Star Formation in GMCs & Galactic star formation

The formation of massive stars
Empirical star formation laws
The IMF
The formation of Pop III stars

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Massive star formation

Nuclear fusion can ignite before accretion process is complete, possibly significantly altering gas accretion due to resulting radiation pressure.

Balancing a star's gravitational force with the force from radiation pressure defines the Eddington luminosity,

$$L_E = \frac{4\pi c G M_*}{\kappa_d}$$

where $\kappa_d \equiv$ the dust opacity per unit mass.

Kennicutt-Schmidt Law

Schmidt Law (1959) relates $\dot{\Sigma}_*$ and the gas surface density:

$$\dot{\Sigma}_* \propto \sigma_{\rm gas}^N$$

where $N \sim 1 - 2$.

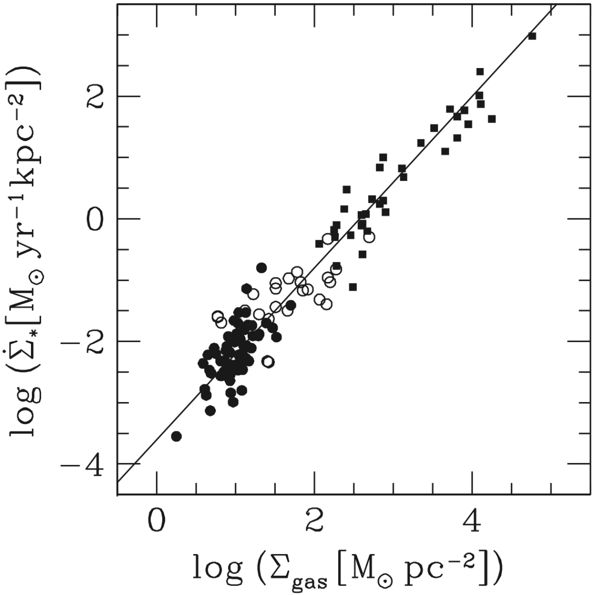
This was extended by Kennicutt (1998) to also include starburst galaxies, finding

$$\dot{\Sigma}_* = (2.5 \pm 0.7) \times 10^{-4} \left(\frac{\Sigma_{\rm gas}}{M_\odot {\rm pc}^{-2}} \right)^{1.4 \pm 0.15} M_\odot/{\rm yr}/{\rm kpc}^2$$

where $\Sigma_{\rm gas} = \Sigma_{\rm HI} + \Sigma_{\rm H_2}$.

Kennicutt-Schmidt Law

The Kennicutt-Schmidt law implies that a galaxy's SFR is controlled by the self-gravity of the gas.

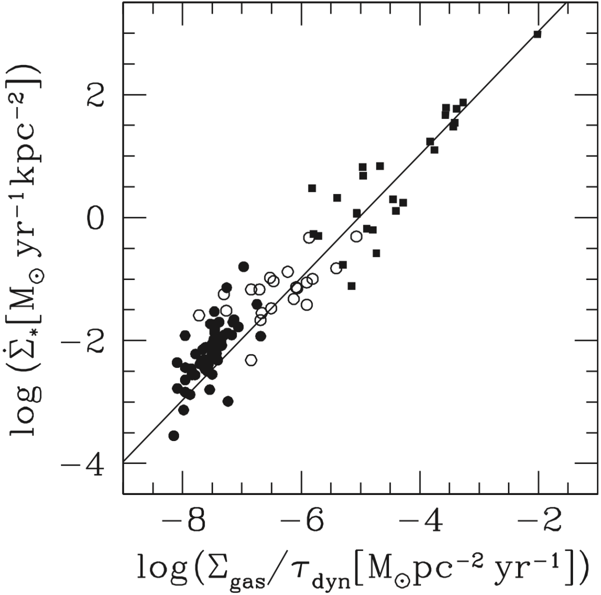


Kennicutt-Schmidt Law

Kennicutt (1998) also observed a similar correlation between $\dot{\Sigma}_*$ and Σ_{gas}/τ_{dyn}:

$$\dot{\Sigma}_* \approx 0.017\Sigma_{gas}\Omega$$

where $\Omega \equiv$ the circular frequency of the galaxy.



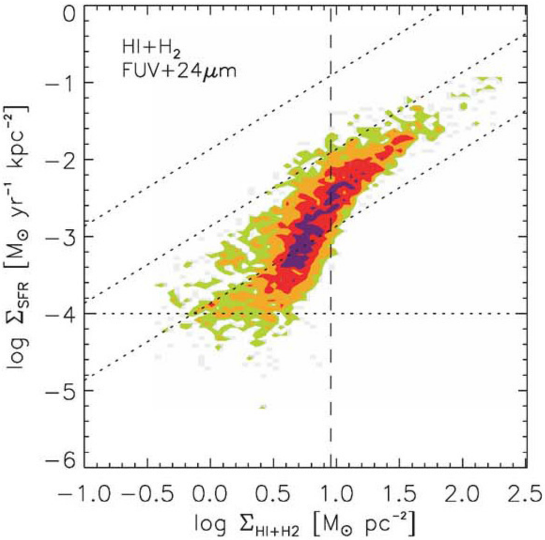
SF thresholds

Possible explanations for lack of star formation in outer disk:

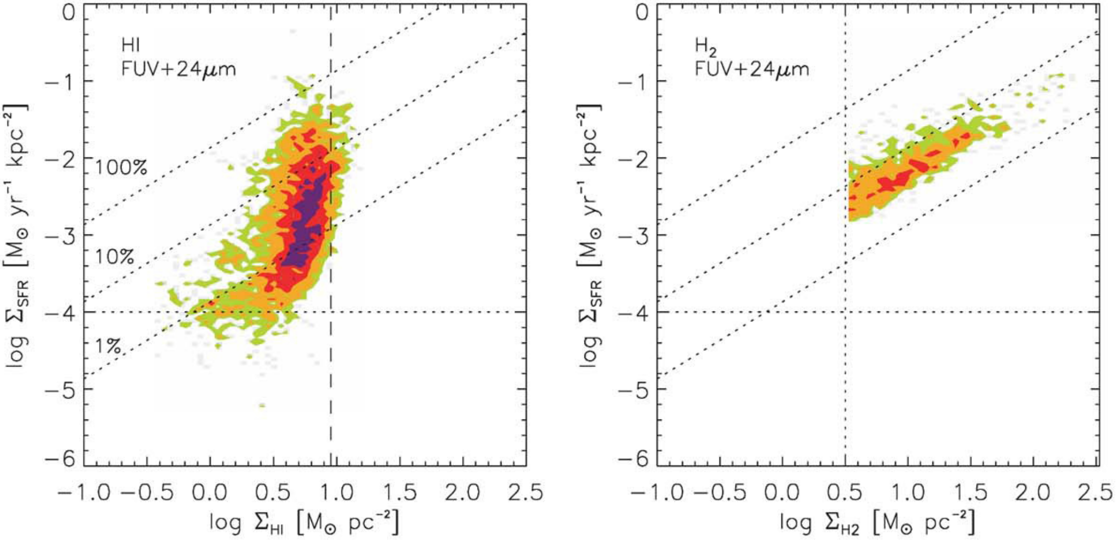
Gravitational instability
: If the gas surface density is too low, then the gas will be stable to gravitational collapse.

Shear instability
: Shear from differential rotation prevents gravitational perturbations from growing.

Ability to form H_2
: If a region's pressure is too low, molecular H will not form.



Local SF laws



IMF

The Initial Mass Function, $\phi(m)\,dm$, describes the relative number of stars formed with masses $m \pm 0.5dm$. It is assumed to be continuous, and can be normalized so that

$$\int_{m_\ell}^{m_u} m\phi(m)\,dm = 1M_\odot$$

Typically, $m_\ell \simeq 0.08M_\odot$ and $m_u \simeq 100M_\odot$.

For a total mass M_* of newly formed stars,

$$dN(m) = M_*[M_\odot]\phi(m)\,dm \qquad dM(m) = M_*[M_\odot]m\phi(m)\,dm$$

The logarithm IMF is also often used, where $\xi(m)\,d\log m = \phi(m)\,dm$. The slopes of the IMF are

$$b(m) \equiv -\frac{d\log\phi}{d\log m} \qquad \beta(m) \equiv -\frac{d\log\xi}{d\log m} = b - 1$$

Constructing the IMF from observations

To define the observed IMF, one must estimate the stellar mass of a collection of stars within some volume from their luminosity.

Along the way, this will also produce the luminosity function, $\Phi(M_r)$, the number density of stars as a function of absolute magnitude.

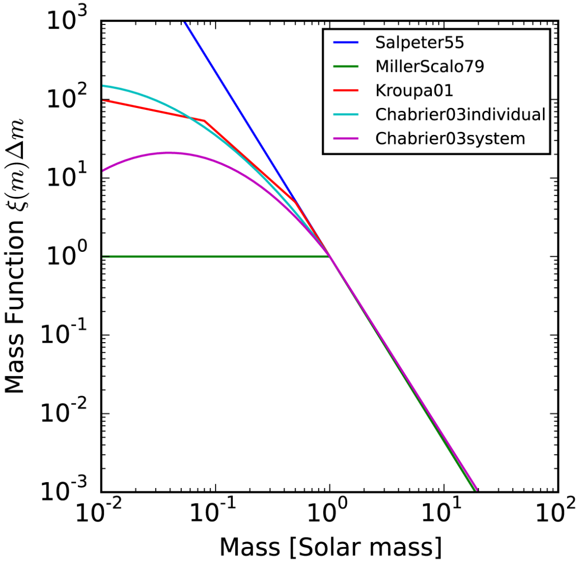
If the IMF is time-independent, then the luminosity function is

$$\Phi_0(M_r) = \Phi(M_r) \frac{\int_0^{t_0} \psi(t)\, dt}{\int_{t_0-\tau_{\mathrm{MS}}(M_r)}^{t_0} \psi(t)\, dt}$$

where $\psi(t)$ is the star formation history in the given volume. The IMF is then

$$\phi(m) \propto \frac{dM_r}{dm} \Phi_0[M_r(m)]$$

Various IMFs from observations



(Non-)universality of the IMF

Our knowledge of the IMF and the processes involved is too incomplete to definitively state whether or not the IMF is universal. Possible reasons to expect it to be non-universal include

Gas-phase metallicity The radiative cooling rate of gas depends on the chemical composition. Low metallicity regions could produce top-heavy IMFs.

Ambient radiation FIR photons can raise both the minimum temperature and the Jeans mass in star-forming clouds, resulting in a top-heavy IMF.