Notes from the meeting on AOTs for the FTS
May 17, 2004 – Paris

Attendance: Jean-Paul Baluteau, Pierre Cox, Sarah Leeks, Tanya Lim, Frederique Motte, Marc Sauvage, Annie Zavagno

Objectives of the meeting: Clarify our ideas on the use of the SPIRE FTS, outline the decision process that an astronomer would follow to go from the science objective to the observation strategy, define the AOTs that need to be in place to allow the options of that decision process, cross-check our current knowledge of the spectroscopic objectives of the GT with the AOTs.

Note to the participants: I took the opportunity to discuss SPOT issues with Sarah Leeks. Notes from that discussion will be incorporated in the technical note I am supposed to write for the Time Estimator work package.

Updated June 21st following comments by Peter Davis-Imhof

Reading guide

This is a long document. If you want to extract it substance, read the clarifications below, then jump to the conclusions of the section "Observing strategies", and try and make sense of the decision flow chart

Some clarifications

Regarding the clarification of the use of the FTS, we reminded ourselves, at least those for whom it was not so clear, that the FTS would always provide a full scan of its spectral range. The only parameter on which the user ultimately plays is the spectral resolution, and obviously a signal-to-noise ratio.

There are two ways to scan the spectral range:

1. **Continuous scan**, in which the mirror is always moving and we read the signal and the mirror position. In that case the sky background signal (telescope essentially) is cancelled by an internal source (SCAL). Here the signal-to-noise ratio on the interferogram is fixed by the number of mirror scan taken at a given sky position.
2. **Step and integrate**, where we move the mirror by small equidistant steps and measure the signal when the mirror is standing still. In that case the sky background is cancelled by chopping on the sky, though SCAL is still on and provides a first-order cancellation of that background. Here the signal-to-noise ratio on the interferogram is fixed by the time spent at a given mirror position.

Spectral resolution is determined by how far we take measurements from the zero-path difference. Because it would be too long to explore the full range of the mirror motion with the Step-and-Integrate, high spectral resolution (HR) is only possible in the scanning mode. Low resolution (LR) is possible both in scanning and step-and-integrate mode.

The signal-to-noise ratio (S/N) turned out to be a confusion-ridden quantity. The astronomers tend to think about the S/N on the resulting spectrum. But the S/N that was mentioned above is on the interferogram and the two are not simply related. In fact when we reconstruct the spectrum from the interferogram there will be noise introduced by the "signal measurement noise", i.e. the fact that at a given point the value of the measurement departs from the actual interferogram value that we should measure, and a "path difference error" coming from the fact that the mirror may not be at the position we think it is. These errors will not only introduce some scatter around the actual spectrum value but they will also distort the shape of the spectrum. How critical is this effect was not clear to us. What was clear was that even though LR is feasible both in scanning and in step-and-integrate, high S/N and correct spectral shape would only be possible in the step-and-integrate mode.

Regarding the "path difference error", how much control we will have over it will depend on how accurate the time-stamping and position read-out are. Predicted accuracies can be checked by comparing scanning mode and step-and-integrate observations performed at the same spectral resolution.

It was also made clear that spectral scans will always be completed before the pointing is changed, i.e. jiggling motions will not be interspersed with mirror motions.

Some figures provided by Jean-Paul Baluteau are also worth remembering.

- In HR (R=1000), scanning mode at the nominal speed of 0.05 cm.s-1, it takes a minimum of 154s to complete a forward and backward scan of the mirror (3.85 cm scan length). Taking into account a specified (but probably optimistic) efficiency of 90% in this mode leads to 171s without instrument overheads.
- In LR (R=40), step-and-integrate mode, if we take the reasonable assumptions of a 2 Hz chopping cycle, with 2 cycles at each mirror position, each position requires 1 s integration. Consulting the SPIRE operating modes document (SPIRE-RAL-DOC-000320) we see that the number of steps is 233 for LR. This it takes a minimum of 233 s to complete a scan, and likely more since moving the mirror will take some time as well. Thus we are taking of a similar amount of time.

These two figures would lead anyone to think that it is not clear why one would choose to do a LR observation. But the second mode is obviously more sensitive to the continuum emission than the first. In fact in an HR observation, only 8% of the total observing time is spent acquiring the low-frequency (i.e. low-resolution observation).

To finish on the clarifications, we also reminded some that lines will not always contain a fixed fraction of the continuum energy (think ultraluminous galaxies for instance, where the lines are sometimes in absorption). We also hope that the SED in the FIR will show some spectral features departing from the simple grey-body spectrum, although we realize that we should not expect the richness found in the MIR. Finally we also note that there are some very good scientific cases for performing some spectral mapping, the Galactic Center being one of them.

Observing strategies

The question of whether or not we should envision the possibility to map a region of the sky with the FTS immediately came into the discussion. We acknowledge the facts that:

1. At the Porquerolles meeting the consortium stated that it would not provide tools to analyze observations other than point sources.

2. Matt Fox's notes from the AOT brainstorming meeting of March 19th 2004 states that mapping should not be offered at first AO.
3. There is some severe vignetting in the field of view of the FTS which will render mapping complex, especially from the calibration point of view

We nevertheless felt that there were sufficient science cases to support the inclusion of mapping, at least within the scope of the present discussion, if not within the scope of the "official" SPIRE AOTs.

Addressing the decision process we arrived after some discussion at the following 2 questions (which are independent of each other):

1. What kind of spatial information is needed on the target?
2. What is the principal objective in the spectrum, lines, continuum or both?

What kind of spatial information is needed on the target?

In a single pointing all the pixels will record an interferogram, therefore any FTS observation will provide some spatial information. Considering the fact that the 7 central pixels in the LW array and 19 central pixels in the SW array are not vignetted, provided that we have calibrated the beam profile of these pixels (which we will probably do up to a certain point), a single pointing FTS observation will realize some spatial sampling of the field of view.

For sources that are strictly point-like, a single pointing with the BSM fixed will provide all the information the user needs, and possibly more with the adjacent pixels.

We can identify cases for which this spatial information will not be sufficient (e.g. point source with imprecise location, extended stellar envelope where the interesting structures may fall "between the pixels", compact star forming region). In those cases the user can use the BSM to obtain more spatial information using a jiggling pattern (up to 64 points to have a full spatial sampling).

We have thus covered the case of sources that fit within a field of view. But there will be sources that are larger and for these we need to implement a "raster" mode. In this mode the telescope is asked to perform a certain raster pattern on the sky. Some synchronization between telescope and instrument is necessary to avoid a telescope motion before the completion of a scan. If the user is satisfied with the sparse spatial sampling provided by the 7/19 unvignetted pixels of the LW/SW focal planes, this is simply a concatenation of "point source" observations. If the user wants more spatial information one way to proceed is to restrict the parameters of the raster (orientation of the raster axes and step between points) to be equal to the magic values proposed by Bruce Swinyard at the London Science Meeting, but see the open question 4).

This leads to **three spatial** modes associated with spectroscopy:

A. **Single pointing**, fixed BSM for point sources or sparse field of view
B. **Single pointing at high spatial resolution** with restoration of the spatial information with BSM, either partially (e.g. 7 points jiggle) or fully (64 points).
C. **Raster** for large areas, either in the sparse map mode or fully sampled mode

We remind that given the current plan for SPIRE interactive analysis and data products, only case A is fully supported (see the minutes of the Porquerolles meeting, or those of the first AOT brainstorming meeting at the Imperial College, on March 16th 2004). We do not foresee that the other cases will require extremely specific calibration information (In fact B and C are just concatenations of As), however we see clearly that they will require dedicated reconstruction tools to go from the individual calibrated pixel outputs to 3D spectral and spatial data cubes. These tools are currently not foreseen to be provided by the SPIRE consortium will not provide.

One objection raised to the existence of modes other than A was their time cost. Indeed with 2-3 minutes at least required to achieve a complete scan, a fully sampled field of view takes more than 3 hours. We felt that it is a serious but not completely valid objection here: the time-cost of a observation falls on the observer, who has to convince the HOTAC that it is worth performing this long observation, and the instrument team should not bar the observer from doing so.

What is the principal objective of the spectrum?

We can broadly summarize the science objectives of a spectroscopic observation in the following sentence: the user either wants to study the lines (and mostly their flux since most will be unresolved) or the continuum emission and possible broad dust features, or both. In fact it is while doing this simplification that we came up with open question 1, regarding the existence of intermediate resolution(s) with the FTS.

If the observer is more interested in extracting information from the lines, then it is clear that the highest spectral resolution should be used, which leads directly to the scanning mode of the FTS. Performing a HR observation with the step-and-integrate mode is simply too time consuming to allow it (the 200s figure quoted above is a minimum duration for this mode). There will obviously be a brightness limit under which the S/N per wavelength interval is too low to do science on the lines. In that case the source may still be observable in LR but the science objective obviously changes and becomes the continuum observation.

If the user is interested only in the continuum, then he or she should check whether chopping is possible. Reasons why chopping may be impossible are for instance that the observed region is within a more complex object (e.g. a galaxy) which would contribute signal to the off beam, or that he or she intends to make a map and that the off beam will at some point fall inside the map, which will render the data reduction even more complex. If chopping is allowed then the next question involves signal-to-noise, source brightness and observing time: using the LR step-and-integrate mode will produce higher signal to noise or will open access to fainter sources than LR scanning mode. On the other hand LR scanning mode will possibly be faster although being restricted to brighter sources. We currently have no clear ideas of what flux would qualify for this brighter or fainter domains.

If the observer wants to study both the lines and the continuum, then a HR scanning mode observation will have to be done, to obtain the lines. This allows computing the resulting S/N on the continuum. If this is enough then the user is satisfied by a single HR observation. If not, then a specific continuum observation has to be done for which the user should follow the decision process outlined in the previous paragraph.

Whereas in the previous section the user could decide on the basis of images of the source which of the spatial mode is required, here we clearly need the time estimator to do so.

To summarize this process leads to the definition of **three spectroscopic modes**:

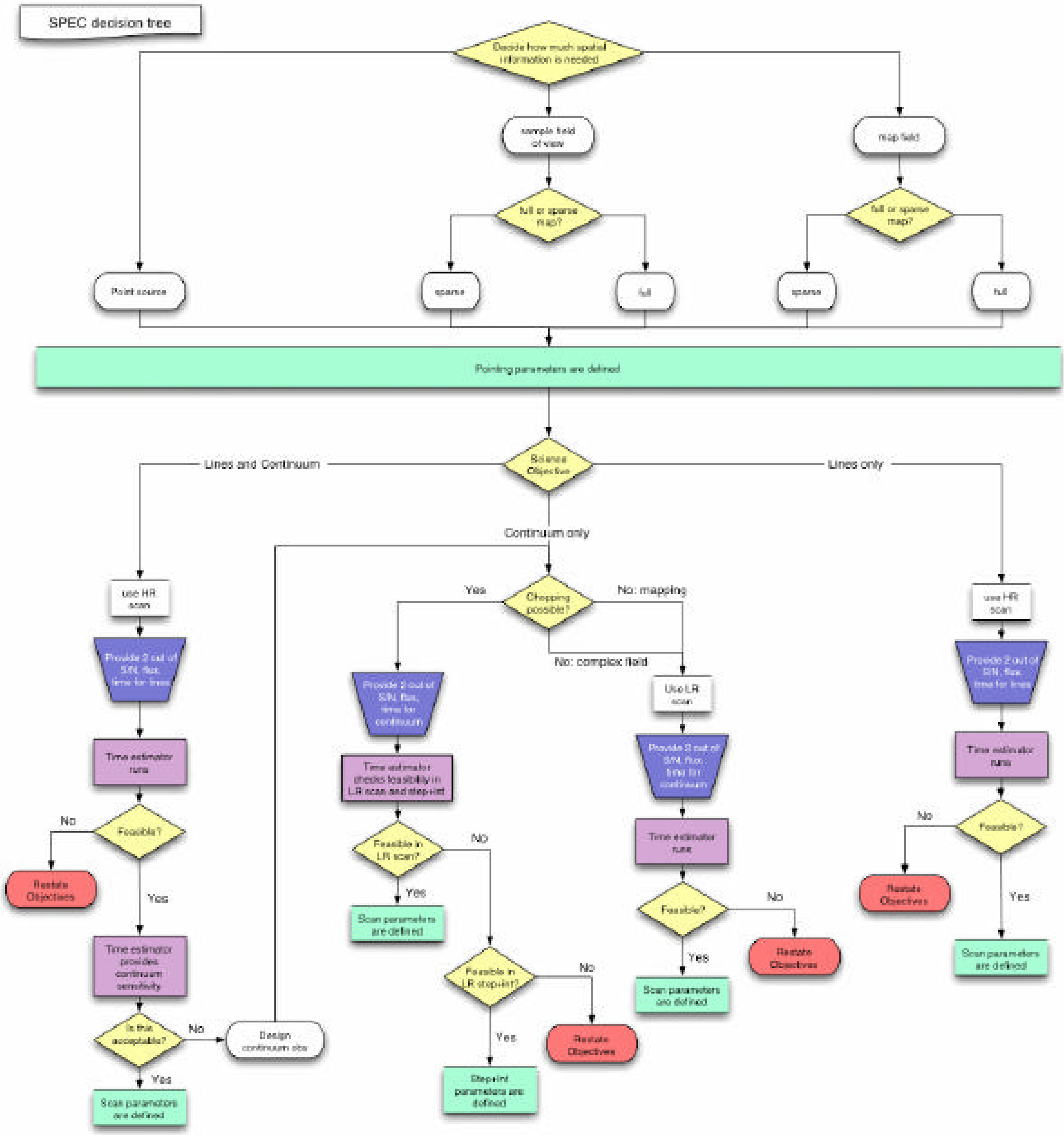
1. High-Resolution scanning mode
2. Low-Resolution scanning mode
3. Low-Resolution step-and-integrate mode

Conclusion on the observing strategy

We have defined 3 spatial modes and 3 spectral modes. In principle this leads to 9 different ways of using the FTS. This is in fact not the case for a number of reasons. First, spectral mode 3, which requires chopping, should best be avoided with mapping mode C, for fear of producing terrible data set to reduce. Second, as stated above, as far as calibration is concerned, spatial mode A and C are identical (remember that we do not deliver software to reconstruct the maps). So we are more faced with only 6 combinations (because C1=A1, C2=A2, and C3 is not allowed). Whether or not this is really manageable is a decision that this group alone is not in a position to make.

SPEC AOT decision tree

To use a more standard terminology I noticed that the spectrometer side of SPIRE is not called the FTS but SPEC, hence the title.



Open questions

In the course of the discussion we came up with a number of questions that we were unable to answer. For those, inputs from the larger OBST and the consortium are requested:

1. How many spectral resolutions shall we offer? The principle of the FTS is that it allows the observer to choose the spectral resolution by adjusting the span of the mirror motion. It is clear that we will not allow this choice but rather propose some fixed resolutions. At the moment we are only thinking it terms of HR (1000) and LR (40). HR targets lines, while LR targets the continuum with a better sampling than the 3 photometer bands (though much lower sensitivity). Do we need to offer an intermediate resolution and for what scientific purpose? At the meeting the only science purpose that we could identify was to allow a blind search of features on a wide spectral band, to prepare for HIFI follow-ups. In that perspective, the width of theses features need to be identified so that the spectral resolution can be adapted.

2. Is there a faster way than 3 minutes to obtain a spectrum? Obviously there is: it can be done in the scanning mode but doubts were raised regarding the quality of the resulting spectrum. It was not obvious to all but a science interest could be found for the possibility of making fast LR spectra. Furthermore, if we consider overheads, about 3 minutes per observation as well, one might wonder if short observations make sense.
3. Slightly related to that question came the provocative question of whether there was any interest in making a LR spectrum of a source. The argument goes as follow: given that the FTS is at least a factor of 5 less sensitive per sampled wavelength than the photometer what gain is obtained with 10-15 points of poor S/N in the SPIRE waveband compared to 3 much higher S/N points on the same SED?
4. Although we acknowledge that the SPIRE consortium will (likely) not support mapping with the FTS we still have considered the issue. Mapping can be performed either by combining jiggling with different sky pointings, or using the method proposed by Bruce Swinyard, where the satellite rasters the sky along one of the "magic angle" with a step taken as a precise fraction of the LW pixel. At some size, one method becomes more efficient than the other and we should identify this size.
5. We have often referred to this alternate mapping method for the FTS proposed by Bruce Swinyard. It is however premature to consider that it is implemented as an observatory function. Further work is needed to validate it.