Adiabatic expansion and magnetic fields in AGN jets

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Outline

1. Observations
2. Theory
   - Shock-in-jet model
   - Adiabatic expansion of shocks
3. Results for
   - 1128-047
   - 2155-152
4. Summary
MOJAVE-II observations

- observed in 2006 (288 hours)

- extended sample of 192 sources
  - complete flux limited MOJAVE-I sample (135 sources)
  - 58 EGRET sources with $\delta > -20^\circ$
  - 11 objects from the 2 cm Survey with unusual kinematics

- polarimetric observations at 8.1, 8.4, 12.1 and 15.4 GHz

- single epoch on every source

- integration time was chosen to achieve roughly the same image rms at each frequency
Shock-in-jet model

- component = shock

- \( N(E)dE \sim E^{-s}dE \)

- \( B \sim d^{-a} \)
  - \( d \) – transverse jet size
  - \( a \) – B-field orientation
  - \( a = 1 \implies B \perp \text{jet} \)
  - \( a = 2 \implies B \parallel \text{jet} \)

- D-factor is constant or changing weakly throughout the jet

A. Marscher, 1990
Adiabatic expansion of shocks

Model brightness temperatures

\[ T_{b\text{jet}} = T_{b\text{core}} \left( \frac{d_{\text{jet}}}{d_{\text{core}}} \right)^{-\xi} \]

(Lobanov et al. 2000)

\[ \xi = \frac{2(2s + 1) + 3a(s + 1)}{6} = [s = 1 - 2\alpha; \ S \sim \nu^\alpha] = 1 + a - \alpha(a + 4/3) \]

Testing the model

- \( T_{b\text{model}} \) vs \( T_{b\text{obs}} \)
- Tune up the model by
  - determining \( \alpha_{\text{obs}} \) for every jet component
  - determining \( a \) for every jet component from 15 GHz P-map
  - \( \xi = f(\alpha, a) \)
Radio Galaxy 1128-047, z=0.266, 3.9 pc/mas
Radio Galaxy 1128-047

$\alpha_{\text{Xu}}$ map with U contours overlayed
clev = 0.0020, peak = 0.456 Jy/beam
Radio Galaxy 1128-047

$\alpha_{\text{XU}}$ map with U contours overlayed

clev = 0.0020, peak = 0.456 Jy/beam
Radio Galaxy 1128-047

B $\parallel$ jet ($a = 2$)

B $\perp$ jet ($a = 1$)
Quasar 2155-152, z=0.672, 7.0 pc/mas
Quasar 2155-152

$\alpha_{UX}$ map with U contours overlayed

clev = 0.0045, peak = 1.000 Jy/beam

g Jets aligned (0.2 mas shift)
Quasar 2155-152

$\alpha_{\text{XU}}$ map with U contours overlayed
clev = 0.0045, peak = 1.000 Jy/beam

jets aligned (0.2 mas shift)
Quasar 2155-152

![Image with labels J1 to J5 and temperature versus distance graph]
Good agreement between measured and model $T_b$

Discrepancy in J2: $\frac{T_{b}^{obs}}{T_{b}^{model}} \approx 20 \implies$ Doppler factor varies

- change of the jet speed
- change of the viewing angle
Quasar 2155-152: Doppler factor variations

Speed changes, viewing angle $\theta = \text{const}$

For J2 component ($\alpha = -0.73$, $S \propto \nu^{+\alpha}$)

$$\zeta = \frac{T_{b}^{obs}}{T_{b}^{mod}} = \left( \frac{\delta_{J2}}{\delta_{jet}} \right)^{3-\alpha} \implies \frac{\delta_{J2}}{\delta_{jet}} = \zeta^{1/(3-\alpha)} = 2.23$$

$$\begin{align*}
\delta_{J2} &= \Gamma_{J2}^{-1}(1 - \beta_{J2} \cos \theta)^{-1} \\
\delta_{jet} &= \Gamma_{jet}^{-1}(1 - \beta_{jet} \cos \theta)^{-1} \\
\beta_{app J2} &= \beta_{J2} \sin \theta (1 - \beta_{J2} \cos \theta)^{-1} \\
\beta_{app jet} &= \beta_{jet} \sin \theta (1 - \beta_{jet} \cos \theta)^{-1}
\end{align*}$$

Let’s find $k = \beta_{J2}/\beta_{jet}$ and/or $m = \Gamma_{J2}/\Gamma_{jet}$
Quasar 2155-152: Doppler factor variations

\[
k = \frac{\beta_{J2}}{\beta_{jet}} = \left[ \beta_{jet}^2 + (1 - \beta_{jet}^2) \left( \frac{\beta_{app, jet}}{\beta_{app, J2}} \cdot \left[ \frac{T_{b, obs}}{T_{b, mod}} \right]^{1/(3-\alpha)} \right)^2 \right]^{-0.5}
\]

\[
m = \frac{\Gamma_{J2}}{\Gamma_{jet}} = \sqrt{\frac{1 - \beta_{jet}^2}{1 - k^2 \beta_{jet}^2}}
\]

From MOJAVE data we have

\[\beta_{app, jet} \approx 10 \quad \Rightarrow \quad \theta \approx 6^\circ\]

\[\frac{\beta_{app, jet}}{\beta_{app, J2}} \approx 11.4\]

then \[\beta_{jet} = 0.995\]
Quasar 2155-152: Doppler factor variations

\[ k = \frac{\beta_{J2}}{\beta_{jet}} = \left[ \beta_{jet}^2 + (1 - \beta_{jet}^2) \left( \frac{\beta_{app, jet}}{\beta_{app, J2}} \cdot \left[ \frac{T_{b, obs}}{T_{b, mod}} \right]^{1/(3-\alpha)} \right)^2 \right]^{-0.5} \]

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From MOJAVE data we have
\[ \beta_{app, jet} \approx 10 \implies \theta \approx 6^\circ \]
\[ \beta_{app, jet}/\beta_{app, J2} \approx 11.4 \]
then \[ \beta_{jet} = 0.995 \]
\[ \beta_{J2}/\beta_{jet} = 0.36 \]
\[ \Gamma_{J2}/\Gamma_{jet} = 0.11 \]
Quasar 2155-152: Doppler factor variations

Then $\Delta \theta$ can be derived from

$$
\begin{align*}
\beta_{app_{J2}} &= \frac{\beta_{jet} \sin(\theta + \Delta \theta)}{1 - \beta_{jet} \cos(\theta + \Delta \theta)} \\
\beta_{app_{jet}} &= \frac{\beta_{jet} \sin \theta}{1 - \beta_{jet} \cos \theta}
\end{align*}
$$

$$
\Delta \theta_{J2} = -5.72 \text{ deg}
$$

The set of parameters found is:

$$
\beta = 0.995; \ \theta = 6 \text{ deg}; \ \Delta \theta_{J2} = -5.72 \text{ deg}
$$

These values provide

$$
\frac{\delta_{J2}}{\delta_{jet}} = \frac{1 - \beta \cos \theta}{1 - \beta \cos(\theta + \Delta \theta)} = 2.09 \quad \text{which is close to detected 2.23}
$$
Summary

- Measured sizes and brightness temperatures of VLBI features in quasar 2155-152 and radio galaxy 1128-047 are found to be consistent with emission from relativistic shocks dominated by adiabatic losses.

- Distinct features in the jets of 1128-047 and 2155-152 may indeed be a collection of plane relativistic shocks.

- Jet in 2155-152 changes its direction by 5.7 deg at \( \sim 3 \) mas from the core and becomes nearly aligned with the line of sight.