



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

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

Phangs



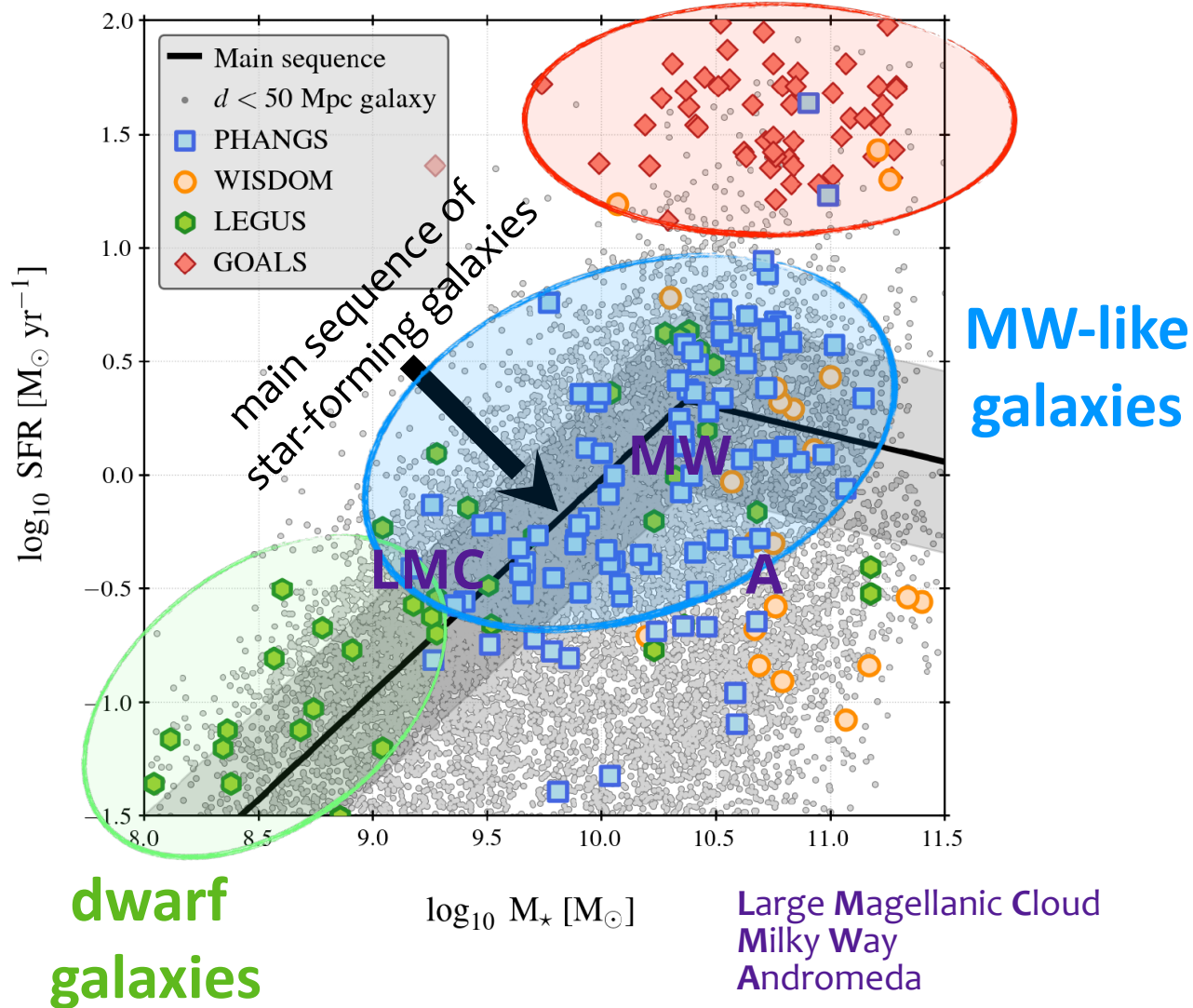
Eric Emsellem

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



Extraordinary structures in nearby galaxies =

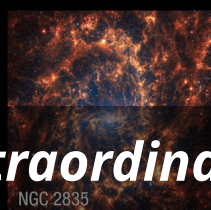
Physics

that drives, regulates, extinguishes Star Formation

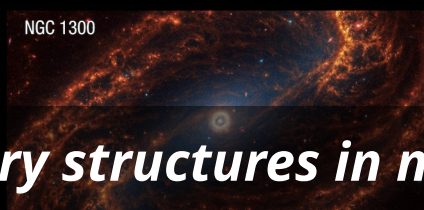
***operating together over
stellar, interstellar, galactic, circumgalactic scales***



NGC 5068



NGC 2835



NGC 1300



NGC 1566



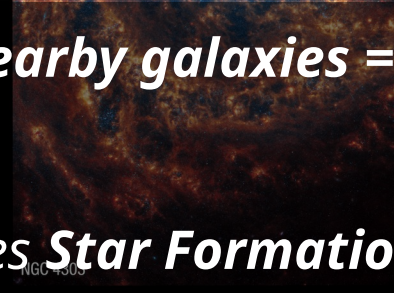
NGC 1365



NGC 454



NGC 3627



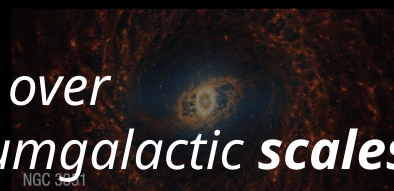
NGC 1385



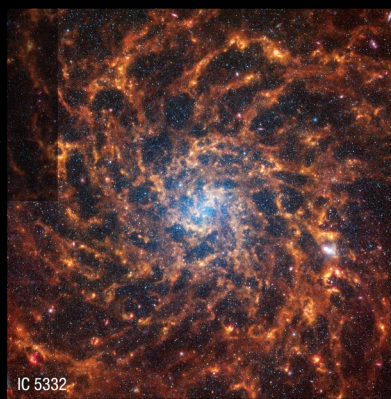
NGC 1512



NGC 1433



NGC 3511



IC 5332



NGC 4321



NGC 4254



NGC 1672



NGC 0628



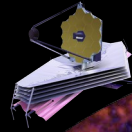
NGC 1087



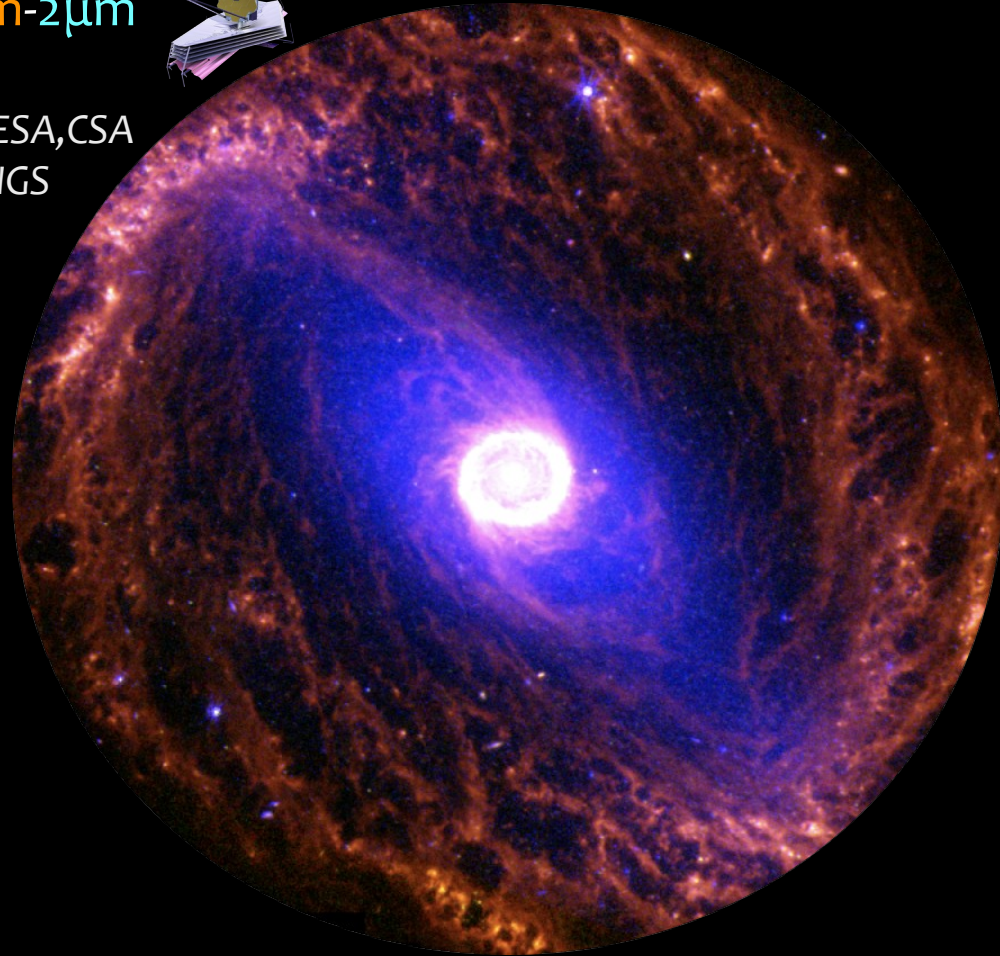
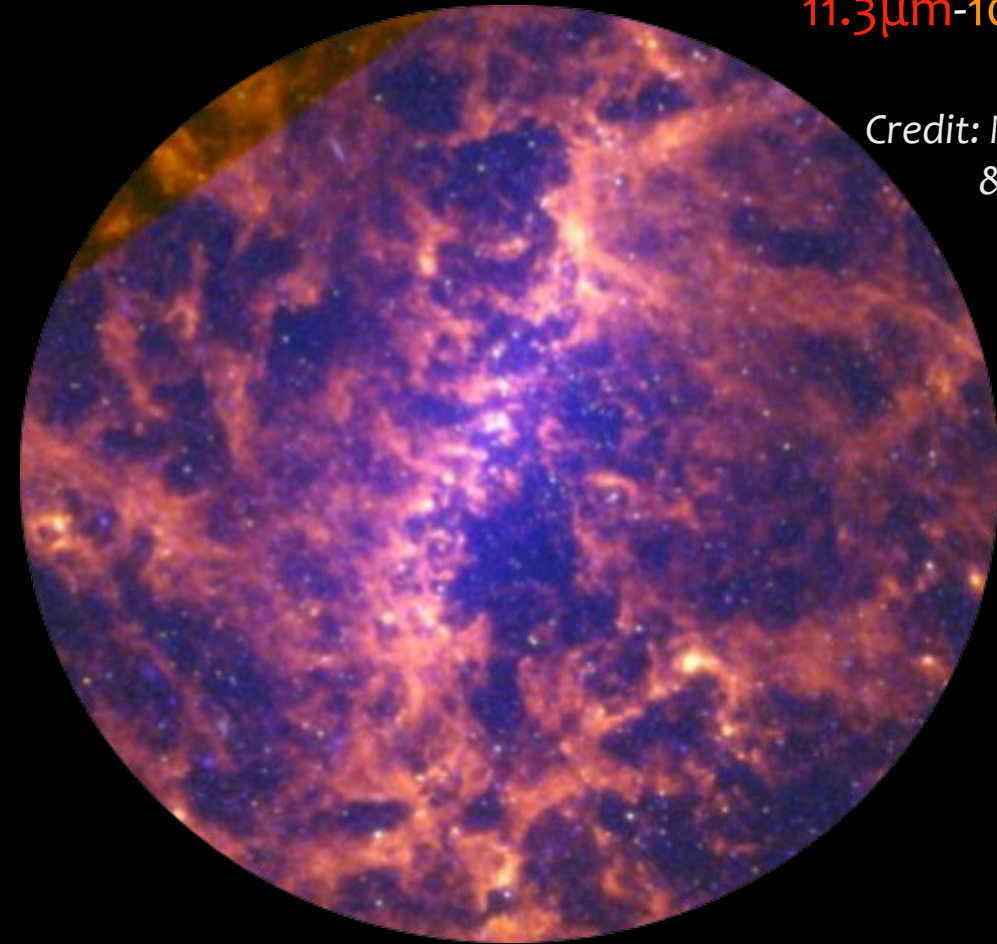
NGC 7496

PHANGS, JWST Jan 2024 DR & NASA PR
Depasquale, Pagan, OPO/STScI (Lee+23)

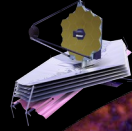
11.3 μm -10.0 μm -2 μm



Credit: NASA/ESA, CSA
& PHANGS



11.3 μm -10.0 μm -2 μm



Credit: NASA/ESA, CSA
& PHANGS

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

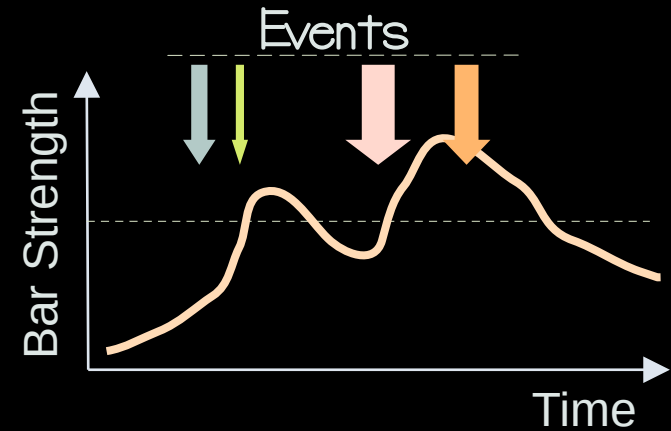
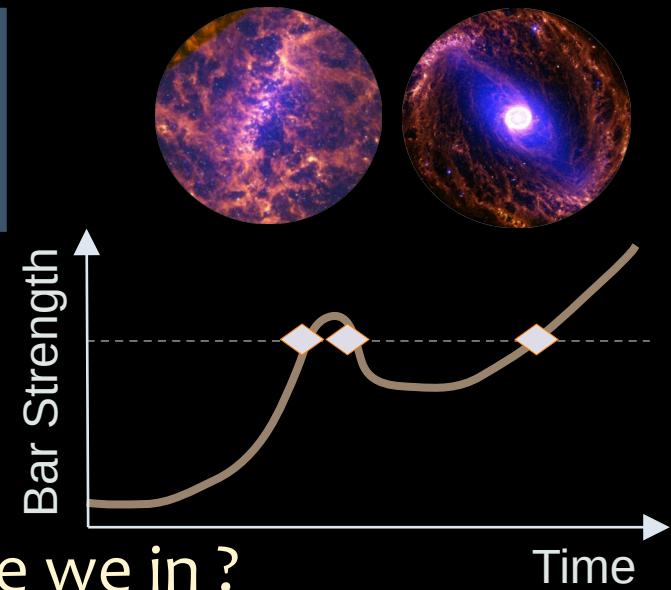


Can we establish a reference pathway for

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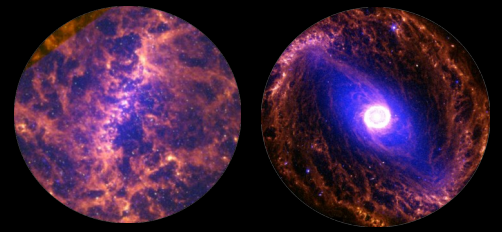
Difficulties – Observations

- 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)



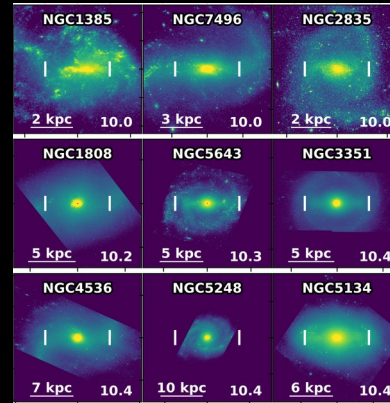
Can we establish a reference pathway for

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Difficulties – Observations

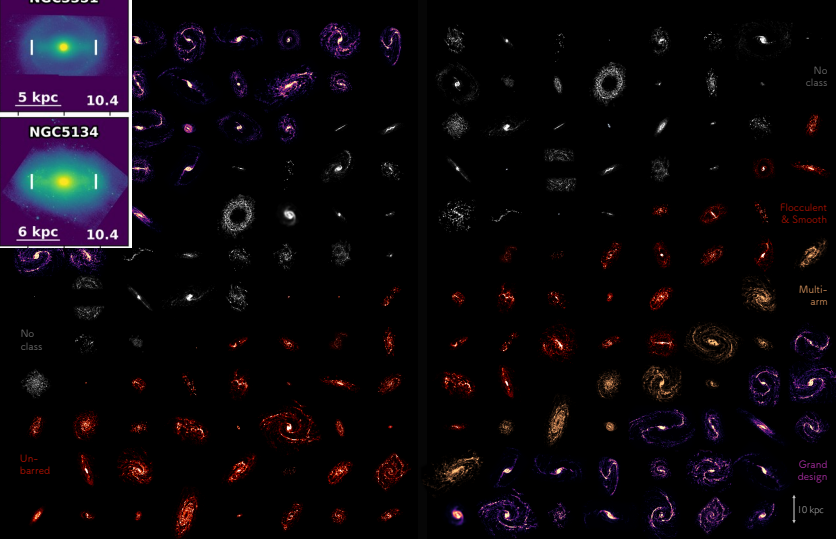
- Diversity of bars & structures
- Dust and Tracers
- Metrics are ill-defined, time-dependent or hard to extract
- Size of a bar = e.g., A2, Qb but see e.g., Ghosh+25
- Mass, kinematic structure



The Zoology

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

Spiral arm classification



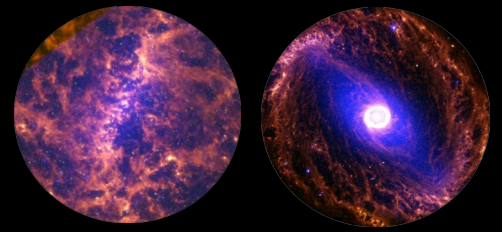
Credit: PHANGS/stuber

Credit: PHANGS / Sophia Stuber



Can we establish a reference pathway for

- bar formation ?
- bar-driven evolution ?



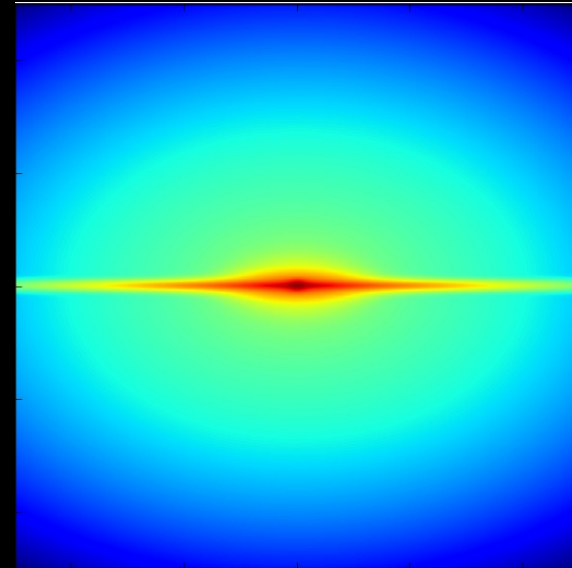
Difficulties – Simulations / Theory

- 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

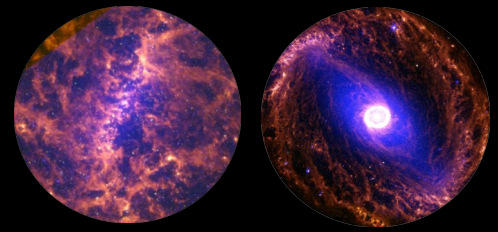
No disc form like that → that seed is never realised

- 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 ?

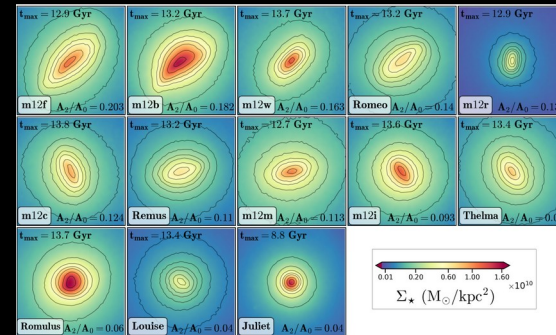


Difficulties – Simulations / Theory

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

→ NO (my 2 cents)

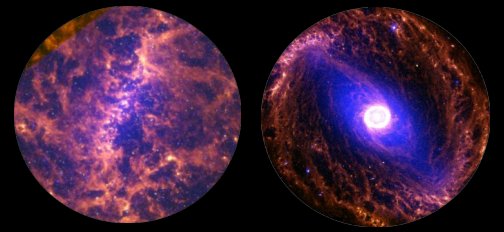
- What are the right metrics ?
 - ▷ *Certainly not something like “look at those bars!” ;-)*



Ansar+24
[FIRE-2]

Can we establish a reference pathway for

- bar formation ?
- bar-driven evolution ?



Difficulties – Simulations / Theory

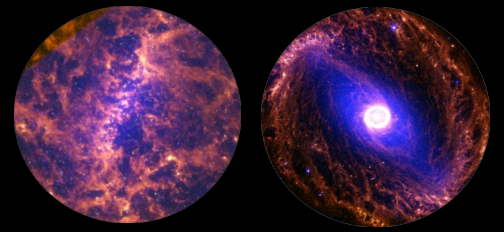
- **We do not have – yet – a robust picture** [my 2 cents again]
 - ▷ The literature is inconsistent
 - ▷ Each new study has a “rather” narrow range of applications
 - ▷ Most suffers from biases (samples/populations, numerics, etc)
- **BUT** = A lot has been done → possibly no need for new simulations

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 ?



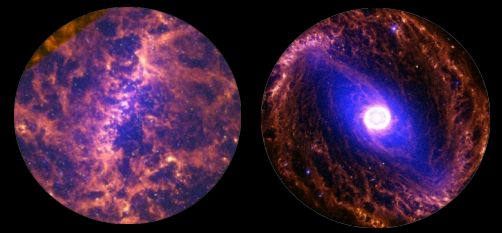
What we know

- 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 ?



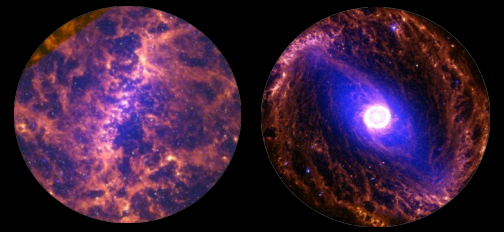
What we do not know

- 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

- bar formation ?
- bar-driven evolution ?

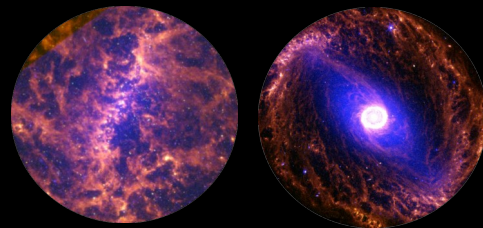


What we may need to work on

- 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

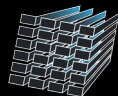
⇒ hydrodynamical simulations
(and Ramses)



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

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

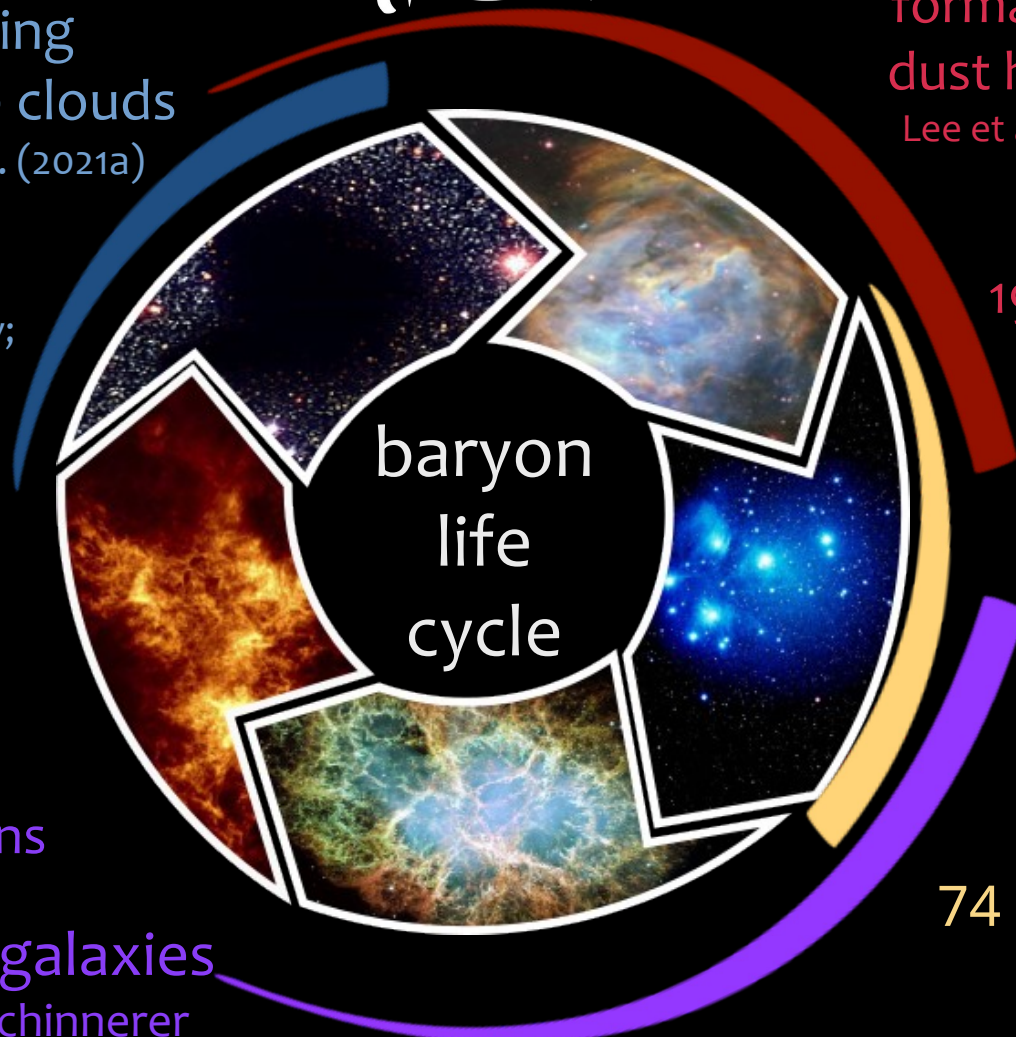
stellar feedback
probed by
~25,000 nebulae
+ stellar populations
Emsellem et al. (2022)



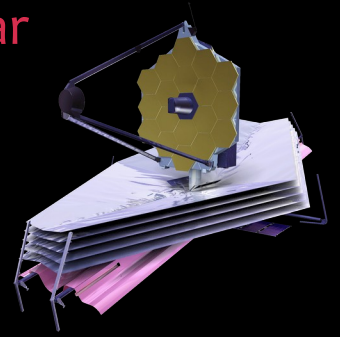
MUSE
multi unit spectroscopic explorer

19+ galaxies
PI Schinnerer

Phangs

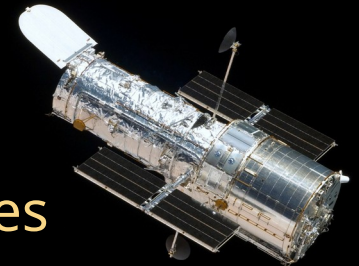


embedded star
formation &
dust heating
Lee et al. (2023)



19 + 55 galaxies
PI Lee + PI Leroy

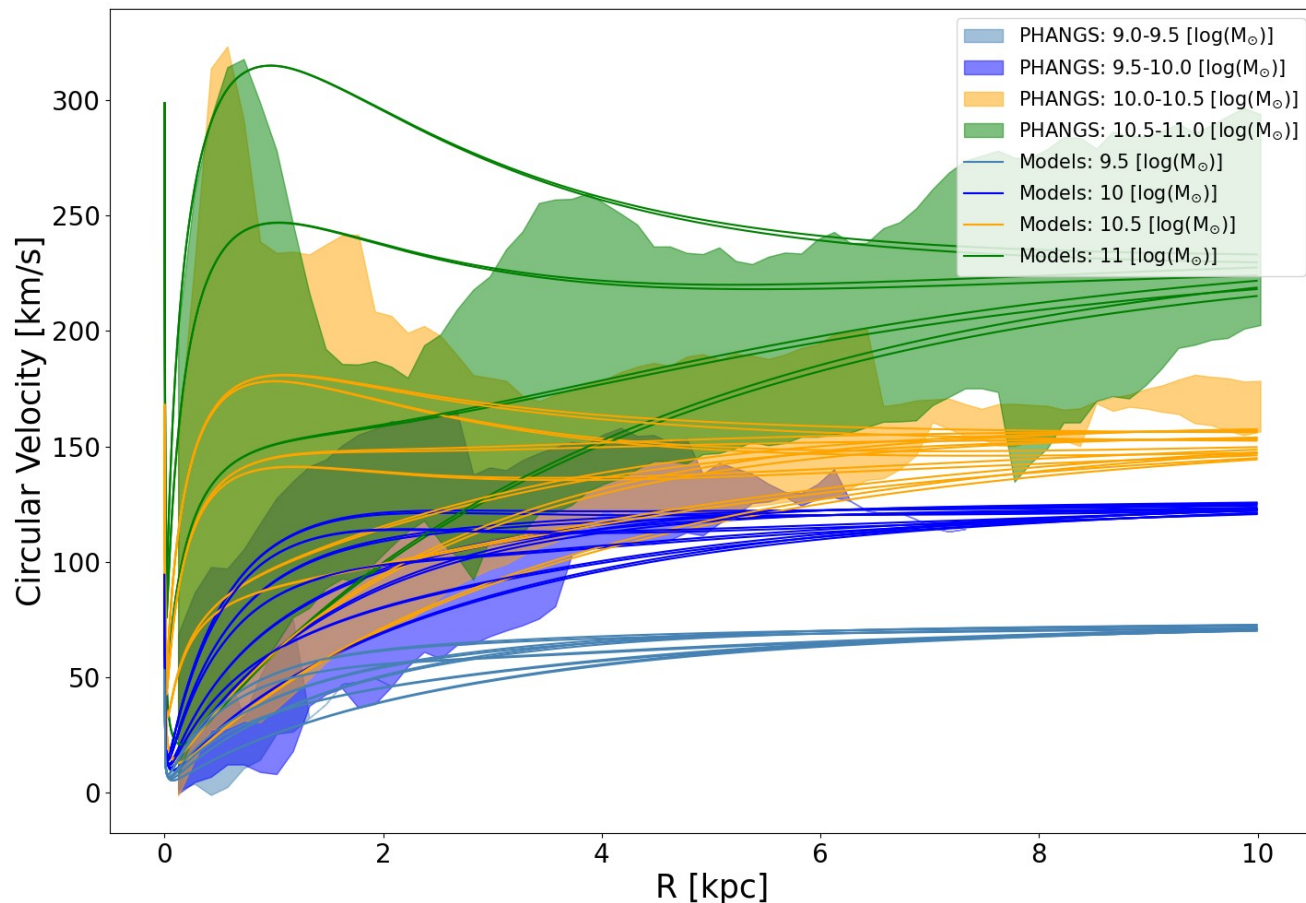
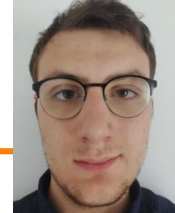
~80,000
stellar clusters
Lee et al. (2022)



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

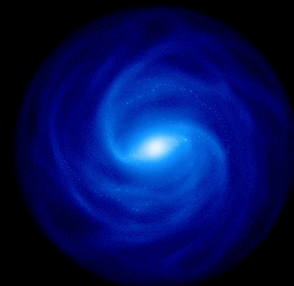
NGC1277

Emsellem 2015

Parametric (1-3D) & profiles / images

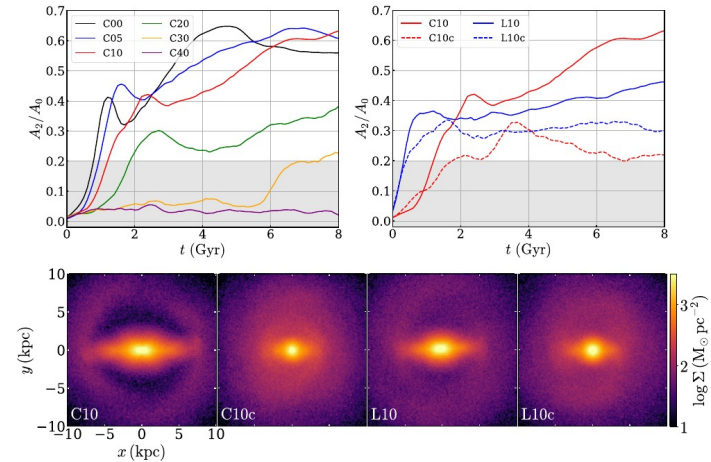
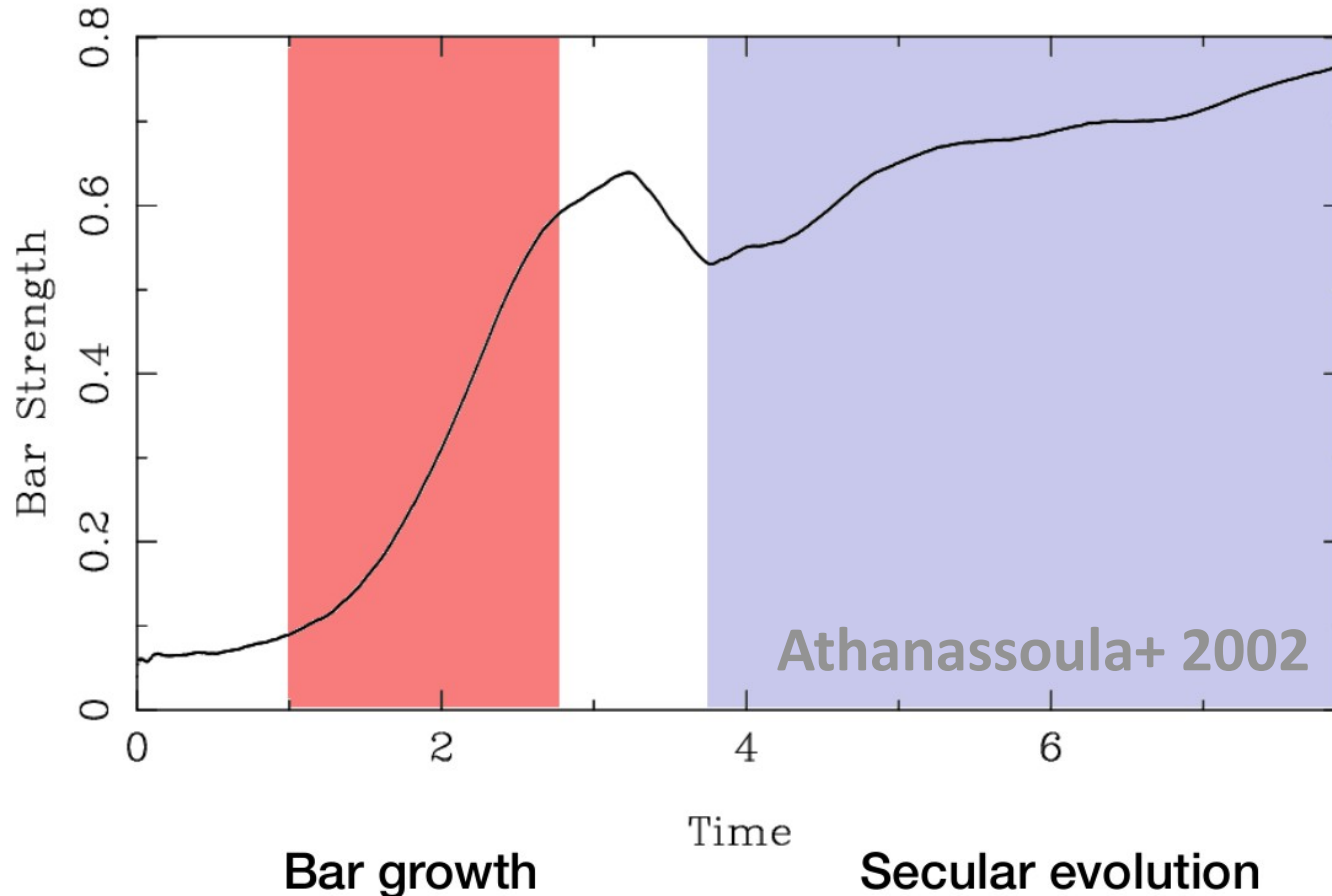
3D Projection/deprojection
Gravitational Potential, density waves,
Generalised Jeans Equations

Stars + gas + DM
⇒ Gadget, Ramses



Bar evolution: 2 phases

⇒ Short-term growth versus Long-term evolution



Jang et al. 2023

Bar evolution: 4 phases

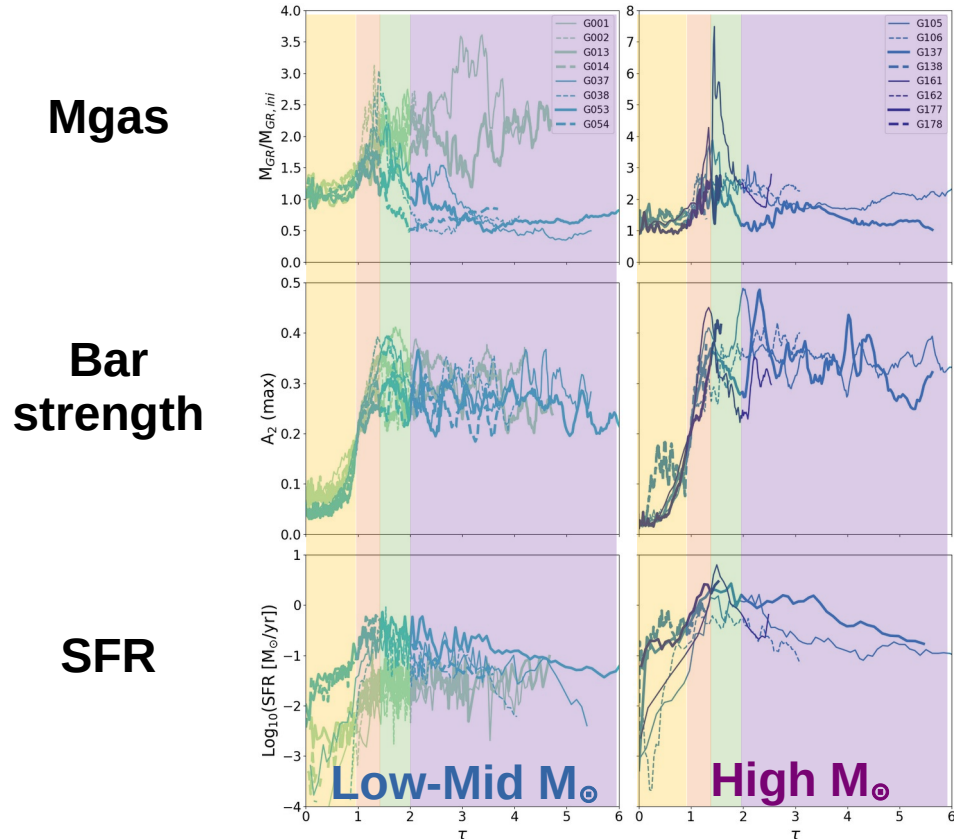
Verwilghen+ 2024



Phangs

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

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



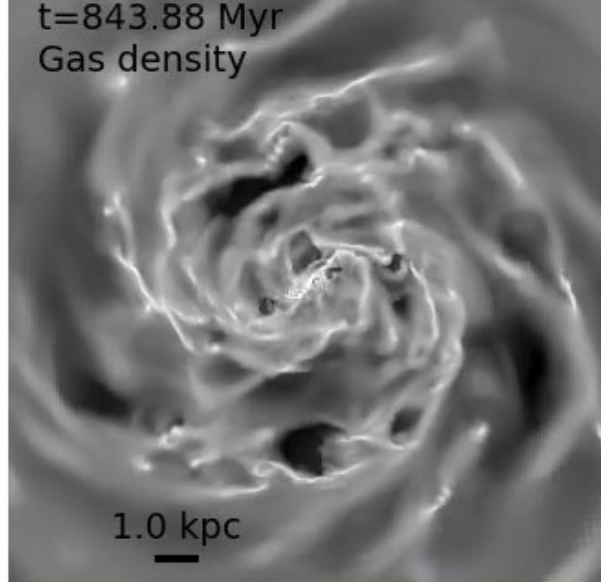
A) $\tau \in [0, 1]$: bar formation

B) $\tau \in [1, 1.5]$: $O_{gas} \nearrow$

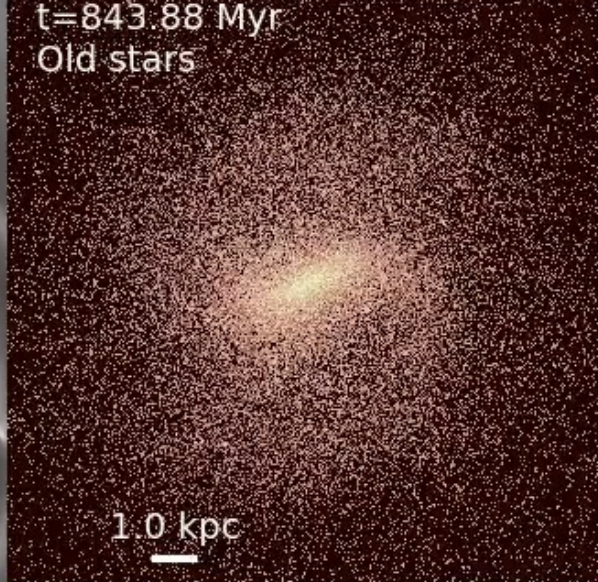
C) $\tau \in [1.5, 2]$: Starburst

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

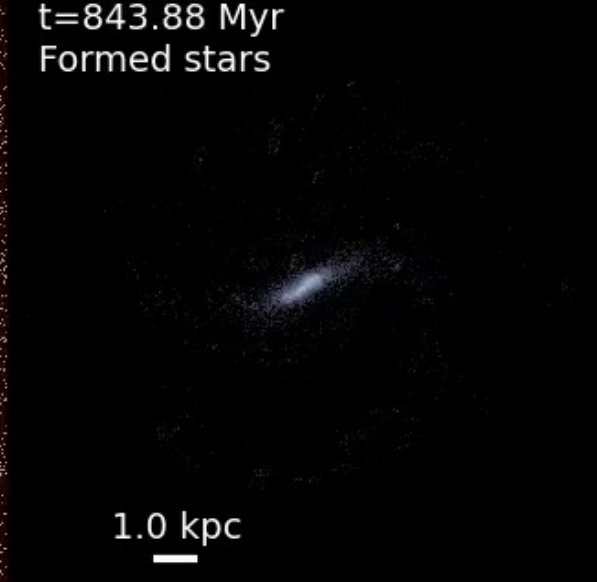
t=843.88 Myr
Gas density



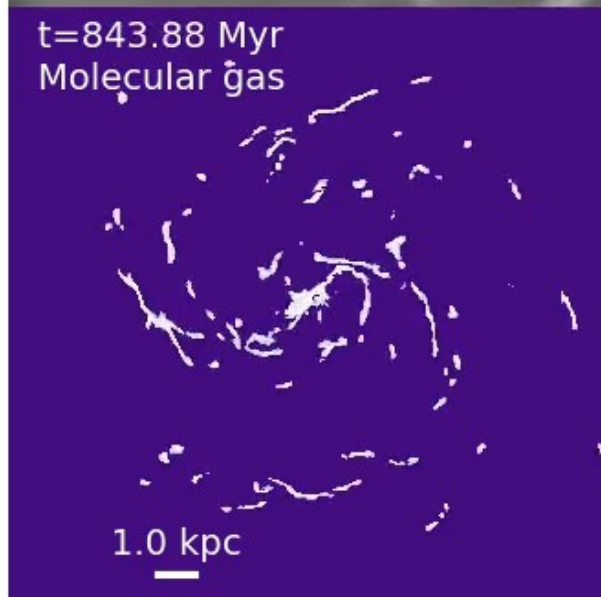
t=843.88 Myr
Old stars



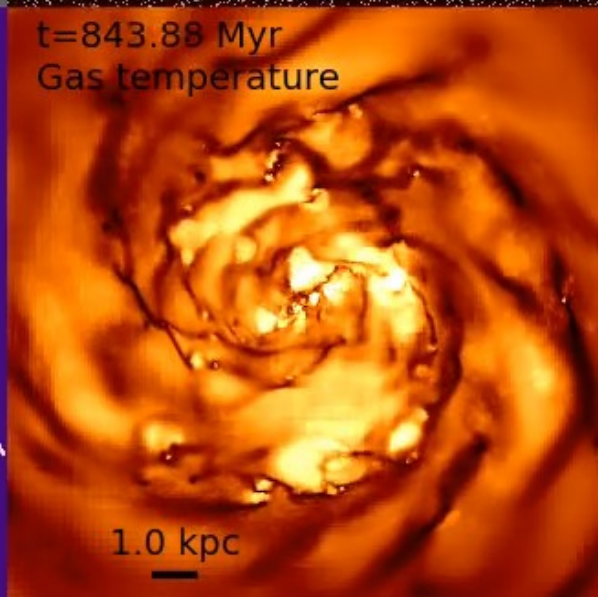
t=843.88 Myr
Formed stars



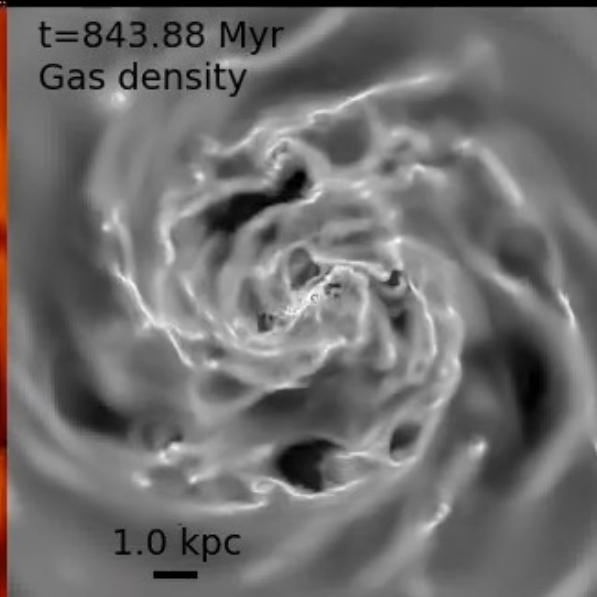
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Molecular gas



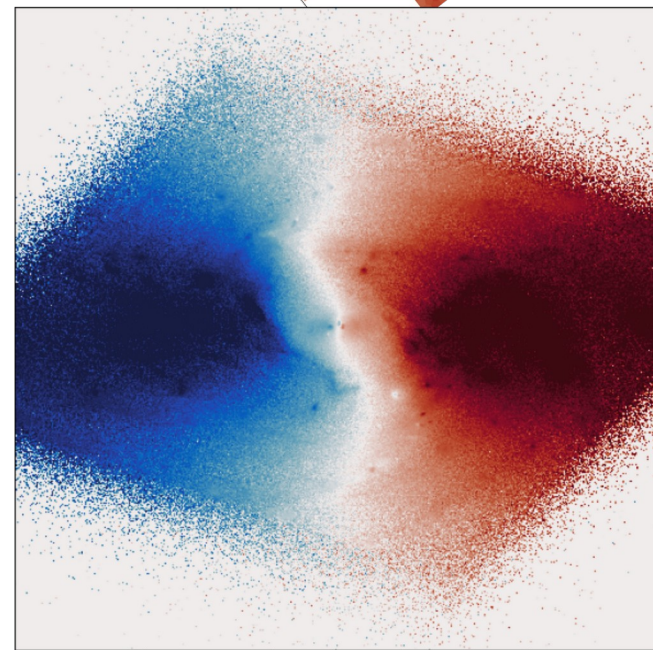
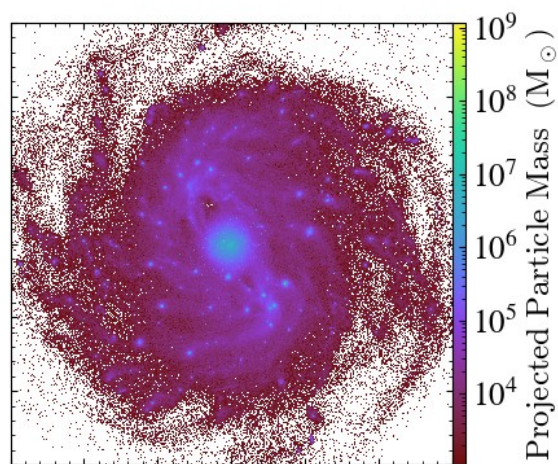
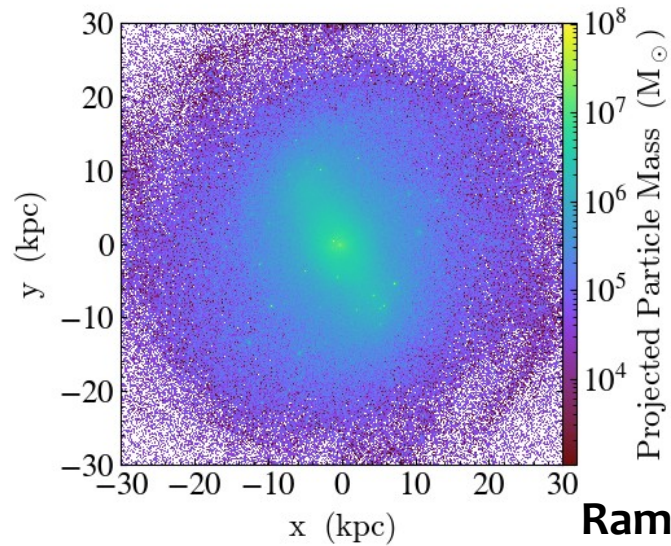
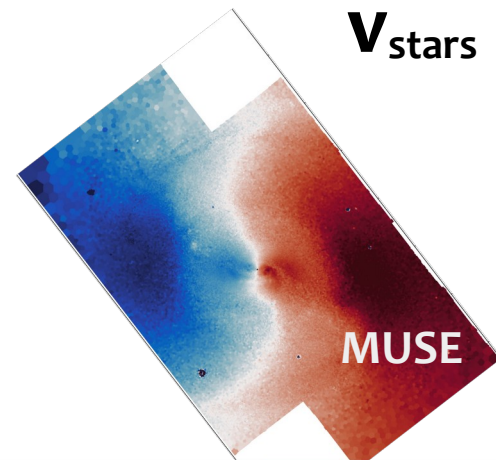
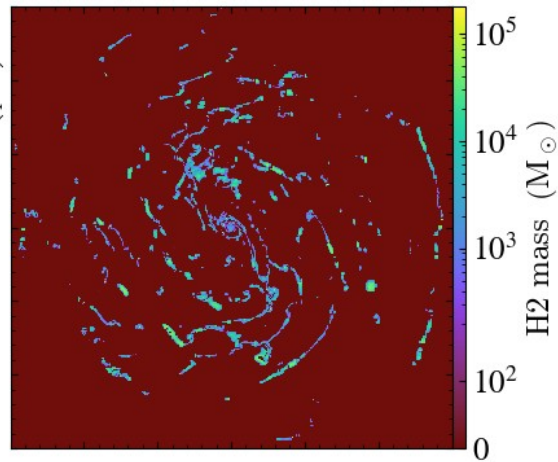
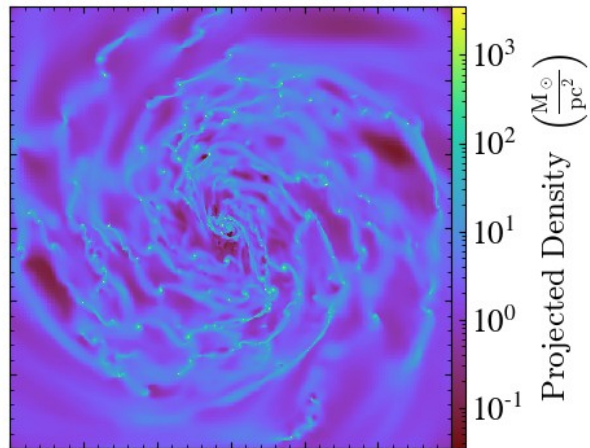
t=843.88 Myr
Gas temperature



t=843.88 Myr
Gas density



NGC 1365



Ramses hydro-dynamical simulation (Emsellem+ in prep)

Central Starburst in NGC1365

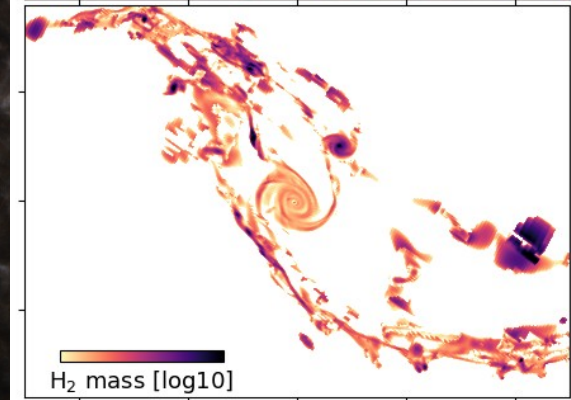
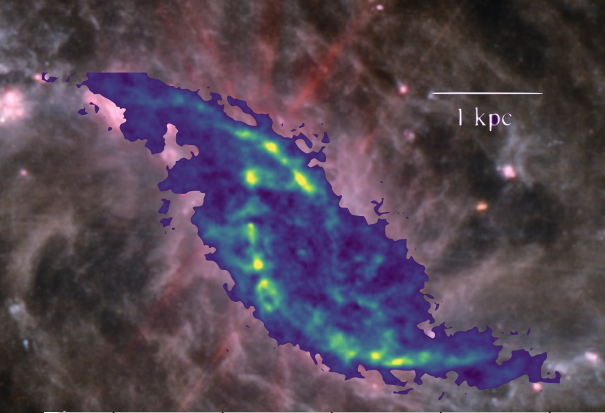
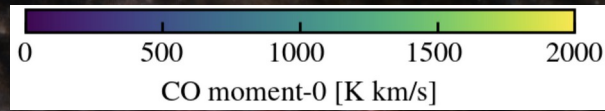
& Bars



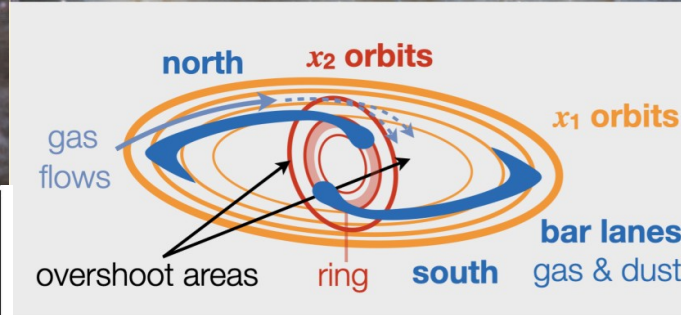
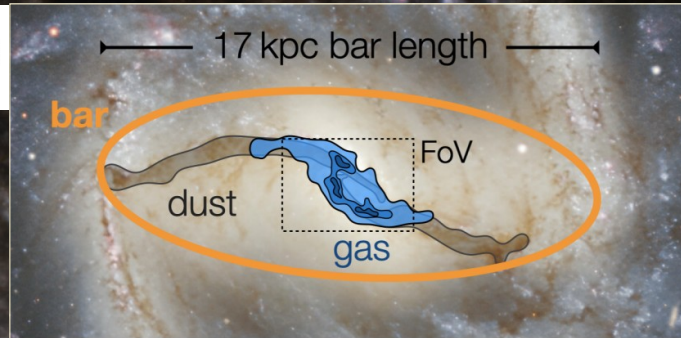
Credit: NASA/ESA, CSA; PHANGS, J. Schmidt (Lee et al. 2023)

21 μ m-11.3 μ m-7.7 μ m-10 μ m

Central Starburst in NGC1365



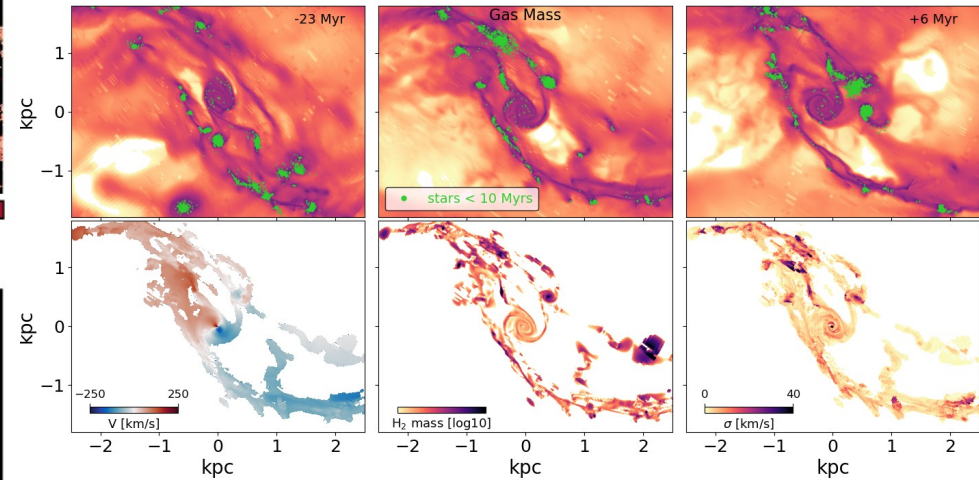
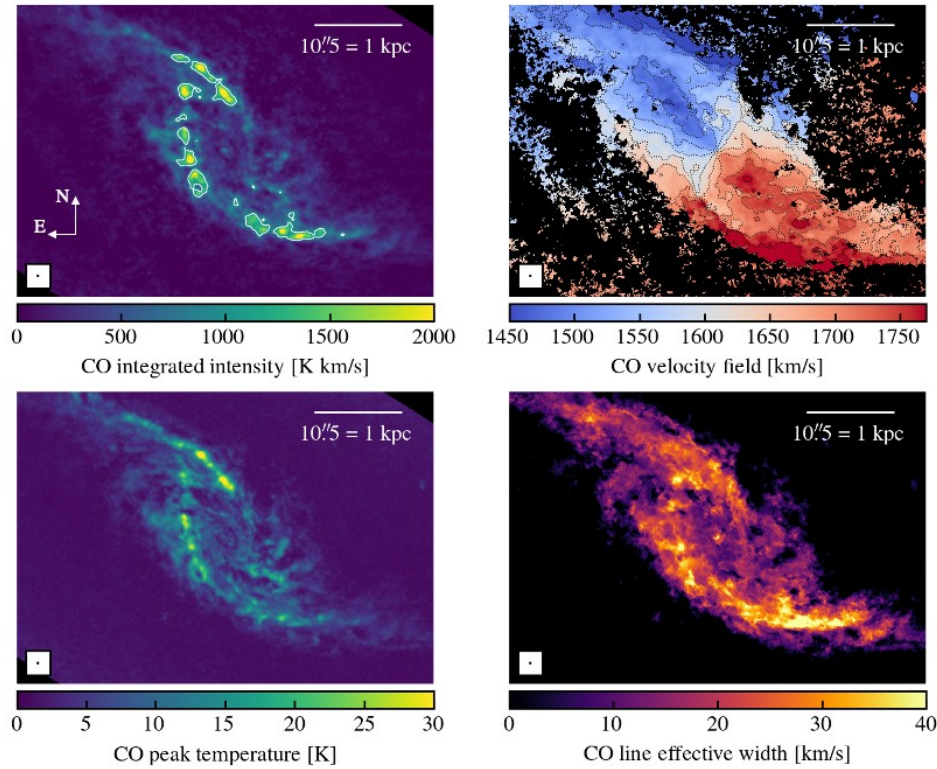
Hydro-dynamical simulation



Schinnerer et al. (2023)

21 μ m-11.3 μ m-7.7 μ m-10 μ m

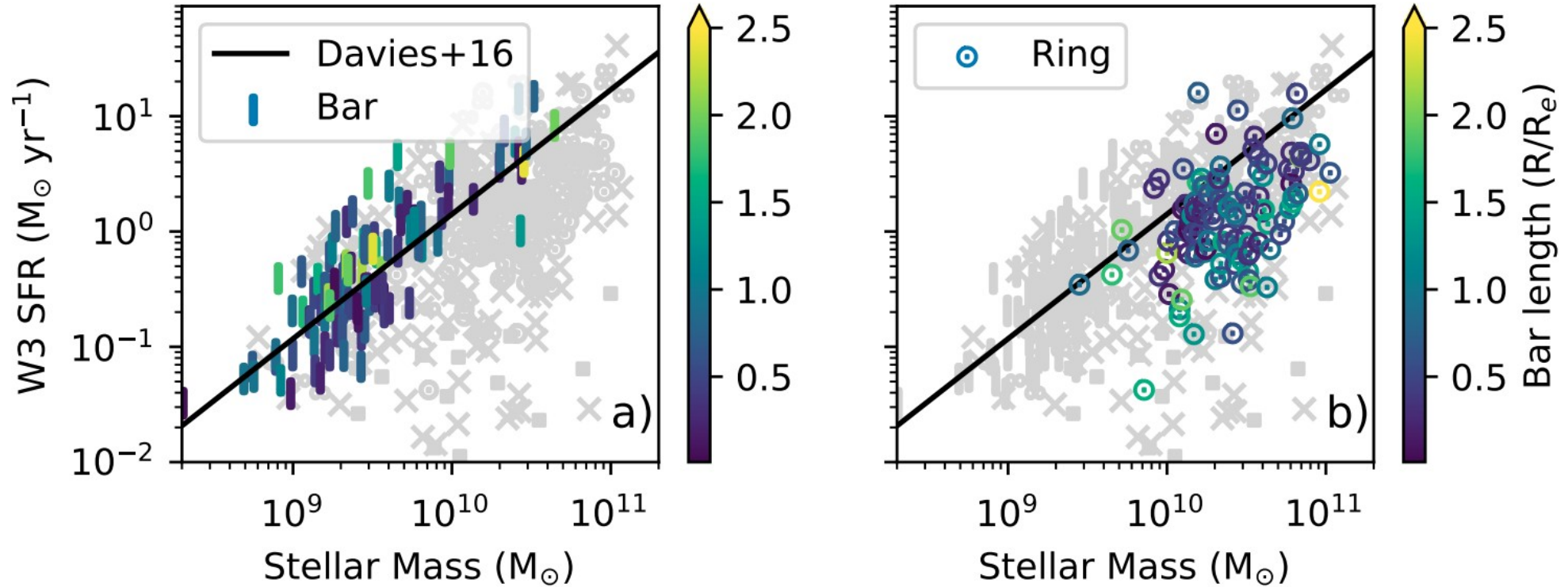
NGC1365



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

Where do stars form & Why ?

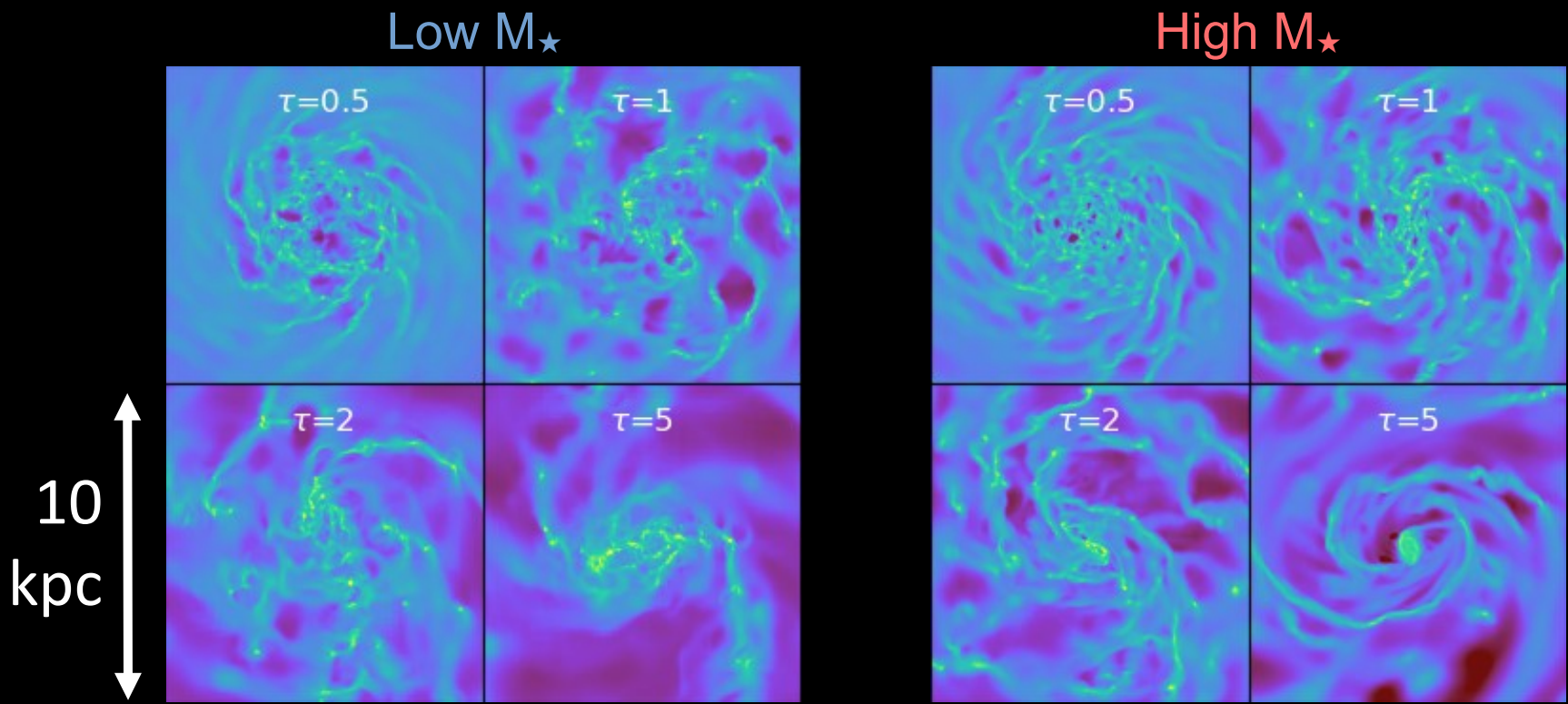
Fraser-McKelvie et al. 2020



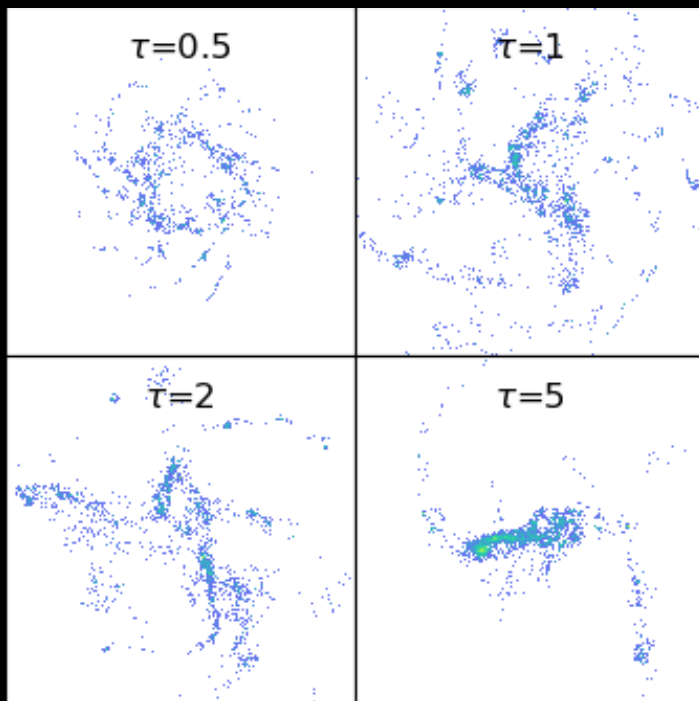
Dependence of SF on stellar mass

⇒ lower-mass = bar

⇒ higher mass = rings / central

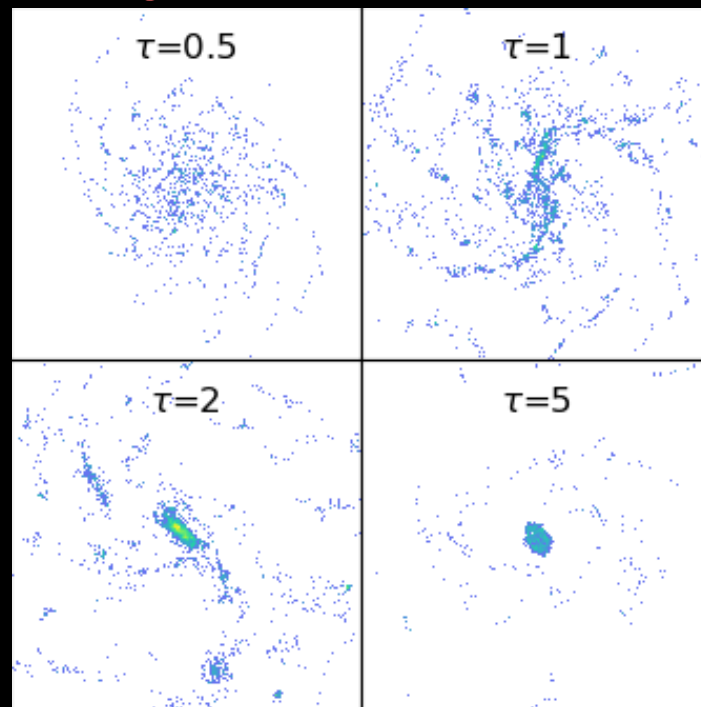


Low $M_{\star}$: Bar but no reservoir



SF along the bar

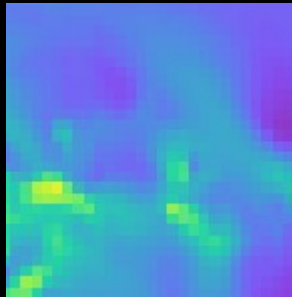
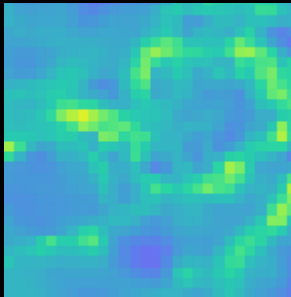
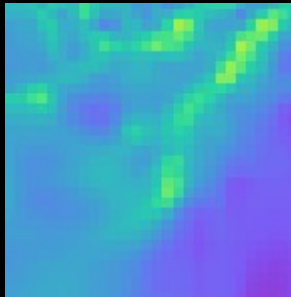
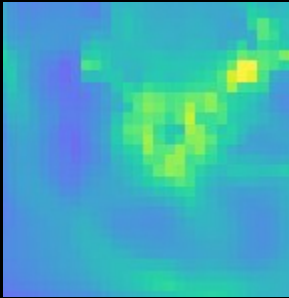
High $M_{\star}$: Bar + reservoir



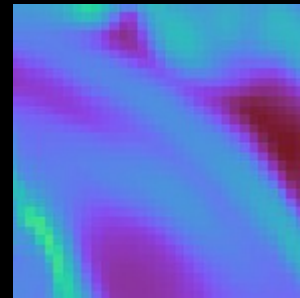
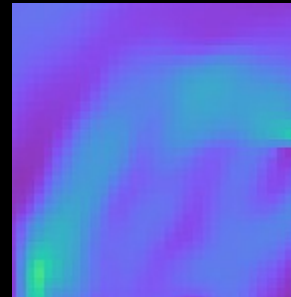
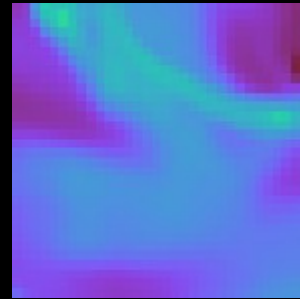
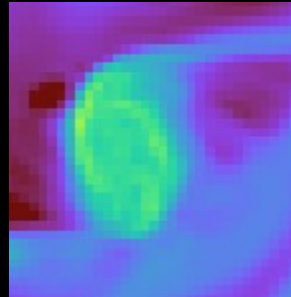
SF within the central reservoir

Consistent with Fraser-McKelvie+2020

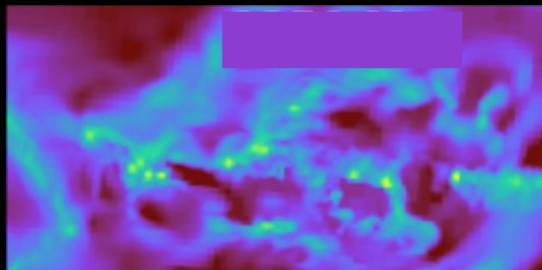
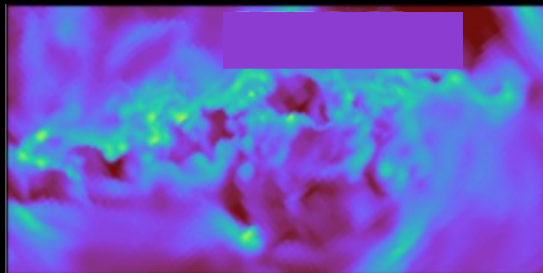
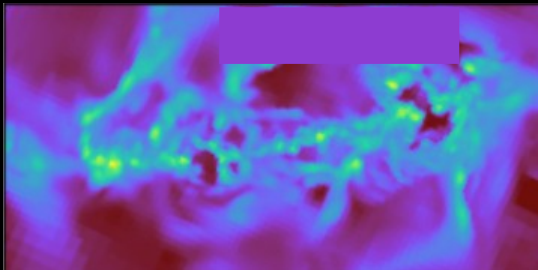
Low $M_{\star}$: where is the bar ?



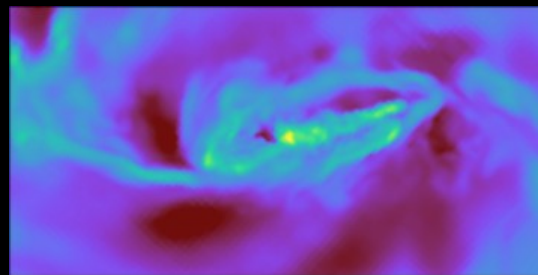
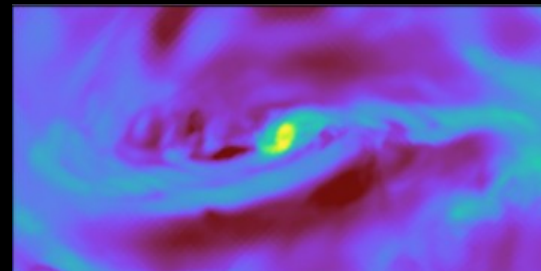
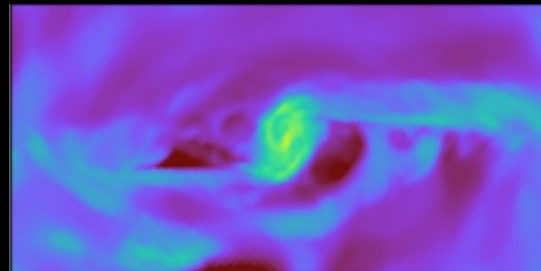
High $M_{\star}$: Bar structuring



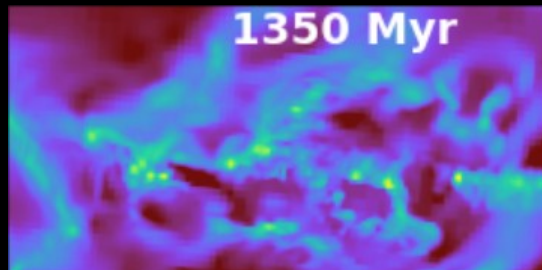
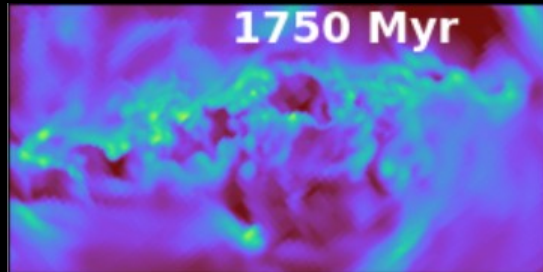
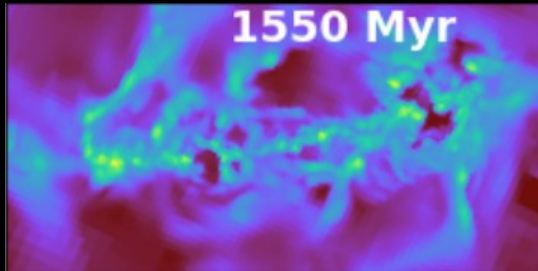
Low $M_{\star}$: evolution ?



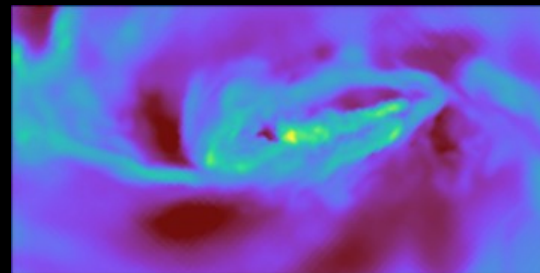
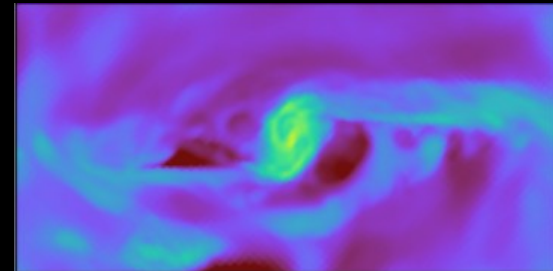
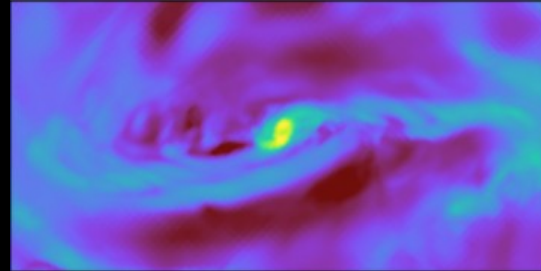
High $M_{\star}$: evolution !

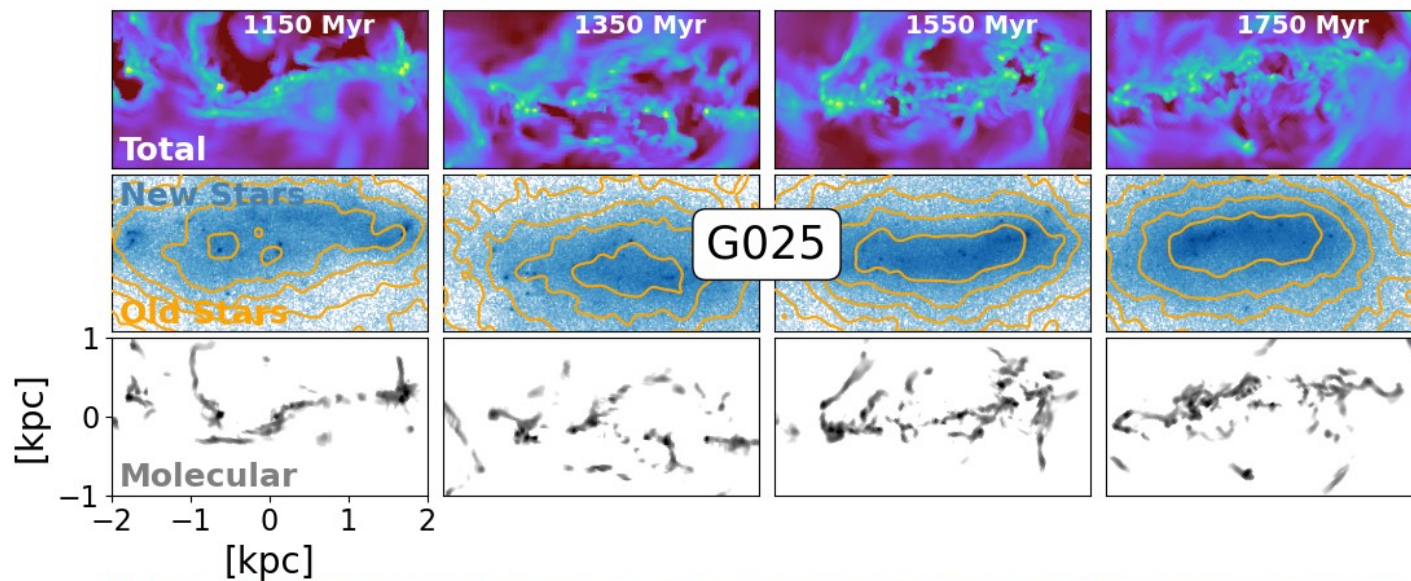


Low $M_{\star}$: evolution ?

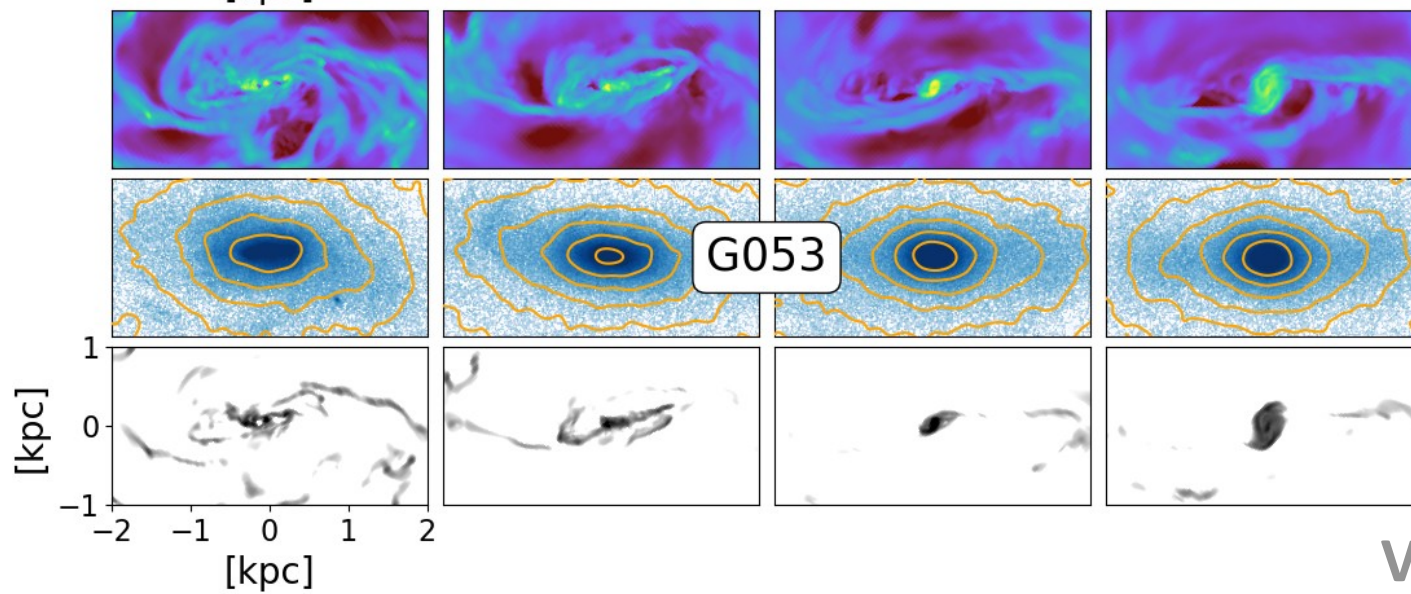


High $M_{\star}$: evolution !





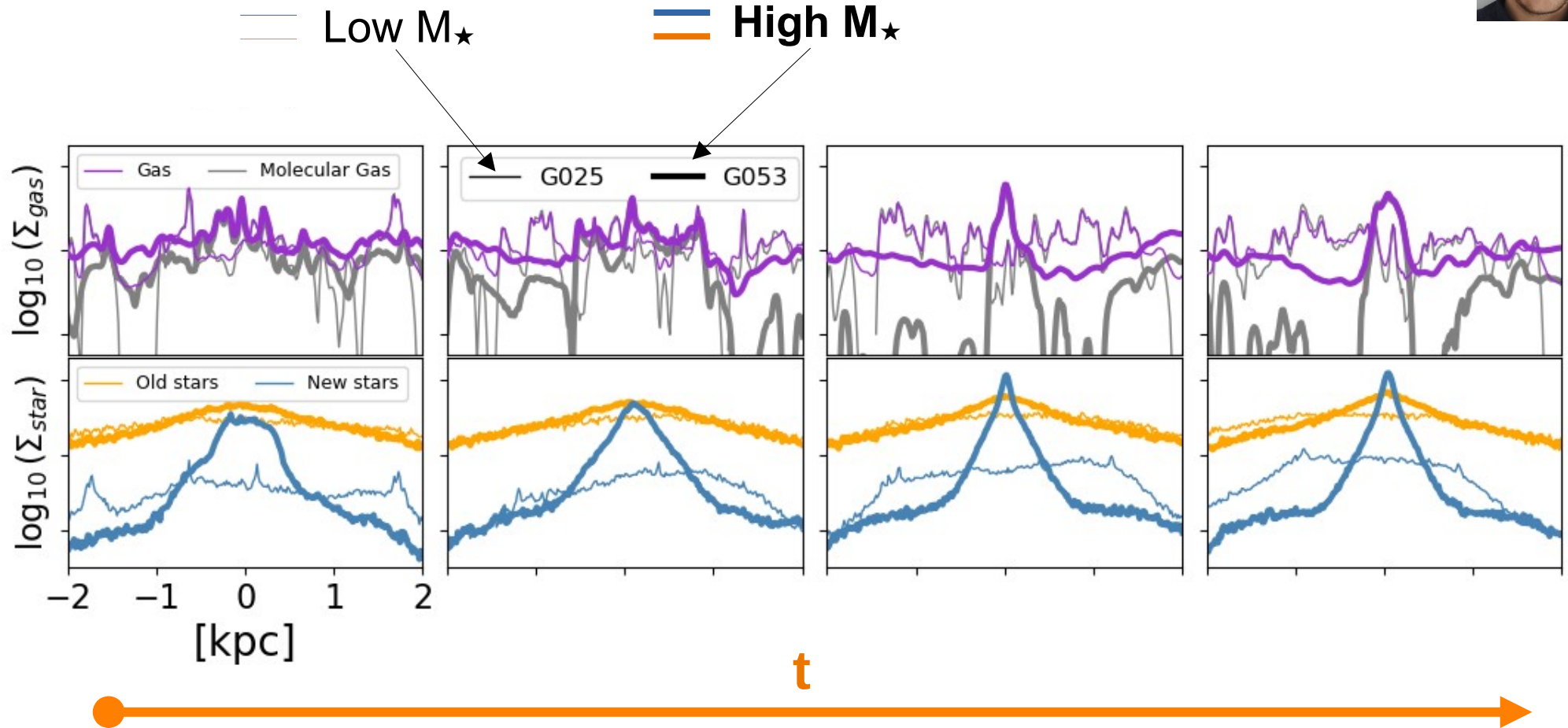
Low $M_{\star}$



High $M_{\star}$

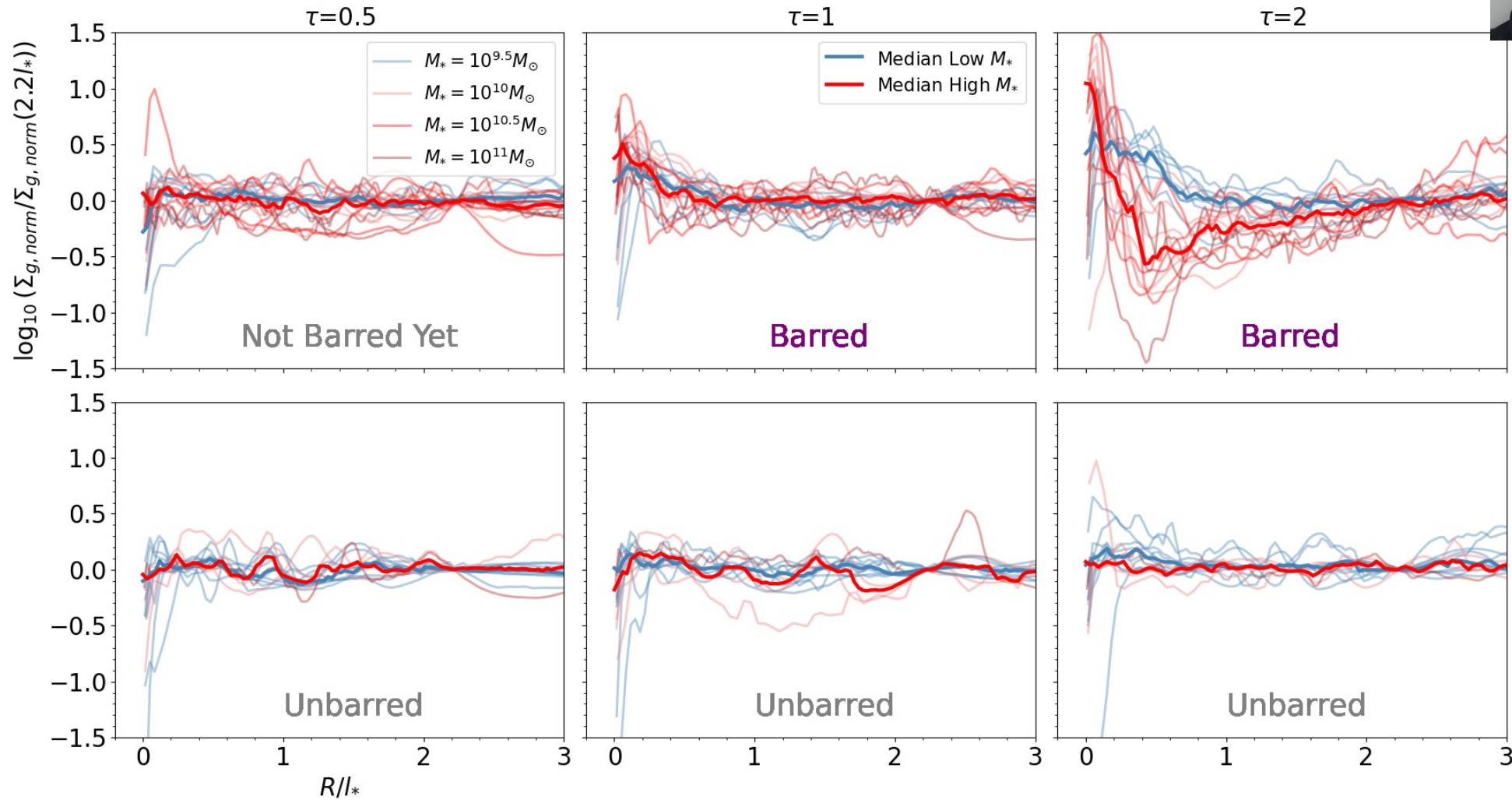
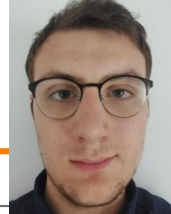
Building of inner discs

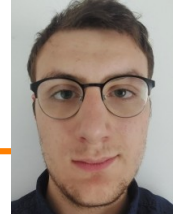
Verwilghen+ 2025



Bar-driven evolution: deserts & peaks

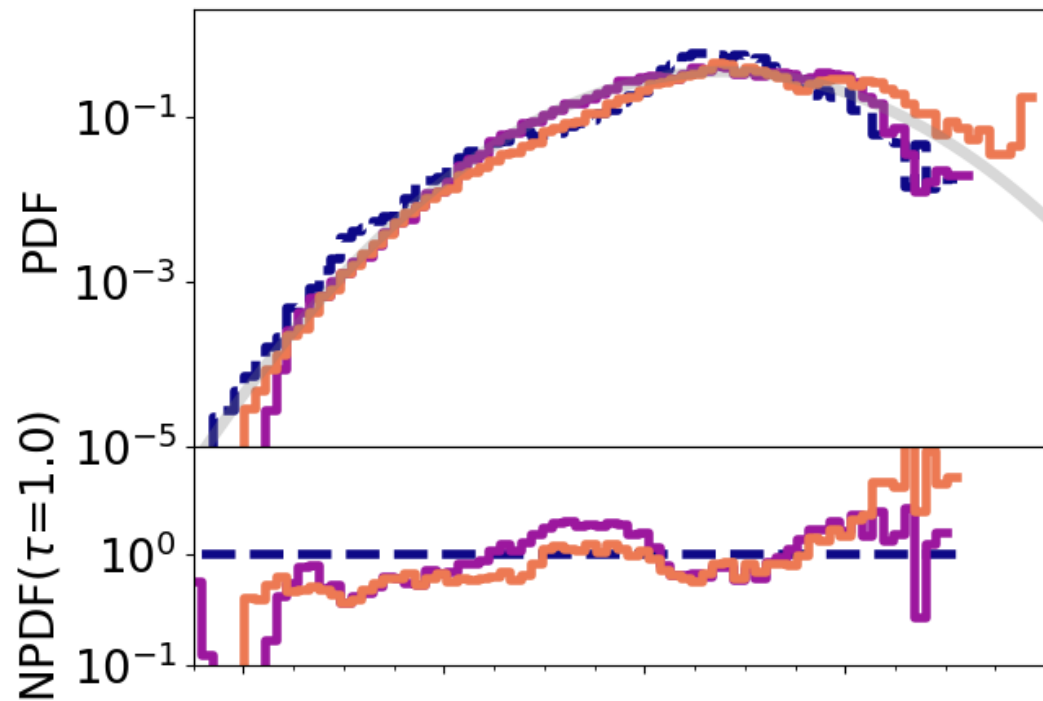
Verwilghen+ 2025





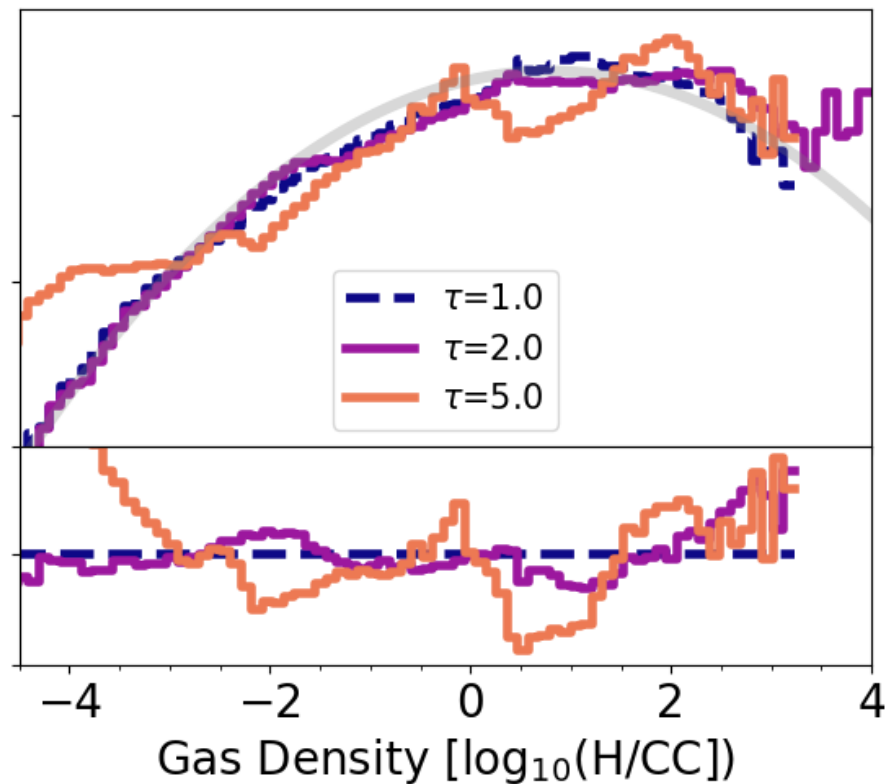
$10^{9.5} M_{\odot}$

G013M095F20L2B00



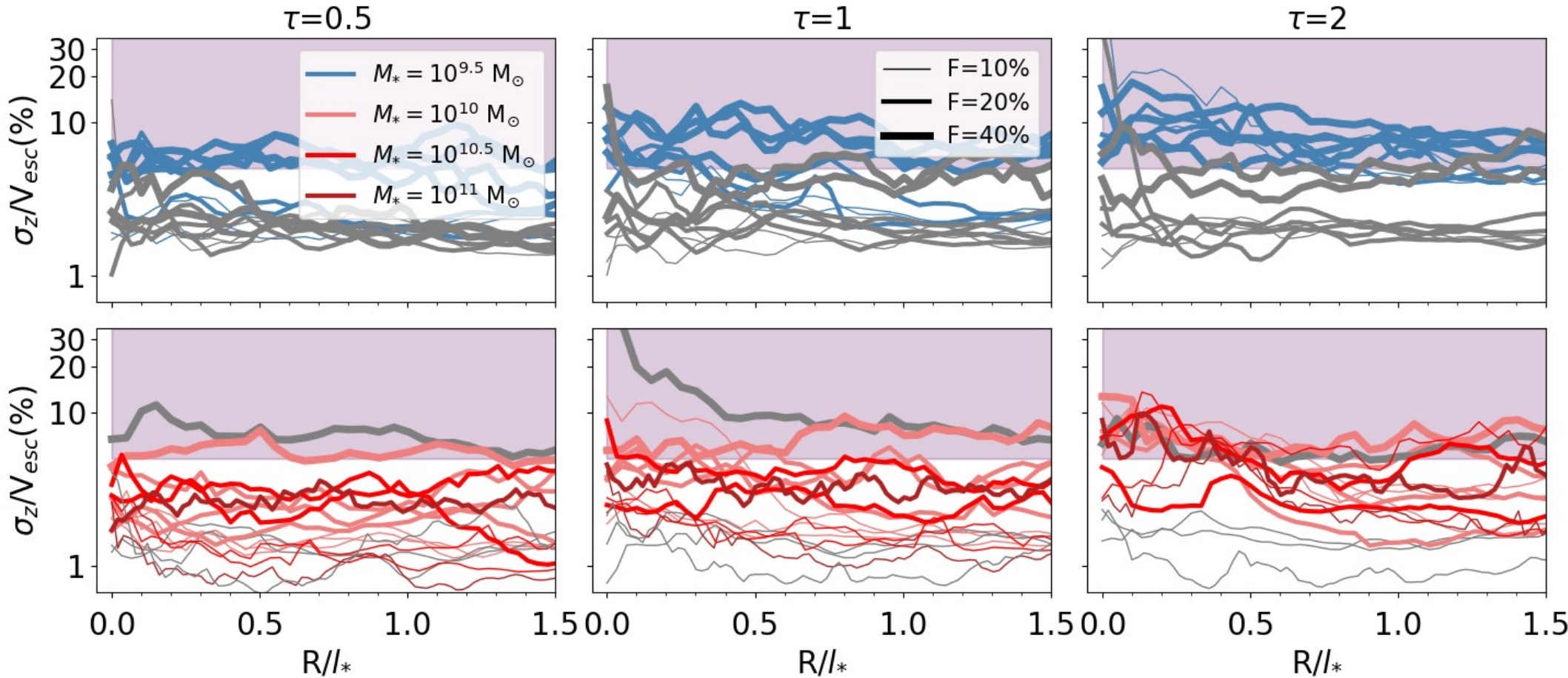
$10^{10} M_{\odot}$

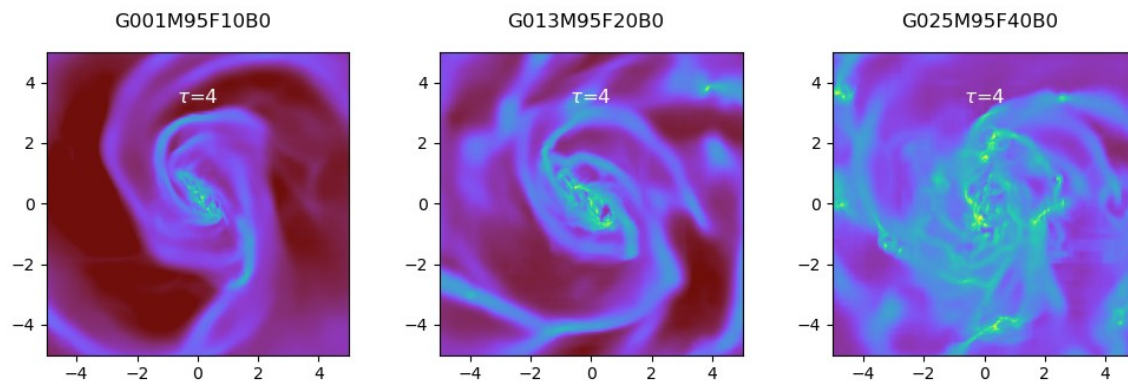
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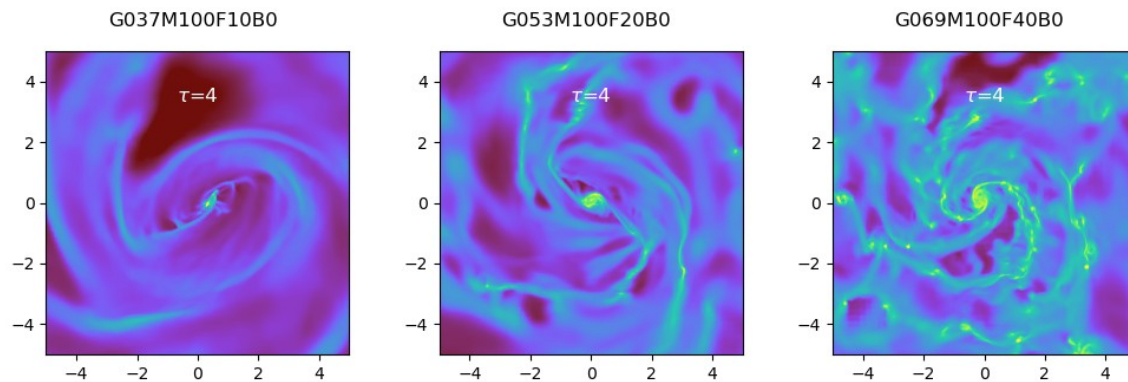
Feedback !

Verwilghen+ 2025

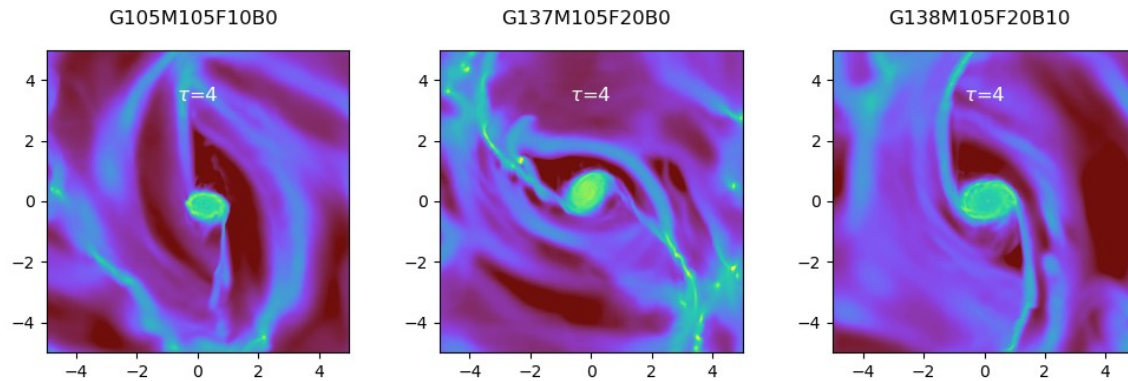




Low $M_\star$

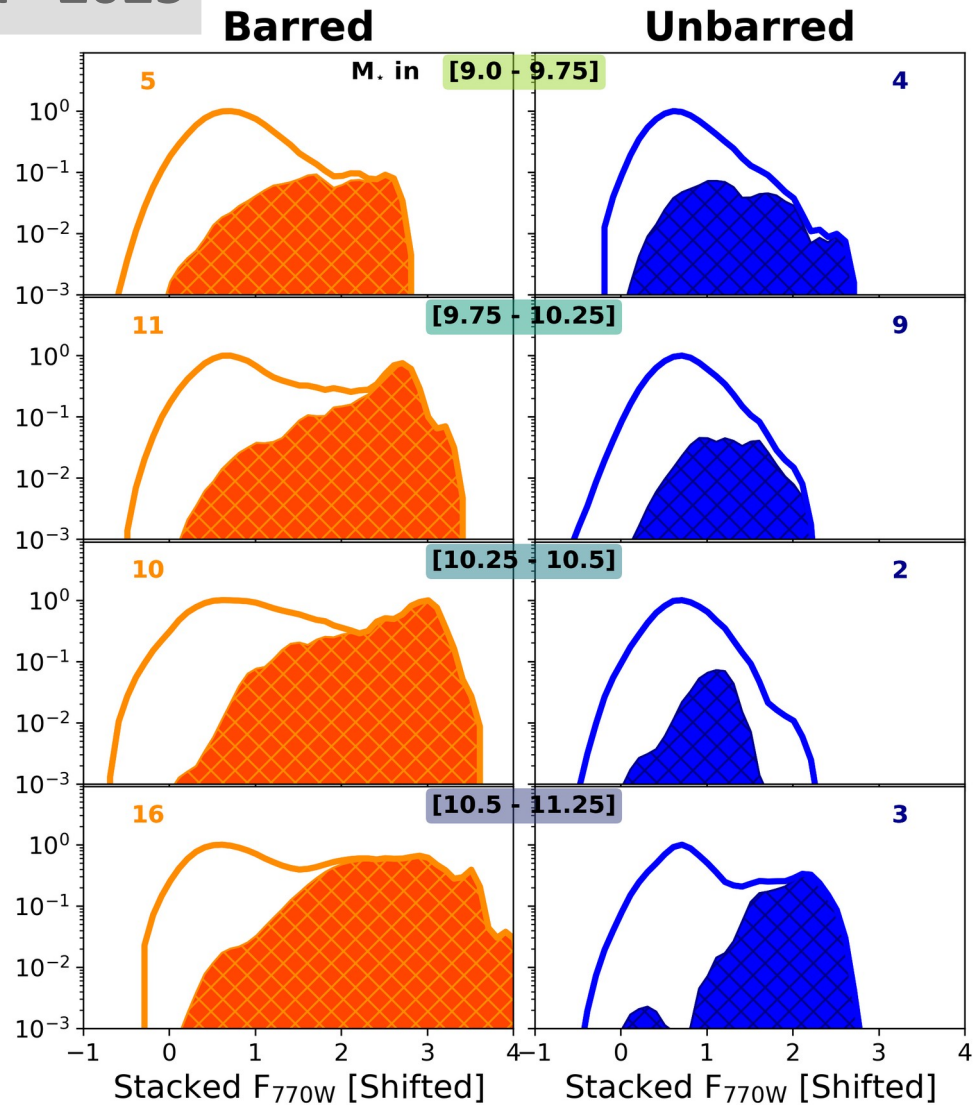
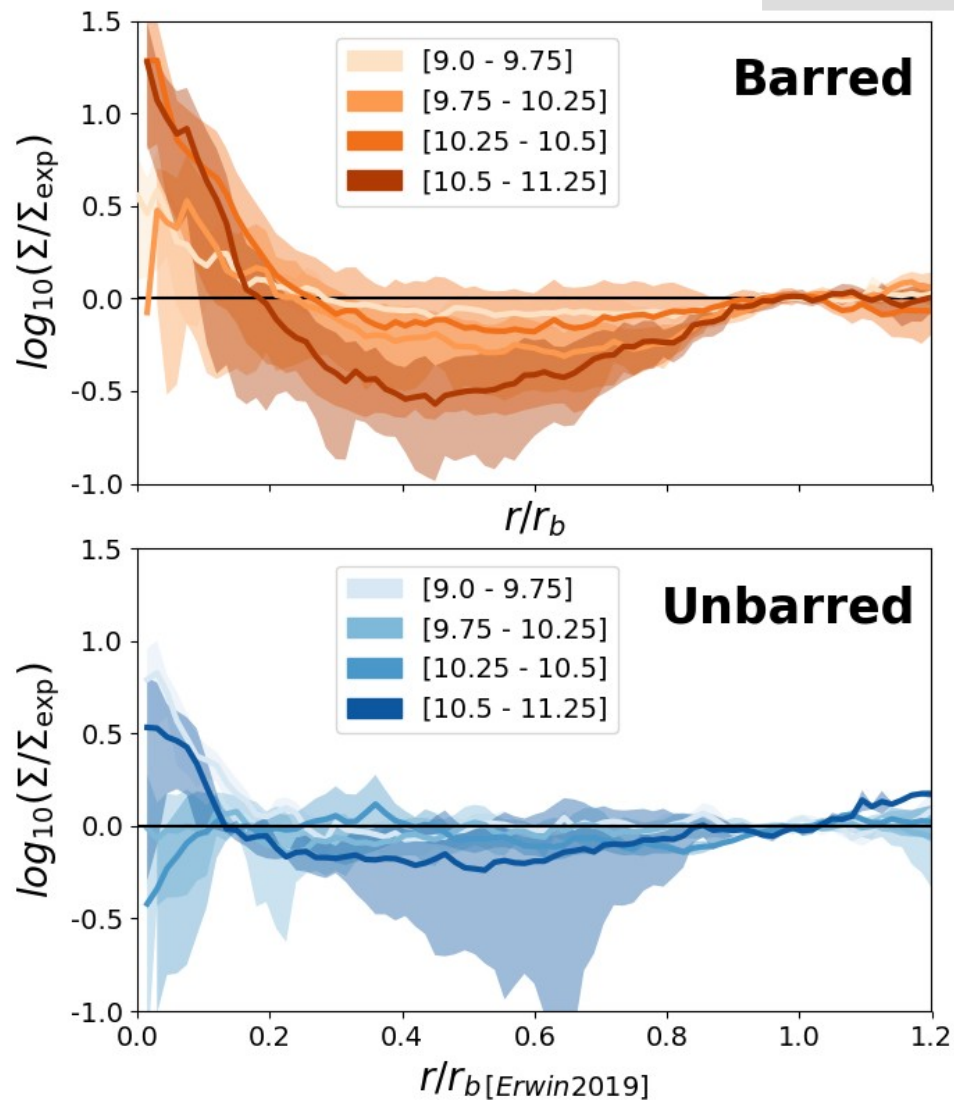


Mid $M_\star$

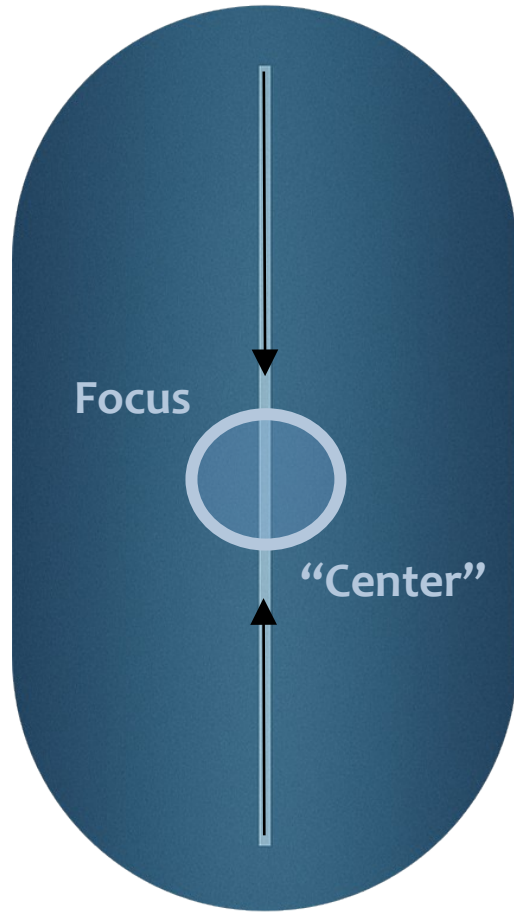


High $M_\star$

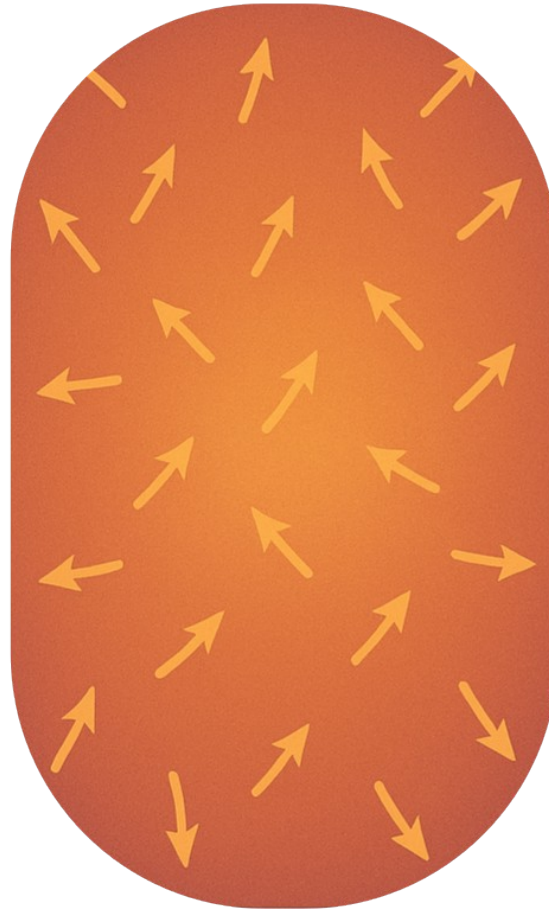
About
Timescales



Convergent
Laminar Inflow



Stellar Feedback
Perturbation



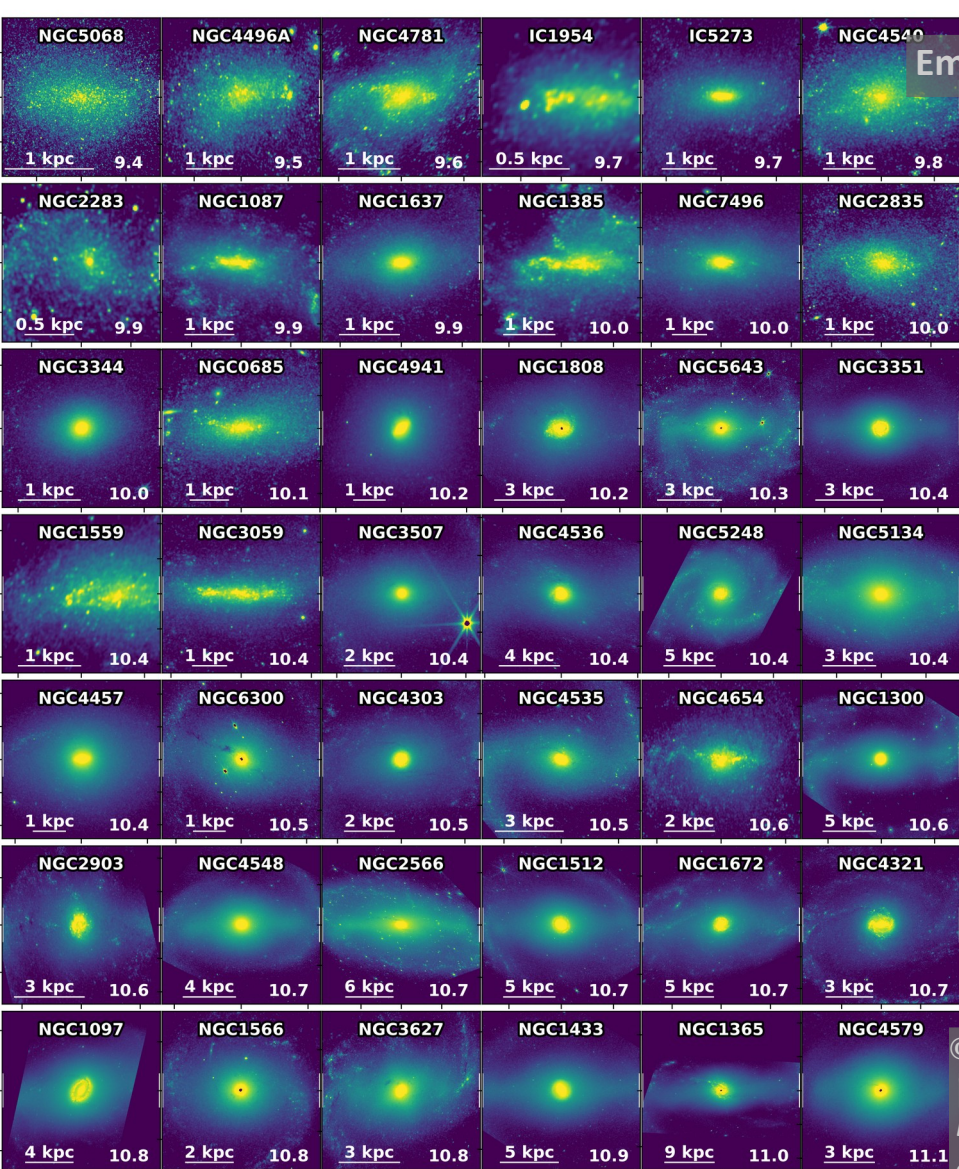
Turbulent,
Chaotic Flow



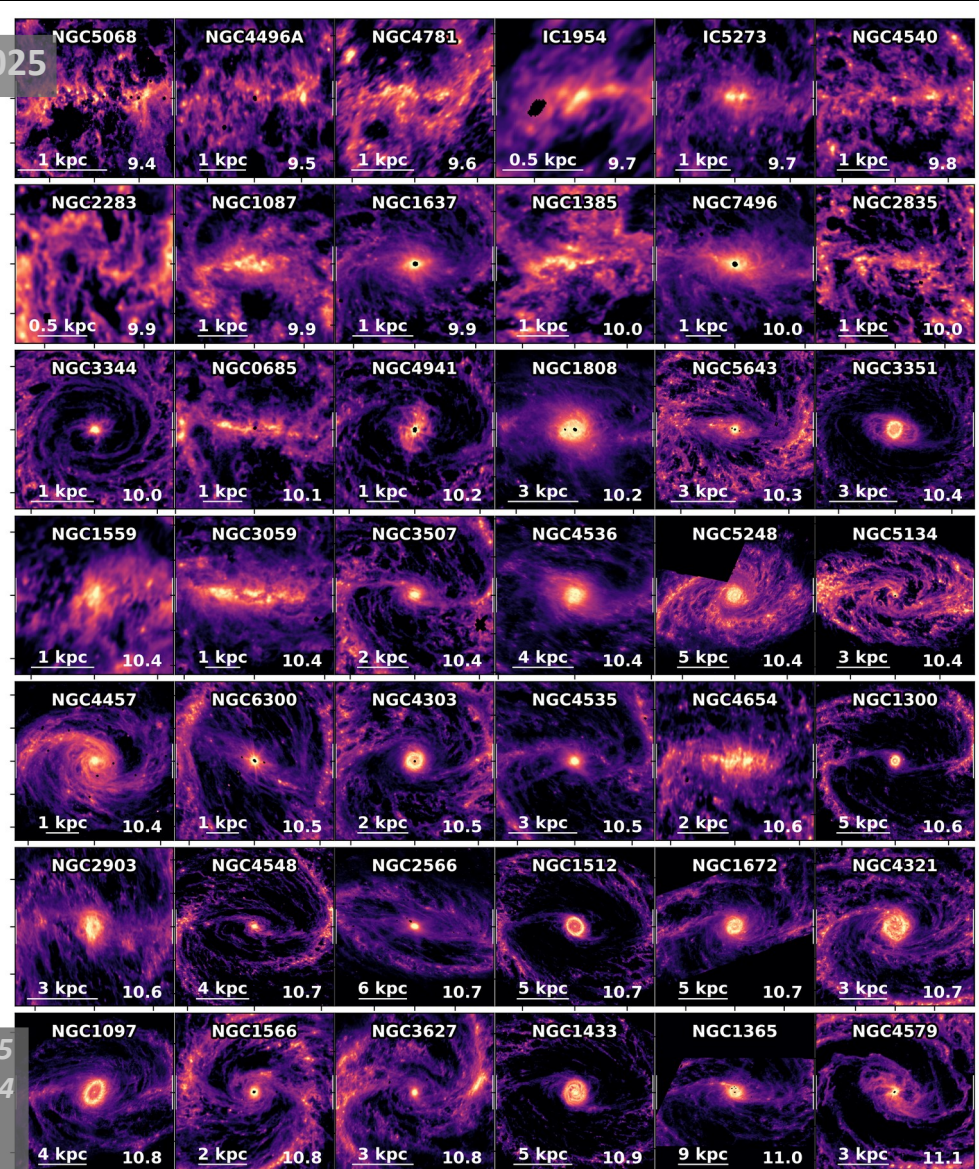
1D



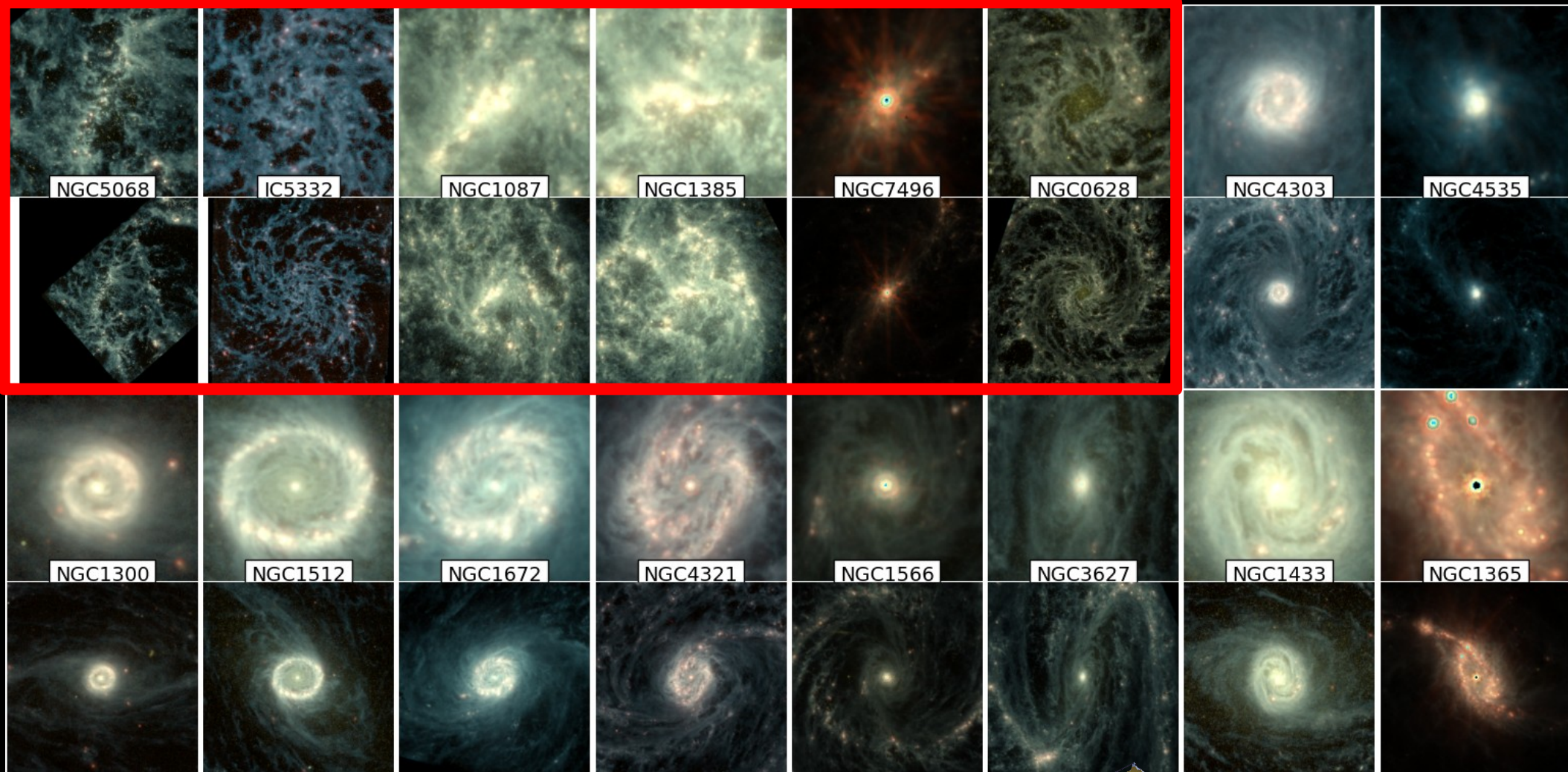
3D



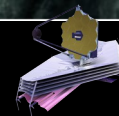
© Chown+2025
Williams+2024
Lee+2023
& Sutter



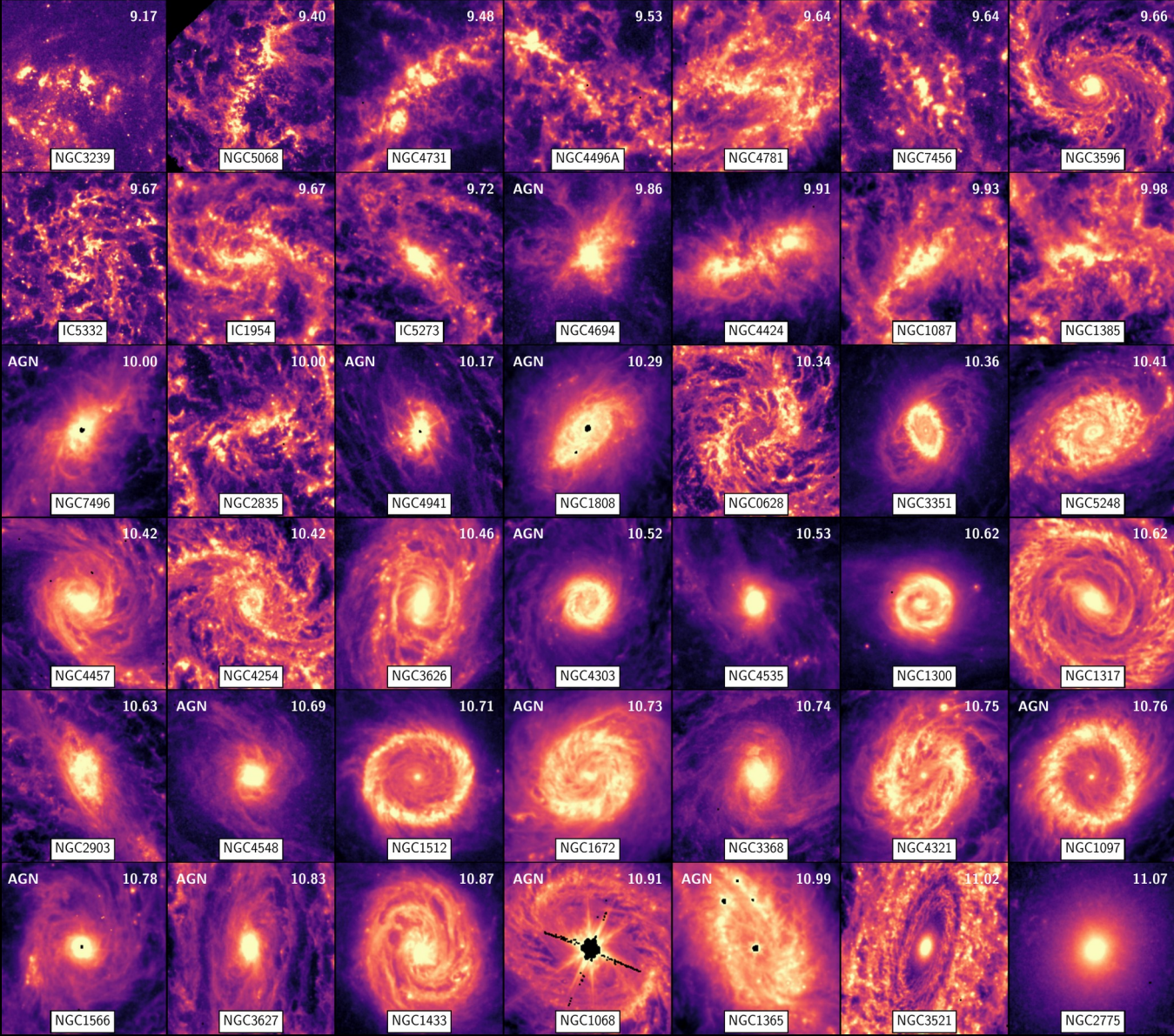
Lower mass systems



Credit: NASA/ESA,CSA; PHANGS / Emsellem

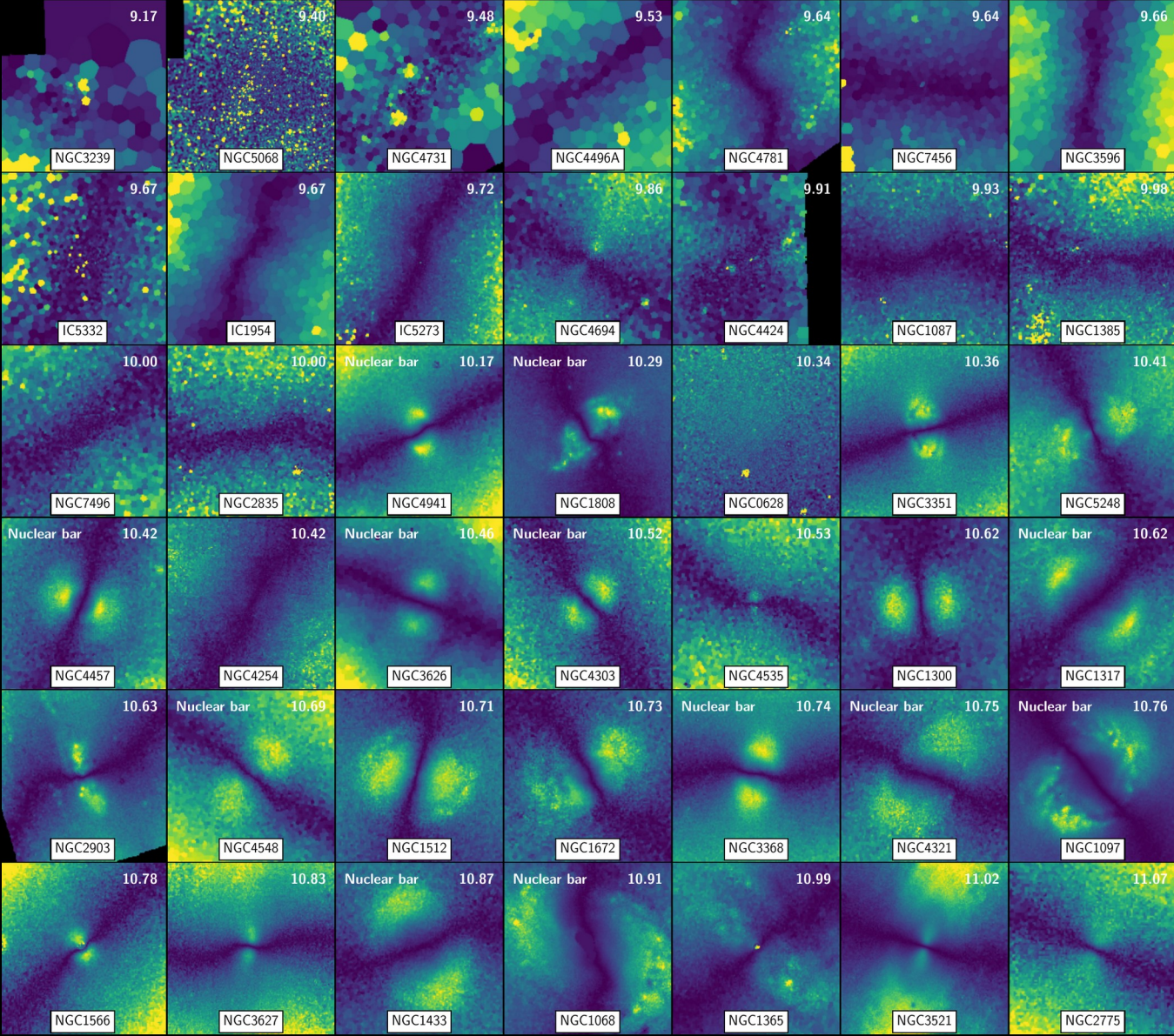


21 μ m-10.0 μ m-3 μ m



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)

