Ay126: Homework 4

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Due COB May 15, 2016 @TA's desk

[1] **Fast Radio Bursts: Constraints from ISM.** The primary purpose of this exercise is to use your knowledge of Ay126 to constrain the locale of Fast Radio Bursts (FRBs).[1]

Background Information. Following an analysis of archival Parkes pulsar data towards the outskirts of the Small Magellanic Cloud D. Lorimer et al. (2007, Science) found the a 30 Jy burst with width < 5 ms that swept through the 1.28–1.52 GHz. From the quadratic frequency dependent sweep the authors inferred a dispersion measure of $375 \pm 1\,\mathrm{cm^{-3}\,pc}$ (hereafter, the *Sparker*). The flux across the observing band could be fitted to a power law model, $f_\nu \propto \nu^{-\alpha}$ with $\alpha \approx -1$. Such a power law index is quite similar to that seen in many non-thermal sources. The Galactic DM (due to WIM) is estimated to be $25\,\mathrm{cm^{-3}\,pc}$ (and verified by the DMs seen towards pulsars in the cluster 47 Tucanae (which is located 4 kpc from us). The authors interpret that the FRB was located in another galaxy and bulk of the DM is due to the IGM. The discovery was reported in 2007. The origin of the Sparker was controversial until six years later when a slew of such events (now renamed to Fast Radio Bursts) were discovered. The homework is concerned about the situation during the interregnum (2007-2013) when additional

Some Clues. It is worth noting that the Southern Hα Sky Survey Atlas (SHASSA)[2] shows no diffuse Galactic Hα emission towards this direction. SHASSA did not find any Hα emission and placed a limit to an Hα surface brightness of 1 Raleigh.[3] Next, the authors fit the arrival time ($t_a(\nu)$) assuming a model appropriate for cold plasma dispersion model, $t_a \propto \nu^{-n}$ with $n = 2$ and then derive the DM quoted above. However, one could be agnostic and instead allow for n to be derived from the data. It is found to be $n = 2 \pm 0.003$. You have been given sufficient information that you can obtain powerful constraints on the ISM along the way (thanks to taking Ay126).

[1] At this point it is generally accepted that FRBs are of extra-galactic origin but the exercise presented here was useful in placing limits on Galactic origin for FRBs. *Only after you have completed this problem set you may wish to read Kulkarni, S. R. et al. ApJ, 2014.*

[2] SHASSA uses a narrow band ($\pm 8\,\AA$) centered around Hα 6563 Å.The width is sufficient to include Galactic Halpha as well as that in SMC and considerably beyond.

[3] `http://www.astronomy.ohio-state.edu/~pogge/Ast871/Notes/Rayleighs.pdf`

The Motivation. The first step in understanding FRBs is, as was the case for GRBs, is the distance. Given the high stakes (the duration and the brightness temperature of the Sparker, if located at extra-galactic distances, would be truly astounding) here we explain other possibilities. We will consider the hypothesis that most of the DM arises due an intervening nebula. The principal parameters are the electron density (n_e), thickness (L) and the distance (d) to the nebula. The obvious constraint is $n_e L$ must account for the DM (less a reasonable contribution from the WIM). Thus there are only two free parameters, In addition, we have a choice: the intervening nebula can be either a sheet whose major axis is the long the light or a sphere. We will use knowledge of Ay126 to place constraints on the parameters. (hint: brush up on free-free optical absorption, radiative recombination, plasma frequency & dispersion relation for propagation through cold plasma).

1.1 Constraint: The Incoherent Brightness Temperature Limit. Assuming that the duration of the burst limits the size of the source estimate the brightness temperature, T_b, of the source. You will find this to be a function of D, the distance to the FRB. Compute D at which T_b is equal to the maximum value allowed by incoherent synchrotron(Ay121; $10^{12}\,\mathrm{K}$)? For simplicity we will also assume that the intervening nebula fills the entire path length to the source. Thus $\mathrm{DM} = Ln_e = Dn_e$. The only free parameter is then n_e. What are the constraints on n_e?[4] 5+10 pts.

1.2 An intervening Galactic ionized nebula? Realizing that giant pulse from pulsars have high brightness temperatures in considerable excess of $10^{12}\,\mathrm{K}$ we abandon the requirement that the source be located so close to us. So we let D be a free parameter, though restricting to the Galaxy, say $D \lesssim 100\,\mathrm{kpc}$. For simplicity we will assume that the intervening nebula is a sheet Since $\mathrm{DM} = n_e L$ the two free parameter for the intervening nebula are n_e and d. Derive the constraints on n_e using *all* possible constraints (hint: four constraints). 10 pts

Note: *When I set out to construct this problem set I had in mind spherical clouds. The finite size of the cloud allows a constraint on d. However, it would require a good understanding of surface brightness and beam size and I elected to simplify the problem. Problem 1.2, as currently posed, does not yield any constraint on d. If you are up to it, assume a spherical cloud of diameter L and you will learn quite a bit!*

1.3 Physical Properties of the putative nebula. Assuming the temperature of the nebular is $T = 8,000$ derive the physical properties of the nebula (pressure, free-free emission flux, rate of ionizing photons over a cube of side L and recombination timescale). 10 pts.

[2] **Scattering of Fast radio bursts.**[5] In class, we computed the temporal and angular

[4] Bear in mind that not all problems have neat solutions.

[5] NOTE: A handy reference for interstellar scintillation calculations is Walker, M (1998) (DOI: 10.1046/j.1365-8711.1998.01238.x). Its a short and easy to read paper. Read it first!

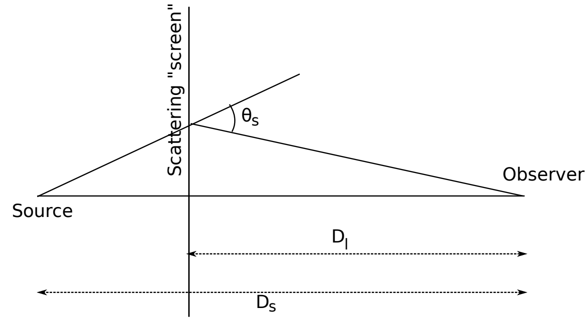

Figure 1: Generic scattering geometry

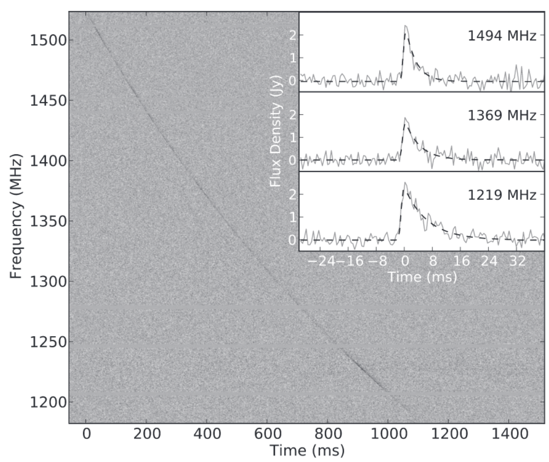

Figure 2: Fast radio burst temporal broadening

broadening for a case where the source was an infinity. Fig. 1 shows a geometry where this requirement is relaxed. Compute the angular size of the scattering disc (as seen by the observer) and the characteristic temporal broadening for this geometry. 5 pts

Fig. 2 shows the dynamic spectrum and temporal profile (inset) in three different frequency channels of a fast radio burst (Thornton et al. (2013) DOI:10.1126/science.1236789). The galactic latitude of the FRB is $\approx -57°$. If the temporal broadening of the FRB was caused due to propagation in a turbulent WIM similar to the Milky-way, what can you say about the distance to the medium? If on the other hand, the broadening was caused by a dense HII region (size $\sim 1\,\mathrm{pc}$) surrounding the source, what can you say about the diffractive scale and electron density in such a medium? 10 pts