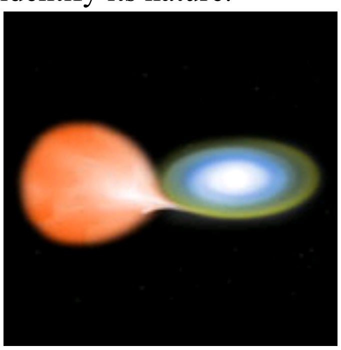
Analysis of Two Pulsating X-ray Sources - a js9 activity

Purpose:

To determine if GK Per and Cen X-3 could be white dwarfs or neutron stars by finding the periods of the X-ray emission pulses using data sets from the Chandra X-ray Observatory.

Background:

js9 can produce a light curve for data gathered by the Chandra X-ray Observatory. A **light curve** is a graph of the brightness of an object versus time. For stellar objects which change brightness over time, such as supernovae, novae and variable stars, a light curve can help astronomers classify the object and identify its nature.



Accreting White Dwarf
Credit: CXC/M.Weiss

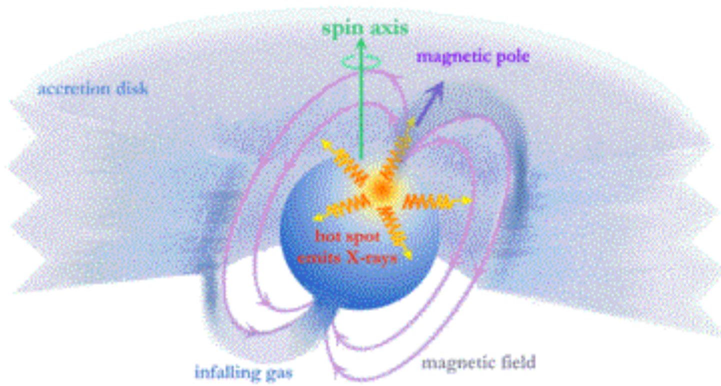


illustration of an accretion powered pulsar

The regularity in the changes in brightness for GK Per and Cen X-3 lead us to believe that there is some periodic mechanism causing this. In the case of rotating variable stars, the brightness in X-rays could change as a “hot spot” rotates in and out of our view. In the case of a white dwarf, such a “hot spot” might occur if a white dwarf with a magnetic field accretes matter from a companion star. The accretion disk is disrupted at small radii by the white dwarf’s magnetosphere. Material leaves the disk and travels along magnetic field lines. At some distance to the surface, a strong shock occurs where freefall kinetic energy is converted to thermal energy. Below this, material settles onto the white dwarf near the magnetic poles. As this material cools, it releases x-rays. If the magnetic axis is offset from the spin axis, the X-ray emission will pulse with the spin period of the white dwarf.

A sun-like star eventually becomes a white dwarf when the core, left behind after a red giant puffs off its outer layers, collapses. An object the size of an olive made of white dwarf material would have the same mass as an automobile!

The central part of a more massive star will collapse even further to form a [neutron star](). Electrons are pushed into protons to form neutrons and the result is a tiny star with very little empty space. A neutron star would have the same density as 10 million full-sized African elephants crammed into the space of a thimble.

A neutron star in a binary system can become an [accretion powered pulsar](), producing a pulsing X-ray emission in much the same way as described above for the white dwarf. A neutron star, however, can spin faster (have a shorter period) because its higher mass and smaller size generates a stronger gravitational field that can prevent a fast spinning pulsar from breaking apart.

Procedure:

1. Go to https://nso.js9.org and **File>close>all images**.
2. Click **The Unofficial Chandra Archive Search Page** button. Enter **3454** where it says "Chandra Obs ID"and click **Search**. Drag the link under to the js9 window.
3. To better see the image, you may wish to use **Scale>Log** and choose a new color map under **Color**.
4. Go to **Analysis>NSO Analysis-Light Curve**. (Be careful! There are two different light curve programs!)
5. On the light curve generated, zoom in on an area on the graph by left clicking and dragging a box of width ~5000 seconds around a region of the graph until you can determine if there appears to be a periodic x-ray pulse.
6. Go to **Analysis>NSO Analysis-Power Spectrum**. This command does a fast Fourier Transform on the data to search for periodicities. If the data isn't periodic, you will not see one large peak as you will for GK Per. Zoom in on the peak by left clicking and dragging a box around a region of the graph until you can determine its frequency. Convert the frequency to period (period = 1/frequency).
7. Go to **Analysis>NSO Analysis> Period Folding**. This will help you to check the accuracy of the period you found in step 4. Enter the value for this period in the window that comes up and click Run. To understand what this command is doing, picture a drawing of a sine wave on a long piece of paper. Cut this paper into sections, each one period long, and put each cycle on top of the first one, adding all the sine waves together. If your cuts are not exactly every period, when you add the sine waves, parts of the waves would cancel out and your composite wave would have a smaller amplitude. How does your Period Fold graph look? Try it again with a period several seconds different than the one you used before. Which graph is more sine-like and has the highest amplitude? If you need to, try Period Fold again with different periods until you produce the best graph. Record this period. This is equal to GK Per's spin period as discussed in the background information.
8. Go to **File>close>all images** and repeat steps #1-7, this time for Cen-X3 with **ObsID 1943**.

Calculations and Interpretations:

The acceleration due to gravity (**g**) on the surface of a star (according to Newton's Universal Law of Gravitation) is given by

$\mathbf{g = (GM)/R^2}$ where $G = 6.67 \times 10^{-11}$ Nm^2/kg^2, M=star's mass and R = star's radius

Centripetal acceleration ($\mathbf{a_c}$) of an object on the surface of a star at its equator is given by

$a_c = V^2/R$ and since $V = 2\pi R/T$ for an object moving in a circle

$\mathbf{a_c = 4\pi^2 R/T^2}$, where R = star's radius and T = star's spin period

If the centripetal acceleration on material on the star's surface for a given rotational period is less than the acceleration due to gravity, the gravitational force would be enough to hold the material on the surface and the star could sustain such a period without disruption.

1. Find the acceleration due to gravity on the surface of a white dwarf. Let the mass of a white dwarf be approximately one solar mass or 2.0×10^{30} kg and its radius, approximately that of Earth or 6.4×10^6 m.

2. Find the acceleration due to gravity on the surface of a neutron star. Let the mass of a neutron star be two solar masses or 4×10^{30} kg and its radius be 10.0 km.

3. Assume GK Per is a white dwarf. Calculate the centripetal acceleration of material on the surface of GK Per (using the period you found from the power spectrum). According to your calculations, can GK Per be a white dwarf*? Why or why not?

4. If your answer above is "no", repeat #3 assuming GK Per is a neutron star.

5. Repeat #3 and #4 for Cen X-3. Is it more likely that Cen X-3 is a white dwarf or a neutron star? Why?

   *Note: If it is possible that a star is a white dwarf according to the types of calculations you did in this activity, other analysis would be necessary to determine if an object is actually white dwarf, such as examination of its temperature and luminosity

Resources (Podcasts – good for introducing the activity)

Supernovas: When Stars Die (contains description of a white dwarf)
http://chandra.harvard.edu/resources/podcasts/media/pod301006.m4v
The Exotic World of Neutron Stars
http://chandra.harvard.edu/resources/podcasts/media/pod300407.m4v

References:

Chandra Education Data Analysis Software And Activities
http://xray1.physics.rutgers.edu/index.html
Chandra Field Guide
http://chandra.harvard.edu/field_guide.html
Variable Star Of The Month Nov. '00: GK Persei (Nova Persei 1901)
http://www.aavso.org/vstar/vsots/1100.shtml
The Encyclopedia of Astrobiology, Astronomy, and Spaceflight - Cen X-3
http://www.daviddarling.info/encyclopedia/C/Centaurus_X-3.html
ASTRONOMY AND ASTROPHYSICS YY Draconis and V709 Cassiopeiae
http://physics.open.ac.uk/~ajnorton/papers/yydra_v709cas.pdf

ANSWERS:

GK Per

power spectrum (period confirmed with "period fold")
frequency = 0.00285 hz
period = 351 s

if white dwarf:

$g = (6.67 \times 10^{-11}\ Nm^2/kg^2)(2.0 \times 10^{30}\ kg)/(6.4 \times 10^6\ m)^2 = 3.2 \times 10^6\ m/s^2$

$a_c = (4\pi^2)(6.4 \times 10^6\ m)/(351\ s)^2 = 2.1 \times 10^3\ m/s^2$

$a_c < g$ so GK Per could sustain this period if it were a white dwarf.

Cen X-3

power spectrum (period confirmed with "period fold")
frequency = 0.208 hz
period = 4.81 s

if white dwarf:

g = same as above for GK Per ($3.2 \times 10^6\ m/s^2$)

$a_c = (4\pi^2)(6.4 \times 10^6\ m)/(4.8\ s)^2 = 1.7 \times 10^7\ m/s^2$

$a_c > g$ so Cen X-3 could not sustain this period if it were a white dwarf.

if neutron star:

$g = (6.67 \times 10^{-11}\ Nm^2/kg^2)(4.0 \times 10^{30}\ kg)/(10000\ m)^2 = 2.7 \times 10^{12}\ m/s^2$

$a_c = (4\pi^2)(10000\ m)/(4.81\ s)^2 = 1.7 \times 10^4\ m/s^2$

$a_c < g$ so Cen X-3 could sustain this period if it were a neutron star.