Gas Phase Processes Affecting Galactic Evolution

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Abstract. Gas processes affecting star formation are reviewed with an emphasis on gravitational and magnetic instabilities as a source of turbulence. Gravitational instabilities are pervasive in a multi-phase medium, even for sub-threshold column densities, suggesting that only an ISM with a pure-warm phase can stop star formation. The instabilities generate turbulence, and this turbulence influences the structure and timing of star formation through its effect on the gas distribution and density. The final trigger for star formation is usually direct compression by another star or cluster. The star formation rate is apparently independent of the detailed mechanisms for star formation, and determined primarily by the total mass of gas in a dense form. If the density distribution function is a log-normal, as suggested by turbulence simulations, then this dense gas mass can be calculated and the star formation rate determined from first principles. The results suggest that only \(10^{-4}\) of the ISM mass actively participates in the star formation process and that this fraction does so because its density is larger than \(10^5\) cm\(^{-3}\), at which point several key processes affecting dynamical equilibrium begin to break down.

Keywords: gravitational instabilities, turbulence, sequential triggering

1. Introduction

Gas processes in the interstellar medium (ISM) are varied and complex. This review is limited to those most closely involved with precursors to star formation. Other talks at this conference cover the high energy phase and the dispersal of gas after star formation. Some ideas expressed here are considered in more detail in Elmegreen (2002).

At the beginning of star formation is cloud formation, but stars are also triggered in pre-existing clouds by processes unrelated to cloud formation (e.g., by supernovae), and many clouds are formed that do not produce new stars (e.g., diffuse clouds). Thus star formation is distinct from cloud formation.

Figure 1 shows a diagram of the flow of energy into ISM structure, starting with sources dominated by young stars, gaseous self-gravity, and magnetism (which derives its energy from galactic rotation via the dynamo). The stellar sources tend to produce expanding regions and cosmic rays, turning their energy into radiation behind shock fronts and turbulent motions that also decay into radiation. Gravity produces contracting regions by swing amplified instabilities and collapse along spiral arms. This contraction releases more gravitational energy as the...
Figure 1. Schematic diagram showing paths from the main energy sources, which are self-gravity, magnetic fields, and stars, to the formation of cloudy structure, going through intermediate steps of explosions, instabilities, and turbulence. The cloudy structure that is formed by these processes is modified further by stars, gravity and magnetic fields.

density increases, and again much of this energy goes into turbulence and ultimately radiation. The shells produced by stellar pressures and the turbulence produced in these shells and by various instabilities makes the observed cloudy structure of the ISM. Other stellar pressures, along with continued self-gravity and magnetic forces, then modify these clouds and eventually produce individual and binary stars on very small scales.

2. Gravitational Instabilities

Gravitational instabilities have two characteristic lengths. One balances pressure and self-gravity and is the Jeans length, $2c^2/G\Sigma$, for velocity dispersion $c$ and mass column density $\Sigma$. The other balances the Coriolis force and self-gravity and is the Toomre (1964) length, $2\pi G\Sigma/\kappa^2$, for epicyclic frequency $\kappa$. The characteristic mass of the Jeans length is $c^4/G\Sigma^2$, which is $\sim 10^7 M_\odot$ for typical stellar disks. This is usually the largest mass of globular clouds in galaxies (Elmegreen & Elmegreen 1983; Grabelsky et al. 1987; Rand 1993a,b).

The Toomre length enters into the separation between spiral arms. Galaxies with relatively large disk-to-halo mass ratios have large Toomre
lengths and few spiral arms in a grand-design pattern. Galaxies with relatively low-mass disks tend to have short flocculent spiral arms (Mark 1976; Elmegreen & Thomassen 1993; Athanassoula, Bosma, & Papaioannou 1987; Fuchs 2003).

Gravitational instabilities in galaxy disks involve a competition between three forces: pressure, Coriolis, and self-gravity. The fastest growing wavelength tends to be determined by the Jeans length alone. If the Coriolis force exceeds the gravitational force at this fastest growing wavelength, then there can be no instabilities at any wavelength. This is the threshold condition written as \[ Q = \frac{c \kappa}{\pi G \Sigma} > 1 \] or \[ \Sigma < \Sigma_{\text{crit}} = \frac{c \kappa}{\pi G} \] (Safronov 1960; Toomre 1964). Kennicutt (1989) and Martin & Kennicutt (2001) noted how star formation tends to end in the outer parts of galaxy disks where this stability threshold is first satisfied.

A similar threshold behavior arises from other processes too. Giant shells can collapse into self-gravitating clouds that form stars when \( \Sigma \) is large compared to the same threshold, \( \Sigma_{\text{crit}} \) (Elmegreen, Palouš, & Ehlerová 2002). This is because Coriolis forces resist self-gravity during the expansion of shells, causing them to twist and stall, and because the characteristic size of a shell at the time of its internal instability is about the Jeans length (divided by \( 2\pi \)).

Turbulence should also show a threshold behavior considering that the ratio \( \Sigma/\Sigma_{\text{crit}} \) equals \( R_{\text{epi}}/H \) for epicyclic radius \( R_{\text{epi}} \) and disk scale height \( H \) (ignoring stars). When the gas is sub-threshold, turbulent eddies swirl around before they accumulate and compress enough gas to make clouds that are gravitationally bound.

The threshold \( \Sigma_{\text{crit}} \) can vary by a factor of 2 around the fiducial value of \( c \kappa/\pi G \), depending on the details of the situation. Magnetic fields in the azimuthal direction increase \( \Sigma_{\text{crit}} \) when shear is high (Gammie 1996), as does the non-zero thickness of the disk (Romeo 1992). Magnetic fields reduce \( \Sigma_{\text{crit}} \) and make the instability more favorable when shear is low because they remove angular momentum from the growing condensation, offsetting the Coriolis force (Elmegreen 1987; Kim & Ostriker 2001). Viscosity does the same thing for the same reason (Elmegreen 1995; Gammie 1996). A soft equation of state makes instabilities easier too by replacing the velocity dispersion \( c \) with the product \( \gamma c \) for ratio of specific heats \( \gamma \), which can be less than 1 (corresponding to the common observation that denser regions are cooler). Combined stars and gas reduce \( \Sigma_{\text{crit}} \) because stars support the self-gravity of the gas (Jog & Solomon 1984; Orlova, Korchagin, & Theis 2002). The Parker instability aids the gravitational instability also by adding compressive forces along the upward-bent magnetic field lines (Chou et al. 2000; Kim, Ryu, & Jones 2001; Franco et al. 2002). Spiral arm compression increases \( \Sigma \) more than \( \Sigma_{\text{crit}} \) (which varies as
\( \kappa \propto \Sigma^{1/2} \) (Balbus 1988). A cool sub-population of clouds can also favor instabilities, which can act primarily in that phase (Ortega, Volkov, & Monte-Lima 2001).

2.1. **Gravitational Instabilities in a Multi-Phase Medium**

The gravitational instability changes significantly in a multi-phase medium. The gas can generate structure by instabilities in the cool phase even when the bulk ISM is stable for total rms speed \( c \) (Wada & Norman 2001). In a diffuse cloud population with a thermal dispersion of \( \sim 1 \text{ km s}^{-1} \), the value of \( \Sigma / \Sigma_{\text{crit}} \) is larger than for the bulk medium by a factor of 10 and the unstable mass is smaller by a factor of \( 10^4 \). In a turbulent medium where the dispersion varies as the square root of length, the Jeans length can be any length, provided the largest turbulent scale is unstable. As a result, an ISM with a cool phase of gas available in equilibrium should be unstable as long as \( \Sigma > c_{\text{low}} \kappa / \pi G \) for \( c_{\text{low}} \) equal to the rms dispersion in the cool phase. This criterion is usually satisfied easily. *Absolute stability therefore requires an ISM that has no cool phase* (Elmegreen & Parravano 1994).

The possibility of continued small scale instabilities in a globally stable ISM raises the question of why \( \Sigma \sim \Sigma_{\text{crit}} \) generally in main galaxy disks. The usual explanation is that star formation regulates the bulk velocity dispersion, \( c \), and therefore regulates \( \Sigma_{\text{crit}} \) so that the ISM is in a state of marginal stability. When \( c \) gets too low, the instability condition is satisfied, star formation gets more active, and \( c \) increases (Goldreich & Lynden Bell 1965). But if cloud-forming instabilities still operate in the cool phase when the bulk ISM is stable (\( \Sigma < \Sigma_{\text{crit}} \)), then such a star formation thermostat cannot be very effective. More likely, turbulence generated by gravitational instabilities keeps \( \Sigma \sim \Sigma_{\text{crit}} \), independent of star formation (Fuchs & von Linden 1998; Bertin & Lodato 2001; Combes 2001). In this case, there would be *no self-regulation of star formation* (i.e., by other star formation), but only a regulation of turbulence using rotation and the binding energy of the ISM.

2.2. **An Absolute Minimum Column Density for Star Formation**

There is growing evidence for an absolute stability condition that corresponds to a minimum column density of around \( \Sigma_{\text{min}} \sim 7 \text{ M}_\odot \text{ pc}^{-2} \) to get a minimum pressure that makes a cool phase (Elmegreen 2002). Such a minimum was first observed in irregular galaxies (Skillman 1987) and is still evident as a threshold for star formation there (Taylor et
al. 1994; Meurer et al. 1996; van Zee et al. 1997; Hunter et al. 1998; Hunter, Elmegreen, \& van Woerden 2001; Young \& Lo 1996, 1997ab).

The outer parts of spiral galaxies tend to become pure warm where star formation stops (Braun 1997). The faint continuation of star formation in some galaxies beyond the $\Sigma/\Sigma_{\text{crit}} < 1$ threshold (Ferguson et al. 1998; LeLievre \& Roy 2000) may be the result of spiral arm compression, which can trigger either gravitational instabilities (Kim \& Ostriker 2002) or an ISM phase change to a cool state (Shu et al. 1972).

Several examples give some indication of the relative importance of $\Sigma_{\text{crit}}$ and $\Sigma_{\text{min}}$. O’Neil, Bothun, \& Schombert (2000) and O’Neil, Verheijen, \& McGaugh (2000) studied low surface-brightness galaxies with $\Sigma > \Sigma_{\text{crit}}$ but not much star formation, thereby violating the usual instability condition. SBS 0335-052 (Pustilnik et al. 2001) is another example: the surface density is below the minimum threshold $\Sigma_{\text{min}}$ and there is not much star formation, but the rotation speed and $\kappa$ are so low that $\Sigma >> \Sigma_{\text{crit}}$. So here again, the usual condition does not work. The inner parts of M33 and NGC 2403 have $\Sigma < \Sigma_{\text{crit}}$ and normal star formation (Martin \& Kennicutt 2001), violating the usual condition again, but these regions still exceed the absolute minimum. Similarly, the nuclear region of the S0/E7 galaxy NGC 4550 has $\Sigma < \Sigma_{\text{crit}}$ with star formation still present (Wiklind \& Henkel 2001).

The $\Sigma > \Sigma_{\text{crit}}$ criterion for star formation works most of the time in many types of galaxies, but the $\Sigma > \Sigma_{\text{min}}$ condition also works and usually both conditions are satisfied. The few odd regions where only one or the other threshold shows up suggest that $\sim 7 M_\odot$ is an absolute minimum for star formation (depending on the radiation field) regardless of $\Sigma/\Sigma_{\text{crit}}$. This result is consistent with the conclusion of the previous section, that $\Sigma_{\text{crit}}$ is not directly related to star formation but more to the regulation of turbulence and cloud formation.

A different value for $\Sigma_{\text{crit}}$ based on the rate of shear rather than the epicyclic rate was recently discussed by Pandey \& van de Bruck (1999). The point of this threshold is to suggest that instabilities always operate regardless of the Toomre condition (angular momentum is removed by magnetic tension and viscosity) and so the formation of clouds depends on the product of the local dynamical rate and the shear time (Elmegreen 1993). This product is approximately $\Sigma/\Sigma_{\text{crit},A}$ where $\Sigma_{\text{crit},A} \sim cA/\pi G$ for Oort parameter $A = -0.5Rd\Omega/dR$ in a galaxy with angular rotation rate $\Omega$. 
2.3. Gravitational Instabilities and Accretion

The gravity from spiral arms generates a torque on the gas and stars that leads to an angular momentum flux and mass motions (Larson 1984; Lin & Pringle 1987). The angular momentum flux is approximately $F = \frac{\pi^3 G^2 r^2 \Sigma^3}{\Omega^2}$. Setting this equal to $3\pi \Sigma r^2 \Omega \nu$ gives an effective viscous coefficient $\nu$ (Takeda & Ida 2001). The accretion time over a distance $D$ then becomes $D^2/\nu$, which is

$$t_{\text{accretion}} \sim \frac{3D^2 \Omega^3}{\pi^2 G^2 \Sigma^2} \sim \frac{1.5D^2 Q^2 \Omega}{c^2},$$

(1)

where the latter expression is for a flat rotation curve. In this case, and with $Q \sim 1$ for most galaxy disks, the accretion speed is

$$v_{\text{accretion}} \sim 0.6c\left(\frac{c}{D \Omega}\right),$$

(2)

that is, the rms turbulent speed times the ratio of this turbulent speed to the shear speed over the distance $D$.

The accretion time may be evaluated for a few interesting cases. It equals about 500 My over the disk Jeans length (several kpc) for stars in the main disks of spiral galaxies. The resulting accretion liberates gravitational energy from the rotation of the galaxy and heats the stars. As a result, spiral instabilities soon stop unless cool stars are added (Sellwood & Carlberg 1984). The accretion time is about 1 Gy over one kpc for the gaseous parts of galaxy disks, considering a column density corresponding to $A_V = 0.5$ mag. This is significantly shorter than the Hubble time, suggesting that accretion can change the surface density profiles of disks (Lin & Pringle 1987; Yoshii & Sommer-Larsen 1989; Saio & Yoshii 1990; Gnedin, Goodman, & Frei 1995; Ferguson & Clarke 2001) and amplify a metallicity gradient. The accretion time is $\sim 1$ Gy over 100 pc in nuclear regions with faint dust disks ($A_V \sim 1$ mag; corresponding to $Q >> 1$), but can be very short, $\sim 30$ My over 100 pc in nuclear starburst regions where $Q \sim 1$ (because of the very high $\Sigma$).

2.4. Gravitational Instabilities and Turbulence

The energy liberated by ISM collapse into spiral arms drives turbulence on kpc scales. The energy liberated by cloud collapse drives turbulence on smaller scales. Thus the entire cascade of turbulent structures can be driven by self-gravity. Stellar pressures contribute to turbulence more locally. This means that $\Sigma \sim \Sigma_{\text{crit}}$ could be controlled by spiral instabilities, not star formation feed-back, as discussed above. Numerical simulations and other theoretical work on this source of turbulence may
be found in Fuchs & von Linden (1998), Semelin & Combes (2000), Bertin & Lodato (2001), Wada & Norman (2001), Huber & Pfenniger (2001, 2002), Vollmer & Beckert (2002), and Chavanis (2002).

Crosthwaite, Turner, & Ho (2000) pointed out that some of the holes in the interstellar medium of IC 342 can be generated by gravitational instabilities. Stellar pressures are not always necessary to make holes. Wada, Spaans, & Kim (2000) also got ISM holes in a simulation with turbulence and self-gravity.

Gravitational instabilities are energetically important as a source of turbulence for the ISM. The power density is approximately the ISM energy density multiplied by the gravitational instability growth rate, $\pi G \Sigma / c$. This amounts to $2 \times 10^{-27}$ erg cm$^{-3}$ s$^{-1}$. The amount is large because the growth time is short, $c/\pi G \Sigma \sim 30$ My. This is also about the energy dissipation time. Vollmer & Beckert (2002) show that the energy flux to small scales from turbulence equals the energy dissipation by self-gravitational instabilities in the disk.

The energy from spiral chaos, as Toomre & Kalnajs (1991) called this process, is comparable to that from supernovae at a rate of one per 100 years in a whole galaxy, assuming a 1% efficiency for converting the explosion energy into ISM motions.

3. The Parker and Balbus-Hawley Instabilities

Magnetic buoyancy and cosmic ray pressure push magnetic field lines out of the galactic plane, and then the gas trickles down into the valleys, forming clouds with low density contrast (Parker 1966). This is an instability because the more the field lines buckle, the greater the streaming speed and collection of gas into the valleys. The unstable growth time is about the propagation time of an Alfvén wave over one scale height.

This is not a particularly good cloud formation mechanism by itself because the flows remain in pressure equilibrium and the maximum density contrast is essentially equal to the ratio of the total pressure to the pure gas pressure, which is only a factor of 3. However, in combination with self-gravity, this mechanism can help to form giant cloud complexes along spiral arms. In this sense, both the gravitational instability and the Parker instability work together. They have comparable time scales and length scales along the mean field direction. Recent simulations of the Parker instability are in Chou et al. (2000), Kim, Ryu, & Jones (2001) and Franco et al. (2002).

The Balbus & Hawley (1991) instability works for either azimuthal or vertical magnetic fields, with the former applicable to galactic disks.
The field couples regions at different radii and transfers angular momentum directly from the inner disk to the outer disk, which is moving at a different angular speed. The outer disk gains angular momentum and goes out even further. This is not a cloud-forming instability but it can generate turbulence at the Alfvén speed. The growth time is about an orbit time, and the energy input rate is \( \sim 0.6\left(\frac{B^2}{8\pi}\right)\Omega \) for galactic rotation rate \( \Omega \) and magnetic field strength \( B \) (Sellwood & Balbus 1999). Sellwood & Balbus suggest that this instability could drive turbulence in the outer parts of galactic disks where the supernova rate is very low and there are no other energy sources. If the outer disks are a nearly pure-warm phase of HI, however (Sect. 2.2), then the modest velocity dispersions observed there can be thermal, in which case no source of turbulence is needed.

4. Clouds from Shells or Turbulence?

HI maps of H\(\alpha \) II (Puche et al. 1992), IC 2574 (Walter & Brinks 1999; Steward & Walter 2000), the LMC (Kim, et al. 1999; Yamaguchi et al. 2001a), and other small galaxies show shell-like structures covering a large fraction of the interstellar volume. Shear is low in all of these cases, as is the ambient pressure, so common supernova explosions and HII region expansions can make these shells and inflate them to large sizes without severe distortion. The expansions may even continue for so long that the stars which initially made them disperse.

The power spectrum of the HI emission from the LMC is a power law with a slope characteristic of turbulence (Elmegreen, Kim, & Staveley-Smith 2001). This seems odd if the HI structure is entirely the result of expanding shells caused by star formation. An alternative model is that the structure comes from turbulence that is indirectly generated by young stars (Wada, Spaans, & Kim 2000). Such turbulence can still make hot shells, but there will not be a one-to-one correspondence between these shells and the OB associations.

Galaxies with higher shear tend to show spiral arms instead of shells. These arms may begin as shells and then get swept back into spiral shapes, or they may have other origins. The faint dust spirals in the nuclei of two early type galaxies, NGC 4736 and NGC 4450, have the same power-law power spectra as the HI emission from the LMC (Elmegreen, Elmegreen & Eberwein 2002). The spirals are probably turbulent in origin, but they do not appear to be connected with star formation, which has a relatively small rate in these high-Q regions.

These observations suggest there are two types of global ISM structures: shells that are made directly or indirectly by the energy of star
formation, and shells or spirals that are made by turbulence originating with instabilities. The first type tends to show up in regions of low shear. This special position could mean that shear alone determines the morphology of clouds. It could also mean that the instabilities depend on shear and vanish when the shear rate is low, leaving only star-formation shells.

5. Correlated Structures in Young Star Fields

Interstellar turbulence from gravitational and other instabilities plus star formation and other pressure sources makes autocorrelated, multifractal structure in the gas. This structure may be interpreted as clouds in an intercloud medium, but the cloudy description is often too simple and can lead to selection effects (Scalo 1990). The same autocorrelated structures appear in young star fields because star formation follows the gas (Heydari-Malayeri et al. 2001; Pietrzynski et al. 2001; Elmegreen & Elmegreen 2001; Zang, Fall, & Whitworth 2001). The resulting stellar patterns can lead to selection effects. Most likely, flocculent spiral arms, star complexes, OB associations, and OB subgroups are equivalent parts of a continuum of structures that extend from the galactic scale height down to the sub-parsec region where dense embedded clusters form (Elmegreen et al. 2000; Elmegreen, Elmegreen & Leitner 2003).

Because of the turbulent origin for much of the ISM structure, the dynamical time for motions varies approximately as the square root of the region size. A similar scaling occurs for star formation: the duration of star formation in a region increases approximately as the square root of the size (Efremov & Elmegreen 1998), always being a few dynamical times (Ballesteros-Parades et al. 1999; Elmegreen 2000).

Stars and clusters form in the densest part of the ISM fractal (Heyer, Snell, & Carpenter 1997) where the gas is molecular because of dust and self-shielding, cold because it is molecular and cools well, and strongly self-gravitating because it is dense and cold. The mass functions for both clusters and clouds are power laws because the motions that make them are turbulent and turbulence makes self-similar structures, which have power-law size distributions (Elmegreen 2002).

6. Triggered Star Formation

Most local clusters look triggered by adjacent HII regions. Yamaguchi et al. (1999, 2001b) estimate that 10%-50% of inner Milky Way star formation, and the same fraction of LMC star formation, is triggered
by expanding HII regions. What is the connection, then, between star formation and turbulence?

Instabilities drive turbulence globally and stellar pressures drive turbulence locally. The instabilities and turbulence together make clouds with a wide range of scales. No Jeans mass is evident except for the “beads” of star formation in stellar spiral arms. Stellar pressures make shells and shape the existing clouds into comets, triggering star formation. The time scale for instabilities is about equal to the crossing time from turbulence, and this is about equal to the time scale for triggering. Thus one group of processes (instabilities and shell formation) makes clouds, while another group of processes (pressurized triggering) often makes stars in these clouds. The time scale is about the same for each, always comparable to the dynamical time.

7. The Star Formation Rate from First Principles

Stars form only at high density yet the star formation rate scales with the average density, \( \rho \),

\[
\text{SFR}(\text{mass/vol/time}) \sim \epsilon \rho (G \rho)^{1/2}
\]

for efficiency \( \epsilon \). In high density cores, the star formation rate should be

\[
\text{SFR}(\text{mass/vol/time}) \sim \epsilon_c \rho_c (G \rho_c)^{1/2} \sim \epsilon_c \rho_c \omega_c
\]

for core efficiency \( \epsilon_c \), density \( \rho_c \), and rate \( \omega_c \).

For a threshold core density \( \rho_c \sim 10^5 \text{ cm}^{-3} \) and typical \( \epsilon_c \sim 0.1-0.5 \), the core star formation rate is constant. At \( \rho_c \sim 10^5 \text{ cm}^{-3} \), big grains stop gyrating (Kamaya & Nishi 2000), molecules freeze onto grains (Bergin et al. 2001), the ionization fraction begins to drop (Caselli et al. 2002), and turbulence becomes subsonic (Goodman et al. 1998).

With these relations, the Schmidt-law implies that \( \rho_c / \rho \) is constant and that \( \epsilon \) is proportional to the fraction of the gas at \( \rho > \rho_c \). If the Schmidt law is not correct, but instead stars form at constant efficiency (Rownd & Young 1999; Boselli et al. 2002), then \( \rho_c \) is constant and \( \epsilon \) is still proportional to the fraction of the gas at greater density.

Wada & Norman (2001) found a log-normal probability distribution function (pdf) for density in their whole galaxy models. The dense gas fraction is the integral over this distribution function above the density threshold. Elmegreen (2002) normalized this pdf to the local density, and then normalized the Kennicutt (1998) Schmidt law to the local density. After these normalizations, the fraction of all the interstellar gas that is forming stars at the local dynamical rate, \( (G \rho_c)^{1/2} \), turns
out to equal the fraction of the ISM pdf with a density larger than \(10^5 \rho_{\text{ave}}\). This mass fraction is \(10^{-4}\) of the ISM. If we multiply this by the core-to-average rate ratio, \((\rho_c/\rho)^{1/2} \sim 300\), then we get the average efficiency of star formation over the average dynamical time in the ISM; this average efficiency is a reasonable \(\sim 3\%\).

The point of this exercise is to show that the Kennicutt-Schmidt law on a galactic scale can arise from numerous events of local star formation, each on the scale of an individual cloud core, if the high formation rate in each core is averaged out over all the ISM gas, considering only the gas that is participating in the star formation process. The core density that is necessary to do this is a reasonable \(10^5 \text{cm}^{-3}\), which is where we think star formation begins anyway, and the fraction of the ISM that has this density or greater is about \(10^{-4}\) if the Wada & Norman pdf shape is correct. In each core, the efficiency of star formation is high, but averaged over all the ISM, it is low, several percent.

8. Conclusions

Instabilities involving gravity, magnetism, and pressure lead to spirals, accretion, clouds, and turbulence. Stellar pressures produce bubbles, more turbulence, and triggered star formation in clouds that already formed. Self-gravity and turbulence combine to structure the ISM, giving self-correlated properties for the gas and young stars with respect to size, velocity dispersion, and crossing time or duration of star formation. Turbulence also gives power law mass functions for clouds and clusters.

The turbulence generated by gravitational instabilities can maintain the ISM in a state of quasi-equilibrium where \(\Sigma \sim \Sigma_{\text{crit}}\). If small scale instabilities continue in the cool component of the gas even when the average rms speed is large enough to give global stability, then star formation cannot regulate the \(\Sigma/\Sigma_{\text{crit}} > 1\) threshold. In this case, there is no self-regulation of star formation involving \(\Sigma_{\text{crit}}\) on a galactic scale. This will be true even if young stellar pressures agitate the ISM locally. They can blow the gas out into the halo and stop star formation locally, but young stars probably cannot fine-tune or moderate their own formation rate so that it stays near the historical or Hubble-type average. Young stars commonly trigger other stars anyway, so the feedback they produce should de-stabilize, not stabilize, the star formation rate, unless the entire local ISM is removed.

The star formation rate depends on the mass fraction in dense gas. Turbulence may determine this mass fraction, independent of the
sources for the turbulence. The global SFR is then independent of the detailed triggering mechanisms. Then again there would be no self-regulation of star formation, only a star formation saturated to its maximum possible value, as determined by the open and tenuous geometry of the gas. In this case, star formation can be halted only by a dominance of the warm phase of the ISM.

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