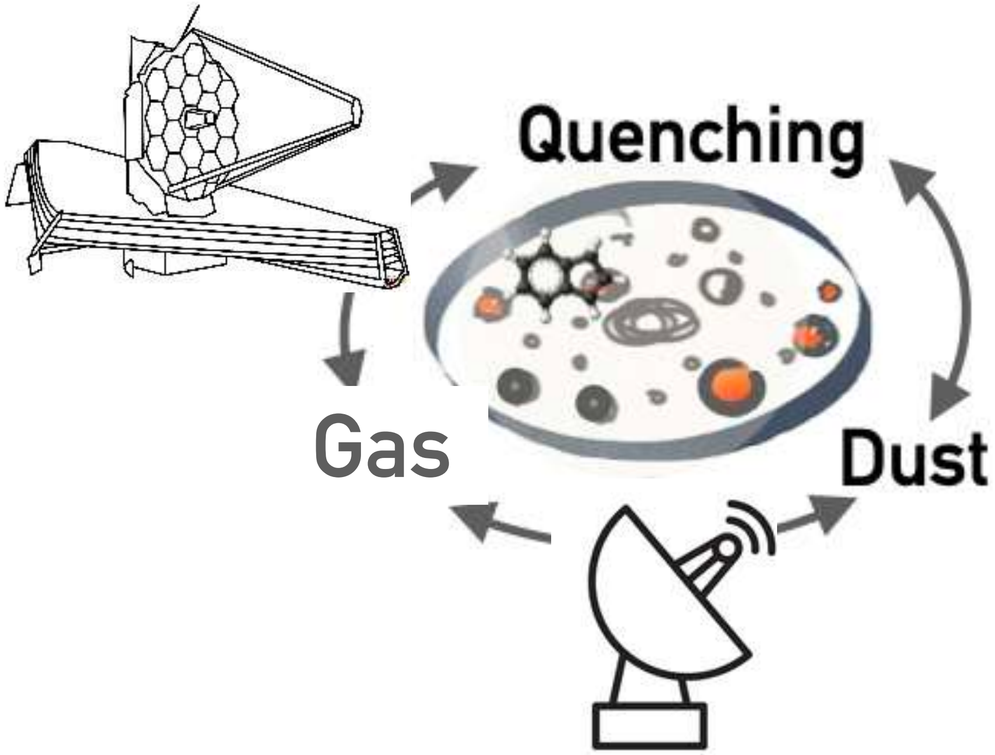
# First View On Dust-Gas Co-Evolution In Quiescent Galaxies

*with ALMA & JWST (and theory!)*




**Darko Donevski**

***Principal Research Scientist | Assistant Professor***

*1) Astrophysics Division, NCBJ, Warsaw*

*2) SISSA, Astrophysics Group, Trieste*

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# Project “DUSTY GIANTS” = First link of dust-gas-PAH in late galaxy evolution

**What?** NCN & Bekker grant funded 4yr project to investigate cold+warm gas and dust in quenched galaxies

## ✱ Who?

**PI: D. Donevski** (SISSA/NCBJ)

+ 2 PhD students (**G. Lorenzon, K. Lisiecki;** NCBJ Warsaw**)**
+ postdoc (**M. Romano** (NCBJ→ Max Planck IfR, Bonn))
+ key collaborators (**A. Man** (*UBC, Vancouver*), **A. Nanni** (*NCBJ*), **K. Whitaker** *(UMass Amherst)*, **D. Narayanan** (U.Florida)
**I. Damjanov (**SMU, Halifax) )

Dr. M. Romano Prof. A. Man

## ✱ Ongoing observational projects:

[1] **ALMA & NOEMA view on cold dust & gas in quiescent galaxies** (73 hours);
[2] **JWST Cycle 4 NIRSpec/MIRI probe of PAH and mol. gas in the CGM** (15 hours)
[3] **Gemini search for dusty clusters** (20 hours)

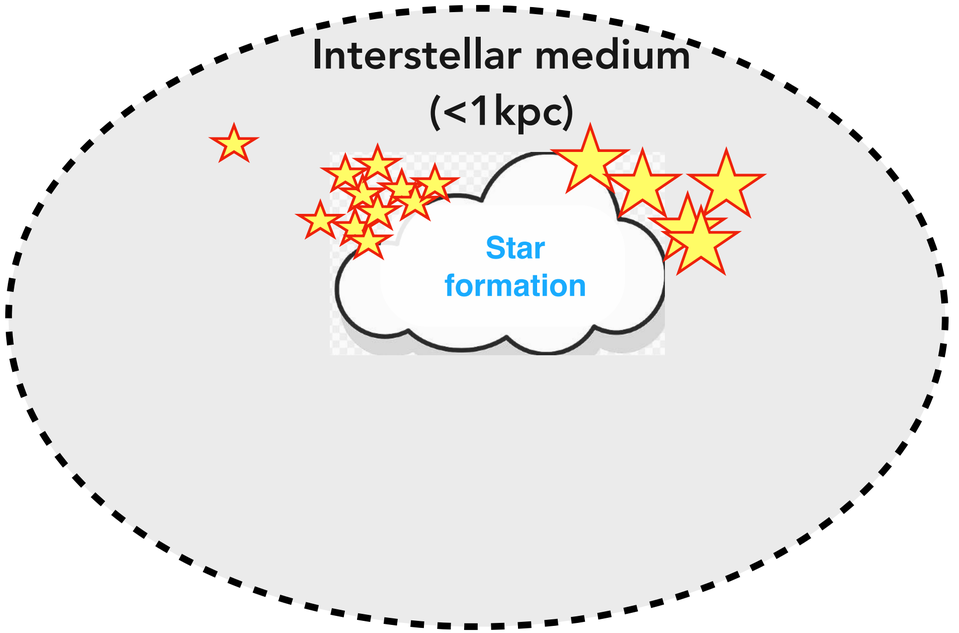
## ✱ Future science missions involvement:

**PRIMA** *(NASA selected Phase-A; 2025-2026)*

## This talk:

- Studying the interstellar medium (ISM) in galaxy evolution in the JWST and ALMA-era
- First identification of cold dust and molecular gas in quiescent galaxies
- Changing the dust-gas-PAH paradigm… and what's next?

# 1.1 Baryonic cycle in galaxies: the key role of dust



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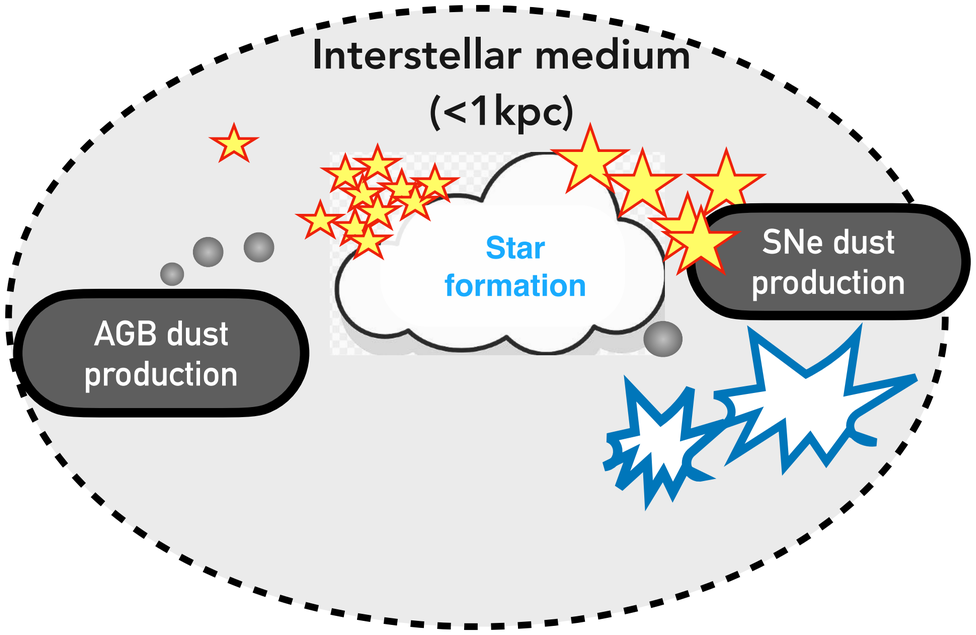

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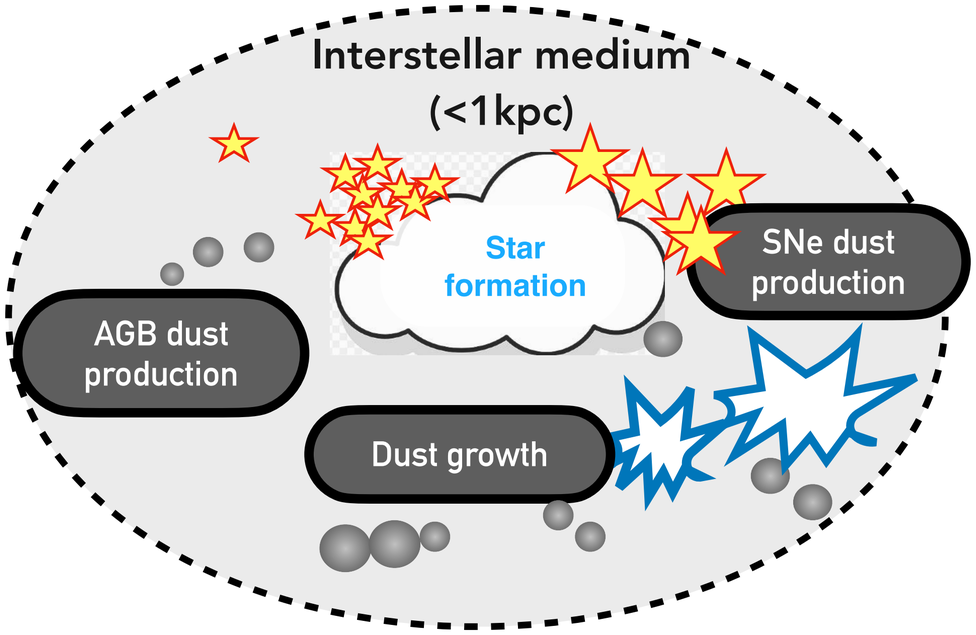

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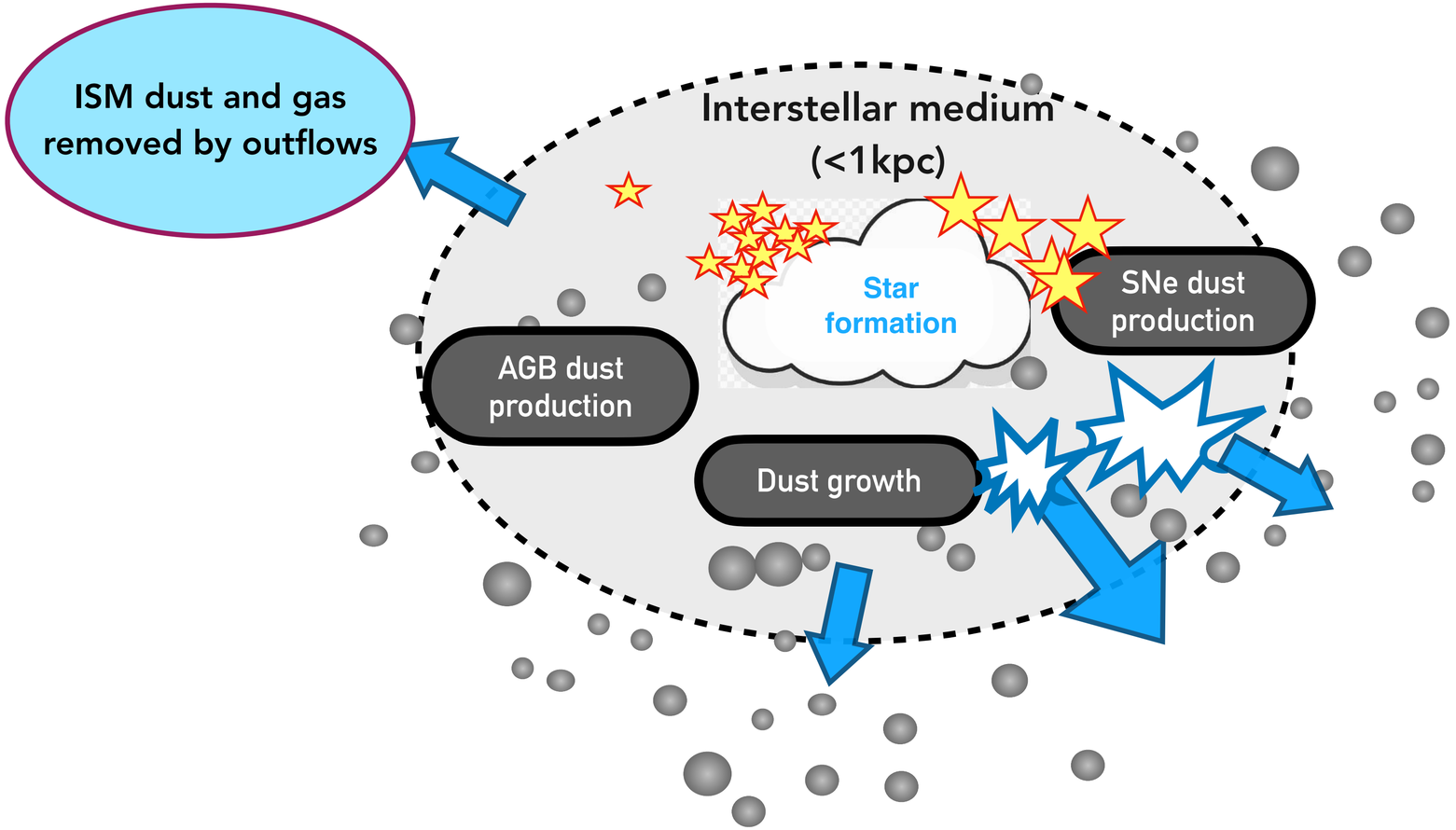

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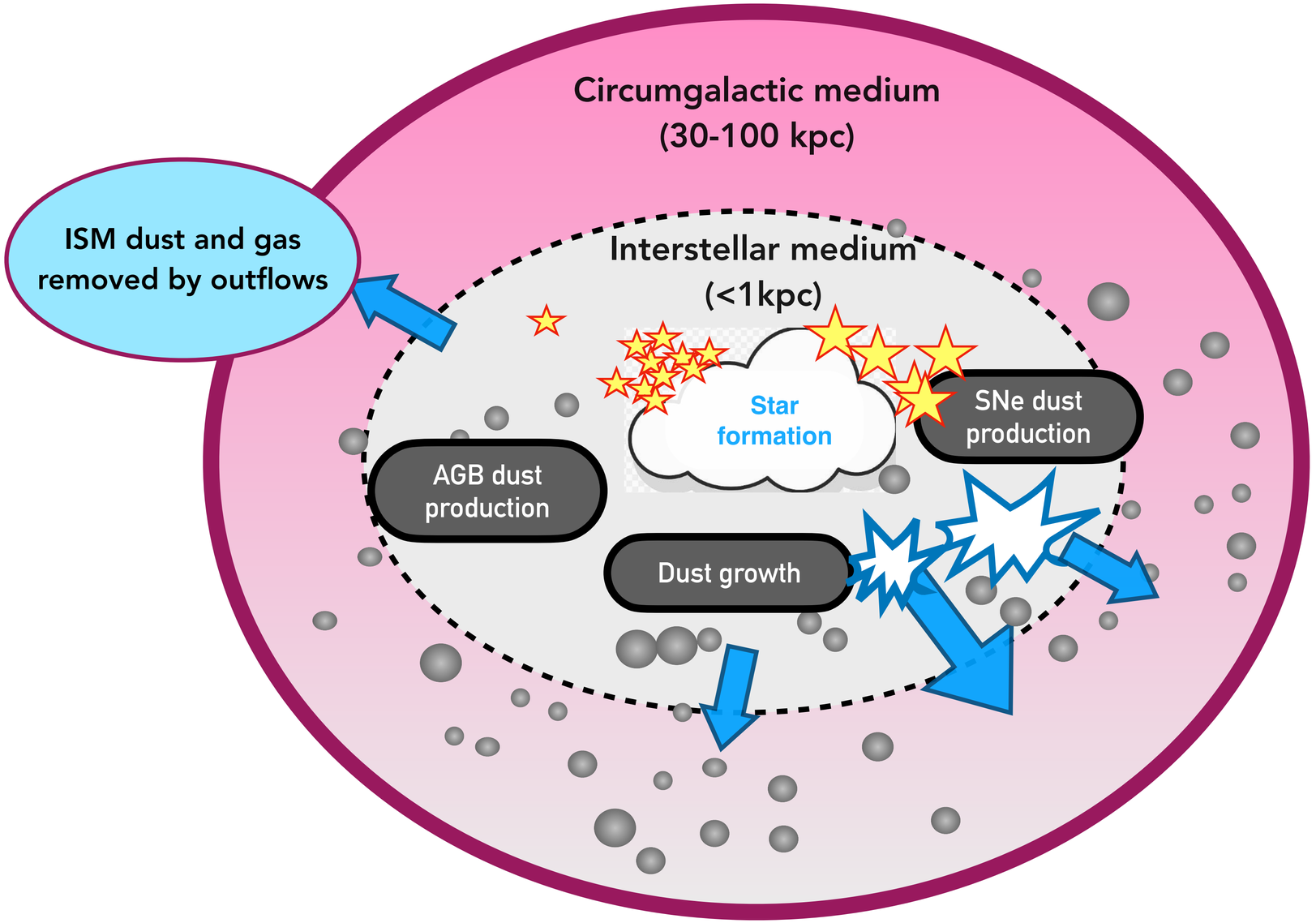

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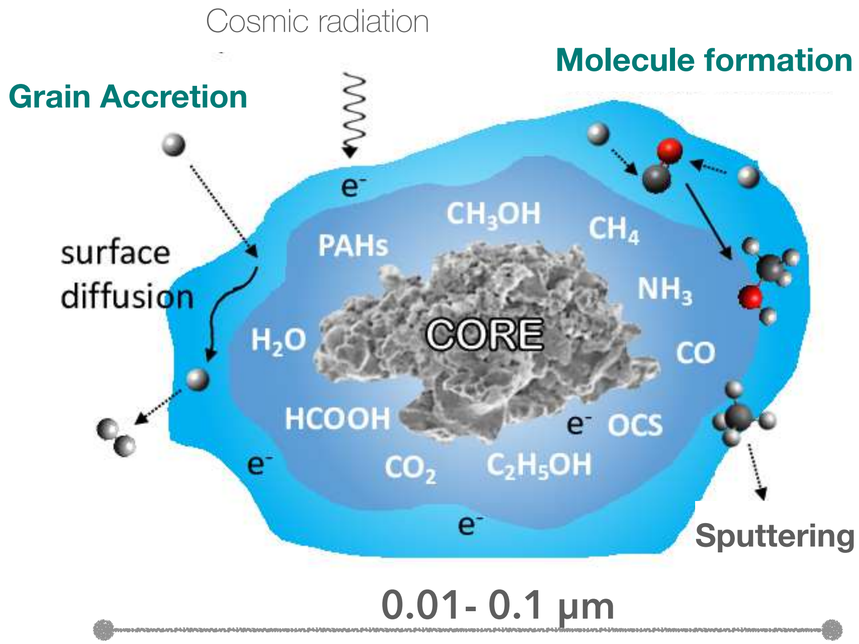
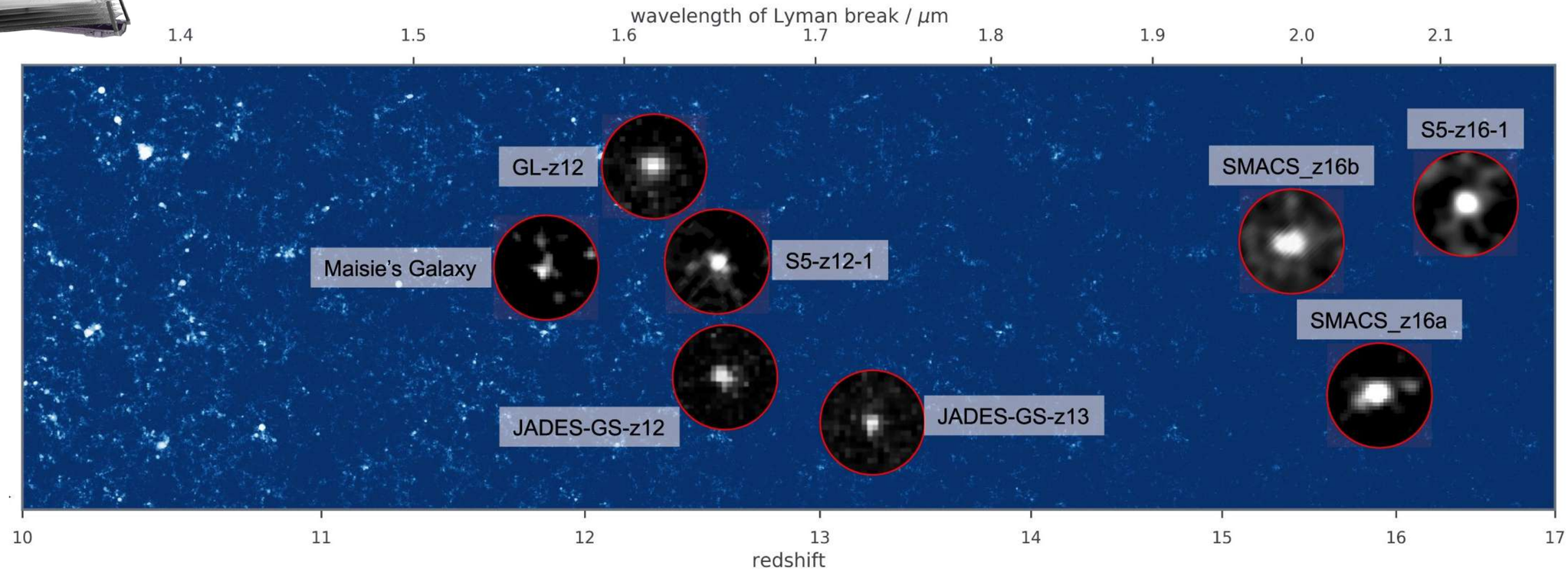



**Dust: a key baryonic regulator in ISM and CGM**

- Absorbs 50% of stellar light in the universe!
- Major ISM coolant in galaxies!
- Supports molecule formation!
- Supports planet formation!

# 1.2. JWST-era: Revolution in galaxy formation & evolution

JWST: Early massive galaxy formation → … early quenching?




Weidel+ 25

# 1.2. JWST-era: Revolution in galaxy formation & evolution

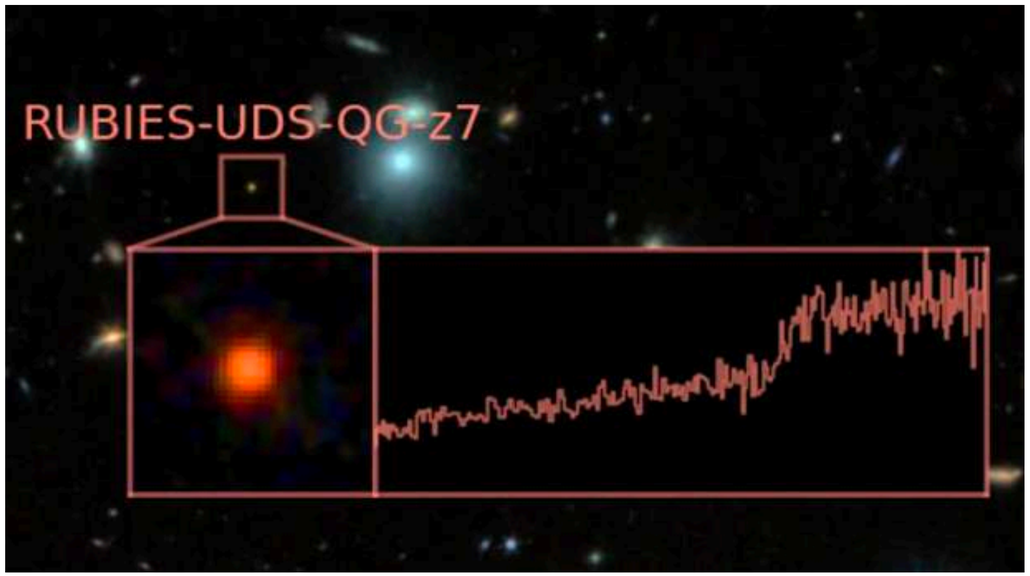
QGs /post-starburst confirmed up to z~7 → **but what about their ISM???**

- **JWST-confirmed QGs up to z~7**
  deGraaf+ 2024, Weidel+ 2025; etc.
- QGs undergo multiple quenching channels:
  Tacchella+2022, Carnall+ 23, Belli+ 2024; etcc


**Efficient formation of a massive quiescent galaxy at redshift 4.9**

Anna de Graaff, David J. Setton, Gabriel Brammer, Sam Cutler, Katherine A. Suess, Ivo Labbé, Joel Leja, Andrea Weibel, Michael V. Maseda, Katherine E. Whitaker, Rachel Bezanson, Leindert A. Boogaard, Nikko J. Cleri, Gabriella De Lucia, Marijn Franx, Jenny E. Greene, Michaela Hirschmann, Jorryt Matthee, Ian McConachie, Rohan P. Naidu, Pascal A. Oesch, Sedona H. Price, Hans-Walter Rix, Francesco Valentino, ... Christina C. Williams + Show authors

*Nature Astronomy* **9**, 280–292 (2025) | Cite this article




Weidel+ 25

**Quenching of star formation from a lack of inflowing gas to galaxies**

Katherine E. Whitaker, Christina C. Williams, Lamiya Mowla, Justin S. Spilker, Sune Toft, Desika Narayanan, Alexandra Pope, Georgios E. Magdis, Pieter G. van Dokkum, Mohammad Akhshik, Rachel Bezanson, Gabriel B. Brammer, Joel Leja, Allison Man, Erica J. Nelson, Johan Richard, Camilla Pacifici, Keren Sharon & Francesco Valentino

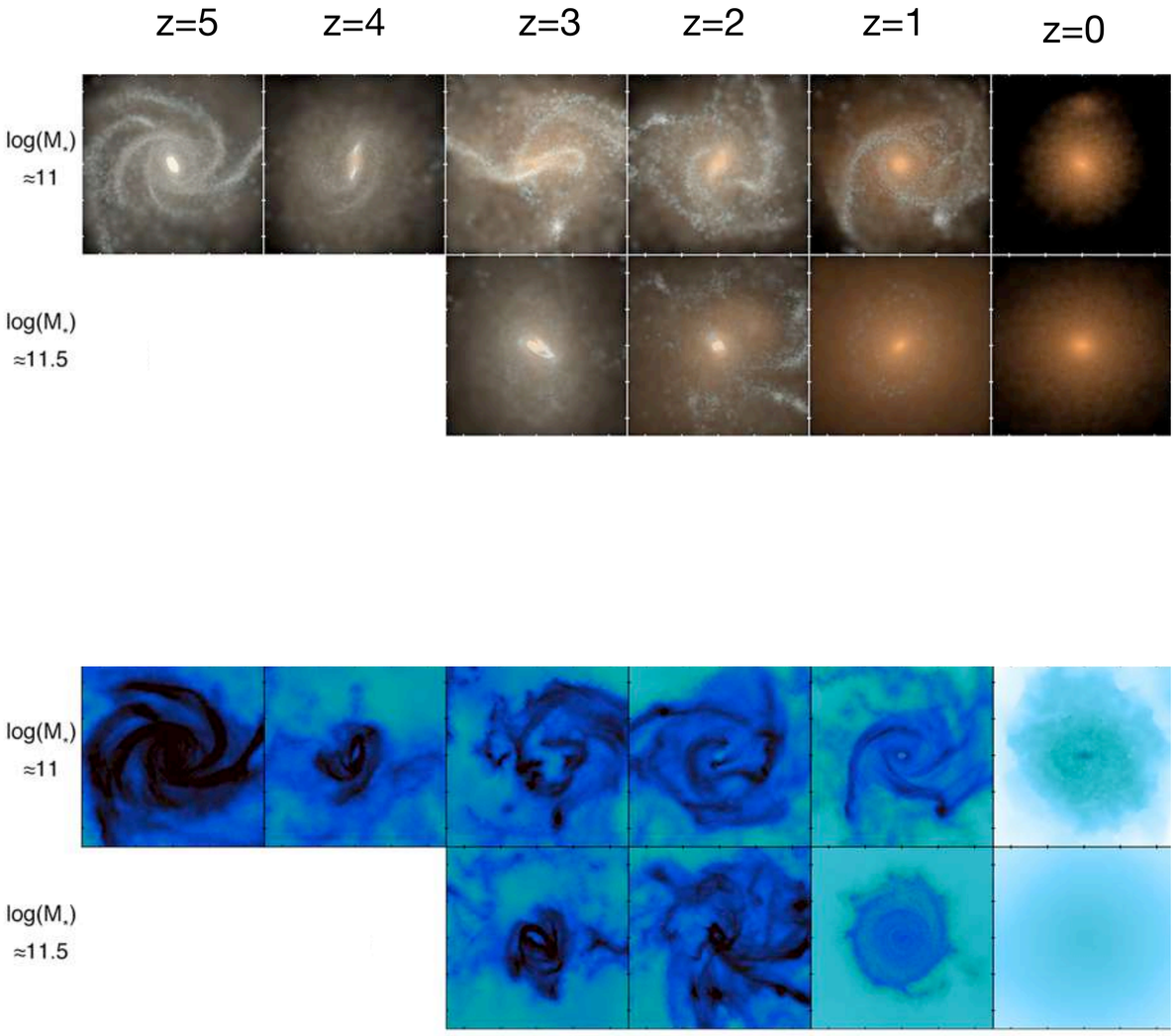
*Nature* **597**, 485–488 (2021) | Cite this article

# 1.3 Dust and Gas in QGs: emerging field & challenge for galaxy formation

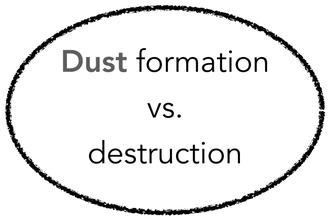
Many **simulations** predicts that cold gas dissapears <100 Myr after quenching: **QGs should be "red an dead"**

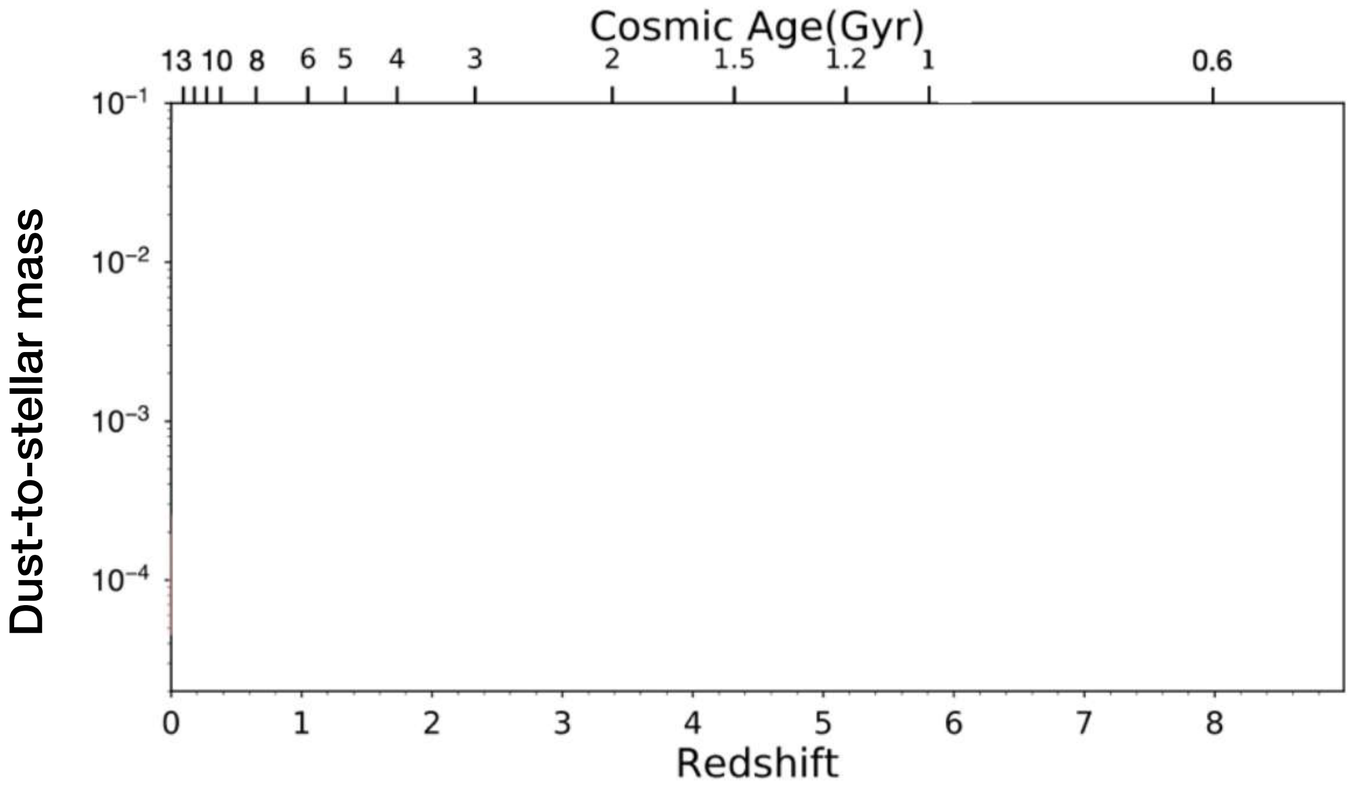
Stellar content

Gas content

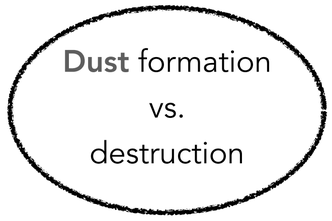


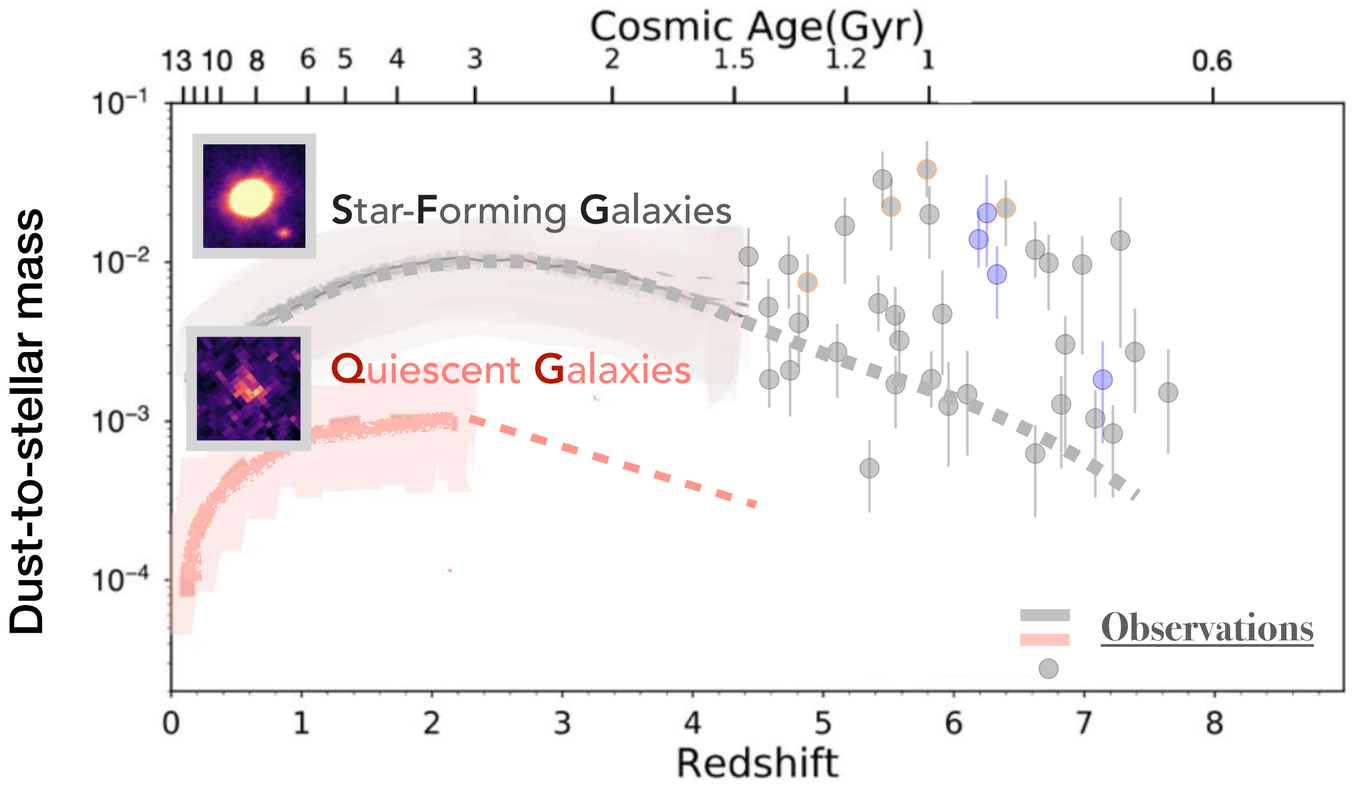

# 1.3 Dust and Gas in QGs: emerging field & challenge for galaxy formation



# 1.3 Dust and Gas in QGs: emerging field & challenge for galaxy formation



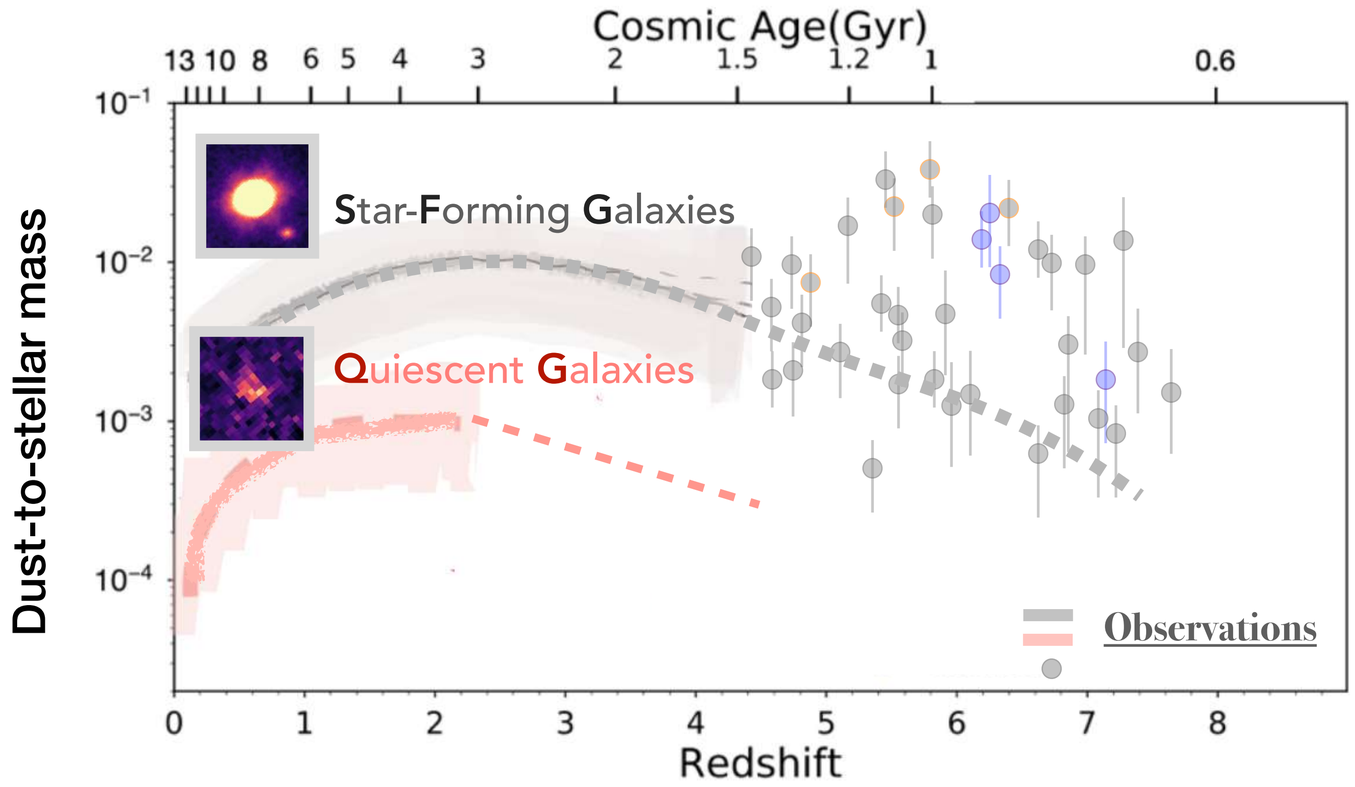

SFGs: **Donevski+20,** Dayal+22; Sawant+25

QGs: Magdis+21; Whitaker+21; Gobat+22; Lee+23
**Donevski+23;** Blanquez+23; **Lorenzon+25**
Whitaker&Bezanson+26

**Linking the peak of SF and quenching with ISM evolution in galaxies!**

# 1.3 Dust and Gas in QGs: emerging field & challenge for galaxy formation

Dust formation
vs.
destruction




SFGs: **Donevski+20,** Dayal+22; Sawant+25
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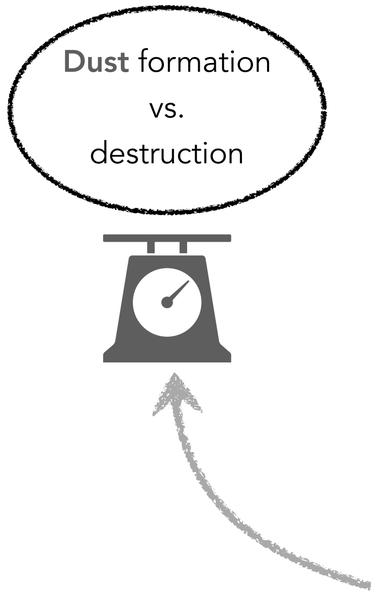
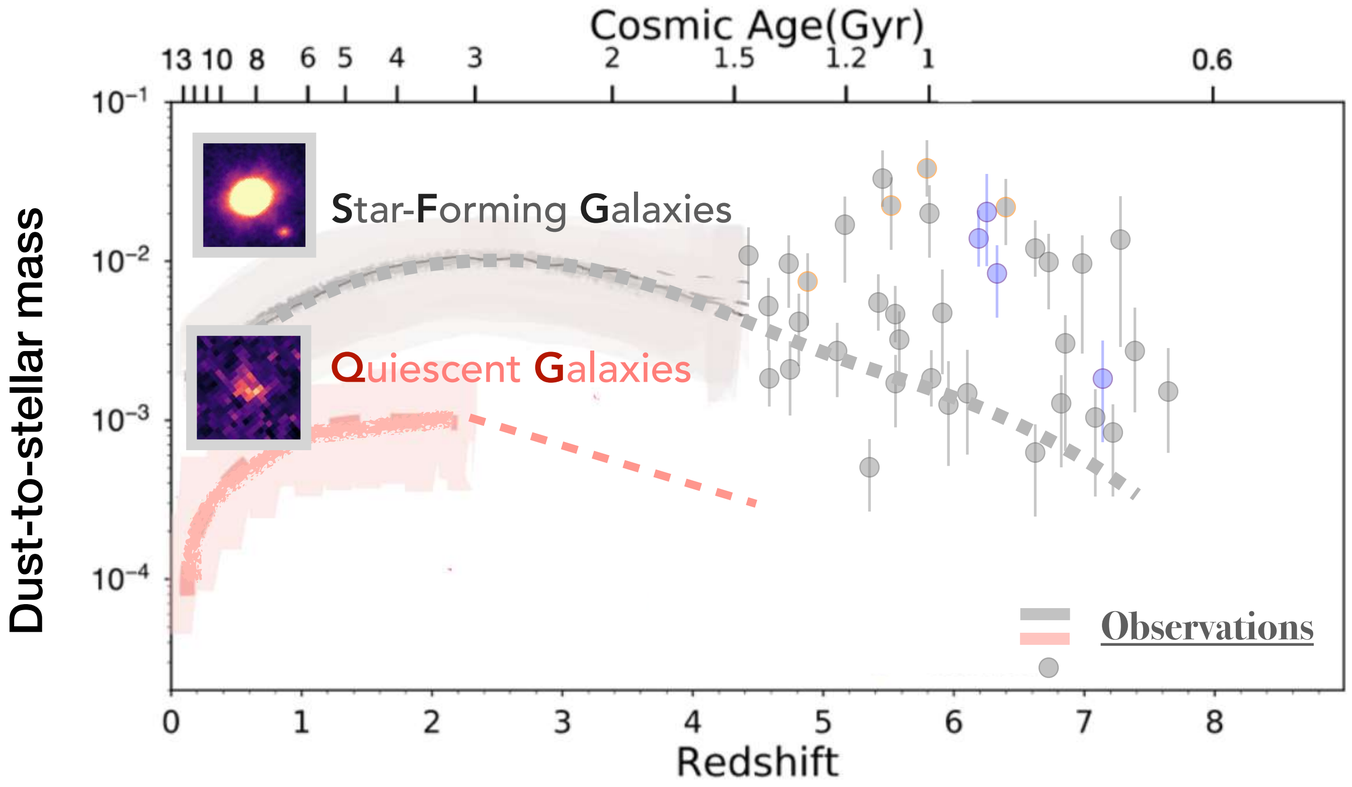
**Donevski+23;** Blanquez+23; **Lorenzon+25**
Whitaker&Bezanson+26

**Problem 1: Faint emission = lack of constraints on cold ISM in individual QGs**

**Problem 2: Simulations (Illustris, EAGLE, Dusty Gadget) don't model self-consistent dust/gas evolution**

# 1.3 Dust and Gas in QGs: emerging field & challenge for galaxy formation

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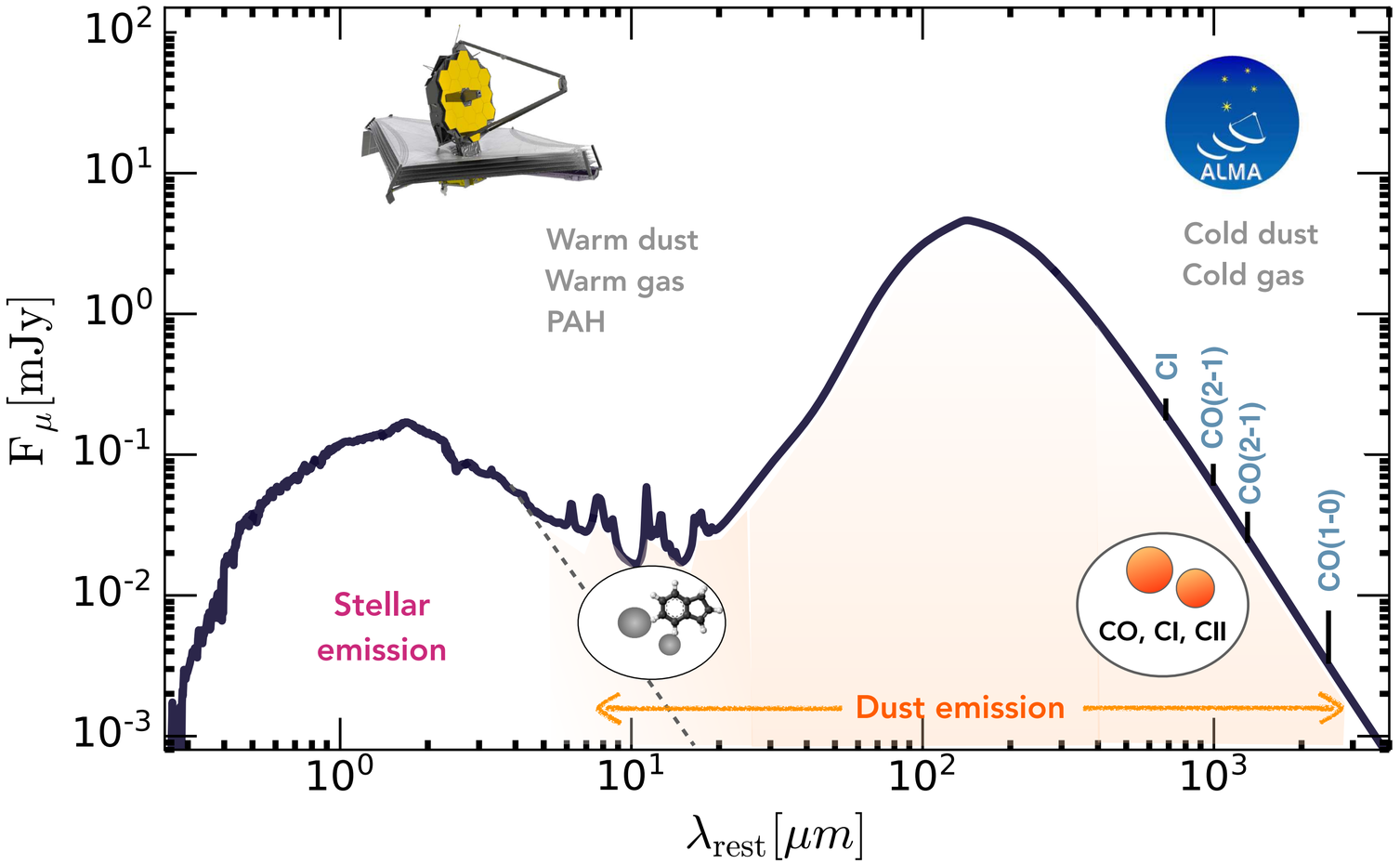
**Donevski+23;** Blanquez+23; **Lorenzon+25**
Whitaker&Bezanson+26

**Big question:**

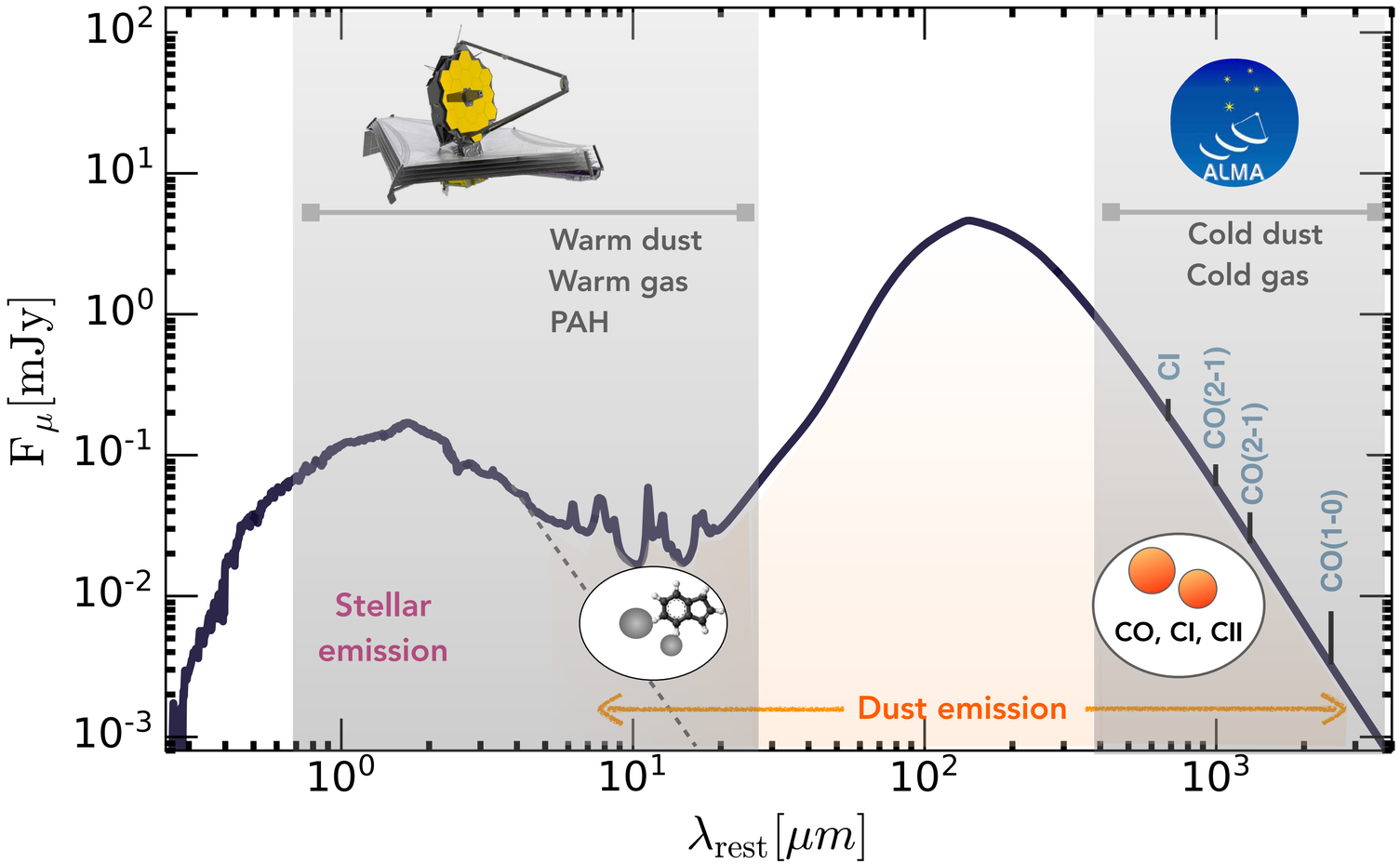
Do gas & dust share same pathways after star formation quenches?

# 1.4 Multiwavelength view of QGs: JWST+ALMA synergy




**JWST+ALMA** = Probing galaxies' dust, gas, PAH, metals & stars !

# 1.4 Multiwavelength view of QGs: JWST+ALMA synergy




**JWST+ALMA** = Probing galaxies' dust, gas, PAH, metals & stars !

# Part II

## *First deep ALMA & JWST view on cold dust & gas in QGs*

(1) Lorenzon, Donevski et al., 2025, ApJL, 995, L63; arXiv:2509.10079

(2) Donevski et al., 2025, submitted


THE ASTROPHYSICAL JOURNAL LETTERS

OPEN ACCESS

ALMA Reveals Diverse Dust-to-gas Mass Ratios and Quenching Modes in Old Quiescent Galaxies

G. Lorenzon, D. Donevski, A. W. S. Man, M. Romano, K. E. Whitaker, S. Belli, D. Liu, M. M. Lee, D. Narayanan, A. Long Show full author list

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The Astrophysical Journal Letters, Volume 995, Number 2

**Citation** G. Lorenzon *et al* 2025 *ApJL* **995** L63

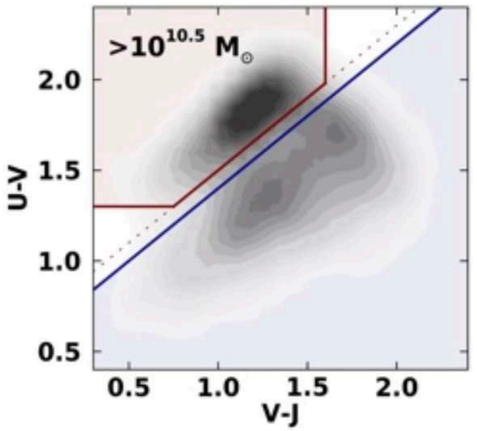
**DOI** 10.3847/2041-8213/ae226c

Giuliano Lorenzon

(3rd yr PhD student @ NCBJ)

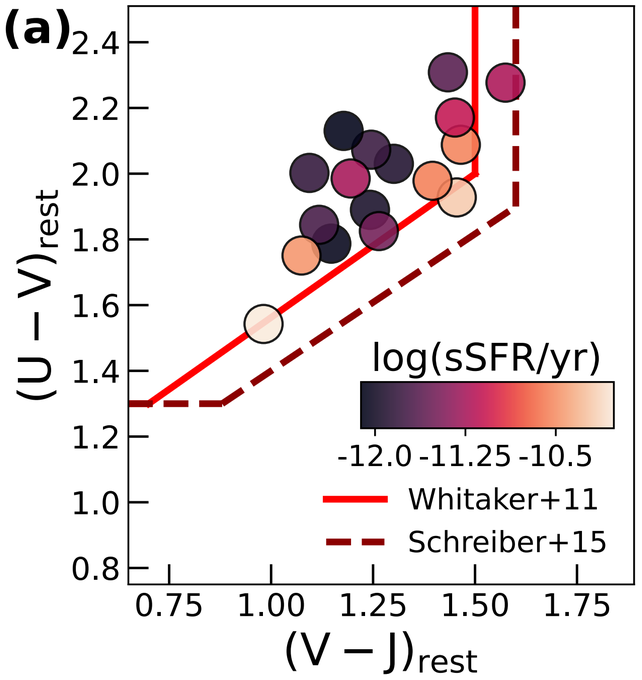
# Searching for dust & mol. Gas in QGs in the Cosmos Web Field

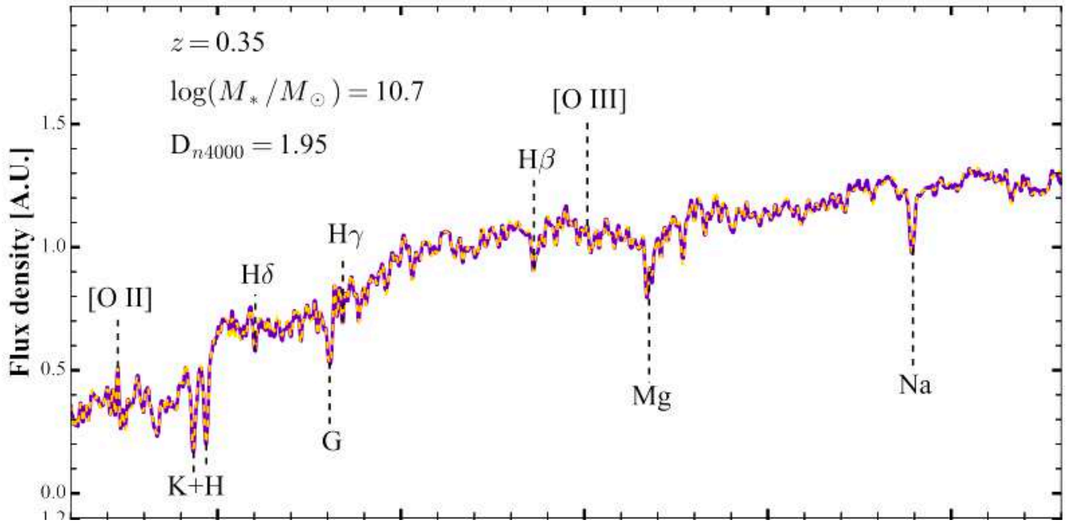
Cosmos Web: million JWST galaxies @ 0<z<14




First catalogue of
500 candidate dust-rich vs. dust-poor QGs!
(Donevski+ 23)

# 2.1 Deep ALMA hunt for dust-to-gas mass ratio in old QGs



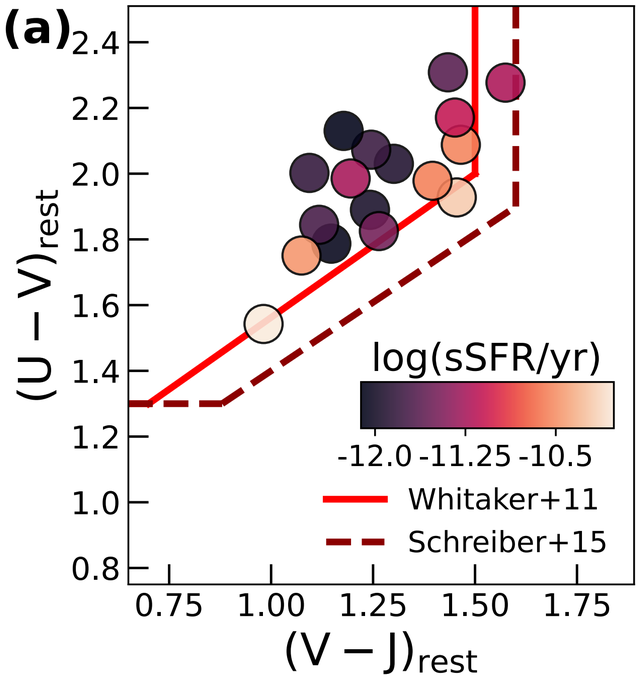



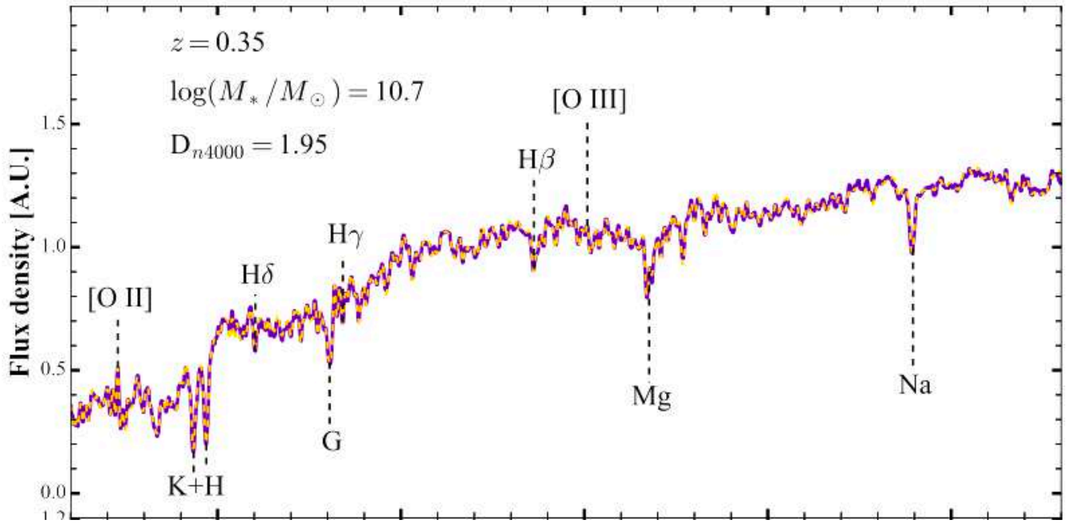

Donevski+ 23; Damjanov+ 25;

ALMA Band 6 hunt for dust & CO emission in QGs

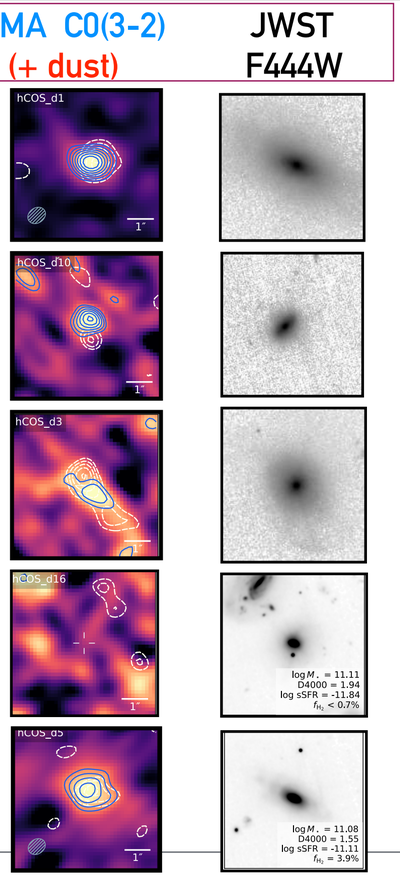
- **Cycle11 ALMA B6 CO(3-2) + dust continuum of 17 QGs at z~0.4 in the Cosmos Web**
- **30h ultra-deep program**
- **Dust continuum** rms ≈7uJy; **CO (3-2)** rms≈10 mJy/beam km/s

# 2.1 Deep ALMA hunt for dust-to-gas mass ratio in old QGs: red but not dead!



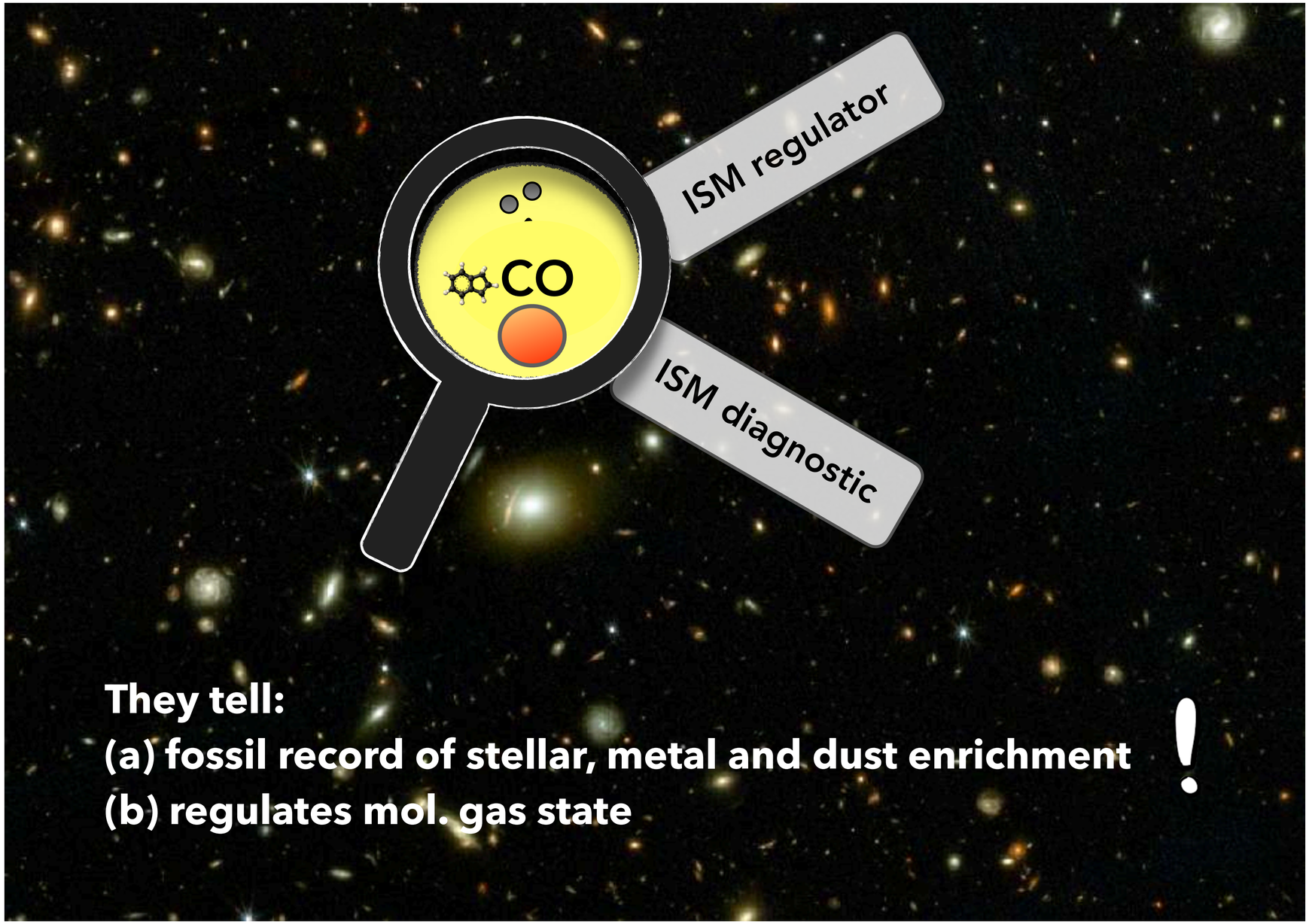

Donevski+ 23; Damjanov+ 25;



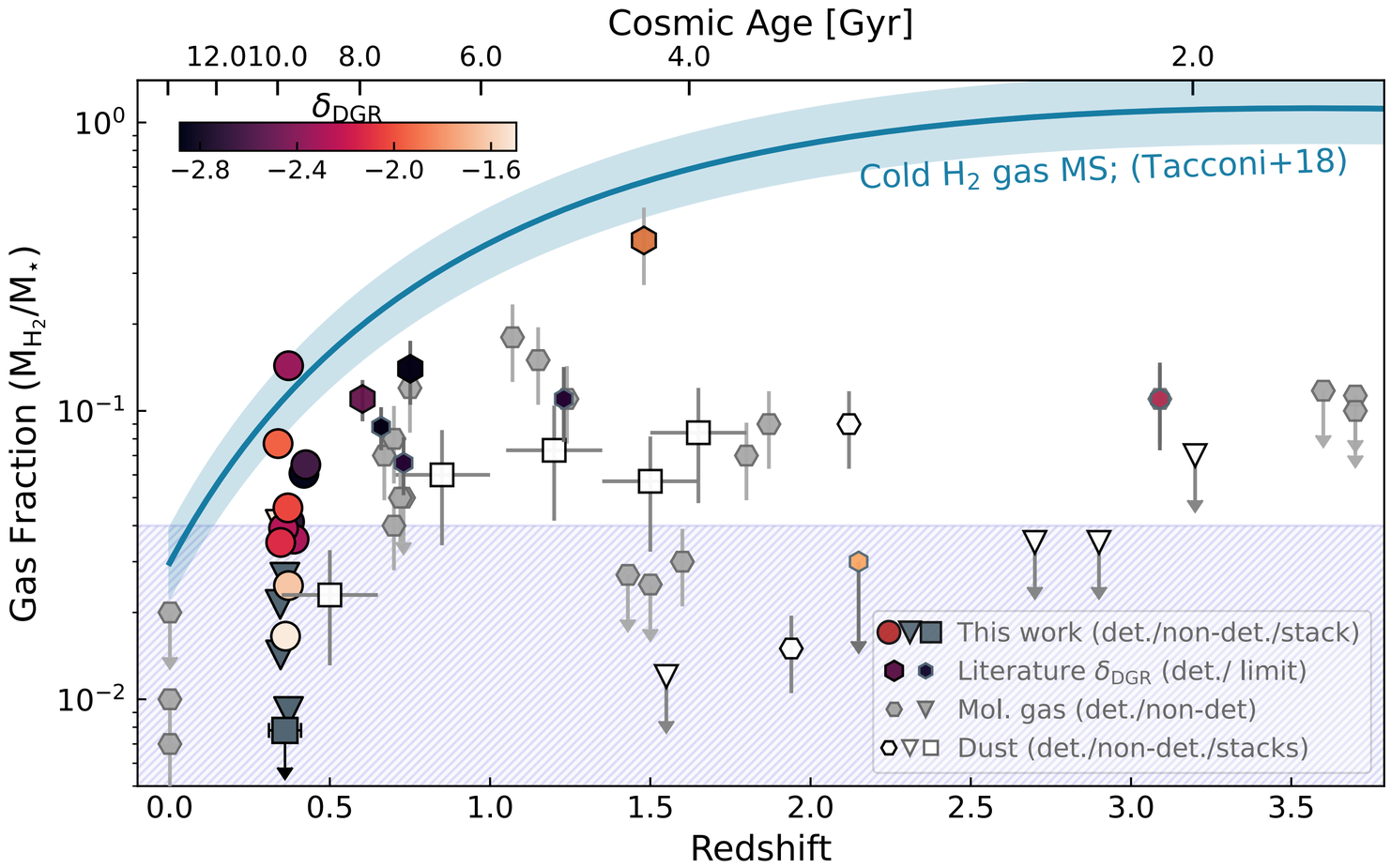

ALMA Band 6 hunt for dust & CO emission in QGs

- Cycle11 ALMA B6 CO(3-2) + dust continuum of 17 QGs at z~0.4 in the Cosmos Web
- Confirmed cold ISM in 12 out of 17 QGs!
- Dust often more extended than cold gas

# 2.1 Deep ALMA hunt for dust-to-gas mass ratio in old QGs: red but not dead!



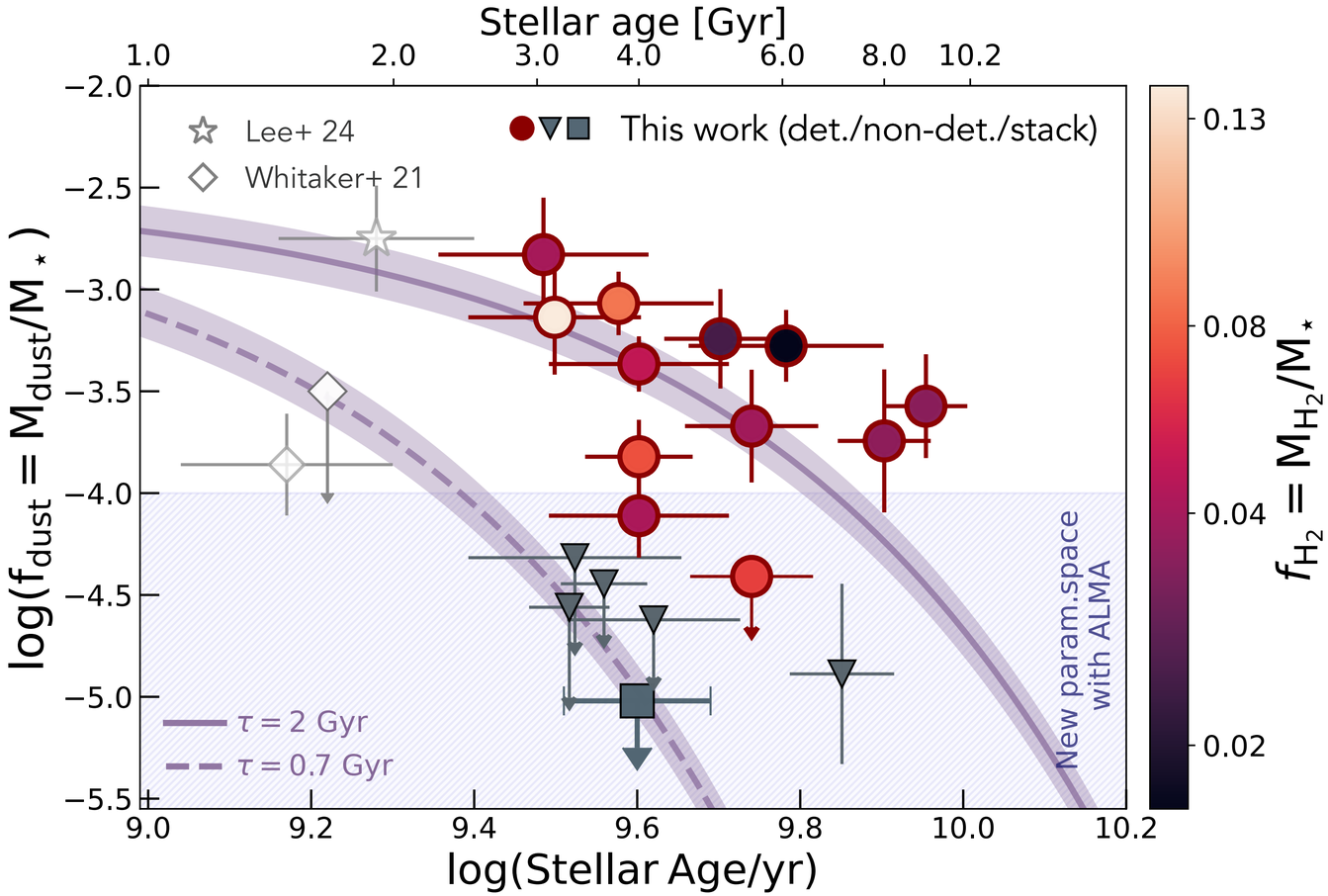
# 2.2 Molecular gas fraction in QGs: roads to quenching




**Lorenzon, Donevski+ 25; arXiv:2509.10079**

Low $H_2$ fraction (~1-5%), but diverse DGR
**→ Quenching is not the sole driver of late ISM evolution in massive galaxies !**

# 2.3 Dust fraction in QGs: diverse decline with stellar age




- Dust is ***not*** only a passive tracer of stellar age
- Dust persists ***much longer*** ( $\gtrsim 2$ Gyr) than expected from age-evolution

$$f_{dust} = f_{H_2} \times DGR \times Z_{gas}$$

**Hypothesis:**

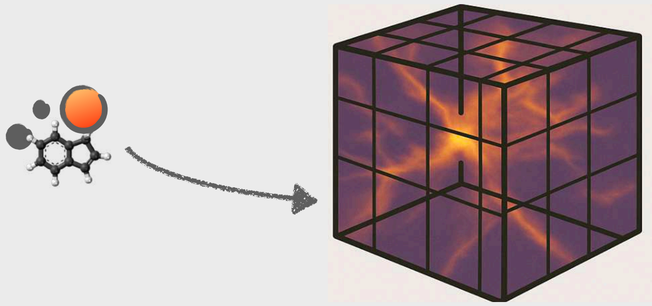
Dust re-formed via grain accretion on metals?

(Hirashita+17, Donevski+ 23, Lorenzon+25)

# Part III

## *Modeling the dust, molecular gas and PAHs in galaxy evolution*

(3) Lorenzon, Donevski+ 2025; A&A; Volume 693, id.A118, 21 pp
(4) Nanni, Romano, Donevski+ 2025; ApJ, 988L, 5N
(5) Donevski+, submitted



# 3.1 Semi-analytic model of dust, gas and PAH

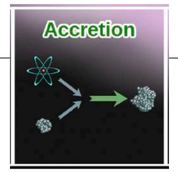
**Two-grain size dust, gss & PAH model**

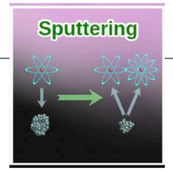
$$\frac{dM_{\rm dust}}{dt} = \dot{M}^{\rm AGB}_{\rm dust} + \dot{M}^{\rm grow}_{\rm dust} + \dot{M}^{\rm in}_{\rm dust} - \left(\dot{M}^{\rm shocks}_{\rm dust} + \dot{M}^{\rm sput}_{\rm dust} + \dot{M}^{\rm AGN}_{\rm dust} + \dot{M}^{\rm out}_{\rm dust}\right) + \dot{M}_{\rm PAH\rightarrow dust} - \dot{M}_{\rm dust\rightarrow PAH}$$

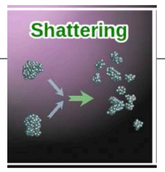
Production

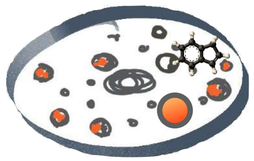
Destruction

Grain size change

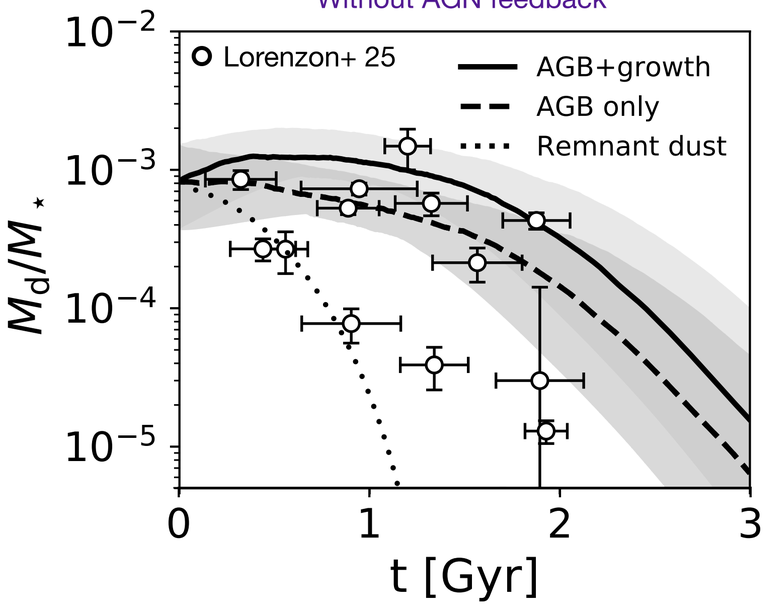


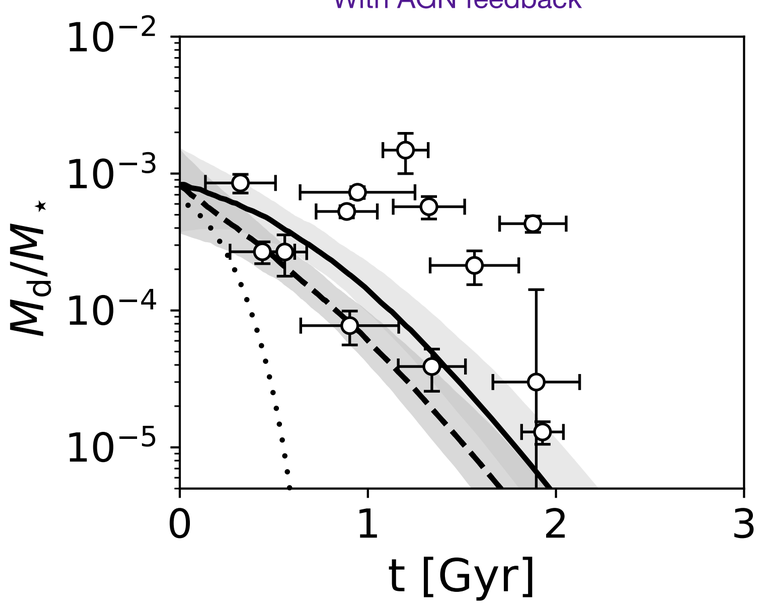



Without AGN feedback




With AGN feedback




Donevski+, submitted

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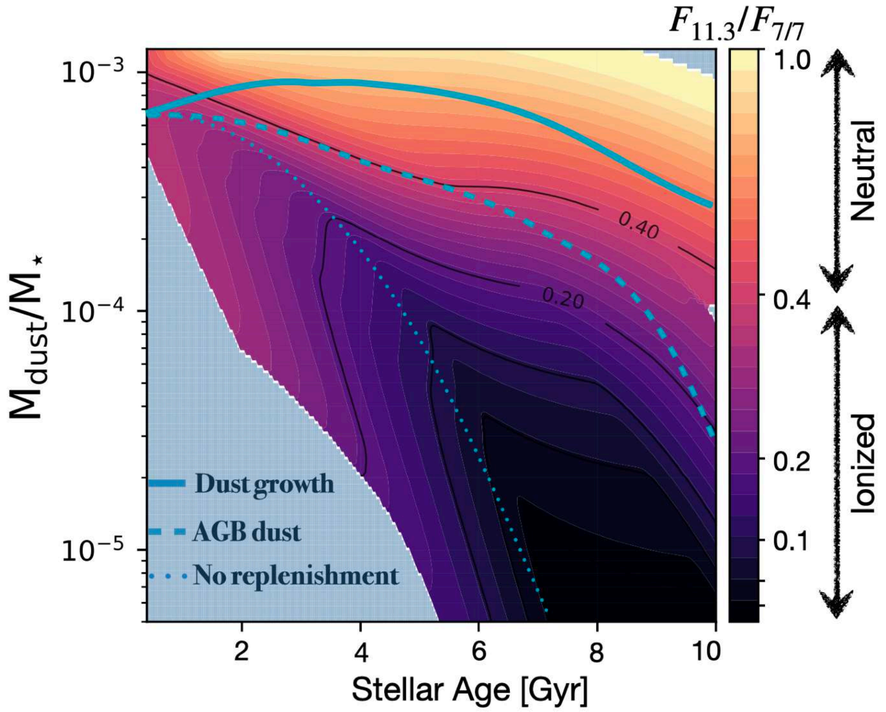
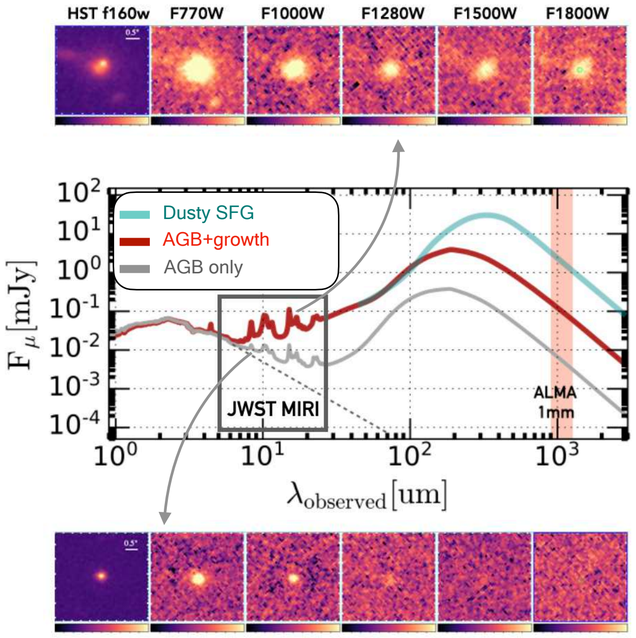



Donevski+, submitted

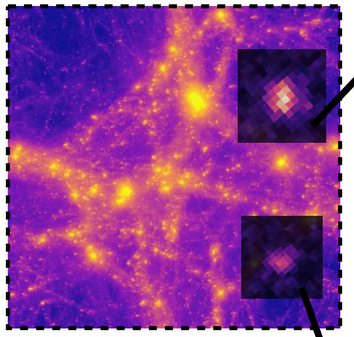
- **Dust regrowth:** new physical mechanism to explain observed SED!
- Dust regrowth → neutral PAHs → MIRI bright

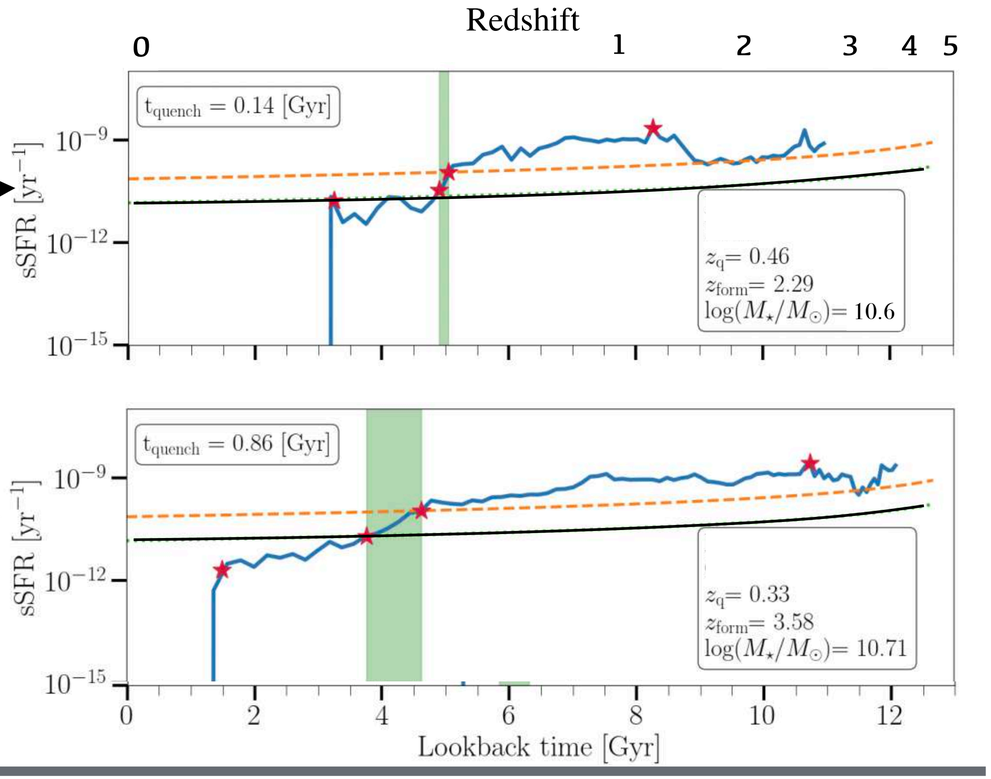
!

# 3.2 Impact of quenching modes on dust & gas: SIMBA simulation

**Method:**

- **High-res SIMBA run** (25 & 50 Mpc/h)
- Track dust & gas change alongside SFH
- **Sample:** 4000+ QGs observed at 0<z<3
- **Radiative transfer:** PowderDay





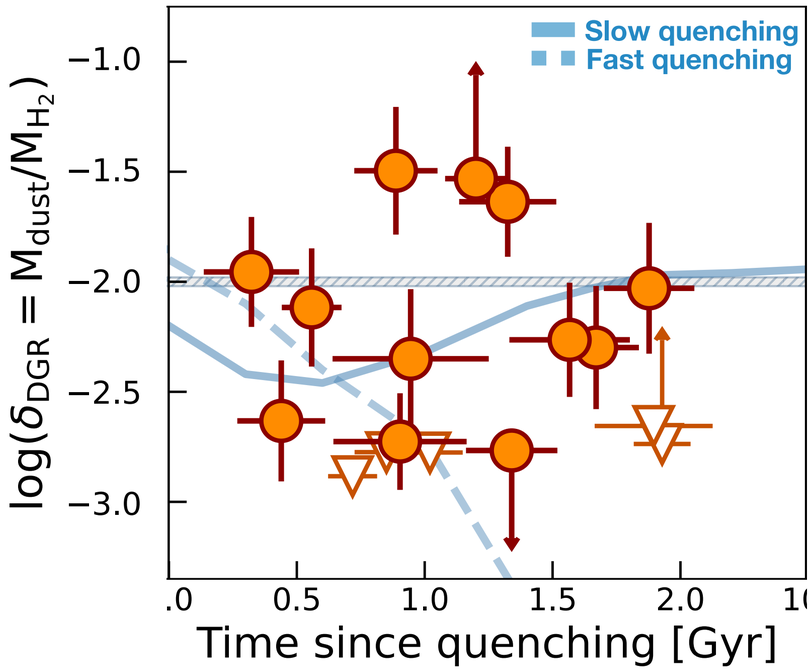

**Bimodaility in quenching pathways: fast vs. slow**

<150 Myr;
AGN Jet Feedback

>150 Myr;
Radiative Feedbackl

Lorenzon, DD+ 2025; A&A; Volume 693, id.A118, 21 pp

# 3.2 Impact of quenching modes on dust & gas: the role of quenching




- **Rapidly quenched QGs (tq~150Myr)** dominated by jet-mode BH feedback. Conditions for dust growth in these sources only if $\tau_{\rm sput} > \tau_{\rm AGN}$

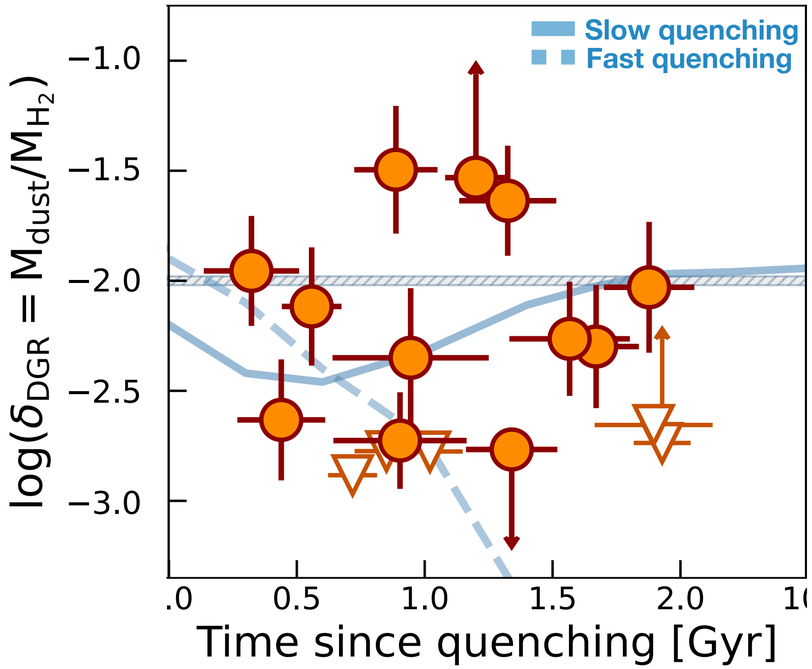
- **Slow-quenchers (tq~500 Myr)** are influenced by jet & radiative-mode feedback. Rapid dust re-formation timescales (<150 Myr) counterbalance dust destruction (removal).

- **DGR > 1dex variation relative to canonical MW value (DGR=1/100)**
- **Weak correlation with quenching modes (fast vs. slow)**

!

In line with theoretical perspectives: Whitaker+ 21; Donevski+ 23; Lorenzon+ 25;

# 3.2 Impact of quenching modes on dust & gas: the role of dust growth




**Cold dust excess:**

AGB dust → Dust Growth ✅

Environments / Rejuvenations ❌

Minor mergers ❌

**Dust reduced (removed):**

Thermal sputtering ✅

+

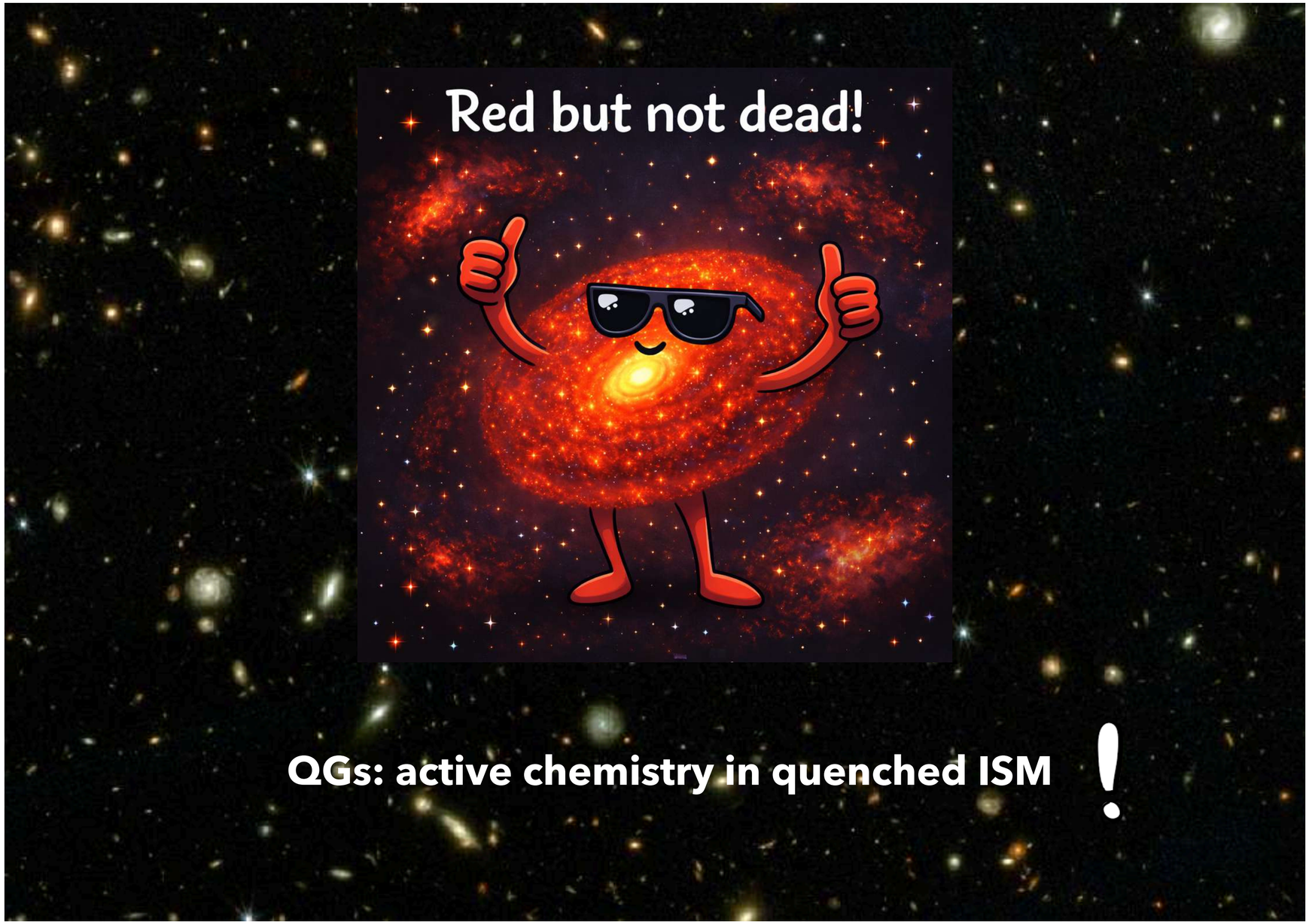
Feedback ✅

**Agreement between SIMBA, semi-analytic model and data**

!

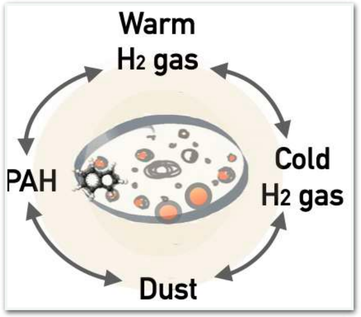
In line with theoretical perspectives: Whitaker+ 21; Donevski+ 23; Lorenzon+ 25;

# Towards a new paradigm of dust grain formation

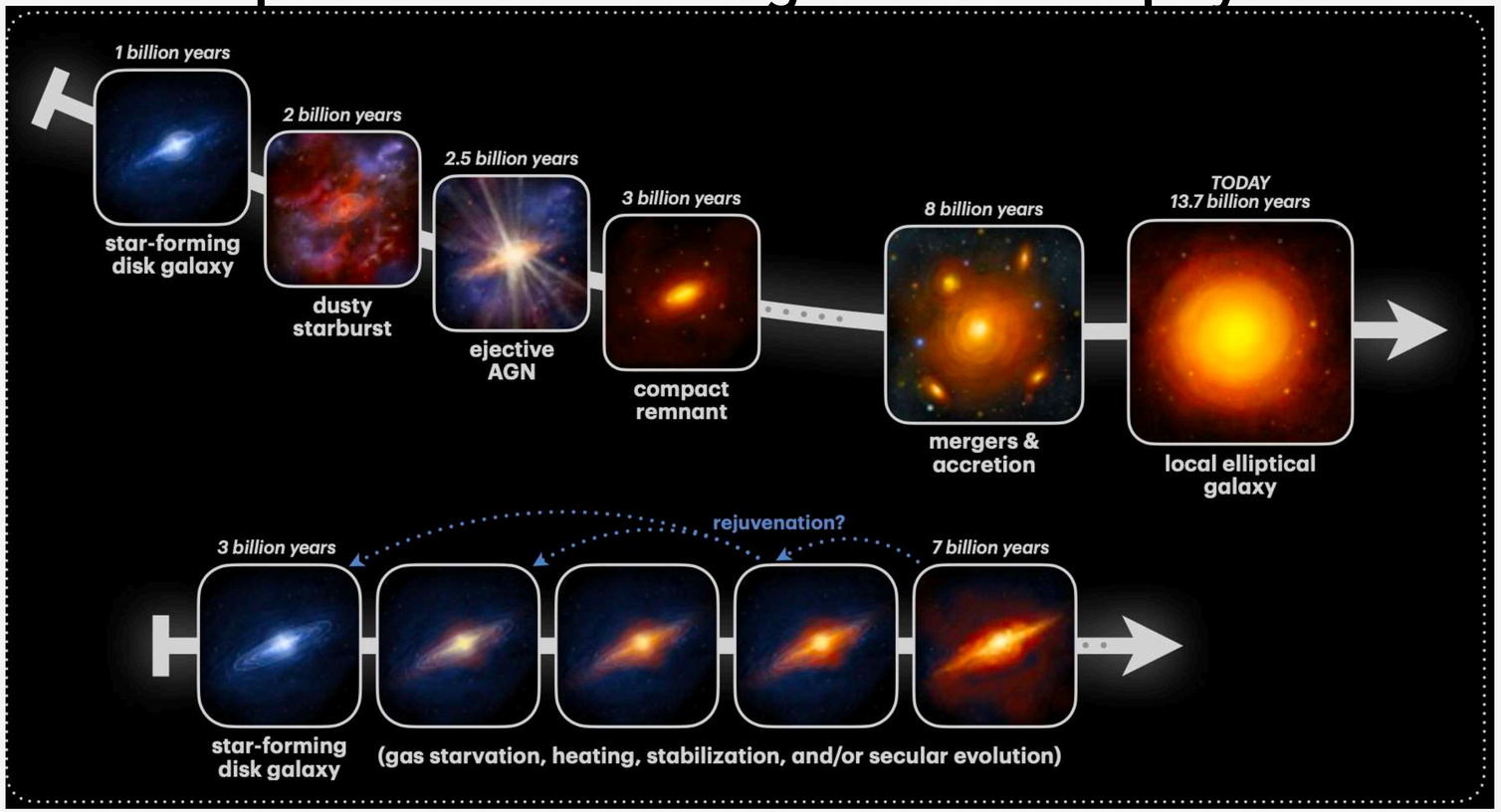


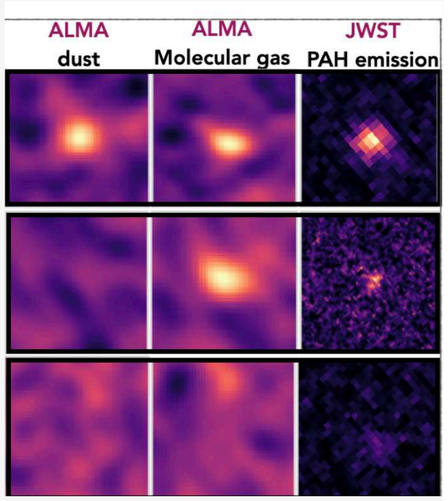
# Towards a new paradigm of dust grain formation

Redefine search & interpretation of dust in spectra




## Implications on Extragalactic Astrophysics

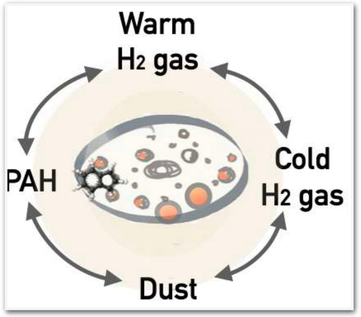


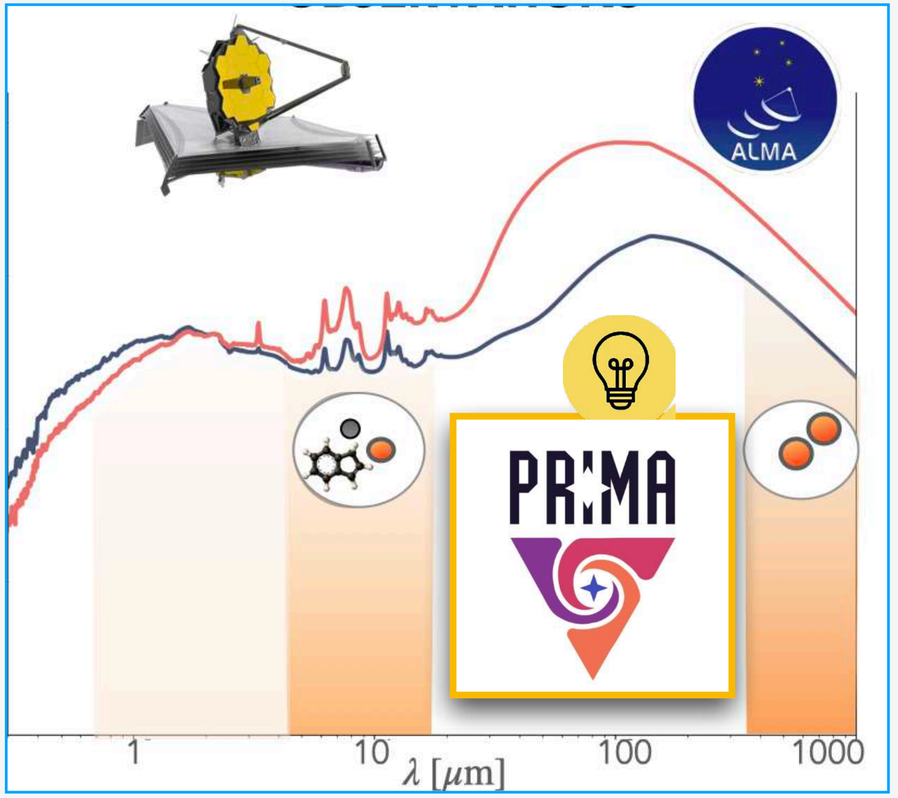

Whitaker & Bezanson, ARAA, 2026

# Towards a new paradigm of dust grain formation

Redefine search & interpretation of dust in spectra




## Implications on Extragalactic Astrophysics

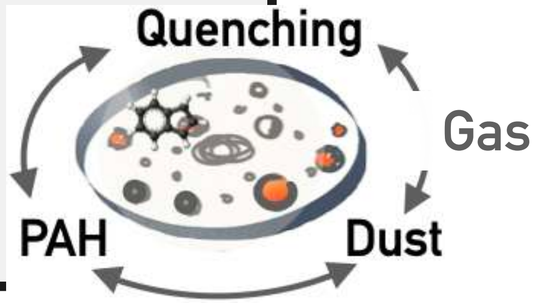


# Remarks

- First direct probe of cold dust & $H_2$ gas in QGs beyond the local universe:
  Unique lab to track the ISM changes alongside SFH.
  Dust-to-gas ratio isn't constant and cannot be securily used to infer $H_2$ mass!
- On the dust origin in QGs
  Diverse dust mass with stellar age, quenching time & CO mass → dust re-formed in QGs
- On the relation with quenching channels
  Quenching mode (jet vs. radiative) is not the sole driver of dust bimodality → key for models

**Future prospects**

- *Observations: What about structural & kinematic properties? PAHs?*
  JWST NIRSpec + ALMA kinematics to complement the picture
  PRIMA Mission → PAH spectra+dust temperature **Stay tuned!**




- PRIMA mission (NASA concept) —> **Resolved MIR spectroscopy in most massive QGs!**

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