SHOCK EXCITATION OF EMISSION LINES IN RADIO GALAXIES

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1. Introduction

We present evidence for the viability of "auto-ionizing" shocks as the dominant ionization mechanism in extended emission-line regions (EELRs) in two radio galaxies, PKS 0349−27 and PKS 2356−61. The application of this model, rather than the nuclear photoionization hypothesis of unified schemes (Barthel 1989), is motivated by observed EELR properties: large line-of-sight velocity widths (up to $\Delta v \sim 500\,\mathrm{km\,s^{-1}}$ for nearby objects and $\gtrsim 1000\,\mathrm{km\,s^{-1}}$ at higher z); kinematics/excitation relationships (Baum *et al.* 1992); the EELR/radio axis alignment (Chambers *et al.* 1987, McCarthy *et al.* 1987); and the correspondence between the brighter EELR and the shorter radio lobe (McCarthy *et al.* 1991), suggestive of jet/gas interactions. We show that the flux, excitation ***and*** kinematics across the gas is self-consistently accounted for in terms of shocks as a single physical mechanism, requiring fewer unknown parameters than nuclear photoionization.

2. Shock Model Compared with Observations

The physical basis for auto-ionizing shocks (Sutherland *et al.* 1993, Dopita and Sutherland, 1995) involves cloud-cloud collisions producing strong shocks with temperature $T \propto v^2$. Shocks with $v \gtrsim 200\,\mathrm{km\,s^{-1}}$ produce substantial UV / soft X-rays and photoionize the precursor, which then contributes to the spectrum; the resulting flux and excitation increase with v.

In Figure 1 we plot [OIII]5007/Hβ vs. Δv for all pixels sampling the EELR in PKS 0349−27 (from a "datacube" of longslit spectra taken with

R. Ekers et al. (eds.), Extragalactic Radio Sources, 473–474.
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https://doi.org/10.1017/S0074180900081535 Published online by Cambridge University Press

Line / Hβ	Obs	B=0	B=1	B=4
[OII]3726,29	6.27	1.73	4.90	6.97
[NeIII]3869	1.51	0.71	0.92	1.13
[OIII]4363	0.15	0.08	0.07	0.08
HeII4686	0.39	0.28	0.33	0.37
[OIII]5007	11.9	8.26	8.00	9.07
[OI]6300	0.43	2.11	2.36	1.67
[NII]6583	2.54	0.98	2.24	2.40
[SII]6716,31	2.00	2.11	1.89	1.42

TABLE 1. Line ratios: PKS 2356−61.

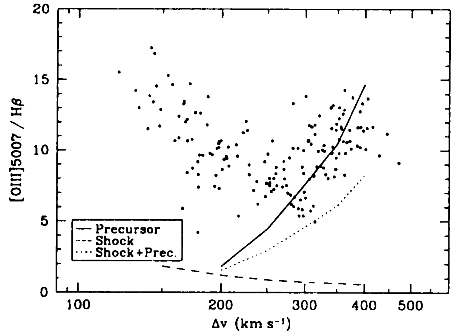

Figure 1. [OIII]5007/Hβ: PKS 0349−27.

the AAT / RGO spectrograph). The curves are model predictions for the shock, precursor and combined spectrum (low-density-limit photon-bounded precursor, transverse magnetic field parameter $B/n^{1/2} = 0\,\mu\mathrm{G\,cm}^{3/2}$). Gas with $\Delta v \gtrsim 250\,\mathrm{km\,s}^{-1}$ (*ie.* the kinematically disturbed central region) shows a clear trend in excitation, consistent with shock-related precursors. The high ionization of gas with lower Δv implies that it is also photoionized but not physically associated with shocks; its flux and excitation are accounted for by $\sim 5-10\%$ of ionizing flux escaping from shocks in the central region.

In Table 1 we present the low-dispersion line ratios for the central EELR of PKS 2356−61, compared with a single-velocity shock+precursor model (the velocity $\Delta v \sim 400\,\mathrm{km\,s}^{-1}$ corresponds to that observed, while the $B/n^{1/2}$ values represent that of the Galactic ISM, $\sim 3\,\mu\mathrm{G\,cm}^{3/2}$). Almost all the lines (*incl.* [OIII]4363) are accounted for to within $30-50\%$ or better.

3. Conclusions

Using simple assumptions about shock properties, we have shown that the fluxes, excitation *and* kinematics of gas in PKS 0349−27 and PKS 2356−61 can be self-consistently described by auto-ionizing shocks. This robustness suggests that shocks may play an important role in a wide range of EELRs.

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https://doi.org/10.1017/S0074180900081535 Published online by Cambridge University Press