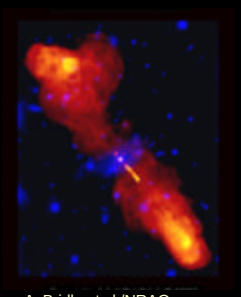
Large-scale Jets in DRAGNs

J. P. Leahy
Jodrell Bank Observatory,
University of Manchester
(Thanks to NRAO for financial support)

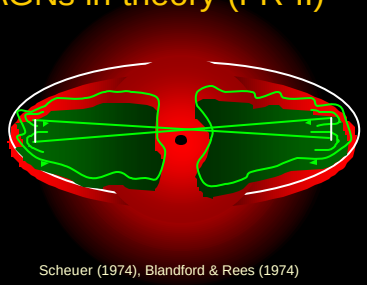
DRAGNs

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



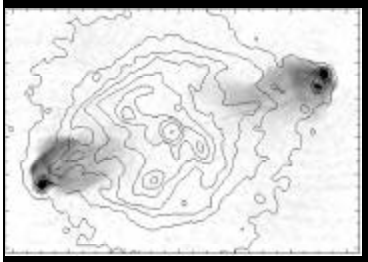
A. Bridle et al./NRAO

DRAGNs in theory (FR II)



Scheuer (1974), Blandford & Rees (1974)

DRAGN in reality (Cygnus A)



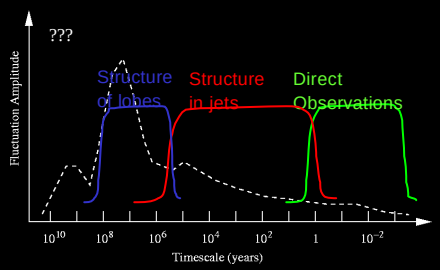
Chandra X-ray contours: Wilson et al. (2001)

VLA radio image: Perley et al. (1984)

Questions

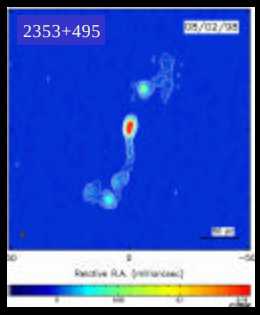
- How are DRAGNs born?
- How stable are the jets?
- How long do DRAGNs live?
- How do they die?
- Is there an after-life?

Activity Power Spectrum



Switch-on

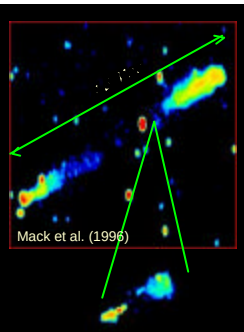
- Smallest DRAGNs have dynamical ages D/v ~ 500 yrs from measured hotspot advance
  - Owsianik& Conway (1998a,b)
- Start-up time ~ 1 Million times shorter than galaxy merger timescale, O(10^8) yrs



(Courtesy G. Taylor)

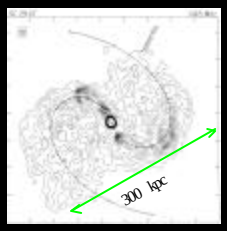
Pointing Stability

- Orientation can be stable for 0(10^8) yr:
  - straightness of some Giant DRAGNs.
  - Expansion speed <0.1c from symmetry statistics (Scheuer 1995)
- BH spin aligns with accreted material in 10^5-10^7 yrs: → stability due to stable accretion
  - (Natarajan & Pringle 1998)



Mack et al. (1996)

Precessing Jets

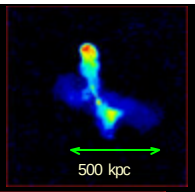


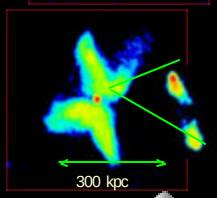
Condon & Mitchell (1984)

Hunstead et al. (1984)

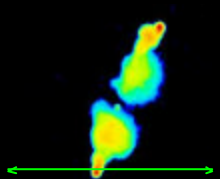
Winged DRAGNs

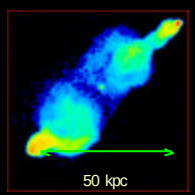
- Multiple outbursts revealed by change of jet axis.
- Few % of powerful DRAGNs
- What happens if axis does not change?





Bottleneck Lobes





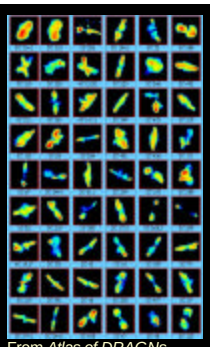
3C390.3

- At ≈ 26° to line of sight
  - Twin-peak Balmer lines (Eracleous & Halpern 1994)
  - Superluminal motion (Alef et al. 1996)
  - Overlapping lobes
- → Extends ≈ 0.5 Mpc along line of sight
- → Near side (NW) seen 1.8 Myrs more developed:
  - Bottleneck
  - More expanded hotspot

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.

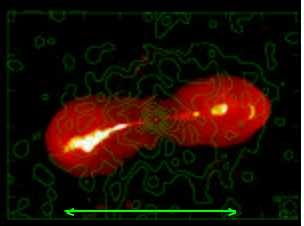


From *Atlas of DRAGNs*
(Leahy, Bridle & Strom 1996)

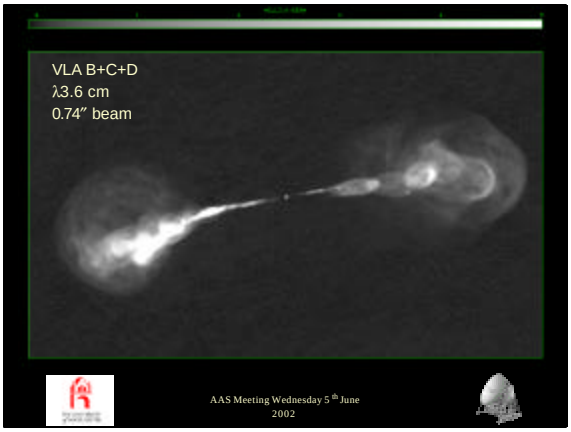
Re-invigorated Jets: 3C 33.1

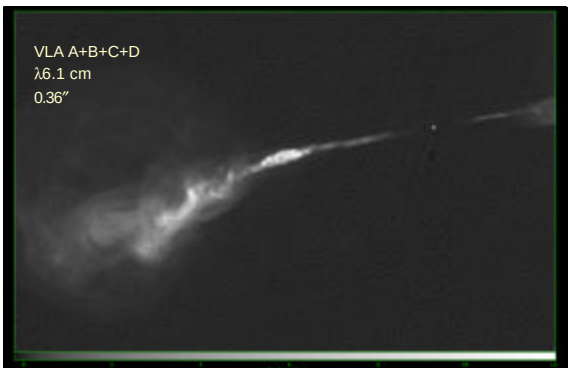
Hercules A

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

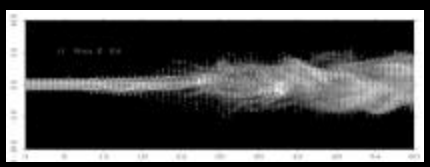


Gizani & Leahy (in preparation)

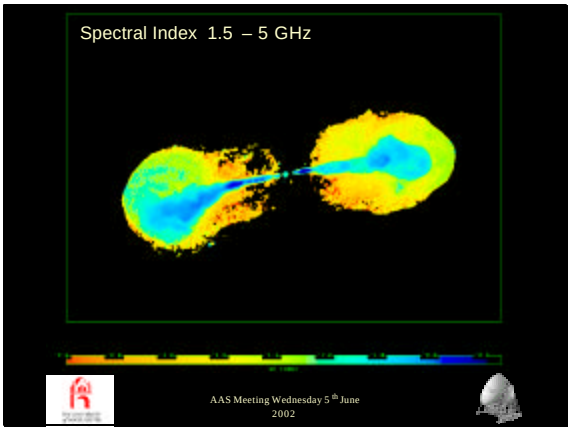




J. Morse, STScI

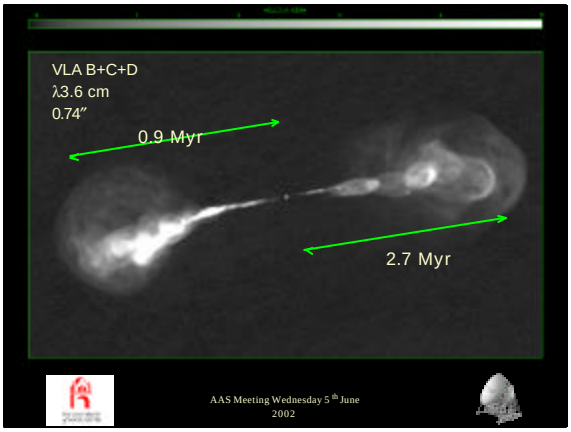


A. Rosen et al. (1999, ApJ)

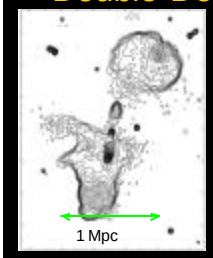


Understanding the "Rings"

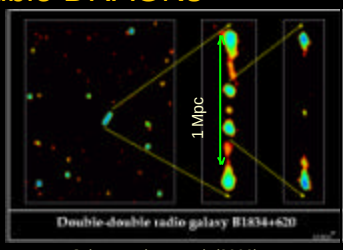
- Rings:
  - Present in both lobes
  - Surround jet features
  - Spectrally young
  - Brighter on outer side
  - Brighter in West lobe
- Jets:
  - brighter jet is nearer, from depolarization.
  - Inclination $i \approx 50°$
- Model:
  - Jet asymmetry due to beaming: $\beta \cos i \approx 0.5$
  - Observed 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

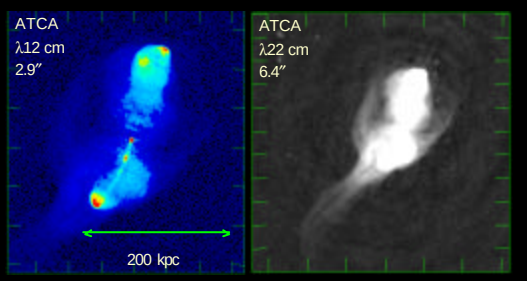


Saripalli et al. (2002)



Schoenmakers et al. (2000)

PKS 1637-77



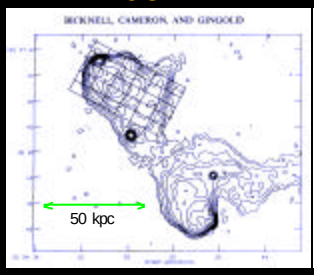
Leahy & Killeen (in preparation)

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: ~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.

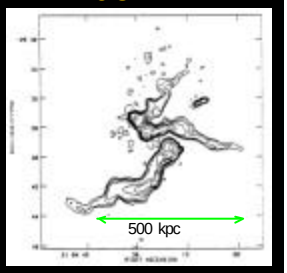
Crossing the F-R Divide

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



Crossing the F-R Divide

- Another case: PKS2104-25N
  - Cameron et al. (1988)
  - Bicknell, Cameron & Gingold (1990)
- Low resolution:
  - Plumes form wide-angle tail.

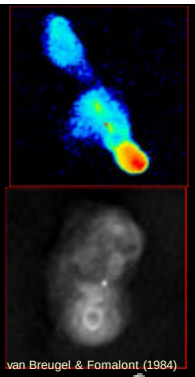


Death of DRAGNs

- 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 $\nu \leq \nu_B$
  - Survey at ν should mostly find DRAGNs with $\nu \approx \nu_B$
  - Not so!



van Breugel & Fomalont (1984)

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?

Abell 2597
(McNamara et al. 2001)

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.