Introduction

\[ \log_{10}(M_\odot \text{ yr}^{-1} \text{ Mpc}^{-3}) \]
\[ \log_{10}(\text{erg s}^{-1} \text{ Mpc}^{-3}) \]

Time (Gyr)

Redshift

\( >0.06 L_z^* \)

Bouwens+'10
(Lilly+'96; Madau+'96)

Secondary
Dust

Calibration

Secondary
Contribution by
old stars

Primary Dust

SN
Radio Synchrotron

HII Regions
UV

[OII]

Ha

Secondary Dust Calibration
Introduction

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure.png}
\caption{Evolution of the star formation rate and the secondary dust contribution with time (Gyr).}
\end{figure}

Bouwens + '10
\( (\text{Lilly} + '96; \text{Madau} + '96) \)

\textbf{Primary Dust}

\textbf{Secondary Dust Calibration}

\textbf{Secondary Contribution by old stars}
Introduction

Dust-unbiased tracers: sensitivity limits at high redshift

Dust-biased tracers still of fundamental importance

IR luminosity can be used to calibrate relations
to correct dust-biased tracers

The data sample

**GMMASS**

*Galaxy Mass Assembly*

*ultra-deep Spectroscopic Survey*

(P.I. A. Cimatti; Kurk+’13)

Chandra Deep Field South

Pure flux-limited sample:

mag (4.5μm) < 23.0

**Ultra-deep spectroscopy** with FORS2

(intergrations up to 30 h)

Multi-wavelength photometric coverage

(from U band to **SPITZER-MIPS 24μm**)

**PLUS**

Spectra from public ESO surveys

(Vanzella+’08; Balestra+’10; Le Fèvre+’05; Mignoli+’05)

Photometric IR data from **HERSCHEL PACS**

(PEP + GOODS-H)

(Lutz+’11; Elbaz+’11; Magnelli+’13)
The sample selection

$1 < z < 3$

Peak of SFRD and AGN activity

Spectroscopy

Secure redshift

Spectral features

Star-forming galaxies

Preliminary selection: NO quiescent/passive NO AGNs

Two sub-samples

Consistency of Spectral features

$\textbf{[OII]-sample}$

- $1.0 < z < 1.6$
- $2700–4300\text{Å}$
- $\text{[OII]\_}3727$ em. line

$\textbf{UV-sample}$

- $1.6 < z < 3.0$
- $1100–2800\text{Å}$
- UV continuum
- ISM abs. lines

FINAL SAMPLE

$\sim 300$ SFGs
Spotting the presence of old stellar populations

- Possible contribution to UV continuum reddening
- Non-negligible contribution to dust heating

Daddi+ '05
Cimatti+ '08
Bruzual '83

Overestimate of total SFR!
Properties of the final sample

- $1 < z < 3$
- Intermediate stellar mass ($10^{9.2} < M/M_\odot < 10^{10.2}$) [completeness limit = $M/M_\odot \sim 10^{10.5}$]
- Blue rest-frame colours
- Blue continuum indices ($\text{MgUV} < 1.2$, $\text{C(29–33)} < 0.6$, $\text{D4000} < 1.6$)
The benchmark: $SFR_{IR} + SFR_{UV(uncorr)}$

$SFR_{TOT} = SFR_{IR+UV} = SFR_{IR} + SFR_{UV(uncorr)}$

(e.g. Papovich+’07; Rodighiero+’10)

- $z_{spec} = 1.99$

- **24μm** + PACS detected (~ 100 gals):
  - MAGPHYS code
  - da Cunha+’08

- **Only 24μm** (~ 100 gals):
  - Main sequence SED templates
  - Magdis+’12
Dust extinction correction: SFR from UV continuum luminosity

**UV-sample**

\[ \text{SFR}_{\text{UV}_0} \propto L_{\text{UV}_0} = \nu L_{\nu} (1500\text{Å}) \]

(Kennicutt+’98)

\[ A_{\text{IRX}} = 2.5 \log (\text{SFR}_{\text{IR}} / \text{SFR}_{\text{UV}} + 1) \]

\[ z \sim 2.3 \]

\[ A_{\text{IRX}} = (1.10 \pm 0.23) \times \beta_{\text{spec}} + (3.33 \pm 0.24) \]
Dust extinction correction: SFR from UV continuum luminosity

\[ A_{IRX} = 2.5 \log \left( \frac{SFR_{IR}}{SFR_{UV}} + 1 \right) \]

\[ A_{IRX} = C_0 \times \beta + C_1 \]

*This work* (4.5\(\mu\)m-selected)
\[ \sigma \sim 0.7 \text{ dex} \]

*UV-selected samples*
\[ \sigma \sim 0.3 \text{ dex} \]

\[ A_{IRX} = (1.10 \pm 0.23) \times \beta_{\text{spec}} + (3.33 \pm 0.24) \]
Dust extinction correction: SFR from UV continuum luminosity

\[ \text{[OII]-sample} \]

\[ \text{SFR}_{\text{UV}_0} \propto L_{\text{UV}_0} = \nu L_{\nu} (1500\text{Å}) \]  
\[(\text{Kennicutt+’98})\]

\[ z \sim 1.3 \]

\[ A_{\text{IRX}} = 2.5 \log \left( \frac{\text{SFR}_{\text{IR}}}{\text{SFR}_{\text{UV}} + 1} \right) \]

\[ \beta \text{ must be derived from photometry} \]

In the [OII] sample relation is slightly flatter than in the UV sample, but the difference is not highly significant.

No evolution of the \( A_{\text{IRX}} \) vs. \( \beta \) relation between \( z \sim 1.3 \) and \( z \sim 2.3 \)

Both samples broadly follow the prediction of the Calzetti law

\[ \text{See also Pannella+’14} \]

\[ A_{\text{IRX}} = (1.03 \pm 0.26) \times \beta_{\text{phot}} + (3.54 \pm 0.25) \]
Dust extinction correction: SFR from $[\text{OII}]\lambda3727$ line luminosity

$SFR_{[\text{OII}]} \propto L_{[\text{OII}]}$ 

(Kennicutt+'98)

$z \sim 1.3$

See also Kewley+’04, Moustakas+’06

\[
\beta_{\text{phot}} = (-1.35 \pm 0.20) \times \log EW_{\text{rest}} + (0.91 \pm 0.30)
\]
Dust extinction correction: Continuum vs. nebular attenuation

\[ A_{\text{IRX}} \frac{\text{Extinction curve}}{\text{Differential attenuation}} A_{\text{[OII]}} \]

\[ E(B-V)_{\text{neb}} = E(B-V)_{\text{cont}} / f \]

\[ A_{\text{[OII]}} = A_{\text{IRX}} \times \left( \frac{k_{\text{H}\alpha}}{k_{1500\AA}} \right) \times f^{-1} \]

\[ SFR_{\text{[OII]}_0} \propto L_{\text{[OII]}_0} \]

(Kennicutt+’98)

Calzetti+’97
Dust extinction correction: **Continuum vs. nebular attenuation**

\[ E(B-V)_{\text{neb}} = E(B-V)_{\text{cont}} / 0.50 \]  

*This work*

Calzetti law

\[ f \sim 0.5 \]

*e.g.*

*Forster-Schreiber*'09

*Wuyts*'11

\[ f \sim 1.0 \]

*e.g.*

*Kashino*'13

*Puglisi*'15

\[ f = 1.00 \]

\[ f = 0.75 \]

\[ f = 0.50 \]

Graph showing the relationship between \( \log(\text{SFR}_{\text{UV}_\alpha}) \) and \( \log(\text{SFR}_{\text{[OII]}}) \) with linear fits for different values of \( f \).
An application: the SFR vs. Mass relation

Close linear relation
$\sigma \sim 0.3$ dex

Slope = ~ [0.7, 0.9]

Weak trends of slope and normalization with redshift

$lg(SFR) = 0.82 \cdot lg(M) - 6.47$

$lg(SFR) = 0.81 \cdot lg(M) - 6.49$

$lg(SFR) = 0.70 \cdot lg(M) - 5.67$

See also e.g.
Daddi+’07; Noeske+’07; Wuyts+’11; Kashino+’13; Rodighiero+’11; Rodighiero+’14
ON-GOING

Look at larger samples, especially on the [OII] side (e.g. zCOSMOS-Bright)

Study dependences of $A_{IRX}$ vs. beta and $[OII]\lambda3727$ EW vs. beta relations

Model the stellar populations of “mixed” galaxies

SUMMARY

We use IR data to derive empirical calibrations to correct UV and [OII]$\lambda3727$ luminosities for dust extinction, and dust-corrected estimates of SFR in a sample of SFGs at $1<z<3$

We find a correlation between the rest-frame EW of the [OII]$\lambda3727$ line and $\beta$ and we use $A_{IRX}$ to calibrate $EW_{[OII]\lambda3727}$ as a dust attenuation probe

Talia et al. 2015, A&A, 582, 80

Thank you!