Physics 785 Problem Set 2

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1 Oxygen Chemical Network

We can gain a qualitative view of the relative abundances of oxygen compounds by looking at the reactants needed to produce each species, and the rate coefficient for the production reactions along with the same information for reactions that destroy that species. If a species has numerous reactions producing it, with relatively high rate coefficeints and abundant precursors, and few destruction reactions, we can expect to find this compound in abundance in the molecular ISM. Since many of the compounds in the oxygen chemical network are also reactants for producing other compounds, to gain a quantitative estimate, integrating the series of coupled differential equations defining the densities of all species would be necessary. However, for a number of species (Especially H_2 and H, the densities are many orders of magnitude higher than other compounds, and reactions involving these species will be very rapid, even with relatively low rate coefficients. Figure 1 shows graph showing the chemical network for oxygen. Reactions that involve additional reactants have their transitions labeled with the additional reactants, and the transitions are colored based on the type of reaction involved. The reaction types and rate coefficients are defined in the table below:

Reaction Type	Rate Coefficient	Colour
Neutral-Neutral without Potential Barriers	10^{-11}	Purple
Photodissociation	10^{-9}	Blue
Ion-Molecule Reactions	10^{-9}	Green
Charge Transfer	10^{-9}	Orange
Dissociative Recombination	$10^{-6} - 10^{-7}$	Red

The charge transfer rate coefficient was estimated to be on the same order of magnitude as the coefficients esstimated in Le Teuff et al. 2000. In addition to the rate coefficients given above, we also need a rough idea as to the abundances of some of the precursor compounds. We know that the abundance of both atomic and molecular hydrogen is many orders of magnitude higher than all the other components of the molecular ISM, and so reactions involving those species will be very efficient.

From looking at the labeled reaction network, we can see that the most efficient reactions (Dissociative Recombination) are occuring in two production reactions that generate OH, and although it is involved in a number of reactions that consume it, these reactions all occur with 2-3 orders of magnitude smaller rate coefficients. This suggests that OH is one of the more common species. The other species involved in dissociative recombination reactions are CO, which is also created 5 separate reactions (also suggesting large abundances in the molecular ISM), CO2 (which is formed from the already established to be abundant OH through a neutral-neutral reaction and from HCO2+, which due to it's single production reaction from HCO+ is likely not as abundant as the previous two species), water (which should be produced at a much lower rate than OH, since its precursor and its super-precursor both will also form OH), and O2 (which has the largest number of reactions involving it, and the only rapid dissociation reaction is from a product that must be itself produced from O2, and so likely is not particularly abundant). Based on the network, I would predict that OH, CO, and CO2 are the most most abundant neutral oxygen species. Since OH+ is formed from abundant OH transfering charge to H+, it is also likely to be relatively abundant (although it will rapidly be turned into H2O+ by reacting with highly abundant H2).

The species I expect to see in the lowest abundances are those that have a small number of slow production reactions coupled with many rapid destruction reactions. O2H+ is an obvious example of this, since it is only formed from O2, and rapidly dissociates back itno O2 and H+. Another likely rare ion is H3O+ (since it is formed from H2O+ which will preferentially form OH, and rapidly is converted into H2O and OH).

2 Clumps in ρ Ophiuchus

Johnstone et al. 2000 contains $850\mu m$ observations of dense molecular clumps within the ρ Ophiuchus cloud using the SCUBA bolometer on the JCMT. Using their mass estimates calculated for a dust temperature of 20K, I generated a differential clump mass function $\frac{dN}{dM}$, and fit a power law to this distribution function:

$$\frac{dN}{dM} \propto M^{-\alpha}$$

I first selected only clumps with mass $> 0.6M_{\odot}$. I chose this selection firstly because it is greater than the incompleteness limit of $0.4M_{\odot}$, and it is the break that Johnstone et al. reports between the two different power-law slopes of $\alpha = 0.5$ (below $0.6M_{\odot}$) and $\alpha = 1.0 \pm 0.5$ for the cumulative mass function $N(M)$ (this would mean a change in slope for the differential mass function as well). I calculated these values by taking a histogram of the base-10 log of the masses to find the number of clumps N_i at a bin $\log M_i$ of width $\delta \log M$. $\frac{dN}{dM}$ was then calculated simply as:

$$\frac{dN}{dM}(M_i) = \frac{N_i}{M_i}$$

I used the width of the bin $\delta \log M$ and the relative Poisson noise $\sqrt{N_i^{-1}}$ as my uncertainties in $\log M_i$ and $\log \frac{dN_i}{dM_i}$ I then used a least squares optimizer from the Scipy python library to fit a power law (linear in logspace) to $\frac{dN}{dM}$ vs. M. I weighted the error function using the geometric mean of my two uncertainties. The result of this fit is a power law with $\alpha = 1.9 \pm 0.3$. This is exactly what we would expect if the cumulative mass function has a power law with $\alpha = 1$, since the derivative will reduce α by one.

$$\frac{dN}{dM} \propto M^{-1.9 \pm 0.3}$$

This fit, along with the data, is shown in figure 2.
Note: All calculations and plots were done using attached code

References

Johnstone et al. 2000 *Large-Area Mapping at 850 Microns. II* ApJ 545, pp. 327
Le Teuff et al. 2000 *The UMIST Database for Astrochemistry 1999* AJS 146, pp. 157

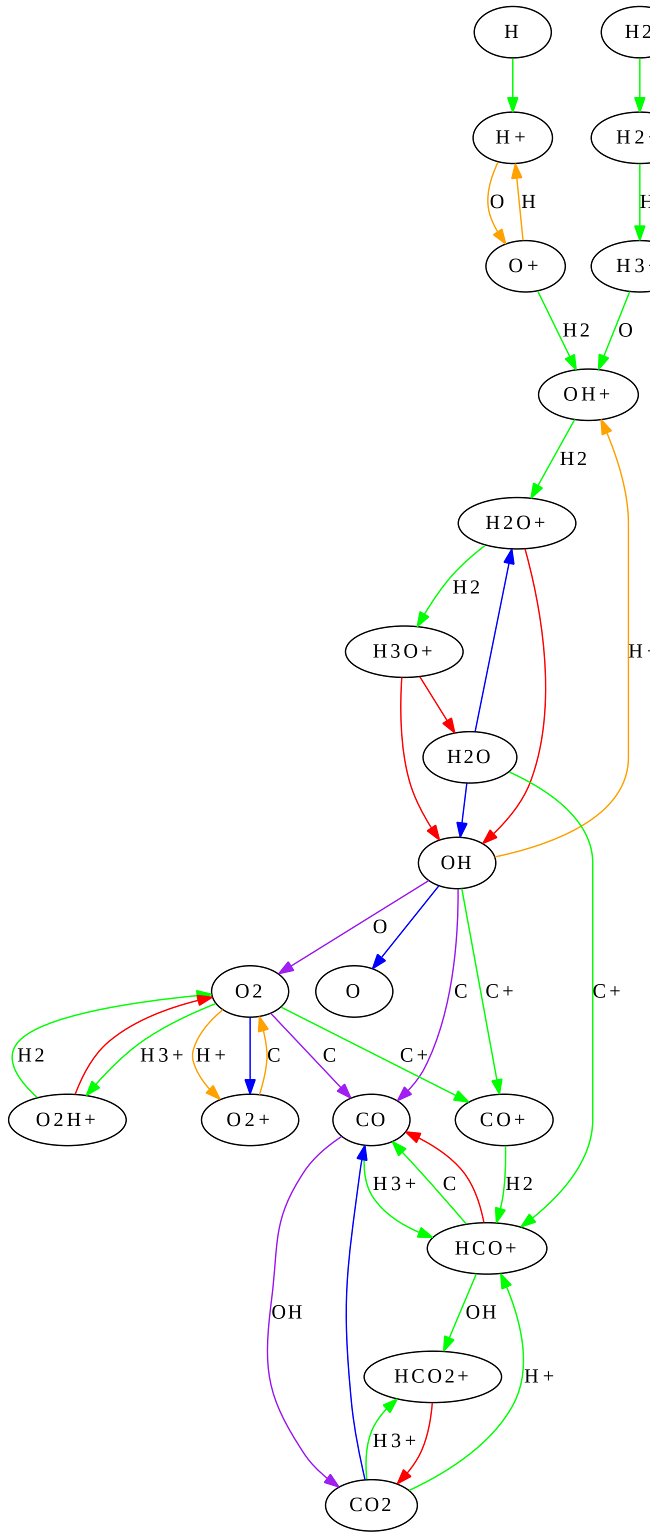

Figure 1: Chemical network for oxygen species

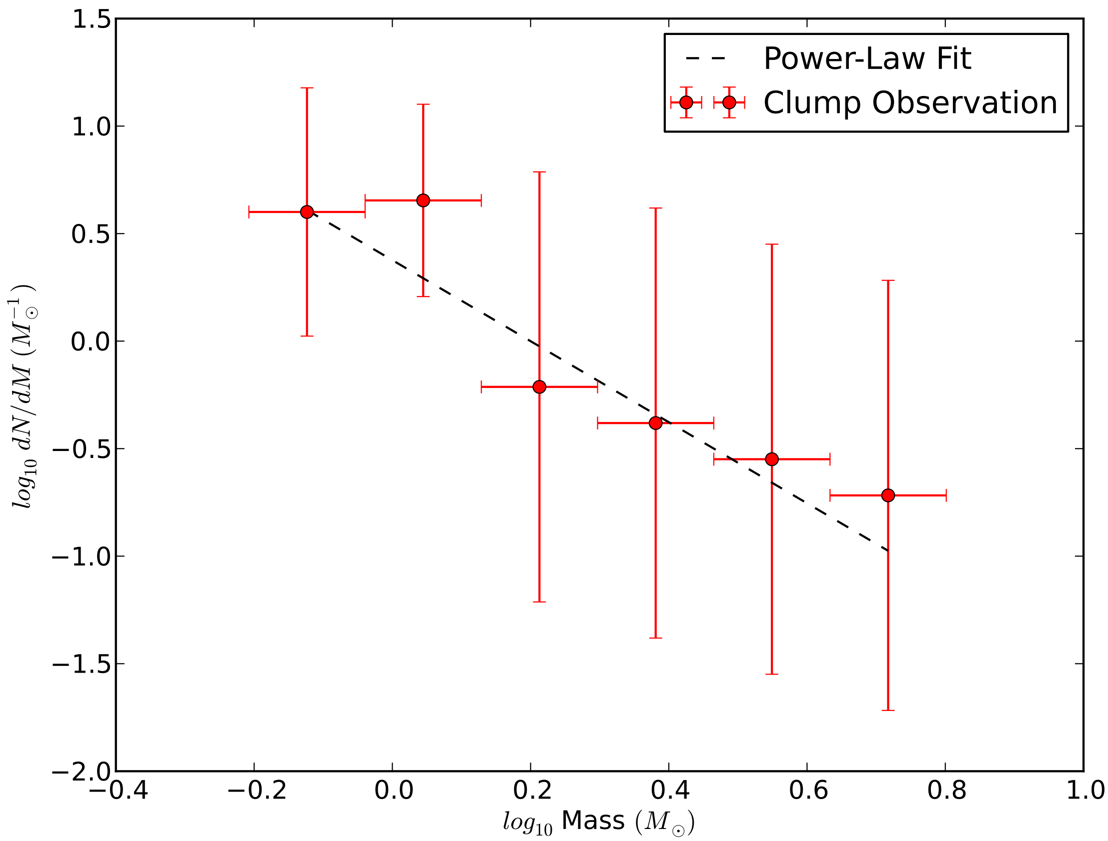

Figure 2: Differential Mass Function dN/dM vs. Clump Mass M