

Carnegie Institution of Washington
Department of Terrestrial Magnetism
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This report covers astronomical research carried out during the period July 1, 2003 – June 30, 2004. Astronomical studies at the Department of Terrestrial Magnetism (DTM) of the Carnegie Institution of Washington include observational and theoretical fields of planet detection, formation, structure, evolution, and atmospheres, the formation of stars, circumstellar disks, meteoritics, and the structure, dynamics, and evolution of galaxies. DTM also hosts the office of the Secretary of the American Astronomical Society.

1. PERSONNEL

- Staff Members: Sean C. Solomon (Director), Conel M. O'D. Alexander, Alan P. Boss, R. Paul Butler, John E. Chambers, John A. Graham (Emeritus; AAS Secretary), Larry R. Nittler, Vera C. Rubin (Senior Fellow), Sara Seager, Alycia J. Weinberger, George W. Wetherill (Director Emeritus)
- Research Scientist: James Cho
- Postdoctoral Fellows: Kathleen Flint, Kathleen E. S. (Saavik) Ford, Nader Haghighipour, Eugenio Rivera, Aki Roberge, Kaspar von Braun
- Predoctoral Fellow: Lindsey S. Bruesch
- Computer and Support Staff: Michael J. Acierno, Alexis Clements, Janice S. Dunlap, Brenda F. Eades, Brooke Hunter, Shaun J. Hardy, Sandra A. Keiser, Oksana Skass, Jianhua Wang, Merri Wolf

2. HONORS

Alan P. Boss — Member, American Academy of Arts and Sciences (2003), Fellow, Meteoritical Society (2002); **S. Seager** — Recipient, Harvard Bok Prize in Astronomy (2004); **V. C. Rubin** — Recipient, Catherine Wolfe Bruce Medal of the Astronomical Society of the Pacific (2003), Honorary D.Sc. Degree, Ohio Wesleyan University (2004), Recipient, James Craig Watson Medal, National Academy of Sciences (2004).

3. RESEARCH PROGRAMS

3.1 Solar System Planets

Sean Solomon is utilizing spacecraft observations to address aspects of the internal and geological evolution of the terrestrial planets. His scientific efforts during the past year have been divided between oversight of the development of the MERcury Surface, Space ENvironment, GEOchemistry, and RANGing (MESSENGER) spacecraft now en route to fly by and orbit the planet Mercury and sharpening of the scientific hypotheses to be tested by observations by that spacecraft.

Mercury has been viewed at close range by only a single spacecraft, Mariner 10, which flew by the planet three times

in 1974-75. Mariner 10 discovered Mercury's global magnetic field, documented the presence of several species in Mercury's exosphere, and imaged about 45% of the surface. In part because of this limited history of exploration, and in part because of several unusual characteristics of the planet, Mercury holds special promise for elucidating general solar system processes. Determining the surface composition of Mercury, a body with an anomalously high ratio of metal to silicate, will provide a unique window on the mechanisms by which planetesimals in the primitive solar nebula accreted to form planets. Documenting the global geological history will elucidate the role of terrestrial planet size as a governor of magmatic and tectonic history. Characterizing the magnetic field and the size and state of Mercury's core will advance our understanding of the energetics and lifetimes of magnetic dynamos in solar system bodies. Determining the full range of volatile species in Mercury's polar deposits, exosphere, and magnetosphere will provide insight into volatile inventories, sources, and sinks in the inner solar system.

The MESSENGER mission to fly by and orbit Mercury, selected in July 1999 under NASA's Discovery Program, will accomplish all of these key objectives. Launched in August 2004, the spacecraft will fly by Earth once (in 2005), Venus twice (in 2006 and 2007), and Mercury three times (twice in 2008 and once in 2009), before orbit insertion is accomplished at the fourth Mercury encounter in March 2011. The instrument payload includes a dual imaging system for wide and narrow fields-of-view, monochrome and color imaging, and stereo; X-ray and combined gamma-ray and neutron spectrometers for surface chemical mapping; a magnetometer; a laser altimeter; a combined ultraviolet-visible and visible-near-infrared spectrometer to survey both exospheric species and surface mineralogy; and an energetic particle and plasma spectrometer to sample charged species in the magnetosphere. During the flybys of Mercury, regions unexplored by Mariner 10 will be seen for the first time, and new data will be gathered on Mercury's exosphere, magnetosphere, and surface composition. During the orbital phase of the mission, one Earth year in duration, MESSENGER will complete global mapping and the detailed characterization of the exosphere, magnetosphere, surface, and interior.

Solomon worked on three aspects of Mercury's interior evolution amenable to testing with observations to be made by the MESSENGER spacecraft. Together with colleagues at The Johns Hopkins University Applied Physics Laboratory and the NASA Goddard Space Flight Center he derived estimates for how well the lowest-order spherical harmonics in Mercury's internal field could be resolved by MESSENGER's orbital observations, given expected external fields and their variability. With collaborators at Caltech and MIT he showed that variations in insolation with latitude and longitude on Mercury could lead to spatial variations in the

depth to the Curie isotherm for remnant magnetization, with the result that a lithospheric shell uniformly magnetized by an ancient internal dynamo field would have a measurable external field even in the absence of a modern dynamo; MESSENGER's determination of the ratio of quadrupole to dipole components will provide a test of this hypothesis. With former DTM postdoctoral associate Steven Hauck, Solomon explored the range of interior thermal history models for Mercury consistent with geological limits to global contraction and with the alternative hypotheses for the origin of Mercury's magnetic field. Mapping the geometry of the internal field, determining the state of Mercury's outer core, and imaging globally the distribution of surface tectonic features by MESSENGER will permit the range of evolutionary models to be considerably narrowed.

Giant impacts play a crucial role in modifying weather, climate, and evolution of planets. Cho and S. Stewart (Harvard) have carried out calculations of giant impacts on Mars and Earth to assess the extent to which the modification is possible. Another aspect of this problem is to study the extent of a "blowoff" (stability) of the atmosphere under such an impact. Calculations are being performed to assess the extent of the blowoff and how the remaining atmosphere readjusts. This work is also being applied to study the atmospheric reprocessing during embryo-embryo collisions in the late stages of the planet formation.

3.2 Origin and Evolution of the Solar System

Chambers continues an ongoing program to study the formation and dynamical stability of the planetary system. The study uses state-of-the-art computer models of the orbital and collisional evolution of the planets and their precursors. These models are run on Carnegie's new Xenia computer cluster shared between DTM and the Geophysical Laboratory. Models for the late stages of planet formation are constraining the main factors that determined the size, orbit and composition of the inner planets, and the circumstances required to form a habitable planet such as Earth. The study finds that the giant planets Jupiter and Saturn played a central role in determining Earth's habitability and water abundance, and giant planets are likely to play a similar role in extrasolar planetary systems. Planet-formation models often produce an arrangement of planets somewhat different than those in the modern Solar System. Chambers has conducted computer simulations which show that an additional terrestrial planet could have survived between the orbit of Mars and the asteroid belt for up to a billion years. Ultimately, such a planet is lost from the Solar System, but not before it dynamically disrupts the asteroid belt. The presence of an additional terrestrial planet could have produced the high rate of impacts on the early Moon known as the lunar late heavy bombardment.

3.3 Presolar Grains in Meteorites

Nittler and Alexander are continuing their research program in meteoritic presolar grains and their implications for stellar evolution, nucleosynthesis, galactic chemical evolution and dust formation around stars. Using a combination of

new chemical dissolution techniques to extract grains from meteorites and an automated isotopic analysis system that they developed, Nittler and Alexander have recently discovered a new class of chromium-rich presolar oxide grains. Isotopic measurements of Cr, Mg and Fe in these grains will help constrain their stellar origins and perhaps help explain isotopic anomalies found in bulk meteorites. With collaborator P. Hoppe (Max Planck Institute for Chemistry, Mainz), Nittler has identified two rare presolar SiC grains whose isotopic compositions indicate an origin in presolar nova explosions. Isotopic data on multiple elements in these grains are providing new constraints on nucleosynthesis processes within novae. With collaborator R. Stroud (Naval Research Laboratory), Nittler and Alexander are also investigating the nanoscale structural properties of presolar grains, using transmission electron microscopy (TEM). TEM studies of two presolar Al₂O₃ grains from asymptotic giant branch stars indicated distinct structures—one is crystalline, the other amorphous—providing complementary information to astronomical observations about dust formation processes in such stars. Recently, Stroud and Nittler made the first TEM observations of SiC grains known to have formed in supernovae; these grains have highly unusual structures reflecting the extreme environments in which they formed.

Nittler has also completed a modeling study exploring the effects of heterogeneous mixing of supernova ejecta into the interstellar medium. Comparison of the distributions of Si, Ti and O isotopes in presolar grains with the model results indicate that the ISM is well mixed at the percent level and confirms that the presolar grains record a history of galactic chemical evolution.

3.4 Interstellar organic matter

Alexander and Nittler continue a collaborative study of the insoluble macromolecular organic matter in meteorites and interplanetary dust particles (IDPs) with G. Cody and M. Fogel (Geophysical Laboratory). This macromolecular material is thought to have largely formed in the interstellar medium (ISM). A detailed understanding of its composition and structure will help elucidate the ISM processes that led to its formation (Cody *et al.* 2002; Cody and Alexander 2004). They are also working to develop quantitative microanalytical techniques that can be applied to the cometary and interstellar particles that will be brought back by NASA's Stardust sample return mission.

3.5 Extrasolar Planet Detection

The California & Carnegie Extrasolar Planet Search (G. Marcy & D. Fischer (UC Berkeley), S. Vogt (UC Santa Cruz), P. Butler (Carnegie DTM)) is currently pursuing 4 primary lines of research, all related to the development of the Iodine precision Doppler technique. The search group introduced the Iodine cell technique in June 1987, and achieved precision of 3 m/s in May 1995. The group is surveying the nearest 1,700 Sun-like stars (F8 - M5) within 50 parsecs with the Lick 3-m, Keck 10-m, Anglo-Australian 3.9-m and the Magellan 6.5-m telescopes. Most of these stars have been added over the last 7 years. These surveys have

produced nearly all the known multiple planet systems, the first (and only nearby) transit planet, nearly all the sub-Saturn-mass planets, and the first Neptune-mass planet. These surveys will be sensitive to Solar System analogs by the end of this decade. Nearly all the planet bearing stars are metal rich relative to the Sun. This year a survey of the 2,000 most metal rich stars within 80 parsecs began, using the Keck 10-m, Subaru 8-m, and Magellan 6.5-m telescopes. The goal is to find short-period planets, which have an enhanced probability of transiting their host star. This survey has already produced 2 planets.

The Planet Search group is working to improve their measurement precision from 3 m/s to 1 m/s. The goal is to achieve 1 m/s precision on the 200 nearest and brightest quiescent dwarf stars within 15 parsecs. This level of precision will allow the detection of Saturn-mass planets at 5 AU, Neptune-mass planets at 0.5 AU, and super-Earths ($M < 10 M_{Earth}$) in short period orbits. This group is one of the two principal planet-hunting teams for the NASA Space Interferometry Mission. They are working on both prioritizing target stars and identifying good reference stars.

Boss and Weinberger are undertaking a new astrometric planet search program with the 2.5-m du Pont telescope at Carnegie's Las Campanas Observatory. Along with the Observatories' I. Thompson, Allegheny's G. Gatewood, and Virginia's S. Majewski and R. Patterson, Boss and Weinberger have begun a long-term search for Jupiter-mass planets and brown dwarfs on long-period orbits (10 years or more) around nearby low mass stars (principally M,L,T dwarfs). Observations have been underway for three years to demonstrate the astrometric stability of the du Pont and to characterize the target stars and their background reference stars. For the latter stars, T2, and DDO51 photometry have been achieved in order to determine their colors, so that the effects of differential chromatic refraction can be removed from the astrometric solutions. Currently the observations are being undertaken with the existing Tek5 camera on the du Pont. In mid-2004, the NSF awarded funds for the construction of a specialized astrometric camera, capable of handling the extreme brightness ratios between the nearby target stars and the more distant reference stars. The camera is expected to be in operation on the du Pont in 2005, when the astrometric program will begin in earnest.

Open clusters potentially provide an ideal environment for the search for transiting extrasolar planets since they feature a relatively large number of stars of the same known age and metallicity at the same distance. With this motivation, von Braun and collaborators S. Seager (CIW/DTM), B. Lee and H. Yee (Toronto), G. Mallén-Ornelas (CfA) and M. Gladders (OCIW) are conducting a photometric monitoring program of Galactic southern open clusters (EXPLORE/OC). This survey is undertaken with the Las Campanas Observatory's 1m Swope telescope using the *I* band (to minimize the effects of limb darkening upon the shape of the transit in the light curve) at high observing cadence (~ 7 min; to be able to temporally resolve the individual elements of the light curves). Smaller stars are favored targets since the depth of the transit signal will be larger and easier to detect. For a given observing cadence, cluster distance and foreground

reddening estimates therefore have to be analyzed in the choice of observing target. A careful selection of open cluster targets under a wide range of criteria such as cluster richness, observability, distance, age, and contamination by field stars is necessary to meet the challenges and maximize chances to detect planet transits. To date, five open clusters have been observed and between five and seven more are planned.

3.6 Extrasolar Planet Atmospheres

Seager has continued to model extrasolar planet atmospheres with a focus on the close-in extrasolar giant planets (CEGPs or hot Jupiters). The CEGPs have ~ 4 day orbits and are therefore intensely irradiated by their parent stars. They are potentially bright in both thermal emission and scattered light, in comparison with giant planets at larger orbital semi-major axes, and so should be the first class of extrasolar planets to be successfully studied observationally. The transiting hot Jupiters offer an additional benefit—they pass in front of their parent stars allowing their radii to be determined. A known radius will help to break degeneracies in reflected flux for determining albedos, and in thermally emitted flux in determining temperatures. Seager has been preparing for interpretation of albedo and temperature measurements for the well-studied transiting hot Jupiter HD209458b. The Microvariability and Oscillations of STars (MOST; Canadian Space Agency, PI J. Matthews UBC) mission will study HD209458b during its secondary eclipse for albedo. Seager and colleagues Drake Deming and Jeremy Richardson (GSFC) have a Spitzer proposal to measure the secondary eclipse at IR wavelengths. In order to understand the reflective nature of the CEGP atmospheres, Seager has worked on a theoretical investigation of photochemistry in the CEGP atmospheres with Caltech collaborators and Yuk Yung and graduate student Mao-Chang Liang (Liang *et al.* 2003, 2004). They determined that the hot Jupiters will not have substantial photochemical products in their atmosphere, due to their high temperatures and lack of or low abundance of CH_4 .

In addition to work on extrasolar giant planet atmospheres, Seager has developed a radiative transfer model for terrestrial planets. Seager worked on models of Venus as an extrasolar planet for the June 2004 transit of Venus. She worked with observers who took photometric and spectral measurements of Venus during transit. The goal was to observe Venus as a test case extrasolar transiting planet. Regarding Earth, Seager has been working on methods to detect the vegetation red edge feature in spatially unresolved data (Seager *et al.* 2004).

Cho, Seager, K. Menou (Columbia University) and B. Hansen (UCLA) are continuing the work on studying the circulation, heat transport, and spectra of extrasolar planets. An extensive program of "extrasolar Earth" climate calculations with Seager has been initiated and is ongoing. A full general circulation model is being modified and run for a wide variety of orbital and physical configurations to assess habitability and to generate realistic spectra. Also continuing is the study of heat transport in the atmospheres of close-in giant planets. Cho, Shukla (NSF Summer Intern), and Seager

have extended previous high-resolution adiabatic calculations to diabatic calculations, using the radiative transfer calculations by Seager; these new, diabatic calculations are the most realistic atmosphere calculations of the close-in giant planet thus far. In addition, Cho is carrying out a careful analysis of the wave/mean-flow/turbulence (WMFT) interactions on, and in, the close-in giant planets; the analysis is required to correctly assess not only the heat and aerosol transport and mixing properties but also the efficiency of tidal dissipation in synchronizing the planets' orbits.

3.7 Dynamics of Extrasolar Planetary Systems

Haghighipour continued work on mapping the parameter space of a three body planetary system in search of stable resonant periodic orbits for habitable planets, in collaboration with NAI/IGPP at UCLA. The results of this research, for a planetary system in a (1:2) resonance, was published in the October 2003 issue of *ApJ*. He has continued his research in this direction for systems at (1:3) resonance with possible applicability to the extrasolar planetary system 55 Cnc.

In collaboration with Rivera, Haghighipour studied the long term stability of habitable planets in extrasolar multi-planet systems, Upsilon Andromedae, 47 Uma, GJ 876 and 55 Cnc. These systems have been shown to support resonant orbits, and/or to resemble our solar system. In a paper on this topic that has been submitted to *ApJ*, Rivera and Haghighipour have mapped the space around these planetary systems where habitable planets can have stable orbits, and have presented a detail study of the dynamics of such planets.

During the summer of 2003, summer intern J. Crossley (New Mexico Tech) and Haghighipour studied the stability of a multi-planet system in the debris disk of β Pictoris. Their work was motivated by the discovery of 4 warps in Beta Pic disk which suggest the presence of 4 planets in that system. Crossley and Haghighipour studied the stability of this system for different values of the mass, and orbital parameters of the planets. Running more than 30000 simulations, their results indicated that the majority of the systems became unstable between 1 to 10 million years. Among all their simulations, only 8 systems stayed stable for 50 million years in which all planets had masses smaller than 2.4 Jupiter mass. The results of this work have been published in the proceedings of the 14th Maryland October Astrophysics Conference.

3.8 Planetary System Formation

Boss continues to calculate the evolution of three dimensional (3D), gravitational, radiative hydrodynamical models of protoplanetary disks, in order to learn the outcome of a phase of gravitational instability. Computing these 3D models requires round-the-clock usage of the 48-processor Carnegie Alpha Cluster of workstations. The 3D models have been investigated in some detail to determine whether or not vertical convection is capable of cooling the disk midplane on a time scale short enough (several orbital periods) to permit a robust planet-forming disk instability to proceed. Evaluations of the rate of transport of thermal energy in the

vertical direction, combined with flow patterns resembling convective cells, and comparison to mixing length theory estimates all present a self-consistent picture of the viability of vertical convection as an efficient means of cooling protoplanetary disks. Other recent 3D models have studied mixing and transport processes in gravitationally unstable disks, finding that gravitational torques are able to move tracers through the 20-AU-size disks on time scales of order thousands of years, comparable to the time scale for dust grains to begin to coagulate and grow to cm-size.

Haghighipour continued his work on the study of the dynamics of solid objects in the vicinity of gas-density enhancements. His previous work on this topic focused on the effects of the appearance of local gas-density enhancements on the dynamics of individual solid objects. During the last year, he extended his work by considering a particulate background for the nebula, and allowing interaction between solid objects and this background material. He studied how the combined effect of gas drag and pressure gradients would affect collisions between 1-1000 micron-sized solid grains, and the submicron particles of the background. By numerically integrating the dynamical equations of a dust grain, Haghighipour showed that, only as a result of sweeping up the smaller particles of the background and growing in size, a micron-sized dust grain can rapidly decouple from the gas and radially migrate toward the location of maximum gas density, while descending toward the midplane. Such rapid migration, results in fast accumulation of cm-sized bodies in the vicinity of the midplane, and enhances the probability of their collision and coalescence to larger objects. The results of this study have been published in two articles, and a comprehensive paper on the evolution of a planet forming nebula and dust coagulation has been submitted to *Icarus*.

3.9 Star Formation

Boss has finished one major survey of 3D radiative hydrodynamics models of the fragmentation mechanism in magnetic molecular clouds with sheet-like geometry, and has begun a new survey for filamentary clouds. Fragmentation, the break-up of molecular cloud cores during their self-gravitational collapse to form stars, is by far the leading explanation for the formation of binary and multiple protostars. Boss's models include many of the effects of magnetic fields, using certain simple approximations. The newest models involve the collapse of initially sheet-like clouds, and it is found that such clouds have three possible outcomes: formation of one or two protostars near the edge of the computational volume, a single protostar near the center of the volume, or formation of a rotating ring near the center of the volume, which appears likely to fragment into two or more protostars. The calculations support the expectation, based on linear theory, that the spacing of protostars in such an infinite sheet will be determined by the critical wavelength for the growth of gravitational instability.

Accreting young stars drive high-velocity bipolar jets, which in turn create knots of shocked gas in the surrounding molecular cloud (Herbig-Haro flows). It was generally thought that only very young class 0 and I protostars drove strong outflows. However, it is becoming clear that 1) older

stars that are almost on the zero-age main sequence can still drive weak jets and 2) optically revealed stars that are no longer embedded in an IS cloud may still be surrounded by diffuse remnant molecular envelopes. There is a need to re-examine star-forming regions for previously unidentified weak Herbig-Haro flows to more accurately characterize the end-stages of star formation. Roberge and Weinberger are performing an unbiased census of Herbig-Haro flows in southern star-forming regions, using the 6.5 meter Magellan telescope. The goal is to completely inventory all Herbig-Haro flows and determine the fraction of older class II and III protostars driving weak flows. The technique consists of narrow-band imaging in the $2.12 \mu\text{m}$ S(1) ro-vibrational H_2 emission line, which is a tracer of shocked molecular gas. They have observed 119 square arcminutes of the R CrA star-forming region, covering the densest portion of the entire cloud.

3.10 Circumstellar Disks

Weinberger studied young circumstellar disks as the sites of planet formation and evolution. She presented the work of a search for warm dust around the young (~ 12 Myr old) stars in the β Pictoris Association. This collection of about two dozen star systems is one of the the closest (~ 40 pc) sites of recent star formation to Earth. Using the W. M. Keck Observatory, she made photometric measurements of 19 stars, including both components of resolved binaries. At these wavelengths, dust of ~ 200 K can strongly dominate the photospheric emission of the stars; thus photometry searches for excess emission due to dust. Of the stars examined, only two had evidence for excess. Results on the first, HD 199143 were published in Kaisler *et al.* 2004, and the second, HR 6070, was presented at the January 2004 AAS meeting in Atlanta. The total statistics for the association are 7 disks out of 33 stars (including cold disks). By 12 Myr, either terrestrial planets have already formed around most stars or they will never form. Warm and cold dust appear to disappear together. Models of terrestrial planet formation generate copious dust during an epoch where large bodies perturb each other and collide. In our own Solar System, collisions must have occurred as late as 30 Myr, the time of the Moon forming impact. This era is nearly over in the β Pictoris Association.

In search of a younger sample of post-T-Tauri stars to examine for disks, Weinberger worked with summer intern A. Aarnio (Smith College) to search for stars associated with the 5 Myr old disk source HD 141569. HD 141569 is actually a triple star system only 5 Myr old and 100 pc from the Sun. A search of the region of sky around it revealed 43 stars with X-ray emission indicative of youth and proper motions similar to HD 141569. Aarnio examined echelle spectra of these stars taken at the duPont Telescope at Las Campanas Observatory, to find their Li 6708 \AA equivalent widths and radial velocities. Six stars were found to have Galactic space motions the same as HD 141569 and likely formed together as an association.

Weinberger continued her detailed examination of the disk of HD 141569 itself by obtaining spatially resolved spectroscopy of the dust at $8\text{--}13 \mu\text{m}$ at the W. M. Keck

Observatory during an observing run in May. Lines from PAHs are seen at 7.9, 8.6, and $11.3 \mu\text{m}$. These lines are actually stronger at increasing radius. Silicates, normally the most common disk constituent and displaying a prominent, broad peak at $\sim 10 \mu\text{m}$ are missing at all distances where we can see the disk –out to 90 AU. It is a mystery why the disk should be dominated by small carbonaceous grains and not small silicate grains such as those found around β Pictoris.

Barbara McClintock fellow Roberge works on multi-wavelength studies of gas and dust in circumstellar (CS) disks around young stars. Her Ph.D. thesis was a far-UV spectroscopic study of gas in these planet-forming disks, focussing on CS molecular gasses. Roberge and Weinberger have completed analysis of the first spatially resolved spectrum of scattered light from a CS disk, using *HST*-STIS “coronagraphic spectroscopy” of the 8 Myr old TW Hydrae protoplanetary disk (Roberge, 2004a). This disk surrounds a classical T Tauri star, and has appeared to be relatively unevolved. Their novel observations provided optical spectra of light scattered by the face-on disk between 40 AU and 155 AU from the star. These spectra show that the grains are larger than typical interstellar grains ($\geq 1 \mu\text{m}$) out to large radii, and that there may be a decrease in particle size in the innermost regions of the disk. The idea that there are more small particles close to the star at first seems counterintuitive, since the coagulation of condensed grains occurs faster at smaller radii. However, the destruction of planetary material also occurs first at smaller radii, as evidenced by central holes in many debris disks. Sub-micron grains in debris disks are produced by collisions among planetesimals. Our spectra may show that the clearing of solid planetary material has begun in the inner disk. We also obtained radial profiles of the integrated disk brightness from our spectroscopic data and from *HST*-STIS broad-band coronagraphic images. The profiles show an asymmetry in the disk not previously noted; interior to 140 AU, the surface brightness interior has a sinusoidal dependence on azimuthal angle. This might be caused by the combination of forward-scattering and an increase in inclination in the inner region of the disk, suggesting that the TW Hya disk has a warp like that seen in the β Pictoris debris disk. Such warps are generally attributed to the presence of an unseen giant planet on a orbit slightly inclined to the main disk. This work demonstrates a useful analysis technique to detect warps in face-on disks, which are hard to observe.

3.11 Extrasolar Cometary Systems

Ford has been working primarily on the characterization of the extrasolar cometary system around IRC +10216. Extensive spectral line searches using the IRAM 30m telescope have secured an unambiguous detection of formaldehyde around IRC +10216, with a spatial distribution consistent with that expected from a cometary system. The abundance of formaldehyde is consistent with that found in our Solar System’s own comets; however, the upper limits on the abundance of methanol around IRC +10216 are quite low compared with Solar System comets. Ford has recently proposed searches for the presence of deuterated molecules around IRC +10216, which would constitute an unambigu-

ous signal of non-stellar (cometary or planetary) material around that star. Ford, Haghhighipour and summer intern A. Fraeman have also been looking at the possibility that the cometary system around IRC +10216 has been gravitationally sculpted by the presence of a giant planet. Initial models suggest that a planet could exist and that a cometary system in 1:1 resonance could be stable for long periods of time (>10 Myr) but further work is required to determine how such a system could be created, and whether it would survive the later stages of stellar evolution.

Ford has begun working on the future capabilities of the Atacama Large Millimeter Array (ALMA), looking at which systems will be good targets for searches for extrasolar cometary systems. She also plans to examine whether ALMA will be capable of detecting close-in extrasolar giant planets around main-sequence stars via the transit method.

3.12 Galactic Open Clusters

The EXPLORE/OC photometric monitoring survey was designed with the goals of maximizing the chance of finding and characterizing transiting planets, and of providing for a statistically valuable astrophysical result in the case of no detections. As a consequence, the open cluster targets have to be analyzed as such with respect to their respective astrophysical parameters and Galactic environments. Von Braun et al. have started an observing program which includes *BVRJHK* photometry observations of the target clusters as well as multislit, low-resolution ($R \sim 1000-5000$) spectroscopy of random stars in the cluster fields. These observations are carried out at the Las Campanas 1m Swope, 2.5m duPont, and 6.5m Magellan Telescopes. The main purpose of the multi-color photometry is to constrain ages and metallicities from multi-color isochrone fitting, as well as calculating estimates for field star contamination which can be severe ($>80\%$) in these fields. The spectral information serves to provide independent checks on cluster membership (and thus contamination) as well as on cluster distances as determined by isochrone fitting.

3.13 Accretion Disks

Cho and S. Balbus (UVa and ENS) have initiated analysis of wave propagation in 3D, incompressible disks. Under appropriate conditions, the dynamics is governed by a linear differential equation with unusual singular properties. The governing equation is somewhat similar to the classic Bessel equation, which is well-studied and which has applications in the dynamics of 2D, incompressible disk under the so-called ‘‘shearing-sheet’’ approximation. Efforts are underway to study the 3D system analytically—especially to identify the presence resonant modes—as well as numerically to assess nonlinear mode coupling. There is a very close mathematical connection between this study and that of the WMFT interaction study for planetary flows.

3.14 Galaxy Kinematics

Rubin and former postdoctoral fellow R. Swatters (University of Maryland) used the Baade telescope at Las Campanas with the B&C spectrograph to obtain spectra in several

positions angles for 10 bulge dominated low surface brightness (LSB) galaxies. Galaxy properties define a continuum, in size, luminosity, mass, and surface brightness. Low surface brightness (LSB) galaxies have significantly extended the range in surface brightness over which galaxies can be studied, and thus have received much attention in recent studies dark matter studies. But LSB galaxies themselves span a range in size, mass, and bulge size. Few giant-sized or bulge-dominated LSB galaxies have been studied. We wish to further our understanding of galaxy formation and evolution by studying dark matter properties of LSB galaxies that are located in this almost unexplored region of galaxy properties. Additional spectra for this study have been obtained by former postdoctoral fellow D. Hunter (Lowell Observatory) using the IMACS spectrograph on the Baade telescope.

Swatters and Rubin (2003) reported on their study of the stellar and gas motions in the polar ring galaxy NGC 4650A, using the B&C spectrograph on the 6.5-m Baade telescope. They have now extended their observations of this galaxy using the same equipment, and have observed additional polar ring galaxies; NGC 5122, AM 1008, and PRGB 21. Major axis spectra centered near the Mg I triplet were obtained for each, and stellar and gas velocities have been measured. Observing times were generally 9×1800 seconds for each position angle.

In May 2003, Hunter and Rubin used the echelle spectrograph at the 4-m KPNO telescope to obtain stellar velocities and velocity dispersion in the dwarf irregular NGC 4449. The stellar velocity dispersion, coupled with rotational information, is a diagnostic of how kinematically hot a system is, and therefore is an indicator of its structure. With collaborators Swatters, S. Levine (USNO Flagstaff), and L. Sparke (U. Wisc.), they are completing modeling and determining the intrinsic shape of this galaxy. NGC 4449 is now one of the few dwarf irregulars for which the stellar velocity dispersion is known.

3.15 Dynamics and Evolution of Galaxies

Flint has continued her work on dwarf galaxies and galaxy groups in the nearby Universe. Her survey of the Leo I group with collaborators M. Bolte (UCO/Lick Observatory) and C. Mendes de Oliveira (University of São Paulo) has recently been expanded to probe the outskirts of the group. Her work on the dwarf galaxy luminosity function in Leo I has revealed a dearth of intermediate luminosity galaxies in the group core, and so the survey extension will reveal any such galaxies that might prefer the lower density edge of the group.

In a collaboration with Bolte and C. Willmer (UC Santa Cruz), Flint’s techniques are being applied to a new study of the dwarf galaxy distribution in the Eridanus cluster. The spatial distribution of the giant galaxies in Eridanus is known to have significant sub-clumping, and several of these sub-clumps appear to have an unusually high mass-to-light ratio — by some accounts the highest measured in a cluster environment. Using extensive multi-color imaging from the Las Campanas 1-m, they are surveying the lower-luminosity galaxies in the group in order to compare the dwarf distribution with that of the giants. They will study whether the dwarf

galaxies have similar inhomogeneities in their spatial distribution, or whether they are more “free-floating” as has been suggested in other dense cluster environments.

Flint also has a project underway to look at the neutral hydrogen distribution in the group. Deep Arecibo observations with Bolte and C. Impey (University of Arizona) of the H I in optically-selected Leo I dwarfs (down to $M_{HI}^{lim} \approx 10^6 M_{\odot}$) suggests a distribution unusually skewed toward gas-poor dwarf spheroidals. They are following up this work with a blind H I survey of the group core, covering an area commensurate with that of Flint’s deep optical survey in Leo I. REU summer intern M. Buckley (MIT) has constructed an integrated H I-flux map of the group from these data, reaching a low-mass limit of $M_{HI} \approx 10^7 M_{\odot}$. While they re-detect the known H I ring in the center of the group, they find the H I galaxy mass function to be unusually sparse down to their limits. This is consistent with the lack of intermediate luminosity galaxies seen, and confirms that no previously undetected, low-surface brightness gas-rich galaxies fill this gap in the luminosity function.

PUBLICATIONS

- Bedding, T. R., Kjeldsen, H., **Butler, R. P.**, McCarthy, C., Marcy, G. W., O’Toole, S. J, Tinney, C. G. & Wright, J. T. 2004, Oscillation Frequencies and Mode Lifetimes in Alpha Cen A, *ApJ*, accepted
- Aharanson, O., Zuber, M. T., & **Solomon, S. C.** 2004, Crustal Remanence in an Internally Magnetized Non-Uniform Shell: A Possible Source for Mercury’s Magnetic Field?, *E&PS Lett.*, 218, 261
- Boss, A. P.** 2003, Rapid Formation of Outer Giant Planets by Disk Instability, *ApJ*, 599, 577
- Boss, A. P.** 2003, New Worlds in the Cosmos: The Discovery of Exoplanets, *Nature*, 426, 386
- Boss, A. P.** 2004, The Solar Nebula, in *Treatise on Geochemistry, Volume 1: Meteorites, Comets, and Planets*, A. Davis, ed. (Oxford: Elsevier), 82
- Boss, A. P.** 2004, On the Fragmentation of Magnetized Cloud Cores, *MNRAS*, 350, L57
- Boss, A. P.** 2004, Convective Cooling of Protoplanetary Disks and Rapid Giant Planet Formation, *ApJ*, 610, 456
- Boss, A. P.** 2004, On the Search for Extrasolar Planets, *Daedalus*, Summer, 116
- Boss, A. P.** 2004, Companions to Young Stars, *Scientific American* (special edition), in press
- Boss, A. P.** 2004, From Molecular Clouds to Circumstellar Disks, in *Comets II*, M. C. Festou, H. U. Keller, & H. A. Weaver, eds. (Tucson: University of Arizona), in press
- Boss, A. P.** 2004, Formation of Gas and Ice Giant Planets, in *Toward Other Earths: Darwin/TPF and the Search for Extrasolar Terrestrial Planets*, R. Launhardt, ed. (Noordwijk: European Space Agency), ESA Special Publication SP-539, in press
- Boss, A. P.** 2004, Outlook: Testing Planet Formation Theories, *Space Science Reviews*, in press
- Boss, A. P.** 2004, Modes of Gaseous Planet Formation, in *Planetary Systems in the Universe: Observation, Formation and Evolution*, A. J. Penny, P. Artymowicz, A.-M. Lagrange, and S. S. Russell, eds. (San Francisco: Astronomical Society of the Pacific), in press
- Boss, A. P.** 2004, Planet Formation, *Bulletin of the American Society of Gravitational and Space Biology*, in press
- Boss, A. P.** 2004, Evolution of the Solar Nebula. VI. Mixing and Transport of Isotopic Heterogeneity, *ApJ*, in press
- Boss, A. P.** 2004, Solar System, in *McGraw-Hill Encyclopedia of Science and Technology*, Tenth Edition (New York: McGraw-Hill), in press
- Boss, A. P.**, Meech, K. & Thorsteinsson, T. 2004, Bioastronomy 2004—Habitable Worlds, *Astrobiology*, 4, 233
- Butler, R. P.**, Marcy, G. W., Vogt, S. S., Fischer, D. A., Henry, G. W., Laughlin, G. & Wright, J. T. 2003, Seven New Keck Planets Orbiting G & K Dwarfs, *ApJ*, 582, 455
- Butler, R. P.**, Bedding, T. R. Kjeldsen, H., McCarthy, C., O’Toole, S. J., Tinney, C. G., Marcy, G. W. & Wright, J. T. 2004, Ultra-High-Precision Velocity Measurements of Oscillations in Alpha Cen A, *ApJ Letters*, 600, L75
- Carter, B. D., **Butler, R. P.**, Tinney, C. G., Jones, H. R. A., Marcy, G. W., McCarthy, C., Fischer, D. A., Penny, A. J. 2003, A Planet in a Circular Orbit with a 6 Year Period, *ApJ Letters*, 593, L43
- Chambers, J. E.** 2004, The Planet V hypothesis: The Stability of a Planet Between Mars and the Asteroid Belt, *Icarus*, submitted.
- Chambers, J. E.** 2004, Terrestrial Planet Formation, in *The Search for Other Worlds*, S. S. Holt and D. Deming eds. (New York: AIP), AIP Conference Proceedings, 713, 203
- Chambers, J. E.** 2004, Planetary accretion in the inner Solar System, *E&PS Lett.*, 223, 241
- Chambers, J. E.** 2004, Planet Formation, in *Treatise on Geochemistry, Volume 1: Meteorites, Comets, and Planets*, A. Davis, ed. (Oxford: Elsevier), 461
- Chambers, J. E.** 2003, Symplectic Integrators with Complex Time Steps, *AJ*, 126, 1119
- Cho, J. Y.-K.** & Stewart, S. 2004, Dispersion of Impact-Generated Aerosols in the Martian Middle Atmosphere, submitted to *Geophys. Rev. Lett.*
- Clayton, D. D. & **Nittler, L. R.** 2004, Astrophysics with Presolar Stardust, *Annual Review of Astronomy and Astrophysics*, 42, 39
- Clayton, D. D. & **Nittler, L. R.** 2004, Presolar Stardust Grains, in *Carnegie Observatories Astrophysics Series, Vol. 4: Origin and Evolution of the Elements*, A. McWilliam and M. Rauch, eds. (Cambridge: Cambridge University Press), in press
- Cody G. D., **Alexander C. M. O’D.** & Tera F. 2002, Solid State (¹H and ¹³C) NMR Spectroscopy of the Insoluble Organic Residue in the Murchison Meteorite: A Self-Consistent Quantitative Analysis, *Geochim. Cosmochim. Acta* 66, 1851
- Cody G. D. & **Alexander C. M. O’D.** 2004, NMR Studies of Chemical Structural Variation of Insoluble Organic Matter from Different Carbonaceous Chondrite Groups, *Geochim. Cosmochim. Acta*, in press
- Crossley, J. H. & **Haghighipour, N.** 2004, On the Stability of a Planetary System Embedded in the Beta Pictoris Debris Disk, in *The Search for Other Worlds*, S. S. Holt and

- D. Deming eds. (New York: AIP), AIP Conference Proceedings, 713, 265
- Danchi, W. C., Deming, D., Kuchner, M. J. & **Seager, S.** 2003, Detection of Close-In Extrasolar Giant Planets Using the Fourier-Kelvin Stellar Interferometer, *ApJL*, 597, L57
- Dyudina, U. A., Sackett, P. D., Bayliss, D. R., **Seager, S.**, Porco, C. C., Throop, H. B. & Dones, L. 2004, Phase Light Curves for Extrasolar Jupiters and Saturns, *ApJ*, in press
- Fischer, D. A., **Butler, R. P.**, Marcy, G. W., Vogt, S. S. & Henry, G. W. 2003, A Sub-Saturn Mass Planet Orbiting HD 3651, *ApJ*, 590, 1081
- Fischer, D. A., Marcy, **Butler, R. P.**, G. W., Vogt, S. S., Henry, G. W., Pourbaix, D., Walp, B., Misch, A. A. & Wright, J. T. 2003, A Planetary Companion to HD 40979 and Additional Planets Orbiting HD 12661 and HD 38529, *ApJ*, 586, 1394
- Ford, K. E. S.**, Neufeld, D. A., Schilke, P. & Melnick, G. J. 2004 Detection of Formaldehyde Toward the Extreme Carbon Star IRC +10216 *ApJ*, in press
- Gold, R. E., McNutt, Jr., R. L., **Solomon, S. C.**, & the MESSENGER Team 2003, The MESSENGER Science Payload, in Proc. 5th Amer. Inst. Aeronaut. Astronaut. Inter. Conf. on Low-Cost Planetary Missions, (Noordwijk: European Space Agency), ESA Special Publication SP-542, 399
- Green, D., Matthews, J., **Seager, S.** & Kuschnig, R. 2003, Scattered Light from Close-in Extrasolar Planets: Prospects of Detection with the MOST Satellite, *ApJ*, 597, 590
- Haghighipour, N.** 2004, Growth and Sedimentation of Dust Particles in the Vicinity of Local Pressure Enhancements in a Solar Nebula, *Icarus*, submitted
- Haghighipour, N.** 2004, The Effect of Density Enhancement Structure of a Nebula on the Formation of Terrestrial Planets and Water-Delivery Mechanism, *International Journal of Astrobiology*, Supp, 1, 72
- Haghighipour, N.** 2004, Growth of Dust Particles and Accumulation of Centimeter-Sized Objects in the Vicinity of a Pressure-Enhanced Region of a Solar Nebula, *Publications of the 35th Lunar and Planetary Science Conference*, 2001
- Haghighipour, N.** 2004, On the Growth of Dust Particles in a Non-Uniform Solar Nebula in The Search for Other Worlds, S. S. Holt and D. Deming eds. (New York: AIP), AIP Conference Proceedings, 713, 119
- Haghighipour, N.** 2004, On the Dynamical Stability of Gamma Cephei, A S-Type Binary-Planetary System in The Search for Other Worlds, S. S. Holt and D. Deming eds. (New York: AIP), AIP Conference Proceedings, 713, 269
- Haghighipour, N. & Boss, A. P.** 2003 On Pressure Gradient and Rapid Migration of Solids in a Non-Uniform Solar Nebula *ApJ*, 583, 996
- Haghighipour, N. & Boss, A. P.** 2003, On Gas-Drag Induced Rapid Migration of Solids in a Non-Uniform Solar Nebula, *ApJ*, 598, 1301
- Haghighipour, N. & Boss, A. P.** 2003 Gas-Drag Induced Migration of Solids in the Vicinity of a Density Enhancement in a Non-Uniform Solar Nebula *Publications of the 34th Lunar and Planetary Science Conference*, 1971
- Haghighipour, N., & Boss, A. P.** 2004, Dynamics of Small Solids in a Gravitationally Unstable Disk: Implications for Collisional Coagulation, in *Astrophysics of Life*, M. Livio, I. N. Reid, & W. B. Sparks, eds. (Baltimore: Space Telescope Science Institute), 10
- Haghighipour, N.**, Couetdic, J., Varadi, F. & Moore, W. B. 2003, On Stable 1:2 Resonant Periodic Orbits in Elliptic Three-Body Systems *ApJ*, 596, 1332
- Hauck, II, S. A., Dombard, A. J., Phillips, R. J. & **Solomon, S. C.** 2004, Internal and Tectonic Evolution of Mercury, *E&PS Lett.*, 222, 713-728
- Jones, H. R. A., **Butler, R. P.**, Tinney, C. G., Marcy, G. W., Penny, A. J., McCarthy, C. & Carter, B. D. 2003, An Exoplanet in Orbit Around Tau1 Gruis, *MNRAS*, 341, 948
- Kjeldsen, H., Bedding, T. R., Baldry, I. K., Bruntt, H., **Butler, R. P.**, Fischer, D. A., Frandsen, S., Gates, E. L., Grundahl, F., Lang, K., Marcy, G. W., Misch, A. A. & Vogt, S. S. 2003, Confirmation of Solar-like Oscillations in eta Bootis, *AJ*, 126, 1483
- Korth, H., Anderson, B. J., McNutt, Jr., R. L., Acua, M. H., Slavin, J. A., Tsyganenko, N. A., & **Solomon, S. C.** 2004, Determination of the Properties of Mercury's Magnetic Field by the MESSENGER Mission, *Planet. Space Sci.*, 52, 733
- Lee, B. L., **von Braun, K.**, Mallén-Ornelas, G., Yee, H. K. C., **Seager, S.** & Gladders, M. D. 2004, EXPLORE/OC: A Search for Planetary Transits in the Field of the Southern Open Cluster NGC 6208, in *The Search for Other Worlds*, S. S. Holt and D. Deming eds. (New York: AIP), AIP Conference Proceedings, 713, 177
- Liang, M., Parkinson, C. D., Lee, A. Y.-T., Yung, Y. L. & **Seager, S.** 2003, Source of Atomic Hydrogen in the Atmosphere of HD 209458b, *ApJL*, 596, L247
- Liang, M., **Seager, S.**, Parkinson, C. D., Lee, A. Y.-T. & Yung, Y. L. 2003, On the Insignificance of Photochemical Hydrocarbon Aerosols in the Atmospheres of Close-in Extrasolar Giant Planets, *ApJL*, 605, L61
- Lunine, J. I., **Chambers, J. E.**, Morbidelli, A., Leshin, L. A. 2003, The Origin of Water on Mars, *Icarus*, 165, 1
- McCarthy, C., **Butler, R. P.**, Tinney, C. G., Jones, H. R. A., Marcy, G. W., Carter, B. D., Penney, A. J. & Fischer, D. A. 2004, Multiple Companions to HD 154857 & HD 160691, *ApJ*, accepted
- McNutt, R. L., Jr., **Solomon, S. C.**, Grard, R., Novara, M. & Mukai, T. 2004, An International Program for Mercury Exploration: Synergy of MESSENGER and BepiColombo, *Adv. Space Res.*, 33, 2126
- Nittler, L. R.** 2005, Constraints on Heterogeneous Galactic Chemical Evolution from Meteoritic Stardust, *ApJ*, in press
- Nittler, L. R.** 2004, Nuclear Fossils in Stardust, *Science*, 303, 636
- Nittler, L. R.** and **Alexander, C. M. O'D.** 2003, Automated Isotopic Measurements of Micron-Sized Dust: Applica-

- tion to Meteoritic Presolar Silicon Carbide, *Geochimica Cosmochimica Acta*, 67, 4961
- Nittler, L. R.** and Dauphas, N. 2005, Meteorites and the Chemical Evolution of the Milky Way, in *Meteorites and the Early Solar System II*, Lauretta, D. S., Leshin, L. A. and McSween, H. Y., Jr., eds. (Tucson: Univ. of Arizona Press), submitted
- Nittler, L. R.**, Gallino, R., Lugaro, M., Straniero, O., Domínguez, I., and Zinner, E. 2005, Si and C Isotopes, in *Presolar Silicon Carbide Grains From AGB Stars, Nuclei in the Cosmos 8 Conference Proceedings*, submitted.
- Richardson, L. J., Deming, D. & **Seager, S** 2003, Infrared Observations during the Secondary Eclipse of HD 209458b. II. Strong Limits on the Infrared Spectrum Near $2.2 \mu\text{m}$, *ApJ*, 597, 581
- Rivera, E. J. & Haghighipour, N.** 2004, On the Stability of Test Particles in Extrasolar Multiple Planet Systems, *ApJ*, submitted
- Rivera, E. J. & Haghighipour, N.** 2004, Stability of Test Particles in Extrasolar Planetary Systems *International Journal of Astrobiology, Supp.*, 1, 33
- Rubin, V. C.** 2003, A Brief History of Dark Matter, in *The Dark Universe*, ed. M. Livio (Cambridge: Cambridge University Press), 1.
- Seager, S.** 2004, Characterizing Extrasolar Earths, in *The Search for Other Worlds*, S. S. Holt and D. Deming eds. (New York: AIP), AIP Conference Proceedings, 713, 213
- Seager, S. & Ford, E. B.** 2004, The Vegetation Red Edge Spectroscopic Feature as a Surface Biomarker, in *Astrophysics of Life*, M. Livio, I. N. Reid, & W. B. Sparks, eds. (Baltimore: Space Telescope Science Institute)
- Seager, S. & Hui, L.** 2004, What Photometric Space Telescopes Can Tell Us About Extrasolar Giant Planets, A. J. Penny, P. Artymowicz, A.-M. Lagrange, and S. S. Russell, eds. (San Francisco: Astronomical Society of the Pacific), in press
- Seager, S.**, Turner, E.L., Schafer, J. & Ford, E. B. 2004, Vegetation's Red Edge: A Possible Biomarker of Extraterrestrial Planets, submitted to *Astrobiology*
- Semenenko, V. P., Girich, A. L. and **Nittler, L. R.** 2004, An Exotic Kind of Cosmic Material: Graphite-Containing Xenoliths from the Krymka (LL3.1) Chondrite, *Geochimica Cosmochimica Acta*, 68, 455
- Solomon, S. C.** 2003, Mercury: The Enigmatic Innermost Planet, *E&PS Lett.*, 216, 441-455
- Stroud, R. M., **Nittler, L. R.** & **Alexander, C. M. O'D.** 2004, Polymorphism in Presolar Al_2O_3 Grains from Asymptotic Giant Branch Stars, *Science*, 5689, 1455
- Tinney, C. G., **Butler, R. P.**, Marcy, G. W., Jones, H. R. A., Penny, A. J., McCarthy, C., Carter, B. D. & Bond, J. 2003, Four New Planets Orbiting Metal-Enriched Stars, *ApJ*, 587, 423
- von Braun, K.**, Lee, B. L., Mallén-Ornelas, G., Yee, H. K. C., **Seager, S.** & Gladders, M. D. 2004, EXPLORE/OC: A Search for Planetary Transits in the Field of the Southern Open Cluster NGC 2660, in *The Search for Other Worlds*, S. S. Holt and D. Deming eds. (New York: AIP), AIP Conference Proceedings, 713, 181
- Weinberger A. J.** 2004, Observations of Dusty Disks, in *The Search for Other Worlds*, S. S. Holt and D. Deming eds. (New York: AIP), AIP Conference Proceedings, 713, 83
- Weinberger A. J.**, Becklin E. E., Zuckerman B. & Song I. 2004, A Search for Warm Circumstellar Disks in the TW Hydrae Association, *AJ*, 127, 2246
- Kaisler D., Zuckerman B., Song I., Macintosh B. A., **Weinberger A. J.**, Becklin E. E., Konopacky Q. M. & Patience J. 2004, HD 199143 and HD 358623: Two Recently Identified Members of the β Pictoris Moving Group, *A&A*, 414, 175
- Wright, J. T., Marcy, G. W., **Butler, R. P.**, & Vogt, S. S. 2004, Chromospheric CaII Emission in Nearby F, G, K, and M Stars, *ApJS*, in press