Astronomy 537

Lecture 11: Spiral structures III

Population synthesis

Computer modeling of galaxy colors or spectra. Inputs:

- Age
- Star formation rate versus time
- Initial Mass Function (IMF)
- Metallicity
- Library of spectra of model atmospheres of stars
- Models of stellar evolution

Findings:

Biggest reason for galaxy color/spectrum variation with Hubble type is star formation rate versus time

The Mass Function

Whenever you have a large number of objects with various masses, useful to describe the number as a function of mass, N(M), or size, N(R). Constrains theories of their origin. Useful for Kuiper Belt, asteroids, impact craters, Saturn's ring particles, stars, gas clouds, galaxies.

Often have many small objects and a few large ones, which we can try to describe with a "power law" mass function:

$$N(M) \propto M^{-\beta}$$

Gives relative importance of large and small objects

For KBOs, can measure reflectivity of Solar radiation. Know distance from Sun by measuring orbit. From this and assumed albedo, can get radius of each. Find

$$N(R) \propto R^{-4}$$

If they all have the same density then M/R^3 = constant, so $M \propto R^3$, so $R^{-4} \propto M^{-4/3}$, and

$$N(M) \propto M^{-4/3}$$

Now can ask, for example, how many are there of mass M_1 vs. $10xM_1$?

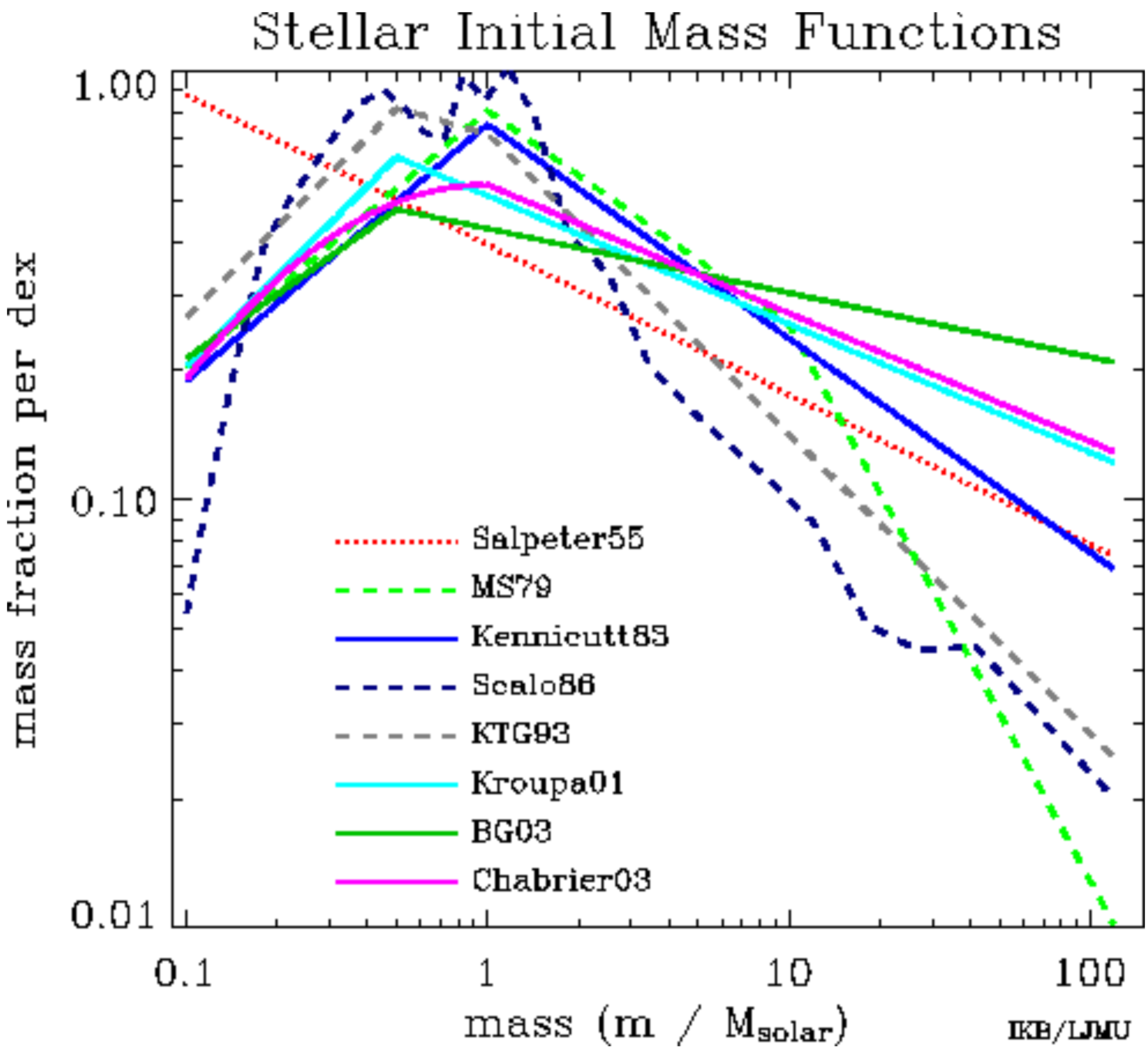
$$N(M_1)/N(10xM_1) = M_1^{-4/3}/(10xM_1)^{-4/3} = 10^{4/3} = 21.5$$

Can also ask: is most of the mass in larger KBOs or smaller ones? For example, how much mass in objects of mass M_1 vs. objects of mass $10xM_1$?

If you have N objects of mass M, the total mass is MxN. So for N=N(M), total mass is MxN(M) α $MxM^{-4/3}$ or $M^{-1/3}$. So relative mass is

$$M_1^{-1/3}/(10xM_1)^{-1/3} = 10^{1/3} = 2.2$$

So more mass in lower mass objects. Recall β was -4/3. Note if $\beta > -1$, more mass in higher mass objects.



Stellar Initial Mass Functions
1.00
0.10
0.01
mass fraction per dex
0.1
1
10
100
mass (m / Msolar)
IKB/LJMU
Salpeter55
MS79
Kennicutt83
Scalo86
KTG93
Kroupa01
BG03
Chabrier03

- **Initial Mass Function for Stars**
- By observing the relative numbers of various masses of stars, we can deduce something about the cloud fragmentation process.

- The *initial mass function* (IMF) describes the relative numbers of each stellar mass. Defined for stars in the Solar neighborhood by Salpeter (1955):

$$\xi(M) = \xi_0 M^{-2.35}$$

- *M* = mass in solar units.
- Thus, the number of stars that form with masses between *M* and *ΔM:*

$$\xi(M)\Delta M$$

- Total number of stars formed with masses M_1 and M_2:

$$N = \int_{M_1}^{M_2} \xi(M) dM = \xi_0 \int_{M_1}^{M_2} M^{-2.35} dM = \frac{\xi_0}{1.35}\left[M_1^{-1.35} - M_2^{-1.35}\right]$$

- Similarly, we can work out the total mass in stars born within that given mass range:

$$M_{tot} = \int_{M_1}^{M_2} M\xi(M)dM$$

- Properties of the Salpeter IMF:

  - most of the stars, by number, are low mass stars
  - most of the mass in stars reside in low mass stars
  - following a burst of star formation, most of the luminosity comes from high mass stars.

The Salpeter IMF fails at low masses, since extrapolating to very low masses means total mass $\rightarrow \infty$

Observations implies Salpeter IMF valid for $M > 0.5\ M_{\odot}$, and that it flattens at lower masses.

- Worksheet:

- Consider a cloud with a total mass of $1000M_{\odot}$.
- How many $10M_{\odot}$ stars are formed if it follows the Salpeter IMF and forms stars over a range from 1 to $50M_{\odot}$?

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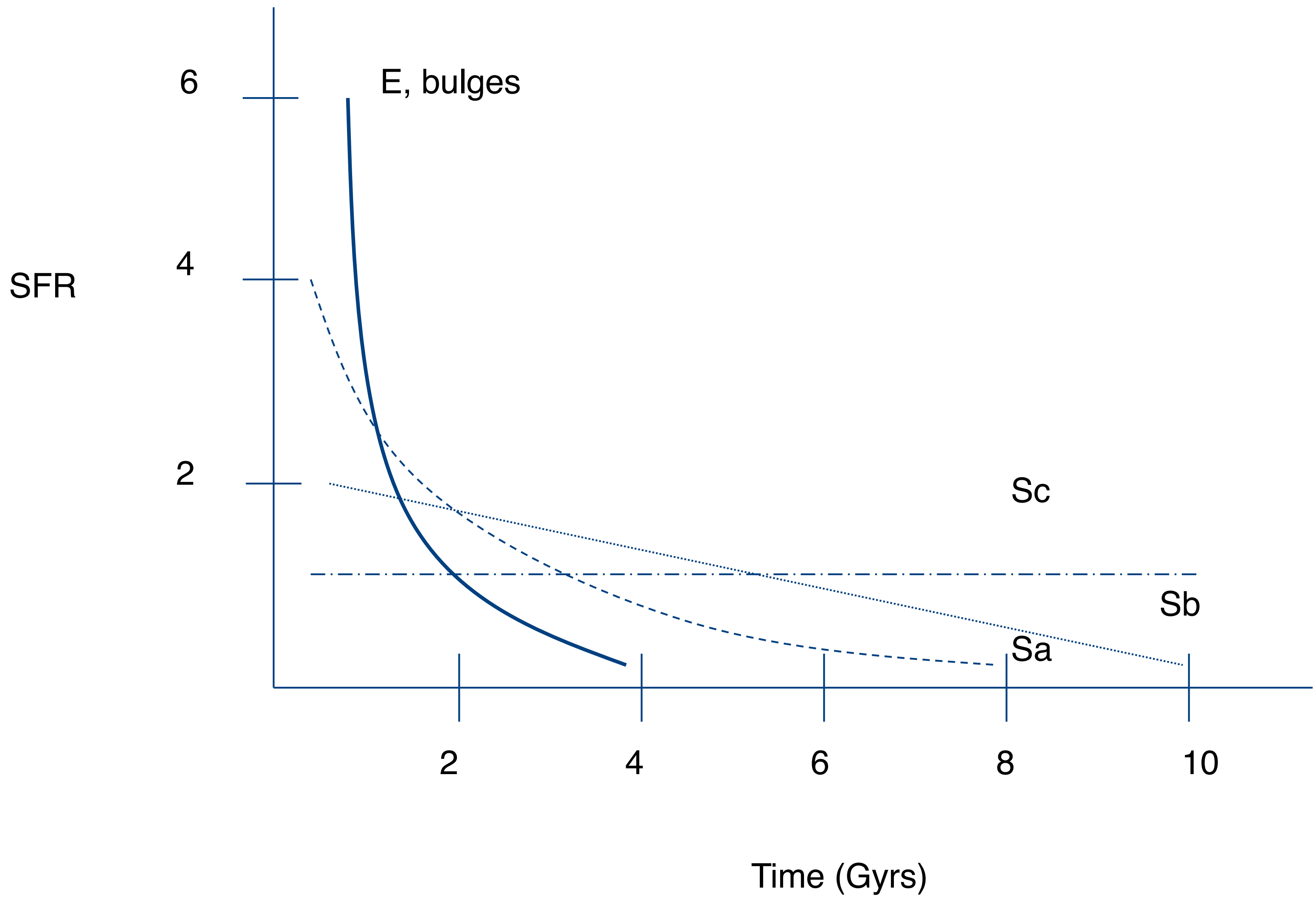
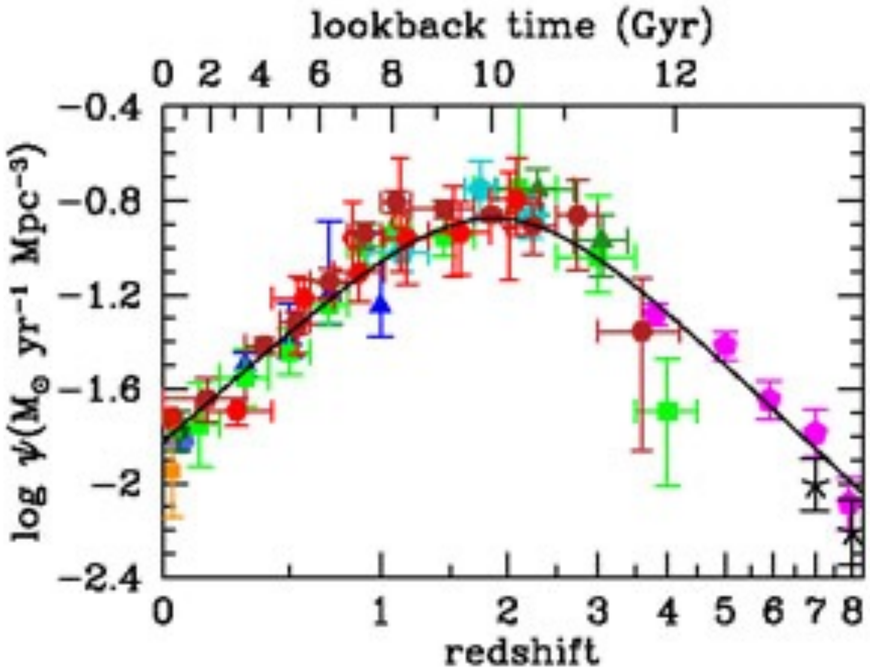
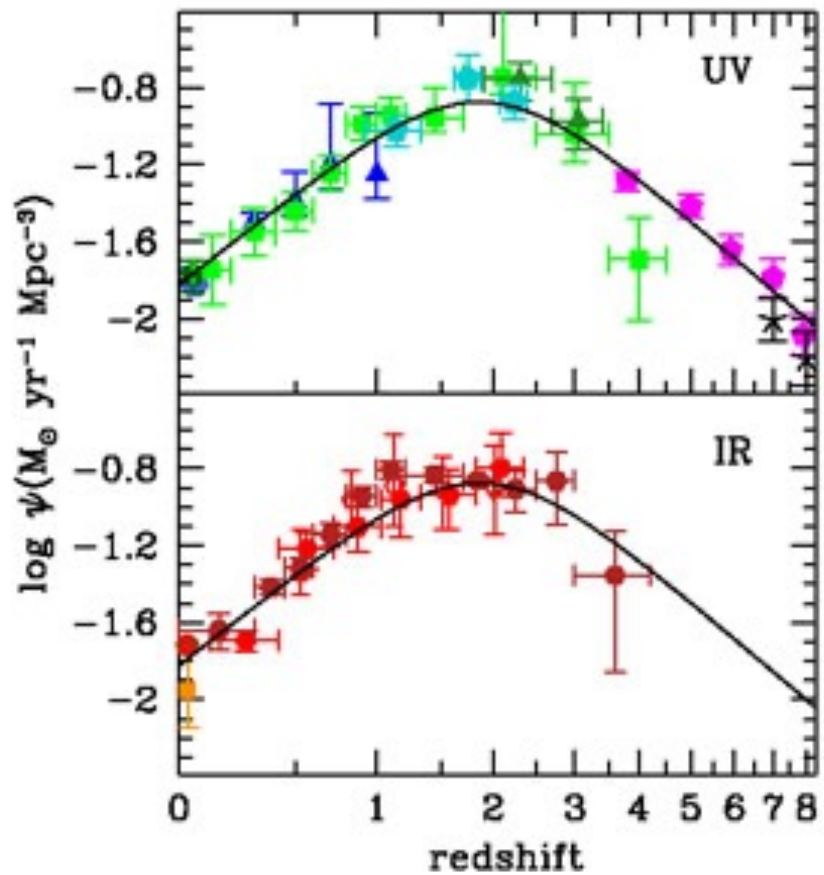
Schematic star formation histories:



Madau Plots





Star formation history of the Universe
Peaks at z=1.9 at an age of 3.5 billion years

Madau et al. (1996); Madau & Dickinson (2014)

Tracers of current star formation

1. Luminosity of Hα emission (what kinds of stars responsible?). Must assume IMF to get total star formation rate (SFR).

$$SFR(M_{\odot}/yr)=8x10^{-42}\, L_{H\alpha}\ (erg/s)$$

2. Far infrared emission (FIR) from dust heated by starlight. Wavelength 10-1000μm (near IR is mostly starlight). Requires satellite observations.

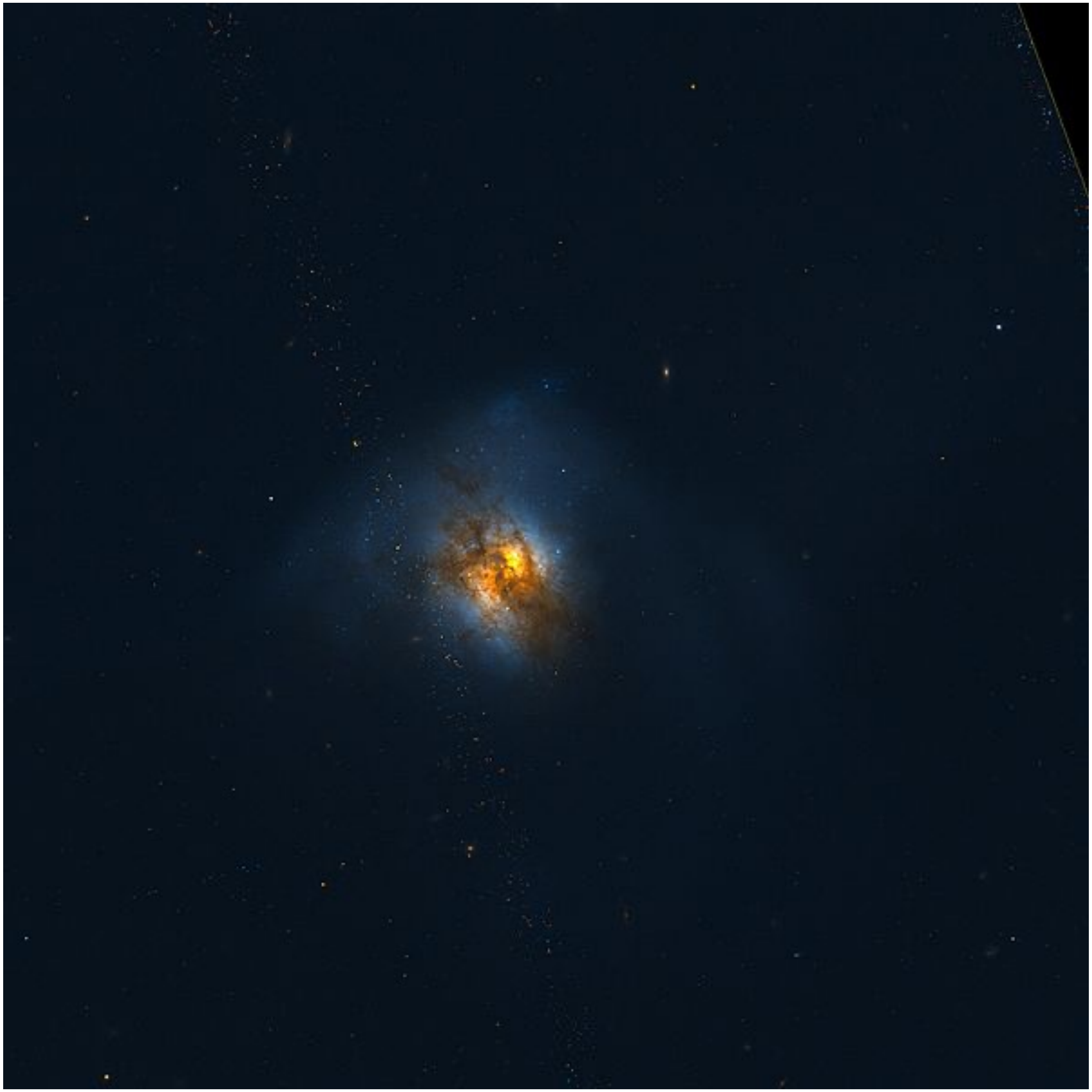
3. Far UV light (~2000Å). UV dominated by short-lived stars with $<10^8$ yr lifetimes.

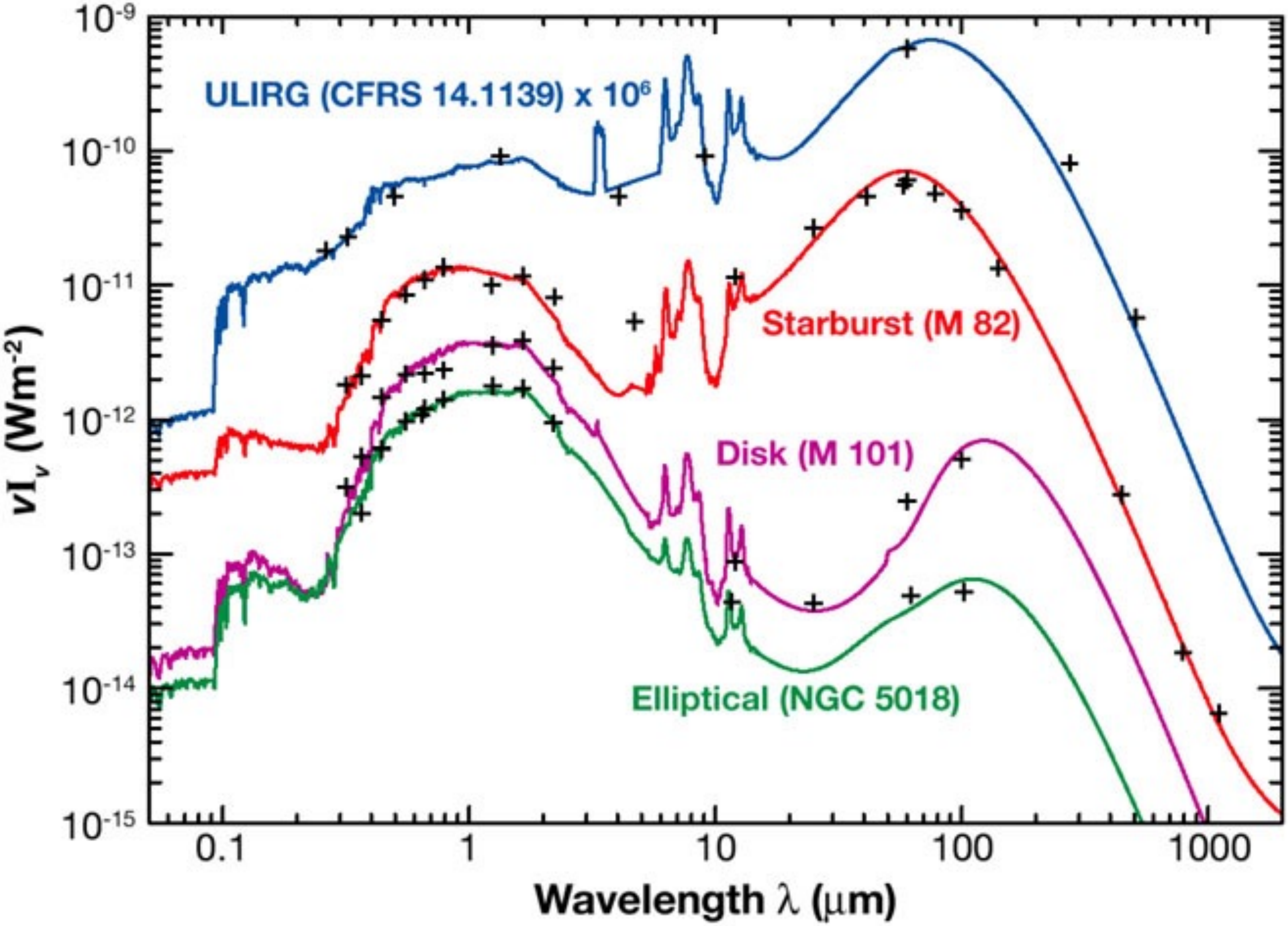
$$SFR(M_{\odot}/yr)=1.5x10^{-43}\, L_{UV}\ (erg/s)$$

where L_{UV} is in the range 1500-2800Å. Sensitive to extinction and form of IMF. Requires satellite observations (except for high-redshift galaxies).

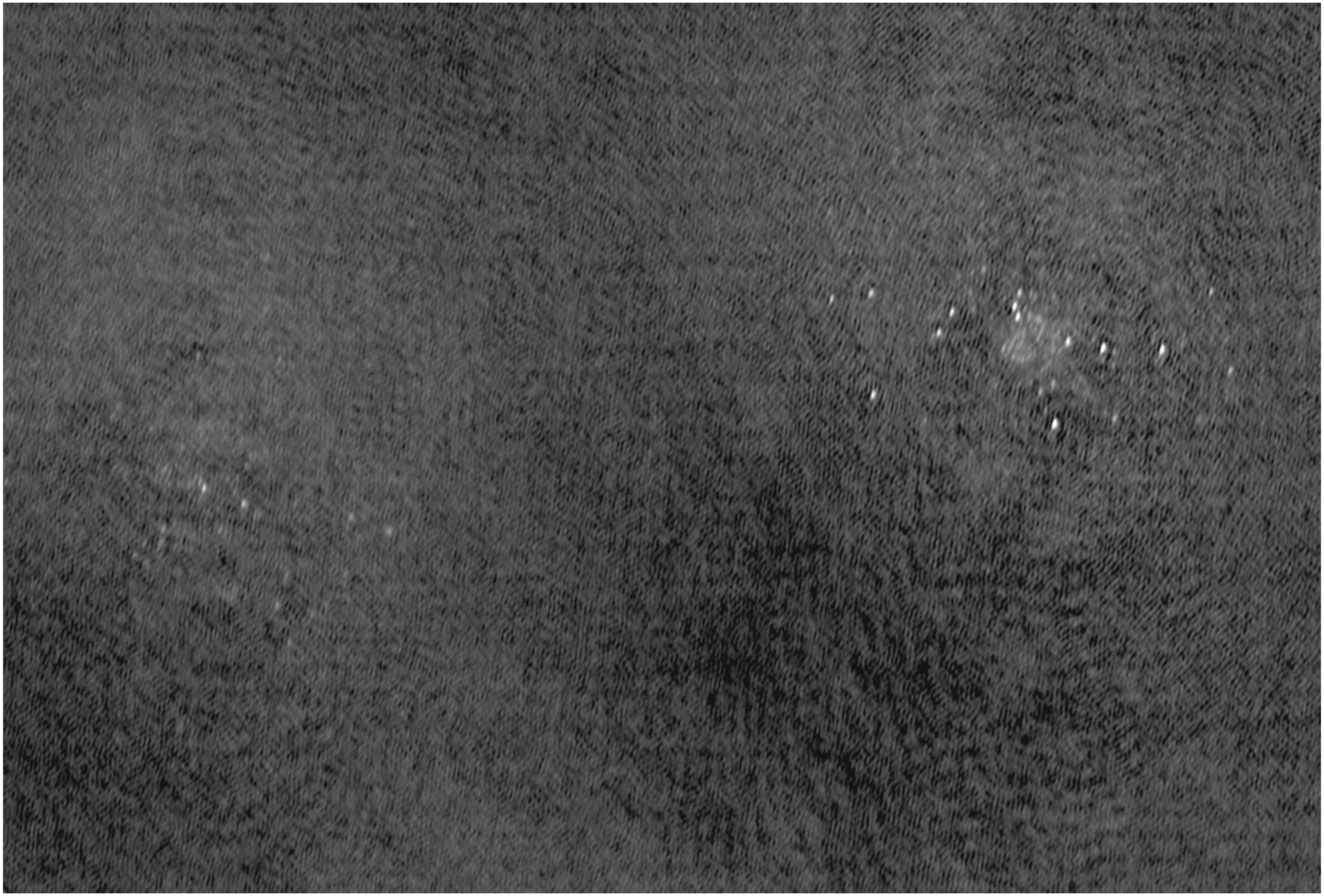
4. Radio continuum emission (because massive star formation leads to HII regions and SNe which make supernova remnants and rel. electrons)

Arp 220 - A starburst Galaxy and nearest ULIRG




ULIRG (CFRS 14.1139) x 10^6
Starburst (M 82)
Disk (M 101)
Elliptical (NGC 5018)
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
νIν (Wm^-2)
0.1
1
10
100
1000
Wavelength λ (μm)

Arp 220 - A starburst Galaxy



VLBA Image of the core of Arp 220 at 1.4 GHz - Lonsdale et al.

SFR vs Hubble type

E	~ 0	$M_\odot\ yr^{-1}$
S0	≤ 0.004	$M_\odot\ yr^{-1}$
Sa	~ 0.3	$M_\odot\ yr^{-1}$
Sb	~ 3	$M_\odot\ yr^{-1}$
Sc	~ 5	$M_\odot\ yr^{-1}$
Sd-Im	~ 1	$M_\odot\ yr^{-1}$ (smaller galaxies)

There are large variations, huge range, often in bursts.

Note: spread within a Hubble type > difference between types.

Specific frequency of globular clusters

N_{GC} = number of globular clusters in a galaxy

$S_N = N_{GC}\, L_{15}/L_V$

where S_N is the specific frequency of globular clusters,
L_V is V-band luminosity
L_{15} is luminosity of standard galaxy with M_V=-15

Sa: $S_N \sim 1.2$
Sc: $S_N \sim 0.5$
E: $S_N \sim 5$ and above

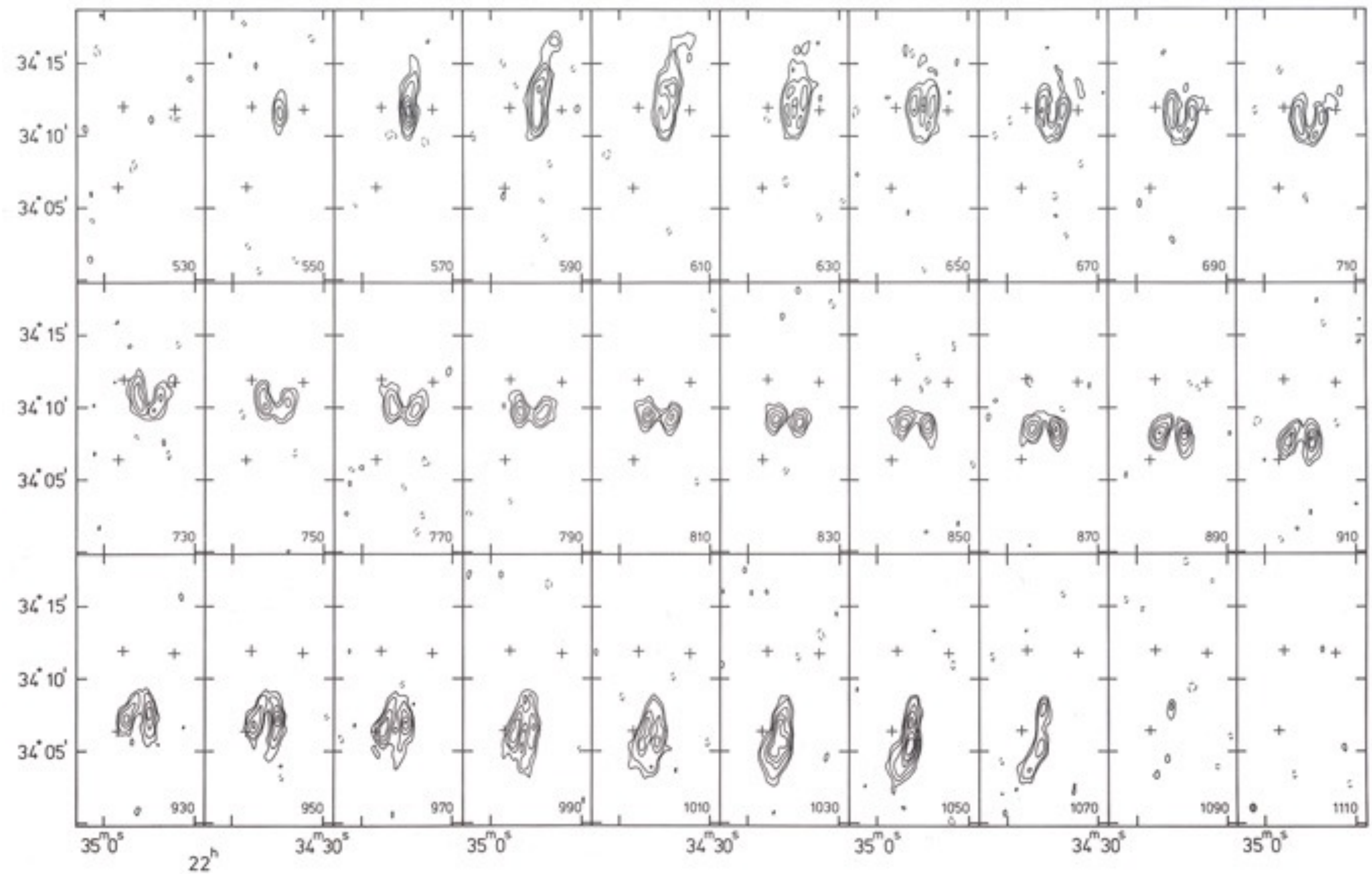
Giant ellipticals have largest S_N , and are found in centers of clusters (as we will see). Provides some information about galaxy formation/evolution.

Key concepts:

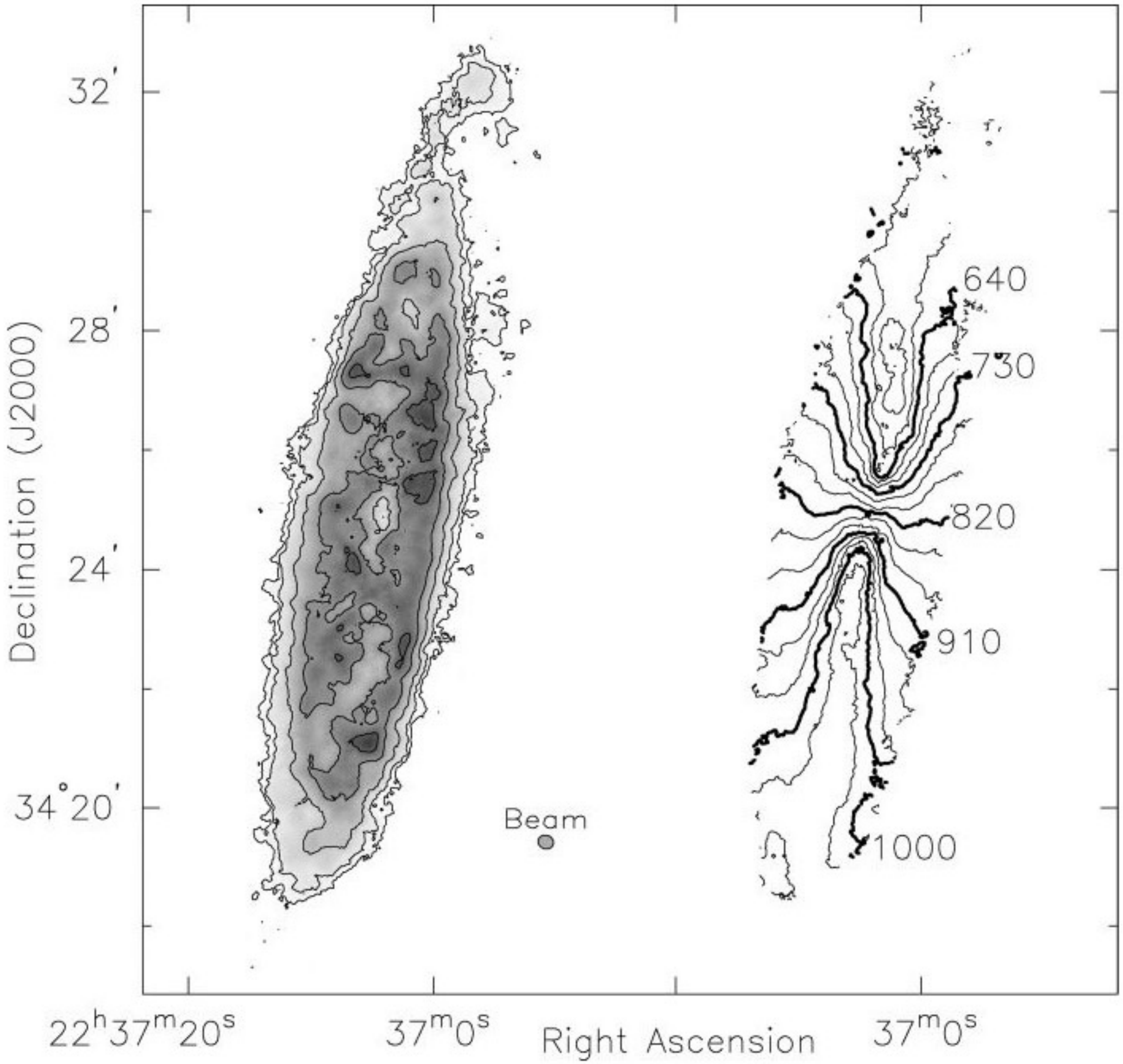
Spiral structure - density waves

Resonances help to create stable structures

HI in NGC 7331



HI in NGC 7331



HI in NGC 7331

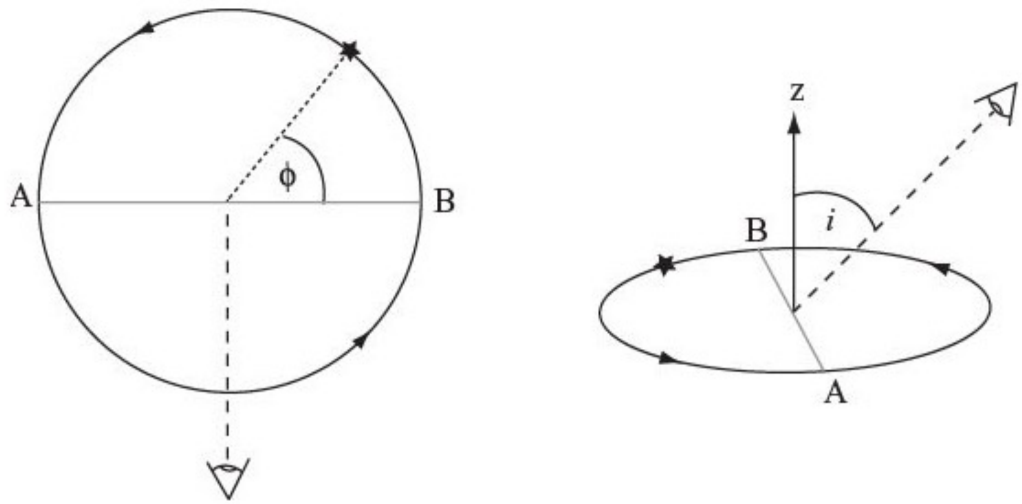


Fig. 5.18. Left, a rotating disk viewed from above. Azimuth ϕ, measured in the disk plane, gives a star's position in its orbit; an observer looks from above the disk, perpendicular to diameter AB. Right, the observer's line of sight makes angle i with the disk's rotation axis z.

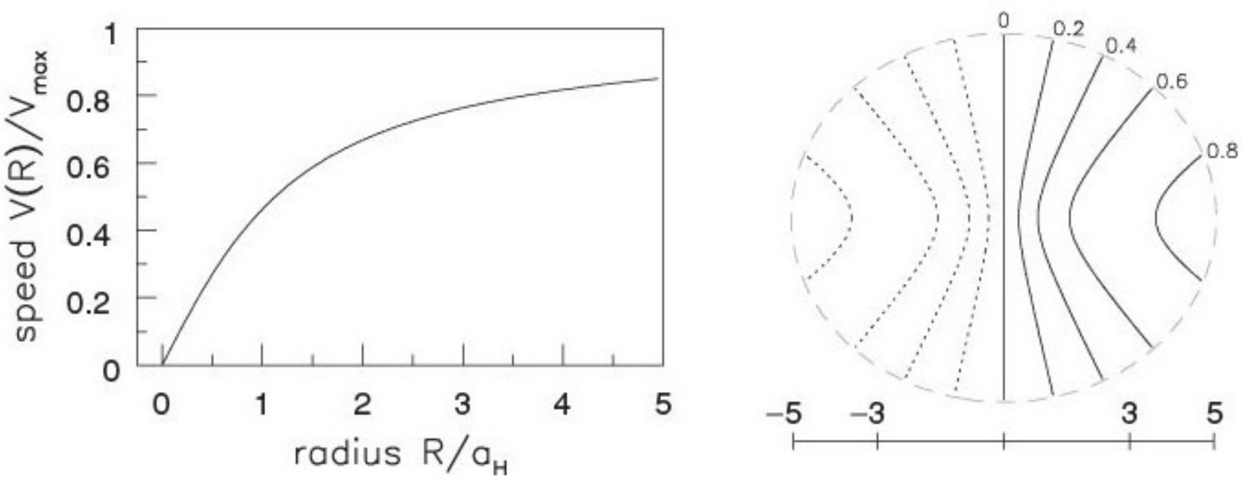


Fig. 5.19. Left, the rotation curve $V(R)$ in the 'dark-halo' potential of Equation 2.19, in units of $V_H = V_{max}$. Right, the spider diagram of $V_r - V_{sys}$ for a disk observed 30° from face-on; contours are marked in units of $V_H \sin 30°$, with negative velocities shown dotted.

Announcements

- **March 2nd: Review Chap 1–5**
- **March 4th : Exam**