Real time evolution of large-scale relativistic jets

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~1'
Very close to GRS 1758-258 is another prototypical microquasar
Let’s state the problem!

• Modeling an ubiquitous process such as jets is a very interesting task in Astrophysics.

• But it needs observation to validate models
• Ejection of jets have been observed close to the central source from nearby Herbig-Haro objects to distant radio galaxies.

• That’s nice, because all the stuff happen “very fast”…

• But…
What’s happening at larger scales?

• I mean really far away from the compact central source, just when the jet interacts with surrounding medium… What’s happening just there?

• And, how does the terminal hotspots structures change, in the case they exist?

• This is a big deal still not completely solved…

• …just because we cannot test the theory, considering that it is not easy to observe the jet evolution at large scales.

• For instance, AGN jets are so huge and are so far that we cannot see them to evolve unless we wait for thousands of years! Even though jets are fully relativistic!

• It’s like what we observe in extragalactic jets were still photograms in a extremely slow-motion movie
• On the other hand, Herbig-Haro and young stellar objects are much more closer, and their jets are much shorter, but they are also much slower...

• ...so, to see a noticeable evolution of jets at large scale we must wait again for hundreds or even thousands of years...

• ...too much for me! However, we have nearby objects emitting relativistic jets, so that we could observe their structural variations at large scales on even “real time”!

• I’m talking about microquasars! There, timescales are proportional to the central compact object mass. Thus, we expect to see the jets evolution on human timescales!
So, let's return to GRS 1758-258.

As we can see, it is a powerful X-ray source. Its spectrum resembles that of the Cygnus X-1 black hole.
So, let's return to GRS 1758-258. As we can see, it is a powerful X-ray source. Actually, it is identified as a low-mass X-ray binary, resembling the Cygnus X-1 black hole.
So, let's return to GRS 1758-258

Actually, it is identified as a low-mass X-ray binary. But, even though stated as a paradigmatic microquasar, nobody has demonstrated its Galactic nature up to now...
That's because it has no obvious counterpart. Only recently our team has proposed a solid infrared one. But, even though stated as a paradigmatic microquasar, nobody has demonstrated its Galactic nature up to now…

**Figure 1.** Representative view of the GRS 1758–258 field as observed with NICMOS in the F110W filter. This image corresponds to the first observation date reported in this Letter. Only one conspicuous point-like source is consistent with the ±0.′′1 accurate VLA radio position shown as a white cross. The circular features around each star correspond to the rings of the Airy disk since this is a diffraction-limited image. Angular scale is given by the included right ascension and declination axes.
Recently, my group proposed a possible infrared counterpart for trying to make a spectroscopic analysis, but the region is so absorbed!

This powerful X-ray emitter also exhibits bipolar radio jets, but nobody has demonstrated its Galactic nature!
Show me those changing jets!

- We chose VLA archival data with enough angular resolution (5" at 6 cm) and sensitivity to extended emission (C configuration) for both GRS 1758-258 (right) and 1E 1740.7-294 (down).

- They span for several years.

- Some D, CD and C projects were used for a deep map of GRS 1758-258.

<table>
<thead>
<tr>
<th>Project Id.</th>
<th>Array Conf.</th>
<th>Observation Date</th>
<th>On-Source Time (s)</th>
<th>Central JD</th>
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<tbody>
<tr>
<td>AM345</td>
<td>C</td>
<td>1992 Mar 21</td>
<td>5280</td>
<td>2448719</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1992 Apr 09</td>
<td>13410</td>
<td></td>
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<td>1992 Apr 11</td>
<td>5130</td>
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<td>AM415</td>
<td>C</td>
<td>1993 Aug 24</td>
<td>8180</td>
<td></td>
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<td></td>
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<td>1993 Aug 27</td>
<td>8150</td>
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<td>1993 Aug 28</td>
<td>8160</td>
<td></td>
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<tr>
<td>AM453</td>
<td>C</td>
<td>1994 Dec 13</td>
<td>11260</td>
<td>2449707</td>
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<td></td>
<td></td>
<td>1994 Dec 27</td>
<td>12690</td>
<td></td>
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<tr>
<td>AM565</td>
<td>C</td>
<td>1997 Jul 25</td>
<td>15070</td>
<td>2450657</td>
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<td></td>
<td></td>
<td>1997 Jul 28</td>
<td>16850</td>
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<tr>
<td>AL511</td>
<td>C</td>
<td>2000 Apr 07</td>
<td>4490</td>
<td>2451642</td>
</tr>
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</table>

(a) This project had insufficient $w$ data to provide another acceptable C-configuration detection of the GRS 1758–258 jets.
• Data was recalibrated using AIPS, and taking special care to remove corrupt visibilities in both the target and the calibrator sources.

• We concatenated short time slots (less than 2 months) of different VLA monitoring projects into a single observing epoch, assuming no important structural changes took place in such a period.

• We use the same angular resolution and PSF (matching beam) in each map so that they could be compared to each other.

• And thus a 6 cm radio map sequence were obtained… To maximize extended emission we applied natural weighting of the interferometric visibilities.

• Do you want to see them?
This 13’’ displacement in 5.4 years implies a projected velocity of 0.32c.

North lobe breaks into fragments in 2001 and a new hotspot appears in 2008, 2’’ away from the former one in 1997.

South lobe is fainter and does not exhibit a so defined structure as the North lobe. Maybe hints of precession are shown. But it dissapears in 2008, which is our more sensitive image.
The more continuous jet in this object changes more subtly
Are differences significative?

1E 1740.7-294

GRS 1758-258

BOTH ARE GALACTIC AFTER ALL!
What causes these changes?

GRS 1758-258  1992

PRECESSION?

1E 1740.7-2942  1992
What if disruption?

- Given that cooling time for relativistic electrons by synchrotron radiation in the jet head is too long (million of years), we suggest that hydrodynamical instabilities (RT and/or KH) are responsible for the observed disruption.
- We define the instability parameter as:

$$\frac{c}{\Omega}$$

- Thus, assuming an observed radius for the jet of ~0.1 pc, the jets could be destroyed by instabilities in a matter of months.
...and what if precession?

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mathematical morphology skeleton</th>
<th>Maxima skeleton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of the precession cone</td>
<td>$\psi = 1^{\circ}8$</td>
<td>$\psi = 2^{\circ}3$</td>
</tr>
<tr>
<td>Inclination of the jet precession axis with the L.o.s.</td>
<td>$i = 65^{\circ}1$</td>
<td>$i = 63^{\circ}0$</td>
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<tr>
<td>Position angle of the jet precession axis</td>
<td>$\chi = 339^{\circ}6$</td>
<td>$\chi = 338^{\circ}5$</td>
</tr>
<tr>
<td>Precession period</td>
<td>$P_p = 481.8$ d</td>
<td>$P_p = 485.5$ d</td>
</tr>
<tr>
<td>Reference JD(**)</td>
<td>$t_{ref} = 2448303.51$</td>
<td>$t_{ref} = 2448307.85$</td>
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<tr>
<td>Jet velocity</td>
<td>$v_{jet} = 0.96c$</td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>$d = 5$ kpc</td>
<td>$d = 5$ kpc</td>
</tr>
<tr>
<td>Approaching jet (N)</td>
<td>$s_{jet} = +1$ (fixed)</td>
<td>$s_{jet} = +1$ (fixed)</td>
</tr>
<tr>
<td>Receding jet (S)</td>
<td>$s_{jet} = -1$ (fixed)</td>
<td>$s_{jet} = -1$ (fixed)</td>
</tr>
<tr>
<td>Sense of rotation (counterclockwise)</td>
<td>$s_{rot} = +1$ (fixed)</td>
<td>$s_{rot} = +1$ (fixed)</td>
</tr>
<tr>
<td>Goodness of fit</td>
<td>$\chi^2_{red} = 1.26$</td>
<td>$\chi^2_{red} = 0.91$</td>
</tr>
</tbody>
</table>

(* Adapted from Hjellming & Johnston (1981).  
(**) Corresponding to zero precession phase.)
In GRS 1758-258, when the North lobe is disrupted, their electrons must diffuse into the medium. This plasma leaving the terminal region of the jet could form a new cocoon-like envelope around the radio lobes, thus creating a cavity similar to those observed in radio galaxies with continuous jets. So, we used all available data (19 hours), including D and CD configuration, in order to obtain the deepest map of GRS 1758-258 up to now (rms noise of 6 \( \mu \)Jy/beam)…
Further information:

- Real-time evolution of a large-scale relativistic jet

- The precessing jets of 1E 1740.7-2942