Radio properties of GPS and CSS sources

Monica Orienti

INAF – IRA Bologna
Outline

Radio properties of CSS/GPS sources
- Morphology
- Variability
- Polarization

The nature of CSS/GPS sources and their physical properties
- The duty-cycle of the radio emission
- Luminosity
- Spectral peak

The ambient medium
- Neutral and Ionized gas
- The ambient medium and the source evolution
Compact radio sources

- Powerful $L_{1.4\,\text{GHz}} > 10^{25} \text{ W/Hz}$;
- Steep spectrum $\alpha > 0.7$;
- $\nu_p \sim 100 \text{ MHz to a few GHz}$
- Compact size $LS < 1 – 20 \text{ kpc}$
- High fraction (15%-30%) in flux-density limited catalogues
- Low (<10%) variability
**Peak frequency – Linear size**

**CSS**
- LLS < 20 kpc
- $\nu_t \sim 50 - 100$ MHz

**GPS**
- LLS < 1 kpc
- $\nu_t \sim 1$ GHz

**HFP**
- LLS < 100 pc
- $\nu_t \geq 4$ GHz

The smaller the source, the higher the turnover frequency (O’Dea 98)
CSS and GPS samples

Selection of CSS and GPS samples from flux density limited radio survey at different frequencies

- **CSS samples**: from 3CRR at 178 MHz, PW at 2.7 GHz, B3 at 408 MHz
  - Spencer+89, Fanti+90, Sanghera+95, Fanti+01, Kunert+02

- **GPS samples**: from 1-Jy catalogue, WENSS at 352 MHz, AT20GHz, Metsähovi at 37 GHz,
  - Stanghellini+98, Snellen+98, Hancock+10, Torniainen+06

- **HFP samples**: cross-correlation of GB6, FIRST, NVSS
  - Dallacasa+00, Stanghellini+09, Partridge+09

- **CSS/GPS selected on the radio structure**: COINS, CORALZ, CJB, VIPS
  - Peck&Taylor00, Polatidis+99, Snellen+04, Taylor&Peck03, Tremblay+09,...
Morphology

Sub-arcsecond resolution is needed for imaging the structure of CSS/GPS objects: VLA, ATCA, MERLIN, VLBI

CSS/GPS are divided into:

- Symmetric (i.e. two-sided)
- Core-Jet
- Complex

LS > 1 kpc: MSO
LS < 1 kpc: CSO
Two-sided structures

The majority of compact radio galaxies have a two-sided structure dominated by mini-lobes/hotspots. Sometimes the faint core is detected.
Asymmetries in “symmetric” objects

Large asymmetry in both luminosity and arm-length ratios between the lobes.

Saikia+ 03, Fanti+ 90, Dallacasa+13

Jet-ISM interaction?
The majority of compact radio quasars and some bright CSS have a core-jet structure or very complex morphology (7% of the PW sample).

“Core-jet”

“Complex”

Boosting effects
Variability

The spectral behaviour is investigated by simultaneous multifrequency observations carried out at various epochs.

High fraction of CSS radio \textbf{galaxies} are not variable, while only \textasciitilde30\% of GPS galaxies preserve the convex spectrum.

Orienti+07, +10, Torniainen+07, Hancock+10
Variability

The spectral behaviour is investigated by simultaneous multifrequency observations carried out at various epochs.

The majority of the CSS and GPS quasars show significant flux density and spectral variability.

See Dallacasa's talk

Mingaliev+12, Torniainen+05, Orienti+07
Variability

The spectral behaviour is investigated by simultaneous multifrequency observations carried out at various epochs.

Variability due to adiabatic expansion of very young objects

RXJ 1459+3337

Optically-thick

Optically-thin

Edge+96, Orienti+08
Polarization properties

LS < 6 kpc
Unpolarized at 1.4 GHz

LS < 3 kpc
Unpolarized at 8.4 GHz
Polarization properties

- Polarized emission from quasars, independently from LS
- Polarized emission from galaxies with LS > 3 pc
- Quasars have higher fractional polarization
- Galaxies have larger RM
- Higher RM from sub-arcsec observations than from single-dish observations: blended components?
- “Re-polarization” at low frequencies: variability and/or multiple components
- Larger polarization asymmetry in CSS than in large radio galaxies: interaction with dense medium?

Mantovani+09, Rossetti+08, Mantovani+13, Cotton+06, Orienti+08, Saikia+03
Polarization properties

- Quasars have higher fractional polarization

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See Cotton's and Pasetto's talks

Mantovani+09, Rossetti+08, Mantovani+13, Cotton+06, Orienti+08, Saikia+03
Galaxies vs quasars

The different characteristics shown by GPS/CSS with different optical identification are consistent with the idea that GPS/CSS galaxies and quasars represent two different radio source populations:

- Galaxies ➔ Compact sources
- Quasars ➔ Blazar objects

Young blazars should exist. Boosting effects may hide the lobe structures.
Young or frustrated?

• Youth scenario:

  Compact  →  Young

  Baldwin 82, Fanti+ 95, Readhead+ 96, Snellen+ 00.....

• Frustration scenario:

  Compact  →  Frustrated

  van Breugel+84, Baum+90
The “frustration” scenario

Compact $\rightarrow$ Frustrated

Observations from radio to X-ray searching for an excess of dust, and cold, warm and hot gas did not provide evidence of a particularly dense environment.

e.g. Fanti+00, Siemiginowska+05

Indirect support to the youth scenario
**Youth: Radio morphology**

Scaled-down version of the extended radio sources. They should represent the young stage in the radio source evolution.

Phillips & Mutel 82

7 pc

Core → HS

350 pc

Core → HS

HS

240 kpc

HS

4.5 kpc
Youth: Proper motion

Detection of hot-spot separation by means of multi-epoch VLBI observations spanning a decade or more

B0710+439

\[ \text{v}_{\text{sep}} = 0.3c \]

\[ t_{\text{kin}} \sim 10^3 \text{ yr} \]

See Rastello's talk
Youth: spectral analysis

B1943+546, Murgia 2003

The radiative age of the electron population can be derived by the break frequency $\nu_b$ and the magnetic field $H$:

$$t_{\text{rad}} \propto \nu_{br}^{-1/2} H^{-3/2}$$

From $\nu_{br}$ in the lobes:

$$t_{\text{rad}} \sim 10^3 \text{ yr}$$
Evolutionary stages

The higher the turnover frequency, the smaller and younger the source is.

See Perucho's talk

HFP → GPS → CSS → FR I/II
Dying objects?

PKS 1518+047

- Lack of hot spots and core components in many CSS/GPS
- Steep spectrum across the whole source
- No injection of fresh particles

See Brienza's and Kino's talks

Orienti+10, Kunert-Bajraszewska+10, Kunert-Bajraszewska+10
Recurrent activity?

- On kpc scales:
  - J0111+3906: 128 kpc
  - B2 0258+35: 160 kpc
  \[ t_{\text{relic}} \sim 10^7 - 10^8 \text{ yr} \]
  (Baum+90; Tinti+05, Shulevski+12)

- On pc-scales:
  - J1511+0518: 50 pc
  - OQ208: 43 pc
  \[ t_{\text{relic}} \sim 10^3 - 10^4 \text{ yr} \]
  (Orienti&Dallacasa08, Lu+07)
The duty-cycle of the radio emission

High angular resolution at low frequency is necessary to detect remnant from previous radio activity around young radio sources to find how many and how long the various phases may last.

See Mahony's talk.
Luminosity evolution

Luminosity increases for LS < a few kpc, then decreases

No faint CSS objects. Sensitivity limitation?
Luminosity evolution

Luminosity increases for LS < a few kpc, then decreases

See also Baldi's talk
Core Luminosity

Luminosity increases for LS < a few kpc, then decreases
The turnover in the spectrum is likely due to synchrotron self absorption
Snellen+00, Tingay&de Kool03, Orienti&Dallacasa08

SSA in a homogeneous component: $\beta = 2.5$

SSA is present BY DEFAULT!
SSA or free-free absorption?

Optically-thick part of the spectrum is too steep to be due to SSA. An additional contribution from FFA is needed to model the spectrum.

H_{SSA} cannot be derived
SSA or FFA?

Inhomogeneous ambient medium
As a consequence of the merger at the origin of the radio emission, the ambient medium surrounding a radio source is rich of gas.

- High incidence of ionized gas (FFA);
  Marr+01, Orienti&Dallacasa08

- Highly depolarized;
  Cotton+03, Fanti+04

- High incidence of HI absorption;
  Pihlström+03, Gupta+05, Morganti+05

- High detection rate of CO emission
  Mack+09

See Allison's, Ostorero's and Chandola's talks
The atomic hydrogen

Anti-correlation between the HI column density and the linear size may be produced by circumnuclear gas with a radially declining density profile.
The molecular gas

Ocaña-Flaquer et al. 2010

Symmetric Doubled-peak profile

Disk structure

$M_{\text{disk}} \sim 1.4 \cdot 10^{10} \, M_\odot$

Similar result for 4C31.04 HCO$^+$ (1-0 and CO (2-1)
Garcia-Burillo+10
HI distribution: VLBI observations

1946+708, Peck+ 99

HI detected against the whole source

Central disk

$\Delta v = 350$ km/s

$N_H \approx 2 \times 10^{23}$ cm$^{-2}$ ($T_s = 8000$ K)
HI distribution: VLBI observations

\[ \Delta V = 150 \text{ km/s} \]

\[ N_H \sim 10^{22} \text{ cm}^{-2} (T_s = 100 \text{ K}) \]

HI located \( \sim 100 \) pc from the core, where the jet bends

Off-nuclear clouds

But see also Labiano's talk
Jet-cloud interaction?

They may influence the source evolution, slowing down its expansion and enhancing the luminosity. They may be responsible for the asymmetries in arm-length and luminosity.

3C 49

Labiano+06

The statistic is still too poor.....
Asymmetries in “symmetric” objects

High flux density ratios cannot be explained by geometrical effects

Excess of asymmetric objects in flux density limited samples?

Jet-ISM interaction?
Conclusions

• Steep-spectrum compact radio sources represent an early stage in the radio source evolution

• Quasars and galaxies have different properties: different sub-classes?

• The peak in their synchrotron spectrum is generally due to SSA, although an additional contribution of FFA is found in the most compact sources

• The ambient medium surrounding young radio sources is inhomogeneous and dense and jet-cloud interaction can take place

• Flux density asymmetries may explain some number excess in flux limited sample

• Not all the CSS/GPS may evolve in extended FRI/FRII galaxies, or many short “radio” phases occur in the same AGN
Thank you