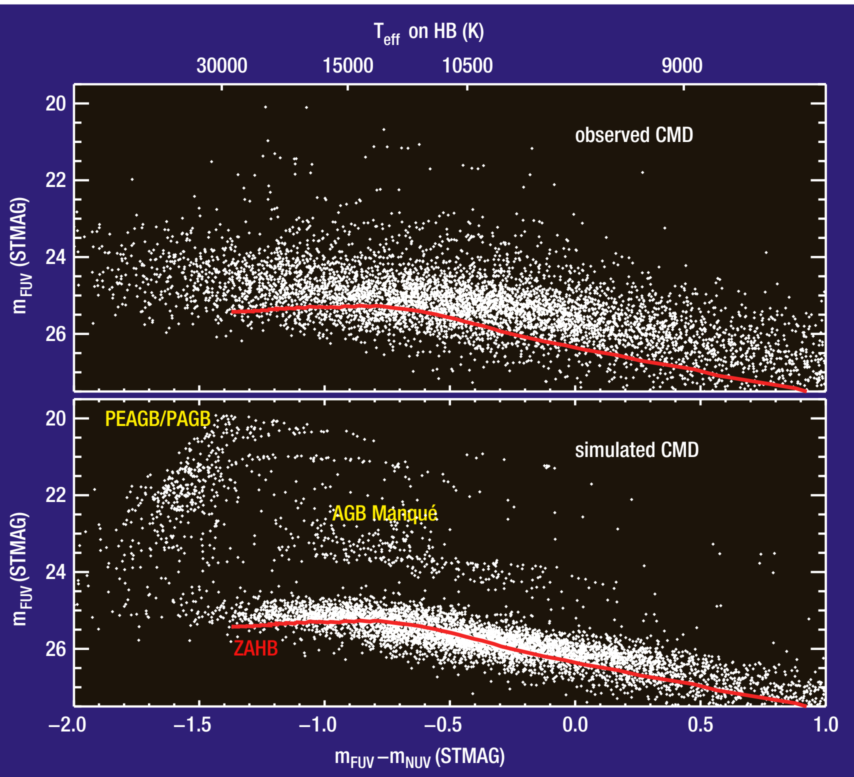
Extended horizontal branch stars

Astronomers met at Keele University, Staffordshire, in June to discuss how observations of extended horizontal branch stars have changed our view of hot star atmospheres, stellar winds, single and binary star evolution, stellar pulsations and the age estimates for elliptical galaxies. **Pierre Maxted** reports.



1: The observed ultraviolet colour-magnitude diagram of M32 (upper panel) compared to the predicted colour-magnitude diagram for canonical evolution models (lower panel). Note the lack of UV bright stars that have evolved away from the asymptotic giant branch (PEAGB/PAGB) or have evolved from the EHB (AGB Manqué). This suggests these phases of stellar evolution are much shorter than predicted. ZAHB is the theoretical zero-age horizontal branch.

Around 40 astronomers from the UK, Germany, Canada, the USA and elsewhere attended the meeting on "Extreme Horizontal Branch Stars and Related Objects" organized by the astrophysics group at Keele University during the week 16–20 June 2003. This class of star has been the focus of intense observational and theoretical work in recent years, principally as a result of two discoveries: many EHB stars are close binaries and some EHB stars pulsate. The aim of the meeting was to disseminate recent results on the properties, formation and evolution of EHB stars and related objects and to assess the impact of these results on other areas of astrophysics. The proceedings of the meeting are to be published in a special edition of *Astrophysics & Space Science* (Kluwer).

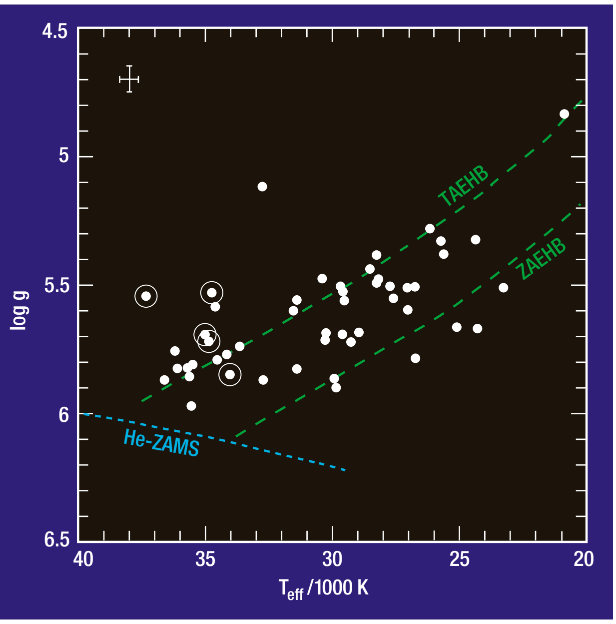
EHB stars are distinguished from normal horizontal branch stars by having extremely thin, inert hydrogen envelopes, ($<0.02\,M_\odot$) surrounding the helium-burning core. They are hot, dense stars ($20\,000\,K < T_{eff} < 40\,000\,K$, $5 < \log g < 6$) with masses in a narrow range near $0.5\,M_\odot$. They dominate the brighter end of surveys for faint blue stars and are one of the main sources of ultraviolet light in old stellar populations such as elliptical galaxies and some globular clusters. Spectra of EHB stars are classified as subdwarf-B (sdB) and almost all sdB stars are EHB stars or closely related stars so the two terms are used almost interchangeably. The meeting began with a historical overview by **Tony Lynas-Grey** (Oxford University) who described how this understanding of EHB stars had emerged. The rest of the morning was devoted to a discussion of the contribution of EHB stars and related objects to the ultraviolet light in old stellar populations and how the resulting *UV upturn* might be used to estimate the ages of distant elliptical galaxies. The theoretical background and implications for cosmology were described by **Sukyoung Yi** (Oxford University) who concluded that while core-helium burning stars such as EHB stars remain the strongest candidate for the UV upturn, there is a growing concern that the canonical models may be missing important elements, e.g. the contribution of binary star evolution to the formation of EHB stars. **Suk-Jin Yoon** (Oxford University) then discussed some of the problems that have been encountered when using the UV upturn as an age indicator for old stellar populations assuming that age is the second parameter (after metallicity) that influences the morphology of the horizontal branch. **Thomas Brown** (STScI) gave a review of observational evidence that leads to the conclusion that EHB stars are the source of the UV upturn. He also presented a deep UV colour-magnitude diagram of stars in M32 (figure 1) obtained with the Hubble Space Telescope. The weak UV upturn in M32 is seen to be due to EHB stars, but the surprise in these data is the almost complete absence in M32 of the many bright post-AGB and post-EHB stars predicted by current stellar evolution models.

After lunch, **Sabine Moehler** (Kiel) presented observations of the *blue hook* stars seen in ω Cen and NGC 2808. These stars are hotter and much richer in helium than EHB stars. The properties of the stars derived from the spectroscopy presented support the hypothesis that these stars arise from stars that ignite helium while cooling to become white dwarfs. **Jorick Vink** (Imperial) presented the results of his calculations for mass loss rates due to stellar winds from horizontal branch (HB) stars. He concluded that mass loss from normal HB stars was not sufficient to turn them into sdB stars, as has been suggested, but that stellar winds from sdB stars do play a role in causing the peculiar pattern of chemical abundances seen in sdB stars. A progress report on a survey for EHB stars in the galactic bulge was presented by **Donald Terndrup** (Ohio). **Amir Ahmad** (Armagh) then discussed the helium-rich sdB stars and sought to clarify their classification and origin.

It has recently been found that more than half of EHB stars are binary, many of them with short orbital periods (hours or days). This has implications for understanding the formation and evolution of sdB stars and other close binary stars. Presentations by **Elizabeth Green** (Steward Observatory), **Luisa Morales-Rueda** (Southampton), **Pierre Maxted** (Keele) and **Ralf Napiwotzki** (Bamberg) gave a good overview of the extensive observational efforts being made to characterize this binary population. Many of the companions to EHB stars are white dwarfs with orbital periods of hours or days or weeks. There are very few low-mass main-sequence companions; those that are known all have very low masses (approx 0.1 $M_\odot$) and short orbital periods (2–3 hours), e.g. the star HS2233+3927 discussed by **Christian Karl** (Bamberg). Poster presentations by **Mike Reed** (Missouri), **Michele Stark** and **Richard Wade** (Pennsylvania) discussed the population of EHB stars with solar-like companion stars in wide orbits. **Philipp Podsiadlowski** (Oxford) presented calculations of the evolutionary paths to EHB stars, including the merging of white-dwarf pairs, common-envelope evolution near the tip of the red giant branch and stable Roche lobe overflow. These can, in principle, explain the observed population – the challenge is now to compare models and observations in detail.

Peculiar chemistry

The temperature, surface gravity and luminosity of a typical EHB star are in the regime where several interesting phenomena affect the chemical abundance at their surface, e.g. stellar winds, radiative levitation and gravitational settling. On the Wednesday morning **Ulrich Heber** (Bamberg) showed that this can lead to some very peculiar chemical abundance patterns in high-resolution spectra of EHB stars, including an apparent over-abundance of elements such as titanium and vanadium by a factor of 1000–10 000 or the complete replacement of the ^{4}He spectral lines by ^{3}He lines. **Thorsten Lisker** (Bamberg) presented effective temperatures and gravities for 53 sdB stars measured from spectra taken with the UVES spectrograph on the ESO Very Large Telescope (figure 2). The spectra of one star suggest that it is the first known close binary system consisting of two helium-rich subdwarfs. **Pierre Chayer** described observations of sdB stars with the Far Ultraviolet Spectroscopic Explorer satellite to determine the



2: The effective temperatures (T_{eff}) and surface gravities (log g in cgs units) of sdB stars observed as part of the Supernova Progenitor survey (SPY) with UVES on the VLT. He-ZAMS is the zero-age main sequence for pure helium stellar models with a range of masses. The ZAEHB and TAEHB are the zero-age and terminal-age extended horizontal branches, i.e. models for stars with masses close to 0.5 $M_\odot$ with a range of hydrogen envelope masses. The circled points denote stars with peculiar Ha profiles indicative of a weak stellar wind.

surface abundance of iron and other elements. The iron abundance is expected to be related to the presence or absence of pulsations, but this is not reflected in any simple way in the surface abundance patterns observed. No talks were scheduled for the Wednesday afternoon so many of the delegates took the opportunity to visit the Gladstone Pottery Museum, including its historic toilet collection.

Presentations during the rest of the meeting discussed pulsating EHB stars. Pulsations with periods of a few minutes in EHB stars were discovered in the prototype sdB pulsator EC 14026–2647 by astronomers at SAAO during the 1990s and, completely independently, predicted from theoretical models by the group at Montréal. **Gilles Fontaine** (Montréal) described how partially ionized iron is thought to be responsible for driving the p-mode pulsations in both these EC 14026 stars and in the newly discovered PG 1716+426 stars. PG 1716+426 is the prototype of variable sdB stars with multiple periods of low amplitude (<1%) and periods of a few hours due to g-mode pulsations. **Steven Kawaler** (Iowa) proposed that the core rotation in sdB stars may be complicating the spectrum of frequencies seen in some EC 14026 stars. **Stephane Charpinet** (Observatoire Midi-Pyrénées) described how optimization techniques are used to find the range of stellar models that best describe the frequency spectrum of an EC 14026 star without the need for mode identification. This objective asteroseismology has been used to study two EC 14026 stars and confirms in both cases that the the total mass is close to 0.5 $M_\odot$ and the hydrogen envelope is very thin (<0.01 $M_\odot$).

The abundant time for discussion after all presentations during the meeting was put to particularly good use in this session for vigorous, friendly, debate over the interpretation of the frequency spectrum of these EC 14026 stars. **Mike Reed** (Missouri) described efforts and strategies to identify the modes responsible for the pulsations in EHB stars and so, it is hoped, resolve much of this on-going debate. Some of the intense observational efforts being devoted to studying pulsating EHB stars were described on the Friday morning. **Roy Østensen** (Isaac Newton Group) presented spectra of PG 1325+101 that show the changes in radial velocity and temperature of the star through the pulsation cycle. **Simon O'Toole** (Bamberg) gave delegates a first look at 399 hours of photometry and 151 hours of time-resolved spectroscopy of PG 1605+072, an EC 14026 star with a complex spectrum of unusually large-amplitude, low-frequency pulsations. **Suzanna Randall** (Montréal) also had results hot-off-the-telescope, in this case the first extensive photometry of a PG 1716+426 star. The target star, PG 1627+017, shows 8 to 10 periods in the range 4500 s to 8900 s with amplitudes of 0.15–0.5%.

As well as the high quality of the presentations and the lively discussion, the meeting benefited from short but informative talks by those presenting posters. **Dave Kilkenny** rounded things off with a review of the meeting that all enjoyed for its informal but informative style. The excitement generated by the flow of new discoveries led to calls for another meeting on the subject – answered by Dr Østensen who is organizing a meeting at La Palma. If you are interested in attending a meeting on EHB stars and other blue stars in old stellar populations in the summer of 2005, please contact Roy Østensen (roy@ing.iac.es).

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