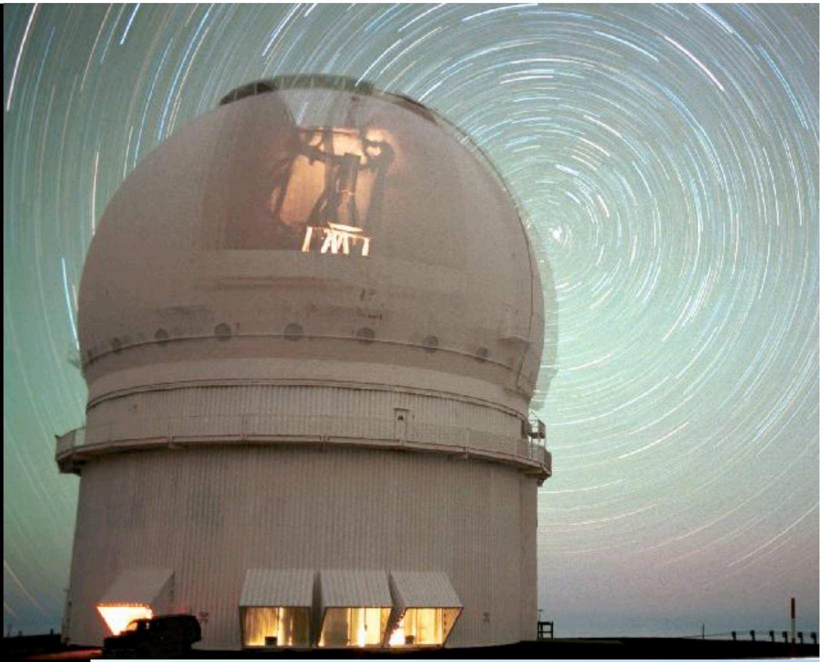
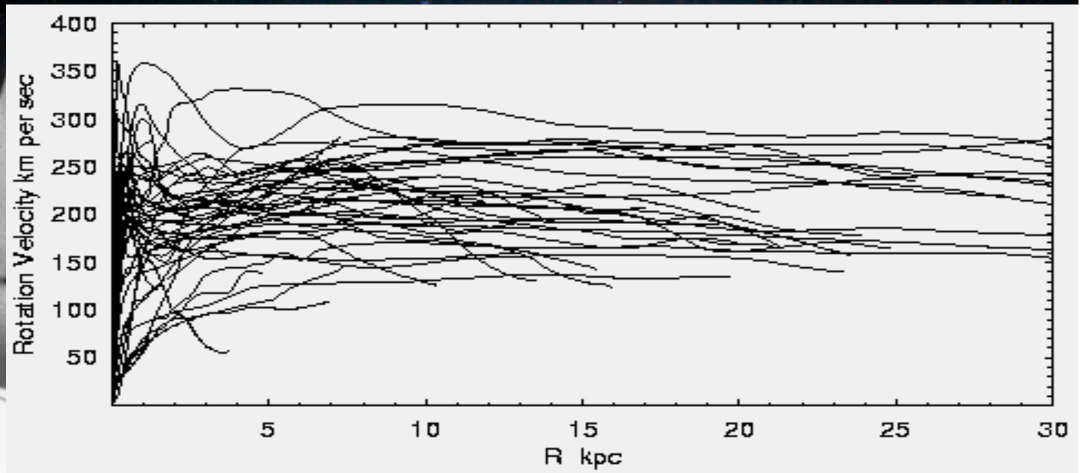
DARK MATTERS

Joe Silk, September 23, 2009



Dark Matter in Galaxies



HELVETICA PHYSICA ACTA
Volumen VI Fasciculus Secundus.

3

5

Die Rotverschiebung von extragalaktischen Nebeln

von F. Zwicky.

(16. II. 33.)

Inhaltsangabe. Diese Arbeit gibt eine Darstellung der wesentlichsten Merkmale extragalaktischer Nebel, sowie der Methoden, welche zur Erforschung derselben gedient haben. Insbesondere wird die sog. Rotverschiebung extragalaktischer Nebel eingehend diskutiert. Verschiedene Theorien, welche zur Erklärung dieses wichtigen Phänomens aufgestellt worden sind, werden kurz besprochen. Schliesslich wird angedeutet, inwiefern die Rotverschiebung für das Studium der durchdringenden Strahlung von Wichtigkeit zu werden verspricht.

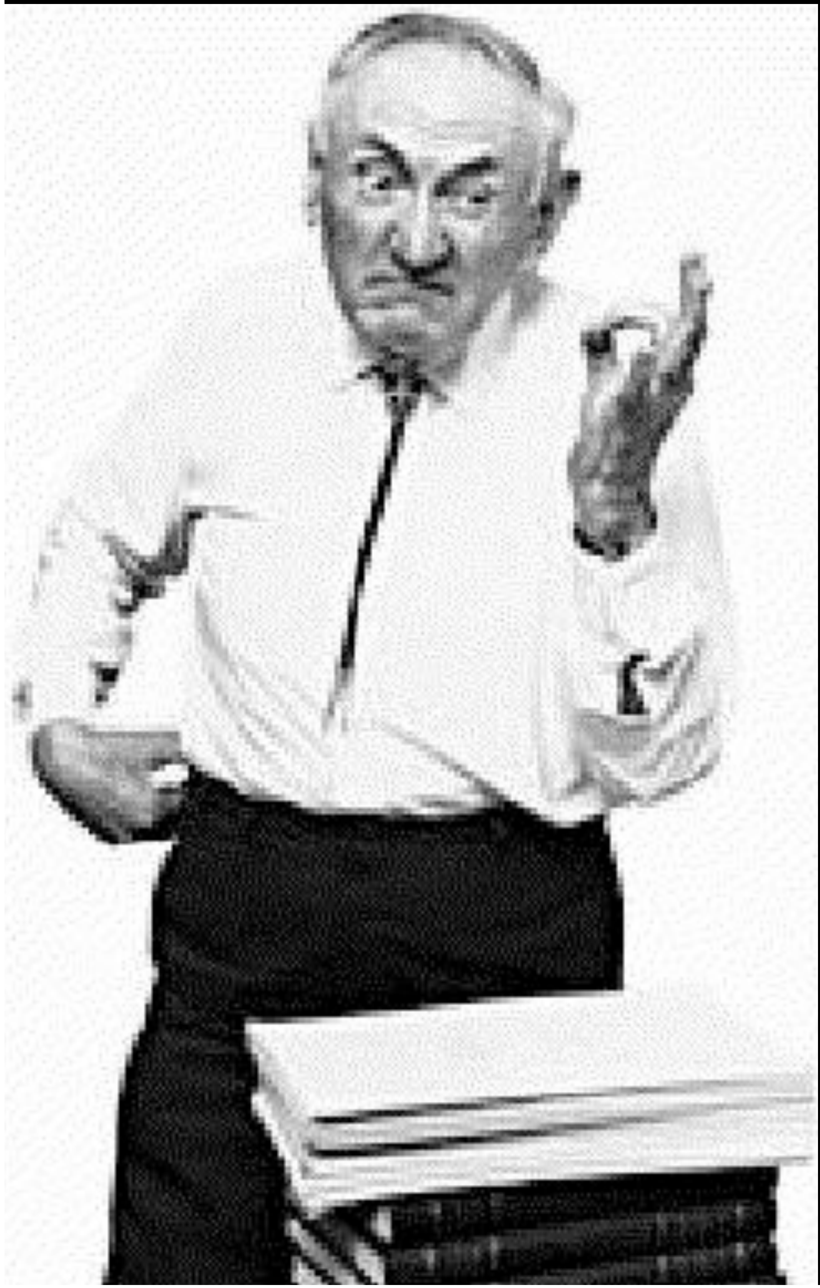
§ 1. Einleitung.

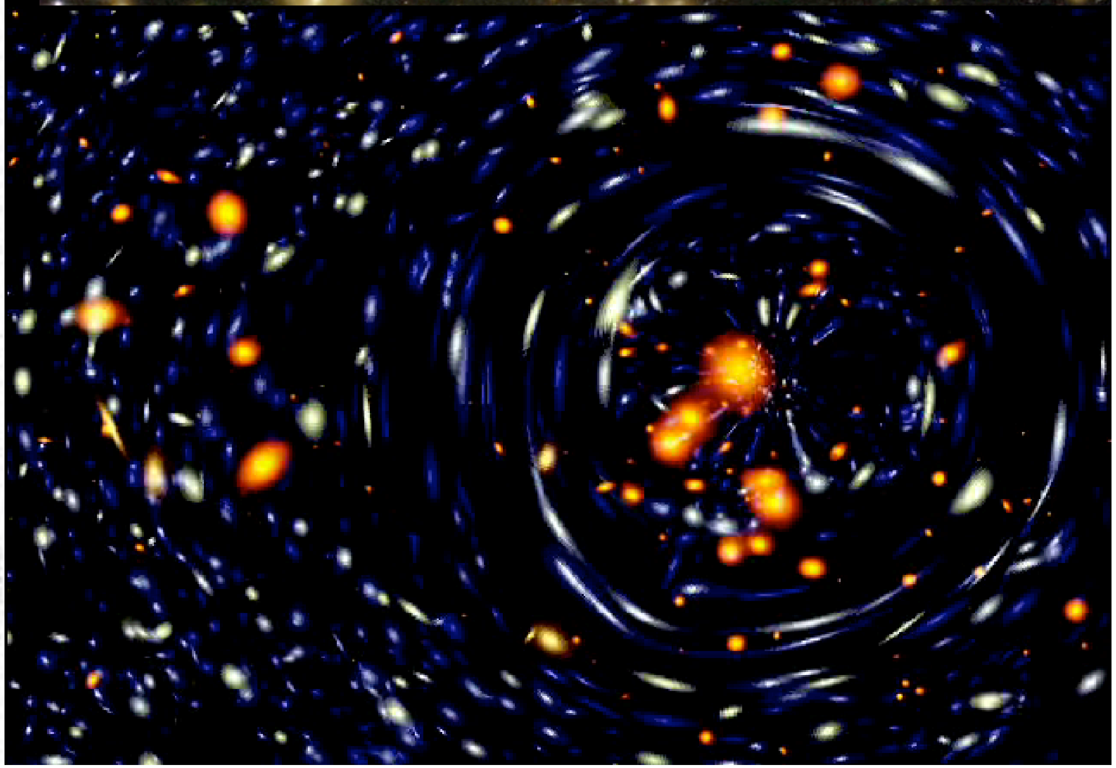
Es ist schon seit langer Zeit bekannt, dass es im Weltraum gewisse Objekte gibt, welche, wenn mit kleinen Teleskopen beobachtet, als stark verschwommene, selbstleuchtende Flecke erscheinen. Diese Objekte besitzen verschiedenartige Strukturen. Oft sind sie kugelförmig, oft elliptisch, und viele unter ihnen haben

…m, wie beobachtet, einen mittleren Dopplereffekt von 1000 km/sek oder mehr zu erhalten, müsste also die mittlere Dichte im Comasystem mindestens 400 mal grösser sein als die auf Grund von Beobachtungen an leuchtender Materie abgeleitete[1]). Falls …ch dies bewahrheiten sollte, würde sich also das überraschende Resultat ergeben, dass dunkle Materie in sehr viel grösserer Dichte vorhanden ist als leuchtende Materie.

2. Man kann auch annehmen, dass das Comasystem sich nicht im stationären Gleichgewicht befindet, sondern dass die ganze verfügbare potentielle Energie als kinetische Energie er-

Dark Matter in Galaxy Clusters





Dark matter: baryonic

Canberra Times
April 1990

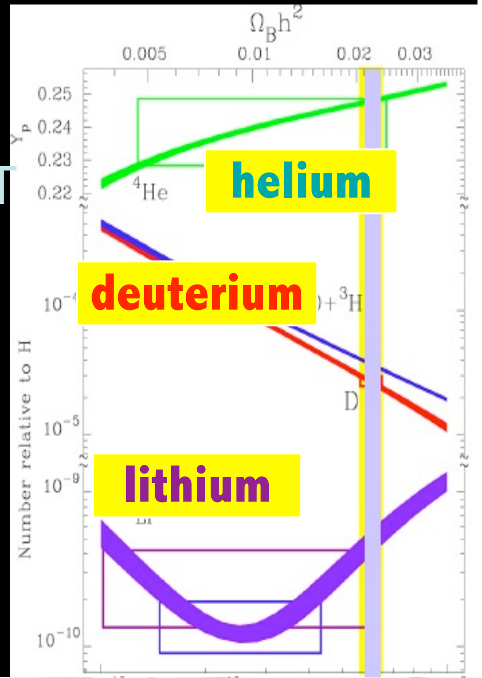
AS the cerebral discussions on the composition of the universe continue among the world's academics, Professor J. Silk, from the Departments of Astronomy and Physics at the University of California arrives at the ANU to deliver a recitation on Baryonic Dark Matter, summarised in an advance notice thus: "At least 90 per cent of the mass of the university is in the form of non-luminous matter." Rumours that a class defamation action is pending are as yet unsubstan-

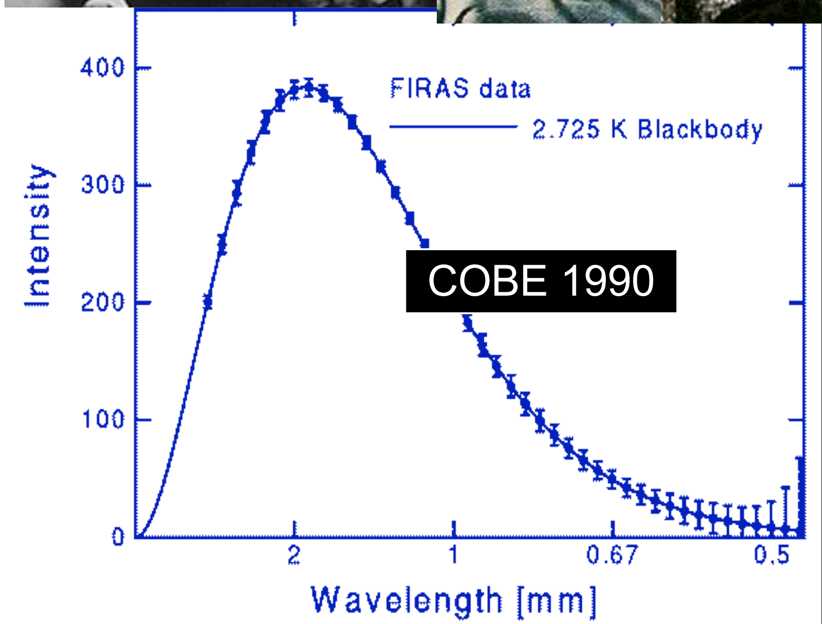
THE MATTER BUDGET

Ω_b=0.03

Ω_*=0.005

Ω_{dm}=0.2





90% OF THE DARK MATTER IS NONBARYONIC

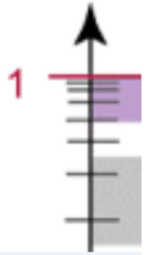
Dark matter: neutrinos

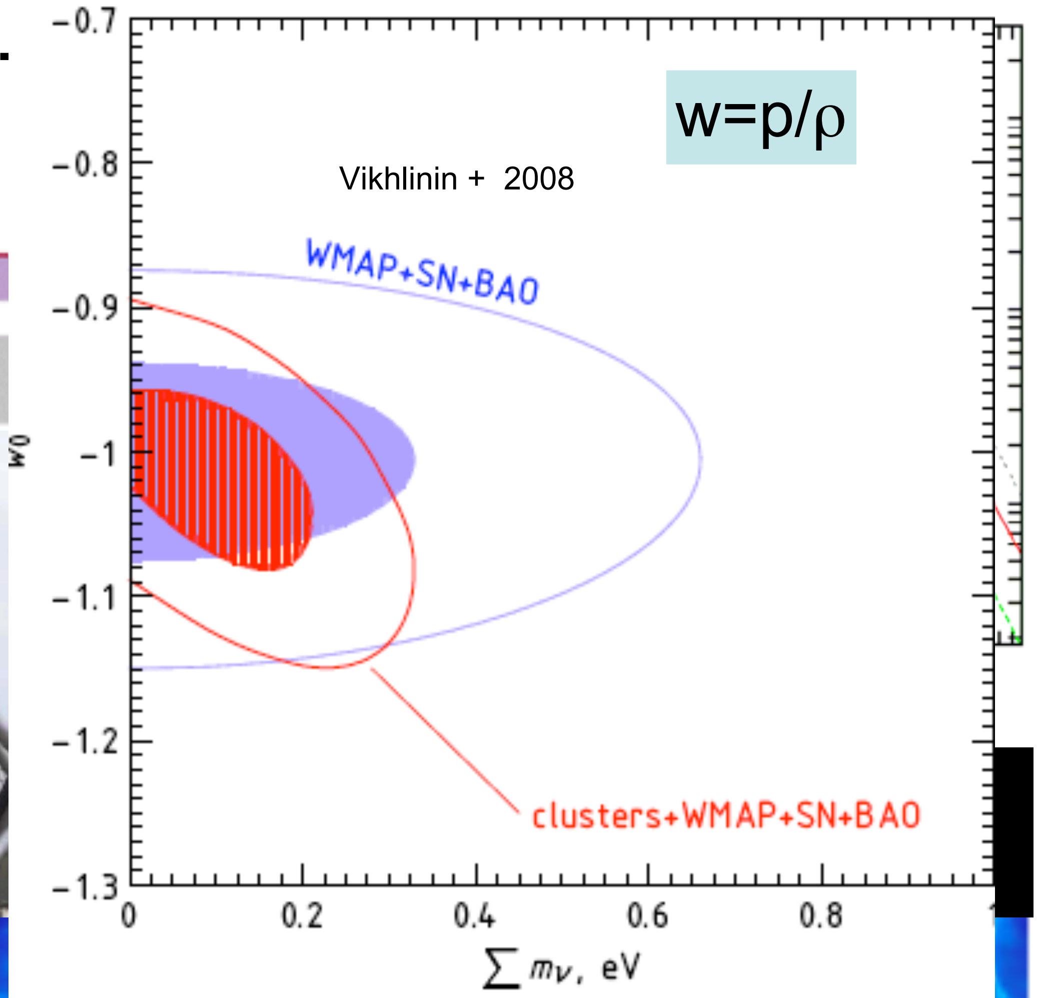
NEUTRINO DARK MAT

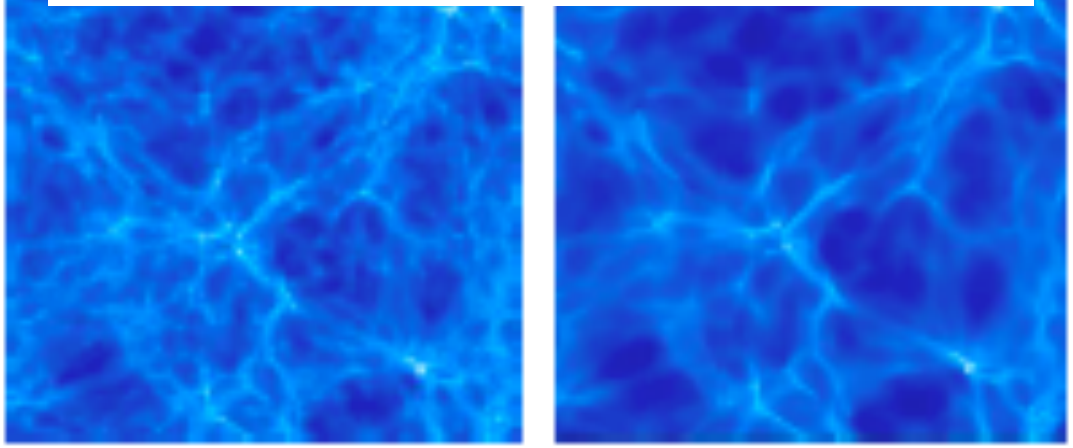
primordial neutrinos as hot dark matter

$\Omega_\nu h^2 = \Sigma m_\nu / 92$ eV

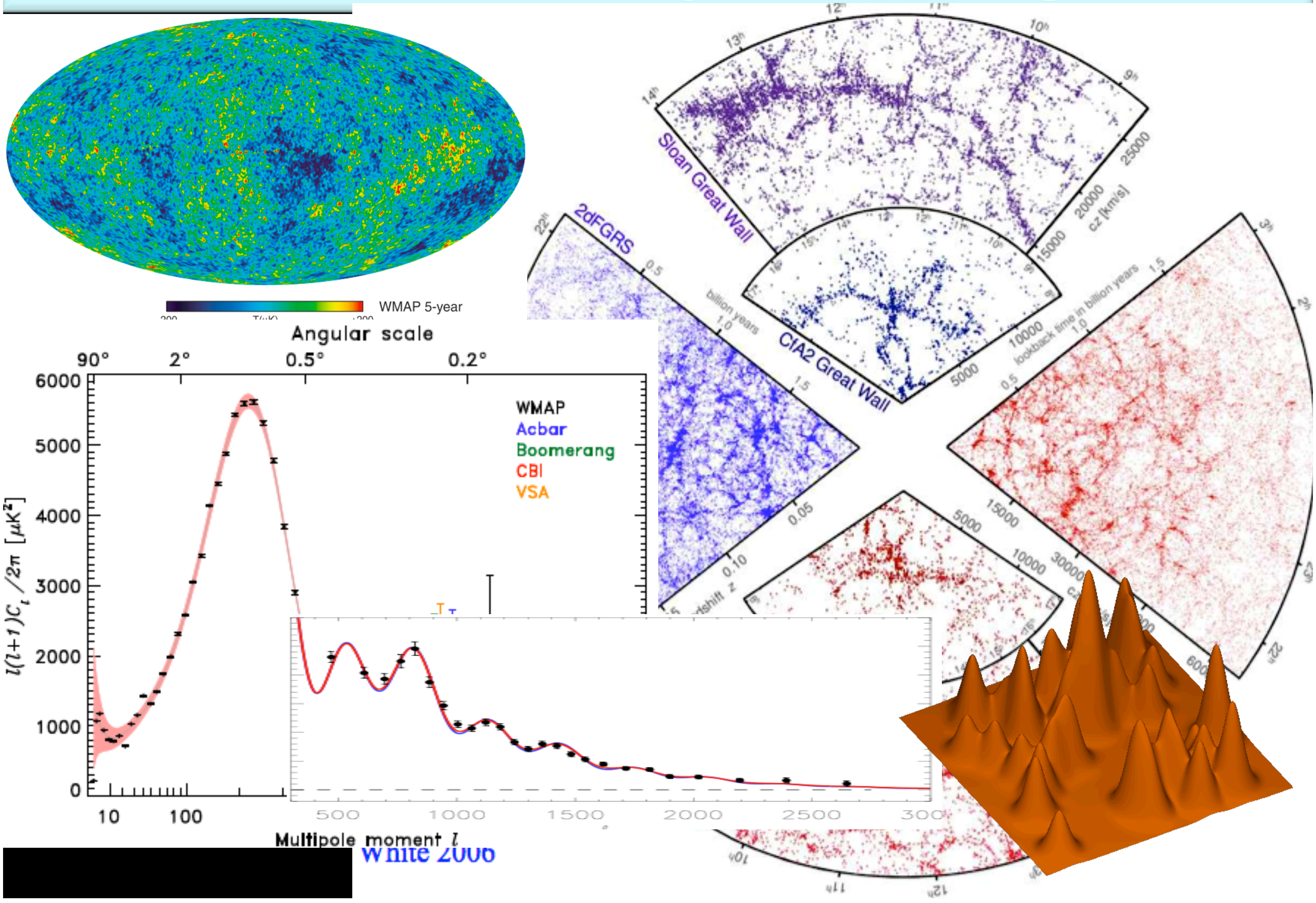
Hubble parameter h= 0.65 (65 km/s/Mpc)



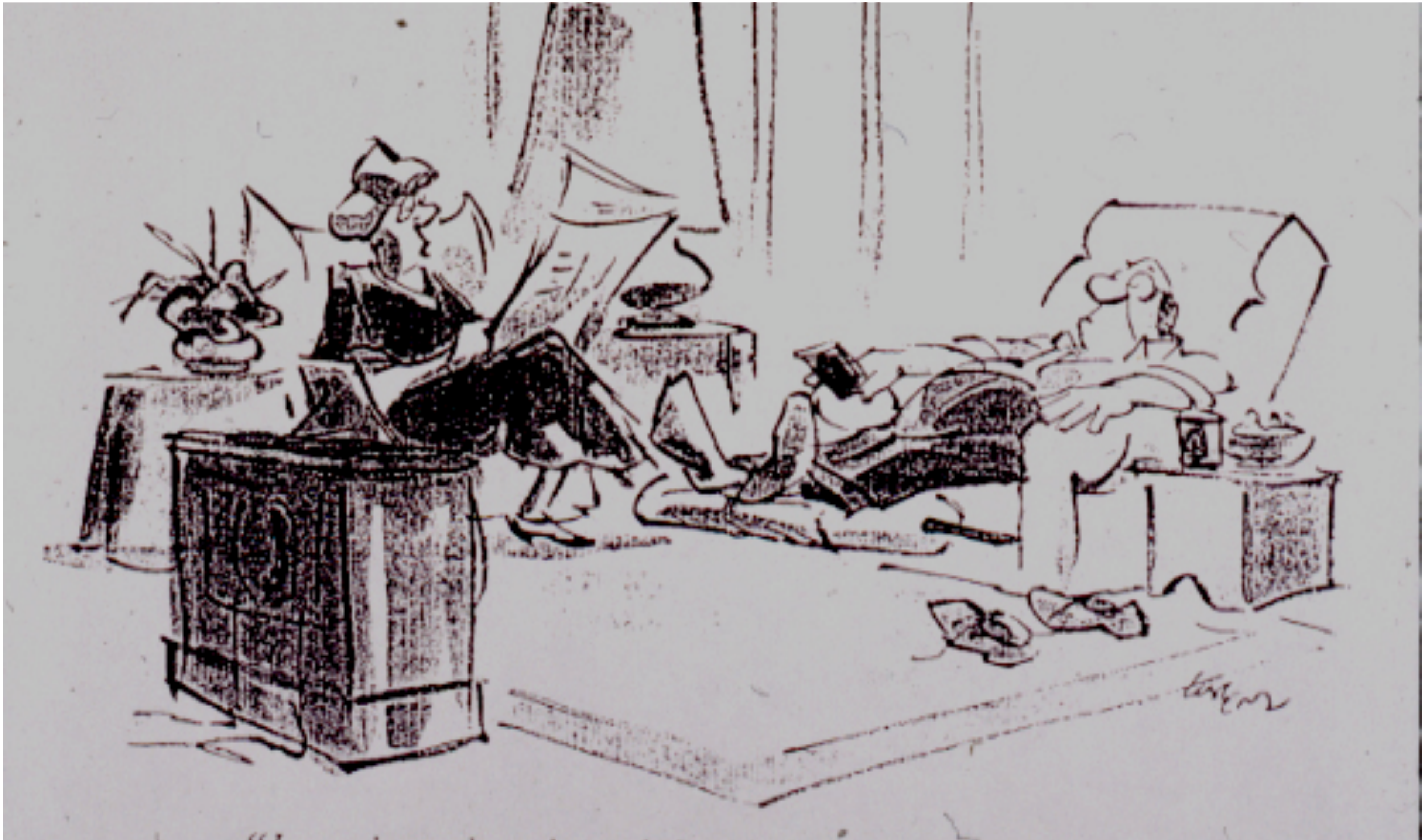




Dark Matter is weakly interacting & cold



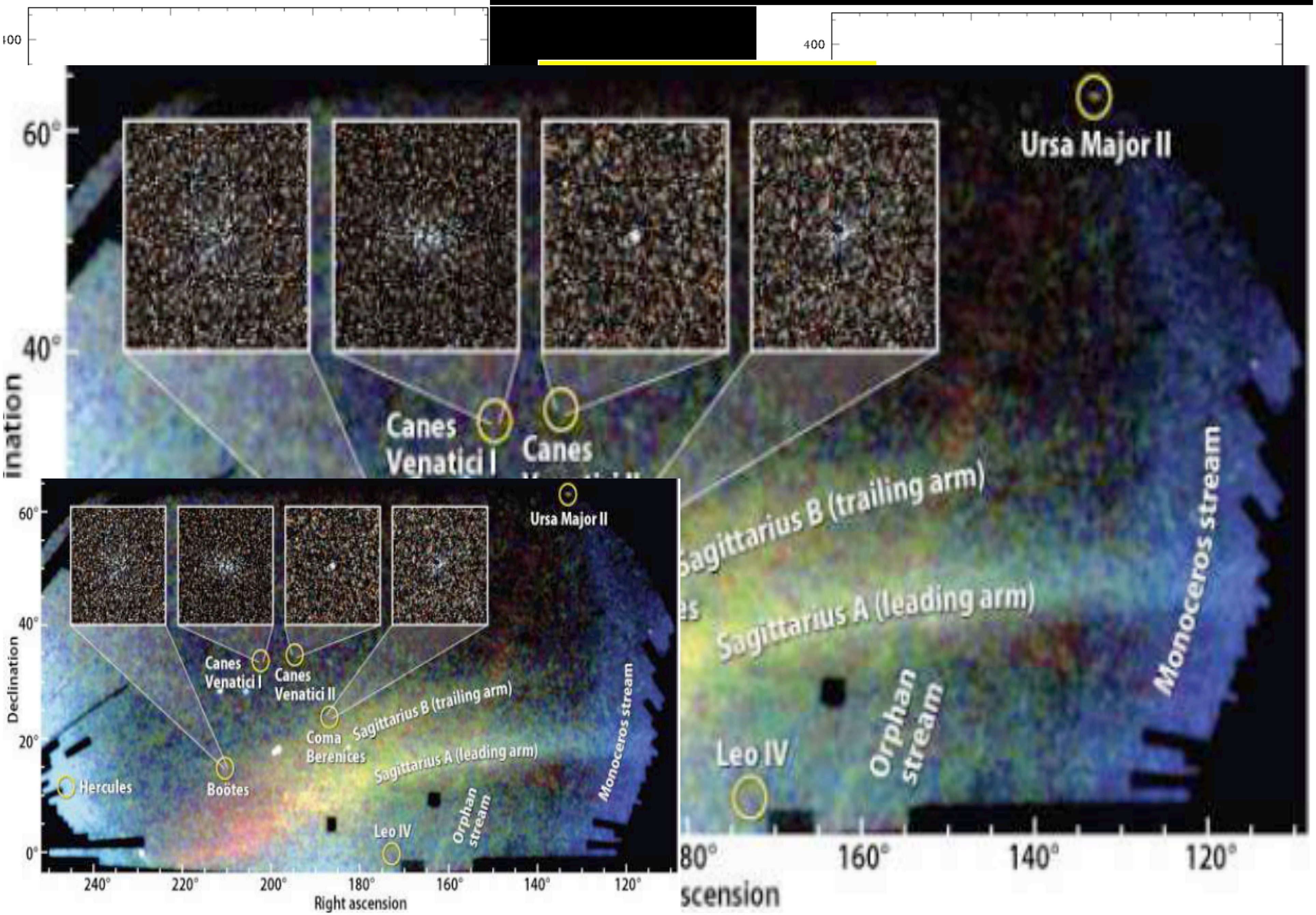
[redacted]



I see here that the universe is thought to be full of dense cold clumps

Via lactea 2

astrophysical feedback needed



Dark matter: neutralinos

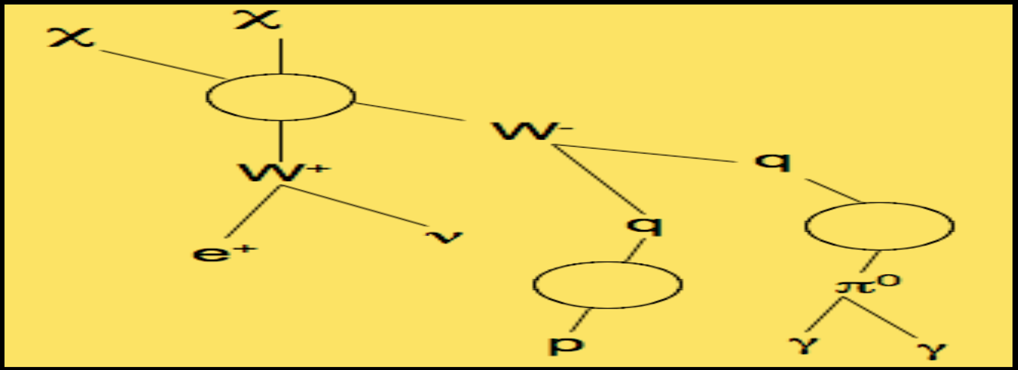
NEUTRALINO DARK MATTER

Favoured SUSY candidate: Weakly Interacting Massive Particle or WIMP

Relic abundance obtained if $<\sigma v> \sim 3 \times 10^{-26}$ cm^3/s $\sim 1/\Omega_x$

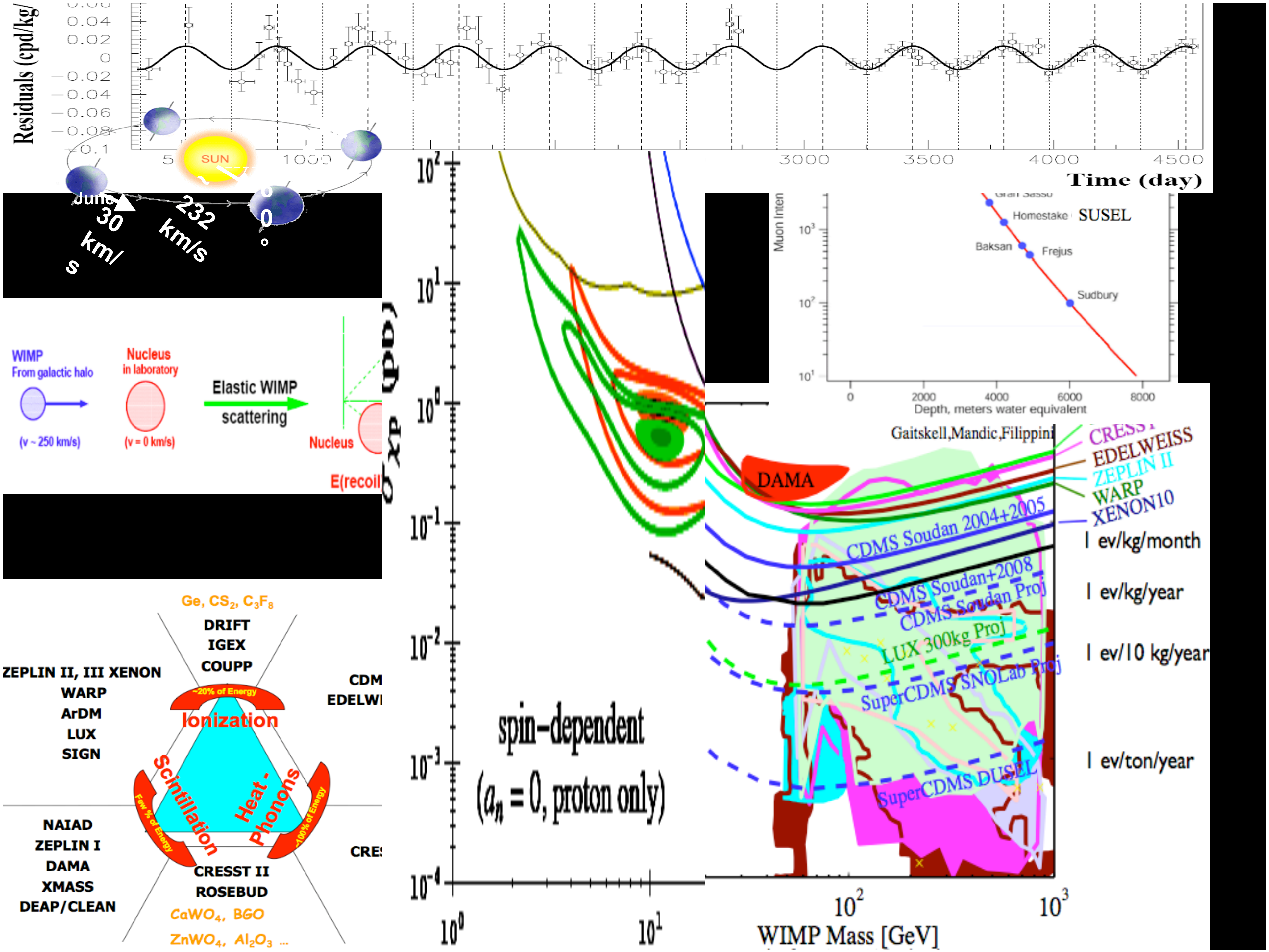
for lightest stable relic: 100-1000 proton masses

DETECTION IN SPACE OR DEEP UNDERGROUND OFFERS STRATEGY TO PROBE MASS RANGE THAT COMPLEMENTS ANY FUTURE COLLIDERS



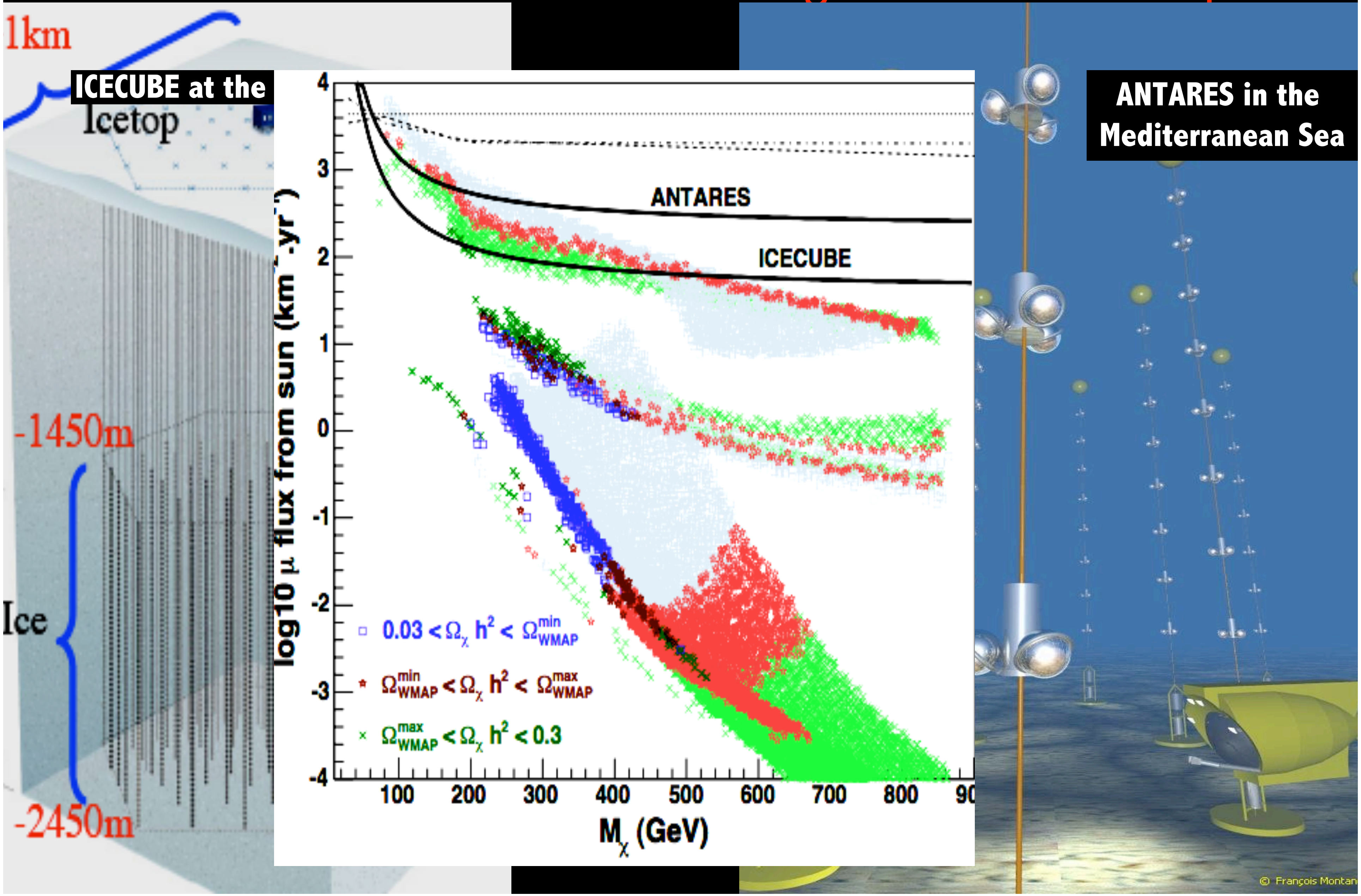
$\sim 10^{39}$ GeV/s in total annihilation power in energetic gamma rays, e+ , pbar , ν

Direct detection


Residuals (cpd/kg/
Time (day)
SUN
June
30 km/s
232 km/s
WIMP
From galactic halo
(v ~ 250 km/s)
Nucleus
in laboratory
(v = 0 km/s)
Elastic WIMP scattering
Nucleus
E(recoil
Ge, CS2, C3F8
DRIFT
IGEX
COUPP
ZEPLIN II, III XENON
WARP
ArDM
LUX
SIGN
CDM
EDELW
~20% of Energy
Ionization
Scintillation
Few % of Energy
Heat - Phonons
~100% of Energy
NAIAD
ZEPLIN I
DAMA
XMASS
DEAP/CLEAN
CRESST II
ROSEBUD
CRE
CaWO4, BGO
ZnWO4, Al2O3 ...
spin–dependent
(a_n = 0, proton only)
Muon Inten
Gran Sasso
Homestake
SUSEL
Baksan
Frejus
Sudbury
Depth, meters water equivalent
Gaitskell,Mandic,Filippini
DAMA
CRESST
EDELWEISS
ZEPLIN II
WARP
XENON10
CDMS Soudan 2004+2005
CDMS Soudan+2008
CDMS Soudan Proj
LUX 300kg Proj
SuperCDMS SNOLab Proj
SuperCDMS DUSEL
1 ev/kg/month
1 ev/kg/year
1 ev/10 kg/year
1 ev/ton/year
WIMP Mass [GeV]

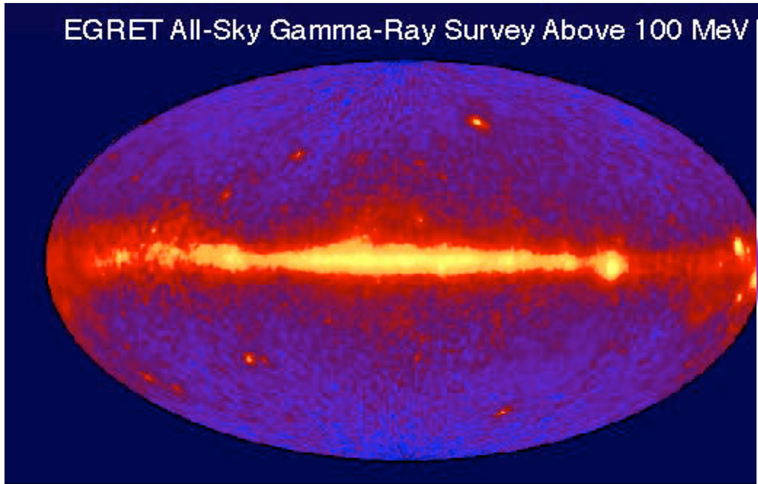
Indirect detection: ν

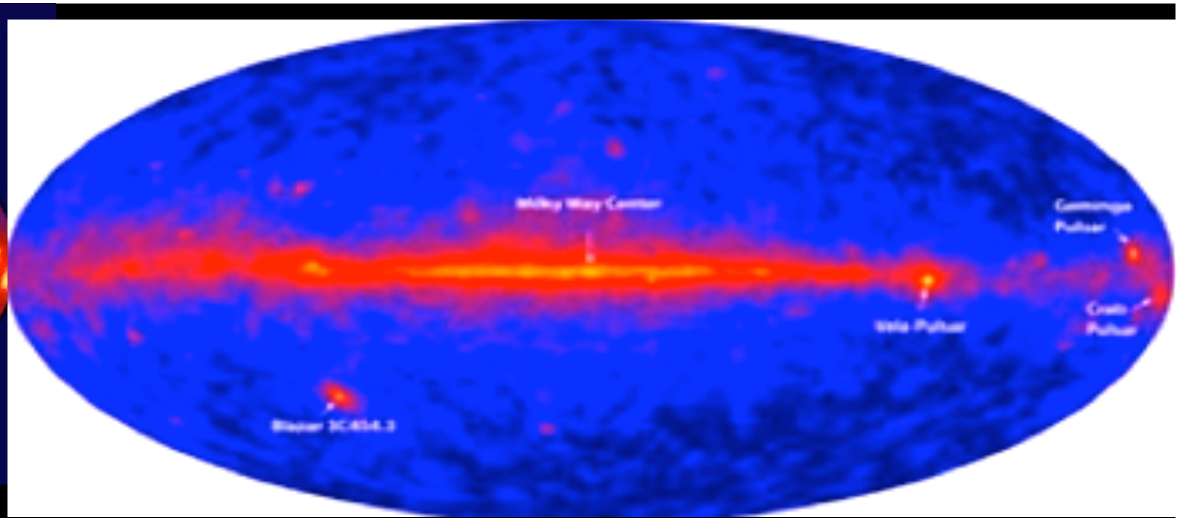
high energy neutrinos from WIMPs annihilating in the sun observable with downward-looking neutrino telescopes



Indirect detection: γ

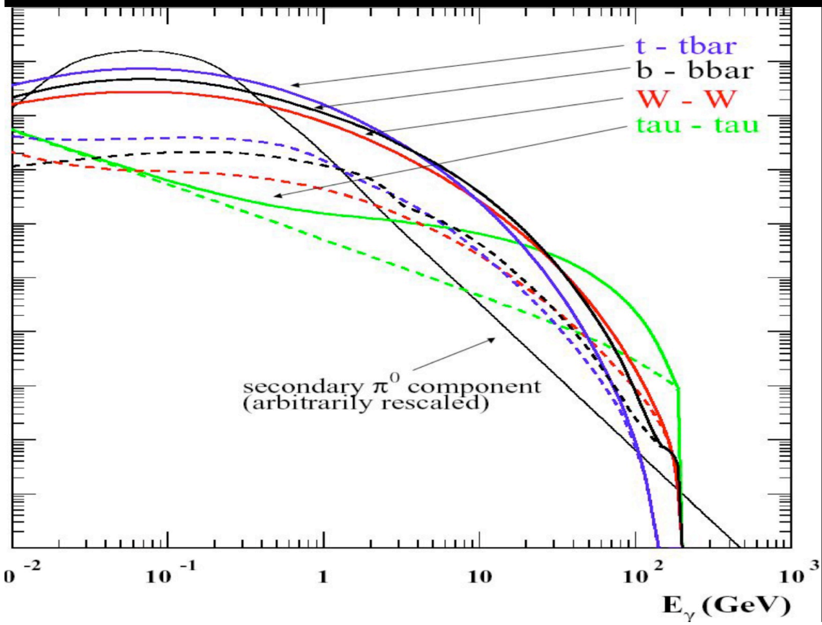
annihilation gamma-Rays from the inner Galaxy

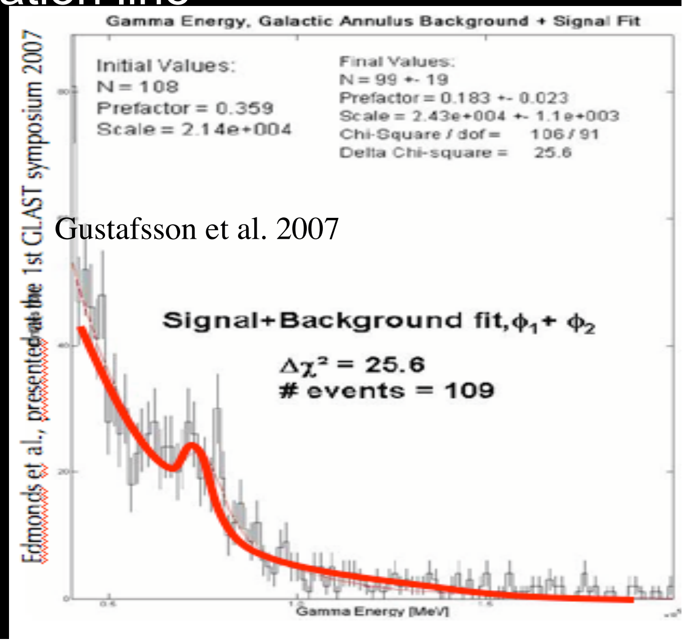




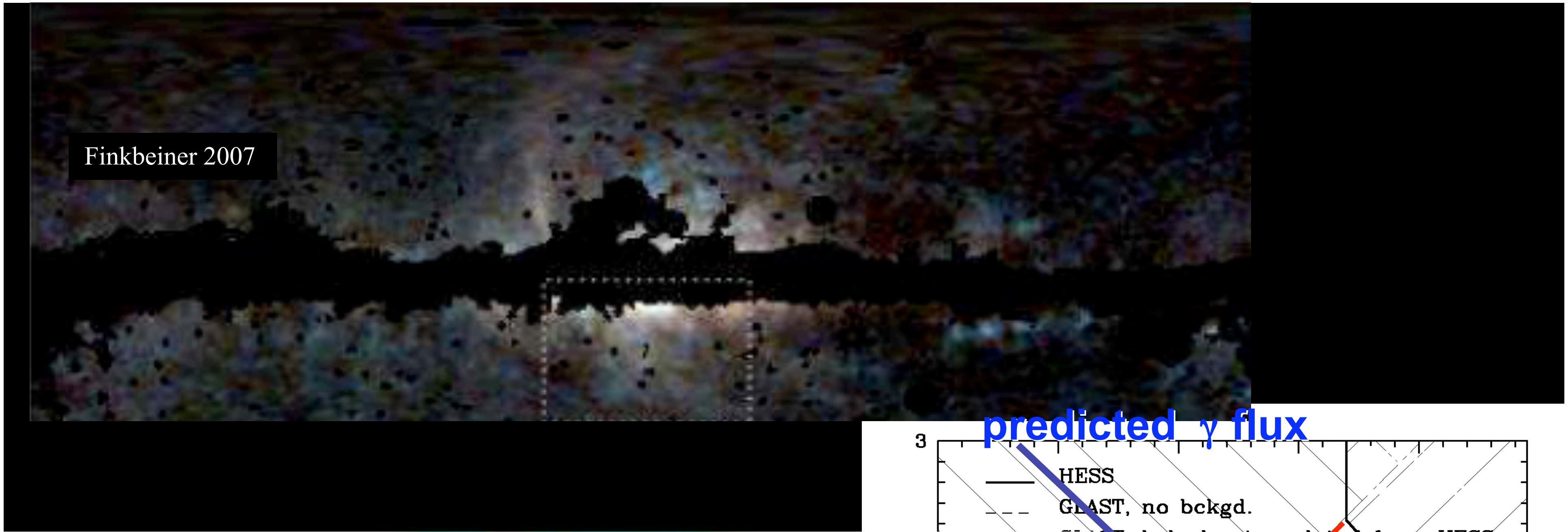
FERMI (2009): 0.02 - 300 GeV, 5^o - 5', $\Delta E/E \sim 0.1$

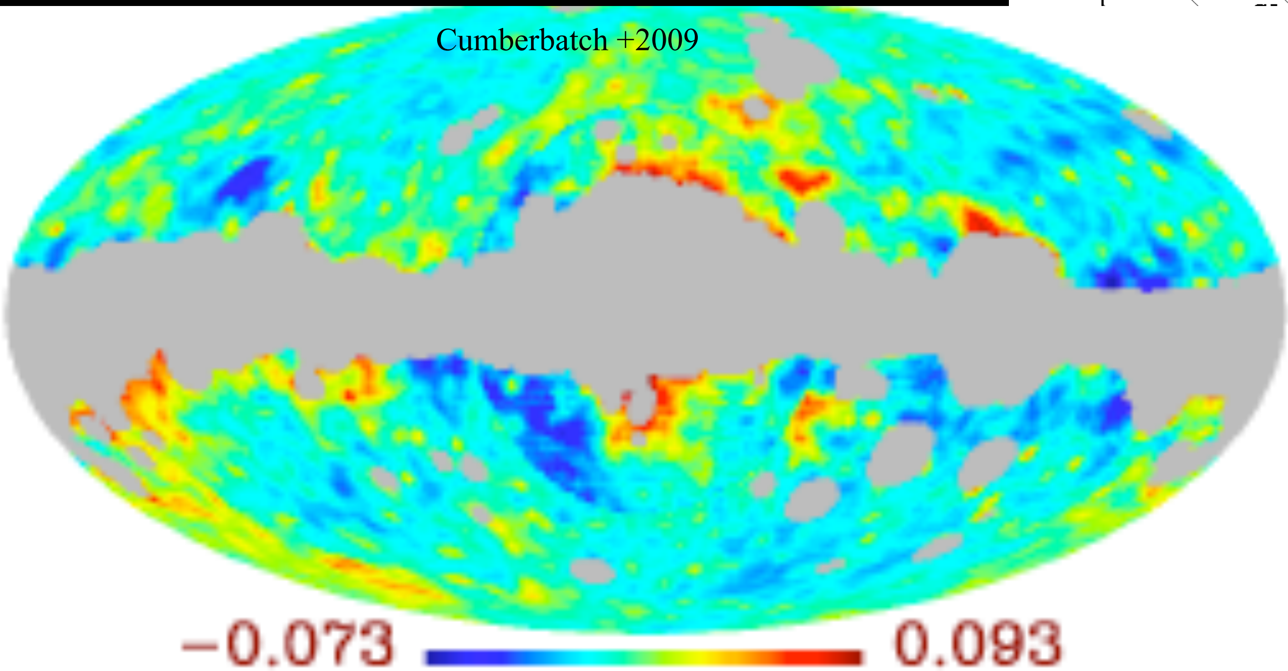
predict γ ray "smoking guns": hard spectrum annihilation line

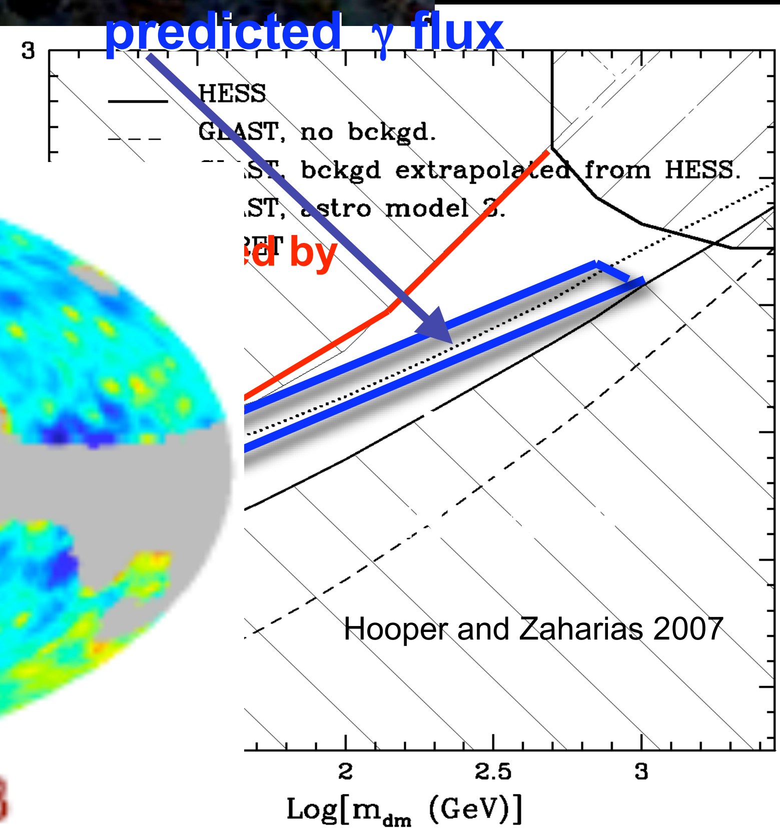




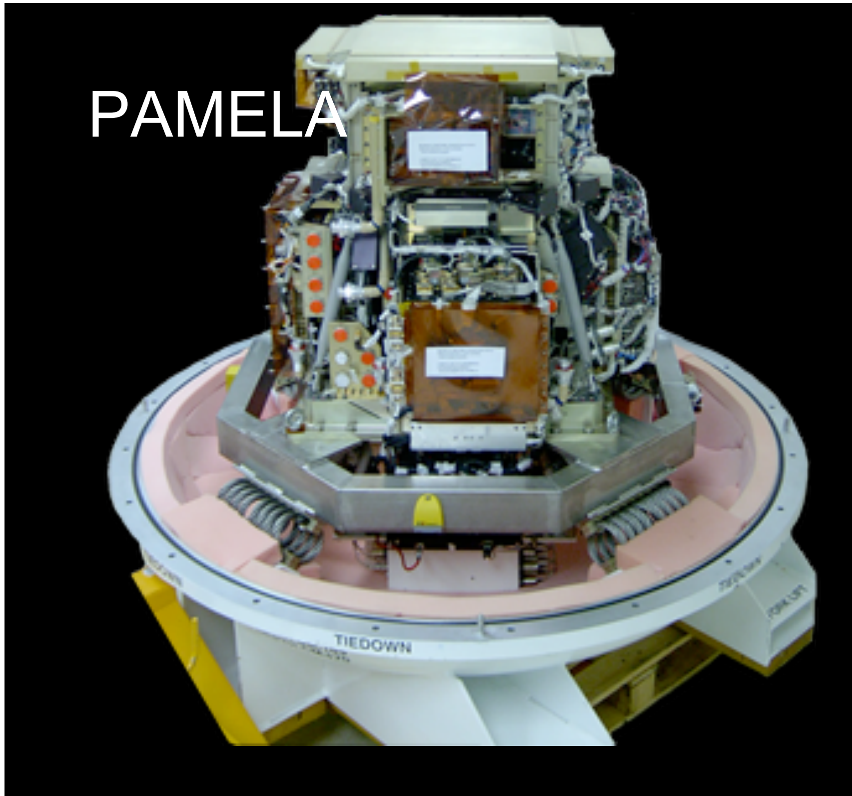
The WMAP microwave haze

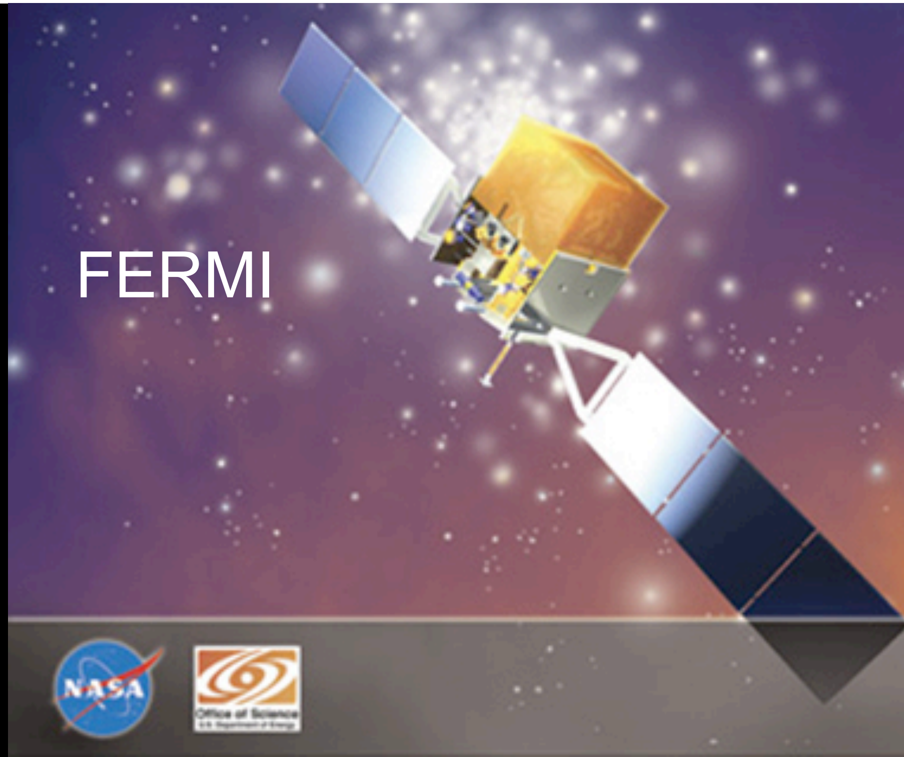






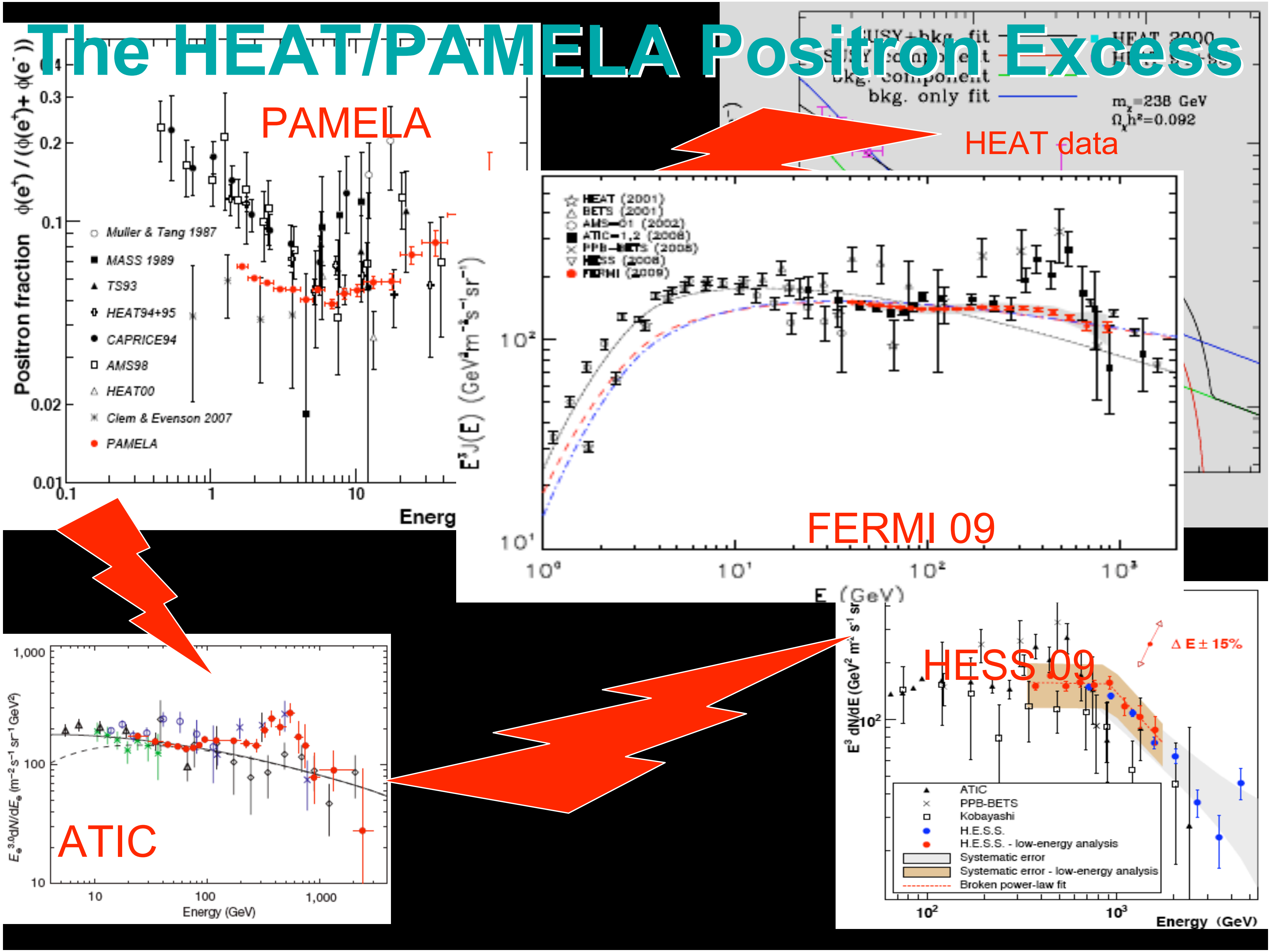
Indirect detection: e^+

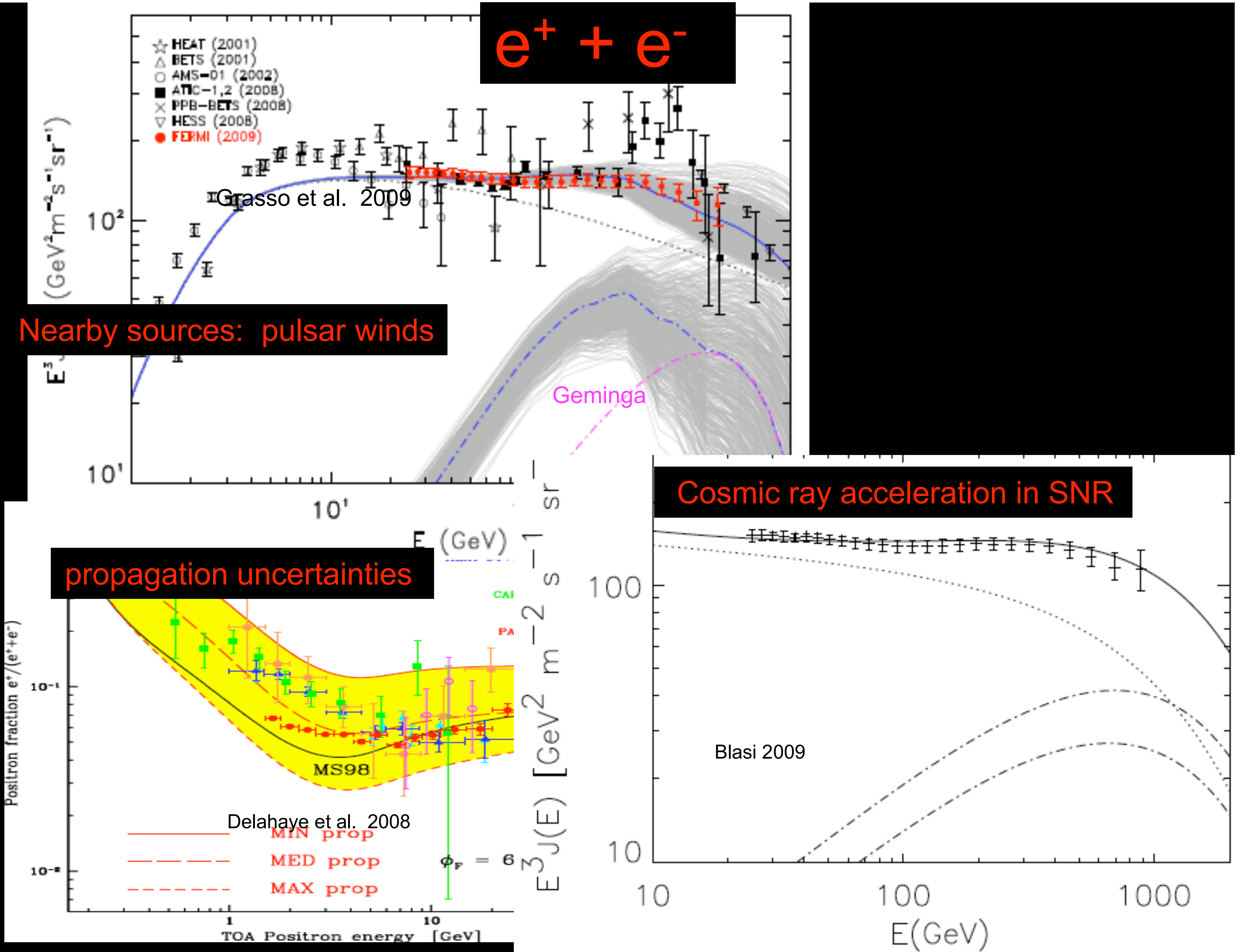

PAMELA
TIEDOWN


FERMI

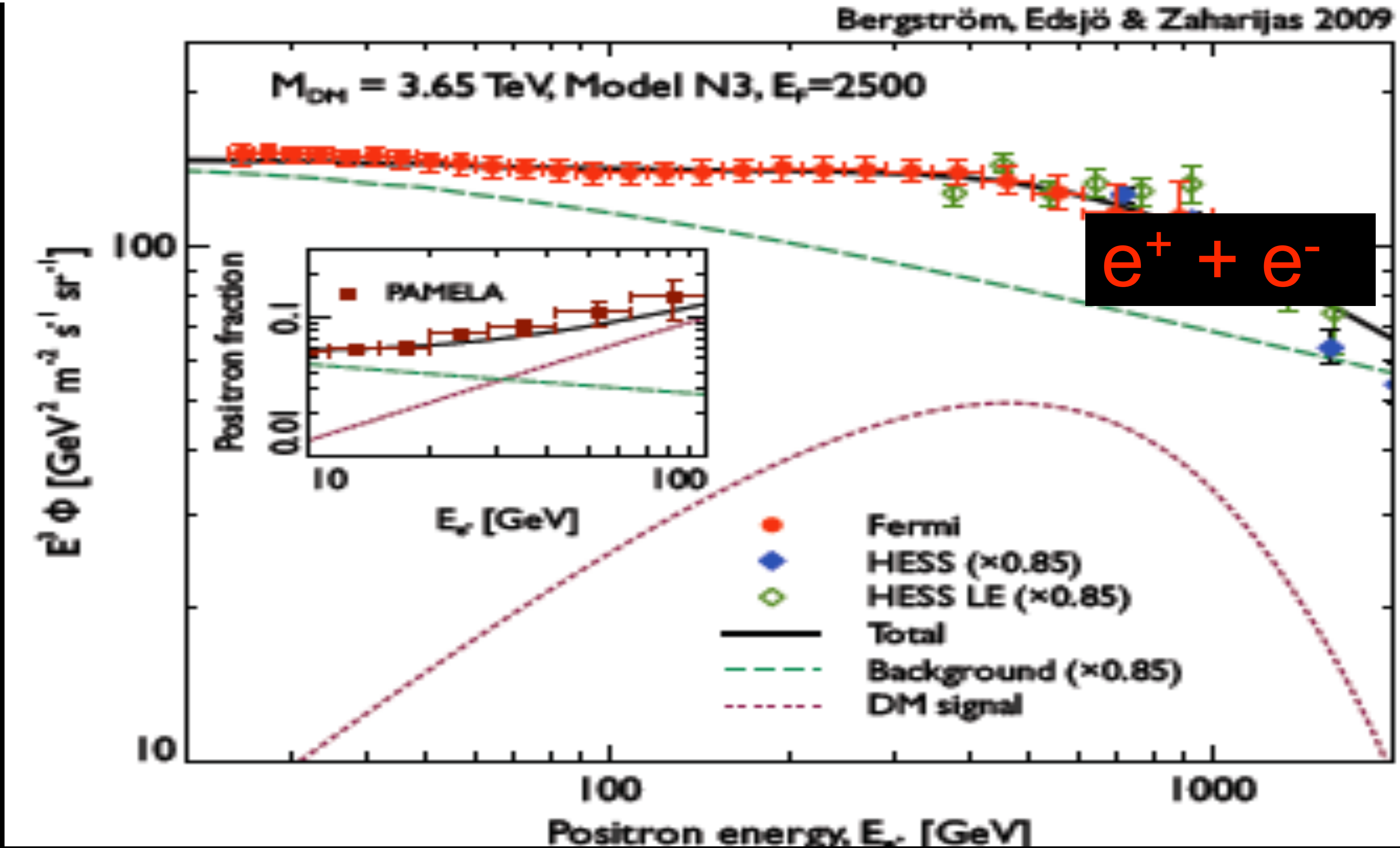

HESS

The HEAT/PAMELA Positron Excess





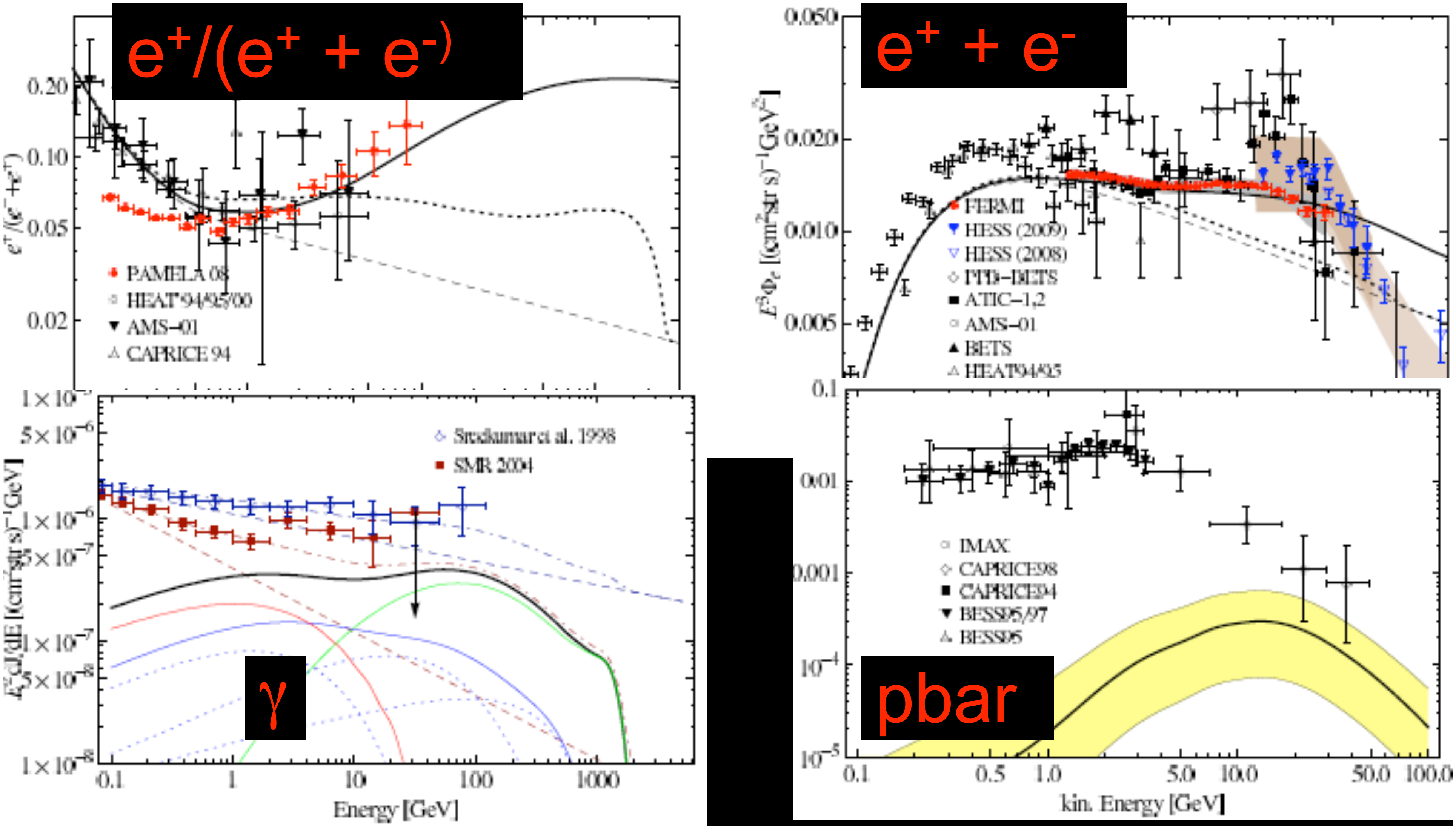
ASTROPHYSICS SOLUTIONS



massive neutralino requires large boost **since flux ~ ρ/m_x^2**

PARTICLE PHYSICS SOLUTION
with annihilating dark matter

Sommerfeld effect provides boost



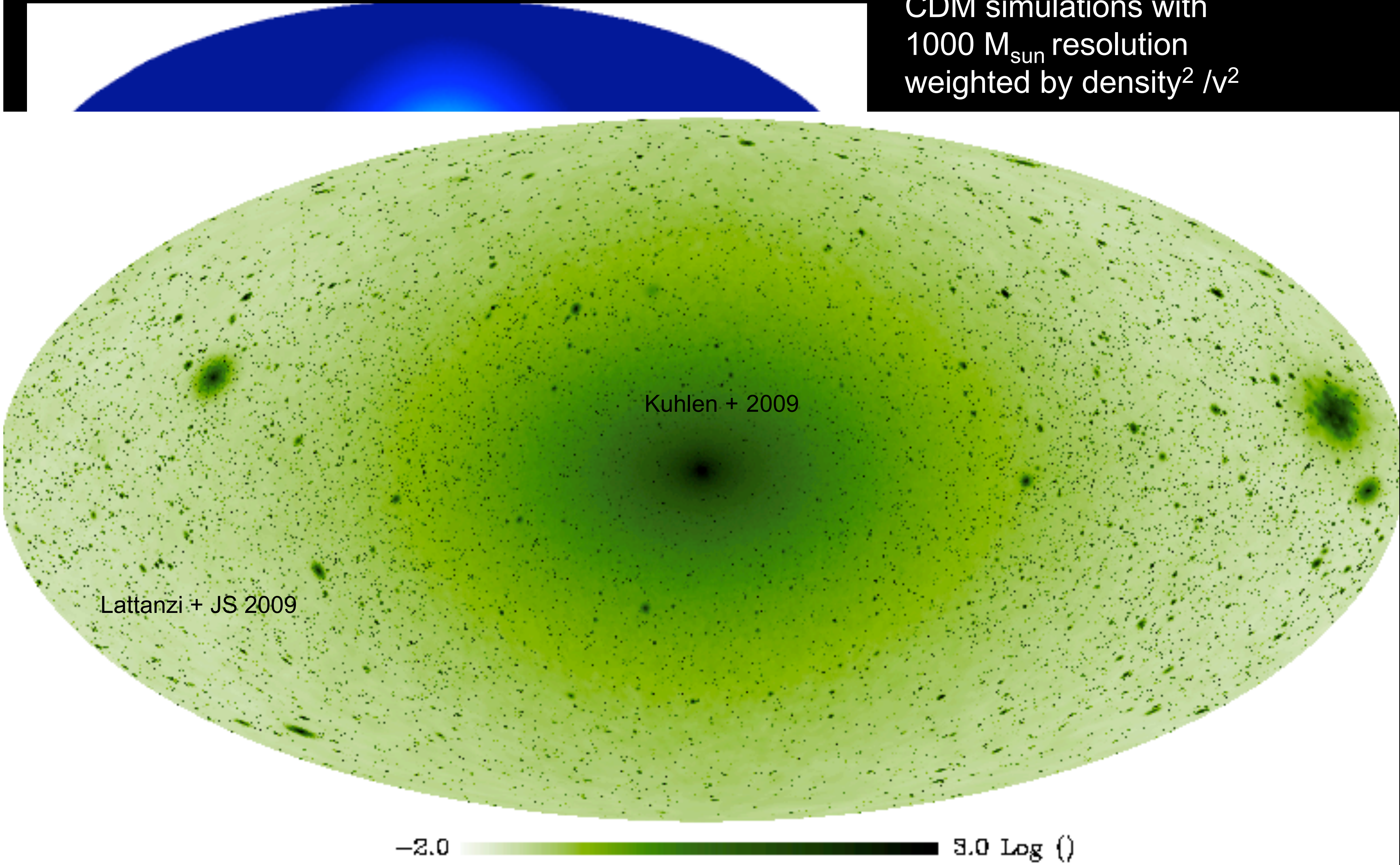
massive neutralino requires decay time ~ 10^{26} sec

PARTICLE PHYSICS SOLUTION with decaying dark matter

Ibarra + 2009

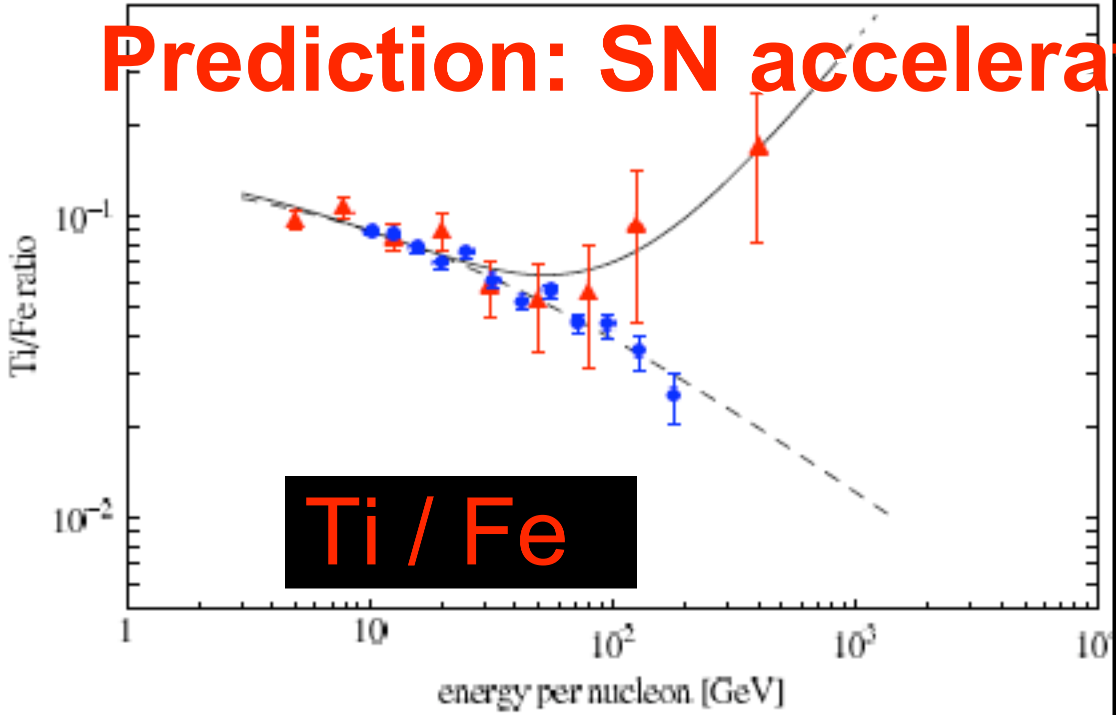
Prediction: dwarfs should be detectable for annihilating dark matter

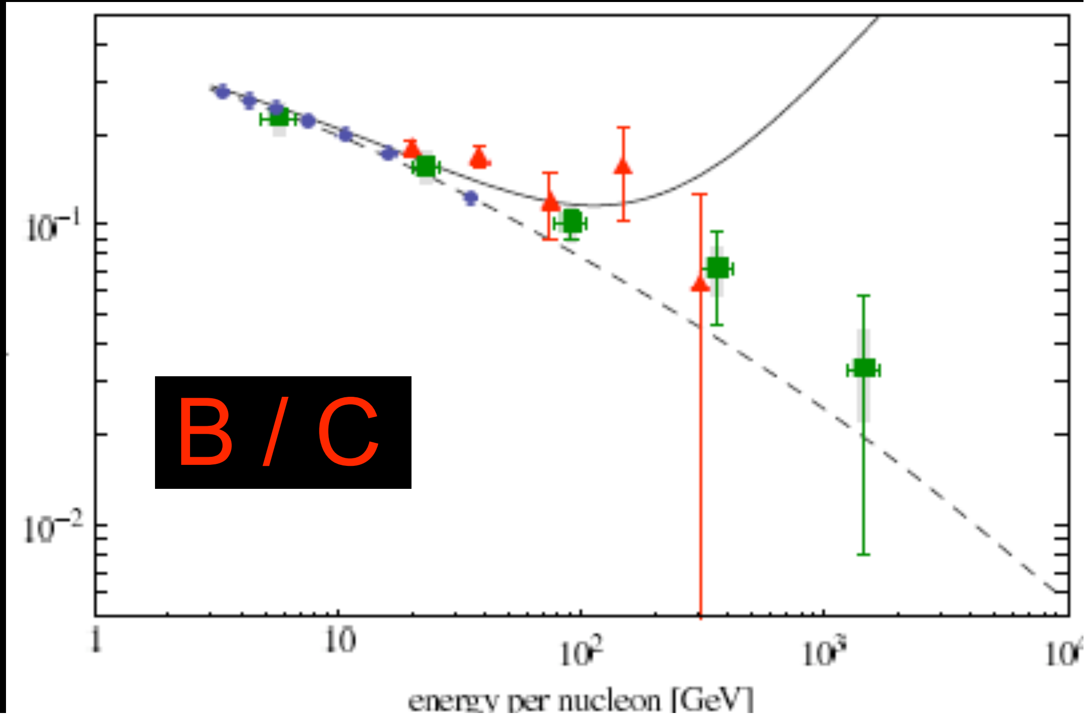
CDM simulations with
1000 M_{sun} resolution
weighted by density^2 /v^2



Prediction: SN acceleration & spallation

Mertsch &Sarkar 2009

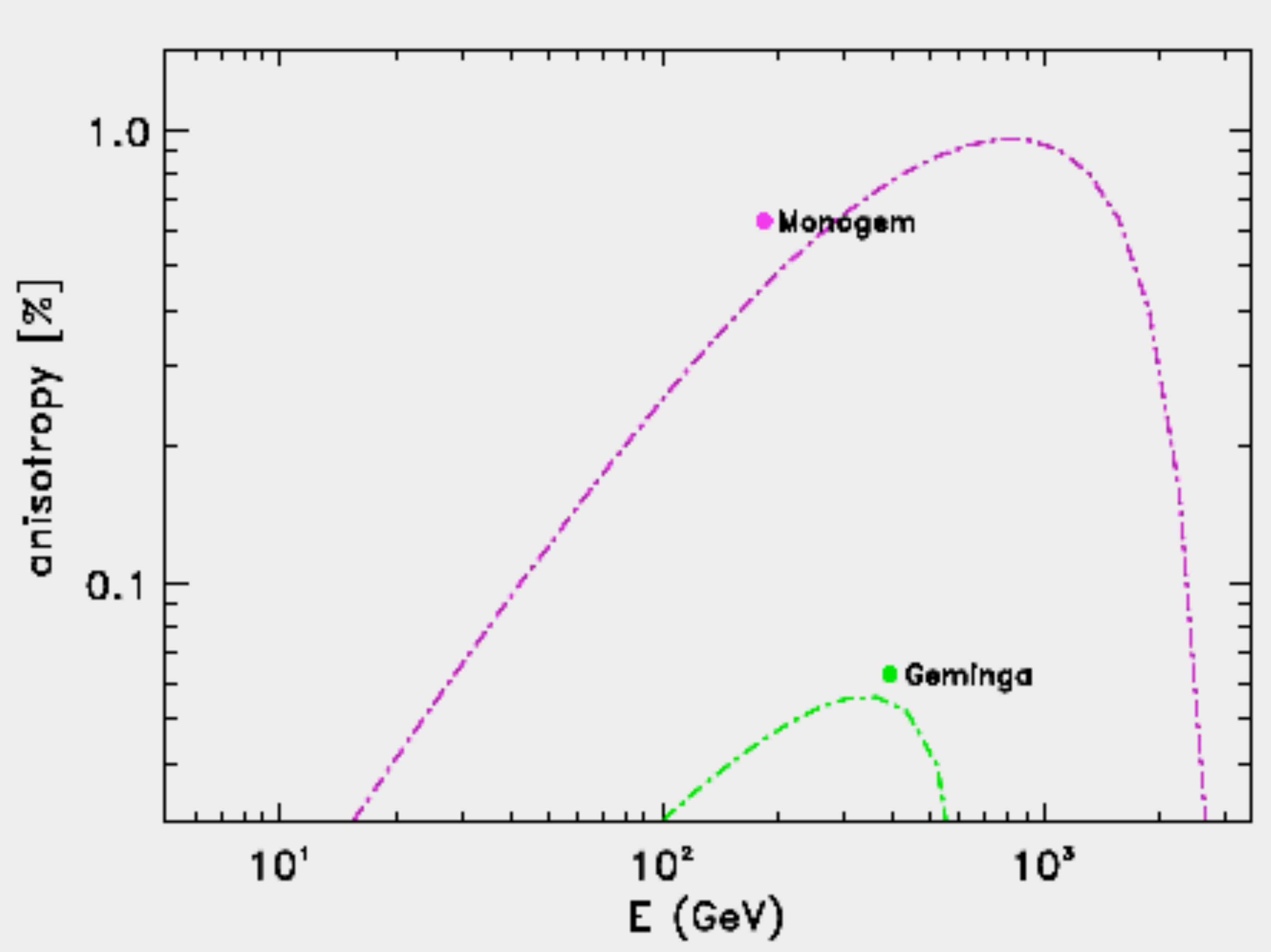




Prediction: anisotropy

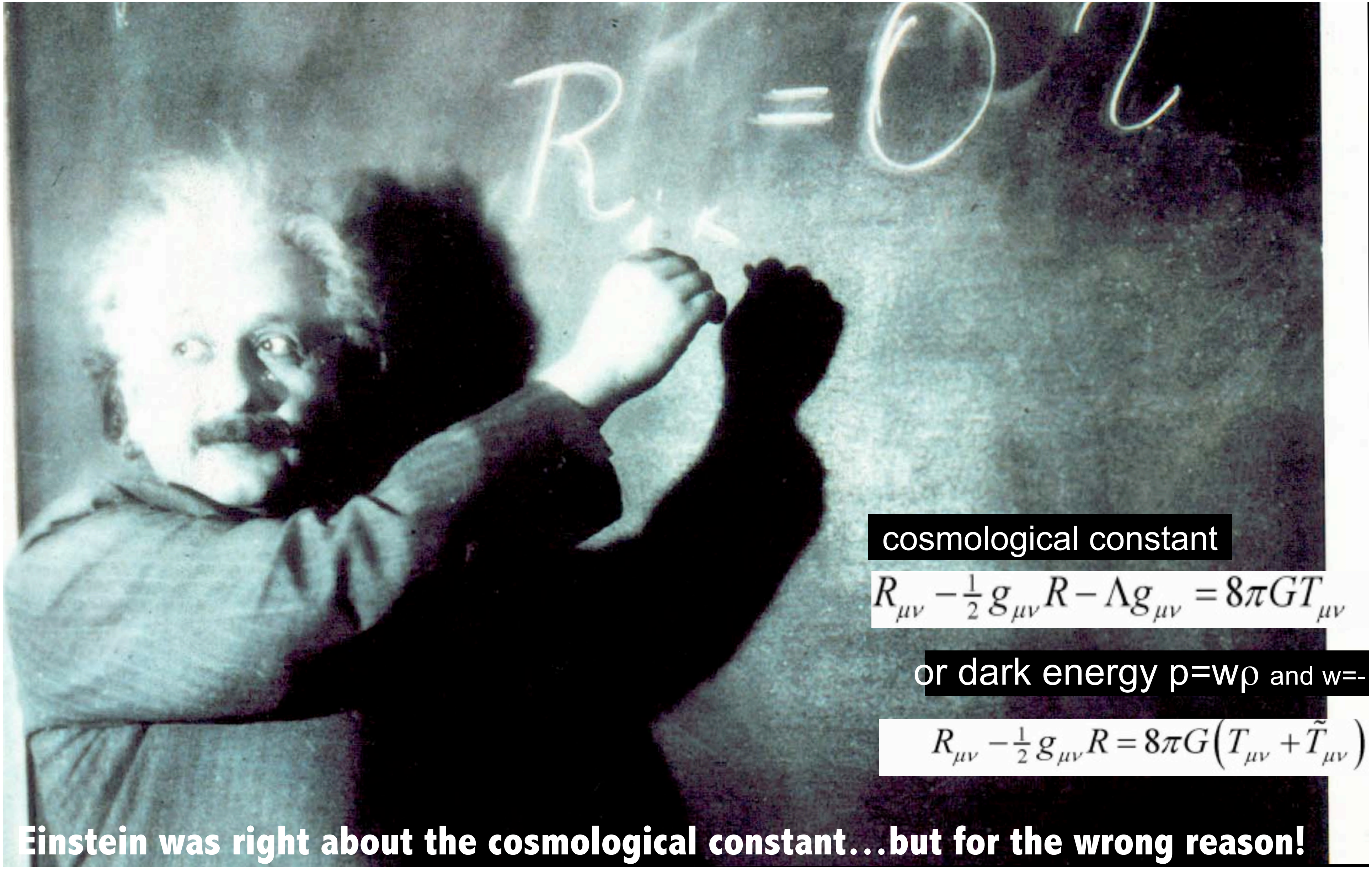
Grasso et al. 2009

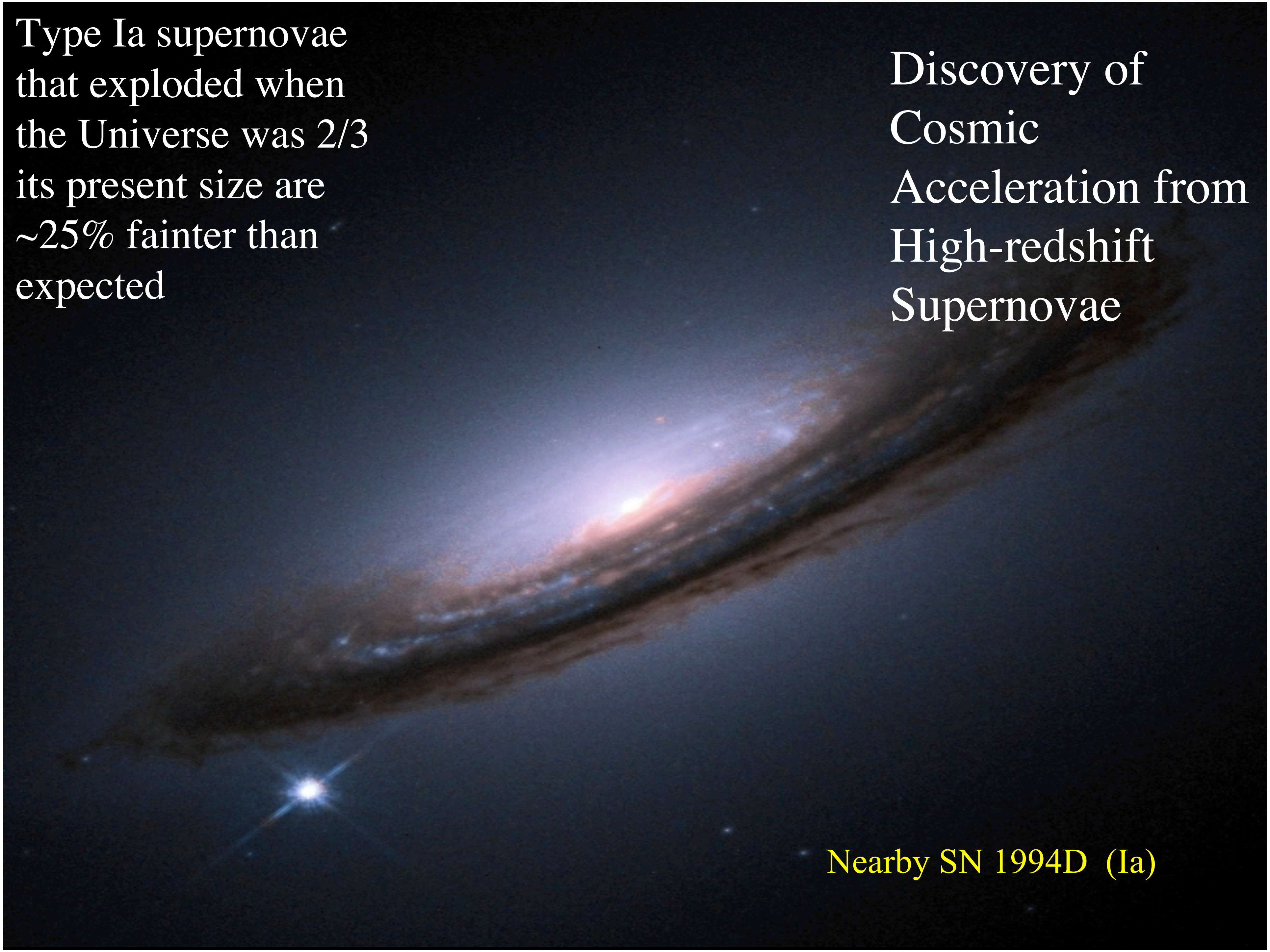
e^+ from nearby pulsars

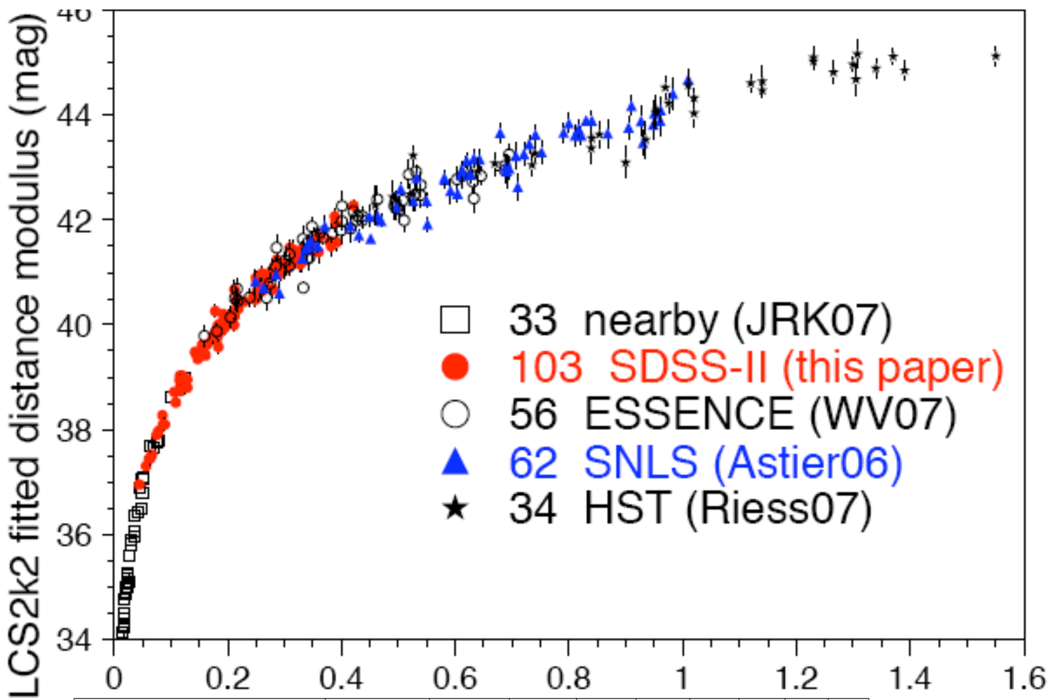


Dark energy

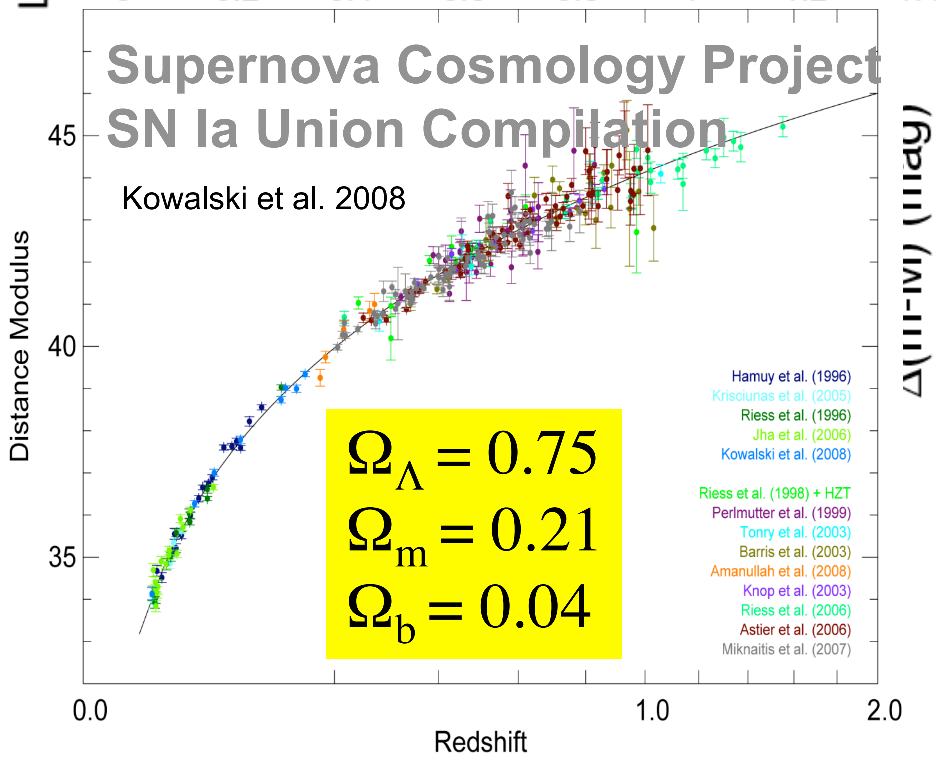
WHERE DARK ENERGY ORIGINATED



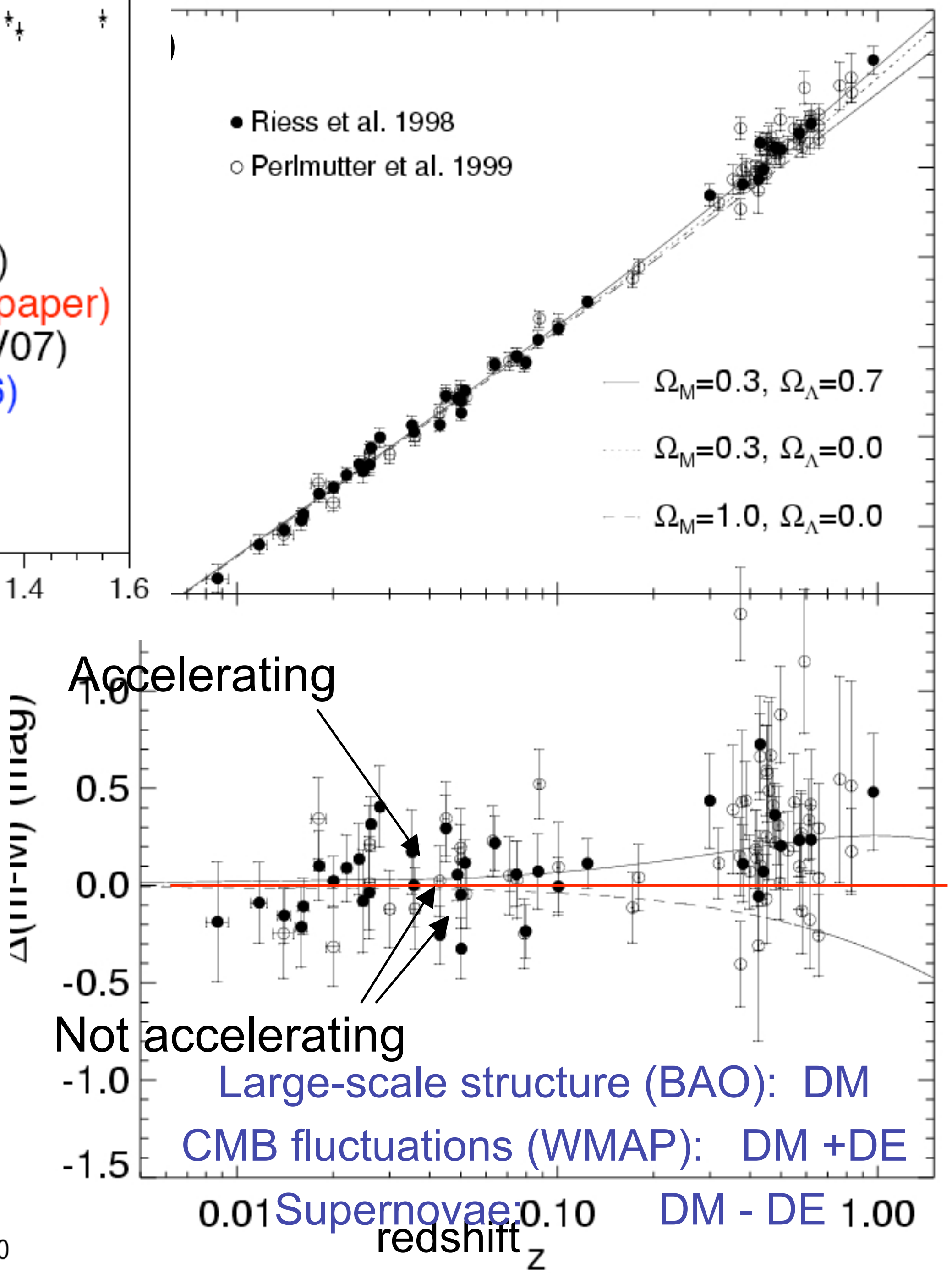

Type Ia supernovae that exploded when the Universe was 2/3 its present size are ~25% fainter than expected
Discovery of Cosmic Acceleration from High-redshift Supernovae
Nearby SN 1994D (Ia)



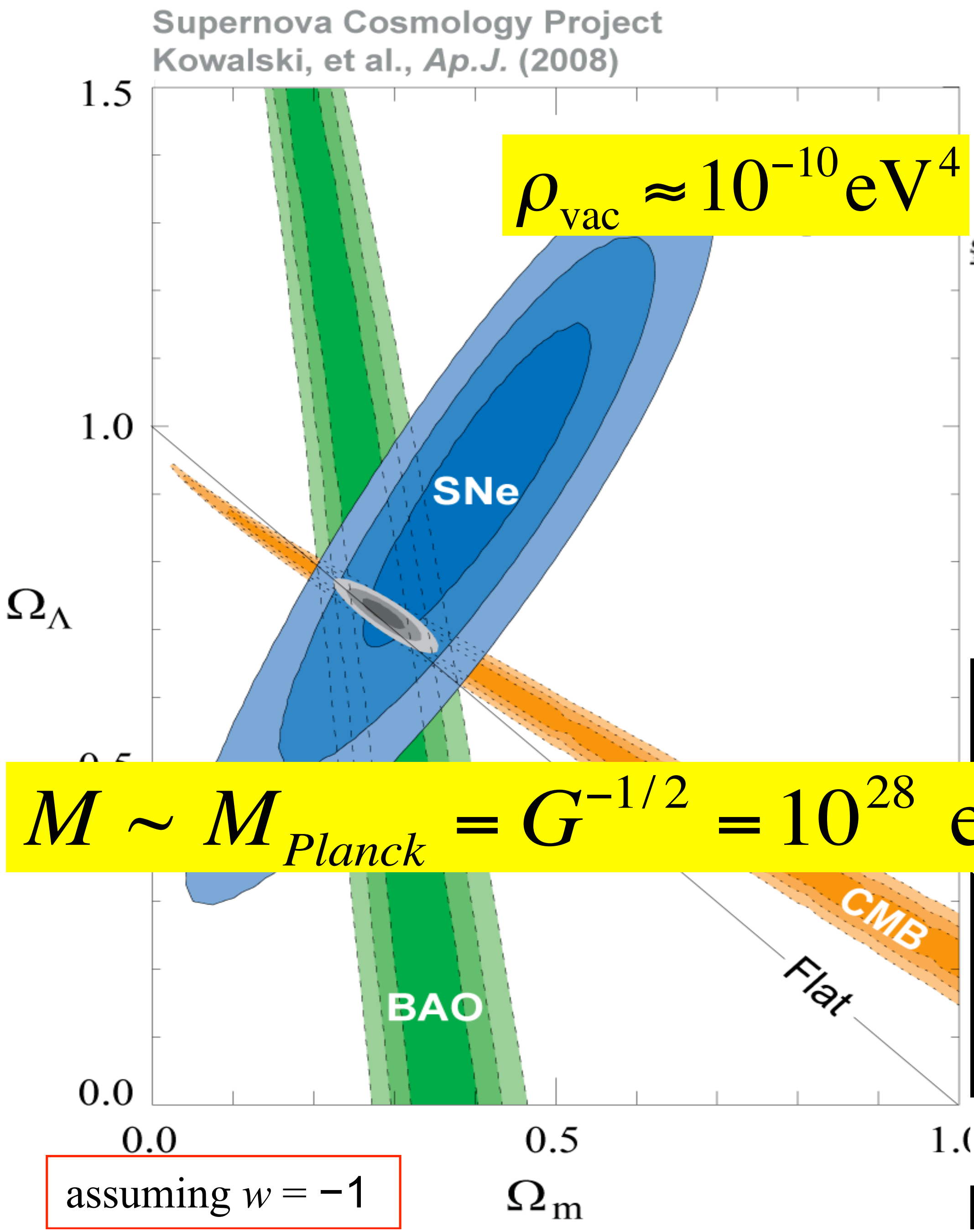
LCS2k2 fitted distance modulus (mag)
33 nearby (JRK07)
103 SDSS-II (this paper)
56 ESSENCE (WV07)
62 SNLS (Astier06)
34 HST (Riess07)



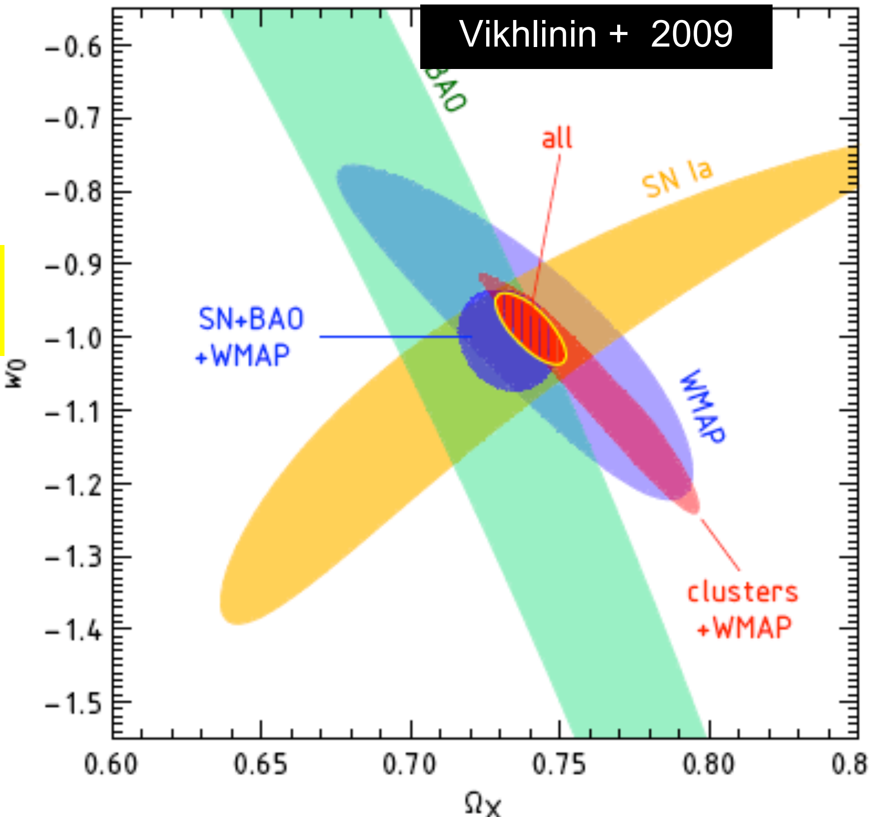
Supernova Cosmology Project
SN Ia Union Compilation
Kowalski et al. 2008
Distance Modulus
Redshift
$\Omega_\Lambda = 0.75$
$\Omega_m = 0.21$
$\Omega_b = 0.04$
Hamuy et al. (1996)
Krisciunas et al. (2005)
Riess et al. (1996)
Jha et al. (2006)
Kowalski et al. (2008)
Riess et al. (1998) + HZT
Perlmutter et al. (1999)
Tonry et al. (2003)
Barris et al. (2003)
Amanullah et al. (2008)
Knop et al. (2003)
Riess et al. (2006)
Astier et al. (2006)
Miknaitis et al. (2007)



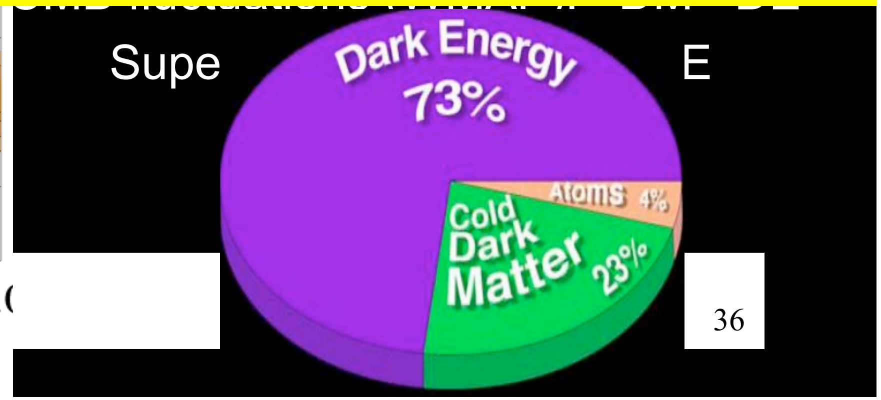
Riess et al. 1998
Perlmutter et al. 1999
Ω_M=0.3, Ω_Λ=0.7
Ω_M=0.3, Ω_Λ=0.0
Ω_M=1.0, Ω_Λ=0.0
Accelerating
Not accelerating
Large-scale structure (BAO): DM
CMB fluctuations (WMAP): DM +DE
Supernovae: DM - DE
redshift z



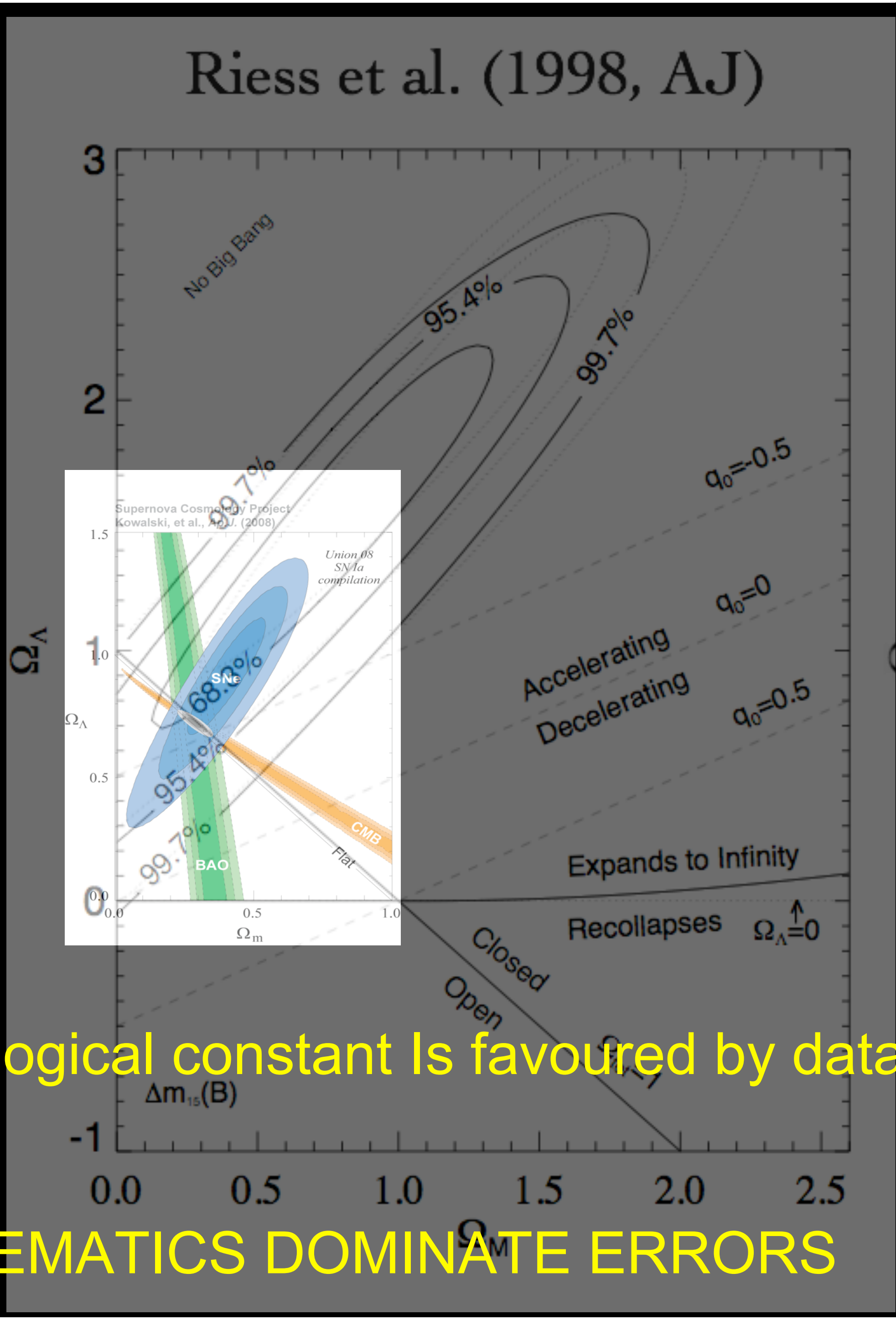
$$\rho_{vac} \approx 10^{-10} \mathrm{eV}^4$$



$$M \sim M_{Planck} = G^{-1/2} = 10^{28} \ \mathrm{eV} \ \Rightarrow \ \rho_{vac} \sim 10^{112} \mathrm{eV}^4$$



assuming $w = -1$

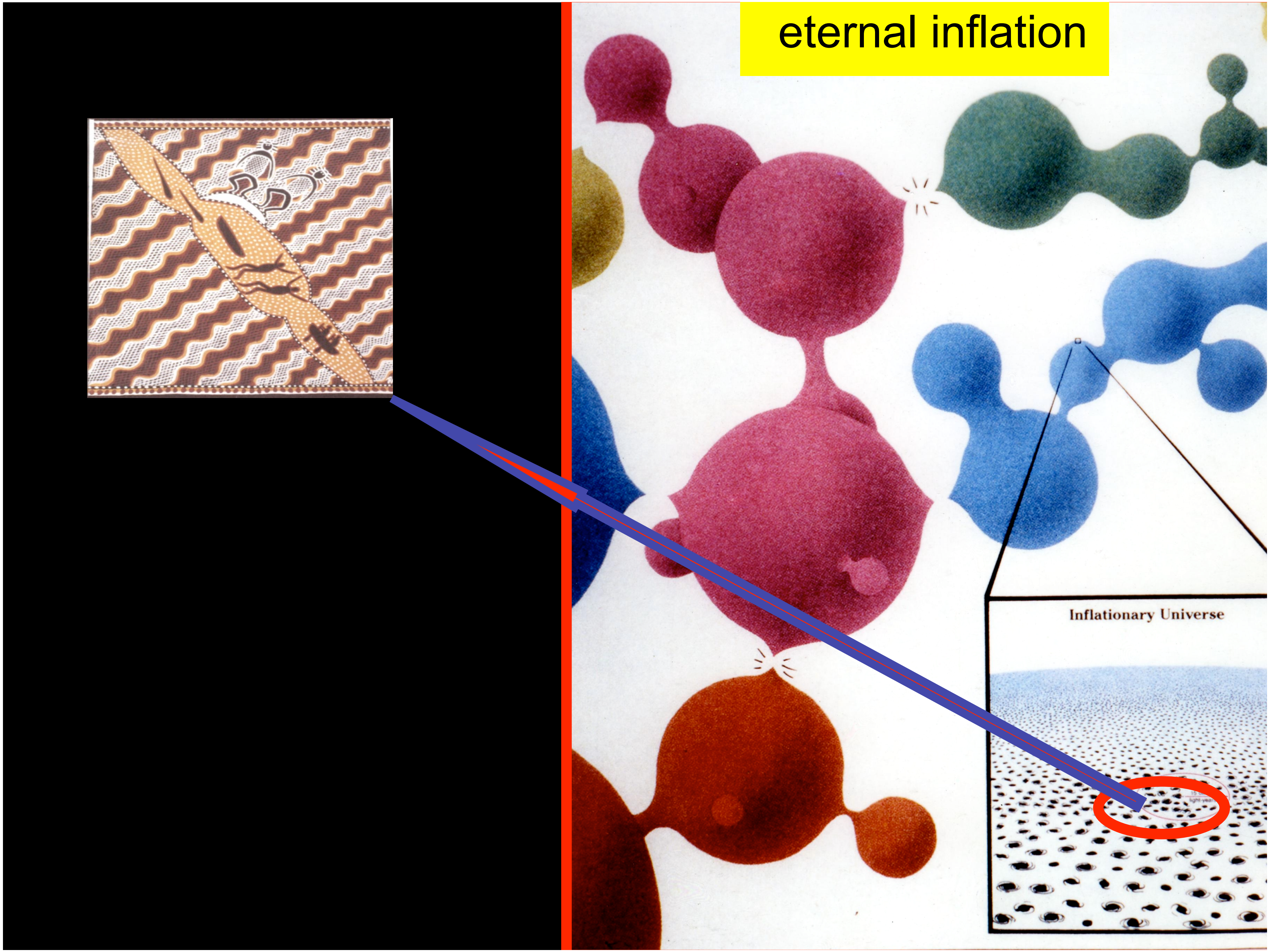


Cosmological constant Is favoured by data

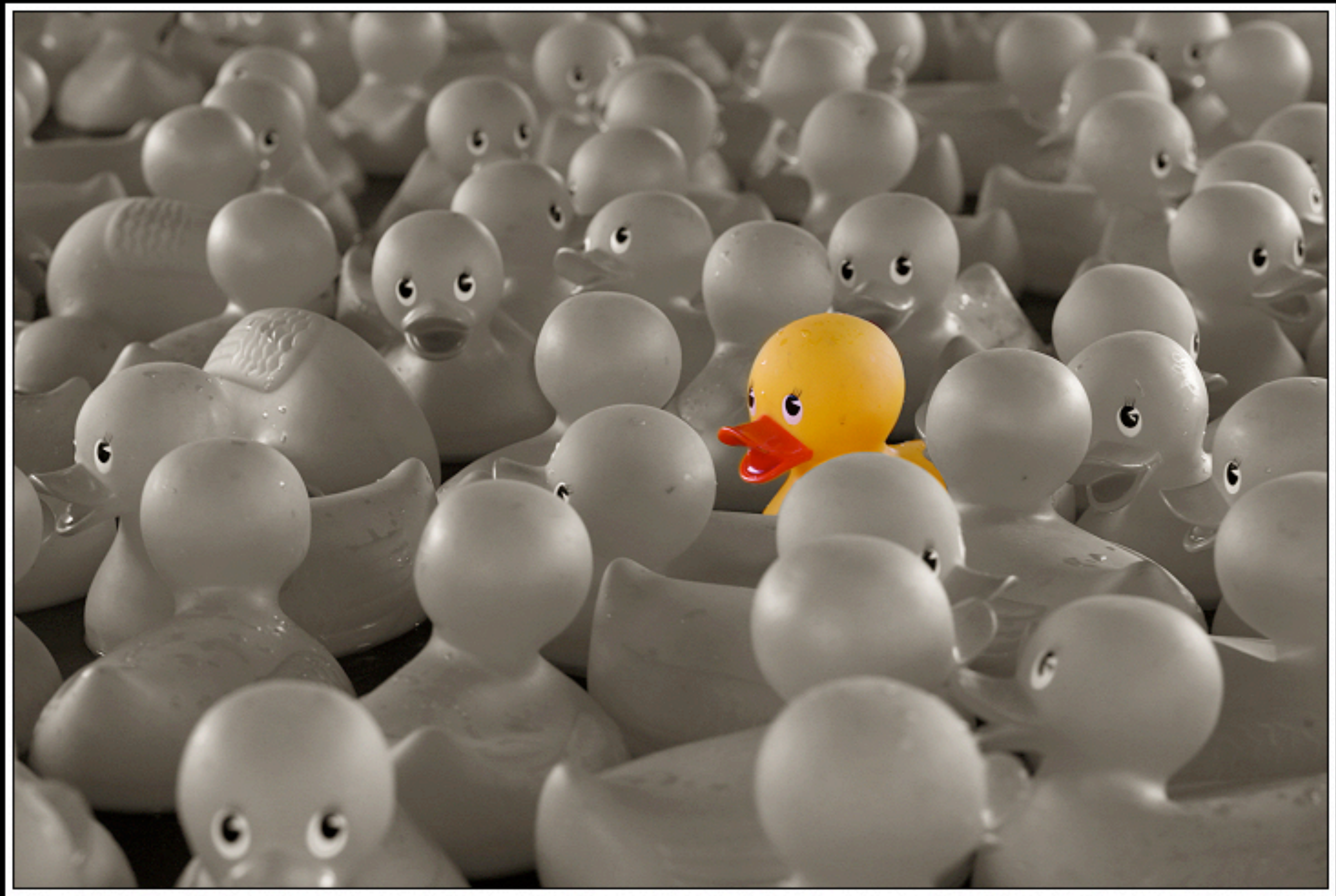
BUT SYSTEMATICS DOMINATE ERRORS

Multiverse explanation

of why dark energy is so small


eternal inflation
Inflationary Universe

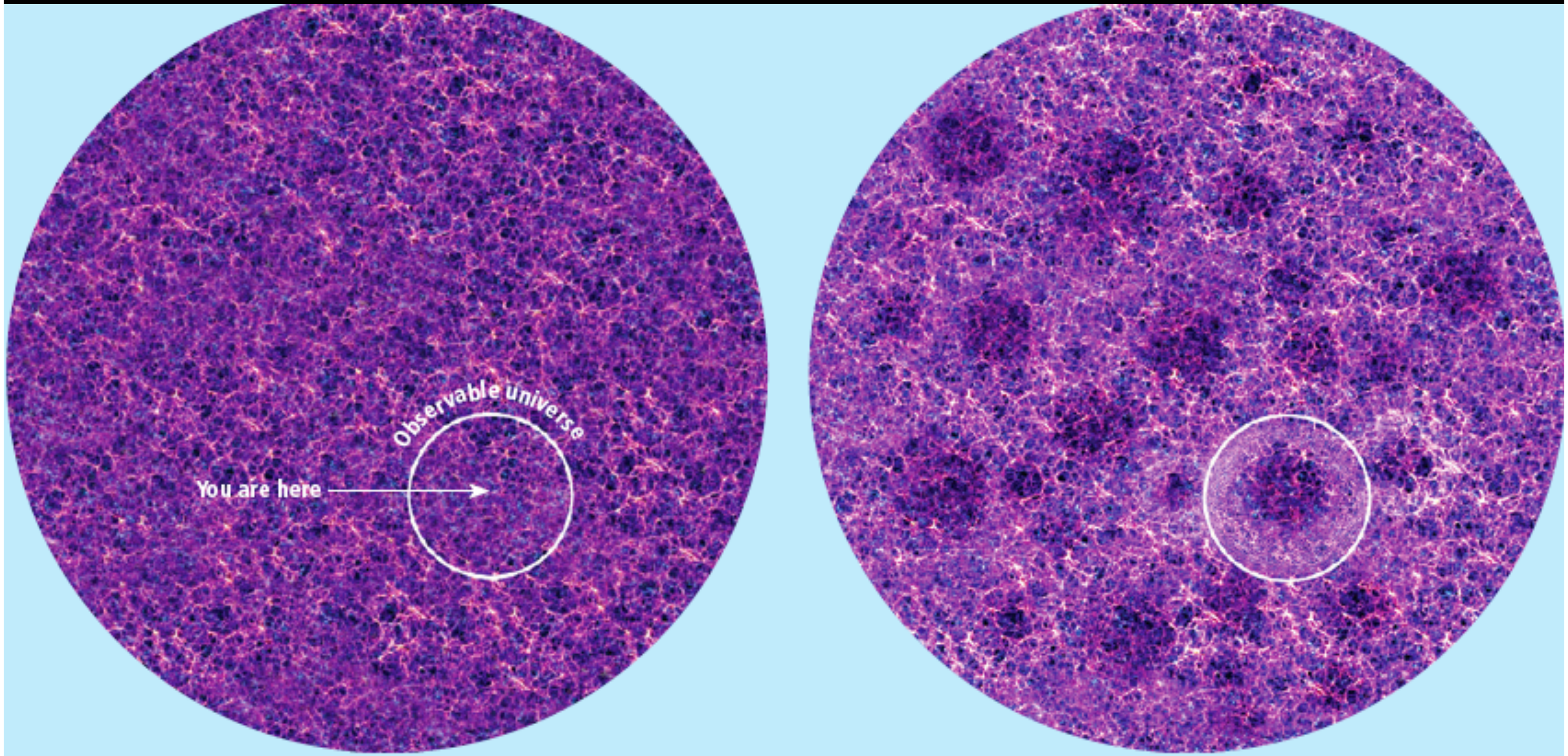
What is so special about our universe?



A. Linde

Alternatively we may hope for a fundamental physics (TOE) explanation
of why dark energy is so small

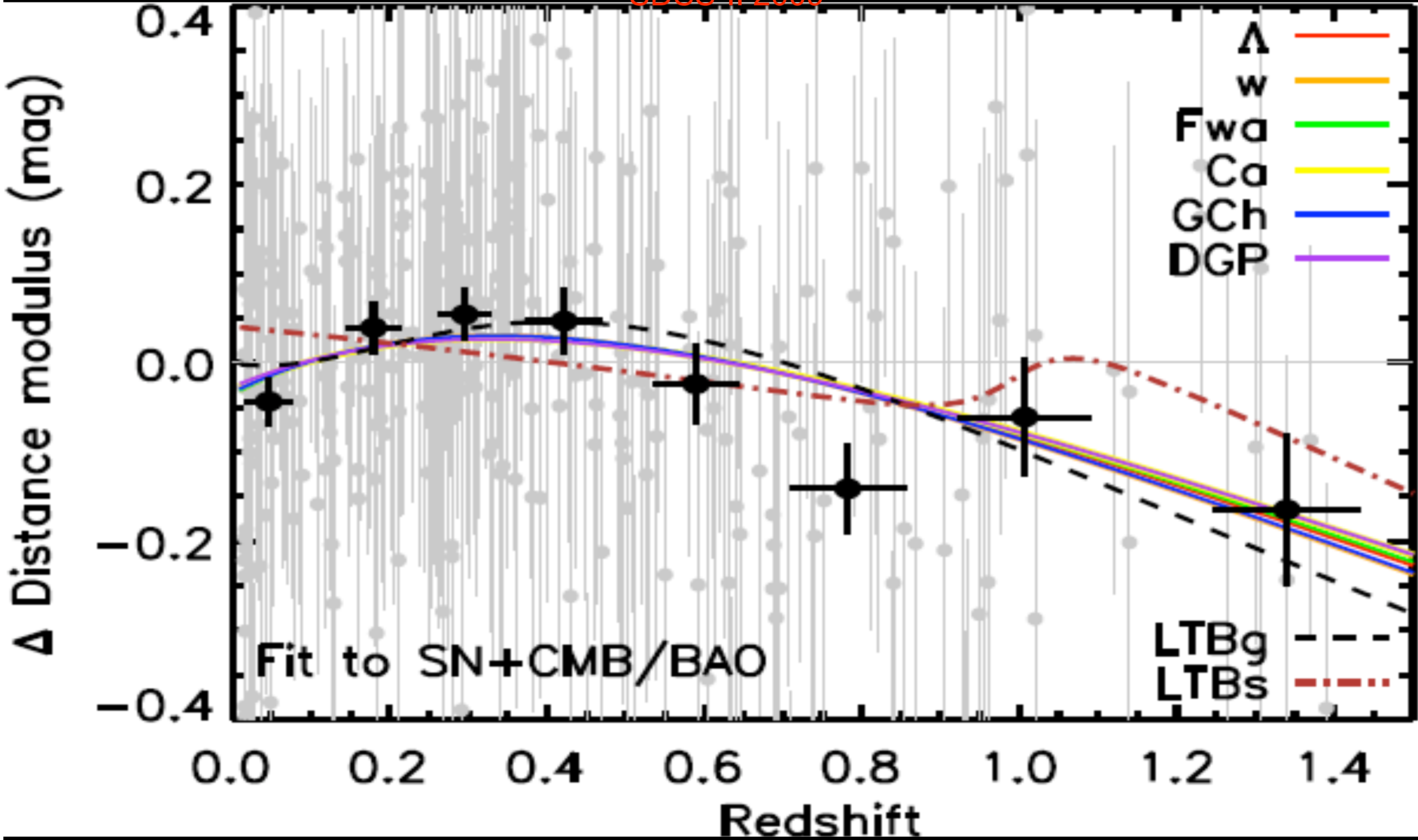
Another explanation



HOMOGENEOUS UNIVERSE: OUR LOCATION IS TYPICAL
In the standard view, galaxies are lined up in a spidery pattern, but overall space looks much the same everywhere, and Earth's position is nothing special.

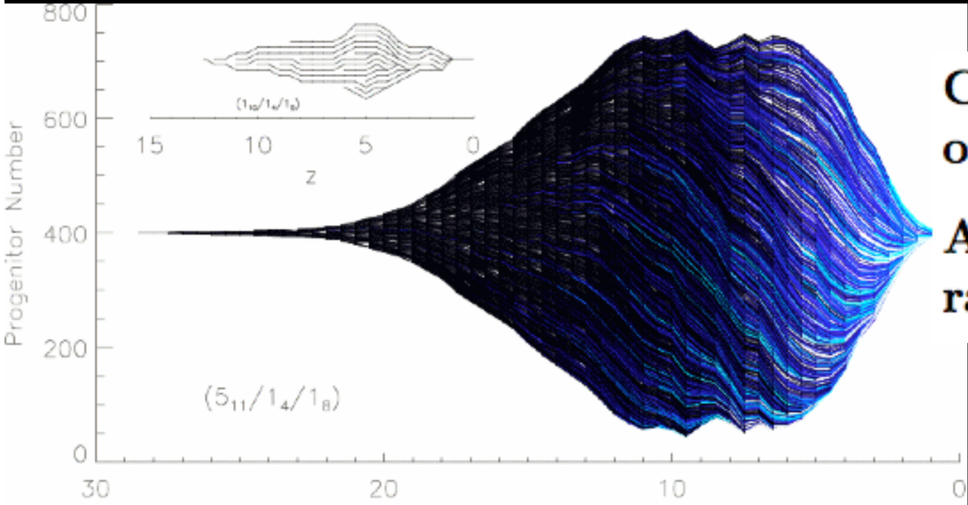
INHOMOGENEOUS UNIVERSE: OUR LOCATION IS SPECIAL
Alternatively, the density of matter could vary on large scales, and Earth may lie at or near the center of a relatively less dense region, or void.

SDSS-II 2009



Λ
w
Fwa
Ca
GCh
DGP
LTBg
LTBs
Fit to SN+CMB/BAO
Δ Distance modulus (mag)
Redshift
0.4
0.2
0.0
−0.2
−0.4
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

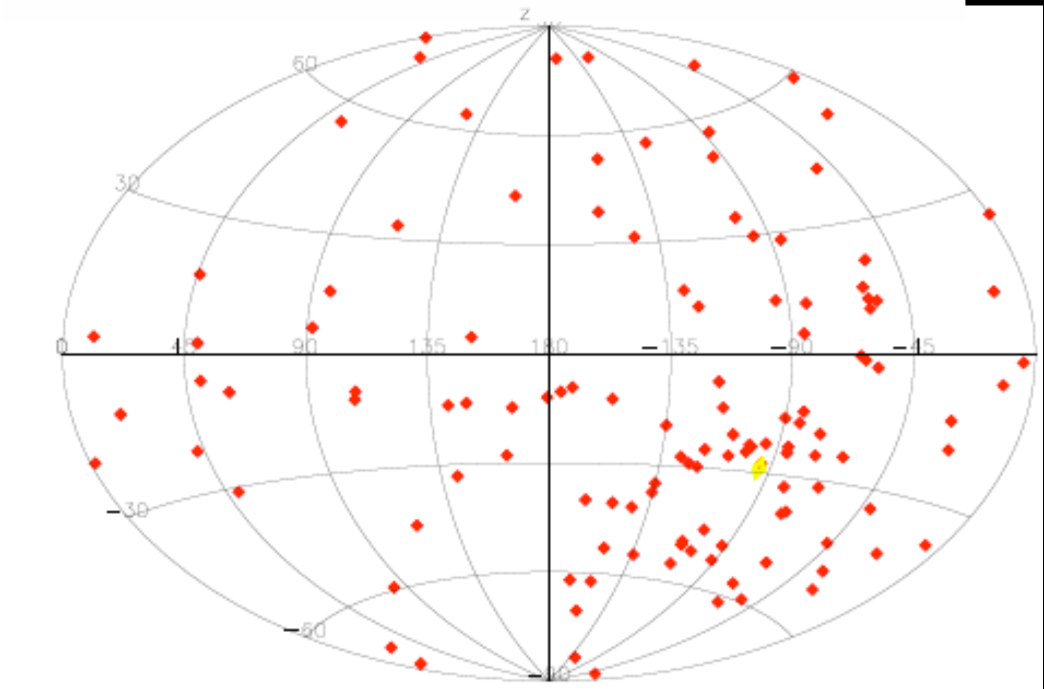
Cold dark matter spikes surround intermediate mass black holes



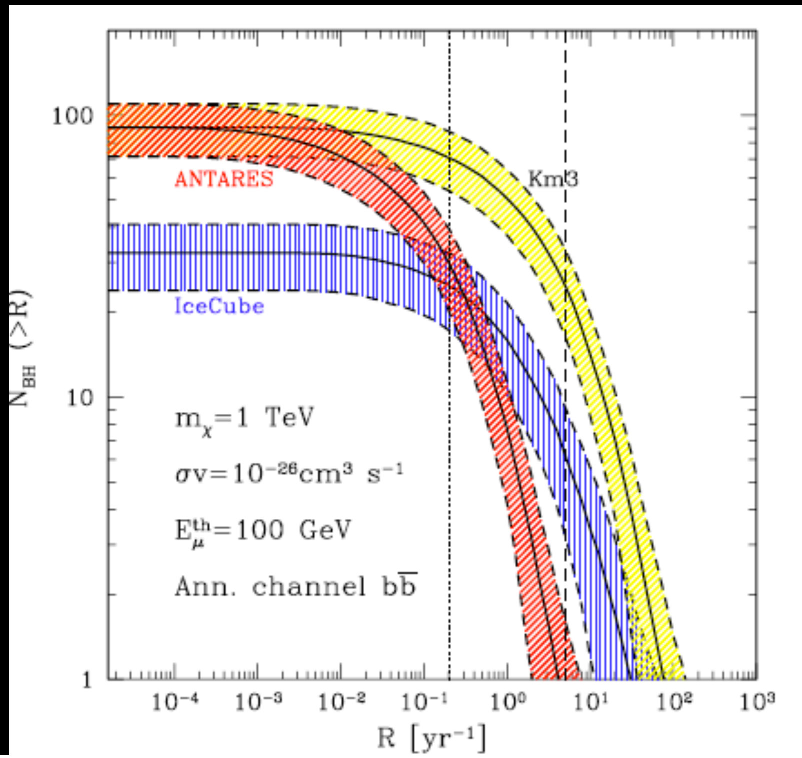
CDM cusp steepens by adiabatic growth of IMBH: $\rho \propto r^{-\gamma} \Rightarrow \rho \propto r^{-\gamma'}$, with $\gamma' = \frac{9-2\gamma}{4-\gamma}$

Annihilation rate is amplified within a radius $GM_{bh}/\sigma^2 \sim 0.003(M_{BH}/10^5 \mathrm{M}_\odot)\mathrm{pc}$

How to detect the nearest IMBHs: neutrinos from dark matter annihilations

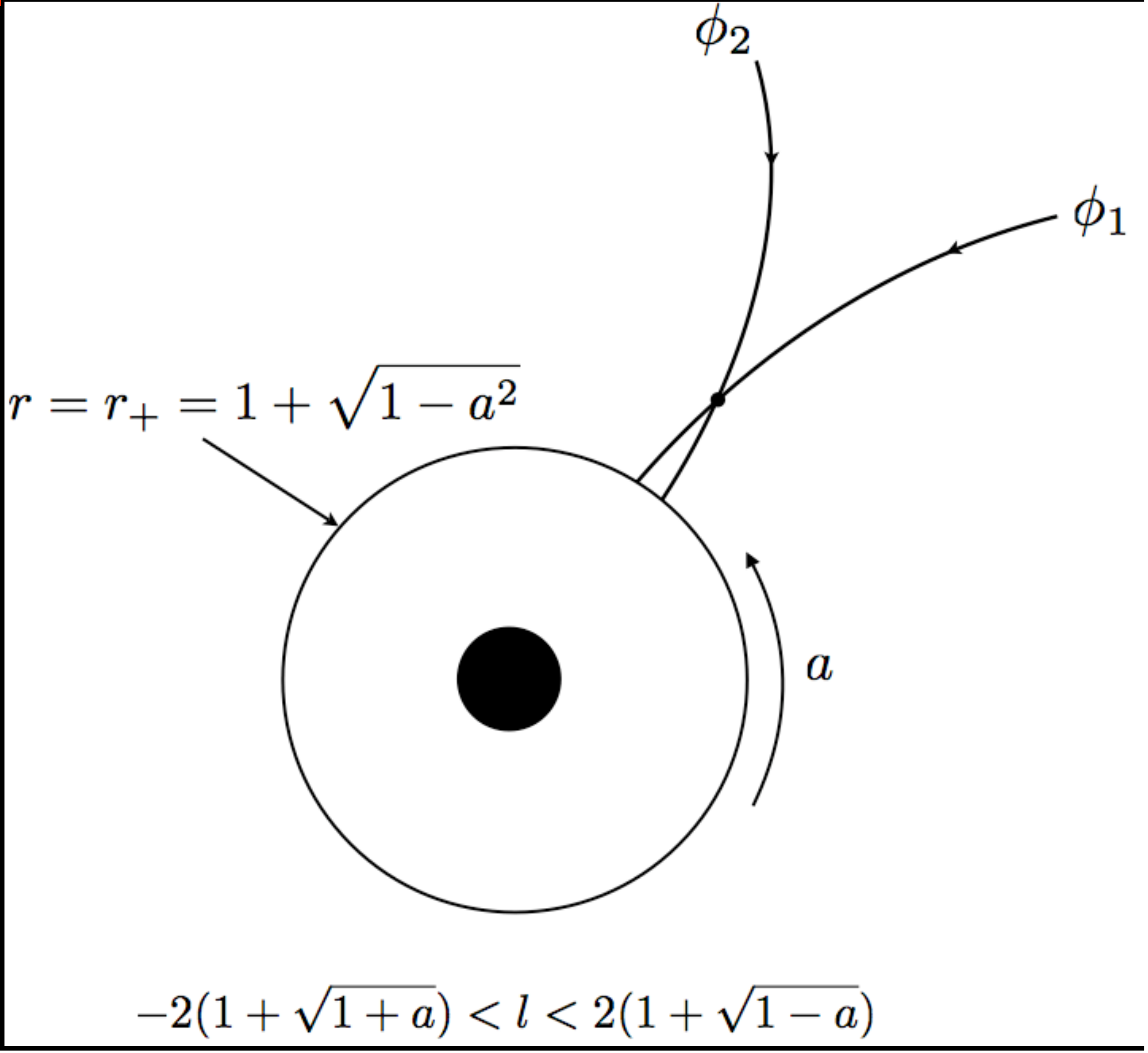


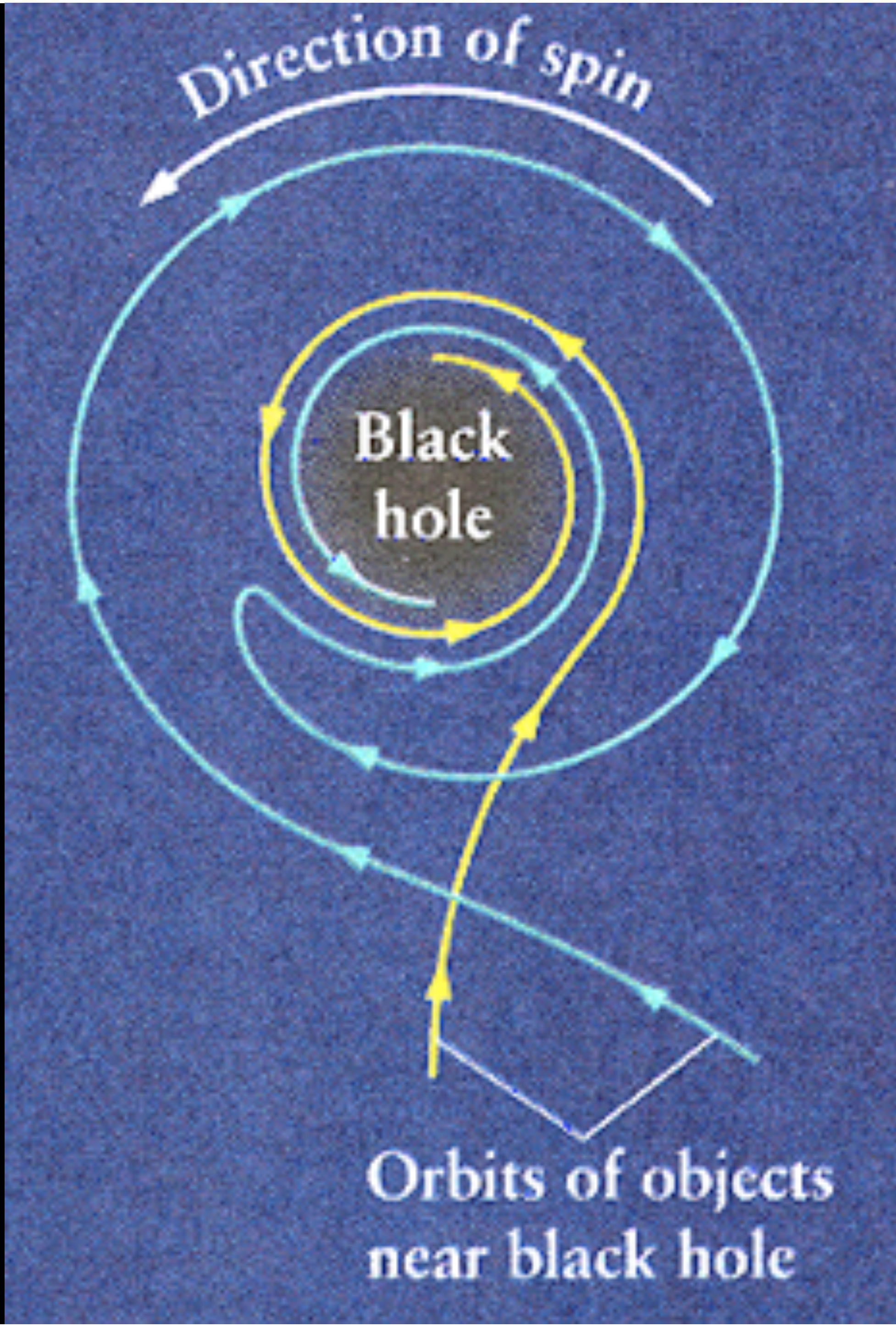
Bertone 2006



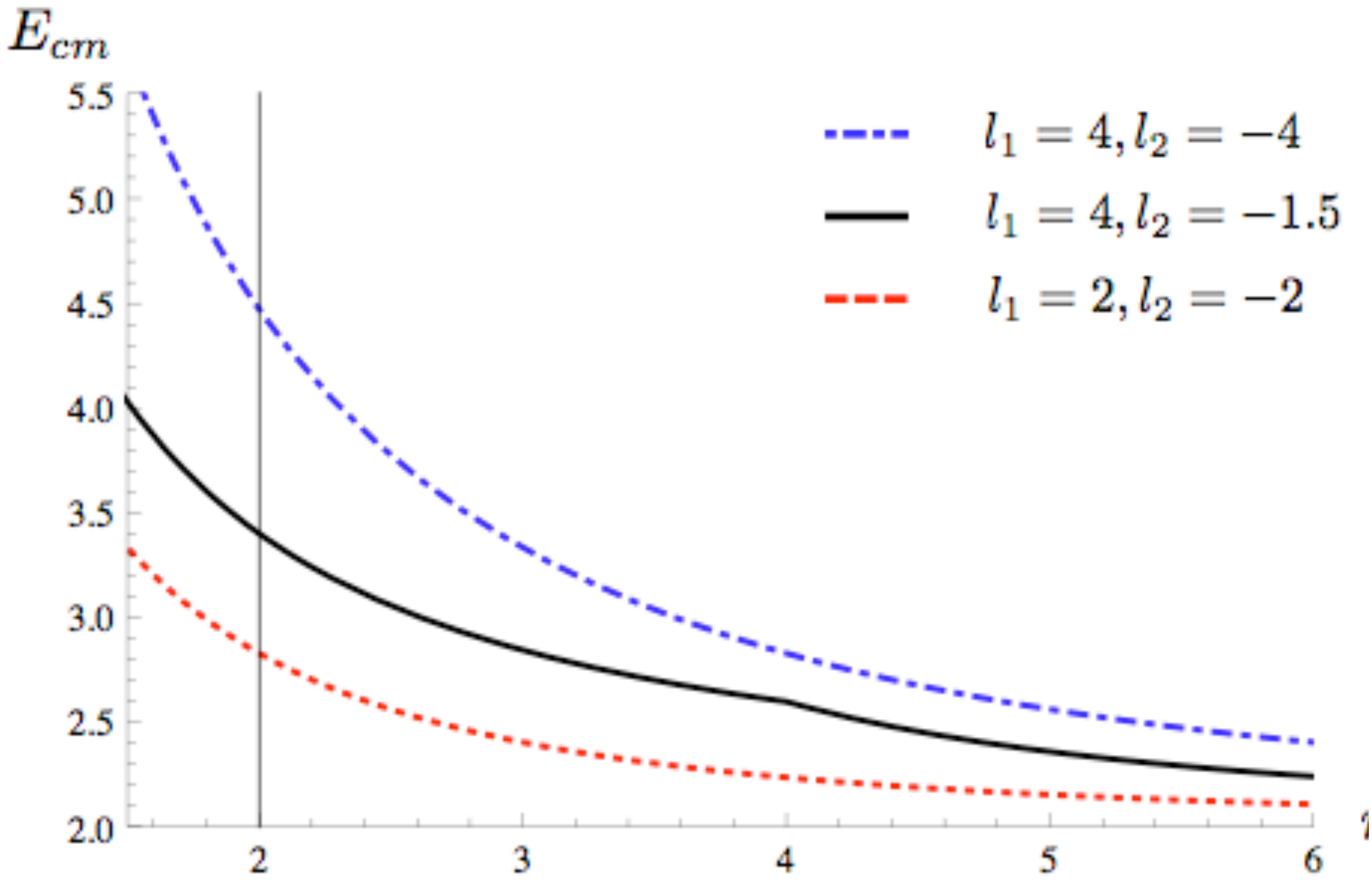
THE ULTIMATE PARTICLE ACCELERATOR:
dark matter cusp around a Kerr black hole

Banados+2009

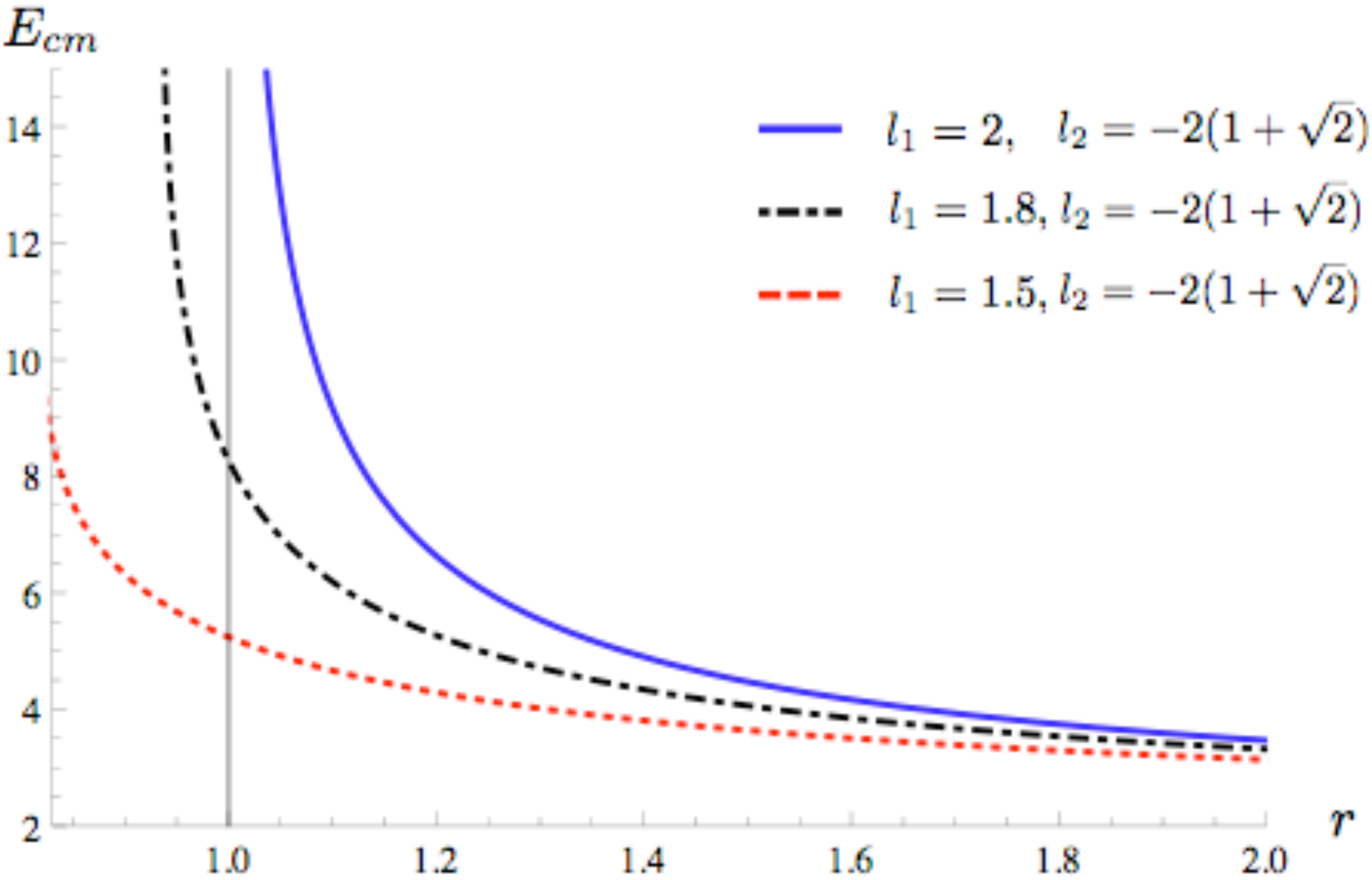



Direction of spin
Black hole
Orbits of objects near black hole

Schwarzschild black hole



Kerr black hole



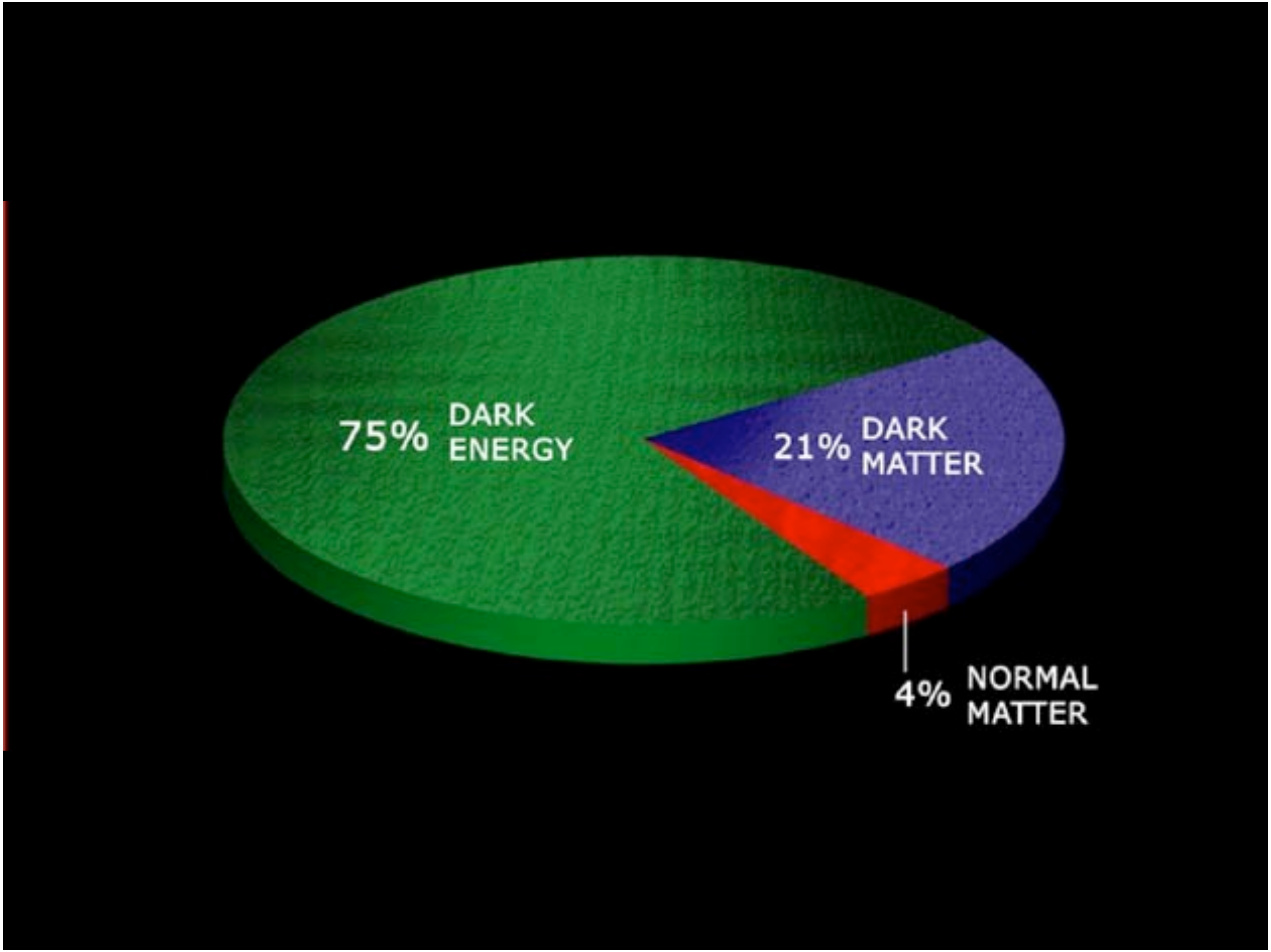
We have identified a potential PLANCK scale particle accelerator

Can have particle collisions with arbitrarily high CM energies

But we have not computed the flux at infinity (in progress)

The energy is redshifted but may retain unique signatures of high energy collisions

Can tap rotational energy of Kerr black hole and have Penrose boost in energy (in progress)


75% DARK ENERGY
21% DARK MATTER
4% NORMAL MATTER

DARK MATTER IS CHALLENGED BY COSMOLOGY

RESURRECTION VIA FUNDAMENTAL PHYSICS

- MODIFYING THE NATURE OF DARK MATTER?
- MODIFYING GRAVITY?

RESURRECTION VIA ASTROPHYSICS

- FEEDBACK

DETECTION IS ESSENTIAL FOR CREDIBILITY!

INDIRECT DETECTION IN MULTIPLE WINDOWS WILL DEMONSTRATE COSMOLOGICAL SIGNIFICANCE

AS FOR DARK ENERGY, WE AWAIT A NEW THEORY