USING `tbgfitflex_exp.pro`

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ABSTRACT

Deriving spin temperatures of self-absorbing HI 21-cm line components has some subtle aspects involving the background continuum. We discuss those here and how to incorporate those considerations into the use of `tbgfitflex_exp.pro` . Also, this program is totally flexible and can be used for fitting all cases of Gaussian components for the 21-cm line.

1. Radiative Transfer of the 21-cm Line

Consider a particular velocity of the 21-cm line for which we have, along the line of sight from near to far::

1. Nearest, an HI cloud with optical depth τ and spin temperature T_s (meant to be the Cold Neutral Medium, or CNM)
2. Next, an HI cloud with negligible optical depth and huge spin temperature (meant to be the Warm Neutral Medium, or WNM) which (in the absence of any foreground absorption or background emission) produces antenna temperature T_W
3. Furthest away, continuum emission with antenna temperature T_C. This might come from any or all of 'pont source', distributed Galactic synchrotron emission, and the Cosmic Microwave Background. T_C always has the 2.8 K CMB and some (perhaps weak) Galactic synchrotron background.

The equation of transfer that specifies the observed antenna temperature T_Z is

$$T_A = T_s\,[1 - \exp(-\tau)] \quad + \quad [T_W + T_C]\exp(-\tau) \tag{1}$$

Normally we perform frequency-switched obseervations. The off-line antenna temperature is just T_C. The switched spectrum is the difference, $\Delta T_A = online\ -\ offline$:

$$\Delta T_A = [T_s - T_C]\,[1 - \exp(-\tau)] \quad + \quad T_W \exp(-\tau) \tag{2}$$

We assume that the observed antenna temperatues versus velocity are known, and that the T_C is known. We assume that, for the CNM, the optical depth profile is given by a Gaussian;

and that, for the WNM, the emission profile is given by a Gaussian. We have many equations like this, each equation at a different velocity. The unknown parameters that we solve for are (1) T_s; (2) three Gaussian parameters for each CNM component; (3) three Gaussian parameters for each WNM component. Our program `tbgfitflex_exp` solves for these unknowns.

2. Running `tbgfitflex_exp`: Comments, etc.

In principle, we could use either equation above in this least-squares solution. In practice, we use equation 1 because it is more straightforward to deal with softwarewise. Thus, the software expects, as input, T_A from equation 1. In contrast, it is often true that you have available to you the switched spectrum ΔT_A from equation 2, in which case you must add T_C to that switched spectrum. Some comments:

1. Use T_A as the input to the program. This means that the 'baseline', the portion of the spectrum that lies outside the line, must *not* be zero, as it is with the switched spectrum ΔT_A, but ratheer should equal T_C outside the line. Thus, if you have only the switched spectrum ΔT_A, use as the input $T_A = \Delta T_A + T_C$.
2. The quantity T_A is never negative. If your spectrum $T_A = \Delta T_A + T_C$ is negative at some velocities (where the CNM optical depth is high) then you are using too small a value of T_C.
3. T_C consists of the CBR (2.8 K), any point- or small-extneded-source contributions, and the Galactic synchrotron background. To estimate this Galactic contribution:
   (a) Go to Haslam, Salter, Stoffel, & Wilson (1982 A&A Suppl 47, 1: 'A 408 MHz all-sky continuum survey. II - The atlas of contour maps'), read off the 408 MHz brightness temperature (or use the electronic catalog version) T_{408}.
   (b) The Galactic synchrotron background has a brightness temperature spectral index of about 2.7. Thus, divide the T_{408} by $\left(\frac{1420}{408}\right)^{2.7}$, i.e. divide by 30.
   (c) When fitting Gaussians, my experience is that it's a good idea to allow for a floating zero offset. That is, allow the program to solve for the continuum zero point by setting `continuum_yn = 1`. This will change the value of `continuum` a little bit, which won't matter much for derived spin temperatures or oher quantities, but it will probably help the fit to converge and provide better Gaussian-fit parameters, particularly for wide lines.
4. Stokes I is the sum of two orthogonal polarizations. If you are fitting a Stokes I profile, realize the following:
   (a) The line profile is Stokes I, which is twice the normal single-polarization value.
   (b) Thus, divide the Stokes I intensities by 2 for the input to this program.

3. `tbgfitflex_exp` Works for Both Absorption and Emission Lines—It's Totally Flexible!

3.1. The CNM and the WNM

`tbgfitflex_exp` is *totally flexible!* It assumes two kinds of 21-cm line. The naming convention is based on the HI being either CNM or WNM, where the CNM components absorb and also emit, while the WNM components are optically thin and have no absorption. If you molecules, such as OH, the optical depth for any component is probably always nonzero, so you can treat all components as being CNM. To be more specific:

1. Components with Gaussian parameters designated by the prefix `cnm` ('Cold Neutral Medium', or 'CNM') have nonzero optical depth and (1) absorb the radiation coming from behind, as well as (2) emit their own radiation. Each Gaussian compoment has a central optical depth, center, width, and spin temperature. Additionally, you have to specify the order along the line of sight (`order`), because nearer clouds absorb the radiation from more distant ones.

2. Components with Gaussian parameters designated by the prefix `wnm` ('Warm Neutral Medium', or 'WNM'), have zero optical depth. Each WNM component can be placed anywhere with respect to all the CNM components, specified by the parameter `fwnm`: `fwnm`=0 means the WNM lies behind all of the CNM components, `fwnm`=1 means it lies in front of all the CNM componnts, and a fractional values between 0 and 1 have the obvious meaning and are allowed.

3. The program requires at least one component of each type. This does not limit its flexibility: for example, if you have only emission lines and optical depths are negligible, then specify a single, exceedingly weak CNM component whose center lies outside the velocity range being analyzed and set all the 'yn' parameters for this component equal to zero so that the program doesn't try to least-squares fit the component. If you have only absorption lines, then do the same for a single WNM component.

4. You also specify the `continuum`, which is assumed to lie behind all of the CNM components. If you are fitting an absorption line of a continuum source (onsrc-offsrc), the `contiinuum` should be the continuum source deflection.

4. Gaining Confidence in `tbgfitflex_exp`

In the subdirectory that contains this procedure there is an IDL command file that generates spectra and then does the least squares solution using `tbgfitflex_exp`. It is called `tst_tbg.idl`, invoked within IDL by typing `@tst_tbg.idl`.