

# Peeking behind the Bars' cloak of invisibility (galactic Speakeasies)

© Judy Schmidt & JWST – NASA/ESA  
Lee et al.

Phangs



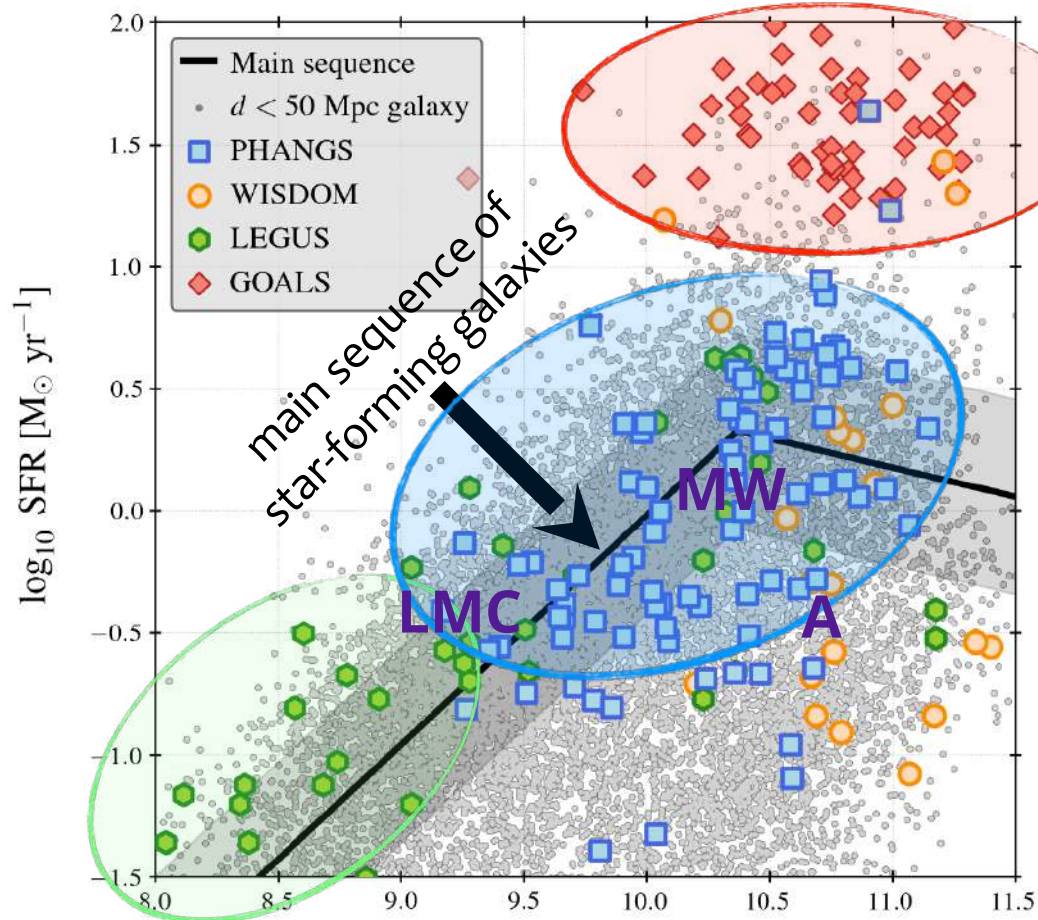
**Eric Emsellem**

*With big thanks to (and significant contributions from):*

**Florent Renaud, Oscar Agertz**

**PHANGS Team, incl. Pierrick Verwilghen, Jessica Sutter, Ryan Shown, Tom Williams**

# Starburst galaxies



MW-like  
galaxies

Most stars  
form  
In discs

dwarf  
galaxies

$\log_{10} M_* [\text{M}_\odot]$

Large Magellanic Cloud  
Milky Way  
Andromeda

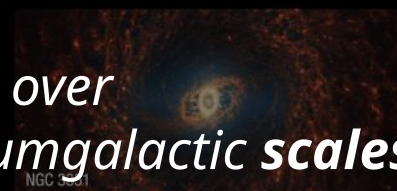
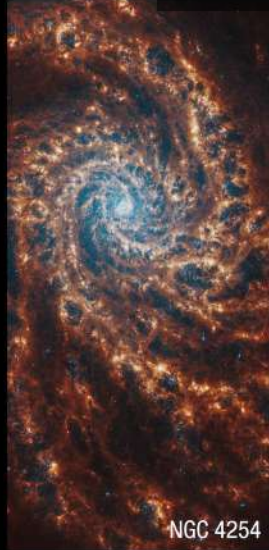


***Extraordinary structures in nearby galaxies =***

***Physics***

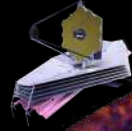
***that drives, regulates, extinguishes Star Formation***

***operating together over  
stellar, interstellar, galactic, circumgalactic scales***

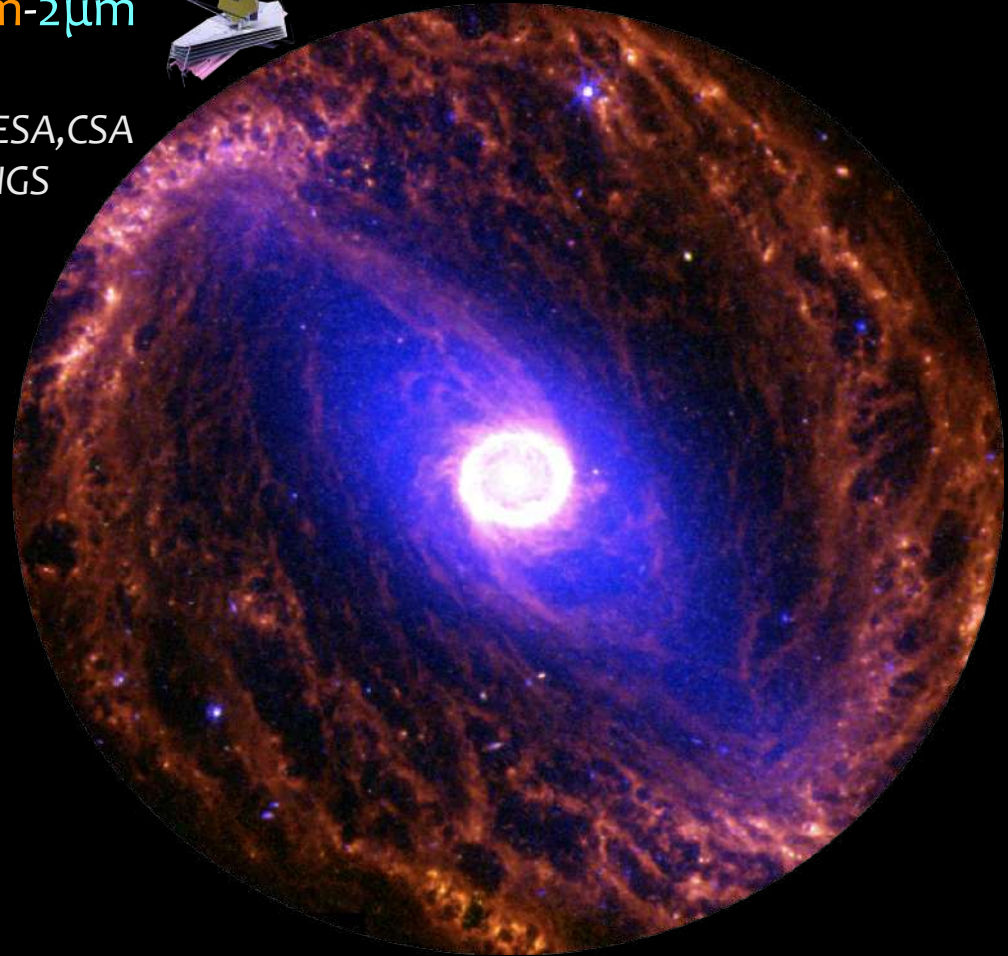
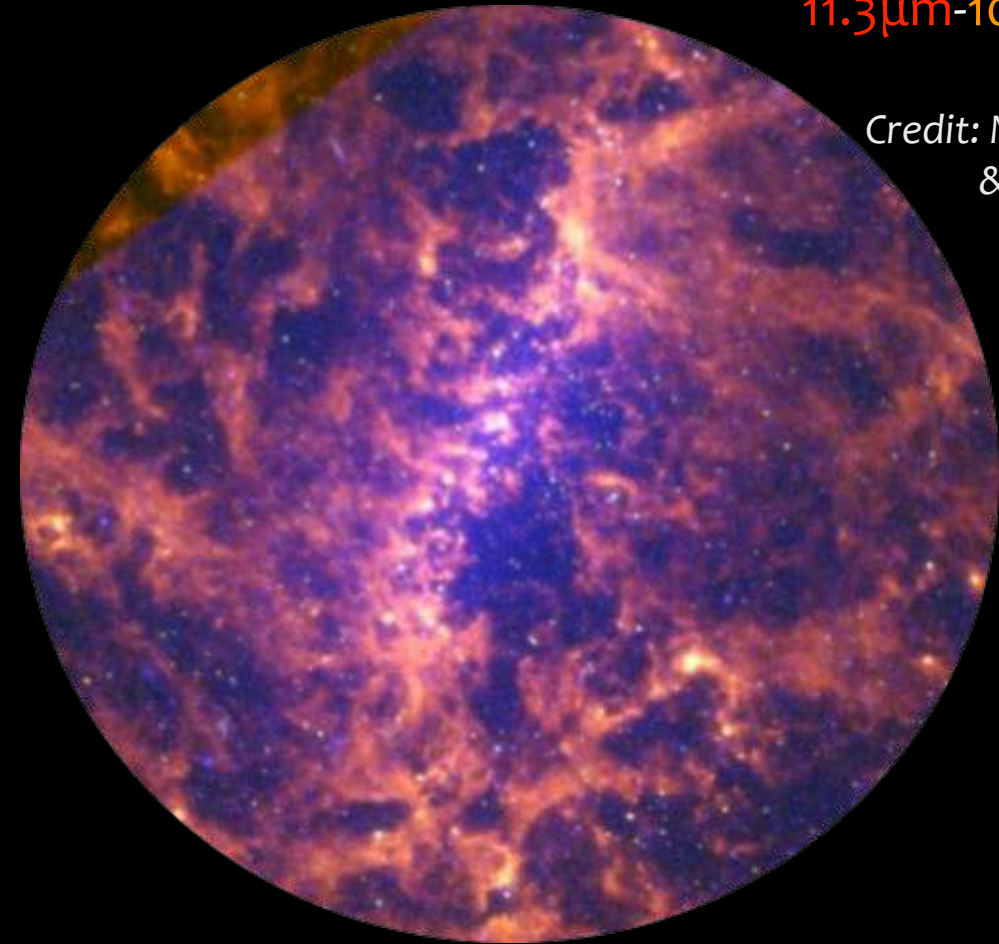




11.3 $\mu\text{m}$ -10.0 $\mu\text{m}$ -2 $\mu\text{m}$

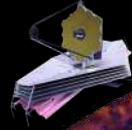


Credit: NASA/ESA, CSA  
& PHANGS





11.3 $\mu$ m-10.0 $\mu$ m-2 $\mu$ m



Credit: NASA/ESA, CSA  
& PHANGS

Can we establish a reference pathway for  
- bar formation ?  
- bar-driven evolution ?

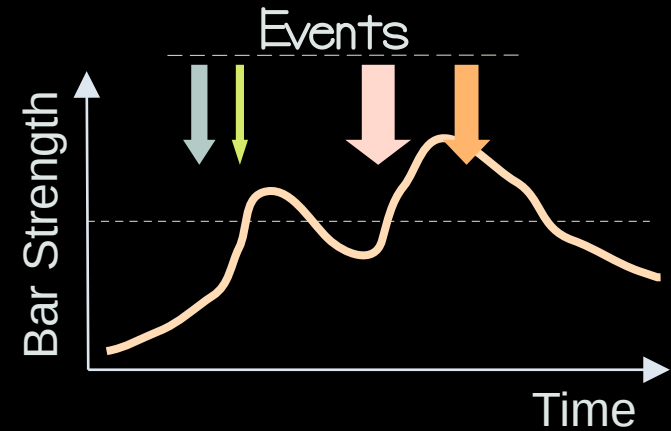
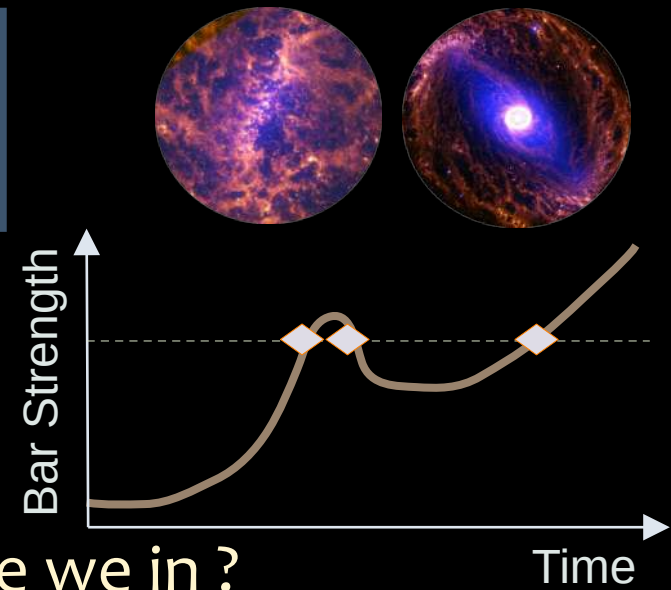


Can we establish a reference pathway for

- bar formation ?
- bar-driven evolution ?

## Difficulties – Observations

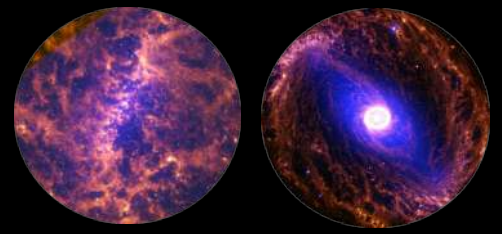
- Time Frozen Snapshots  
→ which phases [growing, weakening] are we in ?
- History is not monotonic (disc → bar → ...)
  - Gas fueling, perturbations / interactions
  - Convolved with the SFH + feedback
- Viewing angles
- Resolution (redshift, wavelength)





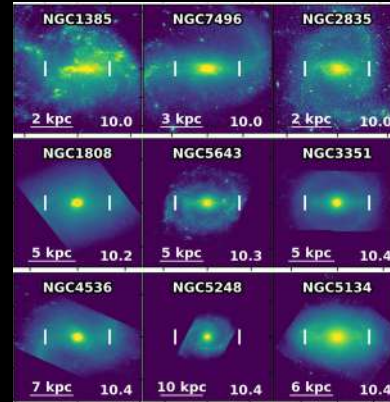
# Can we establish a reference pathway for

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## Difficulties – Observations

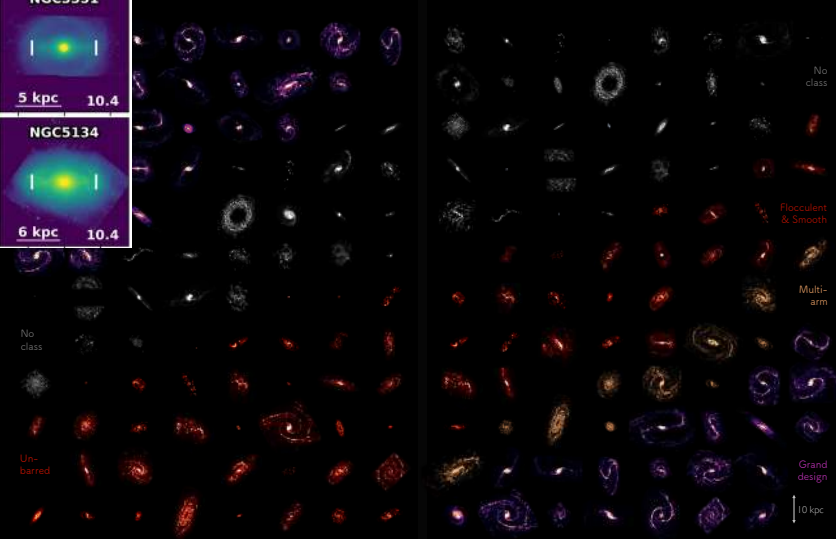
- Diversity of bars & structures
- Dust and Tracers
- Metrics are ill-defined, time-dependent or hard to extract
- Size of a bar = e.g., A2, Qb but see e.g., Ghosh+25
- Mass, kinematic structure



## The Zoology

Molecular CO(2-1) Morphologies in 90 PHANGS-ALMA Galaxies

Spiral arm classification



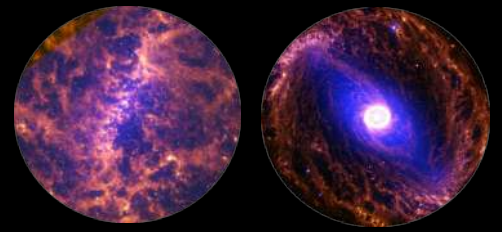
Credit: PHANGS/stuber

Credit: PHANGS / Sophia Stuber



Can we establish a reference pathway for

- bar formation ?
- bar-driven evolution ?



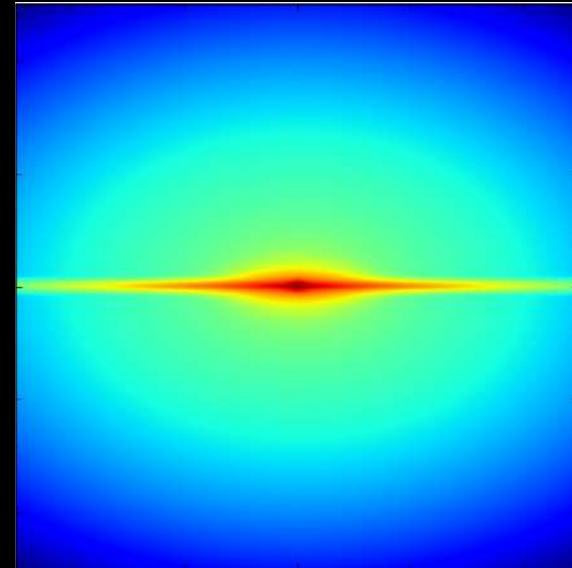
## Difficulties – Simulations / Theory

- Idealised simulations (since the 1980s!)
  - ▷ Many parameters to consider
    - Gas fraction and extent, disk extent, mass concentration, geometry
    - Dark matter distribution and graininess
    - Bulges, really? [spherical bulges don't exist]
    - Internal dynamics, ...

⇒ Initial conditions are an **artificial** setup

*No disc form like that → that seed is never realised*

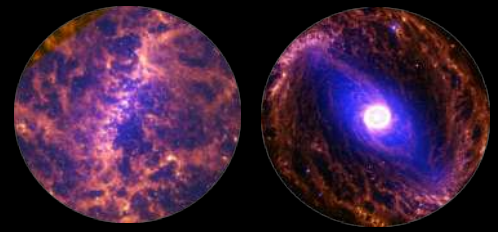
- Basic Physical concepts may need an update
  - ▷ e.g., Inner Lindblad Resonances, see Sormani, Sobacchi, Sanders 2024





Can we establish a reference pathway for

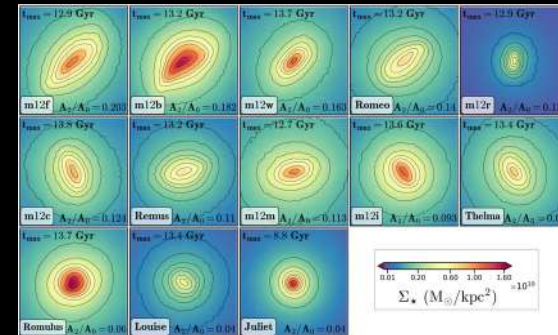
- bar formation ?
- bar-driven evolution ?



## Difficulties – Simulations / Theory

- Simulations in cosmological context (Zoom-in)
  - ▷ Are those [individual] bars the ones we see ?
  - ▷ Is that the right [global] population ?

→ NO (my 2 cents)

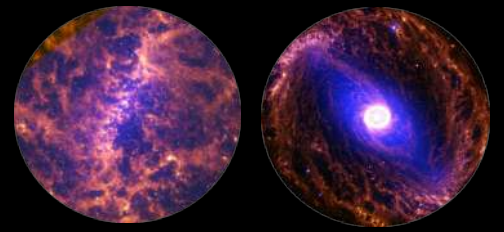


Ansar+24  
[FIRE-2]

- What are the right metrics ?
  - ▷ *Certainly not something like “look at those bars!” ;-)*

Can we establish a reference pathway for

- bar formation ?
- bar-driven evolution ?



## Difficulties – Simulations / Theory

- **We do not have – yet – a robust picture** [my 2 cents again]
  - ▷ The literature is inconsistent
  - ▷ Each new study has a “rather” narrow range of applications
  - ▷ Most suffers from biases (samples/populations, numerics, etc)
- **BUT** = A lot has been done → possibly no need for new simulations

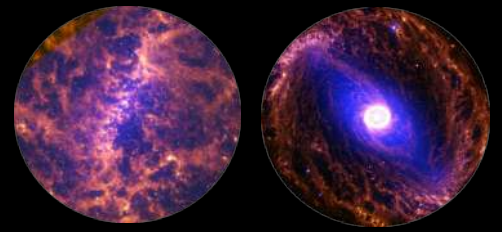
*I believe*

*We need to establish*  
What we **know**  
What we do **not** know  
What **needs** more work



Can we establish a reference pathway for

- bar formation ?
- bar-driven evolution ?



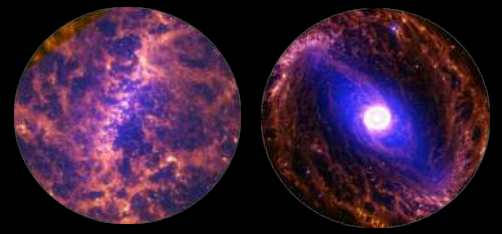
## What we know

- Growth seems to happen in 2 main phases, 4 sub-phases
- Inner mass concentrations delay the first growth phase
- Buckling seems to be a common (universal?) feature
- Building up mass towards the centre may be a common thing
- There “seems” to be some mass-driven trends:
  - ▷ Bar fraction
  - ▷ Structures & Morphology
    - ♦ Gas and SF distribution
    - ♦ Stellar distribution and kinematics

*Are those evolution-driven or a direct mass dependence ? (or both)*

Can we establish a reference pathway for

- bar formation ?
- bar-driven evolution ?



## What we do not know

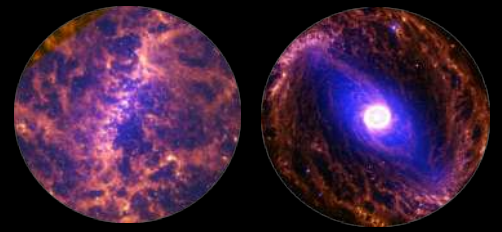
- What **sub-volume** of the full solution space real bars occupy
  - ▷ This is redshift and environment dependent
- Timescales = How fast things go and their dependencies / coupling
  - ▷ Relative to other evolutionary-driven processes
- How disruption events impact seemingly monotonic processes
  - ▷ Quantitative picture of the impact of feedback

What metrics to use to compare simulations and observations  
Which predictions to test



Can we establish a reference pathway for

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- bar-driven evolution ?

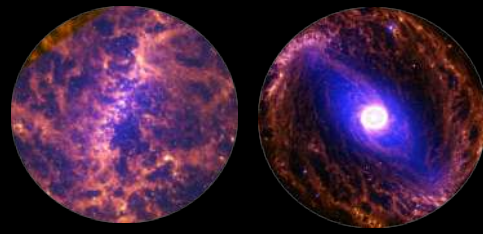


What we may need to work on

- Establish typical pathways for bars with timescales
  - ▷ Secular versus externally-driven evolution
- Establish metrics and criteria (predictions) to compare with

Bars being important agent of the evolution of discs  
*As long as we don't have that right...*

⇒ It is key to know what we can say & predict,  
& what we cannot say



# Time evolution

⇒ hydrodynamical simulations  
(and Ramses)





molecular gas  
probing  
~100,000 clouds  
Leroy et al. (2021a)

90+ galaxies  
Pis Schinnerer; Blanc; Leroy;  
Faesi; Chevance

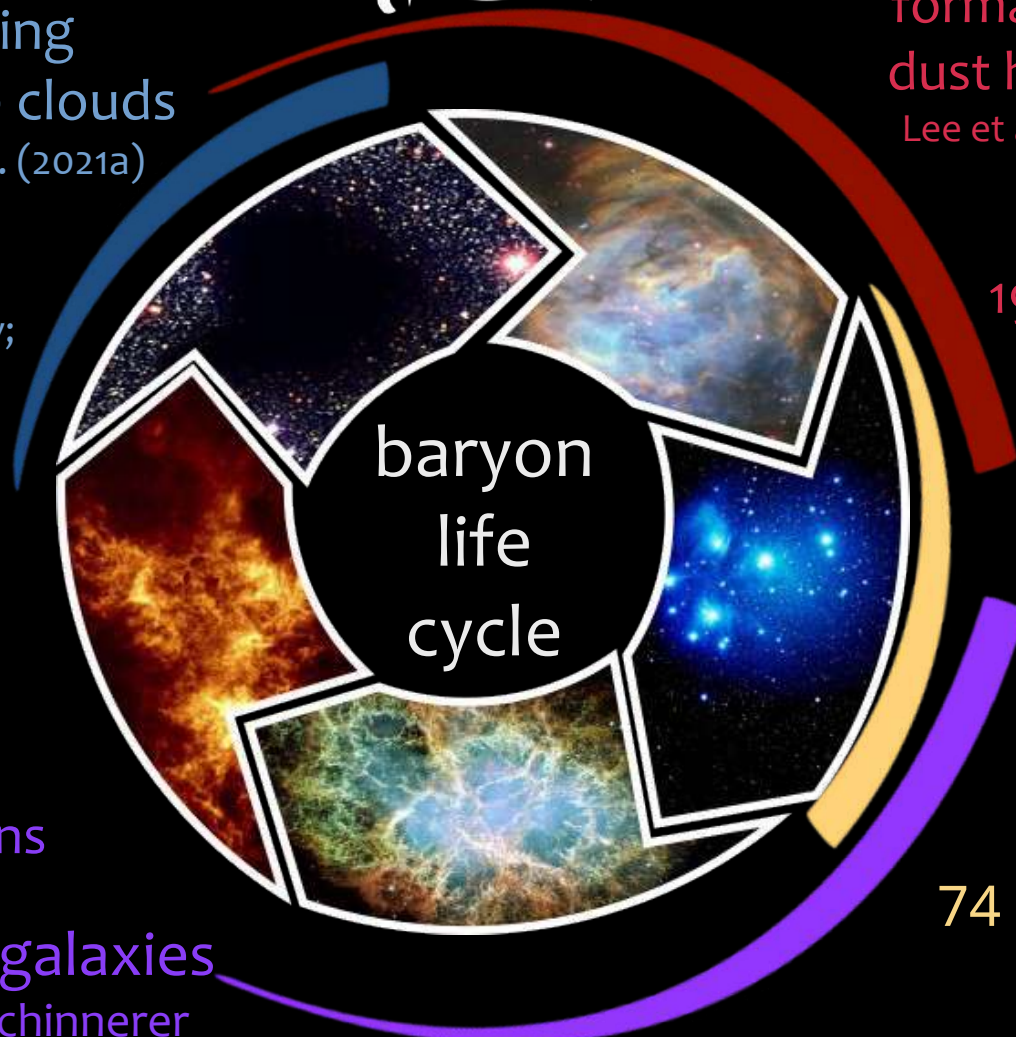
stellar feedback  
probed by  
~25,000 nebulae  
+ stellar populations  
Emsellem et al. (2022)



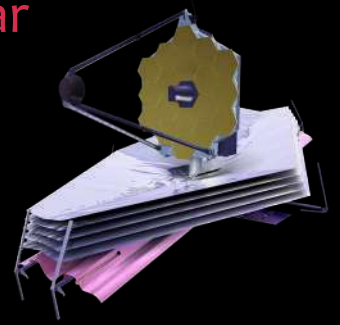
**MUSE**  
multi unit spectroscopic explorer

19+ galaxies  
PI Schinnerer

**Phangs**



embedded star  
formation &  
dust heating  
Lee et al. (2023)



19 + 55 galaxies  
PI Lee + PI Leroy

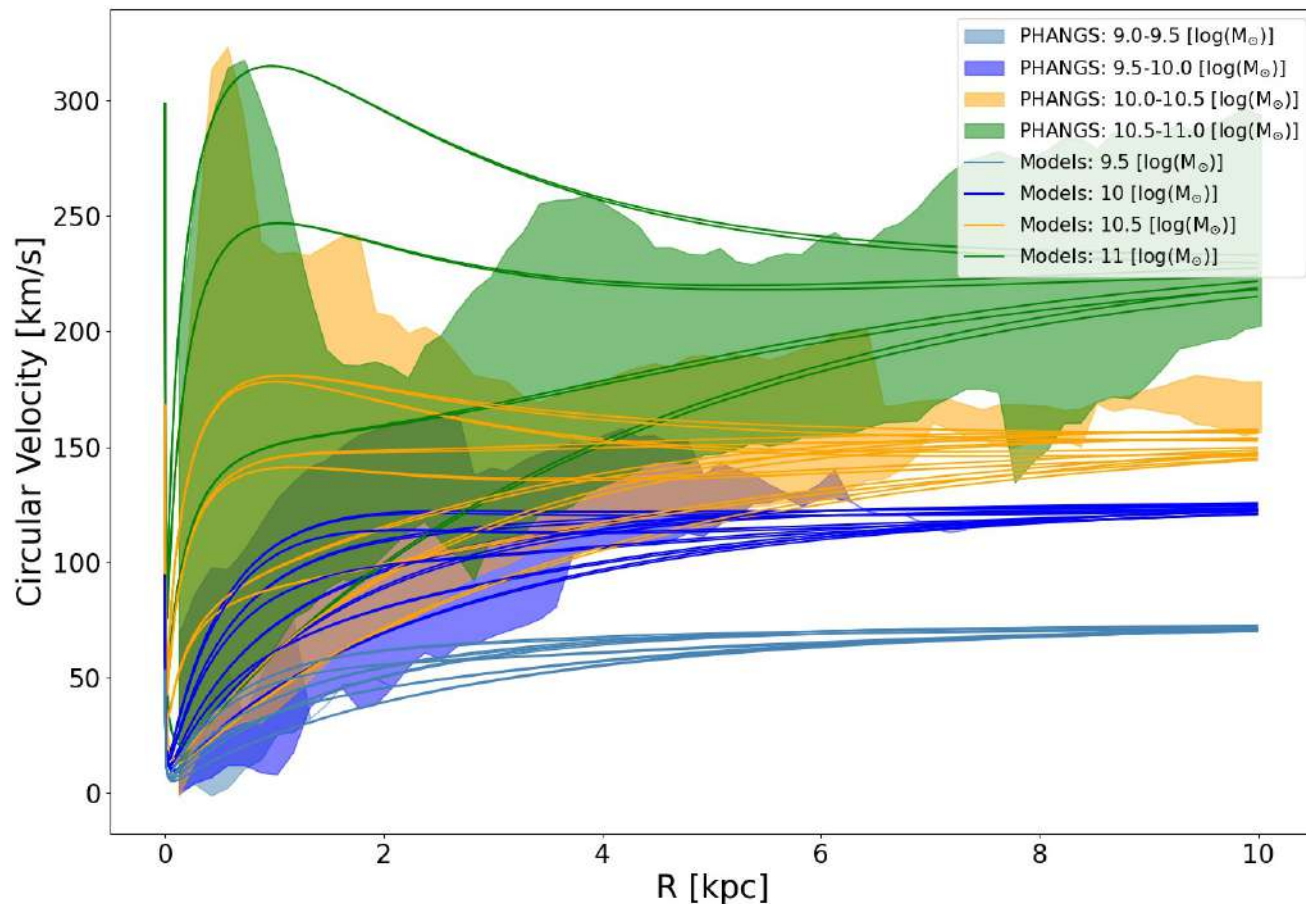
~80,000  
stellar clusters  
Lee et al. (2022)



74 galaxies  
PI Lee

# Generic Simulations of isolated discs

Verwilghen+ 2024



## MGE ICs + AMR RAMSES

- ⇒ Gas, Stars, Dark Matter
- ⇒ Star formation, feedback winds, SNI
- ⇒ ~12 pc cells
- ⇒ 3 Gyr evolution

⇒ Grid of 54 models  
spanning the  
*Phangs* sample



M104

V band

Emsellem 1995  
Baes et al. 2011

MGE model

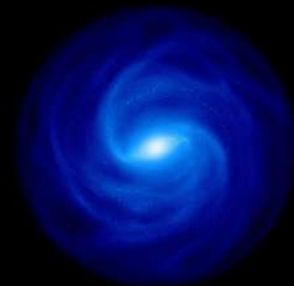
NGC1277

Emsellem 2015

Parametric (1-3D) & profiles / images

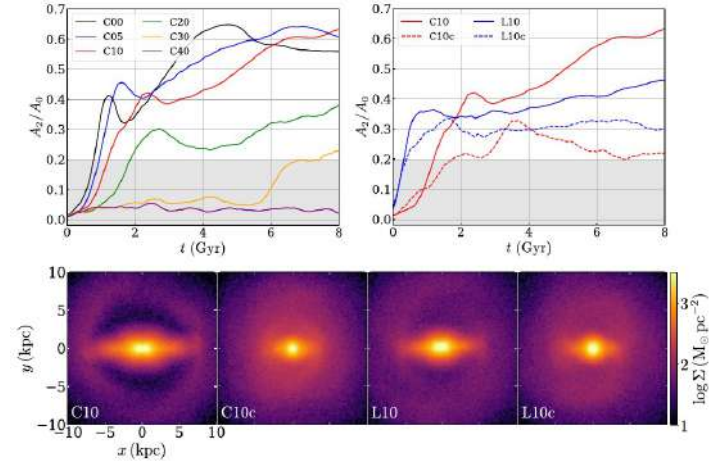
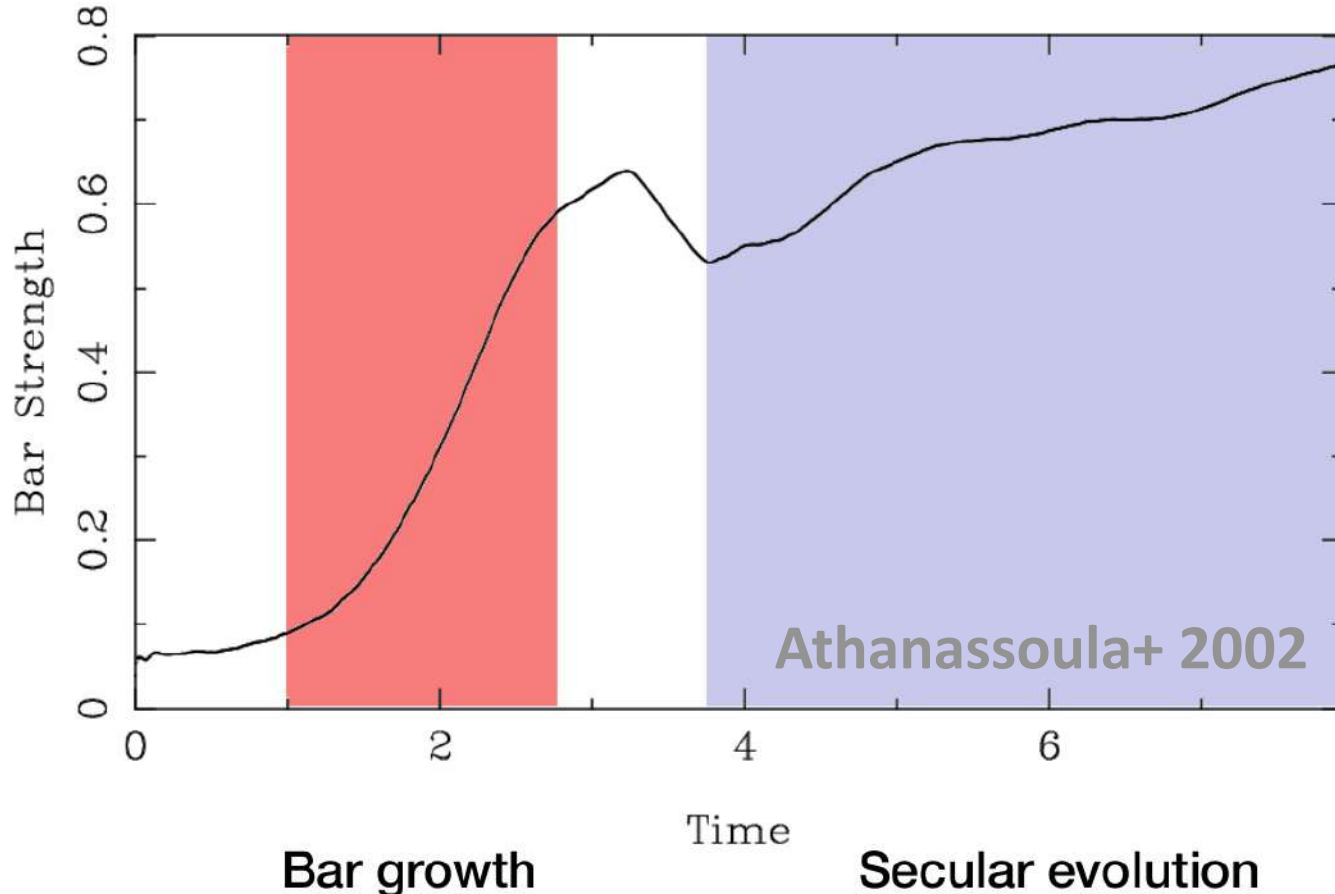
3D Projection/deprojection  
Gravitational Potential, density waves,  
Generalised Jeans Equations

Stars + gas + DM  
⇒ Gadget, Ramses



# Bar evolution: 2 phases

⇒ Short-term growth versus Long-term evolution



Jang et al. 2023



# Bar evolution: 4 phases

Verwilghen+ 2024



⇒ Low vs High mass systems → different **depletion times** ?

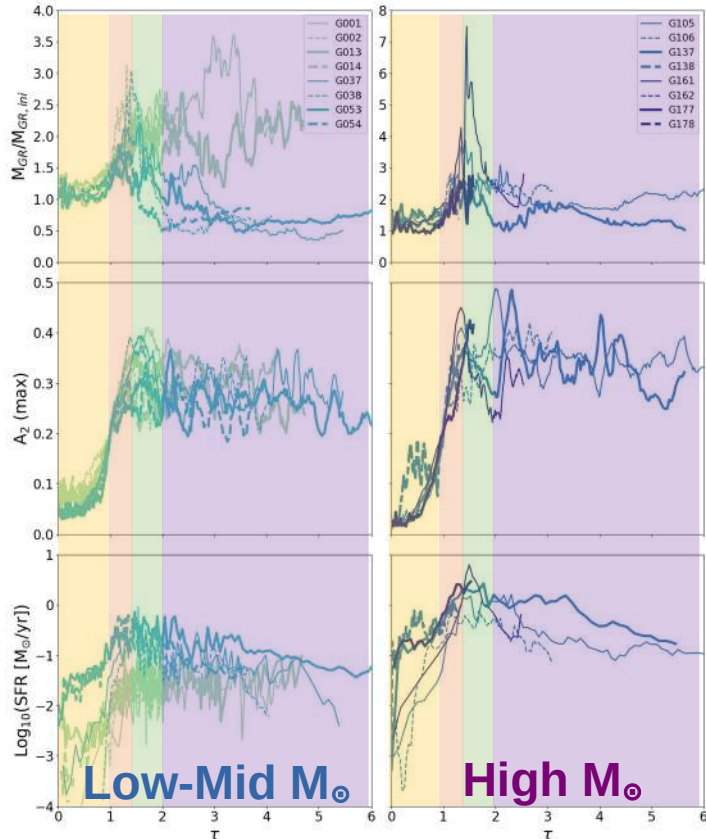
⇒ **Phases** : formation, burst, depletion → central concentration

Phangs

M<sub>gas</sub>

Bar  
strength

SFR

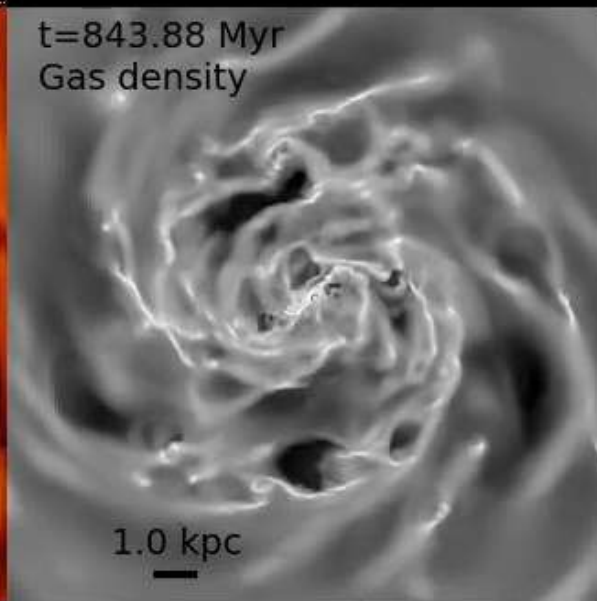
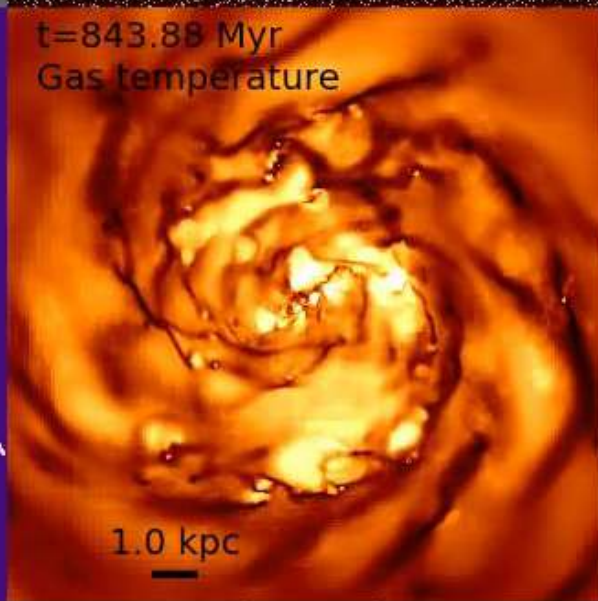
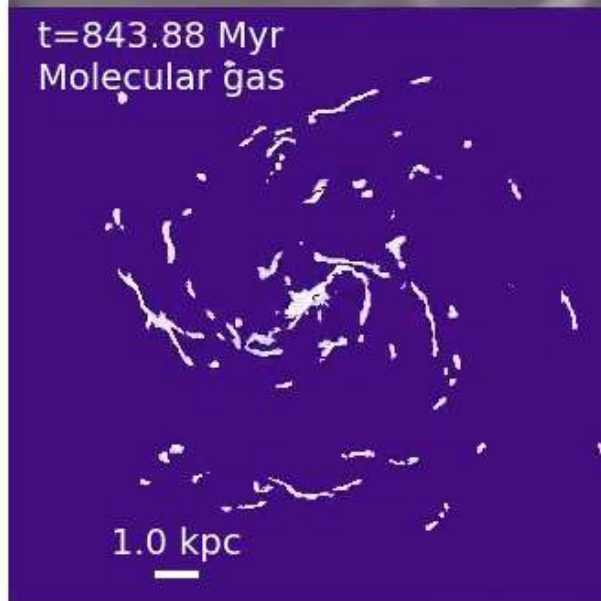
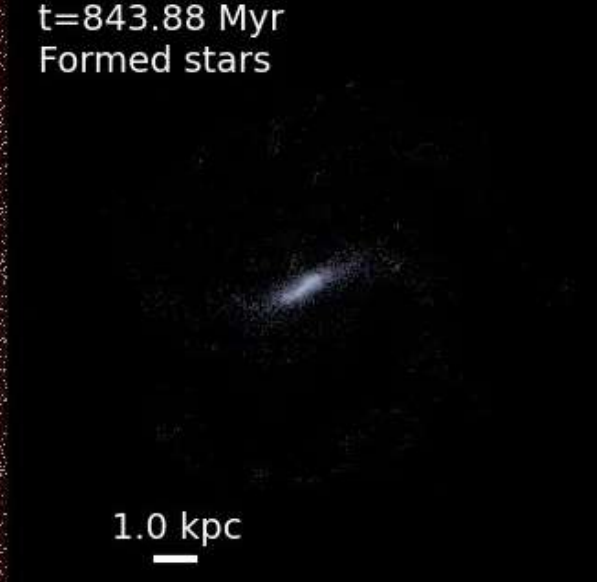
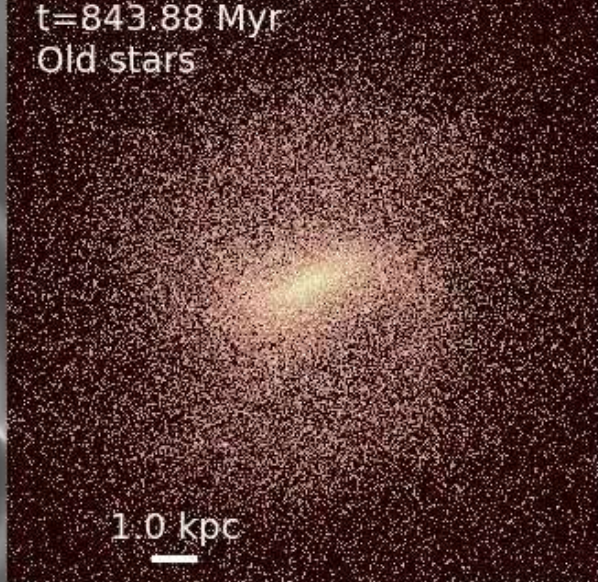
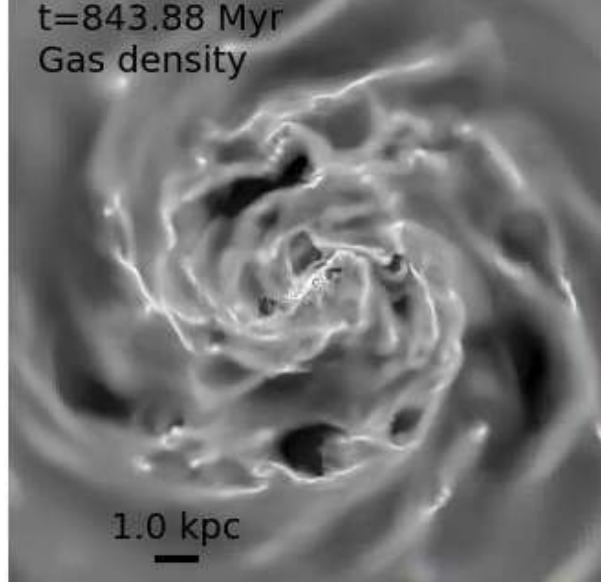


A)  $\tau \in [0, 1]$ : bar formation

B)  $\tau \in [1, 1.5]$ : O<sub>gas</sub> ↗

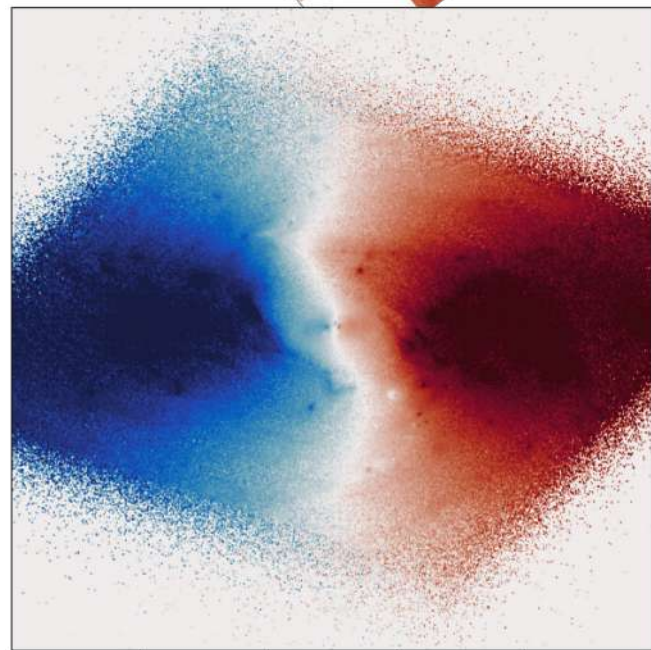
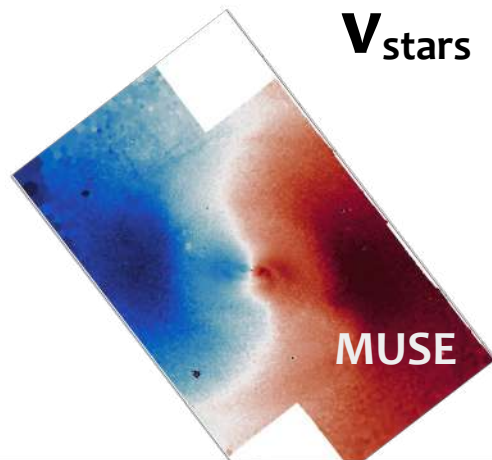
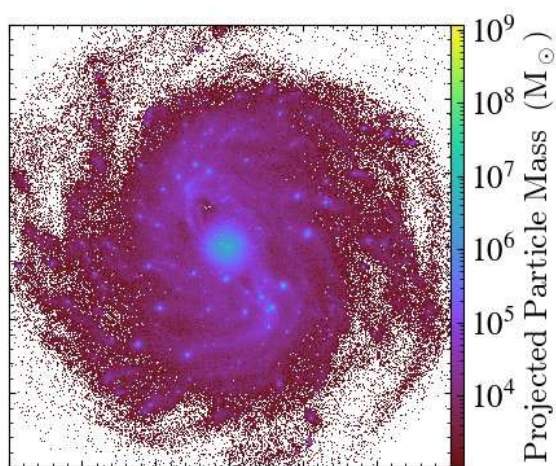
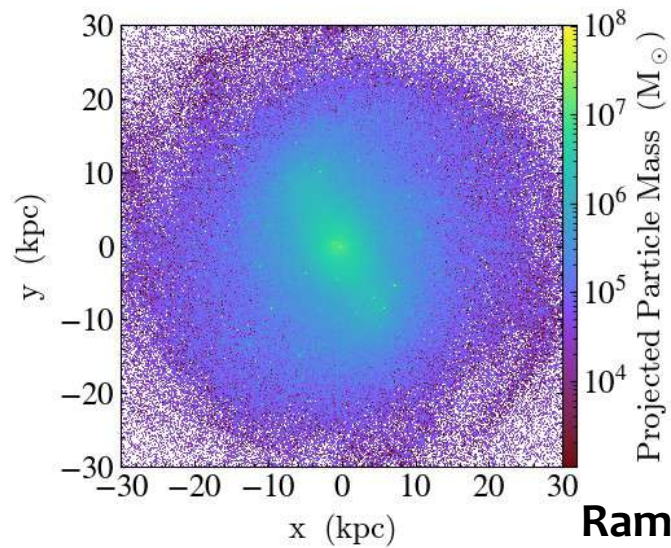
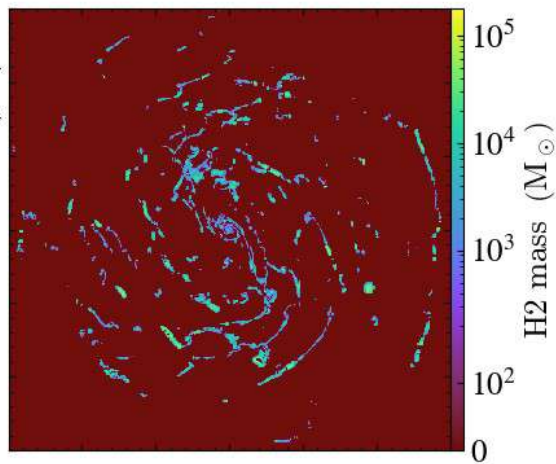
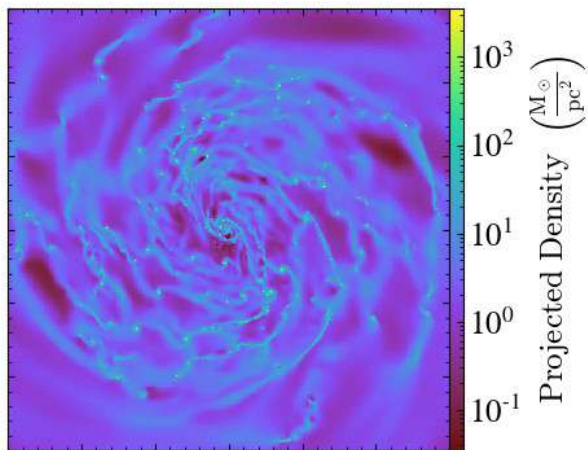
C)  $\tau \in [1.5, 2]$ : Starburst

D)  $\tau \in [2, end]$ : Post-burst  
+Long-term  
consumption/depletion





# NGC 1365

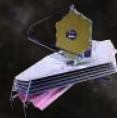


Ramses hydro-dynamical simulation (Emsellem+ in prep)



# Central Starburst in NGC1365

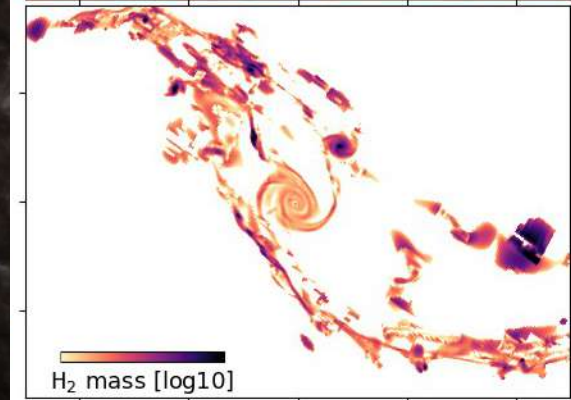
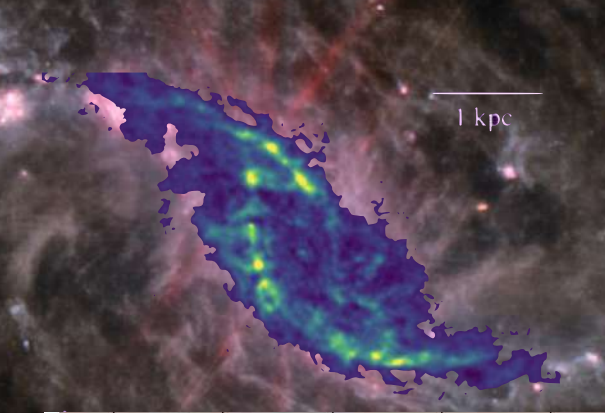
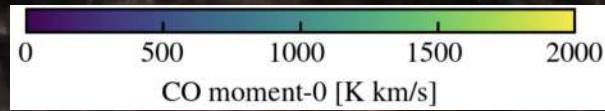
& Bars



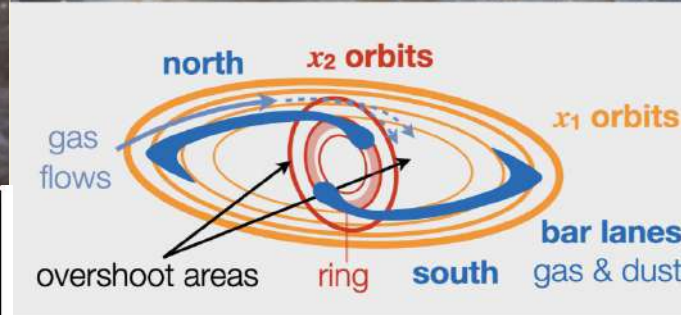
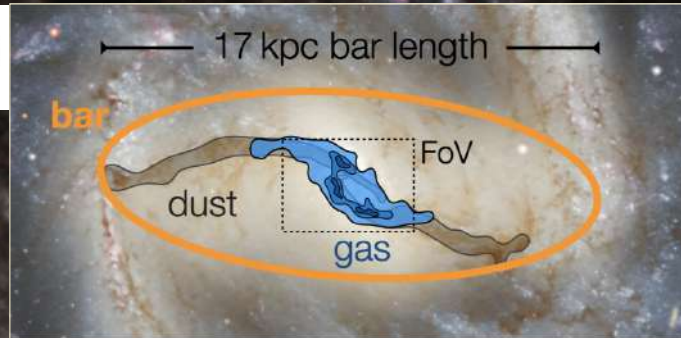
Credit: NASA/ESA, CSA; PHANGS, J. Schmidt (Lee et al. 2023)

21 $\mu$ m-11.3 $\mu$ m-7.7 $\mu$ m-10 $\mu$ m

# Central Starburst in NGC1365



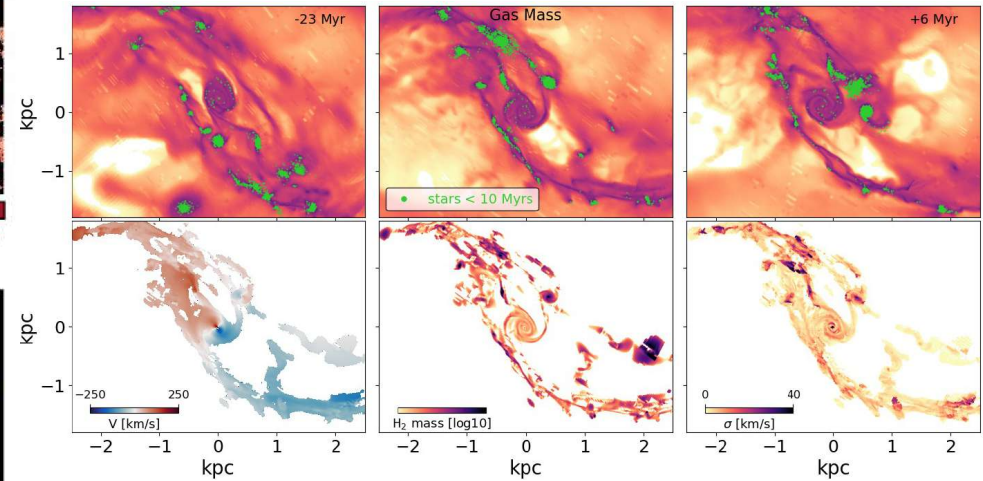
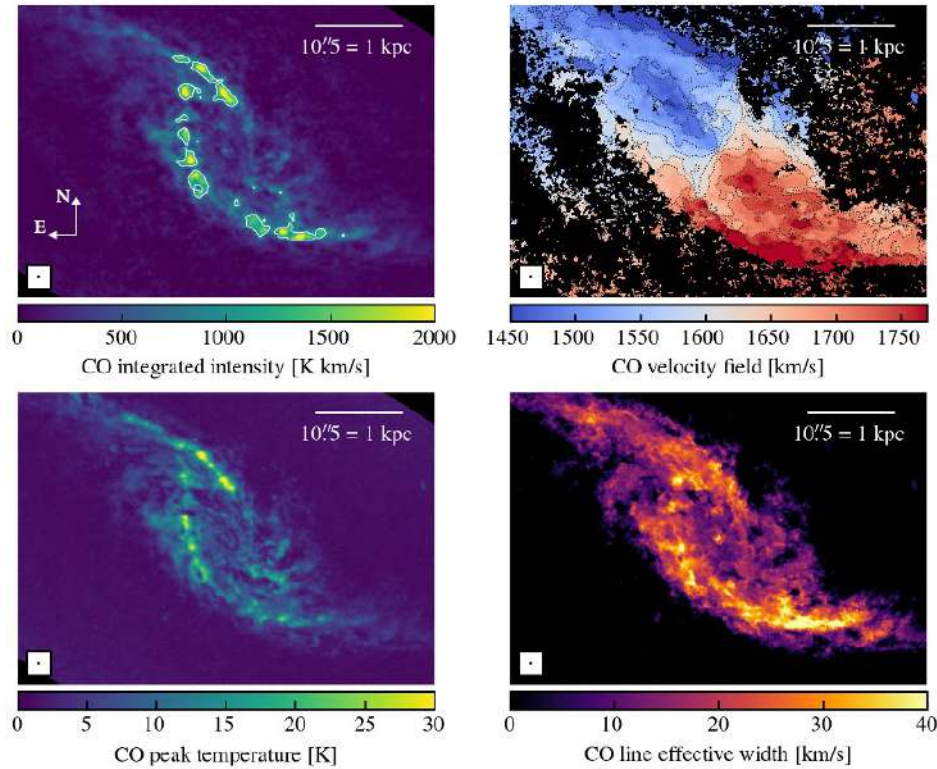
Hydro-dynamical simulation



Schinnerer et al. (2023)

21 $\mu$ m-11.3 $\mu$ m-7.7 $\mu$ m-10 $\mu$ m



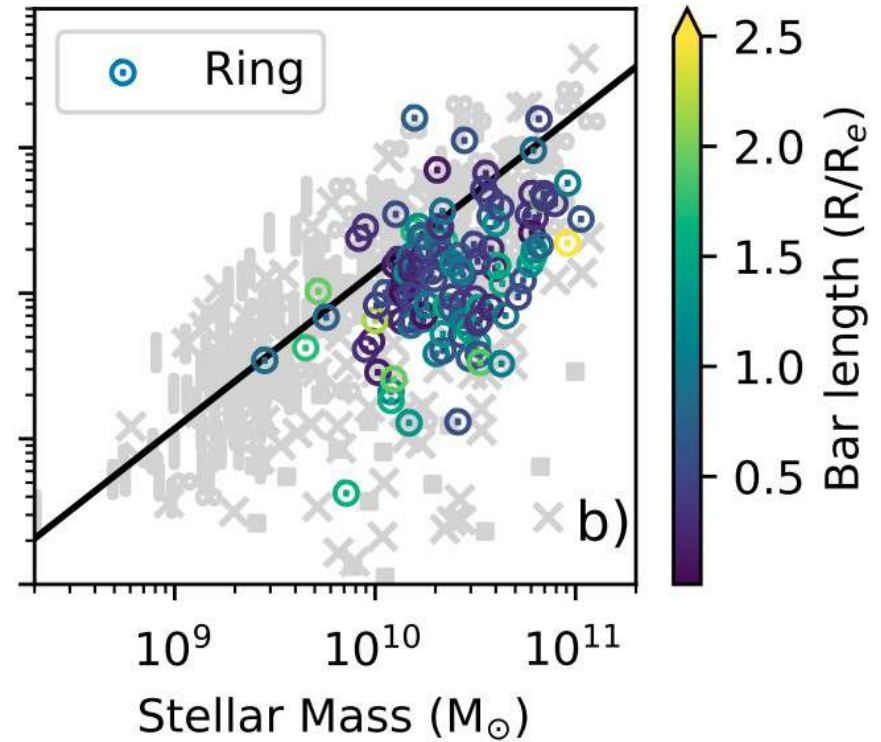
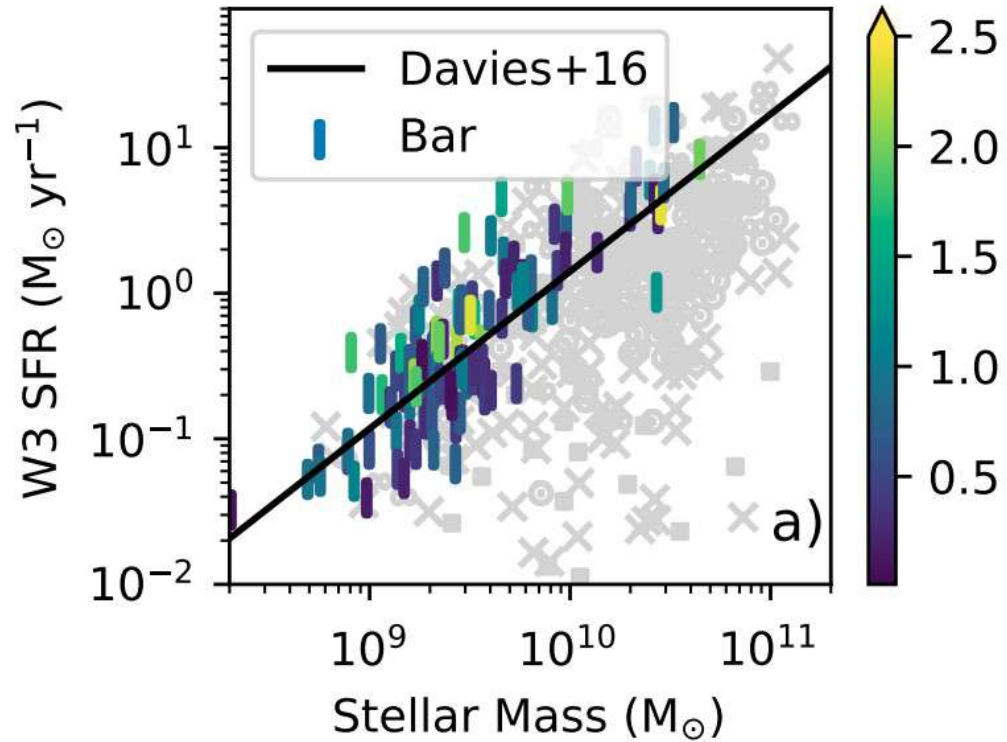


Very rapid evolution  
Cloud pre-processing along the bar  
Inhibiting central SF (self-gravity)



# Where do stars form & Why ?

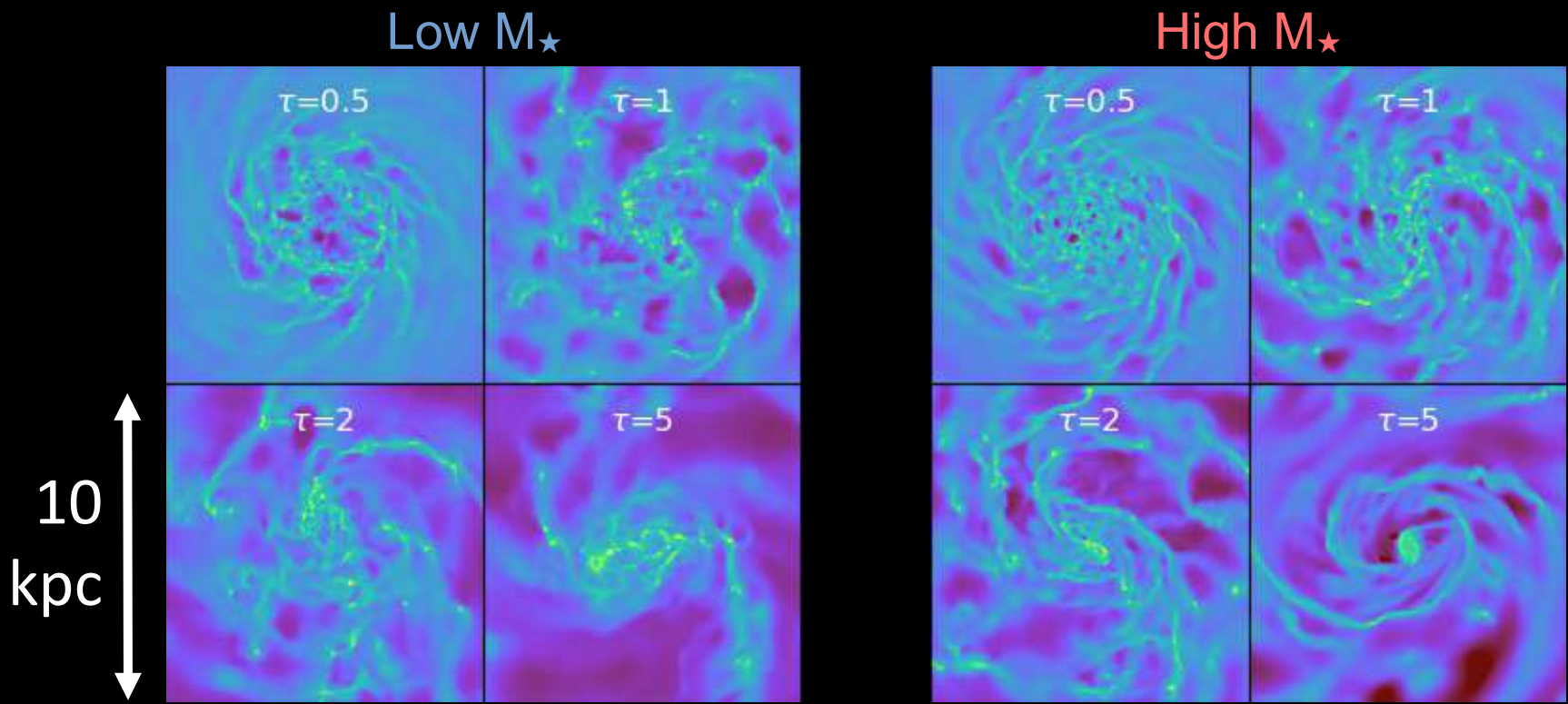
Fraser-McKelvie et al. 2020



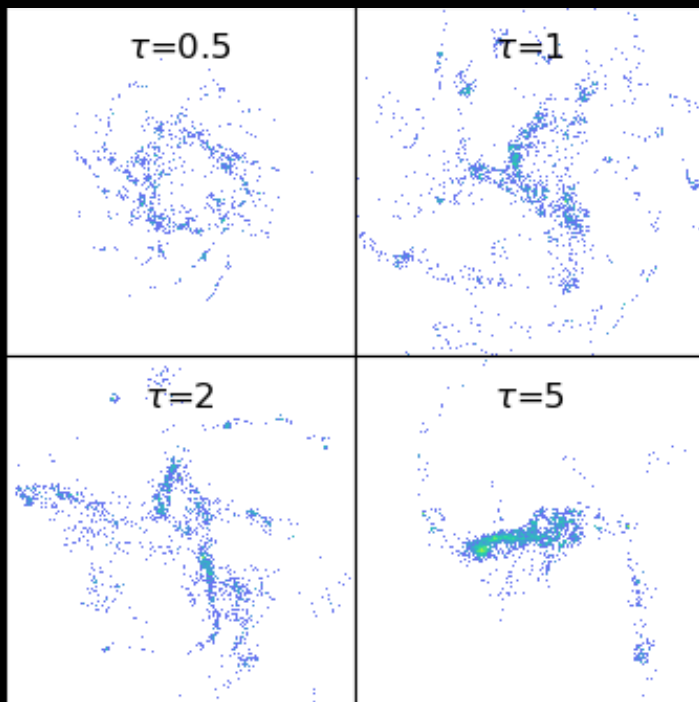
**Dependence of SF on stellar mass**

⇒ lower-mass = bar

⇒ higher mass = rings / central

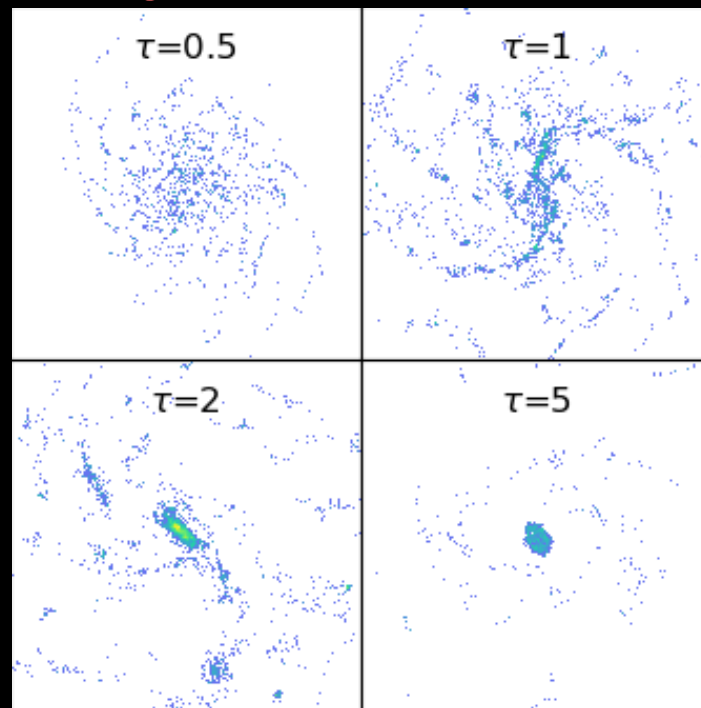


Low  $M_{\star}$  : Bar but no reservoir



SF along the bar

High  $M_{\star}$  : Bar + reservoir

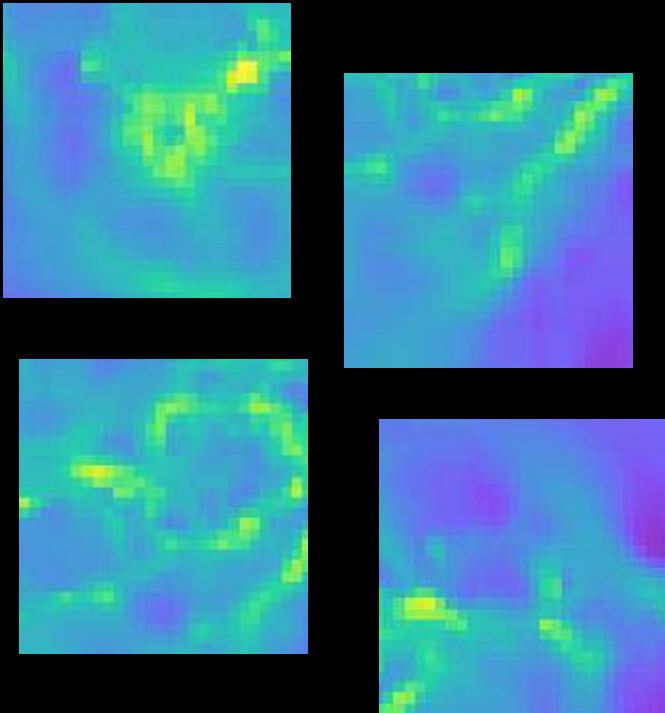


SF within the central reservoir

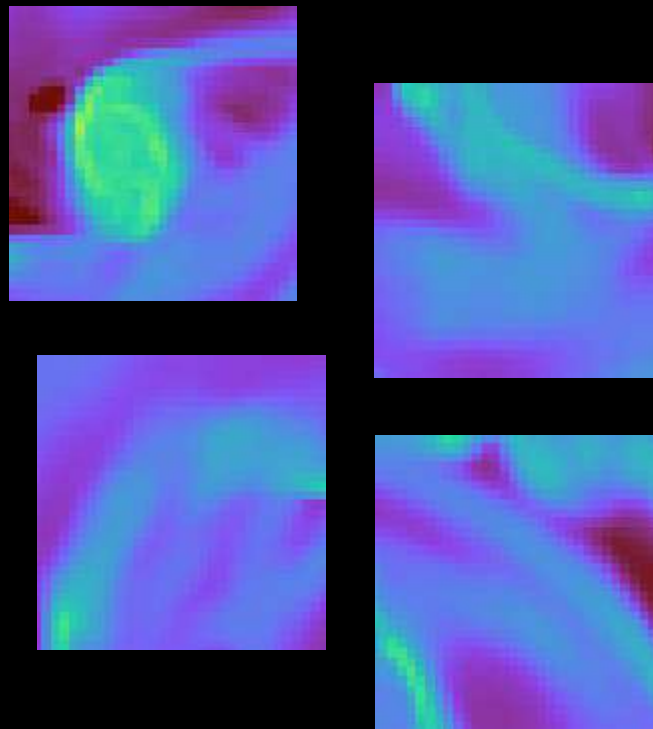
**Consistent with Fraser-McKelvie+2020**



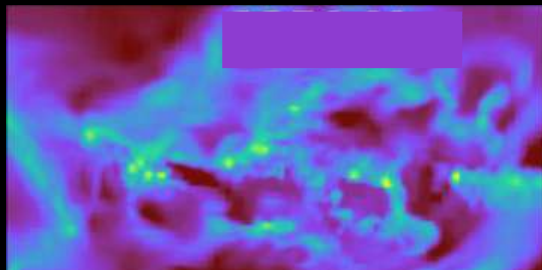
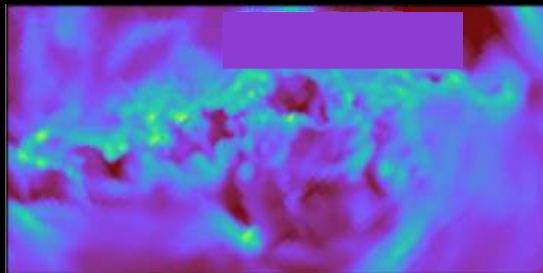
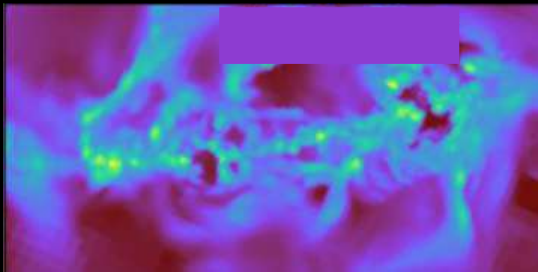
Low  $M_{\star}$  : where is the bar ?



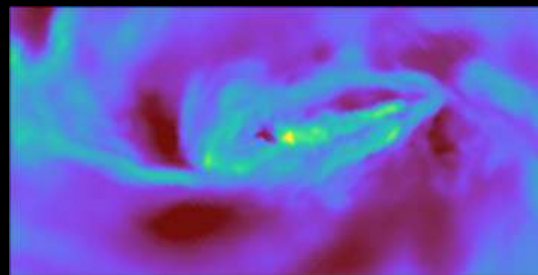
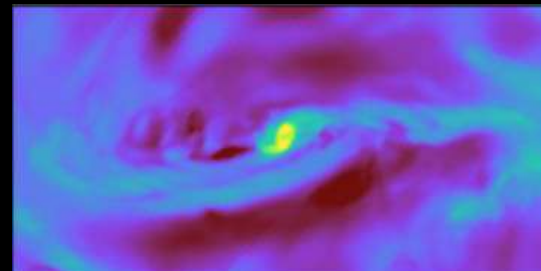
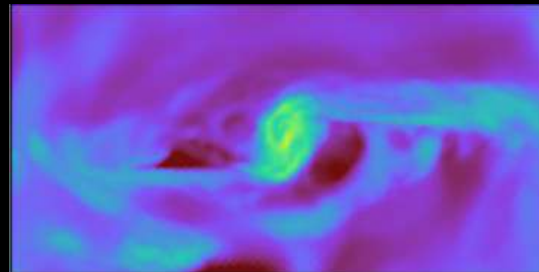
High  $M_{\star}$ : Bar structuring



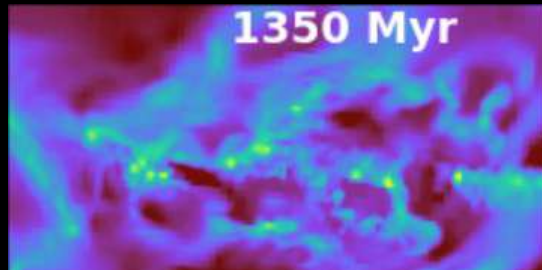
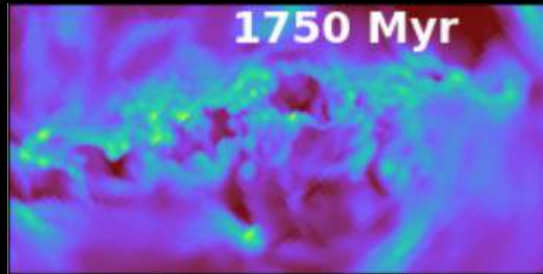
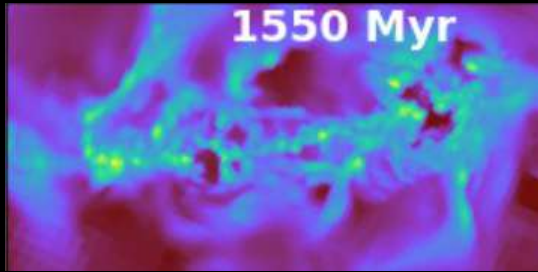
Low  $M_{\star}$  : evolution ?



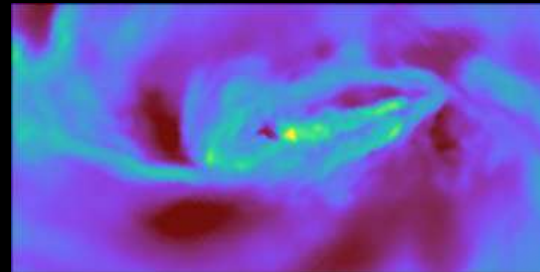
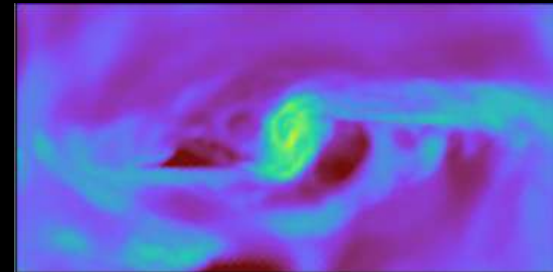
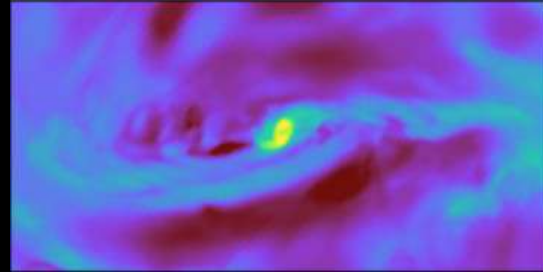
High  $M_{\star}$  : evolution !



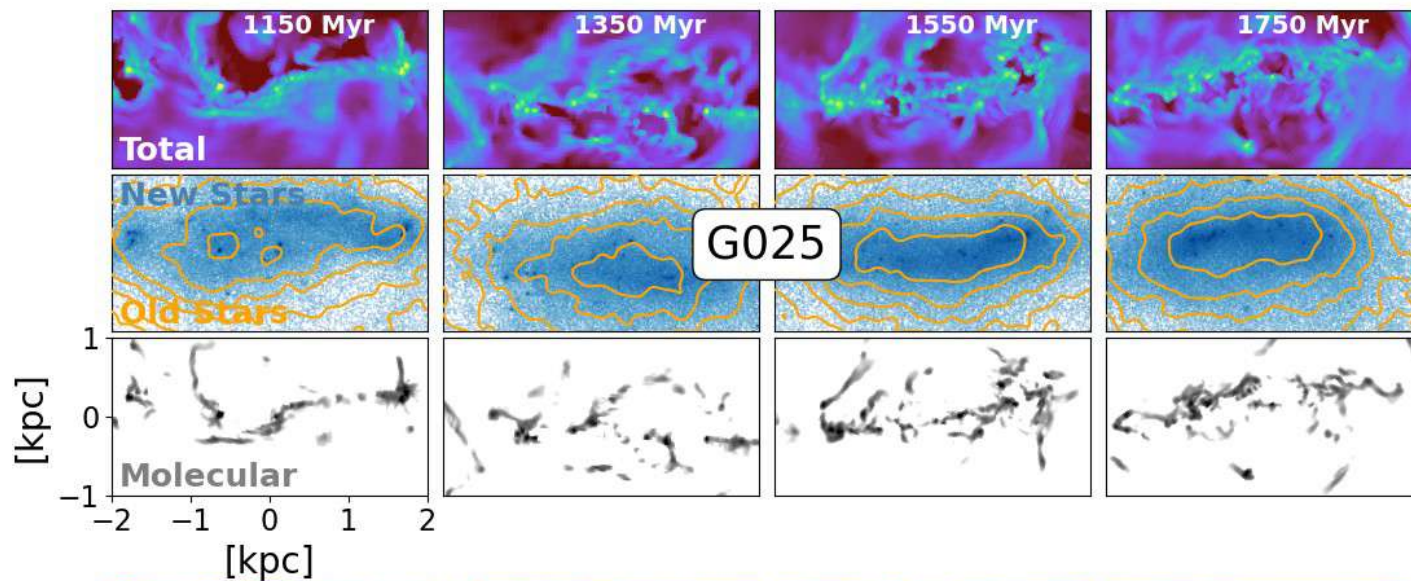
Low  $M_{\star}$  : evolution ?



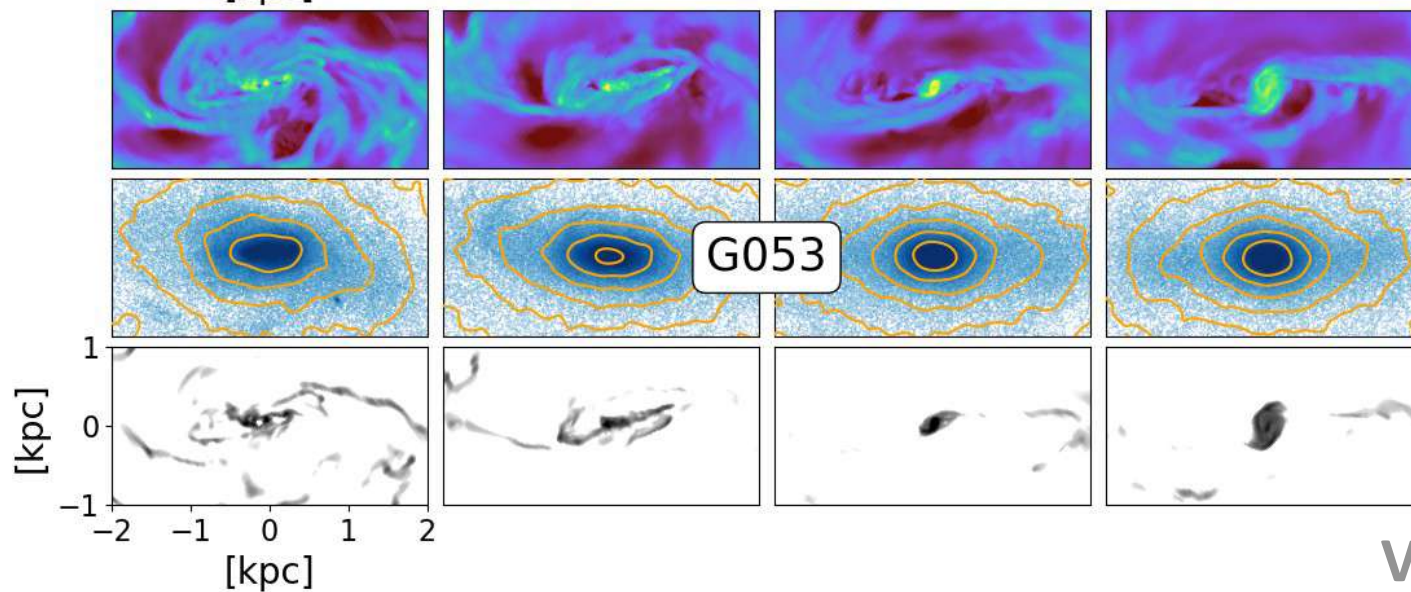
High  $M_{\star}$ : evolution !







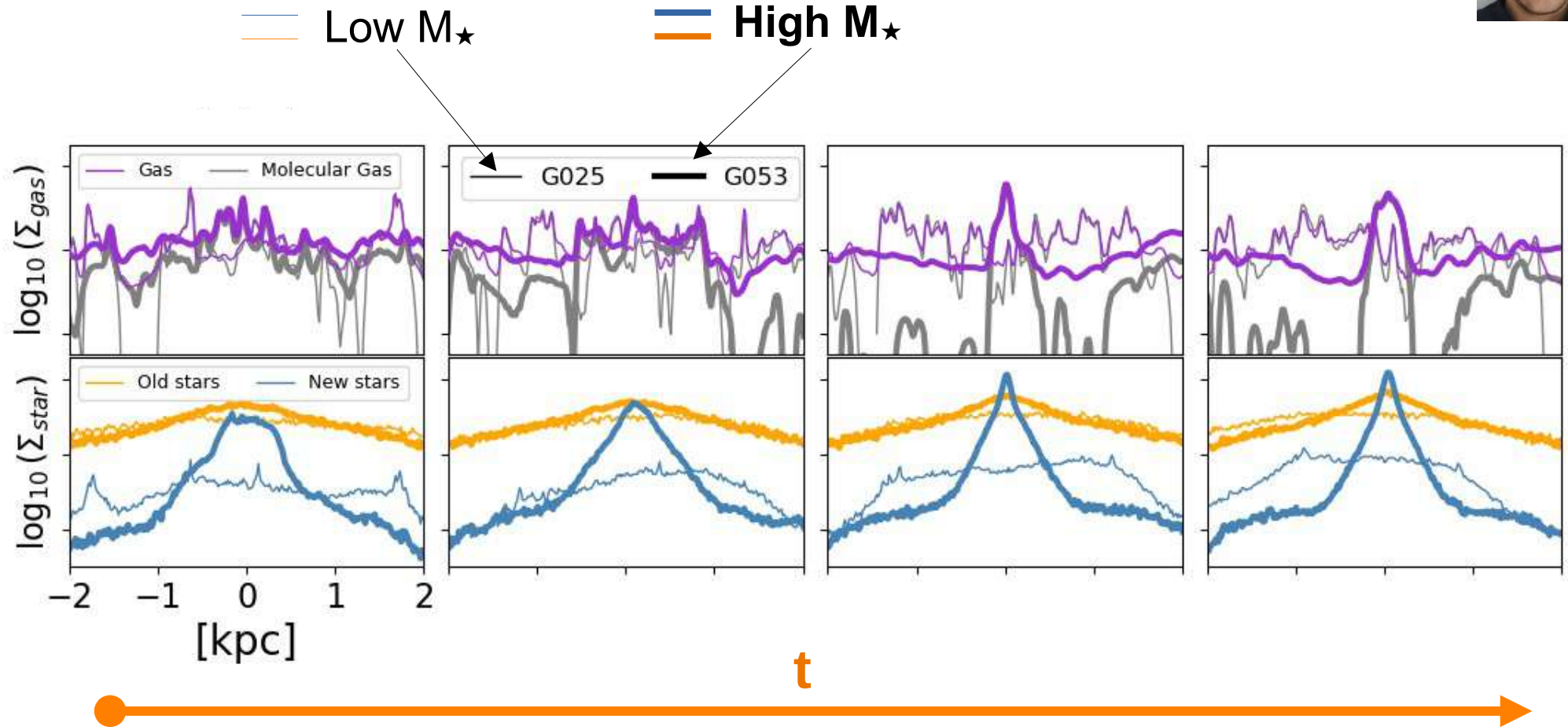
Low  $M_\star$



High  $M_\star$

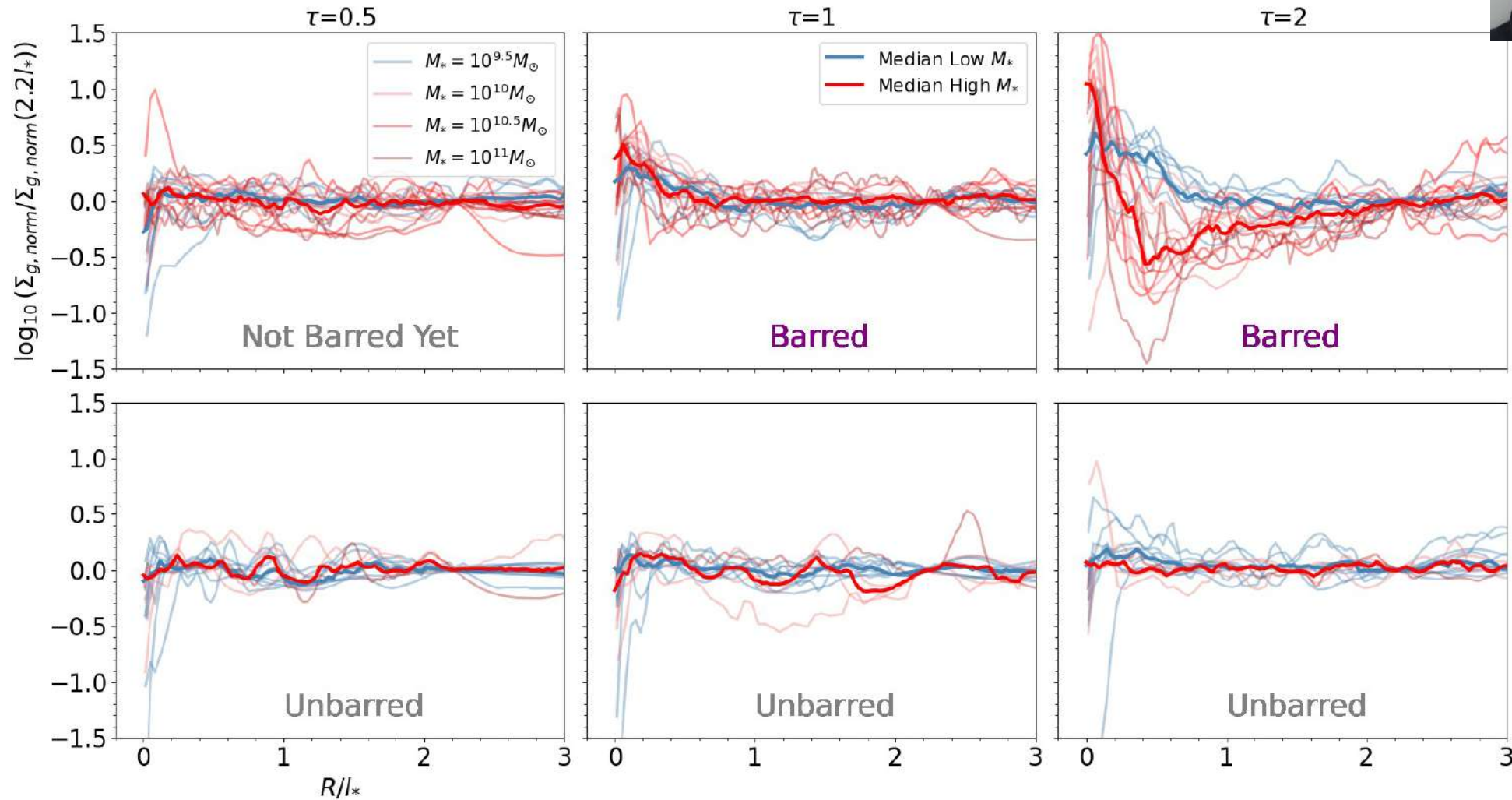
# Building of inner discs

Verwilghen+ 2025

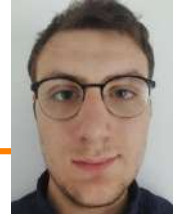


# Bar-driven evolution: deserts & peaks

Verwilghen+ 2025

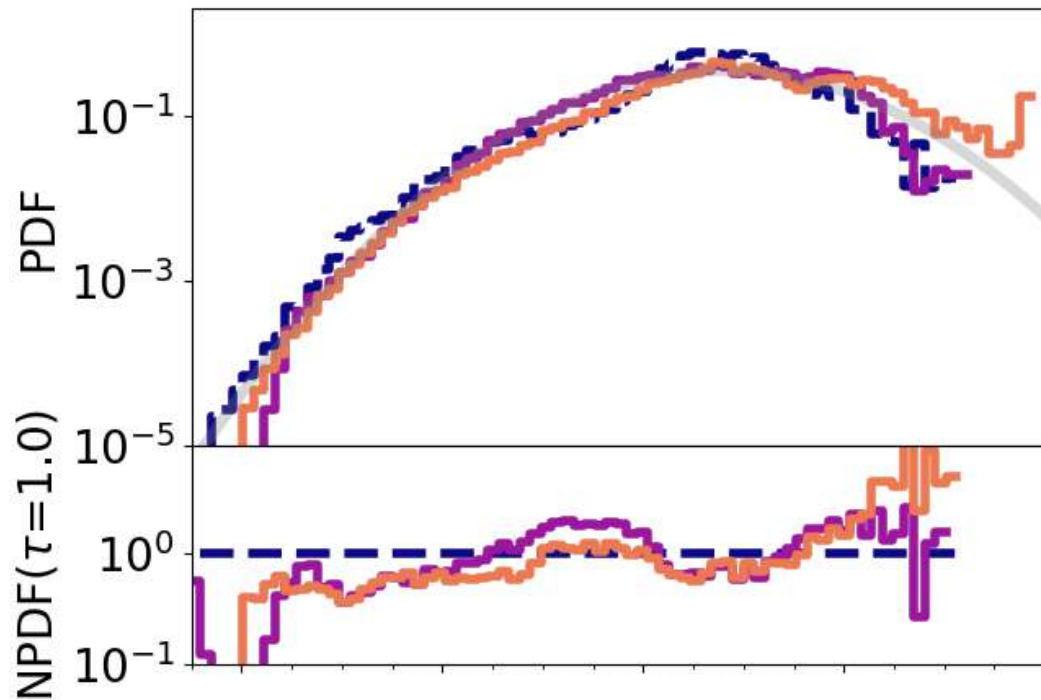






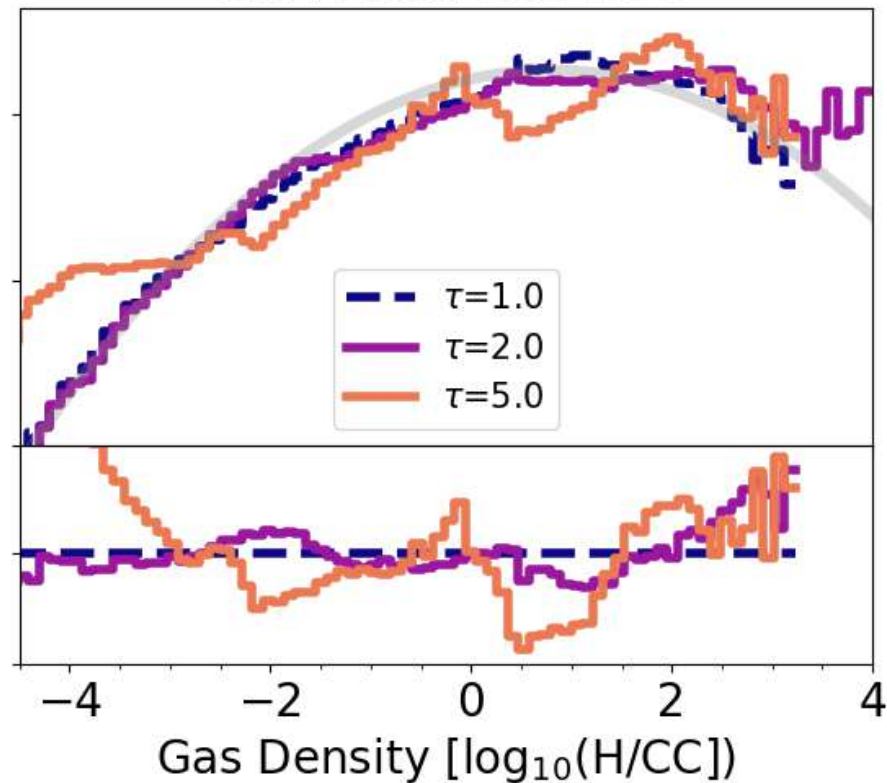
$10^{9.5} M_{\odot}$

G013M095F20L2B00



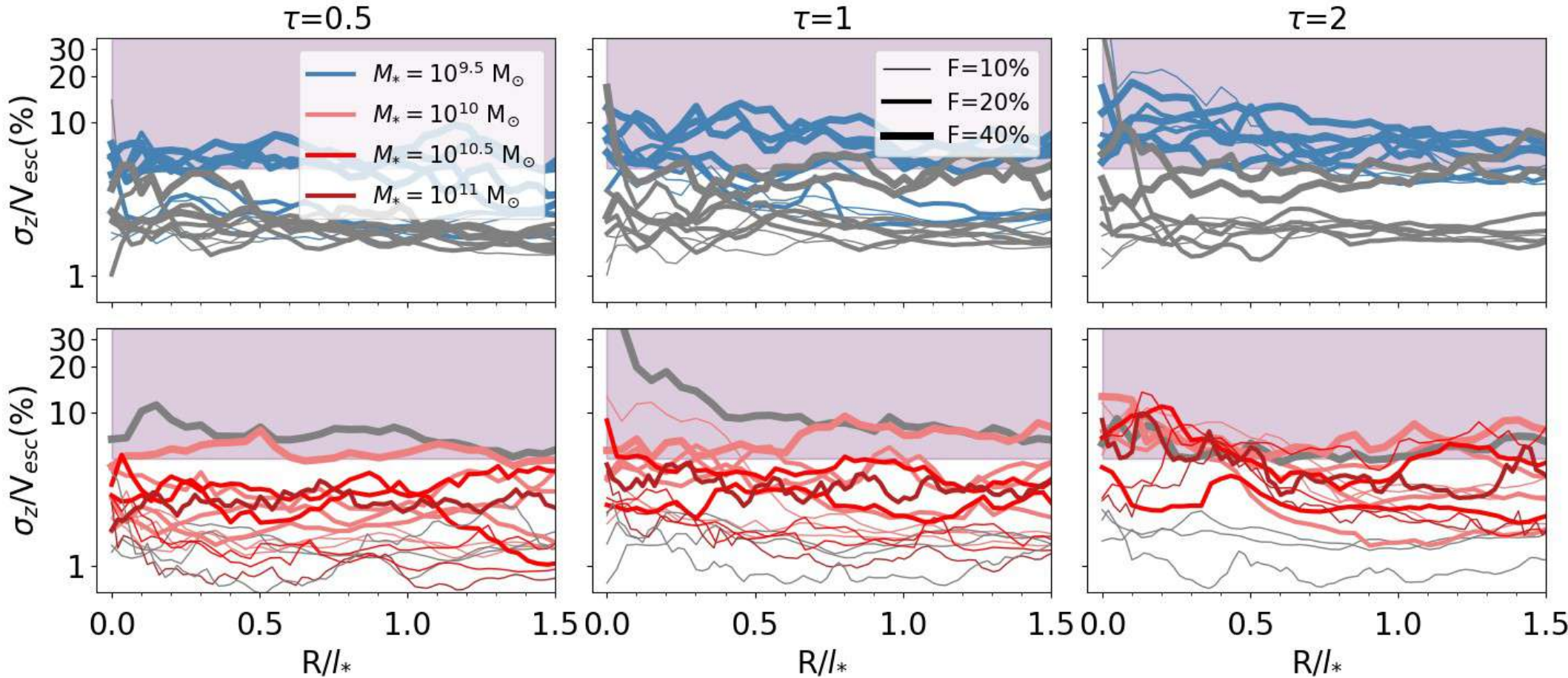
$10^{10} M_{\odot}$

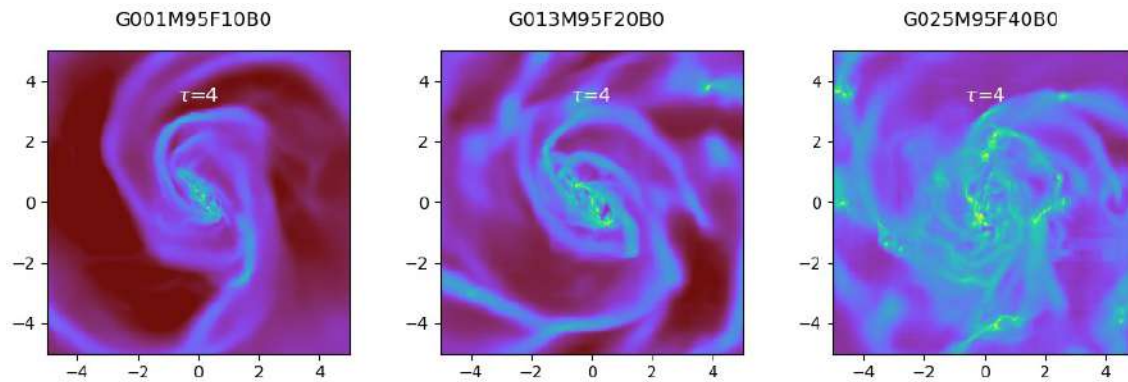
G037M100F10L2B00



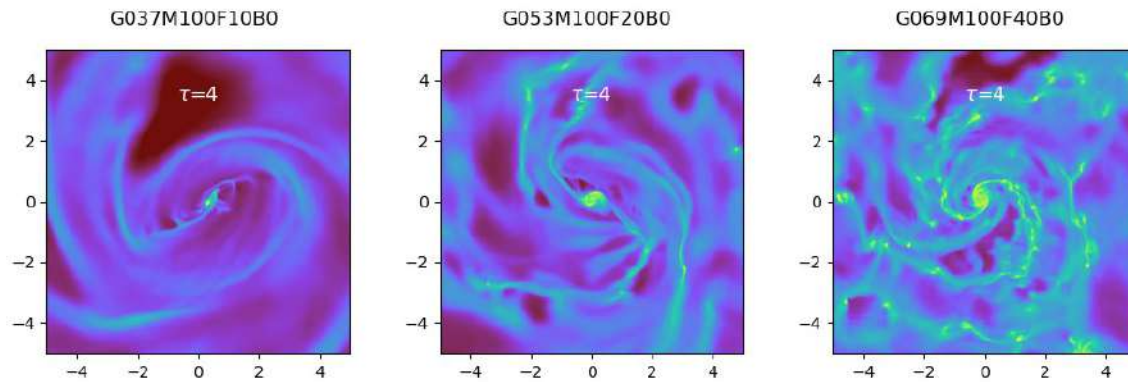
# Feedback !

Verwilghen+ 2025

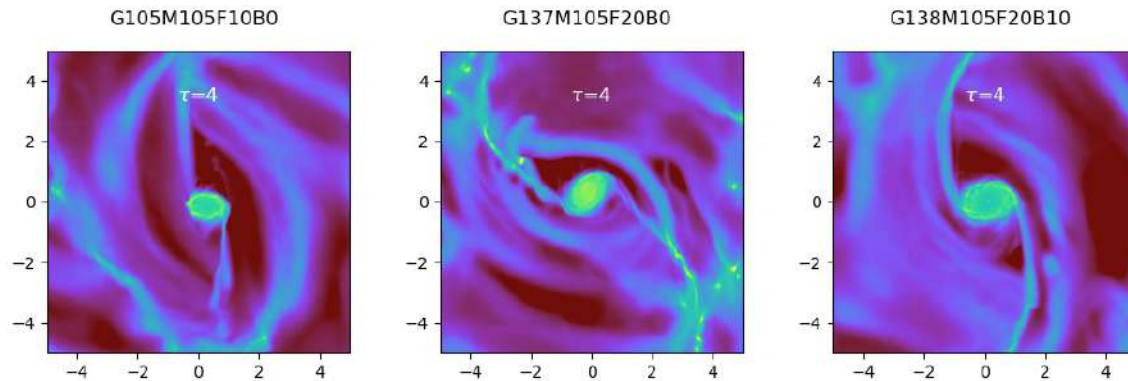




Low  $M_{\star}$



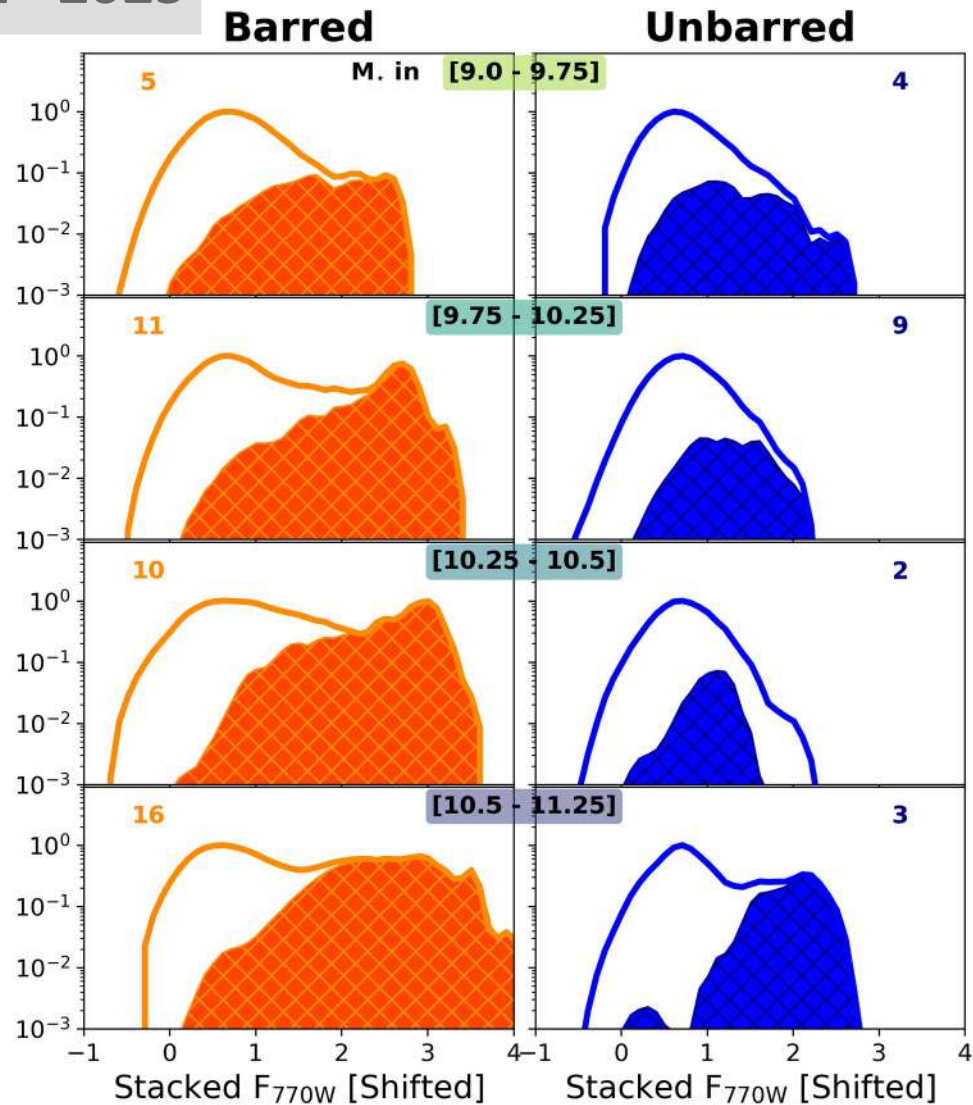
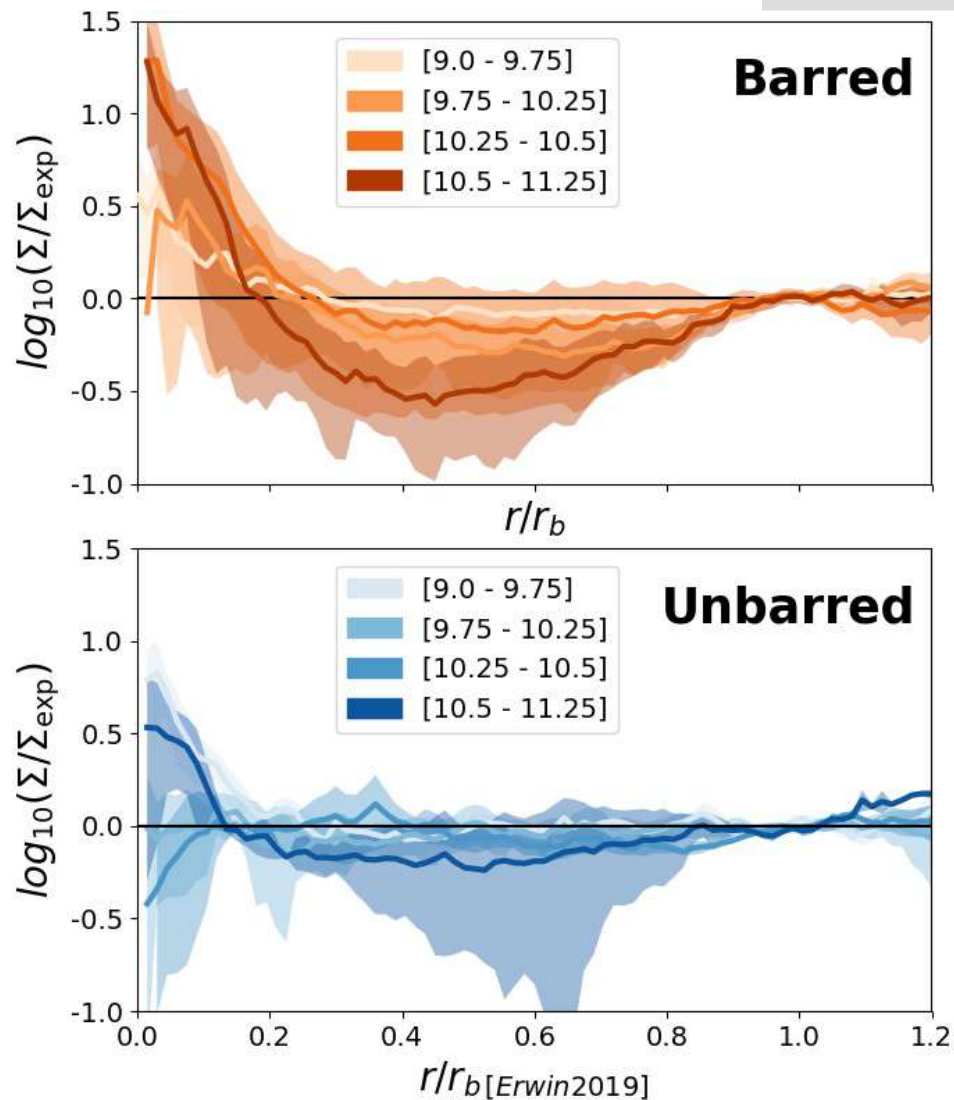
Mid  $M_{\star}$



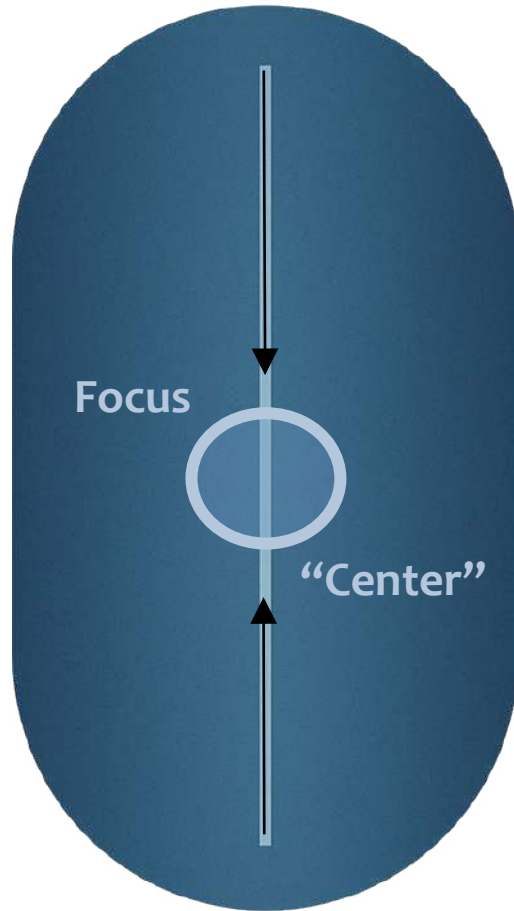
High  $M_{\star}$

About  
Timescales

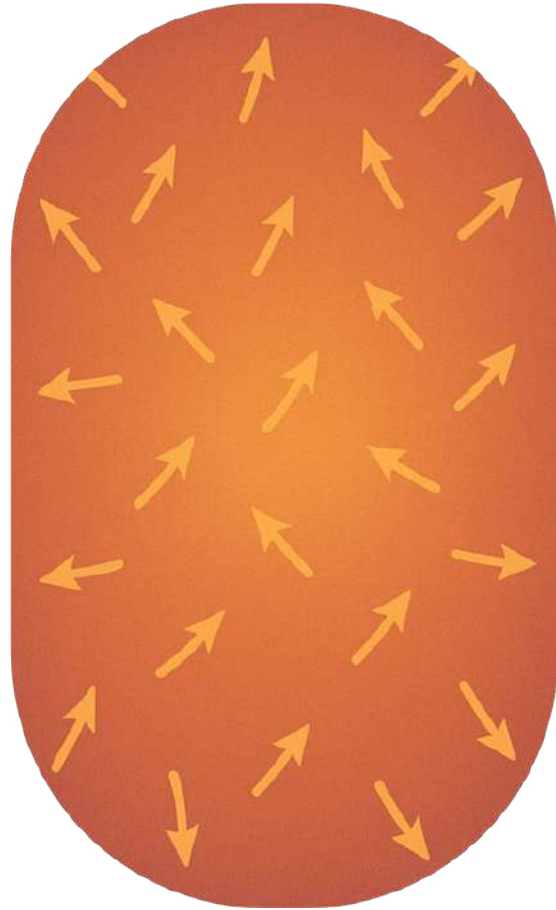




Convergent  
Laminar Inflow



Stellar Feedback  
Perturbation



Turbulent,  
Chaotic Flow

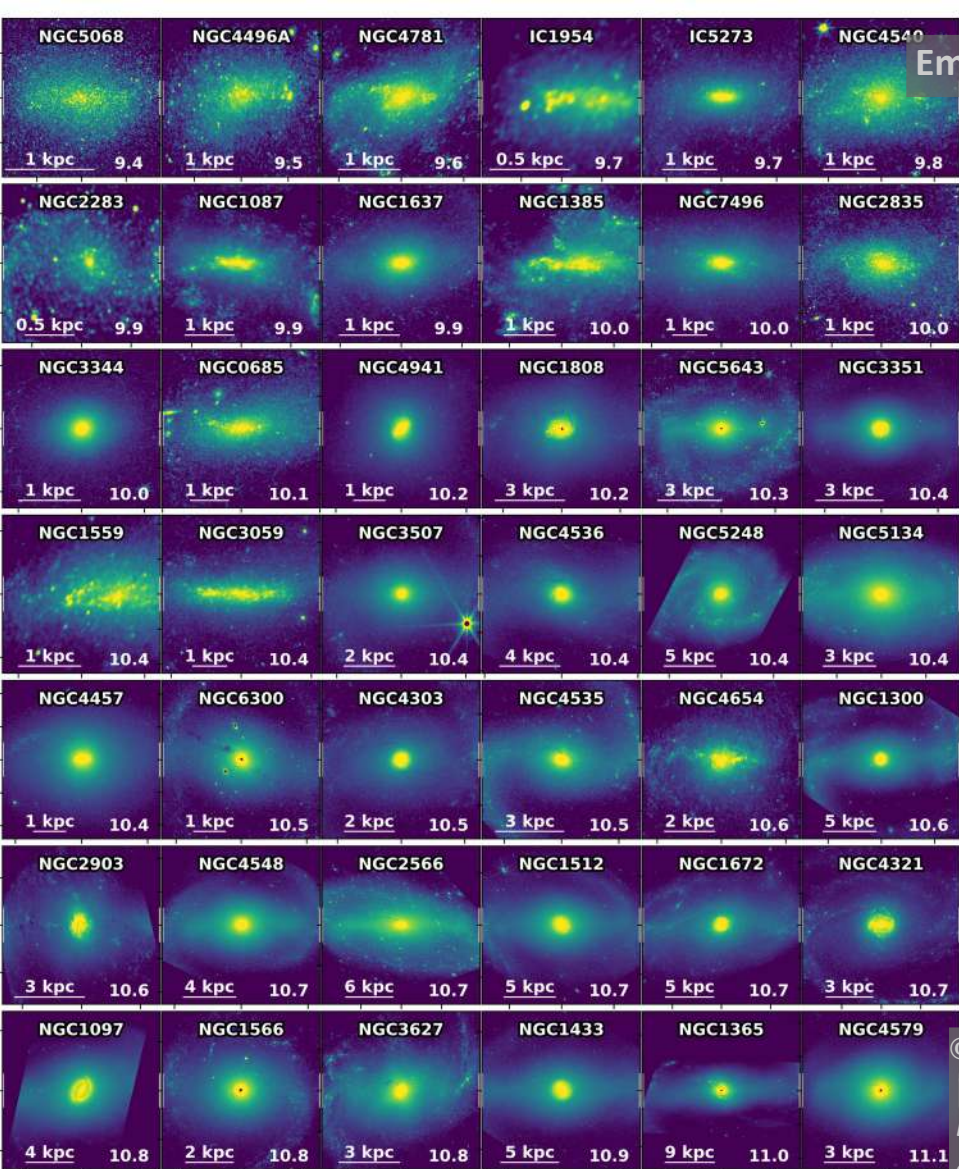


1D

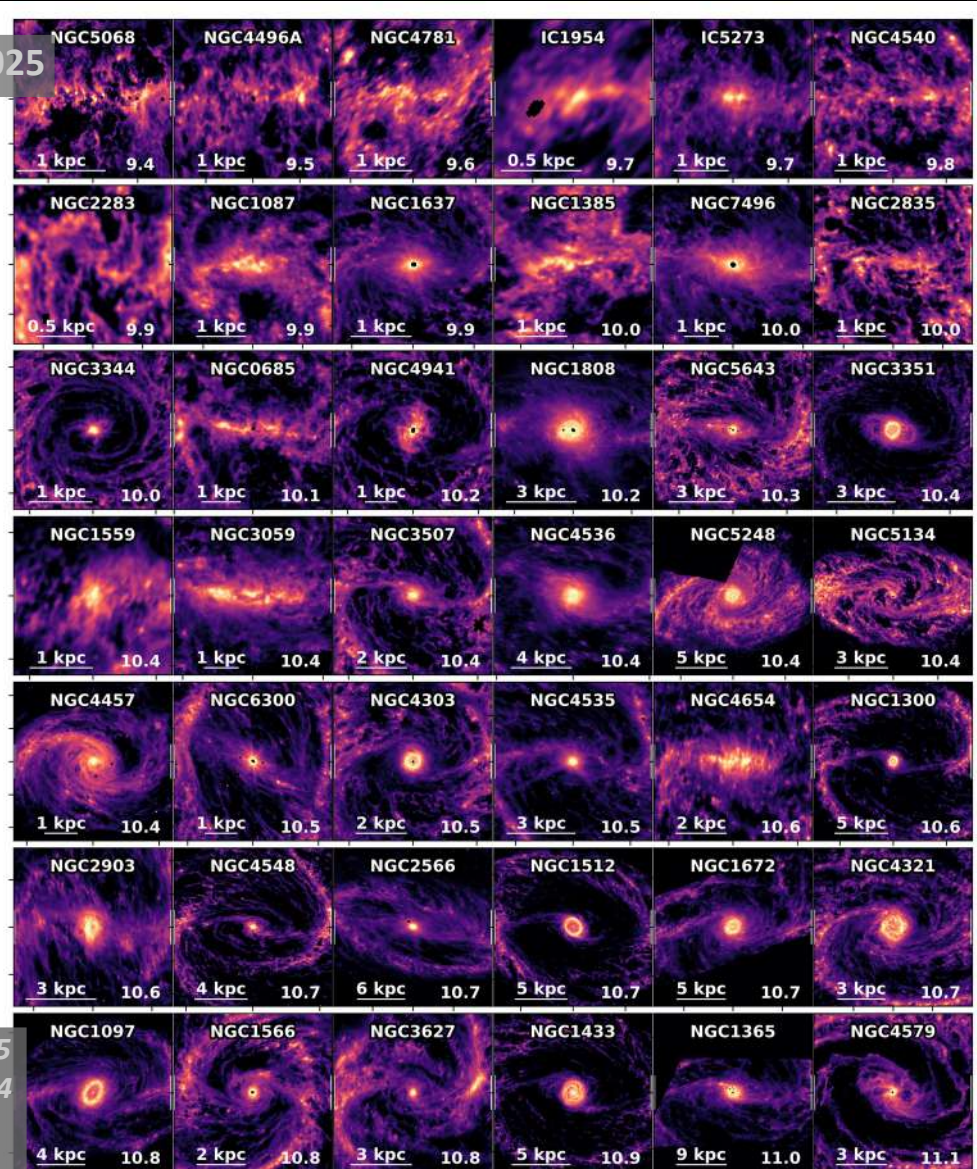


3D



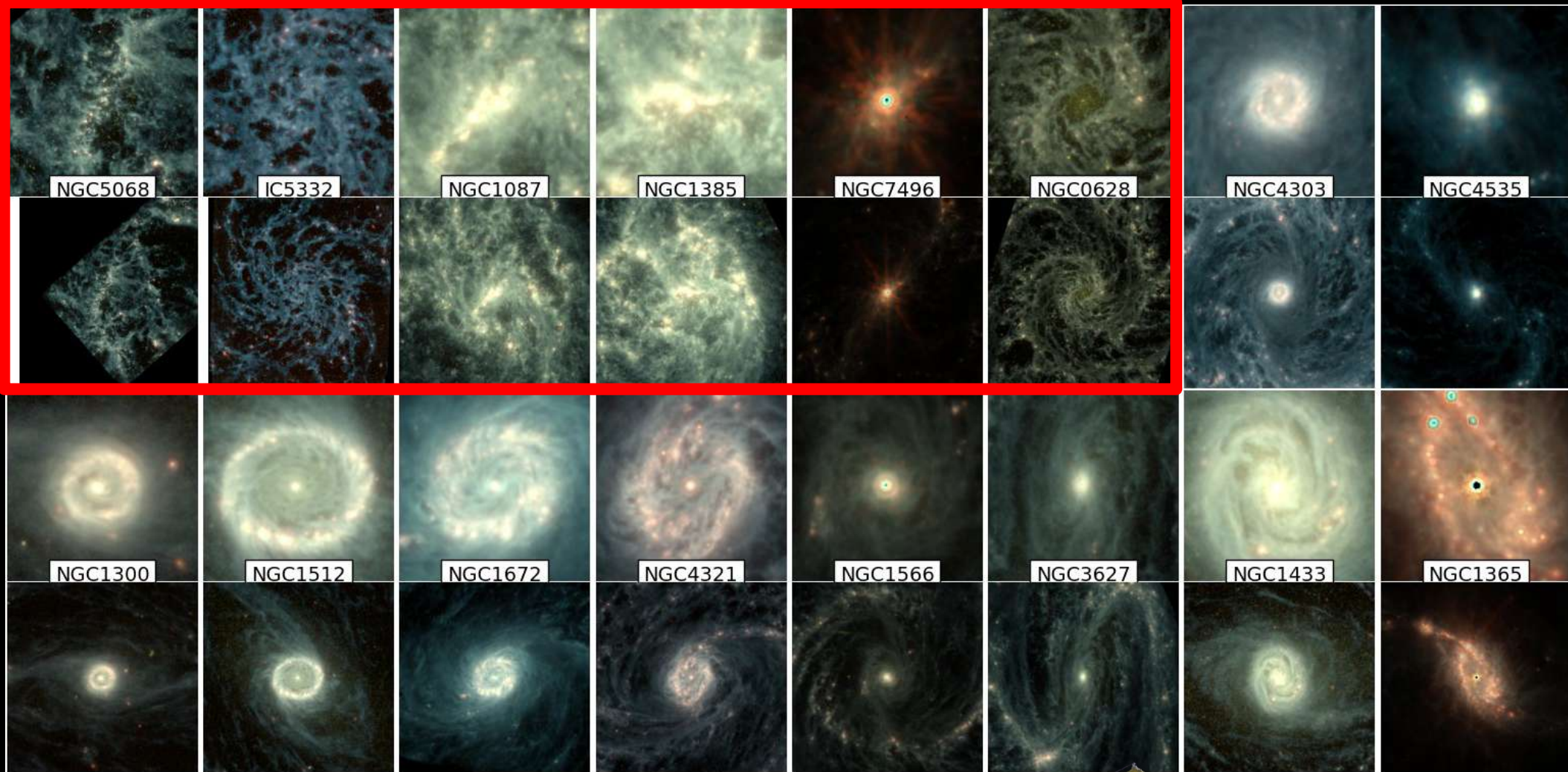


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Williams+2024  
Lee+2023  
& Sutter





# Lower mass systems

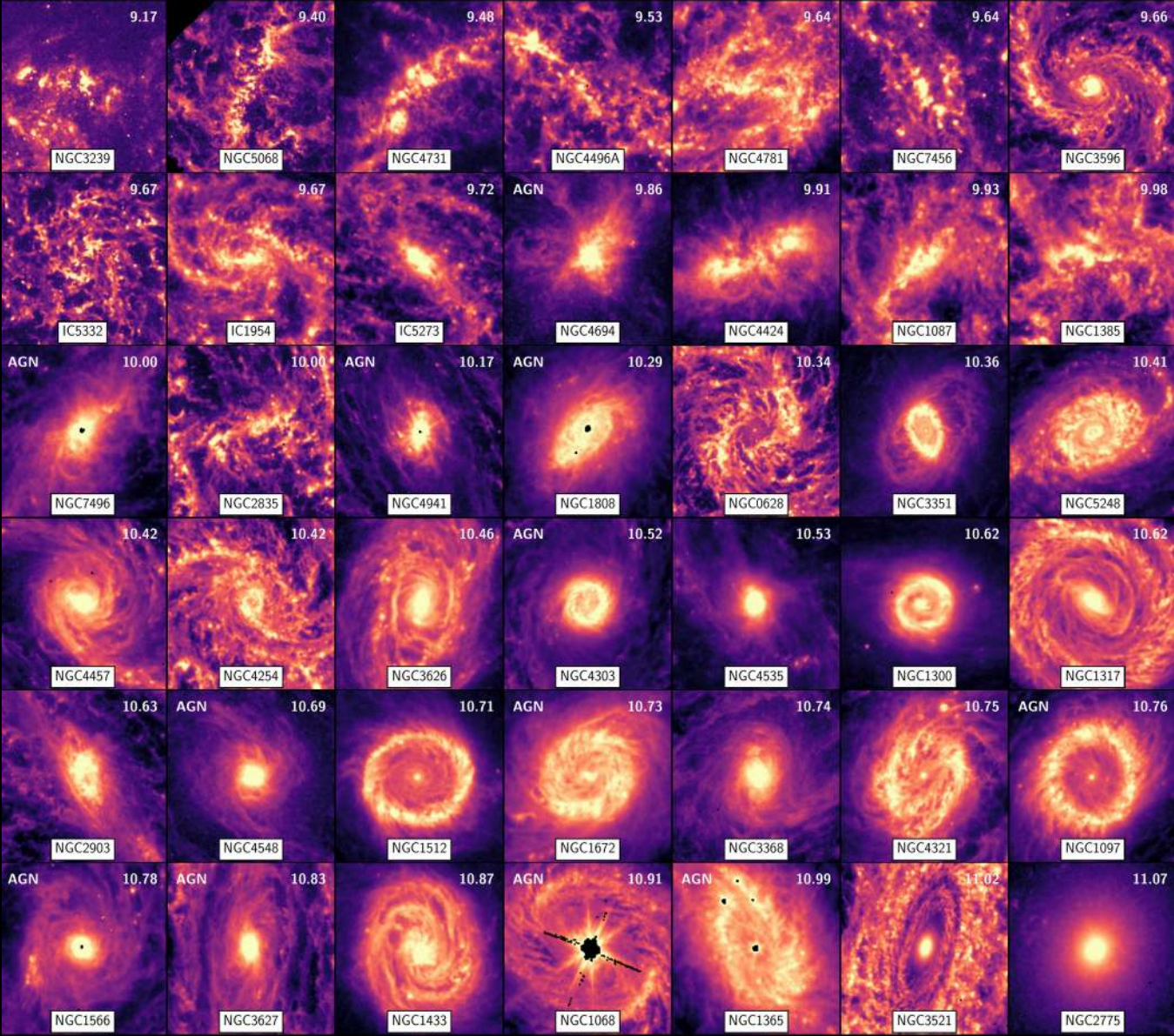


Credit: NASA/ESA,CSA; PHANGS / Emsellem



21 $\mu$ m-10.0 $\mu$ m-3 $\mu$ m

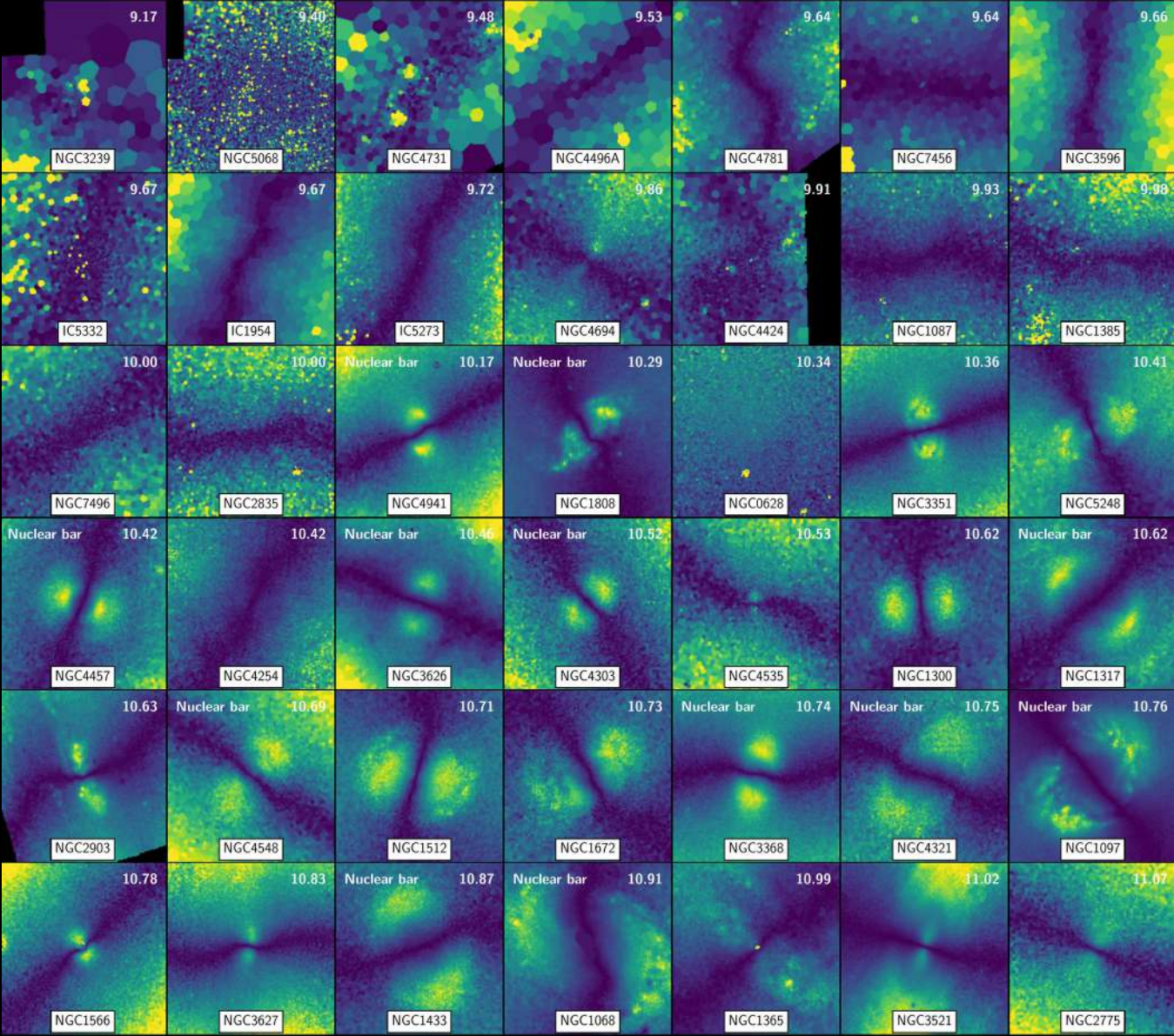




**JWST**  
7.7 μm

© Chown+2025  
Williams+2024  
Lee+2023  
& Sutter





MUSE  
 $|v|/\sigma$

©Emsellem+2022  
& Belfiore, Congiu,  
Egorov, Neumann



# Take home messages

**Bars are hard to avoid in discs (if you have time + reasonable dynamics)**

- **High-mass galaxies : key agents of disc evolution**
  - ▷ Gas and SF deserts + central rings and discs
- **Low-mass galaxies : ... in hiding**
  - ▷ SF regime, PDF, detection at high redshift ?

**Relative imprint of gravity and feedback**

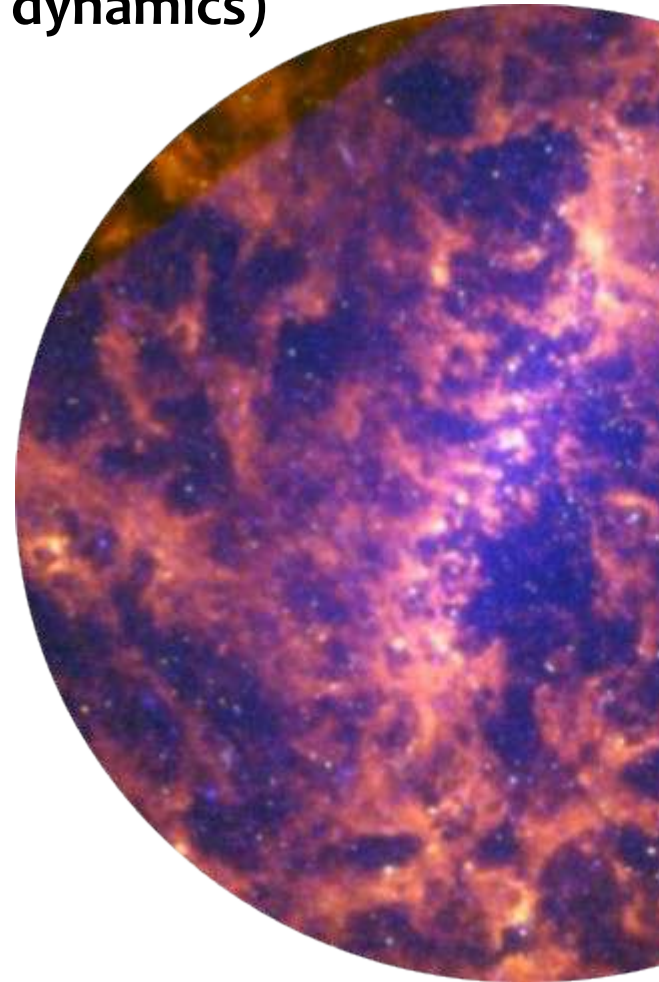
- 1D flow versus 3D flow  $\Rightarrow$  Central attractor
- $\Rightarrow$  requires high-resolution, involves varying timescales

**Regime (mass-dependent) change and galaxy evolution**

- What about high-er redshift galaxies ?

**Serious issues**

Bars = absence / morphology and size  
(Differential) evolution



# Proposal

A huge amount of work has been accumulated over 30 years+

- **Need for a meta-analysis**

- ▷ Quality and relevance of work
- ▷ Robust trends
- ▷ Weak ones
- ▷ What needs to be addressed

- **Reconciling Obs and Sims**

- ▷ Bars are the new graal (for simulations)
- ▷ But let's not repeat the same mistakes... (discs)

