The Resolved Dust and ISM of a z=7.31 Rotating Disk

Cosmic Dawn at High Latitudes

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Stockholm, Sweden
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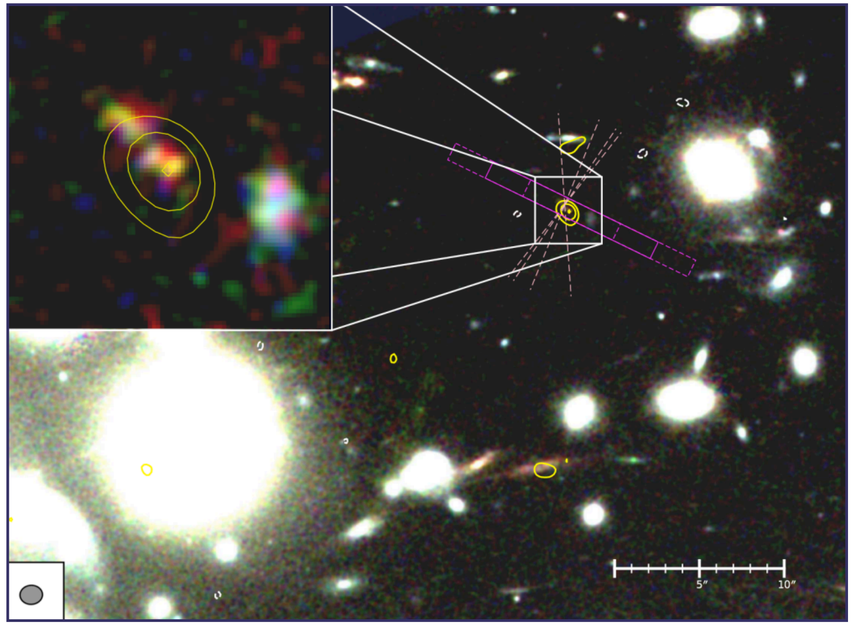
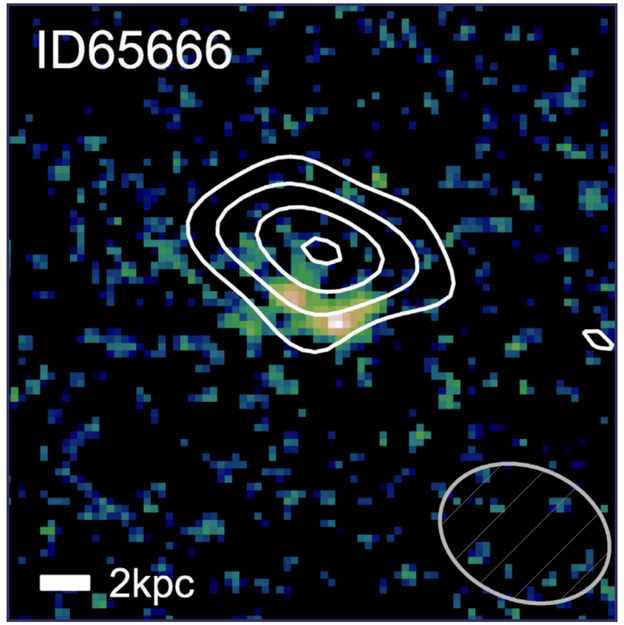
Credit: D. Kordan (ESO)

Dust in the Epoch of Reionization

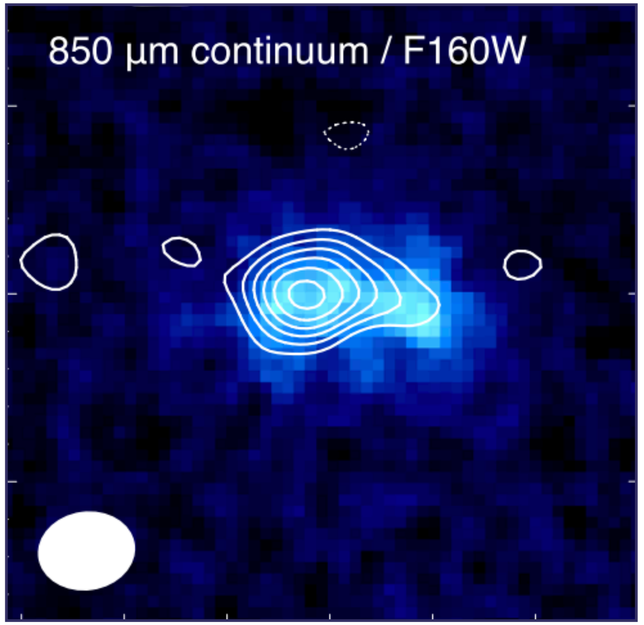
ALMA detections of dust continuum emission in distant galaxies demonstrate dust build-up can proceed rapidly



Watson et al. (2015)



Bowler et al. (2018)

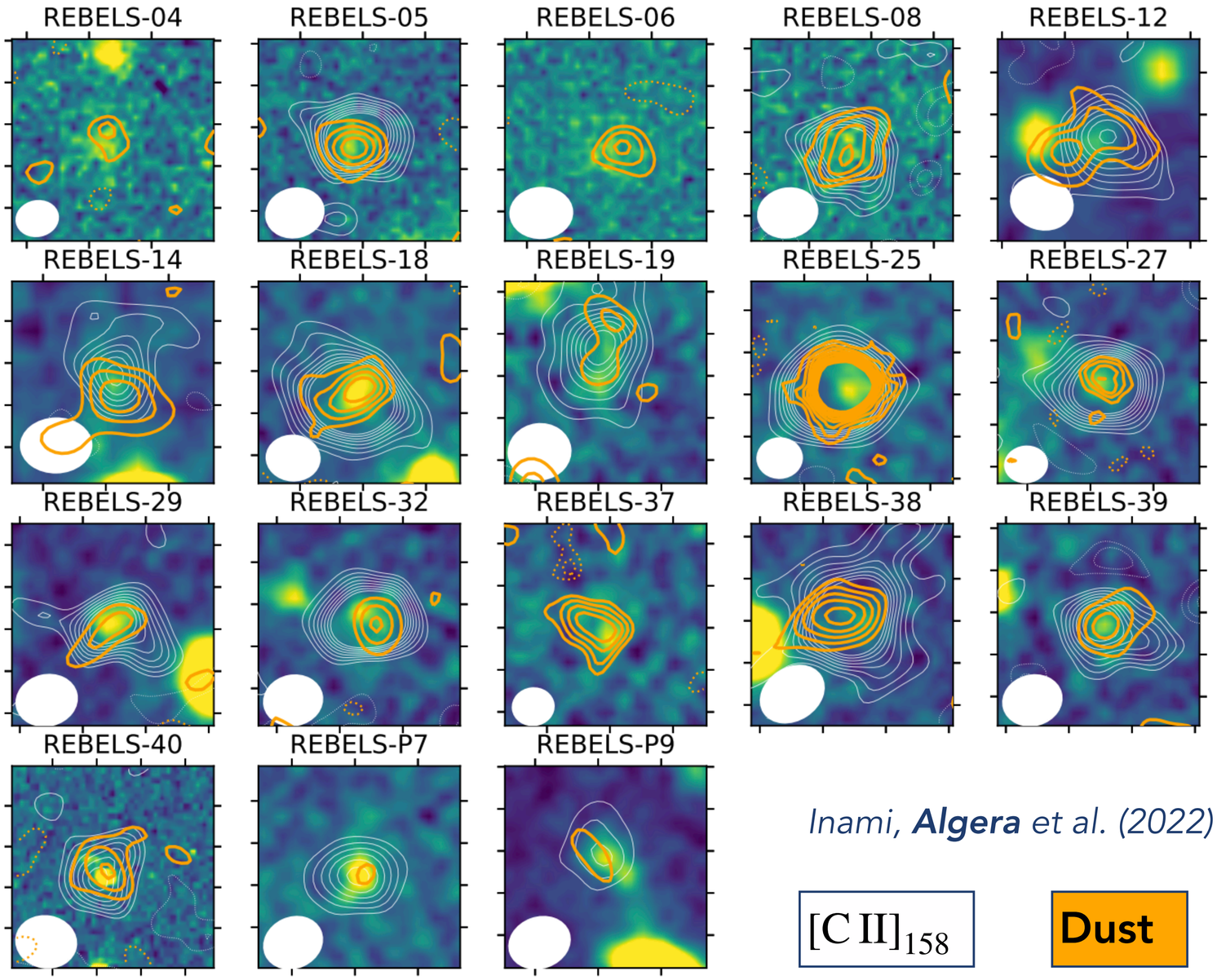


Tamura et al. (2019)

The ALMA REBELS Survey

Cycle 7 ALMA Large Program

- 40 **UV-bright** galaxies at $z_{\rm phot} \gtrsim 6.5$ scanned for the $[\mathrm{C\,II}]_{158}$ line
- 27 lines detected (68%)
- 16 **dust** detections (40%)



16 REBELS + 2 pilot sources

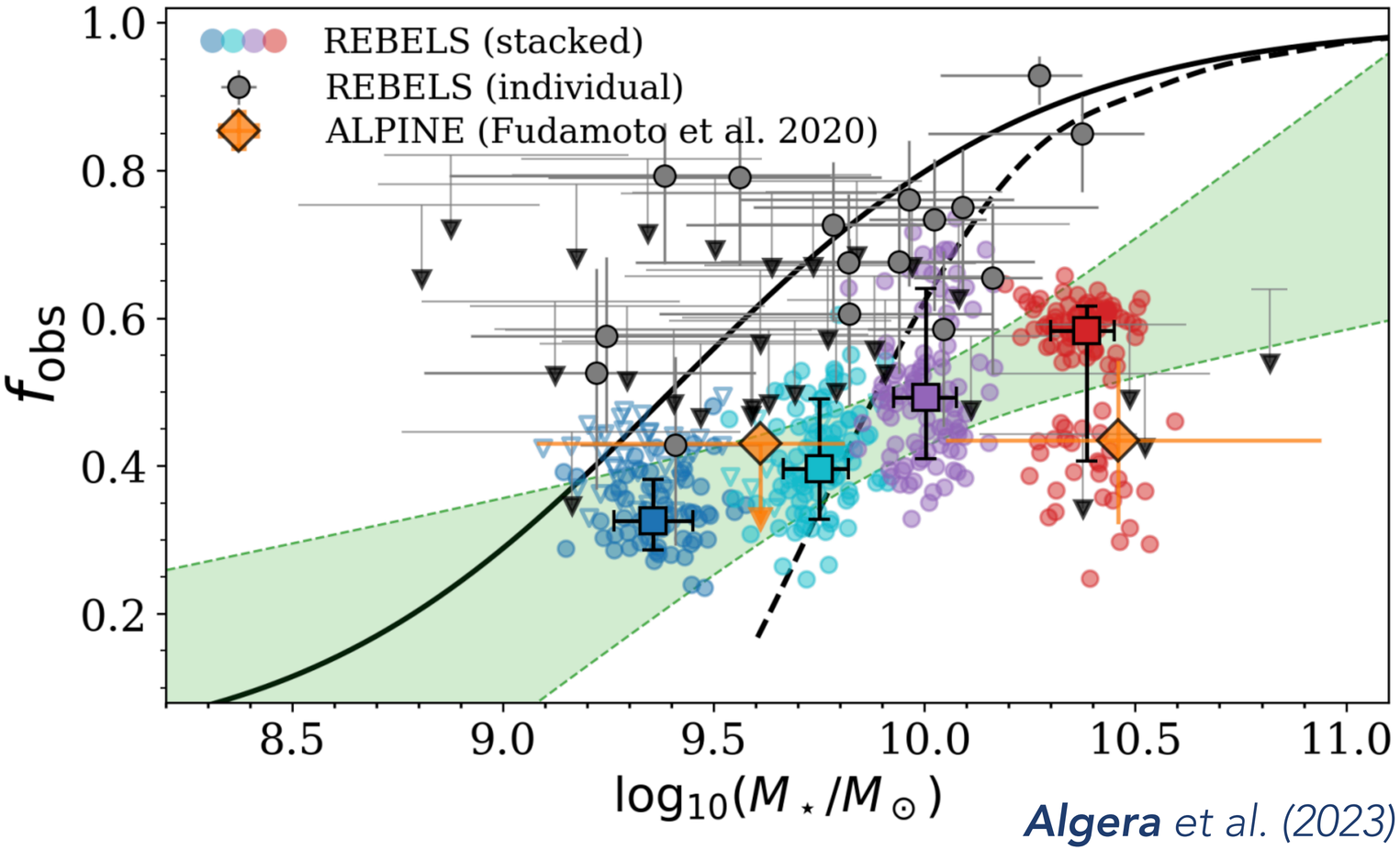
*Inami, **Algera** et al. (2022)*

$[\mathrm{C\,II}]_{158}$ **Dust**

Obscured Star Formation at z~7

- Massive Lyman-break galaxies show $f_{\rm obs} \approx 0.3 - 0.6$

$$f_{\rm obs} = \frac{\text{Obscured Star Formation}}{\text{Total Star Formation}}$$

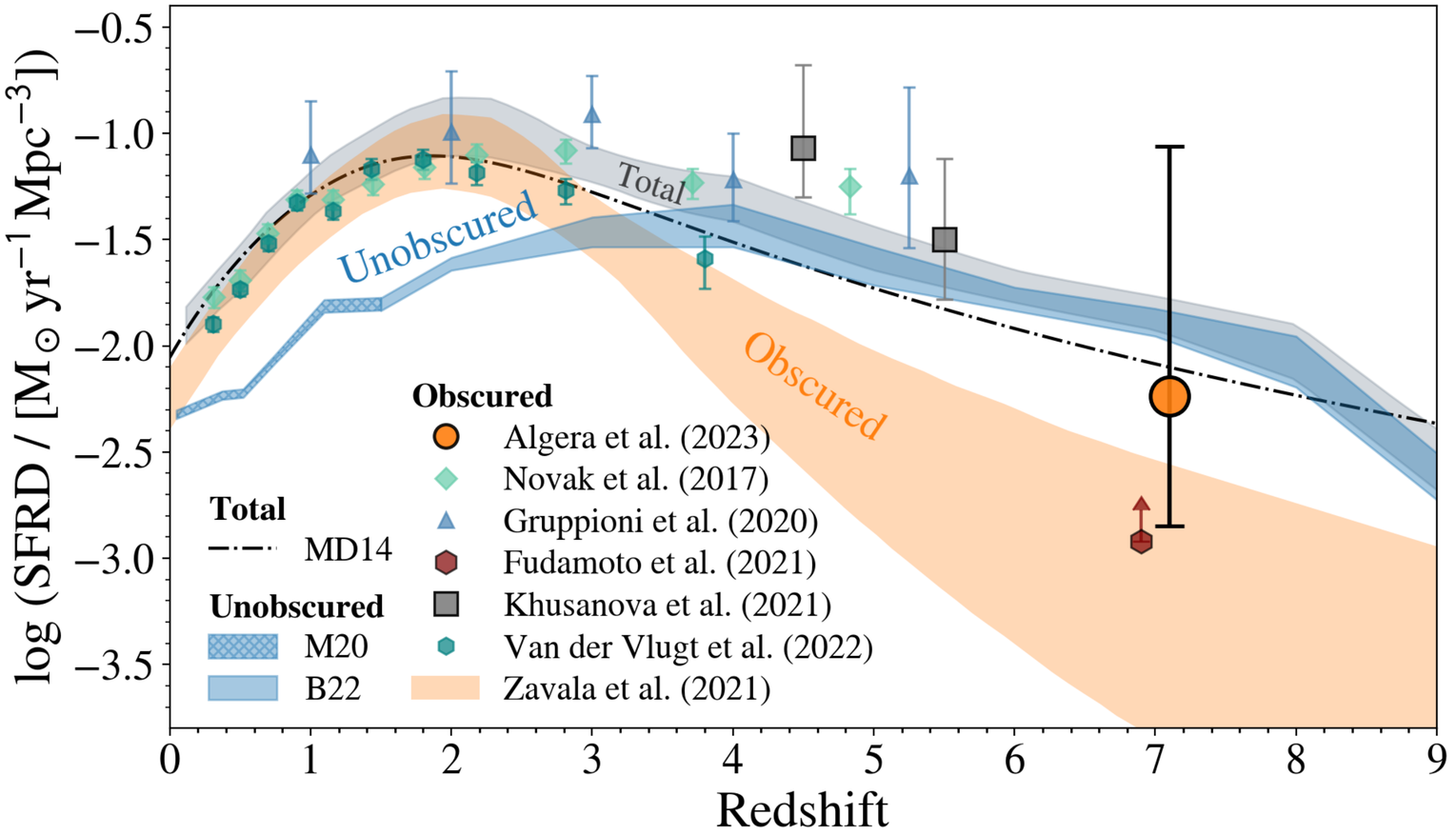


***Algera** et al. (2023)*

See also Fudamoto et al. (2020); Bowler et al. (2023); Mitsuhashi et al. (2023)

Obscured Star Formation at z~7

- Massive Lyman-break galaxies show $f_{\rm obs} \approx 0.3 - 0.6$
- Cosmic star formation rate density is ~30% **obscured**



***Algera** et al. (2023)*

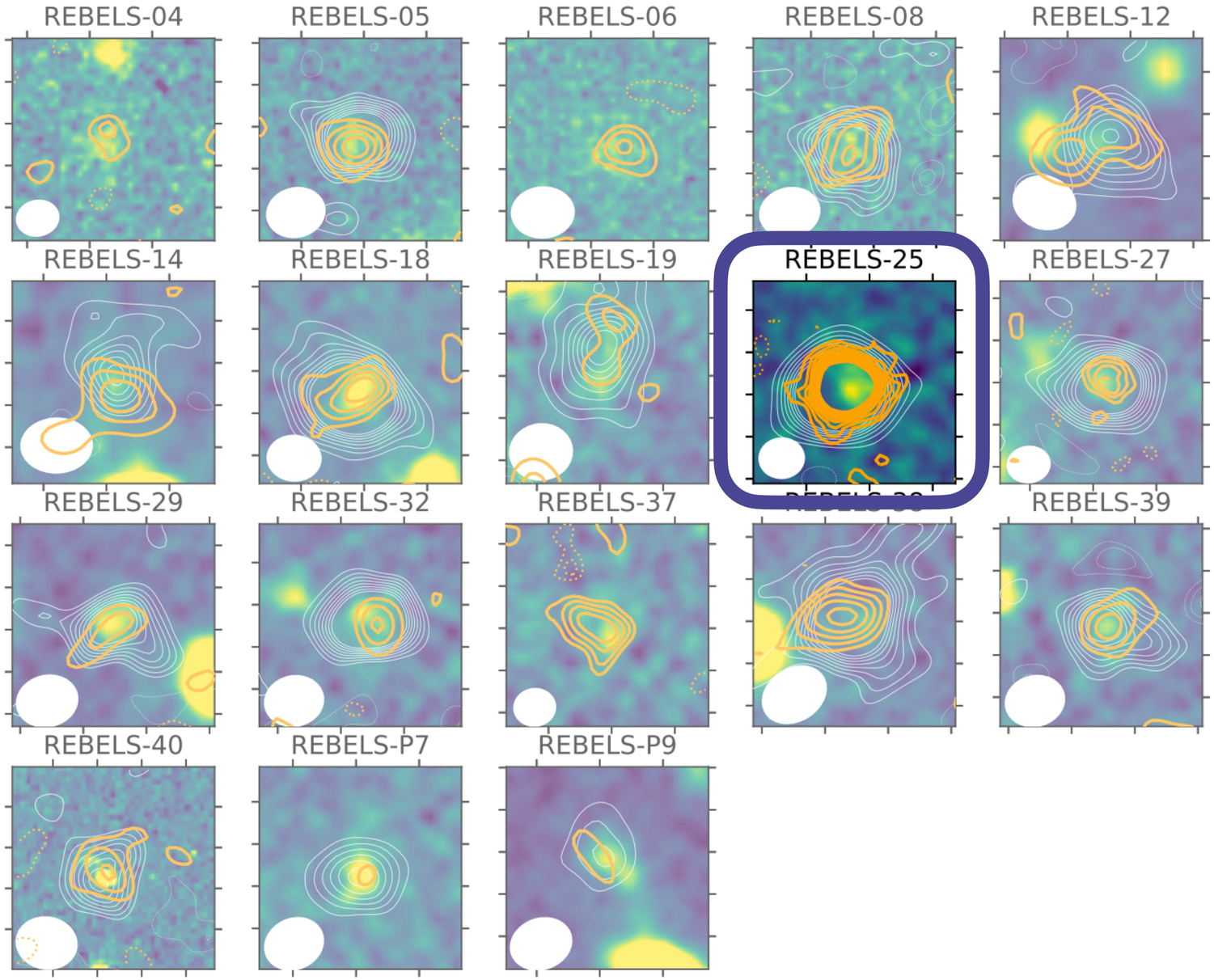
See also Zavala et al. (2021); Barrufet et al. (2023); Fujimoto et al. (2023)

There appears to be a lot of dust at high redshift

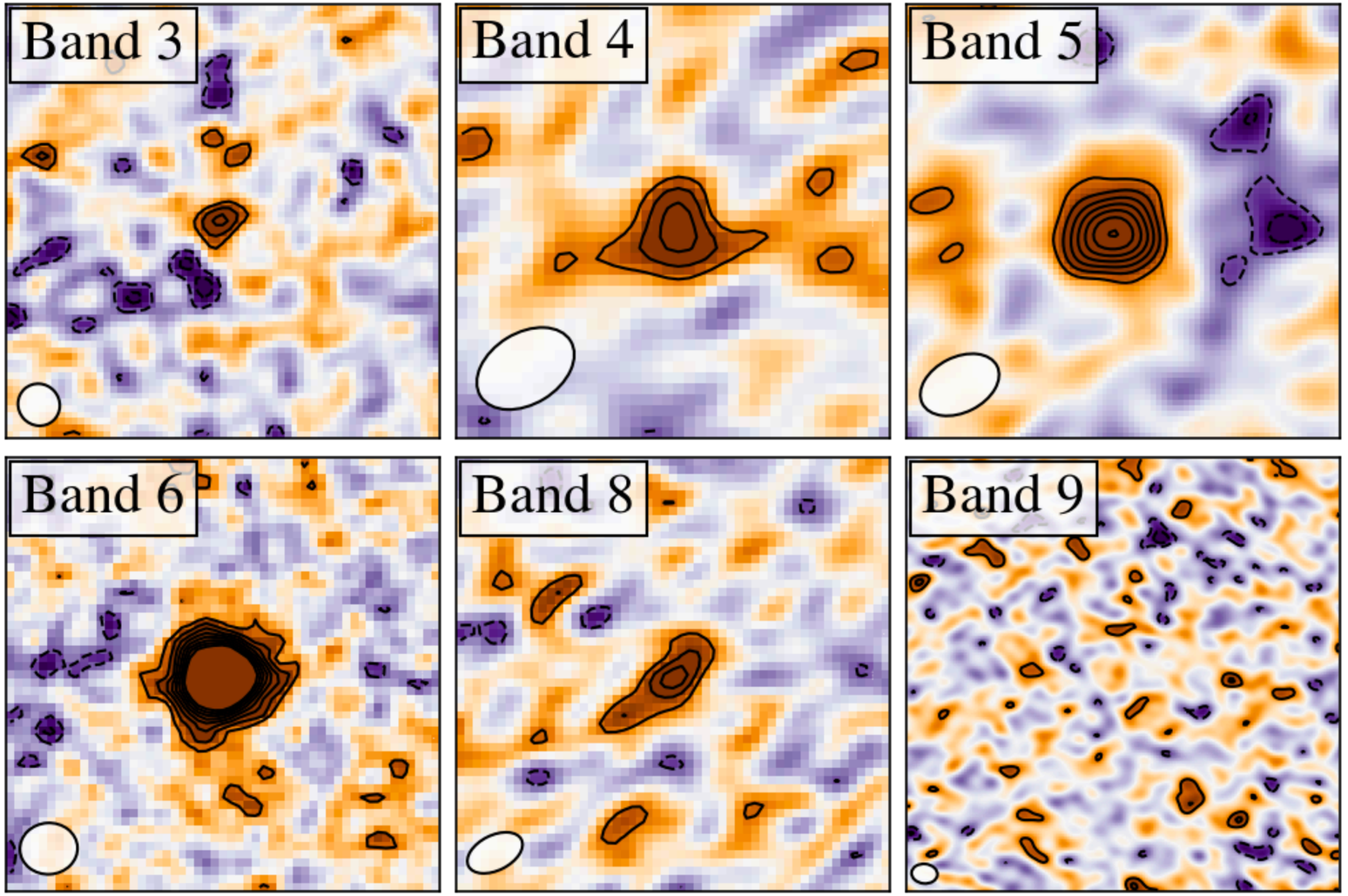
But how does it get there so rapidly?

REBELS-25 at z=7.31

- Brightest Band 6 continuum source in **REBELS**



Dust Continuum Emission in REBELS-25

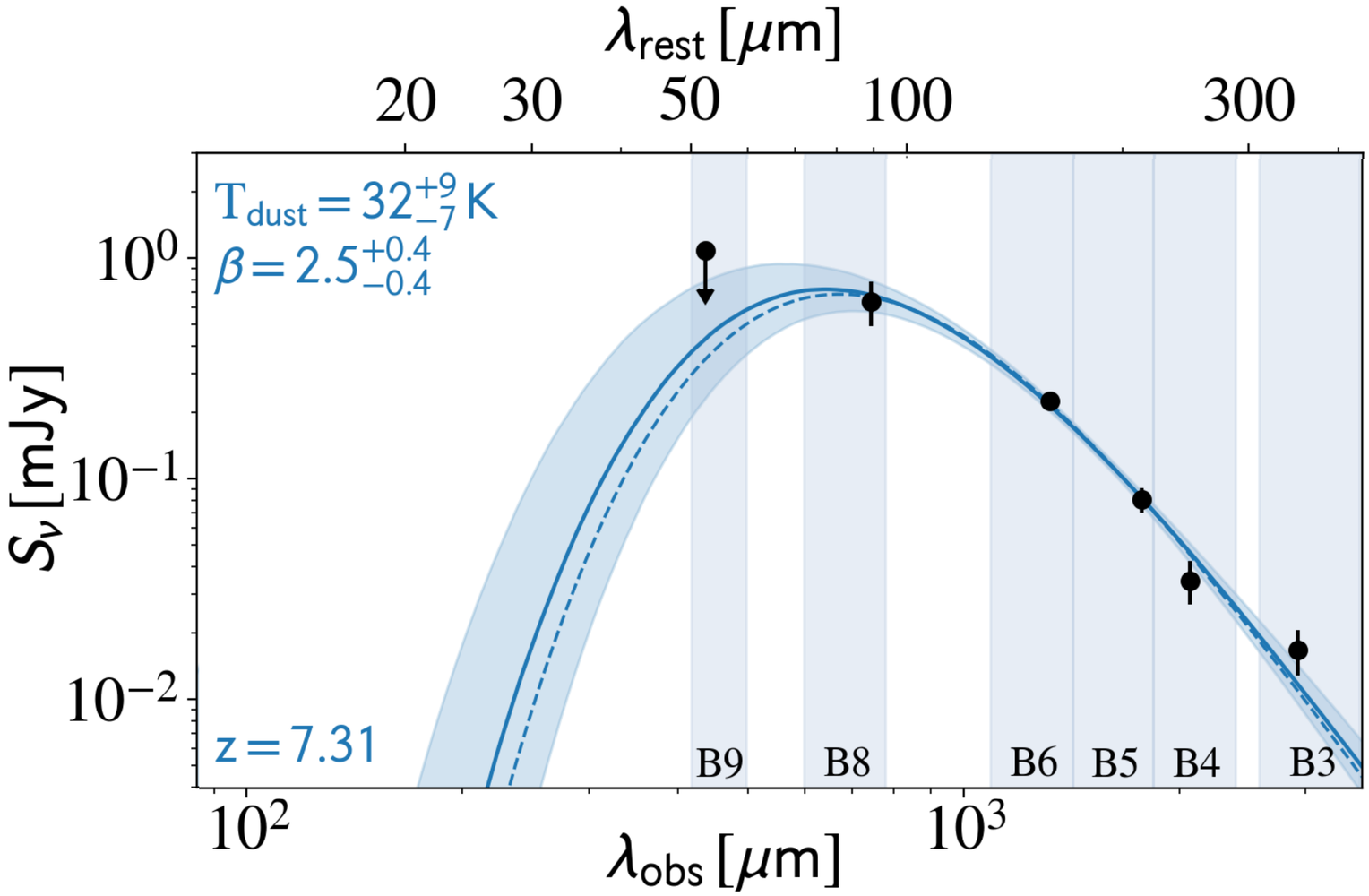


3 mm (B3) - 0.45 mm (B9)

***Algera** et al. (2024b), submitted*

Dust Continuum Emission in REBELS-25

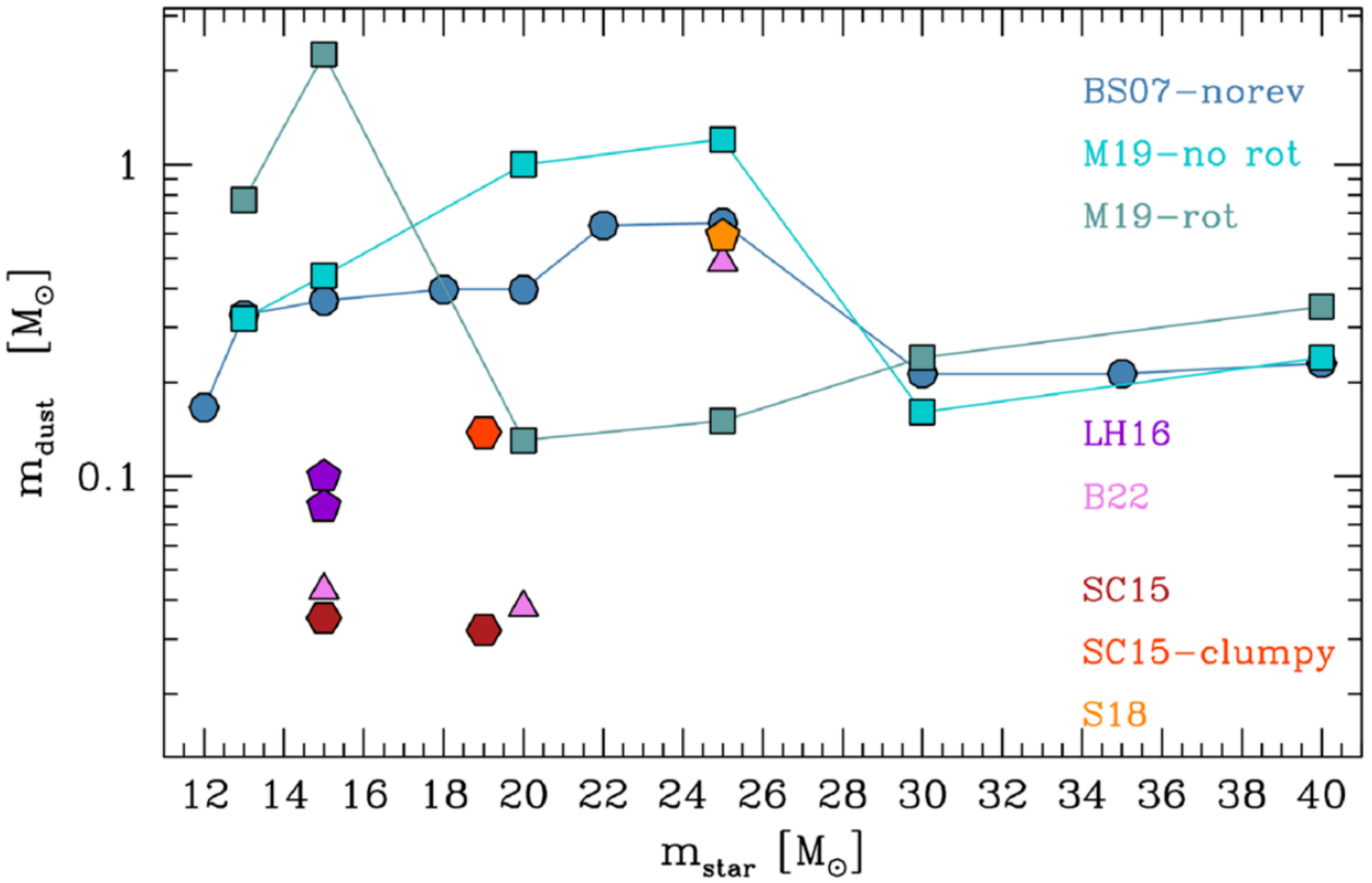
- Massive reservoir of cold dust,
  $\log(M_{\rm dust}/M_\odot) = 8.1^{+0.6}_{-0.4}$
  $\rightarrow M_{\rm dust}/M_\star = 0.8^{+2.0}_{-0.5}\,\%$



***Algera** et al. (2024b), submitted*

Supernova dust?

- Dust production rates prior to the **reverse shock** (which destroys ~20 - 100% of dust)



Schneider & Maiolino (2024)

Supernova dust?

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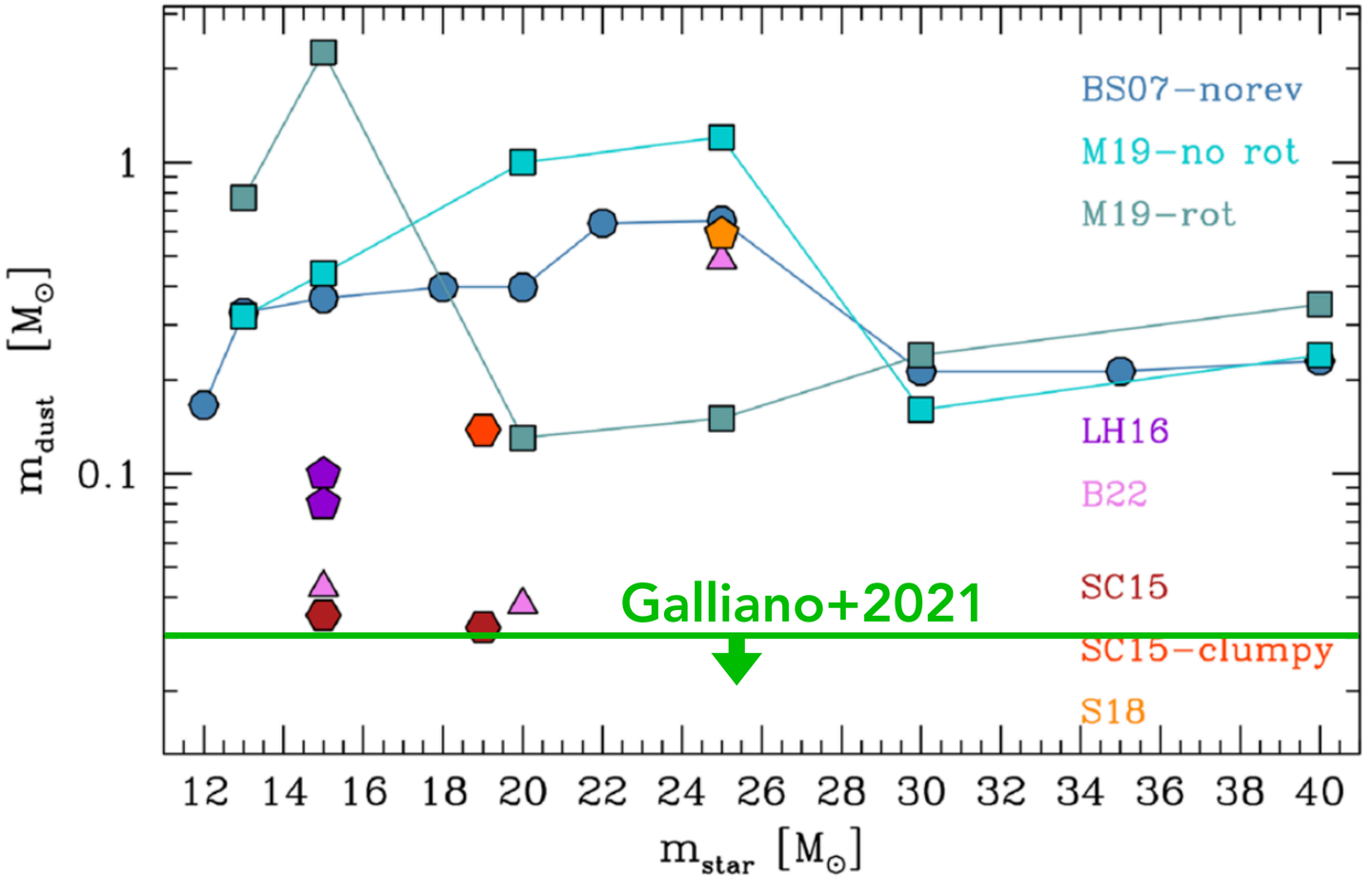
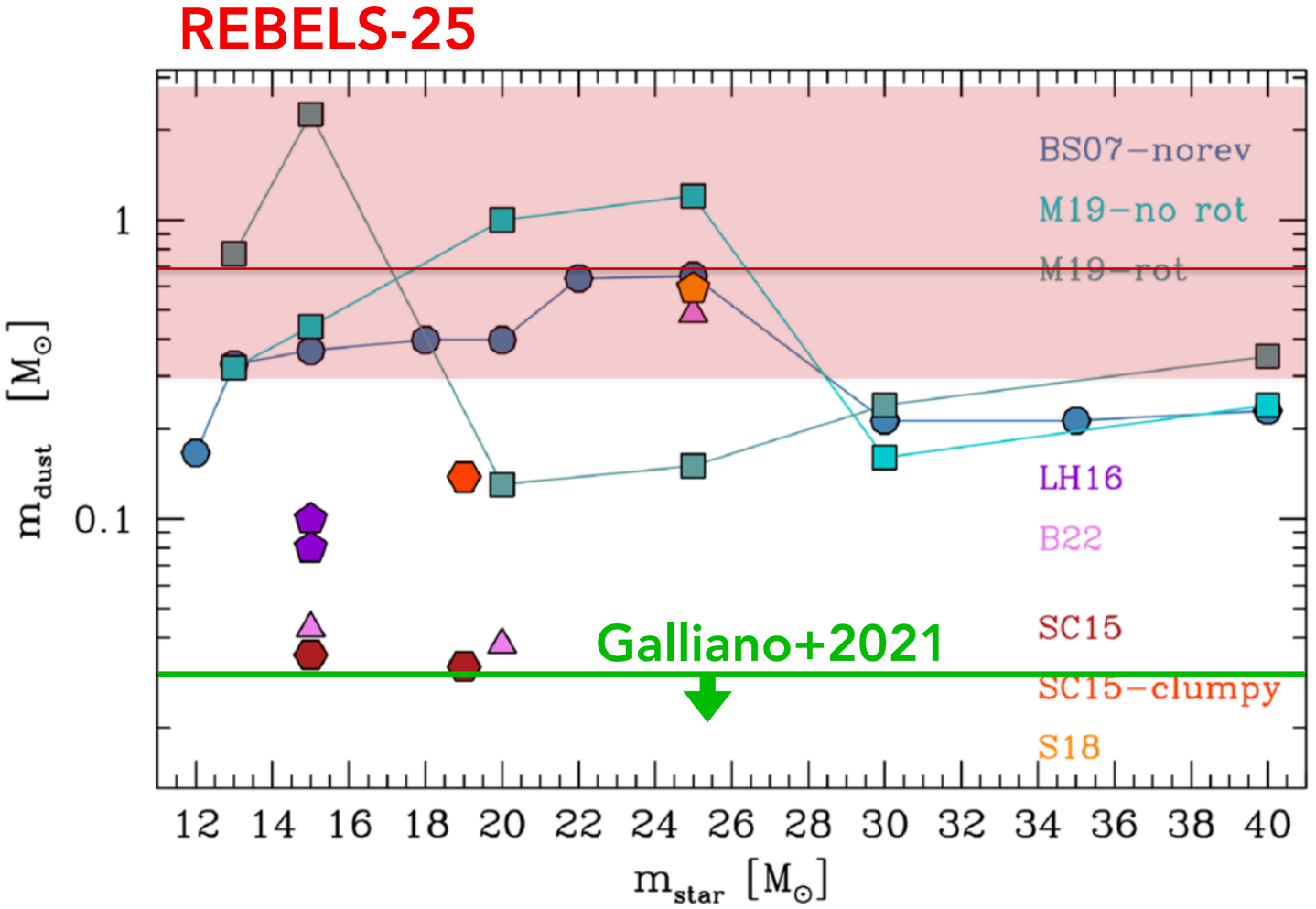


Schneider & Maiolino (2024)

Supernova dust?

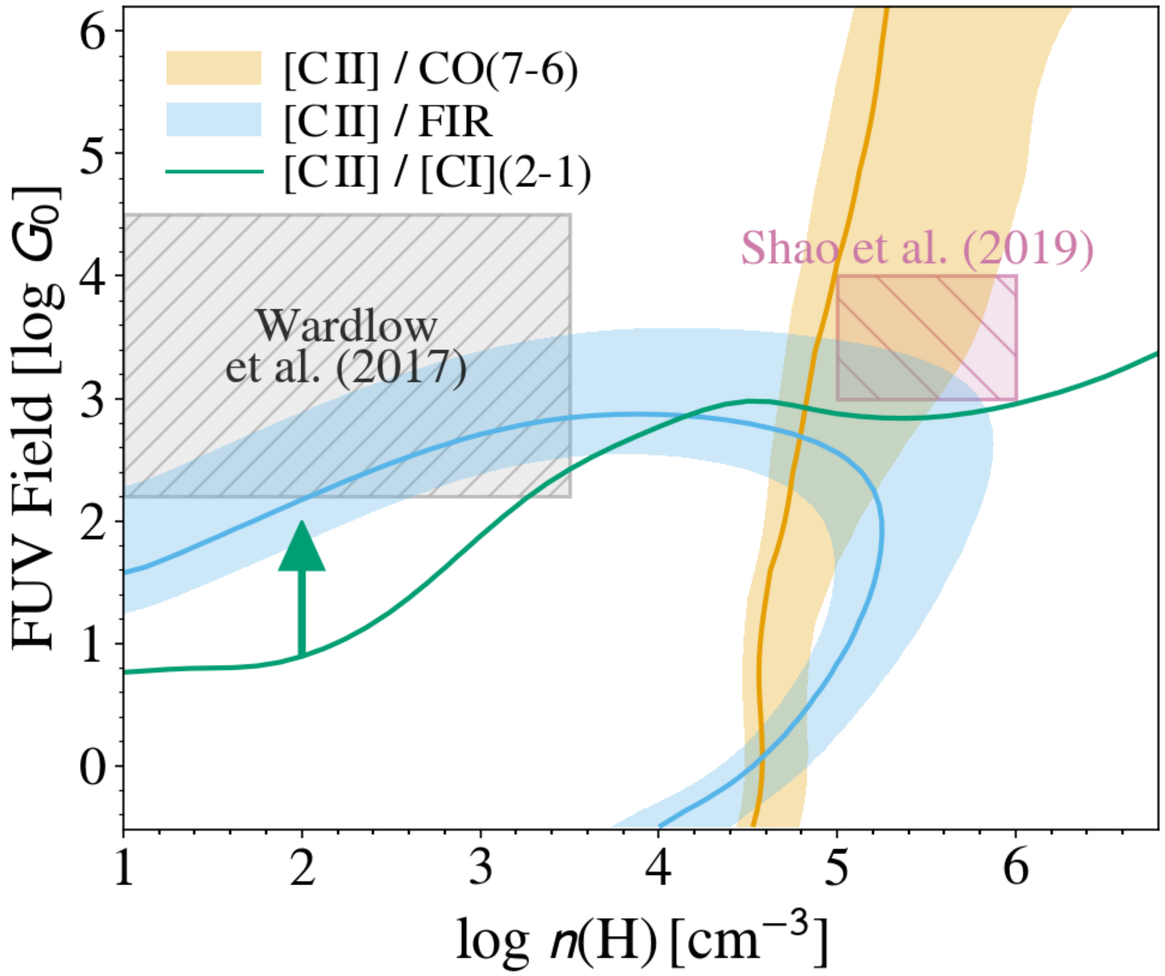
- Dust production rates prior to the **reverse shock** (which destroys ~20 - 100% of dust)
- Require **efficient** supernovae, and little **dust destruction**



Schneider & Maiolino (2024)

Supernovae may not be sufficient: evidence for dust growth in the ISM?

Dust Growth in the ISM

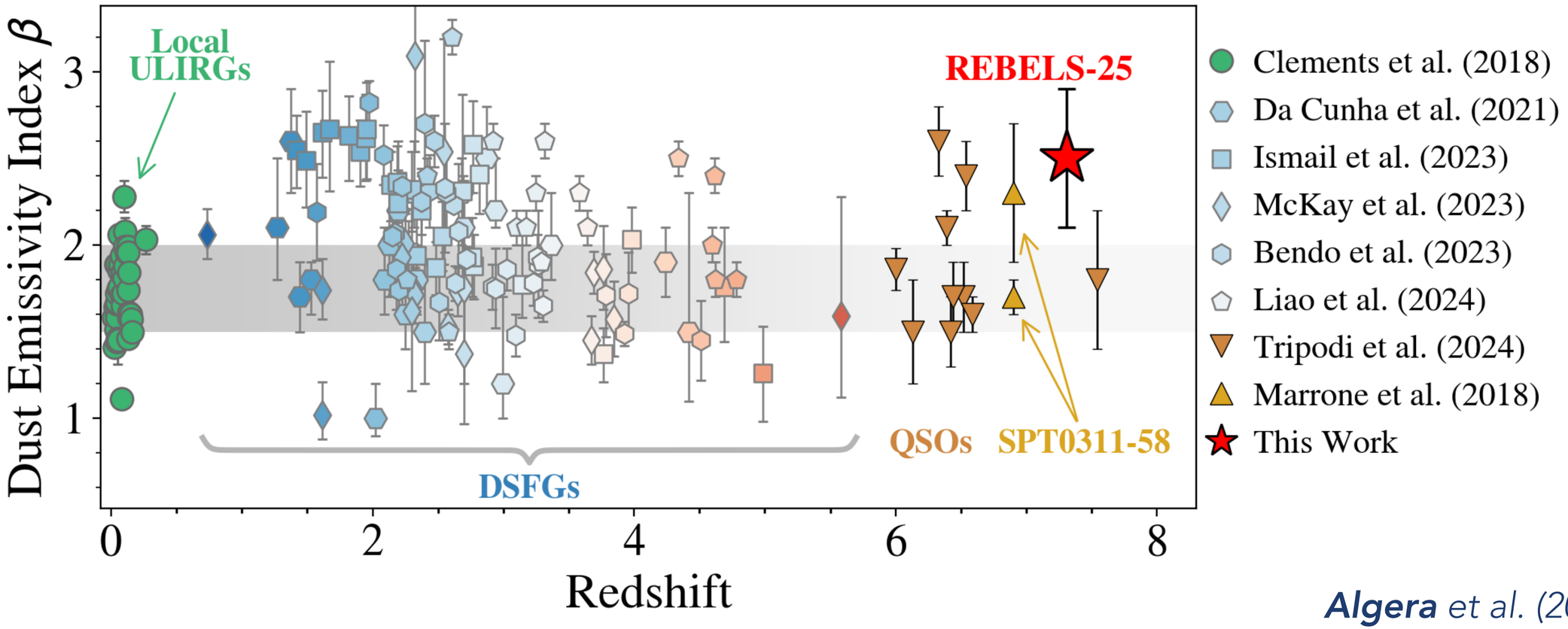


- Detection of the CO(7-6) line + PDR modeling implies a **dense ISM**

*Hygate, **Algera** et al. in prep*

Dust Growth in the ISM

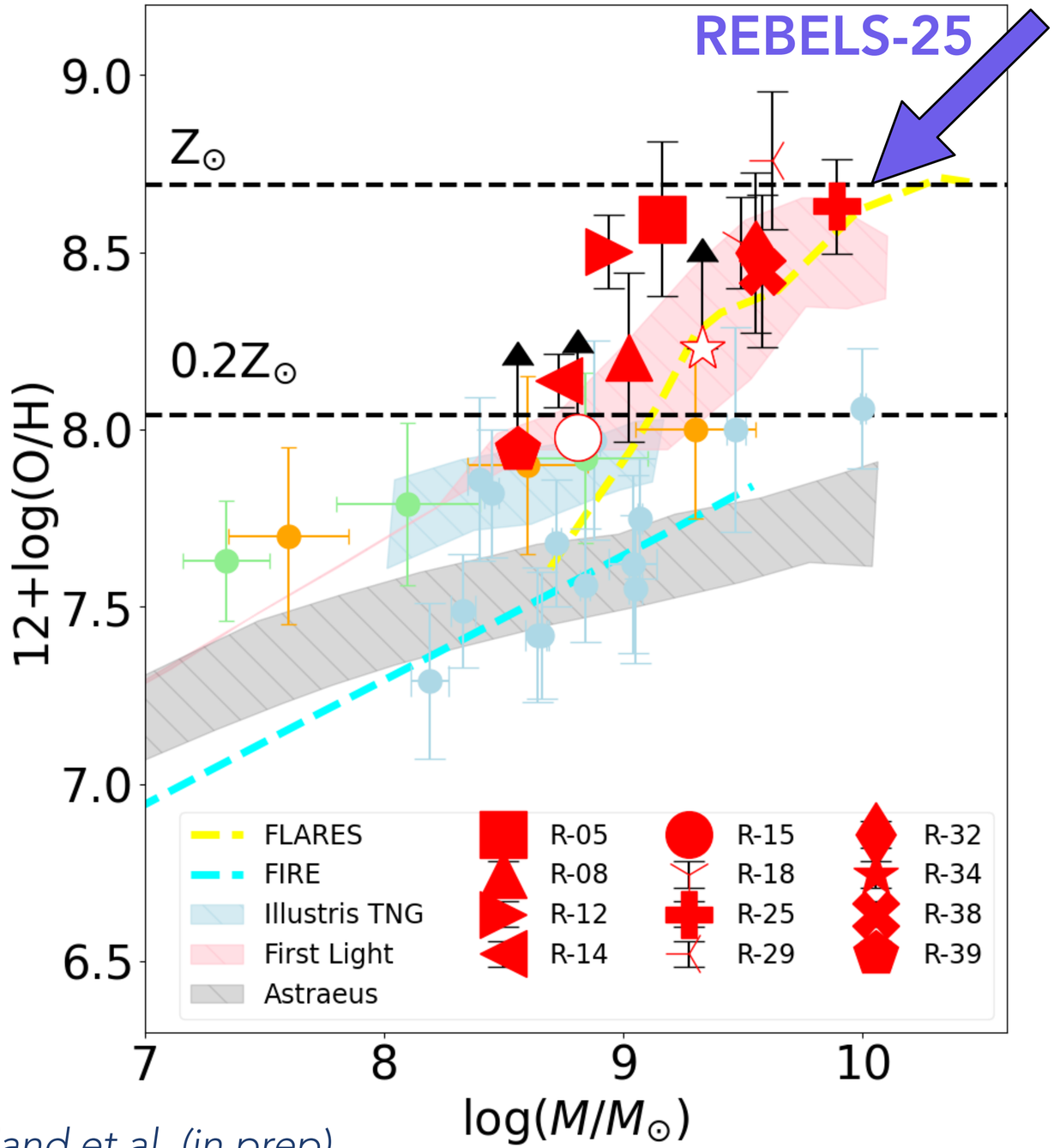
- A steep **dust emissivity index** ($\beta_{\rm IR}$) can arise from large, coagulated dust grains



***Algera** et al. (2024b), submitted*

JWST/NIRSpec IFU Metallicities

- Dust-corrected **R23** where possible; else lower limits from **Ne3O2**
- REBELS galaxies are **enriched**; $Z \gtrsim 0.2\,Z_\odot$
- REBELS-25 may be near-**solar metallicity**

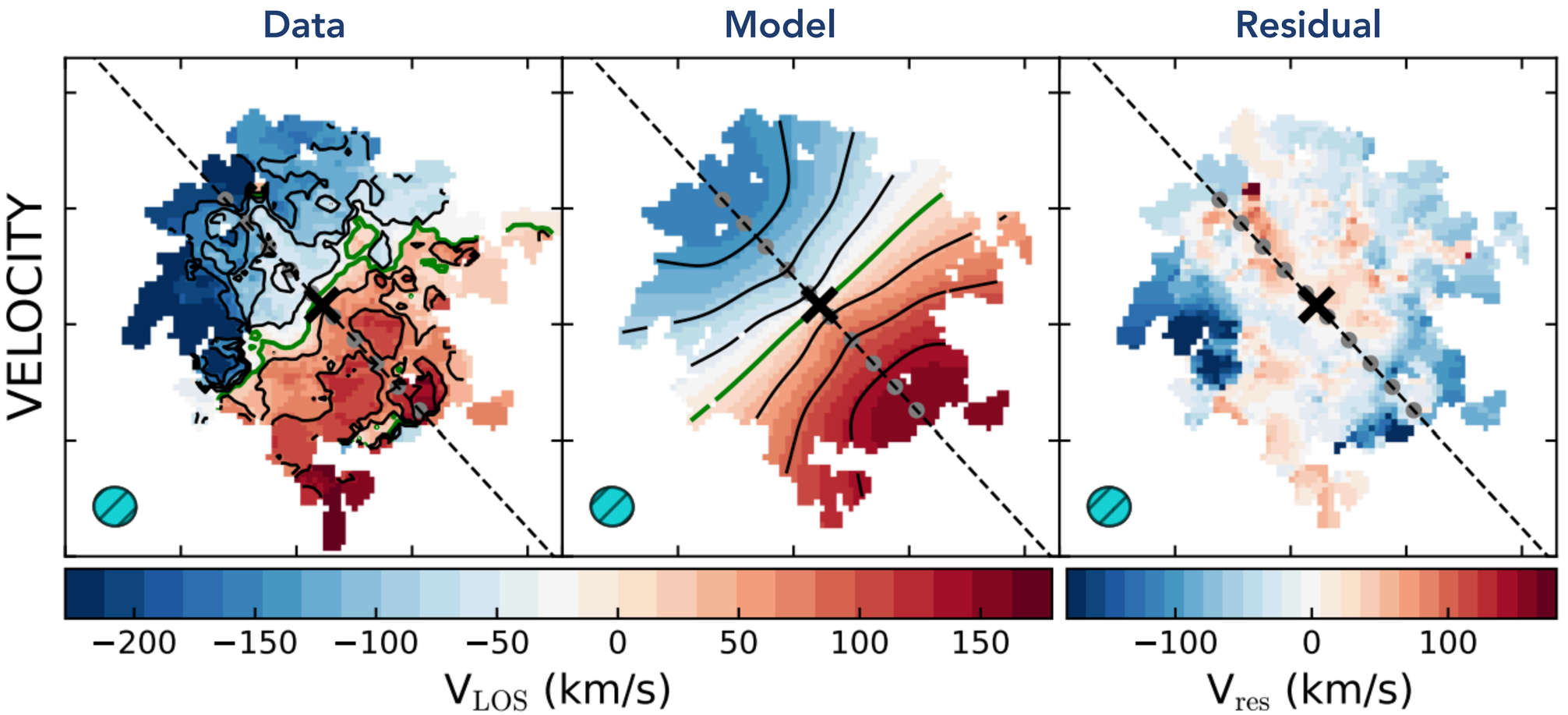


Rowland et al. (in prep)

Onto resolved scales with ALMA + JWST

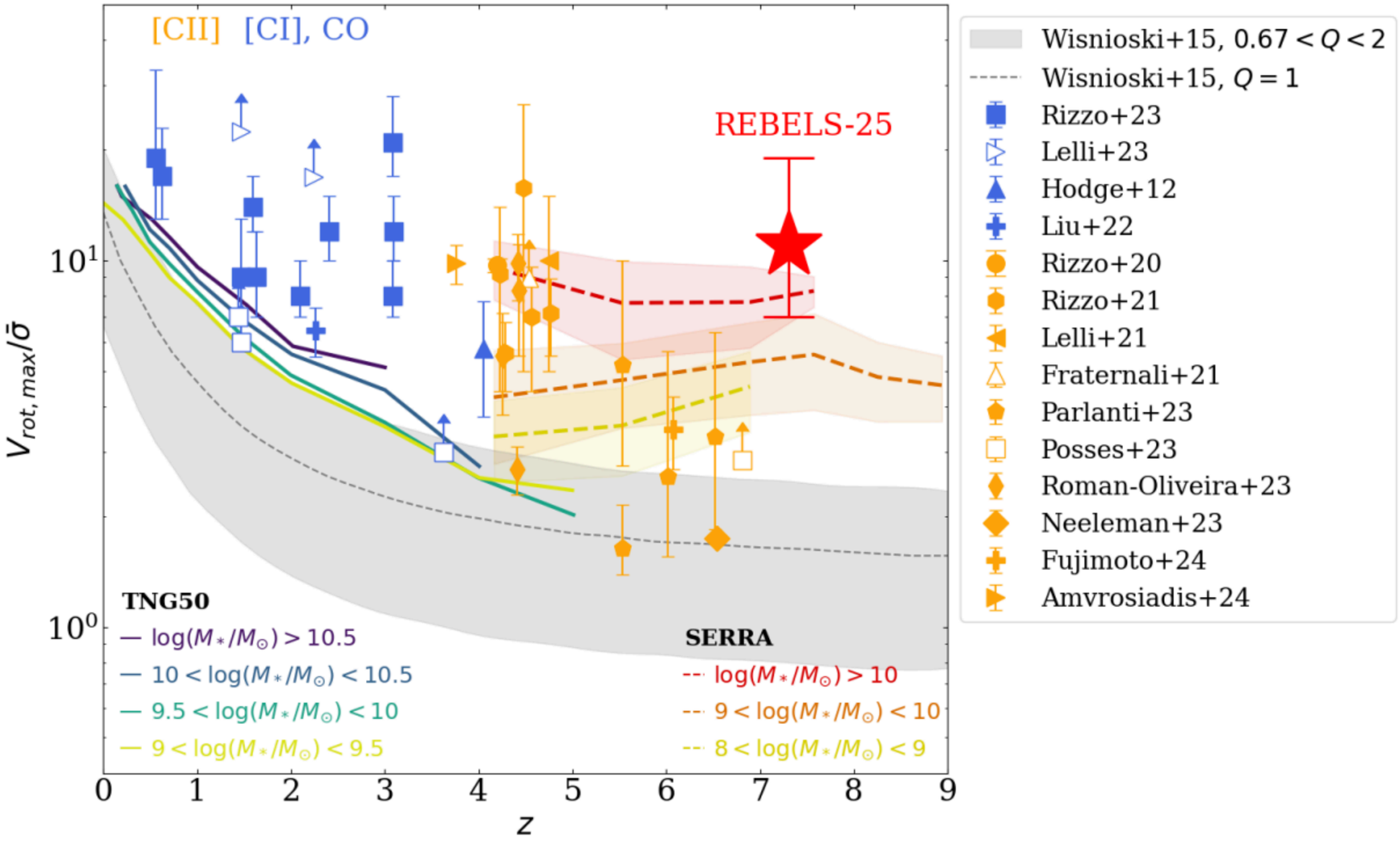
A Resolved View of REBELS-25

- 700pc [CII]158 map of REBELS-25 reveals a **rotating disk galaxy**



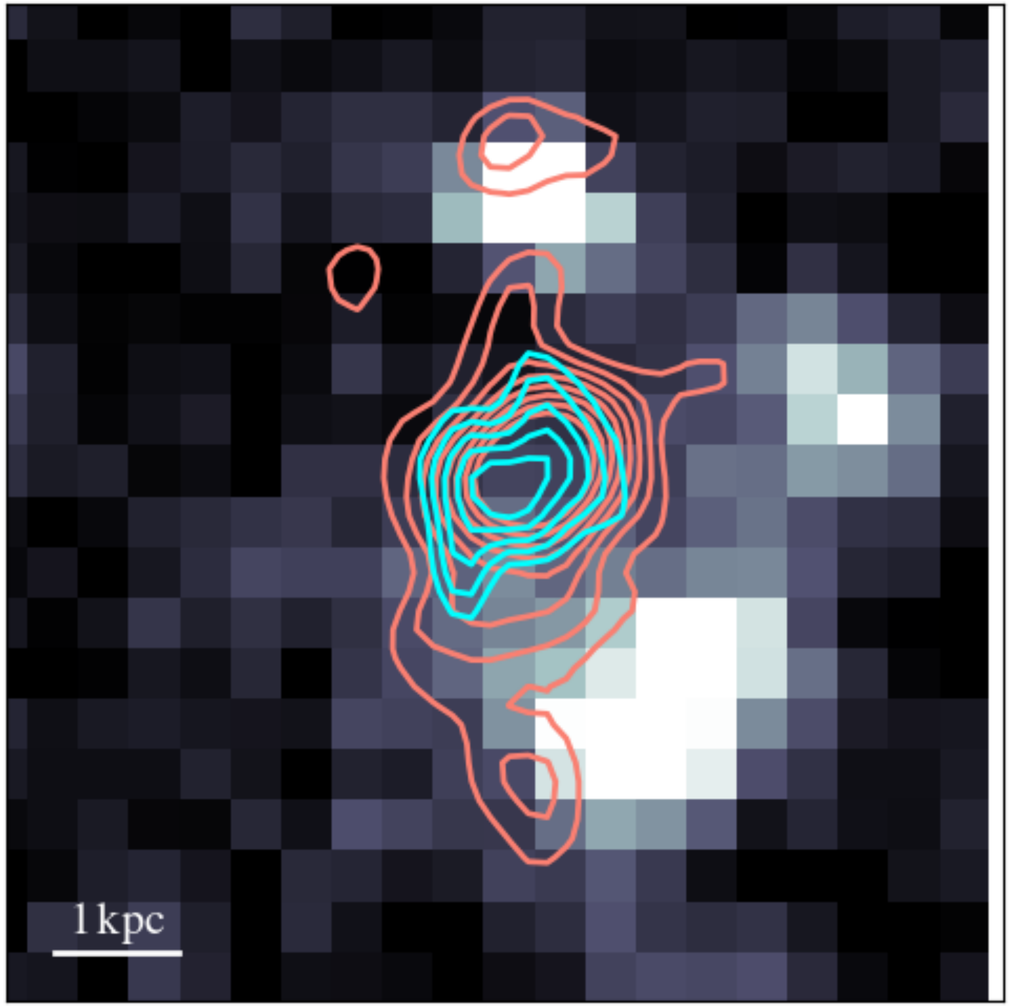
Rowland et al. (2024)

A Rotating Disk at z=7.31



Rowland et al. (2024)

Matched resolution ALMA Band 6 + 8 Observations



Pink: 158μm continuum (cold dust)

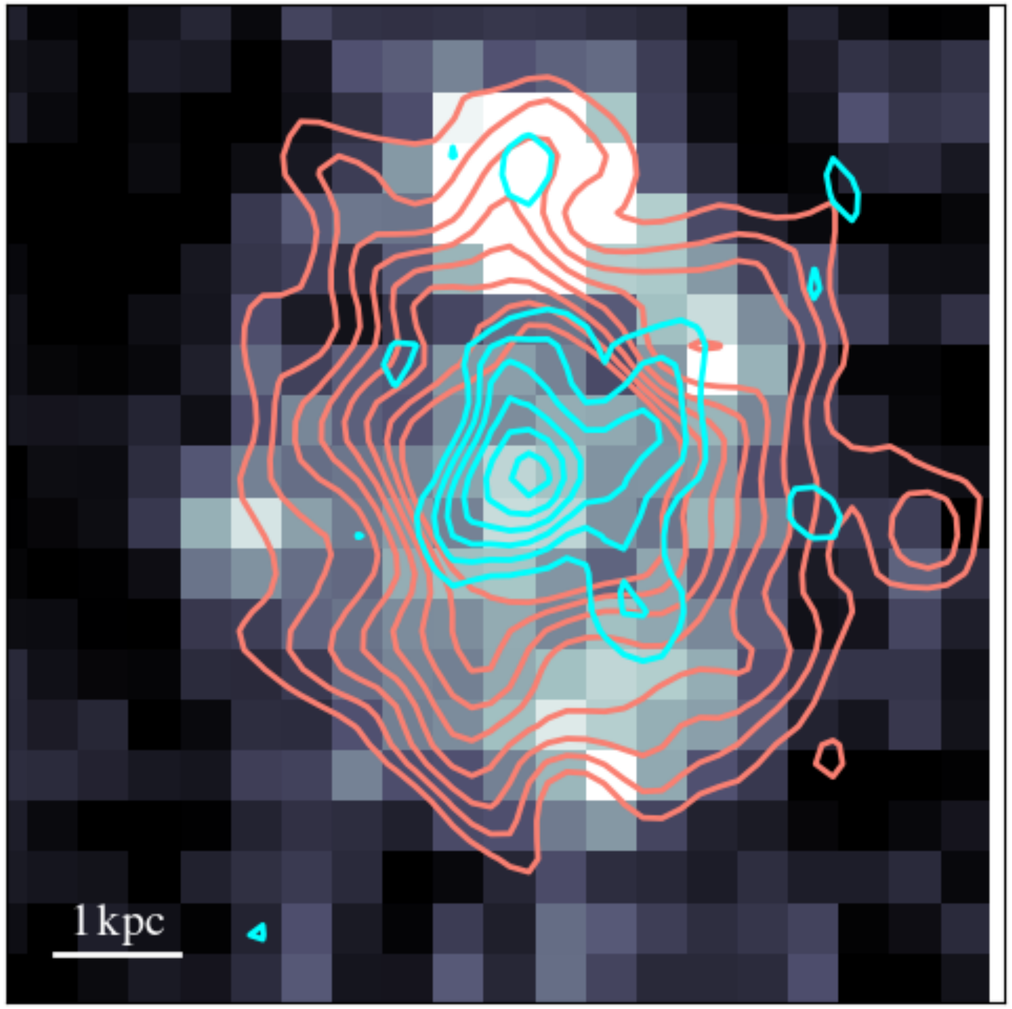
Cyan: 88μm continuum (warm dust)

Background: JWST rest-UV emission

- UV clumps miss **~90%** of the star formation in REBELS-25

***Algera** et al. (in prep)*

Matched resolution ALMA Band 6 + 8 Observations



Pink: $[CII]_{158}$ (neutral / molecular gas)

Cyan: $[OIII]_{88}$ (ionized gas)

Background: JWST $[OIII]_{5007}$

- [CII]158 significantly more **extended** than [OIII]88
- [OIII]88 and [OIII]5007 emission peaks are **spatially offset**

***Algera** et al. (in prep)*

Conclusions

- Dust is an important component of the ISM, even at $z \gtrsim 7$
  - It obscures **~50%** of SF in massive galaxies, and **~30%** of the **SFRD**
- Dust build-up through **grain growth** likely important at high-z
  - The high dust mass, dense ISM, steep $\beta_{\rm IR}$ and high metallicity of **REBELS-25** (indirectly) support this
- Need to be cautious about interpreting **unresolved** ALMA + JWST measurements, as these potentially trace **different regions**