Guide to Planning Observations with SOFIA/GREAT

1. Introduction

GREAT is a heterodyne receiver, similar to HIFI on Herschel, designed to observe spectral lines in the THz region with high spectral resolution and sensitivity. Heterodyne receivers work by mixing the signal from a source at a given frequency ν_s with that from a local oscillator (LO) at a specified (and precisely controlled) frequency ν_{LO} and amplifying the result. The mixing results in two frequency bands, called the signal and the image bands, located symmetrically on either side of ν_{LO} and separated from ν_{LO} by the intermediate frequency $\nu_{IF} = |\nu_s - \nu_{LO}|$. GREAT operates in double sideband mode, i.e. both the image and signal bands are equally sensitive to incoming radiation. By definition the spectral line of interest is always centered in the signal band, which can be chosen to be either above (Upper Side Band, USB) or below the LO frequency (Lower Side Band, LSB); see Figure 1 below. For sources rich in spectral lines, care has to be taken so that a spectral line in the image band does not overlap or blend with the line in the signal band.

A detailed description of the GREAT instrument and its performance during Basic Science can be found in the GREAT special issue (Heyminck et al. 2012, A&A, 542, L1). However, as the instrument is regularly being upgraded and the performance improves, always check the GREAT team web page for the latest information (http://www3.mpifr-bonn.mpg.de/div/submmtech/).

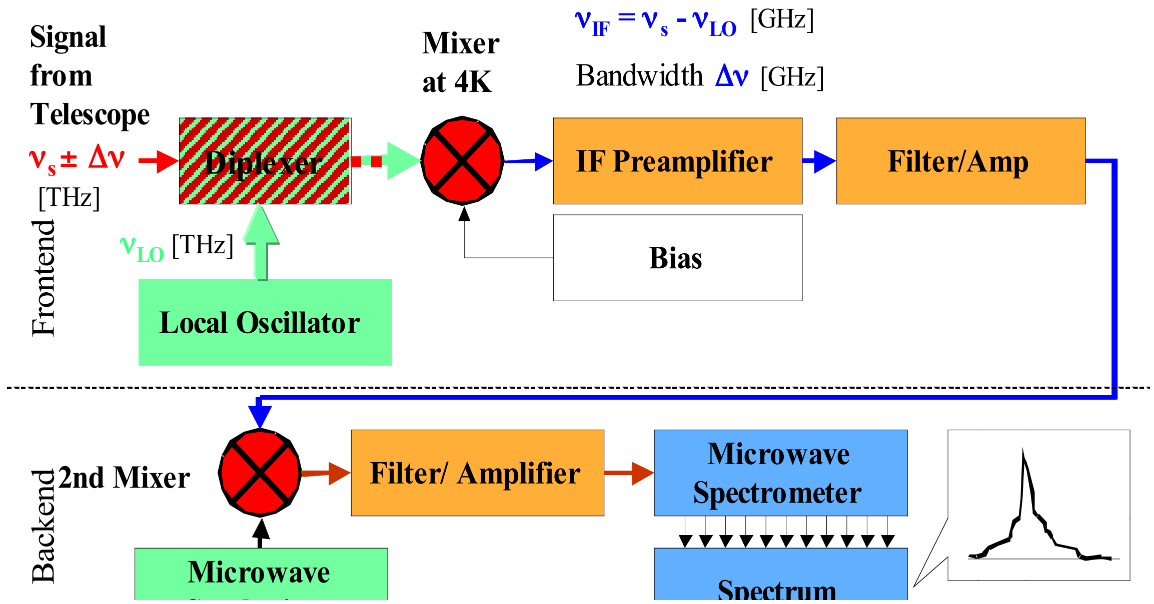

Fig. 1: *Schematics of one GREAT receiver channel. The second mixer-stage is needed to match the operational frequencies of the first mixer-element to that of the microwave spectrometer.*

2. Front-end Set-Up

GREAT is a dual-channel heterodyne instrument. The user must select a different mixer for each channel. These are then operated simultaneously. The mixers that are currently operational are listed in the table below. Not every mixer configuration will be available at any given time. Also, not all frequencies have been checked, so there may be gaps where the LOs do not provide enough power to pump the mixer. Please check the GREAT website or the SOFIA helpdesk for the latest information.

Front-end	Frequencies [THz]	Lines of Interest
Low frequency L1[1]	1.25-1.39	CO (11-10),(12-11), OD, SH, H2D+, etc.
	1.42-1.52	CO 13-12, [NII], etc.
Low frequency L2	1.80-1.90	CO 16-15, [CII], NH_3 3-2, OH $^2\Pi_{1/2}$, etc.
Mid frequency Ma	2.49-2.56	^{18}OH $^2\Pi_{3/2}$
Mid frequency Mb	2.67-2.68	HD 1-0
High frequency H	4.7448	[OI]

In Cycle 3, GREAT offers only two mixer configurations: the low frequency configuration (L1-L2), employing L1 in one dewar and L2 in the second dewar) and the low2 and high frequency configuration, (L2-H), which simultaneously covers the important cooling lines [CII] and [OI], although L2 can also be tuned to molecular lines within that band. Both configurations (L1-L2, and L2-H) are expected to be available for each observing campaign. A configuration change takes three days and is usually done over a weekend.

3. Back-end Set-Up

Each of the two installed mixers is provided with two digital Fast Fourier Transform (FFT) spectrometers: the XFFTS and the AFFTS. The XFFTS has a bandwidth of 2.5 GHz and 64,000 channels, providing a resolution of 44 kHz. The older generation, AFFTS has a 1.5 GHz bandwidth and a resolution of 212 kHz.

The usable instantaneous bandwidth is generally less than that covered by the FFTS. The L1 mixer has a double side band (DSB) receiver temperature of 750 K averaged over a 1 GHz bandwidth. The usable bandwidth is more than 1.5 GHz, but with higher receiver temperatures at the edge of the band. For L2, the DSB receiver temperature is 1100 K, also averaged over a 1 GHz bandwidth. The receiver temperature for the mid-frequency channel Ma is ~ 2200 K averaged over a 1 GHz bandwidth. The receiver temperature for the H-channel is 1400 K over 1.9 GHz, which corresponds to a velocity range of only 120 km/s. The tunability of the H-Channel is limited because the LO, a Quantum Cascade Laser can only be tuned in discrete steps. The standard LO setup of 1.682 GHz (relative

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[1] the gap in the L1 coverage between 1.39-1.42 THz matches the frequencies that are blocked by the atmosphere

to the [OI] rest frequency, 4.74477749 THz) offers usable velocity coverage from -25 km/s to 90 km/s. The negative velocity setup (LO offset 0) provides a usable velocity range from -30 to -140 km/s. For this tuning the signal band has to be USB and therefore the image band moves towards the less transparent part of the atmosphere, but because of the negative velocity shift, the system temperature for both cases is comparable. Both LO setups requires the user to calculate the LSR velocity including Doppler shift, see examples in Appendix 1

4. Observing Modes

Four basic observing modes are currently offered:

1) **Position switching mode.** In this mode the telescope alternates (nods) between the target and a nearby reference position free of emission spending equal amount of time on each position. From the difference of each pair of spectra, i.e. target – reference, often called ON – OFF, the GREAT software produces a spectrum, which is largely corrected for atmospheric and instrumental effects. The integration time spent on a single target position depends on the stability of the receiver and how fast the atmosphere fluctuates. It is typically ≤30 seconds, but can be adjusted during the flight if necessary. If shorter integration times are used, one gets a better cancellation of the sky fluctuations, but adds to overheads and therefore reduces the observing efficiency. The ON – OFF cycle is repeated until the required sensitivity is reached.

   Position switching is used when we want to observe one or a few positions of an extended source, like a large molecular cloud. If the reference position is far from the target position, e.g., 30 arcmin or more, changes in the sky background will result in poor baselines. If you cannot identify a reference position within 30 arcmin from your source position, choose a reference position say half way between your source and measure it against your clean reference position.

2) **Dual Beam Switching (DBS) mode.** In this mode the secondary mirror is chopping between the target (signal) and a sky position (reference) at a rate of 1 Hz. The maximum chop throw must be < 10 arcmin, set by the limits of the chopping secondary. In addition, the telescope nods between the signal and the reference, typically ≤40 seconds. The difference, signal – reference, divided by the reference, produces a spectrum similar to what we get in position switching mode. Because the chopping secondary continuously produces a difference between the target and the sky, this mode results in better sky cancellation and hence better baseline stability.

   Beam switching is typically used for point or compact sources, because the chop throw has to be larger than half of the source size. Keep the chop throw as small as possible, preferably in the range of 60 – 120 arcseconds. Large chop throws introduce coma, i.e. distorts the beam, and uncertainties in the chop throw results in pointing errors, if there is a difference between the chop throw and the nod.

3) **Raster mapping.** This mode is for small maps or strips, where one needs relatively long integration times per map point. A typical example would be a small 3 x 3 map (9 points) with 30 seconds per map point. Raster maps can be done in either beam switched or position switch mode. For larger maps of bright lines the preferred mode is on-the fly mapping (see below), which is more efficient. However, even for a small map the OTF mode is more efficient as long as the lines is bright enough so that one can reach the required signal to noise within 20 or 30 repeats of the map.

4) **On-The-Fly (OTF) mapping.** In this mode the telescope starts with the reference position and then scans along a row (at constant latitude if the map rotation is zero – the default), while the backends are continuously integrating the incoming signal. An average is recorded after the telescope has moved a fraction (typically half to one third) of the beam size. Each average therefore corresponds to a point on the sky with a finite width. At the end of the row the telescope again moves to the reference position where it integrates $\sqrt{N}$ times the integration time per point, where N is the number of points in a row. After all positions in the row and the reference position are completed, the telescope steps about half a beam width in latitude and does a new scan + reference. This process is repeated until we have built up a map of the desired size. The whole map is repeated until the required sensitivity is reached. The grid size must be the same in both latitude and longitude.

   On SOFIA, OTF mapping is more efficient than raster mapping in position switch mode, only if the integration time per position is small. Thus, on-the-fly mapping is the preferred mode when we want to map the distribution of a relatively bright line over a large area (e.g., a map of the [C II] 158 μm line in a molecular cloud). For faint emission, it is therefore better to stick to raster mapping.

   The size of the scan is limited by the stability of the receiver and atmosphere and the time spent on the scan and reference position is therefore typically limited to less than 60 seconds. The minimum integration time per position is 1sec/map point. For a large map one therefore has to break up the map into a number of sub-maps.

5. Sensitivity and Observing Time Estimation

Sensitivities and observing time estimates can be obtained with the online tool http://great.sofia.usra.edu/cgi-bin/great/great.cgi It calculates either the signal-to-noise ratio for a given line brightness and integration time (ON+OFF), or the integration time (ON+OFF) needed to reach a certain RMS noise level for one point on the sky (ON minus OFF). These integration times do not include tuning, chopping, slewing and other observatory overheads. The total time, including all overheads, is determined in SPT or SSPOT after entering the time calculated by the online GREAT time estimator.

As for other heterodyne receivers that use hot and cold loads to measure the receiver temperature, the intensity units are Kelvin (K). The intensity scale used in the online tool is brightness temperature T_R^*. This relates to the measured antenna temperature as $T_A^*=T_R^*\eta_{fss}$ and the main beam temperature (corrected for losses in the side lobes) as $T_{MB}=T_R^*/\eta_{MB.}$ For GREAT, η_{fss}=0.95 and in bands L1 and L2 η_{MB}=0.67. A detailed description of the GREAT intensity calibration is given in Appendix 1. It also contains worked out examples for different observing modes, as well as unit conversions.

The online GREAT time estimator is also useful to determine in which sideband the line of interest is best put, taking into account the atmospheric transmission. System temperatures for the line in the USB or LSB are given, as well as a plot showing the line locations for either LO tuning in comparison with the atmospheric transmission.

6. SSPOT Entries

SSPOT has observation templates (AORs) for the GREAT Single Point, Raster Map and OTF Map modes. The following information needs to be provided:

- Source velocity (LSR) and rest frequencies of the line to be observed with mixer 1 and of the line to be observed with mixer 2. The specific mixers (see the table in section 2) to use must be selected with the buttons. The flight team will decide the optimal LO frequencies for observing these lines (USB versus LSB, position of the line in the IF), taking into account frequency-dependent system performance and atmospheric transmission. If you have specific requests, such as observing other lines in the same setting, please note those in the comments section of the AOR template.
- If you are searching for a line or if you are uncertain about how strong, and at what velocity your line will be, do at least one frequency shift. The easiest way to do this is to change the source velocity (V_{lsr}) by something like 10 to 20 km/s. The mixer will have to be retuned and a new calibration done, which involves a small cost in time (~2 minutes).
- You do not have to choose a backend. Data gets automatically recorded on all backends.
- For all observing modes, the integration time per point on the sky must be entered. This should not be more than ~60 seconds, although for Dual Beam Switch Mode our default is 80 seconds (40 second in each nod position). If longer exposures are needed, which is almost always the case, please increase the number of cycles. For maps, ‘cycles’ indicates the number of times the maps are repeated.
- Plan each AOR so that it does not take longer than about half an hour to execute. If you are making a big OTF map, make it into a set of smaller maps. With the entry “Minimum Contiguous Exposure Time” you can specify the minimum acceptable observing time in case the observation has to be split over multiple parts for, e.g., efficient flight planning.
- For all AORs, the instrument mode ‘Total Power’ refers to position switch.
- In OTF mode, the ‘Single Beam Switch’ instrument mode is rarely used. Position switch is preferred.

- In Dual Beam Switch Mode (for point and raster map AORs), a chopping angle can be specified, defined in the usual 'North through East' direction.
- Choose your reference position as close to your source as possible. Absolutely no further away than half a degree and preferably you can find a reference position within 10 – 15 arcminutes from your source. A reference position, which is more than half a degree away from your target, is not likely to work and may result in really poor baselines. The same is true if you observe in beam switched mode. For most observations a chop throw of 100" or less should be sufficient. Large chop throws degrade the pointing of the telescope, introduces coma into the beam and degrades the data quality.

Appendix 1: GREAT Sensitivity Calculations

The GREAT sensitivities and integration times are calculated with the online tool http://great.sofia.usra.edu/cgi-bin/great/great.cgi Here, the background of these calculations and some worked out examples are presented.

Because of the way a heterodyne receiver is calibrated (i.e. measuring the receiver temperature, T_{rx}, with a hot and a cold load), the logical intensity unit for a heterodyne observation is temperature, expressed in Kelvin (K). Either the antenna temperature, T_A^*, (The asterisk refers to values after correction for sky transmission, telescope losses and rearward spillover, see e.g. Kutner and Ulich, ApJ, 250, 341 (1981)) or the main beam brightness temperature, T_{mb} , are used. Similarly, the noise is expressed in temperature units as well, ΔT_A^* or ΔT_{mb}, and the sensitivity (or signal-to-noise ratio) of the observations are given by the ratio of the source temperature and the rms temperature of the spectrum. In order to calculate these quantities, we first must estimate the single sideband (SSB) system temperature, T_{sys}, which also includes losses from the atmosphere and the telescope. T_{sys} is given by

$$T_{sys} = 2 \text{ x } [T_{rx} + \eta_{telJ} \text{ x } T_{sky} + \eta_{tel} \text{ x } T_s + T_{tel}] / (\eta_{tel} \text{ x } \eta_{sky}) \qquad (1)$$

where

T_{rx} is the double side band (DSB) receiver temperature;
T_{sky} is the radiation temperature of the sky
T_s is the continuum temperature of the source. This term is usually completely negligible (unless you observe an extremely bright object (like Jupiter, Saturn or Sgr B2) and is therefore set to 0 in the GREAT time estimator.
T_{tel} is the Rayleigh-Jeans telescope temperature;
η_{sky} is the fraction of radiation transmitted through the atmosphere; and
η_{tel} is the efficiency of the telescope, which includes ohmic losses and spillover.

The factor 2 in expression (1) assumes that the noise temperature is the same in both signal and image band, which is true for the HEB mixers used by GREAT.

The transmission of the atmosphere, η_{sky}, at the altitude, observing frequency and airmass that we plan to observe at, can be estimated using the atmospheric transmission code ATRAN, available on the SOFIA webpage. The GREAT time estimator calls ATRAN directly, so if you are estimating the integration time you need using the time estimator, there is no need to run ATRAN separately. T_{sky} depends on η_{sky} and the ambient temperature of the sky (T_{amb}) where the signal is absorbed and can be derived from the expression

$$T_{sky} = J(T_{amb}) \times (1 - \eta_{sky}) \qquad (2)$$

where $J(T_{amb})$ is the mean Rayleigh-Jeans (R-J) temperature of the atmosphere, which we assume to have a physical temperature of 220 K at 41,000 ft, resulting in $J(T_{amb}) =$ 177.5 K at 1.9 THz. Likewise the telescope temperature, T_{tel}, is related to η_{tel} by

$$T_{tel} = J_{tel} \times (1 - \eta_{tel}) \qquad (3)$$

where J_{tel} is the radiation temperature of the telescope, with a physical temperature ~ 230 K (J_{tel} = 187.4 K at 1.9 THz). If we assume an η_{tel} of 0.92, then T_{tel} = 14.8 K.

As an example, let us calculate the system temperature at the [CII] fine structure line at 157.74 µm (1.9005369 THz). In this example we calculate what we would have at the beginning of a flight, when we are still at low altitude. We therefore assume that we fly at an altitude of 39,000 ft and observe at an elevation of 30 degree. For a standard atmospheric model this corresponds to a transmission of ~ 76%, which gives T_{sky} = 42.6 K. For a receiver temperature T_{rc} = 1100 K, Equation (1) therefore predicts a single sideband system temperature T_{sys} = 3301 K when observing the sky.

Now we are ready to calculate the sensitivity. The rms antenna temperature, (corrected for the atmospheric absorption, and telescope losses), ΔT_A^*, for both position switching and beam switching is given by

$$\Delta T_A^* = (2 \times T_{sys} \times \kappa) \times (t \times \Delta\nu)^{-0.5} \qquad (4)$$

where κ is the backend degradation factor, t is the total integration time of the number of on and off pairs that we plan to take, and Δν is the frequency resolution of our spectra. Strictly speaking, Δν is the noise bandwidth, which can be slightly different than the frequency resolution, depending on the design of the spectrometer. For our example we expect the Full Width Half Maximum (FWHM) of the line to be a few km/s, and we will therefore calculate the rms for a velocity resolution of 1 km/s, corresponding to a frequency resolution of 6.3 MHz. Since both backends for L2 have much higher resolution, this is not a problem. We can easily bin the spectrum to our desired velocity resolution. For an observation with 3 pairs of 40 seconds in each beam, or t = 4 min, and assuming the backend degradation factor κ=1, we then find ΔT_A^* = 0.17 K, which is the one sigma rms antenna temperature.

To convert antenna temperature to brightness temperature T_R^*, we have to make one more correction.

$$T_R^* = T_A^*/\eta_{fss} \qquad (5)$$

where η_{fss} is the forward scattering efficiency, usually measured for a very extended source (like the Moon). For GREAT η_{fss} = 0.97. Therefore our brightness rms temperature, ΔT_R^* = 0.18 K.[2] Note: The GREAT time estimator assumes the line temperature in T_R^*, and *not in main beam brightness temperature*, $T_{mb} = T_R^*/\eta_{mb}$, which is for a source that just fills the main beam. For the GREAT L1 and the L2 band, η_{mb} = 0.67

If we want to express our results in flux density, S_ν, rather than brightness temperature, we can convert antenna temperature, T_A, to flux density, S_ν, using the standard relation

$$S_\nu = 2 \text{ x } k \text{ x } \eta_{fss} \text{ x } T_A^*/A_{eff} \qquad (6)$$

where k is the Boltzmann constant, and A_{eff} is the effective area of the telescope. A_{eff} is related to the geometrical surface area of the telescope, A_g, by the aperture efficiency, η_a, i.e. $A_{eff} = \eta_a \text{ x } A_g$. For the measured main beam efficiency in early April 2013 (0.67) and a Half Power Beam Width (HPBW) of ~ 15.3 arcsec (+/- 0.3 arcsec) I therefore derive an aperture efficiency[3] of 55 +/- 2 %, equation (6) yields the following simple form for the 2.5 m SOFIA telescope:

$$S\,(\text{Jy}) = 971 \text{ x } T_A^*\,(\text{K}) \text{ or within errors} \sim 1000 \text{ x } T_A^*\,(\text{K}) \qquad (7)$$

Normally we use Jy only for spatially unresolved sources, but we can also use relation (7) to convert line intensities into W/m^2, which maybe a more familiar unit for the far infrared community. If we assume that the [CII] line we are observing is a Gaussian with a Full With Half Maximum (FWHM) of = 5 km/s, i.e. 31.8 MHz, the integrated line intensity is given by 1.065 x T_{peak} x $\Delta\nu$, where $\Delta\nu$ = 31.8 MHz. If we take T_{peak} equal to our rms antenna temperature, we find using Equation 7 that our 4 minute integration therefore corresponds to a one sigma brightness limit of ~ 6.1 10^{-17} W/m^2 for a 5 km/s wide line observed with 1 km/s resolution. If we only aim for a detection, we can probably degrade the resolution to 2 km/s. In this case we gain a square root of 2, and therefore our one sigma detection limit is 4.3 10^{-17} W/m^2.

When you are writing a proposal, you normally go the other way around. You have an estimate how wide and how bright the line is expected to be, and you know what signal to noise you need for your analysis. Let's assume we want to observe the [CII] 158 μm line

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[2] The GREAT Time estimator (http://great.sofia.usra.edu/cgi-bin/great) gives ΔT_R^* = 0.18 K, for USB tuning, which agrees with what we get.

[3] The beam efficiency is directly related to the aperture efficiency by the expression $\eta_{mb}/\eta_a = A_g \text{ x } \Omega_{mb}/\lambda^2$, where Ω_{mb} is the main beam solid angle and λ the wavelength we observe at.

in T Tauri, a young low-mass star. Podio et al. (2012, A&A, 545, A44) find a line intensity of 7.5 10^{-16} W m^{-2} for the Herschel PACS observations, which are unresolved in velocity (the PACS velocity resolution is ~ 240 km/s for [CII]). Here we want to velocity resolve the line to see if it is outflow dominated or whether it is emitted from a circumstellar disk or both. We therefore need a velocity resolution of 1 km/s or better. If we assume that the line is outflow dominated with a FWHM of say 20 km/s (127.2 MHz; little or no contribution from the circumstellar disk) we get a peak antenna temperature (using equation 7) of 0.52 K or a radiation temperature T_R^* of 0.55 K. In this case we want a SNR of at least 10 and a velocity resolution of 1 km/s or better. Let's check whether it is feasible. If we plug in the values we have in the GREAT time estimator (assume 40 degrees elevation, standard atmosphere, and we fly at 41000 ft) or we can estimate it from the equations given above.

With these assumptions ATRAN gives us an atmospheric transmission of 0.86 integrated over the receiver band-pass. The L2 receiver temperature is 1100 K (DSB). Using Equation 2, we find that the sky only adds 24.9 K to the system temperature and from Equation 1 we therefore get T_{sys} = 2881 K. Since we want to reach a signal to noise of 10, the rms antenna temperature ΔT_A^* = 0.052 K. We can now solve for the integration time using Equation 4, where we set $\Delta\nu$ = 6.338 MHz (1 km/s resolution). In this case t= 1937 sec or 32.3 min. The PACS observations show the emission to be compact, so we can do the observations in Dual Beam Switch Mode, with a chop throw of 60 arcsecond. Both Dual BMSW and position switch are currently estimated to have an overhead of 100% and a setup time for tuning and calibration of 2 minutes (which get added when you enter the observations in SPT, the SOFIA proposal tool). Our observation would therefore take 60 minutes, which is completely feasible. The GREAT exposure time calculator gives t = 1930 sec. The difference is negligible.

Sensitivity for an on-the fly map:

Example: For a map of the [CII] line (Half Power Beam Width, HPBW ~ 15 arcsec), we need to sample the beam about every 7 arcsec. If we read out the average once per second, i.e we have a scan rate of 7 arcsec/second. To do a 3 arcmin scan will therefore take 26 sec, resulting in 26 map points, let us make it 27, to get an odd number of points. We therefore need to spend 5.2 seconds on the reference position. We ignore the time it takes the telescope to slew to the next row and any time needed for calibration. For a 3 arcmin x 3 arcmin map, i.e. 27 x 27 positions with a cell size of 7 arcsec times 7 arcsec. The integration time for each row is therefore 5.2 +27 seconds or 32.2 seconds/row. The total integration time for the map is therefore 14.5 minutes. We definitely want to do one repeat, so the total integration time is therefore 29 minutes. For on-the fly maps SPT assumes a 100 % overhead and 2 minute setup for tuning and calibration. The total duration of the 2 maps is therefore 61.9 minutes. Therefore a 3 arcmin x 3 arcmin map in the [C II] line is entirely feasible.

Our 3 by 3 arcmin^2 map with one repeat has an integration time of 2 seconds per map point[4]. However, since we critically sampled the map, each beam is covered by 3.6 data points, which increases the sensitivity by a factor of 1.9. For typical observing conditions, 41000 feet, 30 degrees elevation, the GREAT time estimator gives us an rms temperature/map point of 1.27 K for a velocity resolution of 1 km/s, corresponding to an rms limit of 1.27 K/1.9 or ~0.7 K/beam.

The H-channel

The H-channel (offered on shared risk for cycle 3) is also included in the GREAT exposure time calculator. Since the LO (local oscillator) only can be tuned to discrete settings, there is no Doppler tracking and even with a 2.5 GHz instantaneous bandwidth (158 km/s at the rest frequency of [OI]) the velocity coverage is limited to ~ 120 km/s. The standard setting (LO offset 1.682 GHz) gives a velocity coverage from about -25 to +90 km/s. Let us examine what this means in practice. Below I show a CO spectrum of the young protostellar outflow source NGC2023mm1 and here I simply assume that we could have an [OI] line centered at the same velocity with a similar shape.

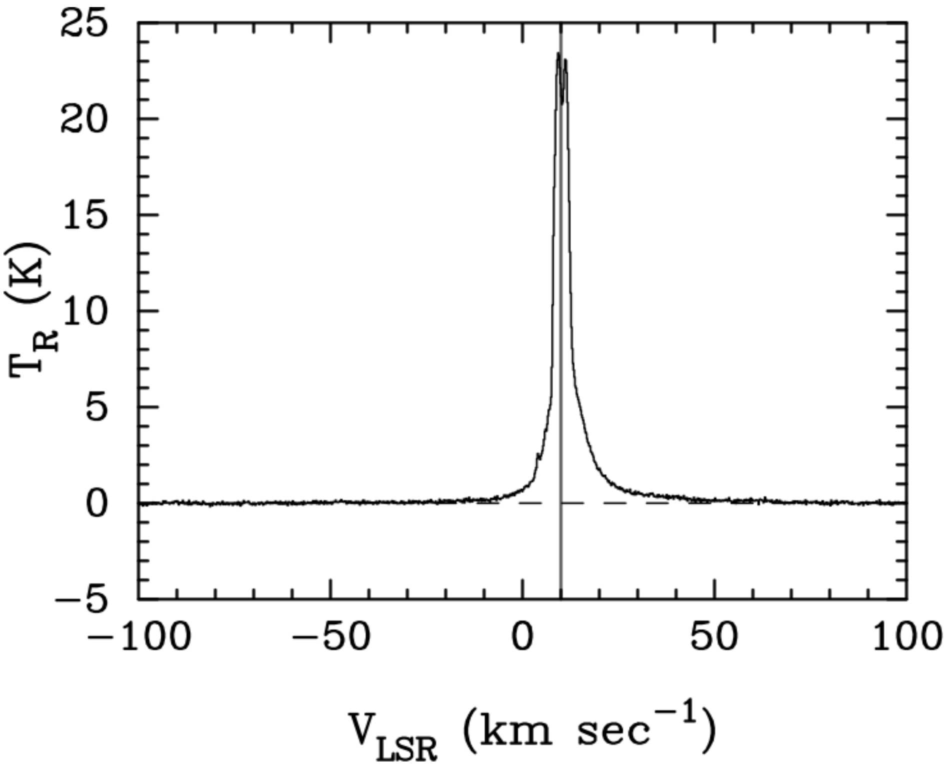

Fig 2. Assumed [OI] spectrum using CO as a proxy. We would like to reach an rms level of 0.2 K for a resolution of 1 km/s

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[4] Remember that the time estimator uses the total integration time (on+off). Here we therefore have to use 4 second as integration time to investigate the sensitivity limit per map point.

Lets start up the GREAT exposure time calculator. The first thing we do is to click on the observer VLSR link. Here we assume that we will observe NGC2023 on March 1, 2015 at UT 10. For observer latitude and longitude we choose Palmdale as our location (this is not very critical); Latitude = 34.58, west longitude = 118.1. The source coordinates are RA = 054124.9, DEC = -021808.5 and Equinox J2000. We work in topocentric reference frame and enter 12500 as elevation. This gives us a solar motion Vlsr of 44.1 km/s, which we have to add to the source Vlsr of 10 km/s. Suddenly our spectrum is centered at +54 km/s and no longer in the center of the covered velocity range, see below:

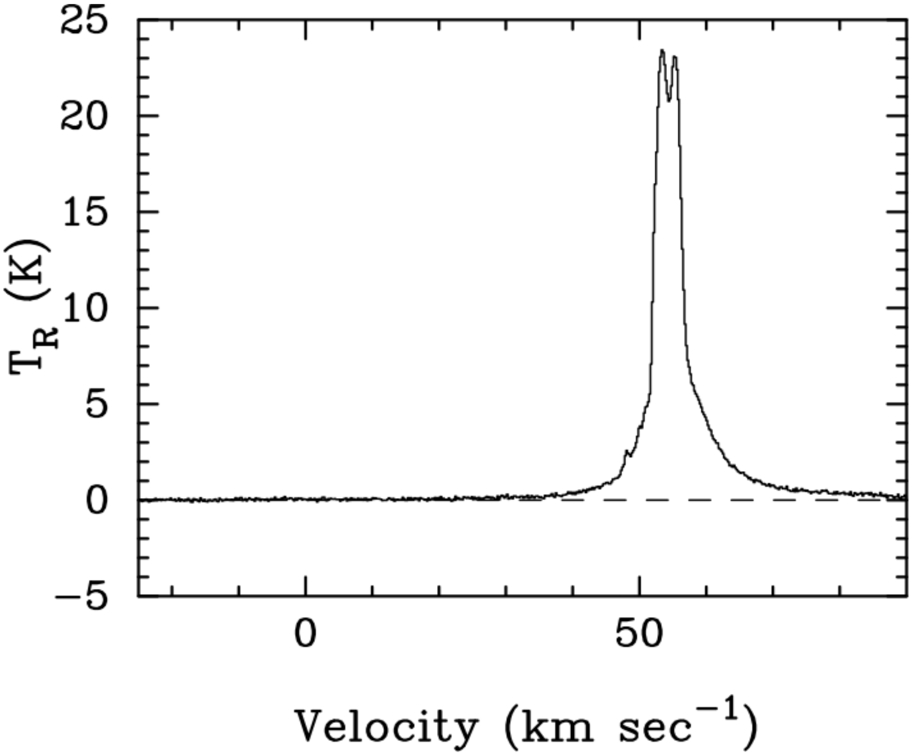


Fig. 3. What the [OI] spectrum would look like if we observed it on March 1, 2015. Now the observations are not feasible, because we have no baseline region on the red-shifted side. We need at least at least 5 – 10 km/s free of emission on both sides to recover the true shape of the spectrum. In reality the noise would also be higher close the band edges.

What if we delayed the observations until December 2015. For Dec 1 the Doppler correction is +10.4 km/s, and now it should be possible to observe NGC2023mm1, see Figure 4. We can now proceed to estimate how long it will take us to reach an rms limit of 0.1 K. If we assume that we observe at 41000 ft with an elevation of 45 degrees, the time estimator gives an integration time of 1312 seconds (LSB tuning) or 22 minutes, which is entirely feasible, see Figure 5, which shows the output from the exposure time calculator.

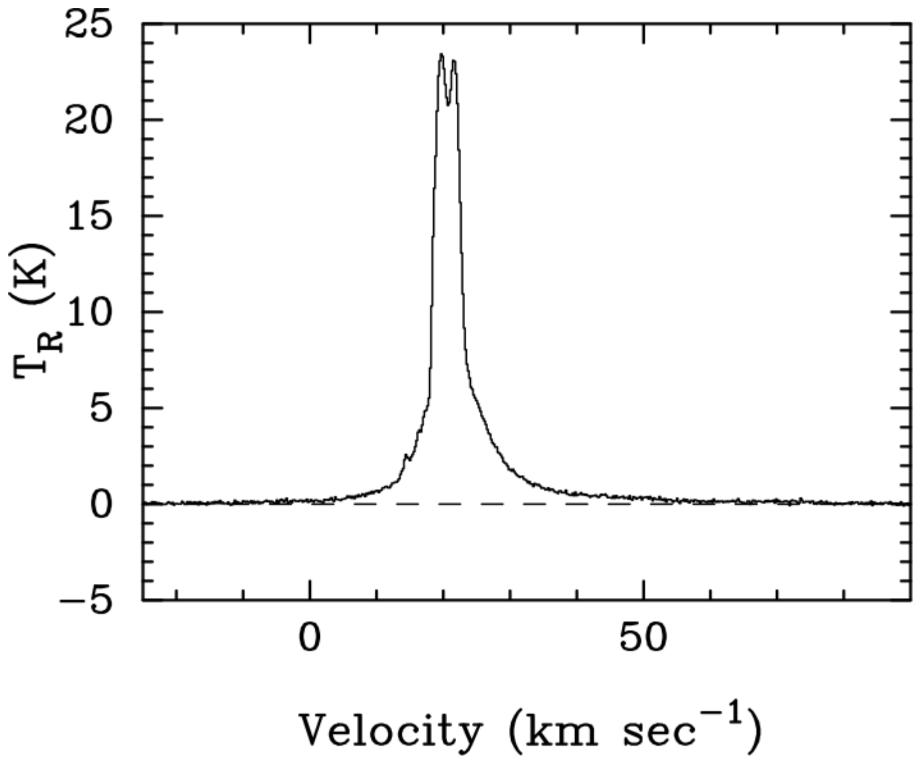
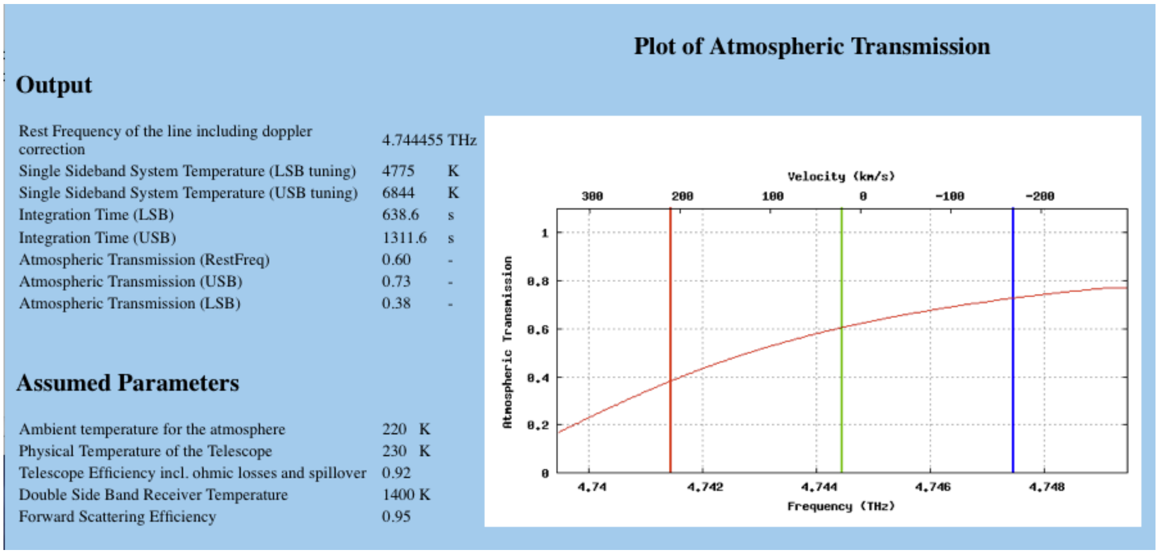


Fig. 4. The same [OI] line for the standard LO setting, but now observed on December 1, 2015. Now the spectrum is well placed within the observable velocity range.



Output

Rest Frequency of the line including doppler correction	4.744455	THz
Single Sideband System Temperature (LSB tuning)	4775	K
Single Sideband System Temperature (USB tuning)	6844	K
Integration Time (LSB)	638.6	s
Integration Time (USB)	1311.6	s
Atmospheric Transmission (RestFreq)	0.60	-
Atmospheric Transmission (USB)	0.73	-
Atmospheric Transmission (LSB)	0.38	-

Assumed Parameters

Ambient temperature for the atmosphere	220 K
Physical Temperature of the Telescope	230 K
Telescope Efficiency incl. ohmic losses and spillover	0.92
Double Side Band Receiver Temperature	1400 K
Forward Scattering Efficiency	0.95

Fig 5.Above the output from the exposure time calculator is shown for the velocity setting from Figure 4. The green line shows where the [OI] line is centered in the signal band, while the blue line shows the center of the image band. The red line shows where the image band would be if we were to place the line in the upper sideband, which would result in much higher noise temperatures.

If we have a source with negative V_{LSR}, we can do the same kind of exercise, but now use the alternative LO setting (offset 0 MHz). This gives us a usable velocity range from -30 to -140 km/s. Other LO settings maybe possible. If you cannot work with either setting, please check with the GREAT PI, Rolf Güsten, to see whether there is another LO setting that might work.