Feasibility of Imaging with a Rotating Scanning Sky Monitor camera

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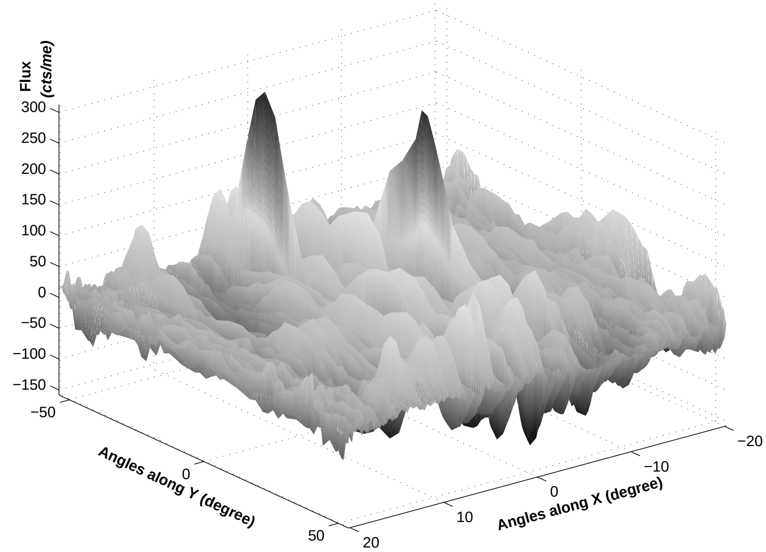
The camera was assumed to rotate at a rate of $\frac{1}{15}^{\circ}$/s along the X direction (the mask coding direction) and at $\frac{1}{75}^{\circ}$/s along Y direction. Now that the camera is continously rotating, we have to select some part of the recorded photon strike positions and *derotate* each of the recorded photon strike positions back to where they could have been if it were to be recorded by a static camera. For performing this derotation, the instances at which the photon strikes the detector should also be recorded along with the positions at which they strike. The exposure time interval was selected in such a way that, at the beginning of the exposure time if a source is illuminating a mask element at one end of the mask plate, it gradually illuminates all the mask elements as the camera rotates and by the end of the exposure time illuminates only the last mask element at the other end of the mask plate. This exposure time is calculated using the value of the rotation rate along X direction, and it is 339.298 s for a rotation rate of $\frac{1}{15}^{\circ}$/s. In real situation, a chunk of data corresponding to this time interval will have to be considered at a time. In our simulations, the photon strikes are recorded precisely for this interval. Maximum number of photons are received from a source which is present through out the exposure time [this is possible if the source illuminates only one mask element at one edge of the mask plate at the beginning of the exposure time]. All other sources go out of view earlier than this source (or come in to view later) and hence smaller number of photons will be received. For the data picked, we define the fiducial time to be half of the exposure time, and derotate the photon strike positions on the detector to this fiducial time. When such a derotation is perfomed, a few of the photon strike positions will exceed the limits of the real detector width (60 mm). So we have a virtual detector plane which is almost three times the width of the detector, containing the derotated photon strike positions and this arrangement emulates a static camera.

Because of gradual decrease in the area of the mask plate exposed to the source, as the camera rotates, the detector-bin-photon-counts (after derotation of the photon strike positions), gradually taper towards zero counts. This behaviour is seen because of sources which appear later in the field of view in one exposure interval, or if the source was already present in the field of view in the chunk of data considered (and because of that the camera moves past the source earlier). If this is reconstructed as it is, sensitivity is lost and locating the source peaks becomes difficult. So these bin-counts have to be normalised prior to reconstruction. The normalisation factors are calculated using the duration for which each of the mask elements will be exposed to the sources at all the sky elements and rotation rate of the camera (along X direction). The reconstruction algorithm has been succesfully tested for sources with different incident angles with respect to the normal.

See **Technical Details** on page 5 for a description of the various calculations involved in developing the algorithm.

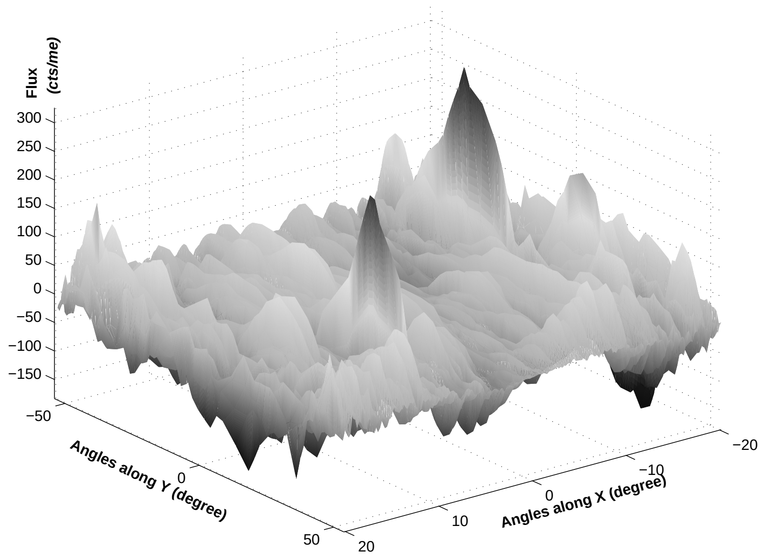
A few examples of raw reconstructed images with two sources at different locations in the sky are shown in the figures. All these cases are simulated with a finite detector resolution. As in the static camera finite σ of 0.5 mm has been introduced along the X direction and 3 mm along Y direction. In all the examples background noise has been added. To simulate the background noise, a count rate of 80 cts/s was used, and Gaussian deviates were recorded for the same exposure time (of 339.298 s). Except for one source all others were simulated assuming the source strength to be 1 crab for which the flux corresponds to 555 cts/me. Since the rotation along Y has not been corrected, the source is often reported at angles along Y direction at offset by about 2° (in adjacent Y-pixel) from the expected location. The peak deflection for any of the sources is lower than the input flux of 555 cts/me by a factor of about two and is spread over a number of pixels due to rotation along Y and the smearing introduced to account



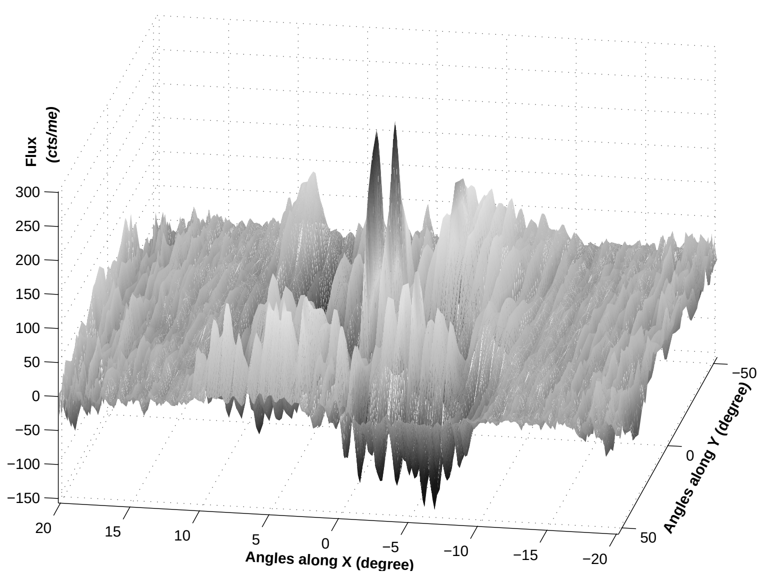
	AngleX (degree)	AngleX Expected (degree)	AngleY (degree)	AngleY Expected (degree)	Peak Deflection (cts/me)	Reconstructed Flux (cts/me)	Input Flux (cts/me)
Source 1	4.43°	4.43°	−32.0°	−35.5°	312.6125	498.5275	555($\Leftrightarrow$ 1 *crab*)
Source 2	−4.43°	−4.43°	−4.6°	−6.8°	301.3289	497.0594	555($\Leftrightarrow$ 1 *crab*)

for the finite resolution of the detector. To obtain the reconstructed flux, we therefore integrate the deflection over two pixels on either side of the peak.

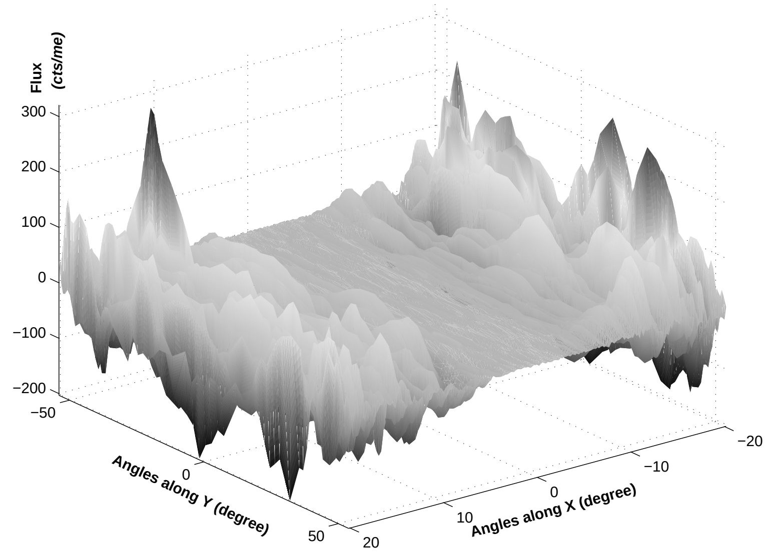
For detecting the sources in the reconstructed images, the possibility of using the procedure of Iterative Removal Of Sources employed for a static camera will have to be explored. If that does not work, some other new scheme will have to be looked for.



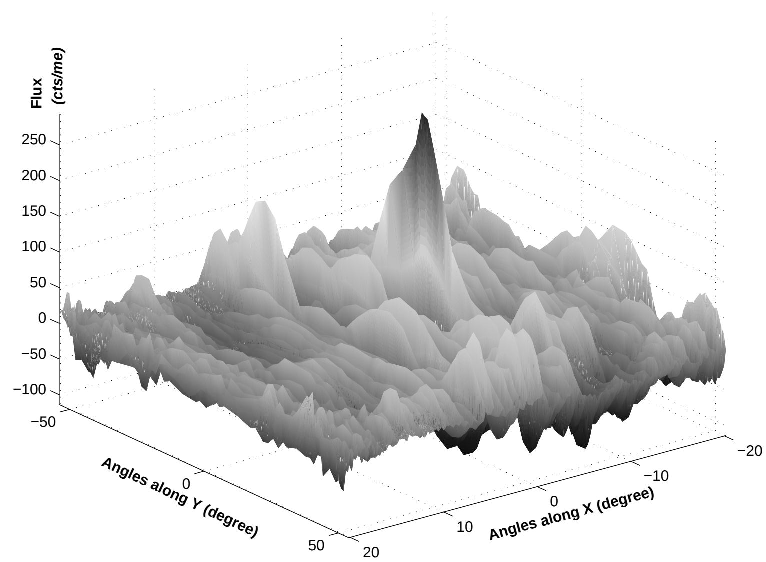
	AngleX (degree)	AngleX Expected (degree)	AngleY (degree)	AngleY Expected (degree)	Peak Deflection (cts/me)	Reconstructed Flux (cts/me)	Input Flux (cts/me)
Source 1	8.95°	8.95°	26.4°	24.5°	293.2414	490.4626	555(⇔ 1 *crab*)
Source 2	−13.49°	−13.49°	−20.6°	−22.6°	326.487	554.1094	555(⇔ 1 *crab*)



	AngleX (degree)	AngleX Expected (degree)	AngleY (degree)	AngleY Expected (degree)	Peak Deflection (cts/me)	Reconstructed Flux (cts/me)	Input Flux (cts/me)
Source 1	0.35°	0.35°	6.8°	4.6°	301.3877	415.7867	555(⇔ 1 *crab*)
Source 2	−0.53°	−0.53°	0.0°	−2.3	298.4778	456.9615	555(⇔ 1 *crab*)



	AngleX (degree)	AngleX Expected (degree)	AngleY (degree)	AngleY Expected (degree)	Peak Deflection (cts/me)	Reconstructed Flux (cts/me)	Input Flux (cts/me)
Source 1	$14.4°$	$14.4°$	$-39.8°$	$-39.8°$	320.898	565.5353	$555(\Leftrightarrow 1\ crab)$
Source 2	$-18.01°$	$-18.01°$	$32.0°$	$28.2°$	261.747	625.446	$555(\Leftrightarrow 1\ crab)$



	AngleX (degree)	AngleX Expected (degree)	AngleY (degree)	AngleY Expected (degree)	Peak Deflection (cts/me)	Reconstructed Flux (cts/me)	Input Flux (cts/me)
Source 1	$4.43°$	$4.43°$	$-32.0°$	$-35.5°$	153.6449	239.3471	$277(\Leftrightarrow 0.5\ crab)$
Source 2	$-4.43°$	$-4.43°$	$-4.6°$	$-6.8°$	293.2895	465.0733	$555(\Leftrightarrow 1\ crab)$

Technical Details

The exposure time is calculated as follows:

$$T_{exp} = \frac{2 \times \tan^{-1}\left(\frac{W}{H}\right)}{R_X} \tag{1}$$

where,

T_{exp}	$\equiv$	Total Exposure Time
W	$\equiv$	Mask Plate Width Along X direction = 60 mm
H	$\equiv$	Height of the camera = 300 mm
R_X	$\equiv$	Rate of Rotation of the camera along X direction = $\frac{1}{15}^{\circ}$/s

The fiducial time is half of the exposure time, that is,

$$T_{fid} = T_0 + \frac{T_{exp}}{2} \tag{2}$$

where,

T_{fid}	$\equiv$	Fiducial Time
T_0	$\equiv$	Start time of the exposure interval

The derotated photon strike positions are calculated as follows:

$$x_{dr} = x_{ph} + H \times \tan\theta_k\left(T_{fid}\right) - H \times \tan\theta_k\left(T_{ph}\right) \tag{3}$$

in which the term $\theta_k\left(T_{ph}\right)$ is given by,

$$\theta_k\left(T_{ph}\right) = \theta_k\left(T_{fid}\right) + R_X \times \left(T_{ph} - T_{fid}\right) \tag{4}$$

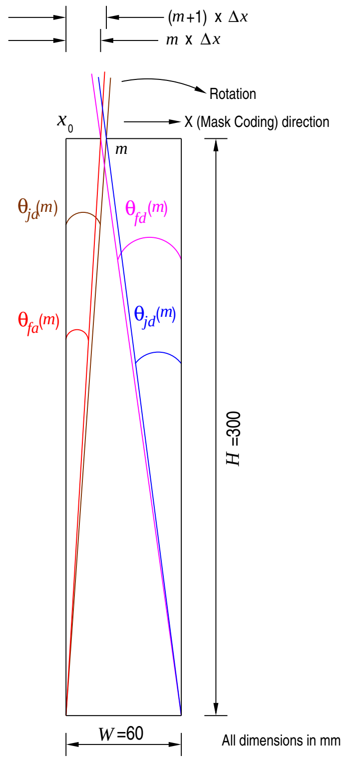
where,

x_{dr}	$\equiv$	Derotated photon strike position
x_{ph}	$\equiv$	Recorded photon strike position
k	$\equiv$	Sky element along X direction ($0 \leq k \leq 250$)
$\theta_k\left(T_{fid}\right)$	$\equiv$	Angle corresponding to sky element k at the Fiducial time
T_{ph}	$\equiv$	Recorded photon strike time
$\theta_k\left(T_{ph}\right)$	$\equiv$	Angle corresponding to sky element k at the photon strike time

To calculate the bin-normalisation factors for each of the mask elements corresponding to different sky elements, consider the figure on page 6.

In the figure,

x_0	$\equiv$	mask origin
N	$\equiv$	number of mask elements = 63
m	$\equiv$	mask element($0 \leq$ m $\leq N$-1)
W	$\equiv$	Width of the camera along the mask coding direction = 60 mm
Δx	$\equiv$	Width of one mask element ($\Delta x = \frac{W}{N}$)
H	$\equiv$	height of the camera = 300 mm
$\theta_{ja}(m)$	$\equiv$	Just Appearance angle of mask element m (in degree)
$\theta_{fa}(m)$	$\equiv$	Full Appearance angle of mask element m (in degree)
$\theta_{jd}(m)$	$\equiv$	Just Disappearance angle of mask element m (in degree)
$\theta_{fd}(m)$	$\equiv$	Full Disappearance angle of mask element m (in degree)



The figure shows the Just and Full, Appearance and Disappearance angles of some mask element m for source at sky element k.

The following equations represent the distances of the left edge and right edge of the mask element m from the origin.

$$x_m^l = x_0 + m \times \Delta x \tag{5}$$

$$x_m^r = x_0 + (m+1) \times \Delta x \tag{6}$$

Assuming the direction of rotation to be as shown in the figure, we define a few angles related to the shadow of a mask element. As the camera rotates, when the right edge of the mask element appears on the detector plane, the angle corresponding to that is Just Appearance angle, θ_{ja} as shown in the figure. Only a part of the mask element will be seen until its left edge also appears on the detector plane, and the corresponding angle is called Full Appearance angle, θ_{fa}. Similarly there are angles, θ_{jd} and θ_{fd} which are Just Disappearance and Full Disappearance angles respectively corresponding to the situations when the right edge of the mask element hits the edge of the detector (along X direction) followed by the left edge.

The following are the expressions for these angles,

$$\theta_{ja}(m) = -\tan^{-1}\left(\frac{x_m^r - x_0}{H}\right) \tag{7}$$

$$\theta_{fa}(m) = -\tan^{-1}\left(\frac{x_m^l - x_0}{H}\right) \tag{8}$$

$$\theta_{jd}(m) = \tan^{-1}\left(\frac{x_0 + W - x_m^r}{H}\right) \tag{9}$$

$$\theta_{fd}(m) = \tan^{-1}\left(\frac{x_0 + W - x_m^l}{H}\right) \tag{10}$$

With these expressions, the angular duration for which the shadow of any mask element m will be (partially or fully) cast on the detector, for different sky elements is given by,

$$
\begin{aligned}
R_X \times \Delta t(m,k) \quad &= \quad [\min\{\theta_{fin}(k), \theta_{jd}(m)\} - \max\{\theta_{in}(k), \theta_{fa}(m)\}] \\
&+0.5 \times \left[\begin{array}{cc} \theta_{fa}(m) - \max\{\theta_{in}(k), \theta_{ja}(m)\}, & \text{if positive} \\ 0, & \text{otherwise} \end{array} \right] \\
&+0.5 \times \left[\begin{array}{cc} \min\{\theta_{fin}(k), \theta_{fd}(m)\} - \theta_{jd}(m), & \text{if positive} \\ 0, & \text{otherwise} \end{array} \right] \qquad (11)
\end{aligned}
$$

where,

m	$\equiv$	Mask element $(0 \leq m \leq N-1)$
k	$\equiv$	Sky element $(0 \leq k \leq 250)$
$\Delta t(m,k)$	$\equiv$	Time duration for which shadow of mask element m will be falling on the detector, partially or completely.
$\theta_{in}(k)$	$\equiv$	Angle corresponding to sky element k at the beginning of the exposure time.
$\theta_{fin}(k)$	$\equiv$	$\theta_{in}(k)$ + Angle corresponding to the amount of rotation in one full exposure interval $(= 22.62°)$.

The normalisation factor for mask element m corresponding to sky element k is given by,

$$N_f(m,k) = \frac{\theta_{HalfRot}}{R_X \times \Delta t(m,k)}$$

where,

$N_f(m,k)$	$\equiv$	Normalisation Factor corresponding to mask element m and sky element k.
$\theta_{HalfRot}$	$\equiv$	Angle corresponding to rotation of the camera from beginning of the exposure time to that at the fiducial time for any sky element k $(= 11.31°)$.

For any sky element k, the photon counts in the detector bin corresponding to every mask element m $(0 \leq m \leq N-1)$ will be scaled by the weighting factor $N_f(m,k)$, before using the bin-counts in cross-correlation.