The answer is at least partly bound up with the range of energies to which the satellite detectors have been sensitive. In the early days of X-ray astronomy (e.g. in the time of the UHURU satellite), the detectors concentrated on rather high energies, up to 10–20 keV or even higher, whereas the EINSTEIN satellite included a detector which could reach down to very low energies, about 0.15 keV. A stellar corona with a temperature of a few million degrees is a very weak emitter at energies of 10–20 keV, and so such sources went essentially undetected by the early satellites. It therefore appears that the capability of the EINSTEIN satellite to probe the Galaxy in “soft” X-rays (i.e. considerably less energetic than 1 keV) was a prime reason why the satellite could make the remarkable and unexpected discovery of coronal X-rays from stars of almost all spectral types.

As an extreme example of the discoveries which can be made with an X-ray detector which is sensitive to very low energies, we may cite another recent report from the EINSTEIN satellite. S. M. Kahn and co-authors have reported very soft X-rays from 4 hot white dwarf stars (Astrophysical Journal, 278, 255, 1984). These white dwarfs belong to a class in which the atmosphere is composed almost exclusively of hydrogen. The abundance of helium atoms is only $(2–600) \times 10^{-5}$ of the abundance of hydrogen atoms, rather than about 0.1 as in normal stars such as the Sun, and there are no detectable “heavy metals”. Gravity is so strong in white dwarfs that heavy atoms are dragged to the base of the atmosphere, with the result that indeed hydrogen is expected to become essentially the only constituent of the atmosphere after some time. When the abundance of “heavy” atoms is very small and when the star is sufficiently hot to ionize the hydrogen, there is very little material which can absorb X-rays in the stellar atmosphere. As a result, the atmosphere becomes exceptionally transparent to X-rays. Hence, an X-ray detector is allowed to “peer in” to very deep subsurface layers, picking up X-rays from material deep inside the star where the temperature is almost $10^6$K. In these stars, then, although one is indeed observing material at temperatures of $10^6–10^7$K (as in the “coronal stars” mentioned by Hertz and Grindlay), one is not observing a stellar corona lying above the surface of the star, but rather interior material lying beneath the surface.

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D. J. Mullan.

A SUPERMASSIVE STAR IN 30 DORADUS?

The 30 Doradus nebula in the Large Magellanic Cloud is one of the biggest and most massive HII regions known. It is a hundred times as massive as the giant nebula associated with $\eta$ Carinae in our own Galaxy and has five times its linear dimension. Associated with the HII region and providing the very large amounts of ionizing UV radiation necessary to power its optical output, is a large grouping of very hot, young supergiant stars. Pre-eminent among these is the star R136, number 136 in the list of the LMC’s brightest stars prepared by Michael Feast, David Thackeray and Adriaan Wesselink at Radcliffe Observatory thirty years ago (Feast, Thackeray...
and Wesselink 1960). R136 is the brightest object in the Magellanic Clouds and quite possibly, the prototype of a new type of supermassive star. New data throws doubt however on whether R136 is a single object at all.

There are several difficulties encountered when one tries to unravel the nature of R136. The first is one of scale. One arc second corresponds, at the distance of the LMC (d = 50 kpc), to 1/15 pc. Although modern telescopes in the best possible sites can resolve down to half an arc second or less, it is difficult to register this resolution. For instance if a photographic plate is used, light scattering will tend to spread the image and thereby degrade resolution. A second difficulty lies in the star density in the Magellanic Clouds. Because we are looking at an object in considerable depth many faint star images will overlap and blend with the object of interest. A further background difficulty arises because of the nebulosity in which R136 is embedded. This leads to a very uneven background which again degrades resolution.

It has been agreed for some time that R136 consists of at least three components spread over the central 3 arc sec and arranged in the form of a reversed ‘comma’ (see e.g. Feitzinger et al 1980). The northern-most of the three, R136a, (the dot of the comma) is the brightest. It is over the nature of R136a that the controversy rages.

An estimate of the mass of a very early type star can be found from the so-called Eddington Limit for the stability of a star (see for example Byrne 1976). This simply says that if a star is to be stable then gravity at each point in the star must be at least as strong as the outward radiation pressure. Otherwise radiation pressure would blow the star apart. There may be other factors in the equation, such as gas pressure, but in the outer layers of very massive stars the balance is essentially between radiation and gravity. We may state this condition as \( GM/R^2 > \sigma L/4\pi R^2 c \) where \( M \), \( L \) and \( R \) are the mass, luminosity and radius of the star, \( \sigma \) is the cross section of the material of the star for photon capture and \( c \) is the velocity of light. We then derive a lower limit to the mass of the star viz. \( M > \sigma L/4\pi Gc \).

The difficulty in evaluating this equation lies in evaluating \( L \), the stellar luminosity. Visual observations of R136a indicate, not surprisingly, that the source is extremely hot. Savage et al (1983) added ultraviolet (IUE) observations to the existing data and argued that the temperature lay in the range 40 000 – 90 000 K. So, with the visual and UV brightness as scaling factors, derivation of the luminosity is possible. Values range from about 300 – 5000 M\( \odot \) depending on the choice of temperature and stellar model. After a lengthy discussion of the observed high-velocity stellar wind in the region of R136 and the excitation of the surrounding nebula Savage et al finally favoured a supermassive star with a temperature in the range 68 000 – 82 000 K and a mass of 1200 – 2400 M\( \odot \), far in excess of the conventionally accepted upper limit to stellar mass ~100 M\( \odot \).

The alternative interpretation of the nature of R136a is that it is not a single object but rather a tight, unresolved cluster of highly luminous but otherwise normal stars. Arguments in favour of the cluster hypothesis were summarized by Walborn (1984). Visual observations by double star observers suggested as far back as the 1920’s that R136a is not a single object (Innes 1927 and van den Bos 1928). Recently Chu, Cassinelli and Wolfire (1984) took photographs under conditions of excellent
seeing and suggested that there were several hitherto undetected stars within the central 3 arc sec of R136. Similarly Weigelt (Melnick 1983) through speckle interferometry resolved R136a into an 0.5 arcsec double and suggested a background composed of many fainter stars. Other speckle observations by Meaburn et al (1982) failed to detect a double at the position of R136a and suggested that it was a single, point source with diameter less than \( \sim 0.02 \) arcsec.

The latest addition to the debate is a paper by Alistair Walker and Darragh O'Donoghue of the South African Astronomical Observatory and the University of Cape Town respectively (Walker and O'Donoghue 1984). They applied two new techniques to the problem. The first is in the domain of hardware i.e. the Charge Coupled Device (CCD) (see Weekes 1982 for a description of the CCD). They used a CCD on the 1-metre telescope under excellent seeing conditions. This instrumental combination resulted in a scale of 0.4 arcsec per picture element (pixel), while the resulting stellar images had a FWHM of 1 arcsec.

The second new element of their result was in the software domain. They used the images of nearby stars which are free of nebulosity and nearby companions to define the shape of the light profile of a single star. They then examined the image of R136 for evidence of multiple images. The method for deciding on the presence of the resulting multiple images is a mathematical method known as MEM (Maximum Entropy Method). This method of reconstructing blurred or partially resolved images was originally developed for use in radio astronomy and is considered to be one of the most unbiased of such methods presently available.

Walker and O'Donoghue's results come down heavily in favour of the cluster interpretation of R136a. They confirm that R136a is a close double as recorded by Chu, Cassinelli and Wolfire but, exploiting the linear response of the CCD detector, give improved photometry for the components. Furthermore they add a number of hitherto unknown stars in the inner 5 arcsecs and accurately estimate their effect on the brightness measures of R136a.

The overall result is that the luminosity estimate of R136a, (the dominant component of R136a) is now substantially reduced. Its absolute V magnitude is only 1.2 mag brighter than R136c (the tip of the tail of the comma). R136c is a Wolf-Rayet star (WN7) which is among the most luminous type of 'normal' star known. Thus 2–3 of these stars in a tight grouping at the position of R136a, could account for its observed visual brightness. Similarly the new estimate of R136a's \( M_V \) is about 2 to 2.5 mags brighter than the brightest O-type stars in the region. Thus about 6–10 such stars could likewise account for the central object of 30 Doradus. The spectrum of R136 shows characteristics of both the most luminous O-type and the Wolf-Rayet stars (Savage et al 1983). So it appears likely, given the complexity of the region, that both types are present within the central arcsecond of R136a.

Walker and O'Donoghue's result is of relevance, not only in the case of the 30 Doradus nebula, but also in the case of the exciting objects within the giant HII regions in external galaxies. Super-massive stars have been suggested in the compact core of M33 and other nearby galaxies (Massey and Hutchings 1983).

A recent review of these arguments has been published in Scientific American (Mathis, Savage and Cassinelli 1984).