Dark Matter and its Detection

Lectures at
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Lecture-1: Introduction & Overview
Organization of the lectures

Lecture 1: Introduction and broad Overview

Lecture 2/Tutorial: Decoupling and thermal freeze out; calculation of the cosmological relic abundance of weakly interacting massive particles (WIMPs) from the early Universe

Lecture 3: Basic phenomenology of direct detection of WIMP candidates of Dark Matter
Some (astronomical) Units

1 parsec (pc) \approx 3.2 \text{ lightyear (ly)} \approx 3.1 \times 10^{18} \text{ cm}

1 M_{\odot} \approx 2 \times 10^{33} \text{ gm} \quad 1 M_{\odot}/\text{pc}^3 \approx 37 \text{ GeV/cm}^3

1 \text{ km/s} \approx 10^{-6} \text{ pc/yr}

Hubble constant : \( H_0 = 100 \text{ km s}^{-1} \text{ Mpc}^{-1} \quad (h \approx 0.7) \)

\( H_0 \approx 1.5 \times 10^{-42} \text{ GeV} ; \quad H_0^{-1} \approx 14 \text{ Gyr} \)

age of the Universe (\( t_0 \)) \approx 13.6 \text{ Gyr}

radius of the visible Universe (\( ct_0 \)) \approx 4200 \text{ Mpc}
Parsec:
Edwin Hubble and the Expanding Universe

\[ z = \frac{\lambda_{\text{observed}} - \lambda_{\text{emitted}}}{\lambda_{\text{emitted}}} \]

\[ 1 + z = \frac{a_{\text{now}}}{a_{\text{then}}} \]

\[ d = \frac{v}{H_0} \approx \frac{cz}{H_0} \]
Basic Equations of Cosmology

\[ ds^2 = dt^2 - a(t)^2 \left( \frac{dr^2}{1 - kr^2} + r^2 d\theta^2 + r^2 \sin^2 \theta \, d\phi^2 \right) \]

\[ \frac{\ddot{a}}{a^2} + \frac{k}{a^2} - \frac{\Lambda}{3} = \frac{8\pi G}{3} \rho \]

\[ 2\frac{\dot{a}}{a} + \frac{\ddot{a}}{a^2} + \frac{k}{a^2} - \Lambda = -8\pi G \rho \]

\[ H^2 = \frac{8\pi G}{3} \rho - \frac{k c^2}{R^2} + \frac{\Lambda}{3} \]

- \( H = \text{Hubble's constant} \)
- \( c = \text{speed of light} \)
- \( G = \text{gravitational constant} \)
- \( \rho = \text{matter density of the Universe} \)
- \( k = \text{curvature of the Universe} \)
- \( \Lambda = \text{cosmological constant} \)
- \( R = \text{radius of the Universe} \)

\[ \Omega = \frac{\rho}{\rho_c} = \frac{8\pi G \rho}{3 H^2} \]

\[ \Omega_M + \Omega_\Lambda + \Omega_k = 1 \]
Hot Big Bang Scenario

• The Universe was hotter and denser in the past. Evidence: The Cosmic Microwave Background Radiation (CMBR).

• At very early times, matter content of the Universe was in the form of “fundamental” particles: quarks, & leptons. There were no protons, neutrons, nuclei, and atoms. Those gradually appeared as the Universe expanded and cooled.

• Formation of galaxies and other structures, and anisotropies in CMBR, require the presence of some kind of very weakly interacting matter – Dark Matter.
History of the Universe

Key:
- \( w, z \) bosons
- photon
- \( q \) quark
- \( g \) gluon
- electron
- \( m \) muon
- \( t, \tau \) tau
- neutrino
- meson
- \( b \) baryon
- star
- galaxy
- ion
- atom
- black hole

Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

- CERN-LHC
- FNAL-Tevatron
- BNL-RHIC
- CERN-LEP
- SLAC-SLC

Inflation

Big Bang
Evidence for Dark Matter

(Basic qualitative ideas)
The “Visible” Universe

Source: Unknown (Web)
Is what we “see” all that is there in the Universe?

Evidently, No! (If Newton/Einstein-ian dynamics is valid on all length scales of interest)

Mass discrepancy

Total gravitating mass in a system estimated from dynamical considerations (for example, from studying the motions of visible objects in the system)

≠

the total masses of the “visible” matter/objects in the system
To explain the formation of structures in the expanding Universe that we “see”, we need a lot of additional matter that we don't see! **DARK MATTER!**

**What is it?** Is it just normal matter in the form of objects that are too faint to see (e.g., planets, gas, black holes, neutron stars,...) or a completely new kind of fundamental particles?

**Where is it?** Is it only in certain places/objects in the Universe, or is it ubiquitous?

**How much of it?** Uniformly distributed or in clumps?

**How do we, or can we at all, detect it** in some controlled experiments? …. ?
Can't directly `see' Dark Matter

Know its presence only through its gravitational influence on visible matter
To explain the kinematics of vertical motion of the disk stars, Oort needed “invisible mass” of density \( \sim 2 \text{ GeV} / \text{cc} \) at the solar neighborhood.

Modern value \( \sim 0.3 \text{ GeV} / \text{cc} \)

We know now that Oort’s “invisible” mass mostly consisted of objects too faint to “see”. But the idea was correct.
“Discovery” of Dark Matter

Fritz Zwicky (1933)


Fritz Zwicky (1898 - 1974)

Coma Cluster: $\sim 1000$ Galaxies

$$D \sim 100 \text{ Mpc}$$

$$M \sim 10^{14} M_{\odot}$$

**Virial Theorem**

$$\langle v^2 \rangle \sim \frac{1}{2} \frac{GM}{r}$$

Measured $\langle v^2 \rangle^{\frac{1}{2}} \sim 1000 \text{ km s}^{-1} \Rightarrow M \sim 400M_{\text{visible}}$!!

— Radial velocities of galaxies in the Coma cluster are too large for the galaxies to be bound in the cluster with the known "visible" mass of the cluster.

Note: Zwicky used (wrong!) $H_0 = 558 \text{ km s}^{-1} \text{ Mpc}^{-1}$ (as measured by Hubble!). Correct result

$$M_{\text{Coma cluster}} \sim 50M_{\text{visible}}$$

SERC School-EHEP, NISER

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Rotation Curves of Galaxies

Rotation of a galaxy is given by the Newtonian equation of motion:

\[ F = \frac{mv^2}{r} = \frac{GmM(r)}{r^2} \]

\[ \Rightarrow v = \sqrt{\frac{GM(r)}{r}} \]

M(r) increases proportionally to r even beyond the visible edge of the galaxy!

– hints to presence of large amount of invisible mass beyond the visible galaxy.

Vera Rubin (1928 - 2016)
Density fluctuations grow too little too late without non-baryonic Dark Matter
Growth of fluctuations and formation of galaxies/clusters

(Source: Web)
Cosmic Microwave Background

- The most perfect Blackbody ever known and measured
- Temperature fluctuations carry info about the total amount of matter and amount of baryonic matter in the Universe
Other evidences

- (Strong) Gravitational lensing
- Bullet cluster
- . . .
“Bullet cluster”: Collision of clusters of galaxies

Images: NASA
Planck 2015

Parameters of the Universe

\[ H_0 = 70 \text{ Kms}^{-1} \text{ Mpc}^{-1} \]

\[ \rho_c = \frac{3H_0^2}{8\pi G} = 0.92 \times 10^{-29} \text{ g cm}^{-3} \]
\[ = 5.16 \times 10^{-6} \text{ GeV cm}^{-3} \]

\[ \rho_{DM} = 0.268 \rho_c = 2.47 \times 10^{-30} \text{ g cm}^{-3} \]
\[ = 1.39 \times 10^{-6} \text{ GeV cm}^{-3} \]

\[ \rho_B = 0.049 \rho_c = 0.45 \times 10^{-30} \text{ g cm}^{-3} \]
\[ = 0.25 \times 10^{-6} \text{ GeV cm}^{-3} \]

\[ \rho_{DE} = 0.683 \rho_c = 3.52 \times 10^{-6} \text{ GeV cm}^{-3} \]
Dark Matter in the Milky Way ("The Galaxy")

- Rotation curve
- Kinematics of vertical motion of disk stars
- Dynamics of the globular clusters and dwarf spheroidal satellites of the Milky way
- High velocity stars
- ...
(Re)constructing the RC of Milky Way

For a particle in a circular orbit

\[ v_c^2(r) = \frac{GM(r)}{r} = rg(r) \]

* Measure \( v_c(r) \), get total \( M(r) \). Not so simple!

* Stars on the disk have approximately circular orbits. But stars beyond the disk (> 30 kpc) have non-circular orbits. Also, there are not many tracer stars beyond the disk. Use 21cm line emission from atomic H as tracer.

* Also, you only measure the line-of-sight component of the velocity.

* Thus the RC, \( v_c(R) \), is not directly measured. It has to be (re)constructed from l.o.s. velocity data.
Rotation Curve of the Milky Way


Clemens (1985)

Dark Matter in the Galaxy

Mass Models: Dark Matter Halo

\[ \Phi_{\text{total}} = \Phi_{\text{visible}} + \Phi_{\text{DarkMatter}} \]

\[ v_c^2 = (v_c^2)_{\text{vis}} + (v_c^2)_{\text{DM}} \]

\[ v_c^2(R) = R \frac{\partial \phi}{\partial R}(R, 0) = R \frac{\partial}{\partial R} \left[ \phi_{\text{DM}}(R, 0) + \phi_{\text{vis}}(R, 0) \right] \]

PB, S. Chaudhury, S. Kundu (2017)
Dark Matter Density near the Solar System

\[ \rho_{dm} = 0.33^{+0.26}_{-0.075} \text{ GeV cm}^{-3} \]

[volume complete; G12*,R14]

\[ \rho_{dm} = 0.25 \pm 0.09 \text{ GeV cm}^{-3} \]

[SDSS; Z13]

Read at IDM 2014
Candidates for Dark Matter
Can Dark Matter in the Galaxy's Halo be some too-faint-to-see compact objects, such as stellar mass Black Holes, Neutron Stars, Planets (like Jupiter), PBHs?

**MACHOS (Massive Compact Halo Objects)?**

MACHOS can do gravitational microlensing – temporary brightening of stars

Probability of microlensing 1 in million years per star

Observe millions of stars

Only a small fraction of DM as MACHO\textsc{s} allowed (depends on the total halo mass)
Fundamental particle candidates of DM

- Weakly Interacting Massive Particles (WIMPs)
- Axion-like particles (ALPs)
- ...
The WIMP `Miracle'

DM must be non-baryonic, and can have only very weak interaction with SM particles

Clustering on (sub)Galactic scales => 'cold', i.e., massive, and hence non-relativistic

⇒ Weakly Interacting Massive Particles (WIMPs)

In the sufficiently early universe, WIMPs would be in thermal equilibrium due to thermal production by collision of, and annihilation into, SM particles: \( \chi \chi \leftrightarrow f \bar{f} \)

In thermal equilibrium, \( \left( \frac{n}{s} \right)_{eq} \propto \left( \frac{m}{T} \right)^{3/2} e^{-m/T} \)

⇒ If thermal equilibrium prevailed till today, present-day abundance would be negligible! But, ...
The WIMP Miracle ...

Annihilation rate \( \Gamma_{\text{ann}} = n < \sigma v >_{\text{ann}} \propto T^{3+p} \)

since \( n \propto T^3 \), \( < \sigma v >_{\text{ann}} \propto T^p \) \( [p = 0(1) \text{ for } s(p) \text{ wave ann}] \)

But expansion rate \( H \propto T^2 \)

So, at some \( T = T_f \), at which \( \Gamma_{\text{ann}}(T_f) \leq H(T_f) \)

the species “freezes out” or “decouples” and leaves the exponentially falling abundance curve

Present -day abundance:

\( \Omega_{\text{WIMP}} \propto < \sigma v >^{-1} \)

(Details in Tutorial)
WIMP abundance today:

$$\Omega_\chi h^2 \sim 0.1 \left( \frac{3 \times 10^{-26} \text{ cm}^3/\text{sec}}{\langle \sigma v \rangle} \right) + \log \text{ corrections}$$

Typically, $$\sigma \sim \alpha^2 / m_\chi \sim 10^{-8} \text{ GeV}^{-2} \sim 4 \times 10^{-36} \text{ cm}^2$$ (with $$\alpha \sim 10^{-2}$$, $$m_\chi \sim 100 \text{ GeV}$$), and $$\langle v \rangle_f \sim 0.25c$$. Also, $$h \sim 0.7$$.

Thus, if there is a WIMP, it is a natural DM candidate!

WIMP annihilation into SM particles $$\Rightarrow$$ WIMPs must also have some (weak) interaction (albeit small) with nuclei, via crossing symmetry $$\Rightarrow$$ Direct detection of WIMPs may be possible.

Also, WIMPs captured within astrophysical bodies would annihilate $$\Rightarrow$$ annihilation products (e.g., $$\gamma$$-rays, $$\nu$$’s) may be detectable. $$\Rightarrow$$ indirect detection through $$\nu$$’s from the Sun, $$\gamma$$-rays from Galactic Centre, dwarf Spheroidal galaxies, . . .
Direct Detection of WIMPs:

Drukier & Stodolsky (1984); Goodman & Witten (1985); Primack, Seckel, Sadulet (1988)
Direct detection: Order-of-magnitude estimates

Event rate:
For a single detector nucleus, the rate of WIMP scatterings, \( R \sim n_x v \sigma_{xN} \), gives
\[
R \sim 2.7 \times 10^{-24} \text{ yr}^{-1} \left( \frac{\rho_x}{0.3 \text{ GeV cm}^{-3}} \right) \left( \frac{100 \text{ GeV}}{m_x} \right) \left( \frac{v}{300 \text{ km s}^{-1}} \right) \left( \frac{\sigma_{xN}}{10^{-36} \text{ cm}^2} \right)
\]

No. of nuclei of atomic number \( A \) in 1 gm is \( 6 \times 10^{23} / A \). So, total rate
\[
R_{\text{total}} \sim 16 \text{ events kg}^{-1} \text{ yr}^{-1} \left( \frac{100}{A} \right) \left( \frac{\rho_x}{0.3 \text{ GeV cm}^{-3}} \right) \left( \frac{100 \text{ GeV}}{m_x} \right) \left( \frac{v}{300 \text{ km s}^{-1}} \right) \left( \frac{\sigma_{xN}}{10^{-36} \text{ cm}^2} \right)
\]

Recoil Energy:
For a WIMP of mass \( m_x \) and velocity \( v \) striking a nucleus of mass \( M \) at rest, \( \Delta p \sim m_x v \). \( \Rightarrow \) Recoil energy of nucleus,
\[
E_r \sim (\Delta p)^2 / 2M \sim 50 \text{ keV} \left( \frac{m_x}{100 \text{ GeV}} \right)^2 \left( \frac{v}{300 \text{ km s}^{-1}} \right)^2 \left( \frac{100 \text{ GeV}}{M} \right)
\]
Proper calculations:

Recoil energy: \( E = (\mu^2 v^2 / M)(1 - \cos \theta^*) \), where \( \mu \equiv m_\chi M / (m_\chi + M) \) = reduced mass, \( v = \) WIMP speed relative to the nucleus, and \( \theta^* = \) scattering angle in the center of mass frame.

Differential recoil rate per unit detector mass, in units of counts/day/kg/keV:

\[
\frac{dR}{dE} = \frac{\sigma(q)}{2 m_\chi \mu^2} \rho \eta(E, t) \equiv \text{Particle Physics } \otimes \text{ Astrophysics},
\]

with \( q = \sqrt{2ME} = \) nucleus recoil momentum, \( \sigma(q) = \) WIMP-nucleus cross-section,

\[
\eta(E, t) = \int_{v > v_{\text{min}}} f(v, t) \frac{d^3v}{v},
\]

\( v_{\text{min}} = \sqrt{\frac{ME}{2 \mu^2}} = \) minimum WIMP velocity that can result in a recoil energy \( E \).

\( f(v, t) \) is the (time-dependent) velocity distribution of the WIMPs relative to detector at rest on Earth.
Astrophysical issues

Expected number of events in direct detection (DD) or indirect detection (ID) experiments, and thus the interpretation of the results of these experiments, depend upon the density and velocity distribution of the WIMPs in the Galaxy.

\[
\text{No. of events (DD or ID)} \equiv \text{Particle Physics} \otimes \text{Astrophysics} \\
\downarrow \quad \downarrow \\
(m_X, \sigma_{X N}) \otimes (\rho_{DM, \odot}, f(v)) \\
\downarrow \quad \downarrow \\
e.g., \text{LHC} \otimes \text{Galactic Dynamics (e.g., rot. curve)}
\]

- Need to fix Astrophysics to extract particle physics of DM \((m_X, \sigma)\).
- Use the observed rotation curve data of the Galaxy to determine the phase space DF of DM particles, i.e., \(\rho_{DM, \odot}, f(v)\).
- Galactic rotation curve near solar location is significantly influenced by visible matter.
- **Self-consistent approach:** Determine the DF of the DM particles by self-consistently including the effect of known visible matter (VM) such that together (DM+VM) they give a good fit to the observed rotation curve data.
Phase space distribution of collisionless systems

- Assume Dark Matter consists of WIMPs

  ⇒ Phase space DF satisfies collisionless Boltzmann (Vlasov) equation (CBE),

  \[
  \frac{df}{dt} \equiv \frac{\partial f}{\partial t} + \mathbf{v} \cdot \nabla f - \nabla \Phi \cdot \frac{\partial f}{\partial \mathbf{v}} = 0 .
  \]

**Jeans Theorem:** Any steady-state solution of the CBE depends on the phase-space coordinates only through integrals of motion in the galactic potential, and any function of the integrals yields a steady-state solution of the CBE.

Simplest choice: \( f(\mathbf{x}, \mathbf{v}) = f(E) \), with \( E = \Phi + \frac{1}{2} v^2 \).

Isothermal DF:

\[
f(\mathbf{x}, \mathbf{v}) = \frac{\rho_0}{(2\pi\sigma^2)^{\frac{3}{2}}} \exp \left[ -E/\sigma^2 \right] ,
\]

with \( \langle v^2 \rangle = 3\sigma^2 \) and boundary condition \( \Phi(0) = 0 \), so that

\[
\rho(\mathbf{x}) = \int f(\mathbf{x}, \mathbf{v}) d^3 \mathbf{v} = \rho_0 \exp \left[ -\Phi(\mathbf{x})/\sigma^2 \right] , \text{ and } \nabla^2 \Phi = 4\pi \rho_0 \exp \left[ -\Phi(\mathbf{x})/\sigma^2 \right] .
\]
The ‘Standard halo model’

Local WIMP velocity distribution, in the Galactic rest frame, is taken as Maxwellian (isotropic isothermal sphere):

\[
\begin{aligned}
f^G(v) &= N \left[ \exp \left( -\frac{|v|^2}{v_c^2} \right) - \exp \left( -\frac{v_{esc}^2}{v_c^2} \right) \right] & |v| < v_{esc}, \\
f^G(v) &= 0 & |v| > v_{esc},
\end{aligned}
\]

where \( N \) is a normalization factor, \( v_c \approx 220 \text{ km s}^{-1} \) and \( v_{esc} \approx 730 \text{ km s}^{-1} \) are the local circular and escape speeds respectively.

Usual fiducial value for the local WIMP density, \( \rho_\chi = 0.3 \text{ GeV cm}^{-3} \).

For an isothermal gravitating sphere, \( \langle v^2 \rangle^{1/2} = \sqrt{\frac{3}{2}} v_{c,\infty} \).

With \( v_{c,\infty} = v_{c,\odot} = 220 \text{ km s}^{-1} \), one has \( \langle v^2 \rangle^{1/2} = 270 \text{ km s}^{-1} \).

**Standard Halo Model** \( \equiv \) Maxwellian velocity distribution with \( \rho_{DM,\odot} = 0.3 \text{ GeV / cm}^3 \) and \( \langle v^2 \rangle^{1/2}_{DM,\odot} = 270 \text{ km s}^{-1} \).
Cosmological density: $\rho_{DM}^{\cos} \sim 10^{-6}$ GeV/cm$^3$

Need $\rho_{DM,\odot}$, $f(v_{DM})_{\odot}$

Typically, one assumes isothermal dist. : $f(v) \propto \exp(-v^2/\sigma^2)$

For isothermal dist., $\rho_{DM,\odot} \sim (0.2 - 0.4)$ GeV/cm$^3$, $\sigma \sim \sqrt{\frac{3}{2}} v_\infty$. Assuming flat rot curve $v_\infty = v_{rot,\odot} \approx 220$ km s$^{-1}$, one gets $\sigma \approx 270$ km s$^{-1}$. Too simplistic!

Also, isothermal model has infinite mass: Need to truncate it self-consistently, else not a solution of CBE.

DM at solar neighborhood strongly influenced by Galactic processes. Galactic dynamics at solar location dominated by visible matter, not DM. Need to self-consistently include the effects of visible matter to determine $\rho_{DM,\odot}$ and $f(v_{DM})_{\odot}$, i.e.,

$$\nabla^2 \Phi_{DM} = 4\pi \rho_{DM}(0) \exp \left[ - \left\{ \Phi_{DM} + \Phi_{vis} \right\} / \sigma^2 \right]. \text{ with}$$

$$\nabla^2 \Phi_{vis} = 4\pi \rho_{vis}^{obs}.$$
Figure 2: Normalized local speed distribution, $f_\odot(v)$, corresponding to the most-likely set of values of the Galactic model parameters determined from fit to rotation curve data, and its uncertainty band (shaded) corresponding to the 68% C.L. upper and lower ranges of the Galactic model parameters.

(From: PB, S. Chaudhury, S. Kundu, S. Majumdar, PRD (2013))
Impact on WIMP Direct Detection

Recoil spectrum: \[ \frac{dR}{dE_R}(E_R, t) = \frac{\sigma q^2 - 2m_N E_R}{2m_\chi \mu^2} \rho_\chi g(E_R, t), \]

with \( \mu = m_\chi m_N / (m_\chi + m_N) \) = reduced mass, and

\[ g(E_R, t) = \int_{u > u_{\text{min}}(E_R)}^{u_{\text{max}}(t)} \frac{d^3 u}{u} f_\odot (u + v_E(t)) \Theta (u_{\text{max}} - u_{\text{min}}), \]

\( u \) (with \( u = |u| \)) = relative velocity of the WIMP with respect to the detector at rest on Earth 
\( v_E(t) \) = time-dependent velocity of the Earth relative to the Galactic rest frame.
\( u_{\text{min}}(E_R) = \left( m_N E_R / 2 \mu^2 \right)^{1/2} \) = minimum WIMP speed required for producing a recoil energy \( E_R \) of the nucleus,
\( u_{\text{max}}(t) \) = lab frame (time-dependent) maximum WIMP speed corresponding to \( v_{\text{max}} = \sqrt{2\Psi} \) 
(defined in the Galactic rest frame).

Can show that \( g(E_R, t) \) is a monotonically decreasing function of \( E_R \), and thus takes its largest value at \( E_R = E_{\text{th}} \).

The lowest WIMP mass that can be probed by a given experiment:
\[ m_{\chi, \text{min}} = m_N \left[ \left( 2m_N (v_{\text{max}, \odot} + v_E)^2 / E_{\text{th}} \right)^{1/2} - 1 \right]^{-1}. \]
Annual Modulation: DAMA Expt.

Modulation Signal

\[ f(\mathbf{v}, t) = f_{\text{Galaxy}} (\mathbf{v} + \mathbf{v}_{\text{Earth}}(t)) . \]

DAMA + DAMA/LIBRA claimed detection based on a claimed positive modulation signal.

Recently, CoGeNT experiment has also claimed detecting an annual modulation in their data.
Detection Strategies

The energy deposited by WIMP-induced nuclear recoil in the detector medium manifests as light (scintillation), sound (acoustic waves/phonons) and charge (ionization).
Signal and Background

- **Electronic Recoils (gamma, beta)**: Background
- **Nuclear Recoils (neutron, WIMPs)**: Signal
Go Underground to reduce Cosmic Ray Background

Exclusion Curves (spin-independent interaction)

P. Cushman et al, arXiv:1310.8327

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Exclusion Curves: Spin-independent interactions

**FIG. 4.** The spin-independent WIMP-nucleon cross section limits as a function of the WIMP mass at 90% confidence level (black line) for this run of XENON1T. In green and yellow are the $1\sigma$ and $2\sigma$ sensitivity bands. Results from LUX [27] (the red line), PandaX-II [28] (the brown line), and XENON100 [23] (the gray line) are shown for reference.

Xenon1T collab. PRL 119 (2017) 181301

PandaX-II collab. PRL 119 (2017) 181302
Exclusion Curves: Spin-dependent interactions

Aprile et al (XENON100) 2013

Amole et al (PICO) PRL 2015
AMS-02: Positron excess in Galactic CR
FERMI-LAT: Gamma rays from WIMP annihilation in dwarf Spheroidal satellites of Milky Way
Super-K, ICECUBE: Neutrinos from WIMP annihilation in Sun
…
Whither WIMP Direct Detection?

Courtesy: Viktor Zacek (adapted from R. Gaitskell)
Ultimate Background: The Neutrino “Floor”

Cushman et al, arXiv:1310.8327

DM detectors will start detecting astrophysical neutrinos through Coherent Neutrino-Nucleus Elastic Scattering (SM process)!
Detecting SN neutrino with DM detectors using Coherent neutrino-nucleus Elastic Scattering

FIG. 1 (color online). Left: Recoil energy spectra (differential event rate as a function of recoil nucleus kinetic energy) for $^8B$ solar neutrinos in a dark matter detector with three different target materials, namely, $^{19}F$, $^{28}Si$ and $^{131}Xe$. Right: The integral recoil energy spectra (total event rate above a threshold recoil energy) as a function of the threshold recoil energy of the detector.

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FIG. 5 (color online). Recoil energy differential spectra (left) and integral spectra as a function of the threshold recoil energy (right) for SN neutrinos in a 1-ton Xe detector. Curves are shown for the Basel/Darmstadt SN model as well as for another SN model with average energies of $\nu_e$, $\bar{\nu}_e$ and $\nu_x$ equal to 10, 12 and 18 MeV, respectively, both for a SN at a distance of 10 kpc from the Earth.
Dark-matter at INO (DINO)

• Use scintillator crystal as detector material
  - CsI(Tl) / CsI
  - GGAG(Ce) / GGAG
  - Gd$_3$Ga$_3$Al$_2$O$_{12}$ (Ce)
  - Tungstates (eg. ZnWO$_4$)

• Proposed to be done in 2 stages:
  - **MiniDINO** : 1 ---> 10 kg active mass expt. at UCIL Jaduguda mine
    (SINP, UCIL, BARC, NISER, TIFR, VECC, ….)
    *Phase I: room temp.*
    *Phase II: Cryogenic expt.*
  - **DINO** : > 100 kg expt. @ future INO cavern
Jaduguda Underground Science Laboratory (JUSL) (Inaugurated on September 2, 2017)

For carrying out background studies towards a Dark Matter (or other rare event) search experiment
At first there was only darkness wrapped in darkness.  
All this was only unillumined water.  
That One which came to be, enclosed in nothing,  
arose at last, born of the power of heat."

Rig Veda (1st Millenium B.C.)

In order for the light to 
shine so brightly, the 
darkness must be present.

Francis Bacon

THANK YOU!