

Improving CoRoT planets parameters with transit reconstruction in the presence of stellar activity

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Abstract

An accurate characterisation of exoplanets is important to constrain planet formation and evolution models. This is difficult to achieve for planets around active stars. We discuss how the transit signal is affected when filtering the stellar variability in the case of a pre-detection filter. We present a new Iterative Reconstruction Filter (IRF) which minimises the effect on the transit signal and improves the estimate of the planet parameters on average. We apply the IRF to CoRoT planets in an attempt to a) refine the planet parameters and b) search for secondary eclipses.

Context

Stellar variability is due to temporal and rotational modulation of structures on the stellar surface (spots, plages, flares, faculae, granulation), and can hinder the detection of planetary transits (Figure 1, black). It typically occurs on longer time scales (hours to days) than the transit signal (minutes to hours). Current 'pre-detection' filters, such as Aigrain & Irwin Nonlinear Iterative Filter (NIF), use this property to remove stellar variability and facilitate the detection of transits. Unfortunately, these filters are known to deform the shape of the transits (Figure 1, green), leading to inaccurate planet parameters.

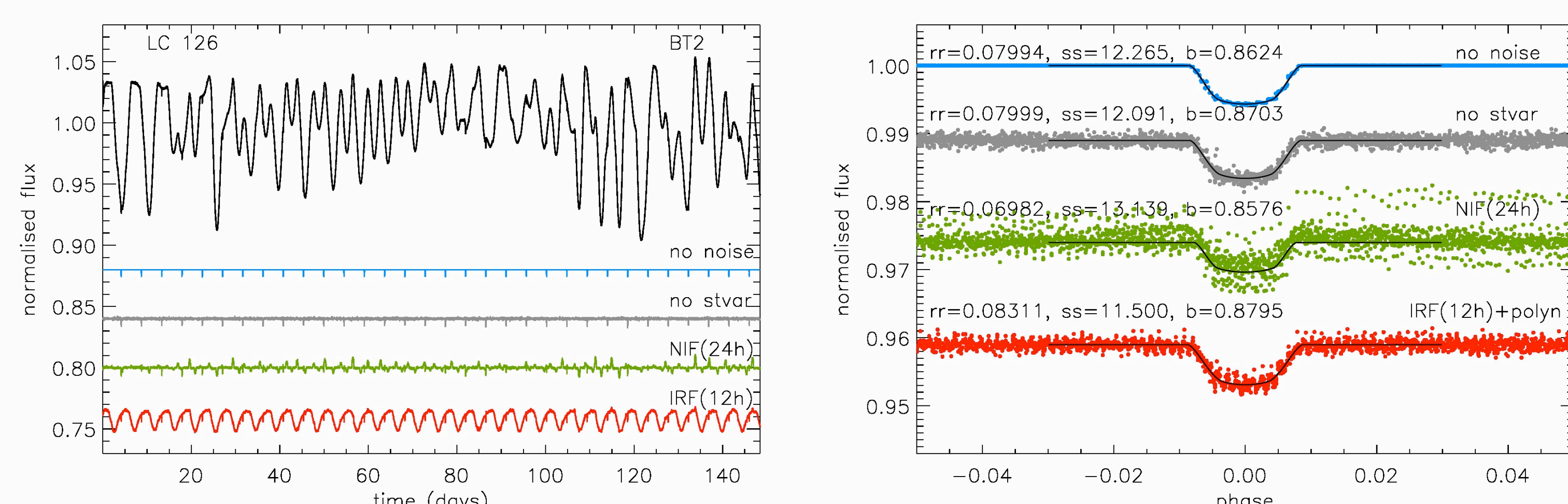
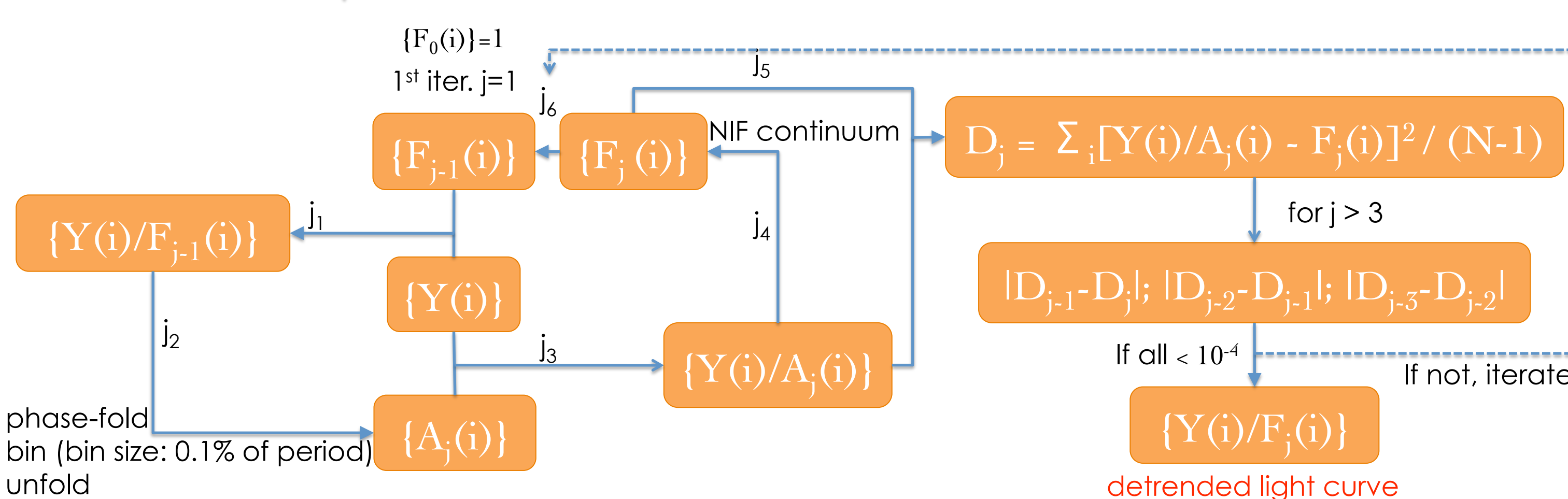


Figure 1 - Top-left: simulated CoRoT Blind Test 2 (BT2) light curve (black) with Saturn-like transits barely visible due to stellar variability. Left and right: NIF-filtered (green) and IRF-filtered (red) version of the same curve, original transit signal only (blue) and with instrumental noise (grey). Right: the NIF-filtered version shows an altered transit shape. IRF recovers the shape of the transit (right, red), and preserves all signal at the period of the transit (left, red).

Iterative Reconstruction Filter (IRF)

The IRF removes stellar variability once the transit has been detected, whilst altering the transit signal as little as possible. It treats the light curve $\{Y(i)\}$ as composed of the stellar variability $\{F(i)\}$, the transit signal $\{A(i)\}$, and some residuals $\{R(i)\}$ such that: $\{Y(i)\} = \{F(i) A(i)\} + \{R(i)\}$. $\{F(i)\}$ is taken as the NIF-estimated continuum of $\{Y(i)/A(i)\}$, the light curve corrected from the transit signal. The IRF iterates to improve the estimate of $\{A(i)\}$, thus providing a better correction to the light curve and allowing a better estimate of $\{F(i)\}$, which is then fed into the next iteration to better estimate $\{A(i)\}$, and so on so forth. The IRF steps are:



The NIF estimates the continuum as followed: i) apply a 1h baseline moving median, ii) apply a 12h baseline moving median, iii) apply a 15min baseline moving average, iv) evaluate the scatter of the residuals of output of iii) minus output of i), v) flag points with residuals more than 150 times the scatter, vi) return to step i), clipping out flagged points to better estimate the continuum, until convergence is reached.

IRF performance on simulated CoRoT light curves

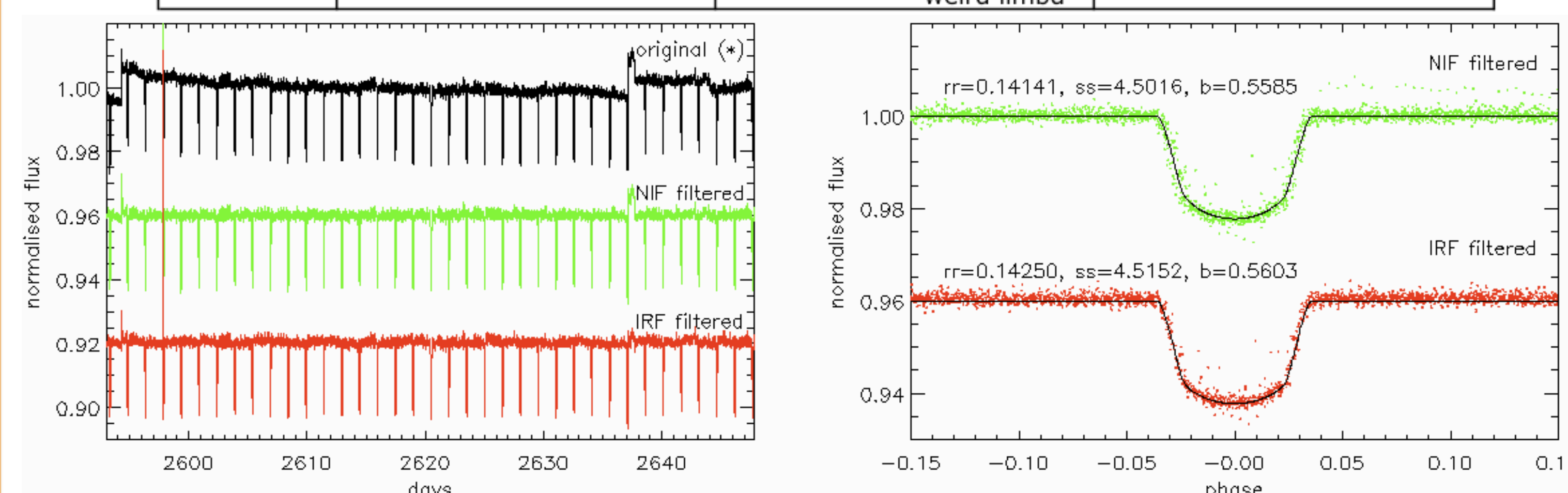
We applied the IRF to the 24 Blind Test 2 (BT2) light curves with planetary transits and compared them to the NIF-filtered versions (e.g. figure 1, red). The IRF recovers all signals at the period of the transits; we subtracted a 2nd order polynomial fit about the IRF-filtered phase-folded transit before fitting it. The phase-folded transits were fitted using Mandel and Agol analytical formulation. The best fits were found using an implementation of the Levenberg-Marquart algorithm, adjusting the system scale (ss) a/R_s , the orbital inclination (which combined with the previous one gives the impact parameter b), the limb darkening coefficients and the radii ratio (r_r) R_p/R_s . The IRF recovered the transit signals of 4 light curves where the NIF-filtered transits were barely detectable. The IRF gave planet parameters in general closer to the expected values than the NIF. The IRF did not perform better than the NIF for light curves with low stellar activity or low signal to noise ratio. Detailed explanations can be found in Alapini & Aigrain (submitted).

IRF applied to a sample of CoRoT planets

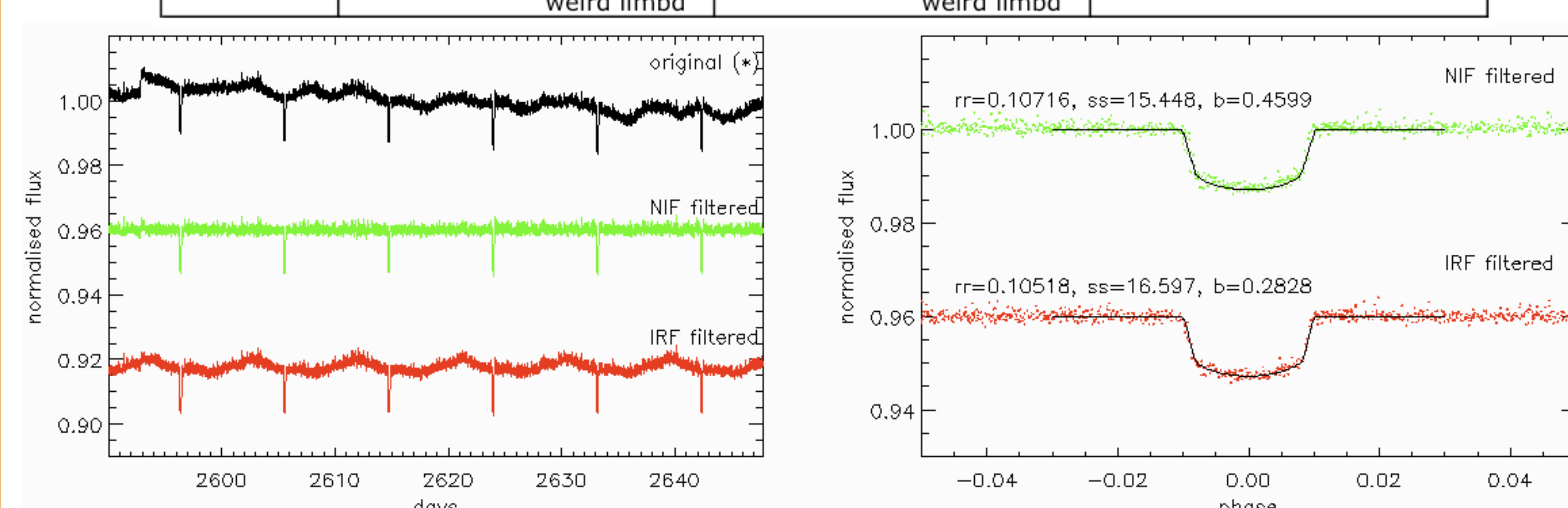
Impact of the IRF on the planet parameters of Exo-1 and Exo-4

The IRF and NIF filtering and fitting methods applied to exo-1 and Exo-4 are as described in the previous section. For Exo-1, no polynomial fit to the phase-folded transit was performed as the IRF-filtered light curve did not show out-of-transit variations. Hereafter are some comparison plots and tables of the IRF and NIF performances on Exo-1 and Exo-4, along with the published planet parameters. The black curves are the original N2 light curves with outliers clipped out.

Exo-1	NIF		IRF		Barge et al 2008	
	linear limbd	quadratic limbd	linear limbd	quadratic limbd	quadratic limbd	uncertainties
a/Rs	4.50	4.50	4.52	4.51	4.92	0.08
i	82.9	82.9	82.9	82.8	85.1	0.5
u1	0.58	0.58	0.51	0.53	0.71	0.16
u2	0.00	0.00	0.00	-0.05	0.13	0.3
Rp/Rs	1.1414	1.1414	0.1425	0.1429	0.1388	0.0021
comments	larger chisq		larger chisq weird limbd			

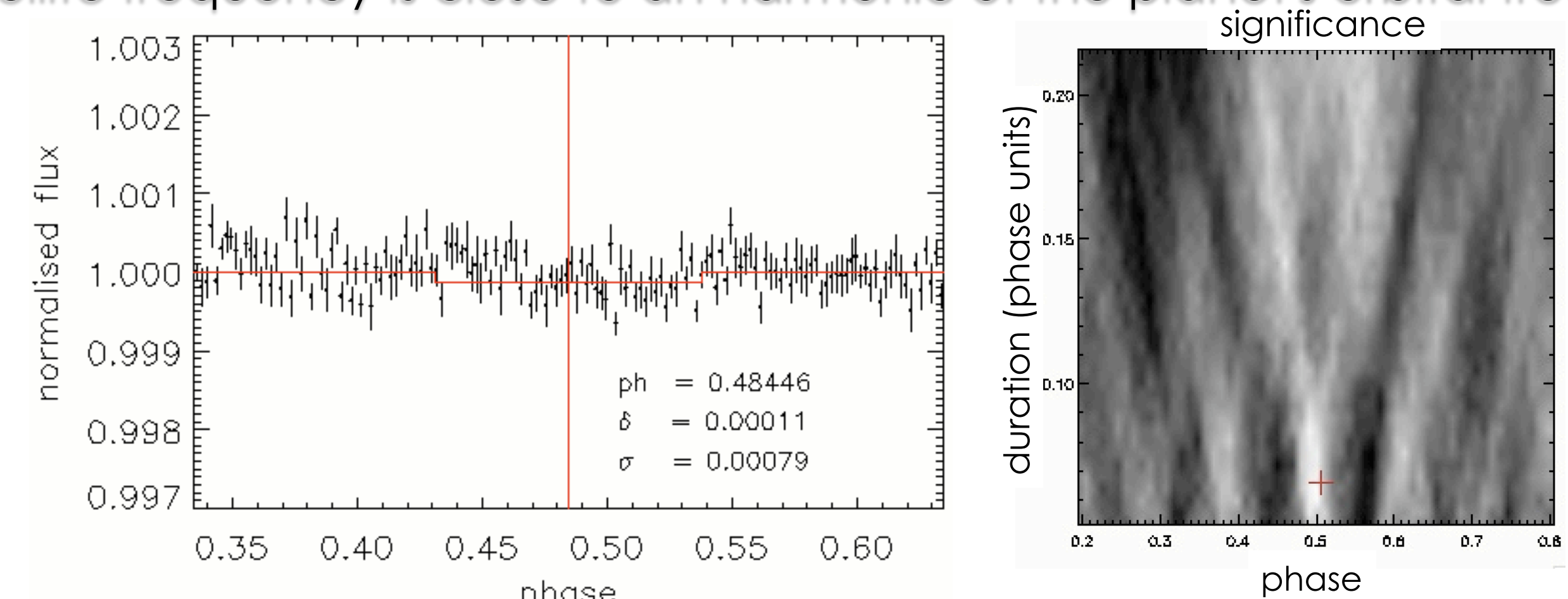


Exo-4	NIF		IRF		Aigrain et al 2008	
	linear limbd	quadratic limbd	linear limbd	quadratic limbd	linear limbd	uncertainties
a/Rs	15.45	15.43	16.60	16.54	17.36	0.25
i	88.39	88.27	89.02	88.96	90.00	0.09
u1	0.46	0.50	0.46	0.50	0.44	0.16
u2	0.00	-0.08	0.00	-0.08	0.00	0.00
Rp/Rs	0.1072	0.1074	0.1052	0.1055	0.1047	0.0041
comments	larger chisq weird limbd		larger chisq weird limbd			



Search for secondary eclipse in the IRF-filtered light curve of Exo-1

We searched for a secondary eclipse using a sliding box at the duration of the transit over the range of phases 0.3-0.7. The out-of-eclipse level was estimated from a section of the same duration either side of the putative eclipse. We thus detected a possible secondary (shown below left) at phase 0.48 with depth $\delta=1.1 \times 10^{-4}$, with significance $S=\delta/\sigma \cdot \sqrt{N}=4.3$, where σ is the local noise level per data point and N is the number of in-eclipse points. To test the reliability of this detection we repeated the sliding box scan allowing both phase and duration to vary. The resulting 2-D significance map is shown below right (white means high S). The periodic structure of the map and the relatively short duration of the most significant event (red cross) indicates that the "detection" may be instrumental in origin (the satellite frequency is close to an harmonic of the planet's orbital frequency).



Conclusions

The IRF is a post-detection stellar variability filter using knowledge of the transit period to improve transit reconstruction. We used synthetic data to show that it performs better than a widely used pre-detection filter for light curves with strong stellar variability. The IRF planet parameters of Exo-1 and Exo-4 are not significantly different from those obtained with the NIF and from the published values, implying that traditional variability filtering method are appropriate for the levels of stellar variability in those light curves. For Exo-1, we obtain a tentative detection of a secondary eclipse implying a high albedo, but a systematic exploration of the phase and duration parameter space for the secondary suggests that this is an instrumental effect related to the satellite orbital period. In the near future we plan to apply the IRF to other CoRoT light curves, in particular that of the highly variable CoRoT-Exo-4.