Report on the Non Destructive Readout mode with threshold limited integration

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Summary:
The IOT observed in time series of XSHOOTER spectra a strange behavior of some emission lines in the NIR arm. Emission lines that should be stable at the time scale of the observation performed showed strong and fast variations. After investigation the reason of such behavior is not related to the object, to the pipeline versions, but is related to a side effect of the NIR readout mode used by XSHOOTER that is the non destructive readout mode with threshold limited integration.
It means that some pixels may follow during the integration different regimes affecting their respective behaviours and values.
This report also concerns HAWK-I, SINFONI, which use the same readout mode than XSHOOTER.

Introduction:

The Non destructive readout mode with threshold limit is reading continuously the detector and if the threshold is reached for given pixel, then the readouts with values above it are ignored. The corresponding ADUs level is interpolated till the end of the DIT with the readouts having values below the threshold. This works independently for each pixel meaning that some pixels can follow the "interpolation regime", some other not.
We strongly recommend that the users follow the indications at the end of this document for preparing their OBs and properly set up the NIR DITs.

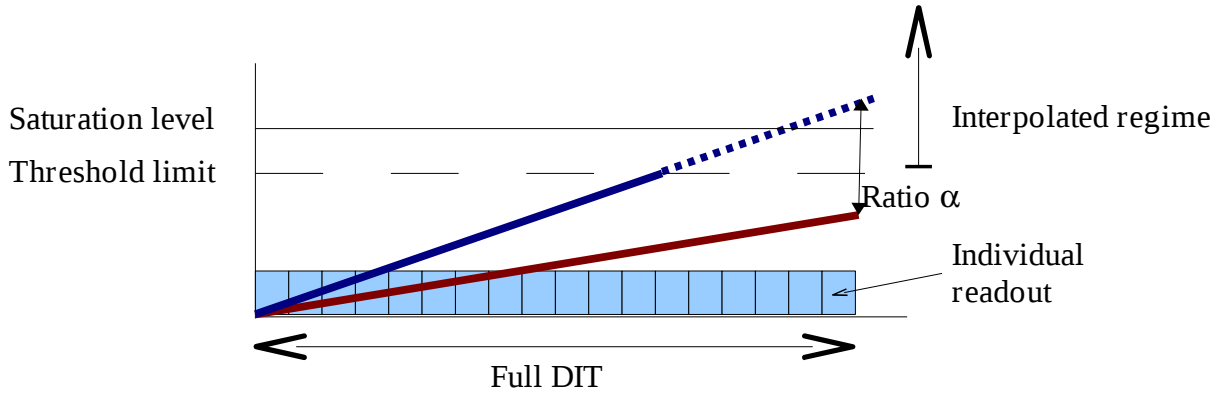


Figure 1: Non Destructive readout mode with threshold limit, the behaviour of 2 pixels is shown. The red one does not receive enough flux for entering the inter/extrapolated regime (all readouts below the threshold). The blue one receive more flux and after 13 readouts will enter the interpolated regime based on the previous readouts with counts below the threshold. The ratio between the red and blue curves is always the same during the DIT, we call it ratio α.

This kind of readout mode is improving the RON and it perfectly suited for most of the observations.
In addition the "extrapolated" regime permits to save the pixels which should have saturated and therefore the corresponding would have been lost.
However, having pixels using different regimes (inter/extrapolated one and normal one) at same time can introduce serious issue and problems for different science cases.

Problems on data:

For instance, let's follow the behaviour of a pixel in an emission-line and a neighbour pixel in the continuum.

-If there is no flux variation of the source or due to the sky (transparency, seeing), the ratio of the line to the continuum should be the same during the entire DIT. Entering the interpolated regime for the emission line should not modify this ratio. It should follow the example shown above in Figure 1.

-If there is a sudden variation of the transparency or the seeing, this could lead to strong and uncontrolled variations of the ratio line to continuum.
In Figure 2, at the start of the integration the atmosphere is clear, then the emission-line (in blue) enters the interpolated regime. At that moment or a little bit later, a cloud is passing, the flux received in the continuum (red curve) will be lower than normally expected. Therefore there is a shear in the behaviour of the continuum pixel and the emission line pixel. This affects the ratio between them that becomes different.

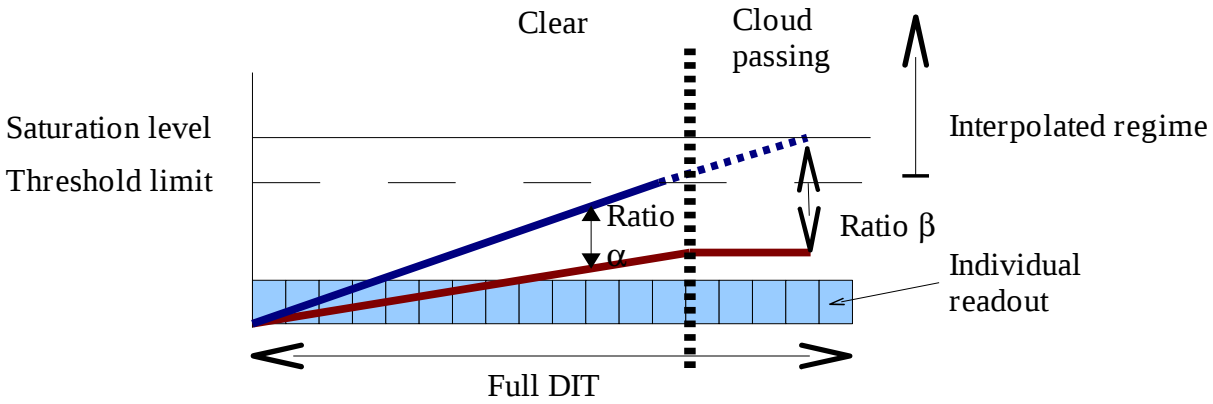


Figure 2: Evolution of a pixel in an emission-line in blue and in the continuum in red. At a given point, the emission-line pixel enters the interpolated regime while the continuum pixel will continue in the normal regime. Then there is a strong flux variation due to a cloud passing for instance, the continuum pixel will receive less flux than expected while the readouts for the emission line pixel are ignored.
Therefore the ratio emission-line/continuum will be modified from ratio α =normal ratio to ratio β.
Here ratio β > ratio α while they should be identical.

In Figure 3, we have the reverse case, the integration starts with a bad seeing for example, the emission line pixel needs more time to reach the threshold and enters the interpolated regime. Until that moment both pixels (emission-line and continuum) are following the same evolution, the ratio stays constant=ratio α. Then suddenly the seeing improved affecting the flux received in the continuum pixel but the readouts for the emission-line pixel are ignored (this variation is not seen by this pixel). Therefore the ratio between the emission line and the continuum changes again.
Here ratio β < ratio α while they should be identical.

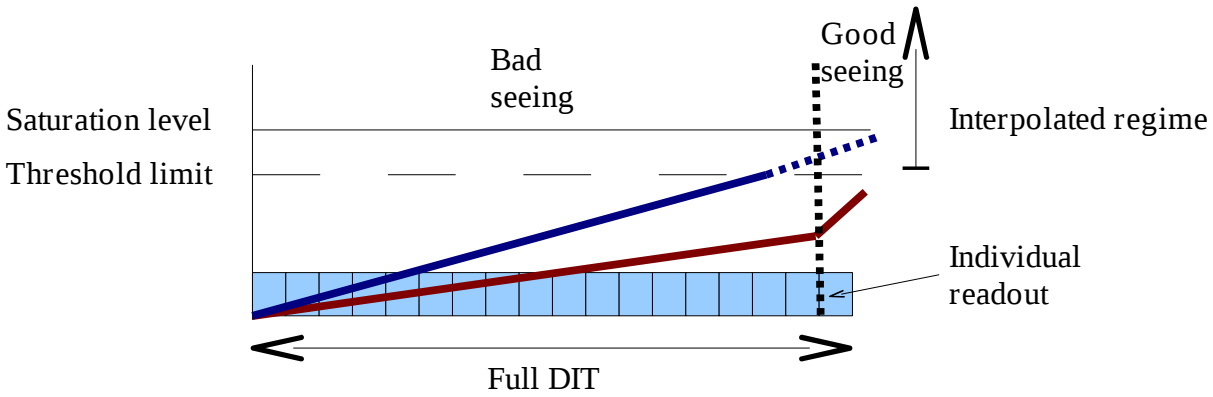
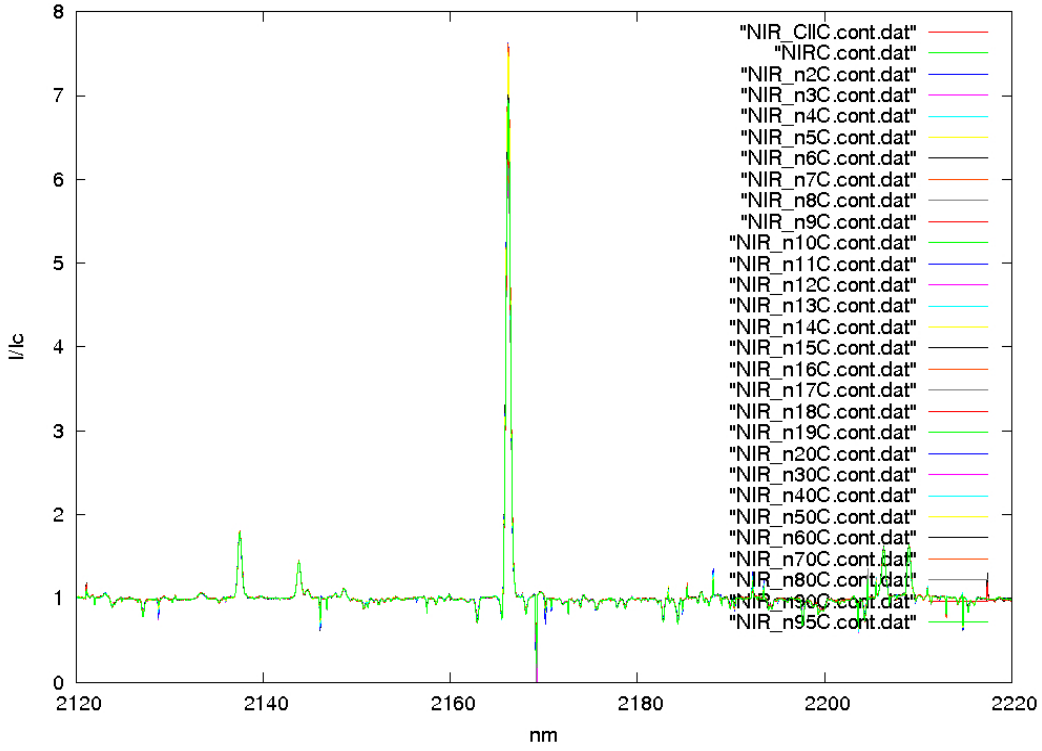
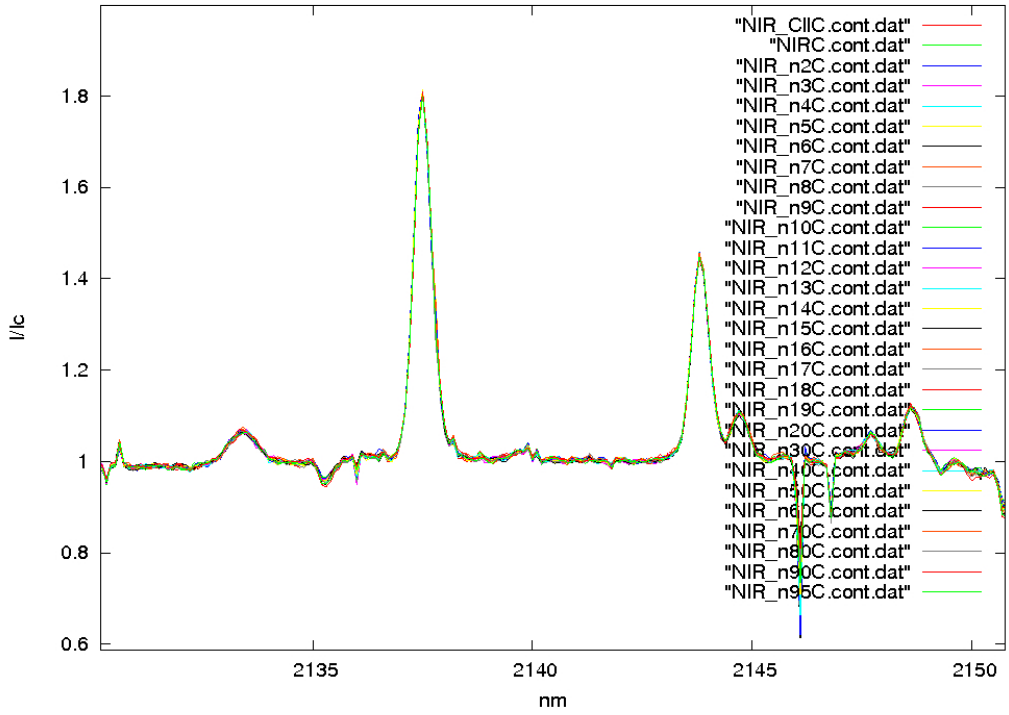


Figure 3: Evolution of a pixel in an emission-line in blue and in the continuum in red. At a given point, the emission-line pixel enters the interpolated regime while the continuum pixel will continue in the normal regime. Then there is a strong flux variation due to the improvement of the seeing for instance, the continuum pixel will receive more flux while the readouts for the emission line pixel are ignored.

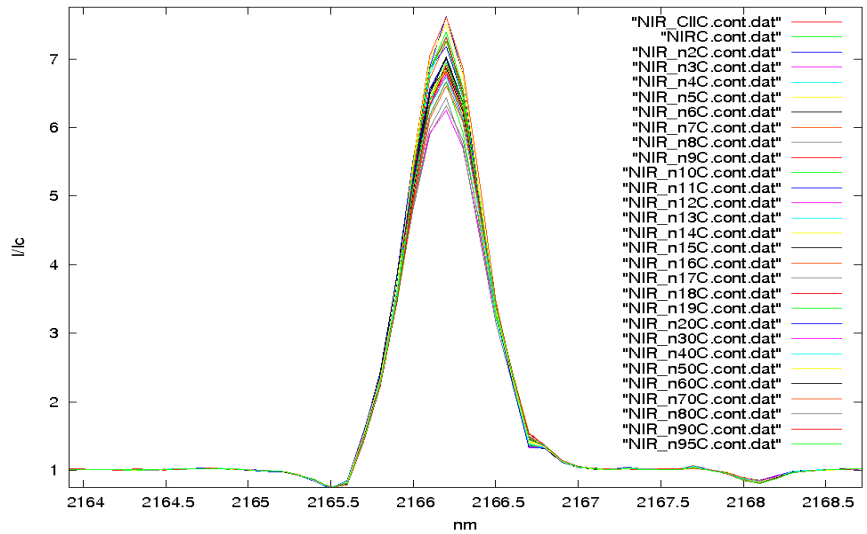
Examples in real XSHOOTER data:



In this NIR spectra extract, there are different emission-lines. They (and the continuum) followed different regimes.

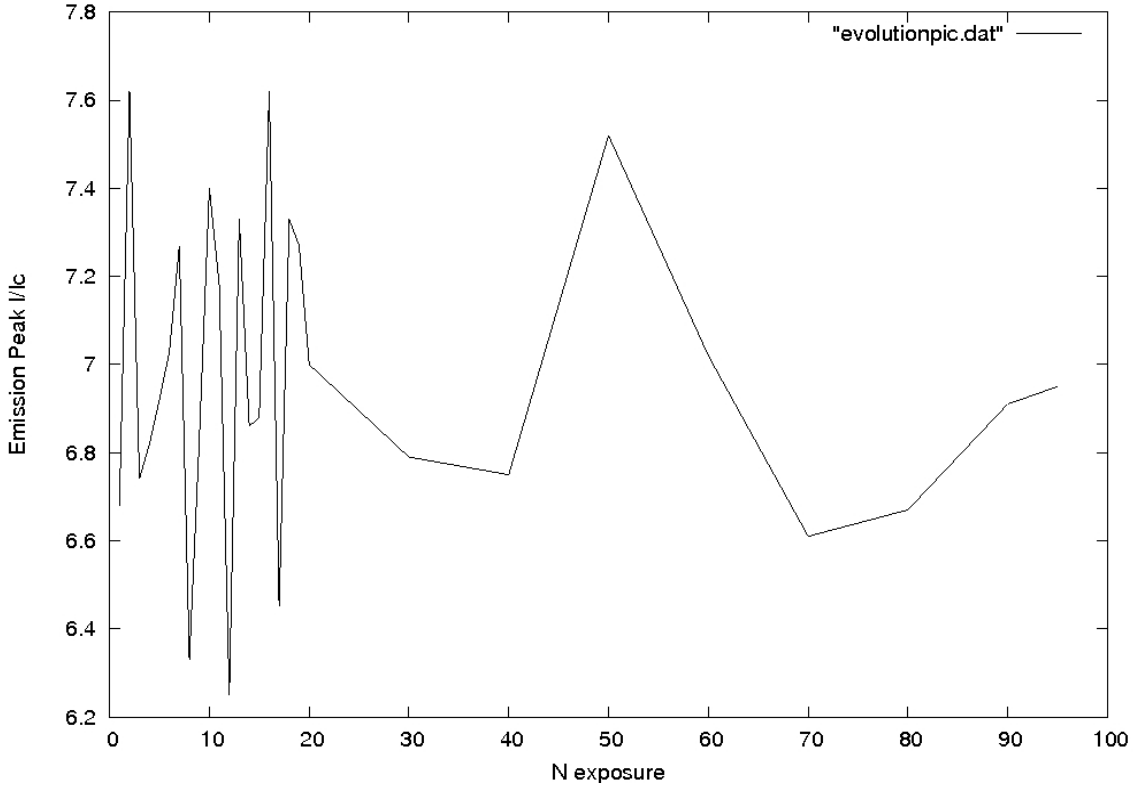


These emission-lines/pixels never reached the threshold, they followed the same evolution of the continuum pixels. Here everything is fine. 30 spectra are displayed and normalized to the continuum for an easy check. The 20 first were obtained in ~30mn, the last ones were obtained 1h later.



Here there is the case of the Br gamma emission-line that reached the threshold and not the continuum. It shows the variations explained above. Same spectra are displayed than before.

The next plot shows the ratio peak of the emission-line Br gamma to the continuum for these 30 spectra. They are plotted wrt the time.



Strong variations between 2 consecutive spectra (in less than 2 mn) can be seen.

Consequences on data quality:
One cannot trust the evolution of the pixels in the inter/extrapolated regime wrt the pixels in the normal regime. Here the study of the ratios between lines is not easily possible as example.

Pro and cons of the Non destructive readout mode with threshold limit:
-increases the dynamics
-lowest possible readout noise
-suitable for faint targets
-always provide an information, as example for the emission line that could saturate in another mode, we still have here the information on the radial velocity.
-Does not allow reliable study between pixels following different regimes (line ratios, ratio continuum/line not possible). This is valid for the continuum, for absorption or emission lines.

How to perform studies with the non destructive readout mode for bright objects:

1) Check with the XSHOOTER ETC version 3.2.13 that indicates which regime the NIR pixels are following
2) Take care that they never enter the extrapolated regime (42000 ADUs or 89000 e-).
3) The saturation occurs at 45000 ADUs and it happens only in case there is not enough readouts for “activating” the extrapolated regime.