Title: The Quantum and the Cosmos

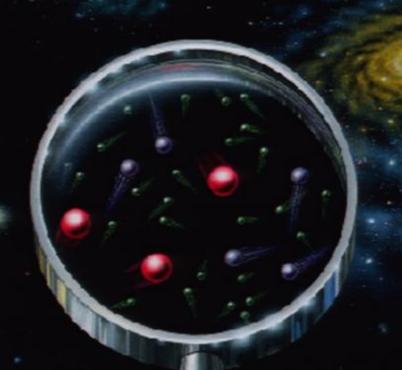
Date: Jun 07, 2006 07:00 PM

URL: http://pirsa.org/06060005

Abstract: Long before the emergence of planets, stars, or galaxies, the universe consisted of an exploding quantum soup of Â"elementaryÂ" particles. Encoded in this formless, shapeless soup were seeds of cosmic structure, which over billions of years grew into the beautiful and complex universe we observe today. The lecture will explore the connection between the Â"inner spaceÂ" of the quantum and the Â"outer spaceÂ" of the cosmos. The inner space/outer space connection may hold the key to the nature of the dark matter holding together our galaxy and the mysterious dark energy pulling apart our universe. Edward W. Kolb (known to most as Rocky) is a founding head of the NASA/Fermilab Astrophysics Group at Fermi National Accelerator Laboratory and a Professor of Astronomy and Astrophysics at The University of Chicago. Presently he is the Director of the Particle Astrophysics Center at Fermilab. A native of New Orleans, he received his Ph.D. in physics from the University of Texas. Postdoctoral research was performed at the California Institute of Technology and Los Alamos National Laboratory where he was the J. Robert Oppenheimer Research Fellow. He has served on editorial boards of several international scientific journals as well as Astronomy magazine. In addition to over 200 scientific papers, he is a co-author of The Early Universe, the standard textbook on particle physics and cosmology. His book for the general event, Blind Watchers of the Sky, received the 1996 Emme Award of the American Aeronautical Society. Rocky teaches cosmology to non-science majors at the University of Chicago and is involved with pre-college education enrichment programs. He has traveled the world, if not yet the Universe, giving scientific and event lectures. He has appeared in several television productions, and can also be seen in the OMNIMAX/IMAX film The Cosmic Voyage. His distinctions include: Fellow of the American Academy of Arts and Sciences, Fellow of the American Physical Society, recipient of the 2003 Oersted Medal of the American Association of Physics Teachers, winner of the 1993 Quantrell Prize for teaching excellence at the University of Chicago, Harlow Shapley Visiting Lecturer and Centennial Lecturer with the American Astronomical Society. He has also presented event lectures at the Royal Society of London, and in Rio de Janeiro, Valencia, and Barcelona. <a href="kw">cosmos, quantum, cosmology, universe, galaxies collide, Barnes, Hibbard, Newton, Einstein, relativity, space, time, origin of the universe, galaxies collide, Barnes, Hibbard, Newton, Einstein, relativity, space, time, origin of the universe, galaxies collide, Barnes, Hibbard, Newton, Einstein, relativity, space, time, origin of the universe, galaxies collide, Barnes, Hibbard, Newton, Einstein, relativity, space, time, origin of the universe, galaxies collide, Barnes, Hibbard, Newton, Einstein, relativity, space, time, origin of the universe, galaxies collide, Barnes, Hibbard, Newton, Einstein, relativity, space, time, origin of the universe, galaxies collide, Barnes, Hibbard, Newton, Einstein, relativity, space, time, origin of the universe, galaxies collide, Barnes, Hibbard, Newton, Einstein, relativity, space, time, origin of the universe, galaxies collide, Barnes, Hibbard, Newton, Einstein, Respective to the second collide, and the second collide, barnes, the second collide, barn dark energy, expansion history, vacuum quantum, Vera Rubin, invisible universe, dark matter, quantum universe, Higgs potential, Big Bang Theory, Hubble, WIMPS, cosmic background radiation </kw>

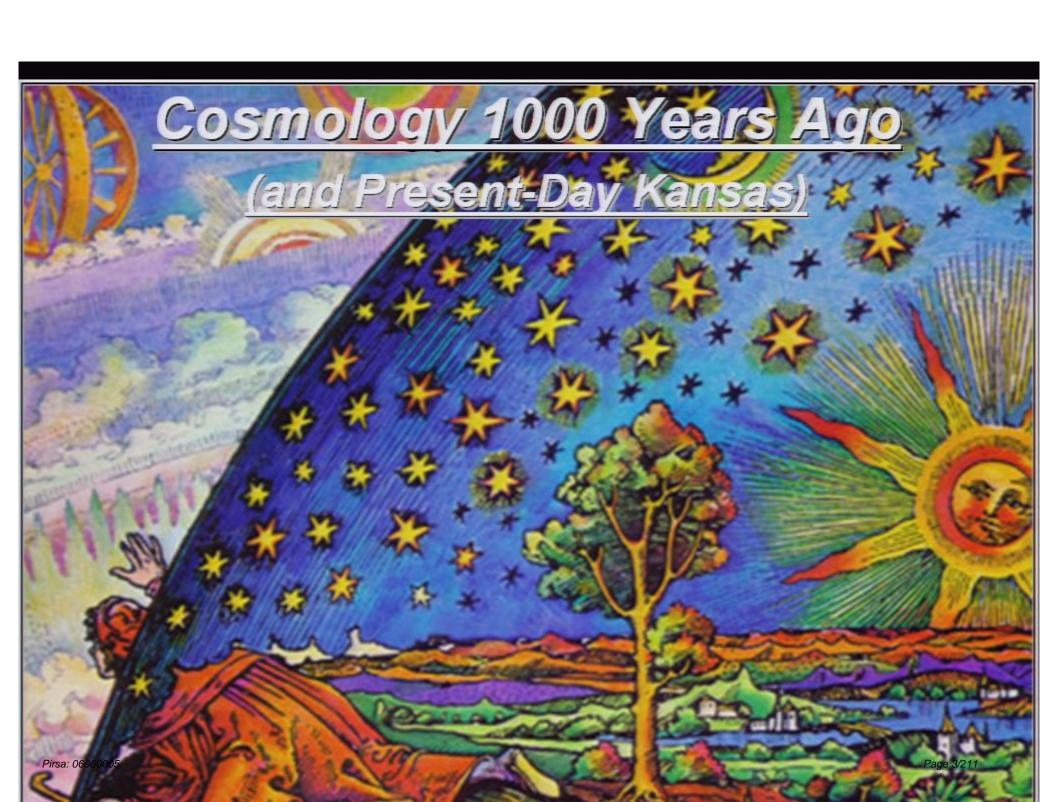
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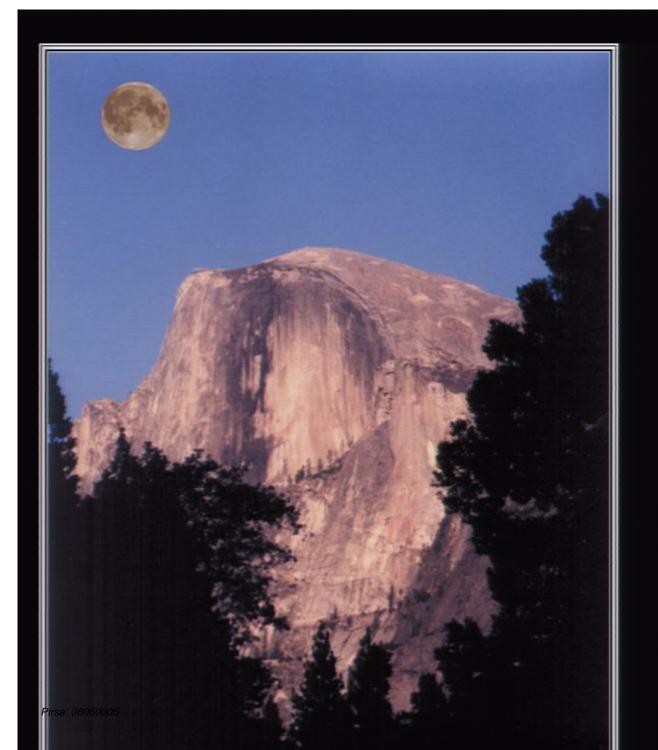
# The Quantum & the Cosmos



Waterloo

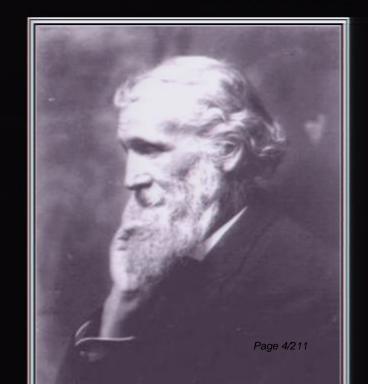
June 2006





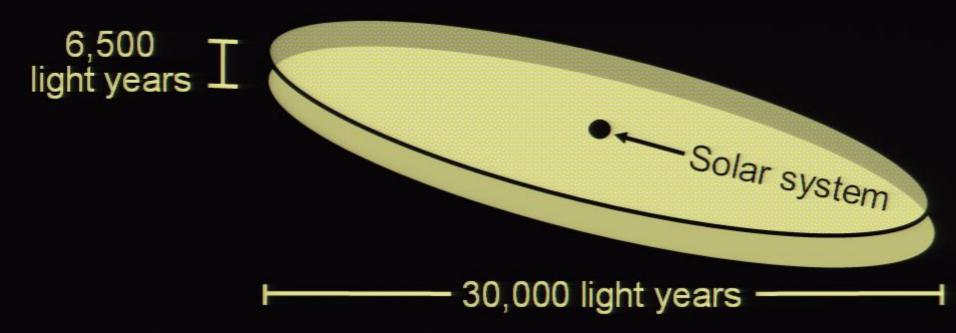
"When we try to pick out anything by itself, we find it hitched to everything else in the universe."

- John Muir



# Cosmology 100 Years Ago

Arrangement of the Universe:



- Nature of space and time: absolute
- Origin of the Universe: not an astronomy issue
- 4) Evolution of the Universe: stationary
- 5) Composition of the Universe: starz' in the hood

# Arrangement

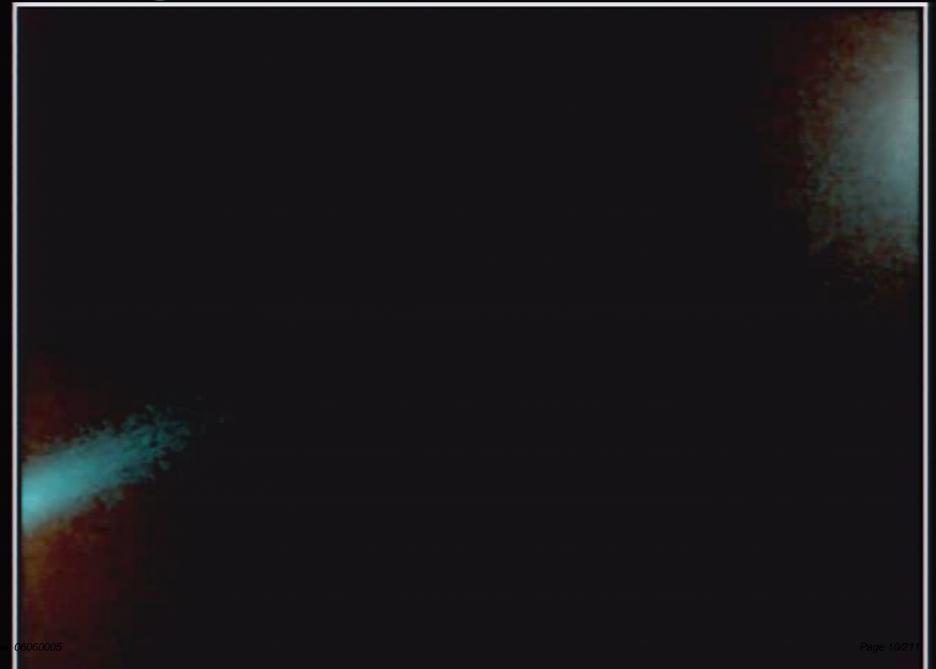


# Arrangement



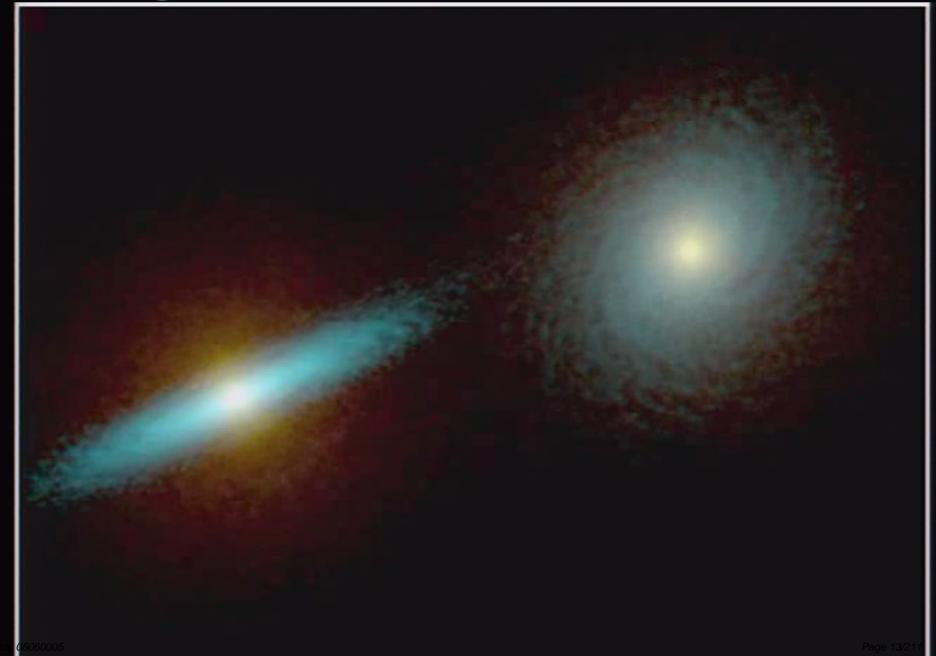


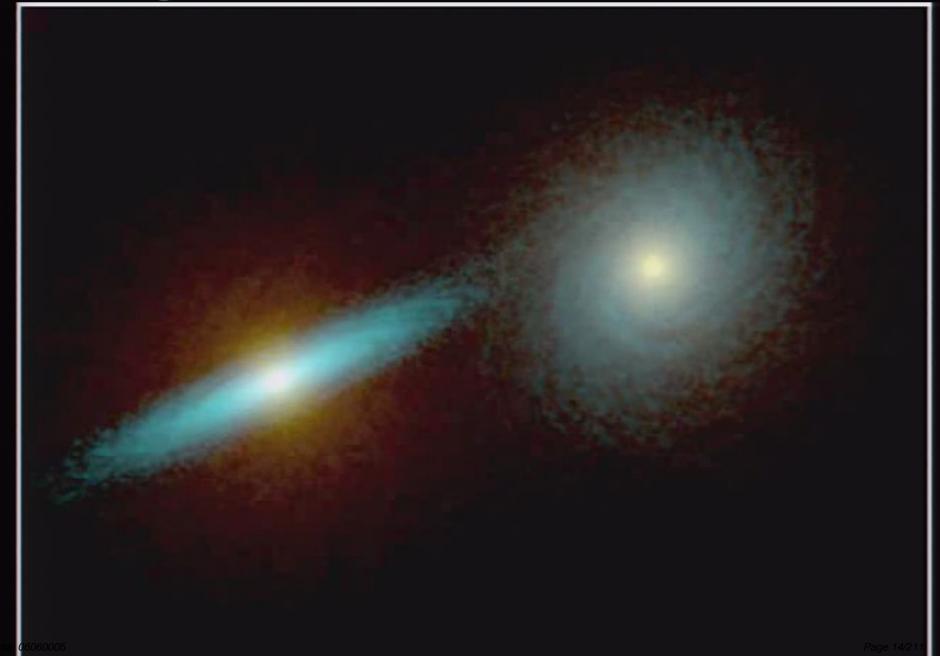


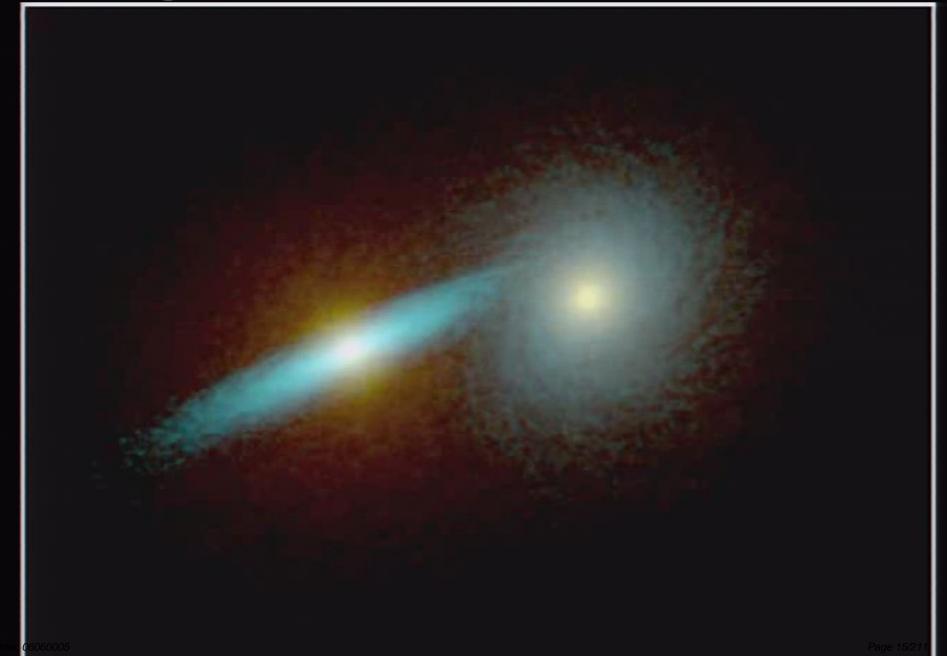




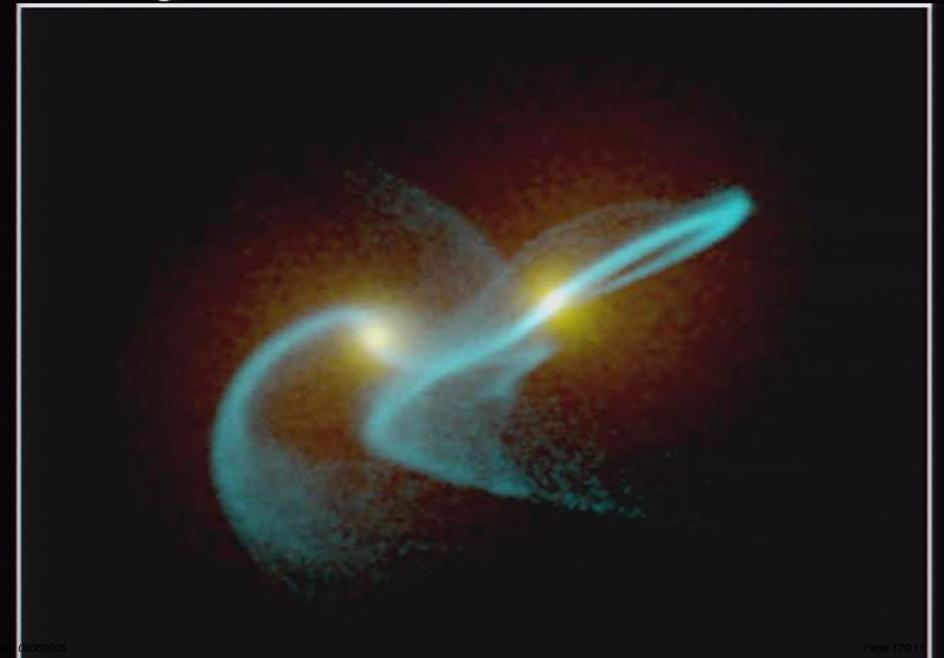




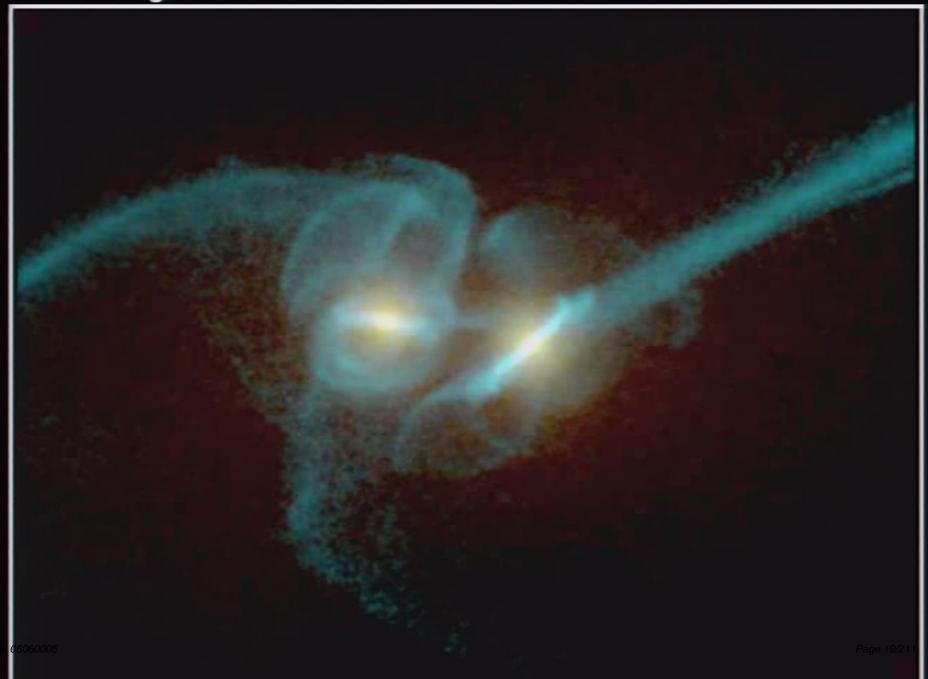


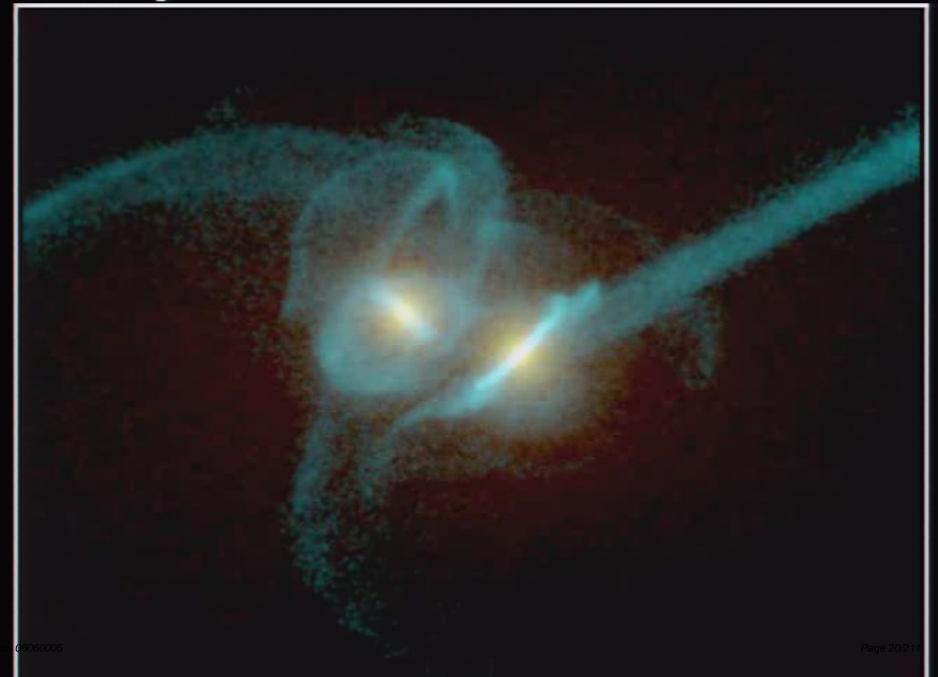


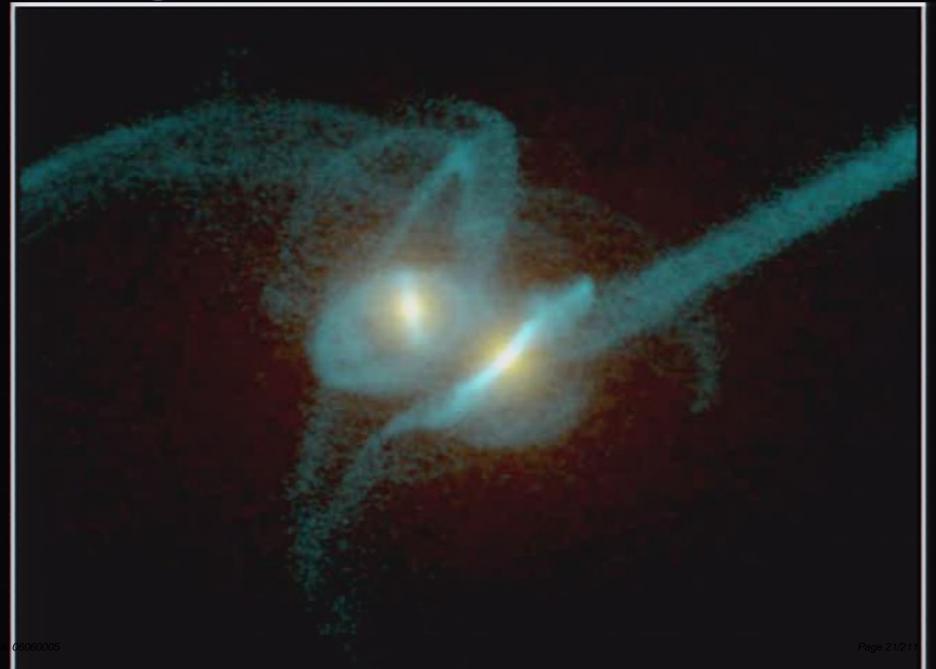


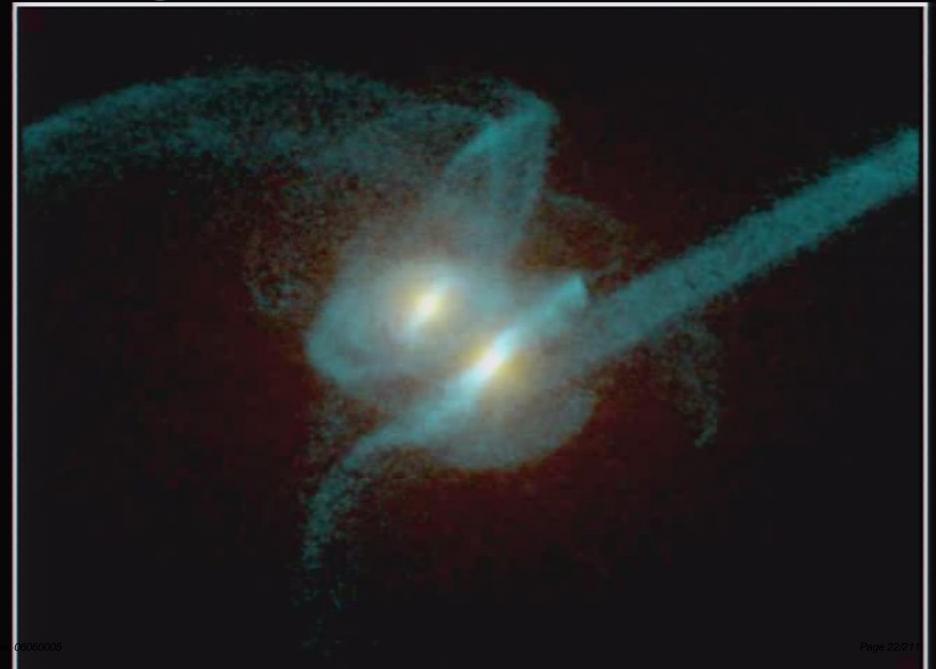






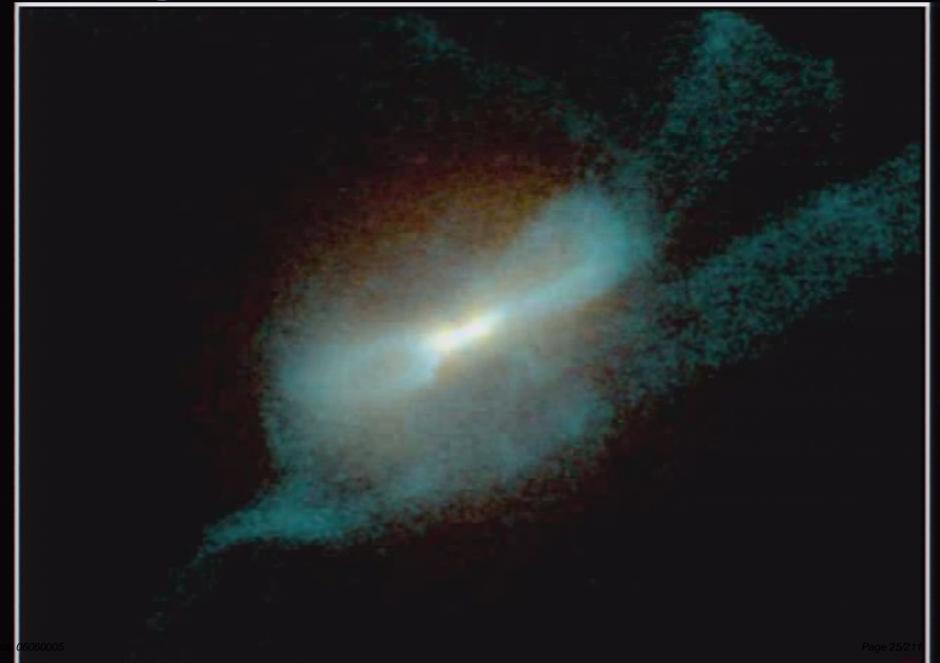


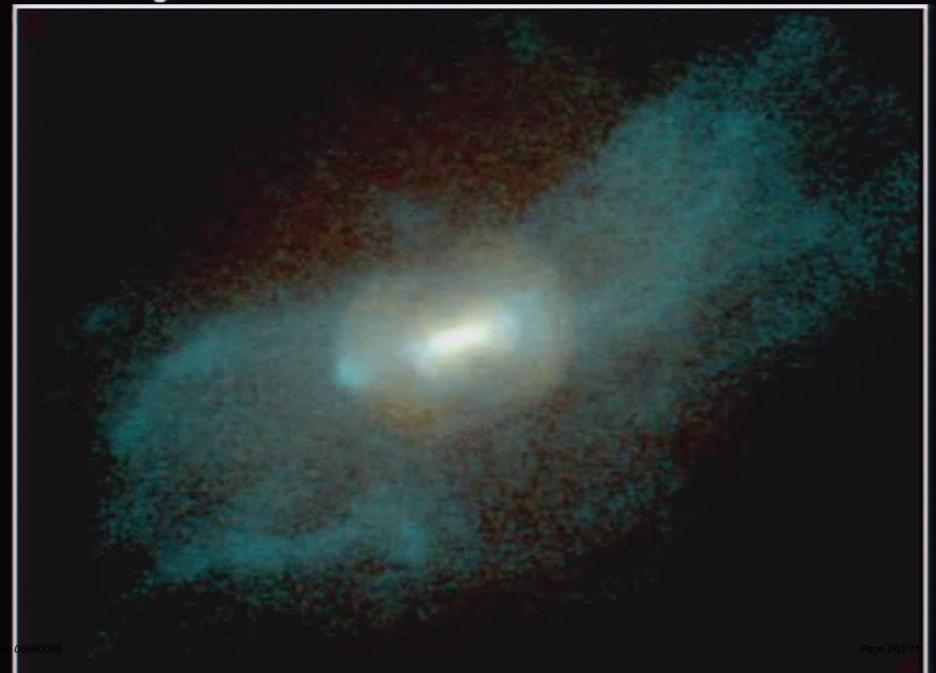


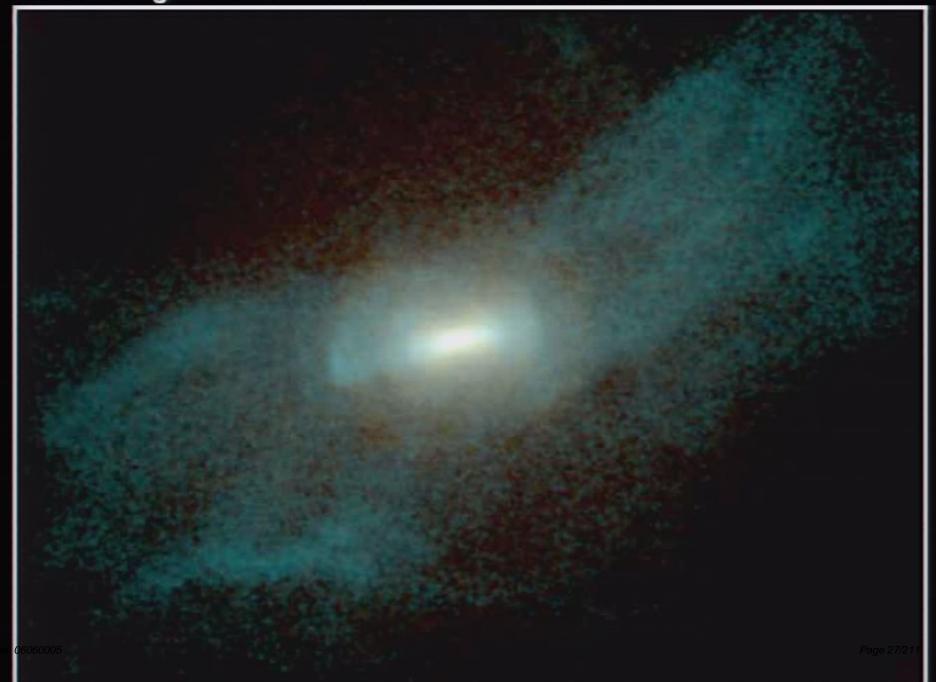


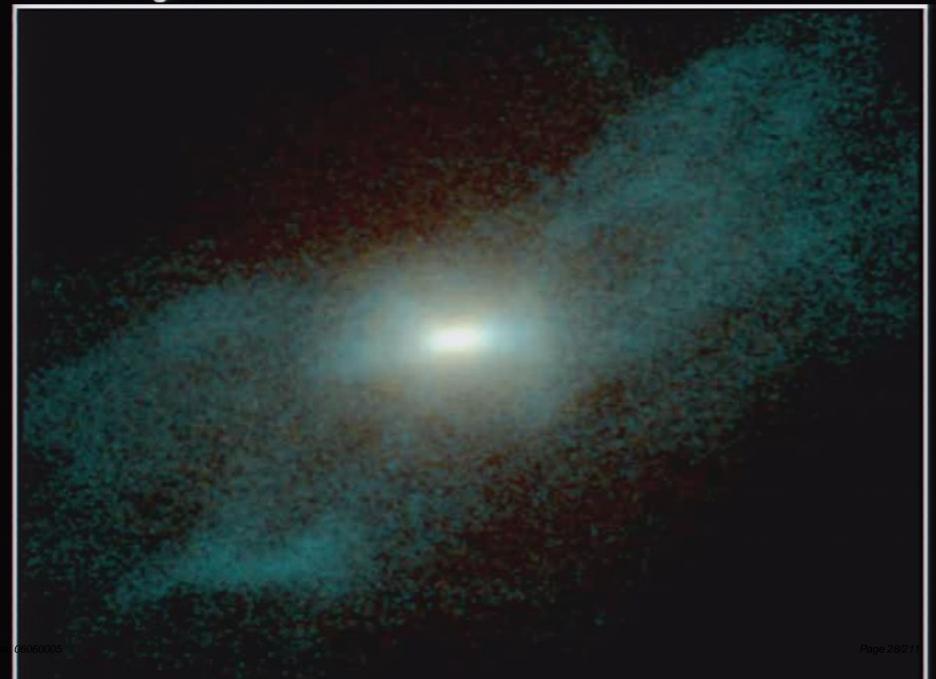


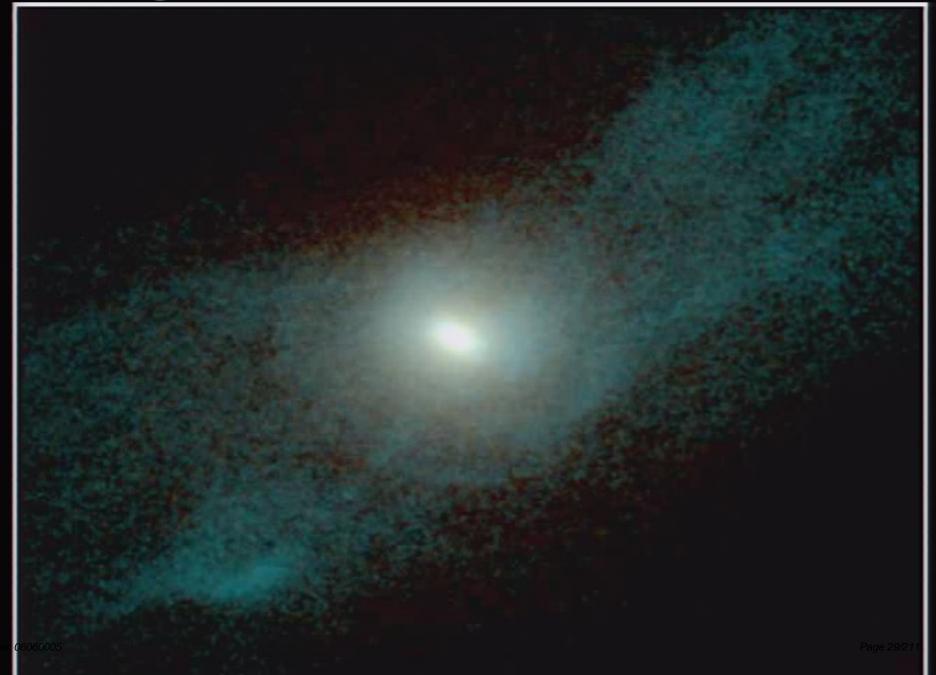


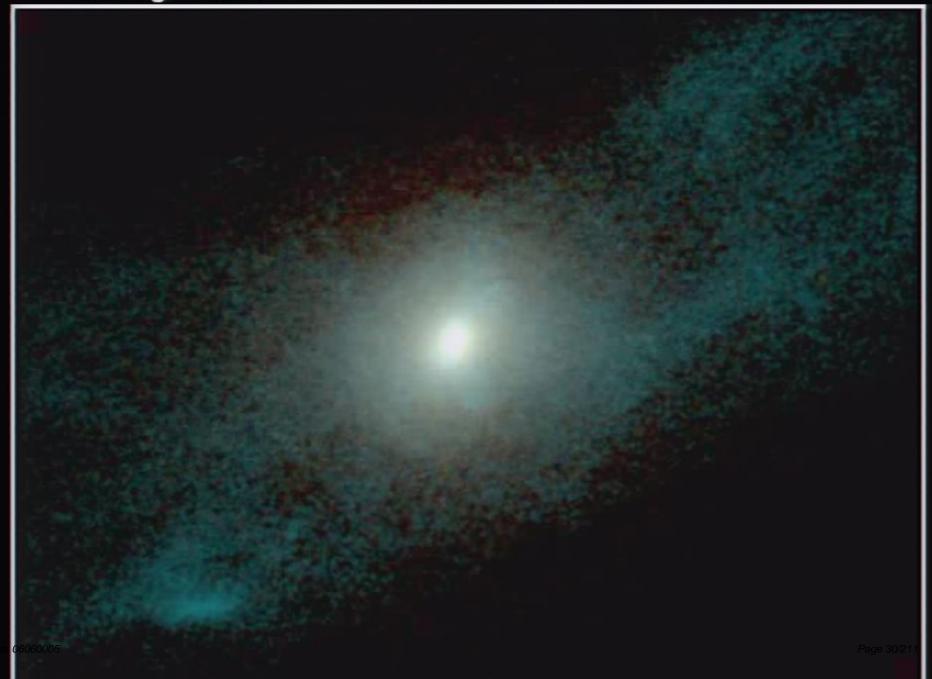


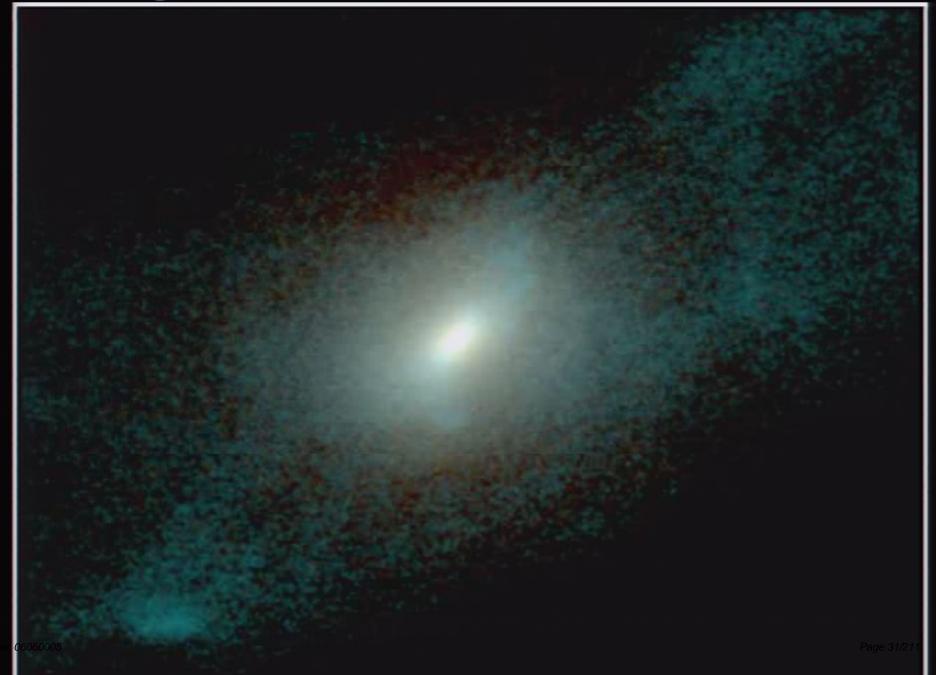


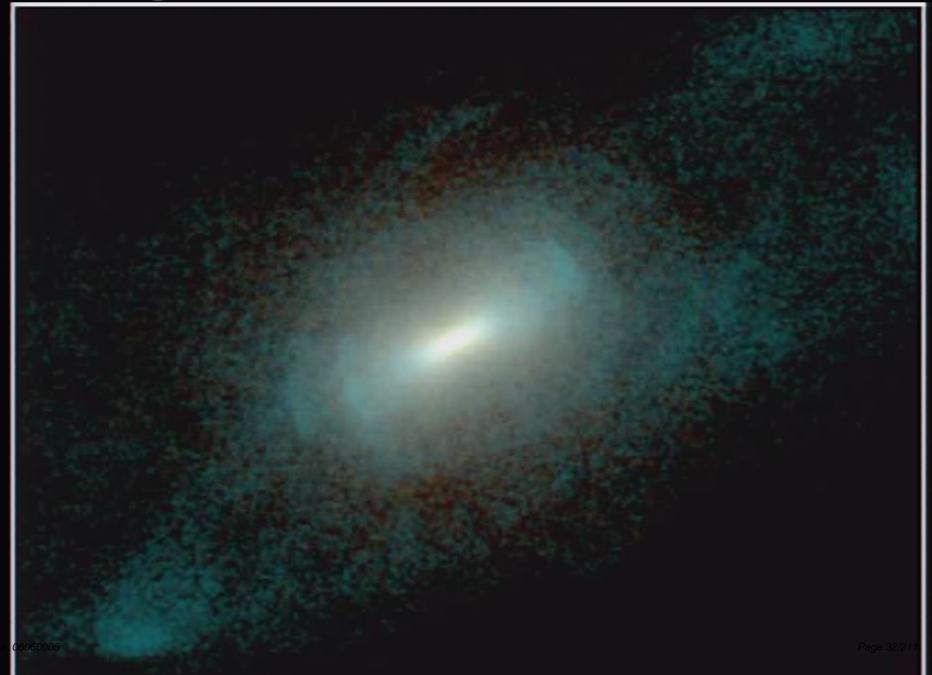


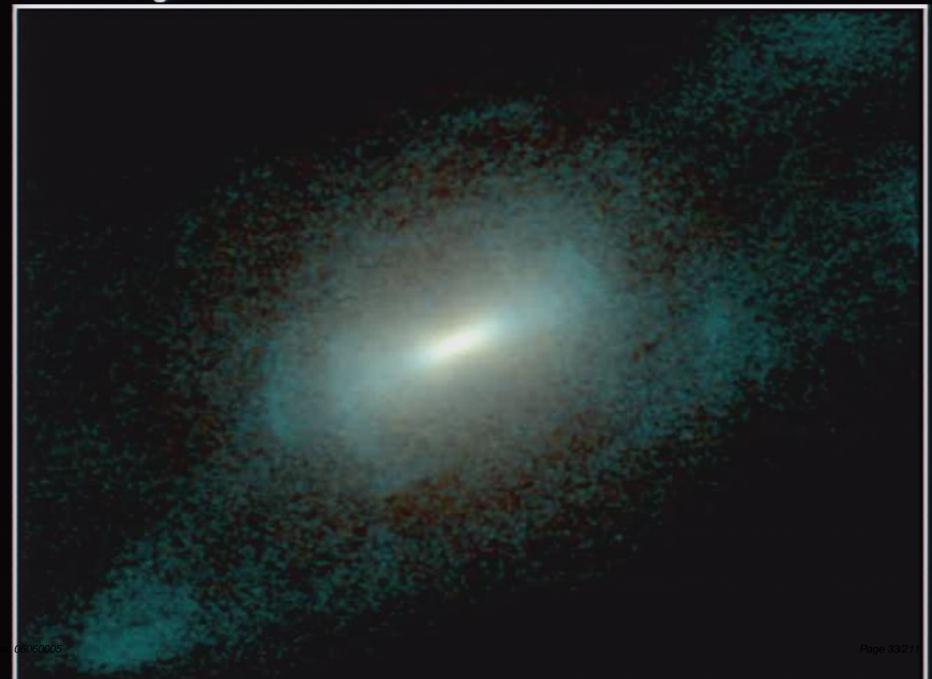


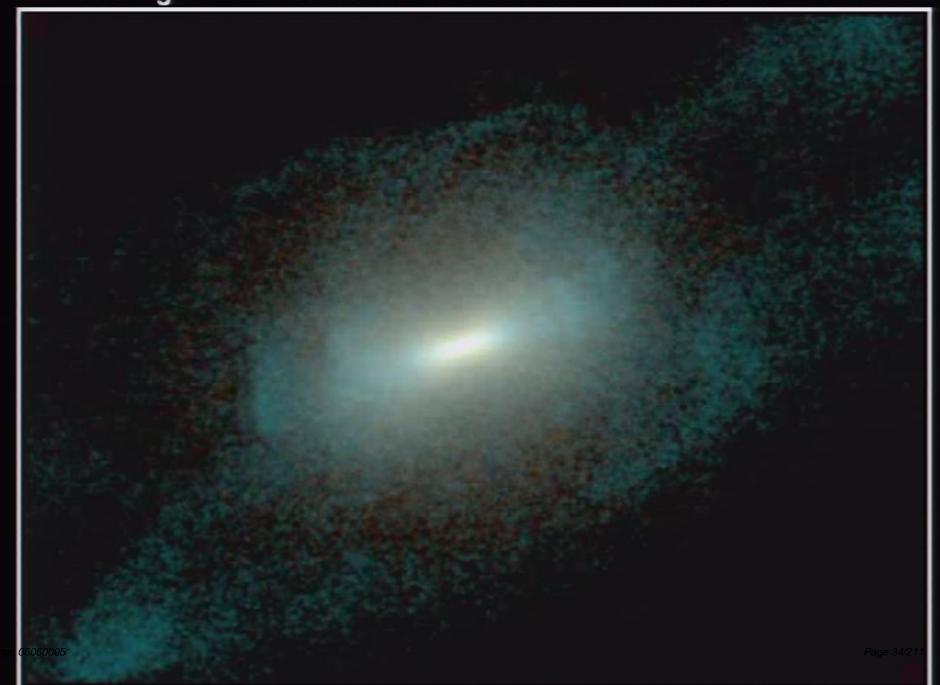


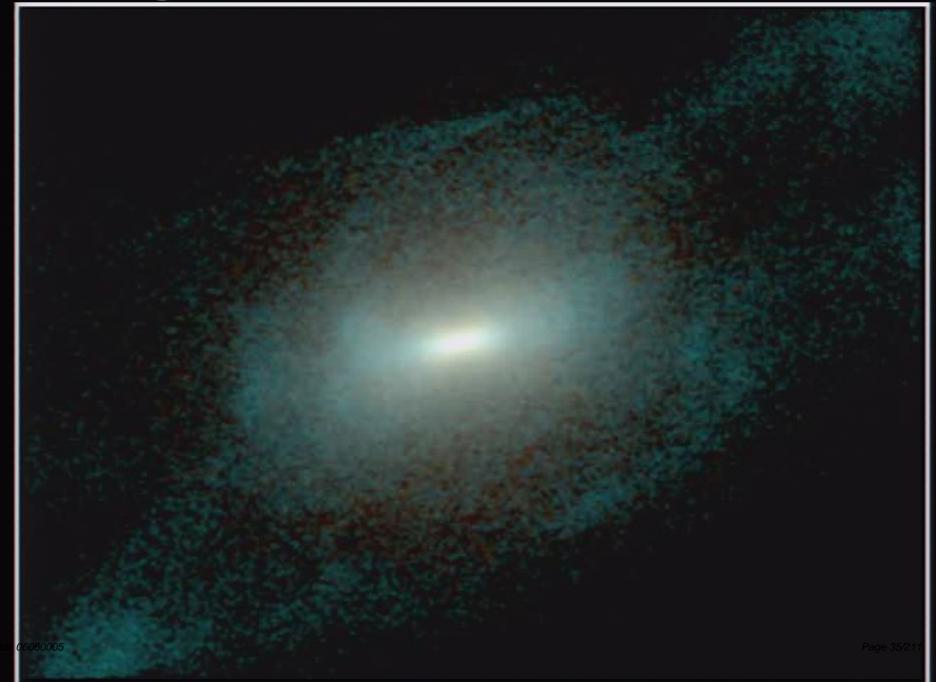


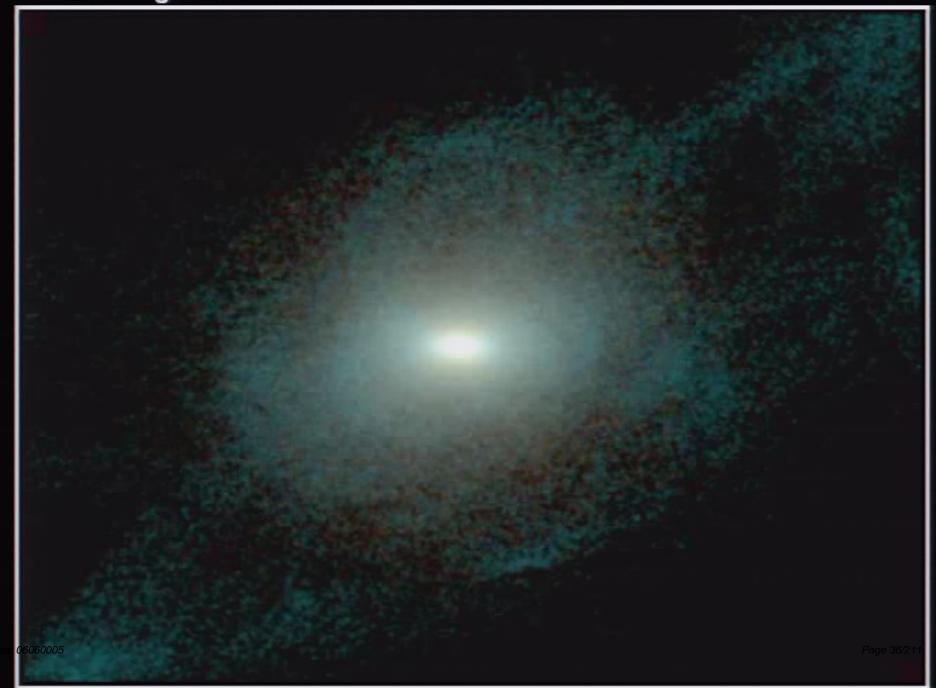


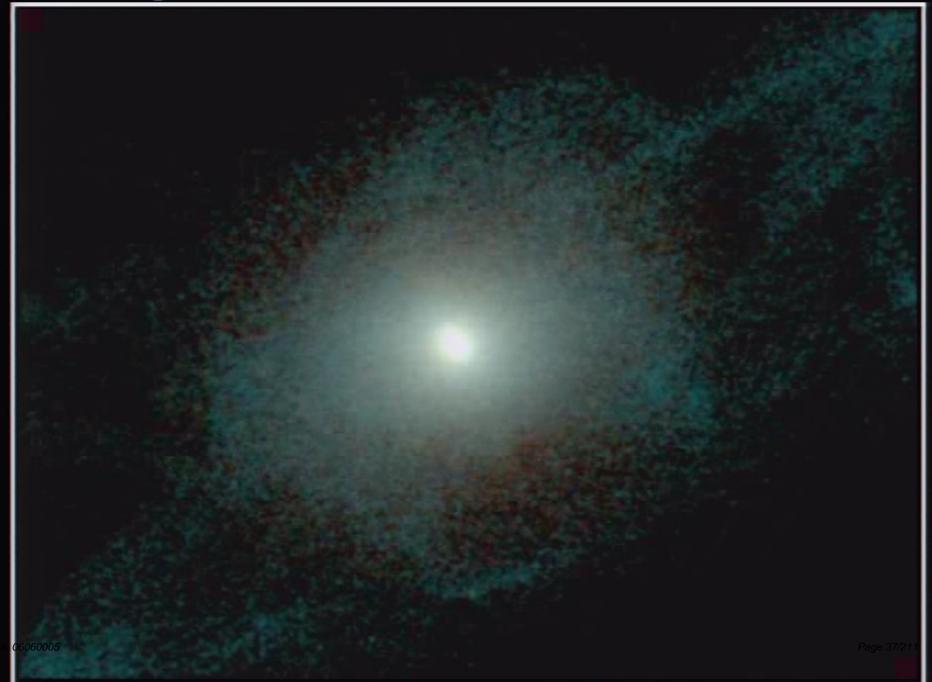


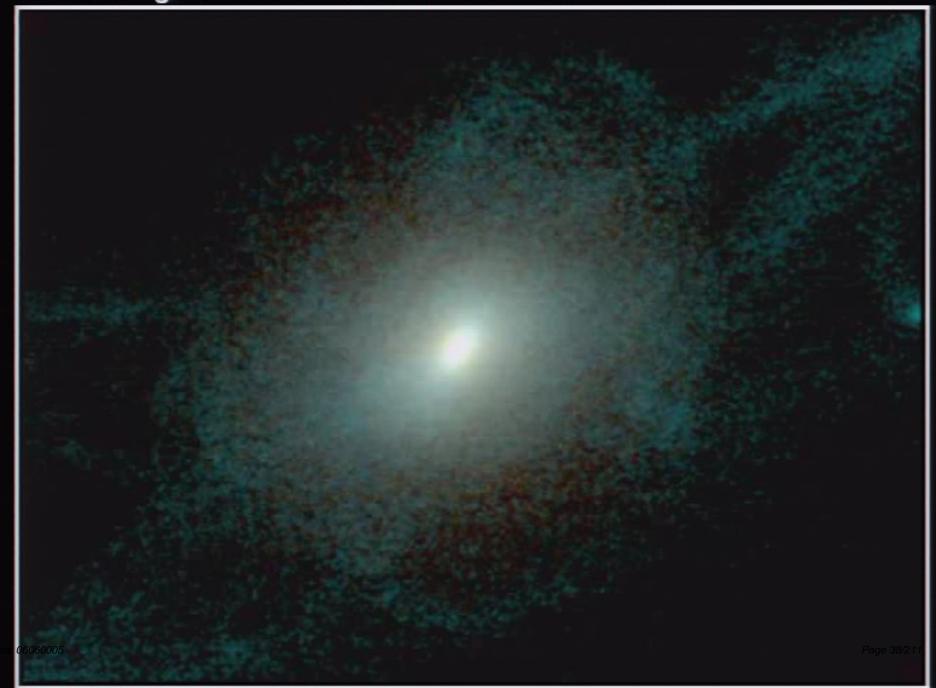


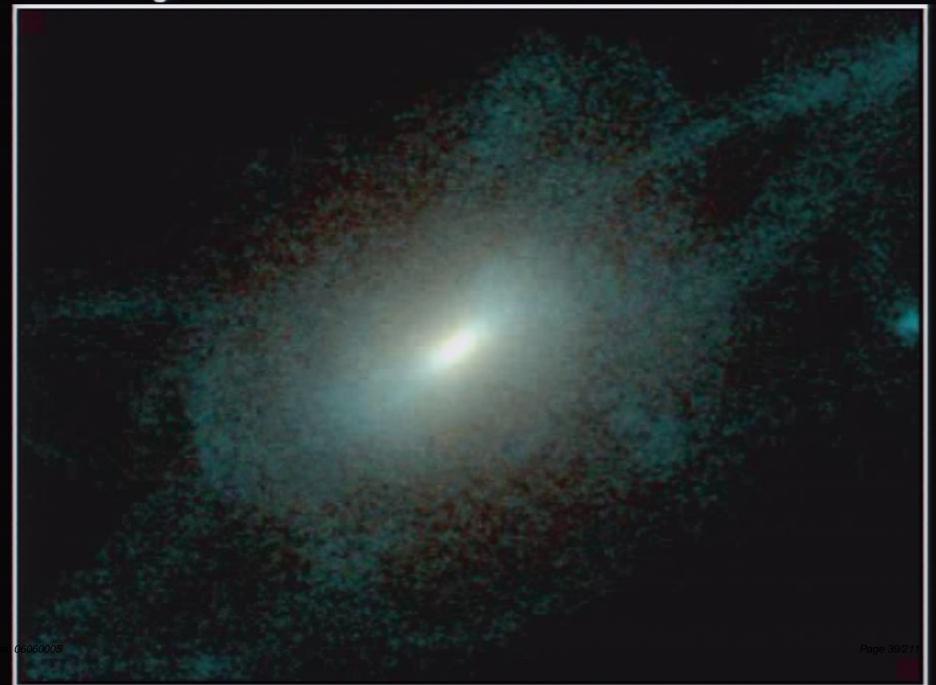


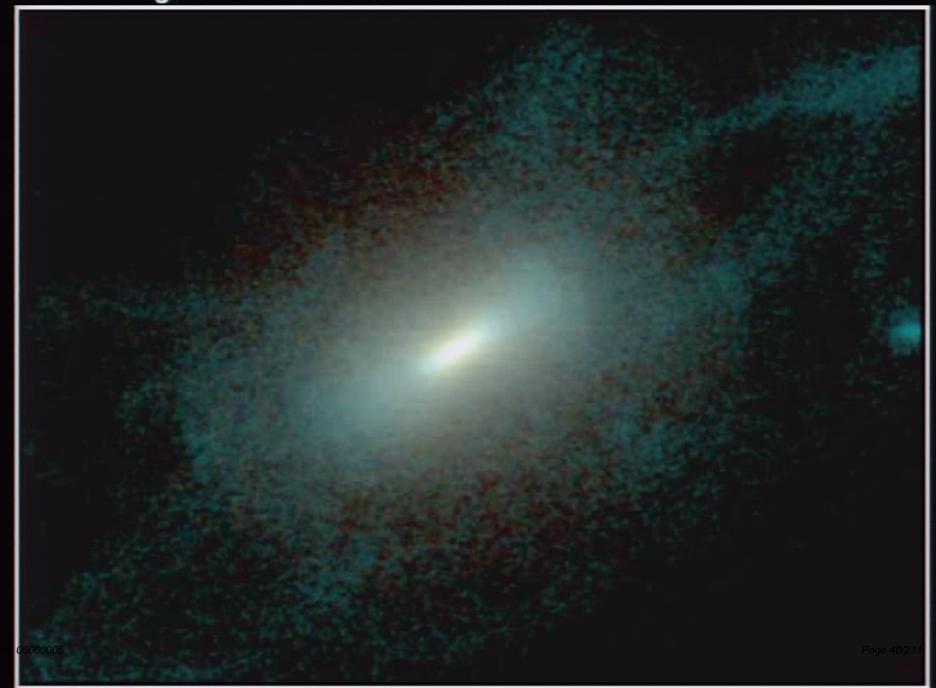


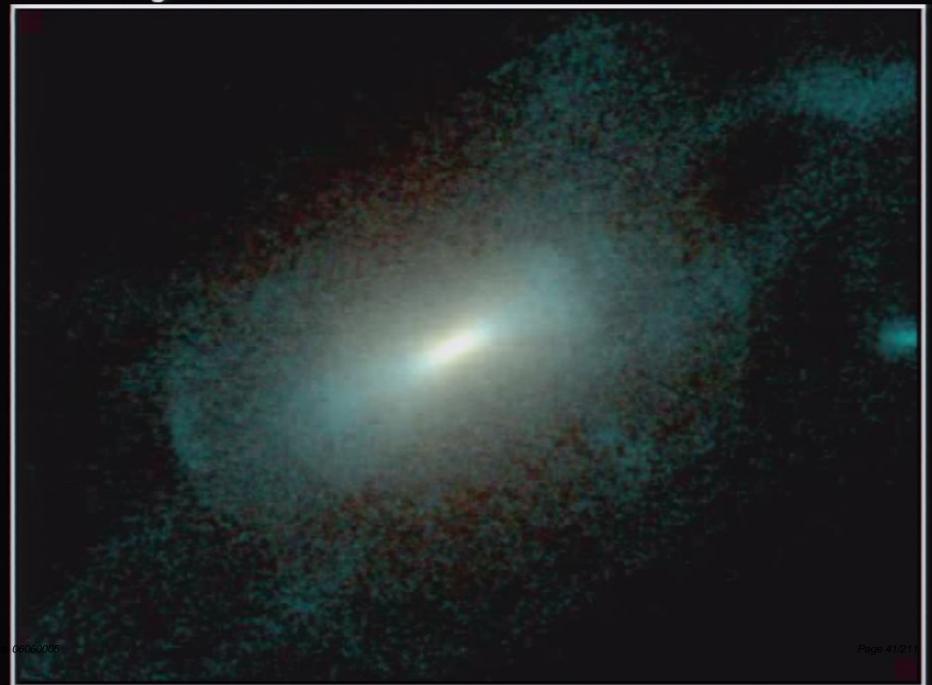


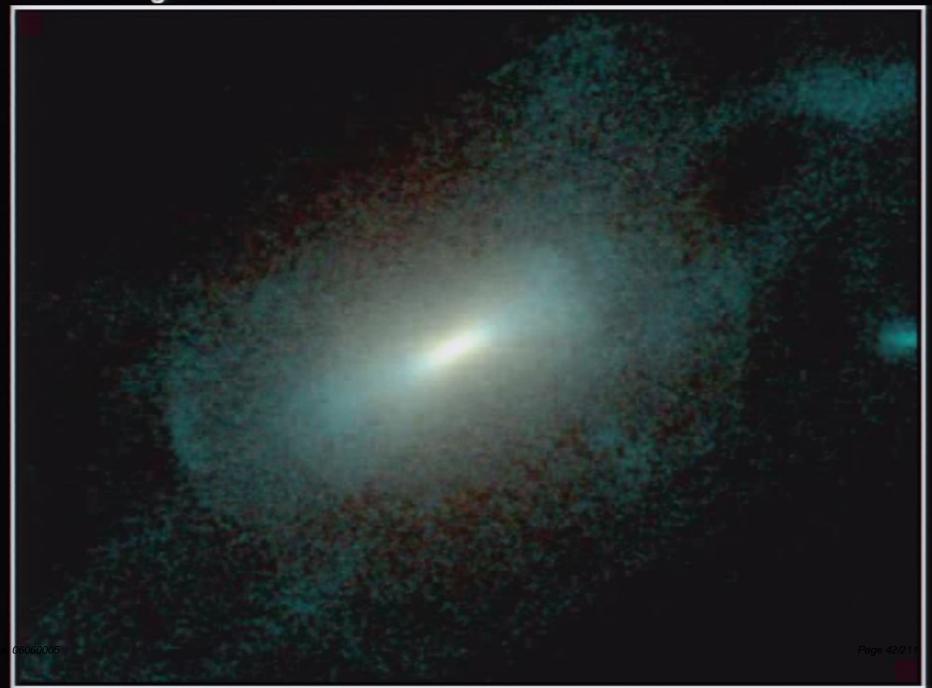


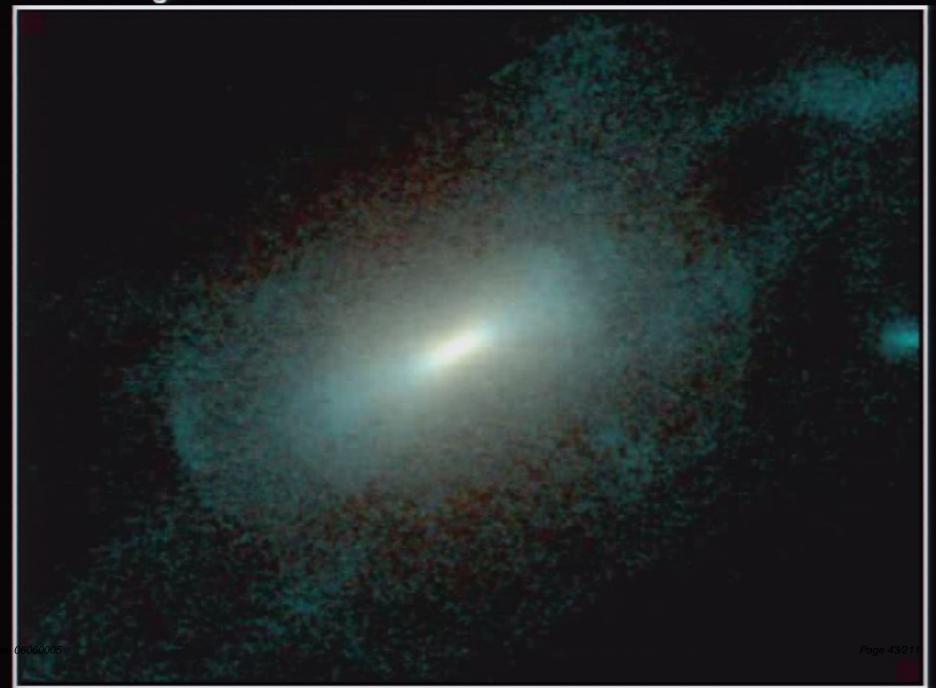


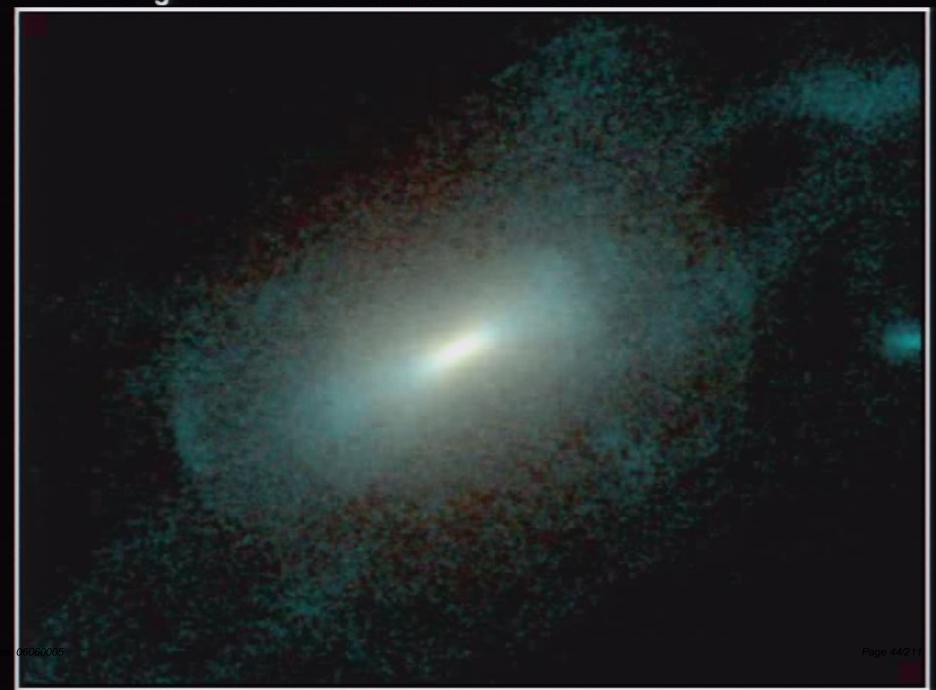


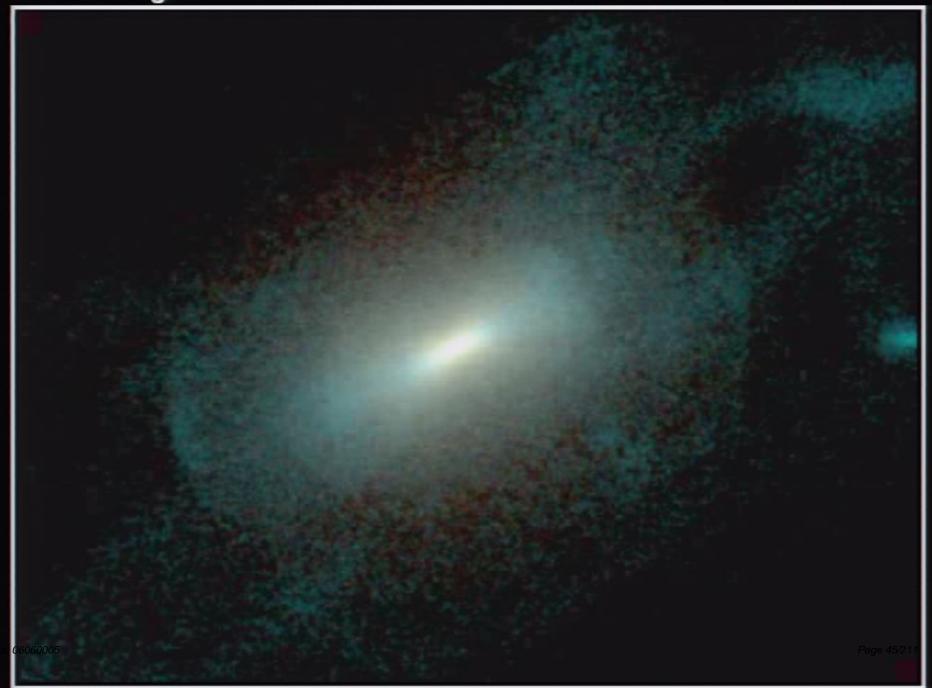


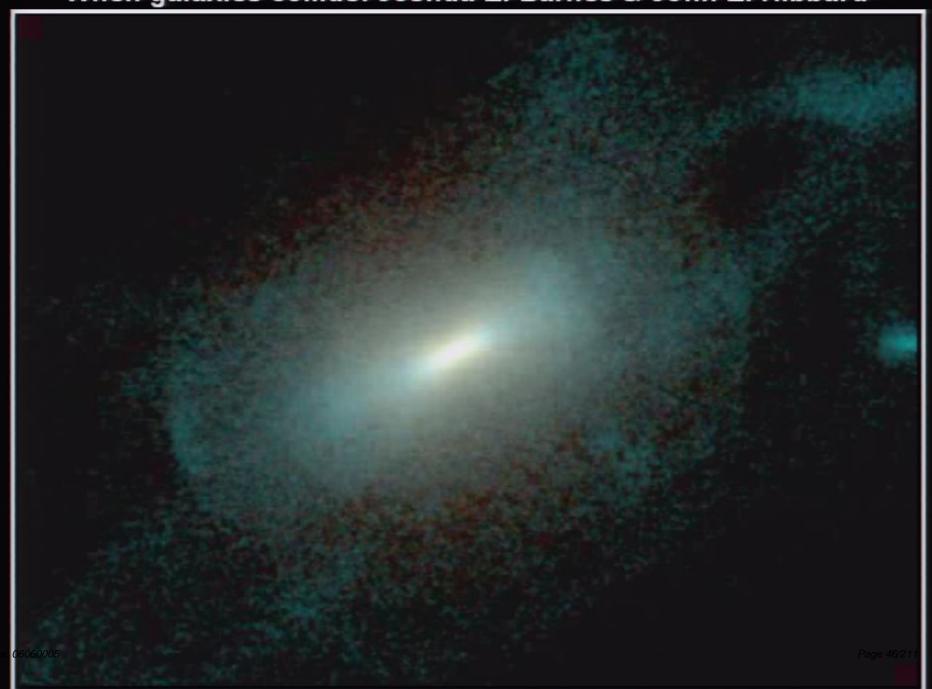


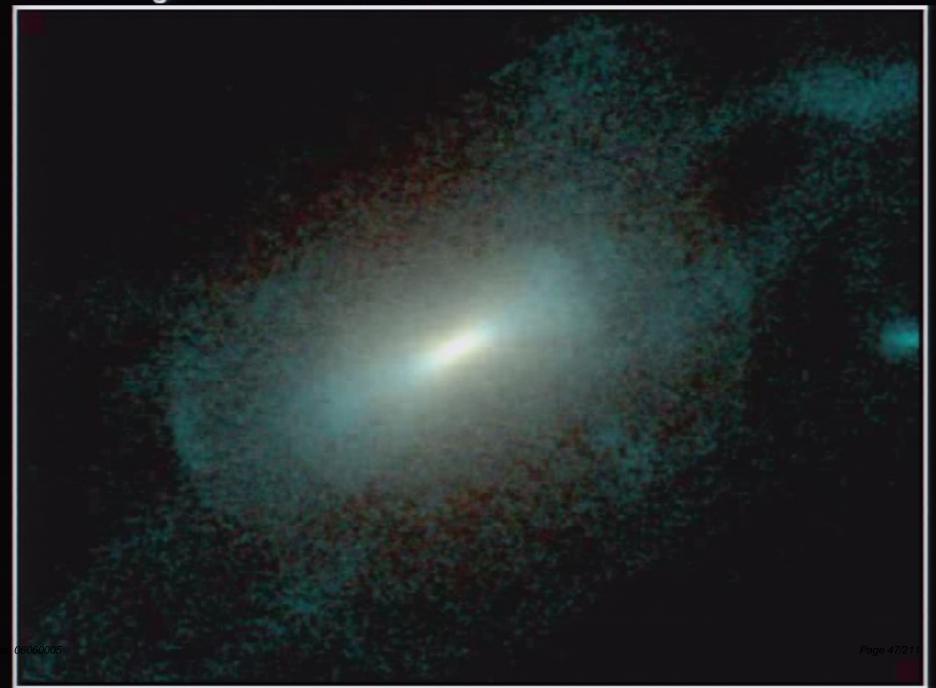


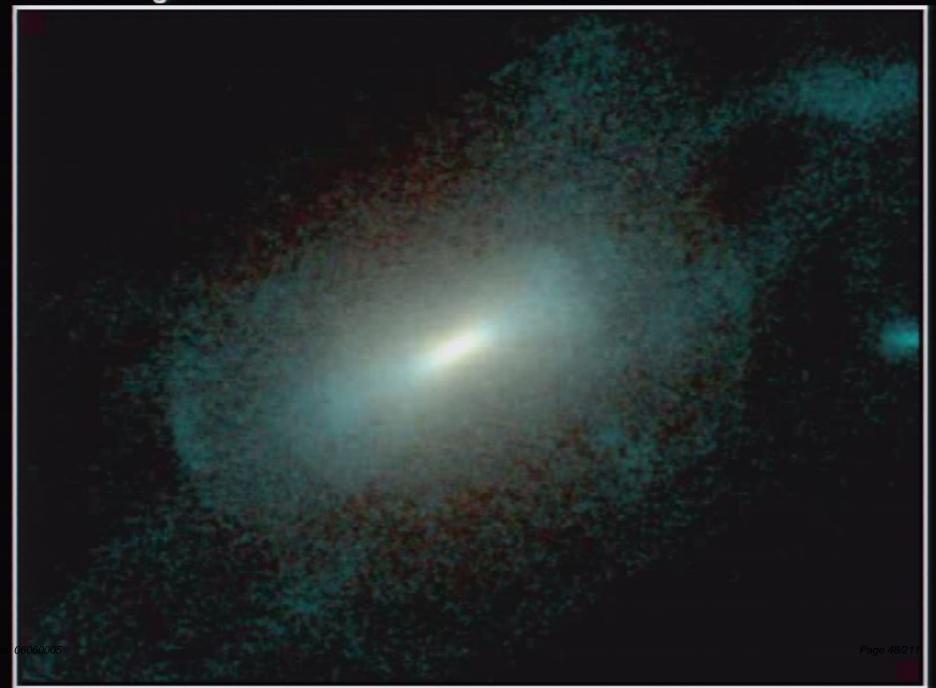


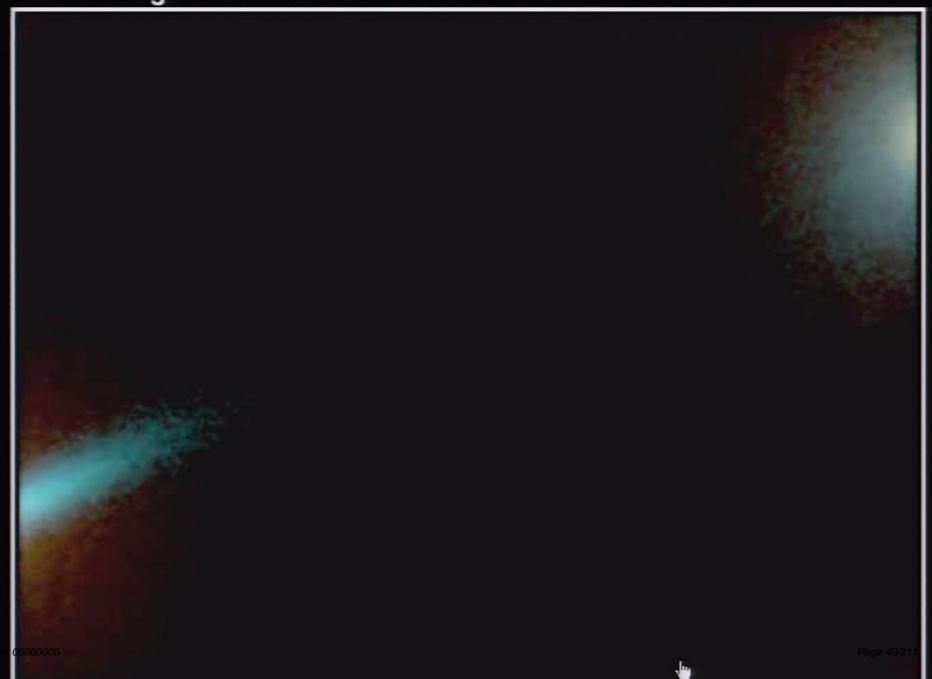


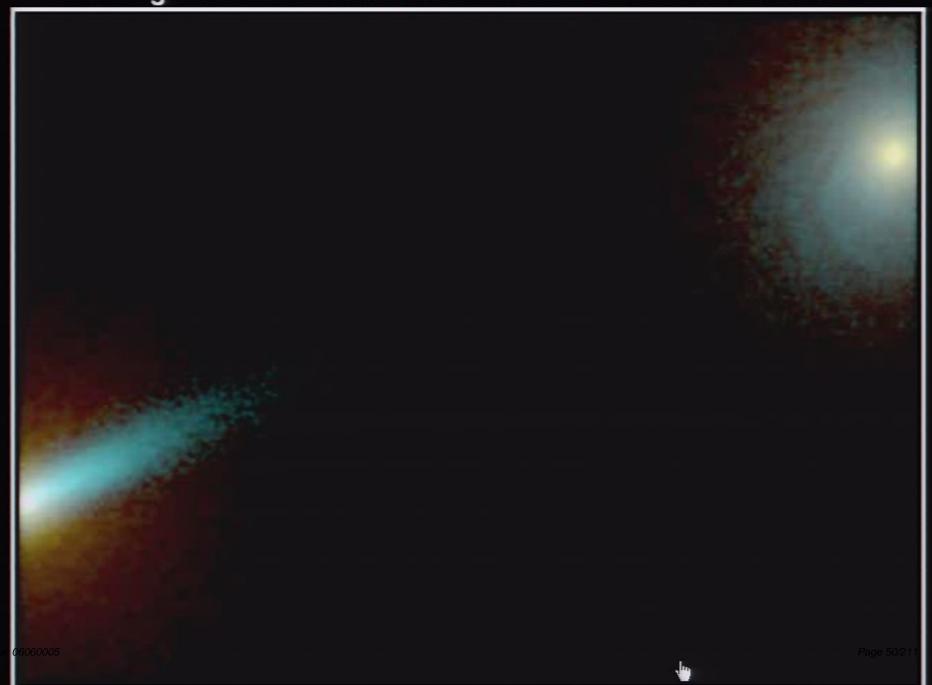


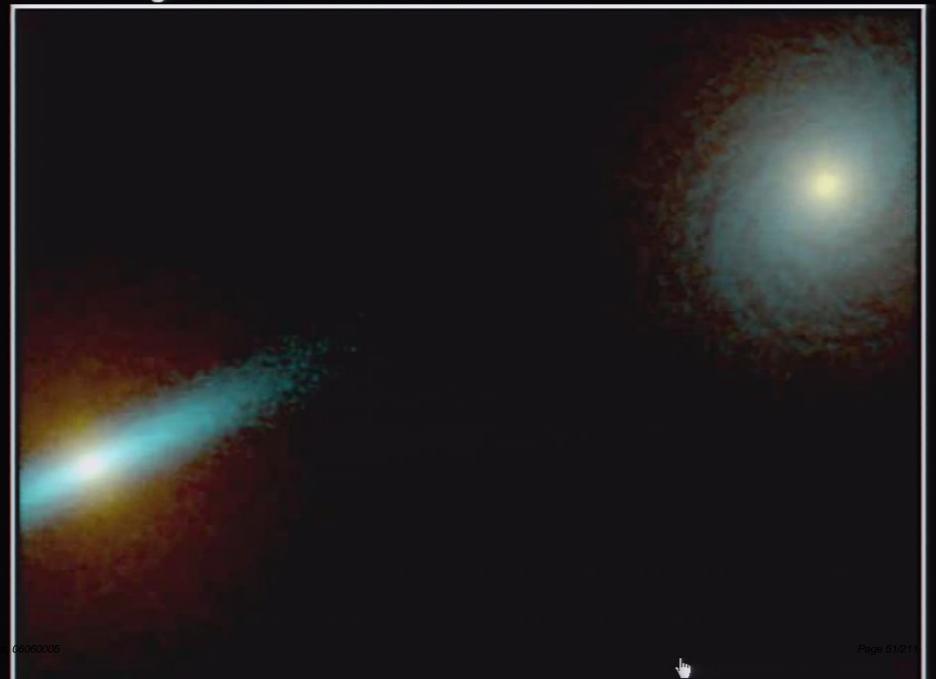


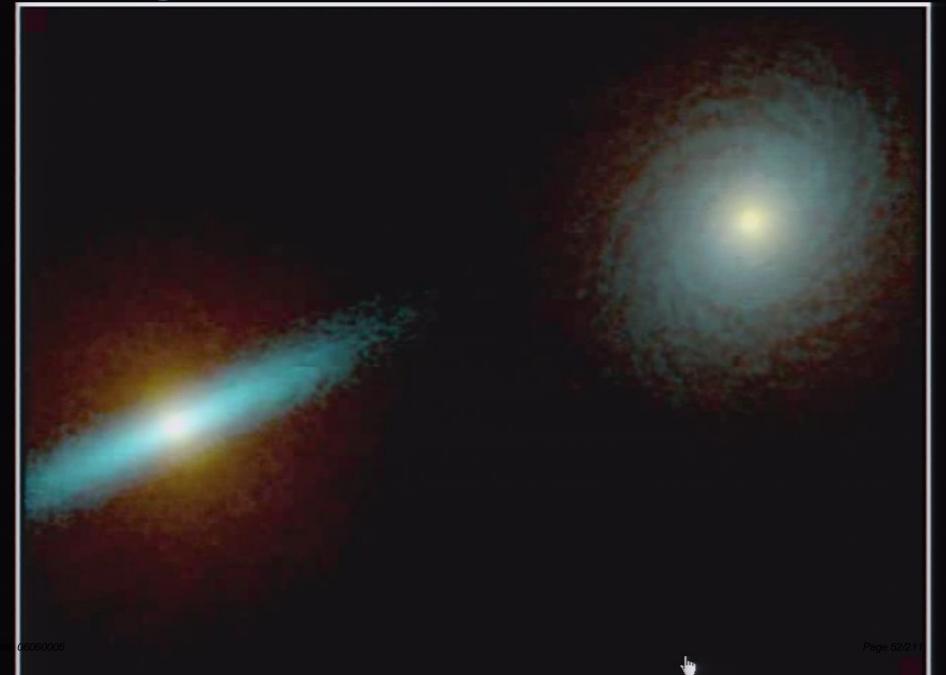


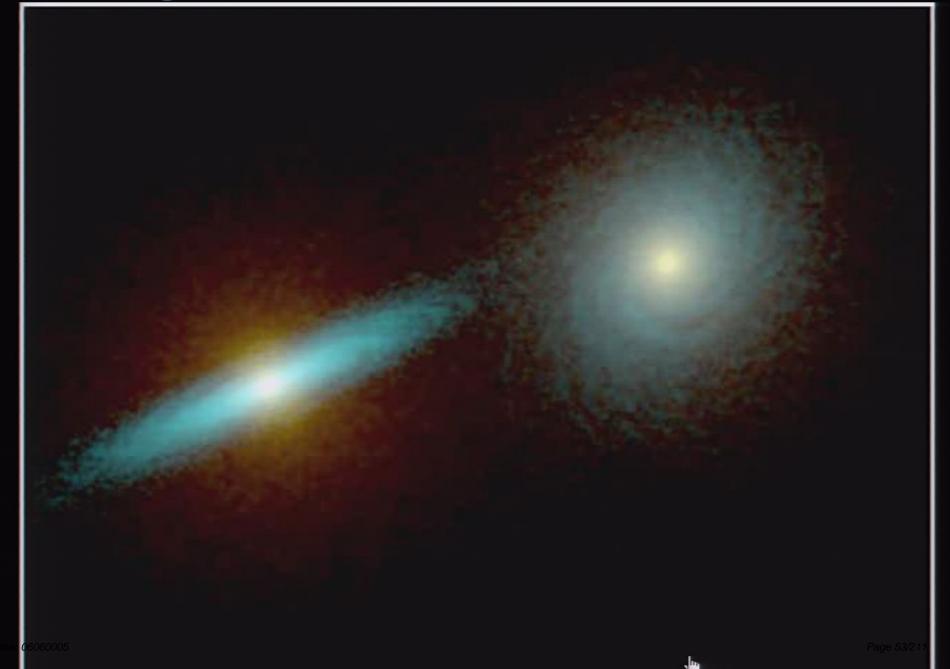


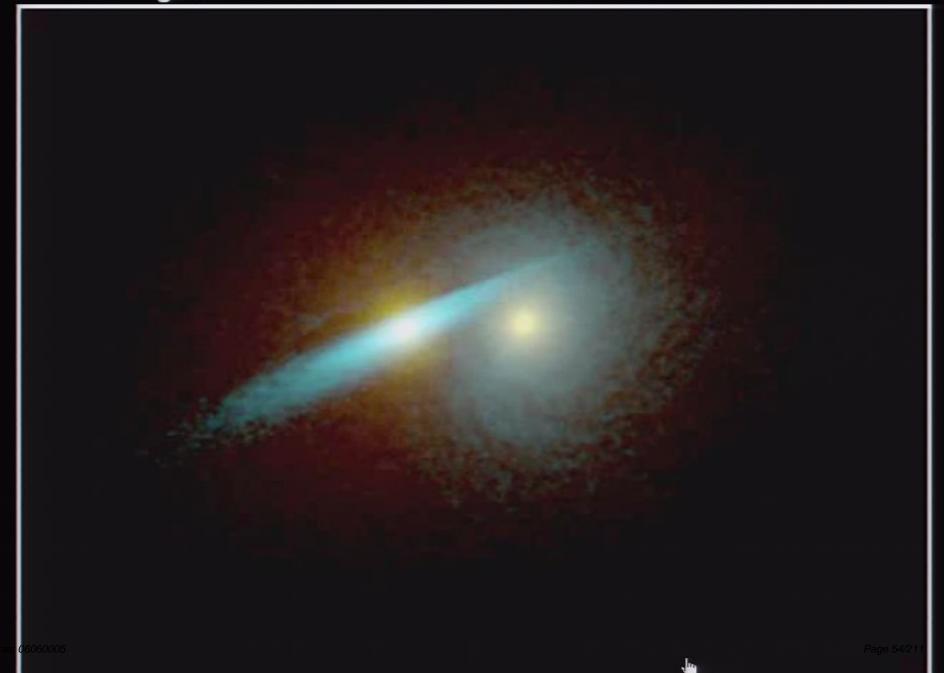


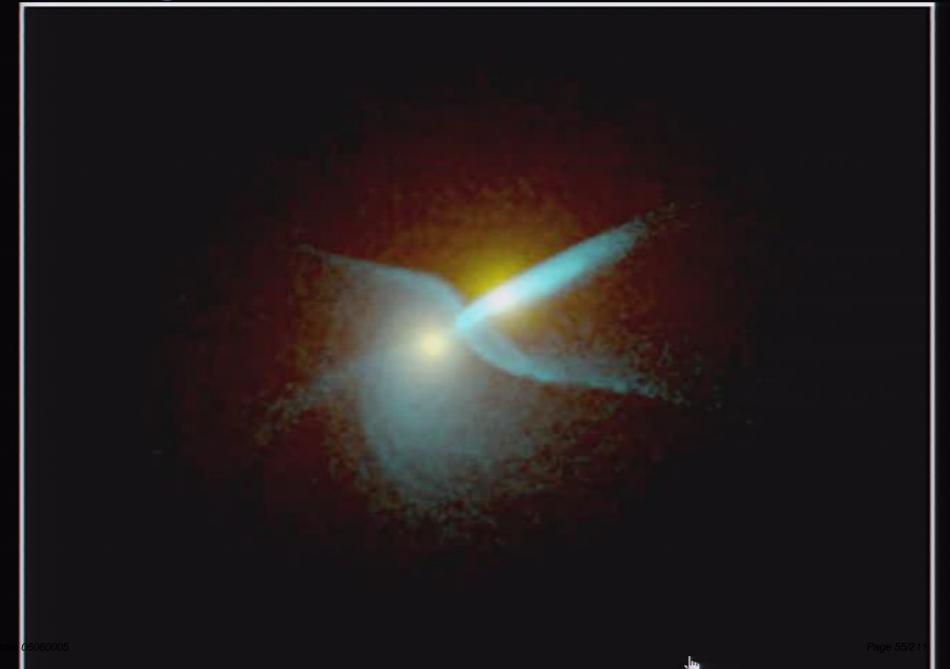


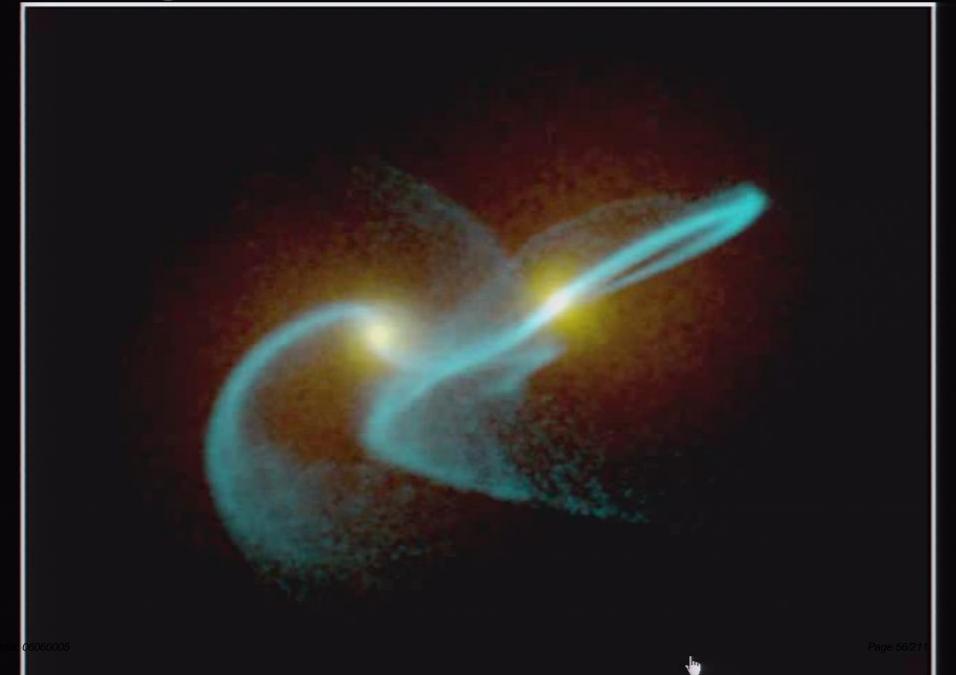


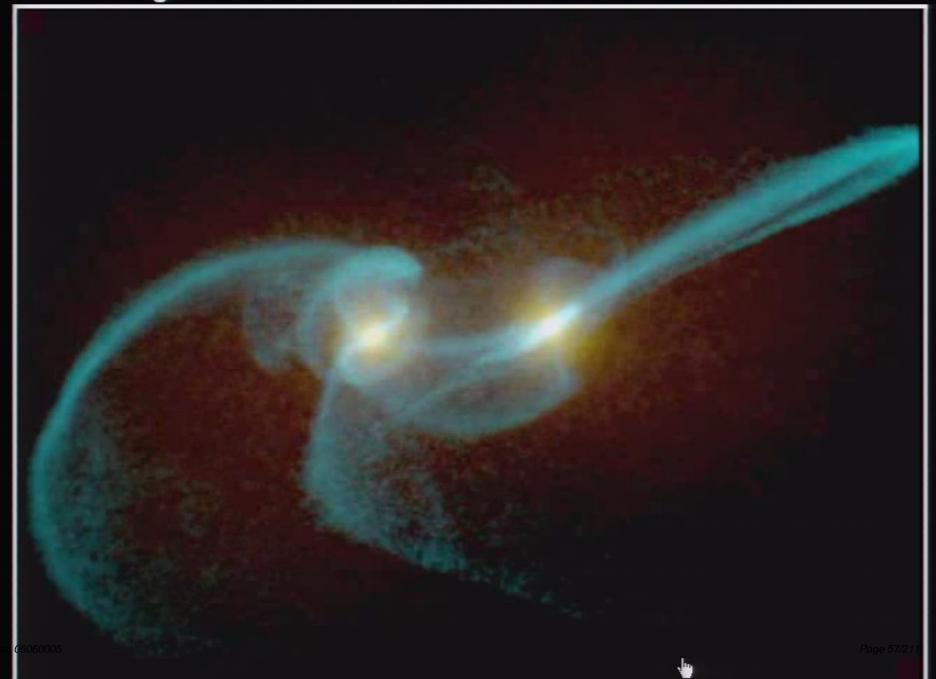


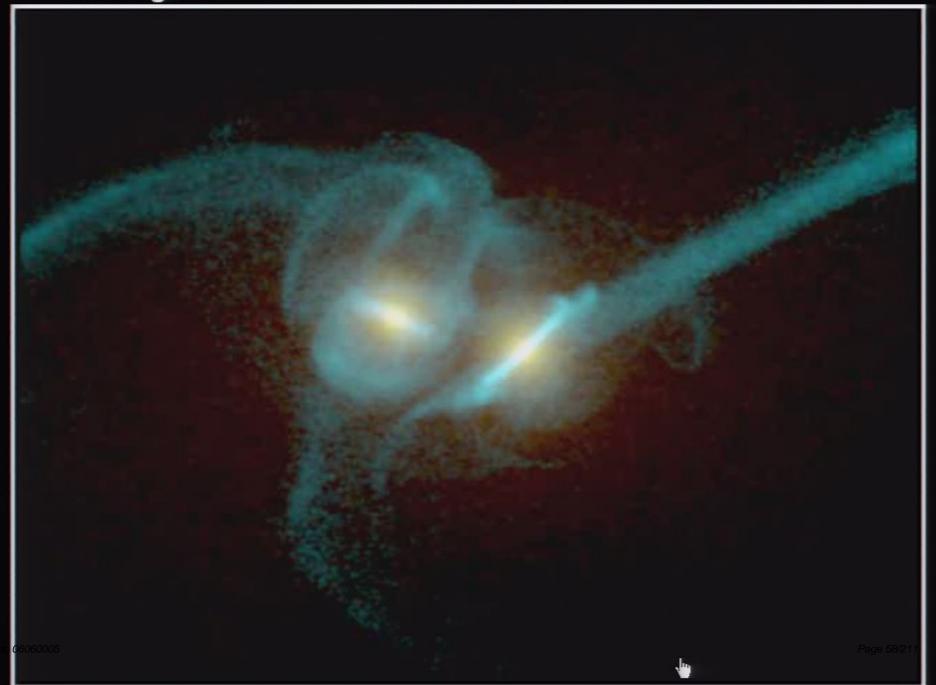


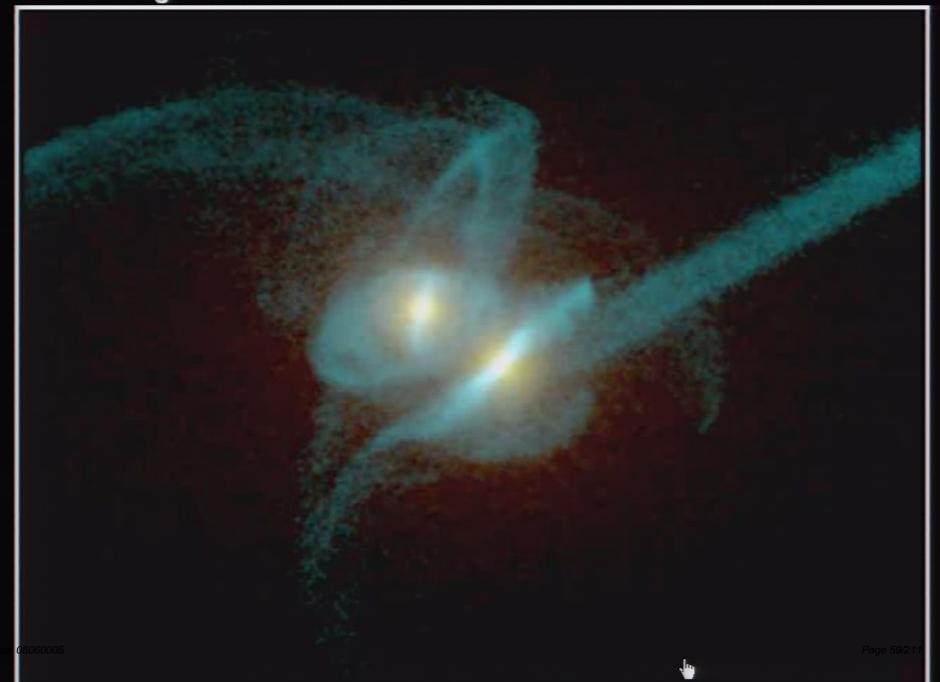


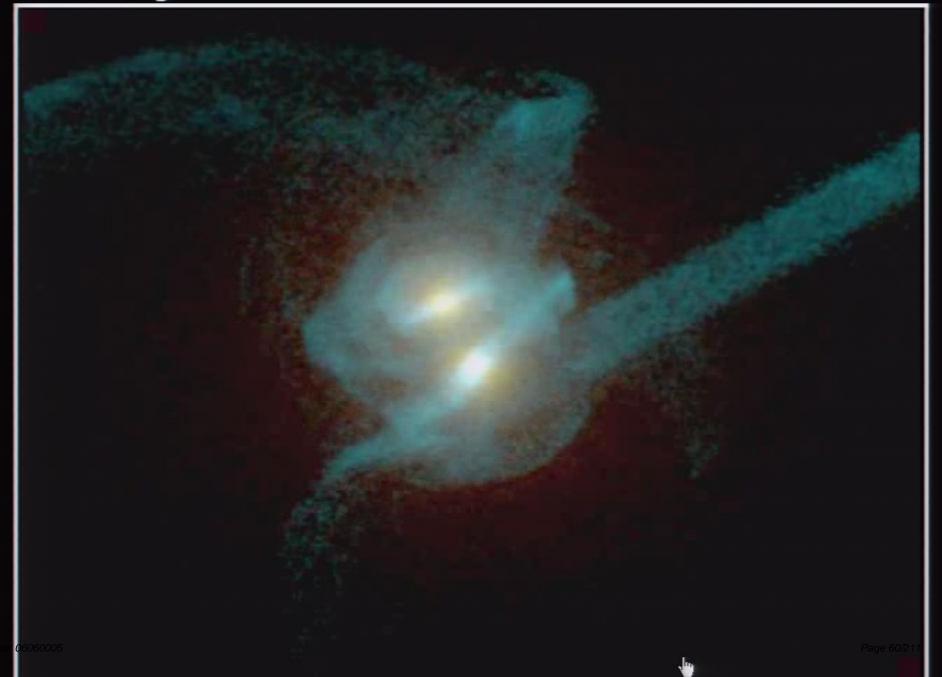




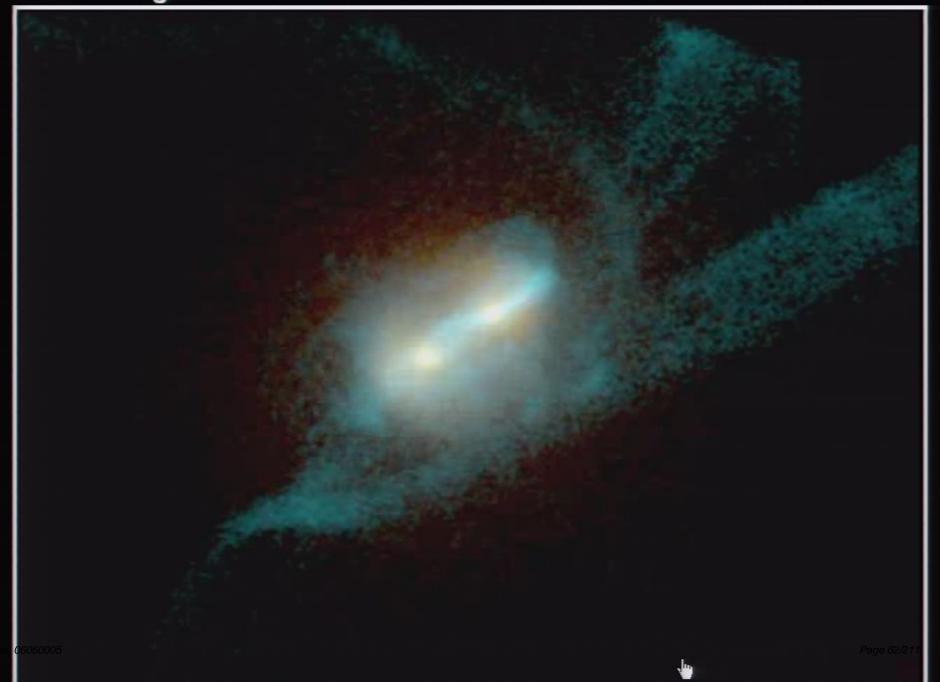




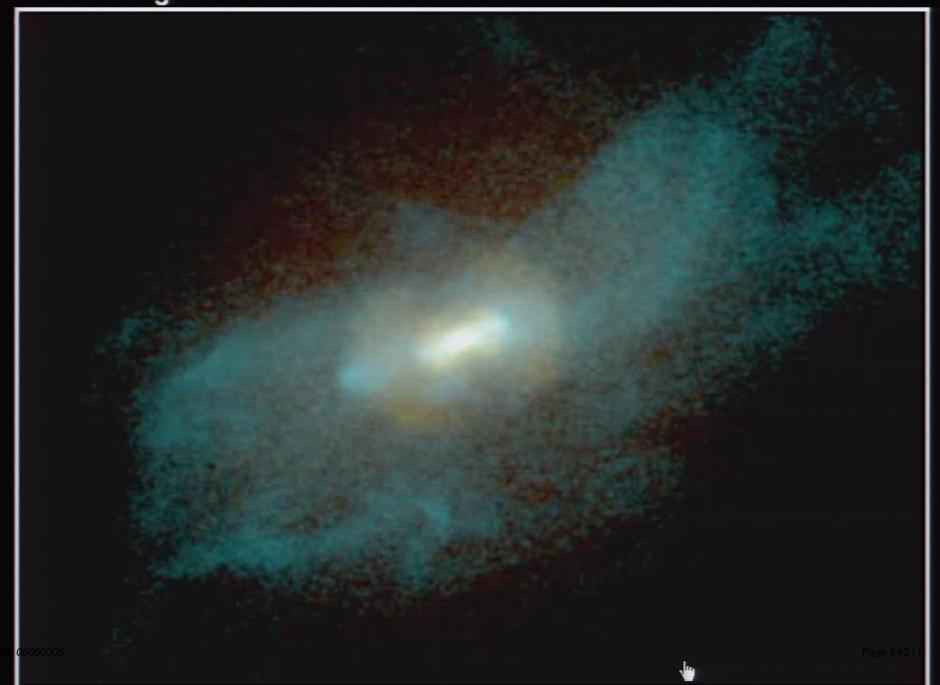


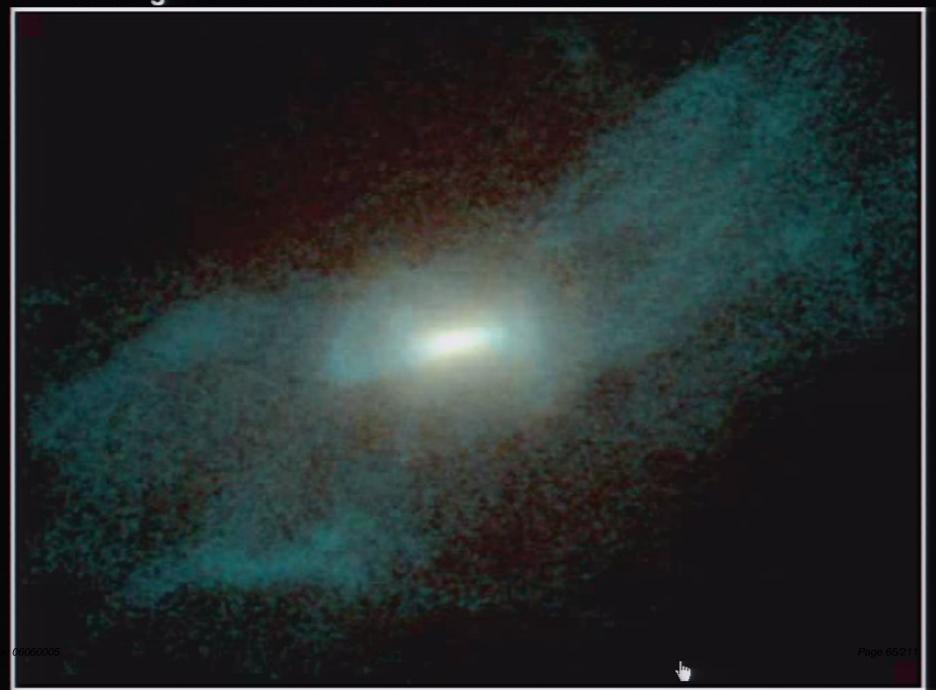


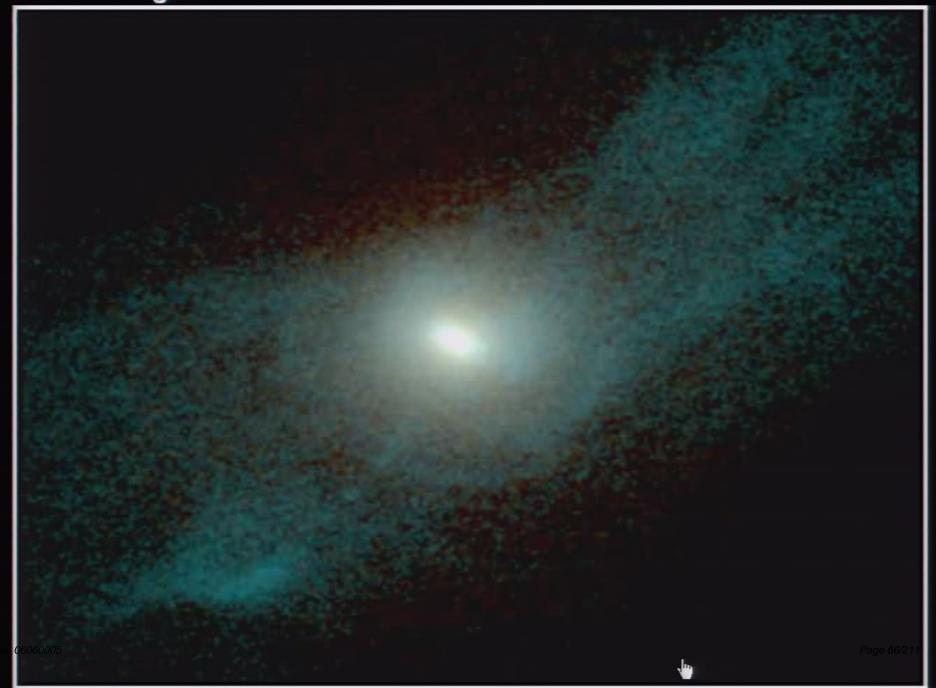


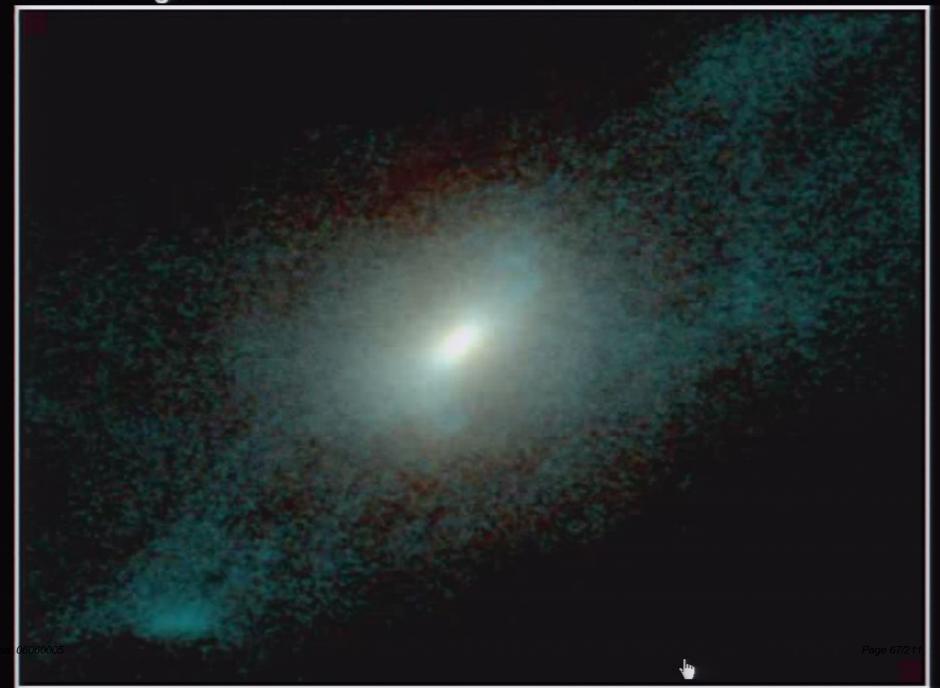


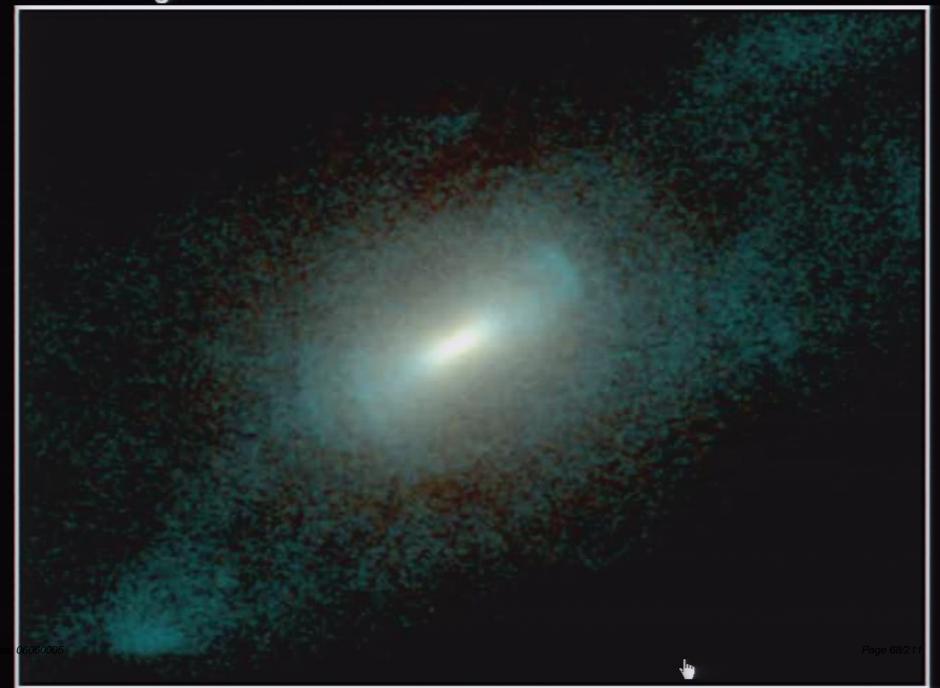


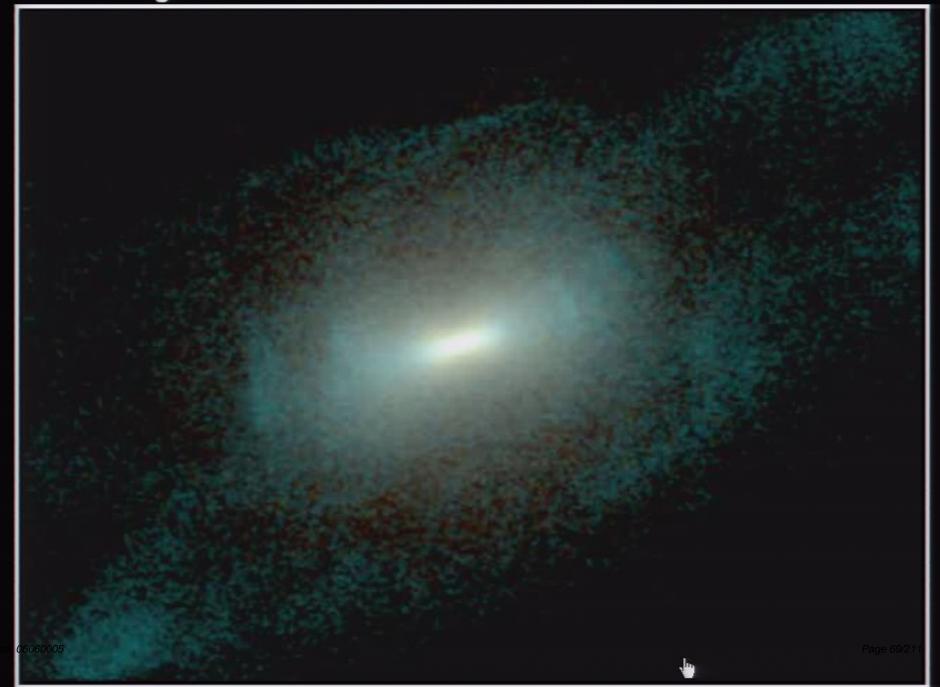


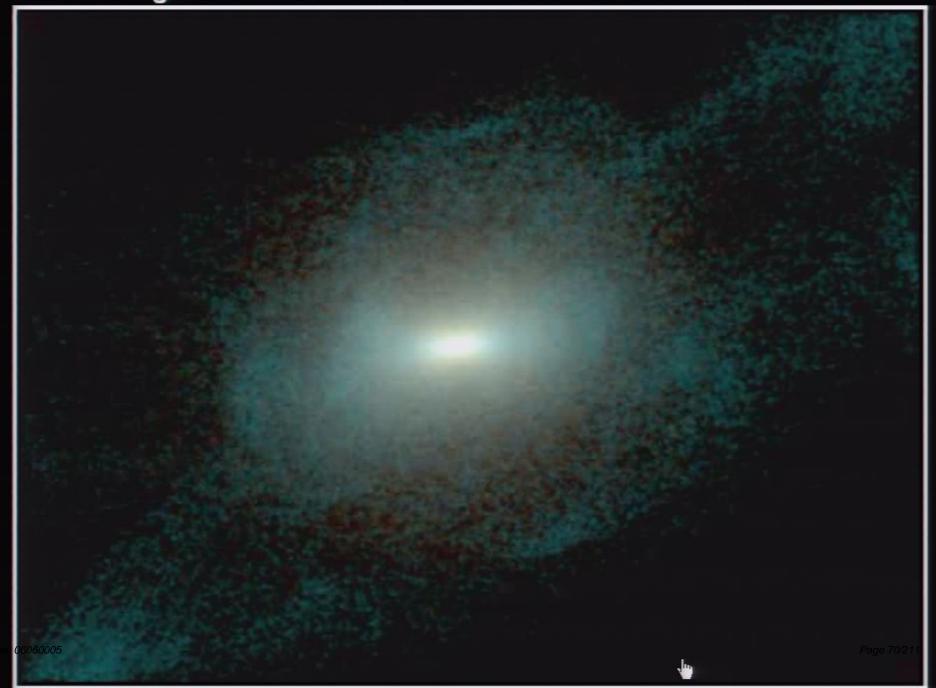


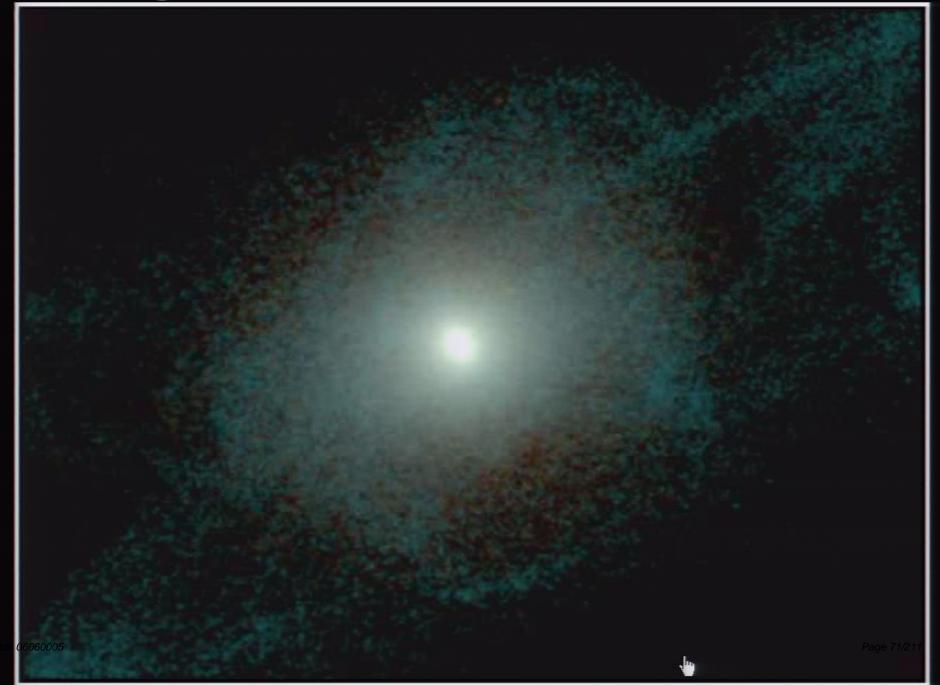


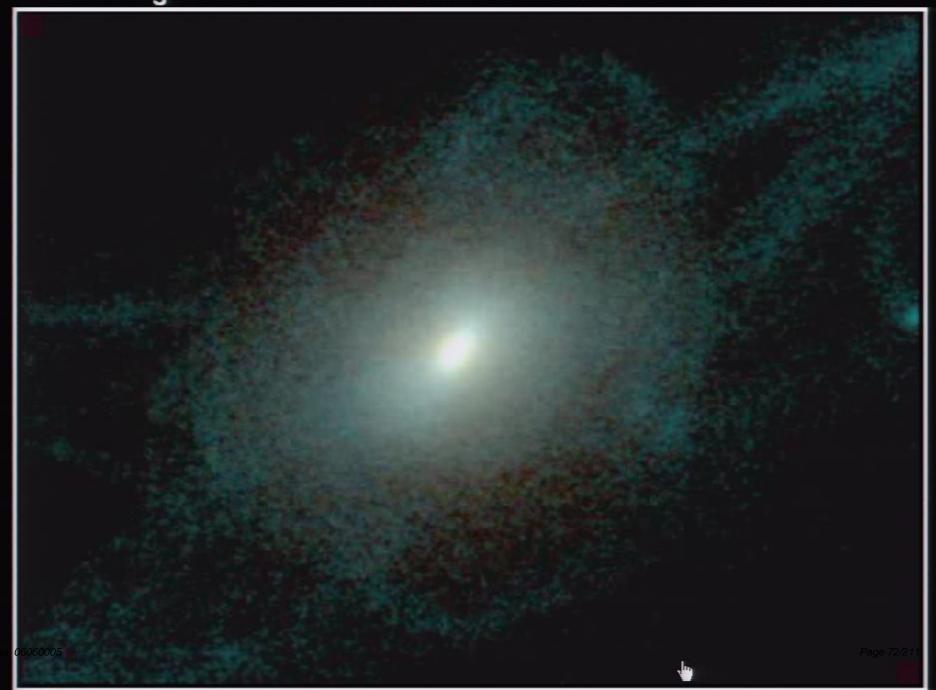


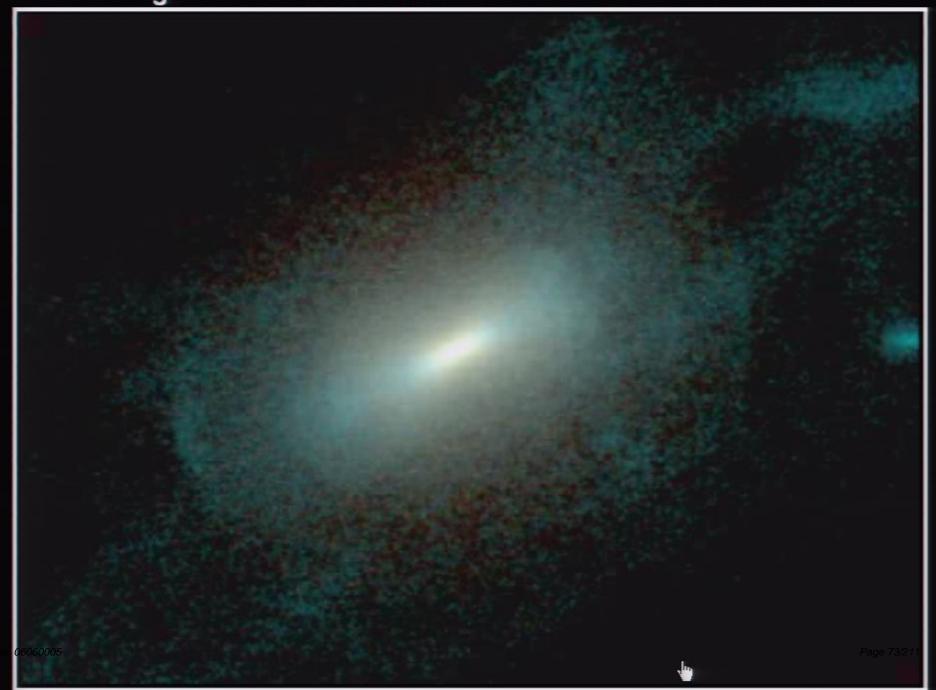


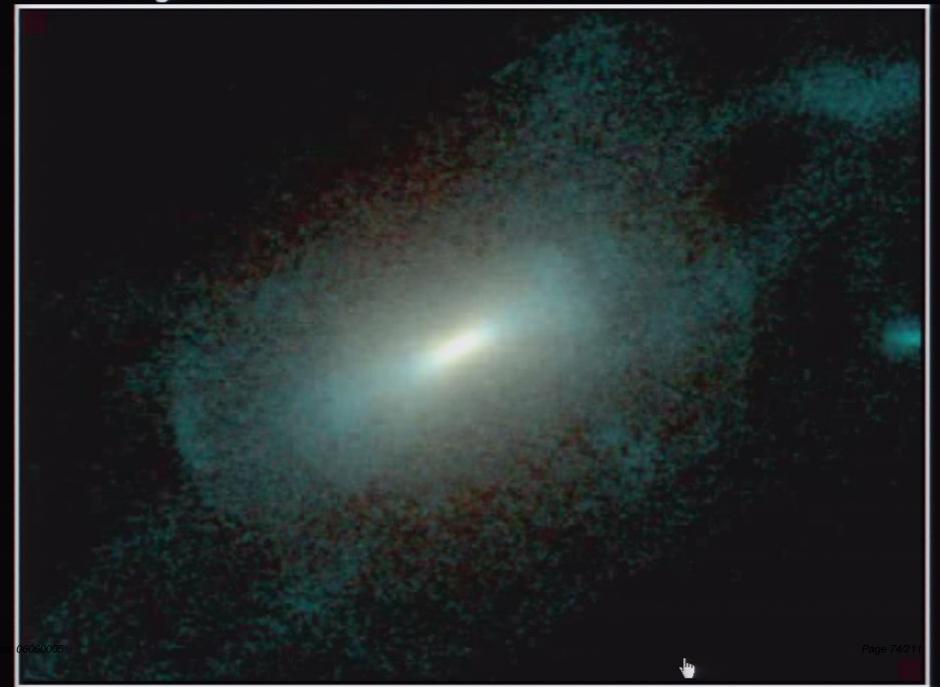


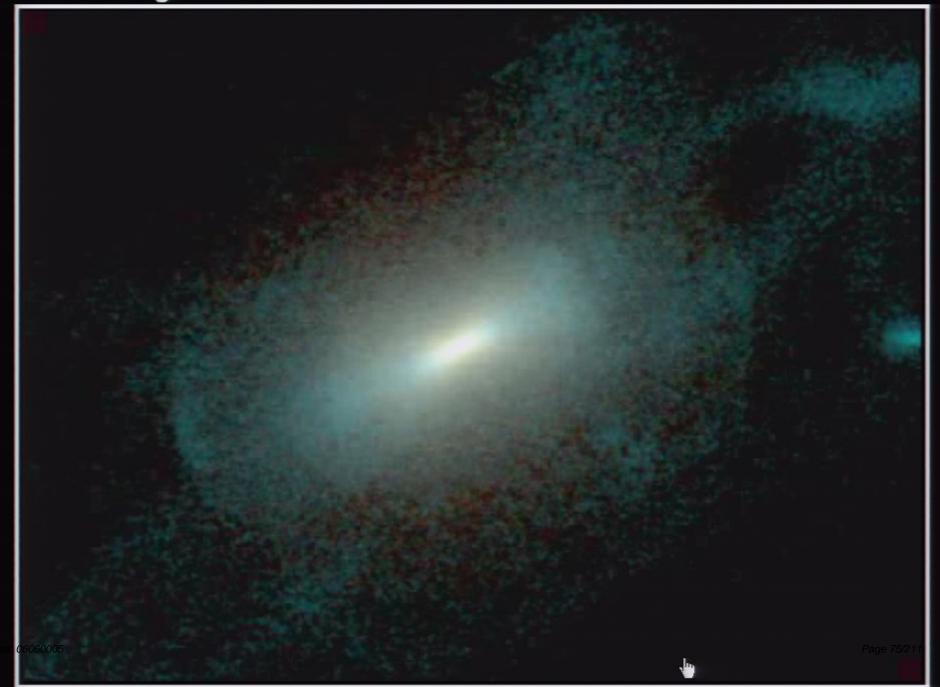


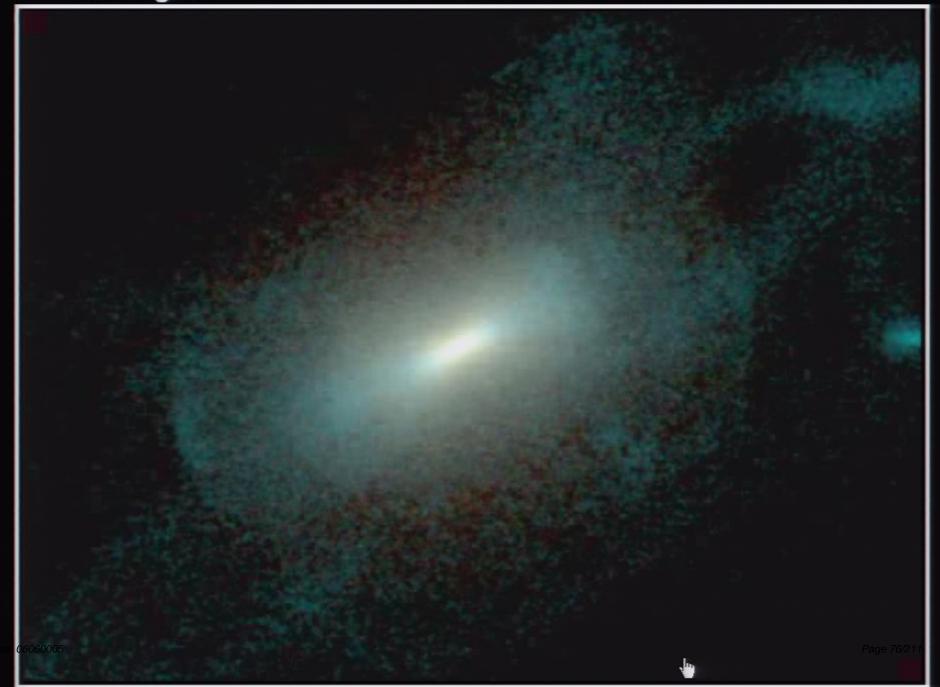


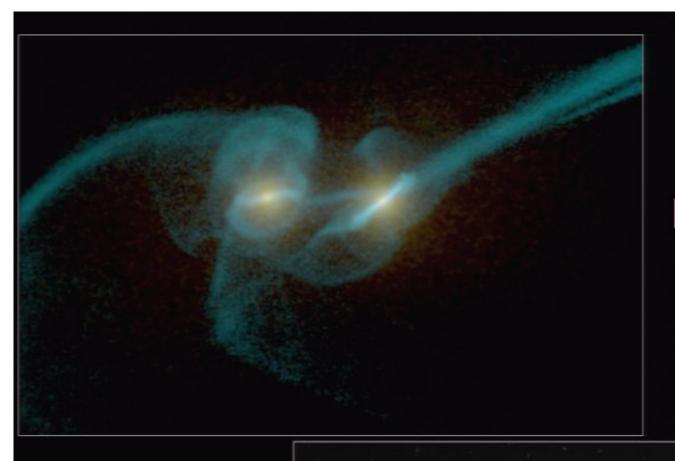












# Barnes & Hibbard simulation

"The Mice"
Galaxies

rsa: 06060005

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# Barnes & Hibbard simulation

"The Mice"
Galaxies

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# Arrangement

Cluster of Galaxies



# Arrangement



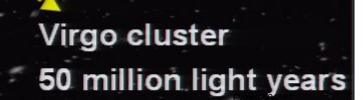
**Andromeda** 



2 million light years - 90,000 mph

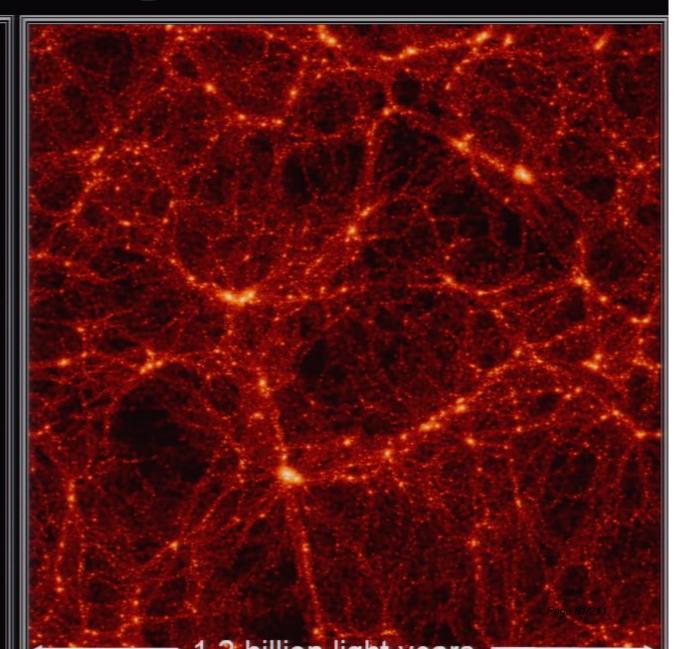


500 million light years



# Arrangement

The Cosmic-Wide Web



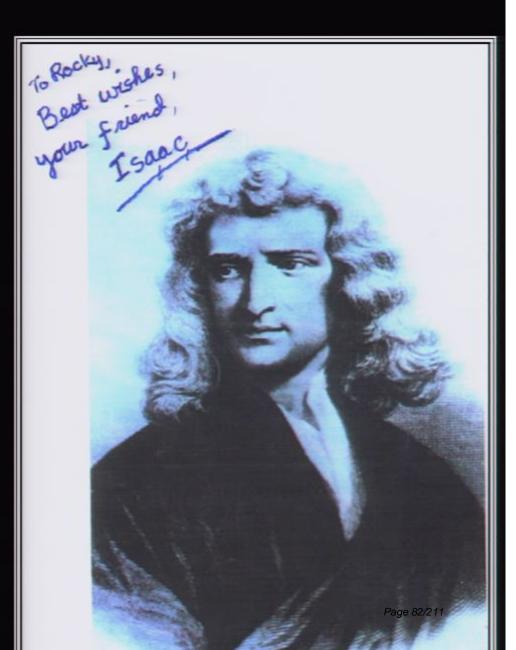
Virgo consortium

## Nature of Space and Time

Absolute space, in its own nature, without relation to anything external, remains always similar and immovable.

Isaac Newton
1687

Philosophiae Maturalis



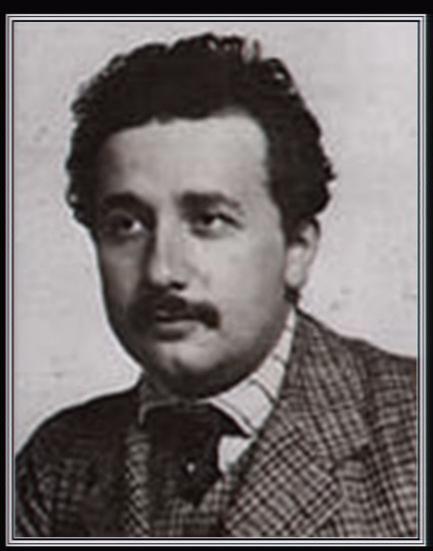
## Normal Is a Relative Thing



"If you are able to accept that space is curved and time is relative ...

Einstein, ca. 1905

## Normal Is a Relative Thing



"If you are able to accept that space is curved and time is relative ... wearing stripes with plaids seems relatively normal."

Einstein, ca. 1905

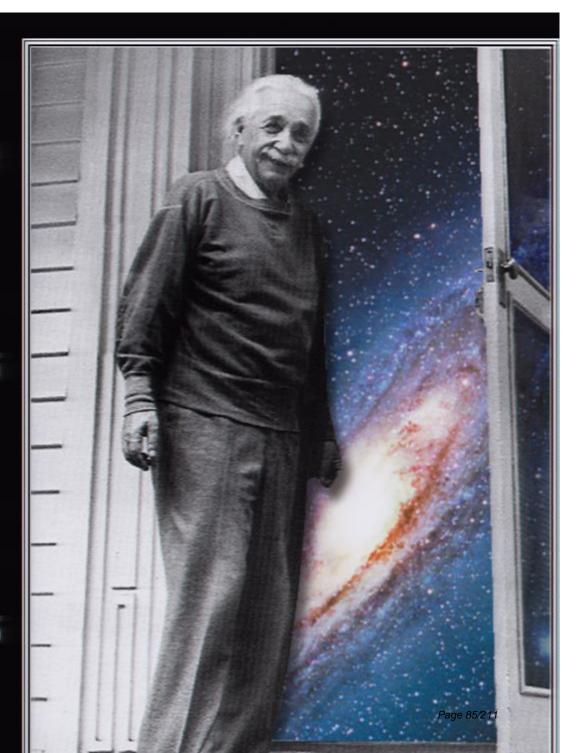
# Nature of Space and Time

They are related.

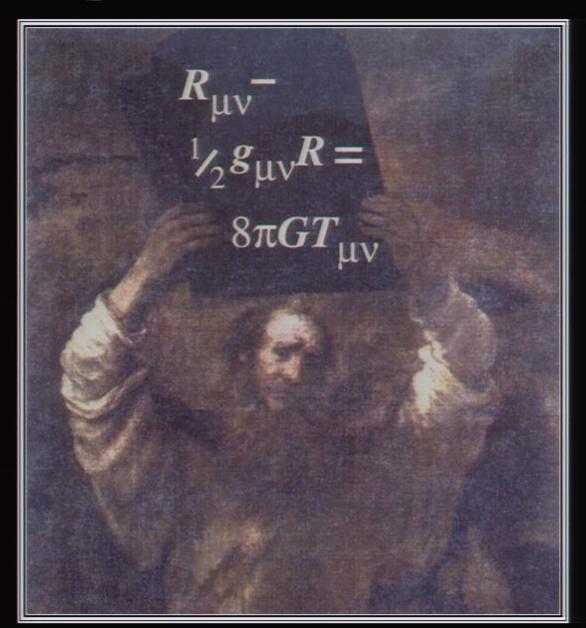
Einstein, 1905

They are dynamical (curved, warped, bent).

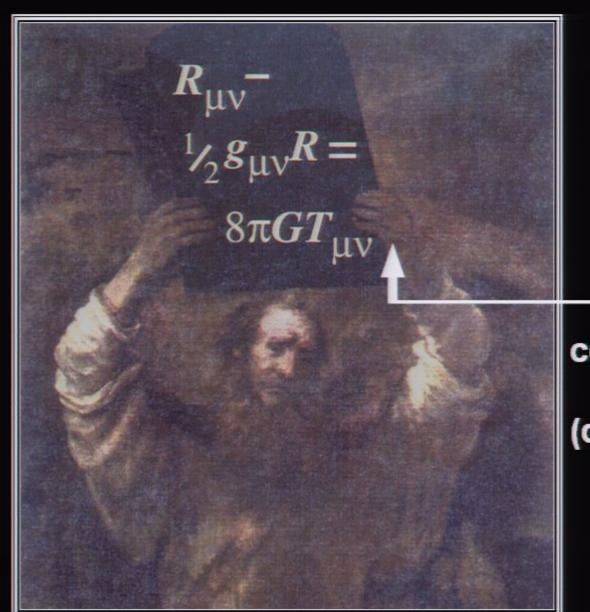
Einstein, 1915



# Origin of the Universe



# Origin of the Universe



- +Λg<sub>μν</sub>
cosmological
term
(dark energy)



# Edwin Hubble

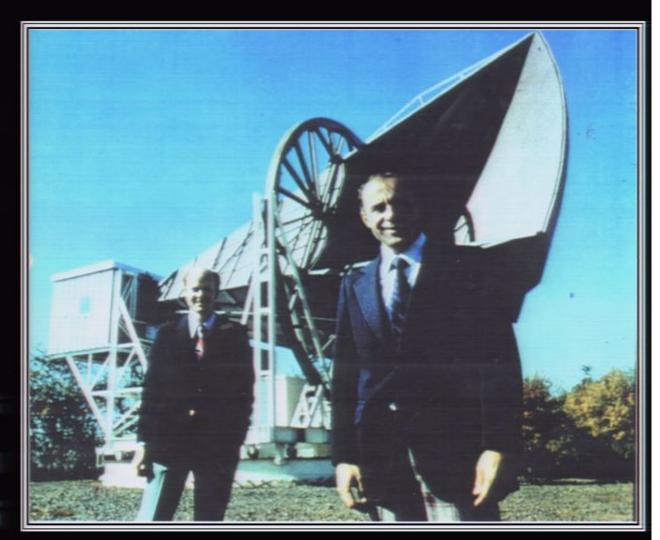
# Space Expands

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Edwin Hubble 1929

# The Universe Is Radiant

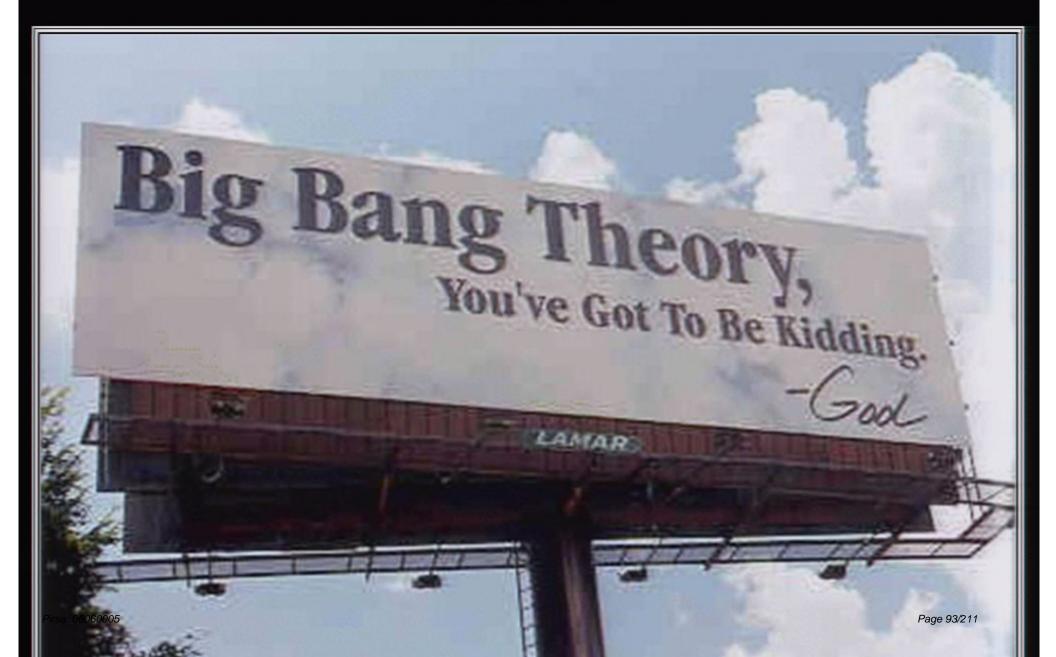
Arno Penzias Robert Wilson 1965



# Cosmic Background Radiation



### Evolution

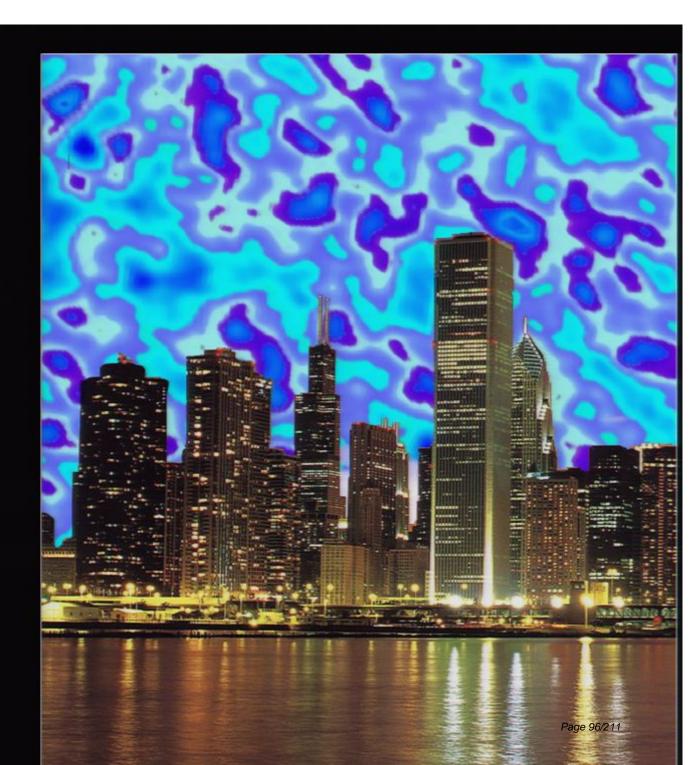


# Cosmic Symphony (Harmonice Mundi)

expansion tempo	movement	epoch	relic
pizzicato	string	10 <sup>−43</sup> s?	???
presto	inflation	10 <sup>−35</sup> s?	temperature fluctuations gravitational waves seeds of structure
allegro	radiation	earlier than 10,000 years	abundances of the light elements
andante	matter	later than 10,000 years	growth of structure: galaxies, clusters,
largo	inflation	day before	acceleration of

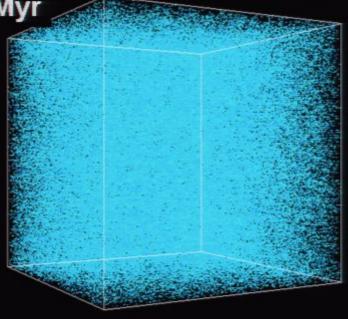
# Primordial Inflation BIG BANG Inflation Big Bang plus 10-35? seconds Big Bang plus 380,000 Years Big Bang plus 14 Billion Years

A pattern of vacuum quantum fluctuations

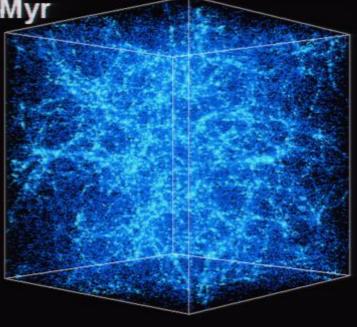


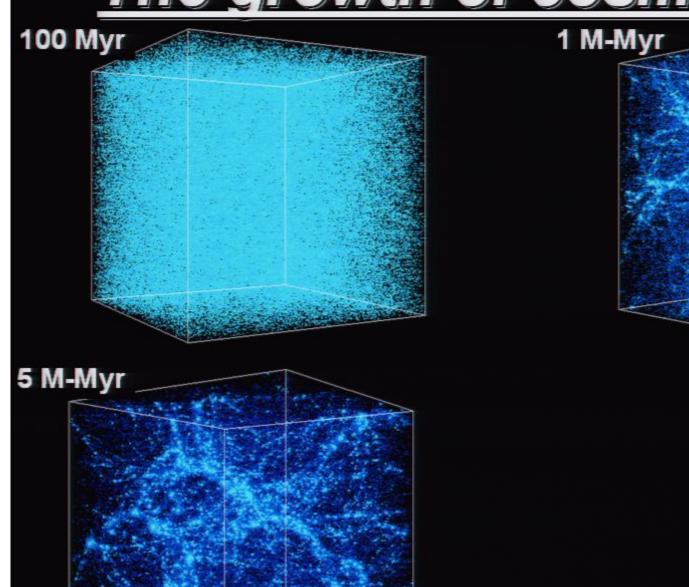
100 Myr

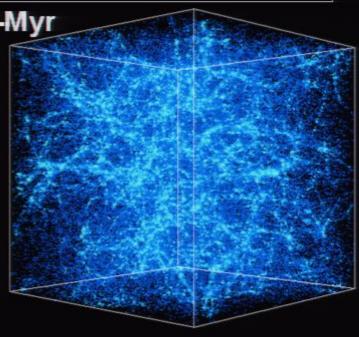
100 Myr

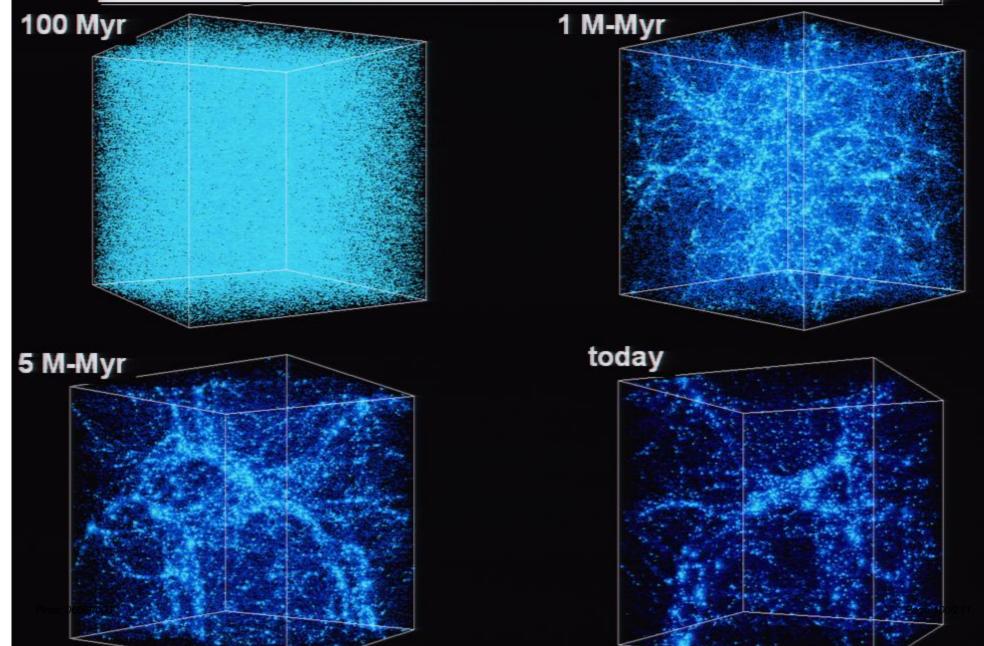


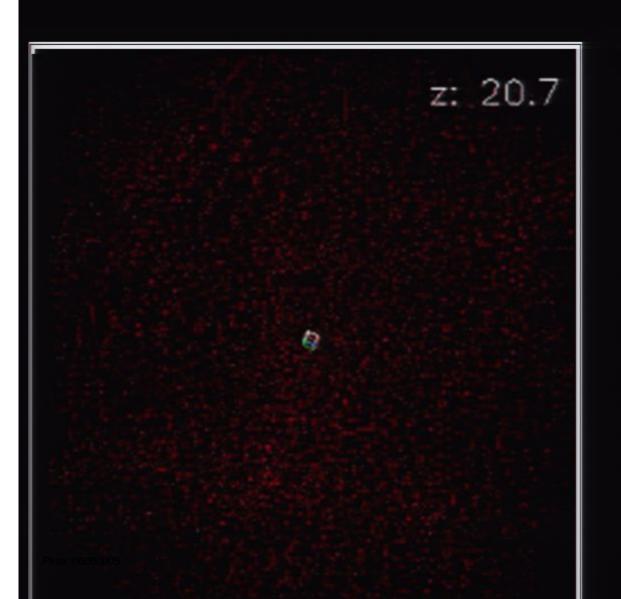
1 M-Myr



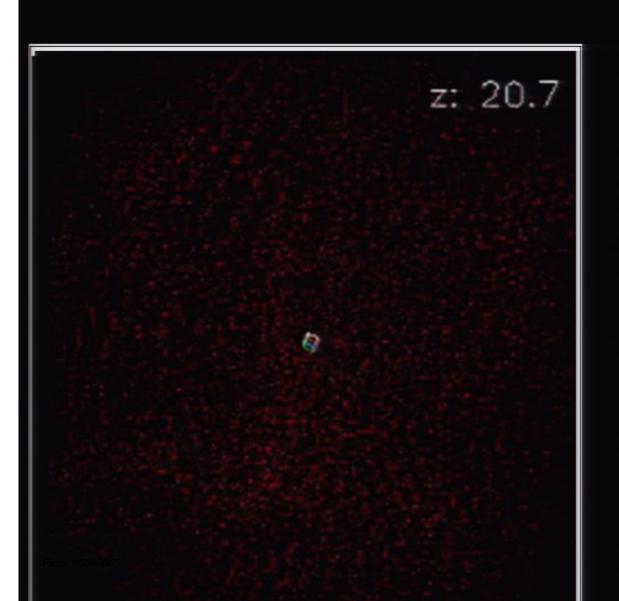








each second is 300 million years



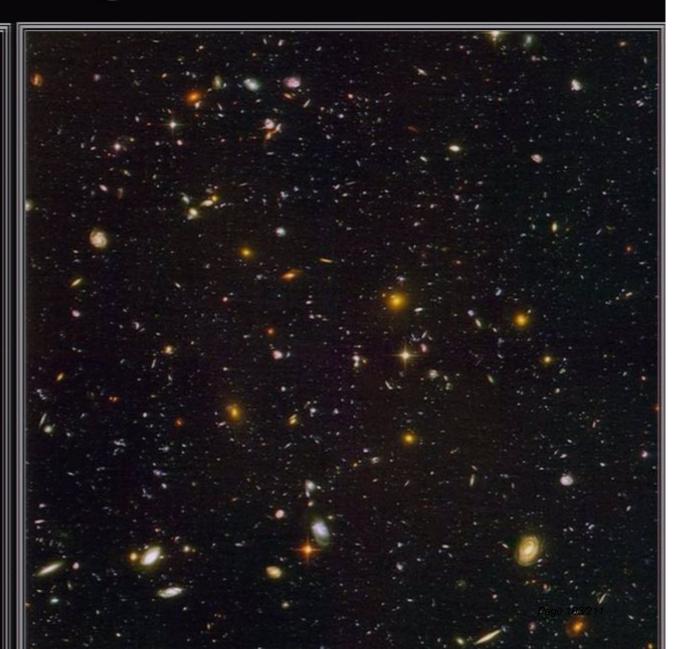
each second is 300 million years

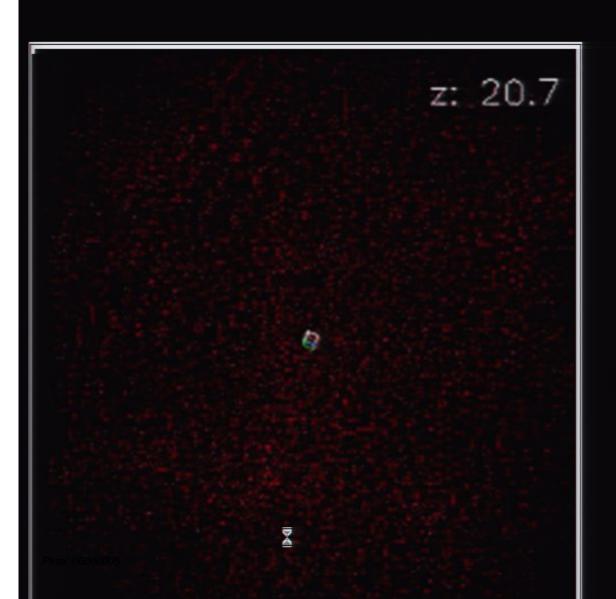
# Composition

# Hubble Ultradeep Field

10,000 galaxies →

50 thousand million over entire sky

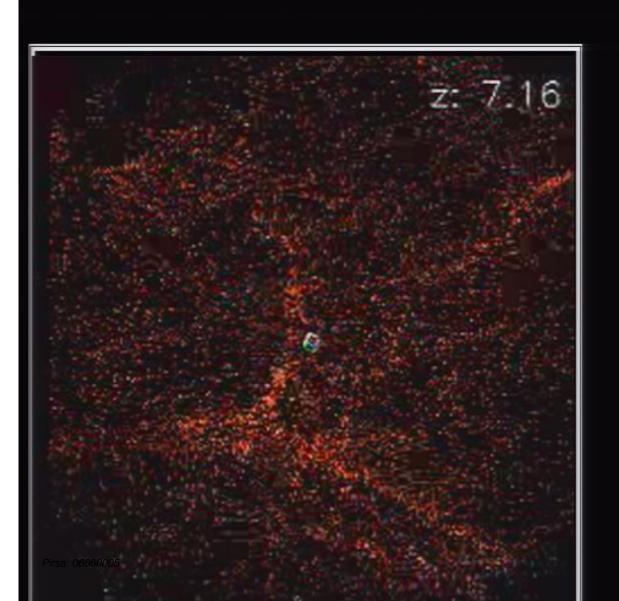




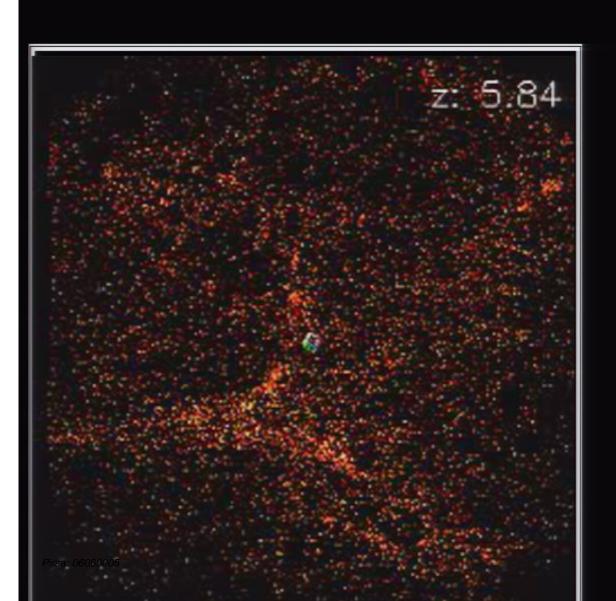
each second is 300 million years



each second is 300 million years



each second is 300 million years



each second is 300 million years



each second is 300 million years



each second is 300 million years



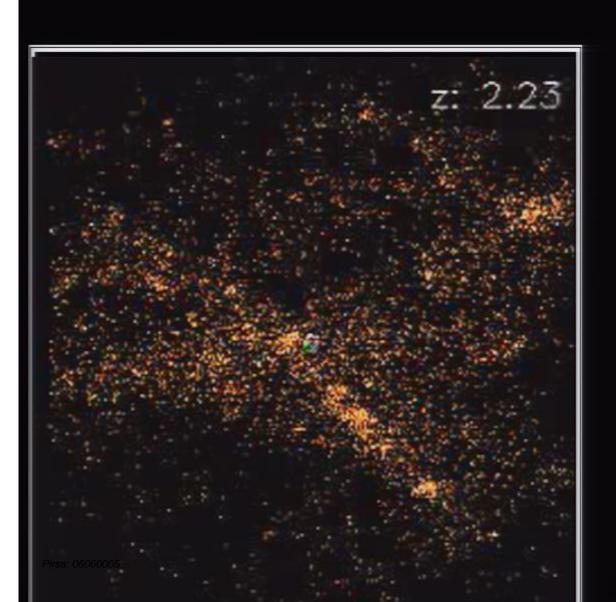
each second is 300 million years



each second is 300 million years



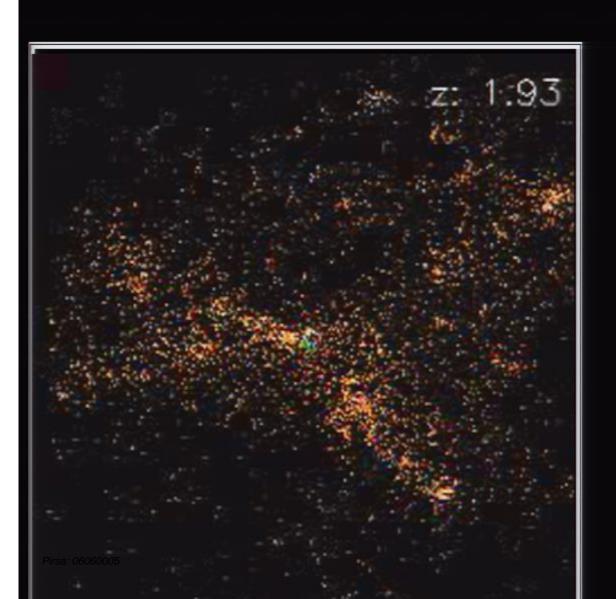
each second is 300 million years



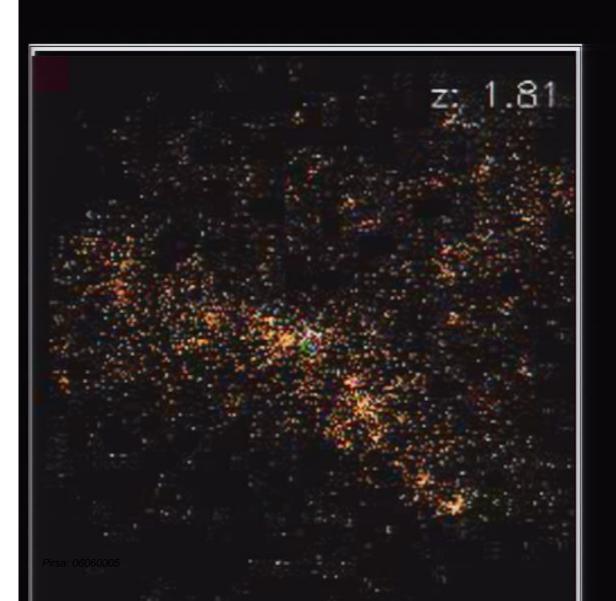
each second is 300 million years



each second is 300 million years



each second is 300 million years



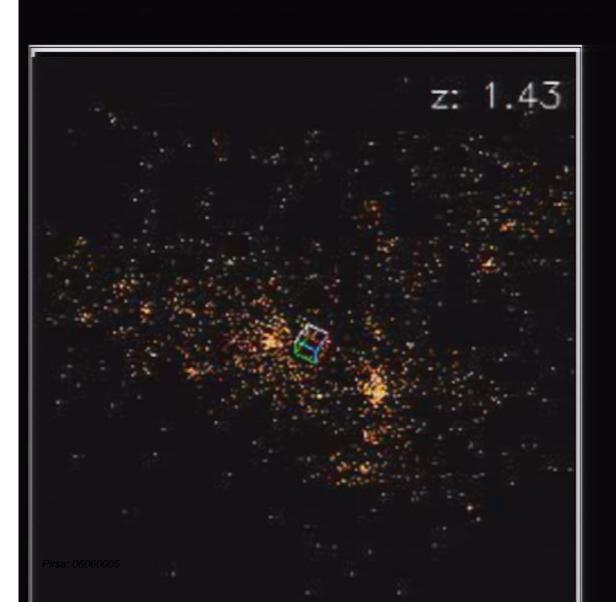
each second is 300 million years



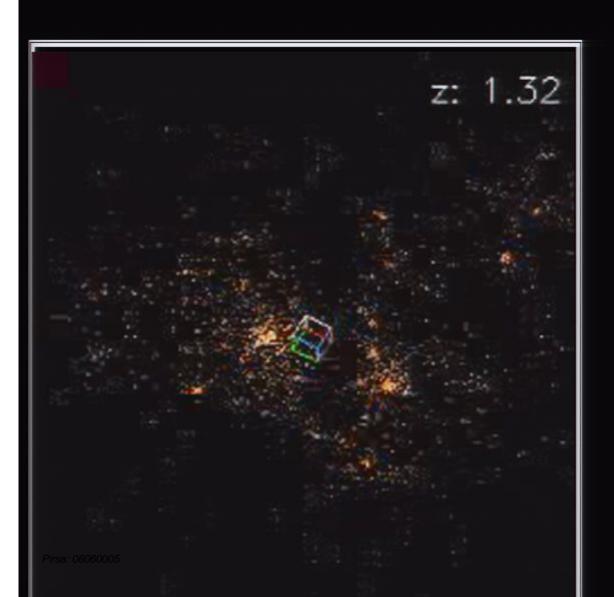
each second is 300 million years



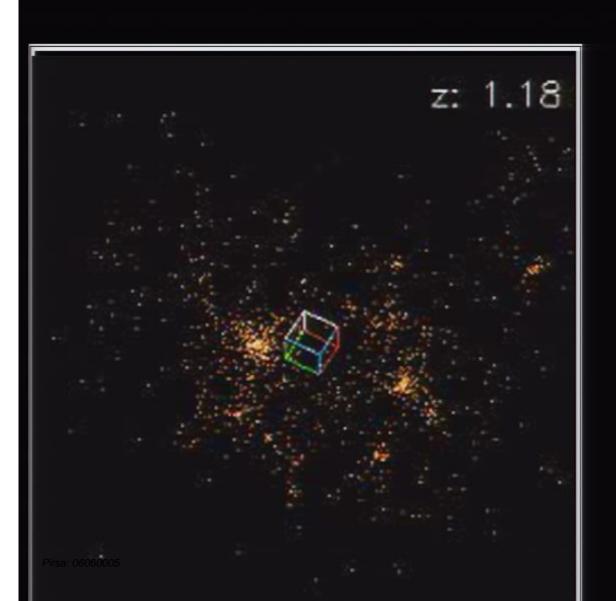
each second is 300 million years



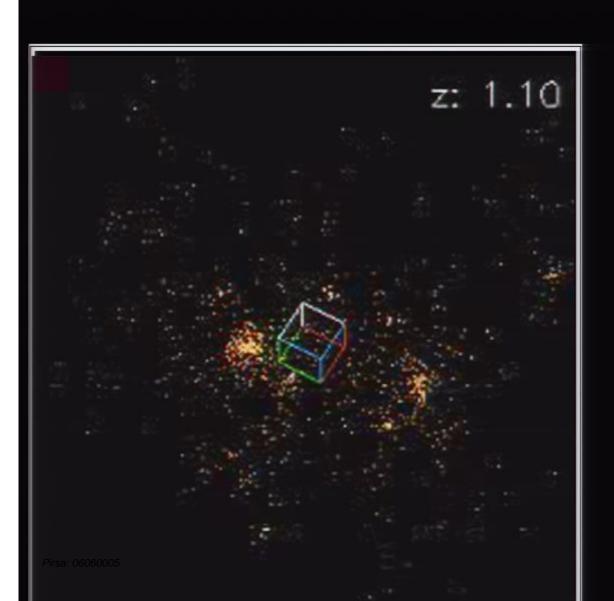
each second is 300 million years



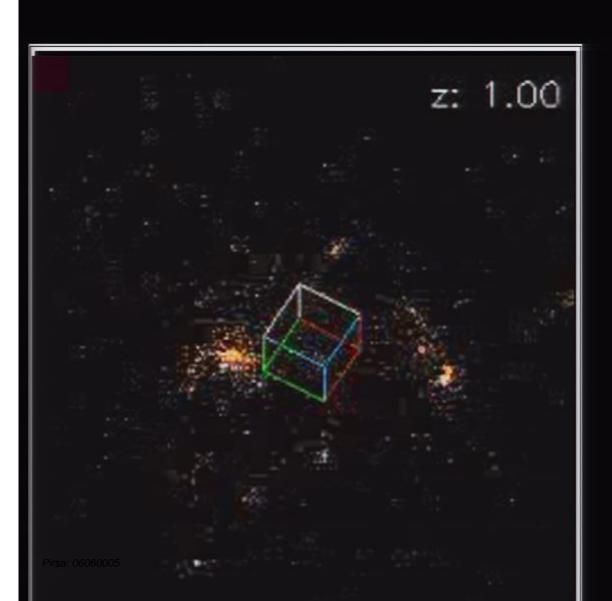
each second is 300 million years



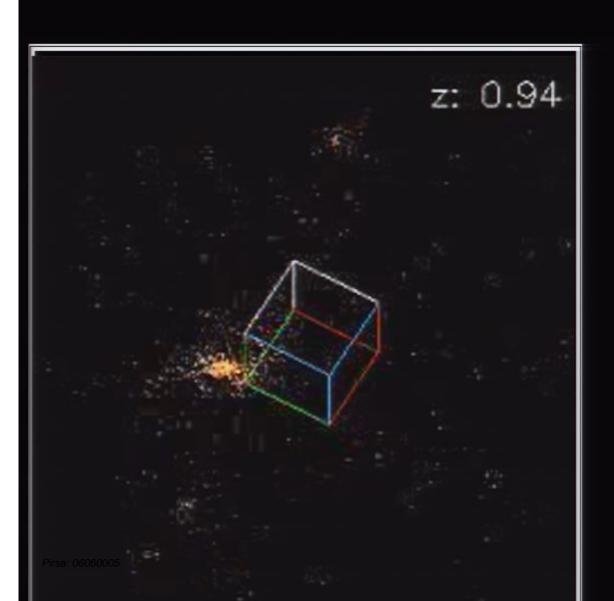
each second is 300 million years



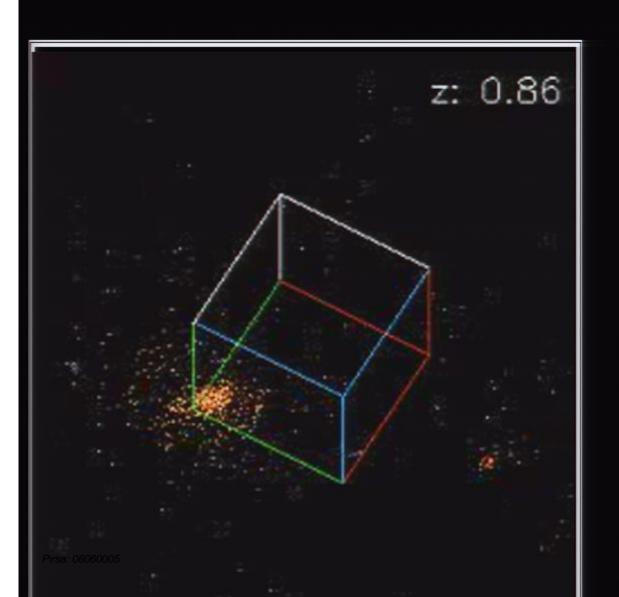
each second is 300 million years



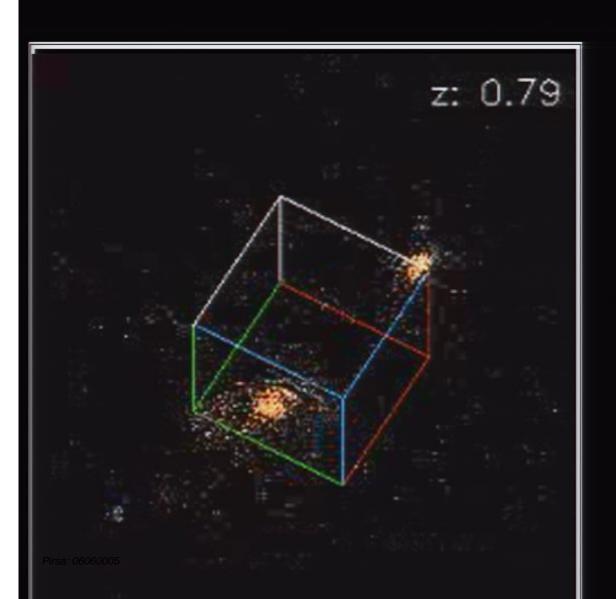
each second is 300 million years



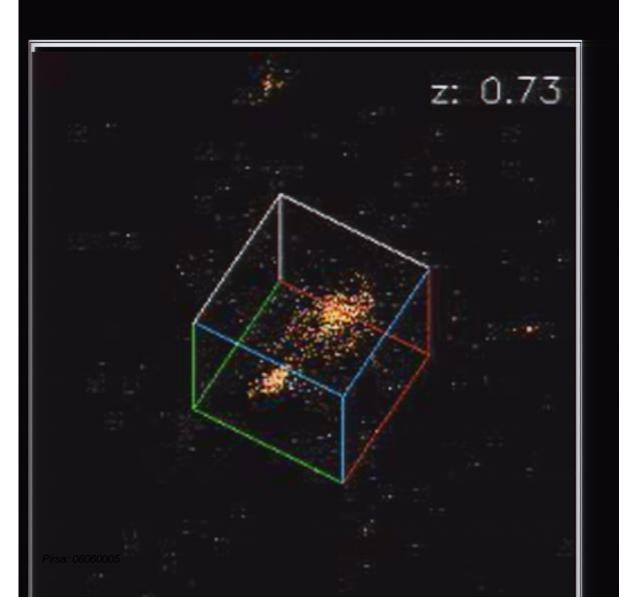
each second is 300 million years



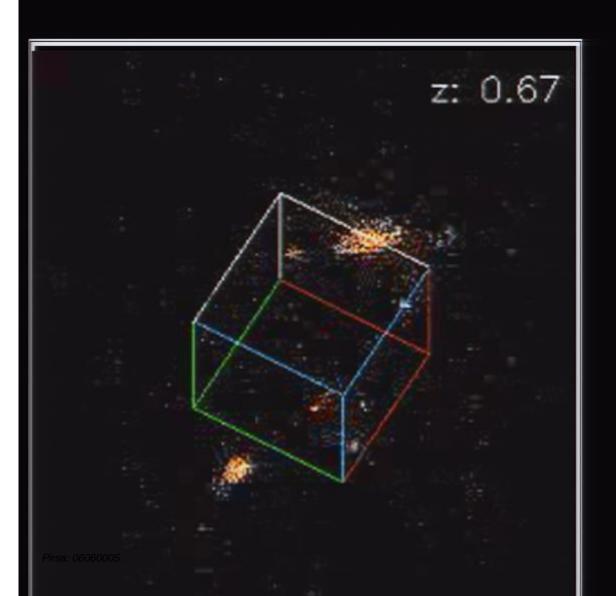
each second is 300 million years



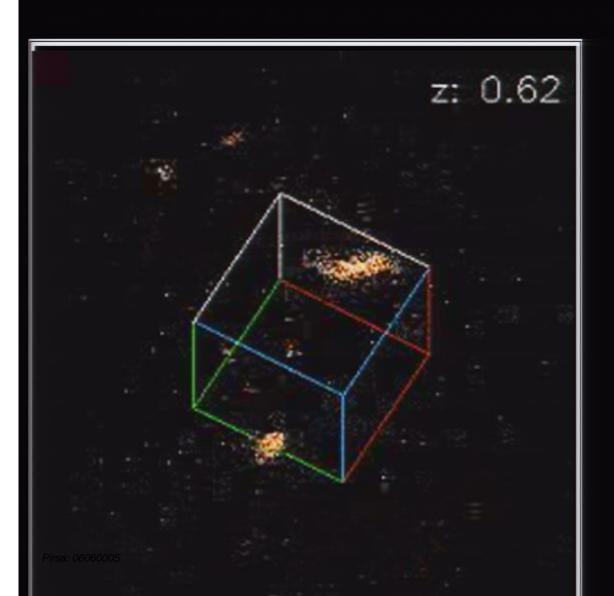
each second is 300 million years



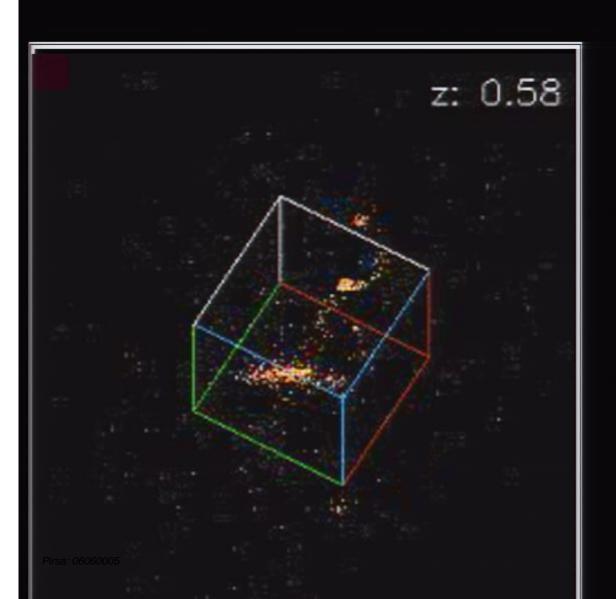
each second is 300 million years



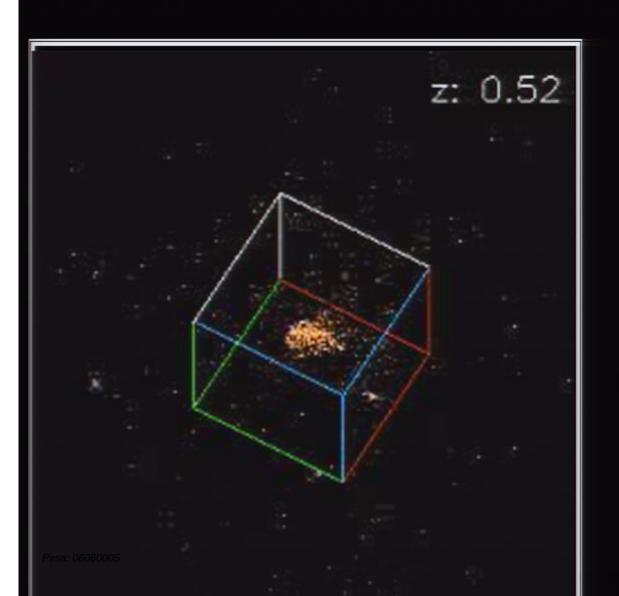
each second is 300 million years



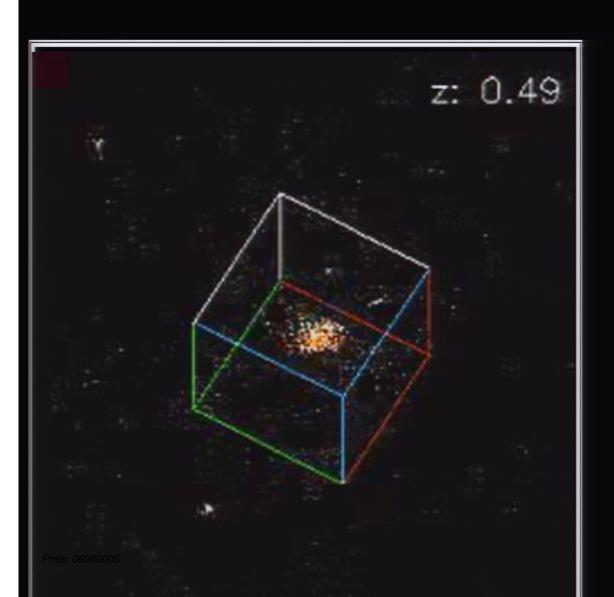
each second is 300 million years



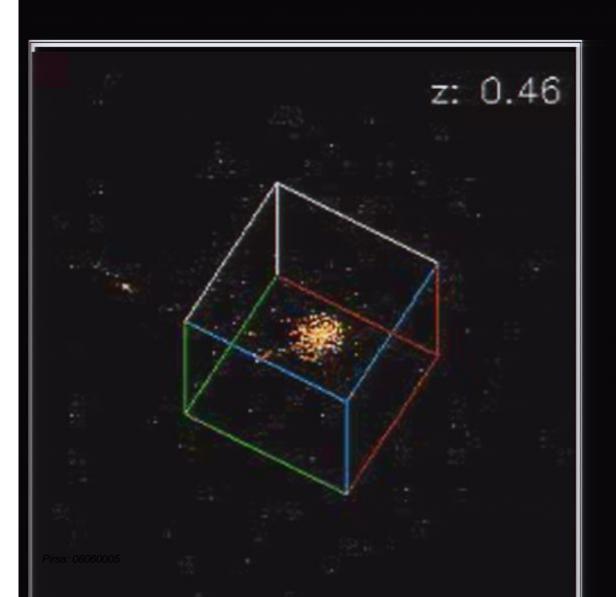
each second is 300 million years



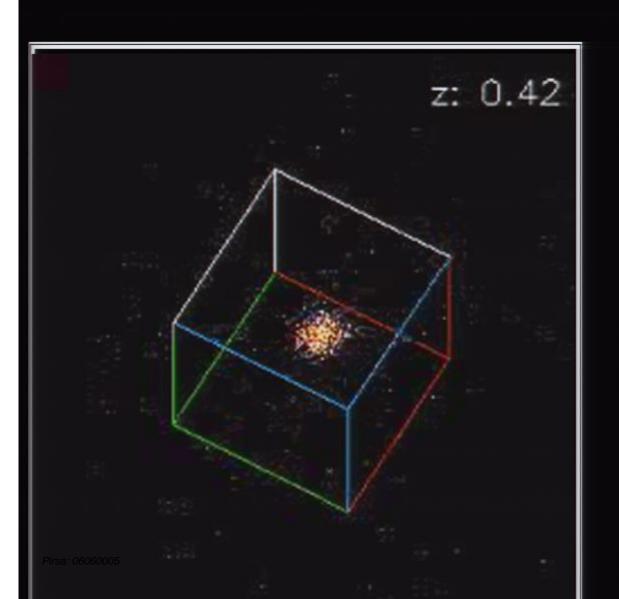
each second is 300 million years



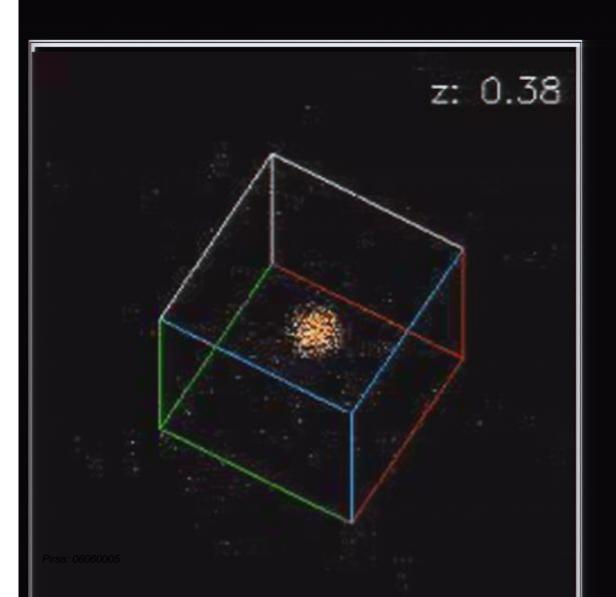
each second is 300 million years



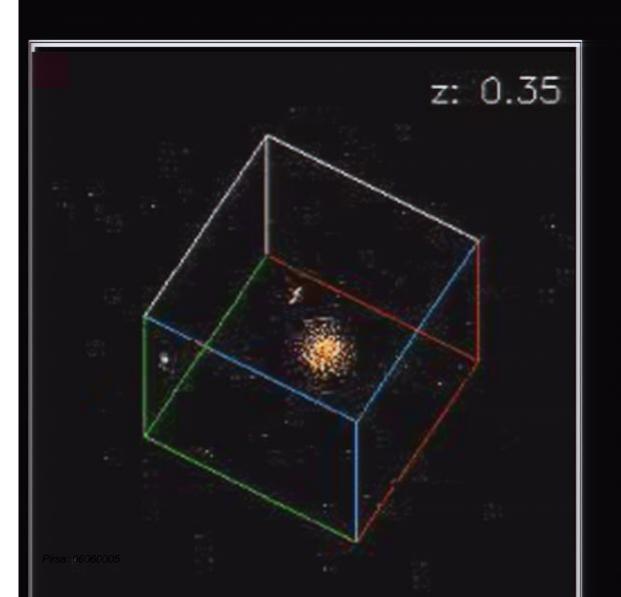
each second is 300 million years



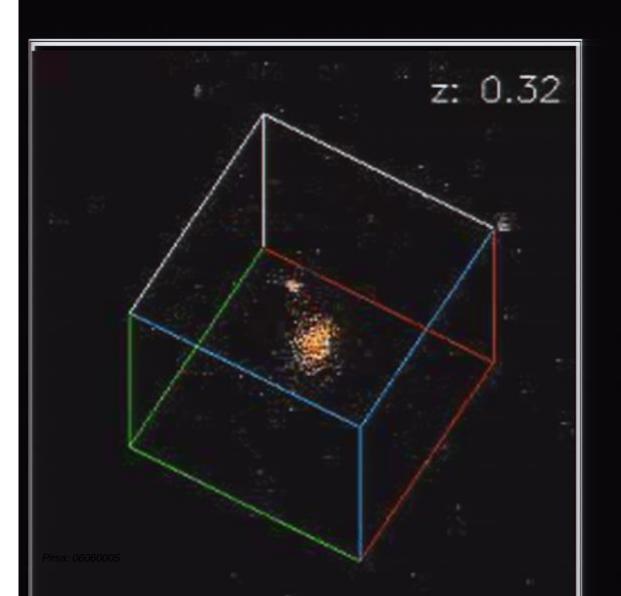
each second is 300 million years



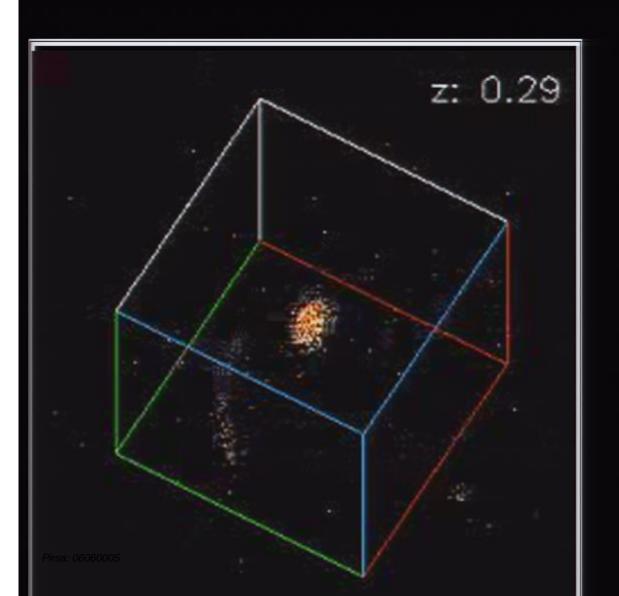
each second is 300 million years



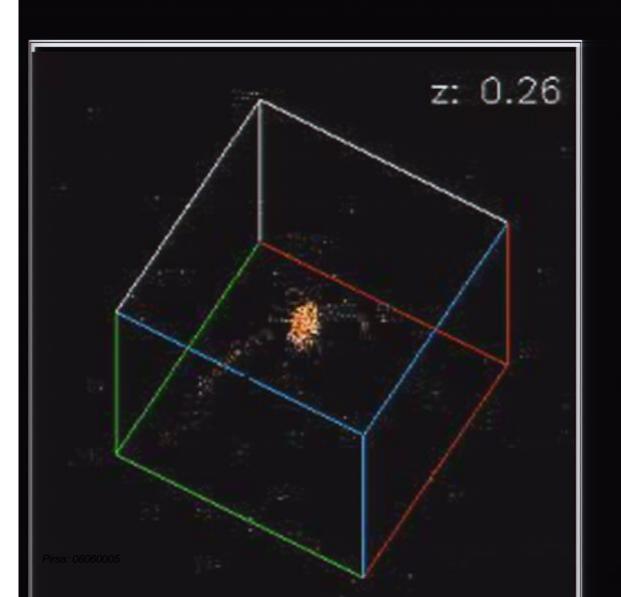
each second is 300 million years



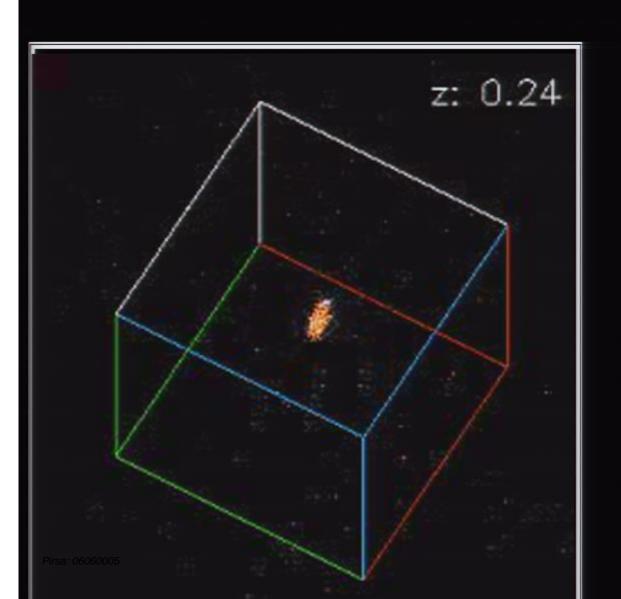
each second is 300 million years



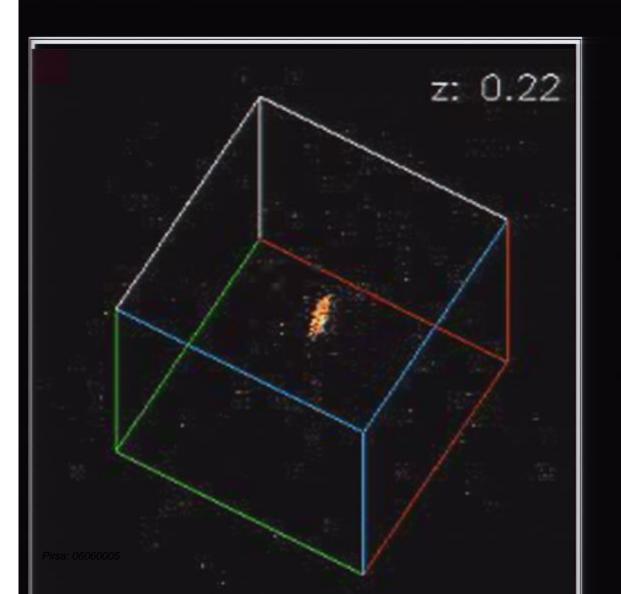
each second is 300 million years



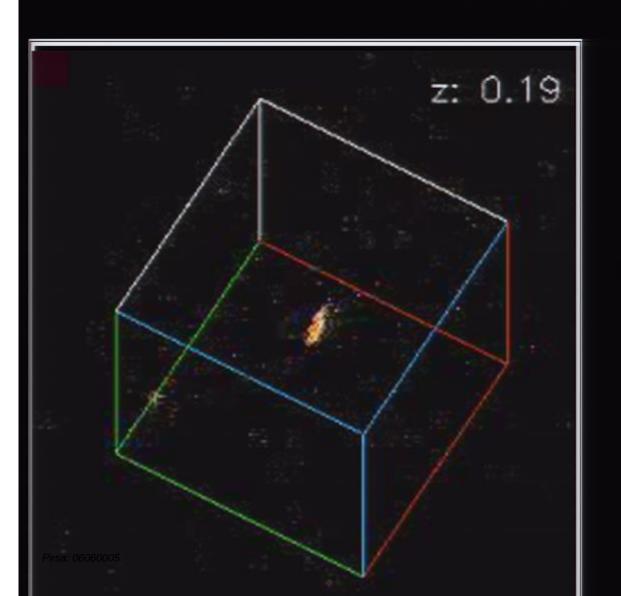
each second is 300 million years



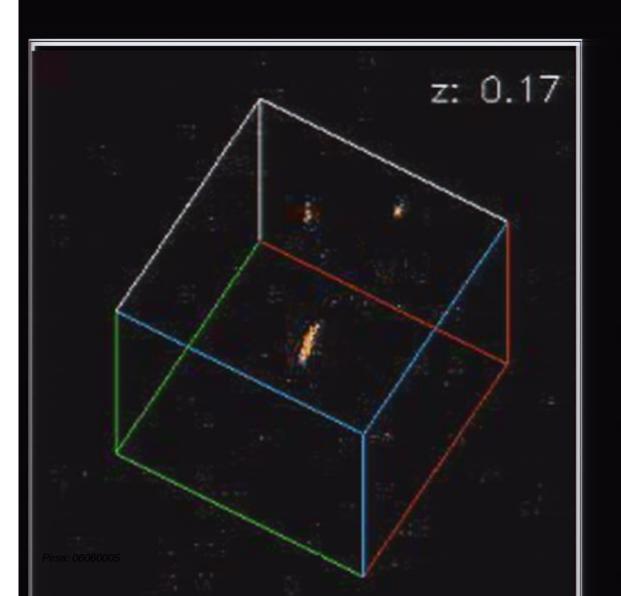
each second is 300 million years



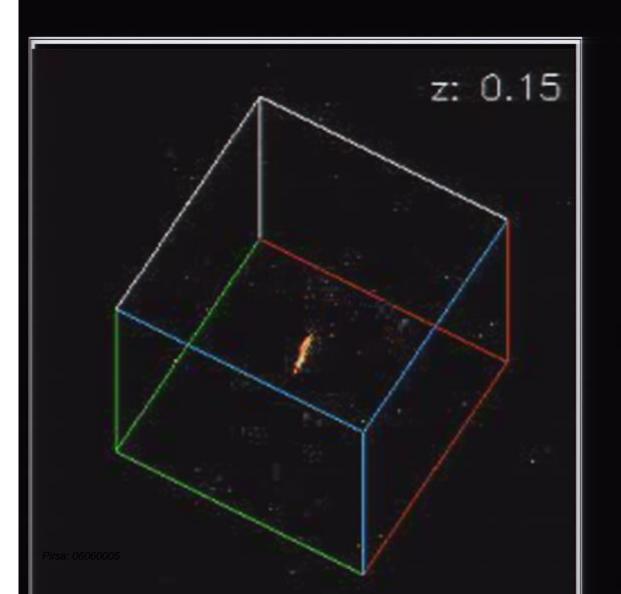
each second is 300 million years



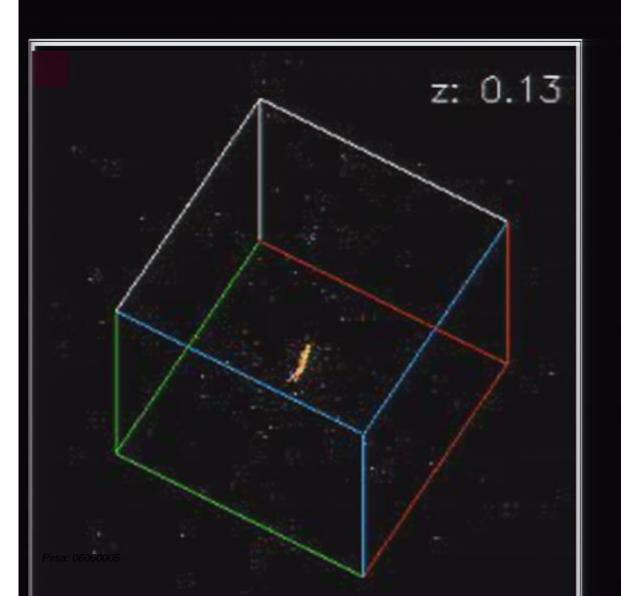
each second is 300 million years



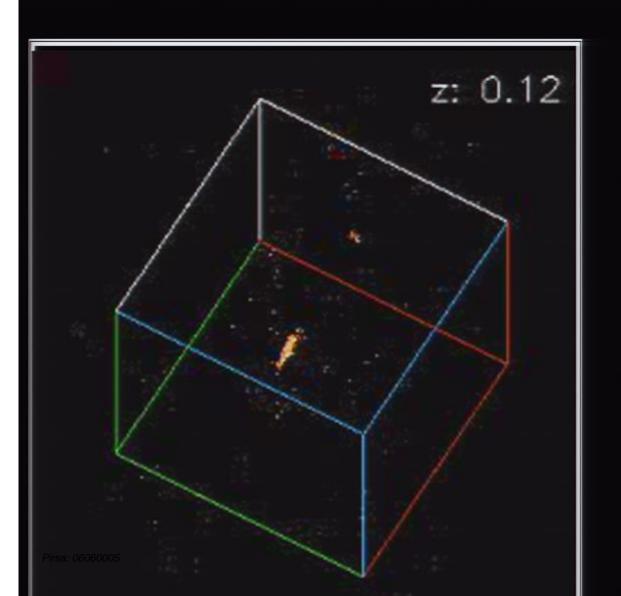
each second is 300 million years



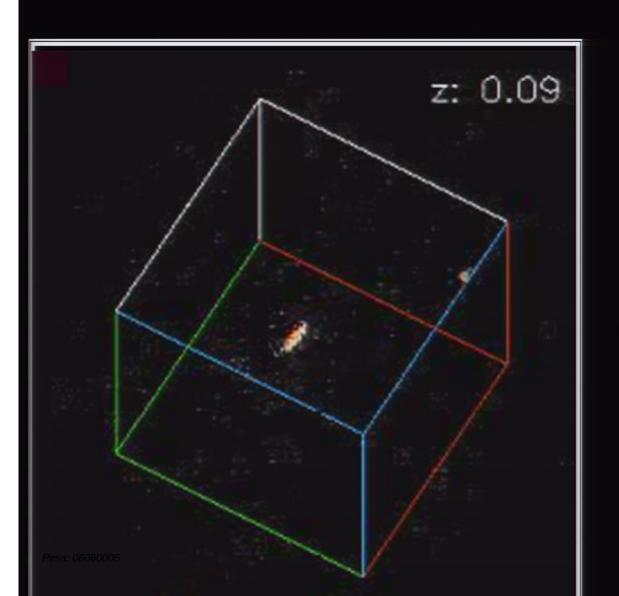
each second is 300 million years



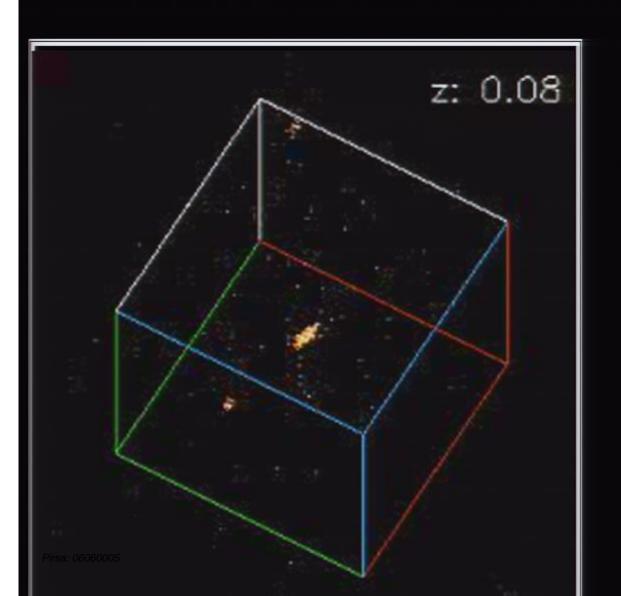
each second is 300 million years



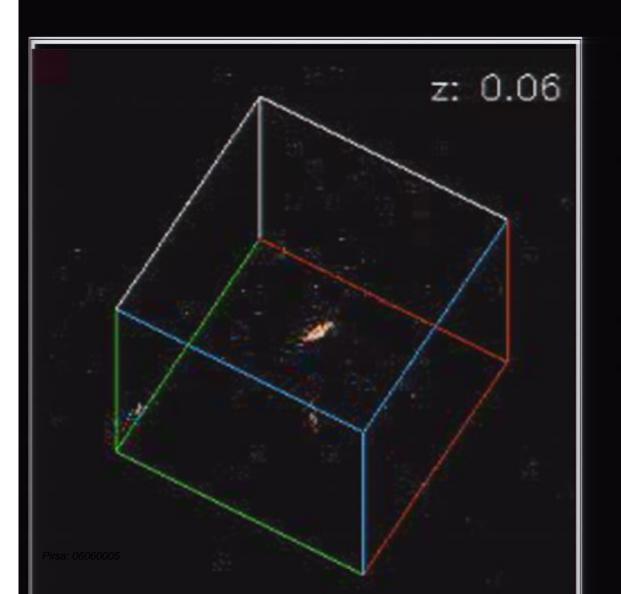
each second is 300 million years



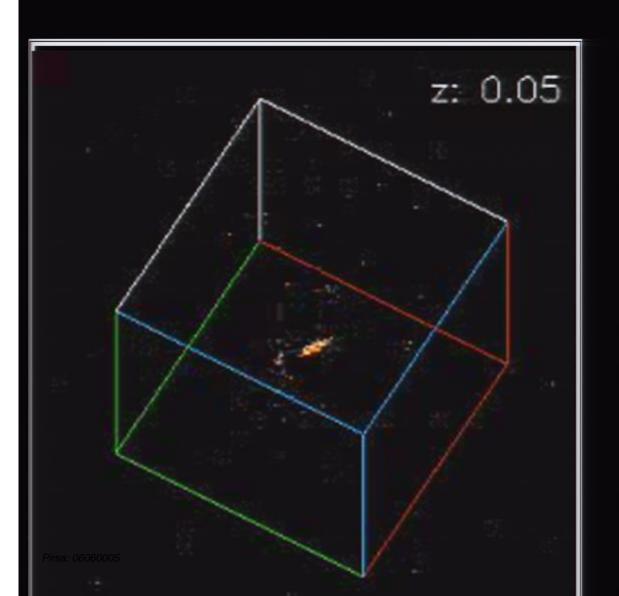
each second is 300 million years



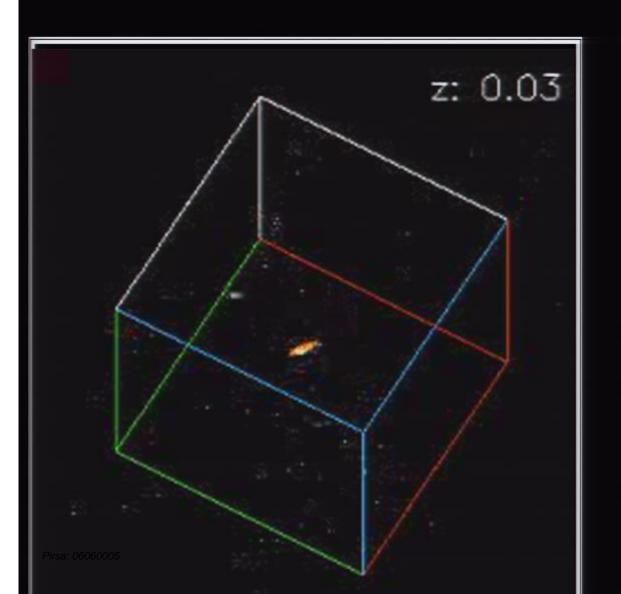
each second is 300 million years



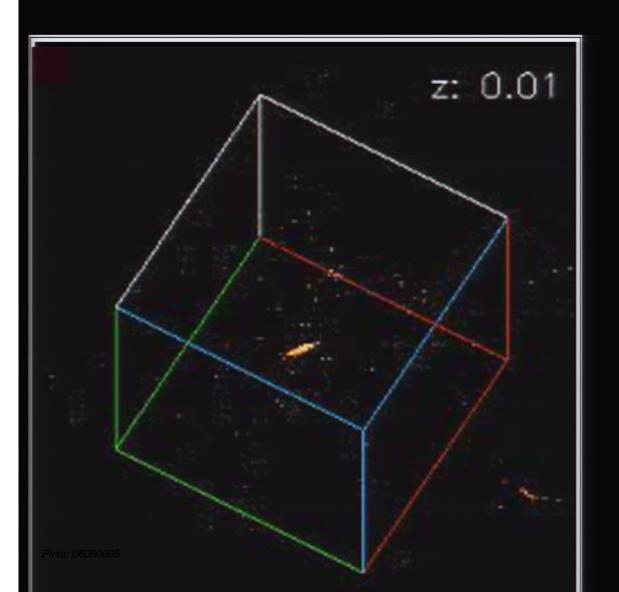
each second is 300 million years



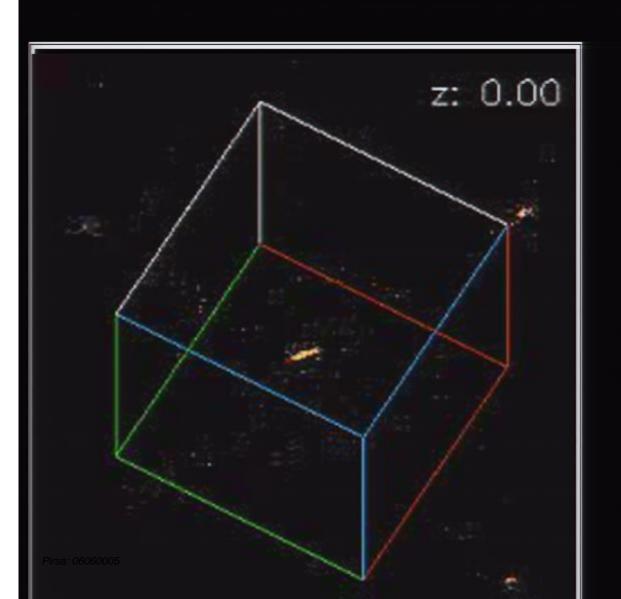
each second is 300 million years



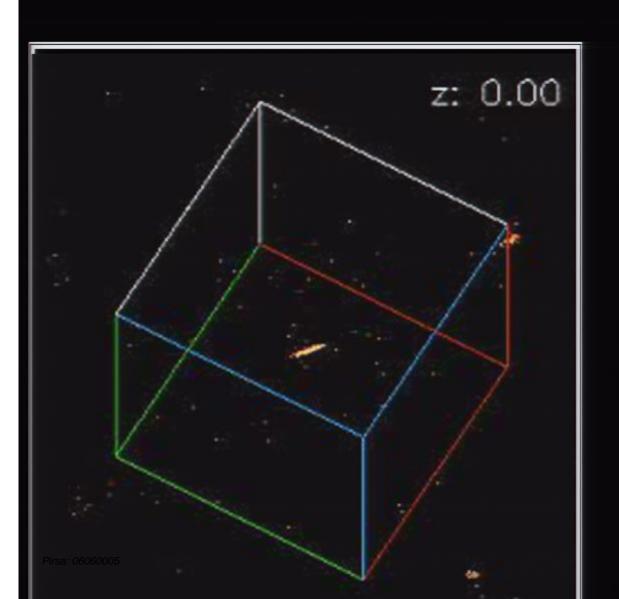
each second is 300 million years



each second is 300 million years



each second is 300 million years



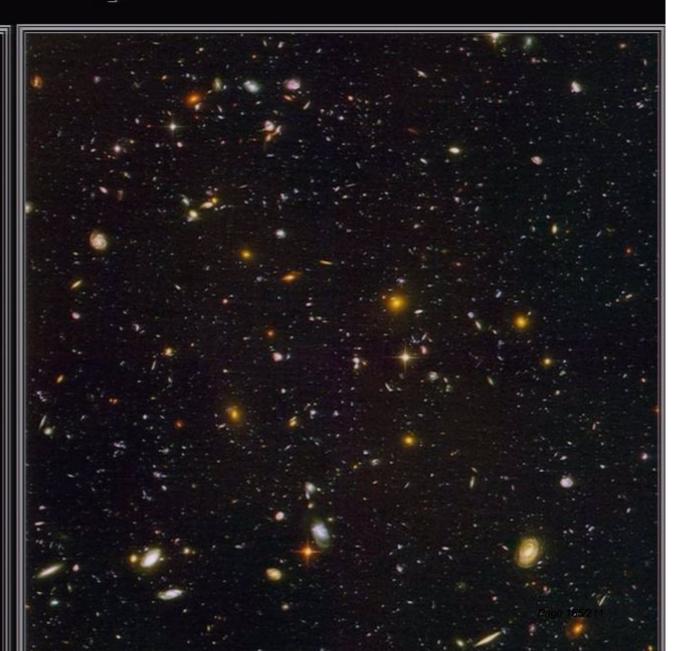
each second is 300 million years

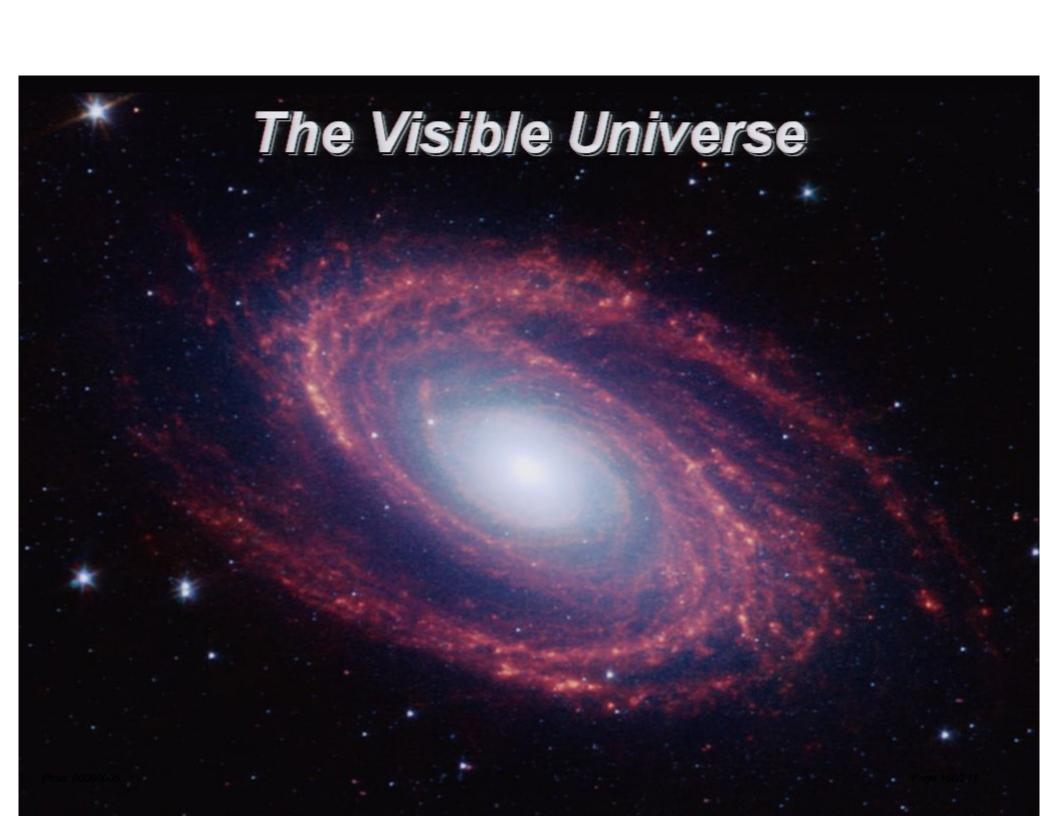
## Composition

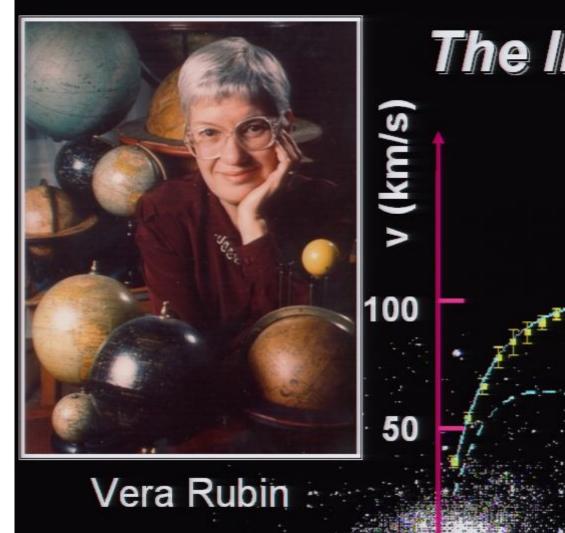
# Hubble Ultradeep Field

10,000 galaxies →

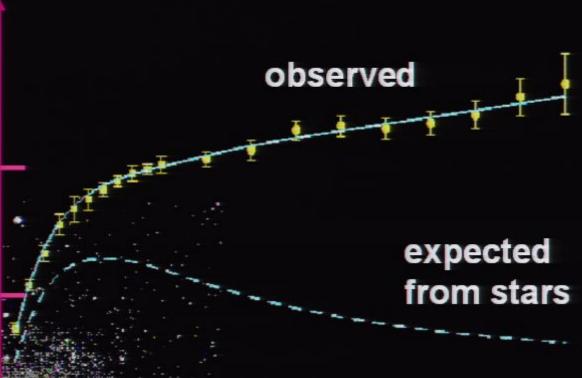
50 thousand million over entire sky



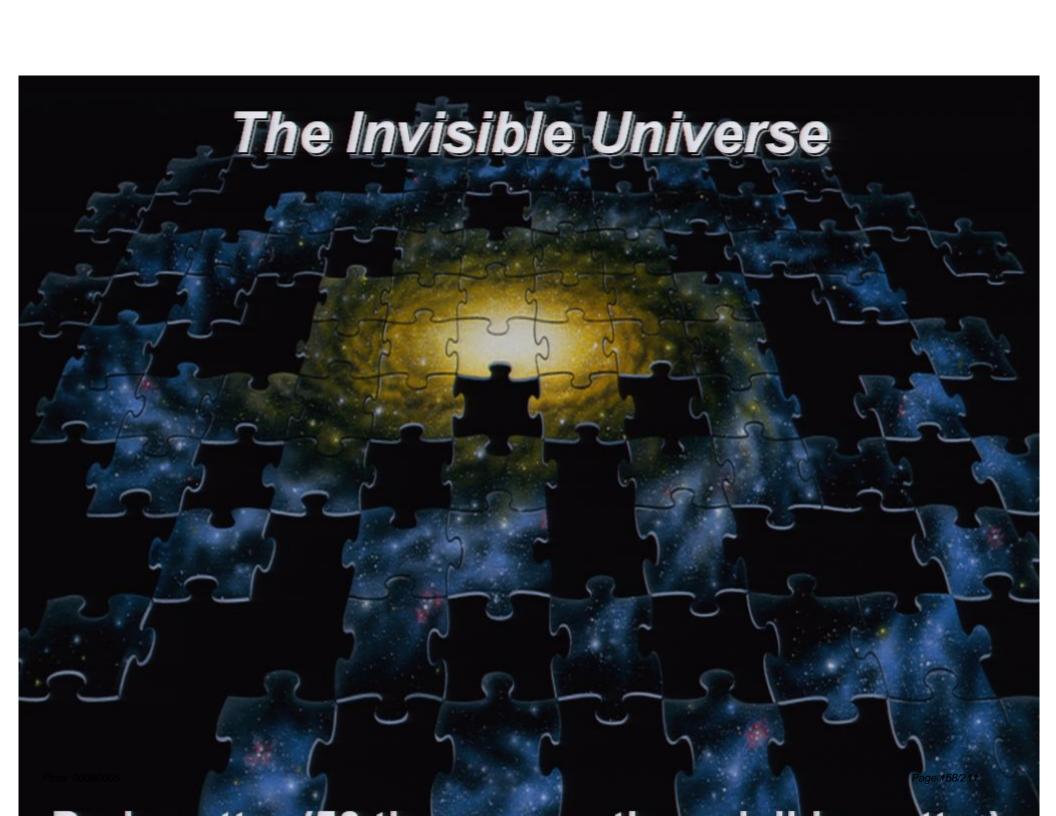




### The Invisible Universe



<sup>5</sup> 10 R (kpc) M33 rotation curve

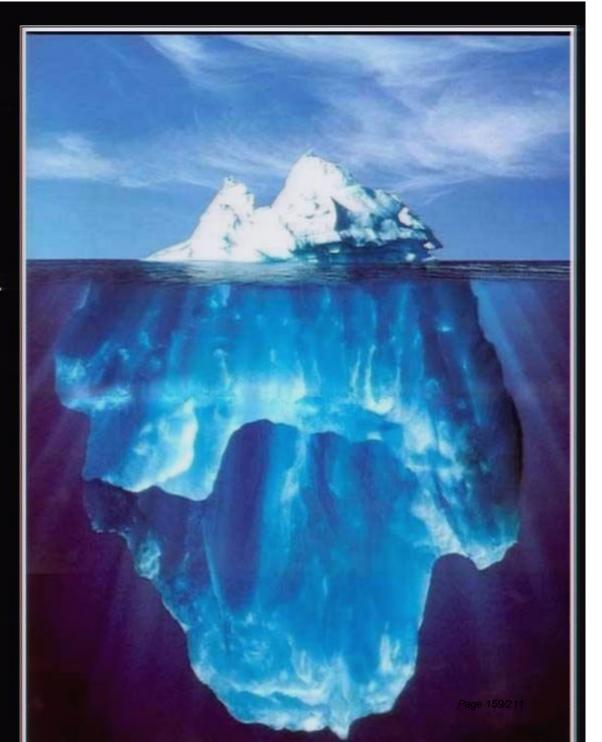


# Dark Matter

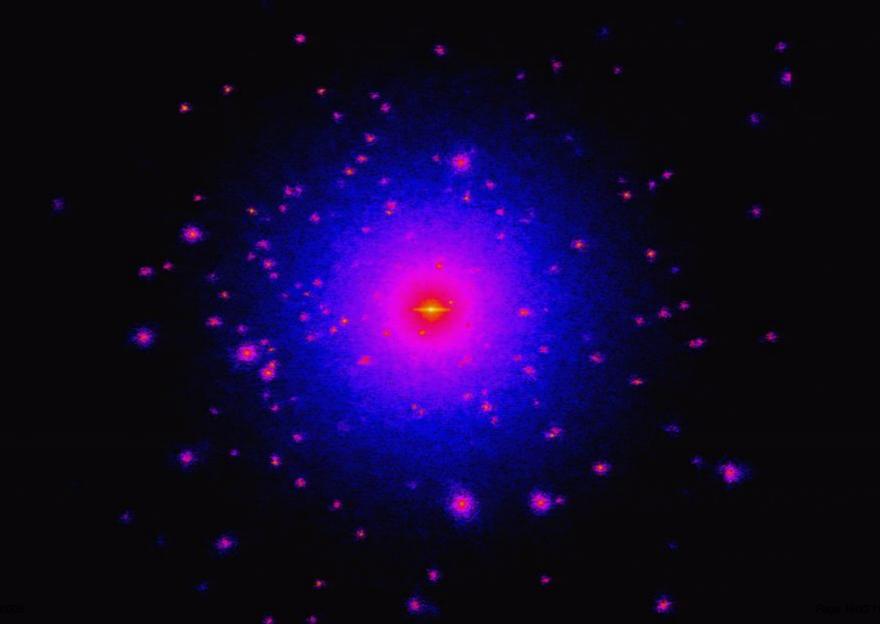
What you don't see, matters.

We don't see most of the matter.

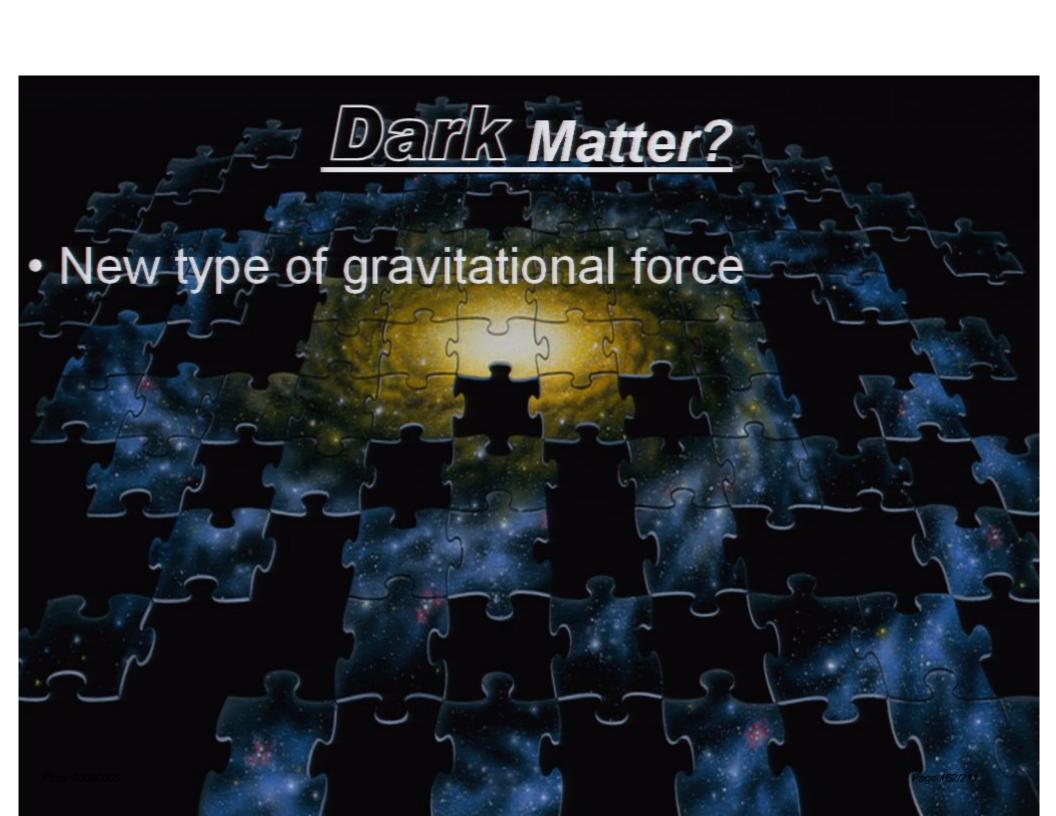
It doesn't seem to be "normal" matter.

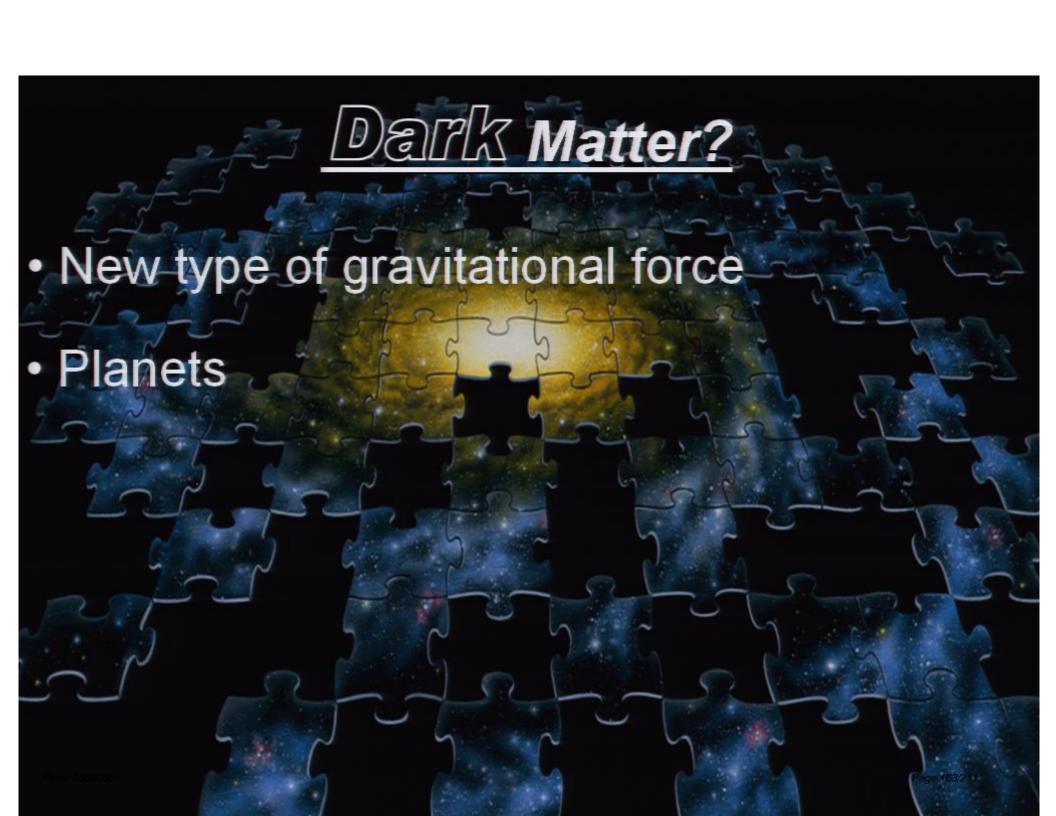


### If We Could "See" Dark Matter

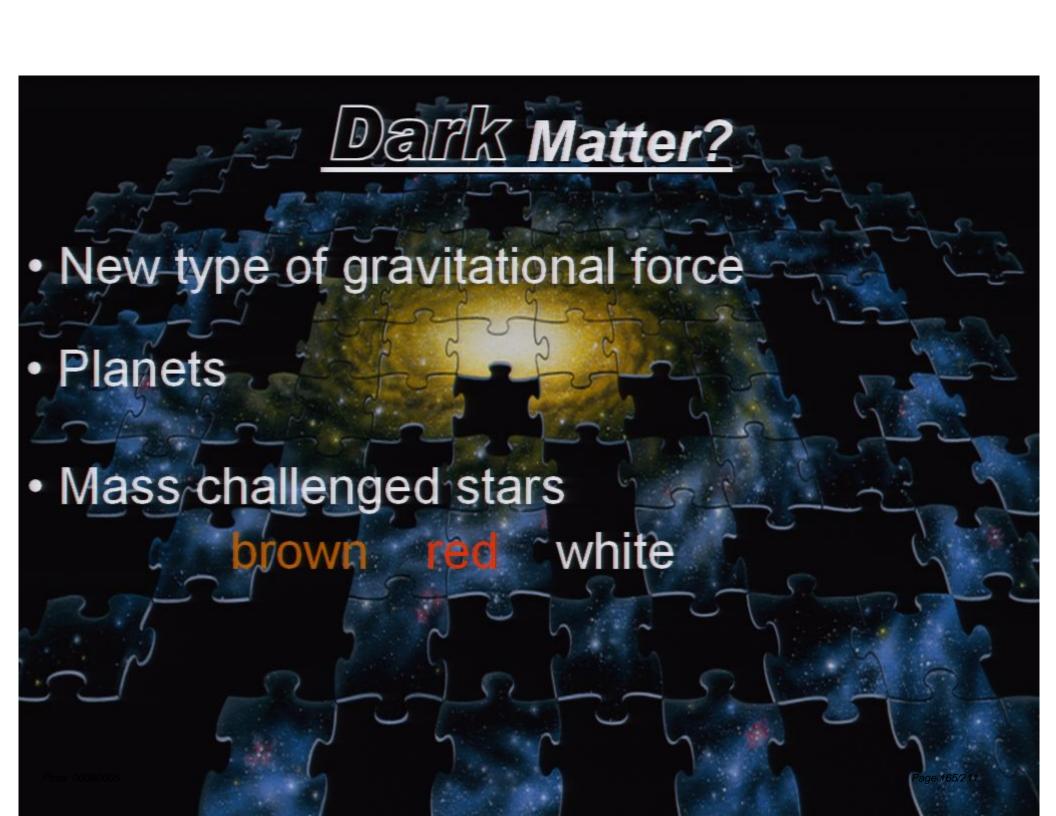


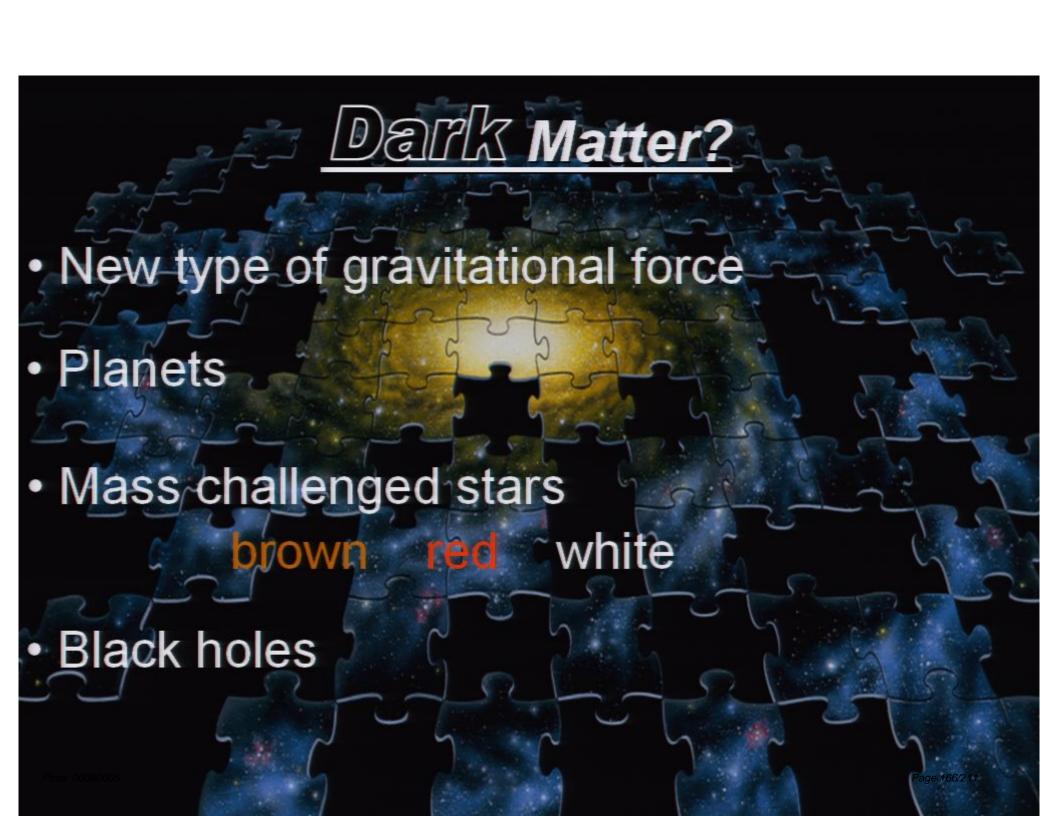


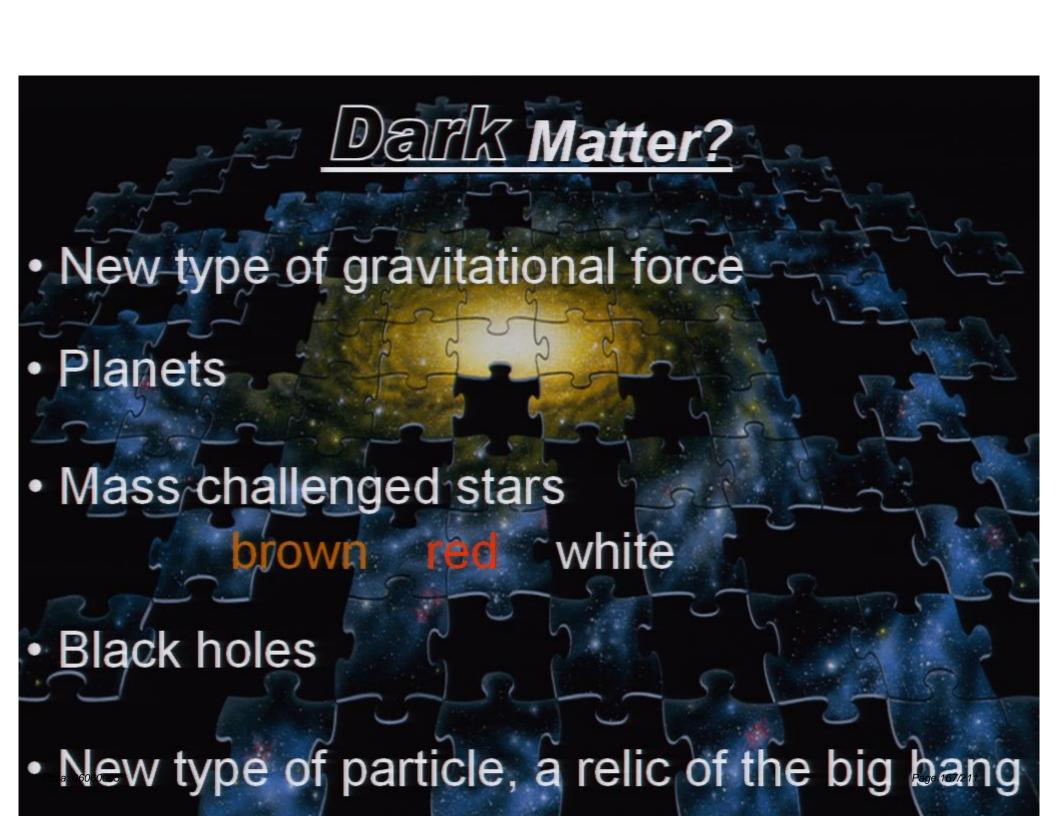


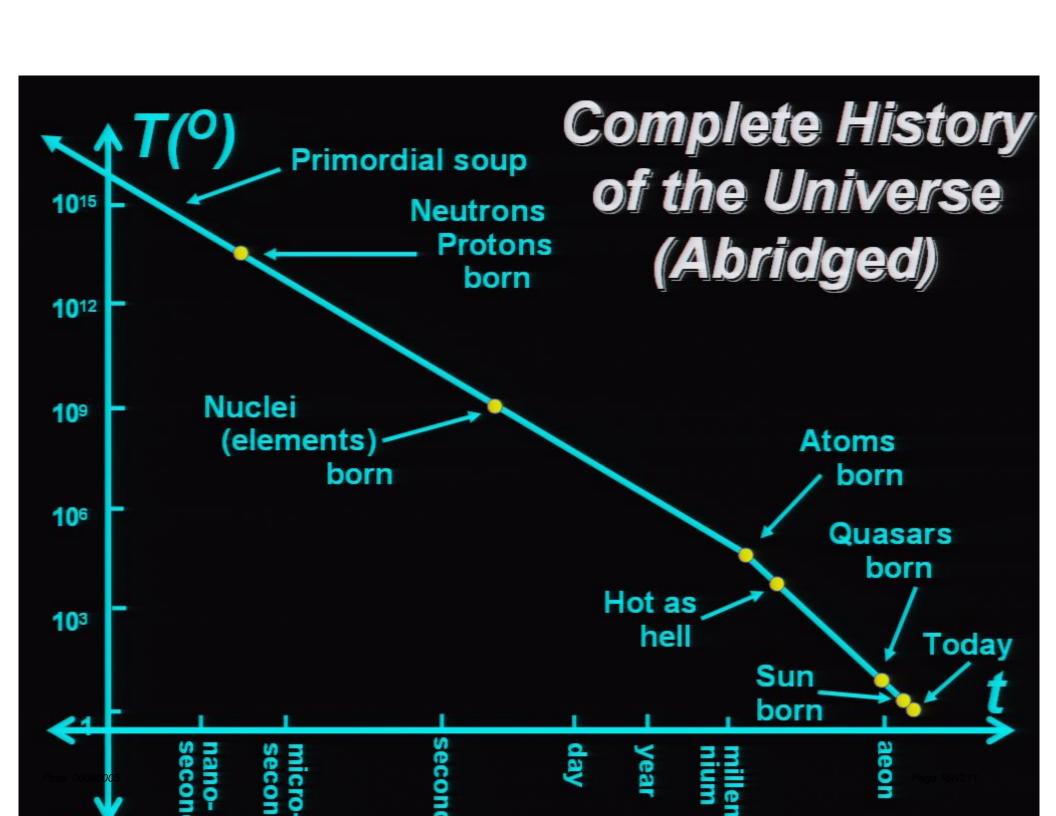


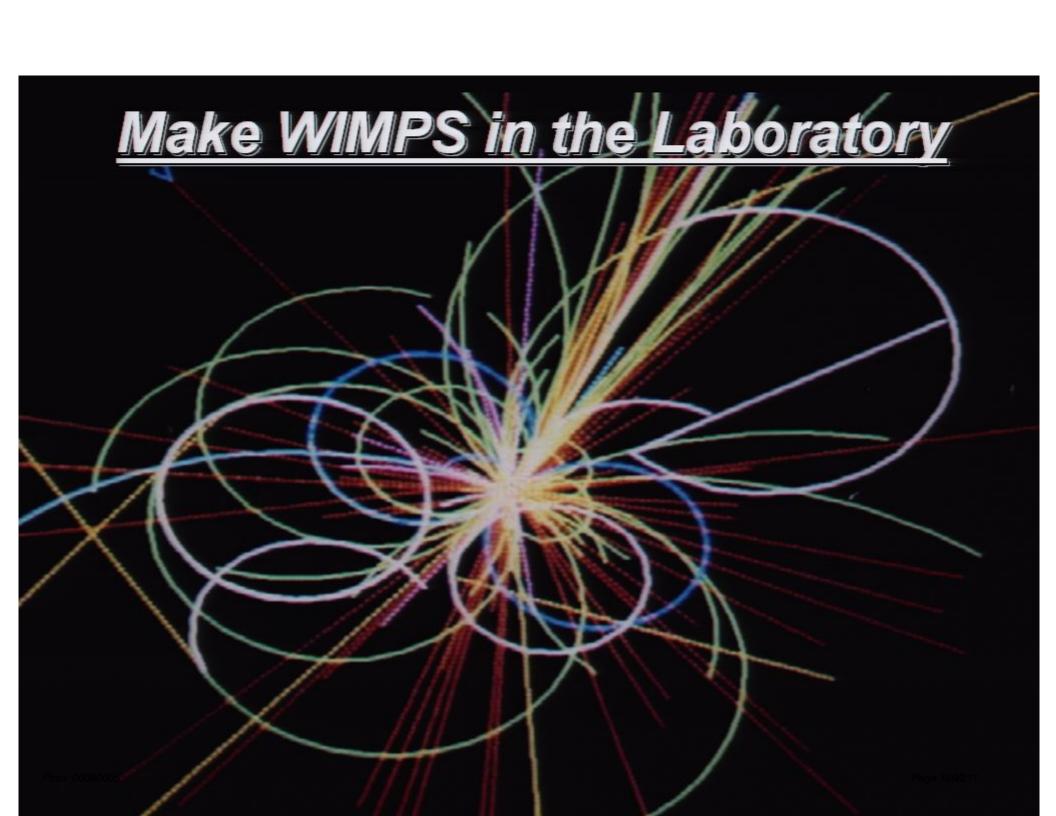






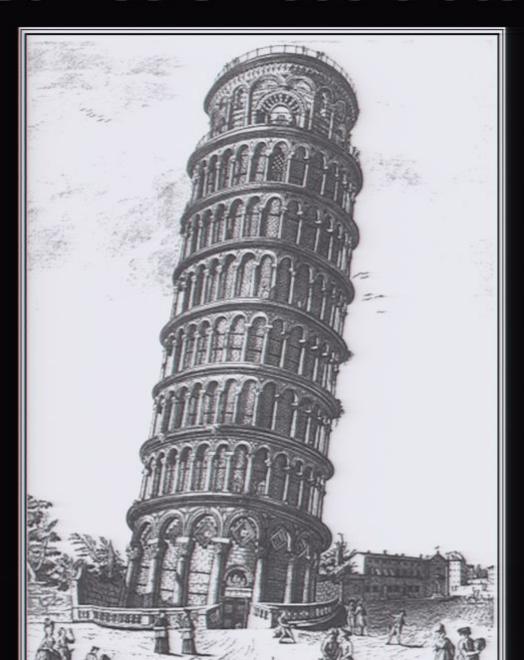








### Galileo's Accelerator





4 million-millionths of a second AB 3,000 million-million degrees



4 million-millionths of a second AB 3,000 million-million degrees

CONDENSED



4 million-millionths of a second AB 3,000 million-million degrees

#### CONDENSED

in one can 50 Earth masses in matter
50 Earth masses in antimatter
+ extra mountain of matter

Primordial

4 million-millionths of a second AB 3,000 million-million degrees

#### CONDENSED

in one can 50 Earth masses in matter
50 Earth masses in antimatter
+ extra mountain of matter

**HOT** 

Primordial

4 million-millionths of a second AB 3,000 million-million degrees

#### CONDENSED

in one can

50 Earth masses in matter

50 Earth masses in antimatter

extra mountain of matter

HOT

per 10 billion years of total erving energy output of sun

4 million-millionths of a second AB 3,000 million-million degrees

#### CONDENSED

in one can 50 Earth masses in matter

50 Earth masses in antimatter

extra mountain of matter

HOT

per 10 billion years of total erving energy output of sun

INGREDIENTS

4 million-millionths of a second AB 3,000 million-million degrees

#### CONDENSED

in one can

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50 Earth masses in antimatter

extra mountain of matter

#### HOT

per 10 billion years of total serving energy output of sun

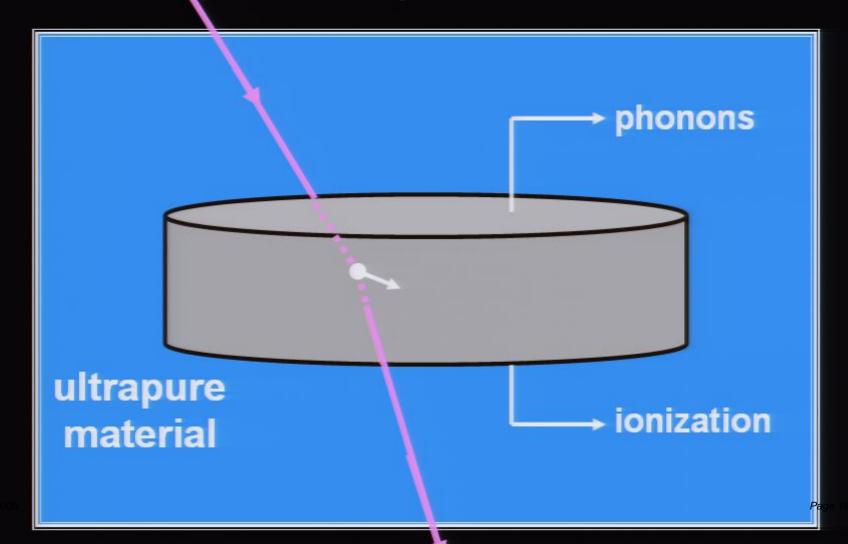
#### INGREDIENTS

in every spoonful 2 every type of elementary particle

### KNOWN INGREDIENTS: 56% QUARKS 16% GLUONS 9% ELECTRON-LIKE PA 9% W's AND Z's 5% NEUTRINOS 2% PHOTONS 2% GRAVITONS 1% HIGGS BOSONS (to be discovered any day) SECRET INGREDIENT: DARK MATTER

### Detect relic WIMPS

WIMP (300 km s<sup>-1</sup>)



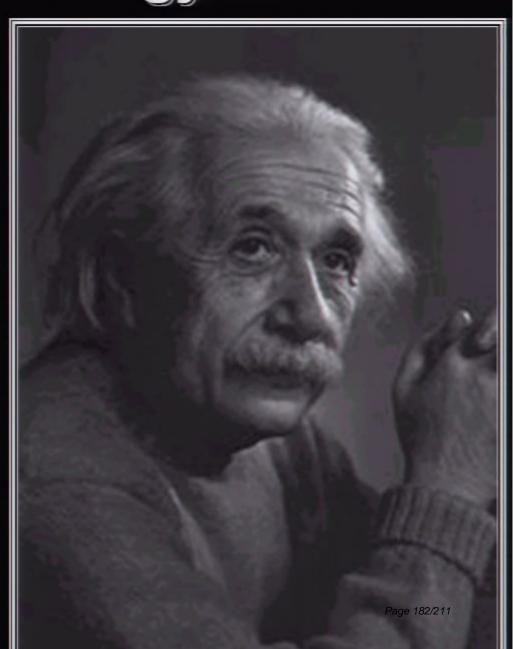
### Dark Energy

1917 Einstein proposed cosmological constant.

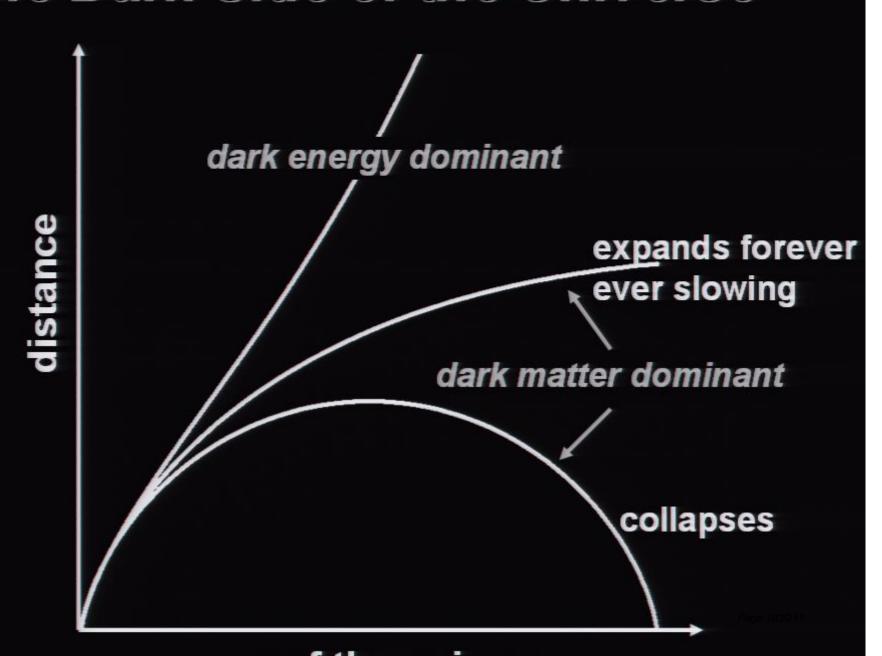
1929 Hubble discovered expansion of the Universe.

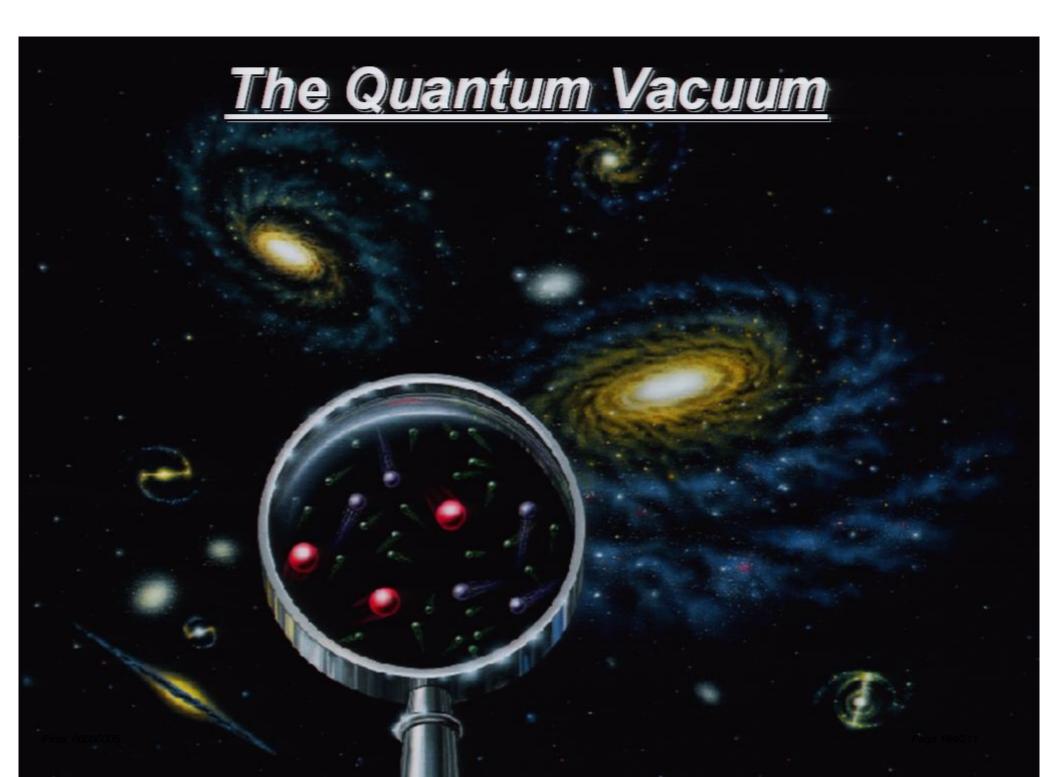
1934 Einstein called it "my biggest blunder."

1998 Astronomers found evidence for it.



### The Dark Side of the Universe





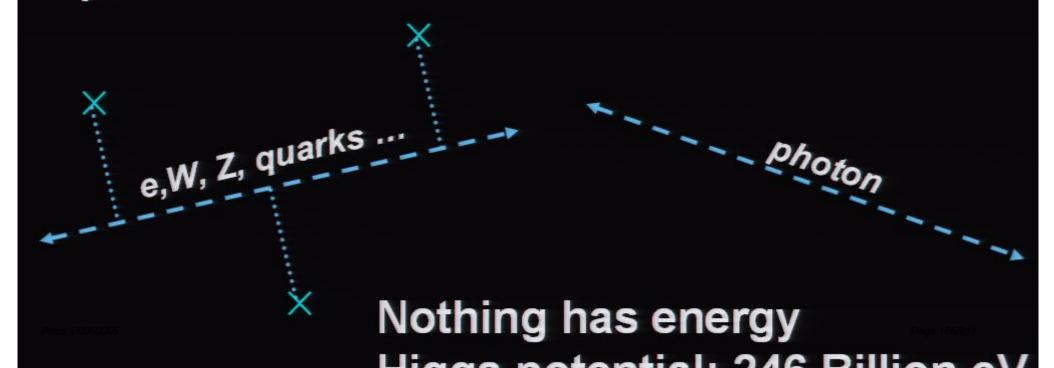
## Uncertainty in the

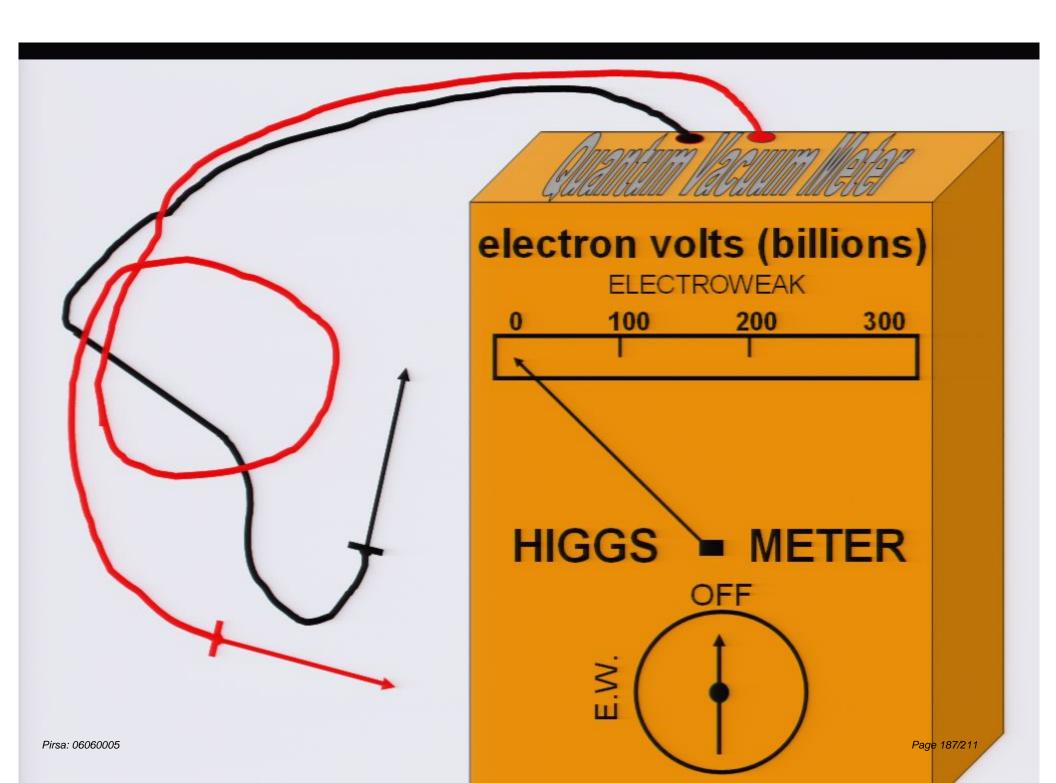
### Quantum Vacuum

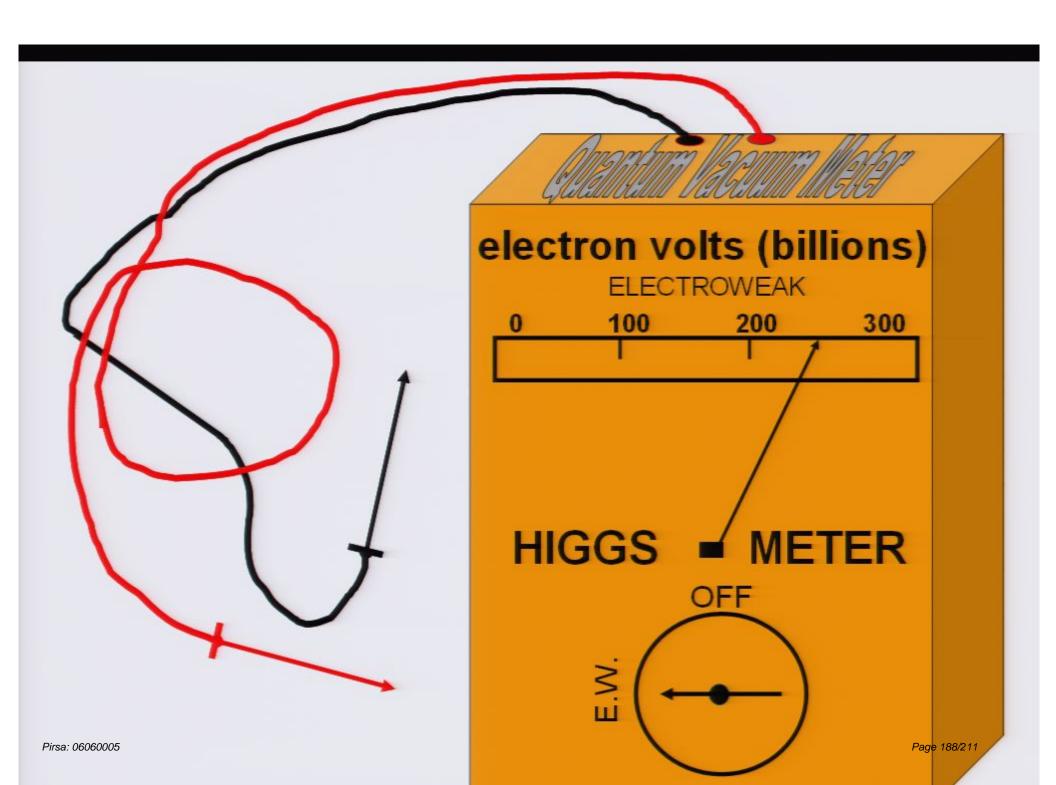


### Higgs in the Quantum Vacuum

- The quantum vacuum has a Higgs potential
- Higgs potential gives mass to quanta like quarks and electrons.







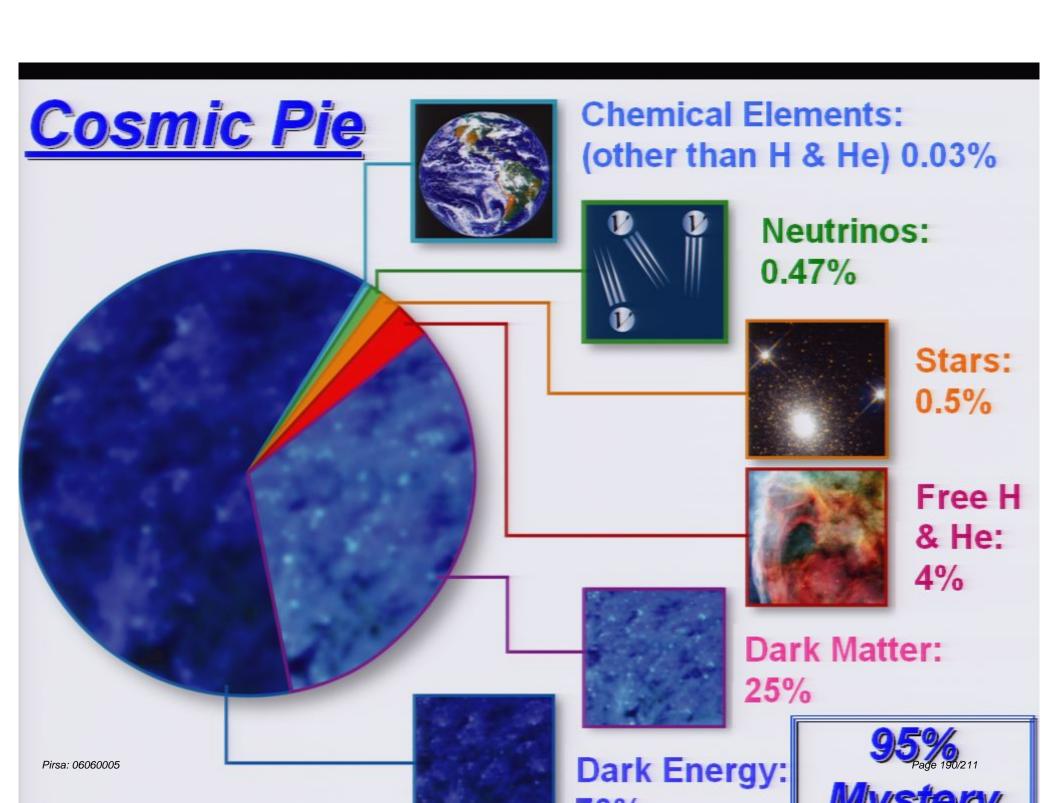


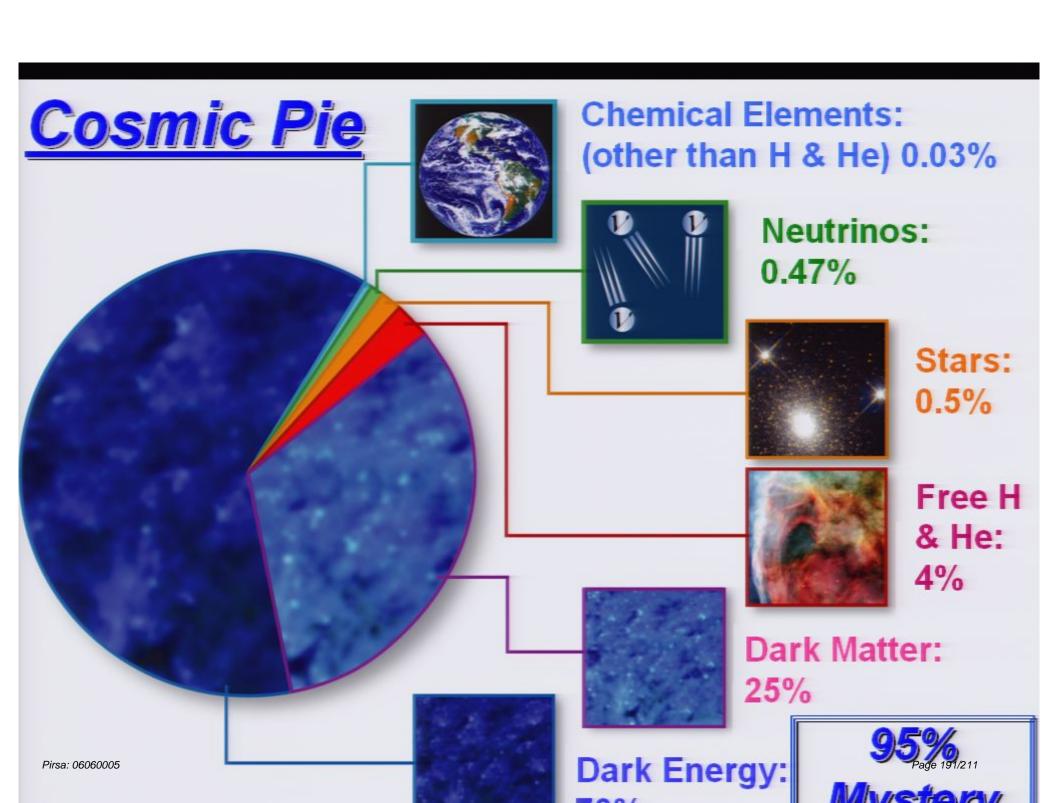
"To me every hour of the light and dark is a miracle. Every cubic inch of space is a miracle."

- Walt Whitman

### Every cubic inch of space is a miracle!

- cosmic radiation
- dark matter
- dark energy
- virtual particles
- Higgs potential



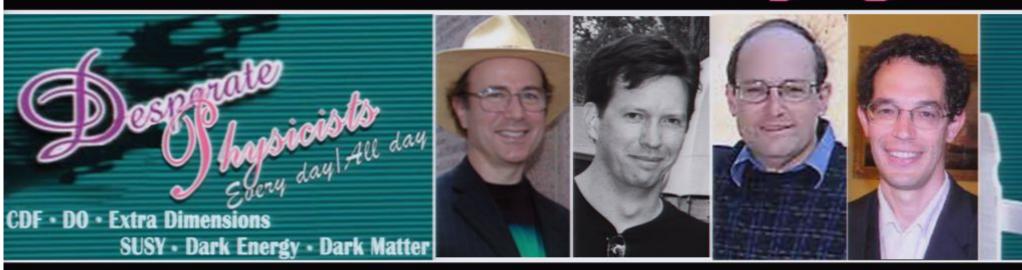




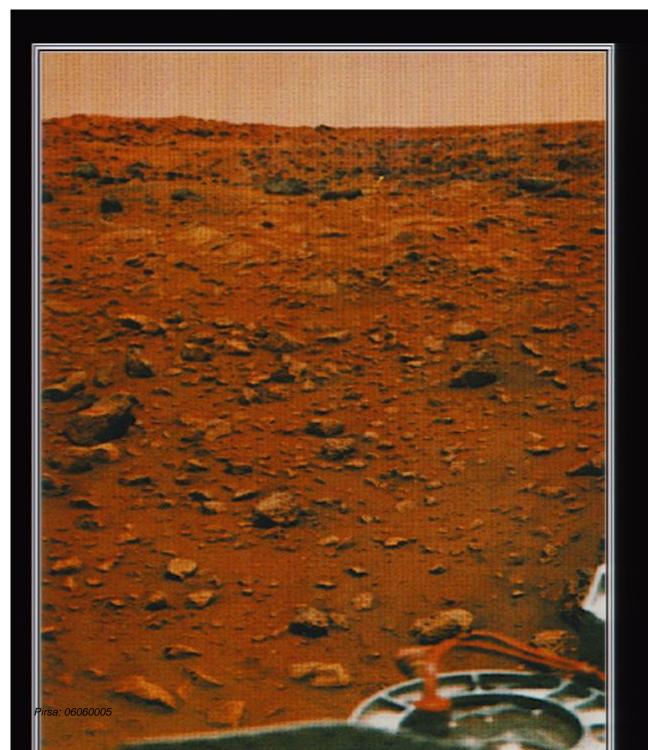
## How Far Will They Go?



## How Far Will They Go?

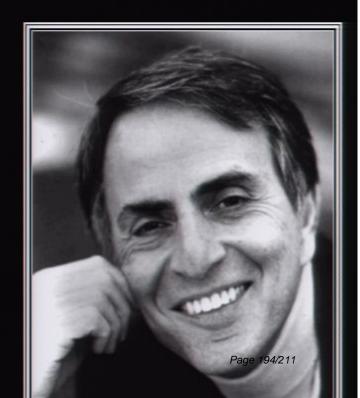


### How Far Will They Go?



"To make an apple pie from scratch, you must first invent the universe."

Carl Sagan



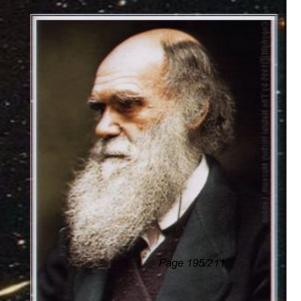
### Cosmology today

- 1) Space and time: relative
- 2) Origin: big bang 13.78 aeons ago.
- 3) Evolution: expanding, cooling, accelerating
- 4) Arrangement: galaxies in the cosmic wide web
- 5) Composition: dark matter and dark energy

There is grandeur in this view ... from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved.

Charles Darwin

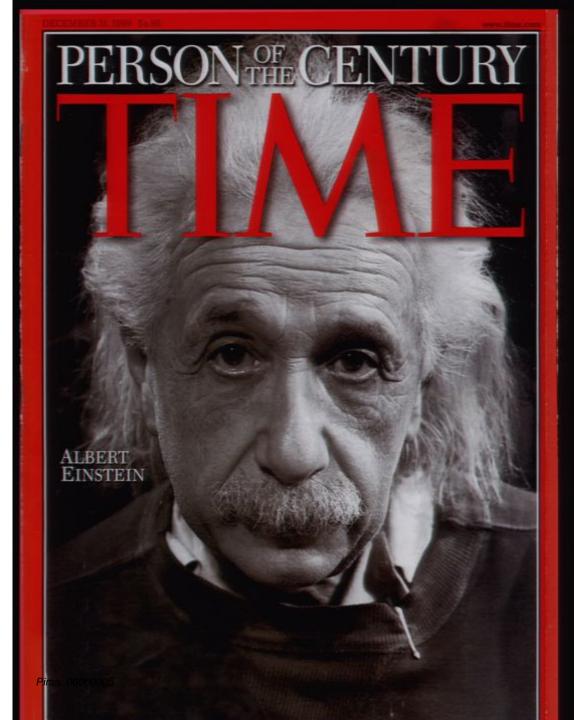
The Origin of Chaples



### The Dark Side of the Universe



95% of the Universe Is Dark!



"The most beautiful thing we can experience is the mysterious. It is the source of all true art and all science. Those to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, are as good as dead: their eyes are closed."

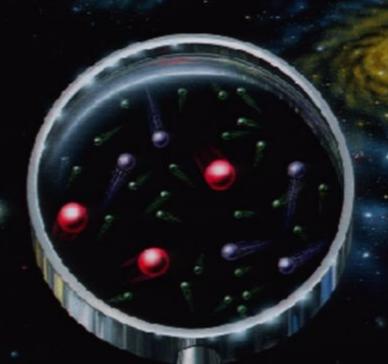
∆lhert Finstein

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.



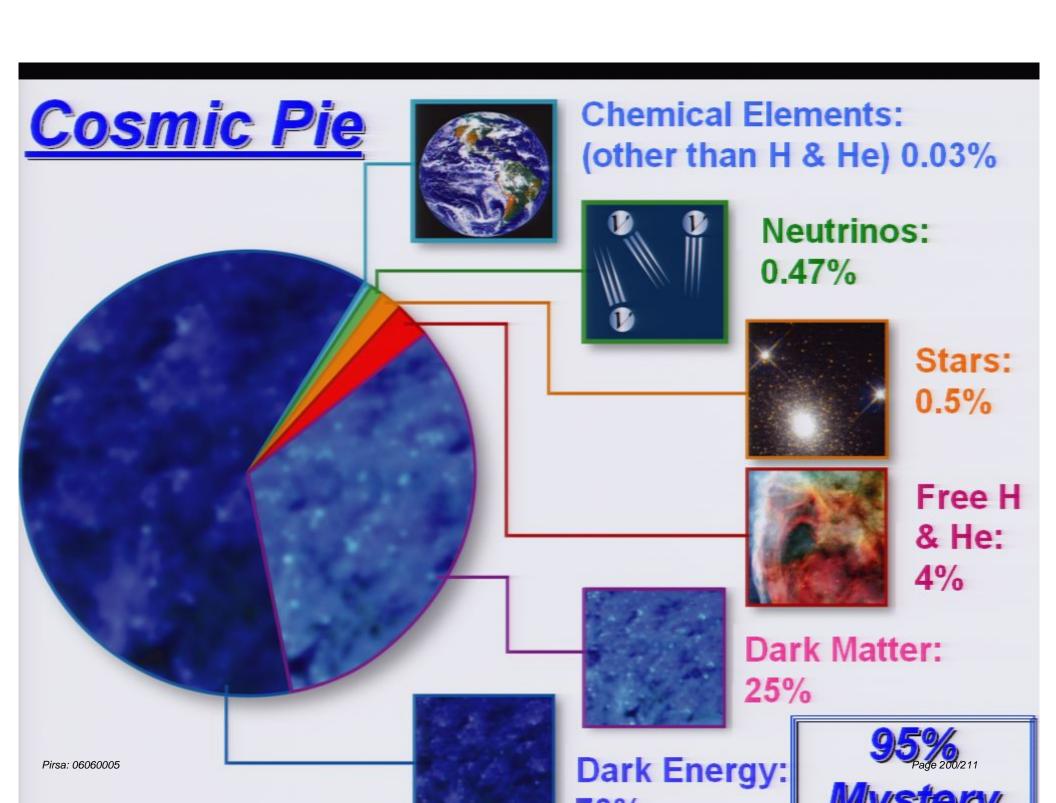
- T. S. Eliot

# The Quantum & the Cosmos

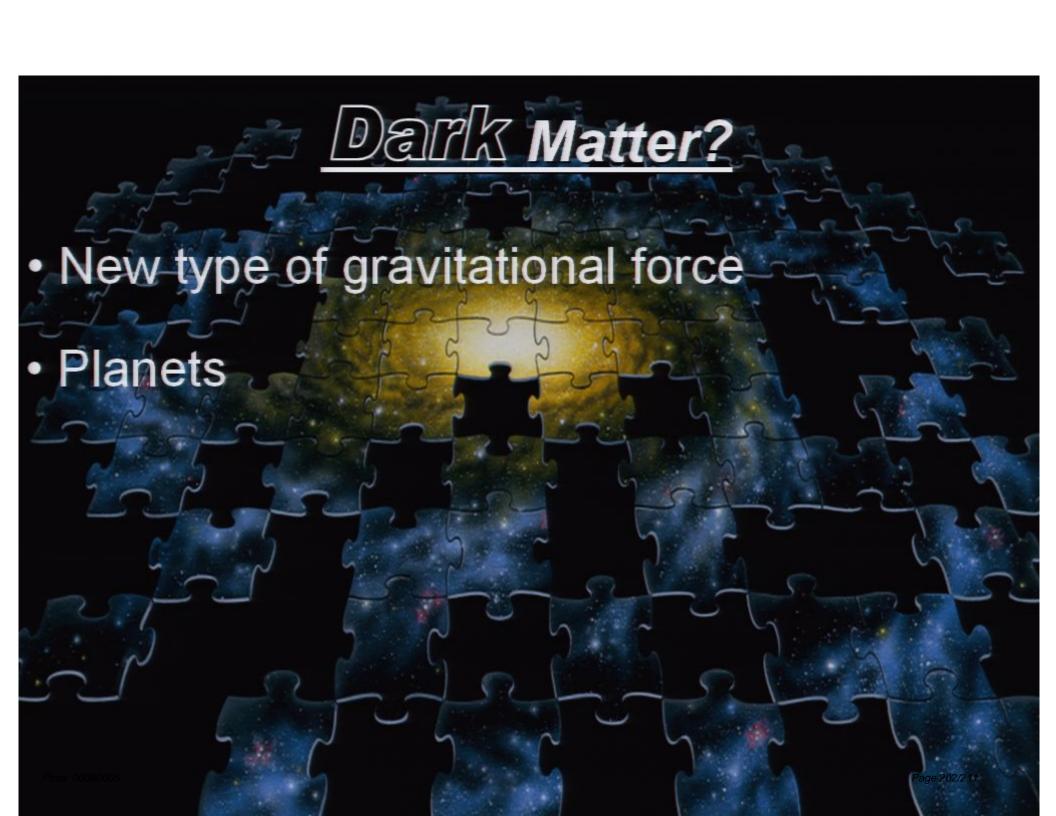


Waterloo

June 2006





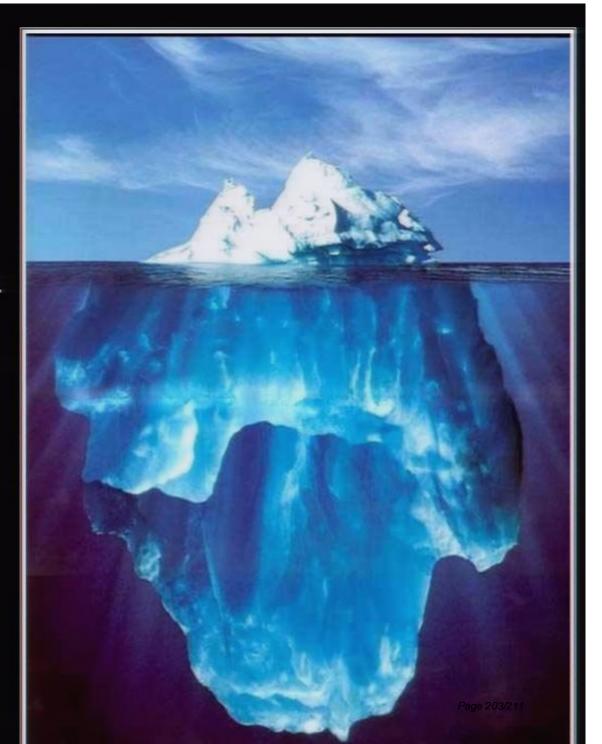


### Dark Matter

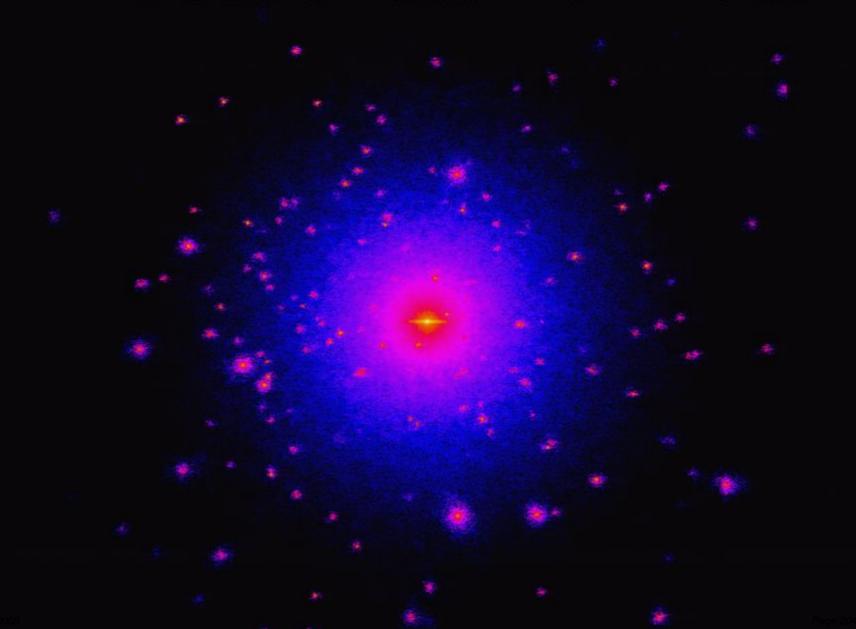
What you don't see, matters.

We don't see most of the matter.

It doesn't seem to be "normal" matter.



### If We Could "See" Dark Matter





### Primordial soup

4 million-millionths of a second AB 3,000 million-million degrees

### CONDENSED

in one can

50 Earth masses in matter

50 Earth masses in antimatter

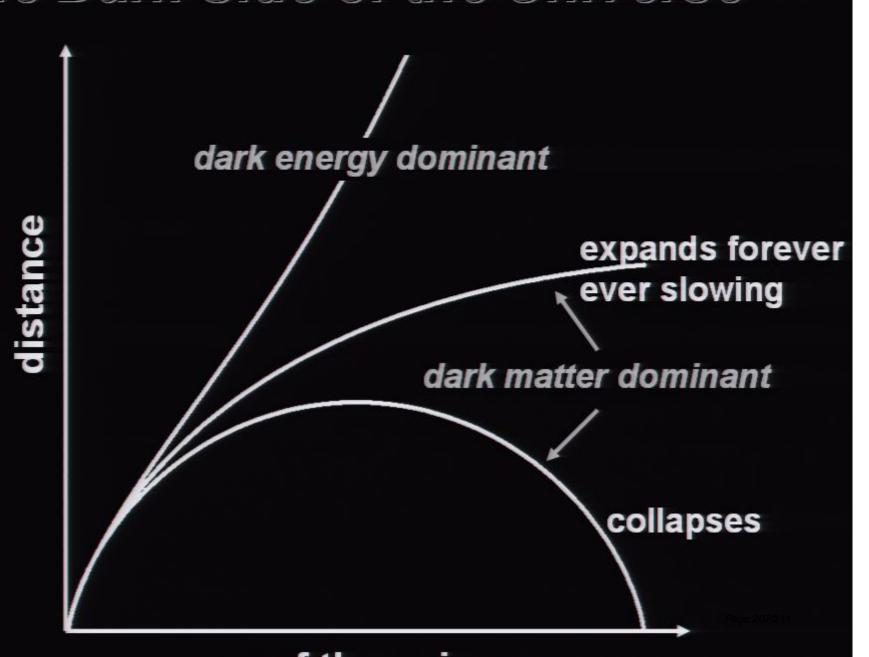
extra mountain of matter

per 10 billion years of total serving energy output of sun

### INGREDIENTS

in every spoonful L every type of elementary particle

### The Dark Side of the Universe



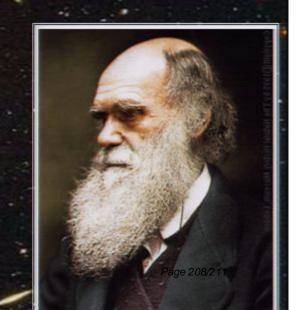
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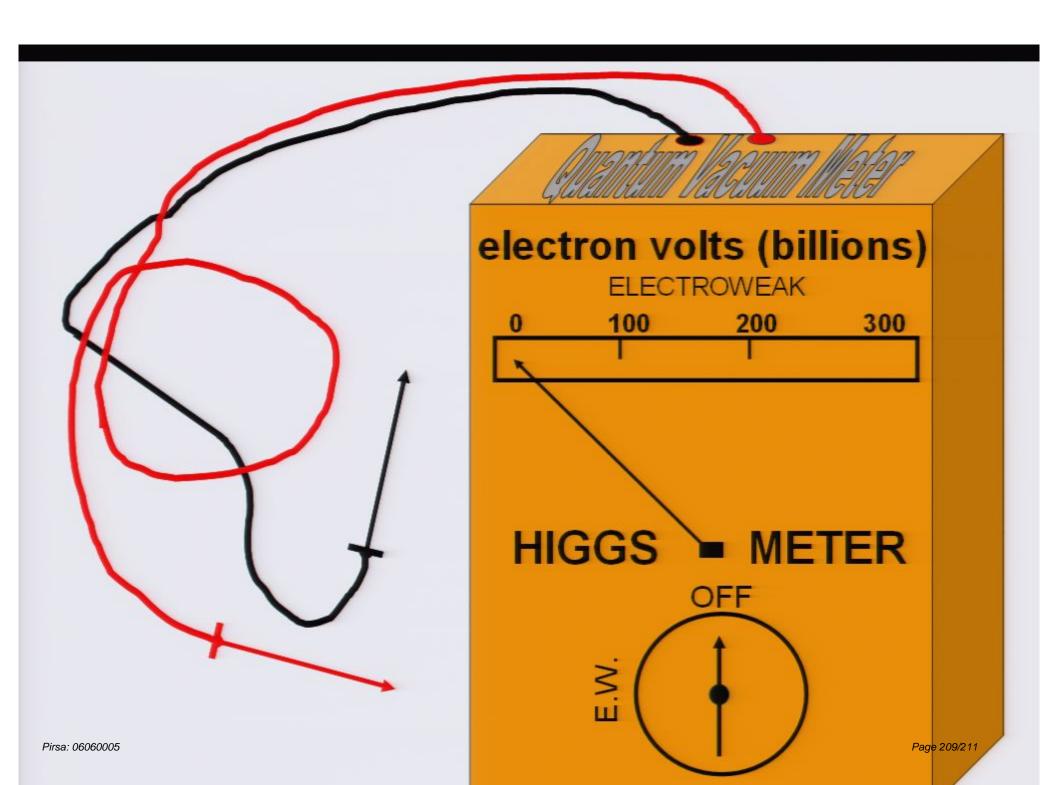
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The Origin of Chaples





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