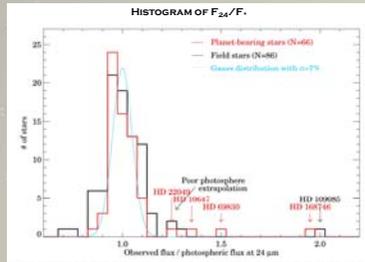


A SPITZER SEARCH FOR DEBRIS DISKS AROUND STARS WITH PLANETS

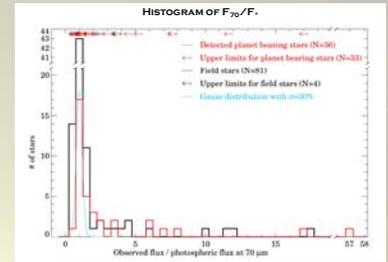
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ABSTRACT: THE DUST IN DEBRIS DISKS IS GENERATED BY COLLISIONS AMONG OR EVAPORATION OF PLANETESIMALS. THE EXISTENCE OF THESE PLANETESIMALS IS A CONSEQUENCE OF THE PLANET-FORMATION PROCESS, BUT THE RELATIONSHIP BETWEEN THESE DISKS AND PLANETS HAS NOT BEEN CLEARLY ESTABLISHED. HERE WE STUDY THE ROLE THAT PLANETS CLOSE TO THE STAR PLAY IN THE GENERATION OF DEBRIS, BY **COMPARING THE INCIDENCE OF DEBRIS DISKS IN STARS WITH AND WITHOUT PLANETS**. WE HAVE SEARCHED THE SPITZER ARCHIVE FOR MIPS OBSERVATIONS (AT 24 AND 70 μ) OF STARS KNOWN, BY THE RADIAL VELOCITY METHOD, TO HAVE PLANETS. WE ANALYZE 71 SUCH STARS, **THE LARGEST SAMPLE EVER ASSEMBLED**. WE USE SURVIVAL ANALYSIS (WHICH ALLOWS US TO USE NON-DETECTIONS) TO COMPARE THE PLANET SAMPLE WITH PUBLISHED DATA OF STARS NOT KNOWN TO HAVE PLANETS. THIS ANALYSIS REVEALS **NO SIGNIFICANT DIFFERENCE BETWEEN THE TWO SAMPLES**. FURTHERMORE, THE PRESENCE OF DEBRIS DISKS IS UNCORRELATED WITH METALLICITY.

REDUCTION: DATA FOR THE STARS WITHOUT PLANETS WAS TAKEN FROM THE PUBLISHED LITERATURE. FOR THE PBS, THE PIPELINE-PRODUCED BCD FILES WERE RE-MOSAICKED WITH MOPEX. APERTURE PHOTOMETRY ON THE MOSAICS WAS DONE USING IDL. AT 24 μ , A CALIBRATION ERROR OF 4% WAS ADOPTED IN ADDITION TO THE PHOTOMETRIC UNCERTAINTIES. AT 70 μ , AN ABSOLUTE CALIBRATION ERROR OF 7% WAS ADOPTED IN ADDITION TO THE PHOTOMETRIC UNCERTAINTIES (DOMINATED BY CIRRUS CONFUSION NOISE). NO COLOR CORRECTION (WHICH WOULD INCREASE THE 70 μ DUST EMISSION BY 10%) WAS PERFORMED. **PHOTOSPHERE PREDICTION:** THE STELLAR FLUXES AT 24 AND 70 μ WERE PREDICTED USING KURUCZ (FOR F, G AND K STARS) AND NEXTGEN MODELS (FOR M STARS) SCALED TO OPTICAL (FROM THE TYCHO/HIPPARCOS DATABASE) AND NEAR-INFRARED (FROM THE 2MASS PSC) DATA.



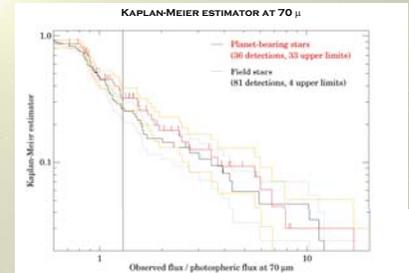
THE WIDTH OF THE DISTRIBUTION IS CONSISTENT WITH THE AVERAGE ERRORS. WE HAVE MARKED THOSE STARS WITH $F_{24}/F_{\lambda} > 1.2$. A KAPLAN-MEIER ESTIMATOR ANALYSIS REVEALS THAT THE PBS 6.1% \pm 2.9% OF STARS HAVE $F_{24}/F_{\lambda} > 1.2$. FOR THE NON-PLANET SAMPLE THE NUMBER IS 4.7% \pm 2.3%. HD 22049 IS EPSILON ERI.



THE DISTRIBUTION OF PBS VALUES CAN BE FIT WITH A GAUSSIAN WITH SIGMA=10%. THE HISTOGRAM BINNING MAKES THE DISTRIBUTION LOOK WIDER. WE SHOW A SIGMA=30% GAUSSIAN.

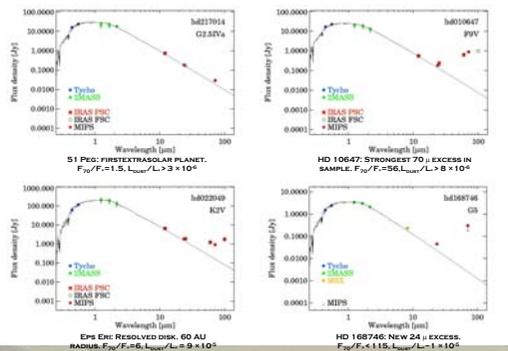
PLANET BEARING STARS (PBS): RADIAL VELOCITY TECHNIQUES HAVE UNCOVERED 200 EXOPLANETS AROUND MORE THAN 150 STARS. A SEARCH OF THE SPITZER ARCHIVE REVEALS THAT 71 PLANET-BEARING STARS HAVE BEEN OBSERVED WITH MIPS. MOST OF THESE DATA WERE OBTAINED IN MIPS PHOTOMETRY MODE. A FEW OF ARE MIPS SCAN MAPS.

WE FIND:
 → 66 PLANET-BEARING STARS OBSERVED AT 24 μ , ALL DETECTED
 → 69 PLANET-BEARING STARS OBSERVED AT 70 μ , 37 STARS DETECTED, 32 UPPER LIMITS
NON-PLANET STARS (FROM BEICHMAN ET AL. 2006): 86 STARS NOT KNOWN TO HAVE PLANETS, OBSERVED WITH MIPS.
 → ALL OF THEM DETECTED AT 24 μ .
 → 85 STARS HAVE 70 μ DATA, 81 STARS DETECTED, 3 UPPER LIMITS



COMPARISON OF F_{70}/F_{λ} FOR PBS AND NON-PLANET STARS. ALSO SHOWN ARE THE ONE SIGMA LIMITS FOR EACH SAMPLE (YELLOW AND GRAY). THE VERTICAL LINE MARKS $F_{70}/F_{\lambda} = 1.3$. FOR THE PBS 32.1% \pm 6.4% OF STARS HAVE $F_{70}/F_{\lambda} > 1.3$. FOR THE NON-PLANET SAMPLE THE NUMBER IS 26.5% \pm 4.9%.

NOTEWORTHY PBS WITH EXCESSES:



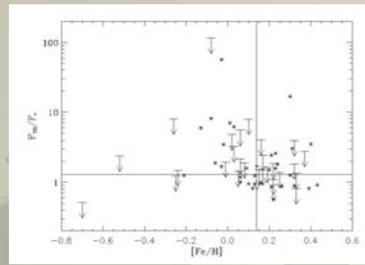
COMPARISON WITH PREVIOUS RESULTS: BEICHMAN ET AL. (2005) ANALYZED A SAMPLE OF 25 PBS OBSERVED WITH MIPS AT 24 AND 70 μ . THEY DEFINED EXCESS AS $(F_{\lambda}/F_{\lambda})/c_{\lambda} > 3$, WHICH CAN ONLY BE CALCULATED FOR DETECTED SOURCES. THEY FOUND NO EXCESSES AT 24 μ . AT 70 μ (5 NON-DETECTIONS) THEY FOUND AN EXCESS FRACTION OF 24% \pm 10%. **THE PERCENTAGE IS REALLY AN UPPER LIMIT** BECAUSE IT ASSUMES THAT THE 5 NON-DETECTED STARS HAVE NO EXCESS. FOR OUR SAMPLE WE FIND:

24 μ EXCESSES: PBS: FOUR OUT OF 66 (6% \pm 3%); NON-PLANET: NONE

70 μ EXCESSES: PBS: 15 OUT OF 69 ($>22\% \pm 10\%$); NON-PLANET: 13% $\pm 10\%$

WHEN CALCULATED IN THIS WAY, OUR PERCENTAGES FOR THE PRESENCE OF EXCESSES ARE CONSISTENT WITH THEIRS.

RELATIONSHIP WITH METALLICITY: IT IS KNOWN THAT, WHILE PBS ARE METAL-RICH (FISCHER & VALENTI 2005), THE SAMPLE OF STARS WITH DEBRIS DISKS HAVE THE SAME METALLICITY AS THE NON-PLANET SAMPLE (GREAVES ET AL. 2006). THIS RAISES THE QUESTION: IS THERE ANY CORRELATION BETWEEN EXCESS AND METALLICITY FOR THE PBS?



EXCESS VS. METALLICITY. THE HORIZONTAL LINE MARKS $F_{\lambda}/F_{\lambda} = 1.3$. THE VERTICAL LINE MARKS $[Fe/H] = 1.6$, THE MEDIAN OF THE PBS METALLICITIES.

WE PERFORMED A CORRELATION TEST USING THE COX PROPORTIONAL HAZARD MODEL. THE TEST SEEKS A CORRELATION, WITHOUT ASSUMING A PARTICULAR CORRELATION FORM. ASSUMING METALLICITY AS THE INDEPENDENT VARIABLE. WE OBTAINED A PROBABILITY OF 0.57 THAT NO CORRELATION IS PRESENT. IN OTHER WORDS, **METALLICITY DOES NOT AFFECT THE LIKELIHOOD OF A PBS HAVING A DEBRIS DISK.**

REFERENCES: BEICHMAN ET AL. 2006, APJ, 652, 1674; BEICHMAN ET AL. 2005, APJ, 622, 1160; FISCHER & VALENTI 2005, APJ, 622, 1102; GREAVES ET AL. 2006, MNRAS, 365, 283; MORO-MARTIN ET AL. 2007, APJ, IN PRESS

USING THE NON-DETECTIONS: SURVIVAL TESTS AND THE KAPLAN-MEIER ESTIMATOR: TO DECIDE WHETHER THE 70 μ PBS SAMPLE IS DRAWN FROM THE SAME DISTRIBUTION AS THE NON-PLANET SAMPLE WITH RESPECT TO F_{λ}/F_{λ} , (THE NULL HYPOTHESIS), WE PERFORM A BATTERY OF SURVIVAL TESTS. IN EACH CASE WE GIVE THE PROBABILITY THAT THE NULL HYPOTHESIS IS TRUE:

- GEHAN'S GENERALIZED WILCOX TEST - PERMUTATION VARIANCE: P = 0.40
- GEHAN'S GENERALIZED WILCOX TEST - HYPERGEOMETRIC VARIANCE: P = 0.38
- LOGRANK TEST: P = 0.41
- PETO & PETO GENERALIZED WILCOX TEST: P = 0.40
- PETO & PRENTICE GENERALIZED WILCOX TEST: P = 0.38

ANALOGOUS RESULTS ARE OBTAINED FOR THE F_{24}/F_{λ} VALUE. THESE TESTS INDICATE THAT HAVING A PLANET THAT CAN BE DETECTED BY RV TECHNIQUES DOES NOT CHANGE THE INFRARED CHARACTERISTICS OF A STAR. (MORO-MARTIN ET AL. (2007) HAVE CARRIED A SURVIVAL ANALYSIS ON SIX PBS AND HAVE ARRIVED TO SIMILAR CONCLUSIONS.)

WHAT DOES IT ALL MEAN?

A PRIORI, IT IS PUZZLING THAT THE PRESENCE OF PLANETS WOULD NOT AFFECT THE PRESENCE OF DEBRIS DUST, AS A PLANETS SHOULD STIR THE PLANETESIMALS, RESULTING IN MORE COLLISIONS AND MORE DUST THAN IN A NON-PLANET SYSTEM. HOWEVER, ONE SHOULD KEEP IN MIND THAT THE EXCESSES UNCOVERED BY SPITZER ARE DUE TO DUST THAT IS FARTHER AWAY (≈ 30 AU FOR A G2 STAR, ASSUMING 50 K) THAN THE LARGEST SEMI-MAJOR AXIS OF MOST PLANETS IN THIS SAMPLE (~ 4 AU). IT REMAINS TO BE SHOWN THAT PLANETS OF THESE CHARACTERISTICS ARE POOR SOURCE OF DYNAMICAL HEAT FOR THE SYSTEM. ON THE OTHER HAND, PERHAPS MOST STARS IN THE "NON-PLANET" SAMPLE HAVE NON-DETECTED PLANETS (>5 AU) AND SO THE TWO SAMPLES ARE INDEED THE SAME. THE LACK OF CORRELATION WITH METALLICITY INDICATES THAT **VERY LITTLE SOLIDS ARE NEEDED FOR THE GENERATION OF DUST.**