STAR FORMATION IN THE ERA OF THREE GREAT OBSERVATORIES: PRIORITIES AND GOALS workshop is sponsored by the Chandra X-ray Center, co-sponsored by the Spitzer Science Center, and organized primarily by the CXC Director's Office. The workshop is being held July 13-15, 2005 in Cambridge, Massachusetts at the Sheraton Commander hotel.

The goal of the workshop is to review topics in star-formation which are inherently multiwavelength, and to both define the current state of knowledge and the points of current controversy where new observations are most needed. We plan to focus on topics for which the Great Observatories have the most to contribute during this unique period of simultaneous operation. We will also consider observations from other facilities as well as theoretical work. We anticipate coverage of galactic and local-group star forming regions and potentially galaxies of the local group. We hope to come away with a white paper containing a list of future strategies and goals to be presented to NASA and the project leaders of each of the three telescopes.

SCIENCE TOPICS:

- The ISM
- Protostars
- Disk Evolution
- Rotation/saturation/dynamos
- Clustering/populations
- Multi-telescope studies in the Orion star forming complex and other star forming regions
- There will be splinter sessions on disk evolution, rotation, populations and other selected topics.

Agenda

Wednesday, July 13

Session 1 9:00 - 10:20 Preliminaries
Posters
Session 2 11:00 - 12:30 The ISM
Lunch
Session 3 2:00 - 3:50 Protostars
Posters
Session 4 4:30 - 6:00 Disks

Thursday, July 14

Session 5 9:00 - 10:30 Rotation/Saturation/Dynamos
Posters
Session 6 11:00 - 12:30 Clustering/Populations
Lunch
Session 7 2:00 - 3:30 Star formation in Orion
Posters
Session 8 4:15 - 6:00 Star formation in clusters

Friday, July 15

Session 9 9:00 - 10:00 Young Stars and Educational Outreach
Posters
Session 10 10:45 - 12:30 Splinter Sessions
Lunch
Session 11 2:00 - 4:00 Report from the splinter sessions
4:00 Adjourn

Acknowledgements

Part of the function of the Chandra X-ray Center is to support workshops on the new scientific avenues being opened by the Chandra X-ray Telescope. I would like to thank the CXC director's office and most especially its director, Harvey Tannenbaum, for agreeing to use the CXC resources, both money and labor, to make this workshop a reality. The stellar community sometimes feels like the ugly stepchild in the high energy realm, but Harvey made it clear that creating a series of X-ray priorities for the star formation community was important to high energy astrophysics as a whole. Further, given the recent launch of Spitzer and the proximity of the IRAC team, this is the time and this is the place to bring together the tremendous wealth of data the Great Observatories have provided.

I would also like to thank George Helou, Executive Director of IPAC, and B. Thomas Soifer, Spitzer Science Center Director, for their support of this meeting. While the whole of the science organizing committee put forward a great deal of effort, I particularly want to thank John Stauffer for bringing this workshop concept to the directors of the SSC and making this a truly unique coming together of NASA's Great Observatories. From the local organizing committee I especially want to thank Brad Spitzbart and Samantha Stevenson for their work on the web site, creation of this abstract book and data management and Michelle Henson for actually making this whole meeting happen. Finally I want to thank the attendees. Since there is no registration fee, there is no money to bring in invited speakers or to help others wishing to attend. I am gratified by the number of people who are attending from across the country and across the Oceans. – Scott Wolk (SOC Chair)

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What Spitzer is teaching us about star and planet formation

Lori Allen, Center for Astrophysics

The Spitzer Space Telescope is NASA's Great Observatory for infrared exploration. I will give a brief update on the status of the mission and an overview of Spitzer's capabilities with respect to star formation. Recent results from Spitzer GO, Legacy, and GTO programs will be presented, including observations of disks around very low mass stars and brown dwarfs, spatial distributions of young stars and protostars on multi-parsec scales, evidence of dust evolution in the inner disks of 3-10 million year old stars, and observations of extrasolar planets. I will review the efforts of various groups to interpret the mid-infrared colors of young stars, aided by comparison with state-of-the-art models of accretion disks and protostellar envelopes.

The State of our Knowledge

Lee Hartmann, Center for Astrophysics

I will attempt to present a very brief outline of what we have learned so far about star formation and protoplanetary disk evolution, with emphasis on contributions from the Great Observatories. Then I will discuss some critical unsolved problems, and indicate a few areas where substantial progress might be made in the next several years.

Studying Star Formation with the Submillimeter Array

Paul T.P. Ho, Center for Astrophysics

The Submillimeter Array (SMA), jointly constructed by the Center for Astrophysics and the ASIAA, began regular operations at the end of 2003 on Mauna Kea. The SMA, operating at a wavelength shortward of 1mm, is particularly sensitive to the dust continuum emission as well as many new spectral lines which are sensitive to high density and temperature. For studying star formation, cluster formation, and the interstellar medium, the SMA provides sub-arcsecond resolution which can reveal the structure and the kinematics in the inner dense cores. This talk will present some of the latest results from the SMA, which demonstrate the current capabilities.

Star Formation Legacy of the Hubble Space Telescope

Deborah Padgett, Spitzer Science Center

I very briefly review the major contributions of the Hubble Space Telescope (HST) to the understanding of star formation within our galaxy. Some of the most significant advancements have been in the areas of circumstellar disks and outflows, as well as the structure and populations of massive star formation regions. I provide an update on the status of current HST star formation projects and speculate on the future of star formation studies with HST.

Chandra - The X-ray View of Star Formation

Scott Wolk, Center for Astrophysics

The Chandra X-ray Observatory, launched in July 1999, is the premier instrument for high spatial resolution X-ray astrophysics. In this quick review I outline the basic function and capabilities of Chandra. I will then outline some of the most prominent mechanisms and forms of X-ray emission from young stars. These X-rays primarily arise from dynamo driven plasma in low mass stars and wind driven plasma in high mass stars. When a disk is present, the star-disk interaction is also a possible source of X-rays. I will end with a survey of a few results from the first 5 years of the Chandra mission.

Spitzer measurements of mid-infrared extinction in infrared-dark clouds

Sean Carey, Spitzer Science Center / Caltech
Russell O. Redman (HIA/NRC Canada), Lori E. Allen (Center for Astrophysics), Joseph L. Hora (Center for Astrophysics)

Infrared dark clouds are dense molecular cores which have been identified as absorption objects in mid-infrared surveys of the Galactic plane. As such they are ideal objects to use in measuring the mid-infrared extinction curve. We present Spitzer and MSX observations of the mid-infrared extinction profiles of three infrared-dark clouds. The extinction is estimated from the diffuse mid-infrared background instead of more traditional stellar reddening measurements due to the low number of observed background objects and relatively large number of embedded protostars. We will compare the spatial profile of the extinction to column density estimates from submillimeter continuum observations of the dust. This work is based on observations made with the Spitzer Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under NASA contract 1407. Support for this work was provided by NASA through contract 1256790 issued by JPL/Caltech.

Phases and Processes in the ISM

Bruce Elmegreen, IBM Watson Research Center

Observations with the three Great Observatories reveal the intricacy of the phase structure of the ISM. Galaxy-scale maps of molecules, atoms, and dust, all with a wide range of temperatures, suggest heat sources primarily from starlight, supersonic expansions, and cosmic rays. ISM motions have similar energy sources, in addition to self-gravity and galactic scale processes like shear, spiral waves, and interactions. The structure of the ISM is mostly determined by the motions, and is therefore a superposition of cavities and shells from the expansions, along with spiral and globular clouds from a combination of shear, self-gravity, and spiral arm shocks. There is also a pervasive fractal hierarchy of cloudy structure from supersonic turbulence wherever the more directed forces are not dominant. The connections between these ISM phases and star formation will be discussed.

The COMPLETE Survey

Naomi Ridge, Center for Astrophysics
The COMPLETE Team

The COMPLETE Survey will produce an unbiased database that will serve the star-formation research community for many years to come. COMPLETE is comprised of CoOrdinated Molecular Probe Line, Extinction and Thermal Emission observations of a small set of large star-forming regions scheduled to be extensively observed as part of the SIRTF c2d Legacy Program (Perseus, Ophiuchus and Serpens). COMPLETE is unique in its coordinated approach - prior observations of the types included in COMPLETE abound, but they only rarely fully sample any region, and no survey has ever covered a single (about 10 pc) region fully with molecular-line, extinction and dust-emission observations. COMPLETE will provide star-formation theories with statistical constraints on the temporal and spatial frequency of inward motions, outflow, cloud disruption, core formation and other key parameters. Here we present some highlights from the "Phase 1" COMPLETE observations and analysis, concentrating on the Perseus molecular cloud complex.

Multi-Wavelength Diagnostics of Starbirth in Starbursts

William Waller, Tufts University

From the Orion Nebula to the Hubble Deep Field, starburst activity can be seen transforming galaxian clouds of gas into populous clusters of stars. The pyrotechnics and chemical enrichment associated with this activity have led to outcomes as ubiquitous as interstellar dust and as exquisite as life on Earth. In this talk, I will focus on the circumstances of star formation in the environmental context of ongoing starburst activity. I begin with the premises that (1) the formation of a single star takes time, (2) the formation of a populous cluster takes even more time, and (3) "stuff" happens in the interim. Hubble images of the Orion Nebula and Eagle Nebula show how hot stars can excavate neighboring clouds of gas and photoevaporate the star-forming cores that are exposed. Hubble observations of giant HII regions in M33 reveal a significant variation in the stellar populations, such that the most metal-rich HII regions contain the greatest proportions of the most massive stars. ISO and Spitzer observations of these same HII regions reveal corresponding variations in the nebular response. These multi-wavelength diagnostics of the stellar-nebular feedback in galaxian starbursts suggest a star-forming mechanism which is subject to photo-evaporative ablation – an erosive process that is mediated by the metal abundance and corresponding amounts of protective dust in the starbursting environment.

FUSE Observations of VV 114: Feedback in a local LBG Analog

John Grimes, Johns Hopkins University
Timothy Heckman (JHU), Charles Hoopes (JHU)

Star formation plays a crucial role in understanding the chemical and thermodynamical evolution of the IGM. In galaxies undergoing intense star formation, outflows powered by supernovae and stellar winds expel metal enriched material and ionizing radiation into the IGM. The higher star formation rates at earlier epochs imply that galactic outflows play an even more important in high redshift galaxies such as the well studied Lyman Break Galaxies (LBGs). The interacting/merging galaxy VV 114 has been identified through SDSS and GALAX observations as a local LBG analog, perfect for studying the outflows spectroscopically in the FUV. Our analysis of the FUSE observations of VV 114 show strong and broad interstellar absorption lines that are typical of LBG galactic winds. We present the results of our analysis of the ISM absorption lines observed in the FUV of VV 114.

High Resolution Radio Observations of Southern Galactic Star Forming Regions

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As part a programme of high resolution radio mapping of Galactic star forming regions, many Galactic star forming regions have been observed at 1280, 610 and 325 MHz using Giant Metrewave Radio Telescope (GMRT), India. GMRT is a synthesis telescope consisting of thirty 45 m diameter parabolic dishes spread in a 'Y' shape configuration. Baselines range from 100 m to 25 km providing high angular resolution (about 3" at 1280 MHz, 6" at 610 MHz and 9" at 325 MHz) as well as sensitivity to diffuse structures. In this paper some of the maps of southern sources will be presented. All the sources are resolved and many show extended diffuse emission. These maps will be compared with available maps at other wavelengths (e.g. millimeter, infrared) to have an understanding of these regions. Radiation transfer modeling of the observed spectral energy distribution from dust continuum, constrained by the radio emission and angular sizes will be presented.

L1014-IRS: A proto-brown-dwarf in a starless core?

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Spitzer recently discovered a very low mass object in the nearby dark cloud L1014, which was previously thought to be starless. With the MMT and SMA we have confirmed that the source, L1014-IRS, is indeed protostellar and embedded within the cloud. It drives a very small, low mass molecular outflow detected in CO 2-1 which has carved out a cavity seen in near-infrared scattered light. The luminosity of L1014-IRS is only 0.025-0.05 L_{sun}, and the inferred mass is of order 25 $M_{Jupiter}$, implying that it is either (1) a very young protostar yet to accrete the bulk of its mass, or (2) the first detected of an embedded, very young brown dwarf. The new data will be presented and its implications discussed.

The First Definite Detection of X-rays from an Extremely Young Protostar

Kenji Hamaguchi, NASA/GSFC/EUD
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Class I protostars exhibit powerful X-ray emission. Their X-ray activity can exceed those of older stars such as T-Tauri and main-sequence stars. Without surface convection to drive a solar-type dynamo mechanism, X-ray activity is suspected to be driven by magnetic activity linked to the mass accretion process. Mass accretion is thought to be more intense in the earliest Class 0 protostar phase, but X-ray emission from them has not been conclusively detected so far. This could be due to stronger X-ray absorption to their protostellar cores, or a certain transition in high energy activity between the Class 0 and Class I phases. With two XMM-Newton observations on March 2003, we detected for the first time strong X-ray emission from an extremely embedded source in the R Corona Australis star forming core, IRS 7 region. (Hamaguchi et al. 2005, ApJ, 623, 291) The source has the radio counterpart 10E (IRS7B) but no near-IR counterpart. These facts plus the strong X-ray absorption of $n_H \sim$ 3e23 cm^{-2} (equivalent to $A_V \sim$ 180m) indicate that the source is a Class 0 or perhaps a Class 0/I protostar. The X-ray spectrum showed thermal emission with kT= 3-4 keV with the luminosity up to $10^{31.2}$ ergs/s. The light curve showed gradual flux increase by a factor of two during 30 ksec, unlike solar-type magnetically driven X-ray flares, which have smaller variation timescales. The source was 10-100 times fainter during Chandra observations which occurred before and after the XMM-Newton observations. The flux enhancement on month timescales might be driven by sporadic mass accretion episode, while the short-term variation during the XMM-Newton observation could be related to the proto-stellar core rotation. We will also discuss the relation to the sub-millimeter outflow activity of Class 0 protostars and absence of X-ray activity on other Class 0 protostars.

X-rays from protostars

Thierry Montmerle, Laboratoire d'Astrophysique de Grenoble (France)

X-ray emission from young stars is most generally a proxy for their magnetic activity. In some cases, the X-rays come from magnetically channeled accretion shocks onto the stars, or from shocks between bipolar jets and the surrounding molecular clouds. In protostars, the X-ray emission may be more closely linked with magnetic interactions between the central, growing stars and their accretion disks, which play a central role in the accretion-ejection mechanism. The stage at which X-rays appear, which may regulate the coupling between the protostellar envelope and the magnetic fields, is however still debated. I will emphasize the importance of a multi-wavelength (X-IR-mm) approach to understand the evolution of protostars.

Spectacular Spitzer images of the Trifid Nebula: Protostars in a young, massive-star-forming region

Jeonghee Rho, Spitzer Science Center/Caltech
W. T. Reach (SSC/Caltech), B. Lefloch (LAOG) and G. Fazio (CFA)

Spitzer IRAC and MIPS images of the Trifid Nebula (M20) reveal its spectacular appearance in infrared light, demonstrating its special evolutionary stage: recently-formed massive protostars and numerous young stars, including a single O star that illuminates the surrounding molecular cloud from which it formed and unveiling large-scale, filamentary dark clouds. The hot dust grains show contrasting infrared colors in shells, arcs, bow-shocks and dark cores. Multiple protostars, previously defined as Class 0 from dust continuum and molecular outflow observations, are revealed in the infrared within the cold dust continuum peaks TC3 and TC4. The cold dust continuum cores of TC1 and TC2 contain only one protostar each; the newly-discovered infrared protostar in TC2 is the driving source of the HH399 jet. The Spitzer color-color diagram allowed us to identify ~150 young stellar objects (YSO) and classify them into different evolutionary stages, and also revealed a new class of YSO which are bright at 24μm but with spectral energy distribution peaking at 5-8μm; we name these sources "Hot excess" YSO. Despite of expectation that Class 0 sources would be "starless" cores, the Spitzer images, with unprecedented sensitivity, uncover mid-infrared emission from these Class 0 protostars. The mid-infrared detections of Class 0 protostars show that the emission escapes the dense, cold envelope of young protostars; the mid-infrared emission cannot arise from the same location as the mm-wave emission, and instead must arise from a much smaller region with less intervening extinction to the central accretion. The presence of multiple protostars within the cold cores of Class 0 objects implies that clustering occurs at this early stage of star formation. The most massive stars are located at the center of the cluster and are formed simultaneously with low-mass stars. The angular and mass distributions of protostars within the dust cores imply that these early protostars are competing for materials and the clustering is consistent with competitive accretion. We also compare statistics and characteristics of the sources detected at infrared wavelengths by Spitzer with the discrete X-ray sources detected by Chandra in the Trifid Nebula. By generating spectral energy distributions of these discrete X-ray sources using data from Spitzer observations (as well as complementary near-infrared and millimeter data), we can classify the detected young stellar objects into their evolutionary stages. We demonstrate the advantage of our multi-wavelength complementary study in understanding a complete population of young stars in a star-forming region and the evolution of protostars and disks.

Spitzer Observations of a Remarkable Star Forming Core in NGC 2264

Erick Young, University of Arizona

We present IRAC and MIPS observations of an extremely young star forming core in the IRS-2 region of NGC 2264. The compact region includes a remarkable collection of Class 0 and Class 1 sources, and outflows. Molecular line observations confirm the presence of extremely dense gas coincident with bright submillimeter continuum concentrations. In one core, the Spitzer observations reveal a dense mini-cluster of recently formed stars.

Spitzer "Cores to Disks" (c2d) MIPS Mapping of the Perseus Molecular Cloud

Luisa Rebull, SSC/JPL/Caltech
K.R. Stapelfeldt (JPL/Caltech), T.Y. Brooke (Caltech), D.L. Padgett (SSC/Caltech), A.I.Sargent, M. Enoch (Caltech), N.J. Evans (Texas), Spitzer c2d Legacy Science Team

The Perseus molecular cloud complex, located at a distance of 320 pc, is one of five nearby star-forming regions being mapped in the Spitzer "c2d" Legacy Science Program. These observations are expected to characterize the luminosity function for low-mass star formation down into the realm of hydrostatic cores, proto-substellar objects, and edge-on disks. By mapping the entire molecular cloud inside the $A_V = 2$ contour, we also expect to reveal any distributed star formation taking place outside the well-known clusters associated with NGC 1333 and IC 348. In this contribution, we present an early look at MIPS scan maps covering ~4 square degrees of the Perseus clouds. Dozens of IRAS PSC objects are spurious patches of extended emission, and many PSC sources are resolved into multiple. Several sources appear extended at 24 microns. Over large areas, there is complex extended emission, dominated by the Gl159.6 HII region which is illuminated by a B0 star.

A Hot Wind from TW Hya: Implications for X-rays

Andrea Dupree, Center for Astrophysics
Nancy Brickhouse (Center for Astrophysics)

The nearby T Tauri star, TW Hya exhibits far ultraviolet and infrared emission lines with a P Cygni shape that signal the presence of a continuous, fast (400 km/s), hot (300,000 K) accelerating outflow with a mass loss rate $10^{-11} - 10^{-12}$ solar masses per year or larger (Dupree, Brickhouse, Smith, Strader, 2005, ApJ Letters in press). Because TW Hya has a low inclination, and the surrounding accretion disk is face-on, the stellar polar regions are observed directly. We consider the emission measure distribution of the star, the sources of the emission and implications for the origin of the X-rays.

X-ray diagnostics of pre-main sequence accretion and outflow activity

Joel Kastner, Rochester Institute of Technology

I summarize the mounting evidence for a direct link betweenpre-main sequence (pre-MS) X-ray emission and pre-MS accretion andoutflow processes. Such a link is supported by three lines ofobservational inquiry rendered feasible by the extraordinarycapabilities of the Chandra and XMM-Newton X-ray observatories,working in concert with space- and ground-based imaging andspectroscopy in the optical and infrared regimes. These threads are:(1) the measurement of anomalous line ratios of He-like ions in high-resolution X-ray spectra of certain young, actively accreting, low-mass (classical T Tauri) stars; (2) the detection of an X-ray eruption from V1647 Ori ("McNeil's Star") that coincided with the accretion-driven optical/infrared outburst from this dust-enshrouded protostar; and (3) the discovery of soft X-ray emission from the immediate vicinities of pre-MS stars that drive well-collimated outflows. Taken together, these results indicate that, in addition to solar-like coronal activity, X-rays may be produced by pre-MS stars via a variety of mechanisms, including accretion shocks, disk wind shocks, and star-disk magnetic reconnection events. Further progress will require intensive modeling efforts as well as sensitive, high-resolution X-ray spectroscopic surveys involving much larger samples of pre-MS stars.

Formation of planets and debris disks in the terrestrial zone

Scott Kenyon, Center for Astrophysics
Ben Bromley (University of Utah)

The discovery of debris disks surrounding nearby stars has revolutionized our understanding of planet formation. Ground-based and satellite images of these systems reveal an interesting variety of large disks, thick tori, and delicate rings of dust. Analyses of these data demonstrate that the building blocks for solar systems commonly exist in disk-like structures around other stars. Theoretical calculations show how collisions and radiative processes transform a massive disk of gas and dust into a planetary system and a debris disk. In this review, I will summarize observations and theory of debris disks in the terrestrial zone and show how data from our and other solar systems improve our general picture of planet formation.

X-ray diagnostics of grain depletion in matter accreting onto T Tauri stars

Paola Testa, MIT Kavli Institute for Astrophysics and Space Research
Jeremy Drake (Center for Astrophysics), Lee Hartmann (Center for Astrophysics)

Recent analysis of high resolution Chandra X-ray spectra has shown that the Ne/O abundance ratio is remarkably constant in stellar coronae. Based on this result, we point out the utility of the Ne/O ratio as a discriminant for accretion-related X-rays from T Tauri stars, and for probing the measure of grain-depletion of the accreting material in the inner disk. We apply the Ne/O diagnostic to the classical T Tauri stars BP Tau and TW Hya—the two stars found to date whose X-ray emission appears to originate, at least in part, from accretion activity. We show that TW Hya appears to be accreting material which is significantly depleted in O relative to Ne. In constrast, BP Tau has an Ne/O abundance ratio consistent with that observed for post-T Tauri stars. We interpret this result in terms of the different ages and evolutionary states of the circumstellar disks of these stars. In the young BP Tau disk (age ~ 0.6 Myr) dust is still present near the disk corotation radius and can be ionized and accreted, re-releasing elements depleted onto grains. In the more evolved TW Hya disk (age ~ 10 Myr), evidence points to ongoing coagulation of grains into much larger bodies that can resist the drag of inward-migrating gas, and accreting gas is consequently depleted of grain-forming elements.

The discovery of extreme disk-jet systems in the Rosette Nebula

Jinzeng Li, National Astronomical Observatory, Chinese Academy of Sciences
Travis A. Rector (U. of Anchorage, Alaska)

We've discovered a set of primarily two extreme jet systems, namely Rosette HH1 & HH2, in the Rosette Nebula (ApJ Letters 600, 67; ChJAA Letters, 3, 495). Contrary to all other known Herbig-Haro jets associated with star forming regions, the Rosette jets are found to have a high excitation nature due to disruptive interaction with the violent environment they reside in. These disk-jet systems are directly exposed to the fierce UV radiation fields of dozens of massive OB stars at the center of NGC 2244, which is the source of ionization that created the spectacular HII region, the Rosette Nebula. High-resolution spectroscopic observations of the Rosette HH1 source shows no evidence of veiling in its continuum though it contrarily displays distinct signiture of enhanced accretion. This leads to conclusions of fast disk dissipation and a different jet formation mechanism under the extreme environment of Rosette. We mention, for the first time, that this offers a potential evolution solution for the formation of brown dwarfs and free-floating giant planets in HII regions and cluster forming environments.

Rotational modulation of X-ray emission in Orion Nebula young stars

Ettore Flaccomio, INAF - Osservatorio Astronomico di Palermo
G. Micela (INAF), S. Sciortino (INAF), E. D. Feigelson (Penn State University), W. Herbst (Wesleyan University), F. Favata(ESA), F.R. Harnden Jr. (Center for Astrophysics, NASA) S. D. Vrtilek(Center for Astrophysics) Harnden Jr. (Center for Astrophysics, NASA) S. D. Vrtilek(Center for Astrophysics)

I will present results of a search for rotational modulation of X-ray light-curves in a sample of young Orion Nebula Cluster stars. The study, aiming at understanding the spatial distribution of X-ray emitting plasma on pre-main sequence stars, is part of the Chandra Orion Ultradeep Project (COUP) and was made possible by the exceptional length of the observation: 10 days of ACIS integration during a time span of 13 days, yielding a total of 1616 detected sources in the 17x17 arcmin field of view. I will focus on a subsample of 233 X-ray-bright stars with known rotational periods. X-ray modulation related to the rotation period is detected in at least 23 stars with periods between 2 and 12 days and relative amplitudes ranging from 20% to 70%. In 16 cases, the X-ray modulation period is similar to the stellar rotation period while in seven cases it is about half that value, possibly due to the presence of X-ray emitting structures at opposite stellar longitudes. These results constitute the largest sample of low mass stars in which X-ray rotational modulation has been observed. The detection of rotational modulation indicates that the X-ray emitting regions are distributed inhomogeneneously in longitude and do not extend to distances significantly larger than the stellar radius. Modulation is observed in stars with saturated activity levels ($L_X/L_{bol} \sim 10^{-3}$) showing that saturation is not due to the filling of the stellar surface with X-ray emitting regions.

Rotation of Low Mass Pre-Main Sequence Stars

William Herbst, Wesleyan University

Photometric monitoring campaigns have yielded rotation periods, with a typical accuracy of about 1stars of low mass in nearby clusters and associations. When combined with stellar radii, these data yield the average specific angular momentum (j) of the surface layer of each star. There are now sufficient data that we can assess on a quantitative statistical basis how the frequency distribution of j depends on mass and age. Empirical results will be presented and an interpretation in terms of the canonical theory of disk locking proposed. The implications of these results for accretion disk lifetimes and for the interpretation of X-ray observations will be briefly summarized.

Rotation and Spitzer/IRAC fluxes in Orion

Luisa Rebull, Spitzer Science Center
J.R. Stauffer, T. Megeath, J. Hora, L. Hartmann

Much effort has been expended in recent years in an effort to decipher the influence of circumstellar disks on rotation in pre-main-sequence stars. Early observations of TTauri stars suggested that stars with evidence of circumstellar accretion disks rotated slower than stars without such evidence. More recent observations have muddied the waters. Complicating this discussion, near-IR circumstellar disk indicators, though the most widely available, are subject to uncertainties that can result from inner disk holes and/or the system inclination. Mid-infrared observations are less sensitive to such effects, but until now, these observations have been difficult to obtain. The Spitzer Space Telescope now easily enables mid-infrared measurements of many stars at once down to substellar masses. In this contribution, we will examine the relationship between rotation and Spitzer mid-IR fluxes for $\sim$ 900 stars in Orion ($\sim$ 5 Myr) for stars between 3 and 0.1 M_{sun}. These data were obtained as part of a Spitzer IRAC and MIPS joint GTO program (Megeath et al. 2005, in prep).

Stellar Rotation: A Probe of Initial Star-Forming Conditions

Stephen Strom, National Optical Astronomy Observatory
Sidney Wolff (NOAO)

Projected rotational velocities (vsini) have been measured for B stars in the rich, dense h and chi Persei double cluster along with 7 young (1-7 Myr age) clusters of intermediate density, and compared with the distribution of rotational velocities for a sample of field stars having similar ages. In comparison with stars populating the field (and presumably formed in low density environments), the observed rotation speeds among stars formed in denser cluster environments are consistently higher. Moreover, the cluster population lacks the large cohort of slow (vsini $<$ 50 km/sec) stars found among field B stars. We argue that both the higher rotation rates and the pattern of rotation speeds that differentiate B stars in clusters from their field analogs were likely imprinted during the star formation process rather than a result of angular momentum evolution. We suggest that these differences may reflect the effects of the higher accretion rates that theory suggests are characteristic of regions that give birth to dense clusters, namely, (1) higher initial rotation speeds; and (2) higher initial radii along the stellar birth line, resulting in greater spin-up between the birth line and the ZAMS.

What are the Drivers of X-ray Production in Pre-Main-Sequence Stars

Keivan Stassun, Vanderbilt University

We present an analysis of Chandra observations of the Orion Nebula Cluster (ONC) to study the X-ray properties of a large sample of pre-main-sequence (PMS) stars with optically determined rotation periods. Our goal is to elucidate the origins of X-rays in PMS stars by seeking out connections between the X-rays and the mechanisms most likely driving their production—rotation and accretion. We find that these stars have L_x/L_{bol} near, but below, the "saturation" value of 10^{-3}, and that X-ray luminosity is significantly correlated with stellar rotation, in the sense of decreasing L_x/L_{bol} with more rapid rotation. These findings suggest that stars with optical rotation periods are in the "super-saturated" regime of the rotation-activity relationship, consistent with their Rossby numbers. However, we also find that stars with optical rotation periods are significantly biased to high L_x. This is not the result of magnitude bias in the optical rotation-period sample, but rather of the diminishingly small amplitude of optical variations in stars with low L_x. Evidently, there exists in the ONC a population of stars whose rotation periods are unknown and that possess lower average X-ray luminosities than those of stars with known rotation periods. These stars may sample the linear regime of the rotation-activity relationship. Accretion also manifests itself in X-rays, though in a somewhat counterintuitive fashion: while stars with spectroscopic signatures of accretion show harder X-ray spectra than nonaccretors, they show lower X-ray luminosities and no enhancement of X-ray variability. We interpret these findings in terms of a common origin for the X-ray emission observed from both accreting and nonaccreting stars, with the X-rays from accreting stars simply being attenuated by magnetospheric accretion columns. We also present results from a simultaneous optical/X-ray monitoring study of variability in the ONC, where we find very little evidence for correlated variability, indicating that X-ray events are not temporally related to accretion events. These findings suggest that X-rays from PMS stars have their origins primarily in chromospheres/coronae, not accretion.

Rotation of Intermediate and High Mass Stars: A Probe of Star-Forming Modes and Initial Conditions

Sidney Wolff, NOAO
S. Strom, L. Rebull, K. Venn, D. Dror, L. Lanz

New IC 348 members in the outer part of the cluster

Laurent Cambresy, Observatoire de Strasbourg
V. Petropoulou (Observatoire de Strasbourg)

The IC 348 star cluster contains about 300 known members. It has been observed at several wavelengths with deep optical and near-infrared ground observations, and from space with XMM-Newton, Chandra and HST observations. The cluster is embedded in the Perseus molecular cloud, making any clustering analysis subject to extinction bias. We propose to revisit IC 348 based a on statistical approach using 2MASS data. We performed a combined analysis of the star density and color in this region in order to establish a surface density map of the cluster. We reach the conclusion that IC 348 is actually significantly larger than previously thought by nearly a factor of 2 and we estimate that more than 50 members brighter than K=14 mag are still unknown. These new members are located in the outer regions of the cluster, where very few dedicated observations have been realized so far, which is probably why they escaped to previous identification. This result will give new insights to study the star formation history and the dynamical evolution of IC 348.

X-ray and Infrared Surveys of Star-Forming Regions

Marc Gagné, West Chester University

Since most stars in the Galaxy probably formed in giant molecular clouds, identifying nearly complete samples of low-mass stars in galactic star-forming regions is an important step in understanding the overall star-formation process. Recent X-ray, optical, and near-infrared studies of the galactic HII regions M8, M16, M17 and M20 have significantly increased the number of known cluster stars. By comparing their X-ray and infrared properties with stars in well-studied regions like the Orion Nebula Cluster, we can estimate distance, age and completeness. These studies will be used to assess the prevalence of triggered star-formation.

A Spitzer Survey of Young Stellar Clusters

Robert Gutermuth, University of Rochester
S.T. Megeath (Center for Astrophysics), J.L. Pipher (UR), L.E. Allen (Center for Astrophysics), P.C. Myers (Center for Astrophysics), G.G Fazio (Center for Astrophysics)

To build a comprehensive picture of star-formation in clusters, we have designed and executed the Spitzer Young Stellar Cluster Survey. We have selected over thirty young (< 3 Myr) stellar clusters and groups within 1 kpc of the Sun that are still associated with their natal molecular clouds for observations with the IRAC and MIPS instruments onboard Spitzer. Almost all of the clusters have now been observed. In addition, we have obtained ground based near-IR, submillimeter and millimeter-wave imaging for the sample. I will present a study of the populations of young stellar objects detected in several of these regions, using combined near-IR and Spitzer colors to identify young stars with disks and protostellar envelopes. The particular emphasis will be on identifying structure in the stellar distributions and relating it to natal gas and dust distributions. These data show that embedded, forming stellar clusters are often not spherically symmetric structures, but can be elongated and clumpy, surrounded by lower density halos of young stars. The morphologies of the clusters may reflect the initial structure of the dense natal molecular gas, and once this gas is dispersed, our data show that stellar dynamical evolution can quickly erase this structure. Finally, we will use these data to explore the impact of high stellar densities and massive star proximity to disk evolution in these clusters.

A Search for Pre-Main Sequence objects near the Taurus and Upper Scorpius Star-Forming Regions

Catherine Slesnick, Caltech
John Carpenter (Caltech), Lynne Hillenbrand (Caltech)

We are conducting a wide-field ($\sim$ 200 square degrees) B,R,I photometric monitoring campaign to identify new young objects towards both the Taurus (1 Myr) and Upper Scorpius (3-5 Myr) star-forming regions. Candidates were chosen for follow-up optical spectroscopy to confirm membership and youth based on large-amplitude variability and/or placement on a color-magnitude diagram. Our primary goals are 1) to assess the mass and spatial distributions of young objects in the outer parts of each association and 2) to study the actvity in young low mass objects and properties of associated circumstellar disks through analysis of H-alpha spectral line profiles and 2MASS colors for confirmed new members. Comparison of results between the two regions will allow us to study evolutionary effects. Our work will provide insight into several aspects of star formation, including the universality of the low mass/substellar IMF, the kinematics of stars as they are forming in their parental molecular clouds, and the prescence/absence of age and mass segregation from central cores to the more extended areas within a cluster. At this conference we will present results from the completed photometric monitoring part of our survey for both clusters and from our initial spectroscopic efforts in Taurus.

Coronal emission in the youngest stars: a Deep Chandra X-ray observation of NGC 2362

Francesco Damiani, INAF - Osservatorio Astronomico di Palermo, ITALY
G.Micela (INAF-OAPA, Italy), S.Sciortino (INAF-OAPA, Italy), N.Huelamo (ESO, Chile), F.R.Harnden (Center for Astrophysics), S.S.Murray (Center for Astrophysics)

We present a deep Chandra ACIS-I imaging observation of the very young cluster NGC 2362. This cluster, only 5 Myr old, is exceptionally free of dust and differential reddening for its age, and offers a unique opportunity of studying its pre-main-sequence stellar population with minimal disturbance from a dense interstellar medium. In this observation of NGC 2362 we detect almost 400 X-ray sources, most of which identified optically with low-mass pre-main-sequence stars. The quiescent X-ray emission of low-mass cluster stars is found to be rather strictly correlated with the stellar bolometric luminosity, with a spread much smaller (a factor of 2 rms) than that found in other young clusters. Such a small spread in the correlation leaves very little room for variability of the X-ray emission, on timescales of either the stellar rotation, or longer (e.g., activity cycles). This puts a strong upper limit on the maximum amplitude of possible activity cycles in very young coronal sources.

A Survey of Massive Star Clusters in the X-ray Emission from Spiral Galaxies

Eric M. Schlegel, Center for Astrophysics

The massive star clusters identified by S. Larsen are compared to the available Chandra observations of face-on spiral galaxies. In each galaxy, a few percent of the Larsen-identified clusters match X-ray-emitting point sources. An additional few match knots of emission in the diffuse emission. The cluster properties are examined to ascertain whether massive star clusters are X-ray sources.

An Archive of Chandra Observations of Regions of Star Formation (ANCHORS)

Bradley Spitzbart, Center for Astrophysics
Natalya Bizunok, Scott Wolk (Center for Astrophysics)

ANCHORS is a web based archive of all the point sources observed during Chandra observations of regions of star formation. It is designed to aid both the X-ray astronomer with a desire to compare X-ray datasets and the star formation astronomer wishing to compare stars across the spectrum. For some 50 Chandra fields, yielding 10,000+ sources, the database contains X-ray source properties including position, net count rates, flux, hardness ratios, lightcurve statistics and plots. Spectra are fit using several models, with final parameters and plots recorded in the archive. Multi-wavelength images and data are cross-linked to other archives such as 2MASS and SIMBAD. The pipeline processing ensures consistent analysis techniques for direct comparisons among clusters. Results are presented on-line with sorting, searching, and download functions HTML/XML interface. We will demonstrate the system and solicit users' feedback.

IR & X-ray Studies of Nearby Young Starforming Regions: Serpens, NGC1333, OMC 2/3

Elaine Winston, Center for Astrophysics
Tom Megeath (Center for Astrophysics), Scott Wolk (Center for Astrophysics), Lori Allen (Center for Astrophysics)

We will present the study of three young, nearby (< 450 pc) stellar clusters at optical infrared and X-ray wavelengths: Serpens, NGC1333, OMC 2/3. Photometry from the IRAC instrument on Spitzer will provide 3.6, 4.5, 5.8, 8.0 micron fluxes, and MIPS will provide 24 micron. With these data we can identify those members with envelopes (Class I), those with disks and no envelope (Class II), those with no observable disks (Class III), and those objects having no discernable inner disk but an excess flux at 24 micron. Class III objects will be identified through examination of their X-ray flux, as they continue to exhibit elevated levels above the background and field stars. We will focus on the X-ray selected sample of young stars, using the Spitzer data to determine the evolutionary class of each of these stars. We will then examine the X-ray properties as a function of the evolutionary class. Such information may provide insight on rapid disk dissipation in the first Myrs.

Spitzer and Chandra Views of Massive HII Regions in the Local Group

Bernhard Brandl, Leiden Observatory

The Spitzer Space Telescope has produced exciting views of the warm interstellar medium in the massive HII regions NGC 3603, 30 Doradus, NGC 346, and NGC 604. Combining these informations with Chandra data on the hot X-ray gas provides new insights in the energetic conditions, structure, and evolution of these regions. In my talk I will present new Spitzer images and spectra and overlays with Chandra images that illustrate the common properties of and differences between these massive star nurseries.

Spitzer View of Star Formation in the Large Magellanic Cloud

You-Hua Chu, University of Illinois

The advent of Spitzer Space Observatory provides for the first time an opportunity to detect and resolve proto stars in the Large Magellanic Cloud (LMC) at 50 kpc. As proto stars have not significantly disrupted their interstellar environments, it is possible to associate the final product of star formation with the initial interstellar conditions and assess the roles played by global gravitational instability and local dynamical triggering. We were awarded Spitzer IRAC and MIPS observations of 7 star forming complexes in the LMC (N11, N44, N51, N63, N70, N144, and N180). Massive proto stars are detected in every region and in the least expected locations. When compared with optical images taken with Hubble or ground-based telescopes and X-ray images taken with Chandra or XMM-Newton, triggered star formation can be unambiguously identified. Beautiful images and exciting results on star formation in the LMC will be presented.

COUP: The Chandra Orion Ultradeep Project

Eric Feigelson, Penn State University

In January 2003, the Chandra X-ray Observatory pointed at the Orion Nebula region nearly continuously for 2 weeks. A wide range of studies by an international collaboration of scientists is emerging from this observation of unprecedented duration and sensitivity. We start with an overview of the X-ray luminosity function of the Orion Nebula Cluster population with insights into the dependencies of magnetic activity on stellar mass, age, accretion and rotation. Hundreds of powerful magnetic reconnection flares are seen at levels orders of magnitude above that seen in main sequence stars. The relationship between X-ray, optical and infrared surveys are then discussed. COUP confirms the cluster membership of 1315 stars, discovers several dozen new members, and places interesting limits on the low-mass population of the embedded cluster around the Orion Hot Core. COUP detects stars with obscuration as high as 500 visual magnitudes. We end with a brief discussion of the potential astrophysical effects of X-rays on star and planet formation. COUP provides new evidence that X-rays can efficiently irradiate protoplanetary disks and, if an embedded cluster is present, will produce X-ray Dissociation Regions over significant fractions of molecular cloud cores.

Radio, X-ray, and infrared variability of Young Stellar Objects in the Coronet cluster

Jan Forbrich, Max-Planck-Institut fuer Radioastronomie, Bonn (Germany)
Thomas Preibisch, Karl Menten

The Coronet Cluster in the nearby R CrA dark cloud offers the rare opportunity to study a sample of at least four “class I” protostars as well as one class 0 source plus a Herbig Ae star within a few arcminutes at a distance of only 150 pc. Most of these sources are detected at radio, X-ray, and infrared wavelengths and present a diverse view in radio and X-ray data we report here. We analyzed multi-epoch Very Large Array (VLA) as well as archival Chandra and XMM-Newton data taken in 1998 and 2000-2003, respectively. Upcoming simultaneous multi-wavelength radio, X-ray, and near-infrared observations will offer the possibility to study interconnections and lead to conclusions concerning the underlying physics. For example, correlations of the variability in hard X-ray and centimetric radio emission from these sources could lead to new insights into their coronal processes, while correlations between lower-energy X-ray and infrared emission could probe accretion activity.

The Spitzer View of Star Formation and Circumstellar Disk Evolution in NGC 2068/2071

James Muzerolle, Steward Observatory
Erick Young (Steward Observatory), S. Thomas Megeath (Center for Astrophysics), Lori Allen (Center for Astrophysics)

I will present results of Spitzer IRAC and MIPS imaging of the star forming region associated with the NGC 2068/2071 reflection nebulae. The region contains moderately dense clusters of young stellar objects of a wide range of evolutionary states. Combining IRAC 3.6-8.0 micron and MIPS 24 and 70 micron photometry with ground-based optical and near-infrared measurements from the SDSS and 2MASS surveys, we have compiled spectral energy distributions for hundreds of sources. I will compare number statistics and spatial distributions for Class 0, I, and II objects from classifications based on the infrared SEDs. Stellar and accretion characteristics for a representative sample of these objects have been determined via low- and high-resolution optical spectroscopy obtained with Hectospec/chelle. Finally, I will show evidence for a significant population of evolved disks, some 5-10% of all disk sources, which suggests a wide variation in timescales for the onset of primordial disk evolution and dissipation in comparison to other regions with older ages.

The low-mass star and disk populations in NGC 6611

Joana Oliveira, Keele University, UK

The aim of our observational program is to find empirical answers to two major questions. Do regions of high-mass star formation also produce lots of solar- and low-mass stars, i.e. is the low-mass IMF unaffected by high-mass siblings? Can low-mass stars in hostile environments retain circumstellar disks? We present results of our survey of NGC 6611, a massive cluster with an age of approximately 2 Myr which is currently ionizing the Eagle nebula. This cluster contains a dozen O-stars that emit 10 times more ionizing radiation than the Trapezium, providing a challenging environment for their lower-mass siblings. Our dataset consists of wide field optical and near infrared imaging, intermediate resolution spectroscopy (ESO-VLT) and deep L-band photometry. We have photometrically selected solar- and low-mass stars, placed them on the HR diagram and determined the IMF over an area sufficient to deal with mass segregation. We show that the IMF in NGC6611 is similar to that of the Orion Nebula Cluster down to $0.5M_{sun}$. Using K-L indices we search for colour excesses that betray the presence of circumstellar material and study what fraction of solar-mass stars still possess disks as a function of age and proximity to the massive stars. By comparing the disk frequency in NGC6611 with similarly aged but quieter regions, we find no evidence that the harsher environment of NGC6611 significantly hastens disk dissipation. Apparently the massive stars in NGC6611 have no global effect on the probability of low-mass star formation or disk retention. We have an approved HST program that will allows us to investigate the very low-mass and brown dwarf populations in NGC6611. And we complement our IR imaging with Spitzer/ORAC data, extending the area of our ground-based survey.

Disks Around Brown Dwarfs and Low Mass Stars in the Orion Molecular Clouds 2 and 3

Dawn Peterson, University of Virginia
T. Megeath (Center for Astrophysics), J. Pipher (Rochester), K. Luhman (Center for Astrophysics), L. Allen (Center for Astrophysics), P. Myers (Center for Astrophysics)

The Orion Molecular Clouds 2 and 3 (OMC 2/3) region is a very active region of ongoing star formation. Submillimeter surveys have found twenty-one protostellar cores in OMC 2/3 (Chini et al. 1997); however it has not been studied as extensively and to similar depth in the infrared as the neighboring Orion Nebula Cluster. Deep near-IR, visible and now Spitzer observations of OMC 2/3 have been obtained and analyzed to identify PMS stars and brown dwarfs. Spectroscopic follow-up has confirmed as many as 17 bona fide brown dwarfs in this region. Circumstellar disks are identified in many of these young objects through infrared excess emission. Spitzer photometry is used to detect mid-infrared excess emission in a dozen OMC 2/3 brown dwarfs, confirming that they exhibit circumstellar disks. Using the ground-based near-IR and Spitzer data, the population of protostars and young stars with disks is identified, and the number and spatial distribution of young stellar objects is presented. By combining this data with the near-IR variabiliity study of Carpenter et al. (2001), a circumstellar disk fraction is determined.

The HST Treasury Program on the Orion Nebula Cluster

Massimo Robberto, STScI

The HST Treasury Program on the Orion Nebula Cluster has been completed in May 2005. It represents the largest investment of HST time (104 orbits) ever dedicated to star formation. Using ACS, WFPC2 and NIC3 in parallel we have mapped with unprecedented sensitivity (23-24 mag), dynamic range, spatial resolution, and spectral coverage (9 filters from U to H) approximately 1/6 of a square degree, nearly centered on the Trapezium stars. The survey provides the richest, most accurate and unbiased dataset of stellar photometry for pre-main-sequence objects ever made. Combined with optical and infrared spectroscopy from the ground and with the data taken by Chandra (COUP) and SPITZER, it will allow to attack key questions on star formation: PMS evolution and the calibration of pre-main-sequence evolutionary tracks, the shape and variations of the initial mass function in different environments, the mass accretion rates vs. age and environment, disk evolution and dissipation in environments dominated by hard vs. soft-UV radiation, stellar multiplicity vs. disk fraction, planetary mass companions, etc. I will give an overview of the program, of the observing strategy, of the data products and present some preliminary results.

The Deep Rho Oph XMM-Newton Observation (DROXO): Status and Initial Results

Salvatore Sciortino, INAF-Osservatorio Astronomico di Palermo
and the DROXO team

In reply to the XMM-Newton AO4 a team of scientists has proposed and got approved an XMM-Newton Large/Joint-ESO Project consisting of a 500 ksec long, almost continuous, XMM-Newton observation together with coordinated FLAMES and ISAAC ESO-VLT observations. This project, dubbed as DROXO (Deep Rho Oph XMM-Newton Observation), aims to characterize mainly the spectro-variability properties of YSOs in the nearby and very young rho Oph star forming region. The X-ray observations have been already performed in 5 consecutive XMM-Newton revolutions from March 8 to March 17, while the VLT observations are in progress. I will present the X-ray data, their analysis status focusing on a few selected initial scientific results for a few interesting sources.

What We Have Learned about Star Formation from the Antennae

Brad Whitmore, STScI

The talk will be in two parts. The first part will be a brief review of what has been learned about star formation using Hubble (primarily), Chandra, and Spitzer observations. The second part will be an outline of a study we are just beginning concerning how spatial resolution affects science results from the three telescopes (and GALAX also).

XMM-Newton observations of the Upper Scorpius association

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The 5 Myr old Upper Scorpius Association, due to its proximity (145 pc) and low interstellar absorption, allows a detailed study of the X-ray emission from PMS stars. We present the results of the analysis of XMM observations of two Upper Scorpius regions. We detected 224 X-ray sources among which we identified 21 Upper Scorpius probable members on the basis of the 2MASS and DENIS photometry. The selected Upper Scorpius sample includes 7 WTTS, while the nature of the remaining 14 sources it is not known. Except the high mass star HD 142578 (spectral type A2), all the other detected Upper Scorpius sources are low mass stars of spectral type ranging from K to late M. The spectral analysis of the most intense sources indicates plasma temperature of ~ 10 MK, resembling the typical coronal emission of active main sequence stars. We study the abundance vs. temperature pattern of Upper Scorpius sources and compare it with that observed for active stars. The Kolmogorov-Smirnov test proves that 67% of the detected X-ray Upper Scorpius sources were variable during the observation, and some of them displayed large flare-like events.

h Persei: Young Star Cluster in X-rays

Natalya Bizunok, Center for Astrophysics
S. J. Wolk, N. R. Evans, B. Spitzbart, F. Seward, S. Kenyon (Center for Astrophysics), T. Barnes (U. Texas), and J. M. Pasachoff (Williams College)

We have obtained a 40 ksec ACIS observation of the open star cluster h Per in December, 2004, from which we have identified more than 200 X-ray sources and found optical counterparts for many of them. We are processing the h Per data with the ANCHORS pipeline, which is being used to process Chandra observations of star forming regions in a uniform manner. This will provide fits to the instrumental low-resolution spectra for cool pre-main sequence stars in h Per including fluxes, temperatures, and absorptions.

Investigation of Diffuse X-ray Emission in the Massive Star Forming Region NGC 6334 with Chandra and Future Prospects with Astro-E2

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Recent studies with Chandra have been revealing that there are various diffuse X-ray emission originated from 10^{6-7} K plasma or possible accelerated particles in massive star forming regions (e.g., Wolk et al. 2002, Townsley et al. 2003). We analyzed Chandra data of the representative massive star-forming region NGC 6334 where hard X-ray emission have been detected with ASCA (Sekimoto et al. 2000). In addition to 800 point sources, we found diffuse X-ray emission (5x9 pc and 2e33 erg/s in the 0.5-8 keV luminosity). It shows positionally different spectra; thermal plasma emission of several keV in low absorption regions, while flat continua in dense cloud cores. The former emission can be explained by hot plasma heated at strong shocks of fast stellar-winds from young OB stars, while the latter by accelerated particles at the shock. We then roughly estimated possible contribution of diffuse X-ray emission in Galactic massive star forming regions to the puzzling Galactic Ridge X-ray emission (e.g., Kaneda et al. 1997) as $\sim$ 10% in luminosity. Related to this issue, we show potential importance of simultaneous observation with Chandra and, the Japanese new X-ray observatory, Astro-E2.

Cluster Recognition Program - Progress Towards an Unbiased Detection and Analysis of Clusters

Bruno Ferreira, University of Florida
Elizabeth Lada (University of Florida)

Having developed and tested a systematic and unbiased method of cluster detection I present, in this poster, the method and the results of this work. In order to make statistically sound affirmations on the properties of young stellar clusters one needs to study a large number of these clusters and to do so in an identical way so as to make their results suitable for comparison. The method developed had that specific goal. Furthermore, so as to not have a biased sample, we removed identification-by-eye and subtituted it with a more robust method.

Star Formation in the Atomic Clouds in the Magellanic Clouds

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We present study of young embedded stars within the warm and dense atomic clouds in the Large and Small Magellanic Clouds with the CASPIR at the Siding Spring Observatory. We use JHKL band of the CASPIR to image six atomic clouds from ATCA+Parkes survey (Kim et al. 2003) which are potential sites of the triggered star formation caused by expanding superbubbles and supershells. We characterize the embedded star clusters from the fit of the near and far-infrared spectral energy distribution (SED) together with the IRAS 25, 60, and 100 micron emission.

The COUP Abundance Study: Spectral analysis of the X-ray brightest late-type stars in Orion

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We present preliminary results of a detailed X-ray spectral analysis of 55 sources in the Chandra Orion Ultra-deep field, identified with late-type stars and having more that 10^4 extracted counts. The aim of this analysis is to provide a census of element abundances in the coronae of these young stars, and to study possible dependences of such abundances on the magnetic activity level, the presence of circumstellar disks, indicators of accretion, and the properties of the local environment. We present here the methodology of such an analysis and results related to the thermal structure of the selected sources, their global metallicity, and abundance determinations for some individual elements. In particular, we show that the COUP X-ray bright sources tend to be metal poor (Fe abundances less than half the solar one, with most frequent values of 0.1-0.2 solar), while they show a larger scatter of Ne abundances, and Ne/Fe ratios from ~ 1 up to ~ 10.

The Spatial Distribution of Low-Mass Members of the Sigma Ori Cluster

William Sherry, NOAO
Frederick Walter (Stony Brook), Scott Wolk (Center for Astrophysics)

The sigma Ori cluster is a cluster low-mass stars within the Orion OB1b group. At a age of about 3 Myrs, Orion OB1b is a fossil star forming region. Star formation is complete and the natal gas/dust has been cleared away. We use broad band photometry to statistically identify the low-mass pre-main sequence population of the Sigma Ori cluster. We find about 140 cluster members with masses between 0.2 and 1.0 M_{sun}. We use likely members of the cluster to estimate a radius of 3 to 5 pc and a total mass of about 225 M_{sun}. Photometric observations of low-mass cluster members (V>15) are very difficult in the inner 30" of the cluster because the 5 stars of the Sigma Ori multiple system are very bright (V=3.8 to V=6.7). We coadded a series of roughly half second V and I band exposures to create high dynamic range images that we could use to search for faint cluster members close to the central O star of the cluster. We report one new likely cluster member in the central 15" of the cluster.

Massive Star Formation in DR21 as Seen by Spitzer

Howard Smith, Center for Astrophysics

Identifying primordial substructure in NGC 2264 with Spitzer

Paula Stella Teixeira, Center for Astrophysics
Charles Lada (Center for Astrophysics), Erick Young (Steward Observatory, University of Arizona), Massimo Marengo (Center for Astrophysics)

We present new results on the massive young cluster NGC 2264 based on the analysis of data acquired from the Spitzer Space Telescope. The MIPS (Multiband Imaging Photometer for Spitzer) has enabled us to identify the most recent episodes of star formation in NGC 2264. In particular, the 24 micron data combined with submillimeter observations from Wolf-Chase (2003) indicate that the most recent star formation events have occurred primarily within dusty filaments of dense gas in the central regions of the complex. These observations provide interesting constrains for theoretical models of collapsing molecular clouds. Additional IRAC (Infrared Array Camera) and near-infrared JHK 2MASS data has enabled us to assemble spectral energy distributions which help elucidate the natures of the deeply embedded sources and confirm their extreme youth and status as protostellar objects.

Is the efficiency of magnetic braking limited by polar spots?

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Ferreira, M. (Centro de Astrofsica da Universidade do Porto; Universidade dos Aores - DCA); Lima, J. (Centro de Astrofsica da Universidade do Porto, Departamento de Matemtica Aplicada, Faculdade Cincias Universidade do Porto)

The presence of high latitude spots on the surface of rapidly rotating cool-stars and the subsequent concentration of magnetic flux near the poles has lead to the idea that this causes a reduction in the angular momentum carried away by the stellar wind. We investigate the influence of the concentration of surface magnetic flux towards the pole on the topology of the coronal magnetic field and its efficiency in removing angular momentum from the star. If we neglect the effect of the wind, then the topology of fully open or partially open magnetic fields high in the corona is largely independent of the degree of field concentration at the surface. Therefore, a highly concentrated surface field or a dipolar field yield similar coronal fields. We apply the analytical MHD wind model of Lima et al. (2001) to determine the influence of the surface flux distribution on the efficiency of the magnetic braking. This model has the desirable properties of allowing different surface fields and, by construction, avoiding the expansion of the polar field to low latitudes. We determine the angular momentum loss rate for different surface field distributions, which have the same total magnetic flux. As the field concentration towards the pole increases, the angular momentum loss increases, contrary to what one would naively expect! This is explained by the fact that a decrease in the mass loss rate is compensated by an increase in the angular momentum loss per unit mass. Our results clearly show that the density, pressure, velocity and toroidal magnetic field variations are as important as the surface field distribution in determining the angular momentum carried by the wind. Further research is required to determine whether our results are a consequence of the particular models considered or can be regarded as a general feature.

Multiplicity Among Massive Stars

Nancy Remage Evans, Center for Astrophysics

Multiwavelength observations as exemplified by NASA's Great Observatories have provided a far clearer picture of the frequency of multiplicity in star systems. Cepheids (typically 5 M_{sun}) are good representatives of massive stars. It is frequently the case that a third star is not apparent until the second star can be directly observed. As an example, the spectra of hot secondaries in Cepheid systems can be obtained in the satellite ultraviolet. In a number of ways (to be illustrated) this has provided evidence of a third star. In a recent compilation of the best studied "binary" Cepheid systems, 44 percent are in fact triple systems.

Large magnetic structures in YSO in Orion

Fabio Favata, European Space Agency

The COUP (Chandra Orion Ultradeep Project) observation of the ONC has for the first time allowed to observe in detail long (up to a few days) flaring events in YSOs. One of the key results of the study of the COUP flares is the existence of a number of flaring events whose spectral evolution implies very long confining magnetic structures, up to 5 stellar radii. Many X-ray flares in more evolved stars have been studied in the past, and in all cases the flaring corona is compact, confined to a fraction of the stellar radius from the photosphere. Very large magnetic structures are thus unique to young stellar objects, which are typically surrounded by accretion disks. From stability considerations (linked to the large rotational velocity of these YSOs) the large flaring structures are likely linking the star with the inner rim of the circumstellar disk. Such magnetic structures are predicted by the magnetospheric accretion scenario, and flaring X-ray emission from them was predicted in the Shu et al. 'X-wind' model. The COUP flares are the first opportunity to determine the size of these magnetic structures and the intensity of the magnetic field. We will present an overview of the results from the COUP flare analysis and a detailed analysis of the evolution of the most notable of the COUP flaring events.

Educational Applications of Star Formation Research

William Waller, Tufts University and NASA/NESSIE
Cathy Clemens (Center for Astrophysics and NASA/NESSIE), Paul Green (Center for Astrophysics and NASA/Chandra)

Research into the formation of stars involves many exciting physical processes – from vast magnetized clouds collapsing under their own weight, to thermonuclear reactions igniting inside dense stellar cores, to powerful jets being shot from proto-planetary disks. Star formation research also touches on many aspects of the educational enterprise that is ongoing in schools, museums, and other community venues. In this presentation, we will (1) show how the science of star formation relates to the various learning goals and standards that currently underlie formal K-14 science and technology education, (2) describe the various opportunities that exist for space scientists to get involved in educational outreach, and (3) provide some examples of available resources that support educational outreach involving star formation.

The Herschel Space Observatory – A great follow up to the Great Observatories

Babar Ali, IPAC/Caltech
William Latter (IPAC), Bernhard Schultz (IPAC), Pat Morris (IPAC), Steve Lord (IPAC), Kevin Xu (IPAC)

The Herschel Space Observatory is the European Space Agency's fourth "Cornerstone Mission" and deploys a passively cooled 3.5 meter telescope to observe the Far-infrared and Submillimeter Universe. Herschel is planned as a three year observatory mission, with a launch date scheduled for late-2007. It will be launched on the same vehicle as the Planck mission, where both will orbit independently around the second Earth-Sun Lagrange point. NASA is a partner in the Herschel Mission, with US participants contributing to the mission; providing mission-enabling instrument technology and sponsoring the NASA Herschel Science Center at IPAC (the NHSC). The NHSC is established to provide the US astronomical community with science and observational support throughout all phases of the Herschel Mission.

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