Relative pointing offset analysis of SPIRE FTS calibration targets with repeated observations

Ivan Valtchanov (1), Tomasz Konopczyński (2), Ros Hopwood (3)

(1) Herschel Science Centre, ESAC, ESA; (2) ESAC trainee; (3) Imperial College, London

Introduction

The SPIRE FTS flux calibration is a two stage process (see [1] for more details):

1. *Extended source calibration*, derived using the telescope as a calibrator, which converts the signal timelines from Volts to $W/m^2/Hz/sr$ to give the *level-1* spectra.
2. *Point source calibration*, derived using Uranus as primary calibrator, to convert from $W/m^2/Hz/sr$ to Jy to give the level-2 spectra. Point source calibration is only applicable for sparse mode observations (i.e. not mapping).

It is essential to know the pointing offset of Uranus for the observations used to derive the point source calibration. A mispointing leads to a loss of flux and increases the error on the conversion factors. In the FTS sparse mode observations we do not have any *a priori* knowledge of the actual pointing of the *Herschel* telescope. We know that the absolute pointing of *Herschel* is ~2" at 68% confidence interval ([3]), and on top of this there is tracking for solar system objects, and even for staring observation there is a jitter of ~1" around the moving target position. These uncertainties in the pointing can lead to an important difference in the derived flux calibration.

Method

To correct the pointing the method utilizes level-1 data of repeated FTS observations. Level-2 data already include a conversion using a Uranus observation that would introducing bias into our analysis. The following assumptions are adopted:

- We only consider the short wavelength array (SSW, from 960 to 1544 GHz) where the beam size is smaller than for SLW and relatively well behaved. A smaller beam means any pointing offset leads to more significant flux loss.
- We only consider that the pointing offset introduces an overall continuum shift, i.e. no colour terms.
- We use observations performed with all spectral resolutions: high (HR), low (LR) and calibration (CR). CR were processed as HR and all HR were smoothed with 20 GHz boxcar.
- We assume the FTS SSW beam is Gaussian with FWHM taken from the latest calibration tree *spire_cal_10_1*.
- We consider Uranus as a disk of radius 1.7".
- Any shift in the overall continuum of repeated observations is only due to a pointing offset.

Assuming we have a reference observation *ref* with the target exactly in the centre of the beam. Then the ratio R(*obs*) = level-1(*obs*)/level-1(*ref*) of any other observation is a measure of the flux loss due to pointing.

When we use Uranus (or other SSOs), the brightness changes as a function of the observing time. This change in brightness has the same effect as a pointing offset and this has to be taken into account, using the ratio of the model predicted brightness (from [2]):

$$R(obs) = 1 - \text{level-1}(obs)/\text{level-1}(ref) \times R(model),$$

where R(model) = model(*ref*)/model(*obs*).

The choice of the reference observation is iterative: we construct R(*obs*) until we find *ref* that results in R(*obs*) > 0 for all observations (see Figure 1). This is equivalent to finding the observation (normalised by the model) that has the highest continuum level. The observed R(*obs*) is then compared to a grid of predicted flux losses **loss(r)** by convolving a disk (or a Dirac δ-function) placed at different distances **r** from the centre of the Gaussian beam (see Figure 2).

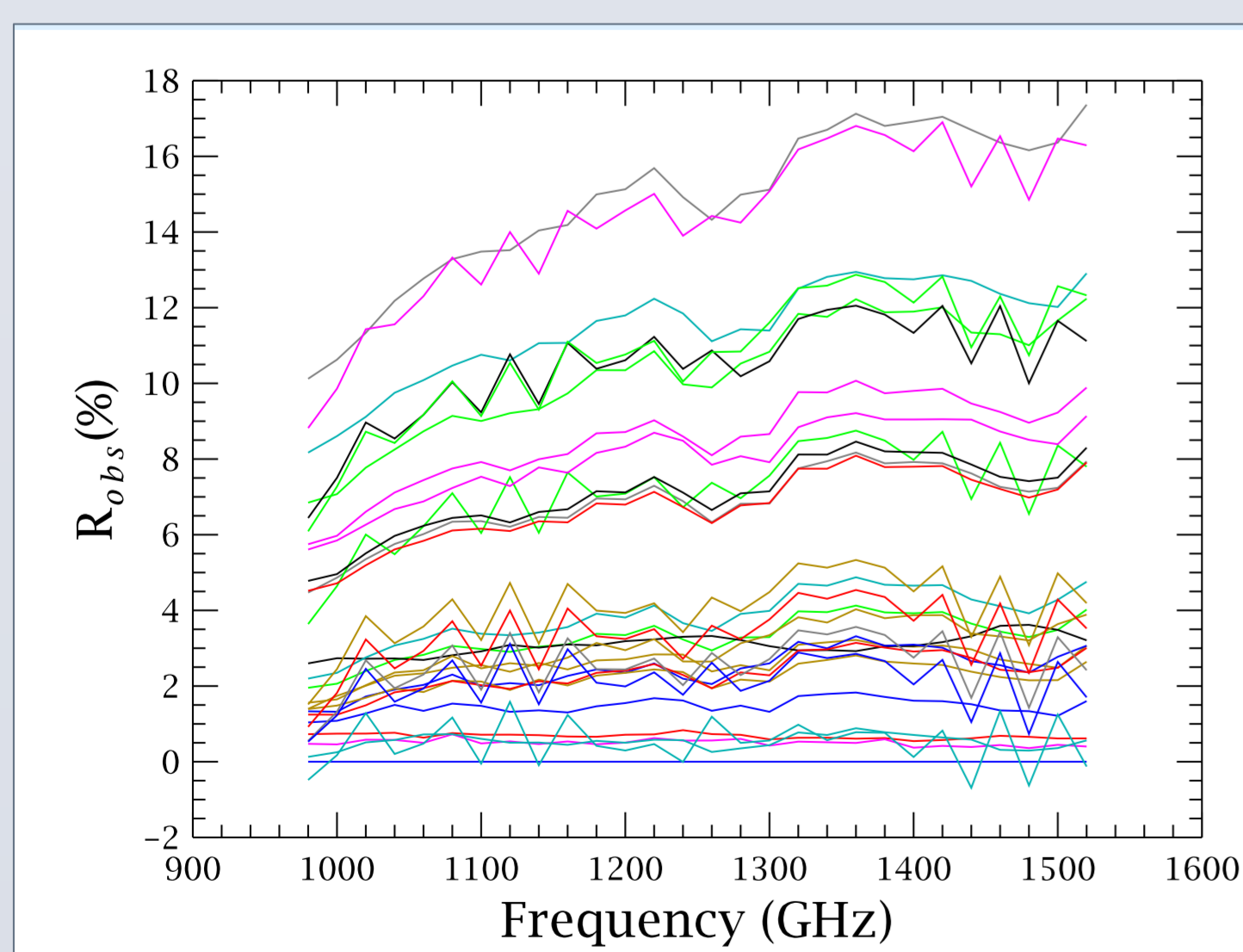By interpolation over this grid we can derive **r** as a function of the frequency.

Figure 1: All Uranus R(*obs*) in % using as reference 0x5001389B (OD1313). All Uranus observations in sparse mode with HR, LR and CR are included.
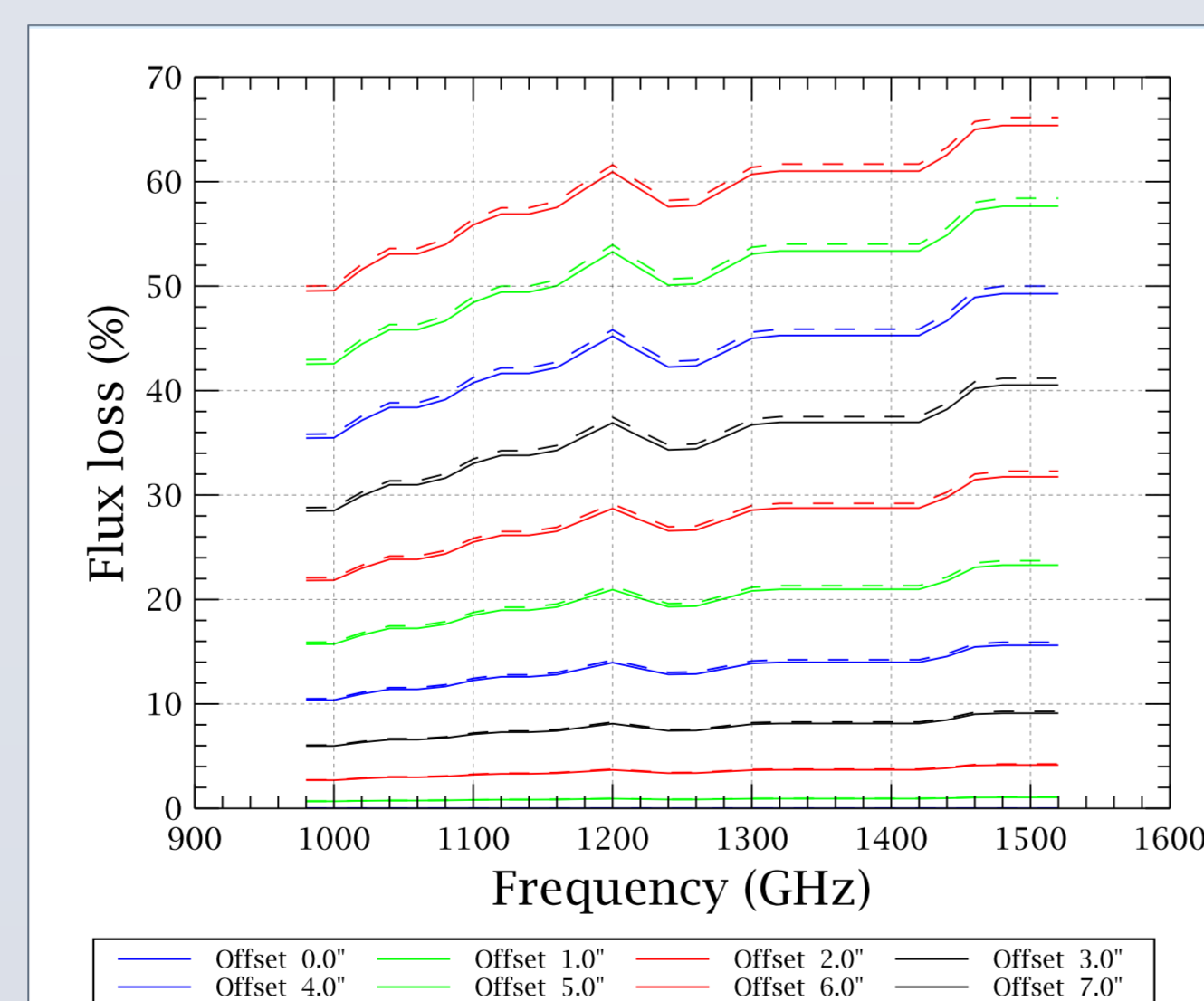

Figure 2: The predicted flux loss for a grid of distances from 0.0 to 10", assuming δ-function (dashed lines) and a disk of 1.7" radius (continuous lines)

Results

We applied the relative pointing offset method on all Uranus, Neptune, Ceres and NGC7027 sparse mode observations, using the latest HIPE v11 processing. Some examples of the method at work are shown in Figure 3. The final relative pointing offset results (only for Uranus and Neptune) are shown in Figure 4.
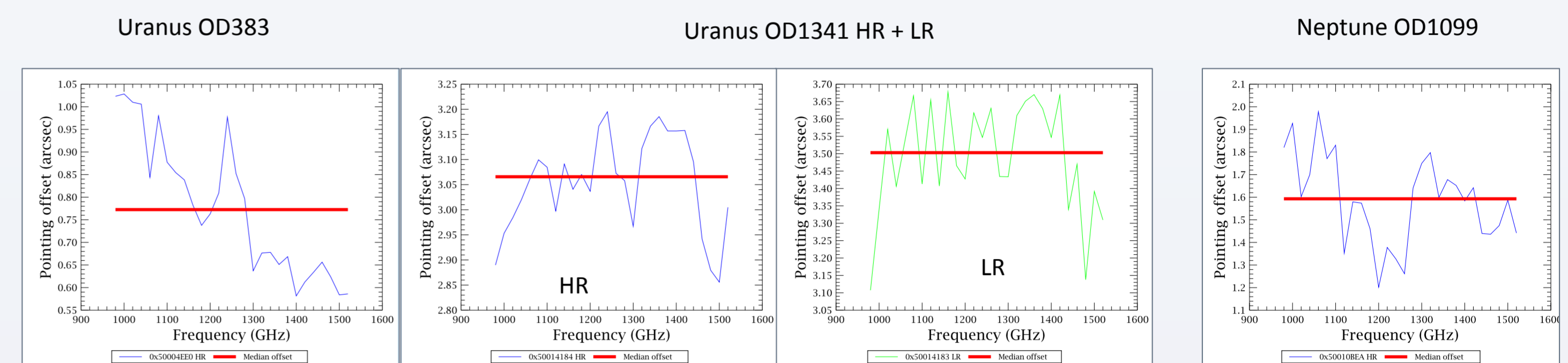

Figure 3: Examples of the method with the derived offsets for a couple of observations of Uranus and Neptune.
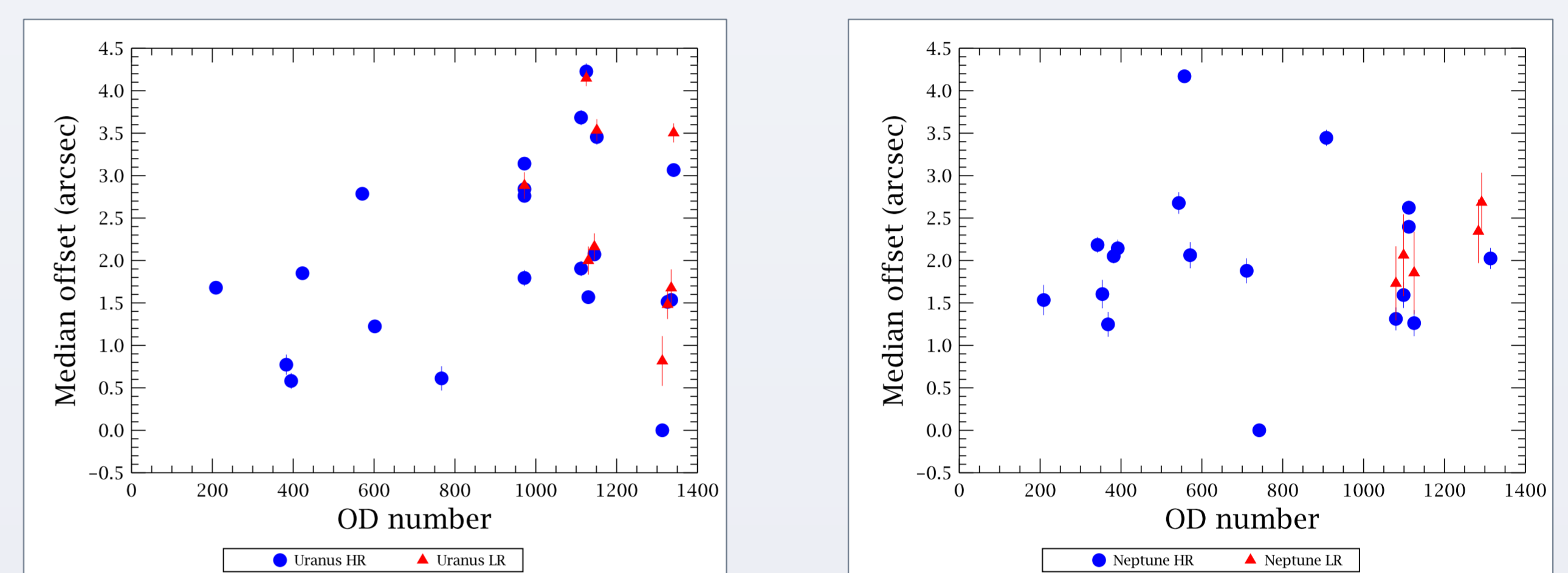

Figure 4: The derived median pointing offsets for Uranus (left) and Neptune (right). The error bars are the median absolute deviation.

Consistency checks

To check the results we used two observations of LR spectral maps of Uranus in OD1112 and OD1313, performed right after the HR observations 0x50010D8D (OD1112) and 0x50013899 (OD1313). The LR map in OD1313 locates Uranus at less than 1" from the centre, this confirms that our reference observation 0x5001389B is indeed one of the most centred ones. In OD1112 the LR map indicates that Uranus is at ~2", which matches well with our derived 1.9" offset. In addition, we have a very good agreement of the derived pointing offsets of the pairs of HR and LR observations in OD 972 and from OD1125 on. In two cases for Uranus (OD972 and 1112) and one for Neptune (OD1112) we performed special observations by moving the beam steering mirror (BSM) from the position used until OD1011 (old home) to a new position (new home). The offset between the two BSM home positions is ~1.7", which is well matched by our estimates of 1.8" for Uranus in OD1112. It is less consistent for Neptune in OD1112 (0.2") and Uranus in OD972 (1.1").

Discussion, conclusions and further steps

We have developed a method that can be used to estimate the relative pointing offsets of calibration targets with repeated observations. The higher the number of repeated observations of a particular target the higher the chances of having one well centred within the beam, and consequently, the derived *relative* pointing offset would correspond to the actual (i.e. the absolute) one.

The method relies on good models for SSO, where a model uncertainty of 5% is equivalent to a pointing offset of 2-3" (see Figure 2). Having the pointing offset for a given observation, it is straightforward to correct it for the flux loss.

Here are the main outcomes from the study:

- The results for Uranus confirm that the deep observation 0x50004EE0 (OD383), used in the current flux calibration (HIPE v10), is well centred although care must be taken in using this calibration for observations after OD1011 (BSM change) because the fringe pattern is different for the different BSM angle.
- We have confidence that the reported pointing offsets for Uranus are correct, within the uncertainties of the models and the telescope jitter when tracking SSOs. This is supported by a number of consistency checks.
- We have applied it successfully to Uranus, Neptune, Ceres and NGC7027 (only Uranus and Neptune results are shown here).

Next steps:

- Further confirm the derived pointing offsets by a combined comparison of Uranus and Neptune and their respective models and cross-calibration checks.
- Correct all Uranus observations for the derived the pointing offset and combine them into two much higher signal-to-noise calibration products, depending on the BSM home position: before OD1011 and after. Care must be taken for the different fringe patterns at different offsets.
- In the current method we only consider the central SSWD4 detector, but extending this to observations where Uranus was placed on different off-axis detectors will improve the point-source flux calibration scheme for the off-axis detectors.

References:
[1] Swinyard B. et al, 2013, this workshop (in preparation).
[2] Orton G. et al., 2013, in preparation.
[3] Pilbratt G. et al., 2010, A&A 518, L1.

Use the QR code to access the details and the results for all calibration targets included in the study.