STAR FORMATION IN THE ERA OF THE THREE GREAT OBSERVATORIES: A WHITE PAPER

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ABSTRACT

As part of *Chandra's* ongoing series, a workshop was held on 13-15 July 2005, entitled: *Star Formation in the Era of Three Great Observatories* (**http://cxc.harvard.edu/stars05**). The goal of the workshop, which was co—sponsored by the *Spitzer* Science Center, was to develop a "white paper" which could serve as a roadmap for the star formation from space. We sought to review topics in star-formation which are inherently multiwavelength, and define both the current state of our knowledge and the points of current controversy where new observations are most needed.

1. INTRODUCTION

We focus on topics for which the Great Observatories (*HST, Chandra* and *Spitzer*) have the most to contribute during this unique period of simultaneous operation. We also consider observations from other facilities including radio and ground based optical in addition to theoretical work. We examine star formation in both galactic and local-group star forming regions. One of the goals we define for star formation is **to understand how stars and their associated accretion disks are assembled from molecular material.** We identified the following *key areas of physics which highlight the complimentary aspects of the great observatories:* 1) Stellar populations. 2) The formation and evolution of disk systems. 3) Rotation and dynamos.

2. CAPABILITIES

The three great observatories study three distinct components of the star formation process (gas, dust and magnetic fields), each with their own evolution but intertwined with the other two. This complimentary nature is extended to ISM studies. The great observatories see structure (HST), thermal states and embedded stars (Spitzer) and hot gas and hot energy sources (Chandra) within the ISM..

- *Hubble* - Traces the evolution of the ionized gas. In its first 15 years HST has changed how we view almost all aspects of the latter phase of star formation. Three highlights are: 1) The discovery of "Proplyds", 2) Evaporation of molecular clouds by O Stars 3) Herbig-Haro object imaging.

- *Chandra* - Traces the evolution of the magnetic field. Highlights of the first 6 years of Chandra included: 1) Demonstrating that X-rays dominate cosmic rays as a source of ionization, 2) The detection of X-ray fluorescence of protostellar disks, 3) The detection of complex flares in protostars.

- *Spitzer* - Traces the evolution of the dust. Recent work from D'Alesso (2004) and Calvet (2004) have demonstrated IRACs ability to discern stars with disks and stars with infalling envelopes (protostars) from both each other and diskless stars (out to some limit) with ease.

3. OPEN QUESTIONS

Here we summarize the open issues raised.

Questions about populations.

- How does one obtain a "complete" census of a cluster?
- What is the general sequence of events by which a star goes from having a full optically thick disk to being "naked"?
- How does high-mass star formation and the large amount of plasma generated effect the ISM?
- Is the X-ray emission of ~1 Myr stars dominated by the same processes that cause X-ray emission in MS stars, or by other processes?
- Are brown dwarfs formed independently, via ejection or both?

Questions about Disks

- What is the feedback between ionization and disk accretion?
- In transitional disks, what produces the inner disk clearing?
- Does the inner disk fill again? Are there repeated episodes of disk clearing?
- How does dust settling and growth lead to planet formation?
- Does rotation at early ages allow one to say anything re: planet formation and the fraction of stars with giant planets (or terrestrial planets? or debris disks?)

- *Questions about Rotation.*
- Is the lack of an obvious rotation-activity correlation at age ~ 1 Myr due to saturation?
- Is there a decrease in X-ray activity at very high rotation rates at age ~ 1 Myr? If so, is this due to super-saturation? [If so, what is the physical cause of super-saturation?]
- Is there a very slowly rotating population at age ~ 1 Myr (in Orion) that is very X-ray inactive?
- Is there a change in the rotational velocity distribution at age~1 Myr below some mass?
- To what extent does the rotational velocity distribution seen in the Pleiades and α Persei for low mass stars reflect what is already established at ~1 Myr, and to what extent does it reflect rotational evolution on PMS tracks and on the MS?

4. ANSWERING THE KEY QUESTIONS:

It is in the synthesis of various individual observations that the physics questions can be addressed:

4.1 CURRENT SPACE OBSERVATORIES

SPITZER

- IRAC and MIPS photometry needed to classify low-mass YSOs.
- Provide catalogs of embedded protostellar objects just emerging from the envelope infall phase to fully revealed star/disk systems.

Chandra

- Deeper *Chandra* observations are needed to identify cluster populations. Future X-ray observatories will not resolve distant, young galactic cluster stars. At 2 kpc and AV ~ 4, a 600 ks ACIS-I exposure is needed to achieve a 2-8 keV log Lx ~ 28.8 for a cluster of about 1Myr, thereby detecting half of all stellar cluster members.
- Map the Spitzer C2D, FEPS and Glimpse legacy fields in X-rays.
- There is additional interest in the role of instabilities and/or turbulence in stabilizing planetary orbits.

HST

- Carry out pathfinder imaging and spectroscopic observations of proto-stellar envelope morphology and kinematics.

Theory

- Improving our understanding of the formation and evolution of the magnetic field and the temperature and pressure balance of the ISM.
- Developing numerical simulation and visualization codes of sophistication sufficient to span the ranges of temperatures, densities and chemical conditions that obtain during the epoch when protostars emerge from molecular cloud complexes.

4.2 FUTURE SPACE OBSERVATORIES

The time and motion domains are still poorly explored. Space/time (astrometry, 3D), and Doppler surveys are needed to understand the long term evolution of clusters. Spatial and spectral capabilties in the mid-IR lag behind the optical and near-IR. The Far-IR and sub-mm regimes are still barely explored. These areas are critical to understanding the earliest phases of stars formation and the evolution of thick disks. Below we list important experiments for upcoming space observatories.

SOFIA – **1)** Detect and measure tracers of shocked and radiatively heated gas produced in infalling envelopes, at envelope/ accretion disk interfaces and by accretion-disk-driven winds and jets.

Herschel (~2008) – **1)** Survey cold cores within 500 pc of the Sun. **2)** Correlate X-ray emission from the interstellar medium with mid-Far IR emission,

GAIA (~2012) – **1)** Distance to Hyades, Pleiades and the various parts of the Orion Complex**. 2)** Optical photometry to well below the brown dwarf limit for all clusters within 1 kpc. **3)** Measure the cadence and magnitude of the optical variability of PMS stars as well as measuring the change as a function of time. This requires extensive monitoring of a range of clusters.

JWST (~2012) – **1)** Quantify envelope infall rates for a large sample of forming stars spanning a wide range in mass: *requires high resolution spectroscopic capability not planned for baseline mission* **2)** Quantify the shape of the stellar initial mass function (IMF) to masses as small as 10 Jupiter masses in nearby star-forming regions **3)** Quantify the IMF down to the hydrogen burning limit in local group galaxies in regions spanning a range of metal abundances.

Constellation-X – **1)** Survey nearby TTS for accretion and infall signatures in their forbidden lines. **2)** Survey nearby TTS using reverberation mapping to map the surface structure of their disks. **3)** Survey all stars with 10 pc for cometary emission as evidence by charge-exchange.

Funding Opportunities: – **1)** The individual observatories are not designed to support synthesis of observations and generally require a wavelength focused approach. This emphasizes the importance of the NASA/ADP and possible "(N)VO"-like opportunities. **2)** Support for "collaborations of scale" sufficient to develop the numerical codes and visualization tools necessary to model the physical and chemical evolution of molecular clouds.