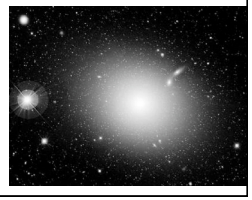
FORMATION AND EVOLUTION OF GALAXIES

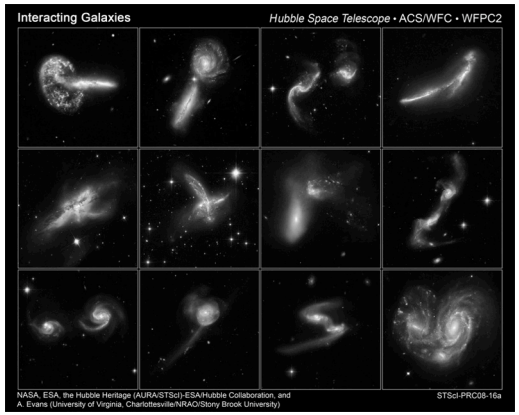
Lecture 18

- Galaxy interactions and mergers
- How to measure star formation
- How to kill a galaxy (effect of environment)



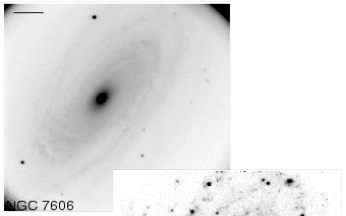
Somak Raychaudhury

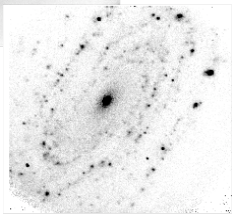
Interacting galaxies



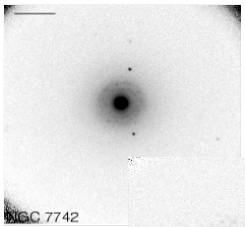
Where - Global

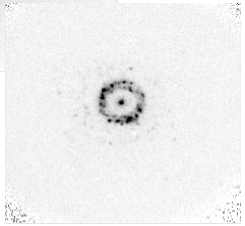
Galactic Disks





(Circum)nuclear





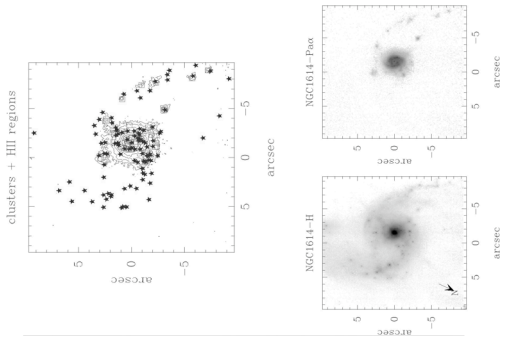
Where - Global Properties

Table 1. Star formation in disks and nuclei of galaxies

Property	Spiral disks	Circumnuclear regions
Radius	1-30 kpc	0.2-2 kpc
Star formation rate (SFR)	0-20 $M_\odot$ year^{-1}	0-1000 $M_\odot$ year^{-1}
Bolometric luminosity	10^6-10^{11} $L_\odot$	10^6-10^{13} $L_\odot$
Gas mass	10^8-10^{11} $M_\odot$	10^6-10^{11} $M_\odot$
Star formation time scale	1-50 Gyr	0.1-1 Gyr
Gas density	1-100 $M_\odot$ pc^{-2}	10^2-10^5 $M_\odot$ pc^{-2}
Optical depth (0.5 μm)	0-2	1-1000
SFR density	0-0.1 $M_\odot$ year^{-1} kpc^{-2}	1-1000 $M_\odot$ year^{-1} kpc^{-2}
Dominant mode	steady state	steady state + burst
Type dependence?	strong	weak/none
Bar dependence?	weak/none	strong
Spiral structure dependence?	weak/none	weak/none
Interactions dependence?	moderate	strong
Cluster dependence?	moderate/weak	?
Redshift dependence?	strong	?

Where - **Local**

HII Regions □

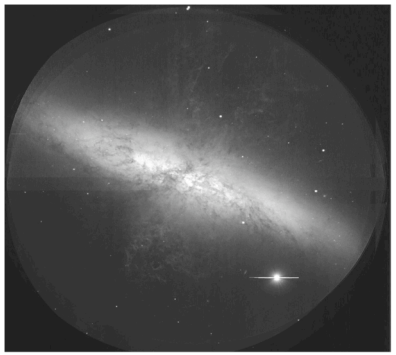


Where - Special Cases

Starbursts

Short-Lived
Intense
Circumnuclear
(kpc Scale)
Dominate L_{bol}

Dust Obscured
Outflows
25% of Local SF



Star formation in Galaxies

Observables

- Broadband colours
- Hα fluxes or other hydrogen recombination lines, but *not* Lyα (resonant scattering eventually followed by dust absorption)
- Far IR
- Radio continuum
- Molecular gas CO- seen in mm waves (cannot observe H_2 directly)

How To:

Measure & Characterize Extragalactic SF:

SFR - Rate (per year; per area)
SFH - History (Continuous/Steady, Instantaneous)
SFE - Efficiency (Gas Conversion)
(Location)

Integrated Measurements, Not Individual Stars
⟶ Synthesis Models (IMF,Metallicity,SFH,Age)

How To:

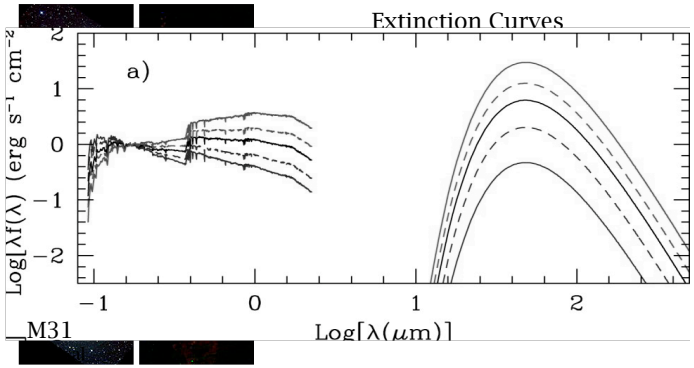
Measure SF:
(X-Ray --> Radio)

- Broad Band Colors
- UV Continuum (most Direct, but A_v)
- Hα, Recombination Lines (Case B combination, A_V)
- Forbidden Lines (Physical State of Gas in HII regions)
- Far-Infrared (FIR) --> Radio Continuum
  (Contribution from AGN &/or Old Stars)

All Dependent on Age, Metallicity
⟶ Can Trace Different SF Populations

How To:

Deal with Dust:
Changes Morphology



Star formation in Galaxies

A simple prescription that seems to work also for starbursts:

- Schmidt law (Schmidt 1959; Kennicutt, 1998)

$$\Sigma_{SFR} \propto \Sigma_{gas}^{N}$$

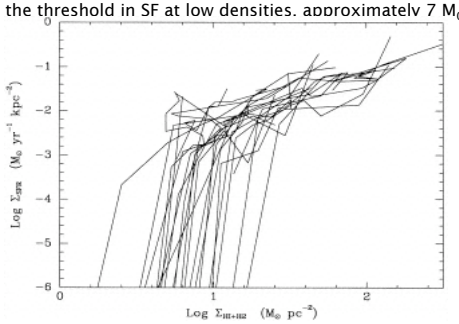
Based on densities of young stars and gas in the galactic disk. Justified globally, not locally.

$$\Sigma_{SFR} \propto \frac{\Sigma_{gas}}{\tau_{dyn}} \propto \Sigma_{gas}\Omega_{gas}$$

This relation is semi-empirical.

SFR vs gas surface density based on Hα for 21 spirals.

Notice the threshold in SF at low densities, approximately 7 M_0 pc^{-2}



Kennicutt 1998, ApJ 498, 541

Estimates of the star formation rate (SFR) are based on a very simple prescription –
•a universal Initial Mass function (IMF) and
•a time dependence whose complexity is hidden in the parameter Ψ(t):

$$dN(M,t) = \Phi(M)\Psi(t)dMdt$$

$$\Phi(M) \propto M^{-\alpha}$$

$$\alpha = 2.35$$ Salpeter IMF (Initial Mass function)

The instantaneous SFR (M yr $^{-1}$) is thus $SFR = \Psi(t_0)\int M\Phi(M)dM$

If e.g. The Hα emission line is used to estimate the SFR, models give approximately

$$SFR(M_\odot yr^{-1}) = \frac{L(H\alpha)}{1.26\cdot 10^{34} W}$$ (Kennicutt et al. -94)

What regulates the star formation?

- Negative and positive feedback processes
  - \+ Gravitational collapse of gas clouds
  - \+ Cooling – atomic, molecular, dust
  - \+ Gas compression from stellar winds
  - \- Sputtering on dust particles
  - \- Ionization
  - \- Heating and expansion of gas clouds
- The normal state is *self regulated* – i.e starbursts are shortlived, effects of galaxy interactions are mostly controlled

Why:

Trigger Mechanism:
Galactic Scale Gravity: Density Waves (Spiral Arms, Bars)
Disk Instabilities
Tidal Interaction --> Mergers
Ram Pressure Stripping

\+ Local Triggers: Turbulent compression (?)
Expanding Shell Collapse (?)

Important Gas Parameters:
Self-Similar (Hierachical Structure)
(ambient) Self-Gravitating
Cool Thermal State

Why - Spiral Arms

M51: Spiral Arms show off-set between Gas and Stars