A+ 100

Ay 208 - ISM   Problem Set 4   5/12/00

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This is how the solution set ~~~ thanks! AG

The spectrum I found is plotted in Mathematica (see over)
I plotted $\log(\nu F_\nu)$ vs $\log(\nu)$.

The spectrum is of the region within 5 arcminutes (radius) of the Trapezium cluster.
Region is roughly centred on J2000 (R.A. $5^h 35^m 15^s$; Dec $-05°23'30''$) which is the centre of the trapezium cluster.

I define a number of regions in the spectrum as follows:

Radio	$\nu < 10^{11}$ Hz
IR	10^{11} Hz $< \nu < 10^{14}$ Hz
Optical/UV	10^{14} Hz $< \nu < 10^{16}$ Hz
X-ray	10^{16} Hz $< \nu$

There are a number of upper limits on gamma ray emission from the Orion nebula, but no detections so I have not put in any gamma ray points.

From what we have learned in class, I expect free-free emission in radio, Dust in IR, stars & reflected/scattered starlight in optical/UV, and not sure what in X-ray. This is indeed what I found, with a high temperature plasma dominating X-ray emission.

Although line emission is important for cooling the HII region, I have not found a single reference that claims line emission dominates over continuum in any waveband, so I have not plotted any lines.
The important lines are of course the Hydrogen lines Hα, Hβ etc, along with the cooling lines of ionized oxygen (eg OIII) and sulphur (SIII), among many others.
Also prominent is the H_2 line at 2.1μ (Hyland et al, 1980)

In the following discussion I will take each of the 4 sections defined above & discuss them separately. I will list references used in each section, rather than all together at the end.

Note on collaboration:

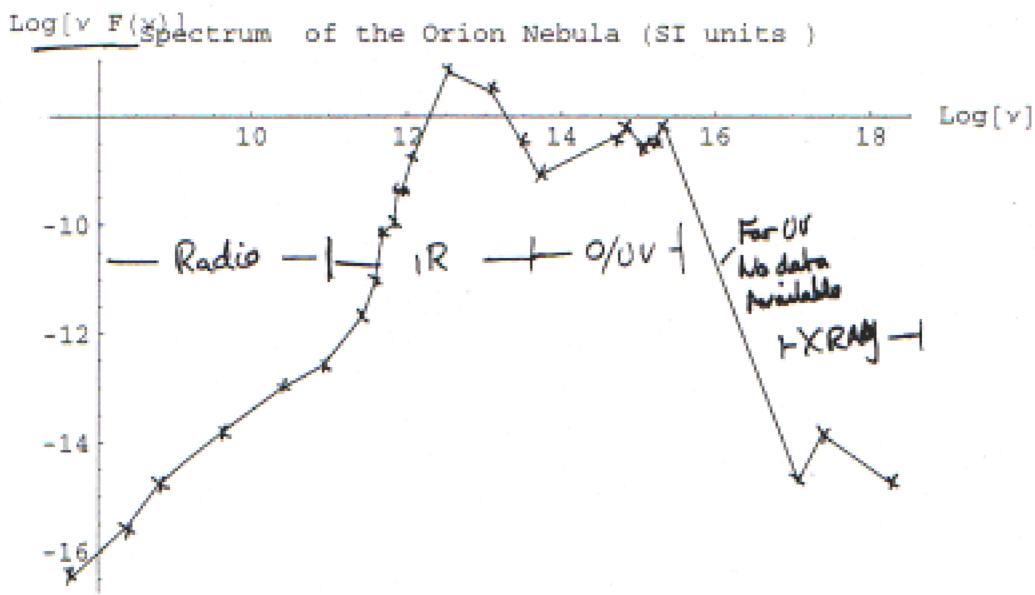
References were exchanged fairly frequently with other students; however all other work is my own unless otherwise stated (ditto when I get numbers from someone's paper...).

Ref Hyland, A.R., Allen, D.A., Barnes, P.J., Ward, M.J.
1984, MNRAS, 206, 465.

Spectrum Of The Orion Nebula.
(Central 5 ArcMinutes)

- **Data points are ones taken from the literature as described in the notes accompanying these graphs.**

```
In[75]:= linear = {{42*^6, 74}, {240*^6, 120}, {600*^6, 268},
             {1.4*^9, 324}, {5*^9, 380}, {23*^9, 400}, {86*^9, 307}, {273*^9, 800},
             {380*^9, 2136}, {480*^9, 14000}, {670*^9, 16000}, {750*^9, 60000},
             {790*^9, 50000}, {850*^9, 48000}, {1.1*^12, 0.13*^6}, {3.3*^12, 2*^6},
             {1.2*^13, 0.24*^6}, {3*^13, 11000}, {5*^13, 1620}, {5.45*^14, 810},
             {6.8*^14, 910}, {1.24*^15, 215}, {1.33*^15, 230}, {1.64*^15, 190},
             {2.14*^15, 333}, {1.2*^17, 1.6*^-6}, {2.41*^17, 5.8*^-6}, {1.8*^18, 1*^-7}};

In[76]:= nufnulin = linear;

In[77]:= Do[nufnulin[[i, 2]] = linear[[i, 2]] * linear[[i, 1]] * 1*^-26, {i, 1, 28}]

In[78]:= nufnulog = N[Log[10, nufnulin]];

In[79]:= ListPlot[nufnulog, PlotJoined → True,
           PlotLabel → "Spectrum  of the Orion Nebula (SI units )",
           AxesLabel → {"Log[ν]", "Log[ν F(ν)]"}]
```



the units used are : F[W m^-2Hz^-1]
ν[Hz]

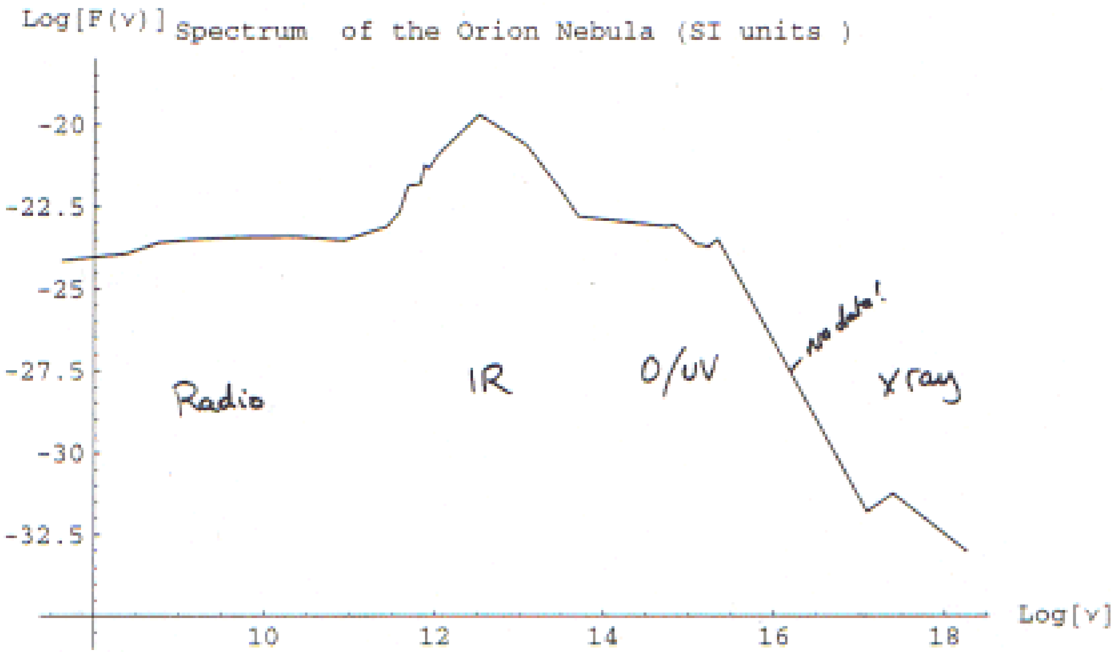
The straight lines are of course artifacts of the poor resolution I have in some parts of the spectrum.

```
In[80]:= fnulin = linear;

In[81]:= Do[fnulin[[i, 2]] = linear[[i, 2]] * 1*^-26, {i, 1, 28}]

In[82]:= fnulog = N[Log[10, fnulin]];
```

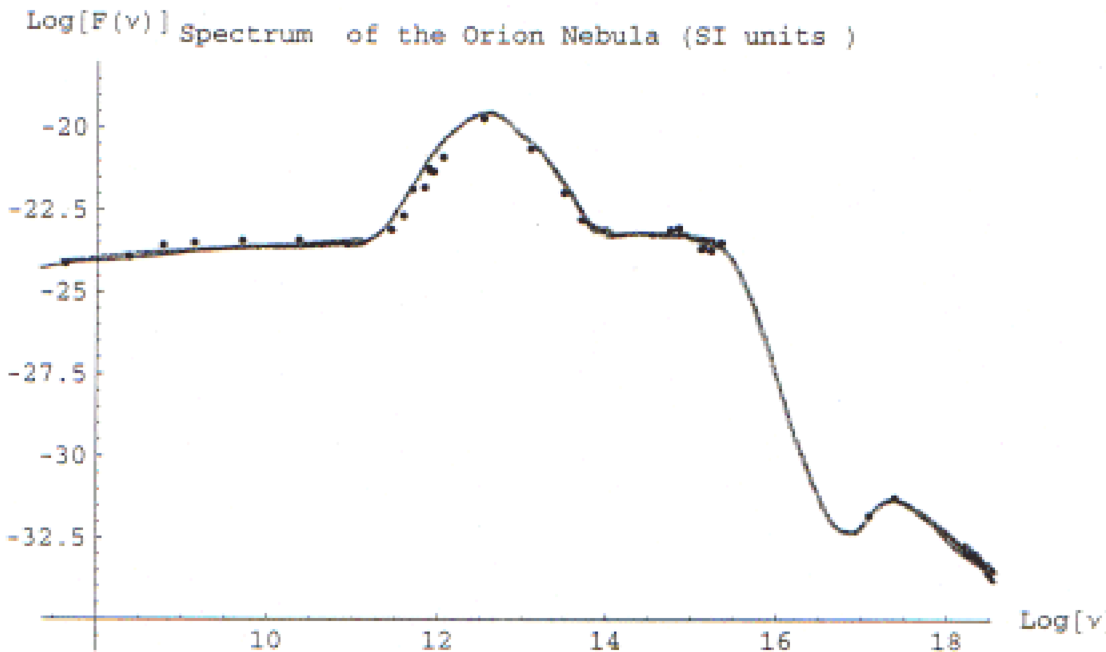
P.T.O. for log(Fν) vs log(ν)

p4

```
In[83]:= ListPlot[fnulog, PlotJoined → True,
          PlotLabel → "Spectrum  of the Orion Nebula (SI units )",
          AxesLabel → {"Log[ν]", "Log[F(ν)]"}, PlotRange → {-36, -18}]
```



```
In[84]:= ListPlot[fnulog, PlotJoined → False,
          PlotLabel → "Spectrum  of the Orion Nebula (SI units )",
          AxesLabel → {"Log[ν]", "Log[F(ν)]"}, PlotRange → {-36, -18}]
```

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Out[84]= - Graphics -
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1) Radio $\nu \lesssim 10^{11}$ Hz

This is the simplest region of the spectrum in terms of continuum emission. There are literally millions of lines all over the spectrum, but they contribute negligibly to the total flux (anything less than "comparable" is treated as "negligible" in the approximations made for this homework set).

The spectrum is essentially flat for all observed ~~wavelengths~~ frequencies less than 10^{11} Hz. This is characteristic of bremsstrahlung emission, and ~~most~~ all authors I have found attribute all of the flux to bremsstrahlung.

The first & primary reference is Goudis (1975), who in table 1 lists all the observations of radio emission from the Orion Nebula (M42) up to 1975. The spectra do include emission from M43, but M42 completely dominates the emission.
The beam sizes of the telescopes used are not given, & some (especially at longer wavelengths) are undoubtedly larger than our 5' radius region, but there are no other nearby sources of free-free to contaminate the signal, so it is ok to use the data.
I basically used this table to fill out gaps in the spectrum where I couldn't find more recent references.

I used data from Felli et al (1993) at 20cm (1.4 GHz).
They took 100m Effelsberg telescope data & integrated the flux over the whole nebula.
I did not use their other data from the VLA because interferometers filter out large angular scale power, which is important, as the authors point out.

I used Gordon et al (1987) data at 3.5mm (86 GHz). They integrated over a 10'x10' field centred on BN/KL nebula ($\lesssim 1'$ from trapezium cluster). This is larger than a circle of radius 5', but only by 25%, so it shouldn't make much difference. The data was taken with the ~~Kitt~~ Peak 12-m mm-wave telescope.

Wilson & Pauls (1984) also used the Effelsberg 100m telescope to map the Orion Nebula at 23 GHz (1·3 cm). They also give an integrated flux density over the whole map. From inspection of their figure 2, almost all of the emission is within 5′ of the central region of the nebula.

Other points are from Goudis (1975) & references therein. As can be seen from the log F_ν vs log ν plot, the spectrum is very flat at all wavelengths/freq. $\nu < 10^{11}$ Hz. This indicates that the HII region is not becoming optically thick to free-free even at the longest wavelengths of $\lambda \sim 10$ m.

Radio Refs

Felli, M., Churchwell, E., Wilson, T.L., Taylor, G.B.
1993, A&AS, 98, 137.

Gordon, M.A., Jewell, P.R., Kafton-Kassin, M.A., Salter, C.J.,
1986 Ap.J., 308, 288.

Goudis, C., 1975, Ap.&S.S., 35, 409.

Wilson, T.L., & Pauls, T, 1984, A.&A., 138, 225.

2) Infrared

From the νF_ν plot, it is clear that this wavelength region emits most of the energy from the Orion Nebula. This is thermal emission from dust in the Orion nebula or in the surrounding molecular gas.
For dust at $T \sim 40$ K, the peak of the BB spectrum (in ν) is at $\sim 2 \times 10^{12}$ Hz.
For $T = 100$ K, the peak is closer to 10^{13} Hz.

Bally, Langer & Liu (1991) give IRAS data for M42. In Figure 8 they plot the intensity of emission in a cut through the nebula in declination.
Unfortunately the 60μ & 100μ integrations are saturated & so cannot be used to calculate flux.
In the end I decided not to use the 12μ & 25μ data either as they are only 1-D emission curves and I do not know the beam shape or orientation of IRAS.

Keene, Hildebrand & Whitcomb (1982) report a 400μ measurement integrated over their 3′ beam of 6000 Jy.
Our region is 5′ radius & so has area $\pi(5')^2 \simeq 80\,\square'$
A 3′ diameter beam has area $\sim 7\,\square'$.
To convert between different beam sizes in the Far-IR I just multiplied by the ratio of the beam areas. This is effectively assuming that emission is uniform over the whole region. While this is a very bad assumption, it is not going to make a factor of more than 3 or 4 difference. Also in the FIR, dust is pretty extended over the whole Orion molecular cloud, although it is very clumpy & wispy.
So I multiplied the Keene et al point by 10 to get 60 kJy.

Lis et al (1998) use the SHARC camera on the CSO to image the OMC. They give the integrated flux over a 12′×12′ region centred on the nebula as 60 kJy. I divided this