Disentangling galaxy and dust evolution mechanisms through chemical abundance

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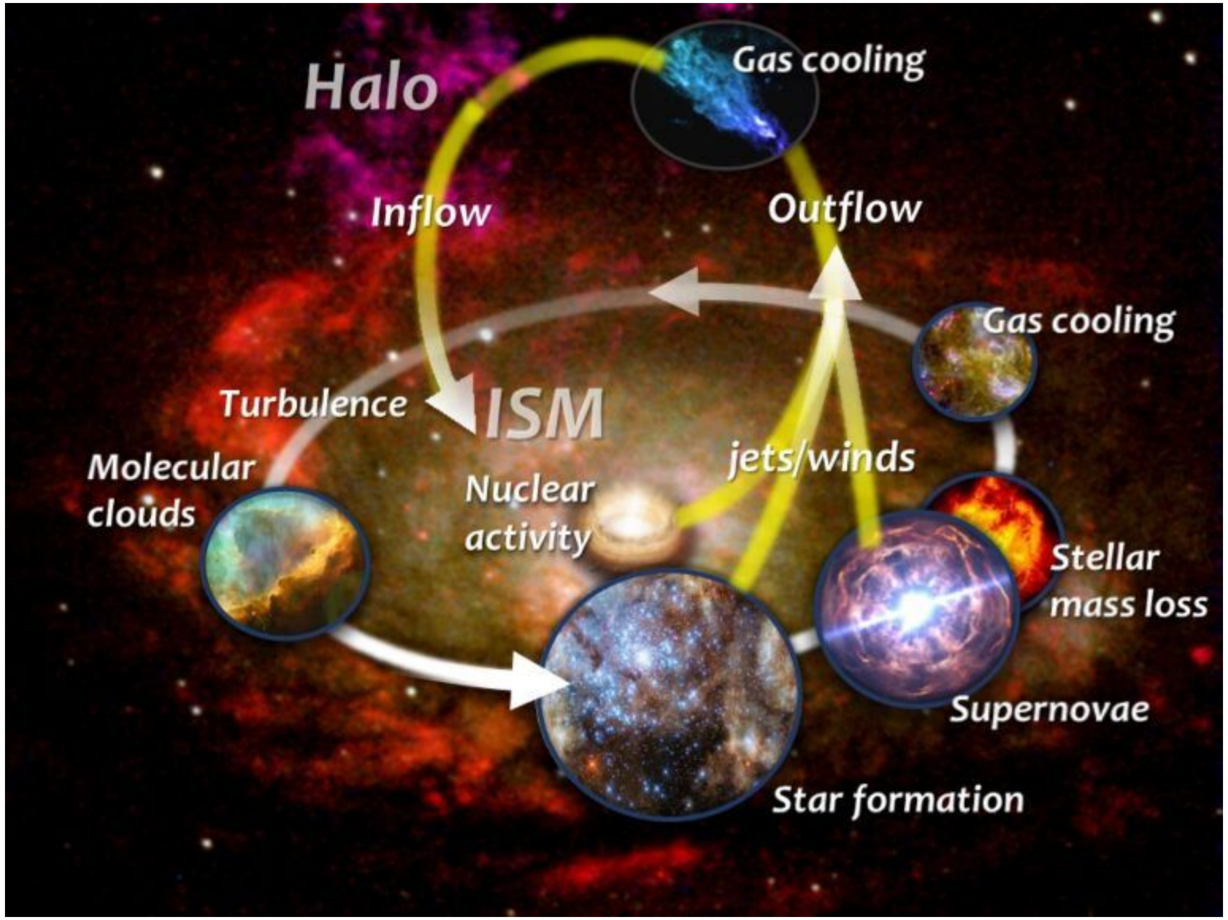
Chemical evolution

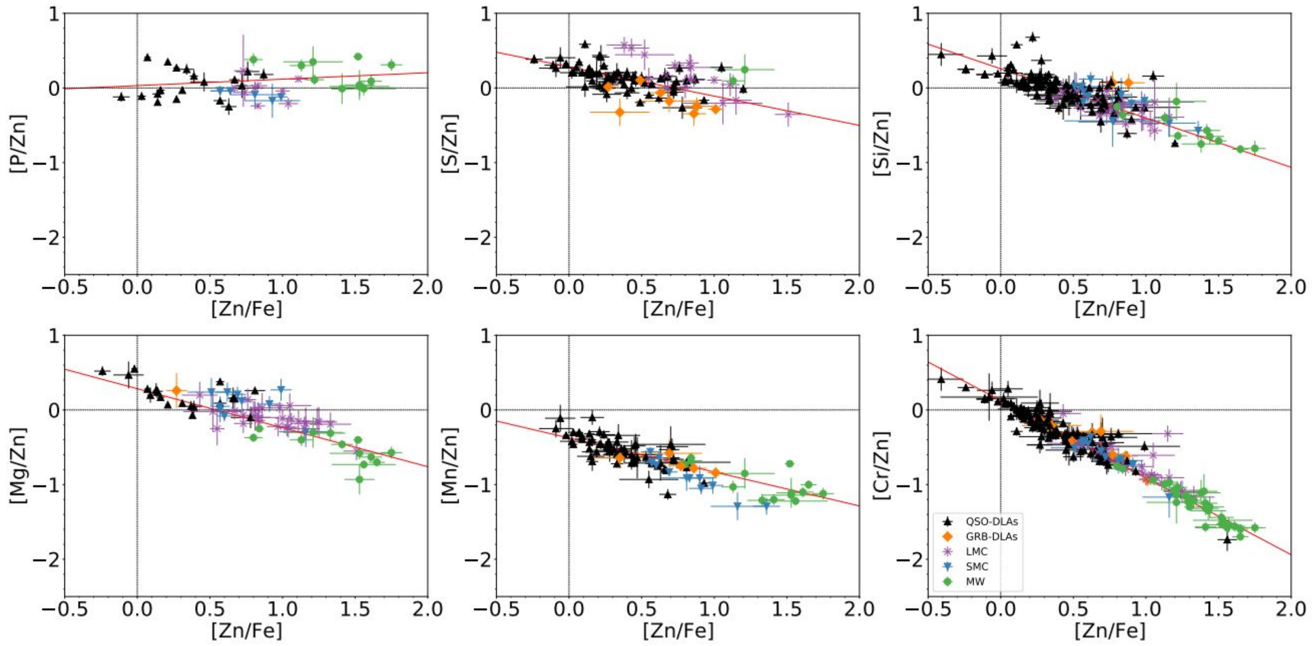
- Gas infall from IGM
- Gas gets converted to stars
- Stars reprocess gas to create heavier elements
- Stars die and let newly formed elements back into ISM
- Feedback processes can blow gas out of the disk
- **But where does dust play a role?**



Credits: Barbara Catinella

Why we should care

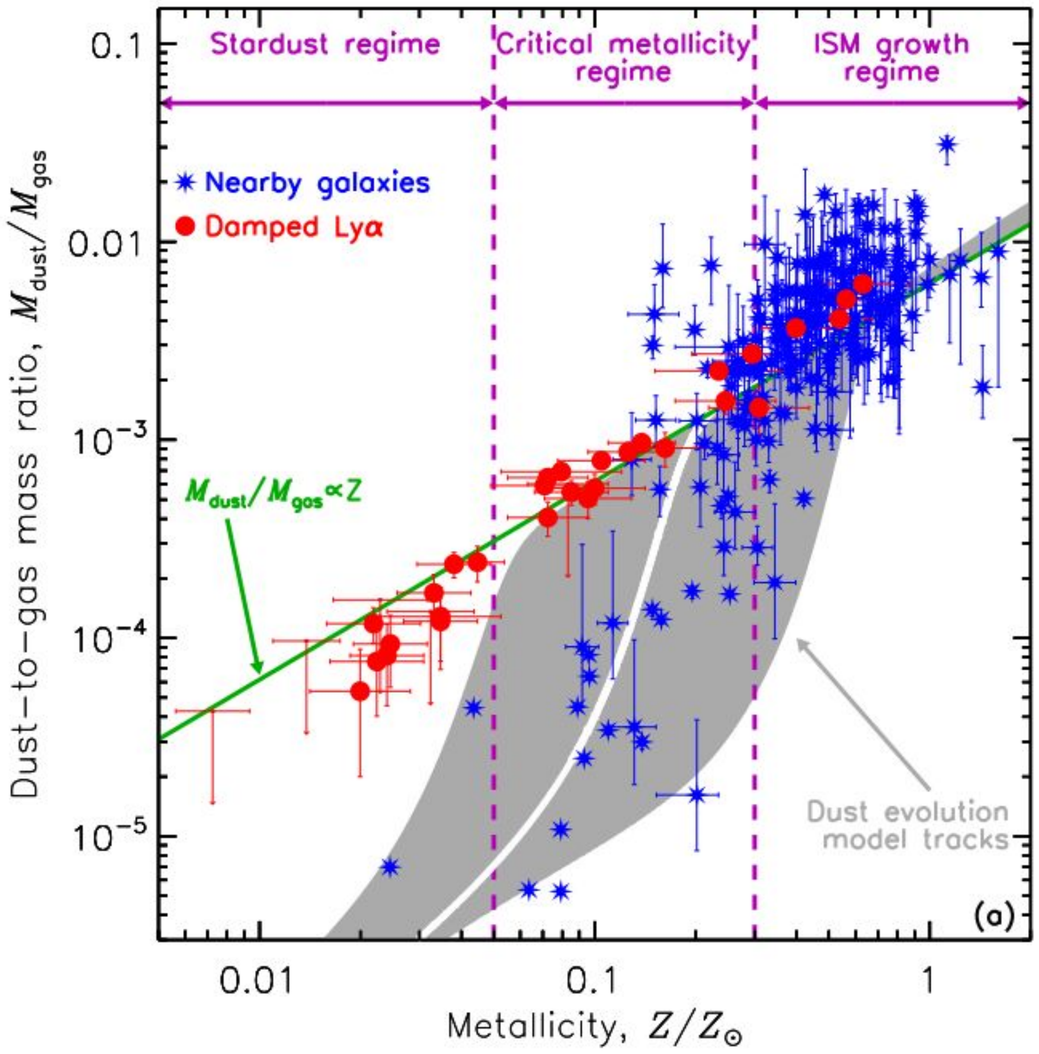
- Metals locked up into dust
    - During stellar production, AGB third dredge up, SNe, etc.
    - Dust accrete metals from the ISM
- Not all metals get locked up easily
    - Carbon grains: C
    - Silicate grains: O, Si, Mg, Fe
    - Not easily depleted: Zn
- Depletion depends on environment



Konstantopoulou et al. (2022)

Dust and metals: true partners in crime

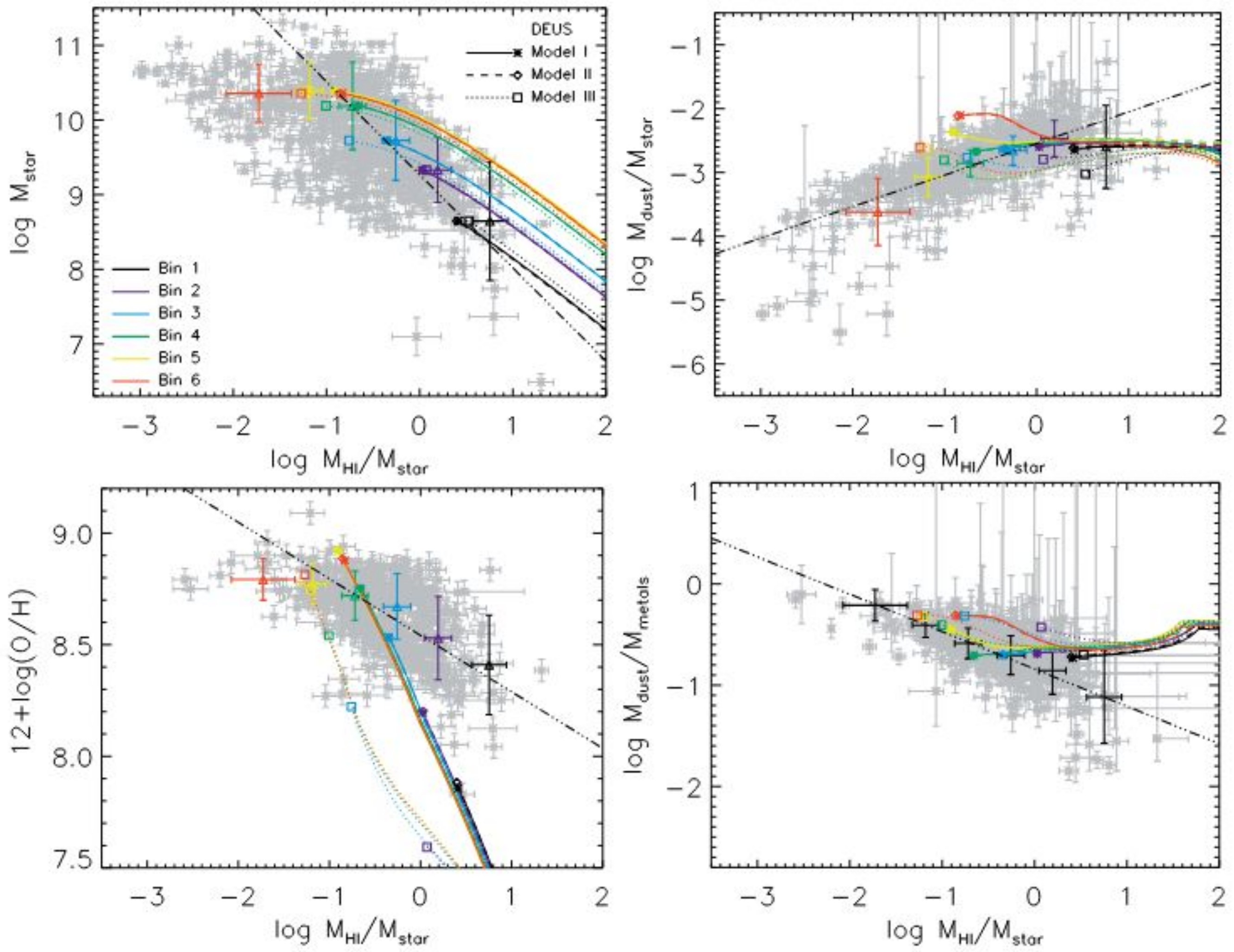
- DGR ratio varies strongly with metallicity
  - DGR ∝ Z above $0.3Z_{\odot}$
- DGR steeply decreases for nearby galaxies
  - Stellar dust vs dust accretion?



Galliano et al. (2018)

Dust and metals: true partners in crime

- Chemical evolution models link stellar evolution with metal evolution
- Constrained dust evolution parameters differ per study
  - Accretion dominated
    (Feldman et al. 2015, Zhukovska et al. 2016, De Vis et al. 2019, Galliano et al. 2021)
  - Stardust dominated
    (De Vis et al. 2017, De Looze et al. 2020, Nanni et al. 2020)



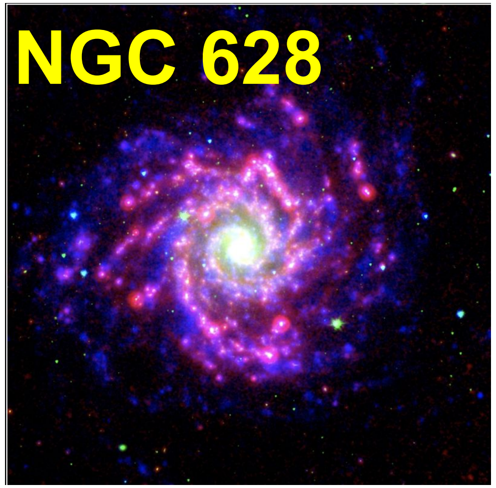
De Looze et al. (2020)

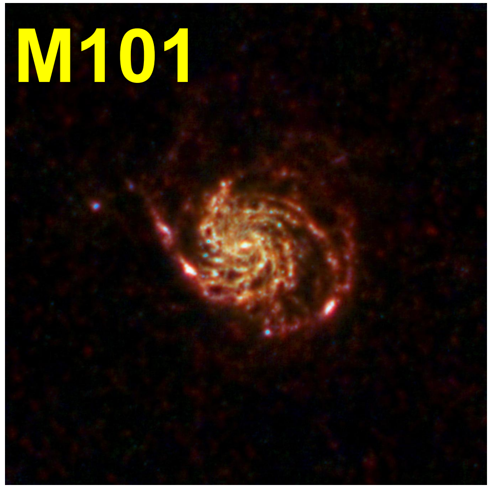
Problems

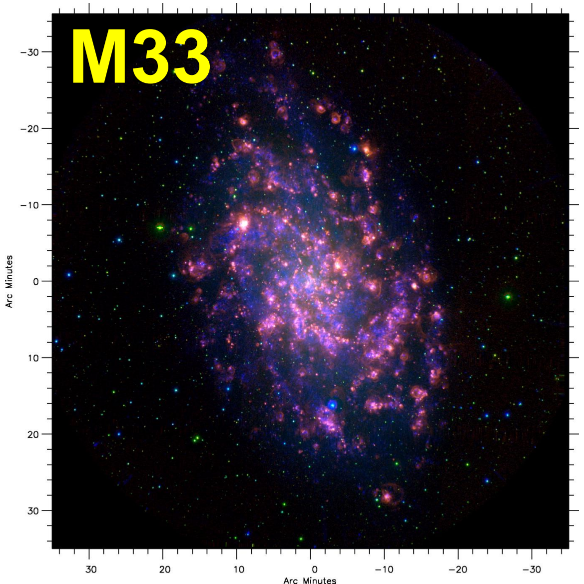
- Current studies only focus on global properties
- Degeneracy in chemical evolution parameters for the same galaxies
    - Including degeneracy in dust-evolution

Spatially resolved observations

- NGC628 and M101, M33, and NGC300
  - Well-studied by e.g., Vílchez et al. (2019), Relaño et al. (2020), Chiang et al. (2021)







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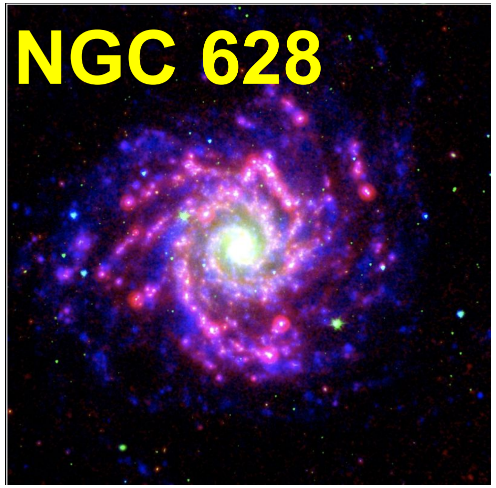
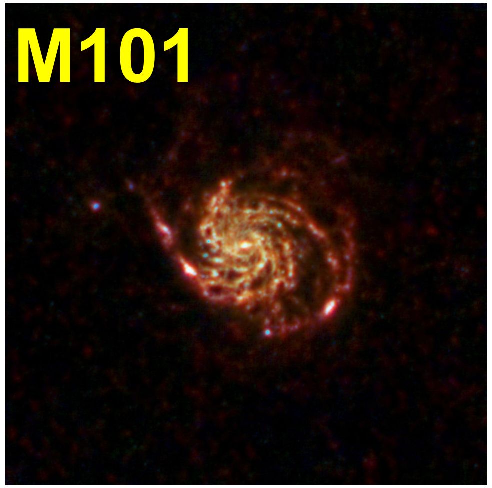
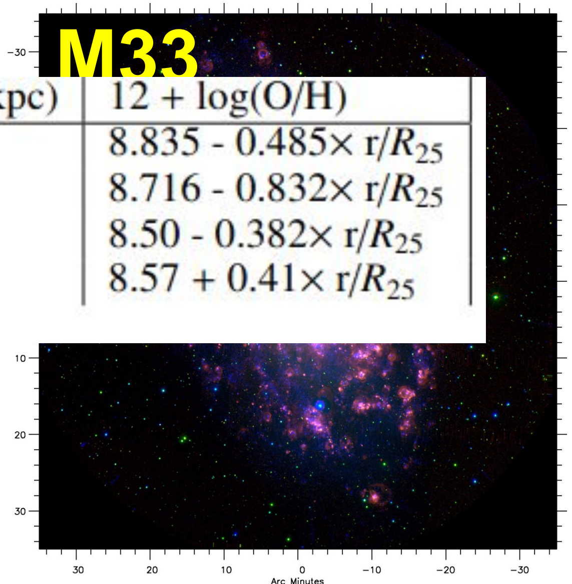
- Difference in oxygen abundance slope







NGC reference	Messier reference	Morphology type	R25(kpc)	12 + log(O/H)
NGC0628	M74	SA(s)c	14.9	8.835 - 0.485× r/R_{25}
NGC5457	M101	SAB(rs)cd	31	8.716 - 0.832× r/R_{25}
NGC0598	M33	SA(s)cd	6.85	8.50 - 0.382× r/R_{25}
NGC0300	-	SA(s)d	5.33	8.57 + 0.41× r/R_{25}

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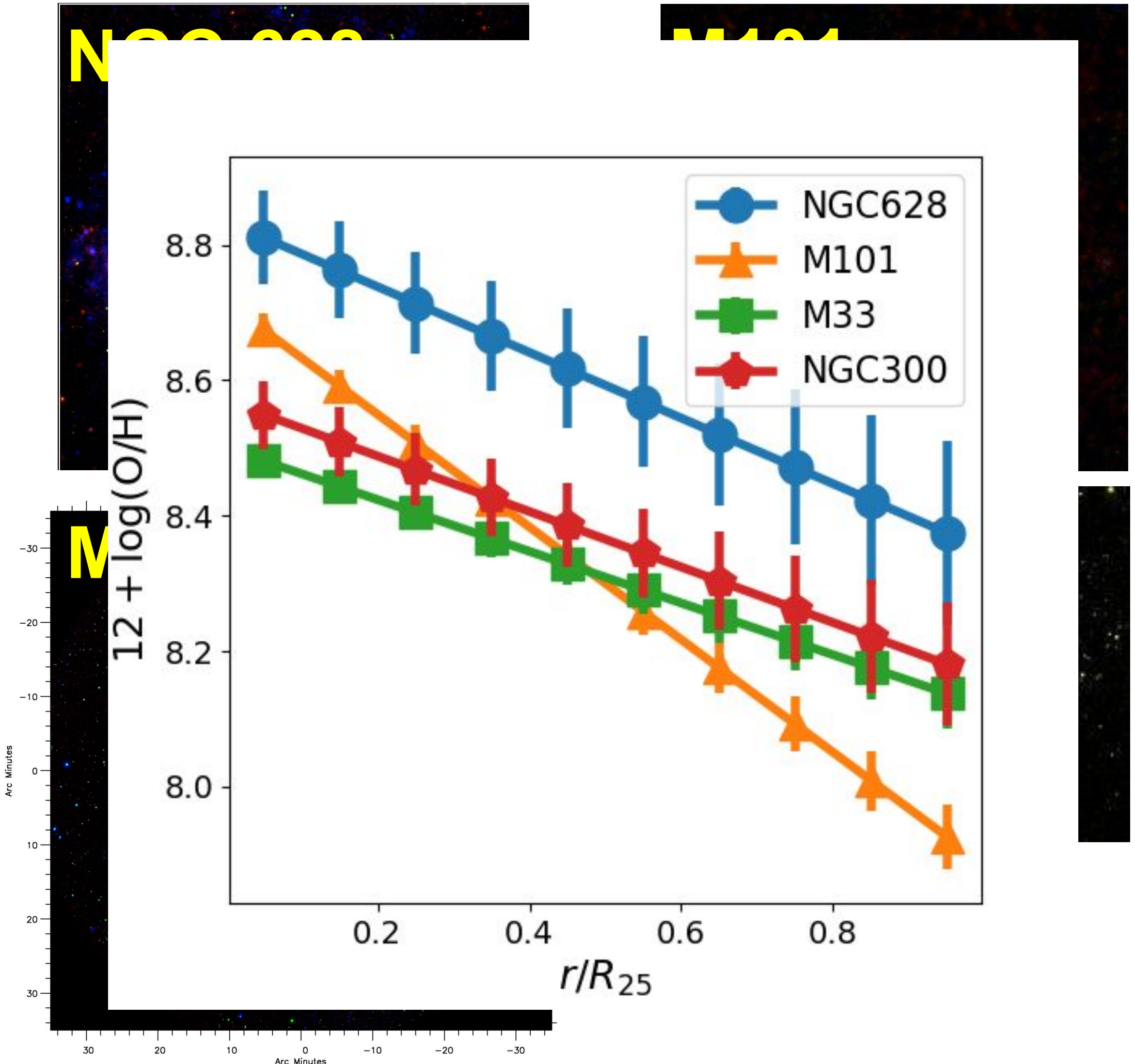

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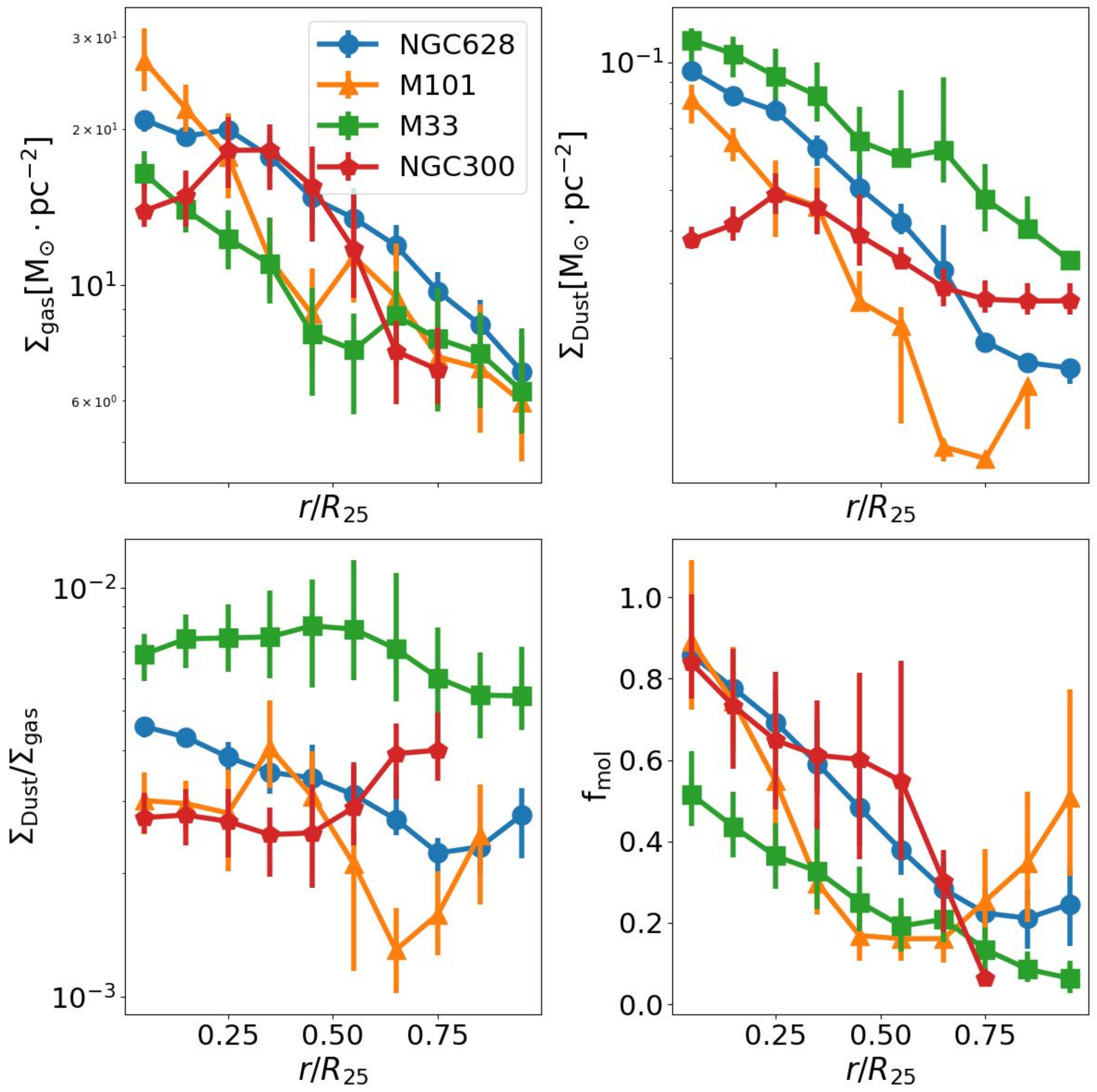
- Difference in oxygen abundance slope
- Different trends in DGR



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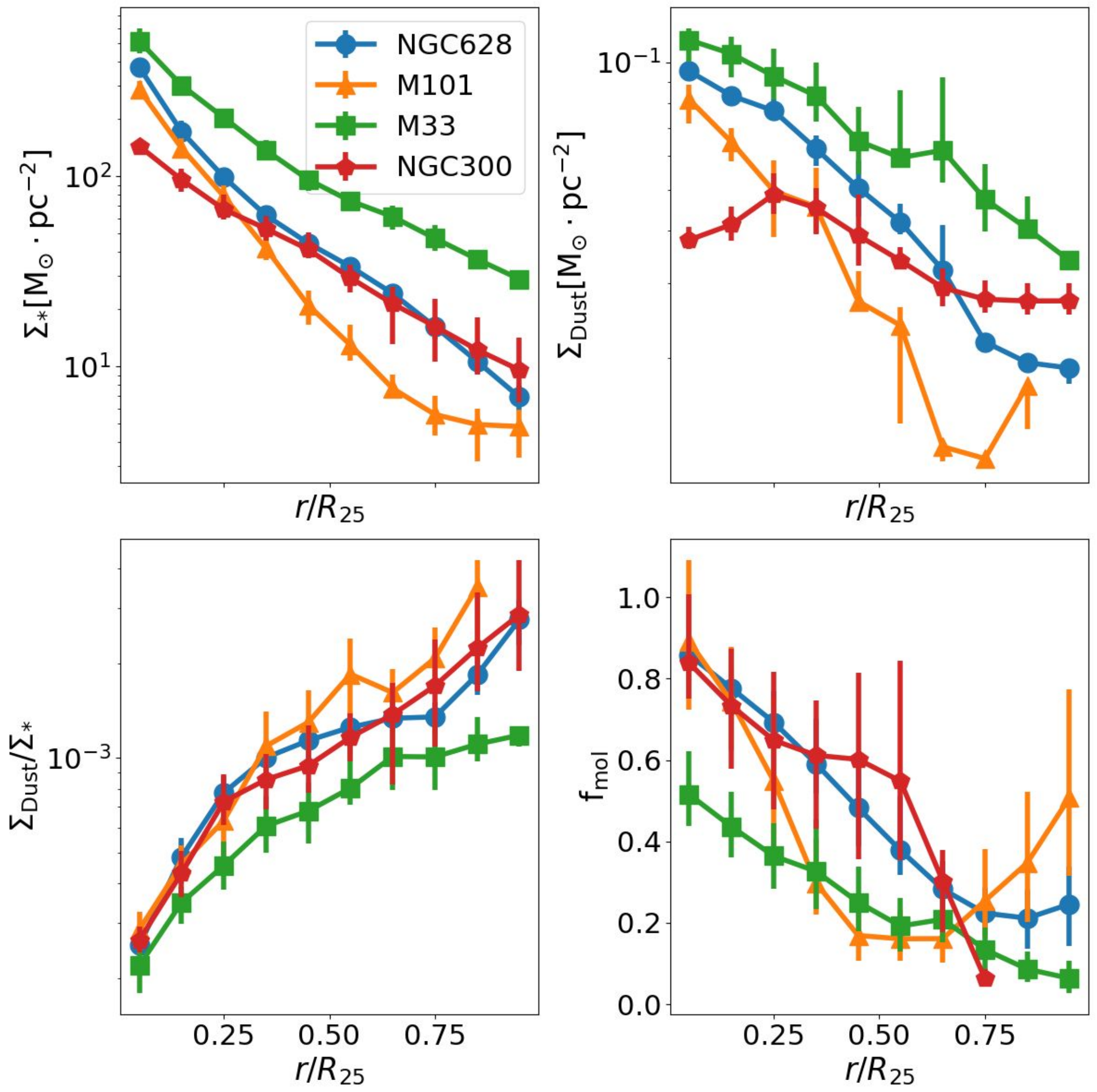
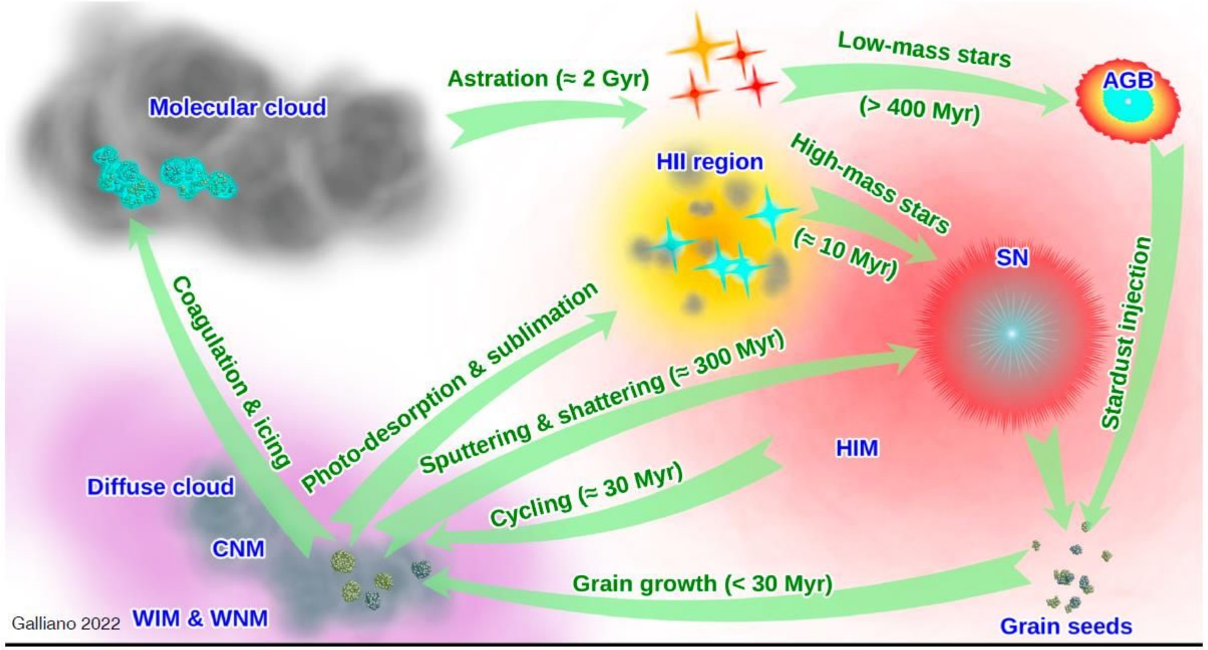
- Difference in oxygen abundance slope
- Different trends in DGR
- DSR suggest increase in dust build-up efficiency with radius



Updated chemical evolution model CHEMEVOL (De Vis et al. 2017, 2021)

- Exponential declining gas inflow rate
- SFH: Schmidt-Kennicutt relation
- Element production using chemical evolution matrix
- Dust evolution mechanisms
  - AGB and SN production
  - Astration and SN destruction
  - Grain growth



Dust, gas, stars and metals are intimately related across the life cycle of the dust

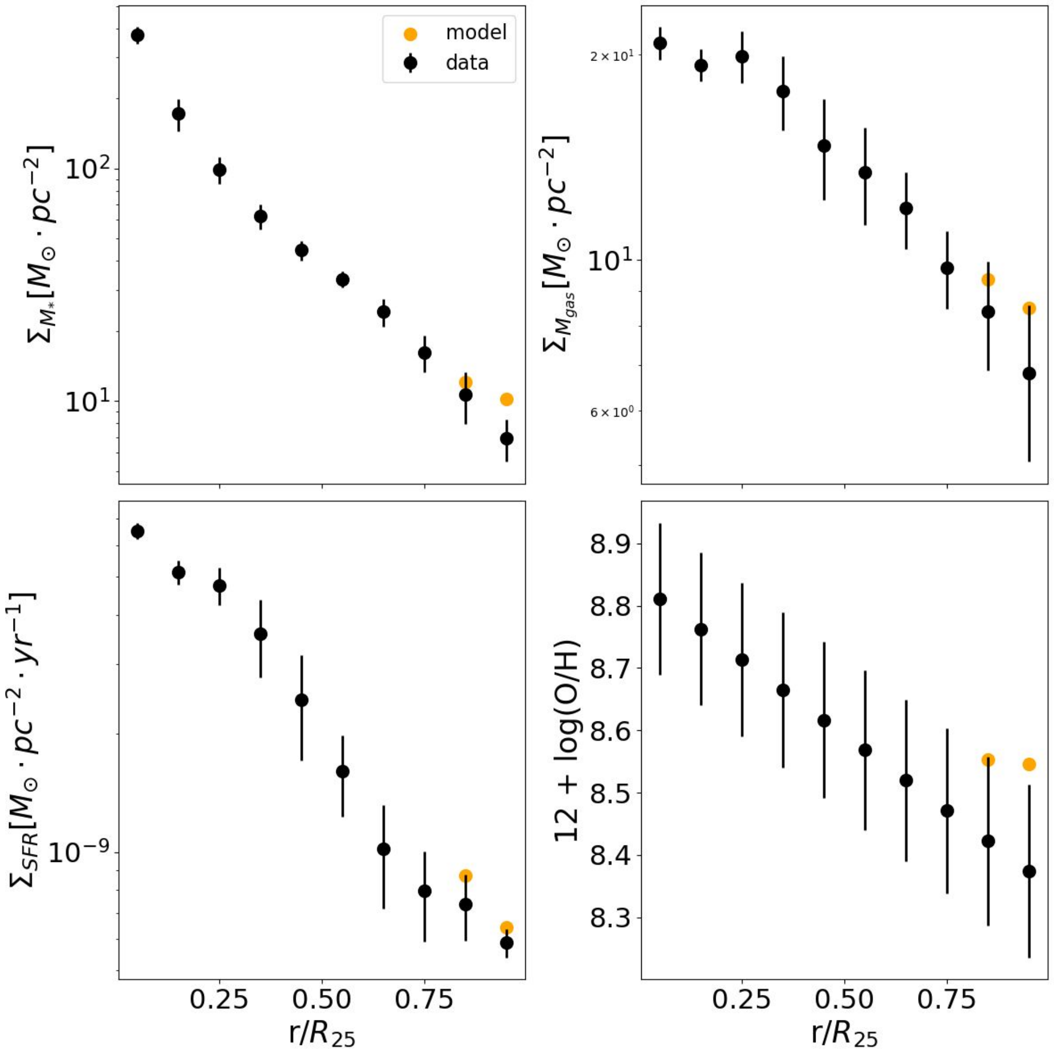
Fitting chemical evolution models

- Fit performed using Nested sampling with DYNESTY (Speagle et al. 2006)
- Constraints for the first run
  - Σ_{gas}
  - Σ_*
  - Σ_{SFR}
  - 12+log(O/H)
- Free parameters
  - Star-formation efficiency ε_{SFR}
  - Gas infall time scale $\tau_{gas,inf}$
  - Initial gas mass infall rate $\Sigma_{gas,inf}(0)$
  - Mass loading factor ν_{out}

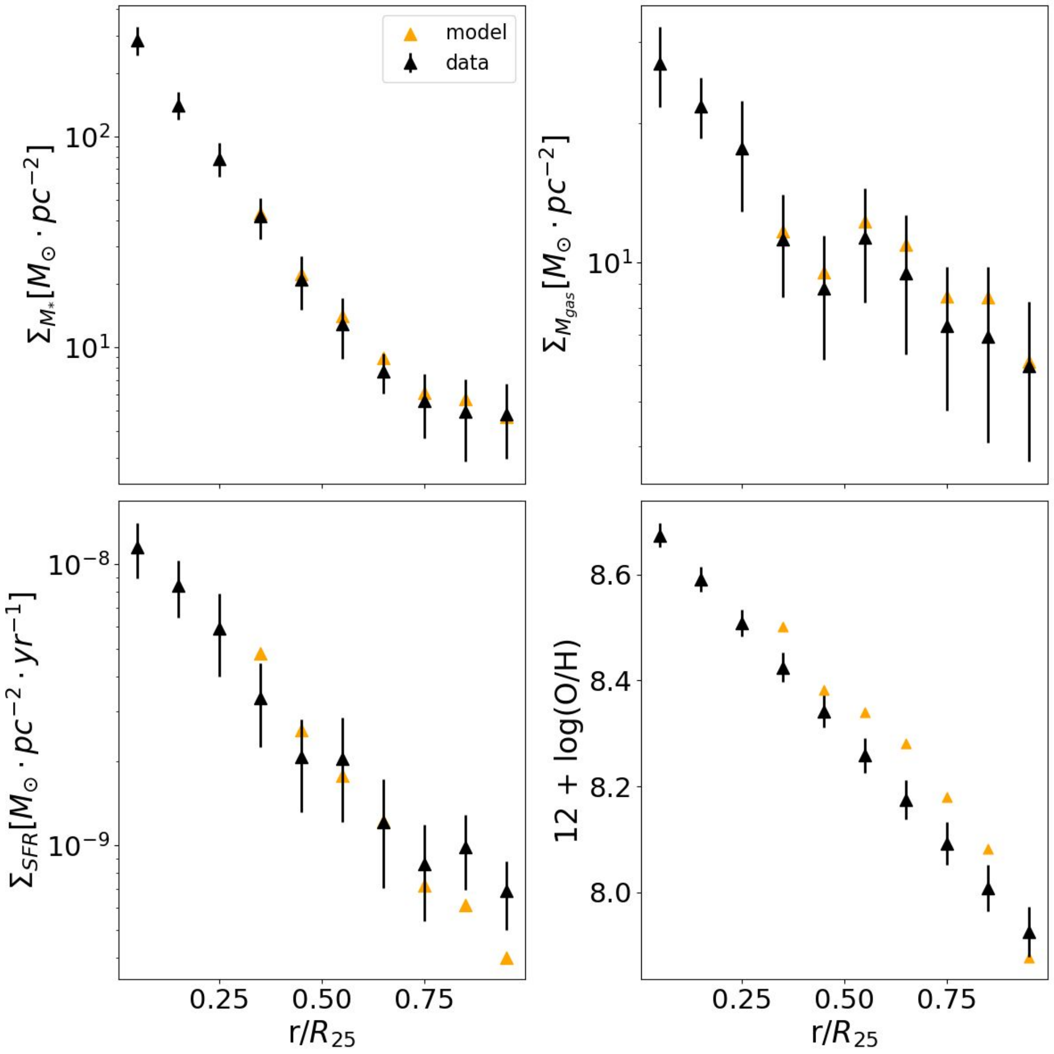
- Constraints for the second run
  - Σ_{gas}
  - Σ_*
  - Σ_{SFR}
  - Σ_{Dust}
  - 12+log(O/H)
- Free parameters
  - Narrow priors from based on the first run
    - Star-formation efficiency ε_{SFR}
    - Gas infall time scale $\tau_{gas,inf}$
    - Initial gas mass infall rate $\Sigma_{gas,inf}(0)$
    - Mass loading factor ν_{out}
  - Dust accretion efficiency e_{accr}
  - Gas mass swept by supernova $M_{gas, SN}$

Fit constraints

NGC628



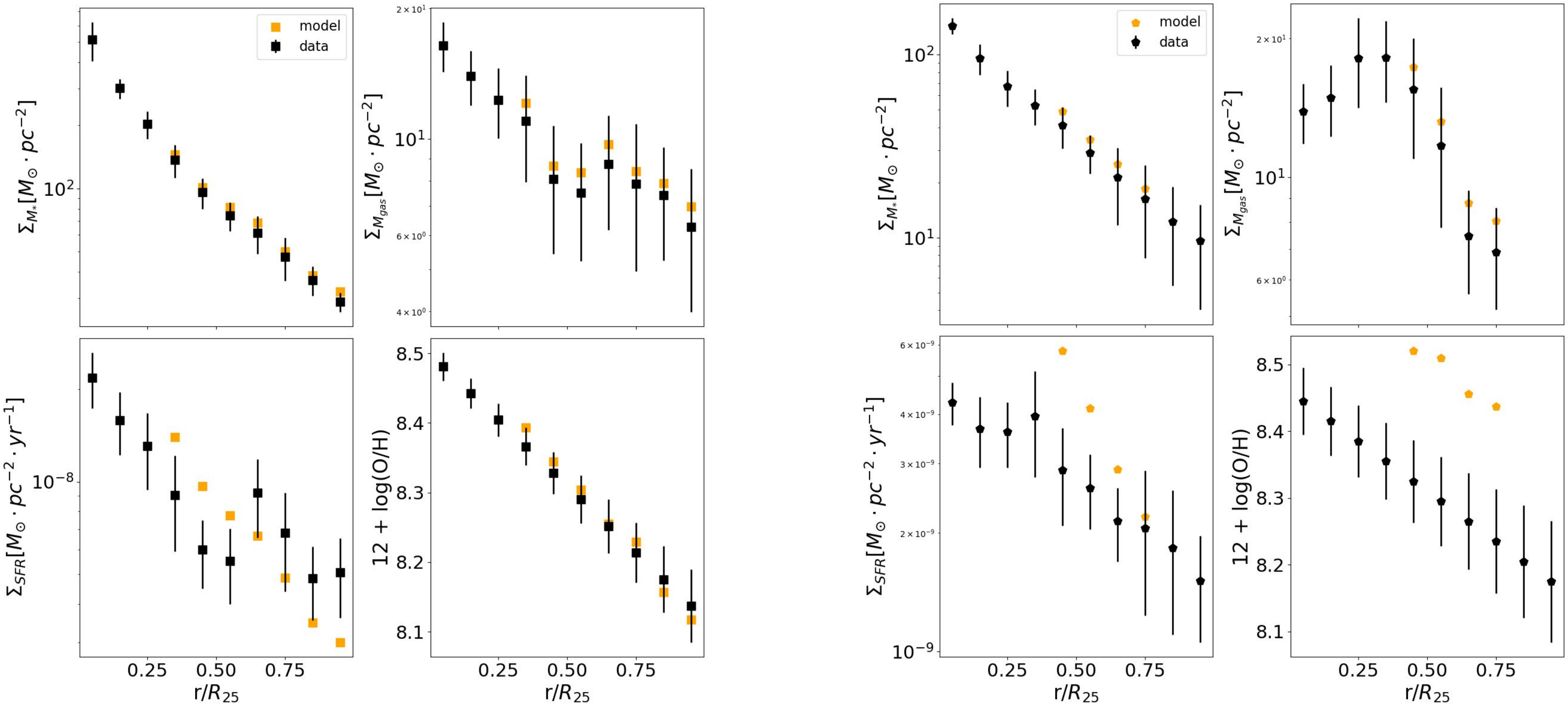
M101



Fit constraints

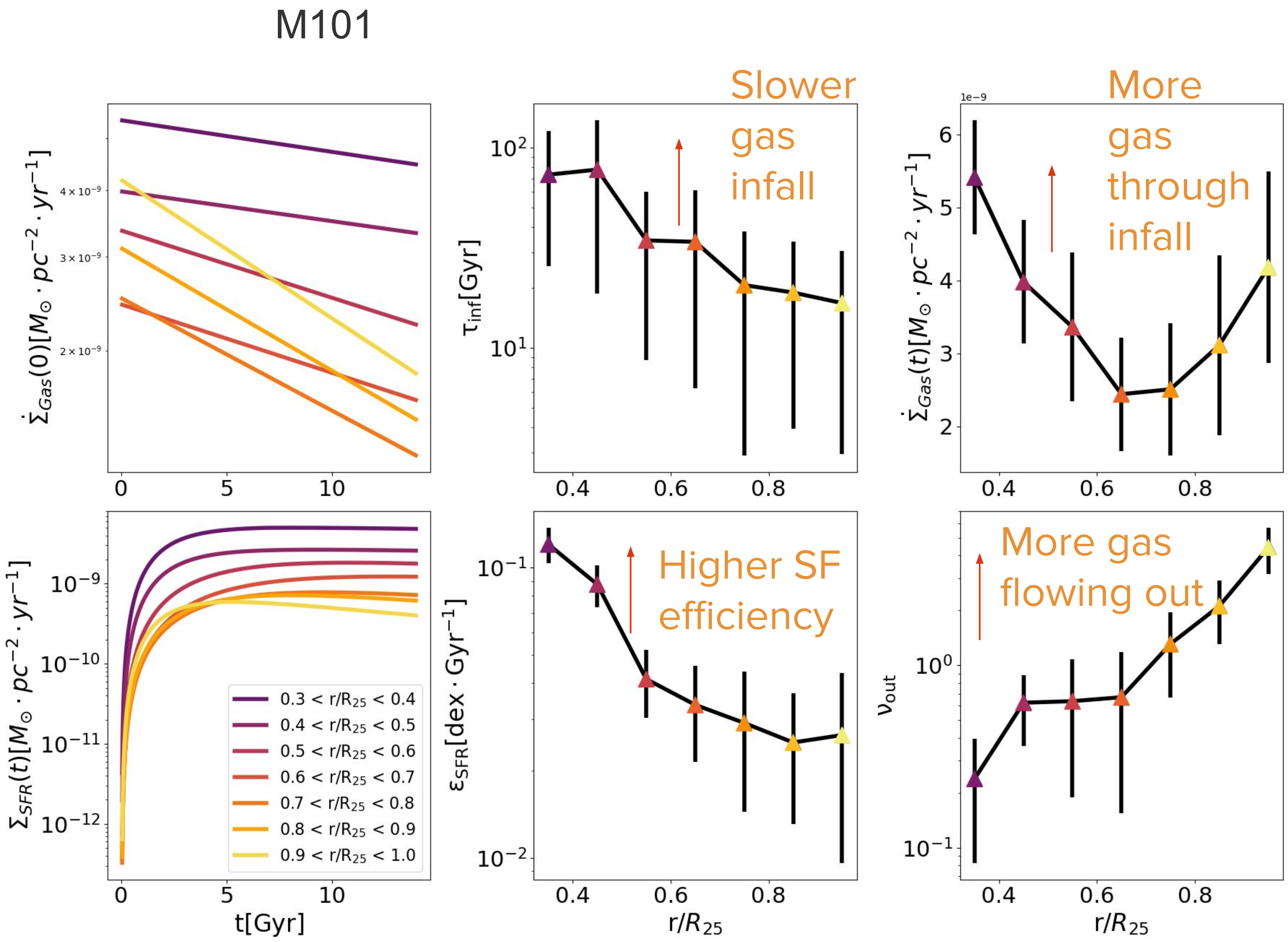
M33

NGC300



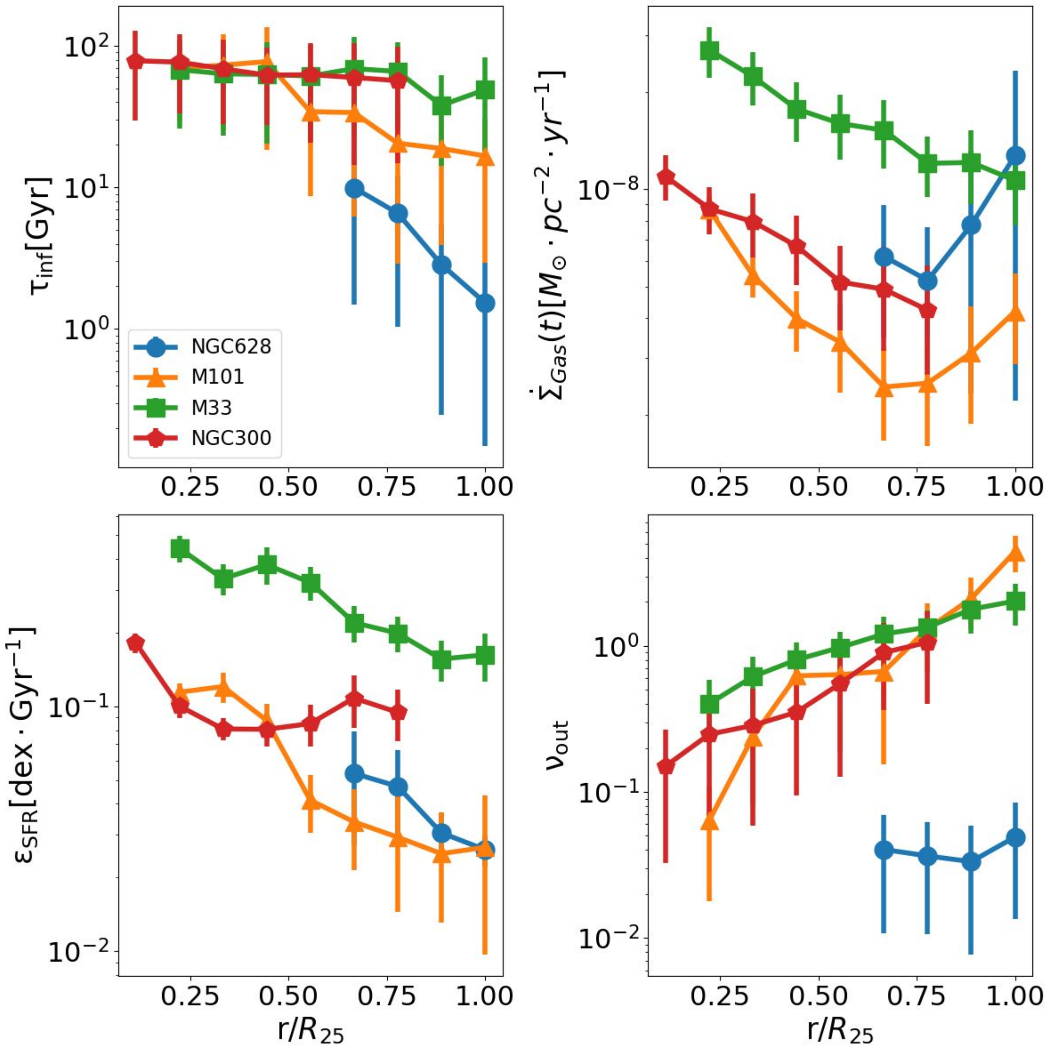
Fit results

- Gradual buildup of stars
- Star-formation efficiency & infall time-scale decreases with radius, mass-loading factor increases



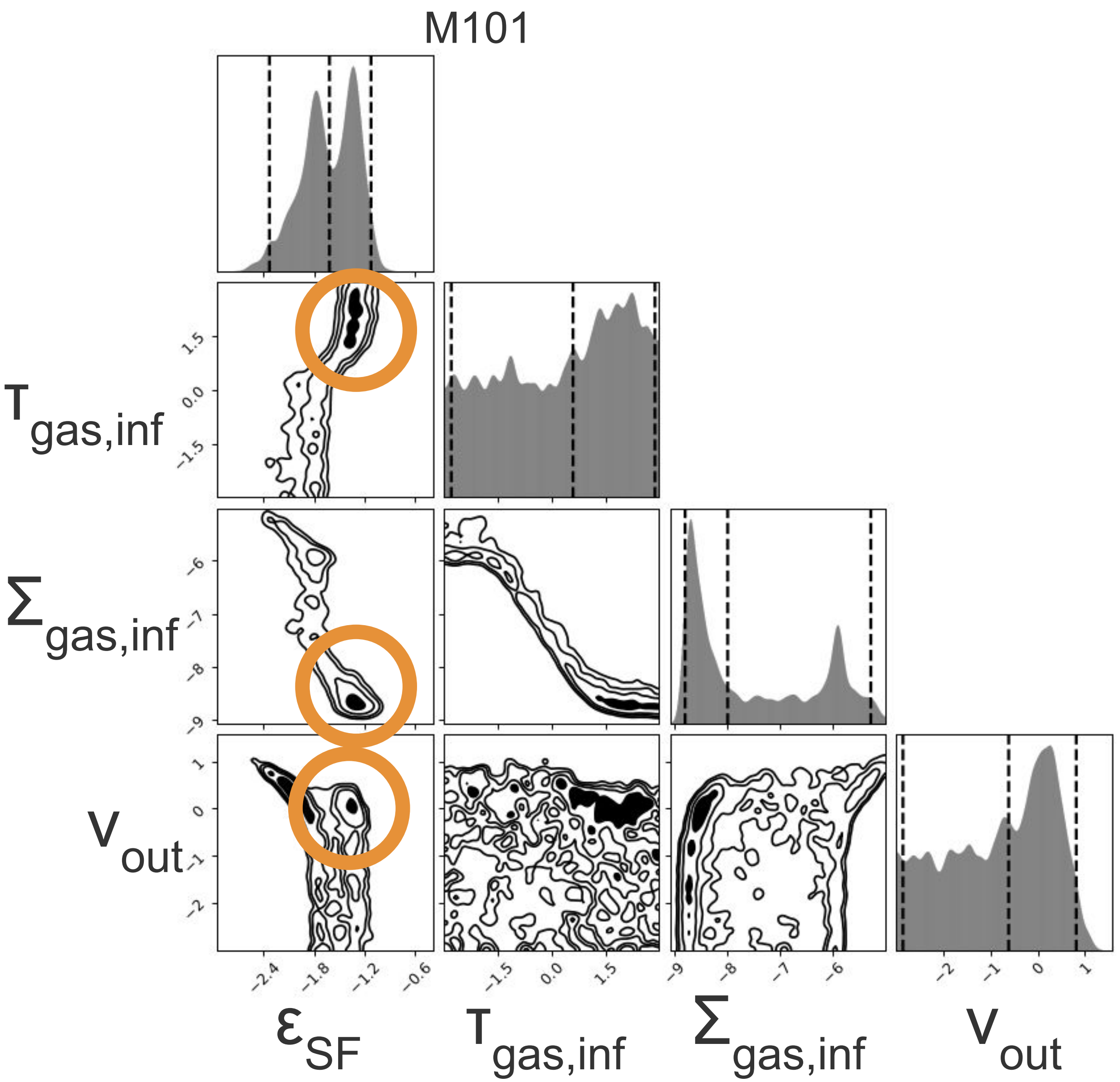
Fit results

- Gradual buildup of stars
- Star-formation efficiency & gas infall time-scale decreases with radius, mass-loading factor increases
- M33 & NGC300 show a slower decrease in star-formation efficiency
- Mass-loading factor is consistent for all galaxies



Fit results

- NGC628 and M101 show two best solutions
  - Slow buildup of stars
  - Early starburst
- Slow build-up matches all quantities
- Early starburst matches oxygen abundance closer to data point, but results in lower SFR
- M33 and NGC300 only show slow buildup SFH



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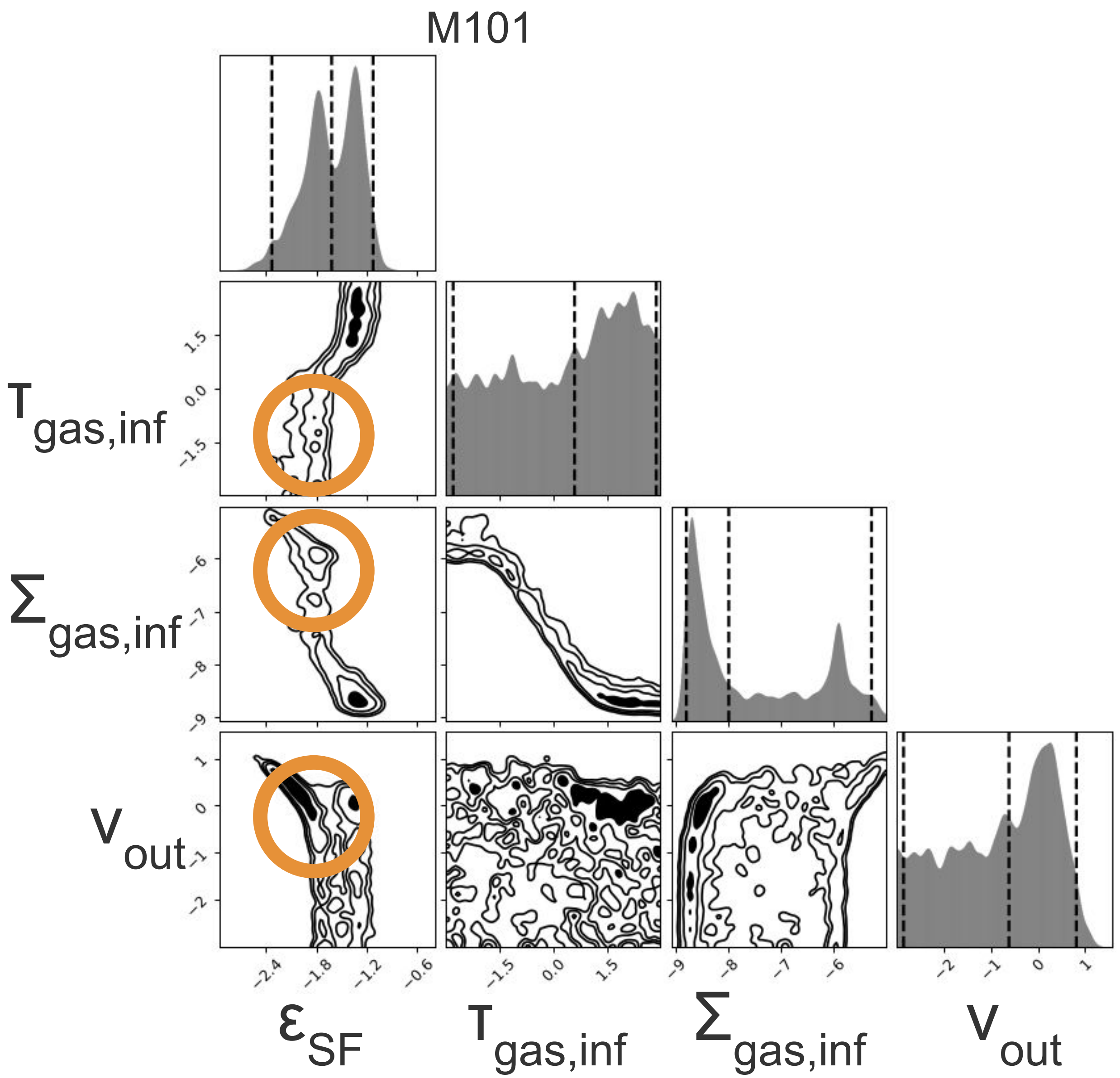
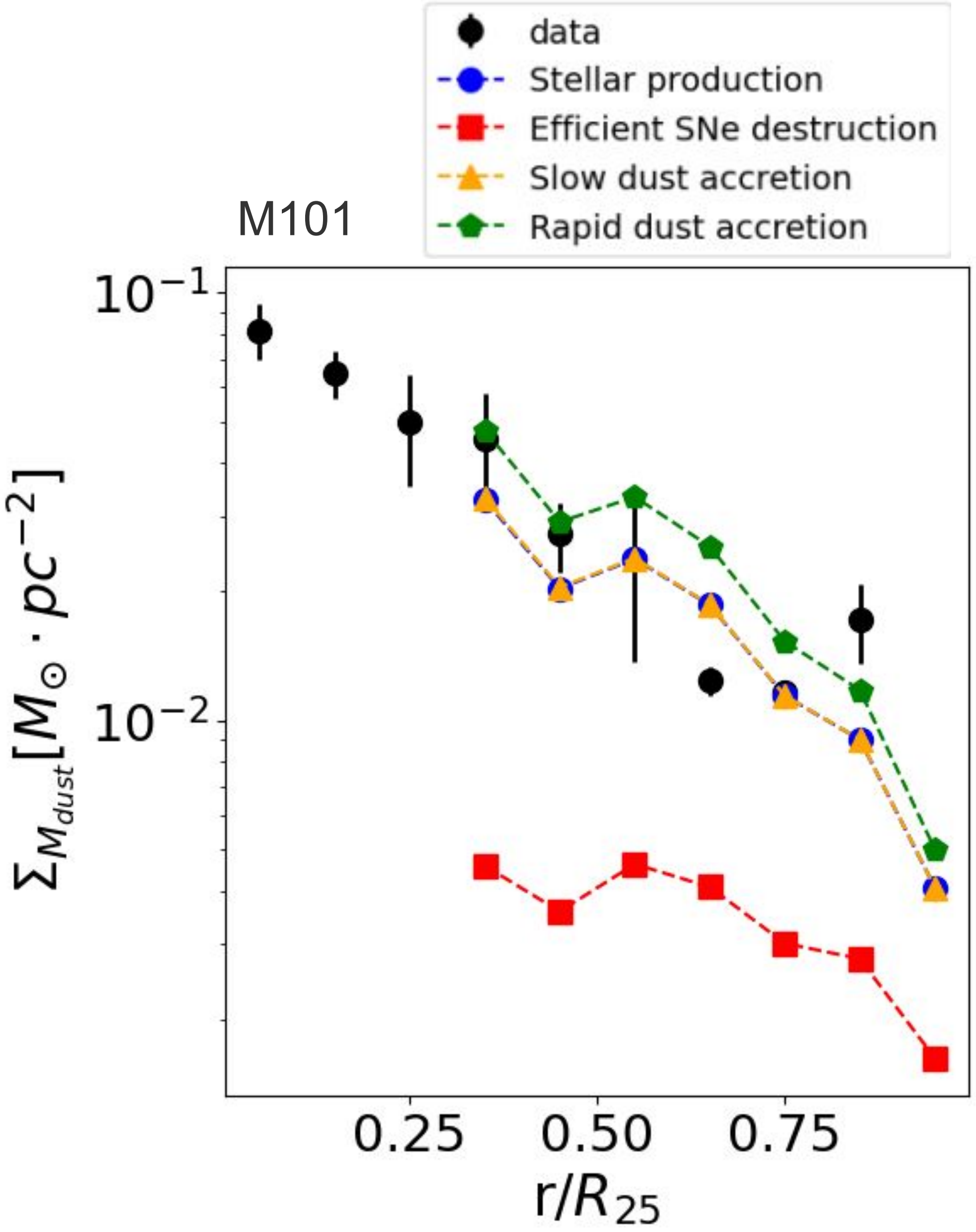


Dust evolution

- Comparing with four different model tracks
  - ○ $e_{accr} = 0$; $M_{gas, SNe} = 10$
  - □ $e_{accr} = 0$; $M_{gas, SNe} = 10^4$
  - △ $e_{accr} = 10^2$ ($\tau_{accr} \sim 10$Gyr); $M_{gas, SNe} = 10$
  - ⬠ $e_{accr} = 10^5$ ($\tau_{accr} \sim 10$Myr); $M_{gas, SNe} = 10$
- Results imply stellar production would be enough
  - Short accretion time scales might explain high values in the outskirts
  - Limit in dust reached as metals run out (van der Giessen et al. 2024)
- More efficient dust formation/less efficient dust destruction at larger radii



Conclusion

- SFH shows inside-out growth evolution.
- Star-formation efficiency and gas-infall time scale decreases with radius.
- Mass-loading factor shows consistent trends (increase with radius) for all three galaxies.
- Dust masses imply stellar production is enough, but short accretion time scales might solve the higher dust masses.
- Chemical evolution models help in not only constraining galaxy evolution, but also dust formation and evolution.

Chemical evolution model CHEMEVOL (De Vis et al. 2017, 2021)

- Exponential declining gas inflow rate
  - Free parameter: gas infall time scale $\tau_{gas,inf}$, initial gas mass infall rate $\Sigma_{gas,inf}$
- SFH: Schmidt-Kennicutt relation
  - IMF: Kroupa (2001)
  - Free parameters: star-formation efficiency ε_{SFR}, mass loading factor ν_{out}
- Element production using chemical evolution matrix **(UPDATED)**
  - SNe: Limongi & Chieffi (2018) R150
  - AGB: Ventura et al. (2013)
- Dust evolution
  - Production: Todini & Ferrara (2001)
  - Destruction: Astration, SNe destruction (Dwek et al. 2007)
  - Grain growth: Mattson & Andersen (2012)
  - Free parameters: amount of gas swept per SN $M_{gas, SNe}$, dust accretion efficiency e_{accr}

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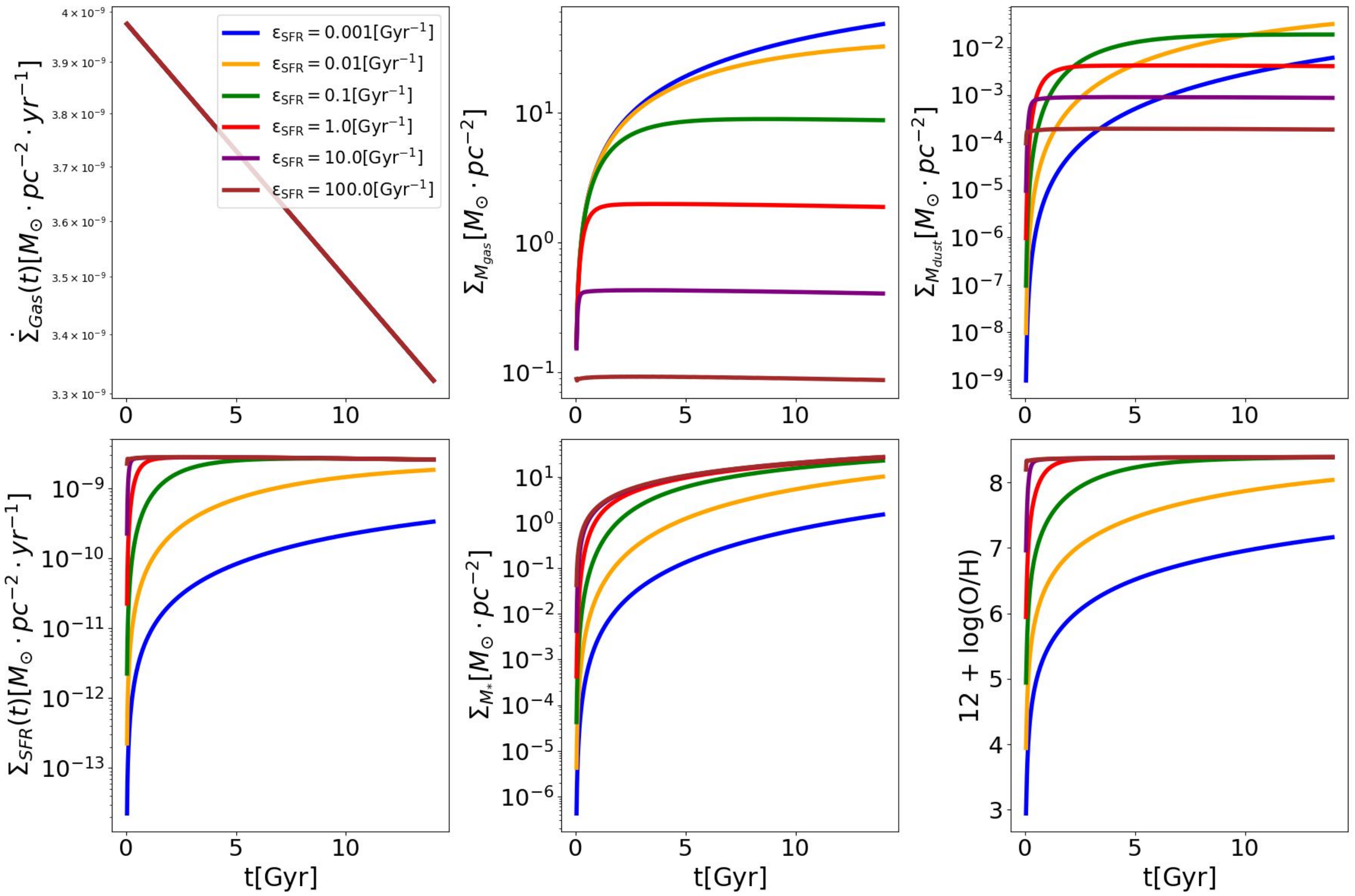

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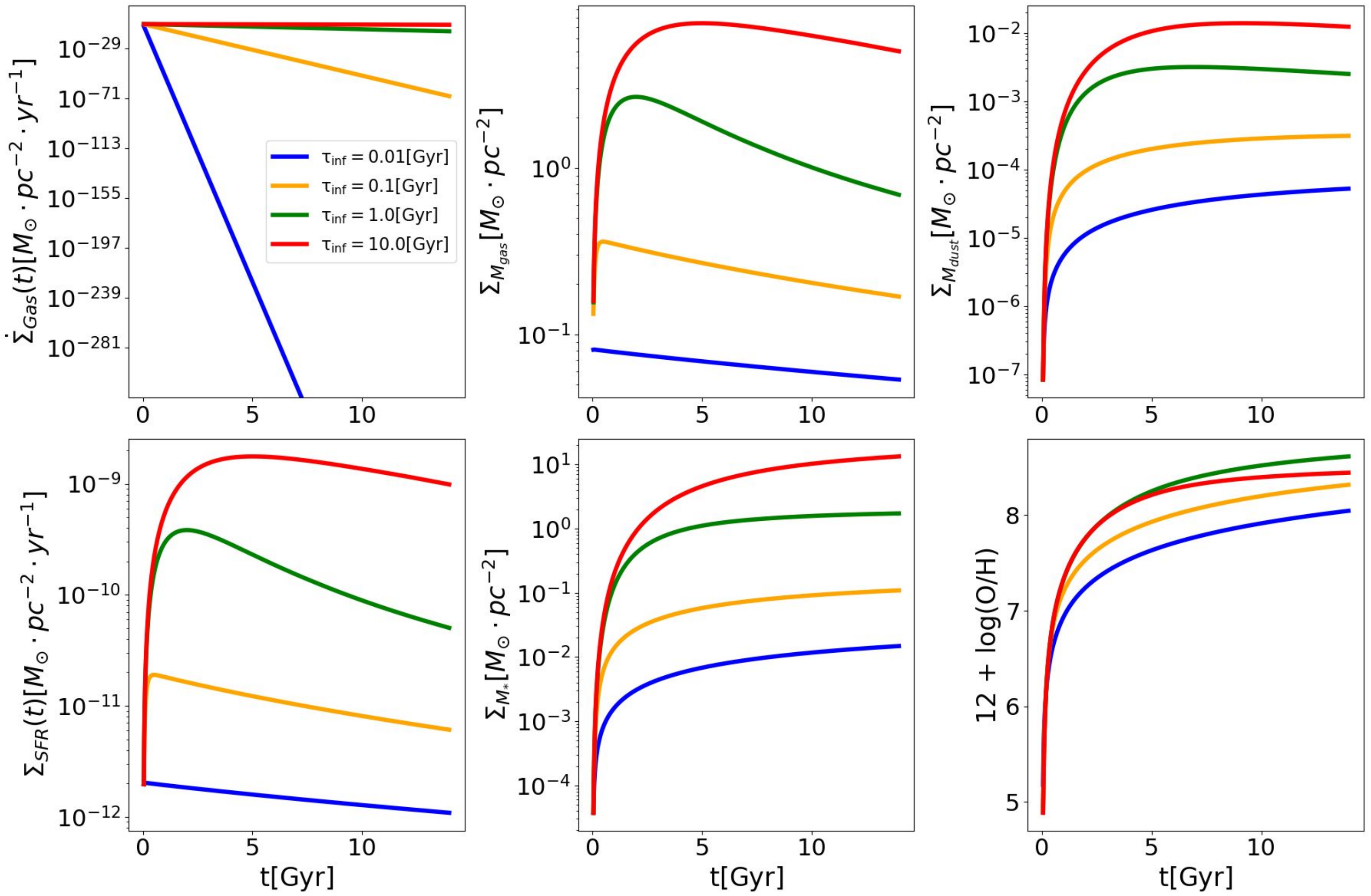

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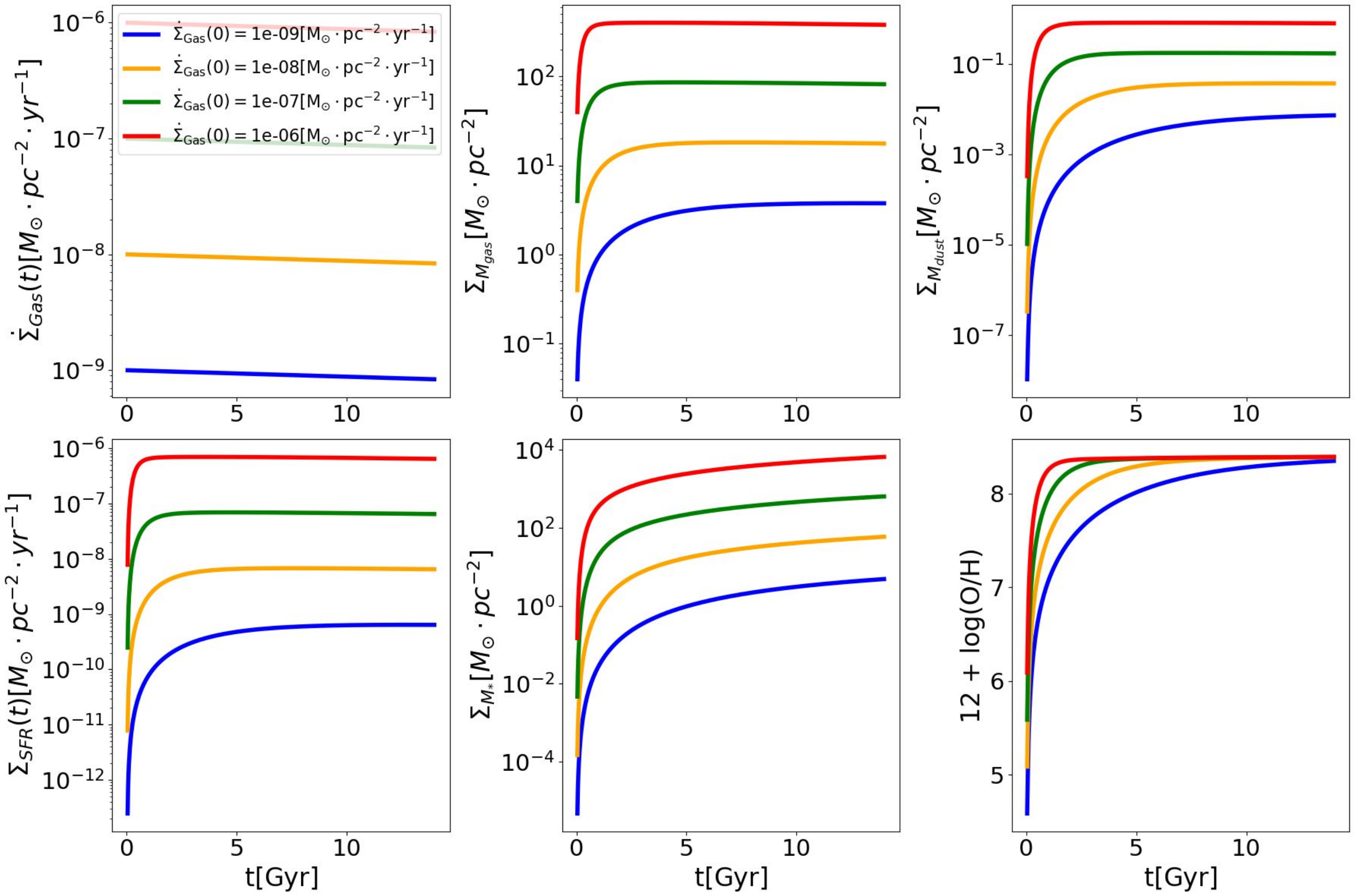

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