Radio to X-Ray Observations of the Quasar 3C 273

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Quasars and active galactic nuclei are the most luminous objects we know. Their emission is distributed over all the spectral bands from radio waves to gamma rays, in such a way that we measure approximately the same flux in each frequency decade of the electromagnetic spectrum. Furthermore, large continuum flux variations are known to occur in most of the spectral bands. The very high luminosity (up to 10^{14} $L_{\odot}$) and the very small size ($\approx$ 1 light month, as deduced from typical variability time scales) of these objects indicate extreme physical conditions, which we are still far from understanding. The relationships between the variations in the different domains of the spectrum can however provide a powerful tool to study the interplay of the various emission components and therefore to understand the physical relations between the different cooling processes and associated electron populations.

In order to study these relations and also to measure the overall continuum emission spectrum avoiding the uncertainties due to the large flux variations observed in the different spectral domains, we performed repeated coordinated multi-frequency observations of the bright quasar 3C 273 from radio waves to X-rays.

Repeated observations of the continuum emission over most of the spectrum are only possible for a few active galactic nuclei which are sufficiently bright to obtain precise and absolutely calibrated flux measurements in relatively short exposures from ground-based telescopes and by space-born instrumentation. The bright and intrinsically luminous quasar 3C 273 was selected for a series of observations during the lifetime of the European X-ray satellite EXOSAT. During more than 2 years, starting in December 1983, we observed 3C 273 in the X-rays with EXOSAT, in the ultraviolet light with the satellite IUE, optically using the instrumentation of ESO and the Swiss telescope at La Silla, in the infrared domain with the UK infrared telescope in Hawaii and at ESO, in the mm band also at the UK infrared telescope and in the radio waves mostly with the Metsaehovi radio telescope in Finland. The results of this effort will be published shortly (1), a presentation of the first data obtained was given in the *Messenger* in 1984 (ref. 2).

Several observations of 3C 273 in each of the spectral domains radio, mm, infrared, optical, ultraviolet, X-rays were performed each observing season (December–July). They showed that there are at least 4 distinct cooling processes which dominate the continuum emission in the far infrared, near infrared, optical-ultraviolet and X-ray domains respectively. That the information acquired in the different bands is not redundant is shown by the fact that flux variations are not correlated in any simple way in the different spectral domains.

Our observations revealed that the flux observed in the different spectral domains varied with time in a complex and seemingly uncorrelated way: We observed an irregular decrease by a factor $\approx$ 2 in the hard X-rays (2–10 keV, observed in EXOSAT's Medium Energy detectors) between December 1983 and May 1984. The fastest flux variation during this period implies a change by a factor 2 in $\approx$ 30 days in this spectral region. At the same epoch the soft X-rays ($\approx$ 0.7 keV, observed in EXOSAT's Low Energy telescope) decreased by about 30 %, no comparable change was observed in any of the other bands. The long term behaviour of 3C 273 between 1984 and 1986 is characterized by a $\approx$ 20 % increase in the ultraviolet flux, a nearly constant flux in the optical and near infrared bands (J, H, K, L), with the possible exception of a "dip" by a factor $\approx$ 2 lasting one month in the near infrared, and a decrease at longer wavelengths by a factor $\approx$ 2 in the 10 μm and 20 μm region, a factor $\approx$ 4 in the mm region and a factor $\approx$ 2 in the radio waves. The soft X-ray flux varied between all observations by 20–30 % with no obvious trend, and the hard X-ray flux remained nearly constant after its initial large decrease until 1985 to increase again by $\approx$ 30 % at the beginning of 1986. The loss of EXOSAT in the spring of 1986 did not allow the monitoring of this new event.

The continuum spectrum shape as we observed it at the beginning of 1984 is shown in Figure 1. It can be described mathematically by the sum of the following functions: one power law of slope (energy index) $\approx$ 0.6 extending from the radio domain to $\approx$ 10 microns, another power law of slope $\approx$ 1.7 in the near infrared region, 2 black body distributions of T $\approx$ 20000 K and $\approx$ 120000 K and a power law with a slope of $\approx$ 0.45 describing the X-ray emission. The parameters describing the spectrum were determined by fitting the total function to the observed continuum data. The large gap in the observed spectrum extending from the ultraviolet (as observed by IUE) and the soft X-rays (observed by the Low Energy telescope of EXOSAT) makes it difficult to describe the exact

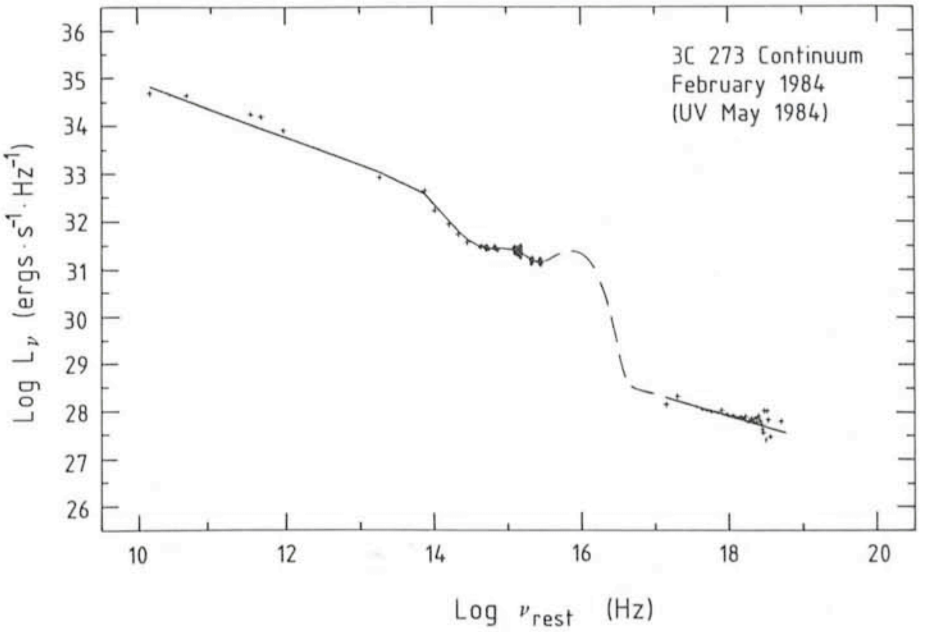

Figure 1: *February 1984 (UV in May) continuum energy distribution of the Quasar 3C 273 from the radio wave ($\approx 10^{10}$ Hz) to the X-ray ($\approx 10^{18}$ Hz) domains. The data are given as crosses and the fitted function (see the text) as a continuous line. The best fit parameters imply a large far ultraviolet "bump" (interrupted line), which will need confirmation with future instrumentation.*

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shape of the extreme ultraviolet bump which is implied by the available data. This is all the more regrettable since the largest contributions to the total luminosity could come from this bump at least at certain epochs. (At other epochs, the luminosity is probably dominated by the hard X-ray emission, up to a few 100's keV).

The flux variations observed in the different bands imply changes in the spectral parameters. The January 1986 spectrum is thus significantly flatter in the far infrared-mm (down to $\approx 5-10\ \mu m$) domain than the 1984 spectrum, whereas the near infrared emission (between $\approx 1\ \mu m$ and $\approx 5\ \mu m$) remained very stable (3). The slope of the X-ray emission remained, however, nearly constant when the flux changed.

The data we have collected can be used to test theoretical model predictions; they are, however, still far too scarce to constrain the models sufficiently to provide a univocal description of the quasar phenomenon. The complex pattern of time variations also provided evidence for a new spectral component: The different (and unexpected) behaviour observed in the mm-infrared domain above $\approx 5-10\ \mu m$ and below this limit (3) showed that the near infrared emission cannot be dominated by the high energy tail of the far infrared component, which is generally thought to be of synchrotron origin. The near infrared emission must therefore have an origin of its own, which we do not understand yet. Another example of different time variability patterns is found in the mm-infrared and the X-ray domains: No large mm-infrared flux variations were observed at the beginning of the campaign while the X-ray flux decreased by a factor ≈ 2. This implies that these two components cannot be emitted by the same electron population, as has often been proposed in the so-called synchrotron self-Compton models.

The time scales of variability in the different bands give useful limits to the size of the respective emission regions provided that no relativistic bulk motion or gross projection effects introduce large correction factors. The sizes we can infer from our observations indicate that the hard X-ray emitting region is of the order of ≈ 1 light month, similar to the near infrared emitting region (provided that the dip we observed is confirmed). The variations seen in the ultraviolet domain prior to our observations (4) also indicate a similar size for the region emitting the (optically thick) blue bump. The variations observed in the far infrared imply a size of less than a few light months. This latter number however cannot be further precised, because of the undersampling of the light curve.

The very different time variation patterns observed in the different bands and the typical variability time scales of ≤ 1 month show the need for numerous more coordinated observations of quasars covering the entire spectrum to reveal the interplay of the different components. Such observing campaigns are difficult to organize as they imply many different observatories around the world and little structure is available to coordinate observations from different institutions. EXOSAT has now finished its life and will not be followed by a European X-ray observing facility for some years. We hope, however, to have access to data from the Japanese X-ray satellite Astro-C to be launched next year to continue our efforts.

References:

1. Courvoisier, T.J.-L., Turner, M., Robson, E.I., Gear, W.K., Staubert, R., Blecha, A., Bouchet, P., Falomo, P., Valtonen, M. and Teräsranta, H., 1986, in preparation.
2. Courvoisier, T.J.-L., 1984, *The Messenger* **37,** September 1984.
3. Robson, E.I., Gear, W.K., Brown, L.M.J., Courvoisier, T.J.-L., Smith, M.G., Griffin, M.J. and Blecha, A., 1986, *Nature,* in press.
4. Courvoisier, T.J.-L. and Ulrich, M.H., 1985, *Nature* **316,** 554.

Modelling Space Telescope Observations

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1. Introduction

A software package designed to simulate observations obtained with the Hubble Space Telescope (HST) has been developed at the Space Telescope European Coordinating Facility (ST-ECF) at ESO, Garching. This report presents a comprehensive description of the reasoning and scientific, technical and operational background that has led to the development of this HST Model. Examples illustrate how the model is used to predict the actual results of observations.

2. Technical and Scientific Background

2.1. Operational differences between ground-based and HST observing

Observing experience cannot be gathered from handbooks and users guides alone. In the case of ground-based observations, it usually is the result of experiments under real observing conditions.

Often the best instrumental set-up and observational procedure is found only after several trials using mediocre atmospheric conditions to prepare for the really good nights.

In view of the expensive observing time and tight scheduling requirements, such a procedure is prohibitive for Hubble Space Telescope (HST) observations (and also not really desirable for ground-based activities). Furthermore, in the case of HST, almost all programmes will be pushing to the absolute limits of feasibility. In order to assure the utmost scientific return it will not be enough to tune the data reduction software to the limits set by information theory. The observational procedures as well will have to be set up in the most efficient way in order to keep the noise level in the data acquired below the largest tolerable value yet spending the lowest possible amount of the precious observing time allocated.

The optimal use of the HST and its scientific instruments for a given scientific problem will (in general) not be obvious to judge from the technical details of the performance alone. Slight changes in the performance of a given part of an instrument might in fact call for a revision of the entire observational strategy, e.g. the choise of grating and detector combination.

It follows that a system capable of simulating observations with the instruments of HST in advance of the layout of proposals and of the real observations can largely compensate for the lack of experience and of the possibility of interaction in operational procedures.

2.2. Technical differences between dedicated space experiments and HST

Usually astronomical space experiments work in frequency domains inac-

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