Indirect Detection of Dark Matter

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Dark Matter
FROM THE COSMOS TO THE LABORATORY

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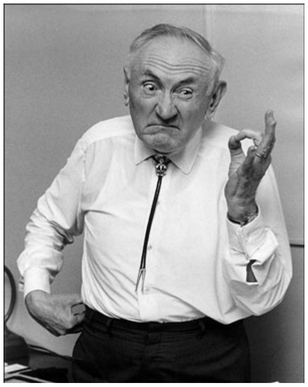
Lecture I

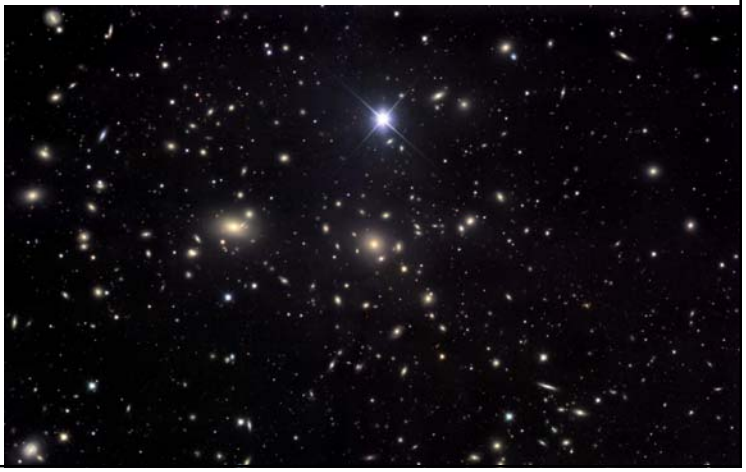
Some notes on the early history of Dark Matter

For more details, see talk by Joel Primack, tomorrow



Fritz Zwicky, 1933: Velocity dispersion of galaxies in Coma cluster indicates presence of Dark Matter , $\sigma \sim 1000$ km/s $\Rightarrow$ M/L ~ 50

"If this overdensity is confirmed we would arrive at the astonishing conclusion that dark matter is present [in Coma] with a much greater density than luminous matter."



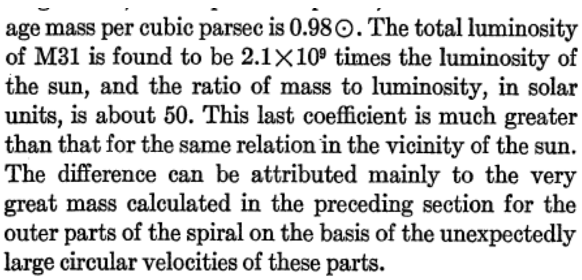
"It is, of course, possible that luminous plus dark (cold) matter together yield a significantly higher density..." - Zwicky 1933

Smith (1936) confirmed Zwicky's results with Virgo cluster.

Zwicky (1937) notes that gravitational lensing may be used as a tool to estimate the total mass of galaxies.

Babcock (1939) measured rotation curve of M31 (Andromeda).

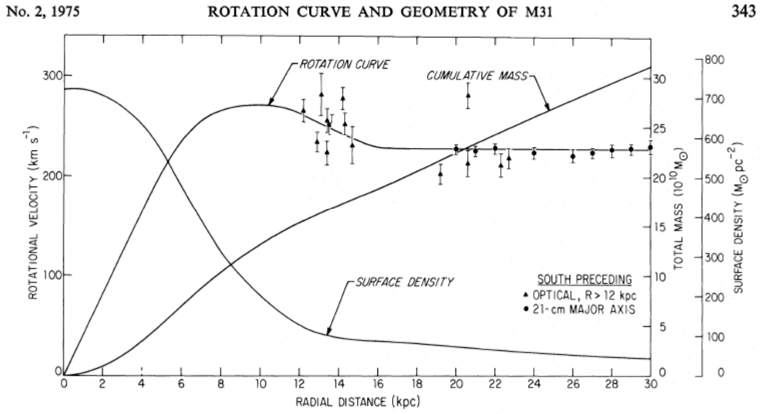
From Babcock's paper, 1939:



age mass per cubic parsec is 0.98⊙. The total luminosity of M31 is found to be 2.1×10^9 times the luminosity of the sun, and the ratio of mass to luminosity, in solar units, is about 50. This last coefficient is much greater than that for the same relation in the vicinity of the sun. The difference can be attributed mainly to the very great mass calculated in the preceding section for the outer parts of the spiral on the basis of the unexpectedly large circular velocities of these parts.

Then essentially nothing
happened for 30 years….

Then Rubin & Ford (1970), and Roberts & Whitehurst (1975) measured a flat rotation curve of M31 far outside the optical radius.



Einasto, Kaasik & Saar; Ostriker, Peebles & Yahil (1974):

Dark halos surround all galaxies and have masses ~ 10 times larger than luminous populations, thus dark matter is the dominant population in the universe: Ω_{DM} =0.2.

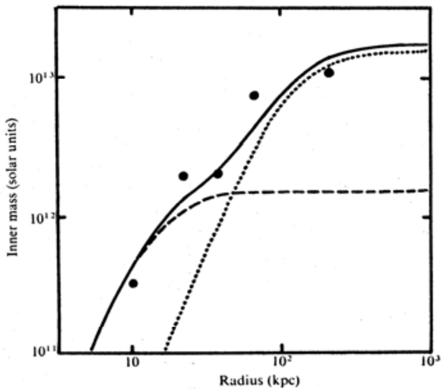
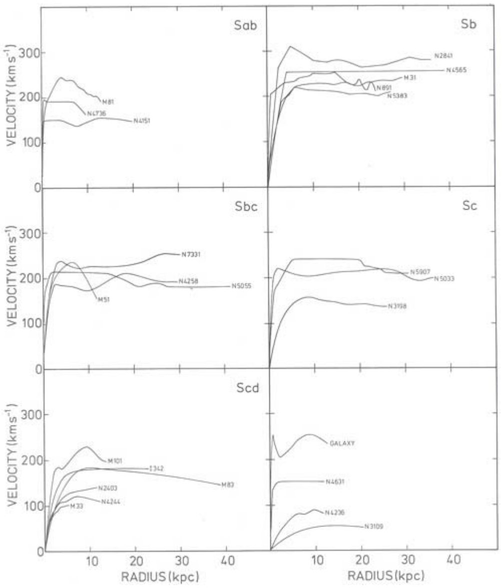


Fig. 2 The distribution of the mean inner mass, $\langle M(R) \rangle$, obtained from 105 pairs of galaxies. Symbols as in Fig. 1.

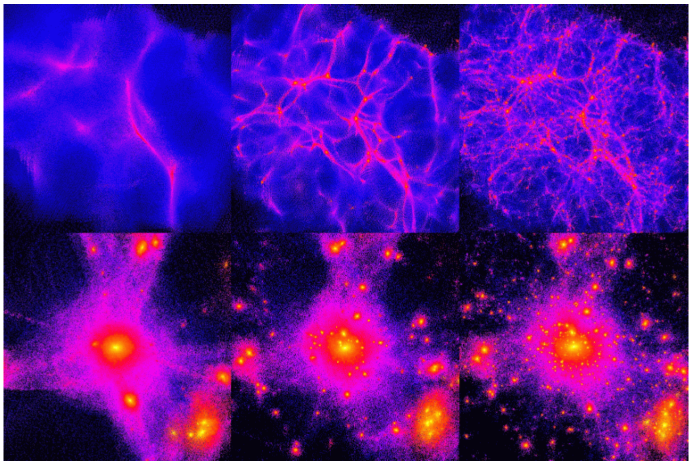
Flat rotation curves are the rule:

From 21 cm results in thesis of A. Bosma, 1978 (cf also Rubin, Thonnard & Ford, 1978):



Around 1982 (Peebles; Bond, Szalay, Turner; Sciama) came the Cold Dark Matter paradigm: Structure formation scenarios (investigated through N-body simulations) favours hierarchical structure formation. Hot Dark Matter (like neutrinos) would first form structure at large scales (Zel'dovich pancakes) which then fragments to smaller scales – does not agree with observations. The theoretical belief was that $\Omega_M = 1$

Melott et al 1983; Blumenthal, Faber, Primack & Rees 1984,...



Hot Dark Matter →

Cold Dark Matter ←

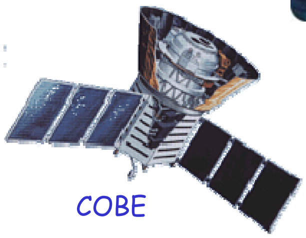
B. Moore

1990’s: Opening of a new era, which has turned the tide in favour of cold dark matter: Precision Cosmology

Nobel Prize in Physics 2006

John Mather

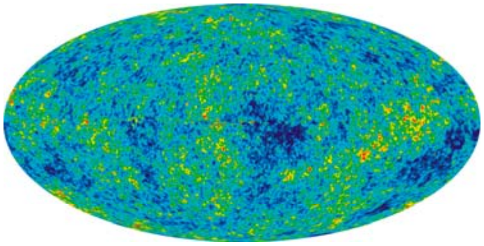
George Smoot



COBE

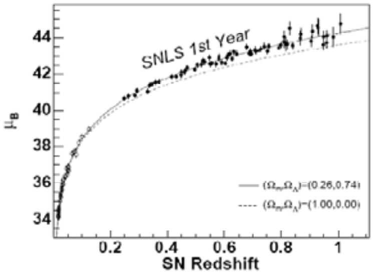
”… for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation.”

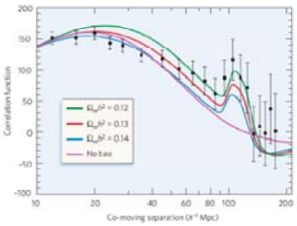
WMAP, 3-year data



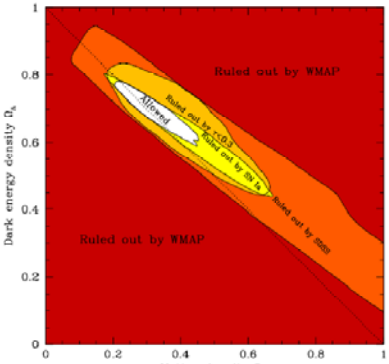
G. Hinshaw et al., 2006

P. Astier, et al., 2005

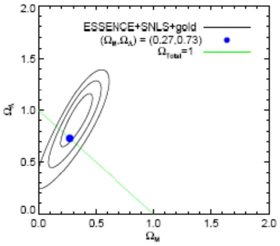




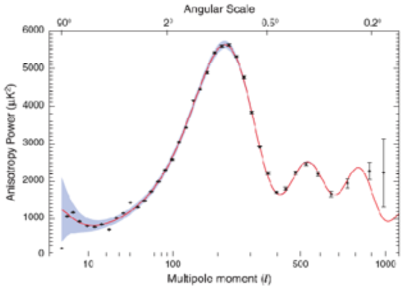
SDSS, 2005

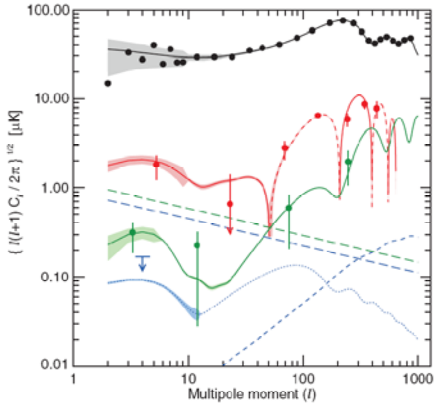


M. Tegmark et al, 2004



W.M. Wood-Vasey et al., 2007



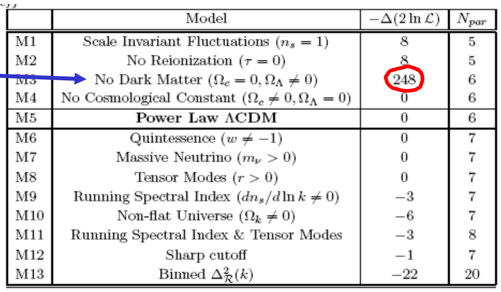


Result from best-fit model from WMAP3, Concordance ΛCDM Model (for flat Universe):

- Only 4.4 % baryonic matter, $\Omega_b h^2 = 0.0223 \pm 0.0009$
- Around 22 % Cold Dark matter, $\Omega_{CDM} h^2 = 0.105 \pm 0.013$
- Around 74 % "Dark energy", $\Omega_\Lambda = 0.74 \pm 0.04$
- Age of Universe: 13.7±0.2 Gyr

WMAP Collaboration (Spergel & al), 2006:

Nonbaryonic Dark Matter exists!

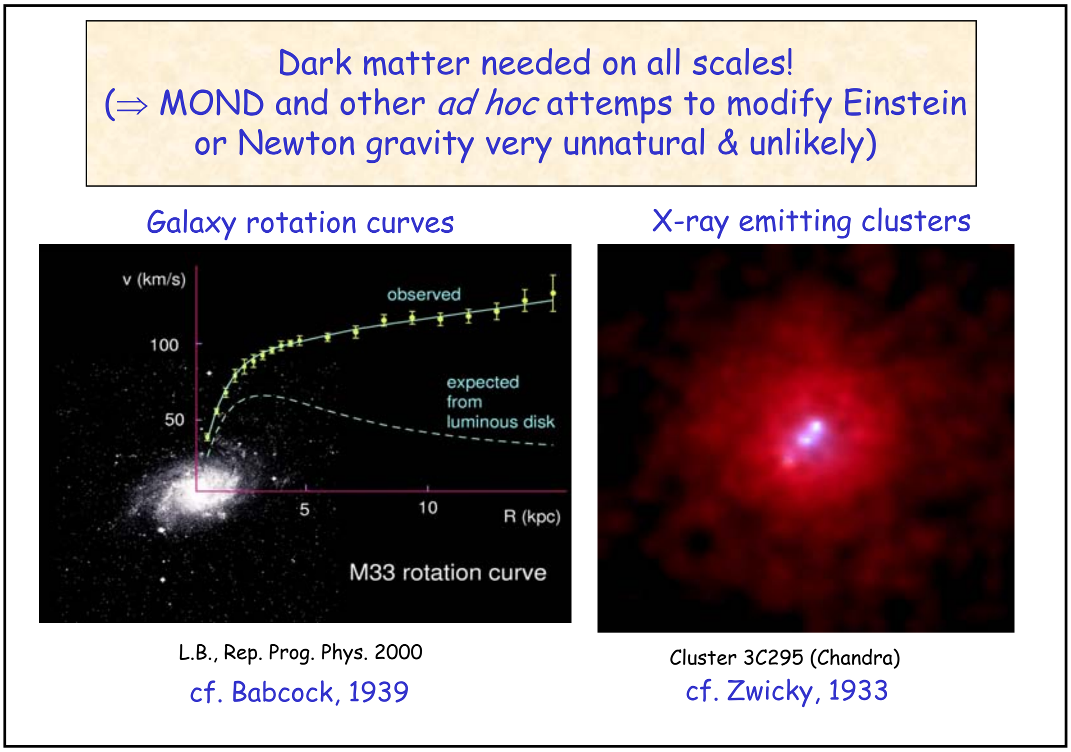


	Model	$-\Delta(2\ln\mathcal{L})$	N_{par}
M1	Scale Invariant Fluctuations ($n_s = 1$)	8	5
M2	No Reionization ($\tau = 0$)	8	5
M3	No Dark Matter ($\Omega_c = 0, \Omega_\Lambda \neq 0$)	248	6
M4	No Cosmological Constant ($\Omega_c \neq 0, \Omega_\Lambda = 0$)	0	6
M5	**Power Law ΛCDM**	0	6
M6	Quintessence ($w \neq -1$)	0	7
M7	Massive Neutrino ($m_\nu > 0$)	0	7
M8	Tensor Modes ($r > 0$)	0	7
M9	Running Spectral Index ($dn_s/d\ln k \neq 0$)	−3	7
M10	Non-flat Universe ($\Omega_k \neq 0$)	−6	7
M11	Running Spectral Index & Tensor Modes	−3	8
M12	Sharp cutoff	−1	7
M13	Binned $\Delta^2_{\mathcal{R}}(k)$	−22	20

At the time the CMBR was emitted, the redshift was $z \sim 1100$. Since $\rho_{CDM} \sim mc^2 \times (1+z)^3$ due to dilution of the number density of particles, and $\rho_\Lambda \sim (1+z)^0 = const$ (cosmological constant), the ratio of energy densities, which is now $\rho_{CDM}/\rho_\Lambda \sim 1/3$, was then

$$\rho_{CDM}/\rho_\Lambda \sim 4\times10^8$$

Cold dark matter ruled the universe! (And it still rules in galaxies…)



Dark matter needed on all scales!
(⇒ MOND and other *ad hoc* attemps to modify Einstein or Newton gravity very unnatural & unlikely)

Galaxy rotation curves

L.B., Rep. Prog. Phys. 2000

cf. Babcock, 1939

X-ray emitting clusters

Cluster 3C295 (Chandra)

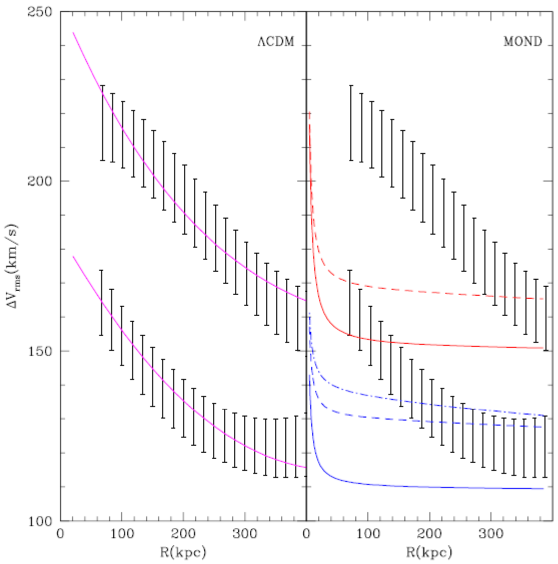
cf. Zwicky, 1933

New, November 2006: Strong new evidence for nonbaryonic dark matter

"Bullet cluster", Clowe, Randall, Markevitch, astro-ph/0611496

(*cf.* the SSI 2007 poster!)

MOND ruled out (or, at least has to have dark matter also…)



Klypin & Prada, June 2007:

Comparison between CDM and MOND for line-of-sight velocity distribution of galactic satellites from Sloan data

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The situation today:

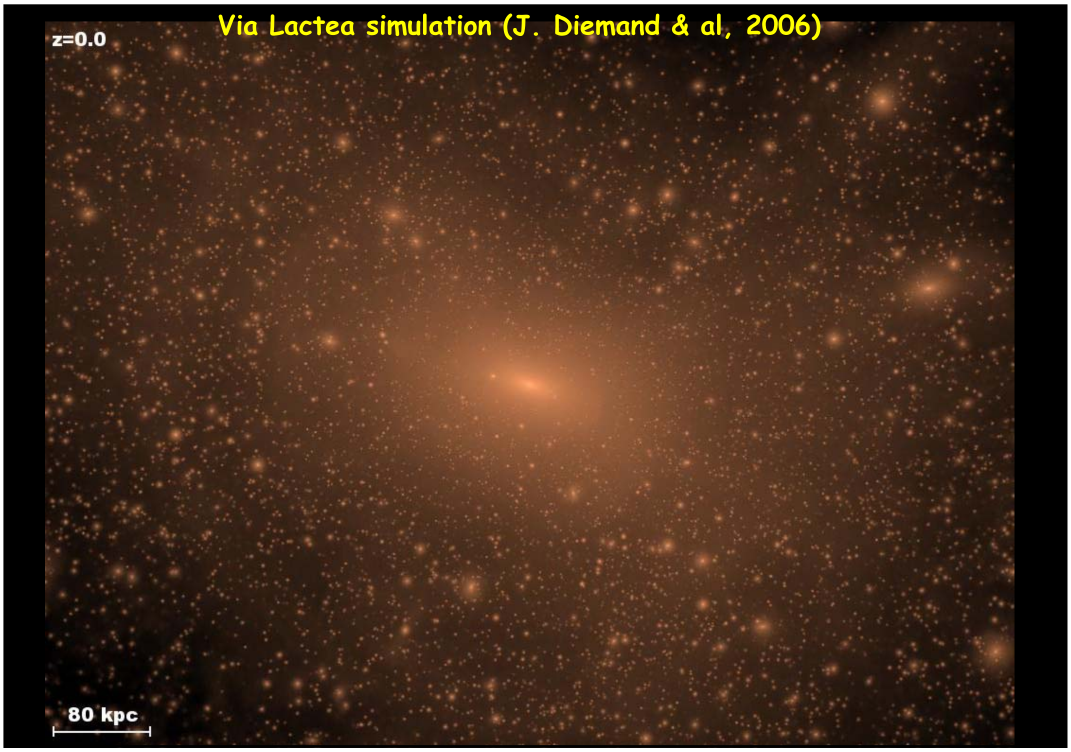
The existence of Dark Matter, especially Cold DM, has been established by a host of different methods…

…but, the question remains:
what is it?

Cold Dark Matter (CDM)

- Part of the "Concordance ΛCDM Model" of cosmology, $\Omega_{CDM} \sim 0.22$, $\Omega_\Lambda \sim 0.22$
- Gives excellent description of CMB, large scale structure, Ly-α forest, gravitational lensing, supernova distances …
- If consisting of particles, may be related to electroweak mass scale: weak cross section, non-dissipative Weakly Interacting Massive Particles (WIMPs). Potentially detectable, directly or indirectly.
- May or may not describe small-scale structure in galaxies: Controversial issue, but alternatives (self-interacting DM, warm DM, self-annihilating DM) seem less successful. Probably non-linear astrophysical feedback processes are acting (bar formation, tidal effects, mergers, supernova winds,…). This is a crucial unsolved problem of great importance for dark matter detection rates.
- Another potential problem may be the exact form of rotation curves: CDM predicts centrally concentrated (cuspy) halos, some observed ones may be better fit by a central core instead. (This may rather be related to the approximation methods when fitting an observed rotation curve to a triaxial real halo.)

Via Lactea simulation (J. Diemand & al, 2006)

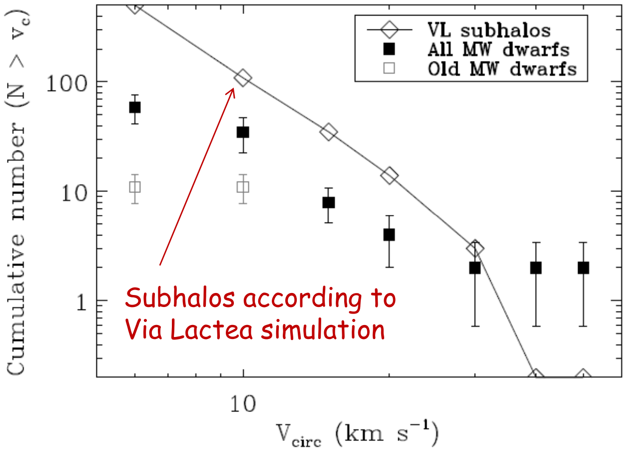


June, 2007: Potential problem now alleviated: The lack of observed substructure (satellite galaxies) in Milky Way neighbourhood (*cf.* talk by L. Blitz). Simon & Geha, 2007.

THE KINEMATICS OF THE ULTRA-FAINT MILKY WAY SATELLITES: SOLVING THE MISSING SATELLITE PROBLEM

JOSHUA D. SIMON
Department of Astronomy, California Institute of Technology, 1200 E. California Blvd., MS 105-24, Pasadena, CA 91125
AND
MARLA GEHA
National Research Council of Canada, Herzberg Institute of Astrophysics, 5071 West Saanich Road, Victoria, BC V9E 2E7, Canada
Submitted to ApJ

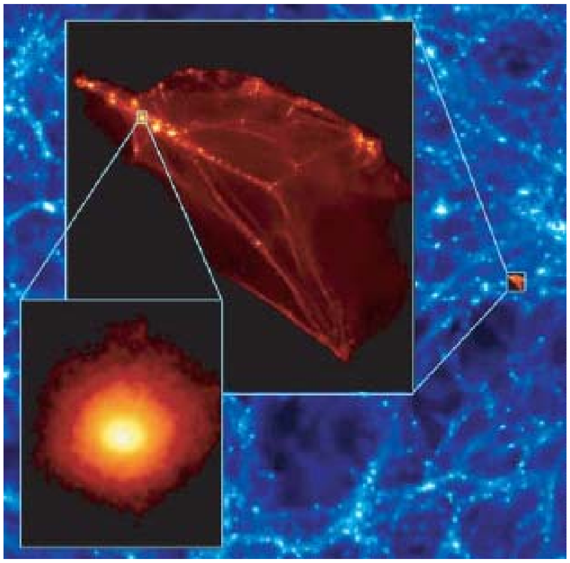
arXiv:0706.0516v1 [astro-ph] 4 Jun 2007



Subhalos according to Via Lactea simulation

Also, the "Gilmore limiting density" of 5 GeV/cm^3 seems violated by factor ~ 5

In fact, the phase space density $Q = \rho/\sigma^3$ has an order of magnitude higher value than for previously known galaxies



Diemand, Moore & Stadel, 2005:

The first structures to form are mini-halos of 10^{-6} solar masses. There would be zillions of them surviving and making up a sizeable fraction of the dark matter halo.

Maybe the dark matter detection schemes will have to be quite different!

(For instance, when the Earth enters such a solar system-sized object, counting rates in direct detection experiments would be very high, and then drop drastically…)

But, will mini-halos survive tidal interactions in the host halo?

Much more work, both analytically, numerically and observationally will be needed to settle this important issue.

So, CDM seems in good shape. But, what is making up CDM? Baryons are only 4 %, so it has to be non-baryonic matter.

Since 1998 (Super-K), we know that non-baryonic dark matter exists!
$\Delta m_\nu \neq 0 \Rightarrow m_\nu \neq 0$
However, neutrinos are hot dark matter and cannot be the main component of dark matter (10% at most) :

- $\Omega_\nu = \dfrac{\sum_\nu m_\nu}{50\,\mathrm{eV}} = \Omega_{DM} \approx 0.2 \Rightarrow \sum_\nu m_\nu \approx 10\,\mathrm{eV}$ Too small for dwarf halos

because Pauli principle $\Rightarrow$ ν's cannot clump in dwarf halos unless $\sum_\nu m_\nu > 120$ eV (Tremaine & Gunn), increased to around 5 keV by the recent Simon & Geha data

- 10 eV is too large for structure formation distribution $\Rightarrow$ limit on sum of ν masses:

WMAP3, Sloan, Ly-α data: $\Sigma\, m_\nu < 0.68$ eV (Spergel et al., 2006)

The Planck satellite and future galaxy surveys will put further constraints on hot dark matter (and perhaps reach the sensitivity to detect a finite mass)

Good particle physics candidates for Cold Dark Matter:

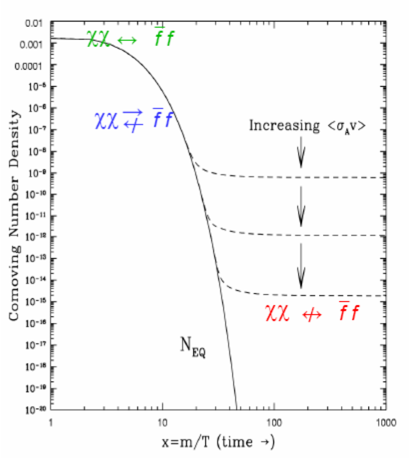
Independent motivation from particle physics

- Weakly Interacting Massive Particles (WIMPs, 3 GeV < m_X < 50 TeV), thermal relics from Big Bang:
  - Supersymmetric neutralino
  - Kaluza-Klein states
  - Extended Higgs sector
  - Axino, gravitino – SuperWIMPS – see Feng's talk
  - Heavy neutrino-like particles
  - Mirror particles
  - plus hundreds more in literature…
- Axions (introduced to solve strong CP problem)
- Non-thermal (maybe superheavy) relics: wimpzillas, cryptons, …

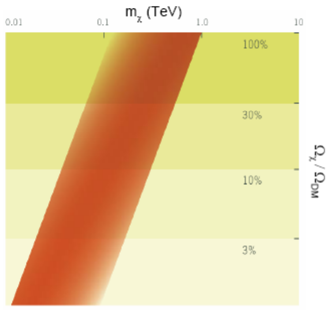
"The WIMP miracle": for typical gauge couplings and masses of order the electroweak scale, $\Omega_{wimp} h^2 \approx 0.1$ (within factor of 10 or so)

From J. Feng:

The WIMP “Miracle”



$\Omega_\chi \sim <\sigma_A v>^{-1} \sim m_\chi^2/(k\alpha^2)$



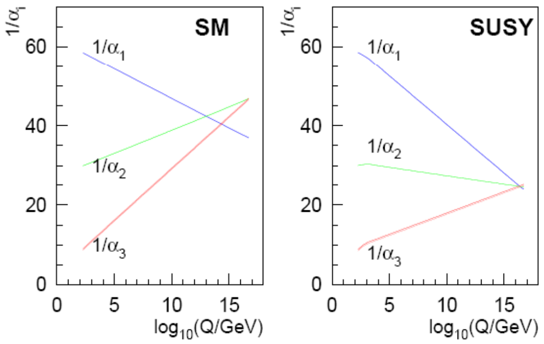
HEPAP LHC/ILC Subpanel (2005)
[k = 0.5 – 2, S- and P-wave]

R parity conservation ⇒ Lightest SUSY particle stable ⇒ relic density can be computed from thermal freeze-out in early Universe

Note that a larger annihilation cross section means a smaller relic density.

Supersymmetry

- Invented in the 1970’s
- Necessary in most string theories
- Restores unification of couplings
- Can solve the hierarchy problem
- Gives right scale for neutrino masses
- Predicts light Higgs (< 130 GeV)
- May be detected at Fermilab/LHC
- Gives an excellent dark matter candidate (If R-parity is conserved ⇒ stable on cosmological timescales)
- Can generate EW symmetry breaking radiatively
- Useful as a template for generic WIMP - Weakly Interacting Massive Particle



The lightest neutralino: the most natural SUSY dark matter candidate (H. Goldberg 1983; J. Ellis & al., 1984). For gravitino, see J. Feng’s talk.

$$\boxed{\tilde{\chi}^0 = a_1\tilde{\gamma} + a_2\tilde{Z}^0 + a_3\tilde{H}_1^0 + a_4\tilde{H}_2^0}$$

Dark SUSY

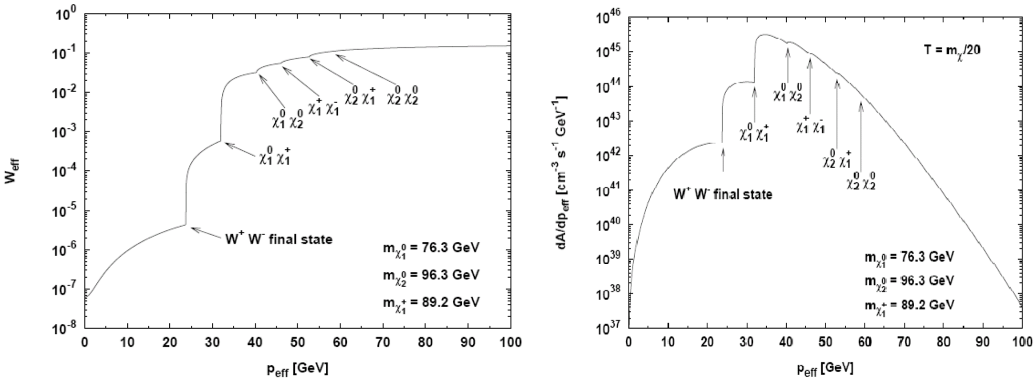
P. Gondolo, J. Edsjö, L.B., P. Ullio, Mia Schelke and E. A. Baltz, JCAP 0407:008, 2004 [astro-ph/0406204]

"Neutralino dark matter made easy" - Can be freely dowloaded from http://www.physto.se/~edsjo/ds

Release 4.1: includes coannihilations & interface to Isasugra

New release soon!

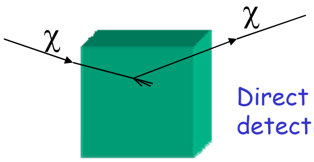
Without coannihilation, $\Omega_\chi h^2 \approx (3\cdot 10^{-27}\ \mathrm{cm}^3\mathrm{s}^{-1})/\langle\sigma v\rangle$. With coannihilation (i.e., when the neutralino is almost degenerate with heavier SUSY particles), the effective cross section and therefore the relic density can be more than an order of magnitude different (usually the relic density becomes smaller in SUSY models – in Kaluza-Klein models it can also become larger).



(From Edsjö and Gondolo, 1999)

Methods of WIMP Dark Matter detection:

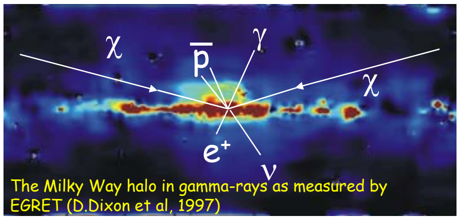
- Discovery at accelerators (Fermilab, LHC,..)
- Direct detection of halo particles in terrestrial detectors
- Indirect detection of neutrinos, gamma rays, X-rays, radio waves, antiprotons, positrons in earth- or space-based experiments
- For a convincing determination of the identity of dark matter, need detection by at least two different methods



Direct detection

$$\frac{d\sigma_{si}}{dq} = \frac{1}{\pi v^2}\left[Z f_p + (A-Z) f_n\right]^2 F_A(q) \propto A^2$$

Indirect detection



The Milky Way halo in gamma-rays as measured by EGRET (D.Dixon et al, 1997)

Neutralinos are Majorana particles

$$\Gamma_{ann} \propto n_\chi^2 \sigma v$$

Enhanced for clumpy halo; near galactic centre and in Sun & Earth

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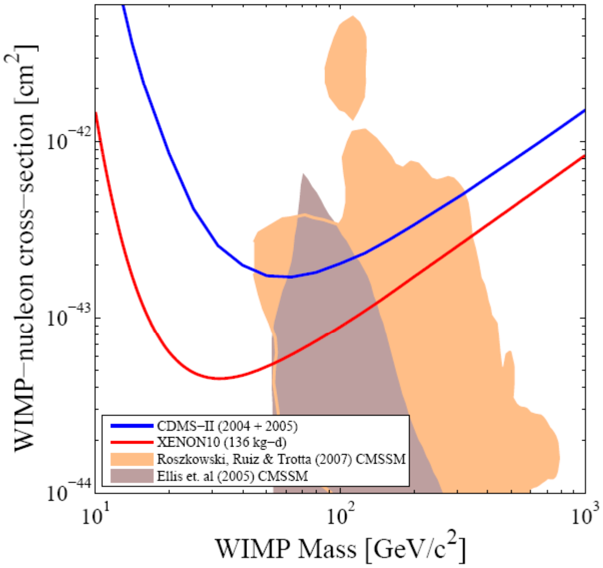
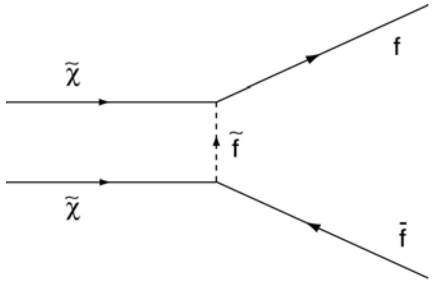
First Results from the XENON10 Dark Matter Experiment
at the Gran Sasso National Laboratory

J. Angle et al., preprint, 2007 (cf E. Aprile's talk)

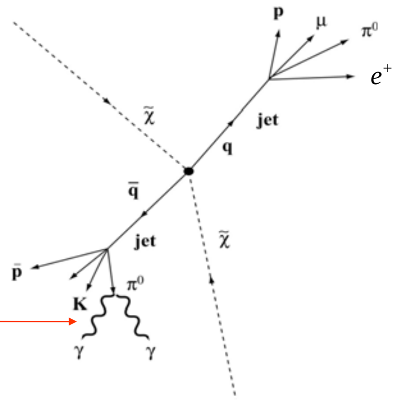


Based on 50 days in Gran Sasso with a 5 kg liquid Xe detector. Technology may be scalable to 1 ton!

Example of indirect detection: annihilation of neutralinos in the galactic halo



Majorana particles: helicity factor for fermions $\sigma v \sim m_f^2$: Usually, the heaviest kinematically allowed final state dominates (b or t quarks; W & Z bosons)



Note: equal amounts of matter and antimatter in annihilations - source of antimatter in cosmic rays?

Decays from neutral pions: Dominant source of continuum gammas in halo annihilations. Fragmentation of quark jets to gammas, antiprotons, positrons well known in particle physics. DarkSUSY uses PYTHIA.

The lightest neutralino: the most natural SUSY dark matter candidate

$$\tilde{\chi}^0 = a_1\tilde{\gamma} + a_2\tilde{Z}^0 + a_3\tilde{H}_1^0 + a_4\tilde{H}_2^0$$

$$\sum_{i=1}^{4}|a_i|^2 = 1;$$

$|a_1|^2 + |a_2|^2 \equiv Z_g$ gaugino fraction

$|a_3|^2 + |a_4|^2 \equiv Z_h\ (=1-Z_g)$ higgsino fraction

Neutralinos are Majorana particles (their own antiparticles)

Tree-level annihilation: $\tilde{\chi}^0 + \tilde{\chi}^0 \to f\,\bar{f}, W^+W^-, Z^0Z^0, H_{1,2}^0H_3^0,...$

$\frac{v}{c} \approx 10^{-3} << 1$ in galactic halos $\Rightarrow$ S-wave should dominate.

However, due to Majorana property,

$(\tilde{\chi}^0\tilde{\chi}^0)_{^3S}$ is forbidden, and due to helicity

$(\tilde{\chi}^0\tilde{\chi}^0)_{^0S} \to f\bar{f} \propto m_f^2$

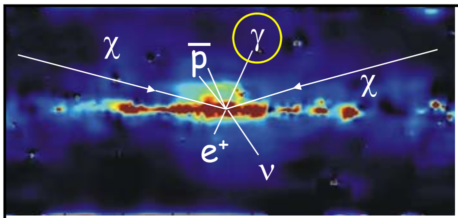
Indirect detection rate = (particle physics part) × (astrophysical part)
PPP APP

PPP: Model for DM particle (spin, mass); $\langle\sigma v\rangle$ at $v/c \sim 10^{-3}$; branching ratio and energy distribution for a given final state particle. Even for relic abundance fixed by cosmology (e.g., $\Omega h^2 = 0.11$), the yield of a specific final state particle at a specific energy can vary by orders of magnitude.

APP: Density of DM particle at production site (halo model and model for subhalos); eventual effects of diffusion and absorption, etc. May give rise to model-dependent predictions which differs by orders of magnitude.

Disclaimer: Unfortunately, no really solid predictions for detection rates can be made; in particular, the absence of a signal cannot directly be converted to a useful limit of particle physics parameters.

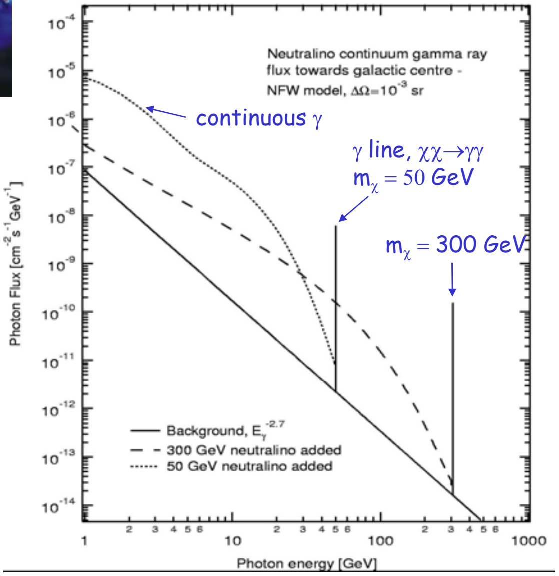
If a signal is claimed to be found, one will probably need some distinctive feature, e.g. energy or angular distribution, to be convinced. Also, cross-correlations between different detection methods (direct, indirect, accelerator) will be crucial.



Gamma-rays

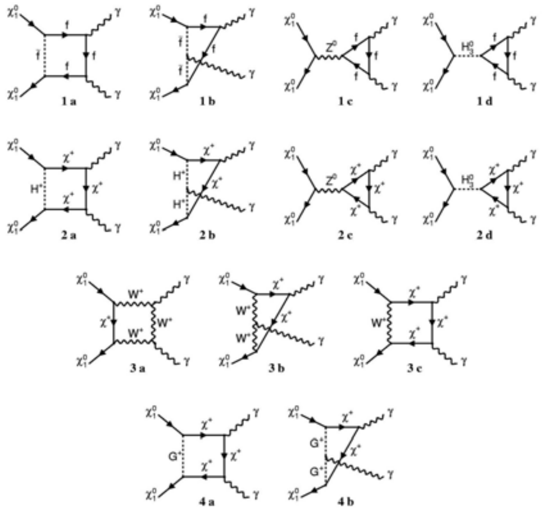
Indirect detection through γ-rays. Two types of signal: Continuous (large rate but at lower energies, difficult signature) and Monoenergetic line (often too small rate but is at highest energy $E_\gamma = m_\chi$; "smoking gun")

Advantage of gamma rays: Point back to the source (no absorption). Enhanced flux possible thanks to halo density profile and substructure (as predicted by CDM)



L.B., P.Ullio & J. Buckley 1998

Loop-induced 2γ (or Z γ) final state: source of nearly monoenergetic photons



L.B. & P. Ullio, 1998

v/c ≈ $10^{-3} \Rightarrow E_\gamma \approx m_\chi$

(for γγ) or $E_\gamma \approx m_\gamma(1-\frac{m_Z^2}{4m_\chi^2})$

(for Zγ)

Rates in SUSY are generally small but can be large (B.R. $\propto 10^{-3}$ - 10^{-2}) for higgsino-like neutralinos (in particular, also for TeV-scale higgsinos).

Major uncertainty for gamma-ray detection from galactic halo: Halo dark matter density distribution. In addition there may be interactions with the stellar distribution, "adiabatic contraction", which may steepen the distribution.

Fits to N-body simulations. Cuspy.

$$\rho_{\mathrm{Moore}}(r) = \frac{c}{r^{3/2}(a^{3/2}+r^{3/2})};$$

$$\rho_{\mathrm{NFW}}(r) = \frac{c}{r(a+r)^2};$$

Fits to rotation curves. Cored.

$$\rho_{\mathrm{Burkert}}(r) = \frac{c}{(r+a)(a^2+r^2)};$$

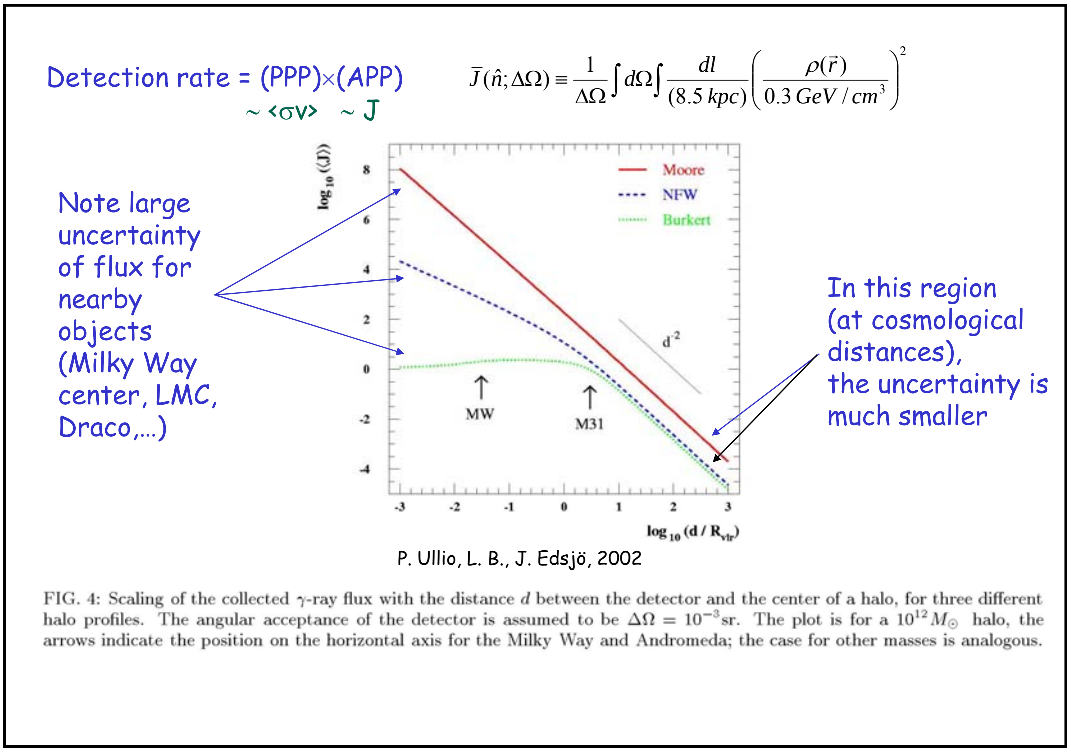
$$\rho_{\mathrm{CIS}}(r) = \frac{c}{a^2+r^2};$$

Fit to lensing (elliptical galaxies).

$$\rho_{\mathrm{SIS}}(r) = \frac{c}{r^2};$$

Berezinsky, Gurevich, Zybin model.

$$\rho_{BGZ}(r) = \frac{c}{r^{1.8}};$$



Detection rate = (PPP)×(APP)

~ <σv>   ~ J

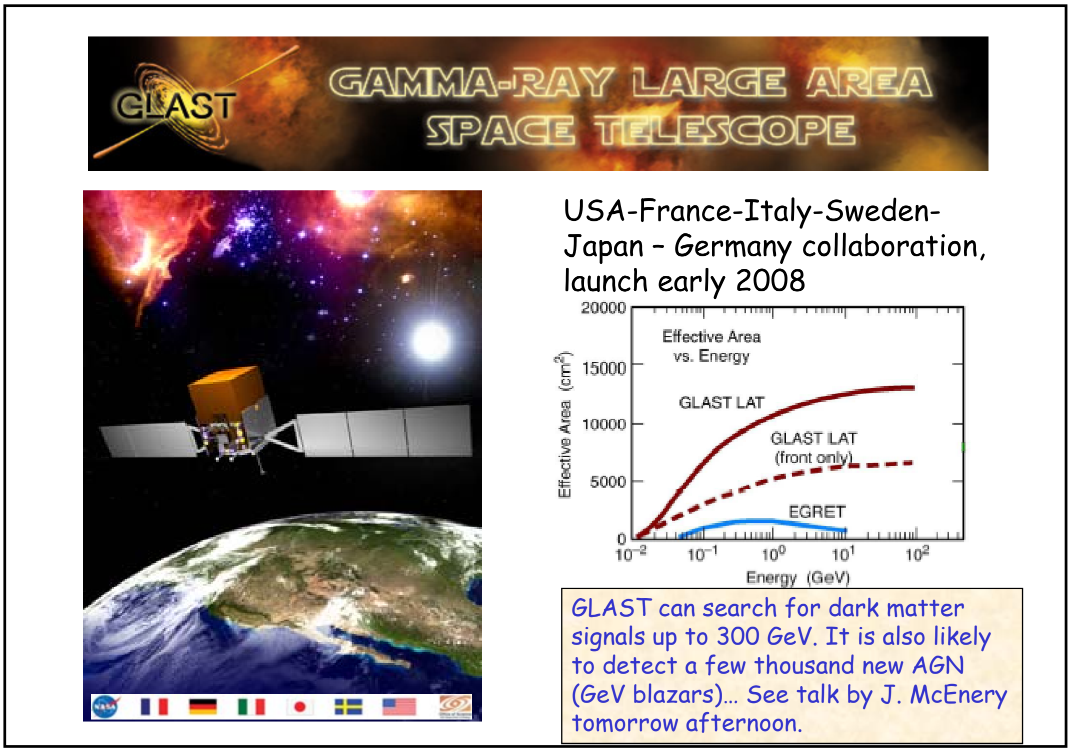
$$\bar{J}(\hat{n};\Delta\Omega) \equiv \frac{1}{\Delta\Omega}\int d\Omega \int \frac{dl}{(8.5\,kpc)}\left(\frac{\rho(\vec{r})}{0.3\,GeV/cm^3}\right)^2$$

Note large uncertainty of flux for nearby objects (Milky Way center, LMC, Draco,…)

In this region (at cosmological distances), the uncertainty is much smaller

P. Ullio, L. B., J. Edsjö, 2002

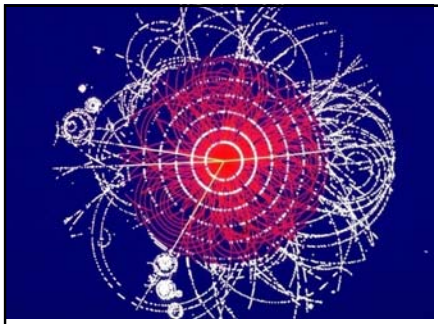
FIG. 4: Scaling of the collected γ-ray flux with the distance d between the detector and the center of a halo, for three different halo profiles. The angular acceptance of the detector is assumed to be $\Delta\Omega = 10^{-3}$sr. The plot is for a $10^{12} M_{\odot}$ halo, the arrows indicate the position on the horizontal axis for the Milky Way and Andromeda; the case for other masses is analogous.



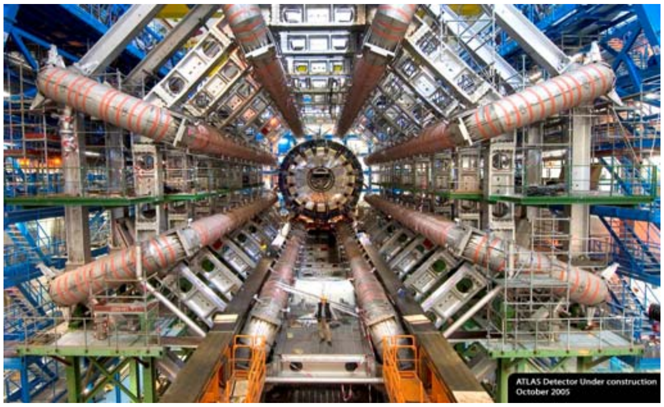
GAMMA-RAY LARGE AREA SPACE TELESCOPE

USA-France-Italy-Sweden-Japan – Germany collaboration, launch early 2008

GLAST can search for dark matter signals up to 300 GeV. It is also likely to detect a few thousand new AGN (GeV blazars)… See talk by J. McEnery tomorrow afternoon.



LHC will also start taking data 2008!

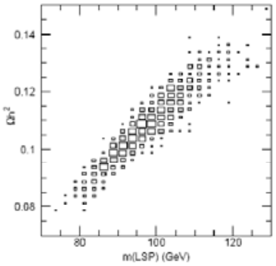


The ATLAS-detector

Will LHC discover dark matter first?

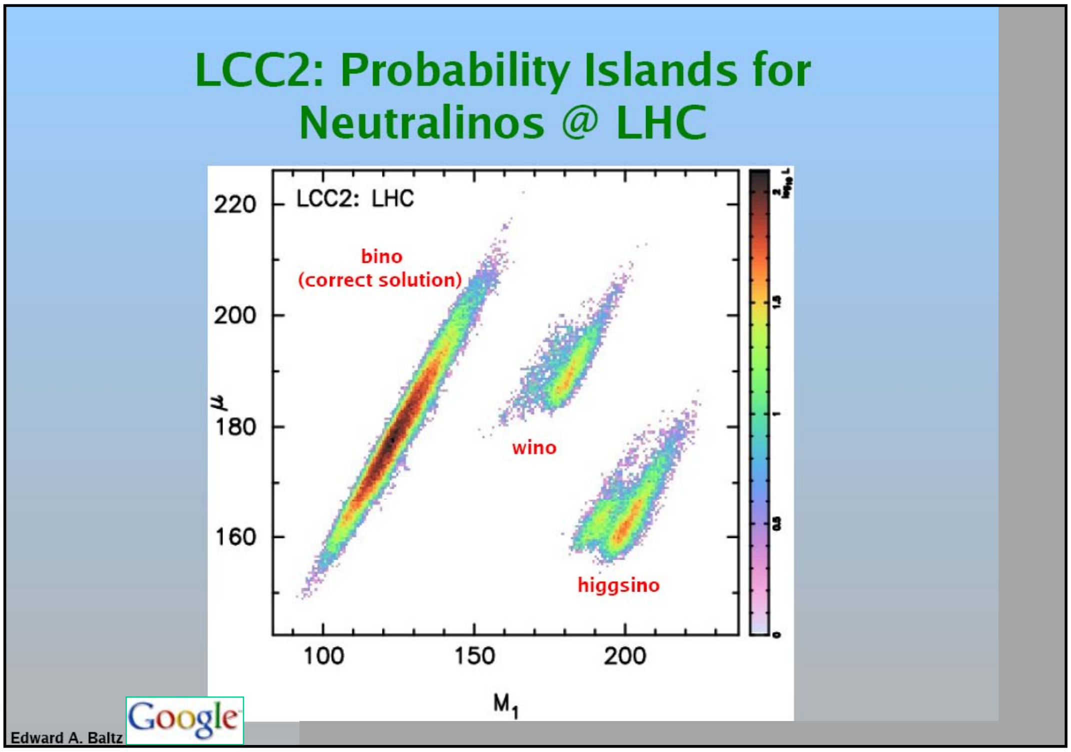
To claim discovery of Dark Matter particles at an accelerator, need to show:

- Particle is neutral, with long (infinite) lifetime
- Has couplings consistent with giving the right $\Omega h^2 \sim 1/\langle \sigma v \rangle \sim 0.1$
- Compatible with direct and indirect detection rates (or limits)



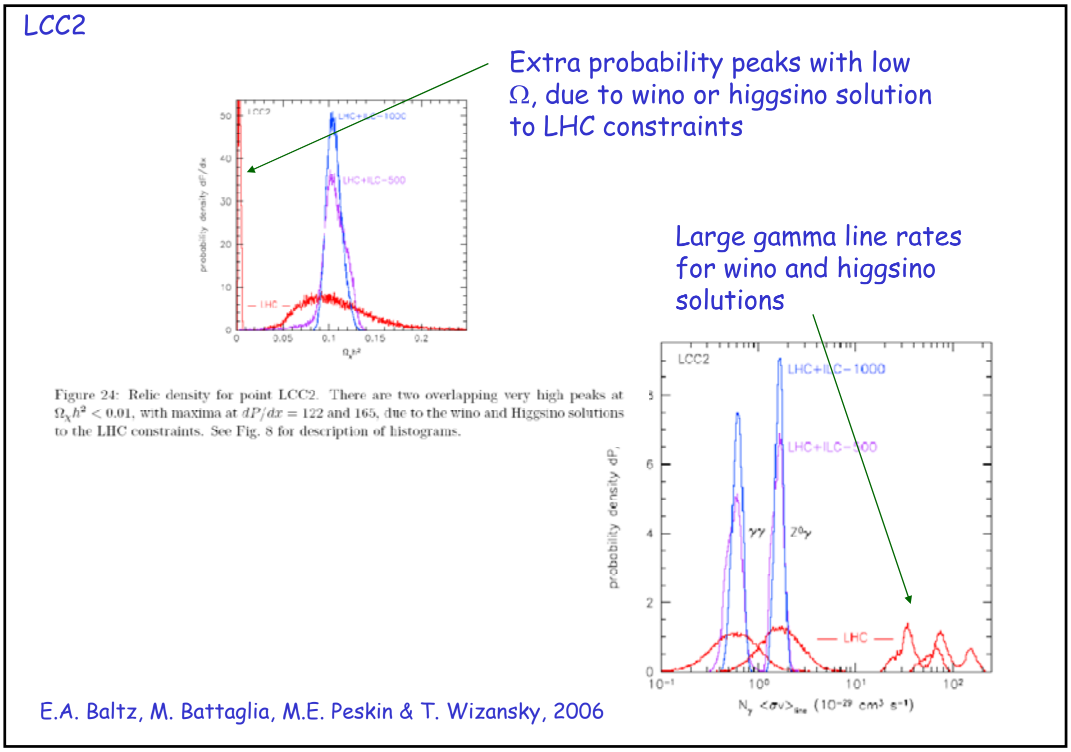
Value of the predicted relic density $\Omega_\chi h^2$ as a function of the measured $\tilde{\chi}_1^0$ mass.

Nojiri, Polesello & Tovey, 2005



LCC2: Probability Islands for Neutralinos @ LHC

Edward A. Baltz



LCC2

Extra probability peaks with low Ω, due to wino or higgsino solution to LHC constraints

Figure 24: Relic density for point LCC2. There are two overlapping very high peaks at $\Omega_\chi h^2 < 0.01$, with maxima at $dP/dx = 122$ and 165, due to the wino and Higgsino solutions to the LHC constraints. See Fig. 8 for description of histograms.

Large gamma line rates for wino and higgsino solutions

E.A. Baltz, M. Battaglia, M.E. Peskin & T. Wizansky, 2006

Must Nature be supersymmetric?

Other model I: A more "conventional" dark matter model with a spin-0 dark matter candidate: Inert Higgs Doublet Model

Introduce extra Higgs doublet H_2, impose discrete symmetry $H_2 \to -H_2$ similar to R-parity in SUSY (Deshpande & Ma, 1978, Barbieri, Hall, Rychkov 2006)

$$V = \mu_1^2|H_1|^2 + \mu_2^2|H_2|^2 + \lambda_1|H_1|^4 + \lambda_2|H_2|^4 \\ + \lambda_3|H_1|^2|H_2|^2 + \lambda_4|H_1^\dagger H_2|^2 + \lambda_5 Re\Big[(H_1^\dagger H_2)^2\Big]$$

$\Rightarrow$ Ordinary Higgs h can be as heavy as 500 GeV without violation of electroweak precision tests

$\Rightarrow$ 40 – 70 GeV inert Higgs H^0 gives correct dark matter density

$\Rightarrow$ Coannihilations with pseudoscalar A are important

$\Rightarrow$ Can be searched for at LHC

$\Rightarrow$ Interesting phenomenology: Tree-level annihilations are very weak in the halo; loop-induced $\gamma\gamma$ and $Z\gamma$ processes dominate!

$\Rightarrow$ The perfect candidate for detection in GLAST!

M. Gustafsson , L.B., J. Edsjö, E. Lundström, PRL, July 27, 2007. See poster by E. Lundström

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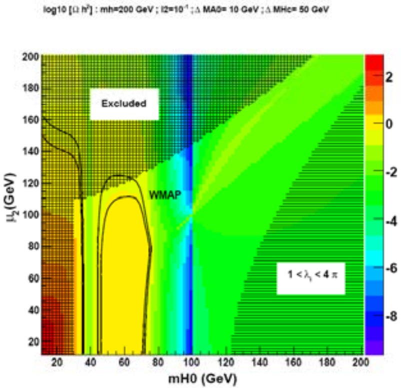
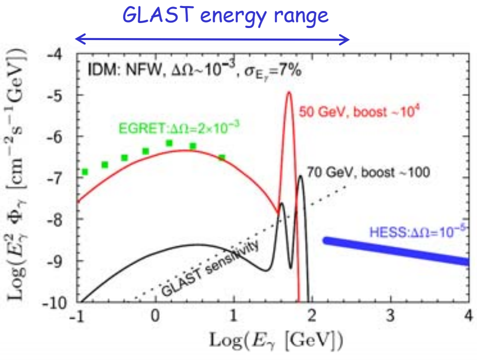
Hambye & Tytgat, July, 2007: This model may also break EW symmetry radiatively (the Coleman-Weinberg Mechanism)

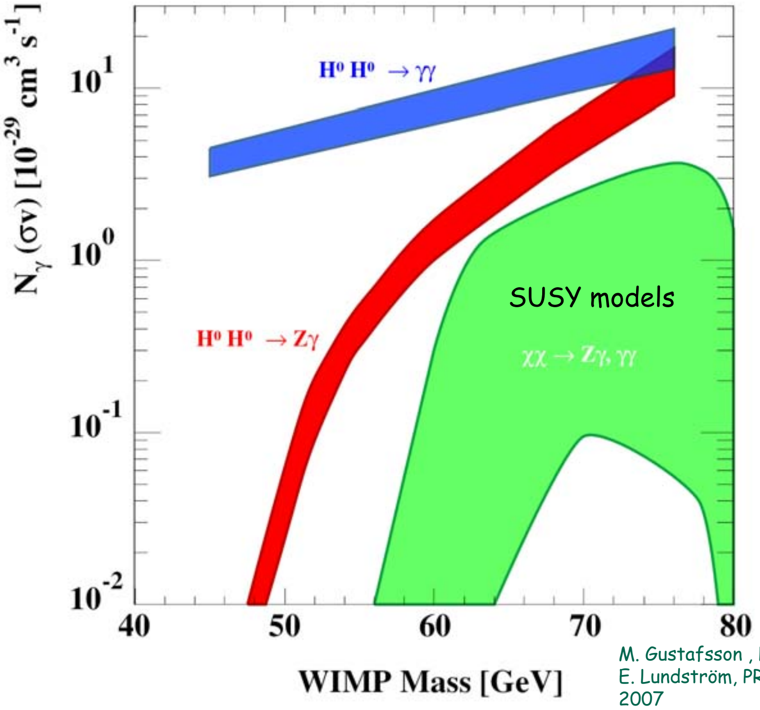


Lopez Honorez et al, 2007



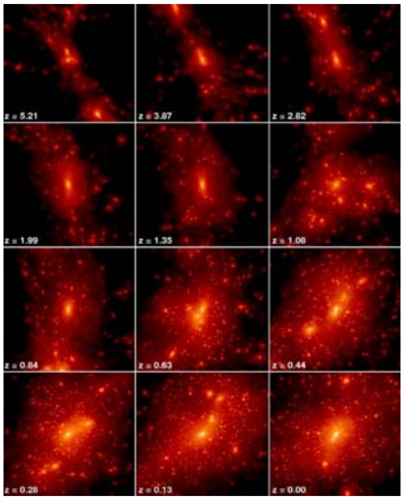
M. Gustafsson , L.B., J. Edsjö, E. Lundström, PRL, July 27, 2007

Note on boost factors: the overall average enhancement over a smooth halo, from DM substructure etc, is hardly greater than 2 – 10. In one specific location, however, like the region around the galactic center, factors up to 10^5 are easily possible.

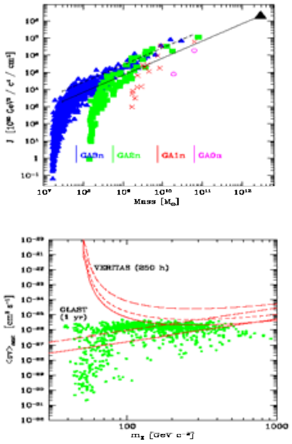


M. Gustafsson , L.B., J. Edsjö, E. Lundström, PRL, July 27, 2007

Boost factor from Dark Matter clumps in the halo



'Milky Way' simulation, Helmi, White & Springel, PRD, 2002



Rates computed with

Dark SUSY

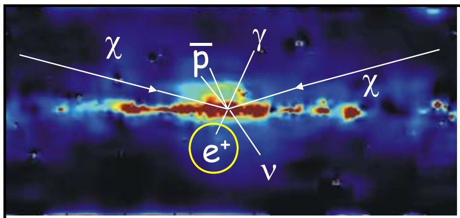
Stoehr, White, Springel,Tormen, Yoshida, MNRAS 2003. (Cf Calcaneo-Roldan & Moore, PRD, 2000.)

Important problem: What is the fate of the smallest substructures? Berezinsky, Dokuchaev & Eroshenko, 2003 & 2005; Green, Hofmann & Schwarz, 2003; Diemand, Moore & Stadel, 2005; Ando, 2005; Diemand, Kuhlen, Madau, 2007,…

Summary for gamma rays:

Detection will be challenging. Rates may be too small to stand out against background. However, the most recent N-body simulations give ground for optimism.

A signal may be discriminated by angular or energy spectrum signature. There are other effects that may help detection (see tomorrow’s talk). GLAST will open an important new window for WIMP search.



Positrons

The APP part for positrons: Diffusion equation (see, e.g., Baltz and Edsjö, 1999):

$$\frac{\partial}{\partial t} f_{e^+}(E,\vec{r}) = K(E)\nabla^2 f_{e^+}(E,\vec{r}) + \frac{\partial}{\partial E}\left[b(E) f_{e^+}(E,\vec{r})\right] + Q(E,\vec{r})$$

Energy-dependent diffusion coefficient

Energy loss (mostly synchrotron)

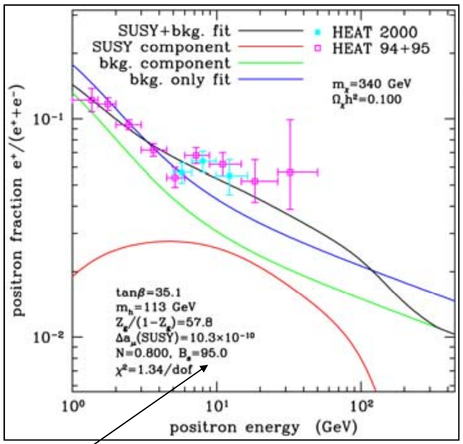
Source term (from annihilation)

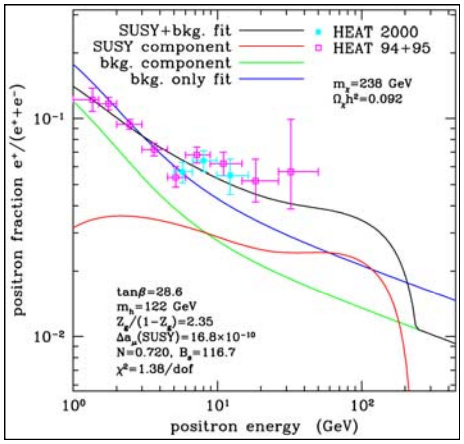
$$b(E) = 10^{-16}(E/1\ \mathrm{GeV})^2 \quad (\mathrm{GeVs^{-1}})$$

$$K(E) = 3.3\times10^{27}\left[3^{0.6}+(E/1\ \mathrm{GeV})^{0.6}\right] \quad (\mathrm{cm^2s^{-1}})$$

Positrons from neutralino annihilations – explanation of feature at 10 – 30 GeV?

New experiments will come: Pamela (successful launch, June 2006; will present results fall of 2007) and AMS (When?)





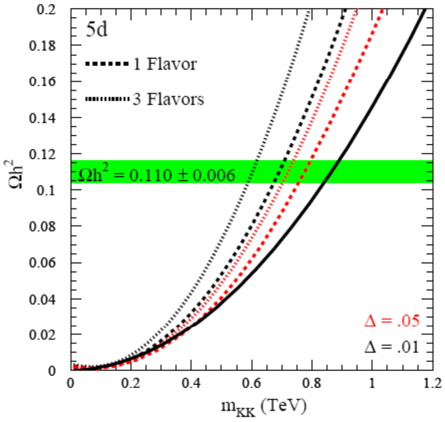
Need high "boost factor"

Baltz, Edsjö, Freese, Gondolo 2002; Kane, Wang & Wells, 2002; Hooper & Kribs, 2004; Hooper & Silk, 2004

Other model II: Kaluza-Klein (KK) dark matter in Universal Extra Dimensions

Universal Extra Dimensions (Appelquist & al, 2002):

- All Standard Model fields propagate in the bulk → in effective 4D theory, each field has a KK tower of massive states
- Unwanted d.o.f. at zero level disappear due to orbifold compactification, e.g., S^1/Z_2 , y ↔ -y
- KK parity $(-1)^n$ conservation → lightest KK particle (LKP) is stable → possible dark matter candidate
- One loop calculation (Cheng & al, 2002): LKP is $B^{(1)}$.
- Difference from SUSY: spin 1 WIMP → no helicity suppression of fermions



Servant & Tait, 2003

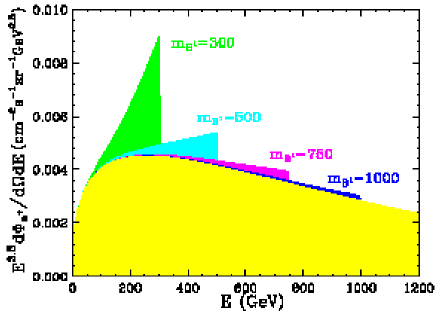
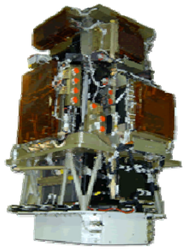


Figure 3. Positron spectra from B^1 dark matter annihilation for various B^1 masses as indicated [22]. The yellow (light shaded) region is the expected background. The differential flux is given in the right panel, and is modified by the factor E^3 in the left panel.

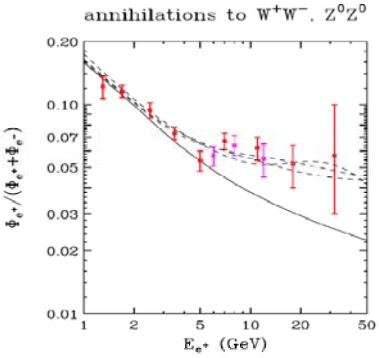
Positrons (Cheng, Feng & Matchev, 2003)

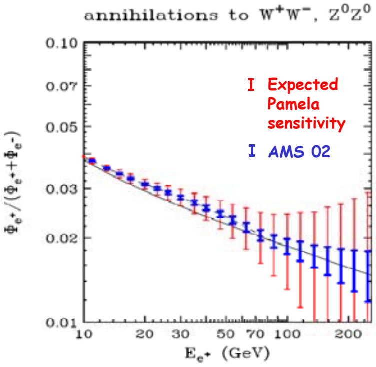
Since June 15, 2006:

PAMELA is in Orbit !



New antimatter space probe, Italy-Russia-Germany-Sweden-USA-India collaboration. Will hopefully give data of unprecedented quality. See talk by M. Pearce tomorrow.





Hooper and Silk, 2005

Summary for positrons:

The advantage compared to gamma-rays is that generated positrons are stored in the galaxy for millions of years. However, the diffusion also smoothes out all spatial and much of the spectral information.

Some non-SUSY models of dark matter give a strong primary source of positrons.

The present indication of an anomaly in the positron/electron ratio will soon be checked by the PAMELA satellite.