SNR-QSO with ESPaDOnS: Tests, impacts, and feasibility
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The scope of the document is to review the tests of the SNR-QSO mode with ESPaDOnS (ESP) in January 2016, to review applicability for this mode as well as follow up on its performance on subsequent 2016 data.

1. Preliminary notes

In January 2016, the ESP control commands were modified in order to take into account a goal SNR and to stop the exposure once the SNR calculated by the exposuremeter has achieved the requested goal. The exposuremeter SNR value is calculated from the received flux per second and calibrated into SNR at 730nm; this calibration includes a necessary correction for the spectrograph (air) temperature, (see sec. 5). The transmission evolution due to mirror degradation with time from aluminization is not taken into account, as for the ETC.

Note that for exposure times <15s, the SNR from the exposuremeter is less accurate and underestimates the real SNR –this should **not be used directly to avoid saturating spectra**.

In **Polar** mode, each exposure of a sequence is treated independently and thus the **4 exposure times have different exposure times**. Changing the individual exposure times in a polar sequence has an effect on the heliocentric correction of each exposure, and thus, on the final velocity profile of the spectrum. At the very small levels of polarization that ESP records, this impact can create an unwanted spectral shift and spurious polarization detections. The main goal of the tests done in January was to quantify this impact.

2. Test description

The first test (Jan 22, 2016) showed that the 'go' command executes as expected, in both modes: when the SNR goal is not achieved before the time set in the Instrument configuration, then the exposure stops normally at this value; otherwise it stops at the goal SNR value. In Polar mode, the four exposures have slightly different exposure times, and we verified that this does not cause any problem for the quicklook nor the pipeline.

The second test was to insert a SNR-mode flag in PH2, and copy the SNR goal given in PH2 into the 'go' command. This was executed successfully on Jan 25, 2016.

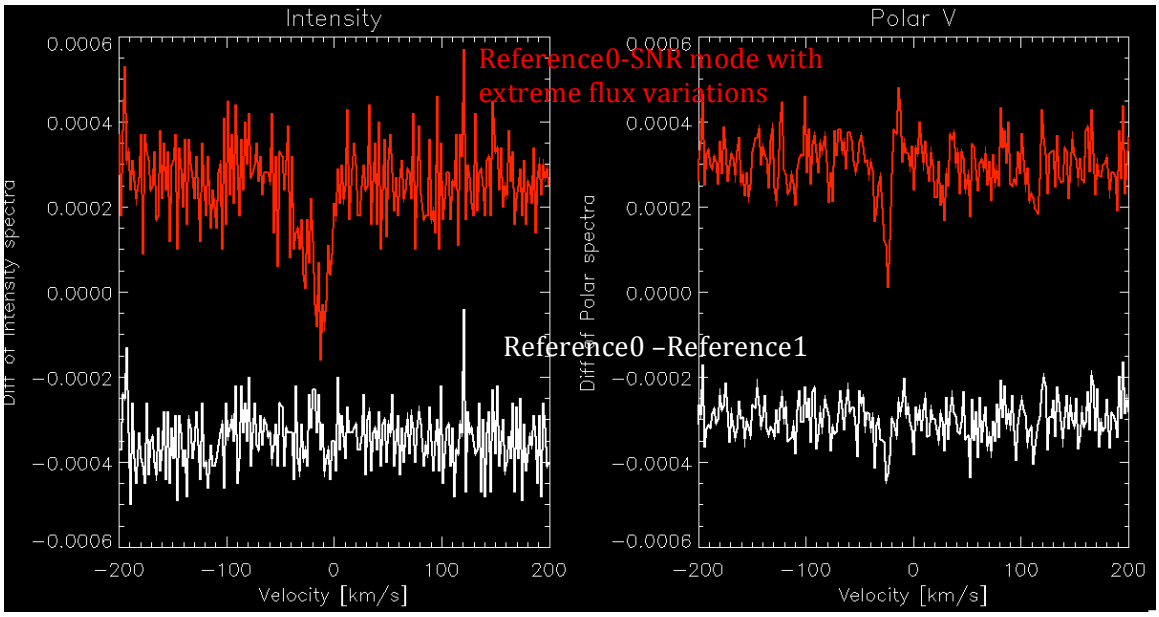
The third test (jan 25 and 26) was to evaluate the limits where SNR mode should be applied. We compare these spectra with the same star observed with same exposure times and varying SNR and with similar exp times and SNRs. To mimic the change of exposure time in a polarimetric sequence, we defocused the telescope during a

polarization sequence in SNR mode, in order to have equal SNR across the sequence and different exposure times.

3. Results

Jan25 test

ID-OG# odometer	Texp max [s]	SNR goal	Exp1	Exp2	Exp3	Exp4	Comments
E93-13 1889425p	60	950	Ef 50740 SNR 695 Texp 60	Ef 48440 SNR 683 Texp 60	Ef 48324 SNR 676 Texp 60	Ef 51111 SNR 695 Texp 60	Reference 0 SNR goal not achieved
E97-3 1889429p	45	-	Ef 49047 SNR 599 Texp 45	Ef 50848 SNR 602 Texp 45	Ef 49855 SNR 597 Texp 45	Ef 50092 SNR 598 Texp 5	Reference 1 no SNR goal
E93-15 1889441p	60	500	Ef 52221 SNR 501 Texp 32.4	Ef 43292 SNR 501 Texp 37.0	Ef 22723 SNR 467 Texp 60	Ef 4094 SNR 258 Texp 60	SNR-mode with defocus

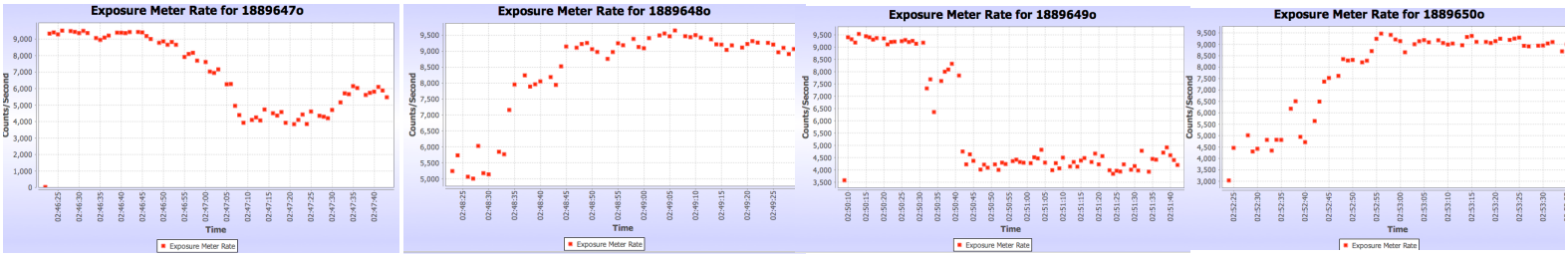


For each spectrum, the mean stellar (LSD) profile was calculated. In red, the SNR-mode profile minus the Reference 0 profile. In white, for comparison, a subtraction of the profiles of both reference spectra. Left: intensity, right: polarization Stokes V. The plots have been shifted for clarity. Note the scale: we look at the 10^{-4} level!

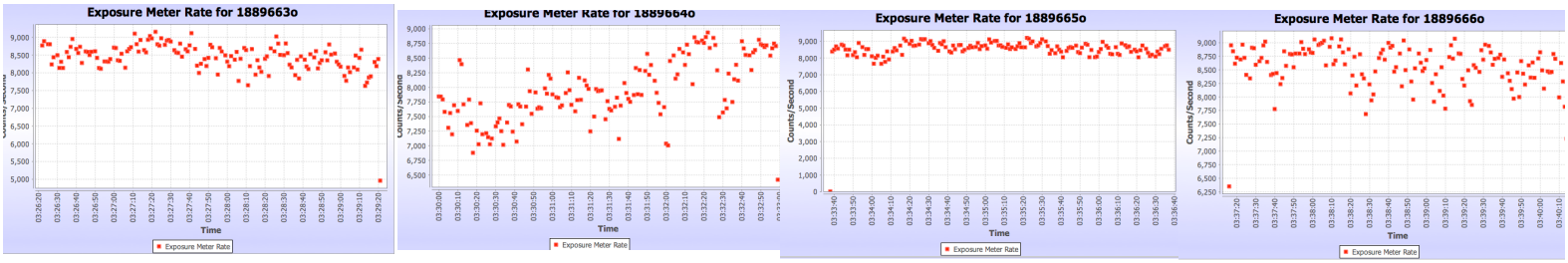
Conclusion of Jan25: When the flux variations are **extreme** (facteur ~15) during a polar sequence, spurious signals are indeed produced. More data with milder variations are needed. A SNR-mode sequence w/o flux variations is also missing.

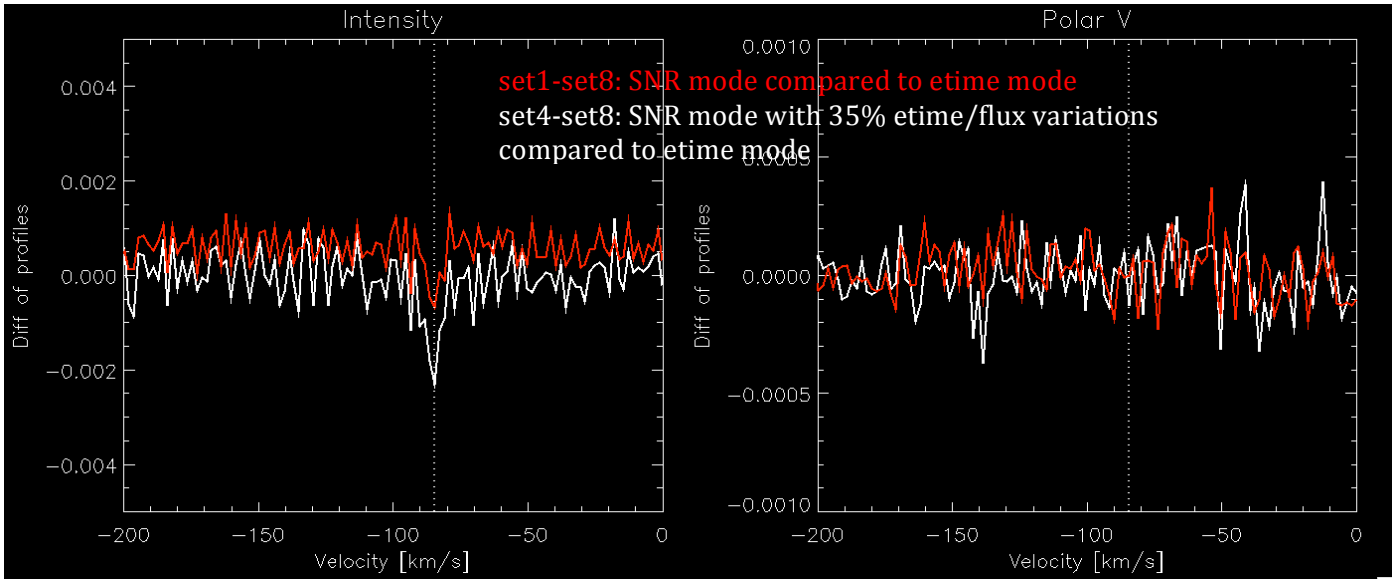
Jan26 test

ID-OG# odometer	Texp max [s]	SNR goal	Exp1	Exp2	Exp3	Exp4	Comments
E93-2 1889635p set1	180	300	Ef 8358 SNR 300 Texp 67.5	Ef 8301 SNR 303 Texp 69	Ef 8370 SNR 300 Texp 68.1	Ef 8516 SNR 301 Texp 66.8	SNR mode normal 3% var etime
E93-2 1889639p set2	180	300	Ef 9118 SNR 301 Texp 62.5	Ef 9012 SNR 302 Texp 63.8	Ef 8581 SNR 301 Texp 65.2	Ef 8697 SNR 304 Texp 65.6	SNR mode 5% var etime
E93-2 1889643p set3	180	300	Ef 8208 SNR 303 Texp 70.5	Ef 8710 SNR 300 Texp 65.2	Ef 9340 SNR 302 Texp 61.3	Ef 8709 SNR 302 Texp 64.3	SNR mode 14% var etime
E93-2 1889647p set4	180	300	Ef 6919 SNR 301 Texp 82.3	Ef 8390 SNR 300 Texp 67.8	Ef 5812 SNR 301 Texp 96.4	Ef 7824 SNR 301 Texp 73.1	SNR mode 35% var etime
E93-2 1889651p set5	180	300	Ef 7326 SNR 301 Texp 77.2	Ef 8418 SNR 300 Texp 67.7	Ef 5904 SNR 301 Texp 96.6	Ef 7408 SNR 301 Texp 77.2	SNR mode 35% var etime
E93-2 1889655p set6	180	300	Ef 8606 SNR 302 Texp 66.1	Ef 8943 SNR 300 Texp 63.4	Ef 8636 SNR 302 Texp 66.6	Ef 7857 SNR 301 Texp 71.9	SNR mode 17% var etime
E93-2 1889659p set7	180	300	Ef 7950 SNR 301 Texp 69.9	Ef 7720 SNR 301 Texp 74	Ef 8539 SNR 301 Texp 65.8	Ef 7718 SNR 301 Texp 73.6	SNR mode 11% var etime
E93-16 1889663p set8	180	-	Ef 8464 SNR 499 Texp 180	Ef 7934 SNR 482 Texp 180	Ef 8572 SNR 502 Texp 180	Ef 8565 SNR 502 Texp 180	Etime mode reference



Exposuremeter plots of the flux/second for set 4 (above) and reference set 8 (below).





*Comparison of intensity and polar LSD profiles for set1 (SNR mode in stable conditions), set4 (SNR mode in variable conditions) and set8 (etime mode**). No spurious detection in polar is seen**. Small depth differences in intensity spectra, probably due to the difference of SNR between set8 (~500) and others (~300).*

None of the sets with modified flux within the sequence produces a spurious signal in polarization. There is always a small difference in intensity profile depth, but this has no consequence.

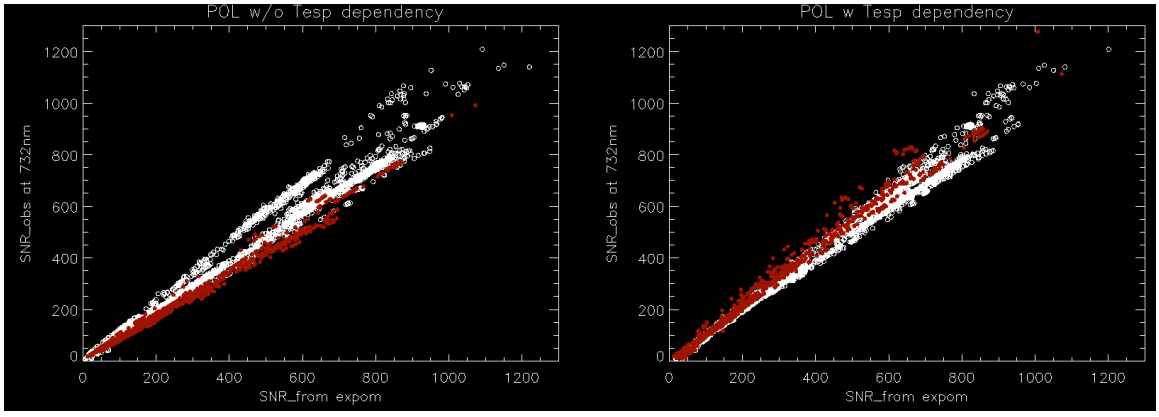
Conclusion: even with 35% variations in the flux and exposure times during a polarization sequence, there is no appearance of spurious polar signals. It is very encouraging and means **we can safely use the SNR mode in most clear conditions**, when flux variations only arise from the unavoidable centering and/or slight turbulence fluctuations. I would not recommend using SNR mode in polar when flux variations are larger than ~30% over the sequence, to be safe.

4. Applicability and limits of ESP SNR-QSO

- **SNR-QSO mode can always be applied in Star+Sky and Star-Only modes**, as long as a SNR goal is given by the PI. This could be the default mode in spectroscopy. One caveat is the case of variable stars, or stars of ill-known temperatures, for which it would be better to slightly increase rather than decrease the e-time in real time. These cases are not dealt with in the current software and we should urge PIs to put some margin (ie, higher SNR goals) if they have doubts.
- SNR-QSO can be used (as coded, with 4 different exposure times) **in the Polar mode when conditions are clear and for certain types of stars.**
- Unsuitable stars may be spectroscopic binaries, fast rotators, extreme variables. So the PI should have the possibility to opt out of SNR mode.

- Unsuitable conditions for SNR mode include cloudy nights where the flux may vary by a factor > 1.3 during a sequence. These may be bad data anyway for spectropolarimetry since the photocenter of exposures varies.
- The use of SNR QSO is thus a **combination of PI option and sky conditions**. It should be possible for the observer (or the software) to **bypass** the PI willingness to use SNR mode if conditions are not good enough, resulting in very different exposure times in a polar sequence. We should avoid situations where some exposures of a polar sequence are stopped by etime and others by SNR.
- Enforcing the use of the SNR mode should be done at PH2 level, since **we need precise information**. Required parameters are: magnitude, Teff (FT), SNR goal (OB), maximum exposure time per exposure (in IC). Default values can be chosen for SNR_wave, IQ limit (very large impact), Airmass limit (very low impact), extinction limit (very large impact), since we try observing in any conditions with ESP. We need to **check the consistency** of these numbers beforehand, for instance when saving the OBs or the OGs and with a web application.
- Technical implication: we need a mechanism to **constantly validate the exposuremeter calibration for SNR**. It can be done daily on calibrations, when the exposure time exceeds 15s. If possible, the optical alignment of the exposuremeter should not be touched.

5. Exposuremeter calibration (update)



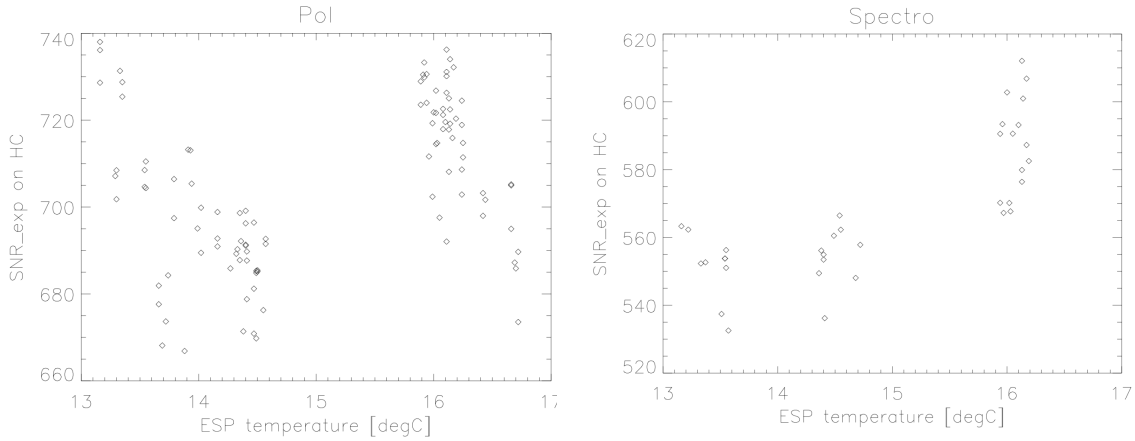
Verification of the exposuremeter calibration and its dependency with the temperature in the spectrograph. SNR measured by the pipeline at 730nm as a function of the SNR calculated in real time by the exposuremeter, in polar mode. In white, all data from 2015 when exposure time is >10s. In red, the most recent data, from December 2015 to January 2016. On the right, a linear dependency with ESP temperature is corrected for and the scatter is reduced. There is no temperature dependency in the spectroscopic mode.

It seems the temperature correction could be adjusted –still some scatter in high SNR regime. Most recent data may represent different thermal conditions since the installation of the GRACES walls, which could explain the need for a (minor) adjustment.

The SNR calculated for the long comparison exposures done each day of an ESP run at least once can be used to check the reliability of the exposuremeter alignment, especially in case something is moved inside the spectrograph.

SNR_expo=705 +-20 in polar mode on 60s HC exposures
SNR_expo=570 +-20 in spectro-SS mode on 60s HC exposures

The plot below shows the behavior of this SNR as a function of temperature [values between 16-17° correspond to the run Q13-Nov23 to Dec03, temperature mainly decreasing during the run; values between 13-15° correspond to the January 2016 run, temperature increasing during the run]. There is no obvious trend with this parameter.

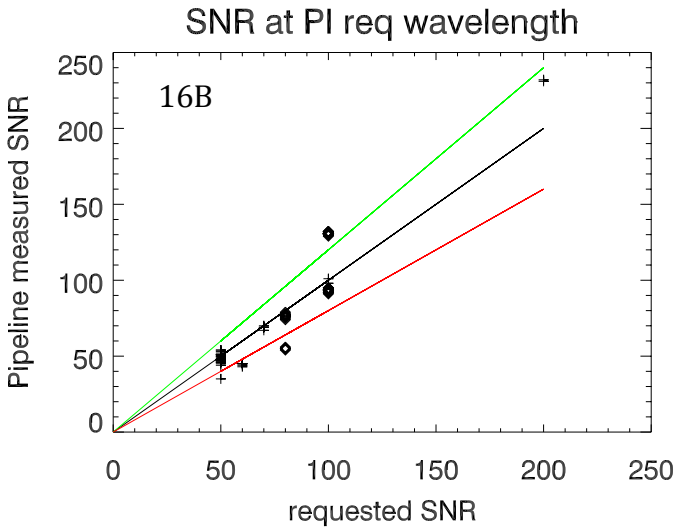


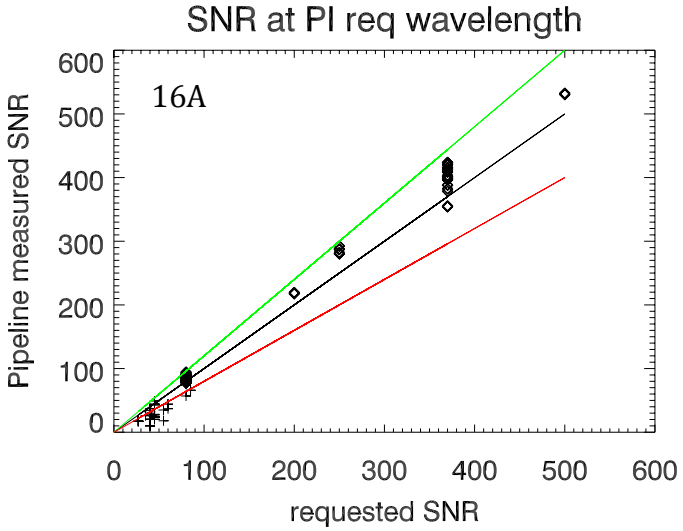
Conclusion: the SNR measured by the exposuremeter daily during a run are fairly stable and can be used to check the validity of the exposuremeter position and calibration. If more precision is needed, a procedure involving the flatfield lamp and exposures >15s could be put in place, with a frequent monitoring. That may not be needed, but we need to keep an eye on the comparison 60s exposure during runs and at checkout. **If SNR drops to <500 (polar) or <350 (spectro), eg the flux drops by a factor 2, a warning should be sent to the Remote Observer and SNR-QSO should be put on hold until it is investigated**.

6. Report on SNR mode performance from Feb2016 to mid August 2016

Time gain: 16A 11.5h, 16B 5.7h / 16A 391 h, 16B 95.97 h requested (3%, 6%)
Time gain on programs that requested SNR mode:
- in POL: 16A 5.3h, 16B 1.8h / 16A 11.7h, 16B 7.87 h validated (45%, 23%)
- in S+S: 16A 5.8h, 16B 3.2h / 16A 11.6h, 16B 10.74 h validated (50%, 30%)

Comparison of the requested and measured SNR: top) at the wavelength requested by the PI, and compared to the LE pipeline measurement, bottom) at the default wavelength (730nm) and compared to the exposuremeter SNR estimate (aligned by construction). The green and red lines show 20% variation in SNR. Only validated exposures are shown.





Diamonds= polar mode
Crosses=Star+Sky spectro