# The multi-phase ISM shaped by the baryon cycle in nearby galaxies


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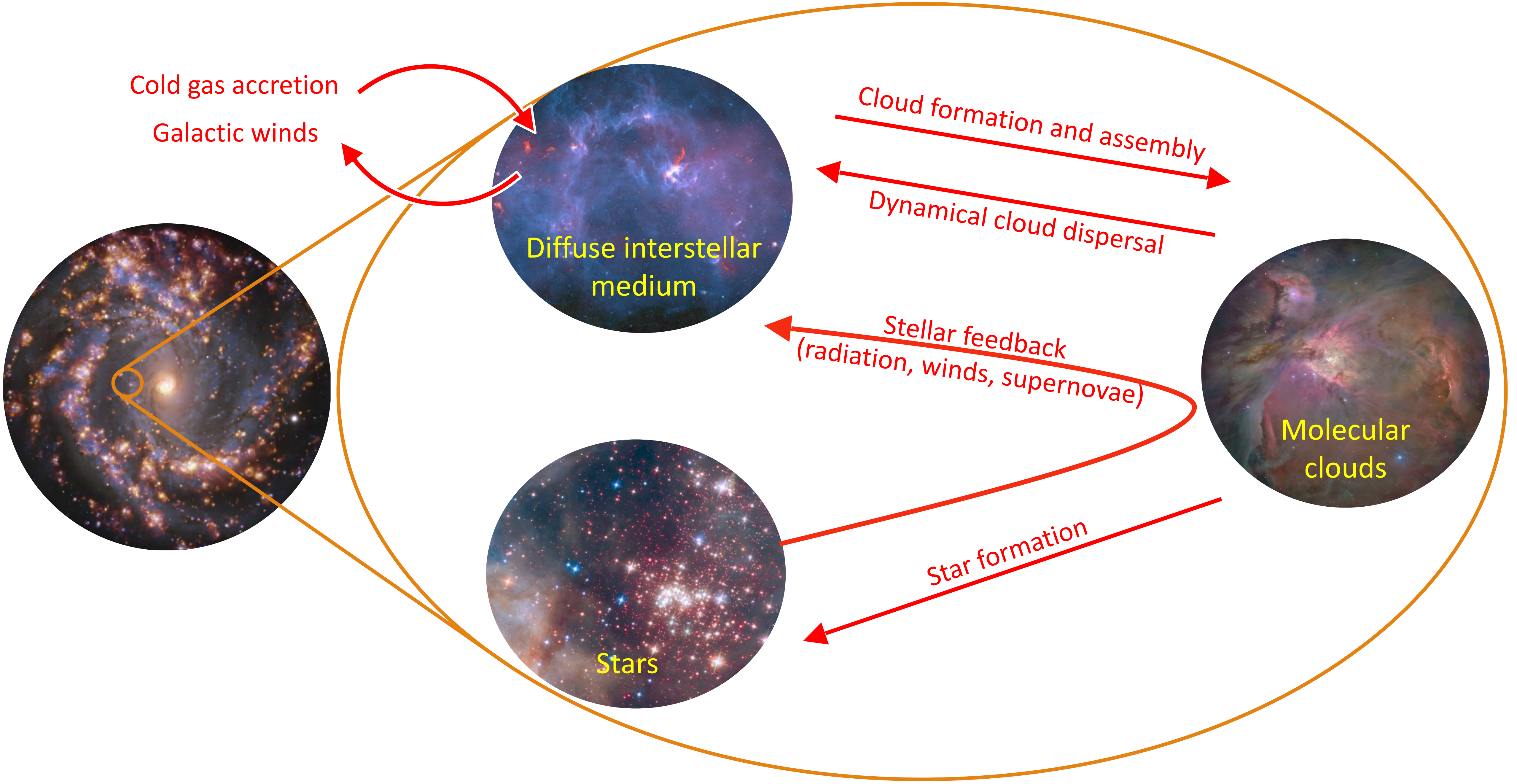
Emmy Noether-Programm

DFG Deutsche Forschungsgemeinschaft

*Future Role of FIR-Submm Space Observations — April 3th 2025*


Cold gas accretion
Galactic winds
Diffuse interstellar medium
Cloud formation and assembly
Dynamical cloud dispersal
Stellar feedback
(radiation, winds, supernovae)
Molecular clouds
Star formation
Stars

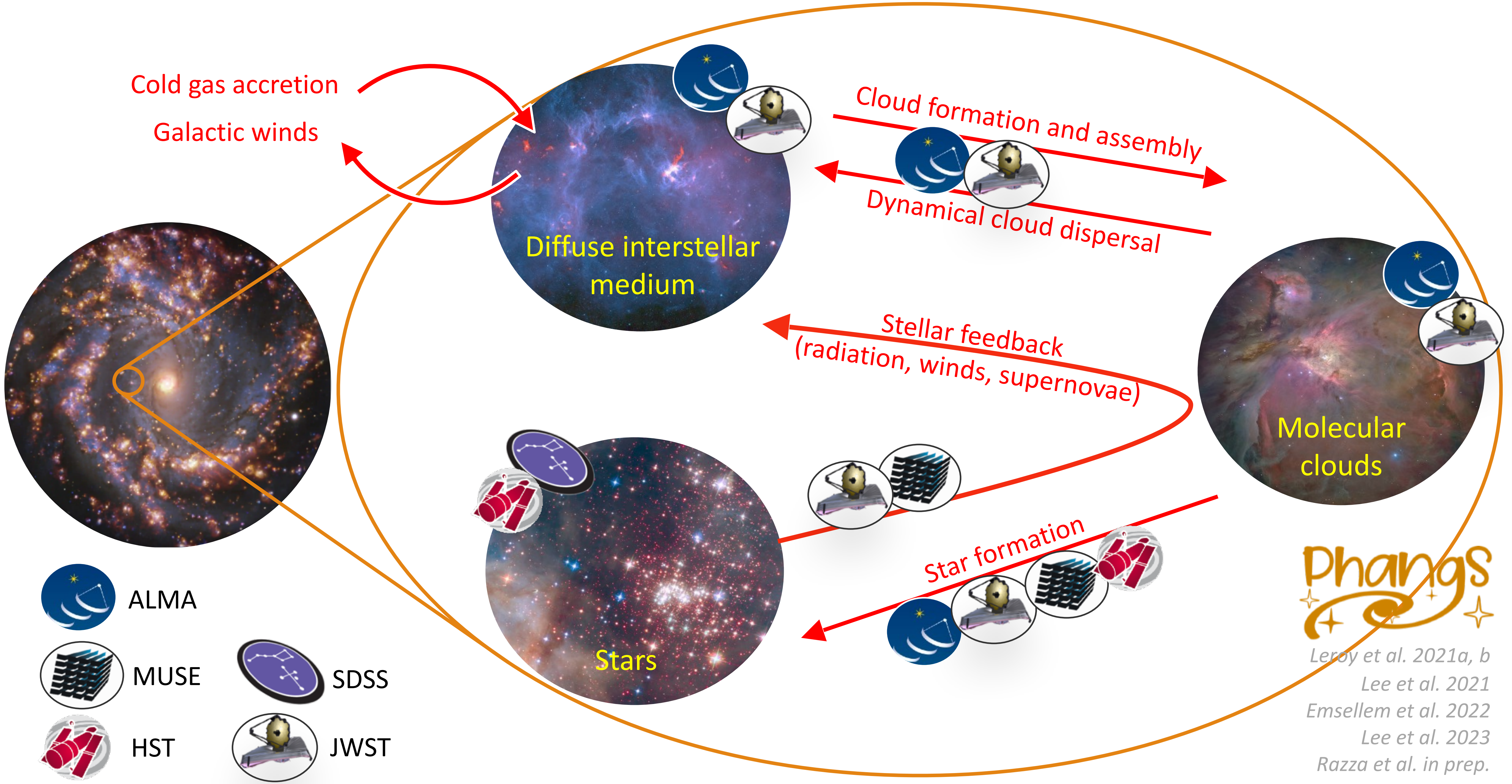
Simulation: *Keller, Kruijssen, Chevance et al. 2022*

Gas density: low – medium – high

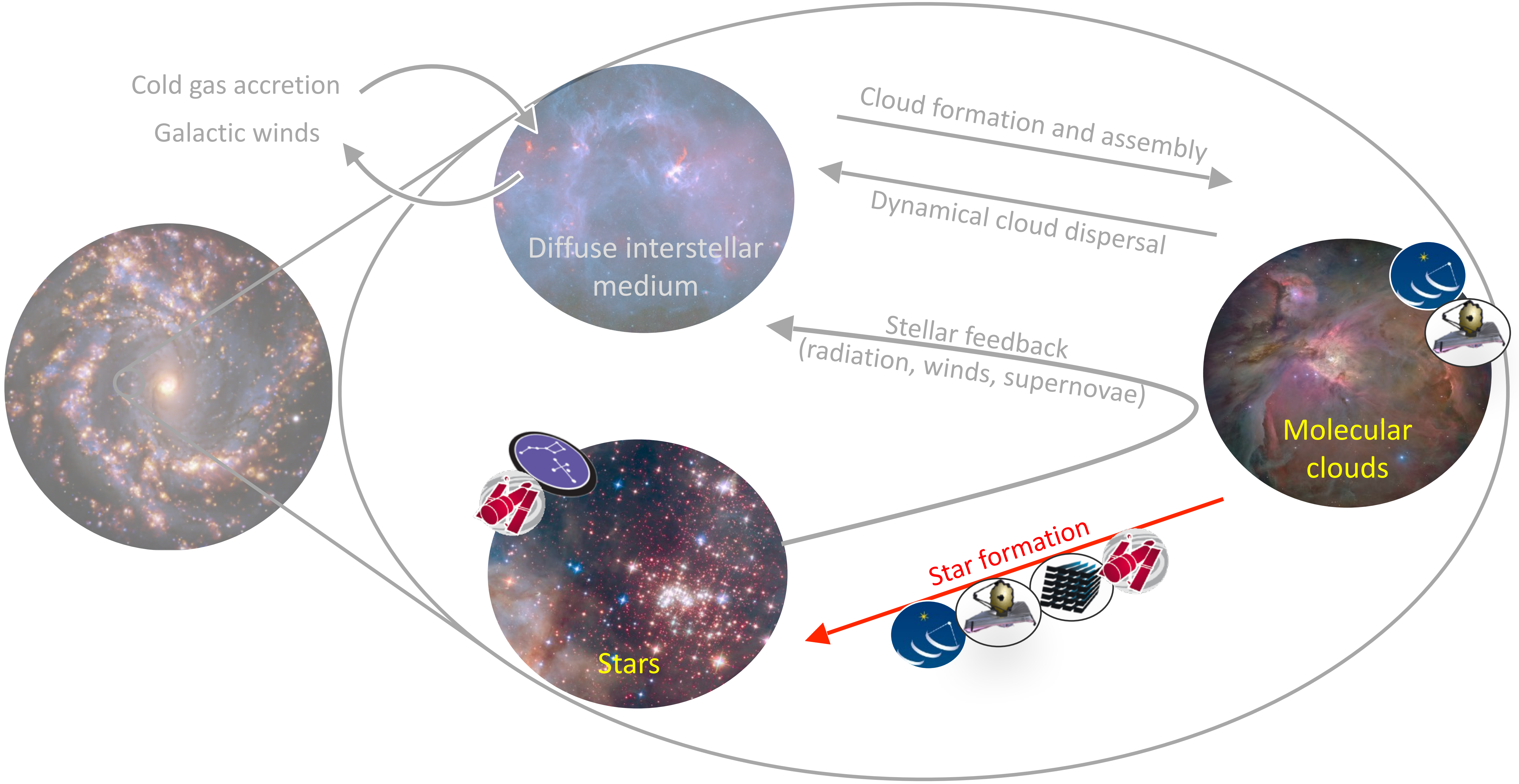

How do galaxies turn their gas into stars?

How do the new-born stars impact the remaining gas?

How does this cycle depend on the galactic properties & environment?




*Leroy et al. 2021a, b*
*Lee et al. 2021*
*Emsellem et al. 2022*
*Lee et al. 2023*
*Razza et al. in prep.*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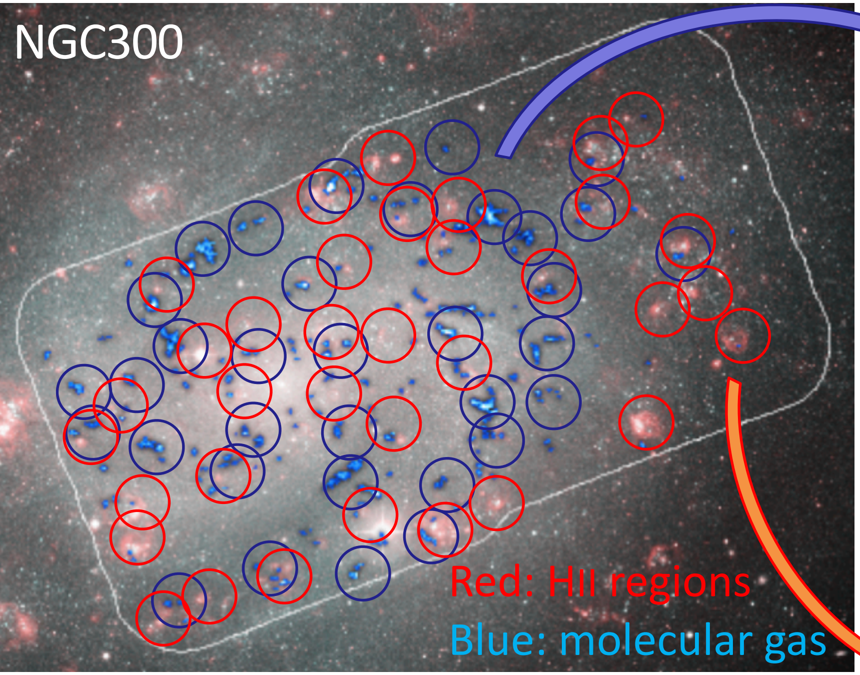
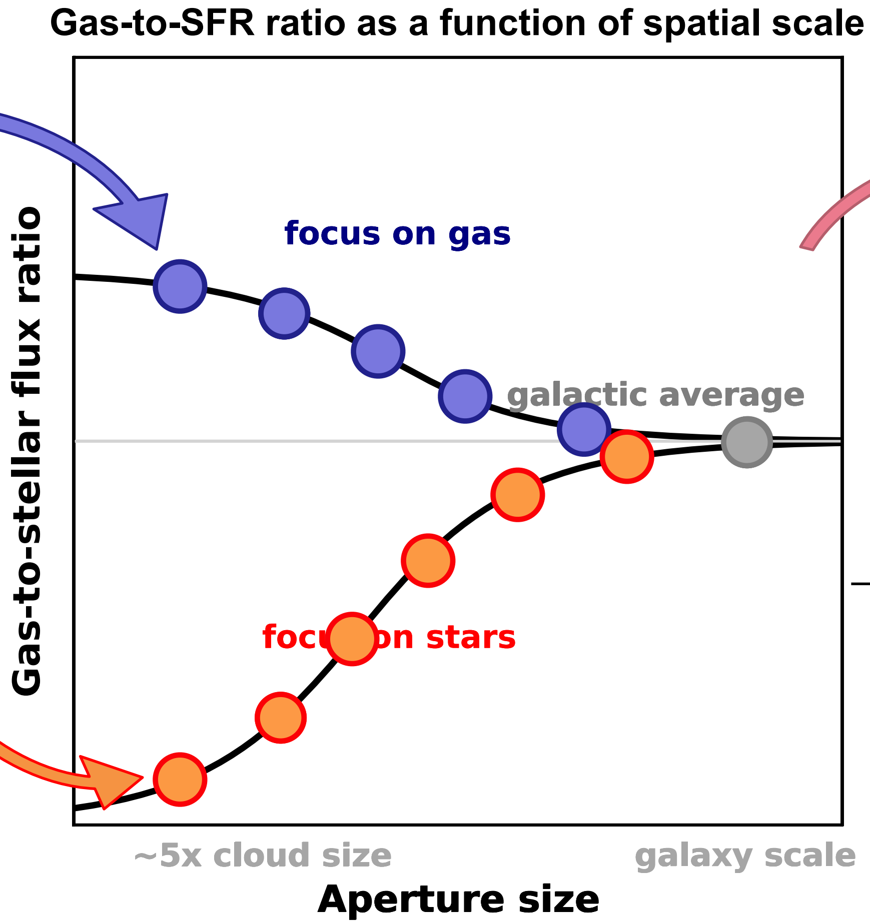
# Measuring Myr timescales — How?

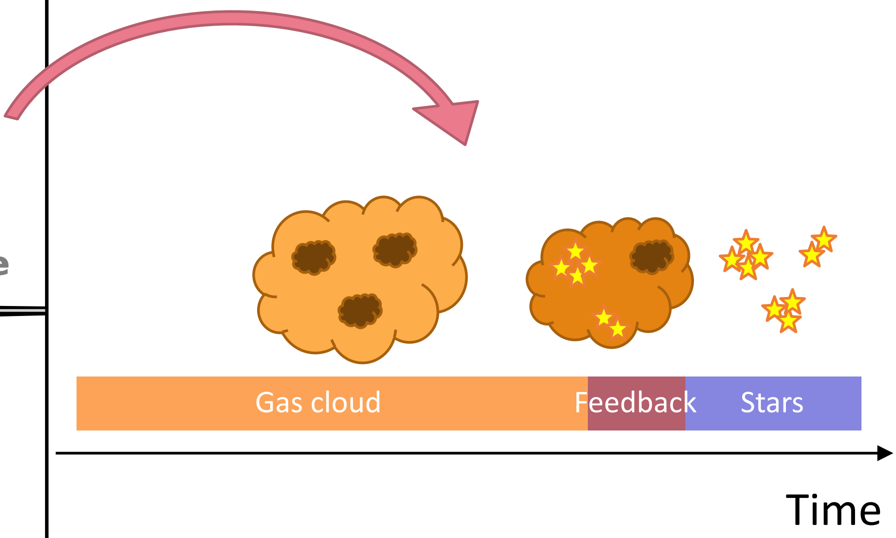
Small-scale variations of gas-to-SFR ratio reflect underlying timeline

*(Kruijssen & Longmore 2014, Kruijssen et al. 2018)*

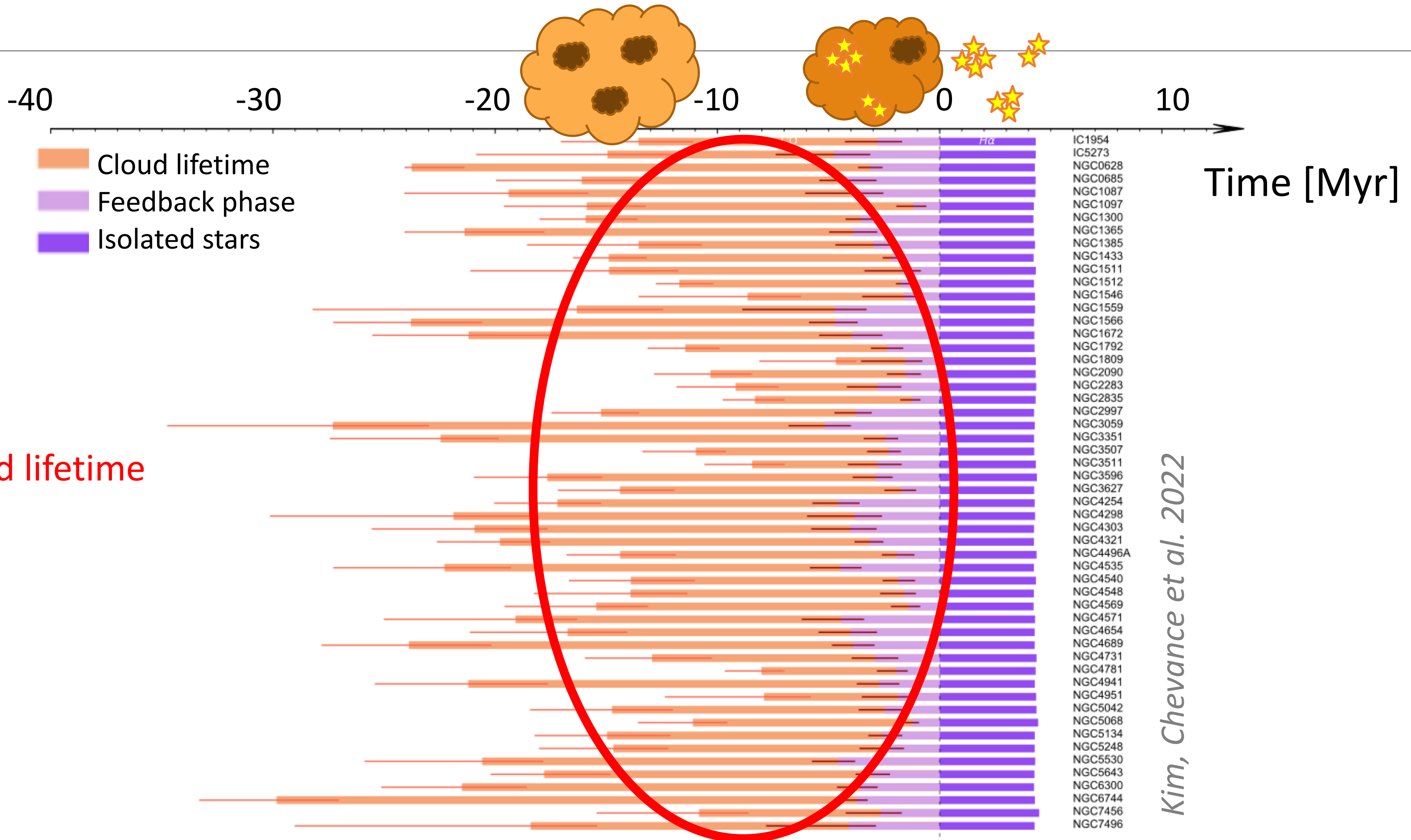
See talk by Diederik Kruijssen



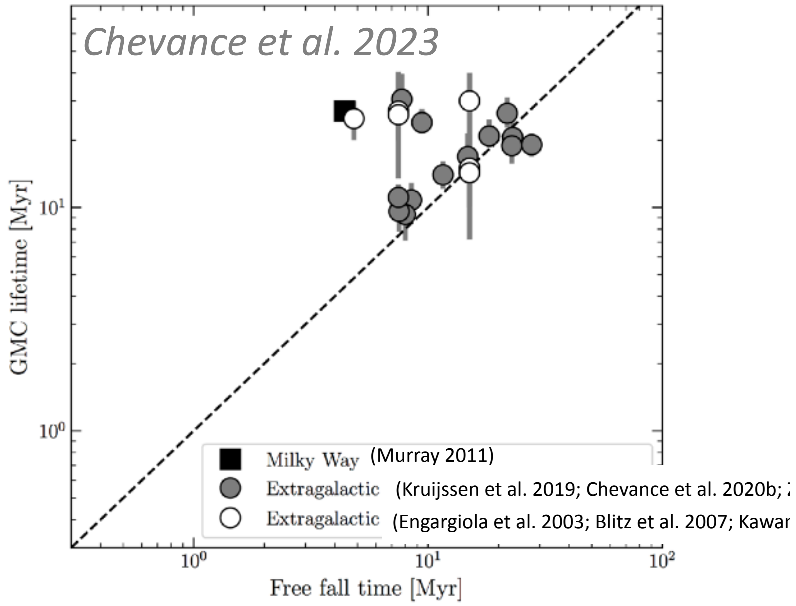
# Molecular cloud lifecycle

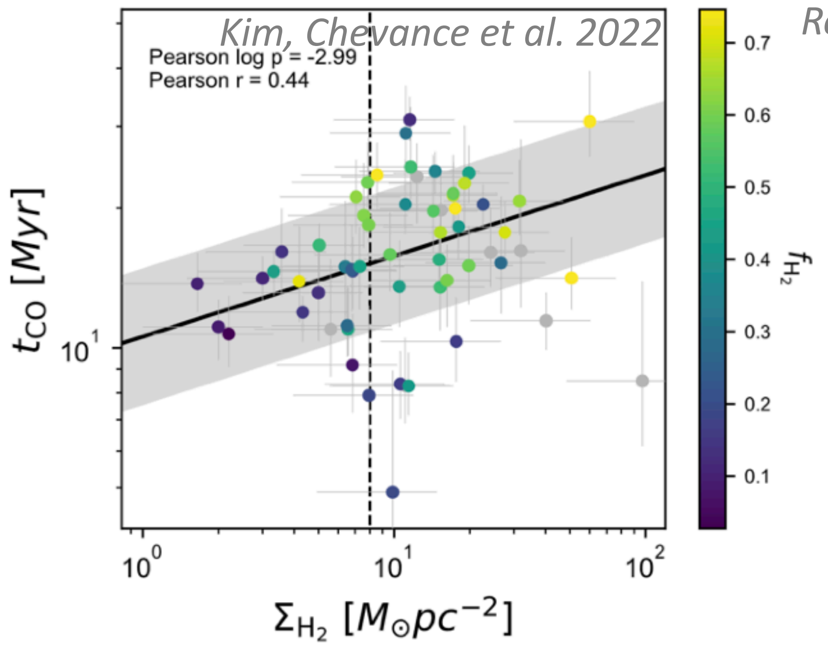


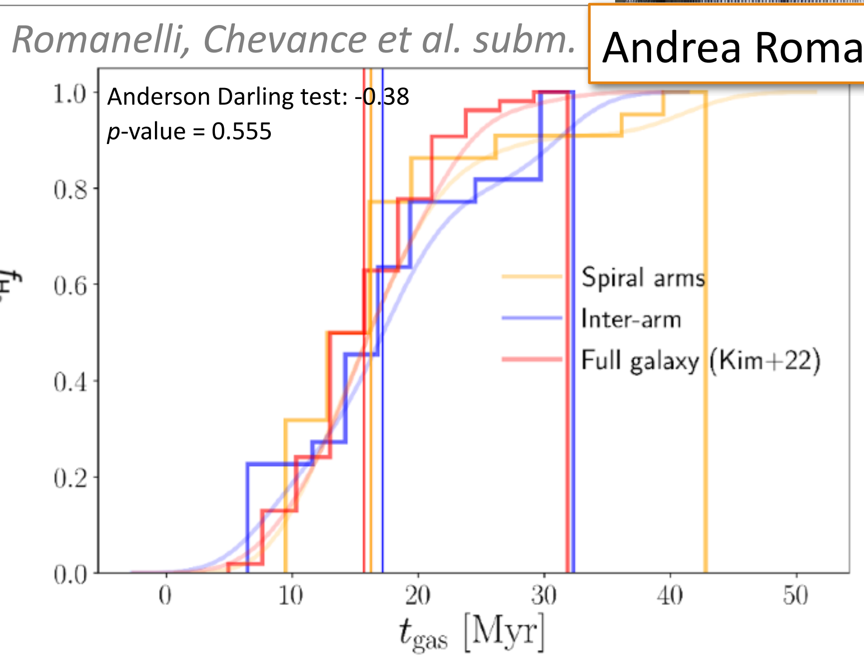

Molecular cloud lifetime

*Kim, Chevance et al. 2022*

# Molecular cloud lifecycle



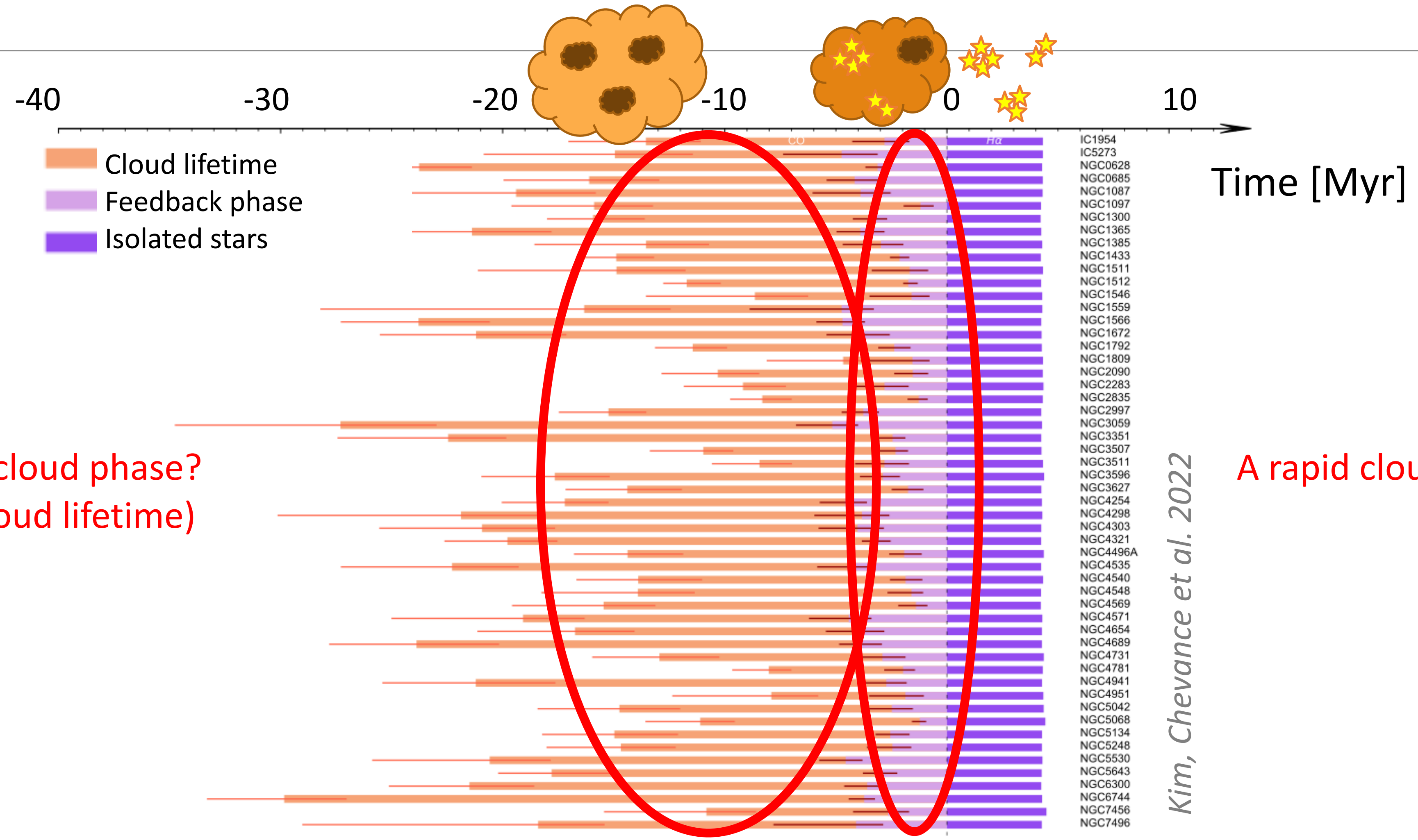

Andrea Romanelli

- Short cloud lifetimes (5-30 Myr), limited to a ***few dynamical times*** (rare cloud dispersal *without* star formation)

- Environmentally dependent

- No evidence for strong spiral arm influence

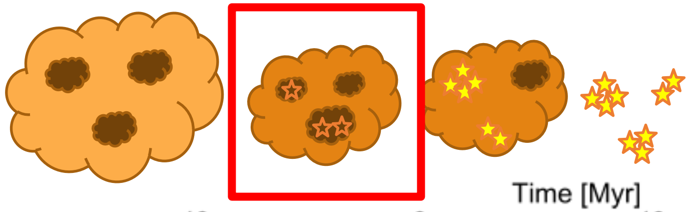
# Molecular cloud lifecycle

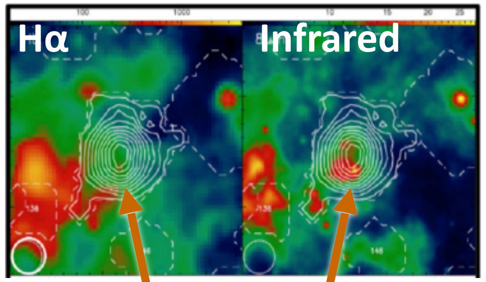



A long ‘inert’ cloud phase?
(70-90% of cloud lifetime)

A rapid cloud dispersal phase

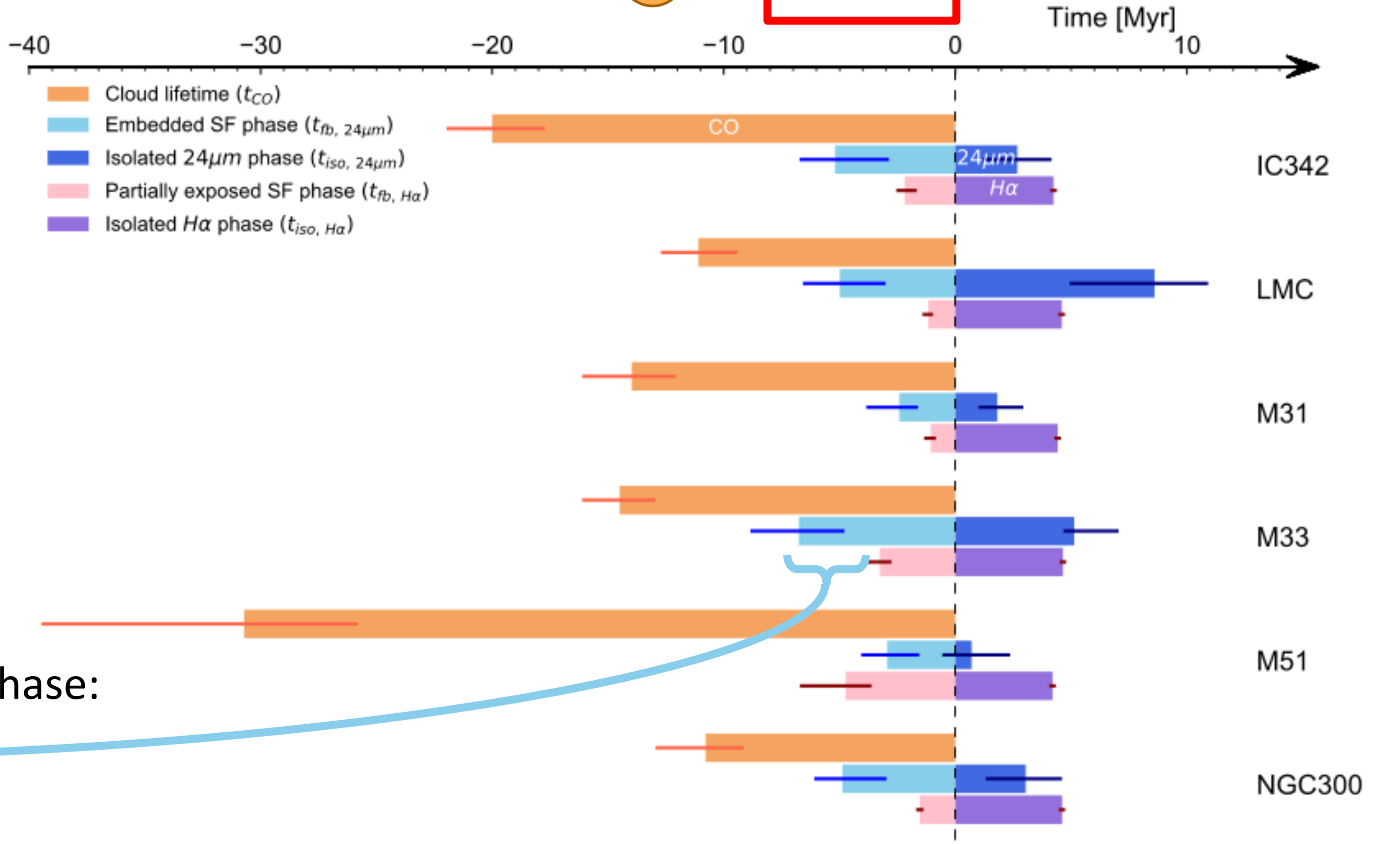
# Refining the gas dispersal process






Embedded young stars

*Corbelli et al. 2017*

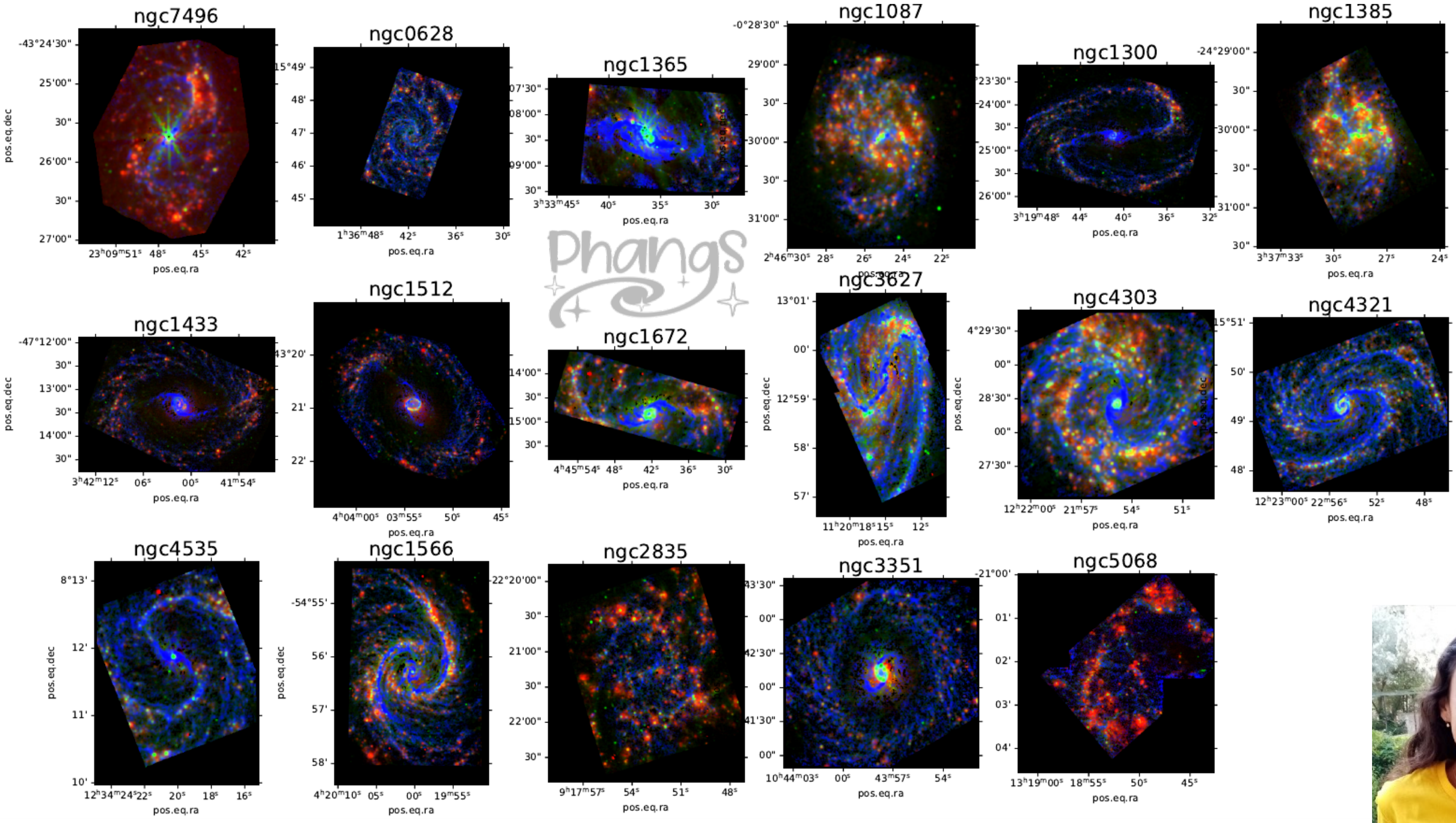



Heavily obscured star formation phase:

1.4-3.8 Myr

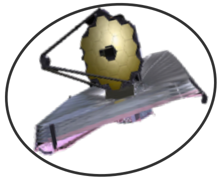
*Kim, Chevance et al. 2021*

➢ Pre-*James Webb Space Telescope*: 6 galaxies

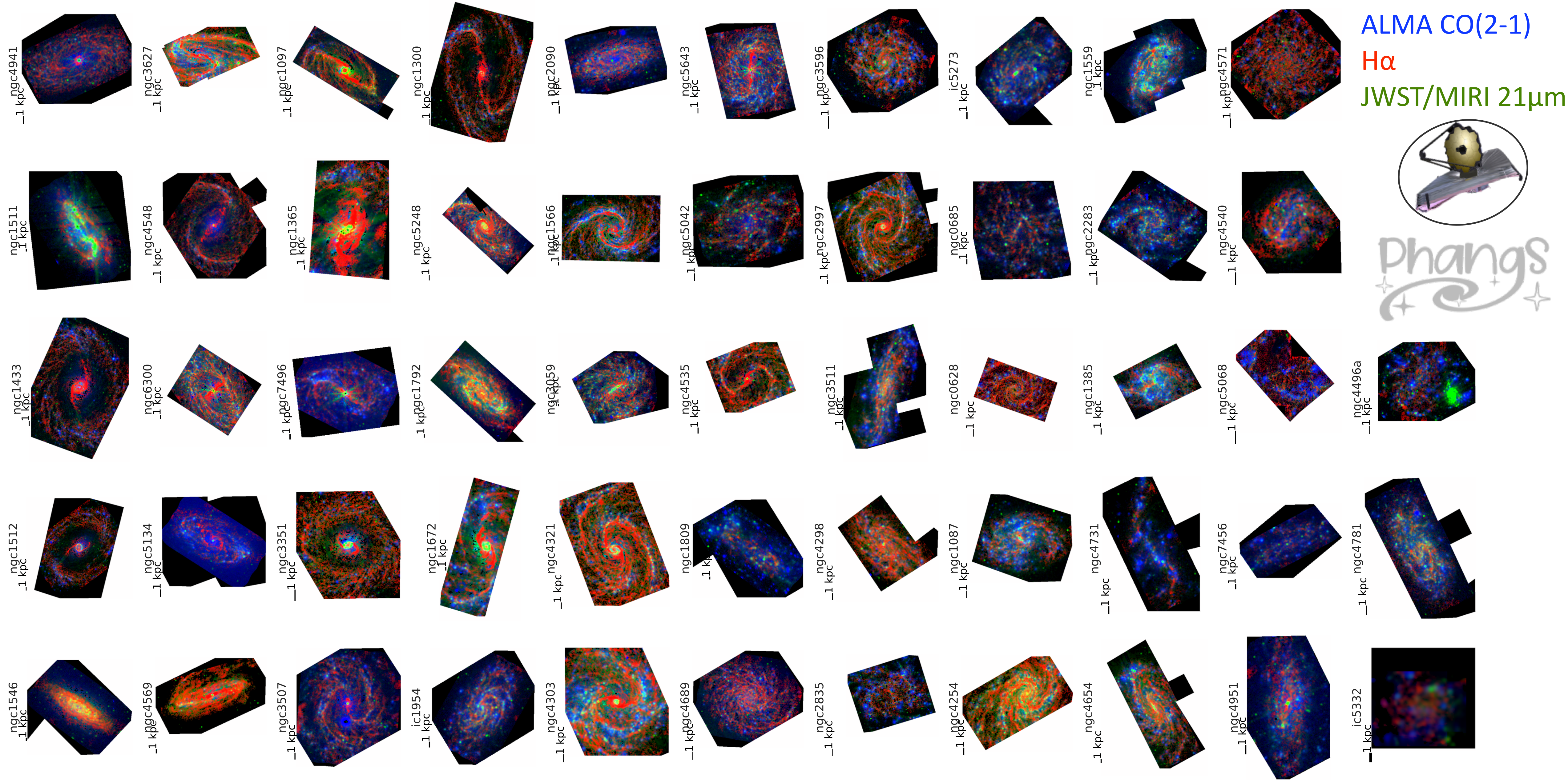



Lise Ramambason

- Pre-*James Webb Space Telescope*: 6 galaxies
- Now: *JWST Cycle 1* Large Programme for **19 additional galaxies**
  *JWST Cycle 2* Large Programme for **55 additional galaxies**



**Special thanks to the PHANGS-JWST reduction team:** *Tom Williams, Oleg Egorov, Kirsten Larson, Elizabeth Watkins, Janice Lee, Dave Thilker, Karin Sandstrom, Adam Leroy, Yixian Cao, Daizhong Liu, Erik Rosolowsky*

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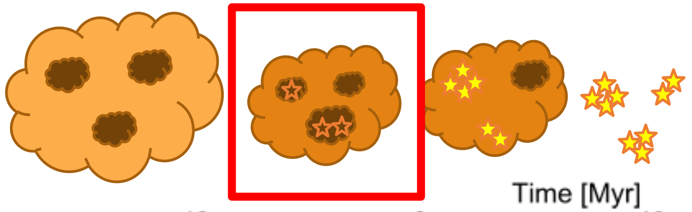

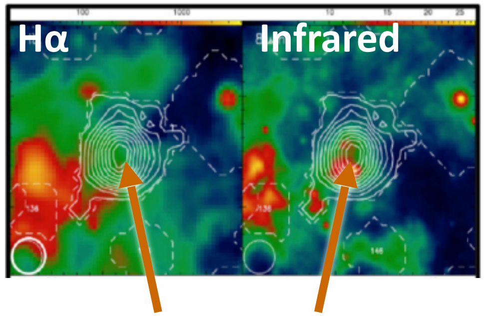


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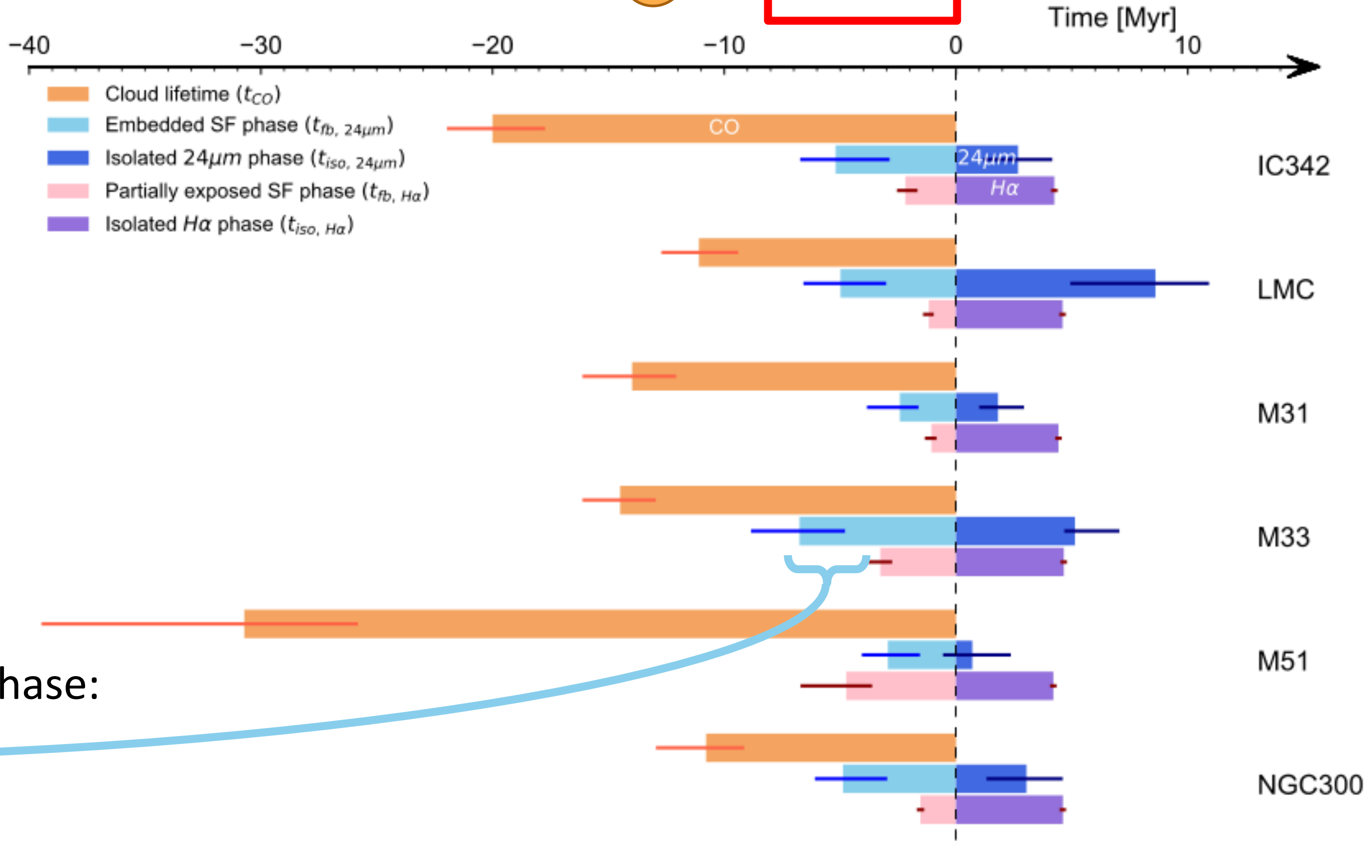


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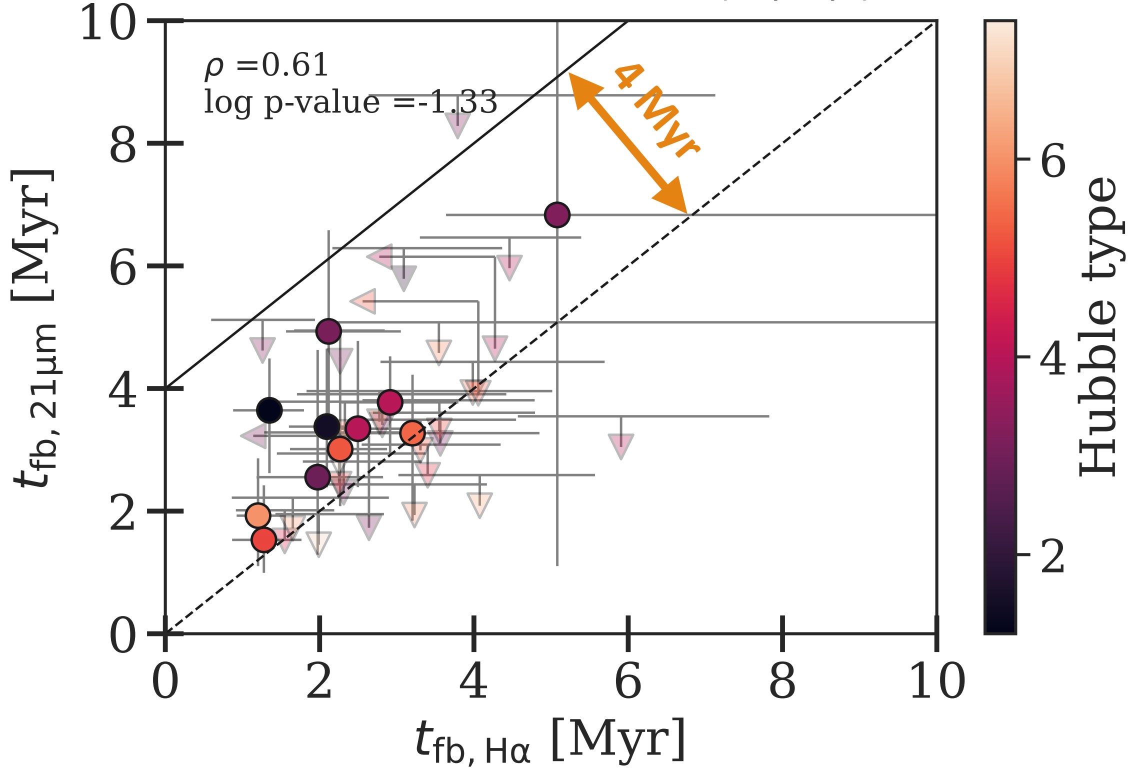
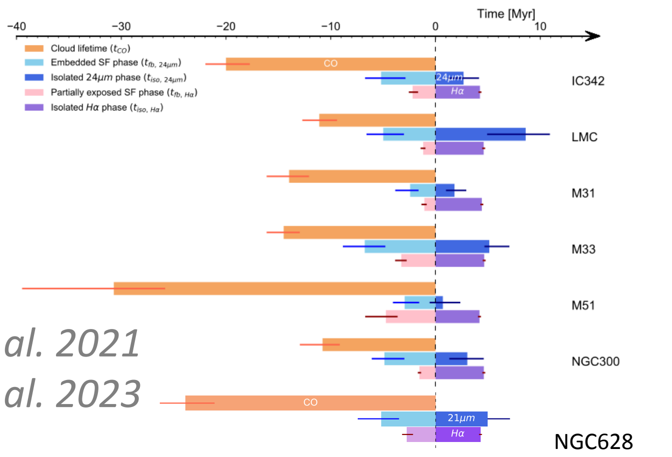
# Refining the gas dispersal process

*Ramambason, Chevance et al. (in prep.)*




*Kim, Chevance et al. 2021*
*Kim, Chevance et al. 2023*

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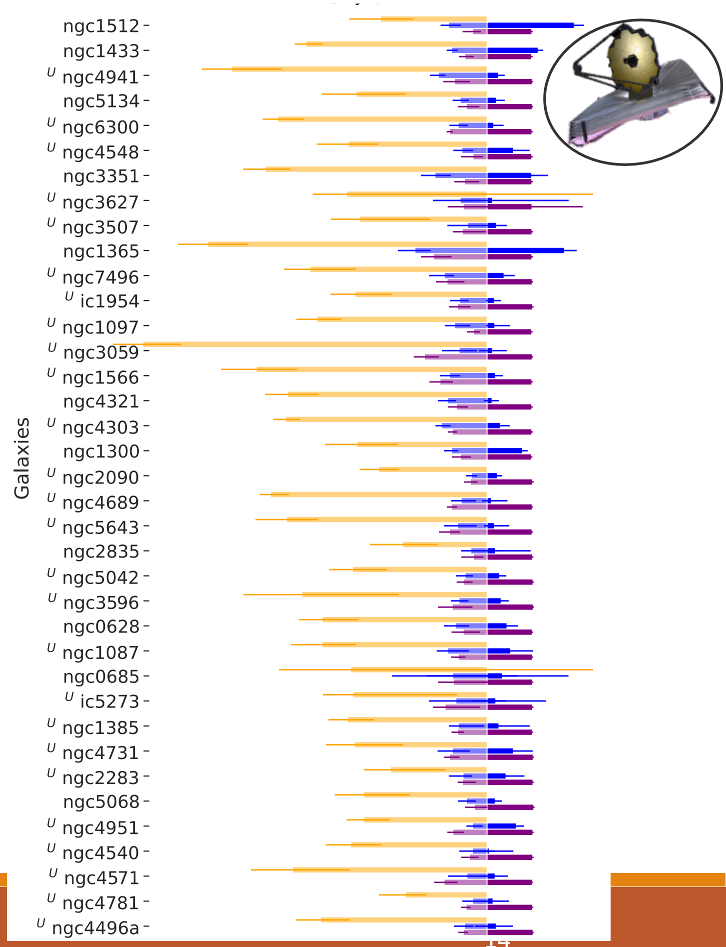


- ➢ Deeply embedded stars (invisible in Hα) for ***~ 0 to 4 Myr***
- ➢ Consistent with statistics of cluster ages: clearing timescales of ~ 2 - 4 Myr

*(e.g, Whitmore+15, Hollyhead+15, Grasha+18, Deshmuk+24, Sun+24)*

# Refining the gas dispersal process

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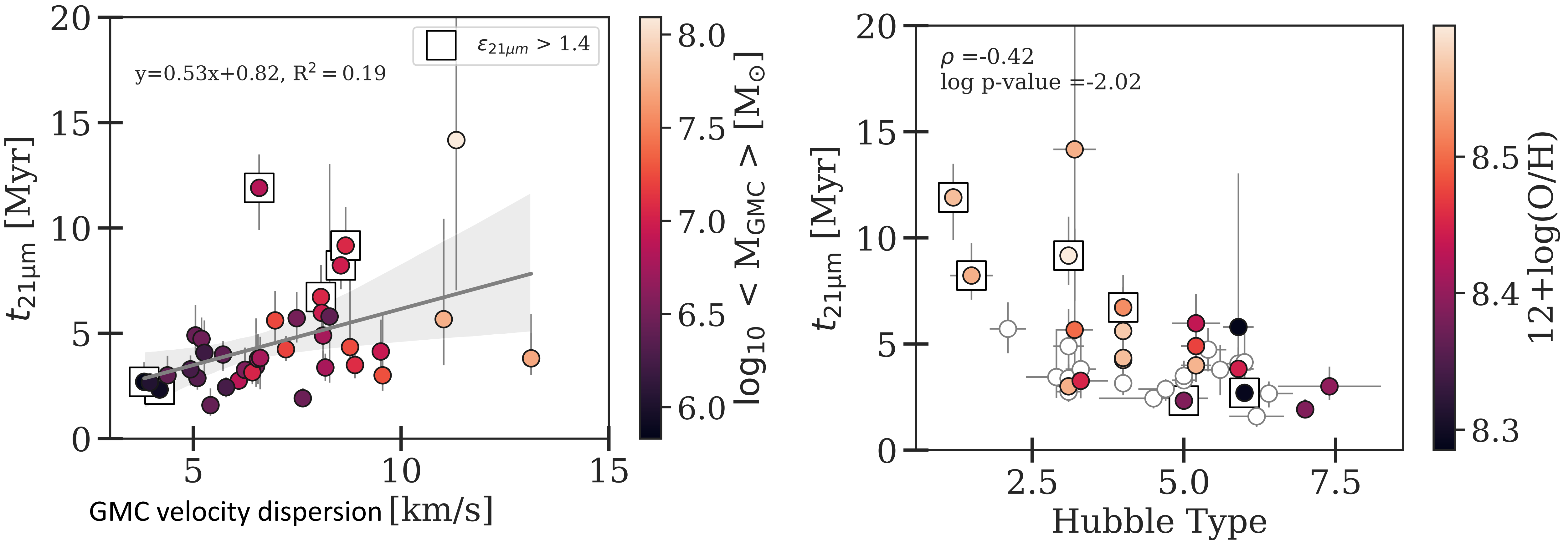
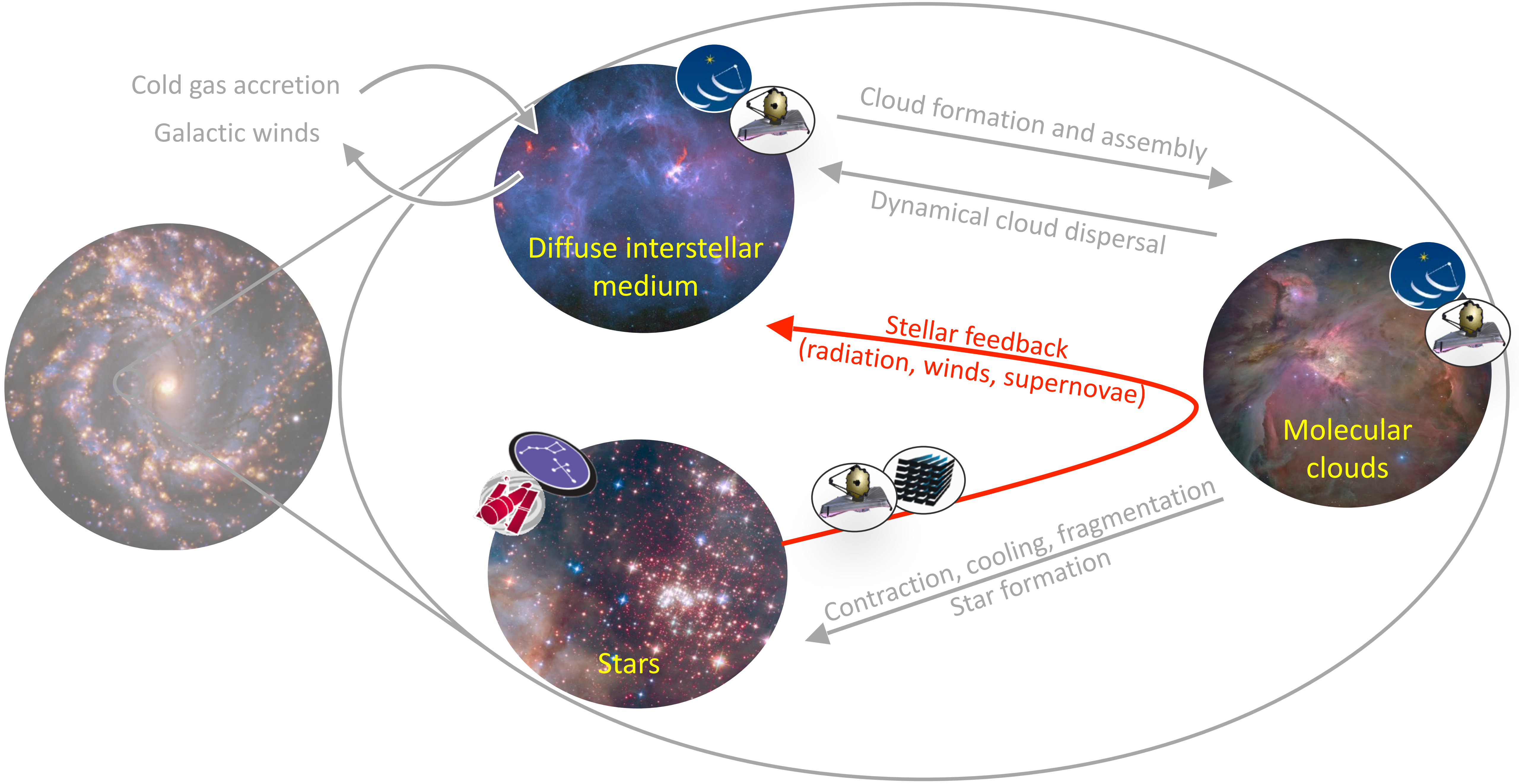



➢ Dependence on ***local (cloud-scale)*** and ***global*** environmental properties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Contraction, cooling, fragmentation
Star formation

# Rapid cloud dispersal: *What stellar feedback mechanisms can disperse the gas so quickly?*

Clouds are ***dispersed***,
not just drifting away
See talk by Diederik Kruijssen

Act on different timescales

- Supernovae

  ~ 3 - 15 Myr

- Ionizing EUV radiation

$$t_{phot} = \frac{4}{7}\left(\frac{3}{4}\right)^{1/2} \frac{r_{Strömgren}}{c_s}\left[\left(\frac{r_{GMC}}{r_{Strömgren}}\right)^{7/4} - 1\right]$$

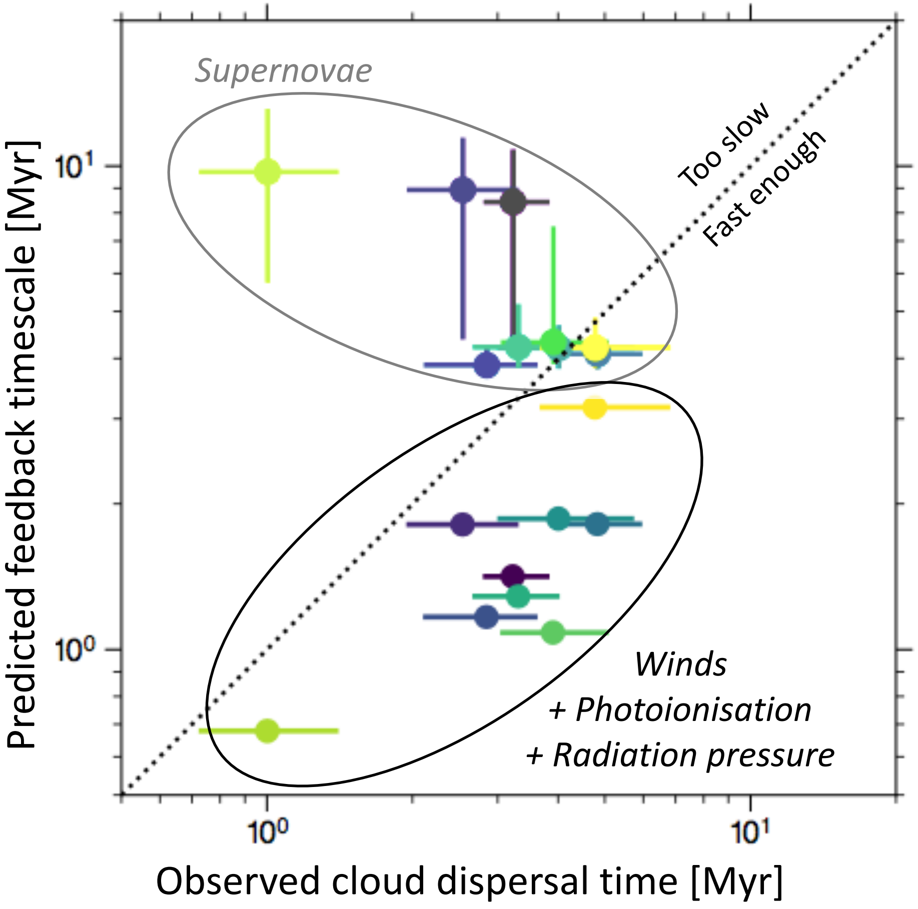
- Stellar winds *(energy driven or energy+momentum driven)*

$$t_{wind} = \left(\frac{154\pi}{125}\frac{\rho_{GMC}}{L_{wind}}\right)^{1/3} r_{GMC}^{5/3} \qquad t_{wind} = \left(\frac{154\pi}{125}\frac{\rho_{GMC}}{L_{wind}}\right)^{4/5} t_{cool}^{-7/5} r_{GMC}^{4}$$

- Radiation pressure

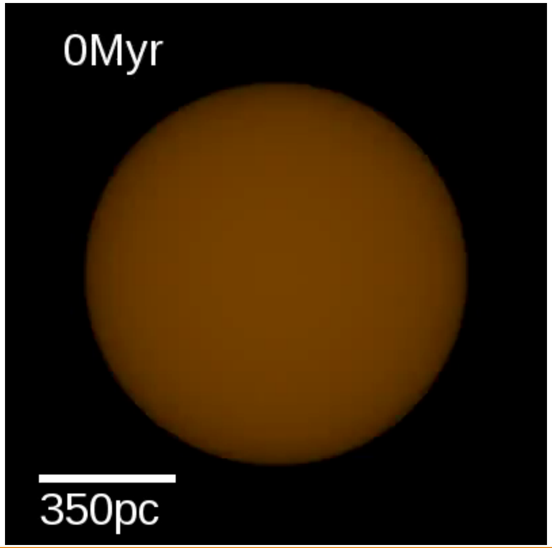
$$t_{rad} = \left(\frac{2\pi c}{3}\frac{\rho_{GMC}}{L_{bol}}\right)^{1/2} r_{GMC}^{2}$$

# Rapid cloud dispersal: *What stellar feedback mechanisms can disperse the gas so quickly?*




*Chevance et al. 2022*

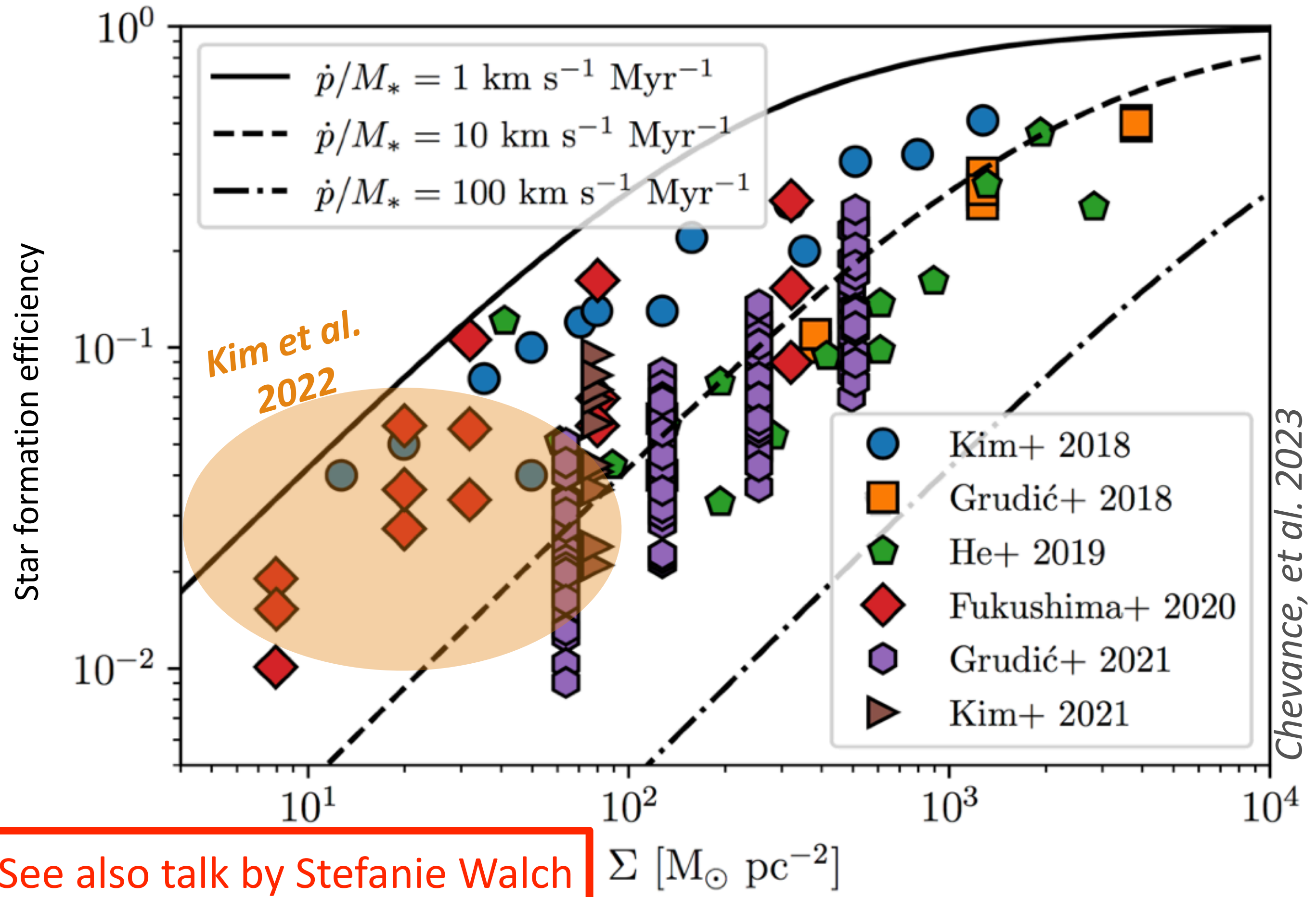
- ➢ ***Pre-supernova*** mechanisms play an important role in dispersing the clouds.
- ➢ Their ***coupling efficiency*** with the surrounding gas is ***not 100%***
  ***-> high escape fractions***
  *(see e.g. Kim et al. 2019, Ramambason et al. 2022)*




*Grudić et al. 2018a*

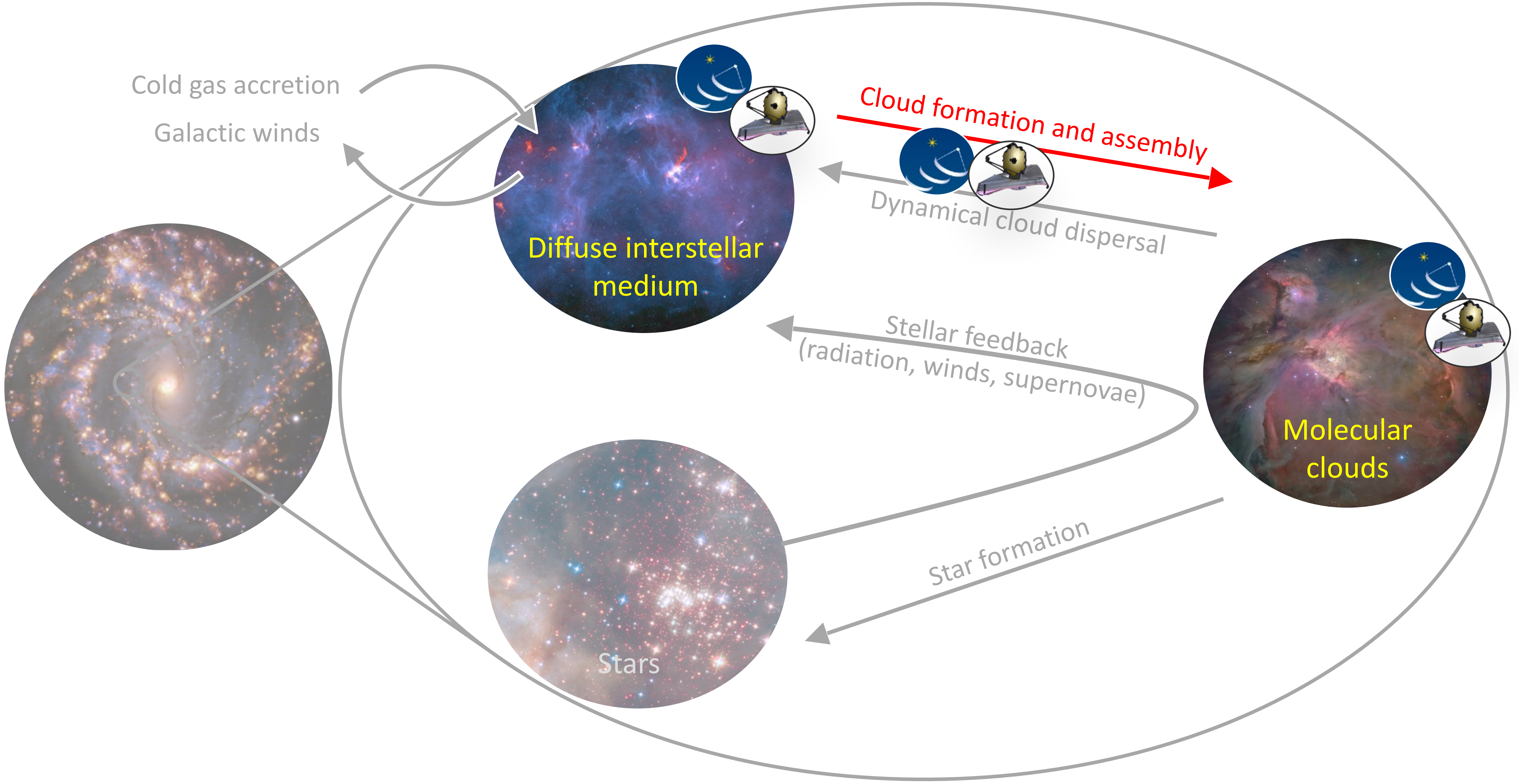
*See also Grudić et al. 2022*

# Rapid cloud dispersal




See also talk by Stefanie Walch

- Short cloud destruction phase (***1-5 Myr***)
  —> Importance of ***pre-SN*** mechanisms
- Environmentally dependent
- No-to-short embedded phase of SF
- Star formation efficiency limited to 1-8 %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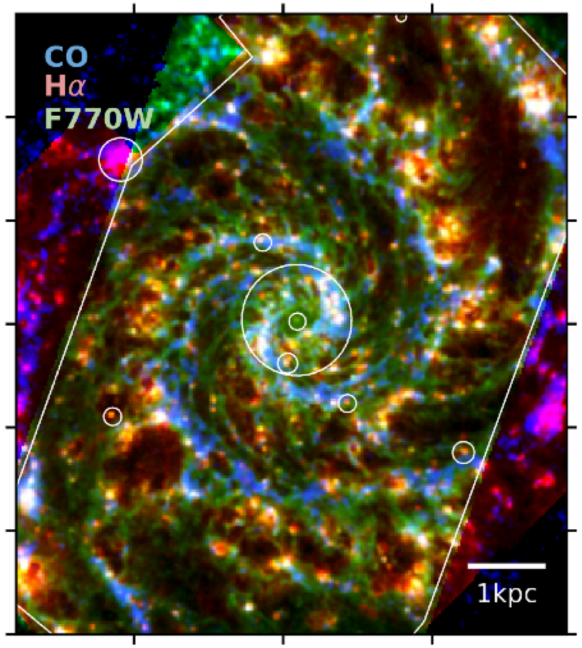
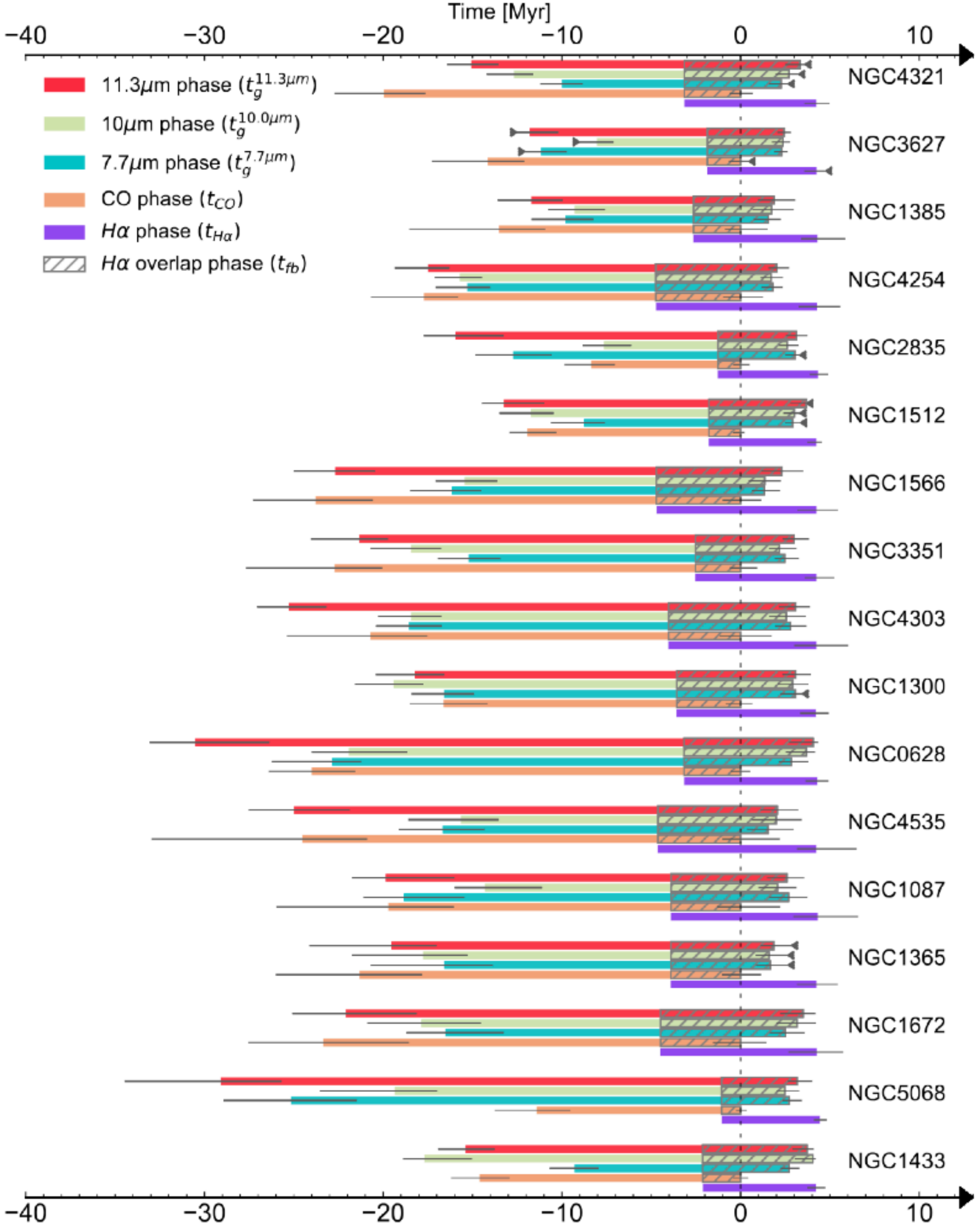
# PAH and dust timescale

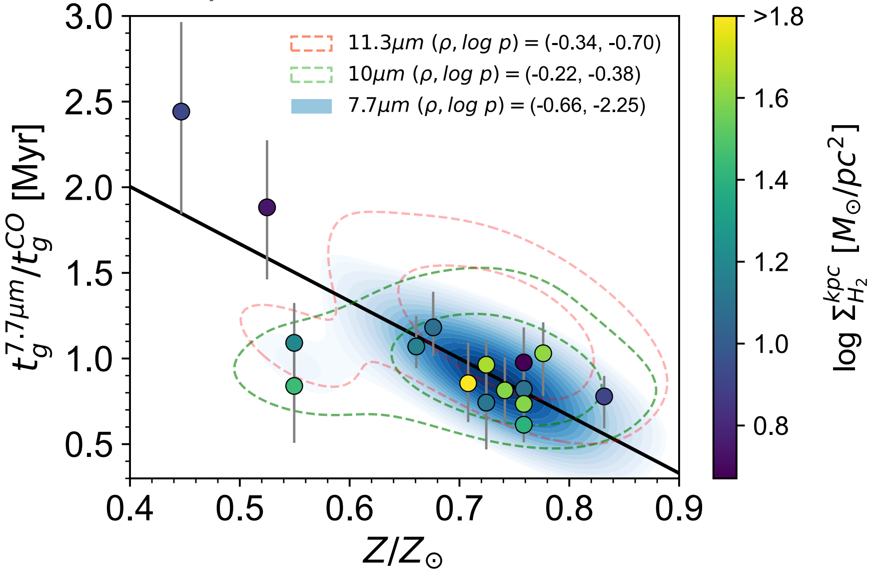
*Kim, Chevance et al. subm.*

NGC 0628



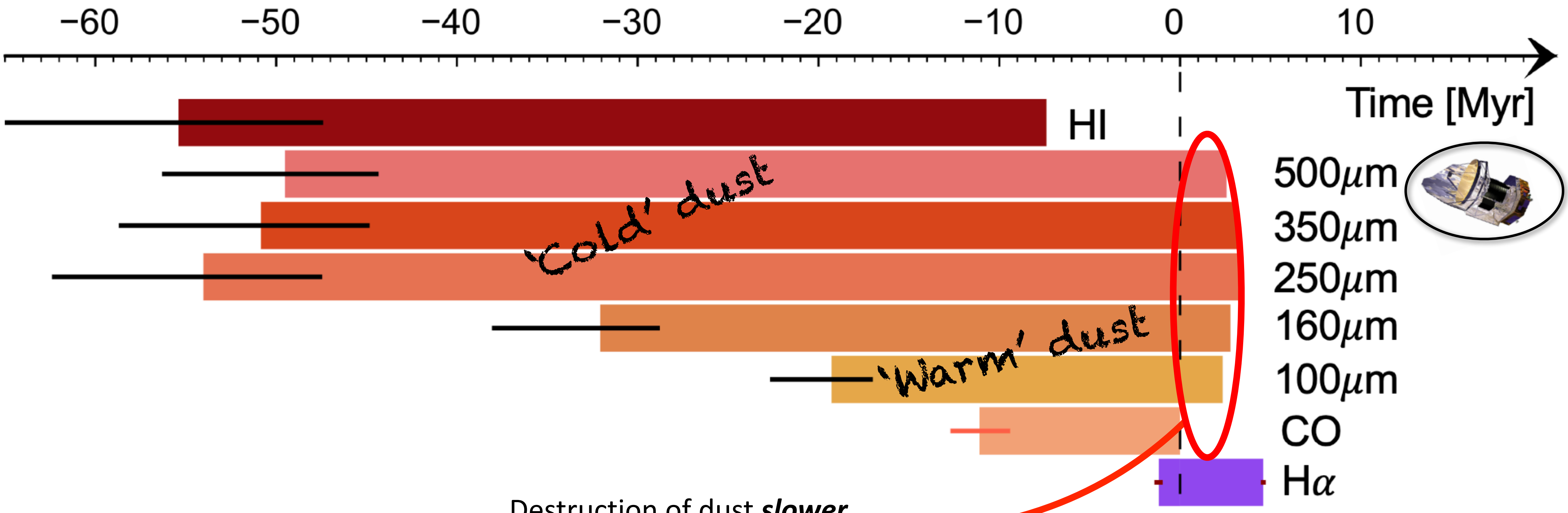




*Kim, Chevance et al. subm.*



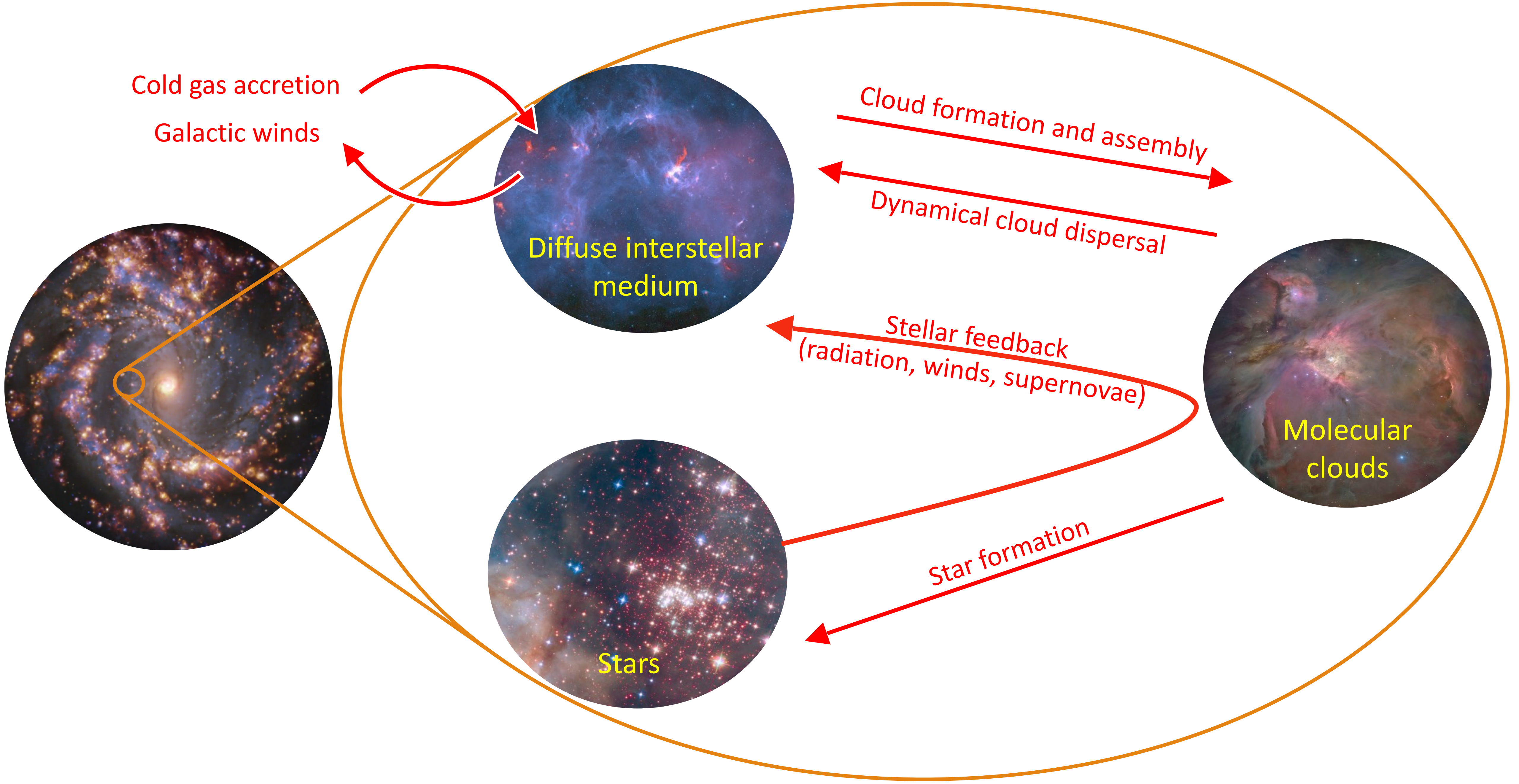

- Fast conversation atomic-to-molecular gas?
- Molecular cloud lifetime limited by CO detection at low-metallicity?

# Large Magellanic Cloud




Destruction of dust ***slower*** than destruction of CO

*Kim et al. in prep*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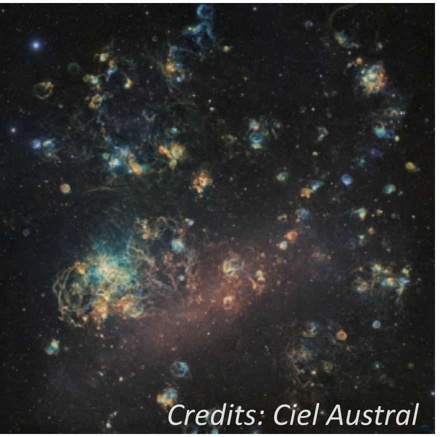
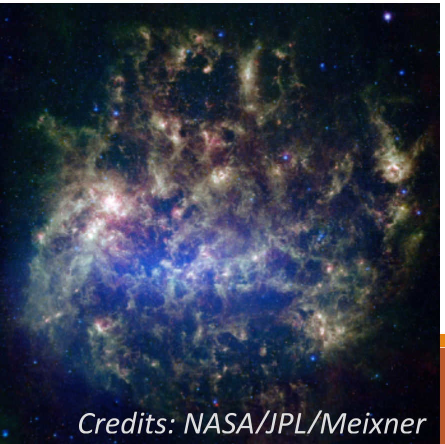
# Large Magellanic Cloud

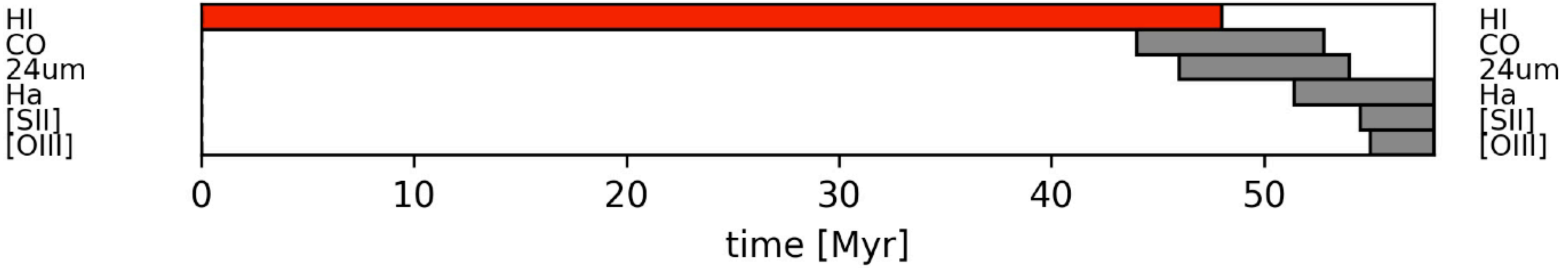

Credits: ESA/Gaia/DPAC


Credits: Ciel Austral


Credits: NASA/JPL/Meixner

- Distance: 50 kpc
- Observed at more wavelengths than any other external galaxy
- High spatial resolution
- Full galaxy coverage

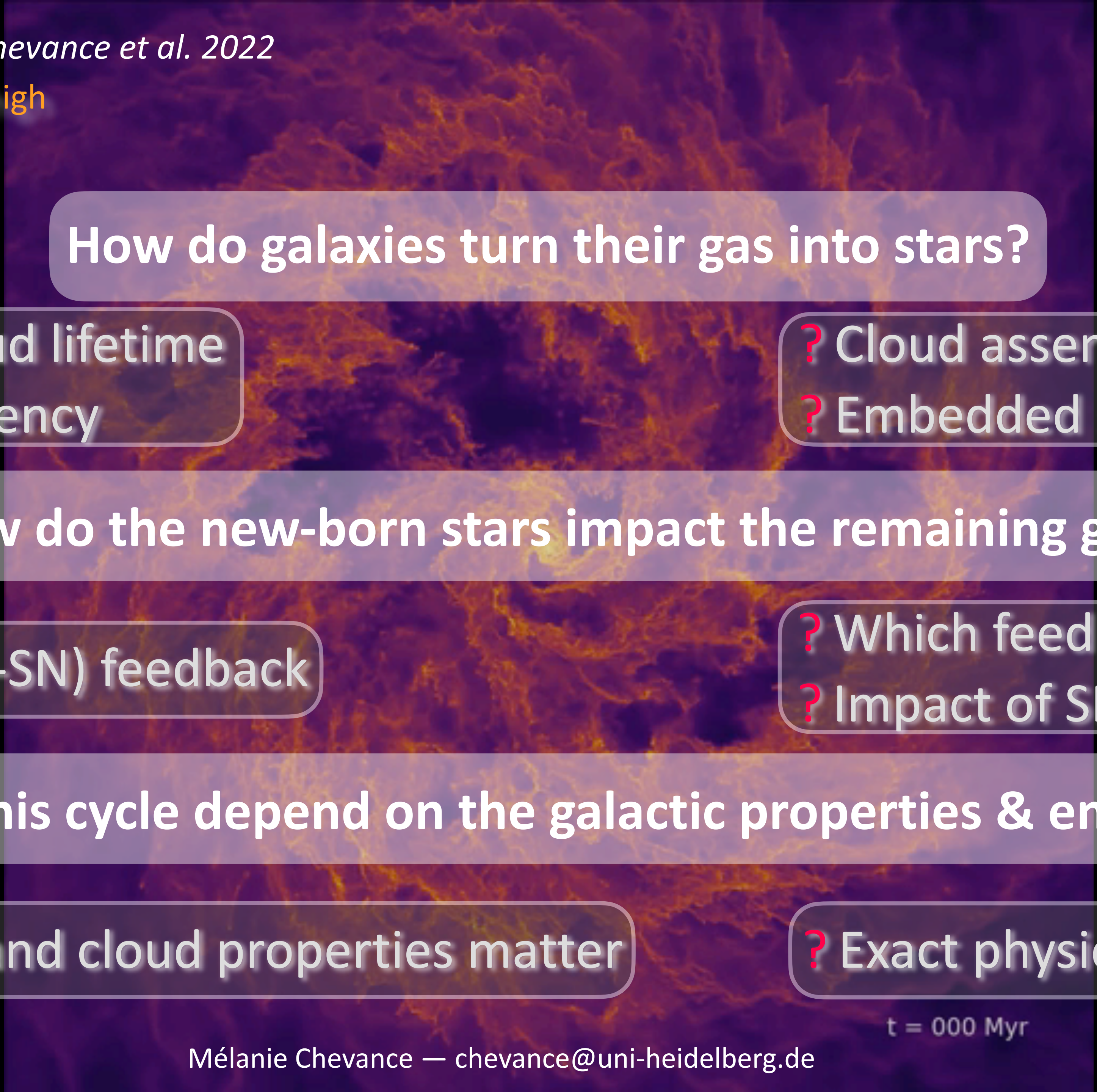
R= HI, G=N/A, B=N/A




*Courtesy of Jacob Ward*
*Ward, Chevance et al. 2020, 2022*
*Kim, Chevance et al. in prep.*

Simulation: *Keller, Kruijssen, Chevance et al. 2022*

Gas density: low – medium – high




**How do galaxies turn their gas into stars?**

✓ Short cloud lifetime

✓ Low efficiency

? Cloud assembly time

? Embedded stellar phase

**How do the new-born stars impact the remaining gas?**

✓ Early (pre-SN) feedback

? Which feedback, when

? Impact of SN

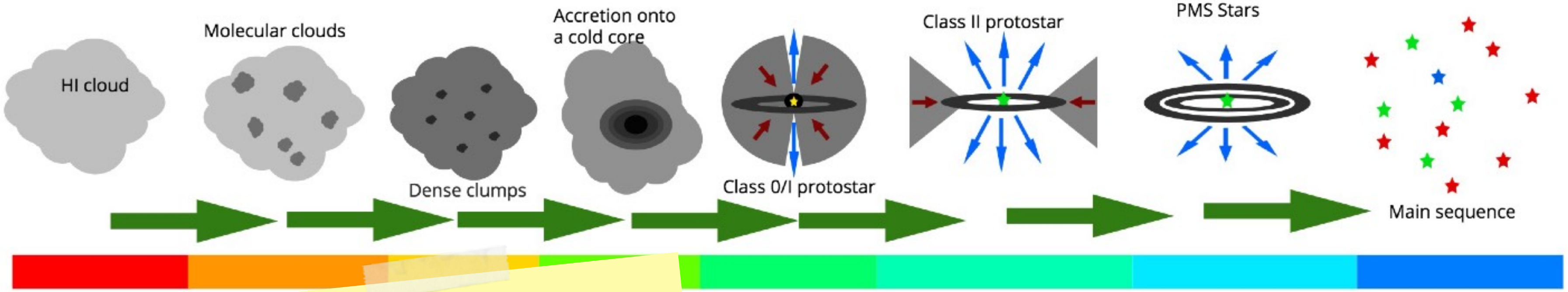
**How does this cycle depend on the galactic properties & environment?**

✓ Galactic and cloud properties matter

? Exact physical mechanisms

# Upcoming observational facilities

➢ ***Finer time resolution*** to identify the individual physical mechanisms at play: ***multi-wavelength observations***




**A new *high spatial resolution* IR observatory?** *~ 1" (or better)*