Star Formation Indicators

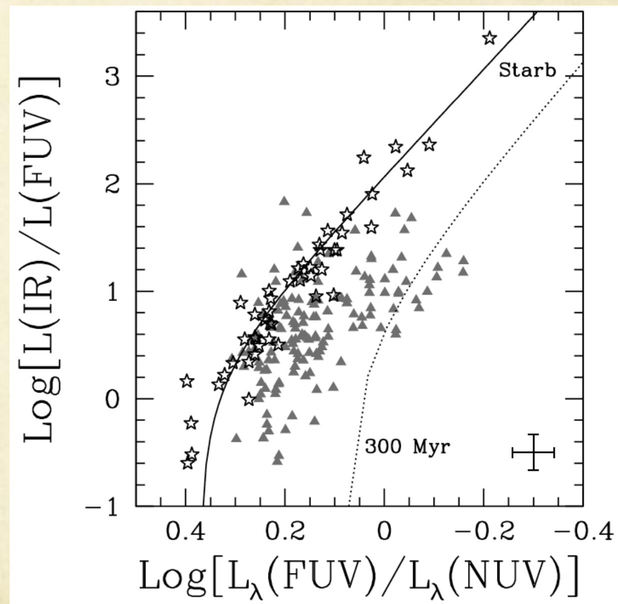
- Calzetti 2007 astro-ph/0707.0467
- Brinchmann et al. 2004 MNRAS 351, 1151

SFR indicators in general

- SFR indicators are defined from the X–ray to the radio
- All probe the MASSIVE stars formation rate
- IMF and population synthesis model assumed
- Other wavelength calibrated against “unbiased” indicators
  - Pα (λ=1.876μm) corrected for extinction using Hα/Pα ratio
- Each calibration is valid in certain cases and has its own limit
  - star-forming region vs. global
  - Star burst vs. normal star-forming
  - High metallicity vs. low metallicity

The Ultraviolet (λ : 912 – 3000Å)

- Motivation: directly probes the bulk of the emission from young, massive stars
- Mass range and time scale: B stars, 100 Myr, not sensitive to SFH
- Cons
  - Highly sensitive to dust reddening and attenuation
  - Well-established correlation between attenuation and SFR
  - Effectiveness of correction techniques depends on the nature of the galaxy
    - FIR/UV ratio vs. UV color
  - Contamination from AGB stars



Calzetti 2007

The Optical and NIR (λ : 0.3 – 2.5 μ m)

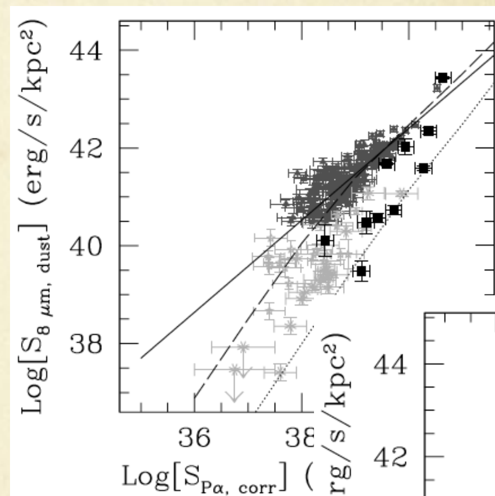
- Motivation: hydrogen recombination lines (Hα, Hβ, Pα) and forbidden line emission ([OII], [OIII]) trace the ionizing photons
- Mass range and time scale: ionizing massive stars (>10$M_{\odot}$), short life span of 10Myr, tracers of the current SFR
- Cons
  - Dust extinction
  - Sensitive to the upper end of the stellar IMF
  - Underlying stellar absorption (H recombination lines)
  - Metallicity and ionization conditions (forbidden lines)
  - Aperture correction (fiber spectroscopy)
  - Continuum and [NII] subtraction (narrow band imaging)
  - Contamination from AGN

Calorimetric FIR (λ : 5 – 1000 μ m)

- Motivation
  - Star–forming regions tend to be dusty and the dust absorption cross–section peaks in the UV
  - Measure star formation via the stellar light that has been reprocessed by dust and emerges beyond a few μ m
- Pros: complementary to UV–optical indicators
- Cons
  - Not all of the luminous energy produced by recently formed stars is re-processed by dust in the infrared, depending on dust amount
  - Evolved non-star-forming stellar populations also heat the dust that emits in the FIR
  - Full energy census needs to be included, otherwise large uncertainty due to extrapolations from sparsely sampled SED

Monochromatic MIR (λ : 5 – 40 μ m)

- Motivation
  - MIR dust continuum: dust heated by hot, massive stars can have high temperatures and will then emit at short infrared wavelengths
  - MIR bands: PAHs are heated by UV and optical photons in the general radiation field of galaxies or near B stars
- 8 μ m
  - Sensitive to both metallicity and star formation history
  - Contribution from dust heated by non–ionizing stellar populations
- 24 μ m
  - Good SFR tracer in absence of strong AGNs
  - Non-liner trend in high L end



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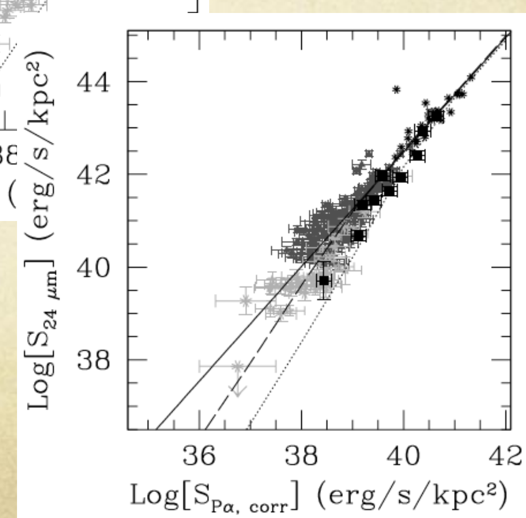
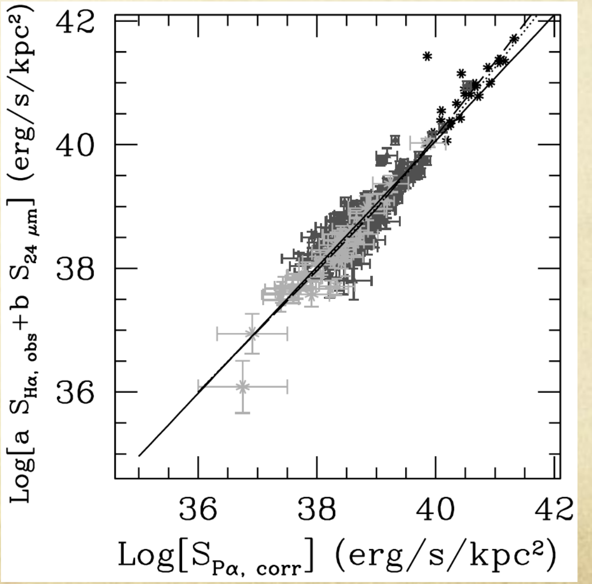


Combining two tracers

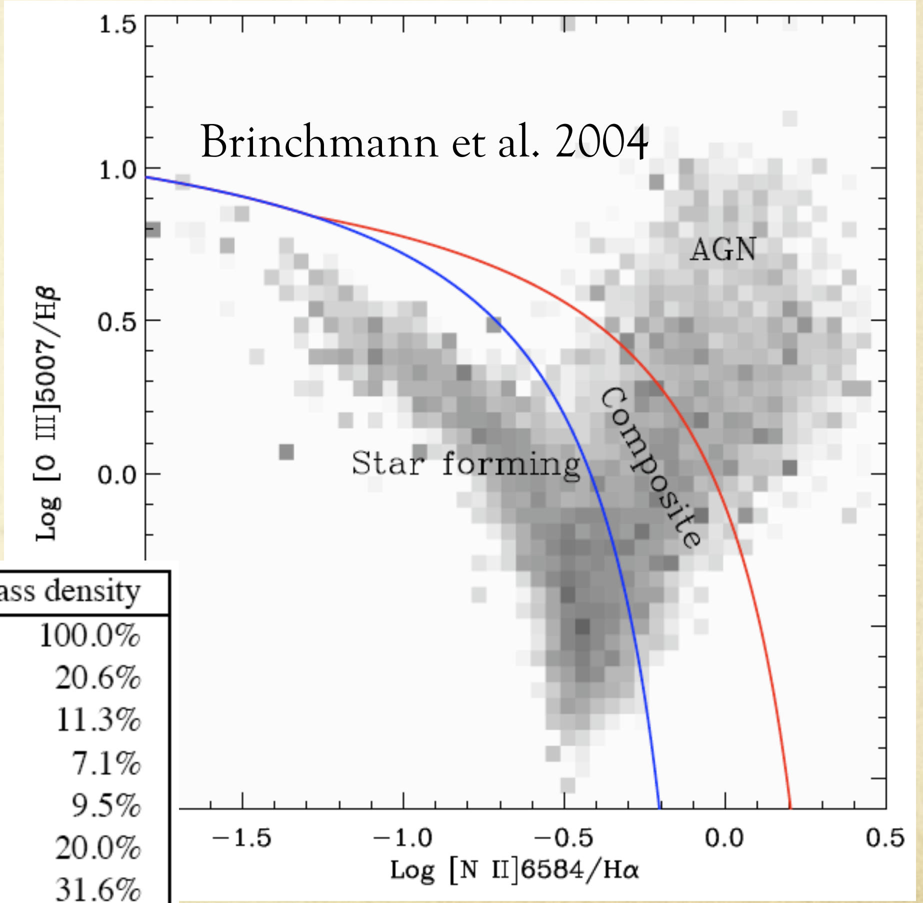
- Motivation
  - Observed H α luminosity: unobscured star formation
  - 24 μ m luminosity: dust-obscured star formation
- Calibration
  - $$SFR(M_\odot\ yr^{-1}) = 5.3 \times 10^{-42}[L(H\alpha)_{obs} + (0.031 \pm 0.006)L(24\ \mu m)]$$
- Pros: unaffected by metallicity variations or stellar population mix
- Cons: deviation from a simple linear correlation at high L surface densities

Calzetti 2007



SFR from Sloan Spectra (Brinchmann et al. 2004)

- Data and classification
  - 146994 galaxies, 14.5<r<17.77, 0.005<z<0.22
  - BPT diagram:
    S/N > 3 in all lines
    including SF, C, AGN
  - Low S/N LINER
    Low S/N SF
  - UnClass:
    weak emission lines
    red galaxies without SF



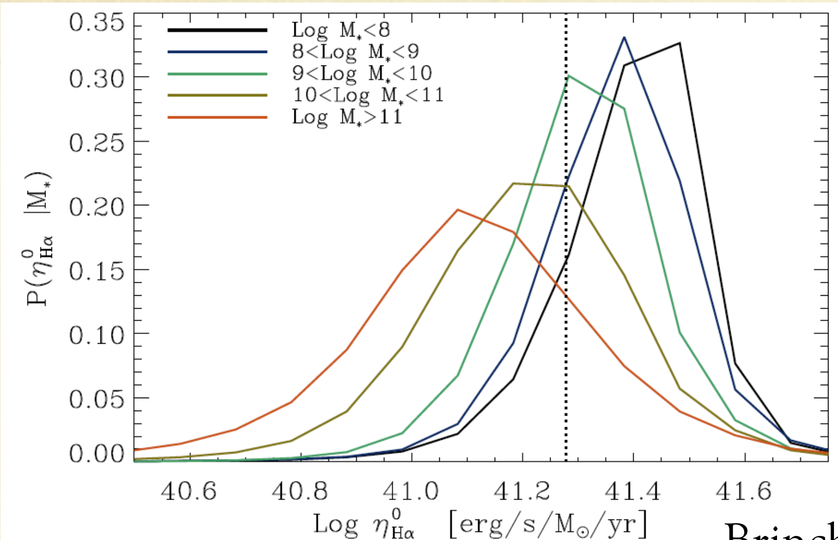
Subsample	Number	Percent	Percent of mass density
All	146994	100.0%	100.0%
SF	39141	26.6%	20.6%
C	14372	9.8%	11.3%
AGN	8836	6.0%	7.1%
Low S/N LINER	11752	8.0%	9.5%
Low S/N SF	29115	19.8%	20.0%
UnClass	43778	29.8%	31.6%

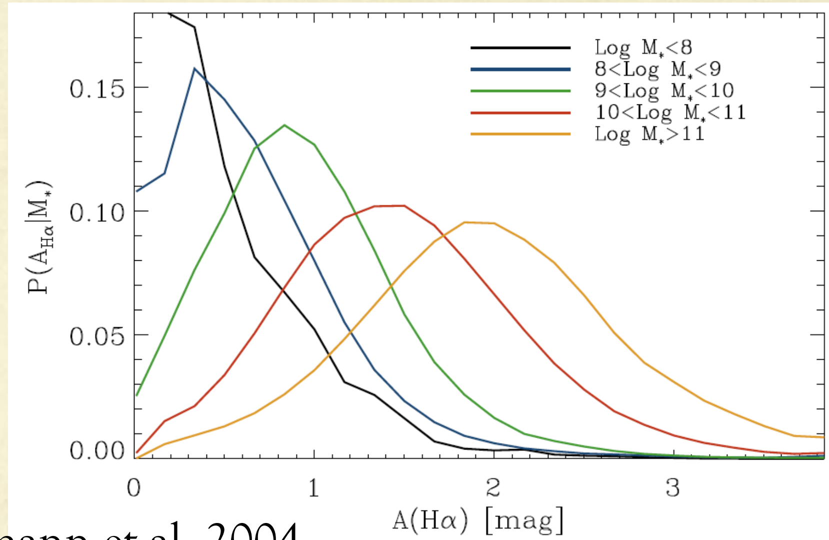
Model and deriving SFR

- Model all emission lines (derive SFR_e for SF class)
  - Galaxy evolution model (B&C02)
    + Emission line modeling (CLOUDY)
  - Parameter: Z, ionization parameter, dust attenuation in V band, dust-to-metal ratio of the ionized gas
  - Constant star formation history at t=10^8yrs
  - Multi-component dust model (Charlot et al. 2000)
  - A grid (library, prior) ~ 2×10^5 model
  - Bayesian approach to calculate the likelihood
    - $$\ln P(M_j | \{L_i\}) = -\frac{1}{2} \sum_{i=0}^{N_{\text{lines}}} \left(\frac{L_i - AM_{i,j}}{\sigma_i} \right)^2$$

Model and deriving SFR

- $L_{H\alpha}$ – SFR_e relationship
  - Calibrated from SF class
    - $SFR_e = L^0_{H\alpha}/10^{41.28}$ (Kennicutt 1998 + Kroupa IMF)



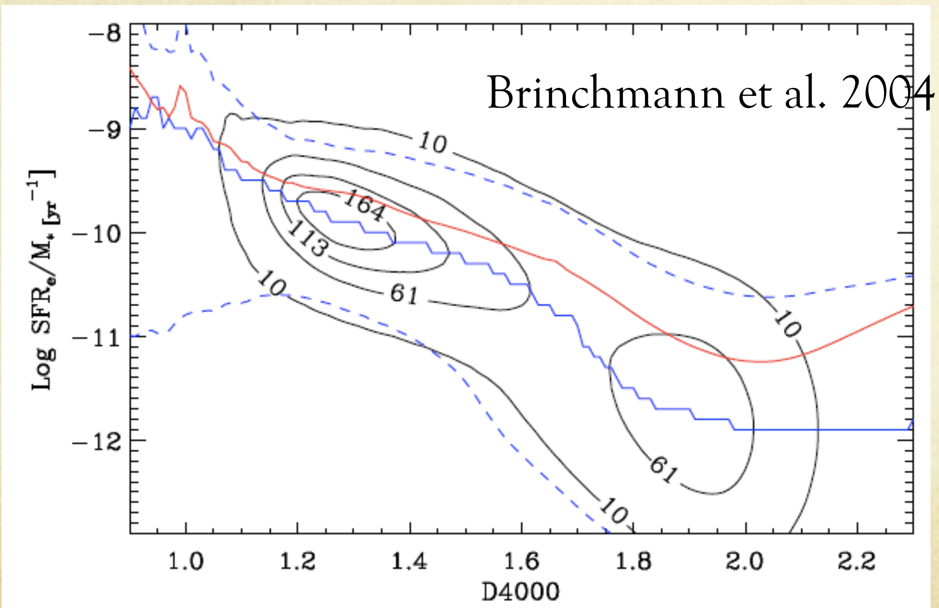


Brinchmann et al. 2004

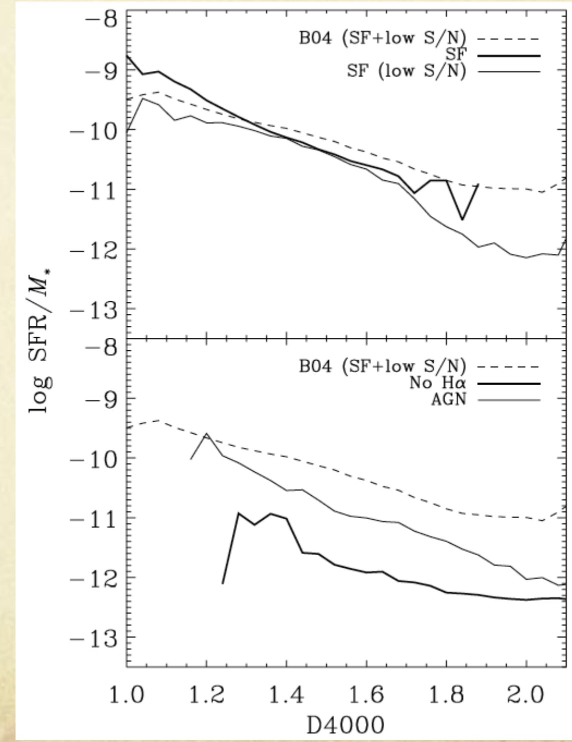
  - Applied on low S/N SF class
    - Use $H\alpha/H\beta$ (intrinsically 2.86) to determine dust attenuation
    - Stellar absorption: assume $EW_{abs}(H\alpha) = 0.6EW_{abs}(H\beta)$

Model and deriving SFR

- SFR_d/M_* – D4000 relationship
  - Calibrated from SF class
  - Applied on AGN, C and unclassifiable classes
  - Invalid assumption (Salim et al. 2007)

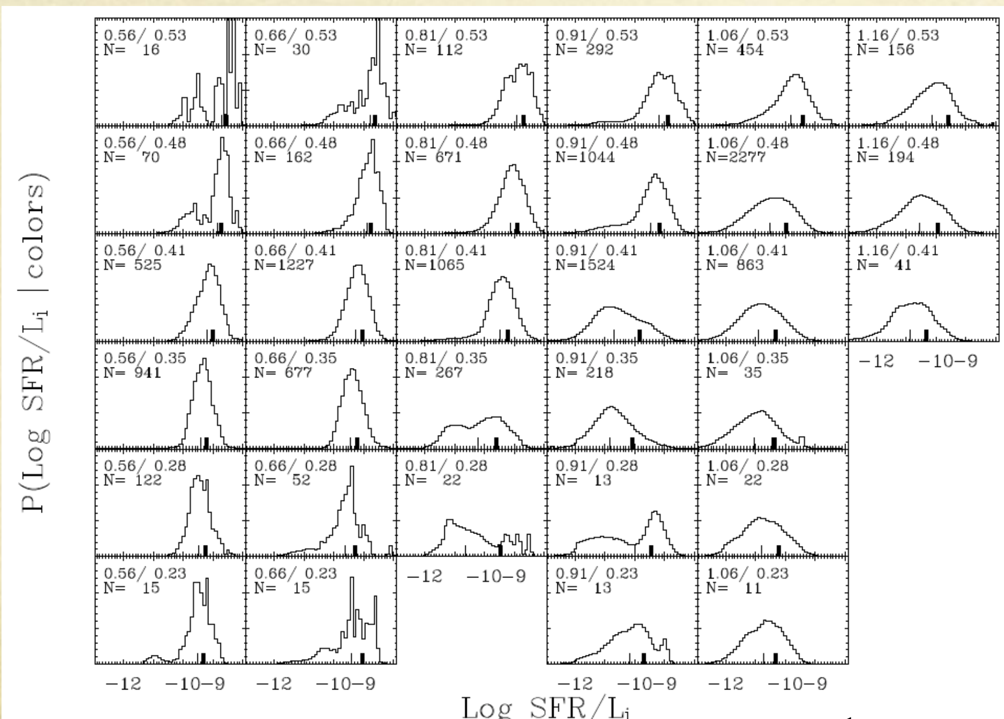


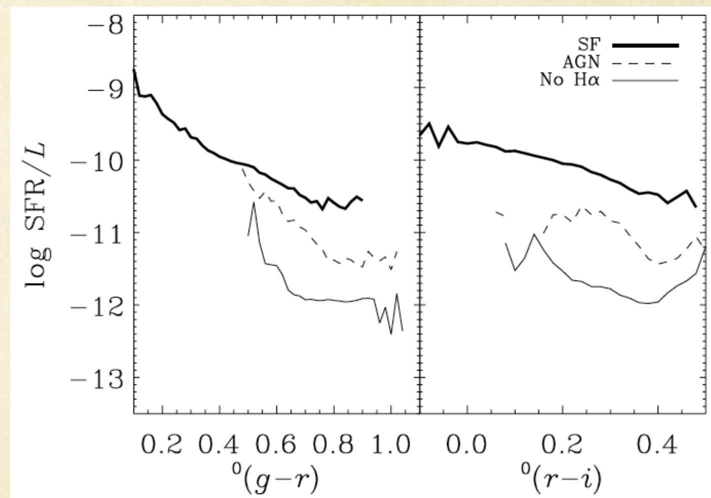
Salim et al. 2007



Model and deriving SFR

- Aperture correction
  - Construct likelihood distribution P(SFR/L_i | color) on a grid with bins of size 0.05 in $^{0.1}$(g-r) and 0.025 in $^{0.1}$(r-i)
  - Assume the distribution of P is the same inside and outside of fiber
  - Invalid assumption (Salim et al. 2007)



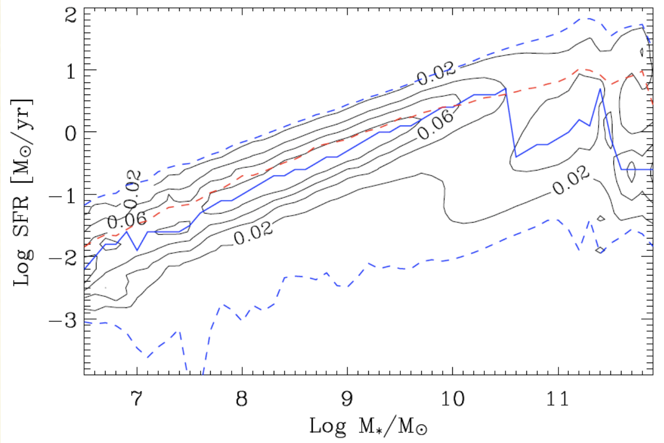


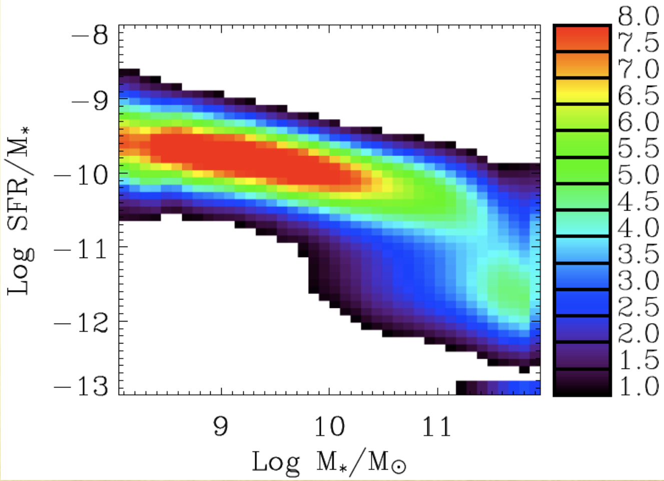
Salim et al. 2007

Brinchmann et al. 2004

Main results

- Total SFR density of the local universe
  - $\rho_{\rm SFR} = 1.915^{+0.02}_{-0.01}(\text{rand.})^{+0.14}_{-0.42}(\text{sys.})10^{-2}\ h_{70}\ M_\odot/\text{yr/Mpc}^3$
- Stellar mass – SFR relationship
- The majority of SF takes place in high mass, high surface brightness, disk-dominated galaxies
- Bimodel natural of specific star formation rate, $r_{\rm SFR}$
- Low mass (constantly) vs. Massive (depressed SFR)





Brinchmann et al. 2004