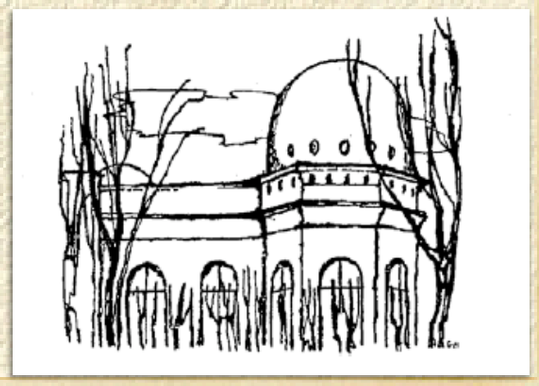
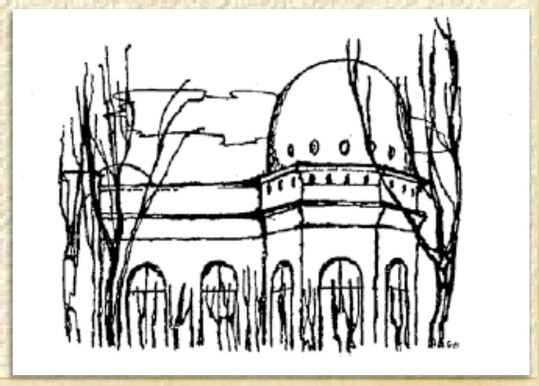
Ecole Internationale Daniel Chalonge



Ecole Internationale Daniel Chalonge



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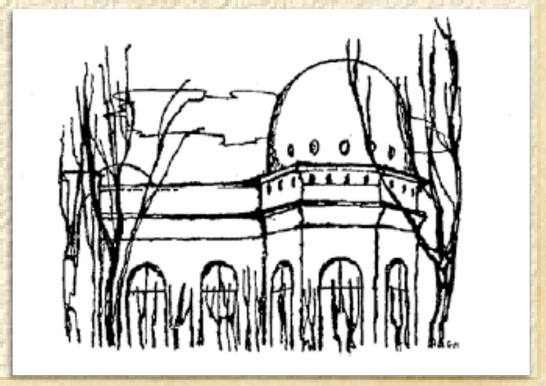
Dark Matter and Dark Energy: Here today and gone tomorrow?

Ecole Internationale Daniel Chalonge

11th Paris Cosmology Colloquium 2007

L.M. Krauss

August 17,2007



The Good, The Bad and the Ugly

The Good, The Bad and the Ugly

Dark Matter

The Good, The Bad and the Ugly

Dark Matter

Dark Energy

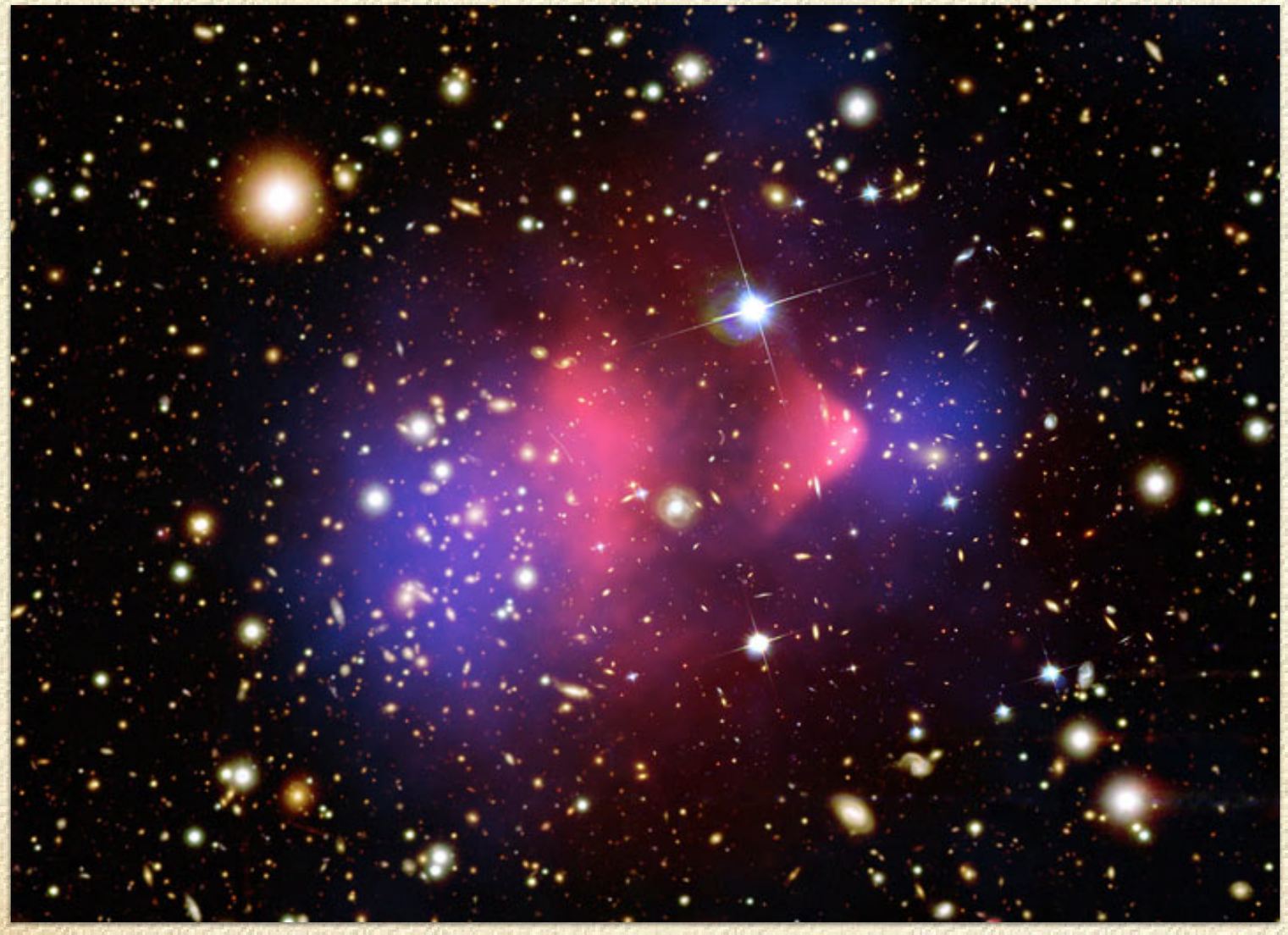
The Good, The Bad and the Ugly

Dark Matter

Dark Energy

The End of the Enlightenment

Here Today: Gravitational Lensing and Dark Matter



Here Today: Gravitational Lensing and Dark Matter

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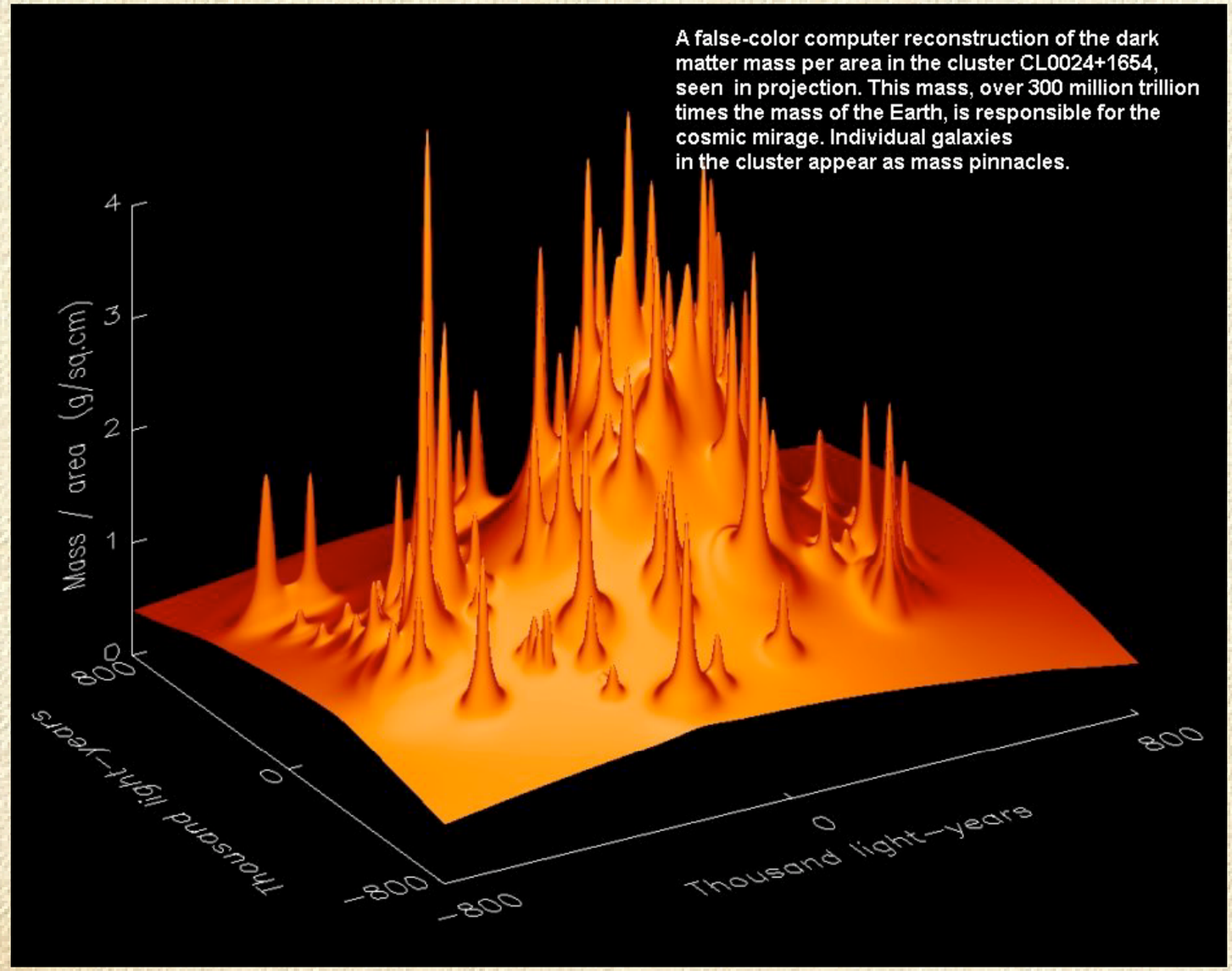
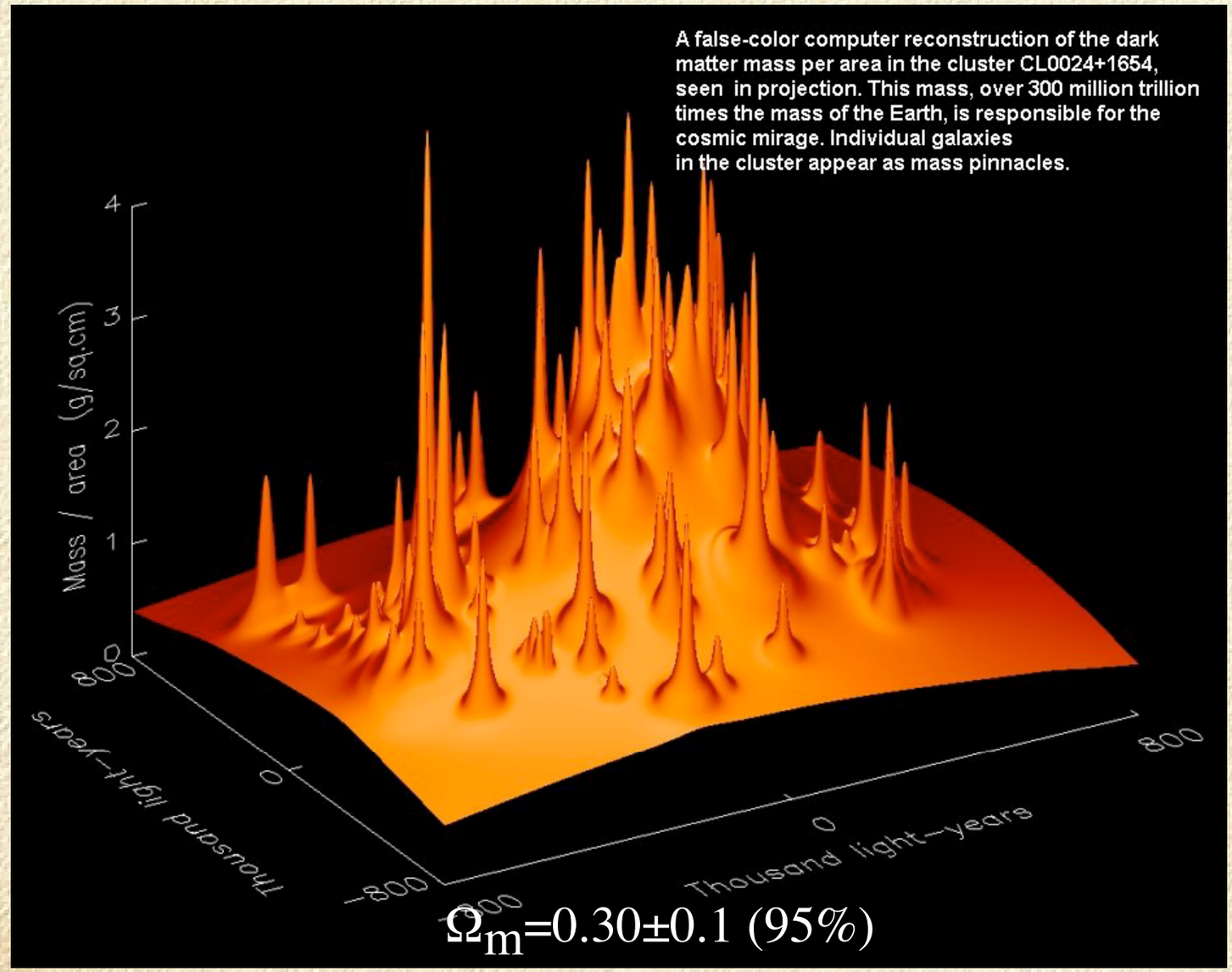


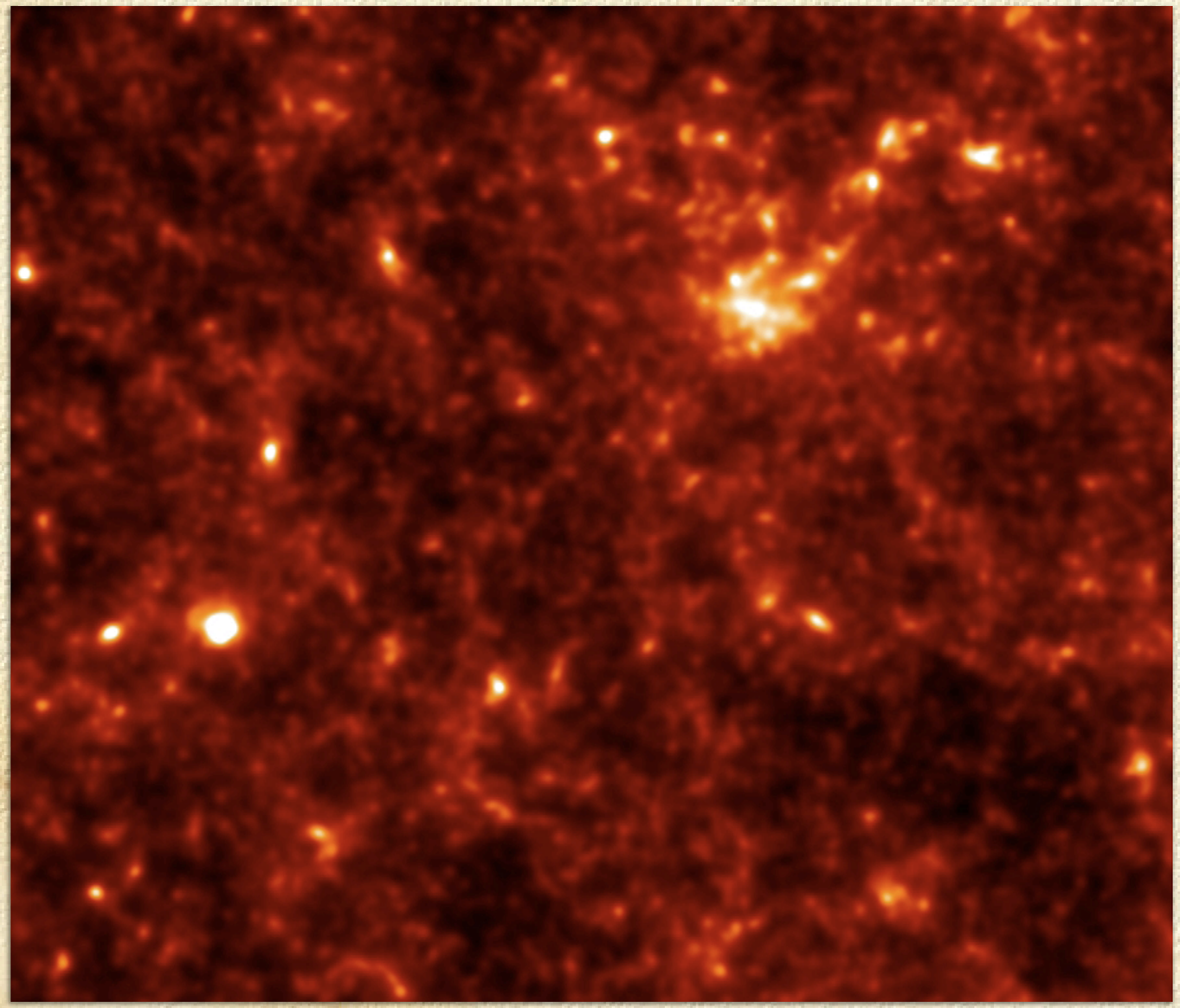
A false-color computer reconstruction of the dark matter mass per area in the cluster CL0024+1654, seen in projection. This mass, over 300 million trillion times the mass of the Earth, is responsible for the cosmic mirage. Individual galaxies in the cluster appear as mass pinnacles.

Here Today: Gravitational Lensing and Dark Matter



Ω_m=0.30±0.1 (95%)

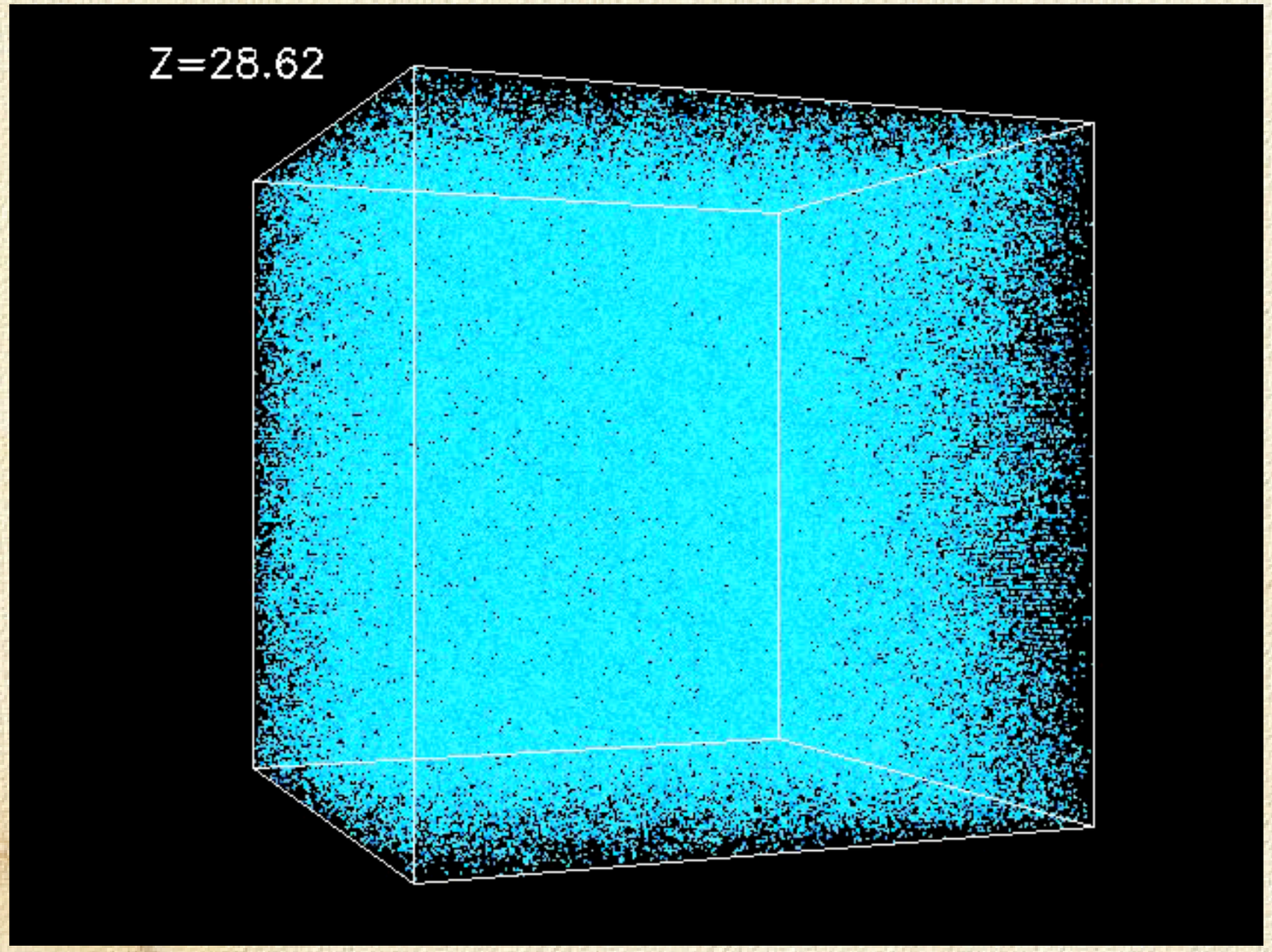
Here Yesterday: Gravitational Lensing: Prospects



15 arcmin square

$z_{source} = 15$
$\theta_{res} = 30''$
"super"-SKA
21cm survey
reconstruction
noise *in*cluded

Here Today?: Numerical Simulations



Here Today?: Numerical Simulations

ΛCDM galaxy halos (without galaxies!)

- Halos extend to ~10 times the 'visible' radius of galaxies and contain ~10 times the mass in the visible regions

- Equidensity surfaces approximate triaxial ellipsoids
  -- more prolate than oblate
  -- axial ratios greater than two are common

- "Cuspy" density profiles with outwardly increasing slopes
  -- $d \ln \varrho / d \ln r = \gamma$ with $\gamma < -2.5$ at large r
  $\gamma > -1.2$ at small r

- Substantial numbers of self-bound substructures containing ~10% of the mass and with $d N / d M \sim M^{-1.8}$

→ Most substructure mass is in the most massive subhaloes

Here Today: Numerical Simulations

Here Today: Numerical Simulations

The observed properties of Galactic satellites are not in conflict with the substructure predicted in CDM models: astrophysics!

Here Today:
The Usual Suspects and More!

Here Today:
The Usual Suspects and More!

DARK MATTER CANDIDATES ARE EITHER:

[redacted]

Here Today:
The Usual Suspects and More!

DARK MATTER CANDIDATES ARE EITHER:

- Born to be dark

Here Today:
The Usual Suspects and More!

DARK MATTER CANDIDATES ARE EITHER:

- Born to be dark
- Achieve Dark Matterdom

Here Today:
The Usual Suspects and More!

DARK MATTER CANDIDATES ARE EITHER:

- Born to be dark
- Achieve Dark Matterdom
- Have Dark Matterdom thrust upon them.

Here Today:
The Usual Suspects and More!

DARK MATTER CANDIDATES ARE EITHER:

- Born to be dark $m_{neutrino} \approx 10$ eV
- Achieve Dark Matterdom
- Have Dark Matterdom thrust upon them.

Here Today:
The Usual Suspects and More!

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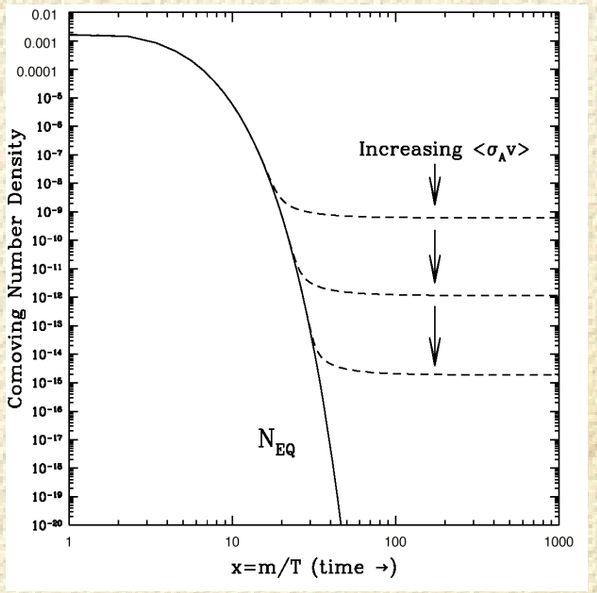

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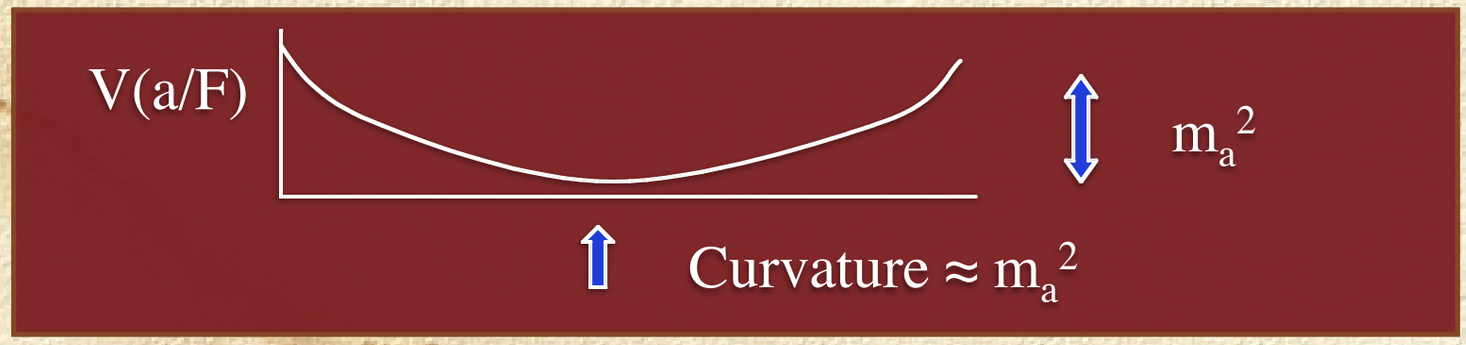

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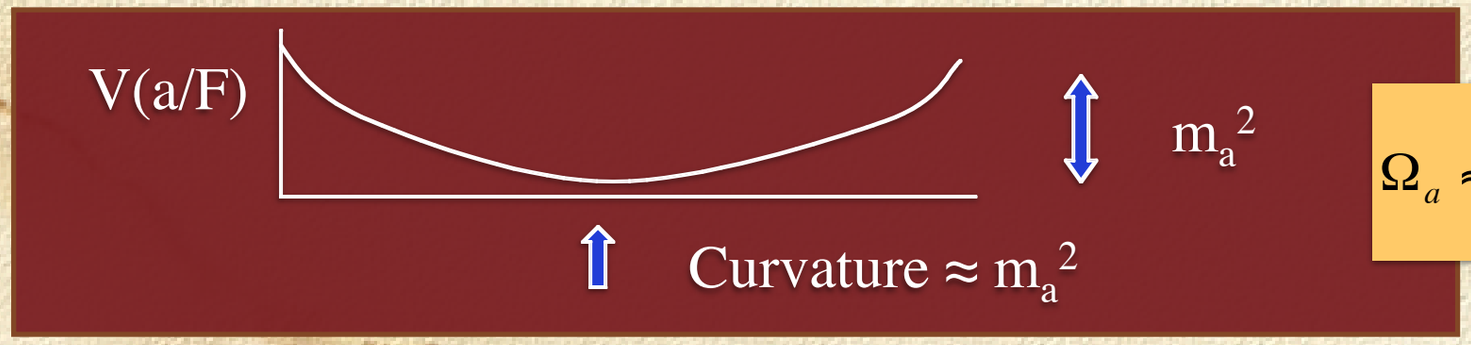

$$\Omega_a \approx \left(\frac{10^{-5} eV}{m_a}\right)^{7/6} \left(\frac{200\ MeV}{\Lambda_{QCD}}\right)$$

SUSY: simply complex

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- The Virtues of Low-Energy SUSY:

SUSY: simply complex

- The Virtues of Low-Energy SUSY:
  - hierarchy problem

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  - hierarchy problem
  - Grand Unification

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  - WIMPs: $\Omega_X = \frac{M_X}{T_0} exp(-M_X/T_{FO})$

SUSY: simply complex

- The Virtues of Low-Energy SUSY:
  - hierarchy problem
  - Grand Unification
  - WIMPs: $\Omega_X = \frac{M_X}{T_0} exp(-M_X/T_{FO})$

$$\approx 1 \; if \; M_X = O(GeV), \; T_{FO} = O(M/20), \; \sigma_A \approx \sigma_{weak}$$

Gone Tomorrow?:

μ

$$\sigma_A \approx \frac{1}{M^2}$$

Gone Tomorrow?:

- LOTs of parameters… natural? μ

$$\sigma_A \approx \frac{1}{M^2}$$

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- non-observation of superpartners and light higgs

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- WMAP value of Omega less than unity $\sigma_A \approx \frac{1}{M^2}$

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- small flavor violating rates

Gone Tomorrow?:

- LOTs of parameters... natural? μ
- non-observation of superpartners and light higgs
- WMAP value of Omega less than unity $\sigma_A \approx \frac{1}{M^2}$
- small flavor violating rates
- parameter space squeezed

Going Non-minimal

- To avoid annihilation problems and allow for light neutralinos and μ problem
- variants: next-to-minimal SUSY, miminal nonminimal SUSY....
- NMSSM: add a single Higgs singlet superfield... resolves μ problem, allows light CP odd Higgs, allows light neutralinos...
-

Are Non-minimal sigs enhanced?

LMK, F. Ferrer, S. Profumo Phys. Rev D15, 74,115007

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- But even here in general well below detection limits.

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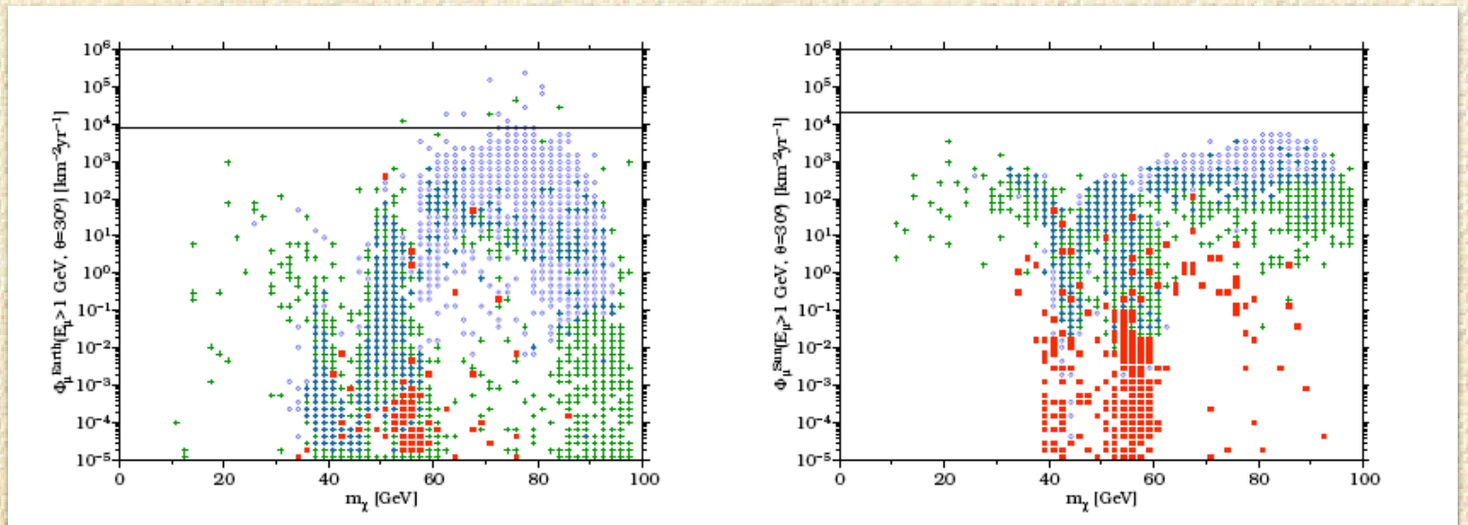

FIG. 3: Integrate muon fluxes above $E_\mu \geq 1$GeV from the Earth (left) and the Sun (right). The horizontal line displays the MACRO bound [48].

Are Non-minimal sigs enhanced? LMK, F. Ferrer, S. Profumo Phys. Rev D15, 74,115007

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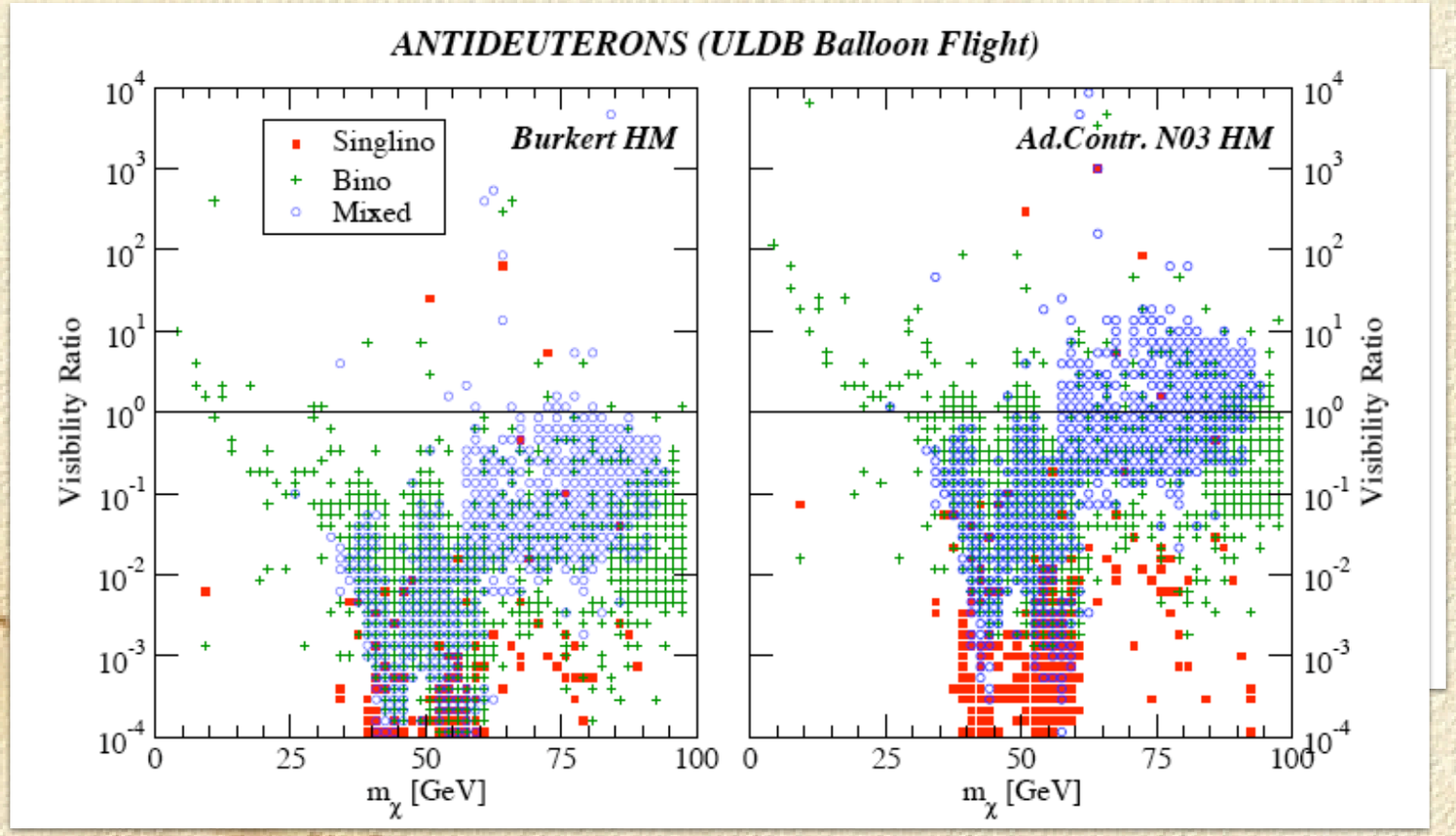

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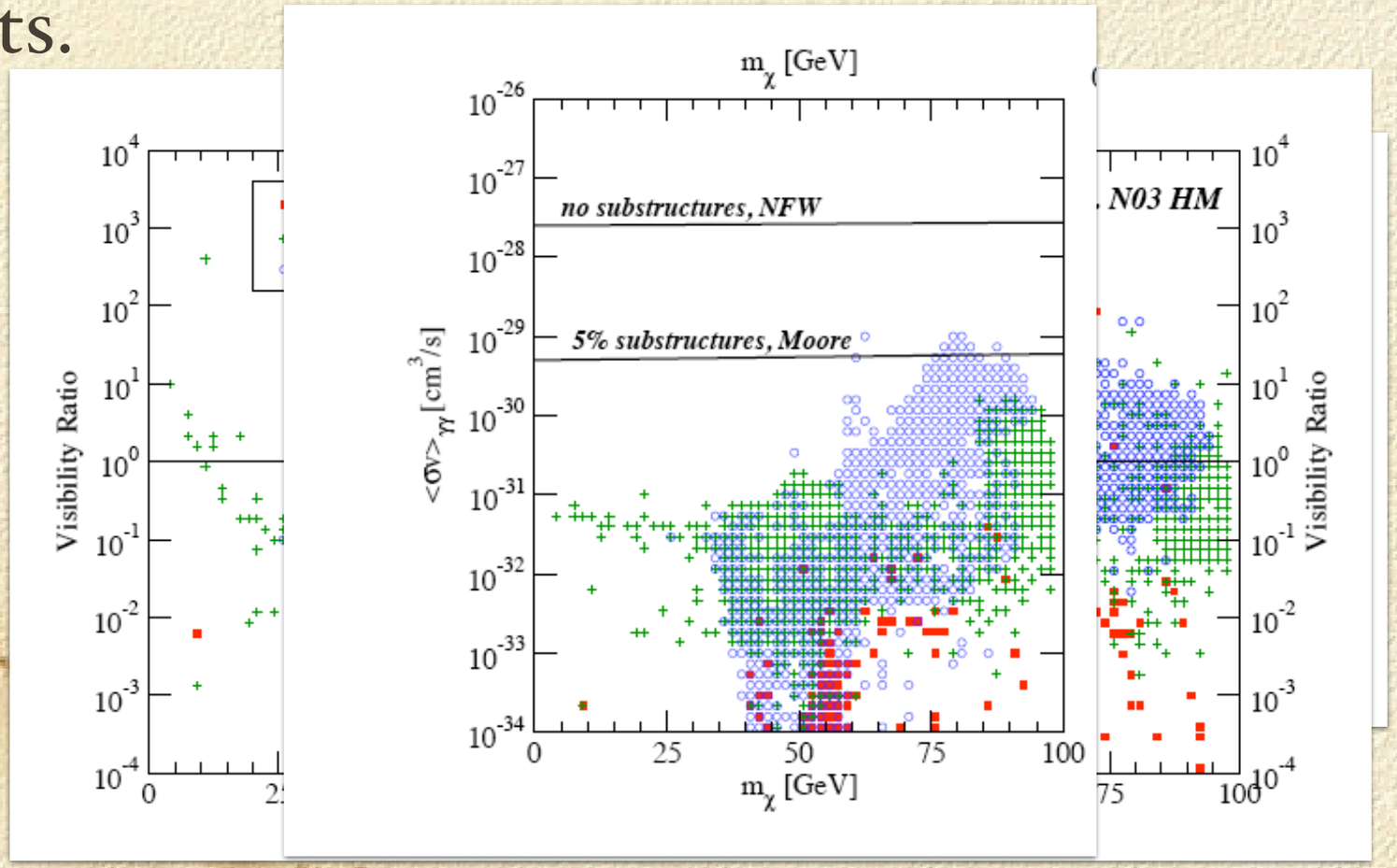

Gone tomorrow?: Detection Prospects

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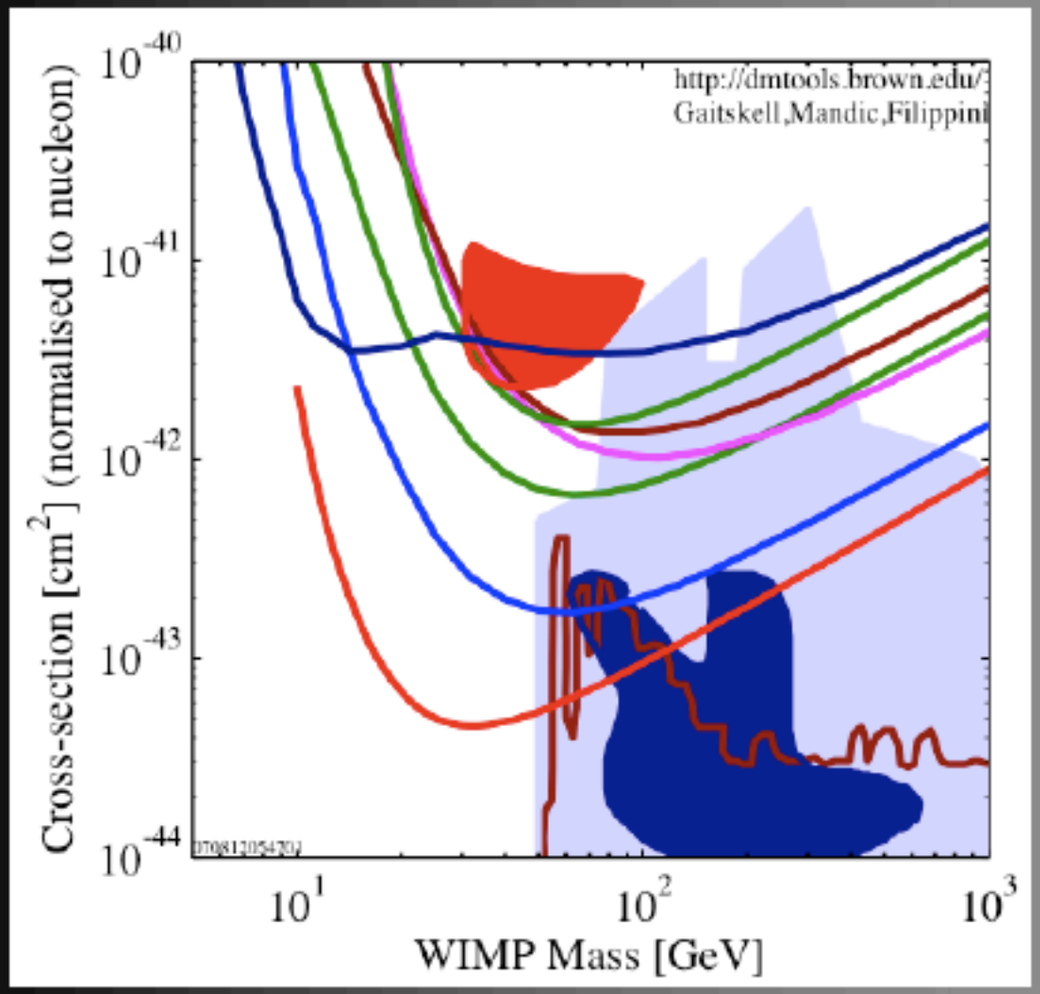
Current status: No WIMPs

Sensitivity race



CDMS II SUF 2000

CRESST 2004 10.7 kg-day CaWO4

Edelweiss I final limit, 62 kg-days
Ge 2000+2002+2003 limit

WARP 2.3L, 96.5 kg-days
55 keV threshold

ZEPLIN II (Jan 2007) result

CDMS (Soudan) 2004 + 2005 Ge
(7 keV threshold)

XENON10 2007 (Net 136 kg-d)

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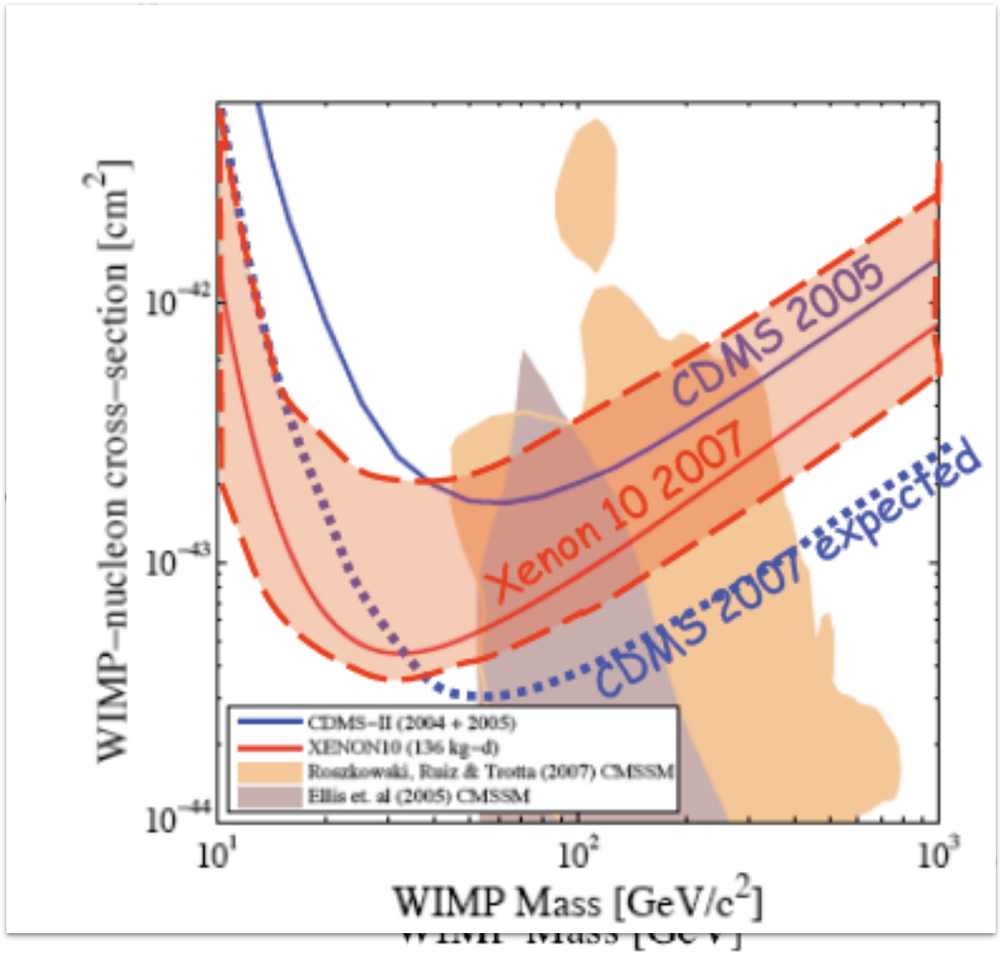

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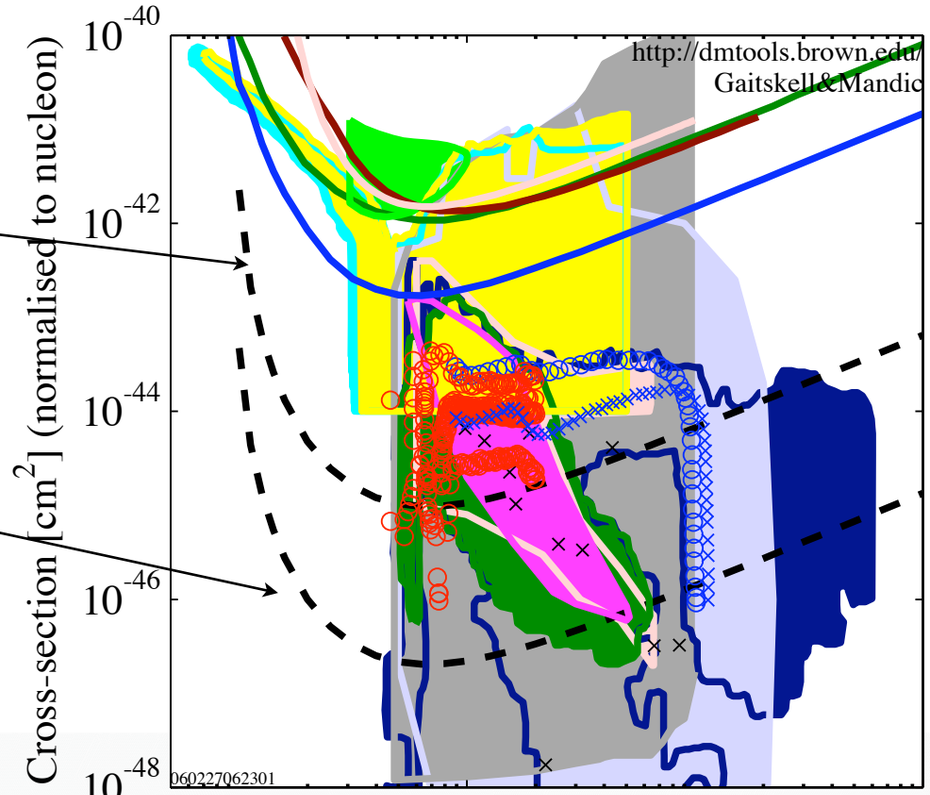
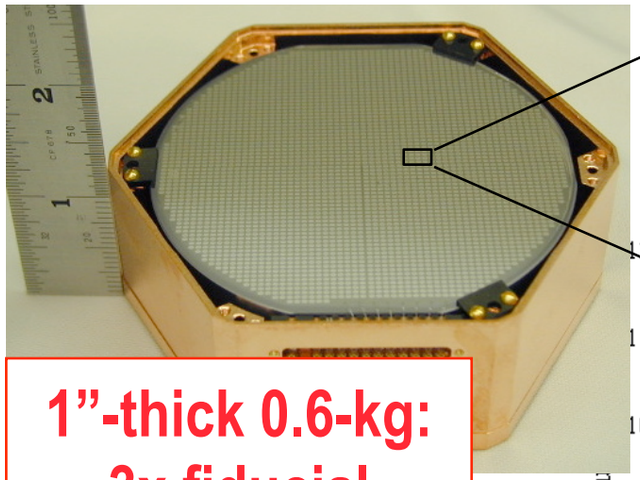
XENON10 2007 (Net 136 kg-d)

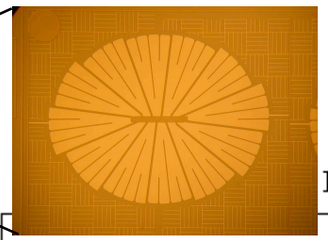
Next for CDMS: SuperCDMS 25 kg

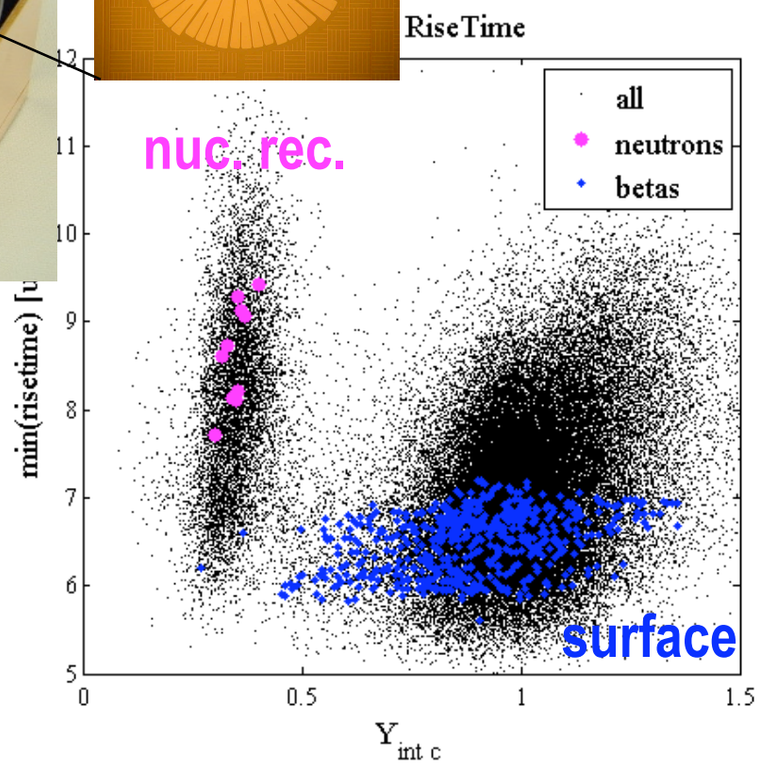
- **Proposed 25-kg experiment based on updated 42 x 600-g Ge ZIPs**
  - 120x beyond current limits
  - 15x beyond CDMS-II goal
  - Approved for space at SNOLAB
  - Next step towards ton-scale goal
- **Detector fab/demonstration underway**

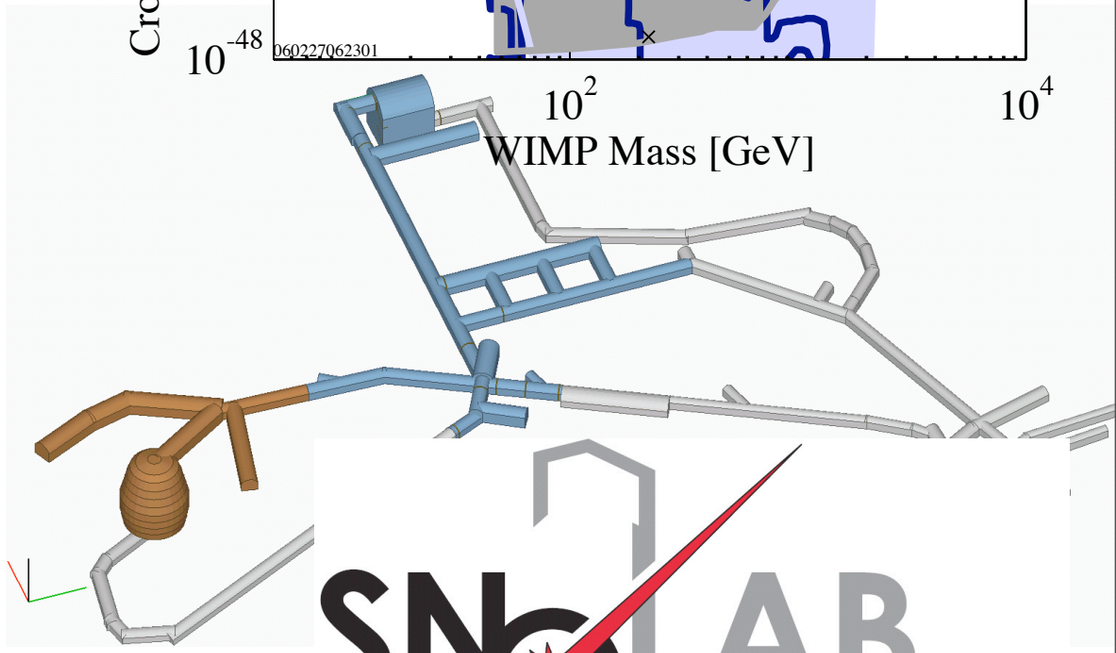




1”-thick 0.6-kg: 3x fiducial mass per s.a.







M. Pyle Session E14

SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

Other Detection Prospects

GLAST Key Features

- **Huge field of view**
  - LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV**
- **Will transform the HE gamma-ray catalog:**
  - by > order of magnitude in # point sources
  - spatially extended sources
  - sub-arcmin localizations (source-dependent)

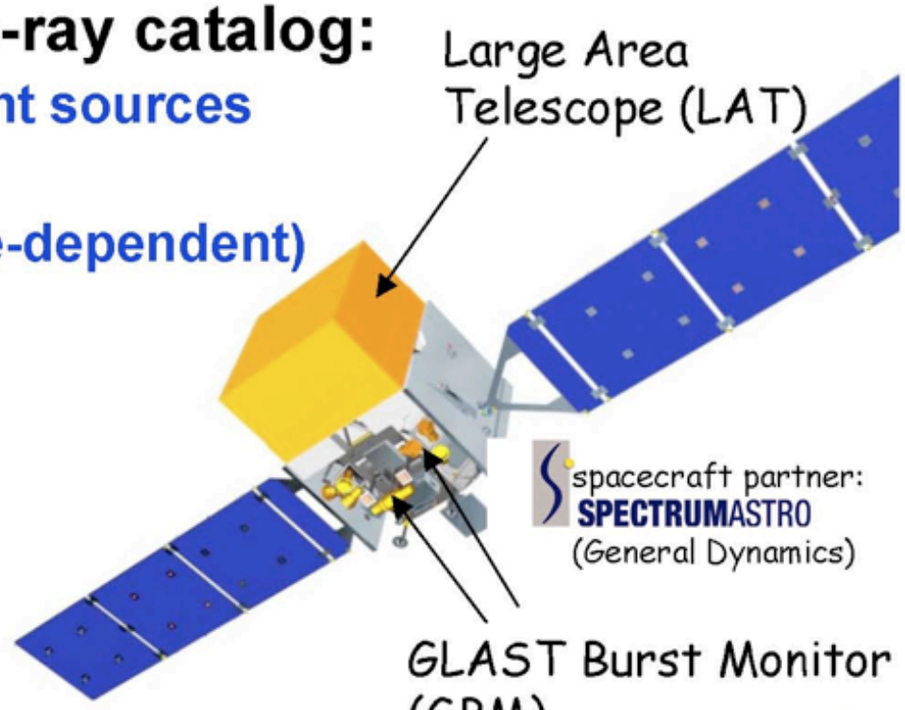
Two GLAST instruments:

LAT: 20 MeV – >300 GeV

GBM: 10 keV – 25 MeV

Launch: 2007

5-year mission (10-year goal)



Gone Today?

Dark Matter Annihilation

For certain kinds of Dark Matter particles

---Self-annihilation is possible
---Annihilation products will typically include γ-rays

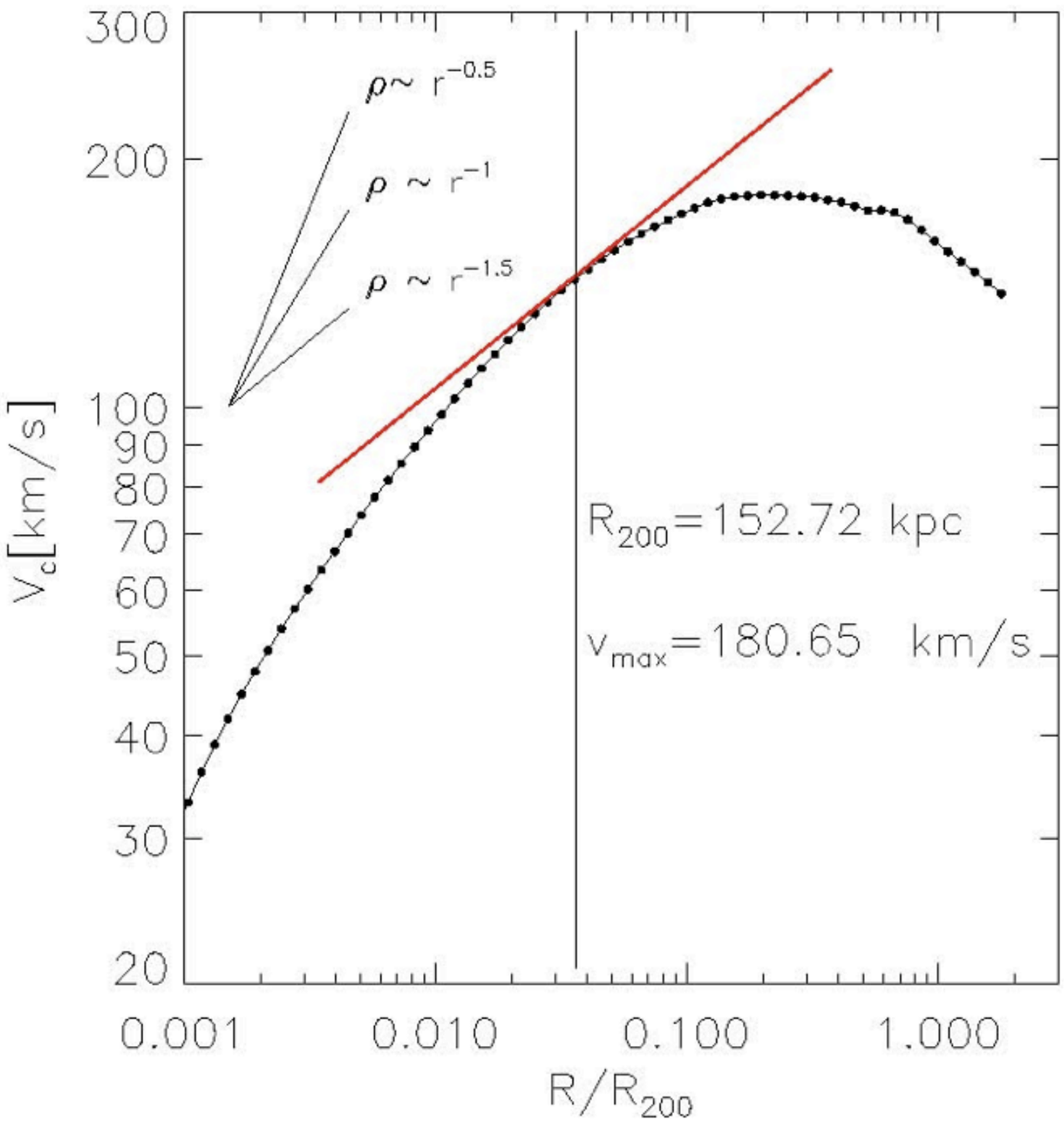
The luminosity density of annihilation emission is

$$\mathscr{L}(\mathbf{x}) \propto n_{\mathrm{DM}}(\mathbf{x})^2 \langle \sigma \ \mathrm{v} \rangle$$

Thus the γ-ray luminosity of an object is

$$L \propto \langle \sigma \ \mathrm{v} \rangle \int \rho^2 \ \mathrm{dV} \propto \langle \sigma \ \mathrm{v} \rangle \int \rho^2 r^2 \, \mathrm{d}r$$

→ critical density exponent for convergence is $\rho \propto r^{-1.5}$



- N_{200} =2.23 x 10^8
- Inner slope > -1
- Annihilation mainly from region where $\gamma \sim -1.5$ $R \sim 5$ kpc
- Baryonic effects will increase the DM density and thus the emission
- Central BH may cause substantial additional effect

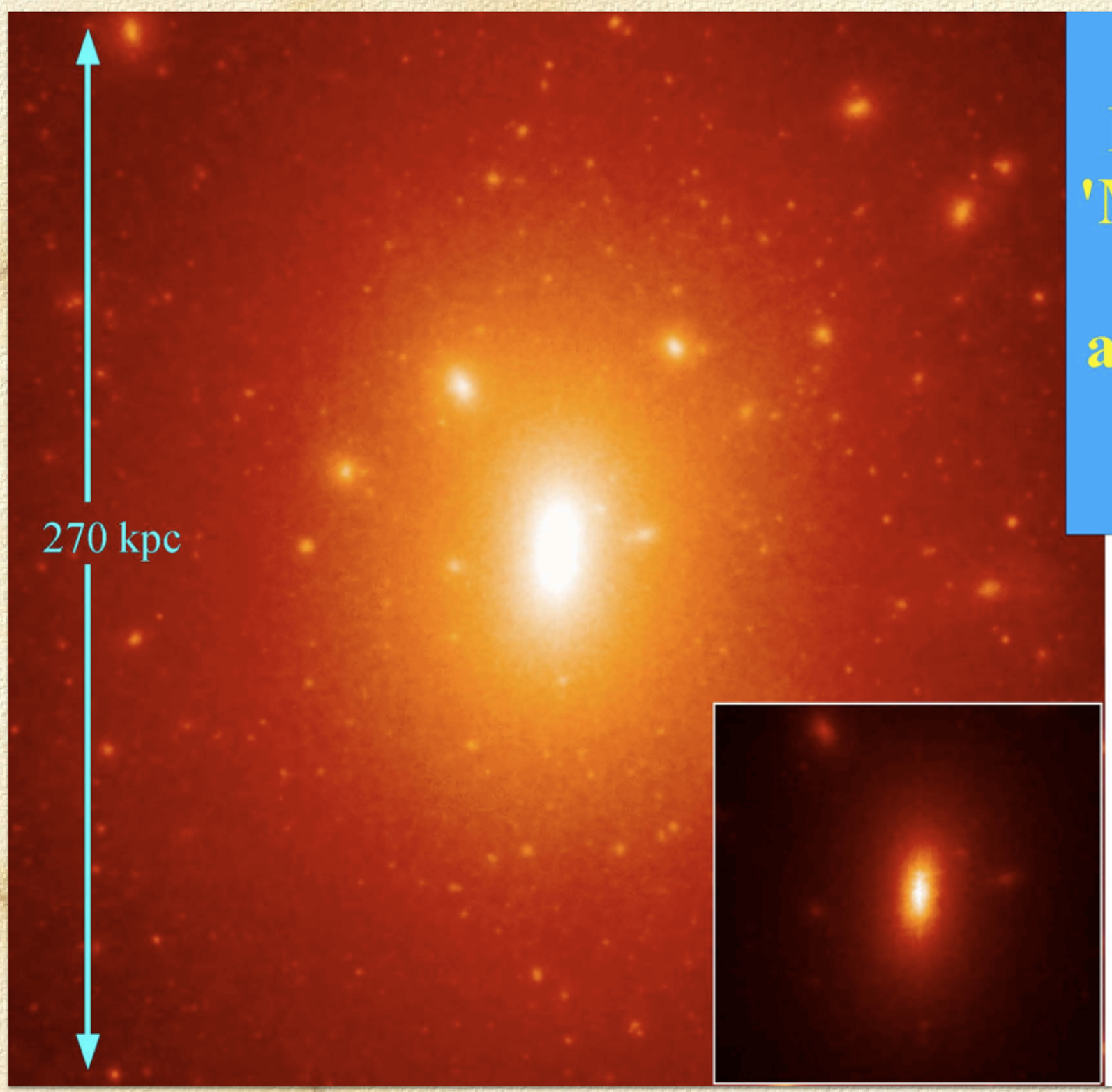
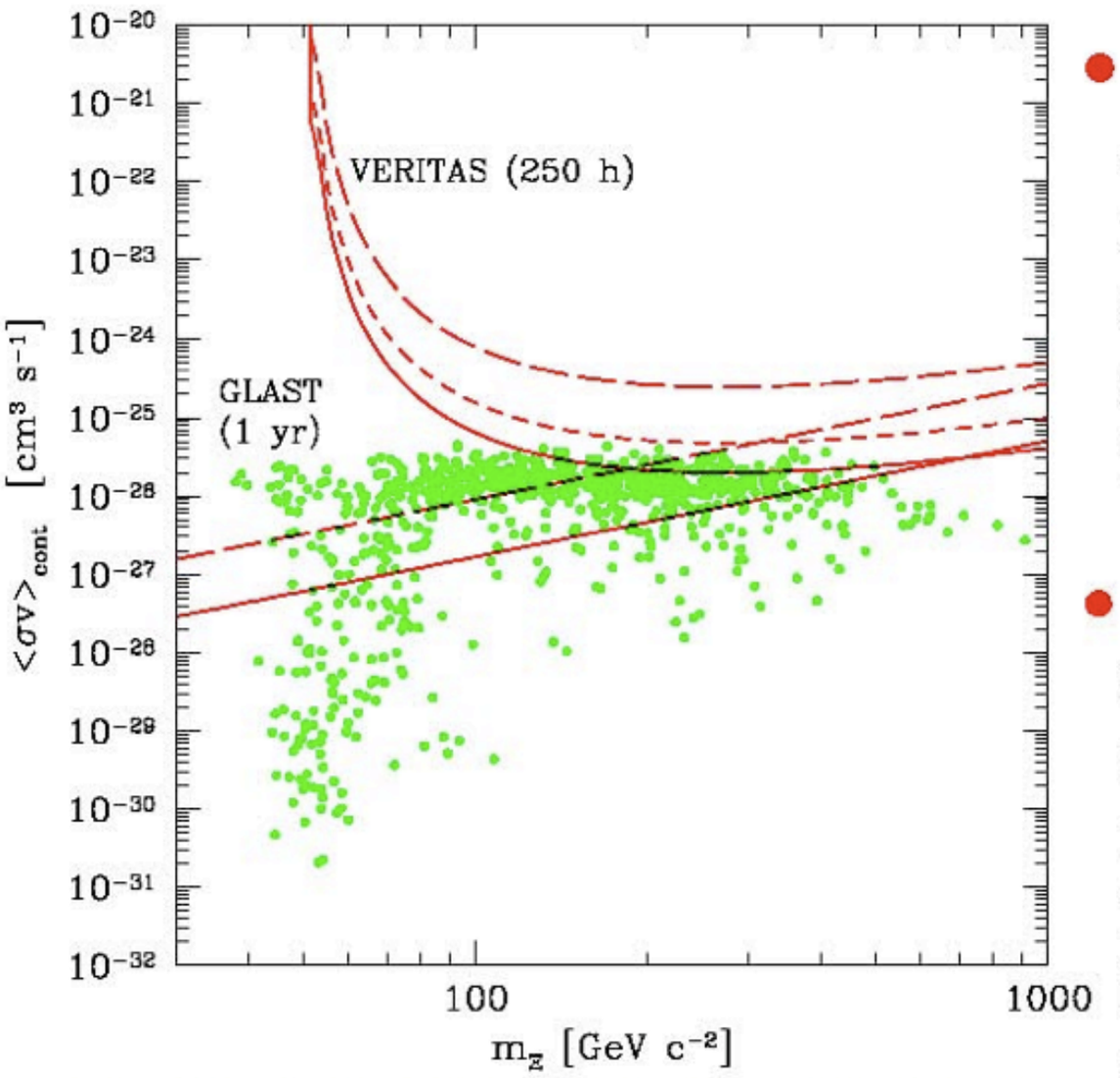


Image of a 'Milky Way' halo in annihilation radiation

Stoehr et al 2003

$$S(\boldsymbol{\theta}) \propto \int \rho^2 \, dl$$

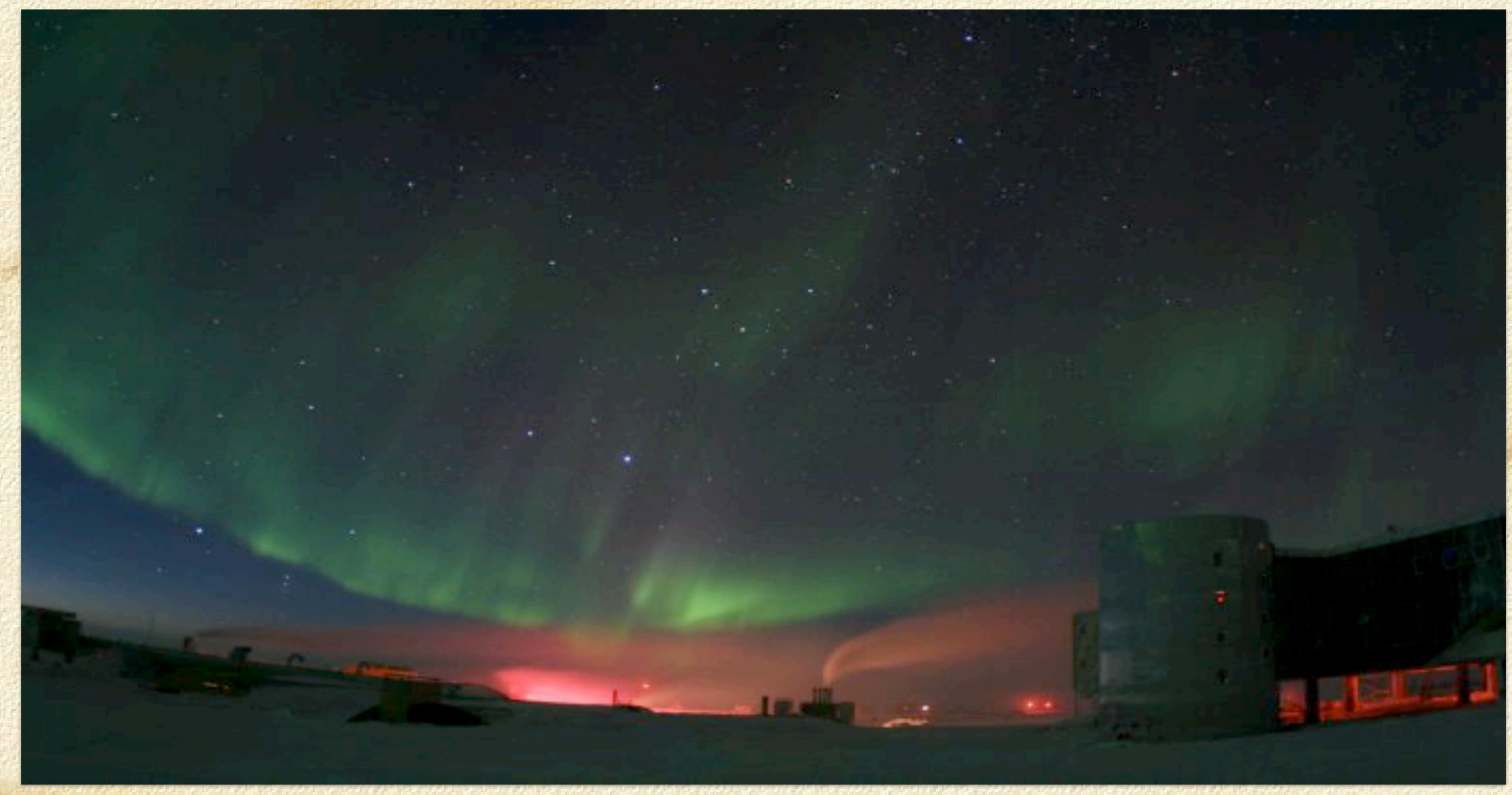
Could GLAST or VERITAS see the Signal?

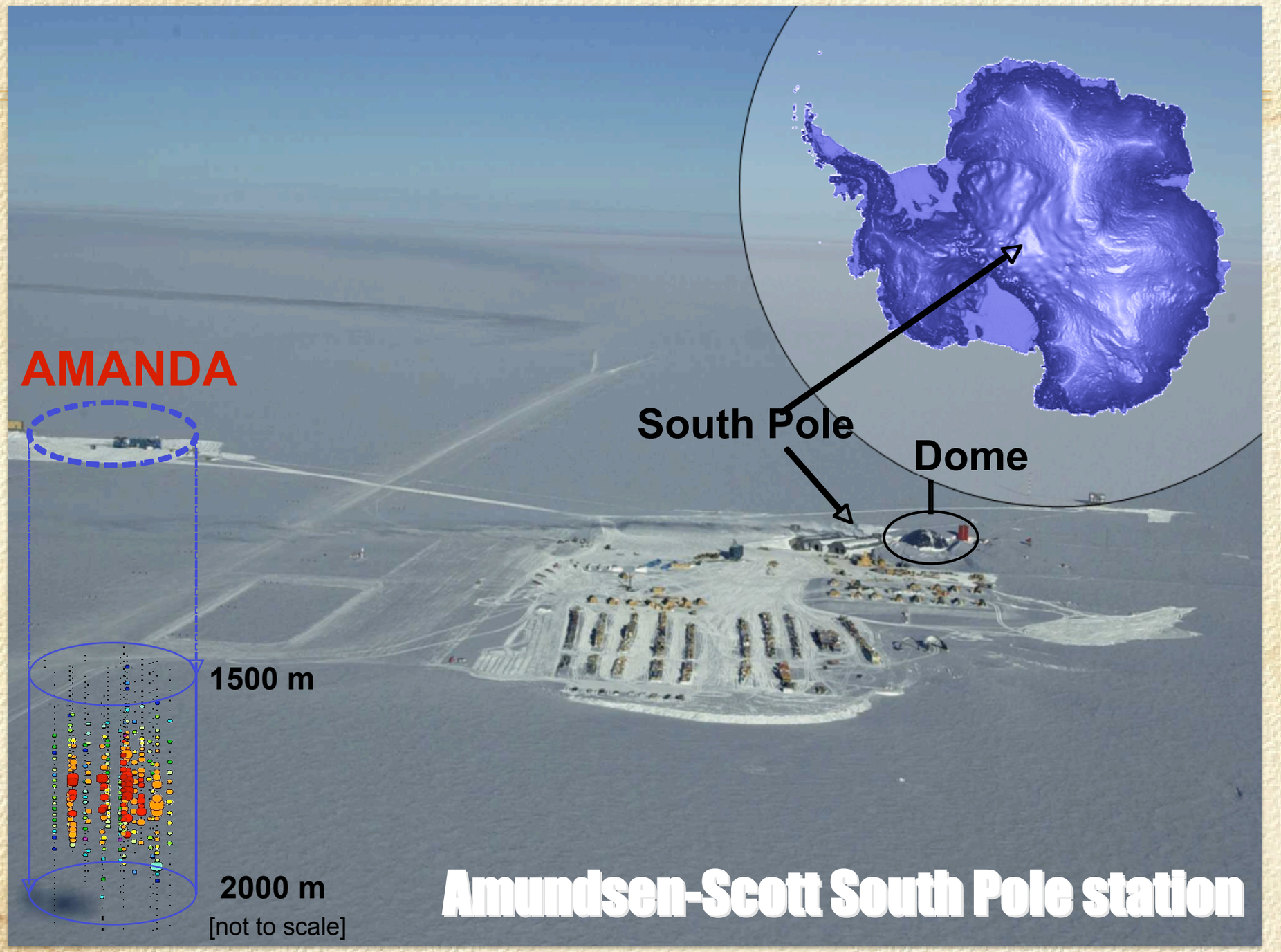


Possible MSSM params from Darksusy

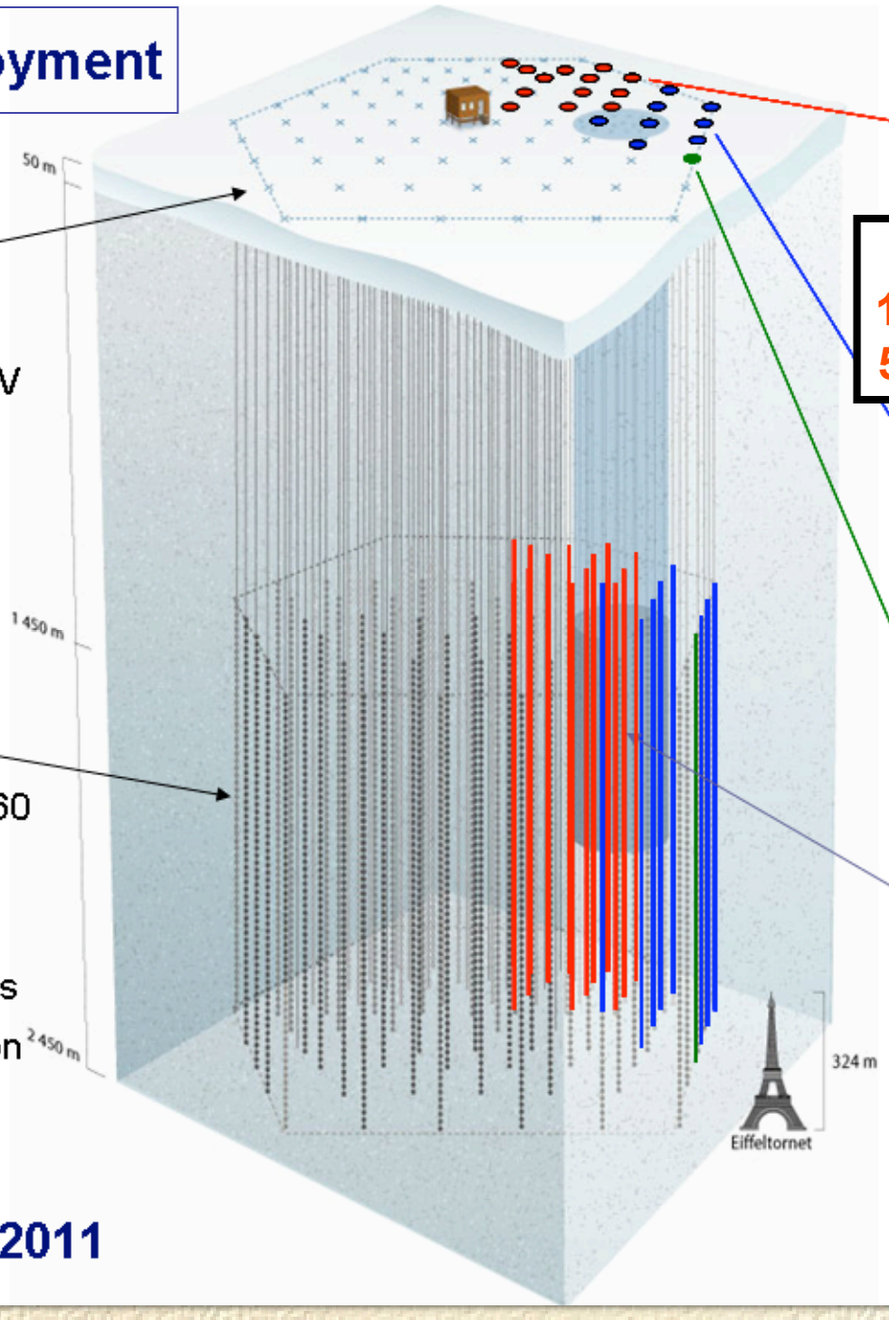
- For VERITAS (a Cerenkov detector with 1.75° FOV) the detectability of the G.C. depends on poorly resolved regions of the simulation and is marginal

- For GLAST (a satellite with 3 sterad. FOV) detection should be possible 20° to 30° from the G.C. in a very long integration and for most MSSM parameters. This does *not* depend on poorly resolved regions of the simulation




AMANDA
South Pole
Dome
1500 m
2000 m
[not to scale]
Amundsen-Scott South Pole station

IceCube Deployment



IceTop

Air shower detector

Threshold ~ 300 TeV

InIce

planned 80 strings of 60 optical modules each

17 m between modules

125 m string separation

2006-2007:

13 strings deployed

22 strings
1320 digital modules
52 surface detectors

2005-2006: 8 strings

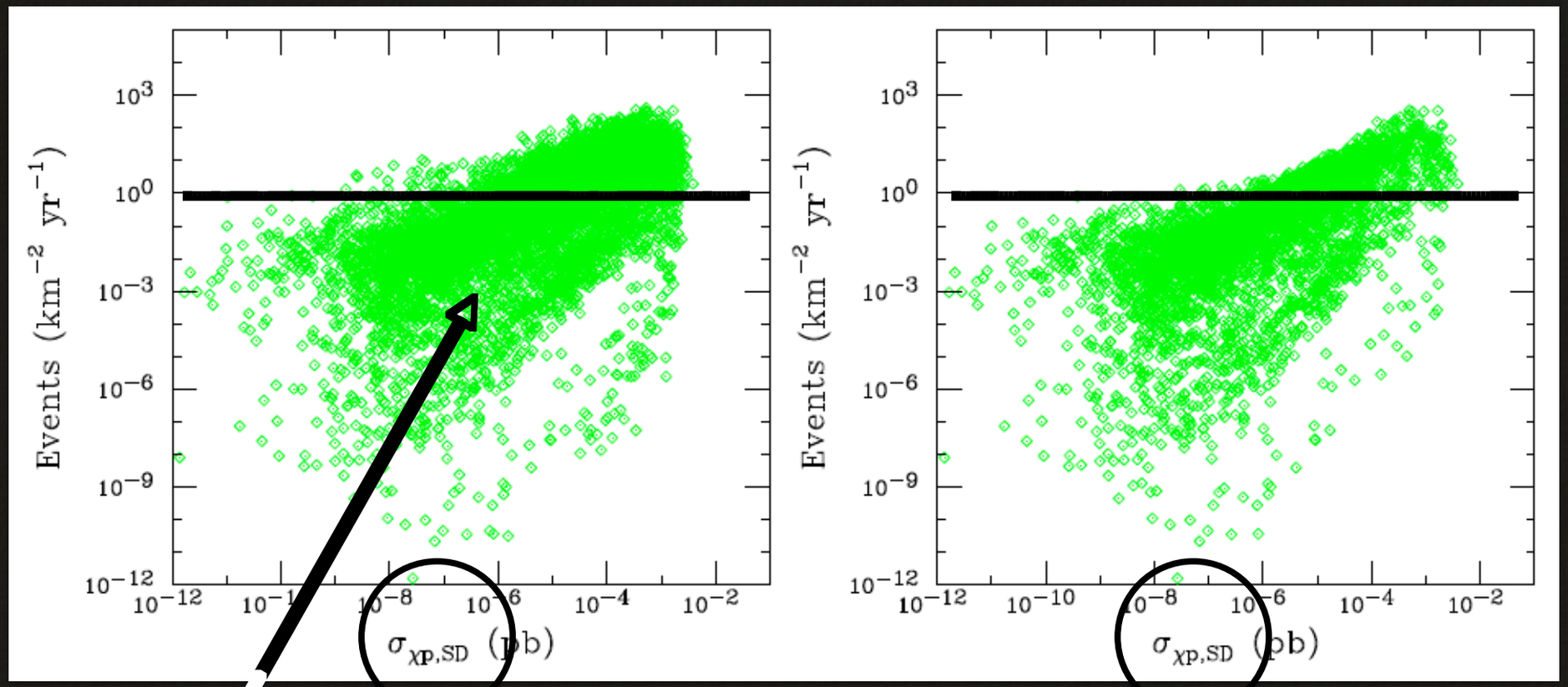
2004-2005 : 1 string

First data in 2005
first upgoing muon:
July 18, 2005

AMANDA
19 strings
677 modules

Completion by 2011

IceCube: events per km^2 year



not ruled out by CDMS (left)

CDMS X 100 (right)

The Bad

Noise is always here today..
and tomorrow

IS NOISE A SIGNAL?

- Uncertainties:
  - halo
  - particle physics
- Can one do better?

Doing Better?: Angular resolution and forward-backward effect

CJC and L. Krauss, *Phys. Rev. D*, **63** 043507 (2001).

CJC and L. Krauss, *Phys. Rev. D*, JAN 2007 ISSUE .

We consider a range of detector taking into account some of the technical challenges being faced.

- 3D: Full three dimensional.
- 3D w/o FB: Three dimensional detector without the ability to determine the track direction (no Forward/Backward discrimination).
- 2D: A two dimensional detector fixed to the surface of the Earth. Recoil tracks are projected onto the plane of the detector.

THE BEST YOU CAN DO?

- Directionality!

THE BEST YOU CAN DO?

- Directionality!

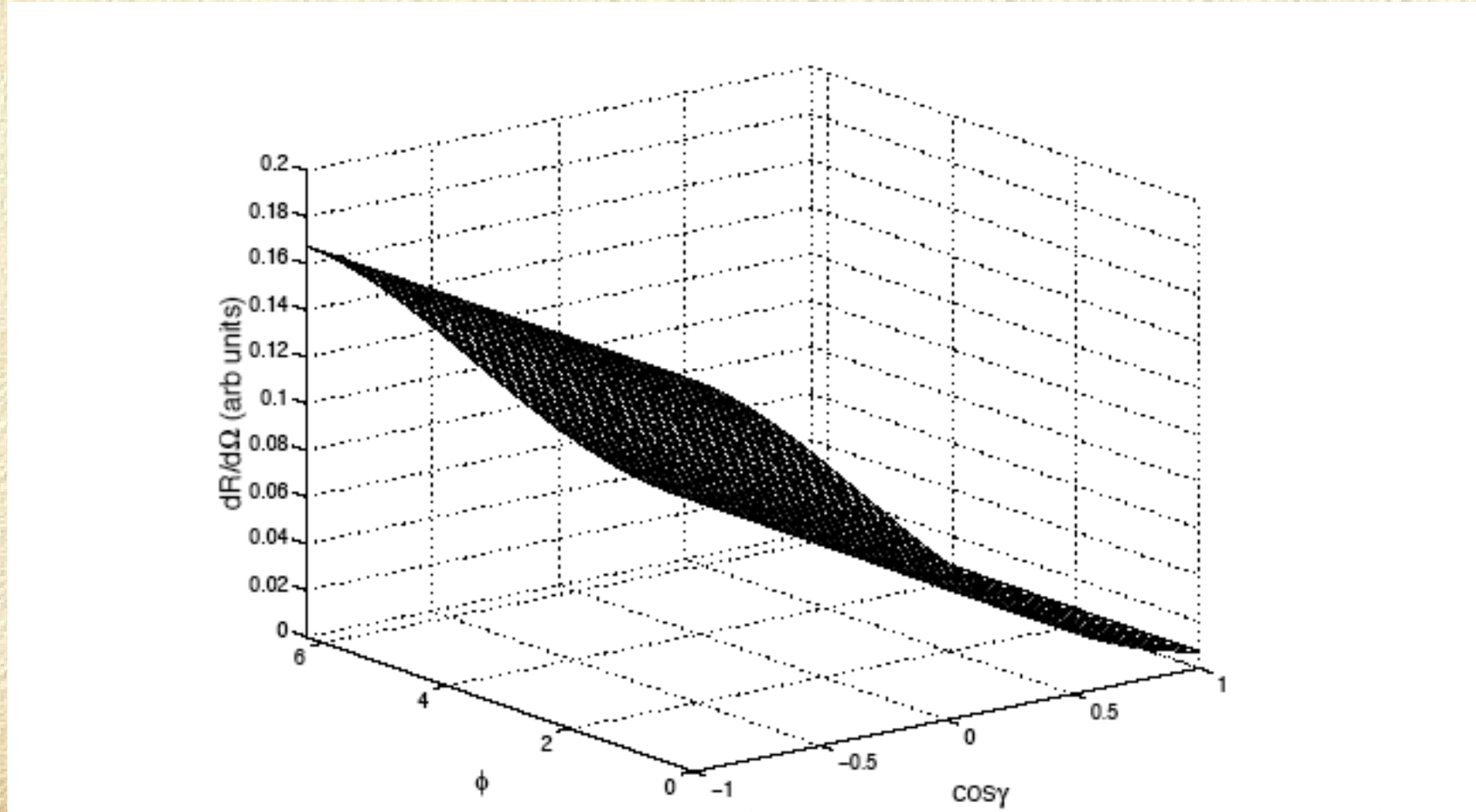


FIG. 2. The angular distribution of nuclear recoil events, $dR/d\Omega$ for an isothermal halo model. Here $v_0 = 220$ km/s and $E_{th} = 0$ keV.

THE BEST YOU CAN DO?

- Directionality!

THE BEST YOU CAN DO?

- Directionality!

TABLE I: The number of events required to identify a WIMP signal above a flat background for different types of detectors and a WIMP mass of $m_\chi = 100$ GeV.

Detector	v_0 (km/s)		
Type	170	220	270
3D (full)	6	11	18
3D without FB	176	1795	$> 35,000$
2D—best/worst	19/45	34/75	61/123
2D rotating	13	24	43

TABLE II: The number of events required to identify a WIMP signal above a flat background for different types of detectors and a WIMP mass of $m_\chi = 1000$ GeV.

Detector	v_0 (km/s)		
Type	170	220	270
3D (full)	14	27	51
3D without FB	152	217	371
2D fixed—best/worst	51/129	97/217	175/368
2D rotating	31	61	125

Axion Naturality?

Axion Naturality?

- $f \approx 10^{16}$ GeV possible if $\Theta \ll 1$

Axion Naturality?

- $f \approx 10^{16}$ GeV possible if $\Theta << 1$
- This is not unnatural if one averages over universes with life in them. … dark matter density peaked near observable value…

Axion Naturality?

- $f \approx 10^{16}$ GeV possible if $\Theta << 1$
- This is not unnatural if one averages over universes with life in them. … dark matter density peaked near observable value…

Tegmark, Aguirre, Rees, Wilczek, 2006

DARK ENERGY:
Bad AND Ugly

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- Incorporating realistic uncertainties does not leave much room for optimism. (i.e. supernovae)

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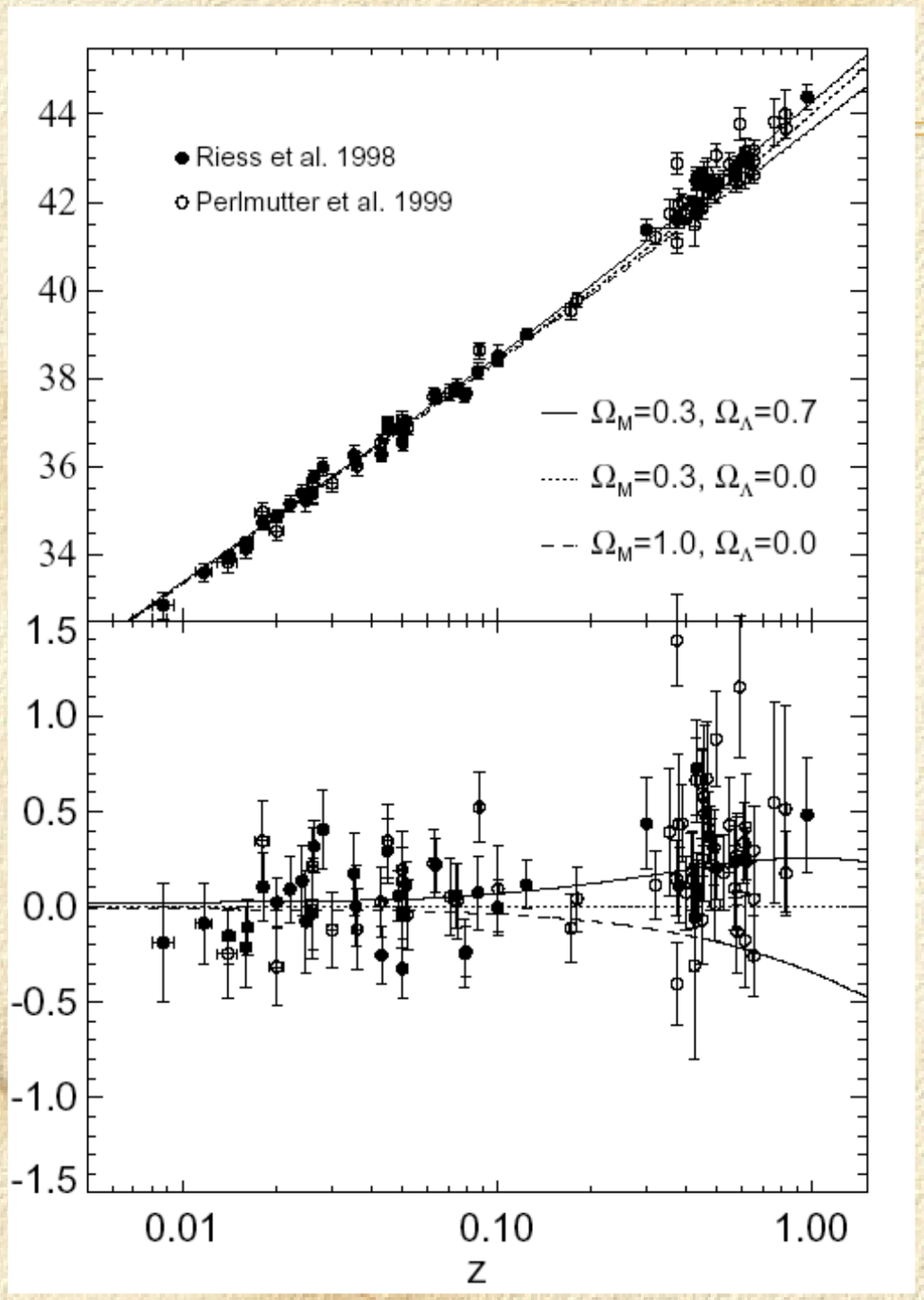
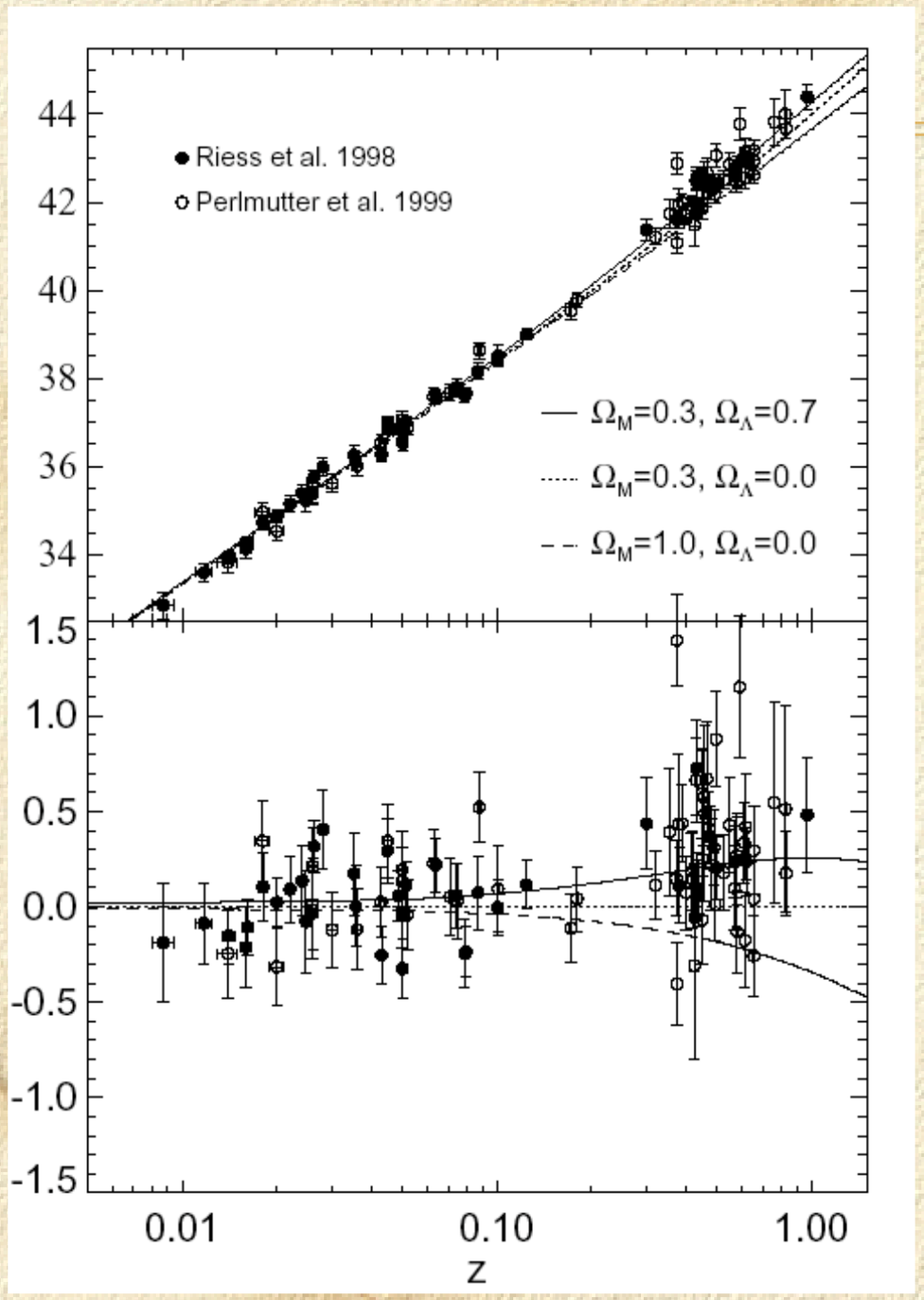
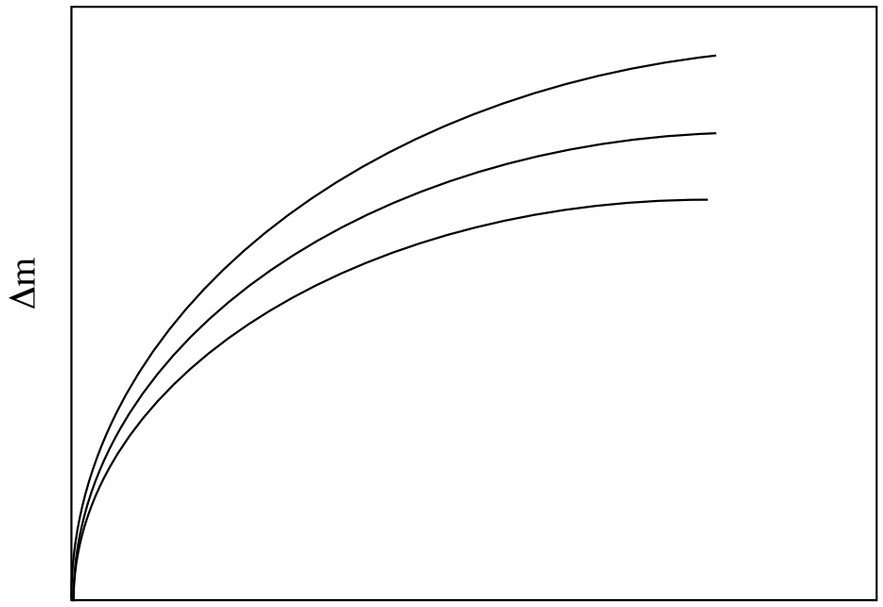
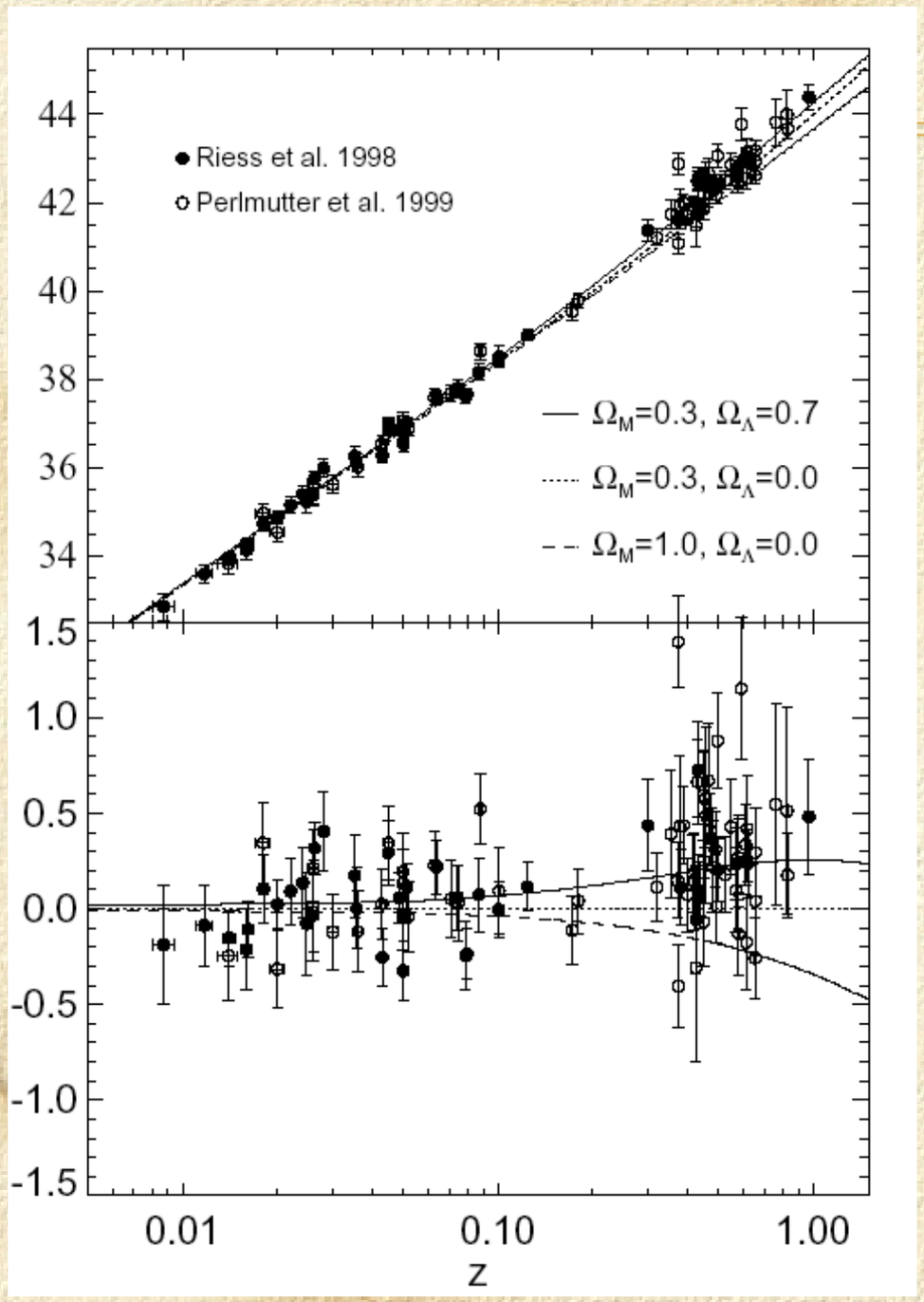
- The PROBLEM: We DON'T HAVE ANY IDEA of w(z). Hence limits on w=constant are not appropriate.


Riess et al. 1998
Perlmutter et al. 1999
Ω_M=0.3, Ω_Λ=0.7
Ω_M=0.3, Ω_Λ=0.0
Ω_M=1.0, Ω_Λ=0.0
44
42
40
38
36
34
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0.01
0.10
1.00
z



w= constant.. differences between diff. w's





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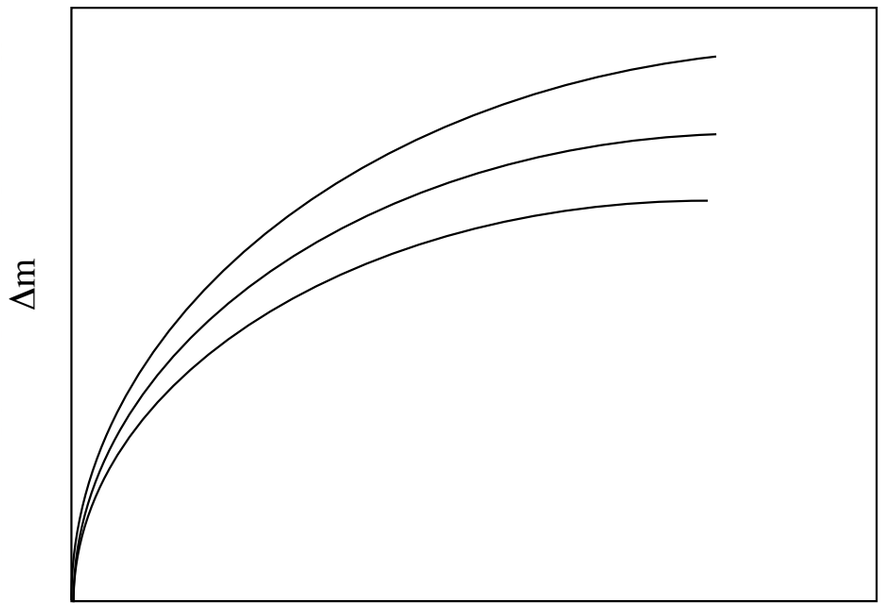

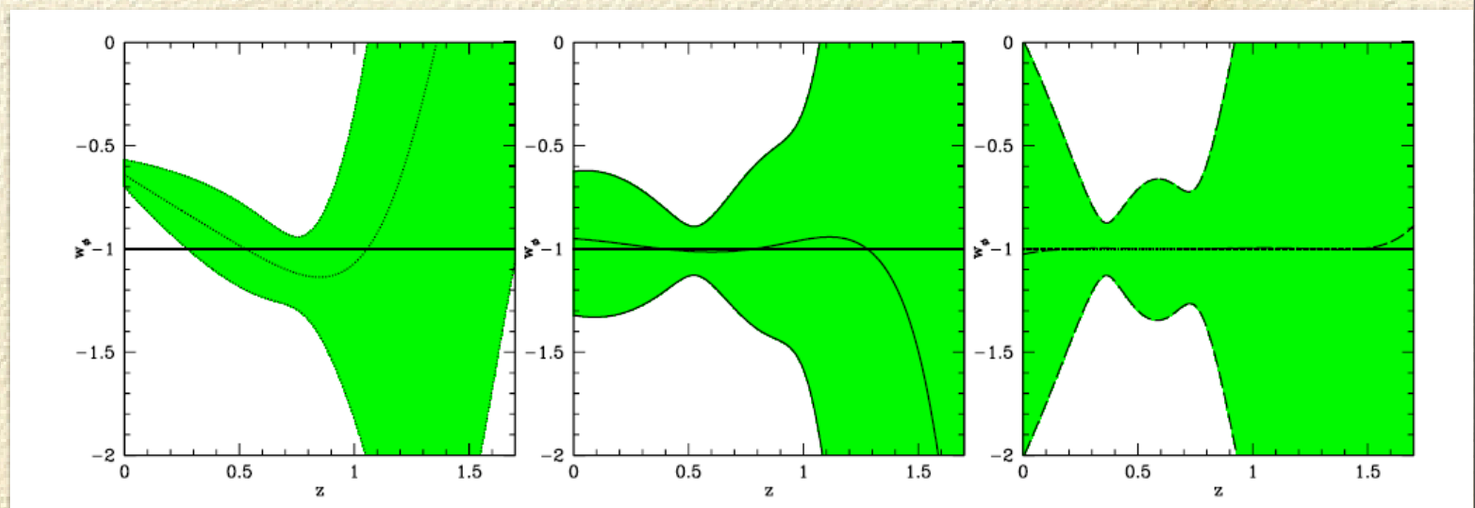

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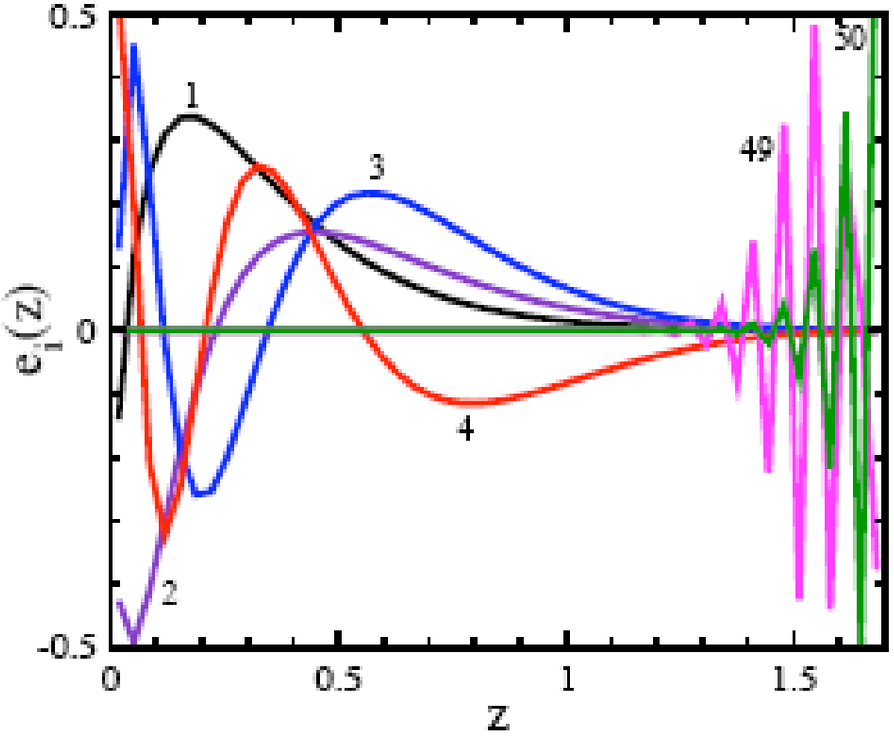
$$\sigma(\alpha_1) \leq \sigma(\alpha_2) \leq \ldots \leq \sigma(\alpha_N)$$

Consider a general description of w (say, w_i in 50 redshift bins at $z \in [0, 1.7]$)

- Compute the covariance matrix for w_i (assuming some SN survey)
- Diagonalize the covariance matrix. Get best, worst measured linear combinations of w_i's.
- $w(z) = \sum_{i=1}^{50} \alpha_i e_i(z)$



Huterer & Starkman 2003

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LMK, D. Huterer, K. Jones-Smith astroph/0701692

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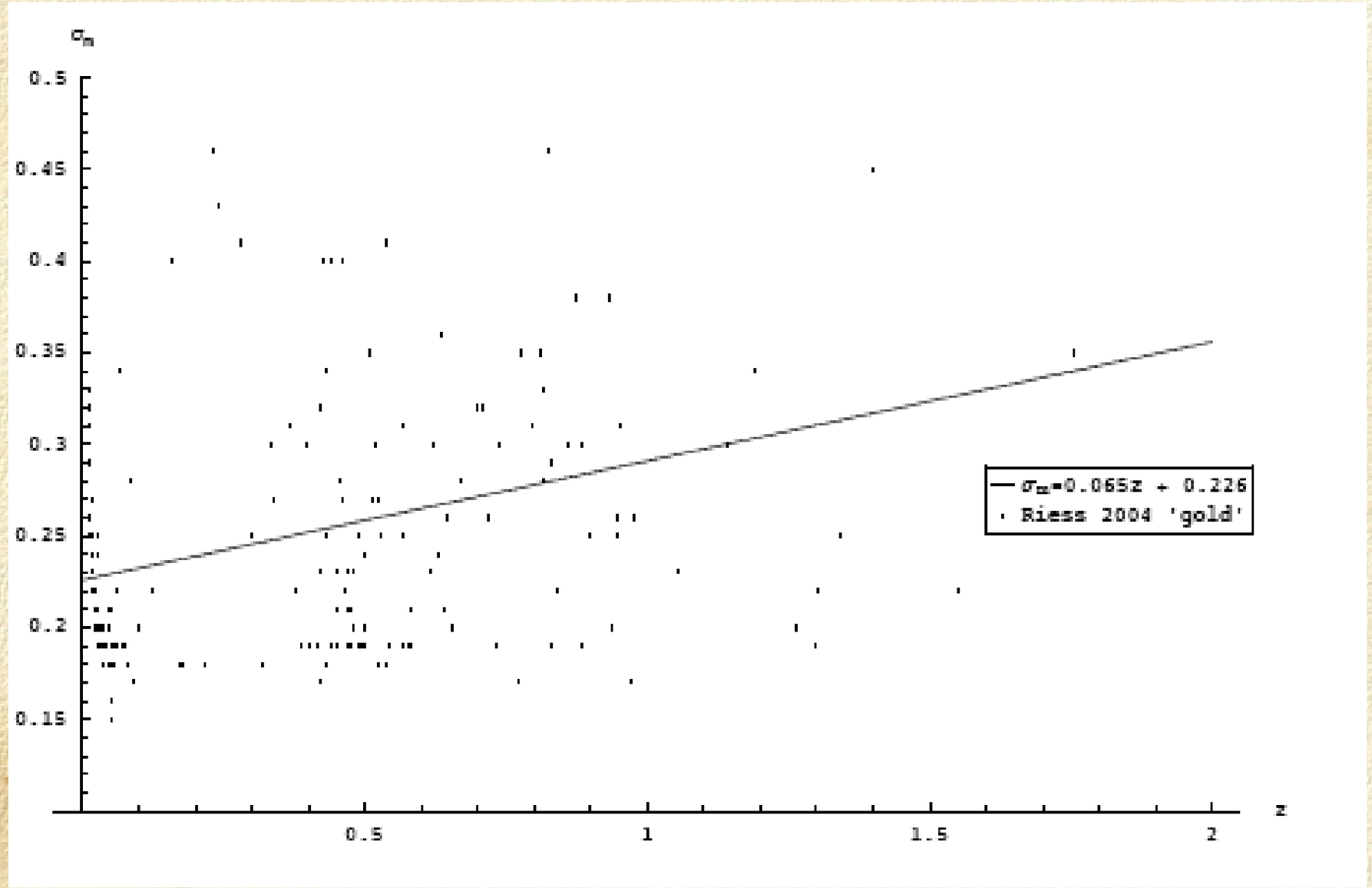
$$\chi^2 = \sum_{i=1}^{M} \frac{(\alpha_i - \bar{\alpha}_i)^2}{\sigma^2(\alpha_i)}$$

Redshift Dependent Uncertainties?



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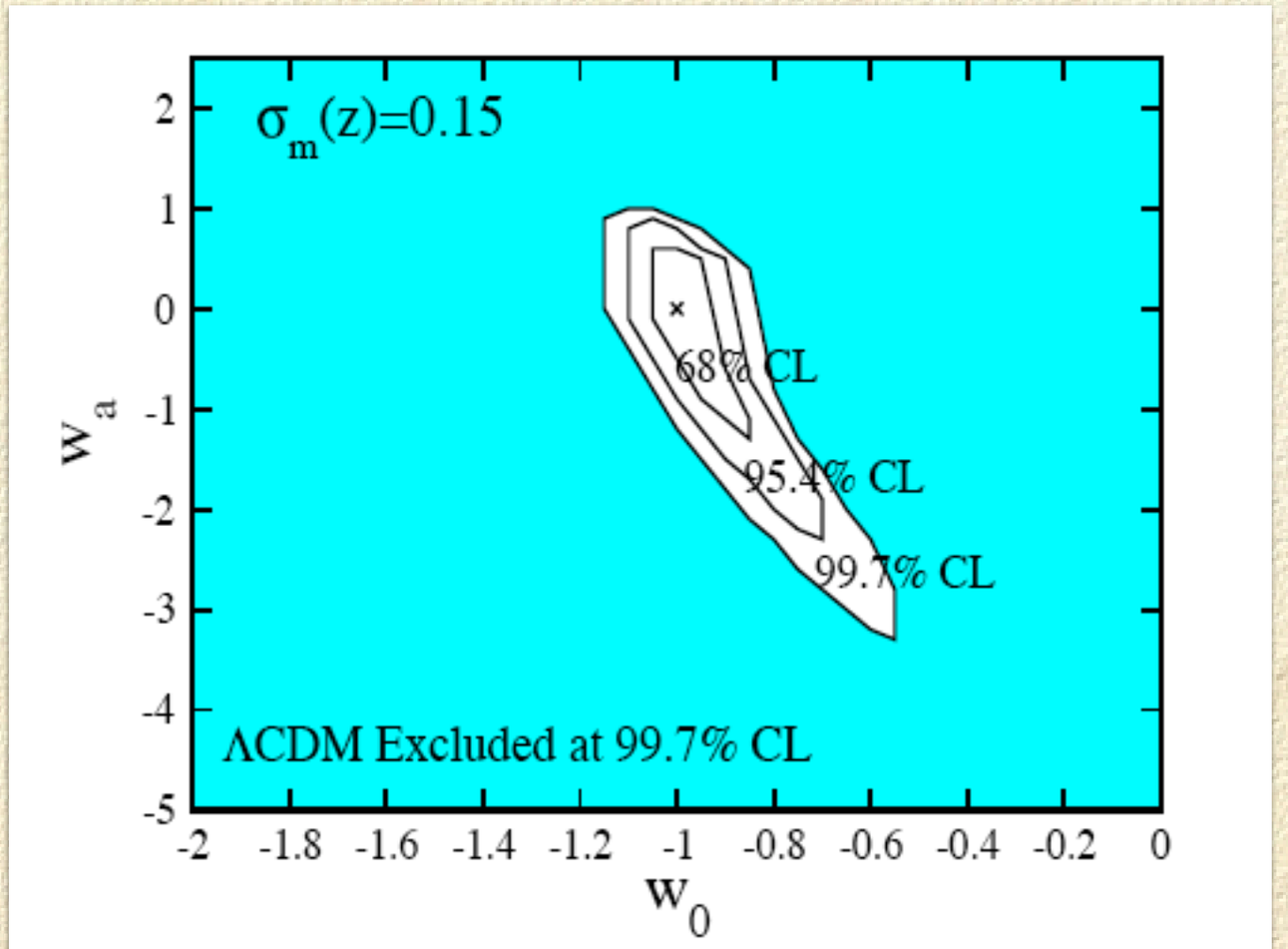

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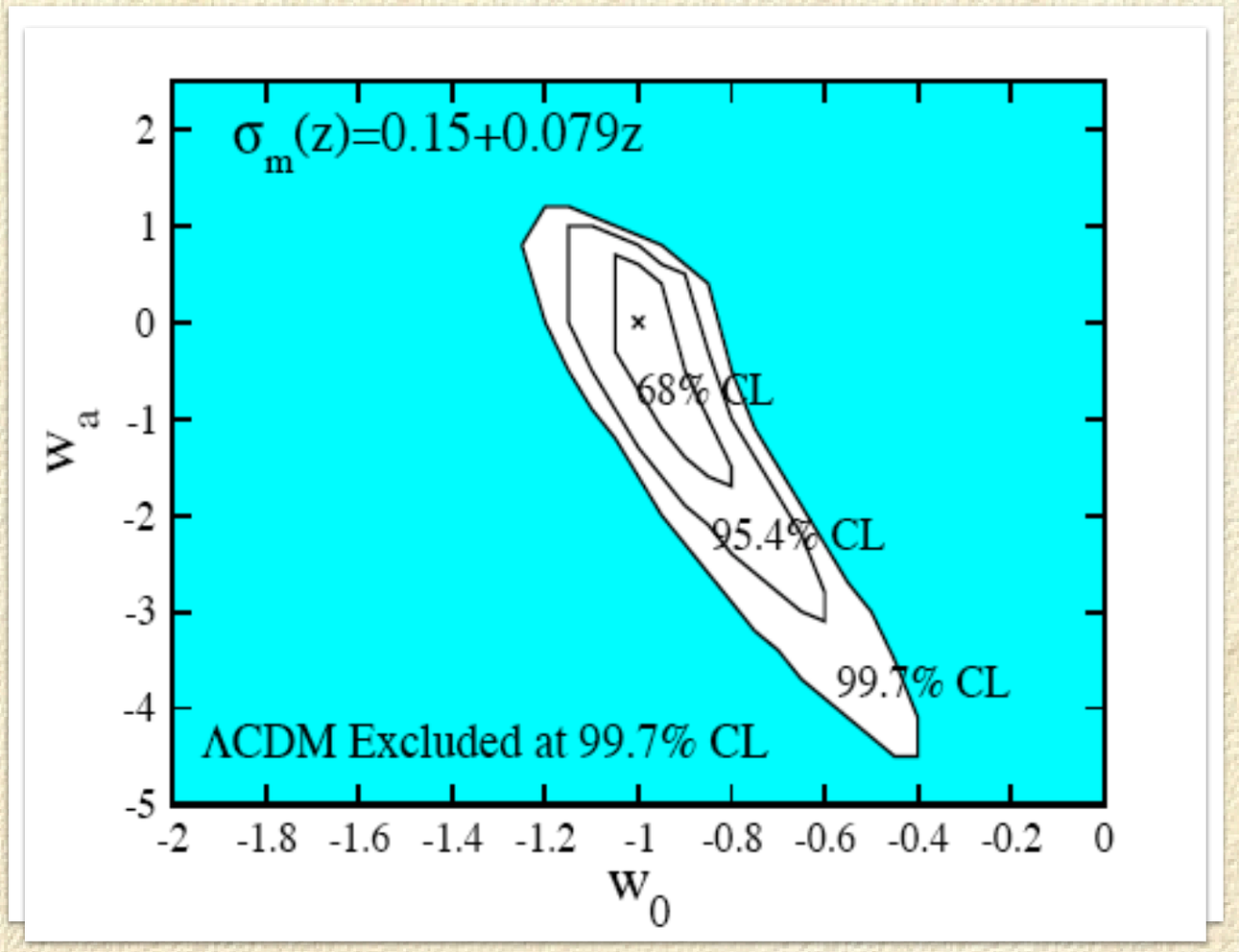

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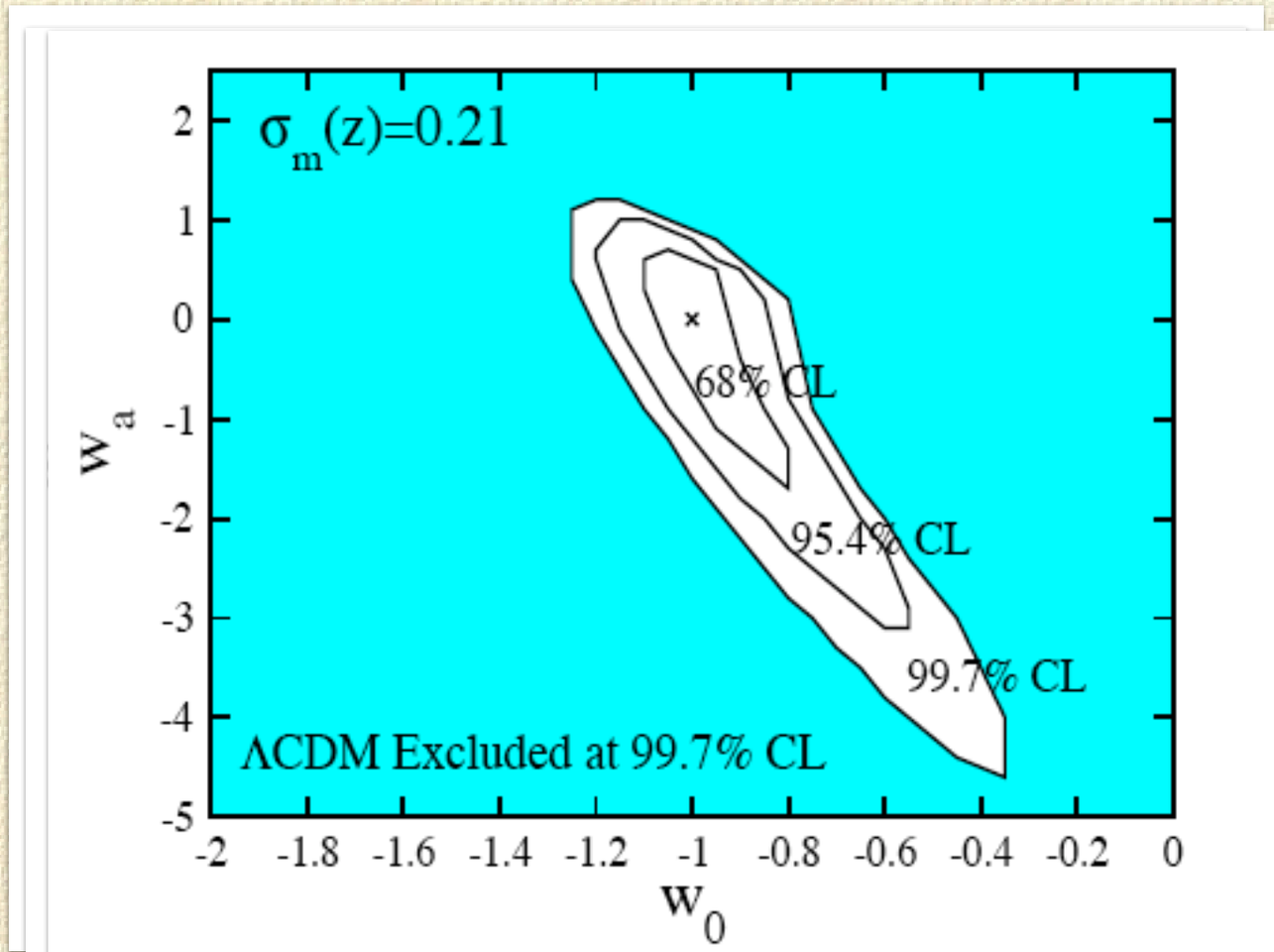

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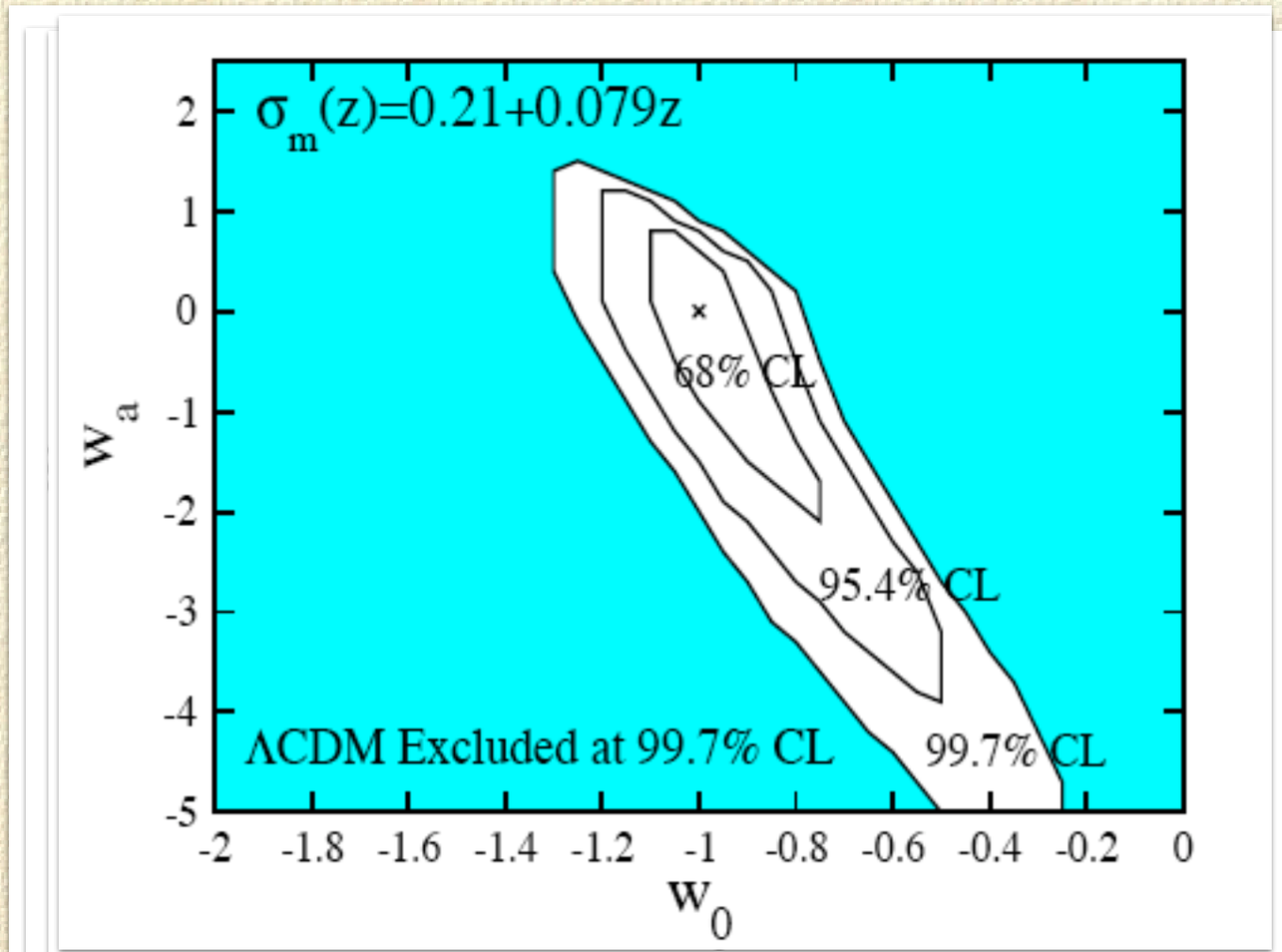

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“The Future ain’t what it used to be!”

Yogi Berra

Gone tomorrow?: An Uncertain Future?

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GEOMETRY ≠ DESTINY

LMK MST 1998

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effects soon "visible!

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FUND COSMOLOGY NOW!

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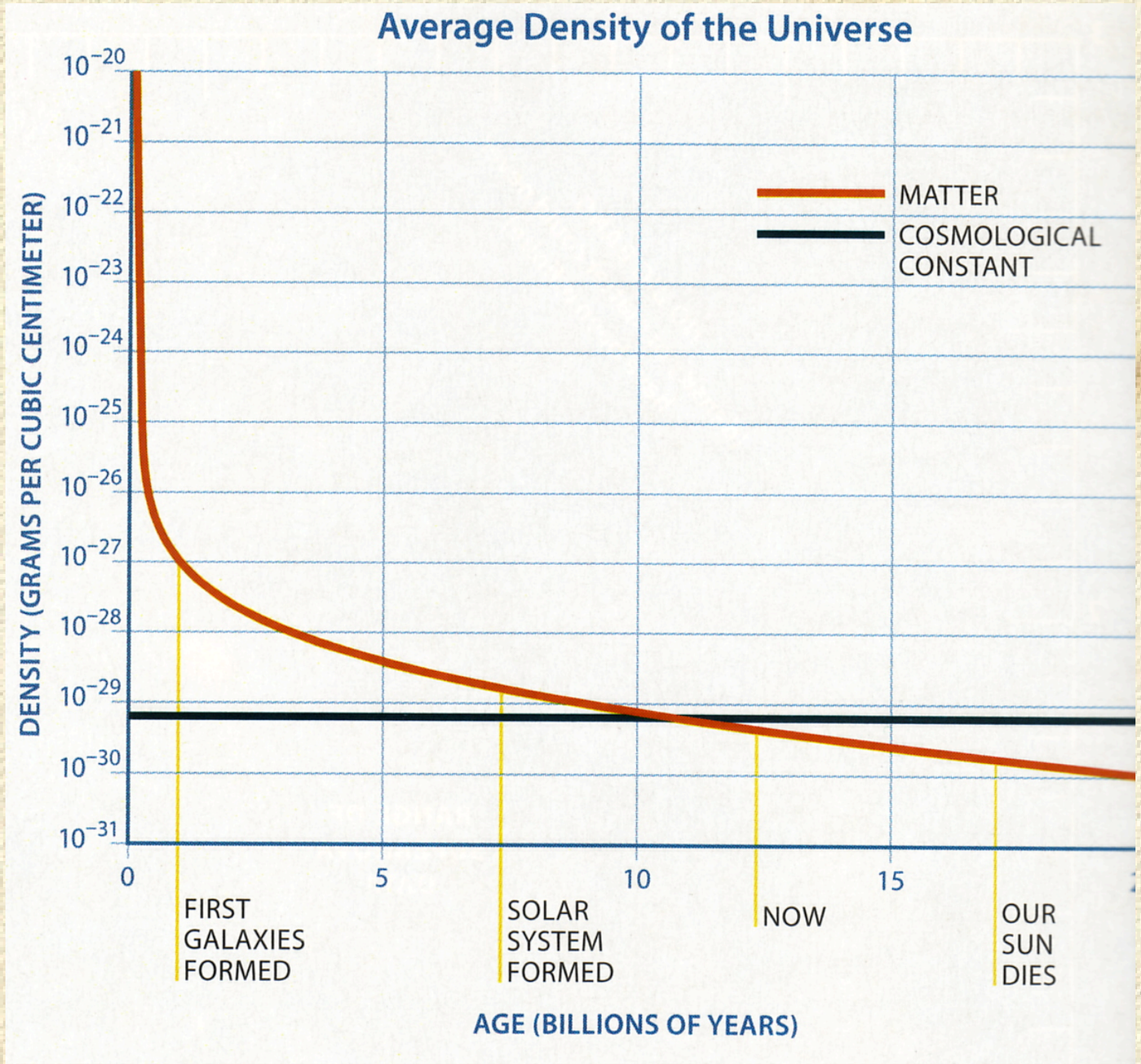

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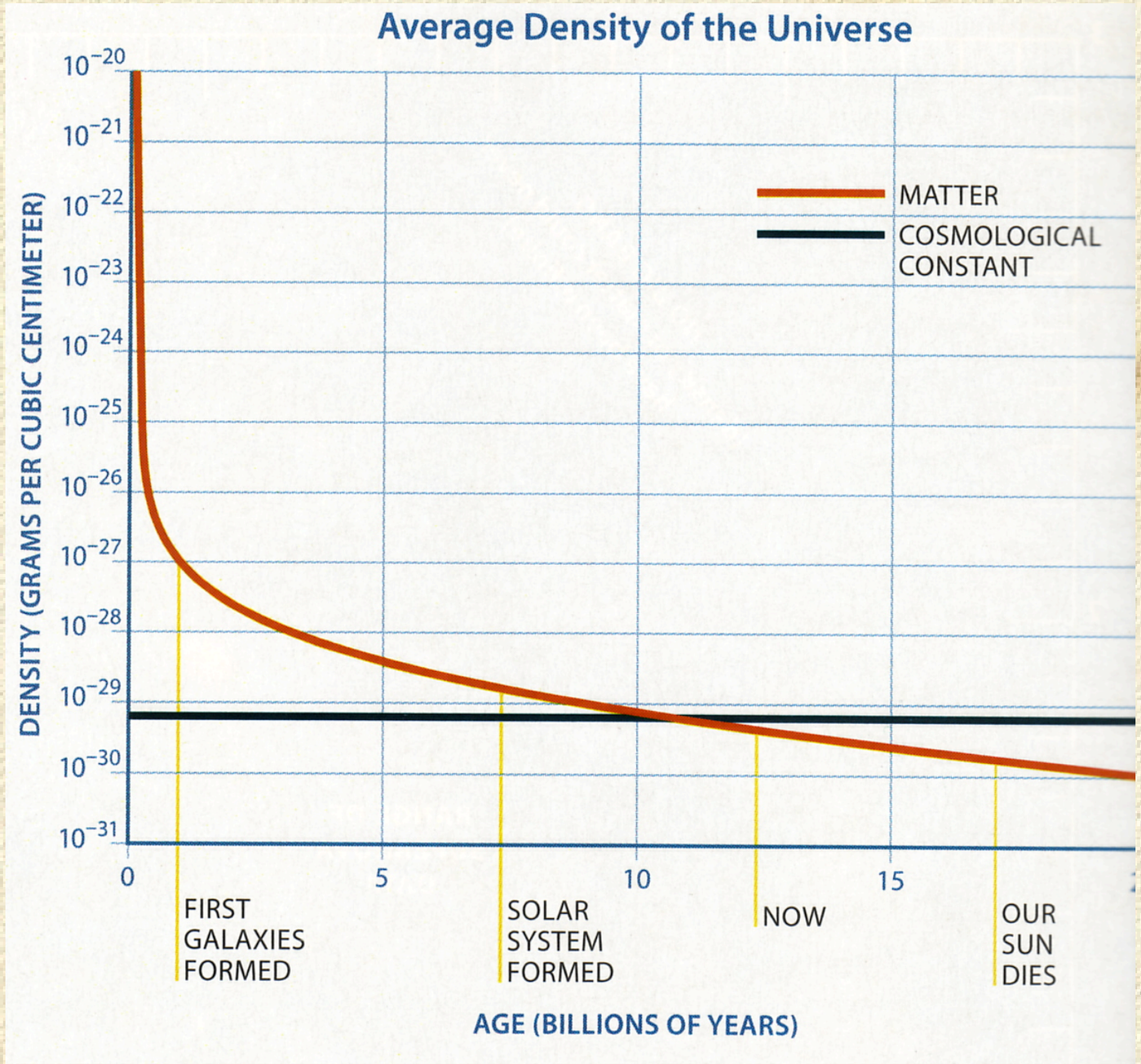

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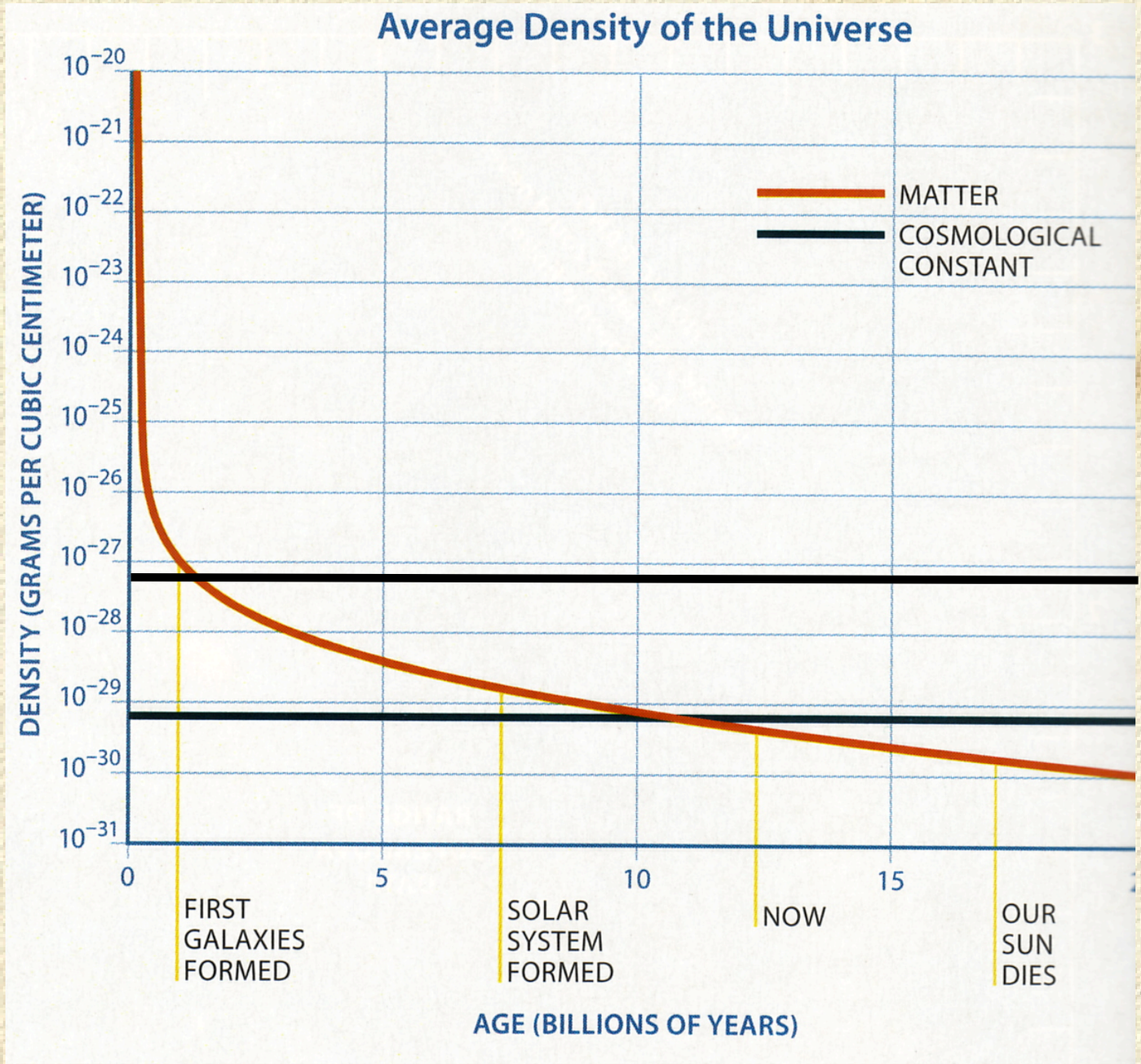

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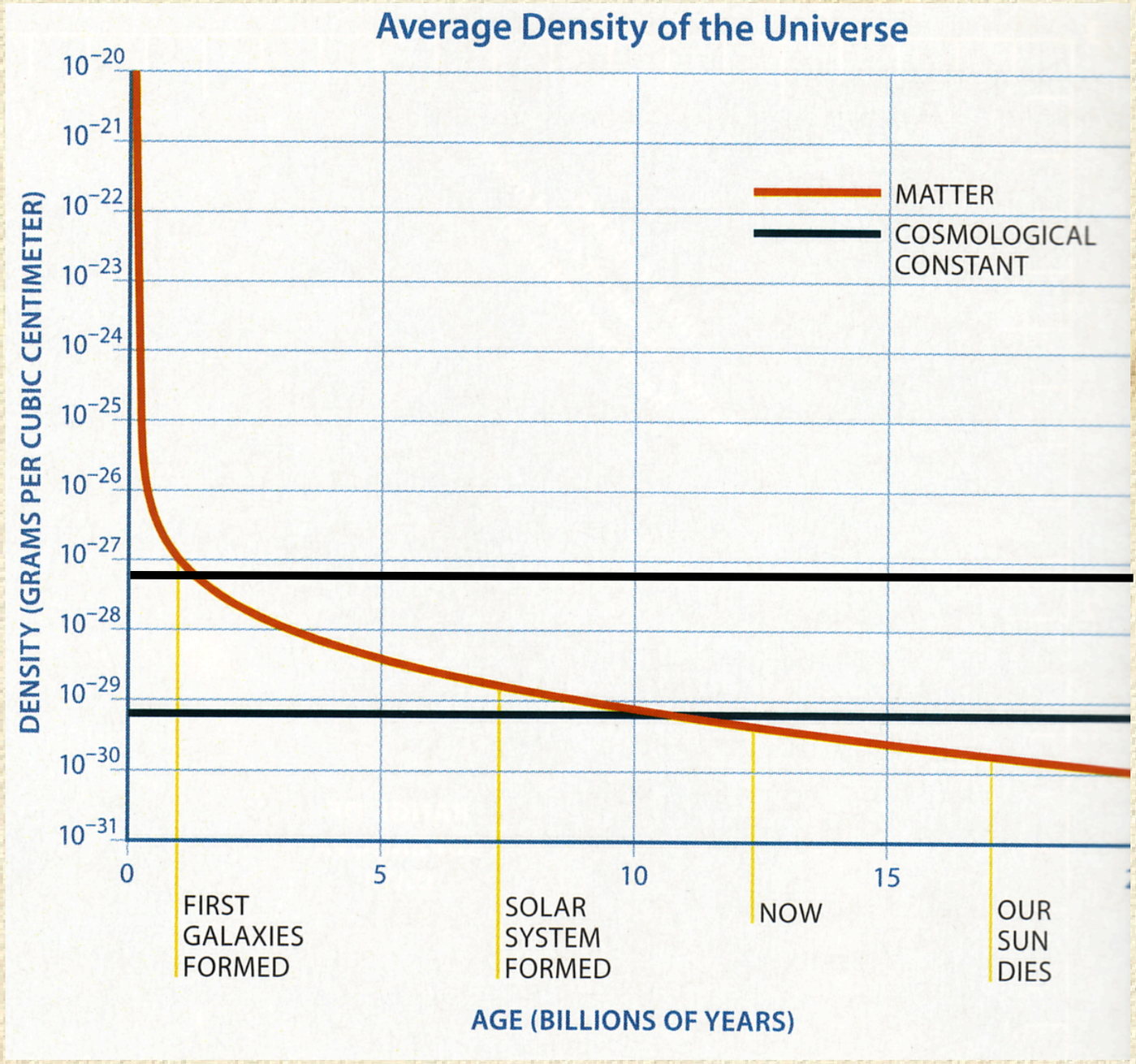

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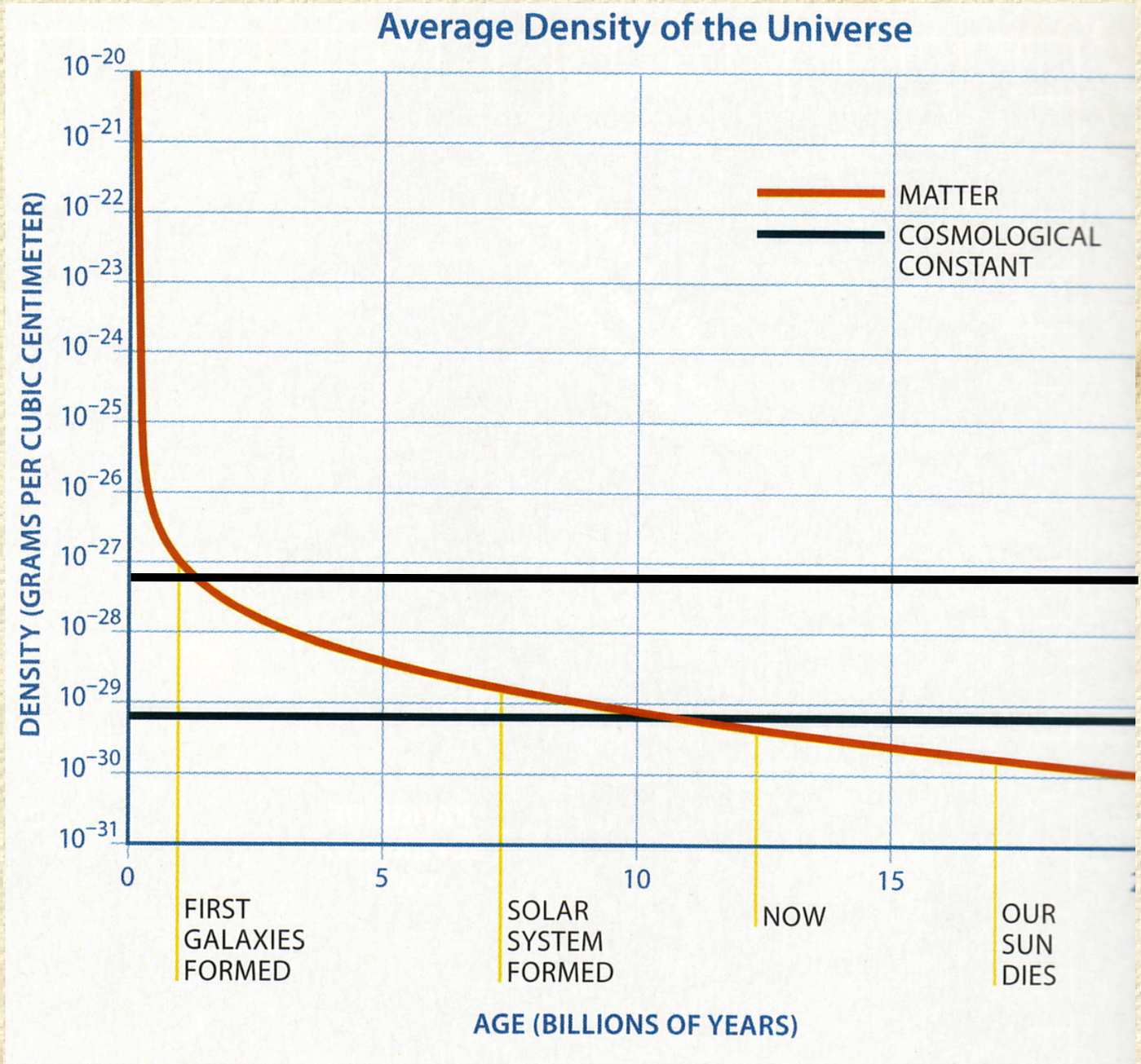
Galaxies Never Form?



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Anthropic Mania

IF there are many different universes, and the energy of empty space can vary in each one, then only those in which it is not much greater than what we measure will galaxies form... and only then will stars and planets form, and only then astronomers....

Why Stop There?

The Constants of Nature and the Puzzles of Modern Physics

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The Landscape of Nothingness

IS THIS SCIENCE?

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Maor, LMK, Starkman 07

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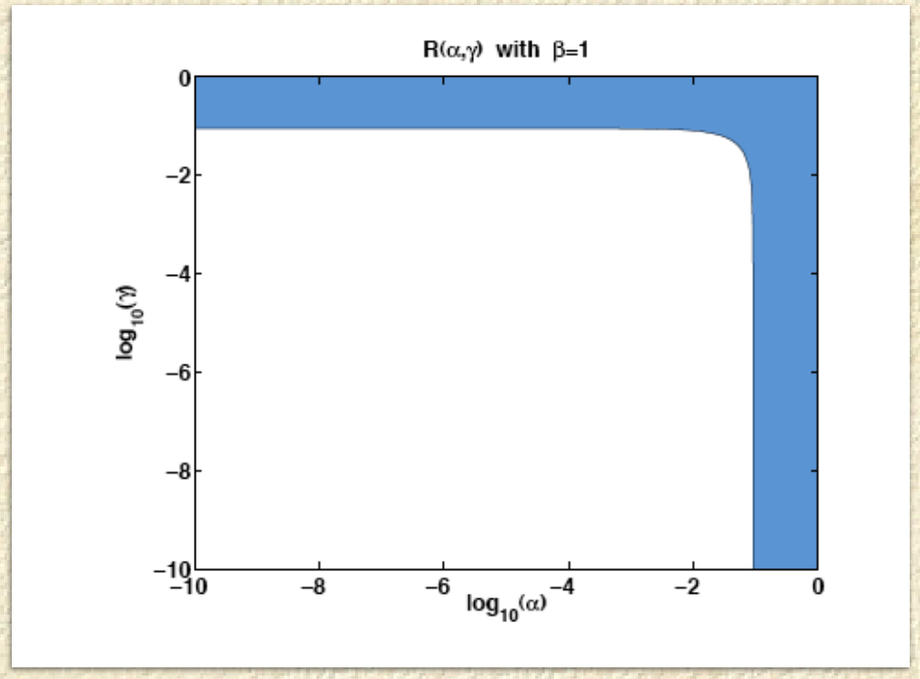

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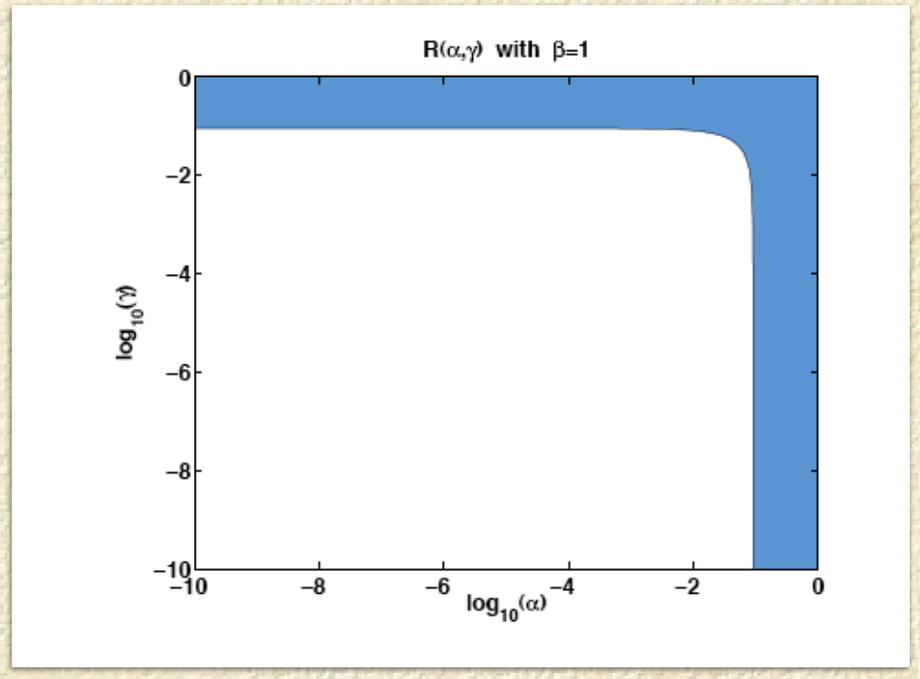

R is small over most of parameter space!

If this weren't bad enough..

“Eternity is a long time, especially near the end”

W. Allen

All Good Things Come to an End

Even that which won't vanish will disappear (LMK GDS 07)

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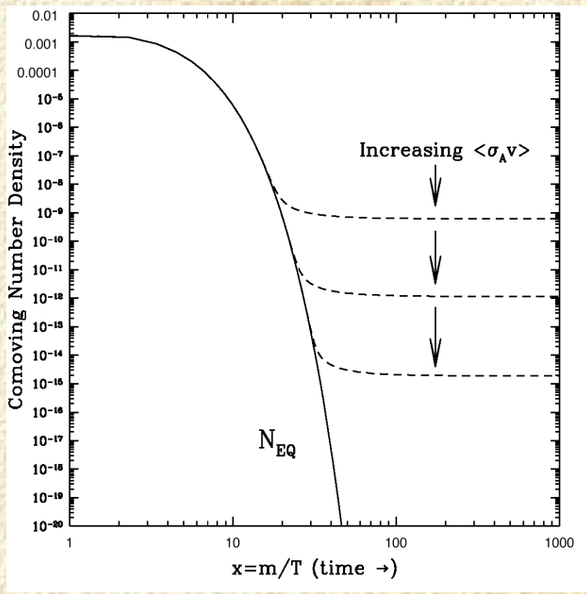

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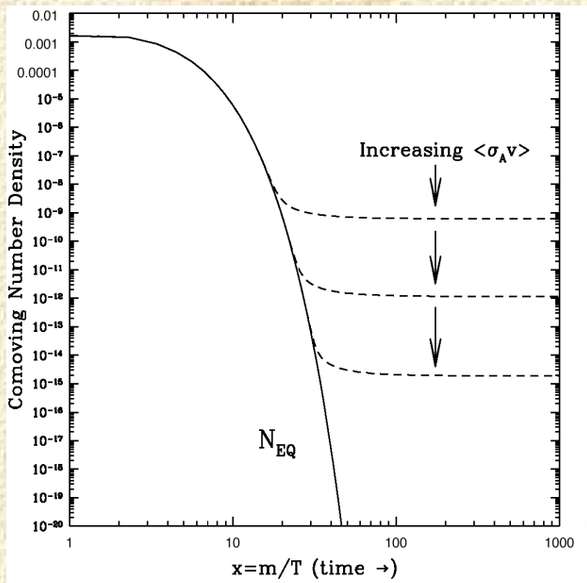

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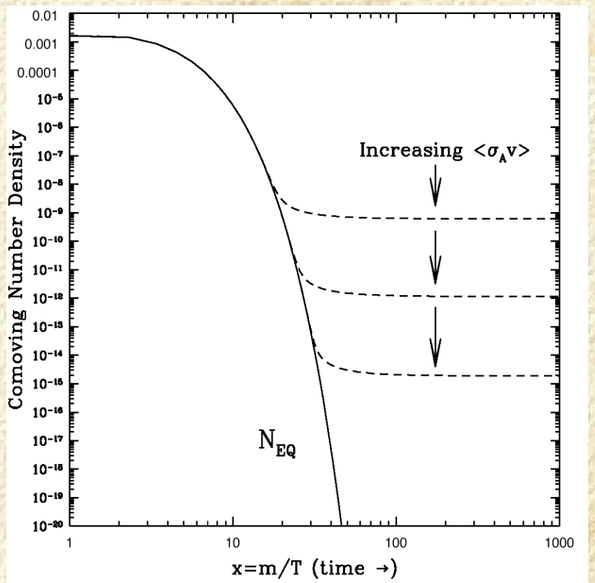

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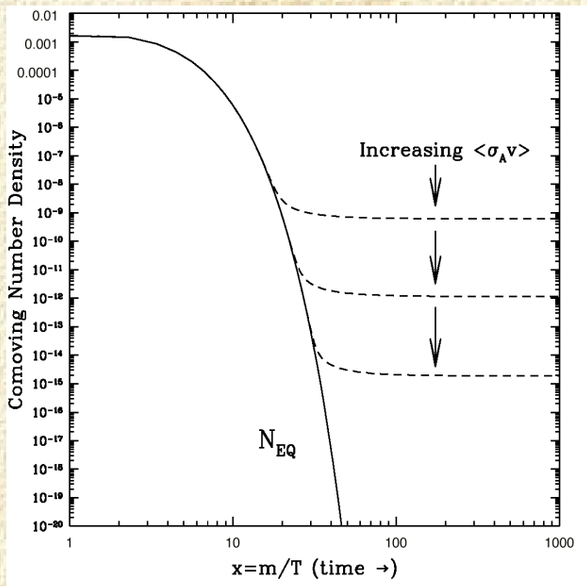

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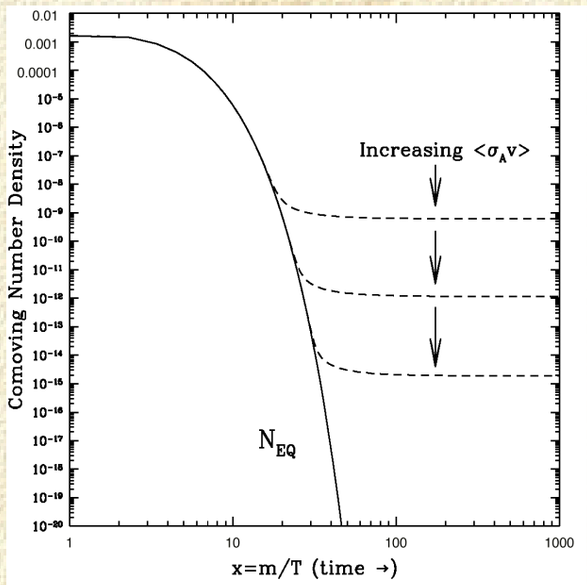

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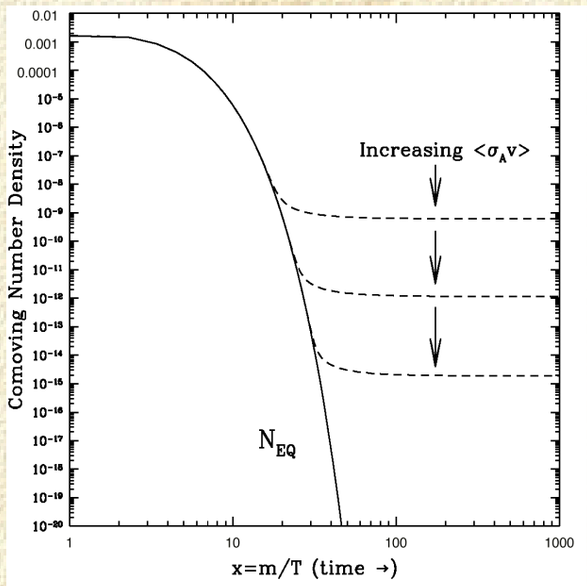

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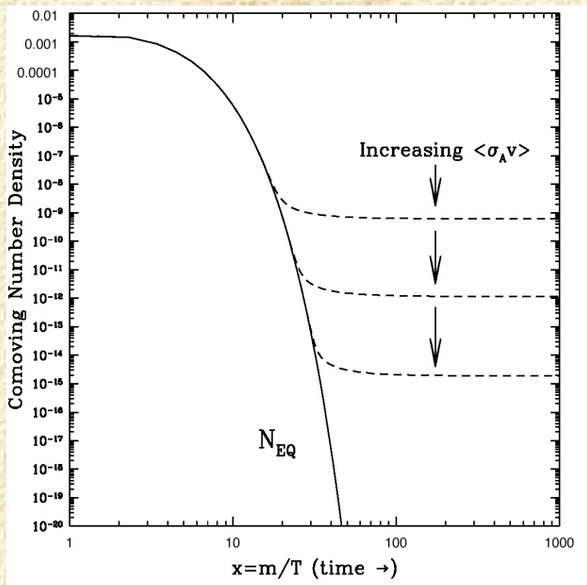

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It gets worse...

The End of Cosmology? (LMK RS 07)

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- What will the future bring?

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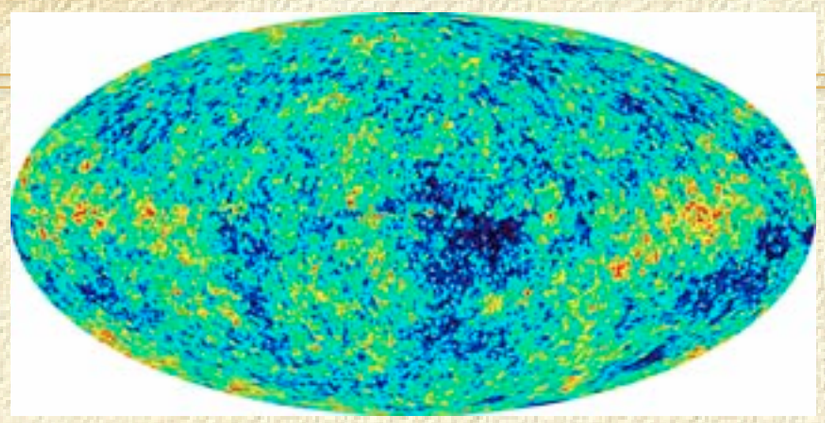

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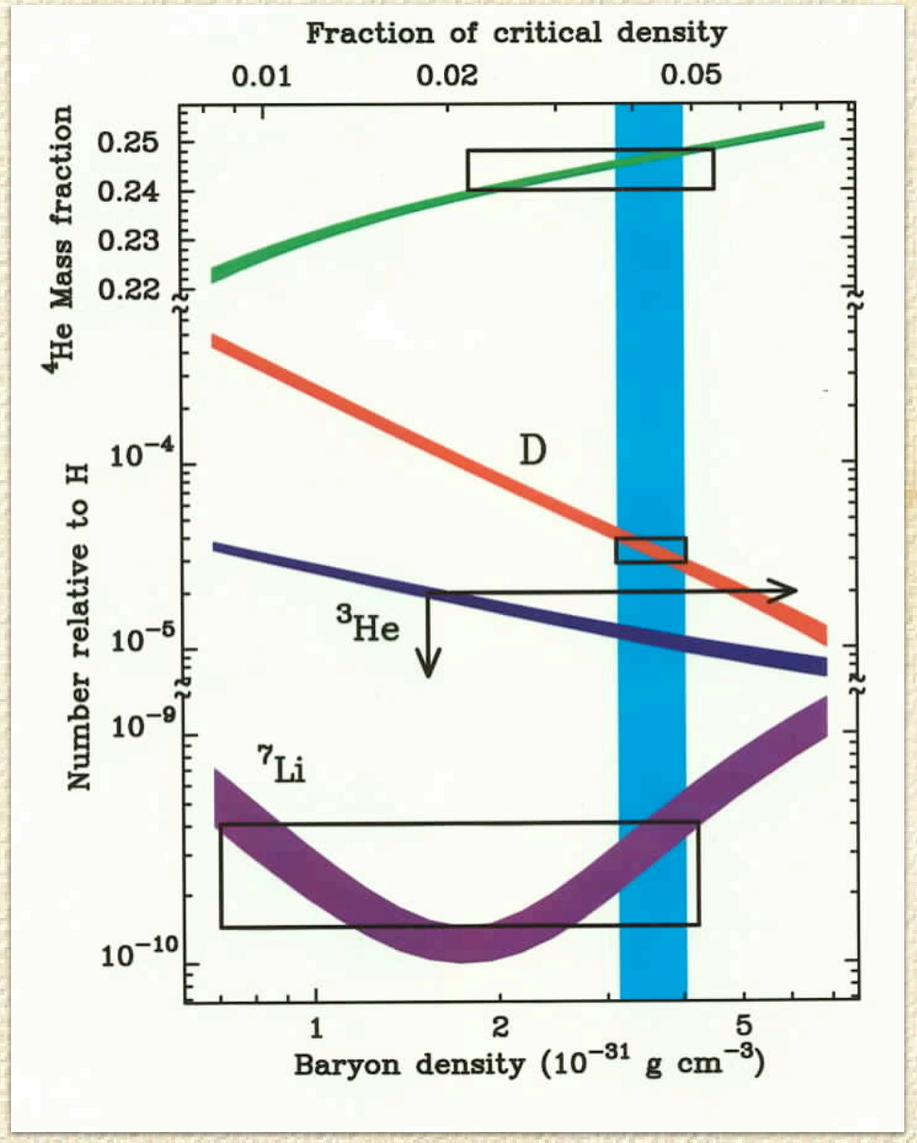

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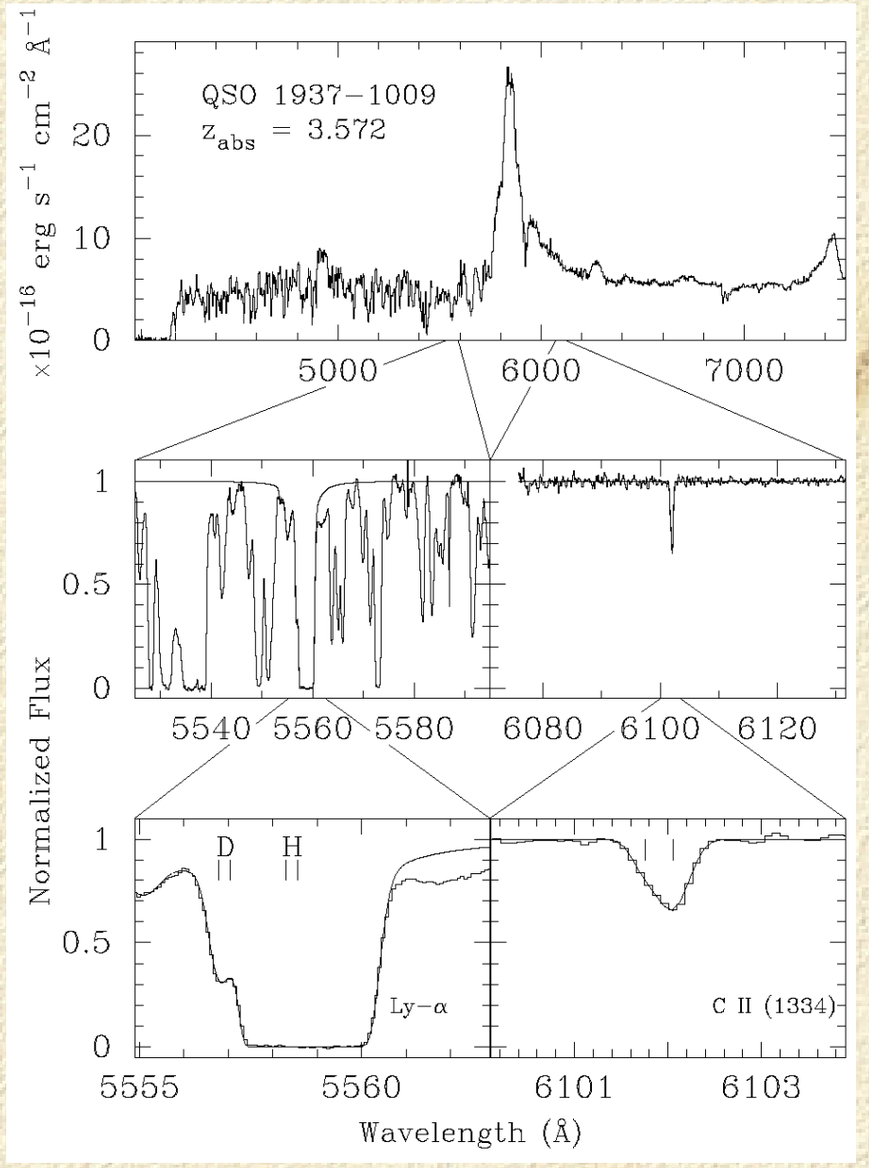

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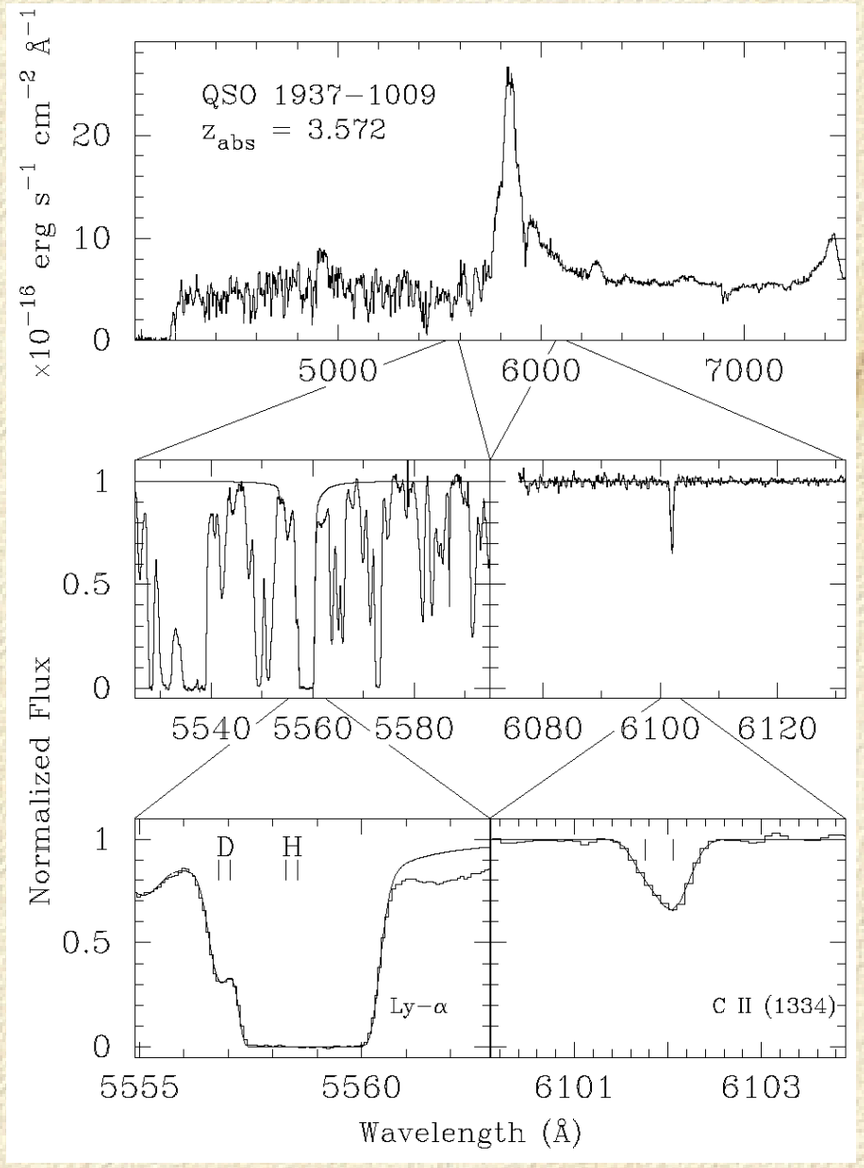

Return of Static DeSitter Universe!

The Good News

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We live in a very special time: the only time when we can observationally verify that we live at a very special time!

..and, Diamonds are forever

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- Hence Ratio =exp (-(k-H)) > 1!

We will be lonely, but dominant.....