Dark Matter

the search for

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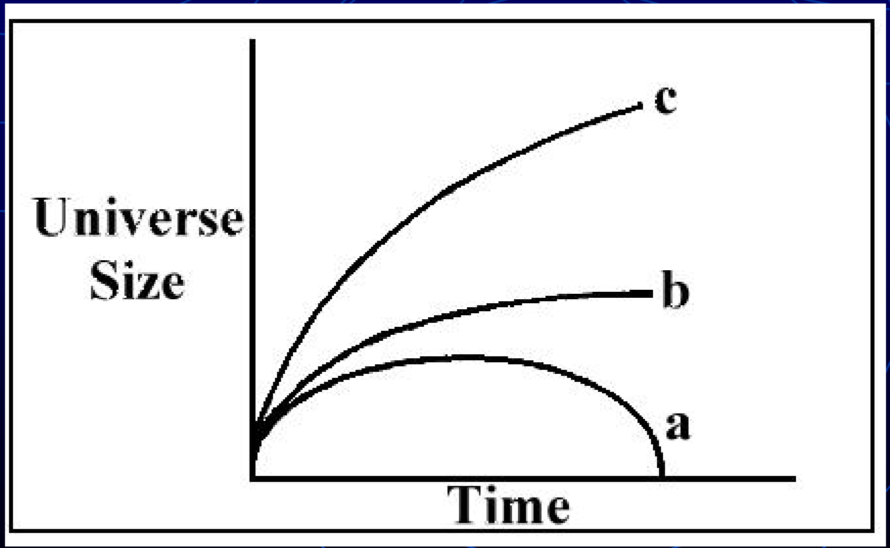
Outline

- Mass Distribution of the Universe
- History of Dark Matter
- Dark Matter Candidates
  - non-luminous baryonic matter
  - neutrinos
  - axions
  - WIMPs
- LSP Detection Techniques

Fate of the Universe

- Four Possibilities
  - $\Omega_{vac} = 0$ and $\Omega_{mat} > 1$ ==> Expands Forever (c)
  - $\Omega_{vac} = 0$ and $\Omega_{mat} = 1$ ==> Stable (b)
  - $\Omega_{vac} = 0$ and $\Omega_{mat} < 1$ ==> Big Crunch (a)
  - $\Omega_{vac} \neq 0$ ==> Accelerates Forever



Current Mass Estimates

- Universe $\Omega_{tot} = 1$
  - Dark Energy $\Omega_{vac} = 0.7$
  - Dark Matter $\Omega_{dm} = 0.25$
    - Hot Dark Matter $\Omega_{hdm} = 0.003$
    - Cold Dark Matter $\Omega_{cdm} = 0.25$
  - Baryonic Matter $\Omega_{bm} = 0.05$
    - Luminous Matter $\Omega_{lum} = 0.007$
  - Radiation $\Omega_{rad} = 0.005$

Early History of Dark Matter

- **Zwicky (1933)**
  - **Measured radial velocities of galaxies in Coma cluster. Obtained velocity dispersion $\sigma = 1019 \pm 360$ km/s. Concluded that cluster density was 400 (50) times what the luminous matter indicated.**
- **Smith (1936)**
  - **Did same for Virgo Cluster and came up with equally large mass-to-light ratio.**
- **Babcock (1939)**
  - **Measured radial velocities for stars in the Andromeda galaxy. Concluded galactic mass was 10 times the luminous mass.**

Stellar Velocities

$$\frac{mv^2}{2} = \frac{G_N m M(r)}{r^2}$$

Luminous Matter Indicates

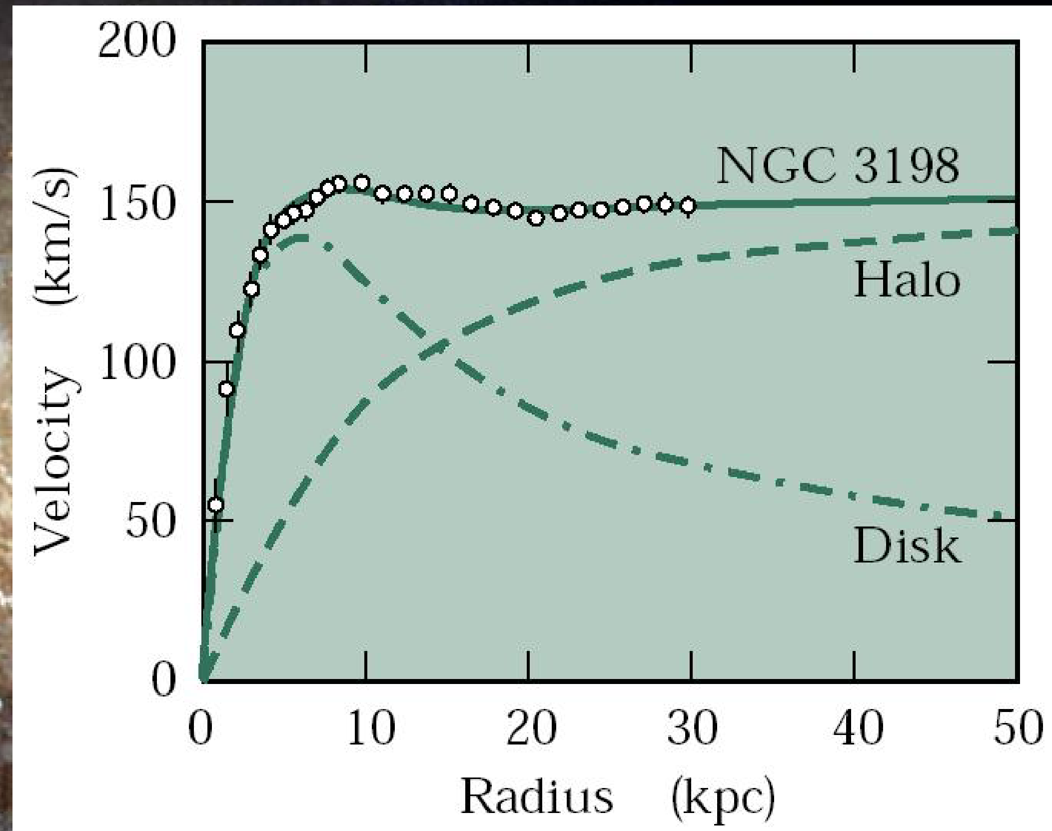
in hub: $v \propto r$

in disk: $v \propto \sqrt{r}$

In Reality

in hub: $v \propto r$

in disk: $v = const$



1

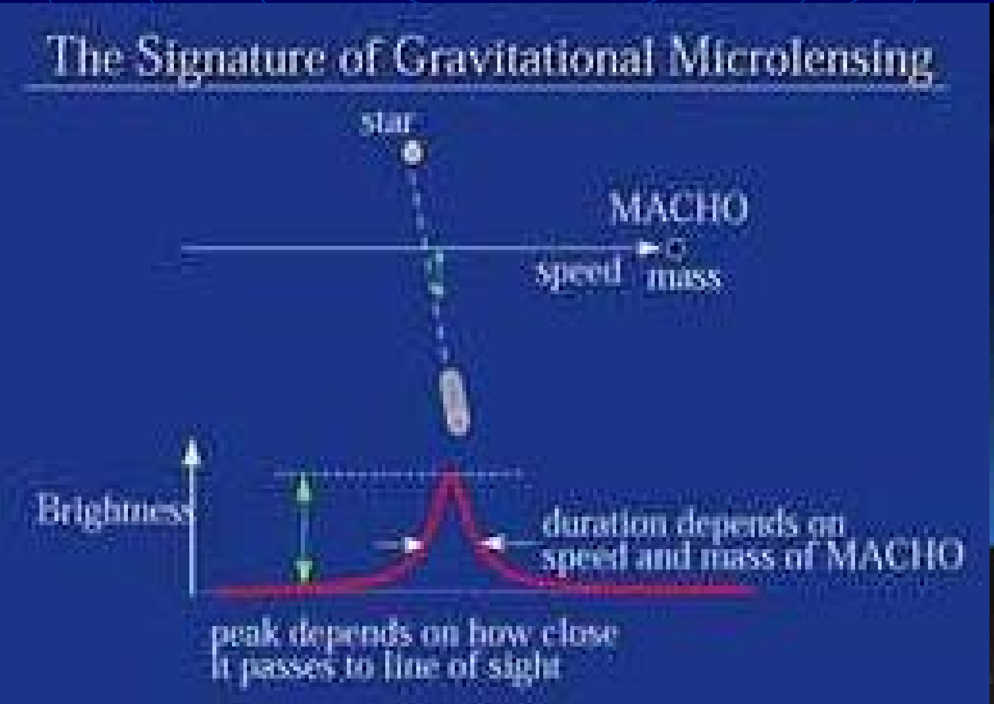
luminous matter

dark matter halo

up to 10

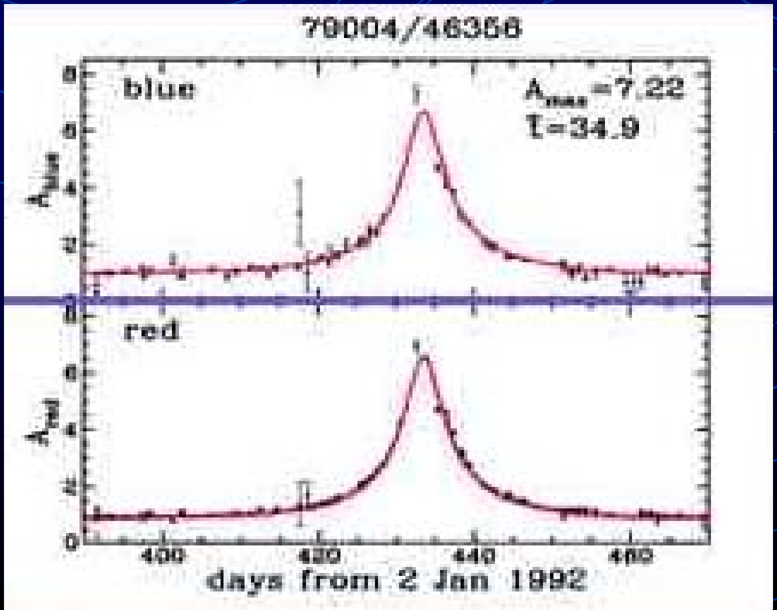
Non-Luminous Baryonic Matter

- Massive (Astronomical) Compact Halo Objects (MACHOs) and gas
- Theoretically possible that baryonic dark matter contributes 100% to missing mass.
- Identified by gravitational lensing effects



MACHO Events

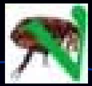
- Since 1992, approximately 20 billion stars in the Large Magellanic Cloud have been monitored for MACHO transits.
- By June 2000, there were only 17 events.
- The upper limit on MACHO contribution to the missing mass is 20%.



First Event:

Day 440

after 01/01/92

 Hot Dark Matter 

- Neutrino density roughly 10^9 times that baryonic matter
- Mass of a few eV would account for all missing mass
- Being relativistic, they would tend to “iron out” any cosmic-scale structure that formed in the universe.
- The current existence of such structure indicates that neutrinos can make up but a small portion of the dark matter, 1/100.

Cold DM Candidate 1 - Axions

- Solve strong CP problem in QCD
- $M_a = f\ \mu eV/c^2$ f = frequency of 1-100 Hz
- The *lower* limit of 1 $\mu eV/c^2$ would provide enough mass to close the universe.
- Decay to two photons. $\tau_a \propto M_a^{-5}$
- Lifetime between 10^{38} and 10^{53} seconds.
- May decay to one microwave photon if inside a magnetized microwave cavity.
- Two current experiments: CARRACK @ Kyoto University and another at Lawrence Liverpool National Laboratory

Cold DM Candidate 2 - WIMPs

- Weakly Interacting Massive Particles
- Of 100s of possible WIMPs, most favoured is the lightest supersymmetric particle (LSP) from the supersymmetric standard model theory (SUSY)
- LSP, the Neutralino ($\Xi^0{}_1$), is a superposition of the photino and zino mixed with neutral Higgsinos.
- Only two interactions with baryonic matter: nuclear scattering and particle-antiparticle pair annihilation/creation.

WIMP Characteristics

- Expected mass $M_\delta > 100$ GeV
- Expected speed $\beta = 10^{-3}$
- Kinetic energy ~100 keV
- Non-relativistic recoil energy:

$$E_R = \frac{4M_\delta M_R}{M_\delta + M_R} E_\delta \cos^2\theta$$

- If $M_\delta \sim M_R$, then $E_R \sim E_\delta \sim 100$ keV, otherwise the recoil energy will be far less and very difficult to detect.
- Scattering rate: 0.1 to 0.0001 $kg^{-1}\ day^{-1}$

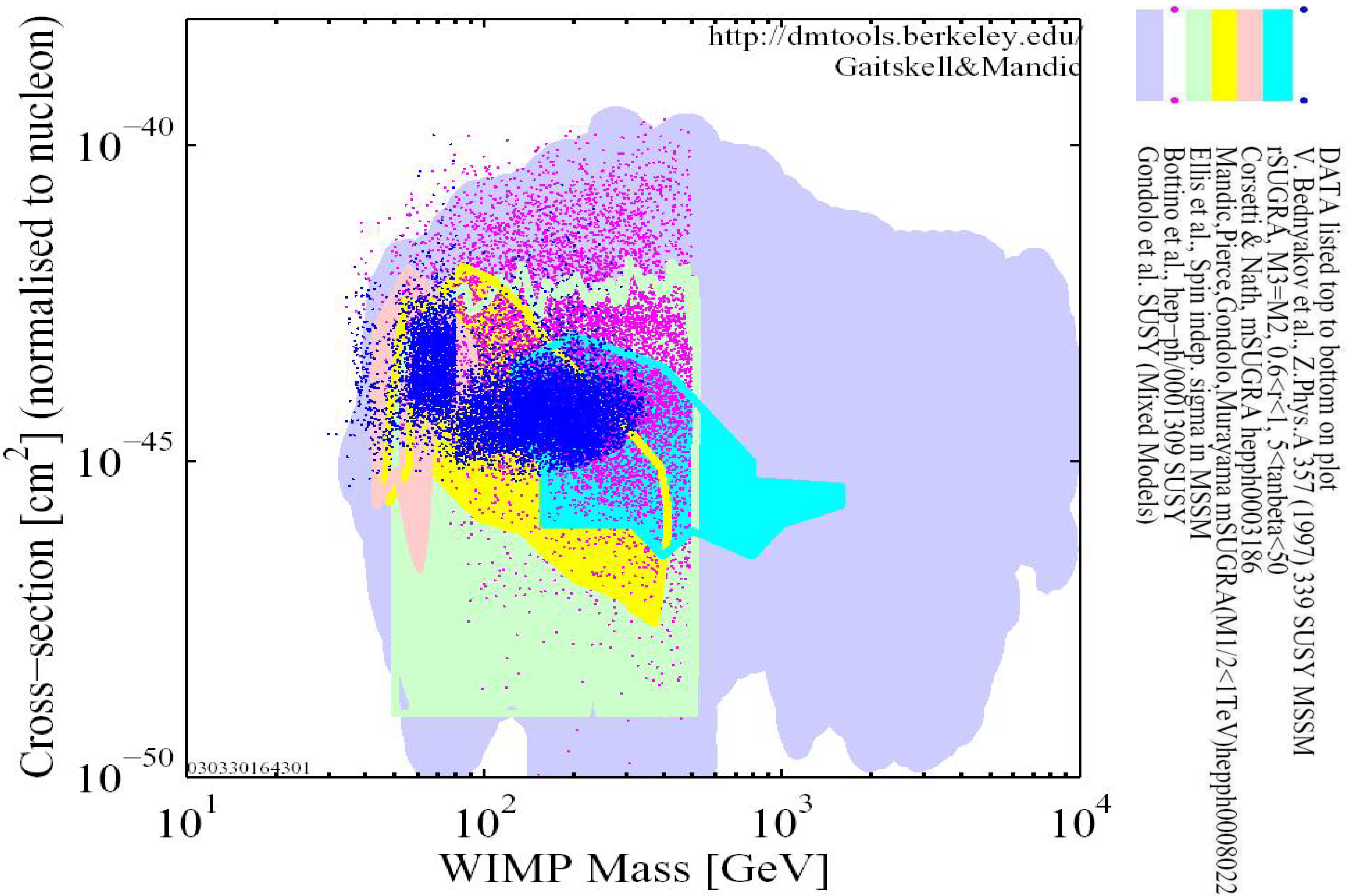
Rate of Nuclear Recoil Events

$$\frac{dR}{dQ} = 2N_T \frac{n_0\sigma_0}{m_w r} F^2(Q) \int_{v_{\min}}^{v_{\max}} \frac{f(v)}{v} dv$$

$$v_{\min} = \sqrt{\frac{2E_R}{m_w r}} \quad , \qquad r = 4\frac{m_w m_n}{(m_w + m_n)^2}$$

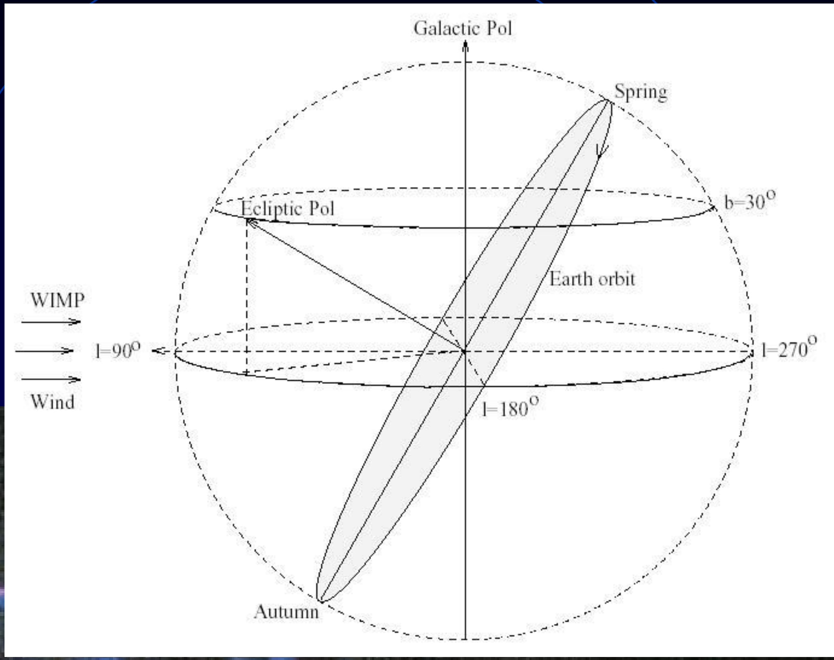
- Unknown values
  - m_w – WIMP mass
  - σ_0 – elastic scattering cross section
- Estimated values:
  - $n_0 = \rho_0 / m_w$ – ρ_0 estimated at 0.3 GeV/cm^3
  - f(v) – using a Maxwellian distribution
  - v_{max} – escape velocity about 600 km/s

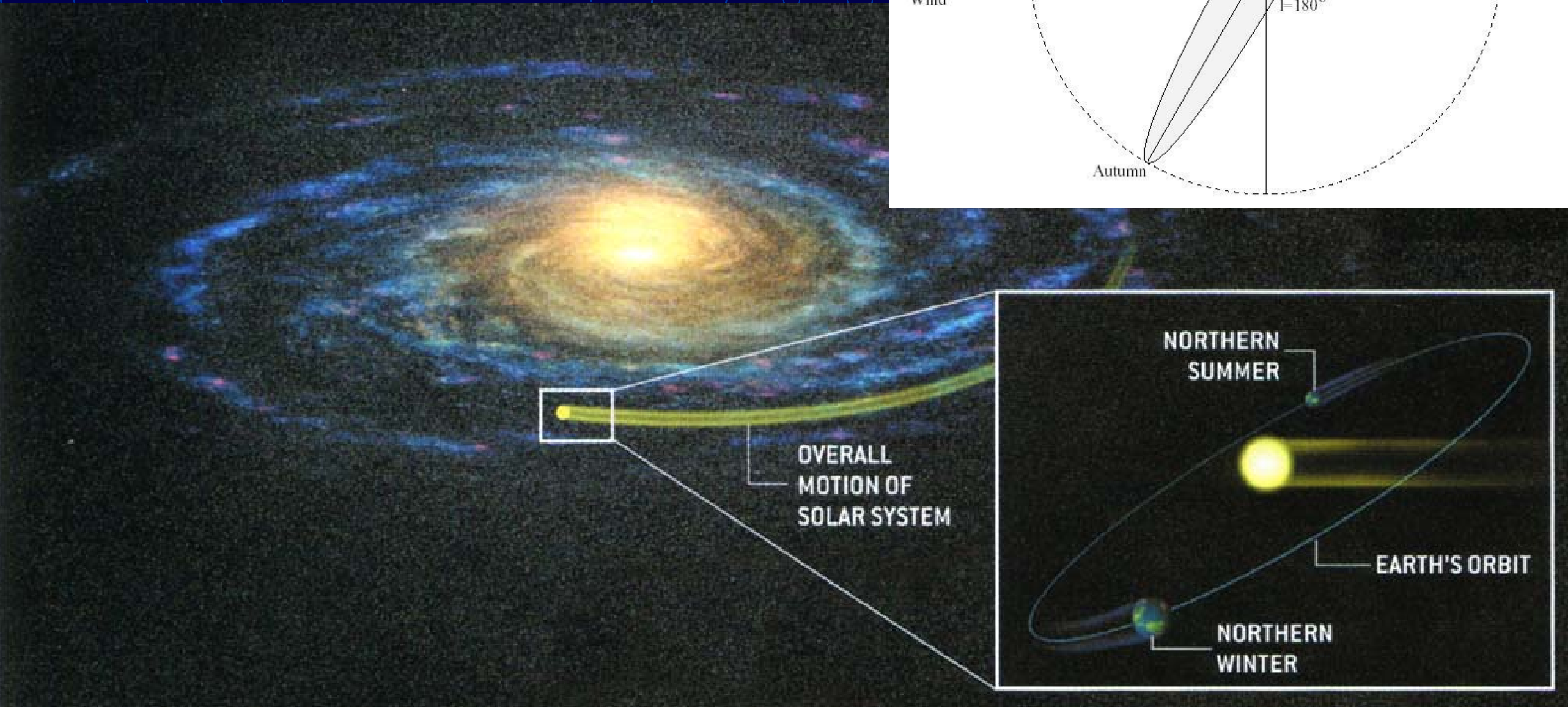
Theoretical WIMP Regions



Annual Rate Modulation

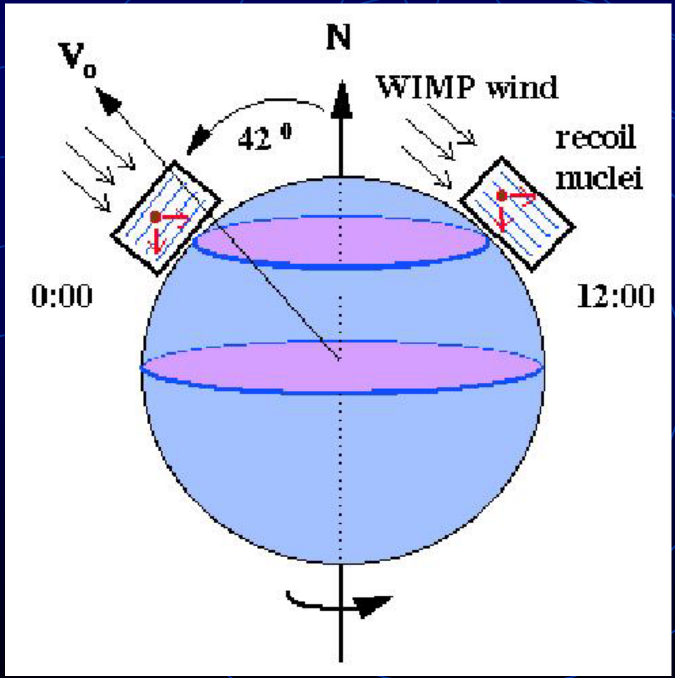
- 220 km/s solar orbit
- 30 km/s earth orbit
- range: 205 to 235 km/s





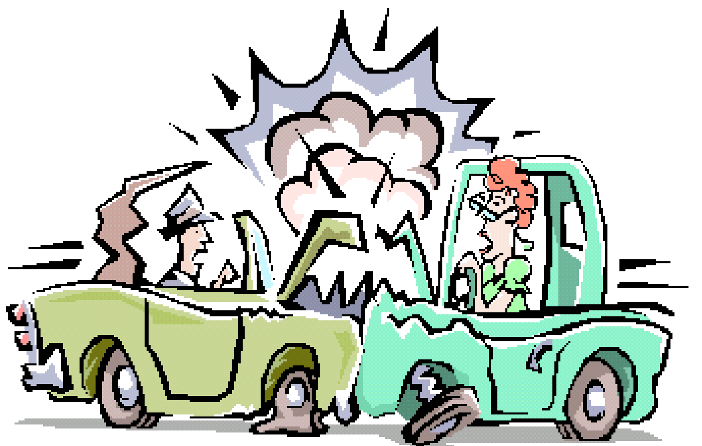
Sidereal Day Rate Modulation

- Direction of nuclear recoils should change on a daily basis
- DRIFT only current experiment capable of exploiting this signature.

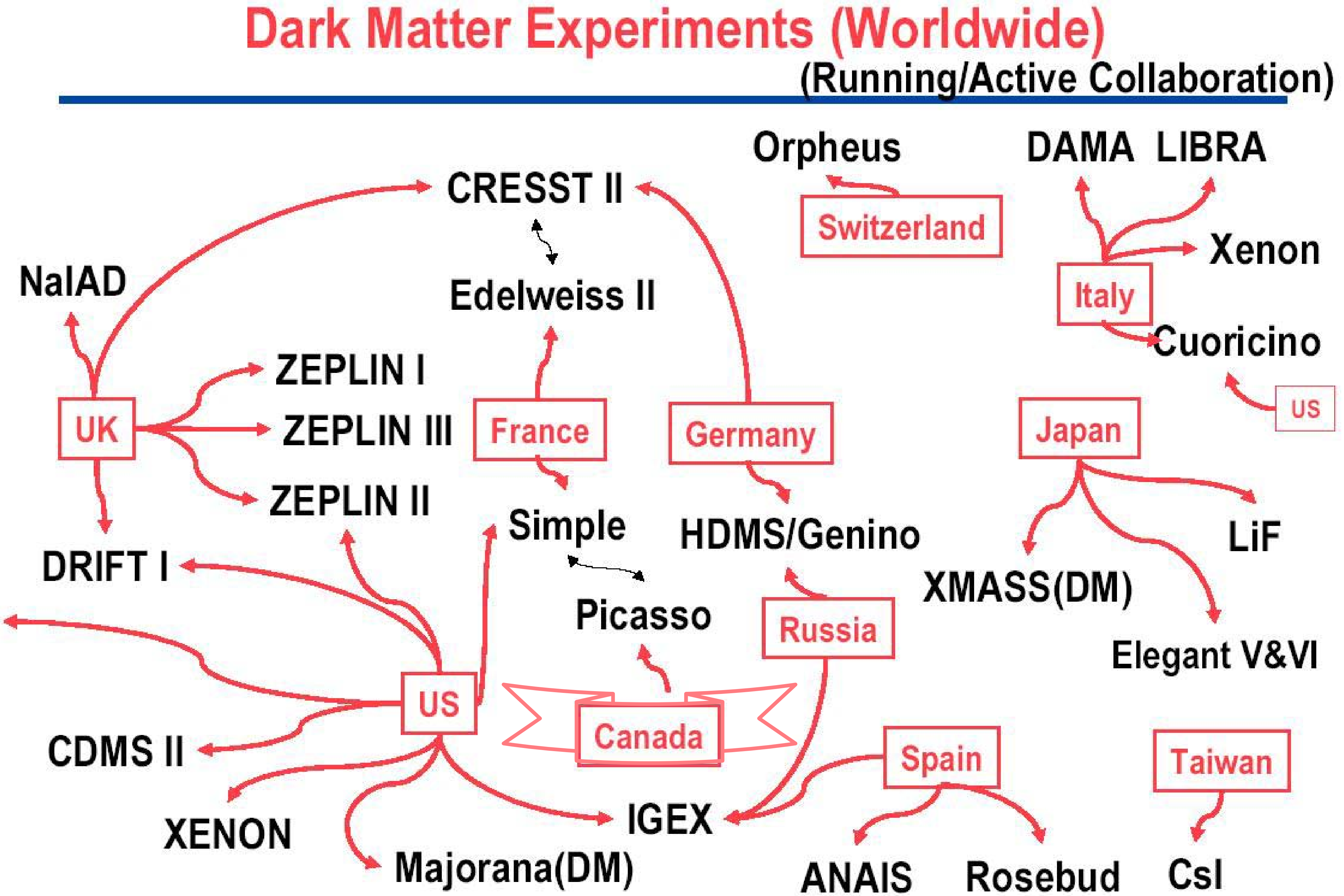


WIMP Detection Methods
Method 1: Particle Accelerators

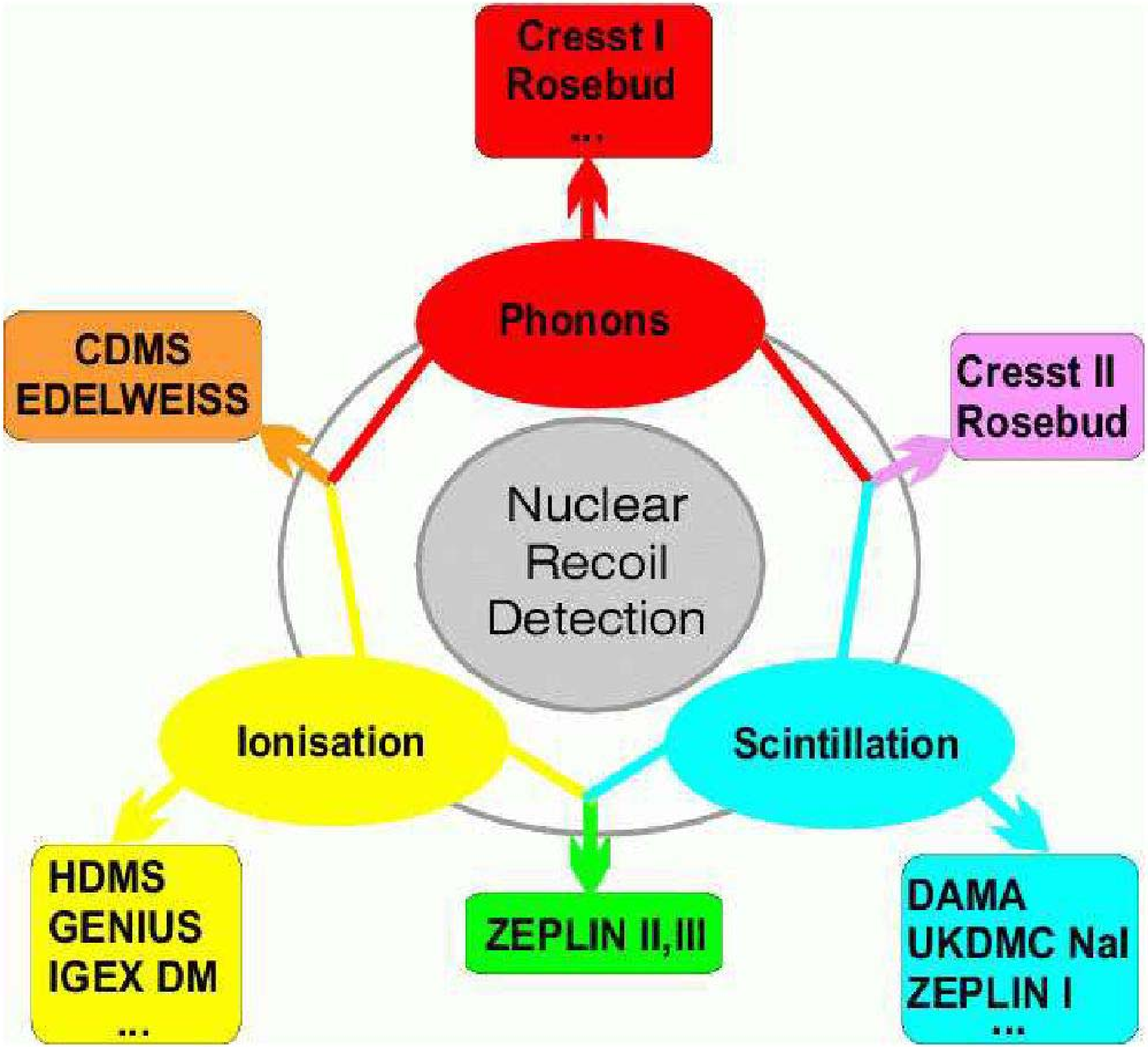
- Once the LHC is up and running, it will be able to probe the lower range of supersymmetric space.
- A non-standard model Higgs particle would be excellent evidence of supersymmetry.
- Should be able to produce neutralinos if they have mass < 500 GeV.



Method 2: Direct Detection



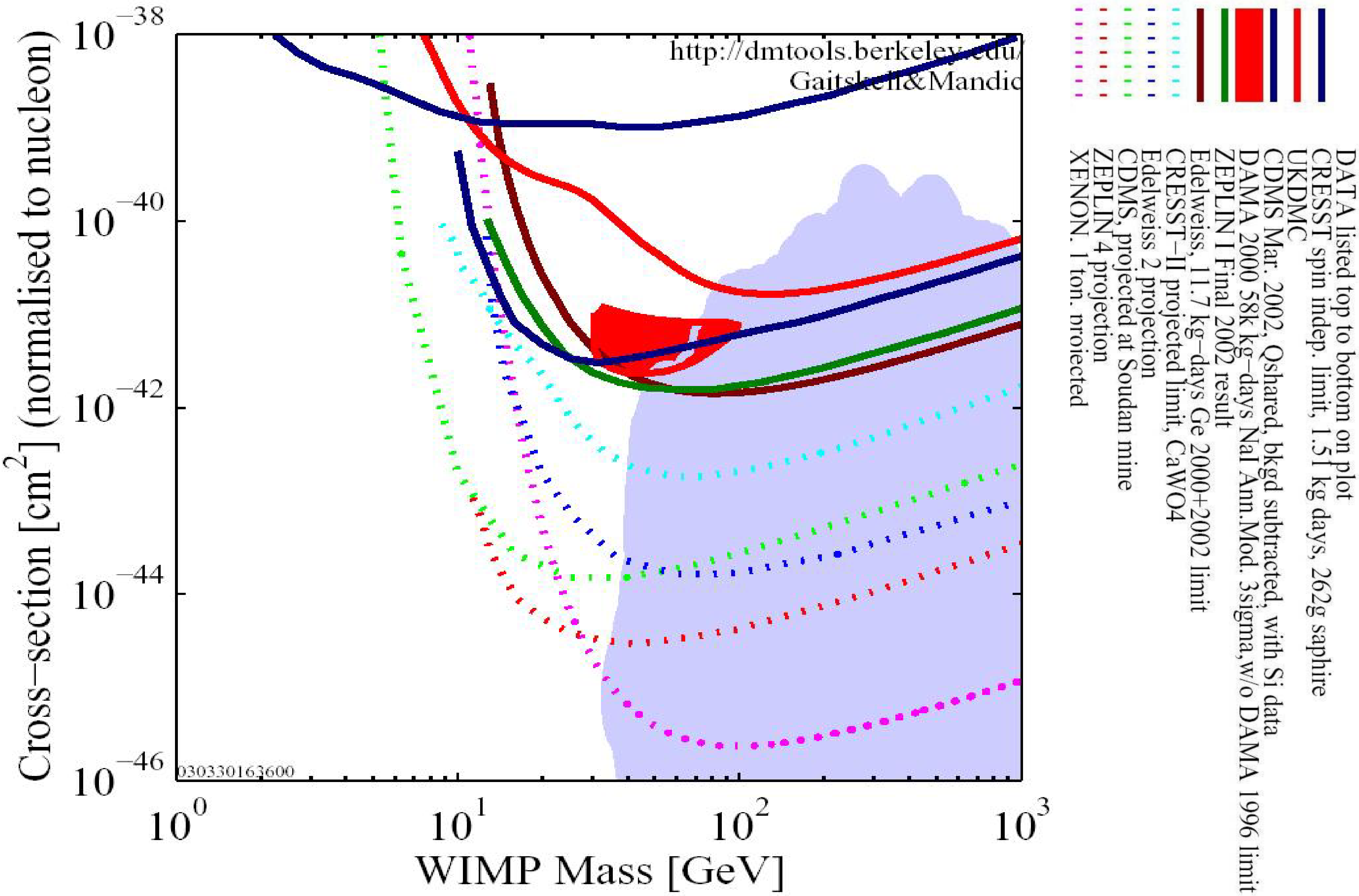
Types of Direct Detection



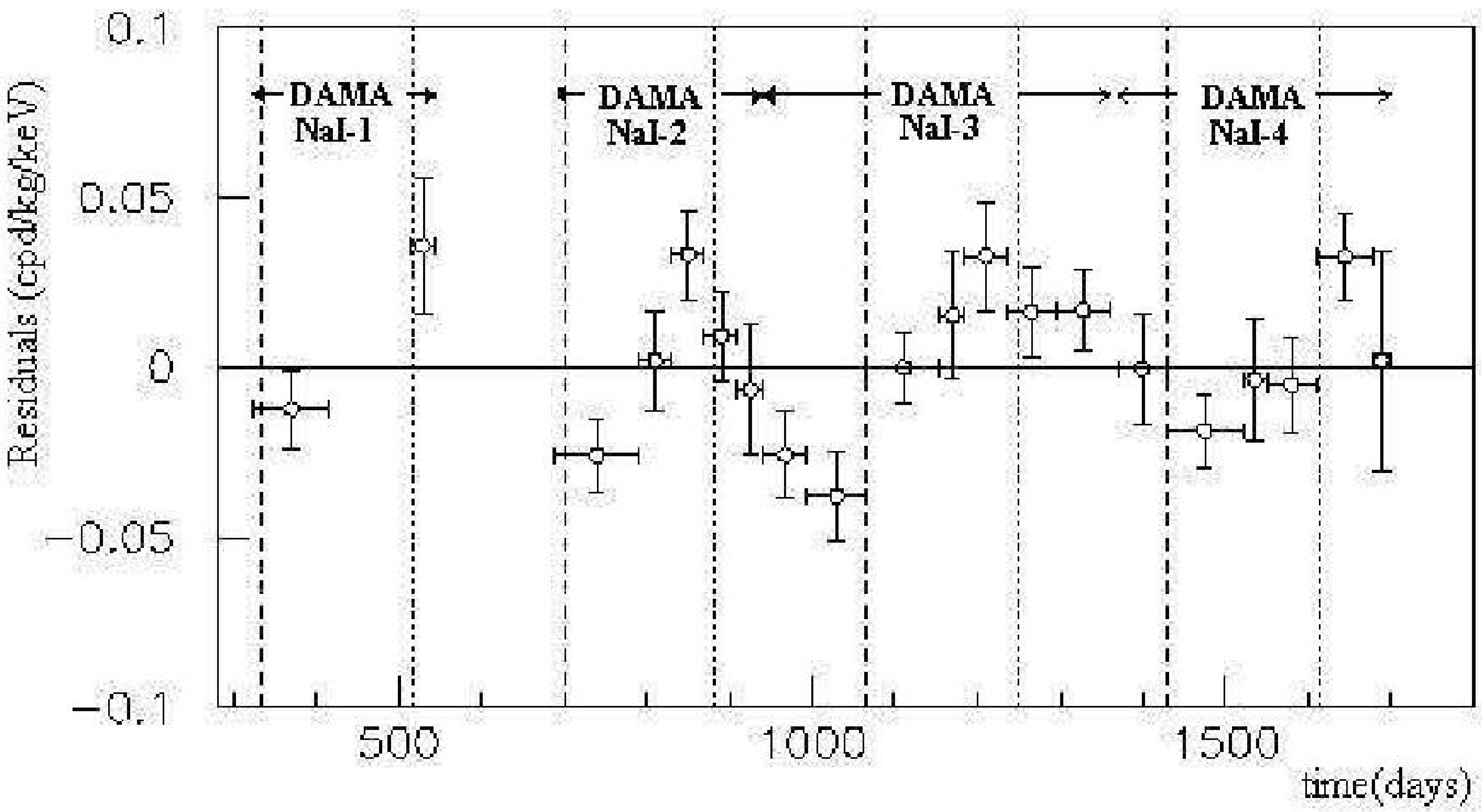
Directional
Discrimination
DRIFT

Liquid Droplets
PICASSO
SIMPLE

Current Experimental Limits



DAMA's Infamous WIMP Signature



Method 3 – Indirect Detection

- WIMPs that take part in nuclear recoil in the sun could lose enough energy to be caught in its gravity well, eventually settling into the core.
- The higher density would increase the self-annihilation rate.
- Neutrinos would be created with roughly ½ the mass of the WIMP, which is much higher than normal solar neutrinos.
- We would be able to infer the existence of WIMPs from the detection of those neutrinos.

Resources

- arXiv.org/abs/astro-ph/9904251
- arXiv.org/abs/astro-ph/0211500
- dendera.berkeley.edu/plotter/
- www.slac.stanford.edu/pubs/beamline/27/3/27-3-rosenberg.pdf
- web.mit.edu/~redingtn/www/netadv/specr/012/012.html
- phya.snu.ac.kr/~jekim/JAP55006.pdf
- exobio.ucsd.edu/Astronomy/ ultimate_fate.htm
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