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$$\mathrm{SFR} = \epsilon_{ff} \frac{M_{\mathrm{selection}}}{t_{ff}}$$

- Galactic Disk kpc simulation (TIGRESS)
- Density selection: thresholds, bins
- Gravity/Energy selection: Φ isocontours bind gas
- Compare various models for "predicting" SFR
- Simple density competitive with other models
- Model parameters vary with threshold density ($\epsilon_{\mathrm{ff}} \sim 0.03 - 0.4$)

Identifying Gas Structures Correlated with SFR in ISM disk simulations

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Gas Structures in TIGRESS

Identify structures using Energy vs. Density

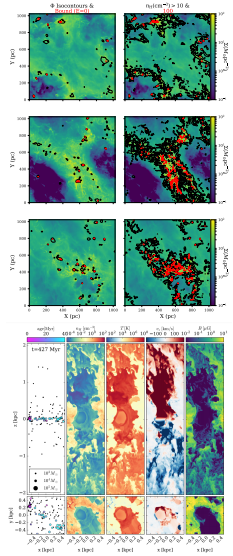

Figure 1: Top: Surface density snapshots with overlaid outlines of identified gas structures taken from the TIGRESS solar neighborhood simulation at $t = 370, 390, \&410$ Myr (top to bottom). Gravitational potential isocontours and zero total energy contours, left column, are compared with density thresholds, right column.

Bottom: XZ (y=0) and XY (z=0) slices of star particles, number density, temperature, vertical velocity, and magnetic field strength from a TIGRESS simulation snapshot at $t = 428$ Myr. TIGRESS simulates the ISM, star formation, and feedback self-consistently in kpc-scale regions, including self-gravity, sheared rotation, magnetic fields, UV heating, and supernovae (see Kim & Ostriker 2017, 2018).

Correlate Gas and SFR

We estimate SFR for a simulation snapshot by considering the stars younger than $t_{*,\max}$:

$$\sum_{*} M_*(t_* < t_{*,\max})/t_{*,\max}$$

For each method of selecting Gas, we consider for a simulation snapshot

$$\sum_{\mathrm{objects}} \left(\frac{M}{t_{\mathrm{ff}}}\right)_i$$

Each snapshot provides a point in the time series.

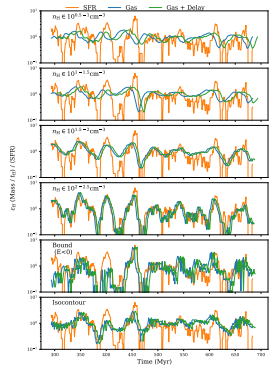

Figure 2: Time series of total mass within gas structures (density bins, gravitational potential isocontours, and $E < 0$ bound objects) compared with SFR, with and without a best fit time delay. Correlation improves with density. Energy-based structures (isocontours, bound) agree fairly well but there can be large errors. Snapshots have Myr cadence and $t_* < 5$ Myr.

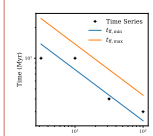

Figure 3: Best-fit lag for density bins in Figure 2, showing that dense gas correlates with SFR with a delay similar to the free-fall time $t_{\mathrm{ff}} = \sqrt{32\pi G \mu n_H/3}^{-1}$.

α_v Models

Each object has M_i, $t_{\mathrm{ff},i}$, $\alpha_{v,i}$. Does an object's virial parameter α_v affect its contribution to SFR?

$$\alpha_v = \frac{2\mathrm{KE}}{-\mathrm{PE}}$$

Here, PE is estimated from the mass and volume (assuming objects are constant density spheres).

Constant model

$$\mathrm{SFR} = \epsilon_{\mathrm{ff}} \sum \left(\frac{M}{t_{\mathrm{ff}}}\right)_i$$

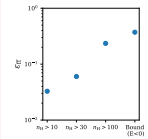

Figure 4: Best-fit ϵ_{ff} ranges from 0.03 - 0.4, increasing with density and largest for bound structures.

Padoan+2012 model

$$\mathrm{SFR} \propto \sum \left(\frac{M}{t_{\mathrm{ff}}}\right)_i e^{-\beta t_{\mathrm{ff}}/t_{\mathrm{dyn}}}$$

$$\mathrm{SFR} \propto \sum \left(\frac{M}{t_{\mathrm{ff}}}\right)_i e^{-\beta\sqrt{(3\pi^2/40)\alpha_{v,i}}}$$

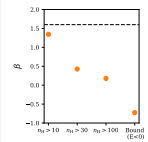

Figure 5: Best-fit β varies with density threshold, becoming close to the Padoan et al. 2012 value of 1.6 for "low" density. Lower β represents a preference for mass with high α_v. Note $\alpha_v < 2$ does not correspond perfectly to boundedness.

Maximum α_v model

$$\mathrm{SFR} \propto \sum \left(\frac{M}{t_{\mathrm{ff}}}\right)_i H(\alpha_{v,\mathrm{cutoff}} - \alpha_{v,i})$$

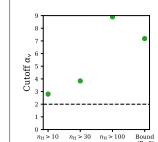

Figure 6: Best-fit cutoff α_v varies with structure type. Note H is the Heaviside step function, imposing a maximum value of α_v for an object to contribute to SFR. A strict, lower cutoff close to 2 is helpful for lower densities. For higher density and bound objects, the cutoff is higher, including essentially all possible objects.

Compare RMS error

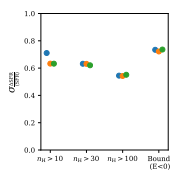

Figure 7: RMS error (scaled to mean SFR) for constant model (blue), Padoan+2012 (β) model (orange), and maximum α_v model (green). The largest advantage for the more complex models appears at "low" density of 10 cm^{-3}. Since constant is the $\beta = 0$ special case of the β model, it must be strictly worse, but does not differ significantly for higher densities. Rather, increasing density provides the best improvement, and bound models suffer from misses apparent in Figure 2.

Results and Interpretation

- ϵ_{ff} similar to theory (Padoan, Haugbolle, & Nordlund 2012)
- ϵ_{ff} similar to observations (Vutisalchavakul, Evans, & Heyer 2016, Oschendorf+2017)
- RMS error comparable but clear preference for high density
- "Gravitational binding" is imperfect predictor of SF in turbulent system, either using gravitational potential structure or estimates for α_v.

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