Observational evidence of star formation stochasticity in the CALIFA dataset

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Stochasticity in star formation

Star formation

- Star forming regions
- Young stars ionize gas clouds
- Spectral quantities: equivalent width

$$\mathrm{EW} \equiv \frac{L_{Ly_\alpha}}{L_{\lambda,UV}} \tag{1}$$

- Low SFR: EW and $\frac{\mathrm{H}_\alpha}{\mathrm{FUV}}$ ratios fluctuate [1], [2]

Stochasticity in star formation

Where does stochasticity arise?

- Star formation
  - Initial Mass Function (IMF)
    - $m_{min} - m_{max}$
    - Relative abundance
  - Cluster Mass Function (CMF)

Stochasticity in star formation

Where does stochasticity arise?

- Sampling of mass functions – SFR
- Low SFR:
  - Lowers probability of massive stars — finite sampling in mass [2]
  - Stellar mass and luminosity — highly nonlinear [3]
  - Total mass and luminosity — no longer deterministic [4]
  - Finite sampling in time — stellar phases [2]
  - $m_{max} < M_{ecl}$ [2]
  - Bursts of SFR [2]

Measuring stochasticity

How does stochasticity translate into observable quantities?

- SLUG: Stochastically Light Up Galaxies [5]
- EW, $\frac{\mathrm{H}_\alpha}{\mathrm{FUV}}$ fluctuates, [1][2]
- "We find that stochasticity alone induces a broad distribution in L_α and EW at a fixed SFR, and that the widths of these distributions decrease with increasing SFR" [1]

Measuting stochasticity

Double power law

$$P\left(\mathcal{M}|\mathrm{SFR}\right) = P_0 \left[\left(\frac{\mathcal{M}}{\mathcal{M}_0} \right)^{-\alpha} + \left(\frac{\mathcal{M}}{\mathcal{M}_0} \right)^{\gamma} \right]^{-1} \tag{2}$$

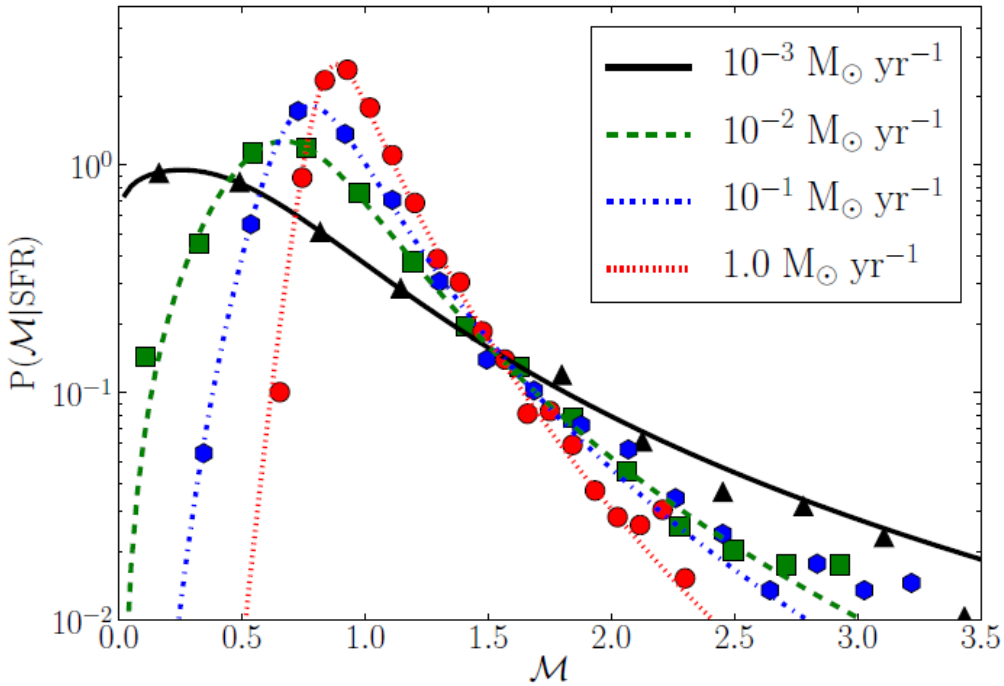

Figure: SFR distributions, $\mathcal{M} = \frac{\mathrm{EW}}{\mathrm{EW}_0}$

Measuring stochasticity

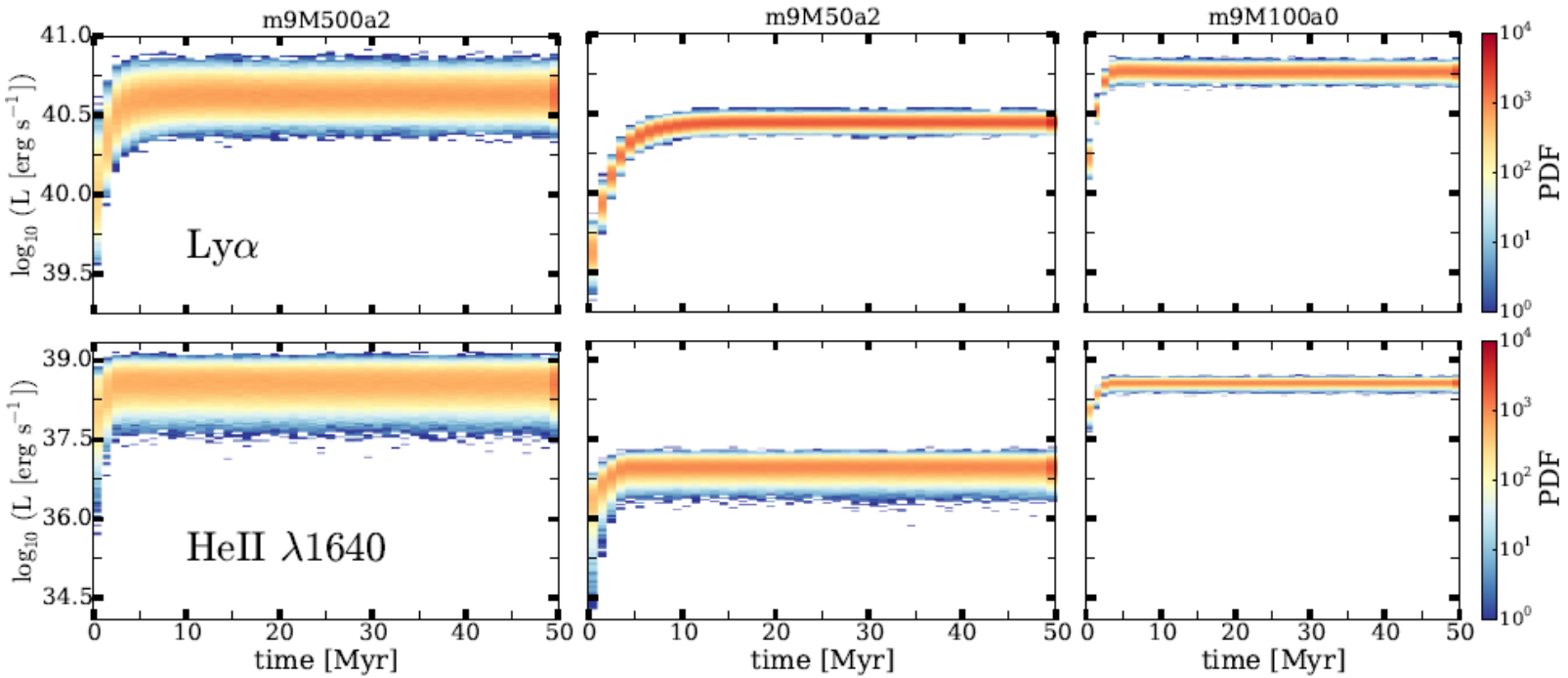

Figure: Mas-Ribas et.al 2016 [6]

Motivation

General objective

"Look for observational evidence of stochasticity in star formation processes in the data published by CALIFA".

Specific objectives

- Develop a simple theoretical model to measure the effects of stochasticity in the EW of the H_α and O_{II} emission lines
- Analize data from the CALIFA survey collaboration
- Compare results between the observed data and the theoretical model
- Conclude if there is enough evidence to claim that stochastic effects have been detected in CALIFA data

Measuring stochasticity

- Balmer decrement
  - Interstellar dust
  - $\frac{H_\alpha}{H_\beta} = 2.85 \rightarrow \frac{H_\alpha}{H_\beta} \geq 2.85$[1]
  - Interstellar reddening

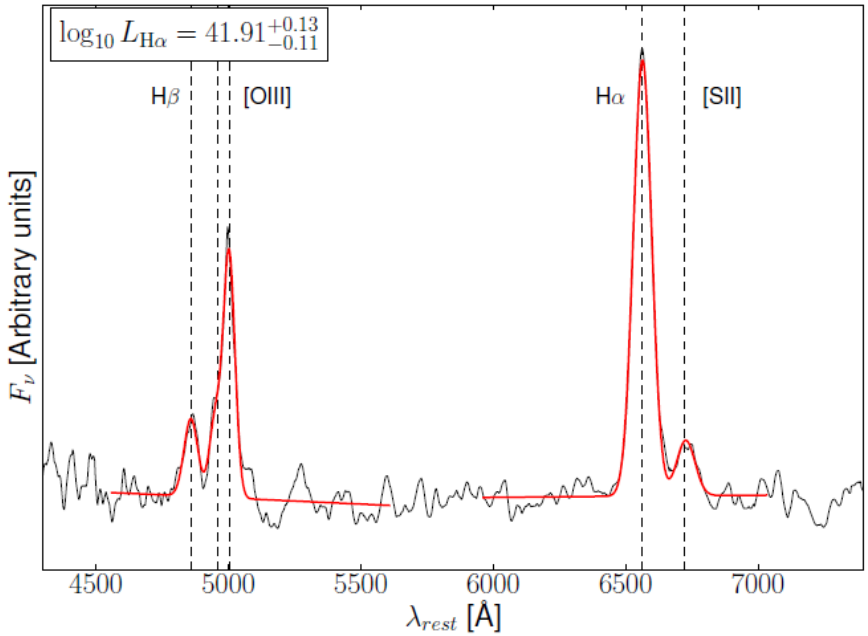

Figure: Domínguez et. al. 2012 [7]

[1] Osterbrock, Astrophysics of Planetary Nebulae and Active Galactic Nuclei, University Science Books, 1989

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The CALIFA survey

- $\sim$ 600 galaxies
- "Largest and most comprehensive wide-field IFU survey of galaxies carried out to date"[8]

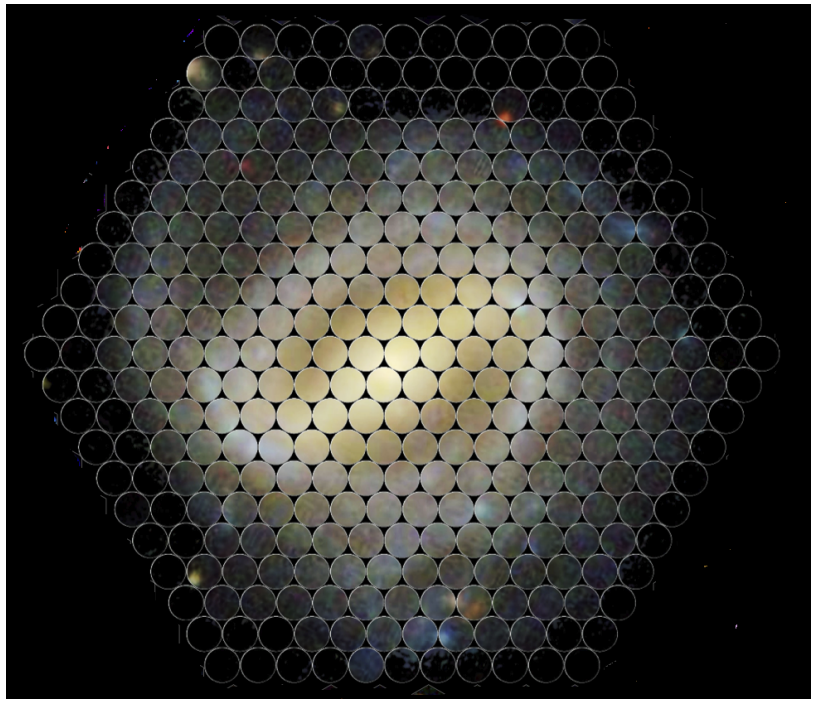

Figure: http://califaserv.caha.es/CALIFA/DATA/Figs/CALIFA_HexDR2.png

The CALIFA survey

- Calar Alto observatory
- Almería, Spain. 2010
- Many spectra per galaxy
- Evolution in mass, brightness of galaxies

The CALIFA datacubes

- 2 setups[2]
- V500
  - 3745 – 7500 Å[9]
  - $^{\lambda}/_{\Delta\lambda} \sim 850$
- V1200
  - 3700 – 4800 Å
  - $^{\lambda}/_{\Delta\lambda} \sim 1650$ [9]

[2] Sánchez et. al. 2011

Data analysis

- Fit spectral lines
  - Stellar population
  - Strong emission lines

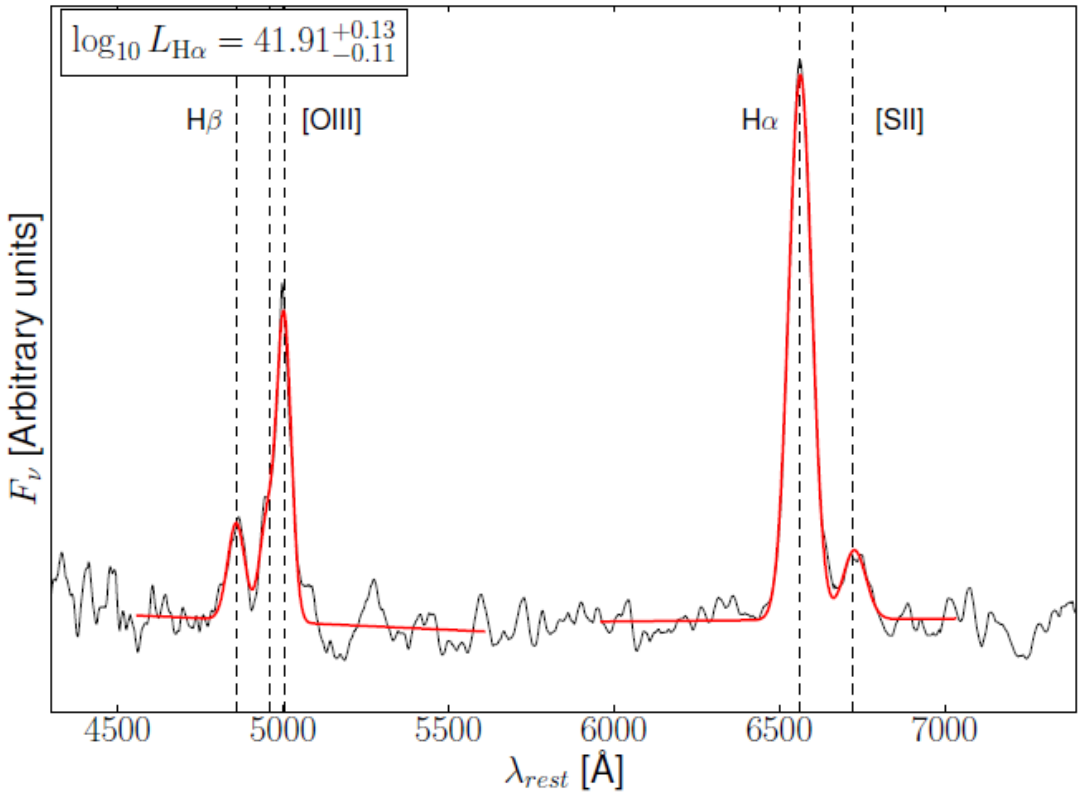

Figure: Spectral fit [7]

Data analysis

- Pipe3D: analysis pipeline [10]
- *"The final product of the data reduction from both surveys is a regular grid datacube, with x and y coordinates that indicate the right ascention and declination of the target, and the z coordinate a common step in wavelength..."*

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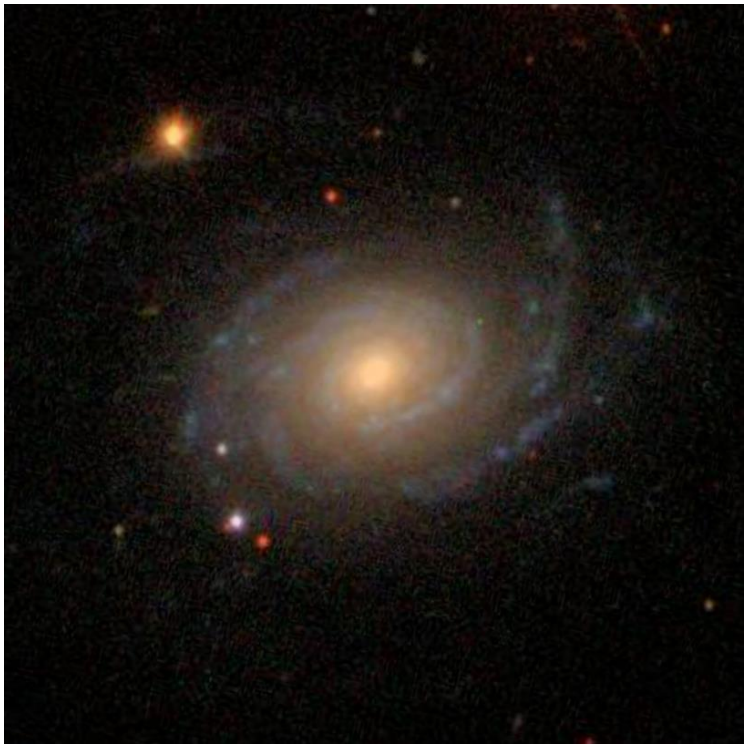
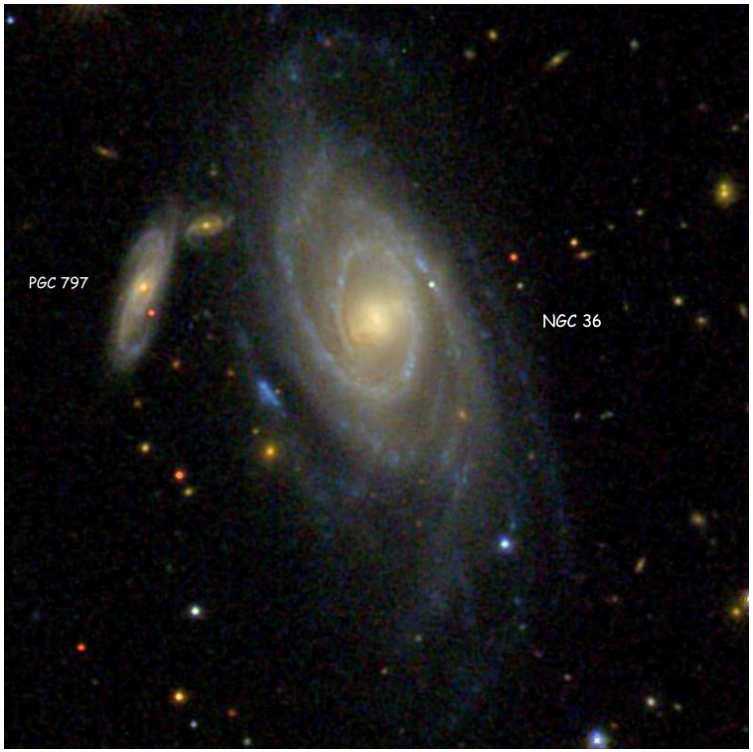
Results



NGC0001
http://www.galaxyzooforum.org/index.php?topic=280028.0



NGC0036 http://cseligman.com/text/atlas/ngc36.jpg

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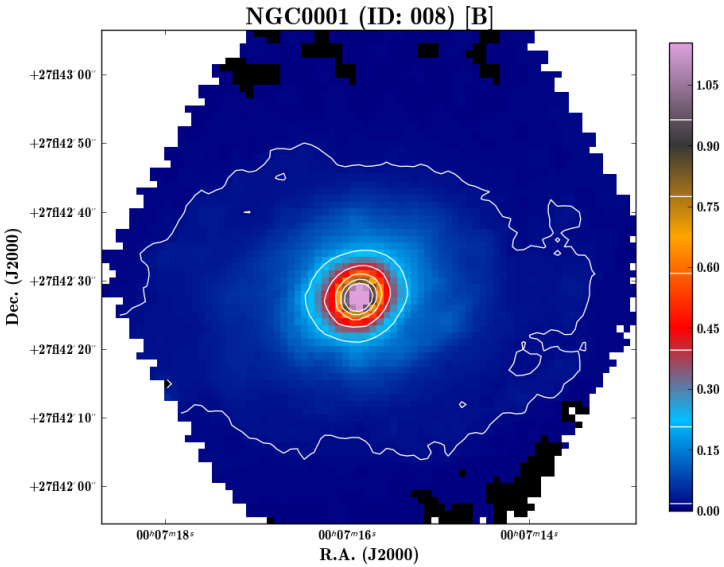

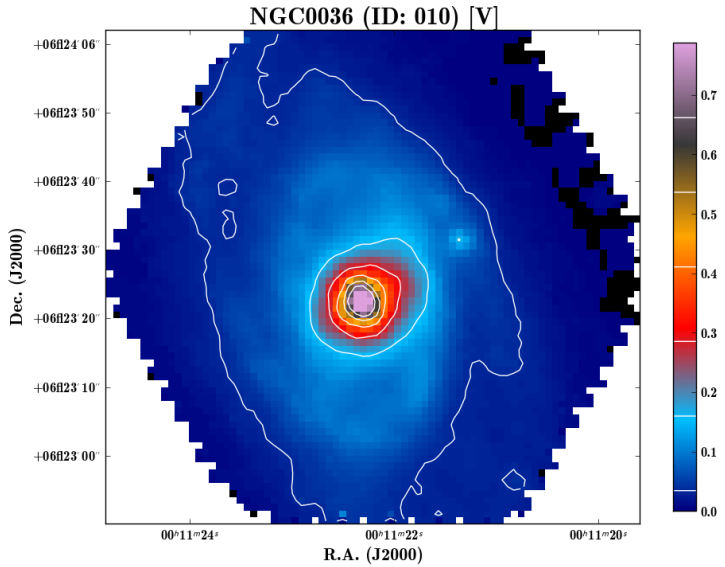

http://califaserv.caha.es/CALIFA/DATA/V1200/v2.2/web/NGC0001_B.png http://califaserv.caha.es/CALIFA/DATA/V500/v2.2/web/NGC003

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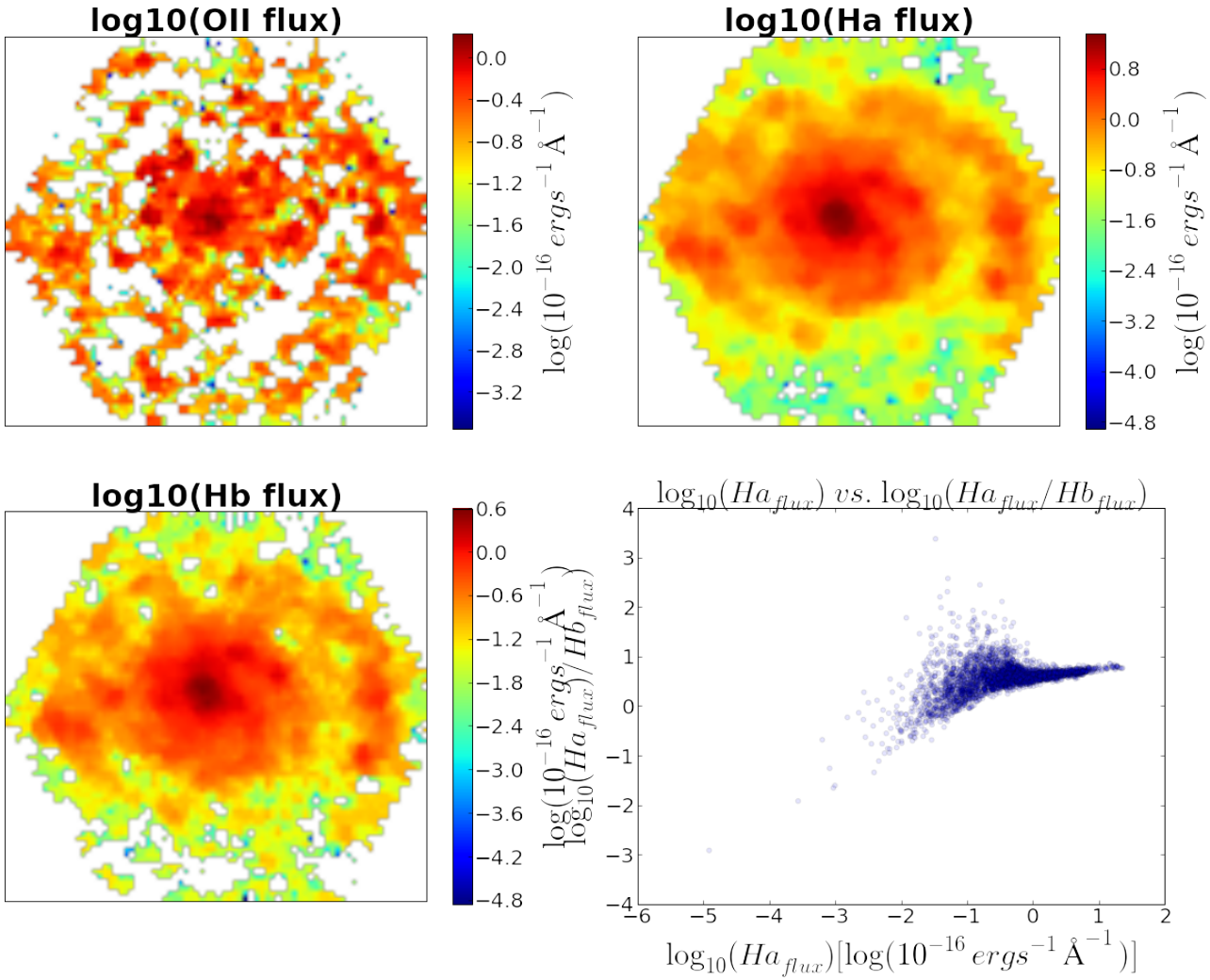

Figure: NGC0001

Results

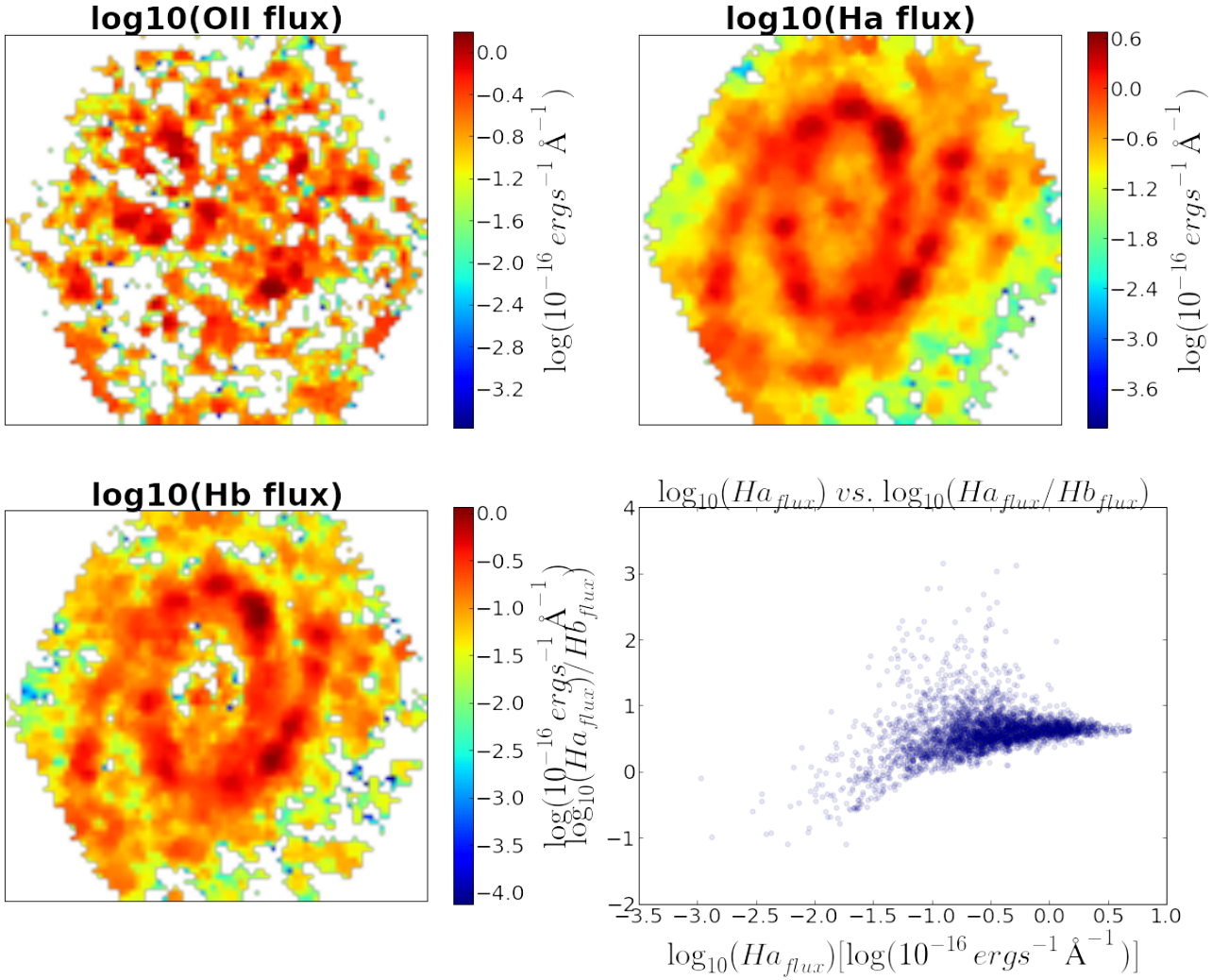

Figure: NGC0036

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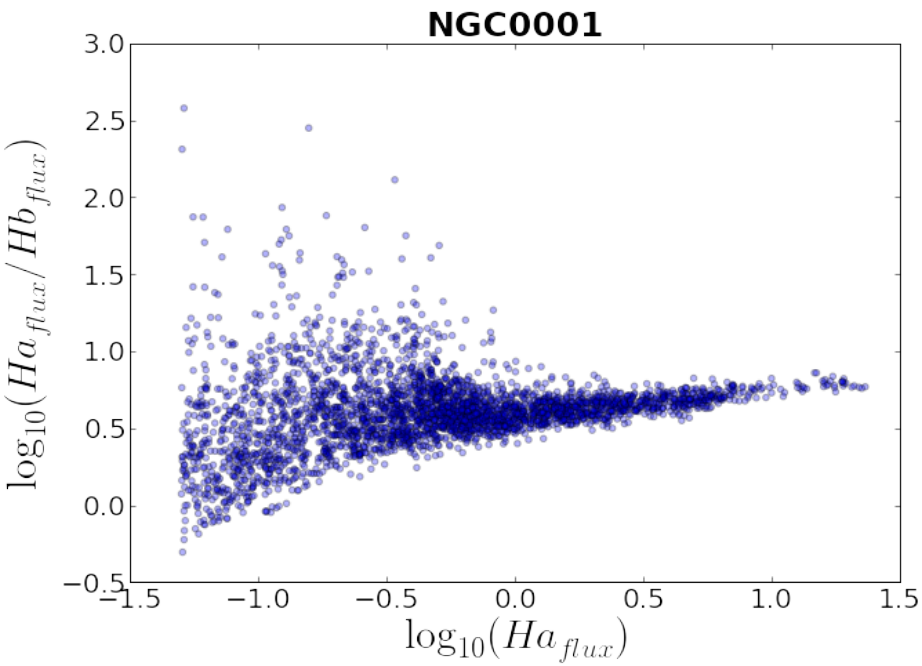


Figure: NGC0001

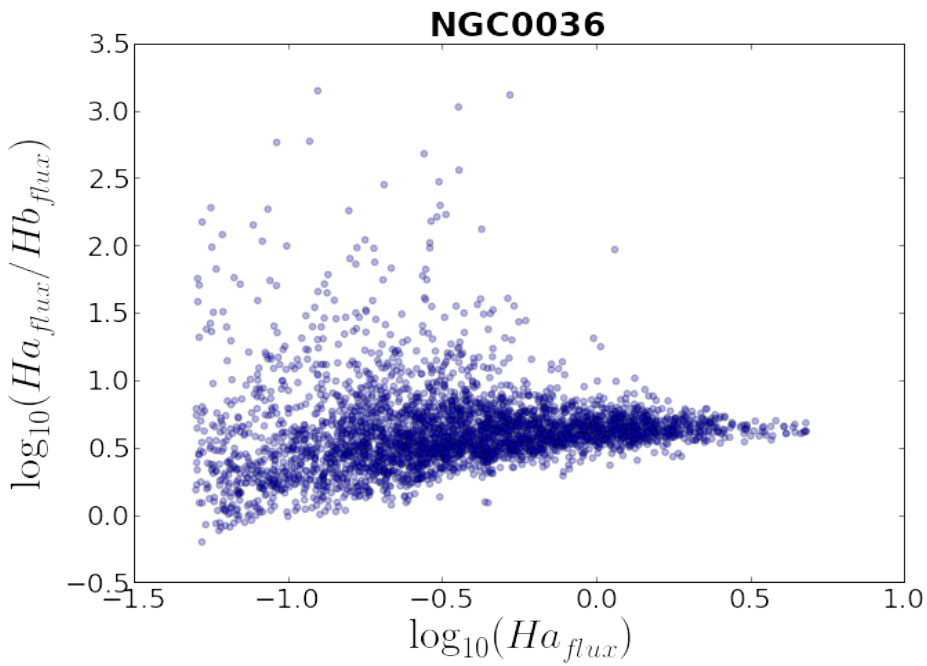


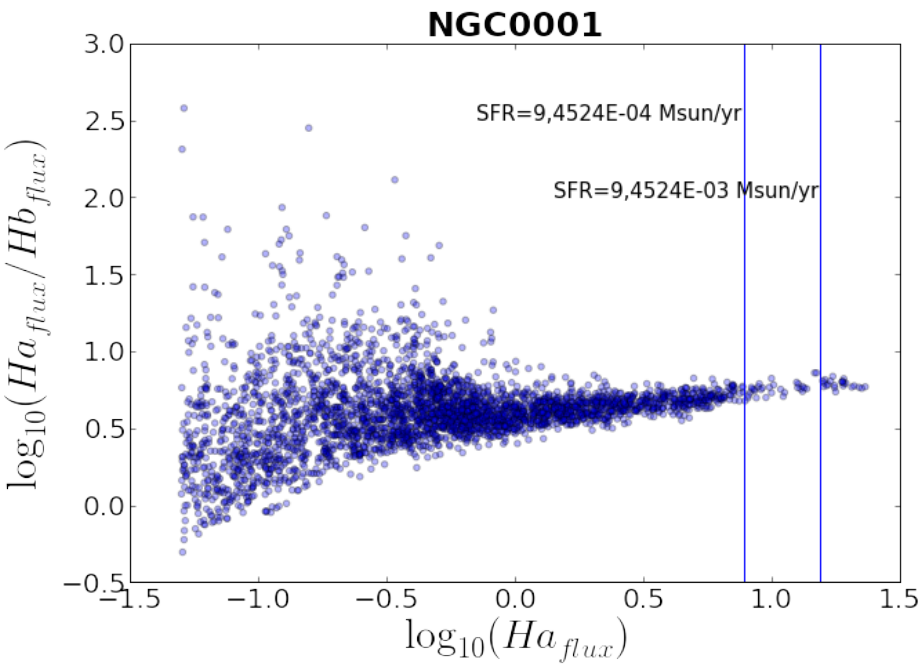
Figure: NGC0036

Results

- H_α luminosity is a direct measure of SFR [11]
- Higher H_α luminosity $\rightarrow$ higher SFR [12]

$$\mathrm{SFR}(\mathrm{M}_\odot \mathrm{yr}^{-1}) = 7.9 \times 10^{-42} L(H_\alpha)(\mathrm{ergs\,s}^{-1}) \tag{3}$$

Results



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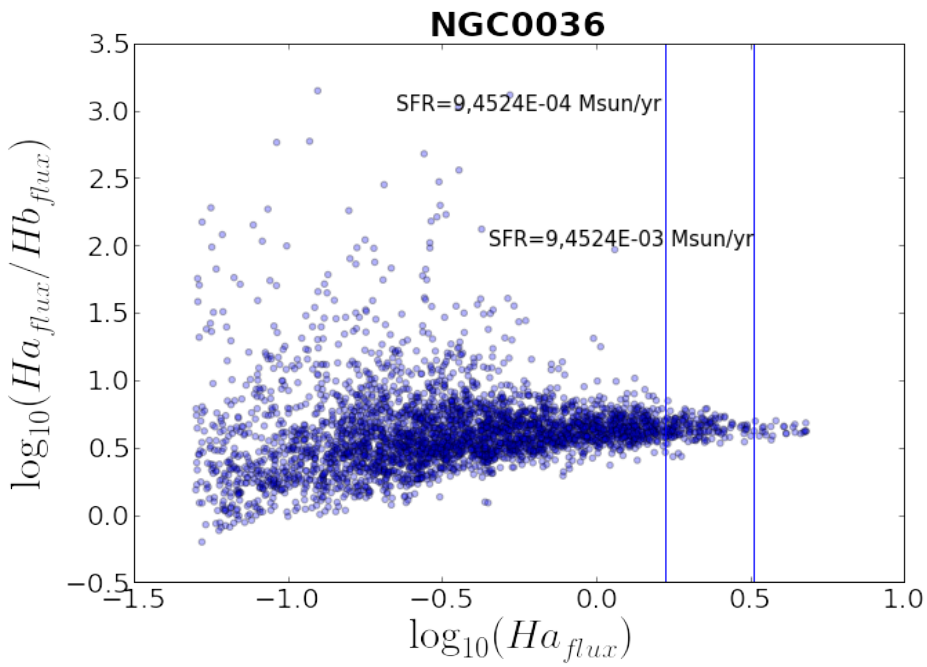

Figure: NGC0036

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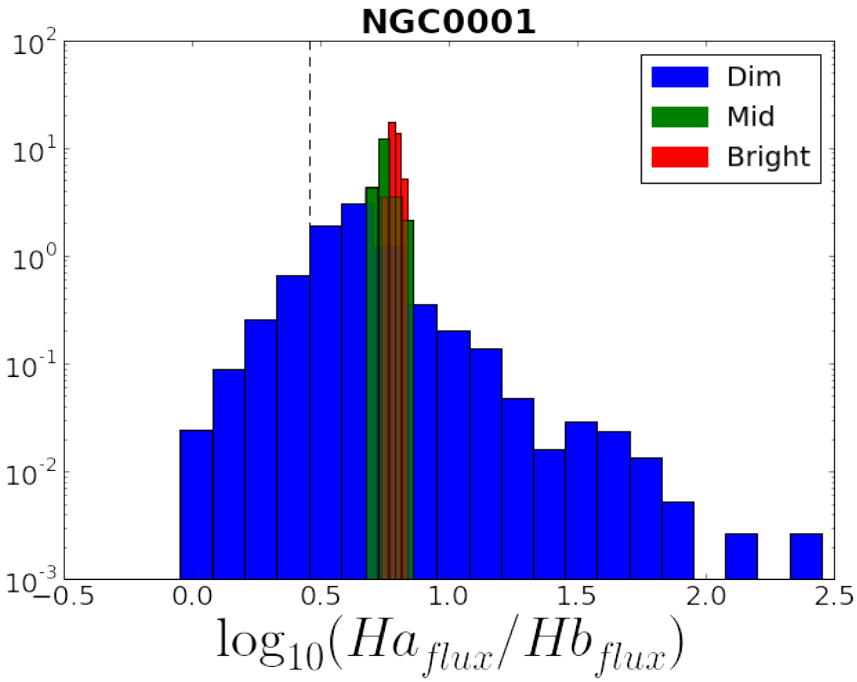

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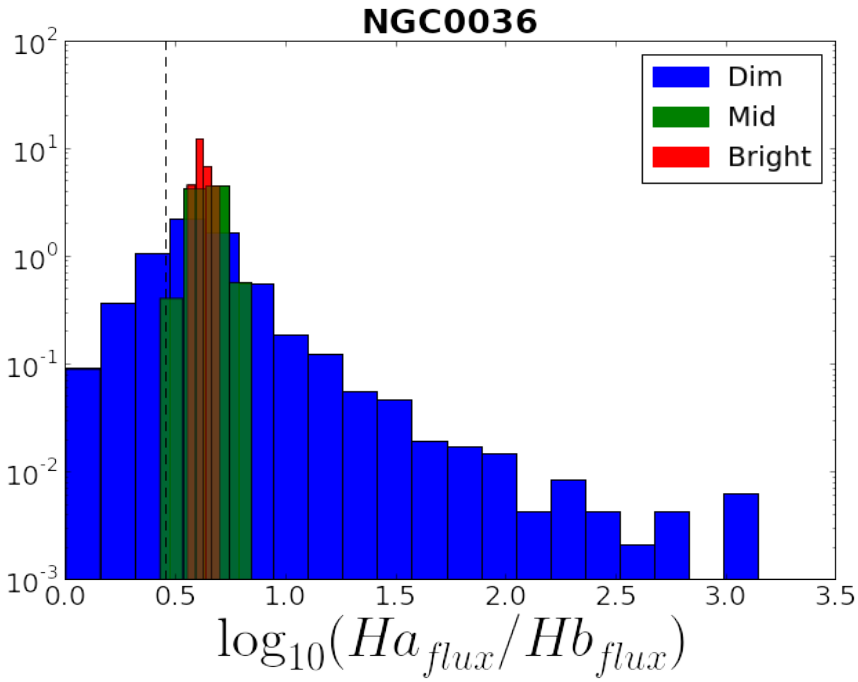

Figure: NGC0036

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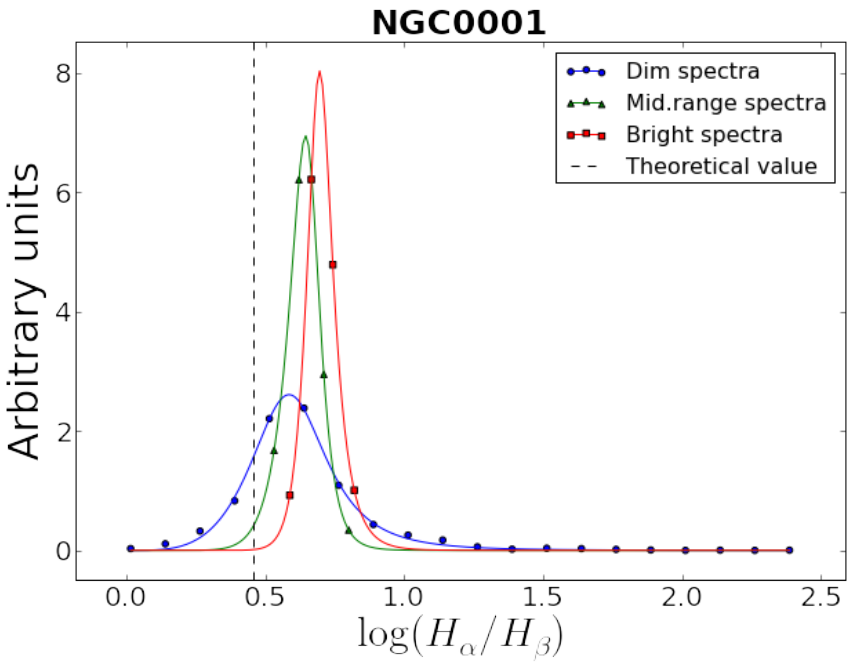

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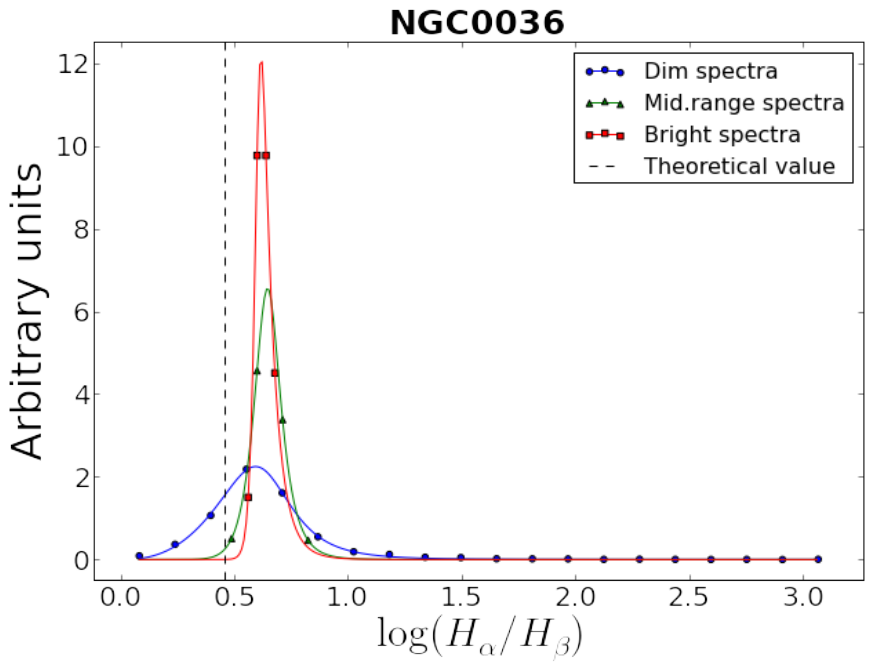
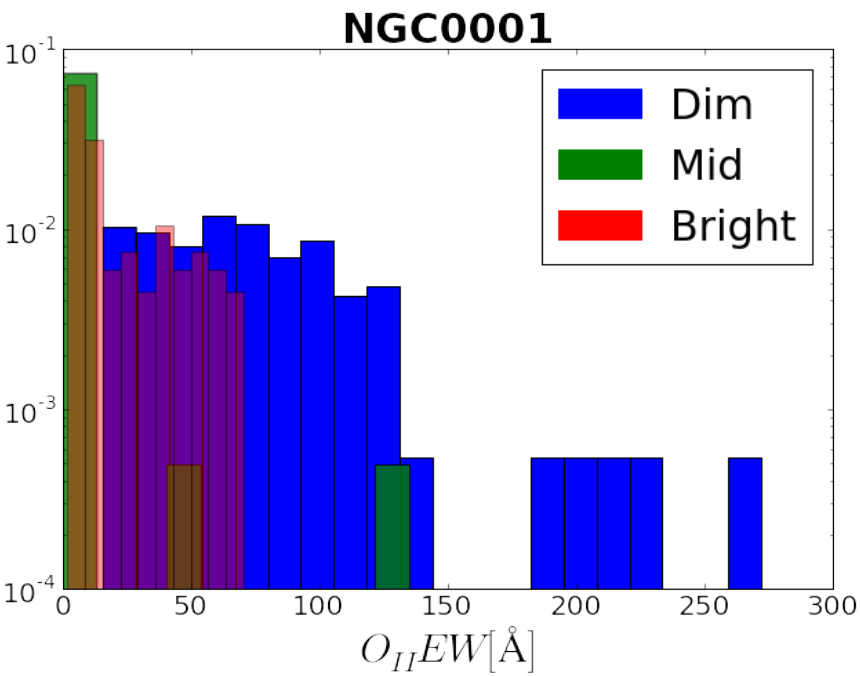


Figure: NGC0036

Results

- OII EW distribution



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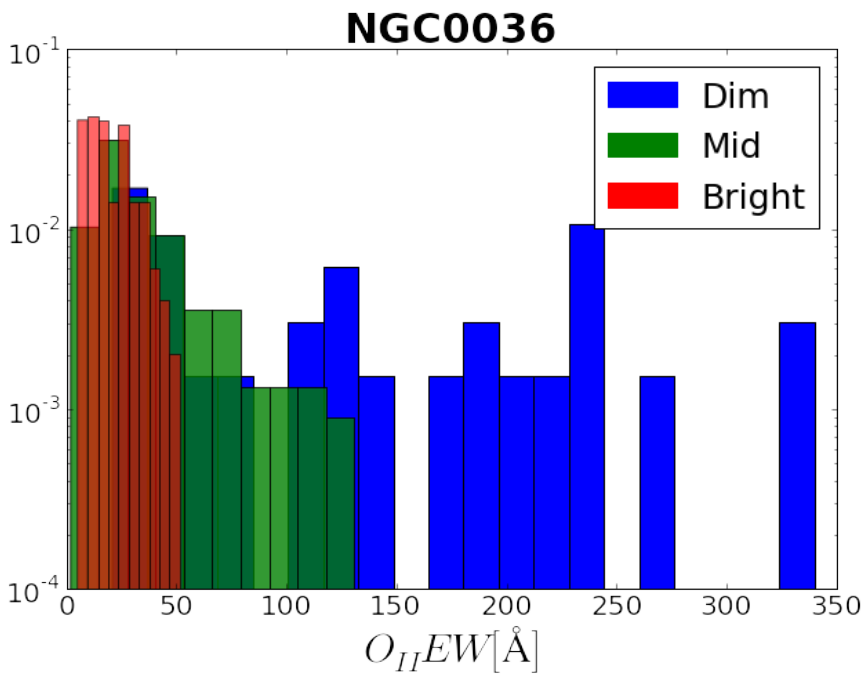

Figure: NGC0036

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Conclusions

- Fluctuation of $\frac{H_\alpha}{H_\beta}$, O_{II} EW was detected.
- Distribution of values follows the double power law (eq. 2)
- We propose stochasticity as a candidate that explains fluctuation of spectral parameters.
- **Further work:** Theoretical work on what is expected of distributions
- Quantify the impact of interstellar dust effects on our results
- Determine if stochasticity is observed
- Expand data sample (MaNGA [13])

References I

J. E. Forero-Romero and M. Dijkstra. "Effects of star-formation stochasticity on the Lyα and Lyman continuum emission from dwarf galaxies during reionization". In: 428 (Jan. 2013), pp. 2163–2170. DOI: 10.1093/mnras/sts177. arXiv: 1206.0726.

M. Fumagalli, R. L. da Silva, and M. R. Krumholz. "Stochastic Star Formation and a (Nearly) Uniform Stellar Initial Mass Function". In: 741, L26 (Nov. 2011), p. L26. DOI: 10.1088/2041-8205/741/2/L26. arXiv: 1105.6101.

References II

JE Andrews et al. "AN INITIAL MASS FUNCTION STUDY OF THE DWARF STARBURST GALAXY NGC 4214Based on observations made with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. These observations are associated with program GO-11360." In: *The Astrophysical Journal* 767.1 (2013), p. 51.

R. L. da Silva, M. Fumagalli, and M. R. Krumholz. "SLUG - Stochastically Lighting Up Galaxies - II. Quantifying the effects of stochasticity on star formation rate indicators". In: 444 (Nov. 2014), pp. 3275–3287. DOI: 10.1093/mnras/stu1688. arXiv: 1403.4605.

References III

Robert L. da Silva, Michele Fumagalli, and Mark Krumholz. "SLUG—Stochastically Lighting Up Galaxies. I. Methods and Validating Tests". In: *The Astrophysical Journal* 745.2 (2012), p. 145. URL: http://stacks.iop.org/0004-637X/745/i=2/a=145.

L. Mas-Ribas, M. Dijkstra, and J. E. Forero-Romero. "Boosting Lya and HeII 1640A Line Fluxes from Pop III Galaxies: Stochastic IMF Sampling and Departures from Case-B". In: *ArXiv e-prints* (Sept. 2016). arXiv: 1609.02150.

A. Domínguez et al. "Dust Extinction from Balmer Decrements of Star-forming Galaxies at 0.75 z 1.5 with Hubble Space Telescope/Wide-Field-Camera 3 Spectroscopy from the WFC3 Infrared Spectroscopic Parallel Survey". In: *The Astrophysical Journal* 763.2 (2013), p. 145. URL: http://stacks.iop.org/0004-637X/763/i=2/a=145.

References IV

- S. F. Sánchez et al. "CALIFA, the Calar Alto Legacy Integral Field Area survey. I. Survey presentation". In: 538, A8 (Feb. 2012), A8. DOI: 10.1051/0004-6361/201117353. arXiv: 1111.0962.
- J. Sánchez Almeida et al. "Qualitative Interpretation of Galaxy Spectra". In: 756, 163 (Sept. 2012), p. 163. DOI: 10.1088/0004-637X/756/2/163. arXiv: 1207.3928.
- S. F. Sánchez et al. "Pipe3D, a pipeline to analyze Integral Field Spectroscopy Data: II. Analysis sequence and CALIFA dataproducts". In: 52 (Apr. 2016), pp. 171–220. arXiv: 1602.01830 [astro-ph.IM].
- L. J. Kewley et al. "The Hα and Infrared Star Formation Rates for the Nearby Field Galaxy Survey". In: 124 (Dec. 2002), pp. 3135–3143. DOI: 10.1086/344487. eprint: astro-ph/0208508.

References V

R. C. Kennicutt Jr. "Star Formation in Galaxies Along the Hubble Sequence". In: 36 (1998), pp. 189–232. DOI: 10.1146/annurev.astro.36.1.189. eprint: astro-ph/9807187.

K. Bundy et al. "Overview of the SDSS-IV MaNGA Survey: Mapping nearby Galaxies at Apache Point Observatory". In: 798, 7 (Jan. 2015), p. 7. DOI: 10.1088/0004-637X/798/1/7. arXiv: 1412.1482.