Adiabatic expansion and magnetic fields in AGN jets

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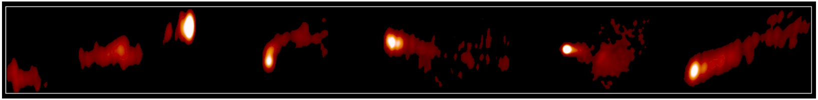
Bologna, September 23, 2008
The 9-th European VLBI Network Symposium



In collaboration with

Yuri Y. Kovalev (MPIfR, ASC Lebedev)
2 cm Survey/MOJAVE team

Outline

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

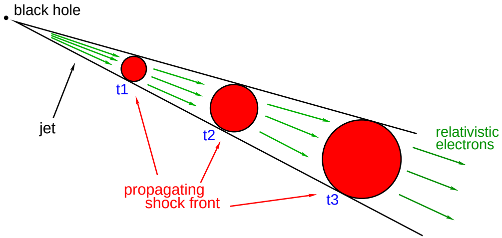
MOJAVE-II observations

- 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

A. Marscher, 1990



- $N(E)dE \sim E^{-s}dE$
- $B \sim d^{-a}$
  d – transverse jet size
  a – B-field orientation
  $a = 1$ ==> B $\perp$ jet
  $a = 2$ ==> B $\parallel$ jet
- D-factor is constant or changing weakly throughout the jet

Adiabatic expansion of shocks

Model brightness temperatures

$$T_{b\,\mathrm{jet}} = T_{b\,\mathrm{core}} \left(\frac{d_{\mathrm{jet}}}{d_{\mathrm{core}}}\right)^{-\xi}$$

(Lobanov et al. 2000)

$$\xi = \frac{2(2s+1)+3a(s+1)}{6} =$$

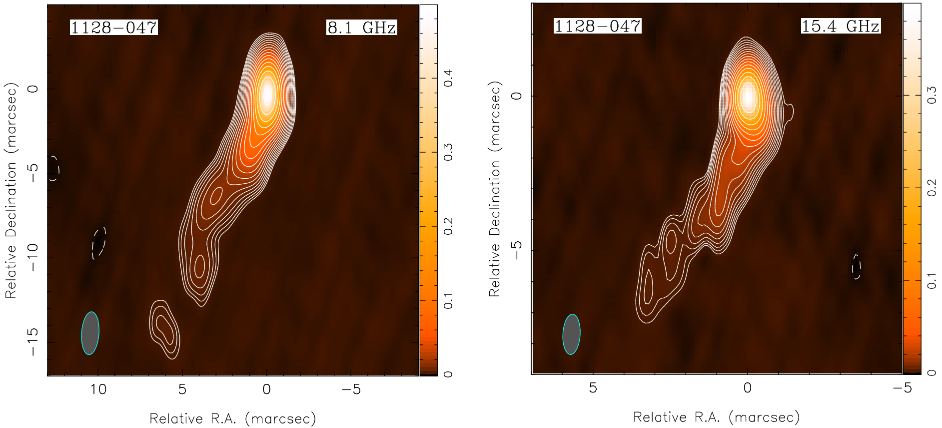
$$= [s = 1-2\alpha; \;\; S \sim \nu^{\alpha}] =$$

$$= 1 + a - \alpha(a + 4/3)$$

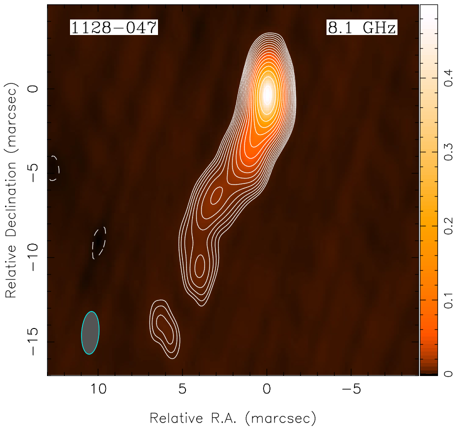
Testing the model

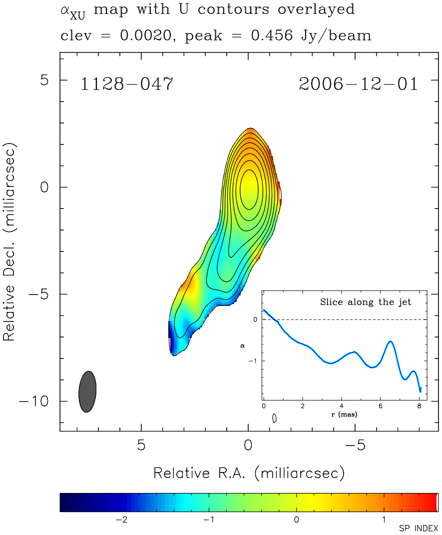
- T_b^{model} vs T_b^{obs}
- Tune up the model by
    - determining α_{obs} for every jet component
    - determining a for every jet component from 15 GHz P-map
    - $\xi = f(\alpha, a)$

Radio Galaxy 1128-047, z=0.266, 3.9 pc/mas

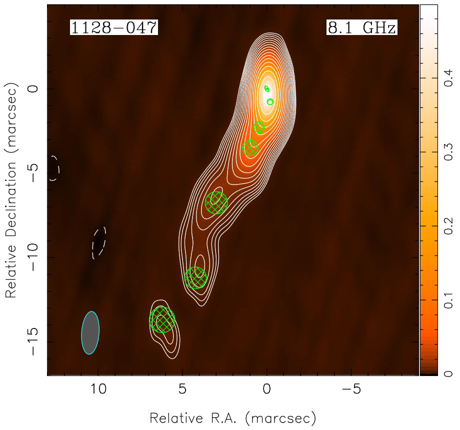


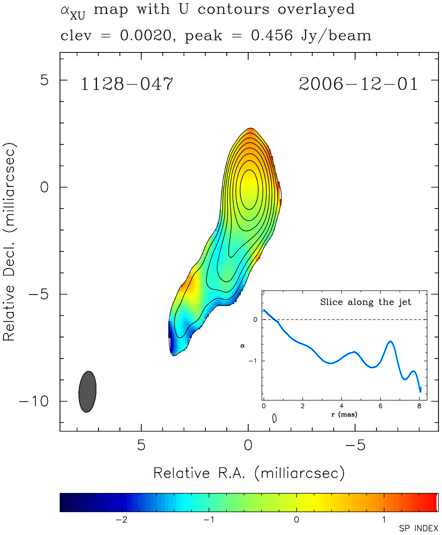
Radio Galaxy 1128-047





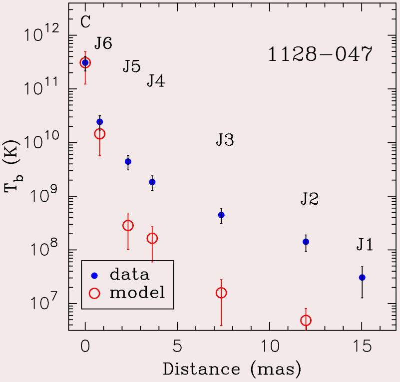
Radio Galaxy 1128-047



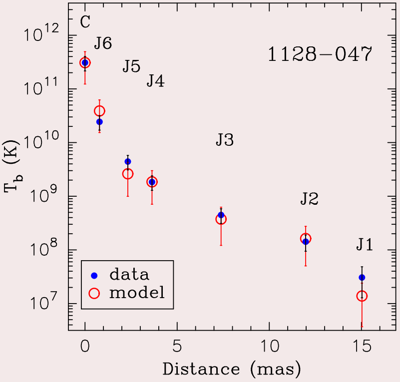


Radio Galaxy 1128-047

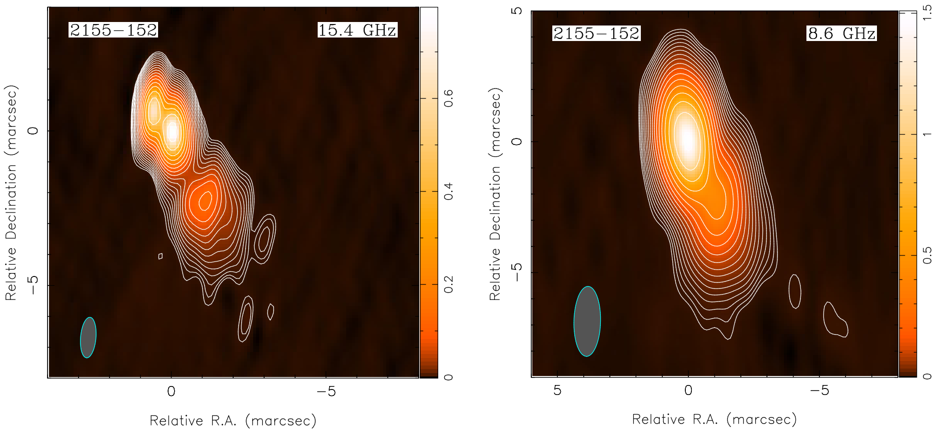
B $\parallel$ jet ($a = 2$)



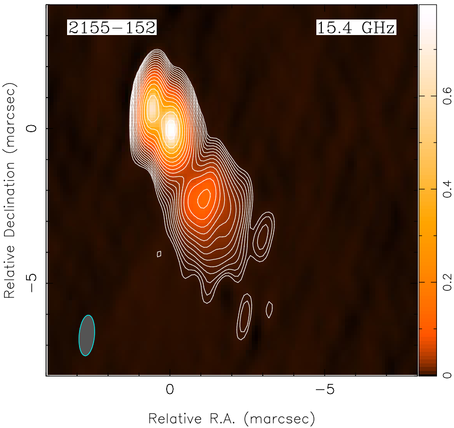
B $\perp$ jet ($a = 1$)

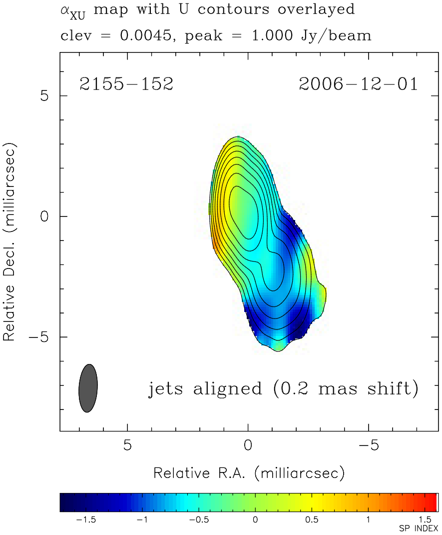


Quasar 2155-152, z=0.672, 7.0 pc/mas

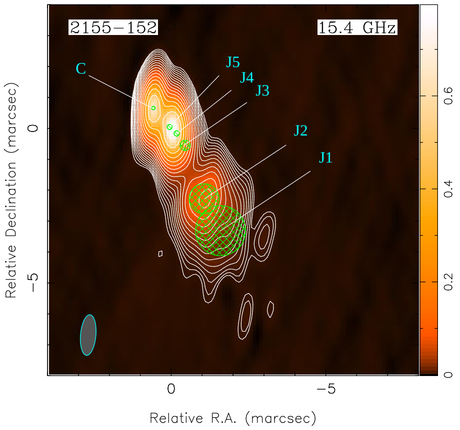


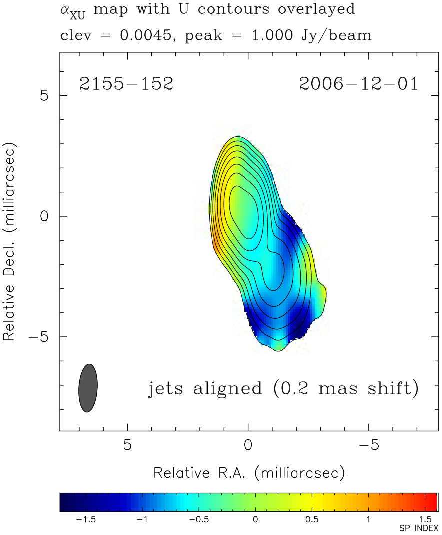
Quasar 2155-152



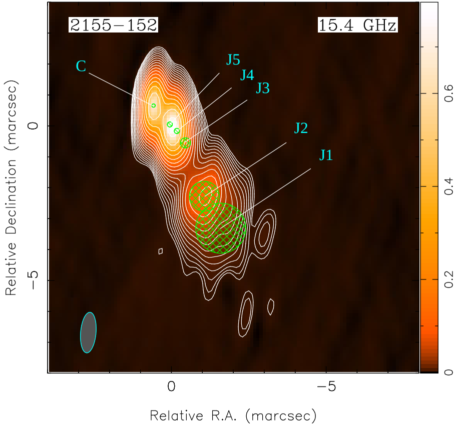


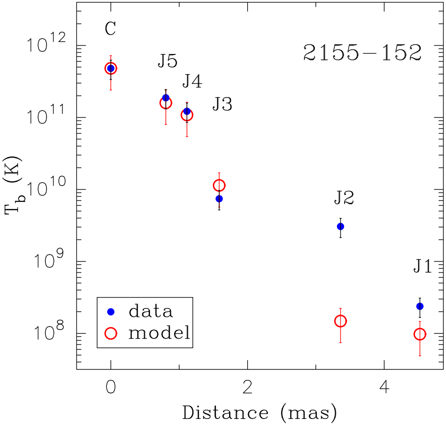
Quasar 2155-152



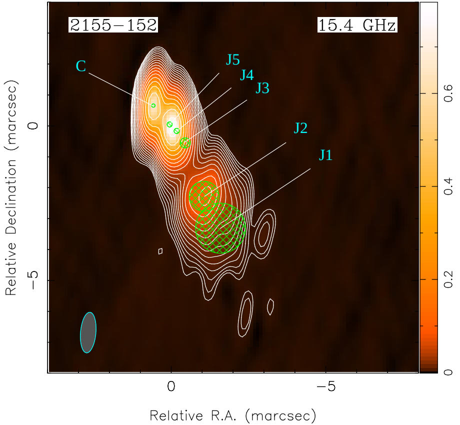


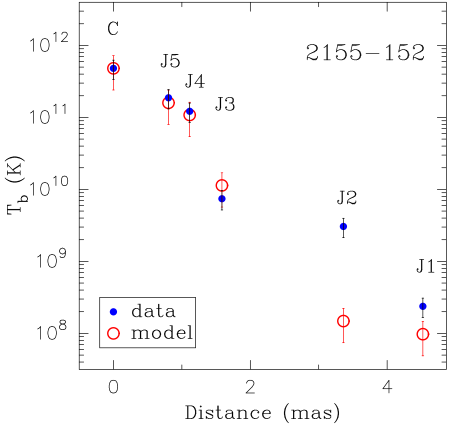
Quasar 2155-152





Quasar 2155-152





Good agreement between measured and model Tb

Discrepancy in J2: $T_b^{obs}/T_b^{model} \approx 20$ ==> Doppler factor varies

- change of the jet speed
- change of the viewing angle

Quasar 2155-152: Doppler factor variations

Speed changes, viewing angle $\theta = const$

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

$$\zeta = \frac{T_b^{obs}}{T_b^{mod}} = \left(\frac{\delta_{J2}}{\delta_{jet}}\right)^{3-\alpha} ==> \qquad \frac{\delta_{J2}}{\delta_{jet}} = \zeta^{1/(3-\alpha)} = 2.23$$

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

Let's find $k = \beta_{J2}/\beta_{jet}$ and/or $m = \Gamma_{J2}/\Gamma_{jet}$

Quasar 2155-152: Doppler factor variations

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

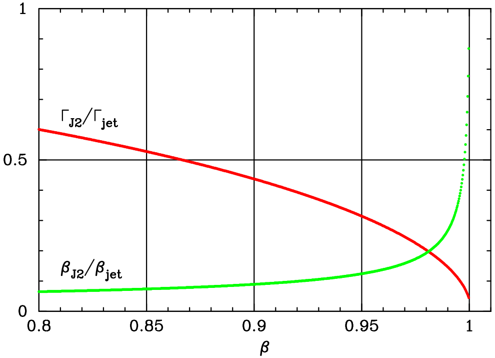
$$m = \frac{\Gamma_{J2}}{\Gamma_{jet}} = \sqrt{\frac{1 - \beta_{jet}^2}{1 - k^2 \beta_{jet}^2}}$$

From MOJAVE data we have

$\beta_{app_{jet}} \approx 10 \quad ==> \quad \theta \approx 6^\circ$

$\beta_{app_{jet}} / \beta_{app_{J2}} \approx 11.4$

then $\beta_{jet} = 0.995$



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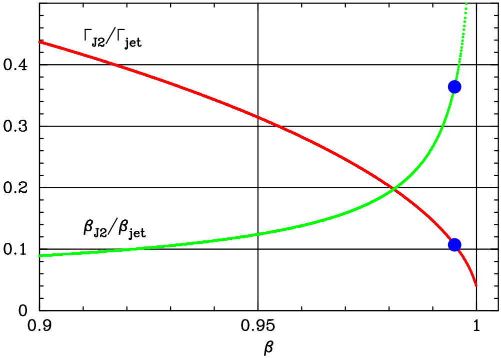
$\beta_{app_{jet}}/\beta_{app_{J2}} \approx 11.4$

then $\beta_{jet} = 0.995$

$\beta_{J2}/\beta_{jet} = 0.36$

$\Gamma_{J2}/\Gamma_{jet} = 0.11$



Quasar 2155-152: Doppler factor variations

Viewing angle changes, $\beta_{jet} = const$

Then $\Delta\theta$ can be derived from

$$\left.\begin{aligned} \beta_{app_{J2}} &= \frac{\beta_{jet}\sin(\theta+\Delta\theta)}{1-\beta_{jet}\cos(\theta+\Delta\theta)} \\ \beta_{app_{jet}} &= \frac{\beta_{jet}\sin\theta}{1-\beta_{jet}\cos\theta} \end{aligned}\right\} \longrightarrow \Delta\theta_{J2} = -5.72\,\mathrm{deg}$$

The set of parameters found is:

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

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 consistant 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.