PROGRESS REPORT

NASA Grant :	NAG5-3224
Institution :	The Regents of the University of Colorado, Boulder CO 80309-019
Principal Investigator :	Dr. Stephen L. Skinner JILA, University of Colorado
Report Covering the Period:	1/25/97 - 1/31/98
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Report Submitted:	6 February 1998

PROGRESS REPORT (1/25/97 to 1/31/98)
NASA Grant NAG5-3224
PI: Stephen L. Skinner (JILA)
Sponsoring PI: Jeffrey L. Linsky (JILA)

Grant Identification - NASA NAG5-3224 funds the research of Stephen L. Skinner under the LTSA program . The proposal title was *X-ray Emission from Pre-Main-Sequence Stars - Testing the Solar Analogy.*

Start Date - The first year of this fellowship commenced at JILA on 25 April 1995.

Report Period - This report covers the period 25 January 1997 - 31 January 1998.

Research Synopsis - This LTSA award funds my research on the origin of stellar X-ray emission and the solar-stellar analogy. The focus during most of this reporting period continued to be on the reduction and analysis of data acquired with the *ASCA* observatory (Advanced Satellite for Cosmology and Astrophysics). This work has been undertaken in collaboration with Dr. M. Güdel (PSI/ETH Zurich), Dr. F. Walter (SUNY - Stony Brook), Dr. F. Nagase (ISAS - Tokyo), Dr. M. Itoh (Kobe University), and Dr. K. Koyama (Kyoto University). During the last few months of this reporting period, considerable time and effort was also devoted to the submission of AXAF observing proposals in preparation for the upcoming AXAF launch.

During this reporting period, five papers appeared in refereed journals for which I was either author or co-author, and two additional papers have recently been submitted to ApJ. Also, three conference proceedings papers were submitted. These publications are listed in the attached bibliography.

Pre-main Sequence Stars: In a paper recently submitted to ApJ in collaboration with researchers at Kyoto University (Tsuboi et al. 1998), we have reported the first detection of superhot flaring plasma at temperatures of ~100 million K in the T Tauri star V773 Tau. Previous strong flares were reported on this young binary system by Skinner et al. (1997). This temperature estimate is based on high signal-to-noise X-ray spectra, and provides the first unambiguous evidence that flare temperatures in young T Tauri systems can greatly exceed those seen on the sun today. These findings are in general agreement with other studies (cf. Güdel et al. 1997) which show that the amount of hot (flaring) X-ray plasma in solar-like stars decreases with age. It thus seems very likely that our sun was a much more violent X-ray source in its youth than it is today. Convulsive releases of X-ray energy by the young sun may have influenced the chemistry, thermal structure, and evolution of the inner nebular disk where the terrestrial planets formed.

In addition to showing very high temperatures, the strong X-ray flare on V773 Tau also displayed other remarkable features. In particular, the metal abundances showed an apparent change during the flare, with larger abundances measured near the flare peak, followed by a slow decline in abundances as the flare decayed. Nearly identical behavior has also been seen in other active late-type RS CVn systems such as that recently reported for the system UX Ari by Güdel et al. (1997, submitted). These new data suggest that mixing occurs during flares, with chromospheric evaporation bringing metal-rich material from the chromosphere up into a metal-poor corona.

In other work in progress, Skinner & Walter (1997) have analyzed a deep ASCA observation of the L1517 star-forming region centered on the unusual T Tauri star SU Aurigae. This pre-main-sequence star is of interest because of its earlier G spectral type (similar to the sun) and the belief that it is experiencing both mass inflow and mass outflow. The ASCA observation detected low-level X-ray variability on a timescale of ~1 day, which may be rotationally-induced. In addition, the ASCA data show hot plasma at temperatures near 30 million K. Such high temperatures cannot be readily explained in terms of accretion shocks, and a corona seems to be the most plausible source of the X-ray emission. The complete results of this study will be submitted to ApJ in the second quarter of 1998.

Young Solar-like Stars: The study of X-ray and radio emission from young solar-like stars continues in collaboration with Dr. M. Güdel (PSI/ETH-Zurich). This is part of a long-term program aimed at understanding the evolution of the sun's X-ray activity over time. Three papers appeared in collaboration with Dr. Güdel in 1997, culminating several years worth of work. We recently submitted several AXAF proposals to continue this study in the AXAF era, and are also planning to make heavy use of the European XMM satellite (1999 launch) for a continuation of this effort.

Massive Stars: The sun, which has been well-studied in X-rays, provides a useful paradigm for explaining much of the X-ray behaviour seen in low-mass stars. There are, however, no nearby high-mass stars that can be studied in such intimate detail as the sun, and the origin of X-ray emission from high-mass stars thus remains much more obscure. Traditionally, X-ray emission from high-mass stars has been attributed to shocks that are set up by their powerful winds. However, as X-ray observations improve this interpretation is coming under close scrutiny and it is not yet clear that shock processes will be able to account for the entire range of X-ray phenomena seen in massive OB and Wolf-Rayet stars. To date, very few high-quality X-ray spectra have been obtained of massive stars, and this area will be one of intense research with the upcoming AXAF and XMM X-ray observatories because of their greatly improved sensitivity.

AXAF grating observations will provide us with the first opportunity to search for X-ray line broadening and line-shifts which should be present if the X-rays from massive stars truly originate in high-speed shock flows. In addition, high-resolution AXAF and XMM spectra will offer the exciting prospect of obtaining reliable X-ray metal abundance estimates which can be directly compared with predictions from evolutionary theories for massive stars. This will be particularly important for Wolf-Rayet stars, whose surface and wind composition is predicted to deviate strongly from solar composition as the result of enrichment from the previous core helium burning phase. I have submitted a recent AXAF proposal which will test these ideas.

The study of X-ray emission from Wolf-Rayet (WR) stars using ASCA continues in collaboration with Dr. F. Nagase (ISAS, Tokyo) and Dr. M. Itoh (Kobe Univ.). In a recent paper (Skinner, Itoh, & Nagase 1997), we have presented results of ASCA observations of the unusual WR star EZ CMa. This star is suspected to be a binary, and it has been suggested by several authors that the companion could be a neutron star. Evolutionary models predict that compact companions (c) should exist around some WR stars as a result of the supernova explosion of the primary in a WR + O system. Even so, there is very little observational evidence for the existence of WR + c systems, with Cyg X-3 being the only convincing candidate to date. Our ASCA observations of EZ CMa showed no evidence for hard X-rays above 5 keV which should be present if the strong WR wind is accreting onto a compact companion. Furthermore, its measured X-ray luminosity is well below that expected for accretion onto a neutron star. These new observations are important since they provide the strongest argument to date against the compact companion model for EZ CMa. The failure to detect evidence for a compact companion around EZ CMa and in another candidate WR + c system WR 147 (Skinner et al. 1997) raises troubling questions about the existence of such systems. It now seems that if such systems exist at all, then they are either very rare or X-ray up to $\sim$12 keV.

PUBLICATIONS RESULTING FROM THIS LTSA PROGRAM
Stephen L. Skinner

Skinner, S.L., Itoh, M., Nagase, F., & Ozawa, H., 1997, *ASCA Observations of the Enigmatic Wolf-Rayet Star AS431 (= WR147)*, BAAS, 29(5), 1278.

Tsuboi, Y., Koyama, K., Murakami, H., Hayashi, M., Skinner, S., & Ueno, S., 1998, *ASCA Detection of a Superhot 100 million K X-ray Flare on the Weak-lined T Tauri Star V773 Tauri*, ApJ, submitted.

Maeda, Y., Koyama, K., Yokogawa, J., & Skinner, S., 1998, *X-ray Evidence for Wind-Wind Collision in the Wolf-Rayet Binary V444 Cygni*, ApJ, submitted.

Skinner, S.L. & Walter, F.M., 1997, *A Deep ASCA X-ray Observation of the Classical T Tauri Star SU Aurigae*, in Cool Stars, Stellar Systems, and the Sun (Tenth Cambridge Workshop), eds. B. Donahue & J. Bookbinder, San Francisco: ASP, in press.

Güdel, M., Guinan, E.F., Benz, A.O., & Skinner, S.L., 1997, *The X-ray and Radio Sun in Time: Coronal Evolution of Solar-Type Stars with Different Ages*, in Cool Stars, Stellar Systems, and the Sun (Tenth Cambridge Workshop), eds. B. Donahue & J. Bookbinder, San Francisco: ASP, in press.

Güdel, M., Guinan, E.F, Etzel, P., Mewe, R., Kaastra, J.S., & Skinner, S.L., 1997, *Assembling Pieces of the Puzzle: A Nearby, Rapidly Rotating Young Sun in 47 Cas?*, in Cool Stars, Stellar Systems, and the Sun (Tenth Cambridge Workshop), eds. B. Donahue & J. Bookbinder, San Francisco: ASP, in press.

Skinner, S.L., Itoh, M., & Nagase, F., 1997, *A Search for X-ray Evidence of a Compact Companion to the Unusual Wolf-Rayet Star HD50896 (EZ CMa)*, New Astronomy, 3, 37

Skinner, S.L., 1997, *Violent Hiccup from a Newborn Star*, Nature, 387, 22.

Skinner, S.L., Güdel, M., Koyama, K., & Yamauchi, S., 1997, *ASCA Observations of the Barnard 209 Dark Cloud and an Intense X-ray Flare on V773 Tau*, ApJ, 486, 886.

Güdel, M., Guinan, E.F., & Skinner, S.L., 1997, *The X-ray Sun in Time: A Study of the Long-term Evolution of Solar-type Coronae with ROSAT and ASCA*, ApJ, 483, 947.

Güdel, M., Guinan, E.F., Mewe, R., Kaastra, J.S., & Skinner, S.L., 1997, *A Determination of the Coronal Emission Measure Distribution in the Young Solar Analog EK Draconis from ASCA/EUVE Spectra*, ApJ, 479, 416.

Skinner, S., & Yamauchi, S., 1996, *ASCA Observations of HD104237 (A4e) and the Origin of X-ray Emission from Herbig Ae Stars*, ApJ, 471, 987.

Stevens, I.R., Corcoran, M.F., Willis, A.J., Pollock, A.M.T., Skinner, S.L., Nagase, F., & Koyama, K., 1996, *ASCA Observations of γ^2 Velorum (WC8 + O9I): The Variable X-ray Spectrum of Colliding Winds*, MNRAS, 283, 589.

Güdel, M., Benz, A.O., Schmitt, J.H.M.M., & Skinner, S.L., 1996, *The Neupert Effect in Active Stellar Coronae: Chromospheric Evaporation and Coronal Heating in the dMe Flare Star Binary UV Ceti*, ApJ, 471, 1002.

Brown, A., Tjin a Djie, H., Blondel, P., Harper, G., Bennett, P., & Skinner, S., 1996, *HST GHRS Observations of the Herbig Ae Star HD104237: First UV Observations of a Hot Disk Wind from a Pre-Main-Sequence Star*, in Accretion Phenomena and Related Outflows (IAU Colloq. 163), eds. D. Wickramasinghe, L. Ferrario, & G. Bicknell, San Francisco: ASP, in press.

Skinner, S. & Brown, A., 1995, *ASCA Spectra of Late-type Giants and Supergiants: the Active G Star β Draconis*, in Ninth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, eds. R. Pallavicini and A. Dupree, San Francisco: ASP, 291.

Skinner, S., 1995, *Millimeter & Submillimeter Emission from Herbig Ae/Be Stars*, in Radio Emission from the Stars and the Sun, eds. A. Taylor & J. Paredes, San Francisco: ASP, 110.

Skinner, S., Walter, F., & Yamauchi, S., 1995, *ASCA Observations of Pre-Main-Sequence Stars*, in Röntgenstrahlung from the Universe, eds. H. Zimmermann & J. Trümper, Garching: ESO, 69.

CU Proposal No.

PROPOSED BUDGET DETAILS

Institution: The Regents of the
University of Colorado
Campus Box 19
Boulder, CO 80309-0019

Title: X-Ray Emission from Pre-Main Sequence Stars: Testing the Solar Analogy

Principal Investigator: Stephen Skinner
Co-PI: Jeffery Linsky

Duration: 5/15/98 - 5/14/99

	5/15/98 5/14/99
A. Salaries and Wages	
Principal Investigator: Skinner	
100% time, 4.5 mo. @ $2881.00/mo.	12,965
100% time, 7.5 mo. @ $2990.00/mo.	22,425
Co-Principal Investigator: Linsky	0
Total Salaries and Wages	35,390
B. Fringe Benefits	
Research Associate: 18.98% as TIAA (9.25%); FICA (6.2%); Workers' Compensation (1.484%); Unemployment (.091%); Annuitants' insurance (.508%); Medicare tax (1.45%) +	6,717
Group Insurance ($279.25/mo.)	3,351
Total Fringe Benefits	10,068
C. Travel	
Domestic Travel	
2 trips to meetings, each for 5 days	2,600
Foreign Travel	
1 European conference for 1 week	2,400
Total Travel	5,000
D. Other Direct Costs	
Computer Supplies	1,100
Long distance communication costs	725
Computer System Support	4,000
Publication costs (18 @ $150/page)	2,700
QPD Shop Charges (@ $60/hr) (Exempt from Indirect Costs)	880
Total Other Direct Costs	9,405
E. Total Direct Costs	59,863
F. Indirect Costs	
On-Campus: 45.1% of M.T.D.C., predetermined for the period 7/1/97 - 6/30/98. 45.5% of M.T.D.C., predetermined for the period 7/1/98 - 6/30/99. Per HHS Agreement dated May 14, 1996.	26,837
Use 45.5%	
G. Total Costs	**$86,700**