A Search for New Solar-Type Post-T Tauri Stars in the Taurus-Auriga and Scorpius-Centaurus Regions

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Abstract

The Taurus-Auriga and Sco-Cen regions of recent star formation were active approximately 1-3 and 10-30 Myr ago, respectively. Over the past several decades several hundred young stars have been identified in each of these regions based on various techniques including objective prism surveys for chromospherically active Hα and CaII emission-line sources, the IRAS survey for objects with substantial mid-infrared excess due to circumstellar dust, and the ROSAT survey for x-ray emission from active young coronae. More recently, deep wide-field optical and near-infrared imaging from the ground has been used to study small portions of these regions (each of which is several 10's of square degrees in total angular extent) with a particular focus on finding young low mass brown dwarfs. Yet the known stellar and sub-stellar populations in these regions is far from complete. Each of the above techniques suffers severe selection and completeness effects which bias existing samples. What is needed is a uniform survey designed to detect a characteristic common to all stars younger than several tens of Myr in order to give us a complete picture of the star formation histories of these regions.

We thus propose to take advantage of the unique capabilities of GalEx for wide-field imaging in the NUV and FUV at high sensitivity to more fully explore the young stellar and perhaps substellar populations associated with these "classic" regions of recent star formation. The chromospheric activity of young stars produces excess flux above their photospheres beginning in the optical U-band and extending to the NUV, FUV, and beyond. We will combine GalEx data with existing 2MASS, Tycho, and our own ground-based U,R,I surveys of these regions in order to identify new chromospherically active young stars for confirmation via follow-up optical spectroscopy.

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Scientific Justification

The GalEx All-sky Imaging Survey(AIS) will provide an unprecedented view into the near- and far-ultraviolet universe. One area of astronomical research that is not well-served by the AIS, due to avoidance of the galactic plane, is young stars. According to Fischer (1998; PhD Thesis, UCSC) only 1% (2/189) of a volume-limited (d < 25 pc) sample of K stars have lithium abundances and chromospheric activity suggesting ages possibly <100 Myr, with an additional 6% (11/189) plausibly 100-600 Myr, and the rest much older (distributed in age consistent with a nearly constant rate of star formation over the entire age of the galactic disk; see also Henry et al., 1996; AJ 111, 439). Despite the negligible surface density of any such very nearby, moderately young stars, the GalEx AIS will be able to find and characterize those at high and intermediate galactic latitudes. However, the AIS misses a substantial portion of the sky *known* to contain very young (<80 Myr) stellar populations.

Census information for stars in the 3-80 Myr age range is woefully incomplete. This is unfortunate since it is exactly the critical time scale for following and developing our understanding of the evolution of circumstellar dust and gas disks, as well as the evolution of stellar rotation and activity. Ages younger than 3 Myr are probed by studies of star forming regions still associated with molecular gas, while ages older than 80 Myr are represented by the well-studied nearby α Persei, Pleiades, Hyades, and other even older open clusters.

We propose here to close the age gap by using GalEx to identify new candidate young stars through their coronal and chromospheric activity which is manifest as ultraviolet emission in excess of photospheric levels. This study will build upon results from previous ultraviolet missions such as the imaging from EUVE and ROSAT/WFC and the spectroscopy from IUE and FUSE which were sensitive to similar chromospherically active young stars in the solar neighborhood but not those at the distances of the nearest regions of recent star formation, where only the most active, youngest (<3 Myr) stars could be observed. Our study will provide catalogs for investigation with Spitzer/SIRTF and SOFIA of dust/gas disk evolution around young stars and potentially with SIM for youthful planets. Our relevancy to NASA Origins Roadmap goals is thus very high.

Young stars are copious coronal x-ray emitters and a large body of literature demonstrates the connection between x-ray emission and chromospheric activity, stellar rotation, and age. Indeed, the surface density distribution of x-ray sources detected by the ROSAT all-sky survey reveals a concentration of objects coincident with Gould's Belt, a local feature in the distant solar neighborhood comprised of an expanding ring of atomic and molecular gas of which nearly all star-forming regions between 50 and 800 pc are a part. These x-ray sources are thought to be the dispersed low-mass counterparts to a series of 1-100 Myr-

old open clusters and OB associations that delineate Gould's Belt (e.g. Torra et al. 2000; Guillot 1998). Follow-up of RASS sources with proper motion data has enabled selection of the nearest of these young, x-ray-emitting stars with space motions consistent with those of higher mass stars having measured parallax, and hence led to estimates of their distances. Follow-up optical spectroscopy of such x-ray + proper motion selected samples is critical for determining spectral types and age indicators and has revealed many tens of bona fide 3-80 Myr old field stars over the past several years (e.g. Alcala et al 2000, AA 353, 186).

However, the RASS-selected sources suffer an important bias which renders the samples of young stars identified thusfar by the above techniques incomplete. Due to sensitivity limits, RASS source lists in the nearest regions of recent star formation are potentially dominated by those young active stars which were undergoing flaring events during the time of observation, a conclusion supported by the results from several much more sensitive Chandra studies of young clusters. In AIS-type 100-300 sec integrations GalEx is sensitive to *stellar photospheres* earlier than mid-G spectral types at the distances of the nearest star-forming regions, and hence can detect very small small excesses above the photosphere. Towards later spectral types only larger excesses are detectable. The unprecedented sensitivity, field coverage, and spatial resolution of GalEx can thus provide a much more complete sample of coronally and chromospherically active young stars compared to e.g. the RASS. It can do so by surveying portions of the Gould's Belt and other sites of local recent star formation without approaching the high background and bright star laden galactic plane.

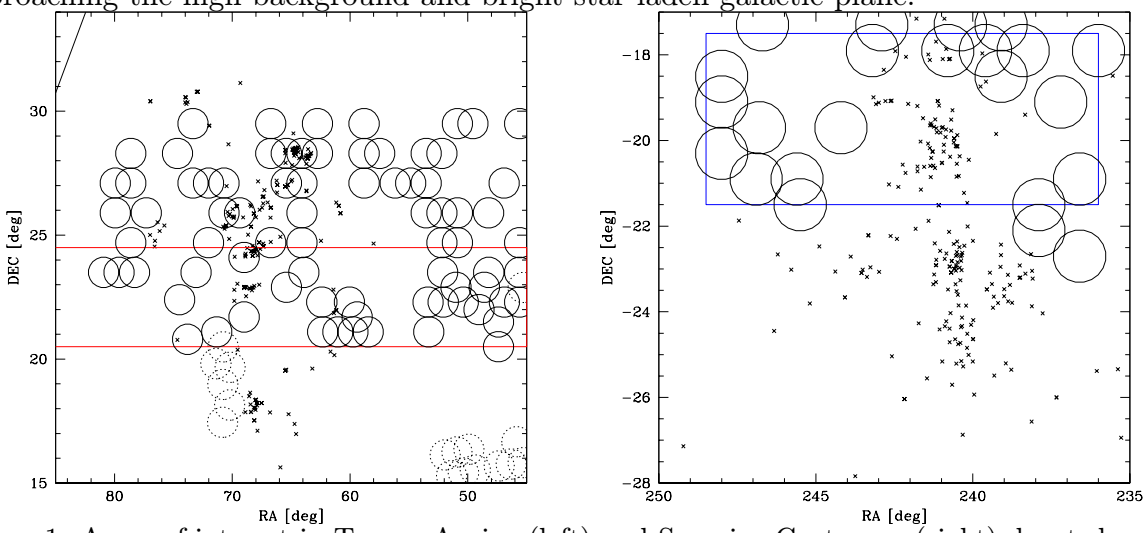

Figure 1: Areas of interest in Taurus-Auriga (left) and Scorpius-Centaurus (right), located approximately 15 and 20 degrees out of the galactic plane, respectively. Proposed GalEx pointings are indicated by solid open circles while existing AIS data included in the DR1 are indicated by dotted open circles. Note that the circles are 1.2 degree in DEC but distorted relative to true size in RA due to the projection. Each of our proposed fields meets the bright star and background safety limits according to the available information in the proposer tools section of the proposer web site. None are slated to be observed in the AIS according to project supplied information. The solid box indicates our existing U,R,I photometric variability surveys in these two regions. Known young pre-main sequence stars in each region are indicated by crosses.

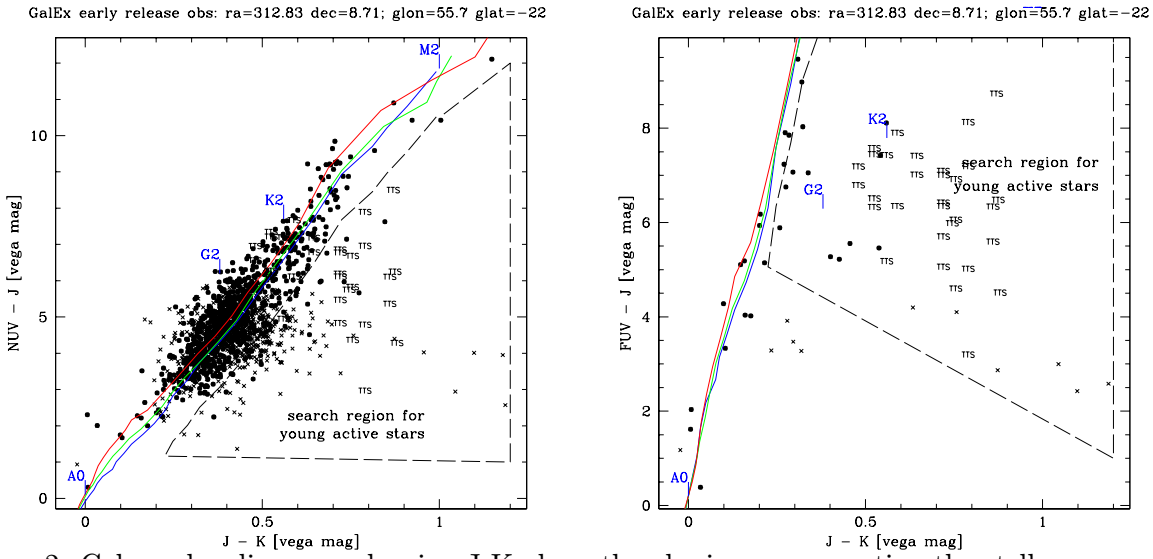

Figure 2: Color-color diagrams showing J-K along the abscissa, representing the stellar photosphere, and NUV-J (left panel) or FUV-J (right panel) along the ordinate, representing a chromospheric activity index. The expected stellar locus is indicated by the solid lines for surface gravities of 5.0 (blue), 4.0 (green), and 3.0 (red) with redder UV-J colors at lower surface gravity in spectral types earlier than M. The young stars targetted in our investigation are expected to have surface gravity values between 4.2 and 5.0. Symbols represent a cross-correlation of a GalEx early release field 22 degrees from the galactic plane with the 2MASS point source catalog. Photometric scatter can be reduced through application of SNR cuts to the data. Dots are J $<$ 14 mag while crosses are J $>$ 14 mag and more likely to be galaxies. We will use this diagram and others like it to select ultraviolet excess objects which we will consider candidate chromospherically active young stars to be followed up with ground-based optical spectroscopy. The density of such candidates per GalEx pointing will be substantially higher in the young Taurus and Sco-Cen fields we propose than in this essentially random field at similar galactic latitude. Objects labelled "TTS" are classical and weak T Tauri stars from the IUE/SWP study of Valenti, Johns-Krull & Linsky (2000; ApJS 129, 399); reported continuum fluxes at 1958 $\AA$ and 1760 $\AA$ are interpretted here as roughly the NUV and FUV GalEx bands. This proposal aims to find objects with chromospheric activity levels like these as well as substantially lower, particularly in the FUV band where the gains over previous pointed surveys are dramatic.

We propose a survey with GalEx in AIS mode of two nearby (150 pc) regions of recent star formation, Taurus-Auriga and Scorpius-Centaurus, as illustrated in Figure 1. The nominal ages of the known young stellar populations are <1-3 Myr for Taurus and 10-30 Myr for Sco-Cen. However, the results from follow-up of RASS sources indicate that towards each of these regions are found older populations ranging up to 120 Myr of age. These older populations are most likely part of the general Gould's Belt population and not necessarily indicative of the spread in star formation times within a single molecular cloud. But their existence means that by surveying over wide fields towards Taurus and Sco-Cen we can detect stars over a broad range of "young" (younger than the Pleiades) ages. Our methodology is described in Figure 2.

Table 1: Proposed Scorpius-Centaurus field centers

RA [deg] (2000)	Dec [deg] (2000)
236	-17.9
238.4	-17.9
239.6	-17.9
240.8	-17.9
243.2	-17.9
237.2	-19.1
248	-19.1
248	-20.3
236.6	-20.9
245.6	-20.9
246.9	-20.9
244.2	-19.7
246.8	-19.7
239.1	-18.5
248.0	-18.5
239.1	-17.3
240.4	-17.3
242.9	-17.3
246.7	-17.3
237.9	-21.5
245.5	-21.5
237.9	-22.1
236.6	-22.7

Description of the Observations

We propose to survey those regions of the greater Taurus-Auriga and Scorpius-Centaurus complexes known to contain young stars that are within the GalEx feasibility and safety parameters but not already being observed as part of the AIS. Our strategy is to adopt the AIS contiguous observation mode but integrate a factor of 3 longer for improved sensitivity to photospheres fainter than solar-type at the 150 pc distance of our targets. Our proposed field centers are shown in Figure 1 and listed in Table 1 (Sco-Cen) and Table 2 (Taurus). We are amenable to any gridding scheme that would best optimize valuable spacecraft orbits and hope to have the opportunity to consult with observatory personnel on exact field centers and gridding issues in Phase 2. Our program has no special requirements.

Table 2: Proposed Taurus-Auriga field centers

RA [deg] (2000)	Dec [deg] (2000)
53.32	21.1
58.46	21.1
59.75	21.1
61.03	21.1
62.32	21.1
71.32	21.1
45.60	22.3
46.90	22.3
52.09	22.3
53.38	22.3
45.60	23.5
48.22	23.5
52.14	23.5
63.92	23.5
73.08	23.5
78.31	23.5
79.62	23.5
80.93	23.5
45.60	24.7
50.88	24.7
52.20	24.7
64.09	24.7
66.73	24.7
72.02	24.7
78.62	24.7
48.24	25.9
50.88	25.9
52.20	25.9
53.53	25.9
64.09	25.9
69.38	25.9
70.70	25.9
77.30	25.9
79.94	25.9
46.92	27.1
53.53	27.1
54.85	27.1
56.17	27.1
58.81	27.1
64.09	27.1
65.41	27.1
70.70	27.1
72.02	27.1
73.34	27.1
78.62	27.1
79.94	27.1
52.20	28.3
53.53	28.3
57.49	28.3
58.81	28.3
62.77	28.3
64.09	28.3
65.41	28.3
66.73	28.3
74.66	28.3
78.62	28.3
45.60	29.5
49.56	29.5
50.88	29.5
58.81	29.5
62.77	29.5
66.73	29.5
73.34	29.5

Feasibility and Safety Considerations

Target availability. Sco-Cen is best observed in June-July of 2005 and Taurus in October 2004 - January 2005 or August-September of 2005 when the zodiacal background is lowest.

Safety. We have checked a grid of field centers tiling most of the area shown in Figure 1. Those meeting the safety standards of the observatory based on the bright star and background web tools have been included in the table given in the "Description of Observations" section. Because our relatively low galactic latitude fields are expected to be rich in stars we have not attempted to list flux levels of our "targets" as in fact the main aim of our proposal is to *discover* interesting targets not point at known objects. Our newly discovered interesting targets should not be of any more danger to the observatory than similar objects in other regions of the Gould's Belt already being observed by GalEx as part of the AIS. Based on the scant literature we know that the brightest young UV excess sources (e.g. those labelled "TTS" in Figure 2) are typically $< 3 \times 10^{-11}$ erg/s/cm^2 at $\sim$2000$\AA$.

If for any reason the observations we have proposed are deemed unsafe we would be willing to retreat to FUV only observations instead of both NUV and FUV. Much can be learned from just FUV data though this is difficult to demonstrate from the early release DR1 fields that are available (e.g. right panel of Figure 2).

Signal-to-noise. We have estimated the signal-to-noise achieved on stellar photospheres using the known distance of our primary targets, the known spectral energy distributions of stars of various temperature, and the on-line sensitivity curves and exposure time calculator. Our integrations should be sensitive to solar-mass photospheres at the distance of our targets and hence even more sensitive to excess emission above these photospheres.

Sensitivity requirements. We aim to detect objects which are brighter than the expected photospheres (see above) with NUV excess 1-5 mag brighter and FUV excess 1-8 mag brighter than the photospheres. We will be sensitive to small excesses around solar-type and earlier (<G) stars and larger excesses around later type (K-M) stars.

Resolution requirements. The 4" spatial resolution of GalEx is acceptable for this study. We will match all NUV and FUV sources to the 2MASS and Tycho catalogs for secure identification (see Figure 2 for example).

Additional Information

The PI and Co-I will work together with an experienced Caltech graduate student on the GalEx data analysis, the combination of resulting data with ancillary information, and requisite follow-up ground-based spectroscopic observations. Briefly, we will analyze the GalEx data and match all detections to the 2MASS and Tycho catalogs in order to assess rough spectral types and the presence of ultraviolet excess. We will also cross-identify sources to known stars through the use of on-line databases (e.g. SIMBAD; Vizier). Once ultraviolet excess objects are identified they will be followed up with optical spectroscopy at Palomar Obseratory in order to characterize in more detail the stellar photospheric properties. A critical diagnostic is Li I 6707 $\AA$ which, due to rapid depletion at the base of the convection zone, is a sensitive indicator of stellar youth from < 3 Myr to at least 300-600 Myr of age.