A 158μm [CII] MAP OF NGC 6946: DETECTION IN EXTRAGALACTIC ATOMIC AND IONIZED GAS

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1. Introduction

The first observations of the [CII] line toward the nuclei of gas-rich external galaxies, showed that the far-infrared line emission contributes up to 1% of the total luminosity and most likely originates from dense photon-dominated regions (PDRs) associated with the surfaces of molecular clouds exposed to FUV from external or embedded OB stars (Crawford *et al.* 1985, Lugten *et al.* 1986, Stacey *et al.* 1991). We have mapped the [CII] emission toward NGC 6946 over an 8'x 6' (23 x 17 kpc) (Madden *et al.* 1991) using the Max-Planck Instutute/U.C.Berkeley Far-Infrared Imaging Fabry-Perot Interferometer (FIFI) on the Kuiper Airborne Observatory (KAO).

2. Origin of the [CII] Emission

Figure 1 suggests a close resemblance between the morphology of the nuclear and spiral arm [CII] components and that of the optical continuum/Hα that traces the current massive star formation activity. Three spatial regions can be distinguished in the [CII] map of NGC 6946: 1) The nucleus associated with the peak intensity (7×10^{-5} erg $s^{-1}cm^{-2}sr^{-1}$; 2) a component tracing the spiral arms, and 3) an extended component existing out to 11 kpc which contains most of the [CII] luminosity. We consider possible origins of the [CII] emisssion in the 3 spatial components of NGC 6946 from neutral atomic gas, extended low density gas (ELD) and PDRs by comparison of the various tracers [CII] (Madden *et al.* 1991), FIR (Engargiola 1991), CO (Tacconi and Young 1989), HI (Tacconi and Young 1986), and 2.8 cm (Klein *et al.* 1982).

2.1 Extended Component. Since the [CII] in the extended component (~3.5'west of the nucleus) is associated with a relatively large mass (10.7×10^{7} M$\odot$), and the HI emission is prominent even well beyond the spiral arms, unlike the distribution of the molecular gas, we estimate the contribution of the [CII] from the diffuse atomic hydrogen ISM.

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Assuming standard atomic clouds with n(H) ~ 30 cm^{-3} and kinetic temperature of 100 K (Kulkarni and Heiles 1988), we estimate the [CII] intensity arising from the observed 21cm HI gas to be ~ 40% of our observed [CII] emission.

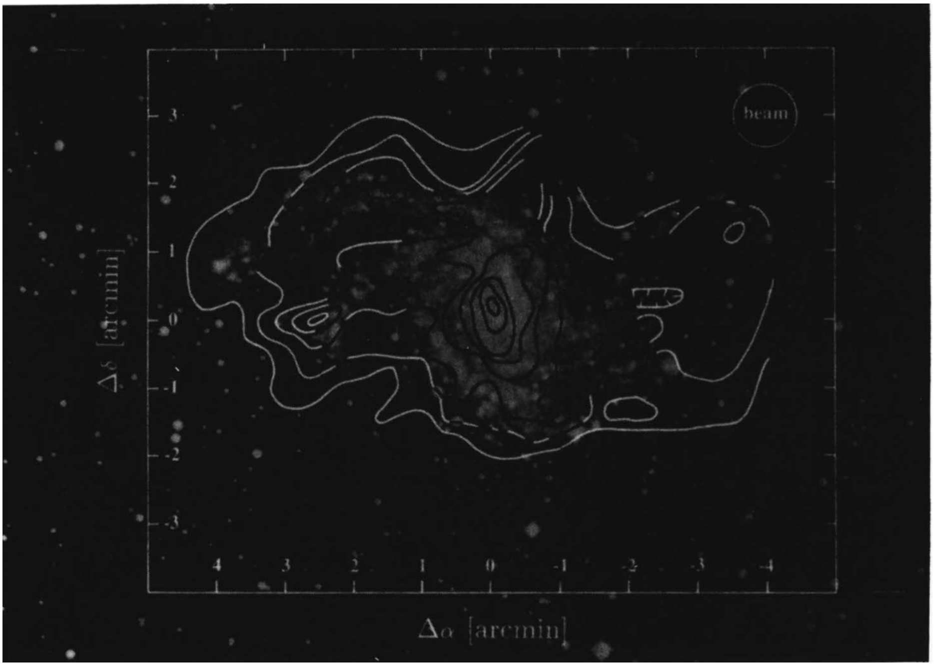

Figure 1. *Integrated [CII] line intensity contours superposed on an optical image of NGC 6946. The contour interval is 1x10^{-5} erg s^{-1} cm^{-2} sr^{-1} and the peak value is 7x10^{-5} erg s^{-1} cm^{-2} sr^{-1}. The beam size is 55". The center position is: RA(1950) $20^h33^m48.8^s$, DEC(1950) +$59^o58'50$.*

[CII] emission may also arise from the fully ionized interstellar medium that has been modeled as extended low density (n(e) ~ 3 cm^{-3}) (ELD) HII regions with electron temperatures ~ 10^4K (Mezger 1978). We derive an expected [CII] line intensity from the ionized gas to be ~ 34(±11%) of our measured [CII] value in the extended component. This supports measurements of the [CII] in the ELD in the Galaxy (see references in Madden *et al.* 1991).

If we assume that [CII] and CO line emission as well as the far-infrared continuum all originate at the surfaces of the UV exposed molecular clouds, then PDR models can be used to derive the physical conditions of the emitting cloud. After subtracting the contribution of the [CII] emission from the ELD HII regions and the HI medium, we determine a PDR solution to the remaining CII emission (5x10^{-6} erg

$s^{-1}cm^{-2}sr^{-1}$). The regions require UV field intensities, $\chi(UV)$, of 700 times $\chi(o)$, the UV field in the solar neighborhood (2.0×10^{-4} erg $s^{-1}cm^{-2}sr^{-1}$), very dense hydrogen densities (~ 7×10^{5} cm^{-3}) and a FIR filling factor, Φ(FIR), of ~ 1%.

2.2 Spiral Arms. We calculate the contribution of the diffuse HI gas to be ~ 10% of our total [CII] emission in the prominent spiral arm 2.5' east of the nucleus. The ELD HII regions can contribute ~ 20% of the total [CII] emission observed toward this spiral arm region assuming the standard conditions for the HI clouds and the ionized gas described above.

The remaining observed [CII] emission in the spiral arm after the ELD and HI contributions are removed, is 3.5×10^{-5} erg $s^{-1}cm^{-2}sr^{-1}$ giving a PDR solution of n(H) ~ 600 cm^{-3} with $\chi(UV)/\chi(o)$ ~ 120. The filling factor for the FIR sources is then 20% (~ 25" sources in our 55" beam), consistent with high resolution Hα and CO data (Bonnarel *et al.* 1986; Weliachew *et al.* 1987, Ball *et al.* 1989).

2.3. Nucleus. The [CII], FIR and CO all peak in the nucleus, substantiating an interpretation of the origin of [CII] from PDRs. The PDR solution implies very dense (n (H)~ 8×10^{5} cm^{-3}) molecular clouds exposed to UV fields of $500\chi(o)$. The beam area filling factor is 12% corresponding to 19" source sizes, in fairly good agreement with the diameter of the nuclear source when observed at high spatial resolution in Hα or CO.

3. References

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