

Cold Molecular Gas as a Possible Component of Dark Matter in the Outer Parts of Disk Galaxies

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Abstract. In the last few years new evidence has been presented for the presence of ongoing massive star formation in the outer HI disks of galaxies. These discoveries strongly suggest that precursor molecular gas must also be present in some physical state which is escaping detection by the usual means (CO(1-0), IR, etc.). We present a model for such a gas in a framework which views the HI as the result of an ongoing “photodissociation \leftrightarrow dust grain reformation” equilibrium in a cold, clumpy molecular medium with a small area filling factor.

1. Young stars and HI in the outer parts of NGC 6822

Recently Komiyama et al. (2003) and de Blok & Walter (2003) have reported the detection of young stars in the outer HI disk of the nearest dwarf irregular galaxy NGC 6822 ($D \approx 490$ kpc) at galactocentric radii well beyond R_{25} . These authors discuss the results in terms of the commonly-accepted picture, where young massive stars form out of the observed HI in response to some “triggering” mechanism such as the passage of a companion galaxy (in this case a massive intergalactic HI cloud). However, an “interaction” scenario is problematic for NGC 6822, since as de Blok & Walter point out there is little evidence for tidal “impact trauma” on the distribution of old stars in the galaxy.

2. Young stars in the outer disk of M31

Cuillandre et al. (2001) discovered a whole population of upper-main-sequence (mostly B) stars in a large field ($28' \times 28'$) in the outer parts of M31 ($23 \leq R_G \leq 33$ kpc at $D \approx 720$ kpc) beyond R_{25} (≈ 21 kpc). Reddening of the accompanying (and much more numerous) red giant stars implied the presence of dust. Both the young stars and the reddening correlated well in position with the brightness of the HI on a scale of $\sim 4' \approx 1$ kpc. The dust/HI ratio is $\geq 1/3$ of the Galactic value near the sun. The HI distribution appears quiescent, showing the general rotation of the galaxy.

3. An “Inverse” Explanation

If the current view that star formation occurs in molecular clouds is correct, then the presence of dust and young stars in the outer parts of galaxies implies that

molecular gas must also be present in these regions. In that case an “inverse” explanation for the close association of HI and young stars is suggested, namely, that *the young stars have themselves produced the HI by photodissociation of their parent molecular clouds*. The dissociated HI re-forms to H₂ on dust grains, and the observed HI column density is a result of a dissociation ⇌ reformation equilibrium. In this case the HI column density can be computed from (cf. Allen et al. (2003) and references given there):

$$N(HI) = \frac{7.8 \times 10^{20}}{(\delta/\delta_0)} \ln \left[\frac{106G_0}{n} \left(\frac{\delta}{\delta_0} \right)^{-1/2} + 1 \right] \text{ cm}^{-2}$$

where $n = n(HI) + 2n(H_2)$. G_0 and δ/δ_0 are the FUV flux and dust/gas ratio w.r.t. the Galaxy near the sun. For instance, $N(HI) \approx 1 \times 10^{20}$ on the surface of a low-density ($n \approx 10 \text{ cm}^{-3}$) low-metallicity ($\delta/\delta_0 \approx 0.2$) molecular cloud can be maintained by a FUV flux of $G_0 \approx 0.002$, the equivalent of \sim one B3V star every ~ 100 pc in the disk. The re-formation time on the surfaces of dust grains in such a medium seems long, $\approx 10^8$ yrs, but in fact this is short ($\approx 10\%$) compared to the rotation time, which is the relevant time scale here in the absence of galactic collisions. An equilibrium is therefore likely even under these extreme conditions of low molecular gas density and low FUV flux. The accompanying molecular clouds will be cold and of low density, rendering the normal molecular tracers (e.g. CO(1-0)) undetectable. More precise calculations are being carried out for M31 where the data of Cuillandre et al. provides a complete census of all upper-main-sequence stars (Diaz-Miller, Allen, & Cuillandre, in preparation). Initial results indicate that most, and perhaps all, of the HI in the outer parts of disk galaxies can be accounted for in this way.

4. Conclusions

- **The hypothesis:** *An H₂ photodissociation ⇌ reformation equilibrium scenario provides a simple explanation for the coexistence of young stars, dust, and HI in the outer parts of disk galaxies.*
- **The hypothesis is falsifiable:** *If we find dynamically quiescent HI regions in the outer parts of galaxies without dissociating stars ($M(V) \leq -1$, B5 or brighter, $M \geq 6M_\odot$) then this idea is wrong.*
- **A prediction:** *Even low surface brightness galaxies such as NGC 2915 will have dissociating B-stars mixed in with their HI.*

References

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 de Blok, W.J.G. & Walter, F. 2003, MNRAS, 341, L39
 Komiyama, Y., et al. 2003, ApJ, 590, L17