EUROPEAN SOUTHERN OBSERVATORY

MEMORANDUM

January 26, 2000

To: FORS1 Team, QC, FORS1 Users
From: F. Patat

Subject: **FORS1 CCD Noise and Contamination Analysis**

1 Introduction

FORS1 images are assumed here to be affected by three different kinds of *noises*:

- Large Scale Gradients (LSG): generated by illumination gradients and possibly by CCD contamination;
- Photon Noise (PN): generated by the photon shot noise and distributed according to poissonian statistics;
- Fixed Pattern Noise (FPN): due to the presence of *permanent* structures in the CCD (bad pixels, scratches on the coating, grains of dust, etc.).

Read–out noise (RON) is neglected here, since at an exposure level of 20,000 ADUs, it contributes less than 0.02% in the global noise budget. For this reason in the following we will assume that the total noise is given by $\sigma_o \sim \sqrt{\sigma^2_{LSG} + \sigma^2_{PN} + \sigma^2_{FP}}$.

2 Estimating the Noises

In the procedures currently implemented in our quality checks, the whole analysis is executed on the master imaging dome flats, which are actually the average of $N = 2$ frames. Despite of this, in the following discussion (and in all plots), all values are computed as if they were measured on raw frames. This was simply achieved by multiplying the measured noises by $\sqrt{N} = \sqrt{2}$ when required. For sake of simplicity, in the following we will assume that the input frames are raw frames. Moreover, we present here only the results obtained for the U passband, since this has been proven to be the most sensitive to the contamination effect.
All the analysis is performed on a small window (in the following 100×100 px). This has the advantage of speeding up the calculations and to allow for a more local treatment of

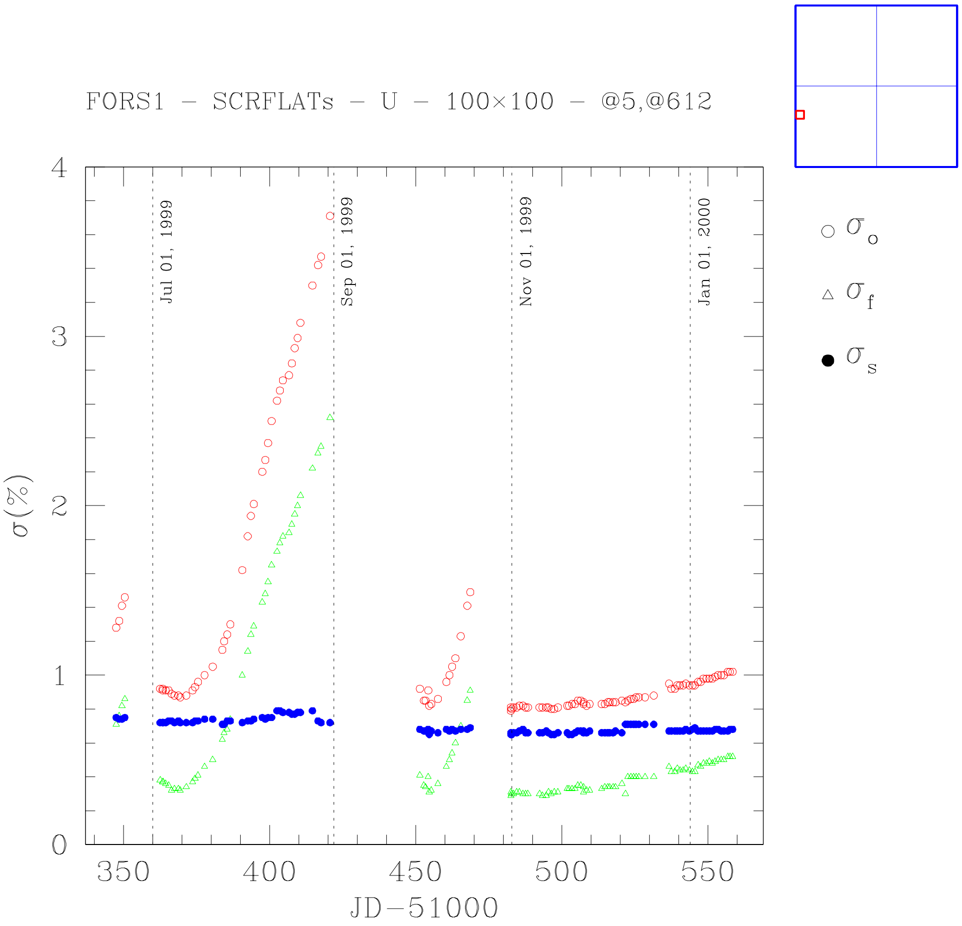

Figure 1: Noise trend analysis for U screen flat fields over a period of about 6 months. All computations have been performed in the 100×100 px box positioned in port A, as shown in the right upper scheme of each panel. The reference frame used is an U screen flat taken on Nov 04,1999. See text.

the problem. The position of the window is chosen to be sensitive to the contamination effect, i.e. close to one of the detector edges.
Due to the way the CCD is illuminated in the dome and to the possible presence of contamination, the screen flats appear to show strong gradients, which need to be removed if one wants to take into account only effects which are intrinsic to the detector. This is very simply achieved by subtracting a smoothed version of the input frame. In the examples which follow a median filter with a smoothing box of 10×10 px was used. This allows one to remove most of the high frequency noise and leaves unchanged the large scale structure. Already the comparison between the RMS of the original image σ_o and the RMS of the filtered image σ_f gives an idea of LSG contribution to the global noise. This is clearly visible in Fig. 1, where σ_o and σ_f are plotted as a function of time (empty circles and empty triangles respectively). All values are normalized to the median exposure level of the 100×100 window. As shown by Fig. 1, the time dependence of the global noise σ_o

is largely due to the variation in the LSG.

Now, one can go a little bit further simply measuring the RMS σ_s of the image obtained subtracting the filtered image from the original frame, i.e. evaluating the noise on the original image after removing the LSG. On the basis of the assumptions that we made, it should be $\sigma_s \simeq \sqrt{\sigma_{pn}^2 + \sigma_{fp}^2}$, where σ_{pn}^2 and σ_{fp}^2 represent the Photon Noise and the Fixed Pattern Noise respectively.

Due to the fact that we used input frames with roughly the same exposure level and since the FPN should be *fixed*, we expect σ_s to be approximatively constant. This is in fact clearly shown in Fig. 1, where σ_s has been plotted using filled circles. The conclusion is that time variations are due by far by changes in the LSG while PN and FPN are reasonably stable.

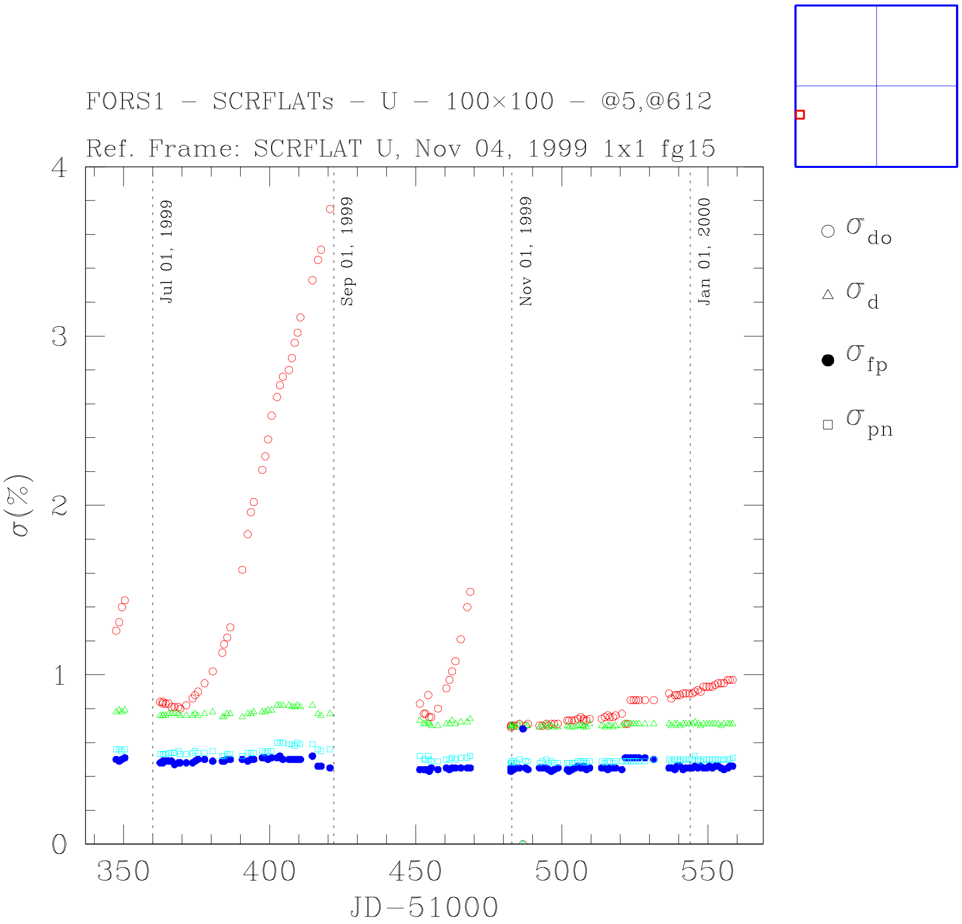

Figure 2: Noise trend analysis for U screen flat fields over a period of about 6 months. All computations have been performed in the 100×100 px box positioned in port A, as shown in the right upper scheme of each panel. The reference frame used is an U screen flat taken on Nov 04,1999. See text.

2.1 Photon Noise and Fixed pattern Noise

We have seen that σ_s collects the contributions of two noises, which we would like to disentangle. This is simply achieved by running the same analysis previously outlined, but this time on frames which are the difference between the input frames and a reference frame. It is in fact clear that, if the Fixed Pattern is stable in time, this operation cancels its contribution and one is left with the Photon Noise only. This of course is true only if no other contributions are present, which is most likely not the case, since we already know that LSG are playing an important role.
For this reason we can compute the RMS on the difference images before and after subtracting the filtered images, i.e. before and after removing the LSG. In this way we obtain what we call σ_{do} and σ_d respectively. As expected, σ_{do} is time dependent (see Fig. 2, lower panel, empty circles), while σ_d is reasonably stable. This gives us enough confidence to believe that $\sigma_{pn} \simeq \frac{1}{\sqrt{2}}\sigma_d$ and hence $\sigma_{fp} \sim \sqrt{\sigma_s^2 - \frac{1}{2}\sigma_d^2}$. The RMS noises σ_{fp} and σ_{pn} are also plotted in Fig. 2.

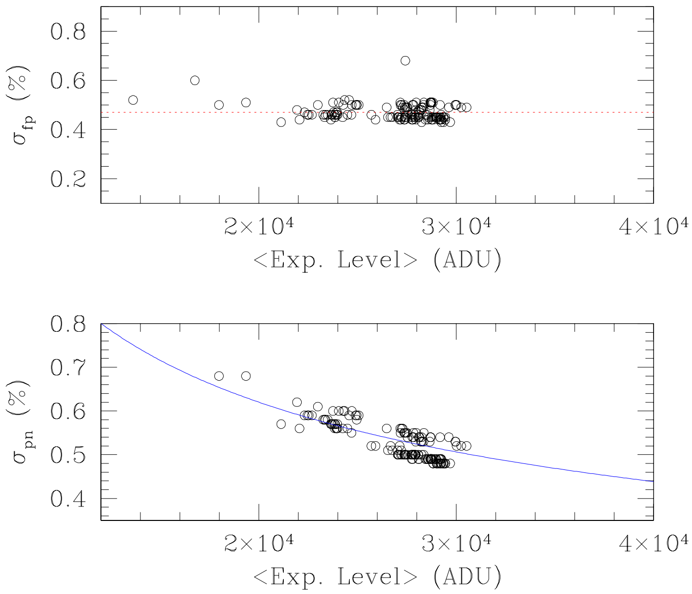

Figure 3: Fixed Pattern Noise (upper panel) and Photon noise (lower panel) vs. median exposure level.

We remark that despite of the significant time variation shown by σ_{do}, the Fixed Pattern Noise appears to be stable around 0.5%. Another result is that σ_{fp} and σ_{pn} are of the same order even if, to be precise, the latter depends on the exposure level. This is clearly seen in Fig. 3, where σ_{fp} and σ_{pn} have been plotted against the median exposure level within the 100×100 px window. While σ_{fp} does not show any evident dependence on the exposure level, σ_{pn} follows the Poissonian prediction. We note that σ_{pn} shows two families of points, which most likely are due to two different gain values.
In principle, even though σ_{fp} is constant, we cannot conclude that the Fixed Pattern is

stable on the basis of these numbers only. Nature could be so perfidious to make the FP change in such a way to leave σ_{fp} constant... By the way, we can already anticipate that the Fixed Pattern is indeed stable, and this has been assessed trough a more local analysis, which we will talk about some other time.

3 Contamination

As one can see in Fig. 2, the empty circles (which trace the original input frames or the original frame differences) show a saw–tooth behavior as an effect of the CCD baking. Fortunately it looks like that after the last work done on FORS1 (end of November) the Contamination is growing with a much slower rate if compared to what as happening after the two previous CCD bakings [1].

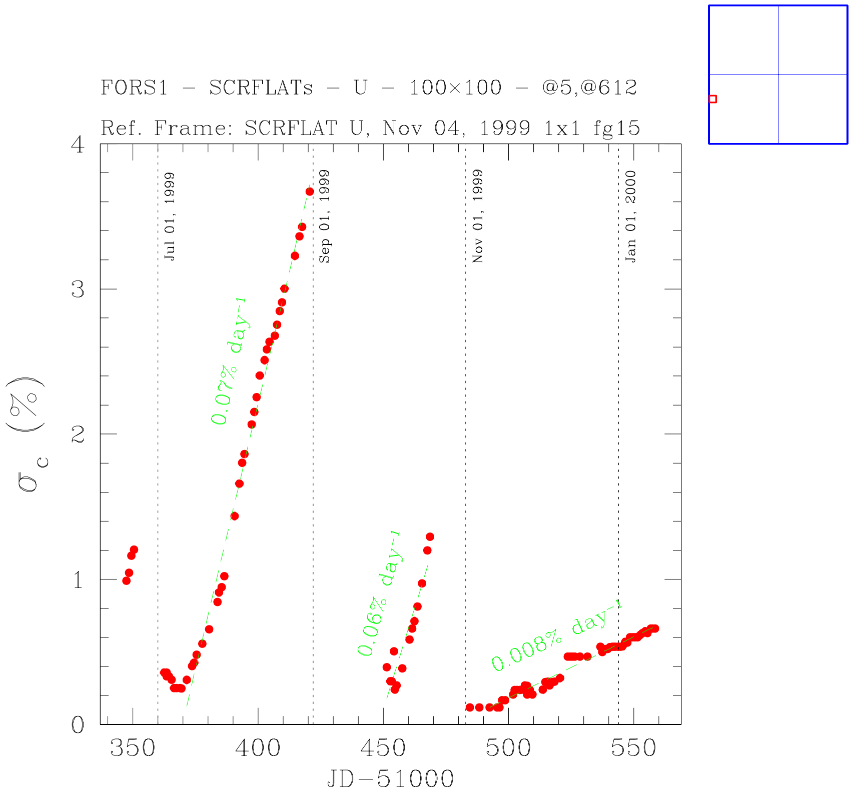

Figure 4: Behavior of σ_c as a function of time. Contamination growth rate has been estimated via a linear least squares fitting to the data after the Solo-Chewbacca relaxation phase.

To have a quantitative measure of the contamination, we introduce $\sigma_c = \sqrt{\sigma_{do}^2 - \sigma_d^2}$. In fact, while σ_d includes only the PN contribution, σ_{do} includes also the large scale

[1] We note that after each CCD baking, the contamination growth is preceeded by a relaxation phase, which is known as the Solo-Chewbacca effect.

gradients. Hence computing the difference between these quantities allows one to estimate the behavior of the LSG alone, which we know is dominated by the contamination effect. In Fig. 4 σ_c is plotted as a function of time, for the U passband. After the last intervention on the CCD, σ_c is growing with a rate of about 0.008% day^{-1}, i.e. more than 8 times less than after the two previous CCD bakings.

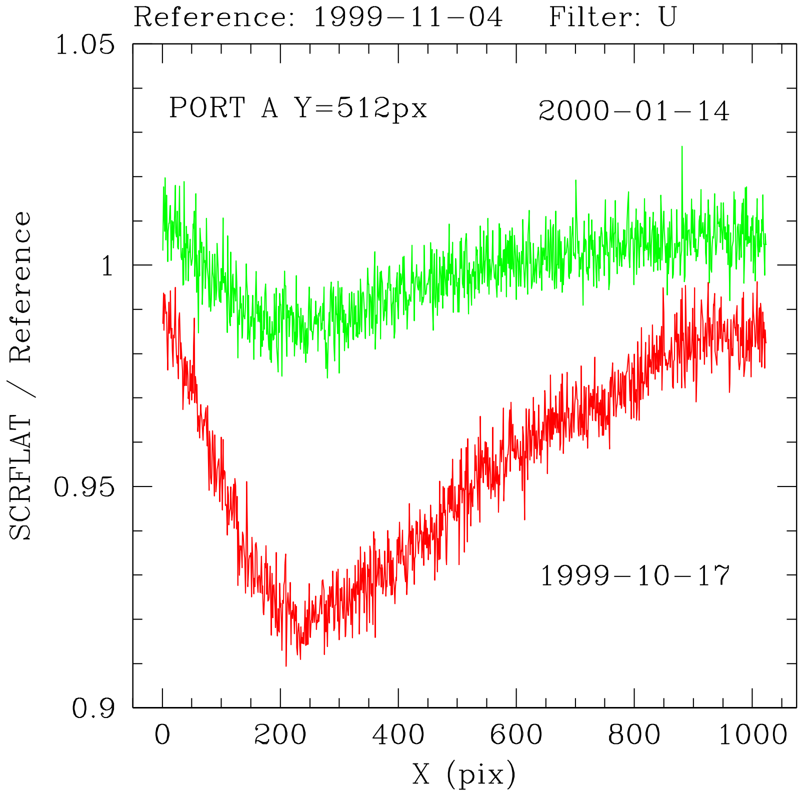

Figure 5: Cross cut at two different epochs of the ratio between the U screen flat and a reference flat.

This improvement in defeating the contamination process is clearly visible also in Fig. 5, where we have plotted a trace of PORT A across the central row (Y=512) for two images obtained dividing two U screen flats taken at different epochs (Oct 17, 1999 and Jan 14, 2000) by a reference U screen flat (Nov 04, 1999). The two epochs correspond to the maximum contamination reached before the last baking and the last measurement used in the present analysis. The difference between maximum and minimum in the two traces is 0.06 and 0.03 respectively. If one then takes into account that the time distance from the respective bakings is 18 and 75 days, then we reach again the same conclusion, i.e. the contamination grows with a rate which is about 1/8 of what it used to be.

4 Conclusions

The results reached by this analysis can be summarized as follows:

1. Photon Noise behaves as expected;
2. Fixed Pattern Noise is stable and is of the order of 0.5%;
3. After the last CCD baking, the contamination in the U band is growing at a rate which is smaller than in the past by a factor of $\sim$8;
4. Sky flats taken at several days from the science frames can be used to succesfully flat field the imaging data;
5. The dome screen flats can be taken at a lower frequence now, say once/twice per week. We could also restrict them to the U band only;
6. CCD baking can be triggered by fixing a threshold for the σ_c parameter. Tentatively, baking should be done once every two months.