CLEAR: Paschen-β Star Formation Rates and Dust Attenuation of Low Redshift Galaxies

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ABSTRACT

We use Paβ (1282 nm) observations from the Hubble Space Telescope (*HST*) G141 grism to study the star formation and dust attenuation properties of a sample of 32 low redshift ($z < 0.287$) galaxies in the CLEAR survey. Many of the galaxies in the sample have significantly higher Paβ emission than expected from the star formation rates (SFRs) measured from their (attenuation-corrected) UV continuum or Hα emission, suggesting that Paβ is revealing star formation that is otherwise hidden within gas that is optically thick to UV-continuum and Balmer line emission. Galaxies with lower stellar mass tend to have more scatter in their ratio of Paβ to attenuation-corrected UV SFRs. When considering our Paβ detection limits, this observation is consistent with burstier star formation histories in lower mass galaxies. We also find a large amount of scatter between the nebular dust attenuation measured by Paβ/Hα and Hα/Hβ, implying that the Balmer decrement underestimates the attenuation in galaxies across a broad range of stellar mass, morphology, and observed Balmer decrement. Comparing the nebular attenuation from Paβ/Hα with the stellar attenuation inferred from the spectral energy distribution, our galaxies are consistent with an average stellar to nebular ratio of 0.44, but with a large amount of excess scatter beyond the observational uncertainties. Together, these results show that Paβ is a valuable tracer of a galaxy's star formation rate, often revealing star formation that is otherwise missed by UV and optical tracers.

SFR indicatorとしてのPaβの有用性

- SFRは銀河進化を理解する上で重要なパラメータ
  - UV continuum は10-200MyrのSFを反映。直接的だが減光に弱い。
  - Balmer輝線は3-10 Myrを反映。やはり(特にHβが)減光に弱い。
  - 異なるtimescaleの指標を比較することで星形成史を推定可能。
    - UV, Balmerでは減光による不定性が大きいのが難点。
- 近赤外なら減光の影響が小さく抑えられ、よりoptically-thickな領域に対しても有効。
- z<0.287の32銀河についてPaβ輝線を使って比較検討:
  - 多色測光カタログから → $SFR^{corr}_{UV}[M_{\odot} yr^{-1}] = (1.09 \times 10^{-10})(10^{0.4A_{280}})(3.3L_{280}/L_{\odot})$
  - 24umが受かっていれば → $\mathrm{SFR}_{UV+IR}[M_{\odot} yr^{-1}] = 1.09 \times 10^{-10}(L_{IR} + L_{2800})L_{\odot}$
  - HST G141分光から → $\log(\mathrm{SFR}_{\mathrm{Pa}\beta})[M_{\odot}/\mathrm{yr}] = \log[L(\mathrm{Pa}\beta)] - 40.02$

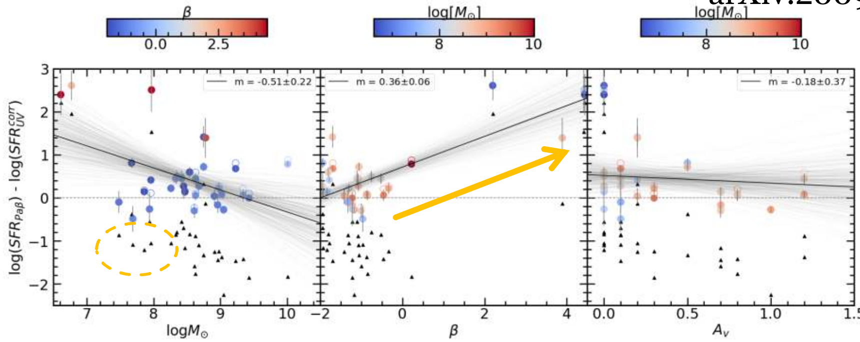

Figure 5. The log ratio of the Paβ and attenuation-corrected UV SFRs with stellar mass (*left*), UV slope β (*center*), and continuum A_v (*right*). Upward facing triangles indicate the 1σ detection limits of Paβ for each galaxy (using Equation 3). We fit each panel with a linear regression line, finding a significant correlation only in the center panel. Galaxies with steep UV slopes ($\beta \gtrsim 0$) tend to have much higher Paβ than UV SFRs, likely indicating star forming regions with high optical depths to UV emission but visible in Paβ emission. There is a marginal (2.3σ) correlation between Paβ excess and stellar mass, and the Paβ detection limits are consistent with higher scatter between the two SFRs (and burstier star formation histories) in low-mass galaxies.

- 左図:右下がりに見えるのは、low mass側ではburstier (>10Myr)なSFによってPaβがupper limitになっているため?
  - Low mass銀河ほどburstinessが高い (Guo+16)。
  - Paβを前提とする本サンプルでは< 10MyrのSFに偏る。
- 中図:UV slope β大 → UVがより減光されPaβ/UV比が増大。
  →減光が強い銀河に対してPaβ SFRは有用。

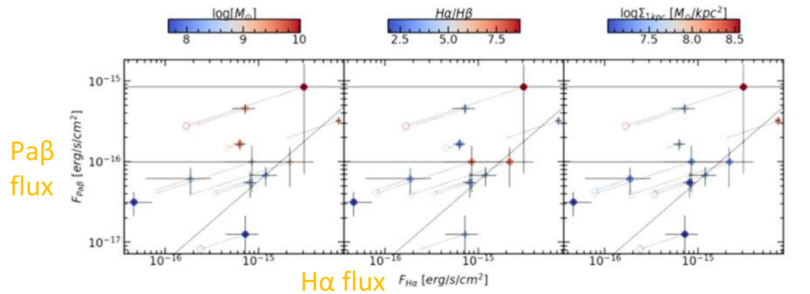

Figure 9. Paβ and Hα fluxes for the 11 galaxies in our sample with TKRS optical spectroscopy, color coded by stellar mass (*left*), Balmer decrement (*center*), and central density (Σ_{1kpc}) (*right*). The gray line indicates Paβ/Hα = 1/17.6, appropriate for Case B recombination with $T = 10^4$ K and $n_e = 10^4$ cm^{-3} (Osterbrock 1989). Open circles show uncorrected fluxes and filled circles are dust-corrected fluxes, calculated using the observed Balmer decrement and a Calzetti et al. (2000) attenuation curve. About half of the sample has dust-corrected ratios of Paβ/Hα that is significantly larger than the expected ratio, over a wide range of stellar mass, UV slope, and Balmer decrement. This suggests that Balmer decrement dust corrections are frequently insufficient and a significant fraction of the Hα emission may be hidden in regions behind optical depths that are seen in Paβ emission.

↑Hαとの比較

- Balmer decrementで減光補正しても両者のSFRは一致しない。
  → Balmer decrementでは減光を過小評価している。

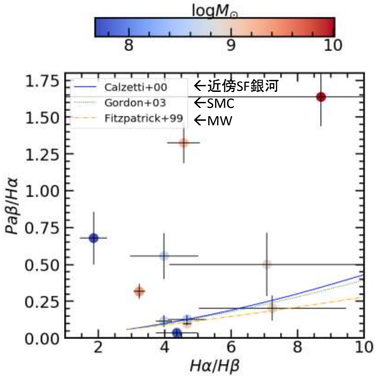

Figure 11. Paβ/Hα and Hα/Hβ ratios for 11 galaxies in the our sample with public optical spectroscopy from TKRS (Wirth et al. 2004). Our sample includes at least one highly dusty galaxy (in the upper right) for which Hα/Hβ is saturated and cannot reliably measure dust attenuation. The blue, green, and orange lines indicate the expected ratios using intrinsic Case B ratios of Hα/Hβ = 2.86 and Paβ/Hα = 1/17.6, and Calzetti et al. (2000) Gordon et al. (2003), and Fitzpatrick (1999) attenuation models. Eight of the 11 points have line ratios within 3σ consistent with the expectation.

←水素輝線比の比較

- 多くのサンプルは(誤差の範囲内で)既存の減光曲線で説明可能。
- 上に大きく外れている3つはBalmer decrementが過小評価されているだろう。
- 過小評価 (i.e., dusty) の銀河はedge-on like (Figure 13)
- Paβ/Hαは良い減光指標

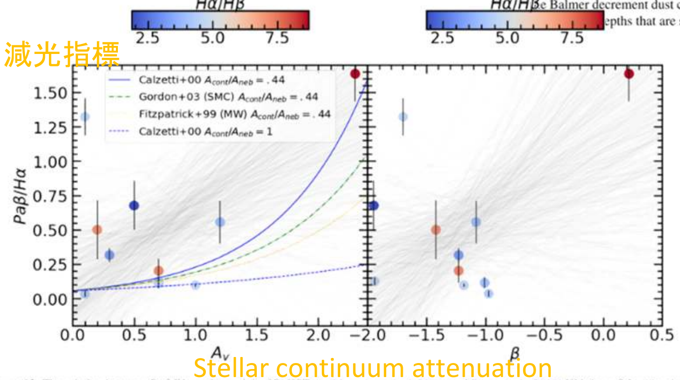

Figure 12. The relation between Paβ/Hα ratios and the 3D-HST A_v (Momcheva et al. 2016) and Barro et al. (2019) UV slope β for 11 galaxies in the our sample with public optical spectroscopy from TKRS (Wirth et al. 2004). Our sample includes at least one highly dusty galaxy (in the upper right) for which Hα/Hβ is saturated and cannot reliably measure dust attenuation. The left panel shows Calzetti et al. (2000), Gordon et al. (2003), and Fitzpatrick (1999) attenuation curves with a stellar to nebular attenuation ratio of 0.44, along with another Calzetti et al. (2000) attenuation curve with a stellar to nebular attenuation ratio of 1.

←stellar / nebular 減光比較

- Stellar と nebular 減光に相関が見られる。
- バラつきは大きいが概ね0.44で consistent (?) (large diversityがあるとも)。上に大きく外れているのはFig.11と同じ銀河。ContinuumやBalmerがoptically thick。