A semi-annual report for

STUDIES OF EXTRA-SOLAR OORT CLOUDS AND THE KUIPER DISK

NASA Grant No.: NAGW-3023

SwRI Project No.: 15-4971

Submitted by:

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March 20, 1993

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Introduction

This is the second report for NAGW-3023 (SwRI Project 15-4971), *Studies of Extra-Solar Oort Clouds and the Kuiper Disk.*

We are conducting research designed to enhance our understanding of the evolution and detectability of comet clouds and disks. This area holds promise for also improving our understanding of outer solar system formation, the bombardment history of the planets, the transport of volatiles and organics from the outer solar system to the inner planets, and to the ultimate fate of comet clouds around the Sun and other stars. According to "standard" theory, both the Kuiper Disk and Oort Cloud are (at least in part) natural products of the planetary accumulation stage of solar system formation. One expects such assemblages to be a common attribute of other solar systems. Therefore, searches for comet disks and clouds orbiting other stars offer a new method for infering the presence of planetary systems.

Our three-year effort consists of two major efforts: (1) observational work to predict and search for the signatures of Oort Clouds and comet disks around other stars; and (2) modelling studies of the formation and evolution of the Kuiper Disk (KD) and similar assemblages that may reside around other stars, including β Pic. These efforts are referred to as Task 1 and 2, respectively. Task 2 is to be carried out as an integral part of Dr. Glen Stewart's proposed origins program.

Recent Results

Task 1: We have undertaken runs at the JCMT and IRAM to study submm telescopes to study one of the best IRAS IR-excess comet cloud candidates, α PsA (Fomalhaut). These runs have resulted in an exciting detection which we summarize as follows:

- S.A. Stern (Southwest Research Institute, San Antonio), M.C. Festou (CNRS, Toulouse), and D.A. Weintraub (Vanderbilt University, Nashville) report mapping observations of 20-21 February 1993 reveal 1.3mm continuum emission in a broad, disk-like region around the nearby, main sequence star α PsA (Fomalhaut A3V; D=6.7pc). The observations supporting this discovery were made using the 7-channel MPIfR bolometer of the IRAM 30-m telescope on Pico Veleto, Spain, with a HPBW at 1.3mm of 12". The emission geometry appears to be a tilted disk with the PA of the major axis near 100 deg and an aspect ratio of 2:1; the major axis emission exceeds 20 mJy at the 450-500 AU contour (1 arcmin from a PsA). Additional emission may be present at larger distances. The peak 1.3mm emission detected is 50 mJy, centered on the line of sight to the star. The emission is ascribed to an assemblage of cold, orbiting dust grains around α PsA. Although IRAS revealed that Fomalhaut is an IR excess source, these observations constitute the first detection of this extended, disk-like emission. Thus, after β Pic (also A3V), α PsA is the second detected disk around a main sequence star, and the first disk around a main sequence star to be mapped in thermal emission. Fomalhaut's 2.5 times closer distance to Earth make it an ideal object for intensive study.

This result was initially published in IAU Cicular 5732, and is now being prepared for a refereed journal. Topmost among our analysis tasks is to derive a mass estimate for the disk. Observing proposals to extend this work to other stars, and to make a second-generation study of Fomalhaut have been submitted to CSO, JCMT, and ESO/SEST submm observatories during this quarter. The Time Allocation Committees (TACs) for JCMT and SEST have not yet met to evaluate proposals. CSO approved our request with a bolometer run scheduled for 13-15 April 1993.

Task 2: We performed scaling calculations to determine the importance of (i) perturbations by passing stars and GMCs on objects in the Kuiper Disk, and (ii) the role of protoplanetary gas drag in providing a lower size cutoff in the inital KD population, and (iii) the likelihood that large ($\sim 10^3$ km) objects populate the KD. This work found that (i) stellar and GMC perturbations are unlikely to be important for objects inside a few hundred AU; (ii) owing to drag during protoplanetary scattering events, objects smaller than $\sim$ 100 m should be strongly depleted in the initial OC/KD size distribution; and (iii) numerous 1000-km bodies may have been present during the accretion of Uranus and Neptune and may now reside in the KD and OC. The later two results are directly related to the initial size spectrum of objects which must be included in our dynamical/collisional model. We have also begun the development with Glen Stewart of the dynamical/collisional model needed to make progress on the KD studies. At present, 25% of the required model code is in place. The first publication resulting from the Stern/Stewart collaboration is now taking place. This work (Stern & Stewart 1993) reports the results of initial collisional calculations constraining the population structure of the Kuiper Disk, and making predictions concerning the far-IR signature of the Kuiper Disk. We expect to submit this publication later this year. The work will also be reported as a contributed talk at the ACM V meeting in June 1993. A popular paper (Stern 1992) has been published in *Astronomy* magazine describing the Stern (1991) paper which resulted from work on this project performed prior to funding. An invited talk summarizing this work has been scheduled for April 27, 1993 at Princeton.

Attachments:

Contour Map of the Fomalhaut Disk Detected at 1.3mm (Stern, et al. 1993)
Followup Observing Proposals to JCMT and SEST
ACM V Meeting Abstract

References

Submm-Studies of Thermal Emission from a Large Dust Cloud Around the IR-Excess Star Fomalhaut. S.A. Stern, M.C. Festou, and D.A. Weintraub, *Science*, in preparation, 1993.

On the Number of Planets in the Solar System: Evidence of a Substantial Population of 1000-km Bodies. S.A. Stern, *Icarus*, **91**, 271, 1991.

Where has Pluto's Family Gone? (popular article). S.A. Stern, *Astronomy Magazine.*, September, 1992.

Collisions in the Kuiper Disk. S.A. Stern and G.R. Stewart, *Icarus*, in preparation 1993.

Technical Presentations

Triton, Pluto, and Charon as Relics of a Large, Ancient Planetary Ice Dwarf Population. S.A. Stern, Spring AGU Talk, May, 1992.

Why Nine? On the Number of Planets in the Solar System. Astrophysics Seminar, University of California at San Diego and CalSpace, May, 1992.

The Kuiper Disk and the Origin of the Pluto-Charon System. Astrophysics Seminar, Princeton University, Princeton, NJ, April, 1993.

ATTACHMENT 1

Contour Map of the Fomalhaut Disk at 1.33mm
(Stern, et al. 1993)

Circular No. 5732

Central Bureau for Astronomical Telegrams
INTERNATIONAL ASTRONOMICAL UNION

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α PISCIS AUSTRINI

S. A. Stern, Southwest Research Institute, San Antonio; M. C. Festou, Observatoire Midi-Pyrenées, Toulouse; and D. A. Weintraub, Vanderbilt University, Nashville, report: "Mapping observations on Feb. 20-21 revealed 1.3-mm continuum emission in a broad, disk-like region around the nearby, main-sequence star α PsA (Fomalhaut, A3V; distance 6.7 pc). The observations supporting this discovery were made using the 7-channel MPIfR bolometer of the IRAM 30-m telescope on Pico Vileta, with a half-power bandwidth at 1.3 mm of 12''. The emission geometry appears to be a tilted disk with the position angle of the major axis near 100° and an aspect ratio of 2:1; the major-axis emission exceeds 20 mJy at the 450-500-AU contour ($\sim$ 1' from the star). Additional emission may be present at larger distances. The peak 1.3-mm emission detected is 50 mJy, centered on the line of sight to the star. The emission is ascribed to an assemblage of cold. orbiting dust grains around the star. Although IRAS revealed that Fomalhaut is an infrared-excess source, these observations constitute the first detection of this extended, disk-like emission. Thus, after β Pic (also A3V), this is the second main-sequence star to have a detected disk, and the disk is the first one around a main-sequence star to be mapped in thermal emission. The fact that α PsA is 2.5 times closer to the earth than β Pic is makes it an ideal object for intensive study."

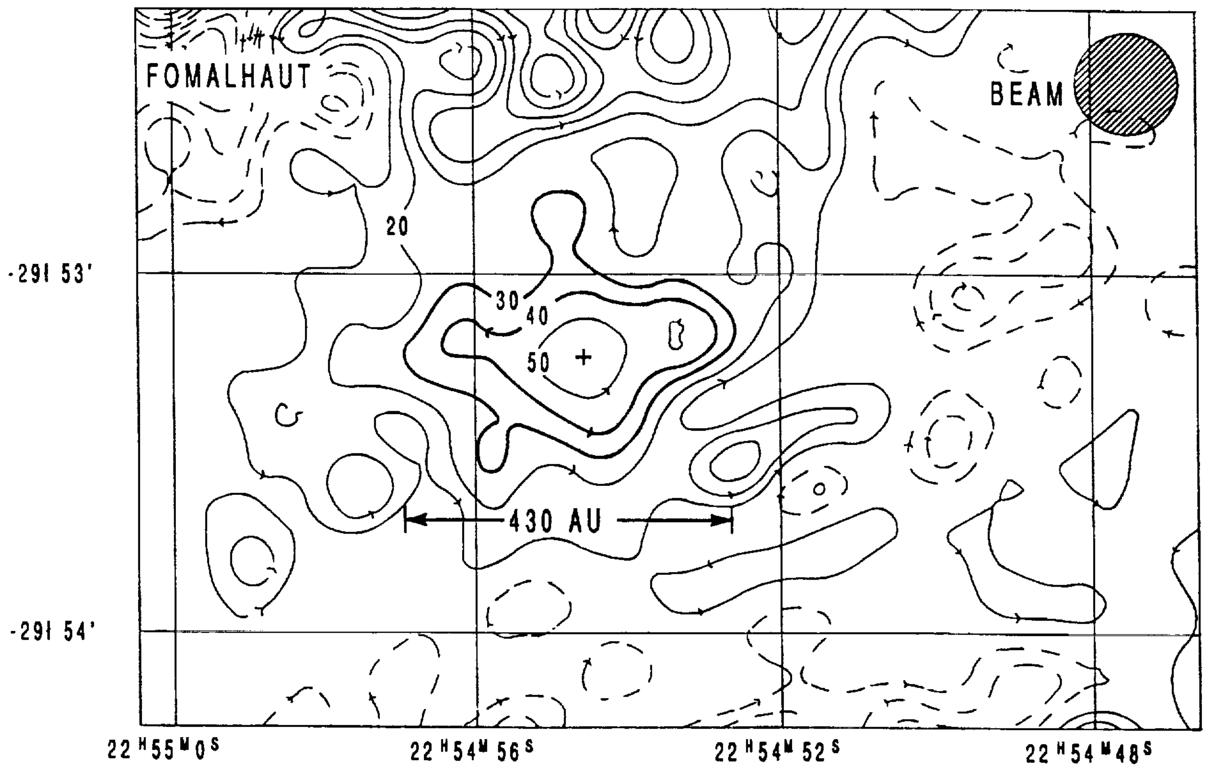
SU TAURI

This R-CrB variable is fading, as indicated by the following visual magnitude estimates, communicated mainly by B. H. Granslo, Fjellhamar, Norway: Mar. 20.51 UT, 10.0 (M. Iida, Nagano, Japan); 23.42, 10.2 (M. Yamada, Ishikawa, Japan); 25.84, 10.4 (Granslo); 26.47, 10.5 (Yamada); 27.44, 10.8 (Yamada); 28.85, 11.3 (Granslo); 29.82, 11.6 (Granslo).

COMET SHOEMAKER-LEVY (1993e)

A. Cochran, University of Texas, reports that she obtained spectra (range 300-570 nm) of this comet with the large cassegrain spectrograph on the McDonald Observatory's 2.7-m telescope on Mar. 28. The long slit was placed along the major axis of the object. A preliminary look at the raw data shows no obvious emissions. The comet was approximately uniformly bright over the inner 30''. There was an approximately uniform section of lower intensity to a total length of 1'. A weak condensation was visible near the western end.

1993 March 30 *Brian G. Marsden*



FOMALHAUT
BEAM
20
30
40
50
430 AU
-29I 53'
-29I 54'
22 H 55 M 0 S
22 H 54 M 56 S
22 H 54 M 52 S
22 H 54 M 48 S

ATTACHMENT 2

Followup Observing Proposals to JCMT and SEST

SCIENCE AND ENGINEERING RESEARCH COUNCIL

serc

POLARIS HOUSE, NORTH STAR AVENUE, SWINDON SN2 1ET

Telephone 0793 411000 Telex 449466 Fax 0793 411348

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APPLICATION FOR TELESCOPE TIME

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REF:-

SEMESTER Y (AUG. 1993 - FEB. 1994)

2 i) Principal applicant:

Surname Stern Title Dr. Initials Alan Possible observer ~~Y/N~~ Yes

Institution .... Department .... Post ....

ii) Principal observer (if different) same Y/N

iii) Collaborators (state institution)

D.A. Leahy/University of Calgary ~~Y/N~~ yes

D.A. Weintraub/Vanderbilt University ~~Y/N~~ yes

Y/N

iv) Principal contact: Dr. Alan Stern Telephone & Ext. (210) 522-5127

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Telex

E. Mail SPAN SWRI::ALAN

3 TITLE OF INVESTIGATION (12 WORDS MAXIMUM) Mini-survey for Cold Dust at Oort Cloud Distances Around Main Sequence IRAS IR Excess Stars

4 SCIENTIFIC CATEGORY ☐ Solar System ☒ Stellar ☐ Galactic & Interstellar ☐ Extragalactic & Cosmology ☐ Other

5 LONG TERM STATUS: ~~Y/N~~ No

If yes total number of useful nights/weeks needed to complete programme

HIGH FREQUENCY: ~~Y/N~~ No

6 ABSTRACT OF PROPOSED OBSERVATIONS

In October 1991 and February 1993 we used the JCMT UKT14 and IRAM 7mm bolometer (respectively) to study extended, submm/mm emission the nearby IRAS IR excess star Fomalhaut. Our data reveal a disk at least 500 AU across around Fomalhaut (α PsA). We propose to extend these observations with UKT14 by (i) exploring the "far-field" extent of Fomalhaut's extended emission and (ii) making observations of 6 additional nearby IRAS IR excess sources. The proposed observations attack the root objective of our NASA Origins of Solar Systems project to search for evidence of cometary Oort Clouds around main sequence stars.

7 ABSTRACT OF BACK UP PROGRAMME FOR POOR OBSERVING CONDITIONS

7 ABSTRACT OF BACK UP PROGRAMME

We will expand on our CSO studies of rotationally-related 1.3mm continuum variability of Pluto and Iapetus.

8 DETAILS OF OBSERVING TIME, INSTRUMENTS ETC FOR THIS SEMESTER

NB. If own instrument, not previously used on telescope, attach a concise description on a separate page.

Shifts (8 hours)	Frontend (see users manual)	Observing Frequencies (molecule/transition)	Sources
7	UKT14	0.8, 1.1mm	see attached Table 1

i) Preferred dates ....SEP-NOV..........

ii) Impossible dates (give reason) ...none........

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9 LIST OF PRINCIPAL SOURCES

Name	RA (hh mm)	Dec (dd)	Brightness/Flux (T_r^* (K) F(mJy))	Vlsr (km/s)	Linewidth (km/s)	Notes priority

see attached Tables 1 and 2

10 BREAKDOWN OF TIME REQUESTED

a) Line observations Receiver(s) UKT14 Backend ....

Rest freq (GHz)	Req sensitivity (rms; K)	Freq resolution (MHz)	Total number of spatial points	Total time (hrs) (incl overheads)

b) Continuum observations Receiver UKT14

Filter (microns)	Aperture (arcsec)	Req sensitivity (mJy)	Total number of spatial points	Total time (hrs) (incl overheads)
800	13.5"(47mm)	8 mJy rms	5/star	8 hours(1 shifts total)
1100	19"(65mm)	4 mJy rms	5/star	48 hours(6 shifts total)

c) Other requirements (own instrument, polarisation, etc.)

11 OBSERVING

Sidereal time interval 07-22 hours (varies with target)

Observing support required ....

12 (i) Have applications for observing time time on other telescopes/satellites for this or similar programmes in the coming semester been made YES/NO

(ii) If YES state: a) Telescope/satellite ....

b) Title of programme ....

c) Whether simultaneous observations required YES/NO

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OF POOR QUALITY

Related PATT applications over last 4 semesters (include unsuccessful applications)

Semester Year	Telescope	Ref	Request	Allocated	Clear nights	Comments
U/1991	JCMT	M/U/016	3	3	2	good data at 1.1mm
W/1992	JCMT	M/W/062	6	0	N/A	1st quartile, no time awarded
X/1992	JCMT	M/X/004	9	0	N/A	1st Quartile, no time awarded

(ii) Title and reference of all publications (incl. preprints) over last 4 semesters which have resulted from PATT time.

Initial detection of extended submillimeter emission around Fomalhaut, Stern, S.A., and D.A. Weintraub, and M.C. Festou Science, submitted.

(iii) Other publications relevant to this application

14 (i) Are the observations primarily for a student research training programme? ~~YES/NO~~ NO

If YES, state a) Name of student(s) ....

b) Project title(s) ....

c) SERC studentship no(s) (UK only) ....

(ii) Are the observations associated with a current research grant? ~~YES/NO~~ YES

If YES, state a) Name of principal investigator S.A. Stern

b) Grant number NASA NAGW-2914

15 Indicate experience of intended observers who have not previously used this telescope

all three observers have JCMT experience

16 FUNDING

Funding Source

(i) Name | No. of nights | Reason (data reduction, etc.) | SERC/NRC/ASTRON/OTHER

(ii) Please indicate any other anticipated expenditure (freight, remote observations etc.)

A Mini-Survey for Cold Dust at Oort Cloud Distances Around Main Sequence IRAS IR Excess Stars

The detection of cold dust at significant distances around main sequence stars was initiated by IRAS, first at Vega (Aumann *et al.* 1984) and then around other stars (Aumann 1985; Stencel & Backman 1991). Owing to the short dust lifetime against radiation pressure and Poynting-Robertson (PR) drag, the detection of continuum emission from dust around such stars strongly implies a present-day source, presumably macroscopic objects (*e.g.*, comets or asteroids) undergoing collisions (Weissman 1984). If one can show that the FIR/submm dust emission is coming from distances of 100s-1000s of AU from the parent star, then such *highly-extended* emission naturally suggests the underlying presence of an Oort Cloud or Kuiper Disk of planetesimals, as suggested by Smith & Terrile's (1984) optical discovery at β Pic (Weissman 1984; Aumann 1985).

Submm/mm searches for extended emission have been reported for only a few main sequence IRAS IR excess sources (*cf.*, Becklin & Zuckerman 1992 (BZ); Chini *et al.* 1990). Most such searches have been limited to distances of 100-200 AU or less from the parent star.

The critical distinction we emphasize is that while dust at distances of 100-200 AU is interesting and may well be related to comet disks and even planetesimal formation, dust at > 1500 AU represents a 'smoking gun' for giant planet formation (Stern, *et al.* 1991). The reason for this is that, assuming the dust is generated by comet collisions (the standard model), giant planets are required to scatter comets to such large distances (this is how our Oort Cloud was formed). As such, comet cloud detection provides extremely strong evidence for the existence of an underlying planetary system with giant planets acting as scattering centers.

To improve knowledge of the frequency and physical properties of Extra-Solar Oort Clouds (ESOCs) as a tracer of giant planet systems, we are engaged in a NASA Origins program to conduct submm/mm continuum observations of nearby main sequence IR excess stars. In that work, we have used the JCMT UKT14 and IRAM 7-chnl bolometer to carry out initial set of one source, Fomalhaut (α PsA). As shown in Figure 1, these observations have revealed clear evidence of a tilted, disk-like dust assemblage with a major axis measuring $\approx$ 500 AU across at a sensitivity of 30 mJy (Stern, et al. 1993). As a result of these observations, α PsA has become both the closest known main-sequence, submm-resolved IR excess source (at 6.7 pc) and the only resolved disk-analog to β Pic.

In addition to the 1.3mm IRAM map presented in Figure 1, 1.1mm JCMT data indicate the presence of extended emission at distances of 2500 AU from α PsA. This is just the distance where models of the sun's Oort Cloud and Kuiper Disk (*e.g.*, Weissman 1990; Stern, *et al.* 1991) predict dust optical depth and submm emission to peak (i.e, 500-3000 AU from the star itself (Stern, et a. 1991). Unfortunately, however, we only have 2 observation points at 2500 AU and therefore cannot determine whether this emission is disk-like or becoming spherical (as our Oort Cloud).

In this proposal we request time to expand on the α PsA results by (i) searching for cold dust assemblages around other nearby main sequence IR excess stars and (ii) making additional observations of α PsA to expand our coverage of 1.1/1.3mm emission at distances of 1000-3000 AU.

Our main objective is to determine if β Pic and Fomalhaut are anomalous or just the 'tip of an iceberg,' representing a broadly common phenomenon related to planetary formation. Table 1 gives the list of 6 candidate stars for our program. We note that these 6 stars branch out beyond AV dwarfs like Fomalhaut and Vega to determine whether such assemblages may be common to other IRAS IR excess types as well. Depending on the number and dates of shifts awarded, we will select a subset of 3-5 of these stars for observation.

As in our Semester U/Fomalhaut program, we will use UKT14 to make this search. Our search strategy will be to make observations at 1.1mm in a five-point cruciform around each program star at a distance of 2500 AU. By observing 4 points uniformly distributed in azimuth around each star, we can make effective use of JCMT's AZ/EL chopping system. The result of such an observing strategy gives us both a measure of the extent of emission at 2500 AU, and a constraint on the geometry of the source at 2500 AU. The five-point cruciform search will allow us to address the question of whether detected emission is derived from either a thick- or tilted- disk, or instead from a more spherical shell.

For a canonical distance of 10 pc and a UKT14 beamwidth of 19 arcsec at 1.1mm, 2500 AU corresponds to 13 beamwidths from the parent star. All of our program stars are between 3 and 16 pc distant, putting the 2500 AU point 7-43 beamwidths off the star. Confirming observations at 1.3 or 0.8mm will be made around those stars for which we find evidence for 1.1mm excess at 2500 AU.

Including offset-pointing, calibration, and normal observing overheads, we estimate UKT14 can complete 1 five-point cruciform search (i.e., one target) per shift at 1.1mm, at a detection limit of 15-25 mJy (4σ). Each cruciform point will consist of 4-to-8, 1000 sec integration blocks, interspersed with calibrator (and pointing updates) as required. In total we request 7 shifts: 5 shifts to study 3-5 new candidates and 2 shifts to make new explorations of the distant emission characteristics and emission geometry of Fomalhaut. As a reduced request, we ask for 4 shifts to study 2-3 new stars and to continue the work at Fomalhaut.

The continuum emission detected at each cruciform station and along the LOS to the star will be used to model the optical depth distribution and total mass of orbiting dust around each program star. This emission will be modeled with a submm/mm dust radiative transfer code developed for just such studies at the University of Calgary (cf., Marshall, Leahy, & Kwok 1992). The model results will be used to infer the mass distribution of the underlying, macroscopic source bodies for the dust. The model employs a standard (*e.g.*, Mathis *et al.* 1977) size distribution, with optical coefficients for the dust taken from Draine (1985), assuming optically thin radiative transport. We will estimate the mass of the underlying bodies generating the dust taking into account production by collisions, as well as radiation, PR, and ISM drag losses (Stern 1990).

This mini-survey of potential Oort Cloud sites is a natural precursor to determine the appropriate strategies and stellar selection criteria for more extensive work using SCUBA in future years.

Aumann. H.. F. Gillet, C. Beichman, T. de Jong, J. Houck. F. Low. G. Neugebauer. R. Walker, and P. Wesselius. 1984. *ApJ.*, **278**. L23.

Aumann, H., 1985. *PASP*, **97**, 885.

Becklin. E., and B. Zuckerman. 1992. Preprint. Submitted to ApJ.

Chini. R., E. Krugel, and E. Kreysa, 1990. *Astron. Ap.*, **227**, L5.

Draine. B.. 1985. *ApJ. Suppl.*, **57**. 587.

Marshall. C.. D. Leahy, and S. Kwok, 1992. *P.A.S.P.*. **104**. 397.

Mathis. J., W. Rumpl, and K. Norsdiek. 1977. *ApJ.*, **217**, 425.

Smith. B.A.. and R.J. Terrile. 1984. *Science*, **226**, 1421.

Stencel. R. and D.E. Backman. 1991. *ApJ. Suppl.*, **75**. 905.

Stern. S.A.. 1990. *Icarus*. **84**. 447.

Stern. S.A.. J. Stocke, P. Weissman. 1991. *Icarus*. **91**. 65.

Stern. S.A.. D.A. Weintraub. and M.C. Festou 1993. *Science*. submitted.

Weissman. P.R.. 1984. *Science*, **224**. 987.

Weissman, P.R.. 1990. *Nature*. **344**, 825.

Table 1: ESOC Search Program Stars (Ordered by RA)

Target	Coords/IRAS Name	Distance (pc)	Type
Procyon	07366+0520	3.5	F5IV wd
DM-23'8646	09399-2341	12	F9IV
β Leo	11464+1451	12	A3V
η CrB	15211+3027	16	G3V G0V
α Lyr (Vega)	18352+3844	7.5	A0V
α PsA (Fomulhaut)	22549-2953	6.7	A3V

Table 2:[a] UKT14 ESOC Observing Time Estimates

λ	JMCT NEFD	Predicted ESOC Flux (30-50 K)	3σ Limit (120 min)	3σ Limit (60 min)
0.8mm	0.7 Jy $Hz^{-1/2}$	24-75 mJy	24 mJy	35 mJy
1.1mm	0.3 Jy $Hz^{-1/2}$	13-40 mJy	11 mJy	15 mJy
1.3mm	0.3 Jy $Hz^{-1/2}$	09-28 mJy	11 mJy	15 mJy

[a] Assumes R-J spectrum extrapolated from 0.8 mm observations. Predicted ESOC fluxes are based on the Fomalhaut (α PsA) model.

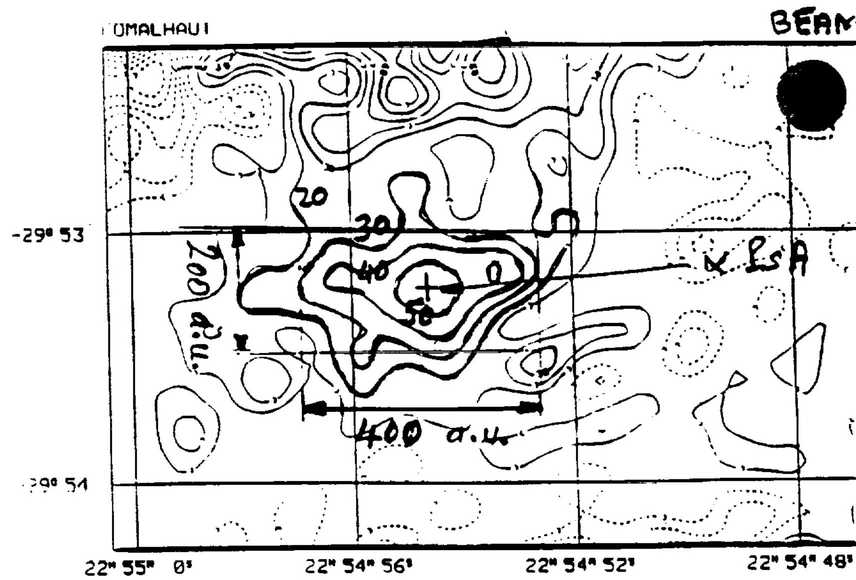

Figure 1: Our 1.3mm emission map showing the detection of extended emission around α PsA by the IRAM 1.3mm bolometer. The emission level at the center is 50mJy; isophotes are shown at 10mJy intervals. A disk-like source is clearly indicated. The source to the north may be related to the ragged edge of an Oort-like halo at distances $> 10^3$ AU from the star.

We have read the Notes for Guidance relating to applications to the Panel for the Allocation of Telescope Time and if an award is made, understand that all participants may be required to sign a form of indemnity before being permitted to use the equipment. We are not bound by any contrary conditions governing the proposed investigation including obligations to third parties incurred in respect of ownership and use of research results and patents.

	Signature	Date
Principal Applicant	[signature]	3/24/93
Principal Observer	[signature]	3/24/93
Head of Applicant's Department/Establishment	Nick Saker	25 March 1993
Administrative Authority (State position held)	N/A	

SUBMISSION OF APPLICATIONS

The original typed copy of the completed application form and scientific case for support, together with EIGHT copies of each and at least THREE copies of any supplementary material, should be despatched to reach the council by the appropriate closing date (see below) and should be addressed to:-

The Executive Secretary,
Panel for the Allocation of Telescope Time,
Science and Engineering Research Council,
Polaris House, North Star Avenue,
SWINDON SN2 1ET U.K.

CLOSING DATES

SEMESTER: August-January — Applications must be received on or before: 31 March

February-July — 30 September

TO BE COMPLETED BY THE APPLICANT

INVESTIGATOR(S) DEPT(S)/ INSTITUTION(S)/T&S REQUIREMENT	SHORT TITLE OF INVESTIGATIONS	COMMENTS AND SCHEDULING PREF.	NO. OF SHIFTS (8 HOURS) REQUESTED	MINIMUM
S.A. Stern Space Sciences Dept. Southwest Research Institute	Oort-Cloud Mini-Survey	2 shifts/day SEP-NOV preferred could be 2 separate runs (e.g. 4 shifts, 5 shifts)	7	3-4

ADDRESS FOR ACKNOWLEDGEMENT

Dr. Alan Stern/Div 15
Space Sciences Dept.
Southwest Research Institute
6220 Culebra Rd.
San Antonio, TX 78238

SCIENCE AND ENGINEERING RESEARCH COUNCIL
POLARIS HOUSE,
NORTH STAR AVENUE,
SWINDON SN2 1ET

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APPLICATION FOR OBSERVING TIME AT LA SILLA, CHILE — PERIOD 52

(Please read the instructions overleaf before filling in the form)

1. Short title (10 words maximum) and classification of proposed programme

Mapping of the Extended Dust Clouds Around α PsA (Fomalhaut) and β Pic at 1.3 mm

1 ☐ 4 ☐ 7 ☐
2 ☐ 5 ☐ 8 ☐
3 ☐ 6 ☐ 9 ☒

2. Abstract (Concise summary of the proposal)

In Feb. 1993 we detected an extended emission around Fomalhaut (α PsA) at 1.3 mm using the new IRAM 7-channel bolometer. We mapped the continuum emission out to distances of 200–300 AU from the star. This emission is hypothesized to be related to the presence of an extended dust cloud, and may therefore represent direct evidence for the formation of a planetary system at Fomalhaut. We propose to conduct a more complete investigation of the characteristics of that cloud, i.e. to determine its exact extension and shape. We also propose to conduct a similar submillimeter investigation of the disc detected in the optical range around β Pic, and perform the first direct comparison of the dust systems detected around main sequence IR-excess A-type stars.

3. Telescope(s) and number of requested nights (hours for SEST, plates for Schmidt).
Mark with "S" if simultaneous observations are essential

3.6 m	3.5 m NTT★	2.2 m	1.5 m	1.4 m★ CAT	1 m	0.50 m	Schmidt	1.5 m Danish	0.50 m Danish	0.90 m Dutch	SEST
											30

4. Indicate required instrument(s) and detector(s)

1.3 mm bolo

5. Indicate whether the programme is suitable for remote observing (only for telescopes and instruments marked with ★)

☐ YES ☒ NO (give reasons in box 23)

6. Category for NTT programmes:

☐ L La Silla ☐ R Remote ☐ S Service

7. Indicate first and second choice for specified period

Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
							1	2			

8. Moonlight preferences:

Dark time ☐ No restrictions ☒
Grey time ☐

9. It is mandatory that the applicant indicates here the number of nights

a) already awarded to the project (please report results in section 13)
0

b) required to complete the project (excluding those requested in this application)
0

10. Name of principal investigator and mailing address

FESTOU Michel C.
Observatoire Midi-Pyrénées,
14, avenue E. Belin,
F-31400 Toulouse
France

11. Co-investigators (name and institution)

STERN S.A.
Southwest Research Institute, San Antonio, TX, USA

WEINTRAUB D.A.
Vanderbilt University, Nashville, TN, USA

/.

12. Name and nationality of the observer: Festou M.C. (French), Stern S.A. (Am.) and D.A. Weintraub (Am.)

13. Report on the last observations conducted at La Silla

A) Title of programme
Observations of Pluto

B) Observing dates and telescope(s)
May 1987, 1m tel (photometer) and 2.2m tel (CCD)

C) Results

Bad weather, no usable results.

14. Applicant's publications related to the subject of this application during the past two years

Stern, S.A., 1990. *Icarus*, **84**, 447.

Stern, S.A., J. Stocke, P. Weissman, 1991. *Icarus*, **91**, 65.

Stern, S.A., M.C. Festou, and D.A. Weintraub, 1993. *Science*, in preparation.

15. If this programme is for thesis work, indicate:

– The name of the student: none

– The status of the work: ☐ Starting ☐ In mid-course ☐ Near completion

16. Special remarks

The targets are rather weak sources that require long integrations. The observing location and period should primarily be selected for its low optical depth at 1.3 mm. The second criterion should be the elevation of the targets, again to minimize the optical depth. Any period between Nov. '93 and mid-Dec. '93 should be appropriate, with a preference for the beginning of this interval.

17. Agreement: If observing time is allotted, applicant(s) and observer(s) will act according to the "Instructions for Visiting Astronomers"

Name(s)	Position at Institution	Date	Signature
FESTOU M.C.	Director of Research at CNRS	25 March 1993	
STERN S.A.	Section Manager at SwRI		
WEINTRAUB D.A.	Professor at Vanderbilt Univ.		

18. Name of Director or Supervisor G. Vauclair

19. Description of proposed programme and applicant's main publications related to it (if papers referred to are not yet published, attach 4 copies of each).
This description has to be restricted to one page only.
The proposal should be self-contained and not simply refer to previous applications.

A)**Scientific rationale**(Scientific background of the project, pertinent list of references; previous work plus justification for present proposal)

B)**Scientific aim**(Immediate objective of the proposal. State what is actually going to be observed and what shall be extracted from the observations, so that the feasibility becomes clear)

A) We observed Fomalhaut (A3V; α PsA) in February 1993 with the very sensitive IRAM 7-channel bolometer and detected its extended cold dust emission for the first time. We obtained an unambiguous detection with a peak signal of 50 $\pm$ 15 mJy (see Fig. 1). However, the low elevation of the object over the horizon did not allow us to collect enough data to delineate the exact extension and geometry of the emission but a *disk-like structure* is clearly indicated in the data (Stern *et al.* 1993).

Owing to the short dust lifetime against radiation pressure and Poynting-Robertson drag, the detection of continuum emission from dust around such stars strongly indicates a *present-day* dust source, which probably consists of macroscopic objects (*e.g.*, comets or asteroids) undergoing collisions (*e.g.*, Weissman 1984). As such, the detection of *highly-extended* IR and FIR emission naturally suggests the presence of an Oort Cloud or a Kuiper Disk-like assemblage of planetesimals (Weissman 1984; Aumann 1985) whose detection provides circumstantial evidence for the existence of an underlying planetary system or at least planetesimal formation (Stern, *et al.* 1991).

Only a handful of the IRAS IR-excess sources are close enough to permit spatial mapping by submm/mm telescopes. Positive detections of extended emission off the stellar line-of-sight have been made for only two of these: β Pic (16.6 pc distant) and α PsA (6.7 pc distant). *Optical* coronograph studies by Smith & Terrile (1984) and 0.8 mm bolometry by Becklin & Zuckerman have revealed evidence for a disk-like assemblage reaching to $> 10^3$ AU around β Pic. Our 1993 millimeter observation is only the second time a dust cloud around a main sequence A-IRAS IR-excess star has been imaged.

B- With this new observation in hands, it is interesting to re-examine the observations we made in 1991 at the JCMT (1.1 mm) which indicated the presence of an extended emission approximately as strong at distances of 2500 AU from α PsA as those 100 AU from the star (Stern et al. 1993). Combining the data sets we obtained on Fomalhaut's dust emission, one is led to believe that the signal should be detected at much larger distances from the star than shown in Fig. 1. Based on models of the sun's Oort Cloud and Kuiper Disk (*e.g.*, Weissman 1990; Stern, *et al.* 1991), one expects dust optical depth and submm/mm emission to peak at $10^{2.5-3.5}$ AU from a star possessing a cloud of interacting (i.e., colliding) comets such as our own (Fig. 2). This suggests that we have detected only the inner part of a dust complex that could be composed of two components made of particles of different origin. Mapping the entire dust cloud requires a much longer observing time than can be achieved from a northern site when observing α Psa. Owing to its southerly latitude, the SEST instrument is located in the most favourable site to conduct such an extensive study and its spatial resolution is better than 1/20 to 1/10 the size of the extended clouds.
We thus propose:

1- To make a complete exploration of the extended emission around Fomalhaut to achieve a high S/N and determine whether the emission we mapped is due to a disk, a spherical source or a doughnut shaped dust structure; and to extend our investigation to much larger distances in an attempt to eventually reveal the presence of a comet cloud around it.

2- To extend our study to the only other star known to have a dust disc, β Pic. The two systems should have the same extension on the sky (the β Pic disc is twice as far and twice as big as that of α PsA). With these data sets on Fomalhaut and on β Pic, we plan to initiate a detailed comparative study of the two systems and derive information on their spatial structure that is instrument and wavelength —thus model— independent.

3- If time allows, we will attempt to map the 1.3 mm emission around a third promising source having shown an IR excess when observed by IRAS, τ Ceti.

Then, the continuum emission detected around α PsA will be used to model the optical depth distribution and total mass of orbiting dust. These parameters will be used to infer the mass and distribution of the underlying, macroscopic source bodies for the dust. Our model employs a standard dust size distribution (*cf.* Mathis *et al.* 1977), with optical coefficients for the dust taken from Draine (1985), and assumes optically thin radiative transport.

Aumann, H. 1985. *PASP*, **97**, 885.— Becklin, E. and B. Zuckerman 1989, preprint (U. of Hawaii). — Draine, B. 1985, *ApJ. Suppl.*, **57**, 587. — Mathis, J. *et al.* 1977, *ApJ.*, **217**, 425. — Smith, B.A. and R.J. Terrile 1984, *Science*, **226**, 1421. — Stern, S.A., M.C. Festou and D.A. Weintraub 1993, *Science*, in preparation. — Weissman, P.R. 1984, *Science*, **224**, 987. — Weissman, P.R. 1990, *Nature*, **344**, 825.

20. Right ascensions, declinations, magnitudes, and, if relevant, angular diameters of objects contained in proposed programme:

α PsA	22 54.9	-29 53	1-2 arc min (inner cloud); 6-10 arc min (outer cloud)
β Pic	05 46.0	-51 04	1-2 arc min (inner cloud); 6-10 arc min (outer cloud)
τ Ceti	01 41.6	-16 11	tbd

21. For SEST proposals, indicate:

a) Your preferred LST interval : Oct.: 1st half Nov.: 20:30-9:30; 2nd half Nov.: 19:30-8:30; 1st half Dec.: 18:30-7:30

b) The period when the targets can be observed, taking into account the Sun constraint (50°) : The main two targets are best visible during the Oct.-Jan. α PsA is seen longer at elevations above 40° at the beginning of this period while β Pic in slightly longer seen in Dec. Our secondary target, τ Ceti, is always well placed in the sky from La Silla. The best date is when the mean optical depth is minimum. All in all, ~~we prefer the month of November.~~

22. Justification of requested number of observing nights. Do not include any correction for expected meteorological conditions:

The two inner dust systems extent out to 1-2 arc min from the stars. The outer clouds may extend much farther away, probably 3 to 5 arc min, or possibly more. If one assumes the cylindrical symmetry for the emissive regions and since we know the orientation of the two dust structures, the observing time can be reduced by $\sim$ 50 % at Fomalhaut and $\sim$ 67 % at β Pic, respectively, by limiting the mapping to 5 by 10 and 3 by 10 arc min rectangles instead of 10 by 10 arc min squares. Since the JCMT observations suggest a more rapid drop of the 0.8 mmm signal at β Pic than at α PsA, we will adopt a conservative strategy concerning β Pic —looking first for the inner cloud—, while we will expose deeply at Fomalhaut to detect the weakest distant emissions. We expect to reach a detection limit as low as 10 mJy, and our time request is based on the complete mapping of the two above-defined rectangles down to that limit (one sigma). If the two dust emissions have similar spatial extension (see box 20) and peak brightness (the two stars have the same IR excess at 100 μ), the 2 maps will require a total of 25 (15 + 10) h. The observation of τ Ceti requires another 5 hours.

23. Reasons why the observations cannot be performed in remote mode.

Neccessity to react quickly to observing conditions and to judge results provided by real time preliminary data analysis

24. **Important notice:**
If the programme described in this application requires excellent seeing or photometric conditions or low water vapour content, **a back-up programme using the same instrumentation** has to be described on a separate page.

25. Description of backup programme.
It must follow the same rules as the scientific justification for the main programme (box 19).
This description has to be restricted to one page only.

Depending on the quality of the atmosphere, it is anticipated that some objectives may not be reached. Although our sources are not bright, their excellent position in La Silla's sky allows us to build a first backup program on the same targets. This simply requires to refine the observing strategy and limit the completness of the cloud mappings. We have set the following priorities in our program to allow us to collect interesting data even in the event only one half of the effective time were available to us due to poor sky conditions:

1- Map the inner part of the Fomalhaut dust cloud to specificy its shape and extend ($\sim$ 50 % of the total time requested for that target).

2- Map the inner dust cloud of β Pic (50 % of the time requested for that target) for comparison with Fomalhaut.

3- Map the outer part of the Fomalhaut dust cloud in the direction of the long axis of the dust cloud ($\sim$ 25 % of the time requested for that target): Oort cloud detection attempt.

4- Determine the 1.3 mm extend of the long axis of the β Pic dust cloud: begin full map of β Pic outer dust cloud.

5- Mapping of inner cloud around τ Ceti.

6- Complete the maps of the two main targets if remaining observing time permits.

If conditions are very poor, we will instead opt to expand our studies of rotational variations of the major satellites of the giant planets as we did in Oct. '91 and will do in May-June '93 at JCMT.

Figure 1: The 1.3 mm emission we detected around Fomalhaut with the IRAM bolometer. In this initial detection of the cloud, the emission at the center is 50 ± 15 mJy and the general shape of the isophotes (separated by 10 mJy; full lines indicate positive values) strongly suggest a disk-like shape. The dust cloud extends *at least* to 200 AU from the star. With greater sensitivity , we expect to detect emission at larger distances, and derive a better constrain on the source geometry

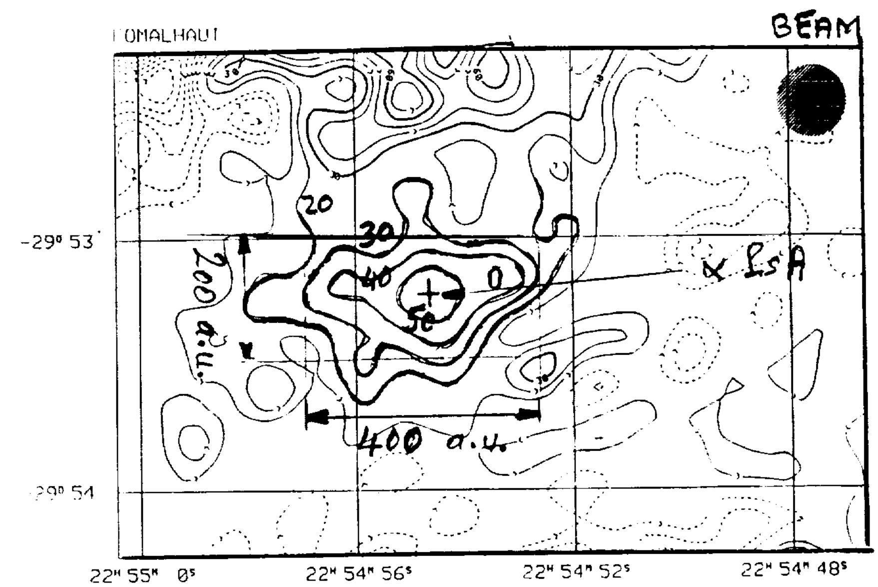
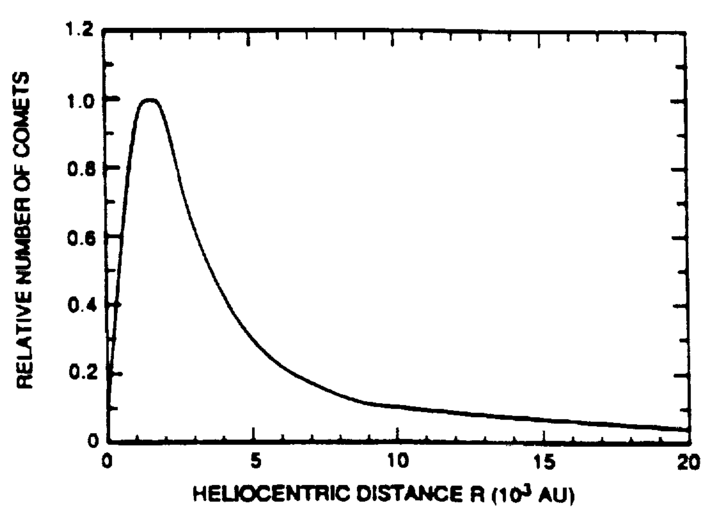


Figure 2: The expected radial distribution of comets in our Oort Cloud when projected onto the plane of the sky (from Stern, Stocke & Weissman 1991).



OBSERVING PROGRAMMES REQUIREMENTS

Indicate clearly with a cross in the appropriate places your telescope(s) and instrumentation requirements. For details check the "Announcement for Observing Time" and the other available ESO documentation.

OBSERVER'S NAME: Festou M.C.

Telescope	Instrument		Detector	
3.6m	Infrared Photometer		Bolometer	
	TIMMI		InSb Detector	
	EFOSC 1		64x64 GaSi Detector	
	MEFOS		CCD TEK#26	
	CASPEC		CCD TEK512#32	
	Link to CES (Specify camera under 1.4m CAT)			
3.5m ★ NTT †	S_A) IRSPEC		CCD TEK1K#25	
	S_A) SUSI ★		CCD TH1K#18	
	S_B) EMMI Standard Red ★		CCD TEK1K#31	
	S_B) EMMI High Res Echelle Red ★			
	S_B) EMMI Standard Blue ★			
2.2m	Direct Imaging		CCD RCA#8 H-Res	
	EFOSC 2		CCD TH1K#19 Coated	
	Infrared Photometer		Bolometer	
	IRAC 1		InSb Detector	
	IRAC 2		64x64 InSb Detector	
			NICMOS III	
1.52m	Cass. B&C Spectrograph		CCD FA2K#24 Coated	
	Echelec Spectrograph		CCD RCA#13 H-Res	
1.4m CAT ★	CES : Short Camera (Blue) ★		CCD FA#30 Coated	
	CES : Short Camera (Red) ★		CCD RCA#9 H-Res	
	CES : Long Camera (Blue) ★			
	CES : Long Camera (Red) ★			
1m	Infrared Photometer		Bolometer	
	Single Channel Photometer		In Sb Detector	
50cm	Single Channel Photometer		P.M.T. RCA 31034	
			P.M.T. EMI 9789 QB	
			P.M.T. EMI 9658	
50cm Danish	uvby Hβ Photometer		P.M.T. HAM R943-02	
1.54m Danish	Direct Imaging		CCD TEK1K#28	
90cm Dutch	Direct Imaging		CCD RCA#5	

Telescope	Instrument		Number of plates required			
Schmidt	With prism		IIa-O[a]		IIIa-F	
	Without prism		IIIa-J		IV-N	

Telescope		Instrument		Detector	
SEST	X	1.3mm Bolometer	X	Narrowband AOS	
		0.8mm Receiver		Broadband 1 AOS	
		1.3mm Receiver		Broadband 2 AOS	
		3.0mm Receiver			

Notes: (★) The combination of these telescopes, instruments and detectors can be used remotely from the ESO Headquarters in Garching.
(†) S_A/S_B Option available simultaneously.
(a) Subject to delivery by Kodak.

SPECTROSCOPY: Indicate wavelength region(s): ____________________

Dispersion(s): ____________________

Desired Signal/Noise: ____________________

PHOTOMETRY: Specify required mode

Standard Photometry ☐ Fast Photometry ☐

FILTERS:

– Indicate colour system(s): ____________________

– If you do not use standard colour systems, indicate which ESO filters you require:

____

OWN EQUIPMENT: On which telescopes has your equipment been tested?

____

and when? ____________________

Weight of your equipment: ____________________

Volume to be transported: ____________________

Value of the equipment: ____________________

What is the focal distance from top adaptor flange? ____________________

Is your adaptor flange compatible with required telescope? ____________________

ATTACHMENT 3

ACM V Meeting Abstract

ACM V Abstract:

Collisions in the Kuiper Disk

S.A. Stern[1] and G.R. Stewart[2]

[1] Space Science Dept., Southwest Research Institute, 6220 Culebra Rd., San Antonio, TX, 78238, USA. [2] LASP, University of Colorado, Boulder, CO 80309

We have constructed models of the collision rates between cometary bodies in the present-day Kuiper Disk (KD) under various assumptions about the total mass and the distribution of orbital (a,e,i) elements in the Disk. These calculations demonstrate that significant collisional evolution can take place in the Kuiper Disk. By computing the optical depth of debris created from collisions in the KD, our calculations reveal that the present-day radial mass distribution of the solar system undergoes a sharp discontinuity (or edge) at Neptune. That is, we can demonstrate that the Kuiper Disk is not massive compared to Neptune. Based on this result, we conclude that either the primordial solar system's mass distribution was similarly truncated near 30 AU, or subsequent collisional/dynamical evolution has depleted the 30-100 AU zone by several orders of magnitude. We will report on these results and a model predicting the detectability of thermal-IR emission from collisionally-produced dust in the Kuiper Disk.