The unique combination offered by ISO and ISAAC instruments promises a decisive progress in our understanding of the origin of the vast amount of energy released by starburst galaxies during their main activity phases.

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The Deep Eclipse of NN Ser

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The elusive nature of NN Ser was discovered in July 1988 (Häfner, 1989a, 1989b) in the course of a search for eclipses in faint cataclysmic variables using the CCD camera on the Danish 1.5-m telescope at La Silla. This target (V ~ 17), then named PG 1550+131 and thought to be such a variable, turned out to exhibit a sine-shaped light curve and a very deep eclipse of short duration repeating once every 3 hours and 7 minutes. Due to the low time resolution of the photometry (3.5 min), the duration of the eclipse (separated by half a period from maximum light) as well as its depth could only be roughly estimated to be about 12 min and at least 4.8 mag respectively. During mid-eclipse no signal from the object was recordable. Two spectra (resolution about 12 Å) obtained near maximum light (A) and near the onset of the eclipse (B) using EFOSC at the 3.6-m telescope revealed mainly narrow emission lines of the Balmer series superimposed on broad absorptions (A) and shallow Balmer absorptions without emission (B). It was immediately clear that such an object could not be a cataclysmic system. The data were rather interpreted in terms of a pre-cataclysmic binary, an evolutionary precursor of a cataclysmic system, consisting of a white dwarf/late main-sequence detached pair. Thus all observed properties of the system find a consistent explanation: the sine-shaped light curve (full amplitude ~ 0.6 mag) is caused by a strong heating effect, the emission lines originate in the heated hemisphere of the cool star and cannot be seen near primary eclipse, the absorption lines originate in the hot star, the steep (ingress/egress ~ 2 min) and deep eclipse of short duration are due to the obscuration of a very hot small object by a much cooler and larger star, a secondary eclipse is not detectable since the cool star does not contribute much to the flux. Based on these observations and assuming M_{hot} = 0.58 $M_\odot$ (mean value for DAwhite dwarfs), T_{hot} = 18,000 K, inclination close to 90º and a circular orbit, a first crude estimate of the system parameters yielded the following results: separation ~ 0.92–1.03 $R_\odot$, R_{hot} ~ 0.01–0.14 $R_\odot$, R_{cool} ~ 0.06–0.33 $R_\odot$, M_{cool} ~ 0.03–0.28 $M_\odot$, T_{cool} (unheated hemisphere) ~ 2600–3300 K, T_{cool} (heated hemisphere) ~ 4300–6600 K, spectral type of cool star ~ M3–M6. The evolution of the system into the semi-detached (cataclysmic) state is only possible via radiation of gravitational waves and was estimated to take some 10^9 years.

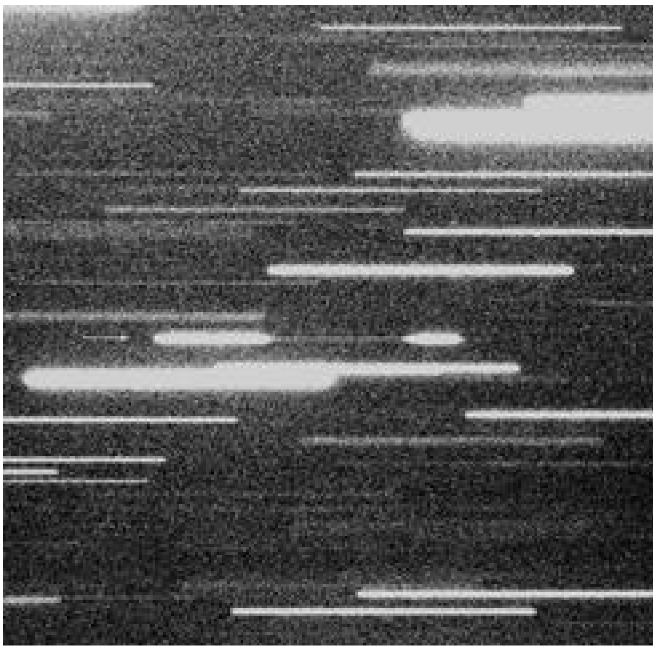

Figure 1: The drift exposure of the sky field around NN Ser (arrow).

Based on optical and IUE spectroscopy as well as further photometry (Wood and Marsh, 1991; Catalan et al., 1994), the pre-cataclysmic nature of NN Ser was confirmed and the range of system parameters could be narrowed down. The IUE data as well as fits of some Balmer absorptions via model atmospheres hint at a white dwarf temperature in the range 47,000–63,000 K, much more than previously assumed. But all studies so far performed were hampered by the fact that the true depth of the eclipse and the duration of the totality (if any), i.e. the inner contact phases of the white dwarf, were not known. This crucial information, important for the determination of the radii of the components, could not be obtained using telescopes of the 4-m class, as several attempts by the author revealed. Even applying sophisticated observing methods and/or using a special photometer, several observing runs (ESO 3.6-m telescope, NTT and Calar Alto 3.5-m telescope) were not successful in this respect.

The powerful combination of the first VLT 8.2-m Unit Telescope (ANTU) and the multi-mode FORS1 instrument (Appenzeller et al., 1998) offered now the opportunity for a new experiment. Since the HIT mode, allowing photometry and spectroscopy with high time resolution, was not yet available at the scheduled time of observation (June 1999) another technique had to be applied: the trailing method, where the tel-

0.1595 ± 0.0155 $R_\odot$ (about 1.5 times the radius of Jupiter).

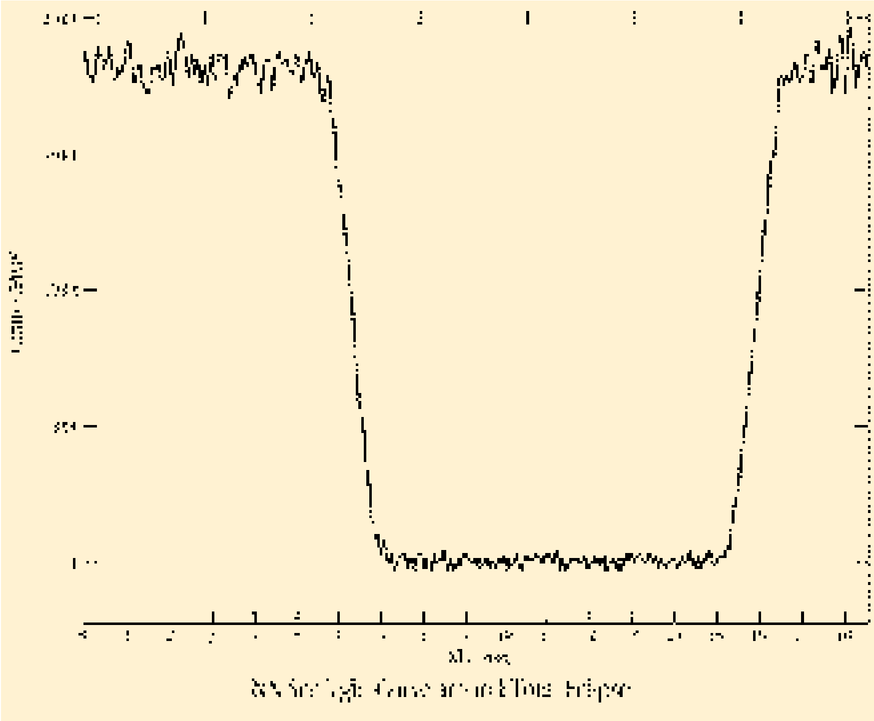

Figure 2: The eclipse light curve of NN Ser as extracted from the drift exposure.

escope performs a controlled continuous motion in RA and DEC, thus registering the light of the targets in the field of view along lines on the same frame. Direction and drift rate had to be chosen very carefully to avoid interference with stars in the neighbourhood of NN Ser and to ensure a reasonable recording of the inner contact phases. Since the brightness of the cool star was unknown, the latter was a tricky task. Using the ETC, the drift rate was eventually fixed at 1 pixel (25 µm) per 3 seconds, a compromise between the presumed integration time and the desired time resolution. Another point of uncertainty was the autoguiding system which was not known to work properly for the drift rate chosen beforehand. It had to be much faster than that needed to follow solar system objects.

However, with no technical problems and aided by excellent seeing of 0.5 arcsec, a 18.5-min drift exposure (SR collimator, V filter) could be obtained in the night 10/11 June 1999. Figure 1 shows the resulting star trails of the field around NN Ser. The trail of the eclipsing system is indicated with an arrow. Figure 2 gives the eclipse light curve of NN Ser as extracted from that trail. The recorded signal during eclipse is well measurable and amounts to about 70 counts/pixel (barely visible in Figure 2, since the full range of the eclipse is shown) down from about 18,300 counts/pixel outside eclipse. This corresponds to an eclipse depth of ΔV = 6.04 and constitutes one of the deepest eclipses if not actually the deepest eclipse ever measured for a binary. Trails of comparison stars on the same frame allow the brightness shortly before/after and during eclipse to be fixed at V = 16.98 and 23.02 respectively. Since the light curve is perfectly flat at the bottom, the eclipse is total, i.e. the white dwarf disappears completely behind the red star. The contact phases are now easily measurable: Totality lasts 7^m37^s, ingress/egress take 1^m26^s each, and the whole eclipse duration amounts to 10^m28^s. These numbers now allow the radii of the involved stars to be derived: R_{hot} = 0.0204 ± 0.0021 $R_\odot$ and R_{cool} = 0.1595 ± 0.0155 $R_\odot$ (about 1.5 times the radius of Jupiter).

Furthermore, it seemed extremely interesting to obtain spectral information on the cool component: With M_{cool} ~ 0.09–0.14 $M_\odot$ (Wood and March, 1991), its mass is very near the upper limit (~ 0.08 $M_\odot$) for brown dwarfs. Even if the object turned out to be 'only' a normal late main-sequence star, with known mass and radius at hand, a spectrum could allow a critical check of current theories of atmospheres and evolutionary computations for late M stars. Since the spectrum had to be taken during the phase of totality, the exposure time had consequently to be limited to about 5 min to avoid any contamination by the white dwarf. Although this seemed to be quite short for a 23-mag object, a faint noisy spectrum could be recorded in the 600–900 nm wavelength region even under mediocre seeing conditions (0.95 arcsec) using the FORS1 longslit option combined with grism 150I+OG590 (0.55 nm/pixel, SR collimator). Figure 3 shows the resulting slightly smoothed tracing together with a spectrum of a M6.5 dwarf star. Several molecular bands of TiO are well visible, additionally some VO bands may also be present. The spectrum does not resemble that of a brown dwarf, it rather hints at a very late dwarf star of spectral type M6 or later. Of course, many such spectra have to be superimposed to allow a definite spectral classification of the cool component in NN Ser which, despite a strong irradiation on one hemisphere, constitutes a 'normal' main-sequence star on the un-heated side.

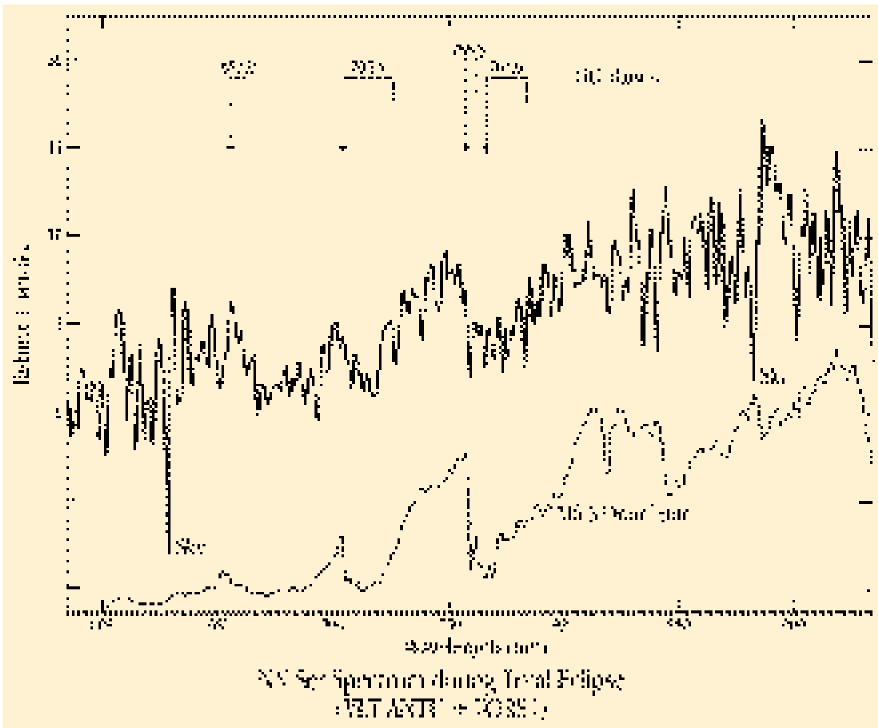

Figure 3: The spectrum of the cool component of NN Ser compared with a spectrum of a M6.5 dwarf star. Residuals from sky subtraction are indicated.

As previously stated, NN Ser belongs to the class of pre-cataclysmic binaries. These systems are thought to be born after the common-envelope evolution of originally wide pairs of unequal mass with orbital periods in the order of a few days. In the pre-cataclysmic state, the binaries exhibit shorter periods, consist then of a hot subdwarf or white dwarf primary and a main-sequence secondary and are surrounded by a planetary nebula which may later disperse. The secondary is believed to remain basically unaffected by this binary evolution process. Presently, we have at least some information on about 50 candidates, about one dozen being still associated with planetary nebulae. Only nine of these 50 systems show eclipses and provide sufficient spectral information to allow the determination of fairly reliable values of masses and radii of the components. Five systems are hot subdwarf/main-sequence binaries, the remaining four (including NN Ser) harbour white dwarf/K-M components. A thorough study of NN Ser will, therefore, also contribute to our knowledge of this interesting evolutionary state of binaries.

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The FORS Deep Field

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1. Deep Fields

Watching the sky with the naked eye we can detect several thousand galactic stars but never more than two or three objects beyond our Milky Way galaxy. On the other hand, already images taken with small telescopes and photographic plates record in fields well outside the galactic plane more distant galaxies than galactic stars. Obviously, an increased sensitivity does not only allow us to see more objects, but, more importantly, we can look deeper into space. During the period when photographic plates were still the prime optical detectors, deep observations were usually carried out using Schmidt telescopes which allowed us to combine a deep look with a large field of view. Telescopes with larger apertures did not provide a great advantage since (because of the non-linearity and poor reproducibility of the photographic process) the flux (or magnitude) limit of photographic imaging was determined by the sky background, which could not be subtracted accurately. Only with the introduction of the essentially linear CCD detectors it became possible to observe objects with a surface brightness well below that of the sky. However, for manufacturing reasons, the achievable dimensions of CCDs are much smaller than those of large photographic plates. Therefore, imaging surveys reaching very faint magnitudes have, so far, been restricted to relatively small *Deep Fields.* Nevertheless, such deep-field surveys have proven to be exceedingly valuable in producing complete inventories of faint objects, for finding very distant objects, and for studying the properties and statistics of galaxies as a function of the evolutionary age of the universe.

Although the mean sky background can be determined and subtracted reliably from CCD frames, the photon noise of the sky, being of stochastic nature, cannot be eliminated. Therefore, even with CCDs, the achievable accuracy of faint-object photometry still depends on the amount of sky flux underlying the object images. Therefore, observations from space provide particularly favourable conditions for deep imaging and photometry since at most visual wavelengths the sky background is lower and since the absence of atmospheric seeing effects normally results in sharper images. It is not surprising, therefore, that two HST-based deep-field surveys (HDF and HDF-S) had a particularly strong scientific impact, providing a wealth of information and inspiring many follow-up studies.

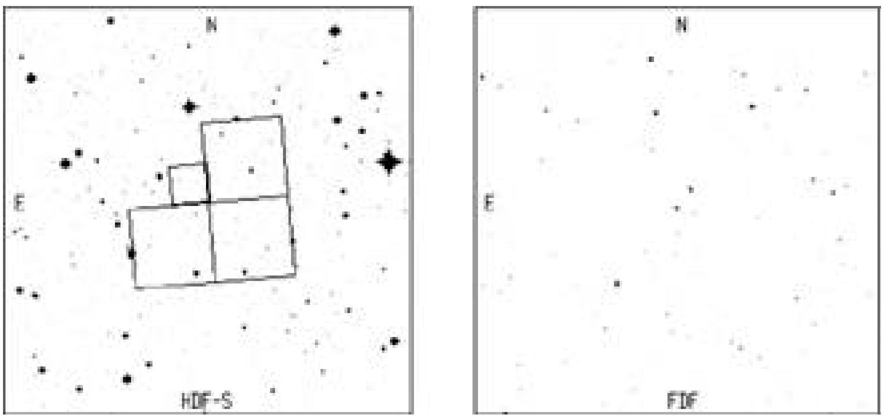

Figure 1: Digital Sky Survey plots of the FDF and of a field of the same size surrounding the HDF-S. Note the lower surface density of bright foreground objects and the absence of bright stars in the FDFregion.

2. Motivation for a FORS Deep Field

In spite of their great importance and success, the Hubble Deep Fields have some drawbacks. One obvious disadvantage is the, compared to modern ground-based faint-object cameras, relatively small field of view of the HST WFPC which limited the Hubble Deep