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Search for Dark Matter

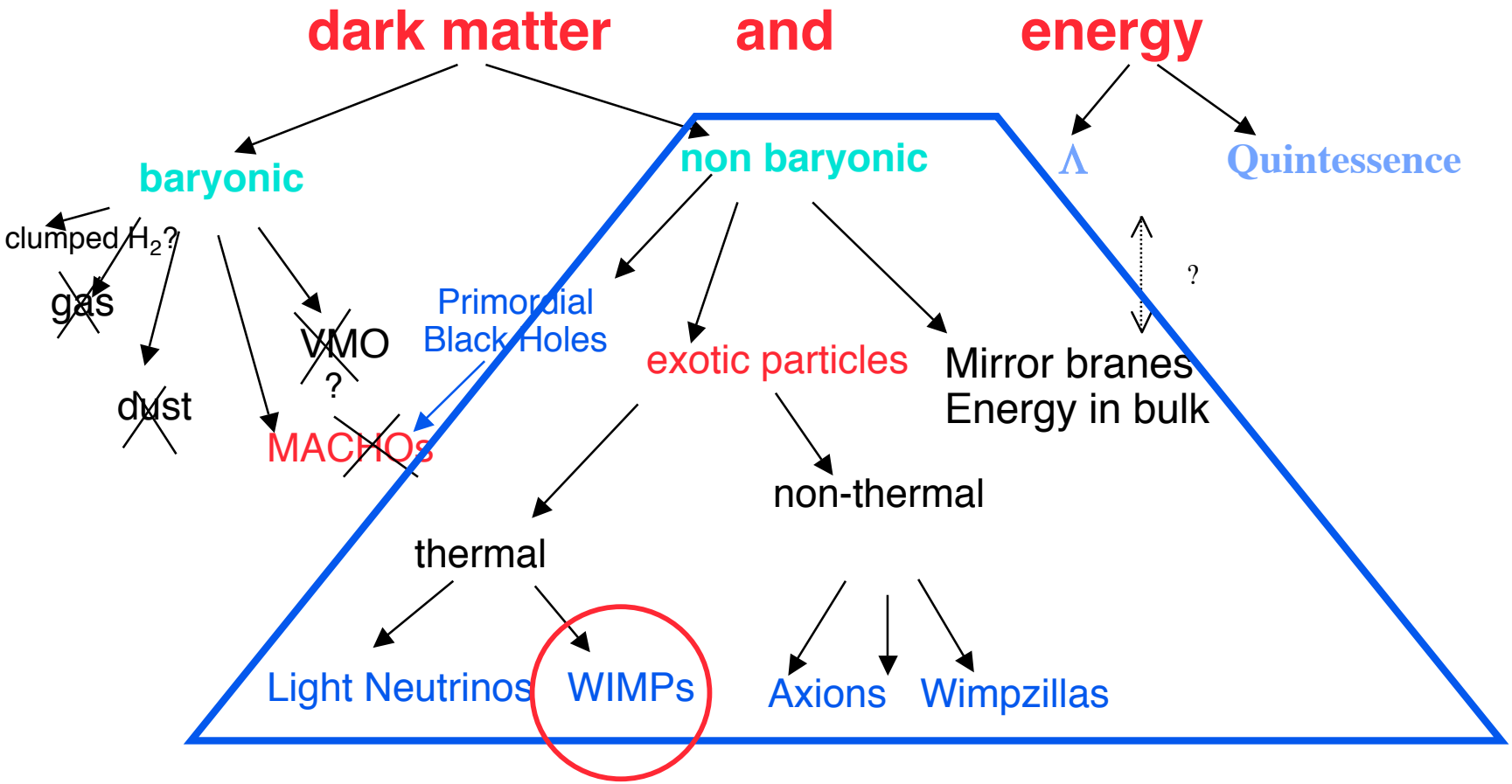
Lecture 5:

WIMPs: Indirect Detection

Non Thermal Candidates

Do we understand Gravity?

Deciphering the Nature of Dark Matter



Weakly Interactive Massive Particles

Particles in thermal equilibrium
+ *decoupling when nonrelativistic*

Freeze out when annihilation rate $\approx$ expansion rate

$$\Rightarrow \Omega_x h^2 = \frac{3\cdot 10^{-27} cm^3/s}{\langle \sigma_A v \rangle} \Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2} \qquad \rho_\chi \approx \frac{M_{EW}^2 T^3}{M_{Pl}}$$

Generic Class

Cosmology points to W&Z scale
Inversely standard particle model requires new physics at this scale
(e.g. supersymmetry) => significant amount of dark matter

We have to investigate this convergence!

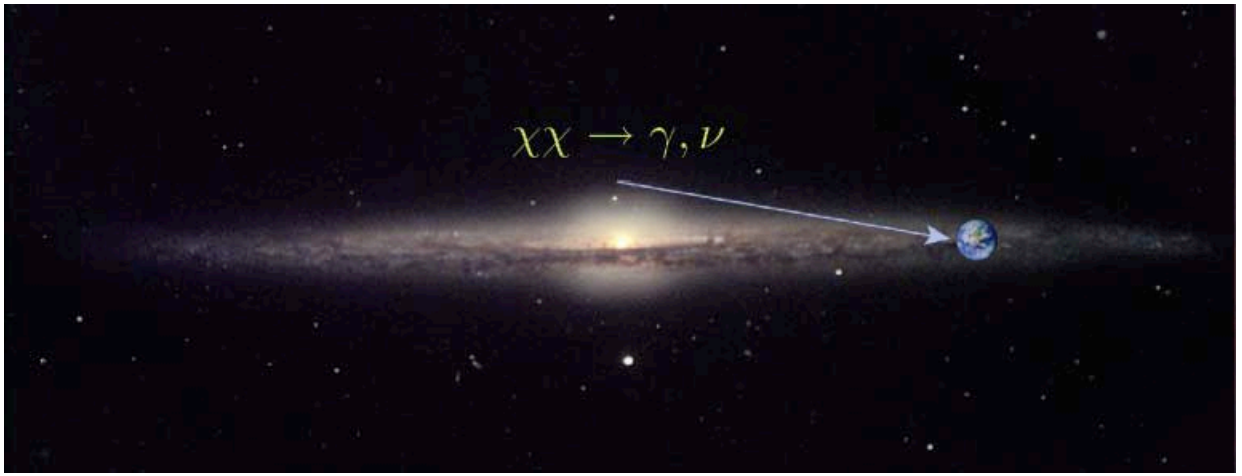
Directly fixes annihilation rate in halo

$$\chi\bar{\chi} \rightarrow \begin{array}{c} \gamma + X,\ \gamma\gamma, \gamma Z \\ e^+ X \\ \bar{p}\ X, \bar{d}\ X \\ \nu\ \bar{\nu},\ \nu\ X \end{array}$$

Sensitive to a number of details fixed by Astrophysics

≈ density^2 i.e. cusp discussion is central
Confinement time
Astrophysics backgrounds (e.g. Supernovae remnants, black holes)

Annihilation in the Galaxy Center



Old result from EGRET

≈ GeV towards Sgr A*

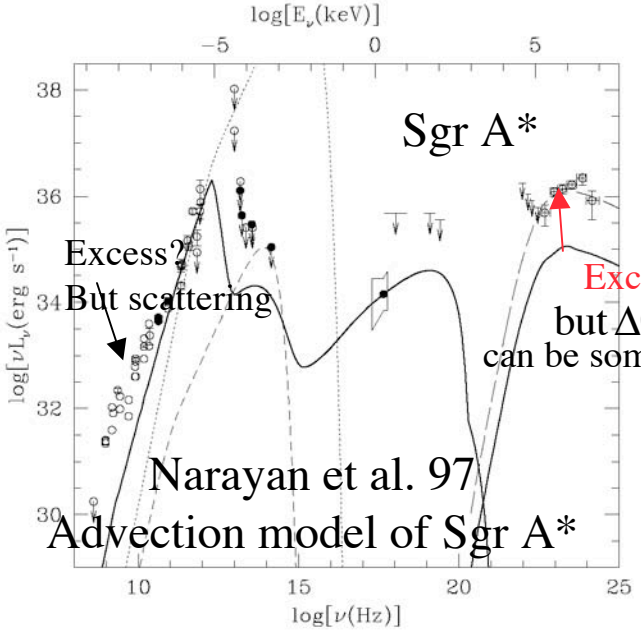
Excess from what expected from

2 10^6 M_{sun} Black Hole?

Synchrotron radiation

Attempt by Gondolo/Silk to put limit on e density

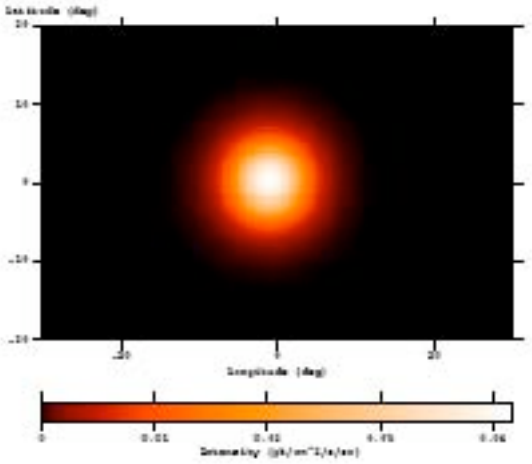
Merck, M., et al. 1996, A&A Sup., 120, 465



511 keV from Galactic Center

SPI/Integral

Weidenspointner et al. astro-ph 0406178



Compatible with bulge: 8° + 3° -2° very round

No solid astrophysics explanation yet

Appear too large for SN Type Ia

Hypernovae?

Annihilation of 1-10 MeV Dark Matter particles

Casse et al astro-ph 0404422

Light dark matter with new gauge coupling

Severe constraints from cosmology and particle physics

Could be test with dwarf galaxies close by

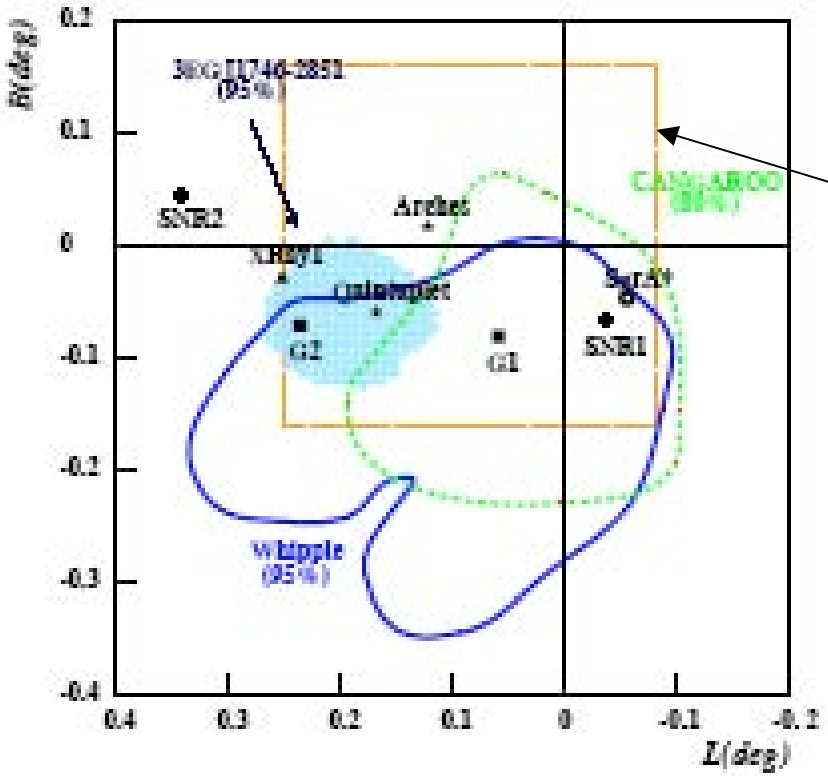
TeV γ from Galactic Center

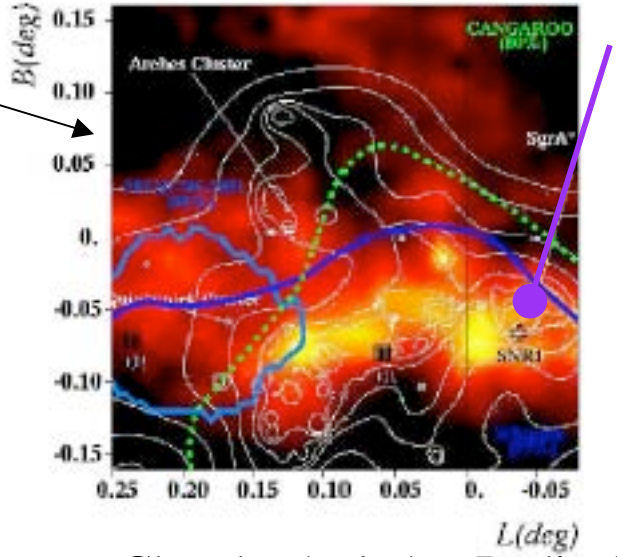
Signal from Atmospheric Cerenkov Telescope

Whipple >2 TeV

CANGAROO >200GeV

HESS ? Higher resolution, resolve disagreement between Whipple Cangaroo



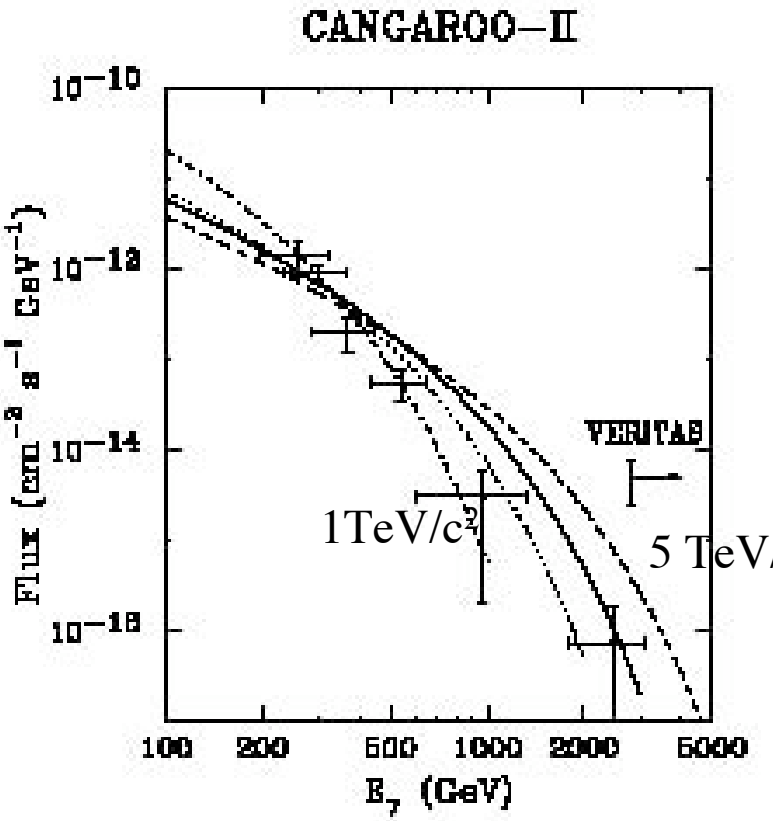


Sgr A*

Chandra (color) + Radio (White)

Gammas from Galactic Center

Analysis by Hooper et al. astro-ph/0402205



If annihilation of WIMPs, requires both

high annihilation cross section

rate ≈ 10^{-26} cm^3/s

high concentration

NFW cusp

adiabatic compression

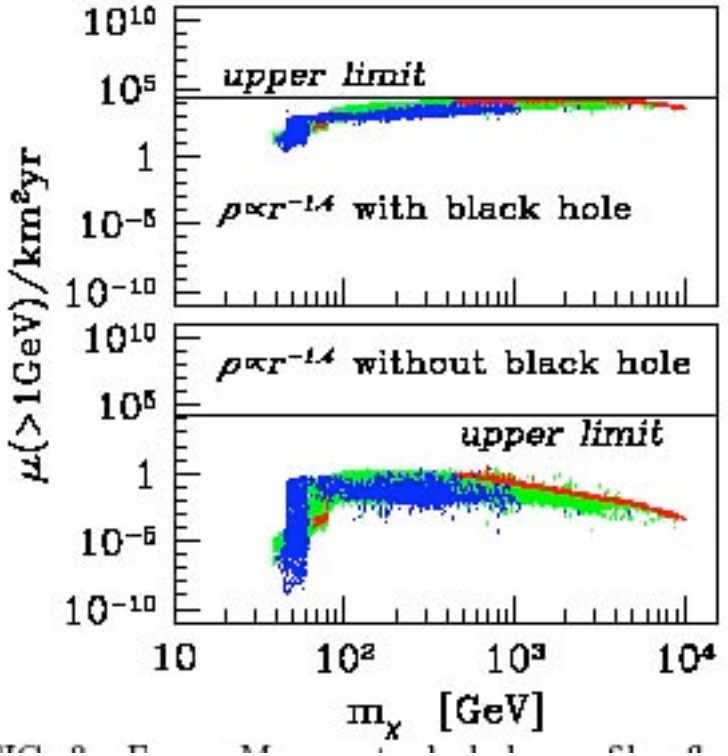
density spike from black hole

Most likely SN remnant

but high energy acceleration

Indirect Detection: Neutrinos

In Galactic Center Gondolo,Silk Astro-ph/9906391



- Current limit

  $2.\ 10^4\ \mu(>1\text{Gev})/\text{km}^2\text{yr}$

- Future: a few

  $\mu(>25\text{Gev})/\text{km}^2\text{yr}$

  Antares/Nestor

  IceCube in wrong hemisphere

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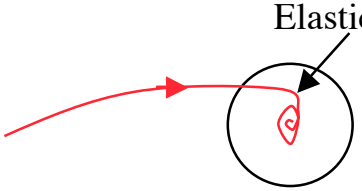
Neutrinos from Sun/Earth

Capture by sun & earth

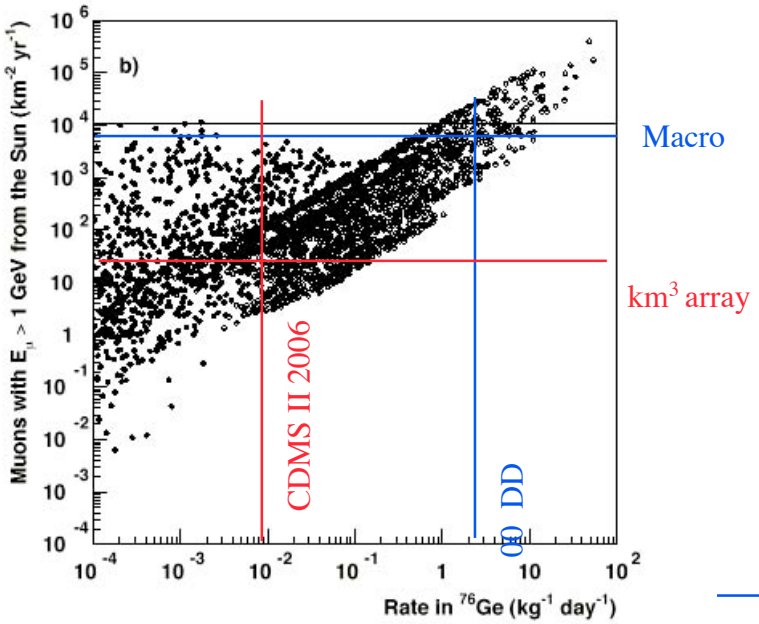
Trapped
=> annihilation in center
Observable: high energy neutrino



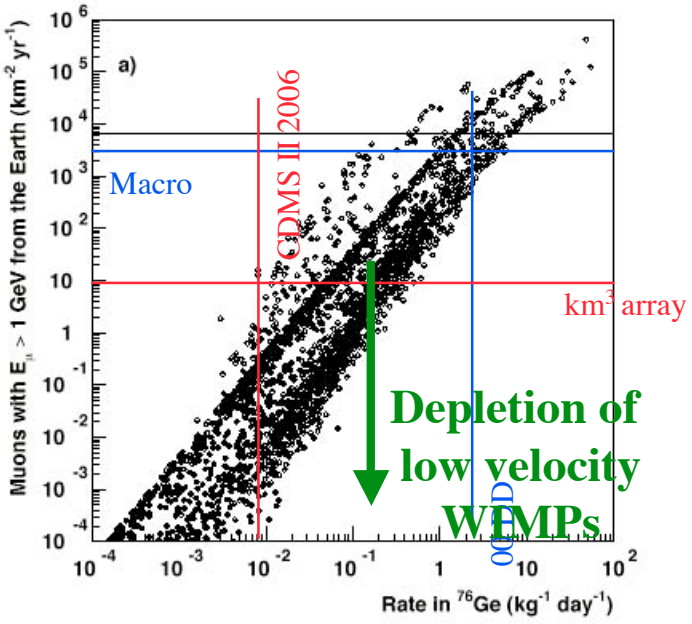
$$\frac{dn}{dt} = \Gamma_{elast} n - \Gamma_{ann} n^2 \Rightarrow \text{in equilibrium } \Gamma_{ann} n^2 = \Gamma_{elast} n$$
$$\Rightarrow \text{ measure elastic scattering}$$

More or less proportional

Sun (also spin dependent)



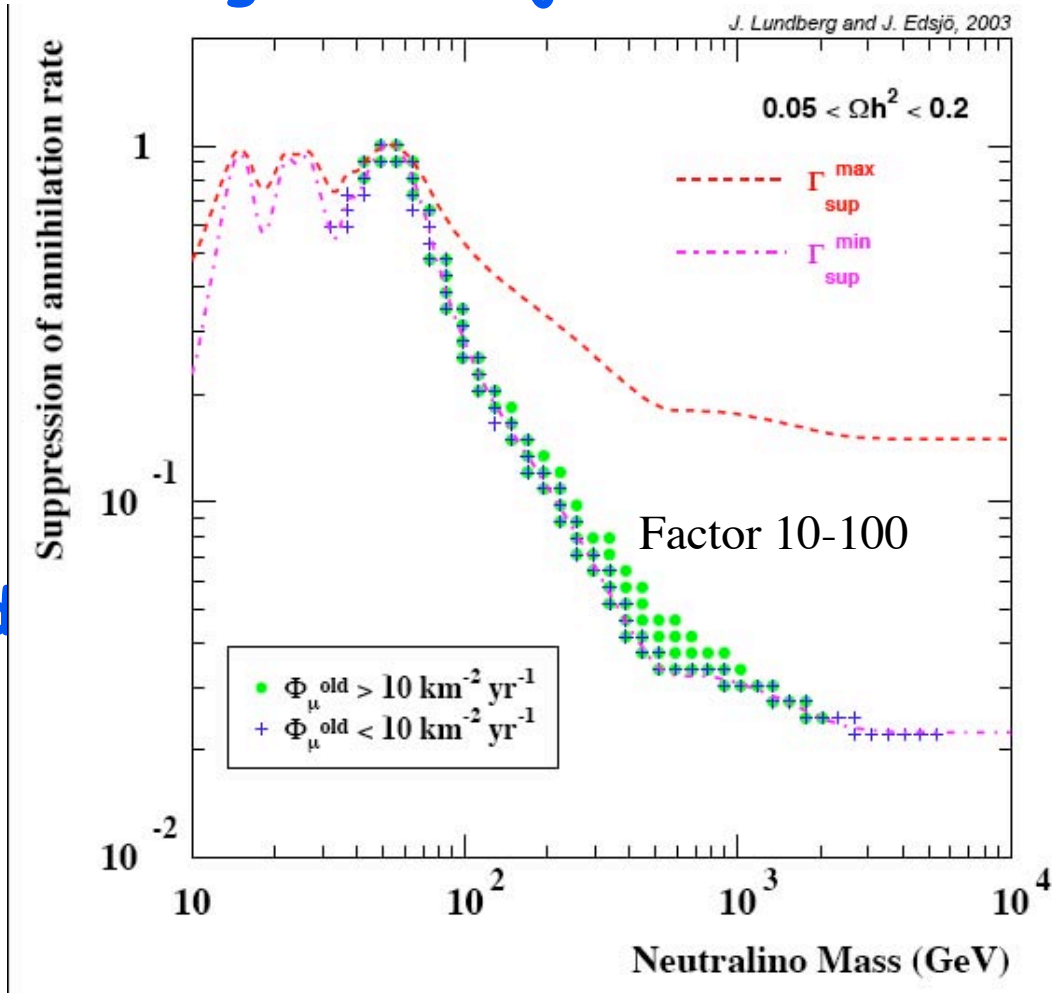
Earth



Neutrinos from Earth

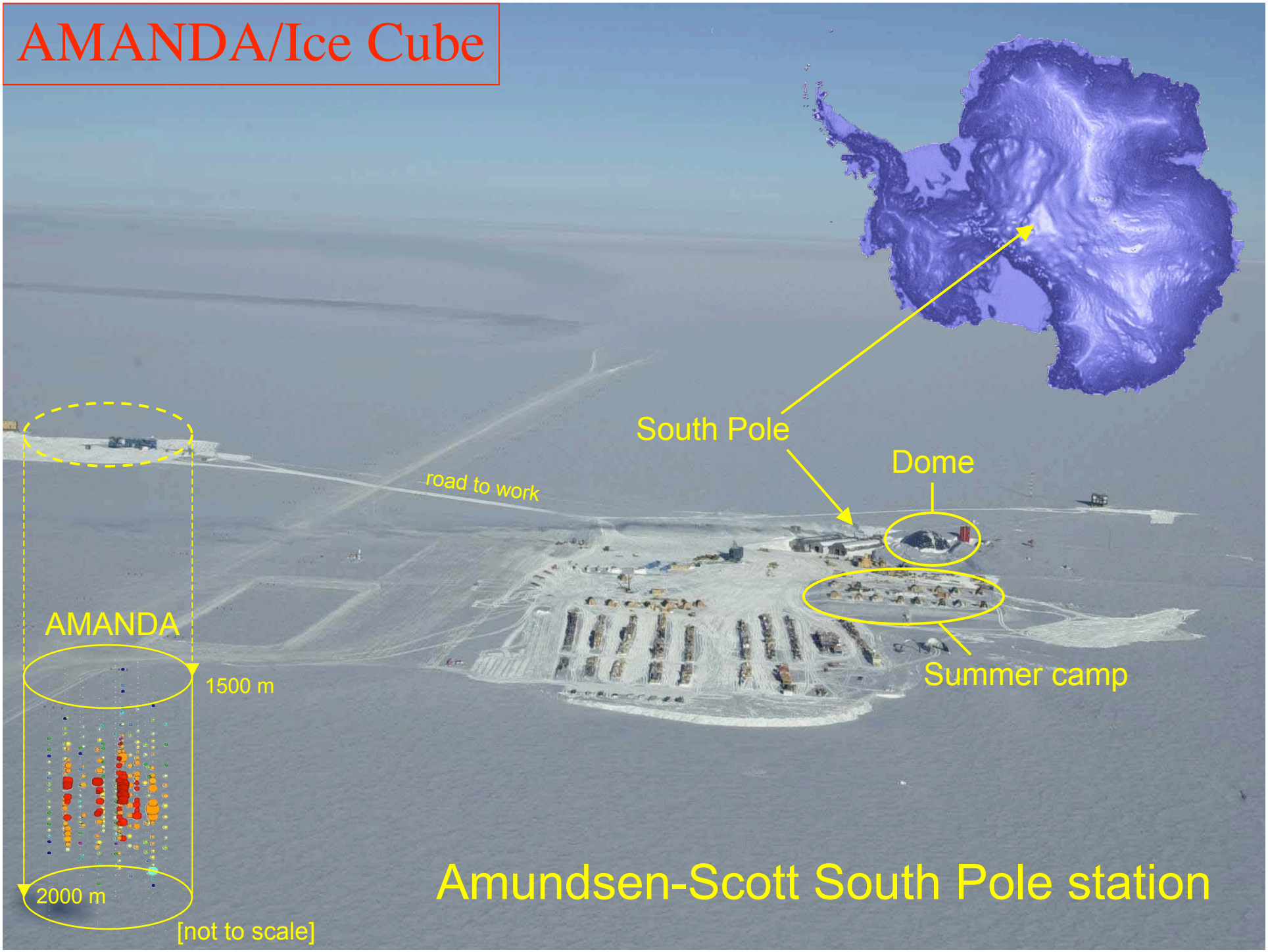
Following initial suggestion of Gould that low velocity WIMPs can be depleted in vicinity of the earth by Venus/Jupiter

Calculation by Lunberg and Edsjo



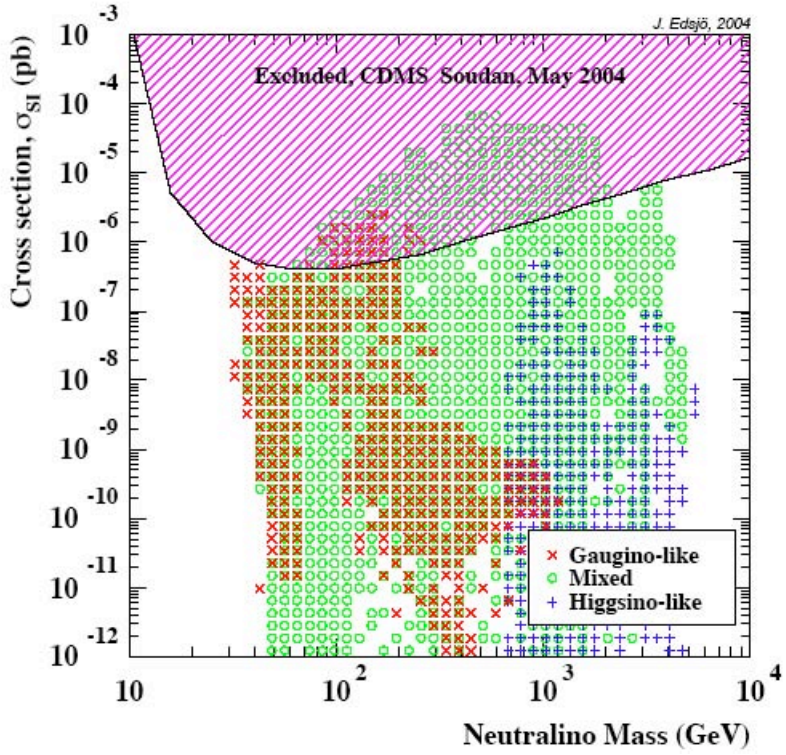
Not very good news for IceCube

AMANDA/Ice Cube



Comparison of Direct/Indirect

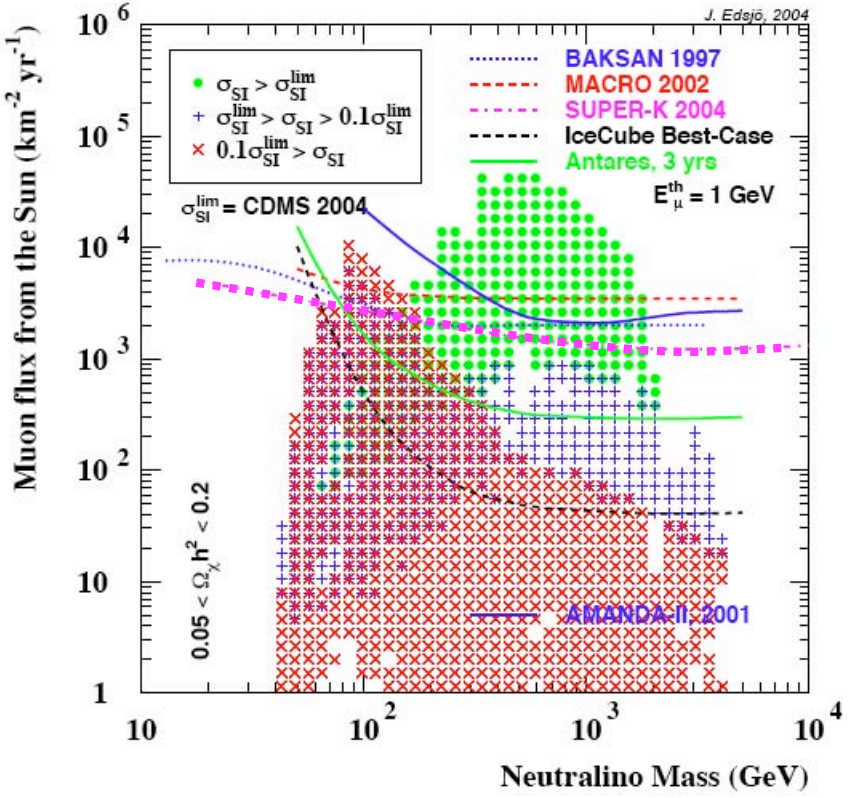
Starting from



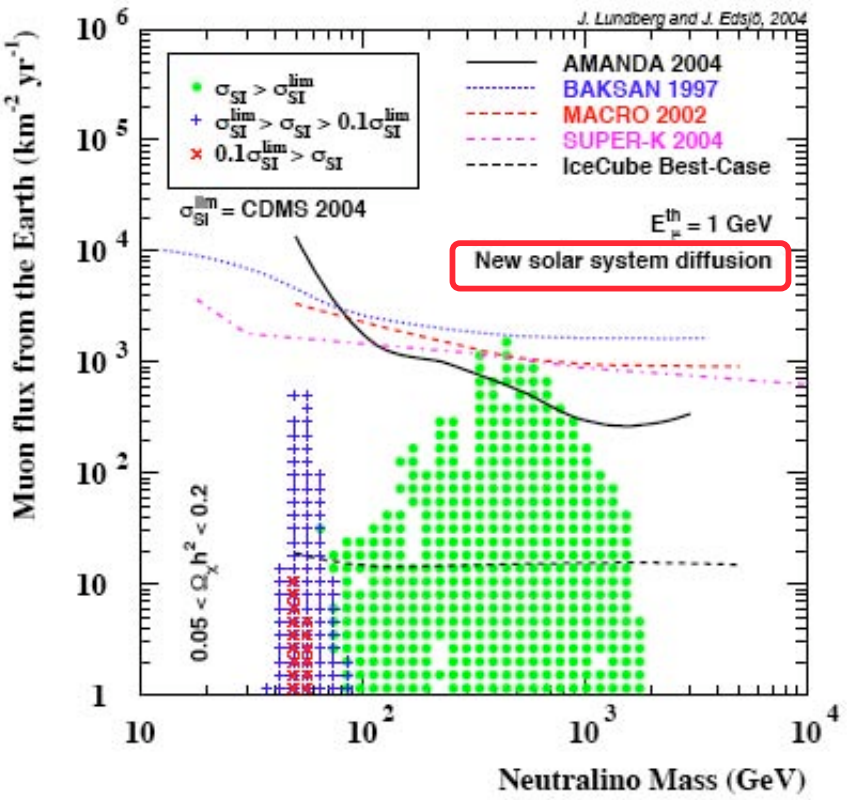
Neutrinos from Sun and the Earth

Present limits compared to exclude by CDMS II

Sun



Earth

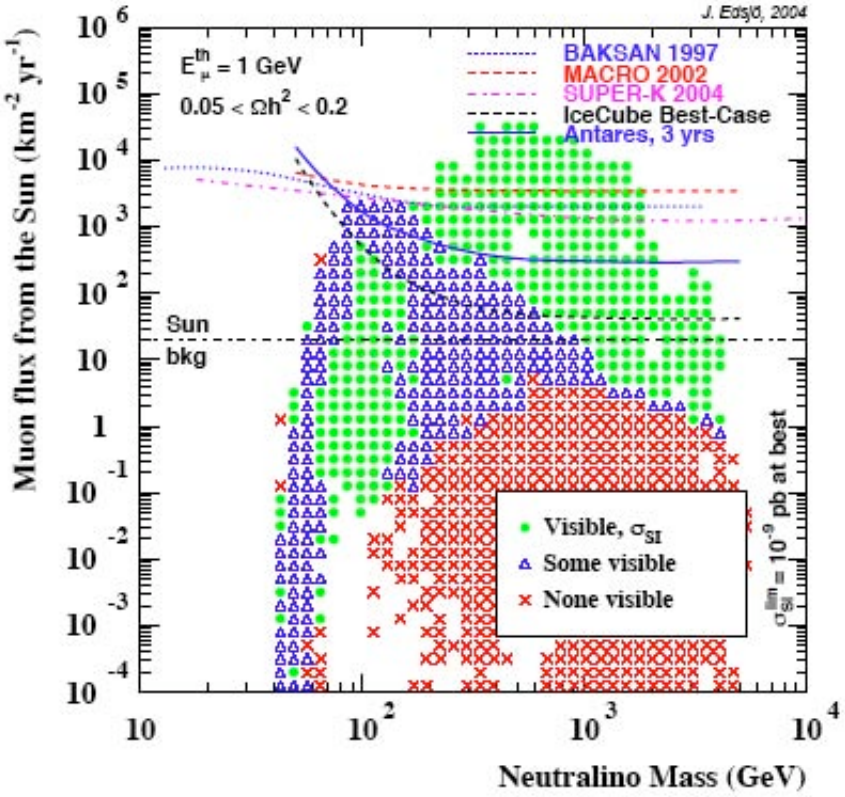


Neutrinos from Sun and the Earth

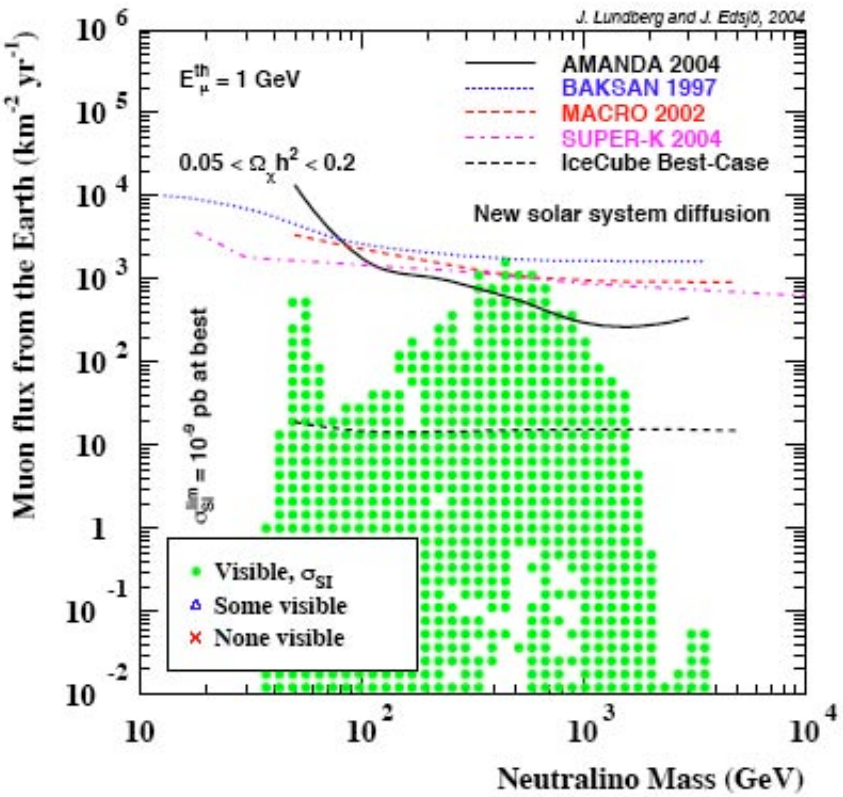
Future

Assuming 10x better sensitivity than CDMS II

Sun



Earth



Indirect Detection

Conclusions

Unfortunately neutrinos from the earth appeared killed

Unless enhancement at low velocities

H.E. neutrinos from the sun

Explore some of the same parameter space as the next generation elastic scattering experiments: cross checks

Somewhat complementary for spin dependent cross sections

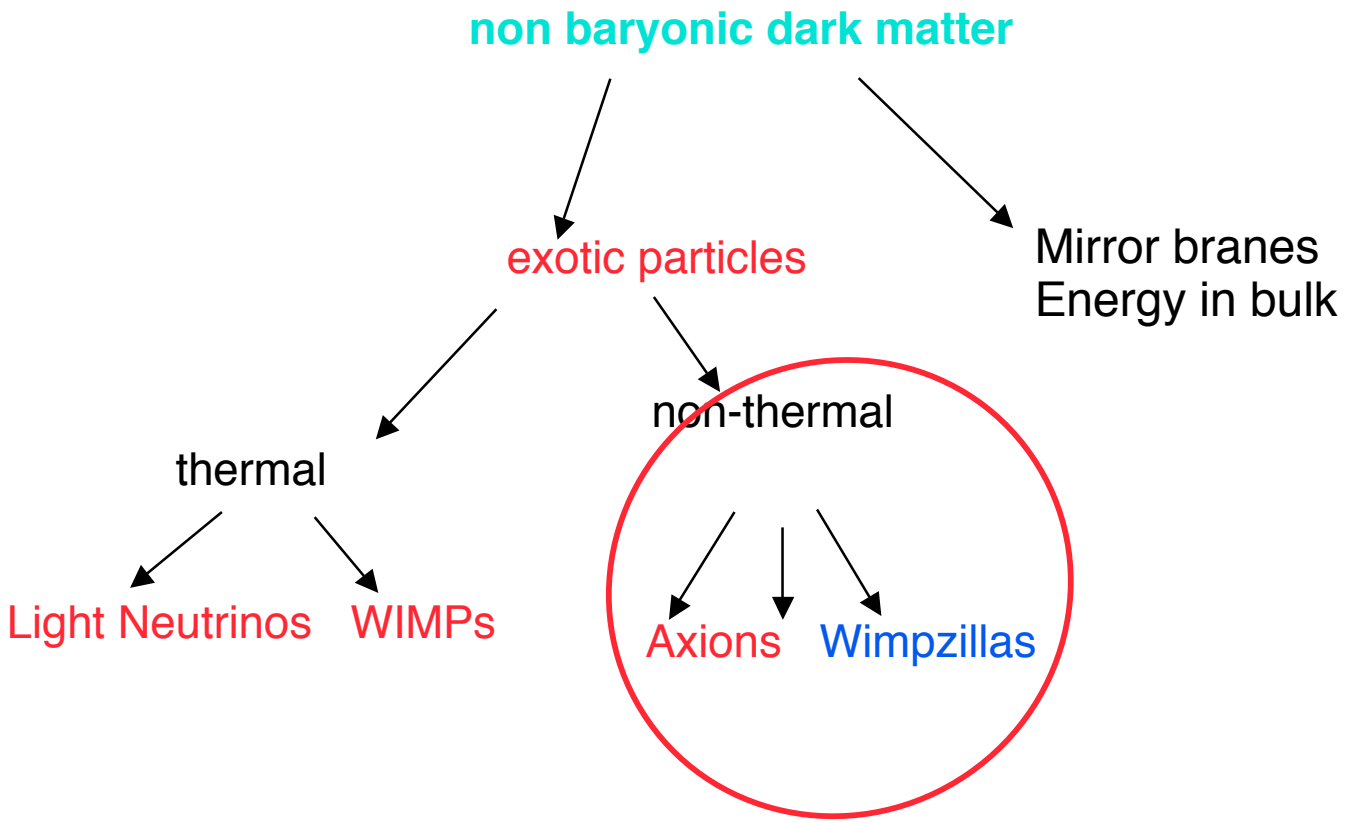
Other channels can also provide complementary informations

Gammas (GLAST, HESS,MAGIC)

Antideuterium

But a lot of "Gastrophysics" to understand

Non Thermal Candidates



Axions

Invented to save QCD from strong CP violation

Current experimental limits are such that if they exist, they have to be cosmologically significant

Window: 10^{-6}-10^{-3} eV

Produced out of equilibrium

Theoretical discussion if Peccei Quinnn symmetry breaking occurs after inflation

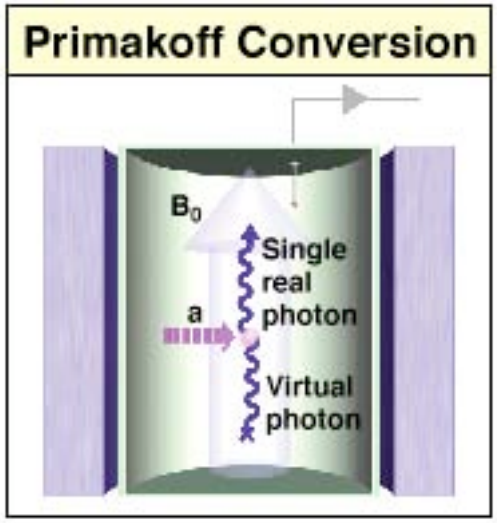
=> global strings which radiate axions. Technically difficult to compute (Shellard≠Sikivie)

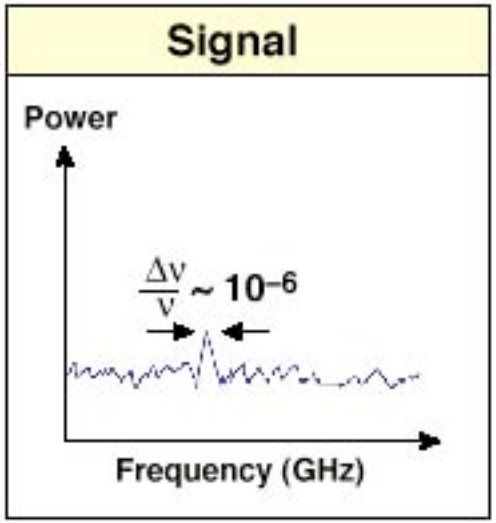
Loss mass region may be not favored

Method of detection

$$m_a = 0.62\,\mathrm{eV}\left(\frac{10^7\,\mathrm{GeV}}{f_a}\right)$$

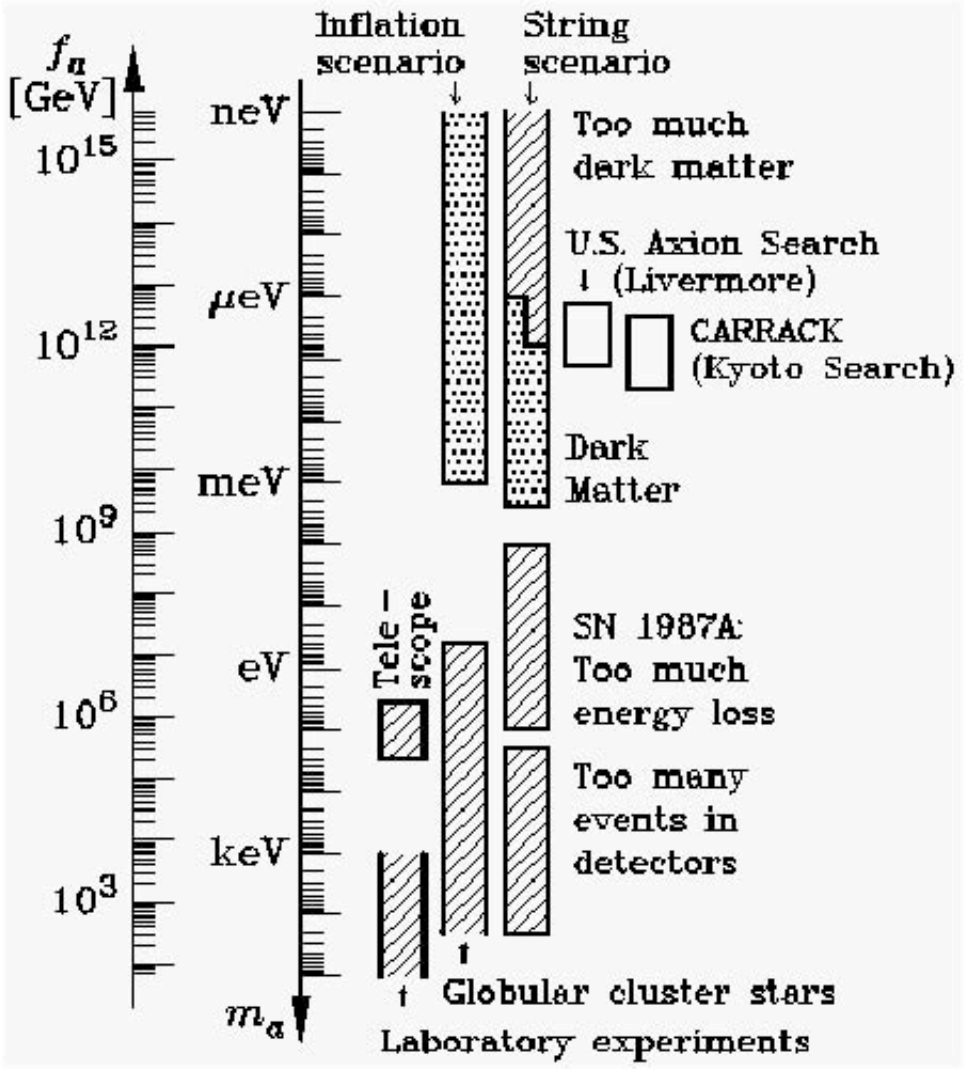
$$L_{a\gamma\gamma} = \left(\frac{\alpha_{em}}{2\pi f_a}\right)\vec{E}.\vec{B}\times O(1)$$





Tunable cavity: Most suitable for low mass region

Axion limits (Raffelt)



Axions

After 2 pilot experiments missing sensitivity

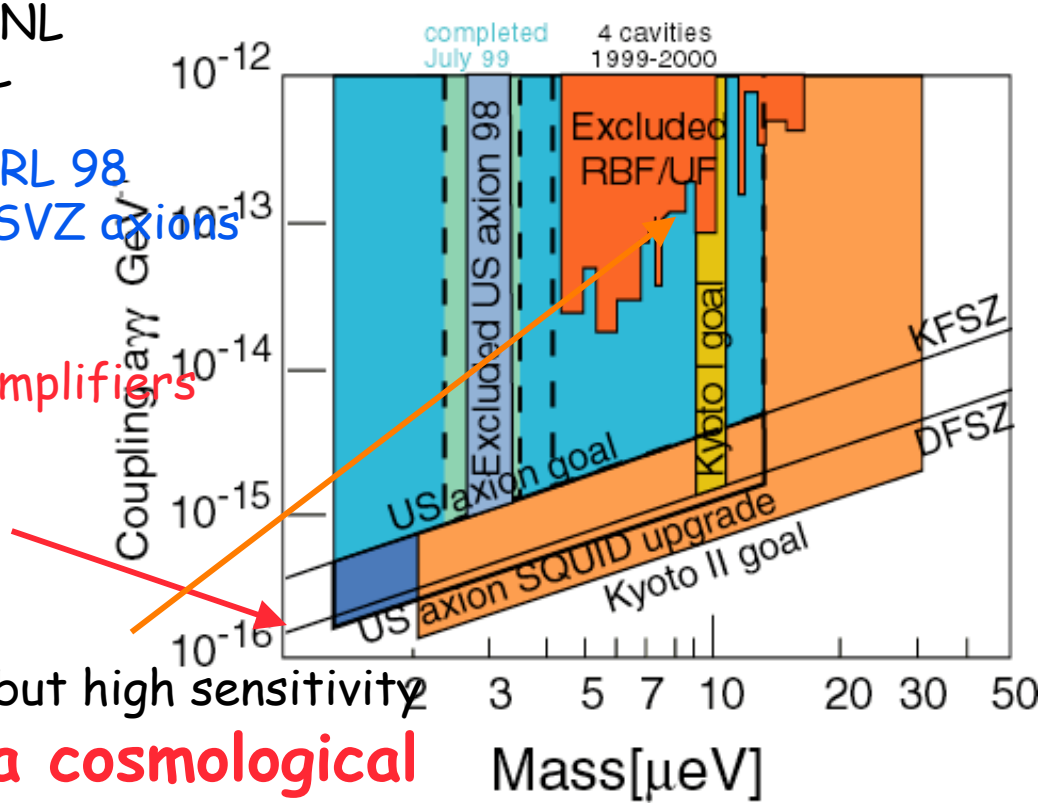
The US axion experiment

Livermore-MIT-UC Berkeley/LBNL
- U. Florida -U. Chicago/FNAL
-INR Moscow experiment

First data analyzed, published, PRL 98
demonstrated sensitivity to KSVZ axions

Currently scanning wider region

Approved upgrade :DC SQUID amplifiers
Allowing to reach DFZS



Kyoto experiment

Matsuki et al. (Rydberg atoms)
Starting in narrow region but high sensitivity

These experiments reach a cosmological sensitivity!

Potential Problem: one decade out three mass decades allowed

New idea (Adelberger et al.)

Torsion balance matter. magnetic field interaction

Other Candidates

WIMPZILLAs

10^{12} Gev/c^2

Gravitational production toward the end of inflation

Chung,Kolb,Riotto Phys. Rev. Lett. **81** (1998) 4048, Phys Rev **D 59** (1999)23501 and **D 60**(1999) 63504

Kuzmin and Tkachev Phys Rept **320** (1999) 199 and Phys rev **D 59** (1999) 123006

Disruption of virtual pairs of particles/antiparticles (vacuum fluctuations) by fast expanding space

Resulting particle density independent of the interaction strength!

Can be electrically charged, strongly interacting etc…

Detection

May be responsible for high energy cosmic rays: fine tuning of decay time?

See e.g. V. Kuzmin astro-ph 9709187, Berezinski et al. Phys Rev **D58** (1998)103515

If strongly interacting, could lead to high energy τ neutrino from sun/earth

Alburquerque,Hui,Kolb Astro-ph/0009017

Many Other Possible Candidates!

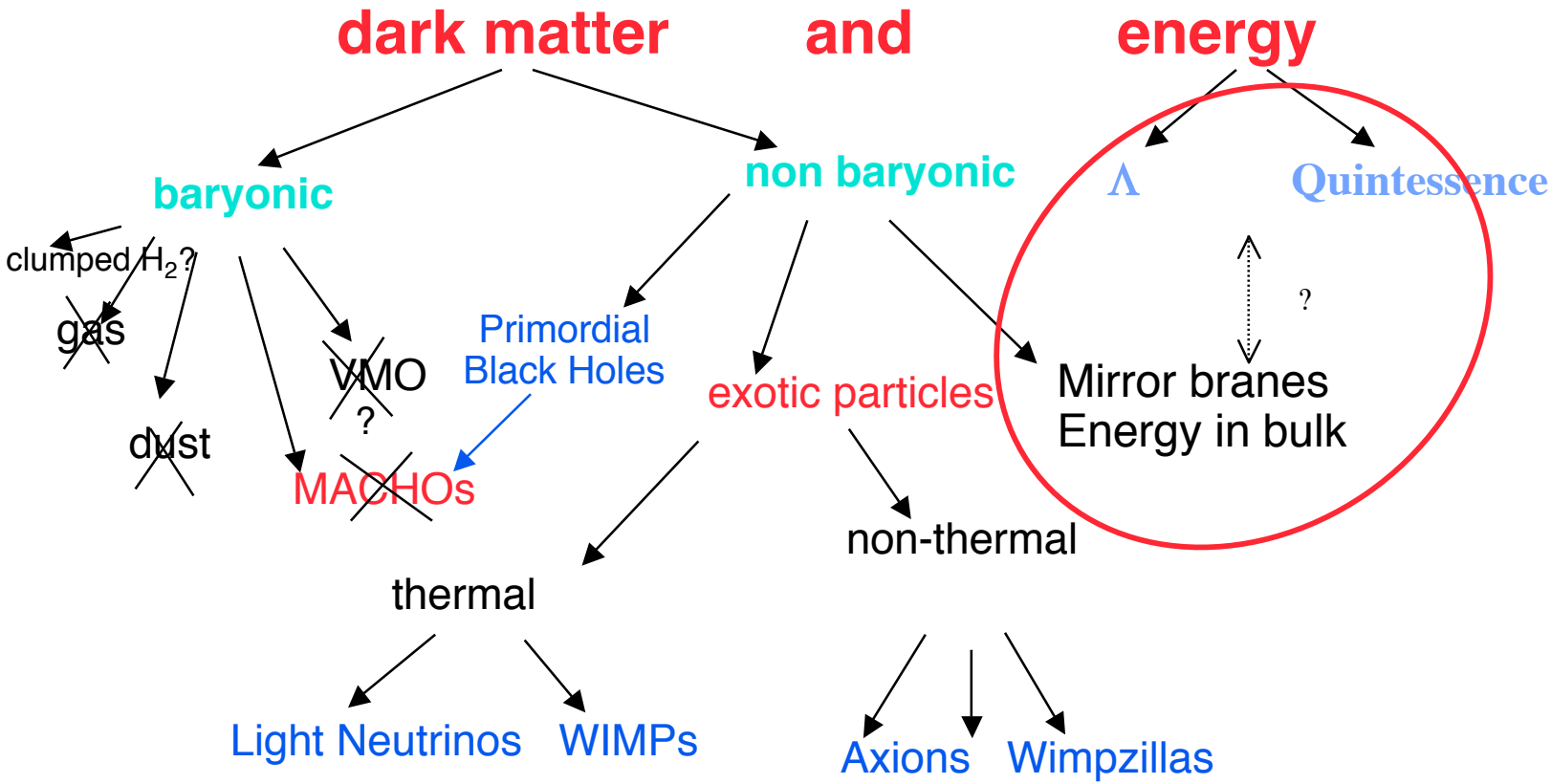
Proposed strategy

Investigate whether they are at all allowed by existing limits

Analyze existing data to put constraints

Only embark in major search program if there are at least two independent justifications and the model is generic

Dark Energy


dark matter
and
energy
baryonic
non baryonic
Λ
Quintessence
clumped H_2?
gas
dust
VMO
?
MACHOs
Primordial
Black Holes
exotic particles
?
Mirror branes
Energy in bulk
non-thermal
thermal
Light Neutrinos
WIMPs
Axions
Wimpzillas

A problem with Gravity?

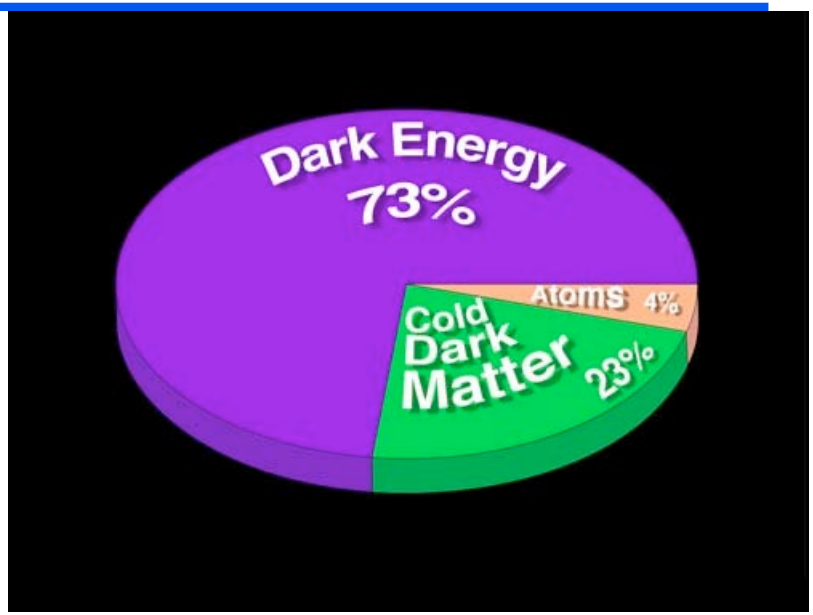
The extravagant universe

Why $\Omega_b \approx \Omega_m \approx \Omega_\Lambda \approx \Omega_\nu$?

What is the fundamental physics behind?

Why now?

Ω_m and Ω_Λ evolve differently with time



Is this cosmological concordance model real or another set of epicycles?

Are dark matter and dark energy just invented to bring an obsolete framework in agreement with new data?

The discovery of dark energy questions our understanding of gravity

Is the Freedman equation <=General Relativity valid?

Much deeper than MOND

(clever but conflict with observation, non relativistic framework)

We know that our framework is incomplete

The Cosmological Constant Problem

Zero point energy

Fundamental to quantum physics: Uncertainty principle

$$H = \frac{1}{2}\sum \hbar\omega_k \left(a^+ a + a a^+\right) = \sum \hbar\omega_k a^+ a + \sum_k \frac{1}{2}\hbar\omega_k$$

$$\rho_{vac} = \frac{1}{V}\sum \frac{1}{2}\hbar\omega_k \approx \int_0^{M_P} \frac{k^3}{h^3} dk \propto {M_P}^4 \approx \left(10^{28}\,\mathrm{eV}\right)^4 >> \rho_\Lambda \approx \left(2\times 10^{-3}\,eV\right)^4$$

$$\sum_k^k \frac{1}{2}\hbar\omega_k \approx \int_0^{\text{SUSY breaking}} k^3 dk = {k_{\max}}^4 \approx \left(10^{12}\,\mathrm{eV}\right)^4 >> \rho_\Lambda \approx \left(2\times 10^{-3}\,eV\right)^4$$

Why "nothing" weighs so little but not zero?

Many Proposals

"Nothing" does not weigh much

Unknown symmetry ->0?
Fuzzy graviton
Random number: anthropic principle
Selection of universe with observers

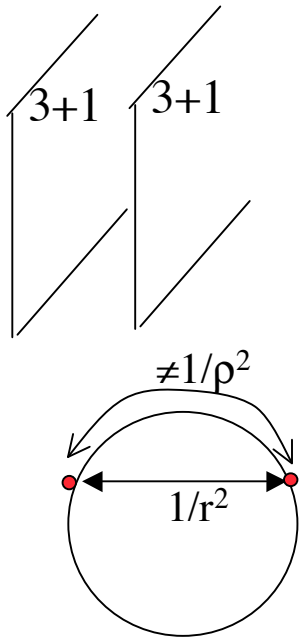
Is the universe at the verge of a new inflation

New unrelaxed field "Quintessence"

Are we living in more than 3+1 dimensions?

Inspired by string theory
e.g. Is gravity operating in 4+1 dimensions

- Mirror universe?
- May explain why its weaker than other forces
- May explain acceleration of the universe



In other words we have no clue

But many of these schemes undermine the theory of gravity as we know it!

How can we make progress?

Better study in cosmological environment

Supernovae +gravitational lensing: Large field of view telescope
in space SNAP/JDMM
on ground LSST

Survey of clusters of galaxies
Optical telescopes: e.g. DEEP II
Cosmic Microwave background sensitive
detector of plasma in clusters
Sunyaev Zel'dovich

The idea is to measure precisely the pressure: at the moment

$$p \approx -u$$

+ precise tests of growth of structure

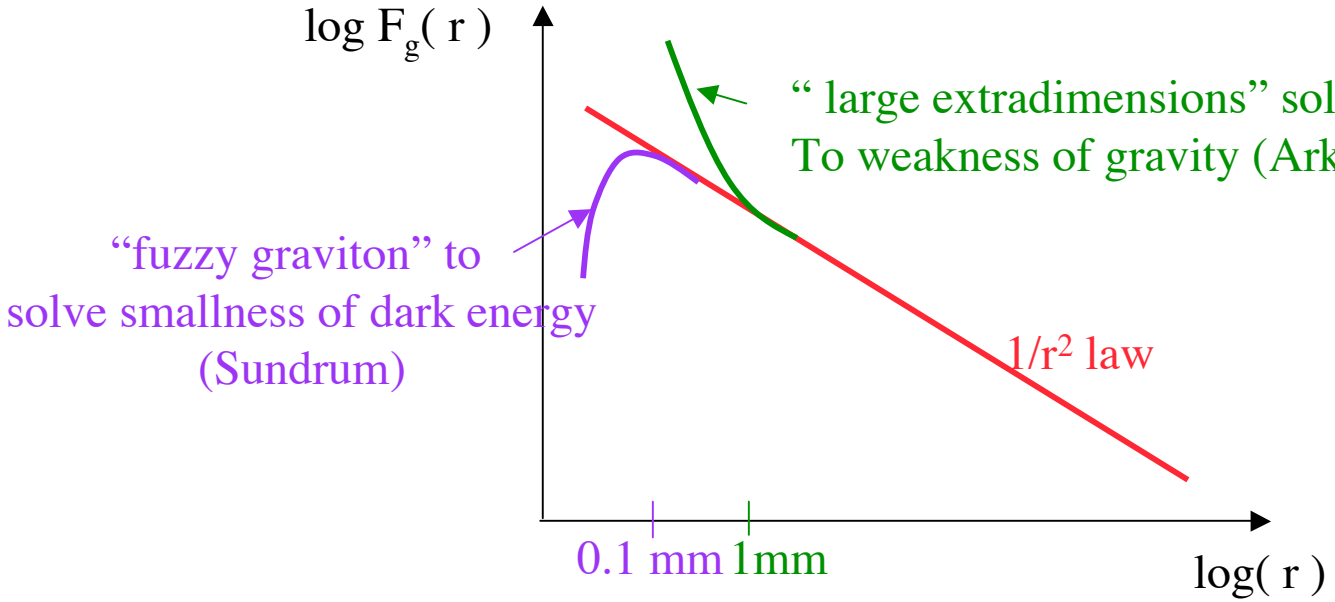
Inconsistencies may point to breakdown of gravity at large scale

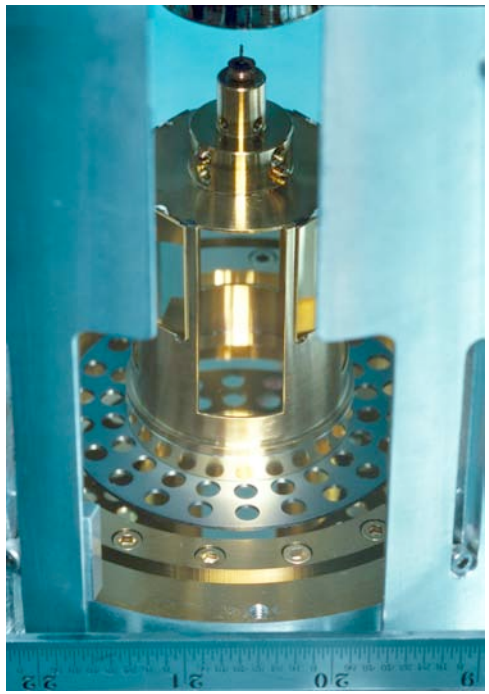
Cosmology= privileged testing ground for gravity

But can we do it in the laboratory?

How can we make progress?

Measure gravity at small distance





Adelberger et al.
U. of Washington

More precise tests of General Relativity in solar system

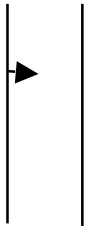
The factor of 10 attainable in laser lunar ranging can test ideas that an extra dimension could be responsible for the apparent acceleration of the universe

Dark Energy Detections in the Lab?

Quantum electrodynamics: Casimir effect

2 parallel metallic plates

Low k (large λ) modes cannot live inside parallel plates



imbalance => pressure

$$P = -\frac{\pi^2 \hbar c}{240\ a^4} = -\frac{1.310^{-13}}{(a/1\mu m)^4}\,\mathrm{N/m^2}$$

Note: also Van der Waals(alternative description) + orientation of micro-crystals: patch effect

Vacuum pressure as measured in cosmology

Not so small: $\rho_\Lambda \approx 3\mathrm{keV/cm}^3 \quad -p = \rho_\Lambda c^2 \approx 3\ 10^{-10}\mathrm{N/m}^2 \qquad \left(\frac{\hbar c}{\Lambda}\right)^3 \approx 10^{-4}\mathrm{m}$

but how to cancel some of the modes / modify boundary conditions

How do we evacuate the vacuum?

If new field (quintessence): possibility of breakdown of equivalence principle

If vacuum energy ????

Conclusions

Fascinating time in cosmology

Extraordinary progress (CMBR, Large Scale Structure)
But profound mystery
What is the non baryonic dark matter?
What is this mysterious dark energy?
+ unnaturalness of the model which recalls the artificiality of epicycles

From this point of view: 2 scientific priorities

Detect Dark Matter: show that it is not an epicycle
if we succeed this would be a second Copernican revolution!
very much linked to fundamental particle physics
Neutrino mass and see saw mechanism
Supersymmetry
May be even baryogenesis
Constrain better the nature of Dark Energy and if possible pin down its properties in the laboratory!
Likely that we are touching some very fundamental underlying property of quantum gravity

Conclusions 2

Searches for WIMPs are essential

Cosmology
Particle Physics and Gravitational Physics

Roadmap

Elastic scattering identifying event by event nuclear recoil
+ linking to galaxy
Phonon mediated detectors are leading the pack
challenge: extrapolate to 100kg/1 ton
Importance => Development of other large mass technology
liquid Xe is best candidate but fundamental response measurements still to be done

Essential of have large mass technology ready to complement LHC (at a very small fraction of the cost)

Best route to connection to galaxy is low pressure TPC: Particle Physics technology: we should be ready to make ≈10000 m^3 chambers + shielding if we see a signal

Keep an eye for indirect detection signal

Somewhat complementary
Unexpected phenomena