SFR of Blue Compact Galaxies



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- Sample selection
- Spec. observation
- Meas.& Correction
- Calculation of SFR
- SFR~M_B, timescale

1. Star Formation Rate

- **Star formation rate**
  - Understanding the SFH of the universe
  - Physical nature of different galaxies
  - Evolutionary histories of galaxies
- **Indicator** : UV Continuum; UBV color; Hα, Hβ; [OII]; FIR/IR; Radio
- **Agreement**: poor!

- **SFR of BCG**
  - SFR is important to study evolution of BCGs
  - few quantitative SFRs for BCGs (small sample)
  - SFRs of BCGs: 10^{-3} –10^{2} $M_{\odot}yr^{-1}$; average SFR 0.1 –10 $M_{\odot}yr^{-1}$

- The underlying reasons : SFR from difference indicators?
- wide range of BCG SFRs: different SFR indicators, sample selection?

[OII], Hα, IR, Radio → SFR

2. BCG Sample Selection

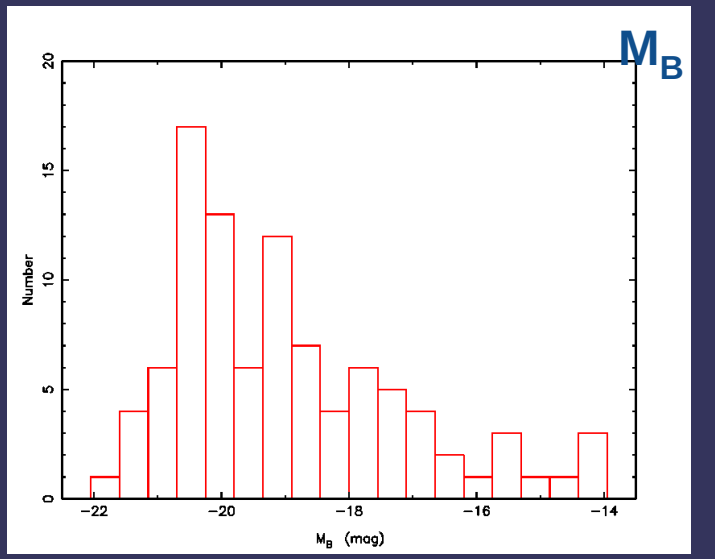
Whether BCGs are unique objects or not?

large spectral sample → Systematic analysis

- Image : perfect !
- Spectrum: published data for particular type of BCGs

Spectra, IRAS, HI line, Radio continuum

→ Age, Metallicity, SP,SFH, SFR



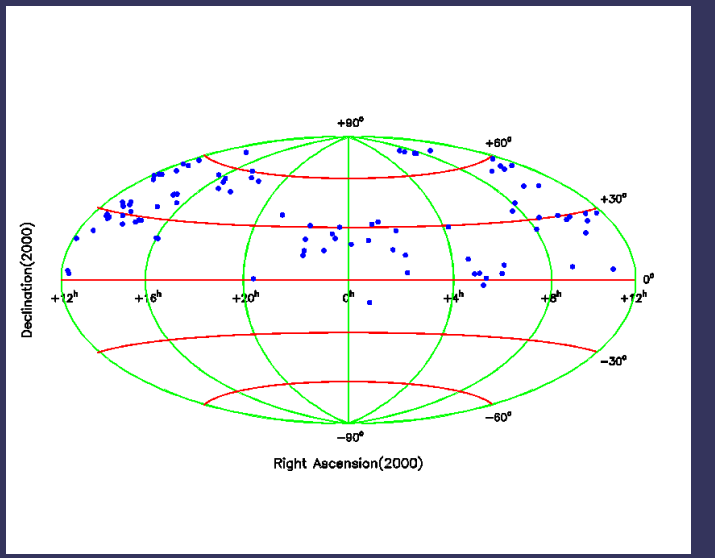
Large HI survey :

- © Gordon & Gottesman (1981): 99
- © Thuan & Martin (1981) :115

Based on the following criteria:

- m_B^c < 17.0 mag instrument limit
- δ_{2000} > – 12° declination limit of obs. site

200 BCGs & BCD 97 BCGs (01/2002)



3. Spectroscopic Observation

Telescope : **2.16** m
Beijing Astronomical Observatory

Data : 26 nights, Mar.1998 — Jan. 2002

Grating : 300 line mm^{-1}, D=4.8 Å $pixel^{-1}$

Slit width : 2″ ~ 3″, according to the seeing

Resolution : ~ 10 Å (FWHM)

Air mass : usually less than 1.2

Exp. time : 1800 — 3600s, m_B and seeing



- **39 objects were observed twice → get a higher S/N**
- **A total 136 BCGs spectra were observed**
- **S/N : average ~ 50**

Kong et al. (2002,A&A,389,845)

Spectrum of BCG

Blue color, UV-excess,
Compactness:
not on spectrum

Emission line

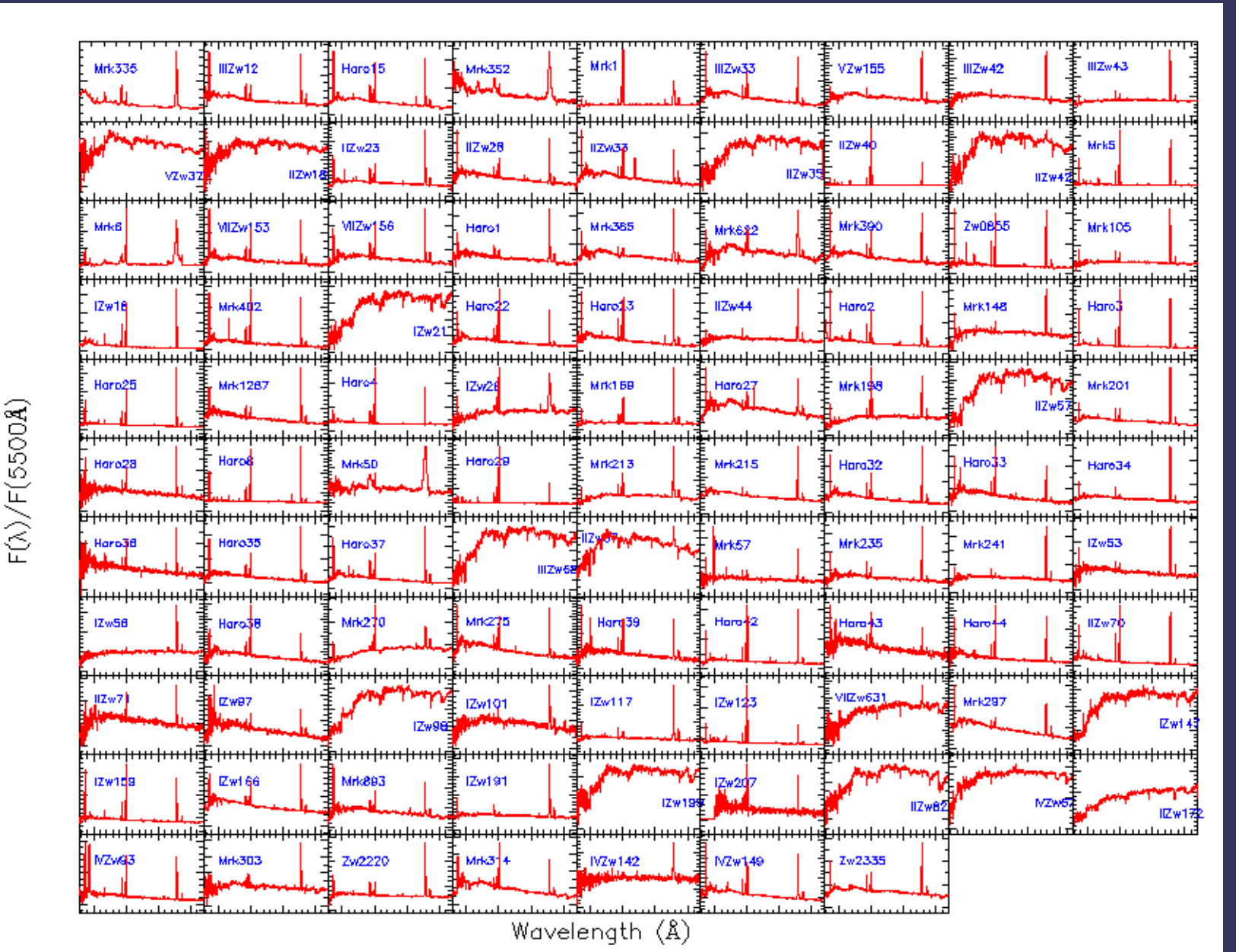
Hα emission line

Broad emission line

log R_{23}>1.1 : Sy2

Log([NII]6583/Hα)>–0.25

72 Star Formation Galaxies (SFG)



4. Measurement & Correction

- **Emission line** → E(B-V) SFR Metallicity
  - Single : direct integral method Blended: Gaussian deblending
  - [OII]3727, Hβ4861, [OIII]4959,5007, Hα6563, [NII]6583, [SII]6716, 6731
  - Hγ4340, [OIII]4363, HeI5876, [OI]6300 **Typical uncertainty: 10% or 20%**
- **Continuum** avoid regions of strong emission or absorption features
  - Δλ=20 Å : 3660, 4020, 4510, 4630, 5313, 5500, 6080, 6630, 7043,7520
  - Point flux : 3784, 3814, 3918
- **Absorption feature**
  - CaII K, CaII H, Hδ, CN, Gband, MgI+MgH, NaI
  - **Uncertainty: <15% (SFG)**

Kong et al. (2002b,A&A,396,503)

absorption feature
continuum colors
→ Empirical Population Synthesis →
stellar population
subtract absorpt.

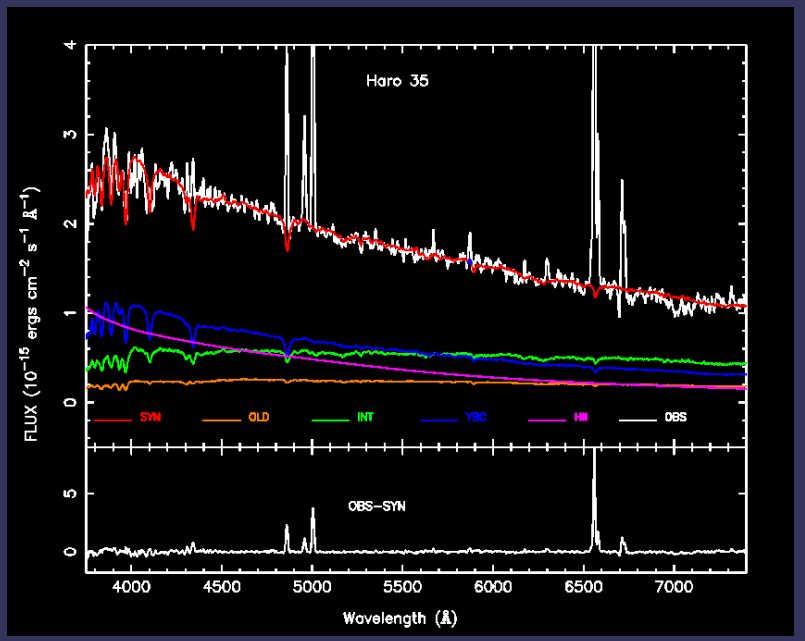
Cid Fernandes et al.(2001,MN,325,60) Bica(1988,A&A,195.76)

4.1 Stellar Absorption Correction

Correct the underlying stellar absorption:

EW= 1.5 – 2 Å

- **Age of star formation burst**
- **Star formation history**

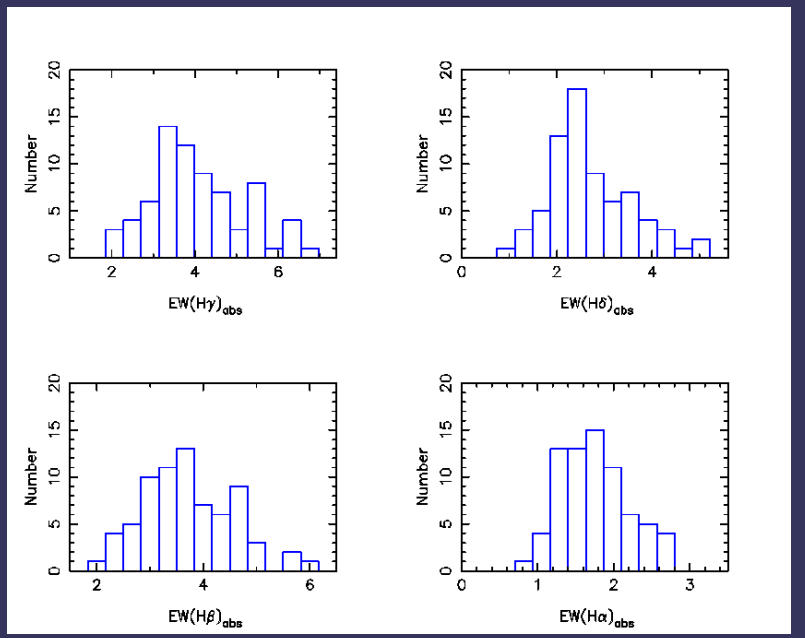


- **EPS → synthetic spectrum →**

EW of Hα,Hβ,Hγ,Hδ

EW(Hβ) > 2Å

EW(Hα) ~1.5 Å



$$F_{line}^{cor} = F_{line}^{obs}\left(1 + EW_{line}^{abs} / EW_{line}^{obs}\right)$$

Kong et al. (2003,A&A,submitted)

4.2 Dust attenuation Correction

- **Effective absorption curve:**

$$\tau_\lambda = \tau_V \left(\lambda/5500\right)^{-0.7}$$

Charlot & Fall (2000,ApJ,539,718)

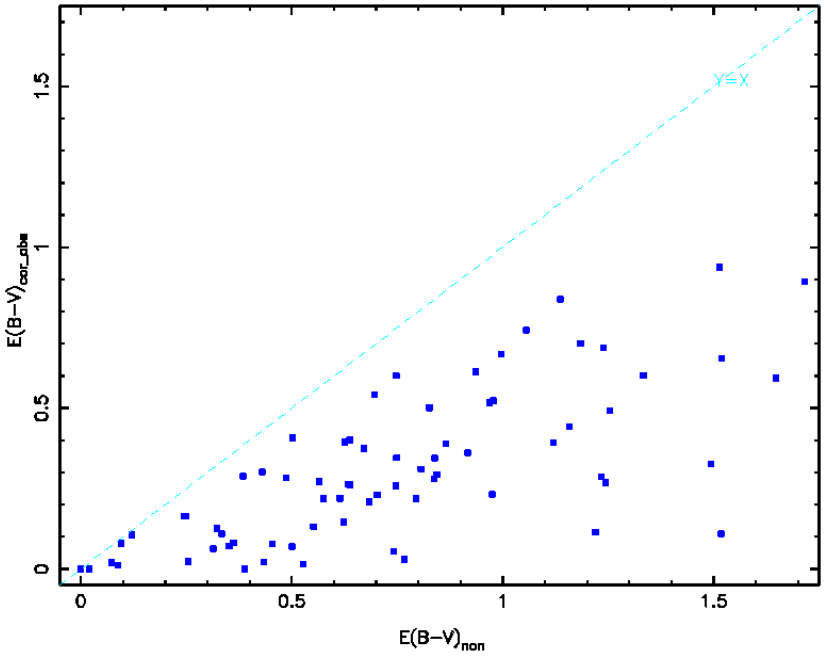
- **Color excesses arising from dust attenuation:** Balmer decrement

$$E_{B-V}^{\text{int}} = A_V / R_V = 1.086\,\tau_V / R_V$$

$$\tau_V = -\frac{\ln[F(H\alpha)/F(H\beta)] - \ln[I(H\alpha)/I(H\beta)]}{[(6563/5500)^{-0.7} - (4861/5500)^{-0.7}]}$$

I(Hα)/I(Hβ) :**intrinsic Balmer flux ratio,2.86**

F(Hα)/F(Hβ): **observed Balmer flux ratio**



- **Intrinsic line fluxes relative to Hβ**

$$I(\lambda)/I(H\beta) = F(\lambda)/F(H\beta) \cdot e^{\tau_V[(\lambda/5500)^{-0.7} - (\lambda_{H\beta}/5500)^{-0.7}]}$$

Correction the stellar absorption is important!

4.3 Correction for Aperture effect

- **Slit : width 2″ ~ 3″; long 3′**

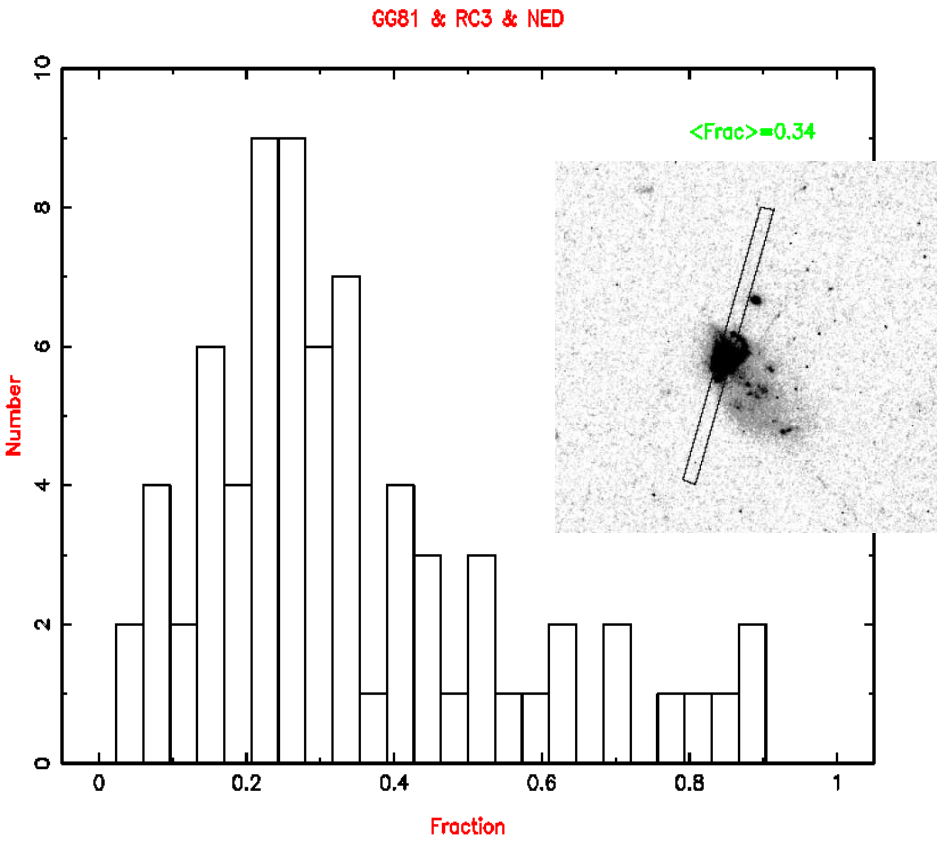
Slit only cover part of the galaxy

- **The slit-covering fraction *f*:**

$$f = \frac{F_B(spec)}{F_B(phot)} = \frac{L_B(spec)}{L_B(phot)}$$

$$= 10^{-0.4[M_B - M_B(spec)]}$$

Convolve the galaxy spectrum with the B-band filter response curve F_B(spec) → m_B → M_B(spec)



- **The intrinsic absolute flux:**

$$F_i = F_{spec} / f$$

***f* : 0.2 — 0.3**

5. SFR from Hα and [OII]

Recombination Lines: Hα,... 72/74 BCGs

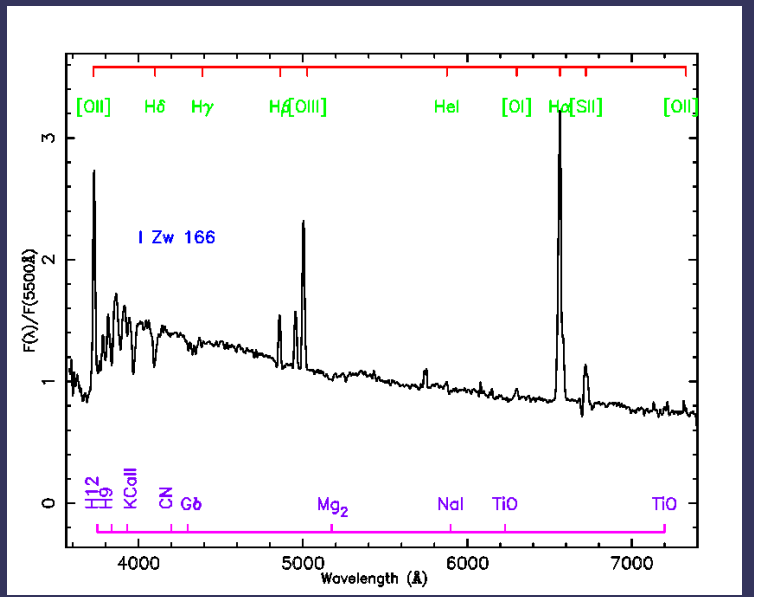
- ➢ Young hot stars→Ha photos →SFR
- ➢ Ionizing radiation escape fraction:

  15-50% individual HII regions;

  <3% whole galaxies

- ✓ High sensitivity (small telescopes)
- × Uncertainties in extinction and the IMF

$$SFR(M_\odot\ yr^{-1}) = 7.9 \times 10^{-42}\ L(H\alpha)\ ergs\ s^{-1}$$ (K98)



Forbidden Lines: [OII]3727

- ➢ not directly coupled to the ionizing luminosity
- ➢ relationship between Hα and [OII]→SFR

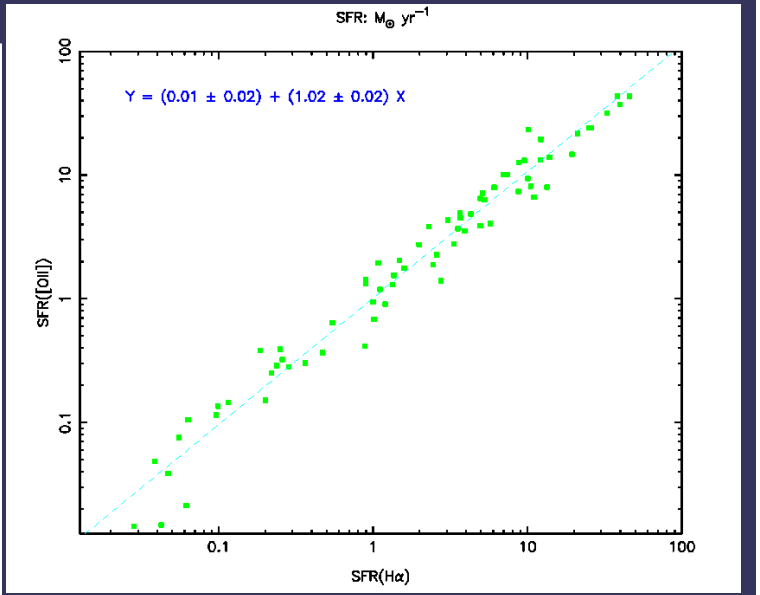
× Extinction, abundance , ionization state

✓ Distant galaxies, check on SFRs derived by others

$$SFR(M_\odot\ yr^{-1}) = (1.4 \pm 0.4) \times 10^{-41}\ L([OII])\ ergs\ s^{-1}$$

(Gallagher et al. 1989,AJ,97,700)

blue ELG:lower limit(1.0) S &Irr.:upper limit (1.8)



Abs. and Reddening Corr.

Log SFR([OII])/SFR(Hα) vs. M_B

Before apply any corr.

- x absorption corr.
- x reddening corr.

SFR(Hα) ~ 1.26SFR([OII])

x abs. corr. ;E(B-V)↑

✓ reddening corr.

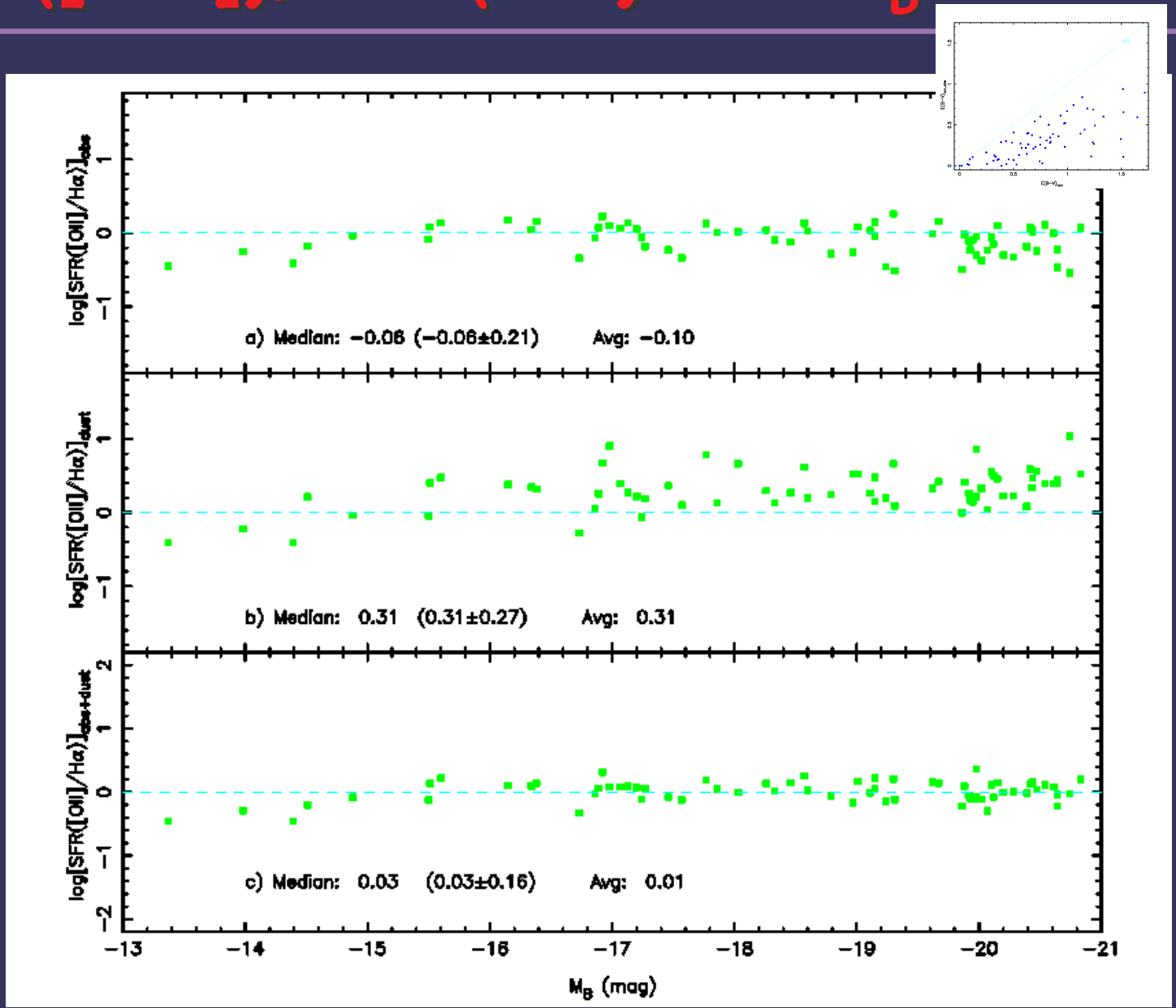
SFR(Hα) ~ 0.5 SFR([OII])

High redshift, SFR([OII])

✓ absorp. corr.

✓ reddening corr.

SFR([OII])~ SFR(Hα)



Subtract the underlying stellar absorption lines from emission lines is important!

SFR from IRAS Flux



Far-Infrared Continuum:

- **Bolometric luminosity→dust→re-emitted in IR**
- **Dust absorption cross section is peaked in UV**

→ IR/FIR→SFR

$$SFR(M_\odot\ yr^{-1}) = n \times 4.5 \times 10^{-42}\ L(IR\ \ 8\text{-}1000\ \mu m)\ ergs\ s^{-1}$$
$$= n \times 7.9 \times 10^{-42}\ L(FIR\ 10\text{-}120\ \mu m)\ ergs\ s^{-1}$$

(K98: Kennicutt, 1998.ARA&A,36,189)

- **dust heating from old stars :coefficient *n* decrease**
- **lower optical depth of dust :coefficient *n* increase**

$n=1\pm 0.3$

55/72 BCGs: IRAS Faint Source Catalog (FSC,2.0) 12, 25, 60, 100 μm

$$F(IR) = 1.8\times10^{-11}[13.48\,f_{12} + 5.16\,f_{25} + 2.58\,f_{60} + f_{100}](ergs\ cm^{-2}s^{-1})$$
$$F(FIR) = 1.26\times10^{-11}[2.58\,f_{60} + f_{100}](ergs\ cm^{-2}s^{-1})$$

IRAS f_ν → $F(IR)$ → $L(IR) = 4\pi D^2 F(IR)$ → SFR(IR)

Log SFR(Hα)/SFR(IR) vs. M_B

Hα : obs. flux

- x abs. & reddening
- SFR(IR) ~ 2.5SFR(Hα)

✓ reddening corr.

x absorpt. corr.

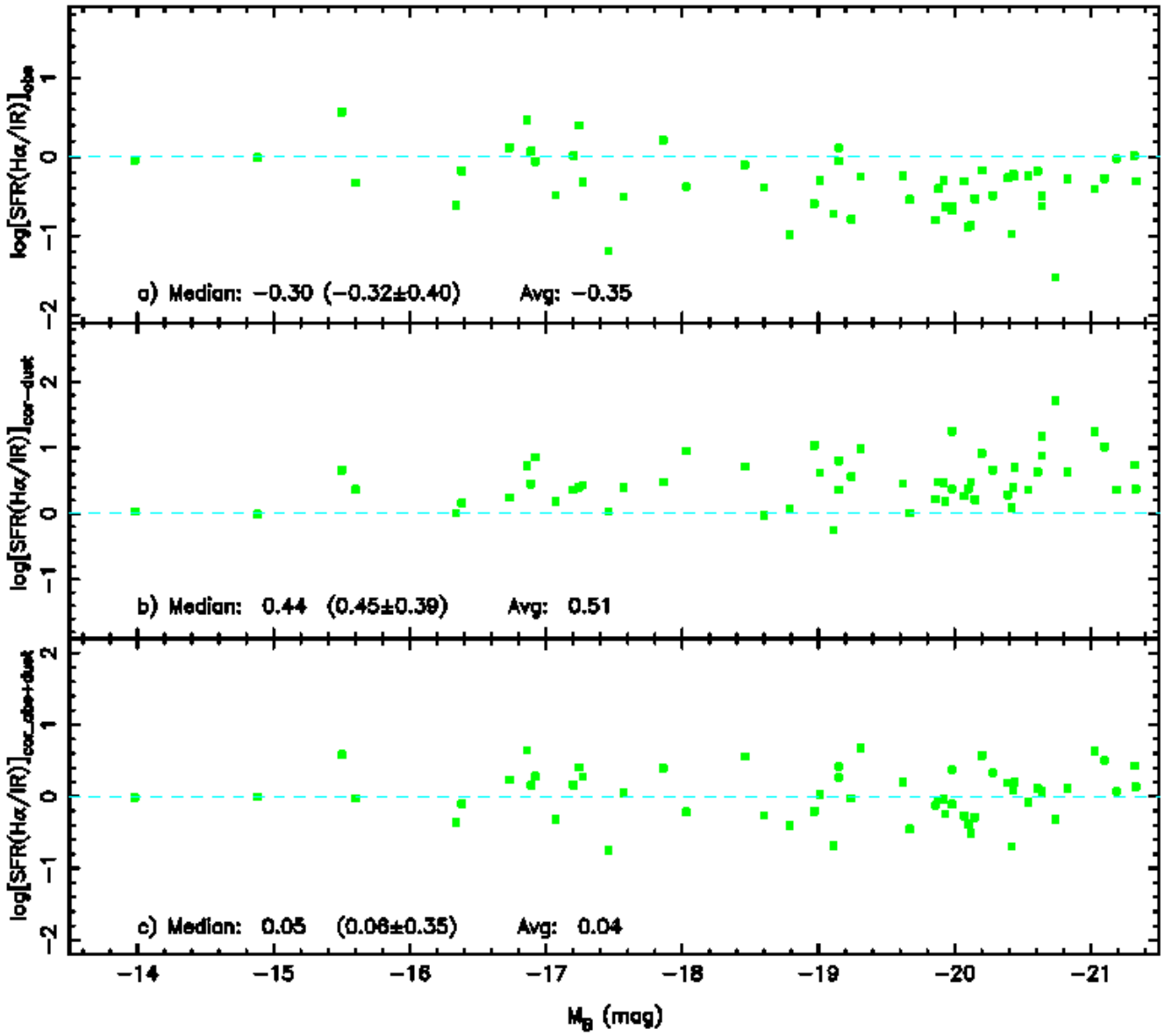
SFR(IR) ~ SFR(Hα)/3.2

✓ absorpt. corr.

✓ reddening corr.

SFR(IR)~ SFR(Hα),

the scatter is large



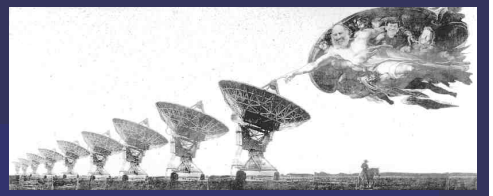
SFR from 1.4 GHz radio continuum

The integrated radio flux at 1.4GHz :

- **non-thermal synchrotron emission from supernovae**
- **thermal Bremsstrahlung from electrons in ionized HII**

Traced to massive ($M > 5M_{\odot}$) stars → IMF → SFR

- **Extinction-free tracer of star formation**



45/72 NVSS : NARO VLA Sky Survey

24/72 FIRST: Faint Images of the Radio Sky at Twenty-cm

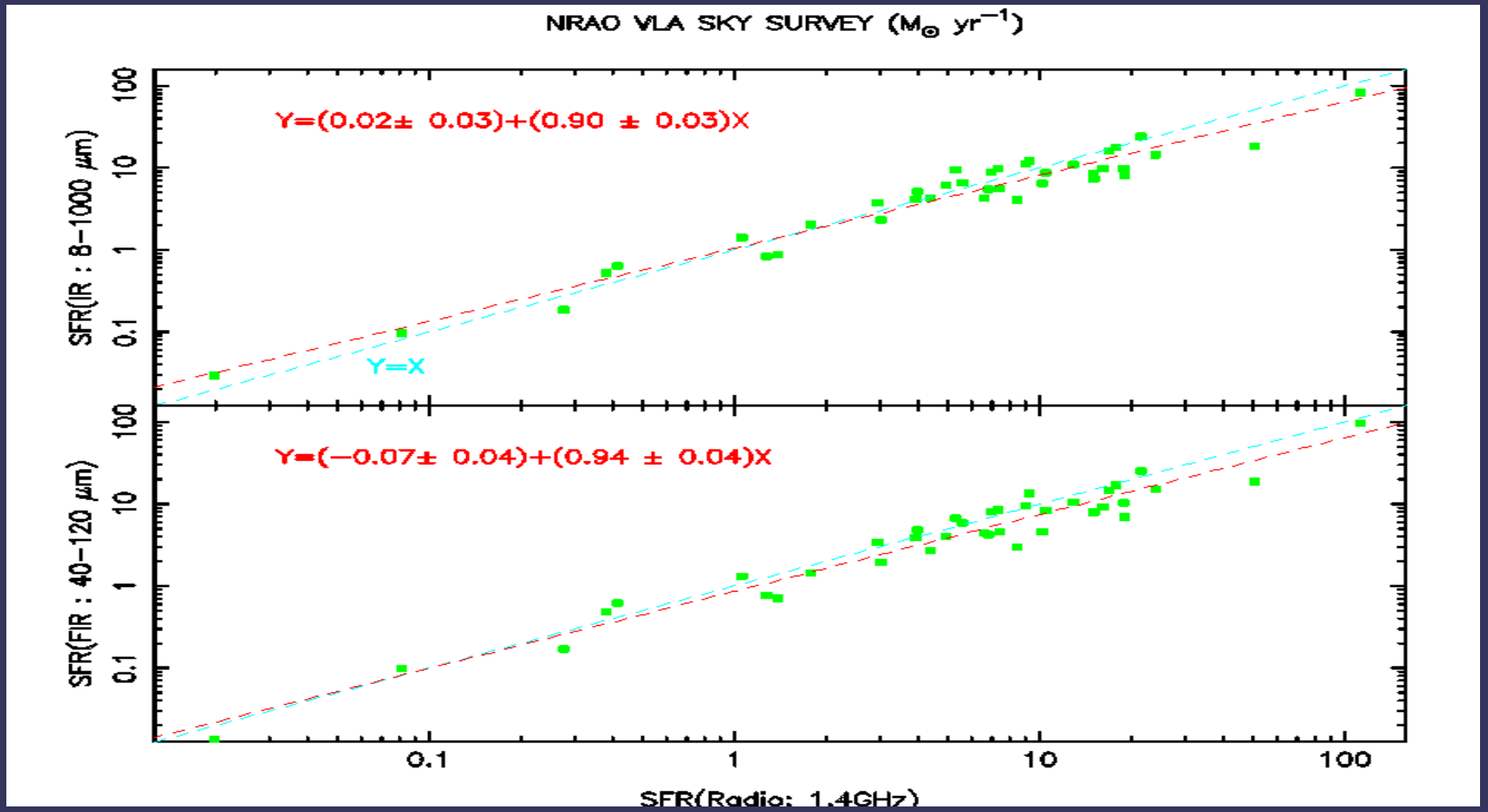
$$\mathrm{SFR}(M_{\odot}\ \mathrm{yr}^{-1}) = Q \times 2.2 \times 10^{-22}\ L(1.4\ \mathrm{GHz})\ \ (\mathrm{W\ Hz}^{-1})$$

$$Q = \int_{0.1 M_{sun}}^{100 M_{sun}} m \cdot \varphi(m) dm \Big/ \int_{5.0 M_{sun}}^{100 M_{sun}} m \cdot \varphi(m) dm = 5.5$$

Salpeter IMF

Hopkins et al. (2002,AJ,124,862)

SFR(radio) vs. SFR(IR/FIR)

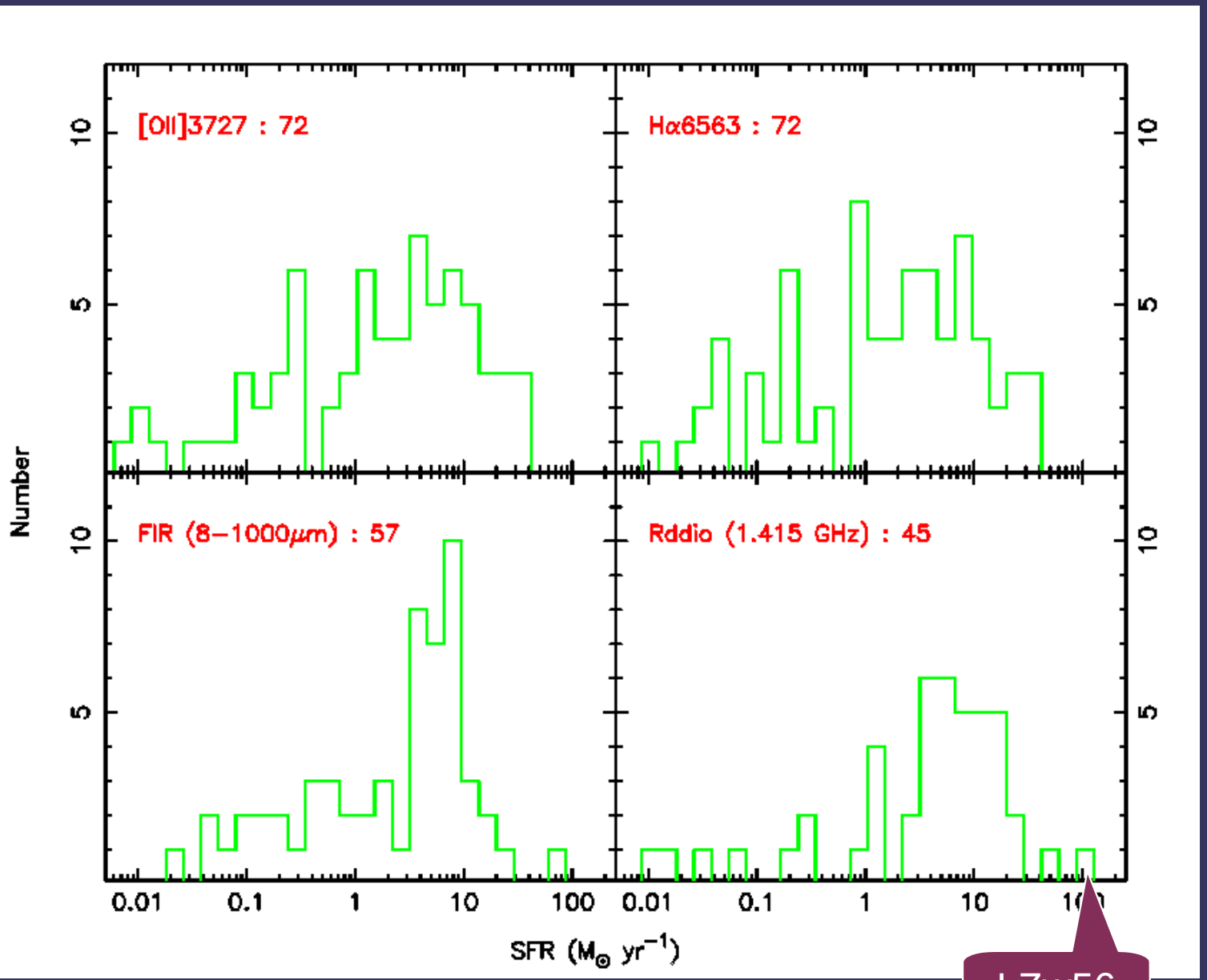


SFR(1.4GHz) = SFR(IR/FIR) :excellent agreement!

Both types of emission have their origin in newly forming massive stars

➔SFR(IR/FIR), SFR(1.4GHz) represent the present SFR

Comparison of different SFR estimators



SFR : $M_\odot$ yr^{-1}

Tracer	SFR_l	SFR_u	SFR_a
[OII]	0.01	48.0	6.59
Ha	0.01	38.0	6.52
FIR	0.03	82.0	6.67
IR	0.01	94.0	6.30
NVSS	0.01	113.0	11.30
FIRST	0.17	113.0	12.70

1. SFR from [OII] to IR is agreement.
2. Radio&IR sample, SFR is large.

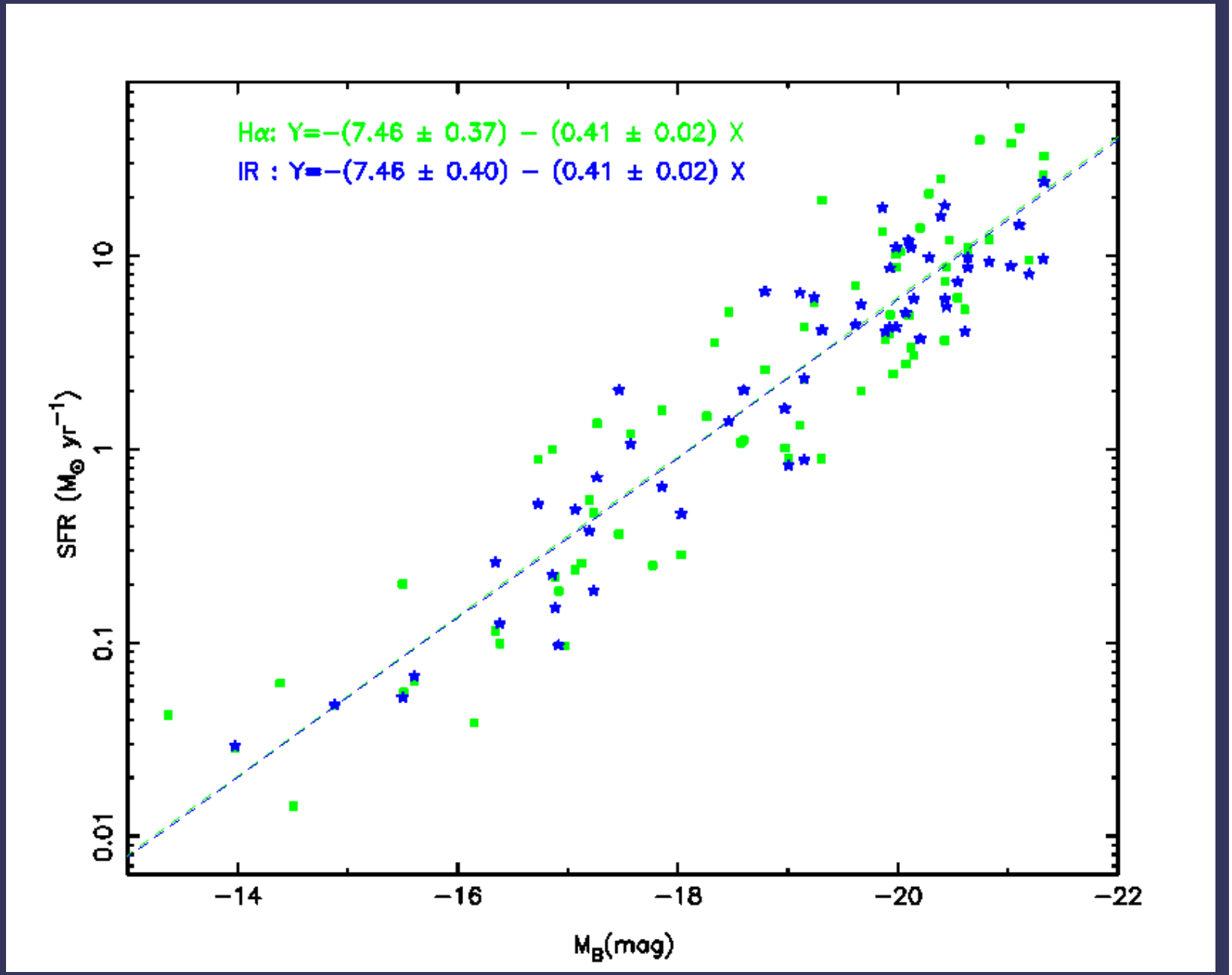
Radio: $L_{ra}/L_{bol} < 10^{-4}$, observe low –luminosity radio source difficult.

IR : Limited by instrument sensitivity

SFR vs. M_B

Bright BCG:

- **High SFR**
- **Intensive SB!**



Gas depletion timescale

$$\tau = M_{HI} / SFR$$

Gordon & Gottesman (1981,AJ,86,161)

Thuan & Martin (1981,ApJ,247,823)

M_{HI} : Mass of HI

SFR: [OII]- radio

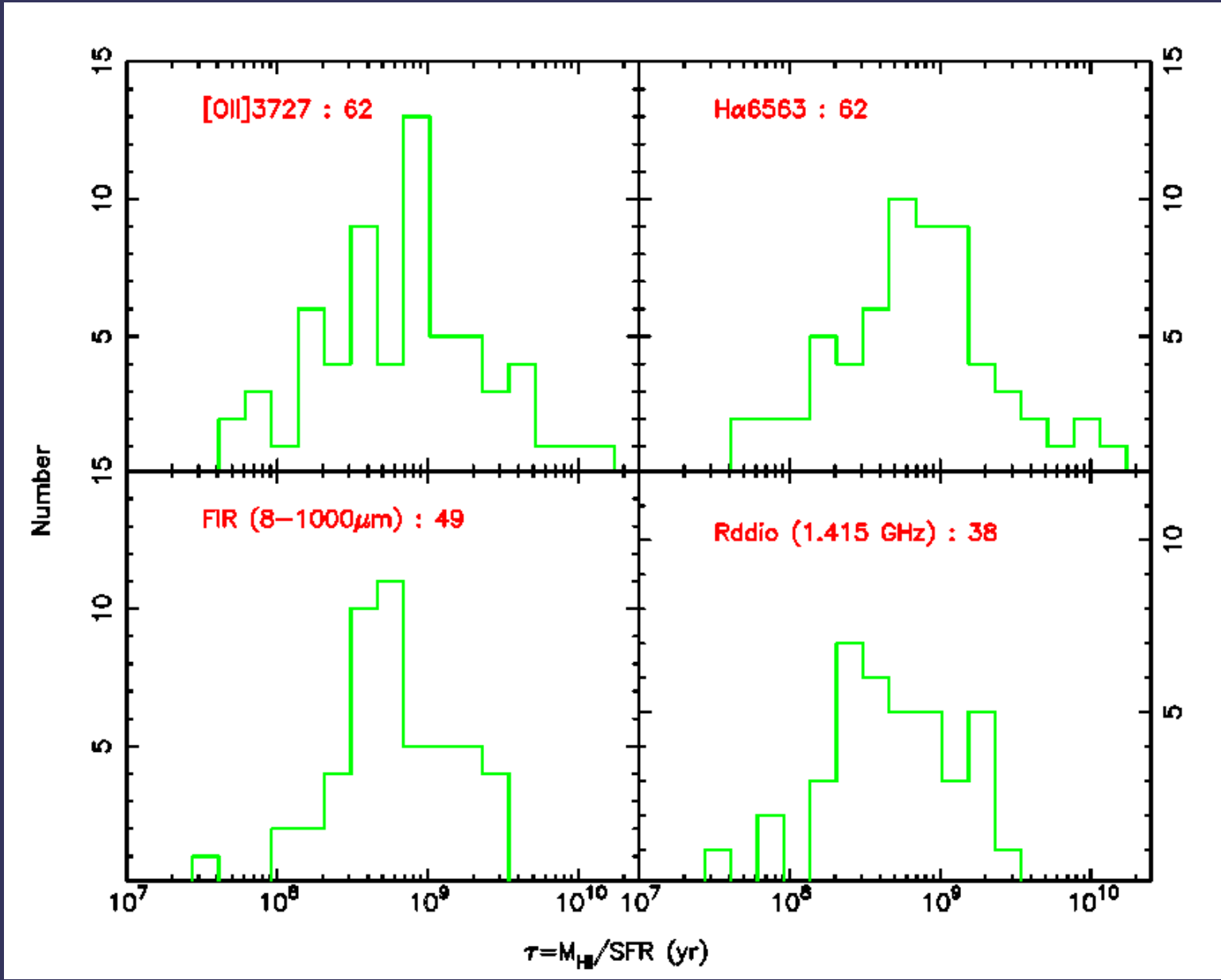
$1/H_0$: 10-20 Gyr

τ : ~ *n* Gyr

$\tau << 1/H_0$

Star Formation History

- star burst
- not continuum



The "typical" timescale for gas consumption in BCGs is a few Gyr

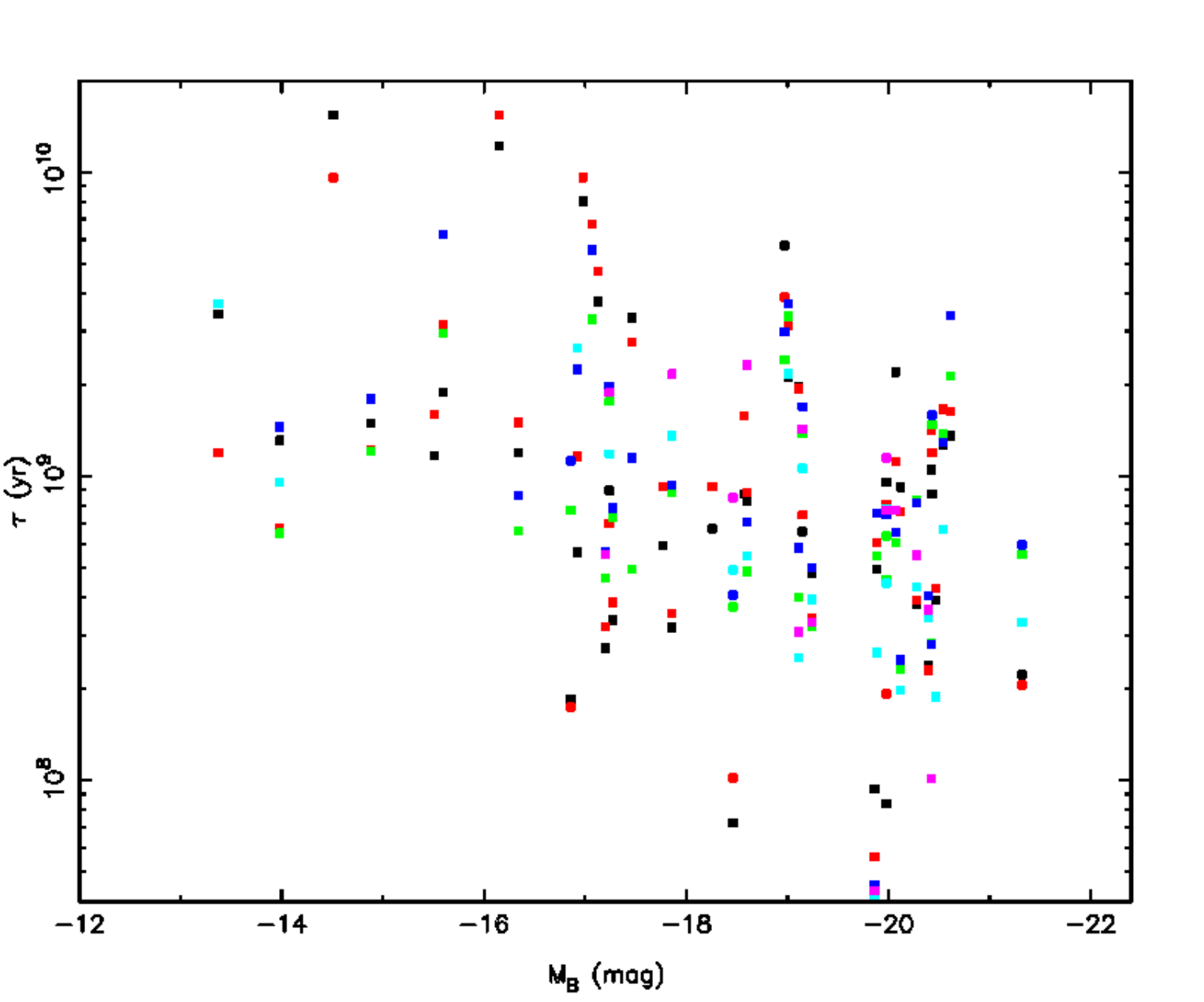
Timescale vs. M_B

Bright BCG

→τ is short

The scanter in the trend is large!

- **High luminosity**
- **SF intensive**
- **Short τ**



6. Summary

- A large homogeneous spectral sample of BCGs (97)
  - 72 SFG; S/N ~ 50
- Flux and EW of line and continuum measurement
  - Typical uncertainty 10 - 20%
- Based on [OII],Ha,IR,FIR,Radio, SFR of BCGs were estimated
  - SFR :10^{-2}–10^{2} $M_{\odot}$ yr^{-1}, τ: ~ *n* Gyr
  - Different indicator: agreement
  - Sampling effect : radio & IR sample,SFR large
- Character with M_B
  - Bright BCG: high SFR, short τ
  - Dwarf BCG: low SFR, long τ

Thank you!


Elena Terlevich
Xu Kong
30 01 2003


Xu Kong
Miguel Cervino
30 01 2003