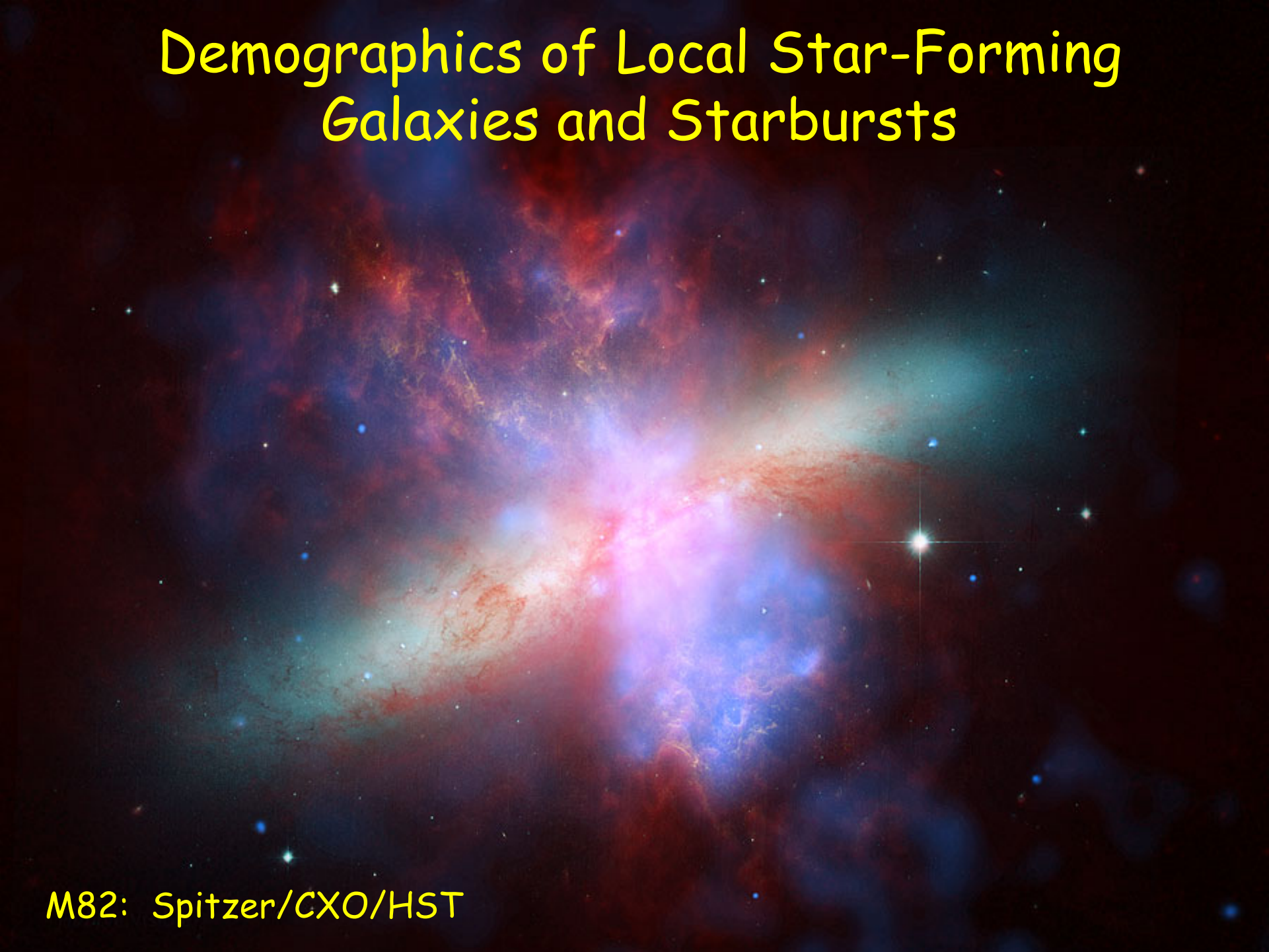
Demographics of Local Star-Forming Galaxies and Starbursts



M82: Spitzer/CXO/HST

Primary Datasets

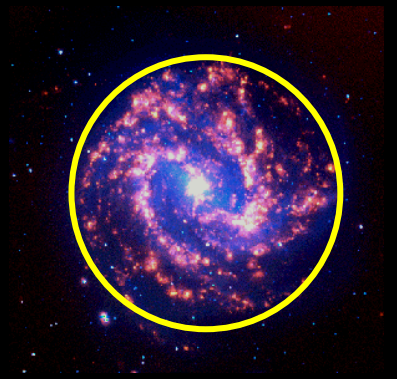
- Spitzer Infrared Nearby Galaxies Survey (SINGS)
  - resolved UV → radio mapping of 75 galaxies
  - selection: maximize diversity in type, mass, IR/optical
- 11 Mpc Hα/Ultraviolet Survey (11HUGS)
  - resolved Hα, UV imaging, integrated/resolved IR of 400 galaxies
  - selection: volume-complete within 11 Mpc (S-Irr)
- Survey for Ionization in Neutral-Gas Galaxies (SINGG)
  - resolved Hα, UV imaging, integrated/resolved IR of 500 galaxies
  - selection: HI-complete in 3 redshift slices
- Integrated Measurements
  - Ha flux catalogue (+IR, UV) for >3000 galaxies within 150 Mpc
  - integrated spectra (+IR, UV) for ~600 galaxies in same volume
    (Moustakas & Kennicutt 2006, 2007)

Demographics of Star-Forming Galaxies

Baseline: 11 Mpc Hα + Ultraviolet Survey (11HUGS)

- all known galaxies w/gas within 11 Mpc + Ursa Major cluster
- companion GALEX Legacy survey coming…

Quantify SF properties in terms of 3 observables:

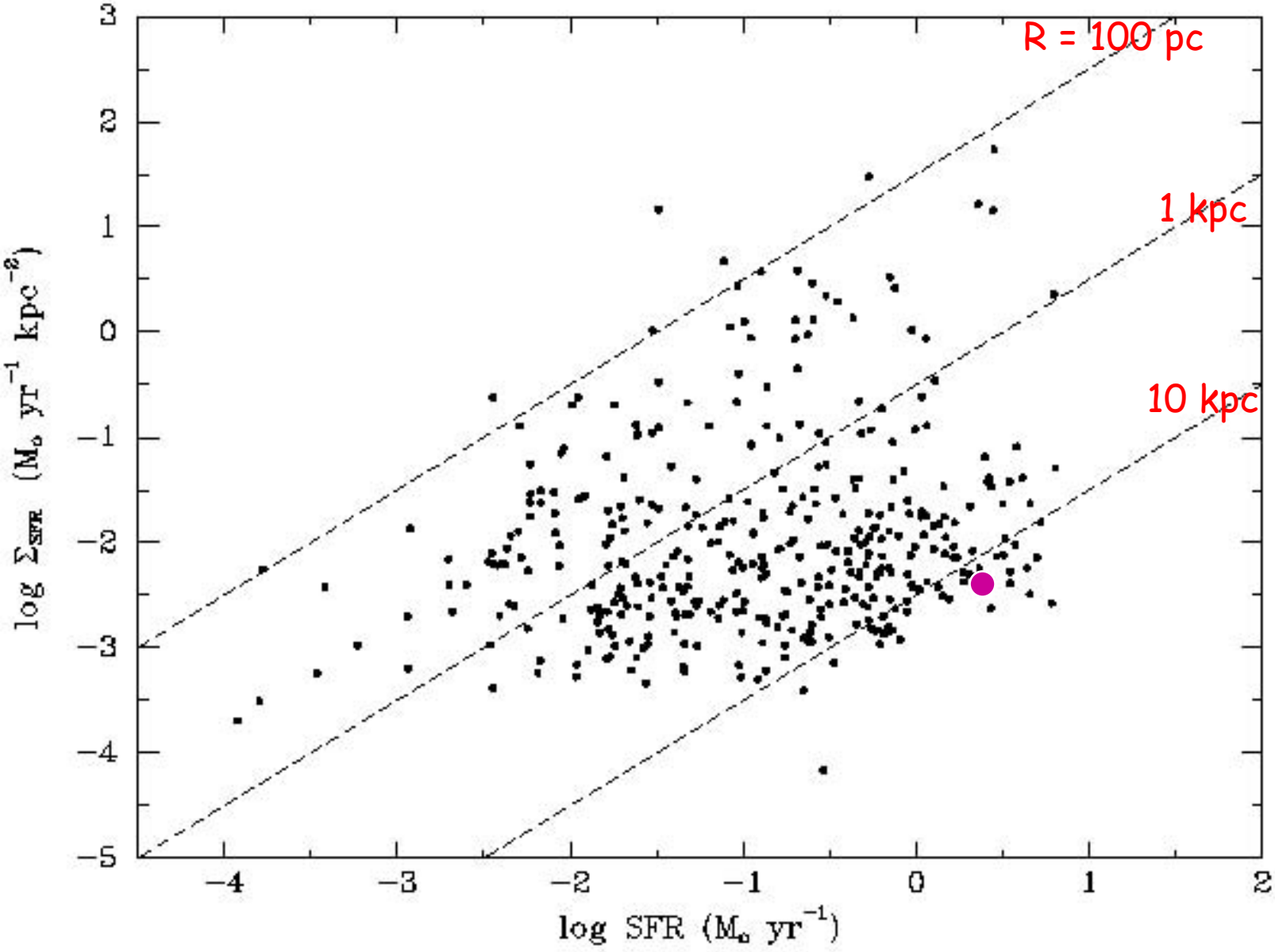


- absolute SFR (M_o/yr)
  - from Hα corrected for [NII], dust
- SFR density, intensity (M_o/yr/kpc^2)
  - defined as SFR/πR^2_{SF}
  - correlates strongly with gas density, SF timescale
- normalized SFR/mass; birthrate parameter b
  - ratio of present SFR to average past SFR
  - defined here globally – integrated over galaxy
  - primary evolutionary variable along Hubble sequence

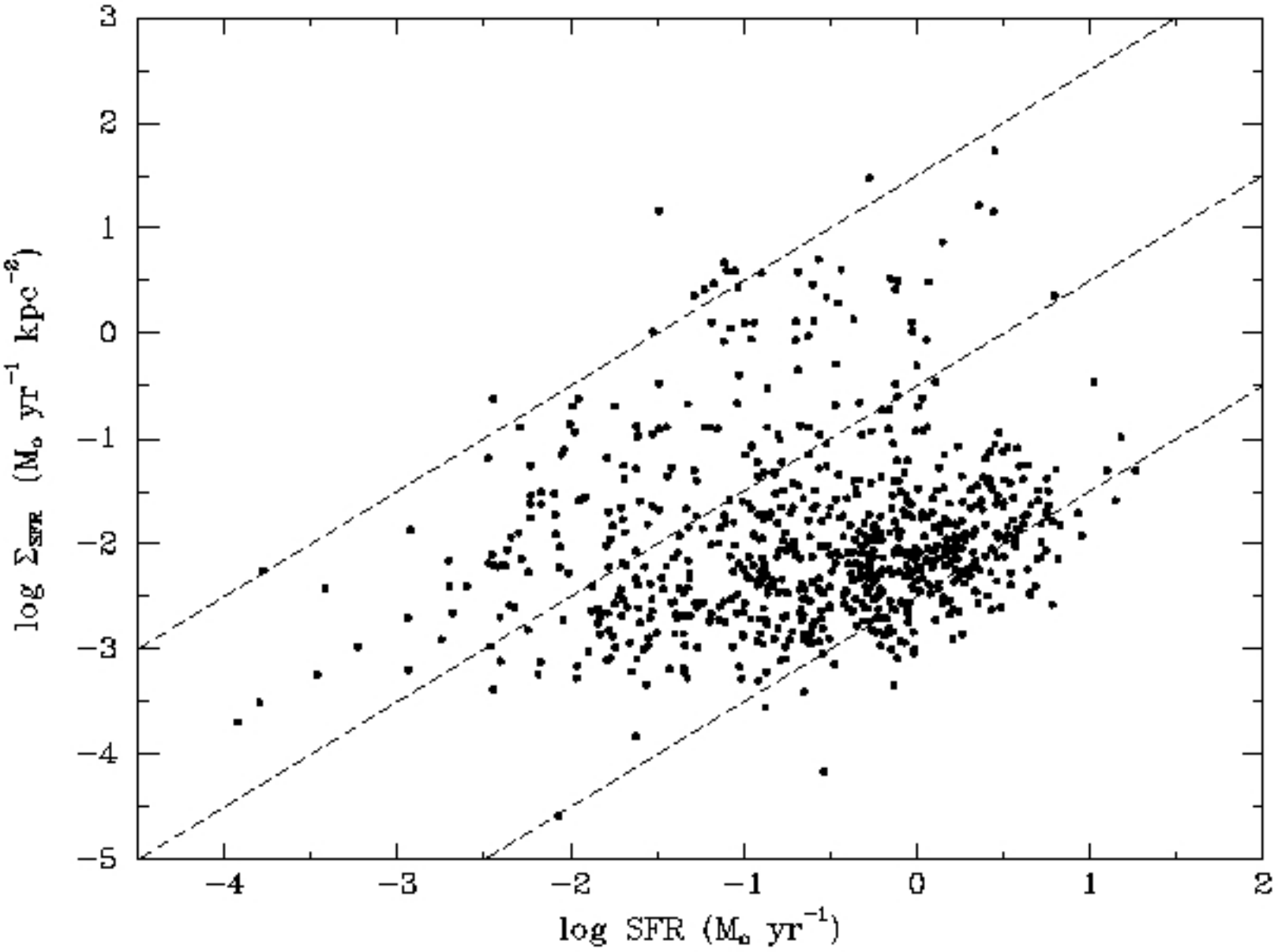
The Starburst Bestiary

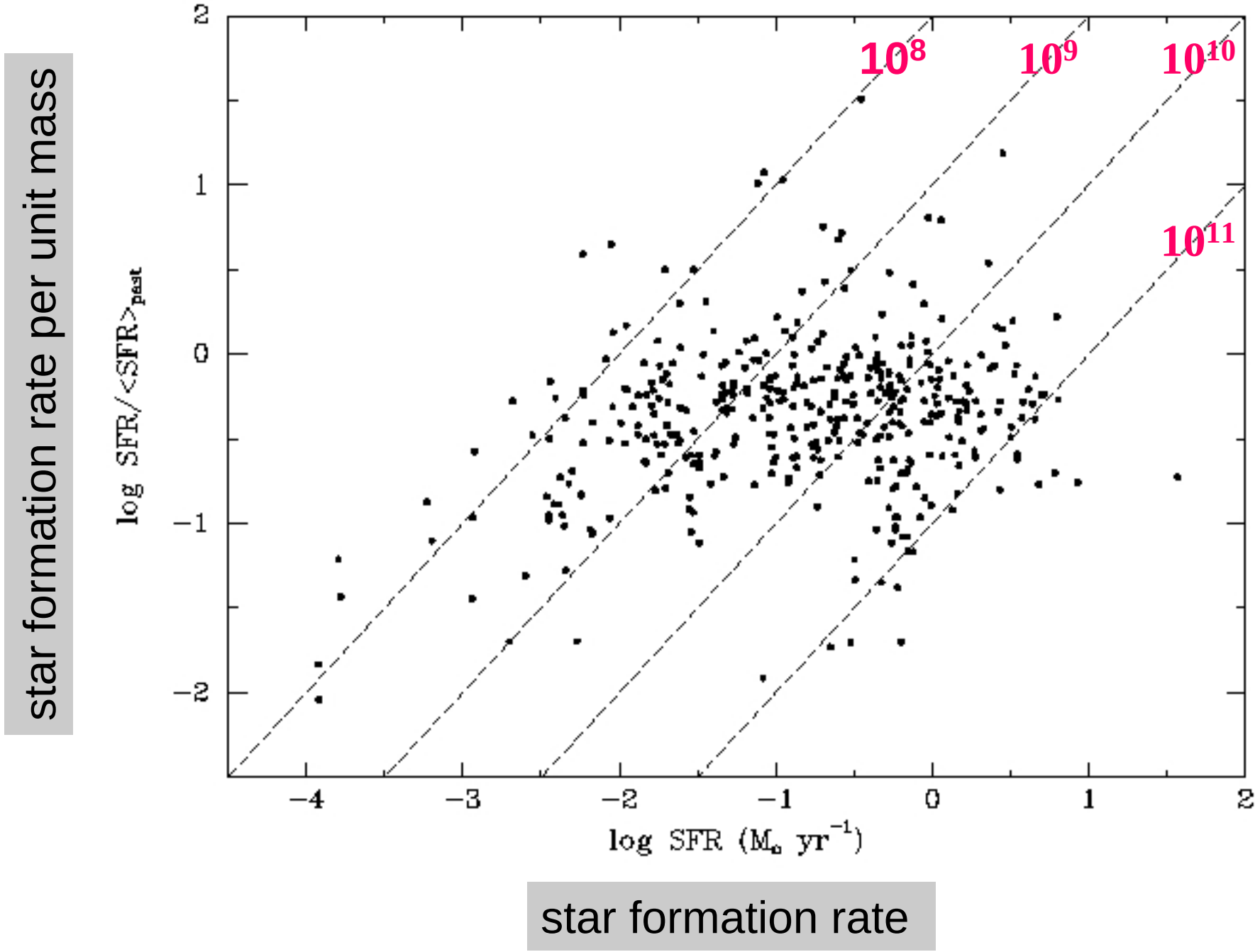
GEHRs	nuclear starbursts
SSCs	circumnuclear starbursts
HII galaxies	clumpy irregular galaxies
ELGs	Ly-α galaxies
CNELGs	E+A galaxies
W-R galaxies	K+A galaxies
BCGs	LBGs
BCDs	DRGs
LIGs, LIRGs	EROs
ULIGs, ULIRGs	SCUBA galaxies
LUVGs, UVLGs	extreme starbursts

11 Mpc Hα Survey: Kennicutt et al. 2008, ApJS, in press

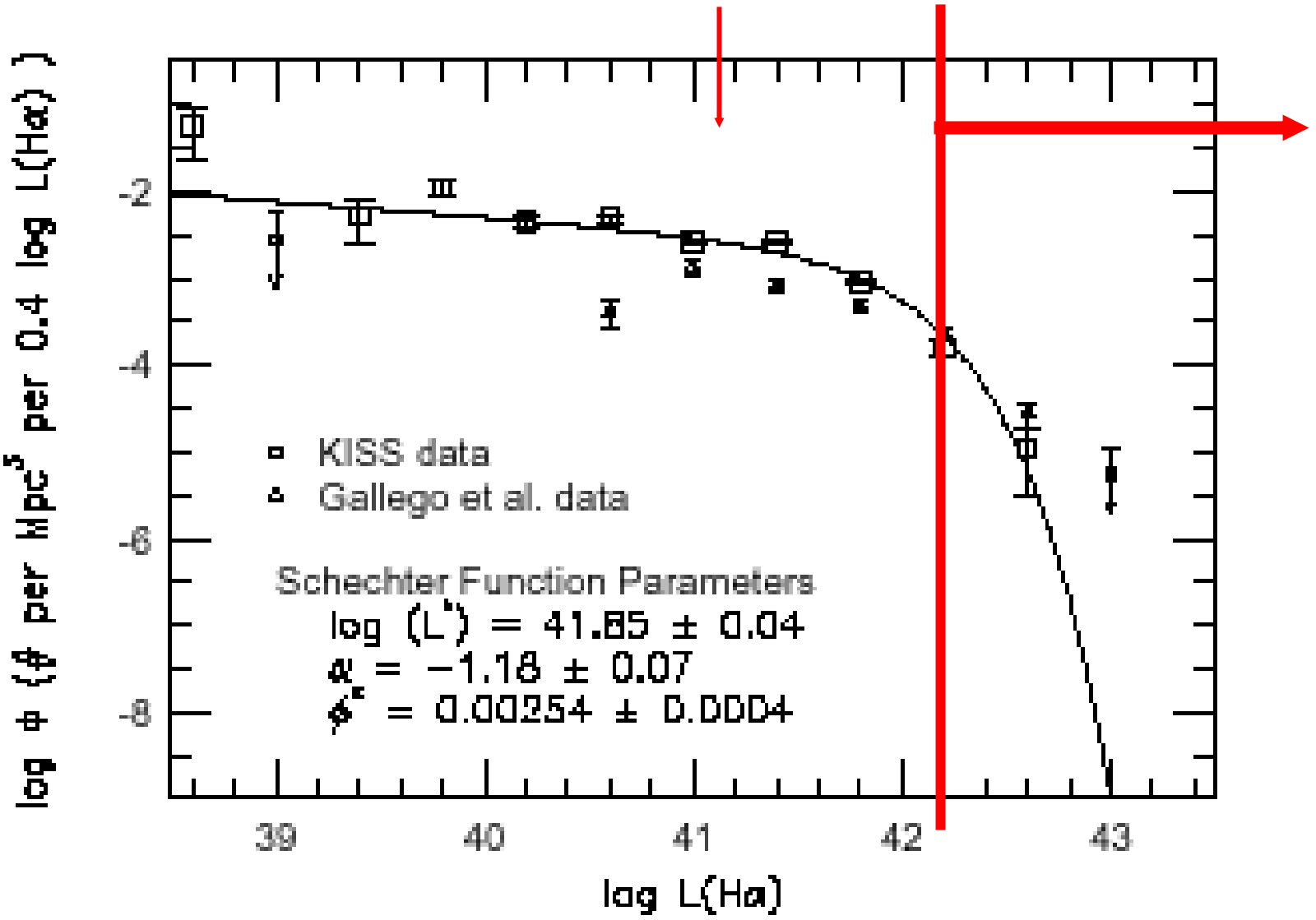


11MPC + HαGS + SINGG+ Hameed + Goldmine



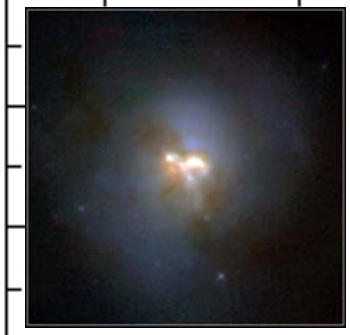

star formation rate per unit mass
star formation rate
10^8
10^9
10^{10}
10^{11}
log SFR/<SFR>past
log SFR ($M_\odot$ yr^{-1})
2
1
0
−1
−2
−4
−3
−2
−1
0
1
2

SFR* ~5 M_o/yr

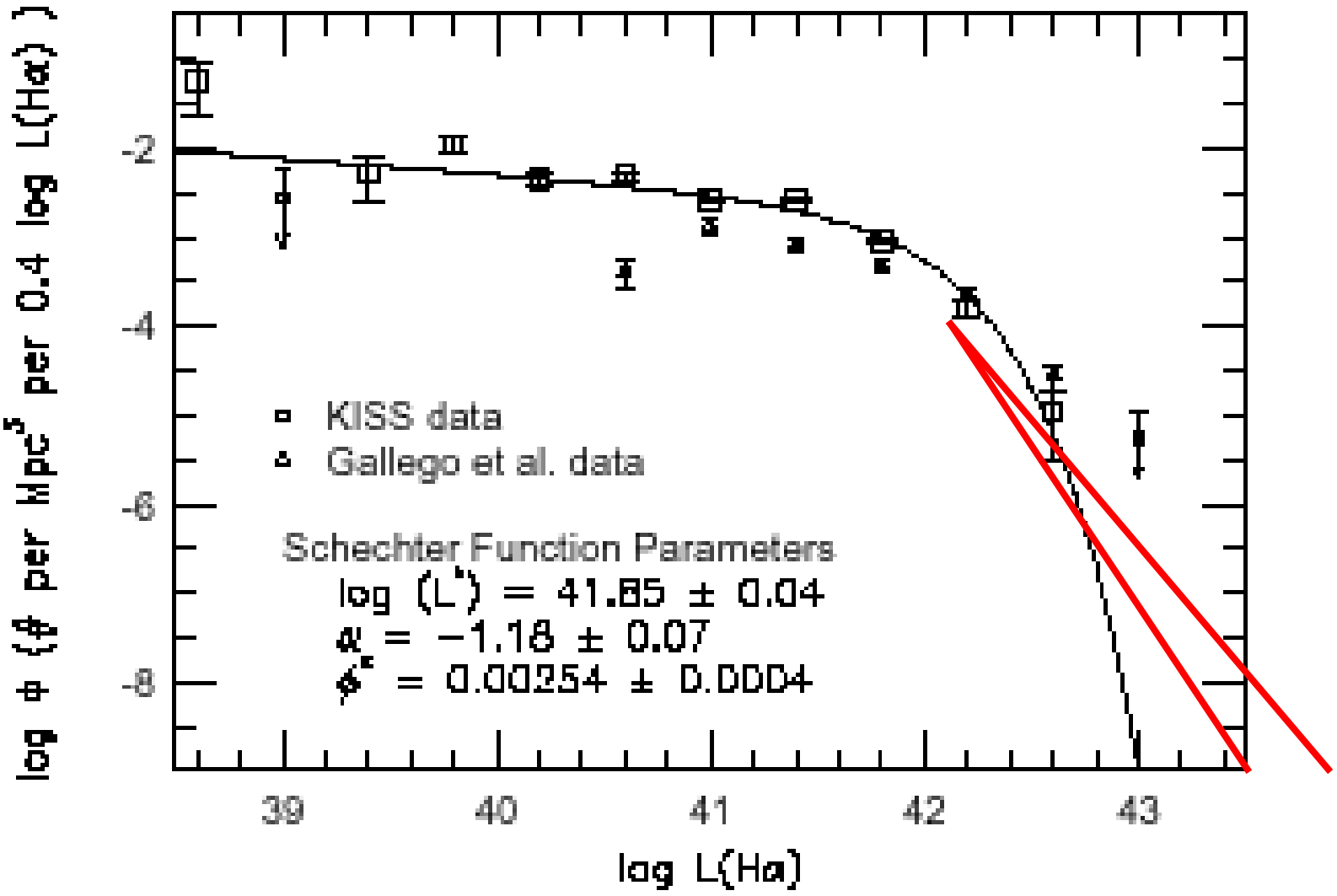


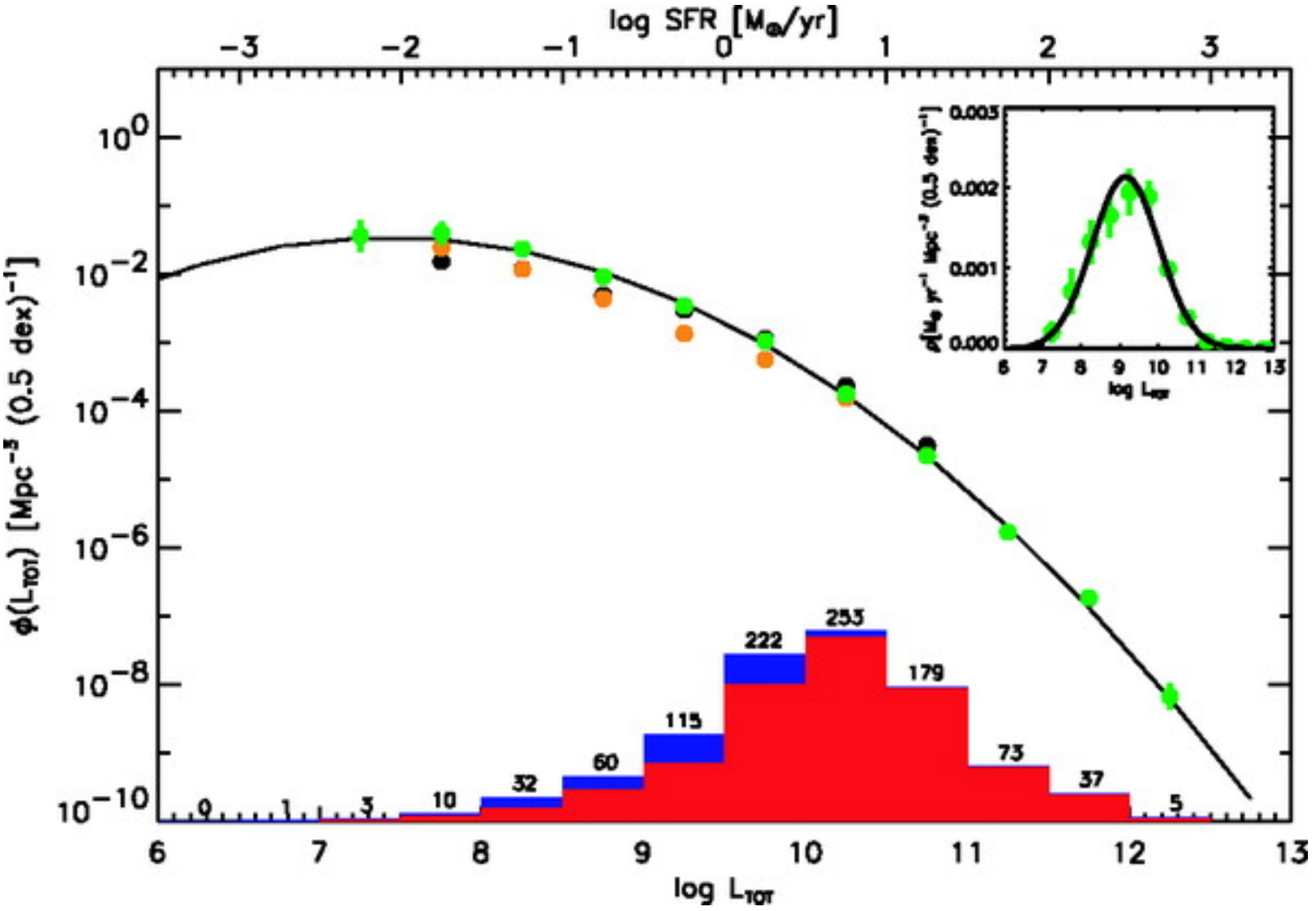
Gronwall 1998

LIGs, ULIGs (Dopita et al., Soifer et al, Scoville et al)



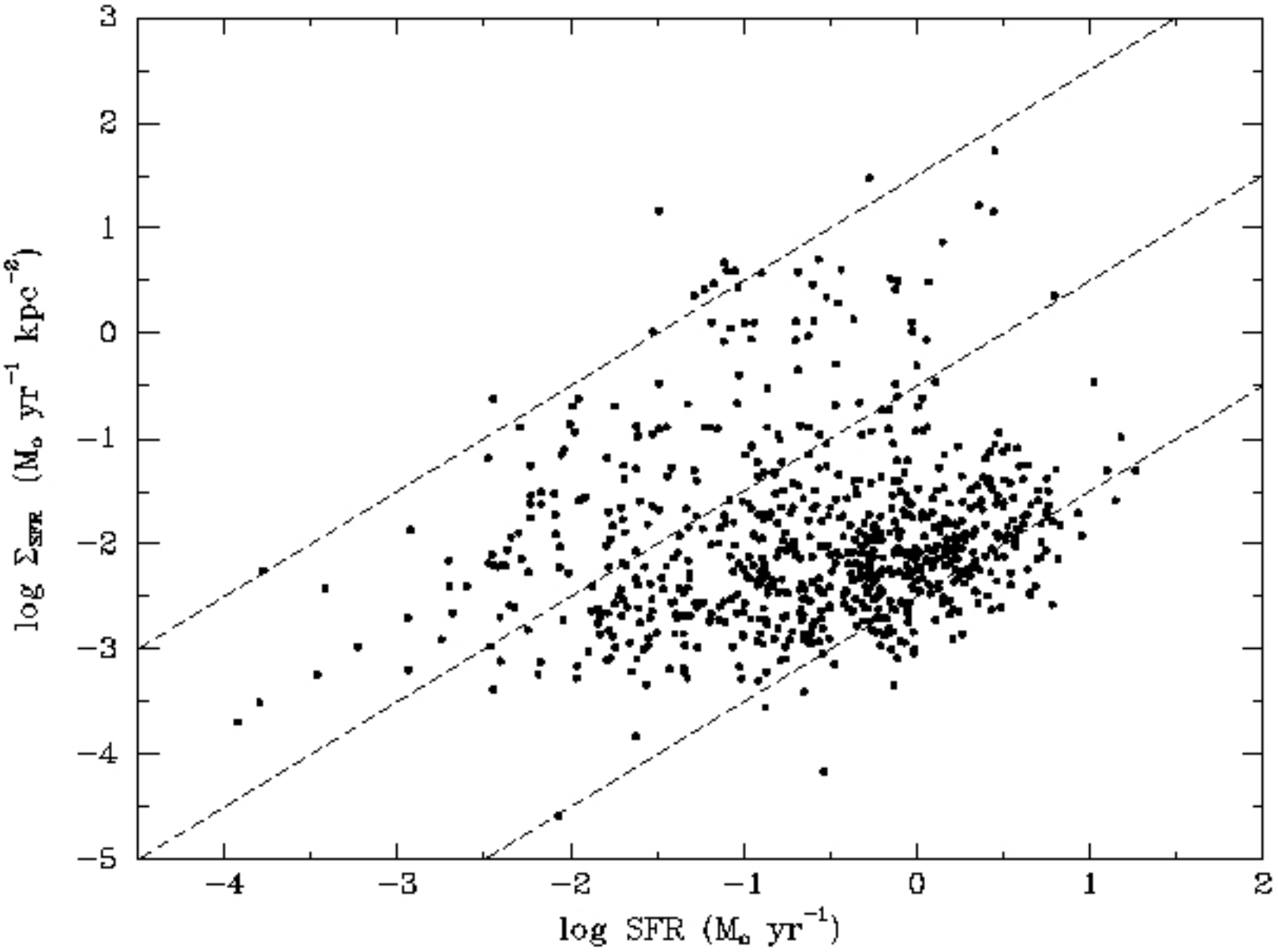
merger-driven
inflows, starbursts

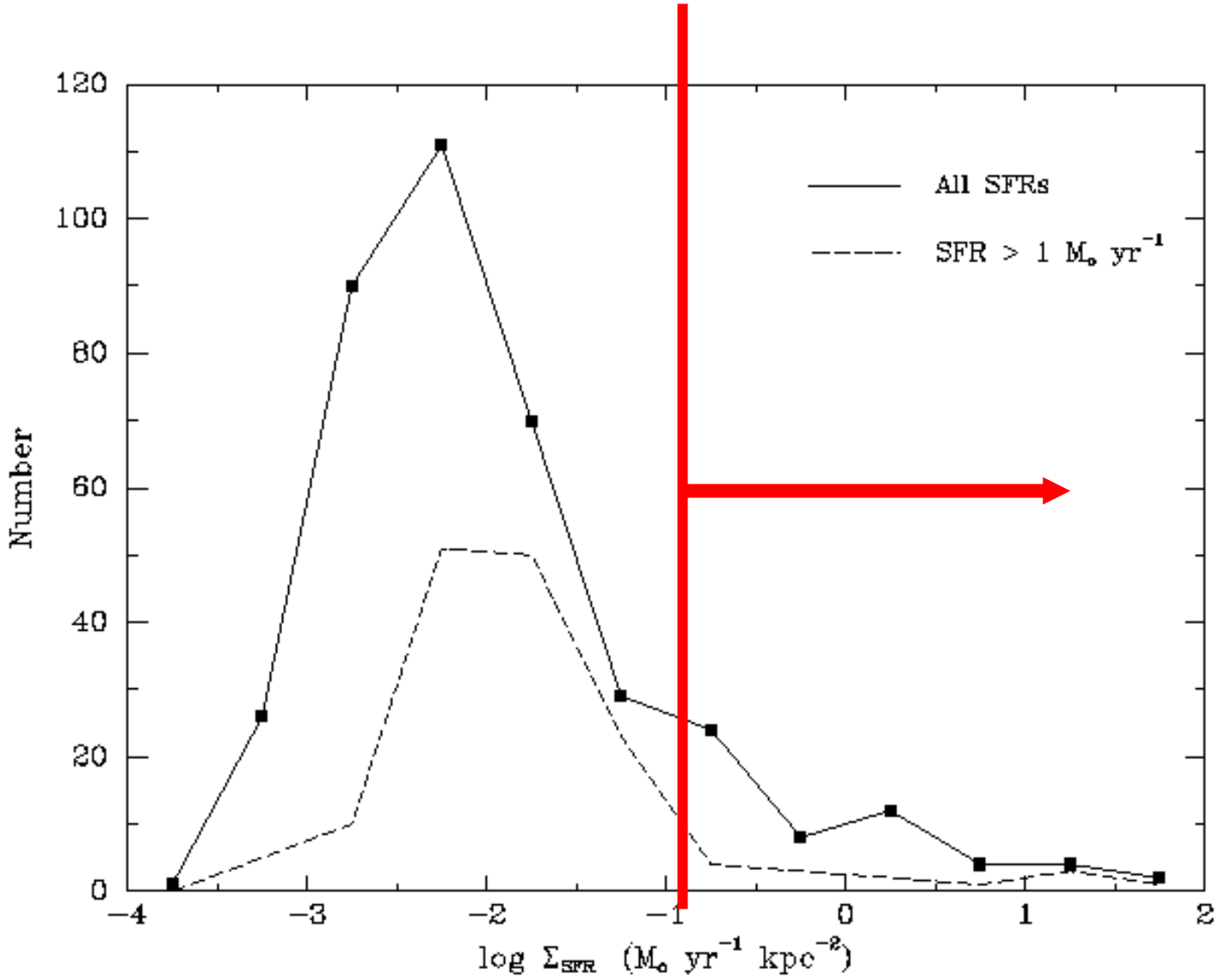

log Φ (# per Mpc^3 per 0.4 log L(Hα))
-2
-4
-6
-8
39
40
41
42
43
log L(Hα)
KISS data
Gallego et al. data
Schechter Function Parameters
log (L*) = 41.85 ± 0.04
α = −1.18 ± 0.07
Φ* = 0.00254 ± 0.0004

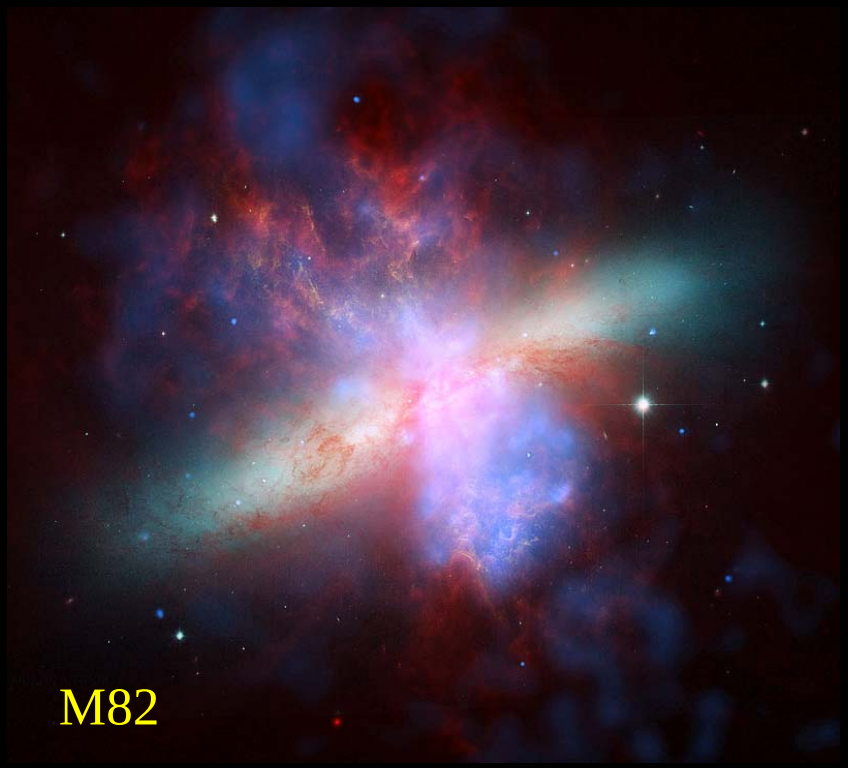


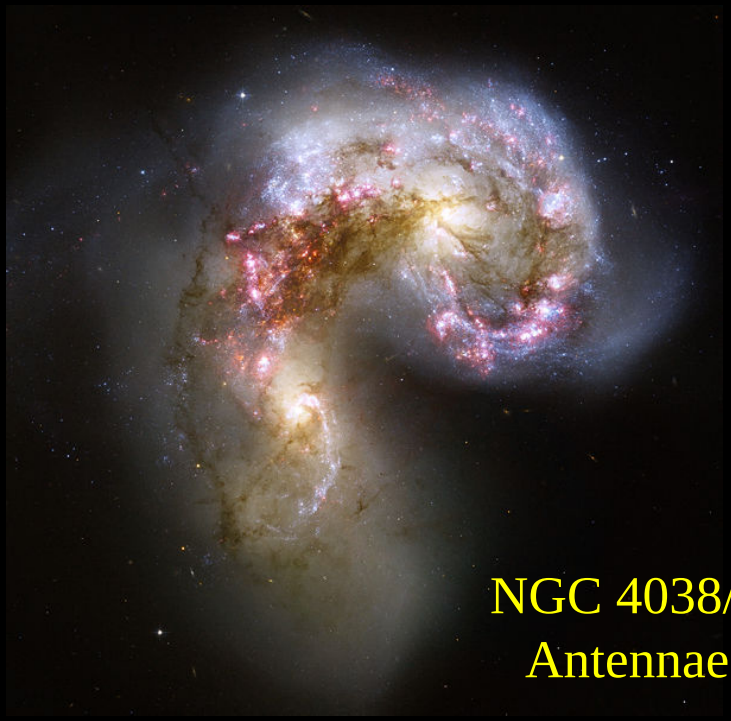
Martin 2005, ApJ, 619, L59

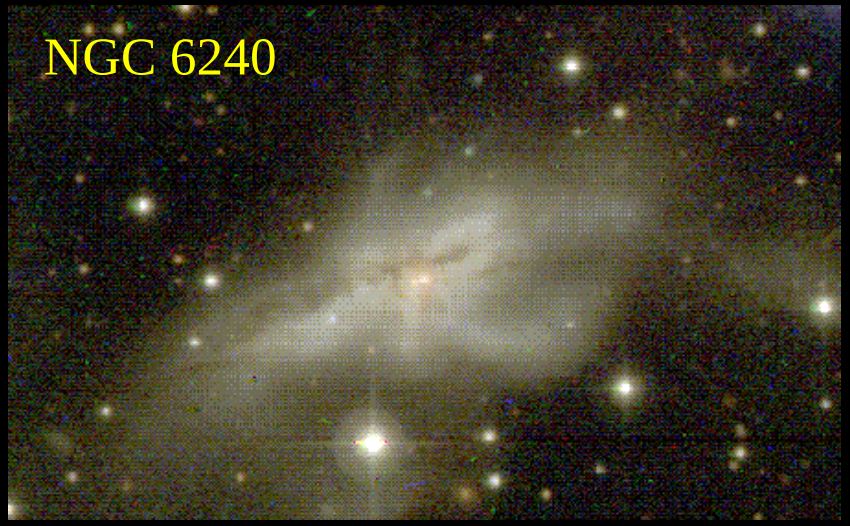
11MPC + HαGS + SINGG+ Hameed + Goldmine

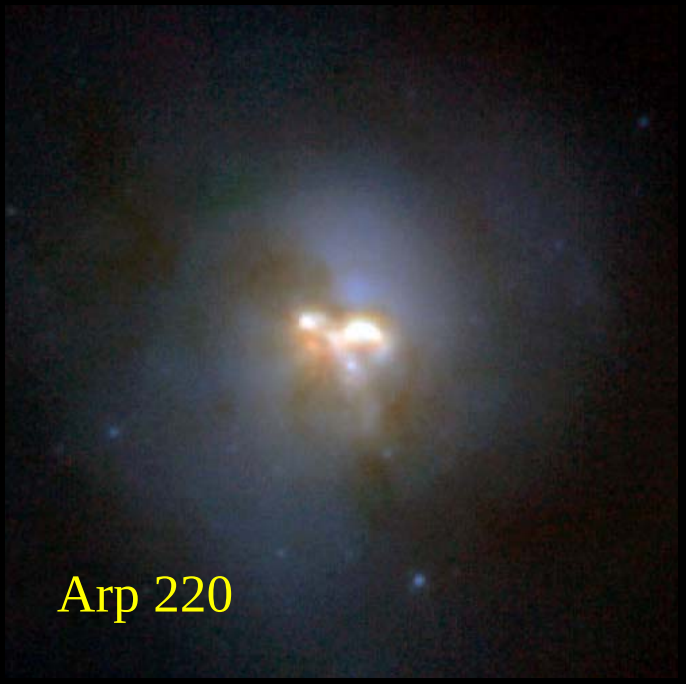


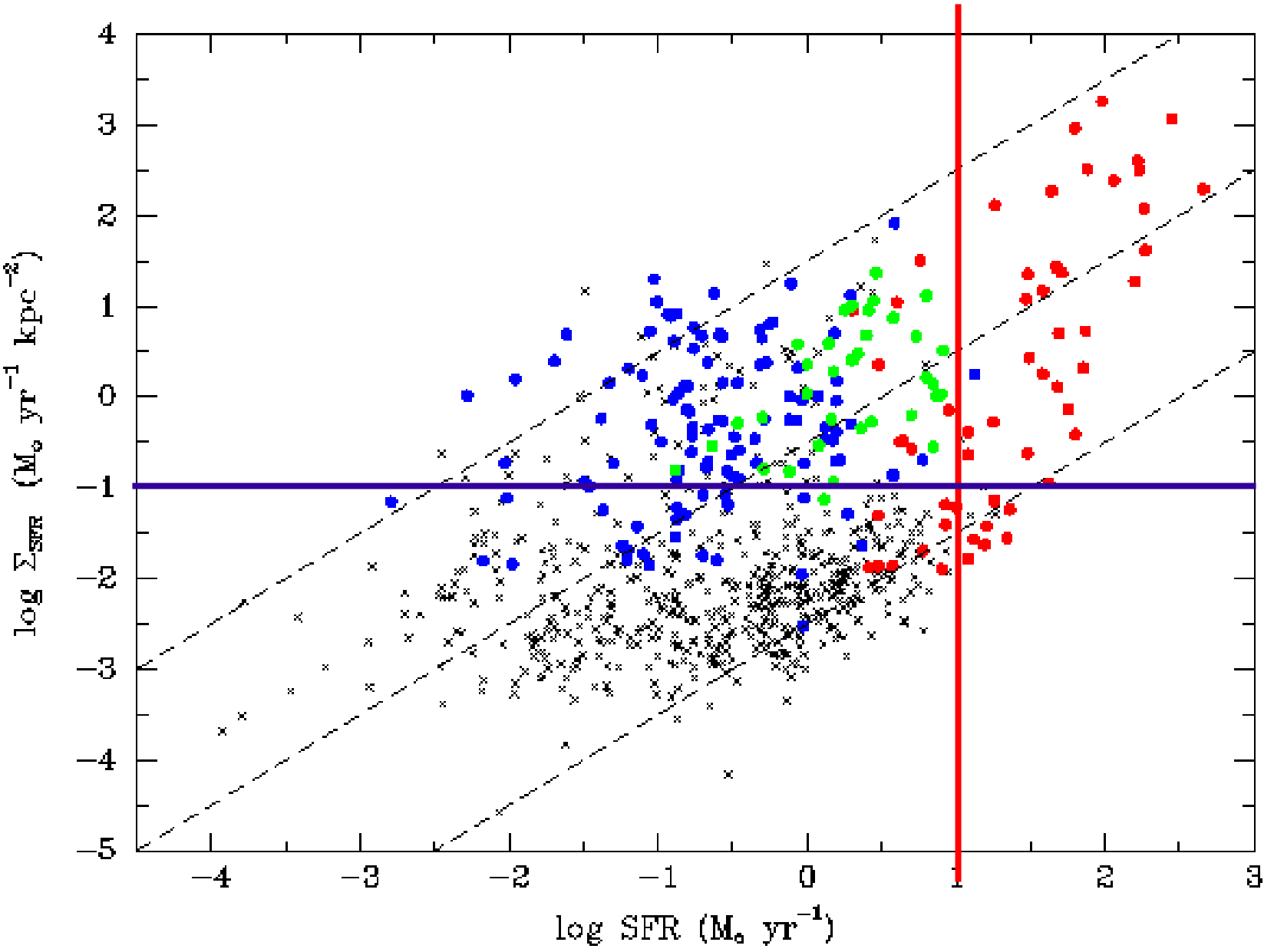

120
100
80
60
40
20
0
Number
−4
−3
−2
−1
0
1
2
log Σ_SFR (M_⊙ yr^-1 kpc^-2)
All SFRs
SFR > 1 M_⊙ yr^-1

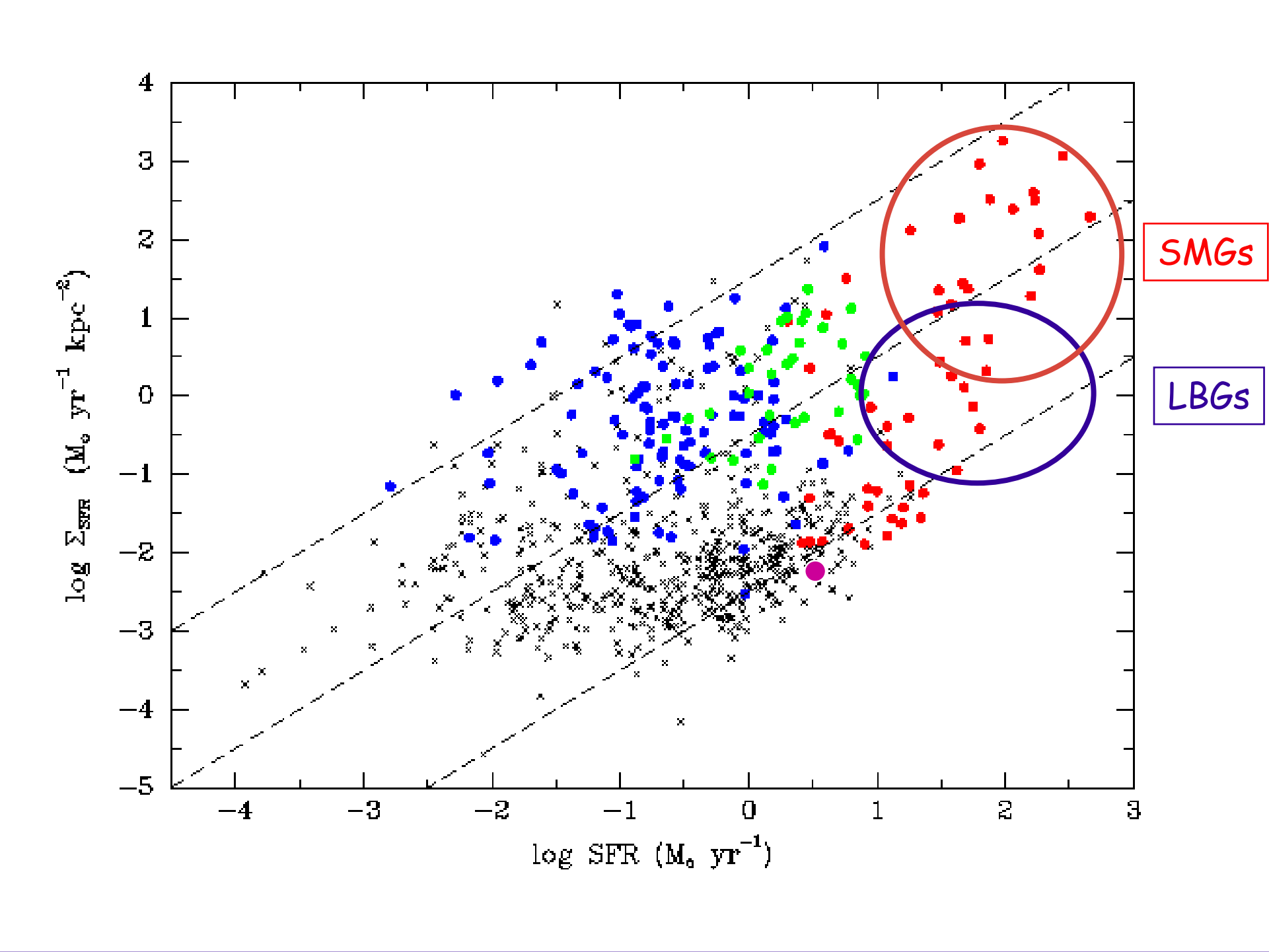

M82


NGC 4038/9
Antennae

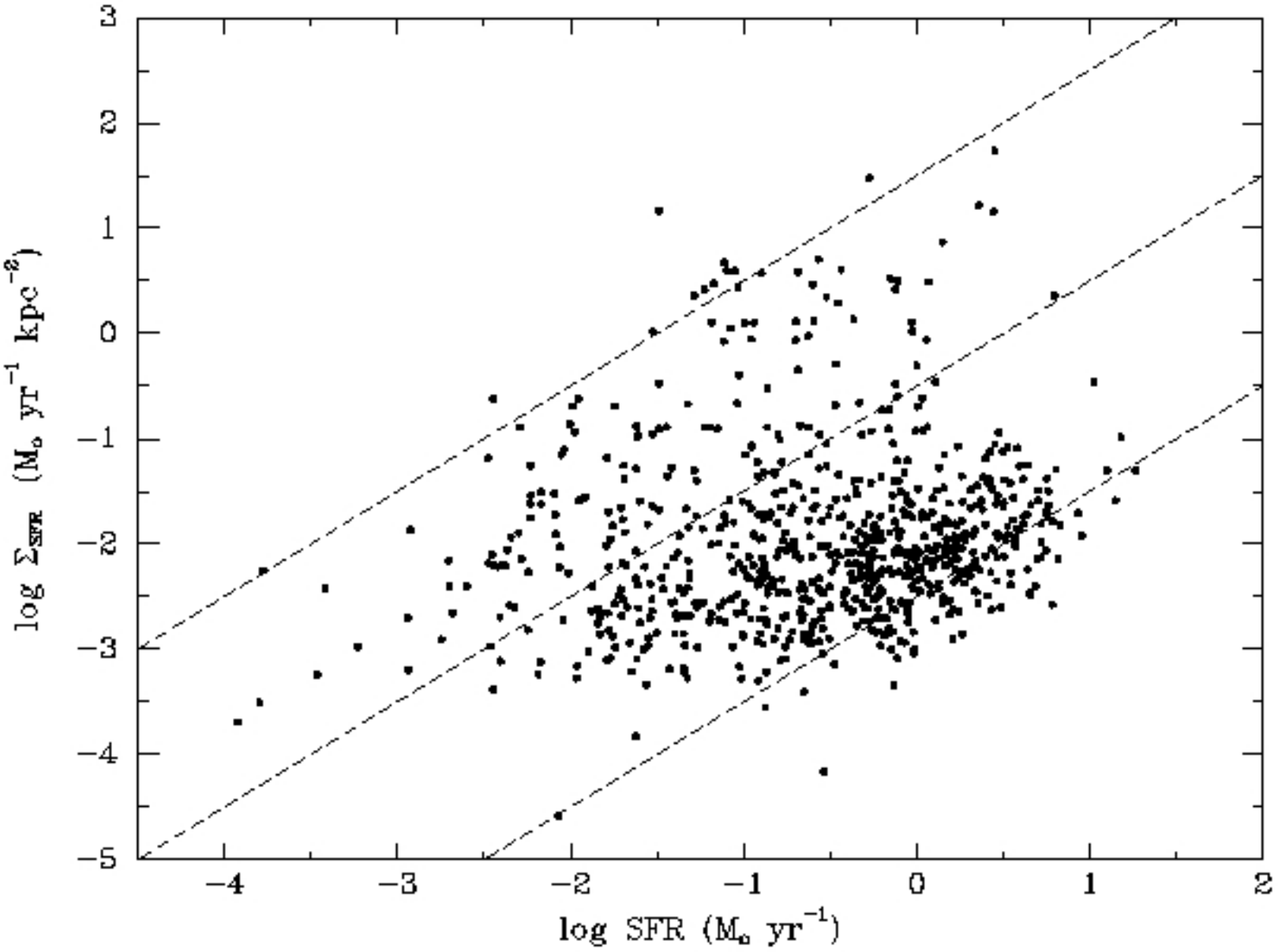

NGC 6240


Arp 220

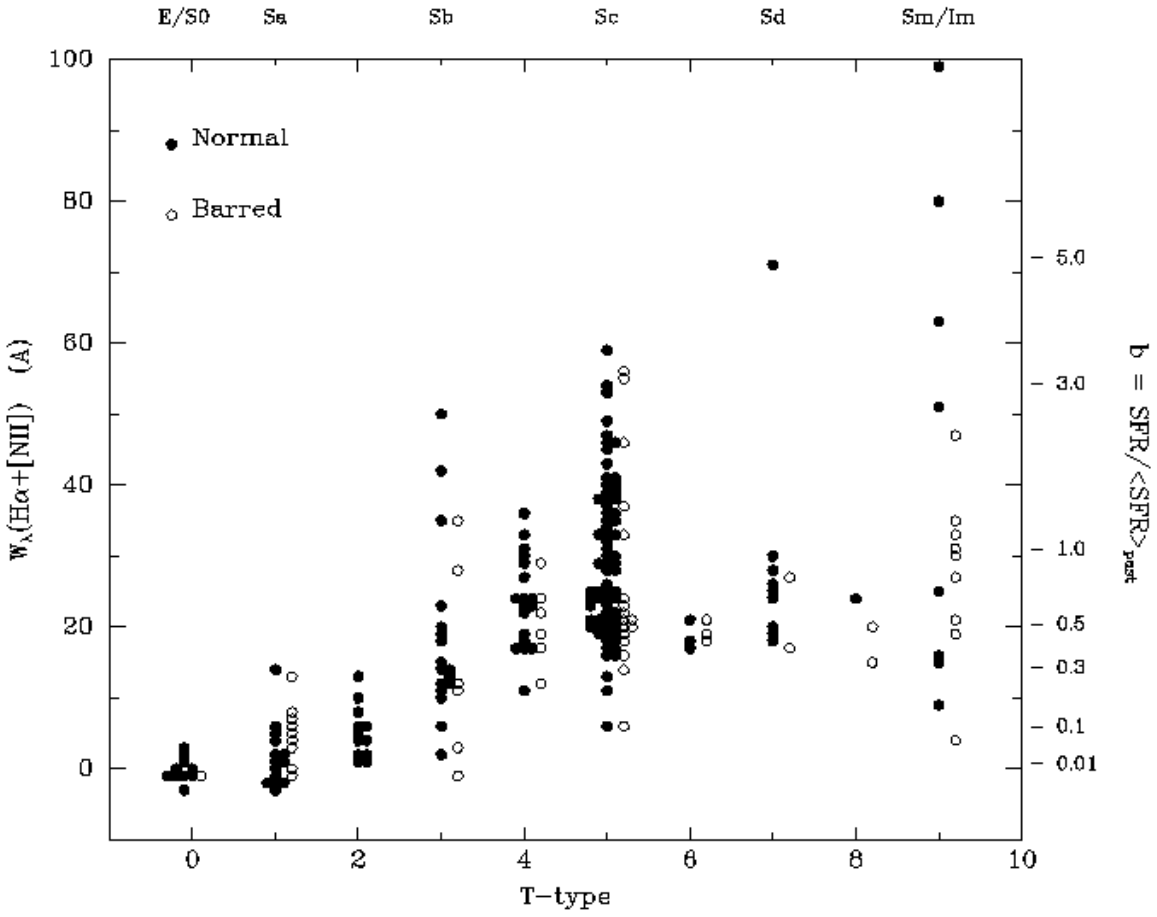

log Σ_{SFR} ($M_\odot$ yr^{-1} kpc^{-2})
log SFR ($M_\odot$ yr^{-1})
4
3
2
1
0
−1
−2
−3
−4
−5
−4
−3
−2
−1
0
1
2
3


SMGs
LBGs
log SFR ($M_\odot$ yr^{-1})
log Σ_{SFR} ($M_\odot$ yr^{-1} kpc^{-2})

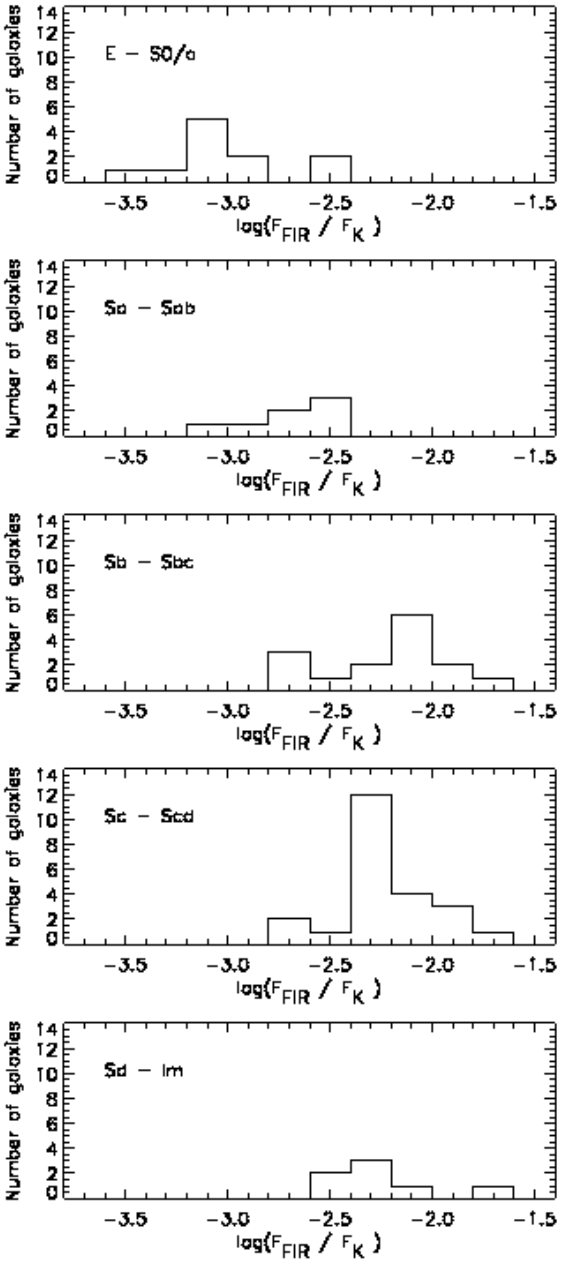
11MPC + HαGS + SINGG+ Hameed + Goldmine



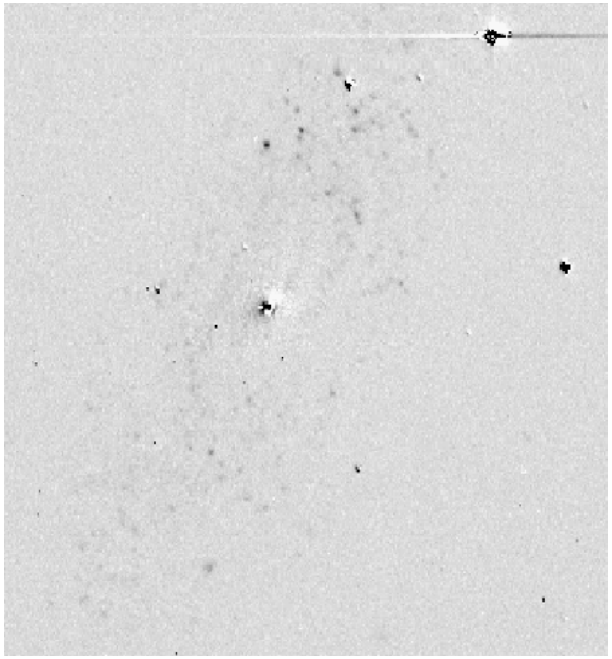
Disk SF – Global Trends

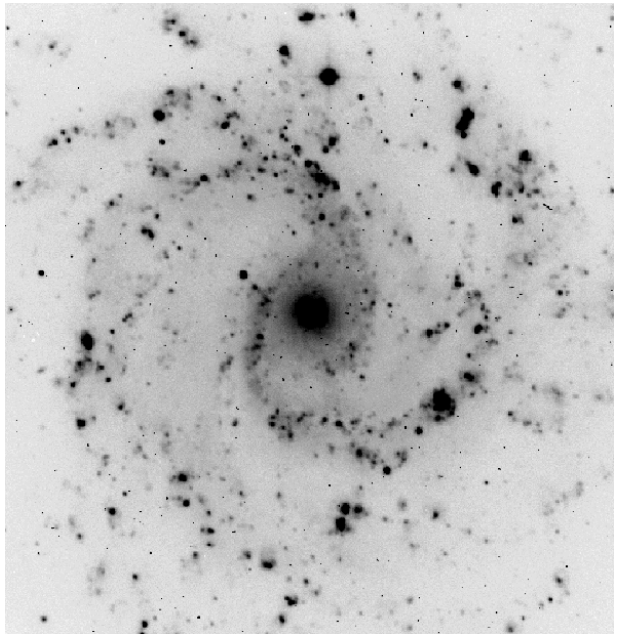


Kennicutt 1998, ARAA, 36, 189

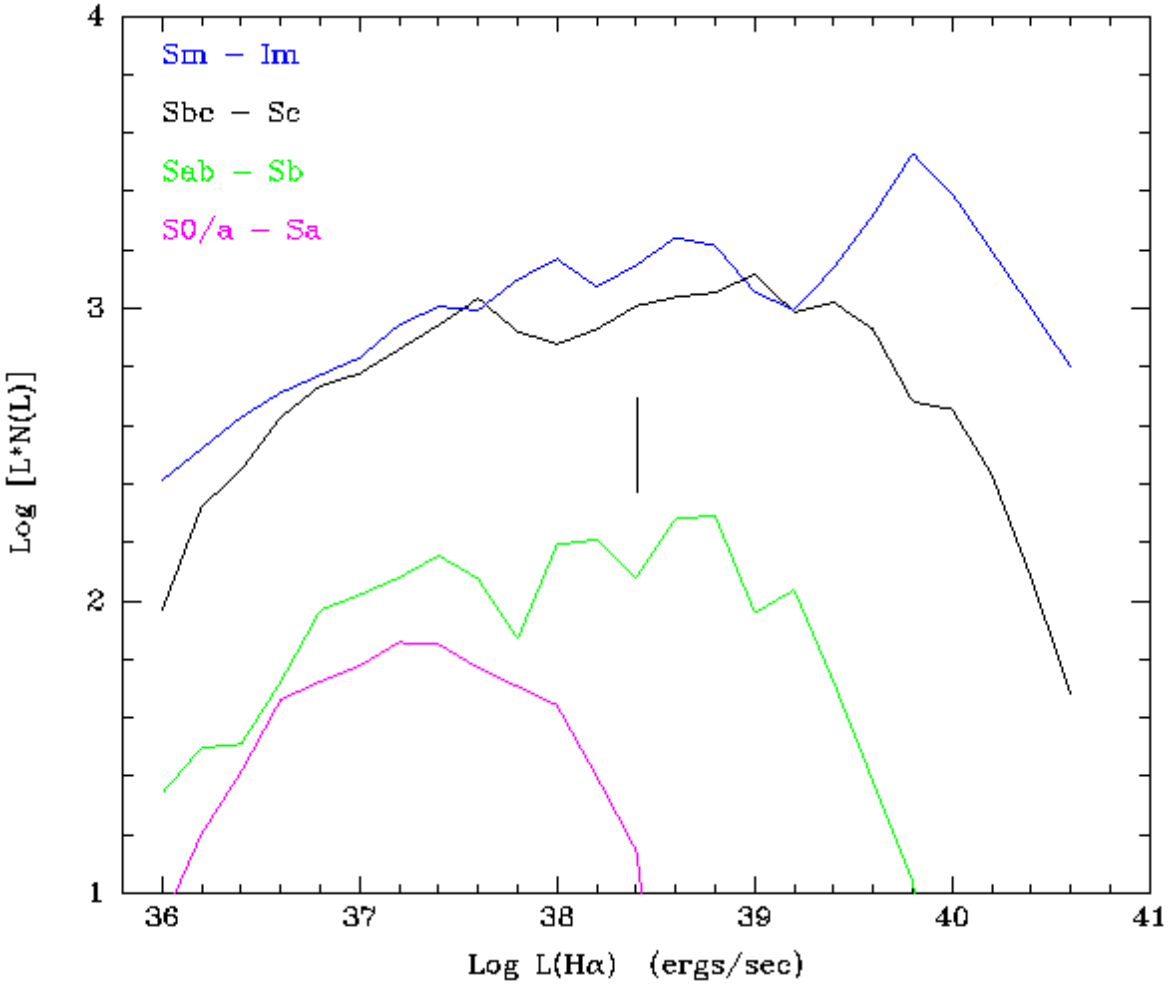


Bendo et al. 2002, AJ, 124, 1380





SFR increase reflects an increase in frequency of SF events, and a shift in the mass spectrum of single events



Disk Star Formation Rates and Histories

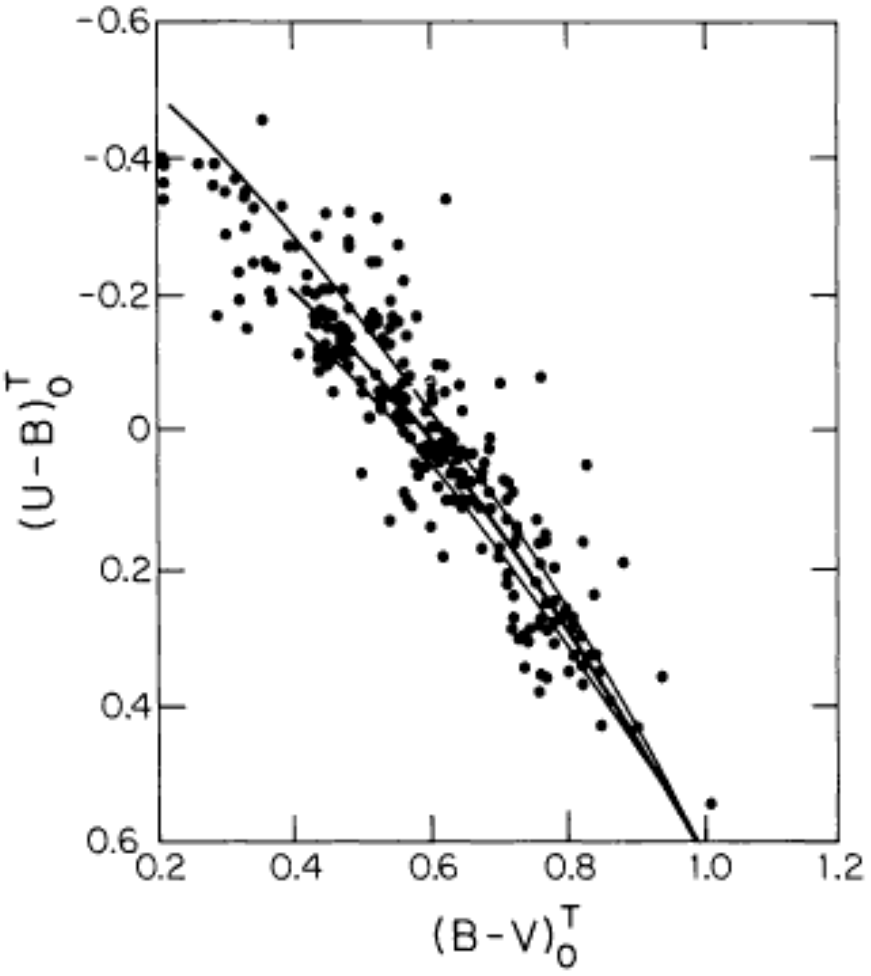
- evolutionary synthesis of integrated colors

  Tinsley 1968, ApJ, 151, 547

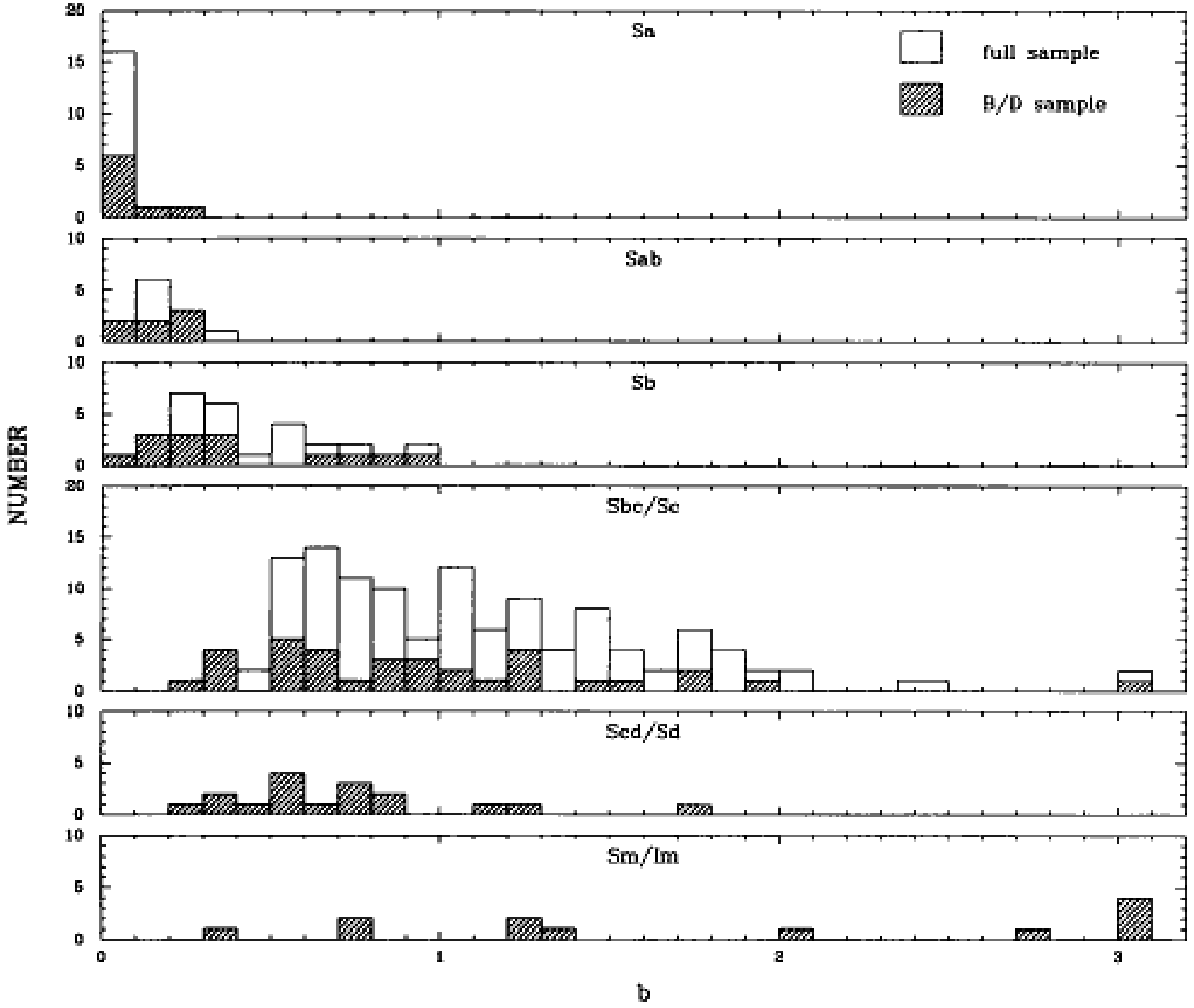
  Searle et al. 1973, ApJ, 179, 427

  Larson, Tinsley 1978, ApJ, 219, 46

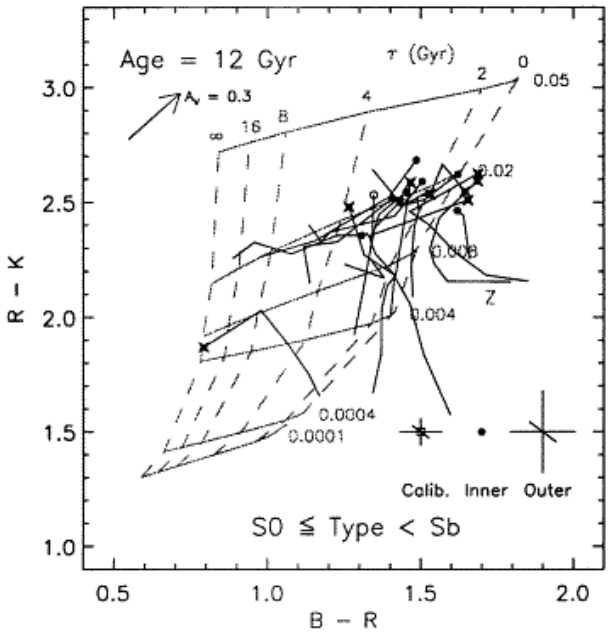
- results
  - disk colors consistent with sequence of constant age, IMF, Z, and variable SF history $\psi(t)$
  - best fit for ~Salpeter IMF
  - spectra fit with similar model sequence

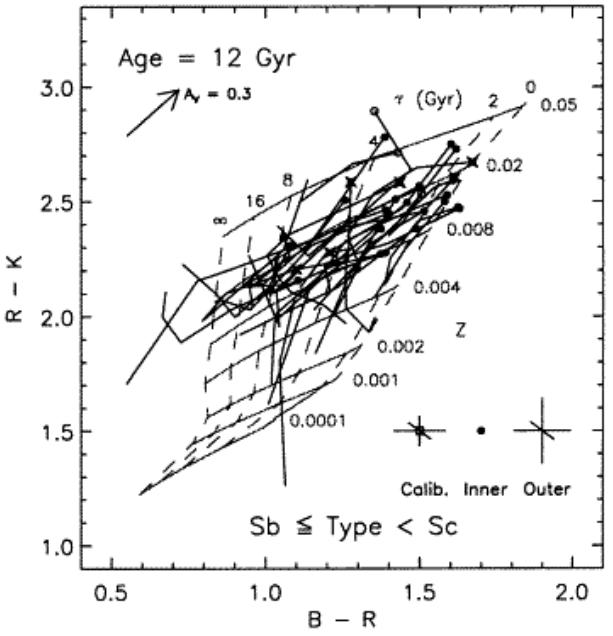


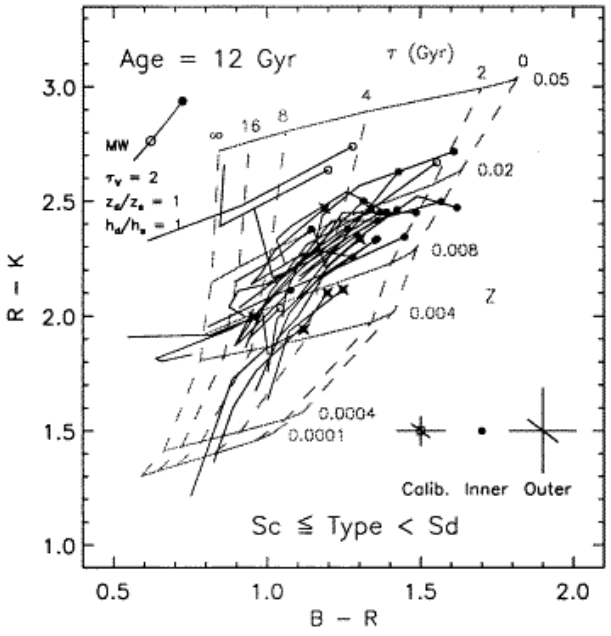
Kennicutt 1983, ApJ, 272, 54

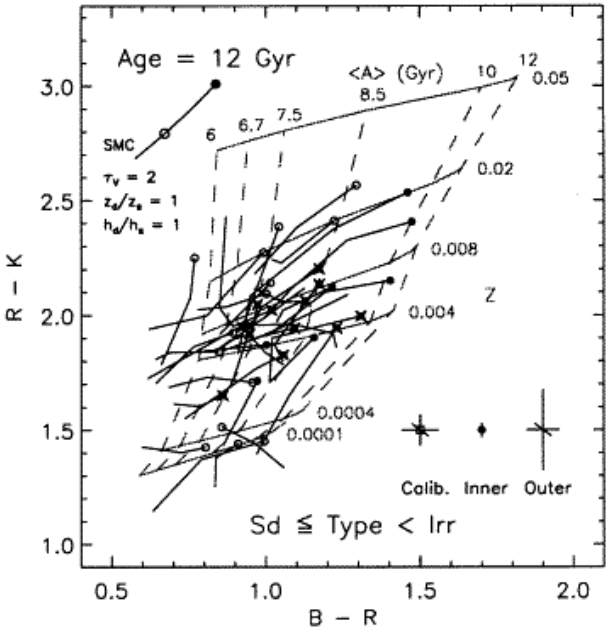


Kennicutt, Tamblyn, Congdon 1994, ApJ, 435, 22

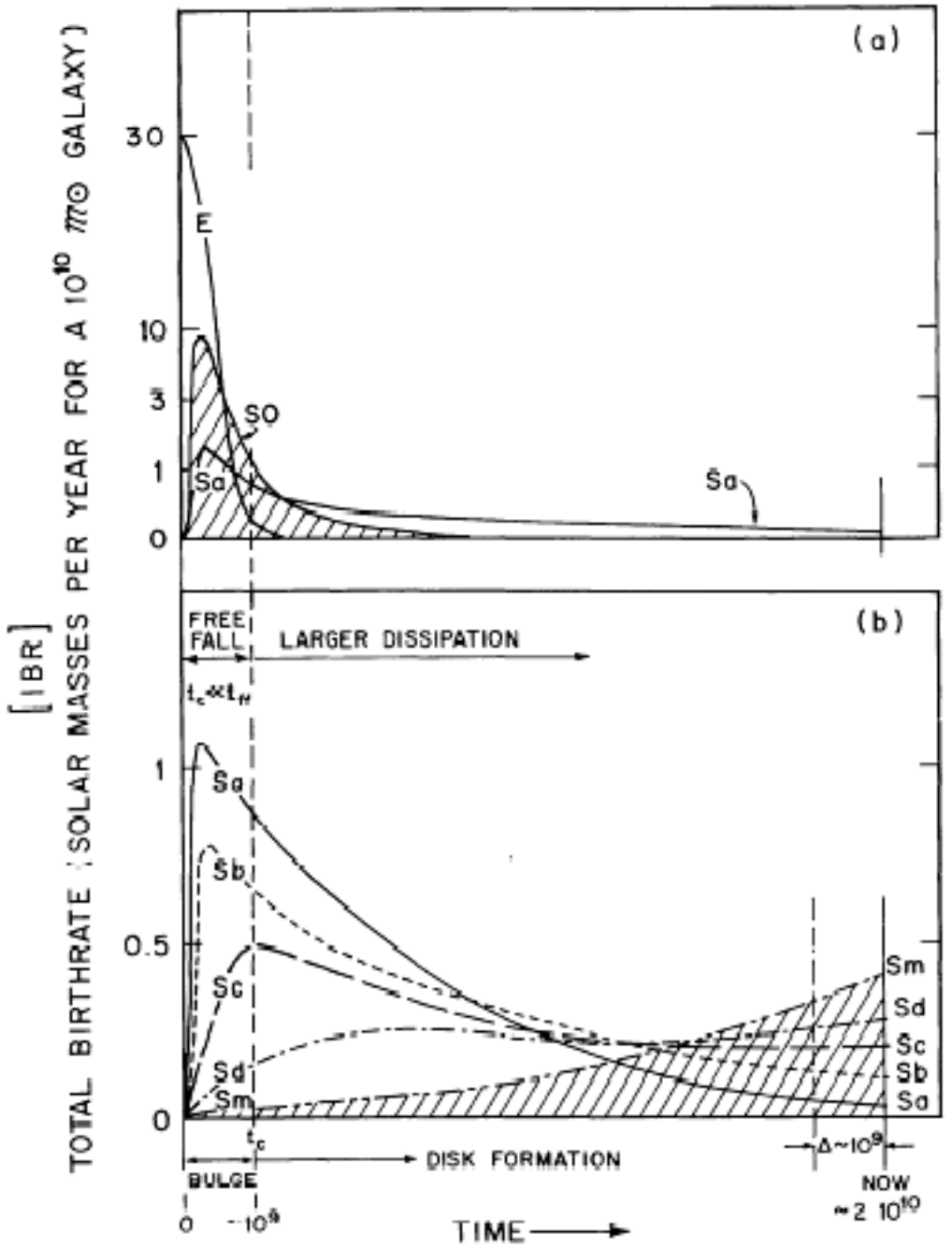




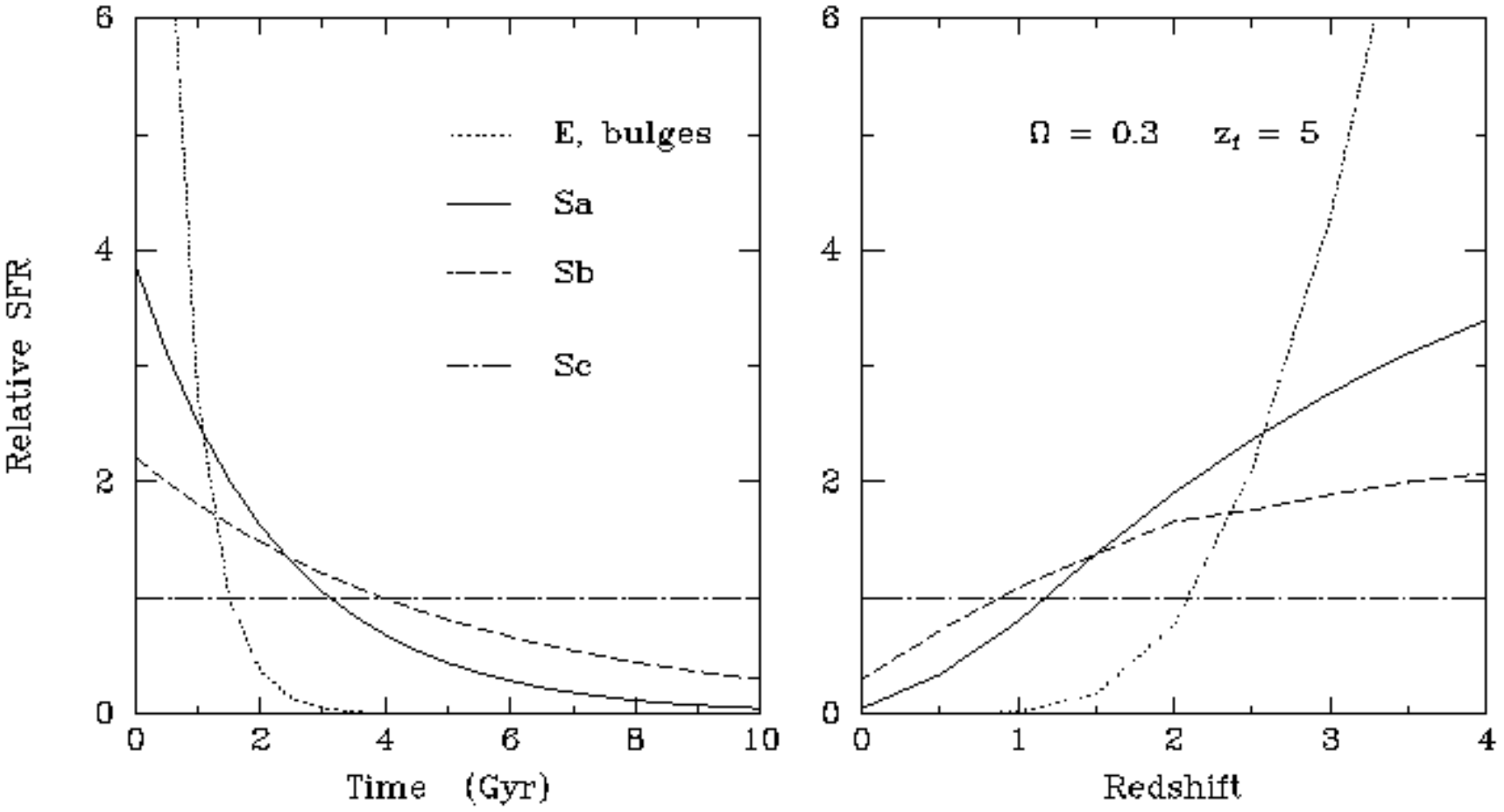




Bell, de Jong 2000, MNRAS, 312, 497

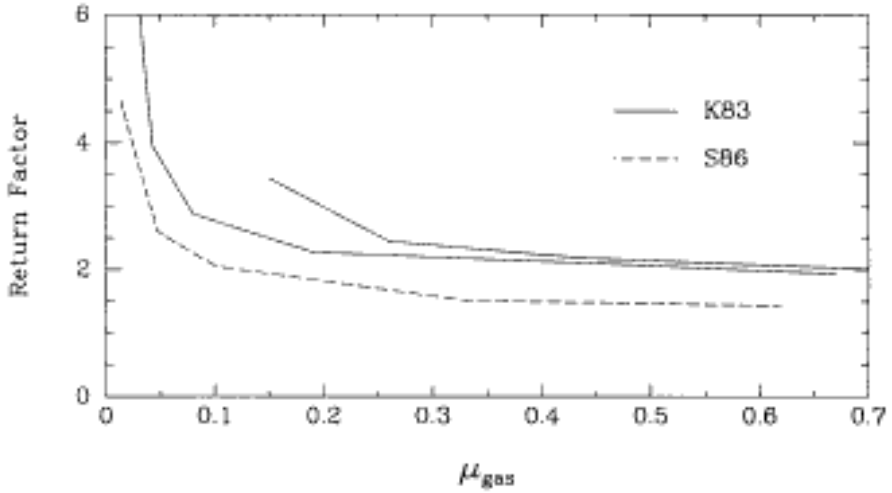


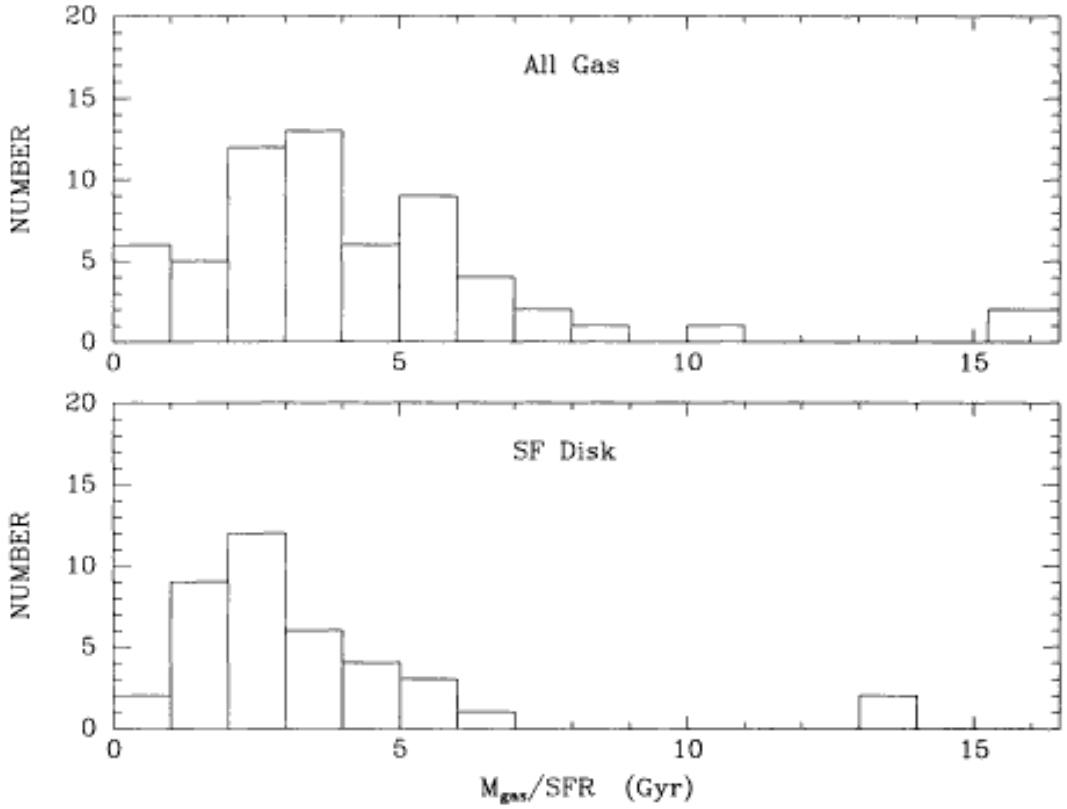
Sandage 1986, A&A, 161, 89



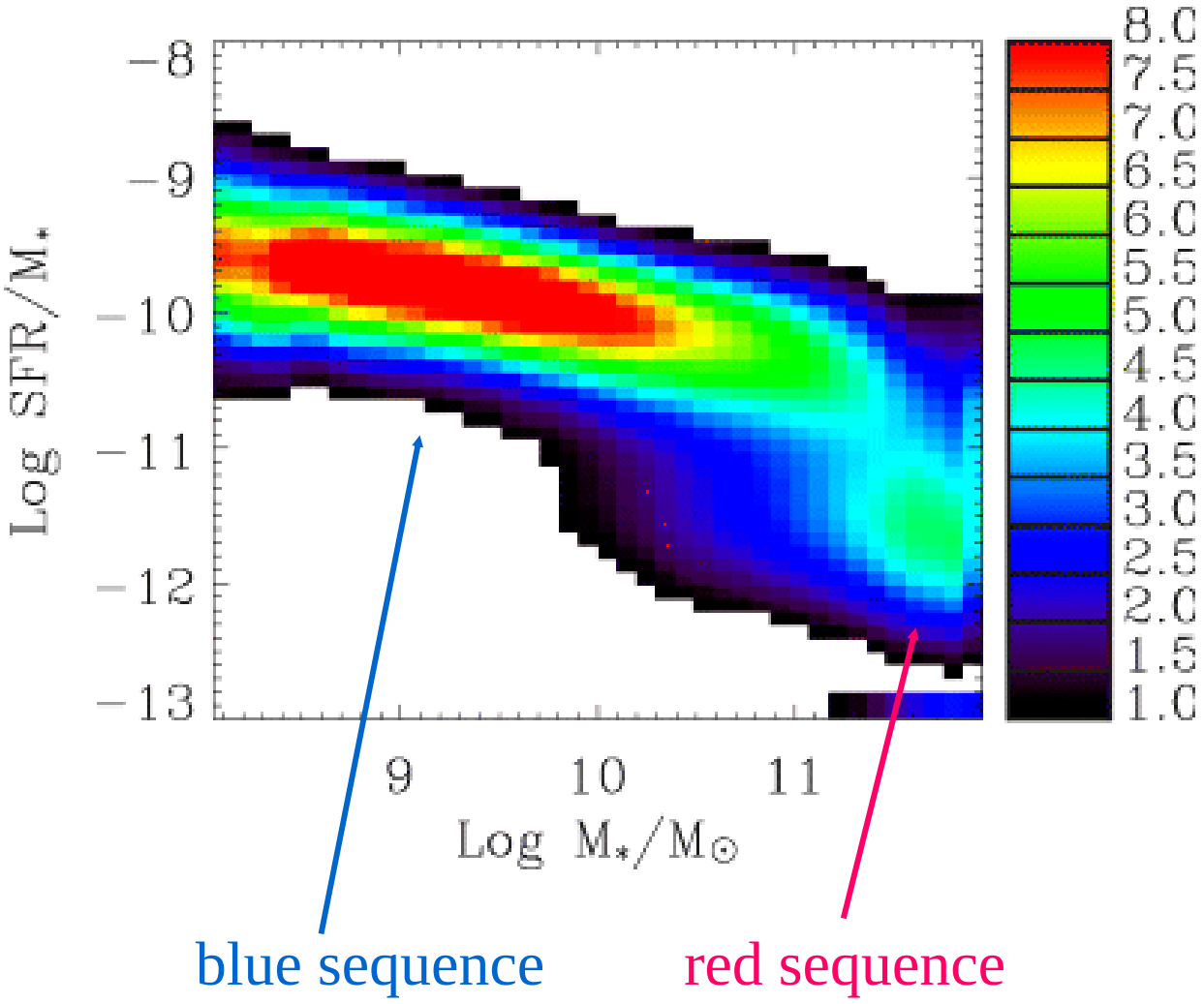
Kennicutt 1998, ARAA, 36, 189

- Gas consumption
  - typical timescales for depletion ~few Gyr
  - stellar recycling of gas is significant factor!



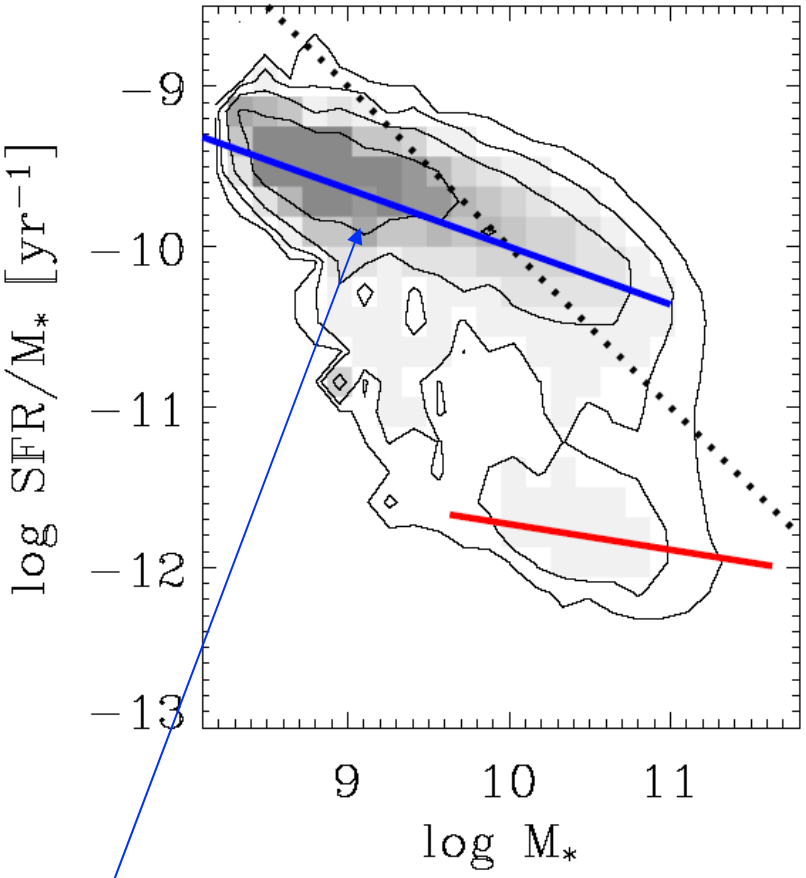


SFRs for 100,000 galaxies with Sloan!



Brinchmann et al. 2006, MNRAS, 351, 1151

SFR/M$_*$ vs. M$_*$ Distribution: Star-Forming Sequence



$$\mathrm{SFR} \propto M_*^{2/3}$$

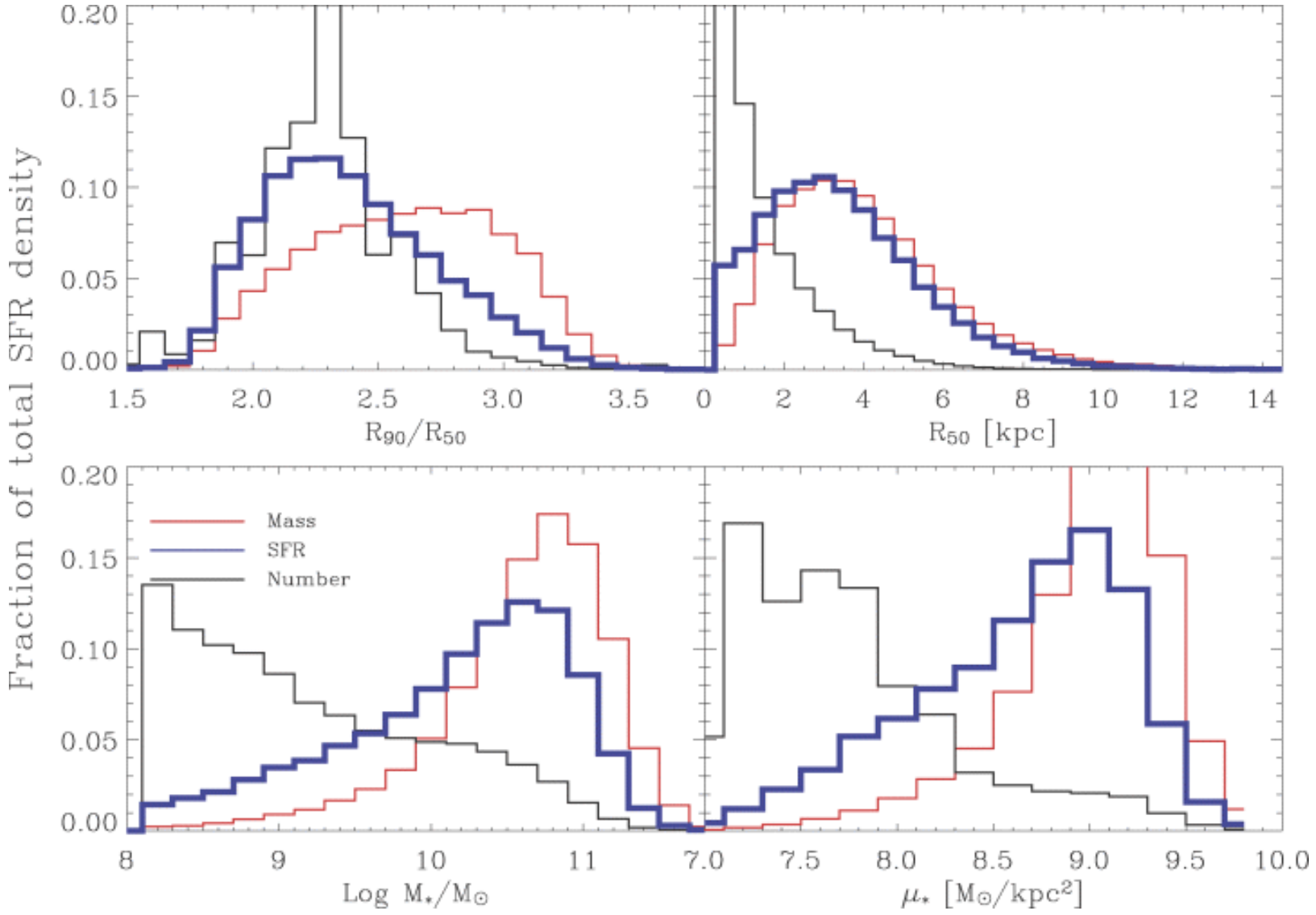
Salim et al. (2007)
Noeske et al. (2007)

see also
Brinchmann et al. (2004),
Feulner et al. (2006)

$\mathrm{SFR} = 1\ \mathrm{M}_\odot\ yr^{-1}$

$$\log SFR/M_* = -0.35(logM_* - 10) - 9.83$$

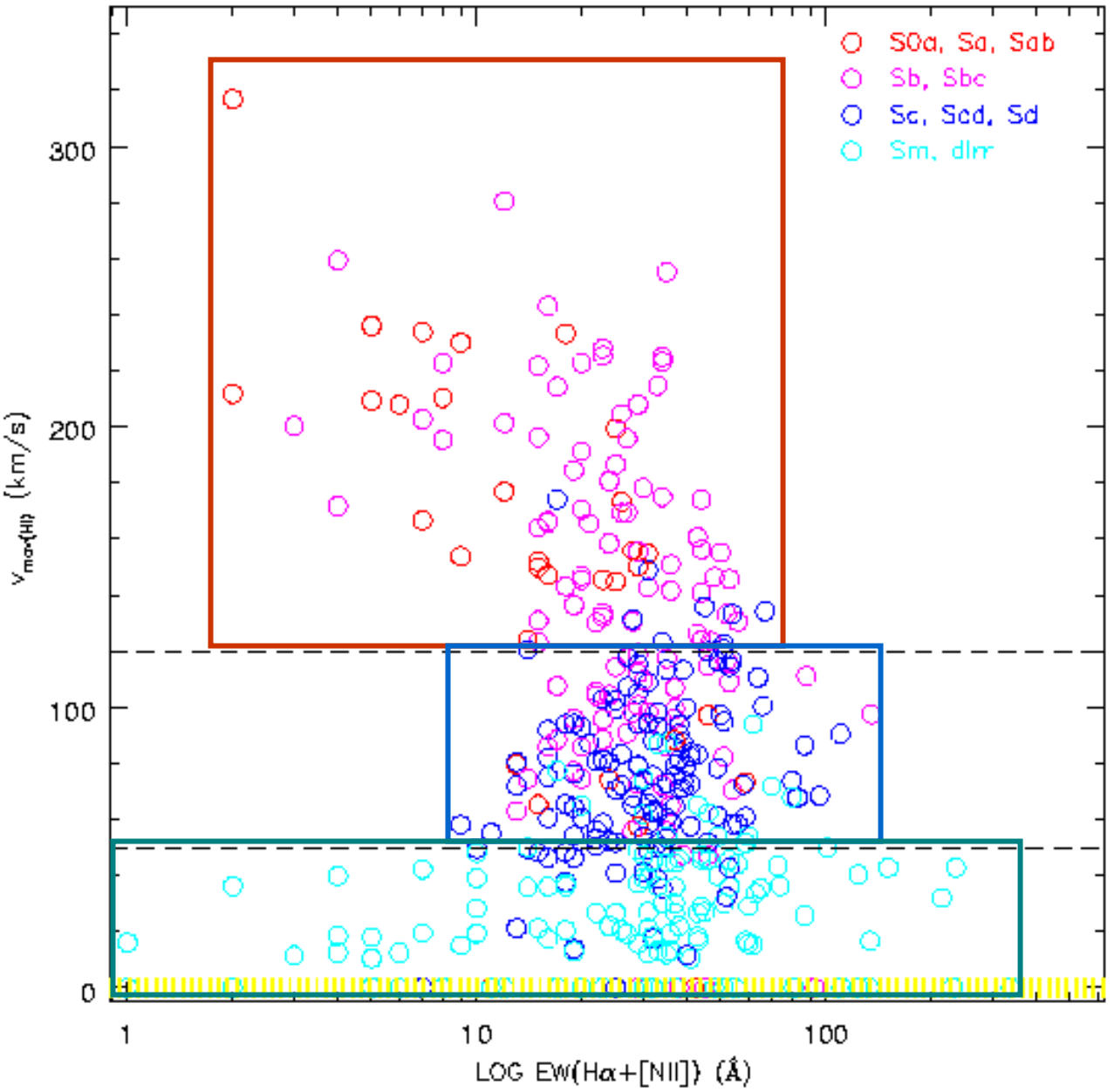
Schimminovich 2007



Brinchmann et al. 2004, MNRAS, 351, 1151

11HUGS Survey

V_{circ}



SFR/mass

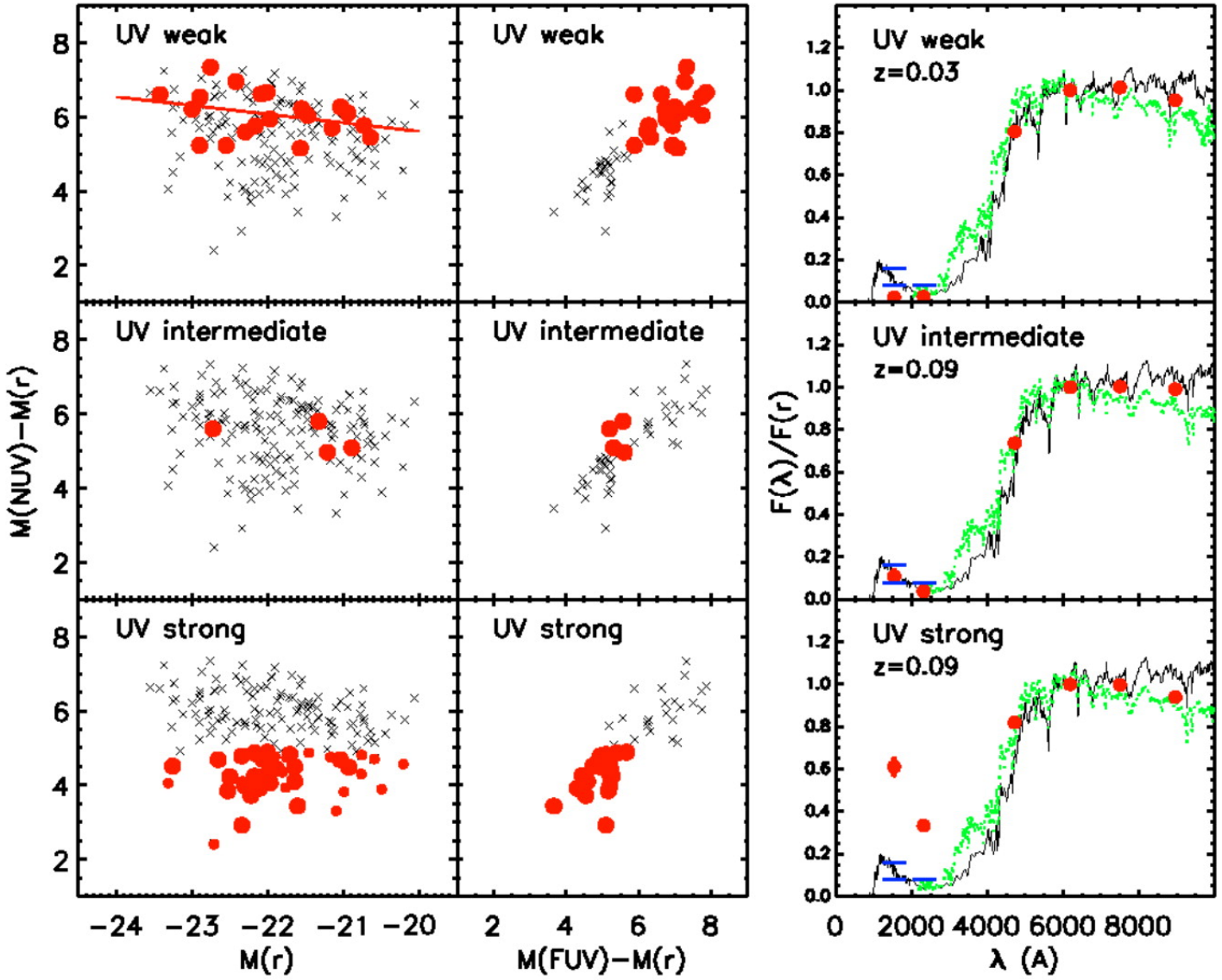
Lee et al. 2007, ApJL, 671, L113

Galaxy Evolution Explorer (GALEX)

- (nearly) all-sky imaging survey, 150/230 nm
- deep pointed imaging, spectroscopy
- several GALEX+Spitzer+optical/radio surveys

Andromeda Galaxy
GALEX

Andromeda Galaxy
Visible light image (John Gleason)

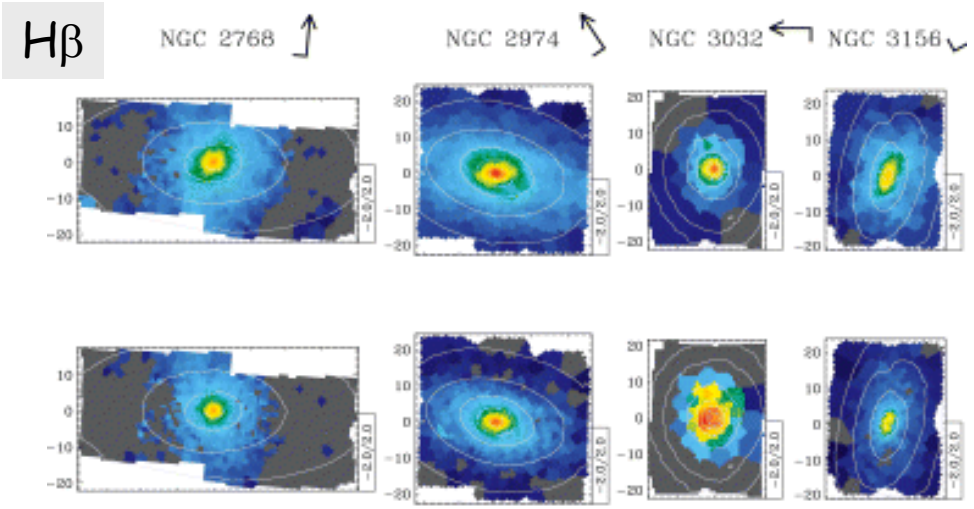


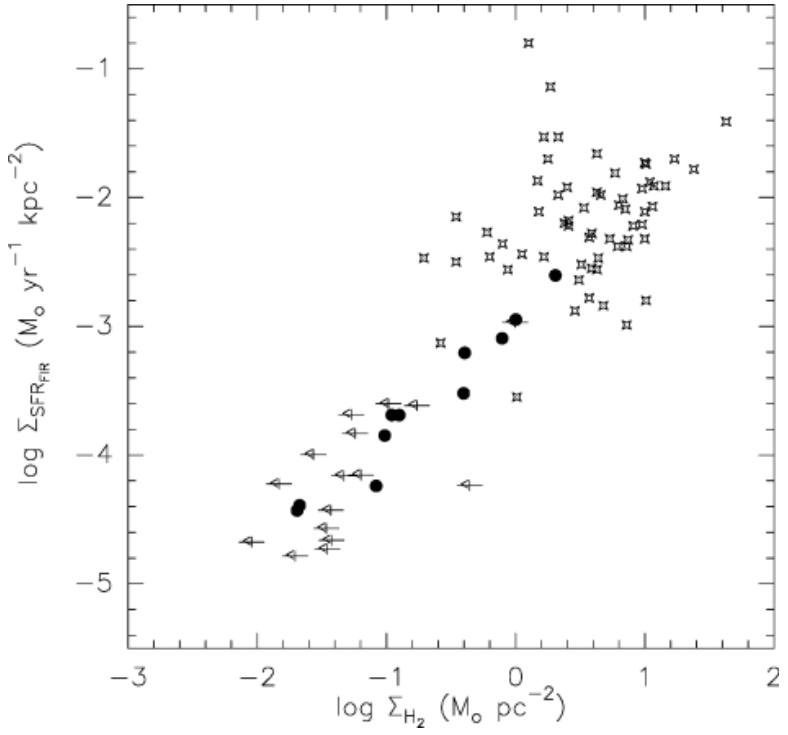
SF in 15% of ellipticals in past 1 Gyr

Yi et al. 2005, ApJ, 619, L111

SAURON Sample

- 48 E/S0 galaxies observed (43 in CO)
- 75% detected in Hβ (16/24 E, 20/24 S0), 28% detected in CO
- typical SFRs of order 0.01-1 M_o/yr
- disk-averaged SF properties extend Schmidt law for spirals





Sarzi et al. 2006, MNRAS, 366, 1151

Combes et al. 2007, MNRAS, 377, 1795

XUV Disks

M 83 (NGC 5236)

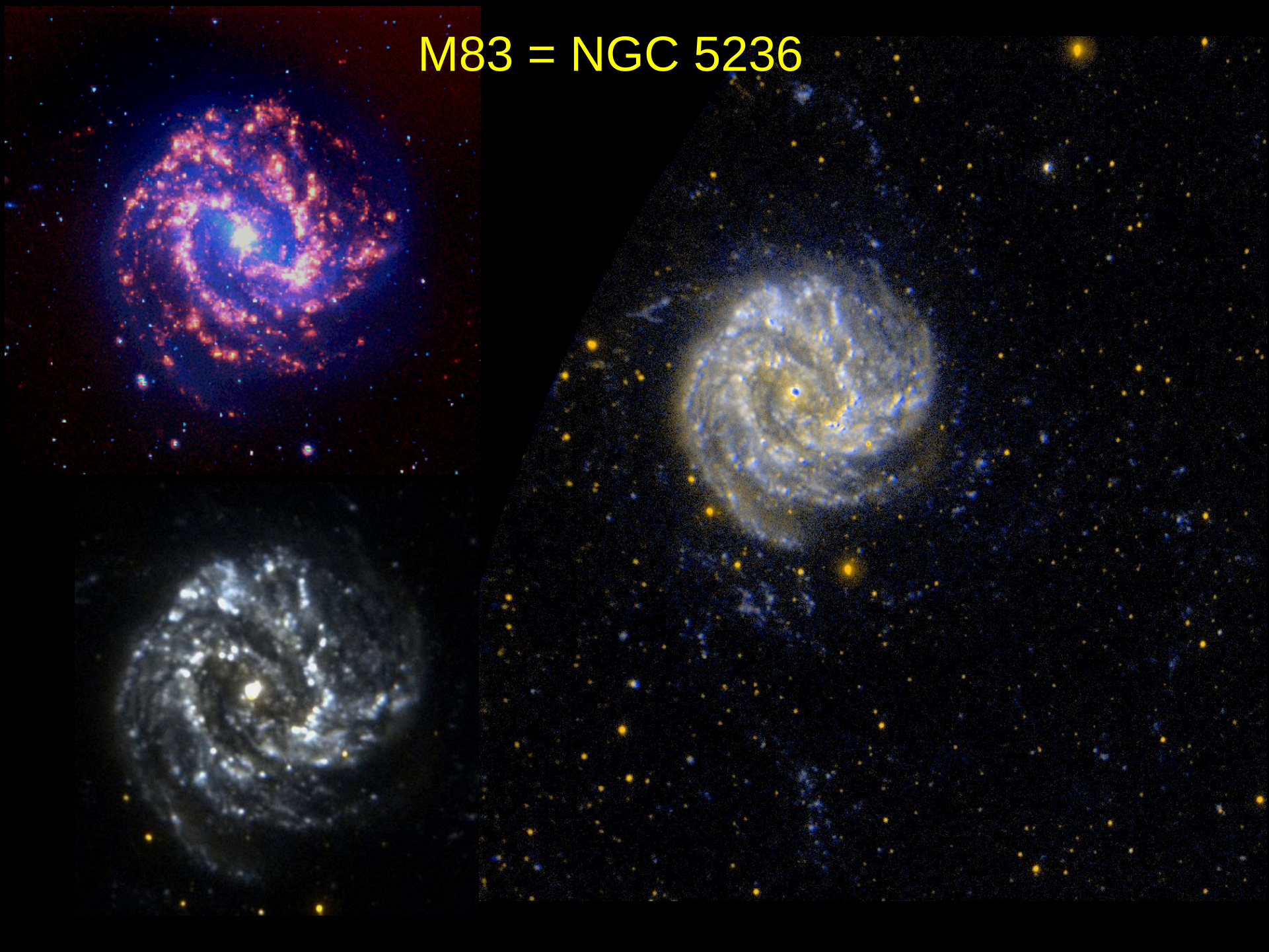
Thilker et al. (2005)

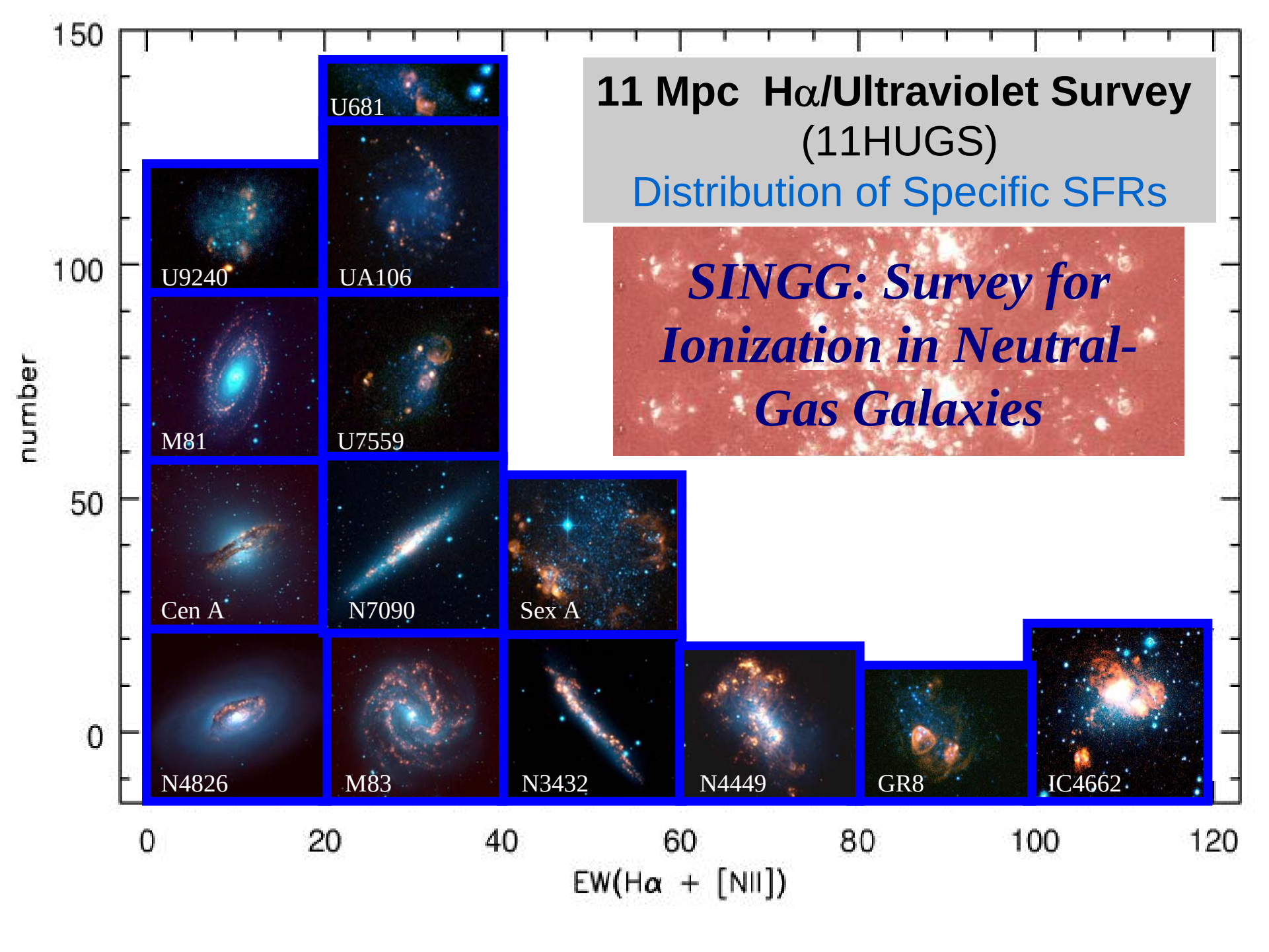
NGC 4625

Gil de Paz et al. (2005)

prepared by A. Gil de Paz

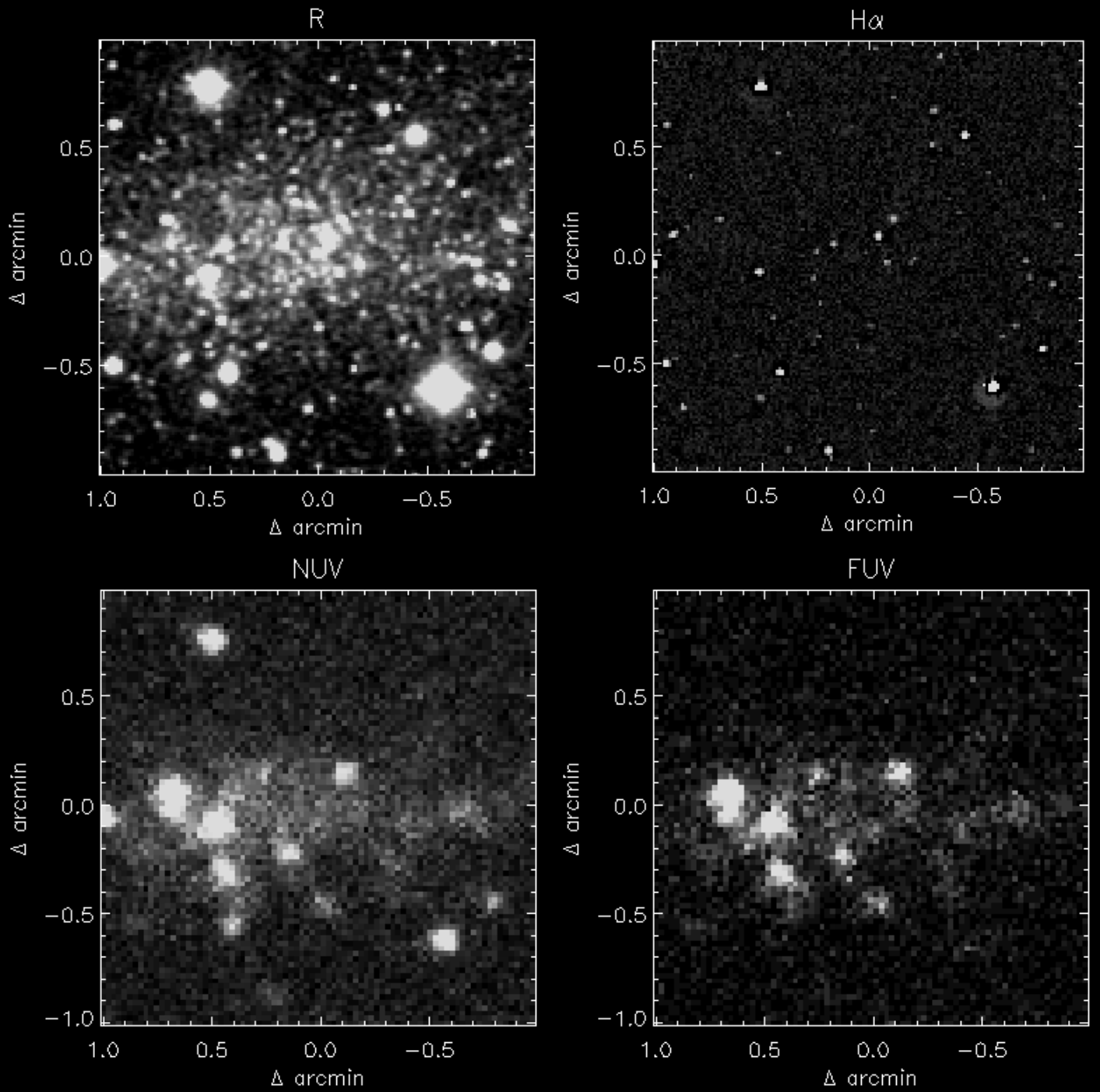
M83 = NGC 5236




11 Mpc Hα/Ultraviolet Survey
(11HUGS)
Distribution of Specific SFRs
SINGG: Survey for Ionization in Neutral-Gas Galaxies
U681
U9240
UA106
M81
U7559
Cen A
N7090
Sex A
N4826
M83
N3432
N4449
GR8
IC4662
number
150
100
50
0
0
20
40
60
80
100
120
EW(Hα + [NII])

DDO 210

IB(s)m
M_B = -12:

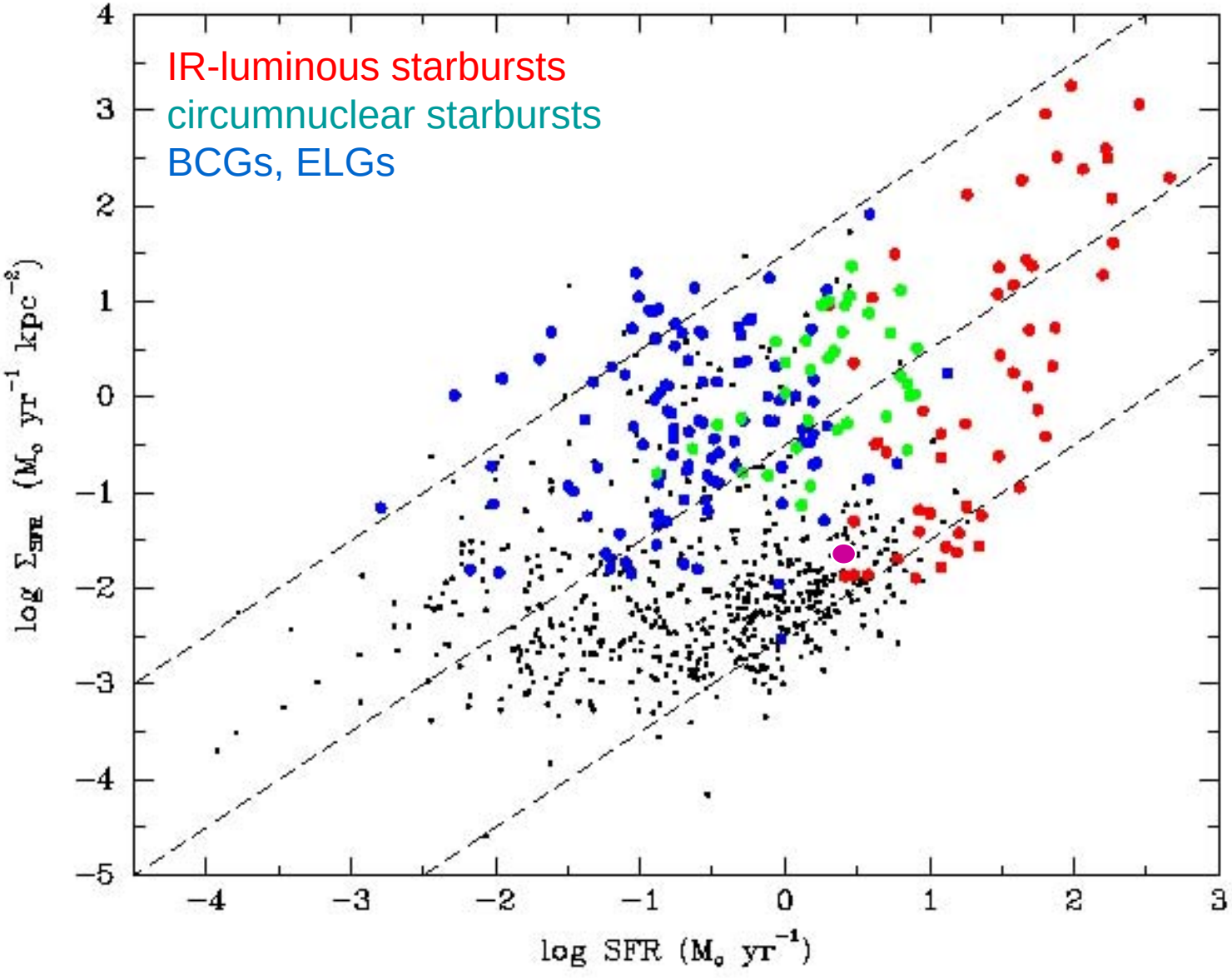


Disk SFRs: Main Results

Kennicutt 1998, ARAA, 36, 189
Brinchmann et al. 2004, MNRAS, 351, 1151

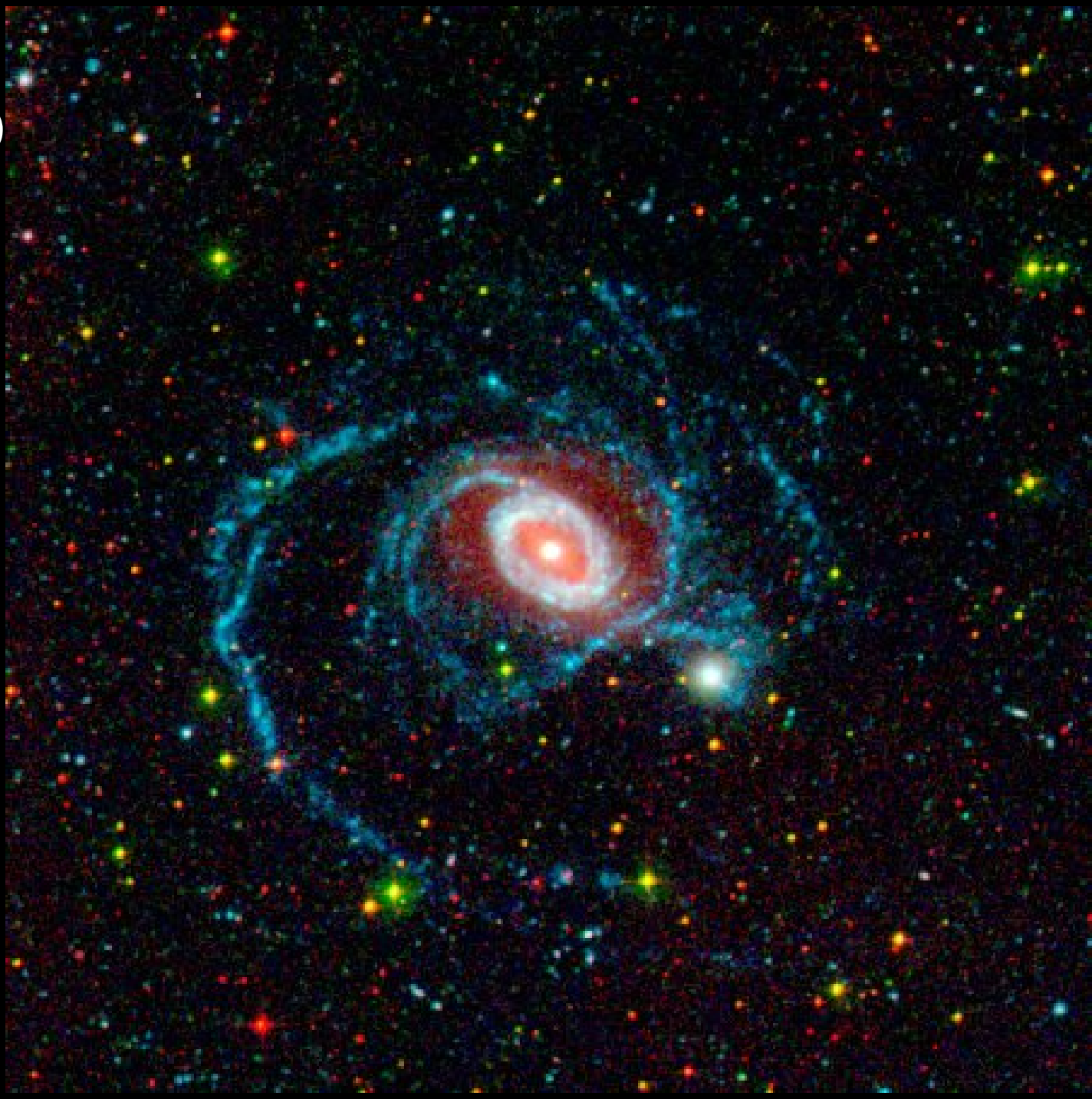
- spectra best fitted with IMF ~ Salpeter for $M^* > 1\ M_\odot$
- SF is ubiquitous when cold gas is present
  - <4% S-Irr non-detects in Hα, nearly all show trace SF in UV
- average SFR/mass increases by 5-10x per type bin (S0 - Sa - Sb, etc)
  - proportional changes in disk SF history with type
  - changes in frequency and characteristic mass of SF events
- large residual variation in SFR within a given type
  - most variation in disk SFR vs B/D ratio
  - more strongly correlated with mean gas density
  - temporal SFR variations (bursts)
- strong bimodality seen in SFR/mass vs galaxy mass
  - extension to dwarfs shows evidence for third mode
- radial gradients in disk age and metallicity

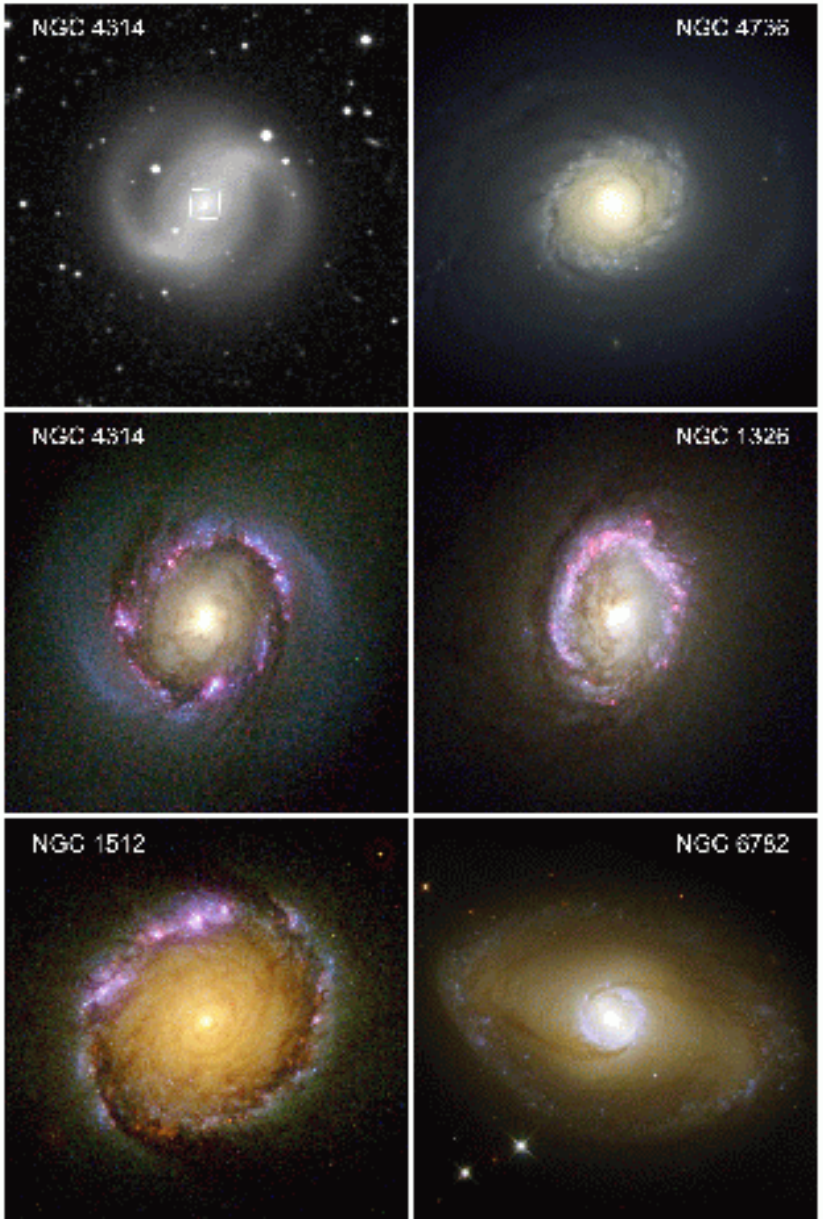
Starbursts

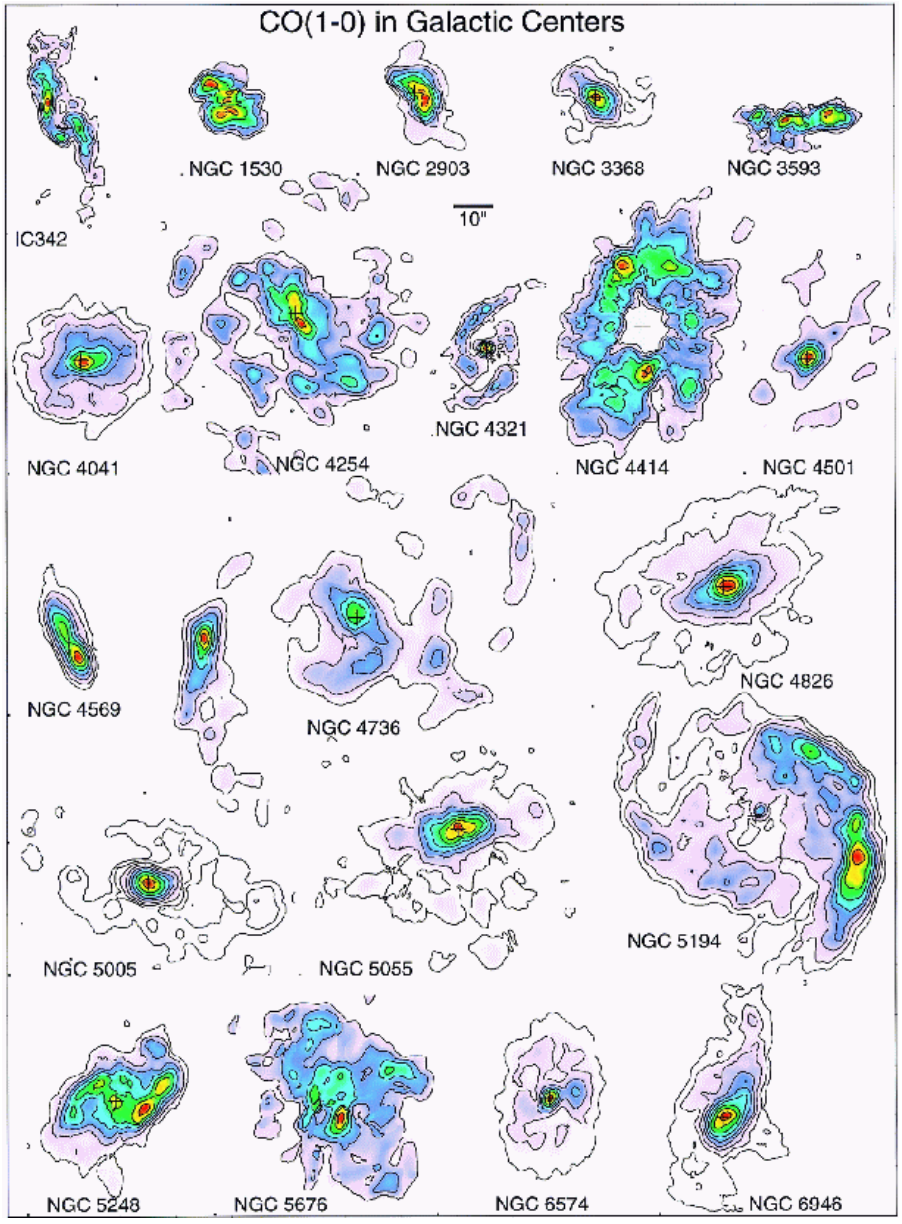

IR-luminous starbursts
circumnuclear starbursts
BCGs, ELGs
log Σ_{SFR} ($M_\odot$ yr^{-1} kpc^{-2})
log SFR ($M_\odot$ yr^{-1})
4
3
2
1
0
−1
−2
−3
−4
−5
−4
−3
−2
−1
0
1
2
3

NGC 1512 (HST)

NGC 1512
(GALEX FUV/NUV)

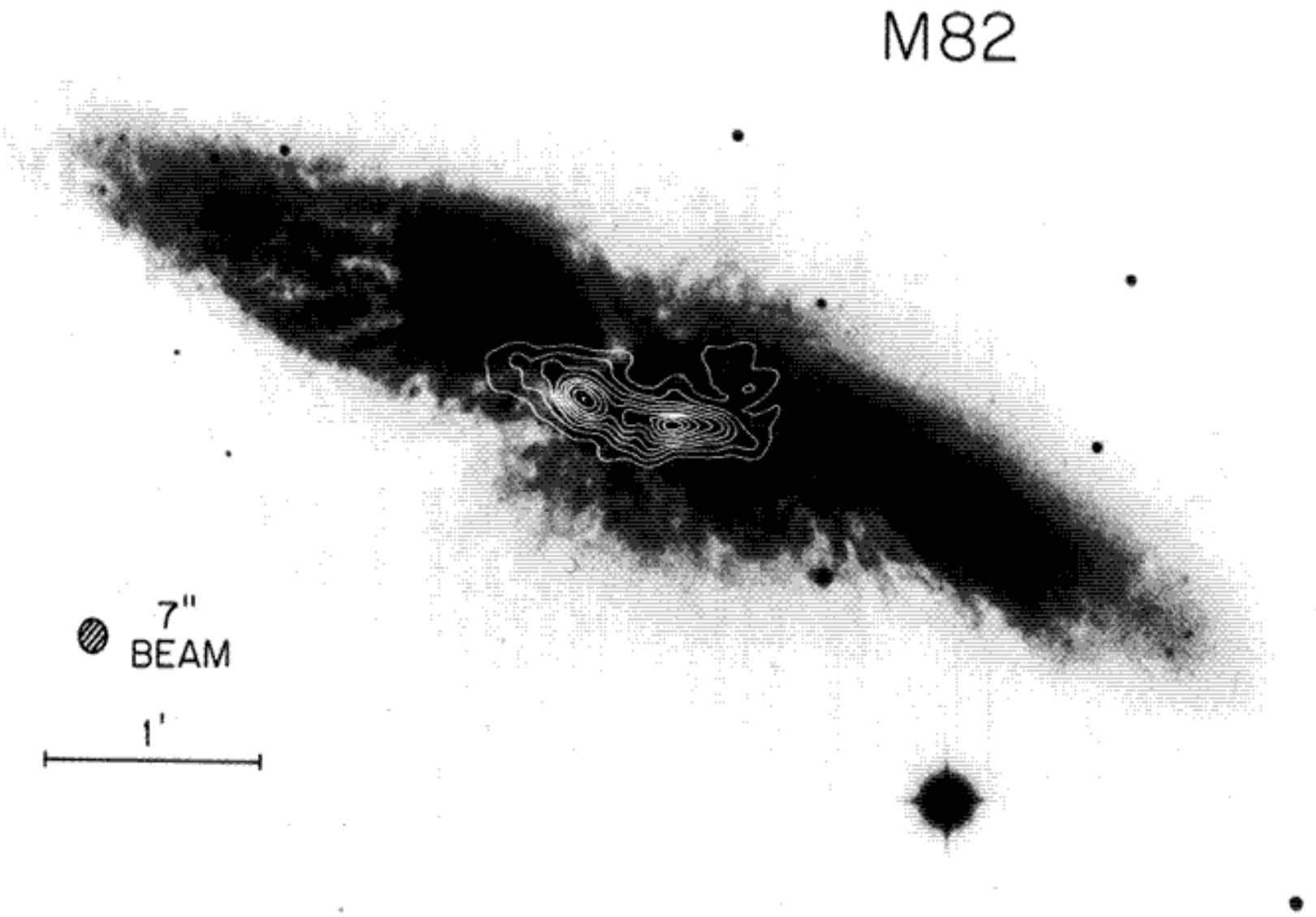






Kormendy & Kennicutt 2004, ARAA, 42, 603

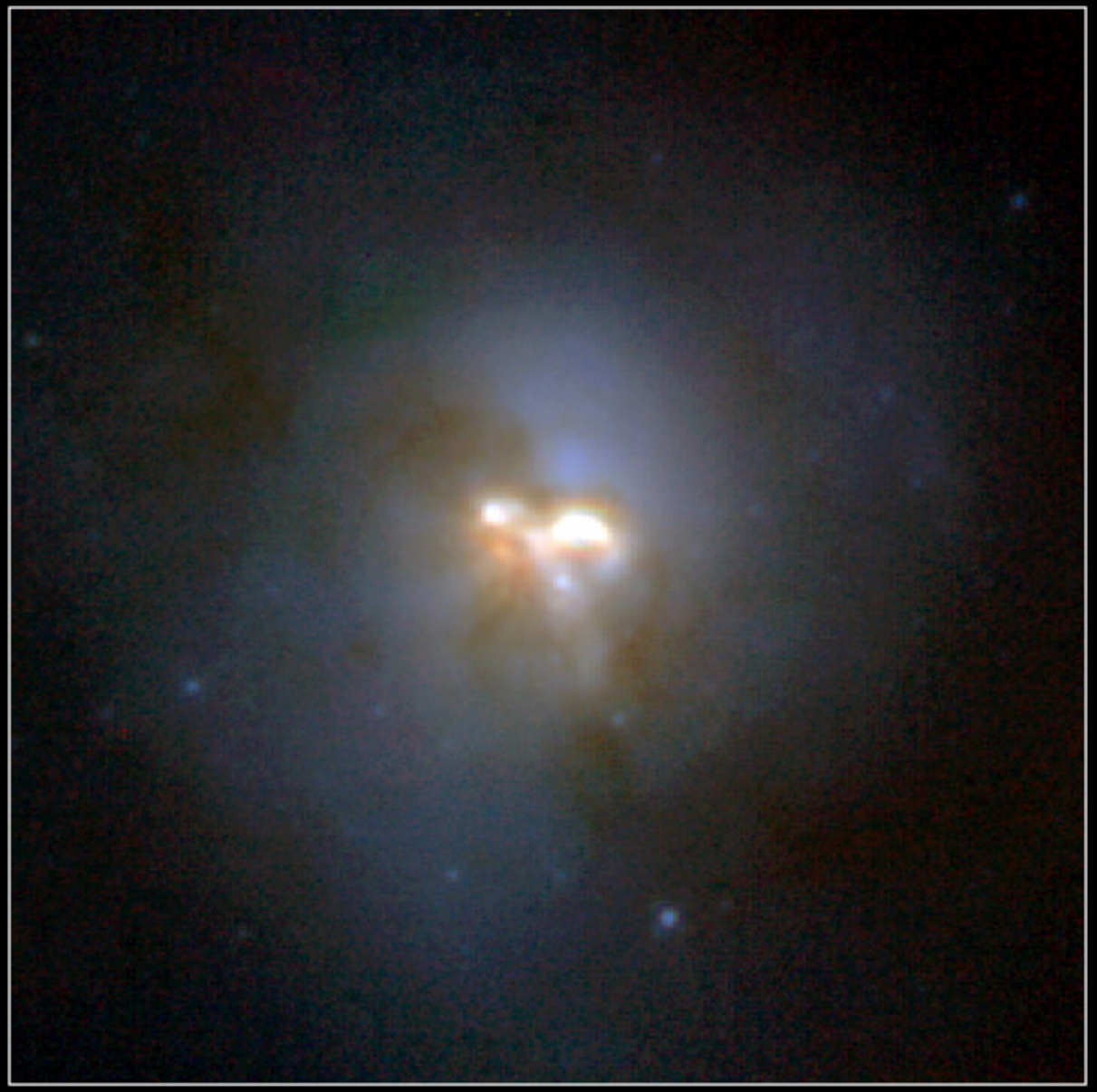
Sakamoto et al. 1999, ApJ, 525, 691



Lo et al. 1987, ApJ, 312, 574

Table 1: Star Formation in Disks and Nuclei of Galaxies

Property	Spiral Disks	Circumnuclear Regions
Radius	$1 - 30$ kpc	$0.2 - 2$ kpc
SFR	$0 - 20$ $M_\odot$ yr $^{-1}$	$0 - 1000$ $M_\odot$ yr $^{-1}$
Bolometric Luminosity	$10^8 - 10^{11}$ $L_\odot$	$10^8 - 10^{13}$ $L_\odot$
Gas Mass	$10^8 - 10^{11}$ $M_\odot$	$10^8 - 10^{11}$ $M_\odot$
Star Formation Timescale	$1 - 50$ 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	$0 - 0.1$ $M_\odot$ yr $^{-1}$ kpc $^{-2}$	$1 - 1000$ $M_\odot$ yr $^{-1}$ k pc $^{-2}$
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	?



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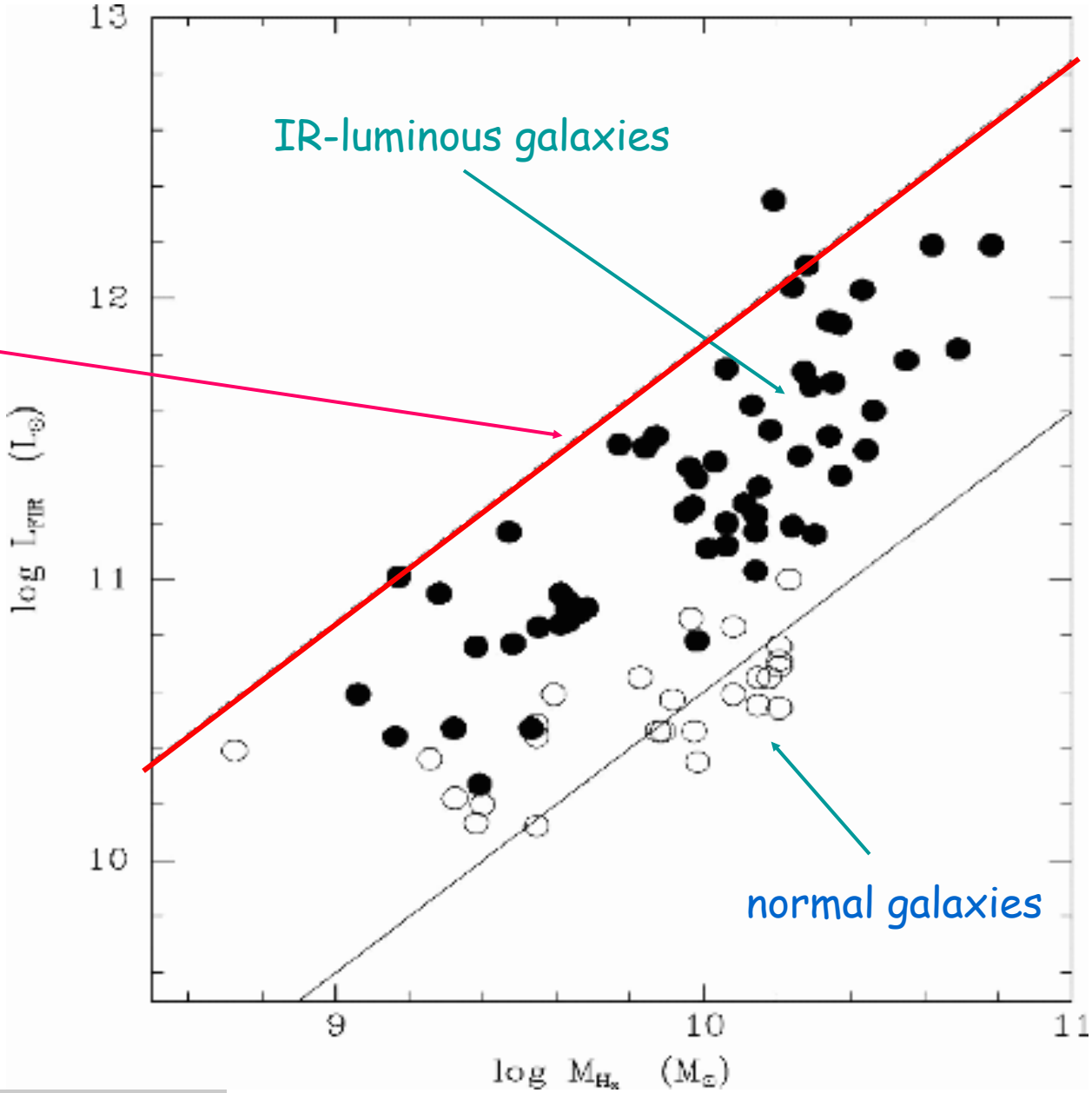
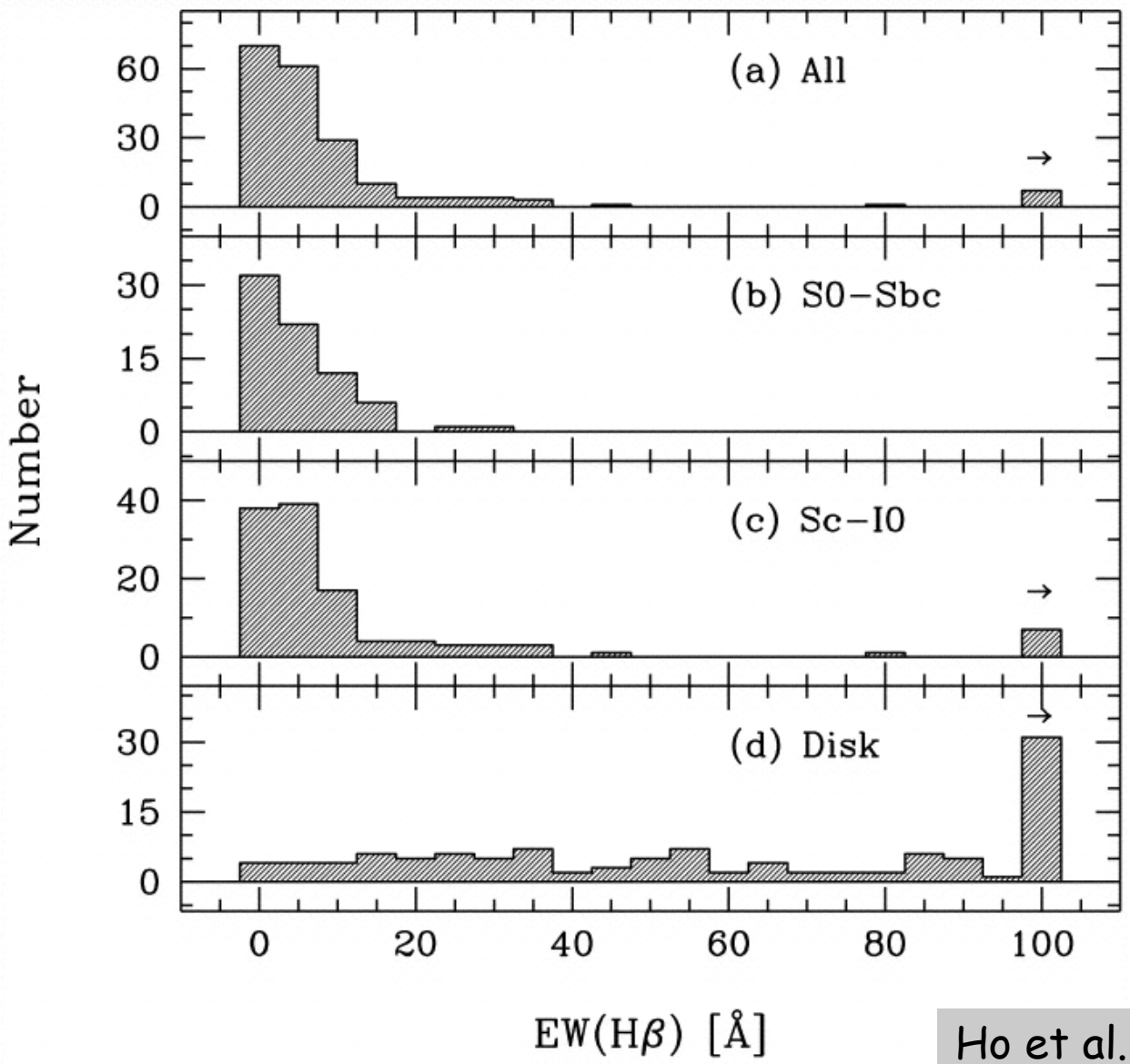
R. Thompson (University of Arizona),
N. Scoville (California Institute of Technology) and NASA



Kennicutt 1998, *ARAA*, 36, 189

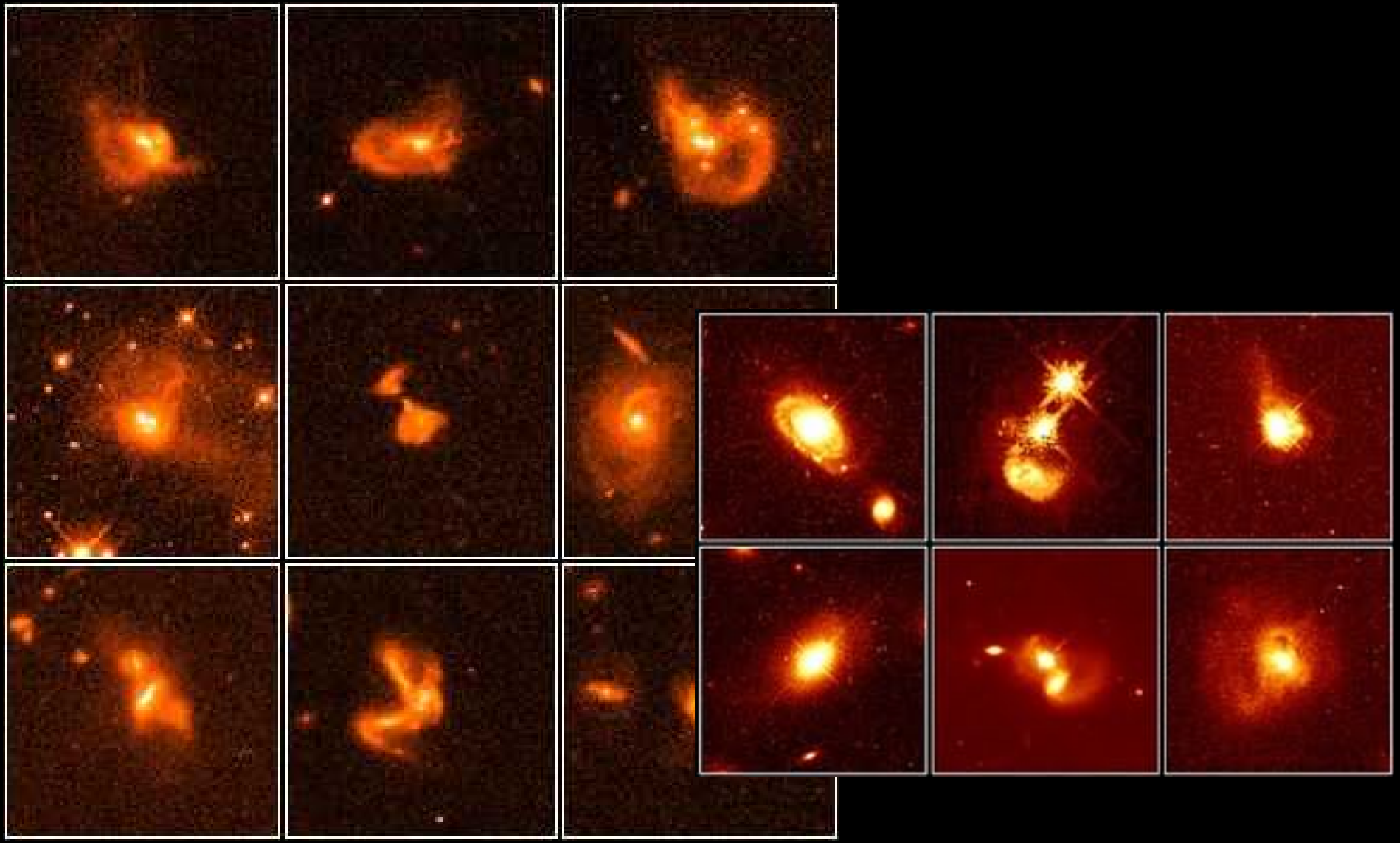
Circumnuclear Star Formation - Trends with Type



ellipticals too?!

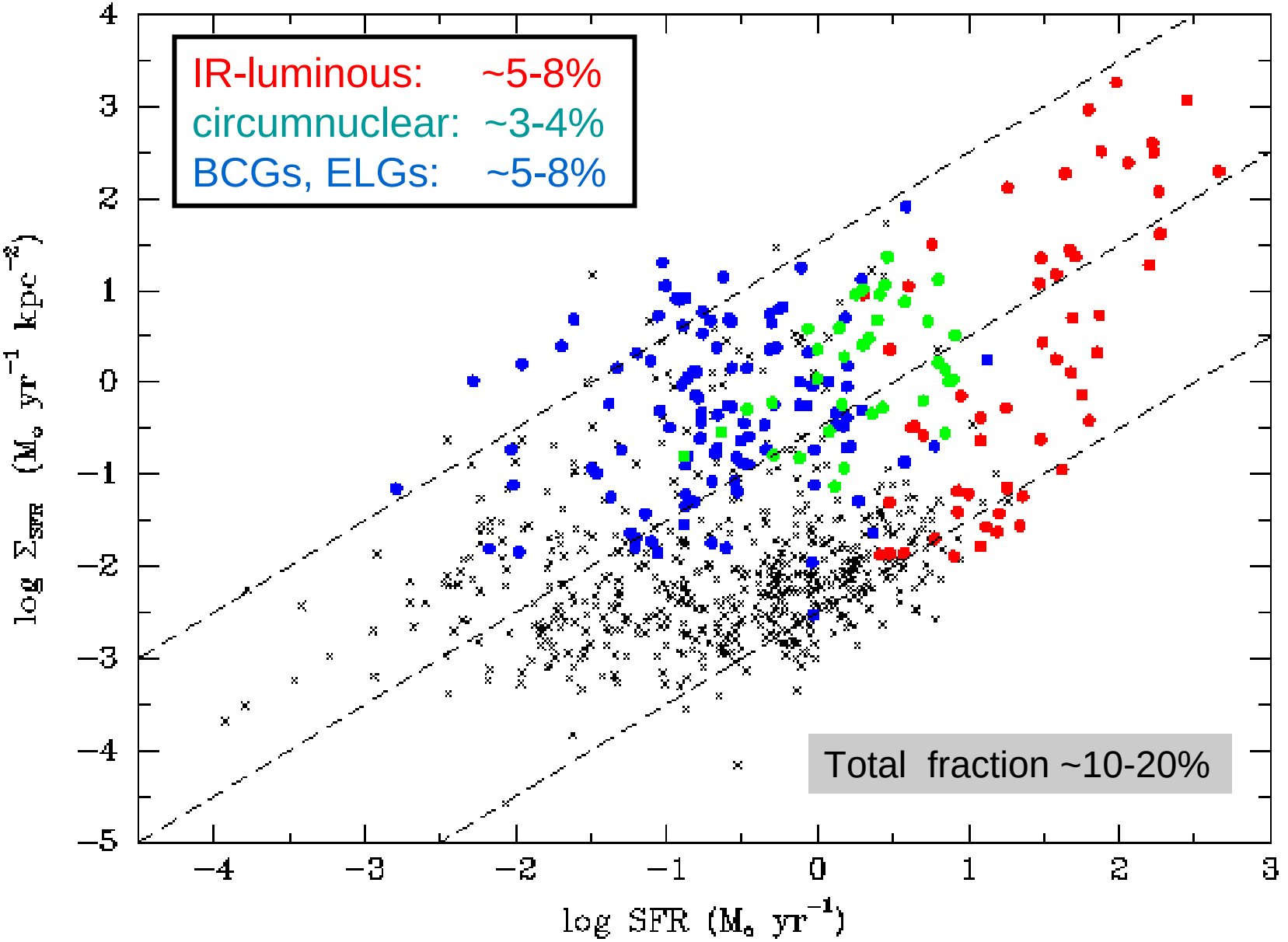
Yi et al. 2005, ApJ, 619, L111

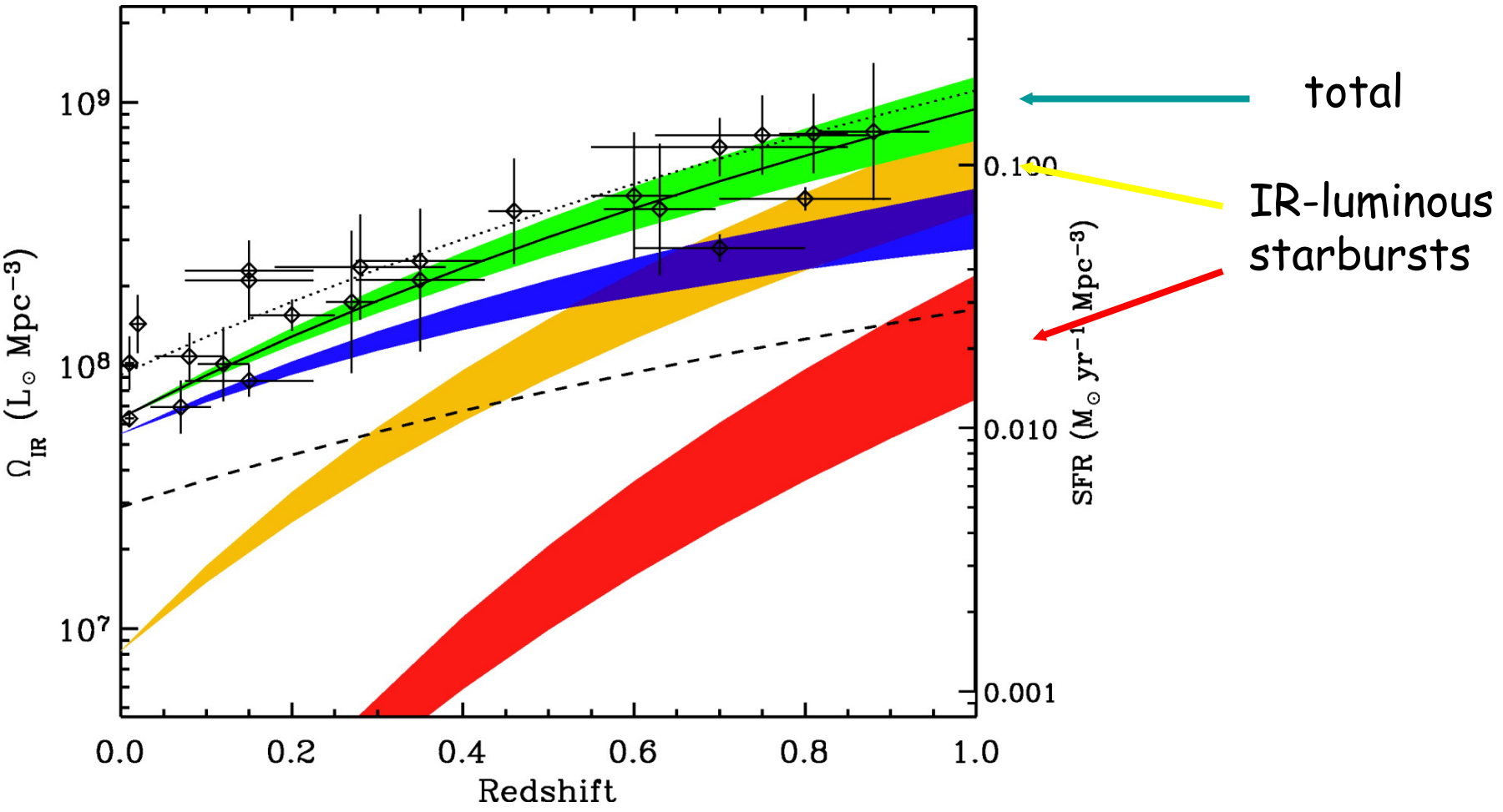
Ho et al. 1997, ApJ, 487, 595



Borne et al. 2000, ApJ, 529, L77

Contributions to the global star formation budget





L'Floch et al. 2005, ApJ, 632, 169