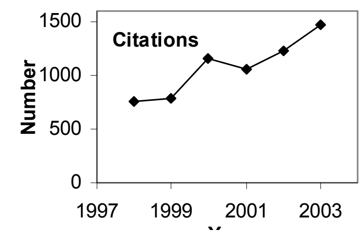
Center for the Study of Cosmic Evolution

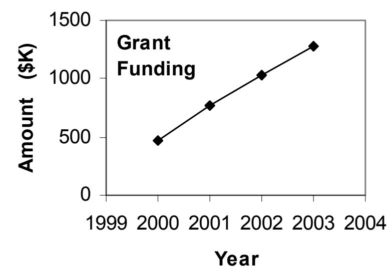
Strategic Plan

March 2006

1.0 The Past Six Years

There has been a remarkable transformation of the astrophysics program at MSU over the past six years. A major catalyst for this has been the excitement of being involved in the SOAR Telescope project. The SOAR connection has helped us to recruit a new set of young faculty members who bring new academic energy and new scientific directions to the prgram. We have channeled some of this energy into completely reshaping and revitalizing our Astrophysics PhD program, which in turn is feeding sharp young graduate students into our research efforts. We have increased the astronomy group's publication and funding rates by large amounts. We have improved our undergraduate curriculum. Strong connections have been built between the astronomy and nuclear physics groups through MSU's participation in the Joint Institute for Nuclear Astrophysics, and through the joint hiring of a top-notch young theoretical astronomer. However, it is vital to recognize that this was all built on the solid base that was already there. The achievements over the last six years were the achievements of the whole group – new faculty members and old. Together the group has built up something that is better than any of us could have built alone. Our goal for the next five years is to stay on this same sort of upwards trajectory.





2.0 The Current Astrophysics Research Program

The overall theme of astronomy and astrophysics is to study the Universe as it is, and to deduce how it came to be here. The general questions that we are seeking to answer are:

- What is the Universe made of?
- What were the first stars like?
- When and how were galaxies assembled?
- How were the chemical elements made?

The CSCE is an important player in this "big picture" research, in two overlapping areas.

2.1 The History of Our Galaxy. This area brings the work of Beers, Smith, Brown, Stein (and to some extent Baldwin) from the astronomy group together with the nuclear astrophysics program at NSCL. A major emphasis is the chemical history of our Galaxy, as deduced from studying stars whose atmospheric chemical abundances preserve the enrichment state of the interstellar gas at the time these stars formed at a series of epochs early in the Galaxy's life. Studies of r- and s-process enhancement follow from programs that first use large-scale surveys to find the oldest stars in the Galaxy, and then detailed high-dispersion spectroscopy to measure chemical abundances. The observational work of Beers and Smith directly connects to theoretical modeling by Brown, and their combined research links directly to the work at NSCL by Schatz, Sherrill, Austin and others. The Joint Institute for Nuclear Astrophysics (JINA) is a major connecting link in all of this, especially through its funding of post-docs and grad students.

Smith's observational work on variable stars, Stein's theoretical modeling of the Solar atmosphere, and Baldwin's observational studies of chemical abundances in planetary nebulae and star-forming regions within our Galaxy also connect into this same thread: What is the detailed history of the Milky Way Galaxy within the environment of the local group of galaxies? Besides the 5 faculty members mentioned above, the astronomy group has 2 postdocs and 5 graduate students carrying out research work in this area, in collaboration with a similar number of MSU nuclear physicists under the CSCE and JINA umbrellas.

2.2 Looking Back in Time over Very Large Distance Scales. This second general research area draws together our studies of the universe on scales much larger than that of the Milky Way. It includes future studies of distant supernovae for cosmological measurements of the change in rate of the expansion of the universe (Voit, Loh, Donahue), and current long-term studies of the rate and processes of formation of giant galaxy clusters (Donahue, Voit), of how galaxies form (Zepf), and of the early chemical evolution of massive galaxies through studies of the emission from the QSOs at their centers (Baldwin). In all, we have 7 faculty (5 astronomy, 2 particle physics), 3 postdocs, and 6 grad students actively involved in research in extragalactic astronomy.

A major thread connecting much of this work is the idea of using telescopes to look back into time, to see various objects as they were many billions of years ago when they emitted the light which we are receiving today. The second reason for looking out to large distances is to encounter objects that are spaced far apart or which occur on bigger scales than the Milky Way, giant galaxy clusters being an example. All of this research ties into the themes of cosmic evolution and cosmology. It is through this sort of study that we have learned about the existence of Dark Matter and placed limits on its nature, and through which we are learning about Dark Energy. These two things make up 96% of the mass-energy content of the universe, so understanding them is of necessity a major goal of physics as well as of astronomy. The connection of the work of the astronomers to that of the particle physicists within CSCE is both deep and obvious.

2.3 Balance Between Observation and Theory. Astronomy depends heavily on observational measurements: usually we first see what is out there, then we try to explain it. However, an intelligent choice of what to spend our time observing, with SOAR and with other telescopes, depends ever more heavily on a close interaction with the “theorists” who spend their time modeling and explaining the results. The recent success of the WMAP experiment illustrates this: many observers who spent a lifetime trying to make classical cosmological tests would never have imagined how much information was hiding in the microwave background. The CSCE is fortunate to have top-notch young theorists working in both of the main research areas; Brown in nuclear astrophysics and stellar phenomena, Voit in extragalactic astronomy. However, there is very significant input also from other members of the department, presently more in nuclear astrophysics, but with a large upside potential in the particle physics area. We see the astronomy group as the essential foundation for a more department-wide interest in astrophysics.

3.0 The Center for the Study of Cosmic Evolution

The underlying goal of the Center for the Study of Cosmic Evolution (CSCE) is to enhance the interdisciplinary linkages outlined above, building around the SOAR Telescope as our major experimental tool. However, we were awarded only partial funding, at a rate of $300K per year for 5 years. This has meant that for the first few years at least, most of the expenditures of these funds *must* be directed at paying off the SOAR Telescope debt and at funding our obligation to provide part of a postdoc to support SOAR operations.

It is our intention that when SOAR is paid off, the activities of the CSCE will turn more directly to encouraging the broad interdisciplinary interaction that we wish to promote. At the present time, we are already offering a CSCE seminar series which we believe is doing a good job of addressing broad issues concerning Cosmic Evolution.

The CSCE will be the major factor driving MSU astrophysics at least through the 2008/2009 academic year, after which the center’s funding comes up for renewal. We want to be sure that our Strategic Plan properly expresses the goals of the CSCE that were described in our initial proposal, since those are promises that we have made to the MSU upper administration. Those goals are duly incorporated into the following discussion.

4.0 The Astrophysics Research Environment in 2010

4.1 NASA and Origins. NASA is currently the major funding source for astronomy. Their "Origins" and "Structures & Evolution" themes encompass the origin of the Universe as well as the origin of galaxy clusters, galaxies, stars, planets and life within the Universe, and set these topics squarely on the front-burner of astrophysics research. While the NSF spent $171 Million on astronomy in 2003, NASA's overall Space Sciences expenditures were $3.4 Billion, including $300 Million targeted directly for grants for university research, plus another very substantial component of research funding to universities through grants to support the use of NASA's major space observatories (the Hubble Space Telescope, the Chandra X-Ray Observatory, and the Spitzer (infrared) Space Telescope.

NASA will continue to be the leading player into the foreseeable future (even if the HST is allowed to fade away over the next few years). Their next really big astrophysics venture will be the 6.5m James Webb Space Telescope, which is designed for studies of the initial round of star formation and the birth of galaxies, through infrared observations of very distant objects seen at large lookback times.

However, many smaller missions are also planned or under study. Among these are the Joint Dark Energy Mission (NASA + DOE), which includes the SNAP proposal, several MIDEX programs (WMAP and SWIFT are examples currently in orbit, Wide Field Infrared Explorer [WISE] is next), the Space Interferometry Mission (SIM) and other planet-finders.

The CSCE must stay in position to be active players in this research area of "Origins". This is an obvious extension of our current work both in extragalactic and Galactic astronomy.

4.2 The National Science Foundation. NSF currently provides funding in two areas that complement the role of NASA. One is to provide personal research grants for 3-year terms. These complement the typical one-year research grants that come with observing time on NASA space telescopes, and thus provide very important continuity and also support for purely ground-based programs that NASA on principal will not support. However, these grants are difficult to get, with a success rate of about 1 in 3. Most astronomers (including here at MSU) have an NSF research grant some of the time, but not all of the time.

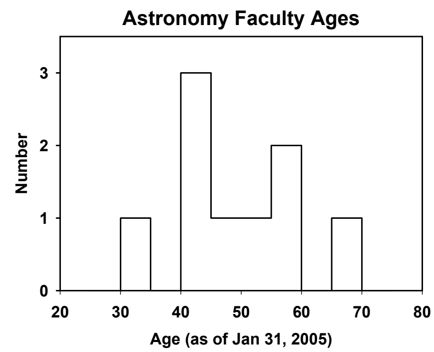
The second NSF funding area of interest to us is for instrumentation. Even though their Advanced Technology and Instrumentation program only rarely funds million-dollar awards, NSF is still a reasonable bet for partial funding for our second generation SOAR instrument. The NSF has already funded the cost of installing two additional detectors for the Spartan camera. By the time we make further applications, we will have established *two* important additional track records: scientific success of the Spartan Camera and scientific success of SOAR.

4.3 Large-Scale Surveys. Astronomy is depending more and more on very large-scale surveys from the ground and in space. MSU is well-positioned to participate as a driving force in many of these efforts, and we should build on these strengths. A short, and incomplete list of several such efforts include LSST (Large Synoptic Survey Telescope), KAOS (Kilo Aperture Optical Spectrograph), DES (Dark Energy Survey), RAVE (Radial Velocity Experiment), SIM (Space Interferometry Mission) and HETRES (Hobby Eberly Telescope R-process Enhanced Star survey). Rapid follow-up with the SOAR telescope of objects of particular interest that are discovered with such surveys will provide a direct means not only for excellent science, but for new funding opportunities.

4.4 Emergence of Virtual Observatories. The data from many of these large-scale surveys is or will be publicly available. The Sloan Digital Sky Survey and the 2 Mass infrared survey are current examples that are having a wide impact. A major effort to consolidate these data bases is the National Virtual Observatory (NVO). It is in truth an international effort that is also getting significant support from Microsoft Corp. Megan Donahue serves on its Science Steering Committee. The NVO's task is to bring together a host of future wide-field or all-sky surveys covering much of the electromagnetic spectrum from gamma rays to radio, into a Petabyte-scale data base that can easily be searched and mined. In the future, this will be a key astronomical resource. We must prepare ourselves and our students for this sea-change in astronomy.

4.5 RIA. A potentially major factor is of course RIA. The connection to astrophysics is the same one that we already have so successfully developed here at MSU: the origin of the chemical elements. As we have amply shown, observational astronomy is the test bed and large-scale laboratory for our understanding of this important area of physical knowledge, and a strong interaction between nuclear physics and astronomy pays huge dividends for both disciplines. We should aim to tap some small fraction of the RIA budget to help support complementary observational and theoretical astronomy research here at MSU. This will be easier if RIA is actually located here at MSU, but is still a natural thing to do (perhaps as an extension of JINA) even if RIA is located elsewhere.

5.0 Personnel Changes



The astronomy group currently has 9 faculty positions. We have found that at this level we can maintain strong undergraduate and graduate teaching programs, provide necessary service teaching (AST 207, ISP 205 [3 sections], ISP 205L), while at the same time (and most importantly) carry out a strong, coherent research program.

As group members retire, our goal is to replace them with highly-qualified young observational astronomers working in two areas that we have identified as critical for future growth in astrophysics, and which will at the same time strengthen our links to the nuclear and high-energy groups. In this way we will deepen the department as whole in the general area of astrophysics, building on our existing strength of having a much broader-based astrophysics program than is usual in universities with separate physics and astronomy departments. These critical research areas are:

5.1 High-Precision Measurements of Chemical Abundances in Stars. This type of observational astronomy is where the rubber meets the road in nuclear astrophysics. It is through high-dispersion spectroscopy on ground-based telescopes that precise relative abundances can be measured for r- and s-process elements in stars that trace the chemical history of our Galaxy. This is a very specialized sub-discipline in astronomy, with a few centers of excellence here in the US, and a reawakening occurring in European astronomy due to their recently acquired access to several 8m telescopes. Part of the problem will be to find a really first-rate young candidate in this area, but if we can do so it would hugely reinforce our current link to NSCL and future links to RIA. Delivery of the Echelle Spectrograph STELES (SOAR Telescope Echelle Spectrograph), which is envisioned to occur in 2006 or 2007, will enable numerous research programs in which MSU will take a leadership role. These include high-resolution spectroscopic follow-up and analysis of metal-poor stars discovered by Beers and colleagues, long-term radial velocity monitoring of carbon-enhanced metal-poor stars identified by Beers and colleagues, individual stars in globular clusters of interest to Smith, chemical abundances in planetary nebulae (Baldwin), and numerous other projects. Because no one on the present faculty has extensive experience with the analysis of echelle spectra of stars, we presently rely on our colleagues at various institutions for this expertise. Clearly, the addition of a young expert with experience in this observational technique would prove valuable for full utilization of this new instrument on SOAR. However, an observer working in this field would also provide strong pressure for guaranteed access to larger telescopes capable of high-resolution spectroscopy of fainter stars, as well as for participation in survey and virtual observatory projects.

5.2 Observational Cosmology. We include in this category a user of ground and/or space-based telescopes for study of the Universe on a large scale and at large lookback times. This connects naturally to NASA's "Origins" theme, but also to the expertise within our High-Energy Physics group since cosmology and the large-scale universe are the arena for the observational study of Dark Matter and Dark

Energy. A position in this area could easily build on and enhance the interest within HEP in participation in projects such as SNAP, the Fermi-Lab's Dark Energy Camera, or their successors. Our participation in SOAR would be a natural drawing card for such a hire, and a bargaining chip for MSU's entry into larger projects. We would expect that hiring a first-rate young researcher in this field would then in turn increase the pressure for MSU participation in a major new observational astronomy project.

6.0 Where We Should Be in 2010

6.1 New Hires. As described above, we should aim to attract very highly qualified observational astronomers who will increase our interaction with the other parts of the department. This will build the strongest whole, drawing on the deep physics base available through our position within a department of physics and astronomy.

6.2 SOAR. The SOAR Telescope is coming into operation at a slower pace than we had hoped, and some modifications are needed before it comes into full science use about a year from now. However, all signs are that it *will* give the imaging performance for which it was designed. In the meantime the instrumentation package is coming together nicely. We therefore fully expect that in 2010 SOAR will be seen as a well-proven scientific success. *However, our number-one short-term priority must be to get SOAR into this state of being an established success.*

MSU has an obligation to provide a 2nd-generation instrument for SOAR. However, the exact timescale for this instrument is open. What we need to do is to move at a pace so that we can pursue an exciting science opportunity using outside funding. To help promote this, we have set aside $85K in the CSCE budget as seed money for matching funds. We should put this money on the line in proposals to NSF (or other funding sources if they come up), and keep submitting interesting proposals until one bears fruit. We do not consider it essential that we actually will have started a 2nd generation instrument by 2010; what is essential is that we keep trying to get funding until we succeed.

6.3 A Leadership Role in a New Joint Institute. The present NSF Frontier Center that MSU is involved with (JINA: Joint Institute for Nuclear Astrophysics) is an example of the sort of entity which the astronomy group plans to take a leadership role in establishing within the Astronomy Division at NSF. Such multi-institutional centers are an ideal vehicle for unifying research efforts at universities such as MSU with places that have small numbers of experts in a given field. We envision that the center concept will be one that the Astronomy Division at NSF may adopt in coming years, and Beers has already begun the "lobbying" effort for their establishment. The center of particular interest to MSU would be one devoted to the study of Galactic Astronomy. Such a "Joint Institute for Galactic Astrophysics" would securely establish MSU as one of the leading institutions in this area of contemporary research.

6.4 Planning for MSU Participation in a Major New Observational Astronomy Project. SOAR is a first-rate 4m telescope. It has *already* proven its worth to our department because it has been the catalyst for a major change in the scientific and academic pace of the Astronomy Group. Over the next 1-2 years SOAR will come into full scientific stride. But it should not be the end-point of MSU's participation in major astronomy projects. SOAR is complementary to other instruments and techniques. SOAR is designed for detailed imaging studies of specific objects and fields, not for wide-scale surveys, so it is an extremely valuable tool for following up on results from such surveys. But neither does SOAR have enough aperture for detailed spectroscopic studies of the faintest objects, so it will also be an extremely important finder-telescope for the very large ground-based telescopes that are now on the drawing boards. Finally, SOAR is a ground-based optical and near-infra-red telescope, and thus is highly complementary to telescopes in space.

Many of these complementary techniques will be available through national facilities. However, there is always a key competitive advantage from being a direct partner in a leading-edge project. We should use our participation in SOAR as a jumping-off point to move up to a new, larger project. That is what it means to "stay on the upward trajectory" that we have been on for the past six years.

One key attribute of this new project is that (as does SOAR) *it should benefit the CSCE as a whole*, not just one or two members of the group. The group as a whole should buy into it. The astronomy group needs to work over the coming few years to identify the best such project, and then to proceed to lay the necessary groundwork. At this point there are many candidate directions. They include:

- Participation in a bigger telescope (20m Giant Magellan Telescope, etc.)
- Active involvement in a large-scale survey (some current examples include Dark Energy Camera, LSST).
- Direct participation in developing the NVO or similar spin-off projects.
- Collaboration in a space mission (such as MIDEX, SIM, Joint Dark Energy Mission, etc.)

By 2010 we should be able to point to SOAR as a past success, and at the same time have convinced the upper university administration that it is time to move on to something newer and bigger. This will require a committed lobbying effort involving “believers” well beyond the CSCE. The medium-term goal for the CSCE is to identify that new direction.

6.5 The Overall Goal: A Nationally Recognized Astrophysics Program. The key aim of the Center for the Study of Cosmic Evolution, and the goal of this strategic plan, is to significantly raise the national recognition level of our astronomy and astrophysics program. Items 6.1 – 6.4 are our strategy for doing that. We have already made important gains and are appearing on more and more radar screens, but we have a ways to go. To see if we succeed in reaching this basic goal, we will use the same metrics that have already been agreed to in connection with the CSCE proposal. These include several typical measures: (1) articles by us or about our work in high-profile public journals such as Scientific American, Sky & Telescope, and the New York Times; (2) publication and citations rates; and (3) grad student quality and job placement. However, we have also set a specific goal of $2.5M annual grant income (in terms of the Award Amounts), which is a factor of five increase over our pre-SOAR funding. Finally, the CSCE plan calls for an outside review of the AST program in 2007 or 2008.The benchmark will be our previous outside review in 2000. The key questions to the committee will be: How do we compare to other astronomy programs and to astronomy departments? How much have we gained since the previous review?

Supplement: Outreach Expansion

Finally, because of astronomy's special attraction to the public, we want to mention the subject of outreach – using astronomy to communicate MSU's scientific research presence to people outside the university. Such a connection to the public is part of MSU's obligation as a land-grant university. Astronomy is a very special outreach tool both for MSU and for our department, because a broad segment of the public is already interested in it.

We are already working hard to take advantage of this opportunity. The Abrams Planetarium is a major science-outreach focus for mid-Michigan, and connects with many thousands of area adults and school children every year. Our public open houses at the campus observatory are highly popular. We give many talks each year, both on- and off-campus, to K-12 students. We offer monthly public evening lectures during the academic year. We circulate a monthly color newsletter to all public libraries within a 50-mile radius and to many other local community centers. We are experimenting with an annual full-color "MSU Astronomy Calendar" which we hope to put into the hands of thousands of Michigan citizens next year. The SOAR remote observing room is designed as a public outreach tool. There will be (as of fall 2005) a SOAR Display at Impressions 5 Museum, reaching many 1000's of K-8 children. We will want to continue refining and growing these existing programs over the next five years.

However, we see important opportunities to also move in new directions. One promising avenue is to make better use of specific outreach funds that are available in connection with observing time awards from NASA. Although the individual grants are small ($15K), they can be ganged together in amounts up to $45K, which if matched with equal funding from other sources would enable significant projects. Similarly, NSF specifically invites the inclusion of an outreach component in their astronomy science grants. One example of how such funds could be used is the Abrams Planetarium's goal of producing a new planetarium show, which could be shared with other planetariums around the country, about Cosmic Evolution. This would greatly broaden the impact and visibility of this MSU facility. Another example would be the purchase of a portable, inflatable planetarium, along with funding to take it to outlying schools. This would clearly add a feather to MSU's "land-grant" cap. A suitable goal for this strategic plan would be for us to bring off one such project.

Abrams Planetarium also has larger goals which must constantly be pushed forward for university development consideration or in proposals to outside agencies. The highest priority would be to purchase a full-dome color projector, which would offer a significant step up over the capabilities of the current DigiStar projector. A second highly-desirable initiative would be to reinstitute a Master's degree in Planetarium Presentation. There is a clear national need for such a program. A third long-range goal is a classroom addition to the planetarium, which would greatly enhance the planetarium's ability to be a learning center for visiting K-8 classes.

Another long-range possibility which we are exploring is to construct an on-line enrichment course about Cosmic Evolution. This would be an outreach activity, not an on-line substitute for ISP 205. It might be a natural outgrowth of the work of Voit and Donahue on introductory astronomy textbooks.