SUMMARY FOR COOL STARS 13: INTERNAL AND EXTERNAL CONNECTIONS

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Abstract

I summarize the important observational and theoretical advances presented at the 13th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun held July 5–9, 2004 in Hamburg Germany. I highlight the increasing number of interconnections between different topics in cool stars research and between the new results presented at this meeting and broader topics in astrophysics. The richness and maturity of cool stars research are both manifest in these interconnections and in the growing importance of studies of star formation, circumstellar material, stellar winds, and infrared observations.

Key words: Stars: structure – Stars: chromospheres – Stars: coronae – Stars: winds – Circumstellar material

1. Introduction

This thirteenth in the series of workshops entitled *Cool Stars, Stellar Systems, and the Sun* has come to an end. After 46 oral presentations and 218 posters, what more can be said? Without doubt the quality of the presentations and the importance of the new observational and theoretical results will rank this meeting as one of the best, if not the best, in the series. Credit for this extraordinarily successful meeting must be given to the Scientific Organizing Committee headed by Prof. Jürgen Schmitt, who arranged the scientific program, the Local Organizing Committee, who arranged the meeting site and the social programs, and, of course, the speakers and poster presenters. We should thank all of them.

What struck me as most exciting at this meeting is the extent to which results in formerly isolated topics in cool stars astrophysics are now interconnecting with research in other cool star topics and with the more general questions of contemporary astrophysics. I will be identifying these internal and external connections throughout this summary, but I want to note first that the number and significance of these interconnections demonstrates the maturity and vitality of the field and its inherent richness.

There are other themes of this meeting that deserve special comment. One is the importance of computer simulations as a research tool for identifying the roles of different physical processes in creating the phenomena that we observe. Many phenomena are sufficiently complicated that simple intuition may be deceptive and, as is common in astrophysics, it is impossible to do controlled experiments in which one changes one independent variable at a time to identify which variables lead to different observational results. Instead, one can use computer simulations in which one includes the essential physical processes, even if only approximately, to determine the sensitivity of observables to changes in each independent variable or the inclusion of each physical process. I emphasize here that it is more important to include the essential physical processes approximately than to include only a subset of the physical processes exactly.

Another theme of the meeting is the importance of acquiring volume-limited or brightness-limited surveys to produce relatively unbiased samples of targets with which to arrive at statistical results that are likely to hold up under the onslaught of future more comprehensive observations. The archives of well-calibrated and easily searched data from such satellites as ROSAT, IUE, HST, Chandra, and XMM-Newton are enormously valuable for this purpose.

A third theme is the increasing application of very sophisticated data analysis tools for the inference of stellar atmospheric structures with dimensions far below the telescope's diffraction limit. The existence of spectra and spectro-polarimetric data with very high signal-to-noise and spectral resolution allows the skillful observer to produce Doppler images and Zeeman-Doppler images that identify the magnetic structures on stars. Also, studies of stellar winds with enough spatial resolution to infer the increase in outflow velocity with height and the presence of inhomogeneous structures in the outer atmospheres of stars are providing the data that will challenge theoreticians to develop more realistic models of stellar winds. The new measurements of mass loss rates from solarlike dwarf stars are an example of the skillful analysis of excellent quality data that will challenge solar wind theoreticians to broaden their horizon.

Last, but far from least, is the overwhelming importance of qualitatively new data to the field. Astronomy has always been a data-driven field, but the qualitatively new X-ray spectra from Chandra and XMM-Newton, the new results from Keck, the VLT, and new interferometers, and very recently the new infrared data from Spitzer are

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changing our understanding of cool stars in major ways. At this meeting we acquired only a taste of what the recently launched Spitzer Observatory will deliver in the way of deep infrared (IR) images and spectra. I predict that Cool Stars 14 will be a celebration of Spitzer's data.

2. Who said this?

Like many scientific meetings, the speakers often introduced curious new jargon or misspoke in ways that are humorous when ripped out of context. I had not planned to list some of the more egregious quotes, as I have done in previous summaries, but many of you asked me to do so. In the oral presentation of this summary, I asked the audience to identify the speaker of each of these quotes. In the absence of a responsive audience for this written version of the summary, I list here the quotes and the speakers, whom I believe will not object to my quoting what they actually said:

"You get what scientists call a mess." *Wolfgang Dobler*
"The purpose of a diagnostic tool is not to verify anything." *Dainis Dravins*
"Recently the agreement of theory and observations has gone downhill."
Jørgen Christiansen-Dalsgaard
"A unique harmonization of data." *Ulrich Cubosh*
"I feel like I should be selling something." *Adam Burgasser*
"Of course we need more candidates and more data." *Nano Santos*
"The synthetic models are wrong. They are always wrong." *Peter Hauschild*
"In order to give you the impression that we have done our job" *Christiane Helling*
"The next talk will be on the weather in Hamburg – rain and clouds" *Peter Hauschild*
"My sophisticated model – a horizontal line at zero." *Jeff Valenti*

3. Progress in Addressing Major Questions

So much for the broad themes and the offbeat quotes, now let us proceed to a more detailed summary of the new results presented at this meeting. Given the limitations of time and my limited ability to assimilate five days of nonstop presentations, I will describe what struck me as most interesting in the oral presentations and in the posters that I was able to read. For a more complete summary, I encourage you to read the publications presented in this book. I organize these results according to the important questions that they help to answer. I list only the first authors of the oral and poster presentations, although most papers have multiple authors. *My comments on these results are listed in italic fonts.*

3.1. Are Climate and Solar activity correlated?

Ulrich Cubasch: The recent warming of the Earth's climate, which is larger than has been seen in the last 1000 years, cannot be explained only by solar forcing. *This is a politically important result that connects solar research with studies of the terrestrial climate.*

Sami Solanki: The Sun has been more active during the last 60 years than in the previous 1100 years.

Phil Judge: If τ Ceti (an old G8 V star) is a reliable indicator of solar activity during the Maunder minimum, then during the Maunder minimum the Sun likely had some Ca II emission and thus a magnetic network and probably a magnetic cycle. The transition region lines of τ Ceti show no redshifts, unlike what is seen on the Sun and more active stars. *This clearly shows that magnetic fields are responsible for the observed redshifts either directly or indirectly.*

Jason Wright (Poster): Most or all of the solar-type stars with very low Ca II emission are actually evolved subgiants located about 1 magnitude above the main sequence rather than solar analogs in a Maunder minimum state. *These stars therefore cannot be used to infer the magnetic properties of the Sun during Maunder minimum.*

3.2. How are coronae heated?

Hardi Peter: Self-consistent three-dimensional MHD models of a solar active region with heating due to braiding of magnetic flux (originally proposed by Parker (1988)) can explain both the differential emission measure distribution, DEM(T), and the observed Doppler shifts as a function of temperature. *Here is an excellent example of how computer simulations can lead to explanations of observables that could not be explained by previous one-dimensional models.*

Karel Schrijver: Potential field extrapolations of the solar global magnetic field with different functional heating laws show that the best fit to Yohkoh X-ray images is with a heating law that is consistent with DC heating by braided coronal magnetic fields with reconnection at the Alfvèn speed. *This result is similar to the previously described conclusions of Peter but was arrived at in a very different way.* The best fuctional heating law predicts flux-flux relations for active stars consistent with observations.

Sam Krucker: RHESSI nonthermal spectra of flares may answer the question of whether microflares are responsible for coronal heating. This will require the analysis of RHESSI data at low energies to determine the total nonthermal energy distribution.

Massimo Landi (Poster): None of the commonly assumed heating mechanisms accurately reproduce the solar X-ray observations. Loop temperatures and transition region emission lines are best reproduced by loops with small cross-sectional areas at their base that expand upwards. *This study demonstrated the importance of magnetic field geometry for the heating of coronae.*

Alessandra Telleschi (Poster): This poster describes the time scale over which young stars change from having very hot coronae with inverse-FIP coronal abundances to stars with cooler coronae and normal-FIP coronal abundances like the Sun.

Giovanni Peres (Poster): This poster describes the scaling laws relating temperature, pressure, and volumetric heating rate as a function of coronal magnetic field loop length. *What remains to be determined is how to identify uniquely which physical processes are important in stellar coronae from these scaling laws.*

Eric Feigelson: X-ray saturation observed in the young Orion stars depends on stellar age like other samples of stars, but the dependence on rotation is different. Accreting PMS stars show lower X-ray emission than nonaccreting stars. *Why does accretion decrease the X-ray emission from young stars? The answer to this question is not clear.*

3.3. Stellar coronal structures

Jan-Uwe Ness: XMM-Newton and Chandra spectra of Fe XXI and Fe XXII imply different coronal electron densities than EUVE spectra. *We need higher S/N and spectral resolution data and, especially, a better understanding of atomic physics to make progress in explaining these discrepancies.*

Paola Testa (Poster): The ratios of He-like Mg XI lines indicate high-density plasma covering 0.01% to 10% of the surface area of active stars, whereas the O VII line ratios indicate cool low-density plasma covering up the entire surface area of active stars. *Does this mean that the high-density plasma occurs only in flares?*

Manuel Güdel (Poster): XMM-Newton observations of the eclipsing M dwarf primary CM Dra include times during both primary and secondary eclipses. *Reconstruction of the coronal structure is crude and probably not unique, but such image reconstructions will become powerful tools when new missions with higher sensitivity and better time resolution become available.*

3.4. Stellar magnetic fields

Moira Jardine: The mixed magnetic polarity at the poles of rapidly-rotating active stars inferred from the analysis of Zeeman-Doppler images can be simulated by models that assume that the rates of magnetic flux emergence are much larger than observed on the Sun. These models also predict enhanced meridional flows. Mixed polarity at the poles may also explain why X-ray cycles, analogous to the solar magnetic cycle, are not observed in the X-ray emission from active stars.

Jeff Valenti: The new generation of infrared spectroscopic instruments on large telescopes now permit the measurement of 2–3 kG magnetic fields in active K dwarfs and PMS stars. He also showed the first measurement of a uniform magnetic field in the accretion shock of a PMS star using spectropolarimetry.

Søren Dorch (Poster): MHD simulations show that M giants and supergiants like Betelgeuse could have 500 G surface magnetic fields, which could influence dust and wind formation. *Such strong magnetic fields have not been detected yet but should be searched for.*

Nils Ryde (Poster): The 12μ Mg I line, which is very Zeeman sensitive, is a good tool for measuring photospheric magnetic fields with new IR spectrographs like TEXES.

Michaelo Weber (Poster): The new robotic telescope STELLA will obtain Doppler images of many active stars. *This and other instruments should study a diverse range of stars and monitor interesting stars over stellar magnetic cycle timescales.*

3.5. The physics of crazy coronal abundances

Marc Audard: It is important to compare coronal abundances with the measured photospheric abundances of the same star. Chemical abundance separation (often called "filtration") likely occurs in the chromosphere where FIP < 10 eV elements are ionized, but the responsible physical processes are not well understood.

David Garcia-Alvarez: The existance of very hot coronal plasma plays a role in determining whether coronal abundances are consistent with the FIP or inverse FIP distribution, perhaps produced by chromospheric evaporation or ionization.

Manfred Cuntz (Poster): The effects of time-dependent ionization are most pronounced in simulations of magnetic flux tubes that diverge slowly with height. *Departures from ionization equilibrium will occur when there are large magnetic filling factors in the photosphere.*

Jorge Sanz-Forcada (Poster): For some stars, inverse FIP abundances disappear when one compares coronal with observed stellar photospheric abundances rather than assuming that the star has solar photospheric abundances.

3.6. High energy particle acceleration

Sam Krucker: The beautiful RHESSI images show the locations of the thermal and nonthermal components of solar flares and detect a plasmoid rising from a reconnecting loop. During a flare near the solar limb, a time display of RESSI images provides evidence for nonthermal electrons and protons in similar nearby loops.

Rachel Osten (Poster): Gyrosynchrotron emission from relativistic electrons is the likely source of variable 3.6 cm and 6 cm emission from the nearby M8.5 V star

TVLM513-46546 observed by the VLA. *The presence of synchrotron emission requires an acceleration mechanism for the electrons and a turbulent magnetic-field structure in a fully convective star. Further development of theoretical models for dynamos and acceleration processes in these very cool stars is needed. Also, is radio emission from very cool stars typical or not?*

3.7. New insights concerning stellar flares

Marc Audard: The Neupert effect (Neupert 1968), previously observed during solar flares, is now observed during flares on several stars like Proxima Cen. Observations of this effect support the chromospheric evaporation scenario in flare models.

Jan-Uwe Ness: Coronal electron densities decreased with time during a flare on Proxima Centauri. *While this is not a new result, the measured decrease in electron densities provides constraints on models for the decay phase of flares.*

3.8. Do A-type stars have hot outer atmospheres?

Beate Stelzer: Observations using ground-based adaptive optics, Chandra X-ray images, and infrared spectroscopy still do not rule out the possibility that X-rays from B stars are in fact emitted by unknown faint close stellar companions. *A different test for whether the X-ray emission is from cool star companions is to look for X-ray variability and hard X-ray spectra that are characteristic of emission from cool star companions.*

Eric Feigelson: The Chandra Orion Ultradeep Project (COUP) images show that the young A and B stars in Orion are either very weak X-ray sources or dark. *This data set suggests, but does not prove, that these stars do not have low mass companions.*

Seth Redfield (Poster): The horned shape of the C III 977 Å and O VI 1032 Å lines of Altair (A7 V) provide the first evidence for limb brightening that one would expect if there is optically thin emission from hot gas above the stellar photosphere. *This result indicates that Doppler imaging of the hot gas in the outer atmospheres of rapidly-rotating stars should be feasible even at the spectral resolution of FUSE and perhaps Con-X.*

Christian Schröder (Poster): There are 73 apparently single A-type stars in the ROSAT All-sky Survey (RASS) pointing error boxes. Some of these sources have L_x values that appear to be too high to be explained by emission from late-type stellar companions. *Since the RASS error boxes are large, a follow-up Chandra study is needed to better identify the sources.*

Jürgen Schmitt (Poster): Some magnetic chemically peculiar (MCP) stars with spectral types B2p–A0p are strong X-ray sources. *The X-rays are probably produced by the wind-driven magnetosphere mechanism (e.g., Linsky, Drake, & Bastian 1992) rather than by solarlike coronal sources.*

3.9. Stellar interior structure and dynamos

Jørgen Christensen-Dalsgaard: To achieve a good match of observed with predicted oscillation frequencies, solar models must include both the settling of heavy elements and the relativistic motions of electrons. However, the new lower oxygen abundance derived by Asplund et al. (2004) using 3D hydrodynamic models for the solar photosphere is creating a serious challenge to solar interior models. The solar models will have to be altered somehow to fit both the oscillation frequencies and the new metal abundance and ionization required by the much lower solar oxygen abundance. *Since oxygen is the most abundant element after hydrogen and helium, a decrease in the oxygen abundance has a major effect on the total metal abundance, which affects the ionization and sound speed in the Sun. The new oxygen abundance also impacts studies of depletions and energy balance of gas in the interstellar medium.*

John Barnes: Differential rotation is observed to decrease with stellar mass until stars cooler than spectral type M1–2V rotate as solid bodies. Thus, the alpha effect must dominate magnetic field generation by a dynamo in M dwarfs.

Michael Weber (Poster): This study of differential rotation of 5 RS CVn-type giants using time series Doppler images shows that some stars are solarlike (the equator rotates faster than the pole) and some stars show the reverse behavior. *This puzzling result should be explored theoretically.*

Wolfgang Dobler: Theoretical models for fully convective stars can and do generate large-scale magnetic fields. *This theoretical work may explain why M dwarfs appear to have large-scale magnetic loops and very energetic flares.*

3.10. Interaction of stars with disks

Eric Feigelson: The deep penetration of hard X-rays and MeV protons from PMS stellar flares can change the chemistry, ionization, and turbulence in the disks of these stars. These changes may determine whether protoplanets migrate inwards to the star to become hot Jupiters or remain further from the star, perhaps becoming habitable Earths. *This speculation, if supported by detailed calculations, could have an important impact on our understanding of planetary evolution and the possible presence of life elsewhere in the universe.*

Scott Gregory: Computed potential magnetic-field extrapolations can predict the location of accretion channels for PMS stars. These models show good agreement between the predicted accretion channel positions and the location of strong polar fields in Zeeman-Doppler images of the rapidly-rotating stars LQ Hya and AB Dor. *The success of this pioneering work should encourage people to compute realistic models for the interactions between the magnetic fields surrounding active stars and the fields in disks.*

Ray Jayarardhana: Since accreting brown dwarfs are slow rotators, the disk-locking scenario for the evolution of stellar angular momentum applies to young brown dwarfs.

Jochen Eislöffel: For very low mass stars and brown dwarfs older than 3 Myr, the disk-locking mechanism probably does not change the stellar rotation significantly.

3.11. Coronal spectral diagnostics

M. Matranga (Poster): The Chandra data provide evidence for significant opacity in the Fe XVII 16.78 Å and 15.01 Å lines. This predicts that the path length for absorption in these lines is about 0.03 $R_\star$. *There have been conflicting reports in the literature concerning the optical depths of coronal emission lines.*

3.12. What is Spitzer telling us about PMS stars?

John Stauffer: Class I premain sequence (PMS) objects near the tips of dark gas and dust clouds (called "elephant trunks" in the case of the Eagle Nebula) are sites of significant star formation. *These nascent clouds are likely photodissociation regions in which the radiation or hot winds from nearby hot stars are dissociating the gas and compressing it to initiate star formation.* Also, the time scale for the dissipation of A star debris disks like those surrounding Vega and β Pic is about 100 Myr.

Adam Burgasser: Spitzer is providing the first good mid-IR spectra of metal-poor L and T subdwarfs that need to be matched by good model atmospheres for detailed analysis.

Michael Cushing: Spitzer spectra are providing the first detections of 7.8μ CH_4 and 10.5μ NH_3 bands in brown dwarfs.

3.13. What is new about brown dwarfs?

Kevin Luhman: Spitzer is an excellent instrument for the discovery of Class I brown dwarfs. The first detected widely-separated brown-dwarf binary system provides the best evidence yet that brown dwarfs are formed by cloud fragmentation rather than by ejection from a multiple system.

Kelle Cruz: The stellar luminosity function turns up at M_J = 14–15 (the stellar-brown dwarf boundary), but Spitzer data are needed to determine the shape of the luminosity function for brown dwarfs fainter than M_J = 16 (spectral type L7).

Subhanjoy Mohanty: At low masses ($\leq 0.01 M_\odot$), stellar radii appear to be too large, suggesting that existing evolutionary tracks may be in error due to the early beginning of deuterium burning.

Hervé Bouy: Analysis of astrometric, photometric, and spectroscopic observations determine the first dynamical mass for a brown dwarf. This result will provide an important test of theoretical models for brown dwarf interior structure and evolution.

3.14. How are stellar winds accelerated?

Stephen Cranmer: The speed, density, and mass flux of the solar wind depend on the magnetic field topology. Large expansion factors produce a slow wind, while small expansion factors lead to a high speed wind. Also, the observed strong departures from Maxwellian velocities of heavy ions indicate that wave dissipation is important for solar wind acceleration. Future observations of ion-cyclotron waves would support this conclusion. *This work is another demonstration of the critical inportance of magnetic field geometry to explain solar and stellar phenomena.*

Brian Wood: The analysis of high-resolution GHRS and STIS spectra of stellar Lyman-α lines has opened a whole new topic of research — the study of dwarf star winds. The apparent decrease in mass loss rates for high X-ray surface fluxes ($\log F_x > 6$) could be due to a topological change in coronal magnetic fields from a solarlike complex field geometry to a nearly dipolar geometry with polar spots. *This result shows how the previously separate studies of stellar winds, stellar magnetic fields, and stellar X-ray emission are beginning to interconnect.*

Susanne Höfner: It is important to include the essential microphysics (e.g., frequency-dependent radiative transfer, time-dependent dust formation, and pulsations) when modeling AGB atmospheres and winds. There is much information available in time-series data.

Cian Crowley: Empirical wind velocity laws for giants in symbiotic binary systems obtained from the N(H I) vs phase data are inconsistent with generally used velocity laws of the form $v(r) \approx v_\infty (1 - r_\circ / r)^\beta$. *This suggests that this functional form for the wind velocity law may not be valid for cool giants and supergiants in general.*

Klaus-Peter Schröder (Poster): A new semiempirical mass loss relation is different from the "classical" Reimers law. This should be important for understanding the evolution of AGB stars.

Alex Lobel: Spatially-resolved spectroscopy of Betelgeuse (α Ori) using STIS in its spectroscopic imaging mode provides evidence for wind acceleration in the upper chromosphere of this supergiant. The coexistence of warm gas and cold dust in the upper chromosphere of a star may require time-dependent wind acceleration models.

4. Looking into the Future

While the future can never be predicted accurately, the results presented at this meeting provide guidance as to what will likely drive cool-star astrophysics into new, exciting directions — qualitatively new data. We had a taste of what the powerful infrared imaging and spectroscopy from Spitzer will provide in the areas of premain-sequence star formation and evolution, brown dwarfs, and circumstellar dust and gas disks out of which planets form. Over the next few years, we should see the full flowering of this new data source and its application to other relevant topics such as stellar winds, dust formation processes, and unanticipated discoveries. In only a few years time, ALMA will begin exploring the millimeter and submillimeter domains with unprecedented sensitivity from its site located at 5,000 meters elevation. I anticipate that ALMA will provide new information on the earliest stages of star formation, given the deep penetration of millimeter waves through cold dust and gas. Ground-based spectroscopy utilizing new instruments with high throughput, high spectral resolution (especially in the infrared), simultaneous multitarget capability, and fed by large telescopes will provide new information on stellar structure (both interior through asteroseismology and exterior through Doppler imaging). Asteroseismology should bloom with new satellite instruments, and the study of exoplanets will be supported by transit experiments (e.g., Kepler) and new missions like SIM, TPF and Darwin in the more distant future. We must not forget the power of robotic telescopes with modest apertures to monitor stars in systematic ways not possible with the larger instruments to discover and monitor phenomena.

Despite these anticipated new sources of data, we face, in the not too distant future, the loss of two major observing capabilities. XMM-Newton and, in particular, Chandra opened up the new field of high (by X-ray standards) resolution spectroscopy and also deep imaging with unprecedented angular resolution. X-ray spectroscopy is providing new information on stellar coronal abundances and coronal properties, while the high-resolution X-ray imaging with moderate-resolution spectroscopy is providing a rich trove of information on Class 0 to II PMS stars. Both Chandra and XMM-Newton are operating beautifully and continue to be supported by NASA and ESA, but their lifetimes are unknown. Astro–E2, the next X-ray mission, will have much lower angular resolution and high-energy resolution only at the highest energies. The diagnostically rich 0.5–2.0 keV region will have only modest energy resolution. A major problem is the lack of funding for future X-ray missions. Constellation-X is now essentially unfunded by NASA and therefore cannot be launched before roughly 2015. The European X-ray mission XEUS lies even further in the future. Thus there could be a hiatus in X-ray studies for many years after the present X-ray observatories have completed their programs.

A more immediate problem is in the ultraviolet. UV spectroscopy revolutionized the study of cool stars beginning with IUE (1978–1996) and continuing with the GHRS and STIS instruments on HST. The combination of much higher throughput and a variety of resolutions up to 100,000, allows us to study velocity fields, winds, chemical compositions, and even a few coronal emission lines. The imaging properties of FOC and STIS are providing information on the velocity structure of the wind of Betelgeuse and are useful in imaging stellar disks of nearby stars. However, the limited lifetime of HST and the small amount of observing time allocated to cool star programs by the HST telescope allocation committees indicate that UV studies of cool stars are coming to an end. It is not widely known in the community that since the electrical system of STIS is no longer redundant, STIS is only one electrical failure away from its demise[1]. At shorter wavelengths, FUSE is still operating well, even in its zero gyro mode, although its lifetime is unknown and NASA is providing decreasing support for its operation.

It is very sad to recognize that beyond HST and FUSE there are no UV spectroscopic missions definitely planned by any space agency. GALAX is providing broadband UV imaging capability and limited UV spectroscopic capability, but this is no substitute for the capabilities of HST and FUSE. The Cosmic Origins Spectrograph (COS), built as a new instrument for HST, is completed and delivered to Goddard, but there are no plans at present to install it on HST or mate it to a new telescope and spacecraft as a future mission. If COS should ever fly, it will provide very sensitive medium-resolution UV spectroscopy but no high-resolution spectroscopy, long-slit imaging spectroscopy, or coronographic UV imaging. Fortunately, people are thinking about how this instrument could be used effectively.

What should be done to minimize the time interval during which astronomers will have little or no observing capability in the UV? First the cool-star community should articulate the critical scientific objectives that require UV spectroscopy and imaging and show how the results of such research would also address major questions in astrophysics. Second, this scientific rationale should be merged with the scientific rationales of other branches of astrophysics into a compelling document that we can all support. Then this document must be publicized and sold to our astronomical colleagues and the space agencies together with an implementation plan.

If vigorously implemented, this approach can address the long-term goal of obtaining new UV data to study new objectives, but if history is a useful guide, the time scale from conception to launch for major missions is at least 20 years. For the near term, I suggest that we pro-

[1] This statement was unfortunately too true. Only one month after this talk, the side 2 electronics on STIS failed, likely ending the seven year life of this highly productive instrument.

pose HST and FUSE legacy programs that will provide a rich archive of data for future analysis. While both missions have useful, well-calibrated archives, there are major gaps in their coverage that should be identified and proposed for filling. During the course of this meeting, several people have stated that our theoretical understanding of atomic and molecular physics limits our ability to analyze both the UV and X-ray spectroscopic data. While this is true today, we should be able to fill in these theoretical gaps in the future. Thus while the UV and X-ray legacy archives may not be fully analyzable today, future researchers should be able to analyze the data in far more detail after we have lost the ability to acquire new data.

There is clearly a need for a moderate-scale UV spectroscopic mission that can address important objectives in the near term before a major new facility can be built. The concept of a World Space Observatory (WSO) may be this critically needed facility.

I conclude that the study of cool stars, stellar systems, and the Sun is kühl in large part because it provides insights into the broader issues of contemporary astrophysics.

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