Star Formation and HI in Groups and Clusters

UAT Ha Followup of Group Galaxies

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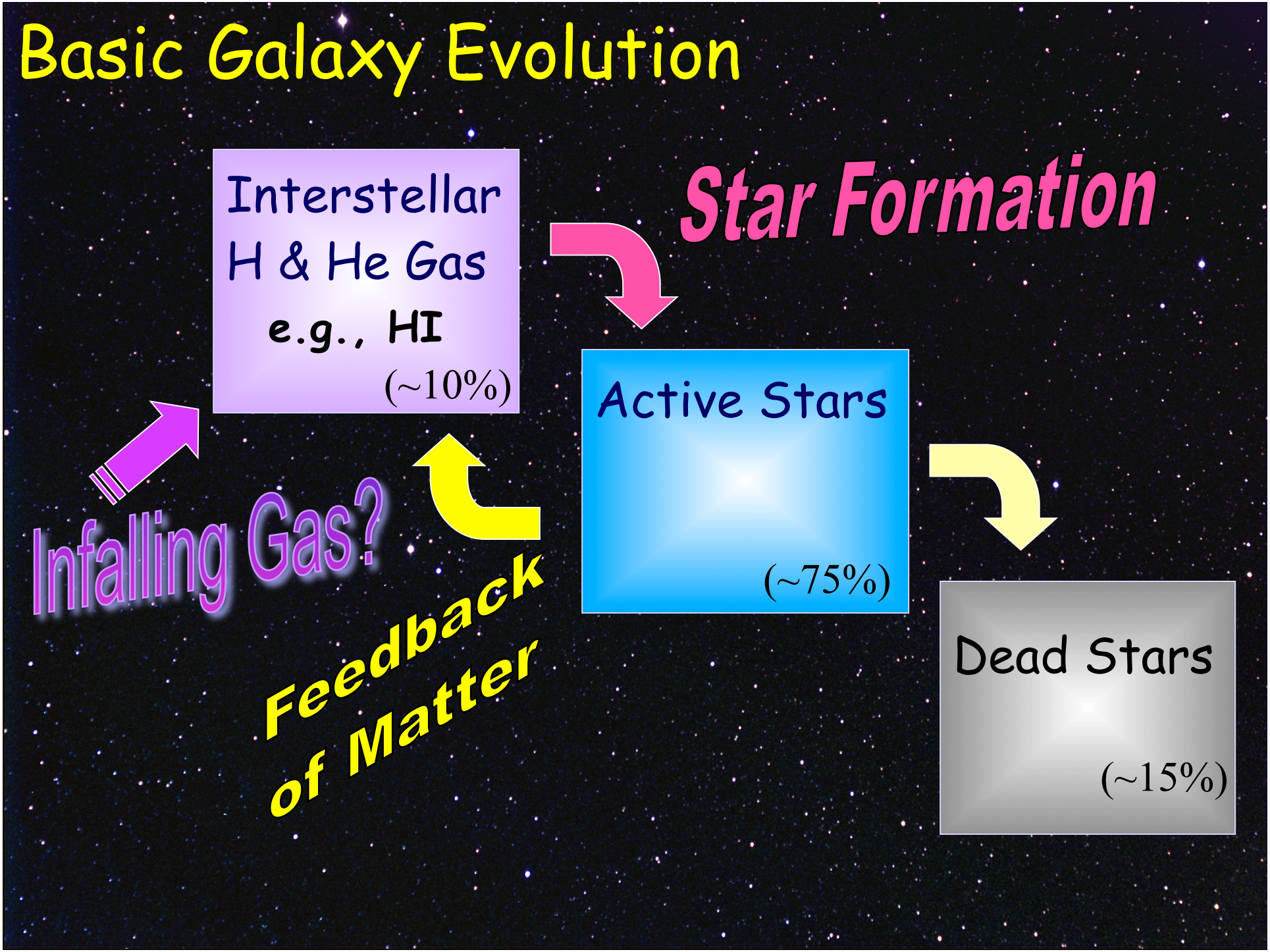
+ Josh Alvarez (WTA&M), Kyle Murray, Steven Grzeskowiak (Hartwick), ...


How is gas converted to stars?
Why do some galaxies have gas and others do not?
What determines star formation history? Morphology?

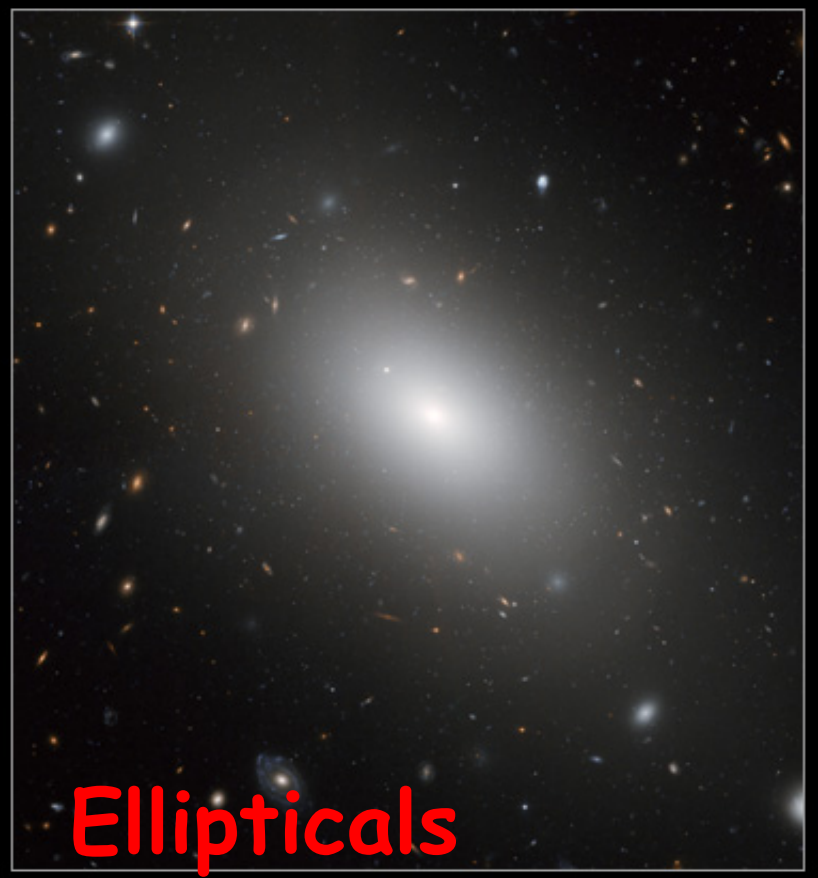
Basic Galaxy Evolution



Morphology

Spirals

- star-forming
- relatively gas-rich
- organized motions

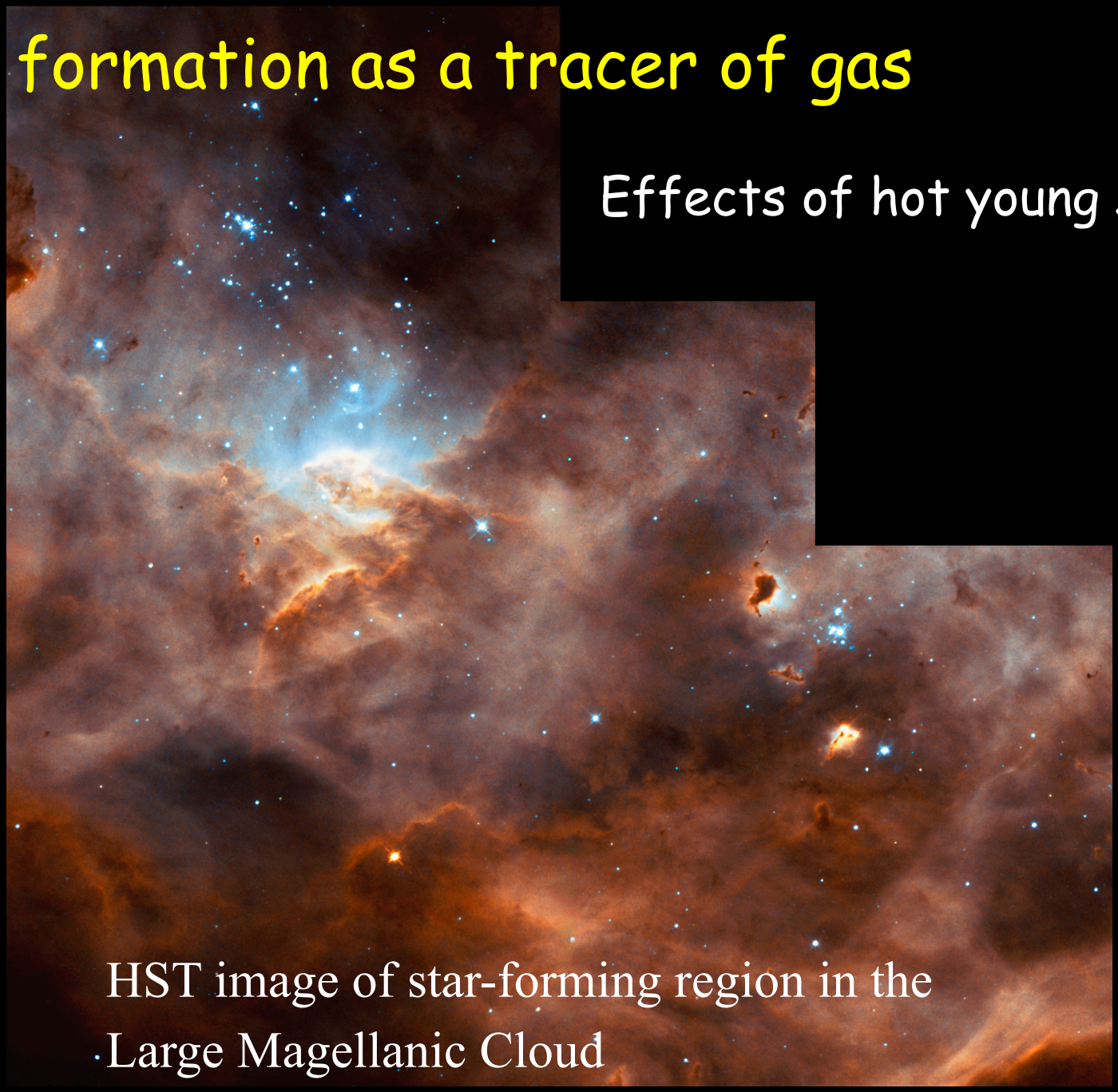


Ellipticals

- little/no star-formation
- relatively gas-poor (cold)
- randomized motions

Star formation as a tracer of gas

Effects of hot young stars



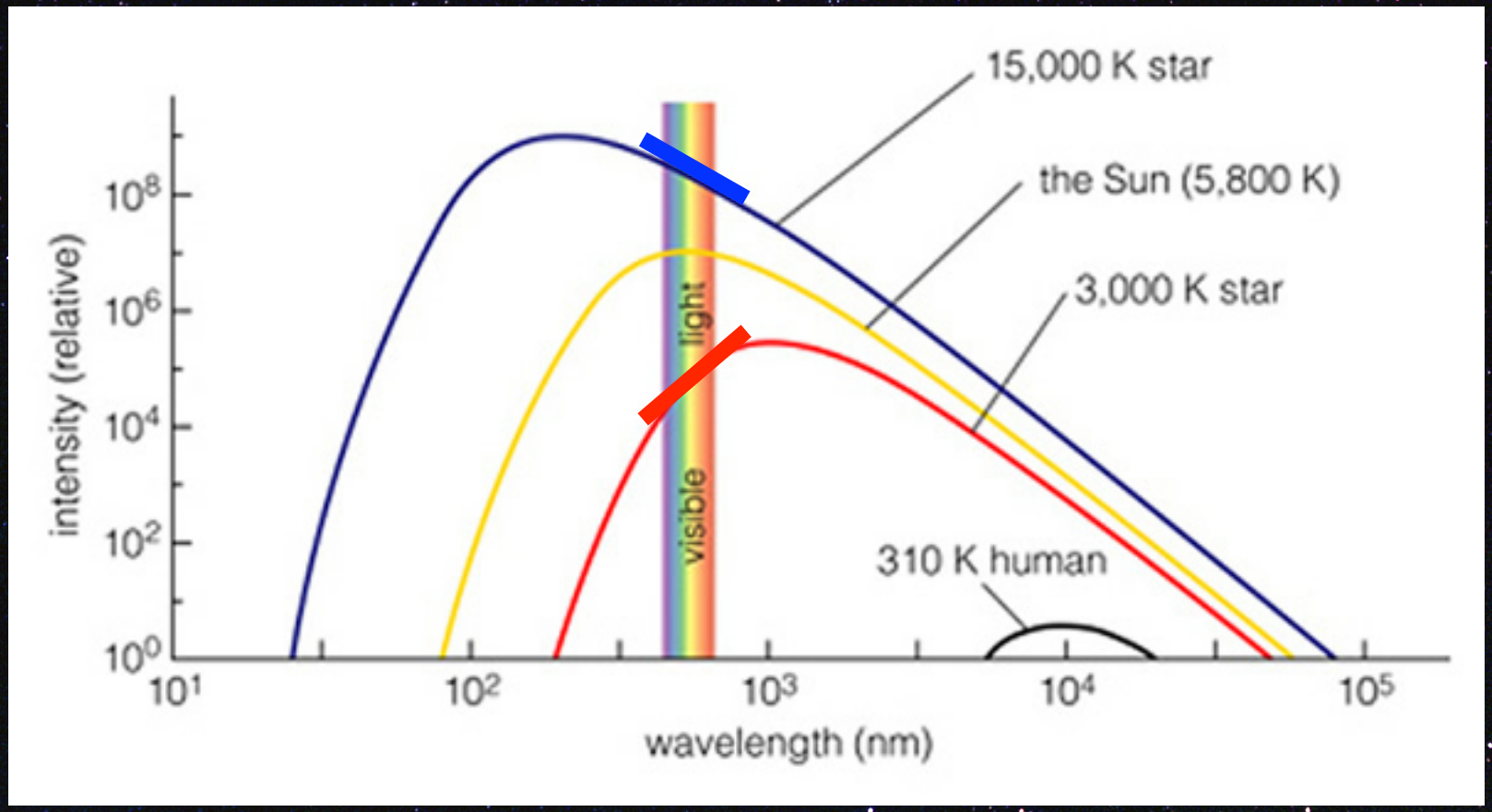
Hydrogen

Oxygen

HST image of star-forming region in the Large Magellanic Cloud

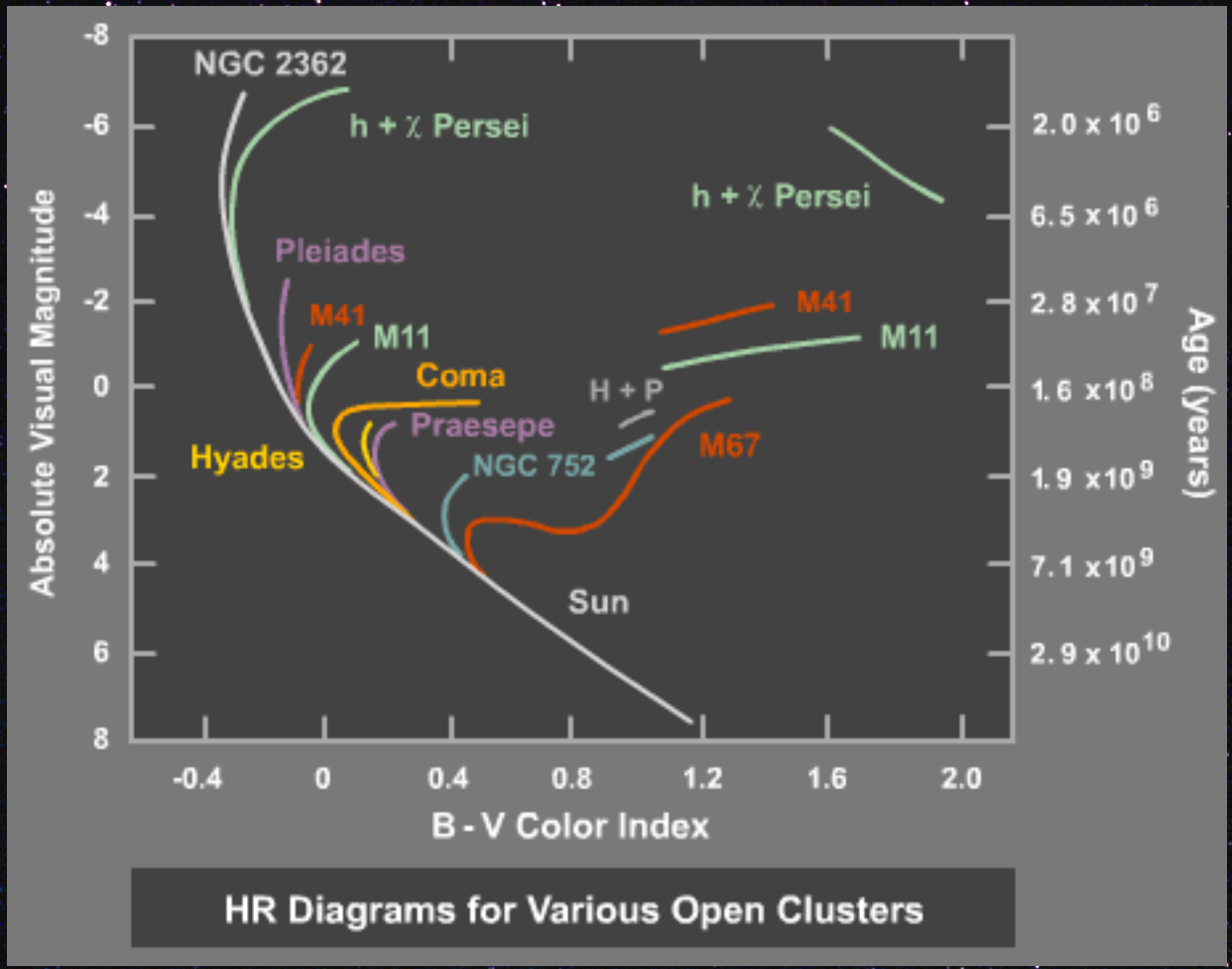
Colors of Galaxies

- First method used to determine SFRs
- Hot young stars are bright in UV and blue
- Older, cooler stars are brightest in red
- Color measures slope across visible region



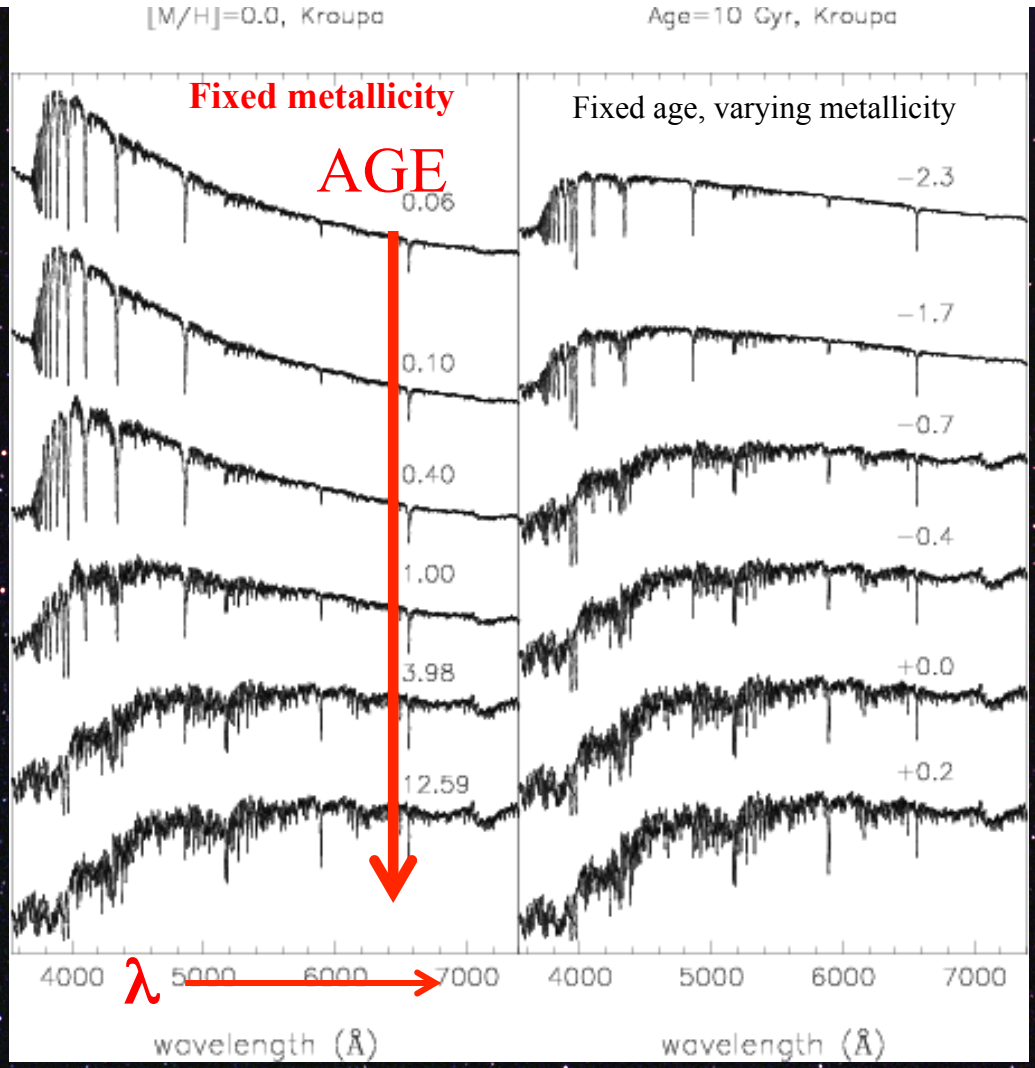
Color-Age Connection

O-B stars burn out quickly and leave main sequence in 10 Myr

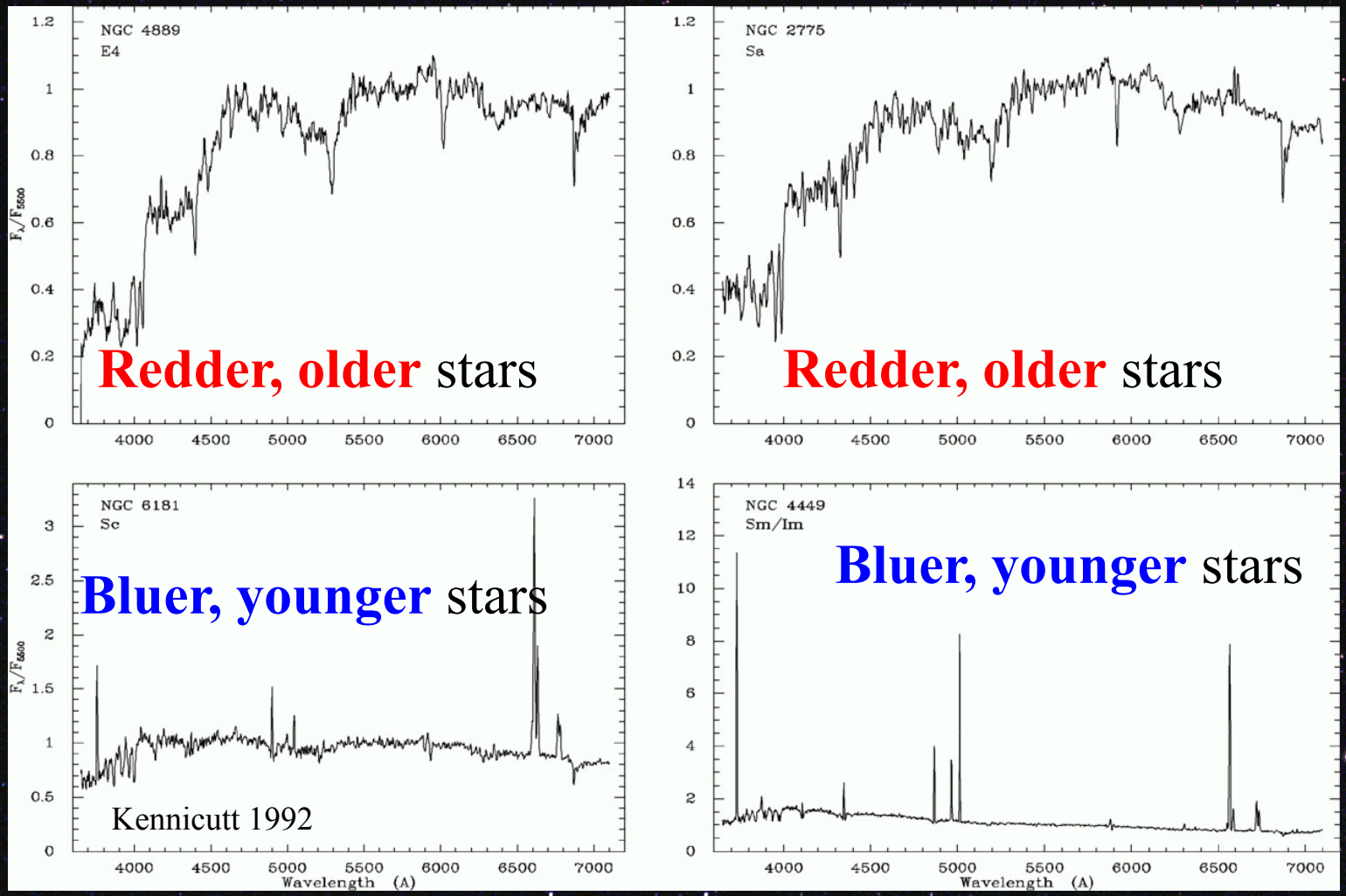


Galaxies have populations of stars: spectrum is net of all stars

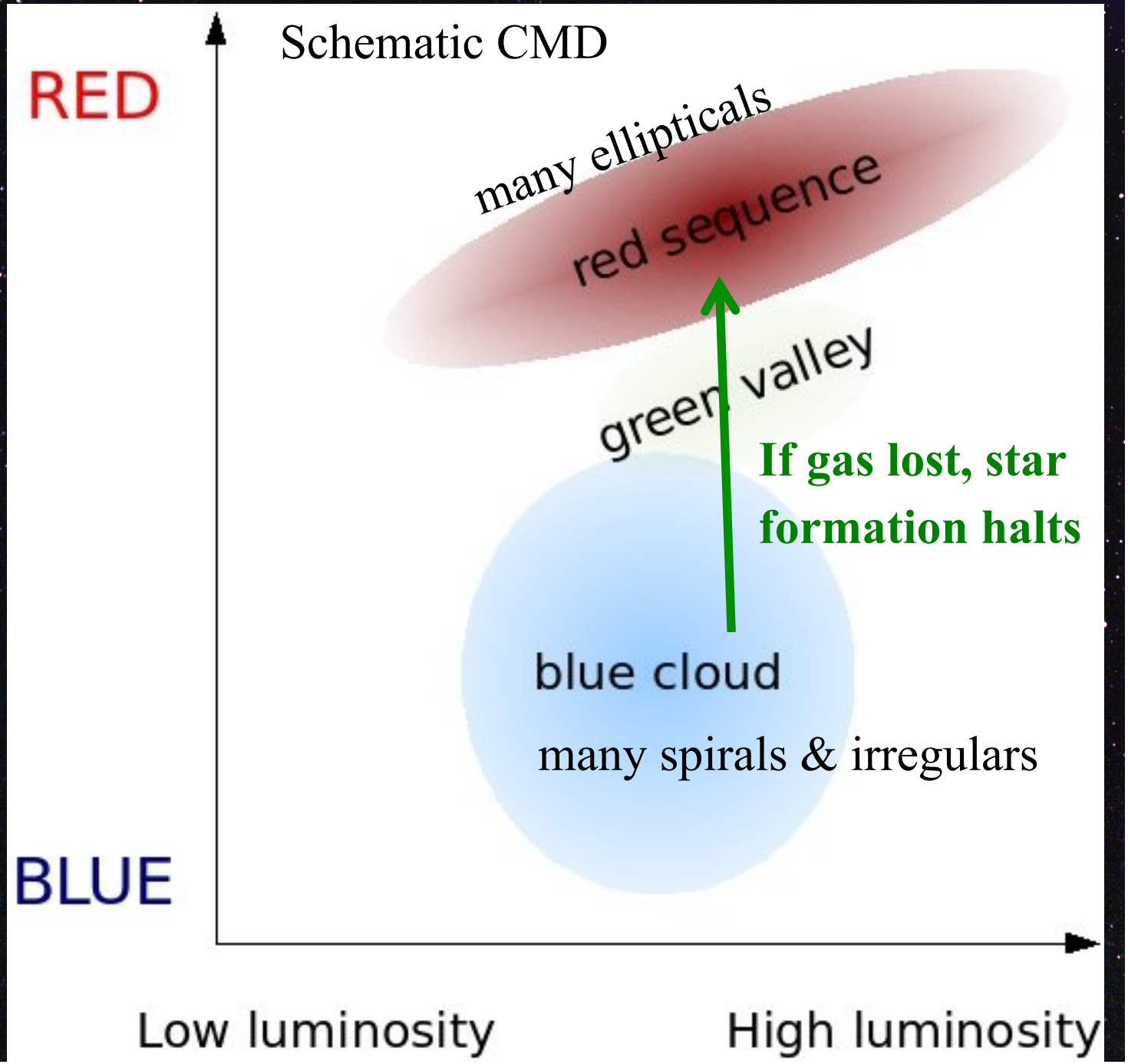
Model populations with collections of stars



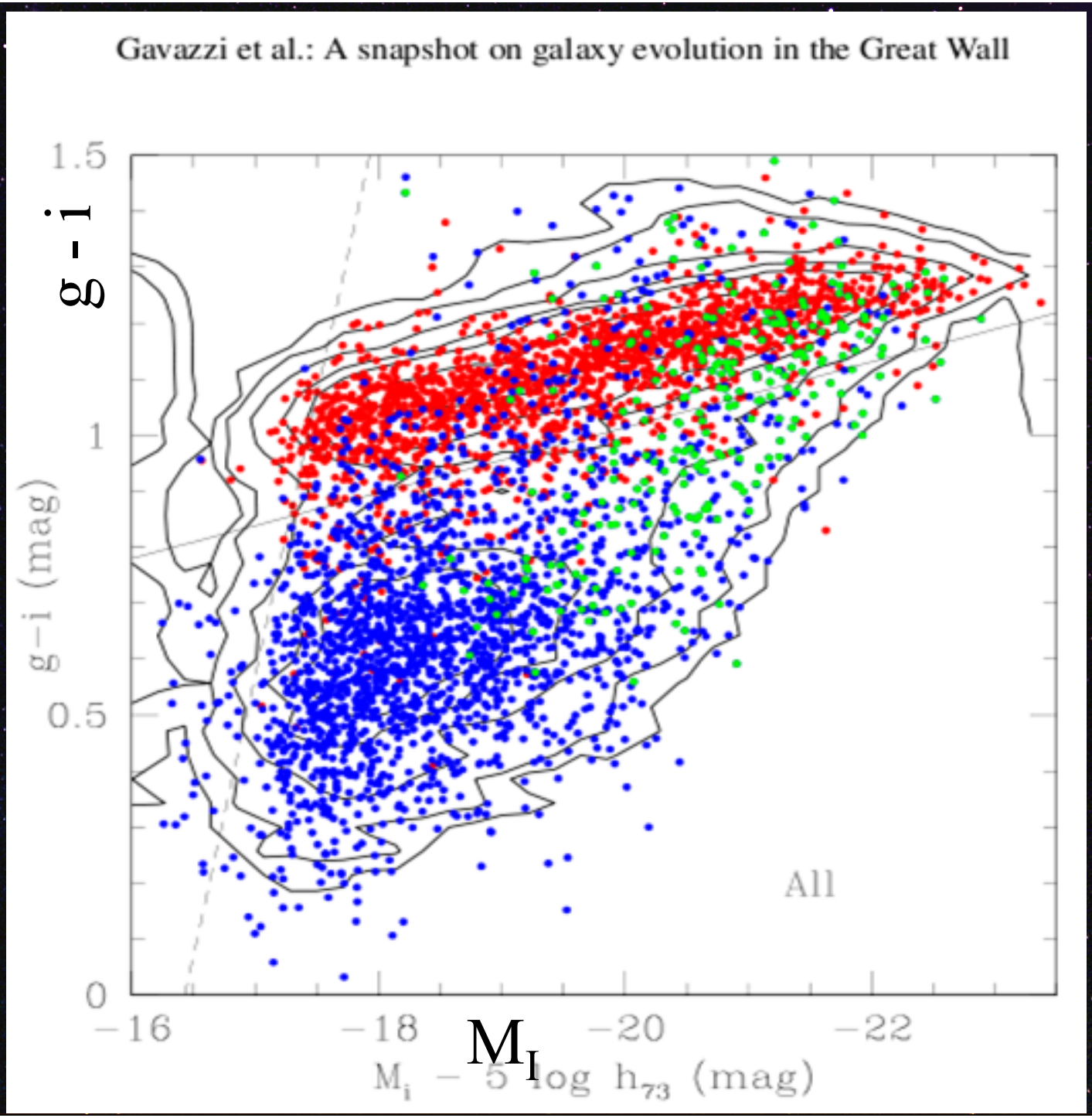
Integrated Spectra of Galaxies



- Color used for quick look or where spectra not available
- Color-Magnitude Diagram (CMD)

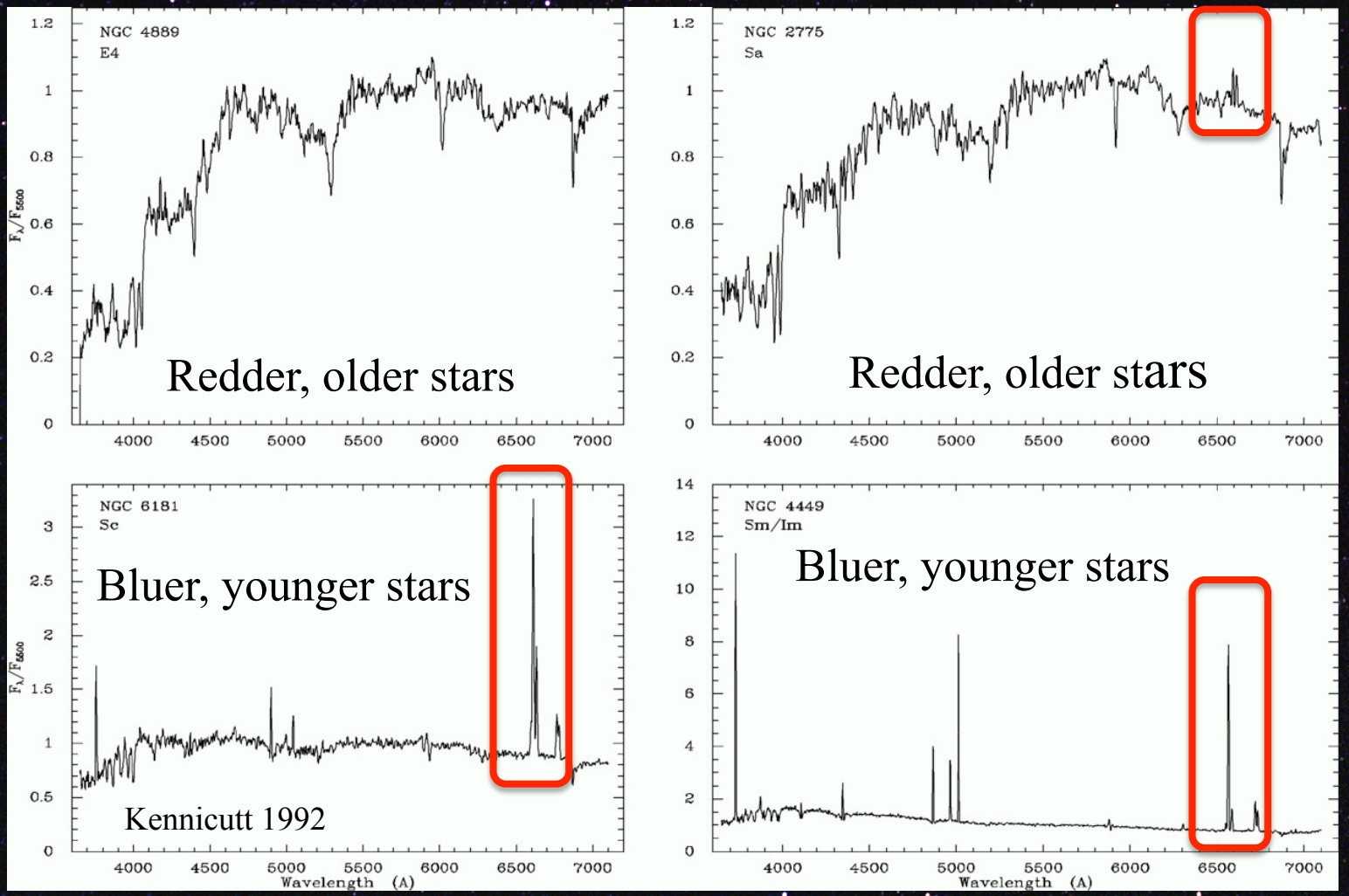


Example CMD

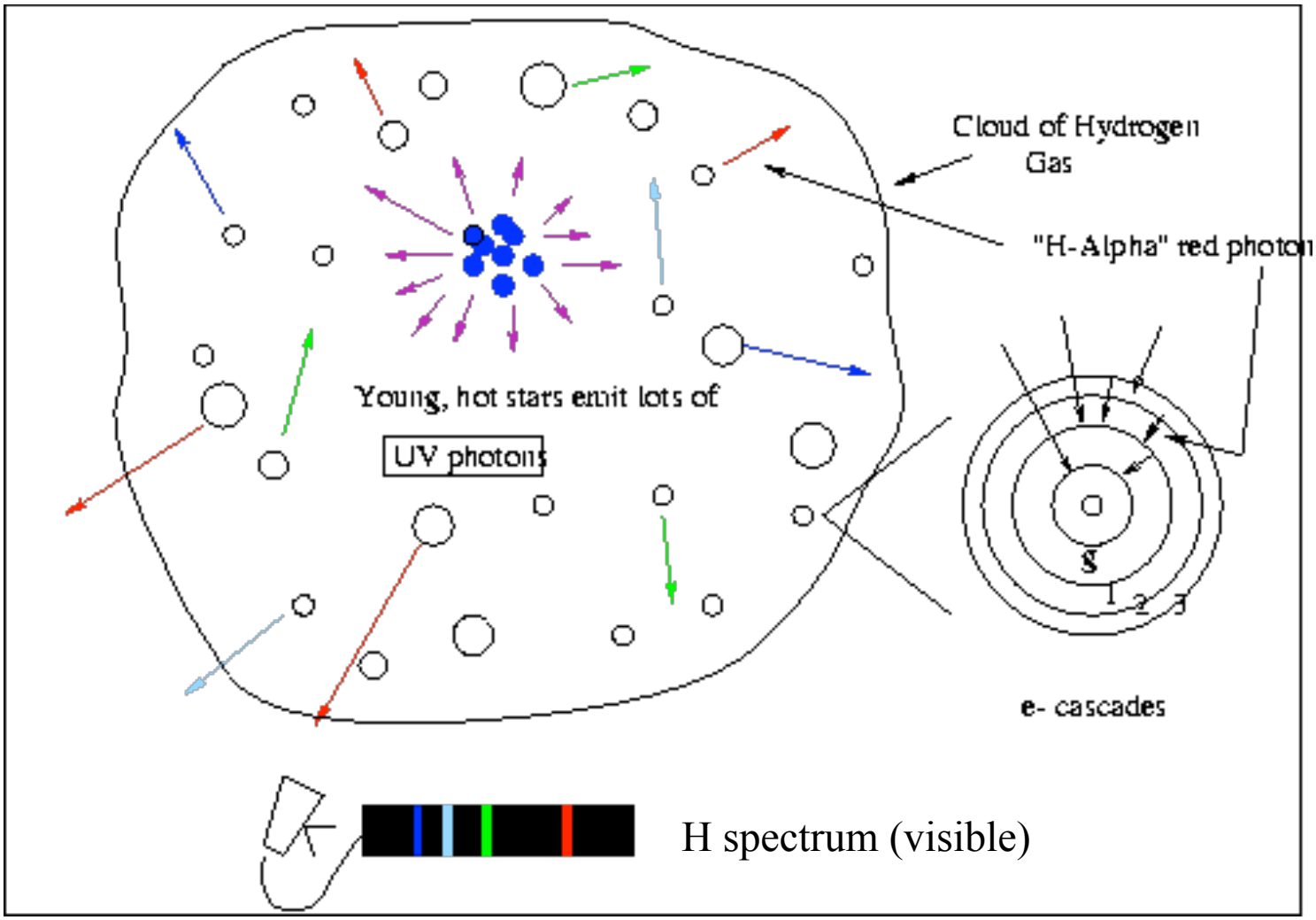

Gavazzi et al.: A snapshot on galaxy evolution in the Great Wall
g – i
g–i (mag)
1.5
1
0.5
0
All
−16
−18
−20
−22
M_I
M_i − 5 log h_73 (mag)

Recombination Lines

Strength of emission lines varies with the age of the stellar population



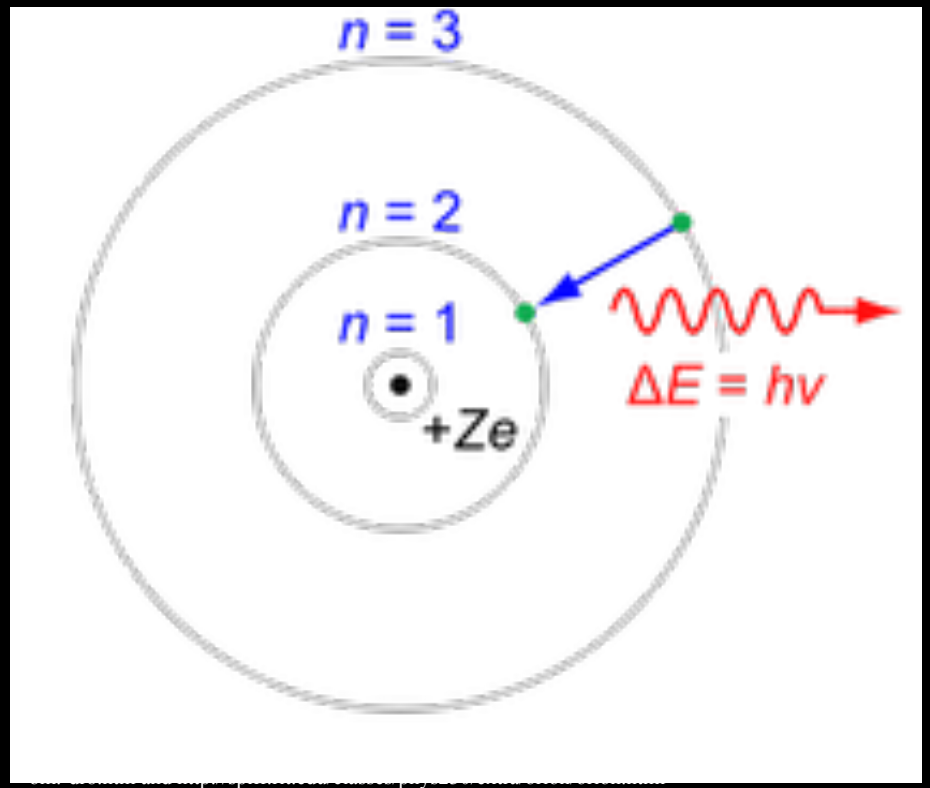
Ha Emission from HII Regions



http://www.ucolick.org/~bolte/AY4_00/week3/HII_region.gif

Ha as a Tracer of Star Formation

- Balmer Series n=3 to n=2 ; 656 nm
- Common line



Measuring Star Formation Rates from Hα

- Relate Hα flux to amount of ionizing radiation
  (Only stars with M >10 M⊙ and lifetimes <20 Myr contribute significantly to the integrated ionizing flux)

- Convert to total star formation rate using stellar initial mass function to determine how many stars of a given stellar mass to use (e.g. Kennicutt 1998)

$$SFR(M_\odot\ yr^{-1}) = 7.9 \times 10^{-42} L(H\alpha)(ergs\ s^{-1})$$

- Hα is used most commonly, but you can use other H lines too (Hβ, Paβ, Paα, Brγ)

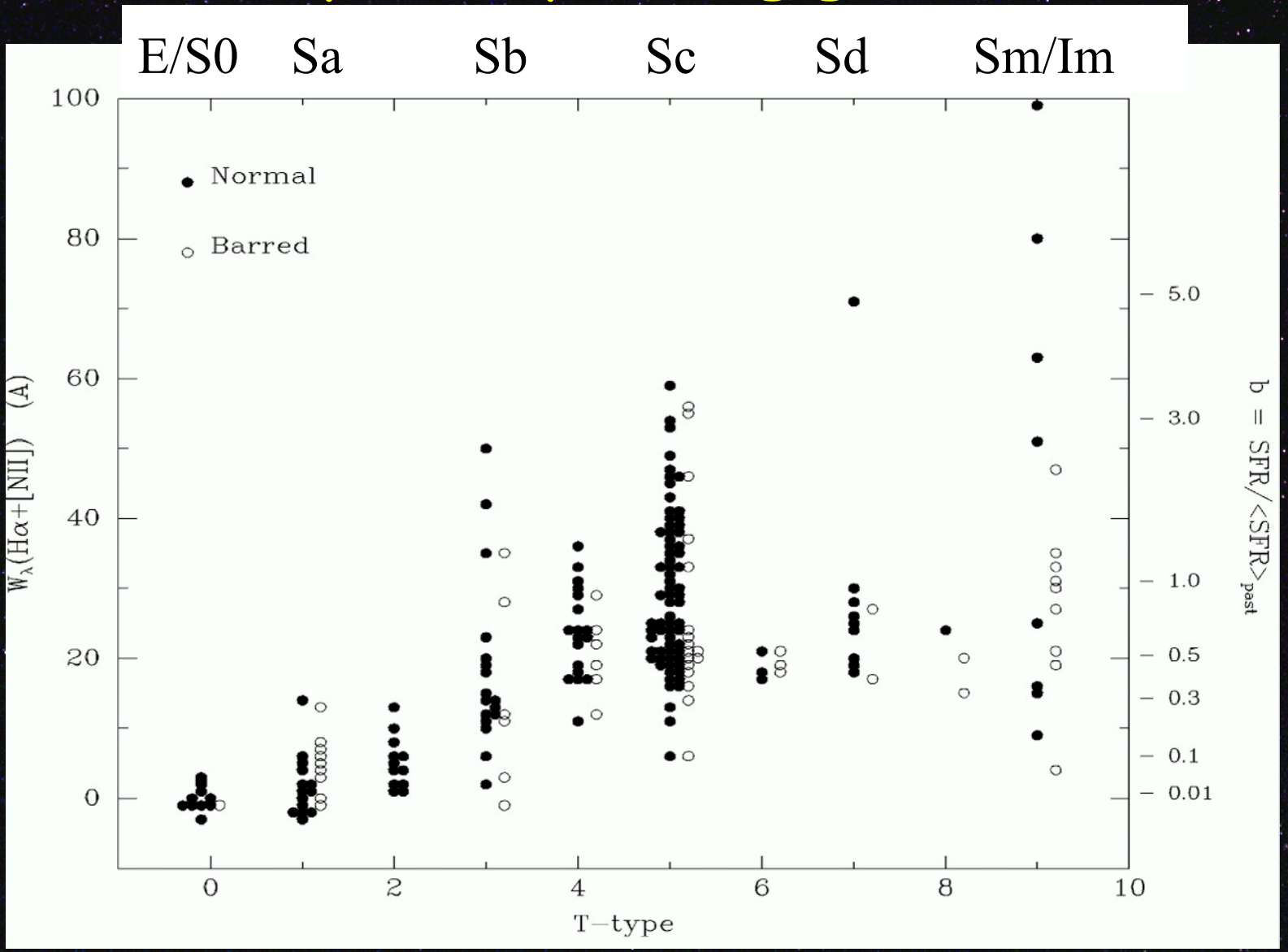
Many other indicators of star formation

- Other recombination lines: H, O
- Ultraviolet: direct tracer of hot stars (but extinction is a problem) GALEX
- Infrared: traces dust heated by hot stars
  - Spitzer, WISE
- All have caveats

Ideally use multiple indicators, e.g. Ha + IR

$$\mathrm{SFR}(M_\odot\,\mathrm{yr}^{-1}) = 5.3\times10^{-42}[L(\mathrm{H}\alpha)_{\mathrm{obs}} + (0.031\pm0.006)L(24\,\mu\mathrm{m})]$$

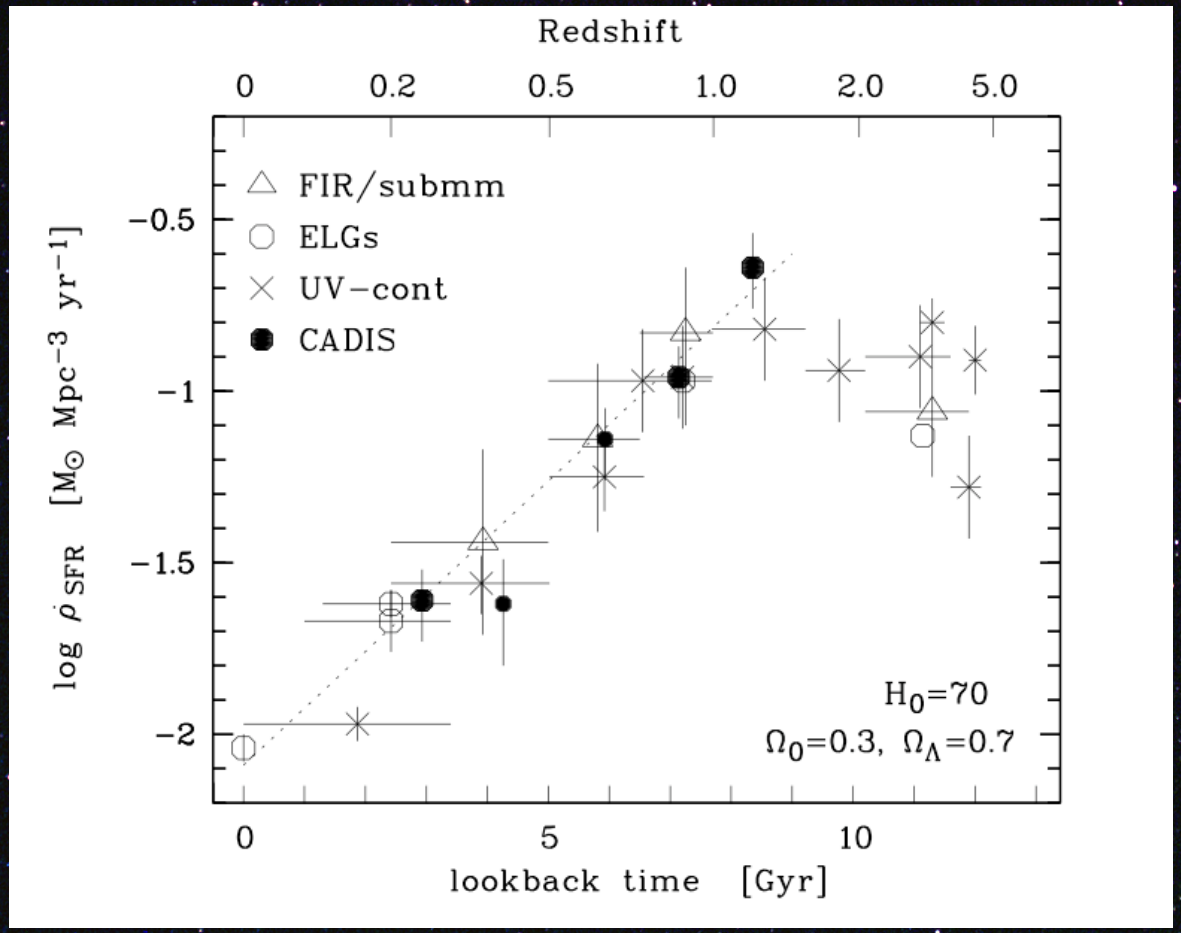
SFRs vary widely among galaxies



Kennicutt 1998

SFRs vary with redshift

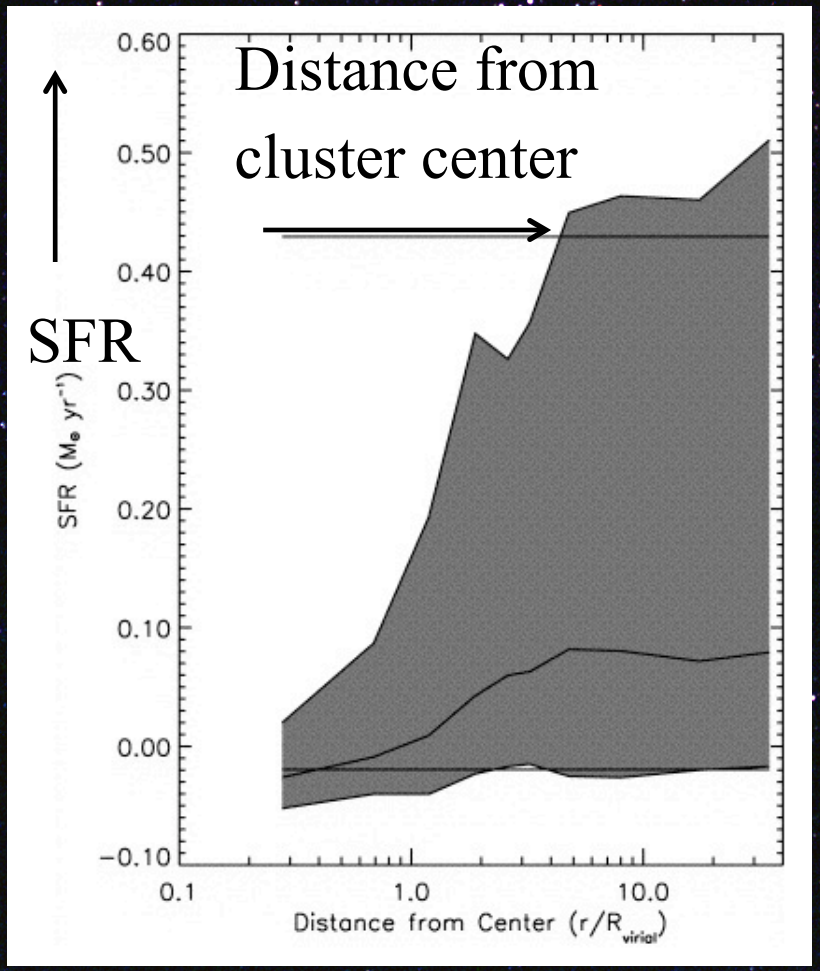
- Observation of high-redshift universe show that SFRs were higher in the past.

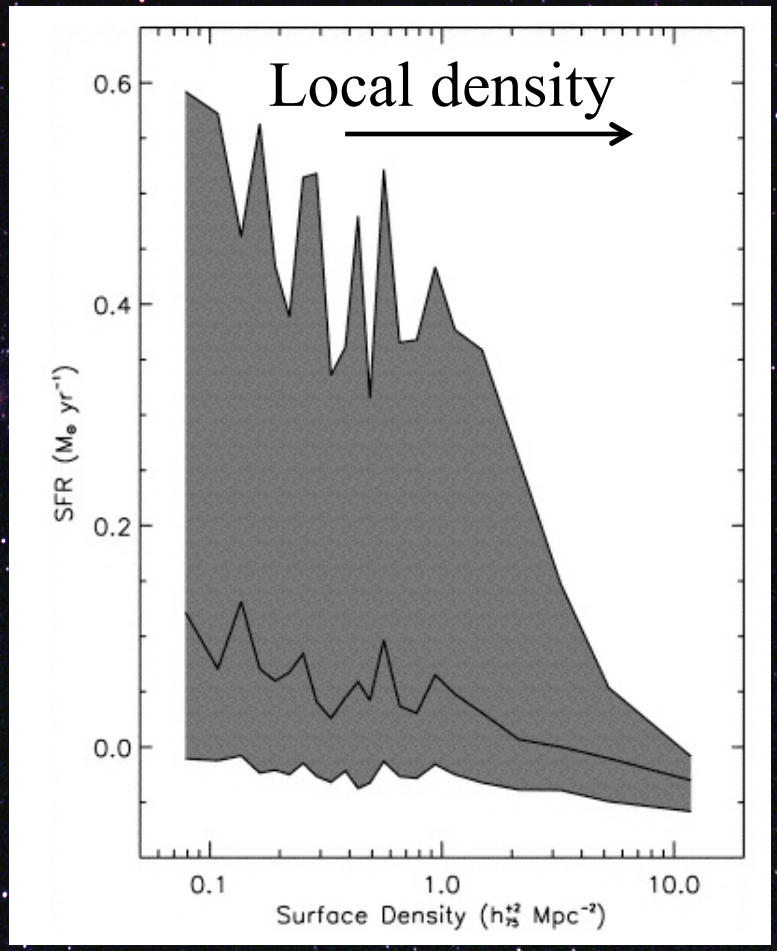


Hippelein et al. 2003

SFRs vary with Environment

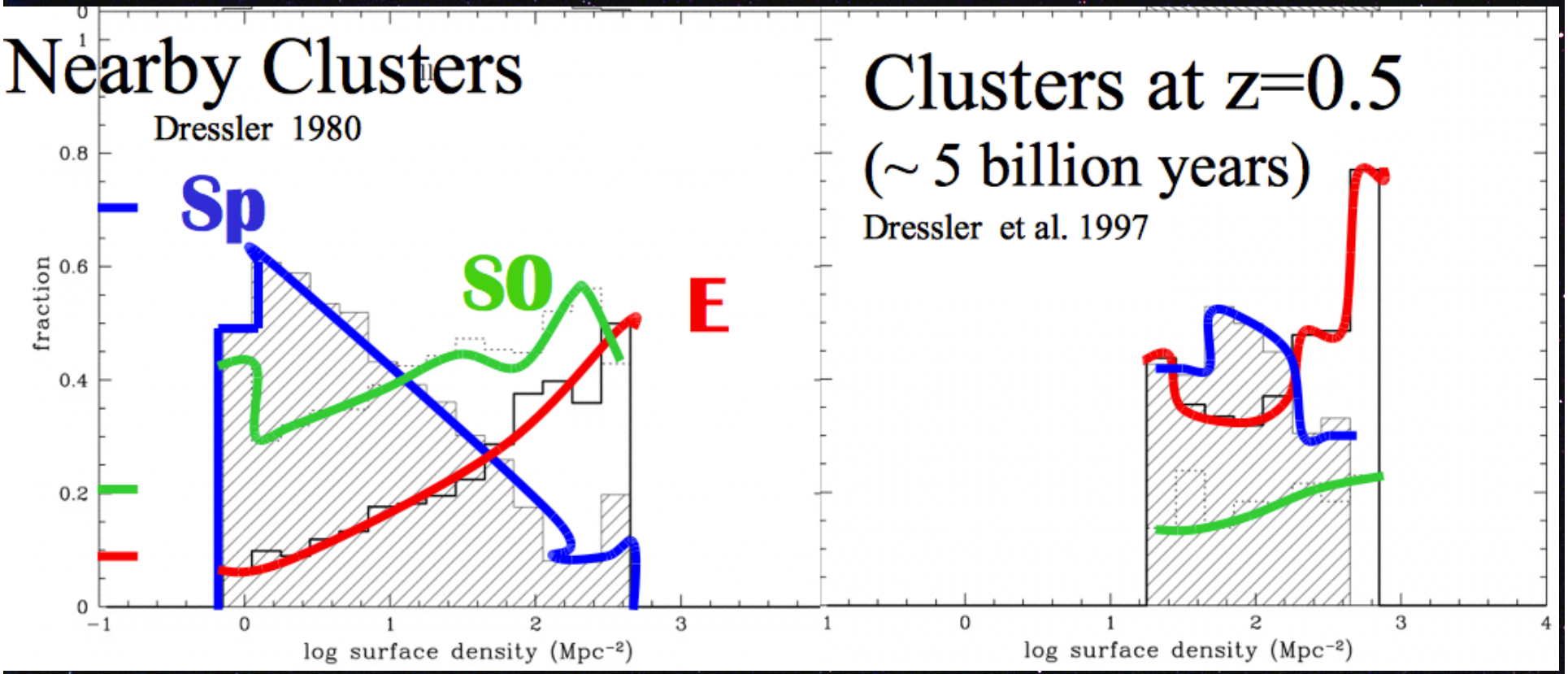
- Observations of local universe show that SFRs are lower in dense environments.





Results from Sloan Digital Sky Survey (Gomez et al. 2003)

Morphology-Density Relation



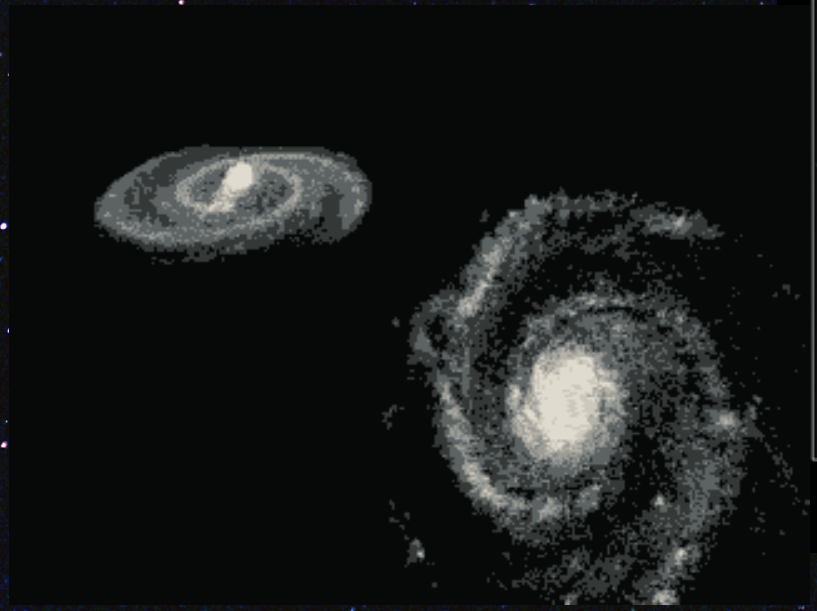
Galaxy Density → Galaxy Density →

Dependent on Environment, Time


Why do galaxy properties vary with environment?
Psychology of Galaxies
Galaxy Formation (Nature)
vs.
Galaxy Environment (Nurture)

Galaxy-galaxy Interactions

Interactions change distributions of gas and stars

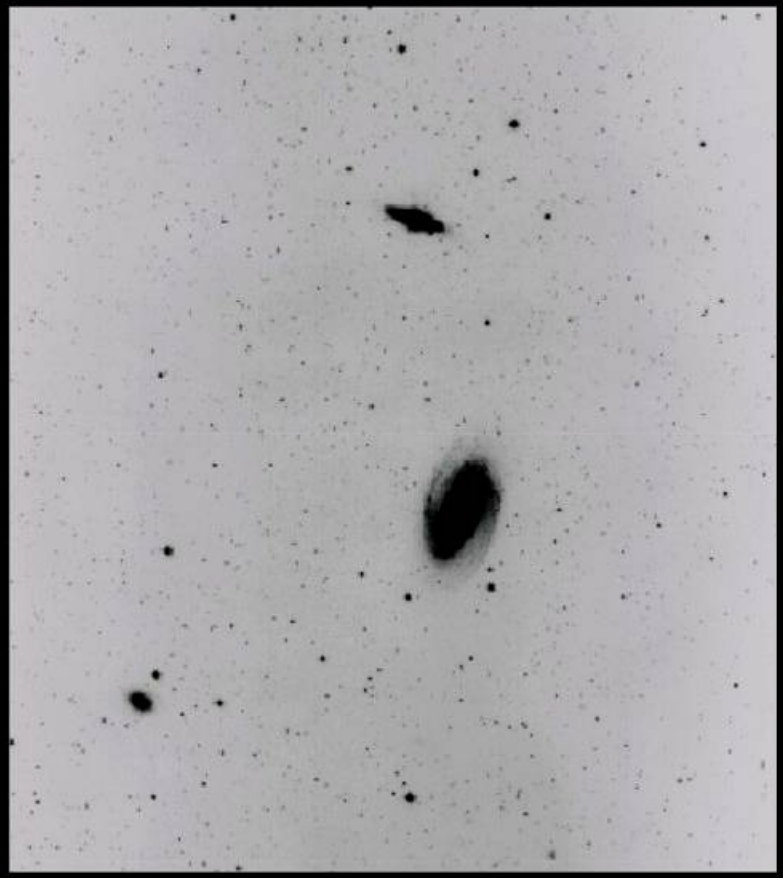


Types of Tidal Interactions

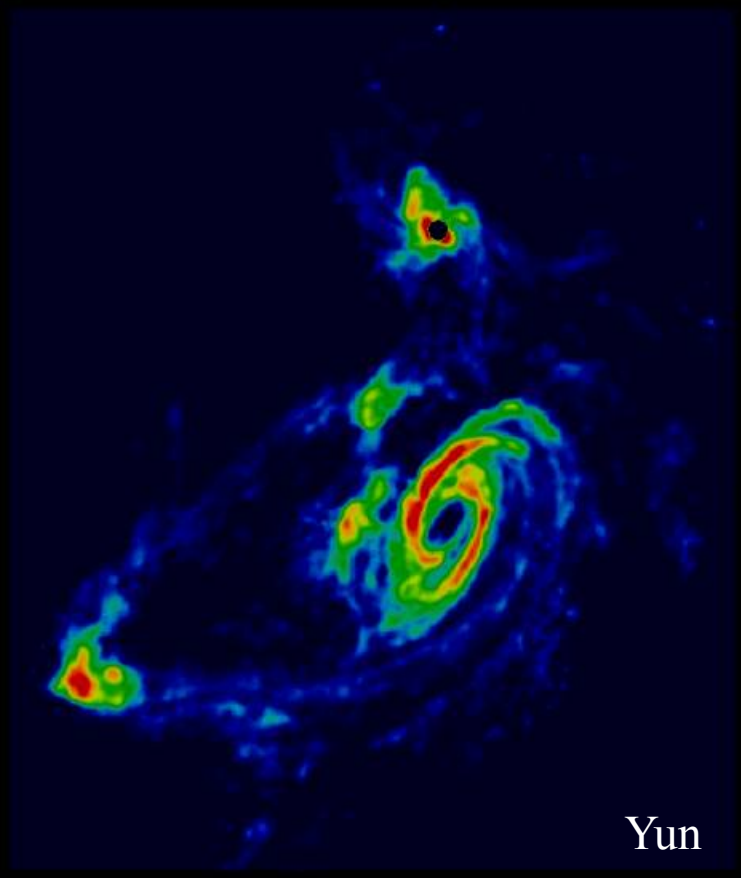
- ★ Result of interaction depends on
  - ★ Mass ratio
  - ★ Relative velocities
  - ★ Gas content
- ★ Merging / Cannibalism / Accretion
  - ★ Slower speeds, e.g., group environments
- ★ Non-merging
  - ★ Faster speeds, e.g. Cluster environments
- ★ Repeated: “Galaxy harassment”
- ★ These interactions affect gas and stars – change morphology?

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution



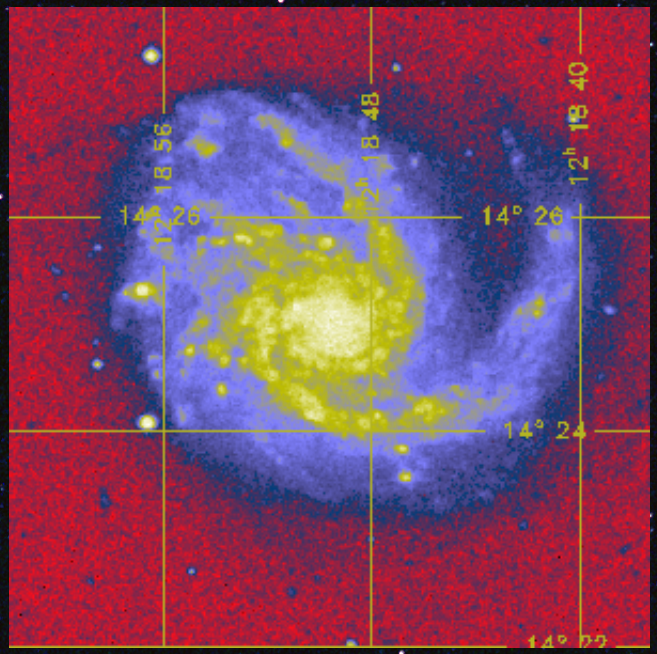
21 cm HI Distribution

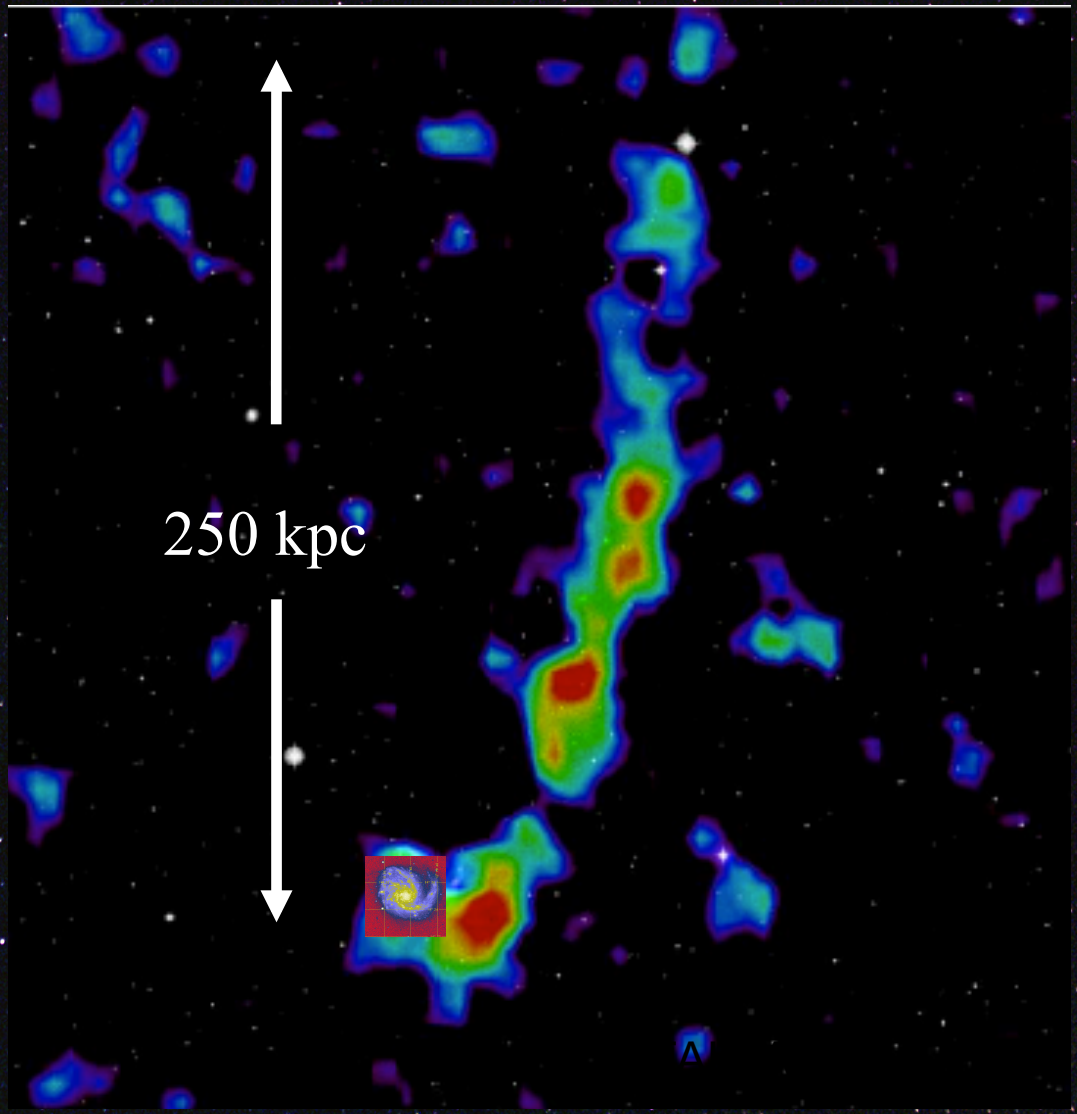


Gas sensitive tracer of interactions

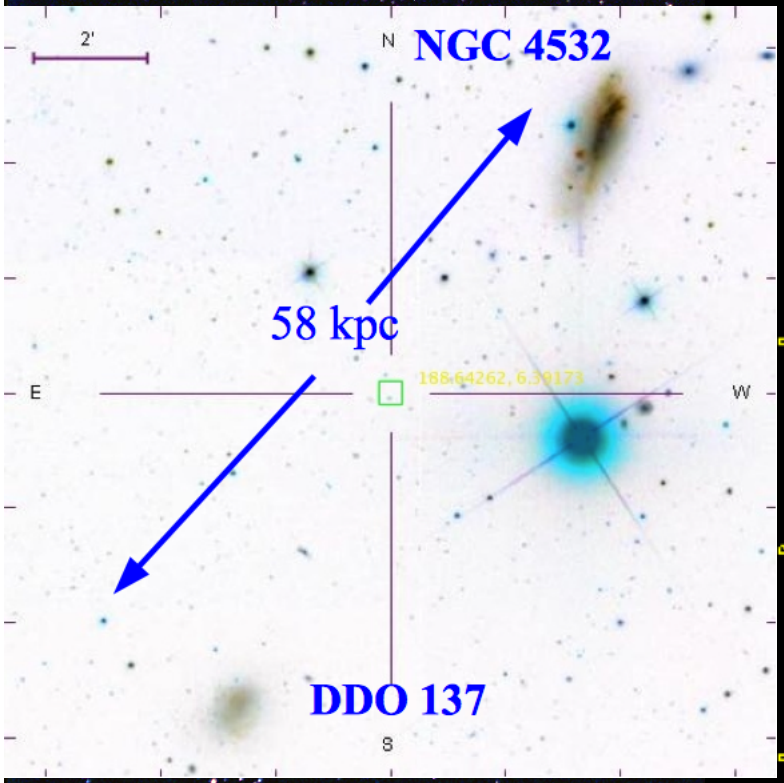
NGC 4254 in Virgo

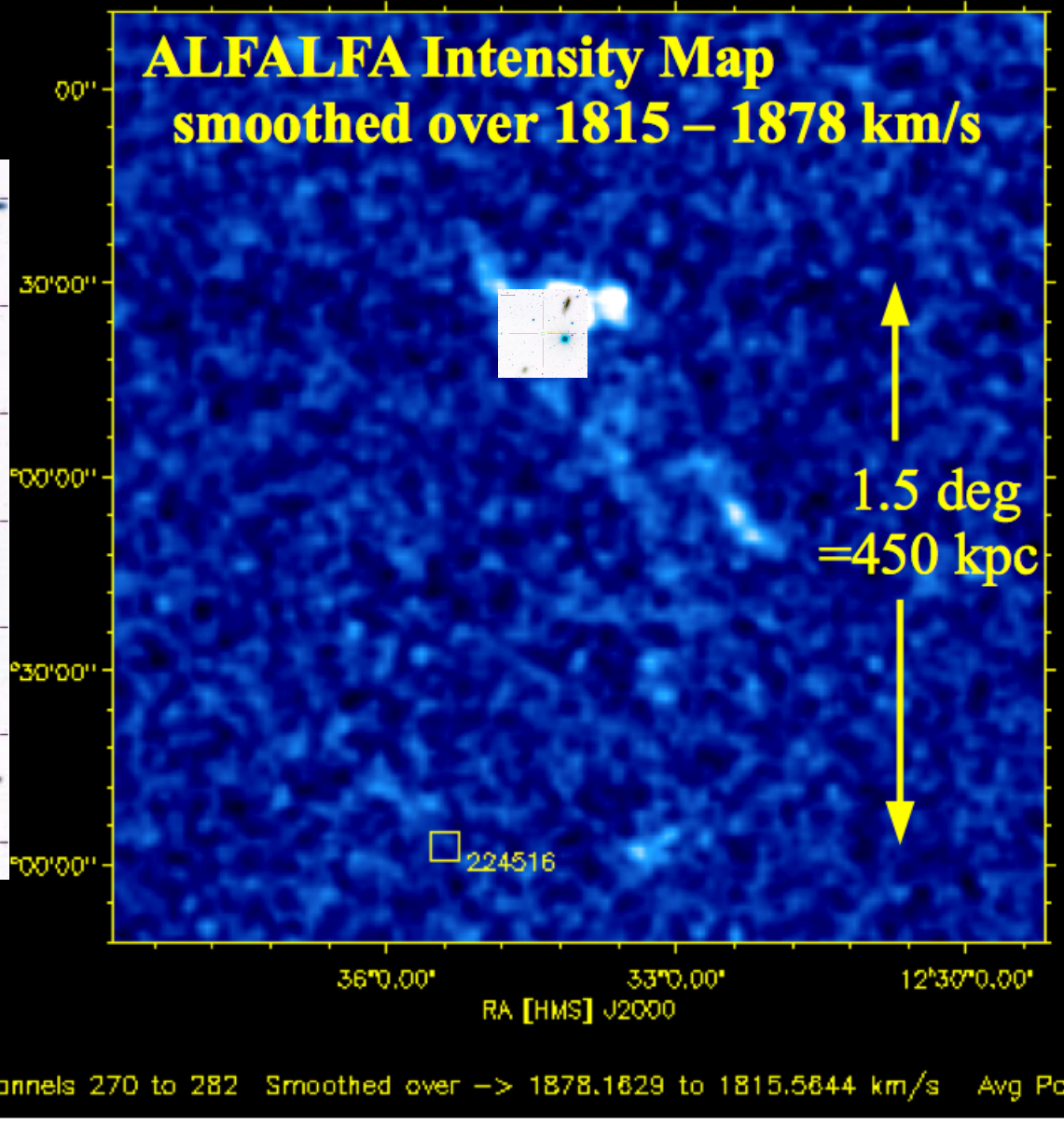
Haynes et al. (2007)



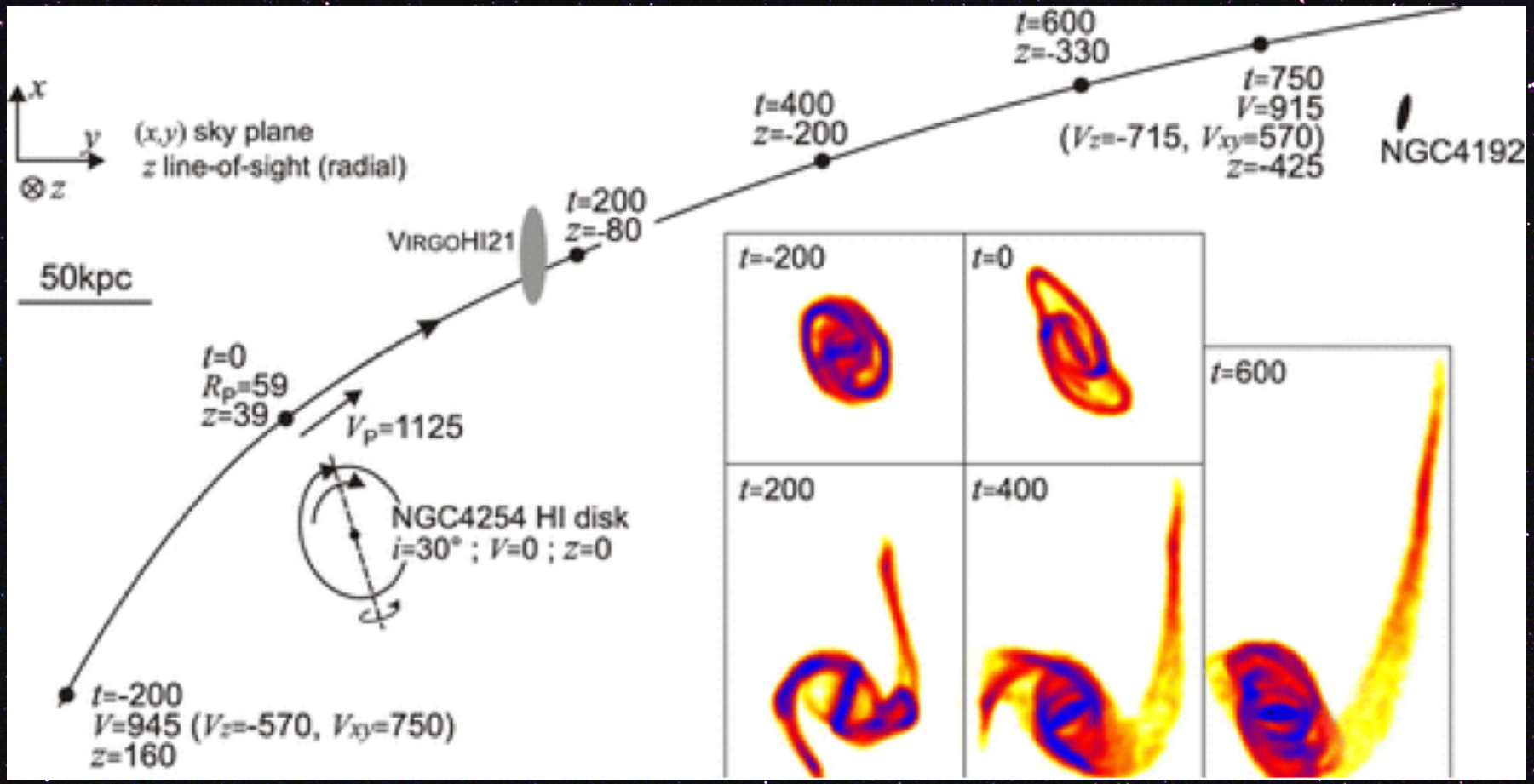


NGC 4532 in Virgo





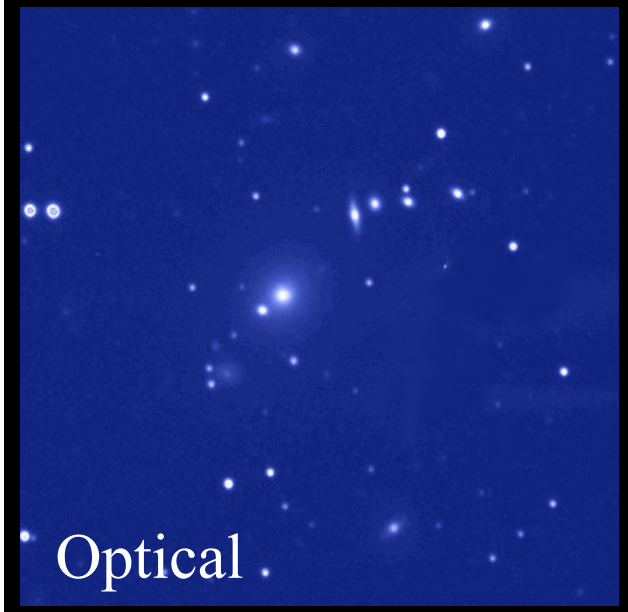
Koopmann et al. (2008)

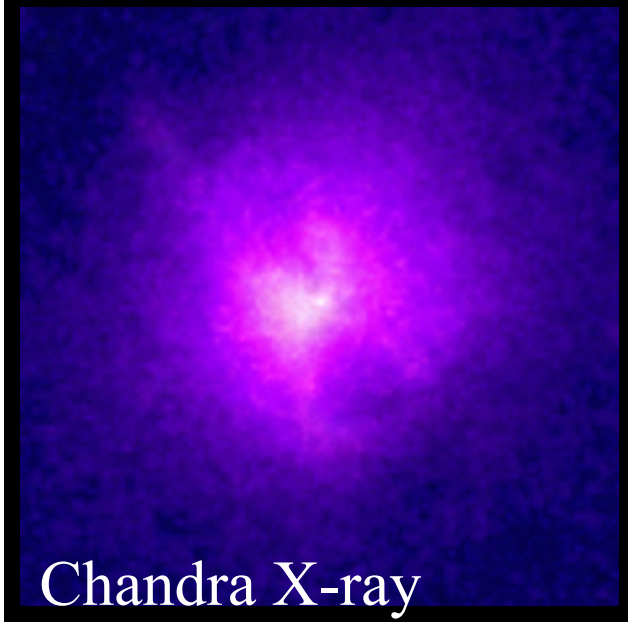


Duc & Bournaud (2007)

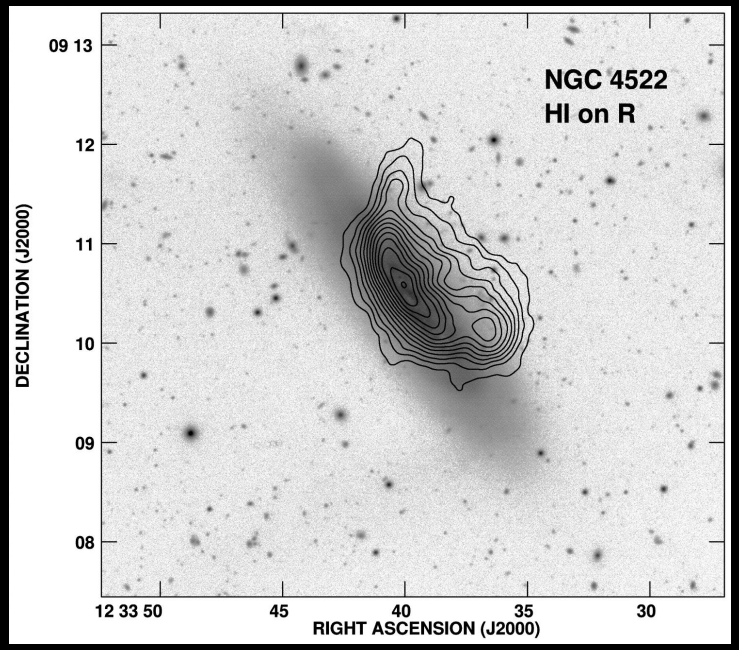
- 1100 km s^{-1}
- 750 Myr
- Mass ratio: 1:1.5
- Possible perturber: NGC 4192

Galaxy-Cluster Interactions: Ram Pressure Stripping

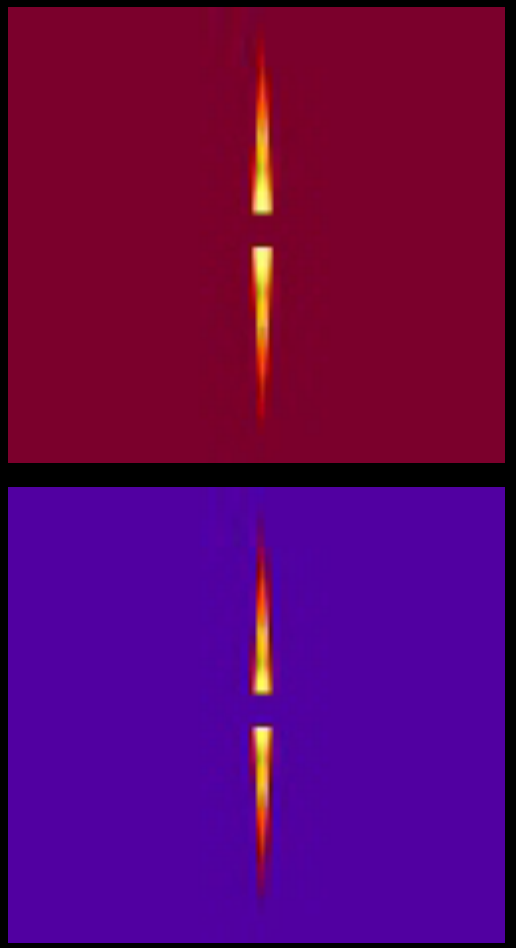




The hot intracluster medium strips neutral hydrogen gas (HI) from galaxies, but stars undisturbed



Kenney et al. (2004)

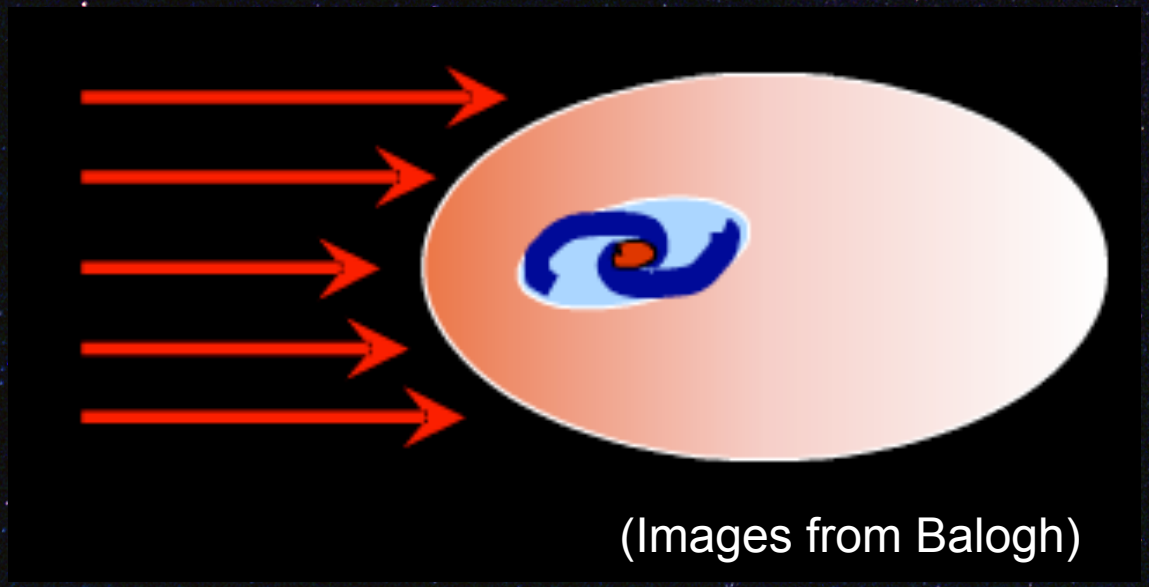


Piontek & Stone (2001)

Starvation/Strangulation

(e.g., Larson et al. 1980)

- Intragalactic medium (IGM) strips extended gas halo
- Milder form of gas stripping
- Prematurely halts star formation



(Images from Balogh)

Galaxies in Clusters: Truncated HI

HI Deficiency Parameter

$$\text{HI Def} = \log \frac{M_{HI}(\text{expected})}{M_{HI}(\text{observed})}$$

Giovanelli & Haynes (1983)
Solanes et al. (2001)
Toribio et al. (2012)

- HI stripped from outside in
- Ram-pressure?

Chung et al. 2007

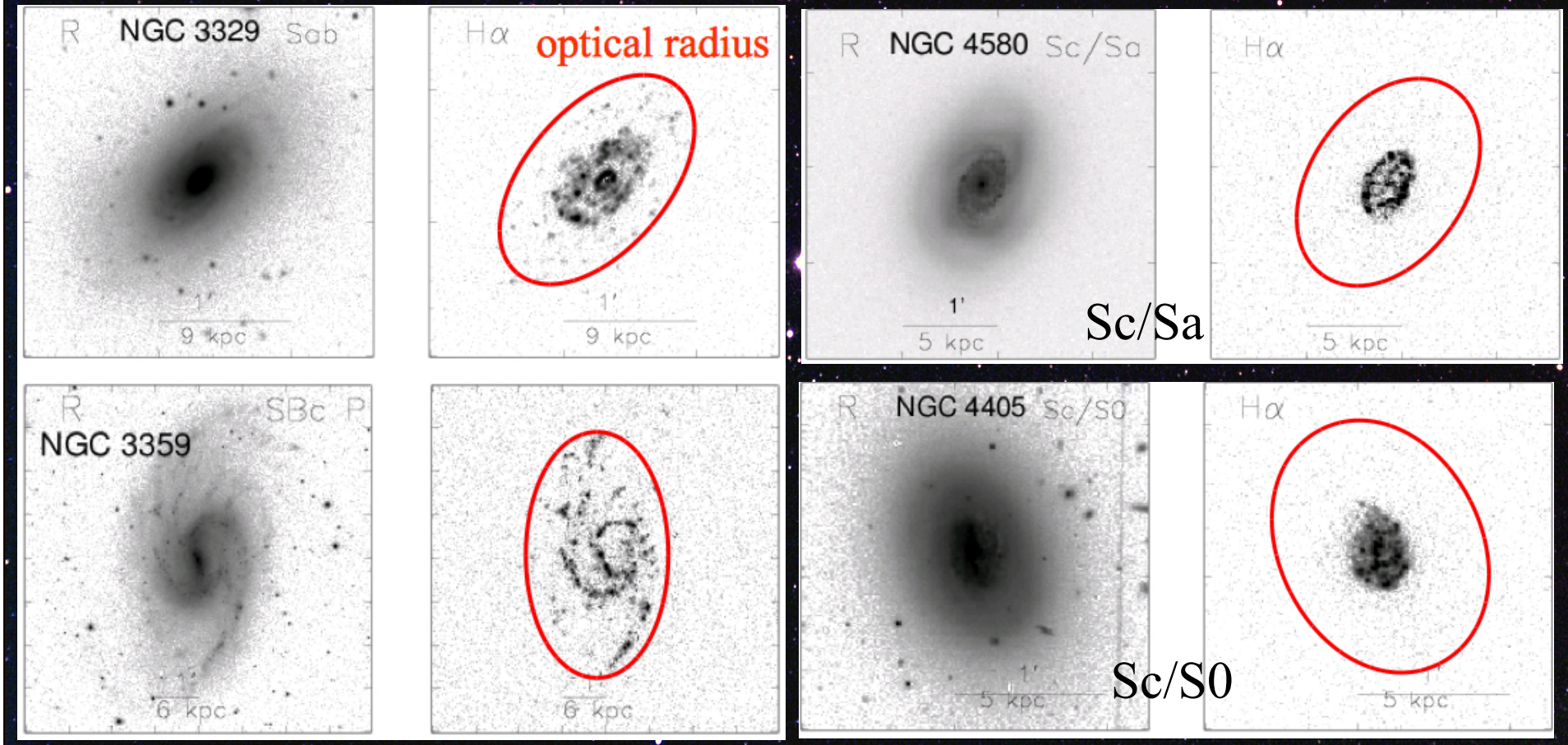
Star-Forming Disks Truncated in Virgo

Isolated

Isolated

Virgo

Virgo



Koopmann & Kenney (2004)

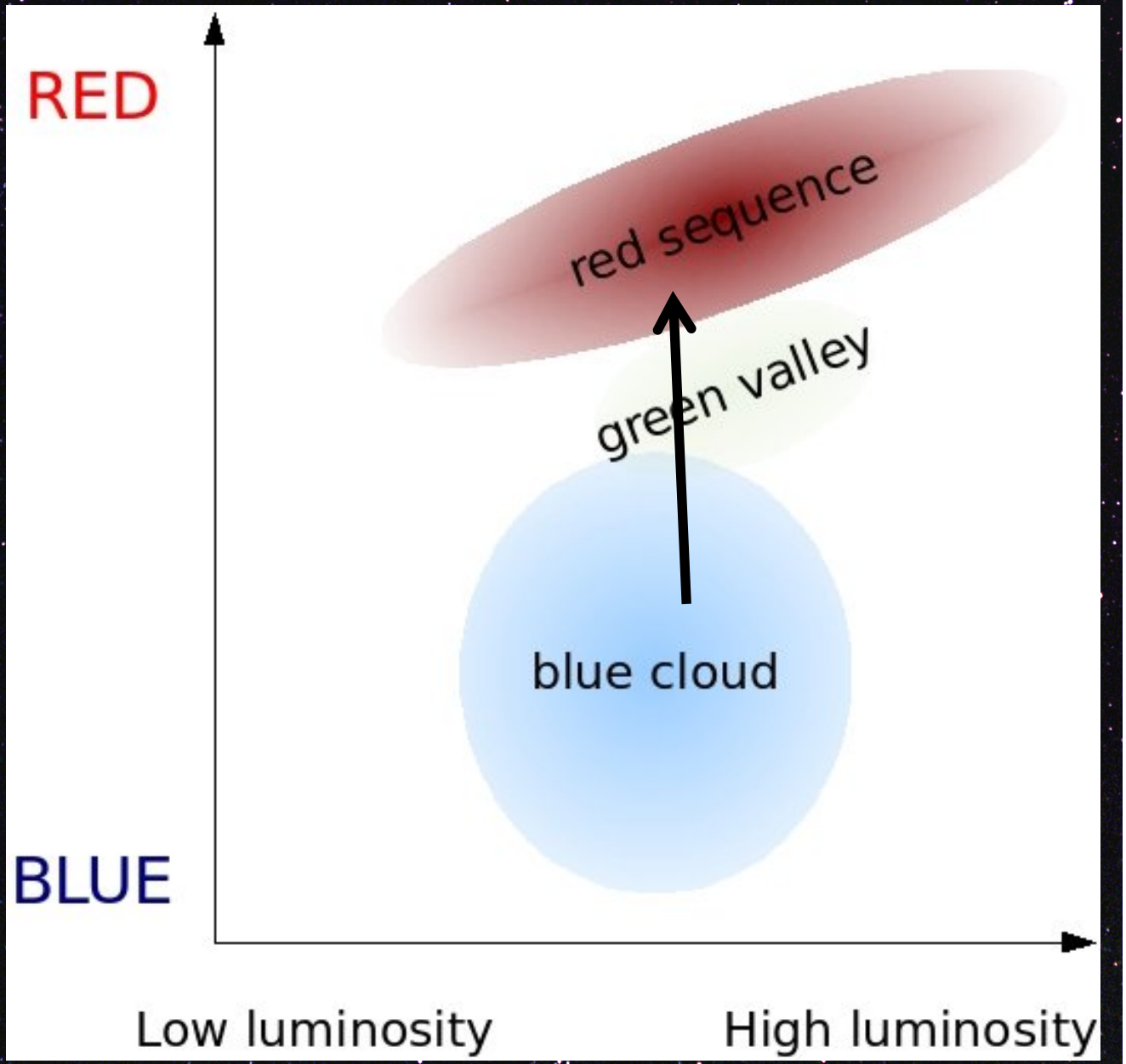
Which Environmental Effects Most Important?

Clusters:

- Conflicting results
- Tidal less important?
- How to explain morphology-density relation?

Groups:

- Less studied
- Tidal more important?
- Pre-processing?



UAT Groups Project

- 11 UAT Institutions
- Study properties of galaxies in groups within ALFALFA and SDSS footprints
- Groups have X-ray observations, some have intragroup medium

UAT Groups Ha Survey Data

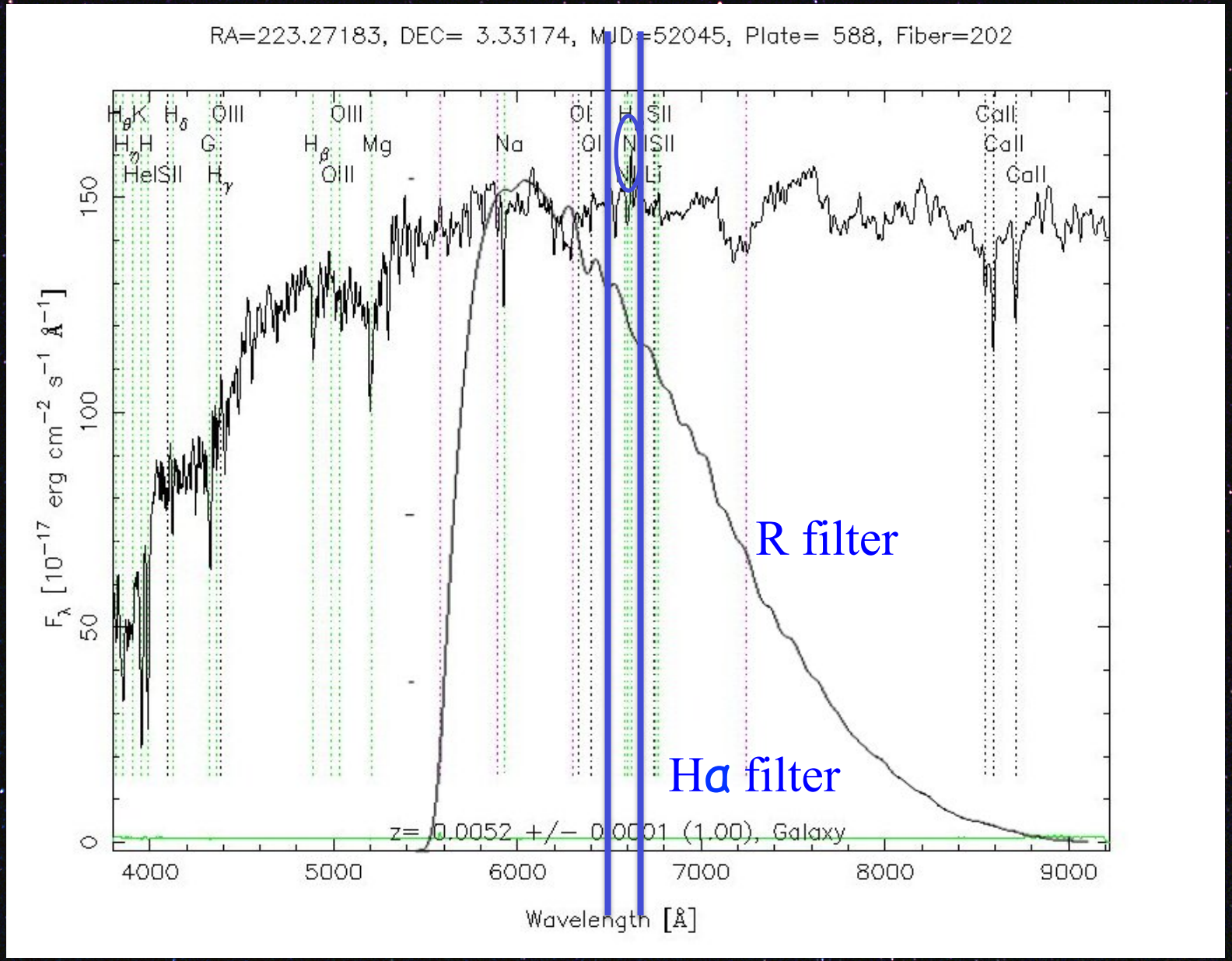
- MOSAIC CCD images from the 0.9 meter telescope at KPNO (Kitt Peak National Observatory) in Arizona
- 3 runs: 2011, 2012, 2013: NOAO/WIYN UWSP
- Broad band R Harris (15 min)
- Narrow band (80 Å) Ha filter (100 min)
- Central field and "outer" field
- All 11 UAT groups have at least 1 field

Team	Group	Alternate Name	# Fields Observed	# Fields Reduced
GSU	WBL 226	NRGb041	2	1
Siena	MKW 10	NRGb151	2	2
SLU	HCG 59	NRGb157	2	2
Hartwick	WBL 368	NRGb168	2	2
UWSP	WBL404/406	NRGb206	4	4
Skidmore/Siena	MKW 11	NRGb247	2	2
Colgate/SLU/ WTA&M	Zw 1400+09	NRGb282	5	4
St. Mary's	WBL 509	NRGb301	2	1
Siena/Colgate	WBL 251	NRGs076	1	0 (part missing)
Union	NGC 5846		7	7
Lafayette	WBL 477	NRGs272	1	1
Siena LCS	NGC 6107	NRGs385	1	0
Siena LCS	MKW 8		1	1

Example of R and Ha Image

R Filter Image

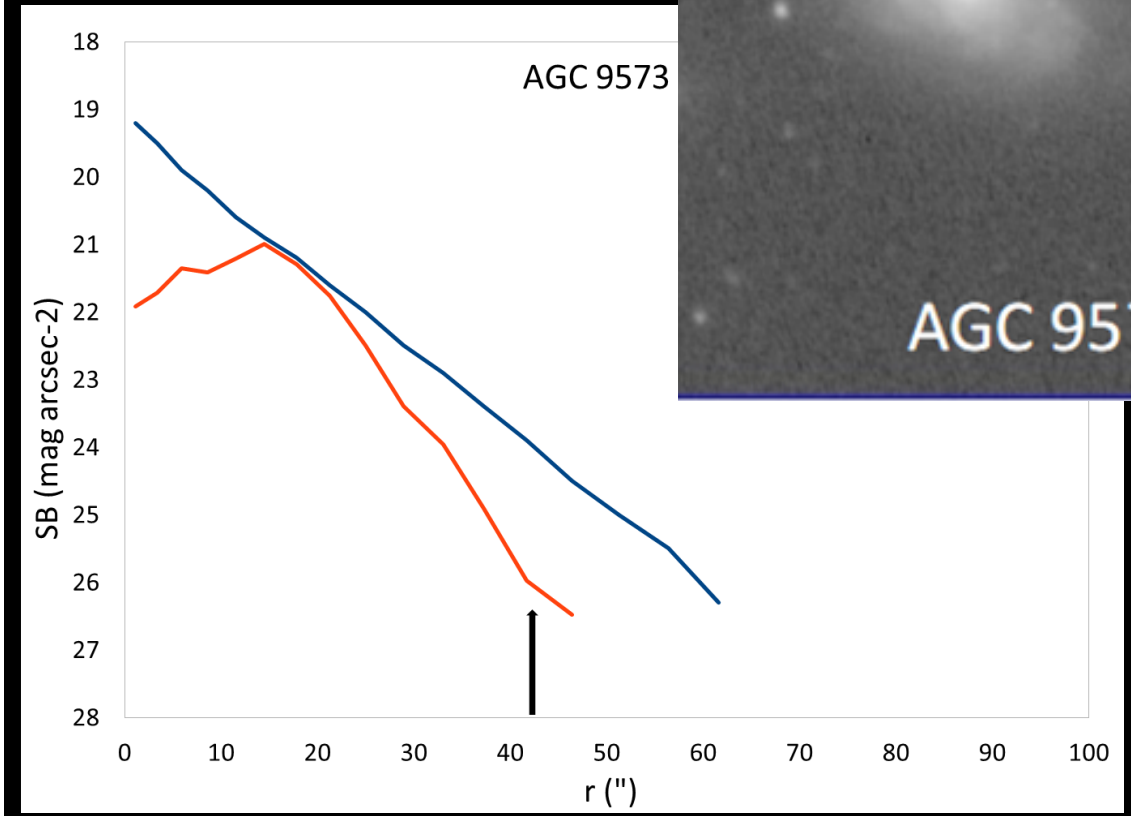
Ha Filter Image

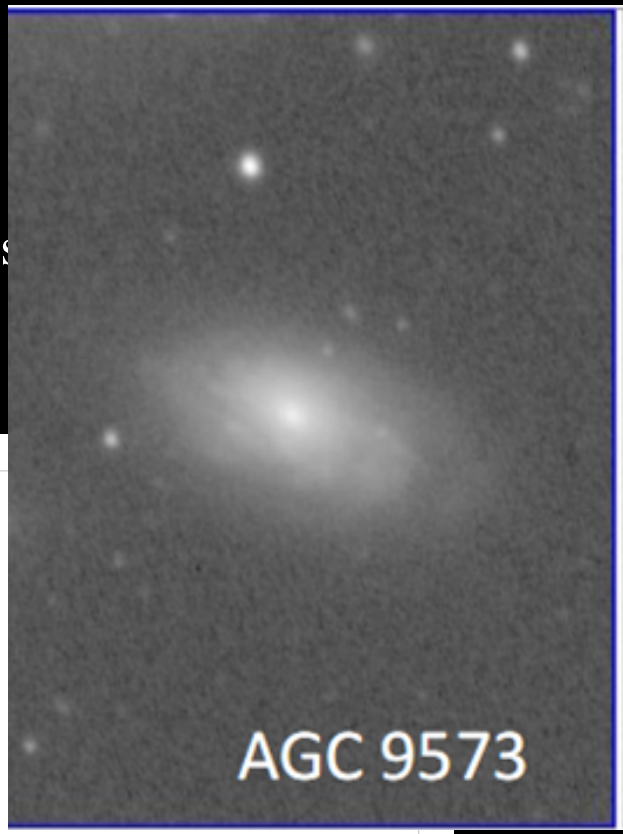


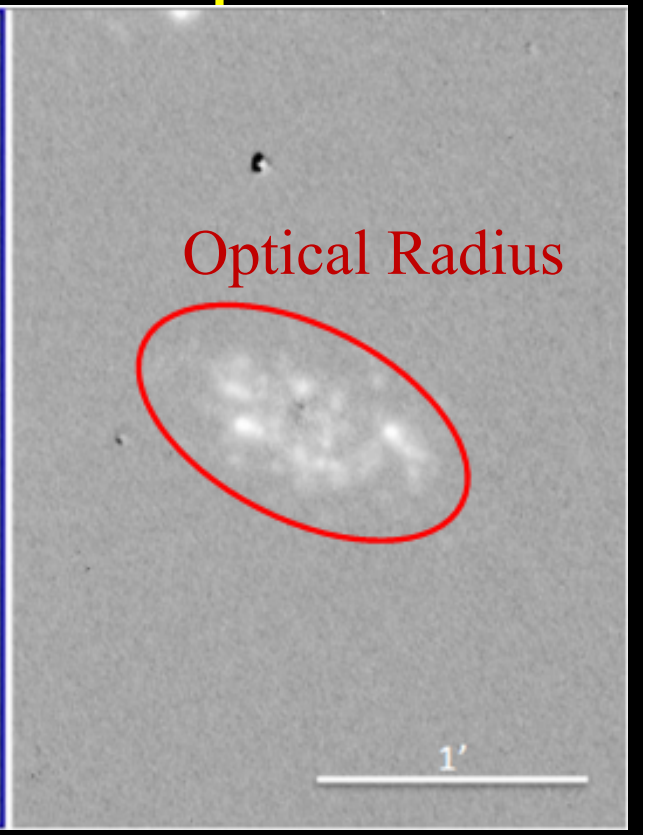
Images from: http://www.ctio.noao.edu/instruments/filters/index.html and http://cas.sdss.org

NGC 5846 Radial Profile Examples

Graphs show surface brightness as a function of radius, with surface brightness found by averaging flux over elliptical annuli

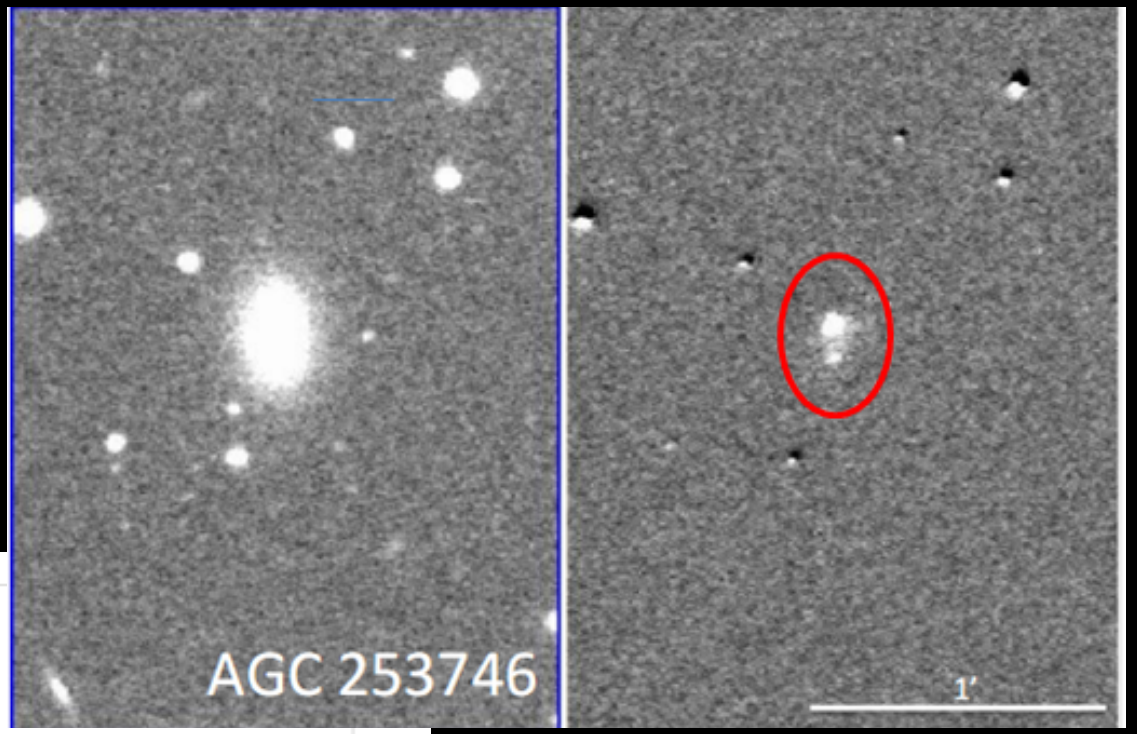


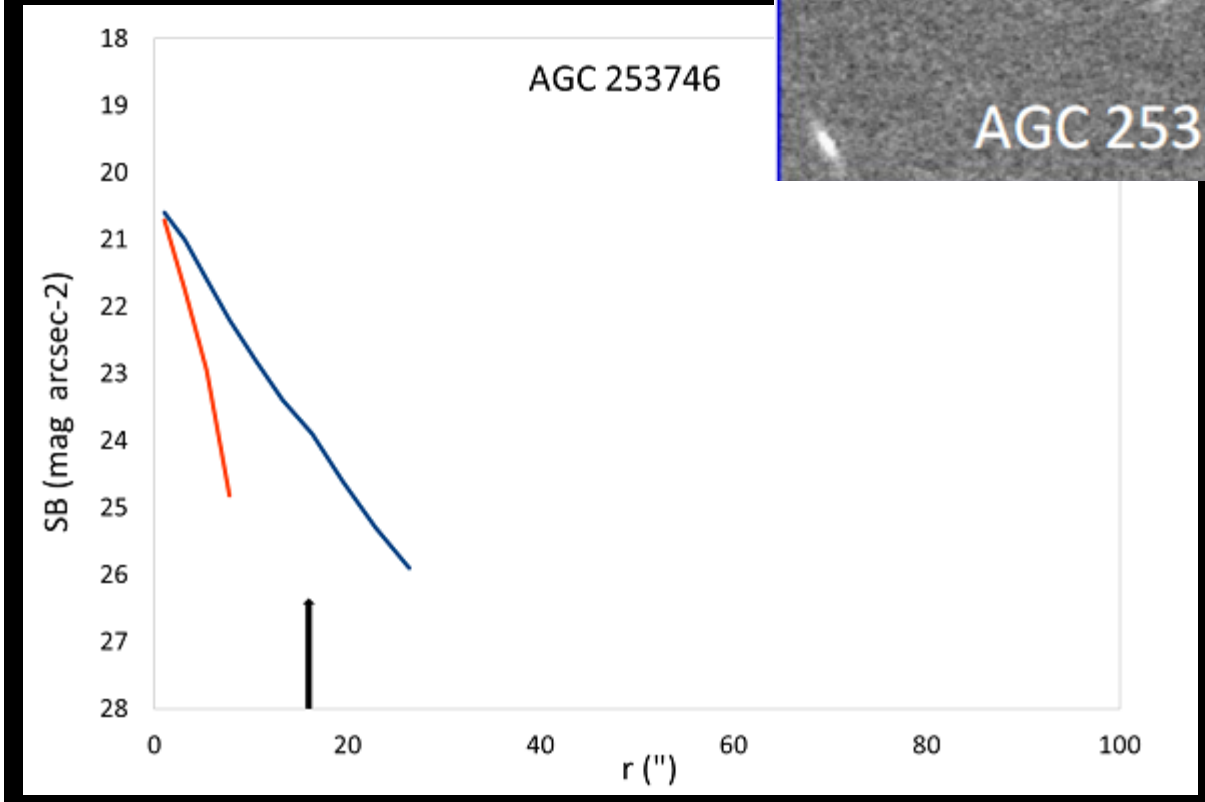




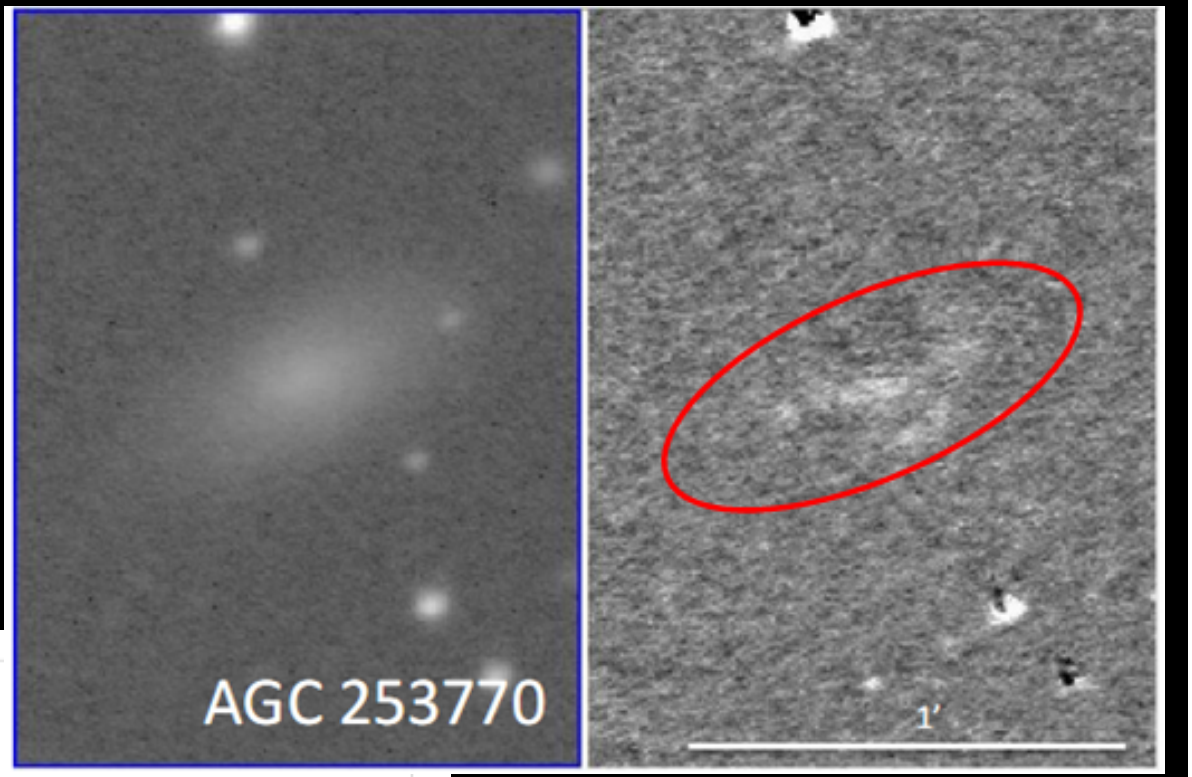
This galaxy exhibits star formation over most of its optical extent

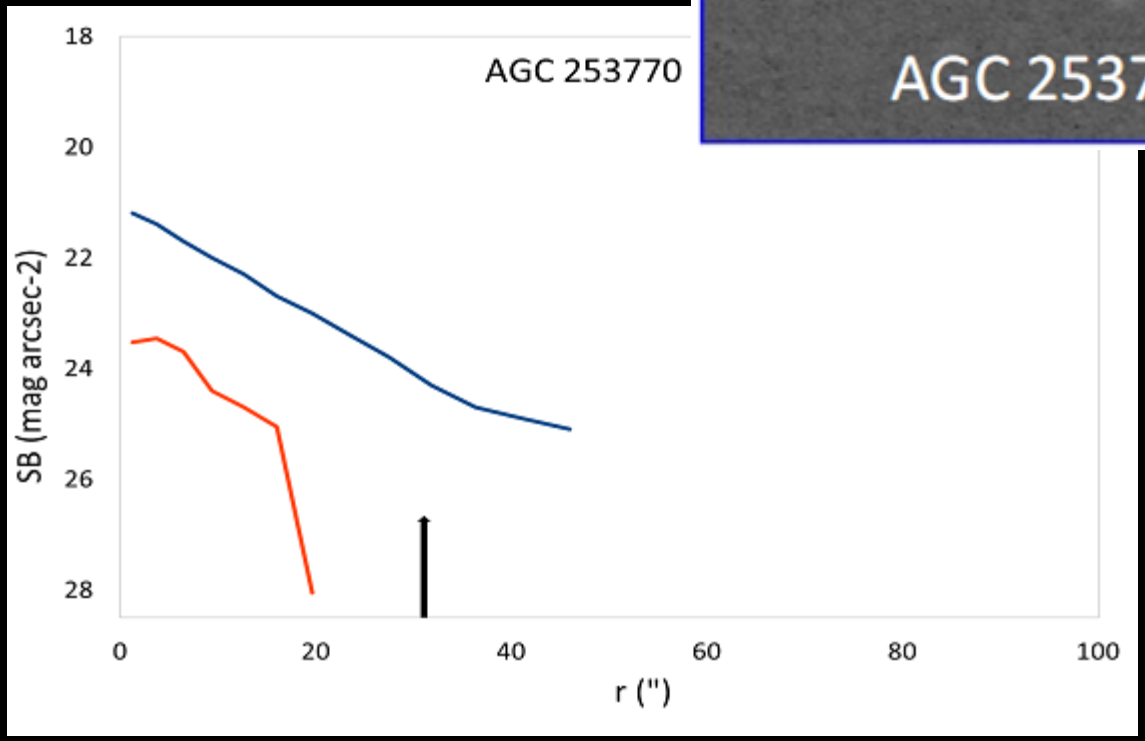
Truncated Star Formation





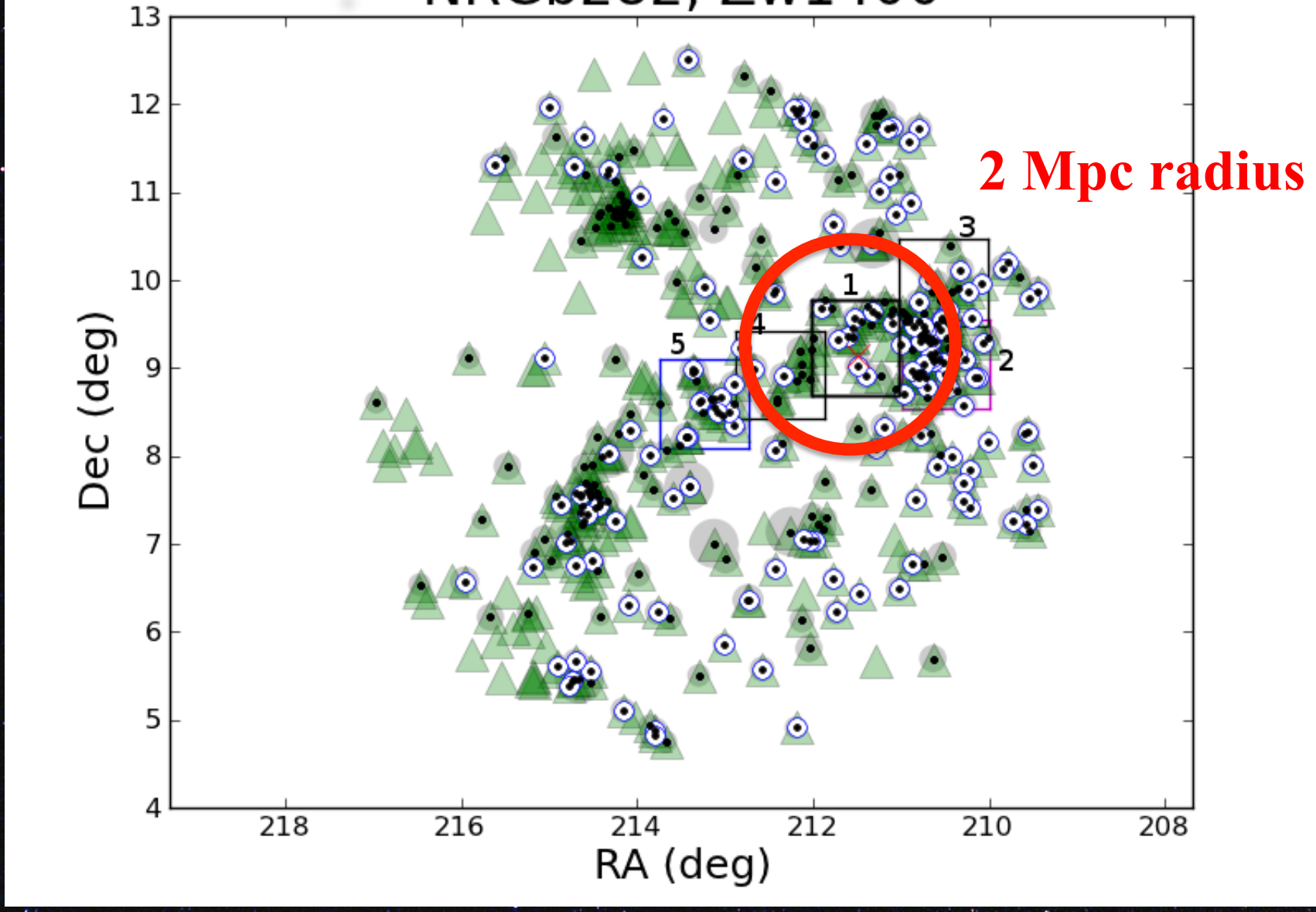
Truncated and Depressed Star Formation



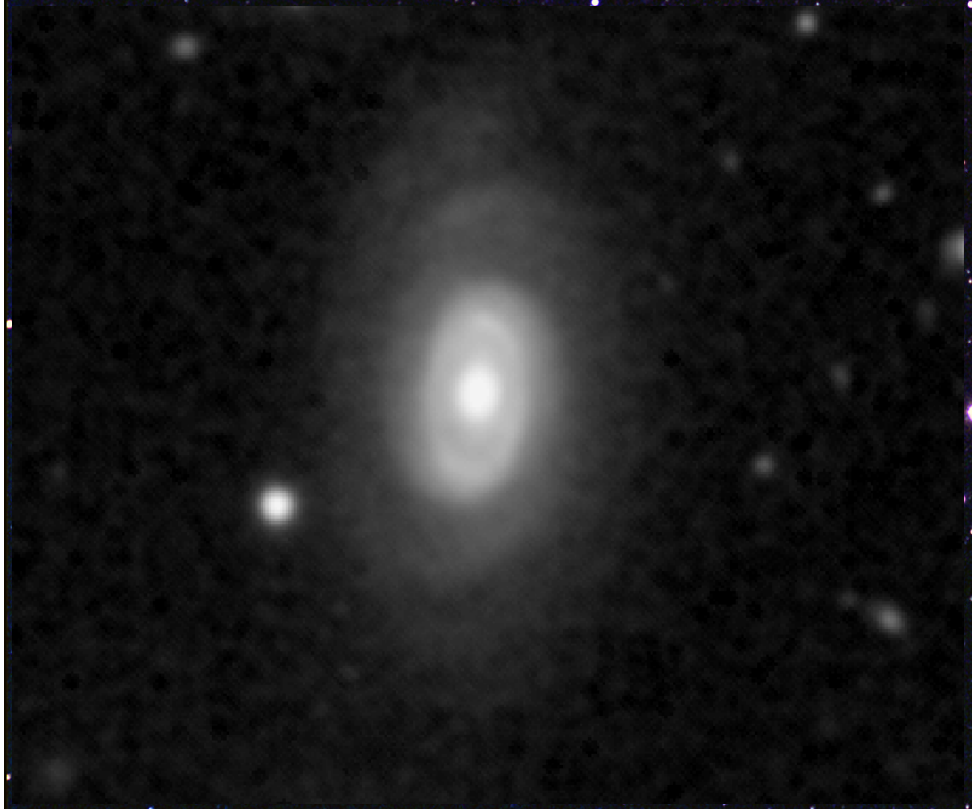


Ha Imaging leads to Follow-up with LBW

- ★ Low mass galaxies and HI-depleted galaxies not detected by ALFALFA
- ★ Star formation indicates gas is present
- ★ Select galaxies for followup:
  - ★ Ha emission in KP image
  - ★ Galaxies w/in 2 Mpc of group center and w/in reasonable velocity range that have SDSS emission lines indicating star formation
  - ★ No/marginal ALFALFA detection


NRGb282, Zw1400
Dec (deg)
RA (deg)
13
12
11
10
9
8
7
6
5
4
218
216
214
212
210
208
1
2
3
4
5
2 Mpc radius

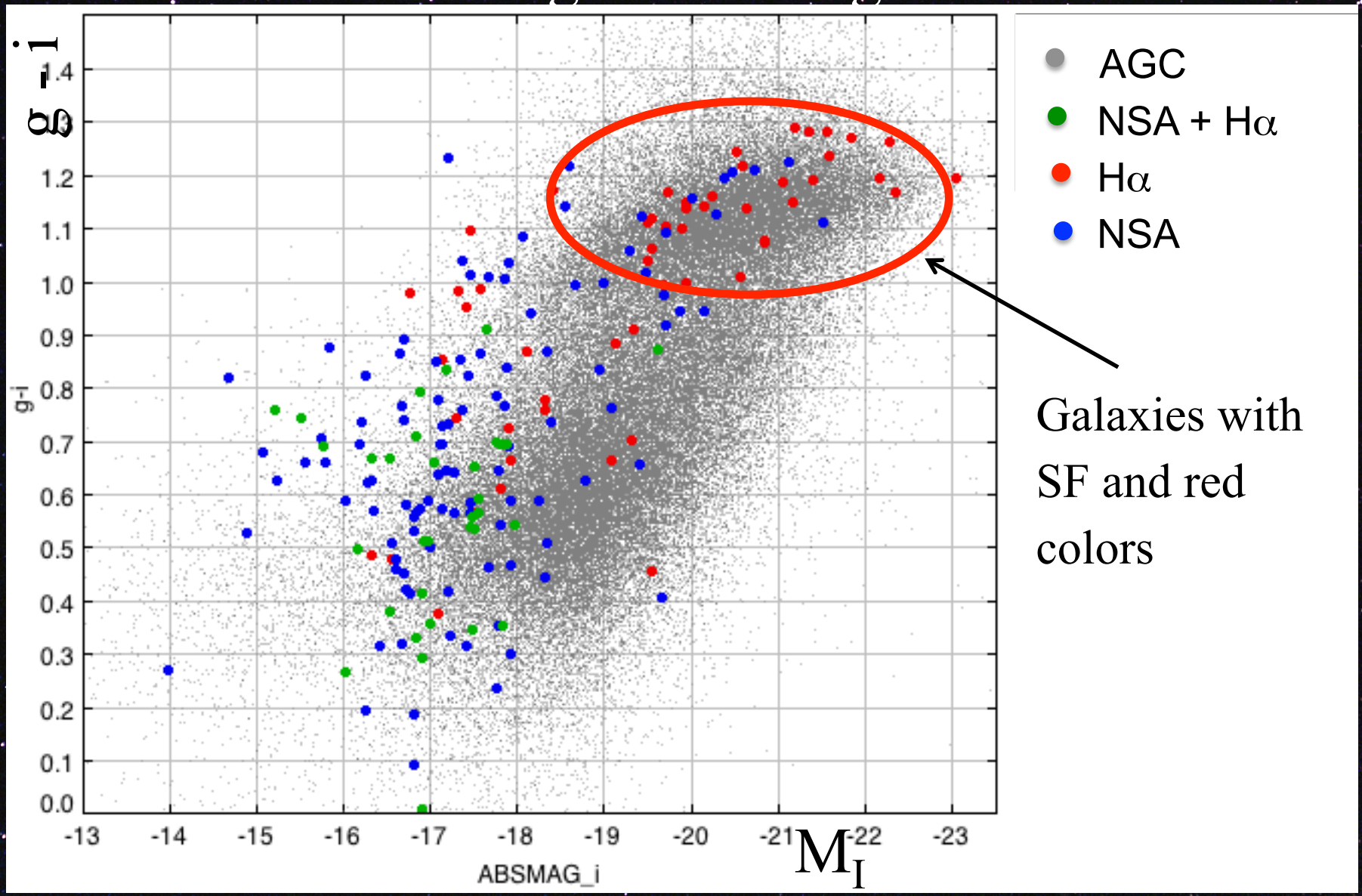
AGC 8478 (MKW 11)



Important caveat for spectra:

SDSS Fiber ~ 4” → only central SF traced

Color-Magnitude Diagram




Let's reduce/observe!