THE WINDOWS DESIGN AND THE RESTORATION OF OBJECT ENVIRONMENTS

C. Dollet, A. Bijaoui, F. Mignard

Observatoire de la Côte d'Azur, Cassiopée, CNRS UMR 6202, BP 4229, 06304 Nice Cedex 4, France

ABSTRACT

For each object detected by Gaia, some windows are transmitted to the ground. Their design depends on the CCD rows of the astrometric fields and on the magnitude of the object. However, the limited telemetry rate limits the size of these windows. Given the selected windows for the Astro Sky Mapper (ASM) and the Astrometric Field 11 (AF11) of Gaia, it is worth investigating what kind of high angular resolution imaging will be achievable at the mission completion. We present a method to restore the environments of the detected objects and stress the astrophysical impact that can be achieved with the transmission of the data vectors issued from the two mentioned astrometric CCD rows.

Key words: Gaia; Imaging; Methods: Data analysis.

1. THE WINDOWS

The on-board detection of the astronomical sources is performed by the first CCD row of each astrometric field, called in the Gaia terminology the Astro Sky Mapper (ASM). Once an object is detected, different windows will be transmitted by following the image displacement along the astrometric focal plane. The design of the windows is adapted to each CCD rows according to their assigned purpose (Høg et al. 2003). In this paper, one considers only the rows ASM and AF11, as their transmitted windows allow small field imaging.

The shape of the window is chosen according to the magnitude of the detected object. Two intervals are in fact used in this study: 12–16 and 16–20. Figure 1 shows the shape of the two ASM windows. The samples are similar to the readout sample (2×2 pixels) excepted for the four corners of the WA0T25 window where the sample is 4×4 pixels.

In Figure 2, are represented the two AF11 windows. They correspond to data vectors because the across scan direction is limited to only one readout sample (1×14 pixels). Along the scan, only some central samples (12 for WA11T40 and 6 for WA11T26) stay at the readout resolution (0.044 arcsec). Outside, a binning of 2 readout samples for the WA11T40 and of 3 readout samples for the WA11T26 are considered.

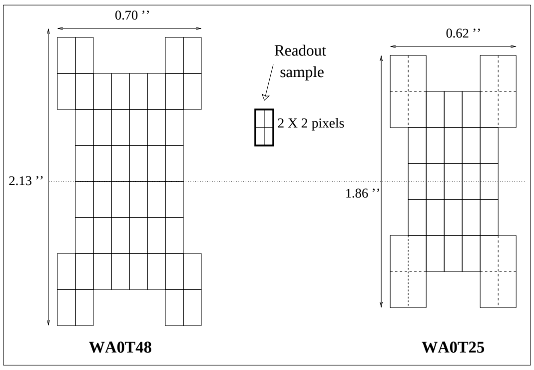

Figure 1. The two windows defined for the Gaia ASM. On the left, when the magnitude of the on-board detected object belongs to the interval 12–16 whereas on the right, it is between 16 and 20.

2. THE COMBINATION

In order to obtain high angular resolution imaging around the detected object, it is necessary to combine the different windows transmitted during the five years of mission. In fact, we will have about 41 observations per CCD row per astrometric field of view. As a result of the scanning law, these windows will have different positions and scan directions relative to the sky. The association of these data following this known angular distribution makes possible the restoration of a single image with a better resolution.

Nurmi (2003) has proposed the drizzle (Fruchter & Hook 2002) as an approach to combine these data. Our proposal is different and reduces to solving a linear system of equations. A given window of data D results from the convolution of the point spread function H with the associated reference area of sky field, namely F. Mathematically this amounts to a matrix product.

A suffix *i* is used in order to indicate the different windows D_i, from the same sky area F, available on ground after the five years of the Gaia mission. For each D_i,

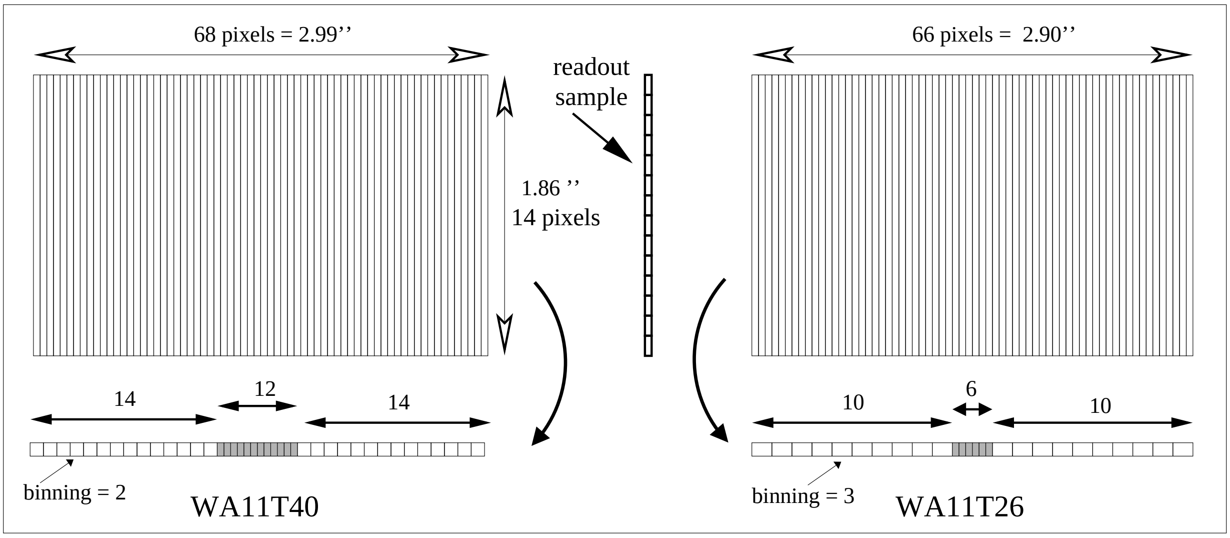

Figure 2. The two AF11 windows. The WA11T40 vector will be transmitted for an object with a magnitude between 12 and 16 whereas WA11T26 will be used for a magnitude between 16 and 20.

the H_i matrix is determined from the position (ΔAL$_i$, ΔAC$_i$) and the orientation θ_i of the window according to the F field.

$$D_i = H_i(\Delta AL_i, \Delta AC_i, \theta_i)\ F \tag{1}$$

As the resolution sought for the F field is higher than that of the windows, H_i is a rectangular matrix. To resolve this linear system and find F, it is then necessary to take into account all the observations transmitted by Gaia to the ground. We search a solution for the F field such that the square of the differences is minimum leading to a new system.

$$min\{\sum_{i=1}^{N}(D_i - H_i F)^2\} \Longrightarrow \sum_{i=1}^{N} H_i^T D_i\ =\ \sum_{i=1}^{N} H_i^T H_i\, F \tag{2}$$

As on average about 40 observations per CCD row will be stacked, there will be $N = 80$ windows to combine. There are infinitely many solutions of this new equation (2). The two sums of matrix products $\sum H_i^T D_i$ and $\sum H_i^T H_i$ must be first calculated. Then Equation 2 is resolved by an iterative regularised algorithm of Tikhonov where a smooth constraint (λL where L is a Laplacian in two dimensions) is applied on top of a least mean square term (see Dollet et al. 2003, for more details).

$$F^{n+1} = F^n + \alpha \sum_{i=1}^{N} H_i^T D_i - \alpha(\sum_{i=1}^{N} H_i^T H_i + \lambda L)F^n \tag{3}$$

3. THE ASTRONOMICAL OBJECTS

This algorithm outlined in the previous section has the advantage of being free of any assumption on the astrophysical contents of the observed fields. We only need an accurate estimate of the position and orientation of each observation in comparison with the F field. Thus every kind of astronomical objects can be handled with this method. We consider in the following three examples: the small stellar systems, the extended objects and the distant objects.

3.1. The Stellar Systems

The algorithm can be used for the study of binaries even if it will be less efficient than dedicated methods developed for these objects to retrieve an accurate value of the angular separation or the photometric information. This algorithm will be useful nevertheless because it can directly supply the number of components in the system, a very useful input for numerically oriented algorithms. We just summarize here the main results described in Dollet et al. (2003).

If the magnitude differences are small (about ± 1 magnitude) for binaries, the secondary can be detected for a separation up to 0.15 arcsec. With an angular distance of 0.20 arcsec, the secondary can be fainter than the primary by 2 magnitudes.

The number 80 or 100 observations is not a limit allowing the restoration of the F field. The distribution of the angle of view for the different windows has however an impact. The absence of uniformity in the angular distribution produces distortions on the reconstructed image due to the Gaia non-isotropic point spread function.

The proposed algorithm becomes more useful and interesting when more than two components are present. Figure 3 shows the restored images from a combination of 100 WA0T25 for four triple systems. The primary has a magnitude G = 17.5. The angular separations ρ_2 and ρ_3 for the two components are smaller than the across scan resolution of the ASM readout sample. They are indicated in Table 1 with the magnitude of the components.

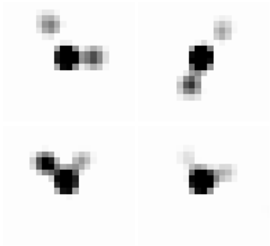

Figure 3. Four triple systems restored after a combination of 100 WA0T25 windows numbered from upper left to bottom right in Table 1.

Table 1. Magnitudes M and angular separations ρ for the two components of the four triple systems in Figure 3.

number	M2	ρ_2	M3	ρ_3
1	18.5	0.17	19.0	0.25
2	18.5	0.19	19.5	0.22
3	18.0	0.18	19.0	0.16
4	19.0	0.14	19.5	0.15

3.2. Extended Objects

The diagonal of the ASM windows is about 2 arcsec wide while that of the AF11 vectors is 3.5 arcsec. These few arcsec covered by the windows will limit the study of the environment of extended objects like the M100 galaxy for example with its 7 arcmin of diameter, but they will be very relevant in the study of multiply imaged quasars.

From a WFPC2 HST observation of the central part of this galaxy, different Gaia observations have been simulated on specific zones. Figure 4 presents a zoom centered on the assumed detected object. The group below the three central points are close to the border of the ASM windows whereas it will be included in the AF11 vectors.

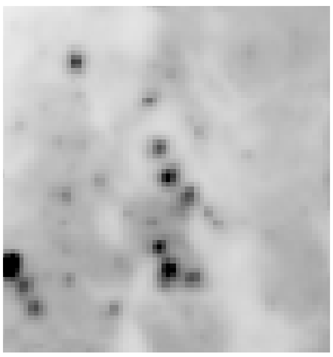

Figure 4. Zoom on a spiral arm of the M100 galaxy, centered on the detected object. The image has a resolution of 0.044 arcsec and a height of 3 arcsec.

Figure 5. Restored image after combination of 100 WA0T25 windows simulated from Figure 4.

Figure 6. 100 WA11T26 windows have been combined to obtain this restored image. The simulations concern the zone of the M100 galaxy illustrated in Figure 4.

It is not possible to describe the real structure of its part of M100 galaxy when only one window is considered. The complex nature of the central group appears after the recombination of several ASM windows. The three points are dissociated as shown in Figure 5. The structure of the group situated below is badly restored.

The wider surface covered by the AF11 windows makes it possible to show also the three components of the object group located near the bottom of the field as shown in Figure 6.

3.3. Distant Objects

Objects with smaller extensions have been considered too. The simulation presented here in Figure 7 has been generated from an image belonging to the Frei catalogue. The initial resolution is of 1.19 arcsec. The galaxy is pushed away in the background of the simulated observations in order to obtain distant objects having an extension similar to the surfaces of the Gaia windows. The square added on Figure 7 delimits the surface covered by all the ASM windows.

The spiral shape of the galaxy is well restored after the combination of different windows following a uniform angular distribution. The restored image on Figure 8

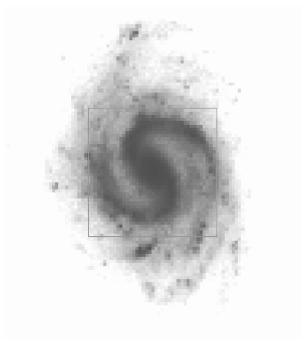

Figure 7. Simulation of a distant structured object. The initial image belongs to the Frei catalogue. Its resolution was 1.19 arcsec per pixel.

presents an aspect of speckles. The artifacts and the noise due to the combination method can be separated from the signal by applying a wavelet decomposition. Most of the noise appears only on the first and second scales as illustrated by the Figure 9.

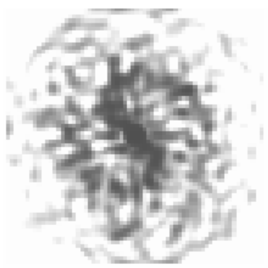

Figure 8. Restored image after combination of 100 WA11T26 windows for the studied distant spiral galaxy.

A statistical study at each scale of an *à trous* wavelet decomposition was made from 100 restored images of this distant galaxy. Each of these 100 images was obtained individually after combination of 100 AF11 WA11T40 vectors. It was in this manner confirmed that the information started to be significant at the second scale. In fact the signal to noise ratio becomes higher than 3. More explanations can be found in Dollet (2004).

4. CONCLUSION

In this paper, an algorithmic approach has been proposed and tested in order to combine all the windows transmitted on ground by Gaia during its 5 years in orbit. The absence of hypothesis on the astrophysical contents of windows allows us to always use the same algorithm for all kinds of objects with a more or less structured environment. This method is powerful in term of versatility. Although it is less efficient than parametric algorithms (e.g., for binaries), it remains a valuable tool to investigate complex sources by indicating in particular the number of components of stellar systems before running a dedicated algorithm.

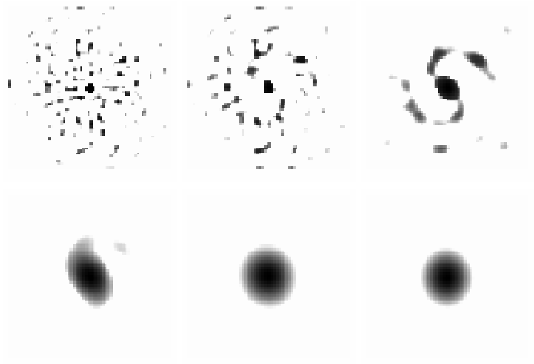

Figure 9. Wavelet decomposition on 6 scales applied to the restored image of the spiral distant galaxy.

This algorithm could be improved in particular by trying out new inverse problem equations. But the interest of this methodological approach is demonstrated here. The combination tests have been carried out from an assumption of stability for the magnitude and the position of objects during the mission. These variations will imply the loss of information at the time of the restoration.

Despite the lack of across scan resolution of the AF11 vectors, high angular resolution images remain achievable thanks to the complementary information brought by the different orientations of the windows transmitted during the mission. That leads us to suggest for the ASM new windows covering the widest surface. The number of values transmitted would remain unchanged in order to respect the telemetry rate constraints but a more important binning could be applied on the readout sample.

REFERENCES

Dollet, C., Bijaoui, A., Mignard, F., 2003, Gaia technical report IC-CDAB-01

Dollet, C., 2004, PhD Thesis, Chapter 5

Fruchter, A.S., Hook, R.N., 2002, PASP, 114, 144

Høg, E., Arenou, F., Mignot, S. et al. 2003, Gaia technical report GAIA-CUO-117

Nurmi, P., 2003, Gaia technical report DMS-PN-01