Lectures on selected topics in Astroparticle Physics:
Direct and Indirect Detection of
Particle (WIMP) Dark Matter

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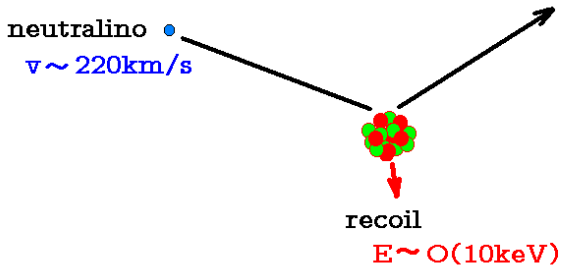
Direct Detection of WIMPs: Order-of-magnitude Estimates



Event rate :

For a single detector nucleus, the rate of WIMP scatterings, $R \sim n_\chi v \sigma_{\chi N}$, gives

$$R \sim 2.7 \times 10^{-25}\,\mathrm{yr}^{-1} \left(\frac{\rho_\chi}{0.3\,\mathrm{GeV\,cm}^{-3}}\right) \left(\frac{100\,\mathrm{GeV}}{m_\chi}\right) \left(\frac{v}{300\,\mathrm{km\,s}^{-1}}\right) \left(\frac{\sigma_{\chi N}}{10^{-37}\,\mathrm{cm}^2}\right)$$

No. of nuclei of atomic number A in 1 gm is $6 \times 10^{23}/A$. So, total rate

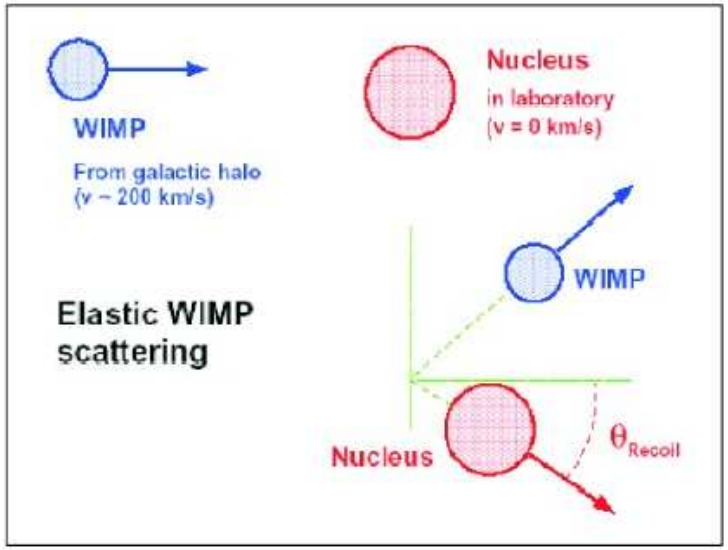
$$R_{\mathrm{total}} \sim 1.6\ \ \mathrm{events\,kg}^{-1}\,\mathrm{yr}^{-1} \left(\frac{100}{A}\right) \left(\frac{\rho_\chi}{0.3\,\mathrm{GeV\,cm}^{-3}}\right) \left(\frac{100\,\mathrm{GeV}}{m_\chi}\right) \left(\frac{v}{300\,\mathrm{km\,s}^{-1}}\right) \left(\frac{\sigma_{\chi N}}{10^{-37}\,\mathrm{cm}^2}\right)$$

Recoil Energy :

For a WIMP of mass m_χ and velocity v striking a nucleus of mass M at rest, $\Delta p \sim m_\chi v$. $\Rightarrow$ Recoil energy of nucleus,

$$E_r \sim (\Delta p)^2/2M \sim 50\,\mathrm{keV} \left(\frac{m_\chi}{100\,\mathrm{GeV}}\right)^2 \left(\frac{v}{300\,\mathrm{km\,s}^{-1}}\right)^2 \left(\frac{100\,\mathrm{GeV}}{M}\right) .$$

Direct detection: kinematics



Non-relativistic elastic scattering:

Simple kinematics: Use conservation of energy and momentum components

. . .

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 (typically measured in units of counts/day/kg/keV :

$\frac{\mathrm{d}R}{\mathrm{d}E} = \frac{\sigma(q)}{2\, m_\chi \mu^2}\, \rho\, \eta(E,t) \equiv \mathrm{Particle\,Physics} \otimes \mathrm{Astrophysics}$,

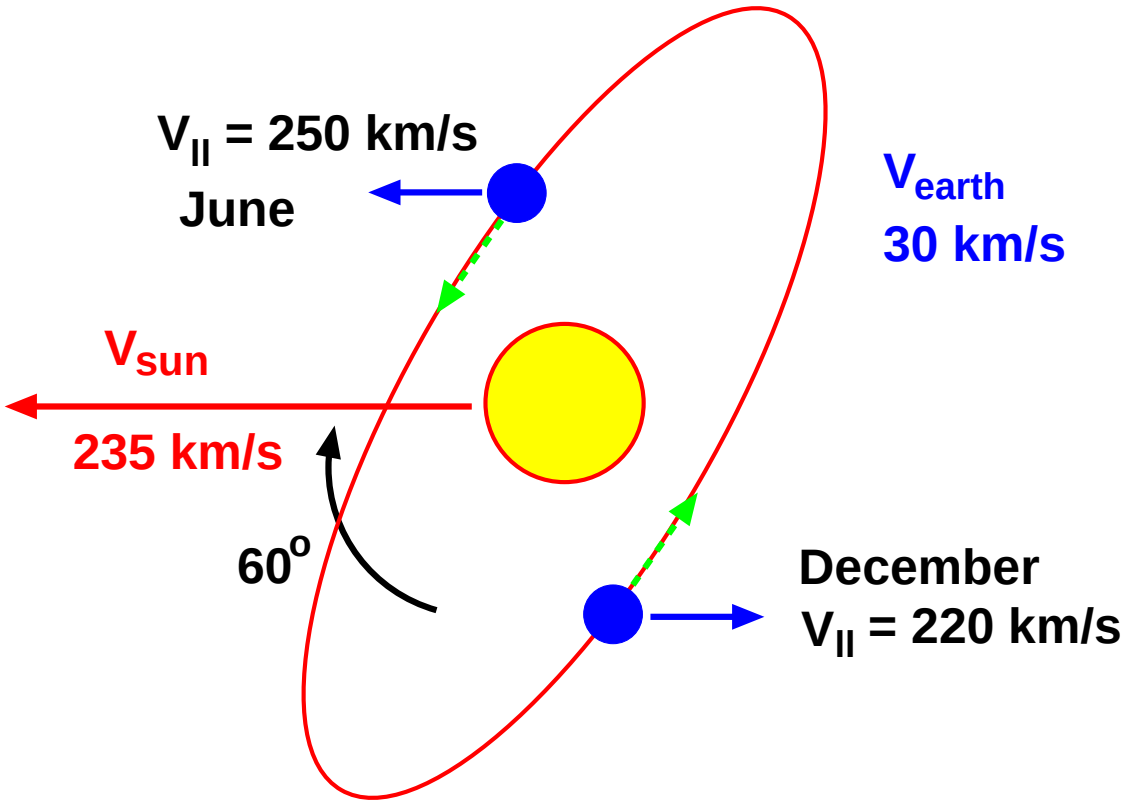
with $q = \sqrt{2ME} =$ nucleus recoil momentum, $\sigma(q) =$ WIMP-nucleus cross-section,

$\eta(E,t) = \int_{v>v_{\min}} \frac{f(\mathbf{v},t)}{v}\, \mathrm{d}^3 v$,

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

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

Modulation Signal



$$f(\mathbf{v}, t) = f_{\mathrm{Galaxy}}(\mathbf{v} + \mathbf{v}^{\mathrm{Earth}}(t)) \, .$$

Modulation analysis . . .

WIMP-nucleus effective cross sections

. . .

WIMP-Nucleus (Effective) Interactions

The effective WIMP-Nucleus X-section can be obtained from fundamental WIMP-quark/gluon x-section: $\sigma_{\chi-A} \leftarrow \sigma_{\chi-N} \leftarrow \sigma_{\chi-q}$

Spin-independent (SI) interaction:

$$\frac{d\sigma(q)}{dq^2} = \frac{1}{4m_n^2 v^2}\sigma_n A^2 F^2(q)$$

V= WIMP-nucleus relative velocity

Form factor: loss of coherence

Coherence

WIMP-nucleon x-section

WIMP-nucleon reduced mass = nucleon mass for m_WIMP>>m_n

Spin-dependent (SD) Interaction:

$$\frac{d\sigma(q)}{dq^2} = \frac{8}{\pi v^2}\Lambda^2 G_F^2 J(J+1) F^2(q)$$

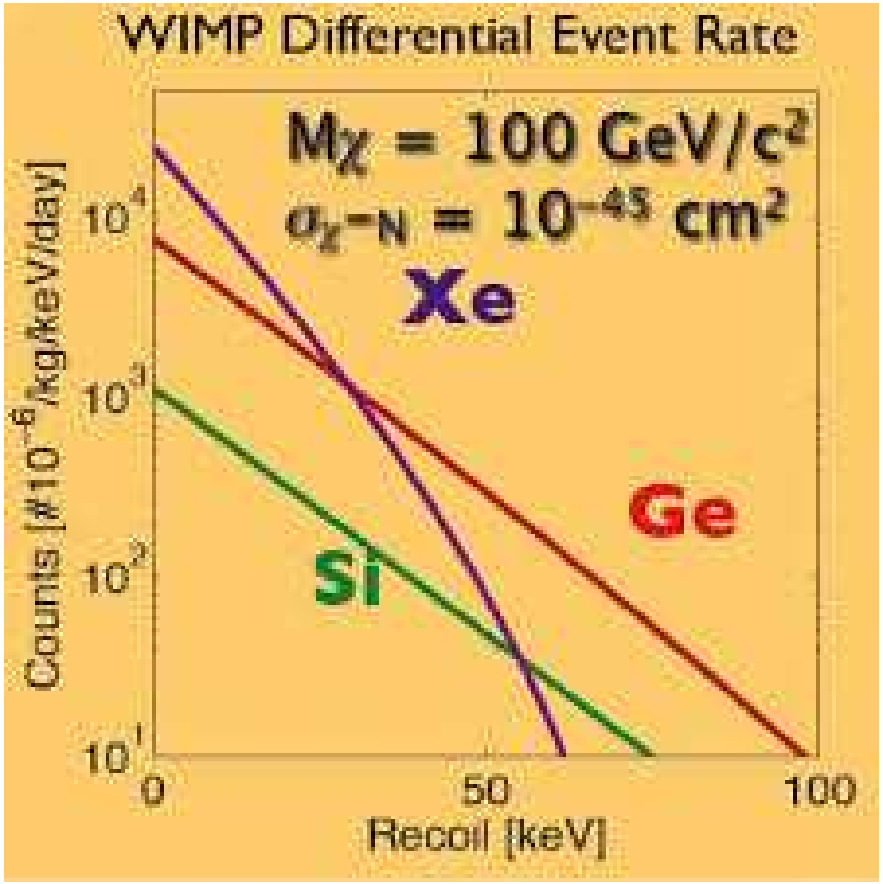
$$\Lambda = \frac{1}{J}\left[a_p\langle S_p\rangle + a_n\langle S_n\rangle\right]$$

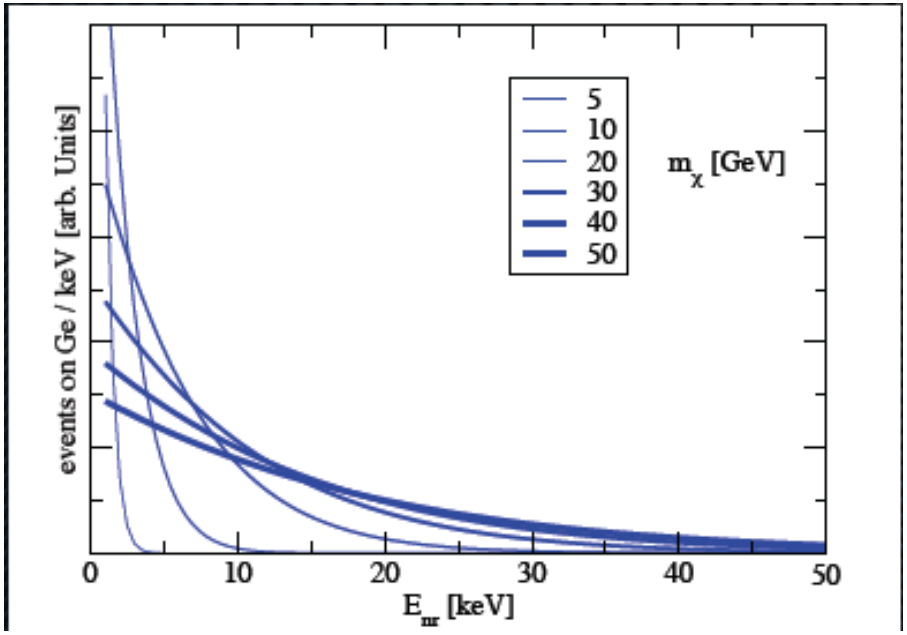
$$\langle S_{p,n}\rangle = \langle N|S_{p,n}|N\rangle$$

measure the amount of spin carried by the p- and n-groups inside the nucleus

a_p, a_n: effective coupling of the WIMPs to protons and neutrons, typically α/m_W^2

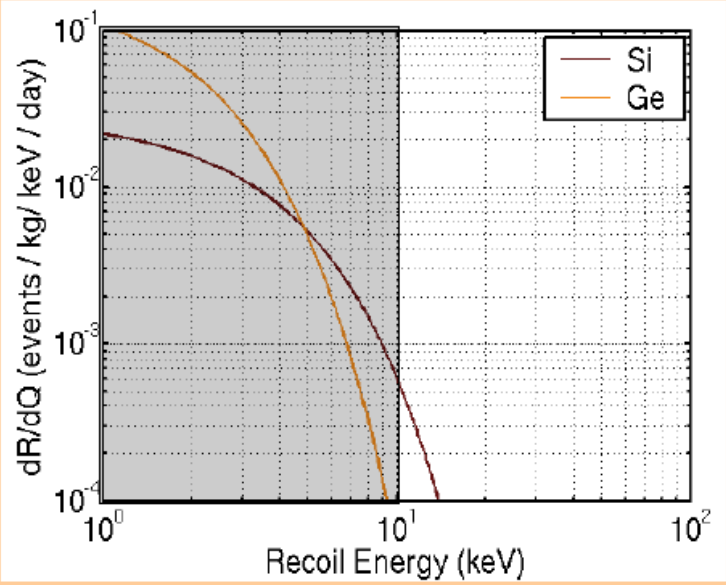
Nuclear Recoil Spectrum

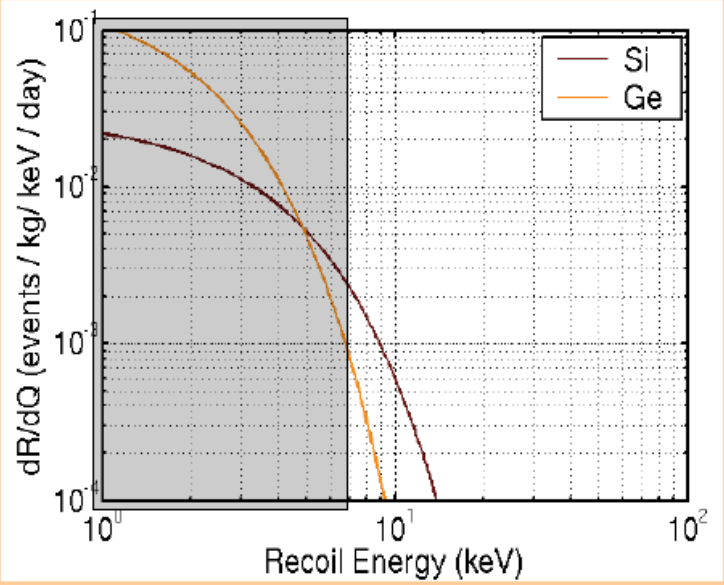




Low mass WIMP: Si vs Ge

m_WIMP=8 GeV



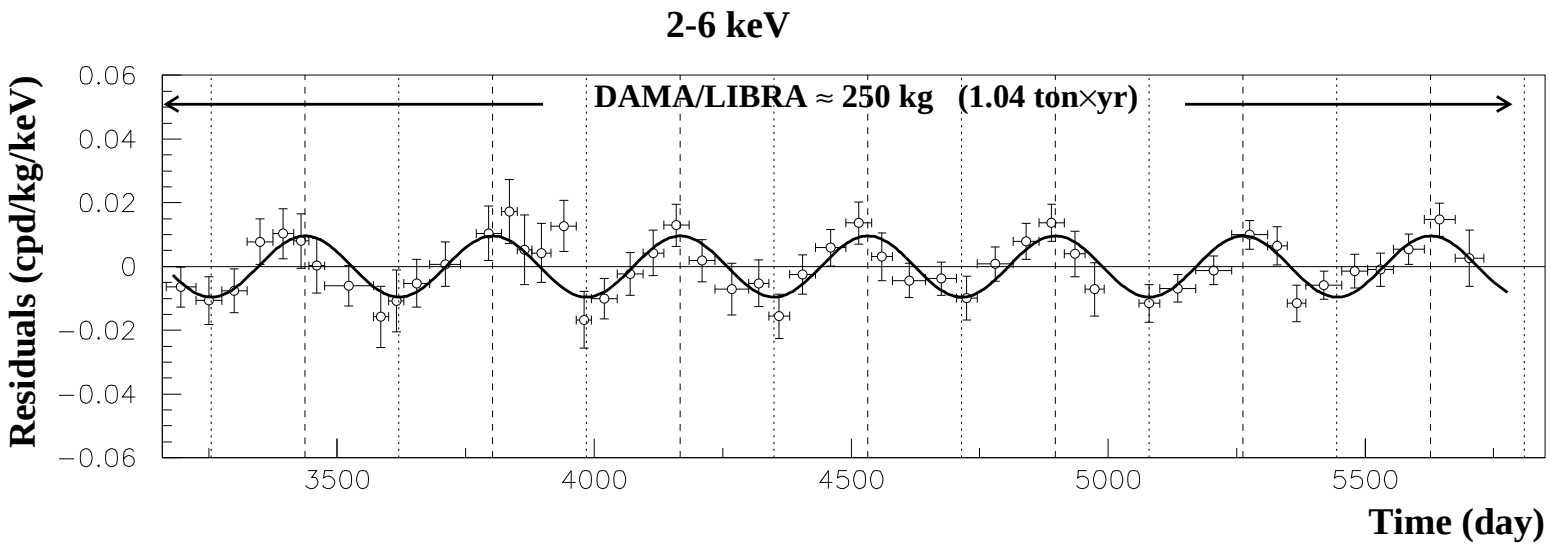


E_th = 10 keV

E_th = 7 keV

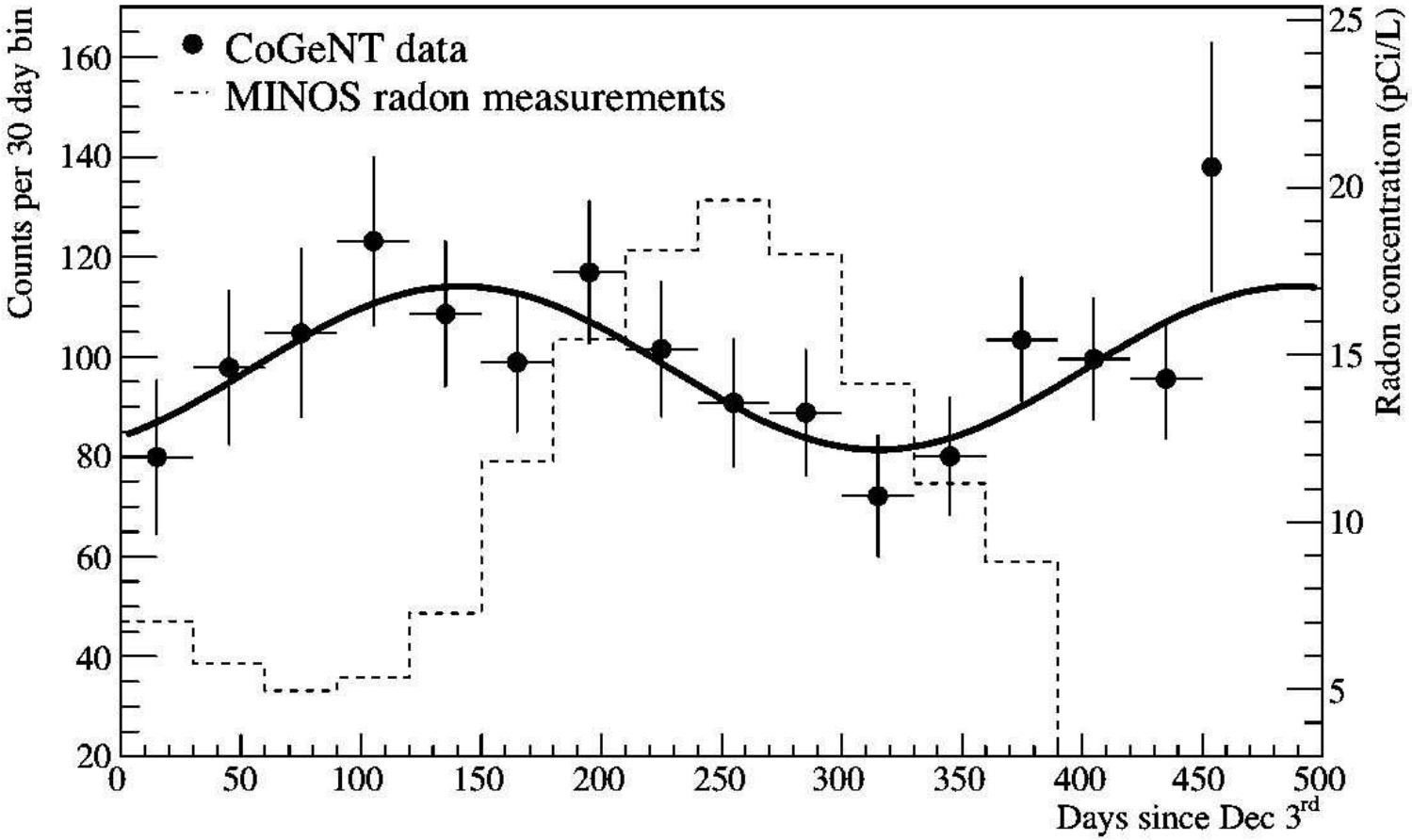
For low mass WIMPs, need lower threshold and lower target nucleus mass

Annual modulation: Detection claim by DAMA/LIBRA Experiment



Temporal variation of single-hit event rate fitted with a sinusoidal curve: $A\cos\omega(t-t_0)$ with a period $T=\frac{2\pi}{\omega}=1$ yr, a phase $t_0=152.5$ day (June 2nd). The zero of the time scale is at January 1st of the first year of data taking of the former DAMA/NaI experiment. Dashed vertical lines: expected maximum (June 2nd). Dotted vertical lines: minimum. (Bernabei et al, arXiv:1308.5109)

Annual modulation in CoGeNT experiment



(Aalseth et al, arXiv:1208.5737

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.

$$\begin{array}{lcl} \text{No. of events (DD or ID)} & \equiv & \text{Particle Physics} \otimes \text{Astrophysics} \\ & & \downarrow \qquad\qquad \downarrow \\ & & (m_\chi\,, \sigma_{\chi N}) \otimes (\rho_{\mathrm{DM},\odot}\,, f(\mathbf{v})) \\ & & \downarrow \qquad\qquad \downarrow \\ & & \text{e.g., LHC} \otimes \text{Galactic Dynamics (e.g., rot. curve)} \end{array}$$

- Need to fix Astrophysics to extract particle physics of DM (m_χ , σ).
- Use the observed rotation curve data of the Galaxy to determine the phase space DF of DM particles, i.e., $\rho_{\mathrm{DM},\odot}$, $f(\mathbf{v})$.
- 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.

Astrophysical Issues contd. . . .

• For drawing conclusions from the results of any direct or indirect detection experiments, we need to specify $\rho_{\mathrm{DM},\odot}$ and $f(u)_{\odot}$, both of which are *a priori* unknown.

• Determine $\rho_{\mathrm{DM},\odot}$ and $f(u)_{\odot}$ from the relevant observational data pertaining to our Galaxy $\Rightarrow$ Rotation curve data, data on the dynamics of satellites of Milky Way, . . .

• Need to start at the level of the Phase Space Distribution Function (DF), $f(\mathbf{x}, \mathbf{u})$, of WIMPs in the Galaxy.

• Theoretically expected DF: a quasi-Maxwellian

Violent relaxation: [Lynden-bell (1967)]

Phase space distribution of collisionless systems

- Assume Dark Matter consists of WIMPs

$\Rightarrow$ Phase space DF satisfies collisionless Boltzmann (Vlasov) equation (CBE),

$$\frac{df}{dt} \equiv \frac{\partial f}{\partial t} + \boldsymbol{v}.\boldsymbol{\nabla} f - \boldsymbol{\nabla}\Phi.\frac{\partial f}{\partial \boldsymbol{v}} = 0\,.$$

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 $E = \Phi + \frac{1}{2}v^2$.

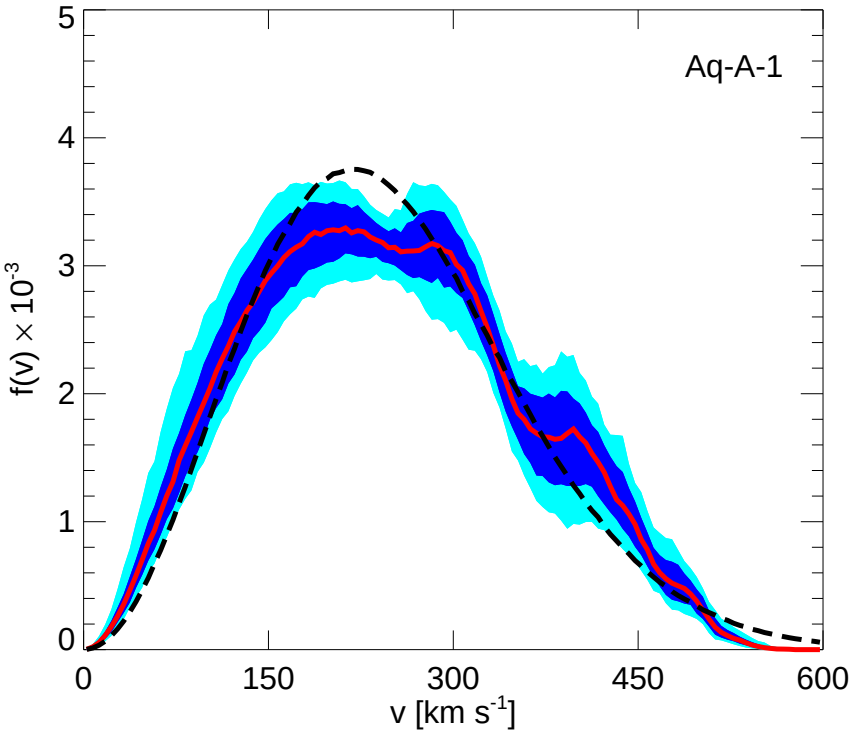
Isothermal DF:

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

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

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

DM Velocity Distribution: Simulations



(From Vogelsberger et al, arXiv:0812.0362)

The velocity distribution can be described by a “quasi-Maxwellian".

Also, the possibility of a "DM thick disc"

The 'Standard halo model'

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

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

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

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

For an isothermal gravitating sphere, $\langle v^2\rangle^{1/2} = \sqrt{\frac{3}{2}}v_{c,\infty}$.
With $v_{c,\infty} = v_{c,\odot} = 220\,{\rm km\,s^{-1}}$, one has $\langle v^2\rangle^{1/2} = 270\,{\rm km\,s^{-1}}$.

Standard Halo Model $\equiv$ Maxwellian velocity distribution with $\rho_{{\rm DM},\odot} = 0.3\,{\rm GeV/\,cm^3}$ and $\langle v^2\rangle^{1/2}_{{\rm DM},\odot} = 270\,{\rm km\,s^{-1}}$.

Problems with SHM

- Isothermal sphere has $\rho \propto r^{-2}$ for large r. $\Rightarrow M(r) \to \infty$ as $r \to \infty$.
  $\Rightarrow$ Need to truncate it, but must do so self-consistently, else not a solution of CBE.

- DF of DM at solar neighborhood is strongly influenced by visible matter. Need to self-consistently include the effects of visible matter to determine $\rho_{\mathrm{DM},\odot}$ and $f(v_{\mathrm{DM}})_{\odot}$.

Two approaches:

• Make a reasonable ansatz for the DF of a finite gravitating system that is a solution of CBE, self-consistently include the effect of VM, and determine the parameters of the model so as to fit the rotation curve data of the Galaxy.

Or,

• Assume a parametrized form of the density profile of DM (based on, e.g., results of numerical simulations) in presence of the (known) VM, determine the parameters by a fit to the rotation curve data, and then 'invert' the density profile to derive the DF by Eddington's (1916) method.

Truncated Isothermal – "King model"

Isothermal model has divergent total mass, $M(r) \propto r$ as $r \to \infty$. Need to self-consistently truncate it.

$$f(x,v) \equiv f(\varepsilon) = \begin{cases} \rho_1 (2\pi\sigma^2)^{-3/2} \left(e^{\varepsilon/\sigma^2} - 1\right) & \text{for } \varepsilon > 0\,, \\ 0 & \text{for } \varepsilon \leq 0\,, \end{cases} \tag{1}$$

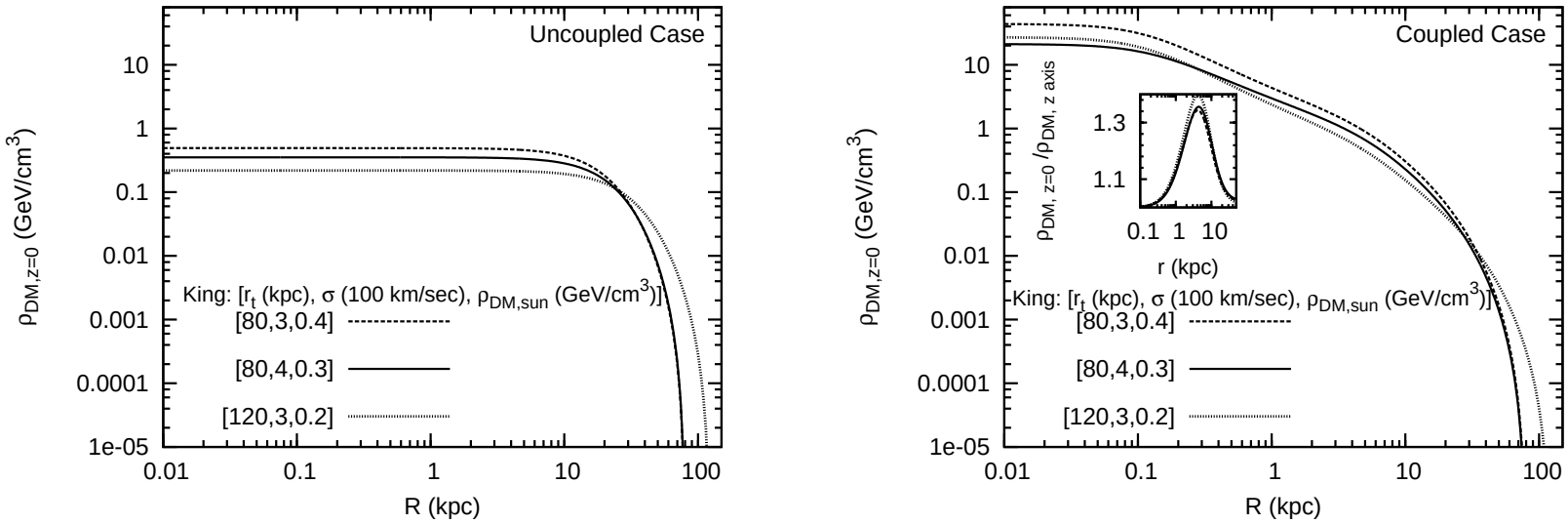
with $\varepsilon \equiv \phi_0 - (\frac{1}{2}v^2 + \phi)$, and $\phi = \phi_{\rm vis} + \phi_{\rm DM} \equiv \phi_{\rm total}$.
$\nabla^2 \phi_{\rm DM}(R,z) = 4\pi G \rho_{\rm DM}(R,z)$, $\nabla^2 \phi_{\rm vis}(R,z) = 4\pi G \rho_{\rm vis}(R,z)$.

$\rho_{\rm DM} \equiv \rho_{\rm DM}[\phi_{\rm vis} + \phi_{\rm DM}] = \int f \; d^3v$. Note Self-consistency.

Three parameters: ρ_1 , σ and ϕ_0 .
$\rho_{\rm DM}$ vanishes at $r = r_t$ where $\varepsilon = 0$.

Three "measurable" parameters of the model:
$\rho_{\rm DM,\odot} = \rho_{\rm DM}(R = R_0, 0)$, $\langle v^2 \rangle^{1/2}_{\rm DM,\odot} = \langle v^2 \rangle^{1/2}_{\rm DM}(R = R_0, 0)$ and r_t.

Self-consistent DM Density Profile

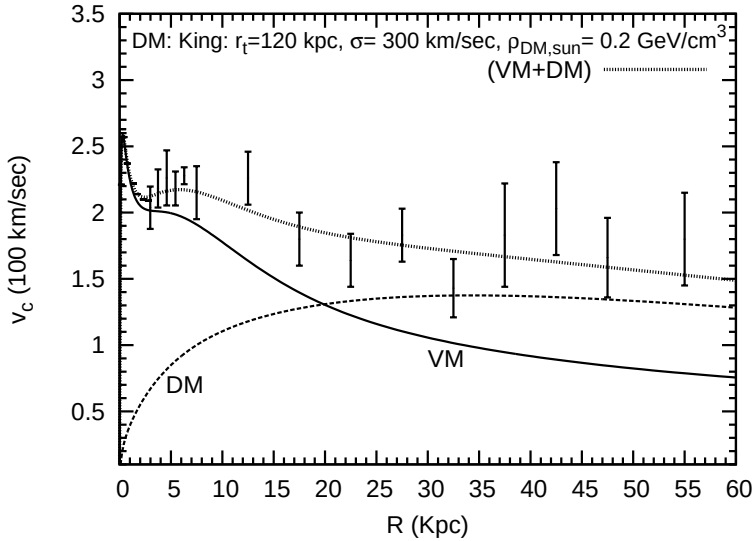


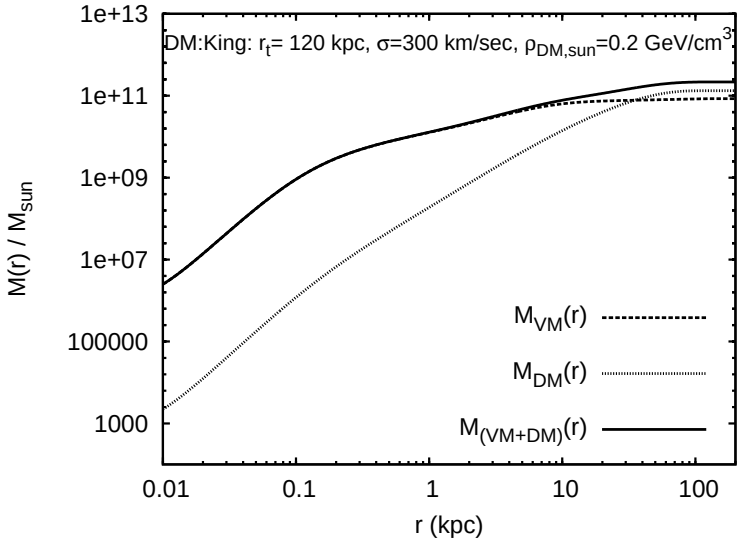
(S. Chaudhury, PB, R. Cowsik, JCAP (2010)) Visible matter “pulls in" the DM; DM density profile made steeper with enhanced density in the inner Galaxy

⇒ Impact on DM annihilation signals from the Galaxy Centre region

Rotation Curves for Truncated Isothermal Models

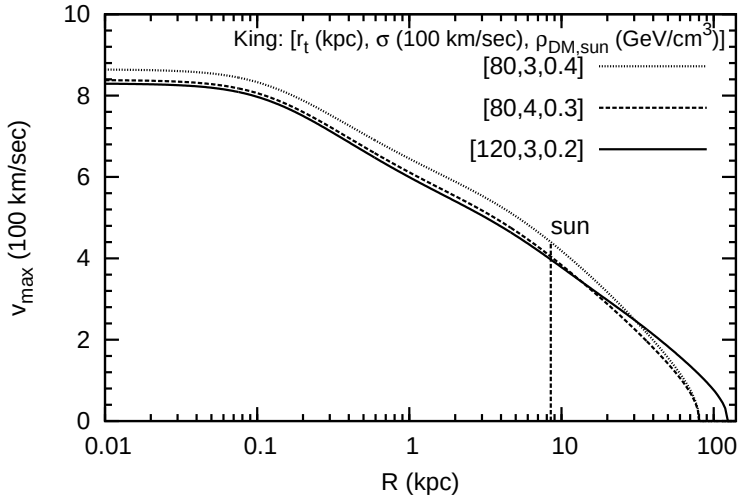
$$v_c^2(R) = R\frac{\partial\phi}{\partial R}(R,0) = R\frac{\partial}{\partial R}\left[\phi_{\rm DM}(R,0) + \phi_{\rm vis}(R,0)\right] .$$

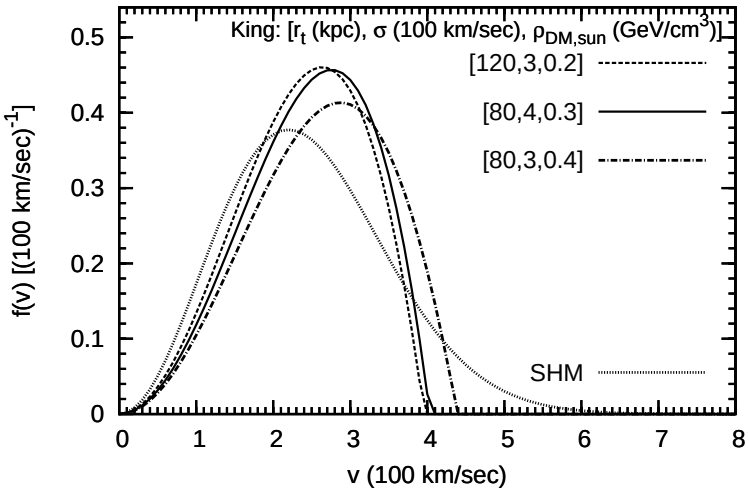




Rotation curve data out to 60 kpc (Xue etal (2008) is used.

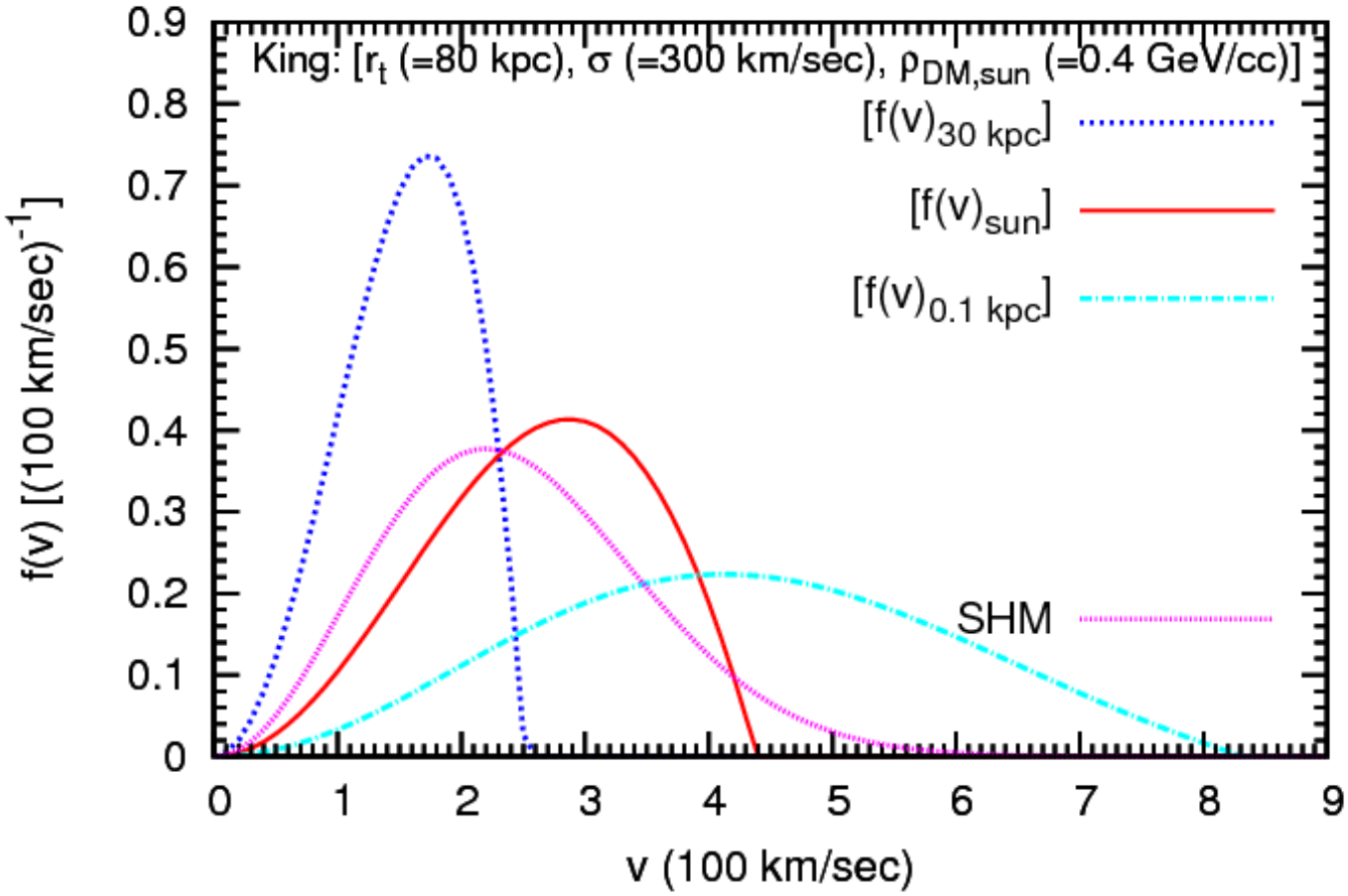
Self-consistent DM Velocity Distribution



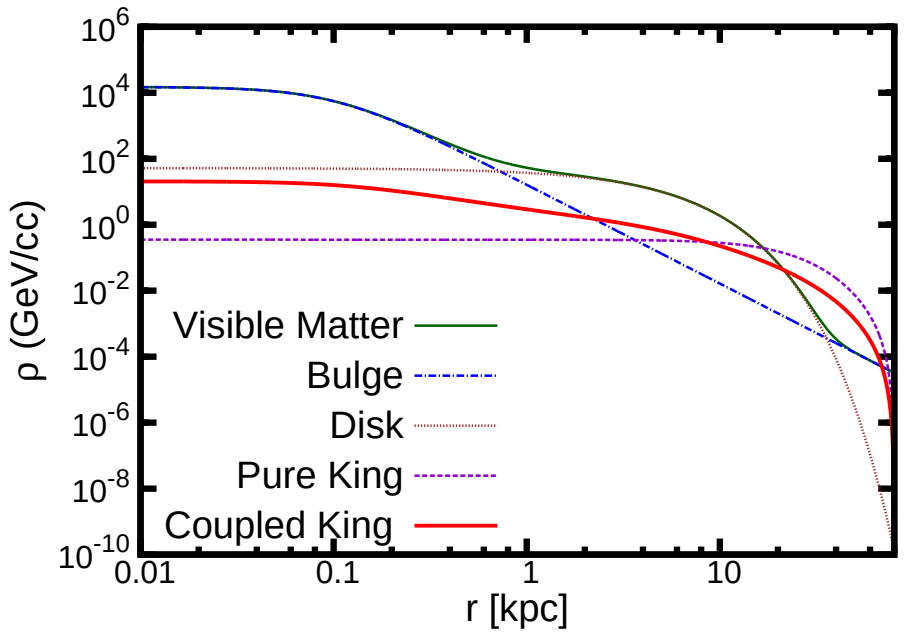


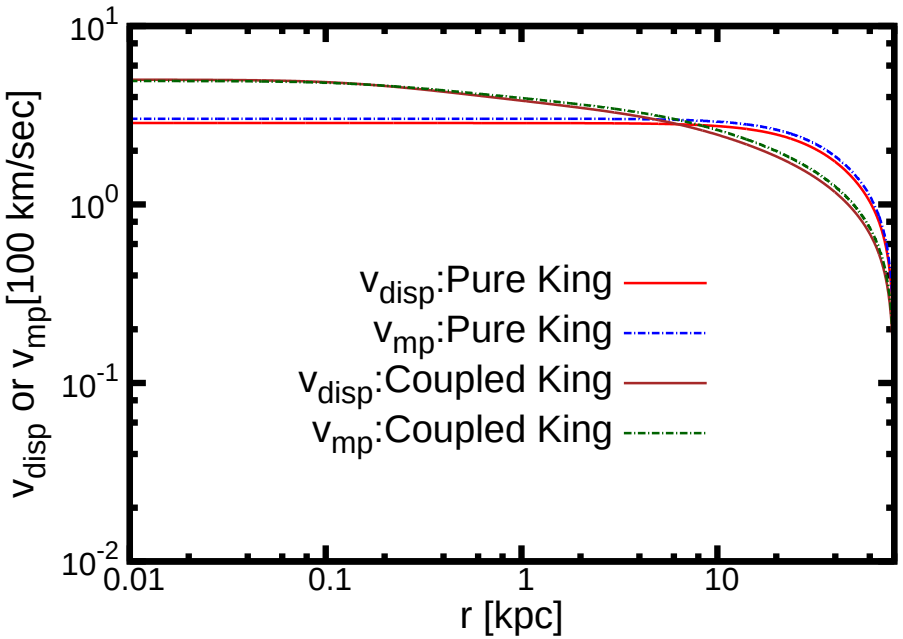
Non-Maxwellian velocity distribution; cutoff speed determined self-consistently

DM velocity distribution at various locations



DM density and velocity dispersion profiles





VDF from ρ : Eddington's Formula

For a given DF, $\mathcal{F}(\mathbf{x}, \mathbf{v})$, we get $\rho(\mathbf{x}) = \int d^3\mathbf{v}\, \mathcal{F}(\mathbf{x}, \mathbf{v})$.

Can we invert this? Given a $\rho(\mathbf{x})$ (or equivalently $\Phi(\mathbf{x})$), can we get a unique $\mathcal{F}$?

Eddington (1916) : Possible for spherical systems with isotropic VDF, i.e., if $\mathcal{F}(\mathbf{x}, \mathbf{v}) \equiv \mathcal{F}(E)$, where $E = \frac{1}{2}v^2 + \Phi(r) =$ Total energy, i.e., if the system is "ergodic". Here $v = |\mathbf{v}|$, $r = |\mathbf{x}|$. Isotropic VDF $\Rightarrow \langle v_r^2 \rangle^{1/2} = \langle v_\theta^2 \rangle^{1/2} = \langle v_\phi^2 \rangle^{1/2}$. Eddington formula:

$$\mathcal{F}(\mathcal{E}) = \frac{1}{\sqrt{8}\pi^2} \left[\int_0^{\mathcal{E}} \frac{d\Psi}{\sqrt{\mathcal{E} - \Psi}} \frac{d^2\rho}{d\Psi^2} + \frac{1}{\sqrt{\mathcal{E}}} \left(\frac{d\rho}{d\Psi} \right)_{\Psi=0} \right],$$

where $\Psi(r) \equiv -\Phi(r) + \Phi(r = \infty) =$ relative potential and $\mathcal{E} \equiv -E + \Phi(r = \infty) = \Psi(r) - \frac{1}{2}v^2 =$ relative energy.

Note, $\mathcal{F} > 0$ for $\mathcal{E} > 0$, and $\mathcal{F} = 0$ for $\mathcal{E} \leq 0$.
Also, $\rho(r) \Leftrightarrow \mathcal{F}(\mathcal{E})$ is unique iff $\int_0^{\mathcal{E}} \frac{d\Psi}{\sqrt{\mathcal{E}-\Psi}} \frac{d\rho}{d\Psi}$ is an increasing function of $\mathcal{E}$.

The VDF, $f_r(\mathbf{v}) = \mathcal{F}/\rho(r)$, has a natural truncation at $v(r) = v_{\max}(r) = \sqrt{2\Psi(r)}$.

Eddington inversion also possible for anisotropic VDF of certain special forms (Osipkov-Merrit)

VDF of DM particles by Eddington's Formula

$$\mathcal{F}(\mathcal{E}) = \frac{1}{\sqrt{8}\pi^2}\left[\int_0^{\mathcal{E}} \frac{d\Psi}{\sqrt{\mathcal{E}-\Psi}}\frac{d^2\rho}{d\Psi^2} + \frac{1}{\sqrt{\mathcal{E}}}\left(\frac{d\rho}{d\Psi}\right)_{\Psi=0}\right],$$

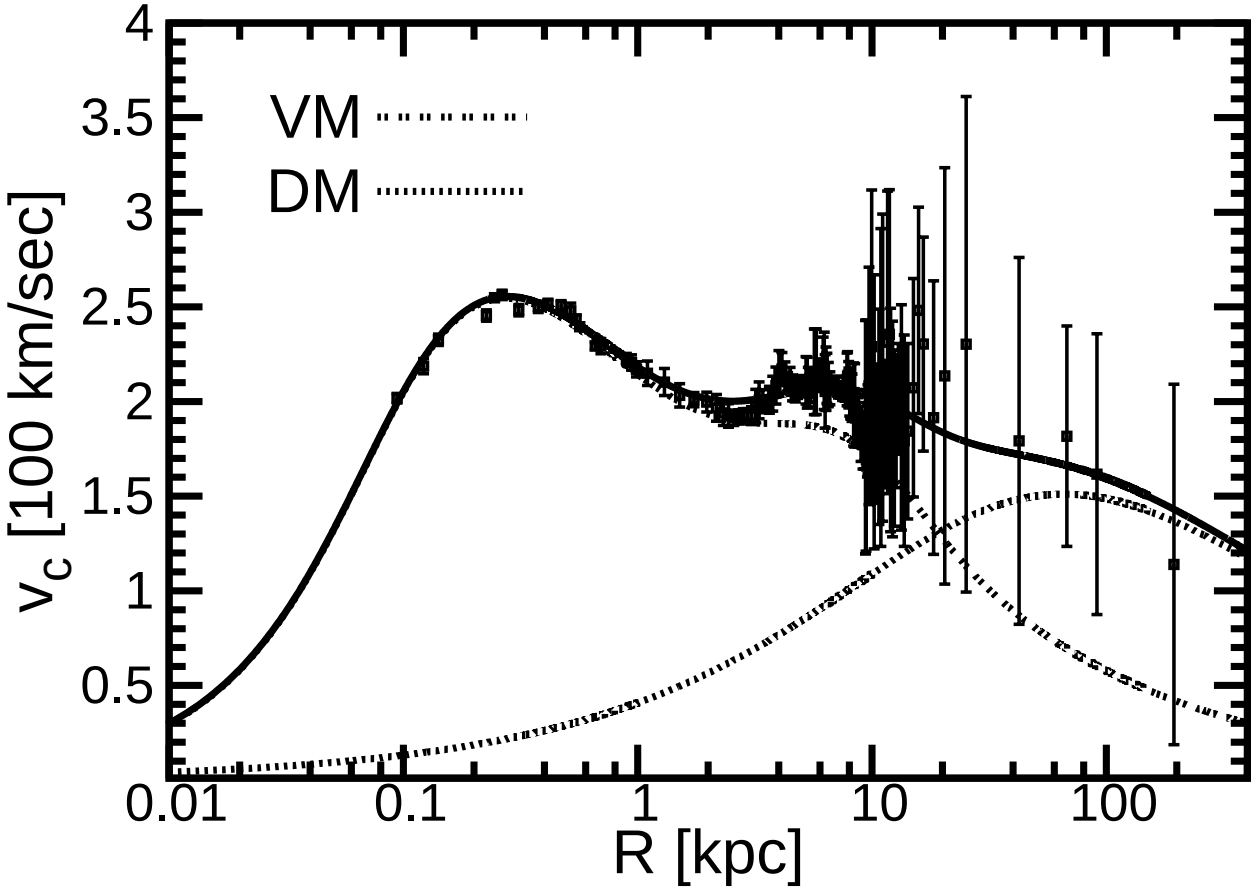
with $\Psi(r) \equiv -\Phi(r) + \Phi(r=\infty)$ and $\mathcal{E} = \Psi(r) - \frac{1}{2}v^2$.

We take $\rho(r) = \rho_{\rm DM}(r)$. But note that $\Phi(r) \neq \Phi_{\rm DM}(r)$.

Rather, $\Phi(r) = \Phi_{\rm DM}(r) + \Phi_{\rm vis}(r)$, since the DM particles "see" and move in the total gravitational potential including that of the visible matter. Actually, since visible matter is still the dominant component in the solar neighborhood. (DM dominates at larger distances), the VDF of DM in the inner regions of Galaxy is essentially determined by VM, not DM.

Parametrize $\Phi_{\rm vis}$ and $\Phi_{\rm DM}$ (or $\rho_{\rm DM}$), and determine the parameters by MCMC fit to the observed rotation curve data, and then use Eddington formula to find $f_r(v)$ at any r.

Rotation Curve



Rotation curve with best-fit values of DM and VM parameters. Data are from Y. Sofue, PASJ **64** (2012) 75; arXiv:1110.4431.

(PB, S.Chaudhury, S. Kundu, S. Majumdar, PRD (2013))

Dark Matter parameters

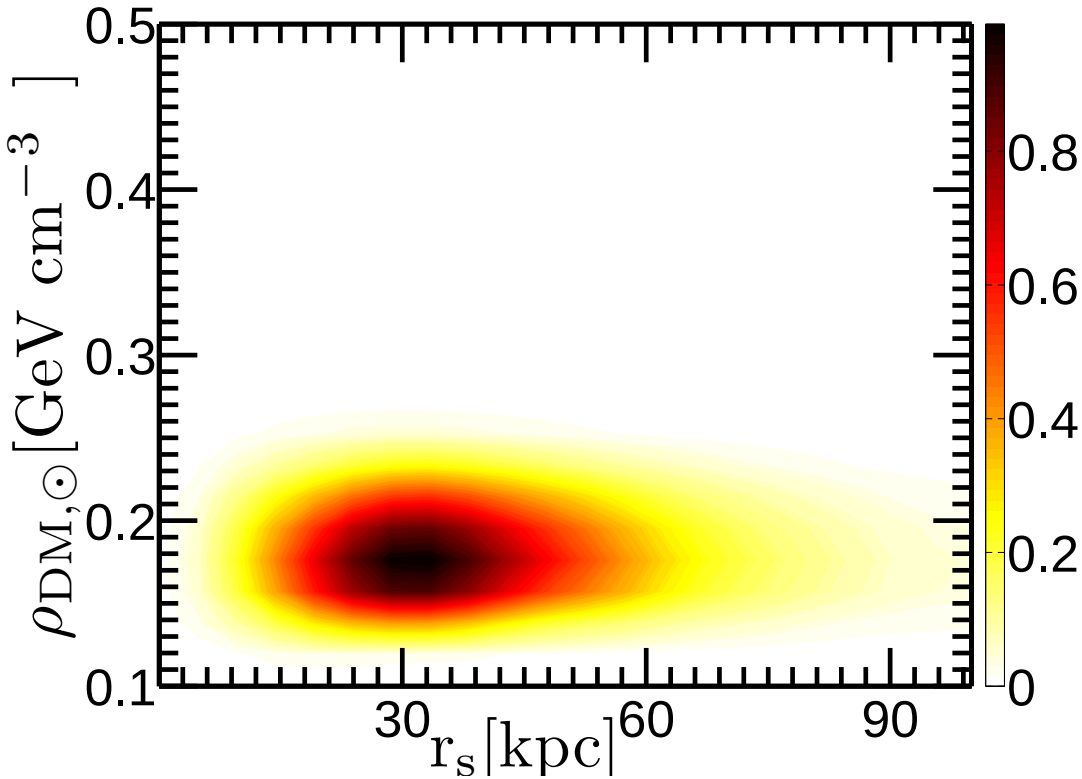
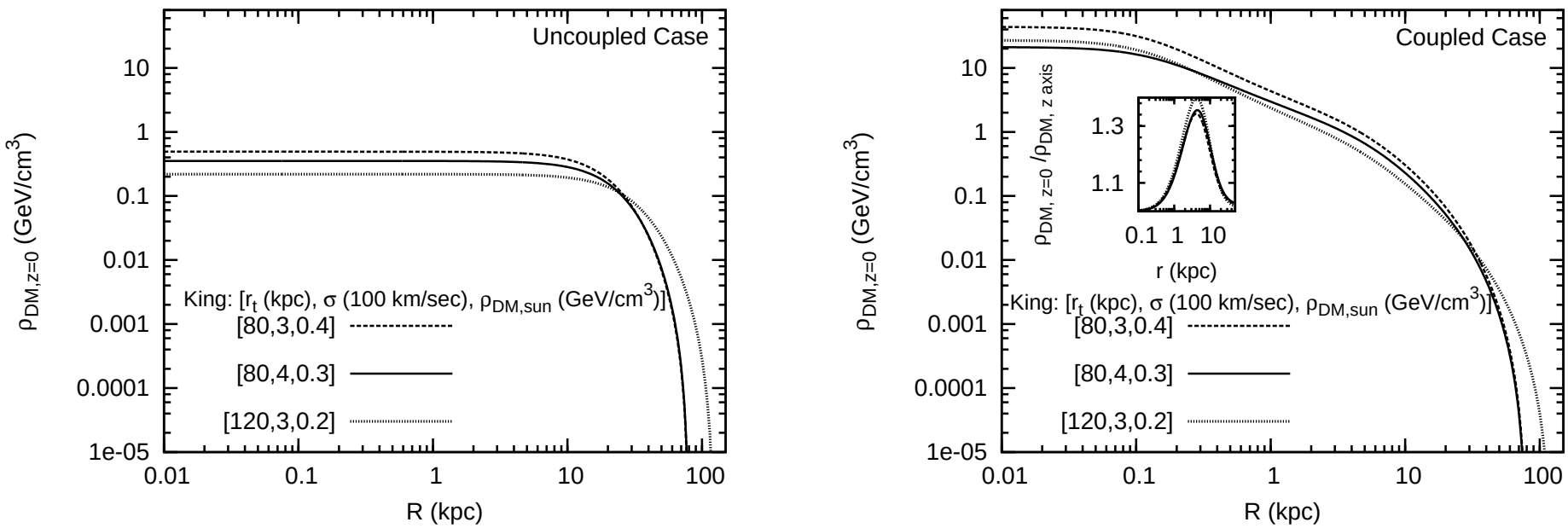


Figure 1: The 2D posterior probability density function for Dark Matter parameters $(r_s - \rho_{\mathrm{DM},\odot})$, marginalized over the visible matter parameters.

(PB, S.Chaudhury, S. Kundu, S. Majumdar, PRD (2013))

Self-consistent DM Density Profile



(S. Chaudhury, PB, R. Cowsik, JCAP (2010))

Visible matter “pulls in" the DM; DM density profile made steeper with enhanced density in the inner Galaxy

⇒ Impact on DM annihilation signals from the Galaxy Centre region

Dark Matter VDF

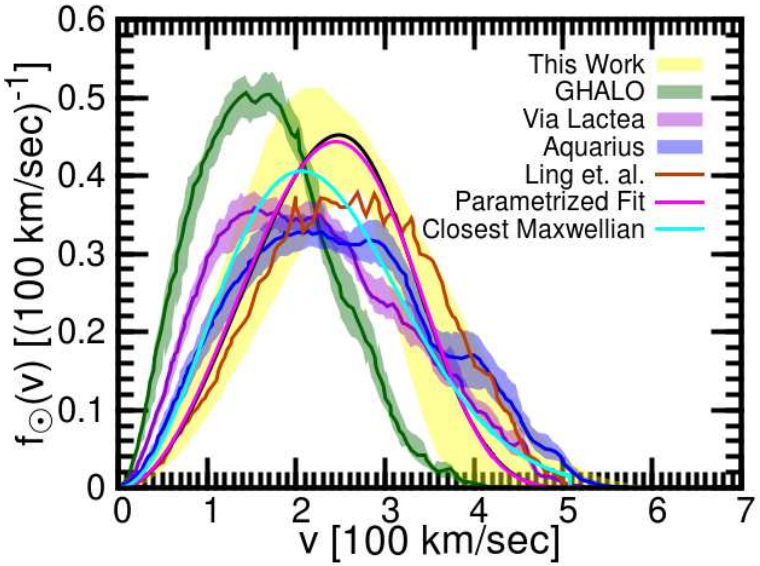


Figure 2: Normalized local speed distribution, $f_\odot(v)$, corresponding to the most-likely set of values of the Galactic model parameters determined from fit to rotation curve data, and its uncertainty band (shaded) corresponding to the 68% C.L. upper and lower ranges of the Galactic model parameters.

Best-fit (non-Maxwellian) speed distribution: $f_\odot(v) \approx 4\pi v^2 \left(\xi(\beta) - \xi(\beta_{\rm max})\right)$, where $\xi(x) = (1+x)^k \, e^{-x^{(1-k)}}$, $\beta = v^2/v_0^2$, $\beta_{\rm max} = v_{{\rm max},\odot}^2/v_0^2$, $v_0 = 339\,{\rm km\,s^{-1}}$ and $k = -1.47$.

(PB, S.Chaudhury, S. Kundu, S. Majumdar, PRD (2013))

Impact on WIMP Direct Detection

Recoil spectrum: $\frac{d\mathcal{R}}{dE_R}(E_R,t) = \frac{\sigma(q^2=2m_N E_R)}{2m_\chi \mu^2}\rho_\chi g(E_R,t)\,,$

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

$$g(E_R,t) = \int_{u>u_{\rm min}(E_R)}^{u_{\rm max}(t)} \frac{d^3\mathbf{u}}{u} f_\odot\left(\mathbf{u}+\mathbf{v}_{\rm E}(\mathbf{t})\right)\Theta(u_{\rm max}-u_{\rm min})\,,$$

$\mathbf{u}$ (with $u = |\mathbf{u}|$)= relative velocity of the WIMP with respect to the detector at rest on Earth

$\mathbf{v}_{\rm E}(\mathbf{t}) =$ time-dependent velocity of the Earth relative to the Galactic rest frame.
$u_{\rm min}(E_R) = \left(m_N E_R/2\mu^2\right)^{1/2} =$ minimum WIMP speed required for producing a recoil energy E_R of the nucleus,
$u_{\rm max}(t) =$ lab frame (time-dependent) maximum WIMP speed corresponding to $v_{\rm max} = \sqrt{2\Psi}$ (defined in the Galactic rest frame).

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

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

Define $\zeta \equiv g(E_R = E_{\rm th})/g_{\rm Maxwell}(E_R = E_{\rm th})$

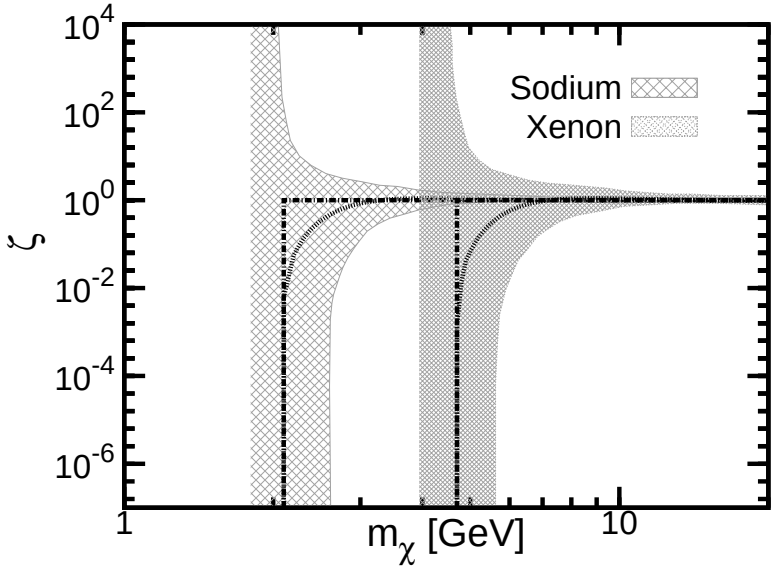


Figure 3: The ratio ζ for most-likely $f_\odot(v)$, with $E_{\rm th} = 2\,{\rm keV}$. The shaded bands correspond to the uncertainty bands of $f_\odot(v)$ from rotation curve. The calculations are for 2nd June, when the Earth's velocity in the Galactic rest frame is maximum.

Effect of departure from Maxwellian VDF is important for low m_χ

$\zeta \sim 10^{-2}$ at $m_\chi = m_{\chi,\rm min}$!

(PB, S.Chaudhury, S. Kundu, S. Majumdar, PRD (2013))

Summarizing . . .

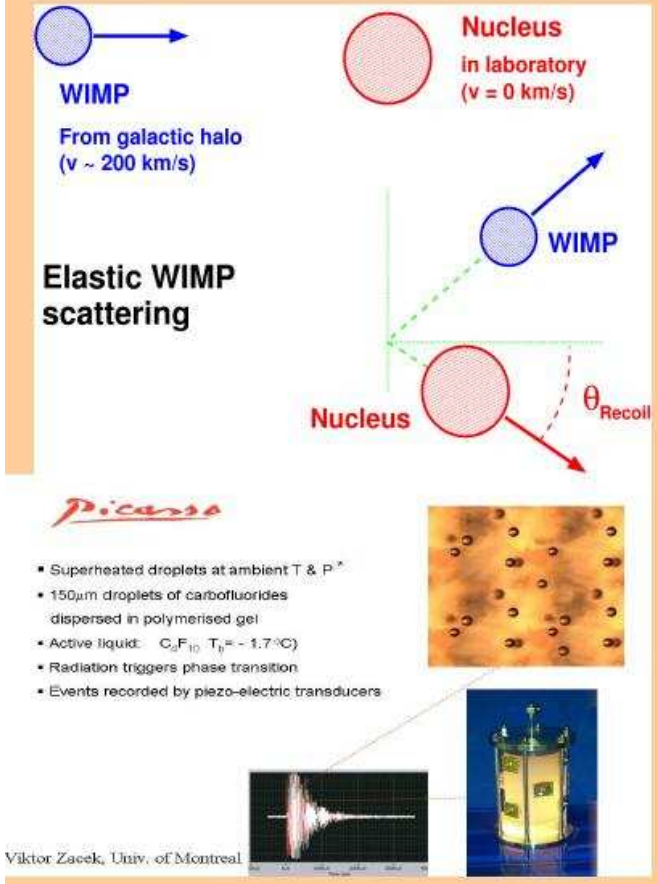
- WIMPs are natural candidates for the Dark Matter in the Universe.
- Direct Detection experiments have already achieved sensitivity at the level of $\sim 10^{-9}\mathrm{pb}$ for SI WIMP-nucleus cross section. Some kinds of WIMPs may be close to detection, if they are there!
- Expected number of events in direct detection experiments depends on $\rho_{\mathrm{DM},\odot}$ and $f(v)_{DM,\odot}$. Must determine these parameters from observational data (e.g., Rotation Curve) by self-consistently including the gravitational effects of the visible matter.
- DM DVF is in general non-Maxwellian, and effect of departure from Maxwellian VDF is important for low-mass WIMPS — Maxwellian overestimates VDF at both high and low-velocity ends.
- Properly determined VDF will impact the interpretation of positron excess etc., from WIMP annihilation (Sommerfeld enhancement etc.).

Dark Matter search initiatives in India

PICASSO/PICO @ SNOLAB: Mainly sensitive to spin-dependent interactions

(mini)-DINO@ (Jaduguda)-INOLab: Mainly sensitive to spin-independent interactions

WIMP Dark Matter Search with Superheated Droplet Detector



Detect the recoiling nucleus with a Superheated Droplet Detector

A superheated liquid drop can vaporize due to energy deposited by the passage of the recoiling nucleus.

Vapour bubbles larger than a critical size expand and finally burst sending out acoustic waves through the medium (gel) in which the liquid drops are suspended. This acoustic signal can be picked up by suitable electronic sensors.

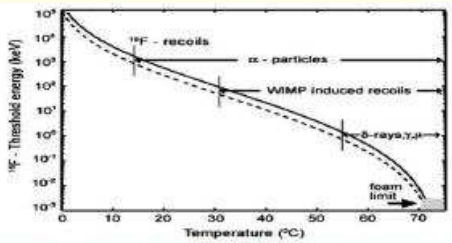


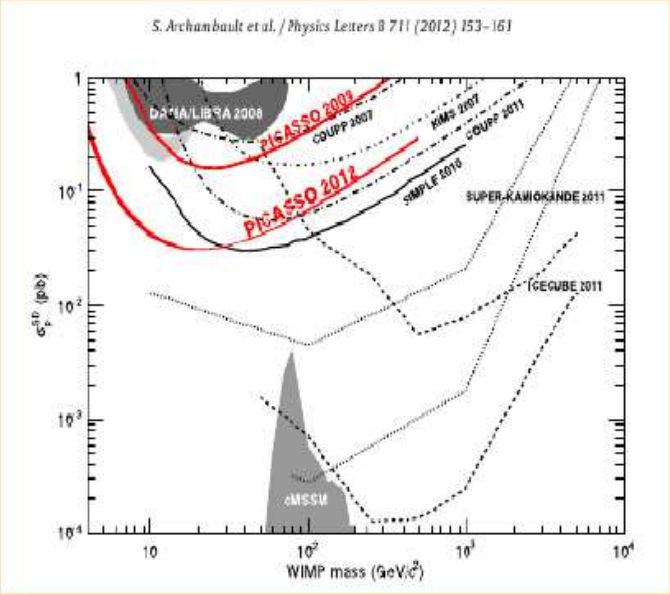
Fig. 2. Evolution of the energy threshold for ^{19}F recoils as a function of temperature (1.23 bars) in C_4F_{10} (b.p. -11.7°C)
At threshold the ^{19}F recoil detection efficiency rises gradually and the broken (continuous) lines indicate 50% (80%) detection efficiencies, respectively. WIMP induced recoil energies are smaller than 100 keV and become detectable above 30°C; at around 15°C the detector becomes sensitive to alpha particles from U/Th contaminations.

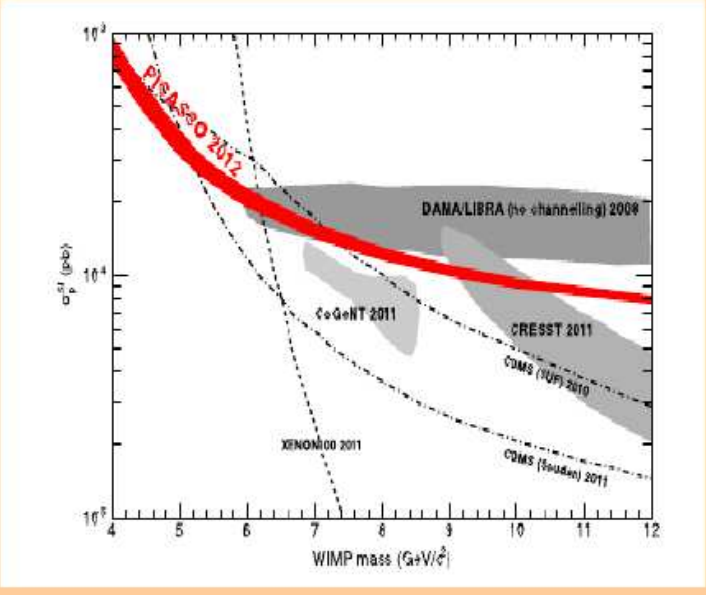
Barnabe-Heider et al *Phys. Lett* B624 (2005) 186

9 organizations from 4 countries with 28 people (at present)

May 2009

PICASSO Results





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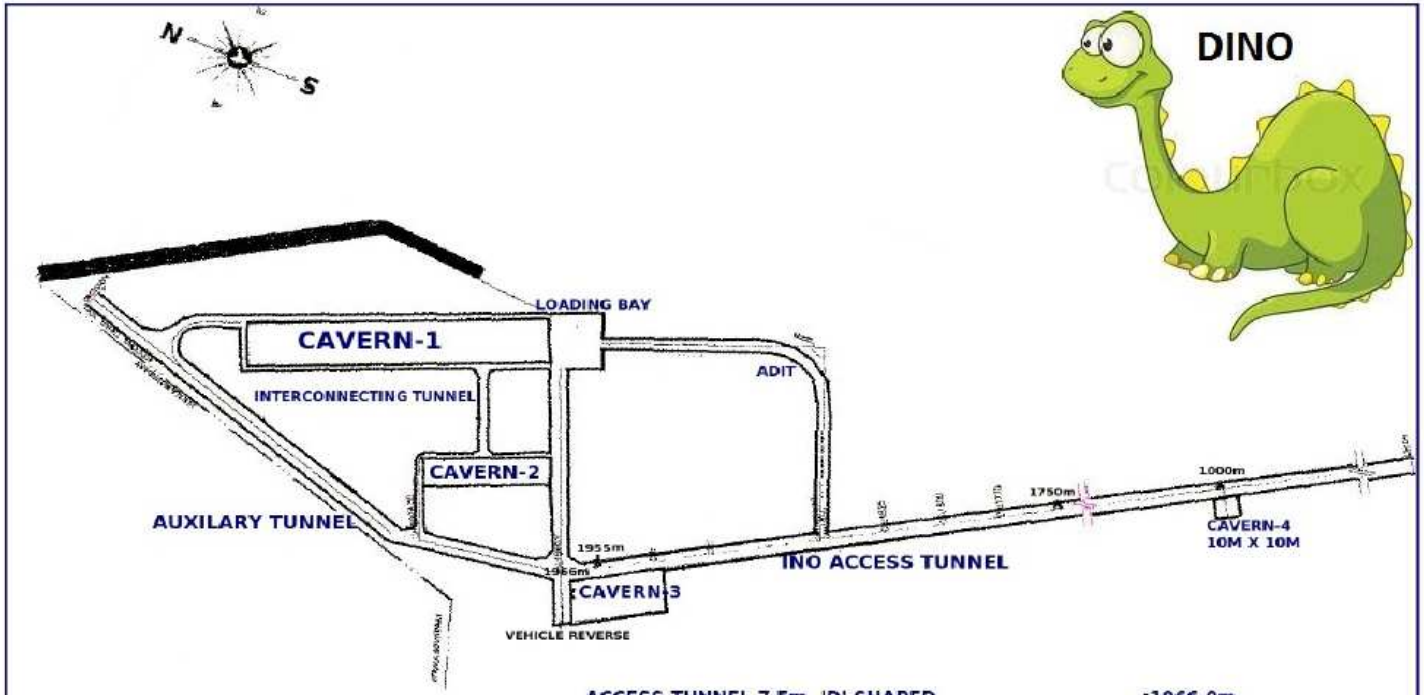
Dark-matter@INO (DINO) Ton-scale 2020



ACCESS TUNNEL 7.5m, 'D' SHAPED :1966.0m
ADDITIONALLY DRIVEN INT. TUNNEL 5.5m 'D' SHAPED: 175.4m
AUXILARY TUNNEL 7.5m 'D' SHAPED : 224.6m
INTERCONNECTING TUNNEL 3.5m 'D' SHAPED : 72.5m
ADDITIONAL TUNNEL 7.5m 'D' SHAPED (future expn) : 50.0m

- **INO Lab Depth 1.3km**

CAVERN -1 : 132m x 26M x 32.5m
CAVERN -2 : 55m x 12.5m x 8.6m
CAVERN -3 : 40m x 10m x 10m
CAVERN -4 : 10m x 10m x 10m

Pottipuram in Bodi West hills

Mini-DINO @ UCIL-Jaduguda Mines

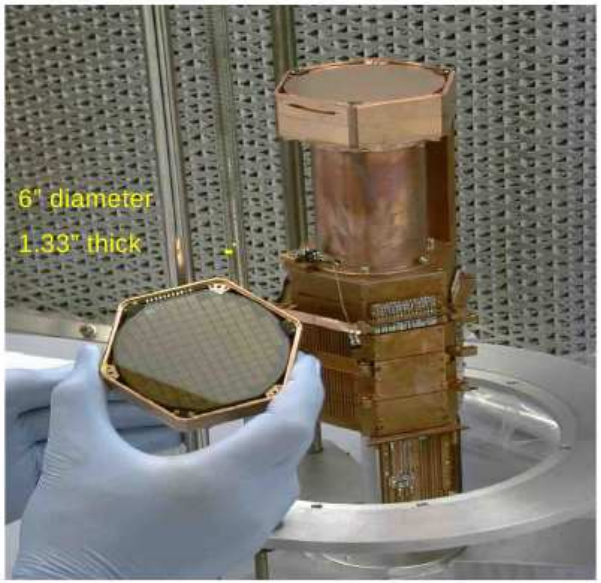
- A 15-30 kg Si/Ge detector for low-mass ($\lesssim 10\,\mathrm{GeV}$) WIMPs
- Two possibilities being explored:
  (i) Use only ionization signal — can operate at 77 K or 4 K with few keV threshold.
  No phonon sensors (which would require TES operating at mK temperatures).
  (ii) Use both ionization and phonon signals at sub-keV threshold
- New iZIP detector technology developed at TAMU: can pick up low-ionization events due to nuclear recoils.
- Discrimination against high-ionization events due to electron recoils possible by pulse-shape-based analysis (R&D going on at SINP & TAMU)

Multi-institutional collaborative effort:

SINP (Kolkata), Texas A&M (TAMU, USA), NISER (Bhubaneswar), TIFR, IIT-Bombay,

IoP-Bhubaneswar, PRL-Ahmedabad, . . .

Proposed Silicon Detectors for DINO



Cryogenically cooled Si detectors with photo lithographically patterned sensors for low threshold (~10 keV), medium energy resolution (~ 1 keV) and 3-D position determination capability

- Passive Shielding (Pb, poly, Pb, poly)
- Active Shielding (muon veto shield)

WHY SILICON in miniDINO ?

- Sensitivity to low mass WIMPs (spin independent sector)
- Trade off between overall higher sensitivity (Ge) and low mass WIMP sensitivity (Si)
- Well-known and well-proven technology
- Easy availability of high purity crystals and low cost (compared to Ge)
- Much higher sensitivity than the silicon payload in CDMS II set up (0.8 kg vs 30 kg)
- All the more important in the present scenario
- Can be an unique experiment

JADUGUDA UCIL MINE SITE : SOME BACKGROUND

UCIL operation in Jaduguda (1967):

Jaduguda Mine
Bhatin Mine
Turamdih Mine
Bagjata Mine
Narwapahar Mine
Banduhurang Mine
Jaduguda Mill
Turamdih Mill
Mohuldih Uranium Project (New Project Under Construction)

The fact sheet about the Jaduguda mine:

- Distance from Kolkata by rail ~ 231 km
- Nearest rail station: Rakha Mines (~6 km from UCIL site)
- Time taken by express trains from Howrah: 3 hrs a few minutes
- Also connected to Kolkata by road via Kharagpur, Jhargram and Ghatshila (~5-6 hrs by road)
- Major junction rail station in the vicinity: Tatanagar (~20 km to the west)
- Time taken to go to Tatanagar by train: ~ 20 minutes
- Time taken to go to Tatanagar by road: ~ 1 hour
- No. of levels in the mine: 2 (550 m and 880 m depth)

JADUGUDA UCIL MINE SITE : A FEW PICTURES

Entry Tower to the mine shaft

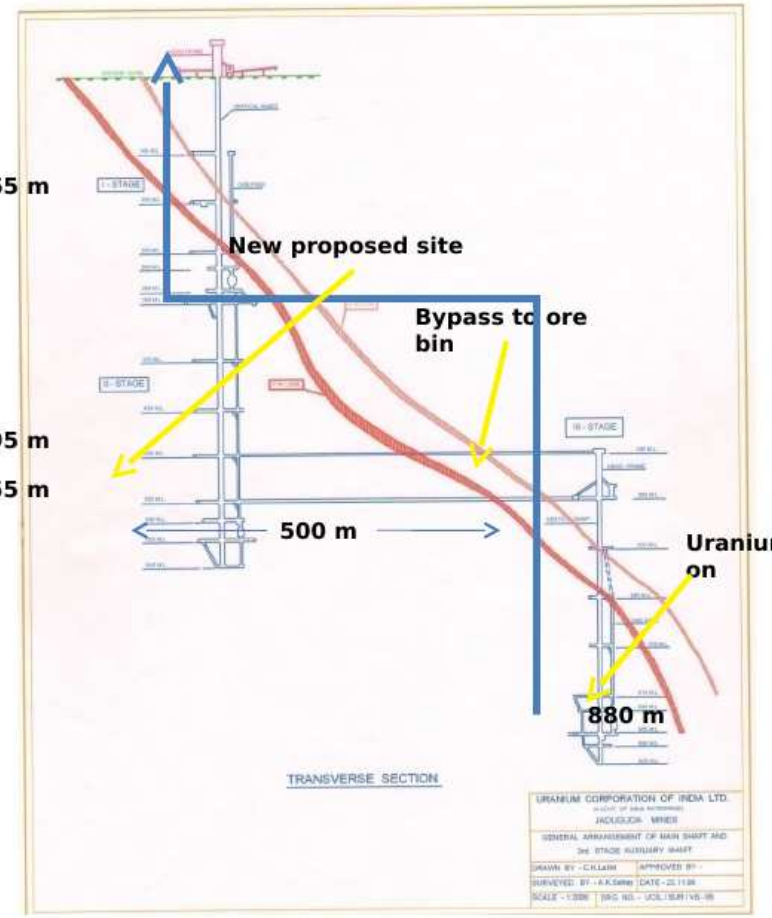
Rakha Mines Rly Station

From the Guest House

Tunnel along 550 m level

Shear zone and Mr Bhowmick, GM (Mines)

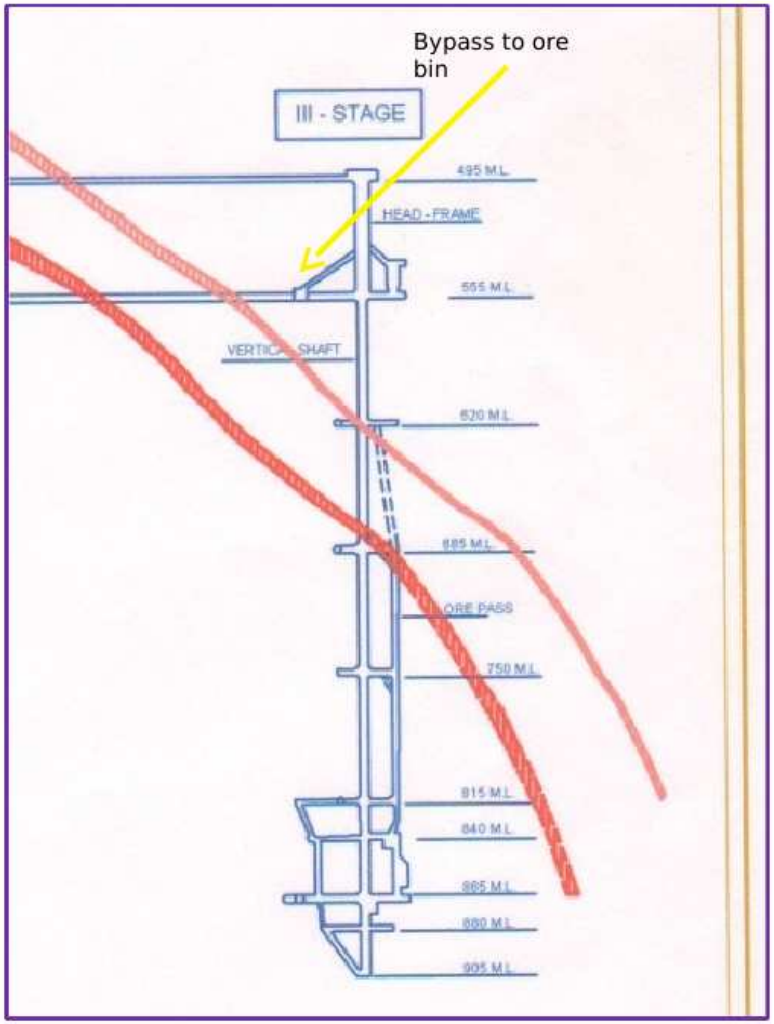
JADUGUDA MINE ELEVATION DRAWING



JADUGUDA MINE ELEVATION DRAWING

The fact sheet about the Jaduguda mine:

- No. of levels in the mine: 2 (550 m and 880 m depth)
- To reach 555 m level: By vertical shaft (shaft I), 3.5 Tonnes capacity, 4-5 km/hr speed
- To reach 880 m level: Walk 500 m horizontally , and go down by another shaft (shaft III)
- Active Uranium mining continuing at 880 m level (at least till 2020).
- Rock data inside the mine: Igneous (granite) stable rock not bearing uranium ore near & below shaft I. Metamorphosed quartz type rock near the shaft III.
- Average rock density = 2.9 gm/cc.



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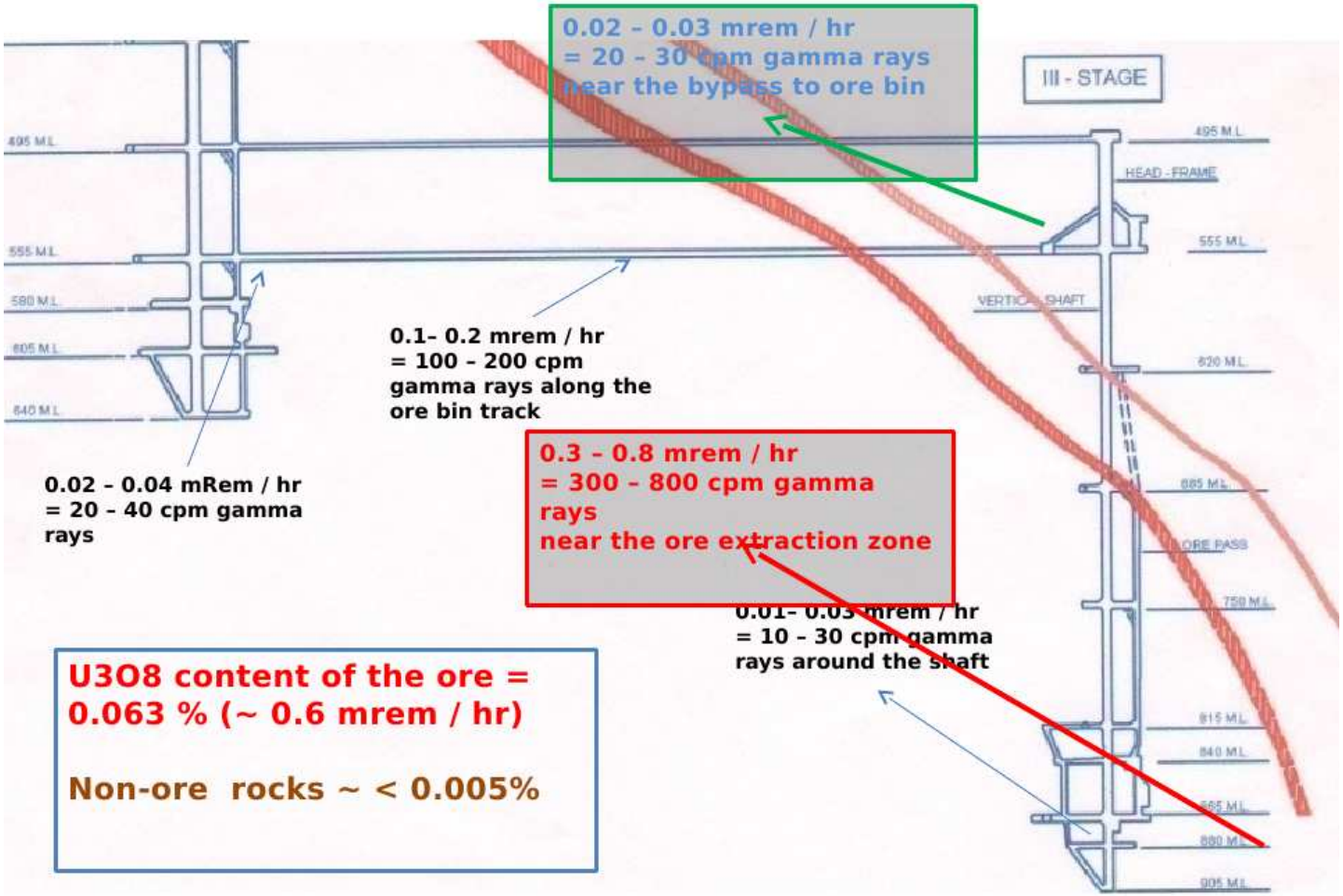
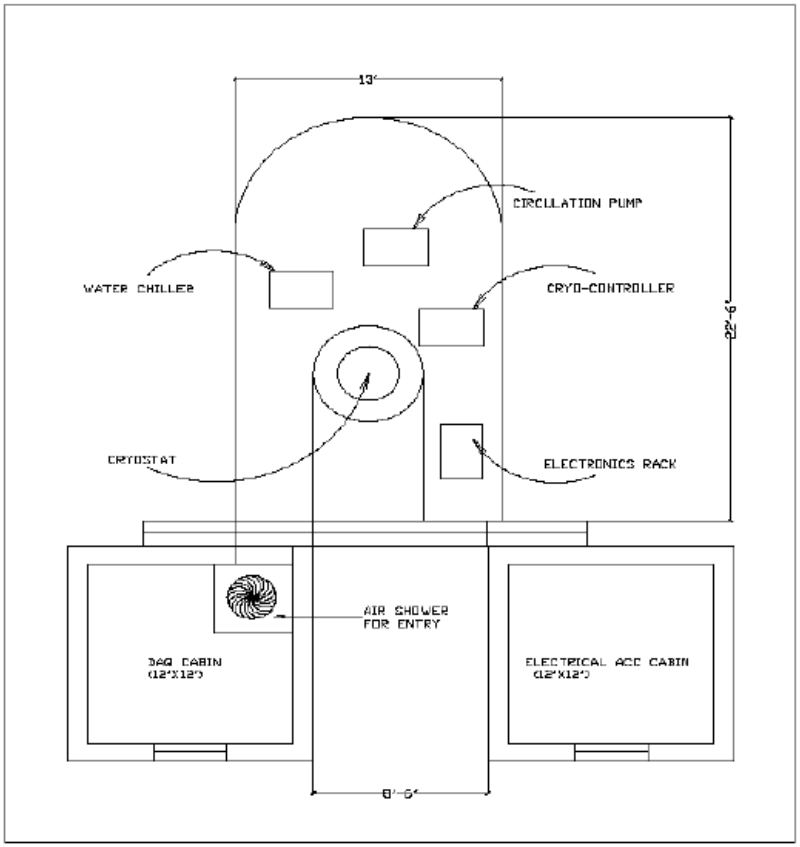
JADUGUDA MINE : VERY PRELIMINARY RADIATION SURVEY



Chemical composition analysis of Jaduguda rock samples (Courtesy: AMD, Hyderabad & Jamshedpur)	
SiO_2	66.45%
Al_2O_3	18.20%
FeO	4.61%
K_2O	2.61%
CaO	1.82%
Na_2O	1.60%
MgO	1.39%
TiO_2	0.59%

SIMULATION SET-UP INITIATED AT SINP
SOME WORK GOING ON AT TAMU & PRL

PROPOSED LABORATORY SITE DETAILS



- AT 550 M LEVEL NEAR THE SHAFT
- SIZE OF THE CAVE: 9 M x 5 M x 2.7 M
- DISCUSSION ON SITE PREPARATION FOLLOWING SINP-UCIL MOU

With several DD and ID experiments running + LHC, the Dark Side of the Universe is looking bright indeed!

Acknowledgments :

Astrophysics & Direct/Indirect detection phenomenology:
Soumini Chaudhury, Susmita Kundu, Ramanath Cowsik, Subhabrata Majumdar, ...

Direct detection experiments: PICASSO, DINO
Mala Das, Susnata Seth, Satyajit Saha, Rupak Mahapatra, R. Ranganathan, ...