Radiation Pressure Supported Starburst Galaxies & The Fueling of Active Galactic Nuclei

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**Abstract.** Radiation pressure from the absorption and scattering of starlight by dust grains may be a crucial feedback mechanism in starburst galaxies and the self-gravitating parsec-scale disks that accompany the fueling of active galactic nuclei. I review the case for radiation pressure in both optically-thin and highly optically-thick contexts. I describe the conditions for which Eddington-limited star formation yields a characteristic flux of $\sim 10^{13} L_\odot$ kpc$^{-2}$, and I discuss the physical circumstances for which the flux from radiation pressure supported disks is below or above this value. In particular, I describe the young stellar disk on $\sim 0.1$ pc scales at the Galactic Center. I argue that its bolometric flux at formation, $\sim 10^{15} L_\odot$ kpc$^{-2}$, and the observed stellar mass and scale height imply that the disk may have been radiation pressure supported during formation.

1. Introduction

Star formation in galaxies is observed to be globally inefficient, with only a few percent of the available gas supply converted to stars per dynamical timescale (e.g., Kennicutt 1998). On smaller scales within individual galaxies star formation is similarly slow (e.g., Kennicutt et al. 2007; Bigiel et al. 2008; Leroy et al. 2008; Krumholz & Tan 2007). This, together with the fact that galaxies are marginally-stable, with Toomre’s $Q \sim 1$ (e.g., Martin & Kennicutt 2001), suggests that they are self-regulated — otherwise, disks should quickly evolve to have $Q < 1$, and fragment on a single dynamical time.

The injection of energy and momentum into the interstellar medium (ISM) by stellar processes (“feedback”), may be responsible for the inefficiency of star formation in galaxies and for their self-regulation. The feedback mechanism thought to stave off self-gravity is uncertain, but may be due to supernovae, stellar winds, expanding HII regions, cosmic rays, and radiation pressure of starlight on dust (e.g., McKee & Ostriker 1977; Chevalier & Fransson 1984; Silk 1997; Wada & Norman 2001; Scoville et al. 2001; Matzner 2002; Thompson, Quataert, & Murray 2005 [TQM]; Li & Nakamura 2006; Socrates et al. 2007). Non-stellar processes can also act as a feedback mechanism by tapping the galaxy’s gravitational binding energy (Sellwood & Balbus 1999).

Both observations and theory suggest that whatever the mechanism, feedback must be yet more effective on parsec scales around active galactic nuclei (AGN), at surface densities in excess of those probed by the densest galaxies that comprise the Schmidt Law. On scales larger than $\sim 0.01$ pc accretion disks...
feeding bright AGN are gravitationally unstable and prone to fragmentation and star formation (Kolykhalov & Sunyaev 1980; Shlosman et al. 1989, 1990; Kumar 1999; Wada & Norman 2002; Goodman 2003). This problem is severe: gas accumulating on ∼ 0.01 – few pc scales to fuel a supermassive black hole may never get there, but instead fragment entirely into stars. Both rapid inflow due to efficient angular momentum transport (e.g., bars) and/or a reduced star formation efficiency have been proposed to help solve this “AGN fueling problem” (Shlosman et al. 1990; Levin 2007; TQM).

A number of observational results also suggest an intimate connection between AGN fueling and nuclear star formation. For example, Storchi-Bergmann et al. (2005) and Davies et al. (2006), (2007) find direct evidence for star formation in the central tens of parsecs of local AGN. Likewise, the young stellar disk on ∼ 0.1 pc scales in the Galactic Center (e.g., Paumard et al. 2006; Lu et al. 2008) may be a vestige of accretion, providing further evidence for a close link between BH fueling and star formation (Levin & Beloborodov 2003; Milosavljevic & Loeb 2004; TQM; Nayakshin et al. 2007). There is further evidence that the fueling of bright high-z quasars is accompanied by intense star formation (e.g., Lutz et al. 2007, 2008; Younger et al. 2008).

In this contribution, I review the arguments for the importance of radiation pressure of starlight on dust grains as an important feedback mechanism in intense starburst galaxies and in the self-gravitating disks that likely attend AGN fueling. In § 2, I discuss some of the physics of this particular feedback mechanism. In § 3, I discuss some examples of starburst systems for which the Eddington limit may be relevant, including local ULIRGs and the young stars at the Galactic Center. Section 4 provides a brief conclusion. Throughout, I borrow from the more extensive discussion presented in TQM. The interested reader is referred there for more details.

2. Radiation Pressure Feedback

The light from massive stars is efficiently absorbed and scattered by dust grains, providing a net force in the direction normal to a star-forming disk. TQM showed that this might be the dominant feedback mechanism in dense optically-thick starbursts and AGN disks (see also Scoville et al. 2001; Scoville 2003; Levin 2007). A basic requirement for radiation pressure to be important in governing the dynamics is that the radiative flux approach the Eddington flux

$$ F_{\text{Edd}} \approx \frac{4\pi G \Sigma_{\text{tot}} c}{\langle \kappa F \rangle} \approx 6 \times 10^{13} \frac{\text{L}_\odot \text{kpc}^{-2}}{\text{g}^2 \text{cm}^{-4}} \langle \Sigma_{\text{tot}} \rangle, $$

(1)

where $\Sigma_{\text{tot}}$ is the total disk surface density and $\langle \kappa F \rangle$ is the column-averaged flux-mean dust opacity (e.g., Elitzur & Ivezić 2001). Note that we expect the gas and dust to behave as a single collisionally-coupled fluid on the scales and at the densities of interest (e.g., Laor & Draine 1993; Murray et al. 2005 [MQT]). Because the radiative flux from galaxies is proportional to the star formation rate per unit area ($F_* = \epsilon \Sigma_* c^2$), equation (1) is an interesting and testable form

$^1\epsilon \approx 10^{-3}$ is an IMF-dependent constant; see Kennicutt (1998).
for the Schmidt Law:

$$\Sigma_{\star,\text{Edd}} \approx \frac{4\pi G}{\epsilon c} \left( \frac{\Sigma_{\text{tot}}}{\langle \kappa_F \rangle} \right) \approx 4000 \frac{M_\odot \text{ yr}^{-1}}{g^2 \text{ cm}^{-4}} \left( \frac{\Sigma_{\text{tot}}}{\langle \kappa_F \rangle} \right).$$

Although $\Sigma_{\text{tot}}$ is relatively easy to measure or estimate in normal star-forming galaxies and starbursts, the coupling between the radiation field and the dust, as expressed in equation (1) with $\langle \kappa_F \rangle$ is more difficult, since the medium is highly turbulent, inhomogeneous, and clumpy. Three simple limits help to illustrate the range of the effective flux-mean opacity in galactic contexts.

### 2.1. Optically-Thin to UV: $\Sigma_g \lesssim 5 M_\odot \text{ pc}^{-2} \approx 10^{-3} g \text{ cm}^{-2}$

When the average medium is optically-thin to the UV radiation from massive stars one finds that for young stellar populations ($\lesssim 5 \text{ Myr}$), standard grain size distributions, and Galactic dust-to-gas ratio that $\langle \kappa_F \rangle \approx 10^3 \text{ cm}^2 g^{-1}$. This limit is only applicable for galaxies with gas surface densities of $\Sigma_g \lesssim 5 M_\odot \text{ pc}^{-2}$, again assuming Galactic dust-to-gas ratio. For typical numbers,

$$F_{\star,\text{Edd}} \approx 6 \times 10^7 \text{ L}_\odot \text{ kpc}^{-2} \left( \frac{\Sigma_{\text{tot}}}{5 M_\odot \text{ pc}^{-2}} \right) \left( \frac{10^3 \text{ cm}^2 g^{-1}}{\langle \kappa_F \rangle} \right).$$

### 2.2. Optically-Thick to UV, but Optically-Thin to Re-Radiated FIR: $5 M_\odot \text{ pc}^{-2} \lesssim \Sigma_g \lesssim 5000 M_\odot \text{ pc}^{-2}$

In normal star-forming galaxies and some starbursts, the average gas surface density $\Sigma_g$ is high enough that the medium is optically-thick to the UV emission from massive stars, but not sufficiently large that the re-radiated FIR emission from dust grains is optically-thick.

In this “single-scattering” limit (see MQT, TQM), UV photons are absorbed once, and then escape the system. For a homogeneous slab of gas and dust and with an incident UV radiation field, it is easy to show that $\langle \kappa_F \rangle \sim 2/\Sigma_g$ (e.g., MQT). Although the applicability of the homogeneous slab is highly uncertain in turbulent star-forming environments, the single-scattering approximation is useful at the order-of-magnitude level for gauging the dynamical importance of the radiation field. In this case,

$$F_{\star,\text{Edd}} \approx 2\pi G \Sigma_{\text{tot}} \Sigma_g c \sim 10^9 \text{ L}_\odot \text{ kpc}^{-2} \left( \frac{\Sigma_{\text{tot}}}{100 M_\odot \text{ pc}^{-2}} \right) \left( \frac{\Sigma_g}{10 M_\odot \text{ pc}^{-2}} \right).$$

### 2.3. The Optically-Thick Limit: $\Sigma_g \gtrsim 5000 M_\odot \text{ pc}^{-2}$

When the galaxy is optically-thick to the re-radiated FIR emission from dust grains, $\langle \kappa_F \rangle$ can be approximated by the Rosseland-mean opacity, $\kappa_R(T)$, where $T$ is the midplane temperature of the star-forming disk. Although the temperature dependence of the opacity is fairly complicated, to rough approximation when $T \lesssim 200 \text{ K}$, $\kappa_R \approx 2 \times 10^{-4} T^2 \equiv \kappa_0 T^2$, and for $200 \text{ K} \lesssim T \lesssim T_{\text{sub}}$, $\kappa_R(T) \approx \text{constant} \approx 5 \times 10^{-2} \text{ cm}^2 \text{ g}^{-1}$ (e.g., Bell & Lin 1994; Semenov et al. 2003). For temperatures above the sublimation temperature of dust $T_{\text{sub}} \approx 1500 \text{ K}$, the Rosseland mean opacity decreases markedly.
The Eddington Limit when $T \lesssim 200$ K: In this limit, the midplane temperature is connected to the effective temperature and the radiated flux by $T^4 \sim \tau T_{\text{eff}}^4 \sim (\kappa_0 T^2 \Sigma_g/2) (F/\sigma_{\text{SB}})$. Additionally, if the radiation pressure balances gravity, $p_r = aT^4/3 \sim \pi G \Sigma_g \Sigma_{\text{tot}}$. These two equations imply that

$$F_{\ast,\text{Edd}} \sim (3\pi c G \sigma_{\text{SB}}/\kappa_0^2)^{1/2} (\Sigma_{\text{tot}}/\Sigma_g)^{1/2} \sim 10^{13} \text{L}_\odot \text{kpc}^{-2} (\Sigma_{\text{tot}}/\Sigma_g)^{1/2},$$

where $\kappa_0 = 2 \times 10^{-4} \text{cm}^2 \text{g}^{-1} \text{K}^{-2}$ has been assumed. For typical values of $\epsilon$ (eq. 2), equation (5) predicts a star formation rate surface density of approximately $\dot{\Sigma}_* \sim 10^3 \text{M}_\odot \text{yr}^{-1} \text{kpc}^{-2}$ required to support the disk with radiation pressure on dust. Note that because we expect starbursts that meet the criteria used to derive equation (5) to be largely gas-dominated, $\Sigma_{\text{tot}} \sim \Sigma_g$ is a reasonable first approximation. Hence, starburst galaxies with $\Sigma_g \gtrsim 5000 \text{M}_\odot \text{pc}^{-2}$ should attain a characteristic flux of $\sim 10^{13} \text{L}_\odot \text{kpc}^{-2}$.

The primary assumptions made in deriving equation (5) are that the medium is optically-thick and that the midplane temperature is less than $\sim 200$ K. For example, a massive starburst with a gas reservoir of $\sim 10^{10} \text{M}_\odot$ distributed on scales $\lesssim 1 \text{kpc}$ should satisfy both criteria over approximately 1 decade in radius, down to scales of $\lesssim 100 \text{pc}$, depending on the radial distribution of the stellar and gas mass. If the surface density increases at smaller radii, the midplane temperature will as well and the assumption that $T \lesssim 200$ K will be violated. Similarly, on somewhat larger scales, the medium is optically-thin to the re-radiated FIR emission and equation (4) becomes applicable.

The Eddington Limit when $T \gtrsim 200$ K: If the equilibrium radiative flux required for hydrostatic equilibrium implies $200 \text{K} \lesssim T \lesssim T_{\text{sub}}$, then $F_{\text{Edd}}$ exceeds the value given in equation (5). In this case, we can approximate $\kappa_R(T \gtrsim 200 \text{ K}) \sim 5 - 10 \text{cm}^2 \text{g}^{-1}$ and

$$F_{\ast,\text{Edd}} \sim 10^{15} \text{L}_\odot \text{kpc}^{-2} \left(\frac{10 \text{cm}^2 \text{g}^{-1}}{\kappa_R}\right) \left(\frac{\Sigma_{\text{tot}}}{10^6 \text{M}_\odot \text{pc}^{-2}}\right),$$

where I have scaled the total surface density for parameters characteristic of $\sim 0.1 - 1.0 \text{pc}$ self-gravitating disks around AGN (see §3.2).

2.4. Stability

Equation (4) implies that if an optically-thick starburst with $T \lesssim 200$ K reaches a characteristic flux of $\sim 10^{13} \text{L}_\odot \text{kpc}^{-2}$, then it can be maintained in hydrostatic equilibrium in the sense that radiation pressure balances the self-gravity of the disk. However, because the diffusion timescale for radiation is very short compared to the dynamical timescale, the disk is unstable. In other words, radiation pressure cannot stave off the local Jeans instability on the scale of the disk gas scale-height because diffusion is rapid (see Thompson 2008). This effect should keep the disk highly turbulent, with the magnitude of the resulting turbulent energy density ($\rho \delta v^2$) set by the magnitude of the radiation energy density. In this way, hydrostatic equilibrium would be maintained statistically. As discussed in Thompson (2008), turbulence may also generate the $\sim$ few mG magnetic field strengths needed in the densest starbursts to explain the fact that these systems lie on the FIR-radio correlation (Thompson et al. 2006).
3. Some Examples

3.1. Local & High-\(z\) Starbursts

The flux predicted by equations (5) and (6) can be compared with observations of local and high-\(z\) ultra-luminous infrared galaxies. Figure 1 (left) shows a comparison between the observed fluxes of local ULIRGs and a set of models with increasing constant gas fraction from TQM. The right panel displays the same data as a histogram, and indicates that ULIRGs may in fact exhibit a characteristic flux of \(\sim 10^{13} L_\odot \text{kpc}^{-2}\). It is also interesting in this context to note that Förster-Schreiber et al. (2003) find that the \(\sim 10\) Myr starburst required to explain the observed stellar population in the central starburst of M82 also attained a star formation rate surface density of \(\Sigma_* \sim 10^3 M_\odot \text{yr}^{-1} \text{kpc}^{-2}\) (see their Fig. 13).

Finally, observations of submillimeter galaxies at high-\(z\) are also in fair agreement with the predictions of TQM; Younger et al. (2008), Walter et al. (2009), and Riechers et al. (2009) argue that the luminosities of the systems they observe indicate that radiation pressure on dust may be dynamically important.

3.2. The Galactic Center & The Fueling of AGN

A number of works have shown that there is disk of young stars around Sag A* at the Galactic Center with total stellar mass \(M_* \sim 2 \times 10^4 M_\odot\), radius \(r \sim 0.1\) pc, scale height of \(h \sim 0.1r\), and an average age of \(\sim 6\) Myr (Levin & Beloborodov 2003; Genzel et al. 2003; Paumard et al. 2006; Lu et al. 2009). Although the
physical origin of these stars is still unclear, it is possible that the stars formed \textit{in situ} in a gaseous disk (Levin & Beloborodov 2003). This star formation episode may have been accompanied by accretion onto the central black hole, perhaps producing an AGN epoch in the Galaxy (e.g., TQM; Nayakshin & Cuadra 2005; Levin 2007). Importantly, its structure may have been determined by the radiation pressure of starlight on dust grains.

A simple estimate for the minimum star formation rate needed to produce the stars that we see now is \( \dot{M}_\ast^{\text{min}} \sim \frac{\text{Mass}}{\text{Age}} \sim 3 \times 10^{-3} \, M_\odot \, \text{yr}^{-1} \), corresponding to a star formation rate surface density of \( \Sigma_\ast^{\text{min}} \sim \frac{\dot{M}_\ast^{\text{min}}}{\pi r^2} \sim 10^5 \, M_\odot \, \text{yr}^{-1} \, \text{kpc}^{-2} \), roughly 100 times the surface density of star formation for the central 100 pc of Arp 220’s western nucleus. Note that the ratio \( L_\ast / M_\ast \) for a few-Myr old stellar population is \( \xi_{1500} \sim 1500 \, L_\odot / M_\odot \), which allows for an order-of-magnitude estimate for the luminosity and flux of the stars at formation: \( L_\ast \sim 3 \times 10^7 \xi_{1500} \, L_\odot \) and \( F_\ast \sim 10^{15} \xi_{1500} \, L_\odot \, \text{kpc}^{-2} \), respectively.

It is interesting to consider the physical conditions of the disk \textit{in formation} using the observed stellar mass density. We can write down an approximate lower limit to the total gas mass required to build the stars we see today by equating the gas mass and the stellar mass: \( M_g \sim M_\ast \). This implies a minimum volumetric and surface gas density of \( n \sim M_g / (2 \pi r^2 h) \sim 10^9 \, \text{cm}^{-3} \) and \( \Sigma_g \sim 2 \rho h \sim 120 \, \text{g cm}^{-2} \sim 6 \times 10^5 \, M_\odot \, \text{pc}^{-2} \), respectively, assuming that the stars formed with \( h \sim 0.1 r \). Note that this estimate for the gas density of the disk during formation implies an average dynamical timescale of order \( t_{\text{dyn}} \sim (G \rho)^{-1/2} \sim 3000 \, \text{yr} \), which implies that the \textit{maximum star formation rate} exceeds \( \dot{M}_\ast^{\text{min}} \) by a factor of \( \sim 2000: \dot{M}_\ast^{\text{max}} \sim 6 \, M_\odot \, \text{yr}^{-1} \).

Given these approximate parameters for the disk in formation, we can ask if it is physically possible for a given mechanism to support the gas in vertical hydrostatic equilibrium with scale height of order \( h \). The effective surface temperature of the disk is \( T_{\text{eff}} \sim (F/\sigma_{\text{SB}})^{1/4} \sim 260 \, \text{K} \) and the total average optical depth in the vertical direction is \( \tau \sim 600 \kappa_{10} \rho h_{0.1} r \), where \( \kappa_{10} = \kappa_R(T > 200 \, \text{K}) / 10 \, \text{cm}^2 \, \text{g}^{-1} \). Note that this implies a midplane temperature of \( \sim 1300 \, \text{K} \), close to — but somewhat below — the sublimation temperature of dust. Given \( T \) and \( n \), the ratio of the radiation pressure to the gas pressure is of order \( \rho R / p_g \sim 20 \).

Hydrostatic equilibrium in the vertical direction requires that the radiated flux equal the Eddington flux. Because the midplane temperature exceeds \( \sim 200 \, \text{K} \), the estimate of equation (6) is appropriate and the ratio of the Eddington flux to the flux from starlight during formation is

\[
\frac{F_{\text{Edd}}}{F_\ast} \sim \frac{2 \pi G c}{\kappa_R \xi} \sim 1 \, \kappa_{10}^{-1} \xi_{1500}^{-1},
\]

where \( F_\ast \sim 10^{15} \xi_{1500} \, L_\odot \, \text{kpc}^{-2} \). The fact that equation (7) yields a number close to unity demonstrates the importance of radiation pressure in this environment for maintaining the disk in vertical hydrostatic equilibrium. Although there is evidence for a top-heavy IMF (Nayakshin & Sunyaev 2005; Nayakshin et al. 2006), there is relatively little uncertainty in \( \xi \) in the above expression relative to the assumption that the disk of observed stars can be treated as a disk of gas with approximately the same geometry. It should be noted again that the uncertainty in \( \kappa_R \) is dominated by the assumption of Galactic dust-to-gas
Figure 2. Predicted star formation rate ($\dot{M}_\star$; solid lines) and gas accretion rate ($\dot{M}$; dashed lines) as a function of radius for conditions appropriate to the Galactic Center, using the model of Eddington-limited star formation in TQM and discussed in §2. The different line sets indicate different input gas accretion rate at a fiducial outer radius of 3 pc, varying from $\dot{M}_{\text{out}} = 0.015 \, M_\odot \, \text{yr}^{-1}$ to $0.015 \, M_\odot \, \text{yr}^{-1}$. Solutions with higher $\dot{M}_{\text{out}}$ produce a peak in $\dot{\Sigma}_\star$ of $\sim 10^5 - 10^6 \, M_\odot \, \text{yr}^{-1} \, \text{kpc}^{-2}$ on 0.1 pc scales.

Equation (7) also shows that radiation pressure supported disks may vastly exceed a bolometric flux of $\sim 10^{13} \, L_\odot \, \text{kpc}^{-2}$ if the midplane temperature of the disk is larger than 200 K (eq. 6). In the case of the Galactic Center, the flux needed for radiation pressure support is of order $F_\star \sim 10^{15} \, L_\odot \, \text{kpc}^{-2}$, and this is in good agreement with the inferred flux from the stars at the Galactic Center. This is strong evidence that radiation pressure may be paramount in the self-gravitating disks that accompany AGN fueling. Indeed, in a detailed study of star formation in local Seyfert nuclei, Davies et al. (2007) find evidence that star formation reaches the characteristic flux of equation (5) on $\sim 1 - 10$ pc scales. More evidence (besides the Galactic Center) that the flux from young stars can exceed $\sim 10^{13} \, L_\odot \, \text{kpc}^{-2}$ on very small scales would be useful in constraining detailed models of AGN fueling (e.g., Levin 2007; Nayakshin et al. 2007).

As an example of a suite of such models, Figure 2 shows the average star formation rate as a function of radius from TQM (solid lines) for parameters appropriate to the Galactic Center, with a central black hole mass of $\sim 4 \times 10^6 \, M_\odot$ and a bulge velocity dispersion of $\sim 75 \, \text{km} \, \text{s}^{-1}$. For a given input accretion rate...
at 3 pc ($M_{\text{out}}$), the disk forms stars at the rate required by the Eddington limit. The dashed lines show the gas accretion rate, which declines as a function of radius towards the black hole as a result of star formation. Models that fuel the black hole with $\sim 10^{-2} M_\odot \, \text{yr}^{-1}$ reach $\Sigma_\star \sim 10^5 - 10^6 M_\odot \, \text{yr}^{-1} \, \text{kpc}^{-2}$ on 0.1 pc scales, producing a sharp peak in the resulting stellar surface density after accretion abates (see Appendix A in TQM).

**Other Sources of Feedback:** In addition to radiation pressure, it is also worth considering other sources of pressure support thought to be important in star-forming environments on galactic scales: gas, cosmic rays, and magnetic fields (e.g., Boulares & Cox 1990). The gas temperature required to support the disk is $T_g \sim \pi G \Sigma_g^2 / nk_B \sim 2 \times 10^4$ K. However, if the medium is optically-thick, then $p_r / p_g \sim 10^4 T_4^{-1} n_9^{-1}$, where $T_4 = T / 10^4$ K. Additionally, cooling timescale arguments and the total energy required from the stellar or AGN radiation field show that $T_g$ is difficult to maintain (although, see the discussion of $p_g$ in Appendix A of TQM). The magnetic field strength required for hydrostatic equilibrium is given by $B^2 / 8\pi \sim \pi G \Sigma_g^2$, which implies $B \sim 0.3$ G for fiducial parameters. For cosmic rays, I assume that a fraction $f$ of the total bolometric output from the stars goes into primary cosmic ray protons: $E_{\text{CR}} \sim f L_\star$, as perhaps might be provided by stellar winds. The cooling timescale is dominated by inelastic proton-proton scattering, with a typical cooling timescale for few-GeV protons of $t_\pi \sim 0.05 n_9^{-1}$ yr. This gives a maximum upper limit to the equilibrium midplane CR pressure of $P_{\text{CR}} \sim f L_\star t_\pi / (3V) \sim 3 \times 10^{-6} f \, \text{ergs cm}^{-3}$, which is very small with respect to the total pressure required for hydrostatic equilibrium, $\sim 3 \times 10^{-3} \, \text{ergs cm}^{-3}$. I conclude that gas pressure and cosmic ray pressure are both likely sub-dominant with respect to radiation pressure in this context, and that magnetic fields of strength approaching $\sim G$ are required to contribute significantly to the pressure budget.

Supernovae are similarly unlikely to have supported the disk, given the youth of the observed stellar population.

4. **Summary & Conclusions**

Radiation pressure associated with the absorption and scattering of starlight by dust grains in rapidly star-forming environments is likely to be an important feedback process, and may be responsible for the regulation of star formation in some circumstances on galactic scales. Here, I have reiterated and clarified arguments in the starburst and AGN contexts developed in TQM. However, much more work needs to be done to assess this mechanism in full. In particular, it is crucial to understand the coupling between the radiation field produced by spatially clustered massive stars and the highly inhomogeneous and turbulent ISM of starbursts (e.g., Krumholz & Matzner 2009; Murray et al. 2009). This remains a primary avenue of future investigation.

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