A SAMPLE OF ASTRONOMICAL TIME SERIES

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ABSTRACT

The observation of variability in astronomical systems provides astronomers with valuable information on the physical nature of the system. The types of variability which astronomers deal with can be periodic, quasi-periodic, or aperiodic. We collect and describe a number of time series data sets which exemplify the types of problems encountered by the modern astronomer and which demonstrate some of the methodological challenges they face. The *Sample* includes data sets with periodic, quasi-periodic and aperiodic behavior, sparse and unevenly spaced sampling, and paired time series requiring cross-correlation. The data sets in the *Sample* are available on diskette, over the Internet using the World Wide Web, or by electronic mail. We hope that statisticians and time series analysts will find problems of interest and be stimulated to apply new techniques to astronomical problems.

Key words: active galactic nuclei, astronomy, binary star, chaos, cross-correlation, deconvolution, fractal, gamma ray burster, irregular sampling, neutrino, periodicity, Poisson statistics, pulsar, quasar, quasi-periodic oscillation, sparse data, sunspot, supernova, time series, variable star.

1 INTRODUCTION

Astronomers operate under a scientific handicap: they can only observe the light (and occasional atomic particles) from stars and other celestial objects. They cannot change the conditions or parameters of whatever experiment the universe happens to be conducting. In addition, only a relatively few properties of cosmic sources which are observable from our terrestrial vantage point are conveyed by light, principally shape, position, color, and brightness. The variability of any of these properties with time provides the astronomer with valuable information which can lead to an understanding of the physical nature of the source.

Elsewhere in this volume, Feigelson (1995) gives an introduction to the types of time series problems astronomers often face. Astronomers are interested in the detection of periodic or quasi-periodic phenomena. They are also interested in the characterization of aperiodic systems; in particular, it is often necessary to determine whether or not a source has varied at all. These problems are complicated by the fact that astronomical data are often noisy, especially when the source being studied is exceedingly faint. Many of the modern detectors which are used to gather light are photon counting devices, so the astronomer is faced with Poisson rather than Gaussian noise processes. Astronomical time series are often irregularly sampled, as observing time can be interrupted by the rising of the Sun or Moon, poor weather, or the unfortunate scheduling of a telescope. This hampers the detection of periodicities or the cross-correlation of time series gathered at different wavelengths.

We have gathered a *Sample of Astronomical Time Series* (hereafter, our *Sample*) containing astronomical time series which illustrate many features of astronomical data and the types of problems facing the modern astronomer. Our *Sample* is available on the diskette included with this volume as well as electronically (see §8). We have grouped the data sets according to some broad definition of the problem they address; they are not presented here in the order in which they appear on the diskette.

The first data set is unquestionably the most famous — the monthly count of sunspots for the past 240 years (§2). It has been used several time in this volume to illustrate a periodic time series (e.g., Priestley

best methods for forecasting the sunspot number. We present several other data sets in which the detection of periodicities is the principle goal of the data analysis (§3). These data sets are complicated by irregular sampling or Poisson noise. A different type of problem in time series analysis is represented by data which consists of the arrival times of photons or neutrinos (§4). Here the question is whether the event rate changed during the observation.

It is not unusual for an object to be observed simultaneously with very different instruments (§5). The heterogeneous, and often irregularly sampled, data sets need to be cross-correlated to reveal relationships between multiple time series. Orbiting telescopes provide astronomers with large time series at high time resolution, so that each time sample has a low signal to noise ratio (§6). Many of the most energetic sources in the universe show variability which is chaotic in nature, and this behavior needs to be characterized. In his contribution to this volume, Scargle (1995) gives examples of wavelet analysis of the data from §6. In the last data set, we present data from a scanning instrument which poses a problem in the deconvolution of a time series (§7).

2 SUNSPOT NUMBERS

The Sun has an active magnetic field. One of the manifestations of the Sun's magnetic activity is the appearance of sunspots on the solar surface. The number of sunspots visible varies periodically with the Sun's 11 year "solar cycle" (actually a 22 year period when the direction of the solar magnetic field is included; see Figure 1 of Feigelson 1995). The 27 day rotation period of the Sun is also apparent in the daily sunspot numbers. In our *Sample* we include the monthly mean sunspot numbers for the last 240 years. These sunspot numbers were obtained from the World Data Center A for Solar-Terrestrial Physics in Boulder, Colorado (see §8).

Establishing the existence of additional real periods in solar data has long been of interest because any real period provides insight into the mechanisms of solar variability and the solar magnetic phenomenon. Two periods which have been proposed recently are those near 155 days (Lean & Brueckner 1989; Sturrock & Bai 1992) and 2.2 years (Shapiro & Ward 1962; Sakurai 1979). There have even been longer periods reported at 31 years (Bai 1988) and 100 years (Yoshimura & Kambry 1993). The behavior of the Sun has direct consequence on the Earth's atmosphere and magnetosphere; therefore there is value in predicting sunspot numbers. The Box-Jenkins (1976) method is most commonly used but a nonparametric Kernel density estimator has recently been proposed (Cerrito 1992). Further references can be found in the recent collection by Sonett et al. (1991).

3 DETECTING PERIODS IN STARS

Just as periodicities in the sunspot number allow fundamental properties of the Sun to be determined, periodicities in the observed properties of stars can be used to establish their physical nature. The data available for detecting periodicities often consist of irregularly sampled, sparse, and noisy time series.

The importance of detecting periods has motivated astronomers to develop and apply a wide range of period detection algorithms. These include Fourier techniques (Leahy et al. 1983; van der Klis 1989a), periodograms (Scargle 1982; Horne & Baliunas 1986), phase dispersion minimization (Stellingwerf 1978; Davies 1990), epoch folding (Leahy et al. 1983), and variants of the Rayleigh test (De Jager et al. 1989; Swanepoel & de Beer 1990; Bai 1992).

3.1 Orbital Periods in Binary Stars

It is generally believed that at least half of the stars in the Galaxy are in binary systems, where two stars orbit each other with strict periodicity. The detection and measurement of orbital periods, along with the application of Kepler's Third Law of Planetary Motion, is the only reliable method for directly measuring the masses of stars.

Except for rare eclipsing binary systems, where the brightness of the system varies, most binaries are identified by periodic variations in velocities measured from Doppler shifts in their optical spectra. These measurements are difficult to obtain, require great patience, and have limited accuracy. The radial velocity curve may be non-sinusoidal if the orbit is elliptical. Thus, detecting stellar binaries depends on locating periodicities of unknown shape in sparse, unevenly spaced, and noisy data. In an important study, Abt & Levy (1976) reported 25 spectroscopic binaries out of 135 stars studied; binaries were determined through least squares fitting of model orbits (see Figure 3 of Feigelson 1995). Using a phase dispersion minimization method and bootstrap resampling confidence intervals, Morbey & Griffin (1987) have called into question the reality of many of these periodicities. In our *Sample*, we include the data (Julian day of observation, radial velocity and 1σ experimental error in km s^{-1}) from Table 1 of Abt & Levy for the four stars HR 219 = η Cassiopeiae, HR 3991, HR 4395 = λ Crateris, and HR 8034 = 1 Equulei. Of these four stars, Morbey & Griffin claim 1 confirmed

3.2 Pulsational Periods in Variable Stars

δ Cephei and RR Lyrae variable stars are two related classes of red giant stars that, for complex reasons relating to the trapping and releasing of energy in certain internal layers, undergo large pulsations on timescales of hours to days. They are extremely important in astronomy because their pulsational periods are strongly correlated with their intrinsic luminosities (Watts of power emitted). This means that measurements of their pulsational periods and mean brightnesses, combined with the period-luminosity relationship, can be used to derive their distances. They are crucial rungs in the 'cosmic distance ladder' by which astronomers can estimate the distances to nearby galaxies. From a statistical viewpoint, the problem is to determine reliably and accurately the period of a star given a sparse, irregularly sampled data set of brightness measurements. The shape of the brightness variation during each pulse differs from star to star. It is usually non-sinusoidal and sometimes double-peaked.

Nemec et al. (1988) have measured the brightness as a function of time for 88 RR Lyrae and δ Cephei variable stars in the Ursa Minor dwarf spheroidal galaxy. They measured all of their program stars simultaneously from a series of photographic and electronic images of the galaxy. Nemec et al. used ordinary periodogram and phase dispersion minimization methods to determine the periods of the stars. In our *Sample*, we provide the Julian day for each measurement and the brightness of the six stars V4, V11, V77, V8, V75, and V100. The brightness is given in units of the B (blue) magnitude and the data are taken from Table 2 of Nemec et al.

3.3 Rotational Period of a Burster

During the 1960s, satellites designed to monitor for atmospheric nuclear weapons tests unexpectedly detected bursts of gamma rays from unknown celestial sources. For several reasons, it was believed that these bursts came from the surface of neutron stars in our Galaxy. Recent results from the Compton Gamma Ray Observatory indicate that the sources may be located among the distant galaxies (Meegan et al. 1992; Schaefer 1994; Fishman et al. 1994). Astronomers are still battling over the implications.

A subset of gamma ray bursters, the Soft Gamma Repeaters, form a separate group and almost certainly are neutron stars in our Galaxy (Norris et al. 1991). Two of them have been located in supernova remnants (Bailyn 1994), the clouds of gas left after a star explodes — a process which often creates a neutron star. Among these repeaters is the brightest gamma ray burster ever observed: the 1979 March 5 event.

The 1979 March 5 gamma ray burst event was unique for several reasons. One of these is the unambiguous detection of pulsations with a period of approximately 8 seconds during the decay phase of the event (Mazets et al. 1979; see Figure 9 of Feigelson 1995). The existence of pulsations implies the source is a rotating compact object. The periodicities set the March 5 event apart as unique, so one wants to squeeze as much information as possible from the data. Are the pulses strictly periodic or is there phase drift? How accurately can the period be determined? Does the pulse amplitude decay in time? In our *Sample*, we present the binned count rates for the decay phase of the March 5 event in units of counts per 0.25 seconds. The data were obtained by digitizing Figures 1 and 2 of Mazets et al. The bins are 0.25 seconds for the first 35 seconds, and 1 second for the remaining 20 seconds. The count rates appear to be quantized in quasi-multiples of 58 counts per 0.25 seconds, so the uncertainty is at least 30 counts per 0.25 seconds.

4 VARIABILITY IN EVENT DATA

Modern astronomical detectors, especially those used in orbiting X-ray and gamma ray observatories and the electronic CCD detectors used in optical and ultraviolet astronomy, detect individual photons. When the photon events are time tagged, the resulting data set is an unbinned time series. Naturally the most difficult statistical problems arise when count rates are low and Poisson statistics dominate.

Often astronomers wish to know if a source is emitting radiation at a constant or variable rate. This is a difficult problem when only a small number of photons have been detected. The most common methods used by astronomers are a simple Pearson's χ^2 test for binned data (Lampton et al. 1976) and the Kolmogorov-Smirnov test for unbinned data (Lightman et al. 1980). A phase averaging version of the χ^2 test has been shown to be superior for low count rate data (Collura et al. 1987). Recently a maximum likelihood method, which assumes Poisson statistics, is applicable to very low count rates, and includes instrumental background effects, has been proposed by Maccacaro et al. (1987) and Sciortino & Micela (1992). In a closely related area, astronomers have expended considerable thought and CPU time on establishing appropriate confidence limits for low count Poisson data (Gehrels 1986; Nousek & Shue 1989; Kraft et al. 1991).

4.1 X-ray Variability in a Quasar

Matilsky et al. (1982) report a detection of rapid changes in the X-ray emission of quasar 1525+337 (see

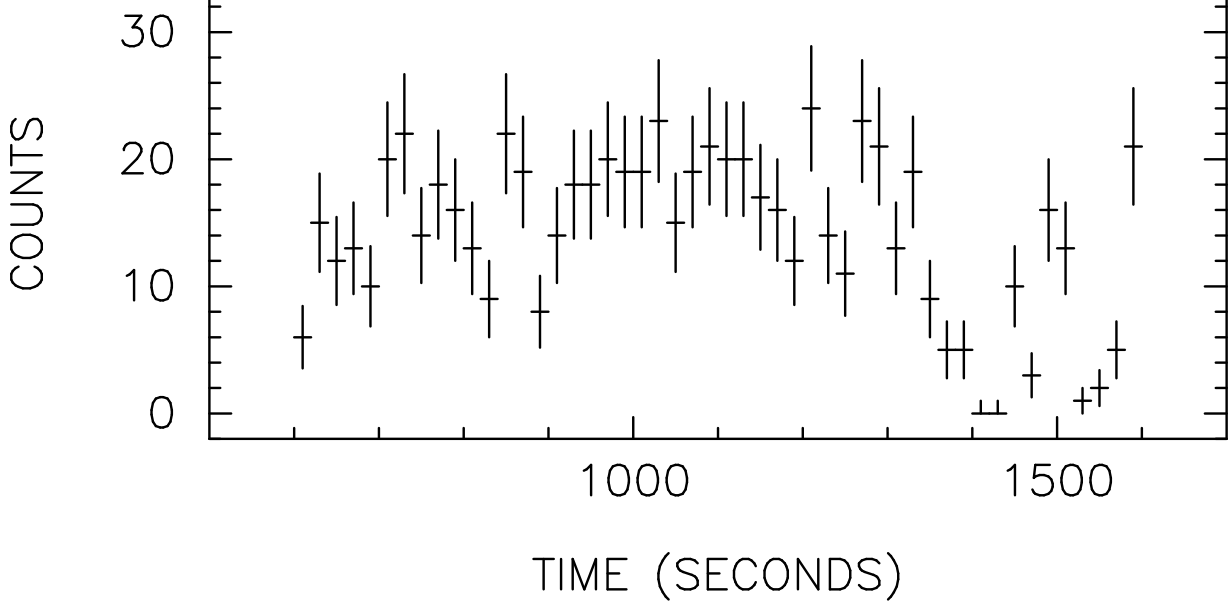

Figure 1: The counts from H0323+022 binned in 20 second bins and drawn with Poisson error bars. Note the decrease in counts after 1400 seconds. (§4.2)

Figure 5 of Feigelson 1995). They use a Pearson's χ^2 test and find significant variation on 200 second timescales at the 99.98% confidence level. However, an unbinned Kolmogorov-Smirnov test does not find a significant effect. Our *Sample* includes the arrival time (in seconds) of the 107 X-ray photons detected during a 1600 second observation with the *Einstein X-ray Observatory* and listed in Table 1 of Matilsky et al. How does one best determine whether a real variation has occurred?

4.2 Variability in a BL Lacertae Object

Another report of rapid variability in the X-ray emission of an active galaxy concerns the X-ray selected BL Lacertae object H0323+022 (Feigelson et al. 1986). Here, the statistical significance of the variation is much stronger: after 12 minutes of approximately constant emission, the X-ray emission suddenly ceases for nearly a minute, and then continues unevenly until the end of the observation. How can such erratic behavior be characterized? What is the "fastest" timescale of significant variation? What is the best test for deviation from Poisson arrival times? Our *Sample* contains the arrival time of 720 X-ray photons in seconds starting at 24000 seconds UT (Figure 1). The data are provided by Eric Feigelson (private communication) from Figure 6 of Feigelson et al.

4.3 Neutrinos from Supernova 1987A

An extremely important sparse data set are the 20 neutrinos detected from the supernova explosion seen on 1987 February 23 from a massive star in the Large Magellanic Cloud (see McCray (1993) for a recent review). The detection of neutrinos confirmed long-standing theories that neutrino emission dominates the supernova event. The duration of the observed neutrino pulse directly constrains the mass of the neutrino particle. The neutrino mass is crucial for particle physics and astrophysics (see Winter (1991) or Hillebrandt & Hoflich (1991) for an overview). A host of papers emerged after the SN1987a event analyzing the neutrino arrival times (see Arnett et al. (1989) for a review); different statistical analyses emerged with neutrino mass limits ranging from < 4 eV to < 32 eV. Which of these many estimates is best? The *Sample* contains the neutrino arrival times, in seconds, from the Kamioka and IMB underground detectors. The data are taken from Burrows & Lattimer (1987).

5 CROSS CORRELATION

Virtually all cosmic sources emit radiation over a broad range of wavelengths. In complex systems ranging from the Sun to active galaxies and quasars, the emission in different bands of the electromagnetic spectrum is due to processes occuring in different regions of the source. We expect correlations in emission at different wavelengths, and the details of these correlations helps us construct detailed models of the systems in question.

The statistical challenge arises because the data are unevenly and non-simultaneously sampled, the time

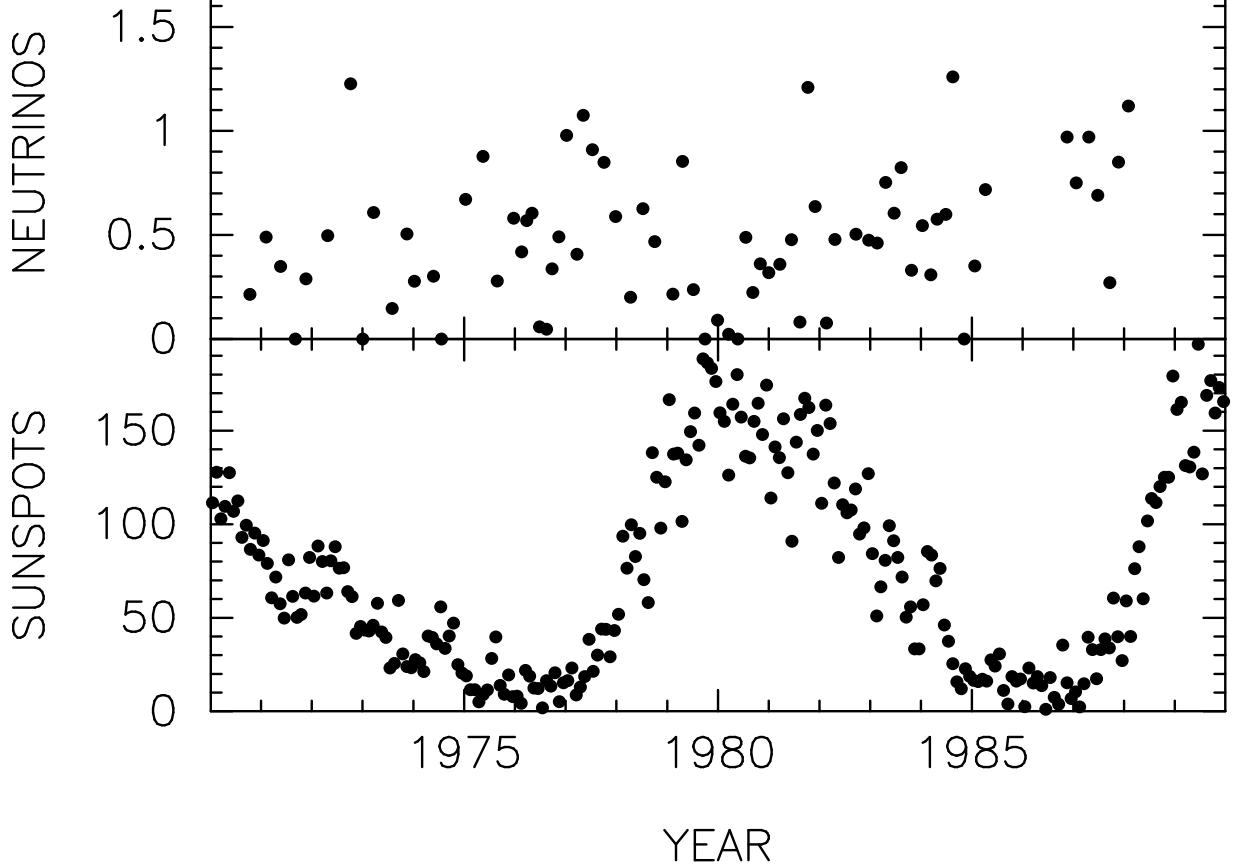

Figure 2: (top) The solar neutrino rate measured over a 20 year period. (bottom) The monthly sunspot number measured over the same 20 year period. Is there an anti-correlation between these two rates? (§5.2)

series are non-stationary, and the variations are stochastic. Astronomers have developed several methods for calculating the auto-correlation and cross-correlation of these non-ideal time series. Some of the methods developed to handle irregular and non-simultaneous sampling rely on time series interpolation (Gaskell & Peterson 1987), periodograms (Scargle 1989), lag time binning (Simonetti et al. 1985; Edelson & Krolik 1988), and linear prediction (Rybicki & Press 1992).

5.1 Correlations in a BL Lacertae Object

Many properties of active galactic nuclei (e.g. quasars, blazars, Seyfert galaxies) can vary in time. In order to understand the complex geometries and physical processes in these objects, astronomers obtain simultaneous time series in two or more properties (see Figure 7 of Feigelson 1995). Our *Sample* contains four time series for the well-studied BL Lacertae object OJ 287, shown in Figure 6 of Hufnagel & Bregman (1992). The data were provided by Beth Hufnagel (private communication), and were originally obtained by Aller et al. (1985) and Webb et al. (1988). Time series of brightness at four wavebands are given: radio flux at frequencies of 15, 8 and 5 GHz; and optical flux in the B (blue) band. Each data point consists of the Julian day of observations, the flux density and 1σ measurement error of the source in mJy.

5.2 Solar Neutrinos

The paucity of neutrinos, observed in a large underground liquid detector, emerging from the Sun is one of the few remaining mysteries in stellar astronomy. Recent analysis has added a twist to the puzzle: the solar neutrino production, produced in the core of the Sun, may be linked to conditions in outer regions of the Sun (Krauss 1990; Bieber et al. 1990; Bahcall & Press 1991). If true, our understanding of neutrinos needs radical revision; e.g., they may have a magnetic moment. However, the data are sparse and have limited accuracies. Published studies concentrate on the statistical analysis of the association between neutrino rate and sunspot number or other solar time series. To avoid the difficult statistical problem of cross-correlation with weighted data, most tests reduce the problem to a correlation or regression, avoiding the time variable.

The data in our *Sample* are those used by Bahcall & Press (1991) and cover the years 1970-1990 (Figure 2).

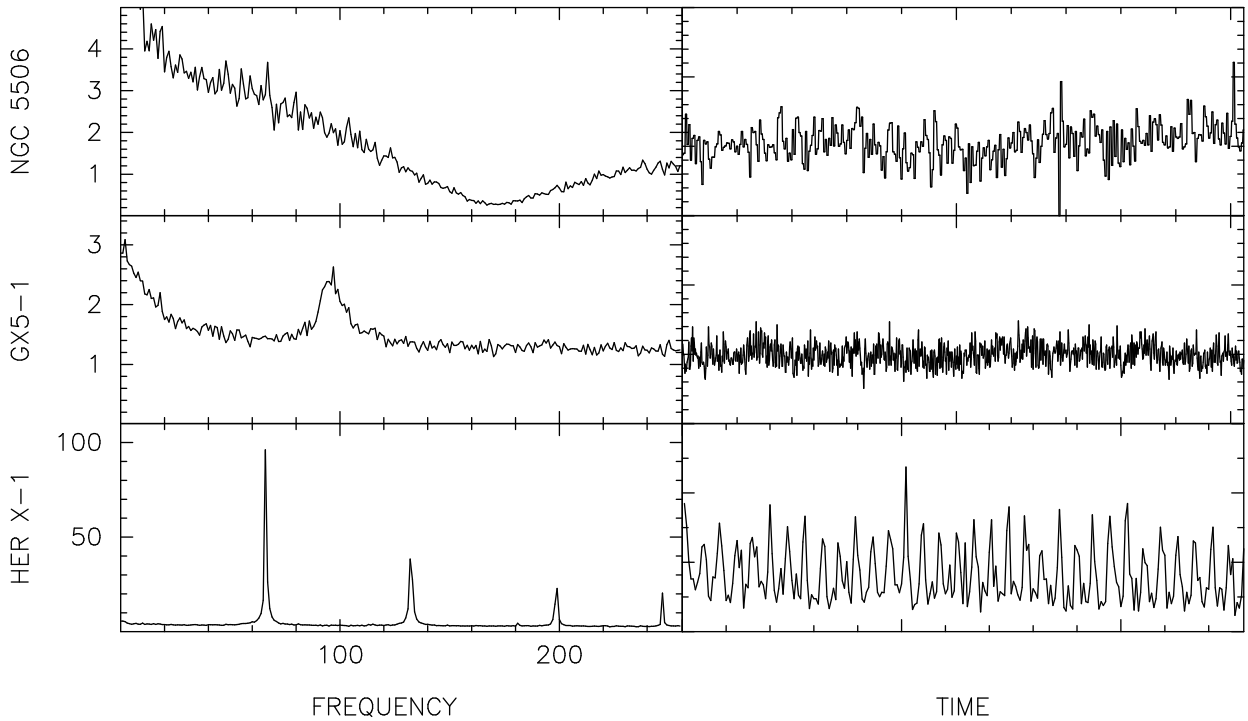

Figure 3: Power spectra and time series for three sources showing complex behavior. (top) The Seyfert galaxy NGC 5506 shows 1/f noise in its power spectrum, and a fractal dimension of 0.6 is claimed. Each frequency channel is 0.2 mHz and the time series is 10240 seconds in duration (§6.1). (middle) The X-ray binary GX5-1 shows quasi-periodic oscillations at 25 Hz and red noise at low frequencies. Each frequency channel is 0.25 Hz and the time series is 8 seconds in duration (§6.2). (bottom) The binary X-ray pulsar Her X-1 is periodic at 0.7 Hz and has been claimed to show evidence of deterministic chaotic behavior. Each frequency channel is 12 mHz and the time series is 41 seconds in duration (§6.3).

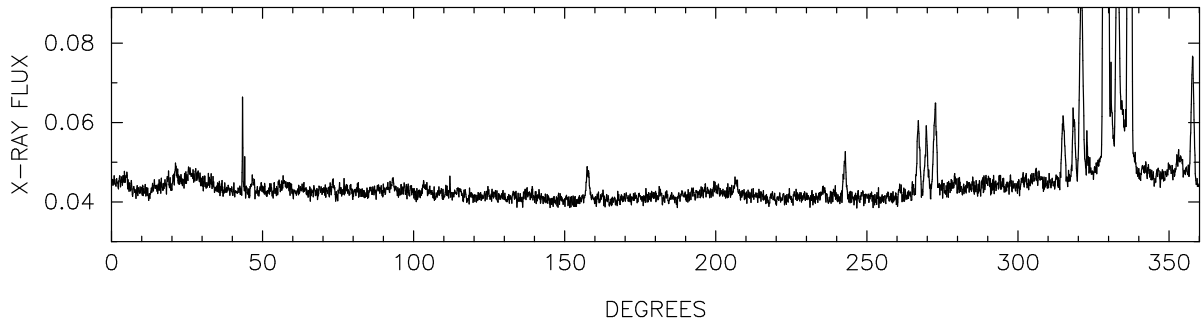

Figure 4: A great circle scan of the X-ray sky obtained on day 279 of 1977 with HEAO A-1. The weakest sources are not visible in this figure. (§7)

The data are from Tables 10.3 and 10.5 of Bahcall (1989); each data point gives the time of exposure (in years), the measured ^{37}Ar rate, and the lower and upper limits to the ^{37}Ar rate. The second variable is the monthly mean sunspot number (Coffey 1990; see §2).

6 APERIODIC VARIABILITY

X-ray astronomy is conducted entirely above the Earth's atmosphere, which is opaque to X-rays. For timing observations, astronomers use a proportional counter to detect individual X-ray photons and time-tag them with high accuracy. The data in our *Sample* were obtained with detectors having millisecond time resolution, typical of instruments orbited between 1977 and 1990. In the next few years, several X-ray detectors, explicitely designed for studying cosmic X-ray sources through their time variability, will be launched (e.g., Bradt et al. 1991; Wood et al. 1994). These satellites will have *microsecond* time resolution and will downlink up to 400 Mbytes of data per day for missions lasting between two and six years. We have included in our *Sample* three data sets which are typical of those which will be generated by the next generation of orbiting X-ray astronomy instruments.

6.1 Fractal Variability in a Seyfert Galaxy

Seyfert galaxies are a subset of galaxies which exhibit evidence for highly energetic phenomena in their nuclei. These active galactic nuclei galaxies, or AGNs, are thought to be powered by accretion onto massive black holes at their centers. The material accreted may be supplied by gas from an interstellar or intergalactic medium, or by stars which wander into the inner portions of the galaxy.

Since X-rays are created preferentially in high temperature, high density regimes, and since matter is fairly transparent to high energy X-rays, monitoring X-ray emission from AGNs provides a view into the core and an attempt to understand the accretion processes there (McHardy 1985, 1989; Krolik 1992). Many observers characterize X-ray variability by the "two-folding" timescale, i.e. the time it takes for the brightness to change by a factor of two. This constrains the emission region to have a size less than a region which light can cross in the two-folding time. However in most AGNs studied, there seems to be no characteristic time scale (McHardy & Czerny 1987; Lawrence et al. 1987; Krolik et al. 1991).

A long uninterrupted X-ray observation of the Seyfert galaxy NGC 5506 was obtained with the EXOSAT satellite (McHardy & Czerny 1987). Their analysis shows that the X-ray varaibility is self similar, with a fractal dimension of 0.6 and a power spectrum slope of -1 (1/f noise). We present in our *Sample* two days of their observation binned into 30 second bins. For each bin we give the bin-number, X-ray flux, and its 1σ uncertainty. The bin number is the time since the observation start in units of 10 seconds. The data were obtained from the NASA High Energy Astrophysics Science Archive Research Center (see §8).

6.2 Quasi-Periodic Oscillations

One of the most important recent discoveries in galactic X-ray astronomy was the 1985 discovery of quasi-periodic oscillations (QPOs) from galactic X-ray binaries. X-ray binaries contain a neutron star accreting material from a nearby companion star; when the material falls onto the neutron star, X-rays are emitted via a variety of mechanisms. QPOs are believed to occur at the beat frequency between the neutron star's spin frequency and the orbital frequency at the accretion disk, which is where the material accretes from. If material accretes in lumps, then these lumps can be modulated by the neutron star's magnetic field, which corotates with the neutron star (see reviews by Lewin et al. (1988) and van der Klis (1988, 1989b)).

The model quoted above predicts several kinds of correlations between QPOs and the red noise which arises from the clump of material accreting onto the neutron star. Shot noise models have been used to try and recreate these correlations (Elsner et al. 1988). Norris et al. (1990) have used designer statistics to show that these correlations are not present in the QPO emission from the X-ray binary GX5-1 (see also Hertz & Norris 1992).

In our *Sample* we give a 512 second excerpt of the Ginga satellite data analyzed by Norris et al. Each bin is the count rate during a 1/128 second integration. There are $512 \times 128 = 65536$ data points in all. The data are the first 25% of that displayed in Figure 2 of Norris et al. and were provided by Jay Norris (private communication).

6.3 Deterministic Chaos in a Pulsar?

Hercules X-1 is a binary X-ray pulsar. Every 1.4 seconds it emits a pulse of X-rays towards the Earth and every 1.7 days it orbits a companion star not unlike the Sun. Material is accreting from the companion star onto a compact neutron star with a very strong magnetic field. The material, which is ionized plasma, is funnelled by the magnetic field onto the neutron star's magnetic poles. There it forms a shock at the neutron

Astrophysical Data System		
	ads@cuads.colorado.edu	http://adswww.colorado.edu/adswww/adshomepg.html
High Energy Astrophysics Science Archive Research Center		
	request@legacy.gsfc.nasa.gov	http://heasarc.gsfc.nasa.gov/
National Space Science Data Center		
	request@nssdca.gsfc.nasa.gov	http://hypatia.gsfc.nasa.gov/about/about_nssdc.html
World Data Center		
	smclean@ngdc.noaa.gov	http://www.ngdc.noaa.gov/wdcmain.html
A Sample of Astronomical Time Series		
	hertz@xip.nrl.navy.mil	http://xweb.nrl.navy.mil/

star surface and X-rays are emitted. As the neutron star rotates, the beams of X-rays sweep past the Earth, like a lighthouse, giving rise to a pulsed light curve.

The search for astrophysical sources showing evidence for deterministic chaos is almost a decade old (see review by Scargle 1992). Voges et al. (1987) have analyzed data from Her X-1 and concluded that it exhibits a fractal dimension of approximately 2.3. They used the method of phase space reconstruction and dimensional extraction of Grassberger & Procaccia (1983) to derive this result. Norris & Matilsky (1989) showed that there is no evidence for a strange attractor in Her X-1; rather there is an ordinary attractor which is contaminated by noise. The resultant smearing of points in the reconstructed phase space necessarily leads to spurious measurements of dimensionality.

We present in our *Sample* some of the data from Norris & Matilsky as provided by Jay Norris (private communication). There are three observations of Her X-1 made with the HEAO A-1 instrument on board the HEAO-1 satellite. Each observation is 3200 seconds long with each bin containing the background subtracted count rate during 0.160 seconds. The data are approximately Poisson distributed (counting statistics to astronomers) but the mean varies with time. The 1.4 second pulsations are clearly visible. The three observations are separated by 20 zeroes in a row. There are thus 60040 data points (20000 per orbit plus two spacers of 20 bins). Some values are negative because the background estimate exceeded the measurement at that time.

7 DECONVOLUTION OF SOURCES

Many surveys of the sky with orbiting instruments are made by scanning an instrument in great circles and allowing the scan plane to precess each day. If the detector records counts as a function of time, then the data are a time series where a source appears as an increase in flux above background with a profile characteristic of the detector and a magnitude proportional to the source's brightness. The problem is to detect sources which are as faint as possible. The shape of the detector response can be derived from bright sources. For each source, one wishes to determine location and flux, and estimate the probability a source is spurious.

In our *Sample* we present two scans obtained by the HEAO A-1 Large Area Sky Survey Experiment (Wood et al. 1984) and provided by Paul Hertz (private communication) (Figure 4). HEAO A-1 was a scanning X-ray instrument which flew during 1977–79. It had a triangular collimator with a 1 degree FWHM width. Each scan represents the average of all scans obtained during a single day of 1977. The data have been binned into 0.1 degree bins, so there are 3600 bins in each scan. The scan is a closed circle, so the last bin is followed by the first bin. An example of fitting scan data are given in Hertz & Wood (1988). Astronomers typically perform least-square fits to the data using the methods of Lampton et al. (1976).

8 ELECTRONIC AVAILABILITY

The *Sample of Astronomical Time Series* is included with this volume on a floppy disk. The *Sample* is also available electronically as 5 ASCII files requiring a total of 0.75 Mbytes of storage. These files may be obtained over the World Wide Web at http://xweb.nrl.navy.mil/. They can also be e-mailed directly to a user; direct requests to P. Hertz (hertz@xip.nrl.navy.mil). Note that the order of the data sets in any of these digital versions of the *Sample* is different than the order presented in this paper.

Additional astronomical time series are available through data archives, principally those maintained by NASA. Data are available through the Astrophysical Data System, a series of Science Archive Research Centers, the National Space Science Data Center, the World Data Center, and dozens of other archives and centers. In Table 1 we give e-mail addresses and universal resource locators (URLs — for use with World Wide Web browsers like Mosaic) for a selection of centers with interesting astronomical time series. Many of these centers deliver data through automated e-mail requests and anonymous ftp.

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