Large-scale Jets in DRAGNs

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- Radio sources powered by jets from AGN:
  - Radio Galaxies,
  - Quasars
  - Seyfert galaxies etc.
- Relativistic (initial) flow speeds:
  - Lorentz factor $\gamma \sim 3-10$

DRAGNs in theory (FR II)


DRAGN in reality (Cygnus A)

Chandra X-ray contours: Wilson et al. (2001)
VLA radio image: Perley et al. (1984)

Questions
- How are DRAGNs born?
- How stable are the jets?
- How long do DRAGNs live?
- How do they die?
- Is there an after-life?

Activity Power Spectrum
Switch-on

- Smallest DRAGNs have dynamical ages $D/v \sim 500$ yrs from measured hotspot advance
  - Owsianik & Conway (1998a,b)
- Start-up time $\sim 1$ Million times shorter than galaxy merger timescale, $O(10^9)$ yrs

(Courtesy G. Taylor)

Pointing Stability

- Orientation can be stable for $0(10^9)$ yr:
  - Straightness of some Giant DRAGNs
  - Expansion speed $\sim 0.1c$ from symmetry statistics (Scheuer 1995)
- BH spin aligns with accreted material in $10^8 - 10^7$ yrs: $\rightarrow$ stability due to stable accretion
  - (Natarajan & Pringle 1998)

Precessing Jets

- Orientation remains stable for $0(10^9)$ yr:
  - Straightness of some Giant DRAGNs
  - Expansion speed $< 0.1c$ from symmetry statistics (Scheuer 1995)

Winged DRAGNs

- Multiple outbursts revealed by change of jet axis.
- Few % of powerful DRAGNs
- What happens if axis does not change?

Bottleneck Lobes

- At $\approx 26^\circ$ to line of sight
  - Twin-peak Balmer lines (Grachvogel & Aipen 1994)
  - Superluminal motion (Alef et al. 1998)
- Overlapping lobes
- Extends $\approx 0.5$ Mpc along line of sight
- Near side (NW) seen 1.8 Myrs more developed:
  - Bottleneck
  - More expanded hotspot

3C390.3

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(Courtesy Leahy & Perley 1995)
Power Stability

- Hotspots in 80-90% of lobes in powerful DRAGNs → jets nearly always "on".
- Hotspot:lobe flux ratio:
  - Median 0.22
  - IQR 0.11 - 0.54
- Jets could fluctuate in power by factors of several.

From Atlas of DRAGNs (Leahy, Bridle & Strom 1996)

Re-invigorated Jets: 3C 33.1

VLA A+B+C+D
125 cm
1.5"
200 kpc

VLA B+C+D
1.36 cm
0.74'' beam

Hercules A

- Powerful DRAGN in cluster-dominating galaxy at z=0.154.
- X-ray parameters typical of Abell clusters.
- Cluster elongated along radio axis.

Gizani & Leahy (in preparation)

VLA A+B+C+D
1.1 cm
0.36"

J. Morse, STScI

Understanding the “Rings”

- **Rings:**
  - Present in both lobes
  - Surround jet features
  - Spectrally young
  - Brighter on outer side
  - Brighter in West lobe

- **Jets:**
  - Brighter jet is nearer, from depolarization.
  - Inclination $i \approx 50^\circ$

- **Model:**
  - Jet asymmetry due to beaming: $\beta \cos i \approx 0.5$
  - Observed timescales 3x different in the two lobes, from light-travel effect.
  - Rings are shocks in old lobes caused by new outburst
  - Fluctuations on many timescales

Double-Double DRAGNs

- Saripalli et al. (2002)
- Schoenmakers et al. (2000)

PKS 1637-77

- ATCA
  - $\lambda$12 cm
  - 2.9"
  - 200 kpc
- ATCA
  - $\lambda$22 cm
  - 6.4"

Leahy & Killeen (in preparation)

Crossing the F-R Divide

- Plume best explained as a remnant of previous FR I phase.
- Luminosity of PKS1637-77:
  - $P_{178} \approx 10^{25}$ W Hz$^{-1}$sr$^{-1}$ (near FR divide).
- Luminosity of plume: $\sim 10^{23}$ W Hz$^{-1}$sr$^{-1}$
  - Characteristic of fainter FR I sources.
- NB: remnant would be hard to see, if new FRII phase was much brighter.
Crossing the F-R Divide

- Another case: PKS2104-25N
  - Cameron et al. (1988)
  - Bicknell, Cameron & Gingold (1990)
- High resolution:
  - Clear FR II
  - With plume

Death of DRAGNs

- Powerful DRAGNs have synchrotron age ≈ 10 Myr
  - Typical lifetime ~20 Myr
- Few DRAGNs are bigger than 1 Mpc:
  - Expansion speed ~0.1c → Max age ~16 Myr?
- Jet shutdown:
  - Hotspots expand, fade
  - Should leave diffuse lobes intact
  - Fade by synchrotron ageing on ~10^8 yr timescale.

Dying DRAGNs?

- Relaxed steep-spectrum DRAGNs should be more common than "Classical" Doubles.
- Actually <10%
- Van der Laan (1969):
  - Age ∝ (Break frequency)^-1/2
  - Detectable if v ≤ ν_B
  - Survey at ν should mostly find DRAGNs with ν ~ ν_B
  - Not so!

Ghost DRAGNs?

- If radio-quiet cavities in clusters are aged relic lobes (e.g. Enßlin 1999), where are the cases visible only in low-frequency images?

Conclusions

- Jets show large-amplitude variability on many timescales.
- With light-travel effects, will disguise intrinsic symmetry.
- Multiple outbursts can dramatically affect large-scale structure of DRAGNs.
- End-point of DRAGN lifecycles poorly understood.