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X-rays from Orion: Identification and cross correlations of young stars in the Orion nebula

Erik Bergstrom

SIMG-503 Senior Research

X-rays from Orion:
Identification and Cross Correlations of Young Stars in the Orion Nebula

Final Report

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Abstract

Recently formed, sun-like stars frequently display large x-ray luminosities. Therefore, x-ray observations provide a powerful means to identify newly formed stars, for the first time. The high spatial resolution of The Chandra X-ray Observatory has given us the ability to identify many stars seen in the x-ray wavelength regime for the first time also. The Orion Nebula is a very well studied region of star formation, and therefore is a good place for initial observations with Chandra.

We have analyzed Chandra imaging observations of The Orion Nebula for the purposes of source detection and source identification. The visualizations of the cross correlations in the near infrared and radio have started us on the path toward learning more about the the nature of stars emitting in x-ray, as well as nature of newly forming stars. Within one arc minute around the Becklin-Neugebauer object, fourteen of eighteen or 78 percent of the x-ray sources have near infrared counterparts. Three out of eighteen or 17 percent have known radio counterparts.

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Title: X-rays from Orion: *Identification and Cross Correlations of Young Stars in the Orion Nebula*

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I would like to thank the following people for their contributions to my effort:

Joel H. Kastner:	My Advisor and Teacher of Astronomy
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Introduction

The Chandra X-ray Observatory, which saw first light in August 1999, has given astronomers the ability to obtain x-ray images of unprecedented quality. The new images have improved spatial as well as spectral resolution as compared to any of its predecessors. With this new technology it is possible to identify many sources that are in crowded regions in the sky. This means that the new space telescope is bringing back to earth data that will make great advancements in the field of x-ray astronomy and astronomy in general. We took this upon ourselves to begin forging ahead with some of this data, to further our knowledge of star forming regions.

Young stars characteristically are strong sources in the x-ray regime. They are on the order of 1000 times brighter in x-rays than our sun. Chandra now has given us the opportunity to locate and study many new x-ray emitters. With this in mind, it is of great interest to study regions where star formation is known to be ongoing. The Orion Nebula is a very well studied region of star formation. This made it an ideal place to examine with Chandra. Data was obtained of the Orion Nebula with Chandra, and we were lucky enough to get our hands on it. The recent Chandra observations of the Orion Nebula, obtained as part of the Massachusetts Institute of Technology's guaranteed time program have given us the ability to begin to further our knowledge of the x-ray emission and nature of young stars.

Background

Chandra

The motivation for this research comes from the collection of recent observations with the Chandra X-ray Observatory (CXO). A diagram of the space ship as well as its internal workings is shown as Figure 1. This is a basic diagram of the parts of the telescope.

The Chandra X-ray Observatory Center (CXC) has over 150 people employed to operate The CXO. They are based in Cambridge, Massachusetts at the Smithsonian Astrophysical Observatory and at The Massachusetts Institute of Technology (MIT)(1). The ability of the telescope to collect x-rays is detailed below. The observatory as a whole can detect a range of photons with energies from 0.08-10 keV(.12nm to 15nm). This encompasses almost the entire x-ray band except for very hard x-rays, due to the inability of the mirrors on the telescope to redirect the photons at this high an energy (2).

There are two types of detectors that are used, which have different purposes. The first is a High Resolution Camera (HRC). It is used to collect high-resolution images of specific sources (1). The second type of detector is called the Advanced CCD Imaging Spectrometer (ACIS). This is used as both an imager as well as a spectrometer (3).

The telescope has transmission gratings that are specialized for either Low Energy (LETG) or High Energy (HETG) photons. These gratings produce spectra at the focal plane, where either the HRC or the ACIS can detect them. The spectral resolving powers (E/DE) range from 100-2000 depending upon the energy of the photon (1).

The point-spread function of the imager on ground calibration had a full width at half maximum of 0.5 arc seconds, which means the resolving power is equal to being able to read a stop sign at 12 miles away (4). This means that the angular resolution is at least an order of magnitude better than any other active or planned x-ray observatory (1).

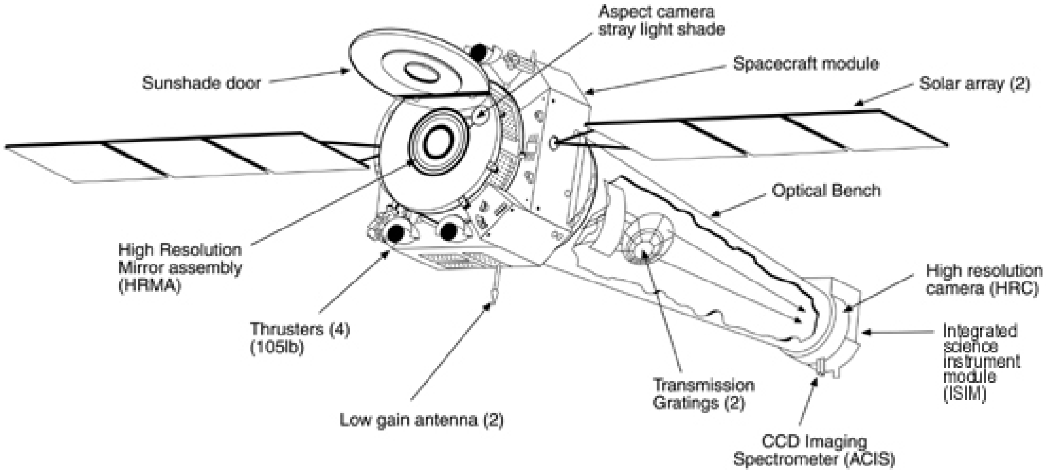

Figure 1: Basic Parts of Chandra

X-rays

X-ray photons, which have a large frequencies and short wavelengths, also have very high energies associated with them (2). Figure 2 shows where x-rays fall within the overall electromagnetic spectrum.

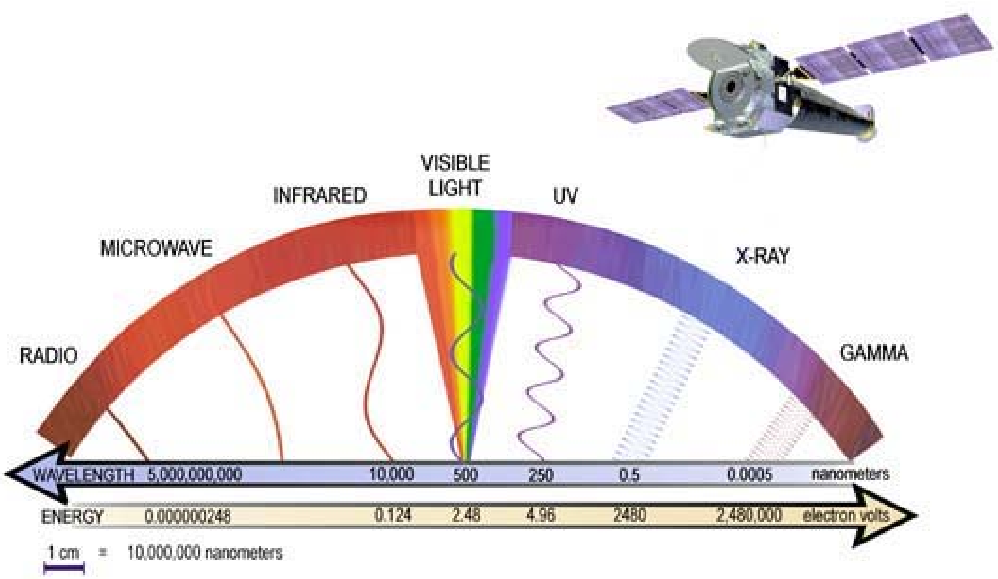

Figure 2: Electromagnetic Spectrum

The emission of x-rays by stars is also coincident with very high temperatures within or around that source. Figure 3 is a representation of different wavelengths of light, which have been viewed, or will be viewed, from space, with an approximate temperature scale underneath. It shows that it takes very hot temperatures (~10 Million K), to create emission of x-rays. It takes extremely violent conditions to cause these types of temperatures (5).

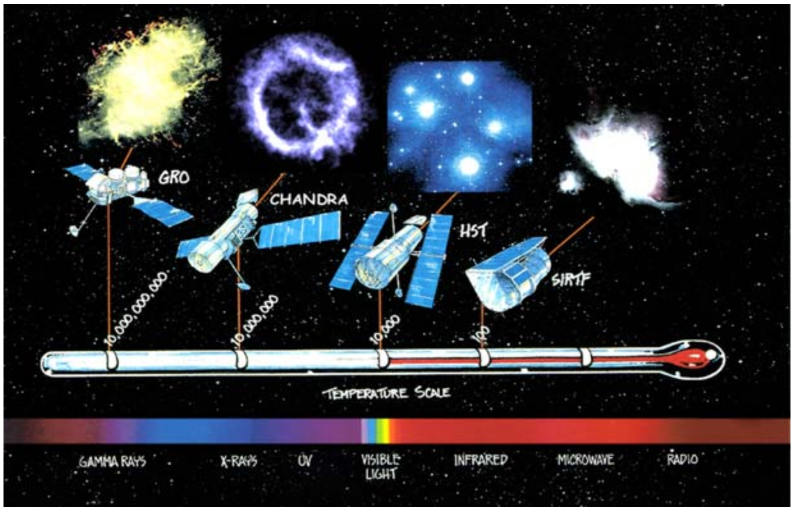

Figure 3: Temperature comparison of Astronomically studied Wavelength Emission

For example, our sun will have an eruption in its upper atmosphere called a solar flare. These flares are often times spectacular to view. The flares create large amounts of x-ray emission. The effects of these flares long-term, on the earth, are unknown, and therefore are an interesting topic of study.

Young stars flare much more often and much more powerfully than our sun. The information from these other stars can help to lead to some discoveries about the effects of x-ray emission of our sun. Even more importantly though, it is a very good source for us to find out about the conditions of early solar system development, specifically what the conditions were like when our sun and solar system were in their early stages. (5).

Apache Point Observatory

The telescope has a 3.5-meter primary mirror and it will be mounted with a GSFC camera. The Apache Point Telescope is shown as Figure 4.The camera has a detector array that is 1024 by 1024 pixels. It has a field of view of approximately 35 arc seconds. The instrument is sensitive to wavelengths ranging from 1.25 to 4.8 microns, with the precise band selected by a set of 5 different filters (6).


Figure 4: APO 3.5 meter Telescope

Infrared and Radio

Substantial amounts of Infrared, (IR) and sub-millimeter emission are indicative of stars with large amounts of dust orbiting them. The emission is produced when the dust particles are heated up by the star. The dust then reradiates the energy as IR or radio emission.

The dust particles orbiting the star could be there for many reasons. The star could be in the early stages of formation itself. Another probable cause for the excess infrared emission is that there are planets in the process of forming around the star. Either case indicates that the star is in the early stages of its life cycle (7).

The Orion Nebula

The constellation Orion is known to even casual observers of the night sky. This constellation contains, the region of interest in this research: The Great Orion Nebula. This nebula is the middle 'star' in Orion's sword. Its positions is shown in Figure 5. This nebula is a well-studied region of star formation containing many hundreds of recently formed stars (8).

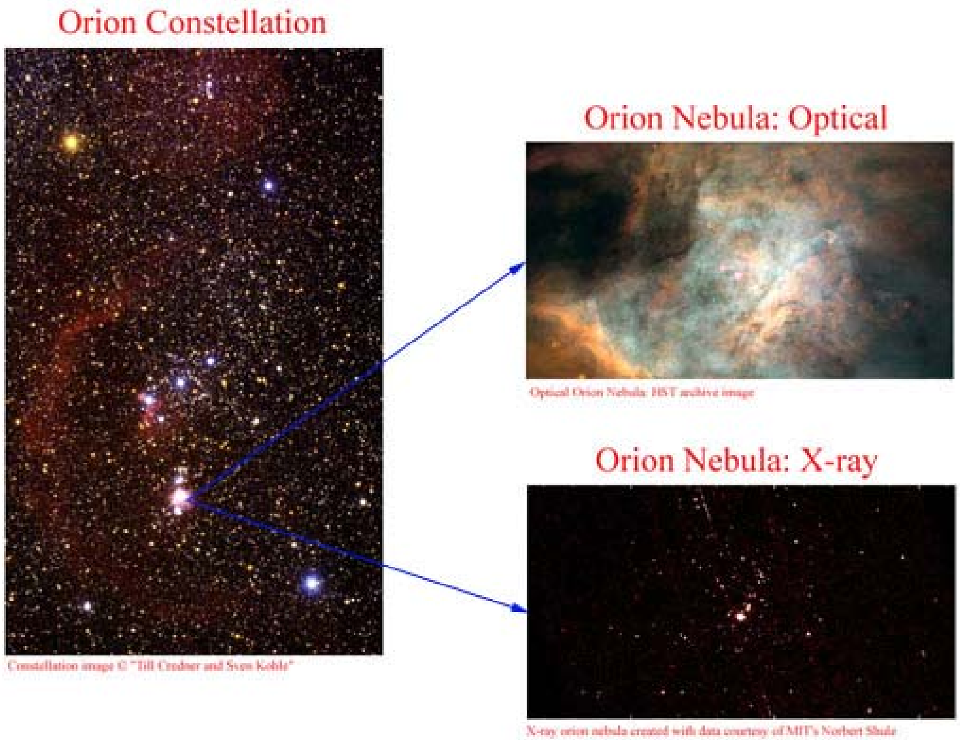

Figure 5: Constellation to Nebula in optical and x-ray

Methods

The data used in this project came from three main sources. Two of these sources of data were new as yet unpublished observations and the third was a database of previously recorded detections of sources. A short summary of each source of data is given.

Chandra Data

The images taken from The Chandra X-ray Observatory are the primary source for finding and interpreting new sources that are likely to be young sun-like stars. Therefore the capabilities of the instruments onboard are very important. The data reduction process has already been done as well, to produce a data product. This data product is an event list, which gives coordinates for each striking of an x-ray photon on the given detector. The CCD detectors chosen to image with are exposed for 3 seconds. The CCD detector was read out and potential x-ray events were identified on the basis of pixel values and detector geometries. Each individual event was then catalogued on the basis of the time it struck the CCD, the position that it occured at and the measured energy by the CCD of the incoming photon. The list of candidate events recorded by the telescope, and not images were then telemetered down to earth.

Reduction was then done on these lists. This reduction involved throwing out events, which were either found to be a bi-product of the collection process, or were found to be unusable. The latter could occur on the rare occasion when more than one x-ray photon struck the CCD detector in a single readout time.

Calibration of the telescope was very important for us to find the correct coordinates for each incoming photon. The CCD position was determined by the overall detector position and the known detector geometry. The detector position was determined by a small on-board optical telescope. The small optical telescope recorded the right ascension and declination of observations by observing 'guide stars' that have well known positions in the sky (1).

The dataset of the Orion Nebula was recorded by Chandra in October, 1999 as part of the MIT HETG team's gauranteed observation time. The observation lasted about 50 thousand seconds, which is about three fifths of a day. The high energy transmission grating was inserted during the observation, but our study focuses on the zeroth order or direct imaging of the region. The MIT HETG team, led by Norbert Schulz, is analyzing spectroscopic content of the data, while we concentrated on the x-ray source identifications.

Apache Point Observatory Data

The near infrared image from the APO was used to determine the positions of the infrared sources in the Trapezium and Becklin-Neugebauer object regions of The Orion Nebula. Both images were near-infrared K-band, two micron, images constructed from mosaics of 5 individual frames with three second integration times. These images were obtained in March of 2000.

SIMBAD

The *Set of Identifications, Measurements and Bibliographies for Astronomical Data* (9), was an important resource of data in my project. This database includes basic data, observational measurements, cross identifications and bibliographies for sources outside of our solar system. The data I retrieved from the database was a list of known sources with coordinates, within 10 arc minutes of the central trapezium cluster in the Orion Nebula.

Analysis

Once the Chandra data was obtained the first step in the process of analyzing it was to create the image. The image was created with routines included in an astronomical package to accompany Interactive Data Language (IDL). The first routine was capable of reading the event list data into an IDL structure. The next routine took the event list structure and binned up the data to create an image. The image of the field, which we studied, is shown as figure 6.

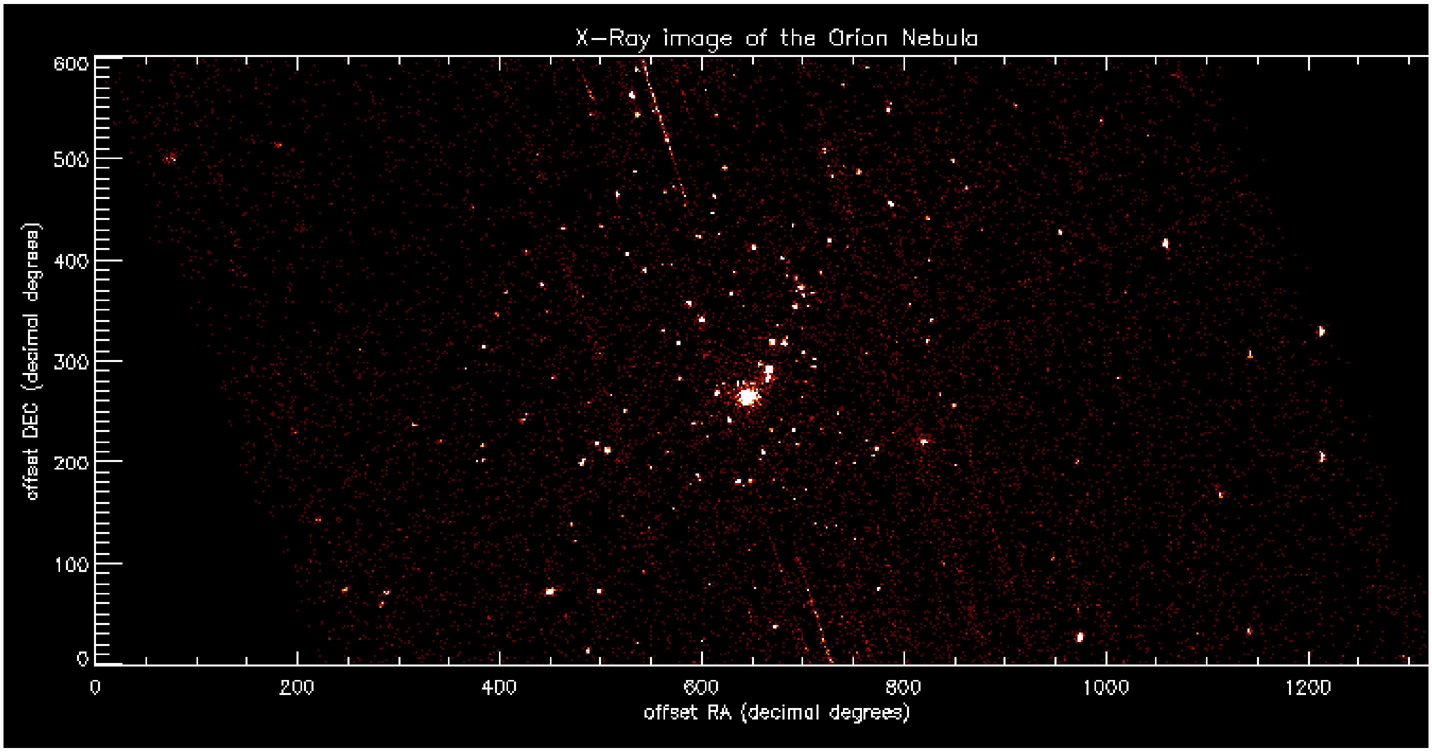

Figure 6: Orion Nebula in X-rays

It was then necessary next to detect all of the sources in the region. This was done two different ways, as to verify the validity of each source that was detected.

The first method entailed using a software package called cell-detect. This piece of software is available from the CXC website. The program goes through the image with a sliding box and determines whether or not there are any sources in that specific region. It then returns the source number, image coordinates, total counts and nominal sky coordinates for each source, which meets its criteria as a 'good' source. Criterion for a good source is when the signal to noise ratio (SNR) is greater than or equal to about three.

The second method was a procedure from a library of IDL routines. The library is the same astronomical library, which was used to read in and create the image. This procedure found every spot in the image that was above a certain threshold that was given to it. Then it used some of the same criteria as the previous program of roundness and sharpness to verify that the source was indeed a legitimate one.

The detection of sources yielded a list where each source had image coordinates, a magnitude, and nominal sky coordinates (from cell-detect). The image of the nebula, with temporary source names plotted over top is shown as Figure 7. The large cluster of sources in the center is then blown up and shown as Figure 8.

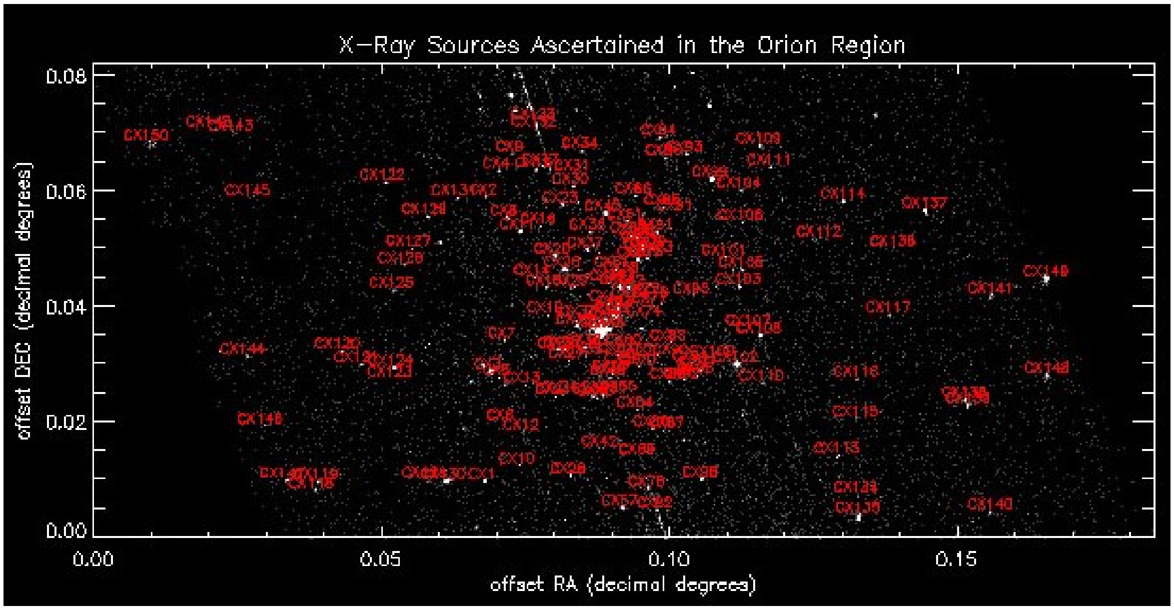

Figure 7: Sources Detected in The Orion Nebula

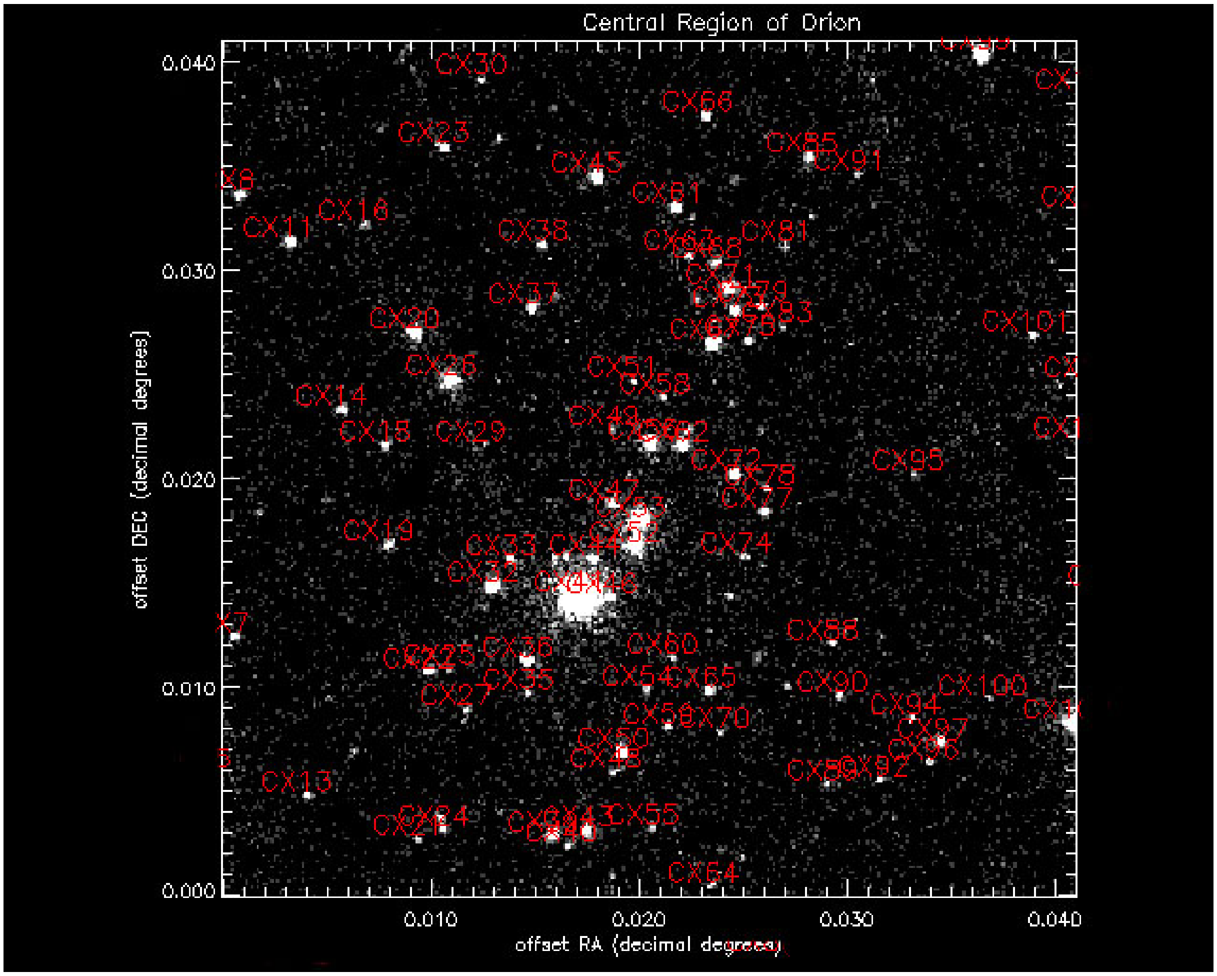

Figure 8: Sources Detected in Central Region of Orion Nebula

The list of sources for the Chandra data had to be adjusted to absolute sky coordinates from the nominal coordinates found previously. It turned out that there was simply a systematic offset, if not exactly, then to an incredibly good approximation. Therefore it could be corrected for by simply shifting the nominal coordinates. Using a star in the region with very well known coordinates, Theta1 Ori C, the exact shift that was necessary was found.

The next phase of analysis came with some cross-referencing of the data. With the help of the SIMBAD, a list of sources in the Orion Nebula at many wavelengths was attained. Two IDL programs were then written in order to accomplish the cross-referencing of the two lists. First the lists were read into IDL structures. The structures allowed each sources Right Ascension (RA) and Declination (DEC) to be accessed. This allowed each source detected to be compared one at a time to each of the sources in the list of sources attained from SIMBAD. Anything within one arc-second of a Chandra detection was added to a running list of possible matches for each source of x-ray emission. The list the program created is included as appendix a.

Comparisons Between X-ray and Infrared Images

In order to better determine the viability of the list of possible matches created, two specific regions of the images were examined in detail. Two images were attained of these particular regions from an observing run to The APO (10). The resulting images were then used as a means by which to visually compare the x-ray data to the near infrared.

In order for the two images to make sense together, it was necessary to make the images the same size and orientation. This was done with the aid of IDL. The first thing that needed to be done was to center the data on the same point in the two fields. Once again, Theta1 Ori C was used as the point of reference. Then it was necessary to make the images the same size and have the same field of view in the right orientation. The former was done by using the size per pixel (plate scale) of each image to create the right size for each different plate scale. The latter was done by rotating each infrared image a certain amount. The Trapezium image was rotated 19.5 degrees counter-clockwise, while the Becklin-Neugebauer region image was rotated 30 degrees counter-clockwise.

The first of these two regions was the Trapezium Cluster. This Cluster is the central cluster within the Orion Nebula. A side-by-side comparison of the Cluster at the different wavelengths is shown in Figure 9.

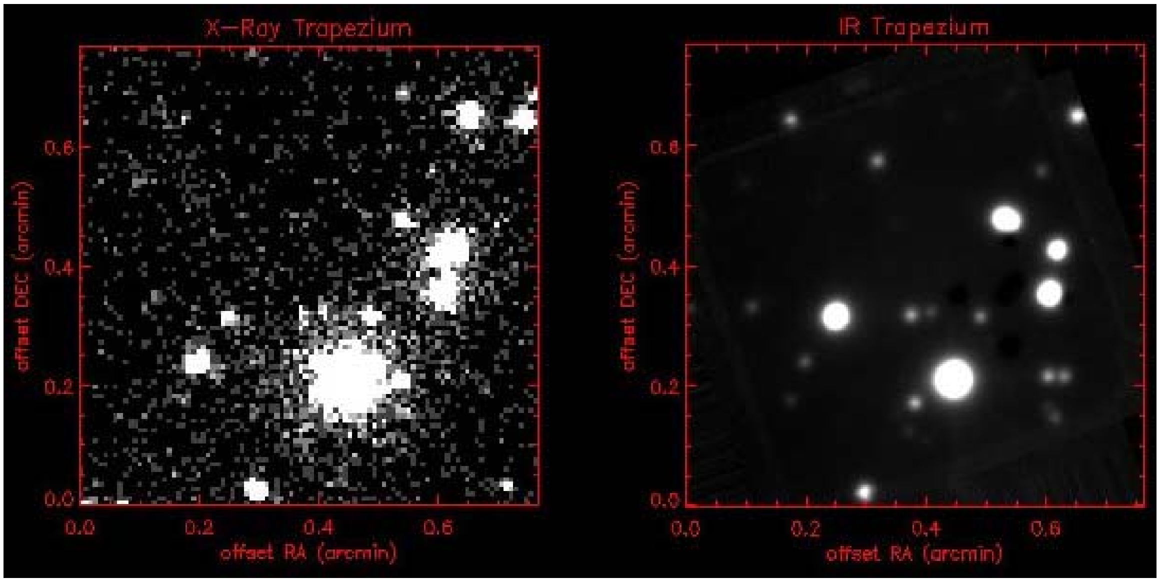

Figure 9: Side by Side Comparison of Trapezium Cluster in x-ray and near infrared

The second region chosen, was the area around the Becklin-Neugebauer (BN) object. The BN object is the brightest source in the infrared image. The side-by-side comparison of the two is shown in Figure 10.

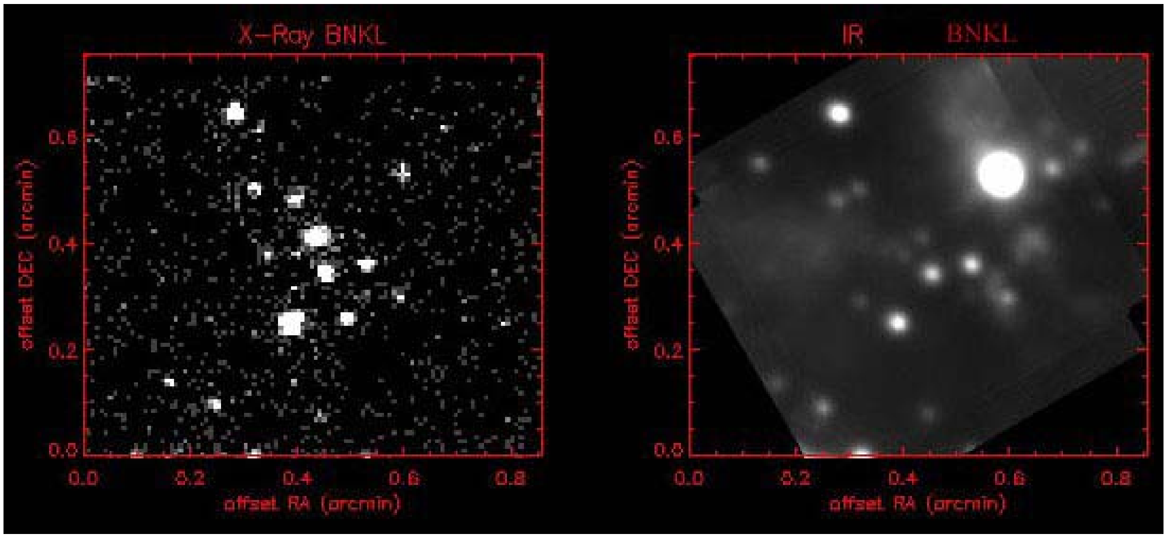

Figure 10: Side by Side Comparison of BN region in x-ray and near infrared

To get an even better idea of how the two images of each region coincided, contour plots of the IR images were made. Two particular procedures (11)
were used in IDL to plot the two images simultaneously and on the same scale and image space, the x-ray being the original image, and the infrared being the contours. The resulting images are shown as Figures 11 and 12. Figure 11 is of the Trapezium cluster, and Figure 12 is around the BN object.

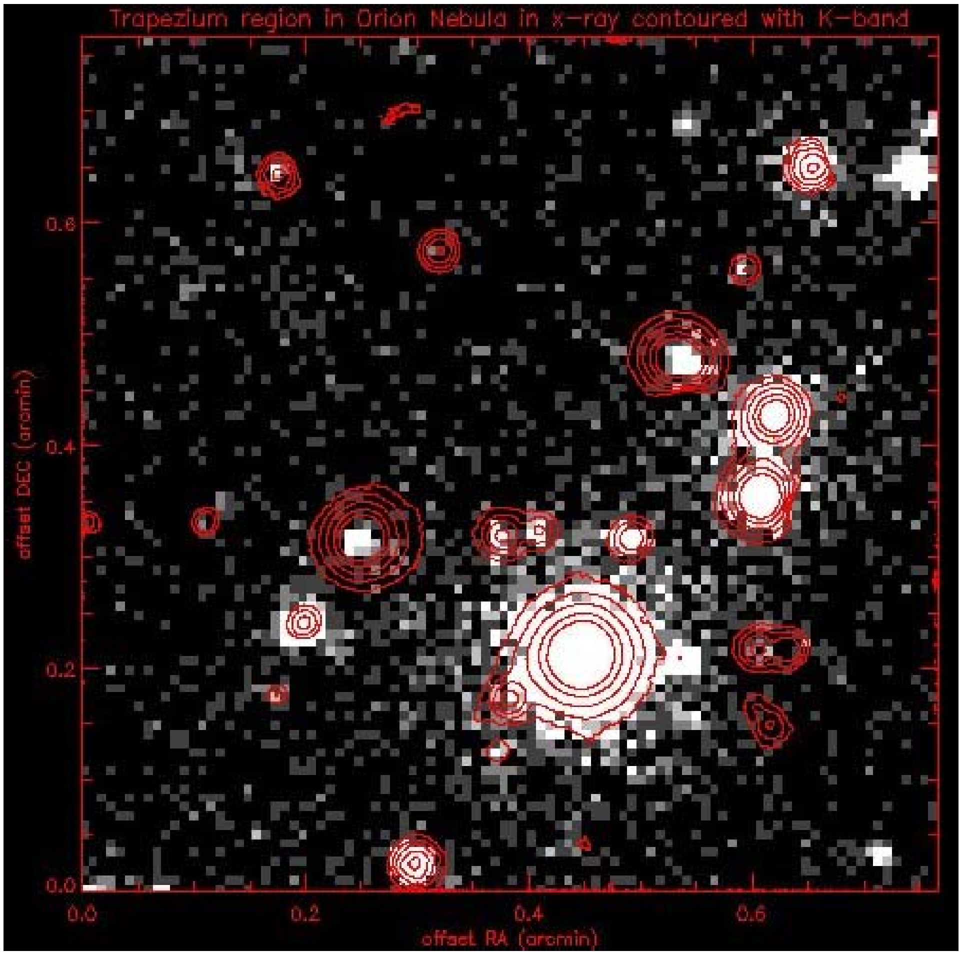

Figure 11: Contour plot of near Infrared over x-ray of Trapezium cluster

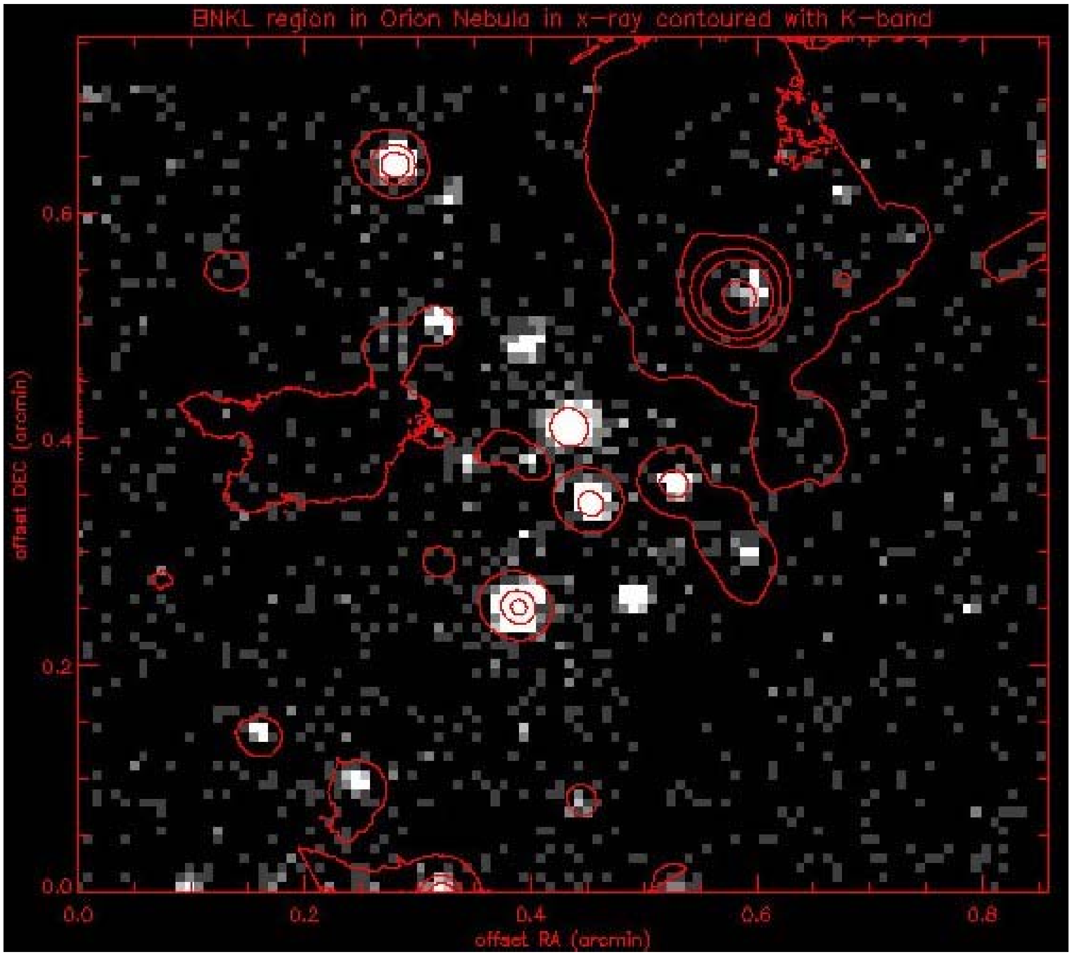

Figure 12: Contour plot of near infrared over x-ray of BNKL region

Another kind of overlay plot was created by plotting asterisks, which represent radio continuum sources, over the x-ray image of the Becklin-Neugebauer region. A list of radio continuum sources in that region was acquired from SIMBAD. These sources then became the asterisks in the plot. This was done in IDL (12). The resulting overlay plot is shown as Figure 13.

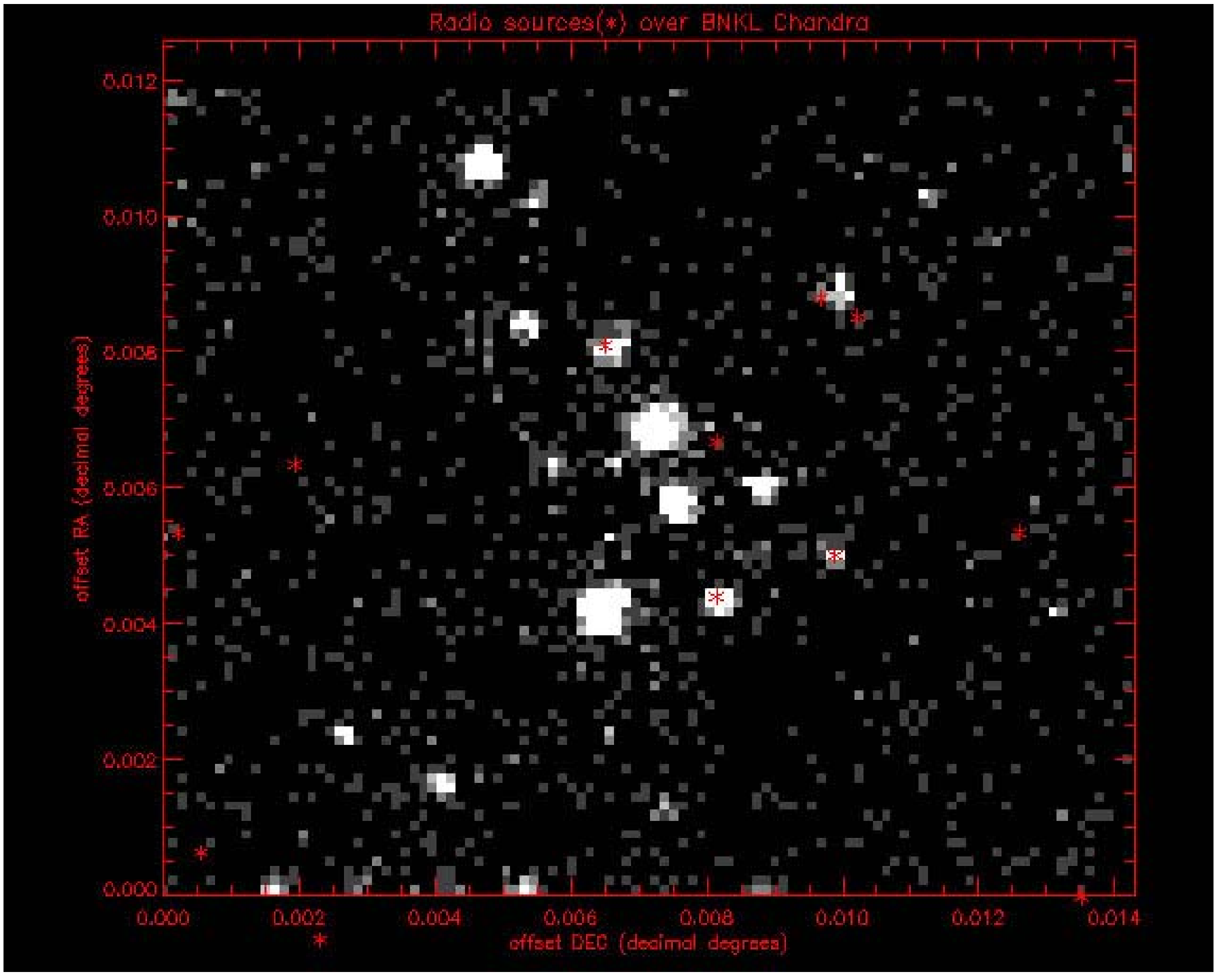

Figure 13: BN region of radio continuum sources plotted over Chandra x-ray image

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Results

The main result is a list of cross-referenced data extracted from the Chandra data and compared to data from SIMBAD. This result is a robust list of possible matches for each detected source in The Orion Nebula. The wavelengths included were near infrared, far infrared, visible, microwave and radio sources, as well as a small number of previously recorded x-ray data from Chandra's predecessors. The list is included as the Appendix.

From Figures 11 and 12
it is possible to find something out about the nature of x-ray emission from sources within The Trapezium and Becklin-Neugebauer regions. It is very difficult to find an x-ray source that is not also an infrared source.

In the Trapezium, it seems that every source has a counterpart in the near infrared except for one which is approximately 3 arc seconds west of theta 1 ori C. One of the sources was very week in the infrared as compared to its x-ray counterpart though, CX32 (referenced from Figure 8).

It was also very difficult to find a source in the BN region that did not also have an infrared counterpart. In this region though, the first visualizations of sources in the x-ray, which did not have counterparts in the near infrared were discovered. CX68 and CX75 (referenced from Figure 8)did not have counterparts in the near infrared from the APO images. The source CX75, however, has shown up in the near infrared, at 2 microns in images obtained by the hubble space telescope (HST) mounted with the Near Infrared Camera and Multiobject Spectrometer (NICMOS). This was ascertained by looking at the matches to each of these two sources in appendix a.

The lack of counterparts for a small number of sources in the BN region made some more study of them necessary. Looking outside of the infrared led us to the search within the radio. Figure 13 led to the discovery that these two sources were in fact radio continuum sources.

Other sources within the region of study were also found to not have counterparts at any other wavelengths. This is shown in the Appendix. These sources seem only to show up in the x-ray, but without further research of them individually, it is premature to conclude that they have not been seen at any other wavelength.

Discussion

Many, but not all, of the recently formed or forming stars in the Orion Nebula are x-ray emitters. Some of the stars in this region seem to emit in the near infrared, but not in x-ray. In the Trapezium, 13/15 of the xray sources had near infrared counterparts in the APO images. In the Becklin-Neugebauer region, 14/18 of the x-ray sources had APO counterparts. This means, that most, but not all stars in a star-forming nebula emit substantially in the x-ray.

This region was observed twice. This work concentrated on the first set of data, which was obtained in October of 1999. Another set of data was obtained for this region in November of 1999. Further comparisons of this later data could show that some of these sources may be variable when it comes to the emission x-rays.

There also seems to be some sources that are found to emit in the x-ray, but are not showing up at other wavelengths. This is not completely confirmed, but sources may be able to be detected for the first time in x-ray.

It seems that a new class of star is being unveiled. It has been suspected through earlier work, but this research has gone further to increase the validity of their existence. The star seems to emit in the x-ray and radio, but not in the infrared. This could happen because the star is so deeply embedded in the star forming cloud, that all of the two-micron emission from that source is being absorbed by it. Another possibility is that the source is still forming, and material in orbit around it is blocking the infrared emission.

One source that was not found to be in the two-micron image from the APO seemed to show up in an image of the same region by NICMOS on HST. This could also show that the recently formed stars, which do not seem to emit in the near infrared could possibly variably emit in the two-micron range.

Conclusions

The objective of this research was to examine recently formed or forming stars from Chandra data, and make some conclusions about the nature of them. It was also an objective to find out about processes that could be applied to our solar system's history. We were fortunate to obtain the data of The Orion Nebula for this purpose.

Is it possible to find out about the nature of newly formed or forming stars with the aid of x-ray data? This work has shown that young stars with x-ray emission do not necessarily have to have emission in the near infrared. This is a defining factor in a new classification of young stellar objects that should be radiating infrared radiation, but are not. We have also shown that the reverse is not always true either. Some young stellar objects that emit substantially in the near infrared do not emit in x-ray, leading one to speculate that the emission of x-rays from young stellar objects may be variable. It may be very hard to predict whether or not a source that emits in the near-infrared may also emit in x-rays. The variability of the ratio of x-ray sources that have infrared counterparts is high enough to say that it may be impossible to predict x-ray emission in young stellar objects.

The fact that x-ray emission may be variable does not mean that the x-ray data is not useful. The nature of high energy processes within young stellar objects can be observed with the help of Chandra. The processes that produce x-rays within our own sun are thought to be the convection of matter, which produces strong magnetic fields. These magnetic fields then are thought to cause flares. As we said in the beginning, these flares coincide with the emission of x-rays. This means that the study of these young stellar objects may inform us more about the early state of our sun and ultimately help us understand more about the processes that cause strong magnetic fields and flaring.

The Chandra data coming back to earth has begun to show great new directions in the field of x-ray astronomy. The Chandra data of the Orion Nebula came to show that the nature of x-ray emission from young stellar objects is hard to predict. With further study it may be possible to confirm our suspicions that x-ray emission is indicative of a young sun-like star.

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10. The raw images attained from the observing run, were reduced by Joel Kastner.

11. The two procedures are included in the Thompson Library of IDL routines.

12. The procedure, xyouts, is included in the standard IDL library

X-rays from Orion

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List of Symbols

CXO	Chandra X-ray Observatory
CXC	Chandra X-ray Observatory Center
CCD	Charge-Coupled Device
HRC	High Resolution Camera
ACIS	Advanced CCD Imaging Spectrometer
EM	Electro-Magnetic
LETG	Low Energy Transmission Grating
HETG	High Energy Transmission Grating
E/DE	Energy divided by Change in Energy
K	Kelvin
K-band	2 micron band of infrared spectrum
IR	Infrared
APO	Apache Point Observatory
SIMBAD	Set of Identifications, Measurements and Bibliograpies for Astronomical Data
IDL	Interactive Data Language
RA	Right Ascension
DEC	Declination
BN	Becklin-Neugebauer
HST	Hubble Space Telescope
NICMOS	Near Infrared Camera and Multiobject Spectrometer
SNR	Signal to Noise Ratio

X-rays from Orion

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Appendix A

This is the preliminary list of sources with their cross-references

Source names correspond to figures 7 and 8

CX1 corresponds to these matches:

Source	Type	Error
[AD95]3095	*	0.000253225

CX2 corresponds to these matches:

Source	Type	Error
[H97b]712	*	7.38398e-05
[AD95]3494	*	0.000252319
[H97b]9278	*	8.37239e-05

CX3 corresponds to these matches:

Source	Type	Error
Parenago1961	*iN	2.68935e-05
[FTC93]	Rad	1.80240e-05
[AD95]3140	*	3.98130e-05
[H97b]9287	*	0.000228509

CX4 corresponds to these matches:

Source	Type	Error
[AD95]2833	*	0.000274891
[AD95]3220	*	0.000184794
V*V1230Ori	Or*	7.24924e-05
[AD95]2834	*	0.000235343

CX5 corresponds to these matches:

Source	Type	Error
[H97b]659	*	0.000264710
[AD95]3135	*	0.000184793

CX6 corresponds to these matches:

Source	Type	Error
[AD95]3306	*	2.47535e-05

CX7 corresponds to these matches:

Source	Type	Error
[H97b]648b	*	3.26596e-05
[AD95]3151	*	1.32978e-05
[H97b]648a	*	3.24241e-05

CX8 corresponds to these matches:

Source	Type	Error
[AD95]3178	*	0.000175935

CX9 corresponds to these matches:

Source	Type	Error
[AD95]3188	*	0.000154889

CX10 corresponds to these matches:

Source	Type	Error
[H97b]625	*	0.000235316
[AD95]2560	*	0.000156364
[H97b]658	*	4.33684e-05
[AD95]2565	*	0.000192773

CX12 corresponds to these matches:

Source	Type	Error
[AD95]3101	*	5.00654e-05
GMRP	Rad	2.48380e-05
[AD95]2594	*	0.000142767

CX13 corresponds to these matches:

Source	Type	Error
[AD95]2647	*	0.000237564

CX14 corresponds to these matches:

Source	Type	Error
[AD95]3268	*	0.000274714
[H97b]9250	*	7.83584e-05

CX15 corresponds to these matches:

Source	Type	Error
[AD95]2828	*	0.000226234
[H97b]9248	*	8.69389e-05

CX16 corresponds to these matches:

Source	Type	Error
[AD95]3176	*	0.000249564
[H97b]9243	*	0.000219677

CX17 corresponds to these matches:

Source	Type	Error
[AD95]3222	*	9.68640e-05

CX18 corresponds to these matches:

Source	Type	Error
[AD95]3267	*	0.000194169
[H97b]598a	*	5.82865e-05
[AD95]2718	*	0.000178045

CX19 corresponds to these matches:

Source	Type	Error
[HHM94]12	IR	5.27577e-06
[AD95]2700	*	0.000247616

CX20 corresponds to these matches:

Source	Type	Error
[SUK94]Clump43	PoC	0.000158208

[AD95]3266	*	0.000166770
V*V1229Ori	Or*	1.86832e-05
GMRF	Rad	5.27530e-06

CX21 corresponds to these matches:

Source	Type	Error
[AD95]3129	*	0.000181005
[BSD98]37	Y*O	9.61287e-06

CX22 corresponds to these matches:

Source	Type	Error
[H97b]9208	*	0.000240172
[H97b]9206	*	0.000214039
TCC105	*	0.000160872
[AD95]3271	*	2.46467e-05
GMRN	Rad	2.29219e-05
[HHM94]11	IR	8.88962e-05
[OW94]182-336	*	2.37624e-05

CX23 corresponds to these matches:

Source	Type	Error
[AD95]3469	*	0.000234934
[H97b]9209	*	0.000126214
[AD95]3180	*	8.03094e-05

CX24 corresponds to these matches:

Source	Type	Error
[H97b]9210	*	3.70867e-05

CX25 corresponds to these matches:

Source	Type	Error
[H97b]9208	*	8.64812e-05
[H97b]9206	*	5.89874e-05

TCC105	*	5.27577e-06
[AD95]3271	*	0.000142842
GMRN	Rad	0.000175456
[HHM94]11	IR	9.03437e-05
[OW94]182-336	*	0.000163271

CX26 corresponds to these matches:

Source	Type	Error
TCC89	*	0.000245116
[AD95]3168	*	4.21633e-05
GMRG	Rad	1.22462e-05

CX27 corresponds to these matches:

Source	Type	Error
TCC76	*	0.000271430
[AD95]3537	*	0.000146216
TCC91	*	0.000152447
[H97b]9195	*	5.68220e-05

CX28 corresponds to these matches:

Source	Type	Error
[H97b]559	*	0.000257707
[AD95]2544	*	0.000143098

CX29 corresponds to these matches:

Source	Type	Error
[AD95]3259	*	4.11403e-05
[H97b]553a	*	3.06064e-05
[MLL95]	Rad	0.000200335
[H97b]553b	*	1.41869e-05

CX30 corresponds to these matches:

Source	Type	Error

[AD95]2816	*	0.000228845

CX31 corresponds to these matches:

Source	Type	Error
[AD95]3532	*	0.000188469
[AD95]3186	*	0.000159987
[H97b]552b	*	1.96976e-05
[H97b]552a	*	9.14547e-05

CX32 corresponds to these matches:

Source	Type	Error
PSH162	*	0.000233496
PSH164	*	0.000162293
[H97b]9180	*	5.55179e-05

CX33 corresponds to these matches:

Source	Type	Error
[AD95]3528	*	0.000237766
[BSD98]6	Y*O	0.000271812
[BSD98]7	Y*O	0.000219433
*tet01OriG	Y*O	0.000148625
[FTC93]	Rad	0.000221242
[OW94]172-317W	*	0.000130792
[AD95]3153	*	0.000178243
HD37023	*i*	0.000275450
[AD95]3536	*	0.000142395
[OW94]178-316S	*	0.000249953

CX34 corresponds to these matches:

Source	Type	Error
[AD95]3225	*	6.82567e-05
[AD95]3467	*	0.000201074

[H97b]9149	*	0.000206415

CX35 corresponds to these matches:

Source	Type	Error
[AD95]3144	*	0.000164682

CX36 corresponds to these matches:

Source	Type	Error
[AD95]3538	*	0.000169505
Parenago1893	*iN	4.62574e-06

CX37 corresponds to these matches:

Source	Type	Error
V*V1333Ori	V*	0.000165495
[AD95]3519	*	0.000242391

CX38 corresponds to these matches:

Source	Type	Error
[H97b]9140	*	0.000209762

CX39 corresponds to these matches:

Source	Type	Error
[AD95]3277	*	9.17533e-05
[H97b]526b	*	4.26674e-05
[H97b]526a	*	1.55333e-05
[GC94b]110	X	0.000202338

CX40 corresponds to these matches:

Source	Type	Error
[GC94b]110	X	0.000277296
[H97b]521	*	0.000160577
V*V1279Ori	Or*	0.000160577

CX41 corresponds to these matches:

Source	Type	Error
SV*ZI429	V*	3.23905e-06

[HHM94]13	IR	7.40092e-06
ADS4186ABCD	**	0.000250675
[BSD98]1	Y*O	4.91718e-05
[OW94]161-323	*	0.000136078
[OW94]160-323	*	0.000146129
CCDMJ05353-0524KL	**	0.000255315
*tet01OriH	Y*O	0.000197912
[AD95]3253	*	0.000195525
Parenago1866	*iN	0.000244880
[BSD98]14	Y*O	0.000223427

CX42 corresponds to these matches:

Source	Type	Error
[AD95]3120	*	0.000176875

CX43 corresponds to these matches:

Source	Type	Error
[AD95]3277	*	0.000259366
[H97b]526b	*	0.000251893

CX44 corresponds to these matches:

Source	Type	Error
[AD95]3528	*	0.000232198
[BSD98]6	Y*O	7.52531e-05
[BSD98]7	Y*O	0.000107841
*tet01OriG	Y*O	0.000127463
[FTC93]	Rad	0.000237893
[YKS96]11	X	0.000210175
[OW94]155-316	*	0.000273346

CX45 corresponds to these matches:

Source	Type	Error

[AD95]3177	*	8.69390e-05
[HAB84]88	IR	3.65246e-05
[H97b]511b	*	8.04581e-05
[H97b]511a	*	0.000163661

CX46 corresponds to these matches:

Source	Type	Error
SV*ZI429	V*	0.000129675
[HHM94]13	IR	0.000126505
[BSD98]1	Y*O	0.000127061
[OW94]161-323	*	4.62577e-06
CTA37	Rad	0.000224410
[OW94]160-323	*	0.000118126
*tet01OriH	Y*O	0.000183319
[AD95]3253	*	0.000106269
Parenago1866	*iN	0.000243093
[BSD98]14	Y*O	0.000196587
TCC26	*	0.000225808

CX47 corresponds to these matches:

Source	Type	Error
[OW94]161-307E	*	1.51264e-05
GMR15	Rad	8.63611e-05
[H97b]9153	*	0.000223857
NSV2291	V*	7.69009e-05
[AD95]2705	*	0.000117077

CX48 corresponds to these matches:

Source	Type	Error
[AD95]2646	*	0.000207274
Parenago1870	*iN	1.41506e-05

CX49 corresponds to these matches:

Source	Type	Error
[HAB84]83	IR	0.000267090
[OW94]165-254	*	0.000157278
TCC55	*	4.47123e-05
Parenago1911	*iN	0.000259389
Parenago1841	*iN	0.000255774

CX50 corresponds to these matches:

Source	Type	Error
[AD95]3138	*	0.000196897

CX51 corresponds to these matches:

Source	Type	Error
Parenago1860	*iN	0.000141686
[JGS92]10	Mas	0.000174065
[JGS92]13	Mas	0.000245062

CX52 corresponds to these matches:

Source	Type	Error
[BSD98]8	Y*O	7.32198e-05
[OW94]158-314N	*	8.22314e-05
V*V1016Ori	V*	1.20476e-05
GMR12	*	2.51970e-05

CX53 corresponds to these matches:

Source	Type	Error
[OW94]159-311	*	0.000276203
GMR25	Rad	2.56497e-05
[AD95]3156	*	7.97452e-05

CX54 corresponds to these matches:

Source	Type	Error
TCC41	*	0.000222925

TCC37	*	1.85661e-06
[AD95]3142	*	0.000114083
[AD95]3143	*	0.000253531
Parenago1844	*iN	0.000220851

CX55 corresponds to these matches:

Source	Type	Error
[AD95]3125	*	7.17421e-05
[AD95]2634	*	0.000210023

CX56 corresponds to these matches:

Source	Type	Error
TCC69	*	0.000236661
[MLL95]	Rad	0.000162120
[H97b]9128	*	0.000256177
Parenago1862	*iN	2.70389e-05
[AD95]3257	*	0.000109626

CX58 corresponds to these matches:

Source	Type	Error
[AD95]3167	*	0.000240271
[H97b]539	*	0.000237073
[AD95]3256	*	0.000254428
[H97b]513	*	0.000235974
[SUK94]Clump35	PoC	0.000232368
[HAB84]46	IR	0.000248980

CX59 corresponds to these matches:

Source	Type	Error
[MLL95]	Rad	0.000194684
[OW94]154-346	*	8.45621e-05
[AD95]3526	*	0.000195554

Parenago1845	*iN	0.000219705

CX60 corresponds to these matches:

Source	Type	Error
[AD95]2669	*	8.45195e-05
TCC29	*	5.30656e-05
[AD95]3145	*	8.69390e-05
[H97b]5177	*	0.000166318

CX61 corresponds to these matches:

Source	Type	Error
V*V1331Ori	V*	0.000132982
Parenago1838	*iN	0.000202556

CX62 corresponds to these matches:

Source	Type	Error
[MLL95]	Rad	0.000174986
Parenago1862	*iN	0.000164637
[AD95]3257	*	0.000141630

CX63 corresponds to these matches:

Source	Type	Error
[H97b]529	*	0.000220671
[HAB84]63	IR	4.85261e-05
[HAB84]57	IR	0.000103317
[H97b]9074	*	0.000107995
[AD95]2763	*	0.000227140

CX64 corresponds to these matches:

Source	Type	Error
[AD95]3404	*	0.000254877
[H97b]9079	*	0.000144573
[H97b]9080	*	0.000116880

[AD95]3102	*	0.000257038

CX65 corresponds to these matches:

Source	Type	Error
TCC37	*	0.000202815
[AD95]3142	*	0.000224008
Parenago1844	*iN	0.000110896

CX66 corresponds to these matches:

Source	Type	Error
Parenago1837	*iN	0.000238704
EQ053247-052356	?	0.000277074

CX67 corresponds to these matches:

Source	Type	Error
[BSD98]35	Y*O	0.000270746
[GWV98]	Mas	0.000250068
V*V1330Ori	V*	0.000162400
[GD77]B	IR	0.000260075
GMRH	Rad	0.000164168
[RLK73]IRc2b	IR	0.000210456
[GWV98]	Mas	0.000168686
[GWV98]	Mas	0.000266798
[GWV98]	Mas	0.000266798
[GWV98]	Mas	0.000242769
[GWV98]	Mas	0.000242769
[GWV98]	Mas	0.000233238
[GWV98]	Mas	0.000242509
[GWV98]	Mas	0.000242509
[GWV98]	Mas	0.000242509
[GWV98]	Mas	0.000253055

[GWV98]	Mas	0.000258346
[GWV98]	Mas	0.000258346
[GWV98]	Mas	0.000248310
LBLSj	IR	0.000254079
[AD95]3169	*	0.000269614

CX68 corresponds to these matches:

Source	Type	Error
[H97b]472b	*	0.000272888
[H97b]9096	*	0.000196877
GMRD	Rad	7.24762e-05
Caswell	Mas	0.000153117
[BE83]	Mas	0.000153117
[JGS92]5	Mas	0.000262720

CX70 corresponds to these matches:

Source	Type	Error
[MLL95]	Rad	0.000177735
[OW94]154-346	*	0.000185856
[AD95]3526	*	0.000161255
Parenago1845	*iN	8.00176e-05
[AD95]3137	*	0.000127892
[AD95]3525	*	0.000219799

CX71 corresponds to these matches:

Source	Type	Error
[GWV98]	Mas	0.000245912
[GWV98]	Mas	0.000245912
[GWV98]	Mas	0.000245912
[GWV98]	Mas	0.000245278
[GWV98]	Mas	0.000245278

[GWV98]	Mas	0.000245912
[GWV98]	Mas	0.000190744
[GWV98]	Mas	0.000190744
[GWV98]	Mas	0.000137089
[GWV98]	Mas	0.000218997
[GWV98]	Mas	0.000218997
GMRI	Rad	0.000247268
[GWV98]	Mas	0.000275550
[GWV98]	Mas	0.000165084
[WCP90]	Mas	0.000193175
[GWV98]	Mas	0.000248740
[GWV98]	Mas	0.000166023
[GWV98]	Mas	0.000167004
[GWV98]	Mas	0.000166023
[GWV98]	Mas	0.000167004
[GWV98]	Mas	0.000167004
[GWV98]	Mas	0.000167004
[GWV98]	Mas	0.000115502
[GWV98]	Mas	0.000249519
[GWV98]	Mas	0.000250327
[RLK73]IRc2a	IR	0.000142651
[GWV98]	Mas	9.24332e-05
[GWV98]	Mas	9.07345e-05
[BE83]	Mas	9.59819e-05
SH2-281	HII	9.59819e-05
[PCC93]69	Mas	9.59819e-05
[BE83]IR	IR	9.59819e-05

[RLK73]IRc2d	IR	0.000105613
[RLK73]IRc2c	IR	0.000204763
EQ053246-052422	?	0.000237071
[H97b]452	*	0.000214452
[JGS92]12	Mas	0.000225751
[HAB84]33	IR	0.000219168

CX72 corresponds to these matches:

Source	Type	Error
[H97b]9085	*	0.000154095
[H97b]9069	*	0.000161408
[AD95]3161	*	0.000245017
[BSD98]34	Y*O	0.000217049
TCC2	*	0.000222231
GMRC	Rad	0.000267550
[AD95]2713	*	0.000195343

CX73 corresponds to these matches:

Source	Type	Error
[SUK94]Peak3	PoC	0.000176901
[OW94]147-234	*	9.25687e-05
[GC94b]101	X	8.50319e-05
[GWV98]	Mas	0.000201460
Parenago1839	*iN	0.000249812
[GWV98]	Mas	0.000250264
[CW97]2	PoC	0.000252636
[MR95c]L	HII	9.46865e-05
LBLSn	IR	9.46865e-05
[MWZ90]OMC-1FIR2	IR	0.000206883

[GWV98]	Mas	0.000274120
[GWV98]	Mas	0.000253875
[JGS92]4	Mas	0.000217453
LBLSf	IR	0.000257298

CX74 corresponds to these matches:

Source	Type	Error
TCC13	*	7.72370e-05
[AD95]3511	*	0.000194002
[MLL95]	Rad	0.000177224

CX75 corresponds to these matches:

Source	Type	Error
[GWV98]	Mas	0.000239384
GMRH	Rad	1.14899e-05
[RLK73]IRc2b	IR	4.48291e-05
[GWV98]	Mas	4.90683e-05
[GWV98]	Mas	0.000134764
[GWV98]	Mas	0.000161304
[GWV98]	Mas	0.000162075
[GWV98]	Mas	0.000162075
[GWV98]	Mas	0.000162075
[GWV98]	Mas	0.000189563
[GWV98]	Mas	9.56344e-05
[GWV98]	Mas	0.000217160
[GWV98]	Mas	9.56344e-05
[GWV98]	Mas	0.000217160
[GWV98]	Mas	0.000217160
[GWV98]	Mas	0.000117970

[GWV98]	Mas	0.000255924
[GWV98]	Mas	0.000255924
[GWV98]	Mas	0.000109097
[CW97]4	PoC	0.000276539
[GWV98]	Mas	0.000236096
[GWV98]	Mas	0.000236096
[GWV98]	Mas	0.000236096
[GWV98]	Mas	0.000241737
[GWV98]	Mas	0.000244698
[GWV98]	Mas	0.000244698
[GWV98]	Mas	0.000143402
LBLSj	IR	0.000223516
[GWV98]	Mas	0.000131707
[GWV98]	Mas	0.000131707
[GWV98]	Mas	0.000136171
[GWV98]	Mas	0.000138929
[GWV98]	Mas	0.000138929
[AD95]3169	*	0.000146067
[GWV98]	Mas	0.000225461
[GWV98]	Mas	0.000225461
[GWV98]	Mas	0.000225461
[GWV98]	Mas	0.000225461
[GWV98]	Mas	0.000212639
[GWV98]	Mas	0.000213785

CX76 corresponds to these matches:

Source	Type	Error
[AD95]2526	*	0.000148418

[AD95]3117	*	0.000228128
[AD95]2524	*	0.000208011

CX77 corresponds to these matches:

Source	Type	Error
[H97b]9061	*	7.20154e-05
[HAB84]39	IR	0.000266539

CX78 corresponds to these matches:

Source	Type	Error
[AD95]3157	*	0.000209660
TCC8	*	0.000153026
TCC3	*	4.77904e-06
[H97b]9045	*	0.000215752

CX79 corresponds to these matches:

Source	Type	Error
LBLSu	IR	0.000171770
Parenago1839	*iN	8.78985e-05
[GWV98]	Mas	7.81051e-05
[CW97]2	PoC	5.99140e-05
[MR95c]L	HII	0.000233654
LBLSn	IR	0.000233654
[GWV98]	Mas	0.000108485
[MWZ90]OMC-1FIR2	IR	9.54383e-05
LBLSf	IR	0.000260776
[OW94]136-233	*	0.000258448

CX80 corresponds to these matches:

Source	Type	Error
V*V1328Ori	V*	0.000186546
[AD95]3100	*	2.81751e-05

CX81 corresponds to these matches:

Source	Type	Error
[H97b]9081	*	0.000276035
[GWV98]	Mas	0.000206735
[GWV98]	Mas	0.000191076
[GWV98]	Mas	0.000191076
[GWV98]	Mas	0.000266190
[MR95c]B	IR	0.000143388
BNKL1	MoC	0.000220892
GMRB	Rad	0.000192275
[M77]HH08	HH	0.000117111
Parenago1821	*iN	0.000109913
LBLSb	IR	0.000263705
[H97b]399a	*	0.000273773
[AD95]3522	*	0.000272009

CX82 corresponds to these matches:

Source	Type	Error
[H97b]3091	*	0.000191340
[AD95]2510	*	0.000209994

CX83 corresponds to these matches:

Source	Type	Error
LBLSp	IR	0.000205929
[JGS92]2	Mas	9.27553e-05
[H97b]9063	*	0.000131858
[GWV98]	Mas	7.98302e-05
[GWV98]	Mas	7.98302e-05
[GWV98]	Mas	7.35403e-05
[GWV98]	Mas	8.49661e-05

[GD77]A	IR	0.000130653
[BE83]	Mas	0.000164386
[GWV98]	Mas	0.000102249
[SUK94]Peak8	PoC	0.000245522
[GWV98]	Mas	0.000102249
[GWV98]	Mas	0.000102249
[GWV98]	Mas	0.000178607
[GWV98]	Mas	1.06895e-05
[GWV98]	Mas	1.06895e-05
[GWV98]	Mas	1.06895e-05
Parenago1822	*iN	0.000173544
[GWV98]	Mas	3.43763e-05
GMRR	Rad	5.02638e-05
[GWV98]	Mas	6.49171e-06
[GWV98]	Mas	3.33107e-05
[GWV98]	Mas	3.33107e-05
[GWV98]	Mas	6.09936e-05
[GWV98]	Mas	0.000116495
[GWV98]	Mas	0.000116495
[GWV98]	Mas	0.000116495
[JGS92]9B	Mas	5.83130e-05
[JGS92]9	Mas	5.83130e-05
[JGS92]9A	Mas	5.83130e-05
[GWV98]	Mas	8.25696e-05
[GWV98]	Mas	8.25696e-05
[GWV98]	Mas	9.13821e-05
[GWV98]	Mas	9.13821e-05

[HAB84]19	IR	0.000203689

CX84 corresponds to these matches:

Source	Type	Error
[H97b]9053	*	0.000216899

CX85 corresponds to these matches:

Source	Type	Error
LBLSs	IR	0.000232107
NAMEOMC1n	Cld	0.000195683
Parenago1819	*iN	3.07058e-05

CX86 corresponds to these matches:

Source	Type	Error
[AD95]3463	*	0.000259451
[AD95]2835	*	0.000206884
[HAB84]29	IR	0.000101310
[SUK94]Clump26	PoC	0.000183140
[AD95]3221	*	8.27155e-05
[AD95]2839	*	0.000260587

CX87 corresponds to these matches:

Source	Type	Error
[AD95]3100	*	0.000270745
[AD95]3539	*	0.000200039
[AD95]3296	*	0.000109981
[AD95]2582	*	0.000220056

CX88 corresponds to these matches:

Source	Type	Error
[AD95]3255	*	2.64765e-05
[AD95]2668	*	0.000162740

CX89 corresponds to these matches:

Source	Type	Error

[HAB84]26	IR	0.000258702
[AD95]3131	*	0.000269867
[AD95]3132	*	0.000183106

CX90 corresponds to these matches:

Source	Type	Error
[AD95]3141	*	0.000181332
Parenago1824	*iN	0.000263763
[AD95]3429	*	0.000236864

CX92 corresponds to these matches:

Source	Type	Error
[HAB84]26	IR	0.000207441
[AD95]3132	*	0.000108738

CX93 corresponds to these matches:

Source	Type	Error
[HAB84]10	IR	0.000135884
[AD95]3223	*	9.93083e-05

CX94 corresponds to these matches:

Source	Type	Error
HBC454	Em*	4.17368e-05
[AD95]3136	*	0.000184494

CX95 corresponds to these matches:

Source	Type	Error
GMRY	*	3.86699e-05
[FTC93]	Rad	4.47127e-05
[HAB84]5	IR	9.42321e-05

CX97 corresponds to these matches:

Source	Type	Error
Parenago1825	*iN	0.000201896
[AD95]3133	*	0.000184020

[H97b]378a	*	2.14704e-05
[H97b]378b	*	2.14704e-05

CX98 corresponds to these matches:

Source	Type	Error
[AD95]3093	*	6.54639e-05
[AD95]2529	*	0.000272906

CX99 corresponds to these matches:

Source	Type	Error
[AD95]2814	*	0.000139723
GMRA	Rad	4.51445e-05
[AD95]3108	*	9.42315e-05
[M77]HH01	HH	0.000218286

CX100 corresponds to these matches:

Source	Type	Error
[H97b]9008	*	1.14849e-05
[AD95]3278	*	5.12503e-05

CX101 corresponds to these matches:

Source	Type	Error
[AD95]3107	*	6.81183e-05

CX102 corresponds to these matches:

Source	Type	Error
Parenago1784	*iN	9.42192e-05
[AD95]3134	*	3.41005e-05

CX103 corresponds to these matches:

Source	Type	Error
[AD95]3162	*	0.000132507

CX104 corresponds to these matches:

Source	Type	Error
[SUK94]Clump10	PoC	0.000269026

[AD95]3248	*	0.000272554
[AD95]3181	*	0.000217023

CX105 corresponds to these matches:

Source	Type	Error
Parenago1783	*iN	0.000248533
[AD95]3166	*	0.000247896

CX106 corresponds to these matches:

Source	Type	Error
[AD95]2767	*	0.000228587

CX107 corresponds to these matches:

Source	Type	Error
[AD95]3148	*	7.82416e-06

CX108 corresponds to these matches:

Source	Type	Error
Parenago1771	*iN	9.76682e-05

CX109 corresponds to these matches:

Source	Type	Error
[AD95]2845	*	0.000222633
[AD95]3251	*	0.000254428
[AD95]3224	*	6.48204e-05

CX110 corresponds to these matches:

Source	Type	Error
[H97b]9001	*	0.000194481
[AD95]3127	*	8.36907e-05

CX111 corresponds to these matches:

Source	Type	Error
[AD95]3250	*	0.000158736

CX113 corresponds to these matches:

Source	Type	Error

[AD95]885	*	5.15882e-05
Parenago1754	*iN	0.000170418

CX116 corresponds to these matches:

Source	Type	Error
[AD95]1030	*	0.000173761
[H97b]276	*	0.000205193

CX117 corresponds to these matches:

Source	Type	Error
[AD95]2326	*	0.000149403

CX120 corresponds to these matches:

Source	Type	Error
[AD95]3327	*	0.000120373

CX121 corresponds to these matches:

Source	Type	Error
[AD95]2667	*	0.000237564

CX122 corresponds to these matches:

Source	Type	Error
[H97b]776a	*	0.000109333
[H97b]776b	*	0.000108579

CX124 corresponds to these matches:

Source	Type	Error
[AD95]3210	*	6.13690e-05
[AD95]2664	*	8.92467e-05

CX125 corresponds to these matches:

Source	Type	Error
[AD95]2729	*	0.000240327
[AD95]3211	*	1.75172e-05

CX126 corresponds to these matches:

Source	Type	Error

[AD95]2754	*	0.000125360
[AD95]3212	*	1.35417e-05

CX127 corresponds to these matches:

Source	Type	Error
[AD95]3213	*	0.000117131

CX128 corresponds to these matches:

Source	Type	Error
[AD95]3316	*	0.000172455

CX129 corresponds to these matches:

Source	Type	Error
[AD95]2794	*	0.000195242
[AD95]3340	*	0.000132507
[AD95]2798	*	0.000241559

CX130 corresponds to these matches:

Source	Type	Error
[M77]HH03	HH	0.000201874
CCDMJ05353-0524EF	**	1.17060e-05
*43Ori	SB*	1.97610e-05
[AD95]3315	*	0.000117131
[AD95]2549	*	0.000260602
[AD95]3316	*	0.000223221

CX131 corresponds to these matches:

Source	Type	Error
[AD95]3336	*	0.000155849

CX132 corresponds to these matches:

Source	Type	Error
[H97b]662	*	0.000250234

CX134 corresponds to these matches:

Source	Type	Error

V*V1324Ori	V*	8.46914e-05
[AD95]877	*	5.90062e-05
[H97b]275a	*	8.56124e-05

CX135 corresponds to these matches:

Source	Type	Error
V*LLOri	Or*	0.000269776

CX136 corresponds to these matches:

Source	Type	Error
[AD95]1052	*	3.55587e-05

CX138 corresponds to these matches:

Source	Type	Error
[AD95]2321	*	0.000267745

CX139 corresponds to these matches:

Source	Type	Error
[AD95]1025	*	0.000165006
[AD95]889	*	3.07941e-05
[AD95]2320	*	0.000177274

CX140 corresponds to these matches:

Source	Type	Error
[AD95]2318	*	0.000264145

CX141 corresponds to these matches:

Source	Type	Error
[AD95]2327	*	0.000124987

CX142 corresponds to these matches:

Source	Type	Error
[AD95]1126	*	0.000121069

CX143 corresponds to these matches:

Source	Type	Error
[AD95]1125	*	0.000232342

CX144 corresponds to these matches:

Source	Type	Error
[AD95]2336	*	0.000191953

CX145 corresponds to these matches:

Source	Type	Error
[H97b]3061	*	4.97291e-05
[AD95]2337	*	0.000133512

CX146 corresponds to these matches:

Source	Type	Error
[AD95]2283	*	0.000151460

CX147 corresponds to these matches:

Source	Type	Error
[AD95]2282	*	0.000153846

CX148 corresponds to these matches:

Source	Type	Error
[AD95]2323	*	0.000117339

CX149 corresponds to these matches:

Source	Type	Error
[AD95]2959	*	4.83579e-05

CX150 corresponds to these matches:

Source	Type	Error
[AD95]2338	*	2.97992e-05

Sources which seem to have no close matches:

- CX11
- CX57
- CX69
- CX91
- CX96
- CX112
- CX114
- CX115
- CX118
- CX119
- CX123

- CX133
- CX137

Source names correspond to figures 7 and 8

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