Galactic-Scale Triggering: a Law for Star Formation.

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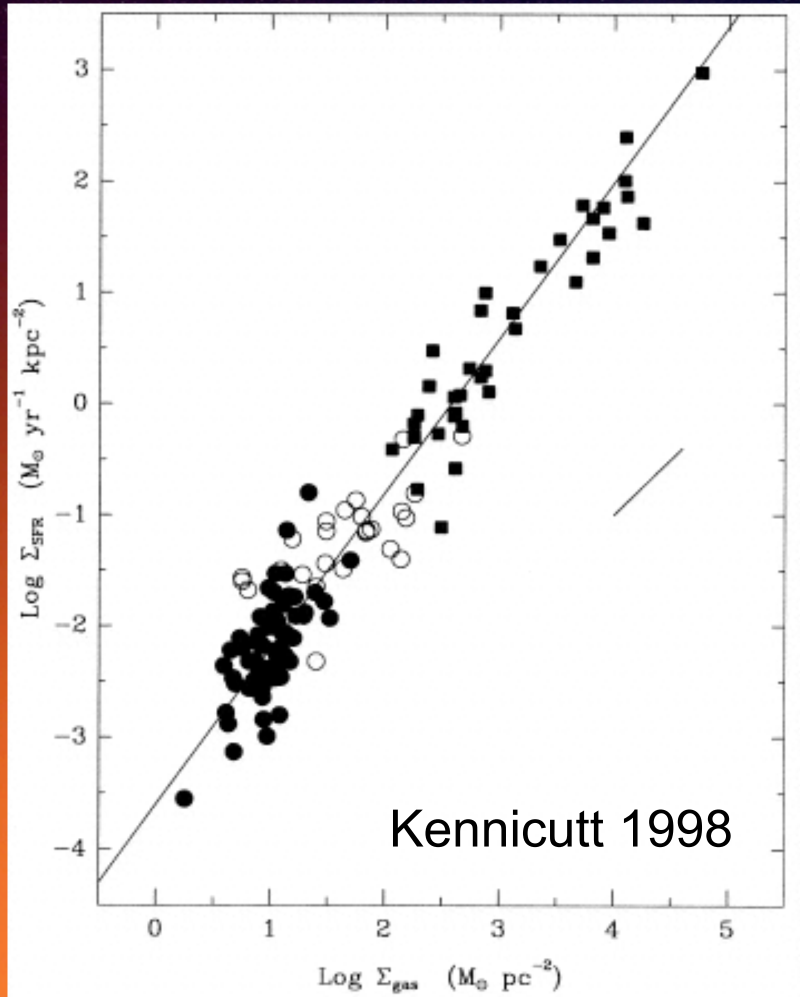
Kennicutt´s Law:



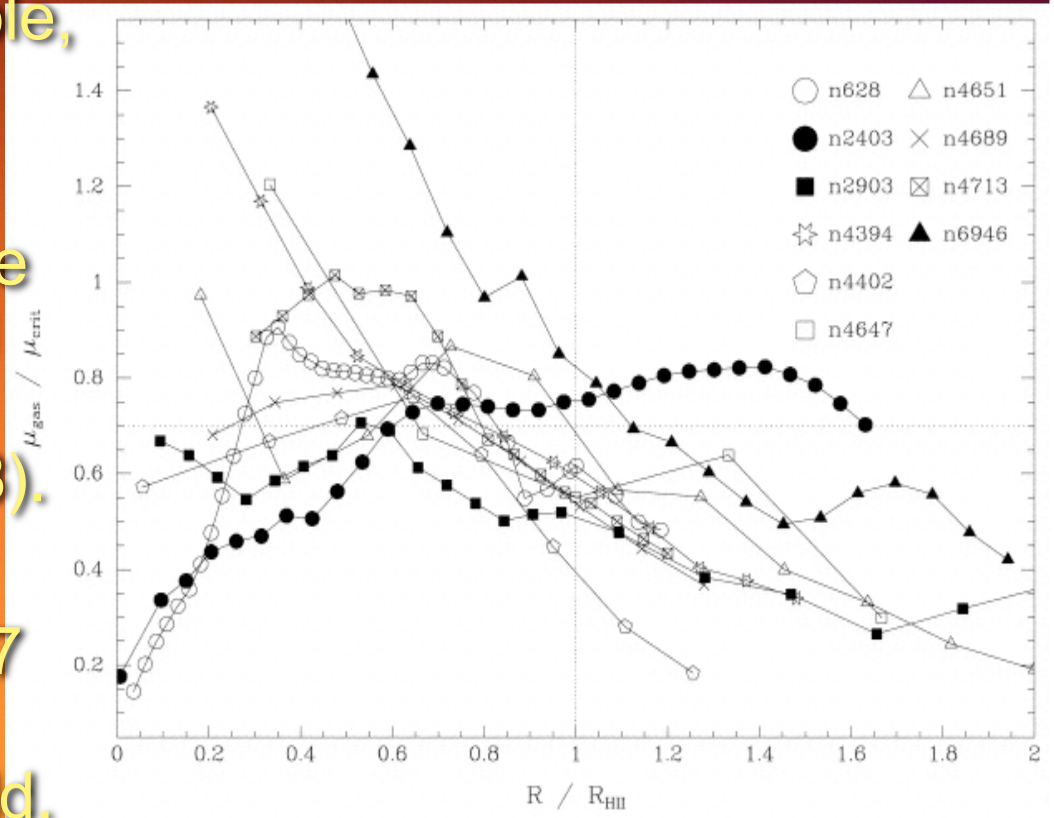
- Because SF is inherently a sub-pc problem, this law suggests a physical connection between galactic (>kpc) and sub-pc scales. In other words, it should be a galactic property relevant in the SF problem, that triggers SF.

Toomre parameter $Q = \Omega v^{turb}/\pi G \Sigma_{gas}$

◊ From grav. instab. arises as natural candidate for large scale triggering. A Q>1 disk is stable, Q<1 is unstable.

◊ However, Q is observed to be always close to 1 in the local universe (Martin & Kennicutt 01; Downes and Solomon 98).

◊ Q~1 makes hard to explain 7 decades variations of SFR/ Area in terms of this threshold.



Self-Regulation Towards Q~1 (Goldreich & Lynden-Bell 65).

Q>>1

No SF->Cooling

Q~1

Q~1

SF -> heating

Q<<1

- Therefore, it is expected than galactic disks are always close marginal Toomre stability.

Self-Regulation Towards Q~1

- ◊ However, something not generally addressed is that the condition of marginal stability can have a range of possible self-regulated states: a Starburst with Q~1 is much more turbulent than a Spiral with Q~1.

- ◊ We next look gravitational inst. analysis, in order to see if there is a galactic quantity responsible this more turbulent behavior of Starbursts relative to Spirals.

Largest Unstable Mass Scale

◊ General result of linear stability analysis (Toomre 64; Escala & Larson 08):

All wavelength between $\lambda_{Jeans} = C_S^2/G\Sigma_{gas}$ and $\lambda_{ROT} = \pi^2 G\Sigma_{gas}/\Omega^2$ are UNSTABLE. When $\lambda_{JEANS} \approx \lambda_{ROT}$, the instability range goes to 0 and Q is ≈ 1.

◊ As in the case of the Jeans Mass, the largest unstable scale λ_{ROT} has an associated mass-scale of $M_{ROT} = \Sigma_{gas}(\lambda_c/2)^2 \propto \Sigma_{gas}^3/\Omega^4$. M_{ROT} a robust galactic scale quantity because it does not depends on complex microphysics .

For Q~1, different equilibriums possible

Self-regulation towards Q~1 ↔ $\lambda_{rot} \sim \lambda_j^{turb} = v^2_{turb}/G\Sigma_{gas}$

Some galaxies (i.e. starbursts) are able to have more turbulent Q~1 equilibriums due to a higher λ_{rot}

Implication for Star Formation

◊ Is believed that turbulence enhances and controls SF (Elmegreen 02, Krumholz & McKee 05, Wada & Norman 07, etc). The SFR depends on the PDF of gas density produced by galactic turbulence.

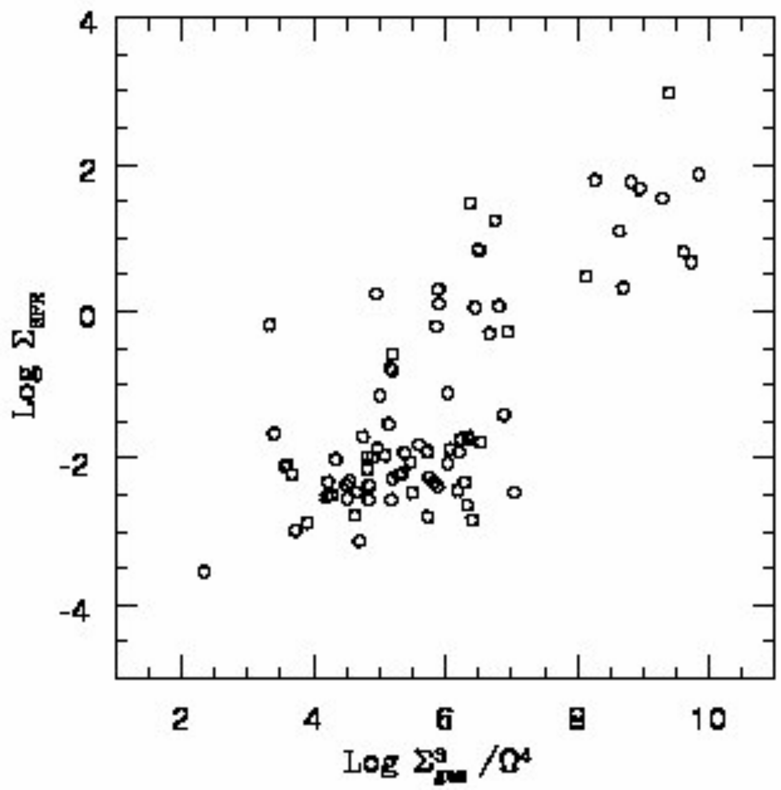
◊ It can be shown for Q~1 that $M_{rot} \sim 8\pi H v_{turb}^2/3G$, which for a disk supported vertically by turbulence ($H=f(v_{turb})$) implies:

$$v_{turb} \propto M_{rot}^{\eta} \qquad \text{with } \eta>0$$

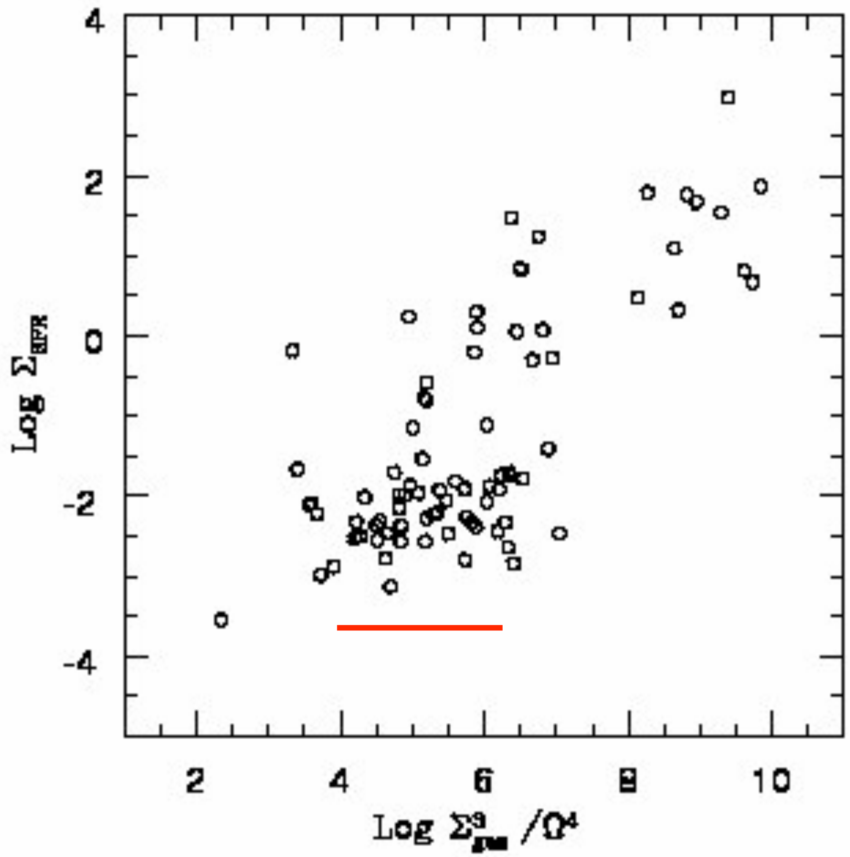
◊ Interesting to explore a possible link between M_{rot} and with SFR, by searching for a correlation M_{rot}-Σ_{SFR}

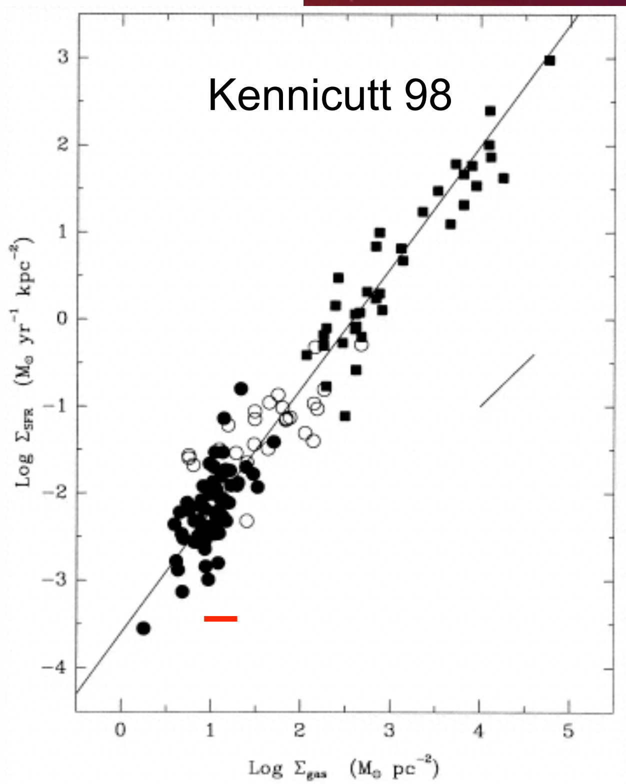
There is a Correlation?

- First approach: to take the tabulated data from the original Kennicutt´s paper (Σ_{gas} & $t_{dyn} = \Omega^{-1}$) to compute $\Sigma^3_{gas} * \Omega^{-4}$



Scatter due Error Propagation





◊ Errors of factors of 2 in Σ_{Gas} & t_{dyn}, implies changes of a factor of 128 in $\Sigma^3_{Gas} * t_{dyn}^4$

Alternative Formulation

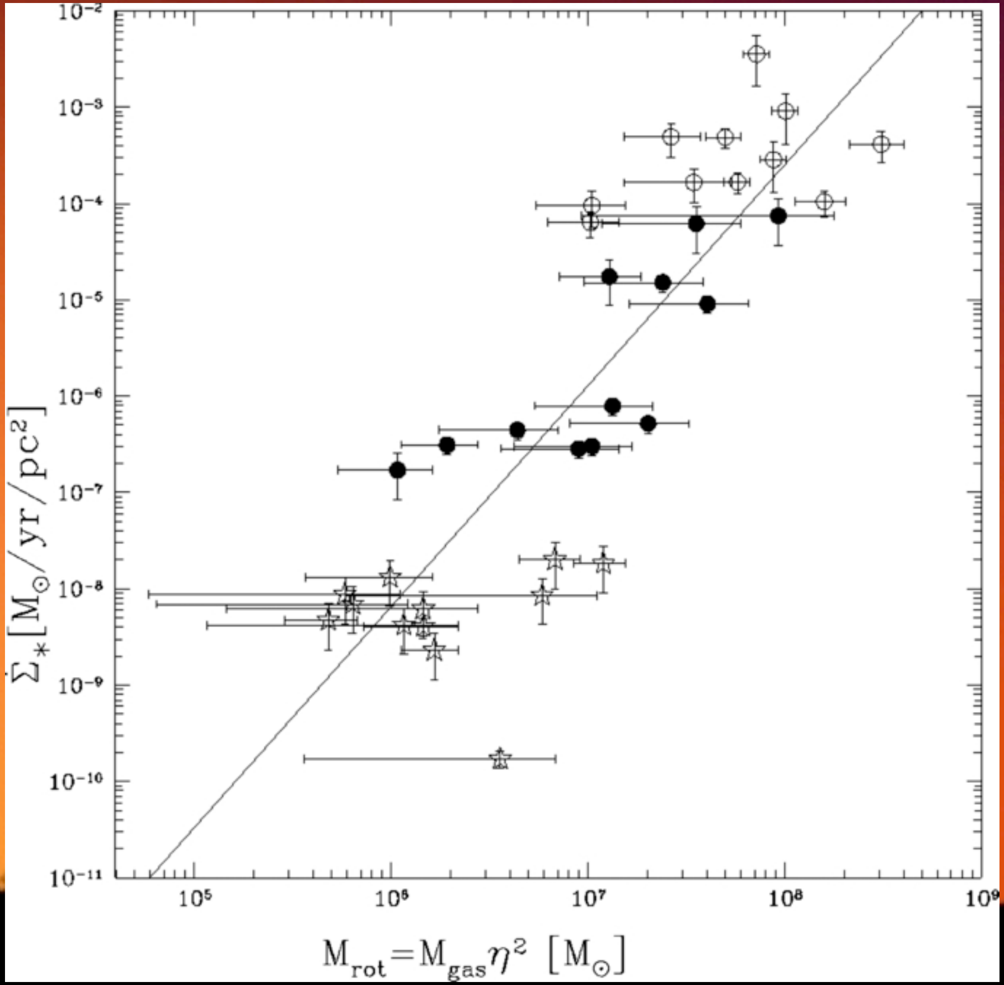
◊ Assumes rotational support, its possible to derive a mass-scale (for a gas fraction $\eta = M_{gas} / M_{tot}$) :

$$M_{rot} = M_{gas}\,\eta^2$$

◊ This expression has the advantage that reduces the scatter due to error propagation.

SFR-M_{rot} Law:

Escala (2011)



A law for

$\dot{\Sigma}_{star} \propto M_{rot}^{2.3}$ is found, with a scatter of 0.21 dex.

Origin of the Correlation: Compute SFR for a Lognormal PDF

◊ Numerical simulations suggest that PDF of a multiphase ISM can be represented by:

$$f(\rho)d\rho = (2\pi\sigma^2)^{-1/2} \exp[-\ln(\rho/\rho_0)^2/2\sigma^2]\, d\ln\rho$$

◊ If the star formation happens ONLY in region with density higher than ρ_C with an efficiency e_C, the SFR per unit volume is:

$$\dot{\rho}_{star} = e_C\, f_C\, <\rho>\, (G\rho_C)^{1/2}$$

where f_C is the fraction of gas denser than ρ_C and $<\rho>$ the average density (both from $f(\rho)$).

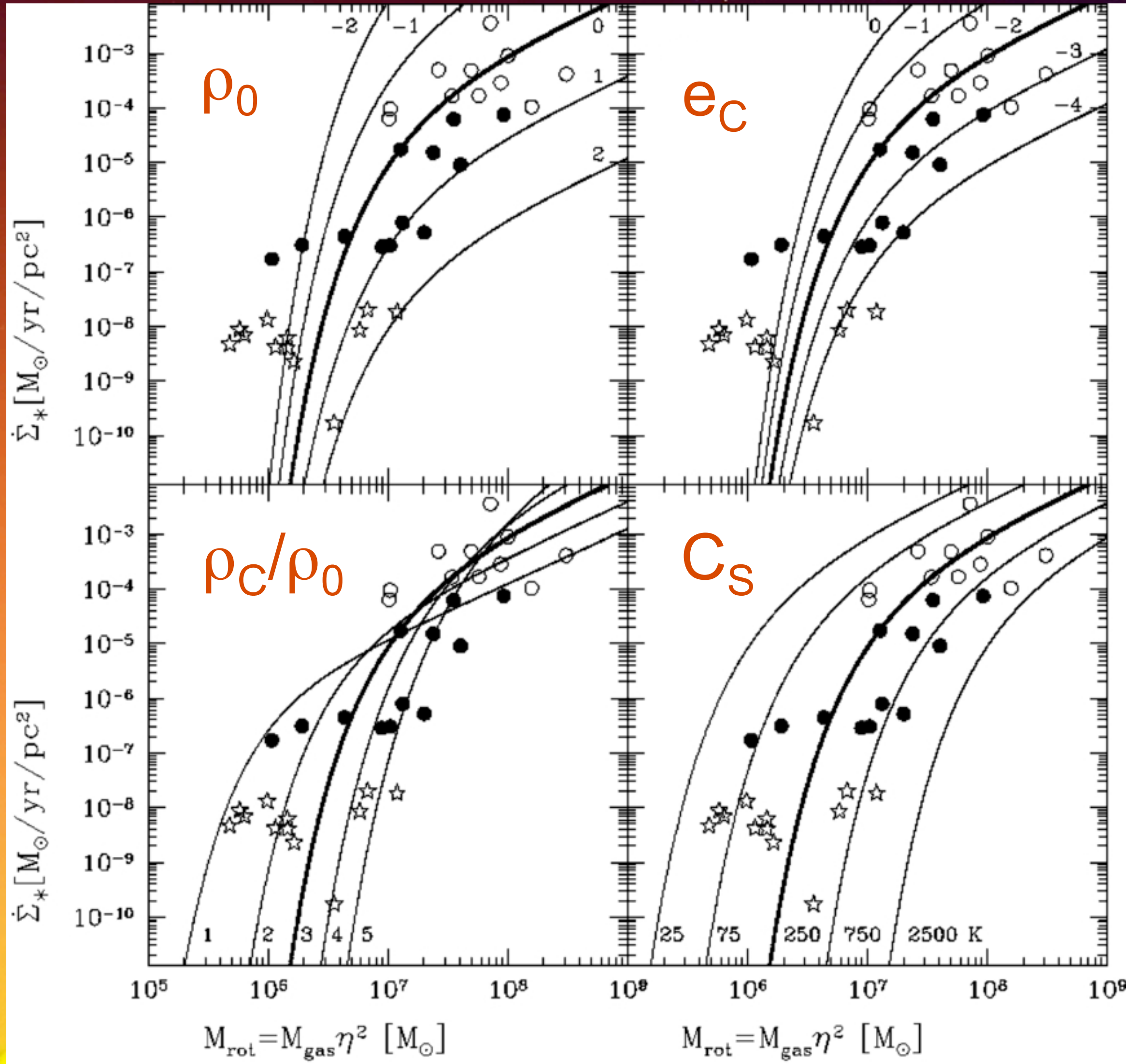
SFR for a Lognormal PDF

- Numerical experiments (Padoan 97; Federrath et al. 10) suggests that the mach number determine the PDF width σ:

  $\sigma^2 = \ln(1+[b\, v_{turb}/C_s]^2) = \ln(1+M_{rot} 3Gb^2/8\pi H C_s^2)$ for the self-regulation scenario with $Q \sim 1$.

- This predicts a relation between SFR - M_{rot}, which can be directly compared to the observed relation.

Predicted SFR vs Data



Escala (2011)

A single set of parameters, can reproduce the whole correlation. Analogous calculations (i.e.Wada & Norman 07) for the KS Law, requires a variable SF efficiency between spirals and starbursts.

Summary

- We found that the largest mass-scale not stabilized by rotation, M_{rot}, strongly correlates with SFR in a wide range of galaxies in the local universe.

- We found that a galactic ISM characterized by a lognormal PDF, in which v_{turb} is determine by M_{rot}, successfully predicts the correlation.

- This scale is the same of the largest collapsing clumps (Escala & Larson 2008), therefore is consistent that high SFR should be related with clumpier and more turbulent ISM as suggested by observations.

- Interesting to see if this correlation exists for high z galaxies, in particular in clumpy disk/chain galaxies which have a clumpier and more turbulent ISM.