

## 7 Time Series Observations

Repeated observations of (inertial) celestial objects that vary with time have become a popular proposal topic. In this chapter, we adapt the real-life example found for the observations of XO-3b, from Spitzer program 90032 (Knutson). The original AORs for this program can be viewed via Spot (choose "View Program" and enter pid 90032), or slightly relabeled AORs that are functionally the same can be downloaded as part of this Cookbook.

Because imaging with IRAC has been covered thoroughly in earlier chapters (see Chapters 4 and 5), we will not spend as much time on those aspects of these observations here; this chapter is meant primarily to give an example of staring at the same object for an extended period of time (days), and using Spot to tell Spitzer exactly how you want the observations carried out.

We will plan an observation of the extra-solar planet XO-3b to get the whole phase curve (covering the whole orbit of the extrasolar planet around the star).

### 7.1 Overview of the Observations

- **Target Selection:** Before being selected for potential Spitzer observation, targets should be checked for conflict with previous observations. See section 7.2.
- **Completing the AOTs:** With IRAC, we specify a short 30 minute AOR to allow the detector to stabilize, and then several long staring mode AORs to cover the whole orbit of the extrasolar planet around XO-3 (3.3 day orbital period). We use the two second frame time in subarray mode to avoid saturation and to avoid producing excessive amounts of data.
- **Constraints:** We impose as broad constraints as possible. We place a timing constraint on the first AOR of the series, and then chain the rest to the first one. See section 7.5.

### 7.2 Target Selection and Suitability

As with all other observations, we need to first check the ROC using Leopard. By looking here, we find that, of course, XO-3b has already been observed. Had this been a real proposal, we could then check the Duplicate Observations Rule to see if the specific proposal idea we have in mind qualifies as a new observation—perhaps we feel we could make a good scientific case for why it would need to be observed more than it already has during the Spitzer mission. However, for purposes of this example only, we will ignore the potential duplication, and continue planning these time series observations of XO-3b.

### 7.3 Target Entry

Start up Spot and enter a new target either by clicking on the bulls-eye target icon on the taskbar, or selecting "New Target" from the "Targets" menu. See Figure 57.

Target

Target Name (required): SIMBAD Resolve the Name

XO-3b Visibility / Orientation Background

Fixed Single Fixed Cluster Fixed Cluster - Positions Moving Single Moving Cluster

Coord Sys: Equatorial J2000

RA: 4h21m52.7040s

Dec: +57d49m00.840s

Epoch: 2000.00

Proper Motion

Use Proper Motion

PM RA (\"/yr): -0.005

PM Dec (\"/yr): 0.002

Number	Offset East/Row/Perpendicular (")	Offset North/Column/Parallel (")
2	-0.352	0.064
3		
4		
5		
6		
7		
8		
9		
10		

Offset Coordinates:  Celestial(E, N)  Array(Row/Perp, Col/Para)

Observe the offsets only

Bright Moving Objects to Avoid

Earth+Moon  Others

Cancel OK

Figure 57: The target window after entering XO-3b.

Click on the "Fixed Cluster" tab to pull up the window, and enter the name "XO-3b" and Resolve the Name using SIMBAD. Add in the proper motion for RA and Dec (get the information from Tycho-2 in Vizier or similar). This is especially important if you are observing objects that are relatively close and have a large proper motion, like white dwarfs. We use the proper motion in program 90032.

You then need to specify the offsets to the subarray sweet spot. These can be found in [http://irsa.ipac.caltech.edu/data/SPITZER/docs/irac/pdrs\\_obs.shtml](http://irsa.ipac.caltech.edu/data/SPITZER/docs/irac/pdrs_obs.shtml). The sweet spot is a position of maximum sensitivity where the Spitzer Science Center has invested a substantial amount of calibration time to build high precision maps of the intrapixel photometric sensitivity. Here we use the offsets for channel 1.

You need to also check the "Array(Row/Perp, Col/Para)" button and the "Observe the offsets only" button. After entering our target information, we click "OK" and we return

to the main Spot screen. Note that the bottom of the Spot screen now tells us which target and target type we have entered. Save your target list, just in case. To retrieve the target list at any time, we can click on the icon that looks like 3 bullseyes on the toolbar.

To find exactly when the target is visible to Spitzer, we can click either on the "Visibility/Orientation" button in the target entry window, or from the target list window, "Calculate Visibility Windows for All" and then "Show Visibility." This shows us a list of the dates when Spitzer can actually observe our target.

#### ***7.4 The IRAC AOR: Exposure Time and Observing Strategy***

In this case, we are looking for tiny variations in the signal from the star+planet system. We could be fooled by variations in the placement of the object on the array (pixel position), or by variations in the flat field. In order to limit these effects, we would like the object to stay in the same place on the array, so we have chosen NOT to dither. We have also placed the target on the subarray "sweet spot", where the sensitivity of the pixel has been highly characterized to allow an accurate correction to the obtained flux density levels. Instead of dithering we use the "repeats" option on the AOT window, located just above the frame time setting. Moreover, in this case, we will take enough frames such that the first frame effect is not as much of a concern as it would be if we were only taking, say, 5 frames. The net result of these decisions is that the relative flux that we measure will be quite good, but the absolute flux might not be as good as it would be had we dithered and not used repeats. Finally, we wish to have as continuous coverage as possible, and that (plus the desire to get the object on exactly the same pixel for the whole series) is more important than multi-wavelength coverage. So, we choose to only use one field of view; we choose 3.6 micron here. We also select to collect data only in that channel and turn off data collection in the 4.5 micron channel (since we have only selected the one field of view; this reduces the amount of extraneous data being saved by the mass memory card onboard the spacecraft).

We specify also a PCRS Peak-Up in the AOT. This will put our target very accurately on the center of the sweet spot pixel in the subarray, which allows for an accurate correction of the flux density levels, depending on where the target is on the pixel. We will do this for all the subsequent AORs as well (and use the cluster offset target). To specify the PCRS Peak-Up here we click in the main AOT window under "Peak-Up Settings" "PCRS Peak-Up" and then in the "Peak-Up Target" window we select "Offset" and leave the RA and Dec offsets to 0.000 (this means that the peak-up will be performed on the target itself, see the link below for information on what the requirements for the peak-up star are). We also add the V-band Vega magnitude of the peak-up star (the target itself) (in this case, 9.910 mag). In cases where the target itself is not suitable for peaking up on, we can select a PCRS Peak-Up star by clicking the PCRS Selection button and selecting a suitable star from the list that comes up. Or we can specify our own peak-up star (but again see the criteria for the peak-up star in the link below). More information about the intrapixel sensitivity corrections is available at <http://irsa.ipac.caltech.edu/data/SPITZER/docs/irac/calibrationfiles/pixelphase/>.

We select a 2 second frame time not only because the source will not saturate but because it will give the best S/N ratio for the observations (usually one selects the frame time that is just below saturation levels for the best S/N ratio). We enter the information into the AOT window; see Figure 58. We select the subarray, just the 3.6 micron field of view, and 11 repetitions of 64 frames of 2 sec each, with no mapping or dithering. We choose "Calc. Obs. Time" to see how long this AOR takes. It is about 1800 seconds, as recommended for the first AOR in a series of long staring observations at [http://irsa.ipac.caltech.edu/data/SPITZER/docs/irac/pers\\_obs.shtml](http://irsa.ipac.caltech.edu/data/SPITZER/docs/irac/pers_obs.shtml). When we click "OK" at the bottom of the AOR window, we will, however, get a warning message (Figure 59) that the best practice with IRAC full array is to use only one frame, not 11. We can ignore this warning (since it does not apply in this science case) by clicking "OK" to close the warning window.

We are planning a time series covering 3.3 days. After creating the first AOR, we choose "copy AOR" 8 times, and change the labels of each one so that we can keep track of which AOR is which. We adjust the number of repeats to 333 in seven of these AORs to stay around the recommended 12 hour duration for a staring mode AOR. We include enough repeats for the last AOR to cover the whole 3.3 days (in this case, about 58 repeats). If we did not already calculate the total elapsed time for this program, we should choose "Recompute All Estimates" from the "Tools" menu so that we know how long is the total program is.

As in all of the earlier chapters, to verify that we are doing what we think we're doing, we should visualize the observation. Since visualization is thoroughly covered elsewhere in this Cookbook, we do not repeat that information here.

Save your AOR(s) early and often. Now would be a good time.



Figure 58: IRAC Post-Cryo Mapping AOT window, filled-in values.

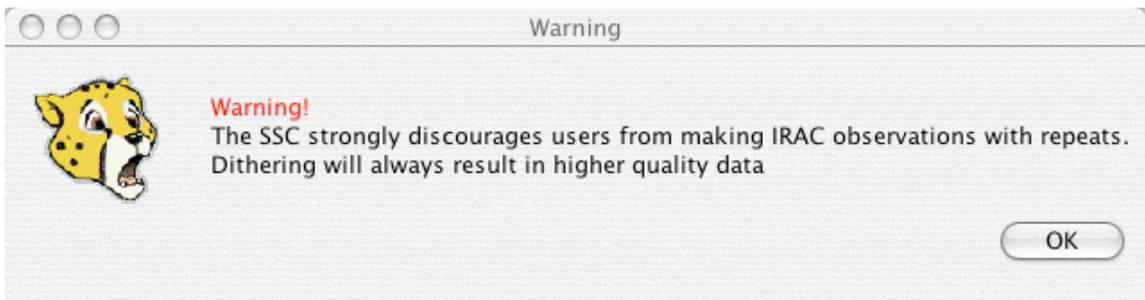


Figure 59: Warning that appears when you have entered in the AOT window Number of Frames >1. For this observation, you can simply click “OK” and ignore the warning.

## 7.5 Constraints

In order to accomplish our science, of course we need to ask Spitzer to complete these observations at the right time. We go away and calculate when we would like these observations to start. In this case, we want to allow for some overlap so that we get the secondary eclipse near the beginning and end of the observation. To provide the maximum possible flexibility, we figure out the right time for these observations to start over many possible orbits of the planet. We also need to be sure that the timing windows we give are consistent with when Spitzer can view the object (available through Spot, see below).

**Note:** In order to accomplish this observation, we do not have to time-constrain each observation! In fact, it provides the most flexibility for scheduling, and the best possible data quality, if we time-constrain the first AOR in the series only, and then chain together the rest of the AORs in the series to be linked to the first.

### 7.5.1 Timing Constraints

In order to impose a timing constraint on the first AOR, we select the first AOR in the list, and then from the "Tools" menu, we select "Timing Constraints." It helpfully provides us with a list of the visibility windows for this object. We also look at the list of possible XO-3b orbits and consider the largest possible window when these observations could start.

We then enter a series of start and end dates and times, and then click OK; see Figure 60. To regain this window at any time in the future, select "Timing Constraints" from the tools window as above. Typically exoplanet observations have a timing window 30 minutes long. If you think you need a shorter window, please provide a good justification in your proposal.

In the main Spot window (see Figure 62), you will note that the checkbox is now checked for this AOR under the "T" column.

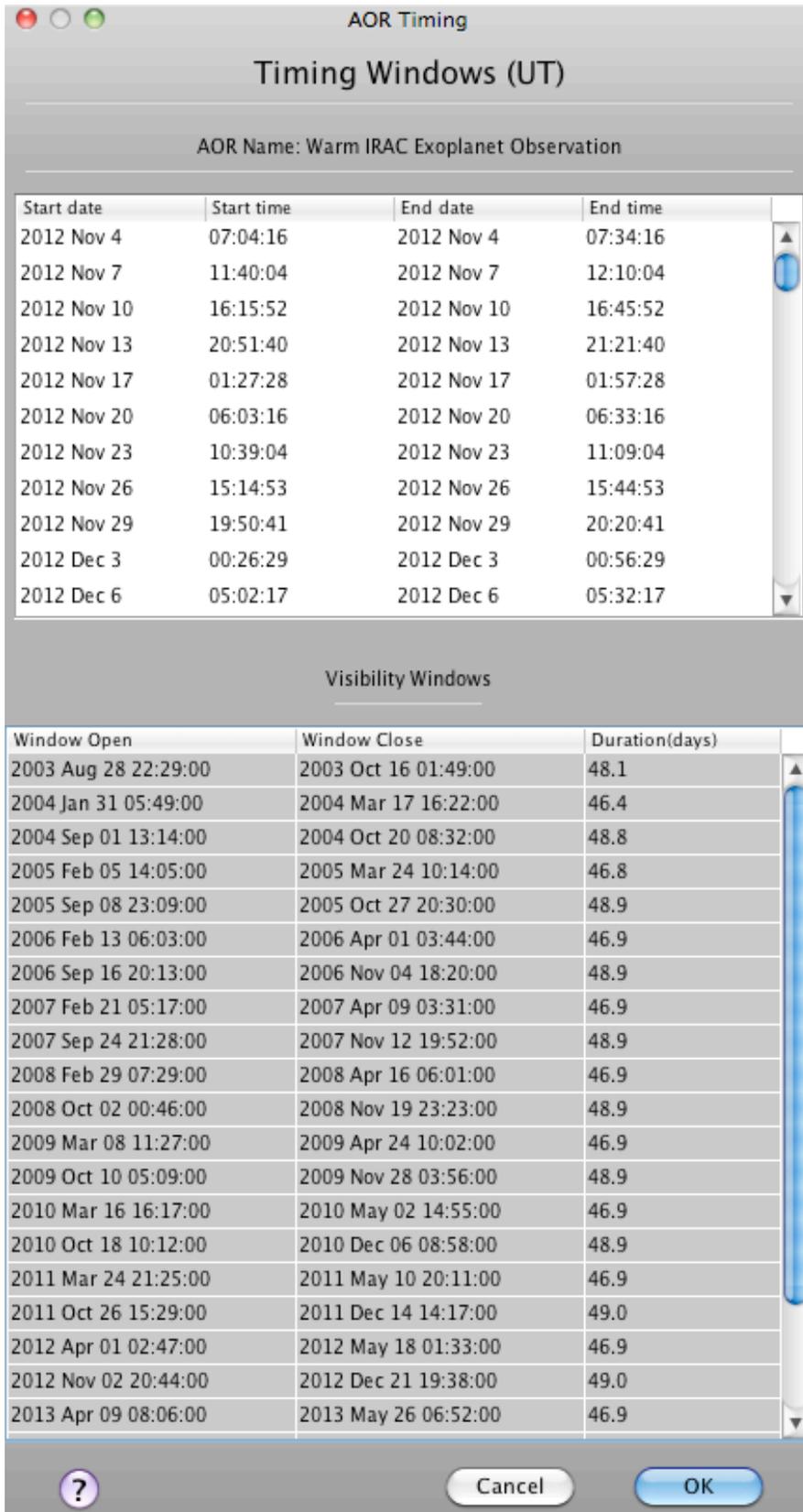


Figure 60: Imposing timing constraints.

### 7.5.2 Chaining AORs

We are not done yet! Next, we need to tell Spitzer that we need to do the rest of these observations in order, without breaks. We would like this series of observations to be done as an ordered non-interruptible group because we need continuous monitoring of this object.

In order to start a chain, we first select "Group/Follow-on Constraints" from the "Tools" menu. The default first tab that appears is the Group tab; we could also select Follow Ons or Shadows (were this a Solar System target) from this same dialog. We want to impose chaining constraints, so we select "Add Chaining." We get a pop-up asking for a name of the constraint—since we only will have one chain, the default "Chain-0000" is fine. An icon and text now appears in the lower part of this Constraint Editor. It tells you the total duration of this Chained series of AORs. Note that the longest possible uninterrupted group of IRAC AORs, without getting a warning message, is 24 hours. If you need a chain that exceeds this amount of time, simply ignore the warning message.

Now, we select the first AOR in the series and drag-and-drop it into the window. It now appears under the "Chain-0000" entry. Next, we drag-and-drop the second AOR in the series here too. We note that the total duration is keeping track of how long this will take. We repeat this for each of the 9 visits. We then note (Spot helps us notice this, if we forget) that the total duration exceeds 24 hours!

Make sure that the first AOR in your chain is the short 30 minute AOR to allow the detector to stabilize.

We click "Apply" to impose this constraint, and Spot will remind us that the chain takes too long. See Figure 61.

**NOTE:** You have to click apply, not just OK, for the constraints to actually stick to the AOR.



**Figure 61: The imposed chaining constraints.**

Having done this, now we see in the AOR list in the main Spot window (Figure 62) that the Group constraint box (“G”) is checked.

Label	Target	Position	Type	T	G	F	Instrument	Duration	Stat	On
Warm IRAC Exoplanet Obs...	XO-3b	4h21m52.7040s,+...	Fixed Cluster-Offsets	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	IRAC Post-Cryo Mapping	1775	new	<input checked="" type="checkbox"/>
visit2	XO-3b	4h21m52.7040s,+...	Fixed Cluster-Offsets	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	IRAC Post-Cryo Mapping	43457	new	<input checked="" type="checkbox"/>
visit3	XO-3b	4h21m52.7040s,+...	Fixed Cluster-Offsets	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	IRAC Post-Cryo Mapping	43457	new	<input checked="" type="checkbox"/>
visit4	XO-3b	4h21m52.7040s,+...	Fixed Cluster-Offsets	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	IRAC Post-Cryo Mapping	43457	new	<input checked="" type="checkbox"/>
visit5	XO-3b	4h21m52.7040s,+...	Fixed Cluster-Offsets	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	IRAC Post-Cryo Mapping	43457	new	<input checked="" type="checkbox"/>
visit6	XO-3b	4h21m52.7040s,+...	Fixed Cluster-Offsets	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	IRAC Post-Cryo Mapping	43457	new	<input checked="" type="checkbox"/>
visit7	XO-3b	4h21m52.7040s,+...	Fixed Cluster-Offsets	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	IRAC Post-Cryo Mapping	43457	new	<input checked="" type="checkbox"/>
visit8	XO-3b	4h21m52.7040s,+...	Fixed Cluster-Offsets	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	IRAC Post-Cryo Mapping	43457	new	<input checked="" type="checkbox"/>
visit9	XO-3b	4h21m52.7040s,+...	Fixed Cluster-Offsets	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	IRAC Post-Cryo Mapping	7857	new	<input checked="" type="checkbox"/>

Target: XO-3b Type: Fixed Cluster-Offsets Total Duration (hrs): 87.2

Proposal - File Name: chap7.aor Net Up Total AORs: 9 / Active: 9

**Figure 62: The Spot window showing the final AORs and the set constraints.**

Now we are done! The AOR file, ready to be loaded into Spot, containing the raw AORs developed in this chapter can be downloaded from the SSC Cookbook webpage: <http://ssc.spitzer.caltech.edu/warmmission/propkit/cookbook/>.

### 7.5.3 Other Kinds of Constraints

Note that for other projects, such a strict ordering as found with a chain constraint outlined in this example might not be justified, and a sequence or group-within or follow-on constraint might suffice.

For example, perhaps we would like to monitor a stochastically variable object (e.g., accretion events). In that case, perhaps the specific start time of the first observation of the series is not terribly important, but perhaps it is important that a small group of IRAC observations are obtained close in time to each other. In that case, a “Group Within” constraint of several days would likely do the job. Imposing a “Group Within” from Spot is essentially identical to imposing a Chain as described above, except obviously we would click on “Add Group Within,” rather than “Add Chain.” This kind of “Group Within” constraint is also appropriate for grouping, e.g., to limit field rotation and avoid gaps between IRAC maps covering a large area.