The Interplay among Black Holes, Stars and ISM in Galactic Nuclei
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Diagnostics of dense irradiated gas around galaxy nuclei

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Abstract. Gas in galaxy centers may be irradiated by far-ultraviolet, X-ray photons or both. We discuss the observational line diagnostics for PDRs (FUV) and XDRs (X-ray).

Gas clouds in the inner kpc of many galaxies are exposed to intense radiation. Far-ultraviolet (6.0 < E < 13.6 eV) radiation from starbursts causes cloud *surfaces* to turn into Photon Dominated Regions (PDRs, Tielens & Hollenbach 1985). Hard X-rays (E > 1 keV) from black hole environments (AGN) penetrate deep into cloud *volumes* creating X-ray Dominated Regions (XDRs, Maloney et al. 1996). For the PDRs the density and strength of the radiation field are respectively $G_0 = 10^5$ and $n_H = 10^5$ cm^{-3}, conditions which are typical for dense central regions of starburst galaxies (like NGC 253) with starformation rates of $\sim 10^2 M_\odot$/yr. For the XDR model we consider a range in the energy deposition parameter H_X/n_H with $n_H = 10^5$cm^{-3}, which covers the range of conditions at a range of distances from an AGN like NGC 1068.

In a PDR, photo-electric emission from (small) dust grains and PAHs dominate gas heating (Bakes & Tielens, 1994). Deeper in the cloud the [OI] 63 μm finestructure line and heating by gas-grain collisions become important. In a XDR, photo-ionization heating dominates photo-electric heating by two orders of magnitude. X-ray photons create fast electrons through photo-ionization. About 40 percent of their energy is lost by Coulomb interactions with thermal electrons.

In a PDR, the chemical structure is stratified. The FUV photons are gradually absorbed and lead to relatively sharp transitions. In Fig. 1, the H/H_2 and C^+/C/CO transitions are shown. Molecular hydrogen is excited by fluorescence (i.e., absorption of FUV photons). In Fig.1 this is shown as H_2V, which indicates a $v = 6$ pseudolevel of H_2 at about 2.6 eV above ground level. X-rays can penetrate deep into a cloud and the chemistry is not stratified. We show the chemistry as a function of X-ray energy at the typical attenuation of 10^{22}cm^{-2} (see Fig.1). For large X-ray energies per particle, the electron abundance is high, due to the ionization of hydrogen by secondary electrons. C^+ is always present but never dominant. H_2 is excited due to collisions with electrons. H_2O and OH are more easily formed when H_2V is present, since the internal energy is sufficient to overcome reaction barriers in the oxygen chemistry. Hence, molecular and ionized species coexist.

At the edge of a cloud in a PDR, the dominant coolant is the [OI] 63 μm finestructure line (see Fig. 2). The [CII] 157.7 μm / [OI] 63 μm ratio is sensitive to the density distribution and the temperature. Deeper in the cloud, cooling by CO becomes important. In a XDR, thermal electrons can excite forbidden lines like [CI] 9823, 9850 Å and [OI] 6300 Å, but the [OI] 63 μm line also is very strong. The [FeII] 1.26, 1.64 μm lines can also be useful tracers when the X-ray illumination (i.e., the temperature) and (column) density is high. When less energy is available H_2 and gas-grain cooling are important.

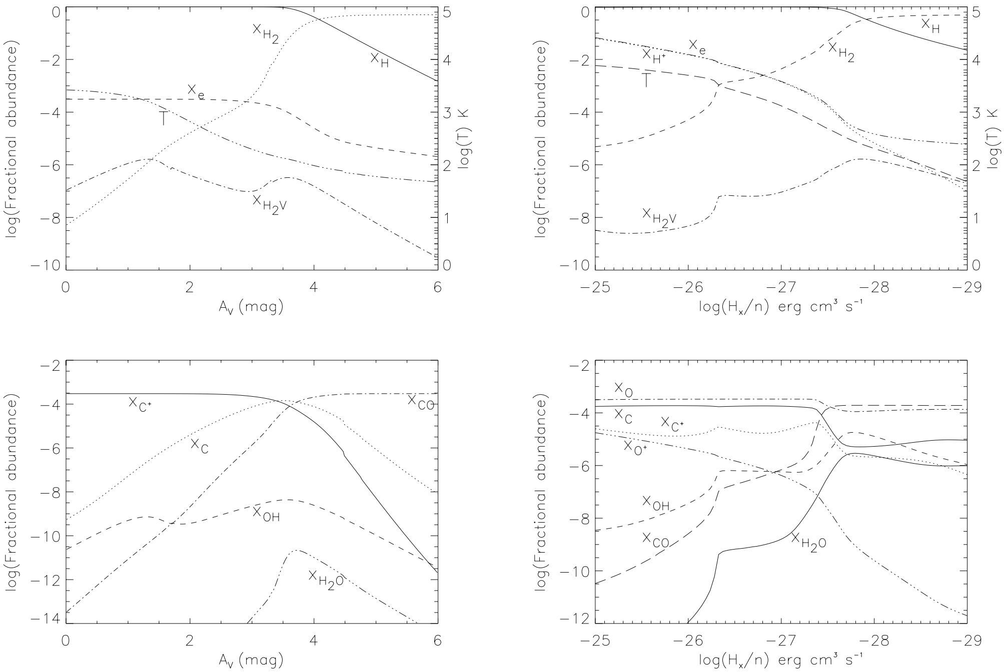

Figure 1. Chemistry in a PDR (left) and a XDR (right)

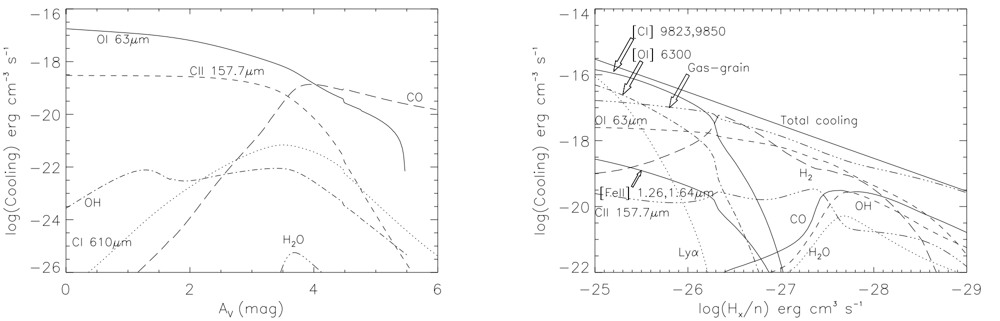

Figure 2. Important coolants in a PDR (left) and a XDR (right).

PDR and XDR models are essential in understanding the physics of clouds in AGN and starburst environments. Our models consider both simultaneously. In a future work, we will investigate various gas geometries, including inhomogeneous and filamentary structures. Our model results constrained by mm and submm observations will determine the physics of nearby active galaxies.

References

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