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Global and Radial Variations in the Efficiency of Massive Star Formation Among Galaxies

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I. Introduction

It is now well established that interacting galaxies and merged systems have among the highest infrared luminosities observed (*cf.* Joseph and Wright 1985). It has also been shown (Young *et al.* 1986; Solomon and Sage 1988) that the global ratio of the far-infrared luminosity to the molecular gas mass is ~ 7 times higher in interacting galaxies than in isolated galaxies. If the FIR luminosity is produced by the heating of dust by young, massive stars, then these results imply that the perturbations due to galaxy-galaxy interactions result in more efficient production of massive stars in these systems than in their isolated counterparts. Because of the low spatial resolution of the IRAS detectors, the FIR luminosity derived from the 60 μm and 100 μm fluxes represents the *global* FIR emission only; it does not contain information on the *distribution* of star formation within a galaxy.

In order to determine the regions within galaxies which give rise to the most *efficient* star formation and to test the hypothesis that galaxies with high infrared luminosities per unit molecular mass are efficiently producing high mass stars, we have undertaken an Hα imaging survey in galaxies whose CO distributions have been measured as part of the FCRAO Extragalactic CO Survey. From these images we have derived global Hα fluxes and distributions for comparison with FIR fluxes and CO fluxes and distributions. Here we present our results on the global massive star formation efficiency (SFE $= L_{H\alpha}/M(H_2)$) as a function of morphological type and environment, and on the radial distribution of the SFE within both peculiar and isolated galaxies.

II. Observations and Analysis

Measurements of the Hα flux were made using the KPNO No.1-0.9m telescope, with either the RCA or TI CCD direct imaging system, on photometric nights. The Hα + [N II] emission line fluxes were obtained by observing each galaxy through two filters: a narrow ($\Delta\lambda$ 75 Å) interference filter centered on Hα at the velocity of the target galaxy, and either a broad R band filter (λ 6470, $\Delta\lambda$ 1110), or a narrow R filter (λ 7024, $\Delta\lambda$ 380). The continuum images were registered and scaled relative to the interference filter images using three to five unsaturated foreground stars. The continuum-subtracted images were flux-calibrated using observations from the same night of CCD photometric standard stars from the KPNO IRS Standard Star Manual.

Some of the Hα fluxes have been corrected for extinction within the target galaxy, using near IR imaging of [S III] λ9532, which suffers less extinction than does Hα (Young *et al.* 1988).

We have derived massive star formation rates from Hα luminosities, using an "extended" Miller-Scalo IMF and following the analysis of Kennicutt (1983), in which

$SFR(> 2 M_\odot) = 3.54 \times 10^{-42} L_{H\alpha}$.

The CO observations were made using the FCRAO 14-m telescope in the J=1→0 transition at 2.6 mm. The CO integrated intensities ($\int T_R^* \, dv \, K \, km \, s^{-1}$) were converted to H_2 surface densities using a constant $N(H_2)/I_{CO}$ conversion factor of $2.8 \times 10^{20} \, H_2 \, cm^{-2}/[K(T_R) \, km \, s^{-1}]$ (Bloemen *et al.* 1986).

Radial distributions in both Hα and CO have been obtained by azimuthally averaging the measurements made along the major axis of each galaxy. The Hα images have been convolved with a 45″ gaussian beam in order to make point-by-point comparisons of the molecular and ionized gas at similar resolution.

III. Results and Discussion

We find the mean global ratios $L_{H\alpha}/M(H_2)$ and $L_{IR}/M(H_2)$ show little variation as a function of morphological type from Sa-Scd, for the galaxies in this sample. Thus, we conclude that disk galaxies have similar *global* star formation efficiencies independent of the galaxy mass and mass distribution. From a comparison of $L_{H\alpha}/M(H_2)$ in isolated galaxies versus interacting/merging systems, we find a factor of ~7 enhancement of this ratio in interacting systems. Although the Hα emission will suffer extinction and thereby provide a lower limit to the high mass star formation rate, we confirm the result that the high-mass star formation efficiency is enhanced in environmentally disturbed systems (Young *et al.* 1986; Sanders *et al.* 1986; Solomon and Sage 1988). Thus, the property which appears to have the strongest effect on the global efficiency of high mass star formation in galaxies is environment.

Within a small sample of peculiar and interacting galaxies, the radial distribution of star formation efficiency shows steep gradients with radius. In particular, M 82 and NGC 660 show star formation efficiencies which decrease by a factor of 10 to 100 with increasing radius. This is in sharp contrast with the relatively constant star formation efficiency found as a function of radius in the isolated galaxy NGC 6946 (Tacconi and Young 1986).

IV. Conclusions

1. On the basis of comparison of the global $L_{H\alpha}/M(H_2)$ and $L_{FIR}/M(H_2)$ for 111 galaxies we conclude that *environment* rather than morphological type has the strongest effect on the global efficiency of massive star formation.

2. Based on our study of a small sample, we find that the largest radial gradients are observed in the interacting/peculiar galaxies, indicating that environment affects the star formation efficiency *within* galaxies as well.

References

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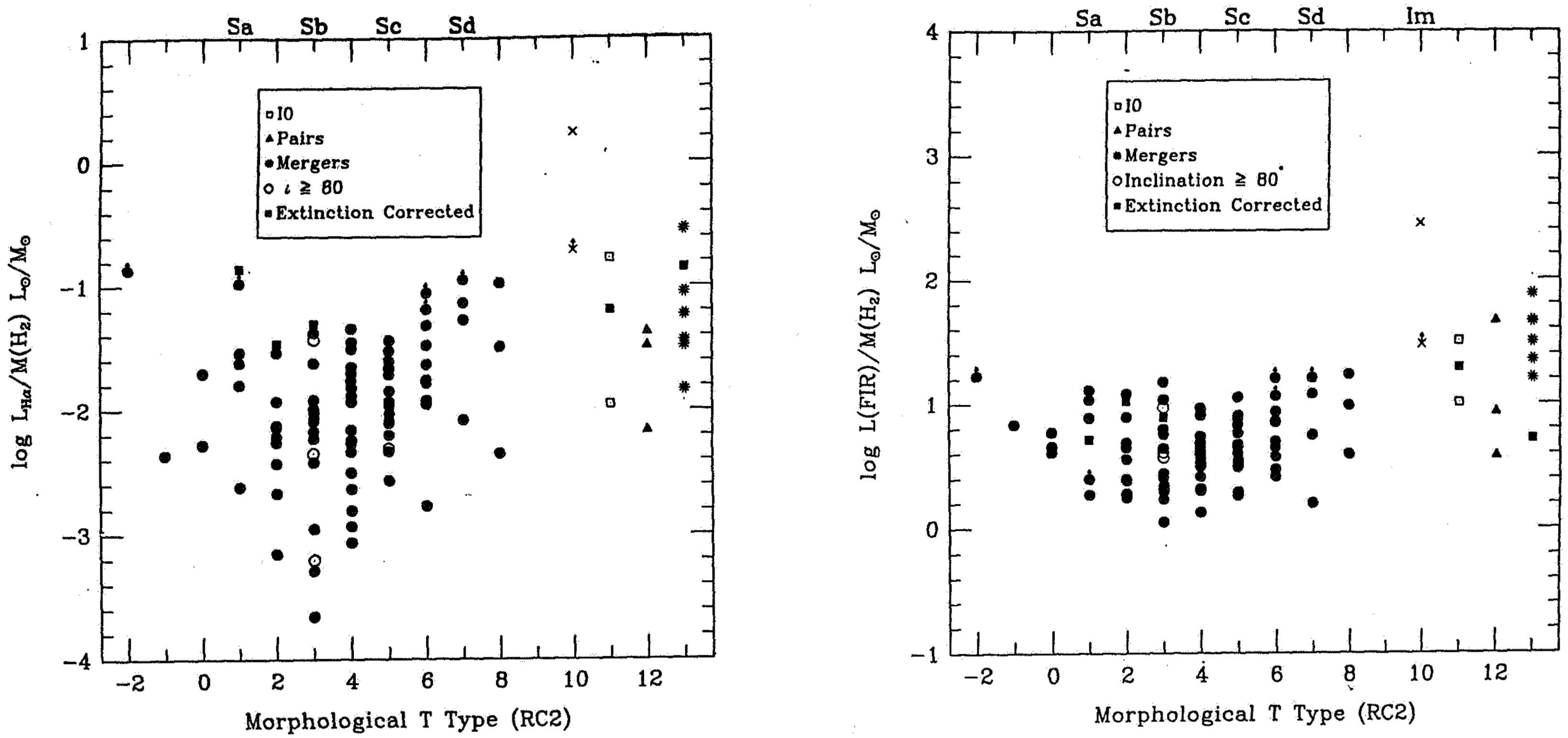

Figure 1. $L_{H\alpha}/M(H_2)$ and $L_{FIR}/M(H_2)$ as a function of morphological type for 111 galaxies. For spirals (types -1 through 8; S0/a through Sdm), the scatt-r within each type is much greater than the difference in the means between types, indicating that the global efficiency of massive star formation is not strongly dependent on galaxy morphology. The irregular/interacting/peculiar galaxies (types 10-13) have a mean global massive star formation efficiency ~ 7 times higher than that in spiral galaxies, as measured by both $L_{FIR}/M(H_2)$ and $L_{H\alpha}/M(H_2)$.

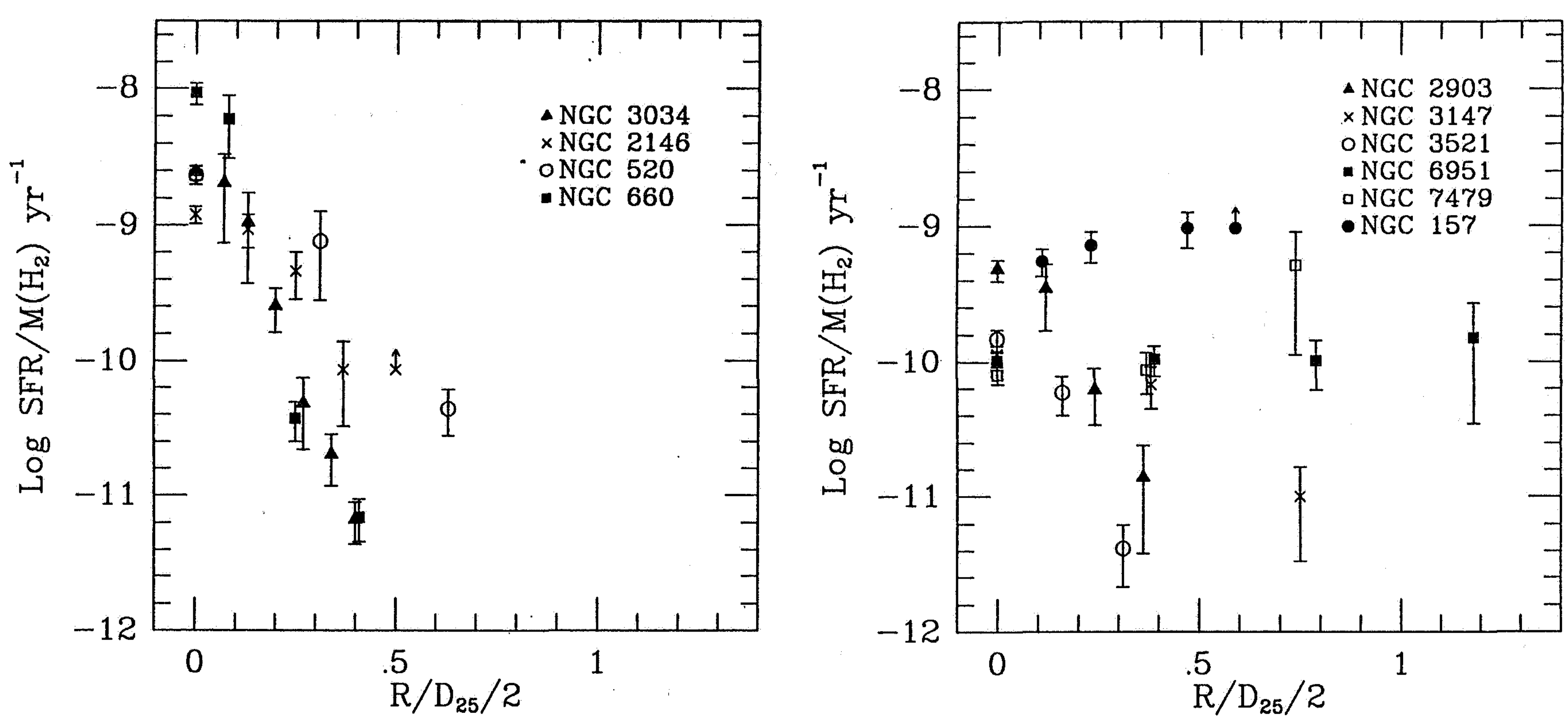

Figure 2. The efficiency of massive star formation as a function of galaxy radius, where the radius has been normalized by $D_{25}/2$ for a) interacting/peculiar galaxies and b) isolated galaxies. Of the interacting/peculiar galaxies, M82 and NGC 660 show the steepest gradients in the radial distribution of the massive star formation efficiency. In M82 the star formation efficiency decreases by a factor of 400 across the galaxy, when the extinction correction has been applied. Without the extinction correction, the radial gradient is still a significant factor of 100. In NGC 660, the extinction corrected data show a gradient in the star formation efficiency of 250, and a gradient of about 10 when no correction for extinction in Hα is applied. NGC 520 and NGC 2146 show significant radial gradients in the SFE after correcting for extinction, but a nearly constant distribution when no correction is made. Of the galaxies in the isolated sample, NGC 7479, NGC 6951, and NGC 157 show roughly constant radial distributions in the SFE. NGC 3147, NGC 3521, and NGC 2903 show radial gradients of $\sim 10 - 40$.