Multiwavelength observations of PKS 2255−282

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ABSTRACT

During high radio frequency AGN monitoring we observed a major millimeter-wave outburst from PKS 2255−282 in 1997 and initiated a campaign for multifrequency radio monitoring and VLBI imaging of the source. In January 1998 the EGRET instrument onboard the CGRO detected a bright high-energy γ–ray outburst from its direction. Thus we had the unique opportunity to monitor the source in detail at various radio frequencies already before the detection of the γ–ray outburst. We also initiated multiwavelength followup observations. In this paper we present multiwavelength data for PKS 2255−282 before and after the γ–ray outburst. Further, based on the observations, we estimate some physical parameters for this source and discuss the various emission mechanisms possibly involved during this outburst.

Subject headings: quasars: general – quasars: individual (PKS 2255−282)

1. Introduction

The radio-loud active galactic nucleus (AGN) PKS 2255−282, z=0.926, is a southern source that did not receive very much attention prior to its flaring at γ–ray energies in January 1998. Historical observations of PKS 2255−282 (Bolton & Butler 1975; Condon et al. 1978; Kühr et al. 1981; Large et al. 1981; Morabito et al. 1986; the Parkes catalog 1990; Robertson et al. 1993; Quiniento & Cersosimo 1993; Steppe et al. 1993; Griffith et al. 1994, and the historical SEST–radio measurements (Tornikoski et al. 1996 and this paper)) show that it is a bright flat-spectrum radio source, with no prominent radio or optical outbursts reported in the literature. Optical polarization measurements conducted in June 1986 (Impey & Tapia 1990) gave a polarization of 2%(±0.4%) and polarization angle of 112°(±6°). This classifies PKS 2255−282 as a low polarization quasar (LPQ), based on the criterion where LPQs have a degree of polarization $p < 3\%$ and for high polarization quasars (HPQ) $p > 3\%$.

Millimeter-wave radio data for PKS 2255−282 have been collected since the end of 1987 as part of the SEST AGN monitoring project undertaken by the Metsähovi group (Tornikoski et al. 1996). Classified as one of the lower priority sources, the data set for this source is initially relatively sparsely sampled. No major outbursts were observed before 1997.

When the mm–flare was observed in 1997, a campaign for more frequent monitoring of the source at several radio wavelengths was initiated. During this campaign, EGRET observations onboard the Compton Gamma-Ray Observatory (CGRO) detected a very bright γ–ray flare in PKS 2255−282.

In the sections 2 to 6 we present multifrequency data obtained before, during and after the γ–ray flare. In section 7 we estimate various physical parameters from our data, (including several estimates of the Doppler factor of the emitting material) and discuss the multifrequency variability behaviour within the framework of common high-energy emission models.

2. Radio variability

2.1. Observations

At millimeter wavelengths PKS 2255−282 was observed as part of the AGN monitoring project with the 15-meter Swedish-ESO Submillimeter Telescope (SEST) at the European Southern Observatory site on Cerro La Silla in Chile. The Metsähovi group has monitored the flux variability of a relatively large sample of AGN at millimeter wavelengths since the end of 1987. The observations have been made at 3 mm / 90 GHz and 1.3 mm / 230 GHz. Until June 1995 the 3 mm observations were made using a dual polarisation Schottky receiver, and after that the measurements were made with an SIS receiver. As a backend, a wide-band (1 GHz) acousto-optic spectrometer was used. For the 1.3 mm observations we also initially used a Schottky reciever and a wide band AOS, but since 1991 measurements have been mainly obtained with a single channel bolometer. All the flux density measurements were made in a dual beamswitching mode, and the flux densities were calibrated against planets. Details about the SEST monitoring project as well as the full data base of the project until June 1994 can be found in Tornikoski et al. (1996).

At centimeter wavelengths PKS 2255−282 was observed as part of an on-going monitoring program undertaken with the Australia Telescope Compact Array (ATCA). Observations were made at 1.6, 2.4, 4.8 and 8.6 GHz. Data were recorded in XX and YY polarisations using bandwidths of 104 MHz and scan lengths of 1–2 minutes per observing frequency. The data were calibrated and reduced using the MIRIAD software package (Sault & Killeen 1996). To estimate the flux density of PKS 2255−282, a point source was fitted to the data. The error bars on the flux density are therefore dominated by the extended structure of the source (the effects of which are small since the source is highly compact). The errors in the flux density scale were estimated to typically be between 1 and 2%. The data points from 1998 January 19 and 27 were based on 15 minute and 5 minute scans at 4.8 GHz and 8.6 GHz, respectively, with a bandwidth of 128 MHz. The error bars for these data points were 5–6% of the flux density. PKS 1934-638 served as a primary calibrator for these data points.

The centimeter wavelength data points presented in this paper were collected between July 1996 and August 1998.

2.2. Radio variability from 1987 to 1997 (before the mm–flare)

Our SEST monitoring data for PKS 2255−282 before 1997 is relatively sparse (between 1987 and 1996 only 1–2 SEST 90 GHz data points per year), but we have complemented our data sets with IRAM data from the literature (Steppe et al. 1988, 1992, 1993; Reuter et al. 1997). The average radio flux densities from this period are given in Table 1. The 90 and 230 GHz flux curves with SEST and IRAM data are shown in Fig. 1.

In spite of the somewhat sparse sampling we can see no indication of any very rapid and strong outbursts before the 1997 flare. In 1988–1989 there was a moderate flare observed, during which the 90 GHz flux increased from ca. 2.5 Jy to the maximum of 5 Jy, and after 1990 the flux level remained at a relatively constant value slightly below 2 Jy.

Towards the end of 1994 there were already indications of the mm–flux starting to rise, but flux levels ca. twice the quiescent flux values (4 Jy at 90 GHz) were not reached until 1996.

We unfortunately had no lower radio frequency monitoring for PKS 2255−282 during the moderate flare in 1988–1989 or the quiescent period in 1990–1996, but we have collected data from the literature (see the references listed in Section 1) indicating that no major flares have been observed in the cm–wave domain.

2.3. Radio variability from 1997 to 1998 (during the mm–flaring period)

In April 1997 the flux density of PKS 2255−282 at 90 GHz was observed to be over 8 Jy, twice the flux density observed 11 months earlier. This was a clear indication of a very strong mm–wave outburst and alerted our group for multiwavelength radio monitoring and more dense sampling.

At the end of June 1997 the 90 GHz flux was 10.1 Jy, making PKS 2255−282 one of the very small handful of sources to ever have exceeded 10 Jy at 3 mm. By August 1997 the flux density was back to 55% of the peak value at 230 GHz and 65% at 90 GHz, but there was a moderate rise in the 90 GHz flux again towards the end of the year.

The multifrequency radio flux curves since the beginning of 1996 are shown in Fig. 2. At 8.6 GHz we observed a notable increase in the flux level simultaneously (within our sampling accuracy) with the higher frequency flux. A moderate increase from the 1996.5 flux levels were also observed at 4.8 GHz and 2.3 GHz, while the 1.6 GHz data showed almost constant flux densities throughout the outburst.

After the peak of the mm–flare was observed, also the 8.6 GHz flux density decreased but from the beginning of 1998 there has been another period of flux increase which still continued in August. By August 5th, 1998, the 8.6 and 4.8 GHz flux curves had reached their all time maxima: 6.6 Jy at 8.6 GHz and 3.6 Jy at 4.8 GHz. The new rising trend in the centimeter flux curves coincides with the very bright γ–ray outburst observed with the EGRET instrument in January 1998 from the direction of PKS 2255−282. The radio flux densities during the γ–ray outburst are given in Table 2.

In the mm–data there is a longer gap in 1998, mainly due to the SEST Sun limit. In August 1998 the 90 GHz flux was observed to be at approximately the same level as in December 1997. The behaviour of the 8.6 GHz flux curve as well as the still relatively high 90 GHz flux levels in late 1998 can be seen as an indication of a continuation of a very active period in the radio domain. The radio flux densities from the followup obserations after the γ–ray outburst are given in Table 3.

When following the approach by Teräsranta and Valtaoja (1994) to calculate the source brightness temperature, $T_{b,obs}$, and then the Doppler boosting factor from the radio variability observations, we get a $T_{b,obs} < 10^{12}$ K for the 90 GHz flare in 1997. This contradicts the T_b estimate from the VLBI data (Section 3) as well as the Doppler boosting factor estimates obtained from the high-energy data (Section 7). This can possibly be explained by the severe undersampling of the mm–data: we can not conclusively say when the flare starts or when it peaks. Another possibility is that there are two superposed flare components in the observed radio flux: one slowly increasing and decaying component, and another very rapid one. Indications of such superposed events also in higher frequency data have been found by Valtaoja et al. (1998) in the well-sampled Metsähovi AGN monitoring data. VLBI data obtained at later post-flare epochs may give us an indication of the true number of the underlying shock components.

2.4. Radio spectrum

The radio spectrum of PKS 2255$-$282 is very flat, especially during the mm–outburst. The quiescent spectra (historical data and epoch 1996.5 data) peak above 10 GHz, and the mm–flare spectrum peaks around 90 GHz. The radio spectral indices α (S$\propto \nu^{\alpha}$) for the quiescent state are $\alpha = -0.03$ betweeen 8.6 and 90 GHz and $\alpha = -0.57$ between 90 and 230 GHz, and during the mm–flare they are $\alpha = 0.22$ and $\alpha = -0.41$, respectively. In a study by Tornikoski et al. (1993) the average spectral index between 8.4 and 90 GHz for southern sources during their quiescent state was found to be $\alpha = -0.25$ for HPQs (14 sources) and $\alpha = -0.46$ for LPQs (24 sources). We can see that even in the quiescent state PKS 2255−282 has a radio spectrum flatter than that of ordinary quasars and even many HPQs, and during the outbursts the spectrum still flattens, so the radio behaviour of this source resembles that of the blazars much more than ordinary quasars.

3. VLBI Observations

VLBA observations of PKS 2255−282 were made on 1997 August 13 in the 5, 22, and 43 GHz bands. The data were reduced in AIPS using the standard set of reduction tasks for continuum VLBI and then imported into the DIFMAP software (1994) for model-fitting and imaging. Fig. 3 shows the resultant 5 GHz image, revealing a bright, marginally resolved core component of 2.8 Jy and a short ($\sim 5\,\mathrm{mas}$) jet extending to the south-west which contributes approximately 0.25 Jy to the image. At both 22 GHz and 43 GHz the jet feature was completely resolved and absent from images, however the core component at these frequencies contained 4.2 Jy and 2.7 Jy, respectively. Previously Fey, Clegg & Fomalont (1996; hereafter FCF) had imaged PKS 2255−282, in 1994, at 2.3 and 8.4 GHz. The structure seen in Fig. 3 is consistent with that of FCF at 8.4 GHz, but at 2.3 GHz FCF show that the jet feature extends approximately 20 mas from the core.

Table 4 lists the models fit using the MODELFIT command in DIFMAP, for our new 5, 22, and 43 GHz VLBA data, in the u-v plane.

Brightness temperature estimates for the core are also listed in Table 4, for the core component, in units of 10^{12} K, for Gaussian, optically thin sphere, and optically thick sphere model components, calculated in the source frame. Even using the least centrally concentrated component, the optically thick sphere, the brightness temperature exceeds 10^{12} K at 22 GHz, indicating that beaming of the radio emission is required.

Moellenbrock et al. (1996) measured the brightness temperature from the observations using single baseline VLBI observations at 22 GHz. Using a Gaussian model component they obtained a lower limit to the brightness temperature of 0.2×10^{12} K. The 1994 VLBA observations by FCF yield a brightness temperature of 2.7×10^{12} K at 8.4 GHz, using a Gaussian component. For the optically thin and optically thick sphere cases, this corresponds to brightness temperatures of 1.2×10^{12} K and 1.0×10^{12} K, respectively.

From the observations of FCF and our new VLBA observations at higher frequency, it appears that the nominal brightness temperature limit of 10^{12} K is being reached and perhaps exceeded in PKS 2255−282. Thus, beaming of the emission is required, which is reasonable for a core dominated radio source such as this. For PKS 2255−282 to produce its high-energy emission in γ–rays it would seem plausible that its intrinsic brightness temperature is close to 10^{12} K, if inverse Compton processes are responsible for the high-energy emission. If this is the case then the amount of Doppler boosting can be roughly estimated by comparing a plausible intrinsic brightness temperature to the measured brightness temperature. An intrinsic brightness temperature close to 10^{12} K and a measured brightness temperature only a factor of 2 to 3 higher means that the Doppler factor, δ, is likely to be 2–3.

With future VLBA observations at 5 GHz, we plan to measure any apparent motion in the jet components of PKS 2255−282 and obtain further constraints on the beaming properties of this source.

4. Optical observations

Historical optical observations for PKS 2255−282 have been published in Wright et al. (1983), Impey & Tapia (1990) and Bowen et al. (1994).

We made optical follow-up observations for PKS 2255−282 in the post-flare phase from July to September 1998 at the 0.35m telescope at Woomera (equipped with a SBIG-ST6 CCD camera) and the 0.9m telescope at CTIO. The Woomera telescope used a standard R-filter, while measurements at the CTIO-0.9m telescope were performed in standard VRI bands. A sequence of nearby reference stars (see Table 5 and Fig. 4) in the field of PKS 2255−282 was established at the CTIO telescope using standard stars from the list of Landolt (1973), and were used for calibrating the measurements of PKS 2255−282. At the Woomera telescope, differential photometric measurements of PKS 2255−282 were performed with respect to these secondary standards. Multiple exposure (8 frames with 4 min integration time each) were obtained to minimize the observational uncertainties. The results are given in Table 6.

5. High-energy observations

During the CGRO observations from 1997 December 30 to 1998 January 12 (VP708/709), PKS 2255−282 was $\sim 13^\circ$ from the center of the field of view of EGRET and COMPTEL. In the EGRET observation of January 1998 a strong outburst, comparable with the 3C 279 flare from June 1991, was detected, position-compatible with PKS 2255−282 (Bertsch et al. 1998). Standard analysis of the summed EGRET maps of viewing periods VP708/709 yields a 9.6σ-detection of PKS 2255−282. Its spectrum follows a straight power law between 30 MeV and 10 GeV with photon spectral index $\alpha_\gamma = 1.58 \pm 0.17$ (reduced $\chi^2 = 1.018$) and no indication of a break at high energies. We use the convention $N_{ph} \sim E^{-\alpha_\gamma}$ for the photon spectrum N_{ph} and use the measured spectral index to convert count rates in energy flux. The integral photon flux >100 MeV reads $(57.1 \pm 10.0) \times 10^{-7}\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. The inspection of the arriving events on a day-by-day basis reveals that the maximum energy output occured around day 9/10 of this viewing period though the most energetic event ($\simeq$ 11 GeV) arrived on day 2. By the end of this viewing period the count rate had dropped by about a factor of 3. The variability time scale lies in the order of several days. Historically, PKS 2255−282 was below the detection threshold of EGRET from 1991–92, yielding a 1σ upper limit of $1.48 \times 10^{-7}\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ (>100 MeV). In November 1997 EGRET measured a flux of $(4.7 \pm 2.3) \times 10^{-7}\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ (>100 MeV), a 3σ-detection, and roughly 10 times smaller than the flux from the January 1998 outburst. The differential EGRET gamma-ray energy spectrum during the January observations is given in Table 7.

The analysis of the BATSE data in the energy range 20–200 keV revealed no significant signal from PKS 2255−282 during the time of the EGRET-outburst. The 2σ upper limit for the time integrated signal (from 1997 December 30 till 1998 January 12) is calculated by folding the time integrated photon flux through the response function with a −2 power law photon spectral index, and is included in Fig. 5 .

COMPTEL has not seen this source, both during its EGRET-flaring state (Collmar 1998) and in previous observations. Therefore, we use the 3σ sensitivity limits for a typical two-week observation run (Kurfess et al. 1997) to constrain the SED in the COMPTEL energy range (0.75 MeV – 30 MeV) (see Fig. 5).

The historical ROSAT measurement point, taken during the ROSAT allsky survey (from 1990–91), gives $(9.43 \pm 3.25) \times 10^{-13}$ erg cm^{-2} s^{-1} in the 0.1–2.4 keV band, and is published in Brinkmann et al. (1994). Probably due to the high HI column density in the direction of PKS 2255−282, this source was not detected either by the IUE or the

EUVE-satellite.

XTE observations of PKS 2255−282 were conducted soon after the January 1998 γ-ray flare, on January 15th, and yield a flux level of $(9.0 \pm 1.4) \times 10^{-12}$ erg cm^{-2} s^{-1} in the 2–10 keV range. This is roughly an order of magnitude higher than the historical ROSAT measurement point.

Data reduction and analysis of the high-energy observations will be given in Chen et al. (1999).

6. The spectral energy distribution (SED)

PKS 2255−282 is one of the few EGRET blazars with a fairly good coverage at cm– and mm–radio wavelengths prior to its first detection at γ–ray energies by EGRET. Therefore we were able to construct its spectral energy distribution in different states of activity. Since the mm–radio data base of PKS 2255−282 is by far the most complete one compared to the other wavelengths, we chose this band to define the different temporal phases except for the flaring state.

We defined the following four activity states for our SED study:

1. The *quiescent state*, defined here as the average intensity between January 1990 and December 1993 in addition to all historical data prior to 1986.

2. The *pre-flare state* January 1994 to December 1997 before the γ-ray flare was observed.

3. The *flare-state*, defined as the time span of the CGRO observation during the γ–ray flare, plus one week.

4. The *post-flare state*, data collected in 1998 after the CGRO observations were ended.

Fig. 5 shows the energy distribution νf_ν for the quiescent, pre-flare, flare and post-flare state.

Only radio measurements are available for the pre-flare state. The flux densities show a continuous increase by a factor 4–5 over this state. The average pre-flare flux densities are given in Table 1. The flare-state includes cm–, mm– XTE– and EGRET–measurements (see Table 2 and Table 7).

In the radio regime the SED (Fig. 5) is well covered and shows a hardening with increasing flux density. This can be understood as the result of an increasing variability amplitude with increasing frequency. We note that the 4.8 GHz and 8.6 GHz flux densities in the post-flare state are still slightly rising, indicating a variability time scale of years. Unfortuntely, no data in the far-infrared frequency band are available, which prevents us from determining conclusively the maximum of the synchrotron hump in the SED. According to Fossati et al. (1998), the maximum synchrotron power in FSRQs is expected to be emitted at $\sim 10^{12} - 10^{14}$ Hz, which is not in conflict with our observations.

Optical photometry was only obtained in the post-flare state. Compared to the historical measurements only a slight brightening of ~ 0.5mag is noted. This would mean either that large-amplitude variability in the optical band happens on time scales less than months, or that only small-amplitude variations occur. The apparent positive slope of the historical NIR/optical data points in the νf_ν-plot may be due to observations at different activity states, while the simultaneous optical post-flare state measurements might indicate the onset of a "blue-bump" observed in a number of blazars. However, this can not be stated conclusively due to sparse frequency coverage in this spectral range. Note also that strong broad emission lines are observed from PKS 2255−282 (e.g., Wilkes 1986; Peterson et al. 1976).

In the high-energy region a second hump in the SED is expected. In PKS 2255−282 the peak of this component must lie at energies > 10 GeV as indicated by the hard spectrum in the EGRET-energy range. The similar power law spectrum in the XTE- and EGRET energy range together with the fact that the XTE-data points lie readily on the extension of the EGRET-spectrum within the observational uncertainties suggest the same origin for the X–ray and γ–ray emission. The dramatic increase of the GeV flux during the outburst, and the degree to which the power in this waveband dominates the νf_ν spectrum, is consistent with the behaviour found in other EGRET-detected flat spectrum radio sources (e.g. von Montigny et al. 1995).

7. Discussion

The observational multifrequency data base we have obtained for PKS 2255−282, complemented with data from the literature, extends from the low radio frequencies to the γ–ray energies, and our longest radio data sets span more than 10 years. Even though our sampling has been somewhat sparse and in most cases the multifrequency coverage has been only semi-simultaneous, we have been able to construct multifrequency spectra and spectral energy distribution diagrams for several epochs and activity states. Furthermore, this data set for the first time includes a significant amount of monitoring data *prior* to a major γ–ray flare.

The γ–ray flare observed in PKS 2255−282 in January 1998 was observed during a period of increased mm–wave activity. PKS 2255−282 has been in the EGRET field of view several times before January 1998, as indicated in Fig. 1, but was not detected in γ–rays until the source was in an active mm–state. This clearly indicates that the γ–ray flare was connected with the brightening in the mm–wave bands. Though the peak fluxes at 90 and 230 GHz were already reached 6 months before the γ–ray flare was observed, the multifrequency radio flux curves indicate that in January 1998 the source was still in a very active state also in the radio domain. So it appears that radio activity in PKS 2255−282 is related to γ–ray emission in the EGRET-energy range. Furthermore, the γ–ray outburst occured during the increasing phase of the cm–radio emission. Valtaoja and Teräsranta (1996) have argued that the detection of γ–ray flares during the onset of high radio frequency flares is a clear indication that γ–rays originate from the same shock as the synchrotron radio emission. The connection between activity in the radio domain and the EGRET energy domain for active EGRET–blazars was also found by Mücke et al. (1996) on a statistical basis. However, due to the undersampling of the γ–ray data for this source, a direct luminosity correlation between radio and γ–ray emission can not be confirmed.

Rapid time variability in the γ–ray regime together with co-spatially emitted GeV and keV photons can place strong constraints on the beaming factor of the high-energy radiation. For PKS 2255−282 the observed GeV and keV fluxes, which we assume to originate co-spatially, imply that the optical depth due to photon-photon pair production can not exceed unity for this source. With this constraint, and using a variability time scale of several days in the γ-ray band we can estimate a lower limit for the Doppler factor (see e.g. Mattox et al. 1993, Eq.4; note, however, that in this equation a factor $(1+z)^4$ is missing),

$$\delta \approx 3(\frac{E_\gamma}{\mathrm{GeV}})^{0.118},$$

where E_γ is the observed γ–ray energy. For $E_\gamma = 0.03 - 10$ GeV the minimum Doppler factor is $\delta = 2 - 4$, in approximate agreement with the “inverse Compton catastrophe” limit derived from the VLBI observations. Note, that neither of these two limits for the Doppler factors depend on a particular model for the high-energy emission.

Simultaneous multifrequency observations may be able to discriminate between the different models for the high-energy emission. From the radio to the UV–band (or even X–ray band in some TeV-blazars) relativistic electrons radiate synchrotron photons, and at higher energies low energy photons are up-scattered to γ–ray energies by the same population of electrons. In the synchrotron self-Compton (SSC) model the target photons for the inverse Compton (IC) scattering originate from the synchrotron photons generated in the jet, and the IC component of the spectrum has the same spectral shape as the synchrotron component. In the SSC model one expects the optically thin synchrotron emission to vary simultaneously, but unequally in amplitude, with the high-energy radiation. In the external inverse Compton (EIC) model the target photons for the IC scattering originate from a photon source external to the jet: an accretion disk (e.g. Dermer & Schlickeiser 1993) or reprocessed radiation from the surrounding BLR and/or the dusty torus (e.g. Sikora et al. 1994, Ghisellini & Madau 1996). If the γ–ray flare is caused by an increase in the electron density in the emerging plasma blob, the EIC model also predicts simultaneous variations of the synchrotron and IC component, but in contrast to the SSC model with comparable amplitudes in both high and low energy components. Unfortunately, neither the luminosities of the synchrotron and IC peak nor the exact epochs of the radio and high-energy peaks can reliably be estimated from our data for PKS 2255−282.

In the EIC model variations can also be caused by changes in the seed photon flux which should be observed before the γ–ray flare. In this case, the synchrotron and IC component would not show correlated variations. However, IR to UV data are not available for PKS 2255-282, preventing us from investigating this possibility. We conclude that, on the basis of our data, it is not possible to decide which of the SSC or EIC mechanisms is dominantly responsible for the high-energy emission from PKS 2255−282.

Adopting a simple one-zone homogeneous SSC model, we can derive an estimate for the beaming factor if the observed X–ray emission is due to the SSC mechanism (e.g., Jones et al. 1974; Marscher 1987). We assume that the electron spectrum (in the jet frame) is distributed isotropically in a spherical plasma blob and follows a power law $\propto \gamma^{-2\alpha-1}$ where

γ is the Lorentz factor of the electrons and α the energy spectral index of the optically thin synchrotron spectrum ($F \propto \nu^{-\alpha}$). Furthermore, the magnetic field is assumed to be homogeneous and isotropic. Following Ghisellini et al. (1996) the minimum Doppler factor for the case of a moving sphere is then given by

$$\delta = f(\alpha)F_m(1+z)[\frac{\ln(\nu_b/\nu_m)}{F_x\Theta_d^{6+4\alpha}\nu_x^{\alpha}\nu_m^{5+3\alpha}}]^{1/(4+2\alpha)}$$

where: $f(\alpha) = 0.08\alpha + 0.14$; F_m is the radio flux from the core; Θ_d is the angular size of the core at the synchrotron-self absorption frequency ν_m; ν_b is the synchrotron high frequency cutoff; and F_x is the X–ray flux at frequency ν_x. From our VLBI images we derive $\Theta_d \approx 0.28\,\mathrm{mas}$, $F_m = 4.2$ Jy at $\nu_m = 22$ GHz and $\alpha = 0.66$ the spectral index between 22 GHz and 43 GHz. We estimate the synchrotron cutoff to be $\nu_b \sim 10^{13}$ Hz. With these numbers we derive $\delta \sim 5$ and 7 using the XTE and ROSAT X–ray flux, respectively. This is roughly a factor of 2 higher than our previous estimates for the beaming factor, however, it is model dependent and also suffers from the non-simultaneity of the radio and X–ray data.

In the framework of a homogeneous SSC model the low-energy component is due to synchrotron radiation and the high-energy component due to inverse Compton (IC) scattering of the low energy component by the same population of electrons. The observed SED (Fig. 5) suggests that the synchrotron peak lies around $\nu_s \sim 10^{13}$ Hz and the IC peak is at $\nu_{IC} > 10^{24}$ Hz. The IC scattering producing the GeV γ–rays mainly lies in the Thomson regime since $\nu_{IC} \leq (\delta mc^2/h)^2/\nu_s$. The Lorentz factor of the radiating electrons in the synchrotron/IC-hump can thus be estimated to be $\gamma_b' = \sqrt{\frac{3\nu_{IC}}{4\nu_s}} \sim 3\times 10^5$. Here and in the following, primed quantities refer to the jet frame. The maximum energy of the synchrotron component is determined by the magnetic field B' and the energy of the electrons γ_b'. Thus, we can estimate the magnetic field with $B' \simeq [(1+z)/\delta][\nu_s^2/2.8\times 10^6\nu_{IC}] \leq (1-2)\times 10^{-5}$ G for $\delta = 2-7$.

8. Conclusions

We have collected multifrequency data for PKS 2255−282 before, during and after the bright γ–ray outburst observed in January 1998.

The radio spectrum of PKS 2255−282 is already relatively flat in the quiescent state, but it still flattens during the active state. The radio spectrum and variability resemble those of blazars. Optical observations were made only in the post-flare phase and show no indications of optical flaring.

In January 1998 the source underwent a short period of activity in the high-energy domain, detected in the EGRET γ–ray and the XTE X–ray observations. We have carried out data analysis based on our quasi-simultaneous multifrequency data. Even though the activity in the radio domain appears to be related to the γ–ray emission, which supports the SSC model, we can not rule out the possibility of the EIC mechanism, either. The similar power law spectrum in the XTE and EGRET energy range suggest the same origin for the X–ray and γ–ray emission. The peak of the high-energy component is expected to lie at energies > 10 GeV.

After the first version of this paper was finished, a study on the γ–ray flaring of PKS 2255−282 was published in Macomb, Gehrels & Shrader (1999). The EGRET data analysis of Macomb et al. differs slightly from the usual method, which was also used in this paper, and yields a total γ–ray flux of >100 MeV $(1.6 \pm 0.3) \times 10^{-6}\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ with a peak flux of $(4.8 \pm 1.1) \times 10^{-6}\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$.

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REFERENCES

Bertsch D., IAUC 6807

Bohlin, R.C., Savage, B.D., Drake J.F. 1978, ApJ, 224, 132

Bolton, J.G., Butler, P.W. 1975, AuJPA, 34, 1

Bowen, D.V., Osmer, S.J., Blades, J.C. et al. 1994, AJ, 107, 461

Brinkmann, W., Siebert, J., Boller, Th. 1994, A&A, 281, 355

Chen A. et al. 1999, ApJ, in preparation

Collmar, W. 1998, private communication

Condon, J.J., Jauncey, D.L., Wright, A.E. 1978, AJ, 83, 1036

Dermer, C.D. & Schlickeiser, R. 1993, A&A, 416, 458

Fey, A.L., Clegg, A.W., Fomalont, E.B. 1996, ApJS, 105, 299 (FCF)

Fossati, G., Maraschi, L., Celotti A., Comastri, A., Ghisellini G. 1998, MNRAS, 299, 433

Ghisellini, G. & Madau, P. 1996, MNRAS, 280, 67

Ghisellini, G., Padovani, P., Celotti, A., Maraschi, L. 1993, ApJ, 407, 65

Griffith, M.R., Wright, A.E., Burke, B.F., Ekers, R.D. 1994, ApJS, 90, 179

Impey, C.D. & Tapia, S. 1990, ApJ, 354, 124

Jones, T.W., O'Dell, S.L., Stein, W.A. 1974, ApJ, 188, 353

Kühr, H., Witzel, A., Pauliny-Toth, I.I.K., Nauber, U. 1981, A&AS, 45, 367

Kurfess, J.D. 1997, in Proceedings of the 4th Compton Symposium, ed. Dermer, C.D., Strickman, M.S. & Kurfess, J.D., AIP Conf. Proc. 410 (New York: AIP), 509

Landolt, A.U., 1973, AJ, 78, 959

Large, M.I., Mills, B.Y., Little, A.G. et al. 1981, MNRAS, 194, 693

Macomb D.J., Gehrels, N., & Shrader R. 1999, ApJ, 513, 652

Marscher, A.P. 1987, in Superluminal Radio Sources, ed. Zensus & Pearson, (Cambridge University press), 280

Mattox, J., Bertsch, D.L., Chiang, J. et al. 1993, ApJ, 410, 609

Moellenbrock, G.A., Fujisawa, K., Preston, R.A. et al. 1996, AJ, 111, 2174

von Montigny, C., Bertsch, D.L., Chiang, J. et al. 1995, ApJ, 440, 525

Morabito, D.D., Niell, A.E., Preston, R.A. et al. 1986, AJ, 91, 1038

Mücke, A., Pohl, M., Reich, W. et al. 1996, A&AS, 120, 541

Parkes Catalogue 1990, Australia Telescope National Facility

Peterson et al. 1976, ApJ, 207, L5

Quiniento, Z.M. & Cersosimo, J.C. 1993, A&AS, 97, 435

Reuter, H.-P., Kramer, C., Sievers, A. et al. 1997, A&AS, 122, 271

Robertson D.S., Carter, W.E., Ray, J.R. et al. 1993, AJ, 105, 353

Sault, B. & Killeen, N. 1996, MIRIAD Users Guide.

Shepherd, M.C., Pearson, T.J., Taylor, G.B. 1994, BAAS, 26, 987

Sikora, M., Begelmann M.C., Rees M.J. 1994, ApJ, 421, 153.

Steppe, H., Salter, C. J., Chini, R. et al. 1988, A&AS, 75, 317

Steppe, H., Lichti, S., Mauersberger, R. et al. 1992, A&AS, 96, 441

Steppe, H., Paubert, G., Sievers, A. et al., 1993, A&AS, 102, 611

Teräsranta H. & Valtaoja E. 1994, A&A, 283, 51

Tornikoski, M., Valtaoja, E., Teräsranta, H. et al. 1993, AJ, 105, 168

Tornikoski, M., Valtaoja, E., Teräsranta, H. et al. 1996, A&AS, 116, 157

Valtaoja, E. & Teräsranta, H. 1996, A&AS, 120, 491

Valtaoja, E., Lähteenmäki, A., Teräsranta, H., Lainela, M. 1999, ApJS, 120. 95

Wilkes, B.J. 1986, MNRAS, 218, 331

Wright, A., Ables, J.G., Allen, D.A. 1983, MNRAS, 205, 793

Zombeck, M.V. 1982, Handbook of Space Astronomy and Astrophysics (Cambridge University Press)

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Fig. 1.— The 90 GHz and 230 GHz flux density curves for PKS 2255−282. The data are from IRAM (Steppe et al. 1988, 1992, 1993; Reuter et al. 1997) and SEST (this paper). The epochs when the source was in the EGRET field of view are indicated by dotted lines. The epoch of the EGRET-detected γ–ray outburst is indicated by a solid line. During the pointings from February 1993 to August 1994 PKS 2255−282 was 30° off-axis where the sensitivity of EGRET is very low.

Fig. 2.— ATCA and SEST observations during the millimeter-flare.

Fig. 3.— The 5 GHz VLBA image of PKS 2255−282 on 1997 August 13.

Fig. 4.— $10' \times 10'$ field showing stars measured at CTIO (PKS 2255−282 indicated by tick marks). (PS image courtesy of STScI.)

Fig. 5.— Spectral energy distribution in different activity states: quiescent state (dashed line), pre-flare state (dotted line) and flare state (solid line). The symbols for data points are as defined in the legend, and the downward pointing arrows denote upper limit values during the flare state.

TABLE 1. Average radio flux densities before the γ–ray flare (pre-flare state). TABLE 2. Radio flux densities during the time of the γ–ray flare. TABLE 3. Radio flux densities after the γ–ray flare. TABLE 4. VLBI data. TABLE 5. Reference stars. TABLE 6. Post-flare optical observations. TABLE 7. EGRET and XTE-observations during the γ–ray flare.