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Physical Conditions in Photodissociation Regions: Application to Galactic Nuclei

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Infrared and sub-millimeter observations are used in a simple procedure to determine average physical properties of the neutral interstellar medium in Galactic photodissociation regions as well as in ensembles of clouds which exist in the nuclei of luminous infrared galaxies. The relevant observations include the IRAS infrared continuum measurements, infrared spectroscopy of the fine-structure lines of SiII 35 μm, OI 63 μm, and CII 158 μm, and the 2.6 mm CO (J=1-0) rotational transition. The diagnostic capabilities of the OI 145 μm line is also addressed.

We attribute these emission lines as well as the continuum to the atomic/molecular photodissociation region on the surfaces of molecular clouds which are illuminated by strong ultraviolet fields. We use the theoretical photodissociation region models of Tielens and Hollenbach (1985, Ap. J., **291**, 722) to construct simple diagrams which utilize line ratios and line to continuum ratios to determine the average gas density n, the average incident far-ultraviolet flux G_0, and the temperature of the atomic gas T. For example, the observed $[I_{\rm OI(63\mu m)} + I_{\rm CII(158\mu m)} + I_{\rm SiII(35\mu m)}]/I_{\rm IR}$ and $I_{\rm CII(158\mu m)}/I_{\rm OI(63\mu m)}$ intensity ratios may be used to determine n and G_0 from Figure 1. The average atomic gas temperature near the cloud surface is easily determined from Figure 2 which shows T_s as a function of n and G_0. In modeling the ensemble of clouds present in galactic nuclei, we adopt a global model of the interstellar medium, consisting of molecular cloud cores with atomic envelopes. In addition to n, G_0, and T, we determine the mass of the molecular and warm atomic gas components as well as estimates of the area and volume filling factors and the number and radii of clouds.

As examples, the procedure is applied to the Galactic photodissociation region behind the Orion HII region as well as to ensembles of clouds in the Galactic center, and the nucleus of the starburst galaxy M82. We find that the Orion photodissociation region is composed of warm ($T \approx 500$ K) high density ($n \approx 10^5$ cm^{-3}) gas which is illuminated by a far ultraviolet radiation field of intensity $\sim 2 \times 10^4$ times the local Galactic field. Within 5 pc of the Galactic center we find ~ 100 clouds of size $r \approx 0.4$ pc, and density $n \approx 10^5$ cm^{-3}. A far-ultraviolet radiation field, most likely from a central source with $L \approx 2 \times 10^7$ $L_\odot$, illuminates the clouds with an intensity $\sim 10^5$ times greater than the local Galactic field and heats gas in the surface layers to ~ 700 K. For the case of M82, we find that the neutral interstellar medium within the nuclear region of diameter < 650 pc consists of a large number, $N_{\rm cloud} \approx 3 \times 10^5$, of small, $r \approx 0.4$ pc, dense, $n \approx 5 \times 10^4$ cm^{-3}, clouds with a volume filling factor $\Phi_V \sim 10^{-4}$, and area filling factor $\Phi'_A \sim 0.3$, which are irradiated by a far-ultraviolet radiation field $\sim 10^4$ times larger than the local Galactic far-ultraviolet field. Thus, except for the scale size, the physical conditions in the center of our galaxy and of M82 are very similar to those in the region surrounding the trapezium stars in Orion. The physical conditions in the neutral atomic gas that we have estimated for the Orion photodissociation region, the Galactic center, and the nucleus of M82, are summarized in Table 1

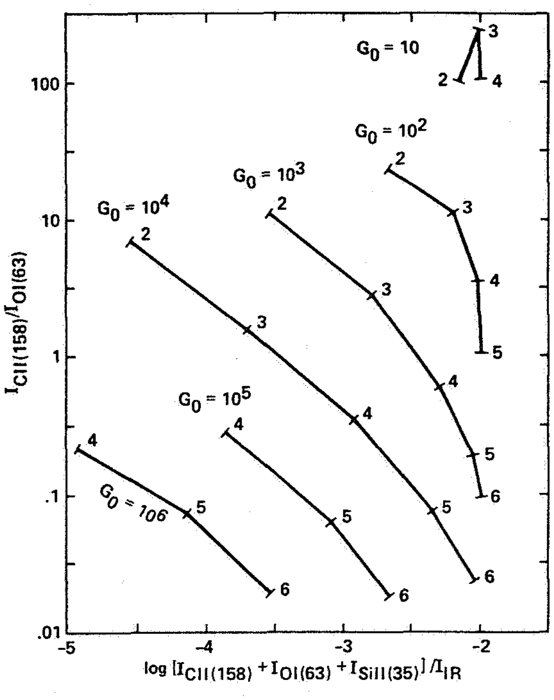

Figure 1 - The ratio of $I_{\rm CII(158\mu m)}/I_{\rm OI(63\mu m)}$ intensities versus the ratio of $[I_{\rm OI(63\mu m)} + I_{\rm CII(158\mu m)} + I_{\rm SiII(35\mu m)}]/I_{\rm IR}$ intensities. Tick marks are labled with log n cm^{-3} and are spaced at one decade intervals along lines of constant G_0.

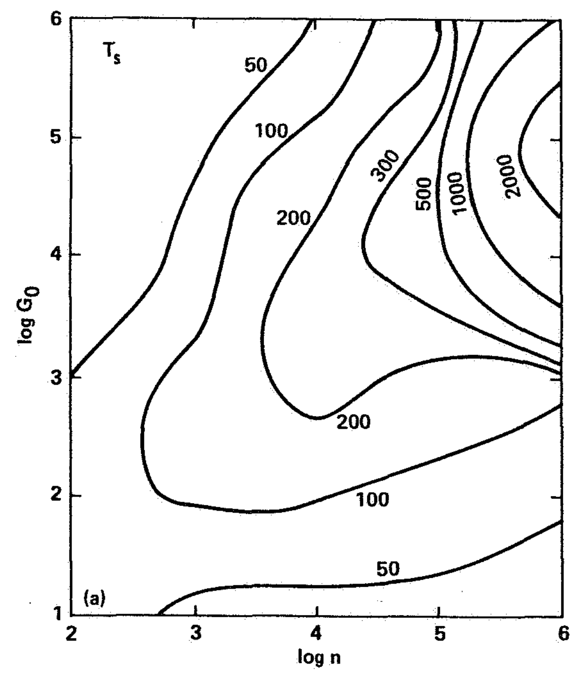

Figure 2 - Surface temperature, T_s (°K), in the atomic gas as a function of n and G_0.

Table 1

Derived Physical Conditions and Global Parameters

		Orion	Galactic Center	M82
			$\lesssim 5$ pc	$\lesssim 330$ pc
Gas density in clouds	n (cm^{-3})	$10^{4.8}$	$10^{5.0}$	$10^{4.7}$
Incident FUV field	G_o (1.6×10^{-3} erg cm^{-2} s^{-1})	$10^{4.2}$	$10^{4.9}$	$10^{3.9}$
Atomic gas temperature	T_a (K)	470	730	370
Atomic gas mass	M_a ($M_\odot$)	2^a	3×10^3	6×10^6 [b]
Molecular gas mass	M_m ($M_\odot$)	50 [c]	7.8×10^4	6×10^7
Atomic to molecular mass ratio	M_a/M_m (%)	4	4	10 [d]
Volume filling factor of clouds	Φ_V	...	6×10^{-2}	4×10^{-4}
Projected Area filling factor of clouds	Φ'_A	...	0.7	0.3
Atomic gas radius	r_a (pc)	...	0.4	0.4
Thickness of atomic layer	$r_a - r_m$ (pc)	...	0.005	0.01
Number of clouds	N_{cloud}	...	100	3×10^5

[a] Atomic gas in C^+ regions within $4' \times 8'$ beam $M_a \sim 40$ $M_\odot$.

[b] Atomic gas in C^+ regions within $1'$ beam (R$\sim$ 500 pc) $\sim 3 \times 10^7$ $M_\odot$.

[c] Molecular gas within $4' \times 8'$ beam $M_m \sim 250$ $M_\odot$.

[d] M_a/M_m ratio is $\sim 50\%$ within central $1'$ (R$\sim$ 500 pc).