X-ray Binaries

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Close Binary Stars
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Overview

Introduction

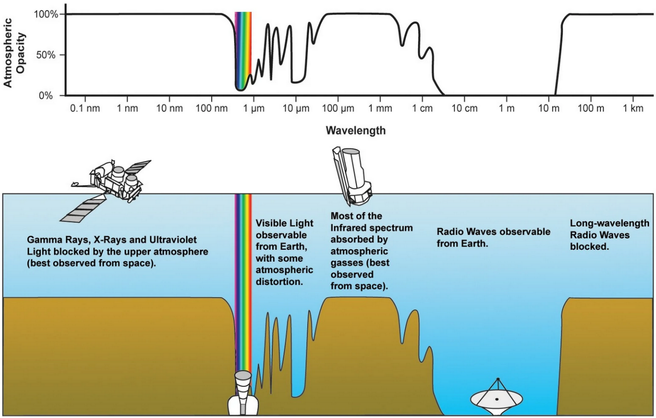

Figure 1: Electromagnetic transmittance of Earth's atmosphere. NASA (original); SVG by Mysid.

History

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- 1894, Nikola Tesla noticed damaged film in his lab associated with Crookes tube experiments and began investigating this invisible, radiant energy.
- 1895, German physics professor Wilhelm Röntgen stumbled on X-rays while experimenting with Lenard tubes and Crookes tubes.
- 1904, John Ambrose Fleming invented the thermionic diode, the first kind of vacuum tube.

Figure 2: print of Wilhelm Röntgen's first "medical" X-ray, of his wife's hand, taken on 22 December 1895 and presented to Ludwig Zehnder of the Physik Institut, University of Freiburg, on 1 January 1896

Applications

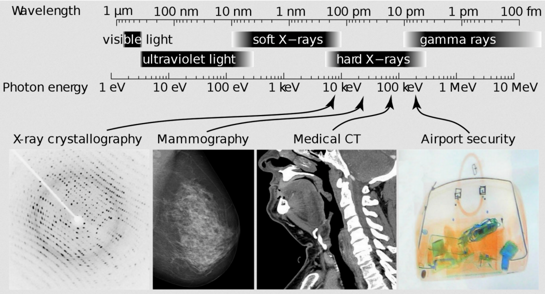

Figure 3: The wavelengths and photon energies of X-rays and a few applications of X-rays.

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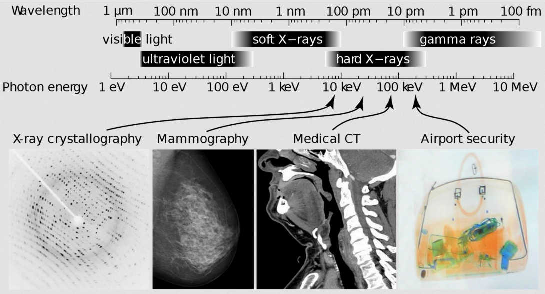

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The Chandra X-ray Observatory, launched on July 23, 1999, has been allowing the exploration of the very violent processes in the universe which produce X-ray

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- High Mass X-ray Binaries (HMXBs):
  Fed directly from the winds of a $\gtrsim 10M_\odot$ companion.

X-ray Binaries

Distinct Galactic distributions associated with Population I and Population II objects:

- HMXBs → lying alog Galactic plane
- LMXBs → clustering towards the Galactic bulge and in globular clusters.

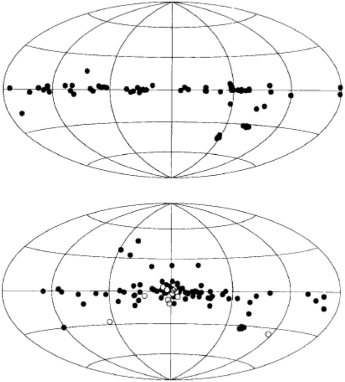

Figure 4: Galactic Distribution of HMXBs (top) and LMXBs(bottom). X-ray Binaries J.Casares 2017

X-ray activity

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The interplay between these three quantities explains:

- Black Hole remnants $\rightarrow$ transient LMXBs
- Neutron stars $\rightarrow$ persistent LMXBs
- Pulsars $\rightarrow$ HMXBs

Xray Binaries: Remnant Masses

By building the mass spectrum of compact objects in X-ray binaries we can therefore obtain new insights onto the physics of core-collapse in Type Ibc and Type II supernovae

Pulsar masses in HMXBs

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$$sin(i) = \frac{\sqrt{1 - (R_{opt}/a)}^2}{cos(\theta)} \quad (1)$$

• θ: eclipse half-angle, a: Binary separation and R_{opt} the stellar radius.
• R_{opt} approximated by "filling factor" $\beta \leq 1$ of the effective Roche Lobe radius R_{Lopt}.
• R_{Lopt}/a is purely a function of the binary mass ratio $Q = M_X/M_{opt} = K_{opt}/K_X$

Pulsar masses in HMXBs

Then, the stellar masses can be solved from the mass function equations:

$$M_{opt} = \frac{K_X^3 P(1-e^2)^{3/2}}{2\pi G sin^3(i)}(1+Q)^2 \tag{2}$$

$$M_X = \frac{K_{opt}^3 P(1-e^2)^{3/2}}{2\pi G sin^3(i)}(1+\frac{1}{Q})^2 \tag{3}$$

P is the binary period and e the orbital eccentricity.

This method has produced nine pulsar masses with relatively high precision listed in Figure 5

Pulsar masses in HMXBs

Object	X-ray Binary Class	Remnant	Mass ($M_\odot$)
OAO 1657-415	HMXB/persistent	X-ray pulsar	1.42±0.26
SAX 18027-2016	,,	,,	1.2-1.9
EXO 1722-363	,,	,,	1.55±0.45
4U 1538-52	,,	,,	1.00±0.10
SMC X-1	,,	,,	1.04±0.09
Vel X-1	,,	,,	1.77±0.08
LMC X-4	,,	,,	1.29±0.05
Cen X-3	,,	,,	1.49±0.08
4U 1700-37	,,	?	2.44±0.27
Her X-1	IMXB/persistent	X-ray pulsar	1.07±0.36
Cyg X-2	LMXB/persistent	NS	1.71±0.21
V395 Car	,,	,,	1.44±0.10
Sco X-1	,,	,,	<1.73
XTE J2123-058	LMXB/transient	,,	$1.46^{+0.30}_{-0.39}$
Cen X-4	,,	,,	$1.94^{+0.37}_{-0.85}$
4U 1822-371	,,	X-ray pulsar	1.52-1.85
XTE J1814-338	,,	msec ,,	$2.0^{+0.7}_{-0.5}$
SAX J1808.4-3658	,,	,, ,,	<1.4
HETE 1900.1-2455	,,	,, ,,	<2.4

Figure 5: Pulsar and Neutron Star masses in X-ray Binaries. X-ray Binaries J.Casares 2017

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Broadening of the donor absorption lines depends on binary mass ratio $q = Q^{-1}$:

$$Vsin(i)/K_{opt} \simeq 0.462q^{1/3}(1+q)^{2/3} \tag{4}$$

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Therefore, the detection of the faint donor star in LMXBs ensures full dynamical solution which makes this technique feasible for transient LMXBs in quiescence or persistent LMXBs with long orbital periods and thus luminous companion stars.

Neutron star masses in HMXBs

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Figure 6: Pulsar and Neutron Star masses in X-ray Binaries.X-ray Binaries J.Casares 2017

Black hole masses

Great majority found in transient LMXBs/IMXBs.

Relatively precise masses have been measured in quiescence through exploiting the photometric and spectroscopic detection of the companion star.

Black hole masses in HMXBs

Object	X-ray Binary Class	Mass ($M_\odot$)
GRS 1915+105	LMXB/transient	$12.4^{+2.0}_{-1.8}$
V404 Cyg	,,	$9.0^{+0.2}_{-0.6}$
BW Cir	,,	>7.0
GX 339-4	,,	>6.0
XTE J1550-564	,,	7.8−15.6
H1705-250	,,	4.9−7.9
GS 1124-684	,,	$11.0^{+2.1}_{-1.4}$
GS 2000+250	,,	5.5−8.8
A0620-00	,,	6.6±0.3
XTE J1650-500	,,	4.0−7.3
GRS 1009-45	,,	>3.6
XTE J1859+226	,,	> 5.42
GRO J0422+32	,,	>1.6
XTE J1118+480	,,	6.9−8.2
XTE J1819.3-2525	IMXB/transient	6.4±0.6
GRO J1655-40	,,	5.4±0.3
4U 1543-475	,,	2.7−7.5
Cyg X-1	HMXB/persistent	14.8±1.0
LMC X-1	,,	10.9±1.4
LMC X-3	,,	7.0±0.6
M33 X-7	,,	15.7±1.5
MWC 656	HMXB/transient (?)	3.8−5.6

Figure 7: Black hole masses in X-ray Binaries.X-ray Binaries J.Casares 2017

Mass Spectrum. Implications for Supernovae Models

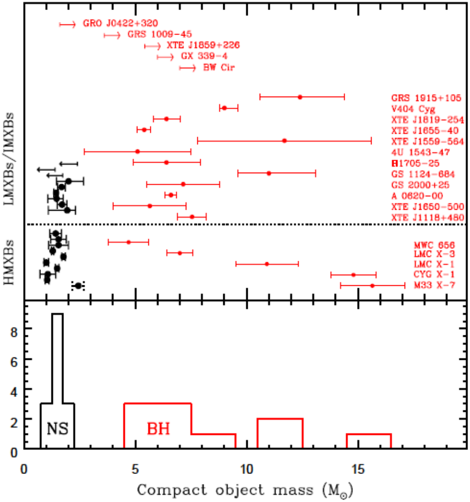

Figure 8: Top: Compact remnant masses measured in X-ray Binaries. Bottom: Observed distributions.X-ray Binaries J.Casares 2017

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- Neutron star masses tend to be larger in LMXBS/IMXBs than in HMXBs

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- Neutron star masses tend to be larger in LMXBS/IMXBs than in HMXBs
- Gap appears between $\sim 2 - 5 M_{\odot}$
- Most massive black holes found in HMXBs

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2. The lack of compact remnants in the gap contrasts with numerical simulations of Supernovae explosions that lead to continuous distributions. Proposed that convection instabilities, growing within 200 ms after core bounce, can sucessfully revive supernovae shock and trigger the explosion, causing the gap.
3. Reflects different binary evolutionary paths, with black holes in LMXBs being limited to $\lesssim 12 M_{\odot}$ by severe mass loss from the Wolf-Rayet progenitor after common envelope phase.

Mass Spectrum. Implications for Supernovae Models

Note: Some aspects of binary and massive stellar evolution (e.g radial expansion, wind mass-loss rates, efficiency of common envelope ejection) are still quite uncertain , which limits our understanding of the formation of X-ray Binaries.

References

X-ray Binaries
J. Casares. PG. Jonker
Astro-ph.HE. 25 Jan 2017

Thanks for your attention