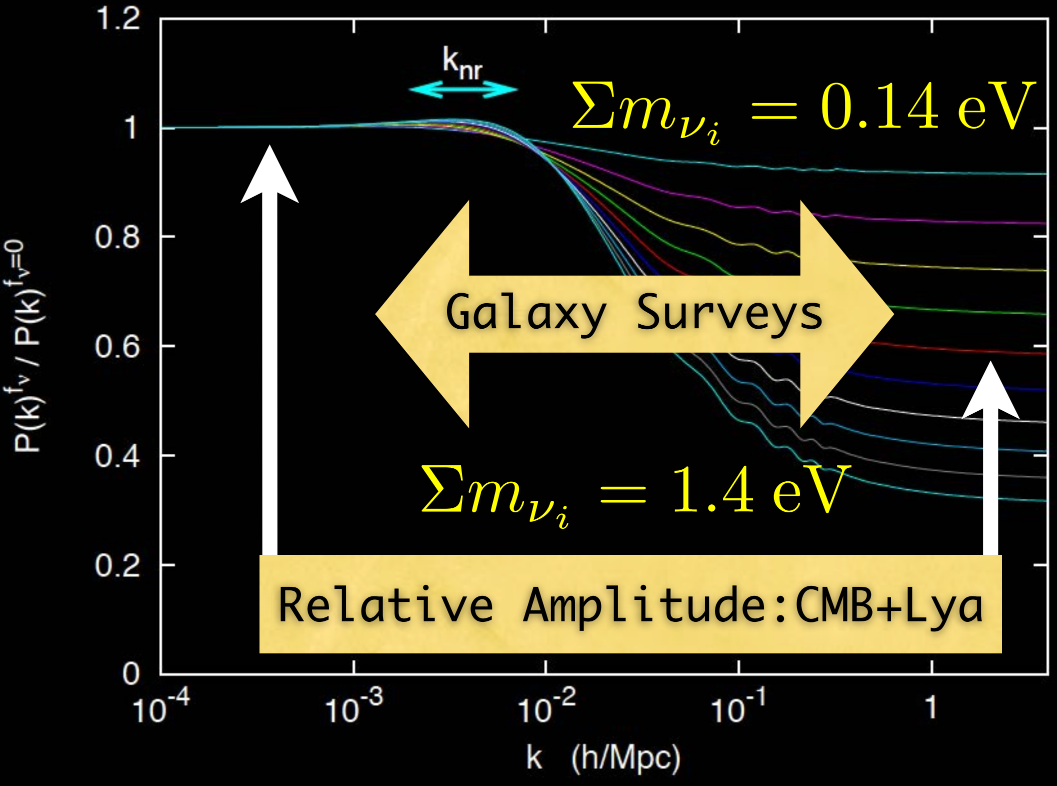


(Dodelson)

Neutrino mass from Cosmology (K. Abazajian)

Distinguishing Features in the Power Spectrum

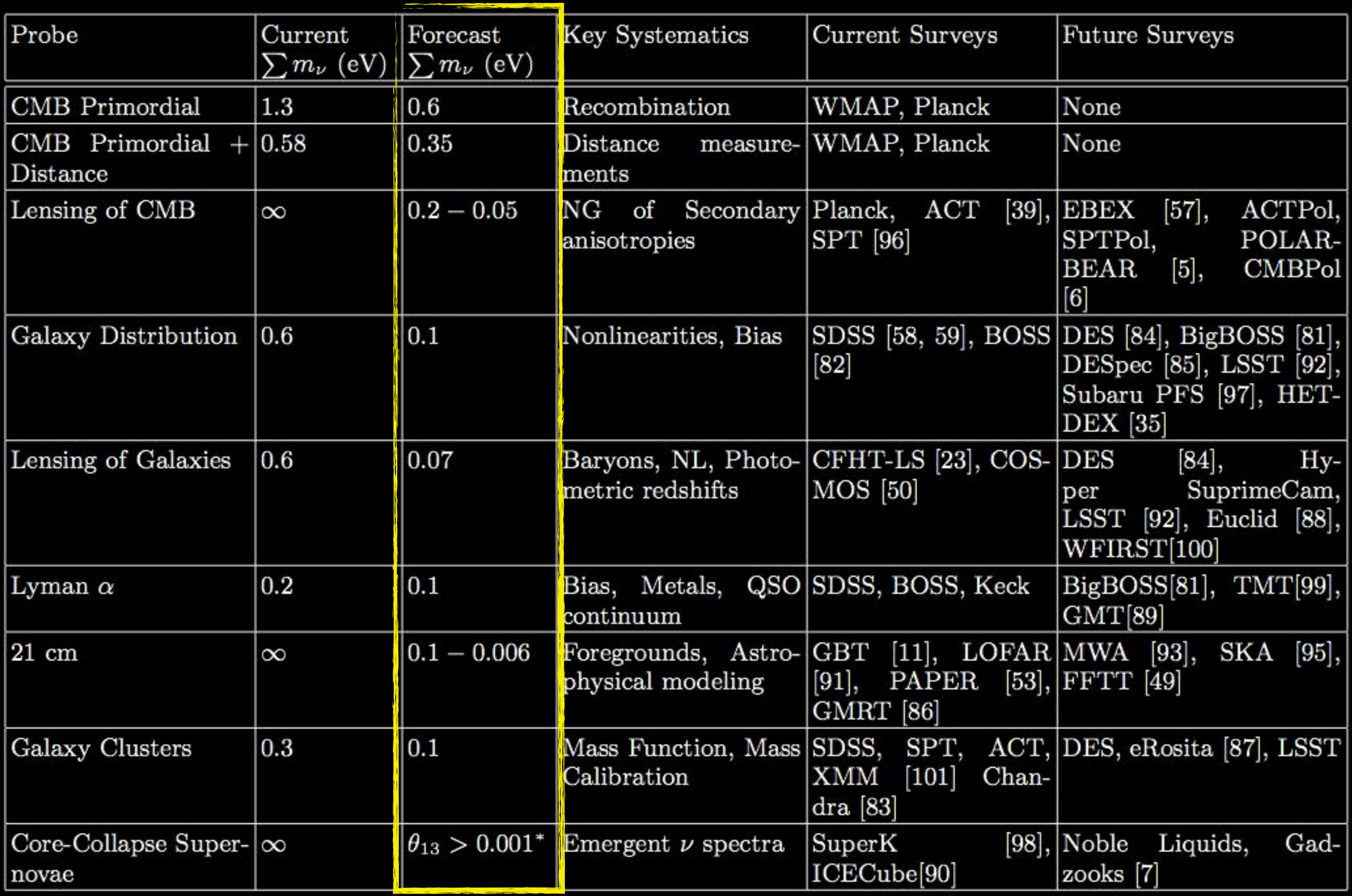




1. Shape Information:
   Galaxy Surveys (Future: Weak Lensing Surveys)
2. Relative Amplitude Information:
   CMB plus Lyman-alpha Forest, Galaxy Bias

$$\frac{\Delta P(k)}{P(k)} = -8\frac{\Omega_\nu}{\Omega_m}$$

Forecast Sensitivities



Probe	Current $\sum m_\nu$ (eV)	Forecast $\sum m_\nu$ (eV)	Key Systematics	Current Surveys	Future Surveys
CMB Primordial	1.3	0.6	Recombination	WMAP, Planck	None
CMB Primordial + Distance	0.58	0.35	Distance measurements	WMAP, Planck	None
Lensing of CMB	∞	$0.2 - 0.05$	NG of Secondary anisotropies	Planck, ACT [39], SPT [96]	EBEX [57], ACTPol, SPTPol, POLARBEAR [5], CMBPol [6]
Galaxy Distribution	0.6	0.1	Nonlinearities, Bias	SDSS [58, 59], BOSS [82]	DES [84], BigBOSS [81], DESpec [85], LSST [92], Subaru PFS [97], HETDEX [35]
Lensing of Galaxies	0.6	0.07	Baryons, NL, Photometric redshifts	CFHT-LS [23], COSMOS [50]	DES [84], Hyper SuprimeCam, LSST [92], Euclid [88], WFIRST[100]
Lyman α	0.2	0.1	Bias, Metals, QSO continuum	SDSS, BOSS, Keck	BigBOSS[81], TMT[99], GMT[89]
21 cm	∞	$0.1 - 0.006$	Foregrounds, Astrophysical modeling	GBT [11], LOFAR [91], PAPER [53], GMRT [86]	MWA [93], SKA [95], FFTT [49]
Galaxy Clusters	0.3	0.1	Mass Function, Mass Calibration	SDSS, SPT, ACT, XMM [101] Chandra [83]	DES, eRosita [87], LSST
Core-Collapse Supernovae	∞	$\theta_{13} > 0.001^*$	Emergent ν spectra	SuperK [98], ICECube[90]	Noble Liquids, Gadzooks [7]

Abazajian et al. 2011

(Kevork Abazajian)

- Please visit the Cosmic Frontier Workshop website:
  - http://www-conf.slac.stanford.edu/cosmic-frontier/2013/

CF4 Summary

Dark Matter complementarity

Konstantin Matchev

UF UNIVERSITY of FLORIDA
The Foundation for The Gator Nation

Cosmic Frontier Workshop
March 8, 2013

Model-independent examples

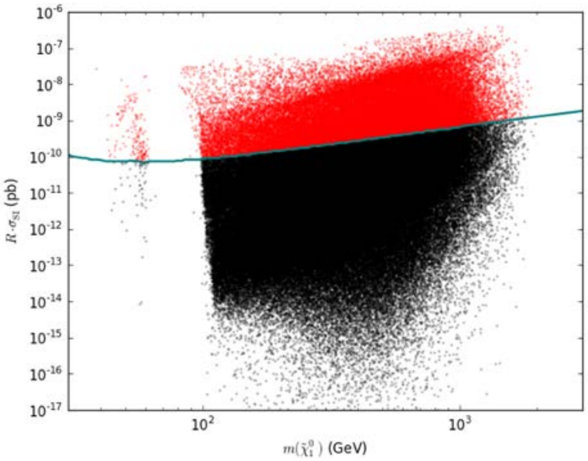
- In the short Complementarity Document:
  - Be agnostic about the underlying theory model
- Parameterize our ignorance about
  - the origin of SUSY breaking
    - pMSSM talks (Ismail, Cotta, Cahill-Rowley, Drlica-Wagner)
  - the type of DM-SM interactions and their mediators
    - effective operators (Shepherd)
- The longer CF4 summary document will also consider specific theory models:
  - CMSSM (Sanford)
  - NUSUGRA (Baer)
  - UED (Kong)
  - NMSSM (McCaskey, Shaughnessy)

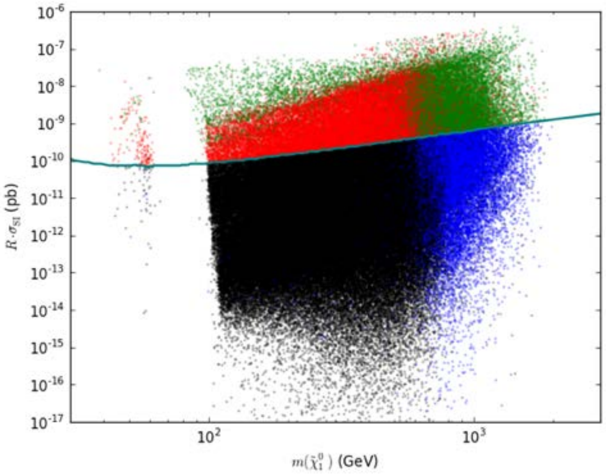
II. The pMSSM approach

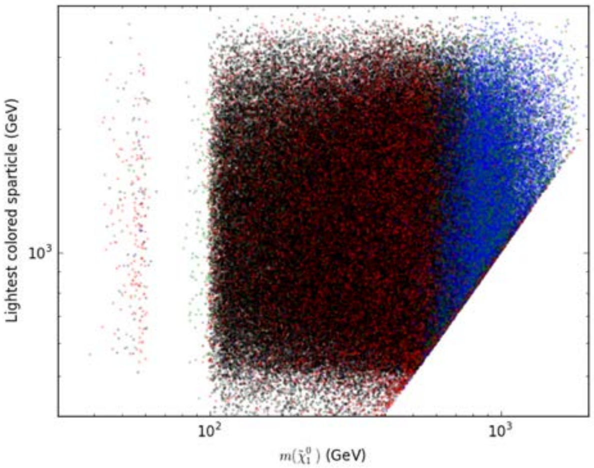
(SUSY without prejudice)

talks by: M. Cahill-Rowley, R. Cotta, A. Drlica-Wagner, A. Ismail, T. Rizzo, M. Wood

- Sequentially apply projected constraints from
  - direct detection (red versus black)
  - indirect detection (red->green; black->blue)
  - LHC

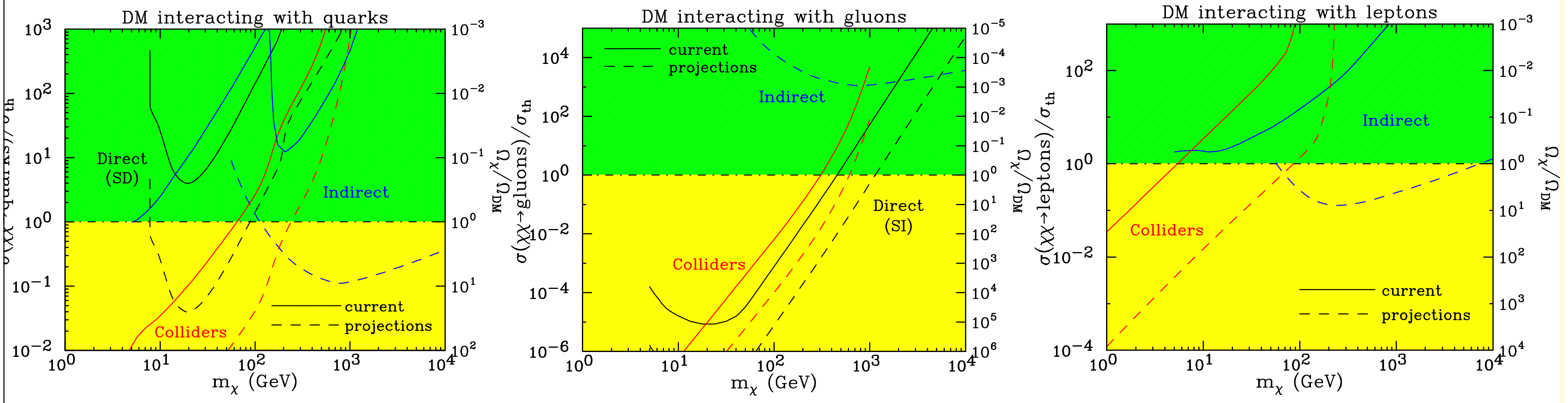






I. Effective operator approach

- Effective theory of SM+DM.



$$\boxed{\frac{1}{M_q^2}\ \bar\chi\gamma^\mu\gamma_5\chi\sum_q\bar q\gamma_\mu\gamma_5 q+\frac{\alpha_S}{M_g^3}\ \bar\chi\chi G^{a\mu\nu}G^a_{\mu\nu}+\frac{1}{M_\ell^2}\ \bar\chi\gamma^\mu\chi\sum_\ell\bar\ell\gamma_\mu\ell}$$

D8 D11 D5

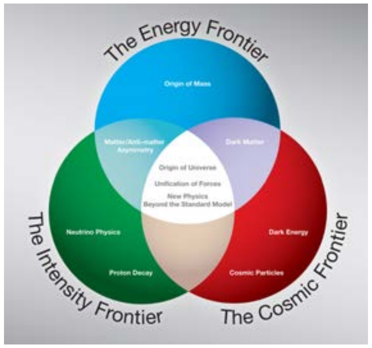
CF6: Cosmic Particles & Fundamental Physics

J. Beatty, A. Nelson, A. Olinto, G. Sinnis

CF6-A Cosmic Rays, Gamma Rays and Neutrinos (conveners: **Gus Sinnis**, Tom Weiler)

CF6-B The Matter of the Cosmological Asymmetry (convener: **Ann Nelson**)

CF6-C Exploring the Basic Nature of Space and Time
(conveners: Aaron Chou, **Craig Hogan**)



Overlaps with
CF1,2,3,4,5 +
Intensity Frontier: IF3: Neutrinos;
(Nu6) Astrophysical and Cosmological Neutrinos
Instrumentation Frontier

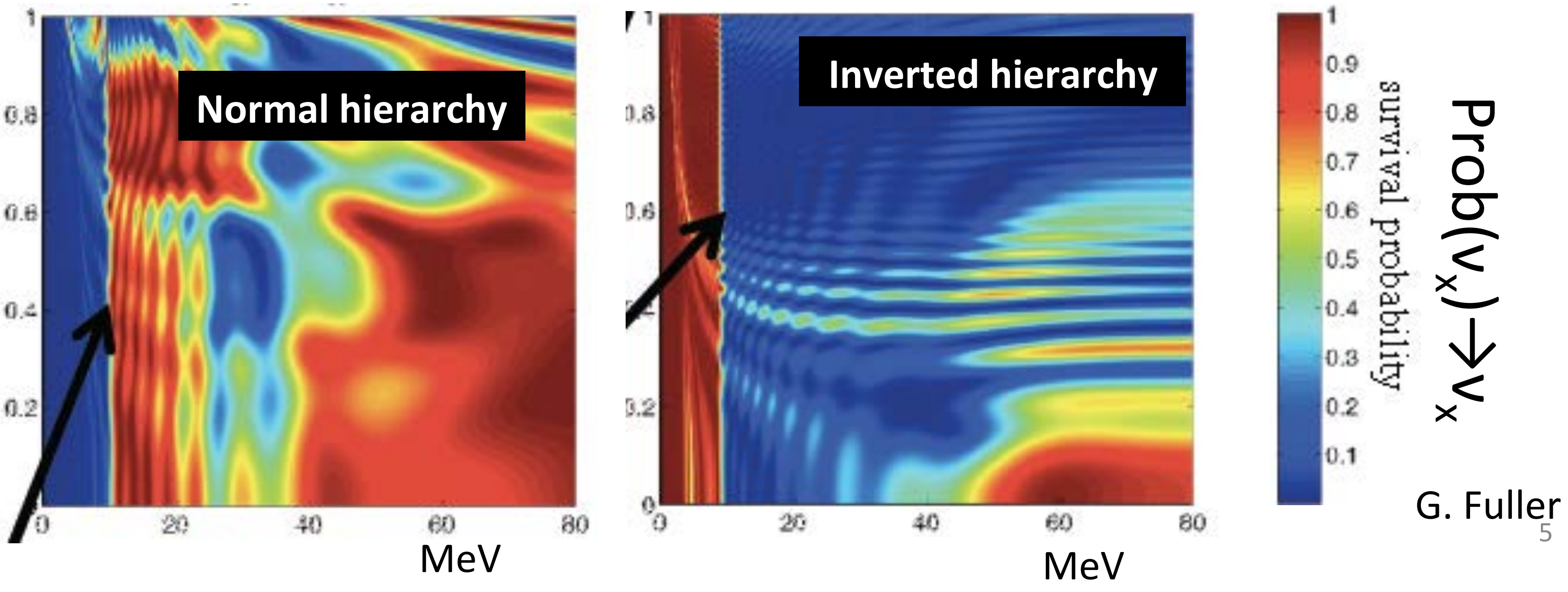
CF6A: Cosmic Rays, Gamma Rays and Neutrinos

Fundamental Physics from Cosmic Messengers

- Neutrino mass hierarchy
  - Supernova burst neutrinos (LBNE underground)
  - Atmospheric neutrinos (PINGU at South Pole)
- Probing physics at the Plank scale
  - Sensitivity to violations of Lorentz invariance (Fermi, HESS, VERITAS, CTA, HAWC)
- Probing scale of extra dimensions
  - Neutrino cross sections at high energies (IceCube, ARA, ARIANNA, EVA, JEM-EUSO)
- Measure particle interactions at 60 (300) TeV Auger (JEM-EUSO)

Neutrino Properties from Astrophysics

- Supernova burst neutrinos
  - Neutrino mass hierarchy (G. Fuller)
  - Supernova physics (JJ Cherry)
- Collective oscillations of ν_x leads to a “spectral swap”
  - Normal hierarchy ν_x oscillate to other flavor states below ~10 MeV
  - Inverted hierarchy ν_x oscillate to other flavor states above ~10 MeV
- A large (~10 kT) liquid Argon detector sensitive mostly to ν_x could detect swap (need to go underground!)



G. Fuller

Baryogenesis and dark matter

- Sigurdson: dark matter carries anti baryon number and catalyzes unusual “proton decay” events
- Zhitnitsky: semi-Exotic quark and antiquark nugget dark matter
- Fan: some dark matter is asymmetric, self interacting via a dark photon, and collapsed into a dark disk parallel (?) to ours

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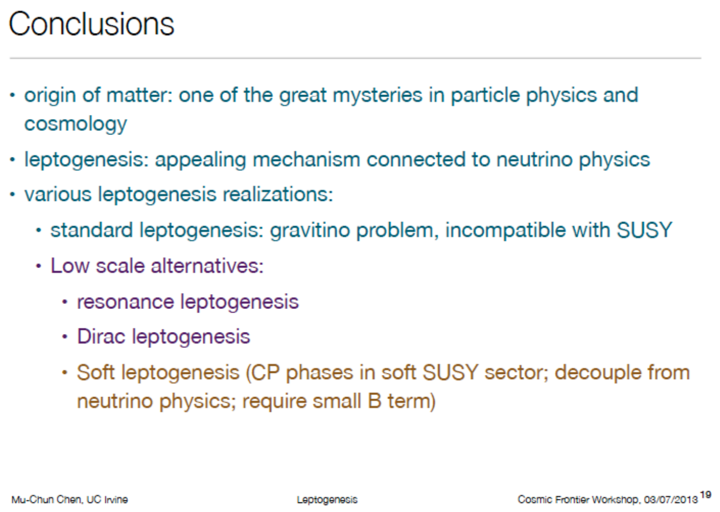
Leptogenesis

Mu-Chun Chen



Conclusions

- origin of matter: one of the great mysteries in particle physics and cosmology
- leptogenesis: appealing mechanism connected to neutrino physics
- various leptogenesis realizations:
  - standard leptogenesis: gravitino problem, incompatible with SUSY
  - Low scale alternatives:
    - resonance leptogenesis
    - Dirac leptogenesis
    - Soft leptogenesis (CP phases in soft SUSY sector; decouple from neutrino physics; require small B term)

Mu-Chun Chen, UC Irvine Leptogenesis Cosmic Frontier Workshop, 03/07/2013 19

Basic Nature of Space and Time

- Lenny Susskind: Field theory and string theory do not predict detectable Planck scale effects on laboratory scales
- Craig Hogan: In some forms of quantum geometry, Planckian information density is detectable as transverse position uncertainty
- Aaron Chou: The Fermilab Holometer is in commissioning, and will achieve Planck spectral density sensitivity within ~2 years

- Please visit the Cosmic Frontier Workshop website:
  - http://www-conf.slac.stanford.edu/cosmic-frontier/2013/

Extra Slides

Dark Matter Intro

Gravitational effect of DM is visible in many astrophysical settings.

Bullet cluster image shows gravitational mass inferred from lensing (blue) and X-ray emission from baryonic matter (red).

Not modified gravity, not gas - dark matter behaves like stars, weakly interacting particles

$$\text{From WMAP}: \ \Omega_{\rm DM} h^2 = 0.1123 \pm 0.0035$$

For a thermal relic of the big bang, the larger the annihilation cross section the longer the DM stays in equilibrium and the larger the Boltzmann suppression $\sim e^{-m_\chi/kT}$ before freeze-out.

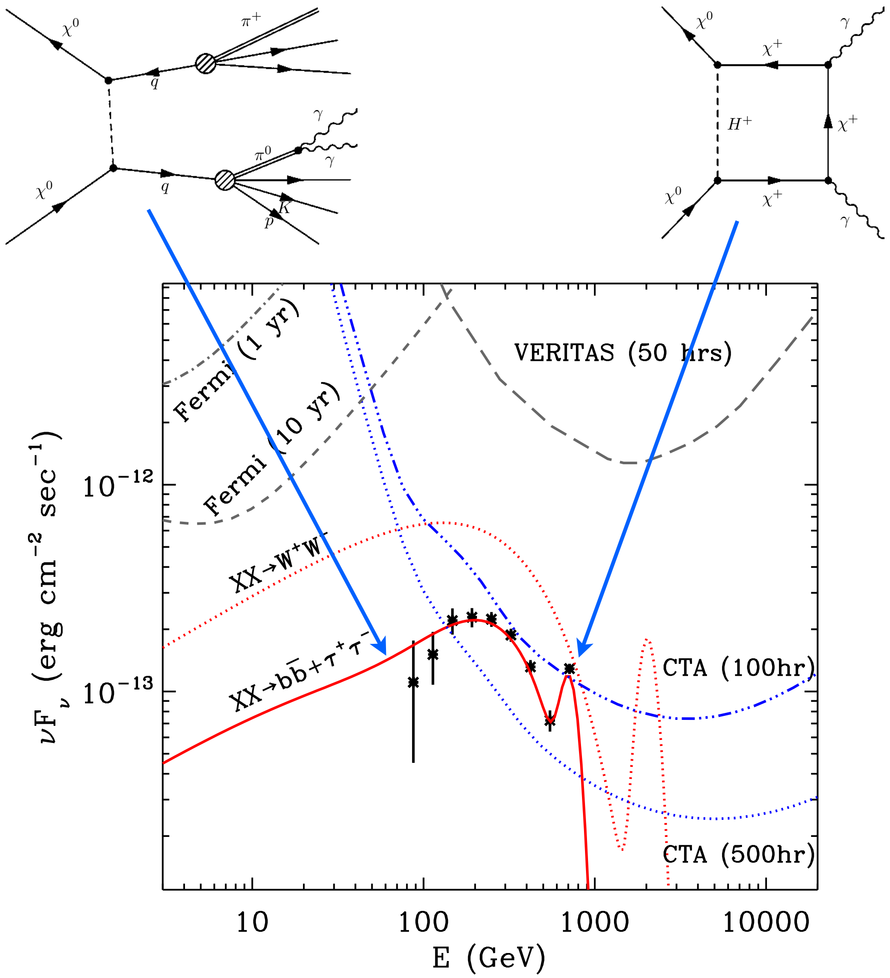
$$\Omega_\chi \approx \frac{0.1}{h^2}\left(\frac{3\times10^{-26}\mathrm{cm}^3\mathrm{sec}^{-1}}{\langle\sigma v\rangle}\right)$$

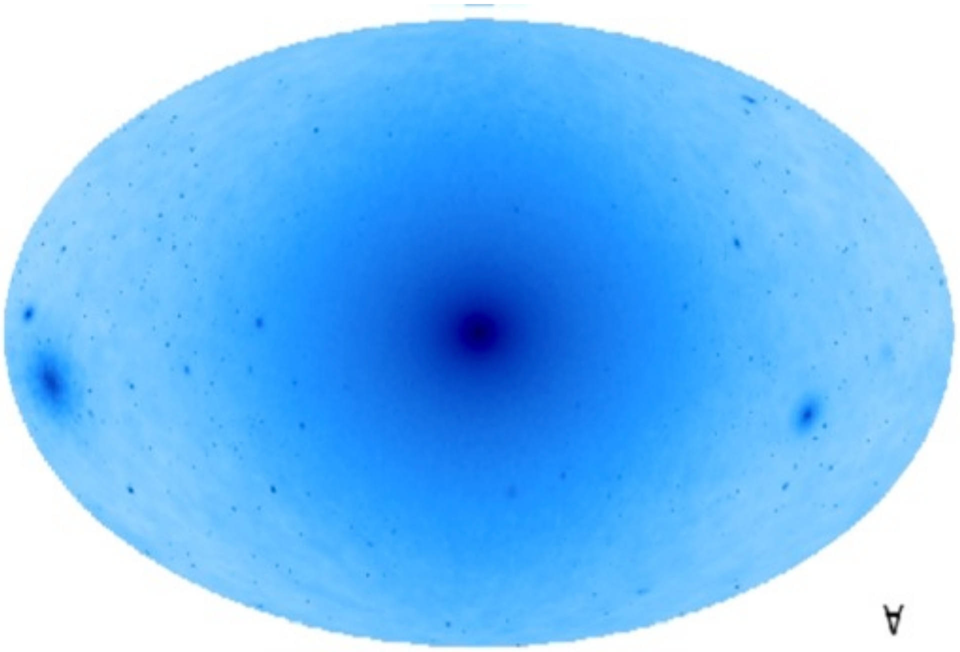
** Gamma-ray production by annihilation in the present universe is closely correlated to decoupling cross section in the early universe*

Gamma-rays from DM

$$E_\gamma \Phi_\gamma(\theta) \approx 10^{-10} \underbrace{\left(E_{\gamma,\mathrm{TeV}}\frac{dN}{dE_{\gamma,\mathrm{TeV}}}\right)\left(\frac{\langle\sigma v\rangle}{10^{-26}\mathrm{cm}^{-3}\mathrm{s}^{-1}}\right)\left(\frac{100\,\mathrm{GeV}}{M_\chi}\right)^2}_{\text{Particle Physics Input}} \underbrace{J(\theta)}\ \mathrm{erg\,cm^{-2}s^{-1}sr^{-1}}$$

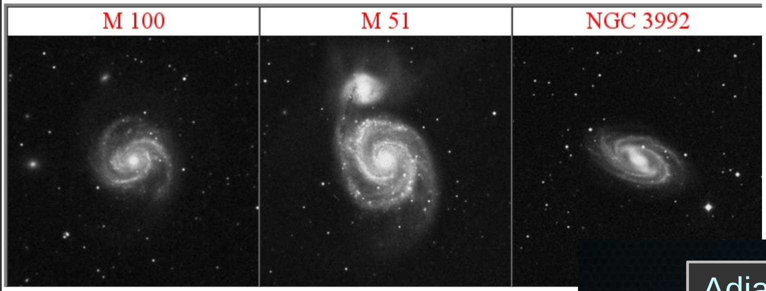
$$J(\theta) = \underbrace{\frac{1}{8.5\,\mathrm{kpc}}\left(\frac{1}{0.3\,\mathrm{GeV/cm^3}}\right)^2\int_{\mathrm{line\ of\ sight}} \rho^2(l)dl(\theta)}_{\text{Astrophysics/Cosmology Input}}$$





Line-of-sight integral of ρ^2 for a Milky-Way-like halo in the VL Lactea II ΛCDM N-body simulations (Kuhlen et al.)

Baryonic Feedback



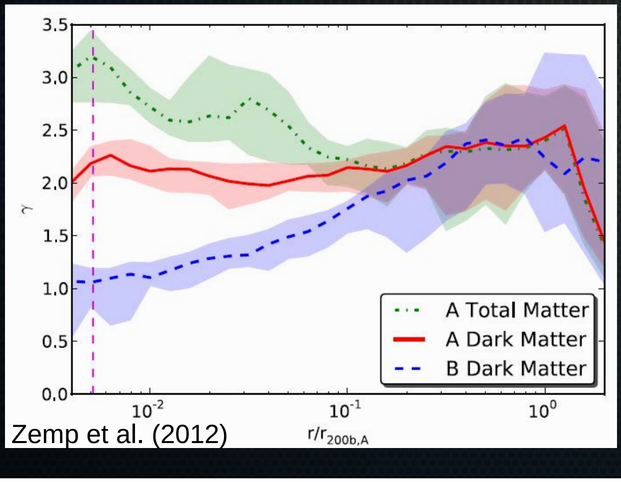
- Adding Baryons to N-body simulations starting to give amazing results - similar morphology, Tully-Fisher relation.

- But jury is out on effects on Milky Way-like (or Dwarf) halos.

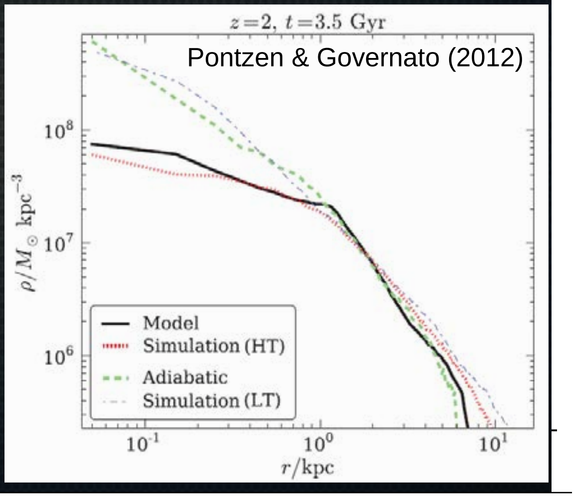
Adiabatic contraction steepens the DM profile and **increases central DM densities**.

⟷

Impulsive supernova (or AGN) feedback **removes DM from the center** and flattens the DM cusp.



Zemp et al. (2012)

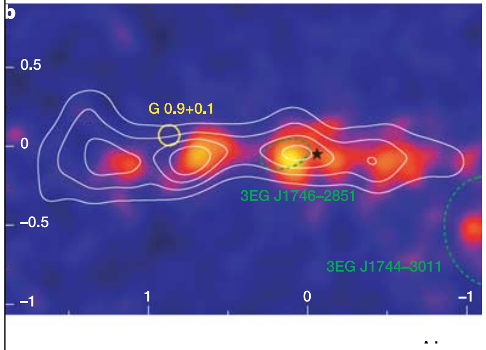


Pontzen & Governato (2012)

Top 10 Myths

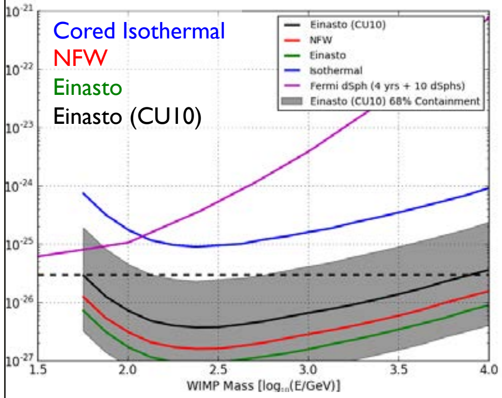
- Astrophysical backgrounds make indirect detection impossible

How bad are astrophysical backgrounds? Total γ-ray flux (1-3 GeV) within $1^\circ \sim 1 \times 10^{-7} \mathrm{cm}^{-2}\ \mathrm{s}^{-1} \Rightarrow \langle \sigma v \rangle = 1.6 \times 10^{-25}\ \mathrm{cm}^{3} \mathrm{s}^{-1}$ (*Tim Linden's talk*)



  - At very high energies, fewer backgrounds

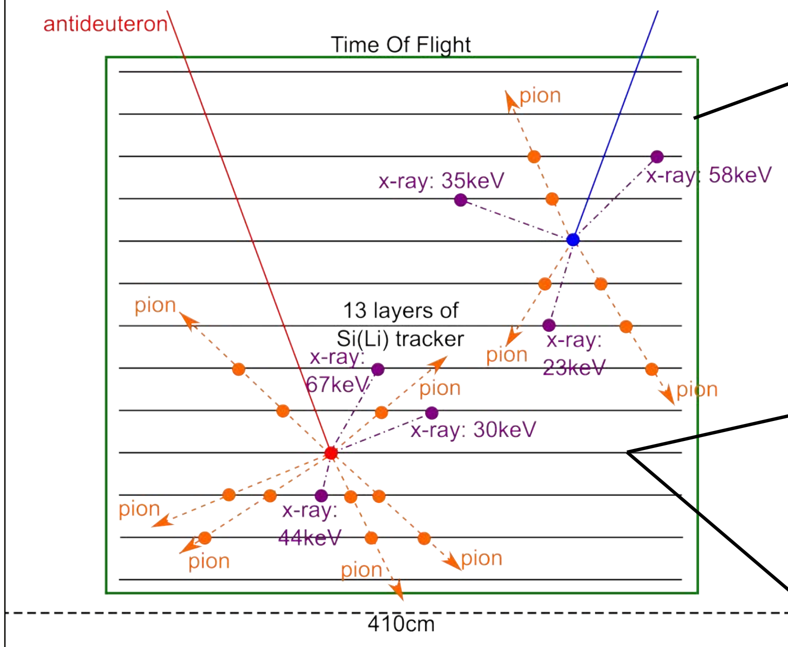
- Uncertainties in Halo profiles mean that gamma-ray limits are wildly uncertain!
  - For GC this is worse than for Dwarfs, but may only amount to an order of magnitude uncertainty (see talk by Alex Drlica Wagner, Ferrer)

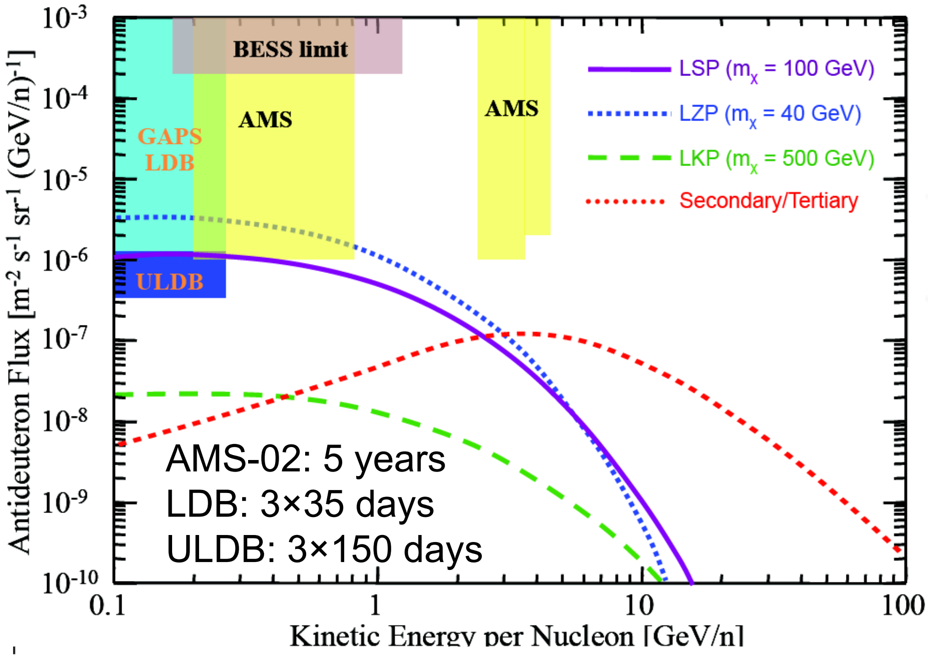


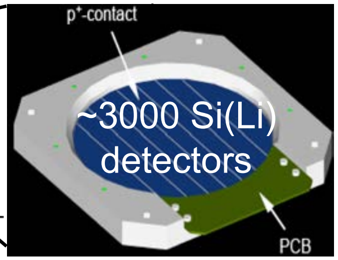
- Gamma-ray, Neutrino and Cosmic-Ray antimatter do other Astrophysics besides Dark Matter
  - So do big, wide-field optical telescopes.
  - We can live with that! Supermassive black holes, pulsars, supernova remnants, EBL and LIV probes, numerous papers and theses

GAPS

(talk by P. von Doetinchem)







- GAPs looks for anti-deuterons (hard to produce as CR secondaries), uses TOF, X-rays from short-lived exotic atom, pion star from annihilation

Recurring scientific themes in CF3

Axionic dark matter structure formation: Is this a unique signature, it this observable (e.g., via strong-lensing halo structure)?

SUSY: Friendly with WIMPs, but not married to WIMPs. Other candidates include gravitinos, axinos, Q-balls, etc.

Sterile neutrinos. Many discussions on searches and phenomenology.

Asymmetric dark matter.

Reconsider quark-nuggets and black holes. Review observational constraints. Consider WIMP-like particles with pure electron couplings.

Axion and ALP searches: Now sensitive and moving into the realm of “definitive searches”

Astrophysics: Improve observations and theory. How to turn hints into detections.

A closer look at warm-dark matter and self-interacting dark matter.

Etc., etc., etc.

Some themes in non-WIMP dark matter sessions

Discovery involves guessing the answer.
Guesses include a very broad range of dark-matter candidates.

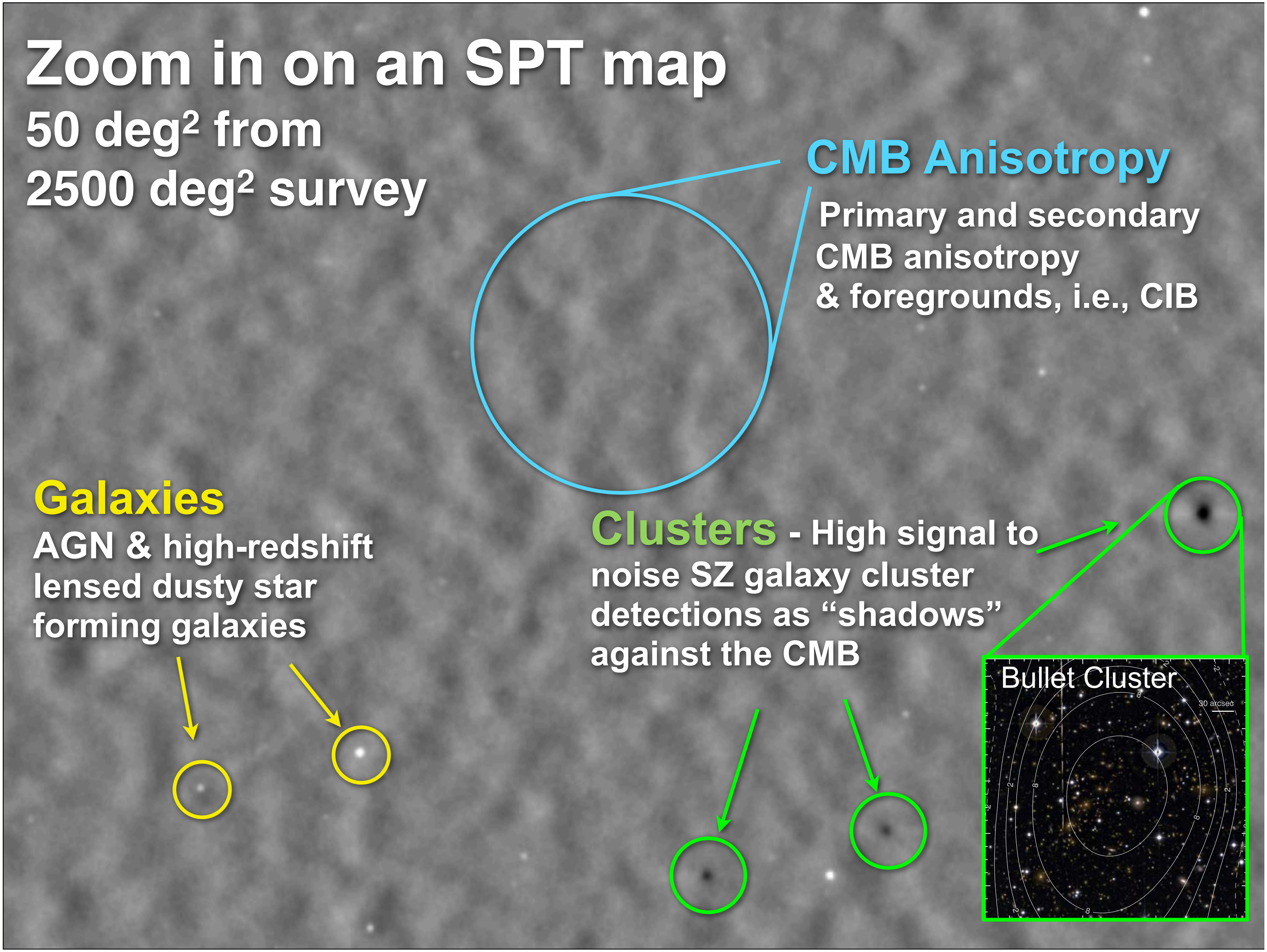
The guesses incorporate compelling theoretical Ideas and astrophysical hints.

The guesses also account for available technology. There's nothing wrong with searching under the lamppost If you don't know where you lost your keys.

There's a scientific ideology at play in the sessions:
1. Balanced approach: Input taken from everybody. The body didn't think any one path is necessarily the answer.
2. Comprehensive: Broad set of theory and observational strategies.
3. "Holistic": Take what nature's telling us. Take various constraints *in toto*.

Zoom in on an SPT map

50 deg^2 from 2500 deg^2 survey



CMB Anisotropy

Primary and secondary CMB anisotropy & foregrounds, i.e., CIB

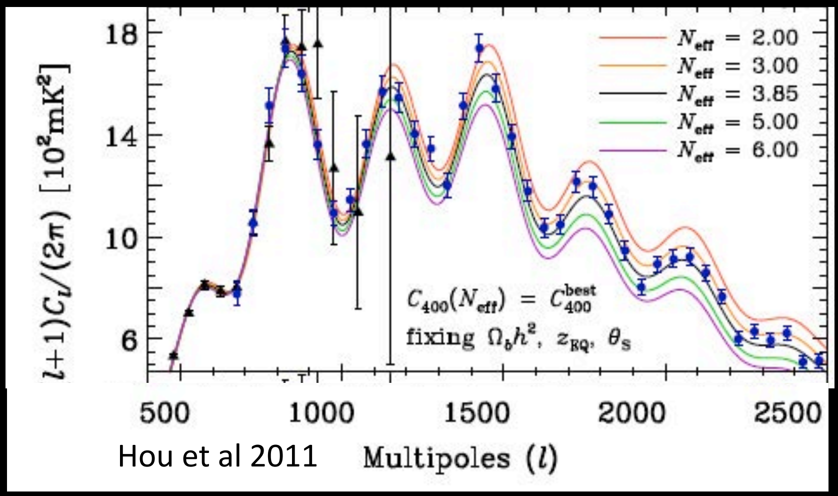
Galaxies

AGN & high-redshift lensed dusty star forming galaxies

Clusters - High signal to noise SZ galaxy cluster detections as “shadows” against the CMB

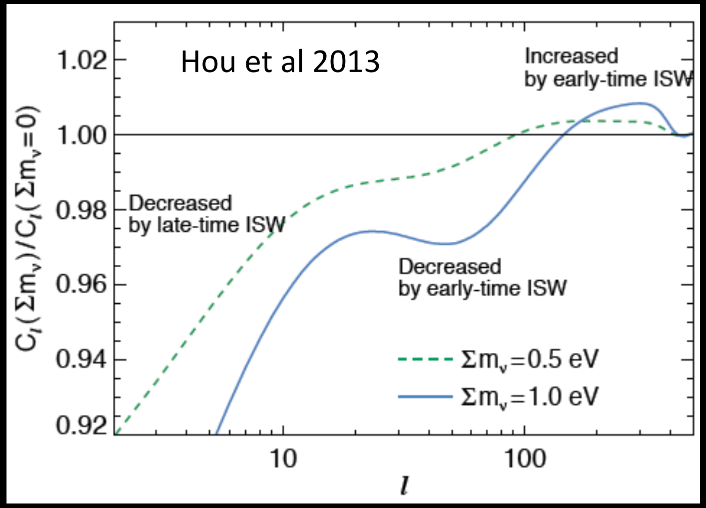
Neutrinos

N_{eff}



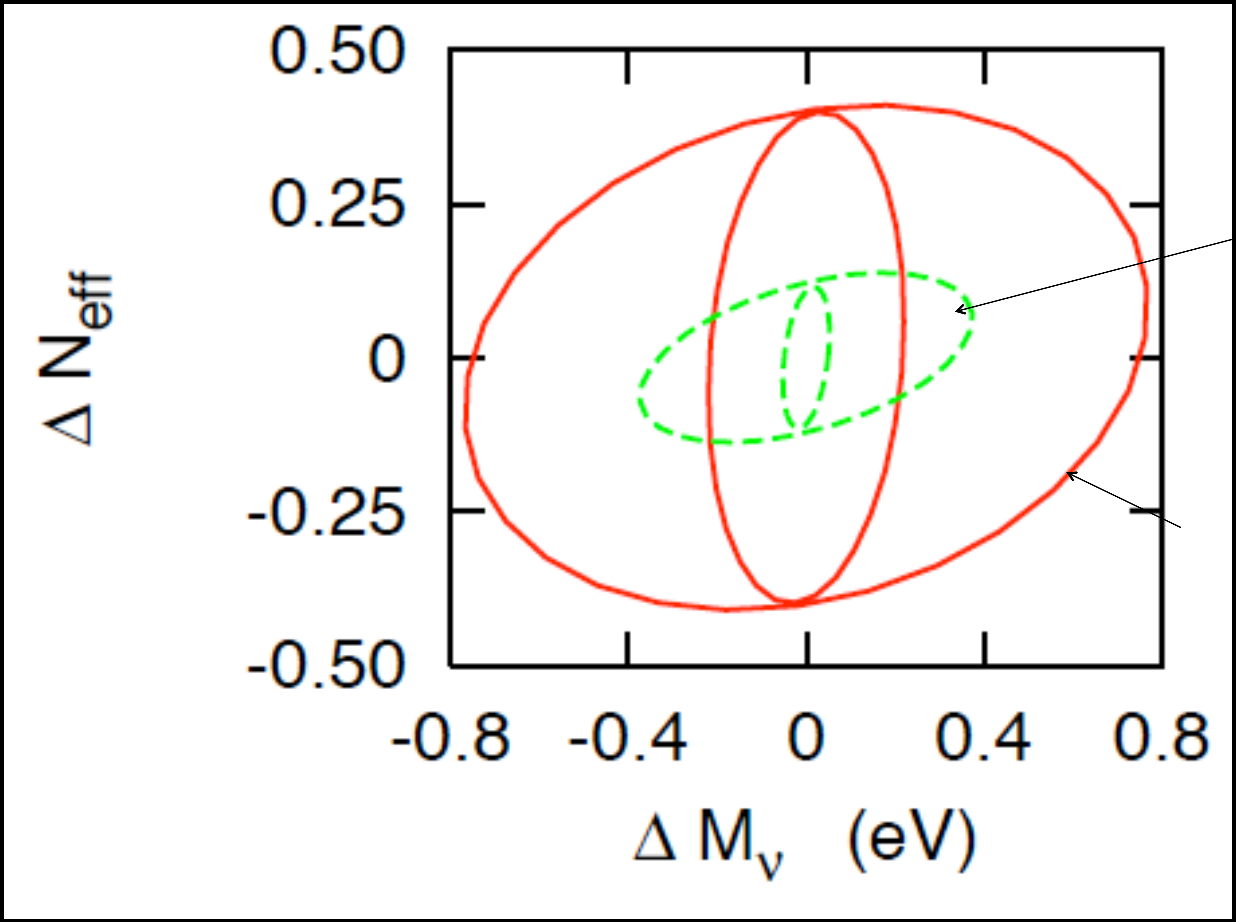
Hou et al 2011

Mass



Hou et al 2013

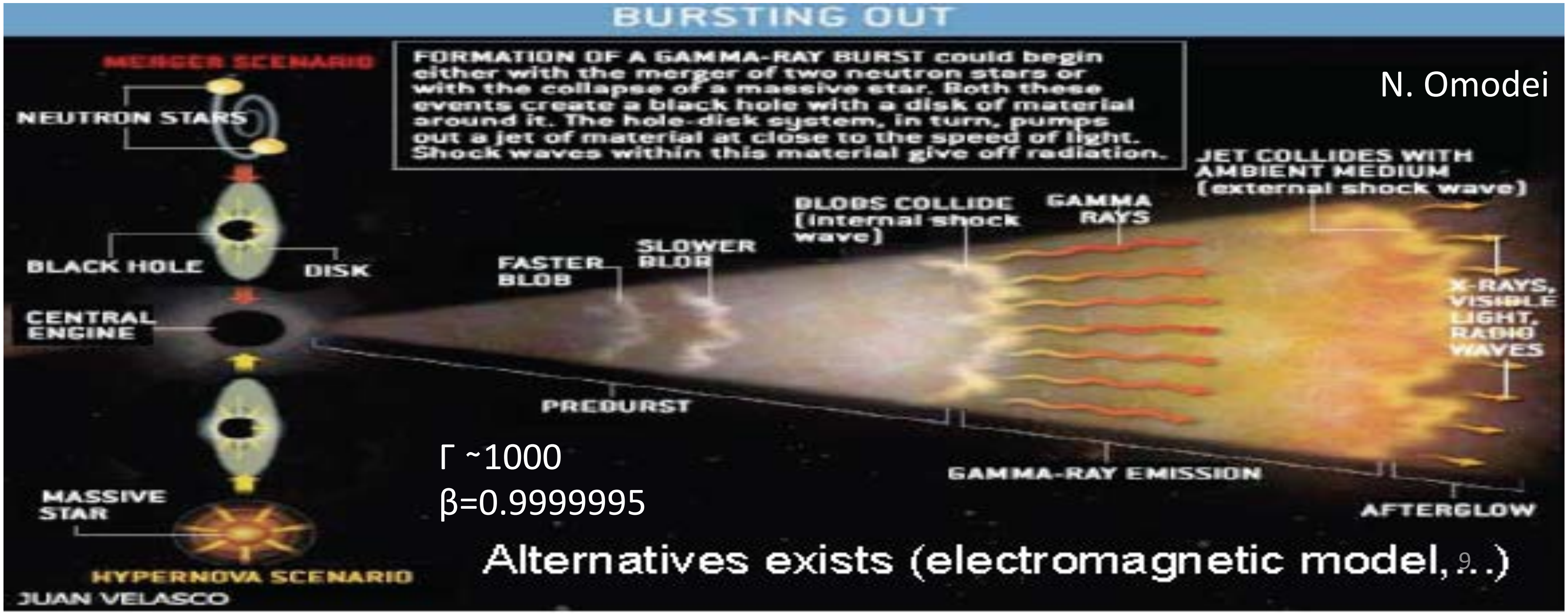
Neutrinos



Stage IV

Cosmic Particle Acceleration

- Particle acceleration to extreme energies is of fundamental interest
    - How does nature create particles with 10^{20} eV?
- Gamma-Ray Bursts provide a short pulse (~1sec) of gamma rays that light up the universe
    - Use to probe Lorentz Invariance violation



FORMATION OF A GAMMA-RAY BURST could begin either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk system, in turn, pumps out a jet of material at close to the speed of light. Shock waves within this material give off radiation.

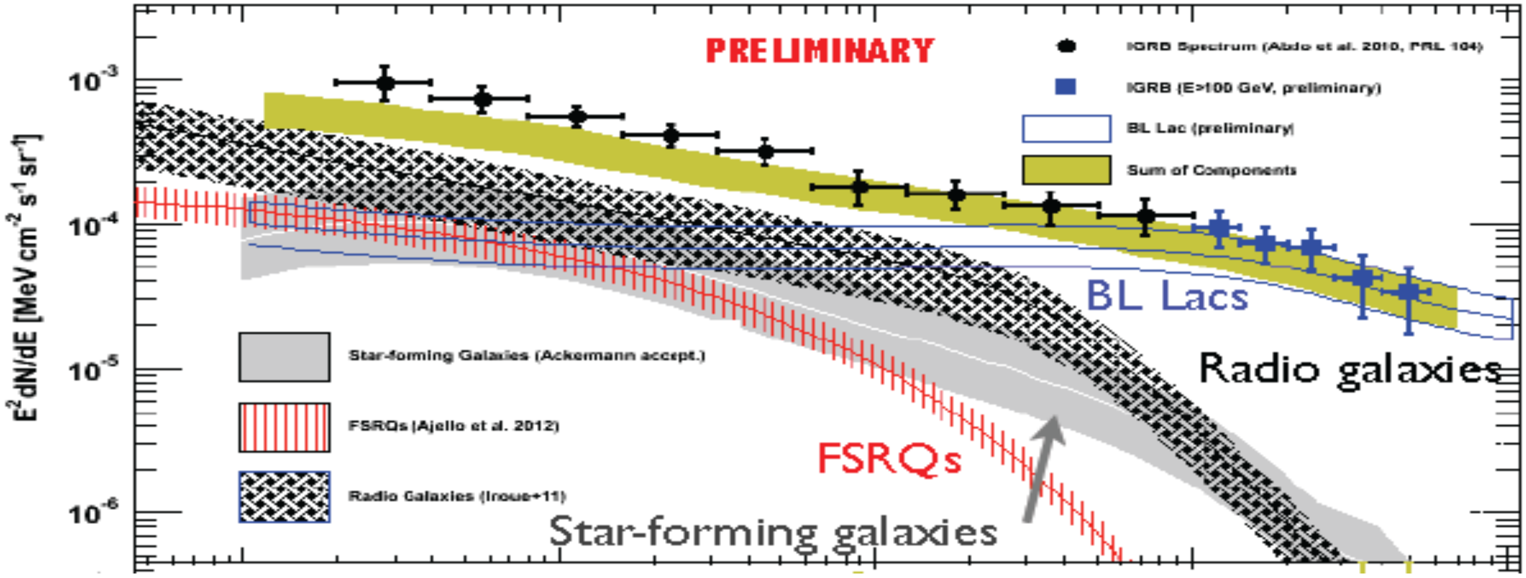
N. Omodei

Γ ~1000

$\beta=0.9999995$

Alternatives exists (electromagnetic model, …)

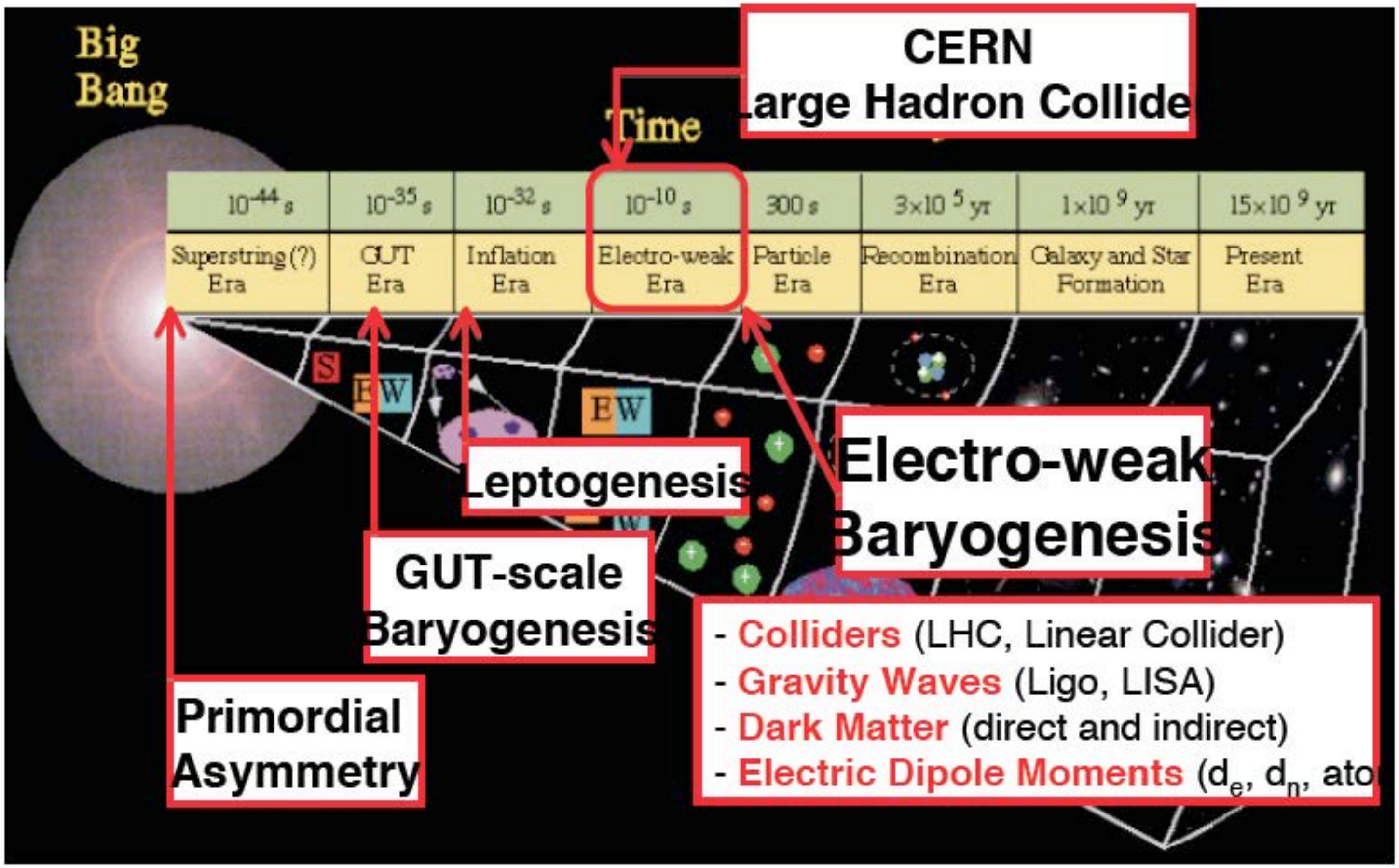
Isotropic Diffuse Gamma-Ray Backgrounds



- What is the origin of the diffuse excess?
- Examine angular power spectrum
- AGN account for all of the observed angular power but only 20% of the required intensity
- Dark matter? Star forming galaxies?

J. Siegal-Gaskins

No “Standard Model” of Baryogenesis!



CERN
arge Hadron Collide

Leptogenesis

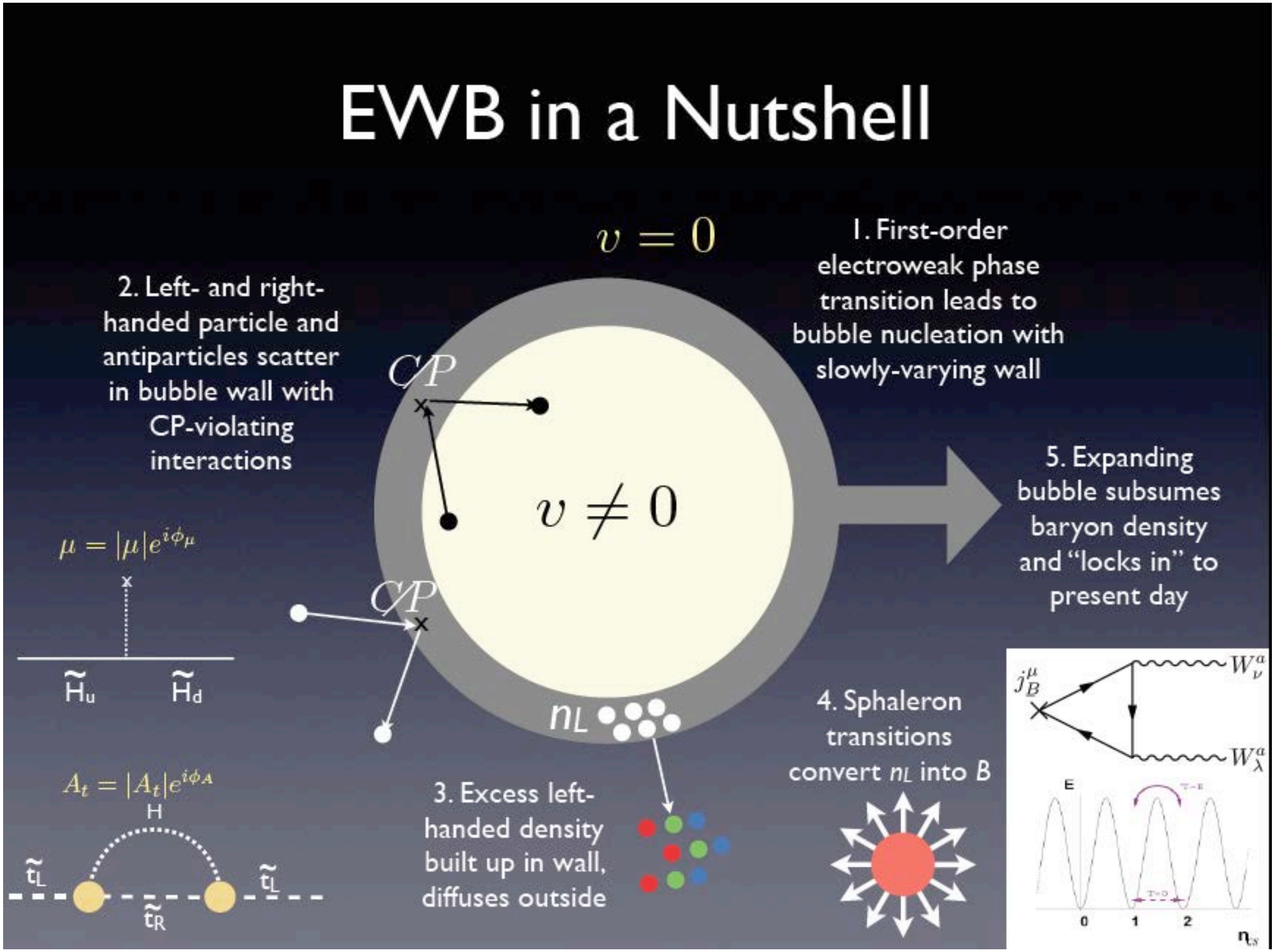
Electro-weak Baryogenesis

GUT-scale Baryogenesis

Primordial Asymmetry

- **Colliders** (LHC, Linear Collider)
- **Gravity Waves** (Ligo, LISA)
- **Dark Matter** (direct and indirect)
- **Electric Dipole Moments** (d_e, d_n, ato

Chris Lee



EWB in a Nutshell

1. First-order electroweak phase transition leads to bubble nucleation with slowly-varying wall

2. Left- and right-handed particle and antiparticles scatter in bubble wall with CP-violating interactions

3. Excess left-handed density built up in wall, diffuses outside

4. Sphaleron transitions convert *nL* into *B*

5. Expanding bubble subsumes baryon density and "locks in" to present day