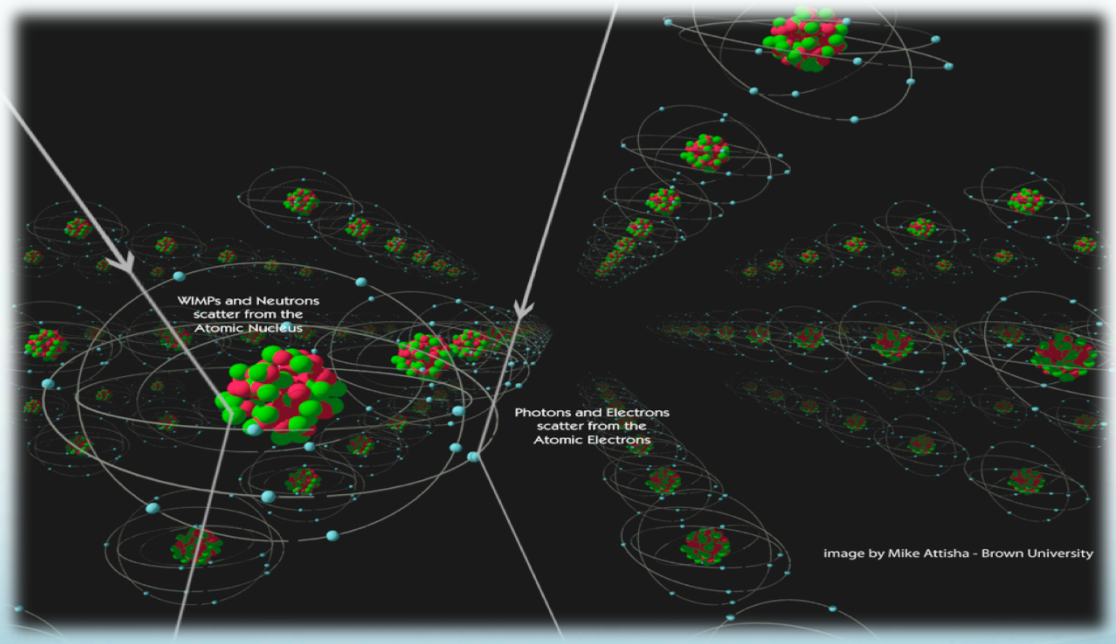
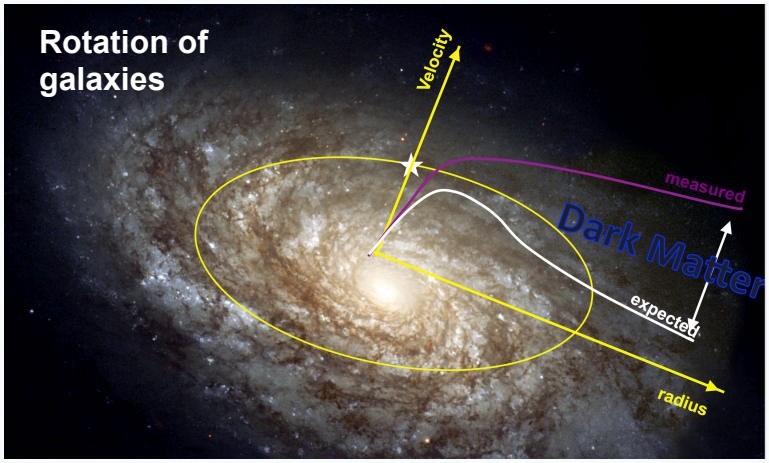
Status of Direct Dark Matter Search

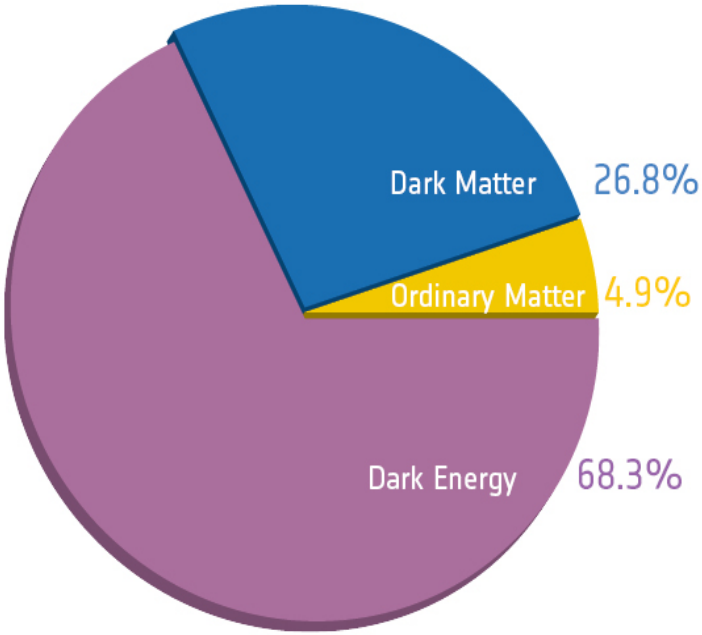
Bruno Serfass – UC Berkeley

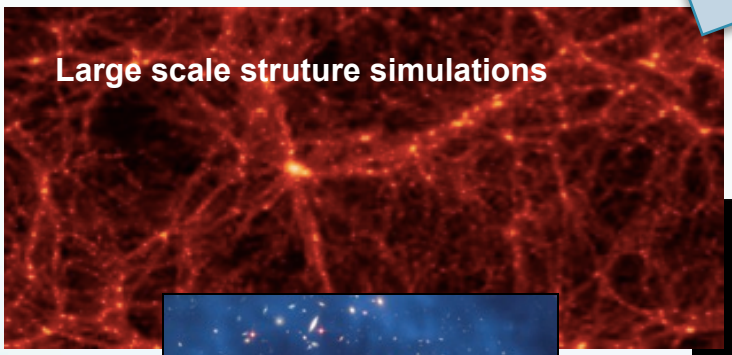


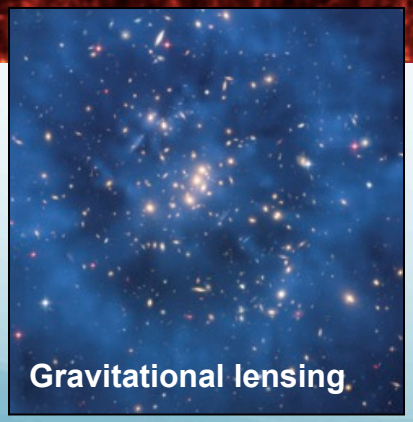
TeVPA Oct 26-30, 2015

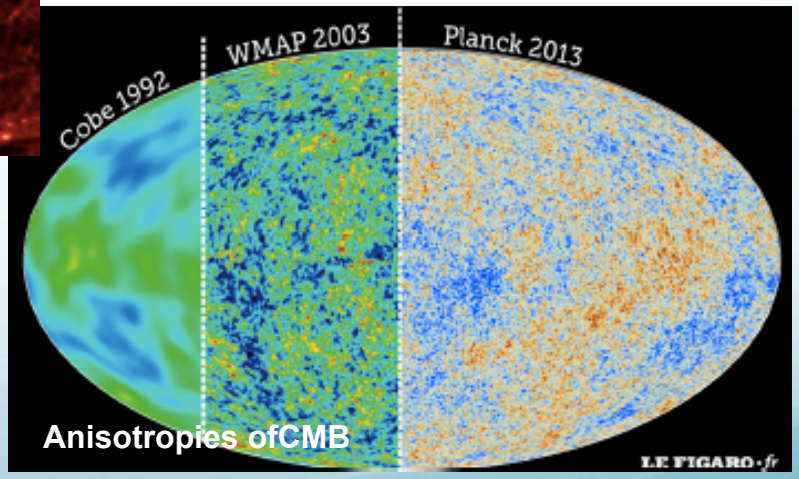
Dark Matter


Rotation of galaxies
Velocity
measured
Dark Matter
expected
radius


Dark Matter
26.8%
Ordinary Matter
4.9%
Dark Energy
68.3%


Large scale struture simulations


Gravitational lensing


Cobe 1992
WMAP 2003
Planck 2013
Anisotropies ofCMB
LE FIGARO.fr

Dark Matter

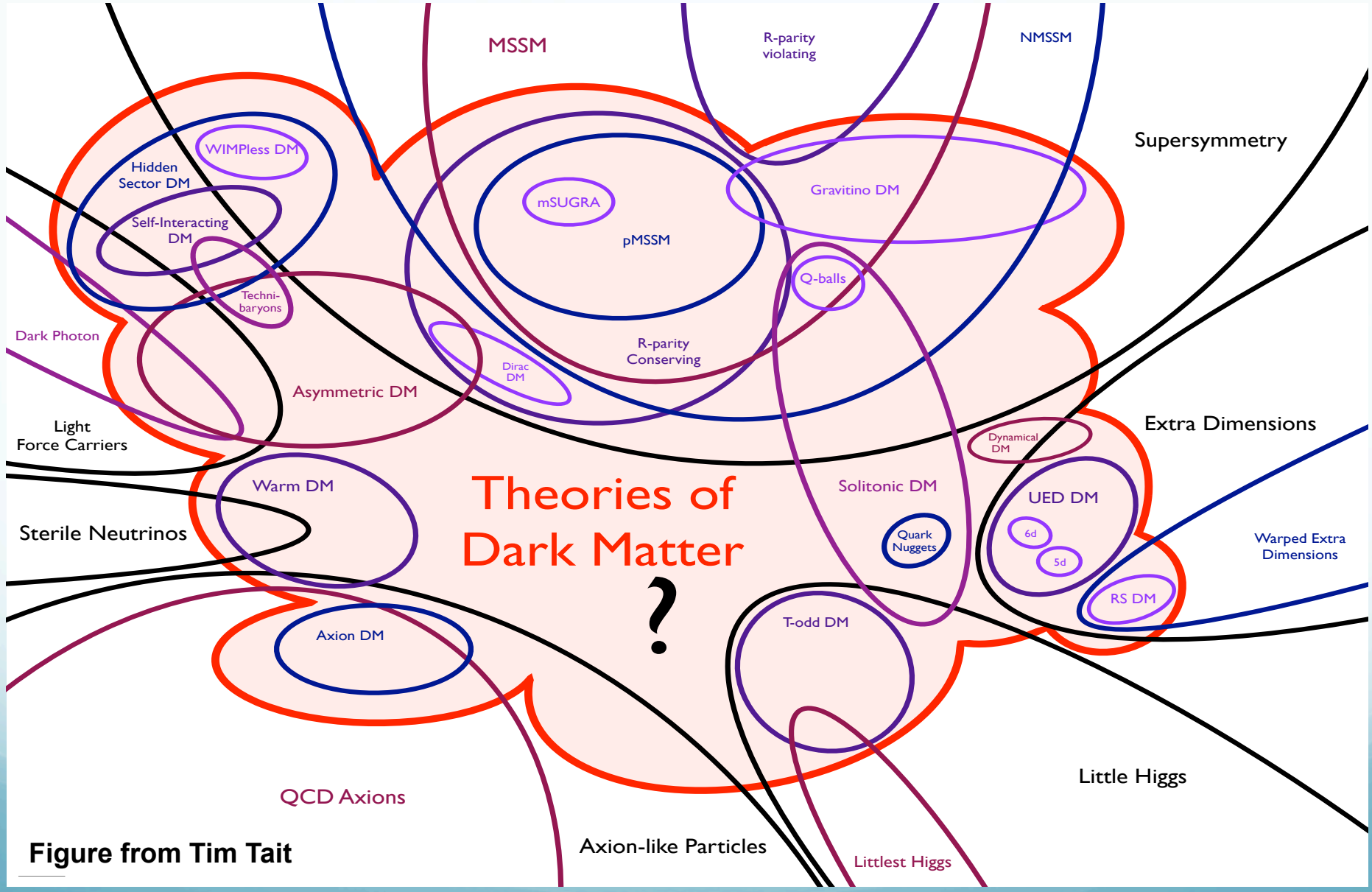


Figure from Tim Tait

Dark Matter

Hidden Sector Particles

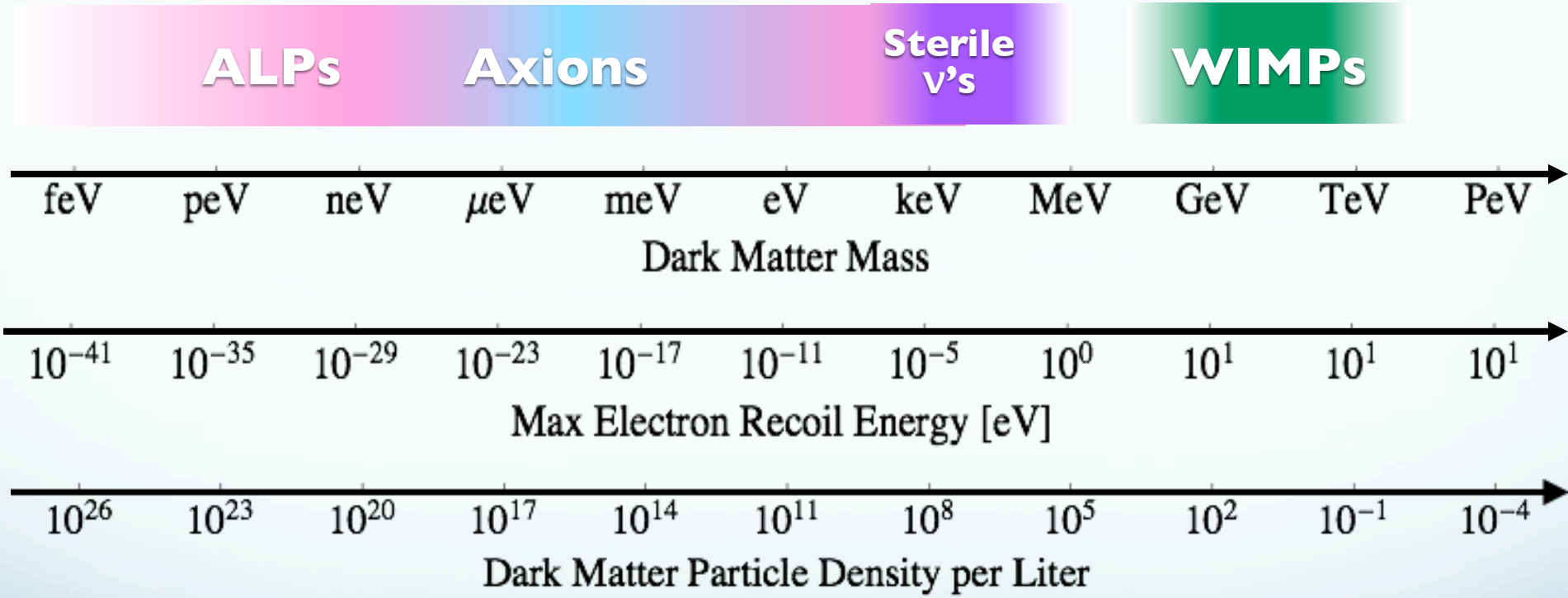


Figure from Tali Figueora-Feliciano

Dark Matter

Hidden Sector Particles

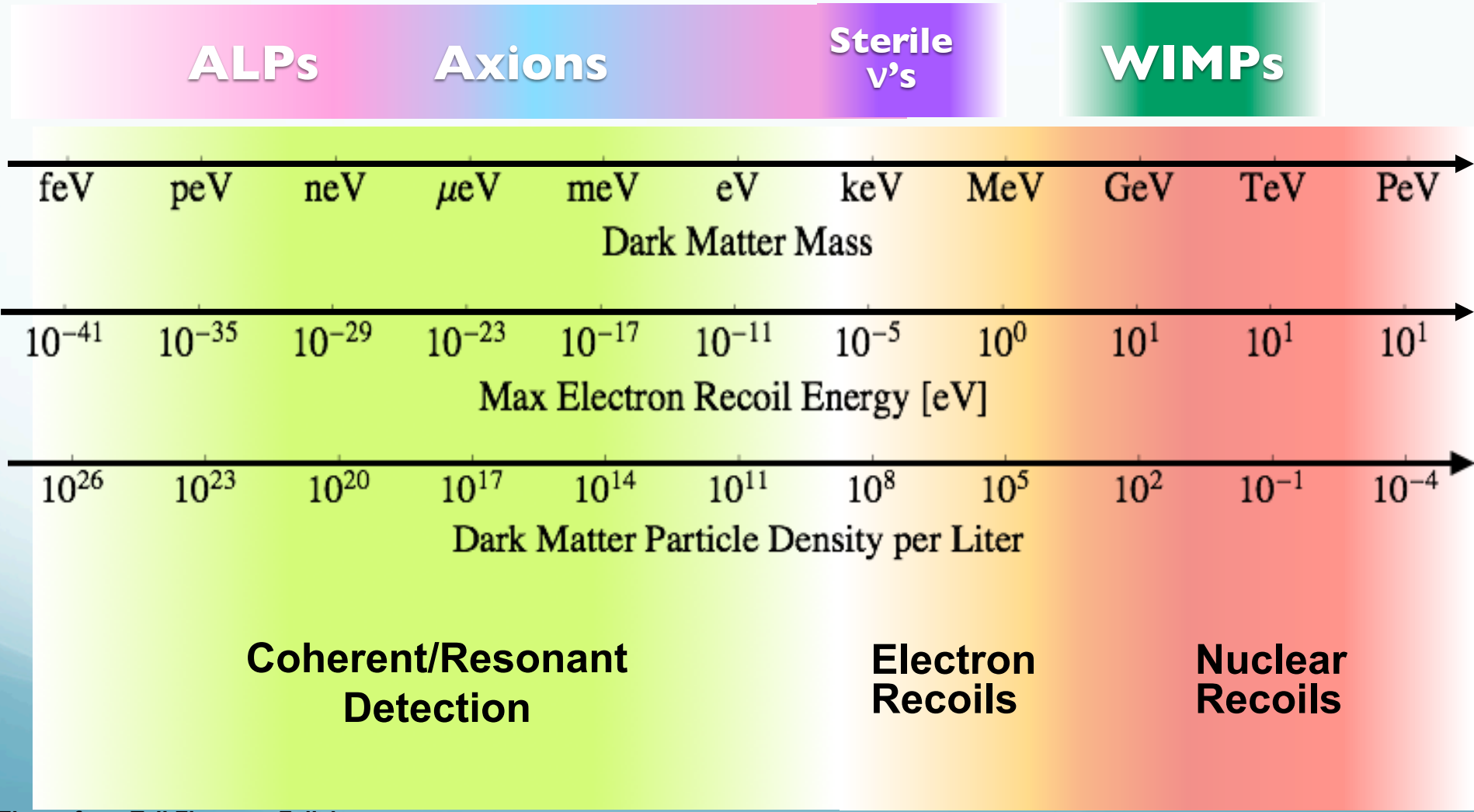
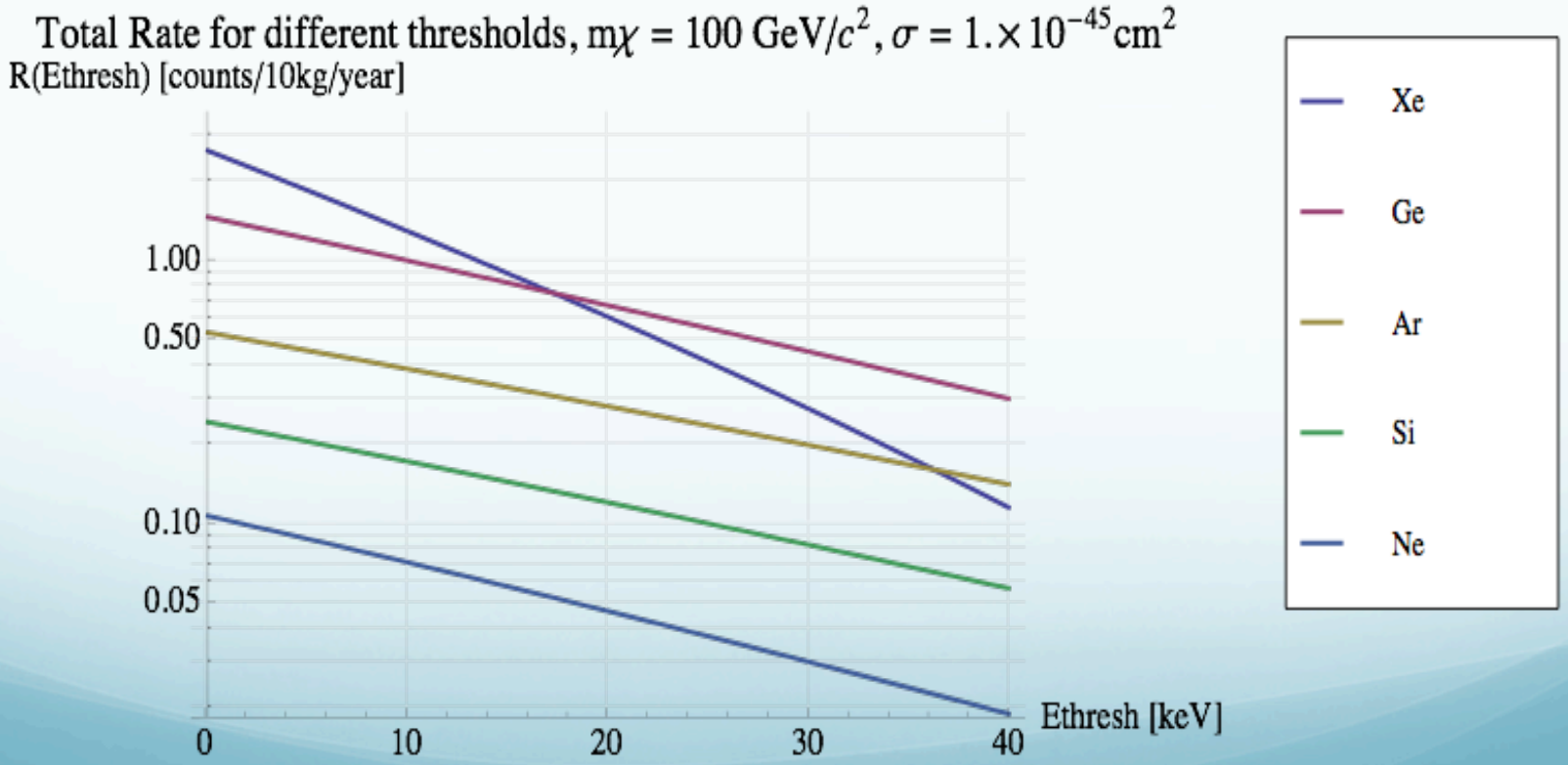


Figure from Tali Figueora-Feliciano

Direct Detection of WIMPs

If WIMPs are the halo, detect them via elastic scattering on target nuclei (*nuclear recoils*)

- **Energy spectrum and rate depend on the target nucleus mass and WIMP distribution in Dark Matter Halo**



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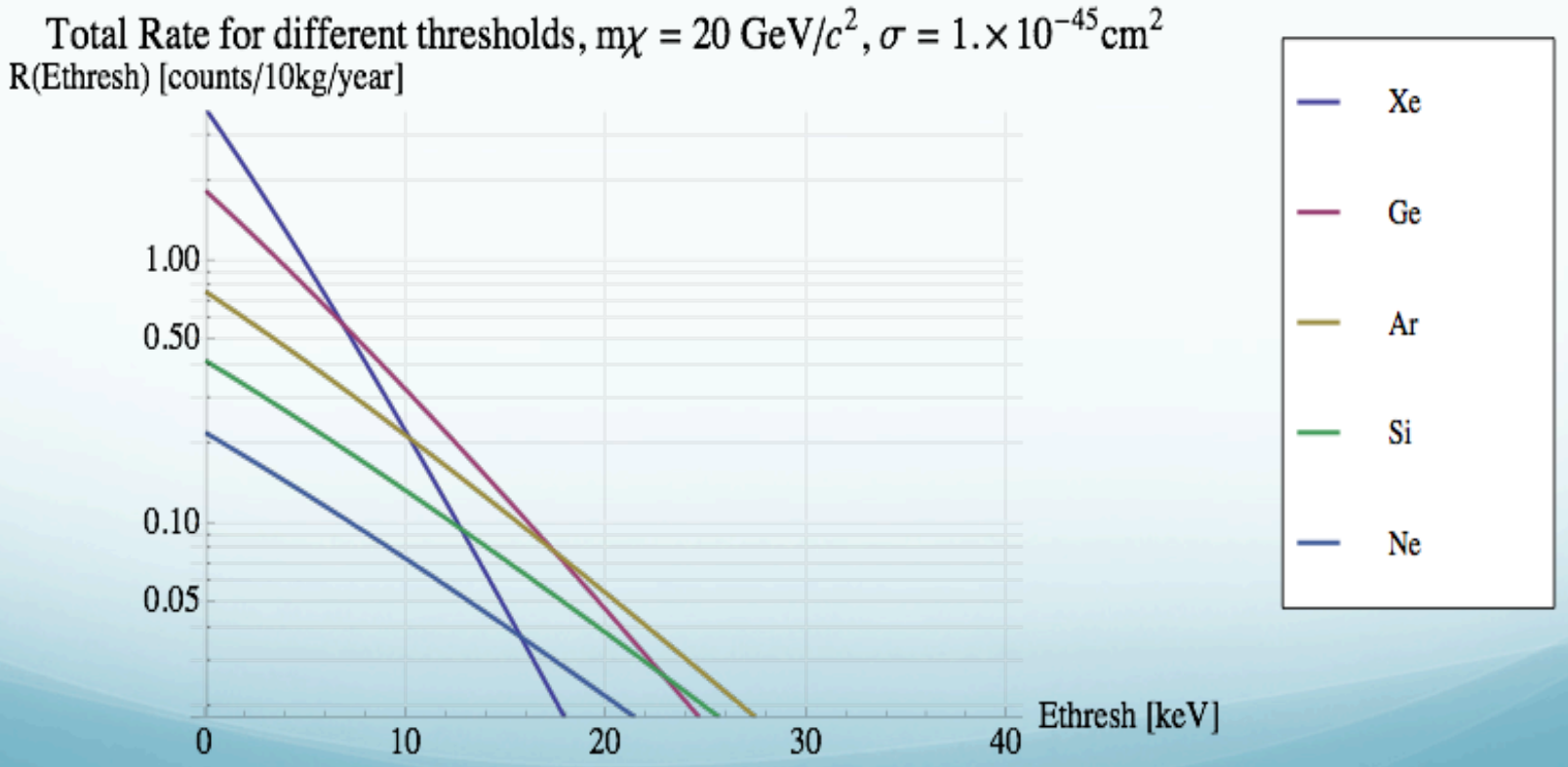

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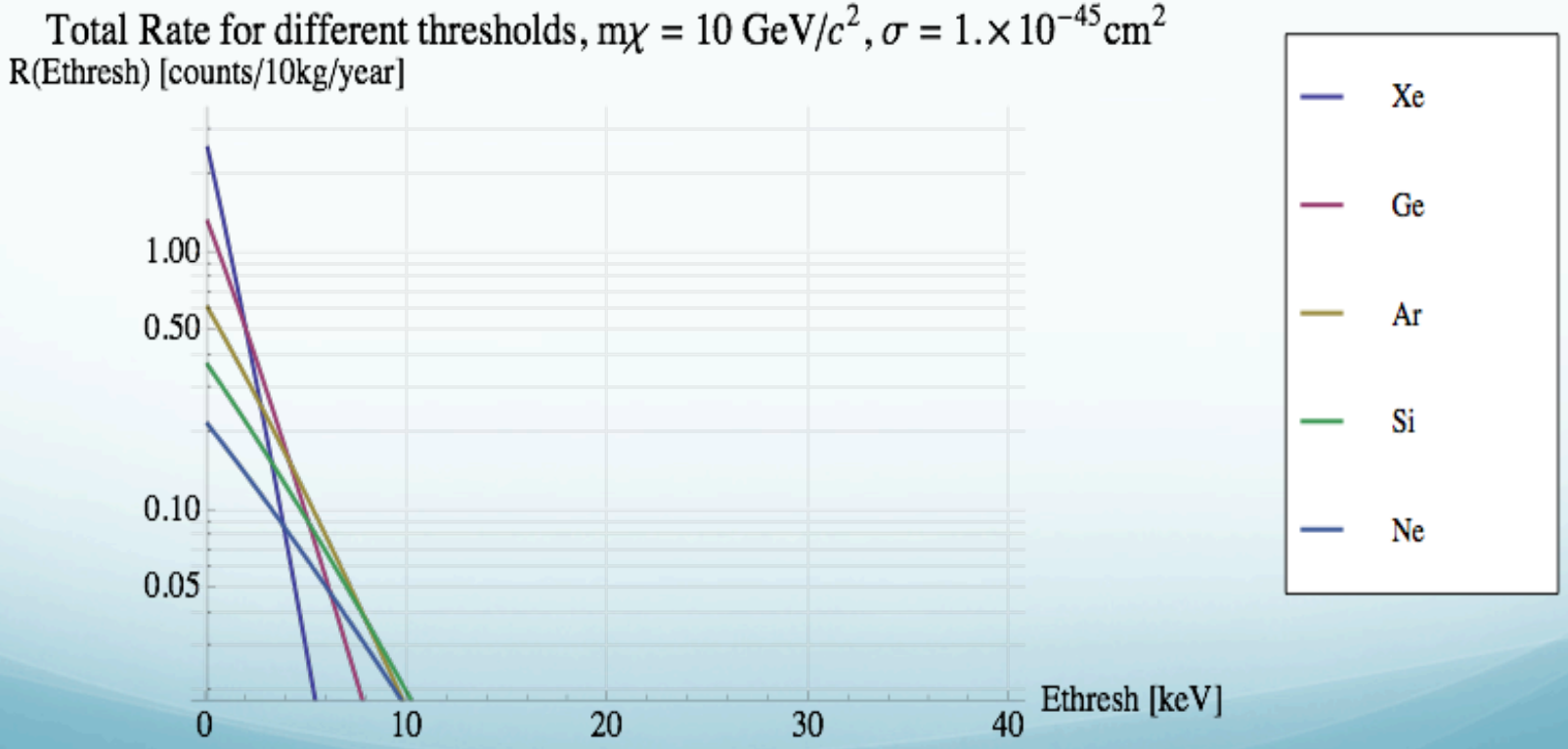

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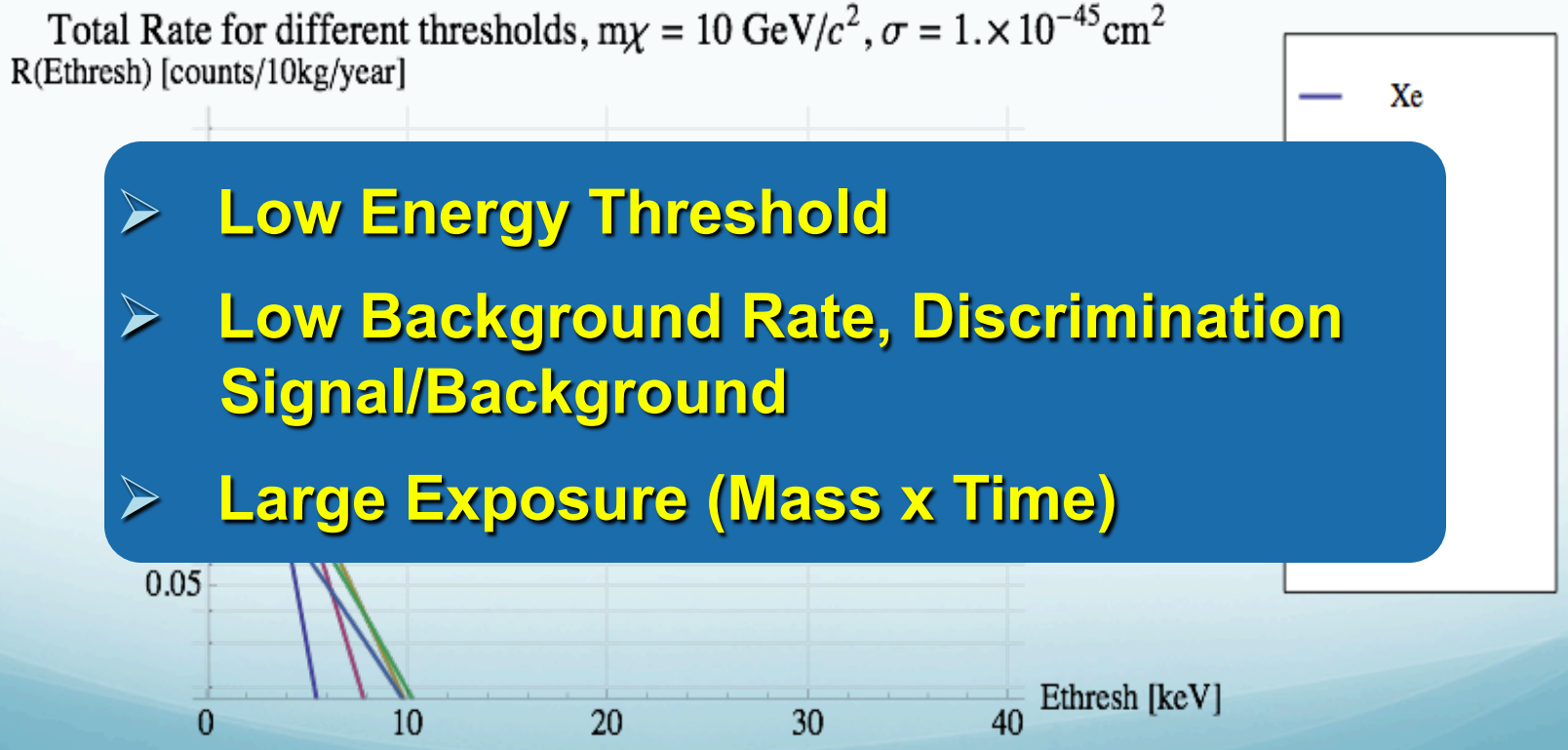


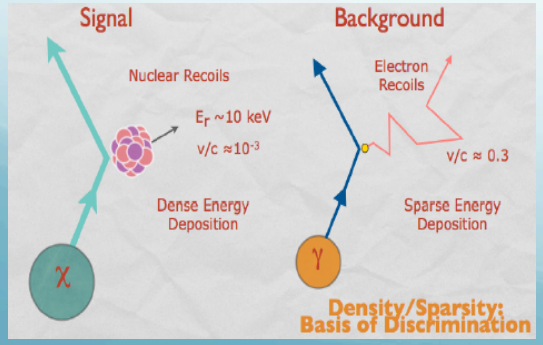
- **Low Energy Threshold**
- **Low Background Rate, Discrimination Signal/Background**
- **Large Exposure (Mass x Time)**

Direct Detection of WIMPs

Goal: find a very small WIMP signal in presence of many other background particles interacting in detectors

Techniques:

- **Statistical signatures**
  - annual modulation
  - diurnal direction modulation
- ***Event by Event* signatures**
  - **Nuclear recoils:** dense energy deposition
  - **Electron recoils (α, β, γ):** sparse energy deposition



DAMA/NaI, XMASS, DEAP/CLEAN
KIMS, DM-Ice
~100 eV / photon

Scintillation

Superheated liquid: COUP, PICO

CRESST, ROSEBUD

XENON, LUX, DARKSIDE, PandaX…

Phonons

CDMS, Edelweiss

Ionization

~10 meV / phonon

CRESST I, CUORE

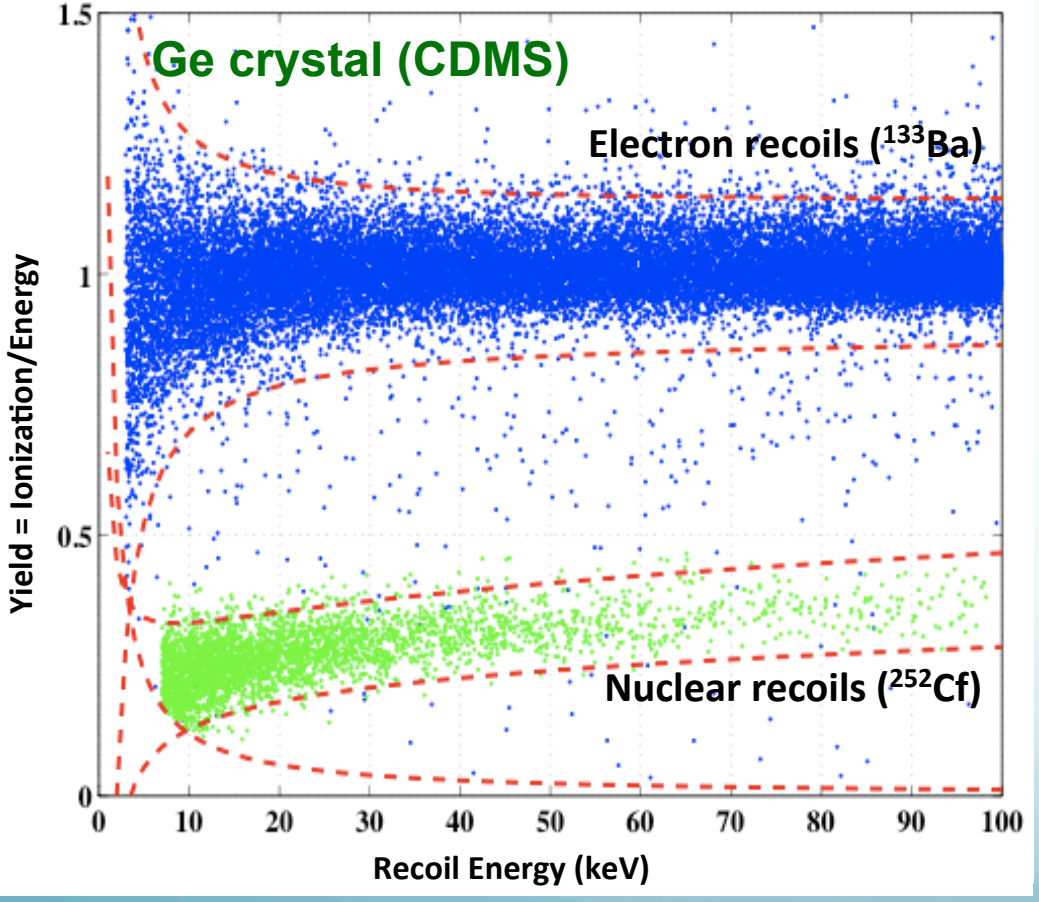
~10 eV / carrier pair

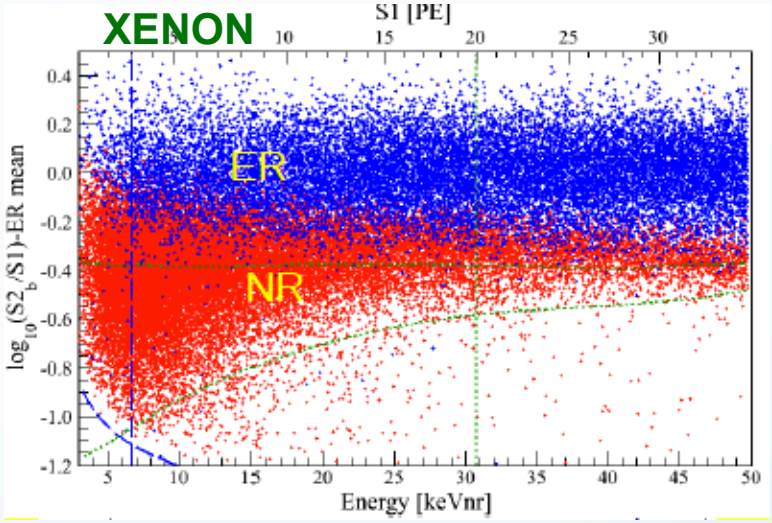
CoGeNT

Direct Detection of WIMPs

Nuclear/Electron Recoils (NR / ER):

Amount of charge or light created after an event depends on the type of interaction = "Quenching factor" (Q)





Energies calibrated with gamma sources are called "electron equivalent energies" ("keVee")

Worldwide DM Search

Many experiments around the world. Deep underground to avoid cosmic rays

Sensitivity for a ~50 GeV WIMP:

- **Current Generation:**

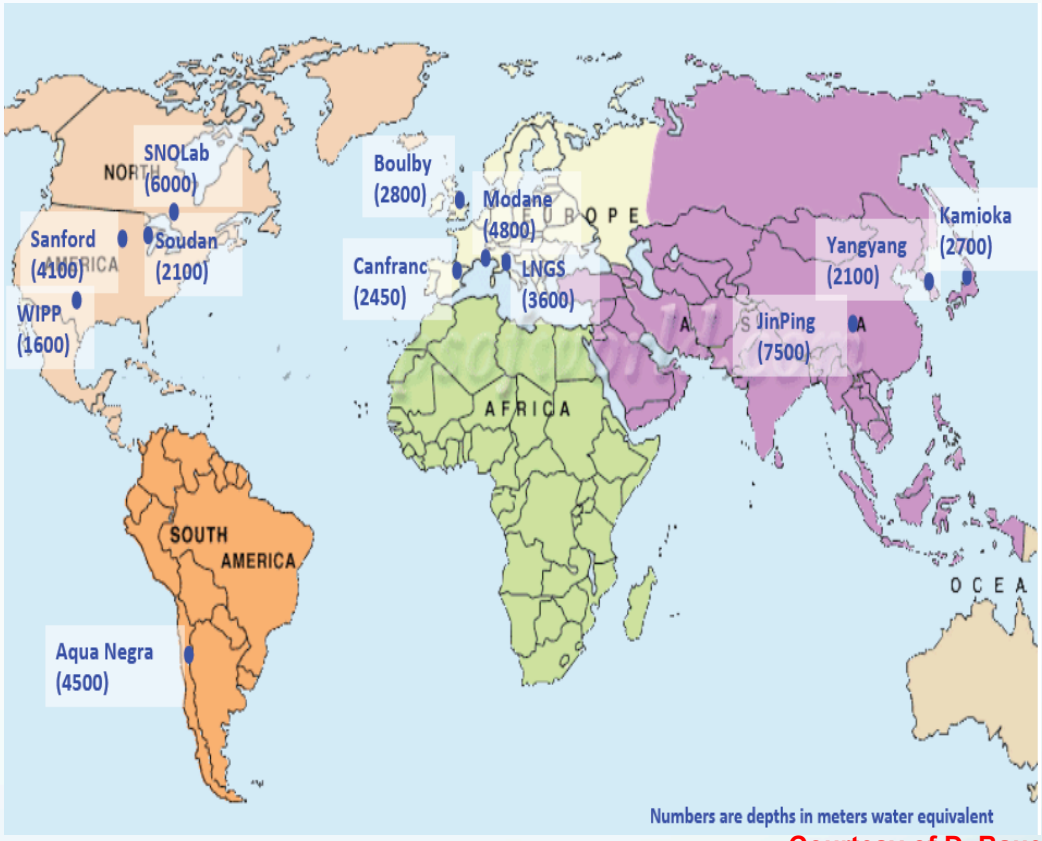
  $\sigma_{SI} \sim 10^{-45} cm^2$

- **Next step ~1 ton Exp. (under construction / development):**

  $\sigma_{SI} \sim 10^{-46}$, few $x10^{-47}$ cm^2

- **Plans for multi-ton Exp. (>5 years)**

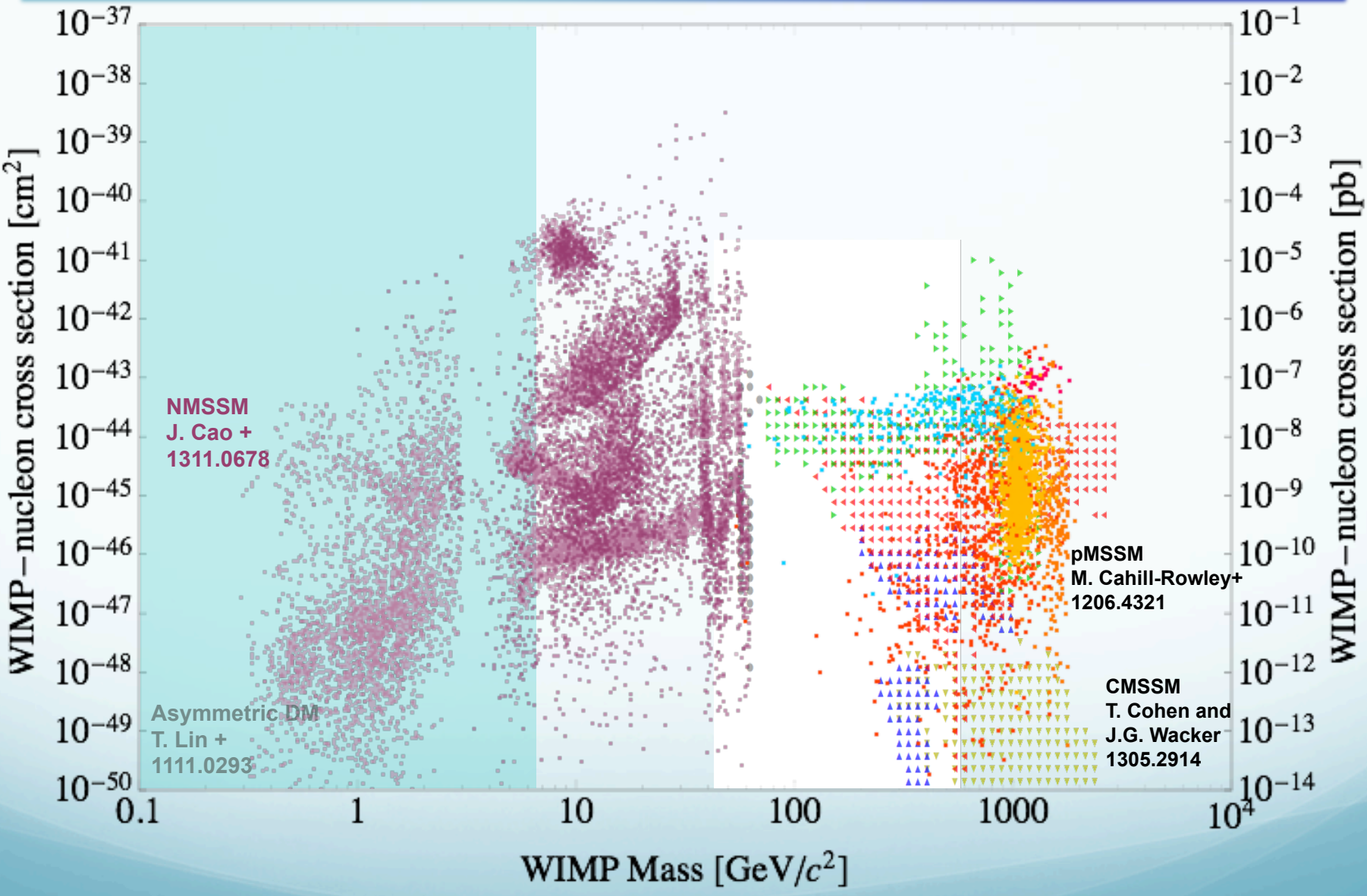
  $\sigma_{SI} \sim$ few $x10^{-48}$ cm^2



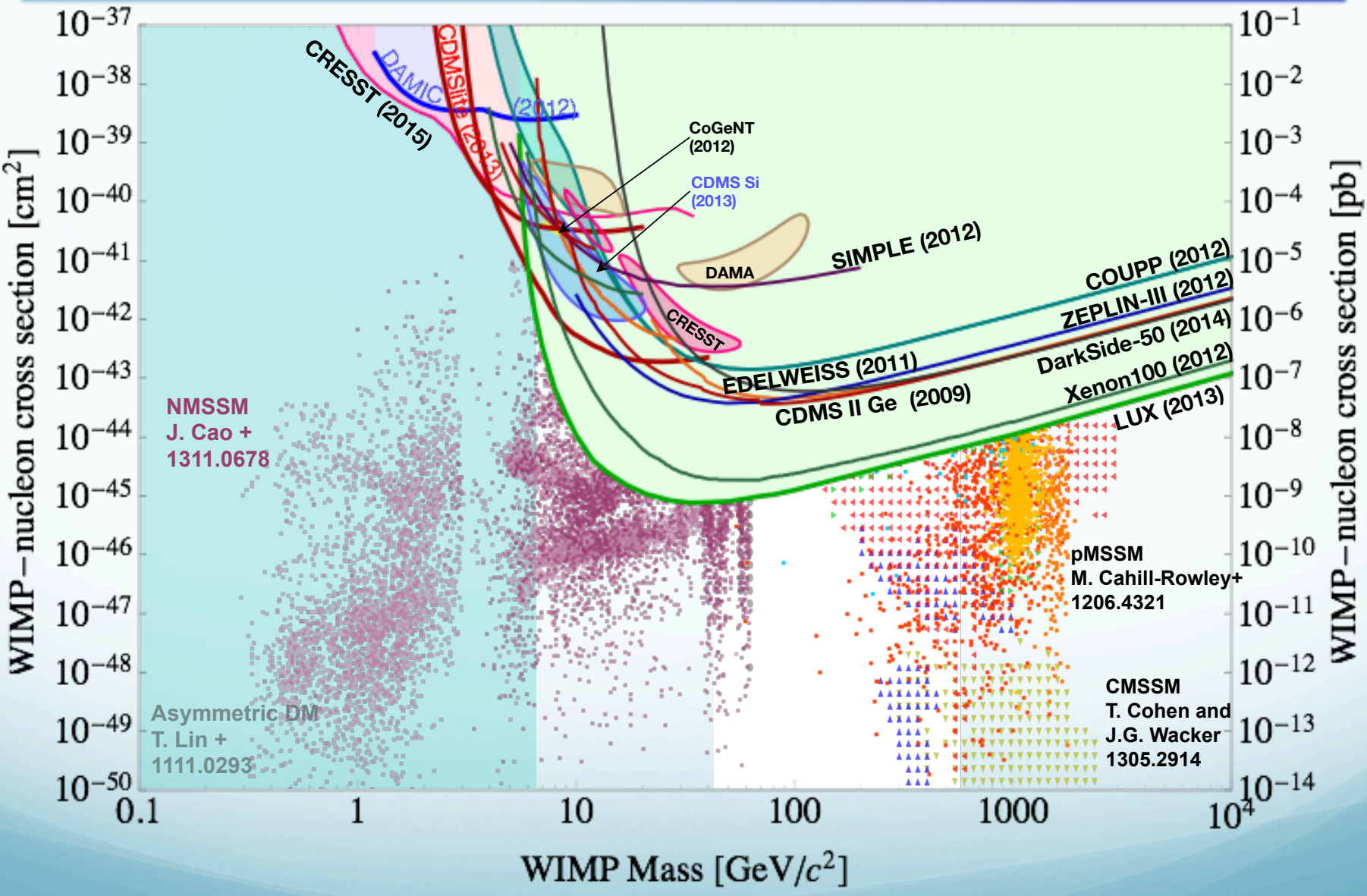
Courtesy of D. Bauer

End of the road? Not so far away from being limited by backgrounds from low energy solar neutrinos

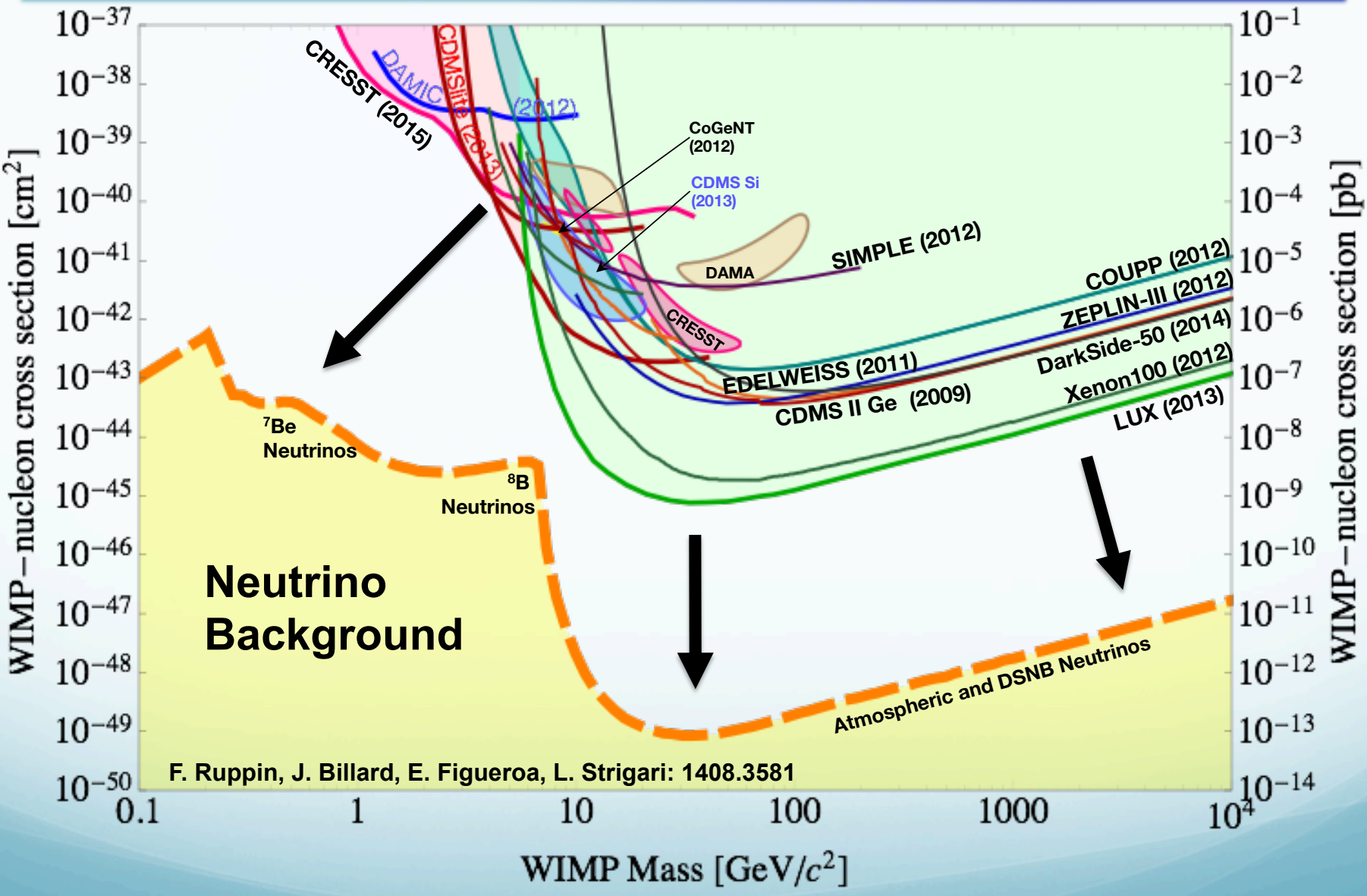
Current Landscape



Current Landscape



Current Landscape

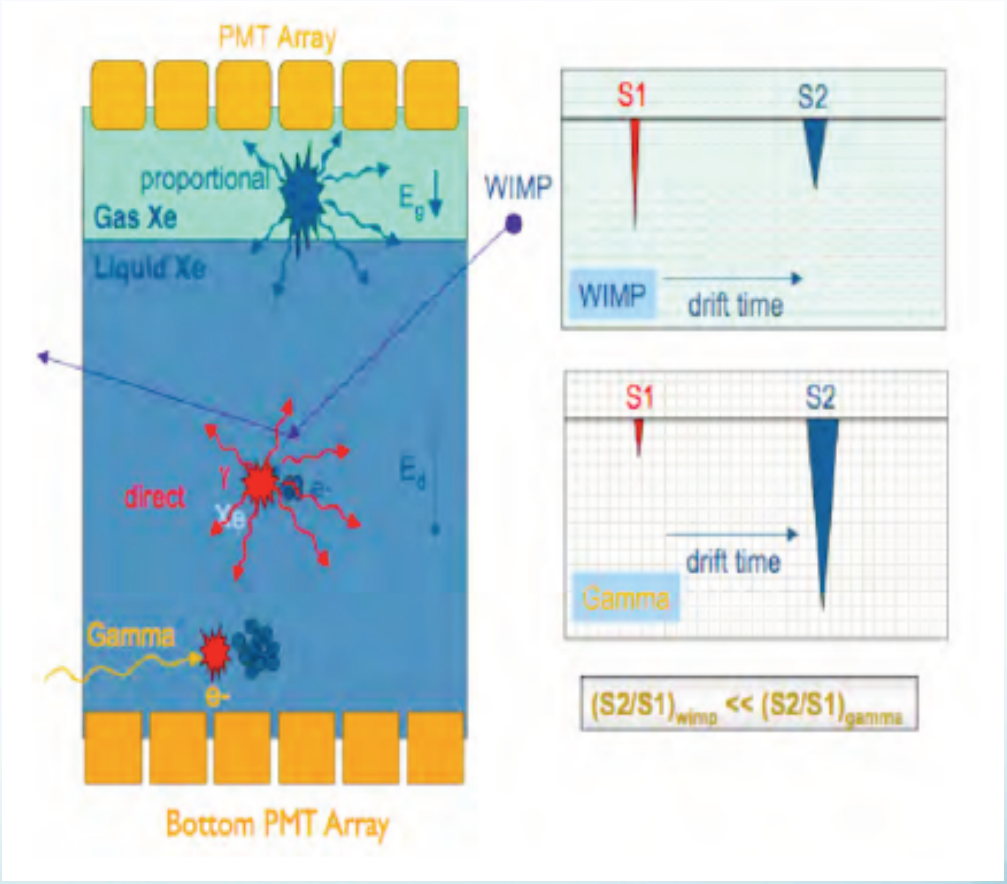


Noble Liquid Detectors (Xe, Ar, Ne)

Nuclear/electron recoil discrimination methods:

- Ionization and direct excitation ratio
- Pulse shape discrimination:
  Singlet/triplet ratio
  NR:ER = 10:1

  Time constants (singlet/triplet):
  Xe: 3ns/27ns, Ar 10/1500ns



Implementation:

- Single phase: measure scintillation only
- Double phase: measure also ionisation through electroluminescense

Noble Liquid: Two-Phase

- **XENON-100 (Gran Sasso)**

New Results further excluding DAMA

- **Search for DM interacting with electrons**

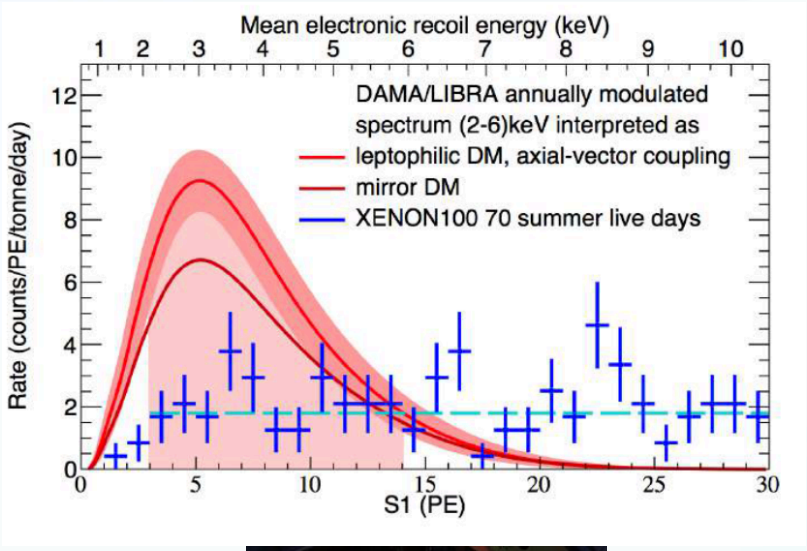
Exclude the DAMA signal as being induced by WIMPs interacting with e- according to

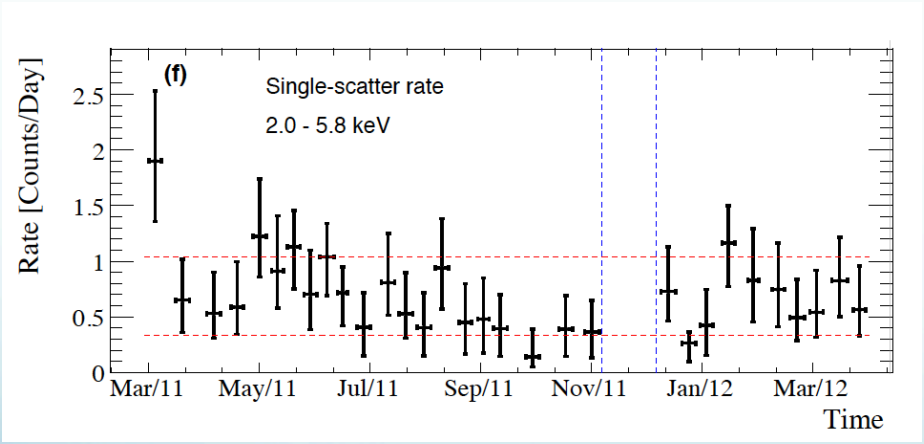
- **AV Coupling at 4.4 σ, Mirror DM at 3.6 σ, Luminous DM excluded at 4.6 σ**

Talk by F. Gao

- **Modulation**

Assuming AV coupling of WIMP to e-, DAMA annual modulation is excluded at 4.8σ





- **XENON-1T (Gran Sasso)** **Talk by D. Coderre**

Building/Commissionning well underway, start science end of 2015 , 2 t*y => σ=1.2·10^{-47}cm^2 @ 50 GeV

Noble Liquid: Two-Phase

- **LUX 300 kg Xe (Sanford)**

  Reanalysis 2013 data (« a few weeks away »)
  - new calibrations, better fiducialization
  - Lower threshold, sensitive down to 3.3 GeV
  - 10% more exposure

- **LUX ZEPLIN – "LZ"**

  8 tons LXe, reuse LUX water tank, installation start 2016

Noble Liquid: Two-Phase

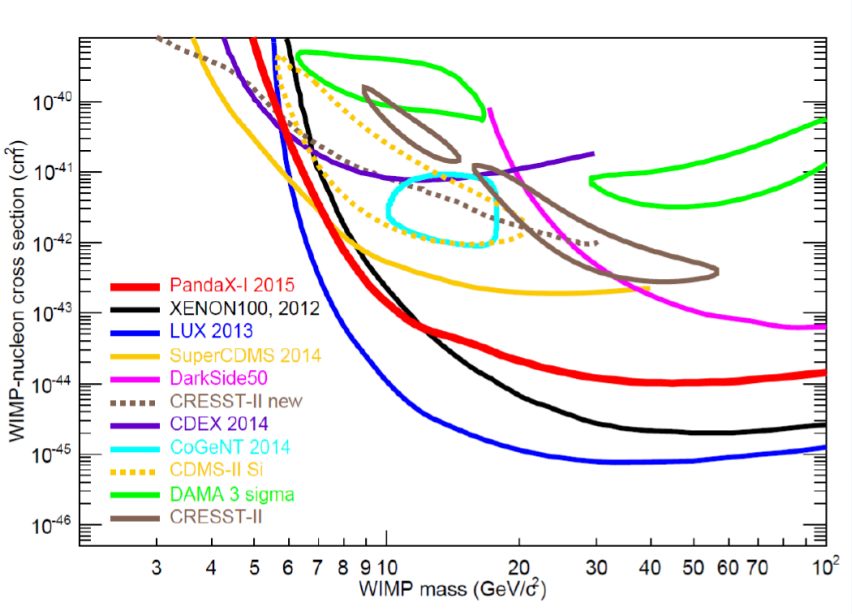
- **PandaX-I (Jin Ping)** arXiv:1505.00771v1

  LXe TPC, 54 kg fid, 80 days :
  - 5keV NR threshold probing M_{WIMPS}<10GeV
  - 7 events ~ expected background

  Talk by X. Chen

- **PandaX-II (Jin Ping)**

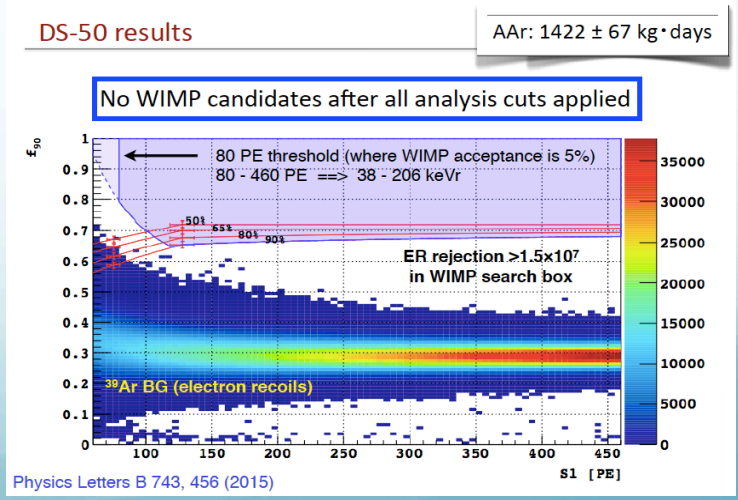
  Same vessel/infrastructure, 300 kg fiducial
  Science start in 2015



- **DarkSide 50 (Gran Sasso)**

  - Results with AAr ~ CDMS for M_{WIMPS}=100 GeV
  - DM search with underground LAr started in April 2015. First Result with 70 days soon

  Talk by M. Wada

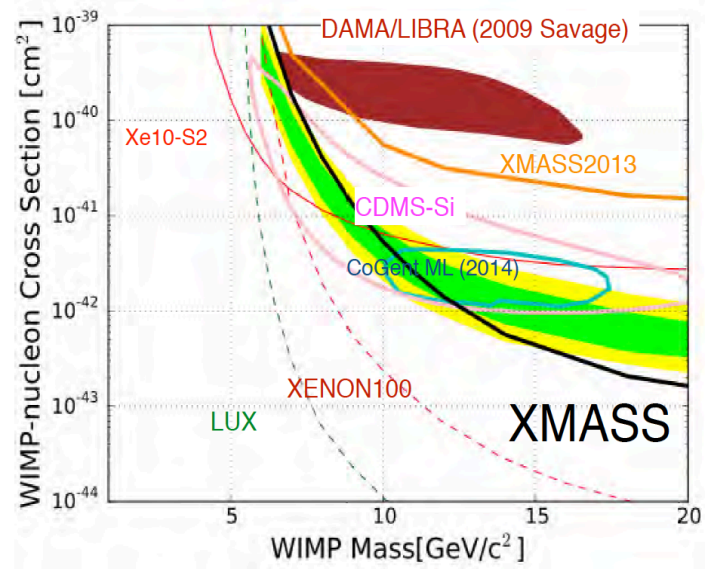


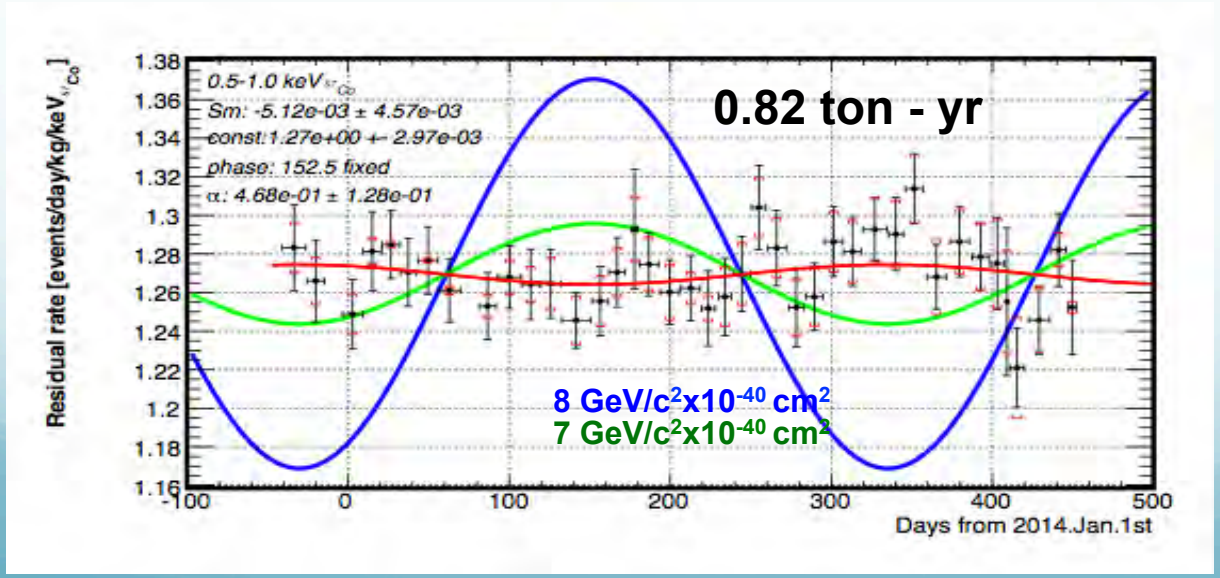
Noble Liquid: Single-Phase

- **XMASS-I (Kamioka)**
  - 2013 refurbishement: 10x lower bg
  - Annual modulation analysis: No significant mod. limit consistent with previous Xe results
  - Adding 2nd year data

Talk by H. Ogawa

- **XMASS-I.5:** 1 ton FV in 2016
- **XMASS-II:** 10 ton FV

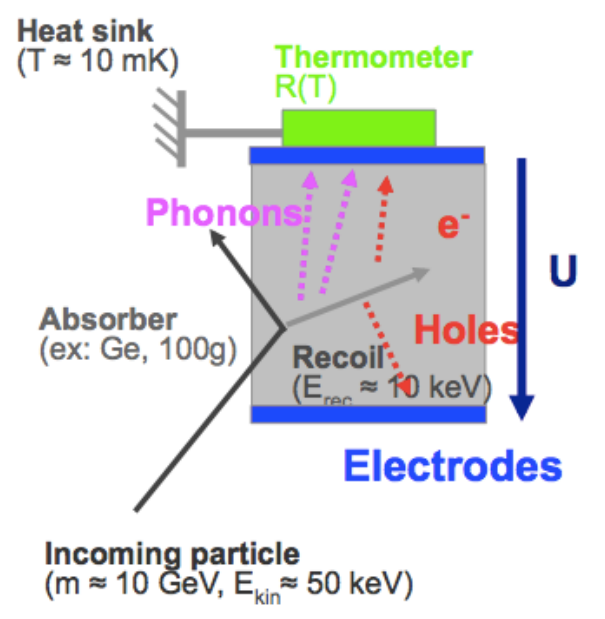


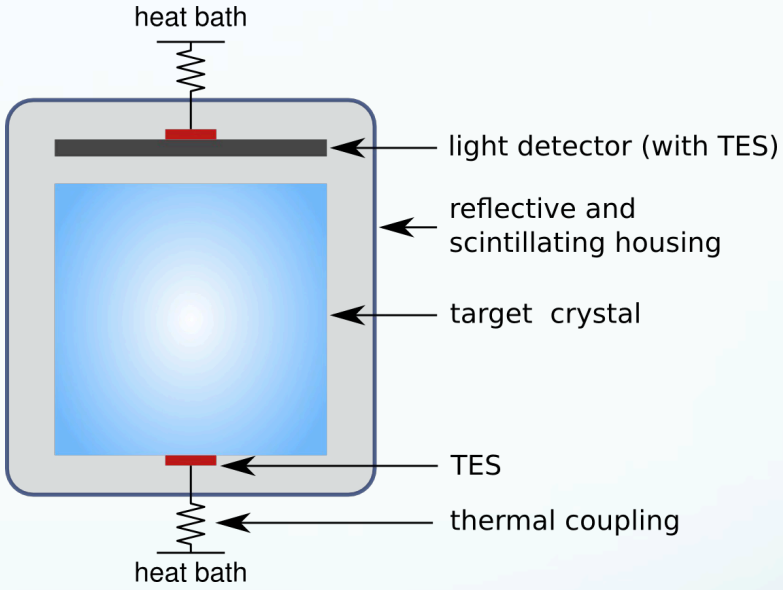


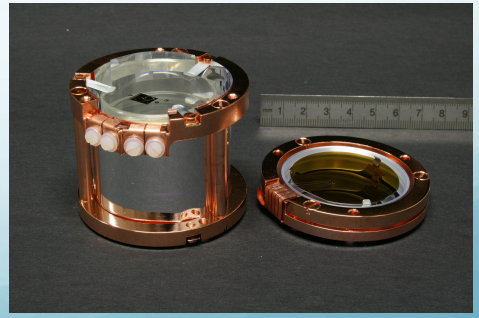
Cryogenic Crystals Detectors

Measure Phonon and

Ionization (CDMS, Edelweiss) or Light (CRESST)







2 modes:

- Small voltage (<8V)
- High Voltage (~100V)
  - Amplification of ionisation
  - Readout via phonons
  - Loss of ER/NR discrimination

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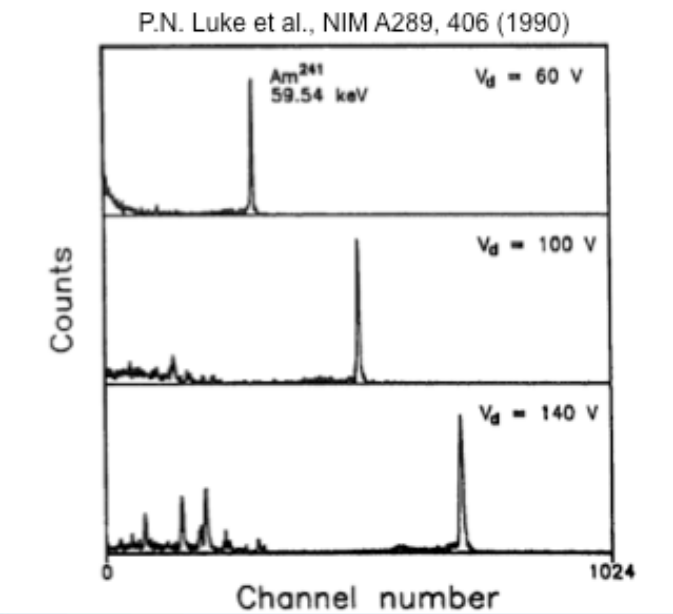

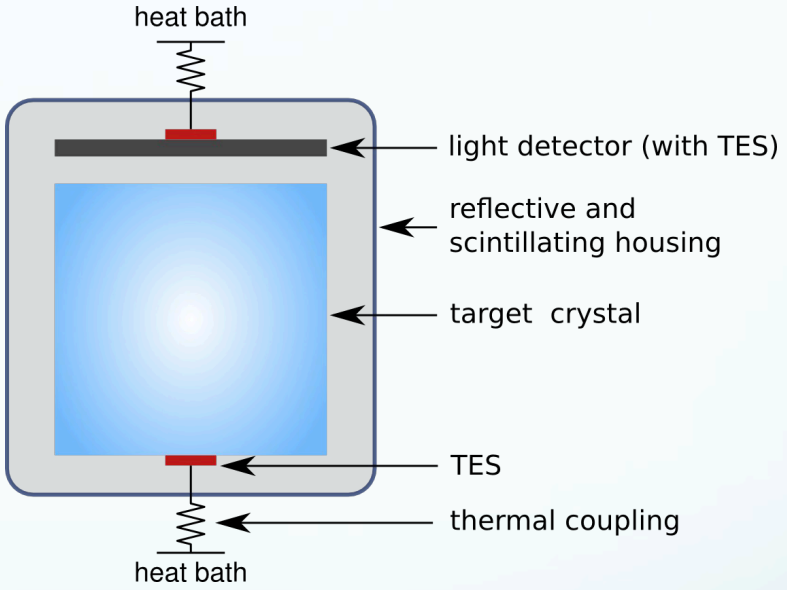

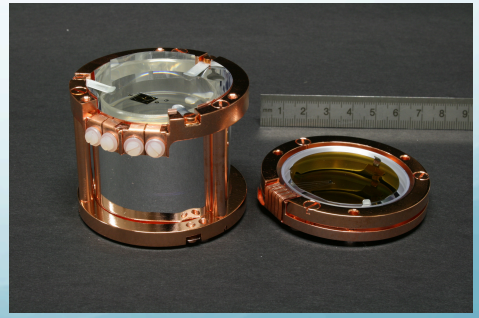

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Cryogenic Experiments

- **CRESST-II (Gran Sasso)**

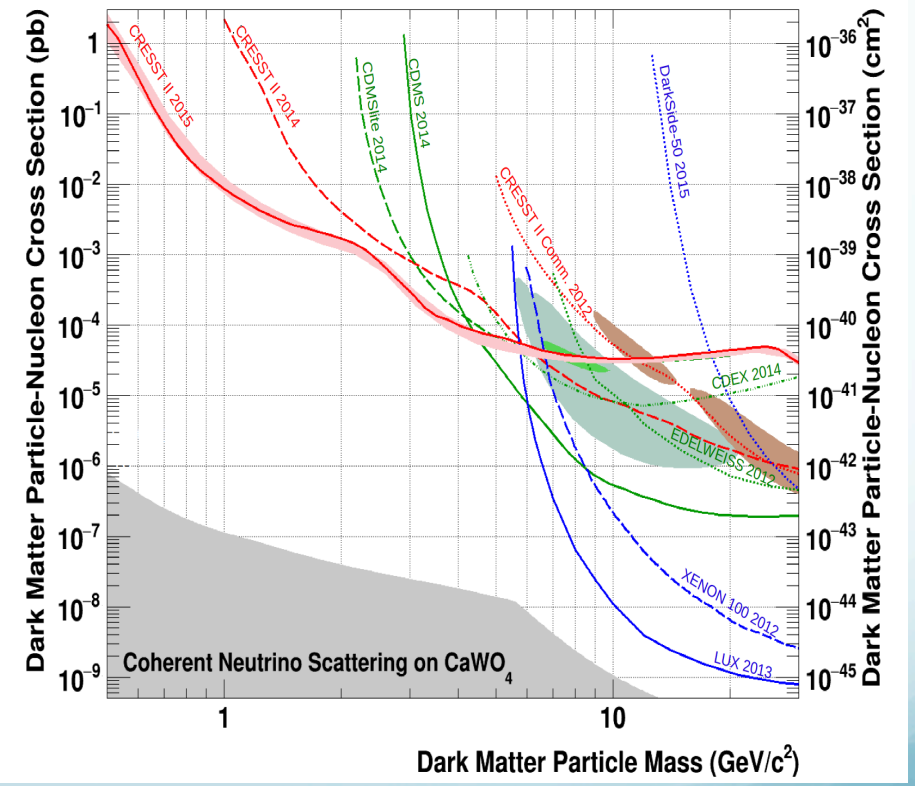
  Scintillating CaWO4 300g crystals as target

  - **Newest Result (2015)**
    - 307 eV energy threshold
    - Probes sub-GeV/c^2 WIMP mass!

- **CRESST-III**

  Phase 1 (start end 2015): 50 kg-days
  1 year of running with 10 small modules

  - Prototype successfully tested
  - Production of modules ongoing



Talk by R. Strauss

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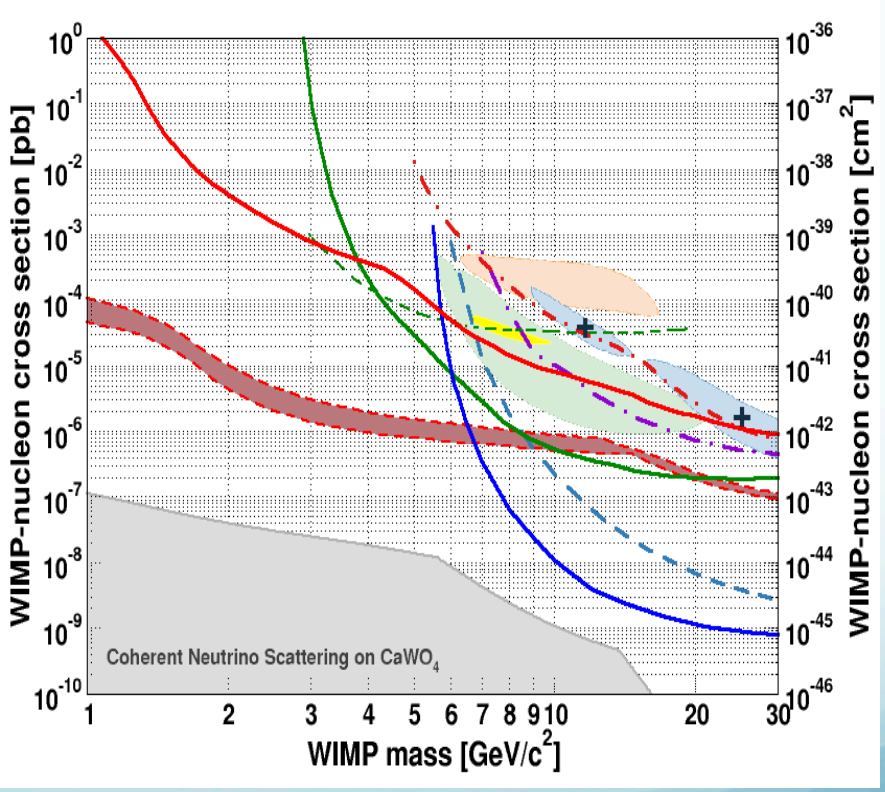
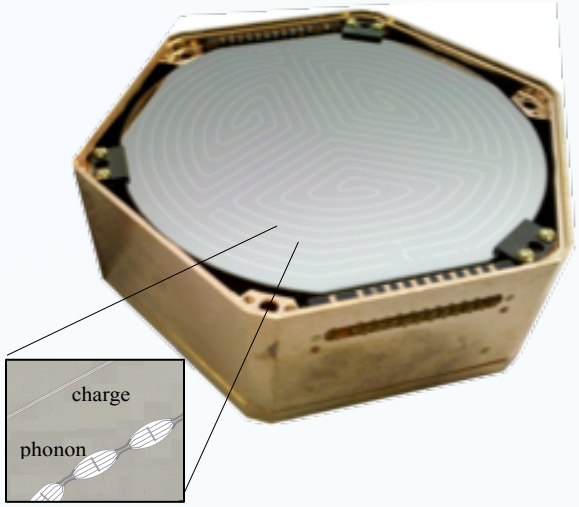


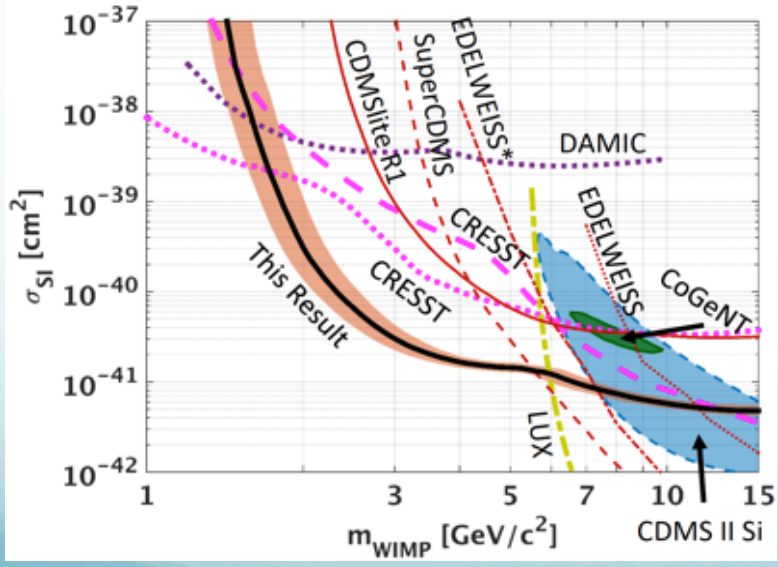
Talk by R. Strauss

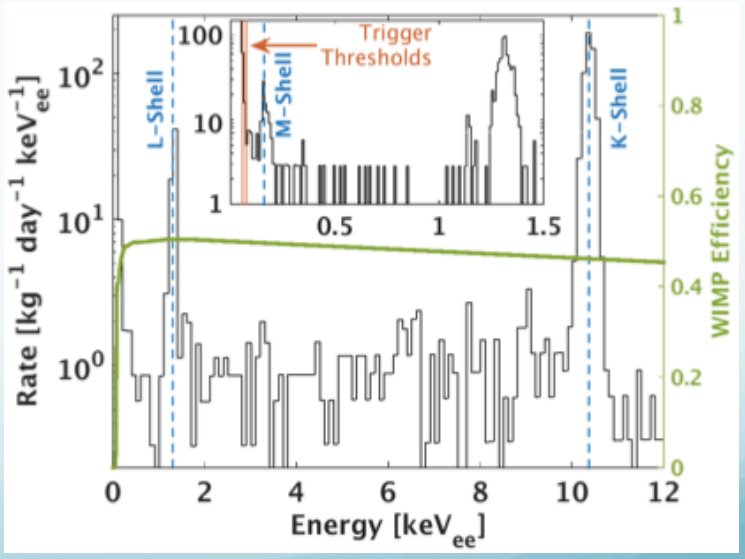
Cryogenic Experiments

- **SuperCDMS (Soudan)**
  - 15 Ge detectors (total ~9kg) in operation until recently
  - 8 phonon + 4 charge channels, interleaved
  - Operate single detector ("CDMSLite") at high bias (~70 V)



  - ➢ **Newest CDMSLite Result (2015)**
    - 70.1 kg-d exposure
    - 56/75 eV ionization Trigger Thresholds





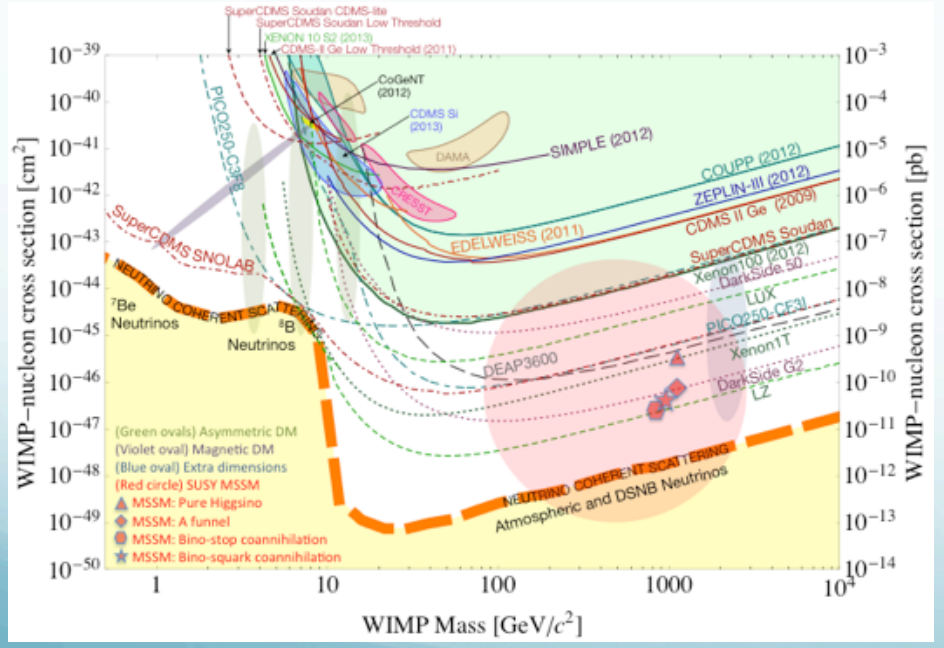
Cryogenic Experiments

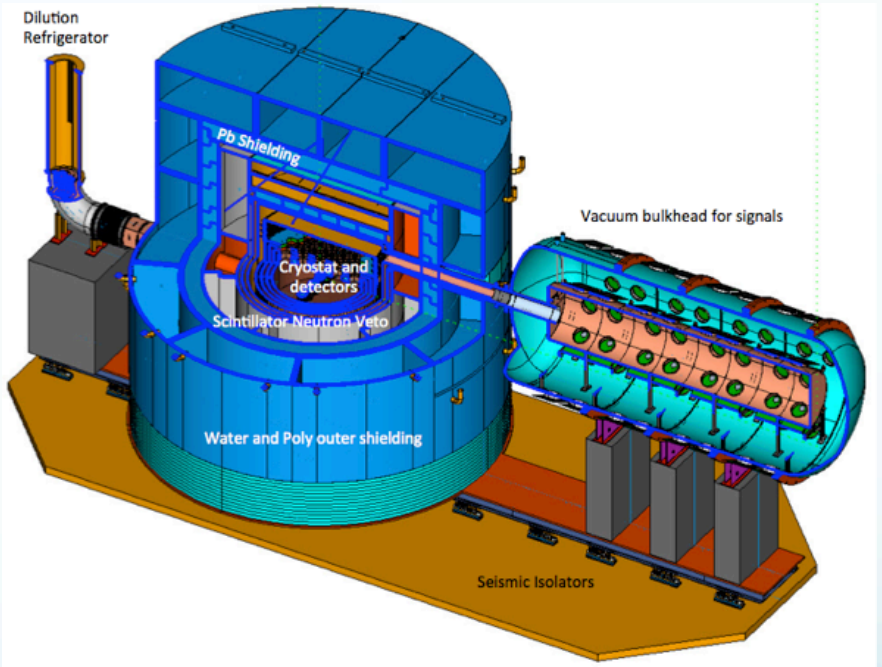
- **SuperCDMS-SNOLAB**

Planning underway to build at SNOLAB

Goals: Low mass WIMPs

- Mixture of Ge & Si targets, larger crystals than SuperCDMS Soudan
- Mixture of iZIPs and HV detectors



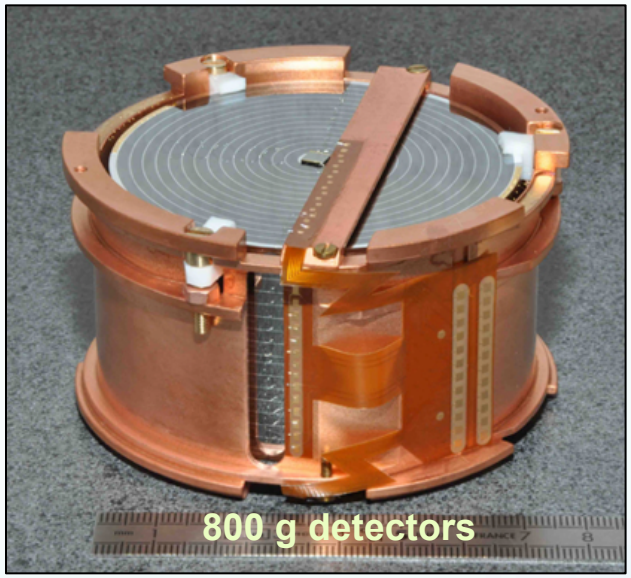


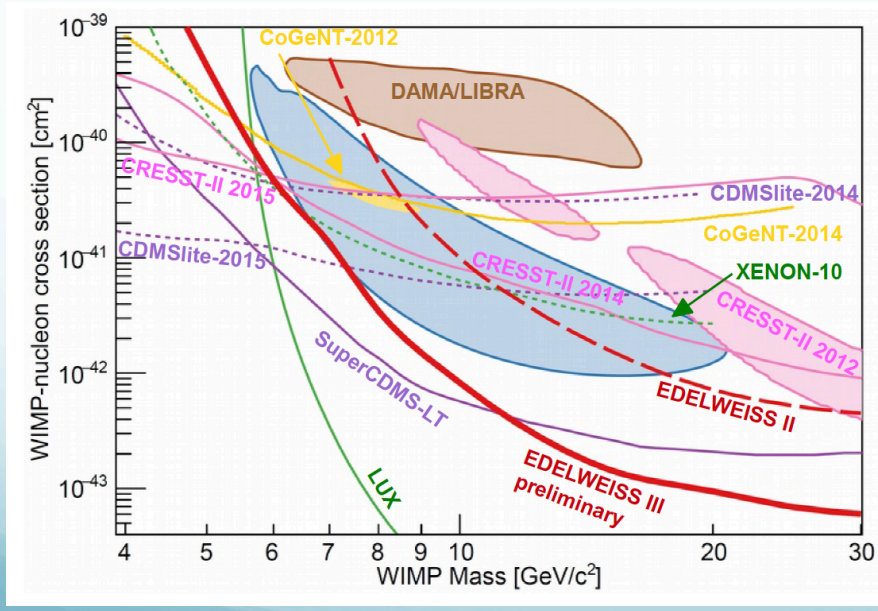
Cryogenic Experiments

- **EDELWEISS-III (Modane)**
  - 8 months physics data 2014/2015 with 24 Ge Full InterDigit ("FID800") detectors
  - Current run resumed in June 2015 with 23 FID800 (12 new) + 1 FID200 for "High-Voltage" R&D

➢ **Newest Result (2015)**

- 8 detectors with good baseline resolution
- 4x FID800 @ 1.0 keVee, 4x FID800 @ 1.5 keVee



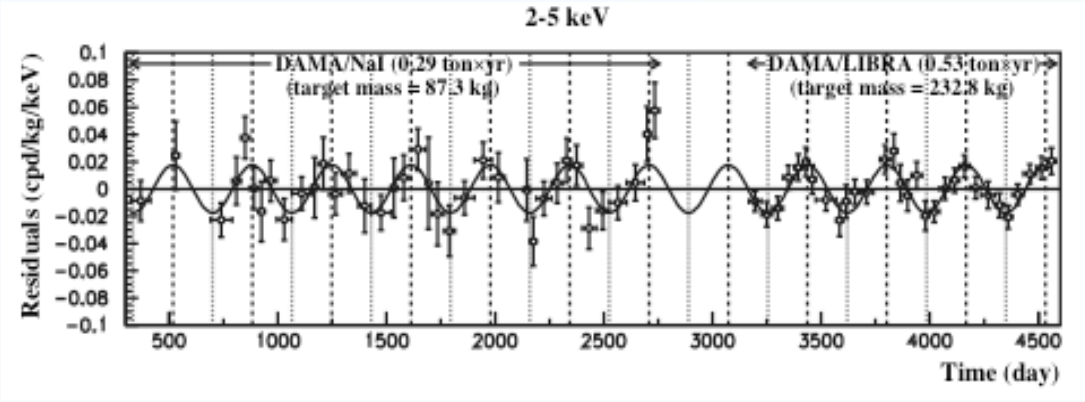


Talk by E. Armengaud

NaI Detectors

Checking DAMA/LIBRA Modulation

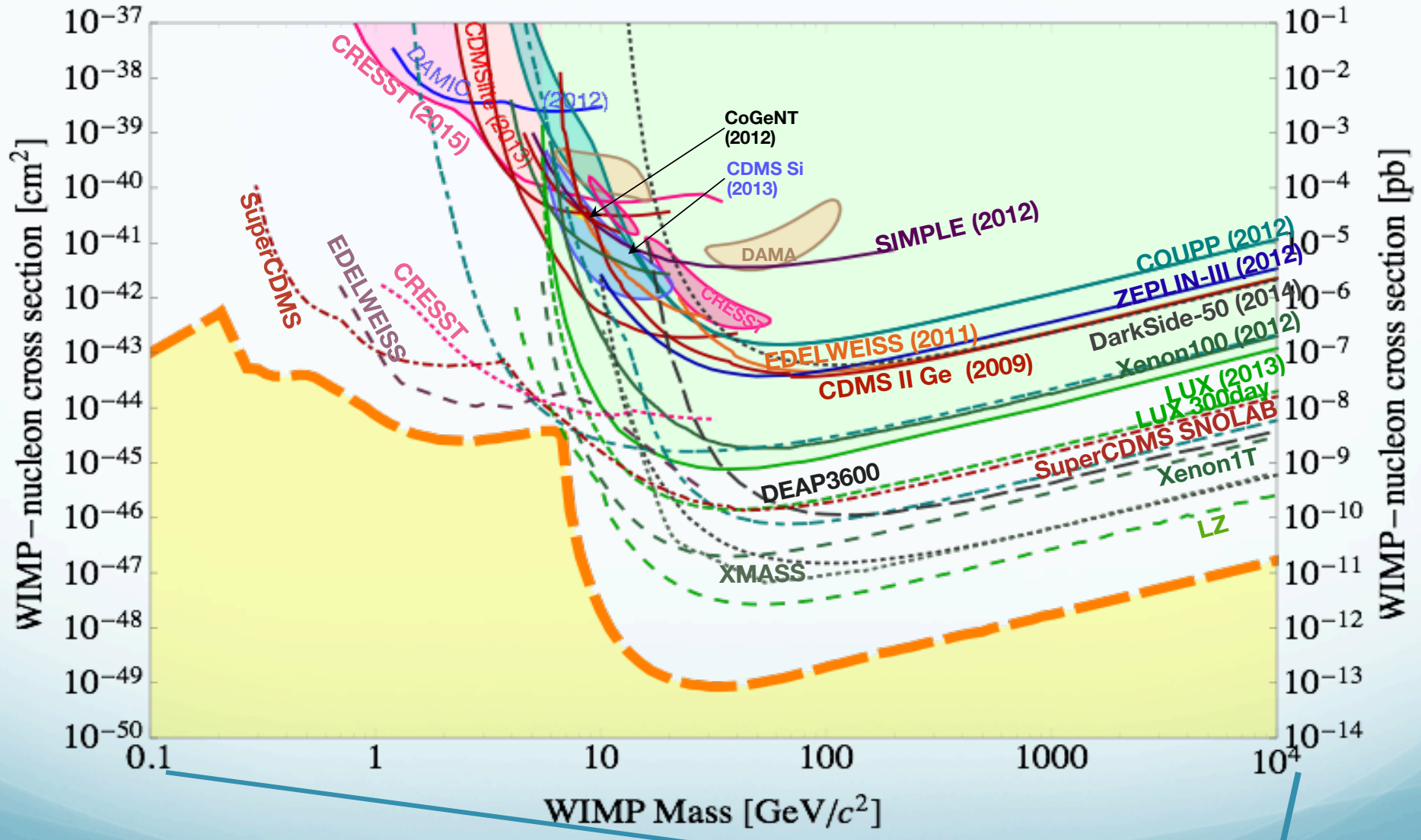
DAMA/LIBRA Time Dependence of Residual Singles Rate in 2-4 keVee bin



Northern Hemisphere	Gran Sasso **DAMA/LIBRA** 250 kg running	Boulby **DM-Ice North** 37 kg R&D 250 kg planned	Canfranc **ANAIS** 37 kg R&D 250 kg planned	Y2L **KIMS** 45 kg R&D 200 kg planned	Gran Sasso **SABRE** R&D	Kamioka **PICO-LON** **KamLAND-PICO** R&D
Southern Hemisphere		South Pole **DM-Ice** 17 kg running 250 kg planned			Stawell **SABRE** Lab completion 2017	rock ice

Ultra-pure crystal development underway by DM-Ice, KIMS, ANAIS, SABRE, and PICO-LON collaborations

WIMP Search: Perspective



Summary/Outlook

- **No firm evidence of WIMP signal yet:**
  - **DAMA/LIBRA modulation still a mystery: excluded by LUX, XENON100, SuperCDMS, and EDELWEISS**
  - **Need to repeat experiment (DM-ICE, ANAIS, etc.),**

- **Next Generation WIMP search experiments under development/construction, covering a lot of new parameter space**

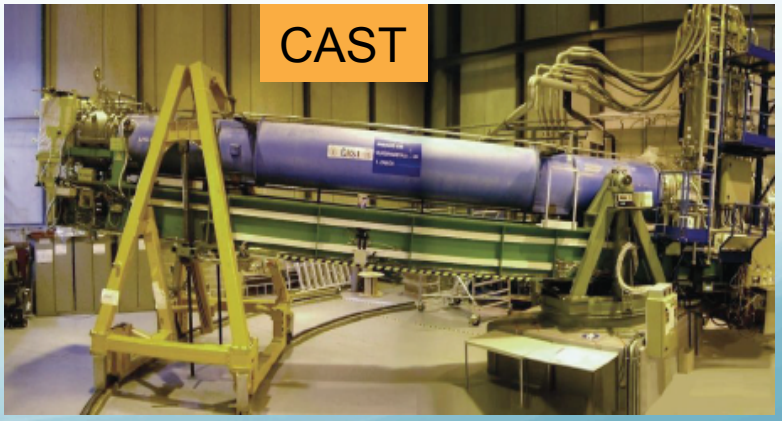
- **Given the wealth of theoretical possibilities, multiple detectors /techniques will be required to build a robust case**

Extra Slides

Searching for Axions

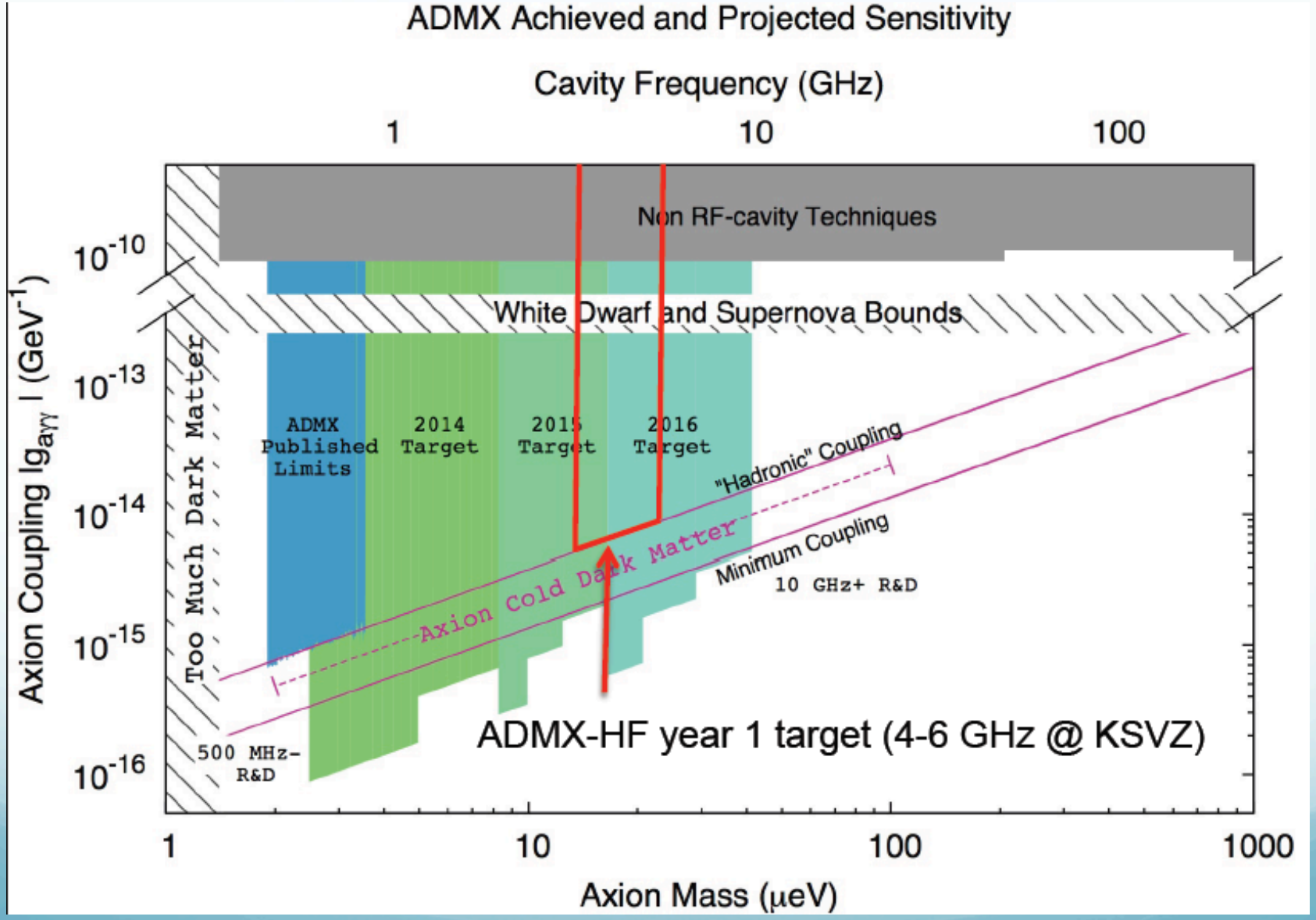
- **Light pseudoscalar particle**
  - introduced to solve strong CP problem (Peccei-Quinn)
  - weak couplings
  - born non-relativistic (cold dark matter)

- **Detection rely on induced coupling to photons**
- **Techniques:**
  - ADMX: high-Q resonance cavity in an external B field
  - CAST: conversion of solar axions to photons in magnetic field (using LHC prototype magnet B~10T)



IAXO proposal: search for meV mass axion

G2 ADMS Search Capability



Noble Liquid: Single-Phase

- **DEAP-3600 (SNOLAB)**

  - 3600 kg LAr , 1000 kg fid
  - Goal in 3t.y σ=2·10−46cm2 @ 100 GeV
  - Commissioning with argon gas followed by cooldown/liquid argon fill by end of year