

Metals and dust content across the discs of nearby galaxies

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In collaboration with:

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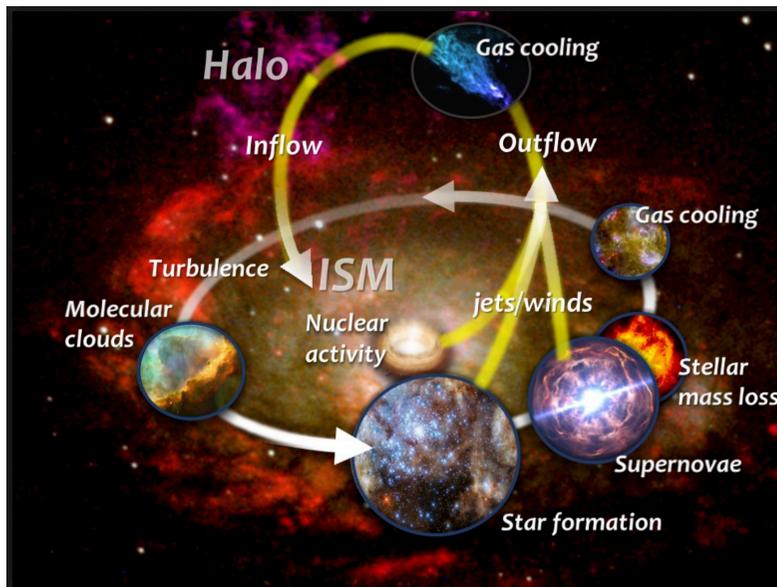


OUTLINE

- ✓ Motivation and introduction
- ✓ Sample and data
- ✓ Results
- ✓ Conclusions

Motivation

- Gas and dust are related through all the life cycle of the ISM.



Credits: SPICA Mission http://www.spica-mission.org/science_galaxies.xhtml

The chemical and dust evolution of galaxies is a powerful way for understanding the history of the star formation and the evolution of galaxies.

We have chosen a set of three galaxies and we have studied the relation of the gas and dust across their discs

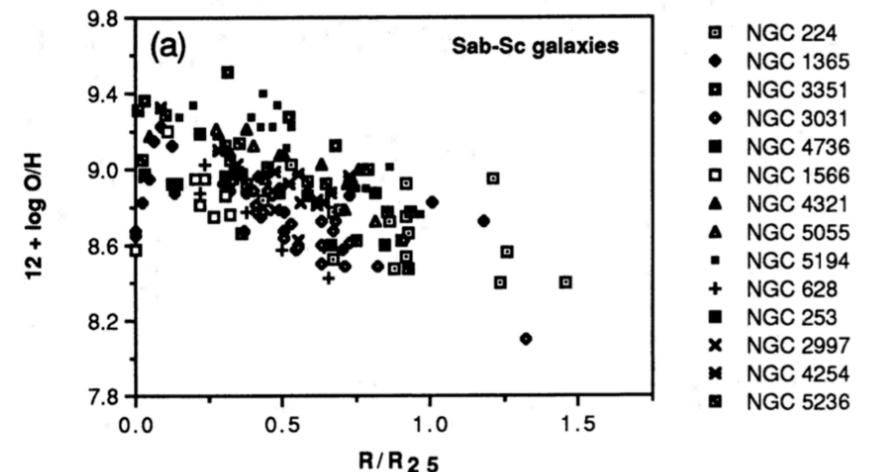
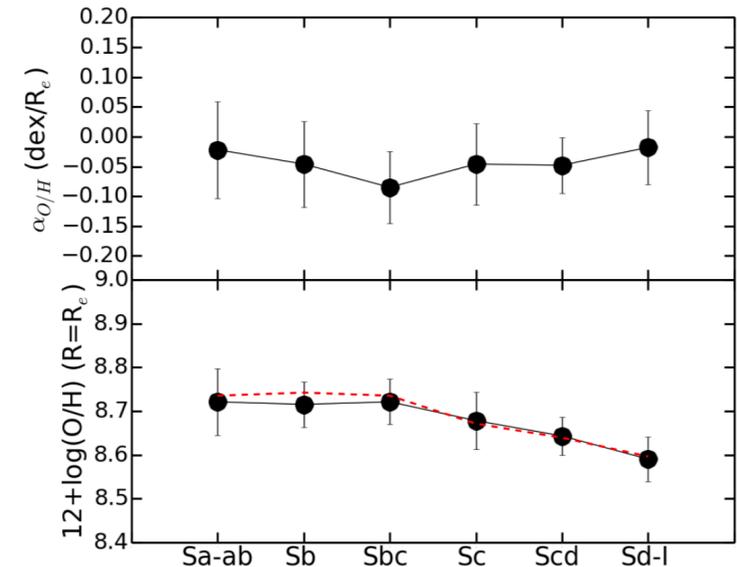
Interstellar Gas

Chemical abundances of gas ($12+\log(\text{O}/\text{H})$) define in most spiral galaxies radial gradients that reflect the star formation and chemical history of the galaxy.

Metallicity across galaxy discs can be now easily measured using IFU surveys (CALIFA, MANGA, SAMI) but they rely on *strong-line calibration methods*, affected by high uncertainties (Kewley & Ellison 2008)

Direct chemical abundances: Obtained using the electron temperature previously derived from Te-sensitive auroral emission lines. They are more precise than strong-line metallicity derivations.

Pérez-Montero et al. 2016



Vila-Costas & Edmunds 1992

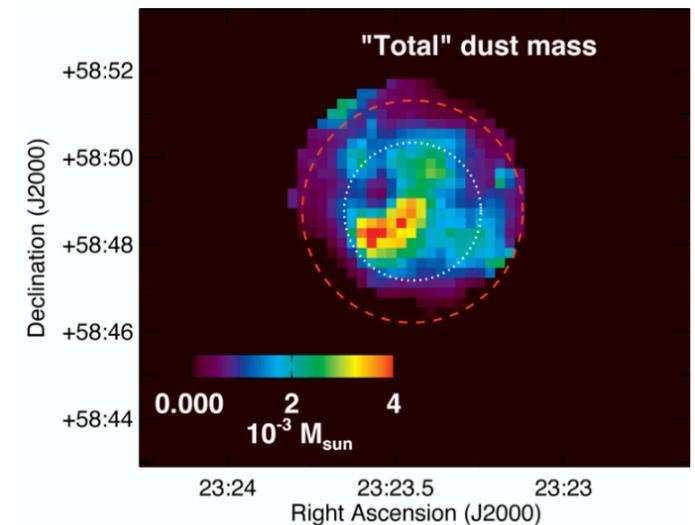
Interstellar Dust

Dust (~1% of total ISM mass) plays an important role in several astrophysical processes (photo-electric heating, H₂ formation on dust grains, etc...)

Where does the dust come from?

- Stellar atmospheres of **asymptotic giant branch (AGB) stars** ($M_{\text{sun}} < M_{\text{star}} < 8 M_{\text{sun}}$) (e.g. Valiante et al. 2009)
- Expanding ejecta of **supernova remnants (SNRs)** (= remnants of stars with masses $8 M_{\text{sun}} < M_{\text{star}} < 40 M_{\text{sun}}$) (e.g. Bianchi & Schneider 2007)
- Dust grows in the ISM due to accretion of metals in the gas phase (Dwek, 1998; Zhukovska et al. 2008).

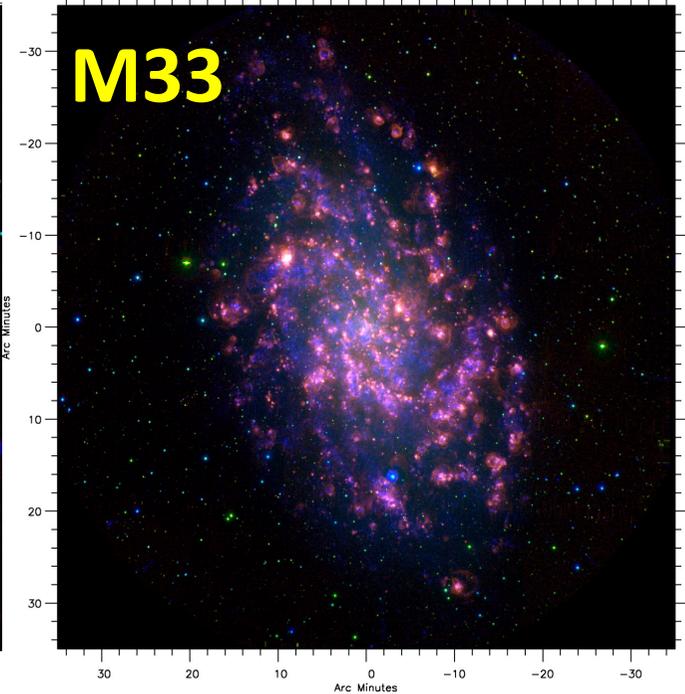
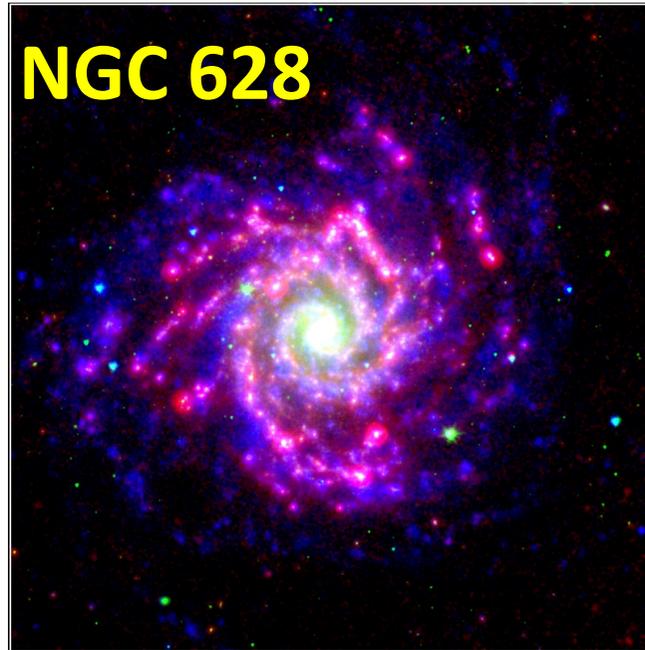
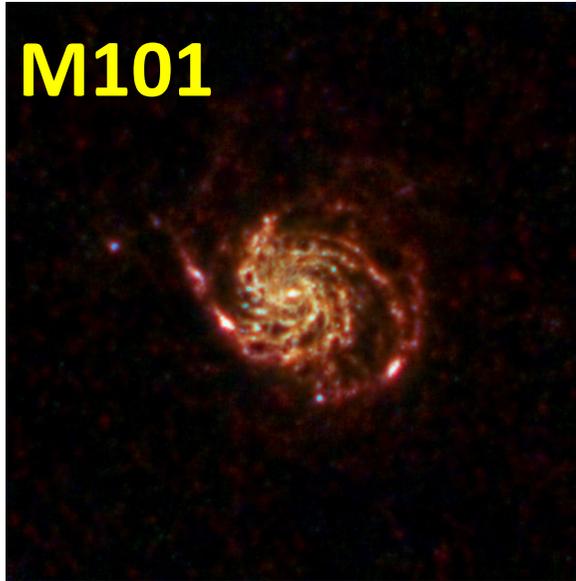
De Looze et al. 2017



Concentration of cold dust in the interior of Cas A: a total mass of 0.3–0.5 M_{\odot} of silicate grains are freshly produced in the SNR (lower limit of ≥ 0.1 –0.2 M_{\odot})

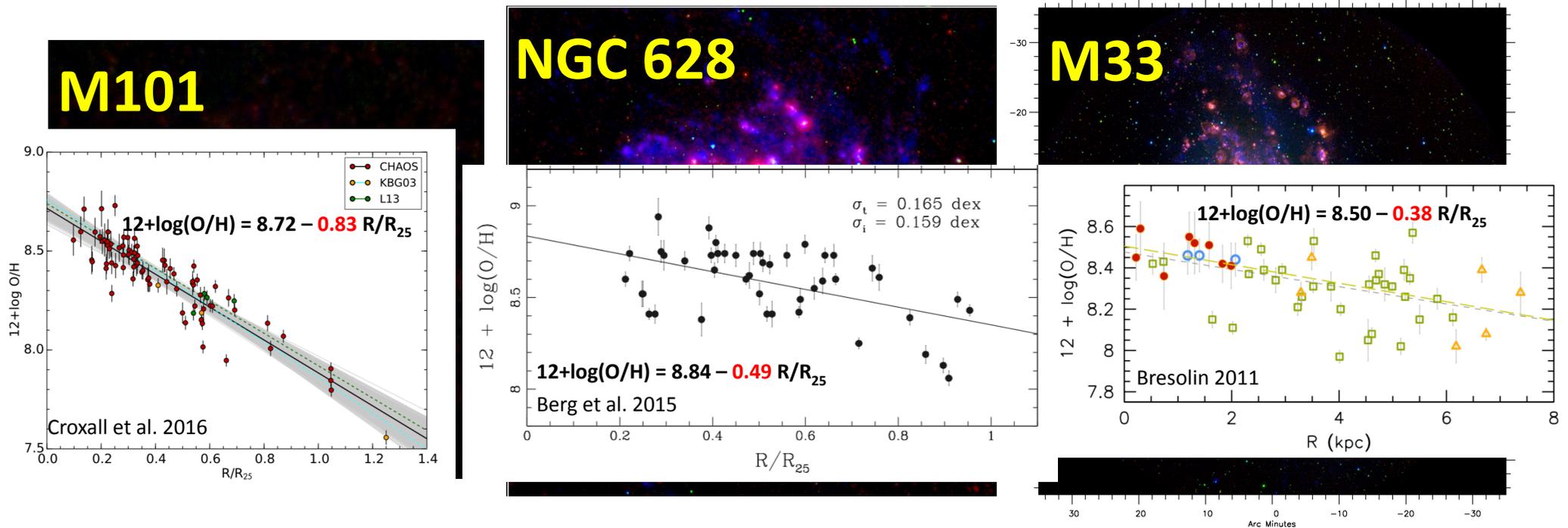
Dust evolves in the ISM changing grain size and even being destroyed through grain heating evaporation, sputtering, shattering, astration, accretion and coagulation.

Our sample: M101, NGC 628 and M33



Property	M101	NGC 628	M33
Morph. Type	SABcd	SAC	SA(s)cd
Distance (Mpc)	7.4	9.77	0.84
pc/''	~36	~47	~4
PA (°)	39	12	23
inclination (°)	18	5	57
R ₂₅ (kpc)	31.0	14.9	8.5
log M _★	9.56	9.98	9.65

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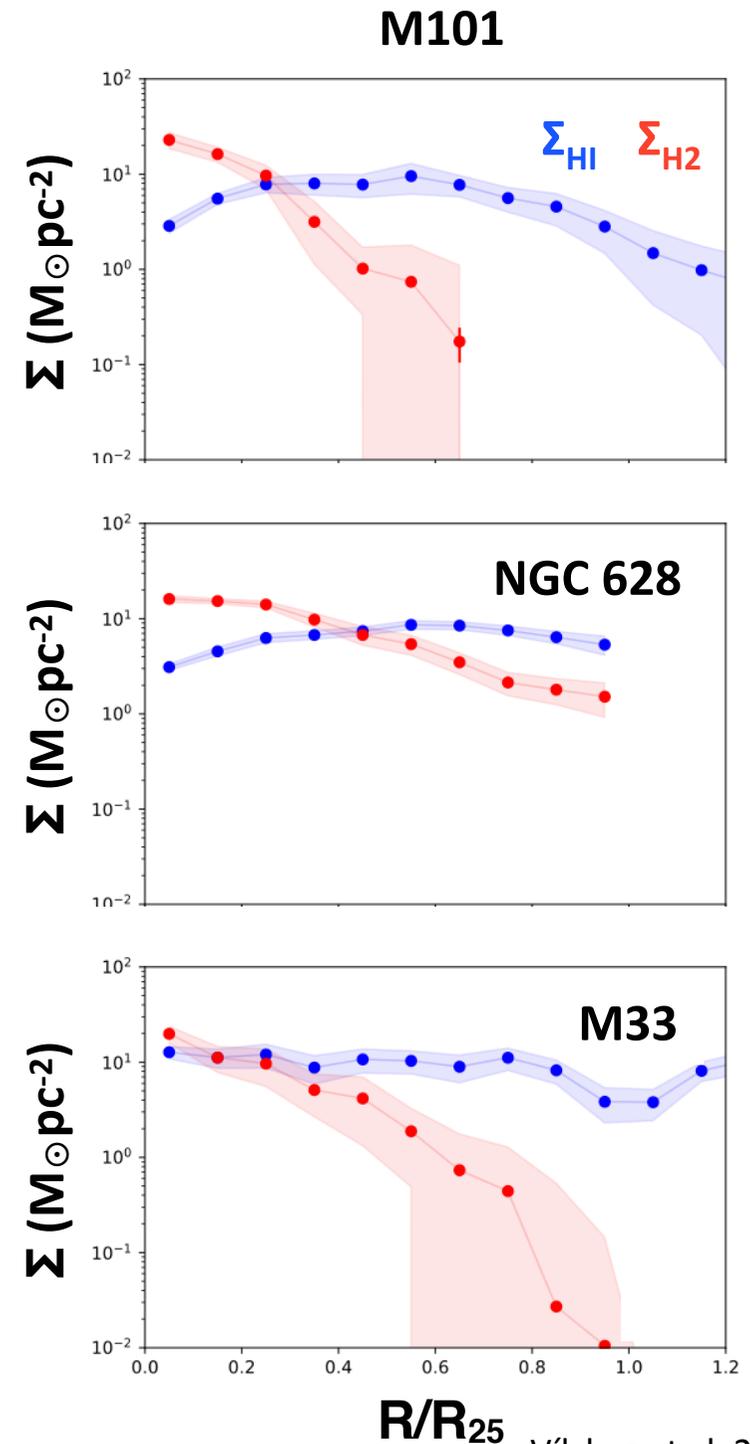
Direct oxygen abundances derivations using electron temperature sensitive lines

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- ✓ Zero points for M101 and NGC 628 are similar within the errors
- ✓ O/H slope is flatter for NGC 628 presenting a higher O/H abundance than M101 along the disc within R₂₅
- ✓ M33: O/H abundance zero point and gradient are lower than NGC 628 and M101

DATA

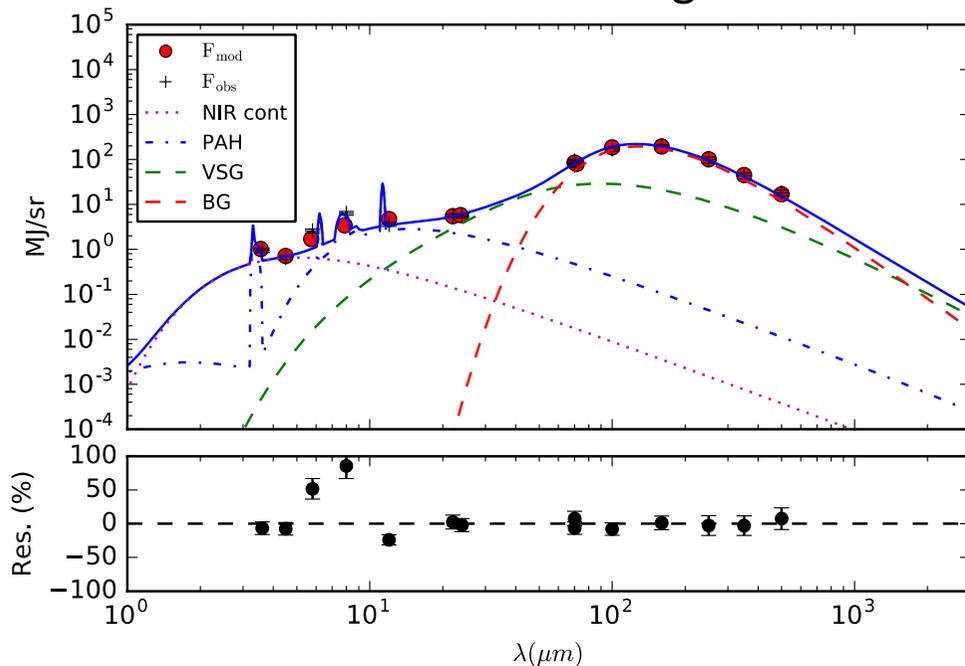
- ✓ **Gas:** HI (21cm) and $^{12}\text{CO}(2-1)$ images (Walter et al. 2008, Leroy et al. 2009, 2013, Gratier et al. 2010, Druard et al. 2014)
- ✓ **Stars:** 3.6 μm and 4.5 μm IRAC maps are used to produce stellar mass maps (S4G survey, Querejeta et al. 2015) (not for M33)
- ✓ **Dust:** Spitzer (IRAC/MIPS), WISE (12 μm /22 μm) and HERSCHEL (PACS/SPIRE) images (Kingfish/HerM33es surveys)
- NGC 628 and M33 present CO emission up to $\sim R_{25}$
- M101 CO emission is restricted to the central $R \leq 0.7 R_{25}$
- Σ_{H_2} is obtained from CO observations assuming a X_{CO} factor proportional to Z^{-1} for M101 and NGC 628, and $X_{\text{CO}} = 4$ for M33 (Gratier et al. 2017).



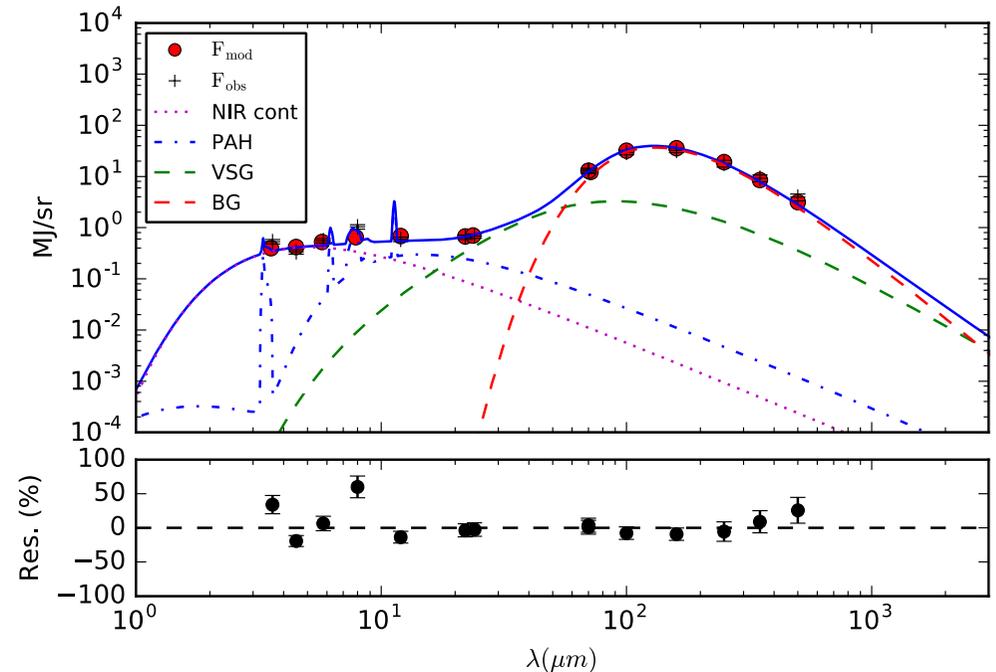
Spectral Energy Distribution Modelling

- ✓ Dust model (*DustEM*, Compiegne et al 2011, Desert et al. (1990)): Combination of different grain types (PAH, VSG, BG) and incident ISRF from the solar neighbourhood (Mathis et al. 1983).
- ✓ Pixel by pixel SED fitting: Bayesian approach (da Cunha et al. 2008): input parameters ($Y_{\text{PAH}}, Y_{\text{VSG}}, Y_{\text{BG}}, G_0$) and NIR continuum (G_{NIR}).

Star-forming

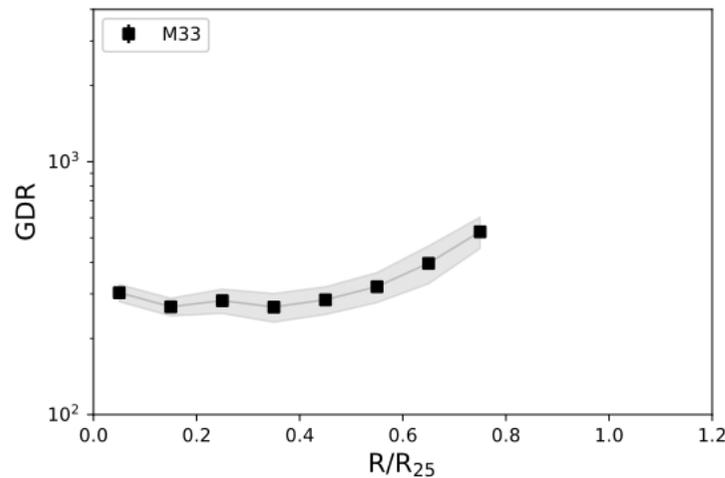
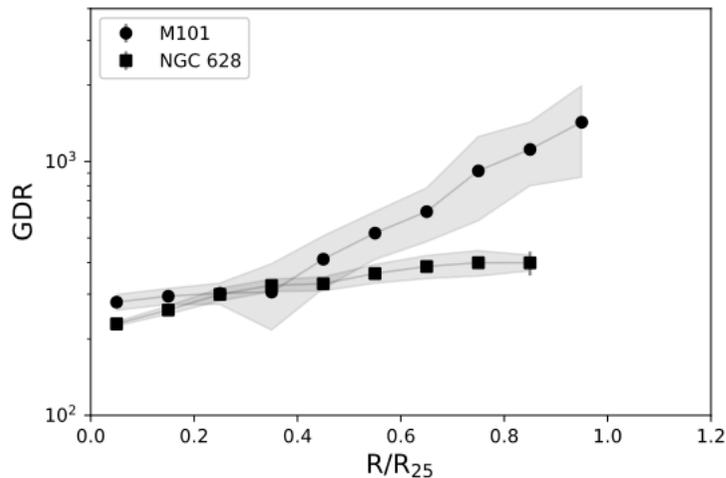
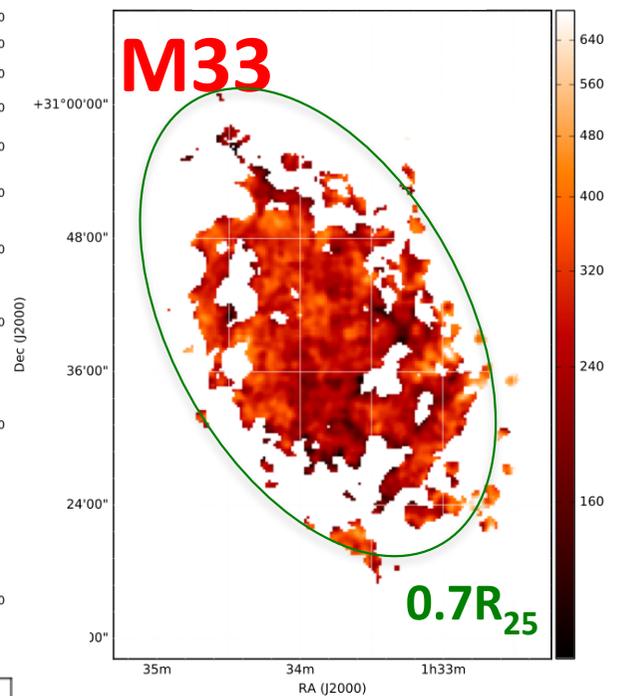
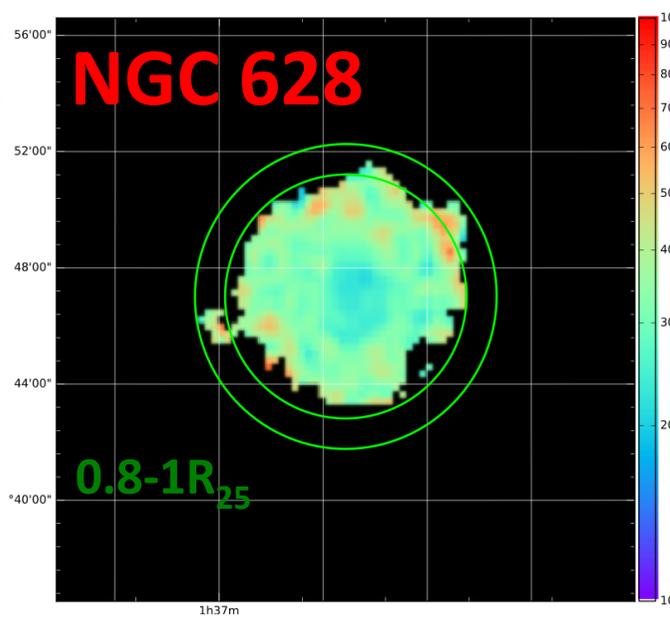
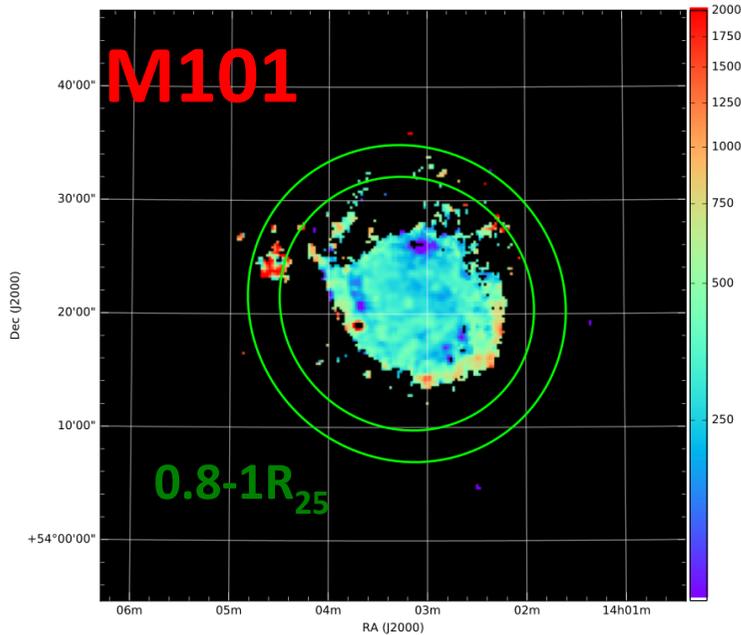


Diffuse location



Two different pixels corresponding to **star-forming** and **diffuse areas** within the disc of M33 (Relaño et al. 2018)

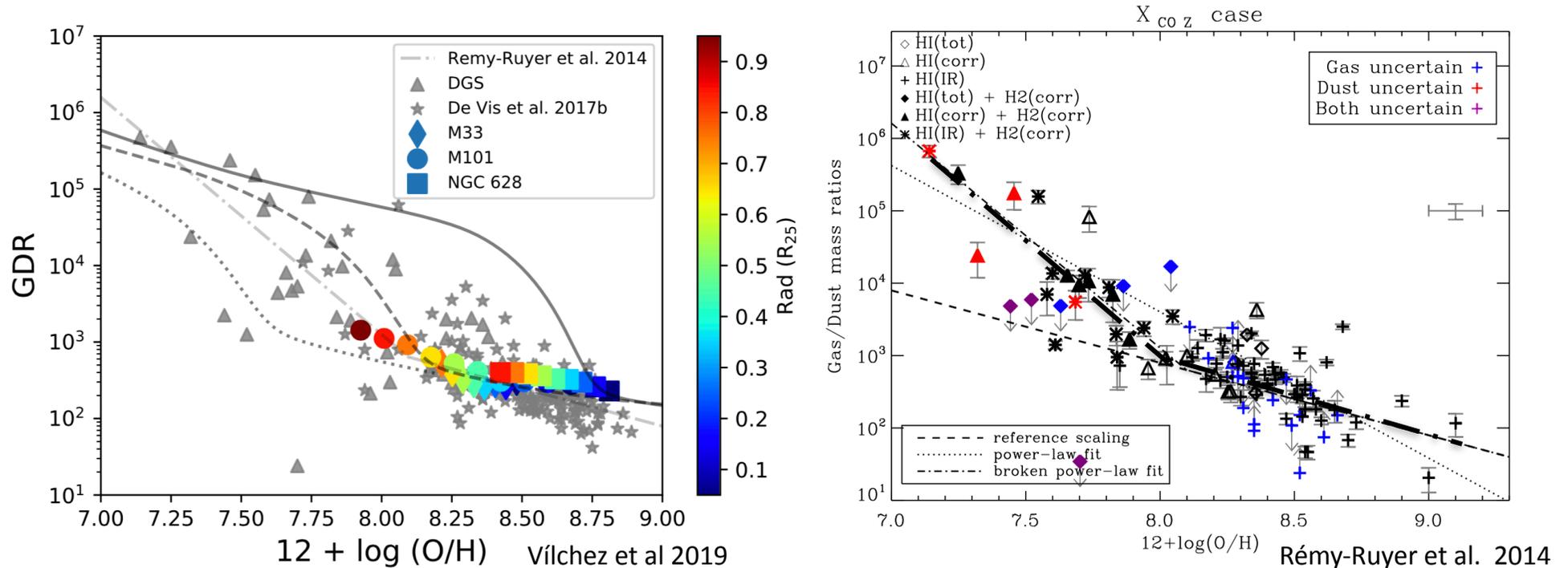
Gas to dust mass ratio (GDR)



- ✓ NGC 628: GDR~200 to 300
- ✓ M101: broken radial profile, at $0.5 \sim R_{25}$ GDR increases dramatically
- ✓ M33: mild increase towards outer radii with a similar trend as M101

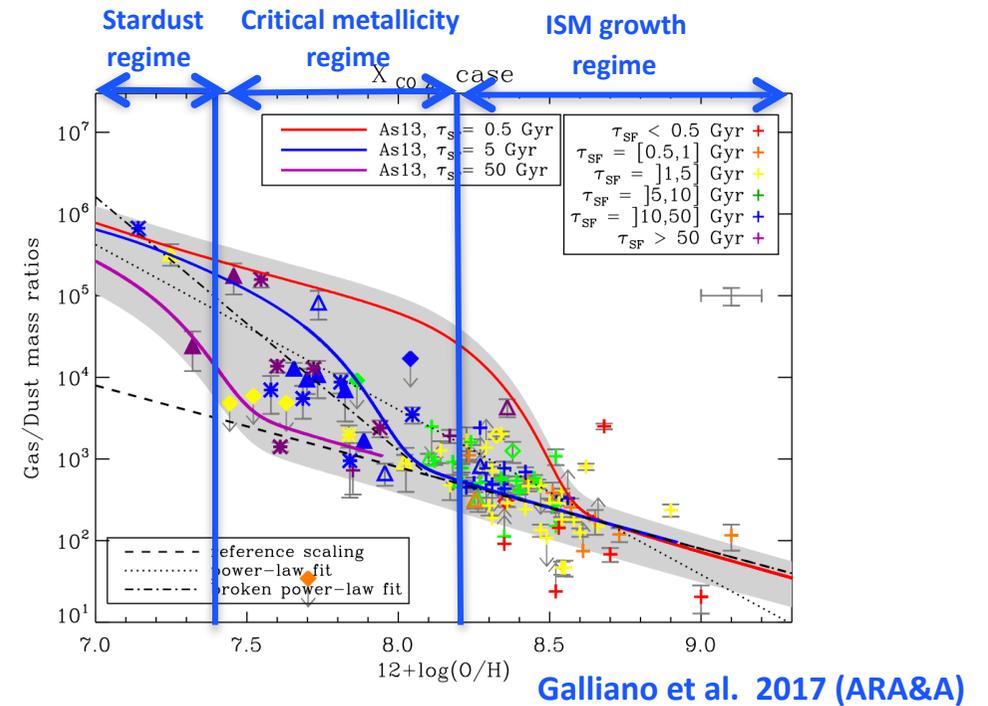
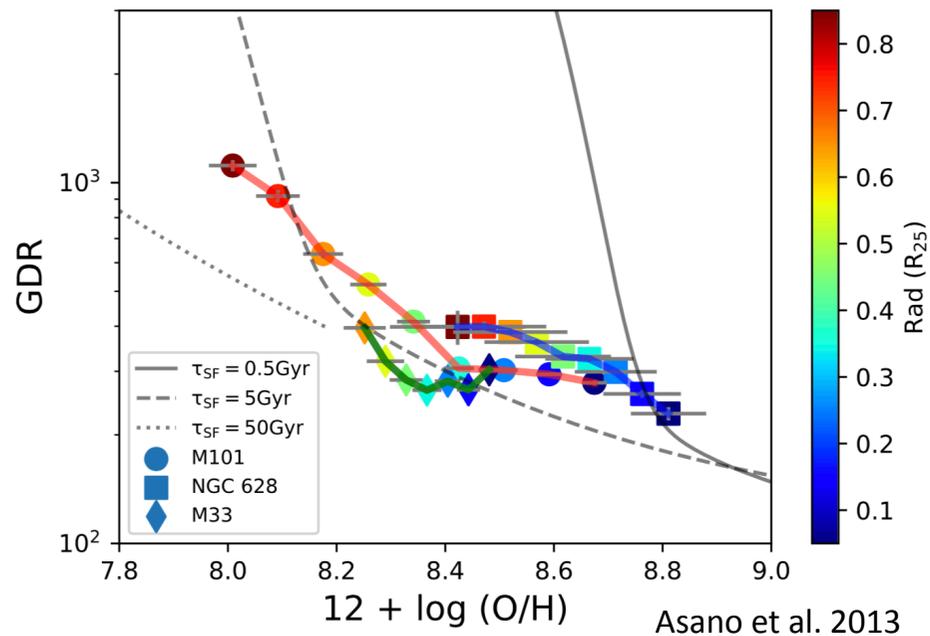
M101 radial profile agrees in general with the results presented I-Da Chiang on his talk on Monday (Chiang et al. 2018)

Gas to Dust mass ratio and metallicity



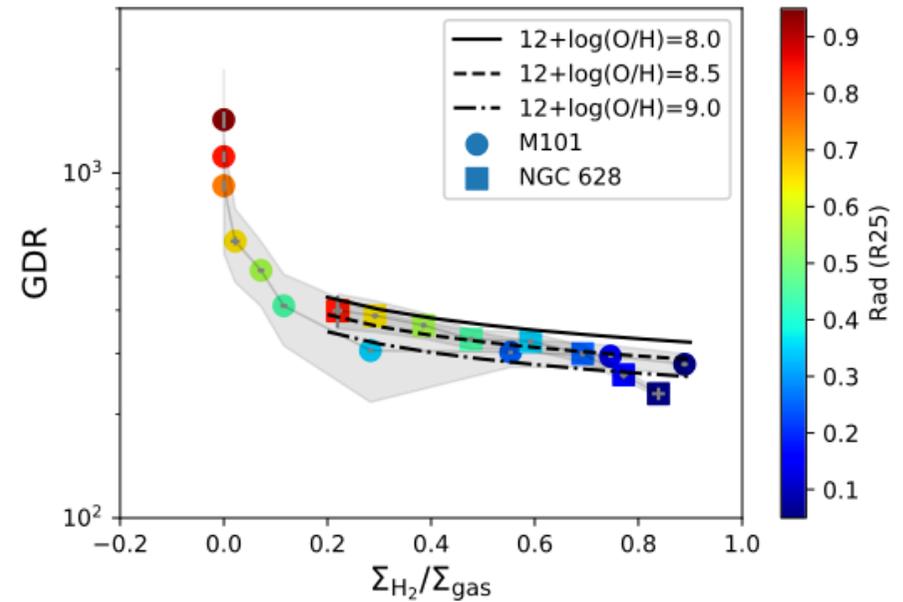
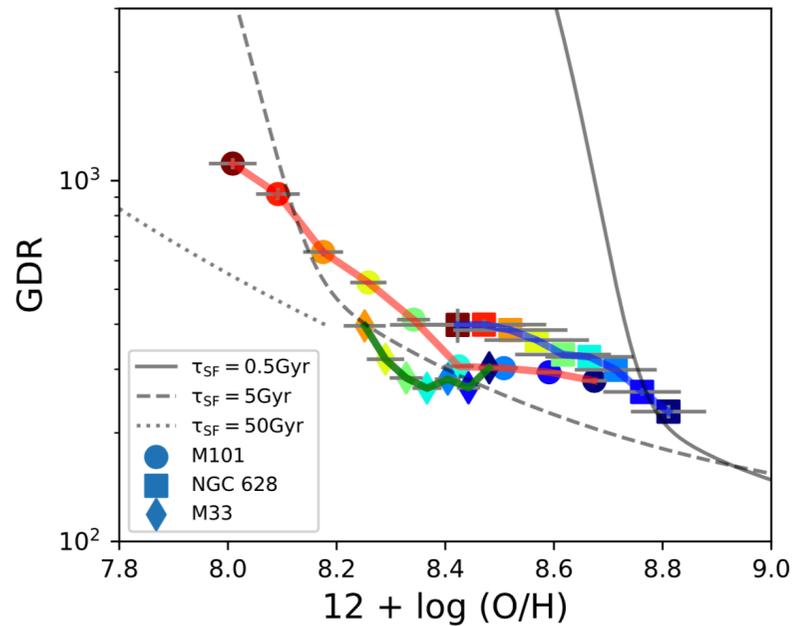
- ✓ Spatially resolved studies with direct chemical abundance derivations show less dispersion than for entire galaxies.
- ✓ Two slope behaviour with a break at $12 + \log(O/H) \approx 8.4$ (Rémy-Ruyer et al. 2014 found a break at 8.10 ± 0.43).
- ✓ In general agreement with GDR-metallicity relations found from previous studies (Chiang et al. 2018 for M101 and Draine et al. 2014; Smith et al. 2012 for M31)

Gas to dust mass ratio: dust formation mechanisms



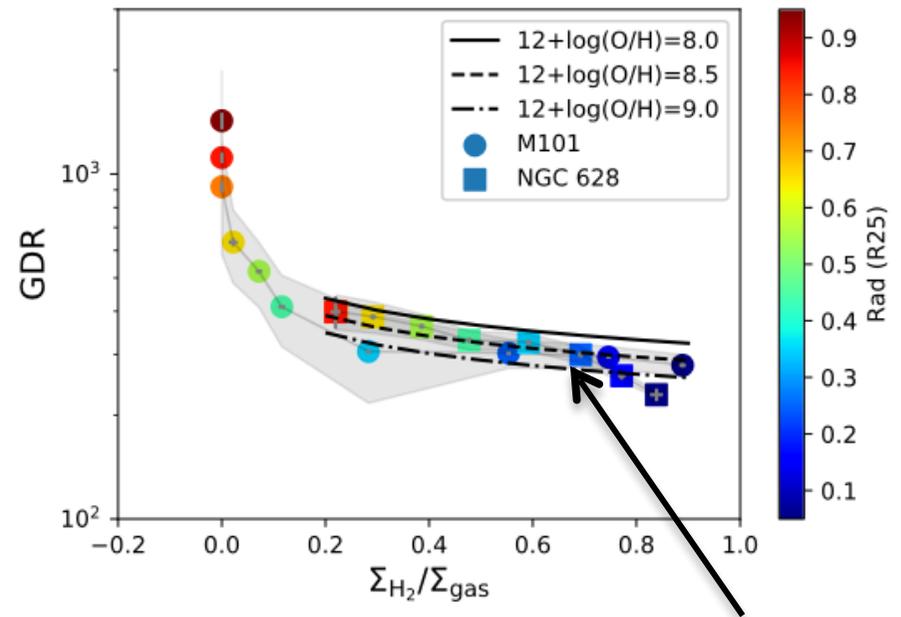
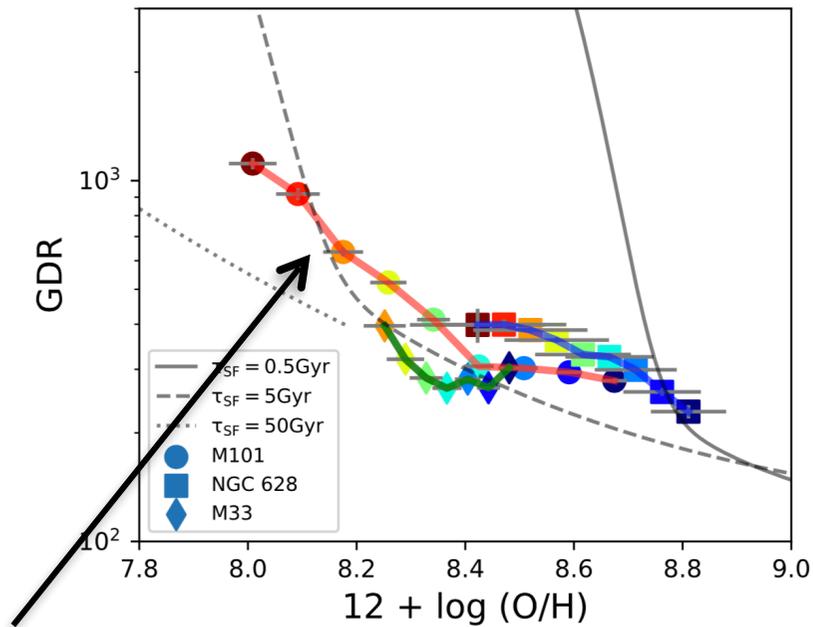
- ✓ Asano et al. 2013: Dust formation regulated via AGB stars, SNe II and dust growth in the ISM via accretion. Dust is destroyed by SN shocks. Close-box model. Star formation time scale, $\tau_{SF} = M_{ISM}/SFR$
- ✓ Two regimes: high metallicity where dust evolution is mainly driven by dust growth via accretion and low metallicity where dust is given by metals produced and ejected in the ISM by stars.
- ✓ M101 and M33 show signs in their galactic disc of both regimes, while over the whole disc of NGC 628 the dust seems to be formed by accretion (Roman-Duval et al. 2014, 2017 for similar results in the LMC, SMC)

Gas to dust mass ratio: dust formation mechanisms



- ✓ Asano et al. 2013: accretion time for grain growth is proportional to Z^{-1} and to the inverse of the fraction of cold (molecular) component of the ISM ($\Sigma_{H_2}/\Sigma_{gas}$ = molecular to total mass ratio)
- ✓ In the areas where dust is mainly formed by accretion we would expect a correlation between M_{dust} and the molecular gas mass fraction
- ✓ Two-fold behaviour for the GDR with a clear change at $12 + \log(O/H) \sim 8.3-8.4$

Gas to dust mass ratio: dust formation mechanisms

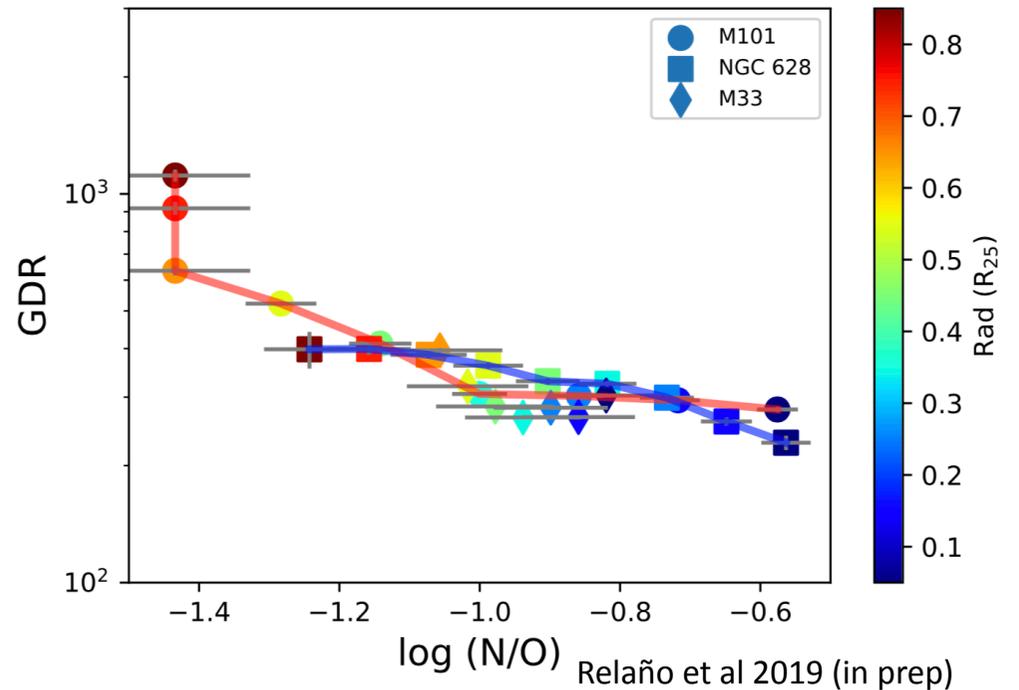
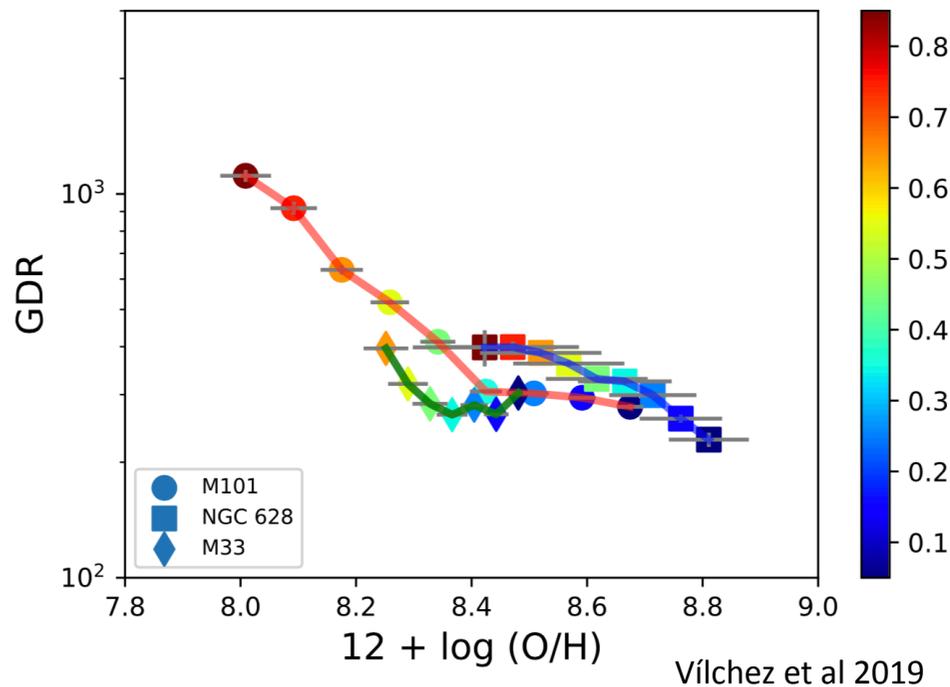


$$\log(\text{GDR}) = (-1.33 \pm 0.05) \times (12 + \log(\text{O}/\text{H})) + (-13.7 \pm 0.4)$$

$$\log(\text{GDR}) = (-0.1 \pm 0.2) \times (12 + \log(\text{O}/\text{H})) + (-0.2 \pm 0.1) \times \log(\Sigma_{\text{H}_2} / \Sigma_{\text{gas}}) + (3.3 \pm 1.6)$$

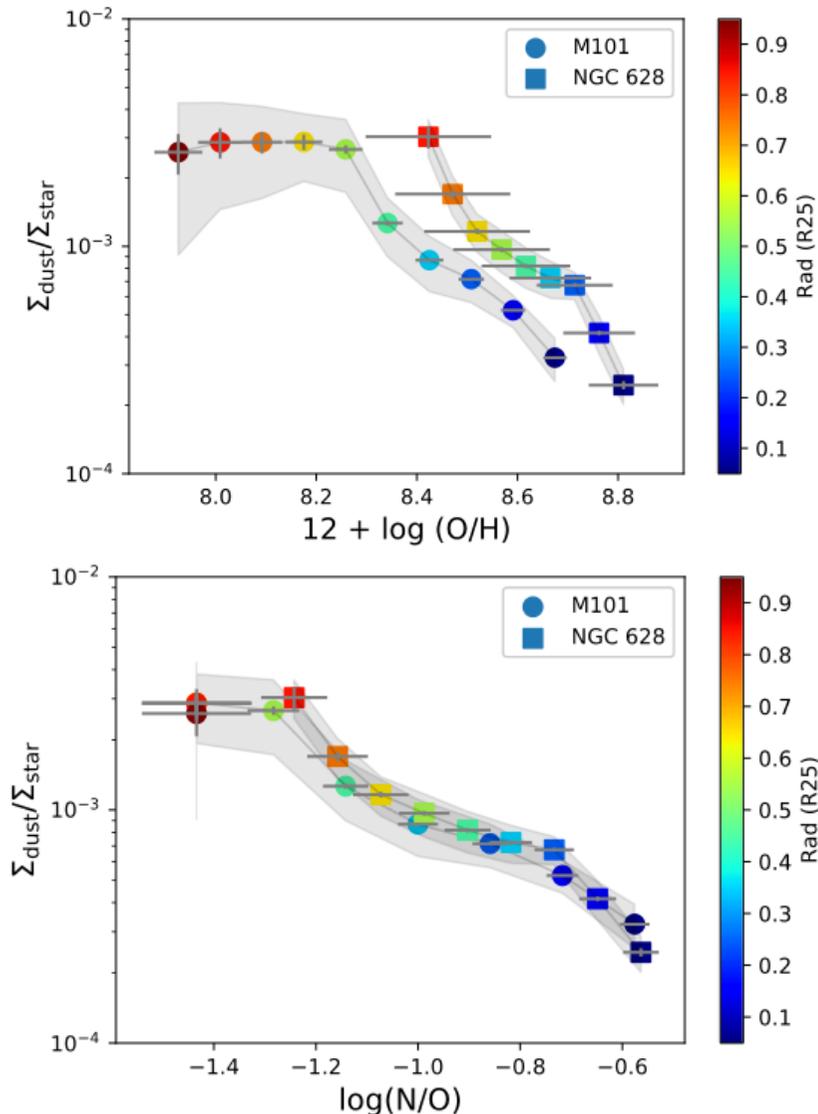
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Gas to Dust mass ratio and N/O



- ✓ Nitrogen is produced mainly by LIMS ($1M_{\odot} < M < 8M_{\odot}$) (Henry et al. 2000). These stars are the progenitors of the AGB stars that produce dust in their cool and dense atmospheres.
- ✓ Oxygen is mainly produced by massive stars \Rightarrow therefore N/O traces the presence of the AGB stars in the galactic disc.
- ✓ Since AGB stars are major dust producers (AGBs can dominate stellar dust production at ages $\sim 150-500$ Myr depending on the IMF, SFH and Z_{star} , Valiante et al. 2009) \Rightarrow we would expect a relation between the amount of dust and the presence of the AGB stars in the disc.

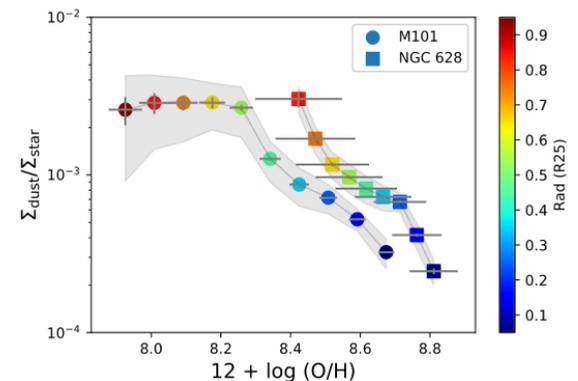
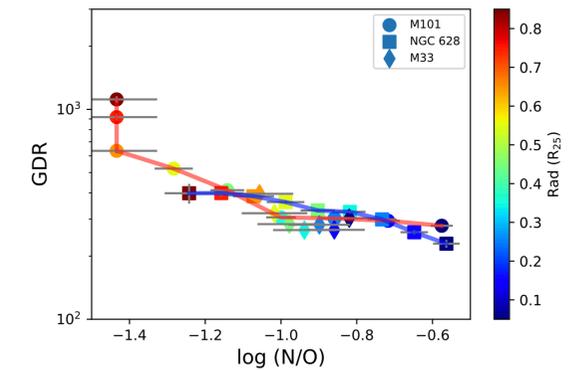
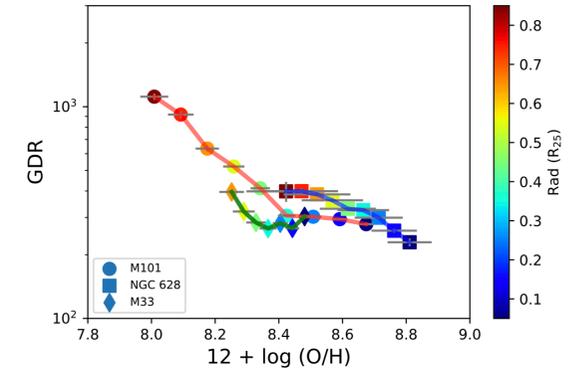
Dust to stellar mass ratio: stellar dust production



- ✓ $\Sigma_{\text{dust}}/\Sigma_{\text{star}}$ is constant in the outer parts of M101 (for $12 + \log(\text{O}/\text{H}) < 8.2$)
- ✓ In this regime the dust is mainly produced by stars
- ✓ For $12 + \log(\text{O}/\text{H}) > 8.4-8.3$ there is a strong correlation between $\Sigma_{\text{dust}}/\Sigma_{\text{star}}$ and $12 + \log(\text{O}/\text{H})$ for both galaxies
- ✓ A better correlation is shown for $\Sigma_{\text{dust}}/\Sigma_{\text{star}}$ and $\log(\text{N}/\text{O})$
- ✓ N/O behaves as a better tracer of dust than the oxygen abundance

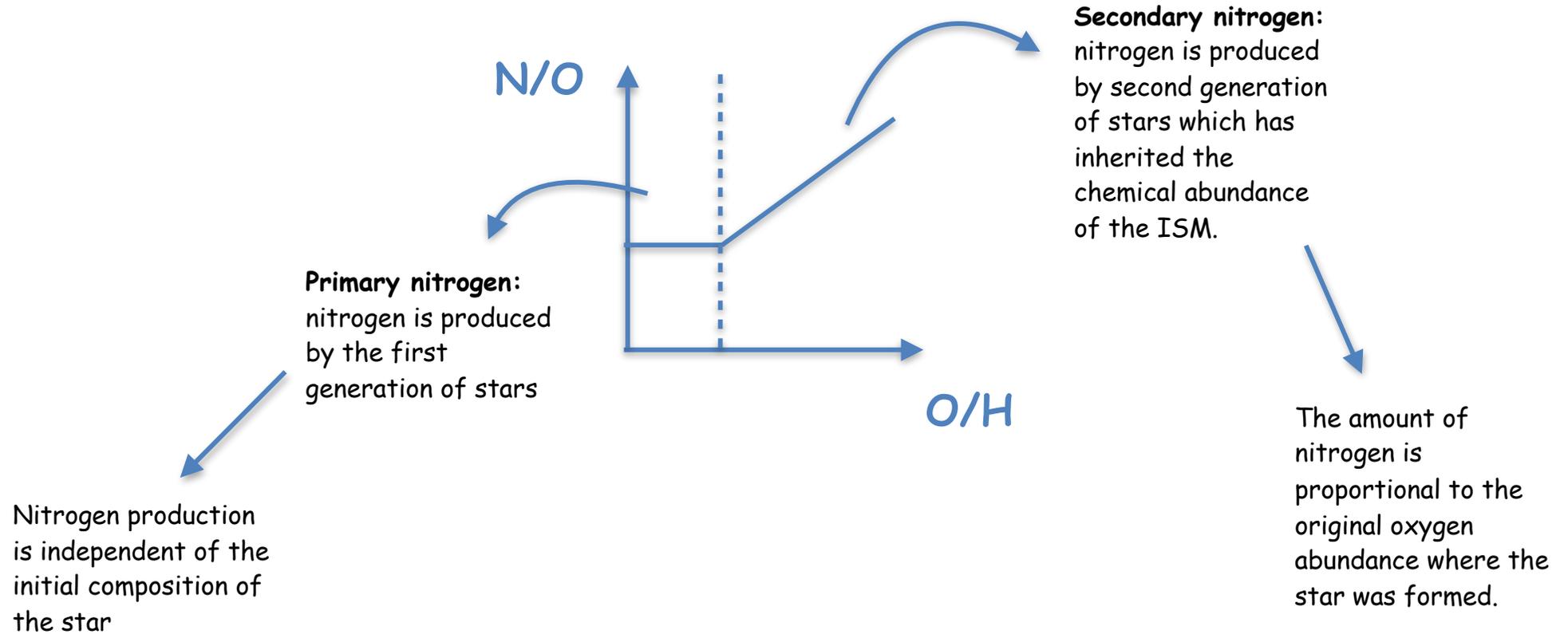
Conclusions

- We estimate the GDR across the discs of 3 galaxies covering a wide range in $12+\log(\text{O}/\text{H})$ and found consistent GDR values.
- Dispersion is significantly reduced in the GDR-Z relation when spatially resolved and direct abundance derivations are taken into account.
- GDR also correlates with N/O , a tracer of the presence of the AGBs in the galactic disc.
- GDR at high metallicity depends not only on Z but also on the molecular gas fraction.
- $\Sigma_{\text{dust}}/\Sigma_{\text{star}}$ is constant in the outer parts of M101, showing that dust has a stellar origin at these locations.



Thank you!

Nitrogen production



A simple scenario that does not take into account: 1) the mean lifetime of stars, 2) the star formation efficiency and SFH, and 3) the metallicity dependence of the stellar yields (e.g. Mollá et al. 2006, Henry et al. 2000).