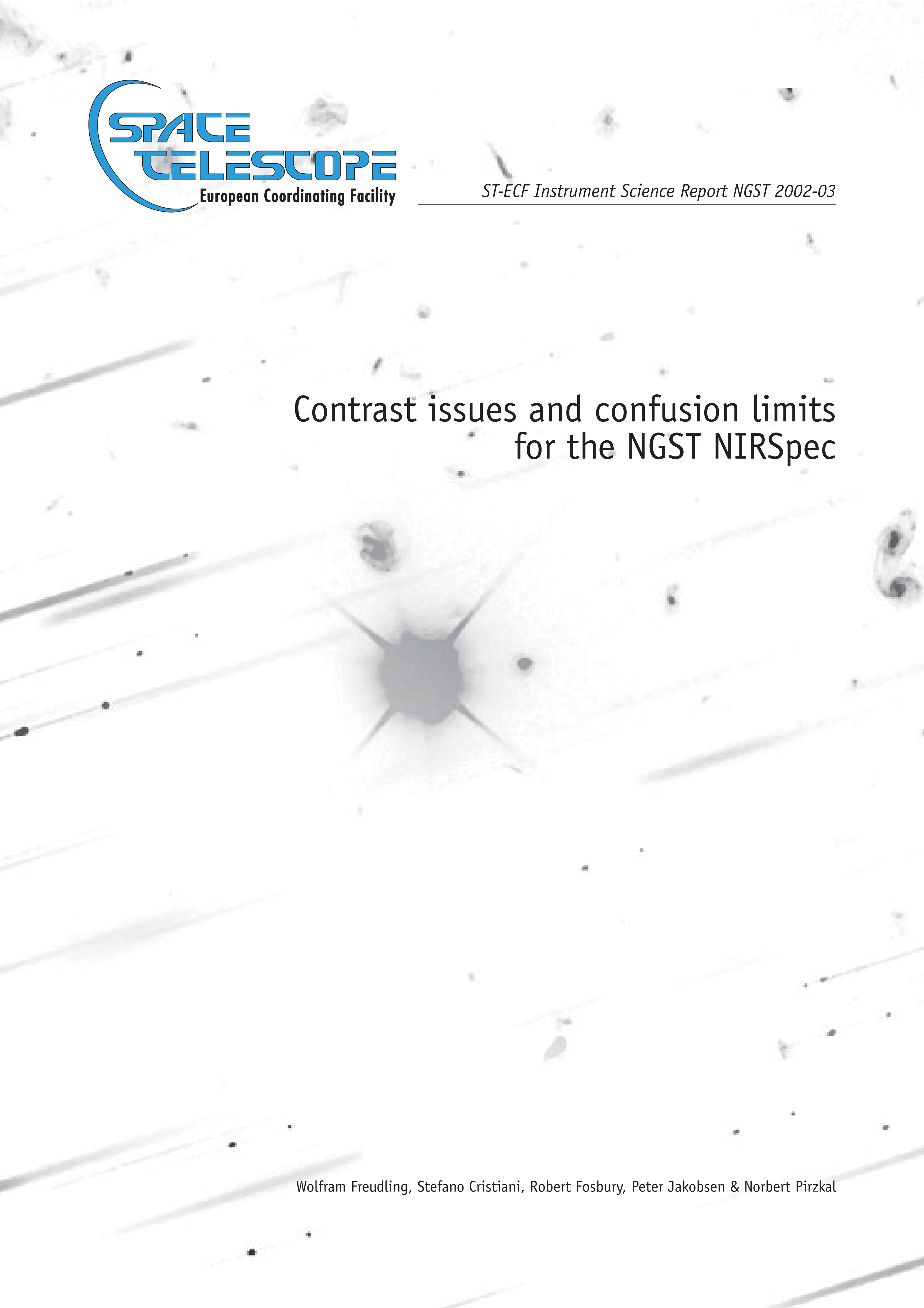

SPACE TELESCOPE
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ST-ECF Instrument Science Report NGST 2002-03

Contrast issues and confusion limits for the NGST NIRSpec

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V1.1, April 2002

Abstract

A crucial concern for MEMS-based spectrographs is the fate of light that enters the spectrograph from objects located in parts of the field not selected as open slits. The spectra from such objects will confuse the target spectra. We have investigated the effects of such confusion on deep spectroscopic observations. At the Galactic pole, the minimum acceptable level for the supression of light from an object outside a slit is a factor of 1,000 but a factor of 10,000 is highly desirable. In the Galactic plane, a much higher contrast factor is needed.

1. Introduction

The preferred slit-generating system for the Next Generation Space Telescope near-infrared multi-object spectrograph (NIRSpec) is a shutter array which consists of a micro electro-mechanical system (MEMS). An alternative MEMS technology is the creation of slits with mirror arrays. Any MEMS solution will not be perfectly ‘binary’ in the sense that elements which are in the ‘off’ position will still deliver some light to the spectrograph from bright objects in the field of view via leakage, diffraction and scattering processes. By virtue of that fraction of the leaked light which enters the spectrograph collimator, these ‘spoilers’ will appear as attenuated spectra on the detector and some of them will overlap the spectra of the faint target sources. In this report, we investigate the impact of this effect on spectroscopic surveys, both at high and low Galactic latitudes.

2. Sizes of spectra

The number of spectra that are ‘spoiled’ by overlaps depends on the contrast ratio reached by the MEMS device, the area on the sky covered by an individual spectrum and on the number density of potential spoilers at a given magnitude. The expected number of objects for a given magnitude limit strongly depends on the Galactic latitude. Here, we consider the extreme cases of a spectroscopic survey at the Galactic poles and in the Galactic plane.

At the poles, stars dominate the object number counts up to a magnitude limit of $K \sim 16$. Surveys to fainter magnitude limits are dominated by galaxies. By contrast, in the Galactic plane, stars dominate at any magnitude limit. We have used galaxy count extrapolations based on data from Maihara et al. (2001) and McCracken et al. (2000), stellar counts from the 2MASS Second Incremental Data Release
http://www.ipac.caltech.edu/2mass/releases/second/
to estimate the expected cumulative number counts at the poles and in the plane. The

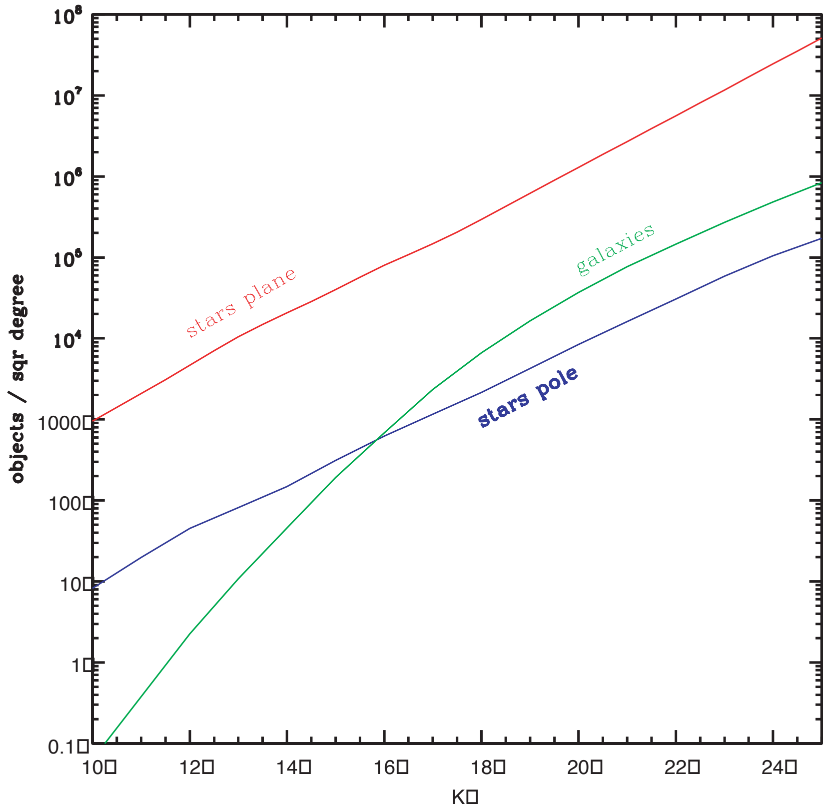

Figure 1: *Adopted K-band counts for galaxies and stars at the Galactic plane and poles.*

adopted numbers are plotted in Figure 1.

The angular size of the spoiler determines the area on the sky in which spectra of target objects are contaminated. For stars, we assumed a width of the spectrum of 3 pixels corresponding to 0.3 arcsecs. For galaxies, we adopted a size-magnitude relation which was derived as follows. For the sizes, we used the half-light radii r_h measured from the HDF-N NICMOS F160W observations of Thompson et al. (1999). The K magnitudes of the galaxies we estimated from the F160W as $K = m_{F160W} - 1.5$. The data are plotted in Figure 2. Superimposed is a line $r_h = 0.48 - 0.059\ (K - 20)$ which we adopted as the mean r_h. The width of spectra was assumed to be twice that value.

Finally, we have assumed that the length of the spectra in the dispersion direction is about 440 pixels and 750 pixels for the low and high resolution modes, respectively.

3. Probability of overlap

For the purpose of this study, we consider the spectrum of a target and a potential spoiler to overlap if the spoiler is located within the spectrum of the target or an area twice the size of the spoiler spectrum around the target. The expected number of galaxies in this region is $\rho\ \Omega_r$, where ρ is the number density of objects (galaxies/degree^2) derived from Figure 2, and Ω_r is the region where spoilers overlap the target spectrum. Assuming a Poissonian distribution of the objects, the probability P_m that a target spectrum is spoiled by another spectrum of an object of a given magnitude bin is then $1 - \exp(\rho\ \Omega_r)$. The probability that the target spectrum is contaminated by a spoiler of any magnitude is $P = \prod(1 - P_m)$ where the product includes all galaxies bright enough to significantly contaminate the target spectrum even

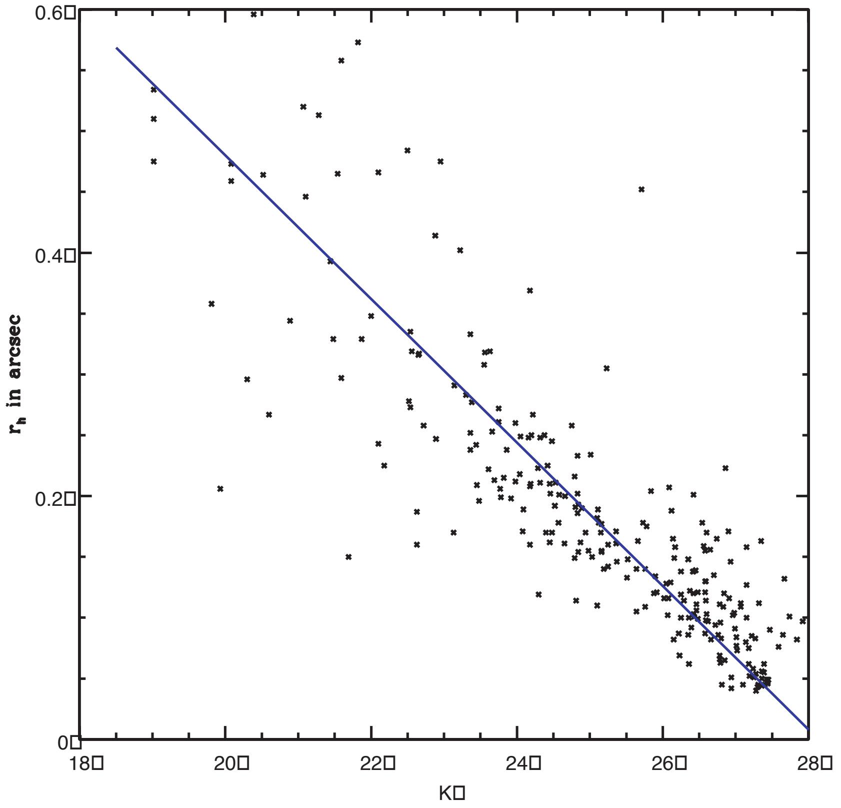

Figure 2: *F160W half-light radii measured by Thompson et al. (1999) as a function of estimated K-magnitudes. The line shows the relation used for the estimates of the width of spectra.*

when its MEMS facets are turned off.

4. Results

We have computed the probability that a spectrum is spoiled for different contrast ratios. The computations were carried out using four half-light radii as the size of the spectrum. Alternatively, we assumed a fixed size of 0.3 arcsec to approximate a situation where larger galaxies are avoided. The results for different contrast ratios are shown in Figures 3 and 4. The figures show the probability that a spoiler spectrum overlaps that of a target object as a function of the K magnitude of the target object. These curves are shown for spoilers which are 100, 1,000 and 10,000 times brighter than the target object. Each curve has been computed by varying the assumptions for the number counts and sizes within their uncertainties. The area between the maximum and minimum value for each K magnitude is shaded and reflects the the uncertainty in predicting the overlap probability.

These curves can be used to evaluate the necessary contrast ratios of the MEMS device. A strict requirement might be that the attenuated spectrum of a spoiler must be fainter than 10% of the target spectrum and that a spectrum is considered to be spoiled if any fraction of its area includes the spoiler. For a contrast ratio of 10,000, such an requirement implies that the spoiler must be fainter than 1000 times the flux of the target. Therefore, the green (central) curves of Figures 3 and 4 apply. At the Galactic pole, the probability of an overlap is about 5% for the low and 10% for the high resolution mode. However, in the Galactic plane, the probabilities of an overlap in this situation are about 80% and 90% respectively.

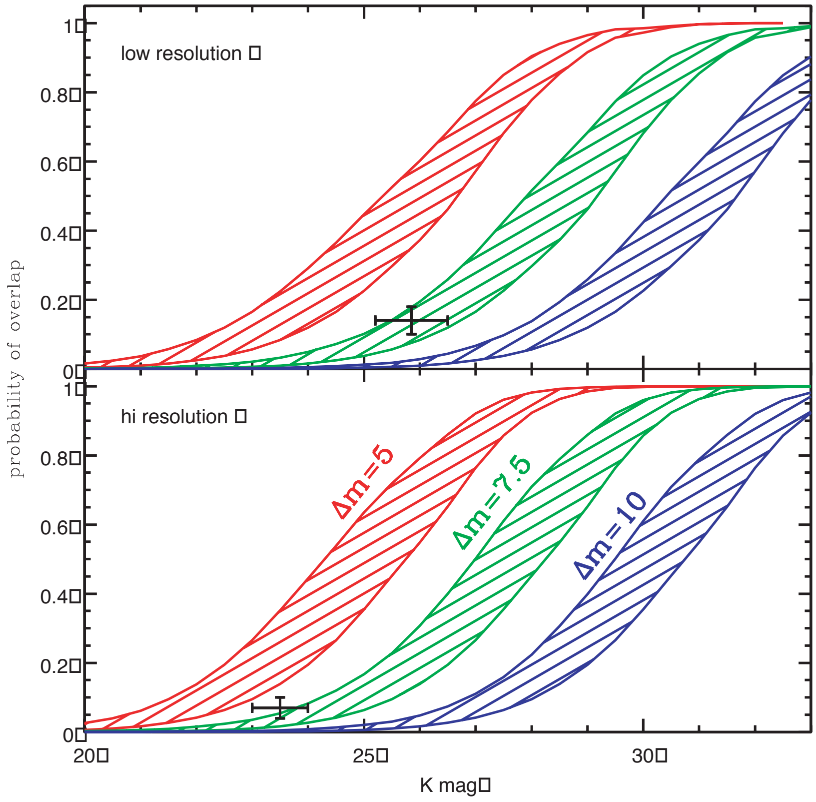

Figure 3: *Probability that spectra are contaminated at the Galactic pole as a function of the magnitude of the target galaxy. The red (left), green (centre) and blue (right) curves were computed for spoilers that are 100, 1,000 and 10,000 times brighter than the target. The black points with error bars show the fraction of spoiled spectra counted manually on the simulations (see text). The parameters for the simulations and counts are similar to the ones used in the green (central) curves.*

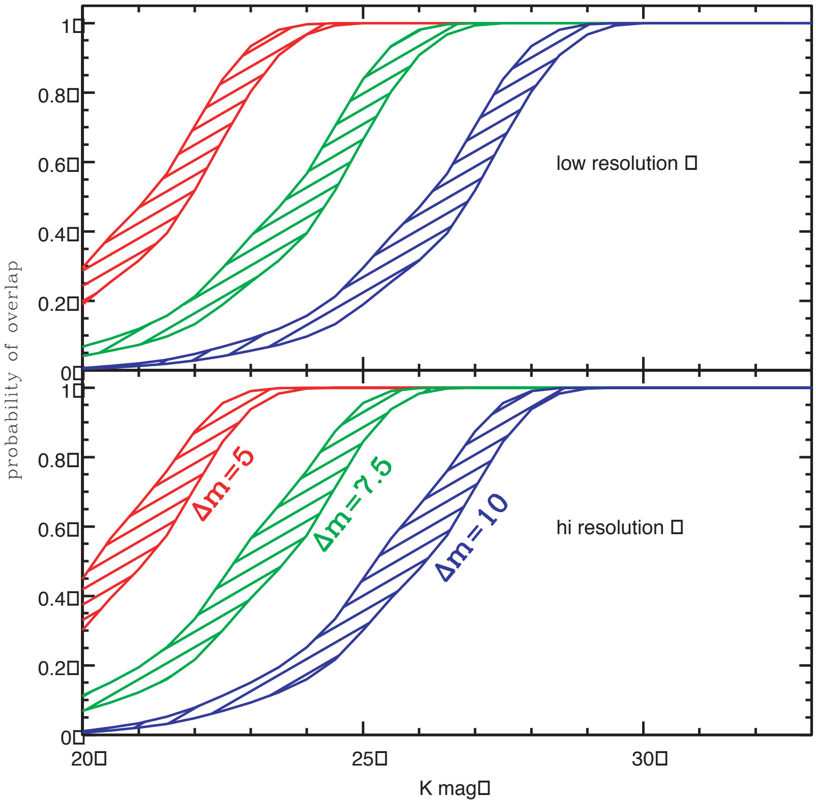

Figure 4: *Same as Figure 3 but for source densities appropriate to the Galactic plane.*

Therefore, such a contrast ratio of 10,000 will enable a deep spectroscopic survey at the poles but not in the plane.

To estimate the minimum requirement for the contrast, one can relax the above criteria so that only spoilers with an attenuated flux equal to the target spectrum are considered as a case for rejection. The justification for this relaxed criterion is that most spoiler spectra will overlap only a fraction of the area of the target spectrum. With an appropriate deblending procedure, one can recover the target spectrum by subtracting the flux from the spoiler. This could for example be achieved by taking a background spectrum which all shutters open. With this relaxed criterion, the above contamination rates can be achieved with a contrast ratio of 1,000.

The corresponding numbers for a contrast of 1,000 read from the plots are an overlap probability of about 30% and 50% at the poles. A spectrograph which reaches that contrast would therefore only marginally be useful for a deep spectroscopic survey. We therefore conclude that a contrast ratio significantly higher than 1,000 is necessary for a useful performance of spectrograph. Reaching a contrast ratio of 10,000 is highly desirable.

5. Simulations

In order to illustrate the effect, we have carried out a number of simulations. Figure 5 shows a simulated deep NIRSpec image with a field of view of 3' × 3'. This image has been created by replicating several copies of the HDF-S NICMOS field, as can be recognized by the repeated pattern of galaxies. Catalogues of galaxies which include positions, magnitudes and shapes were created from this image. The detected galaxies were assigned spectra of various redshifts and types (from elliptical to very young star forming) on the basis of their observed flux and morphology, according to a neural network algorithm trained on the photometric redshifts of Fontana et al. (1999).

The spectra include typical Lyman break galaxies with H ~ 24.5 to 25 which we consider to be the targets of a spectroscopic survey. The object shapes and spectra were then converted into a simulated NIRSpec image using a Python grism simulator code (SLIM: Pirzkal & Pasquali, 2001). Finally, noise was added according to the NGST telescope and spectrograph performance as defined in the NGST Mission Simulator
http://www.ngst.stsci.edu/nms/main/

Figure 6 (see also the greyscale images in the appendix) shows the simulated low resolution (R ~ 100) spectroscopic NIRSpec image which corresponds to the field shown in Figure 5. The spectra of the target galaxies appear in light blue. This corresponds to a spectral image if the MEMS devices delivered a perfect contrast ratio of infinity. The orange spectra are of the attenuated spoiler sources. A contrast ratio of 1,000 was assumed for the spoilers. The image simulates a 20 hour exposure. Typical magnitudes of the candidates are H ~ 27 to 28 with half of them containing very strong H II region type emission lines. This exposure delivers a continuum S/N ~ 10 at H = 28

Figure 7 (see also the greyscale images in the appendix) shows the same field observed with the high-resolution (R ~ 1000) in the spectral range 1.2 to 2.4 μm. The exposure is nearly 13 hours (46 × 1000s). Again, the orange sources are of the attenuated spoilers with a contrast ratio of 1,000.

To estimate the number of overlaps in the simulation, we compared the spectra of the targets extracted from the simulation corresponding to an infinite contrast with those ex-

Figure 5: *Simulations of NIRSpec images based on the NICMOS HDF. The selected tagets are marked with small vertical bars (representing slits) and the remaining sources in the field have been attenuated by the contrast factor of 1000.*

tracted from the simulation assuming a contrast of 1000. Since in this simulation no background subtraction is necessary, only bright spoilers or very close to the target position will impact the extracted spectrum. If more than 10% of the spectrum is affected at more than 10% level by the presence of another, non-perfectly attenuated object, the object is counted as 'spoiled'. The number of such spoiled spectra should therefore roughly correspond to the more relaxed of the two criteria used above. The resulting percentages of spoiled spectra in both the low- and high-resultion case are shown in Figure 3 with the error bars extending over the magnitude range of the candidates. The numbers are consistent with the theoretical curves. Figure 8 shows some examples of spoiled spectra.

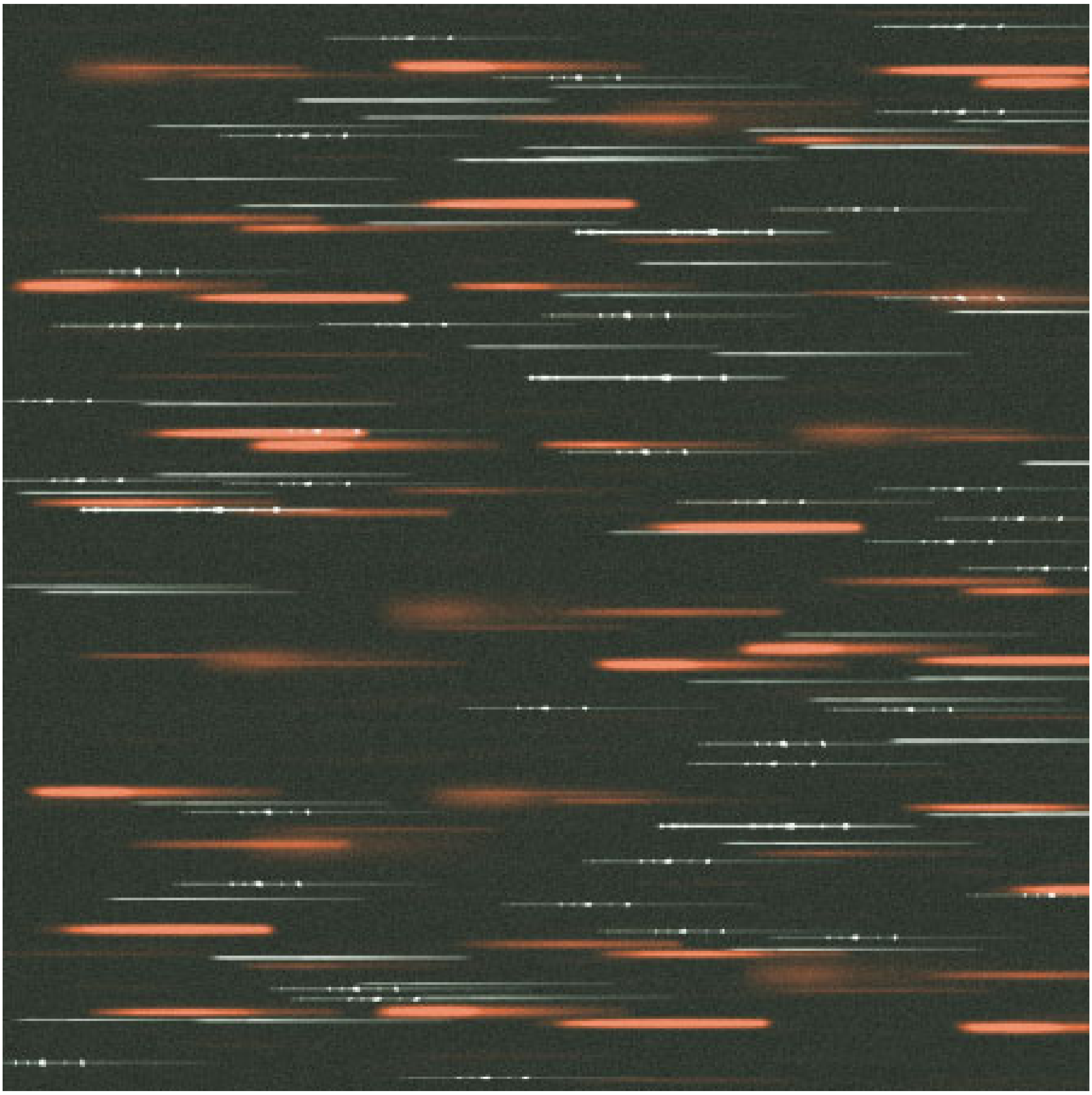

Figure 6: *Simulated low resolution spectra (R ~ 100) of the field shown in Figure 5. The light blue spectra are of the target galaxies. The attenuated spoiler spectra are superimposed in orange (see the appendix for greyscale versions). Half the target galaxies have strong H II region emission lines*

6. Conclusions

At the magnitude limit of the spectrograph (K ~ 25), high resolution spectra of a substantial fraction of all galaxies will be confused. A minimum contrast ratio of several thousand must be achieved if a majority of galaxies at this magnitude limit is to be observable at the Galactic poles. At lower Galactic latitude, or if a more stringent requirement on the quality of the extracted spectra is applied, significantly higher contrast ratios are needed. With a contrast ratio of 10,000, fewer than 10% of all galaxies will be contaminated by overlapping spectra brighter than 10% of the flux of the target spectrum. However, even with such a high contrast ratio, faint spectroscopy can only routinely be carried out at high Galactic latitudes.

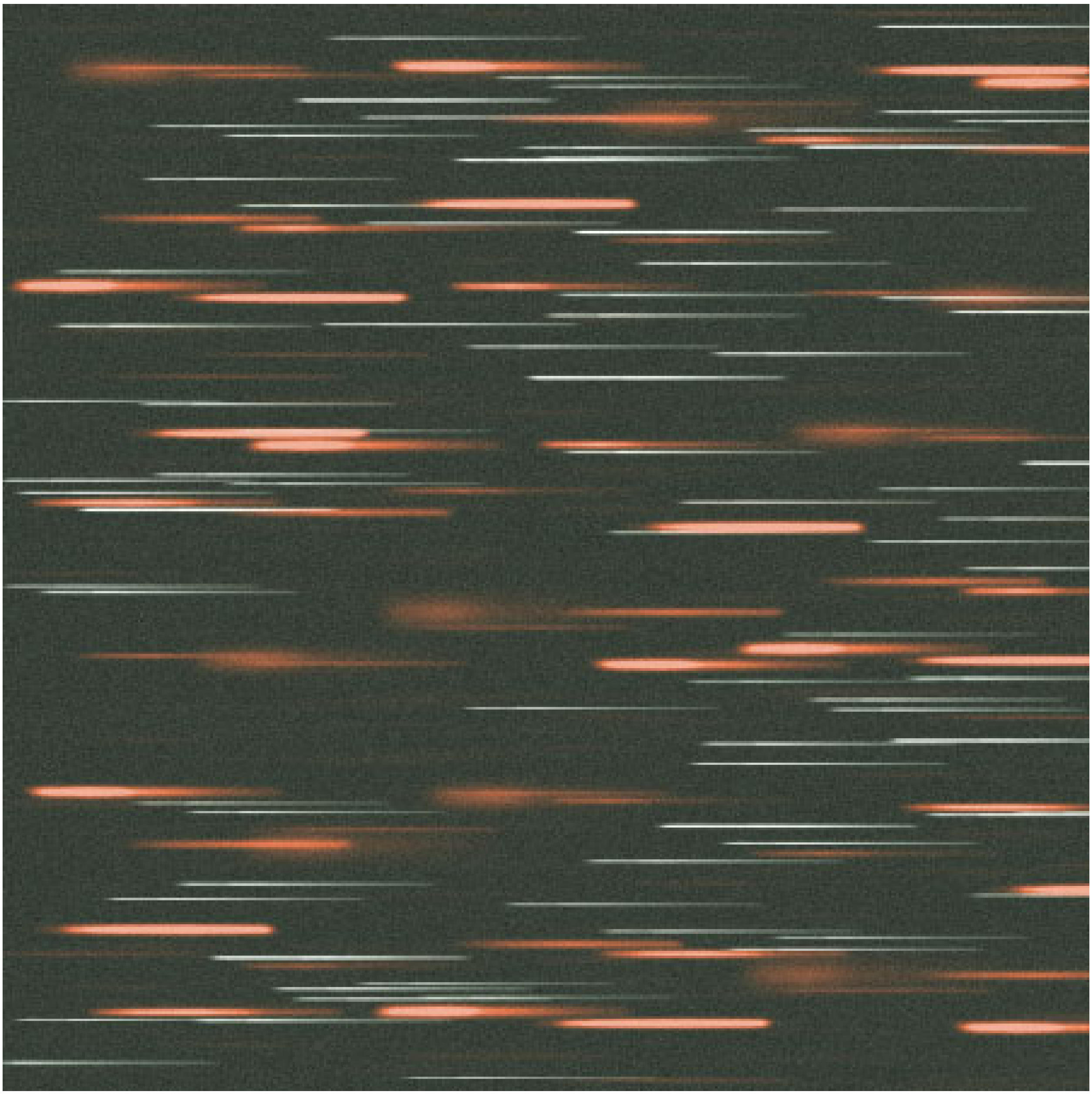

Figure 7: *Simulation at R ~ 1000 in the spectral range 1.2 – 2.4 μm. Again, light blue spectra are of the target galaxies. The attenuated spoiler spectra are superimposed in orange (see the appendix for greyscale versions).*

Acknowledgments: We thank Eros Vanzella for devising a procedure based on neural networks for the assignment of redshifts to the galaxies in our simulations.

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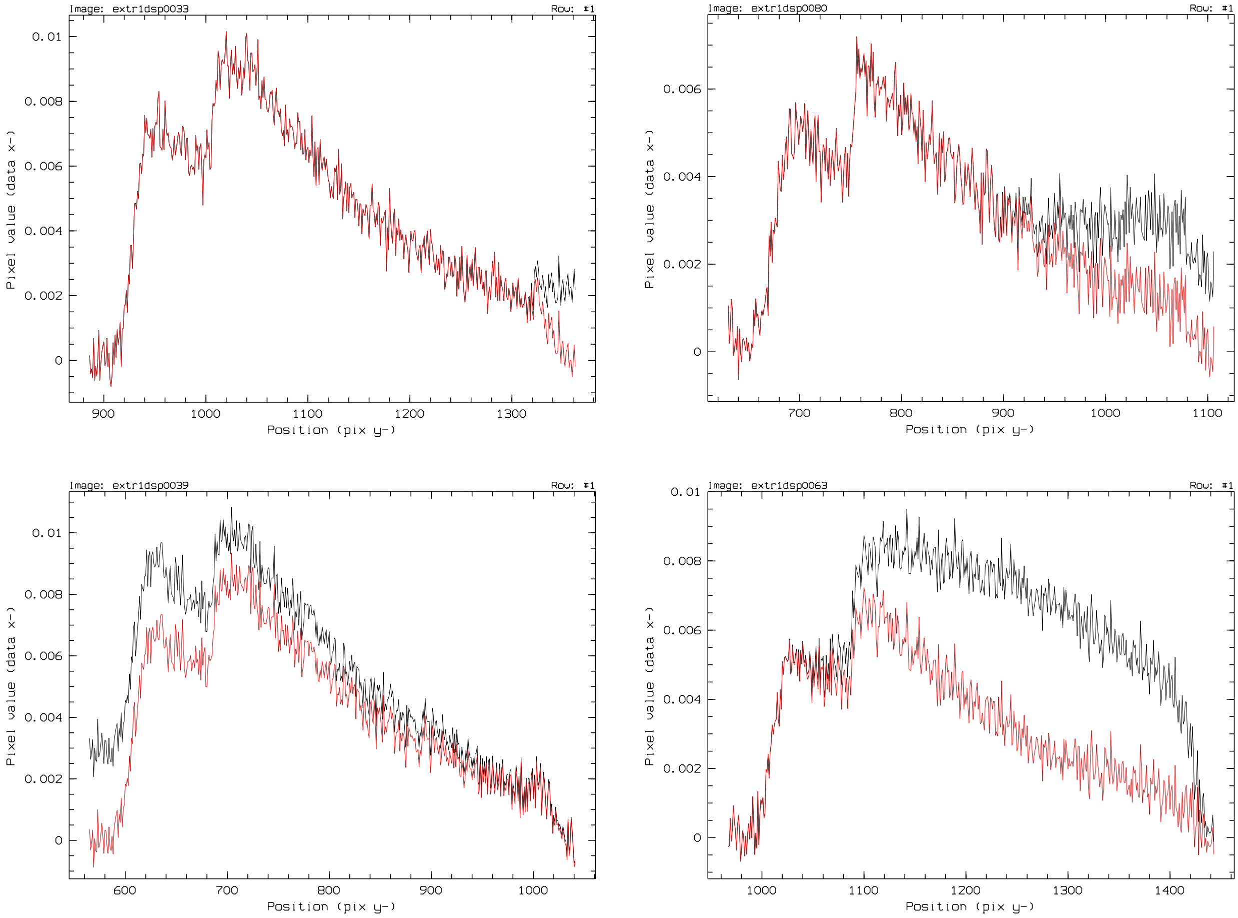


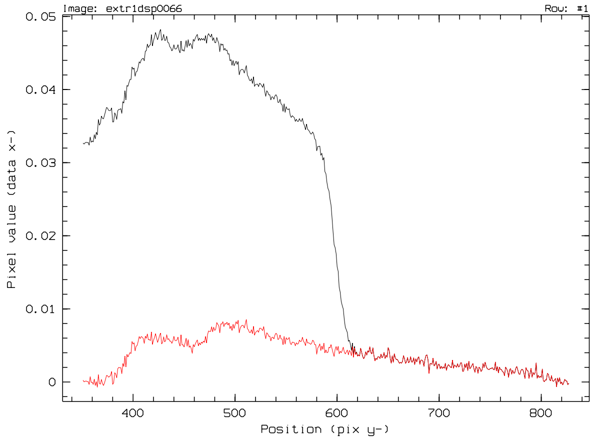
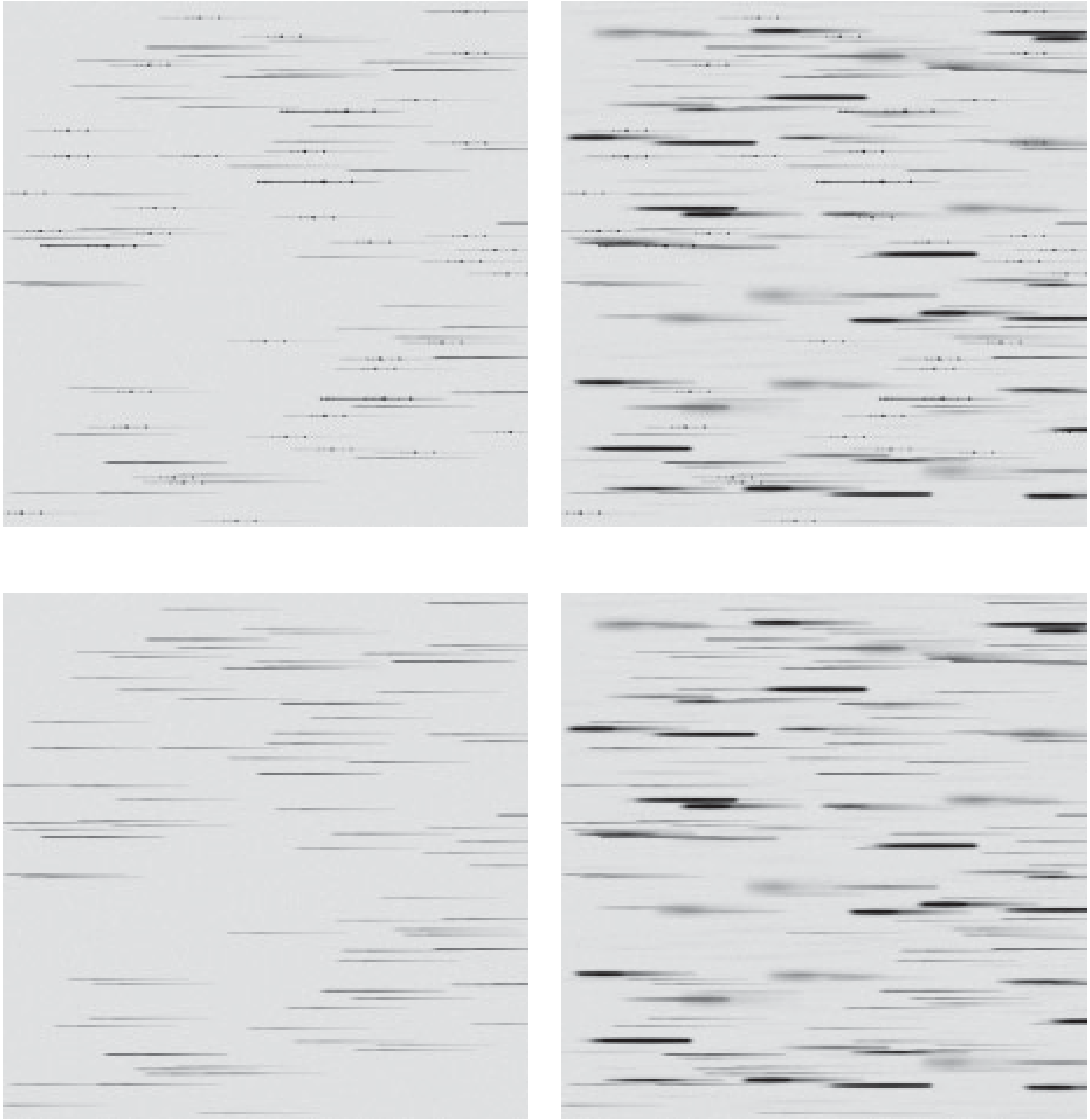


Figure 8: *A series of extracted spectra from the data in Figure 6 showing (from top left to bottom right) an increasing degree of spoiling. The red (lower) curves are extracted from the simulation without the spoilers, whereas the black curves are extracted from the full simulation.*



Appendix: *Greyscale representations of the simulated images shown in colour in Figures 6 (top pair; R = 100) and 7 (lower pair; R = 1000) The left panels show the target spectra only while the right panels show the target spectra with the attenuated spoiler spectra superimposed.*