Star Formation and U/HLX's in the Cartwheel Galaxy – a js9 activity

Purpose: To examine the Cartwheel Galaxy in both optical and x-ray bands and determine the sources of the ultra- and hyperluminous x-ray sources.

Background:

(excerpted from the Hubble News Release, January 10, 1995):

Credit: Kirk Borne (STScI), and NASA

"A rare and spectacular head-on collision between two galaxies appears in this NASA Hubble Space Telescope true-color image of the Cartwheel Galaxy, located in the constellation Sculptor. The new details of star birth resolved by Hubble provide an opportunity to study how extremely massive stars are born in large fragmented gas clouds.

The striking ring-like feature is a direct result of a smaller intruder galaxy — possibly one of two objects to the right of the ring — that careened through the core of the host galaxy. Like a rock tossed into a lake, the collision sent a ripple of energy into space, plowing gas and dust in front of it. Expanding at 200,000 miles per hour, this cosmic tsunami leaves in its wake a firestorm of new star creation. Hubble resolves bright blue knots that are gigantic clusters of newborn stars and immense loops and bubbles blown into space by exploding stars (supernovae) going off like a string of firecrackers.

The Cartwheel Galaxy presumably was a normal spiral galaxy like our Milky Way before the collision. This spiral structure is beginning to re-emerge, as seen in the faint arms or spokes between the outer ring and bulls-eye shaped nucleus. The ring contains at least several billion new stars that would not normally have been created in such a short time span."

(excerpted from the Chandra Press Release, January 11, 2006):

"When the most massive of these stars explode as supernovas, they leave behind neutron stars and black holes. Some of these neutron stars and black holes have nearby companion stars, and have become powerful sources of X-rays as they pull matter off their companions."

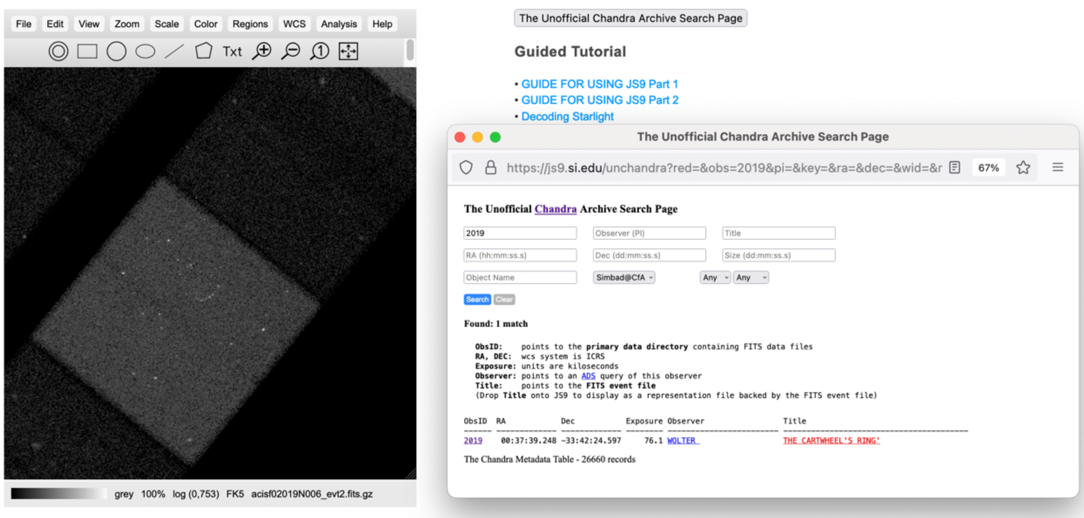
Procedure:

Acquiring the x-ray image:

1. Go to https://chandra.si.edu/js9/ and **“File>close>this image”**

2. Click ”The Unofficial Chandra Archive Search Page” button and type “2019” in the ObsID box and click “Search.”

3. Drag the link “THE CARTWHEEL’S RING” to the js9 window. It may take a few minutes to appear. The image should now be in the js9 viewer. Go to **Zoom>Zoom 4**.



Acquiring the optical image:

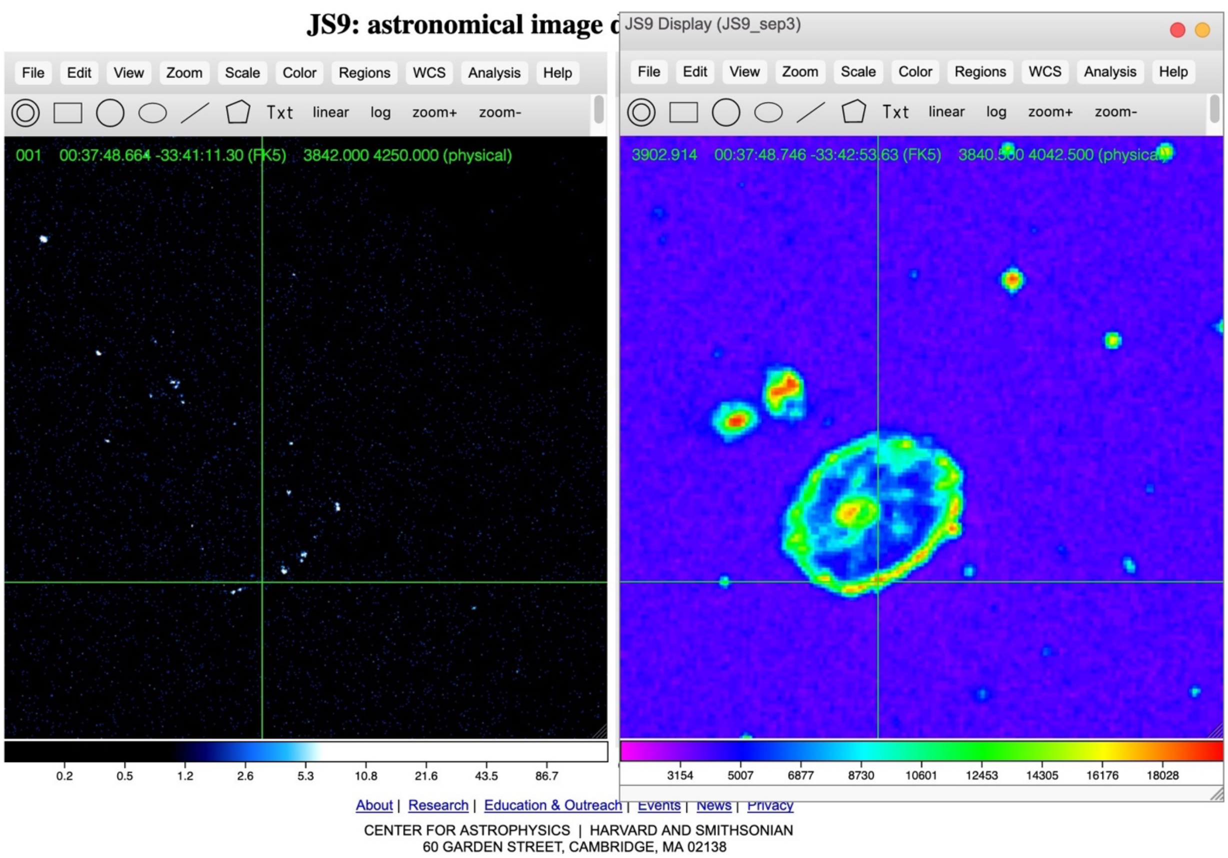
4. Go to **View>Archives & Catalogs**. In the pop-up box, select "Image Servers" and "DSS1@SAO". Then, click on "Set RA/Dec" and "get data."
5. The new image will be layered over the old one. Go to **Zoom>Zoom 4** and then **File>separate>separate these images** so that they appear side by side, with the new image on the right.
6. Rescale the optical image on the right so that it is the same size as the x-ray image by going to **WCS>wcs reproject> acisf02019N005_evt2.fit**s.

Define the point sources on the x-ray image:

7. In the x-ray image box, go to **Scale>log** and **Color>cool**. Play around with other combinations of scale and color if you wish. You can also try changing the contrast and bias by holding the left mouse button down and go back and forth and up and down along the image. Contrast and bias can also be changed by going to **Color** and typing in numbers. Try 4.0 for contrast and 0.4 for bias. In this menu, you can also **reset contrast/bias**.

Explore where these x-rays sources are located in the optical image:

8. Go to **View>show>crosshair for this image**. Hold down the shift key and move the mouse to make the crosshairs appear. DO NOT click with the mouse or you will change the contrast and bias. Repeat this process for the other image. You now will have both images with crosshairs displayed.
9. Go to **View>show>match wcs crosshairs** to synchronize the two crosshairs. If you hit the shift key and move the mouse (without clicking), the crosshairs will move together over the images.
10. You may wish to choose a scale and colormap on the optical image to better see the features. Try **Scale>linear** and **Color>more colormaps>rainbow**.



Determining the size of the ring:

11. On the optical image, go to **Regions>Circle**. Click on the circle that appears. You can move the center of the circle over the cartwheel galaxy by left clicking in the center and moving it with your mouse. Resize this circle by left clicking on one of the squares in the corner and dragging your mouse. The circular region should be just big enough to enclose the whole ring.

12. Go to **Regions>List**. The radius of the region (and of the Cartwheel Galaxy) in arc seconds is the last number in parentheses. Record below.

    radius = ______________________ "   diameter = ______________________ "

13. 1 radian = 206,265 arc sec. Convert your answers from #14 to radians.

    diameter = __________________ radians

14. Use the small angle formula below to determine the size of the ring in light years. The distance to the Cartwheel Galaxy is ~380 million light years.

    angular diameter in radians = (actual diameter of object) / (distance to object)

    How does the size of the ring compare to that of the Milky Way (~100,000 light years across)?

Conclusions and Analysis:

1. How do the locations of the majority of x-ray sources compare to the areas of new star formation in the optical image? Explain your answer using information from the background information on the first page and your js9 investigations.

2. Using background information and your answer to #16, determine how long ago the collision of galaxies may have occurred. (1 lightyear = 5.88×10^{12} miles)

From NASA's "Imagine the Universe!":

An AGN is short for "Active Galactic Nucleus." Some galaxies have nuclei (centers) that are 'active', meaning they emit large amounts of radiation (radio, optical, X-rays, gamma-rays, particle jets, etc.), and/or are highly variable. (For example, a galactic nucleus starting at 30 billion times as bright as the Sun, then growing to 45 billion times as bright as the Sun in just half an hour).

Since they vary so rapidly, the important region must be small, no larger than the inner solar system (since the time over which something can vary is limited to the time it takes light to get from one side to the other). Since they are so bright, that small region must have unbelievable energies in it.

Gigantic black holes, billions of times as massive as the Sun, swallowing stars and gas clouds, are the only reasonable theories that seem to fit the data at this time.

3. From your comparison of the x-ray and optical images of the Cartwheel Galaxy, does it seem to have an AGN? Explain.

From "Nick Strobel's Astronomy Notes" at http://www.astronomynotes.com:

Some representative lifetimes for other stars are given in the table below. Stars that have fewer elements heavier than helium in them compared to other stars, will have slightly shorter lifetimes than those given in the table.

Star Mass (solar masses)	***Time (years)***	***Spectral Type***	***Color***
60	*3 million*	*O3*	*bluest*
30	*11 million*	*O7*	*bluest*
10	*32 million*	*B4*	*bluish*
3	*370 million*	*A5*	*blue-white*
1.5	*3 billion*	*F5*	*white*
1	*10 billion*	*G2 (Sun)*	*yellow*
0.1	*1000's billion*	*M7*	*red*

4. What types of objects might each of the x-ray sources be? Explain your reasoning using background information, the chart above, and your analysis. Please note that you may have a different answer depending upon the location of the x-ray source (i.e. along the ring, within the ring, outside the ring).

5. Compare your findings to those of the scientists in the paper, *Nonnuclear Hyper/Ultraluminous X-Ray Sources in the Starbursting Cartwheel Ring Galaxy*, Yu Gao,[1] Q. Daniel Wang,[1] P. N. Appleton,[2] and Ray A. Lucas[3], **The Astrophysical Journal Letters**, 596:L171–L174, 2003 October 20.

   https://arxiv.org/pdf/astro-ph/0309253.pdf

   Does this paper suggest other investigations you might do with js9? If so, what?

Below are suggestions for further investigations in ds9 of colliding or starburst galaxies:

The Antennae: Chandra Locates Mother Lode of Planetary Ore in Colliding Galaxies
http://chandra.harvard.edu/photo/2004/antennae/

M82: Images From Space Telescopes Produce Stunning View of Starburst Galaxy
http://chandra.harvard.edu/photo/2006/m82/index.html

To load the images into js9, use the steps #1-3 in the procedure as a guide. You can get the ObsID numbers from the Fast Facts sections in the links above.

Answers:

Determining the size of the ring:

12. The radius of the ring is ~42" and the diameter is ~84"
13. 84")/ 206,625"/rad) = 0.00041 rad
14. (0.00041 rad)(380 ly) = 160,000 ly

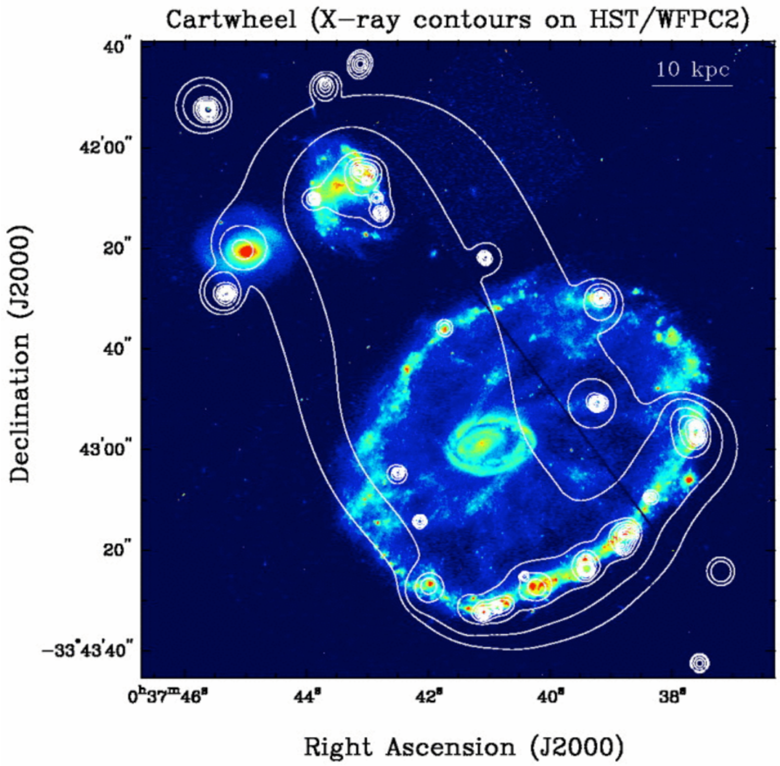
Conclusions and Analysis:

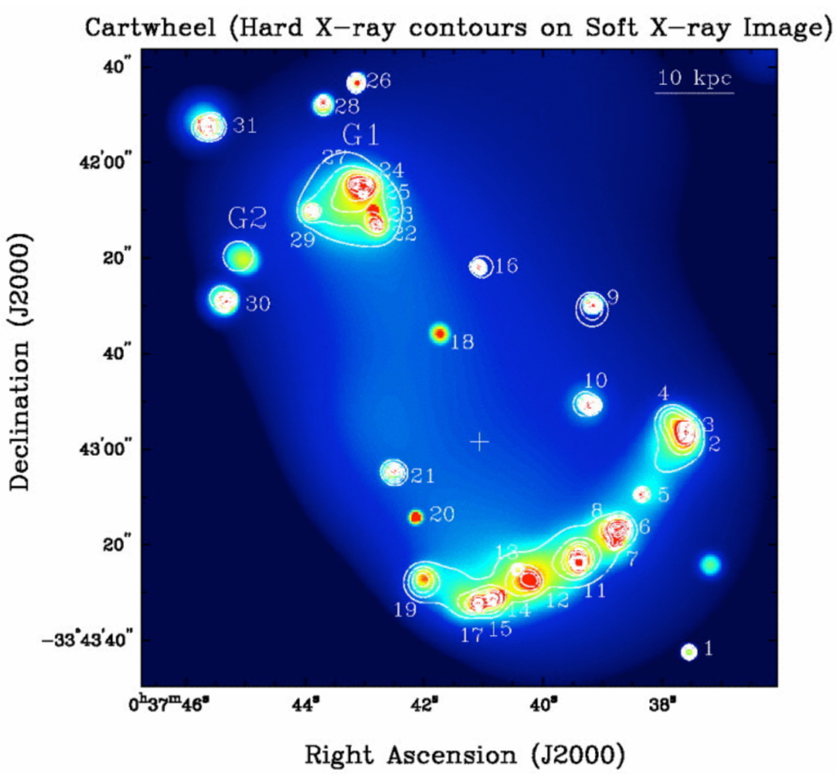
1. Most of the x-ray sources are along the lower part of the ring where Hubble observed bright blue knots that are gigantic clusters of newborn stars.
2. Using the expansion rate given in the background material and the distance over which the ring has moved from the center which is half your answer to #16:

$$v=[(200{,}000 \text{ mi/h}) \text{ X } (24 \text{ h/day}) \text{ X } (365.25 \text{ days/y})] / (5.88 \text{ X } 10^{12} \text{ mi/ly}) = 0.0003 \text{ ly/y}$$

$$v = d/t \text{ so } t = d/v = (80{,}000 \text{ ly}) / (0.0003 \text{ ly/y}) \sim 270 \text{ million years}$$

3. No, there is no x-ray source corresponding to the galactic nucleus as seen in the optical image.
4. answers may vary, but x-ray sources along the ring could be supernova remnants, neutron stars or black holes because the lifetime of a massive star is less than 300 MY which is about when the galaxy collision occurred and new star formation was triggered.
5. From *Nonnuclear Hyper/Ultraluminous X-Ray Sources …*
   A. "It has been argued on observational and theoretical grounds (Appleton & Struck-Marcell 1996; Bransford et al. 1998) that the triggering of newly formed stars in ring galaxies occurs approximately simultaneously as the wave propagates out through the disk—the outer ring representing the most recently formed stars, with representative ages < 10^7 yrs. In this picture, the ring represents the outermost progress of a wave that began at the disk-center some 300 Myrs previously, created by the central perturbation of the intruder, either G3 or G1."
   B. "Almost all the Xray emission in the Cartwheel originates from point-like sources within the southern quadrant of the outer ring. The sources are nearly coincident with the strong Hα, radio continuum emission and blue super-star clusters (SSCs)."
   C. "The companion galaxy G1 (spiral) contains 6 point-like X-ray sources, and the early-type spiral G2 is seen as a fainter diffuse source (Fig 1). The farthest companion galaxy G3 is also significantly detected, with one ULX in the eastern edge of its disk. In addition, a faint, diffuse X-ray envelope which includes the Cartwheel, G1 and G2 is marginally detected."
   D. "The absence of any point-like X-ray source in the nuclear region of the Cartwheel rules out the existence of AGN."
   E. "A point-like source 31, 10 kpc north of G2, is likely a background galaxy or AGN as it has a faint optical counterpart in the HST image."
   F. "The two most likely sources of X-ray emission associated with massive young star-forming regions are probably supernovae (SNe) or extremely young SN remnants (SNRs) and the high-mass X-ray binaries (HMXBs). We can almost rule-out low-mass X-ray binaries (LMXBs) to be the significant sources for H/ULXs along the Cartwheel narrow ring, although intermediate mass black holes (IMBHs, see review by Miller & Colbert 2003) are likely viable. It is conceivable that LMXBs and/or background sources could be responsible for the three ULXs interior to the ring. Three "ULXs" outside the Cartwheel with faint optical counterparts are likely background galaxies. "


Cartwheel (X−ray contours on HST/WFPC2)
10 kpc
Declination (J2000)
Right Ascension (J2000)
40"
42'00"
20"
40"
43'00"
20"
−33°43'40"
0h37m46s
44s
42s
40s
38s


Cartwheel (Hard X−ray contours on Soft X−ray Image)
10 kpc
G1
G2
Declination (J2000)
Right Ascension (J2000)
40"
42'00"
20"
40"
43'00"
20"
−33°43'40"
0h37m46s
44s
42s
40s
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