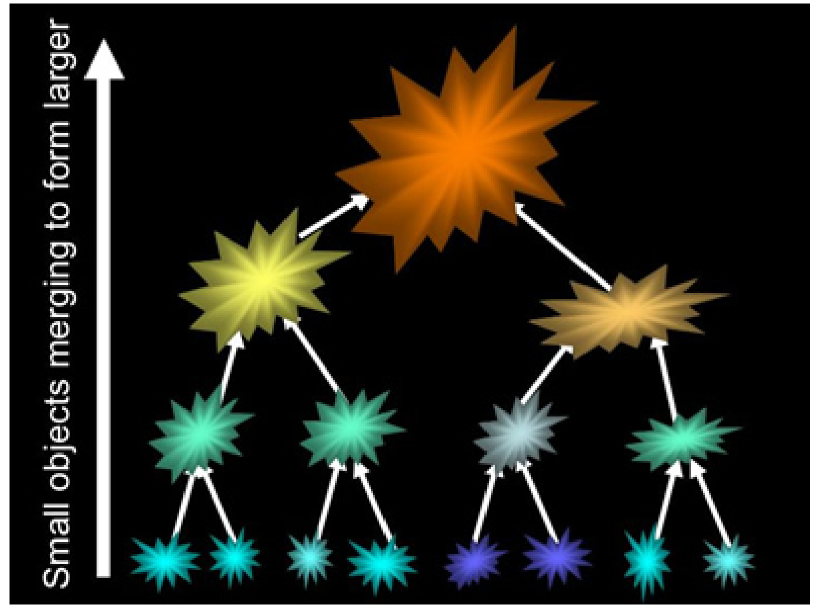
End of Lecture 1

What Did we cover?

- Big picture of galaxy research
  - brief history
- What are galaxies
  - 2 generic classes
- How Many Galaxies are There
- How Old are Galaxies
- Galaxies do not live alone- large scale structure
- Baryons, dark matter and how they are sampled by galaxies -complex relation between how the dark matter and baryons (gas and stars) are related and distributed on a wide variety of scales

How Things Form

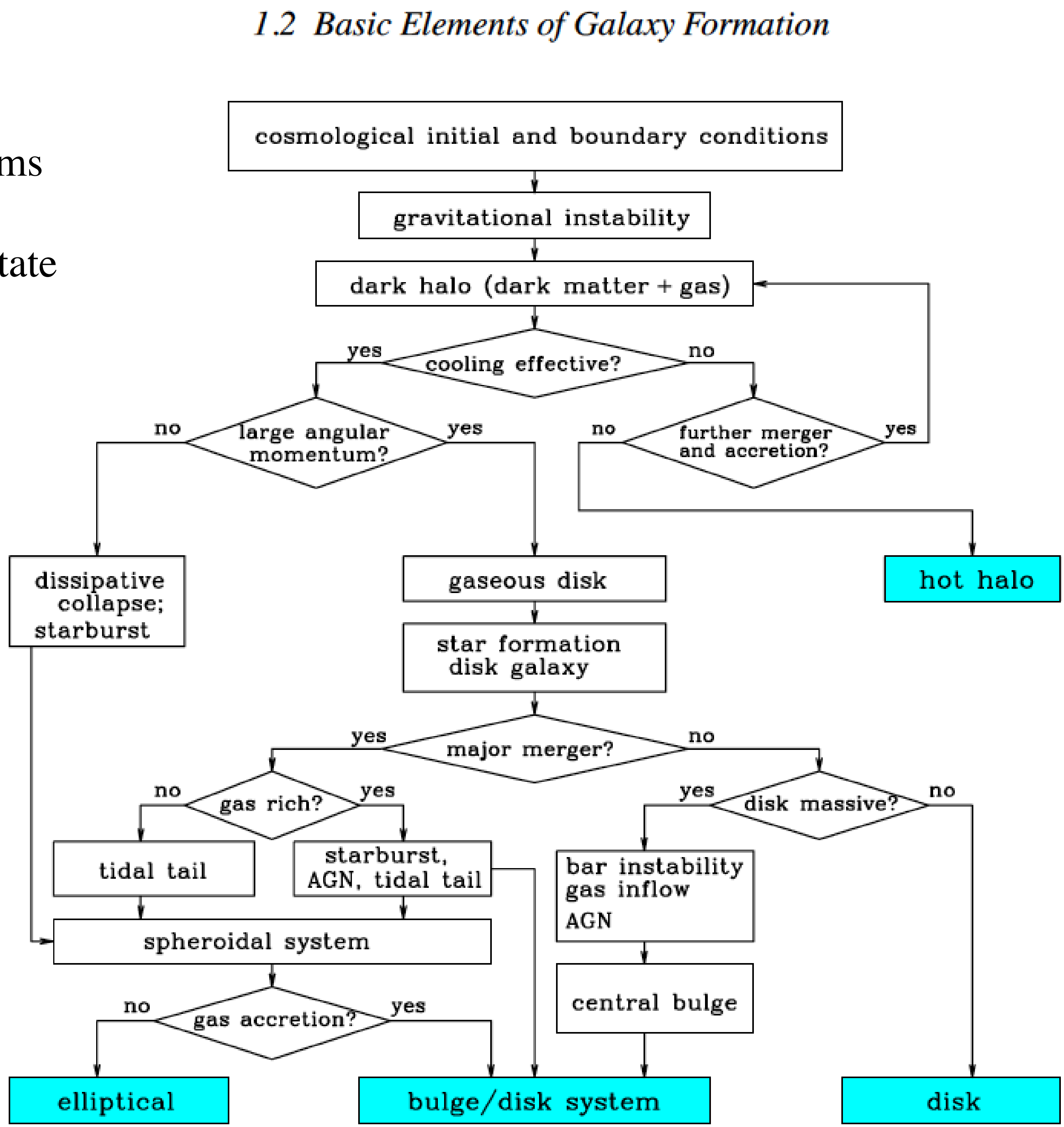
- Gravity acts on overdensities in the early universe making them collapse.
- As time goes on these collapsed regions grow and merge with others to make bigger things



•Hierarchical clustering (or hierarchical merging) is the process by which larger structures are formed through the continuous merging of smaller structures.

•The structures we see in the Universe today (galaxies, clusters, filaments, sheets and voids) are predicted to have formed by the combination of collapse and mergers according to Cold Dark Matter cosmology (the current concordance model).

MWB fig 1.1
Notice the vast range
of physical mechanisms
and interconnectivity
blue boxes are final state
of system



Galaxy formation : Many relevant and interacting processes

Cooling (metallicity, structure, ...)

Star formation (threshold, efficiency, IMF, ...)

AGNs (BH growth, feedback, ...)

Dust (formation, distribution, heating & cooling, ...)

Galaxy formation & evolution

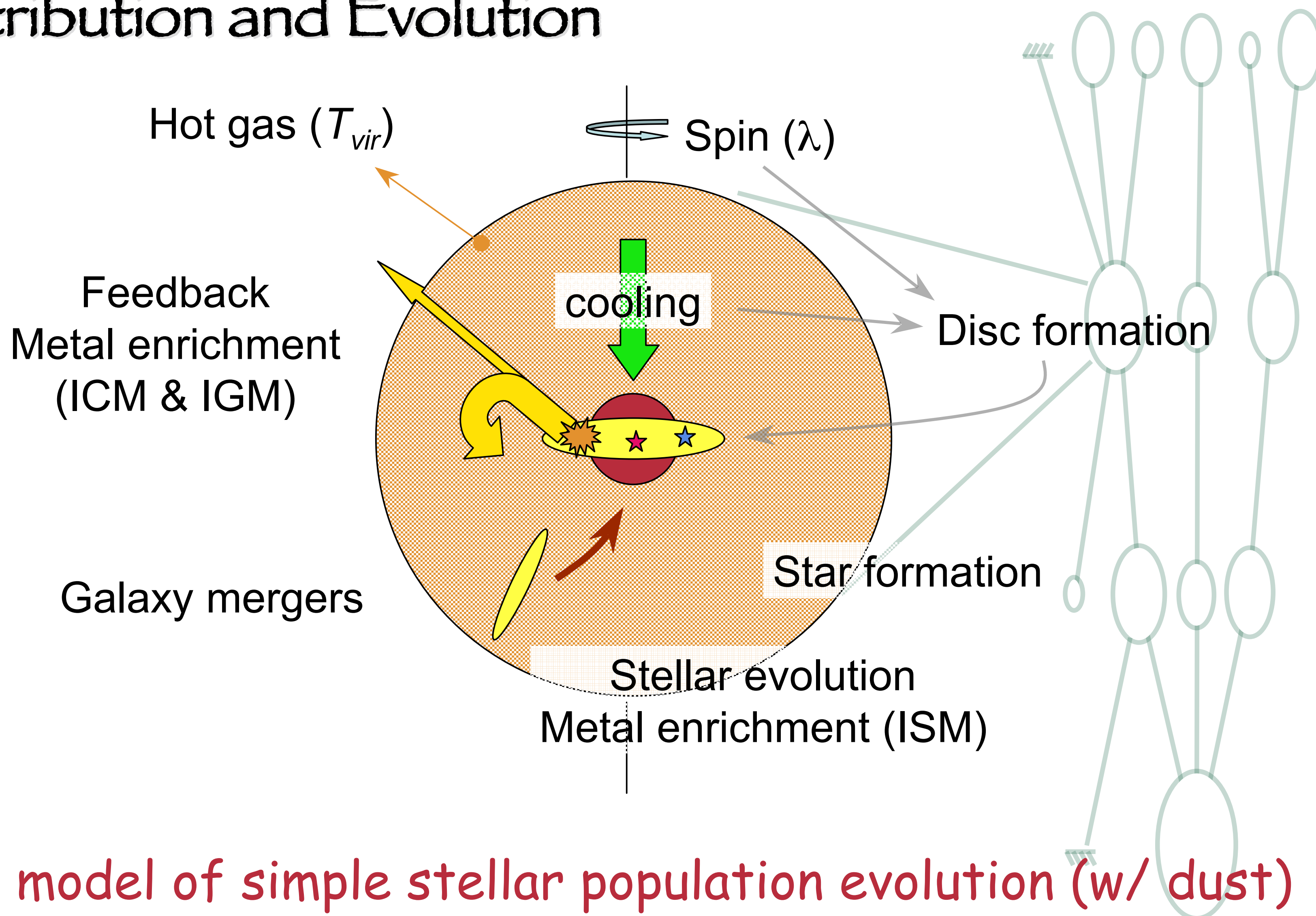
Galaxy interactions (morphological transformations, starbursts, intracluster stars, ...

Winds (IGM heating, enrichment, SN feedback, etc...)

Stellar evolution (spectro-photometric evolution, yields, SN I/II rates,...)

taken from **J. Blaizot** presentation

What Physics Goes on Top of the Dark Matter Distribution and Evolution

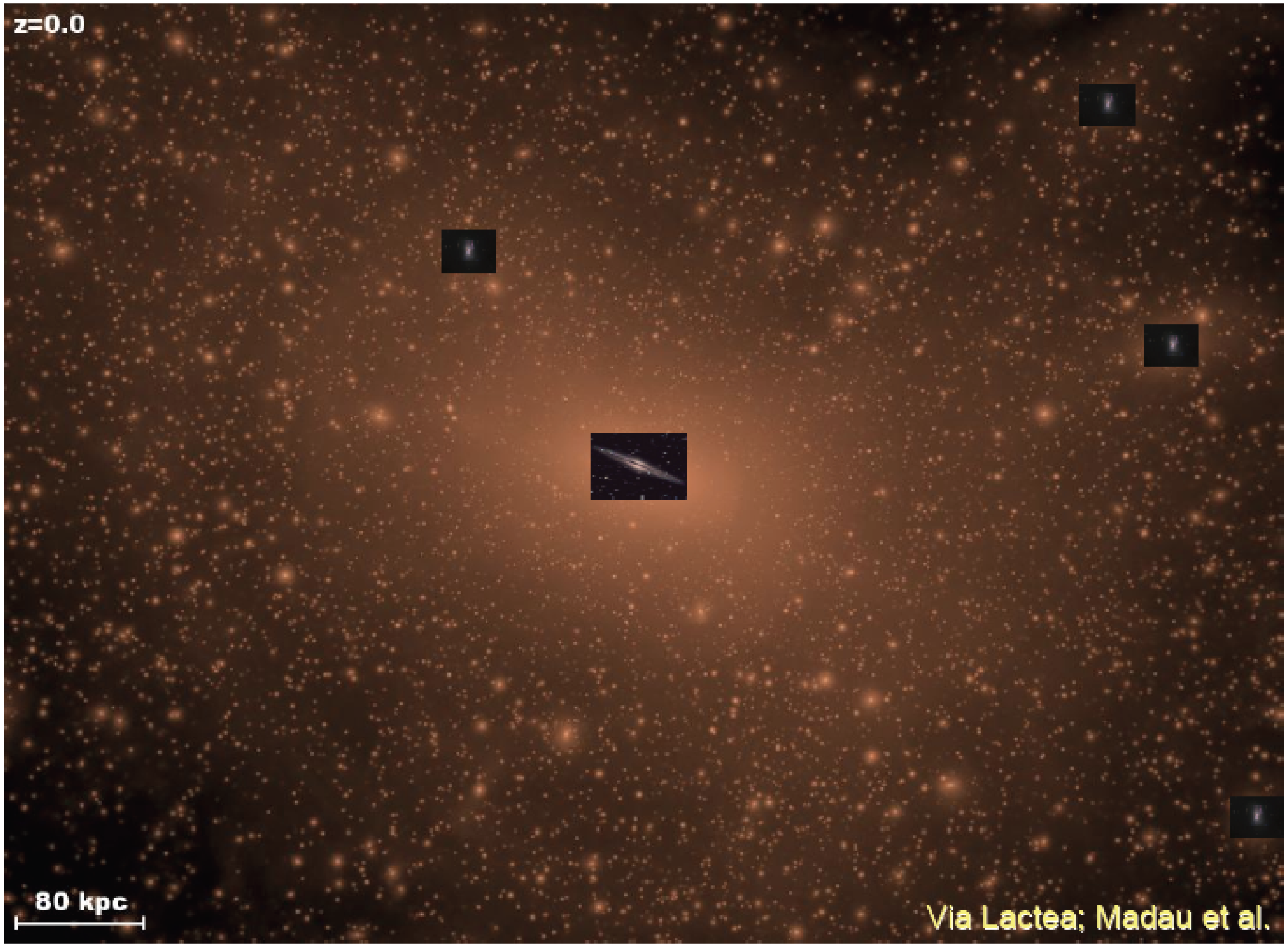


+ model of simple stellar population evolution (w/ dust)

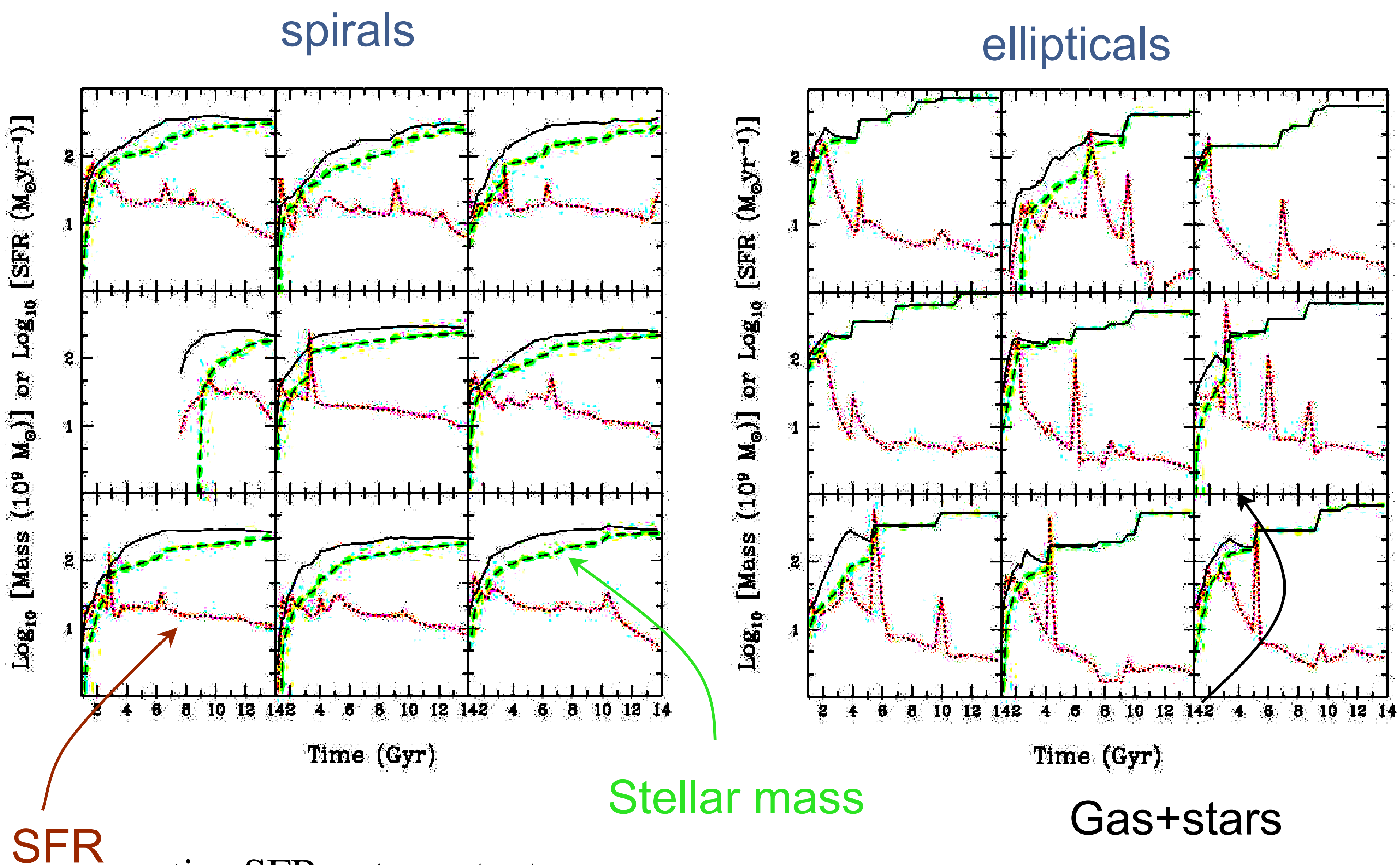
taken from J. Blaizot presentation

Dark Matter Distribution and Galaxies

- A numerical simulation of the formation of structure (Madau et al 2008) shows the scale of dark matter and the baryons can be rather different- notice that many of the dark matter halos are NOT populated by stars.

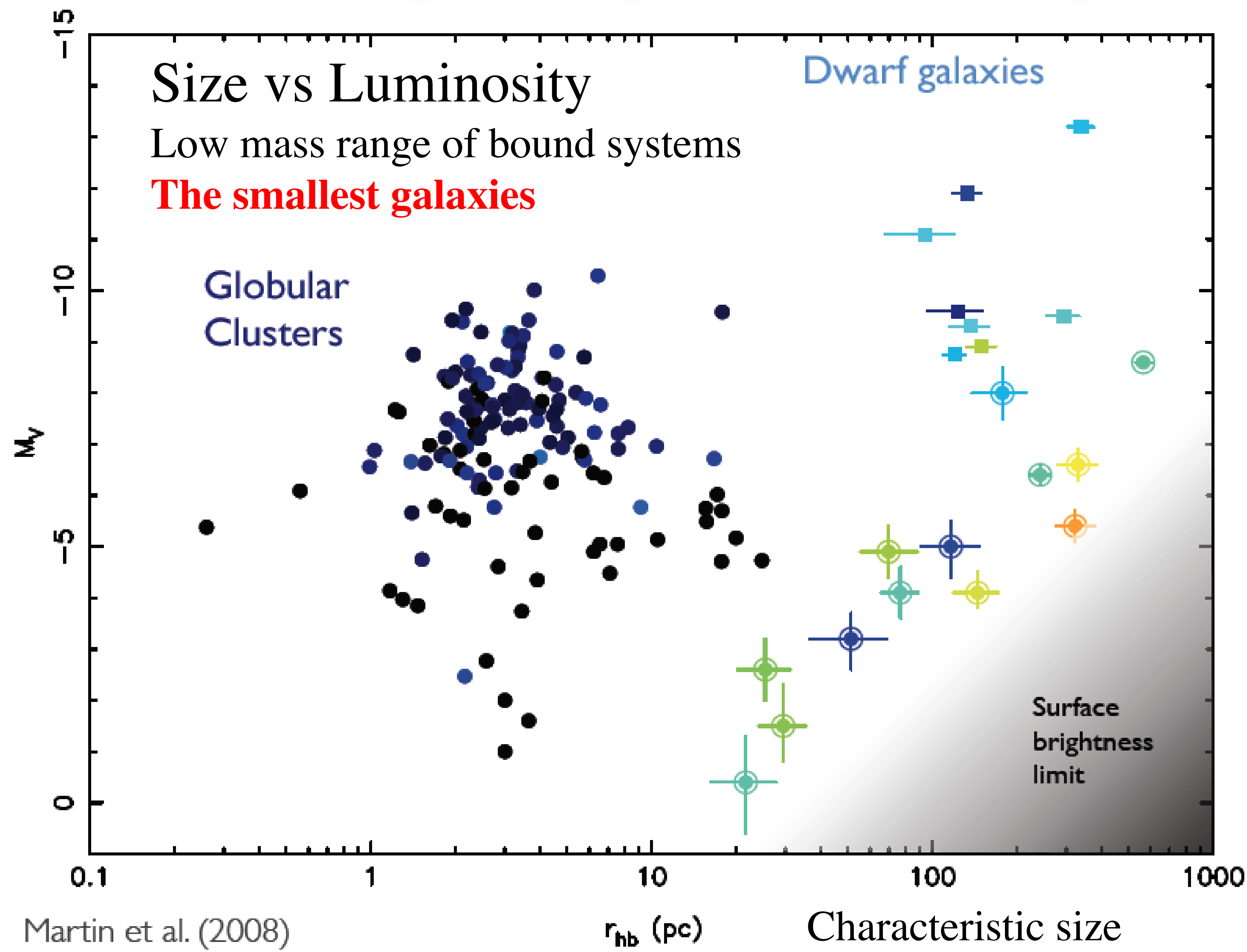


A set of results from numerical simulations



notice SFR not constant

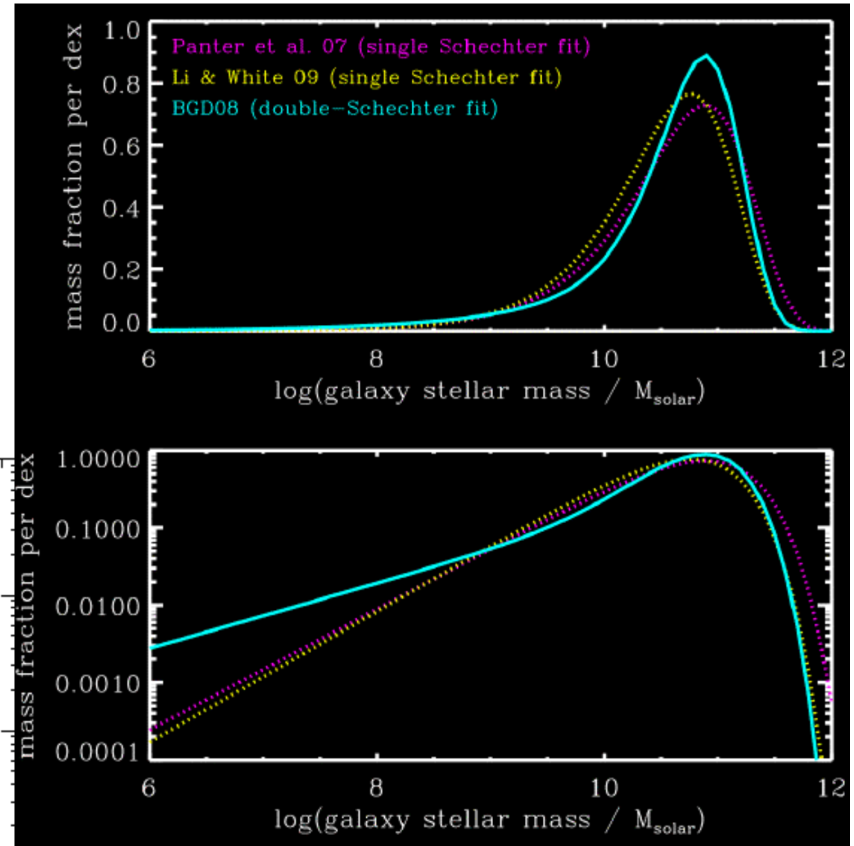
mass growth has 'jumps' - mergers J. Blaizot-

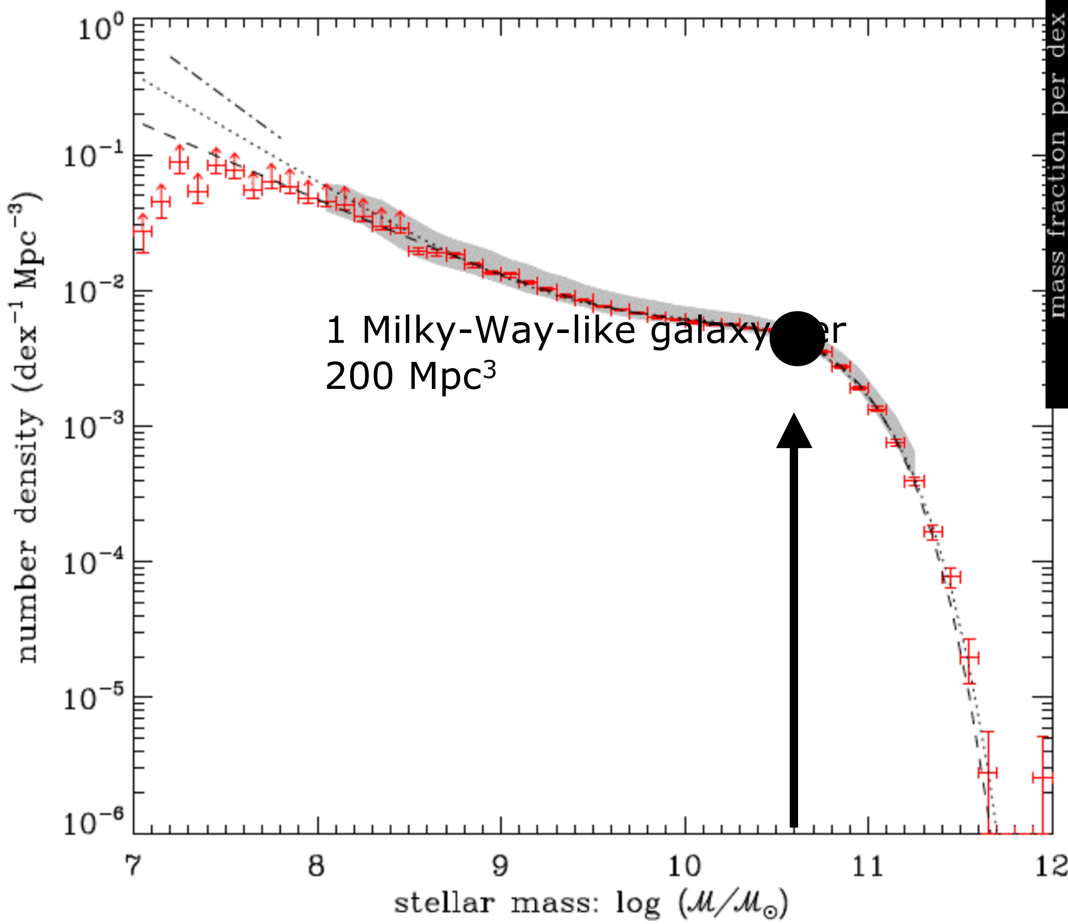


Size vs Luminosity
Low mass range of bound systems
The smallest galaxies
Dwarf galaxies
Globular Clusters
Surface brightness limit
−15
−10
−5
0
M_V
0.1
1
10
100
1000
r_hb (pc)
Characteristic size
Martin et al. (2008)

How Many Galaxies are There

- The mass function of galaxies (#/volume)





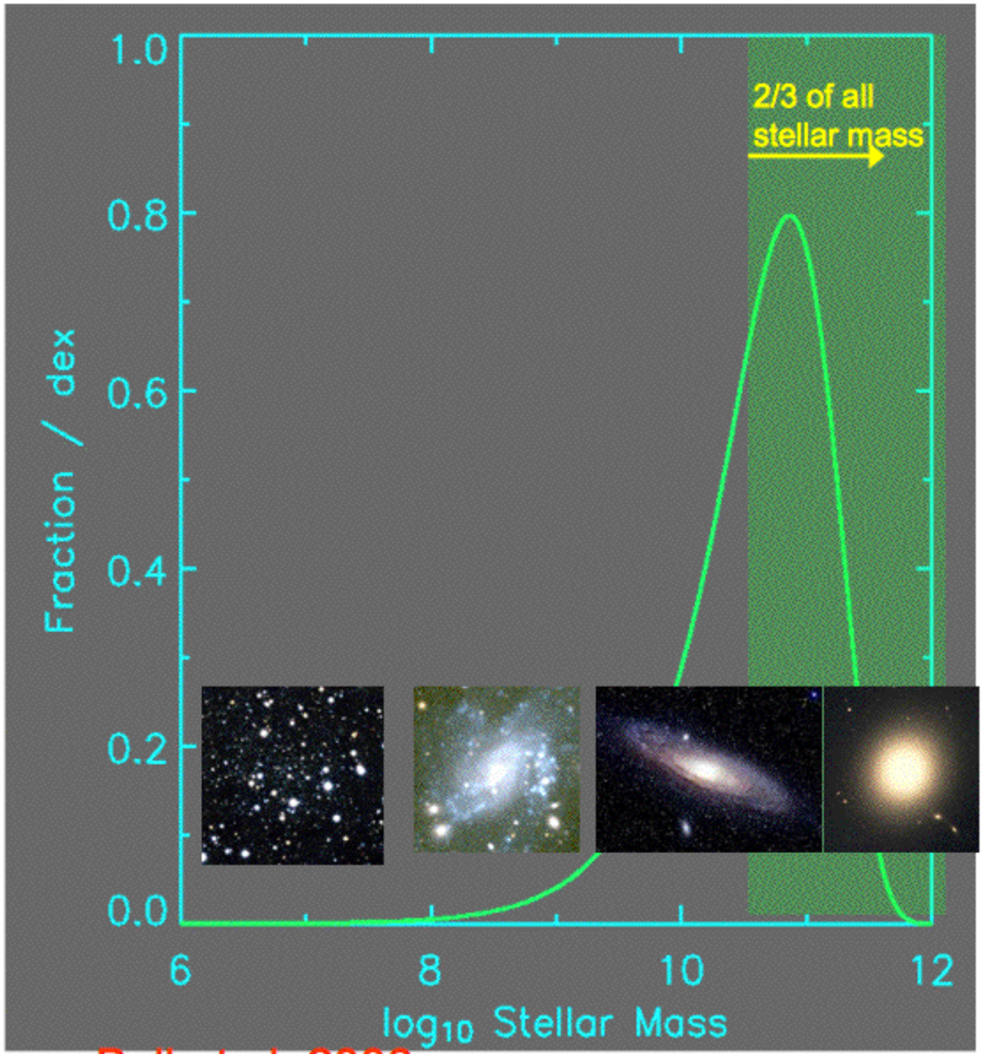
Rix 2009)

where is the mass- narrow distribution around log $M \sim 10.5 M_{\odot}$.

In mass MW is typical

Galaxies Have a Wide Range in Mass

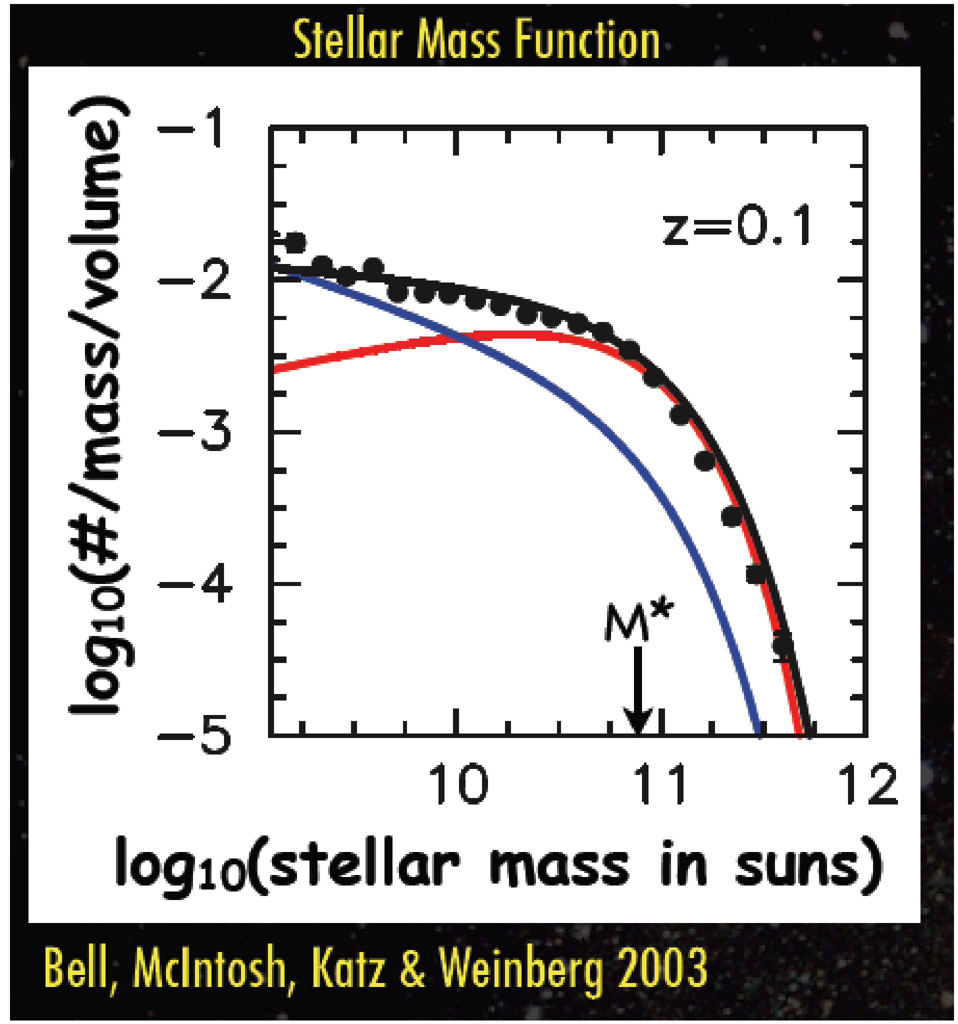
- There is a range of $\sim 10^8$ in galaxy masses- but most stars reside in galaxies in a narrow mass range $\sim 6 +/- 3 \times 10^{10} M_\odot$ (in stars)
- The baryons are distributed in gas, stars and dust; wide range in gas/stars, relatively narrow range in dust/gas.



Bell et al. 2003

Mass Function of Galaxies

- The sum of the mass function for spheroids (red) and disks (blue) at z=0 add smoothly together
  - spirals are systematically less massive than ellipticals but the functions strongly overlap

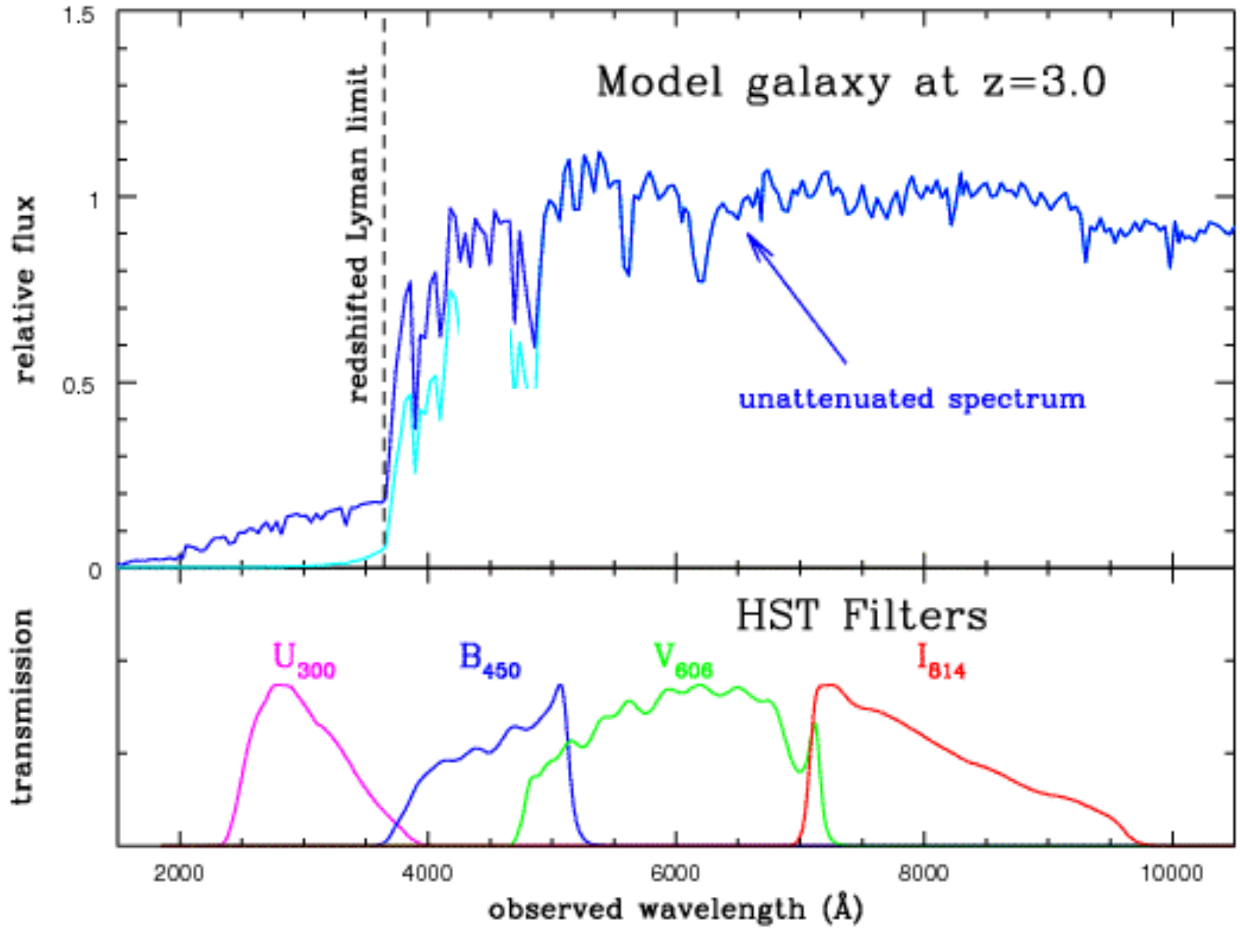


Galaxies Have Very Different Appearances in Different Wave Bands

- The physical processes which dominate in different wavebands are often very different
  - optical - starlight
  - UV- starlight from massive young stars
  - near IR old stars
  - far IR - dust
  - radio - synchrotron emission from relativistic particles
  - x-ray - x-ray binaries and hot gas

Use of Filters to Determine Redshift of Distant Galaxy

- HST filter set is different and depends on which camera is used.
- observe galaxies in broad-band filters, and then interpret the resulting spectral energy distribution to learn about the galaxies' masses, star formation rates, ages, and metallicities.
- Need a detailed understanding of the stellar populations within the galaxy, and on accurately characterizing the luminosities and colors of the billions of stars which contribute to a galaxy's light (J. Dalcanton)



Panchromatic MilkyWay

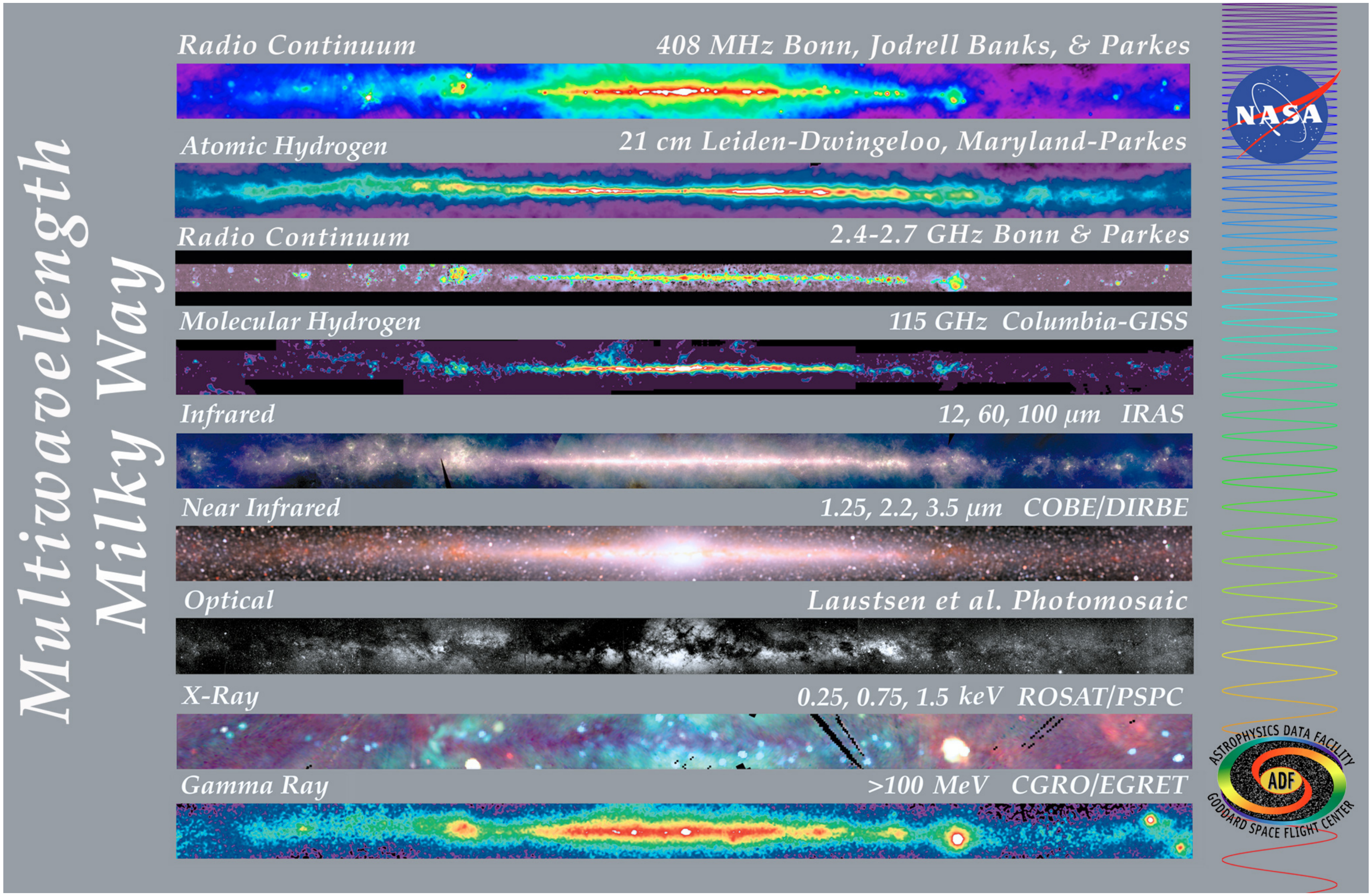
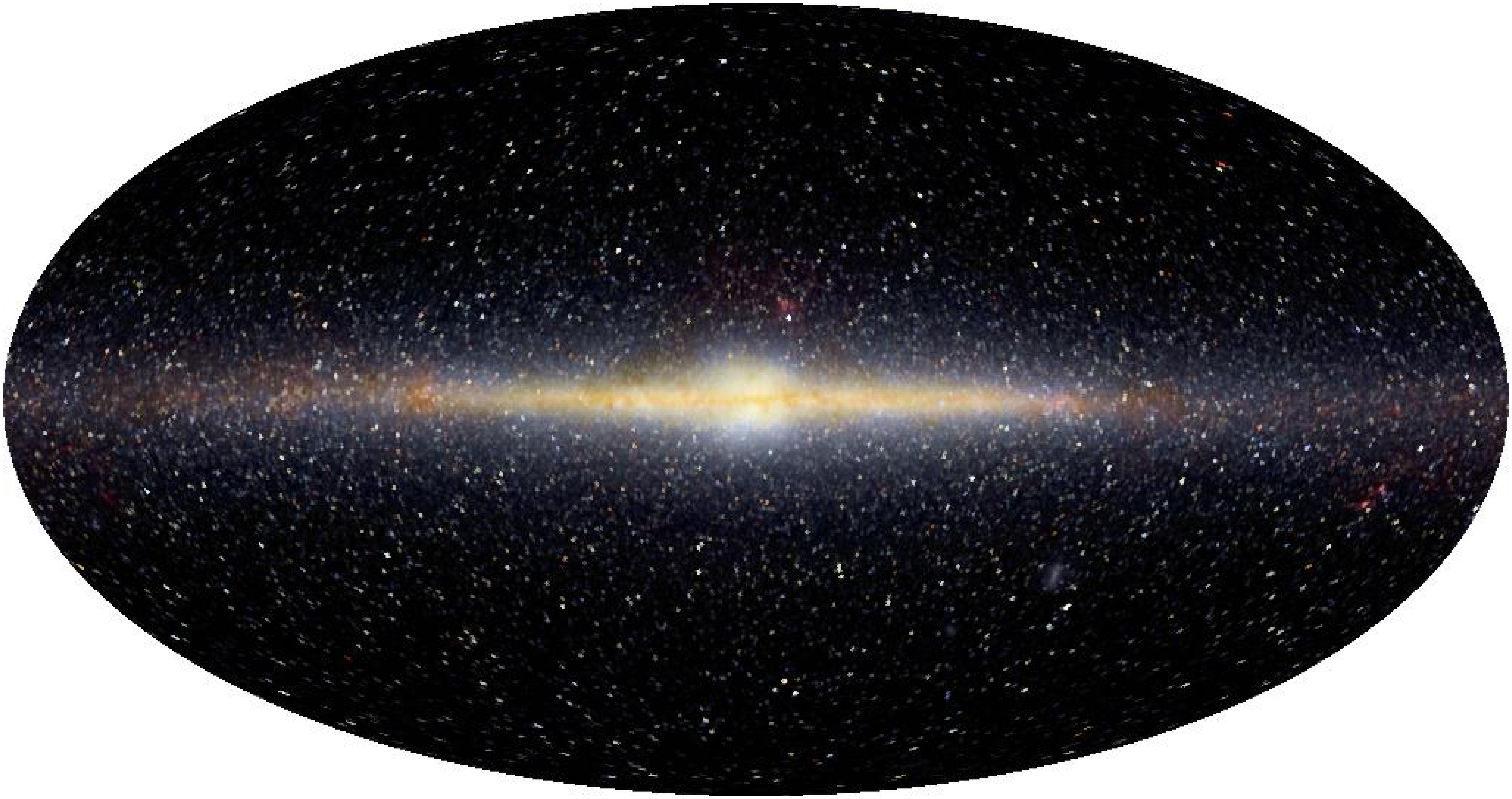


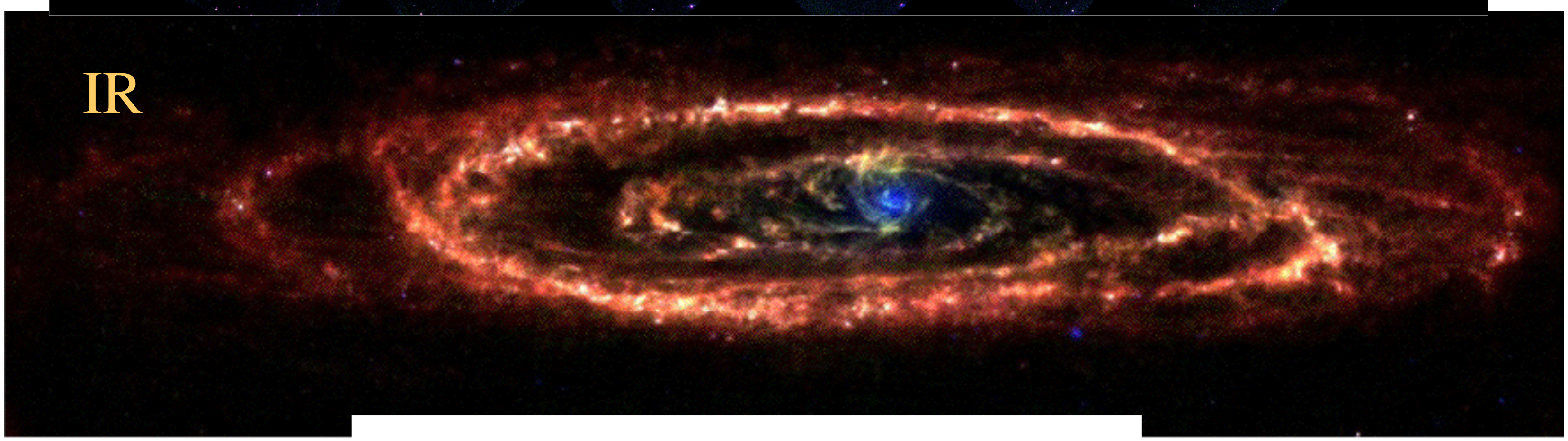
Image of MW galactic plane from radio through γ-rays

Image of MW in IR From COBE



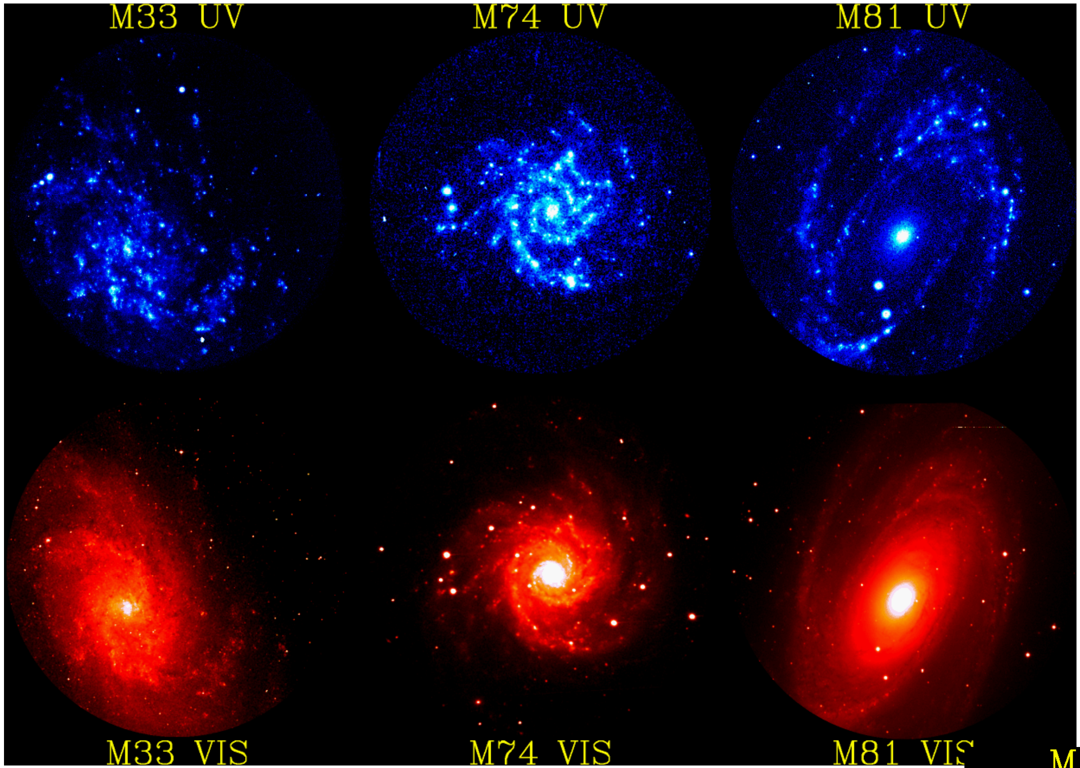
In the IR the effects of dust are minimized and one can see the true distribution of emitted radiation. In this wavelength band the emission is due mostly to old low mass stars

Different Appearances at Different Wavelengths



M31 -- 24 (MIPS),160 (PACS),350 (SPIRE) um

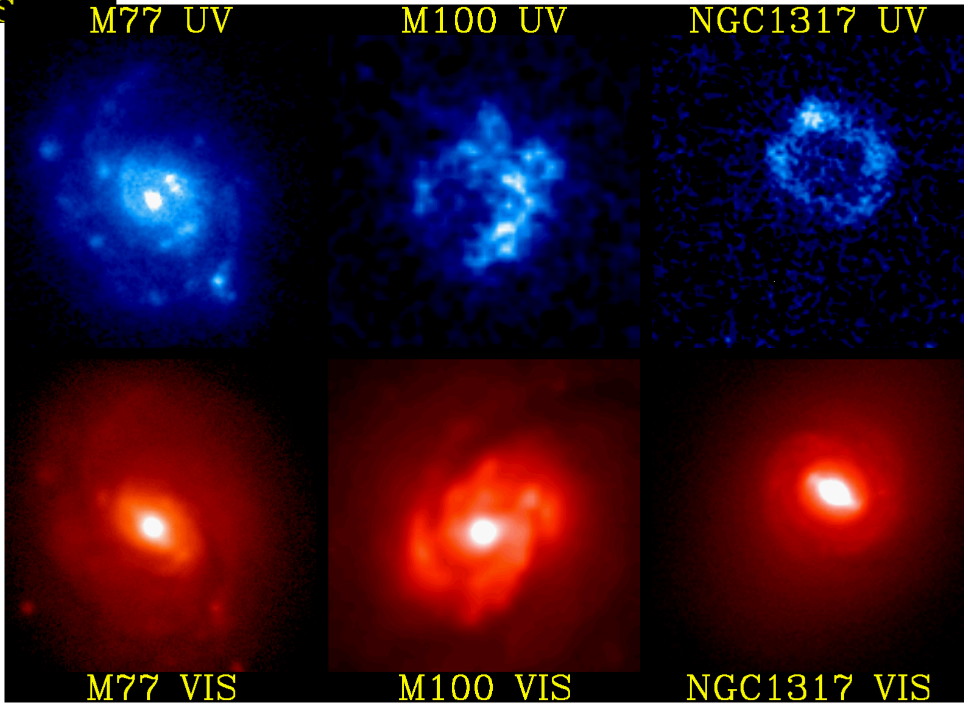
at long IR wavelengths the emission is due to dust which has reprocessed optical/UV light



12 galaxies observed in UV and optical

Notice different patterns of UV light - this is affected not only by the distribution of hot young stars but also by dust

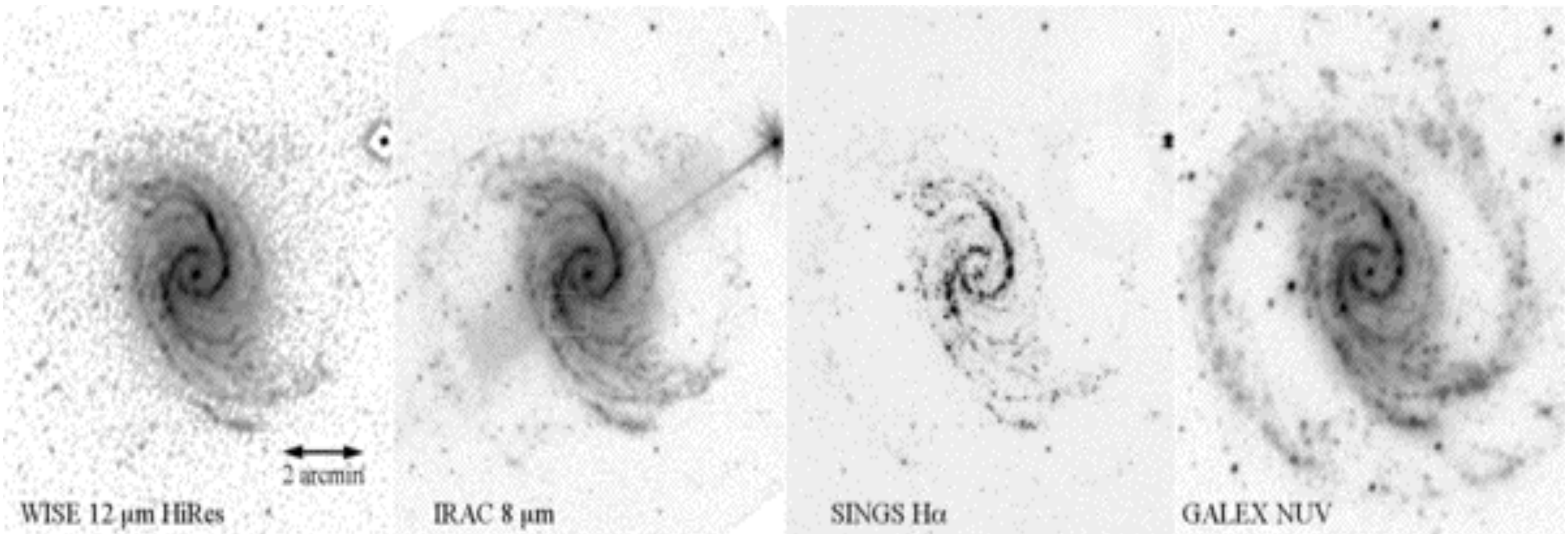
From UIT team



Difference between UV, optical and IR becomes important in studying the high redshift universe

NGC1566 in 4 Bands

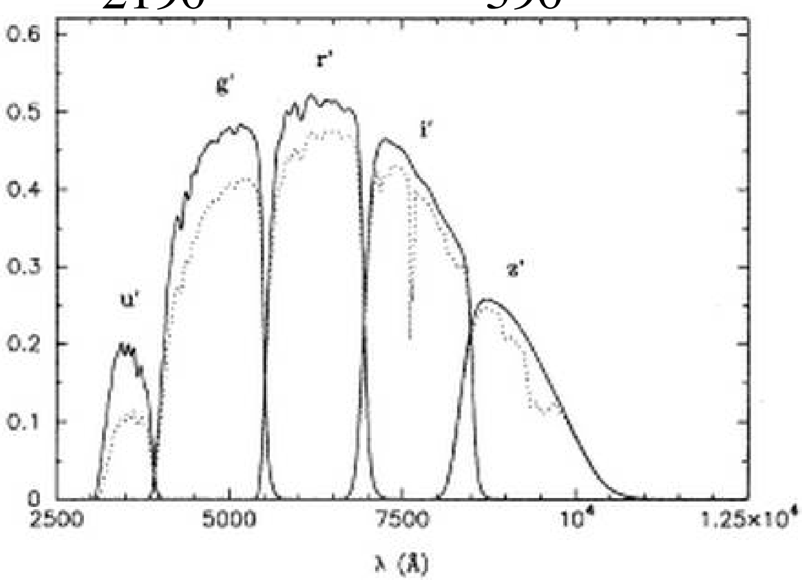
- Each of these bands reveals different information about the stars, dust and star formation rate in the galaxy
- Hα- youngest stars
- NUV young stars
- IR emission from small molecules (PAHs)
- IR emission from dust



Dust PAH Hα NUV

A Bewildering Variety of Bands and Names

Name	wavelength nm	Δλ
U	365	66
B	445	94
G	482	140
V	551	99
R	658	138
I	806	149
z	900	140
Y	1020	120
J	1220	213
H	1630	307
K	2190	390



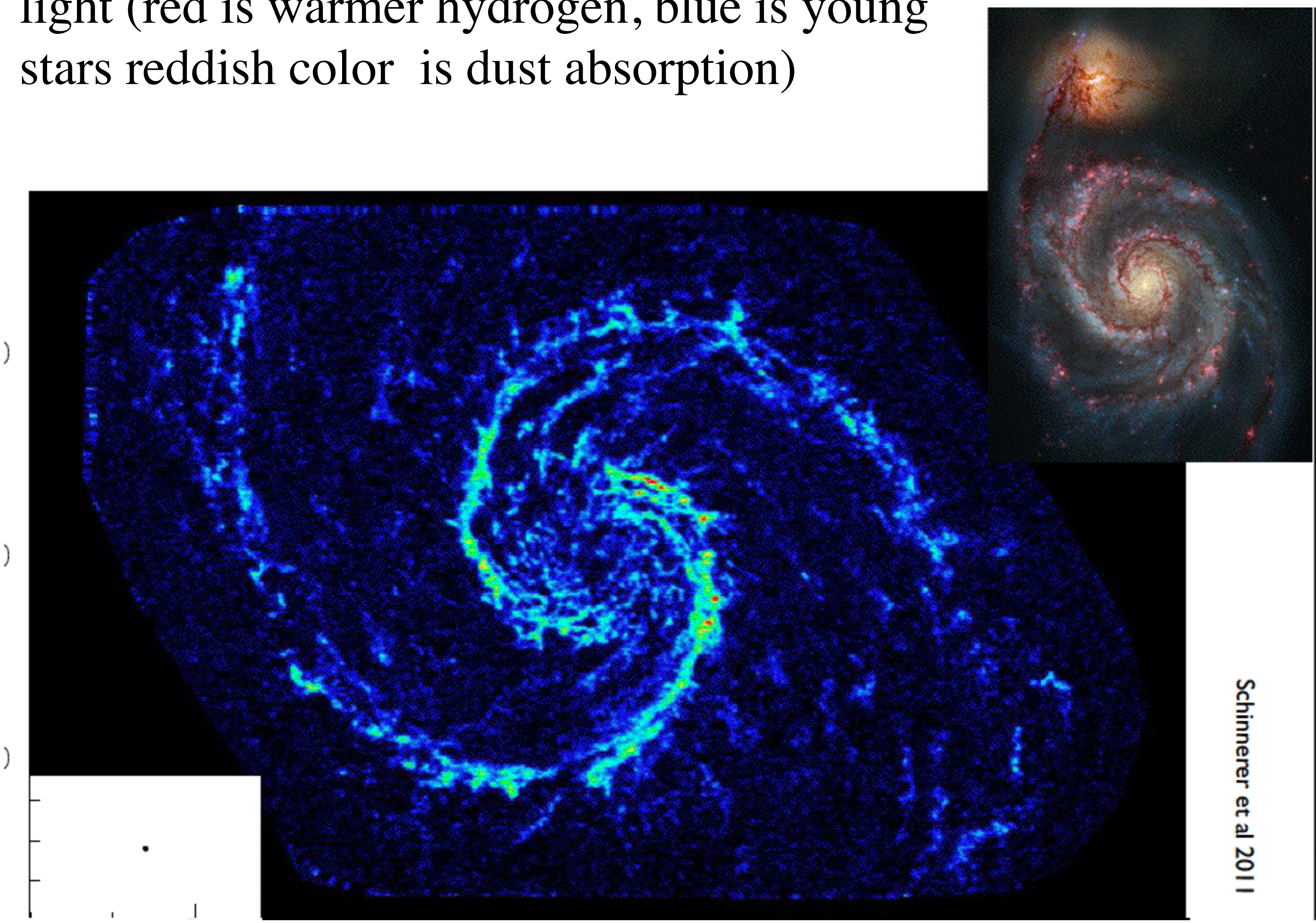
There are 2 different magnitude systems

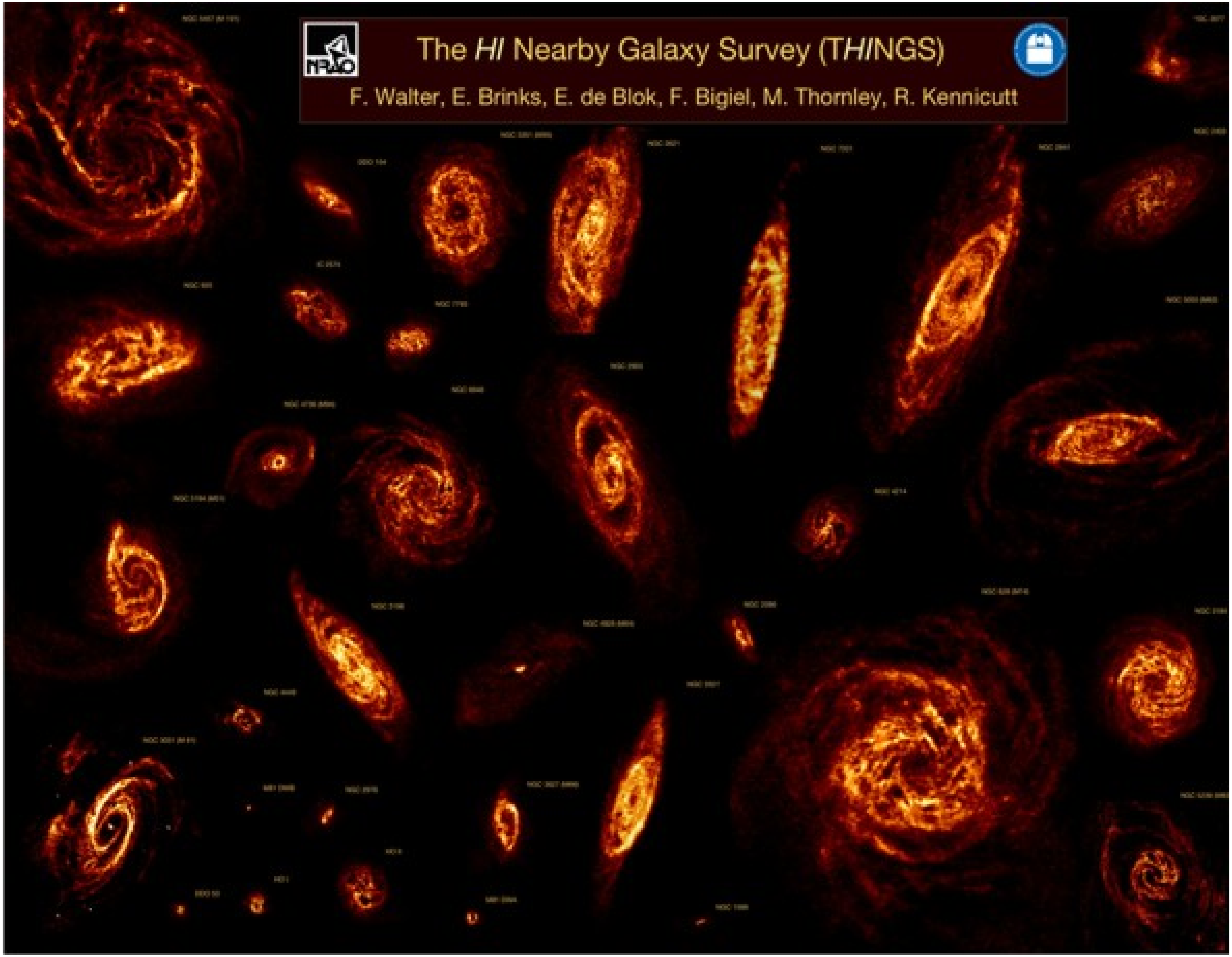
AB system (Oke & Gunn 1983), magnitude 0 object in all bands has the same flux F_ν = 3631 Jy
a object with a flat energy distribution (F_ν= constant) has the same mag in all colors; 3631 Jy is how bright Vega is in the V band!
Absolute mag of sun in SDSS filter set
u;g;r;i;z 5 lg h = 6:80; 5:45; 4:76; 4:58; 4:51

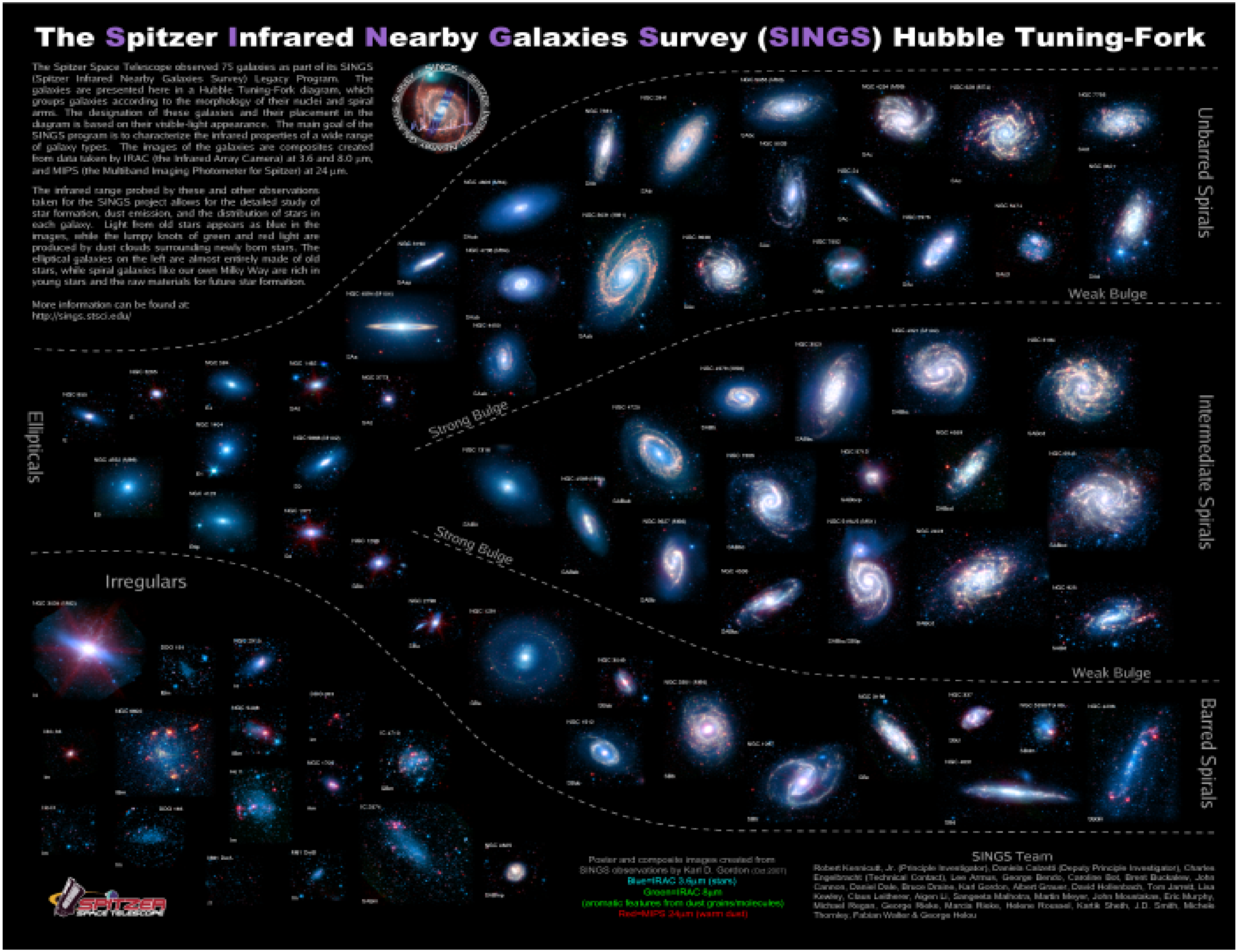
The **Vega** system by definition, Vega's magnitudes are 0.0 in all filters.

there are many other filter 'sets' each based on different needs, uses (the UBV data set was developed for use
with photographic plates, the SDSS set for use with CCDs circa 1995 technology)

'Cool gas' (HI-hydrogen) and color coded light (red is warmer hydrogen, blue is young stars reddish color is dust absorption)




The HI Nearby Galaxy Survey (THINGS)
F. Walter, E. Brinks, E. de Blok, F. Bigiel, M. Thornley, R. Kennicutt


The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork
The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0 μm, and MIPS (the Multiband Imaging Photometer for Spitzer) at 24 μm.
The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.
More information can be found at:
http://sings.stsci.edu/
Unbarred Spirals
Weak Bulge
Strong Bulge
Ellipticals
Intermediate Spirals
Strong Bulge
Irregulars
Weak Bulge
Barred Spirals
Poster and composite images created from SINGS observations by Karl D. Gordon (Oct 2007)
Blue=IRAC 3.6μm (stars)
Green=IRAC 8μm
(aromatic features from dust grains/molecules)
Red=MIPS 24μm (warm dust)
SINGS Team
Robert Kennicutt, Jr. (Principle Investigator), Daniela Calzetti (Deputy Principle Investigator), Charles Engelbracht (Technical Contact), Lee Armus, George Bendo, Caroline Bot, Brent Buckalew, John Cannon, Daniel Dale, Bruce Draine, Karl Gordon, Albert Grauer, David Hollenbach, Tom Jarrett, Lisa Kewley, Claus Leitherer, Aigen Li, Sangeeta Malhotra, Martin Meyer, John Moustakas, Eric Murphy, Michael Regan, George Rieke, Marcia Rieke, Helene Roussel, Kartik Sheth, J.D. Smith, Michele Thornley, Fabian Walter & George Helou
SPITZER SPACE TELESCOPE

Astronomers Have a Enormous Appetite for Jargon

- "Normal" ellipticals: giant ellipticals (gE's), intermediate luminosity (E's), and compact ellipticals (cE's), range in absolute magnitudes from M_B ~23 to M_B ~15.
- Dwarf ellipticals (dE's): significantly smaller surface brightness and a lower metallicity.
- cD galaxies. extremely luminous (up to M_B~25) and large (up to R~1Mpc) galaxies found only near the centers of dense clusters of galaxies.
- Blue compact dwarf galaxies. (BCD's) bluer than the other ellipticals, and contain an appreciable amount of gas.
- Dwarf spheroidals (dSph's) exhibit a very low luminosity and surface brightness. as faint as M_B ~-8.
- **Thus 'elliptical' galaxies span an enormous range (10^6) in luminosity and mass**

Do these terms carry a physical meaning?- *Yes* the 'names' and the physics have a strong linkage- what, why and how

- abstracted from P. Schneider Extragalactic Astronomy and Cosmology An Introduction Springer

Summary of 2nd Lecture

- Most of the universes baryons do not lie in galaxies
  - Dark matter is dominant
- in a LCDM universe structure tend to grow hierarchically (e.g. small things form first, then merge into larger things, but growth also occurs from infall)
- The physics of galaxy formation and evolution is complex, with needed input from almost all of astrophysics
  - star formatiom
  - ISM physics (cooling heating)
  - Effect of AGN
  - Dust changes the observational aspects greatly
- Visual appearance of galaxies changes strongly across the electromagnetic spectrum with different wavelength ranges best suited to observe certain phenomena
- There is a physical meaning to the classification of galaxies into spirals and ellipticals
  - they have different mass functions
  - different star formation histories