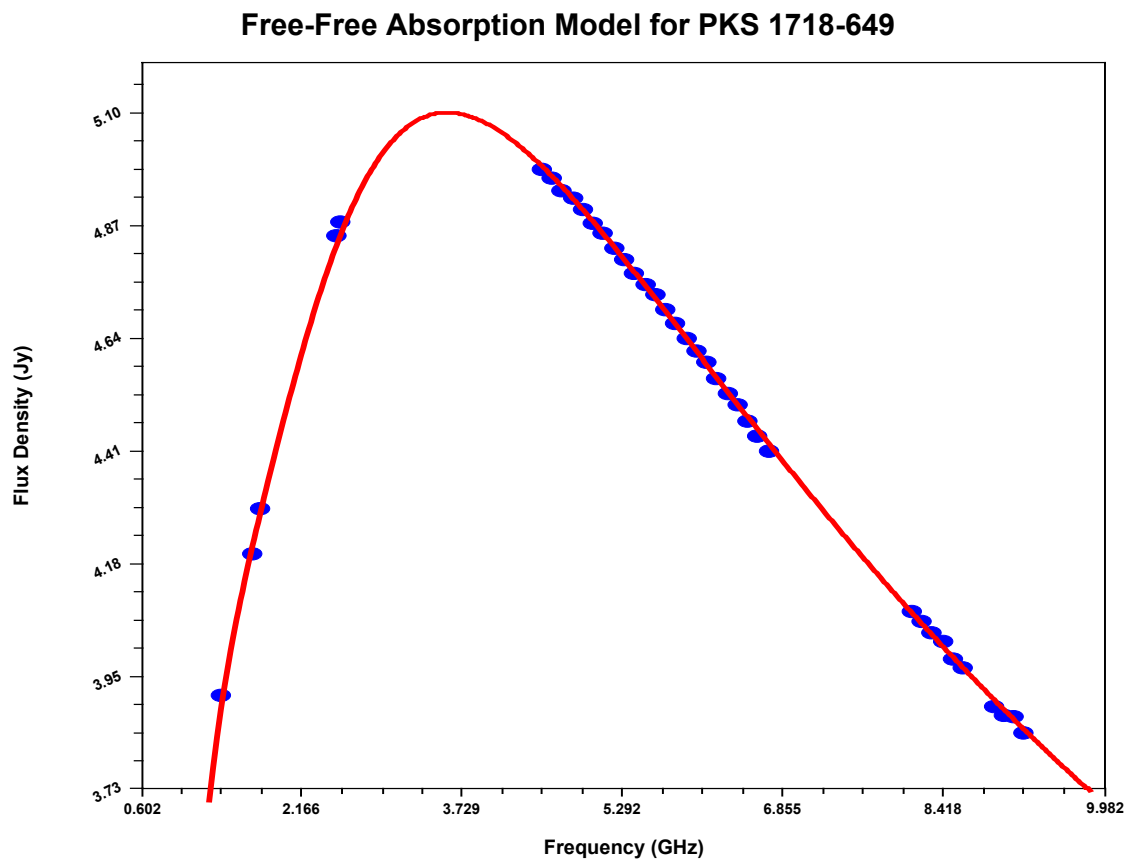


# Calculating a free-free absorption model for PKS 1718-649



Submitted by:

**Dennis Ward**

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## Abstract

In this paper, radio spectrum data from PKS 1719–649 was compared to a simplified free–free absorption (FFA) model to determine whether FFA could be used to account for the spectrum observed at radio wavelengths. PKS 1718–649 is a GHz peaked-spectrum (GPS) radio galaxy, consisting of two compact radio sources separated by approximately 2 pc. Agreement between the FFA model and the data presented suggests free–free absorption as a plausible explanation of the PKS 1719–649 radio spectrum. However, this agreement is not conclusive and there may be other physical processes, such as synchrotron self-absorption, that could account for all or part of the observed spectrum.

**Key Words:** galaxies: individual (NGC 6328) — quasars: absorption lines  
galaxies: active — radio continuum — physical data and processes

## 1. Introduction

### *GHz-peaked-spectrum Radio Sources*

GHz-peaked-spectrum (GPS) radio sources are generally defined as those extragalactic sources with central peaks that fall within the range of 0.4 – 5.0 GHz (Tingay et al., 1997). The other defining characteristics of these enigmatic objects include their peaked radio spectra with narrow spectral shape, low radio polarization, large luminosities, and compact radio structure (O’Dea, Baum, & Stanghellini, 1991). One of the most distinctive characteristics of GPS sources is a spectral turnover near 1 GHz.

Optical identification reveals these sources to be a mixture of galaxies and quasars. The GPS quasars have very high redshifts—approximately 50% of these quasars exhibit a redshift of  $z > 3$ . The quasars’ host galaxies may be protogalaxies with clumpy and dense interstellar media (ISM) (O’Dea et al., 1991).

The GPS galaxies tend to have more symmetric milliarcsecond radio structures than do GPS quasars. CCD imaging of GPS galaxies suggests that they tend to be merging and/or interacting. Spectroscopy supports the hypothesis that they have highly reddened and unusually dense narrow-line regions. They may have a dense and clumpy nuclear ISM due to recent cannibalization of a gas-rich companion (O’Dea et al., 1991).

There are two basic hypotheses that have been put forth to explain the peaked radio spectra observed in these sources. The first (synchrotron self-absorption) could explain the observed spectra if the source is compact enough and the absorption is *intrinsic* to the source. The other (free–free absorption) involves absorption *extrinsic* to the source in a high-density environment (Tingay et al., 1997).

## ***PKS 1718–649***

PKS 1718–649 is an example of a GPS galaxy. At a distance of ~56 Mpc, it is the nearest GPS galaxy—more than four times closer to us than any previously observed GPS object. Extensive observations have revealed that PKS 1718–649 is made up of two sub-parsec-scale components separated by approximately 2 parsecs. Its radio spectrum is narrow, peaking near 3 GHz (Tingay et al., 1997).

In this paper, I discuss recent observations of PKS 1718–649 and apply the model developed by Bicknell et al. to these data. This model favors the free–free absorption explanation for the observed spectrum’s shape.

## ***Free–Free Absorption***

Generally speaking, if a freely traveling electron passes near an ion (as in a gas cloud), and is not captured by the ion, there will be a finite change to its kinetic energy, corresponding to the emission or absorption of a photon. This is known as free–free emission or absorption because the electron moves freely before and after the encounter (Encyclopedia of Astronomy and Astrophysics, 2000).

More specifically, free–free absorption is the absorption of photons by these electrons. This must occur in the vicinity of a charged particle, as a single electron cannot absorb a photon and conserve momentum—a third body is required for the momentum conservation. The overall effect is a reduction in the emission from an astronomical object, such as a galaxy, as a function of frequency (Ord, 2001).

It is this reduction across a range of frequencies that was modeled by Tingay et al. (1997) and which is investigated again herein.

## **2. Data Reduction**

### ***Observations***

High precision flux density measurements of PKS 1718-649 made between 1.4 and 9.2 GHz are plotted in Figure 1. The data was obtained from observations made with the Australia Telescope Compact Array (ATCA), and was made available by Steven Tingay.

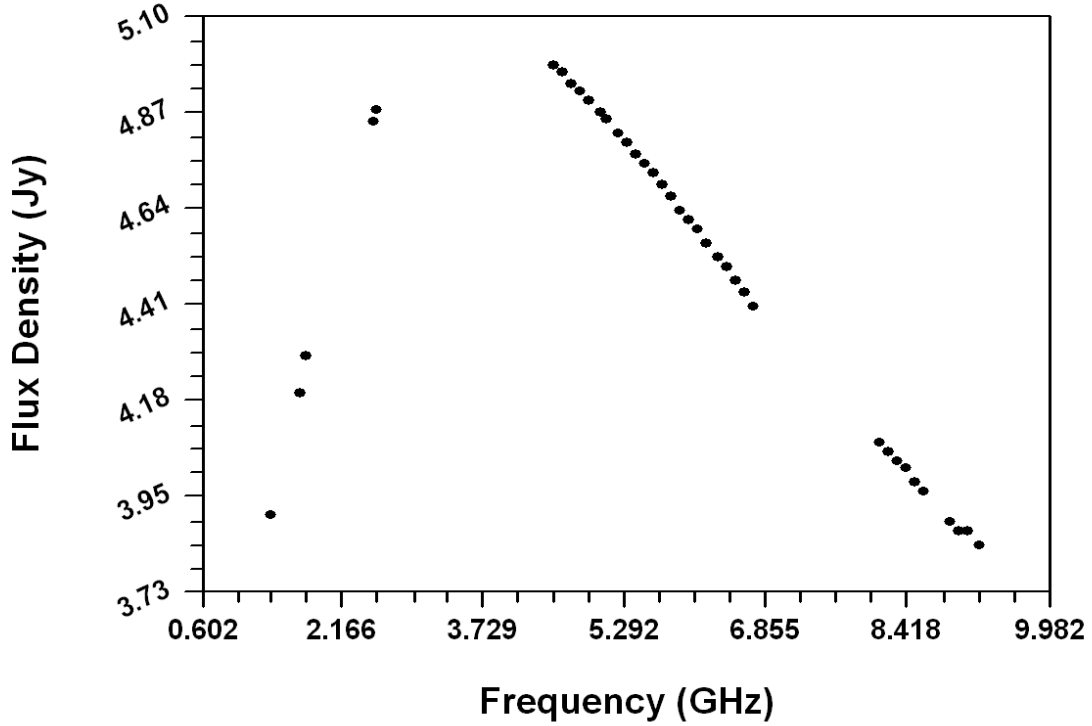


Figure 1. ATCA Observations of PKS 1719–649

### ***Evolution of Numerical Models***

In order to test the hypothesis that the GPS observed is the result of free–free absorption (FFA), an equation describing the absorption model is required.

$$B_{abs}(v_9, x) = A(x)v_9^{\alpha(x)}e^{-\tau_1(x)v_9^{-2.1}} \quad (1)$$

Equation (1) is a general formulation of the FFA model (Tingay & Murphy, 2001). In order to evaluate the fit of the observed data to this model, the curve fitting software CurveExpert was utilized. This allows the statistical estimation of the parameters as a function of the fit (defined as least squares) between the given data and the estimated model.

In order to more easily model the FFA, equation (1) was simplified and initially recast as follows:

$$y = a(x)^b e^{-c(x)^{-2.1}} \quad (2)$$

Equation (2) was reformatted as  $y = a * x^b * \exp(-c * x^{-2.1})$  for use in the curve-fitting software. The software estimates the best fitting equation in order to obtain estimates of the unknown parameters, a, b, and c. After 36 iterations, the fit of the data and the model were substantial, but not compelling, as shown below in Figure 2.<sup>1</sup>

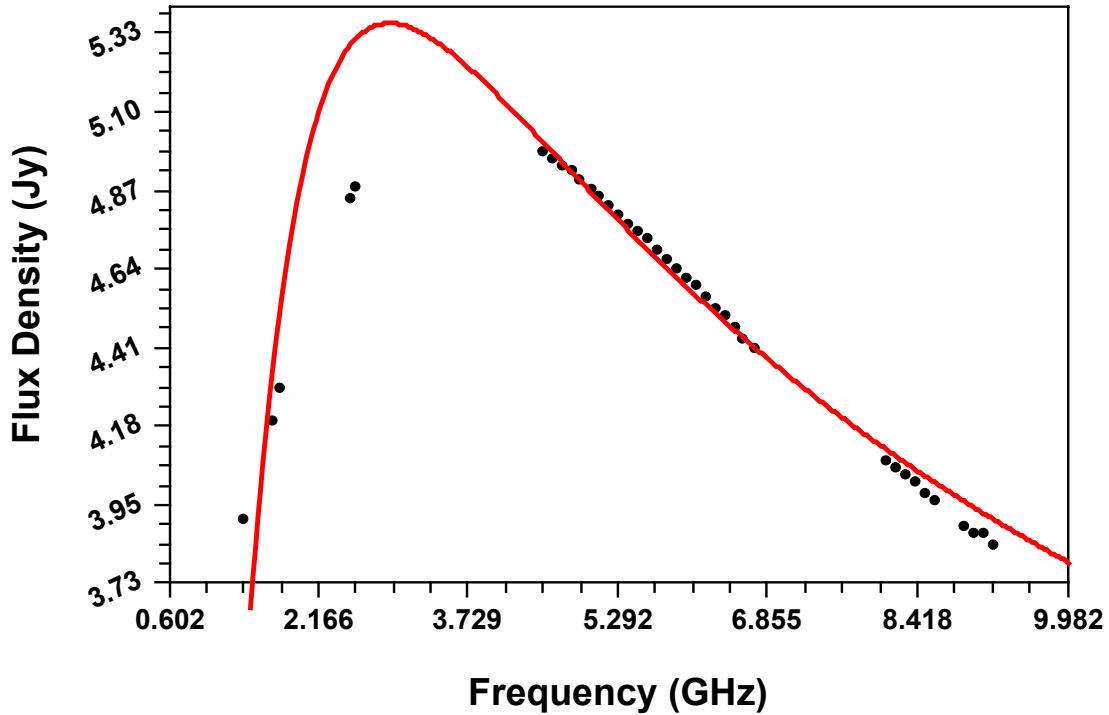


Figure 2. Results of matching observed data to equation (2)

While the data seems to fit the curve to a certain degree, the standard error as given by CurveExpert was 0.146 and the correlation coefficient was 0.93. A correlation of 0.93 implies that about 81% of the variance in the flux density (y) is explained by the estimated model. Indeed the standard error of approximately 0.15 shows that about 68% of the prediction will fall within 0.15 Jy of the prediction. As shown in Figure 2, this model overpredicts flux density substantially in the 2-4 GHz range and modestly at the high end of the frequency range (above 8 GHz). This suggests that it is useful to probe further this model.

Revisiting equations (1) and (2) led me to modify equation (2) as follows

$$y = a(x)^{b(x)} e^{-c(x)^{-2.1}} \quad (3)$$

<sup>1</sup> The final estimated values were a = 10.439837, b = -0.43419439, and c = 1.9224735

To be honest, I don't remember what on Earth led me to think that  $b$  needed to be raised to the power of  $x$ , but the results were interesting, as shown in Figure 3.

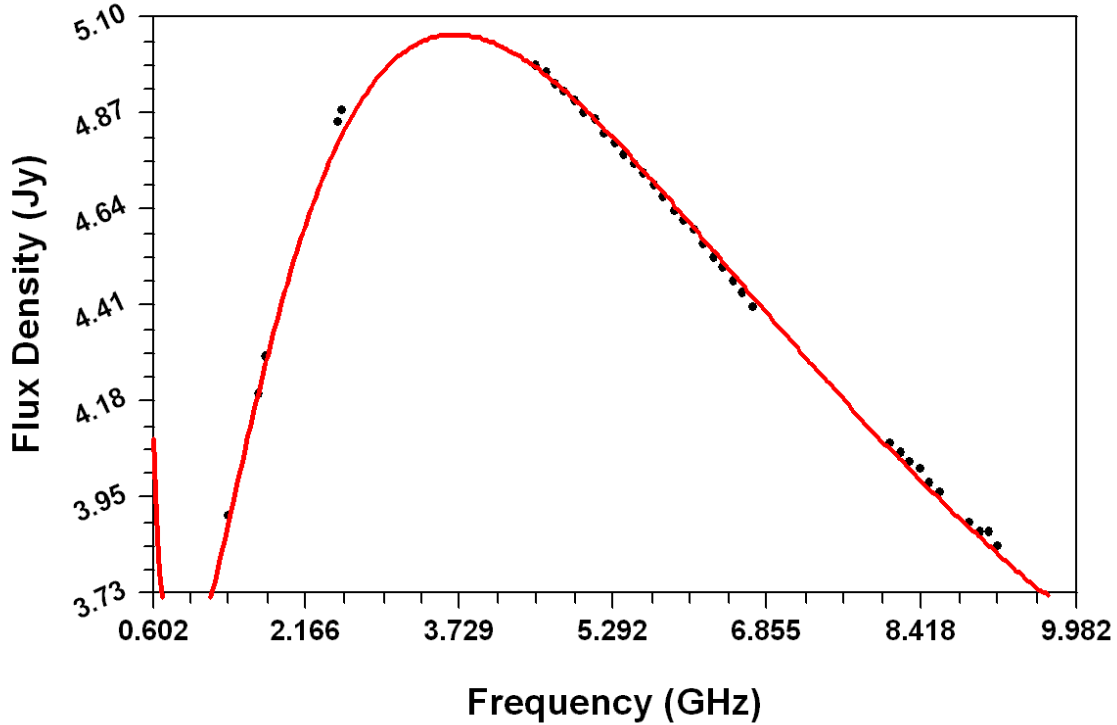


Figure 3. Intermediate model results (incorrect)

Using this model, CurveExpert reported that the standard error was reduced to 0.017 and the correlation coefficient was 0.999. This suggests, as shown in Figure 3, that the data and the estimated equation are virtually indistinguishable. While these results were certainly encouraging, it was quickly pointed out that the model represented by equation (3) had no relation to the physical domain. Again, more work was needed.

### Survival of the Fittest

In order to determine why equation (2) didn't yield the expected results, it is necessary to review the terms in equation (1) and how they were simplified in order to derive equation (2).

The first term in equation (1),  $A(x)v_9^{\alpha(x)}$ , represents the source's intrinsic spectrum, while the second term,  $-\tau(x)v_9^{-2.1}$ , represents the free-free absorption that modifies the intrinsic spectrum.

However, PKS 1719–649 is not a solitary radio source. It is made up of two compact radio sources separated by approximately 2 pc (Tingay et al., 1997). Therefore, the observed spectrum is actually the sum of two separate spectra. Each of the individual spectra will have its own intrinsic spectrum, modified by a separate free-free absorption term.

$$y = [Int. Spectrum_1]e^{[FFA_1]} + [Int. Spectrum_2]e^{[FFA_2]} \quad (4.1)$$

$$y = a_1(x)^{b_1} e^{-c_1(x)^{-2.1}} + a_2(x)^{b_2} e^{-c_2(x)^{-2.1}} \quad (4.2)$$

Equation (4.2) expands equation (4.1), replacing each of the symbolic terms with the terms from the simplified version presented in equation (2). This equation is a better theoretical representation of the underlying physical phenomena and therefore should also accurately model the observed spectrum, taking into account the individual components that comprise the aggregate observed values.

### 3. Results

In order to test the corrected model against the observed spectral data, equation (4.2) was reformatted as  $y=a*(x)^b*\exp(-c*x^{-2.1})+d*(x)^e*\exp(-f*x^{-2.1})$  for use by CurveExpert. After 73 iterations, the following results were returned:

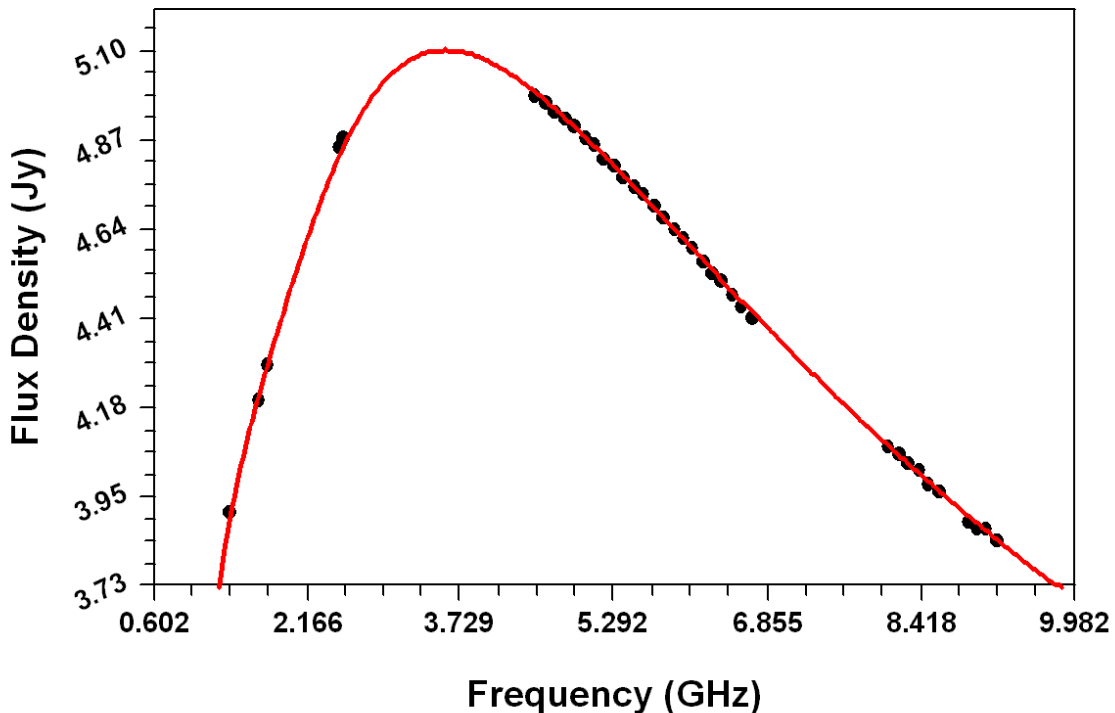


Figure 4. Final model results based on equation (4.2)

Using the updated model as given by equation (4.2), the correlation coefficient was calculated to be essentially 1.0 (specifically, 0.9998), with a standard error of very close to zero (0.0088).

Clearly, the observation data fits the updated model to a high degree of precision *and* adequately represents the physical processes known to be involved. Thus, it better represents the process, both theoretically and empirically. But does this prove conclusively that a two-component free-free absorption model is the physical process that describes the data?

## 4. Conclusion

One might be tempted at this point to say that the two-component FFA is in fact the physical process that results in the observed spectrum. Unfortunately, this conclusion is not provable. Just because the model fits the data well does not prove that the model is correct. At this point, the most that can be said is that a greatly simplified two-component FFA model may be used to accurately fit the observed data. Indeed, of the models examined herein, it is superior on theoretical as well as empirical grounds.

What other processes could account for the observed data? One such process is synchrotron self-absorption (SSA), which is based on absorption intrinsic to the radio source, as opposed to FFA, which depends on absorption extrinsic to the radio source (Tingay et al., 1997). Another possible interpretation is that there might be a combination of SSA and FFA taking place in either or both of the sources that make up PKS 1719–649.

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