Can the Existence of Dark Energy Be Directly Detected

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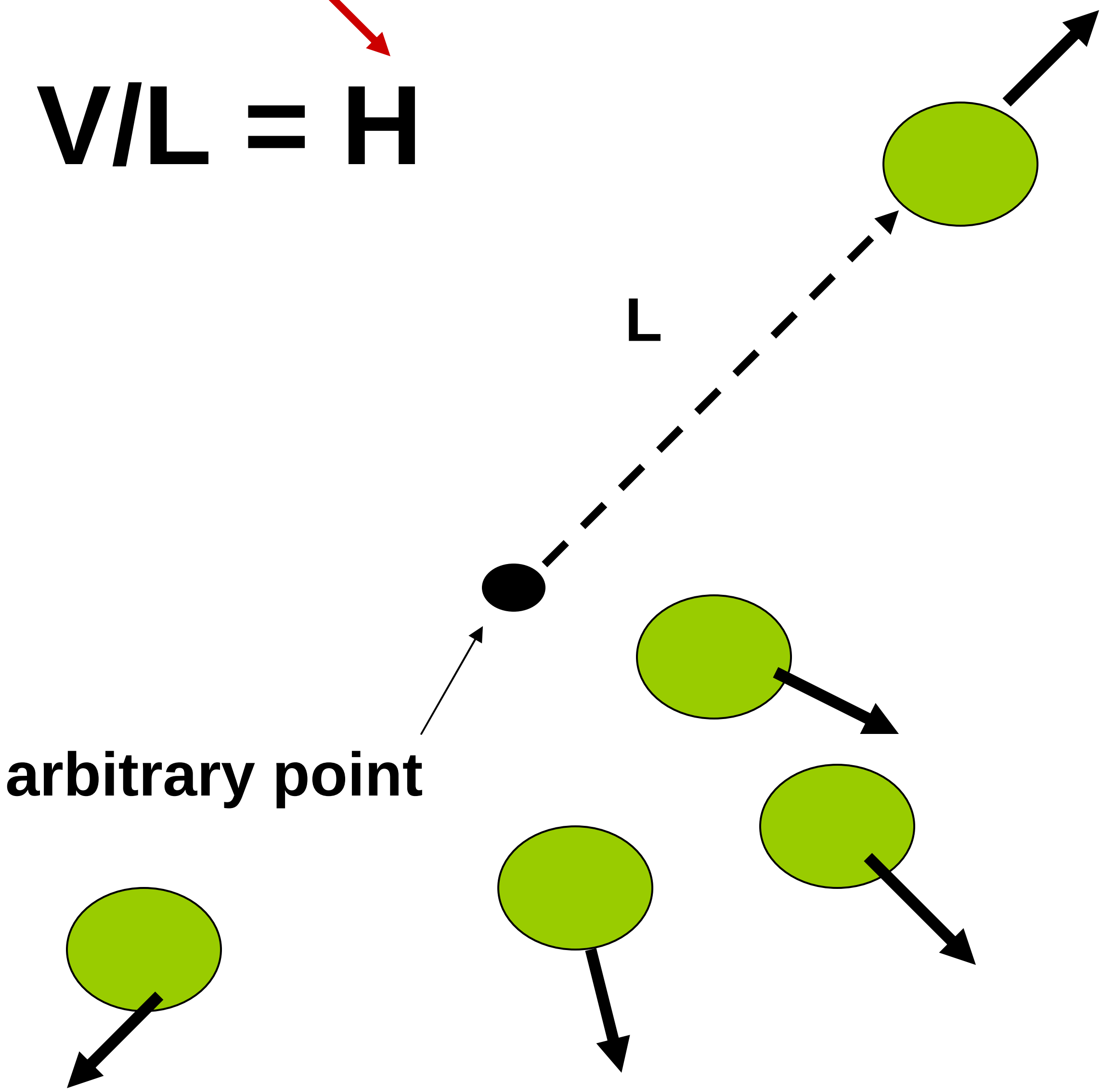
The majority of astronomers and physicists accept the reality of dark energy but also believe it can only be studied indirectly through observation of the motions of galaxies [P. J. E. Peebles and B. Ratra, *The Cosmological Constant and Dark Energy* arXiv:astro-ph/0207347v2, (2002)]

I open the experimental question of whether it is possible to directly detect dark energy through the presence of dark energy density. At present I do not have a practical answer to the question: Can the existence of dark energy be directly detected?

This talk has seven parts. The first part is about Hubble's law, the expansion of space, and General Relativity.

Expansion of Space and Hubble's Law

$$V/L = H$$



H called Hubble parameter is time dependent.

Expansion of Space and Hubble’s Law

Hubble’s law and parameter derive from astronomical observation and measurement.

Expansion of Space and Hubble's Law

At present we measure $H \approx 2 \times 10^{-18}\ s^{-1}$

Example: Nearest galaxy Andromeda

1 ly=1 light year = 10^{16} m

For Andromeda galaxy L=$2.5\text{x}10^{6}$ ly

Hence V(Andromeda)= $5\text{X}10^{-12}$ ly/s

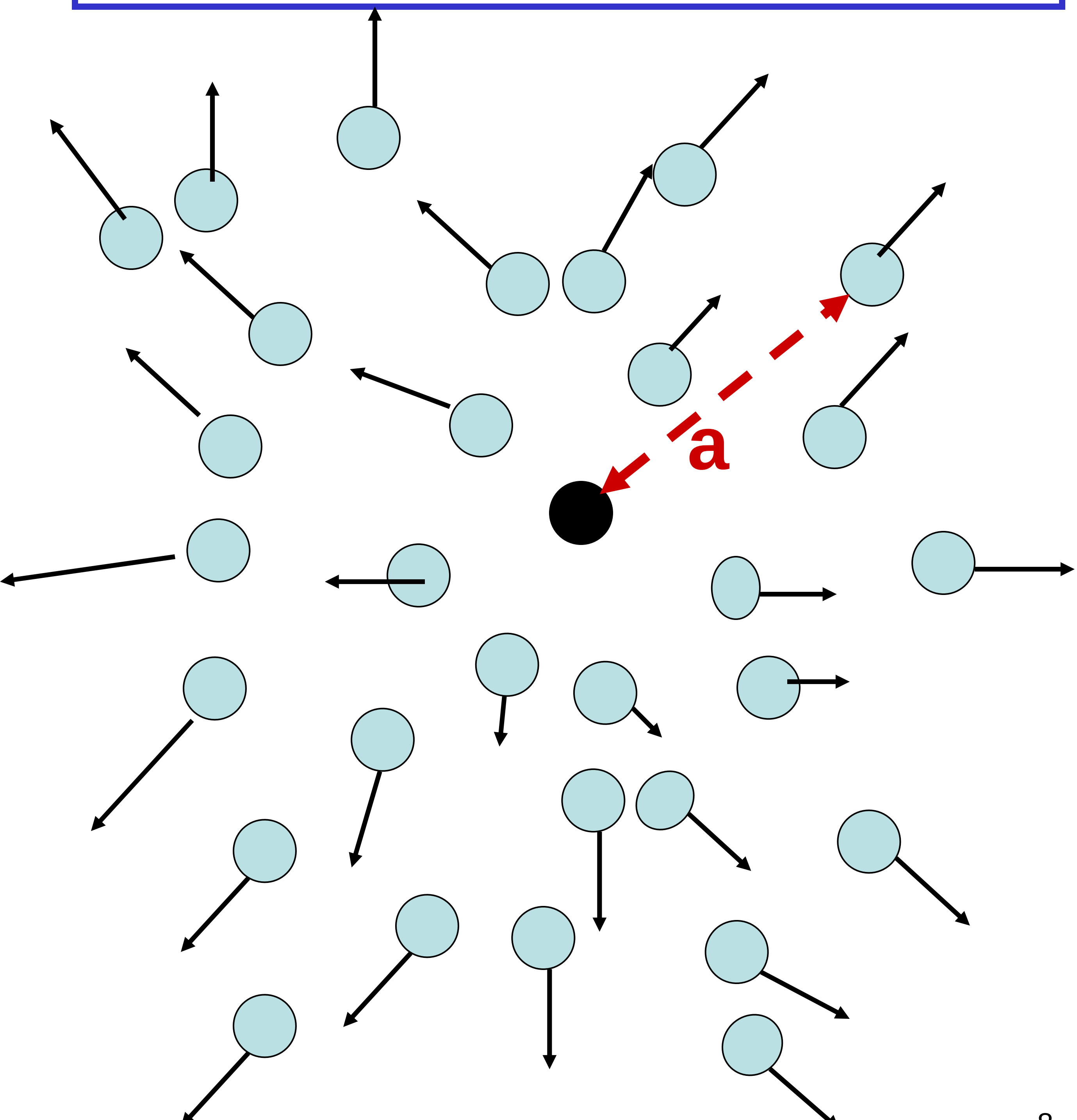
=50,000 m/s

Expansion of Space and Hubble's Law

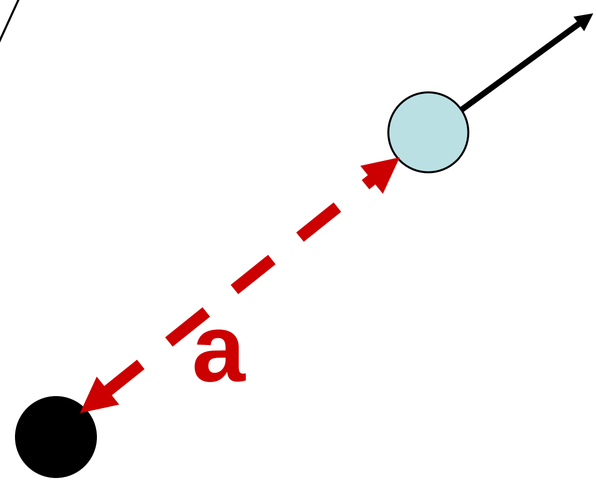
The picture is that space is *expanding* as time increases but the objects in space: atoms, planets, galaxies, clusters of galaxies are not expanding.

A difficult concept when we think about distances between clusters or larger

Expansion of Space, Hubble's Law and Scale Factor a



Expansion of Space, Hubble’s Law and Scale Factor a



$$\frac{da/dt}{a} = H$$

Expansion of Space and General Relativity

- General relativity
- Thermodynamics
- Astronomical data that shows space-time is flat
- Astronomical data that shows more matter than photons in the universe

These theories and observations predict the behavior of H with time will be:

$$H/H_0 = (t/t_0)^{-1/3}$$

Expansion of Space, Hubble parameter H, and Scale Factor a

$$H/H_0 = (t/t_0)^{-1/3}$$

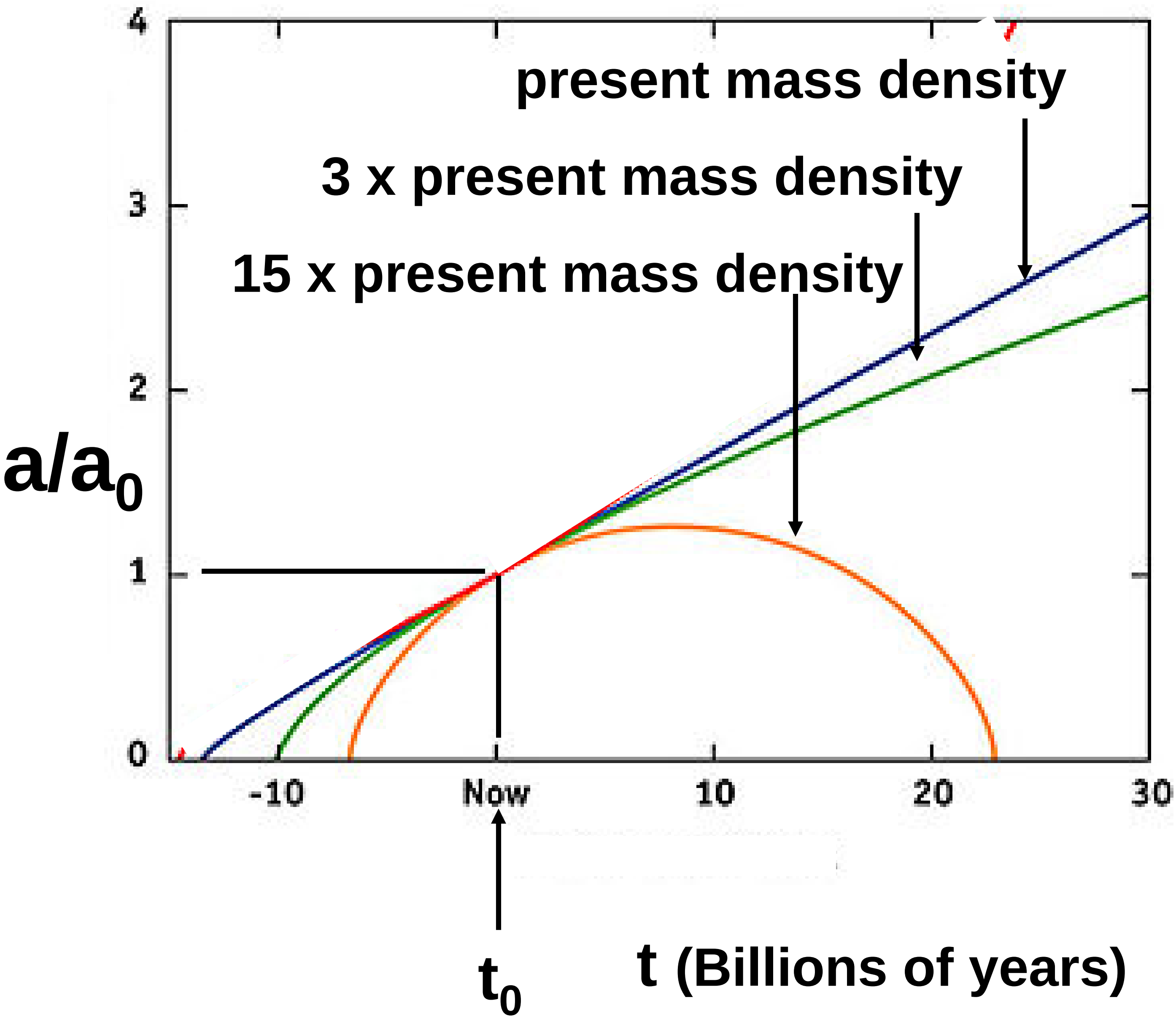
$$a/a_0 = (t/t_0)^{+2/3}$$

This predicts that as time increases:

- **H will decrease**
- **Scale factor a will grow more and more slowly**

- **Space will expand more and more slowly**

Expansion of universe in terms of normalized scale factor a/a_0 versus time. Only matter

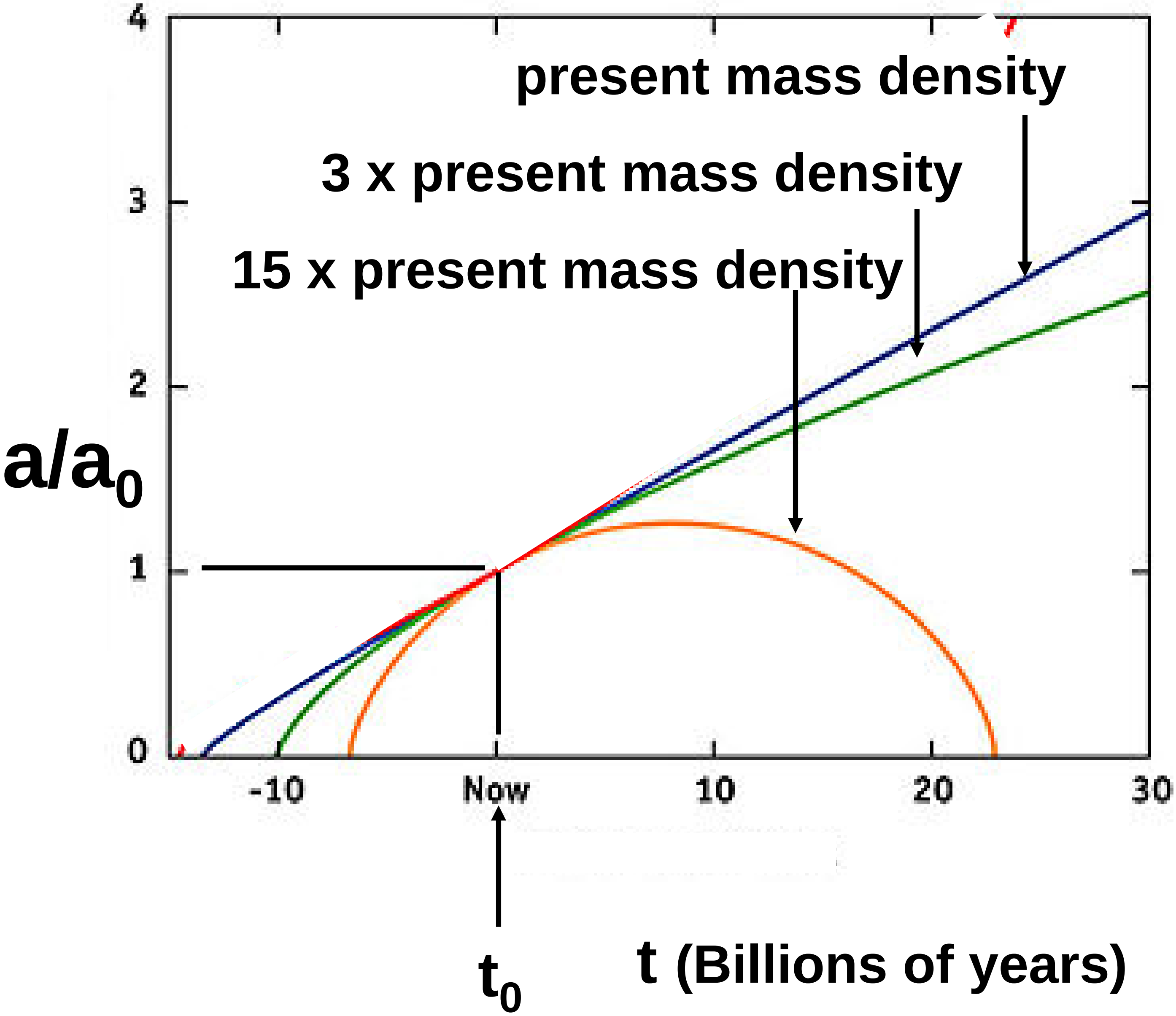


Expansion of Space, Hubble parameter H, and Scale Factor a

This prediction is based on the astronomical observations that the universe is dominated by the presence of matter including dark matter as opposed to being dominated by photons.

The gravitational attraction between all this matter slows up the expansion of the universe. but does not reverse the expansion.

Expansion of universe in terms of normalized scale factor a/a_0 versus time. Only matter



Expansion of Space, General Relativity and *Dark Energy*

But recent measurements of the motion of far off galaxies show with fairly good data that a is increasing faster with t and that H can be fit by a constant

This has led to the hypothesis that there is a large amount of unknown energy in the universe, about 3 times the equivalent energy of the matter in the universe.

Called *Dark Energy*

The second part of this talk describes the Dark Energy Model

Dark Energy is a misleading name.

It has nothing to do with dark or black.

It is not the ordinary kind of energy. Ordinary energy such as nuclear or electromagnetic acts as matter in gravitational fields since $M=E/c^2$.

It has other names usually cosmological constant or quintessence. But these names are model dependent.

Dark Energy Model

$$H = H_0 = \text{constant}$$

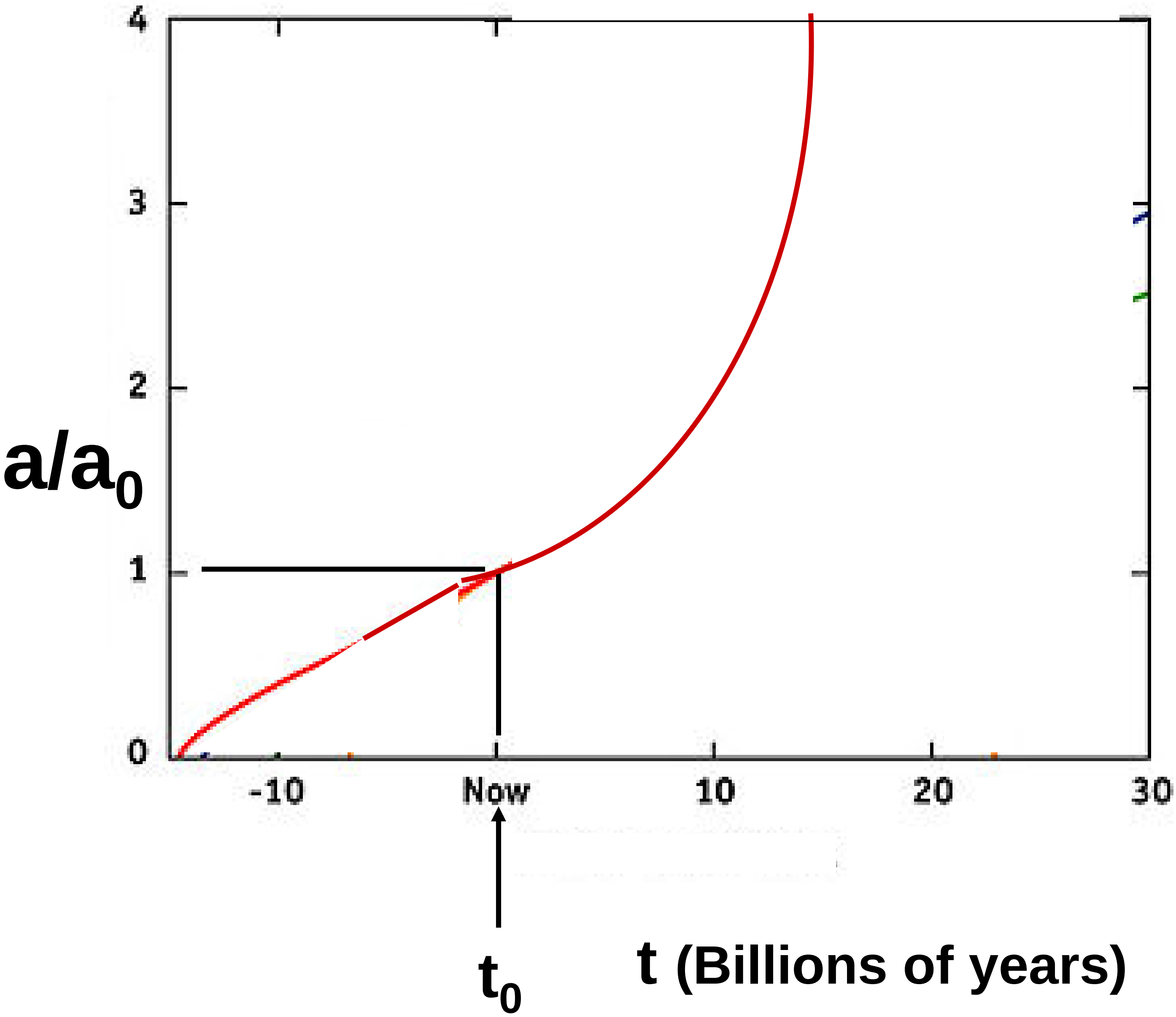
$$\frac{da/dt}{a} = H_0$$

$$a/a_0 = e^{H_0(t - t_0)}$$

This predicts that as time increases:

- **H is constant**
- **Scale factor a grows exponentially**
- **Space will expand exponentially**

Expansion of universe in terms of normalized scale factor a/a_0 versus time. Dark Energy only.

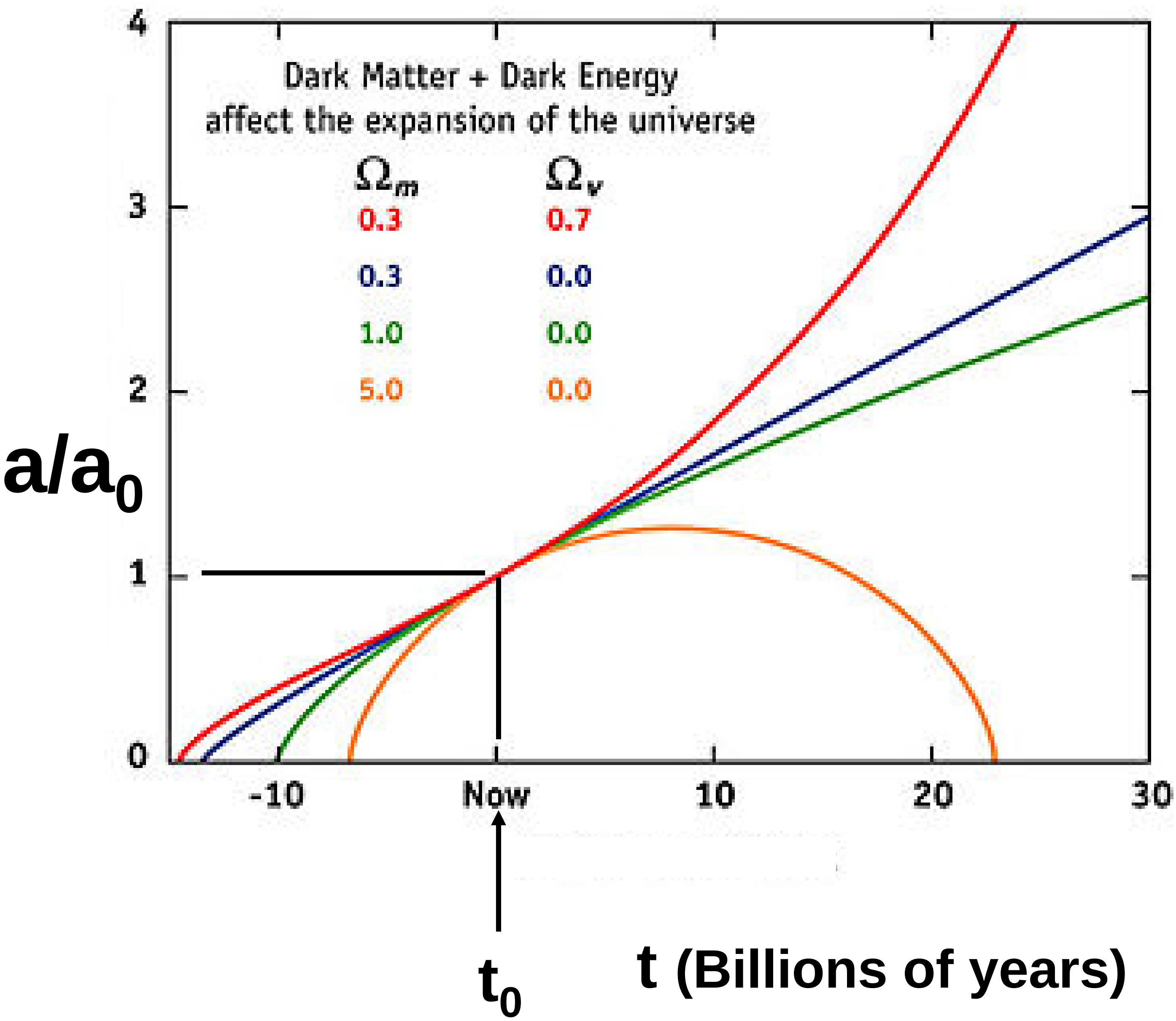


Present Dark Energy plus Matter Model of Universe

The present model of the universe is that is made of about:

- **70% Dark Energy**
- **30% Matter**

Expansion of universe in terms of normalized scale factor a/a_0 versus time. Matter + Dark Energy



Average Density of All Energy , Mass and Dark Energy in the Universe

Present Model

**Counting mass as energy via $E=Mc^2$,the average density of all energy is 9 x10^{-10} J/$m^{3.}$
J means joules). This is call the critical energy**

ρ_{crit} = 9 x10^{-10} J/m^3

Average Density of All Energy , Mass and Dark Energy in the Universe

Present Model

$\rho_{mass} \approx 0.3 \text{ x } \rho_{crit} = 2.7 \text{ x} 10^{-10} \text{ J/m}^3$

$\rho_{dark\ energy} \approx 0.7 \text{ x } \rho_{crit} = 6.3 \text{ x} 10^{-10} \text{ J/m}^3$

↓

ρ_{DE}

Dark Energy Density and Related Densities: Magnitude of Dark Energy Density

$\rho_{DE} \sim 6.3 \times 10^{-10}$ **Joules/m^3**

Compare to electric field of *E*=1 volt/m

using ρ_E = electric field energy density. Then

$\rho_E = e_0 E^2/2 = 4.4 \times 10^{-12}$ **J/m^3**

This is easily detected and measured. Thus we work with fields whose energy densities are much less than ρ_{DE}

Dark Energy Density and Related Densities: Magnitude of Dark Energy Density

Obvious reasons for ease of working with electric fields:

- **q*E* force is strong in laboratory**
- **electron currents**
- **magnetic fields**

Dark Energy Density and Related Densities: Gravitational Energy Density

ρ_G = gravitational energy density =

$$\rho_G = g^2/(8\pi G_N)$$

At earth's surface $\rho_G = 5.7\times 10^{+10}$ J/m^3

and $\rho_{DE}/\rho_G \sim 10^{-20}$.

If detection method for ρ_{DE} is at all affected by gravity, cannot work on earth's surface.

Dark Energy Density and Related Densities: Gravitational Energy Density (continued)

The distance from the sun required to reduce ρ_G to ρ_{DE} is

$r_{from\ sun}$ =3x10^{14} m =2000 AU

This is in the Oort Cloud region. Hopeless!

Obvious Experimental Problems in Detecting Dark Energy Density

Cannot turn dark energy on and off.

Cannot find a zero dark energy field for reference.

In the some hypothesis about dark energy, its field may not exert a force on any material object beyond its mass equivalent.

This concludes Part Two of my talk in which I have outlined the motivation for introducing Dark Energy and the Dark Energy Model (The talk has seven parts)

In the next part, Part Three, I discuss the Planck quantities that have important but confusing roles in gravitation, General Relativity and cosmology

Planck Magnitudes

$$M_{Planck} = [\hbar c/G]^{1/2}$$

$\hbar$ = Planck's constant

c = velocity of light

G = Newton's gravitational constant

$$M_{Planck} = 2.2 \times 10^{-8}\ \text{kg}$$
$$= 1.2 \times 10^{19}\ \text{GeV}/c^2$$

enormous mass

$$E_{Planck} = M_{Planck}\, c^2$$

$$E_{Planck} = 2.0 \times 10^{9}\ \text{J}$$

Another Planck Magnitudes

$$L_{\text{Planck}} = [\,\hbar G/c^3\,]^{1/2}$$

$$L_{\text{Planck}} = 1.6 \times 10^{-35}\ \text{m}$$

My Skepticism on Significance of Planck Magnitudes

Things that bother me:

M_{Planck} mixes a constant from quantum mechanics with two classical constants

It is often said that the Planck Energy is the region where quantum mechanics intersects with general relativity in an intimate way. Not everyone agrees, for example [F. Dyson, New York Rev. Books, 51, (2004)]

What do these quantities have to do with Dark Energy?

In Part Four coming up, I discuss a general relation between the range of a force and the associated particle that might help see if Dark Energy has a particle aspect.

The General Mass-Length Relationship: Yukawa Potential

Early example: Non-relativistic Yukawa potential using his interpretation of nuclear force as caused by pion exchange.

The relation between a force of range *L* carried by a particle of mass *M* is

$$M \times L = \hbar / c$$

$$= 1.97 \times 10^{-13}\ \text{MeV}/c^2\ \text{meters}$$

$$= 3.51 \times 10^{-43}\ \text{kg meters}$$

Thus for nuclear force with $L=10^{-15}$meters pion mass = 197 MeV/c^2

The General Mass-Length Relationship: Weak Force

Weak force example:

Use W and Z^0 masses about 100 GeV/c^2 = 10^5 MeV/c^2

Use L_{weak} = 1.97 x $10^{-13}/10^5$ =2 x 10^{-18} m

Often use approximation that
σ = cross section ~ L_{scale}^2

Thus σ_{weak} ~ L_{weak}^2 ~ 10^{-36} m^2 ~ picobarn

Crude average

The General Mass-Length Relationship: Electromagnetic and Gravitational Forces

The electromagnetic and gravitational force have L infinite, compatible with $\text{Mass}_{\text{photon}} = 0$ and $\text{Mass}_{\text{graviton}} = 0$

The General Mass-Length Relationship: Dark Energy Length and Frequency

To calculate a length, L_{DE} for dark energy it is conventional to use

$$L_{DE} = [\hbar c / \rho_{DE}]^{1/4} = 84 \times 10^{-6}\ \mathrm{m}$$

$$\approx 100\ \text{microns}$$

The General Mass-Length Relationship: Dark Energy Length and Mass

We already have

$L_{DE} = 84 \times 10^{-6}$ **m**

Then using $M = (\hbar / c) / L$

$Mass_{DE\_} = 2.5 \times 10^{-9}$ MeV/c^2

Does this make sense or is it just dimensional analysis?

The General Mass-Length Relationship: Dark Energy and another Mass calculation.

Using dimensional analysis there are other calculations for M_{DE}

Following Wesson. [P. S. Wesson, *Is mass quantized?*,Mod.Phys.Lett.,A19:1995 (2004)]

define

$$L'_{DE}=c^2/(\rho_{DE}G_N)^{1/2} = 1.4\text{x}10^{26}\ \text{m}$$

Very long range since diameter of visible universe ~ 10^{11} light years ~ 10^{26} m

Then $M'_{DE} = 3\text{x}10^{-69}$ kg $=1.5\text{x}10^{-39}$ MeV/c^2, very light particle.

This concludes the fifth part of my talk.

In the sixth part I discuss the attempts to explain Dark Energy as being Zero Point Vacuum Energy.

This is a vexing problem.

The Zero Point Vacuum Energy Puzzle in Fundamental Quantum Mechanics

ω

$\omega = 2\pi f$
f = frequency

Electromagnetic field in a conducting cavity has modes

$\omega_1, \omega_2, \omega_3 \ldots$

With n_i in photons in mode ω_i, the energy is

$E_i = [n_i + ½]\hbar w_i$

With zero photons: $E_0 = 1/2 \hbar w_i$

the zero point energy

The Zero Point Vacuum Energy Puzzle in Fundamental Quantum Mechanics

Integrating over all zero point energies gives

$$\rho_{VE} = \hbar\, \omega_{max}^4 / 16\pi^2 c^3$$

↑

$\rho_{vacuum\ energy}$

But what is ω_{max}? Why should there be an upper limit

The Zero Point Vacuum Energy and Dark Energy

Old idea set $\omega_{max}=2\pi c/L_{Plank}$ where

$L_{Plank} = 1.6 \times 10^{-35}$ m

Then $\omega_{max} = 1.2 \times 10^{44}\ s^{-1}$

and

$\rho_{vacuum\ energy} = 4.8\ x10^{114}$ J/m3

Reminder about $\rho_{\text{dark energy}}$ and comparing with $\rho_{\text{vacuum energy}}$ just calculated

$\rho_{\text{dark energy}} \approx$ **0.7 x** ρ_{crit} **= 6.3 x10^{-10} J/m^3**

$\rho_{\text{vacuum energy}}$ **= 4.8 x10^{114} J/m^3**

$$\frac{\rho_{\text{vacuum energy}}}{\rho_{\text{dark energy}}} \approx 10^{124}$$

Infamous, senseless result

The Obscure Relation of Dark Energy to Vacuum Energy

Some "cures":

Assume the existence of many fields exquisitely cancels the large ρ_{VE} almost exactly.

Assume ω_{max} is cutoff at much less than ω_{Planck}.

Adopt the Volovik view of dark energy using analogies to solid state physics. I don't understand his ideas.

[G. E. Volovik, *Vacuum Energy: Myths and Reality*, arXiv:gr-qc/0604062v4, (2006)] *This concludes the sixth part of my talk.*

In the final part I discuss experimental ideas for probing Dark Energy density.

Experimental Probe: Electromagnetic

C. Beck et al. [C. Beck and M. C. Mackey, *Electromagnetic dark energy*, Int. J. Mod. Phys., D17,71(2008); C. Beck and C Jacinto de Matos, arXiv: gr-qc/0709.237v1(2007)] **have proposed that the noise spectrum in superconductors will decrease for frequencies above $f_{DE} = 4 \times 10^{12}$ Hz. They propose using Josephson junctions for the test.**

This idea is criticized by P.Jetzer and N. Straumann [P.Jetzer and N. Straumann *Has Dark Energy really been discovered in the Lab?* astro-ph/0411034v2, (2004)]

Experimental Probe: Gravitational

Does the gravitational inverse square law

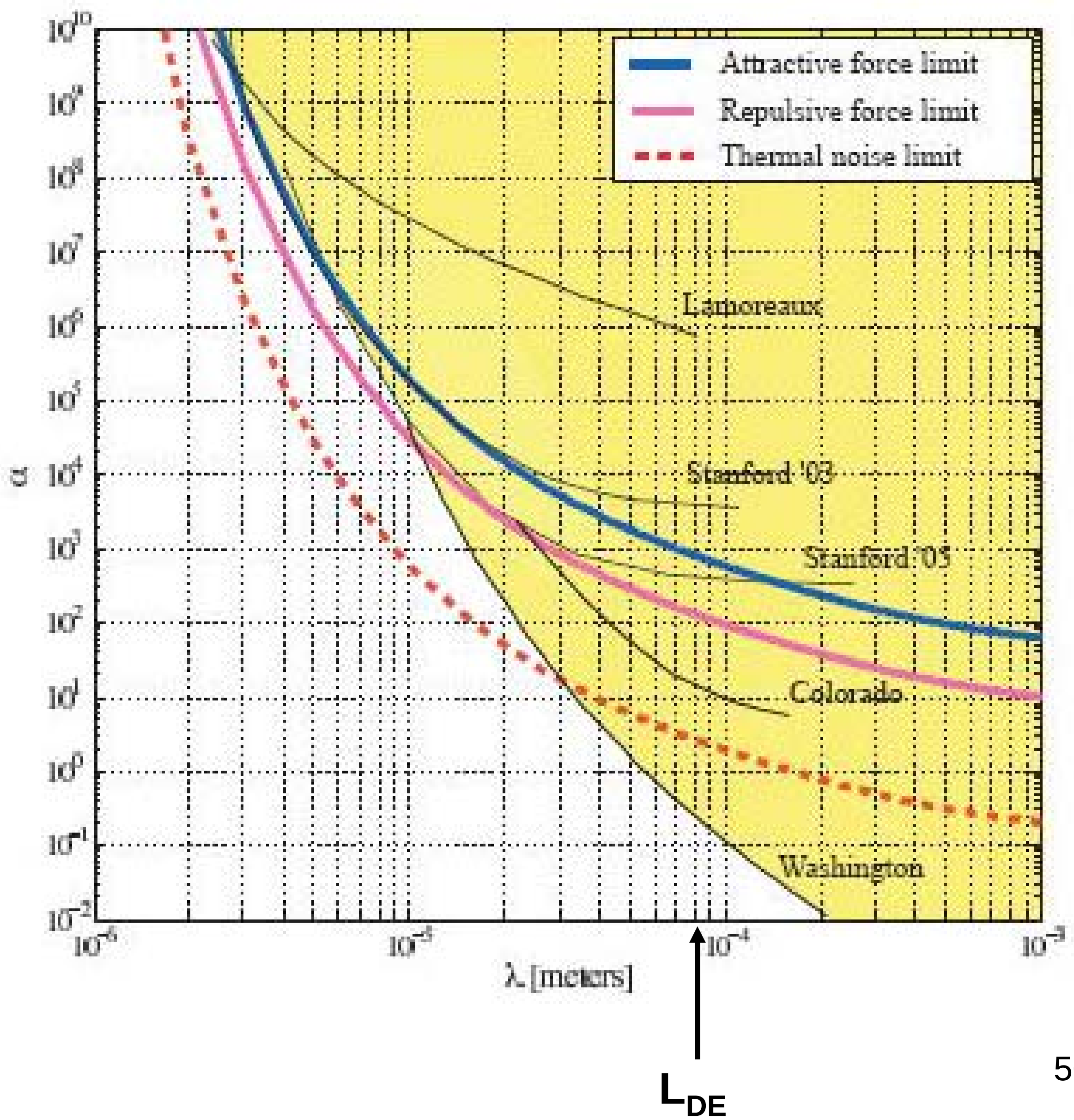
break down at distances < L_{DE} = 84 x 10^{-6} m?

Use:

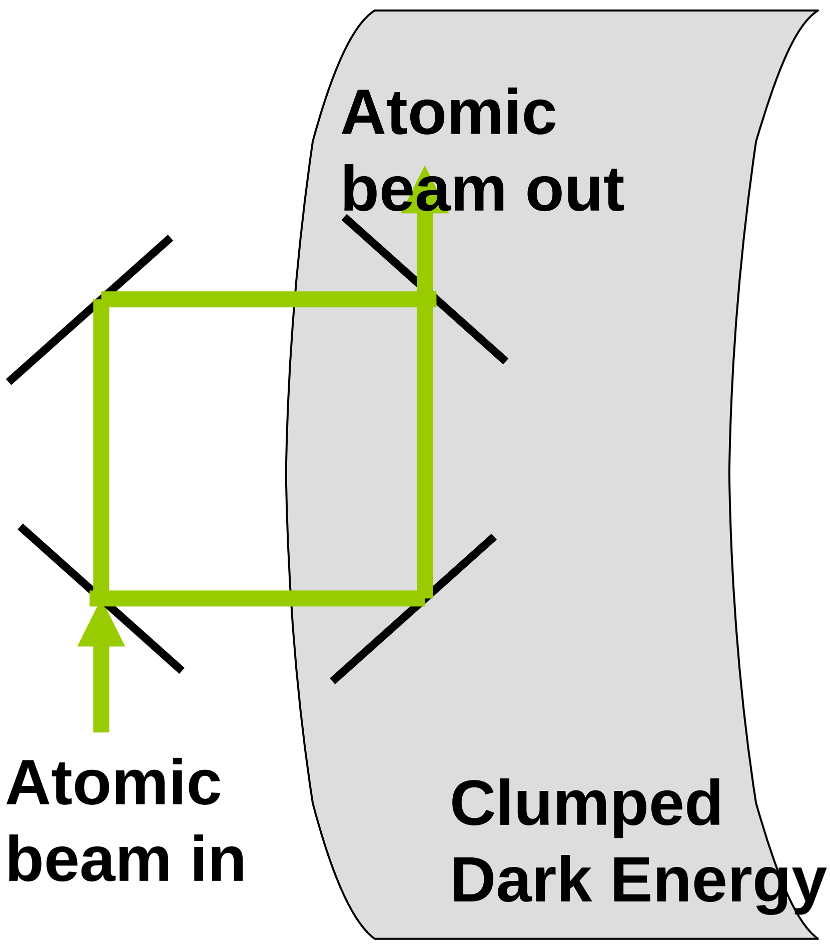
$V(r) = -G\ (m_1 m_2/r)\ [1+a\ \exp(-r/l)]$

Experimental Probe: Gravitational

D. J. Kapner et al., *Tests of the gravitational inverse-square law below the dark-energy length scale.*, Phys. Rev. Lett. 98, 021101 (2007)



Experimental Probe: Atom Interferometry



Atom Interferometry (San Diego, Academic Press, 1997), Ed. P. R. Berman

Experimental Probe: Hypothetical Particle Nature of Dark Energy

Does dark energy have a particle nature consistent with our 90 year old understanding of quantum mechanics?

Can this be used to detect ρ_{DE}?

With $L_{DE} = 84 \times 10^{-6}$ m

Then $M_{DE} = 2.5 \times 10^{-9}$ MeV/c^2

But if M_{DE} is a conventional particle it will act as matter not as Dark Energy

There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy.

Shakespeare

Thank you