STELLAR FEEDBACK IN THE STAR FORMATION-GAS DENSITY RELATION:

COMPARISON BETWEEN SIMULATIONS AND OBSERVATIONS

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CONTEXT

The Kennicutt-Schmidt (KS) relation is an empirical law that relates the projected star formation rate density ($\dot{\Sigma}_\star$) to surface gas density (Σ) through a powerlaw:

$$\dot{\Sigma}_\star \propto \Sigma^{\beta}.$$

Although proved to be robust at Galactic scales, its behaviour down at cloud scales is not fully understood. While recent high-resolution observations shed light on this relationship in individual clouds, **understanding how stellar feedback affects the relation remains challenging** due to the numerous processes at play and observational biases. Therefore, we investigated the role of stellar feedback from the **numerical** point of view. aiming to identify distinct signatures that can be observed and analyzed.

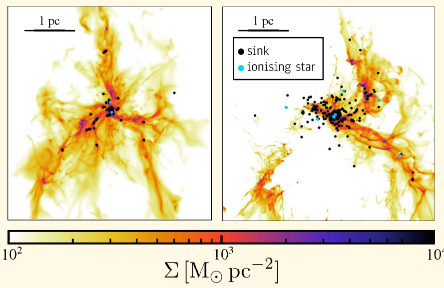
SIMULATIONS

We analysed the set of MHD simulations performed in **Verliat et al. (2022)**. They reproduce the evolution of an isolated $10^4 \mathrm{M}_\odot$ cloud under four different feedback prescriptions:

HIIR+PSJ

- **Protostellar Jets** and **ionising radiation from massive stars** (HIIR+PSJ)
- Protostellar Jets only (PSJ)
- Ionising radiation only (HIIR)
- No feedback (NF)

These achieve a **maximum resolution of 0.0073 pc**



Snapshots at 2.7 Myr (left) and 3.0 Myr (right) of simulation `HIIR+PSJ`, *showing the formation of a central hub with converging filaments and its subsequent disruption due to a powerful HII region.*

METHODS

We extract the physical quantities as in Pokhrel et al. (2021) and Bieging & Kong (2022).
We divide the projections of each snapshot into a series of column density contours.
From each of them, we recover:

- total area (A);
- average gas column density (Σ);
- star formation rate density, computed as

$$\dot{\Sigma}_\star = \frac{\textit{Mass accreted by sinks in the last 0.05 Myr}}{\textit{0.05 Myr} \cdot A};$$

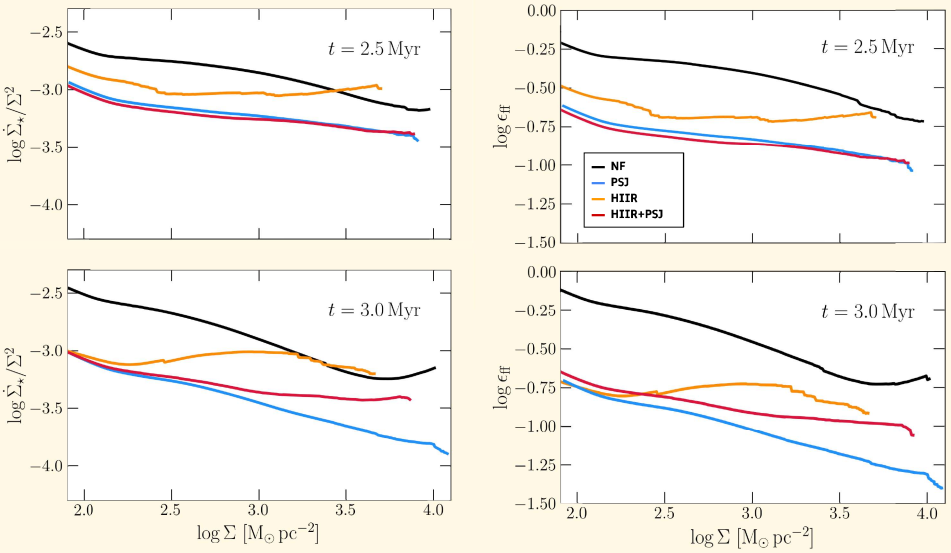
- efficiency per free-fall time:

$$\epsilon_{\mathrm{ff}} = \frac{\dot{\Sigma}_\star}{\Sigma} t_{\mathrm{ff}},$$

with the free-fall timescale estimated under uniform sphere approximation, as done in the reference observational studies

$$t_{\mathrm{ff}} = \sqrt{\frac{3\pi}{32\, G \rho_{\mathrm{avg}}}}, \quad \rho_{\mathrm{avg}} = \frac{3\sqrt{\pi}}{4} \Sigma A^{-\frac{1}{2}}$$

RESULTS: FEEDBACK AFFECTS THE TEMPORAL EVOLUTION OF THE KS RELATION AND ϵ_{ff}



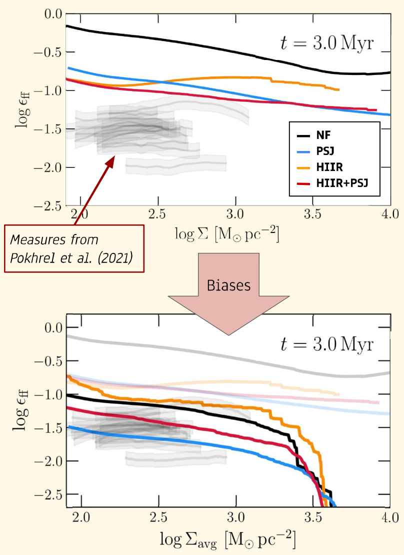
The numerical simulation allows us to follow the **temporal evolution of the relation** in the cloud. We find that:

- **ionising radiation steepens the relation**, leading to higher $\dot{\Sigma}_\star$ and ϵ_{ff} at high column densities;
- by the end of the simulations, only **runs with ionisation settle on a slope of $\beta \approx 2$**;
- the evolution of ϵ_{ff} closely follows that of the KS relation, achieving a **flatter slope in runs with radiation**;
- the resulting ϵ_{ff} is higher than what is generally reported in observational studies.

BIASES DECREASE THE OBSERVED ϵ_{ff}

Addressing biases in our column density maps, we recovered agreement with observations.
Specifically, through simplified prescriptions we included:

- sensitivity to young stellar objects (YSOs) → YSOs above 1700 $\mathrm{M}_\odot\,\mathrm{pc}^{-2}$ are masked★
- resolution → maps smoothed with a gaussian beam with a std. of 0.05 pc.▲
- uncertainties on the YSOs ages → SFR averaged over 0.5 Myr▼



★*Column density above which a 0.5 $\mathrm{M}_\odot$ Class II YSO at 700 pc is not detectable by Spitzer telescope (D. Russeil, priv. com.)*
▲*Herschel resolution at 650 pc*
▼*cf. Lada et al. (2017)*

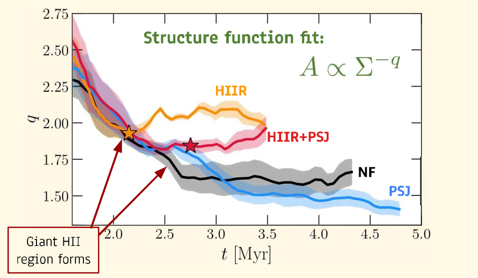
THE CLOUD STRUCTURE GOVERNS THE RELATION

Since star formation primarily takes place at high densities, the *integrated SFR* ($\dot{M}_\star$) of each contour level weakly correlates with column density at low Σ

Given that

$$\epsilon_{\mathrm{ff}} \sim \dot{M}_\star \Sigma^{-3/2} A^{-3/4} \qquad (t_{\mathrm{ff}} \sim \Sigma^{-1/2} A^{1/4})$$

to recover a constant ϵ_{ff} as well as a relation $\dot{\Sigma}_\star \sim \Sigma^2$, the cloud structure function must satisfy $A \sim \Sigma^{-2}$, which is indeed achieved in the radiative simulations



This result matches with the findings from Abreu-Vincente et al. (2015), who find an average slope of 2.1 in Galactic molecular clouds with large HII regions.

CONCLUSIONS

- **The KS relation is steeper in clouds with HII regions**, with higher ϵ_{ff} at high Σ
- Our simulated clouds report **higher** ϵ_{ff}. By introducing simple prescriptions to emulate **observational biases** this gap can be filled
- The structure function of the cloud primarily governs the shape of the relation. **HII regions act steepening the area-column density relation** to a value of q=-2

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