TRISEP 2013

COSMOLOGY & DARK MATTER

Part III

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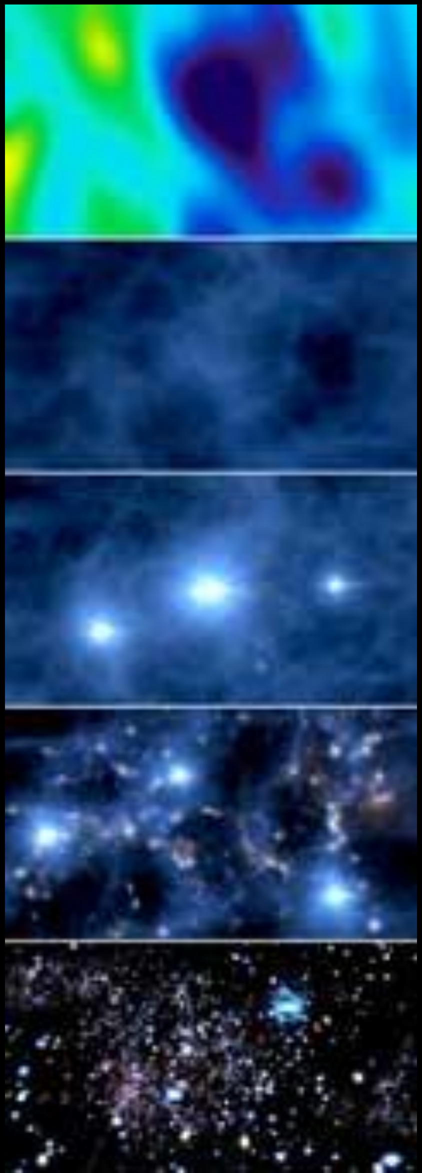
TRIUMF July 2013

Lecture III

- Dark Matter and Large Scale Structure
- Dark Matter candidates
- Neutralino interactions with Matter
- Status of indirect search experiments
- Status of direct search experiments
- Future directions

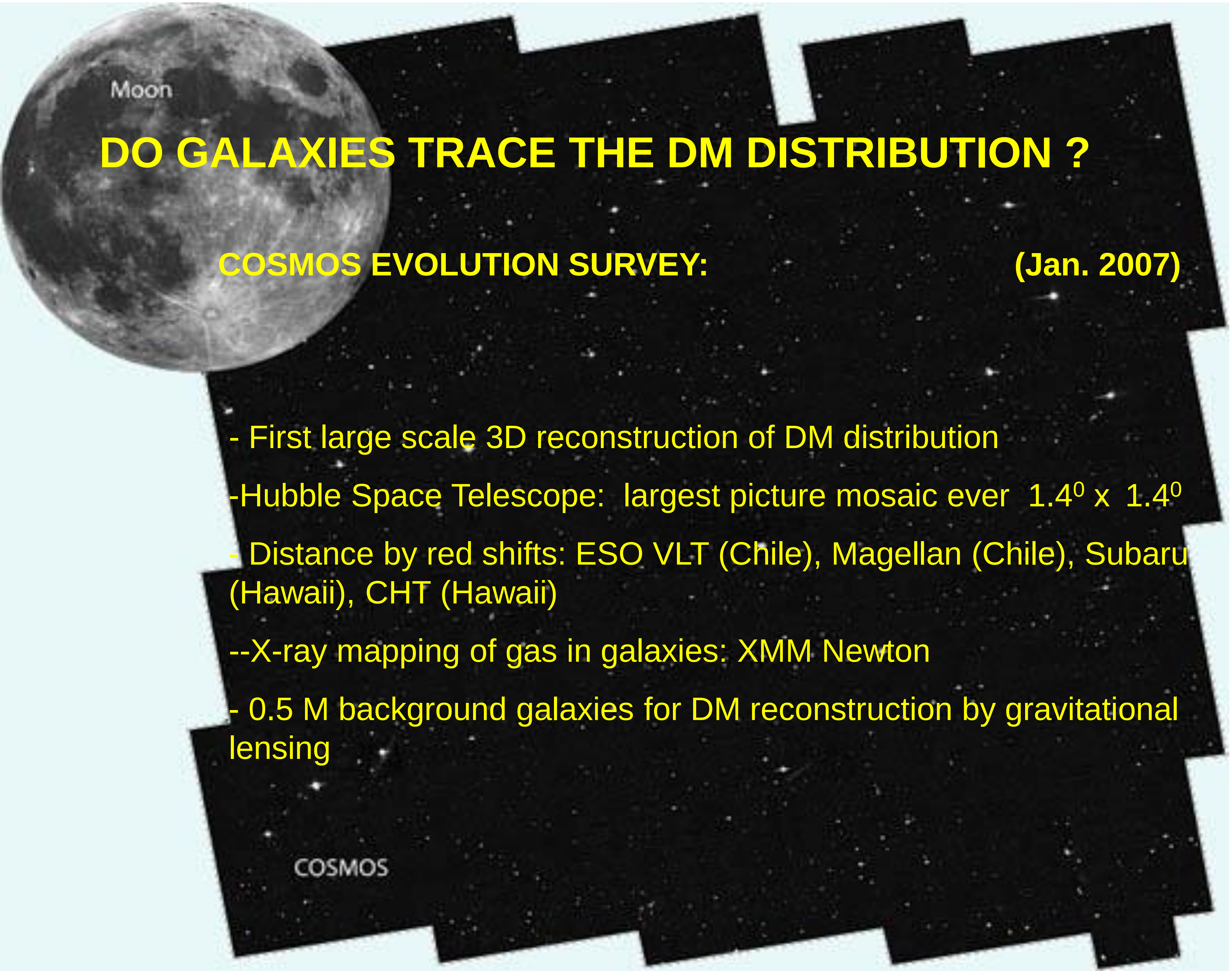
DM & DEVELOPMENT OF STRUCTURE



- BB creates DM + ord. Matter
- DM decouples early
- Clumps
- Ordinary matter flows in
- Galaxies form
- Galaxies trace DM distribution

DO GALAXIES TRACE THE DM DISTRIBUTION ?

COSMOS EVOLUTION SURVEY: (Jan. 2007)



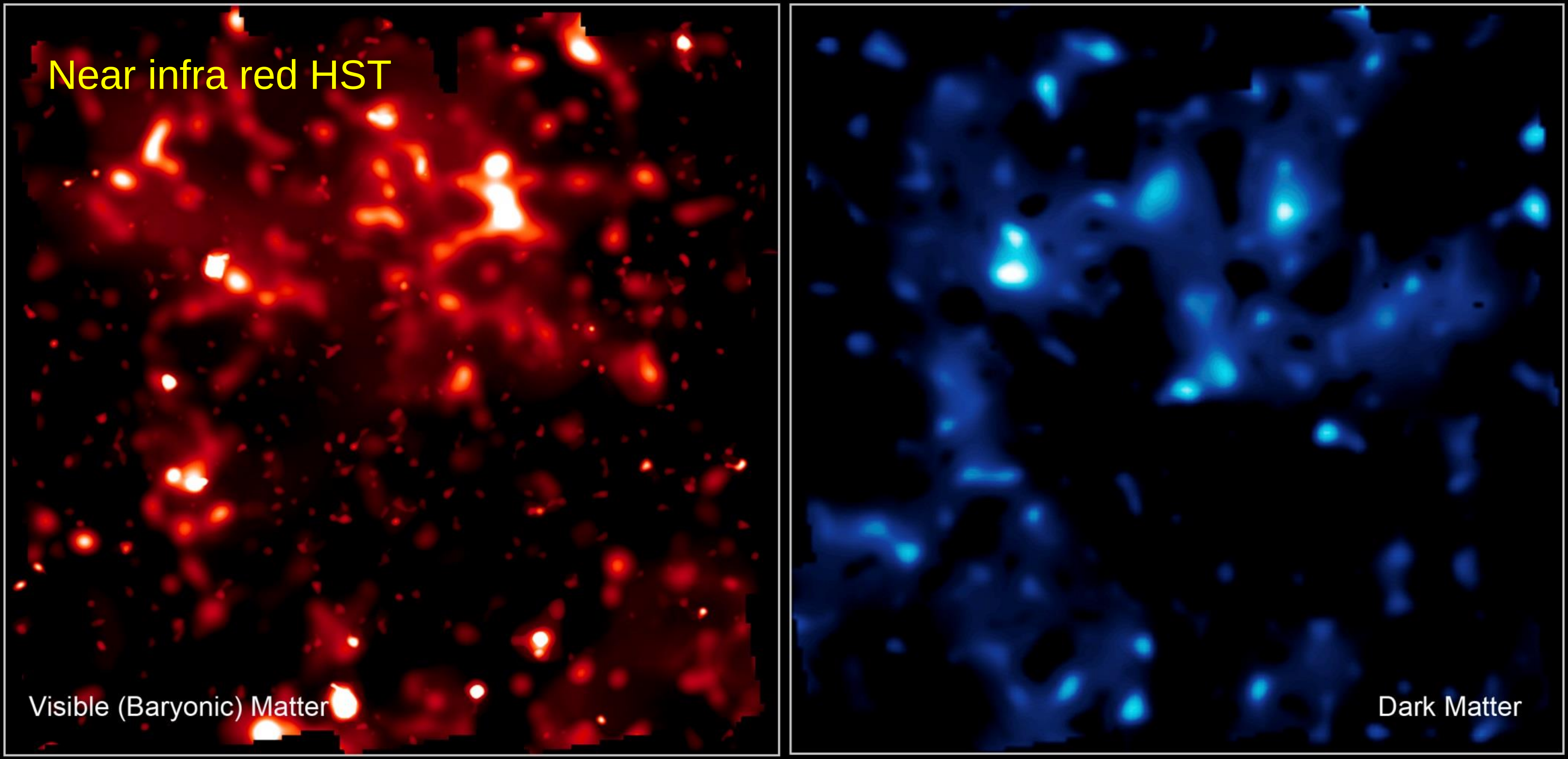
- First large scale 3D reconstruction of DM distribution

-Hubble Space Telescope: largest picture mosaic ever 1.4^0 x 1.4^0

- Distance by red shifts: ESO VLT (Chile), Magellan (Chile), Subaru (Hawaii), CHT (Hawaii)

--X-ray mapping of gas in galaxies: XMM Newton

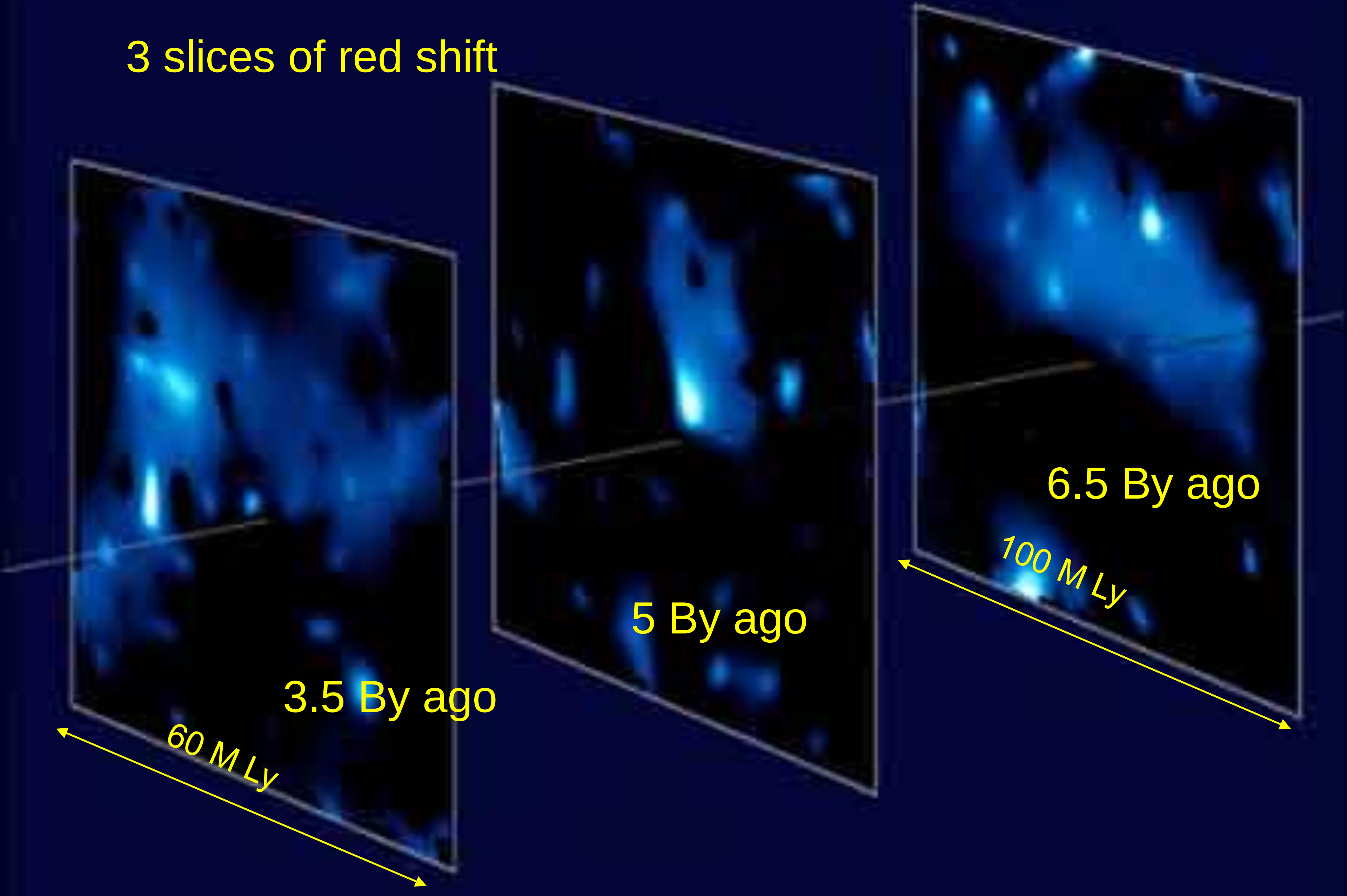
- 0.5 M background galaxies for DM reconstruction by gravitational lensing



DM > six times more abundant than ordinary matter

Growing clumpiness of DM & ordinary matter flowing in

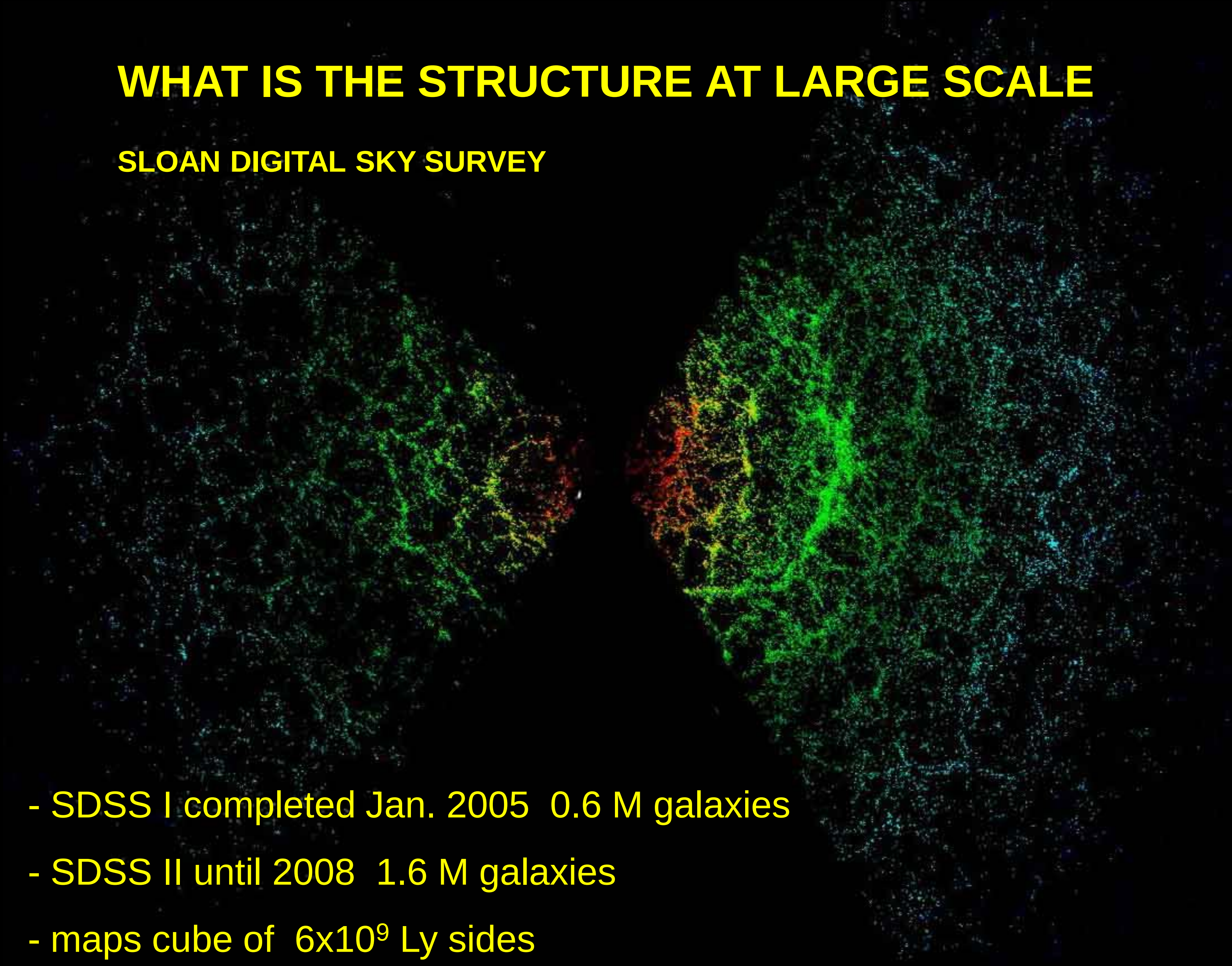
3 slices of red shift



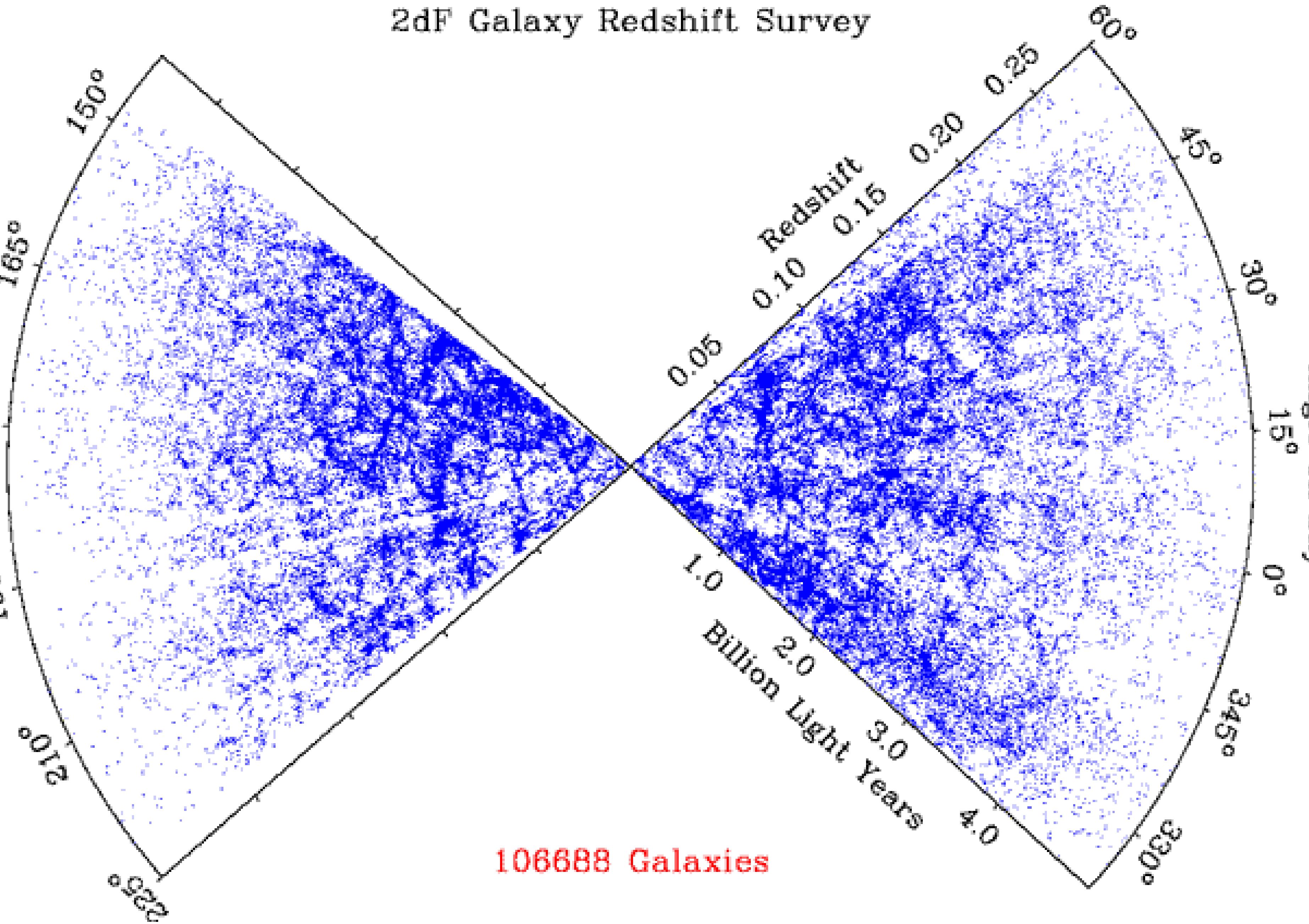
Growing clumpiness of DM & ordinary matter flowing in

WHAT IS THE STRUCTURE AT LARGE SCALE

SLOAN DIGITAL SKY SURVEY



- SDSS I completed Jan. 2005 0.6 M galaxies
- SDSS II until 2008 1.6 M galaxies
- maps cube of $6x10^9$ Ly sides



2dF Galaxy Redshift Survey
Redshift
0.05
0.10
0.15
0.20
0.25
Billion Light Years
1.0
2.0
3.0
4.0
Angle on Sky
60°
45°
30°
15°
0°
345°
330°
150°
165°
180°
195°
210°
225°
106688 Galaxies

WHAT KIND OF MATTER CAN EXPLAIN LSS?

Baryonic matter @T=225s (BBN) cannot clump to form voids (200MLy) filaments & superclusters

…structures thinned out by Hubble expansion

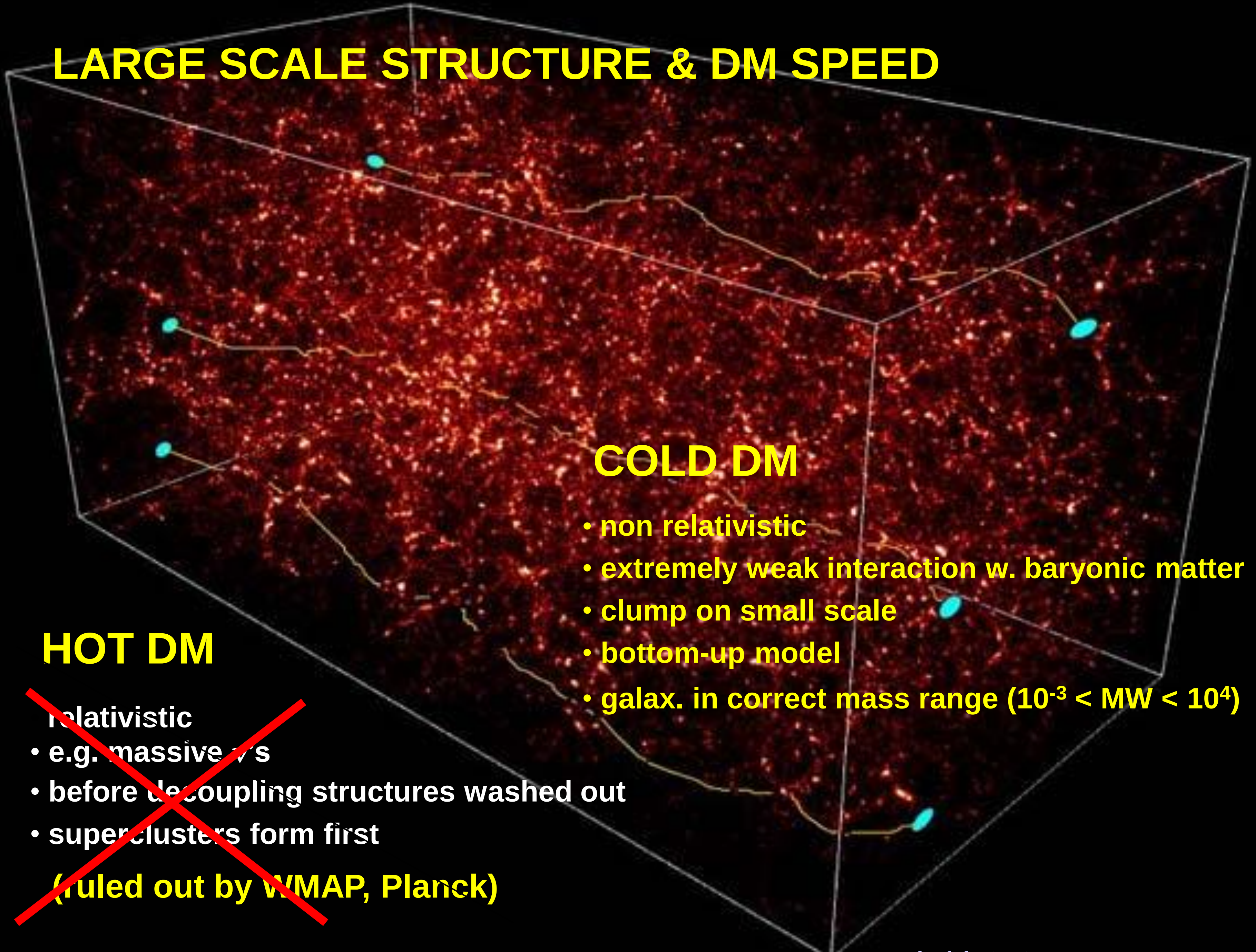
Assume DM decouples earlier @ $T < T_{BBN}$ and interacts weakly

- **longer time to develop structure**
- **clumps earlier**
- **baryons fall into troughs**

3 problems solved:

- **galaxy formation**
- **Large scale structure**
- **Dark Matter**

LARGE SCALE STRUCTURE & DM SPEED



COLD DM

- non relativistic
- extremely weak interaction w. baryonic matter
- clump on small scale
- bottom-up model
- galax. in correct mass range (10^{-3} < MW < 10^{4})

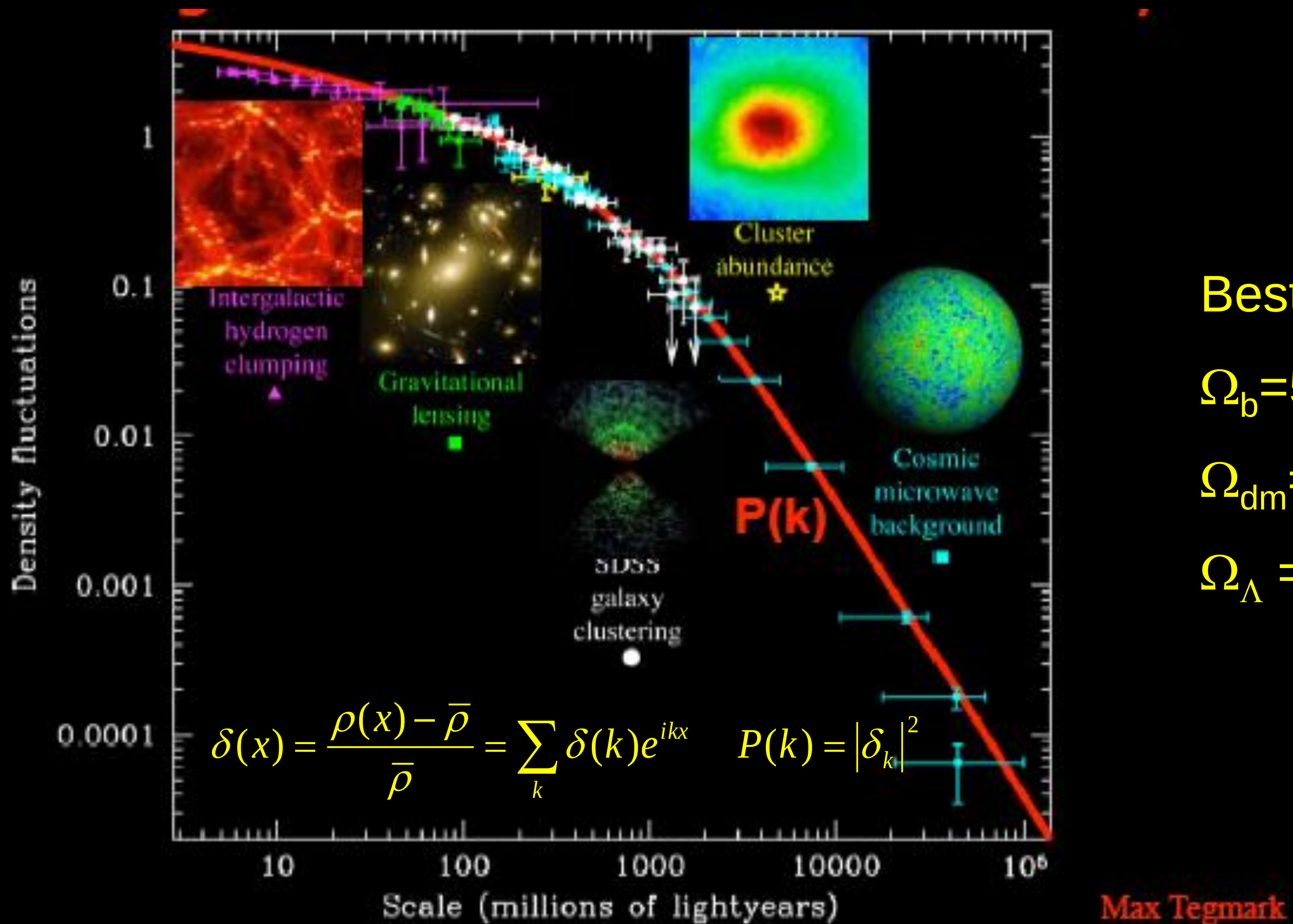
HOT DM

- relativistic
- e.g. massive ν's
- before decoupling structures washed out
- superclusters form first

(ruled out by WMAP, Planck)

cdm-hdm1-princeton.mpeg

LARGE SCALE STRUCTURE



$$\delta(x) = \frac{\rho(x) - \bar{\rho}}{\bar{\rho}} = \sum_k \delta(k) e^{ikx} \qquad P(k) = |\delta_k|^2$$

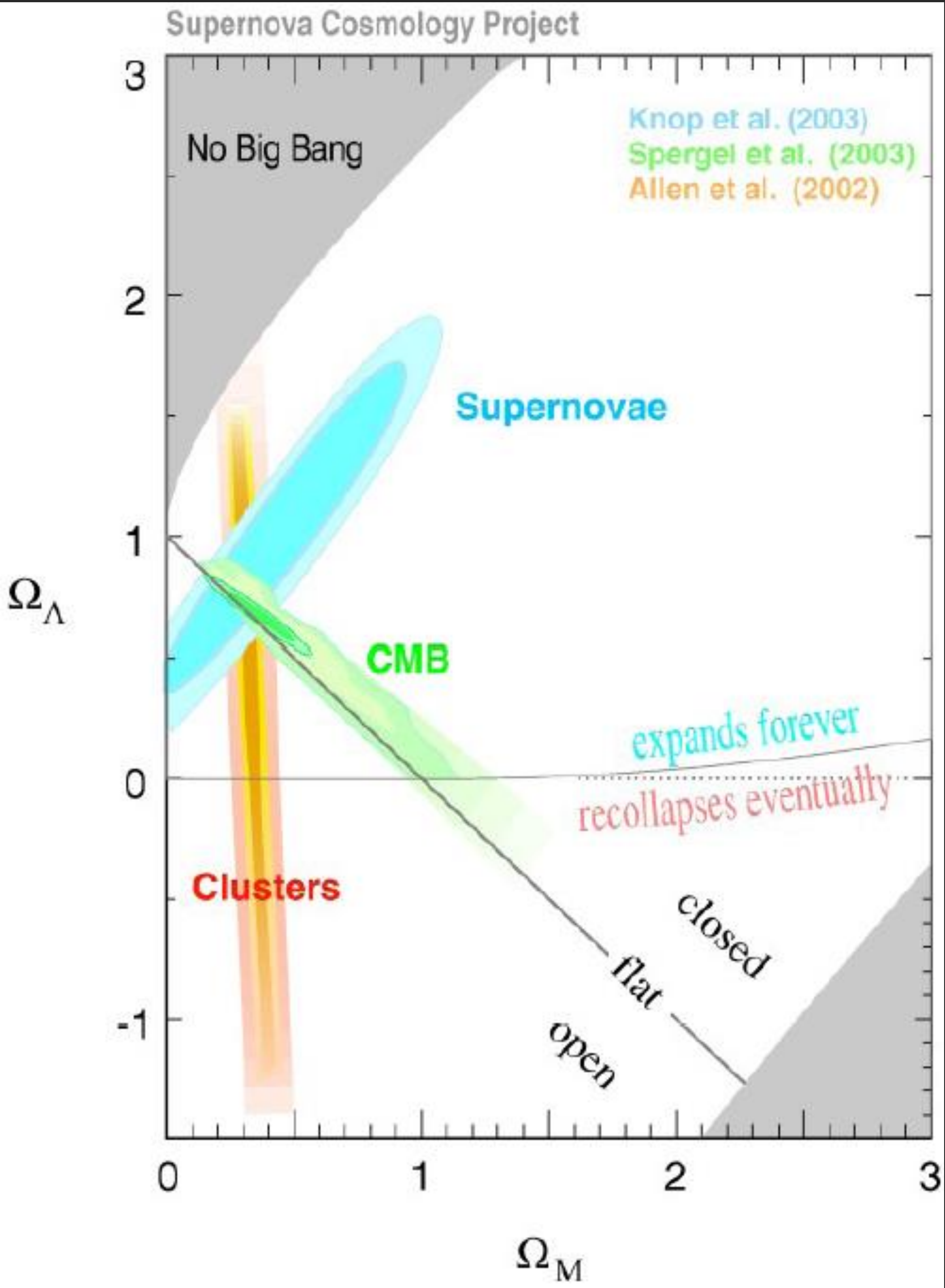
Best fit:

Ω_b=5%

Ω_{dm}=25%

Ω_Λ =70%

The larger the scale we average the more uniform becomes the Universe!



CONCORDANCE MODEL

$\Omega_{tot} = 1$

$\Omega_\Lambda = 0.7$

$\Omega_b = 0.05$

$\Omega_{dm} = 0.26$

$H_0 = 0.67$ km/s/Mps

$T_0 = 13.8$ Gyr

BUT WHAT IS DARK MATTER ?

Where do we find it and how much of Ω_m?

- DM in clusters of galaxies
- DM from galaxies and their rotation curves
- Compare to luminous matter, stars
- DM inferred from x-ray clouds around clusters of galaxies
- DM from large scale flows of galaxies
- DM by gravitational lensing

THE DARK MATTER PROBLEM - FIRST INDICATIONS

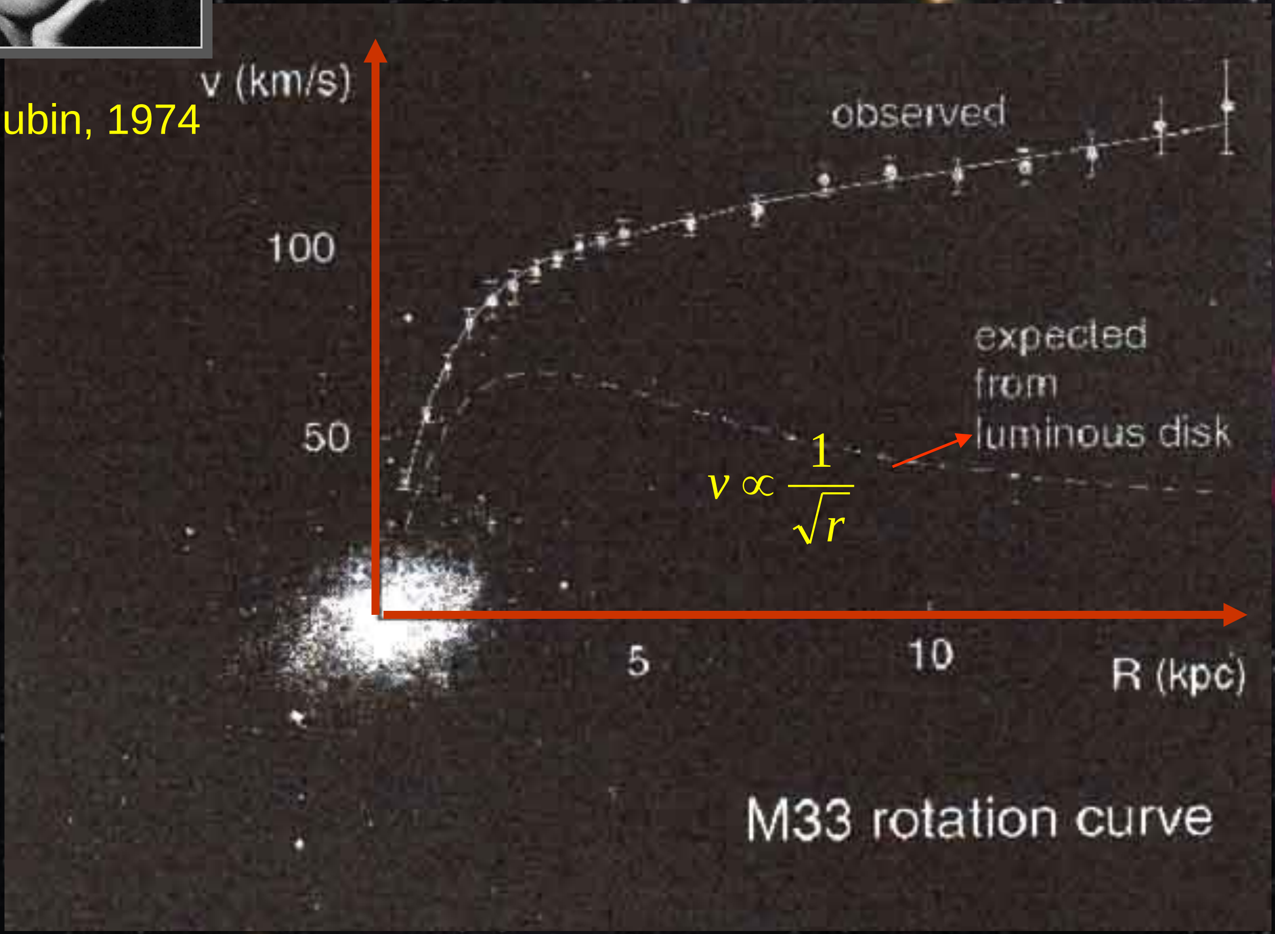
Fritz Zwicky, 1937

- Studies kinetic energies of 8 galaxies of the Coma Cluster
- finds velocities are much larger than expected
- apparently Coma cluster contains 200 x more mass than is visible in form of galaxies

The “hidden mass” problem becomes a “key problem” of modern cosmology

DARK MATTER & GALACTIC ROTATION CURVES

Vera Rubin, 1974



$$v \propto \frac{1}{\sqrt{r}}$$

$$\frac{v_{rot}^2}{r} = \frac{GM(r)}{r^2}$$

$M(r)$ mass within r

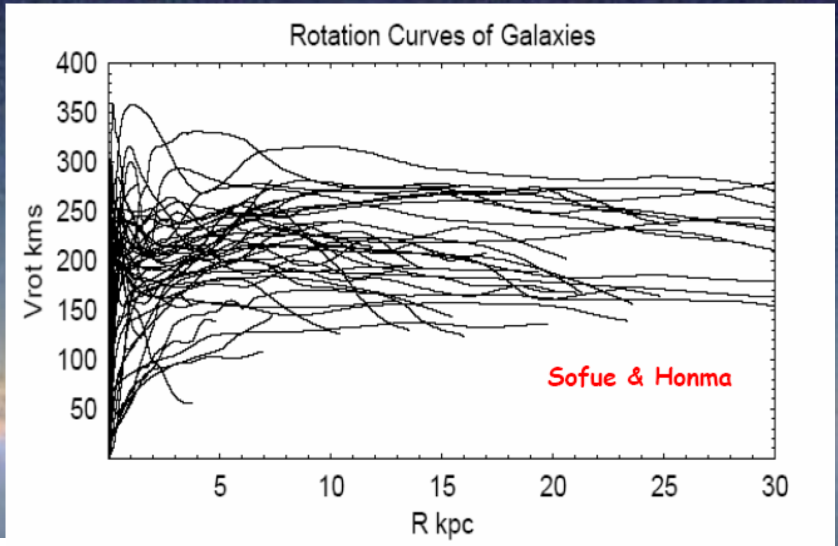
M increses linearly for v_{rot} = ct.

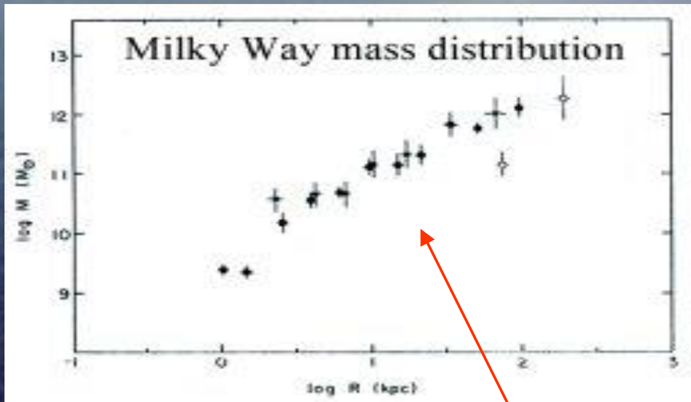
for large r halos of galaxies start to overlap

Doppler shift of star light and of HI distribution

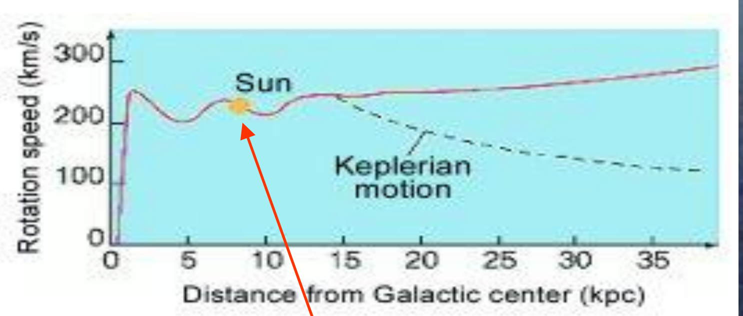
$M_{halo} > 10 \times (M_{lum} + M_{gas})$

DARK MATTER IN OUR MILKY WAY





Mass increases up to 200 kpc



Schematic flat rotation curve for the Milky Way galaxy

1kpc = 3.259 10^3 Ly

$$M(r) = \frac{v_{rot}^2 r}{G}$$

$\rho_{DM} \sim 0.3\ m_p/cm^3$

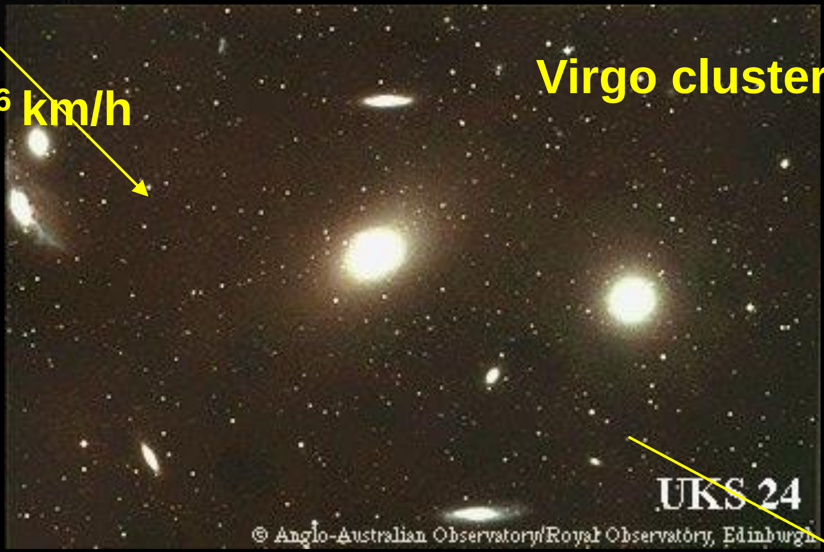
2MASS two Micron All Sky Survey

…only 5-10% of matter visible!

DARK MATTER AT LARGER SCALES

- **Size of Local group 2.2 MLy**
- **MW & M31 dominate Local Group**
- **Enormous gravit. pull between the two galaxies**
- **Invisible mass > 10 x M_{MW}**
- **Local group at fringe of Virgo cluster**

v ~ 1.6x10^6 km/h

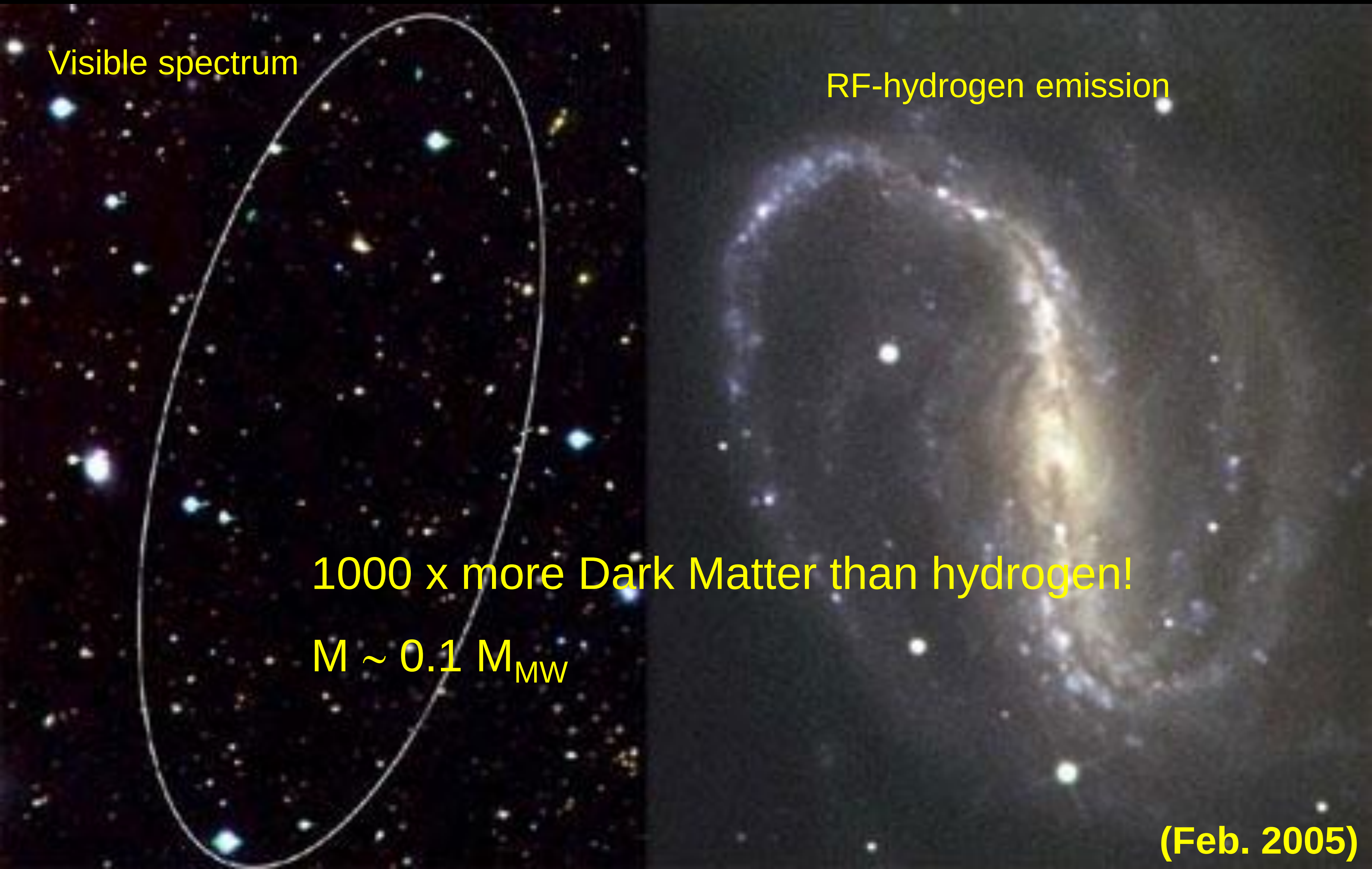


v ~ 2 x 10^6 km/h

- **Size of Virgo cluster 50MLy**
- **Local group pulled towards Virgo cluster**
- **invisible mass > 10 x M_{vis}**

Virgo Cluster pulled towards an invisible “Great Attractor”

VIRGOHI21: A GALAXY OF DARK MATTER ! (50 M Ly)



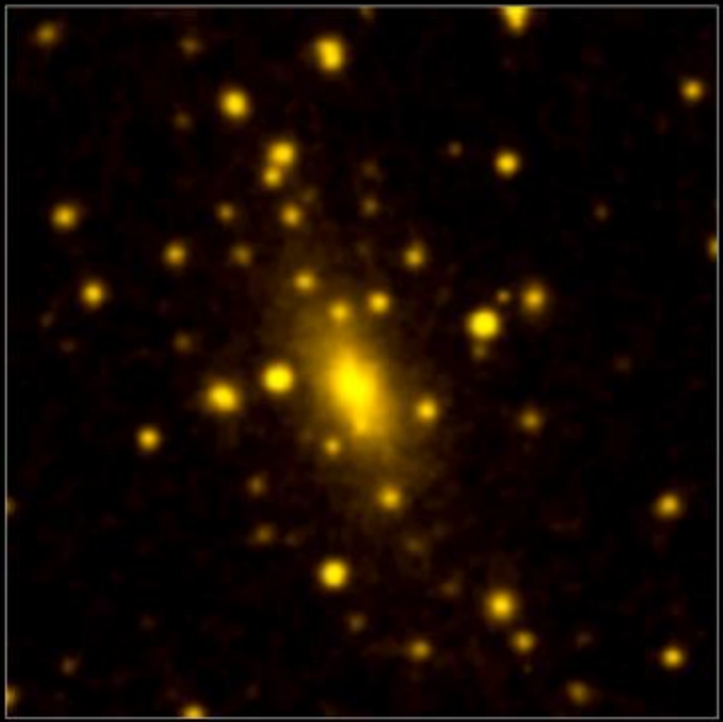
1000 x more Dark Matter than hydrogen!

$M \sim 0.1\ M_{MW}$

(Feb. 2005)

DARK MATTER AROUND OTHER GALAXIES

CHANDRA X-RAY



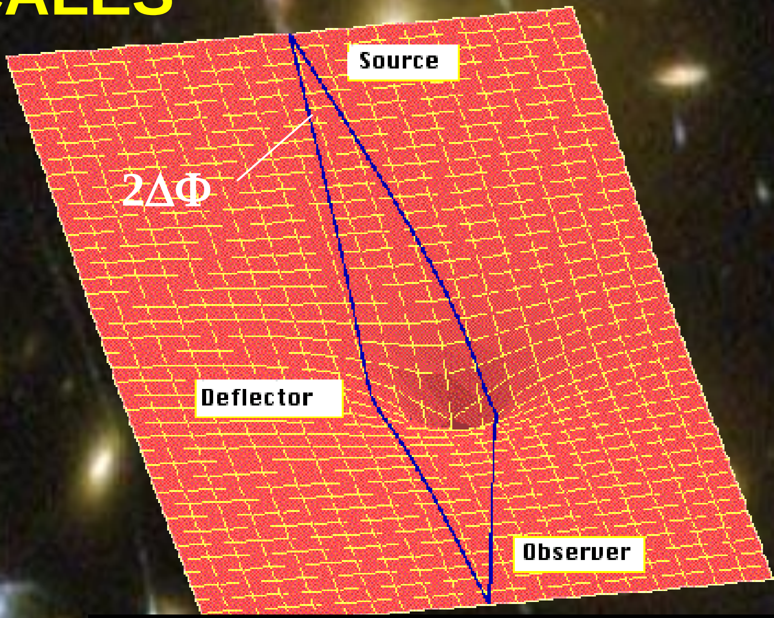
DSS OPTICAL

Abell 2029 (~ 100 Mpc)

- a cluster of thousands of galaxies
- surrounded by gigantic clouds of hot gas
- T~ 10^6 K

$M_{tot} > 10\ M_{vis}$

DARK MATTER AT AT LARGER SCALES

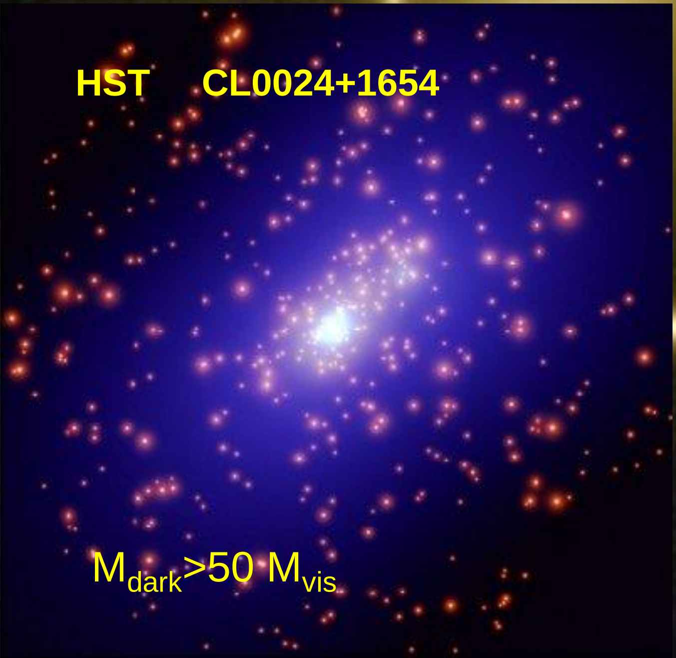


Gravitational lensing

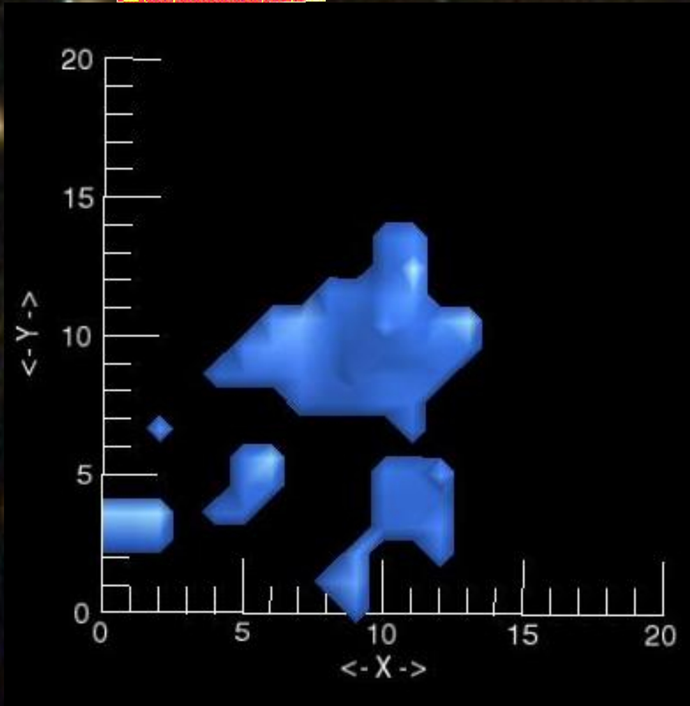
- **grav. potential φ causes time delay of light (Shapiro) → refractive index *n***

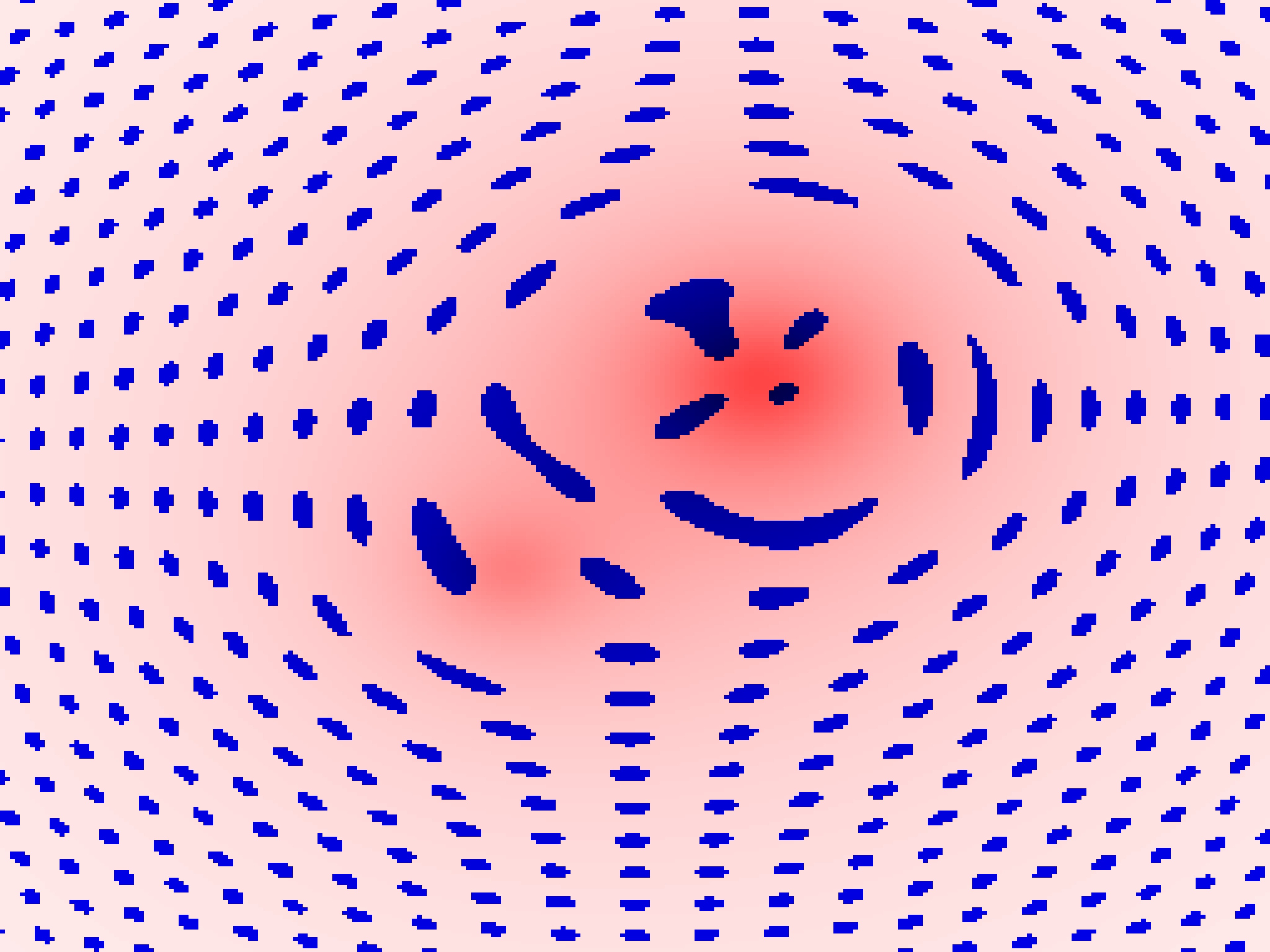
  $n = 1 - \varphi$

$$\Delta\Phi = -\int \nabla_{\perp} n dl = -\int \nabla_{\perp} \varphi dl$$



- **provides evidence of large masses between source and MW**
- **recently 3D reconstruction of clusters of Dark Matter**





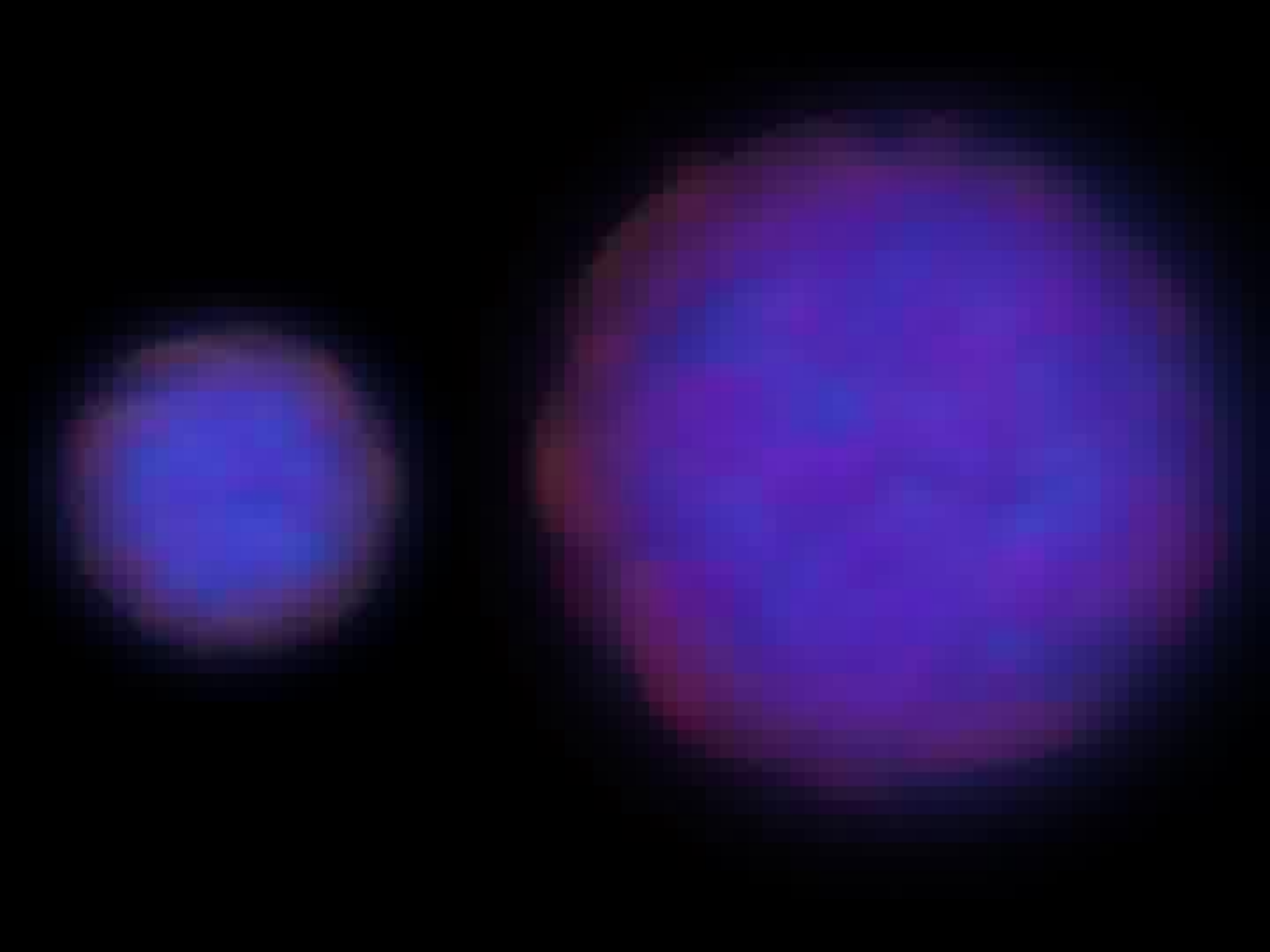
THE BULLET CLUSTER IE0657-56 (~ 1 Gpc)

High velocity merger of clusters
of galaxies 4500 km/s

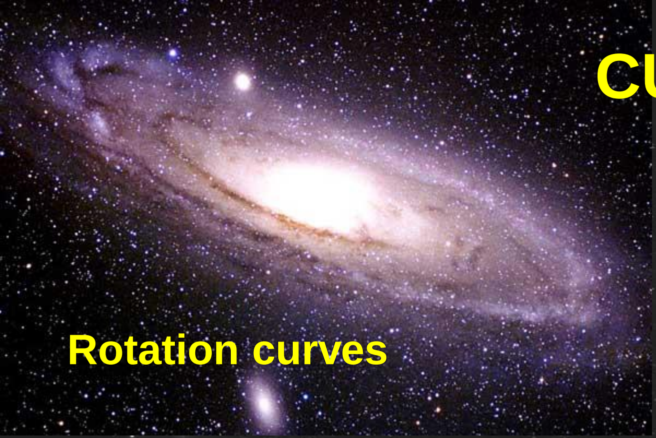
10^8K

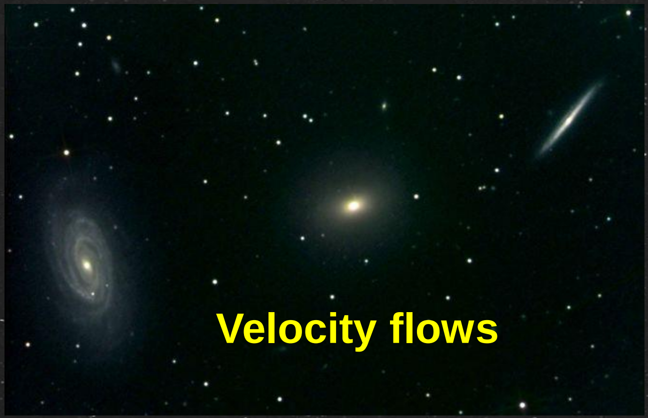
$M_{dark} > 49\ M_{vis}$

M. Markewitch et al: HST, Magellan, Chandra (August 2006)

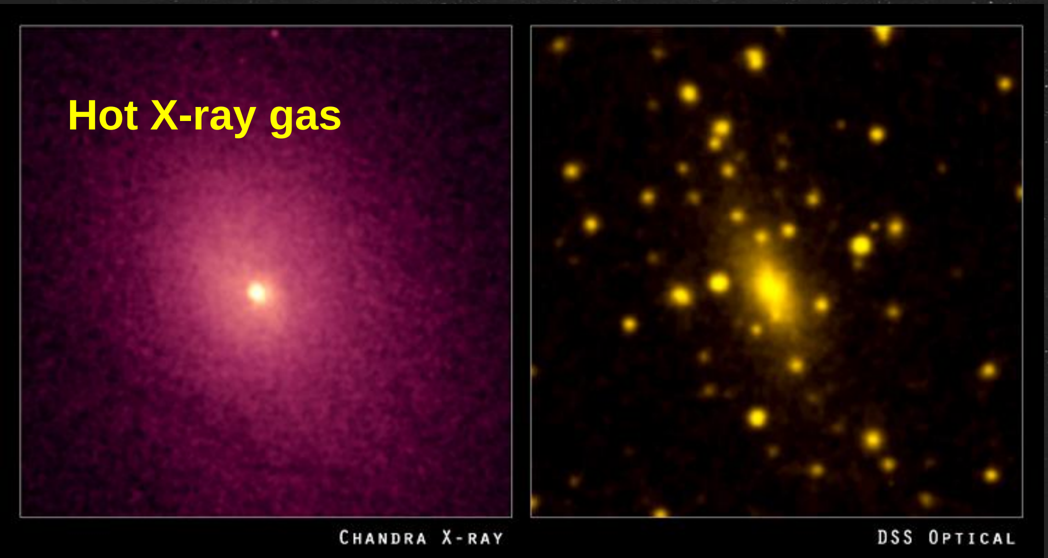


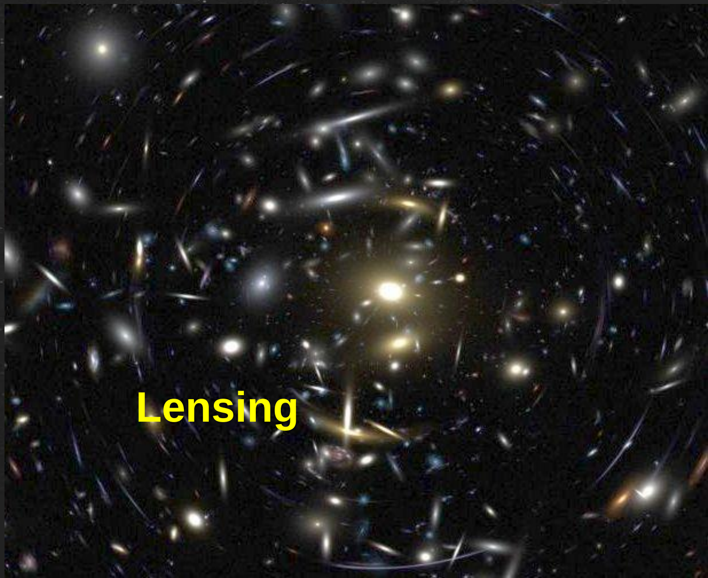
CURRENT EVIDENCE FOR Ω_m





$\Omega_m \sim 0.2\text{-}0.3 \rightarrow$ **Coinc. Model!**





…BUT WHAT PARTICLE IS A GOOD CANDIDATE?

Reduction due to Hubble expansion

DM self annihilation

Boltzmann

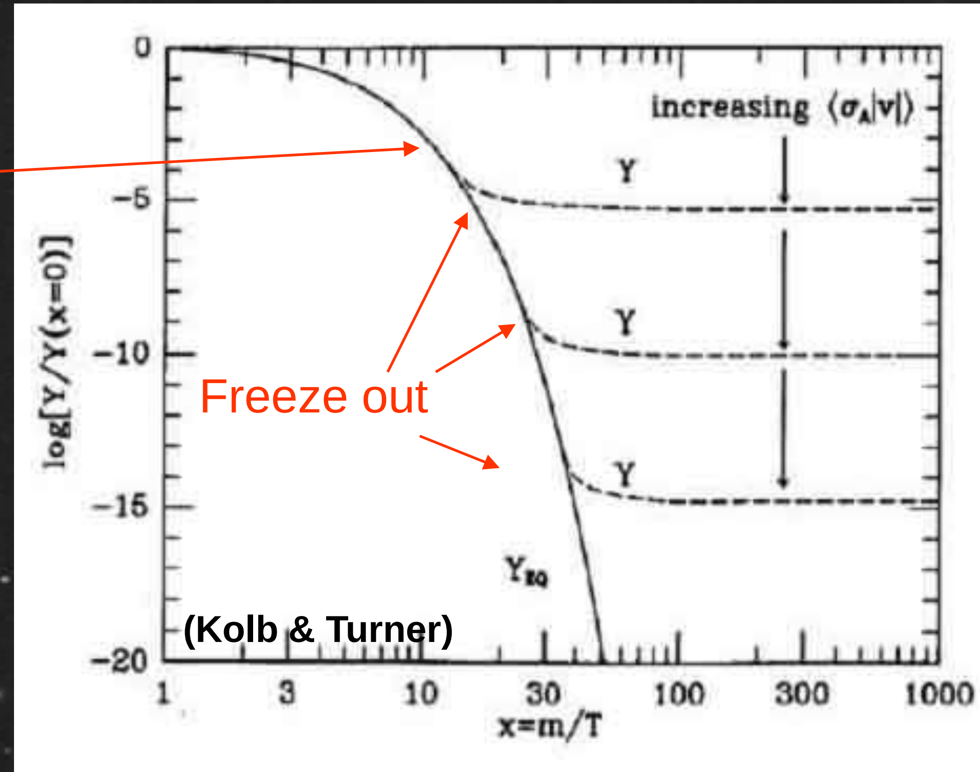
$$\frac{dn_x}{dt} = -3Hn_x - n_x^2 \langle \sigma v \rangle (x\bar{x} \rightarrow ordinary\ matter) +$$
$$+ n_{ord}^2 \langle \sigma v \rangle (ordinary\ matter \rightarrow x\bar{x})$$

Particle production

- in equilibrium: creation = annihilation
- ordinary particles stay longer in equilibrium

PARTICLE ABUNDANCE IN THE EARLY UNIVERSE

$$n_x^{eq} \propto (mT)^{3/2} e^{-m/kT}$$



After freeze out:

$$\Omega_x \approx \frac{3 \cdot 10^{-27}\, cm^2 \sec^{-1}}{\langle \sigma v \rangle h^2}$$

In order to get:

$$0.17 < \Omega_x < 0.25$$

…need stable particle which annihilates with electro-weak scale cross-section

Strategy:

- chose a particle
- know all the annihilation channels!
- calculate Ω_x
- compare to Concordance Model

THE NEUTRALINO: A CDM CANDIDATE

- χ_1 can be lightest stable super symmetric particle – LSP
- Majorana fermion
- interaction with matter electro-weak
- can provide closure density
- relic population from early BB

$$\chi_1 = N_{11}\tilde{\gamma} + N_{12}\tilde{Z} + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

"photino" "zino" higgsino" "higgsino"

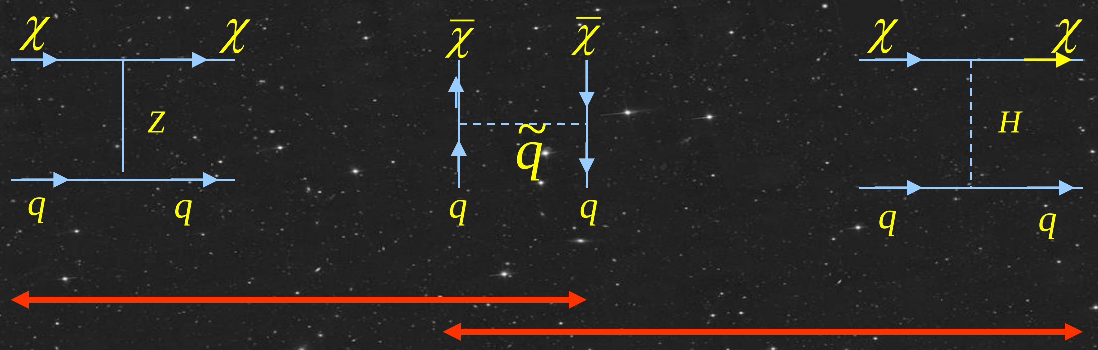
45 GeV < M_χ ≤ 600 Gev - 7 TeV

Accelelerators

SUSY structure

cosmology

NEUTRALINO INTERACTION CROSS SECTIONS



Spin-dependent

Spin-independent

General form of cross sections:

Enhancement factor

$$\sigma_A = 4G_F^2 \left(\frac{M_\chi M_A}{M_\chi + M_A} \right)^2 C_A F(q^2)$$

C_A^{SI} : Spin independent – coherent interaction $\propto A^2$

C_A^{SD} : Spin dependent interaction $\propto \langle S_{p,n} \rangle^2$

$F(q^2)$: nucl. form facor $\rightarrow$ important for large q^2 and large A

SPIN-INDEPENDENT ENHANCEMENT

SD or coherent interaction described by scalar coupling to nucleons

$$C_A^{SI} = \frac{1}{4\pi}\left[Zf_p + (A-Z)f_n\right]^2$$

Coupling to n, p

- $f_p = f_n$ coherent interaction $\propto A^2$
- $f_{p,n}$ can also interfere destructively!

To compare theory with experiments and different experiments
$\rightarrow$ normalization to nucleon X- section σ_p

$$\sigma_p^{SI} = \frac{1}{A^2}\left(\frac{\mu_p}{\mu_A}\right)\sigma_A^{SI}$$

$\mu_{A,p}$: χ -nucleus, p -χ reduced mass

(assuming $q^2 \approx 0$ and $f_p = f_n$)

SPIN- DEPENDENT ENHANCEMENT

$$C_A^{SD} = \left(\frac{8}{\pi}\right)\left[a_p\langle S_p\rangle + a_n\langle S_n\rangle\right]^2 (J+1)J$$

D.R. Tovey et al; PLB 88(2000)17

Coupling constants

Averaged *p, n*- spin

Total spin

$C_A^{SD} \propto \lambda^2 J(J+1)$

^{19}F most favorable!

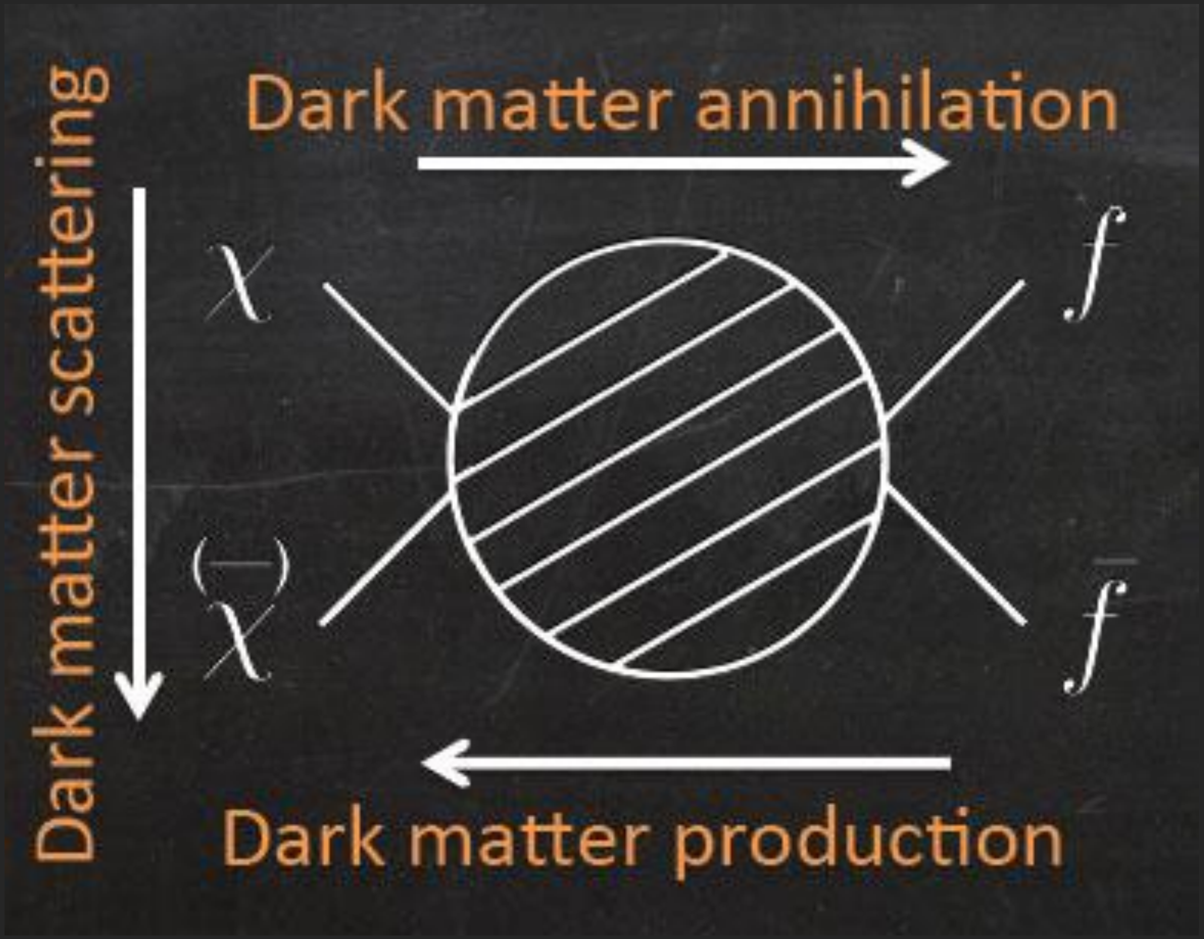
(PICASSO, SIMPLE, KIMS, COUPP)

Isotope	Spin	Unpaired	λ^2
^{1}H	1/2	p	1
^{7}Li	3/2	p	0.11
^{19}F	1/2	p	0.863
^{23}Na	3/2	p	0.011
^{29}Si	1/2	n	0.084
^{73}Ge	9/2	n	0.0026
^{127}I	5/2	p	0.0026
^{131}Xe	3/2	n	0.0147

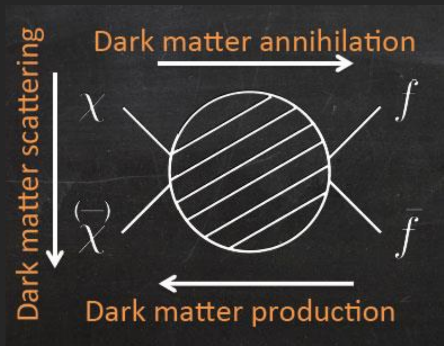
Normalization of σ_A to $\sigma_{p,n}$

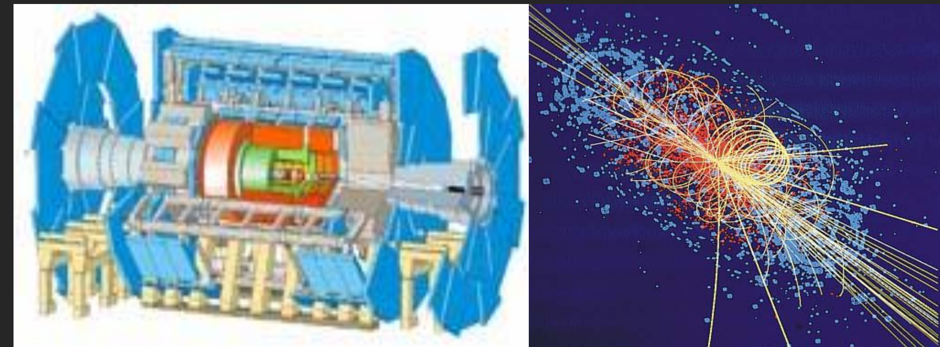
$$\sigma_{p,n}^{SD} = \frac{3}{4}\frac{J}{J+1}\left(\frac{\mu_{p,n}}{\mu_A}\right)^2 \frac{1}{\langle S_{p,n}\rangle^2}\sigma_A^{SD}$$

WHAT CAN WE DO WITH IT?

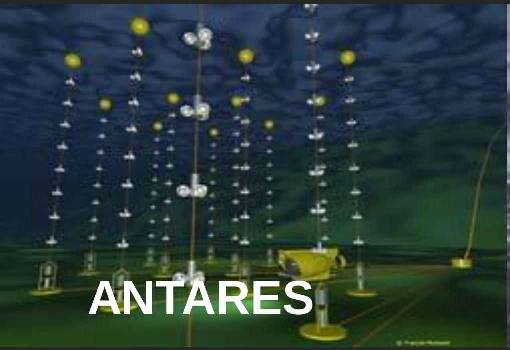


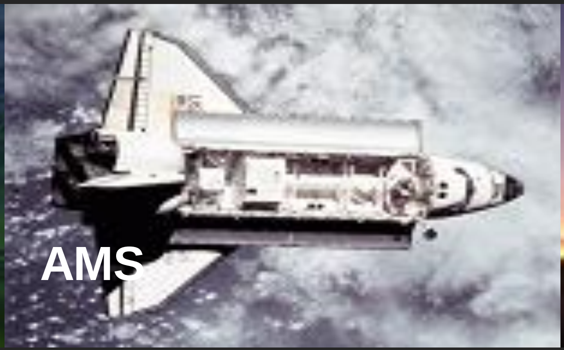
Searches for DM Particles

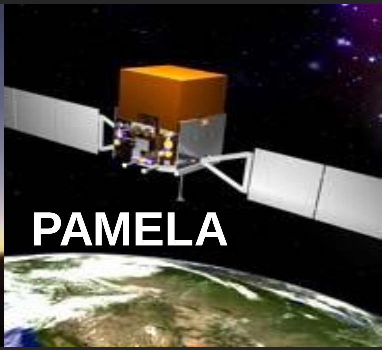




Production in situ at accelerators





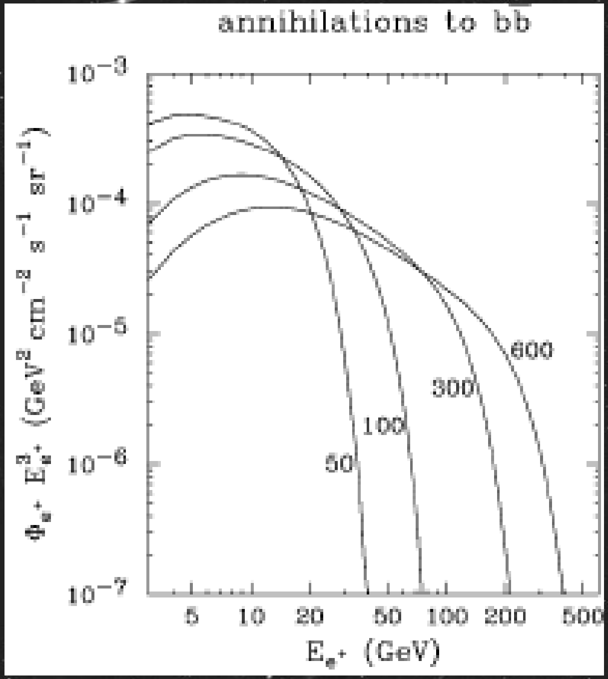


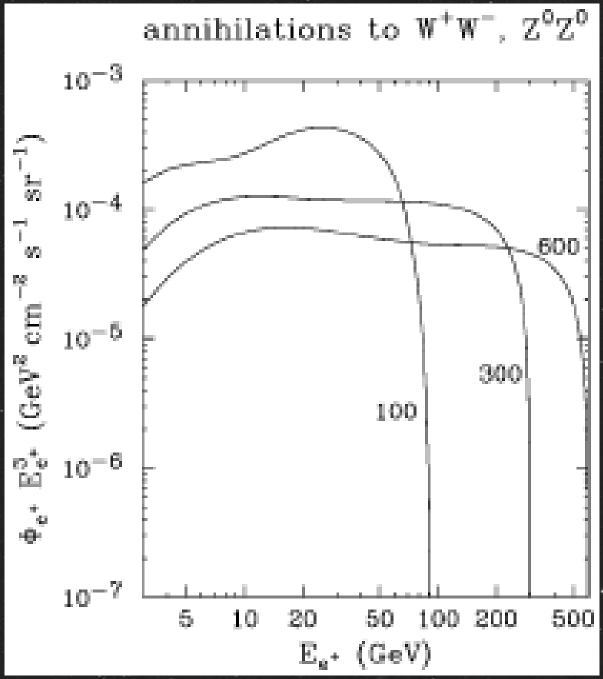
Indirect detection via DM annihilation in Sun, Earth, Galaxy
ν, γ-rays, anti-protons , positrons

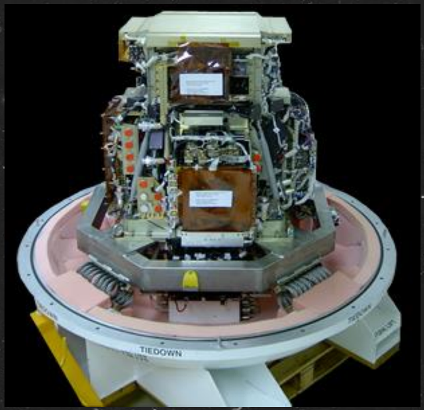
Direct detection in u/g laboratories

NEUTRALINO ANNIHILATION IN THE HALO

- Antimatter from neutralino annihilation in the halo
- Energy spectrum depends on annihilation mode







PAMELA (June ’06) !

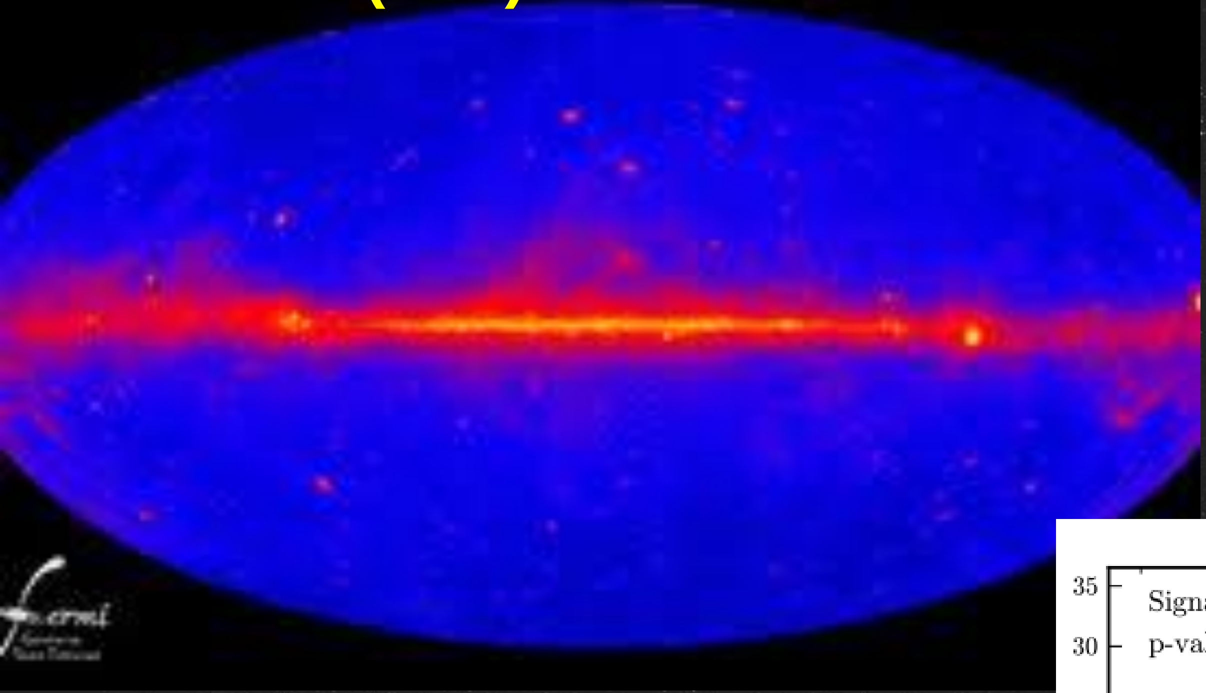
AMS-2013 !

FERMI

e^+ -spectrum depends on diffusion constant, energy loss, halo structure…

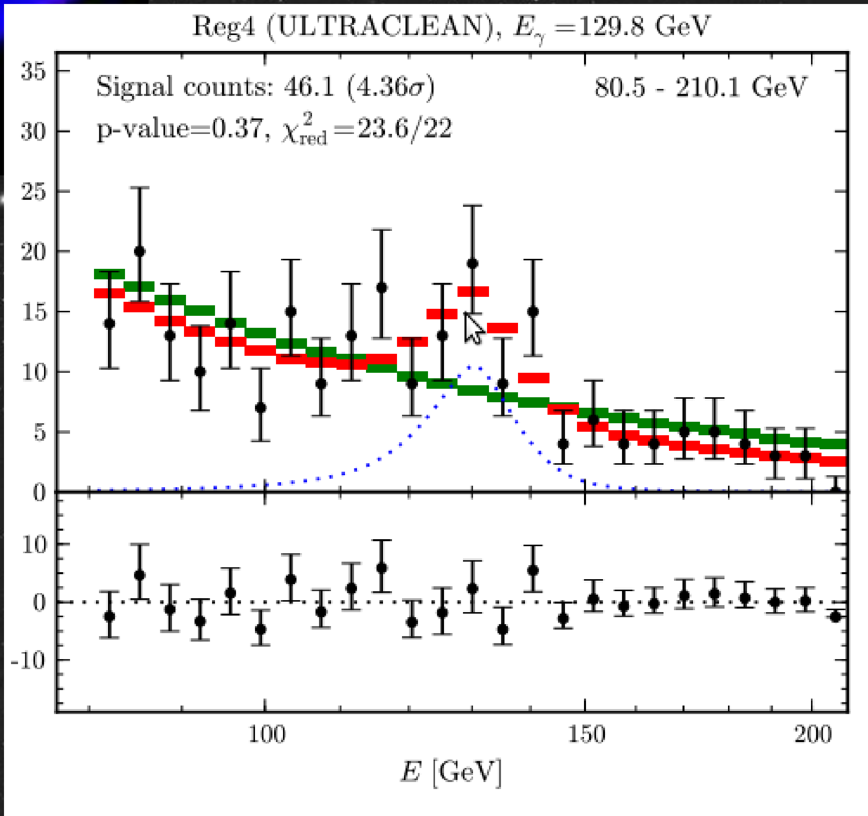
D. Hooper, Dark Matter 2006, Maruna del Rey

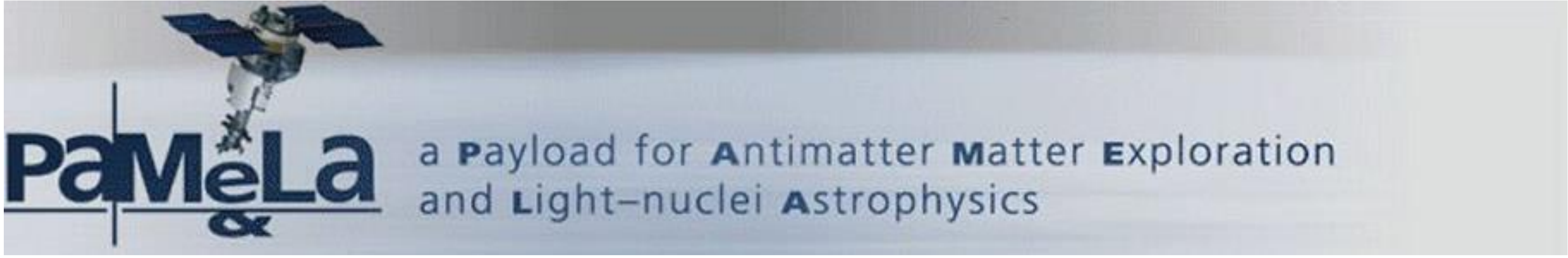
FERMI (LAT) LARGE AREA TELESCOPE



- HE γ-ray spectrometer
- Launched in 2008

- Nov. 2012 spike at 130 GeV -> gal. center
- Reanalysis: CR induced γ's in earth atm. ?
- Effect seems to fade away?



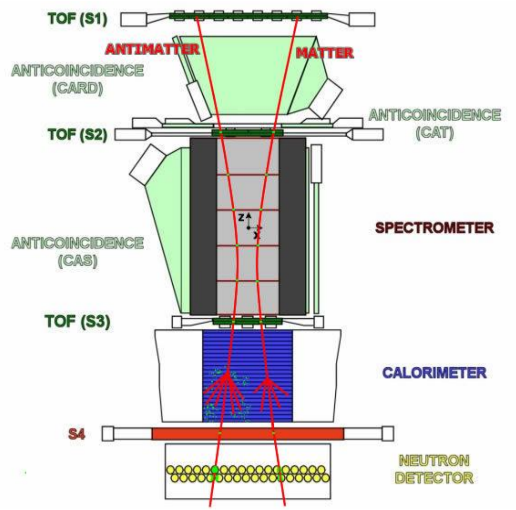


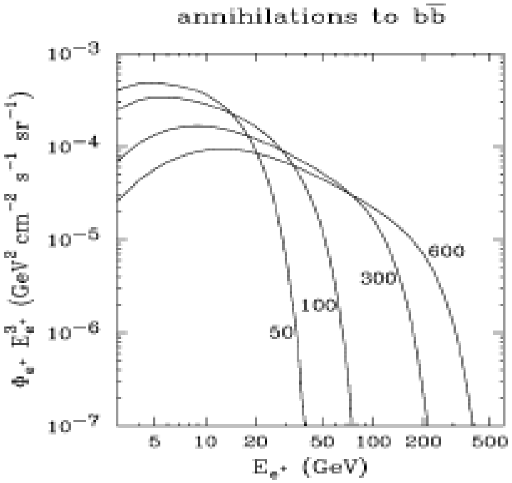
Study anti protons, positrons and electrons

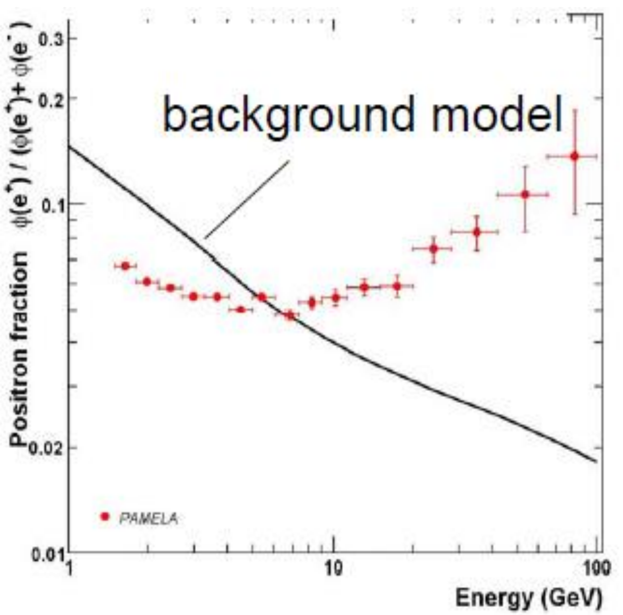
Search for anti nuclei, esp. Anti-He

WIMP annihilation in the halo

Study CR propagation models







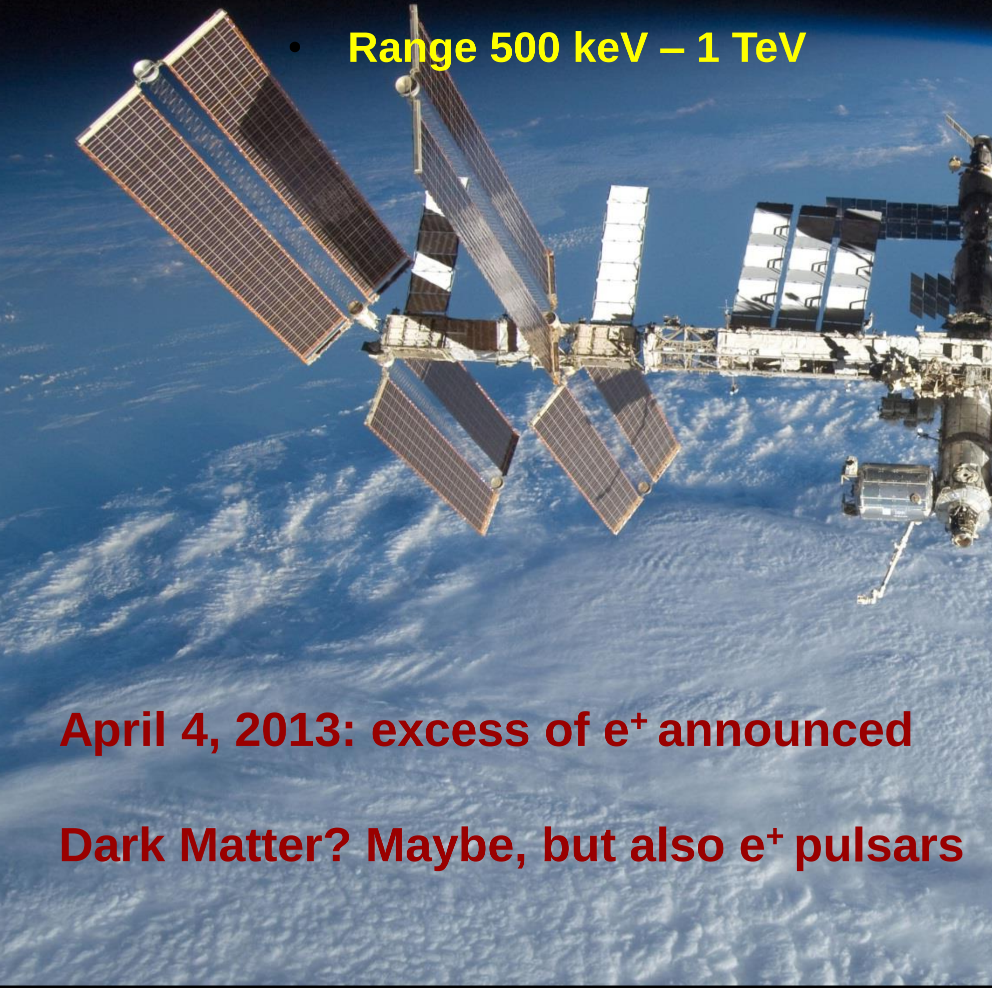
Explanation:

- Modification of acceleration & propagation models for CR
- DM annihilation
- Pulsars

e⁺ -spectrum depends on diffusion constant, energy loss, halo structure…

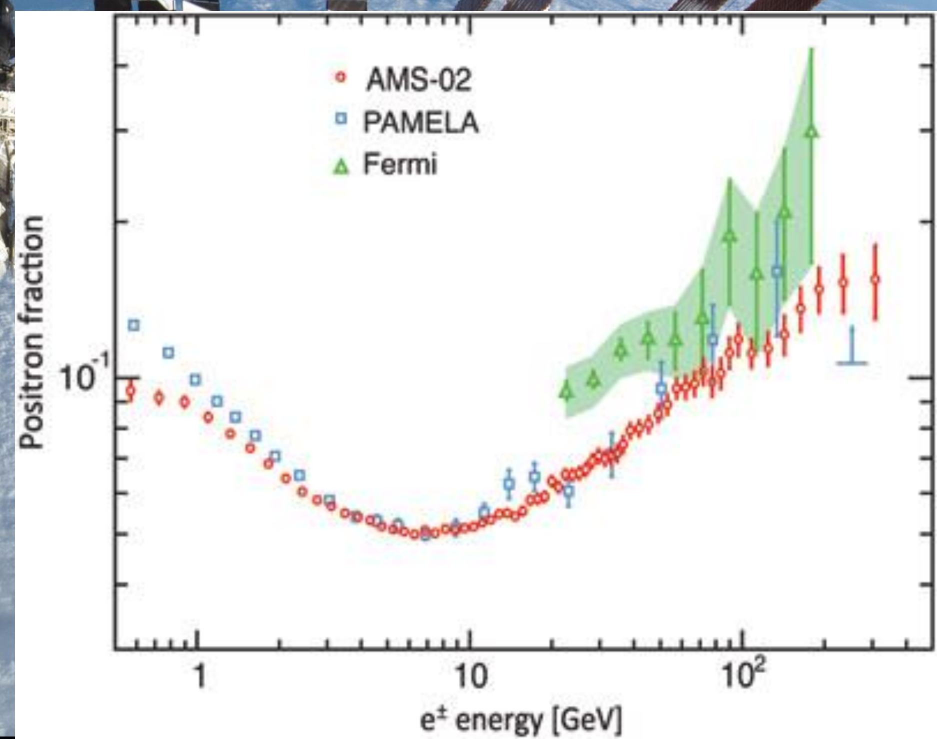
ALPHA MAGNETIC SPECTROMETER (AMS)

- Search for antimatter
- Since 2012 installed on ISS
- E, m. spectrometer 7.5t
- Supraconducting magnet 1m Ø
- Range 500 keV – 1 TeV

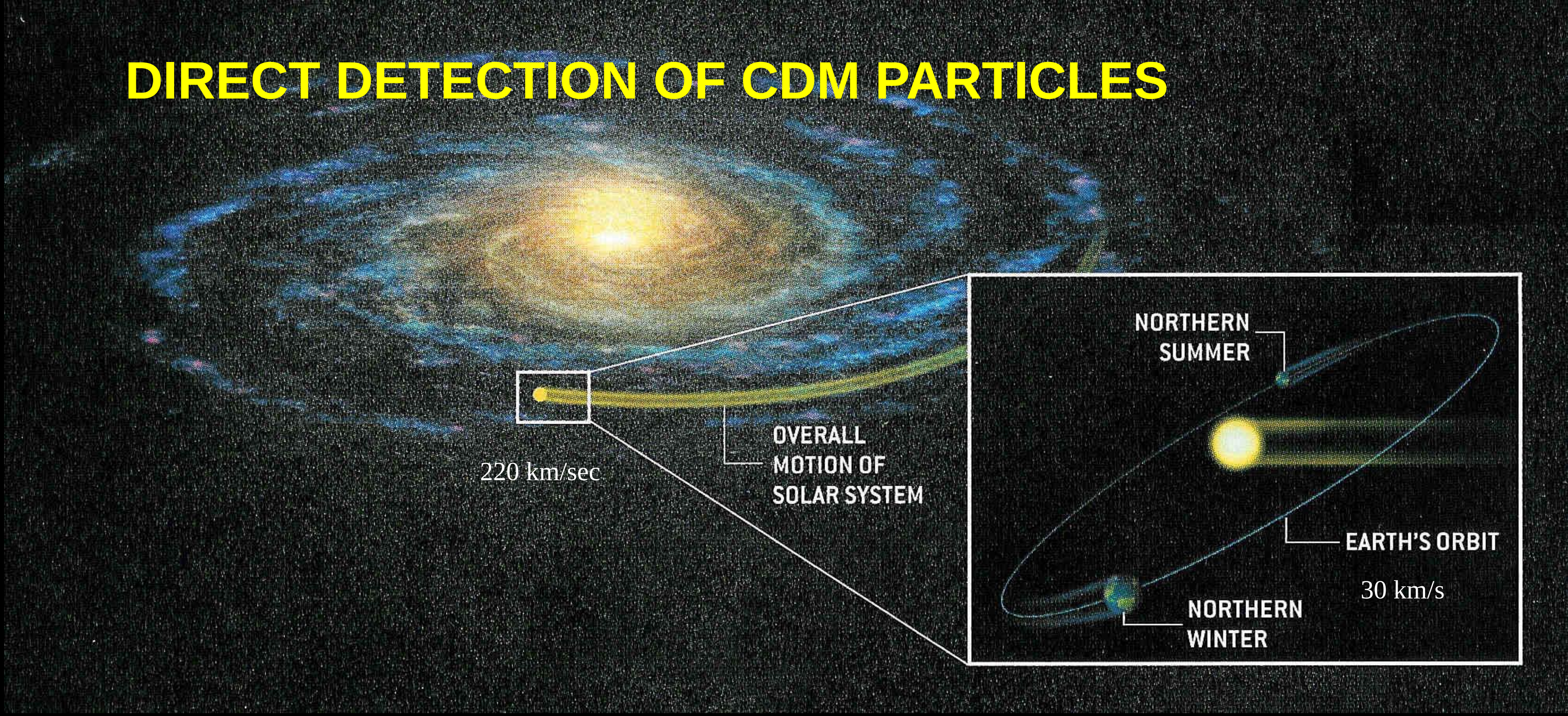


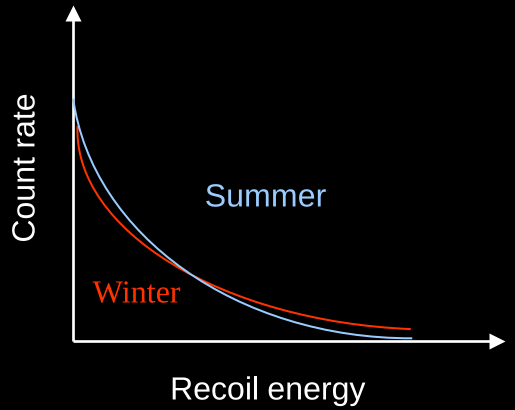
April 4, 2013: excess of e^+ announced

Dark Matter? Maybe, but also e^+ pulsars



DIRECT DETECTION OF CDM PARTICLES

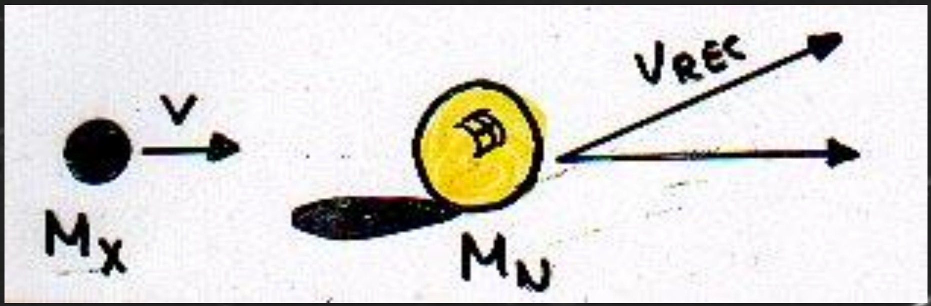




- Seasonal variation of WIMP speeds
- Modulation of recoil spectrum
- Annual rate modulation $\approx 5 - 7\%$
- Day- night variation $\approx 7 - 17\%$

A. Drukier, K. Freese, Spergel PRD 33(86)3495

DIRECT DETECTION OF CDM PARTICLES



via scattering off detector nuclei & recoil detection

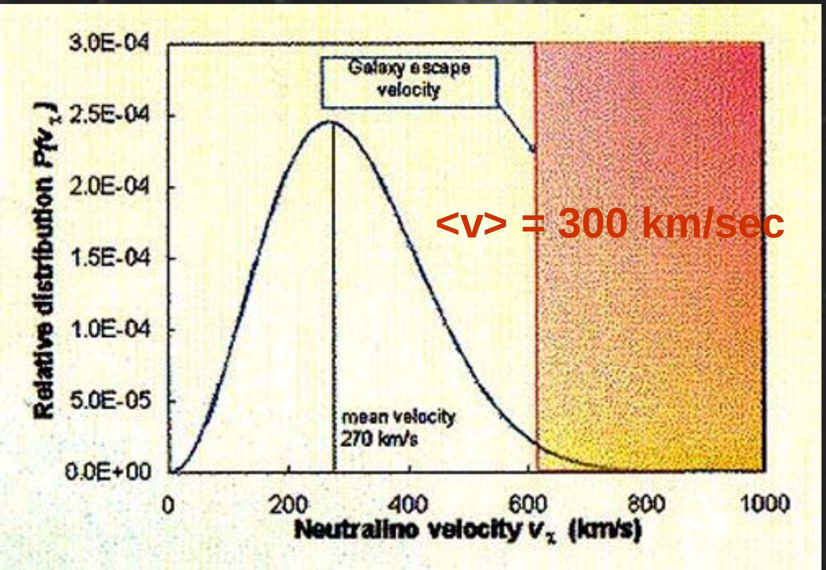
Interaction rate:

$$R = N_T \bullet v_x \bullet \rho_x \bullet \sigma$$

χ density in halo

 # target nuclei

av. velocity

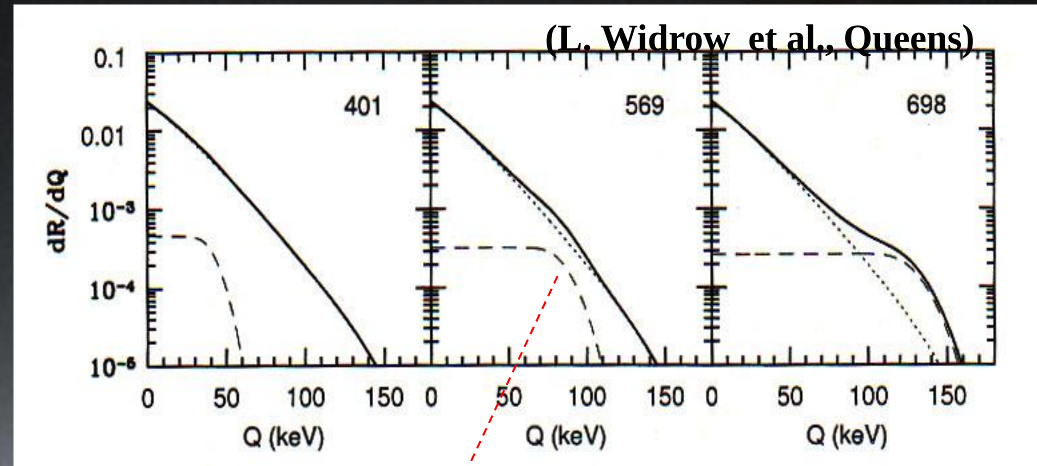


<v> = 300 km/sec

- χ in self gravitating halo
- Maxwellian v-distr.
- $\rho \sim R^{-2}$
- $\rho_{sun} \sim 0.3$ GeV / cm^3
- annual variation!
- extragalactic streams?

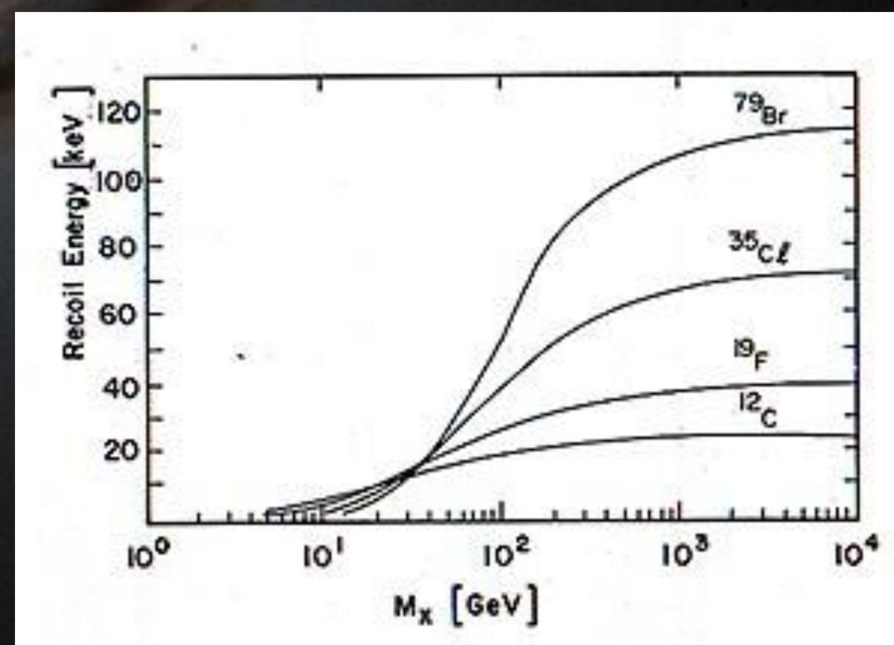
RECOIL SPECTRA & RATES

$$\frac{dR}{dE_r} = C \cdot \exp\left(- E_r \big/ \langle E_r \rangle \right)$$



Extragalactic stream

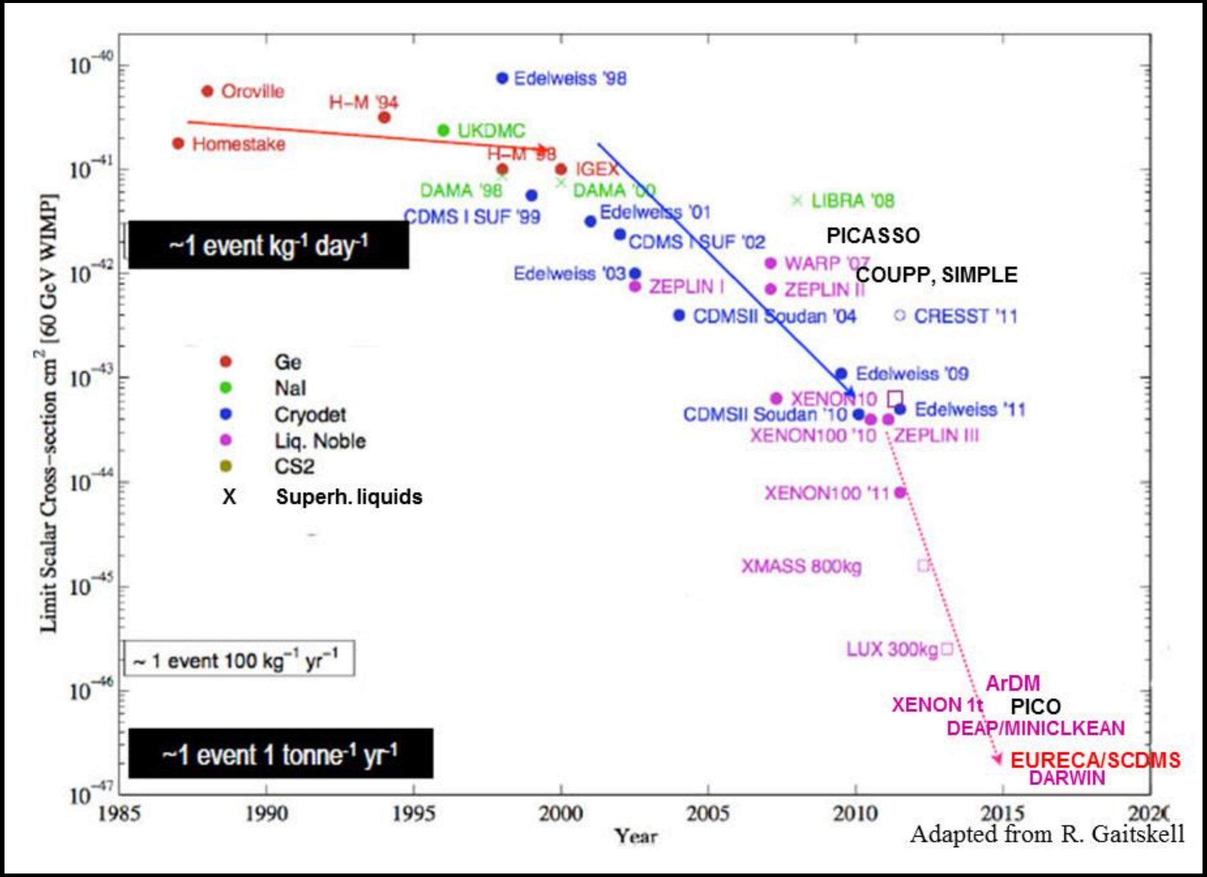
$$\langle E_r \rangle \approx 2 \cdot \left(\frac{M_N}{1GeV} \right) \cdot \left[\frac{M_\chi}{M_\chi + M_N} \right]^2 \ [keV]$$



Average recoil energy: keV range !

RATES & LIMITS

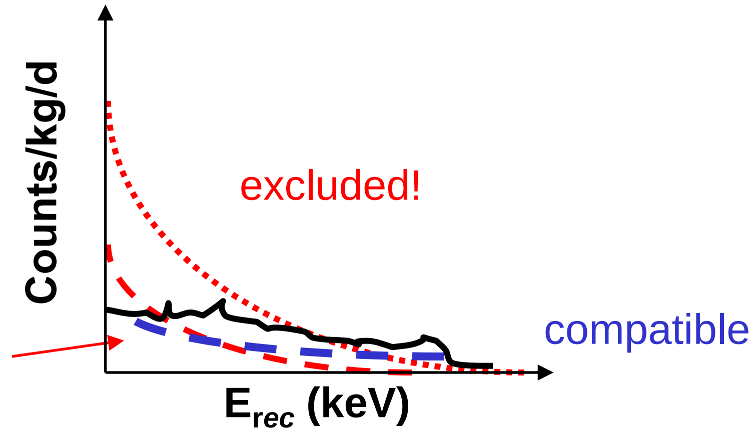
$$R_0 \cong \frac{403}{A}\left(\frac{GeV}{M_\chi}\right)\left(\frac{\rho_\chi}{0.3\ GeV/cm^3}\right)\left(\frac{\langle v_\chi\rangle}{230\ km/s}\right)\left(\frac{\sigma_A^{SD,SI}}{pb}\right)\ \frac{counts}{kg\cdot day}$$

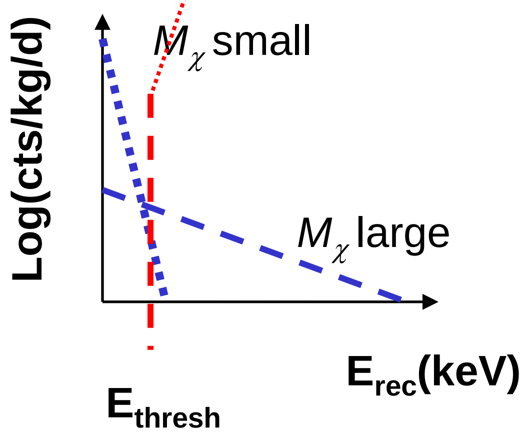


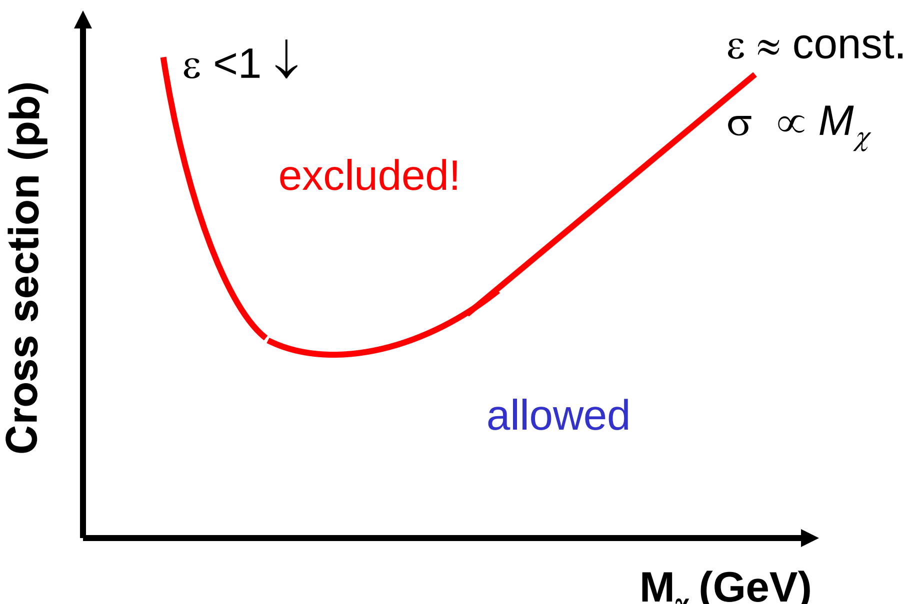
HOW TO EXTRACT LIMITS?

$$\sigma = Const.\frac{M_\chi}{\varepsilon(M_\chi)} R_{max}$$

max. count rate still compatible with data







GENERAL STRATEGY FOR DARK MATTER SEARCH

Requirements

- Very low, threshold → keV
- Very small intrinsic and induced background → <0.1 cts/kg/d
- Located in underground laboratories in radio-pure environment
- Screened from neutrons
- With capability to discriminate signal from background
- Superb stability and control of systematics
- Large detector mass → 100kg

-Signatures

- Annual modulation → statistics
- Depenance on target A (SI) or target spin (SD)
- Directionality → statistics, low pressure
- Absence of multiple events → detector arrays

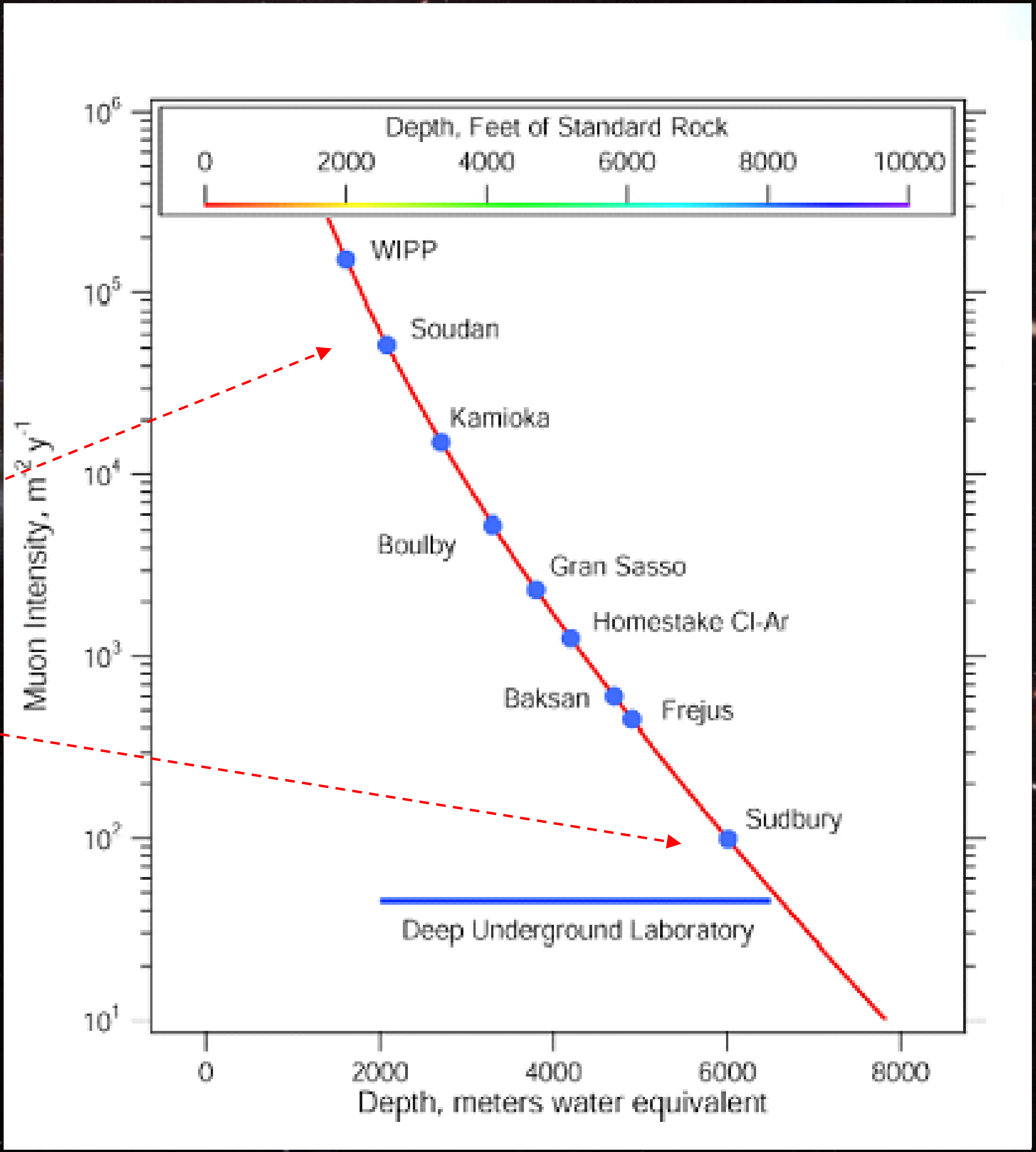
COSMIC RAY INDUCED NEUTRONS

Neutron- production by

- μ spallation in det. material
- μ spallation in det. shielding
- μ spallation in rock

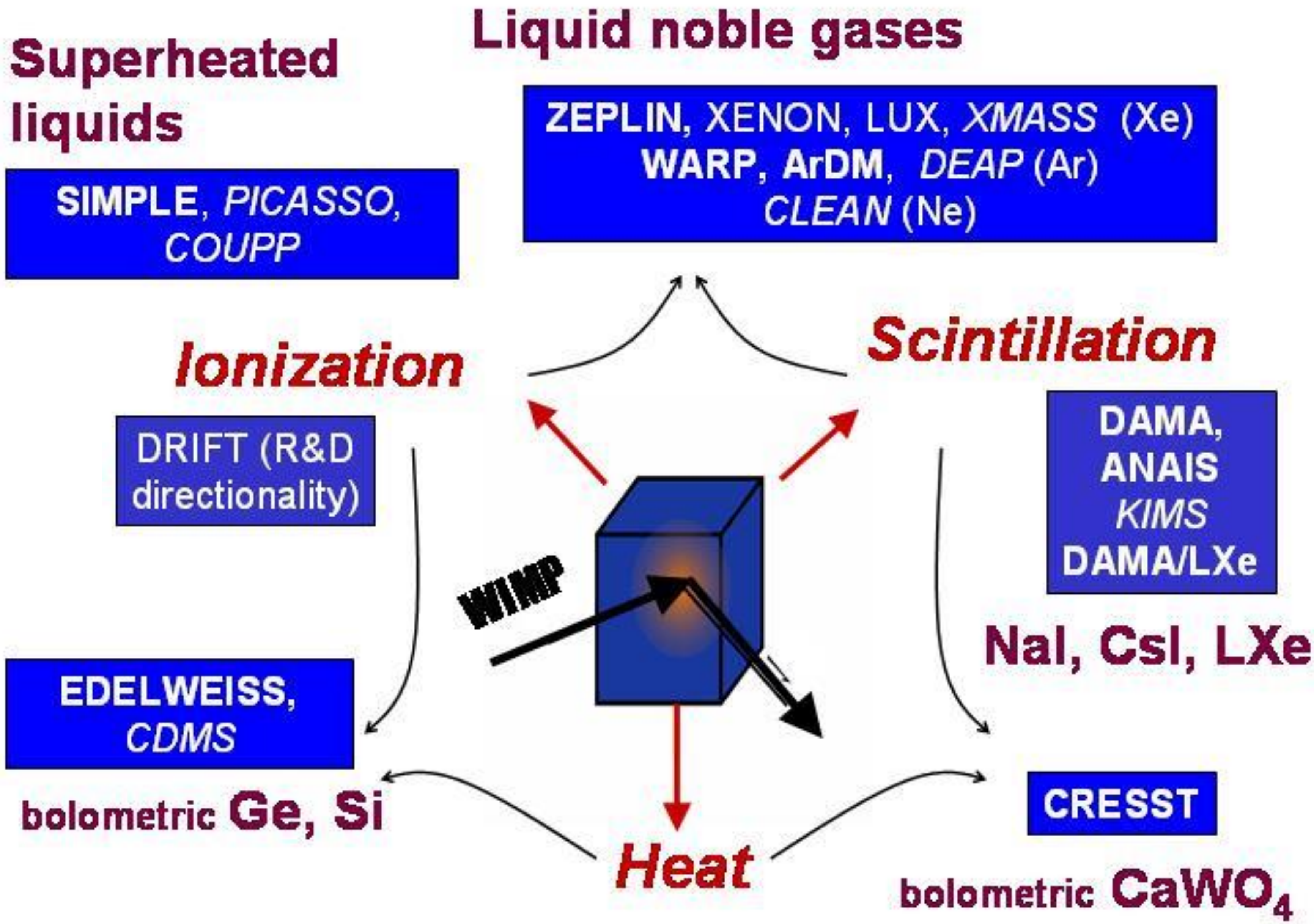
SOUDAN: 0.05 n / kg-d

SNOLAB: 0.2 n / ton-y



SUMMARY DIRECT DETECTION ACTIVITIES

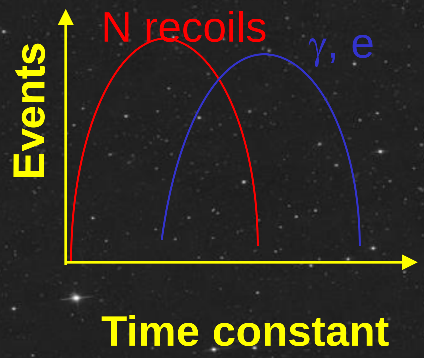
Experiment	Detector	Staus	Location	Collaboration
DAMA/LIBRA	NaI	running	Gran Sasso	Italy, China
ANAIS	NaI	constructing	Canfranc	Spain
KIMS	CsI	running	Korea	Korea
HDMS	GE	running	Gran Sasso	Germay, Russia
Dama -LXe	LXe	running	Gran Sasso	Italy, China
Zeplin II	LXe	terminated	Boulby	PT, UK, RU, US
Zeplin III	LXe	terminated	Boulby	PT, UK, RU, US
XENON 10	LXe	running	Gran Sasso	DE, IT, PT, US
LUX	LXe	running		US
XMASS	LXe	running	Kamioka	Japan
WARP	LAr	running	Gran Sasso	Italy, US
ArDM	LAr	R&D	Canfranc	CH. ES, PO
DEAP	LAr	commissioning	SNOLAB	Canada, US
CLEAN	LNe	commissioning	SNOLAB?	US, Canada
Rosebud	Bolometer/scintill.	R&D	Canfranc	Spain, France
EDELWEISS	Bolometer	running	Frejus	F, GE, RU
CRESST	Bolometer	running	Gran Sasso	DE, UK, IT, RO
CDMS	Bolometer	running	Soudan	US
SIMPLE	Superheated liquids	running	Rustrel	PT, F, US
PICASSO	Superheated liquids	running + R&D	SNOLAB	CA, US, CZ
COUPP	Superheated liquids	running	Fermilab	US
Drift	Xe gas	R&D	Boulby	UK, US
MIMAC	^{3}He gas	R&D		France


Liquid noble gases
Superheated liquids
SIMPLE, PICASSO, COUPP
ZEPLIN, XENON, LUX, XMASS (Xe)
WARP, ArDM, DEAP (Ar)
CLEAN (Ne)
Ionization
Scintillation
DRIFT (R&D directionality)
DAMA, ANAIS KIMS DAMA/LXe
WIMP
NaI, CsI, LXe
EDELWEISS, CDMS
bolometric Ge, Si
CRESST
Heat
bolometric CaWO4

SCINTILLATOR EXPERIMENTS

Principle:

- crystals (NaI, CsI), Liquids (Xe, Ar, Ne, CaF_2(Eu)) emit light if hit $\propto$ radiation
- light collected by photo multipliers ($\varepsilon \sim 15\%$) or photo-diodes
- ΔE / photon ~ 15 eV
- light gain ~ 2-8 phe/keV



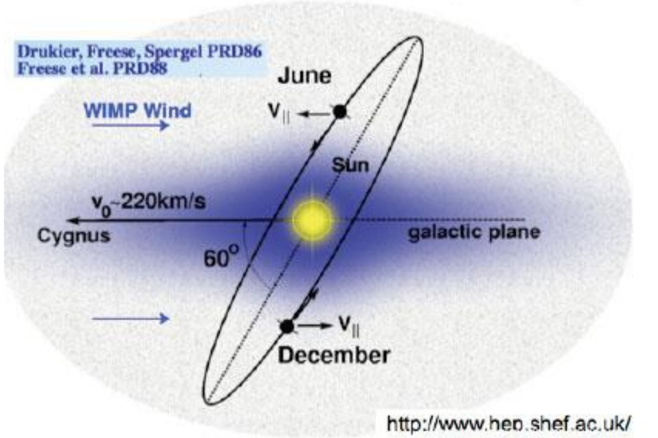
Background rejection:

- different pulse shape (time constant) for nuclear recoil or e, gamma induced events

Experiments:

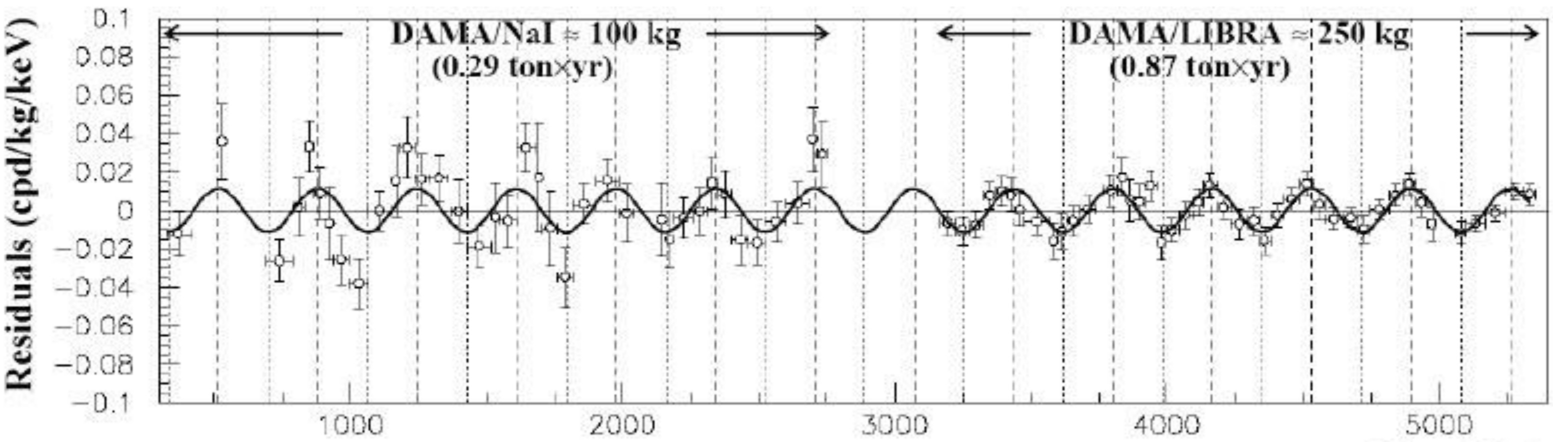
DAMA, NAIAD, ANAIS, KIMS, DEAP…

DAMA / LIBRA NaI (Gran Sasso)

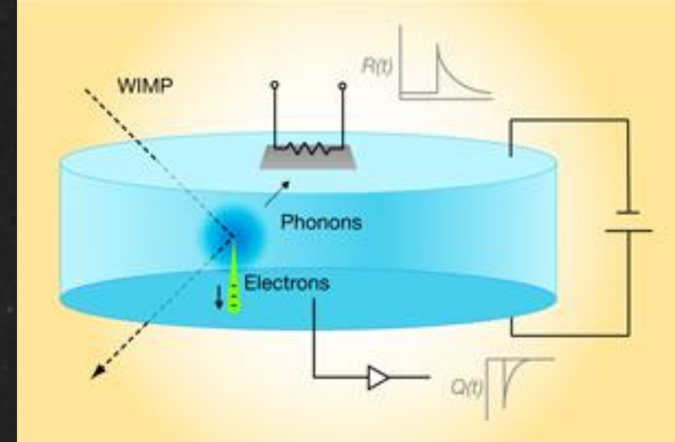


- 250 kg of NaI crystals
- 13 annual cycles show a modulation at 8.9σ
- period T=1.00 ± 0.01 y; A = 0.0195 ± 0.003 cts/kg/d/keV
- modulation at low energies 2-6 keV
- total exposure 1.17 ton y
- **Signal: $M_\chi \sim 10 - 50$ GeV/c^2; $\sigma_{SI} \sim 10^{-6}$ pb**

R. Bernabei et al.; PLP 24(1998) 195, R. Cerulli, IDM2012



CRYOGENIC EXPERIMENTS

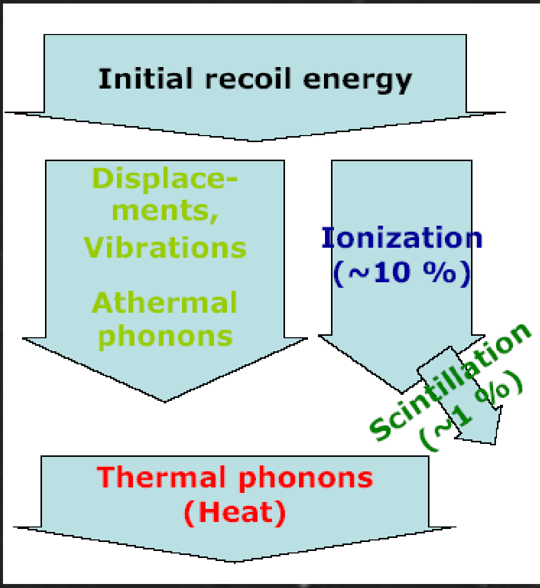


Principle:

- Crystals (Al_2O_3, Ge, Si, TeO_2) at sev. mK
- Particle interaction produces phonons (heat)
- Energy per phonon ~ meV → FWHM 4.5 eV @ 6 keV_x
- Temperature rise measured by semi/superconducting thermometers

Background rejection:

- Ionization / scintill. light yield depends on recoiling particle
- Compare phonon with ion. / scintill. signal

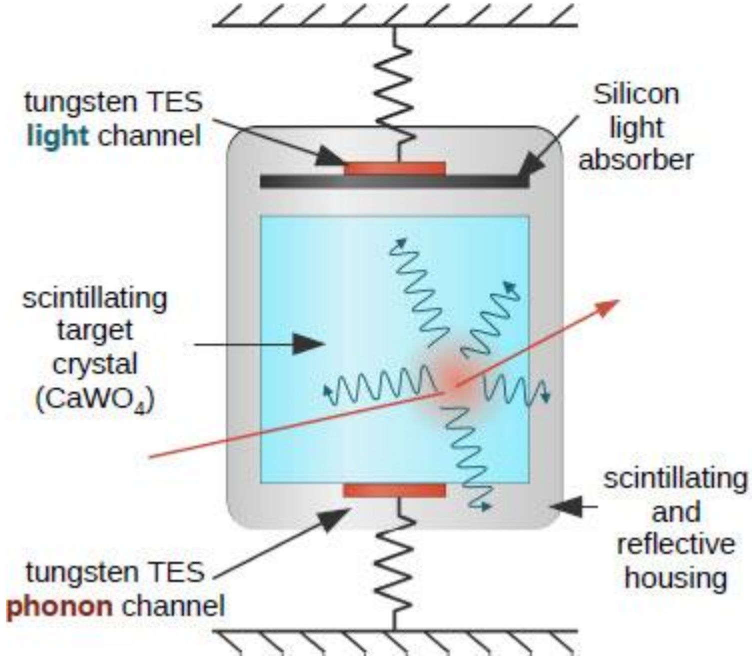


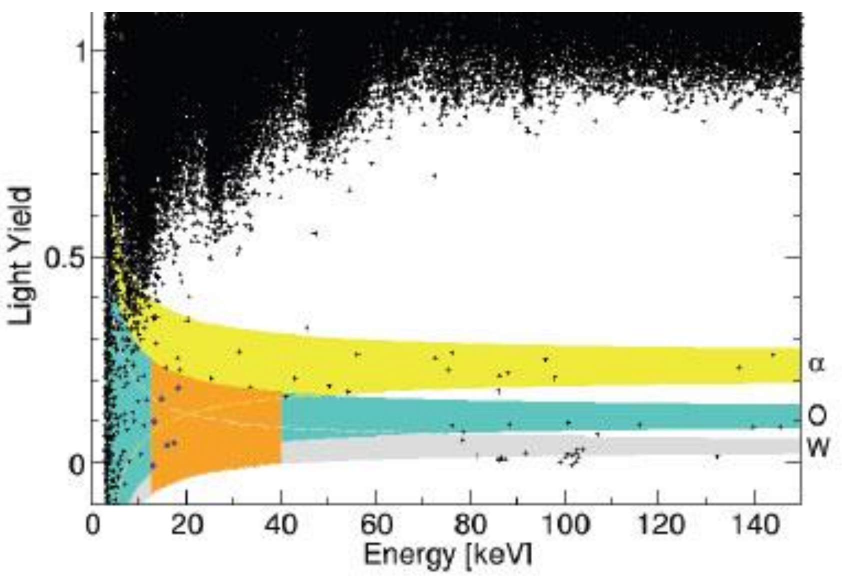
Experiments:

CDMS, CRESST, ROSEBUD, CUORE, EDELWEISS,..

CRESST II (Gran Sasso)

- 300 g crystals of $CaWO_4$
- Transition edge sensors @10 mK
- Phonon (energy) + light signal
- 3 different targets → $M_W \sim$ 12, 25, 50 GeV/c^2





C. Strandhagen, IDM 2012 ; arXiv 1109.07020:

Results:

- 8 Modules → 730 kgd
- 67 accepted events
- Two solutions:

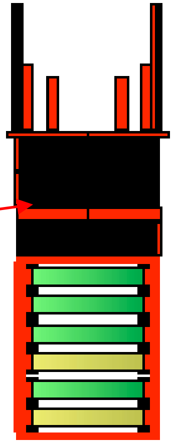
M1: 25.3 GeV/c^2 σ_{SI} =1.6x10^{-6} pb @ 4.7 σ

M2: 11.6 GeV/c^2 σ_{SI} =3.7x10^{-5} pb @ 4.7 σ

Light WIMP or Background?

2012: M1 < 2.5σ M2 < 1.9σ

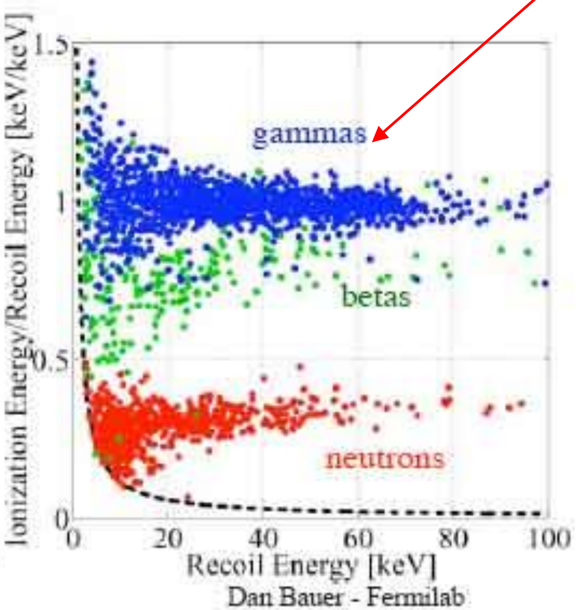
CDMS II (SOUDAN)



- 250 g Ge, Si crystals at 50 mK
- arranged by 6 modules/tower
- 5 towers operated since Oct. '06
- total mass 4.5 kg Ge, 1.1 kg Si
- ionisation + heat + risetime
- γ rejection > 99.9998 %, 99.75 for β's

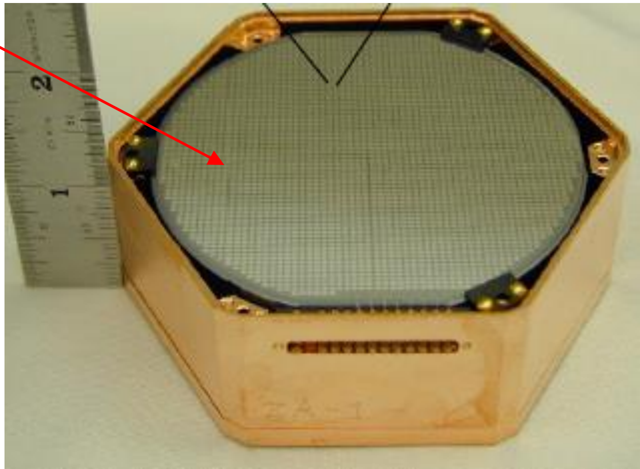
CDMS II SI

- April 2013 $\rightarrow$ 140 kgd
- 3 ev. Backg. 0.7 ev
- **σ_{SI} ~ 2 10^{-5} pb , M_W = 8.5 GeV/c^2**



superCDMS (SNOLAB)

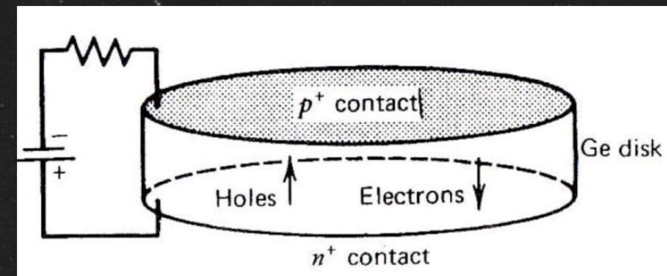
- 640 g detector modules
- 25 kg active mass (2012)
- Larger cryogenic system
- x 40 backg. Rejection
- **Goal $\rightarrow$ σ_{SI} ~ 10^{-9} pb**



GE- IONISATION EXPERIMENTS

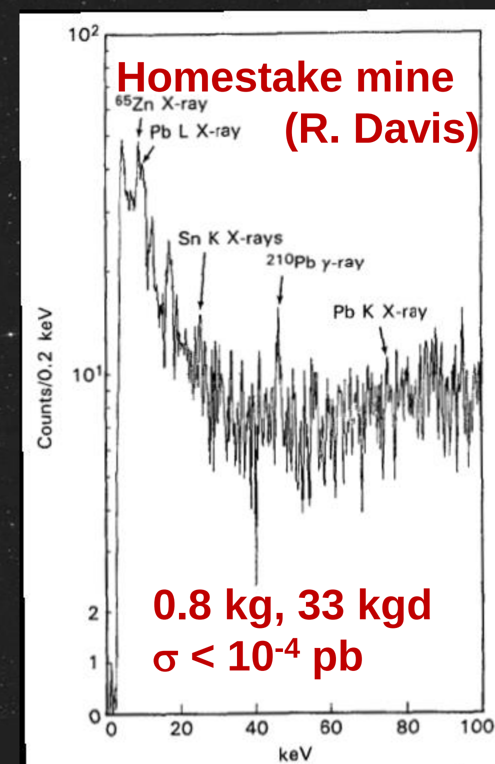
Principle:

- High purity Ge- crystals (LN_2 Temperature)
- ΔE / e^- -ion pair: 3 eV
- Resolution: 400 eV @ 10 keV



Background rejection:

- high intrinsic purity
- anti-coincidence veto



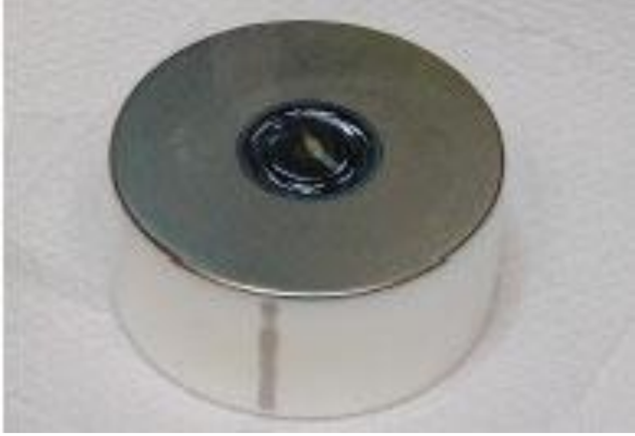
Phys. Lett. B, 195 (1987)

LIMITS ON COLD DARK MATTER CANDIDATES FROM AN ULTRALOW BACKGROUND GERMANIUM SPECTROMETER

S.P. AHLEN [a], F.T. AVIGNONE III [b], R.L. BRODZINSKI [c], A.K. DRUKIER [d,e], G. GELMINI [f,g,1] and D.N. SPERGEL [d,h]

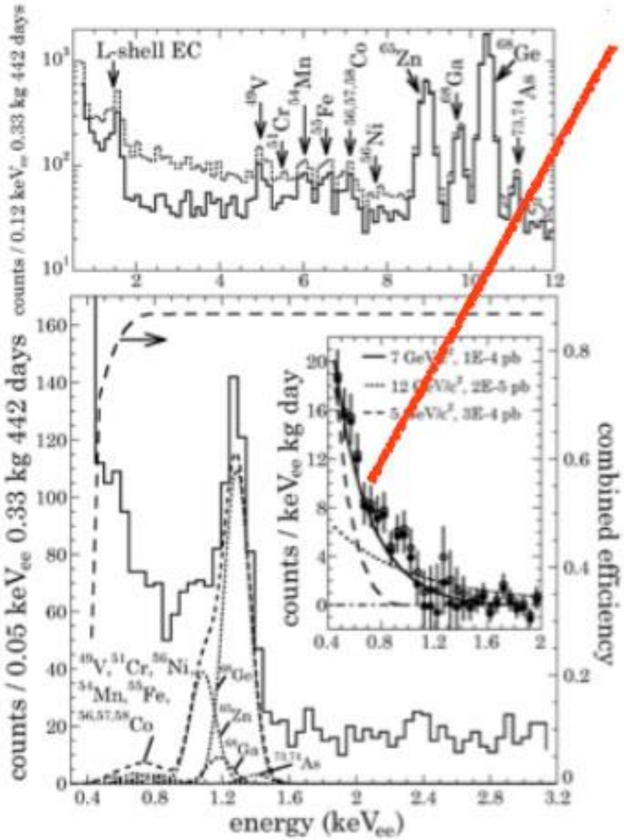
Experiments: IGEX, COSME, CoGENT, NeCaPSI…

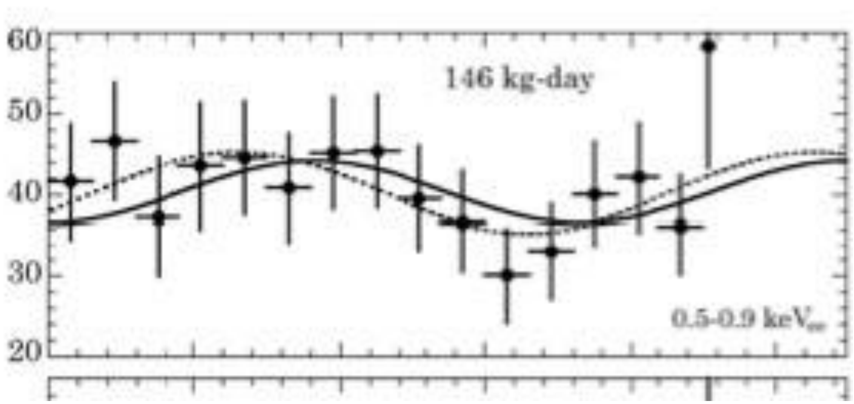
COGENT (SOUDAN-LAB)



- Single 440 g HPGe crystal
- Point contact electrode: C↓ low noise
- Optimized for low E, low backg.
- Threshold @ 0.4 keV_{ee}

M_W = 7 GeV/c^2 spectrum!



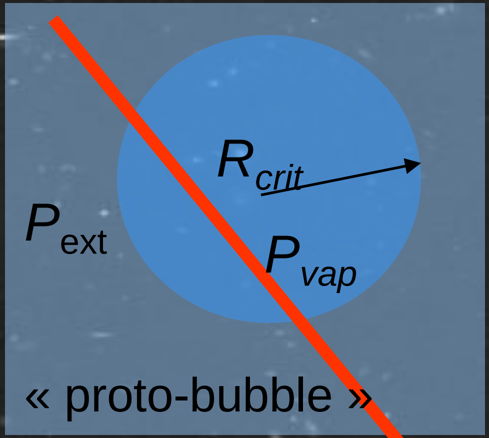


TAUP 2011:

- **DAMA like modulation**
- **DAMA like σ ~ 7x10^{-5} pb …in 2011**
- **CRESST?**

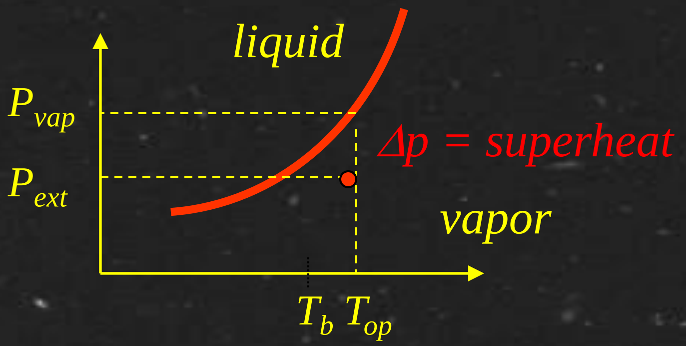
R. Gaitskell, DM2012,; arXiv: 1106.0650v3

SUPERHEATED LIQUIDS



Principle:

- Bubble chamber technique
- $E_{th} \sim 1$ keV for nuclear recoils
- full efficiency for nucl. Recoils



$$E_{dep} = \frac{dE}{dx} \cdot R_{crit} \geq E_{min}$$

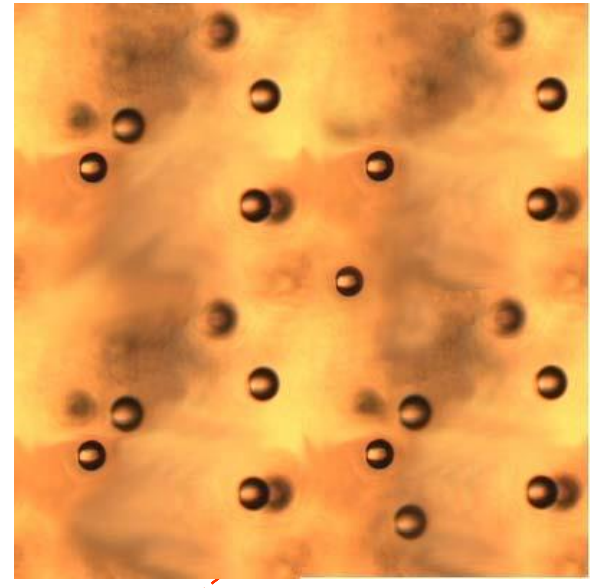
Background rejection:

- $dE/dx_{Bragg} \rightarrow$ discriminates recoil nuclei from γ, e, μ !
- gamma rejection better than 10^{10} at E_{rec}= 5 keV

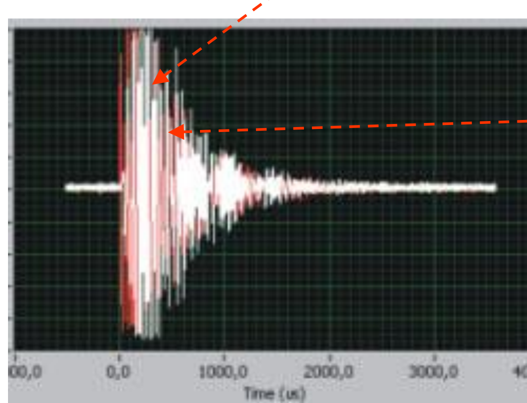
Experiments:

- PICASSO, SIMPLE, COUPP…

Picasso (SNOLAB)

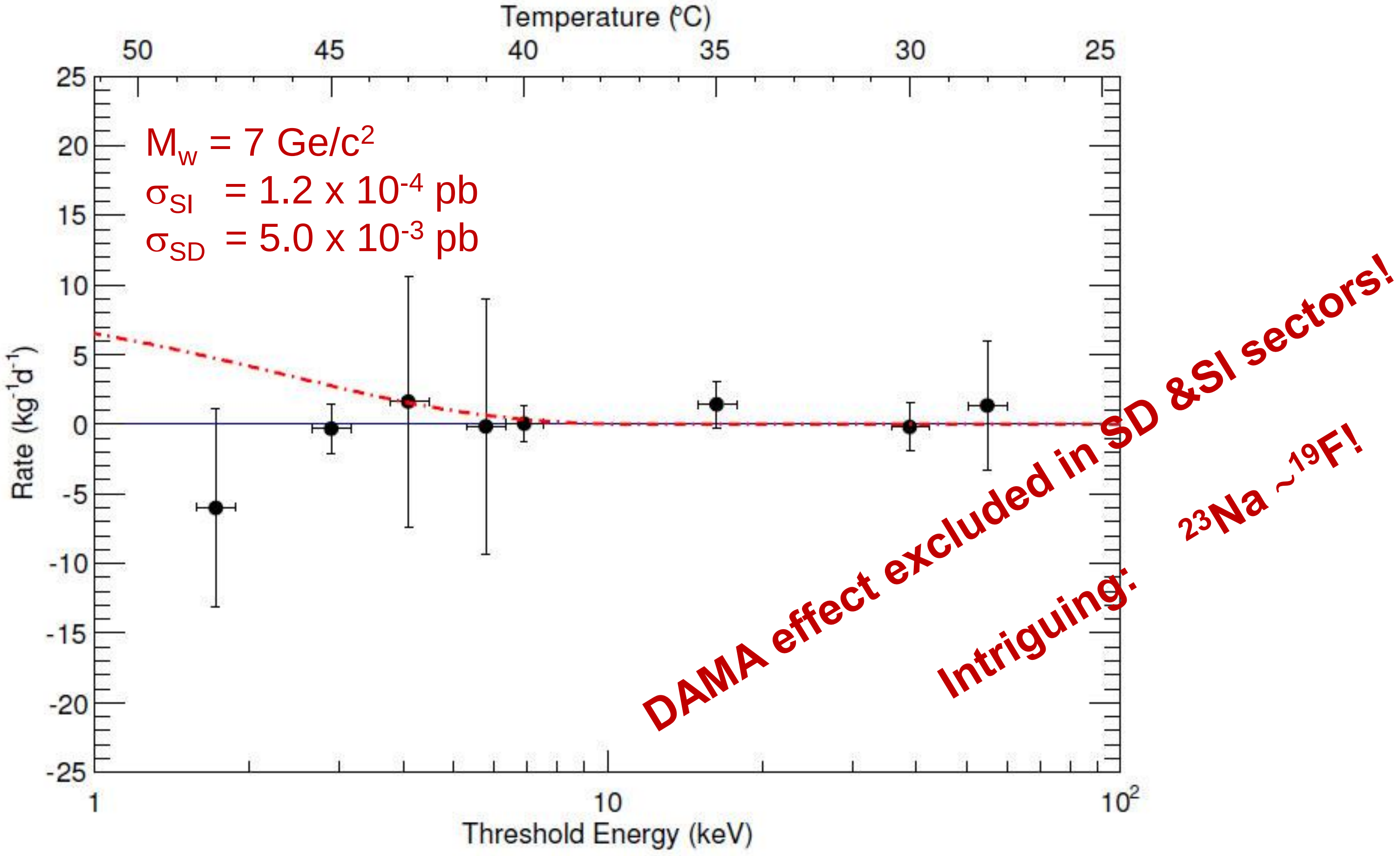


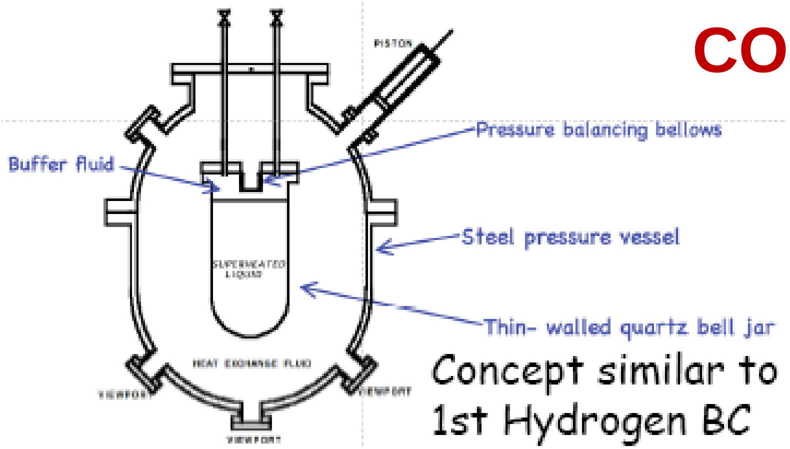
- 150 μm droplets of C_4F_{10} dispersed in polymerised gel
- Droplets superheated at ambient T & P (T_b= - 1.7 °C)
- Radiation triggers phase transition
- Operating temperature determines energy threshold
- **insensitive to γ - background**
- **Acoustic α / recoil discrimination!**
- **Calibrated down to 0.8 keV**



Physics Analysis (2012)

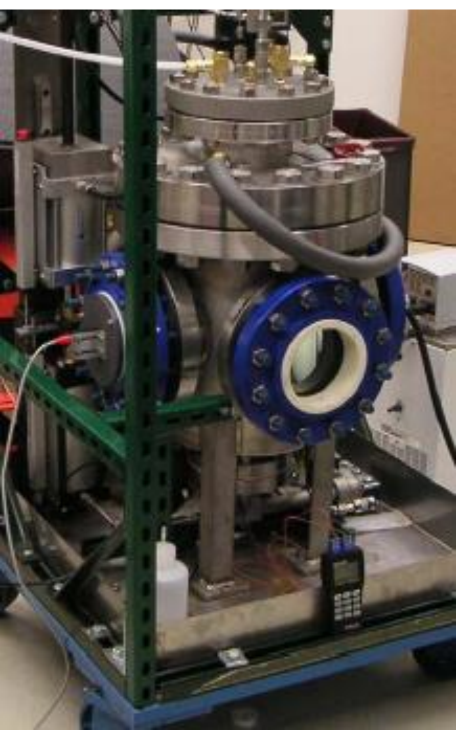
- 10 « golden detectors »; 140 kgd exposure
- ^{19}F & low threshold (1.7 keV)→ improved sensitivity for M_W < 15 GeV/c^2





COUPP (SNOLAB)

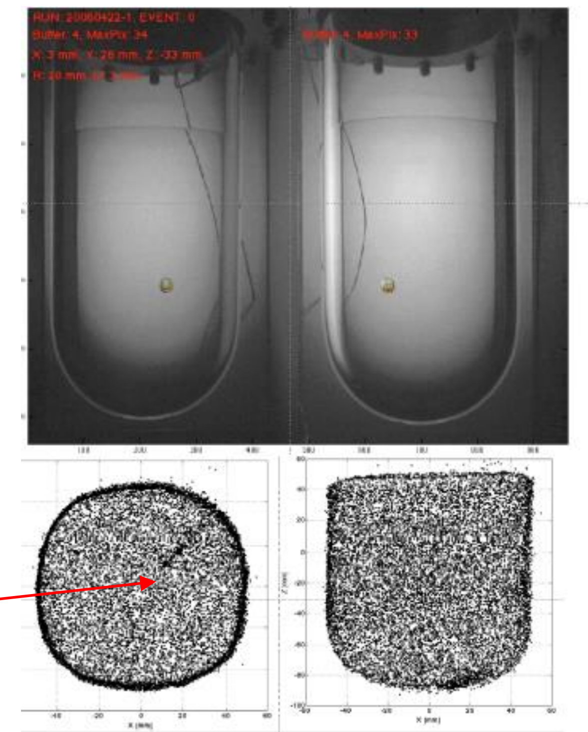
- 2 kg CF_3I Bubble chamber
- can explore SD and SI interactions
- acoustic trigger & events optically recorded
- **σ_{SD} < 5 10^{-2} pb, σ_{SID} < 5 10^{-6} pb,**



Ongoing

- 30 L bubble chamber (60 kg) @ SNOLAB
- water Cerenkov veto

Bckg. In liquid mainly Rn decays



Spatial distribution of bubbles (~1 mm resol.)

60kg chamber construction & testing

COUPP60 (SNOLAB)

- Data taking at SNOLAB started June 2013

exp. sensitivity:

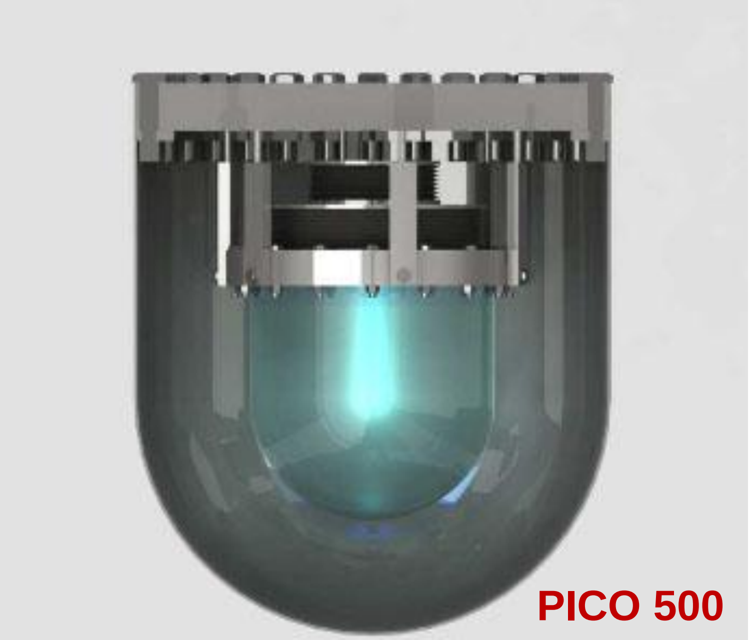
$\sigma_{SD} < 10^{-5}$ pb,

$\sigma_{SID} < 5\ 10^{-9}$ pb,

PICASSO + COUPP = PICO

500 kg $C_3F_8 \rightarrow$ 2015

exp. sensitivity: $\sigma_{SD} < 10^{-7}$ pb $\sigma_{SID} < 10^{-10}$ pb,



PICO 500

LIQUID NOBLE GASES

Principle

- Single phase: LXe,LNe, LAr $\rightarrow$ scintillation
- Dual phase liquid /gas $\rightarrow$ scintillation + ionisation

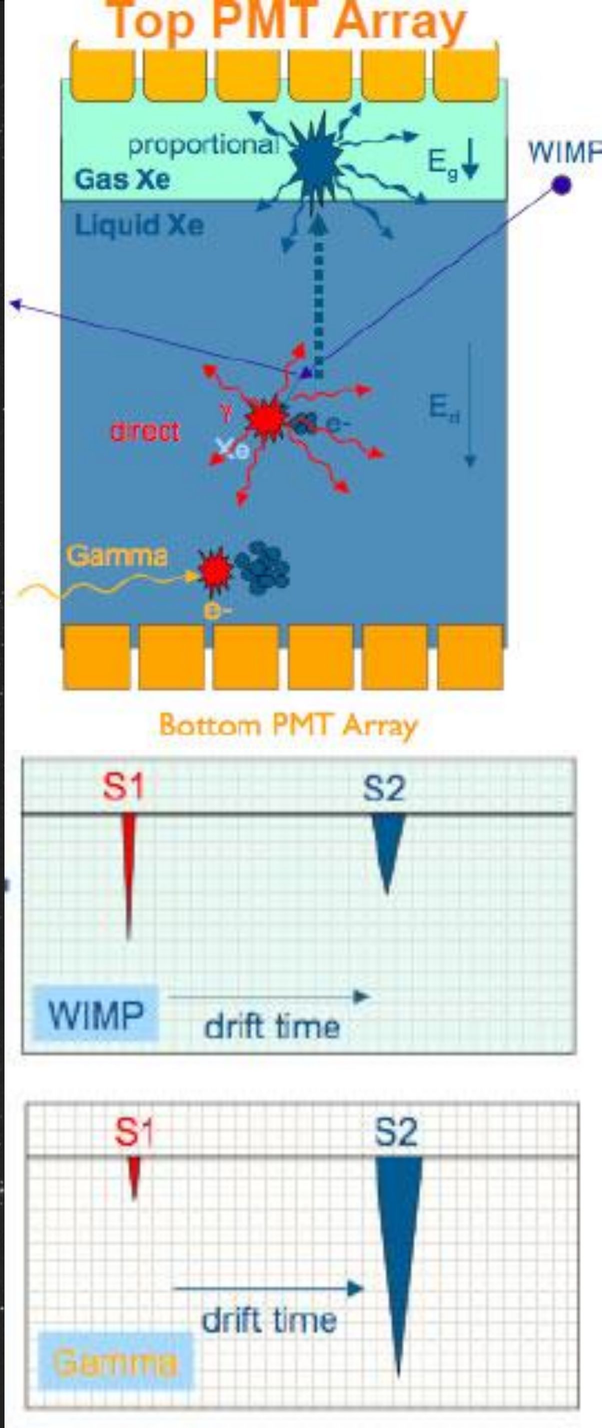
Background rejection:

- pulse shape discrimination / single phase
- Xe^{*} +Xe recombination $\rightarrow$ UV γ (S1) 10:1 nuclear : electron
- double/phase: part of e^{-} drifted into gas phase
- sec. Ion. in strong field (10kV/cm) $\rightarrow$ delayed scint. γ's (S2)

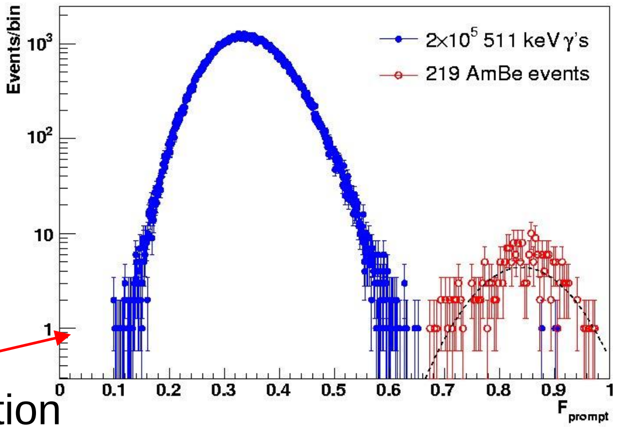
Advantages:

- large mass
- Re-purification
- Good particle ID

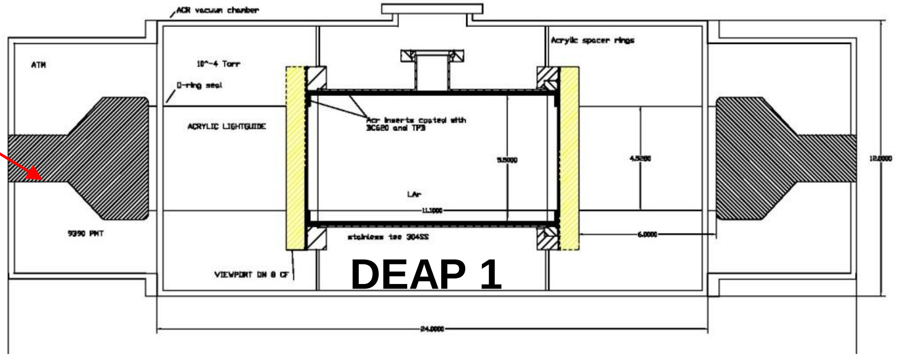
Gas	Single phase	Double phase
Xenon	ZEPLIN I, XMASS	ZEPLIN, XENON, LUX
Argon	DEAP, CLEAN	WARP/ DarkSide, ArDM
Neon	CLEAN	SIGN

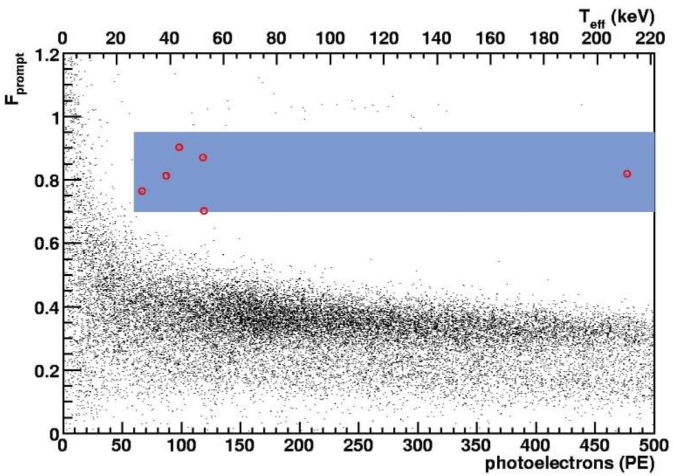


DEAP (SNOLAB)



- Detects scintillation light in LAr at 85K
- Light yield 4×10^4 γ's/MeV threshold ~ 10 keV
- excited dimers of Ar^*_2 in singlet/ triplet states
- different lifetimes and S/T fraction depending on ionisation
- $\rightarrow$ pulse shape discrimination
- 7 kg of Lar $\rightarrow$ SNOLAB early '07
- **Goal $\rightarrow$ σ_{SI}~ 10^{-8} pb after 1 year**

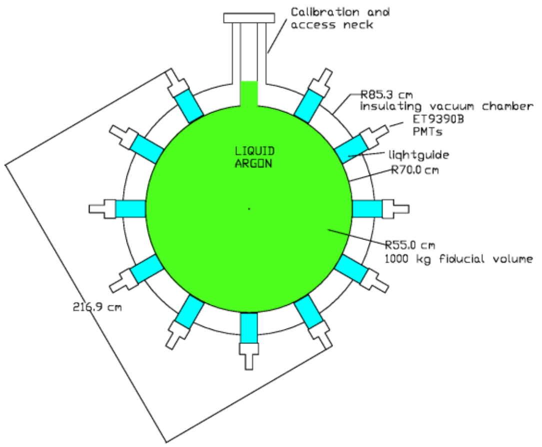


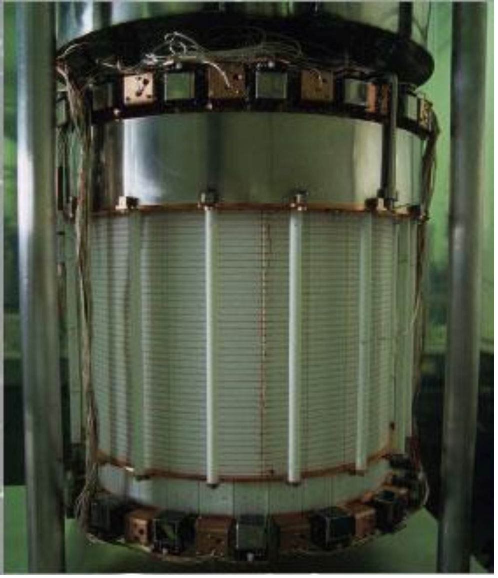


Unshielded tests at Queen's

Future: **DEAP 3**

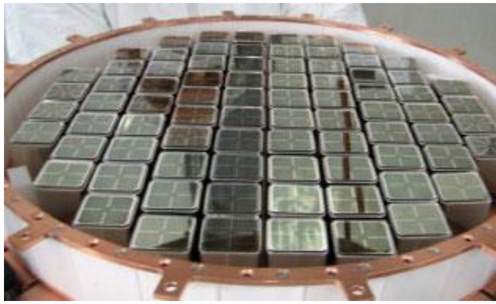
- 1 tonne Lar
- 5m diameter tank
- 500 PMT's





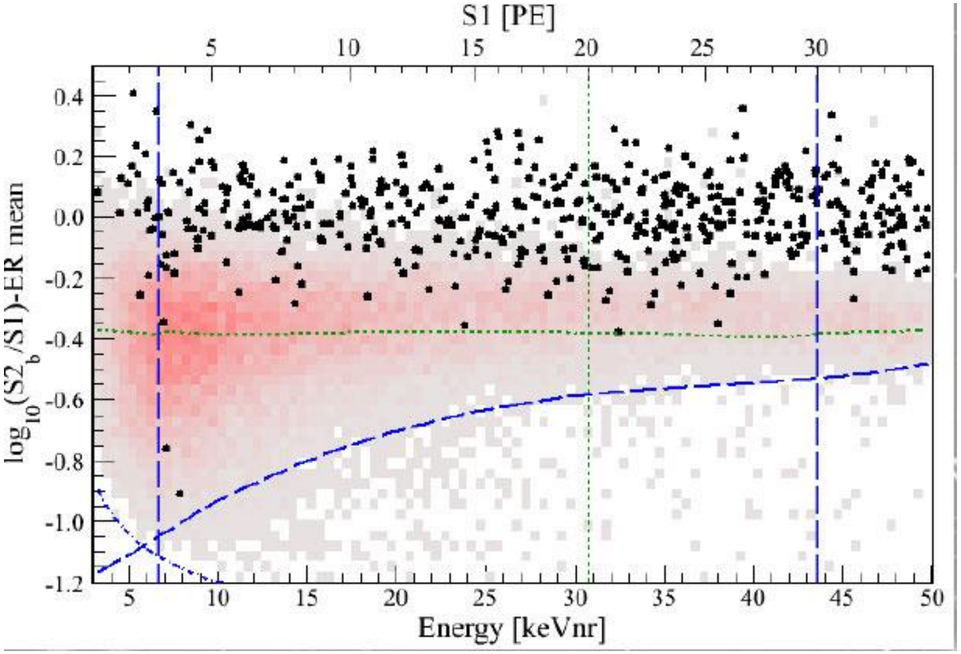
XENON 100 (Gran Sasso)

- 30 cm drift x 30 cm ∅ TPC
- 162 kg Lxe (A=131)
- 241 1” PMT
- LXe veto around
- Kr: 19 ppt



2012 Results :

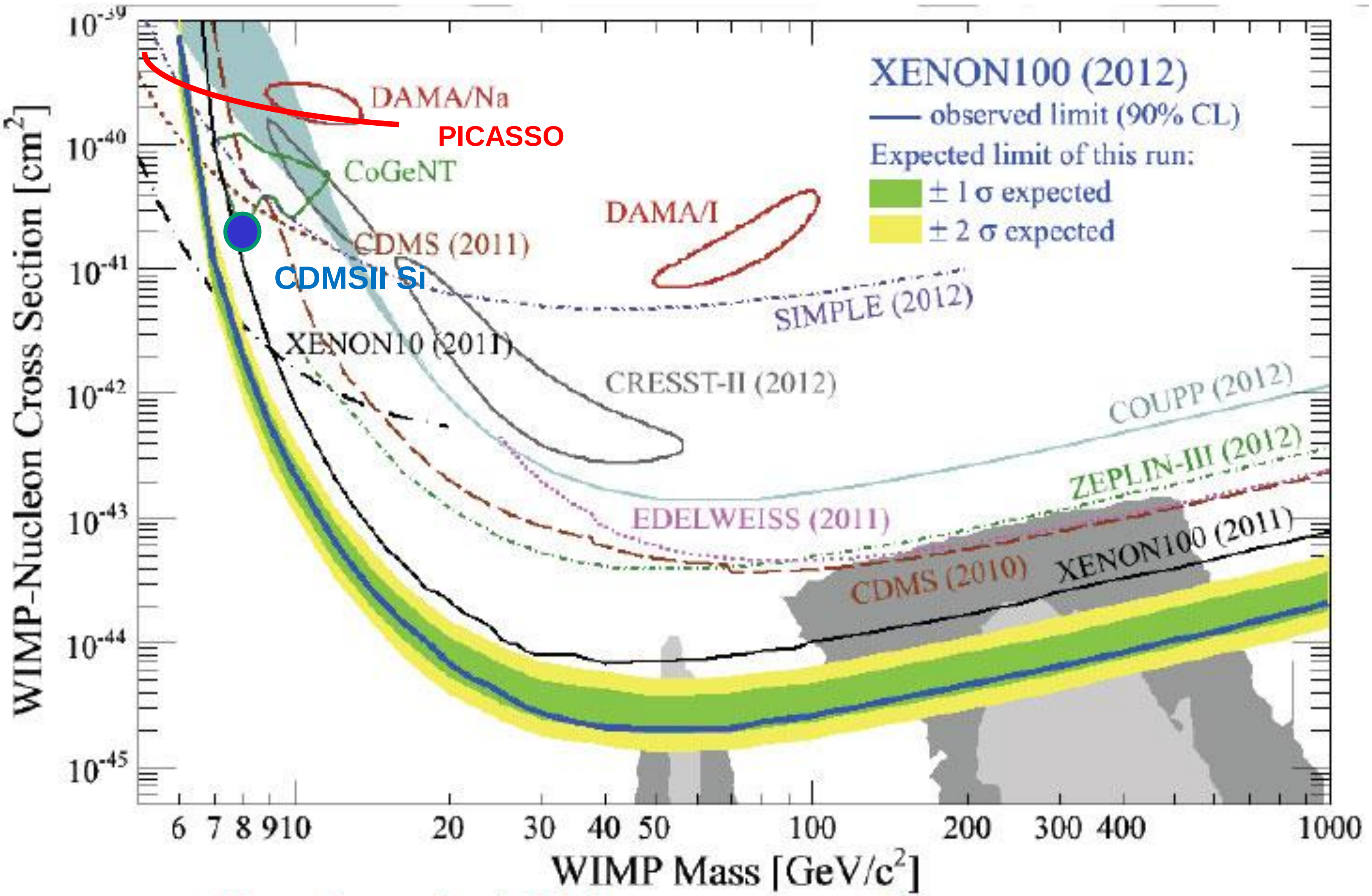
- Fid. Vol. 34 kg 224 days
- Define scaling region (calib.)
- 2 events observed after unbldg.
- 1 ± 0.2 expected
- no events below threshold



Upper limit: 2×10^{-9} pb for 55 GeV/c^2 (90% C.L.)

J. Malgarejo, IDM 2012

CURRENT STATUS SPIN-INDEPENDENT SECTOR



ONE CLAIM FOR DISCOVERY: DAMA

CAN THESE RESULTS BE MADE COMPATIBLE

Proposed sources for DAMA's annual modulation:

- Ambient temperature variation
- μ-flux depends on atm. temperature/pressure
- Spallation neutrons from muons in rock
- Rn diffusion from rocks may be varying with time

(all explained away by DAMA)

Detector Effects?

- Quenching & channeling
- Threshold effects (Collar)

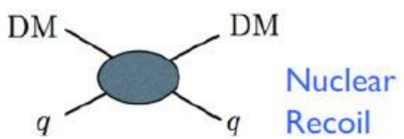
Astrophysical effects?

- different halo compositions
- v_χ and ρ_χ different than expected
- diff. exp. thresholds

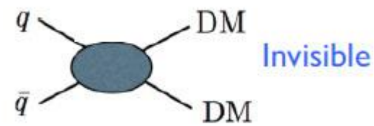
Due to nature of DM?

- Different experiments diff. sensitivities to candidates
- Isospin violating DM: e.g if $f_p = -f_n \rightarrow$ no Xe effect!
- ????

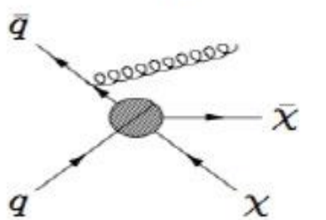
DIRECT DETECTION & LHC → MONO-JETS

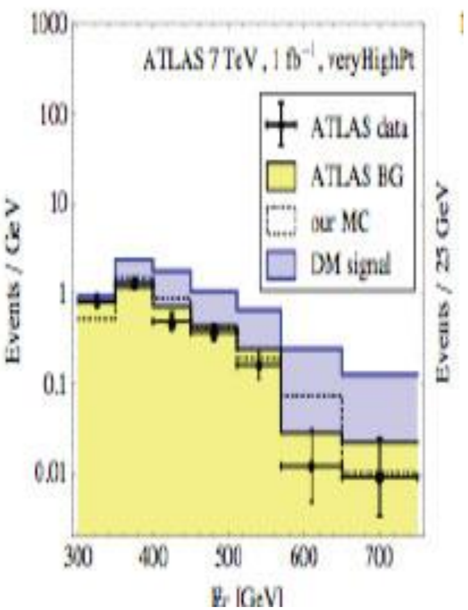


Direct searches (non-relativistic)



LHC searches (highly relativisic)



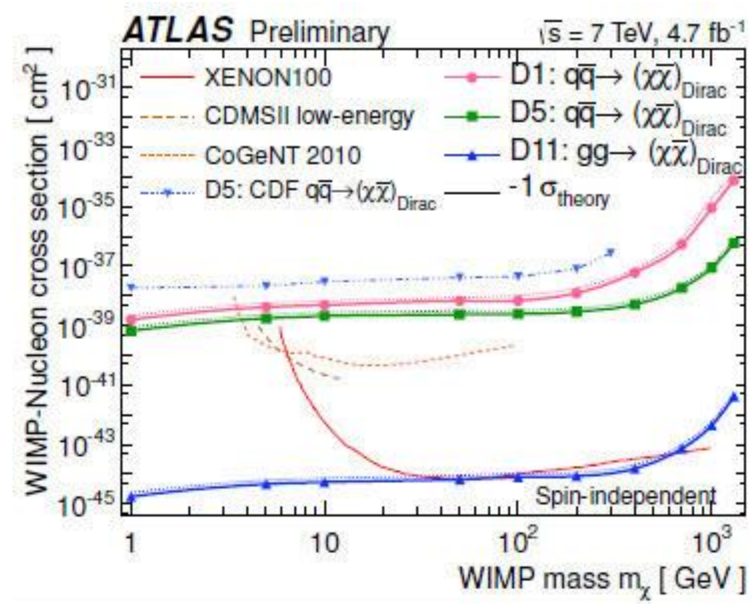


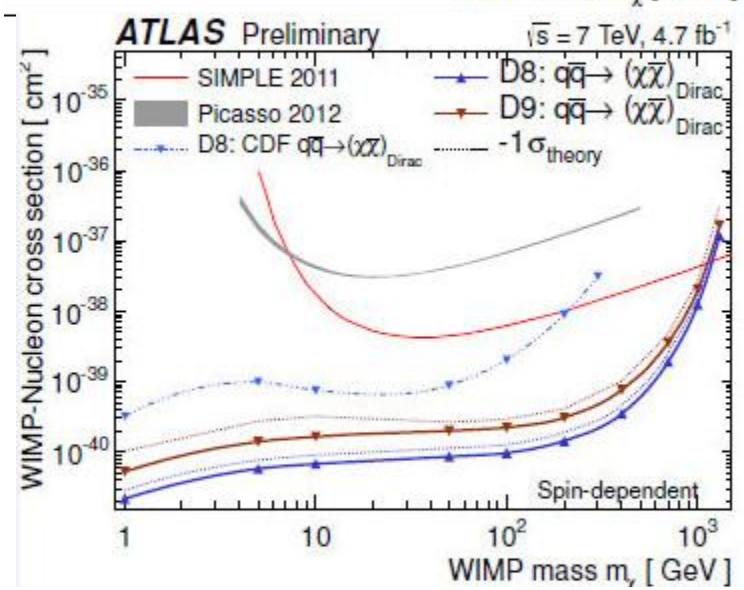
- Tagging by j / γ + E_t^{miss}
- Search for excess
- Suppose contact interaction
- Relate to direct $\sigma_{SI,\ SD}$

Impressive limits….

BUT:

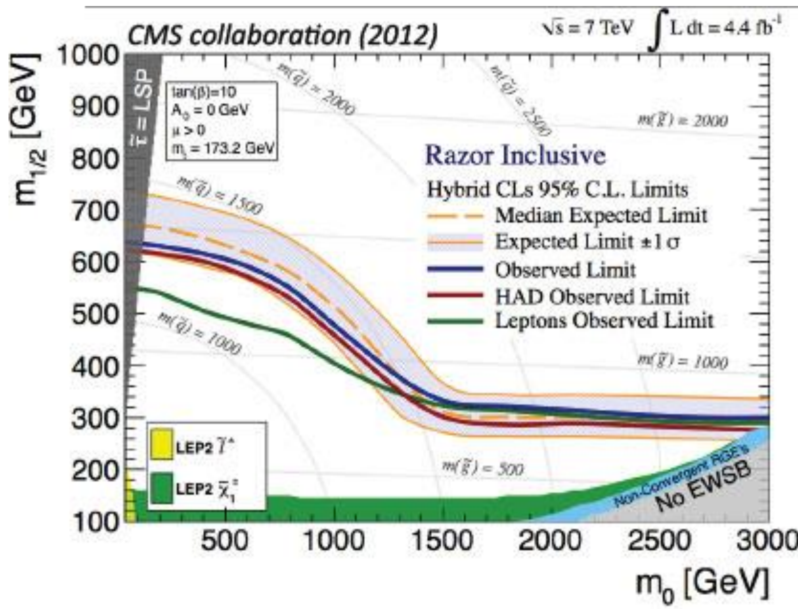
...works only well for mediator mass > few TeV





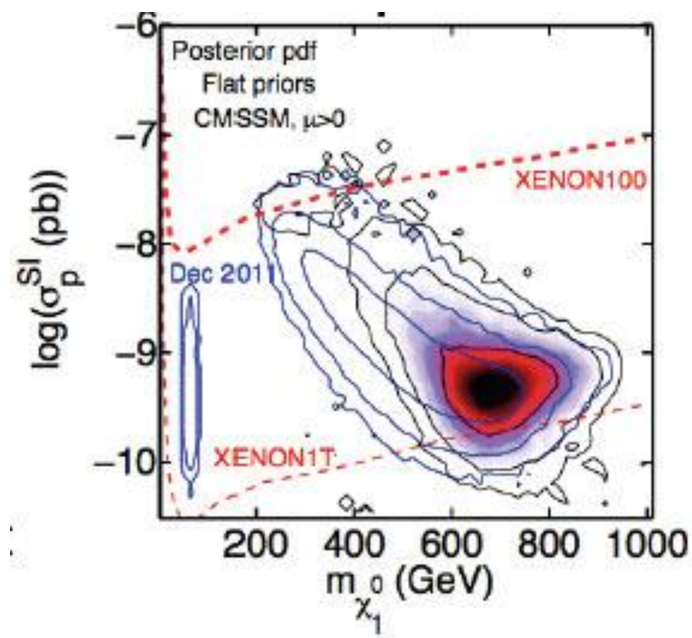
DIRECT DETECTION & LHC $\rightarrow$ SUSY SEARCH

- cMSSM: m_0, $m_{1/2}$, A_0, $\tan(\beta)$, sign(μ)
- Apply contraints (closure density...)
- + LHC (non)-observational results



- LHC exclusion limits cut deep into cMSSM parameter space
- Add Higgs mass constraints...

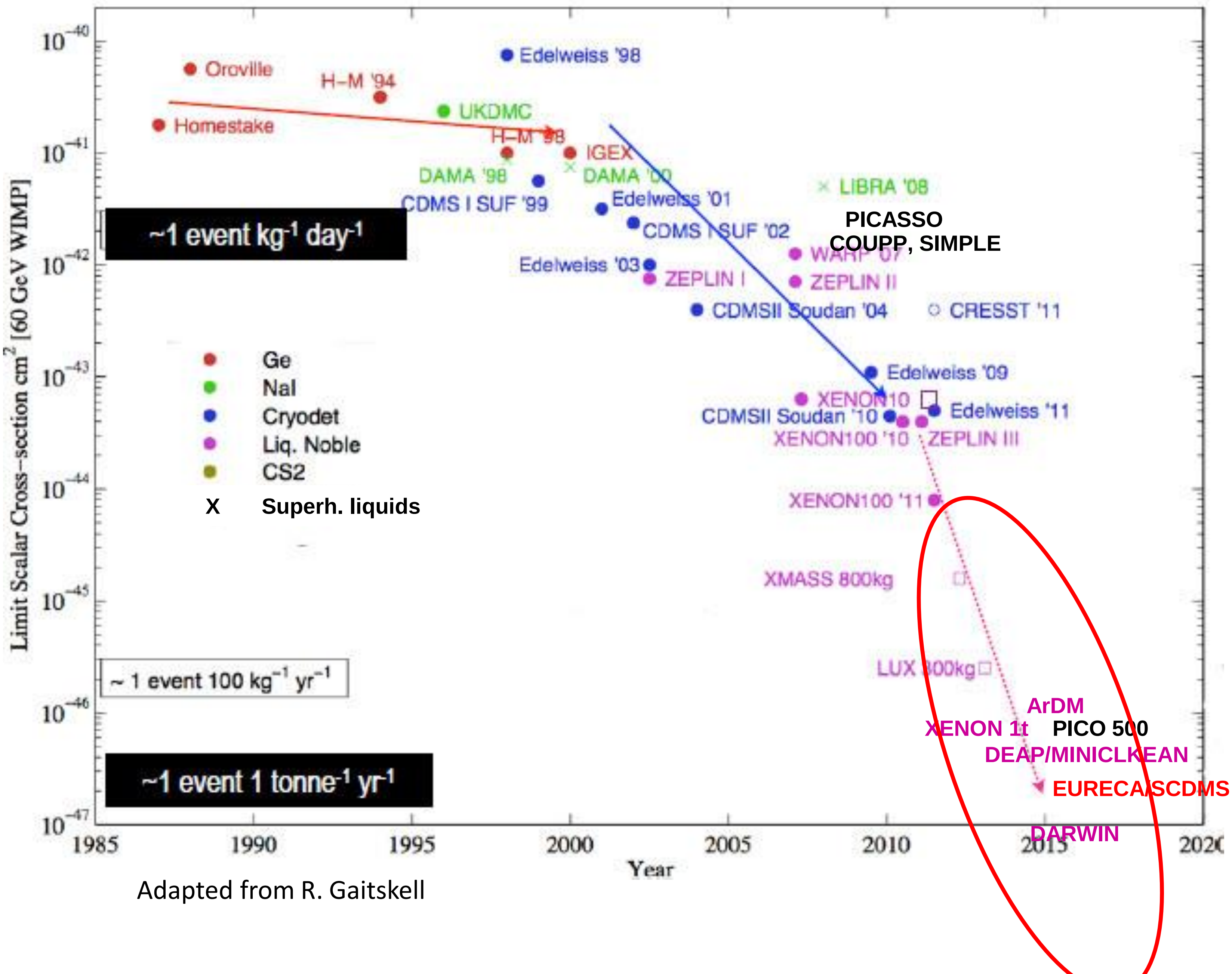
M_W `> 500 GeV/c^2 + small x-sections!



BUT:

- SUSY parameter space large
- other models...UED etc

THE FUTURE OF DIRECT DM SEARCHES

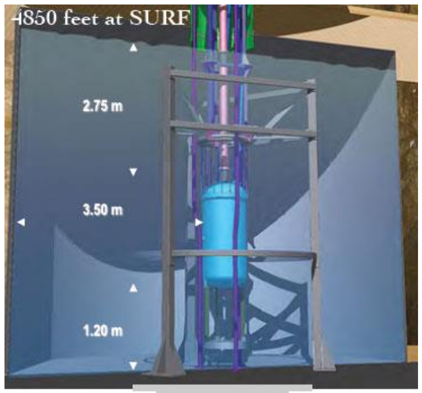


Adapted from R. Gaitskell

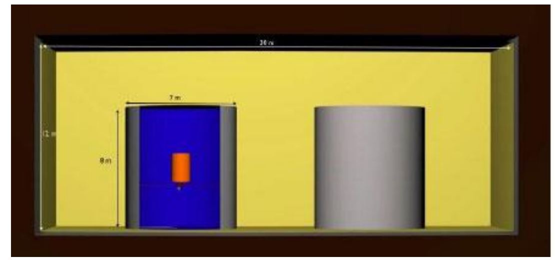
THE FUTURE OF DIRECT DM - SEARCHES

Trend towards a few very large experiments....

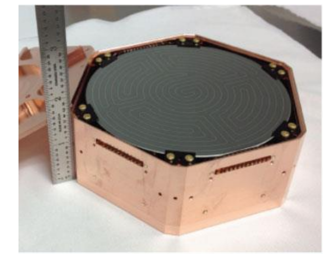
ArDM 850 kg



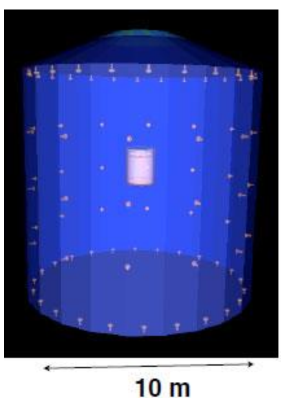
LUX 350 kg Xe



EURECA 0.1 -1t

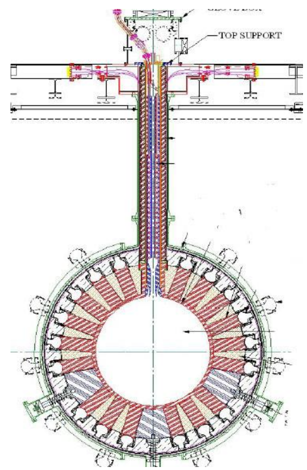


Super CDMS 0.2 t Ge
→ GEODM 1.5t Ge

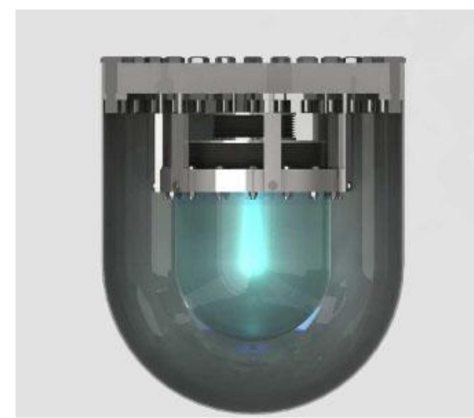


XENON 1t

DARWIN 20t Xe / Ar



DEAP 3.6 t Ar



PICO 0.5 – 1t
(PICASSO-COUPP)

Summary

- Concordance Model : Ω_{tot} =1, Ω_{dm} = 0.3, Ω_b = 0.05 ,Ω_Λ = 0.7
- Astronomical observations + WMAP strongly support CDM
- CDM responsible for 85% of gravitationally traceable matter
- Direct, indirect and accelerator searches on the way to explore theoretically interesting X- section ranges
- 10^{-10}pb (SI) and 10^{-6}pb (SD) in reach within next 7-8 years
- Tantalising results in low Wimp mass region $\rightarrow$ tension between experiments
- Increasing synergy and complementarity between accelerator, direct and indirect searches