PPC 2012

SIZING UP THE GALACTIC Weakly Interacting Massive Particle (WIMP) DARK MATTER..

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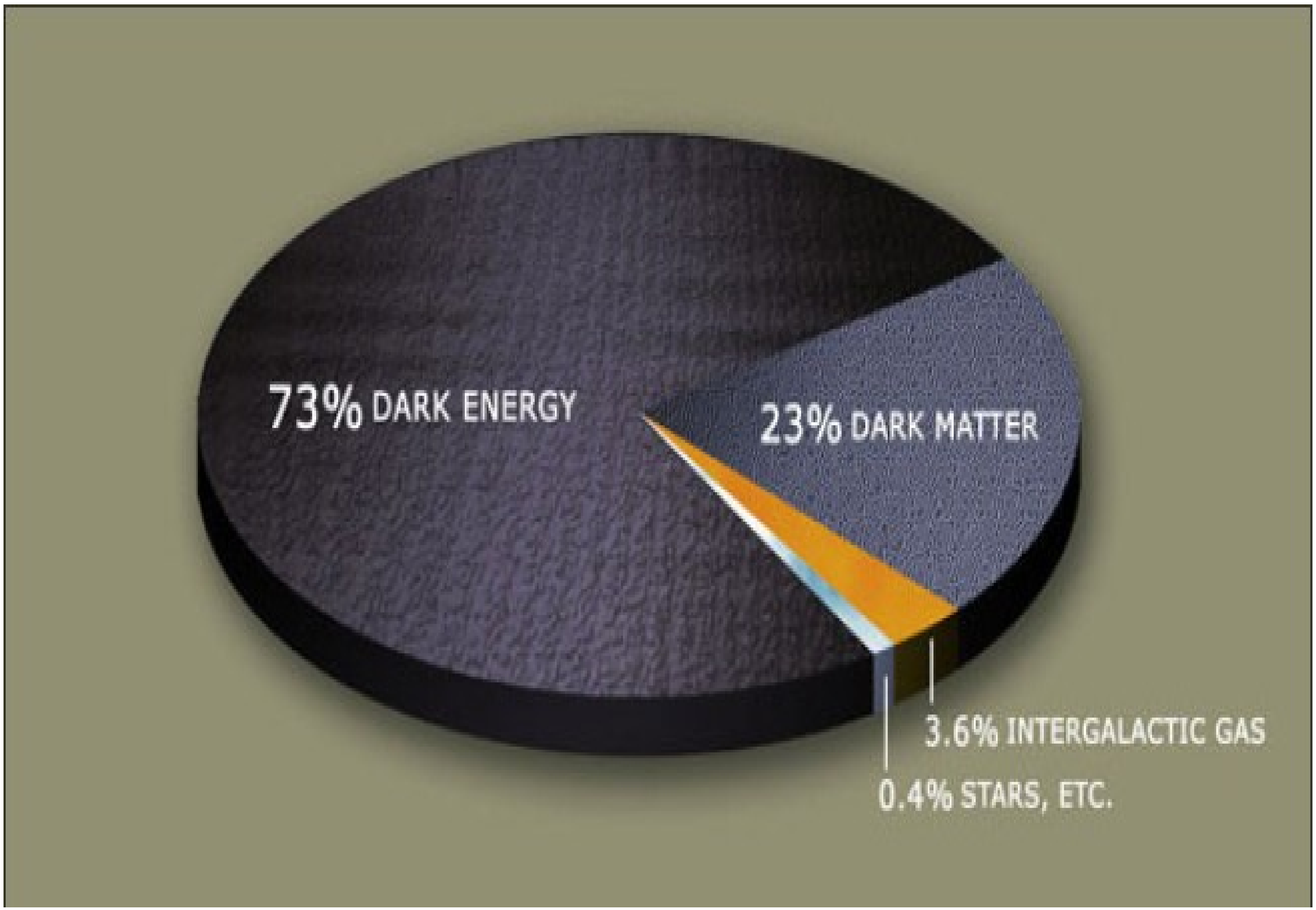
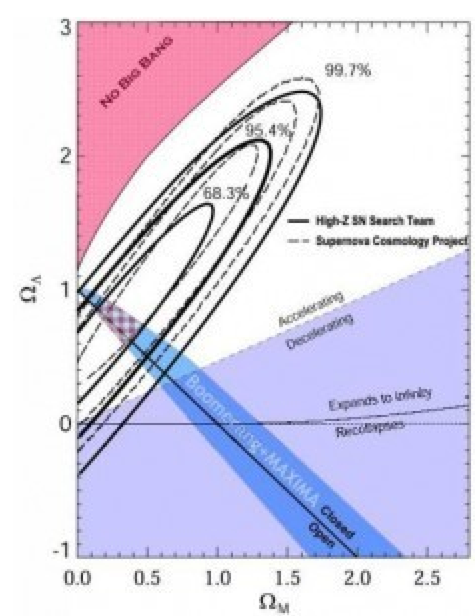
CALCUTTA
ADVANCEMENT OF KNOWLEDGE

COMPOSITION OF THE UNIVERSE

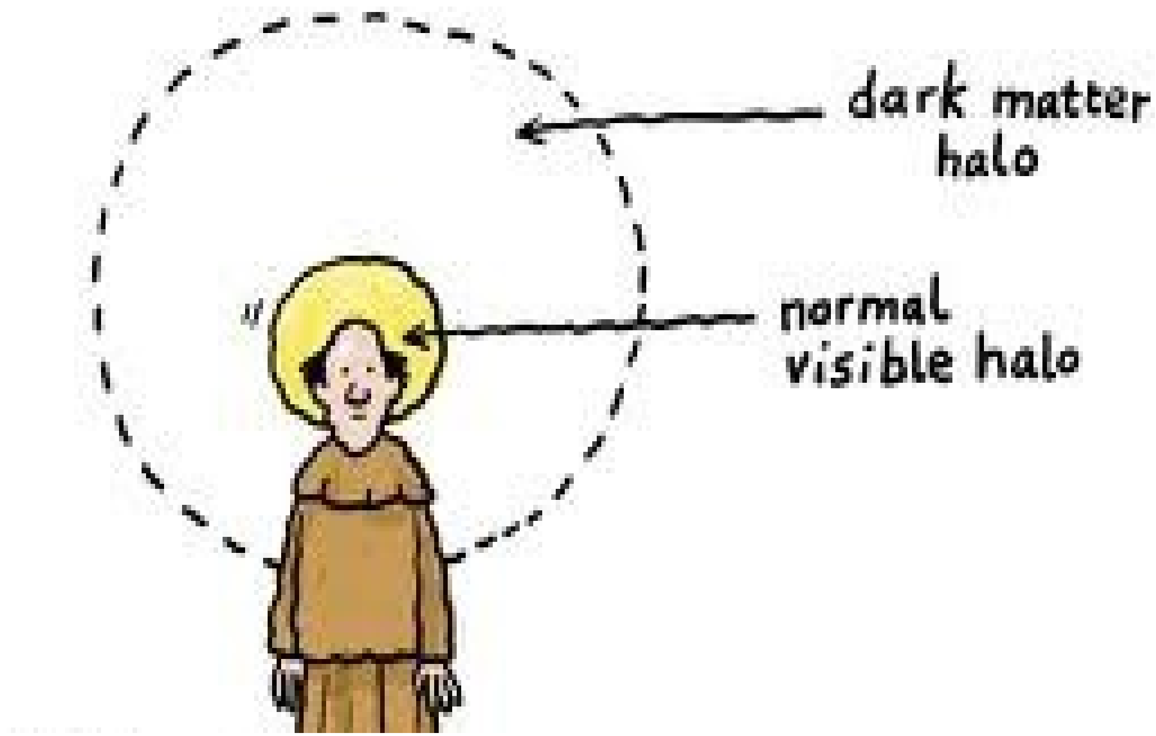




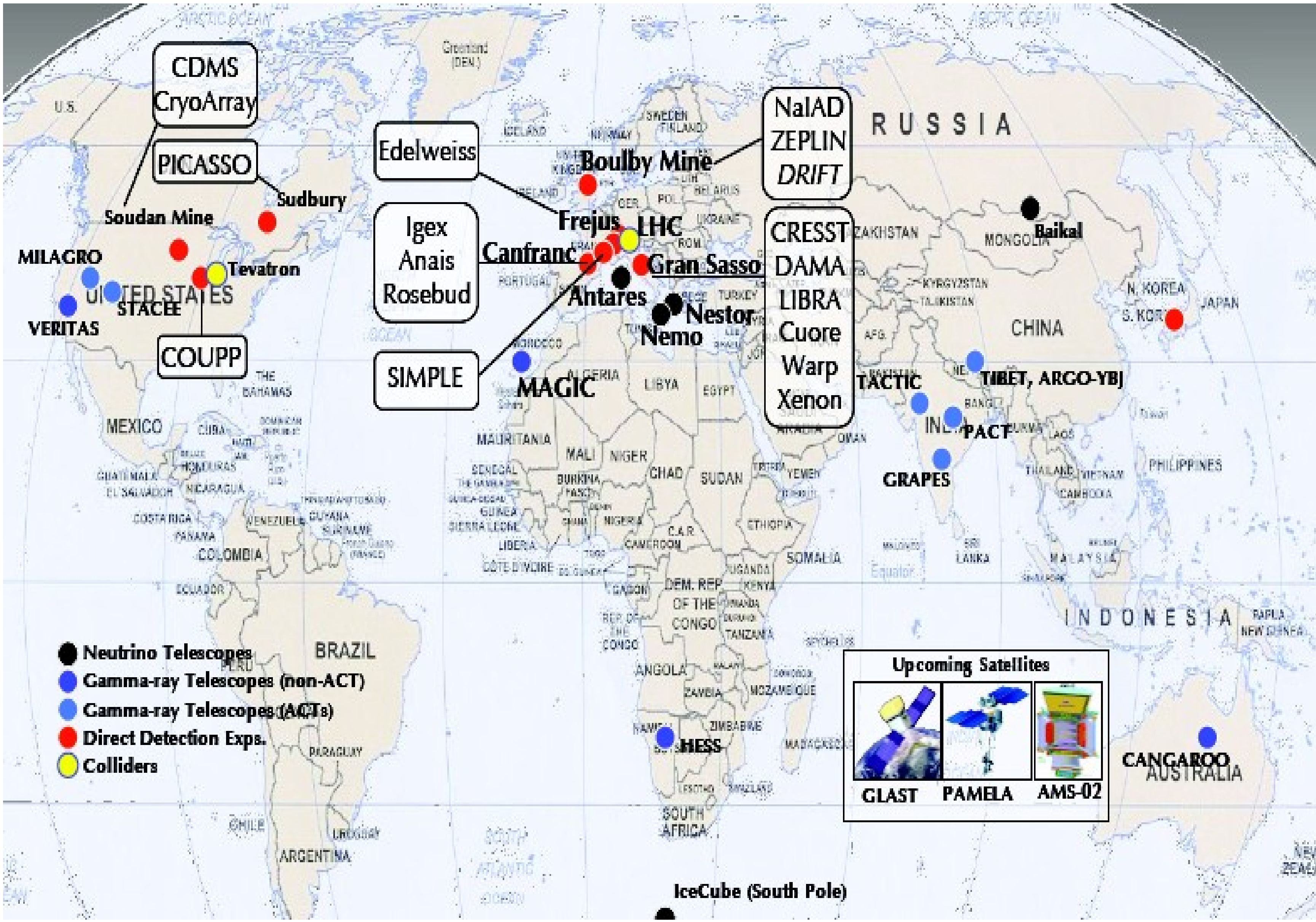
COSMOLOGICAL SCALE

TO

GALACTIC SCALE

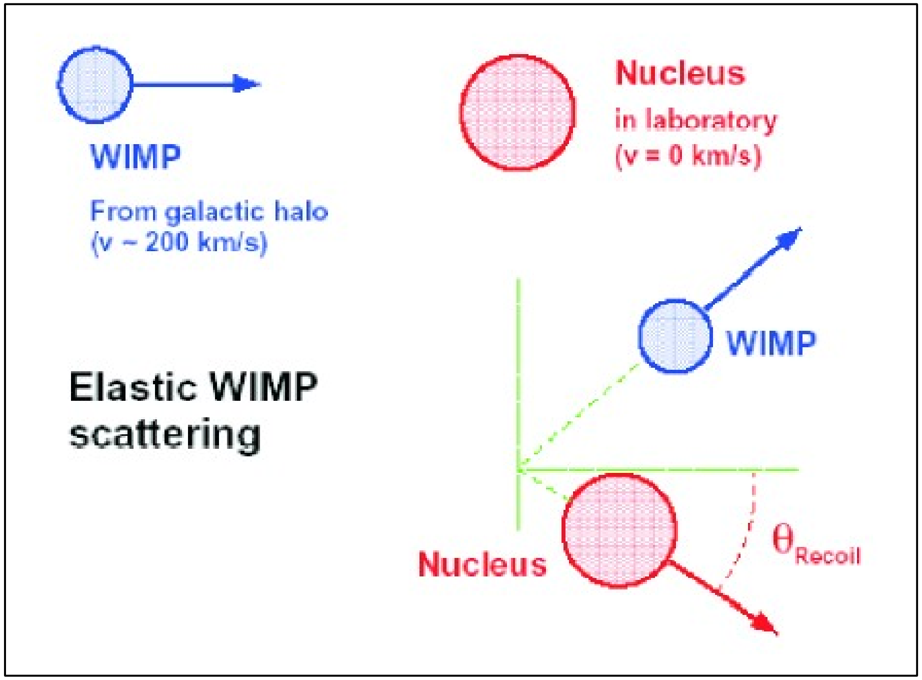


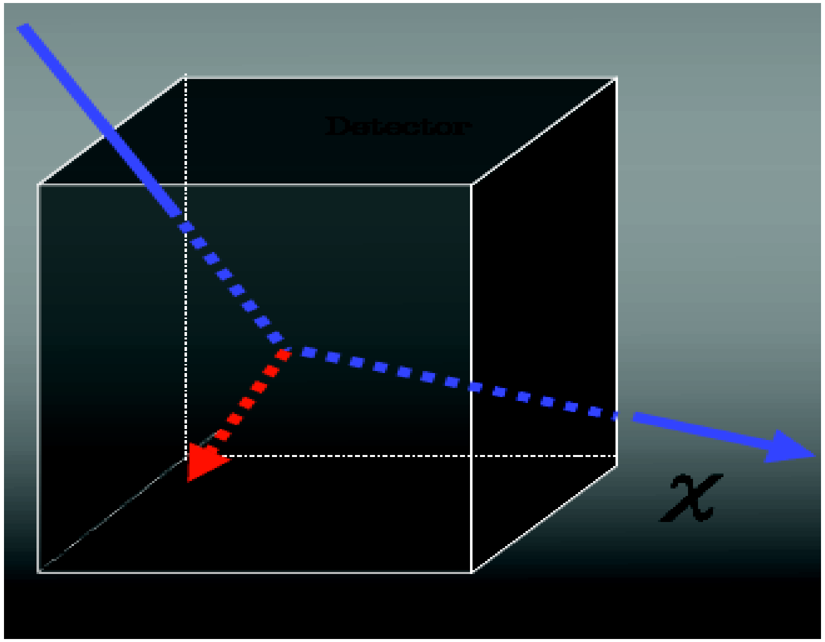
How to detect WIMP-s??????????



CDMS
CryoArray
PICASSO
Soudan Mine
Sudbury
MILAGRO
Tevatron
STACEE
VERITAS
COUPP
Edelweiss
Igex
Anais
Rosebud
SIMPLE
Boulby Mine
Frejus
LHC
Canfranc
Gran Sasso
Antares
Nestor
Nemo
MAGIC
NaIAD
ZEPLIN
DRIFT
CRESST
DAMA
LIBRA
Cuore
Warp
Xenon
Baikal
TACTIC
TIBET, ARGO-YBJ
PACT
GRAPES
HESS
CANGAROO
IceCube (South Pole)
Neutrino Telescopes
Gamma-ray Telescopes (non-ACT)
Gamma-ray Telescopes (ACTs)
Direct Detection Exps.
Colliders
Upcoming Satellites
GLAST
PAMELA
AMS-02

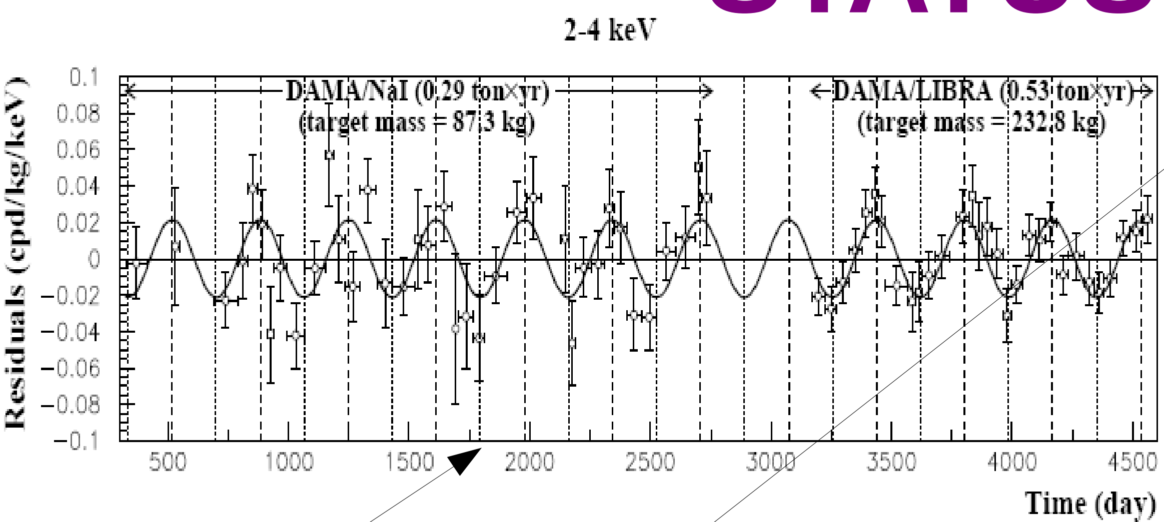
DIRECT METHOD

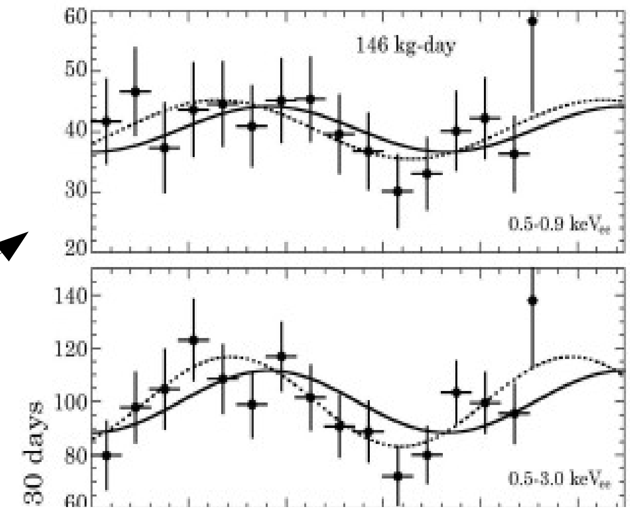


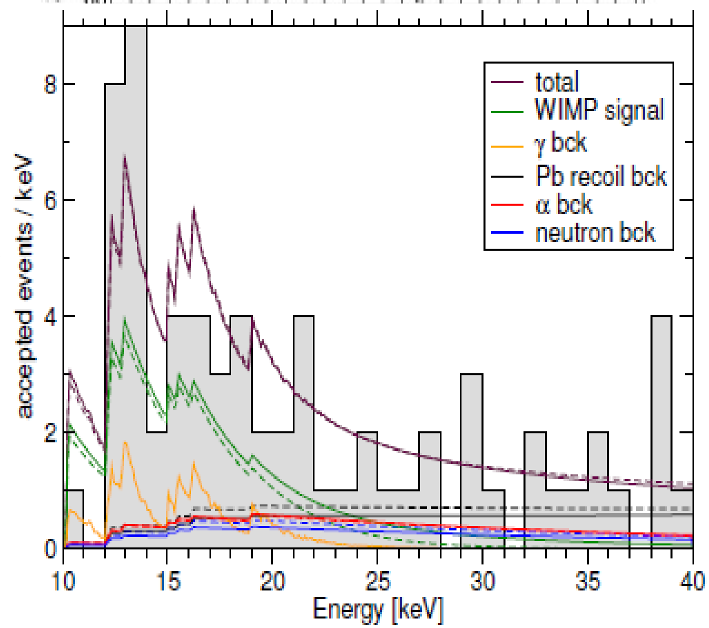


STUDYING WIMP RECOILS WITH TARGET NUCLEI IN DEEP UNDERGROUND MINES..TO SUPRESS BACKGROUNDS LIKE COSMIC RAYS.. SHIELDS TO WARD OFF LOCAL RADIOACTIVITY

STATUS..







- Till date DAMA and CoGeNT has reported to observe annual modulation of the events..
- CRESST-2 has claimed to have observed a positive signal..
- CDMS-II has seen two events but ascribed them to background..
- XENON-100 has reported null result and provide more stringent bounds on the cross section..(arxiv:1104.2549)

DIFFERENTIAL SPECTRUM

for a single nuclei species

$$\frac{dR(E_R)}{dE_R} = \frac{\sigma^0_{N\chi}}{2\mu^2_{N\chi} m_\chi}[F^2(E_R)]_{SD/SI}\, \rho_\chi \int_{v_m}^{v^{earth}_{max}} \frac{f_{earth}(\vec{v},t)}{v} d\vec{v}$$

$$\mu_{N\chi} = \frac{m_\chi m_N}{m_\chi + m_N}$$

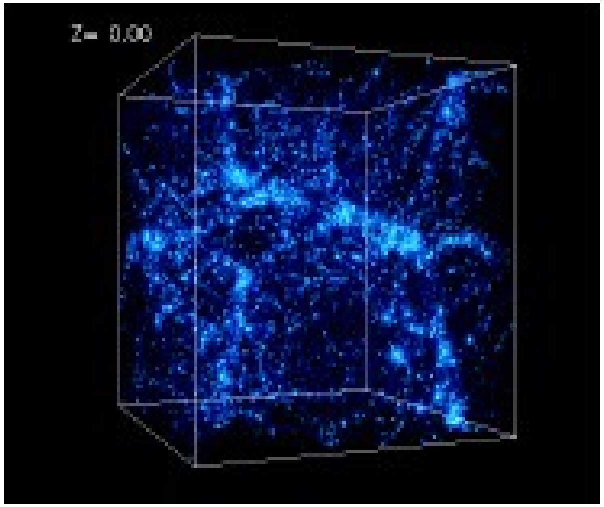
$$g(E_R, t)$$

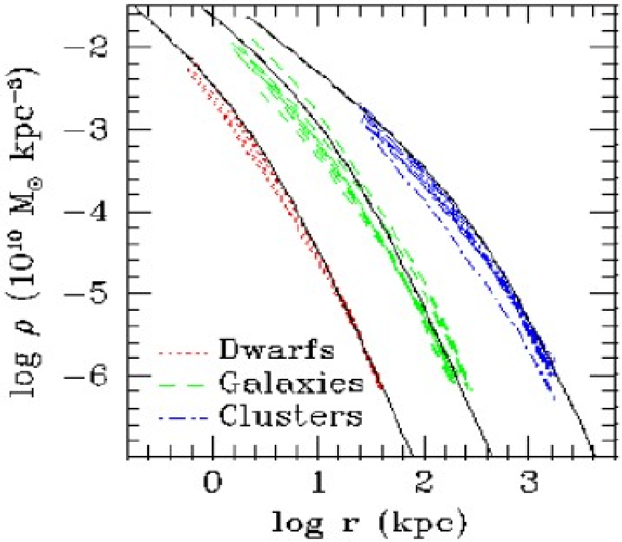
$$v_m = \sqrt{\frac{1}{2E_R m_N}[\frac{E_R m_N}{\mu^2_{N\chi}}]}$$

m_χ = mass of WIMP
ρ_χ = local density of WIMP
$\sigma_{N\chi}$ = WIMP-nucleon cross section
F = Nuclear Form factor

NFW PROFILE..

- N-body simulations have become the standard way to investigate the structure, dynamics and evolution of dark halos.
- Navarro-Frenk-White (1996) found that they revealed “universal” properties..
- Cuspy density profile..

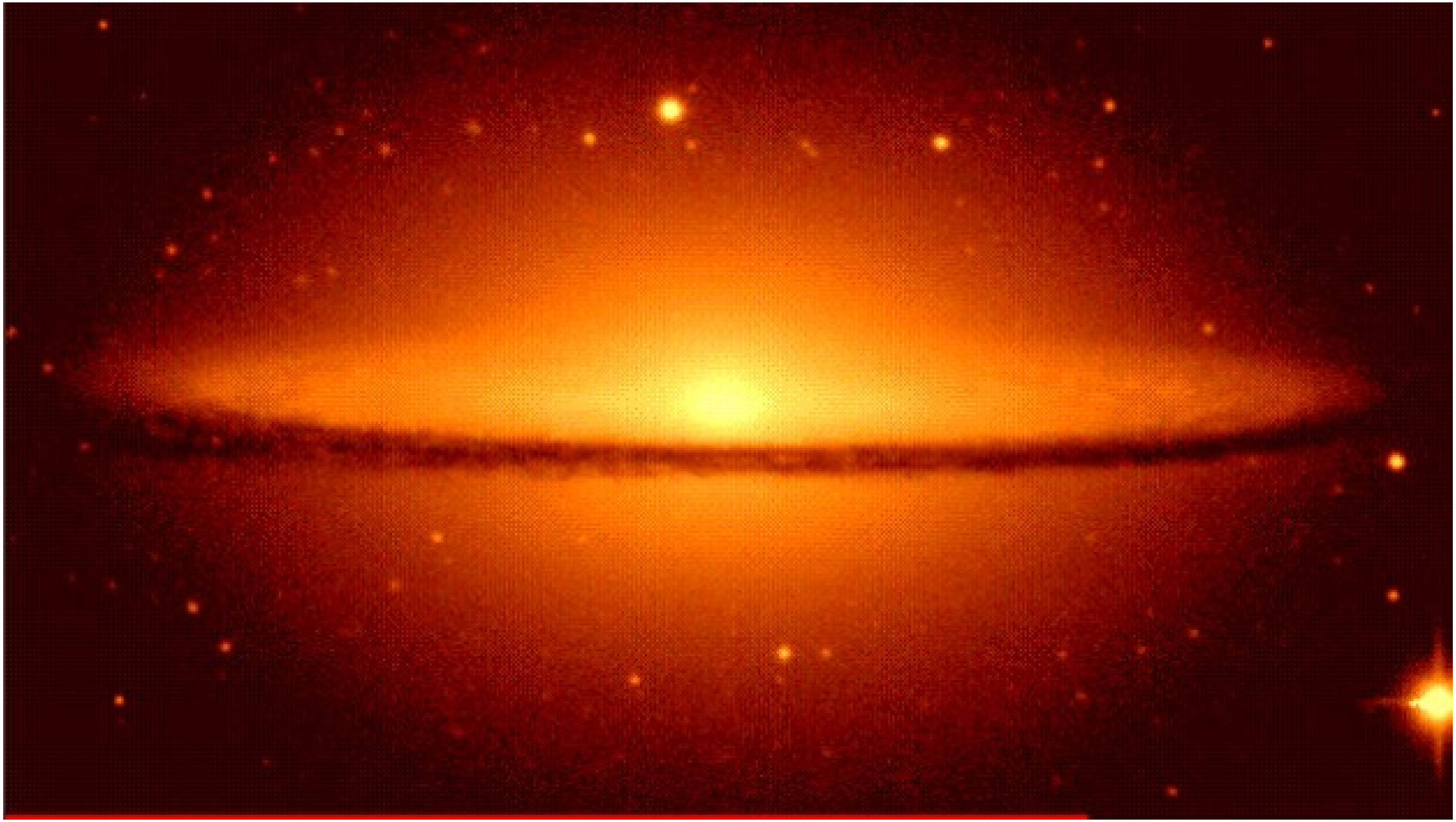




$$\rho_{DM}(r)=\rho_{sun}\frac{R_{sun}}{r}\frac{(r_s+R_{sun})^2}{(r_s+r)^2}$$

Free parameters: ρ_{sun}, r_s

VM PROFILE OF A TYPICAL MILKY WAY TYPE GALAXY..



VM COMPONENTS

- Central bulge:

$$\rho_b(r) = \rho_0 \left(1 + \frac{r^2}{a^2}\right)^{-3/2}$$

- Exponential disk:

$$\rho_d(R,z) = \frac{\Sigma}{2\mathrm{h}} e^{-\frac{R-R_0}{R_d}} e^{-\frac{|z|}{h}}$$

Solving for the Rotation velocity profile..

- Density profiles known from constant mass-luminosity ratio.

$$\rho_{VM} = \rho_{Bulge} + \rho_{Disk}$$

- Solving Poisson's equation.

$$\nabla^2 (\Phi_{VM} + \Phi_{DM}) = 4\pi G (\rho_{VM} + \rho_{DM})$$

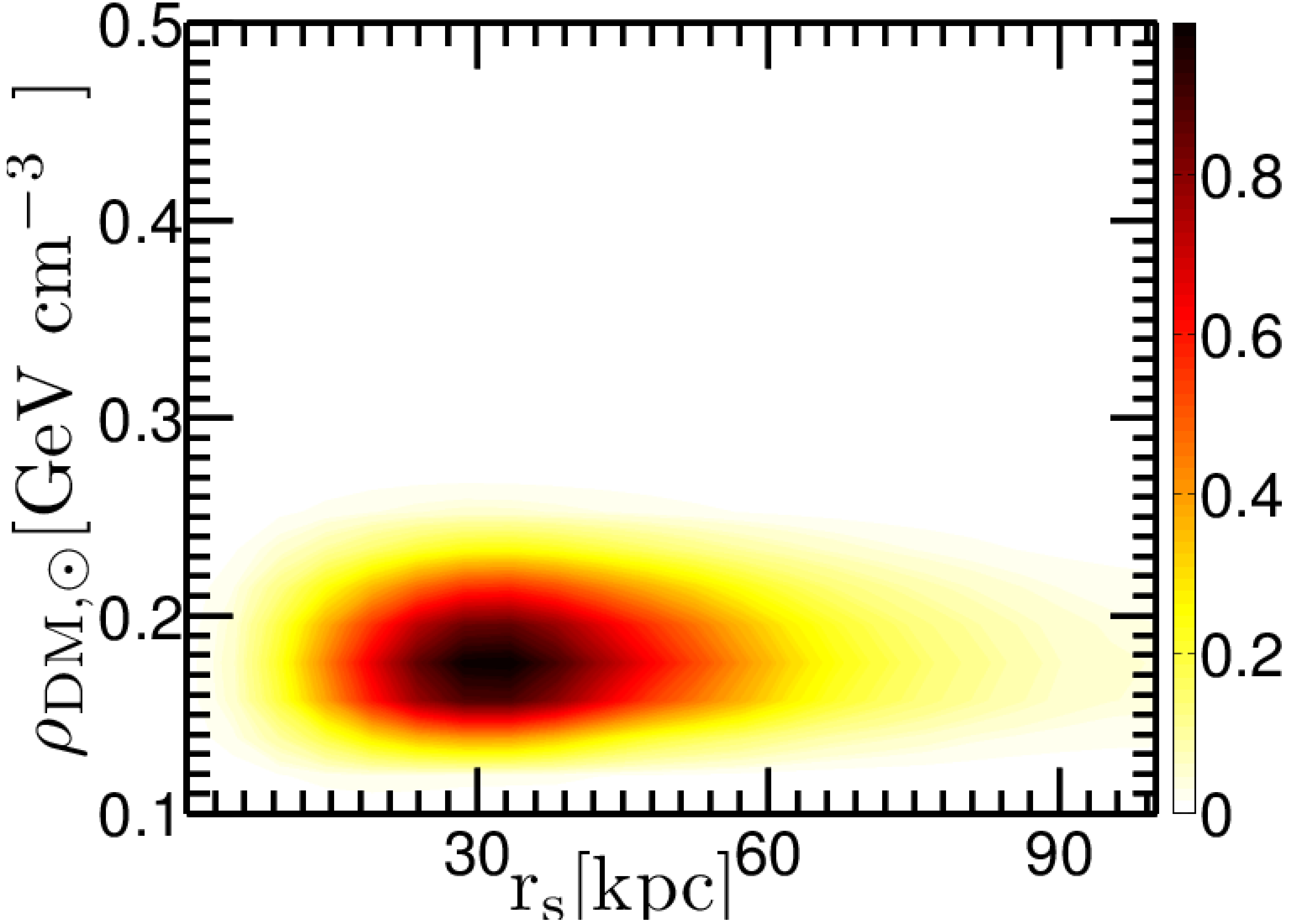
- Rotation velocity(r) follows from

$$v_c(R) = \sqrt{-R \nabla \Phi_{total}(R,z)_{(z=0)}}$$

- MCMC analysis to fit the recently compiled set of Rotation curve data by Sofue [Ref: PASJ 2012, Vol 64, 75] .
- VM prior ranges were set to consistent with observation.
- DM parameter space generated with marginalising over all VM parameter space..

RESULTS

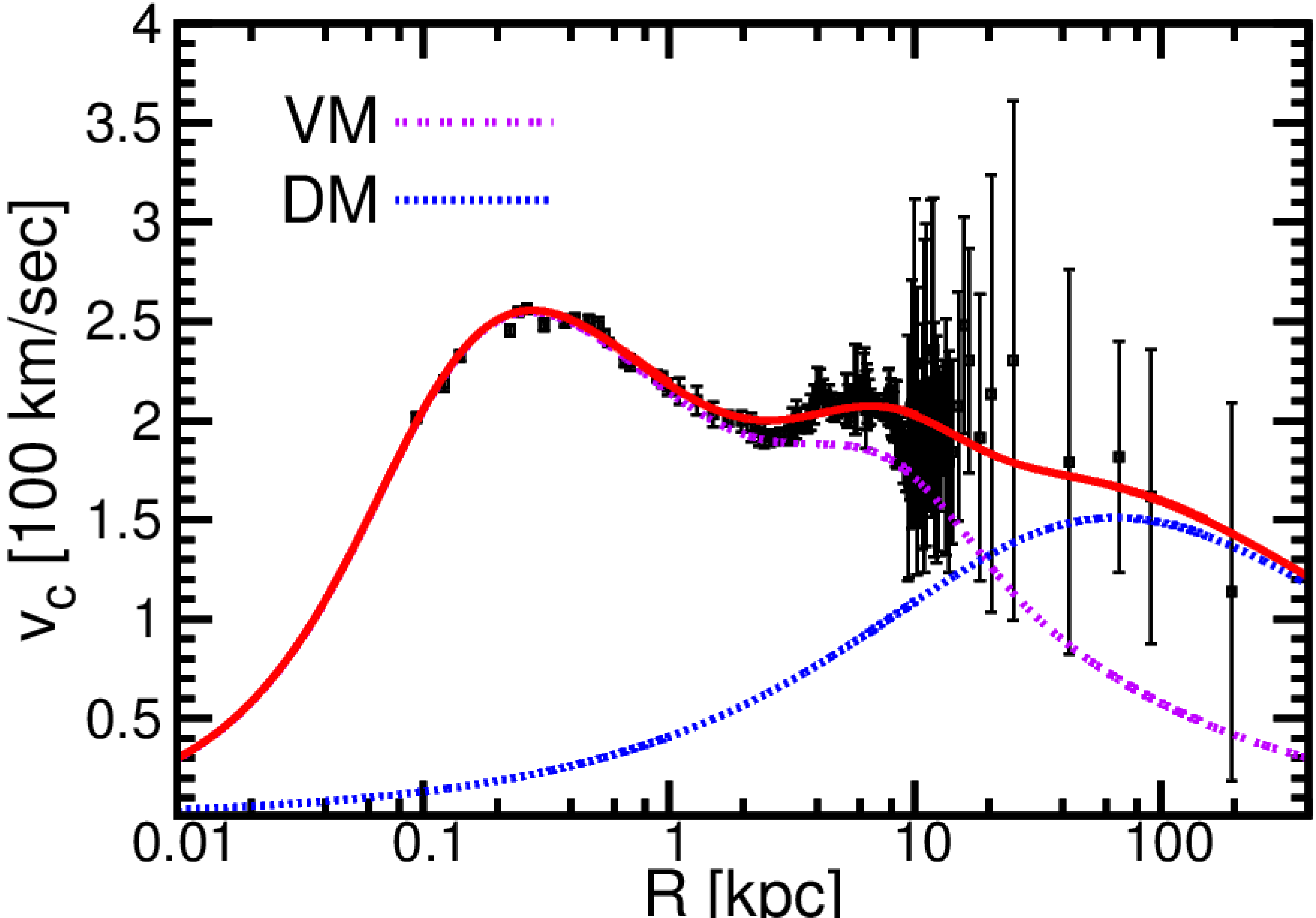
DM PARAMETER SPACE



MOST LIKELY ROTATION CURVE

Data:Y. Sofue, Ref: PASJ 2012, Vol 64, 75

standardised at LSR: R_{sun} = 8 kpc, v_{sun} =200 km/sec



DERIVED QUANTITIES..

Derived Quantities	Unit	Values
Total Bulge Mass	$10^{10}\ M_\odot$	$3.53^{+1.81}_{-1.29}$
Total Disk Mass	$10^{10}\ M_\odot$	$4.55^{+0.2}_{-0.22}$
Total Baryonic Mass (M_b)	$10^{10}\ M_\odot$	$8.07^{+2.01}_{-1.51}$
Halo mass $\leq\ R_\odot$	$10^{10}\ M_\odot$	$1.89^{+0.72}_{-0.3}$
Halo Virial Mass (M_h)	$10^{11}\ M_\odot$	$8.61^{+14.01}_{-5.22}$
Total Mass of Galaxy M_{b+h}	$10^{11}\ M_\odot$	$9.42^{+14.21}_{-5.37}$
Virial Radius ($r_{\rm vir}$)	kpc	$199.0^{+75}_{-53.5}$
Concentration Parameter($\frac{r_{\rm vir}}{r_s}$)		$6.55^{+5.01}_{-2.05}$
Total Mass$\leq\ R_\odot$	$10^{10}\ M_\odot$	$7.09^{+1.9}_{-1.15}$
Total Mass$\leq$ 50 kpc	$10^{11}\ M_\odot$	$3.35^{+1.64}_{-1.09}$
Total Mass$\leq$ 60 kpc	$10^{11}\ M_\odot$	$3.93^{+2.15}_{-1.41}$
Total Mass$\leq$ 100 kpc	$10^{11}\ M_\odot$	$5.92^{+4.35}_{-2.56}$
Local Circular velocity	km s^{-1}	$206.47^{+24.67}_{-16.3}$
Local escape velocity	km s^{-1}	$516.02^{+120.85}_{-97.58}$
Total Surface Density	$M_\odot\ \mathrm{pc}^{-2}$	$11.31^{+2.42}_{-1.16}$

EDDINGTON-S FORMULA

Given a spherical system of collisionless particles like NFW halo, Eddington's formula can be used to derive the Phase Space Distribution Function assuming the Velocity profile to be isotropic..

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

$f_r(v)=F(E')/\rho(r)$ is the velocity profile at any location r

with $v_{max}(r)=\sqrt{2\psi(r)}$.

Here, E' = the negative of the total energy E per unit WIMP

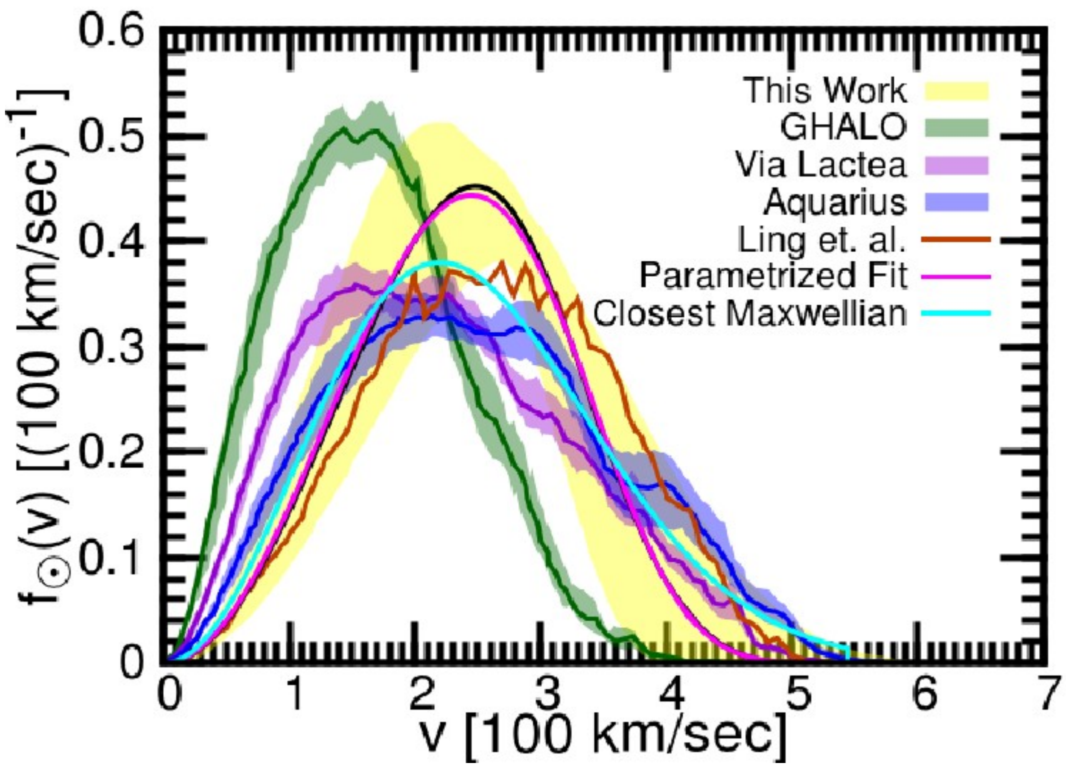
Mass. = $\Psi-\frac{v^2}{2}$ where, Ψ = the negative of the total

gravitational potential.

LOCAL f_{sun}(v)..PROPOSED FIT..

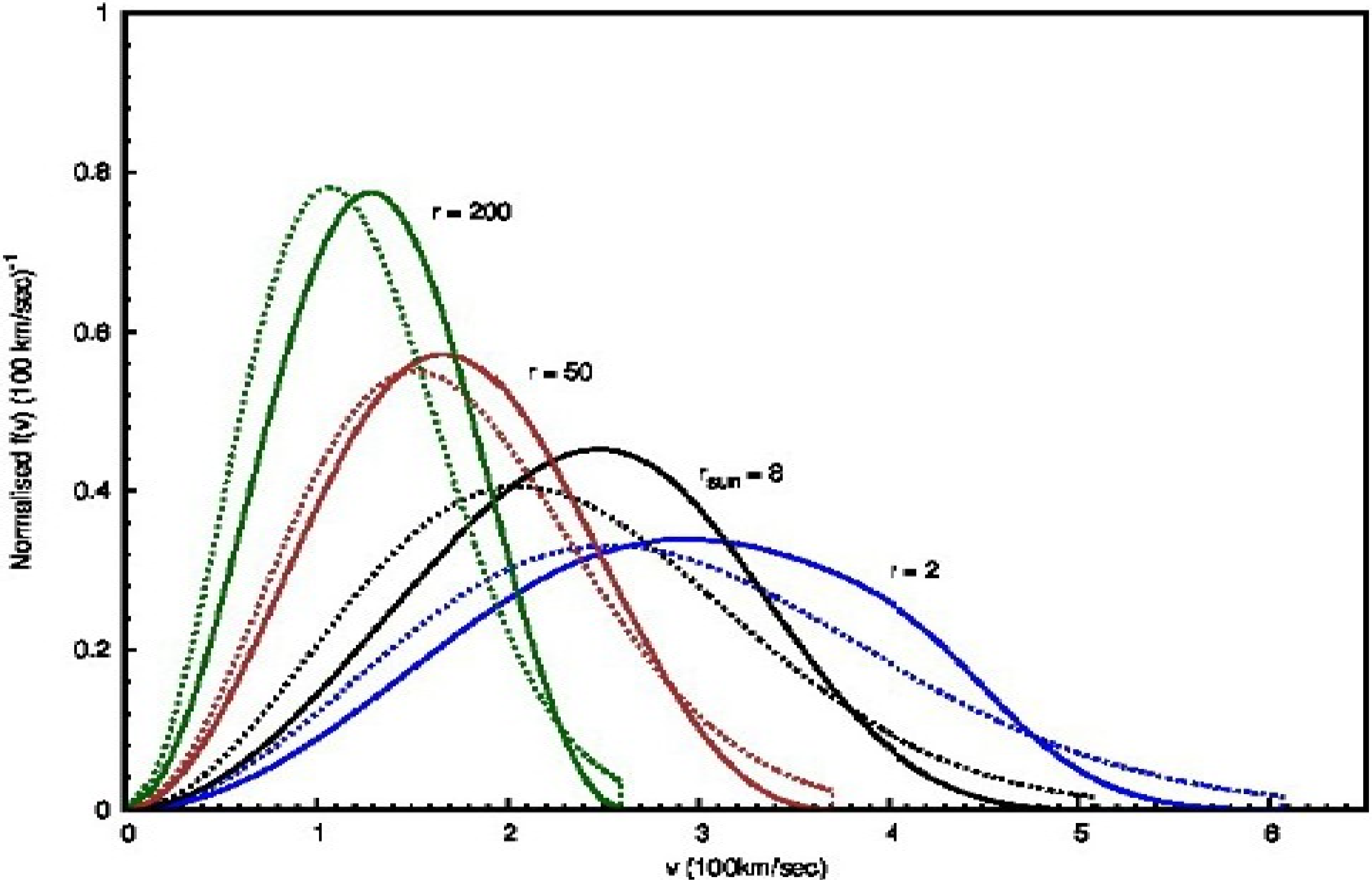
Proposed fit: $$f(v) \propto 4\pi v^2 [\eta(\beta) - \eta(\beta_{max})]$$

$$\eta(x) = (1+x)^k e^{-x^{(1-k)}} \qquad \beta = v^2/v_0^2 \qquad \beta_{max} = v_{max,sun}^2/v_0^2$$



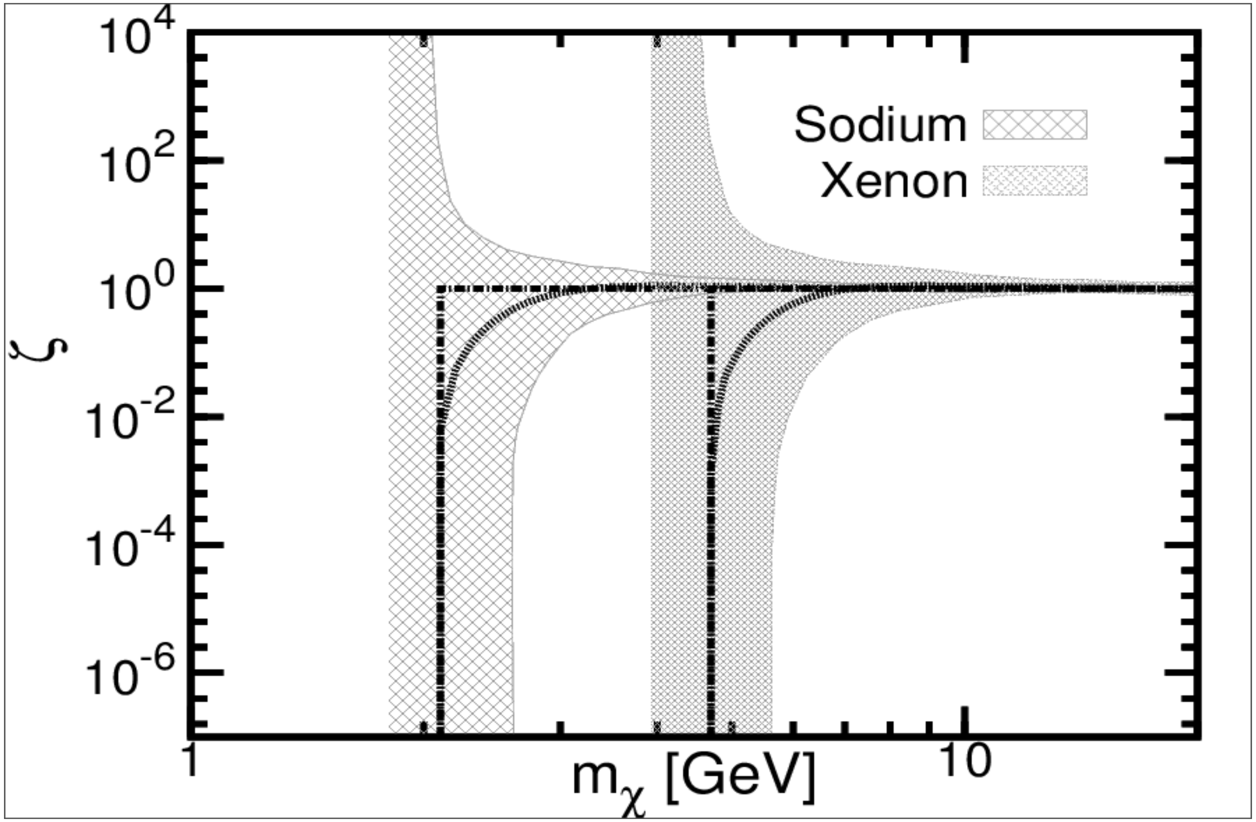
β = 339 km/sec, k = -1.47 with $k \rightarrow 0$ gives standard Maxwellian profile..

f(v) at other galactic positions.. deviations from close fit Maxwellian



Effect on Experimental rates

$$\zeta = \frac{g_{model}}{g_{closest\ maxwellian}}$$



The ratio is ~100 at the minimum probed mass..

(With E_R set at a typical value of 2 KeV..and t at June 2nd..)

WRAPPING UP..

- **.Obtained best fit profile with NFW halo extended rotation data upto 300 kpc**
- The most likely halo scale radius=30.36 kpc, local density 0.19 Gev/cc(<0.3 GeV/cc), Halo mass 8.6X10^11 Solar Mass, Local escape speed 516 km/sec unlike the customarily used value of 544 km/sec (RAVE Survey)
- **Local f(v) turned out to be better fitted with a non Maxwellian form as indicated by recent simulations..Even f(v) at other galactic positions appears to be non Maxwellian..**
- The effect of f(v) is significant (as much as two orders of magnitude) on the direct detection rates..below closest Maxwellian..

Reference:

arXiv: 1210.2328

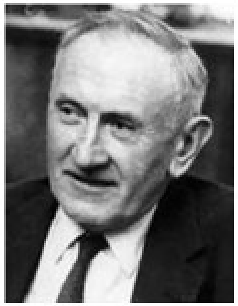
work done with -

Pijushpani Bhattacharjee, SINP, India

Susmita Kundu, SINP, India

Subhabrata Majumder, TIFR, India

ZWICKY'S WORK



- F.Zwicky in 1933 measured the dispersions (1019 \pm 360 km/sec) of 7 galaxies of coma cluster and estimated total dynamic mass of the cluster by virial theorm.

$$2 < T > = - < V >$$

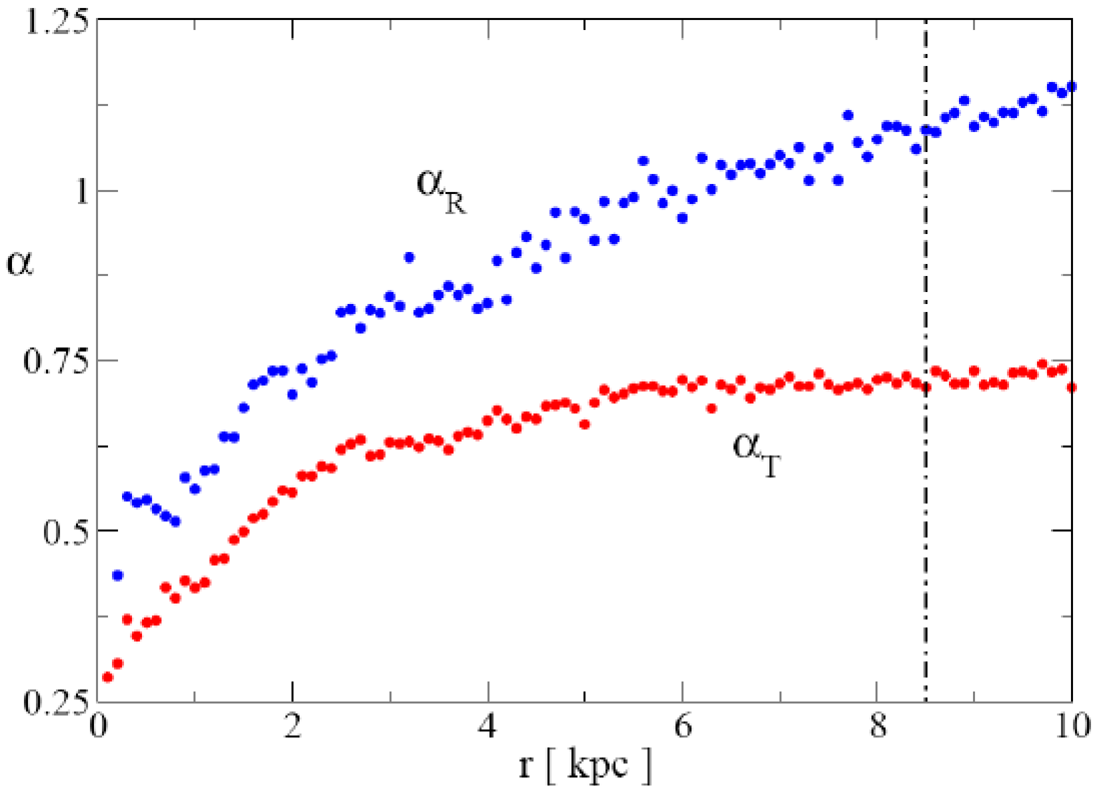
$$< v^2 > = \frac{GM_{tot}}{r_g}$$

- Estimated the Mass with the mass to Light ratio of nearby spirals with luminosity concluded :

$$M_{tot} \approx 400 \times M_{Visible\ Mass}$$

- Same conclusion for unaccounted mass was drawn by Smith in 1936 for Virgo cluster..

Via Lactea non-Gaussianity and anisotropy



INTERACTIONS

SPIN INDEPENDENT: the DM interacts with the mass of the nucleus as a whole
Scattering amplitude from nucleons add coherently..

SPIN DEPENDENT: the DM interacts with the non zero total spin angular momentum of the nuclei..

$$C_{SI}^{p=n} = A^2 ; C_{SD}^{p/n} = \frac{4}{3}[\Lambda_A^{p/n}]^2 J(J+1)$$

$$\Lambda_A^{p/n} = \frac{a_n S_{n,avg} + a_p S_{p,avg}}{J\, a_{p/n}}$$

A=mass no of nucleus
J=spin angular momentum of the nucleus
a_n a_p = WIMP-nucleon coupling
S'_n or S'_p =Average nucleon spins

$F(E_R)$ = Form Factor arising due to finite nulcear size.

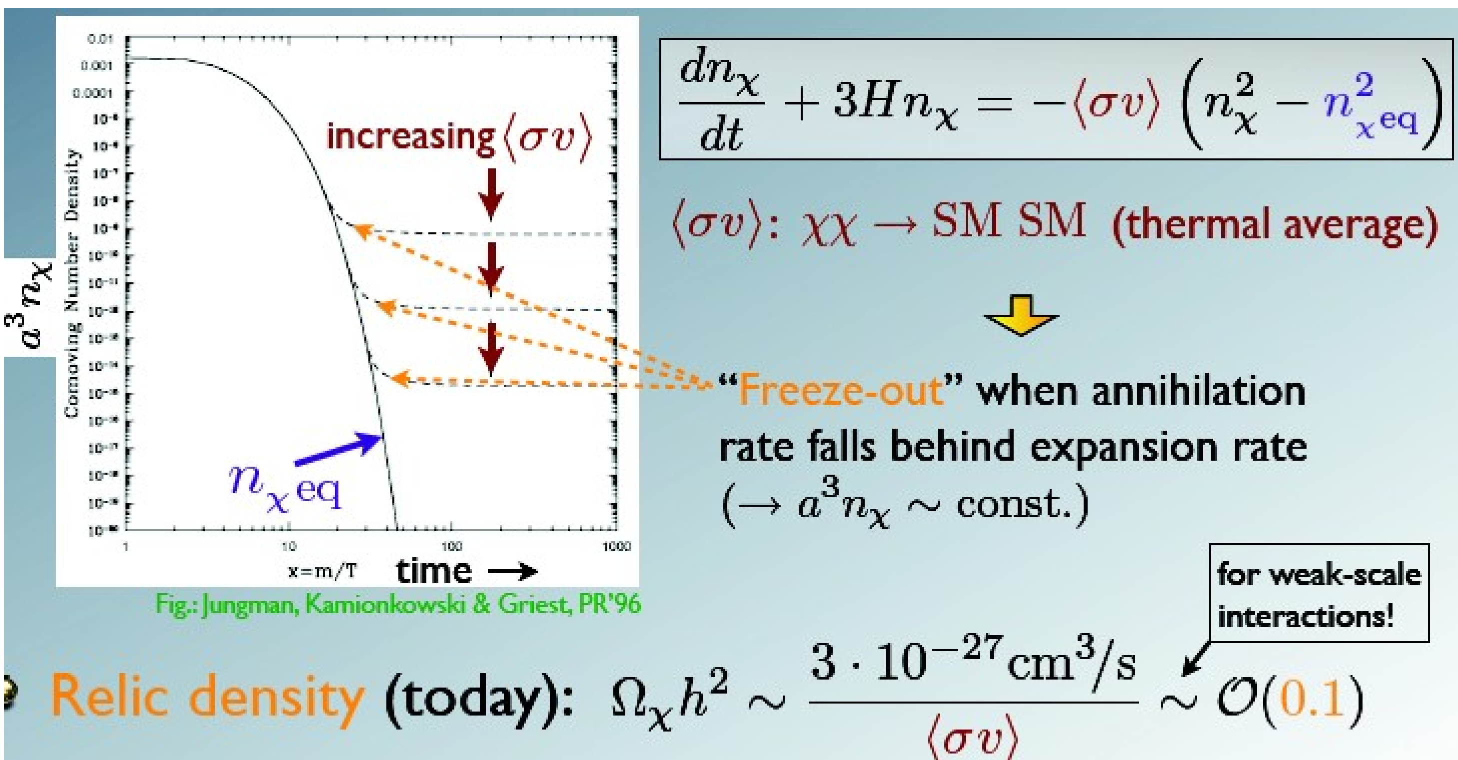
$$F_{SI}(Q) = 3\frac{j_1(Qr_0)}{Qr_0} e^{\frac{-(Qs)^2}{2}} \qquad Q = \sqrt{2E_R m_N}$$

WEAKLY **I**NTERACTING **M**ASSIVE **P**ARTICLE

currently the most favoured DM candidate.

particles at GeV-TeV scale that produce the DM thermal relic density at EW scale.

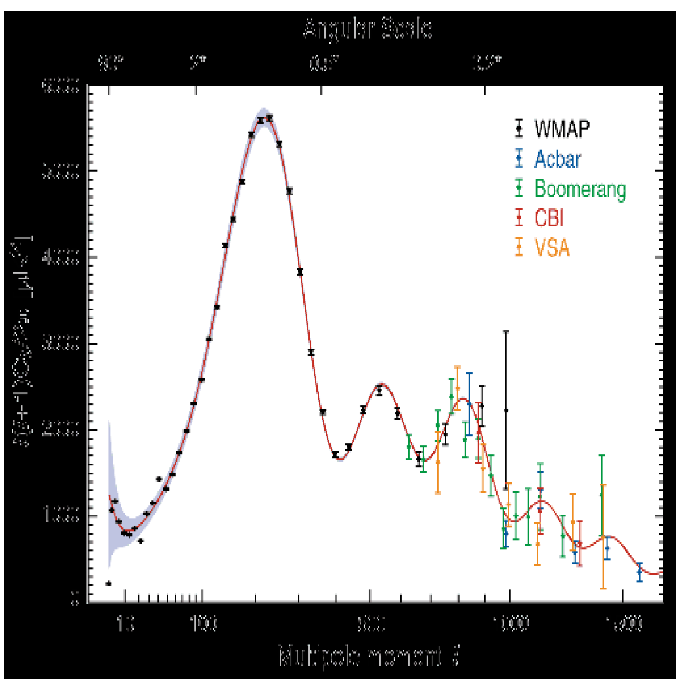
- **ABUNDANCE GOVERNED BY BOLTZMANN EQUATION**

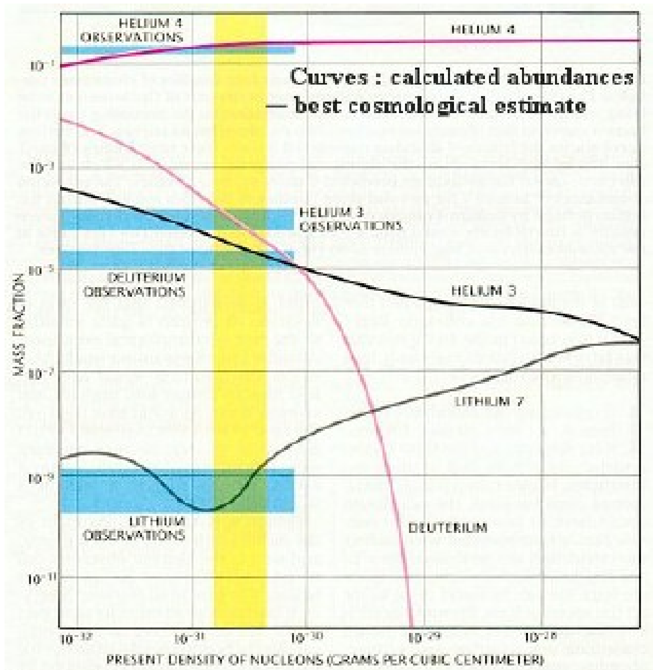


Gamma_ann = <sigmaann v>n <H

Nature???

•Electrically neutral & no Strong interaction.
•Gravitational interaction..
•Expected to have Weak Interaction; Weakly Interacting Massive particles (WIMP-s) can reproduce cosmological DM relic density..
•Neutralino (Lightest SUSY) is one of the favoured WIMP-s
•CMB and Primordial nucleosysnthesis indicates them as mostly non baryonic.
•LSS scales indicates 'Cold' nature..
•CDM simulations suggest towards a Cuspy profile for the DM Halos..





MCMC RESULTS WITH 68% CL BOUND..

Parameter	r_s	$\rho_{\mathrm{DM},\odot}$	ρ_{b0}	r_{b}	$\Sigma_\odot$	R_{d}
Unit	kpc	GeV/cc	10^4GeV/cc	kpc	$M_\odot$ pc^{-2}	kpc
Best-Fit	30.36	0.19	1.83	0.092	57.9	3.2
Lower	14.27	0.17	1.68	0.083	55.51	2.99
Upper	53.37	0.23	2.0	0.102	58.0	3.27
Mean	41.35	0.20	1.84	0.092	54.30	3.14
S. Dev.	20.51	0.02	0.059	0.001	3.47	0.11

$R_\odot$ = 8.0 Kpc & R_z = 340 pc

- **COMPONENTS OF UNIVERSE:**
-
- **Visible Matter:** *It's all that we can see..stars,galaxies, gases,dust etc.*
- **Dark Matter**:*Mostly new form of non-baryonic matter..outside SM*
- **Dark Energy:***Exerts negative pressure..leads to accelerated expansion of universe in present epoch..type-1a supernovae with known intrinsic brightness can be taken as standard candles to estimate the expansion rate of universe..*

  showed nonlinear Hubble relationship due to acceleration..how?

MODULATION

$$\frac{dR(E_r,t)}{dE_r} \approx S_0(E_r) + S_i(E_r)\cos[\omega(t - t_0)]$$

$$S_m(E_r) = \frac{1}{2}\left[\frac{dR\ (E_r, June\ \ 2^{nd})}{dE_r} - \frac{dR(E_r, Dec\ \ 2^{nd})}{dE_r}\right]$$

Scintillation : Recoil energy of nucleus taken up by electrons which radiate through scintillation detected by photomultiplier tubes.**[DAMA,XENON]**

Ionization : As the nucleus moves through the target mass it ionizes other target atoms and Electrostatic field detected. **[CDMS,CoGeNT,XENON]**

Phonons : Detected by semiconductor and superconductor-junction sensors. Recoil energy is detected by change of semiconductor (doped Ge) resistance in a bolometer under cryogenic condition (<50 mK)**.[CDMS,CRESST?]**