

SHEDDING
LIGHT
ON
DARK
MATTER

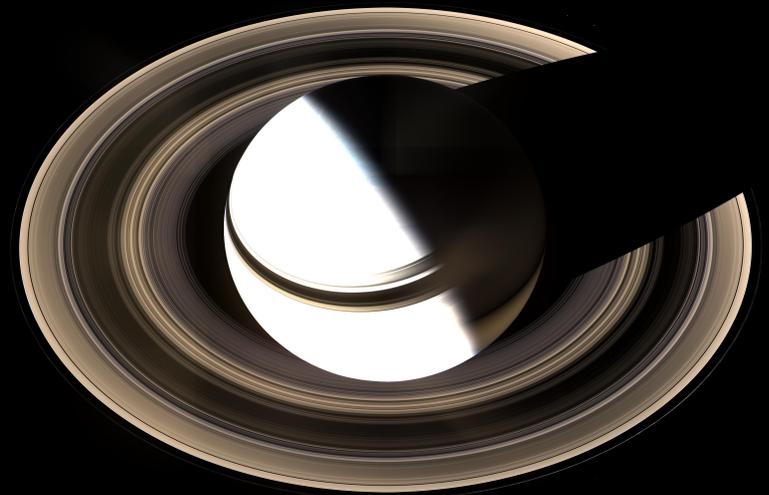
SCOTT V. BURGER

WESTERN WASHINGTON UNIVERSITY

OVERVIEW

WHAT WE PLAN TO ACCOMPLISH

- Misconceptions of Dark Matter
- Dark Matter versus 'normal' matter
- History of Dark Matter



http://apod.nasa.gov/apod/image/0703/saturnfromabove_cassini.jpg

DATA CENTER (DM) IN POPULAR CULTURE

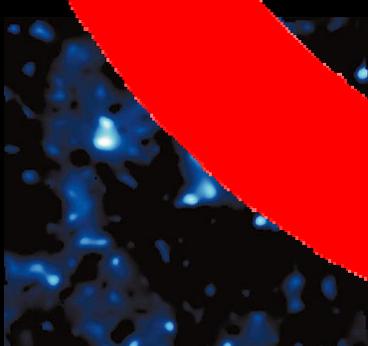
Star Trek



Science Fiction



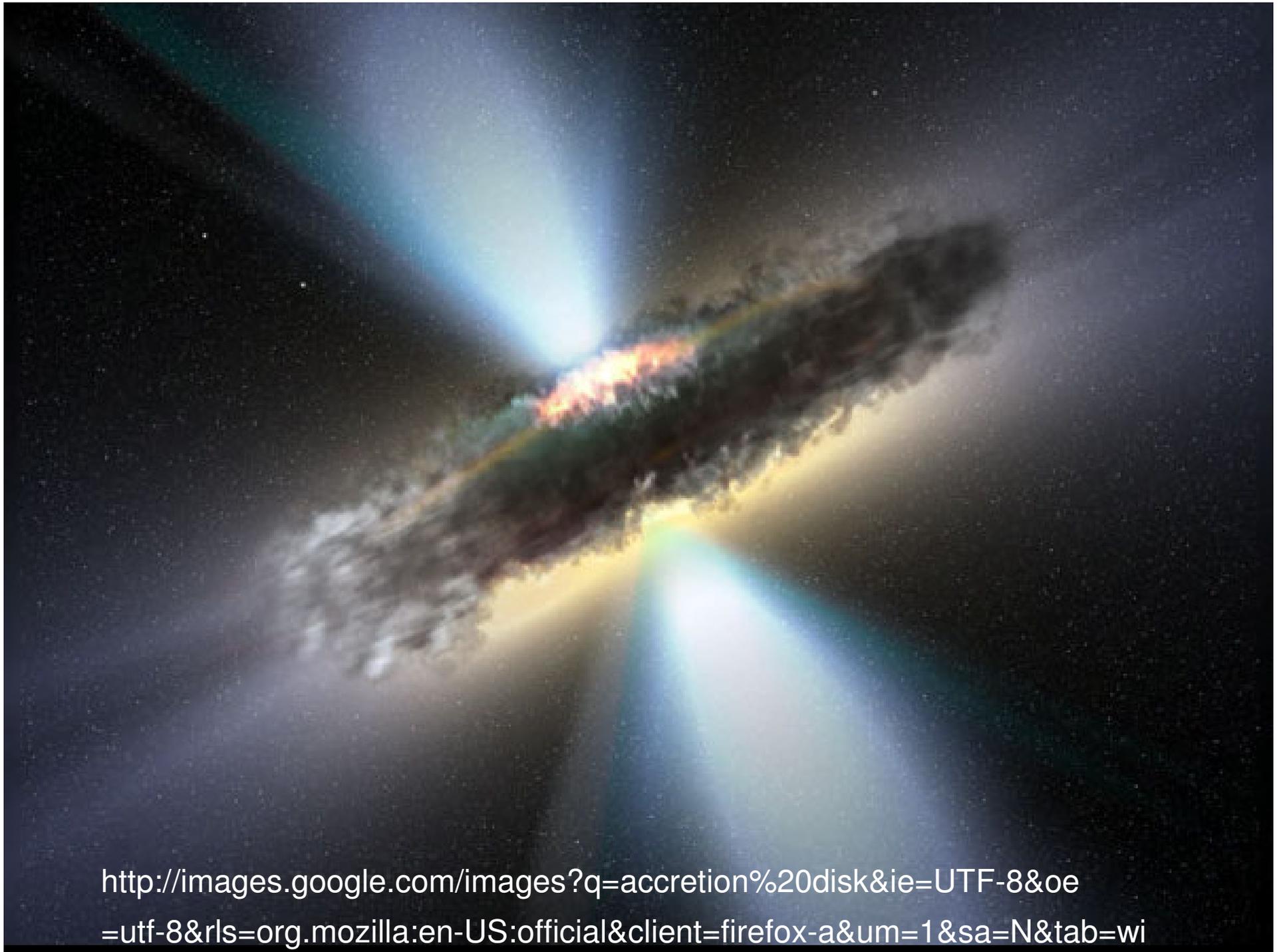
Outer Space



Totally wrong...



<http://imgsrc.hubblesite.org/hu/db/2004/04/images/a/formats/print.jpg>

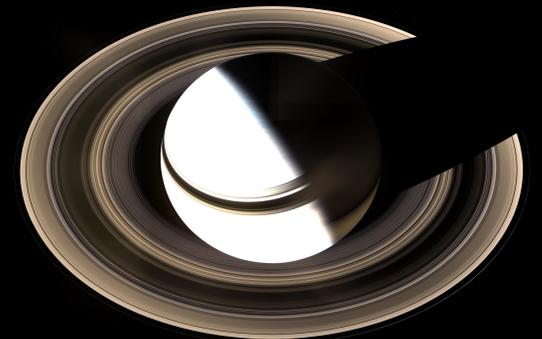


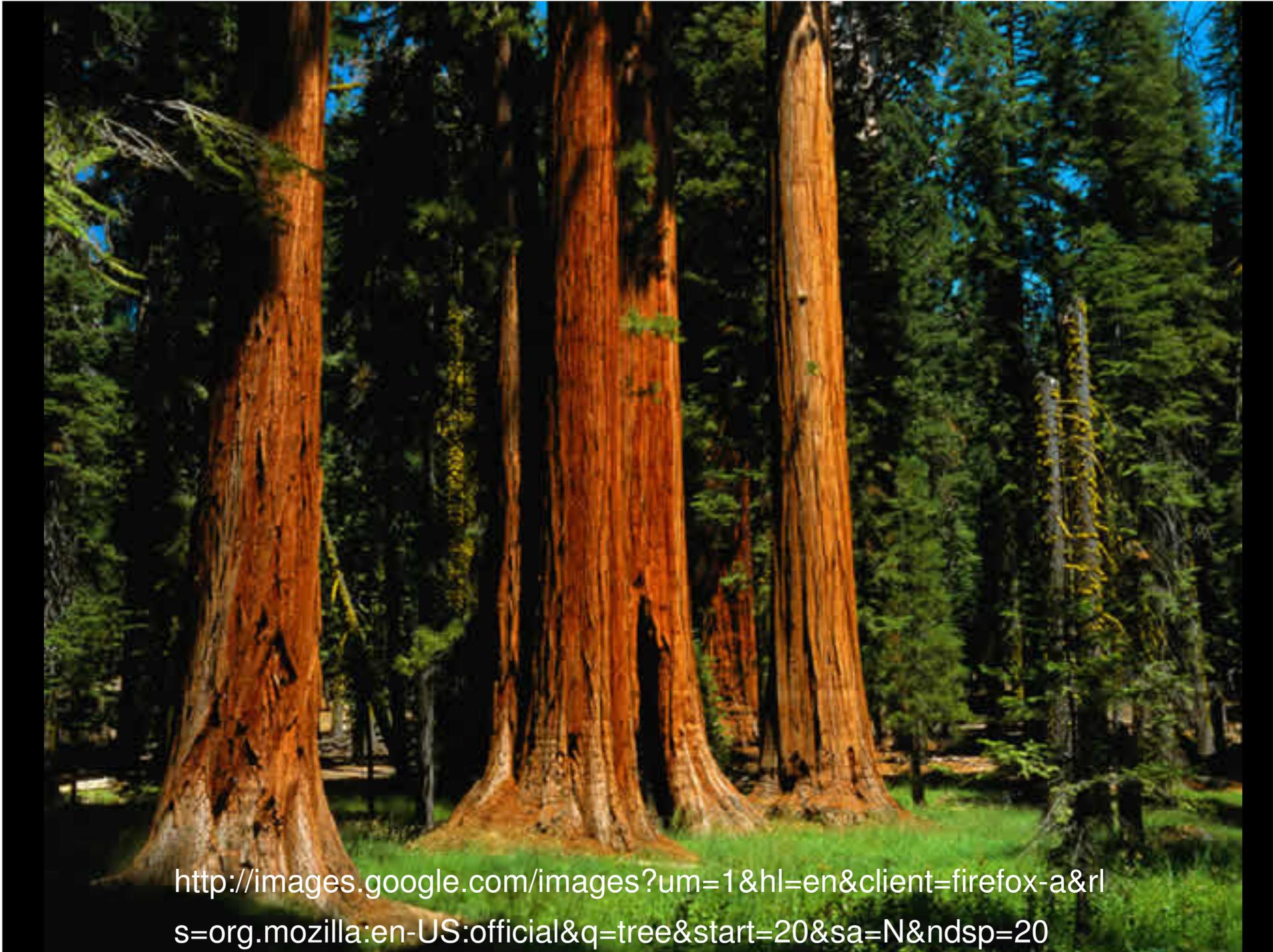
<http://images.google.com/images?q=accretion%20disk&ie=UTF-8&oe=utf-8&rls=org.mozilla:en-US:official&client=firefox-a&um=1&sa=N&tab=wi>

SHADY COMPOSITION

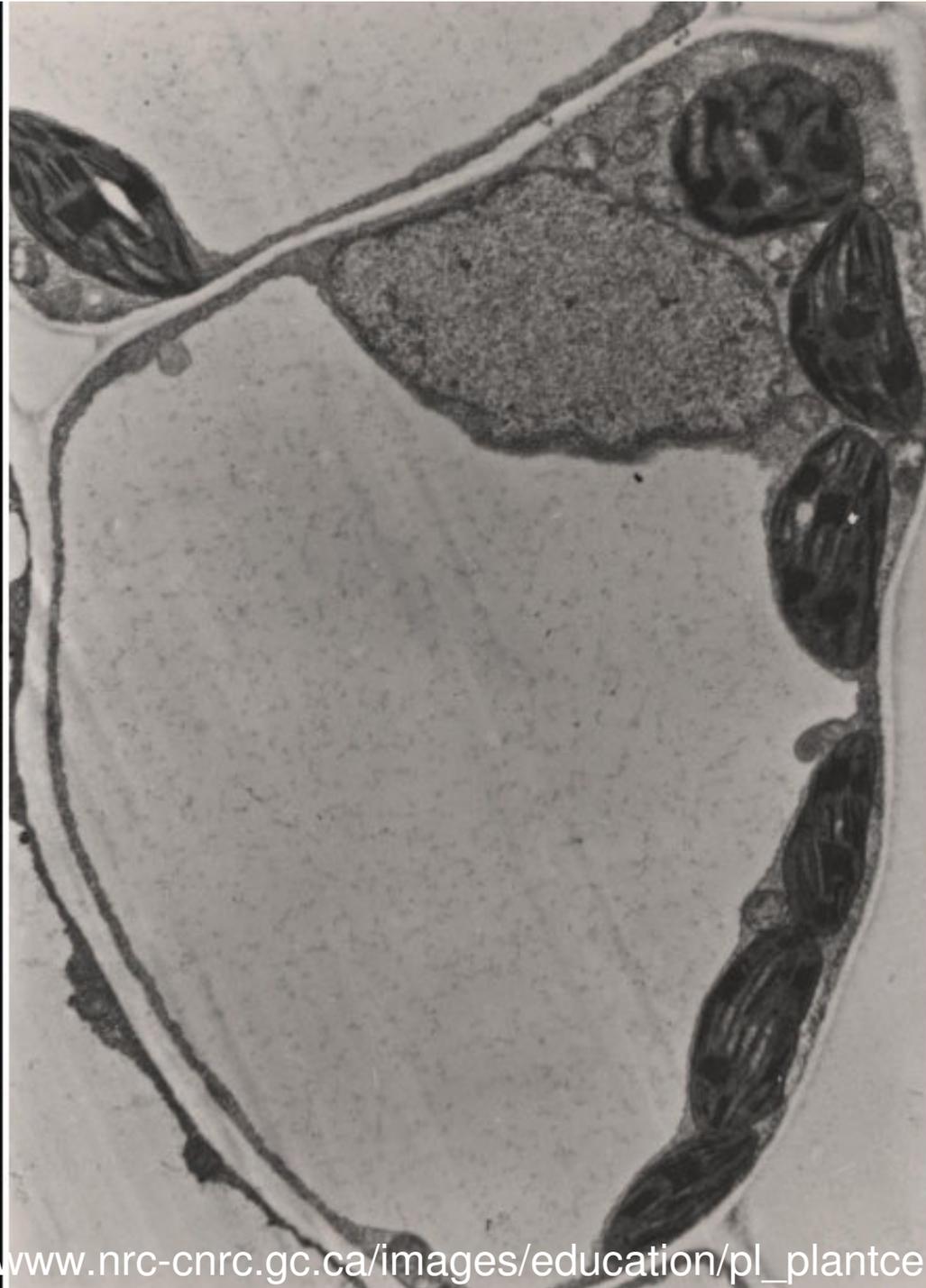
WHAT IS DM MADE OF

- What is matter?
 - Everything we see, touch, taste, smell or hear is made of matter. The chairs you're sitting in to the beams of electrons in the television.

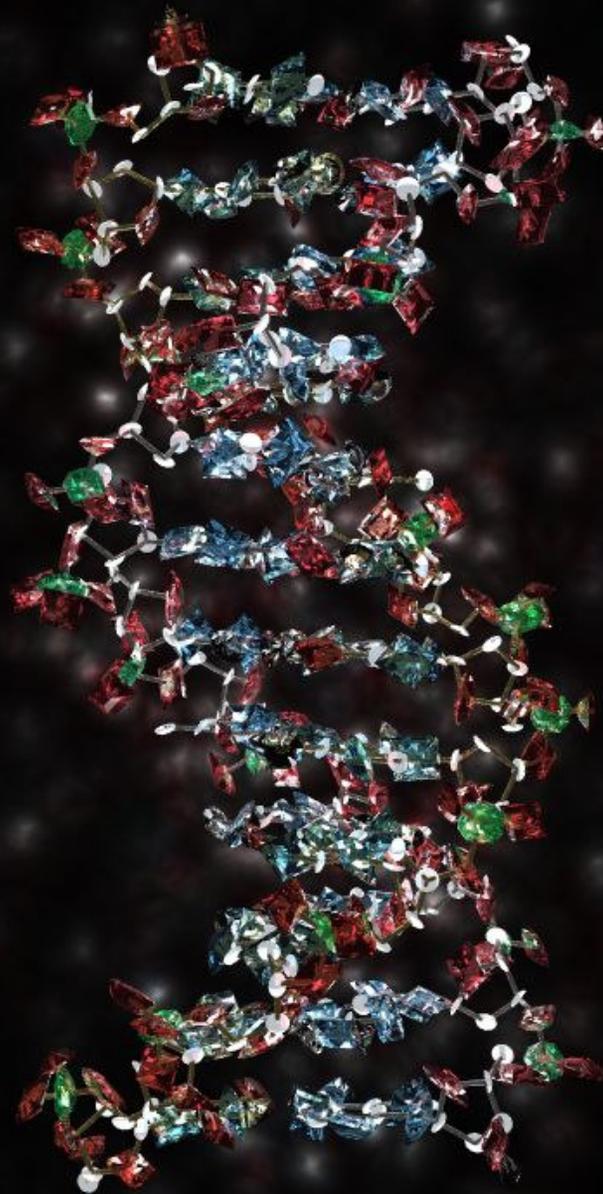




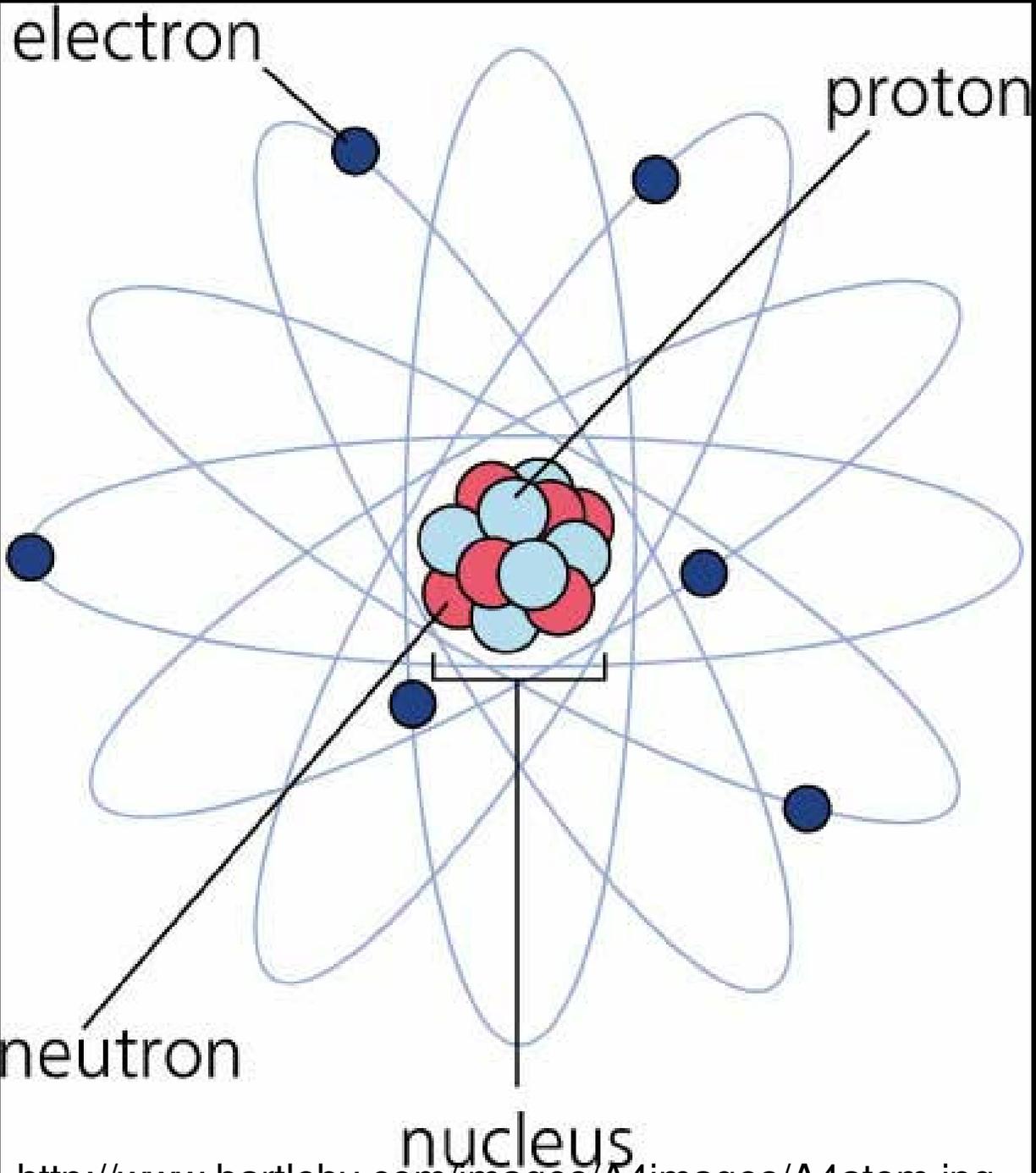
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http://www.nrc-cnrc.gc.ca/images/education/pl_plantcel.jpg

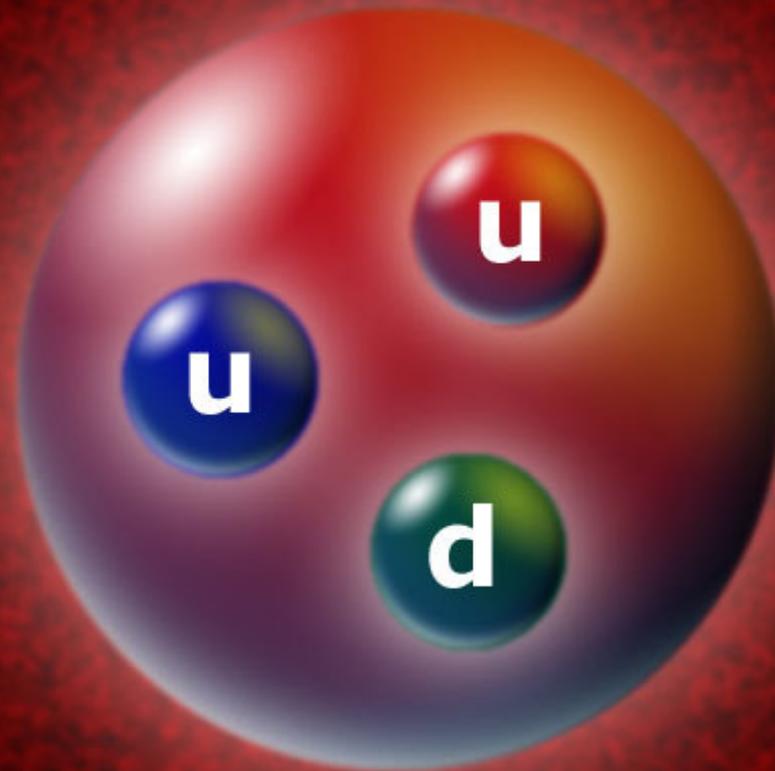


<http://www.blog.speculist.com/archives/gem-dna.jpg>



<http://www.bartleby.com/images/A4images/A4atom.jpg>

Academy Artworks



proton

[http://images.google.com/images?q=quark&btnG=Search+Images
&um=1&hl=en&client=firefox-a&rls=org.mozilla%3Aen-US%3Aofficial&sa=2](http://images.google.com/images?q=quark&btnG=Search+Images&um=1&hl=en&client=firefox-a&rls=org.mozilla%3Aen-US%3Aofficial&sa=2)

Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge	Flavor	Approx. Mass GeV/c ²	Electric charge
ν_e electron neutrino	<1×10 ⁻⁸	0	U up	0.003	2/3
e electron	0.000511	-1	d down	0.006	-1/3
ν_μ muon neutrino	<0.0002	0	C charm	1.3	2/3
μ muon	0.106	-1	S strange	0.1	-1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ tau	1.7771	-1	b bottom	4.3	-1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of \hbar , which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58 \times 10^{-25}$ GeV s = 1.05×10^{-34} J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c² (remember $E = mc^2$), where $1 \text{ GeV} = 10^9 \text{ eV} = 1.60 \times 10^{-10}$ joule. The mass of the proton is $0.938 \text{ GeV}/c^2 = 1.67 \times 10^{-27}$ kg.

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1			Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge	Name	Mass GeV/c ²	Electric charge
γ photon	0	0	g gluon	0	0
W⁻	80.4	-1			
W⁺	80.4	+1			
Z⁰	91.187	0			

Color Charge

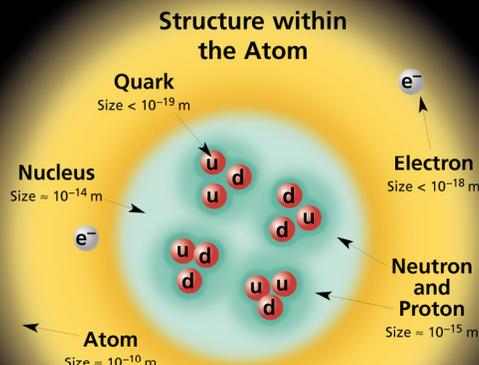
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and **W** and **Z** bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons

One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq .

Residual Strong Interaction

The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.



If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

PROPERTIES OF THE INTERACTIONS

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$					
Baryons are fermionic hadrons. There are about 120 types of baryons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c ²	Spin
p	proton	uud	1	0.938	1/2
\bar{p}	anti-proton	$\bar{u}\bar{u}\bar{d}$	-1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	-1	1.672	3/2

Property	Interaction	Gravitational	Weak		Electromagnetic		Strong	
			(Electroweak)		Fundamental		Residual	
Acts on:		Mass - Energy	Flavor		Electric Charge		Color Charge	See Residual Strong Interaction Note
Particles experiencing:		All	Quarks, Leptons		Electrically charged		Quarks, Gluons	Hadrons
Particles mediating:		Graviton (not yet observed)	W⁺ W⁻ Z⁰		γ		Gluons	Mesons
Strength relative to electromag for two u quarks at:	10^{-18} m 3×10^{-17} m for two protons in nucleus	10^{-41}	0.8		1		25	Not applicable to quarks
		10^{-41}	10^{-4}		1		60	
		10^{-36}	10^{-7}		1		Not applicable to hadrons	

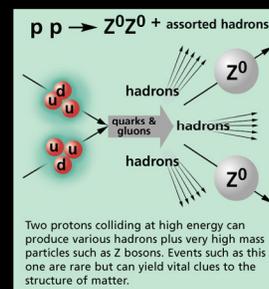
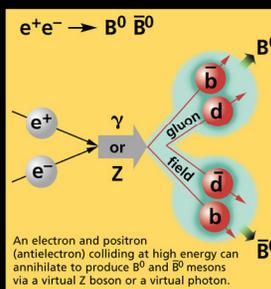
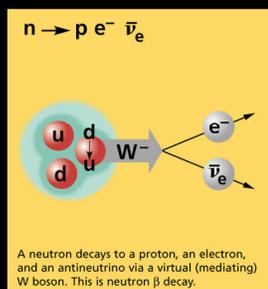
Mesons $q\bar{q}$					
Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c ²	Spin
π^+	pion	u\bar{d}	+1	0.140	0
K^-	kaon	s\bar{u}	-1	0.494	0
ρ^+	rho	u\bar{d}	+1	0.770	1
B^0	B-zero	d\bar{b}	0	5.279	0
η_c	eta-c	c\bar{c}	0	2.980	0

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or - charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0 , γ , and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

Figures

These diagrams are an artist's conception of physical processes. They are not exact and have no meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.



The Particle Adventure

Visit the award-winning web feature *The Particle Adventure* at <http://ParticleAdventure.org>

This chart has been made possible by the generous support of:

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American Physical Society, Division of Particles and Fields
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<http://CPEPweb.org>

BARYONIC MATTER

THE HEAVY HITTERS



Barry Bonds

Barry Bonds

Barry Bonds



Three Strikes, YOU'RE OUT!

WHAT'S THE MATTER

ENERGY DENSITIES

- All energy in the universe is mass
- All mass in the universe is energy

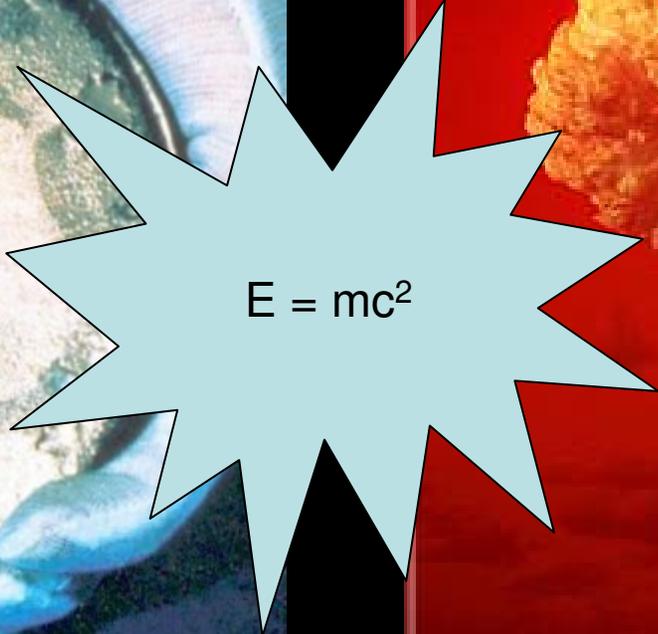
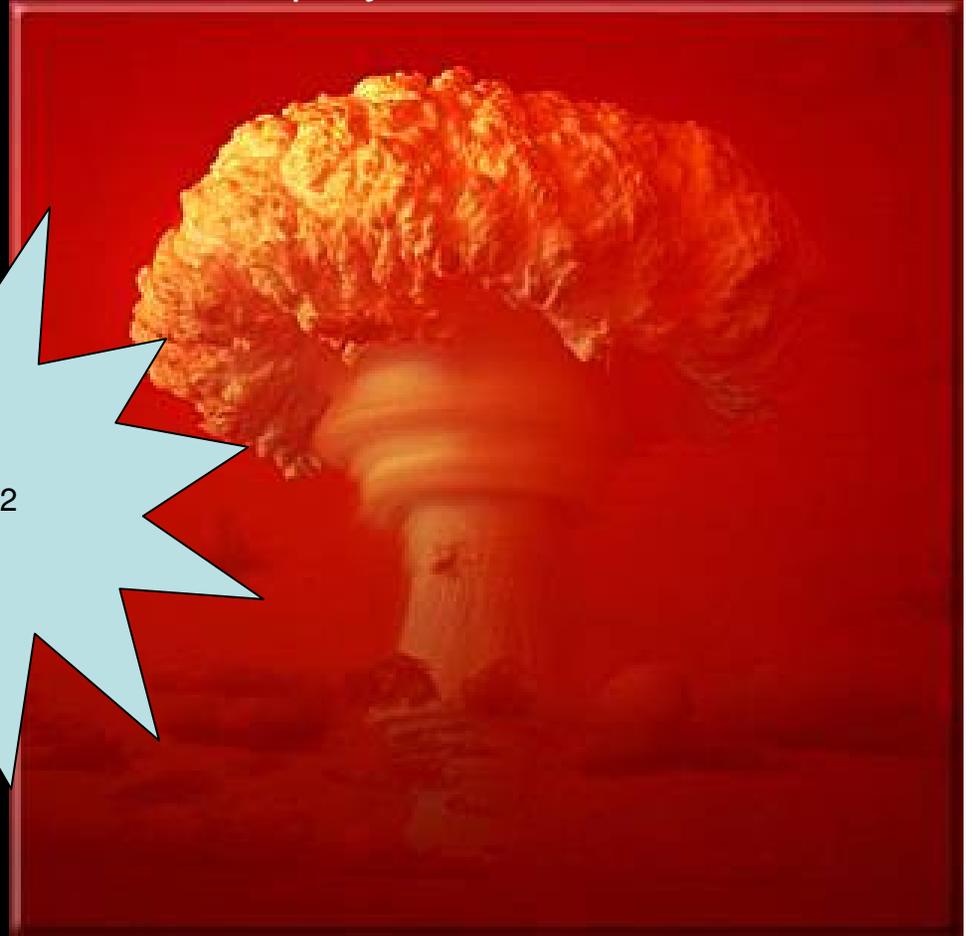
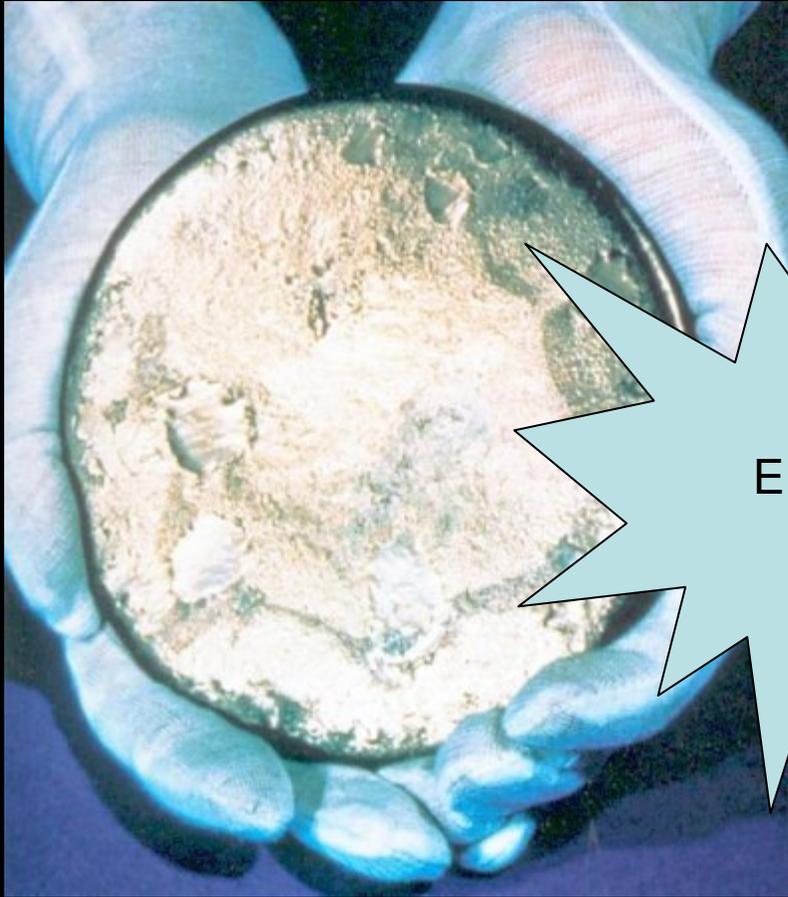
$$E = \sqrt{m_0^2 c^4 + p^2 c^2}$$



[http://images.google.com/images?ndsp=20&um=1&hl=en&](http://images.google.com/images?ndsp=20&um=1&hl=en&client=firefox-a&rls=org.mozilla:en-US:official&q=ivy+mike&start=0&sa=N)

[client=firefox-a&rls=org.mozilla:en-US:official&q=ivy+mike&start=0&sa=N](http://images.google.com/images?ndsp=20&um=1&hl=en&client=firefox-a&rls=org.mozilla:en-US:official&q=ivy+mike&start=0&sa=N)

<http://universe-review.ca/I14-03-U235.jpg>

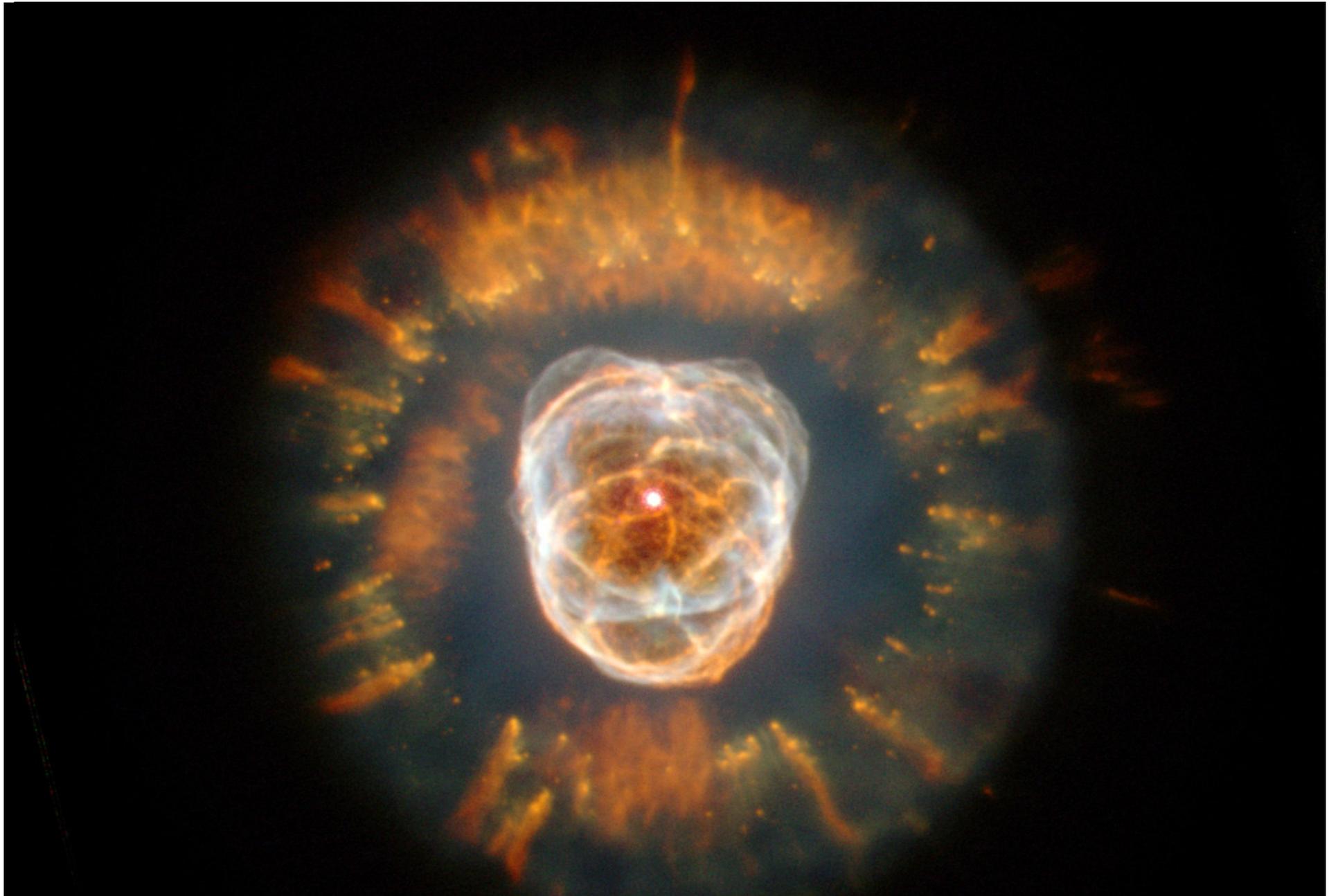


U 235

U GOT A BIG PROBLEM

WHERE'S THE MATTER
THE ORIGIN OF 'STUFF'

- Big Bang Nucleosynthesis
 - Gave birth to hydrogen and trace amounts of helium and lithium
- Stellar Nucleosynthesis
 - Gave birth, through fusion, of the 'heavy' elements: those with a higher atomic number than 2 or 3
 - Elements past iron are made in supernova explosions



http://www.nasa.gov/images/content/169665main_image_feature_762_ys_full.jpg





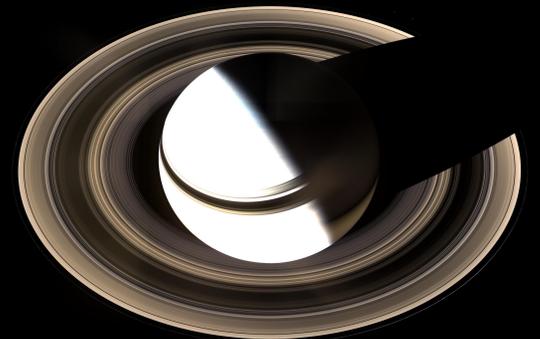


www.jonathanminard.com/EarthSpace/Hubble_Ultra_Deep_Field_Black_point_edit.jpg

MATTER REVIEW

DID YOU MEMORIZE THE CHART

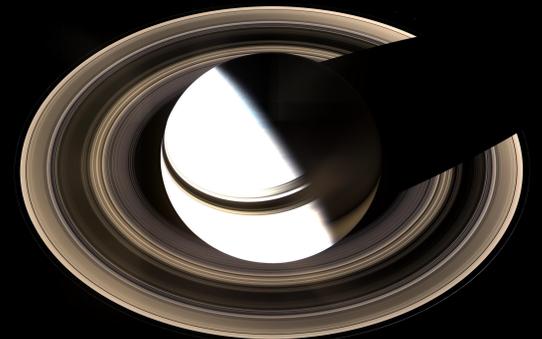
- Is hard
- Made in stars
- Everything we see



THE DARK SIDE OF MATTER

NOT MADE OF VADER PARTICLES

- Just what IS dark matter?
 - Current knowledge in three words: we don't know.
- Anything kind of like what dark matter should be?
 - Talked about baryons, now onto leptons.



FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0
e electron	0.000511	-1
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μ muon	0.106	-1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	-1

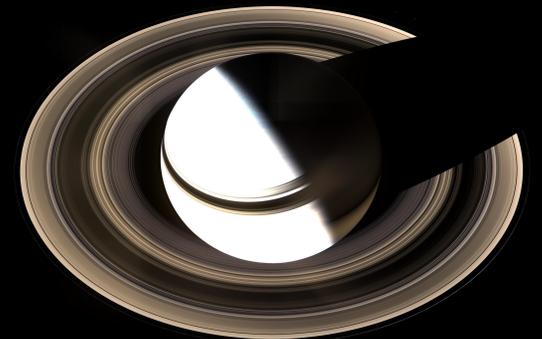
Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c ²	Electric charge
u up	0.003	2/3
d down	0.006	-1/3
C charm	1.3	2/3
S strange	0.1	-1/3
t top	175	2/3
b bottom	4.3	-1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of \hbar , which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58 \times 10^{-25} \text{ GeV s} = 1.05 \times 10^{-34} \text{ J s}$.

THE FAMILIAR LEPTON

THE ELECTRON

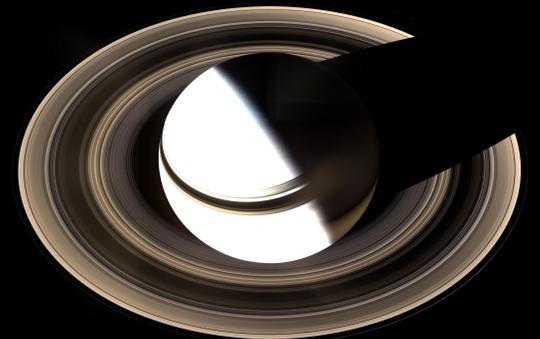
- Electromagnetic force
- Chemical interaction
- Keeps your shirt from actually touching you



THE UNFAMILIAR LEPTON

THE NEUTRINO

- Virtually massless
- Neutrally charged
- Very weakly interacting
 - Experiments to detect neutrinos have to be *huge*

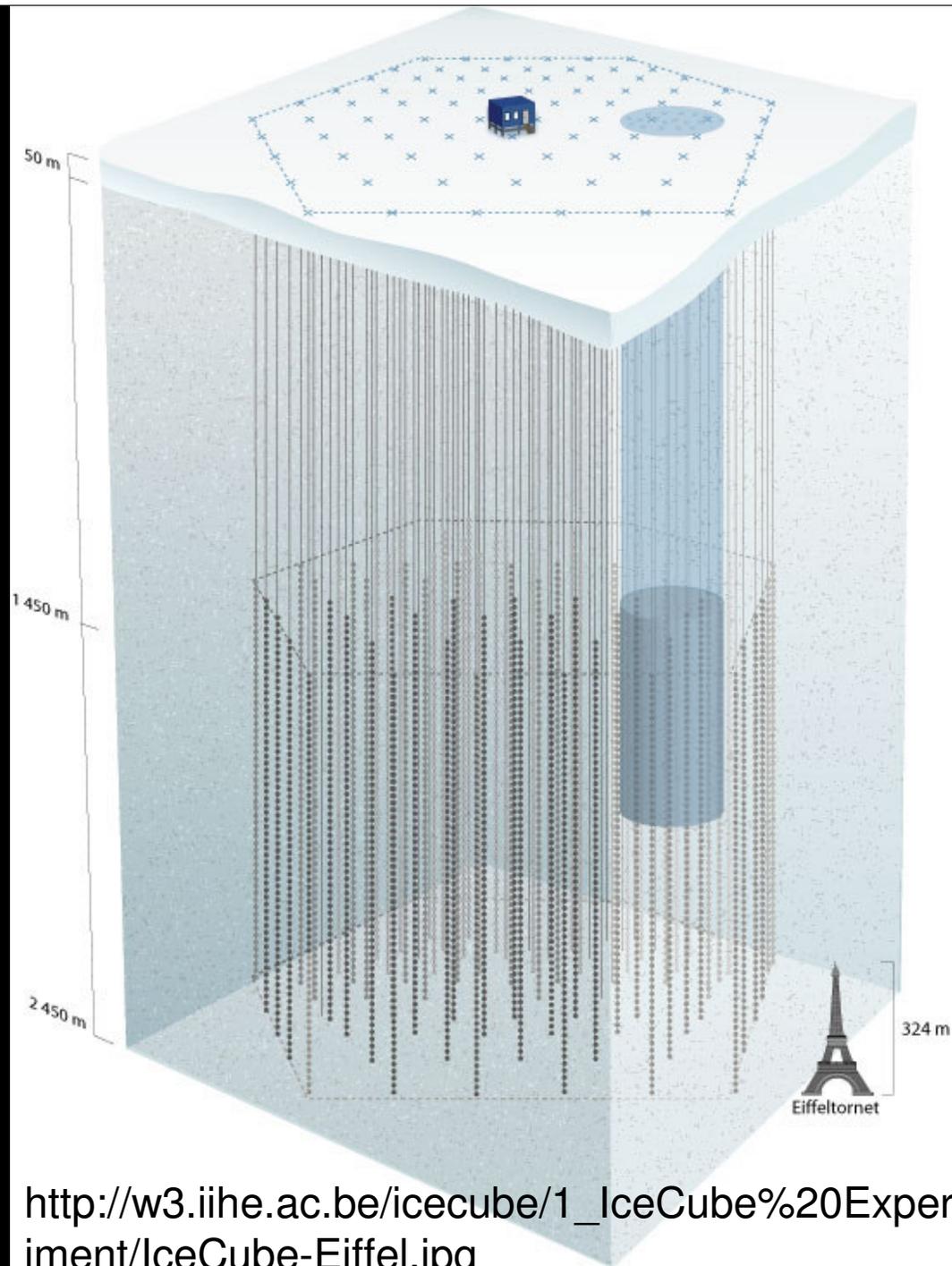




<http://images.google.com/images?q=keck+observatory&btnG=Search+Images&um=1&hl=en&client=firefox-a&rls=org.mozilla%3Aen-US%3Aofficial&sa=2>



<http://gallery.icecube.wisc.edu/external/main.php>

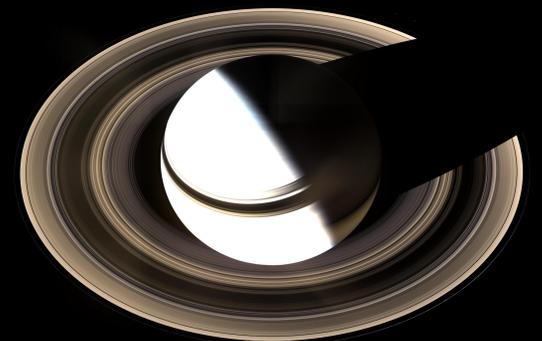


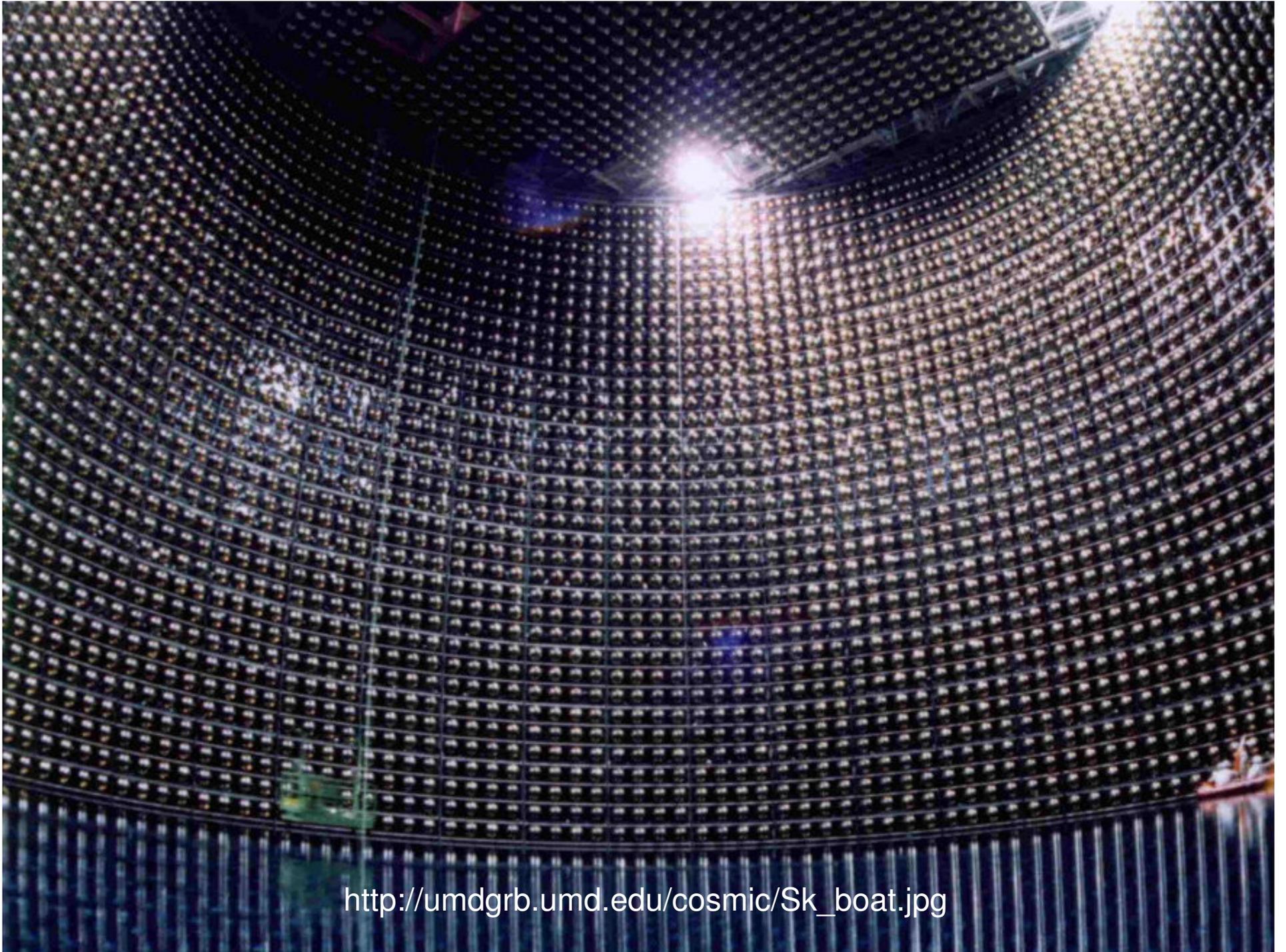
http://w3.ihe.ac.be/icecube/1_IceCube%20Experiment/IceCube-Eiffel.jpg

ICE CUBE

COOL PHYSICS

- 1 full cubic kilometer of detection capability





http://umdgrb.umd.edu/cosmic/Sk_boat.jpg

WHY SO BIG

DOES SIZE REALLY MATTER

- YES! (at least for neutrino detection)
- At any given second, 70,000,000,000 neutrinos pass through your thumb.





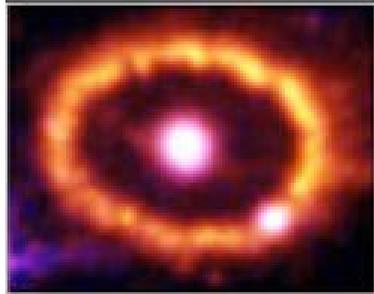
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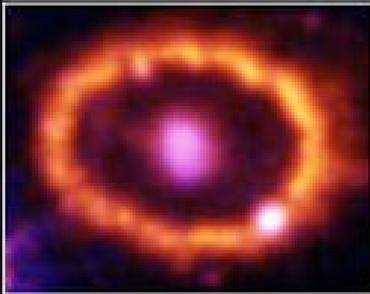
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Supernova 1987A 1994-2003

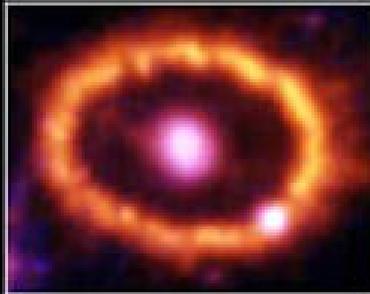
HST • WFPC2 • ACS



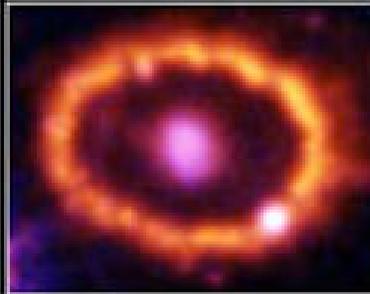
September 24, 1994



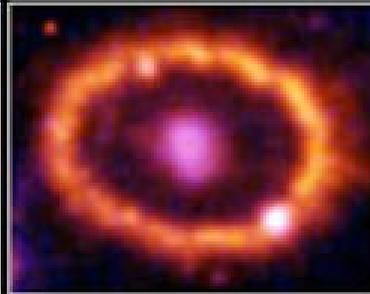
March 5, 1995



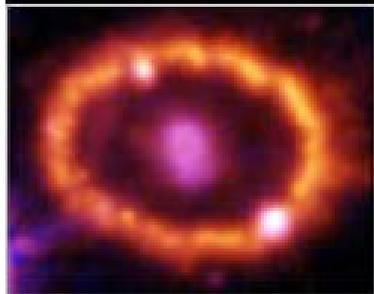
February 6, 1996



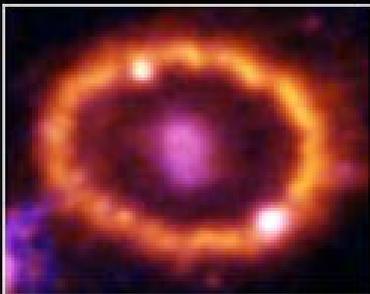
July 10, 1997



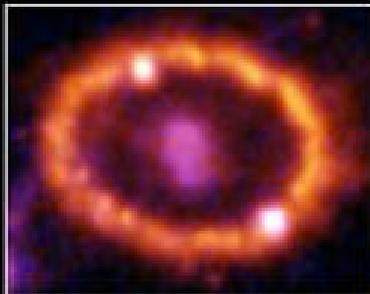
February 6, 1998



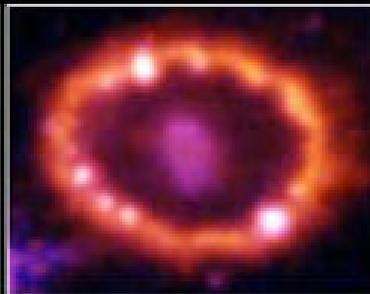
January 8, 1999



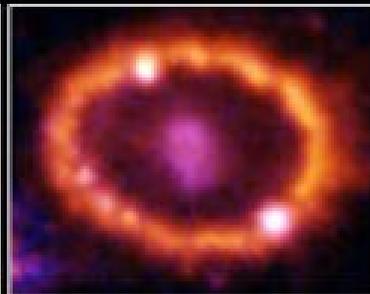
April 21, 1999



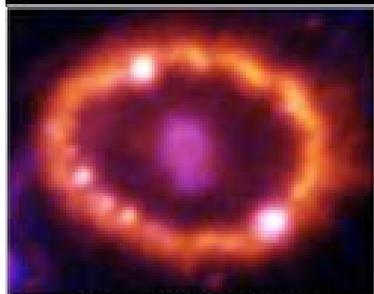
February 2, 2000



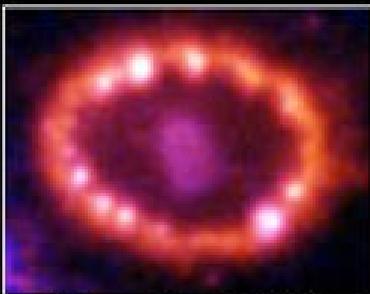
June 16, 2000



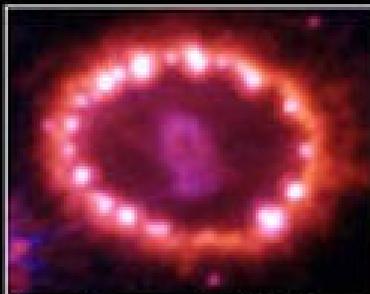
November 14, 2000



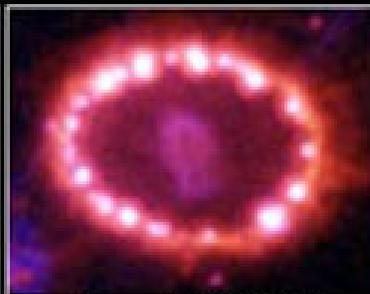
March 23, 2001



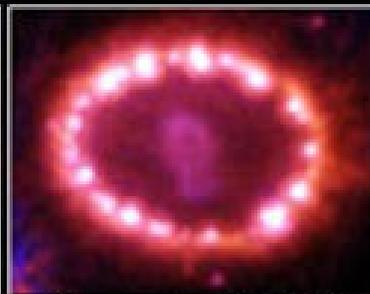
December 7, 2001



January 5, 2003



August 12, 2003



November 28, 2003

NASA and R. Kirshner (Harvard-Smithsonian Center for Astrophysics)

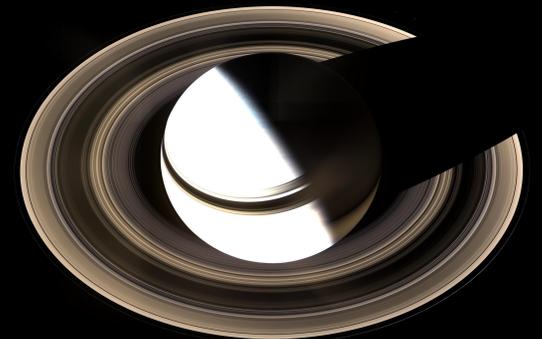
STScI-PRC04-09

http://megalego.free.fr/astro/supernova_fichiers/SN1987Atimelapse.jpg

LEPTONS AS DARK MATTER

WORKING FOR THE EMPIRE

- May be a type of dark matter, but it's unlikely
 - We can detect leptons (even neutrinos)
- Even given their numbers, because of such small mass, they cannot account fully for the gravitational effects



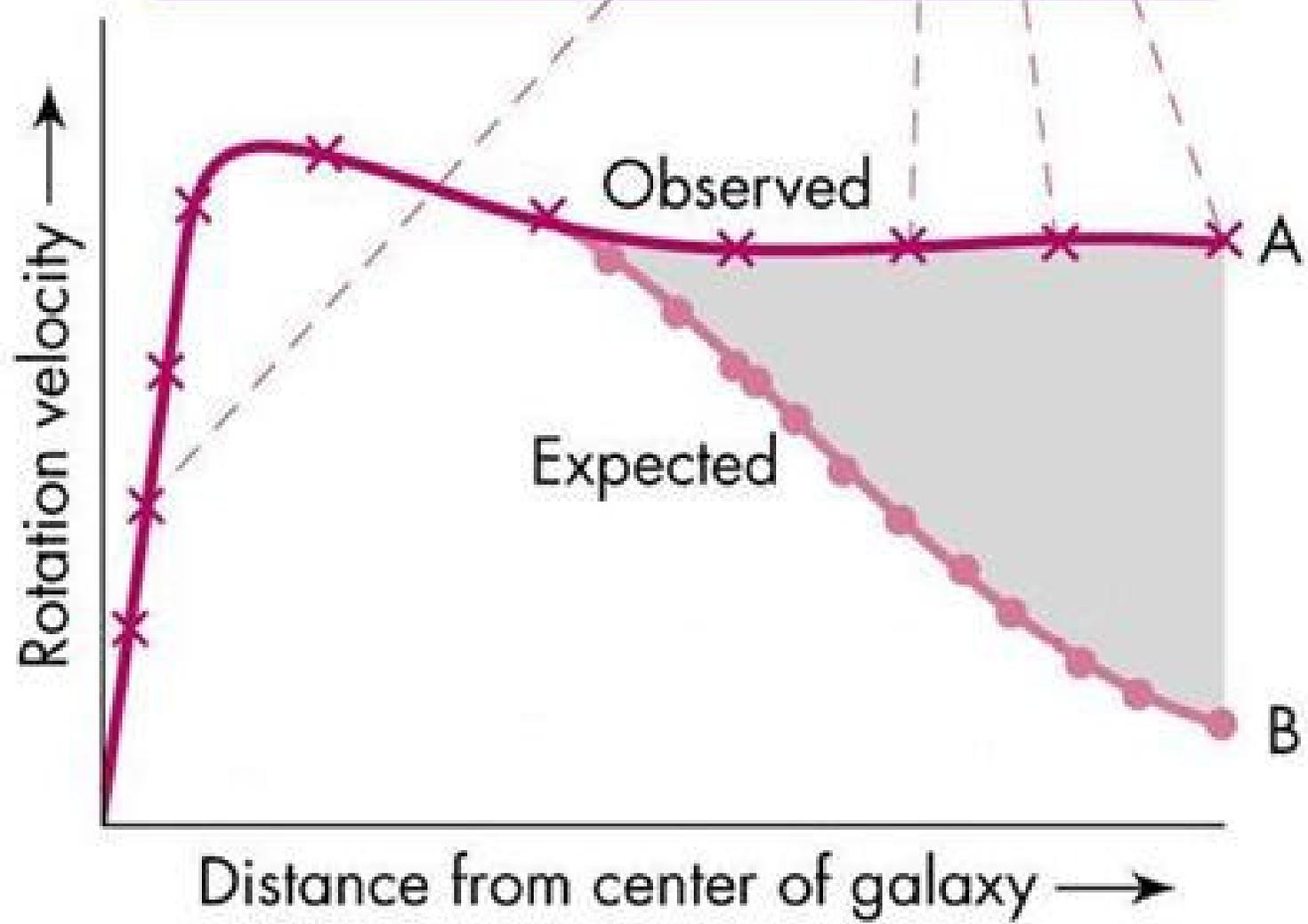
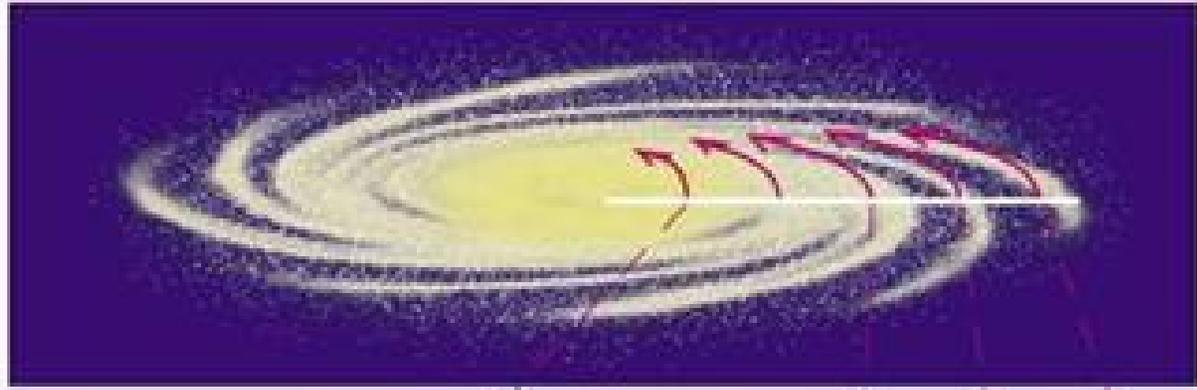
A BRIEF HISTORY OF DARK MATTER

FROM ZWICKY TO DM GALAXIES

- Analysis of galactic clusters showed that rotation curves did not fit Newtonian gravitational theory
 - Huh?



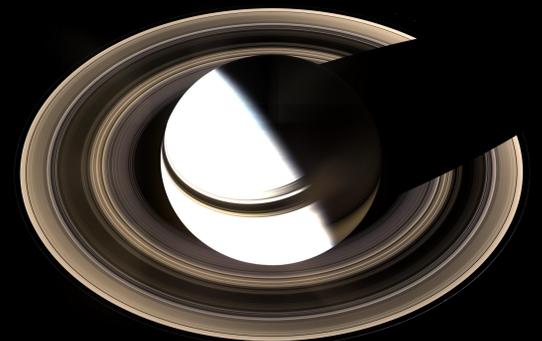
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MODERN OBSERVATIONS

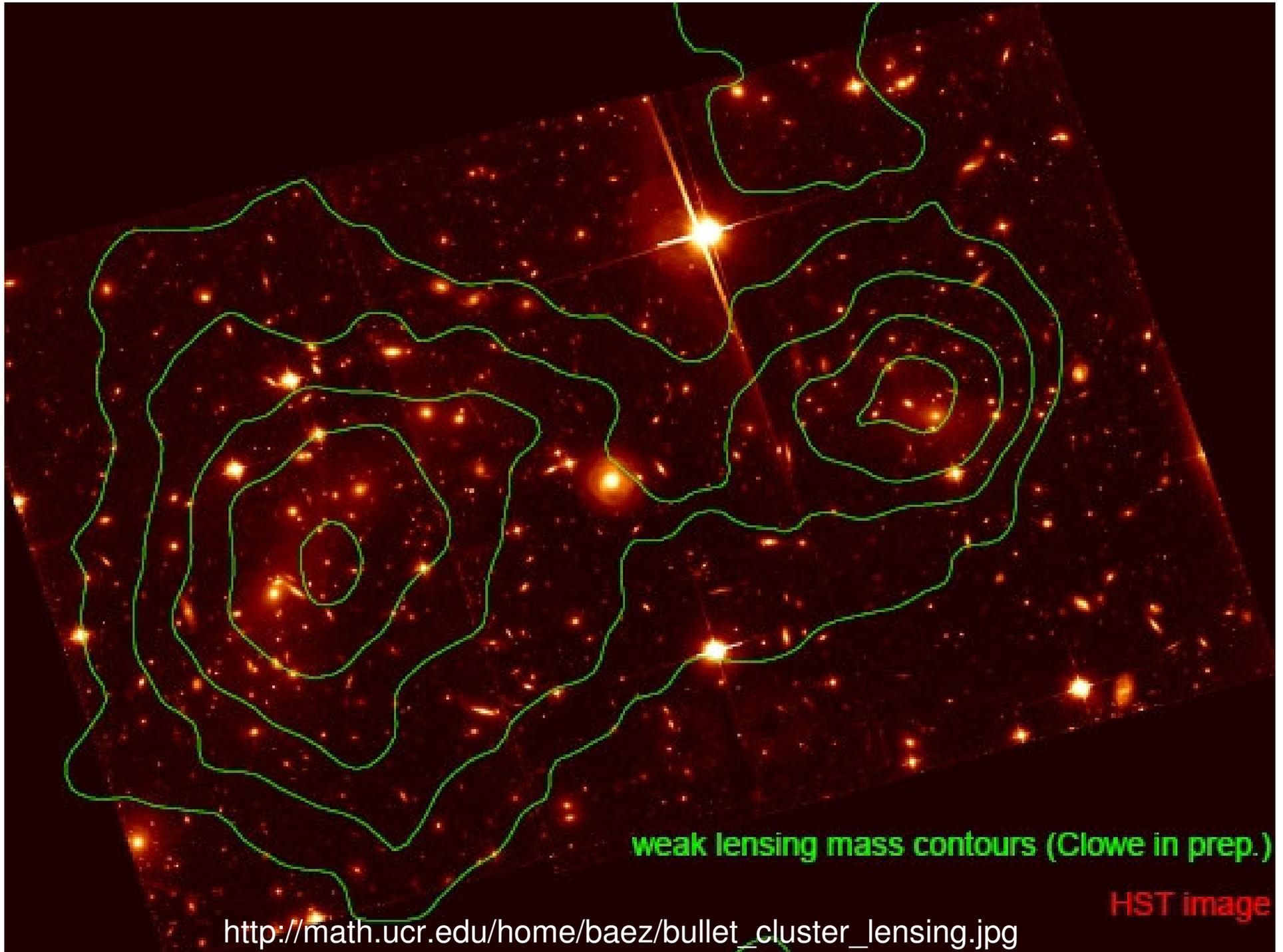
CLOWE-SING IN

- 2006 team headed by Douglas Clowe investigated the Bullet Cluster of galaxies
- Matter separated from the clusters, DM separated from everything else.





http://www.nasa.gov/images/content/155539main_1e0657_516x374.jpg



weak lensing mass contours (Clowe in prep.)

HST image

http://math.ucr.edu/home/baez/bullet_cluster_lensing.jpg

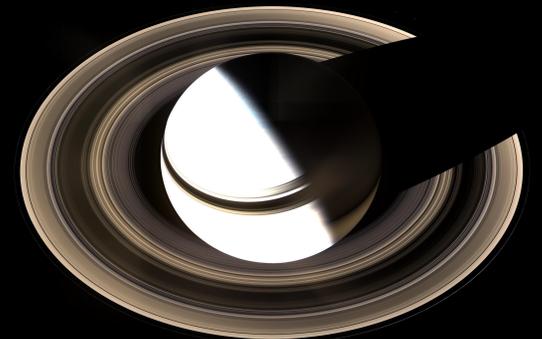


http://homepage.mac.com/dtrapp/chemGraphics.f/Bullet_darkmatter.jpg

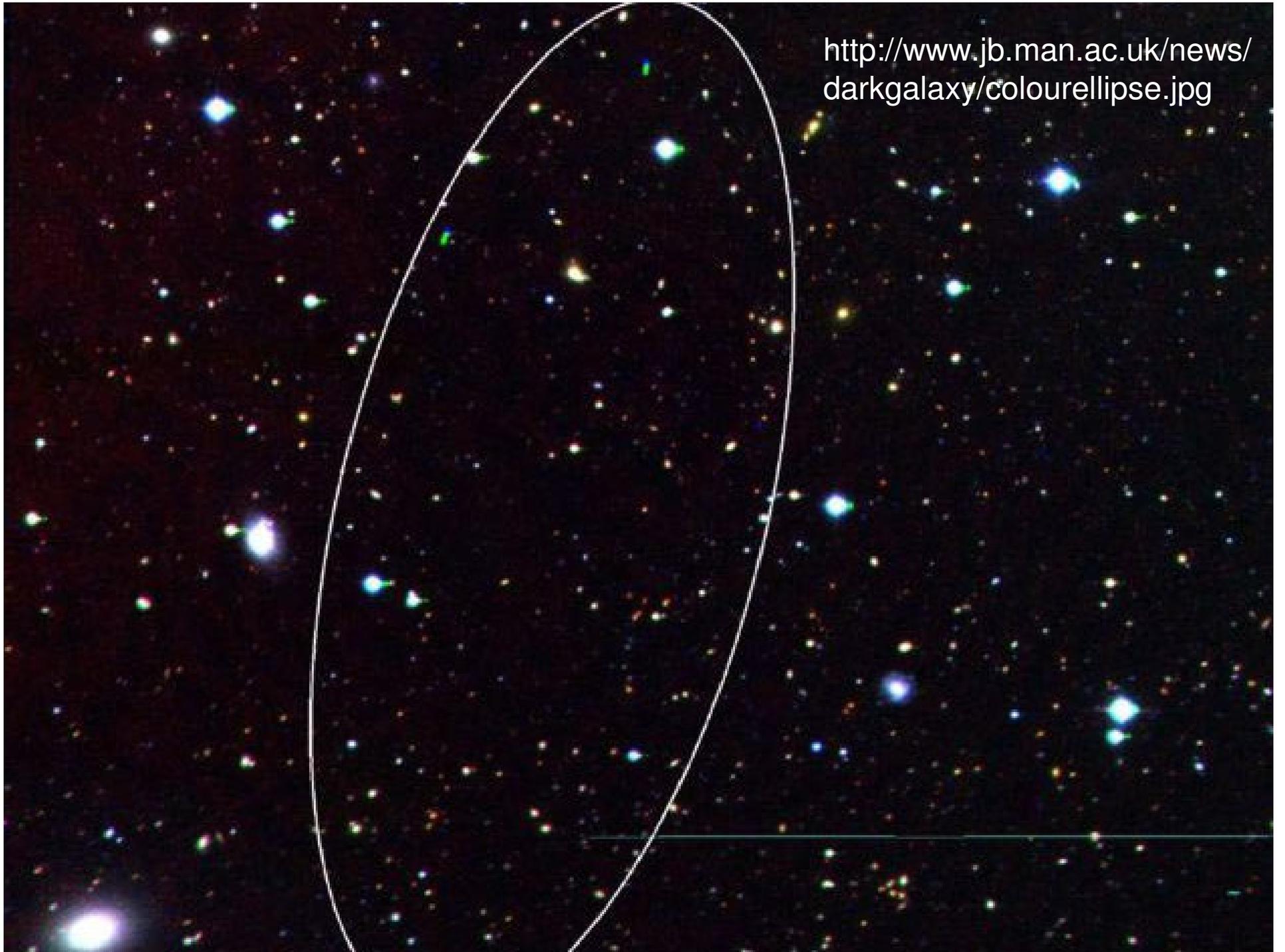
VIRGOHI-21: THE DM GALAXY

ARE THE STARS OUT TONIGHT

- Found through gravitational interaction with neighboring galaxies
- Region estimated to be average galaxy size, but no stars are visible



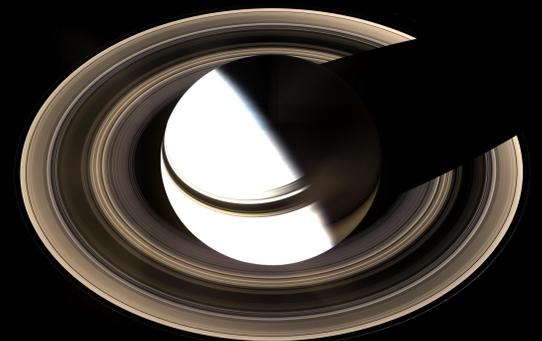
<http://www.jb.man.ac.uk/news/darkgalaxy/colourellipse.jpg>



VIRGOHI'S COMPOSITION

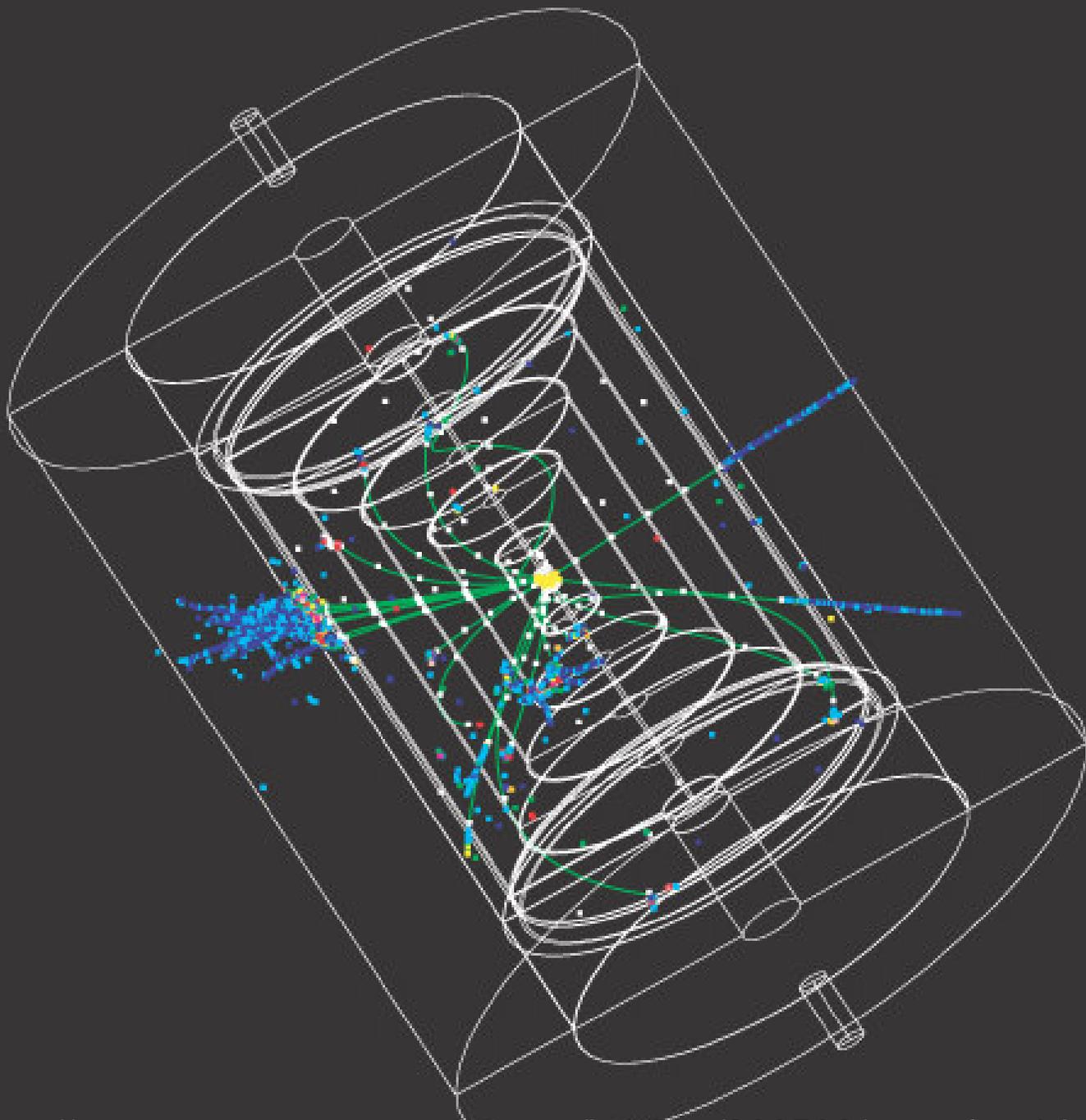
MACHOS VS WIMPS

- VIRGOHI-21's gravity could arise from Massive, Compact Halo Objects (MACHO)s or Weakly Interacting Massive Particles (WIMP)s





http://dunningrb.files.wordpress.com/2007/12/lg_protoplanet.jpg

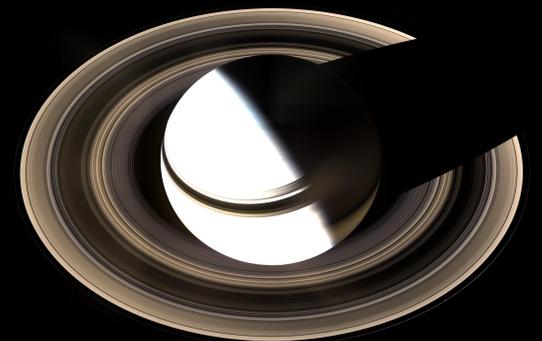


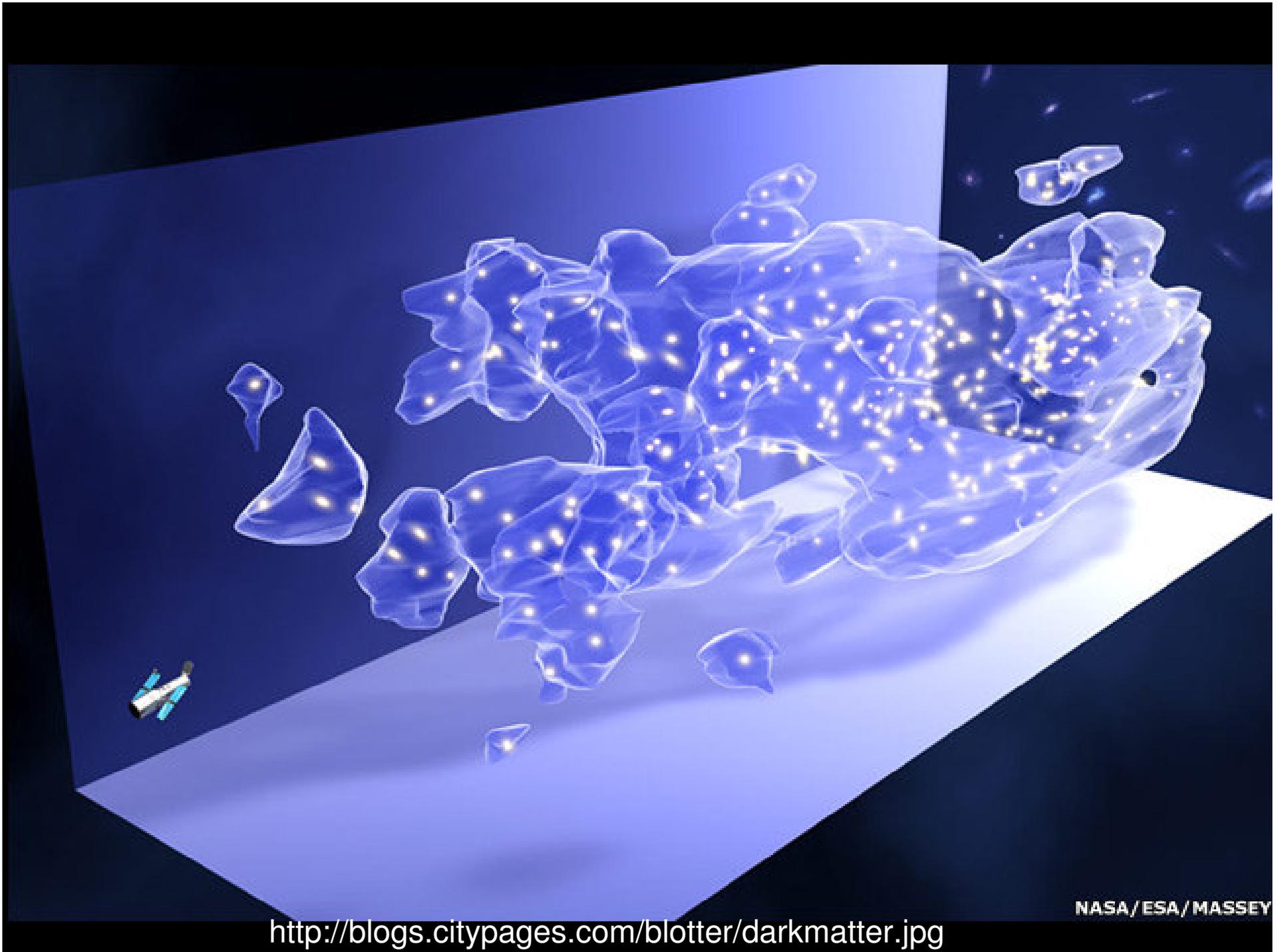
<http://www.symmetrymagazine.org/images/200509/superfast1.jpg>

MAPPING DARK MATTER

HERE BE DRAGONS

- January 2007, scientists unveiled a dark matter map made by over 1,000 hours of observing time with the Hubble Space Telescope.





NASA/ESA/MASSEY

<http://blogs.citypages.com/blotter/darkmatter.jpg>

MODIFIED NEWTONIAN DYNAMICS

MONDO PHYSICS

- Changes Newtonian gravitation to fit the rotation curves
- Bad science?

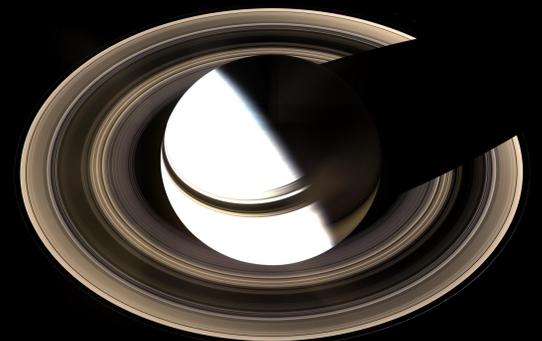
$$F = \frac{GMm}{r^2}$$

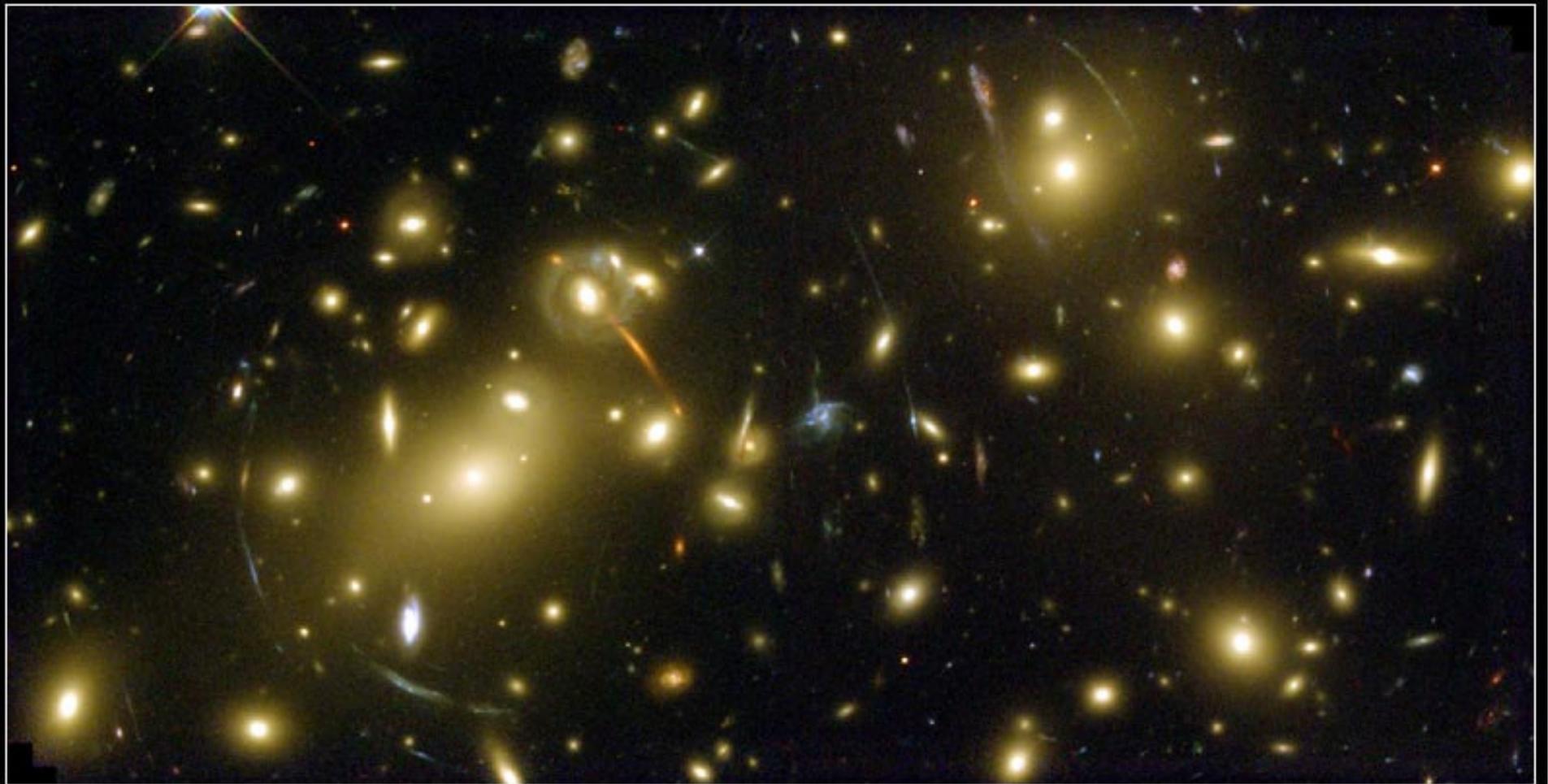
$$\vec{F} = m \cdot \mu\left(\frac{a}{a_0}\right) \vec{a}$$
$$\mu(x) = 1 \text{ if } x \gg 1$$
$$\mu(x) = x \text{ if } |x| \ll 1$$

GRAVITATIONAL LENSING

WARPING SPACE AND TIME

- Matter warps space and time
- Dark matter also warps space and time through gravitational effects
- Galaxy clusters with enough dark matter act like big 'lenses' in space

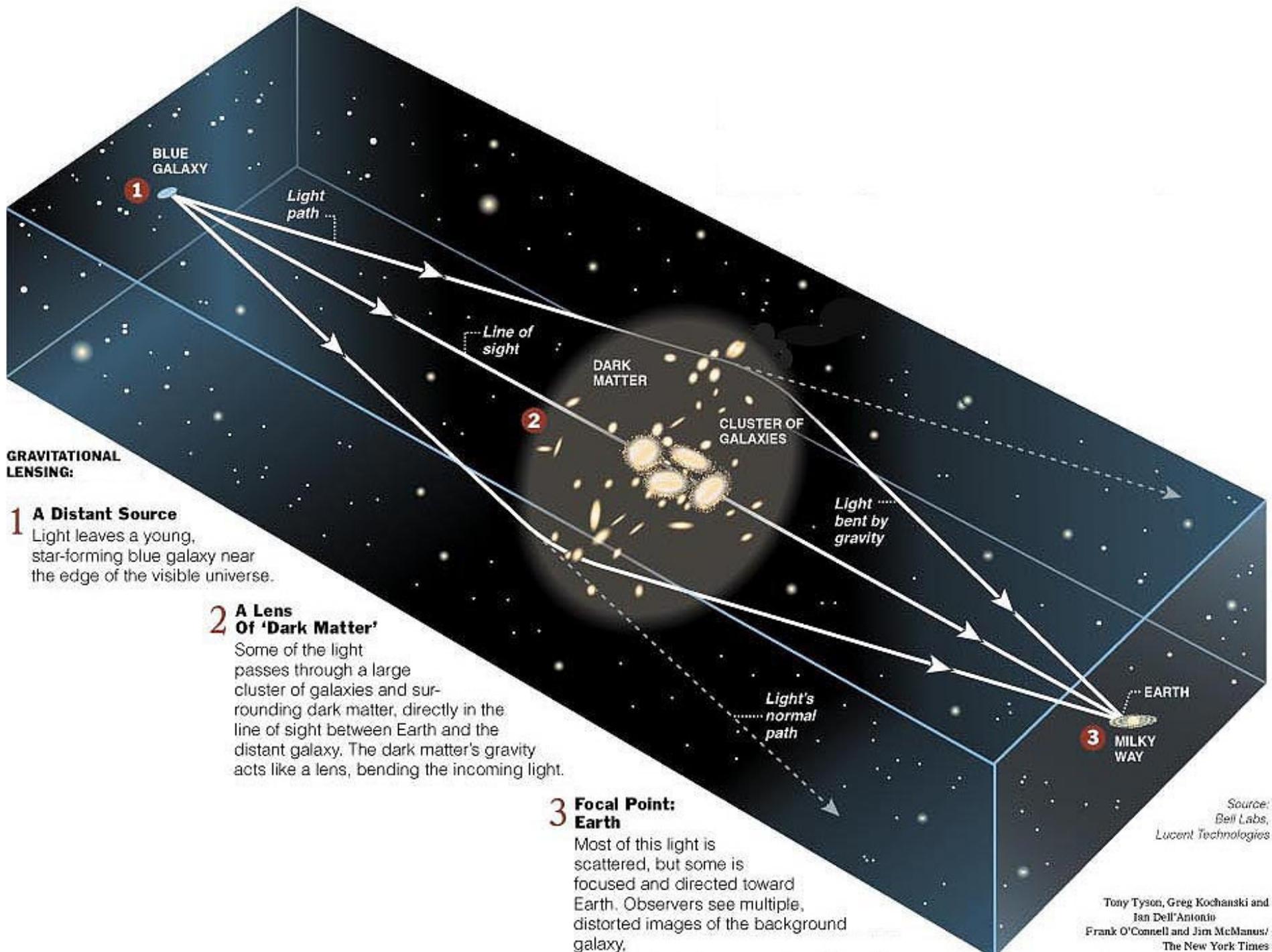




Galaxy Cluster Abell 2218

HST • WFPC2

NASA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-08



GRAVITATIONAL LENSING:

1 A Distant Source

Light leaves a young, star-forming blue galaxy near the edge of the visible universe.

2 A Lens Of 'Dark Matter'

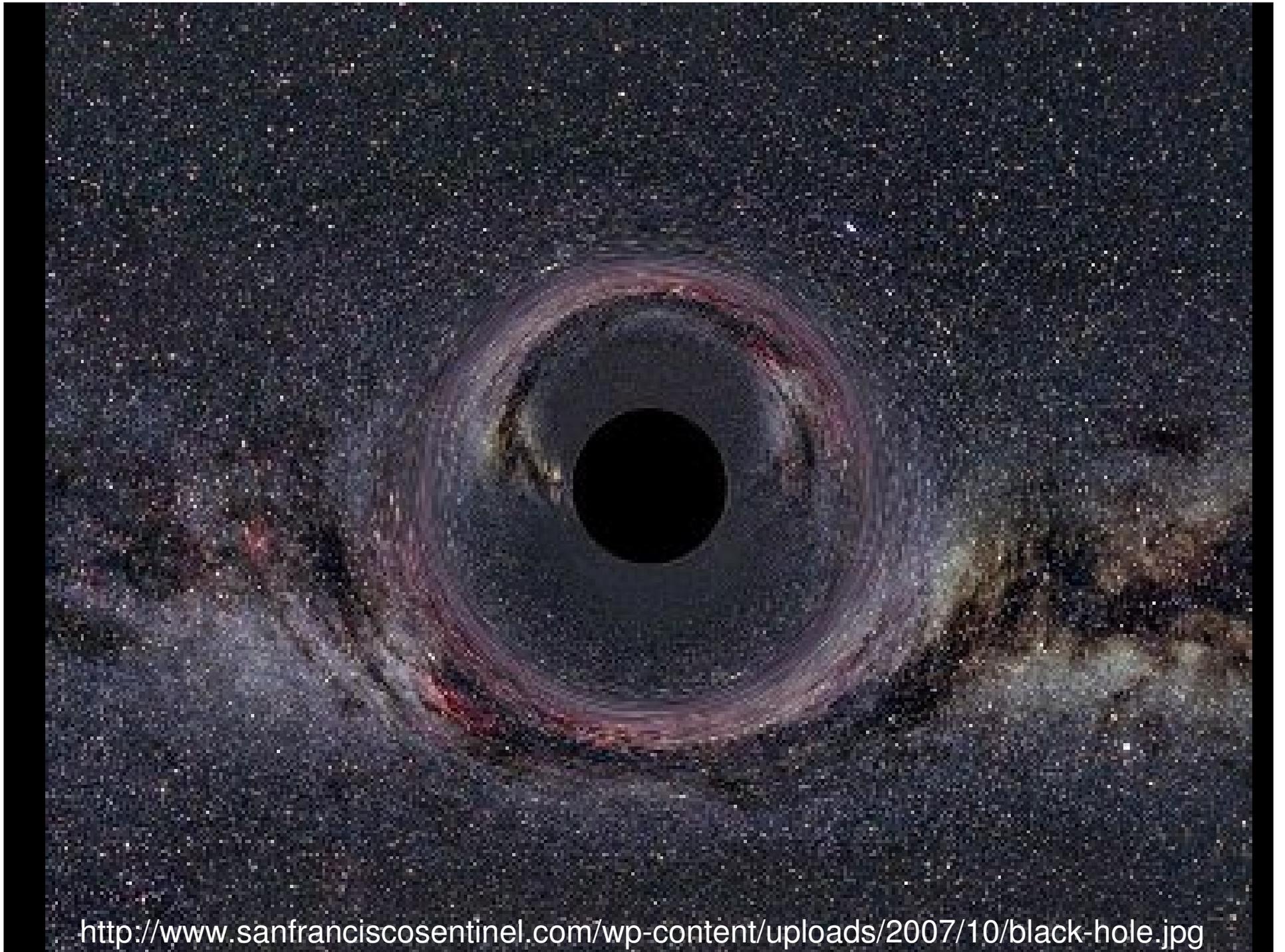
Some of the light passes through a large cluster of galaxies and surrounding dark matter, directly in the line of sight between Earth and the distant galaxy. The dark matter's gravity acts like a lens, bending the incoming light.

3 Focal Point: Earth

Most of this light is scattered, but some is focused and directed toward Earth. Observers see multiple, distorted images of the background galaxy.

Source:
Bell Labs,
Lucent Technologies

Tony Tyson, Greg Kochanski and
Jan Dell'Antonio
Frank O'Connell and Jim McManus/
The New York Times

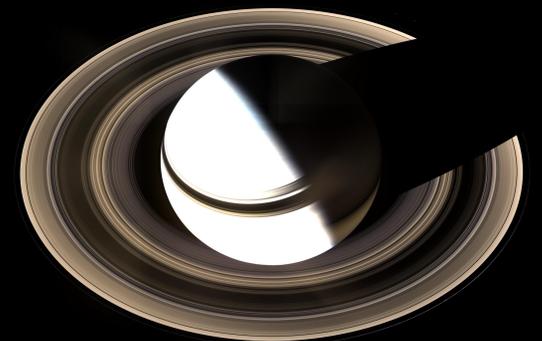


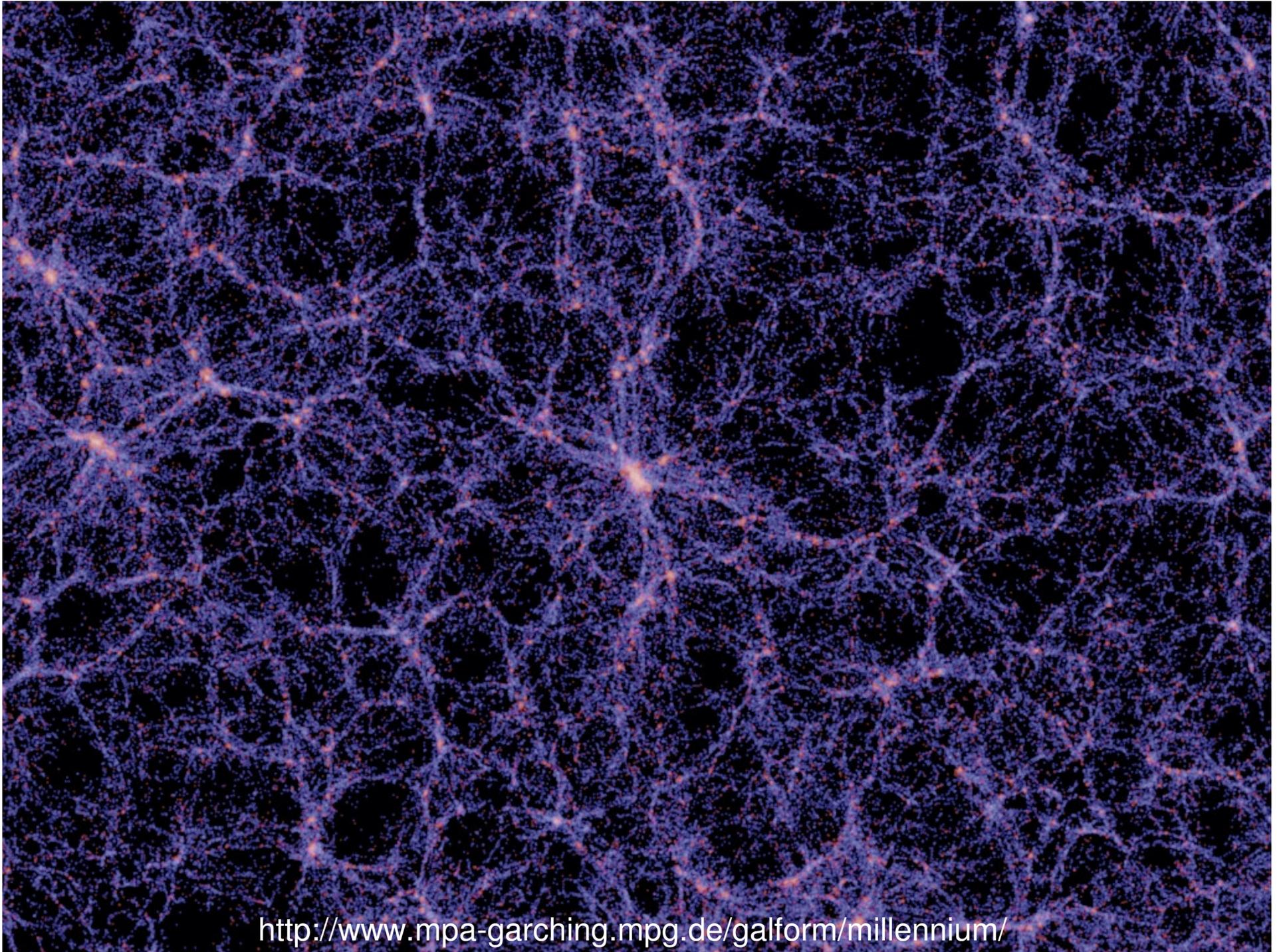
<http://www.sanfranciscosentinel.com/wp-content/uploads/2007/10/black-hole.jpg>

THE MILLENNIUM RUN

MORE THAN 12 PARSECS

- Simulation of universal evolution
- 6 months to process with supercomputers
- Generated a universe similar to ours, including massive dark matter halos



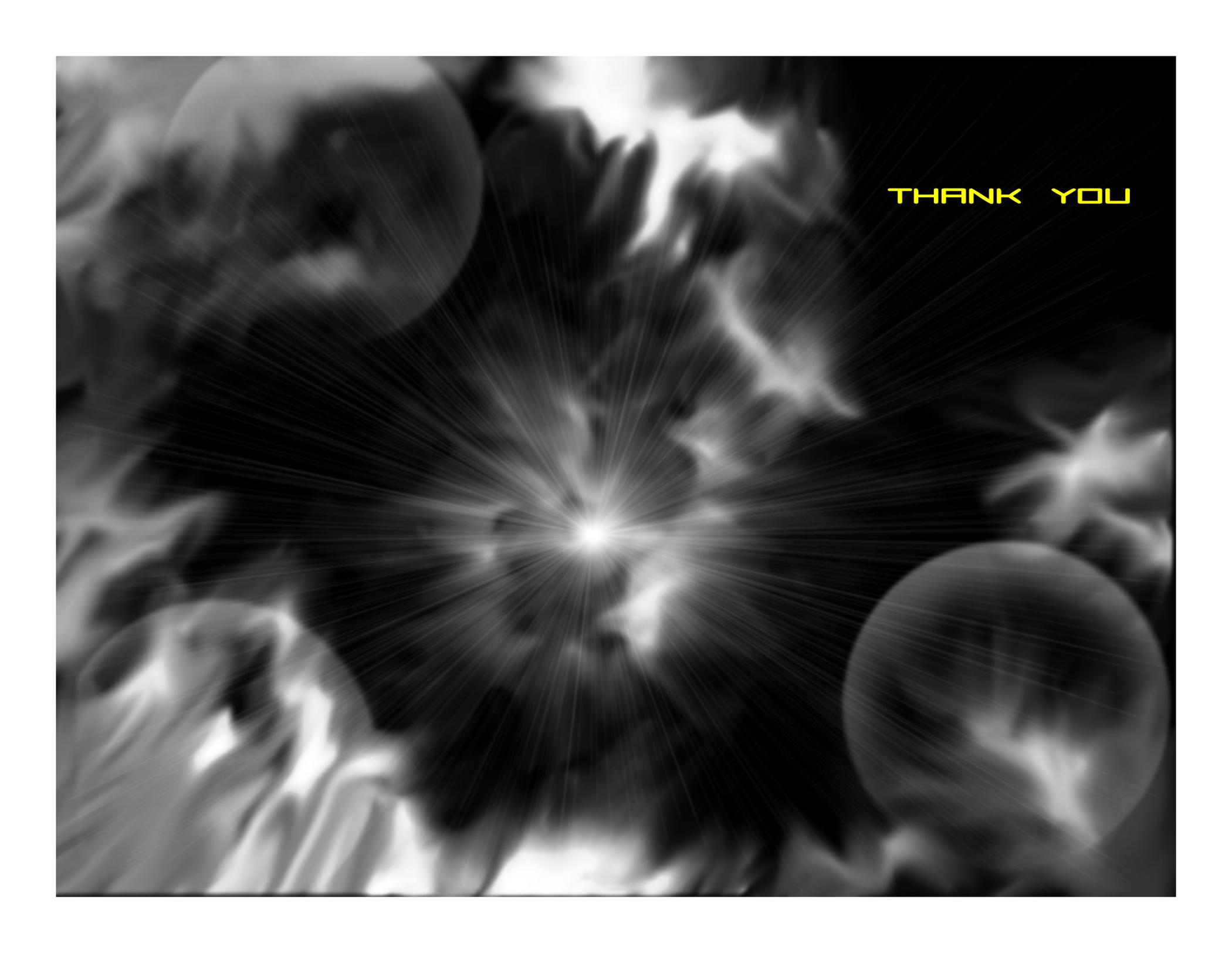


<http://www.mpa-garching.mpg.de/galform/millennium/>

THE FUTURE OF DARK MATTER

SHEDDING LIGHT

- Dark matter and dark energy are the forefront of the physics world
- Don't know what DM is, but can see its effects
- Ripe for Nobel Prizes all over the place
 - What is DM composed of?
 - How does DM interact?
 - Where did DM come from?
 - What applications does DM have?



THANK YOU