ANNUAL PROGRESS REPORT: JOINT RESEARCH INTERCHANGE

TITLE:	**Dust Properties in Comets and Protoplanetary Disks**
Type of Report:	Final Report
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Participating Collaborator:	Dr. David E. Harker
Period Covered by report:	10/01/2002 – 04/30/2004
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Cooperative Agreement #:	**NCC 2-5520**

1. JRI Work Efforts and Accomplishments

Our fundamental science goal is to characterize the connections between grain (siliceous and carbonaceous) mineralogy and the origins and evolution of disks and protoplanetesimals. To achieve this goal, we proposed a cooperative agreement which was divided into two separate yet complementary work efforts: 1) the study of solar system comets and 2) the study of dusty protoplanetary disks. In this final report we look at the goals achieved in each of these efforts and compare them with our initial stated goals. We also highlight our scientific findings accomplished under this JRI work effort.

1.1 Solar System Comets

Eight work efforts were identified in the original proposal relating to the study of solar system comets. We will identify them here and address our progress.

1) "Participate in writing observing proposals."

We have jointly submitted 7 observing proposals to observatories such as the Keck 10m telescope, the NOAO Gemini-North and Gemini-South 8m telescope, the NASA Infrared Telescope Facility (IRTF) and the European Space Agency (ESA) Very Large Telescope (VLT). To date we have been awarded time on Gemini-South and the IRTF. The IRTF observations occurred on November 10 – 12, 2003. Unfortunately, we lost our Gemini-South time because of instrument problems which were out of our control (many other observers also lost their time). We anticipate further observations on Gemini in the coming year when instrument problems are resolved. Two other proposals were written to the IRTF for HIFOGS time and MIRSI time which were awarded two nights each. These four observing runs will occur in late Spring and Summer of 2004. We also submitted proposals to use the *Spitzer* space telescopes to observe comets. Both were awarded time (PID 2136 and PID 3152).

2) "Participate in HIFOGS mid-IR spectroscopy of comets 2P/Encke in November 2003 and C/2001 Q4 (Neat) in May-July 2004"

Encke was observed using MIRSI (instead of HIFOGS which had been damaged during shipment) in November 2003. The data has been reduced and shows that Encke did not have an emission feature arising from small grains. The results are still in the preliminary stage to be written up for publication.

Time was awarded to observe Q4 Neat at the IRTF, but those observations occurred outside of the period covered by this JRI.

3) "Produce radiative equilibrium models of spectral energy distributions (SEDs)..."
4) "Constrain dust parameters by least-squares-fitting of models..."

Models have been produced to match the measured HIFOGS spectrum of comet 19P/Borrelly, although the results are still preliminary. Other models to match future observations will be addressed in future progress reports. These same models are being used to model the emission of Encke, and is still a work in progress.

5) "Present results at domestic and international meetings."

During the time period covered by the report, we have presented results at the annual Winter Meeting of the American Astronomical Society in Seattle (January 2003) and at the IAU meeting in Australia.

6) "Publish results in the refereed literature."

Results are still preliminary on the model fit to comets Borrelly, and Encke and future papers are awaiting forthcoming observations and analysis.

7) "Participate in preparation of proposals to NASA ROSS Research Announcements."

Three proposals directly related to comet work were submitted to the NASA ROSS; specifically, two to the Planetary Geology and Geophysics (Harker PI, Wooden CoI) and one to Planetary Astronomy (Wooden PI, Harker CoI). The first year PGG proposal was not funded, but the PAST proposal was awarded funding.

8) "Write proposals to the NSF Division of Astronomical Sciences."

A proposal related to comet work was submitted to the NSF was funded with Harker as CoI.

1.2 Dusty Protoplanetary Disks

Twelve work efforts were identified in the original proposal relating to the study of dusty protoplanetary disks (DPDs). We identify them here and address our progress.

1) "Participate in writing observing proposals."

We have jointly submitted 7 observing proposals to observatories such as the Keck 10m telescope, the NOAO Gemini-North and Gemini-South 8m telescope, the NASA Infrared Telescope Facility (IRTF) and the European Space Agency (ESA) Very Large Telescope (VLT). To date we have been awarded time on the IRTF to look at DPDs (as well as comets; see 1.1). The IRTF time was scheduled for November 10 – 12, 2003 and we obtained data using MIRSI.

2) "Participate in writing General Observer proposals to *Spitzer*"

GO proposals to observe with *Spitzer* were written (and awarded) to observe comets.

3) "Participate in HIFOGS mid-IR spectroscopy of Herbig Ae stars and T Tauri stars."

Successful HIFOGS observations of DPDs were conducted in November 2002 by both Wooden and Harker. We performed successful observations looking at DPDs and comets in November 2003.

4) "Produce mineralogically-enhanced Chiang and Goldreich radiative equilibrium disk models...to fit to SEDs..."

5) " Provide the least-square-fitting model parameters to model SEDs"

We have successfully modeled three Herbig Ae/Be stars using the mineralogically-enhanced model of Chiang and Goldreich. We continue to improve the modeling code and apply it to other data sets, including those from ISO and HIFOGS. This model will eventually be used to model *Spitzer* data. Details of our findings from the current modeling efforts are addressed in the next section.

6) "Produce wavelength-dependent opacities of relevant mineral species and grain sizes for incorporation into Bell's...models."

7) "Compare IDL version of Chiang and Goldreich model with Bell's models."

Opacities have been created and given to Dr. Bell for incorporation into her model. In October 2003, Harker, Wooden and Bell will have a week long meeting at which point comparisons of Bell's and Harker's models will be made and Bell will instruct Harker and Wooden on the use of her model to create SEDs for comparison with data sets.

8) "Investigate...degeneracy...between [model parameters]."

This is an ongoing process as we continue to use the model to create SEDs. While we have found a weak degeneracy between disk scale height and disk radius, we can still fit our data uniquely by varying these two parameters (see section 2).

9) "Present results at domestic and international meetings."

During the time period covered by the report, we have presented results at the annual Winter Meeting of the American Astronomical Society in Seattle (January 2003) and at the IAU meeting in Australia.

10) "Publish results in the refereed literature."

Results based on our fitting of three Herbig Ae/Be stars has been accepted by the Astrophysical Journal after some minor corrections.

11) "Participate in preparation of proposals to NASA ROSS Research Announcements."

One proposal directly related to DPDs was submitted to the NASA ROSS; specifically the Astrophysics Data Program (Harker PI). This proposal was not funded.

12) "Write proposals to the NSF Division of Astronomical Sciences."

A proposal related to DPDs was submitted to the NSF, however it was not funded.

2. Scientific Findings

1) Solar System Comets:

Currently, our most notable findings concern the dust emission from comets 19/P Borrelly and 2P/Encke. Both comets produce a featureless 10 micron emission feature, implying a lack of small silicate dust grains. With the lack of a silicate feature, this makes modeling the emission from Borrelly and Encke difficult but not impossible. We are being careful to explore the degeneracies between parameters to make the best conclusions possible about the featureless dust grains. Currently our finding indicate that the dust from both comets is dominated by large porous dust grains.

2) Dusty Protoplanetary Disks:

I have used the passive disk model first developed by Chiang & Goldreich (1997, ApJ, 490, 368) to compute the SEDs for three HAeBe stars. Using their model as a starting point, I have expanded it to include the emission from other minerals, especially crystalline silicates. Of the objects I modeled, two show clear evidence of crystalline silicates (HD 100546 and HD179218), the third is dominated by amorphous silicates (HD 150193). For the two objects with crystalline silicates, we find that the best fit to the observed SEDs is produced if we use a model in which a higher ratio of crystalline to amorphous silicates is located in the inner regions of the disk (< 5 AU) compared to the outer regions of the disk (5 - 150 AU). The inner region of HD 100546 has 30% more crystalline silicates compared to the outer region. This is contrary to the findings of Bouwman et al. (2001, A&A, 375, 950) who used a spherical shell model to calculate a factor of almost 10 higher fraction of crystalline silicates in regions greater than 10 AU. The inner region of HD 179218 has 76\% more crystalline silicates compared to the outer region. Other key findings include:

- The disk of HD150193 is much smaller (5AU) than the disks of HD 100546 and HD 179218 (150 AU).
- HD 100546 has a disk that flares at a rate of about 80\% more than the disk around HD179218 and 25\% more than HD 150193.

- All three objects are best fit using the same grain size distribution, $a^{-3.5}$. By mass, HD 100546 has the largest amount of crystalline silicates (30\% in the region < 5~AU and 21\% in the outer region 5 -- 50 AU) followed by HD179218 (33\% in the inner region and 8\% in the outer region) and finally HD150193 (no crystalline silicates).

This work has been accepted for publication in the ApJ following minor revisions.

Overall we are very pleased with the work produced under this JRI, and we look forward to continuing this collaborative effort to maximize our scientific results and disseminating them into the community as efficiently and as quickly as possible.

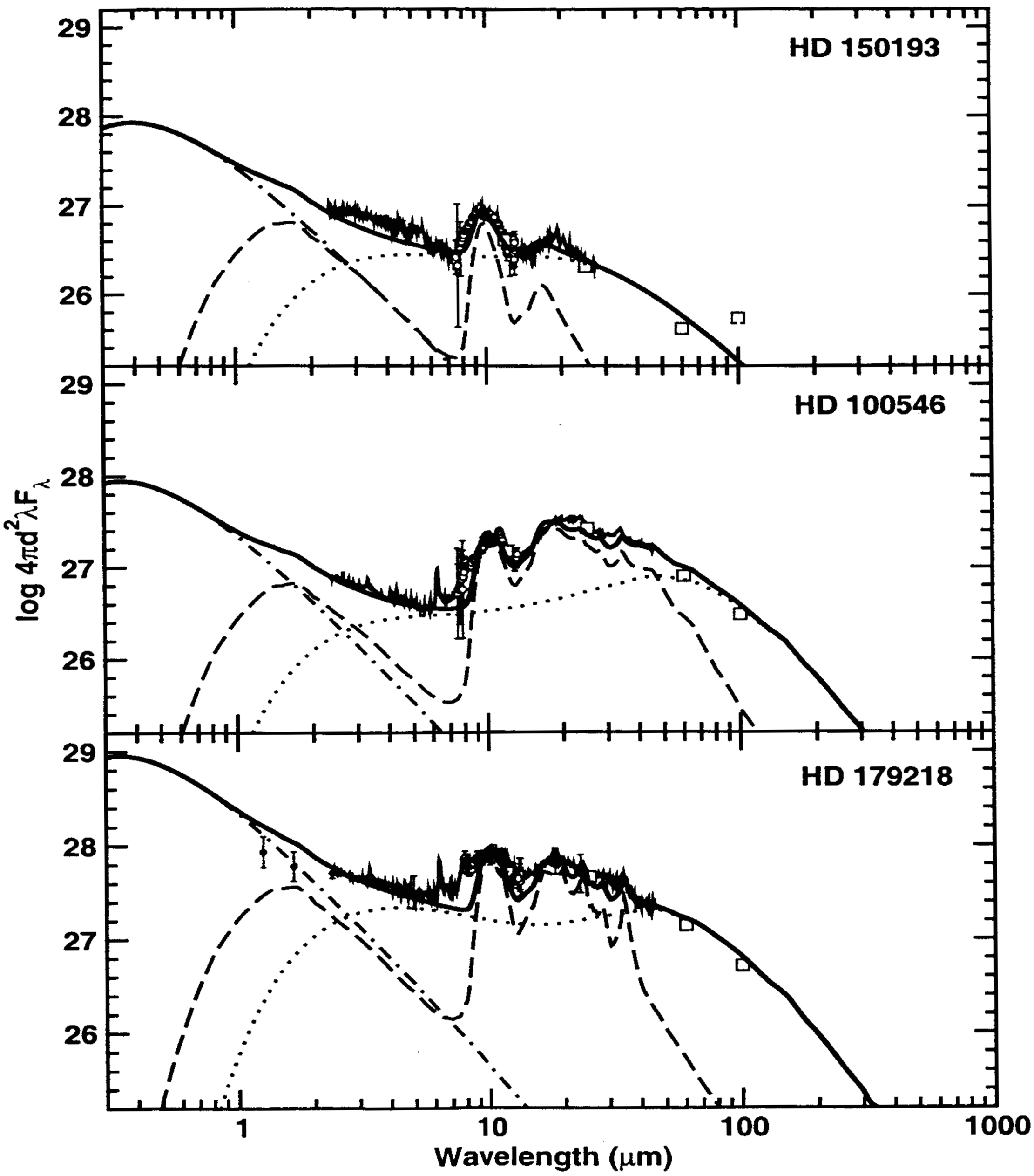

Fig. 1 - C01 model computed for three Herbig Ae stars: HD 150193, HD 100546 and HD179218. The disk interior (dotted line), disk surface (dashed line), and stellar blackbody (dot-dash line) are co-added to produce the model SED (black line). The model SED is compared to the assembled data sets including: ISO SWS spectra (jagged black line), HIFOGS spectra (open circles) and IRAS photometry points (gray squares). HD 179218 also has Mt Lemmon Observing Facility photometry points (closed circles).