



Universiteit
Leiden
The Netherlands

Near-infrared imaging of gigahertz-peaked-spectrum radio galaxies: tracing the evolution of giant ellipticals?

Snellen, I.A.G.; Bremer, M.N.; Schilizzi, R.T.; Miley, G.K.

Citation

Snellen, I. A. G., Bremer, M. N., Schilizzi, R. T., & Miley, G. K. (1996). Near-infrared imaging of gigahertz-peaked-spectrum radio galaxies: tracing the evolution of giant ellipticals? *Monthly Notices Of The Royal Astronomical Society*, 283, L123-L126. Retrieved from <https://hdl.handle.net/1887/6699>

Version: Not Applicable (or Unknown)
License: [Leiden University Non-exclusive license](#)
Downloaded from: <https://hdl.handle.net/1887/6699>

Note: To cite this publication please use the final published version (if applicable).

Near-infrared imaging of gigahertz-peaked-spectrum radio galaxies: tracing the evolution of giant ellipticals?

I. A. G. Snellen,¹ M. N. Bremer,^{1,2} R. T. Schilizzi^{1,3} and G. K. Miley¹

¹*Leiden Observatory, PO Box 9513, 2300 RA Leiden, The Netherlands*

²*Institute of Astronomy, Madingley Road, Cambridge CB3 0HA*

³*Joint Institute for VLBI in Europe, PO Box 2, 7990 AA, Dwingeloo, The Netherlands*

Accepted 1996 September 26. Received 1996 September 23; in original form 1996 July 4

ABSTRACT

In this Letter we present *K*-band data for a sample of gigahertz-peaked-spectrum (GPS) radio galaxies. We show that the dispersion of the *K*-band Hubble diagram is small and comparable to that of the *R*-band Hubble diagram for these sources. The *r* – *K* colours of GPS galaxies evolve with redshift in agreement with models for both passively evolving and non-evolving elliptical galaxies. This behaviour indicates that the optical and infrared emission from these sources is dominated by starlight with little or no contamination by light from the active nuclei. At $z \sim 1$ the absolute *K*-band luminosities are about a magnitude fainter than expected for passively evolving ellipticals, just as in the case for radio-quiet giant ellipticals at similar redshifts. The lack of luminosity evolution may be caused by the dynamical evolution in the galaxies counteracting a change in the mass-to-light ratio of the systems: if the galaxies undergo mergers at $z > 0.5$, the high-redshift systems will be less massive than those at low redshift. In contrast to powerful radio sources in general, we believe that GPS radio galaxies are representative of early-type galaxies and may be excellent objects for studying the evolution of giant ellipticals at $z > 1$, given their relative ease of selection.

Key words: galaxies: active – galaxies: elliptical and lenticular, cD – galaxies: evolution – galaxies: photometry – infrared: galaxies.

1 INTRODUCTION

Gigahertz-peaked-spectrum (GPS) sources are a class of compact extragalactic radio sources characterized by a convex radio spectrum peaking at a frequency of about 1 GHz. The turnovers in their radio spectra are assumed to be due to synchrotron self-absorption caused by the high density of relativistic electrons in these compact sources. It is believed that GPS sources are confined to the inner regions of their host galaxies, either because they are young radio sources (Phillips & Mutel 1982) that will evolve eventually into extended (FRI and/or FRII) radio galaxies (Readhead, Xu & Pearson 1994; Fanti et al. 1995; Readhead et al. 1996), or because they are surrounded by a particularly dense interstellar medium (O’Dea, Baum & Stanghellini 1991). It is possible that GPS sources represent an important stage in the evolution of radio sources.

Recently, we have discovered (Snellen et al. 1996, Paper I) that the *R*-band Hubble relation for GPS galaxies has a

low dispersion and steep slope. Its dispersion is significantly smaller than that for 3C radio galaxies, but comparable to that for low-redshift first-ranked cluster galaxies (Hoessel, Gunn & Thuan 1980). In addition, GPS galaxies are clearly fainter in *R* than 3C galaxies at $z > 0.5$. This may be due to GPS galaxies not having the extended excess UV–optical component that is often seen in high-redshift 3C radio galaxies. Furthermore, in Paper I we showed that the *R*-band GPS Hubble diagram is consistent with that for galaxies having an old stellar population that undergoes no cosmological evolution, and that the galaxies at high redshift are too faint for consistency with a passively evolving elliptical scenario. To study further the cosmological evolution of the spectral energy distribution of GPS radio galaxies, we have obtained near-infrared *K*-band images of a subsample of GPS galaxies from Paper I. In this Letter we present the *K*-band Hubble diagram and the *r* – *K* colours as a function of redshift for the GPS galaxies, and discuss these results in the context of evolution of giant elliptical galaxies.

2 OBSERVATIONS AND REDUCTION

A sample of GPS galaxies, consisting of all sources presented in Paper I within the declination range of $4^\circ < \delta < 60^\circ$ (12 sources), were observed with the United Kingdom Infrared Telescope (UKIRT). Observations took place between 1994 May and 1995 November, using the IRCAM3 array in the $0.3 \text{ arcsec pixel}^{-1}$ mode. Each source was observed in K band with a nine-position jitter pattern. The images were dark-subtracted and then flat-fielded by median-filtering the image stack. The frames were then normalized and mosaicked together to produce one final image per object. UKIRT faint standard stars were observed immediately before and/or after the observations of each galaxy.

We determined the K -band magnitudes by measuring the flux within a standard metric diameter of 32 kpc (Gunn & Oke 1975), assuming $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $q_0 = 0.5$. The background contribution within this aperture was estimated by determining the median sky values in several blank sky apertures around an object. The variation in the median background values dominates the uncertainties in the magnitudes. The resultant magnitudes were then corrected for galactic foreground extinction using the values from Paper I, assuming an extinction curve proportional to λ^{-1} (see Paper I for a discussion of the uncertainties in this procedure).

Most of the r -band magnitudes in Paper I were obtained from the literature and measured by several different authors, often using different methods from that discussed above. In order to compare our K -band data with the r -band data, we also have to determine K -band magnitudes using large enough apertures that all light from the object is included. Even though this less rigorous method increases the uncertainties in the K -band magnitude, it is more consistent with the methods used to determine the r -band magnitudes, and has therefore been used by us to study the $r-K$ colours of these objects.

3 RESULTS

The results of the observations are given in Table 1, where column 1 gives the source name, column 2 its redshift, column 3 the date of observation and column 4 the weather

conditions, where p = photometric and c = cirrus. Column 5 gives the galactic foreground extinction in K , columns 6 and 7 give the total K -band magnitude K_{tot} and the K -band magnitude within a metric of 32 kpc, $K_{32 \text{ kpc}}$, both corrected for galactic foreground extinction. Columns 8 and 9 give the absolute magnitude of each source and the colour correction used (see below).

The K -band Hubble diagram is shown in Fig. 1. One of the sources, 0710 + 439 ($z = 0.518$), is clearly discrepant in that its K -band magnitude lies below the tight relation defined by the others. Our K -band image shows that the near-infrared emission from this object is dominated by a point source nucleus. We shall discuss this source later.

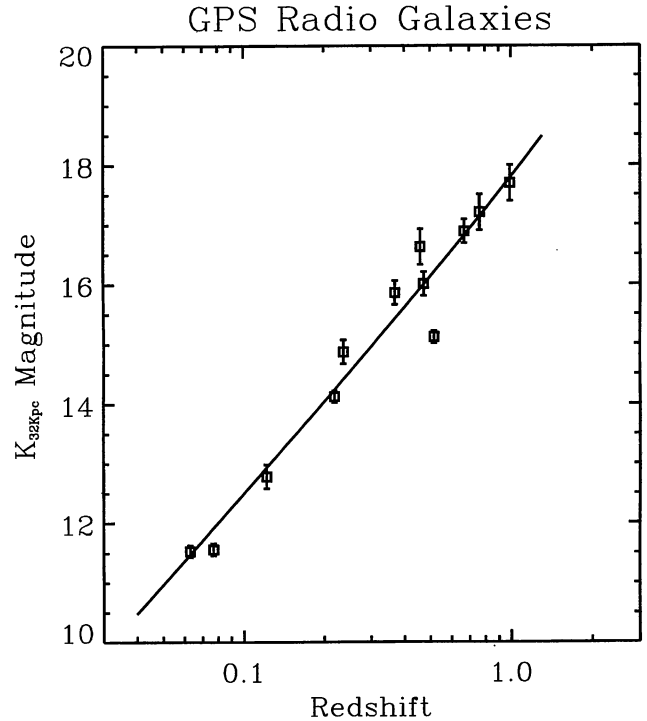


Figure 1. The K -band Hubble diagram for GPS galaxies. The K -band magnitudes are measured with a standard 32-kpc aperture. The line represents the best-fitting Hubble relation described in the text.

Table 1. UKIRT observations in the K band of GPS galaxies.

Source	Redshift	Observing Date	weather	Gal. Ext	$K_{\text{total}}^{\text{corr}}$	$K_{32 \text{ kpc}}^{\text{corr}}$	Colour Corr.	$K_{32 \text{ kpc}}^0$
0108+388	0.669	10 Aug 1995	p	-0.05	16.70 ± 0.2	16.89	+1.24	-26.06
0428+205	0.219	10 Jan 1995	p	-0.35	13.64 ± 0.1	14.12	+0.68	-26.23
0710+439	0.518	20 Nov 1995	p	-0.06	14.73 ± 0.1	15.12	+1.09	-27.20
1031+567	0.459	20 May 1994	c	-0.00	16.37 ± 0.3	16.63	+1.05	-25.37
1144+352	0.063	13 July 1994	p	-0.00	11.32 ± 0.1	11.53	+0.25	-26.24
1323+321	0.369	10 May 1994	c	-0.00	15.74 ± 0.2	15.86	+0.97	-25.60
1345+125	0.122	20 May 1994	c	-0.00	12.54 ± 0.2	12.78	+0.43	-26.37
1404+286	0.077	12 Feb 1995	p	-0.00	11.50 ± 0.1	11.56	+0.29	-26.63
1607+268	0.473	13 July 1994	p	-0.02	15.91 ± 0.2	16.01	+1.06	-26.07
1843+356	0.763	7 July 1995	p	-0.07	16.77 ± 0.3	17.21	+1.32	-26.08
2128+048	0.99	6 July 1995	p	-0.04	17.39 ± 0.3	17.70	+1.63	-26.15
2352+495	0.237	3 Aug 1994	p	-0.14	14.63 ± 0.2	14.87	+0.72	-25.64

Excluding 0710 + 439, we find a Hubble relation of

$$K = M_K + 5 \log \left[z \left(1 + \frac{z}{2} \right) \right] + 2.5(1 + \kappa) \log(1 + z) + 43.89,$$

where $M_K = -26.33$ is the absolute magnitude and $\kappa = -1.59$, which is a first-order colour correction (see Paper I). The dispersion around the fit is 0.31 mag, which is comparable to that found for the R -band Hubble diagram for GPS galaxies (see Paper I).

Fig. 2 shows the $r-K$ colours for GPS galaxies. The superimposed dotted line is the expected $r-K$ colour for an unevolving old stellar population, using the observed spectral energy distribution from Coleman, Chi-Chao Wu & Weedman (1980) which is extended to the near-infrared using data from Thuan & Puschell (1989). The observed colours were also compared with those of a range of elliptical galaxy models generated using the spectral synthesis code GISSSEL (Bruzual & Charlot, in preparation). All the model galaxies were assumed to undergo a single burst of star formation at a given redshift, and to evolve passively thereafter. The same standard Salpeter initial mass function with lower and upper stellar mass limits of 0.1 and 30 M_\odot was used for each model. The models differed in the redshift of the burst, which varied from $z=2.5$ to 10. The dark

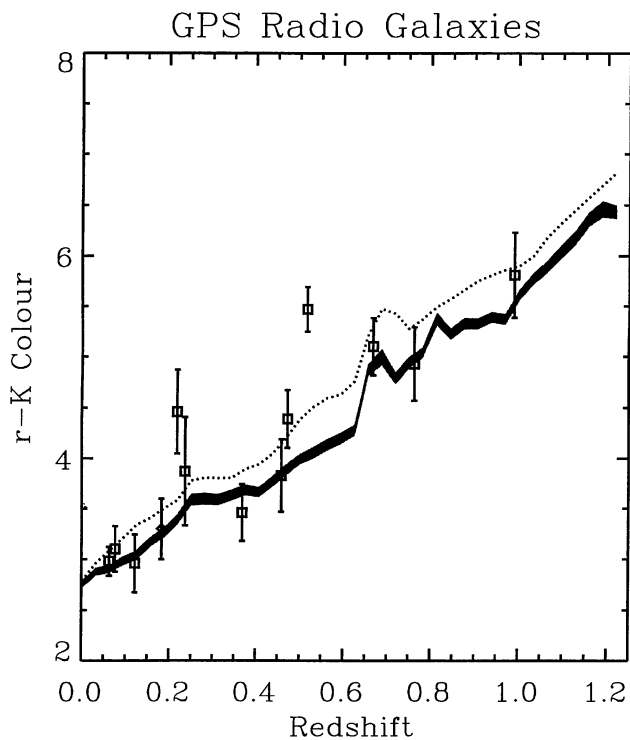


Figure 2. The $r-K$ colours of GPS galaxies as a function of redshift. The diamond symbol represents the $r-K$ colour for 1934 – 638 at $z=0.183$. The r magnitude was taken from Paper I and the K magnitude from Ward et al. (1982). The dotted line is the expected curve for a non-evolving elliptical. The dark band represents the range of colours for the passively evolving elliptical galaxy models discussed in the text. Note that no objects are significantly bluer than expected from these scenarios. Hence, for $z < 1$, there is no indication of significant star formation.

© 1996 RAS, MNRAS 283, L123–L126

band in Fig. 2 delineates the range of expected $r-K$ colours for these models. The higher the redshift of the burst, the redder the expected colour. This shows that such models are consistent with the data, but predictably no one model is favoured.

The two outlying points are from 0428 + 205 and 0710 + 439, which have redder colours than predicted by the models. The first object is relatively faint in r , presumably because of underestimation of the galactic foreground extinction (see Paper I). The second object was previously mentioned, and is relatively bright in the K band, probably due to the presence of a nuclear point source.

We have also derived the absolute magnitude, $K_{32 \text{ kpc}}^0$ for each of the galaxies. To do this we used a K -correction appropriate for the Bruzual & Charlot models plotted in Fig. 2. The K -corrections and absolute magnitudes are given in columns 8 and 9 of Table 1. The differences between the K -corrections for these models and the non-evolving case are negligibly small in comparison with the uncertainties in the observed $K_{32 \text{ kpc}}$ magnitudes. The absolute magnitudes are plotted in Fig. 3 along with the predictions for the luminosity evolution of the synthesized galaxy models.

4 DISCUSSION

We have shown that the $r-K$ colours of GPS radio galaxies vary as a function of redshift as expected for the evolution of an old stellar population out to $z=1.0$. No distinction can be made between the $r-K$ colours expected for passively evolving elliptical models and those for an unevolving old

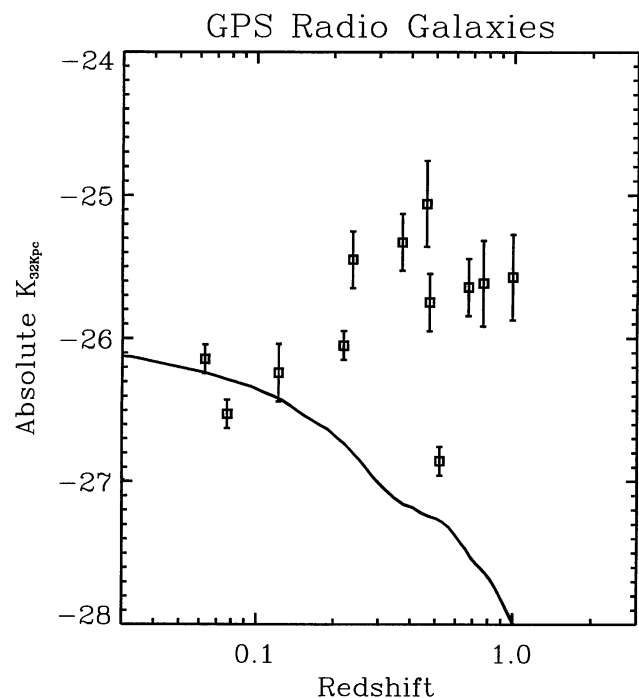


Figure 3. The absolute K magnitude (32-kpc aperture) for GPS galaxies as a function of redshift, assuming $q_0=0.5$. The line represents the expected absolute magnitudes for the passive evolution models used previously.

stellar population. However, the colour-corrected K -band luminosities decrease slightly with increasing redshift, whereas it is expected that a passively evolving elliptical galaxy would have been more luminous in the past.

Ordinary ellipticals do show an increase in luminosity evolution at high redshift, but a lack of luminosity evolution is seen for the most massive ellipticals and those that are brightest cluster galaxies (BCGs). Aragón Salamanca et al. (1993) found a relation of the form $L_K(z) = L_K(0)(1+z)^\gamma$, with $\gamma = -0.6 \pm 0.3$, for a sample of BCGs out to $z=1$. For our sample of GPS galaxies, we obtain $\gamma = -1.2 \pm 0.4$, corresponding to a luminosity decrease from $z=0$ to 1 of 0.8 mag. However, note that two of the nearby GPS galaxies, 1404 + 286 and 1345 + 125, may have some contamination from a quasar nucleus, which may have steepened this relation. In contrast, 3C radio galaxies *increase* in K -band luminosity at high redshifts ($\gamma = +1.1 \pm 0.3$; Aragón Salamanca et al. 1993). We have already shown in Paper I that GPS radio galaxies at $z > 0.5$ are less luminous in R than 3C sources.

All of the above is consistent with there being no appreciable contamination of optical and near-infrared light from an active nucleus (either directly or by scattering) in most of these sources. Moreover, the stellar populations of these galaxies seem to be unaffected by the powerful radio source at their centres. The fact that we see weak emission lines from these galaxies implies that some ionizing radiation does escape from the nucleus. In 3C radio galaxies, both the optical and infrared emission is contaminated by the presence of a powerful active galactic nucleus (e.g. Dunlop & Peacock 1993; Eales & Rawlings 1996), and their $R-K$ colours are systematically bluer than those expected for passively evolving elliptical galaxies (Lilly & Longair 1984). In any event, the broad-band optical and near-infrared properties of the host galaxies of GPS sources seem to be indistinguishable from those of optically selected giant elliptical galaxies, and are clearly different from those of 3C radio galaxies.

One explanation for the lack of luminosity evolution in both GPS galaxies and BCGs out to a redshift of 1 is that both grow by mergers of galaxies of similar colours. Thus the lower mass-to-light ratio is counteracted by the lower masses of the systems at high redshift, leading to no net increase and perhaps a decrease in overall luminosity. This can be seen as a consequence of cluster-cluster mergers where current-day BCGs are built up from the merger of the several BCGs in high-redshift subclusters. This explanation would imply that GPS galaxies are also BCGs or central cluster galaxies.

These results suggest that the evolution of the optical and near-infrared properties of GPS galaxies can be treated as representative of giant elliptical galaxy evolution. Given the difficulty of finding high-redshift giant ellipticals by purely optical means, and the comparative ease of selecting GPS sources from radio surveys, the GPS selection technique may be the most effective way of assembling samples of high-redshift giant ellipticals. In a sample of GPS sources selected at the North Ecliptic Pole from the Westerbork Northern Sky Survey, one-third of the sources are galaxies with estimated or measured redshifts above $z=1$. This corresponds to a source density on the sky of one per 20–30 square degrees (Snellen et al., in preparation).

5 CONCLUSION

We have shown that the K -band Hubble diagram for GPS radio galaxies has a small scatter, comparable to the scatter in the R -band Hubble diagram. The $r-K$ colours of these galaxies are consistent with models of passively evolving and non-evolving old stellar populations. This behaviour is in contrast to that of the host galaxies of powerful extended radio sources such as those in 3C, for which the scatter in the Hubble diagram is larger and the colours are bluer.

In contrast to models of passive evolution, the higher redshift sources seem to have lower optical/near-infrared luminosities than those at low redshift. This behaviour mirrors that seen for brightest cluster galaxies at similar redshifts. This may indicate that higher redshift systems are less massive than nearby GPS galaxies, and that the galaxies become more massive over time by merging with other galaxies that have similar colours.

Given that the optical properties of the host galaxies of these GPS sources appear to be unaffected by the presence of the radio source, we can use the GPS selection technique to study ‘ordinary’ giant elliptical galaxies out to higher redshifts more effectively than using optical selection alone.

ACKNOWLEDGMENTS

The United Kingdom Infrared Telescope is operated by the Joint Astronomy Centre/Royal Observatories on behalf of the UK Particle Physics and Astronomy Research Council. We thank the UKIRT service team and especially John Davies for their support. We thank Gustavo Bruzual and Stephane Charlot for providing us with their Isochrone Synthesis Spectral Evolution Code (Bruzual & Charlot, in preparation). We thank Matt Lehnert for useful discussions. MNB acknowledges financial support from an EC twinning project and a programme subsidy from the Dutch Organization for Scientific Research (NWO).

REFERENCES

- Aragón Salamanca A., Ellis R. S., Couch W. J., Carter D., 1993, *MNRAS*, 262, 764
- Coleman G. D., Chi-Chao Wu, Weedman D. W., 1980, *ApJS*, 43, 393
- Dunlop J. S., Peacock J. A., 1993, *MNRAS*, 263, 936
- Eales S. A., Rawlings S., 1996, *ApJ*, 460, 68
- Fanti C., Fanti R., Dallacasa D., Schilizzi R. T., Spencer R. E., Stanghellini C., 1995, *A&A*, 302, 317
- Gunn J. E., Oke J. B., 1975, *ApJ*, 195, 255
- Hoessel J. G., Gunn J. E., Thuan T. X., 1980, *ApJ*, 241, 486
- Lilly S. J., Longair M. S., 1984, *MNRAS*, 211, 833
- O’Dea C. P., Baum S. A., Stanghellini C., 1991, *ApJ*, 66, 380
- Phillips R. B., Mutel R. L., 1982, *A&A*, 106, 21
- Readhead A. C. S., Xu W., Pearson T. J., 1994, in Zensus J. A., Kellermann K. I., eds, *Compact Extragalactic Radio Sources*. NRAO, p. 17
- Readhead A. C. S., Taylor G. B., Pearson T. J., Wilkinson P. N., 1996, *ApJ*, 460, 634
- Snellen I. A. G., Bremer M. N., Schilizzi R. T., Miley G. K., van Ojik R., 1996, *MNRAS*, 279, 1294 (Paper I)
- Thuan T. X., Puschell J. J., 1989, *ApJ*, 346, 34
- Ward M., Allen D. A., Wilson A. S., Smith M. G., Wright A. E., 1982, *MNRAS*, 199, 953