Introduction to DM direct detection

WIMPs
1-1000GeV
In our Milky Way

Charling Tao

May 2019,

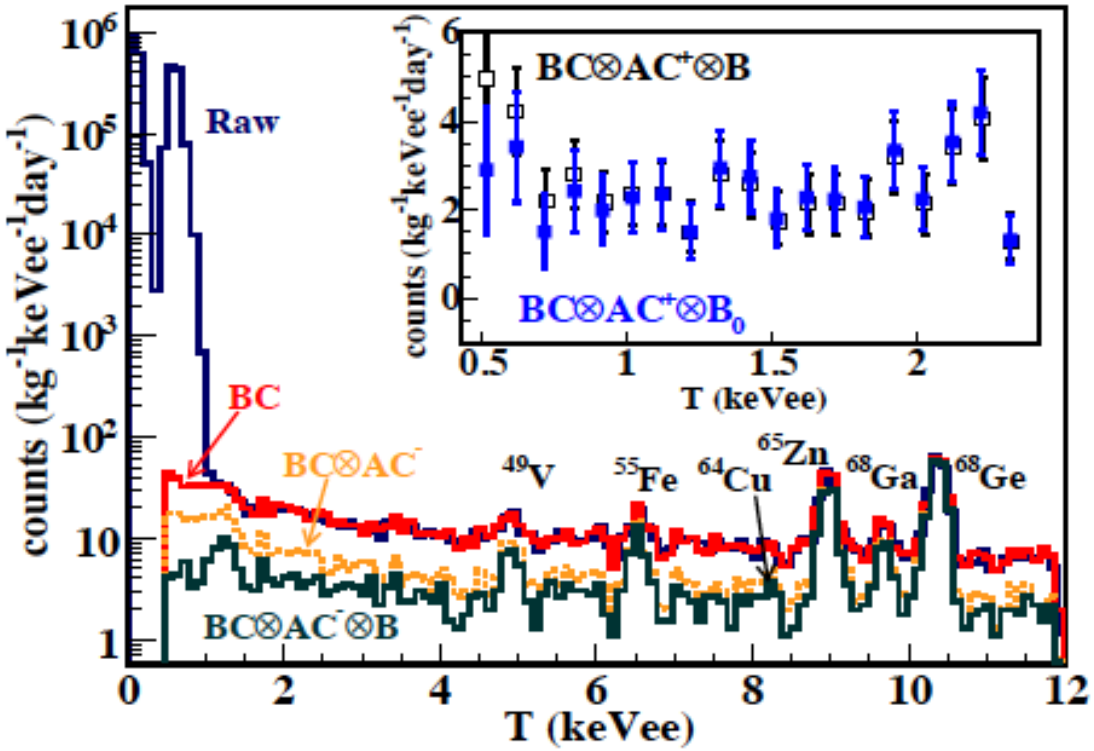
HUST China

The lab experiment

1. Concept of **keV particle** detection with **a NaI(Tl)** detector and a **SiPM LySO** detector
2. Energy **calibration** with radioactive sources
3. Energy **resolution**

4. **Background** measurements: rates and identification of background observed
5. **Comparison** with measurements underground with a Germanium detector
6. **Design you ideal deector!**

CDEX: reaching best present Ge limits in 5 years!



10 kg Ge crystal

Y.Qian et al., arxiv 1404.4946

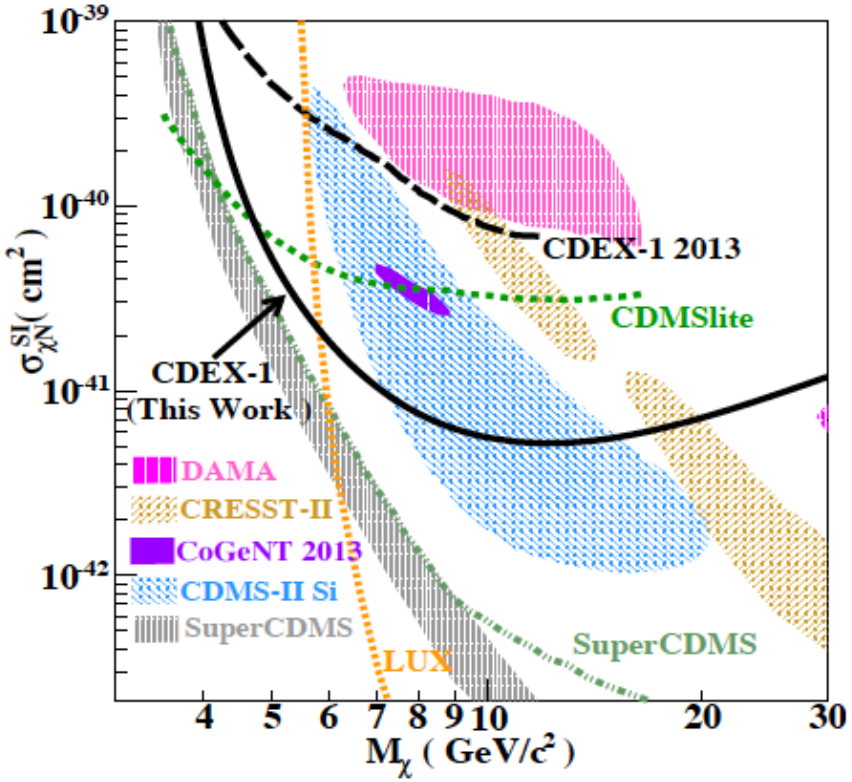


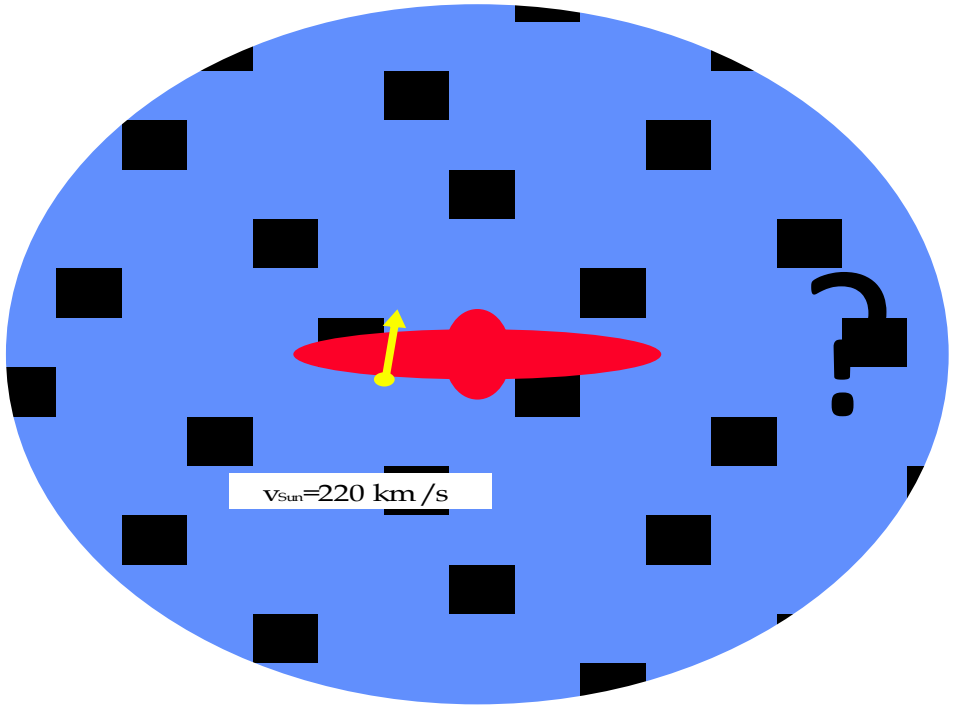
FIG. 4: The 90% confidence level upper limit of spin-independent χN coupling derived from this work, superimposed with the results from other benchmark experiments [2–5, 7, 9, 10, 14].

Cosmogenics Ge-68 has 270.8 days half-life!

Usual assumptions of DM distribution in our Galaxy

Usual assumptions:

Usual η ψ π ο τ η ε σ ι σ
ρ_{DM}= 0.3 GeV/cm^3, β=10^{-3},
Maxwellian distribution of velocities, v_{rms}=270 km/s



« Simplified Model »of Matter in our Galaxy:
SMMG

Used for most comparisons…

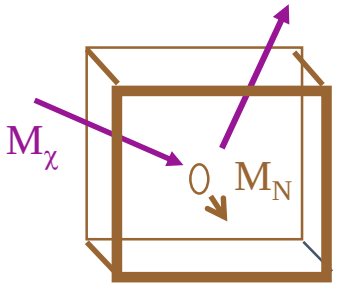
But is it the reality? Clumps? Corotation?

WIMP searches: Direct detection

- **Principle :** (Goodman and Witten,1985, Drukier and Stodolsky 1984)

Elastic scattering of galactic DM off detector nuclei

Nuclear recoils of a few keV



Ge, Si, NaI, LXe, …

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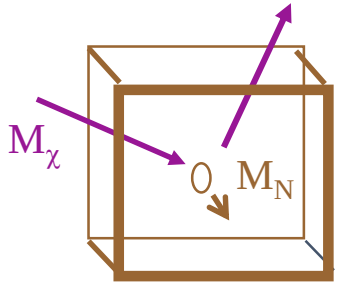


Ge, Si, NaI, LXe, …

- **Exponential recoil energy distribution**

event rate per unit mass

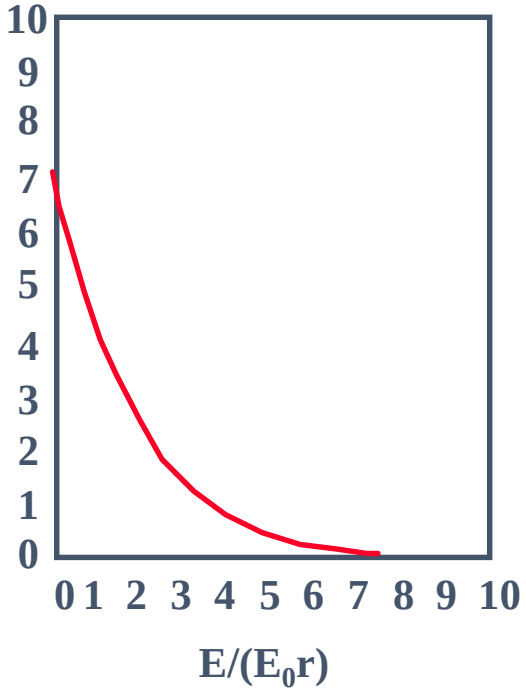
total event rate (point like nucleus)

$$\frac{dR}{dE_R} = \frac{R_o}{E_o r} e^{-E_R/E_o r}$$

recoil energy

incident energy

kinematic factor $= 4M_\chi M_N/(M_\chi + M_N)^2$



- **Rates: Weak interactions or smaller**

Differential rate for WIMP elastic scattering

$$\frac{dR}{dE_R} = N_T \frac{\rho_0}{m_W} \int_{v_{\min}}^{v_{\max}} d\vec{v} f(\vec{v}) v \frac{d\sigma}{dE_R}$$

$$v_{\min} = \sqrt{\frac{m_N E_{th}}{2m_r^2}}, v_{\max} = v_{esc}$$

$$f(v)dv = 4\pi \left(\frac{3}{2\pi \bar{v}^2}\right)^{3/2} v^2 \exp\left(-\frac{3v^2}{2\bar{v}^2}\right) dv, \bar{v} \approx 270\, km/s$$

$$E_R = \frac{m_r^2 v^2 (1-\cos\vartheta)}{m_N}$$

$$\frac{d\sigma}{dE_R} = \frac{\sigma_0}{E_R^{\max}} F^2(E_R), \ \sigma_0 = \frac{1+m_W/m_p}{1+m_W/m_N} A^2 \sigma_{scalar}^{nucleon}$$

Direct detection: Interaction rates

Depend on several parameters

- Astrophysical hypothesis: model of DM in Galaxy (SMMG)

  ρ_{DM}, $f(v)$

- Nuclear form factors F^2 important for heavy nuclei
- Detector response Quenching factors, resolutions, thresholds,....
- Particle physics <u>Nature of WIMP and cross-sections</u>

σ_χ

Coherent

Spin Independent (SI)

eg, Dirac ν

Axial

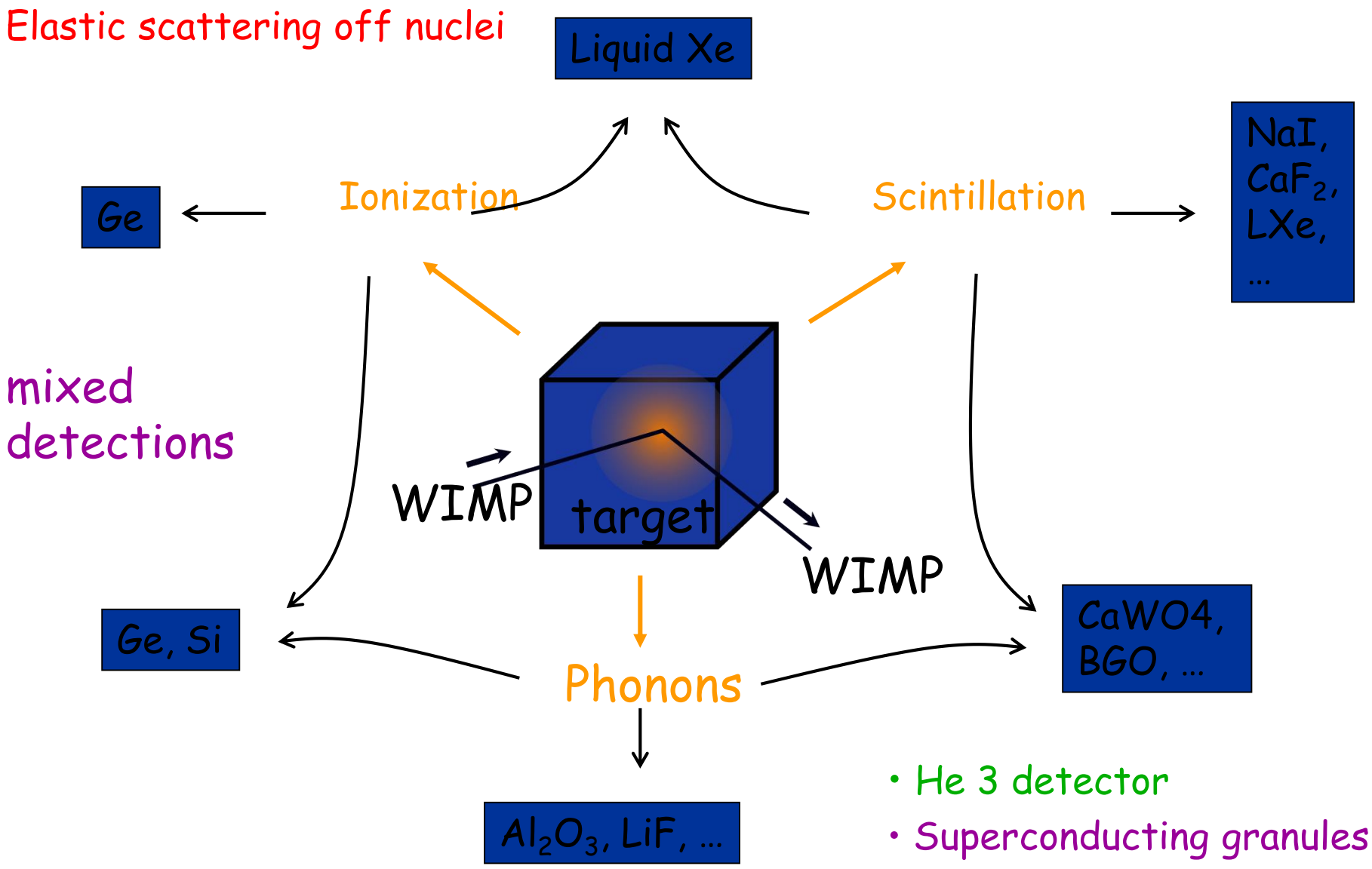
Spin Dependent (SD)

eg, Majorana ν

Neutralinos are a linear combination of higgsinos and gauginos

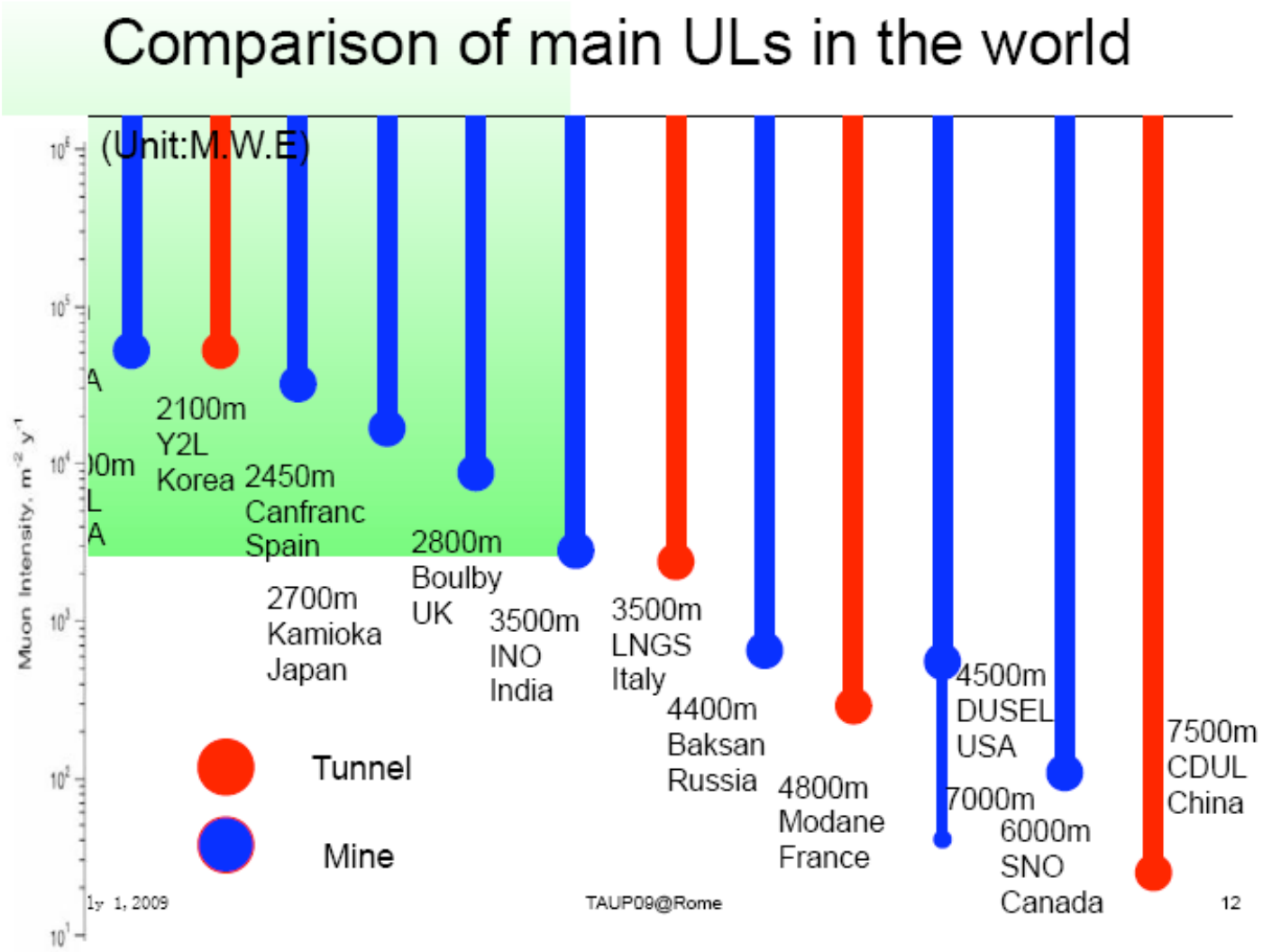
with cross-sections $< 0.1\ \sigma_\nu$

WIMP direct detection with and w/o background rejection



- He 3 detector
- Superconducting granules
- Freon aerogel

Need mountain coverage

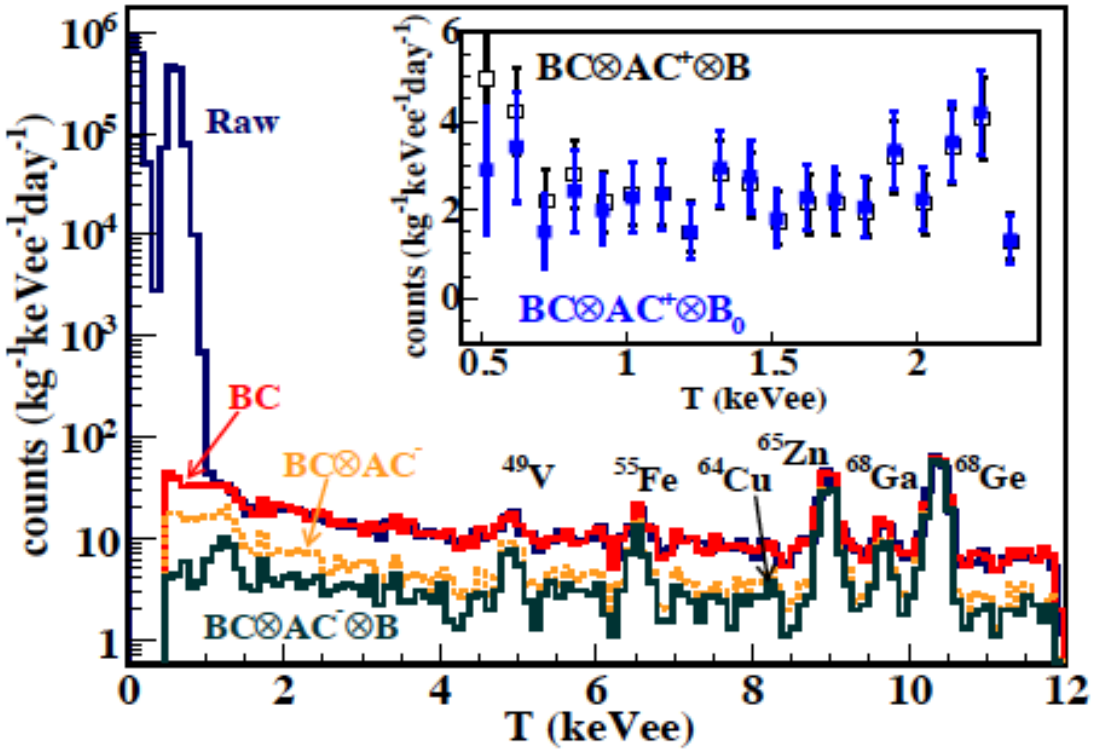


Chinese Underground Laboratory in Jinping CJPL

Road and Tunnel

Yue Qian 岳骞, 2009

CDEX: reaching best present Ge limits in 5 years!



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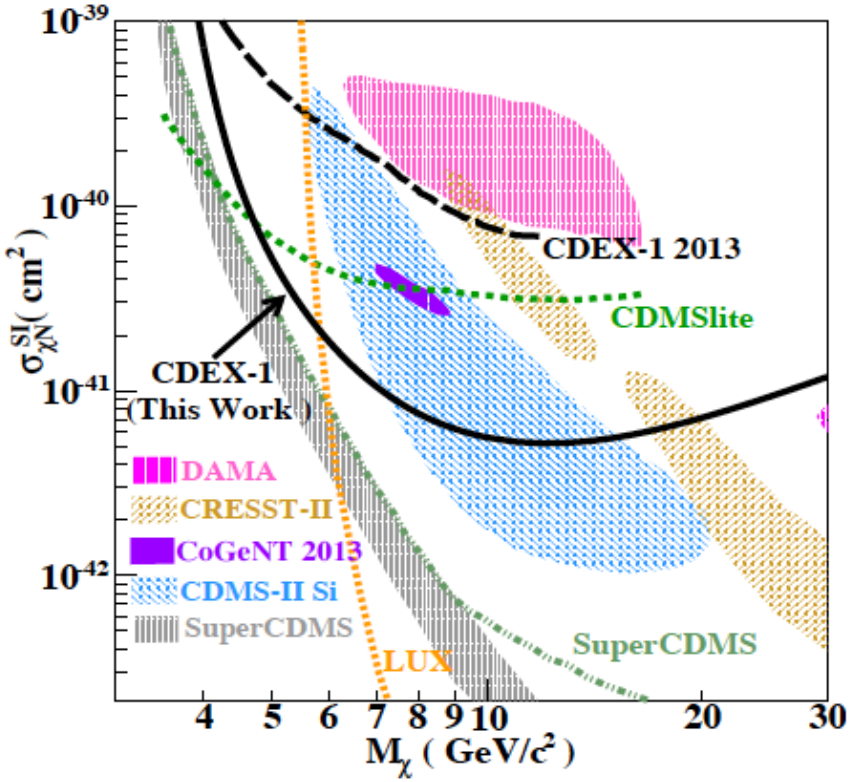

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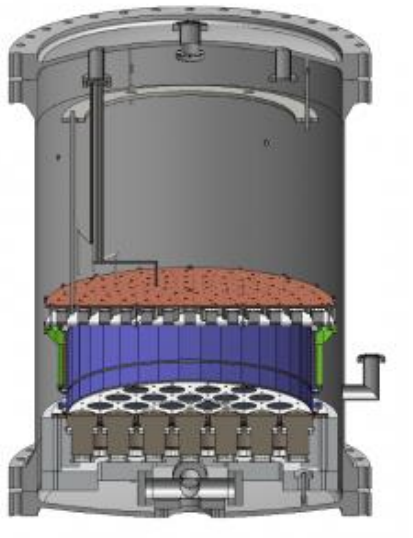
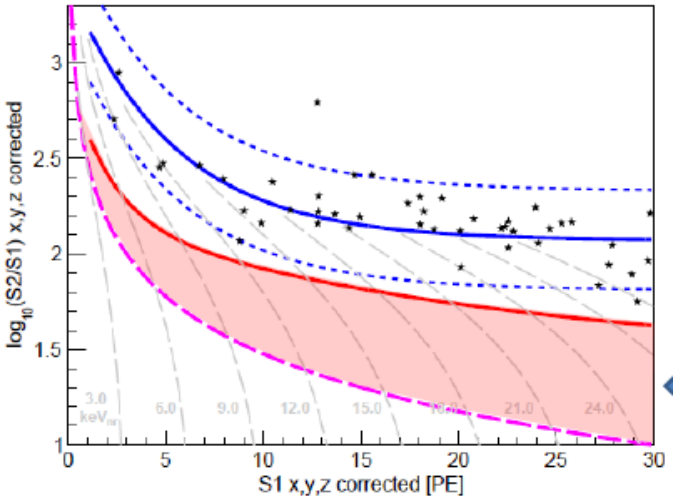
Pandax: inauguration end march 2014 – First results 2016

- Ton scale liquid Xenon two phase (liquid and gas) TPC
- Project lead by SJTU





No events found in the DM search region!

WIMP searches Direct detection : a summary

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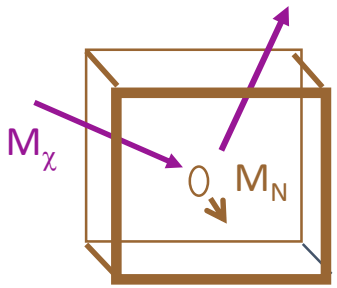

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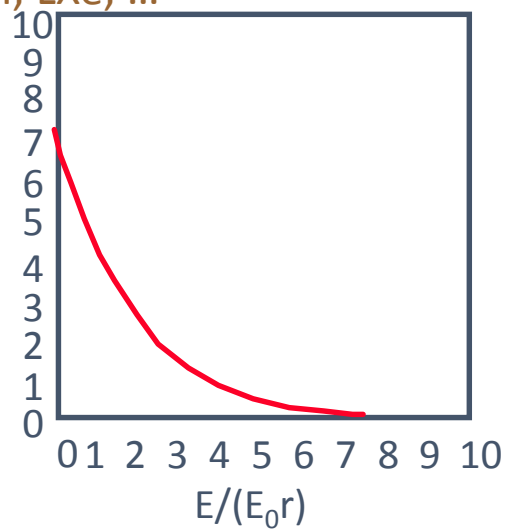
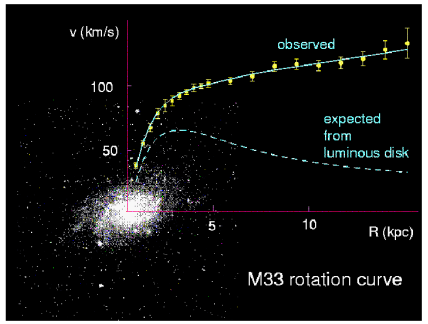


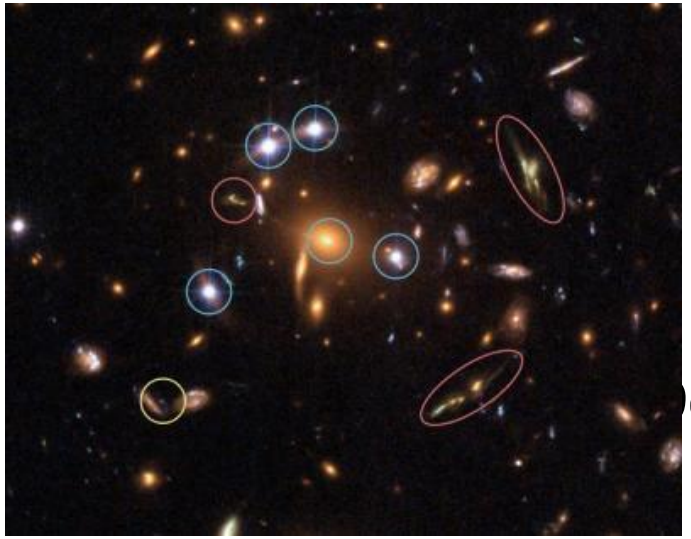
- **Rates: Weak** interactions or smaller

- **Need of signatures** for identifying galactic origin
  - –Annual modulation **with MASSIVE detectors**
  - –Directionality : **low pressure TPC?**
  - –**Dependence on nucleus**

Wealth of Evidence for DM

- Galaxy rotation curves (V. Rubin)
- Dynamics of galaxy clusters (Zwicky)
- Gravitational lensing mass reconstruction





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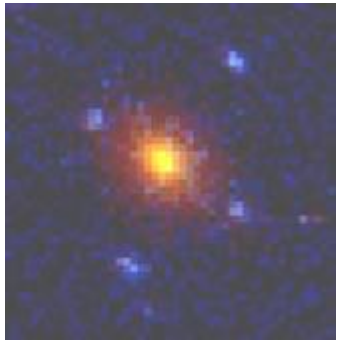
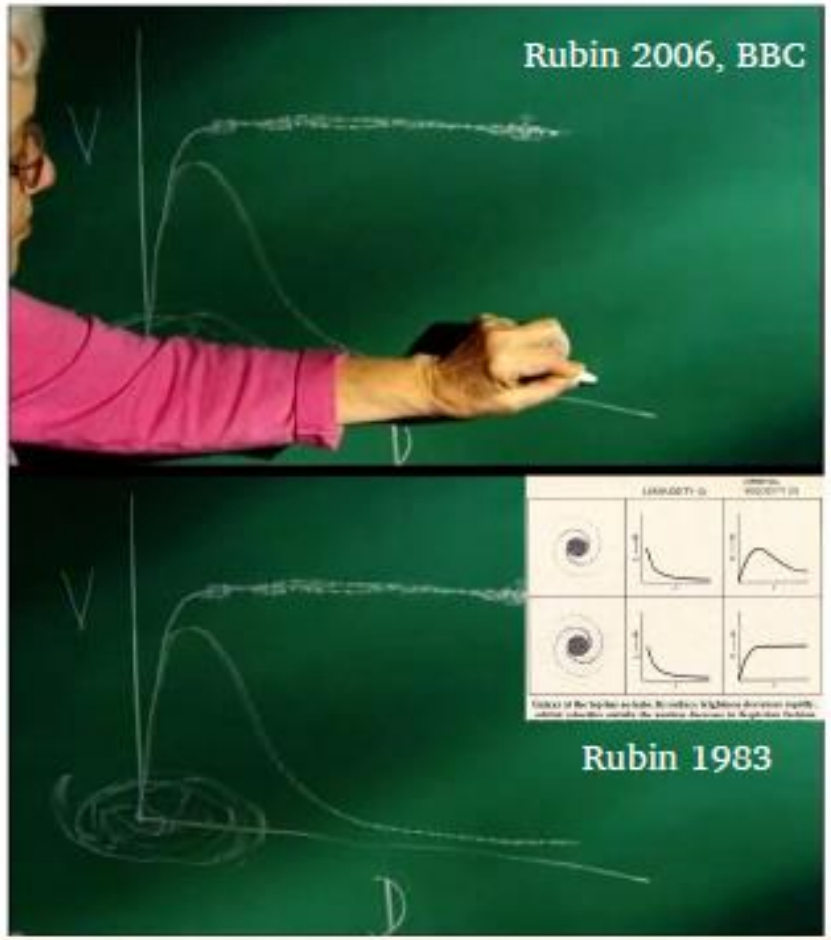


Wealth of evidence for DM

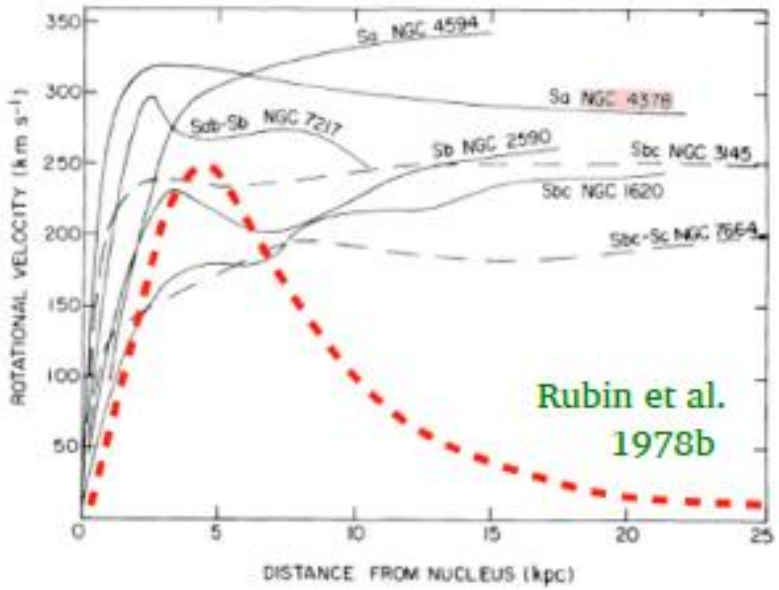
is astrophysical

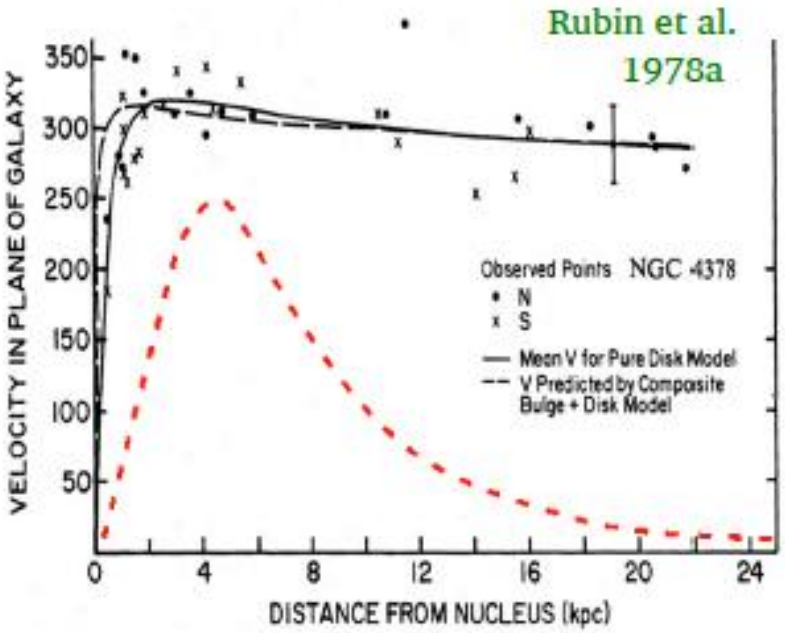
More Complexity!

Rotation curves : what is often said [incorrectly] to be expected



Galaxy at the top has no halo. Its surface brightness decreases rapidly, orbital velocities outside the nucleus decrease in Keplerian fashion.





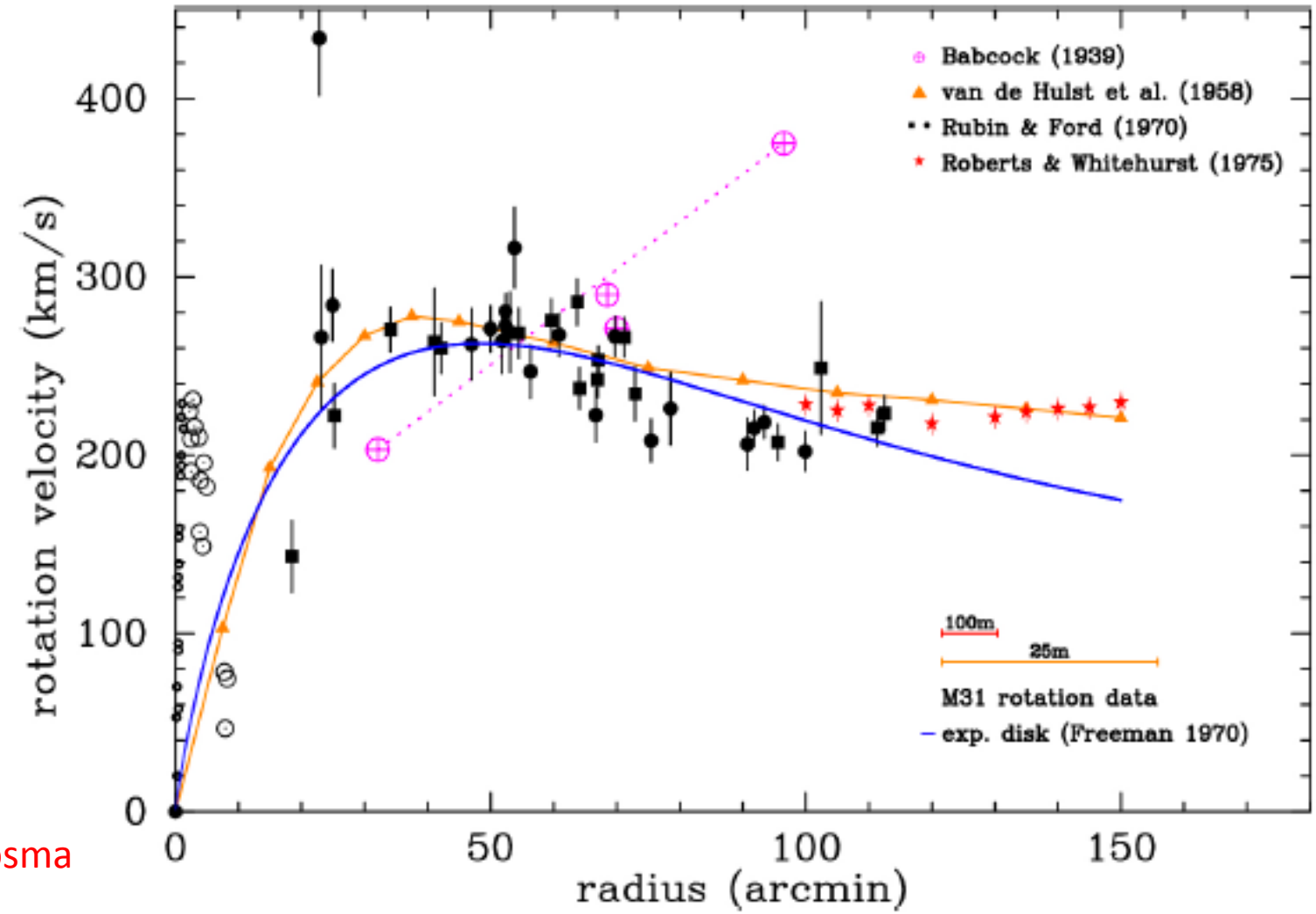
Keplerian behaviour just outside the nucleus can NOT be expected

A. Bosma

Freeman 1970, appendix

For NGC 300 and M33, the 21-cm data give turnover points near the photometric outer edges of these systems. These data have relatively low spatial resolution; if they are correct, then there must be in these galaxies additional matter which is undetected, either optically or at 21 cm. Its mass must be at least as large as the mass of the detected galaxy, and its distribution must be quite different.

M31 – Need for dark matter based on radio data



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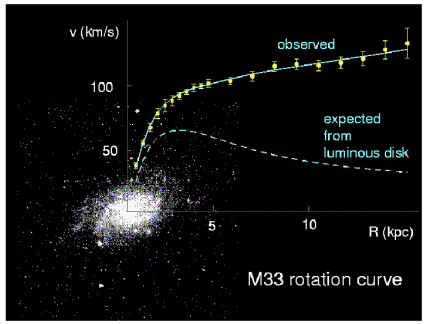
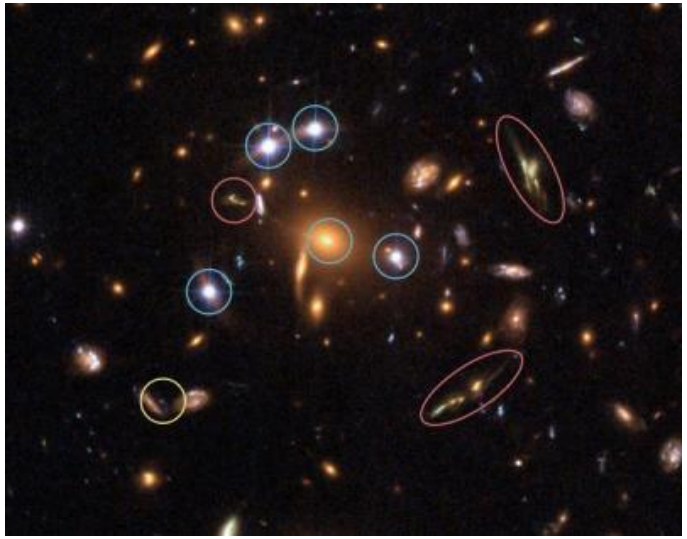
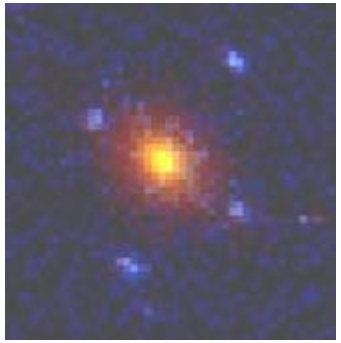






- Bullet cluster (Clowe+,2006)

N-Body simulations: CDM

- Preferred paradigm: CDM

- Most N-Body simulations use stable CDM halos as seed for structures:
- structures evolve, merge and cluster

- Properties of CDM halos
  - cuspy density profiles,
  - Triaxial halos
  - - central density depends on the mass of the halo.

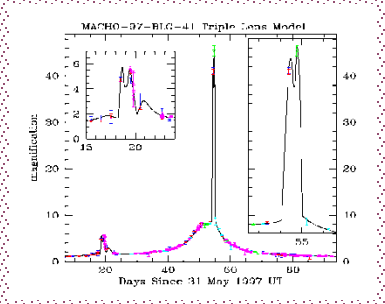
Very different DM candidates

Modified Gravity

dust

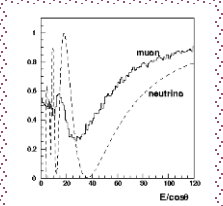
Cold Molecular Hydrogen

MACHOs



Black holes

SIMPs

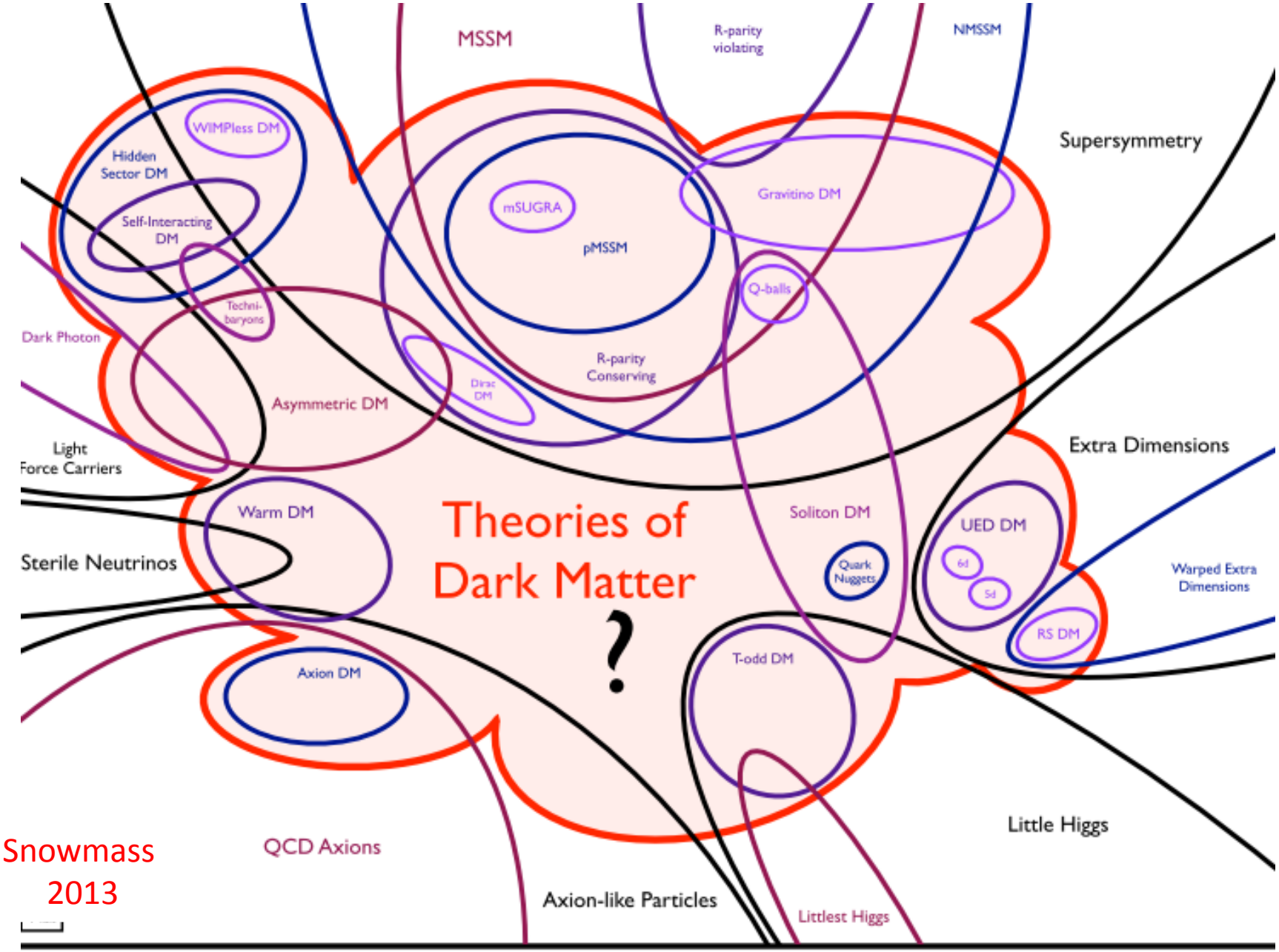


1Neutrino

2. WIMPs
Weakly interacting massive particles
10-1000GeV

3. Light axions

Exotica



Snowmass 2013

Why WIMPs?

"WIMP" = "Weakly Interacting" Massive Particles

- **Arguments in the 1980's:**

- Need for Cold Dark Matter from Large Scale Structures
- Very good Particle physics candidate: SUSY LSP
- Weak neutrino size cross sections expected which our detectors Ge, NaI were sensitive to…

Particle physics preferred DM: SUSY Neutralinos ?

- A natural particle physics solution
- Stable linear combination gauginos and higgsinos (LSP)
- SUSY > 7 parameters MSSM ➔ no predictive power
- Experimental Constraints LEP, pp, b-->sγ, + **LHC** ...

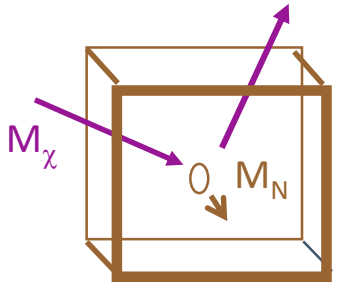
Look everywhere possible !

Direct and Indirect

Detections

WIMP searches

Direct detection



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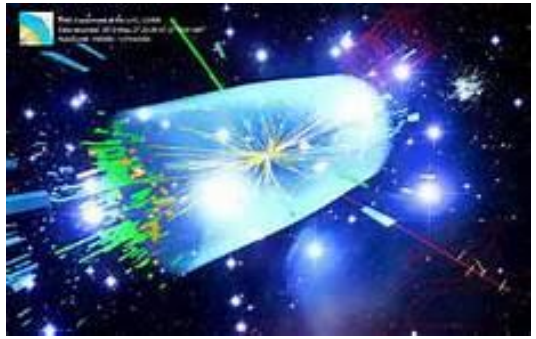
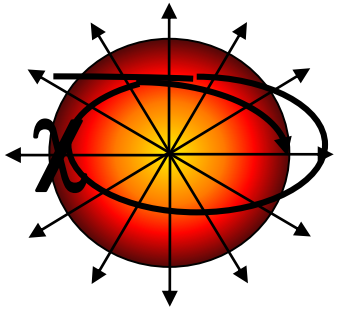


Accelerator particle production,
eg, LHC

Indirect detection



ν, γ, p, e^+

+ Galactic, cluster, Universe scales…