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Desmearing Solar System Objects in Chandra Data

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Abstract. Observations by the Chandra X-Ray Observatory are made in a coordinate frame that is essentially fixed. Most objects observed with Chandra, such as supernova remnants, quasars, or pulsars, are at infinity for all practical purposes and the observations produce sharp, focused images. However, the motion of objects observed within the solar system, such as planets or comets, will cause the object's image to appear blurred when viewed in a fixed frame. This effect is similar to the blur which would be seen if a fixed camera were to take a photograph of a fast moving car.

To reconstruct the image, the CXC CIAO tool sso_freeze corrects for this effect. An origin is chosen at the center of the object, and moves along with the object as it moves with respect to inertial space. The positions of the source photons are then recalculated with respect to this moving origin. The image formed from the recalculated photons now shows a clear object, such as a disk for a planet. As an effect of this processing, fixed X-ray sources become smeared in the image. The effect is similar to moving the camera to follow the fast moving car in the earlier example. The car becomes clearly focused, and the scene around the car is blurred. Images which demonstrate the effect of sso_freeze are shown for Jupiter and Comet C/1999 S4 Linear.

1. Introduction

Data from the Chandra X-Ray Observatory are assigned positions in the International Celestial Reference System (ICRS) World Coordinate System. The motion of most of the distant targets observed by Chandra are negligible in this reference frame. However, certain objects, such as those within the solar system, can move with respect to the ICRS frame during the observation interval. As a result, the image of the observed object is spread across the observed region and blurred. This effect is similar to that seen when an optical camera is used to take a picture of a fast moving object, such as a race car. Just as the car's image would be blurred in the picture, local objects appear blurred in the Chandra image.

In order to resolve the local object cleanly, without any blurring, photons from the object need to be displayed in an alternate World Coordinate System—one which moves with the object, as opposed to being fixed to distant points. At the top of Figure 1, the ICRS reference frame is shown as a coordinate system

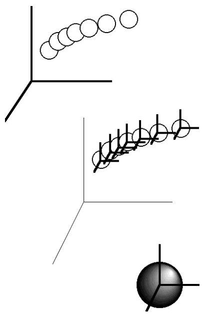

Figure 1. Fixed and Moving Reference Frames

with heavy lines. An example of the motion possible by a solar system object is shown as a series of circles extending up and to the right.

To redisplay the image without any blur, an instantaneous coordinate system with an origin at the center of the solar system object is defined. This is illustrated in the center image of the figure, where a new coordinate system is attached to each image of the object. Finally, data from the observation are redisplayed in the new, object centered coordinate system. The result is shown in the bottom portion of Figure 1, where a discernible object is seen instead of the previous blurred images.

In the actual implementation for Chandra data, a new object-centered coordinate system is defined for each new photon timetag (unlike the example in the figure where the time steps are much coarser). An effect of this processing is that non-solar system object X-ray sources are also displayed in the new, moving coordinate system. This has the effect of sometimes blurring what would otherwise be X-ray point sources. The origin of the object-centered reference frame is defined as the instantaneous ephemeris of the solar system object.

2. Jupiter Example

An example showing Chandra data for an observation of Jupiter both before and after processing with sso_freeze is shown in Figure 2. The image on the left shows the photons from a Jupiter observation in SKY (X,Y) coordinates, which are based on the ICRS world coordinate system. Near the center of the image are two lines, starting in the left half of the image and continuing slightly downward and to the right. These are X-ray emissions from Jupiter's poles, and trace the upper and lower bounds of the disc of Jupiter as it travels across the field of view during this observation.

The image on the right shows the same data in Object Centered coordinates (OCX,OCY). Jupiter is clearly visible as a disc, and the strong X-ray emissions near the polar regions show up as brighter regions. Since the entire image is

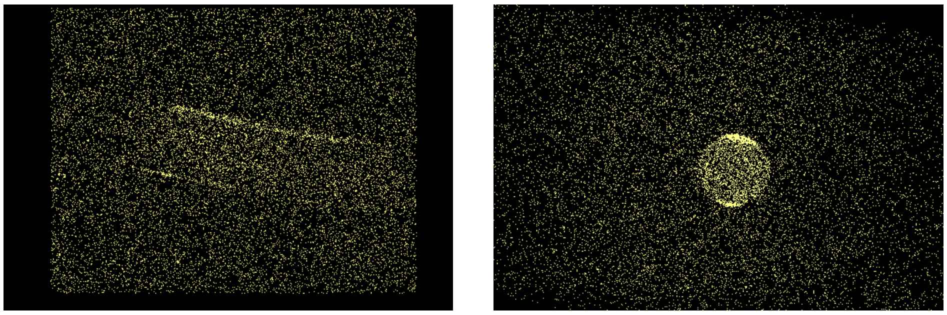

Figure 2. Jupiter in ICRS and Object Centered coordinates

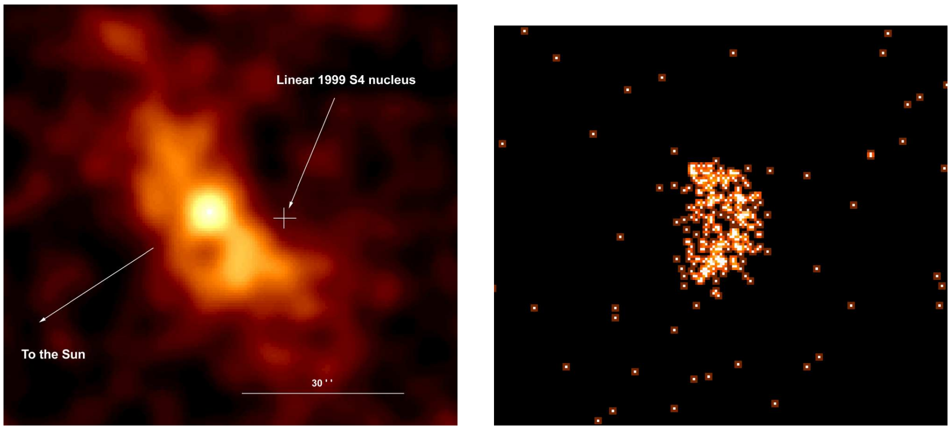

Figure 3. Comet 1999/S4 Linear and Venus in X-rays

displayed in Object Centered coordinates (not just the disc of Jupiter), note that the clean rectangle of the left image has been smeared a little in the right image. If a strong X-ray source were present in this observation, it would been seen as a clean point source in the left image, but it would appear to be smeared left to right in the image on the right. Since only background data seem to be present, the random nature of the events does not appear to be any different in either coordinate system.

Two other images produced with data processed by sso_freeze are shown in Figure 3. On the left, a Chandra X-ray image of Comet C/1999 S4 (LINEAR) (Lisse et al. 2001) shows X-rays from oxygen and nitrogen ions, which are produced by ions in the solar wind colliding with with gas in the comet. On the right is the first X-ray image ever made of Venus (Dennerl et al. 2002). The X-rays seen in the half crescent come from that part of Venus' atmosphere at an altitude of 120 to 140 kilometers illuminated by the Sun. They are produced by fluorescent radiation from oxygen and other atoms.

3. Code Highlights

There are three sets of input files required by sso_freeze. The events files provide the SKY (X,Y) coordinates for the observation, the spacecraft ephemeris files specify the Chandra ephemeris parameters, and the 'sso' ephemeris files specify the solar system object ephemeris parameters.

Both the Chandra ephemeris data and the solar system object ephemeris data are interpolated to the exact time of the current event record. Each time a new event record is read, if the timetag increases, ephemeris data are reinterpolated.

Coordinate transformation information is read from the input file to convert SKY (X,Y) coordinates to the ICRS world coordinate system. This coordinate transformation information for the first file is stored, so that subsequent input files can use this data to reproject SKY coordinates into the same reference frame as the first file, allowing all the SKY data in the single output file to be in the same coordinate system.

The vector from Chandra to the object is calculated, and the vector elements are used to compute the Chandracentric RA and Dec of the object. This data, updated for each new ephemeris position, is used to define the new object centered coordinate frame, and the SKY coordinates are then reprojected in this frame.

If several observations are made of an object which are significantly separated in time, the change in distance between the object and Chandra due to the respective relative motion between the two may cause the object to appear to be larger or smaller in later observations. To normalize the data so that the size of the object appears constant, an option to output linear coordinates (kilometers) can be selected.

Future plans for sso_freeze include incorporating the tool into pipeline processing, and adding the ability to produce exposure maps which are also in object centered coordinates. This project is supported by the Chandra X-ray Center under NASA contract NAS8-39073.

References

Lisse, C.M. et al. 2001, "Charge Exchange-Induced X-Ray Emission from Comet C/1999 S4 (LINEAR)", Science, 292, 1343

Dennerl, K. et al. 2002, "Discovery of X-rays from Venus with Chandra", A&A, 386,319