Dark matter and exotic matter

Reading: "State of the Universe" Ch. 10,.11 (p. 170-196)

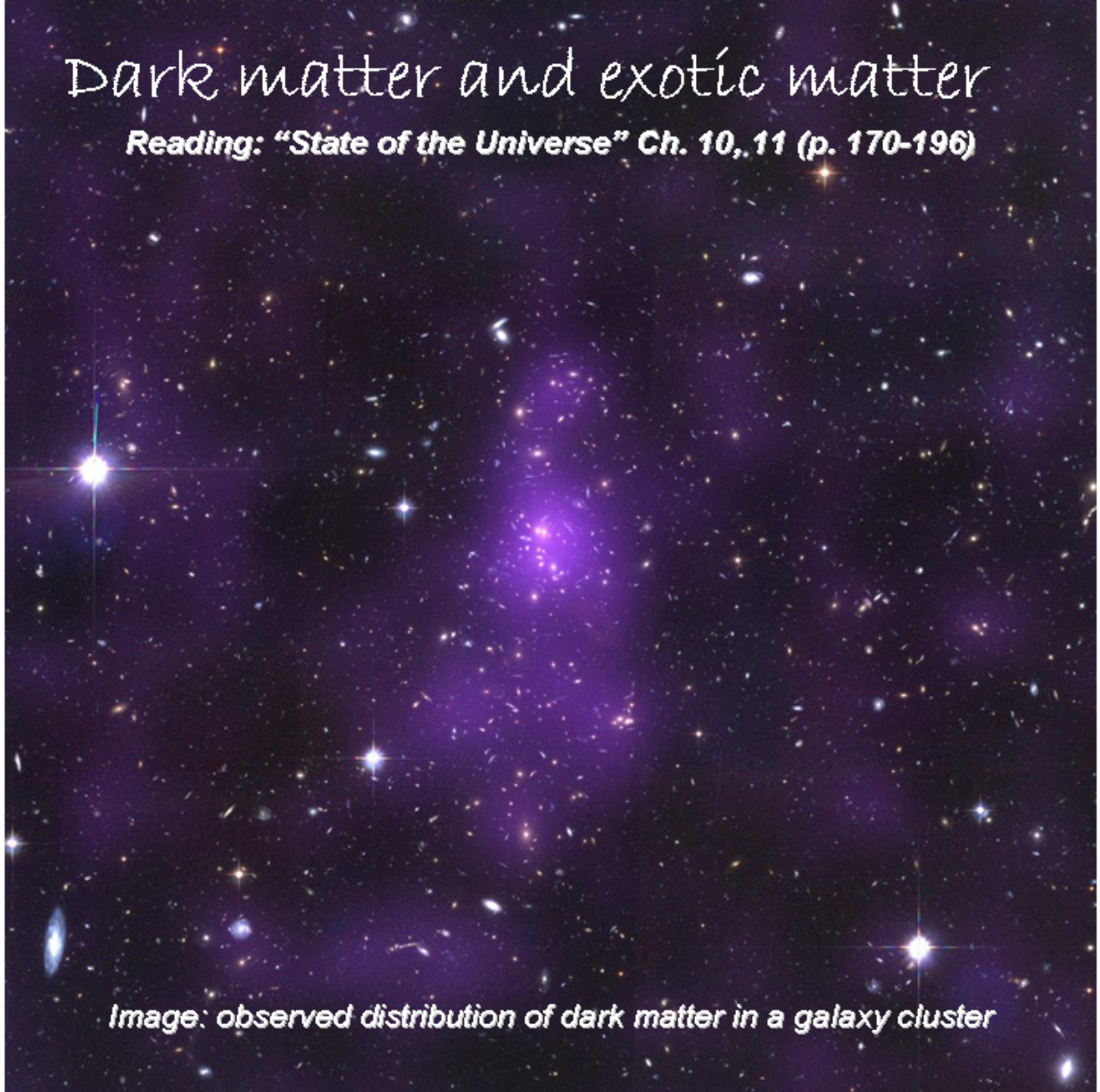


Image: observed distribution of dark matter in a galaxy cluster

Next Monday, Nov 20, 1:30pm

tour of Juan Collar's dark matter detection lab in LASR building

(meeting in class as usual)

Postdoctoral Fellow Andrew Sonnenschein and graduate student Dante Nakazawa testing the first COUPP detector at KICP

Assistant Prof. Juan Collar, the leader of the COUPP lab

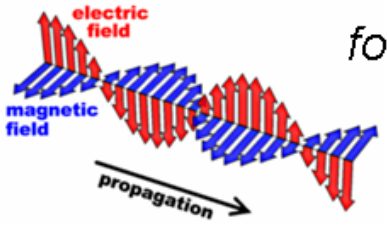
http://collargroup.uchicago.edu/index.html

The dark side of the Universe

- *Big Bang model presents a coherent and successful model for observed Universe. Many of its predictions have been tested by observations. It all makes sense*
- *However, as the more data about galaxies and the Universe was collected in the 20th century, it has become clear that the Universe is full of puzzles. One of the main puzzles is the apparent presence of dark, invisible matter in the Universe.*
- *We can only see its gravitational influence on the usual matter probed by observations.*
- *There is no shortage of ideas for what this can be, and understanding this dark stuff is one of the main areas of research in modern cosmology…*

What is the ordinary, "visible" matter?

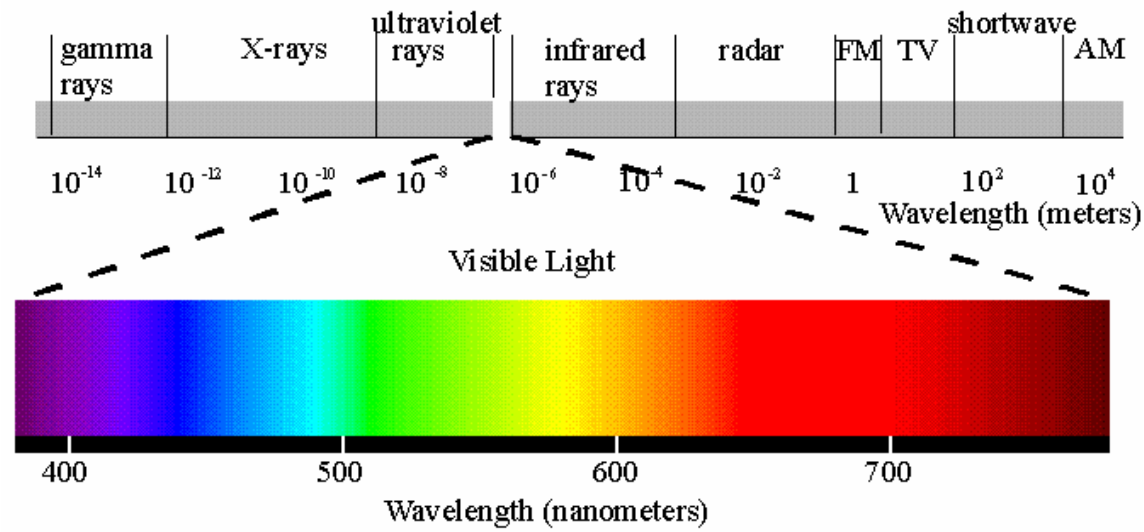
It is the stuff we can probe directly using experimental techniques,



for example by detecting EM radiation from it

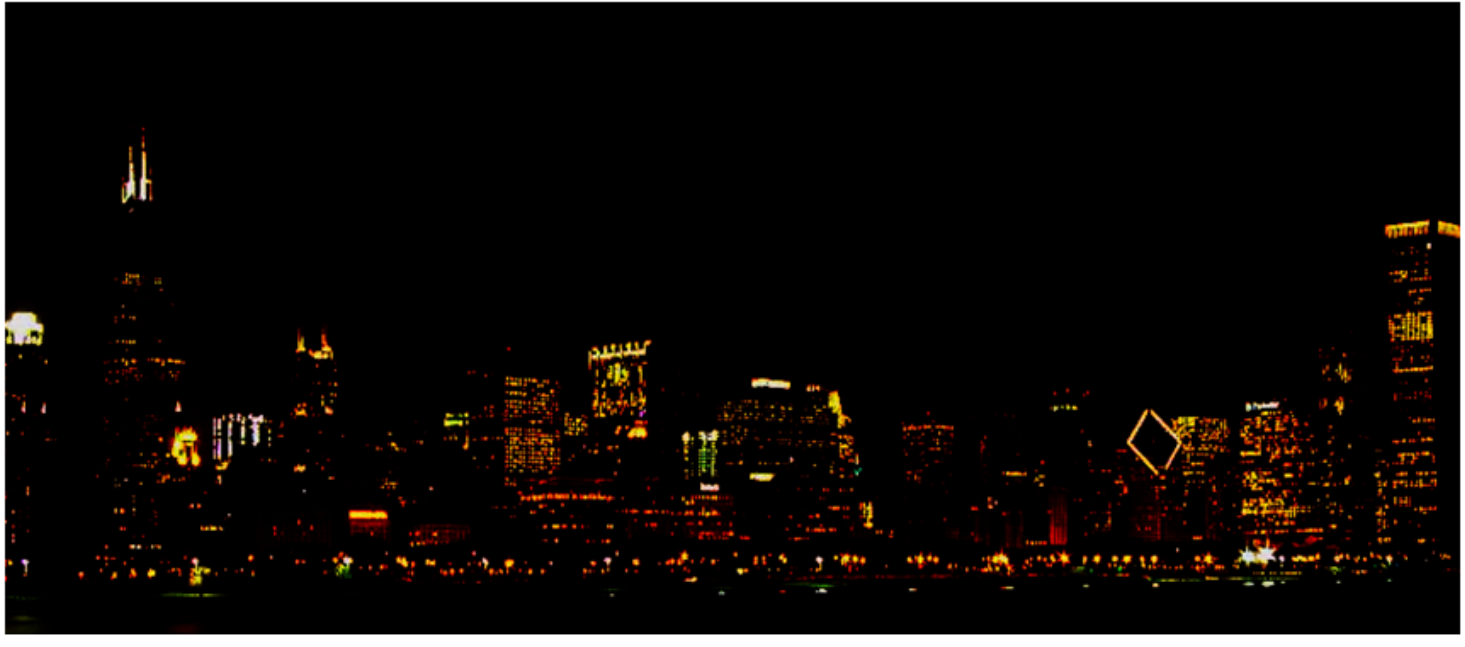
spectrum of electromagnetic radiation

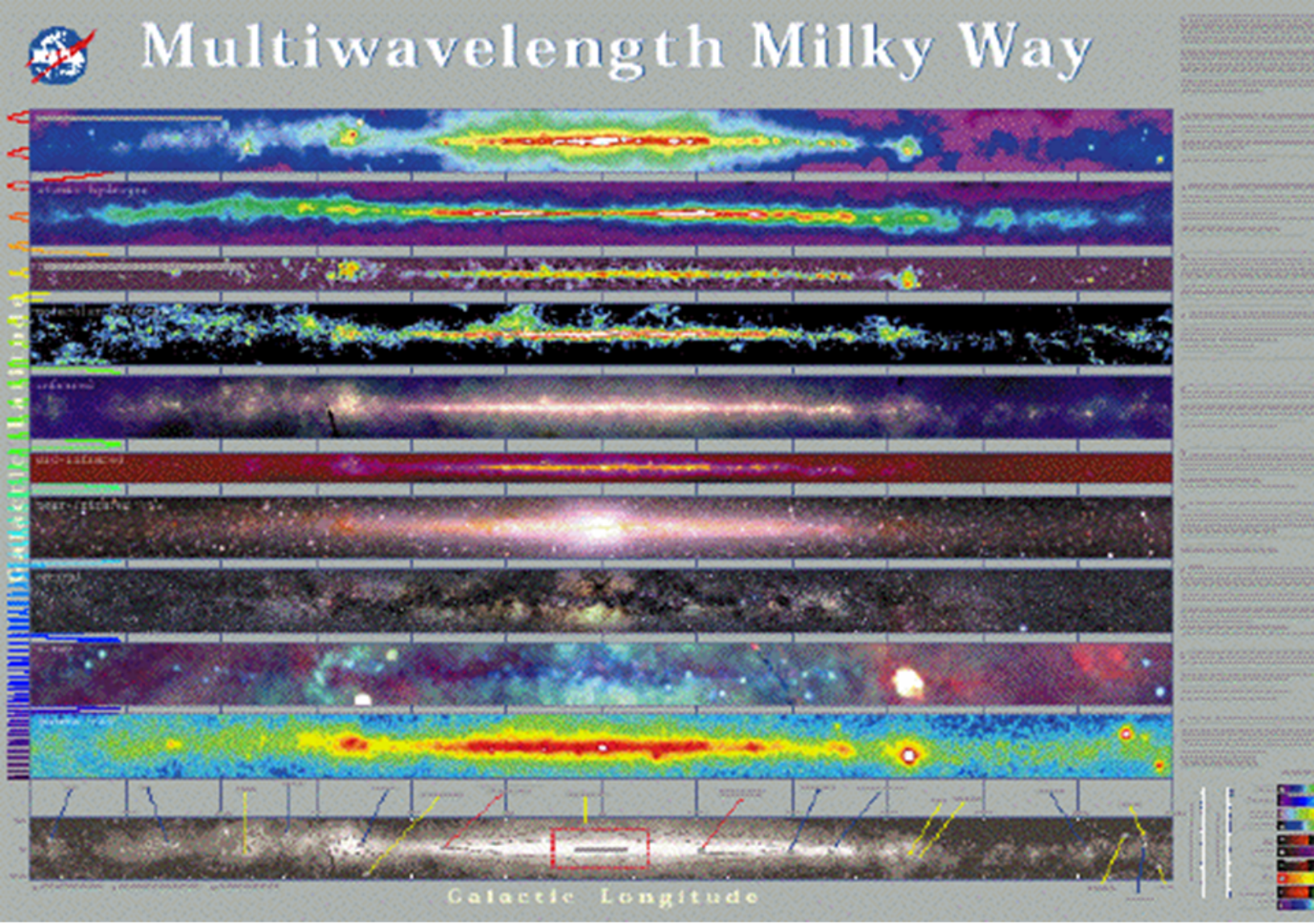
increasing energy, decreasing wavelength



learning about the city by its lights

Observing radiation at different wavelength is like looking through infrared goggles to get a more complete picture…





http://adc.gsfc.nasa.gov/mw/mmw_images.html

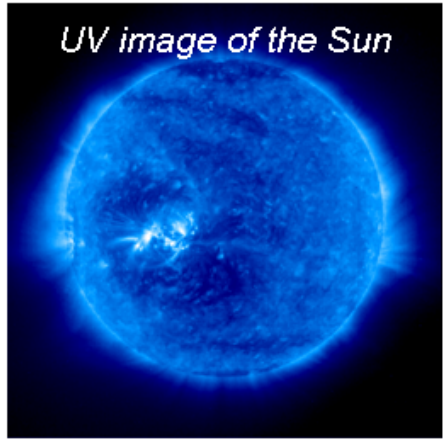
Optical observations in visible light

Optical image of a galaxy from the

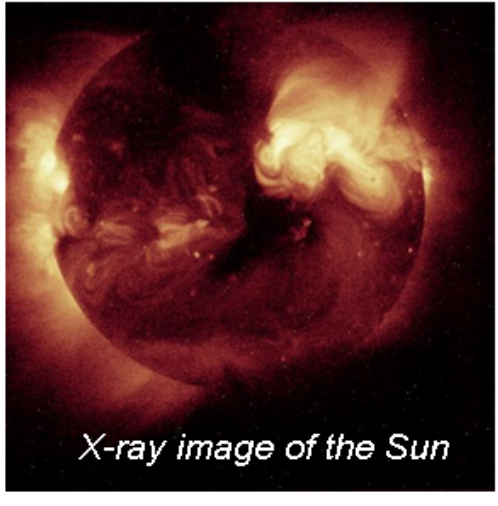
Hubble Space Telescope with a dust lane (dust absorbing light)

Galaxy M82 with an active nucleus

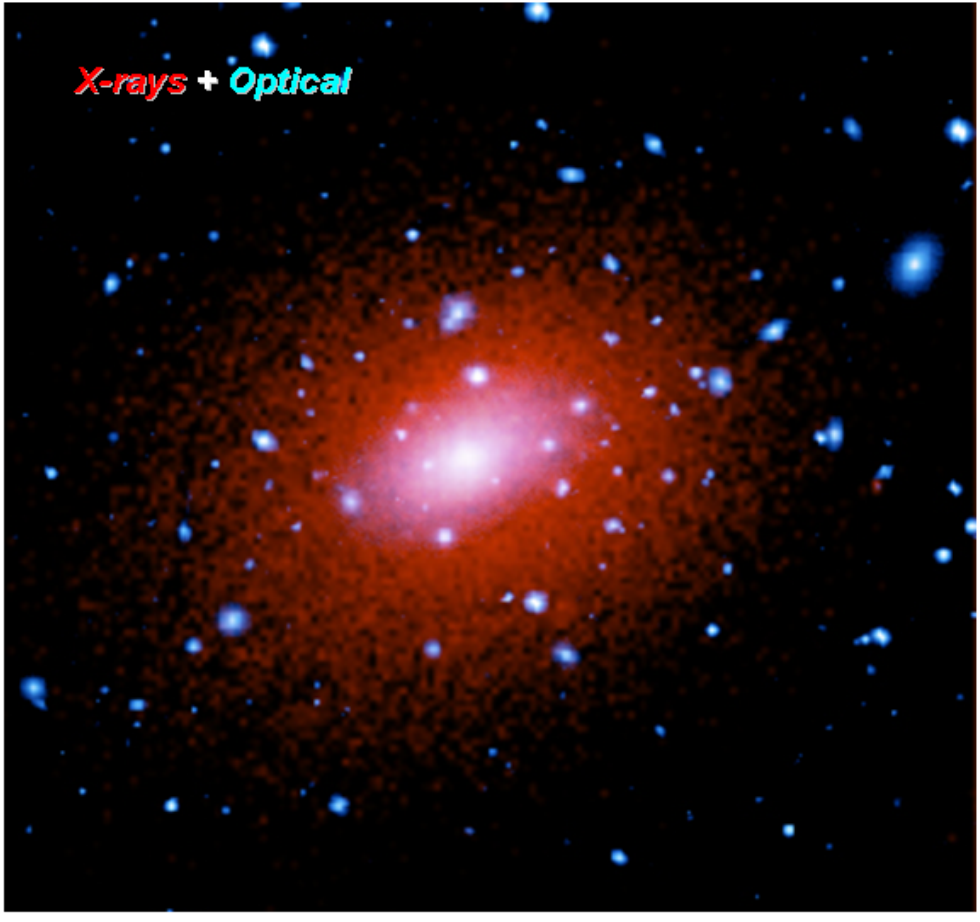
UV/X-ray observations



Roentgen's postcard with an X-ray photograph of his wife's hand

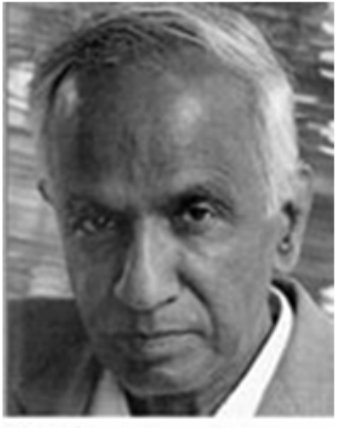


X-ray observations



a cluster of galaxies

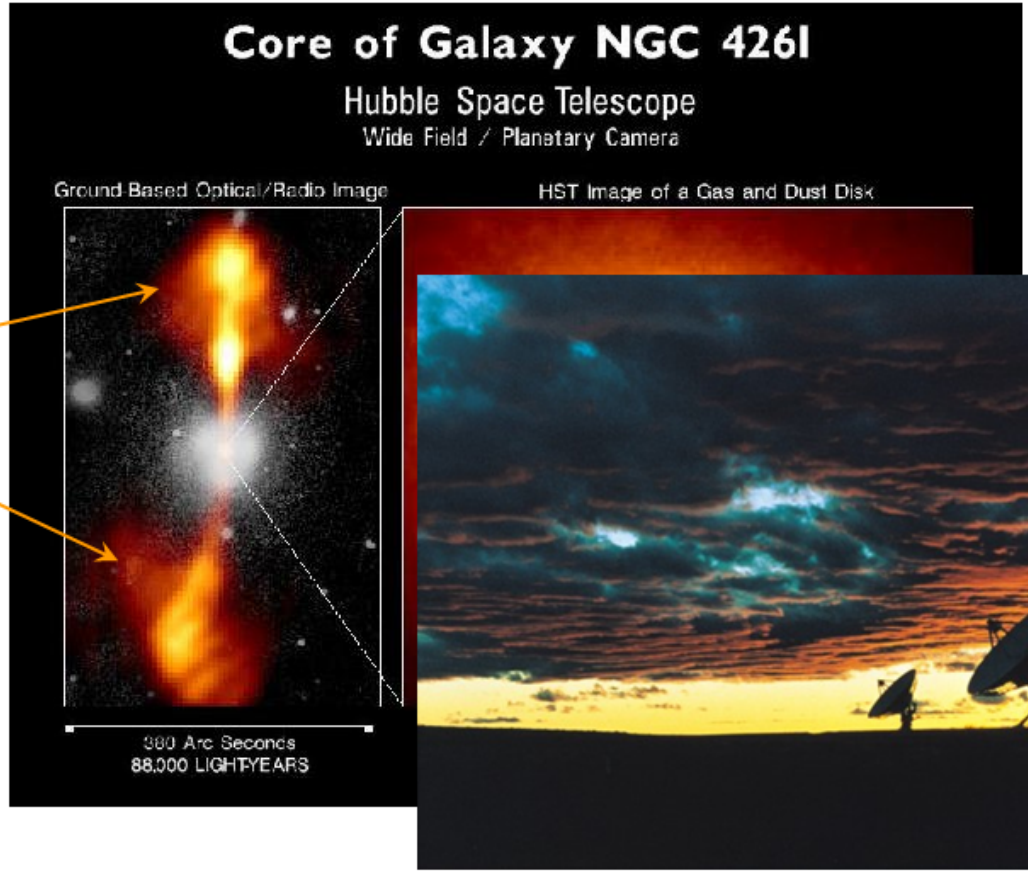
NASA's X-ray satellite "Chandra"



S. Chandrasekhar

Subramanyan Chandrasekhar ("Chandra") - U.Chicago professor of Astronomy and Physics 1937-1995

Radio observations



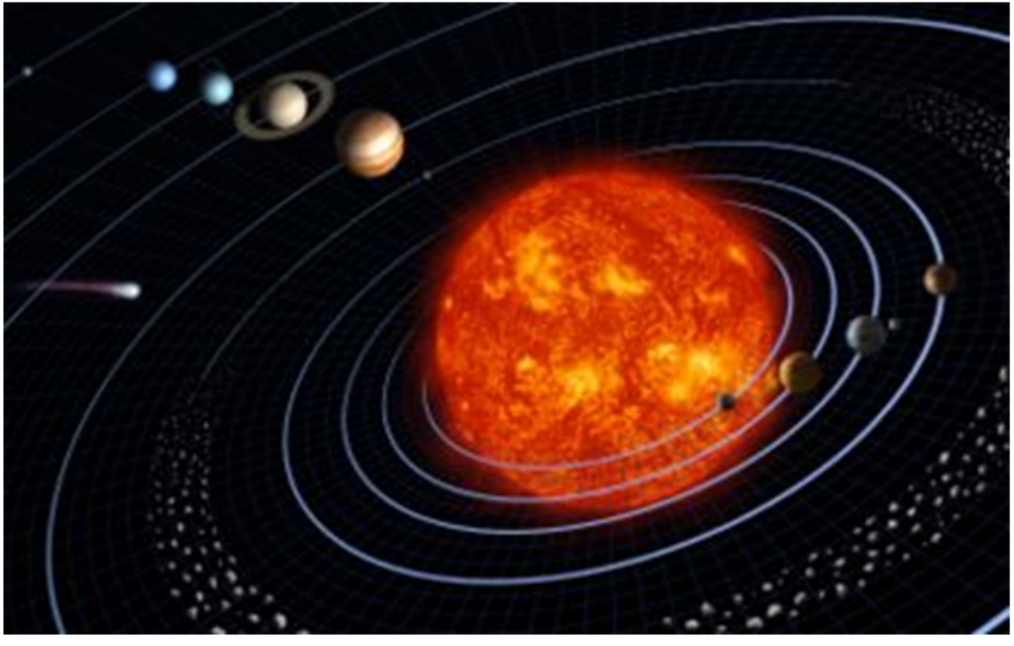
radio emission

Very Large Array (VLA) – interferometric array of radio antennas in New Mexico near Soccorro

The Universe visible to us now via multiwavelength observations is very different from what was the visible 100 years ago

Still, radiation is not the only way to explore the Universe and to learn about what's out there…

Using movement to measure mass



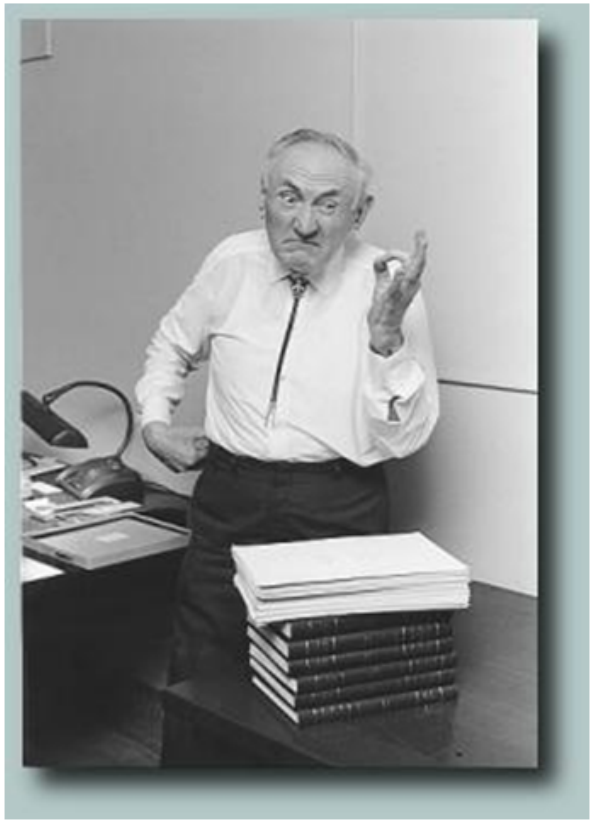
According to Newton's law of gravity:

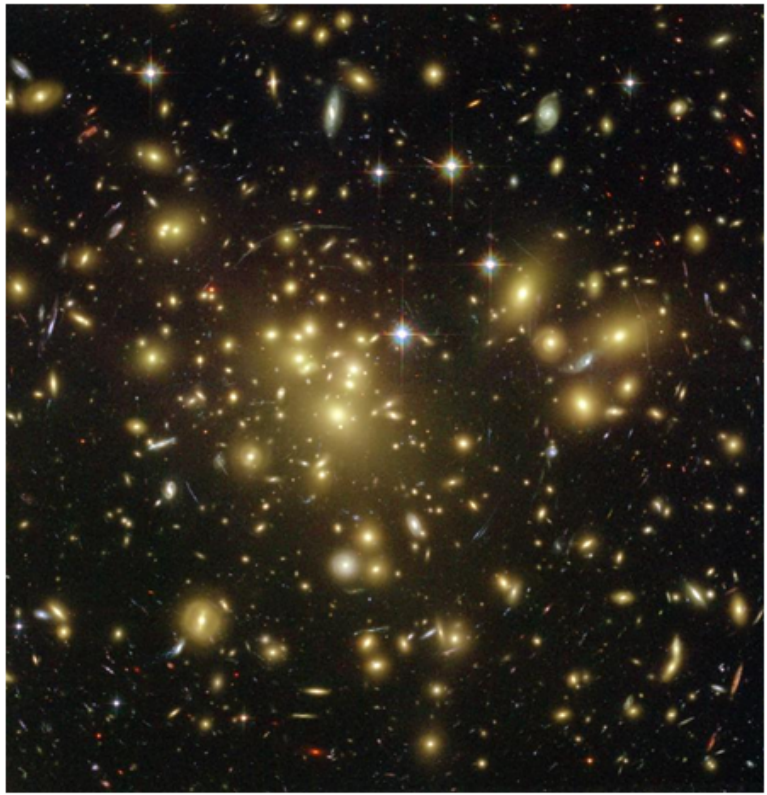
$$M(R) = \frac{V_{rot}^2 R}{G}$$

I soon became convinced... that all the theorizing would be empty brain exercise and therefore a waste of time unless one first ascertained what the population of the universe really consists of.

Fritz Zwicky

Fritz Zwicky in 1930s pointed out that galaxies in clusters are moving too fast to be explained simply by their combined mass

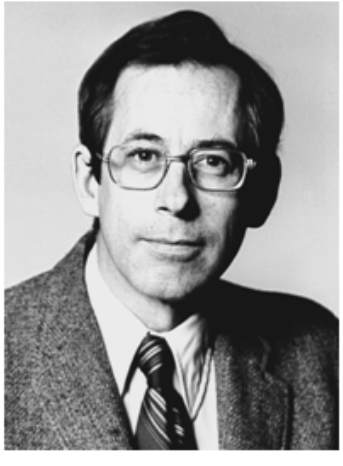




Fritz Zwicky (Caltech), 1898-1974

Disk galaxies without dark matter are unstable

Jeremiah Ostriker



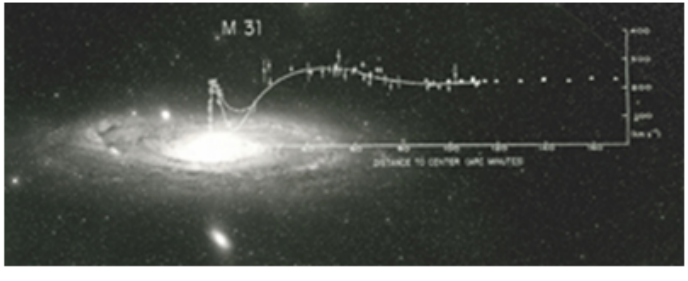
Jim Peebles

- *In early 70s Ostriker & Peebles were trying to construct computer models of rotating galaxy disks*
- *To their surprise, they could not do it. The disks were unstable and would not stay as disks, instead creating bars and other instabilities.*
- *Ostriker & Peebles argued that if the space in between stars was filled with unseen matter, the disks could be made stable and could resemble the real disks*
- *However, they needed 10 times more unseen matter than the mass in observed stars in gas. Their ideas were not immediately accepted…*

Rotation of galaxies and dark matter

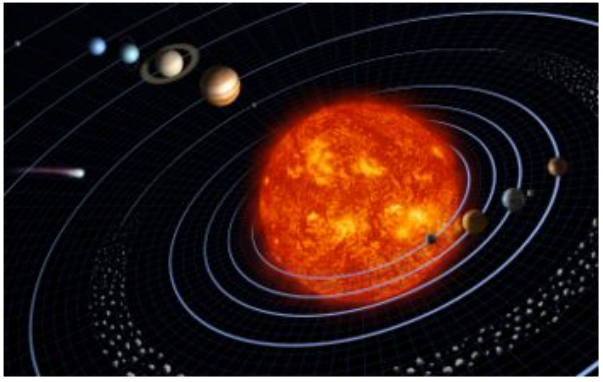
Vera Rubin

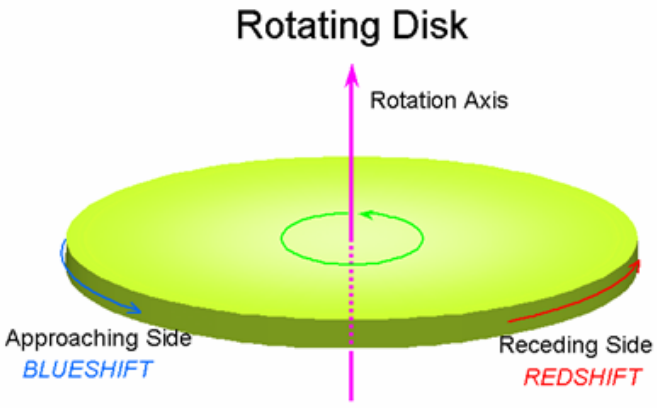
The situation changed when Vera Rubin showed that observation of rotation of galactic disks in their outer parts also required a lot of unseen mass…



Vera Rubin, with DTM image tube spectrograph attached to the Kitt Peak 84-inch telescope, 1970.

Using movement to measure mass





According to Newton's law of gravity:

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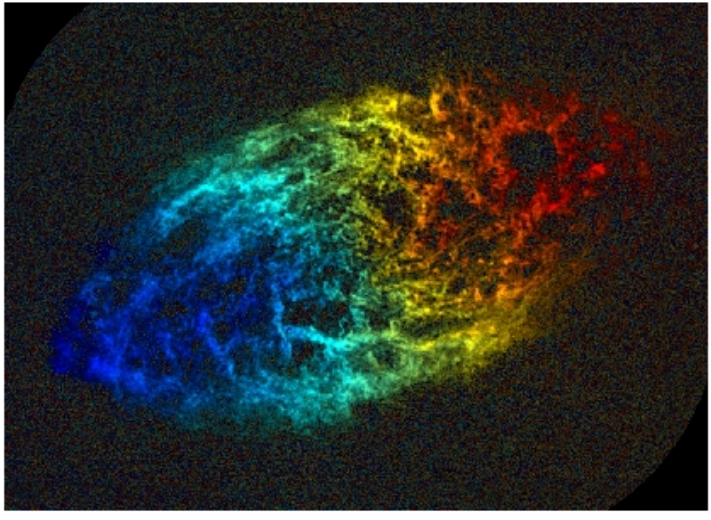
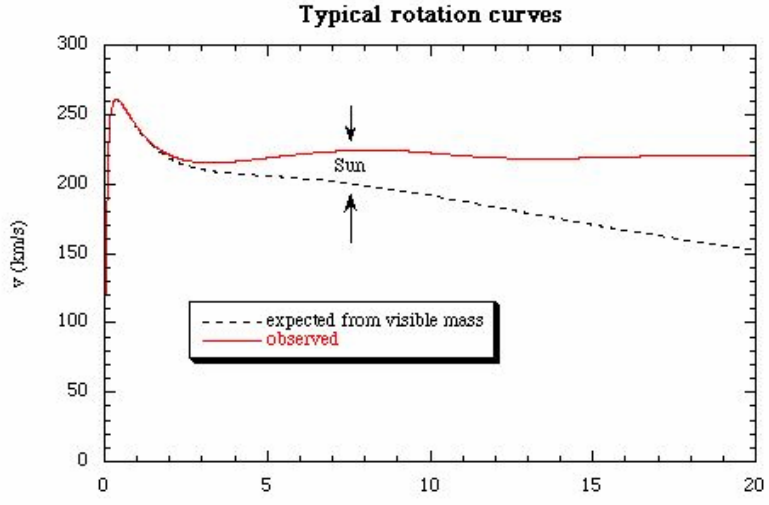
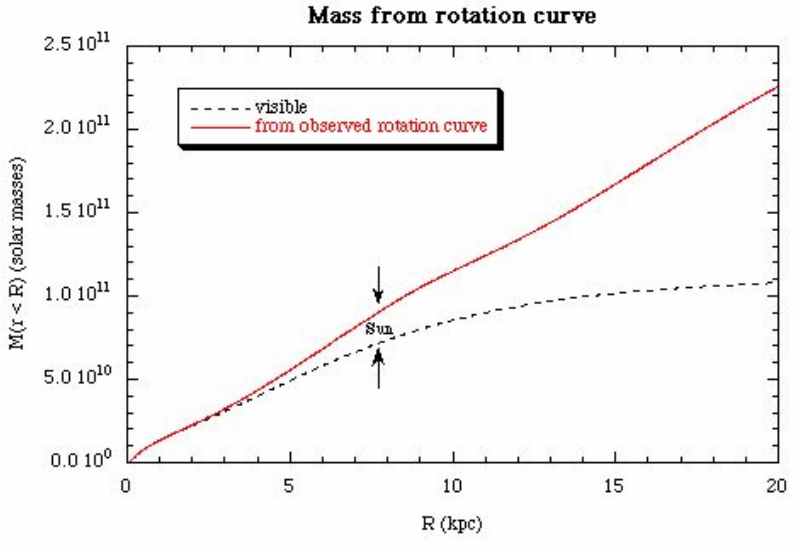
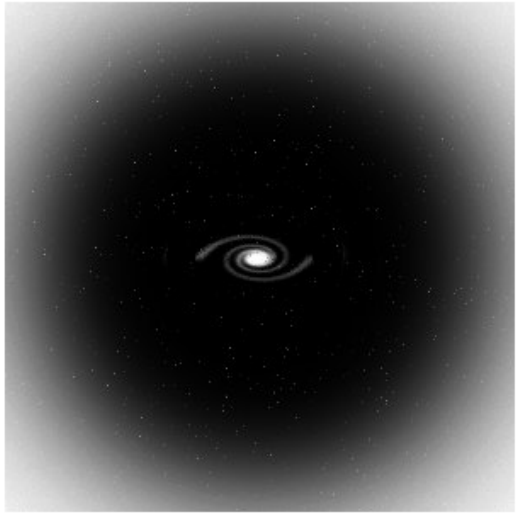
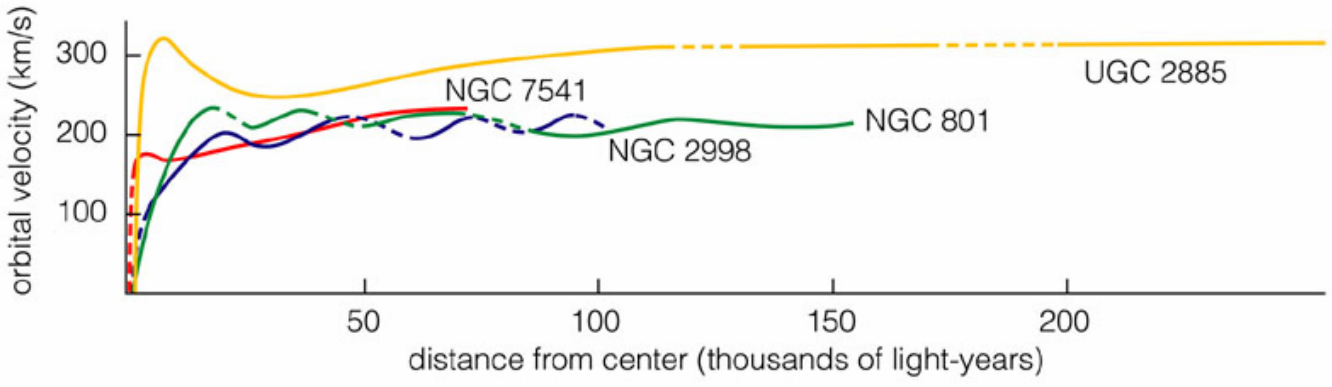



Typical rotation curves
v (km/s)
300
250
200
150
100
50
0
0
5
10
15
20
Sun
expected from visible mass
observed


Mass from rotation curve
M(r < R) (solar masses)
2.5 10^11
2.0 10^11
1.5 10^11
1.0 10^11
5.0 10^10
0.0 10^0
0
5
10
15
20
R (kpc)
visible
from observed rotation curve
Sun

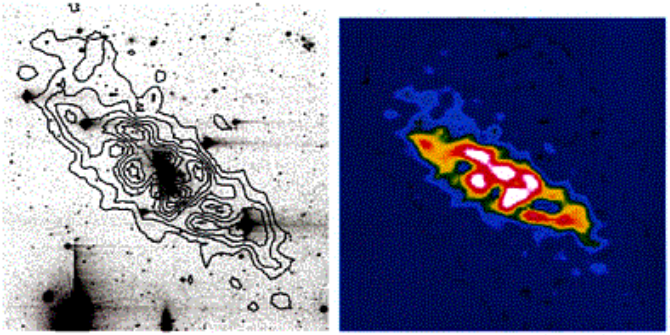


flat rotation curves are ubiquitous and have been observed in many galaxies

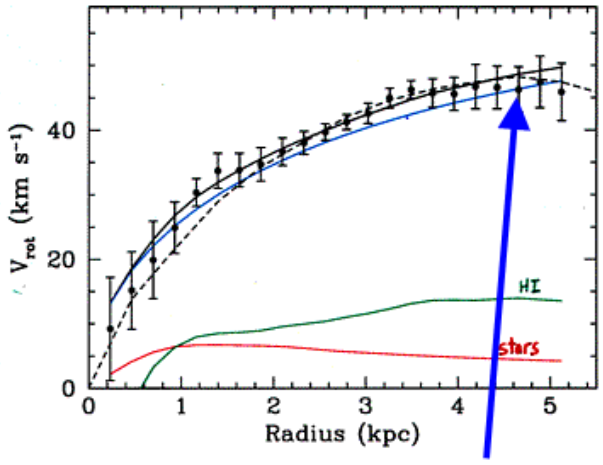


Some of the smallest "dwarf" galaxies seem to be mostly made of dark matter

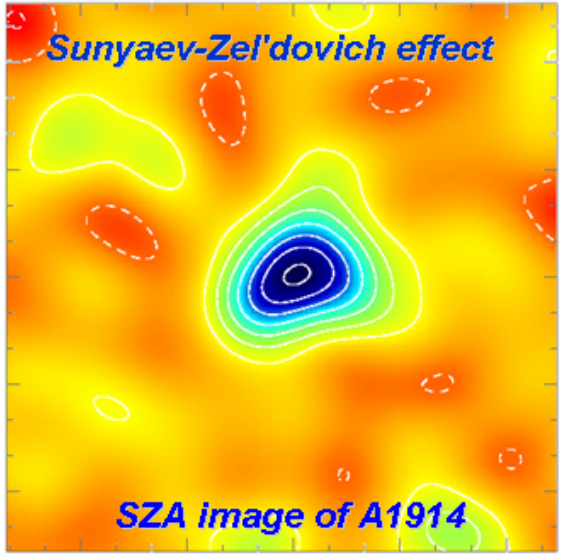
DDO 154

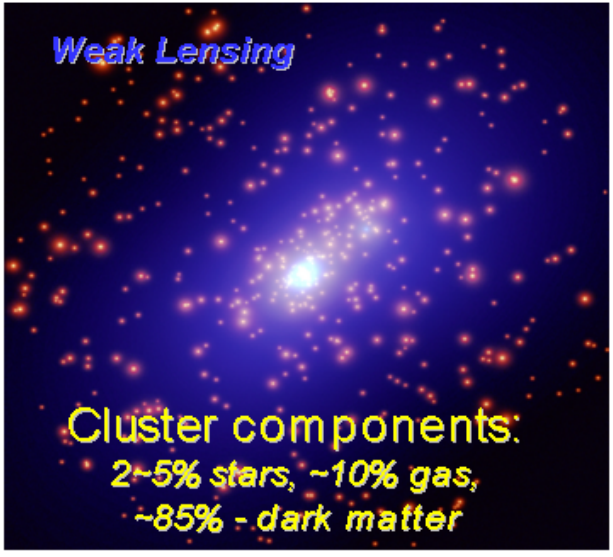


(Original HI data from Carignan & Purton, 1999)

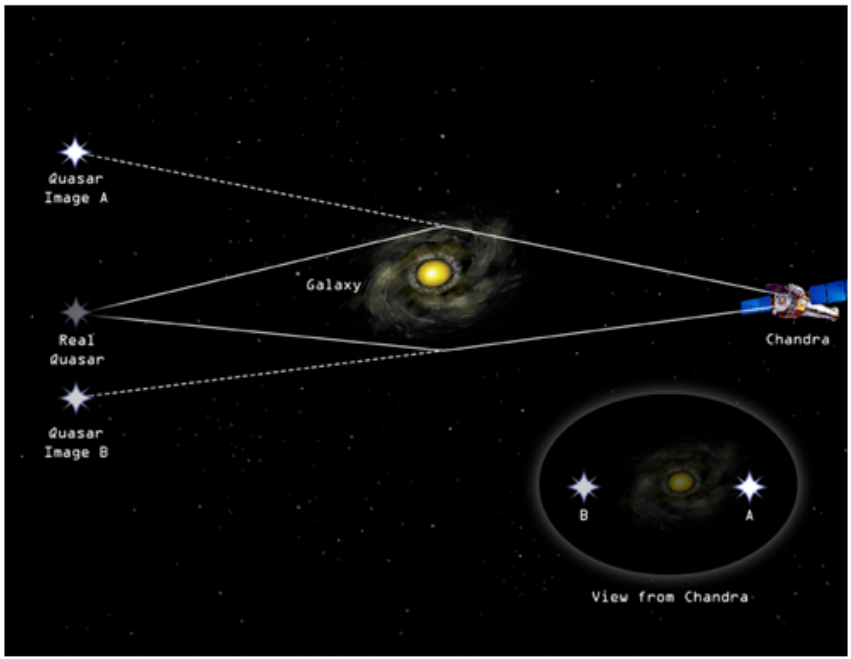


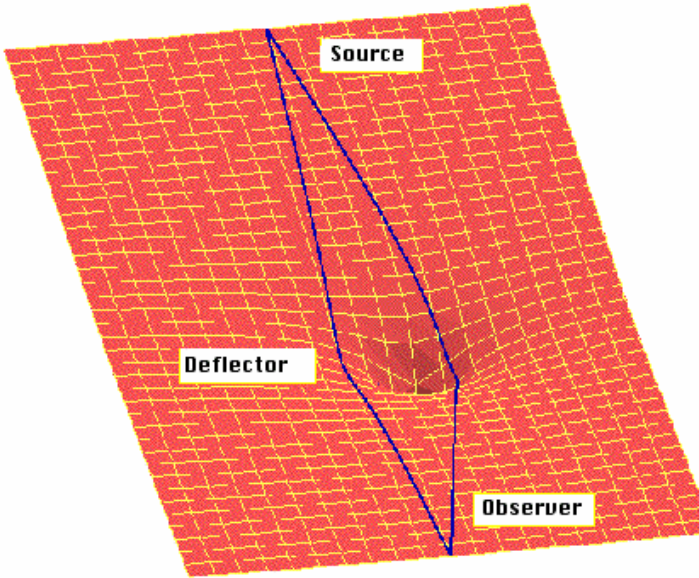
Galaxy clusters provide evidence for the existence of dark matter because galaxies move fast and Intergalactic gas is very hot

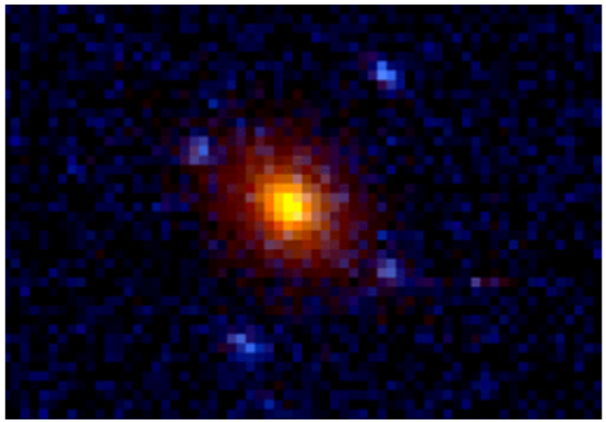




Gravitational lensing by galaxies & clusters





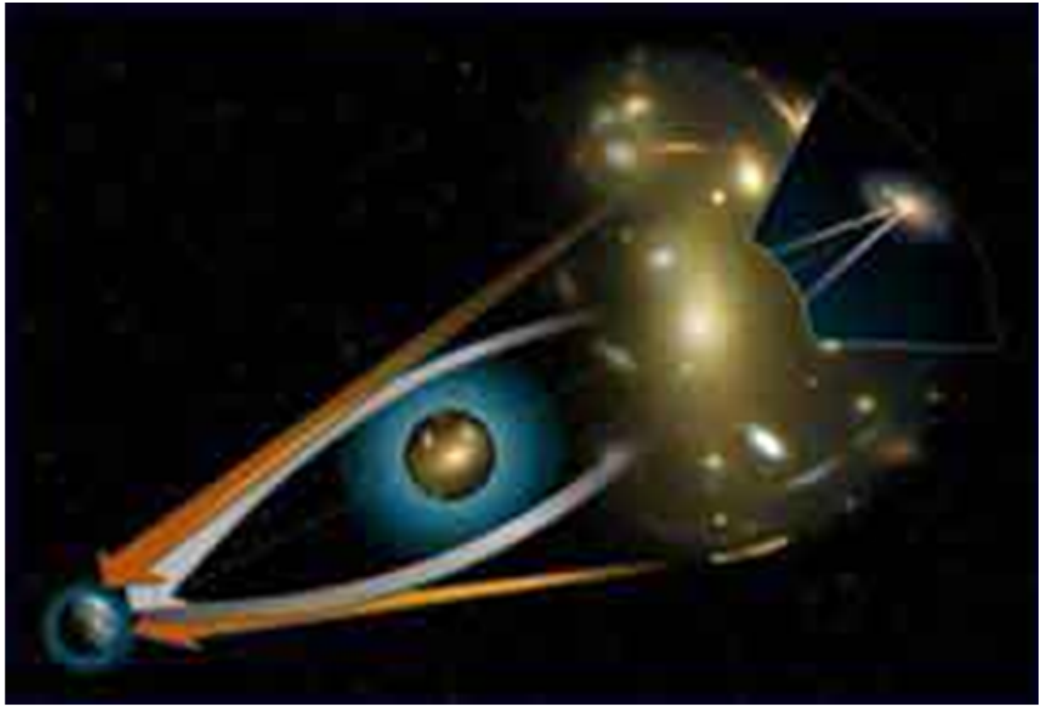


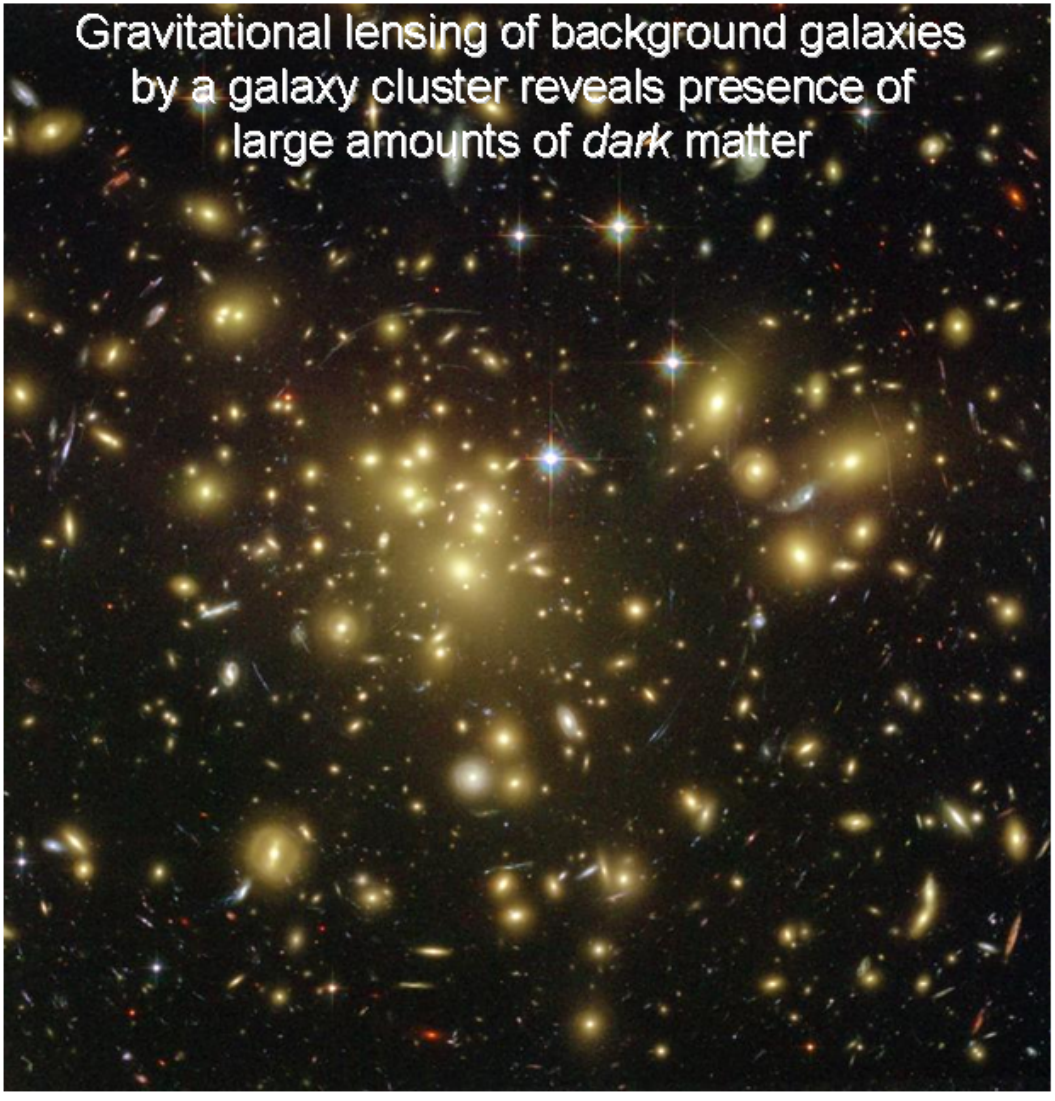
Backgroun galaxy split into 4 images by lensing

Gravitational lensing is a well-understood process that can be accurately modeled

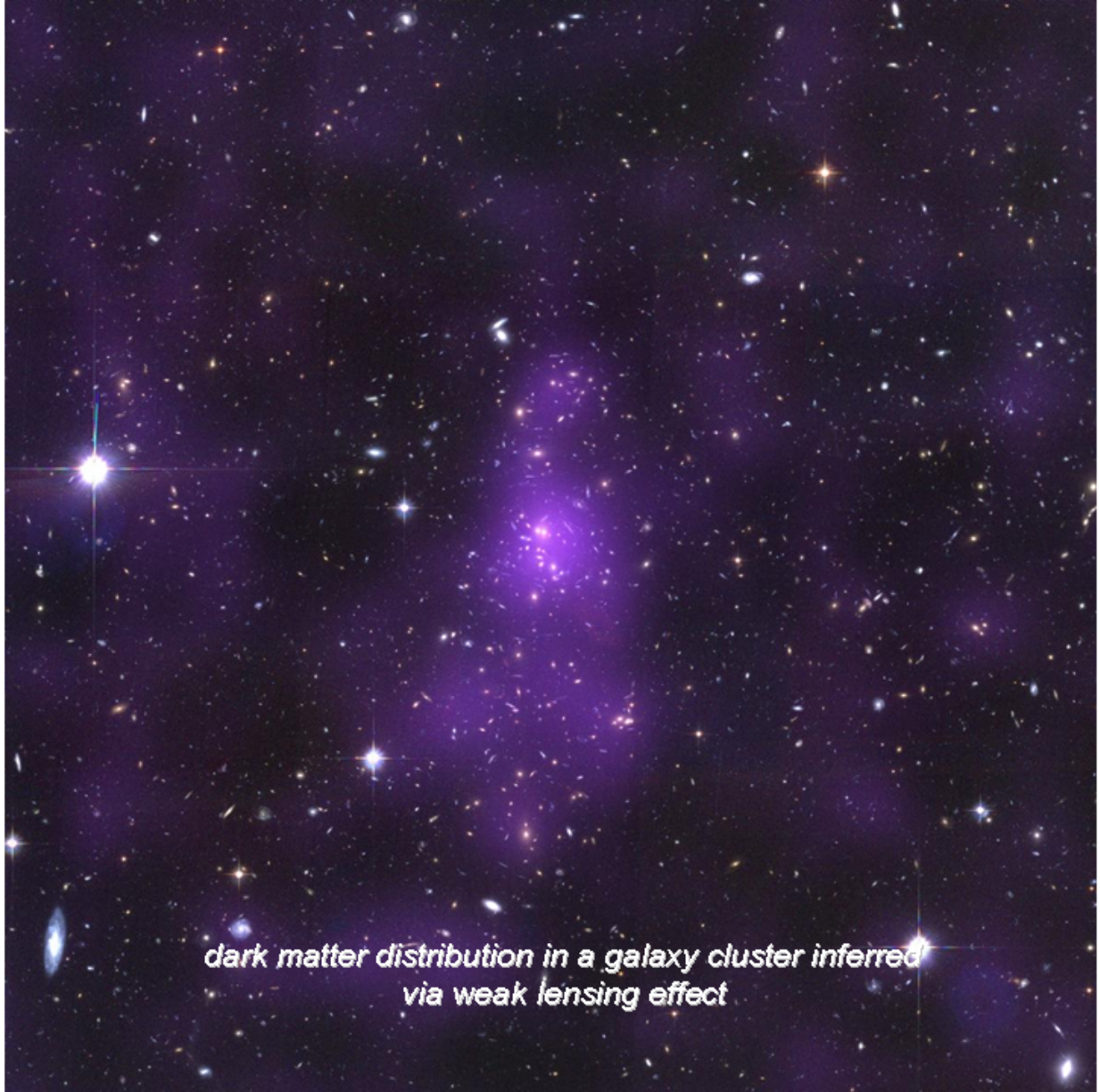
Lensing of the Castle (Mall, Washington, DC) by a black hole with the mass of Saturn

Gravitational lensing by galaxies and clusters: lensing distorts images





http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/01/



dark matter distribution in a galaxy cluster inferred via weak lensing effect

evidence for dark matter in a galaxy cluster