Deep Surveys
or
How We Learn About the Early Universe When We Can't Measure All that Would Be Nice!

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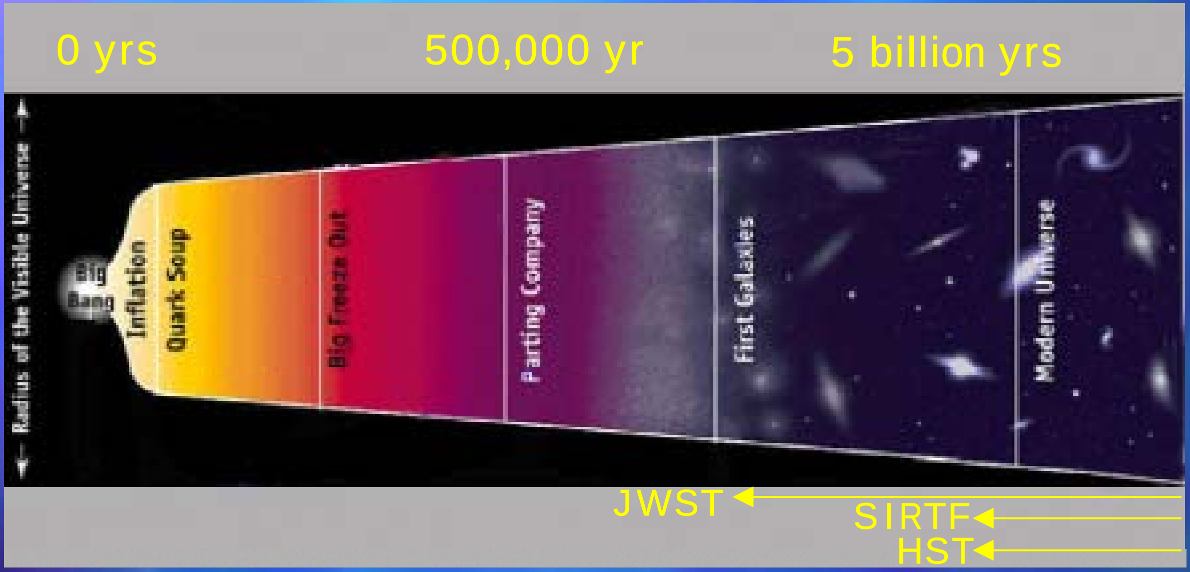
Slides available at http://ircamera.as.arizona.edu/~marcia/AAS_seminar

What's Deep ? What's Early?

Deep = survey to as faint a limit as practical over as large an area as possible → see many objects as far away as you can.



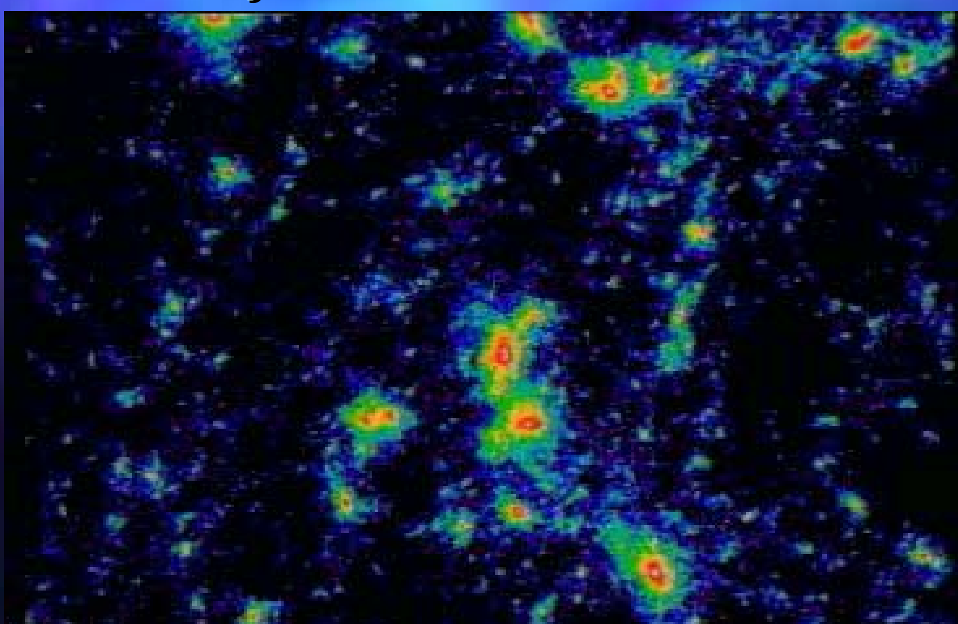
Far away means seeing young objects so the "early" Universe can be studied.

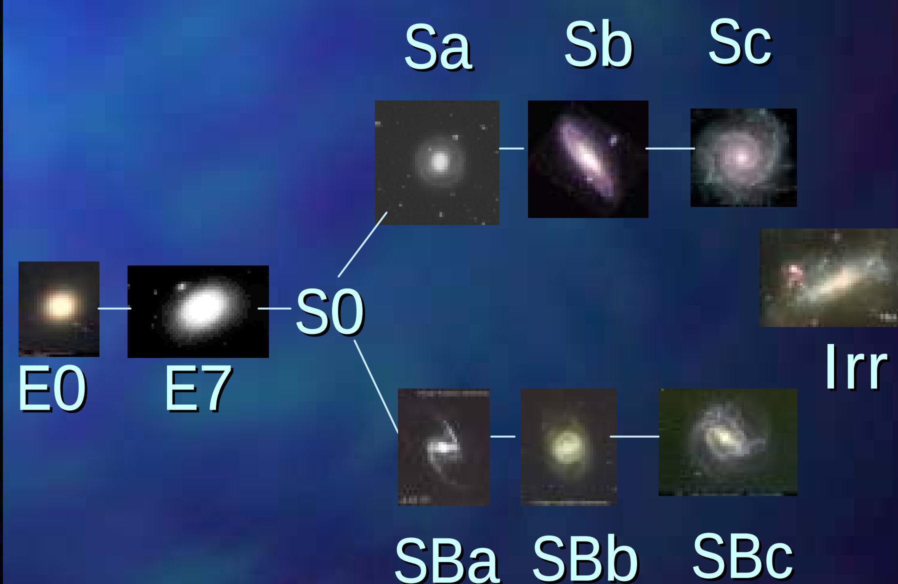
"Early" depends on the whether observing from ground or space and with what telescope or mission. Groundbased telescopes have contributed redshifts while spacebased telescopes find the sources, see their shapes and soon will observe over a very broad wavelength range.

What's the Goal?

To learn how galaxies

- form from the nearly uniform medium after the Big Bang
- assume the shapes we see today (eg. Hubble sequence)
- come to have the collections of stars, gas, metals we see today





From http://archive.ncsa.uiuc.edu/Cyberia/Cosmos/CosmosCompHome.html

What Does it Take to Answer These Questions?

- Detection of galaxies as faint and distant as possible -- need a sample to define what's happening

JWST Simulation by Im and Stockman.

- Distances -- otherwise nearby but faint objects will be confused with objects faint because of their distance

- Shapes -- do ellipticals grow from spirals, how important is merging?

HST image of the merging galaxies called the Antennae.

- Energy output over a broad range of wavelengths -- separate stars from black hole activity

Footnote on Infrared Astronomer Units

Wavelengths in infrared astronomy are commonly expressed in microns = micrometers = μm

5000Å = 500 nm = 0.5 μm   Visible light

~0.9 to 5μm   Near-infrared

5μm to ~30μm   Mid-infrared

30μm to ~350μm   Far-infrared

Brightnesses or fluxes are most likely to be given in Janskys (Jy) or mJy (milli Jy) μJy (micro Jy).

1 Jansky = 10^{-26} Watts/m^2/Hz

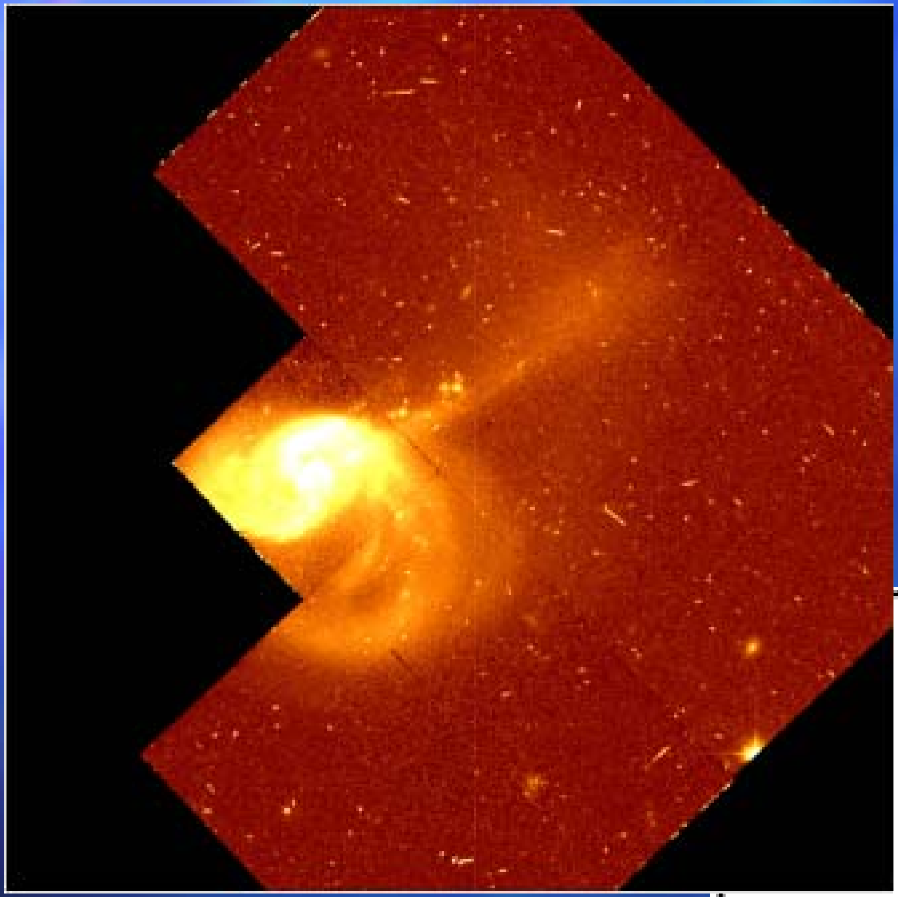
Jy can be converted to magnitudes which are rarely used in the mid- or far-infrared.

Mergers and Starbursts

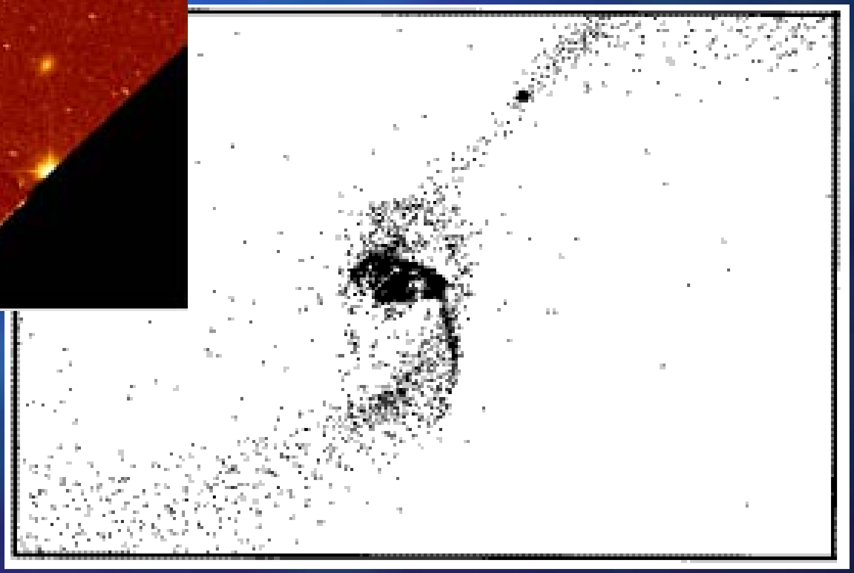
All of the very luminous galaxies in the nearby Universe are merging and are bright “starburst” galaxies. Will distant and hence younger galaxies show even more starburst activity?

Deep WFPC2 Image of NGC 1614 ←

Output of a merging disk galaxy simulation by Barnes and Hernquist, 1996, ApJ, 471, 115 ↓



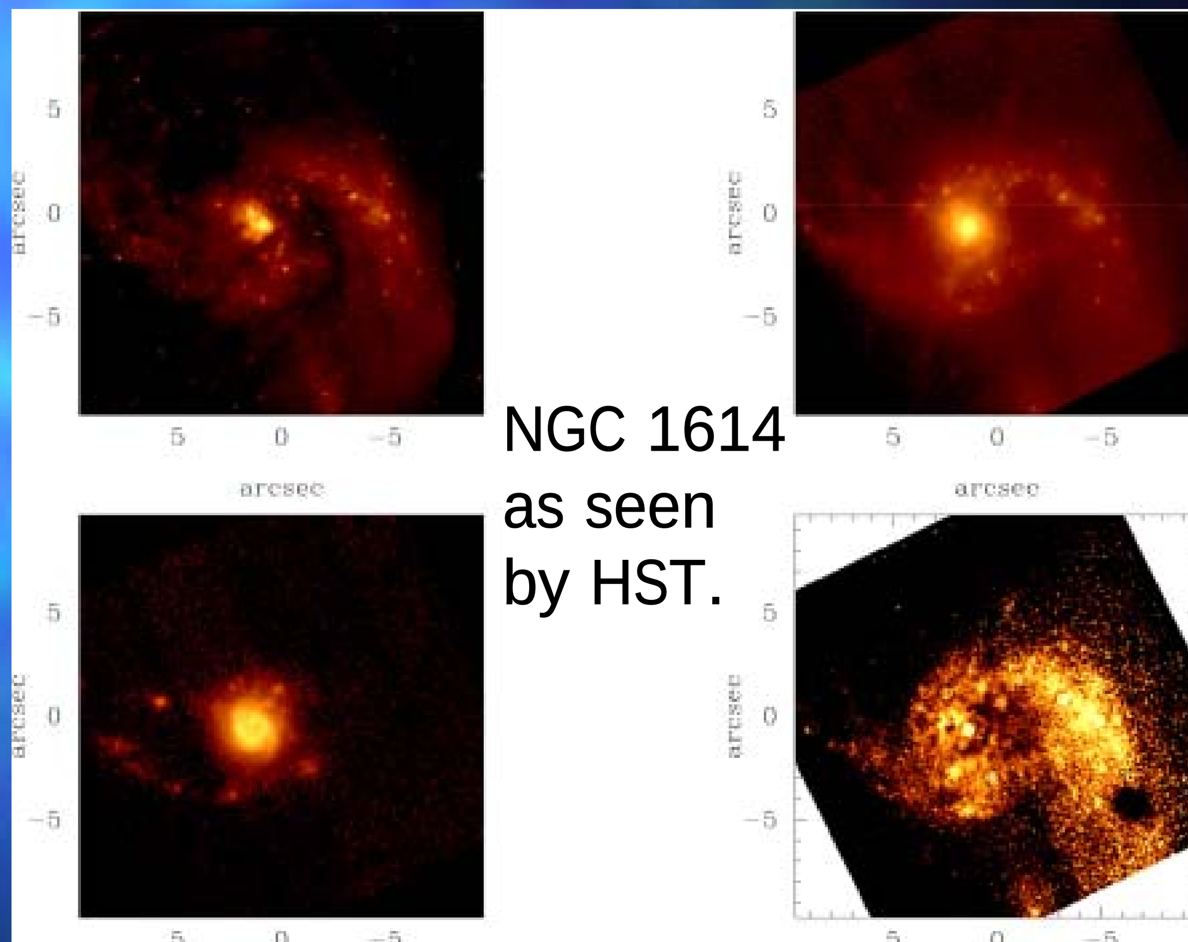
NGC 1614: Nearly Face-on with A_V ~5 = Starburst Laboratory



Mergers and Starbursts, Pt. 2

Many nearby mergers have been studied in detail and it is clear that collisions between galaxies trigger star formation by compressing gas. Is this a common or even dominant mode for star formation in the early Universe where mergers are likely to have been common?

.606μm 1.6μm



Pa 1.875μm H-K,dark = bigger A_V

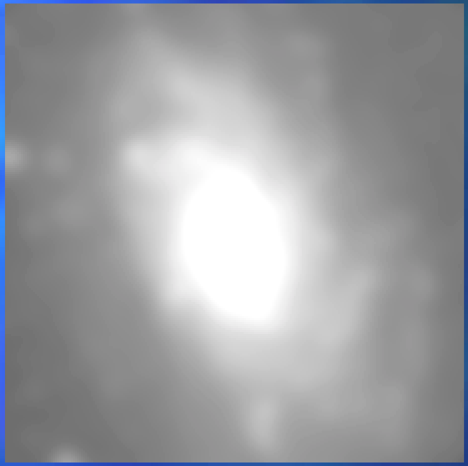
Images from Alonso-Herrero et al. 2001 ApJ, 546, 952

Galaxies at Many Wavelengths

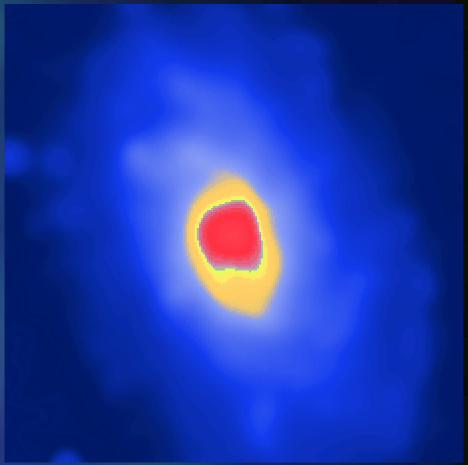
When comparing images at different wavelengths, check that the spatial resolution is comparable.

Original Visible Light image

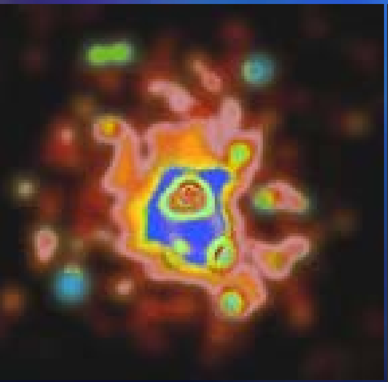
Smoothed to Far IR resolution



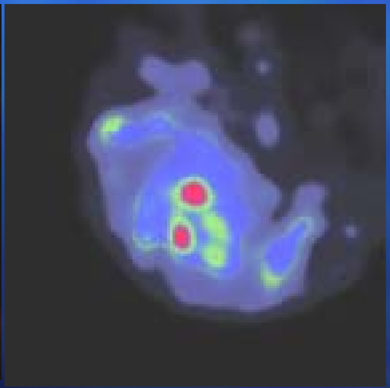
Intensities translated to colors



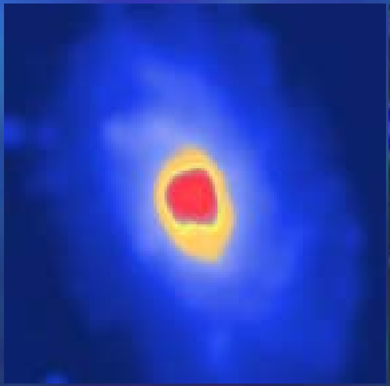
X-ray Chandra



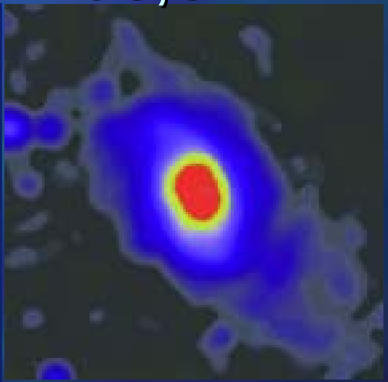
UV GALXEX,HST



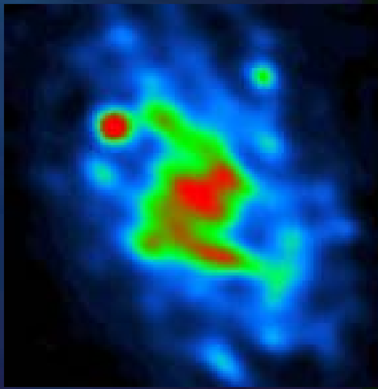
Visible HST



Near IR 2MASS, NIC-MOS,SIRTF

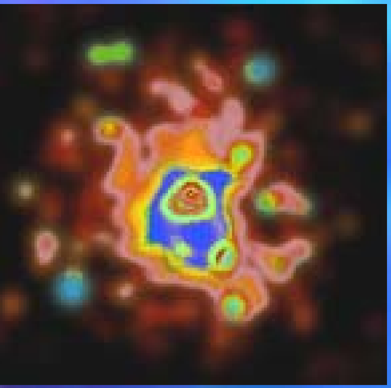
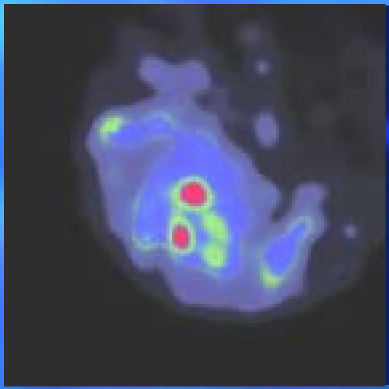
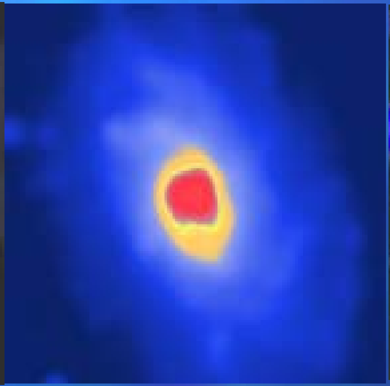
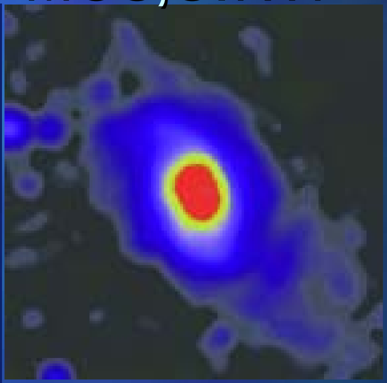
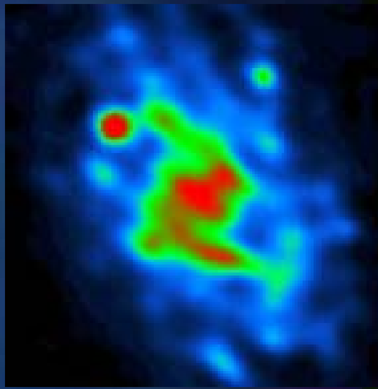


Far IR SIRTF



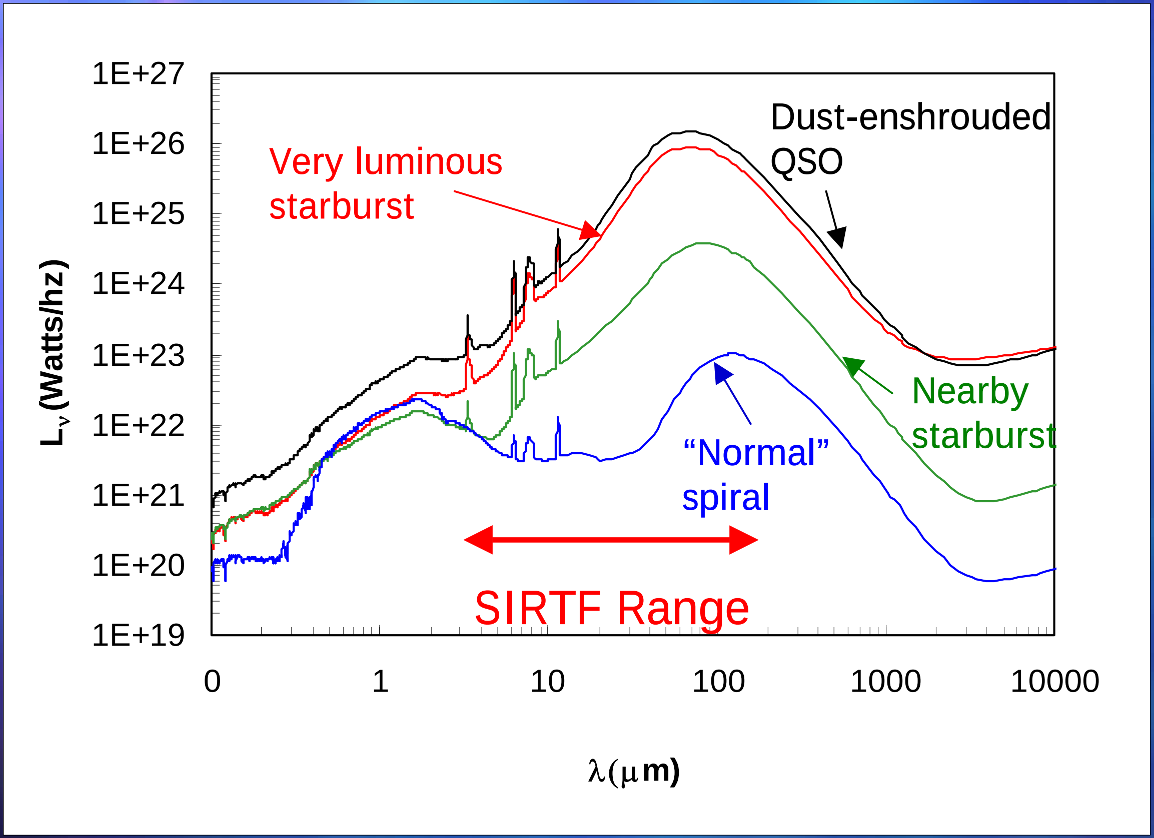
Images originally from http://sirtf.caltech.edu/Education/Messier/m33.html

Galaxies at Many Wavelengths, Pt. 2

X-ray Chandra	UV GALEX,HST	Visible HST	Near IR 2MASS, NIC-MOS,SIRTF	Far IR SIRTF
				
2 nm	200nm	500nm	1600nm	100,000nm
$1.5x10^6$K	14,500K	5800K	1800K	29K
Black Hole accretion disks	Hot stars = young stars	Run of the mill stars (all ages)	Very cool stars (usually old)	Cool dust - heated by hot stars

Recall Wien's Law: Wavelength_{Max} (nm) = $2.9x10^6$ / T(°K)

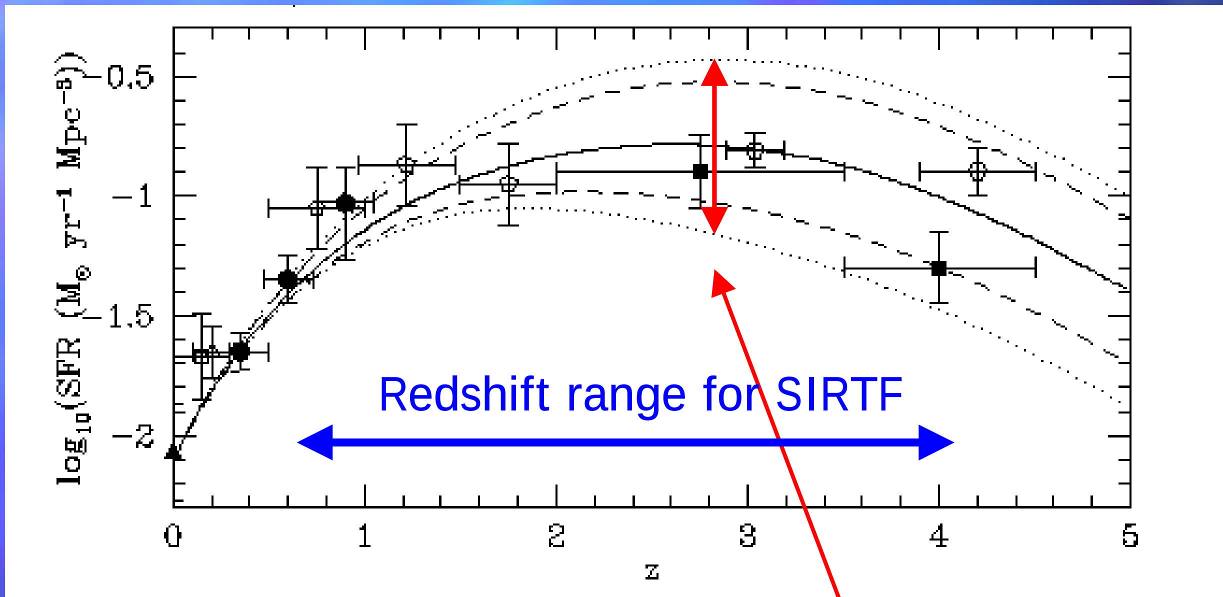
What SIRTF Will Do



- Detect galaxies at wavelengths where star formation dominates -- two cameras cover 3.5 to 160 μm with a field of view larger than any HST camera's
- Detect galaxies to great distances (eg. SIRTF is very sensitive)

What SIRTF won't do: Measure shapes of distant galaxies with most distant galaxies being indistinguishable in shape from a star to SIRTF.

Star Formation History of the Universe



SIRTF should settle the question of how much star formation was obscured by dust and not seen in the UV or even in the visible.

Rest-frame UV

Rest-frame Visible

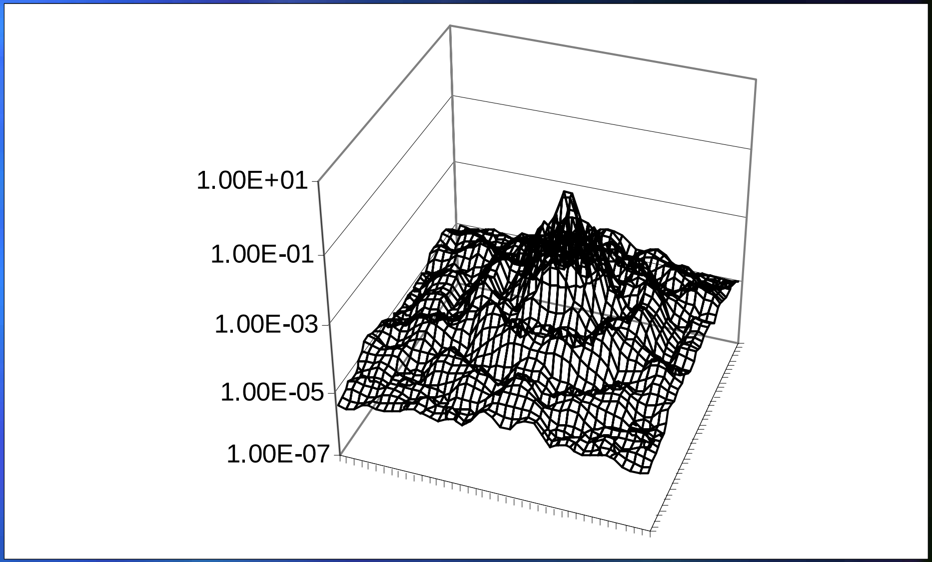
Images from HDF.

Current estimates of high redshift star formation rates all rely on UV light which can be easily scattered by dust -- nearly 10x range in star formation rates permitted by observations so far.

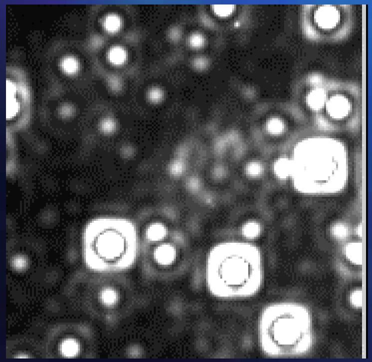
Diffraction-Limited Images

Every telescope in space can produce images limited only by the effects of diffraction - effect is stronger for longer wavelengths and smaller telescopes, but diffraction will only be noticed if the camera on the telescope samples the telescope's output finely enough.

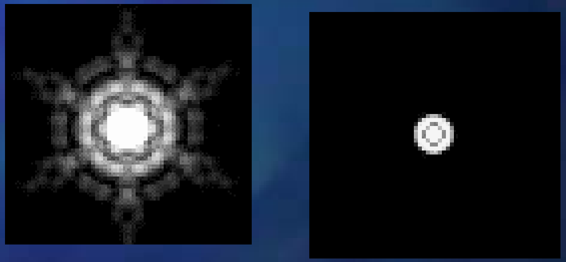
Most of SIRTF's images will show diffraction rings because of the telescope's small size (85cm) and long observing wavelengths (8-160μm). The size of patch on the sky (pixel size) that SIRTF will measure increases in size from 1.2" at 3.5μm to 15" at 160μm.



SIRTF image pattern shown in 3D.

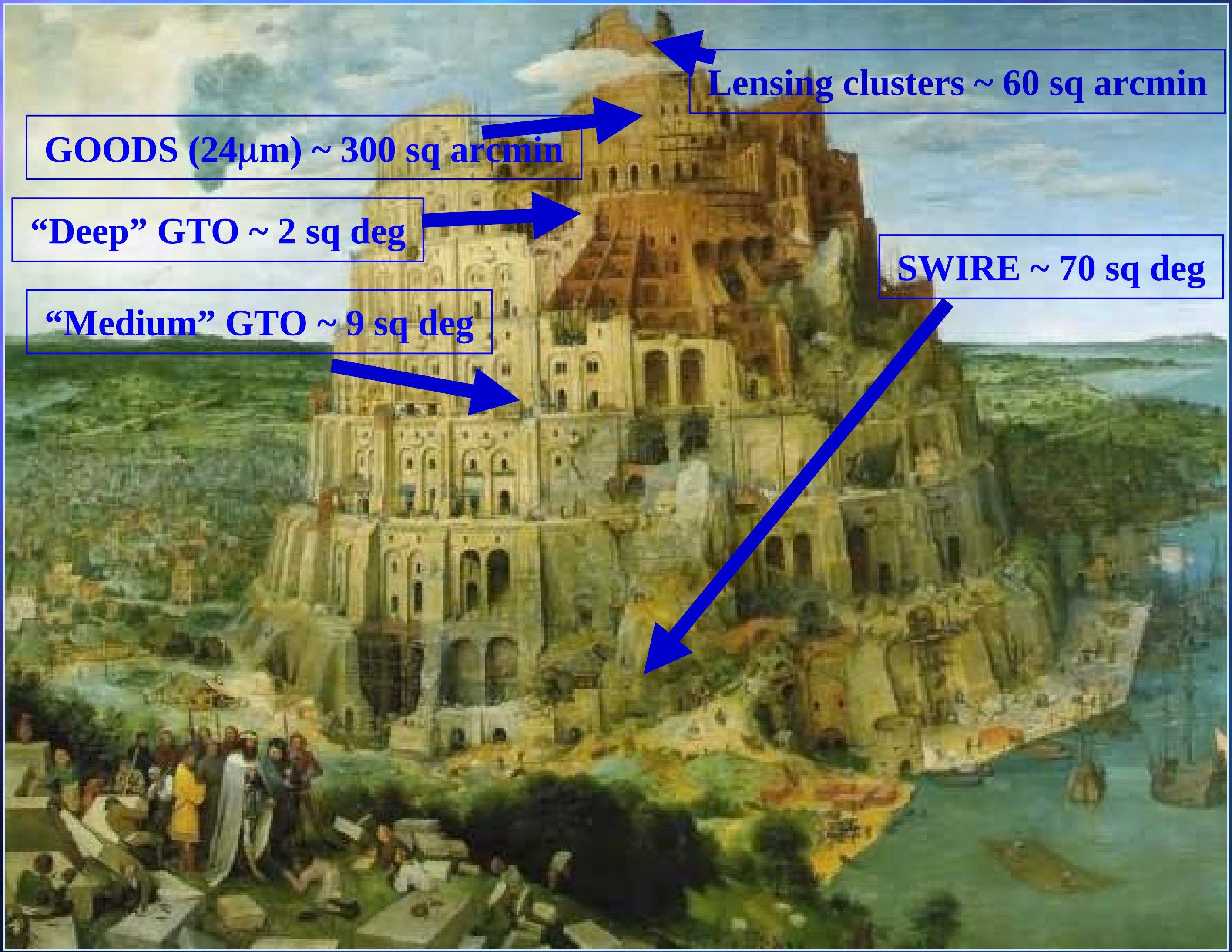


Actual image from NICMOS on HST showing diffraction rings (Airy rings) around stars at the Galactic Center.



SIRTF image pattern (PSF or point spread function) shown using two different brightness scalings

Survey Strategies



SIRTF deep surveys have several levels to ensure finding bright but rare objects and finding the most distant and faintest as well.

The Tower of Babel by Pieter Breughel the Elder

Obscured Black Holes

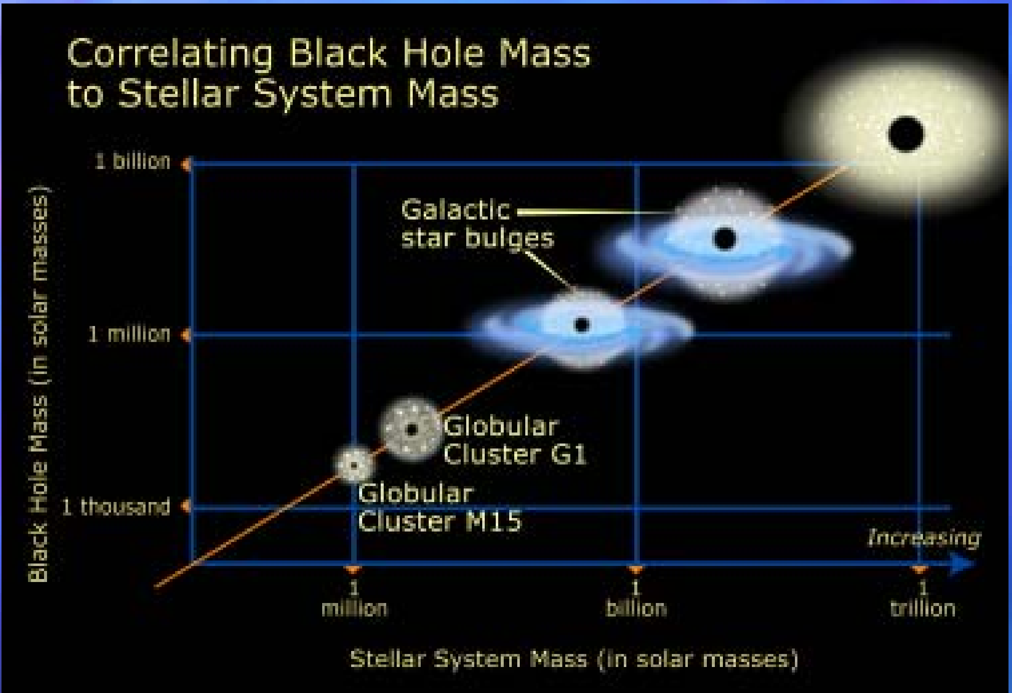


Chart from http://hubblesite.org/newscenter/archive/2002/18/image/f

How important are black holes to galaxy evolution?

-- do galaxies grow around black hole seeds?

-- or do the black holes appear later?

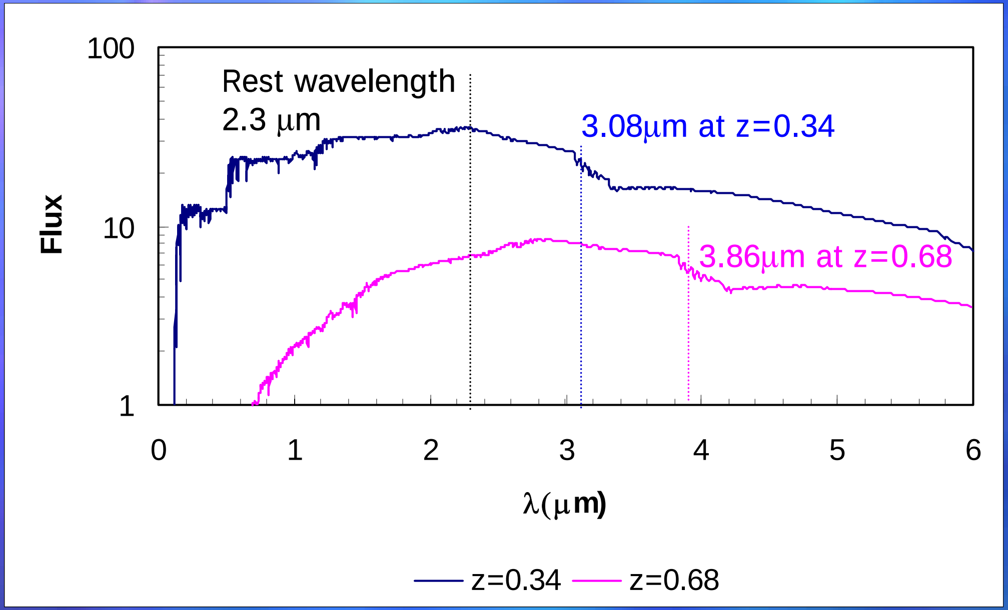
Recent discoveries of the correlation between black hole mass and galaxy bulge mass adds impetus to answering these questions.

What SIRTF will do:

Accretion disks around black holes can heat dust just like hot stars do so SIRTF will detect the energy generated by obscured black holes.

SIRTF surveys cover areas surveyed by Chandra and XMM so comparison of results will show what SIRTF sources are powered by black holes and will show what Chandra sources are surrounded by dust and not likely to have been detected at visible wavelengths.

Distances Can Be Difficult!

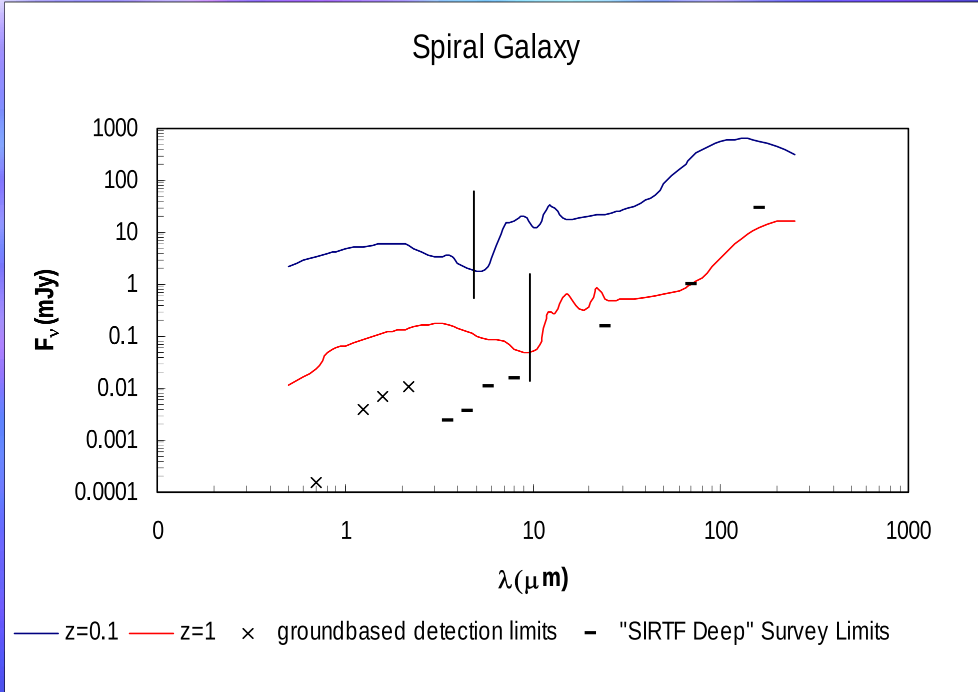


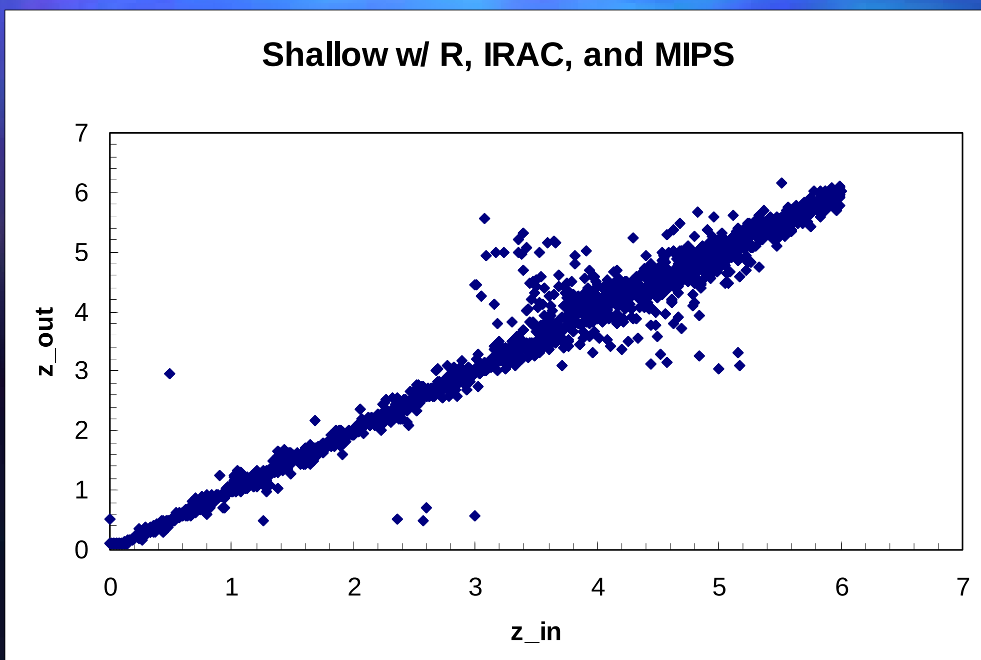
Getting a redshift for every object would be ideal but is not possible (and because it is always possible to detect fainter objects in an image than can be detected with a spectrometer, this will always be true!).

Two strategies:

1) Analyze numbers of galaxies at each brightness level

2) Look at shape of energy output and estimate a redshift ("photometric" redshifts)





Photometric Redshifts

If an galaxy can be observed through enough filters (eg. wavelengths), then a computer can analyze the brightness pattern across wavelengths and estimate the galaxy's redshift and type. A library of galaxy spectra is needed beforehand.

Simulation of SIRTF photometric redshifts.

Power of Number Counts

Look at the galaxies in a thin shell at distance D. If the galaxies have similar properties (eg. luminosity) and if they have the same density everywhere:

No.of galaxies in a shell = $2\pi D^3 \rho$ where D=distance, ρ = density of galaxies

$$\text{Apparent brightness} = \text{Flux} = \frac{\text{Luminosity}}{4\pi D^2} \quad D = \sqrt{\frac{\text{Luminosity}}{4\pi \times \text{Flux}}} = \left(\frac{\text{Lum}}{4\pi \text{Flux}}\right)^{\frac{1}{2}}$$

$$\text{No. of galaxies in a shell} = N = 2\pi\rho\left(\frac{\text{Lum}}{4\pi \text{Flux}}\right)^{\frac{3}{2}}$$

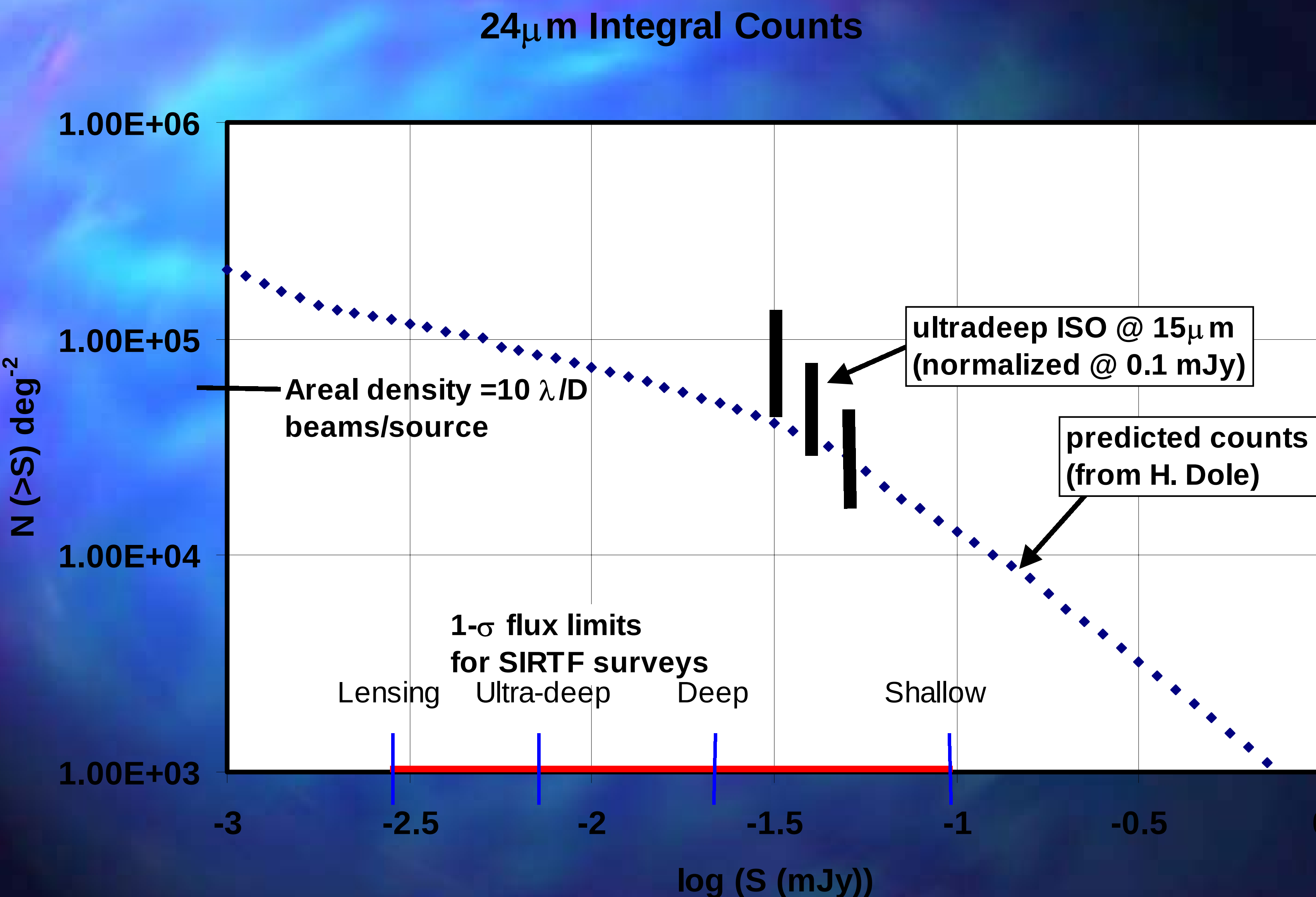
log N = -3/2 log Flux + Constant

The above is only true if 1) Universe has Mr. Euclid's shape;
2) Galaxies have the same luminosities at all distances;
3) Galaxies have the same density (No./cubic Megaparsec) everywhere

If any of these are wrong, a plot of Log N versus Log Flux won't have slope = -1.5 ==> You can learn a lot by counting!

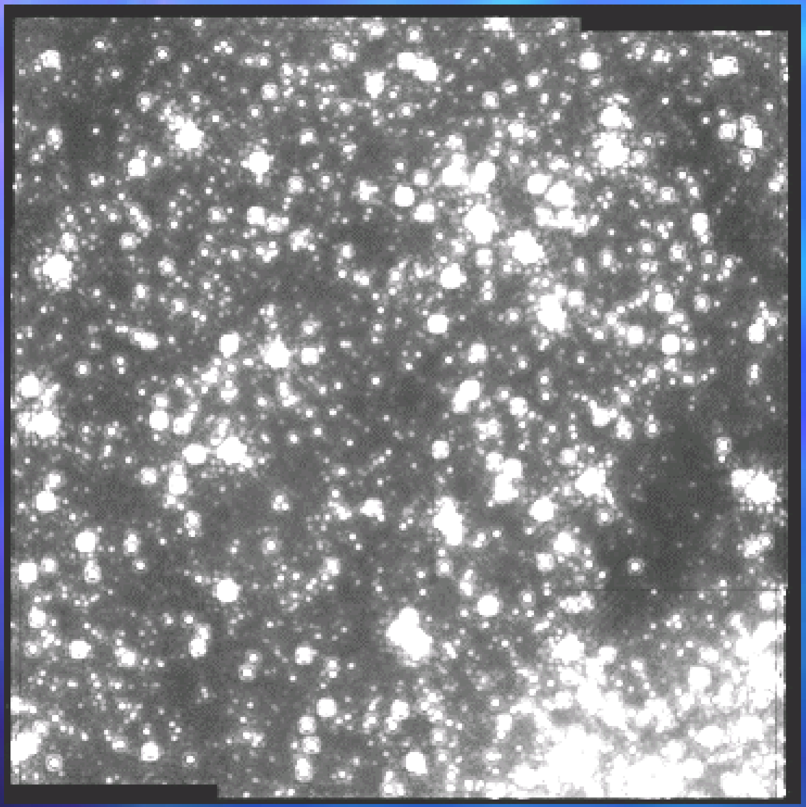
Power of Number Counts, Pt. 2

Number per unit area brighter than S



Brightness in logarithmic units

Fluctuations and Power Spectra



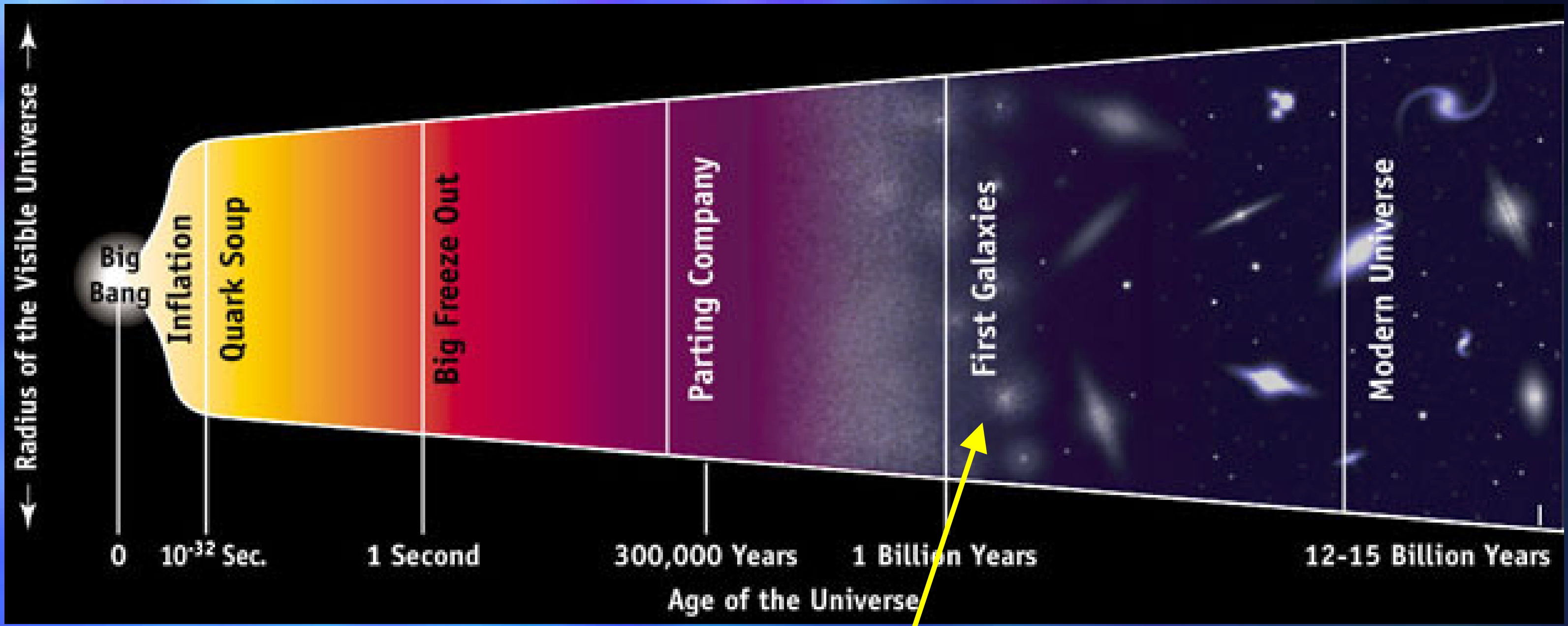
Example of a “confused” field from NICMOS observations near the Galactic Center.

Because of SIRTF’s high sensitivity and relatively large diffraction limited image size at the longer wavelengths, SIRTF images will be **confusion** noise limited. This means that there will be no truly empty or dark places in a SIRTF image with light from distant galaxies everywhere.

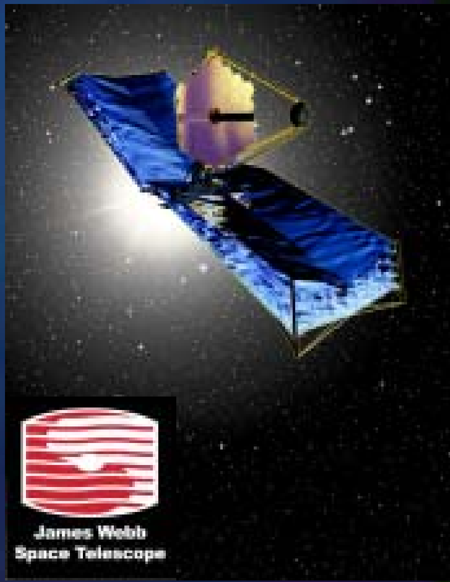
By studying the fluctuations (variations in brightness) from one patch of sky to the next, we may be able to learn more about the most distant galaxies.

Power spectrum analysis meaning studying mathematically how the brightness varies with size of the patch on the sky will be used to quantify the fluctuations.

What's Left for the Future?



Neither SIRTF or HST can see to high enough redshift to detect the first galaxies -- need a larger telescope sensitive to near- through far-infrared wavelengths. JWST (James Webb Space Telescope) is being designed to fill much of this role.



Timeline from http://cmb.physics.wisc.edu/tutorial/bigbang.html