# Worked example: CII line in the Horsehead Nebula Map with GREAT

So you want to observe a CII line on a wide region and map kinematics... let's go through the steps to determine whether that is doable and how to implement such a program in USPOT, using the example of the Horsehead nebula, which has already been observed by SOFIA (https://www.sofia.usra.edu/science/proposing-and-observing/proposal-calls/sofia-directors-discretionary-time/horsehead-nebula-c)

**- is there a CII line covered by a SOFIA instrumen**t?
Search transitions in a line catalog (Splatalogue for example https://www.cv.nrao.edu/php/splat/): there is a fine structure line at **1.9 THz = 157.7 microns**
The instrument summary https://www.sofia.usra.edu/science/instruments
and Observers Handbook https://www.sofia.usra.edu/science/proposing-and-observing/observers-handbook-cycle-8 will tell you whether that wavelength is covered
→ both GREAT (LFA array) and FIFI-LS (red channel) cover that line

**- is the spectral resolution sufficient for my science purpose?**
We need to resolve to line (~20 km/s) to get kinematics at a **1 km/s** level
Based on the Observers' Handbook, GREAT's resolution is 44 kHz, at 158 microns this corresponds to 7 m/s... this is more than sufficient.
FIFI-LS red channel resolution is only 260 km/s: not adequate for kinematics but could be more efficient if we only want to map intensity.

**- is the source a duplication / reserved source?**
https://www.sofia.usra.edu/sites/default/files/Other/Documents/SOFIA_Cy8_CfP.pdf - Appendix A1 to look at the ROC catalog.
https://dcs.arc.nasa.gov/dataRetrieval/SearchScienceArchiveInfoBasic.jsp to look in the archive (search for All Levels processing state).
This specific source has been observed in CII with GREAT before – we would need to thoroughly justify re-observation.

- **how much observing time would I need?**
- First we need to determine what we expect as source brightness temperature, and what we want in terms of mapped area size, SNR for science (all of those points will be checked by technical review!).
We can look at GREAT's image of Horsehead CII from the SOFIA archive. (For this we are using SOSPEX – the Sofia Spectral Explorer – available from https://github.com/darioflute/sospex).
In the regions we want to explore, Tmb~9.3 K, which would mean **brightness temperature of 6.5K** (Tr*= MBeff x Tmb = 0.7 x 9.3). We want a **SNR of 10** on those regions (or enough to justify duplication!).
We want the same map size: 12'x17' = **720" x 1020" -> 128 x 170 points with 6" steps** (the recommended step size for optimal sampling is ~ half a beam).

-- Then we use SITE to get an estimate of the integration time per ON point:
https://dcs.arc.nasa.gov/proposalDevelopment/SITE/index.jsp
For a 1 km/s resolution, source brightness temperature of 6.5K, desired SNR = 10, map 12'x17', default elevation angle/water vapor, Total Power (better for a crowded field), OTF (better efficiency for a shallow integration on a large map): **observing time per ON point: 3.6 seconds**
In OTF mode with the LFA array, the central region is covered ('sweeped') by all 14 pixels (7 pix x 2 polarizations)-> effectively 14 times more integration time. **We only need ~ 0.3 seconds per ON point.** Total of ~6500 seconds on-source time, or about 4h including overhead: reasonable for a proposal.

**- What mapping strategy?**
SITE also gives the recommended number of on points along the scanning direction (most effective way to set up the map): **Non=85**
Knowing that the maximum points on non-scanning axis is 100 points, we could make 4 submaps (4 AORs) of 85x64 points, slightly overlapping

This project is doable – **Launch USPOT** (latest version: 410) to define the AORs and refine the strategy.

- define the target: 'New target' in Target tab

- create AOR: GREAT  OTF mapping in Observations Tab
**Only starred items are necessary at the Phase I stage**

- check total time estimate: 3738 seconds per AOR including overheads. Fits nicely into one flight leg, and matches our ~4h overall estimate.

- load a DSS map and overlay AOR in Images tab

- adapt map offset in AOR accordingly

- duplicate AOR icon to make a similar AOR with different map offset.

- repeat and adjust parameters. Position of ‘off’ beam. Rotation of map.

- The most important thing for Phase I is having the observing time request correct. You need the correct number of AORs but the precise offsets, array rotation angle, map rotation angle, and off position do not need to be fixed until Phase II. Playing with these does allow you to demonstrate the area that you intend to map, however, which could be useful for your proposal.

Questions:
Is the ‘magic angle’ of 19.1 degrees for equal beam spacing the same for the HFA?

- Yes, this is from the hexagonal geometry of the 7 beams and is the same for both HFA and LFA.

Is the HFA cut-off at a velocity of 100 km/s going to change?

- No, this is primarily imposed by the atmosphere. If we look at the atmospheric transparency plot produced by SITE for the [OI] line (4.744777490 THz) at 100 km/s, we can see that transparency has fallen to about 50% at that point. Can use FIFI-LS to look at higher velocity extra-galactic [OI] on the other side of the atmospheric feature (around 1800 km/s).