Time Allocation Committee for
MPG time at the ESO 2.2m-telescope
c/o MPI für Astronomie
Königstuhl 17
D-69117 Heidelberg / Germany

Application No.	
Observing period	October 2020
Received	

APPLICATION FOR OBSERVING TIME

from [X] MPIA [ ] MPG institute [ ] other

1. Telescope: 2.2-m [X]

2.1 Applicant

Dr. Sebastian **Marino**	Max-Planck-Institut für Astronomie
Name	Institute
Königstuhl 17	69117 Heidelberg
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Sebamarino	marino@mpia.de
ESO User Portal username	e-mail

2.2 Collaborators

Th. Henning, A. Kospal, D. Kossakowski	MPIA
name(s)	institute(s)
A. Muller, M. Schlecker; P. Abraham, A. Moor	MPIA; Konkoly Observatory
name(s)	institute(s)

2.3 Observers

Marino	Kossakowski, Schlecker
name	name

By specifying the names under item 2.3 it is obligatory to also send out these observers to La Silla, if required. Correspondence on the rating of this application will be sent to the applicant (P.I.) as quoted under 2.1 above.

3. Observing programme: Category: E

Title : **Spectroscopic study of newly discovered extreme debris systems**

Abstract : Warm extreme debris disks with high fractional luminosities are rare systems. Not reconcilable by steady-state evolutionary models, these peculiarly dust-rich disks are likely associated with the final accumulation phase of terrestrial planet formation that is thought to be hallmarked by giant collisions between planetary embryos. By combining data from the AllWISE and Gaia DR2 catalogs, we identified 29 new extreme debris disks. Here we propose to use the *FEROS* spectrograph to obtain high-resolution optical spectra for 17 of these stars and determine their main stellar properties and ages. Together with the data of previously known extreme debris systems this will allow us, for the first time, to put significant constraints on the timeline of rocky planet formation.

4. Instrument: [ ] WFI [X] FEROS [ ] GROND

5. Brightness range of objects to be observed: from 9.7 to 14.4 V-mag

6. Number of hours:

applied for			already awarded	still needed
14			none	none
no restriction	grey	dark		

7. Optimum date range for the observations: .... 15.12.20 – 20.02.21
Usable range in local sideral time LST: .... 02:00h – 23:00h

Astrophysical context

According to the current planet formation theories the final accumulation of rocky planets occur via a chain of collisions between large planetary embryos ([5]). With the exception of Venus, traces of such giant impacts can be found on all terrestrial planets in our Solar System ([24]). The most well-known example is the Earth-Moon system, whose formation was likely associated with such an event ([4]). These giant collisions are thought to be accompanied with the release of large amount of smaller fragments and vaporized material in the inner regions. By exhibiting very strong excess emission at mid-infrared (mid-IR) wavelengths the emerging debris cloud can serve as signposts of ongoing rocky planet formation in exosolar systems (e.g. [10]).

The past decade has seen the discovery of several Sun-like (FGK-type) stars that are surrounded by unusual debris disks which exhibit high dust temperature of >300 K (<1 au), very high fractional luminosity of $\frac{L_{\rm dust}}{L_*} > 10^{-2}$, and strong mid-IR solid state features implying the presence of small, submicron-sized dust particles ([15]). Mid-IR *Spitzer* photometric monitoring revealed that most of these *extreme debris disks (EDDs)* display significant variability on monthly to yearly timescales ([14, 15], [21]). These properties cannot be explained by the steady state collisional evolution of an inner planetesimal belt but instead point to a recent collision between large planetary embryos in the terrestrial zone (e.g. [13]), making EDDs the best candidates to explore these processes.

Besides providing a unique insight into the immediate aftermath of large collisions, EDDs also allow us to study the time period when these events can happen. In our Solar System the giant impact stage in the terrestrial zone lasted ∼100 Myr ([24]). Numerical simulations of rocky planet formation predict that this era could extend up to a few hundred Myr, but most giant collisions are thought have occured in the first 100 Myr (Fig. 1). Contrary to these predictions, however, in our recent study (Moór et al. in prep.) we found that the majority (60%) of EDDs are older than 100 Myr (Fig. 2), hinting that the intensity of rocky planet formation processes does not decay significantly even after this time.

Immediate aim

The current sample of 15 known EDDs in Figure 2 is still quite small for an adequate statistical study of the age-related trends. Here we propose to use the *FEROS* spectrograph to obtain high-resolution optical spectra for Sun-like (F7-K7 type) main-sequence host stars of 18 newly identified EDDs (see *Previous work*). Using these data we will 1) determine effective temperature, surface gravity, and metallicity of the stars; 2) measure their projected rotational and radial velocities (RV) and 3) measure the strength of the λ 6708 Å lithium absorption line.

By combining the derived parameters with complementary information we will determine the ages of the targeted systems. Together with the data of previously known EDDs we will build up a larger, statistically meaningful sample that will allow us, for the first time, to put significant constraints on the timeline of rocky planet formation. Based on this new database, we will also examine how the level of EDDs' mid-IR variability depends on the age and other properties of the host stars.

Previous work

Using a combined data set, based on the WISE mid-infrared photometric (AllWISE, [6]) and Gaia DR2 astrometric ([9]) catalogues, we identified 29 additional EDDs, thereby tripling the sample size. All of these newly discovered warm, dust-rich disks surround F7-K7 type main-sequence stars that are within 400 pc. In the current proposal we will focus on those 17 targets, that are located at $\delta < 25°$ and observable from La Silla in P106. Based on time-domain WISE data we found that 11 of these sytems displayed significant variability in the period between 2010 and 2018 (see an example in Fig. 3). Apart from 5 objects all of the targeted stars have been observed or will be observed by the TESS spacecraft providing high precision photometric data that allow us to measure their rotation periods.

Layout of observations

We request a total of 14 hours to observe 17 stars hosting EDDs using *FEROS*. Our observations will be carried out in the "object-sky" mode of the instrument. We will use the CERES tool ([1]) to extract the spectra and to determine RVs. Stellar parameters ($\log g$, $T_{\rm eff}$, and [Fe/H]) and projected rotational velocities ($v \sin i$) will be estimated using the ZASPE code ([2]). The derived stellar properties will allow us to refine our current photospheric models that are based on photometric data. By combining the measured radial velocities with astrometric data from the Gaia DR2 catalogue we will determine the stars' kinematic properties (galactic space motion). For age estimates then we will combine different empirical diagnostic methods based on the stars' lithium content, rotation (the rotation periods are determined based on the TESS light curves of the sources), rotation driven activity indicators, and stellar kinematics.

Strategic importance for MPIA

MPIA is at the forefront in modeling planet formation. Our proposed project will provide significant observational constraints on the formation of rocky planets around Sun-like main-sequence stars thereby supporting these modeling efforts.

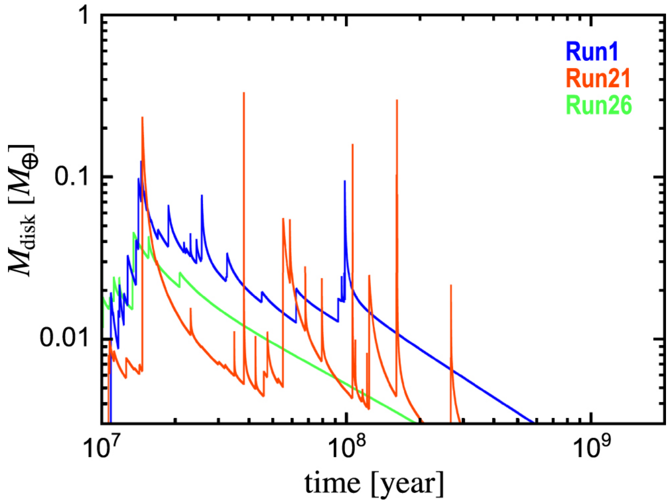

Figure 1: *Evolution of debris material produced in series of giant impacts happened in the terrestrial zone (between 0.5 and 1.5 au) around a 1 $M_\odot$ star (fig. 5 from [10]). Each spike corresponds to a large collision between planetary embryos. The plot shows results for three selected simulation runs from the 50 ones.*

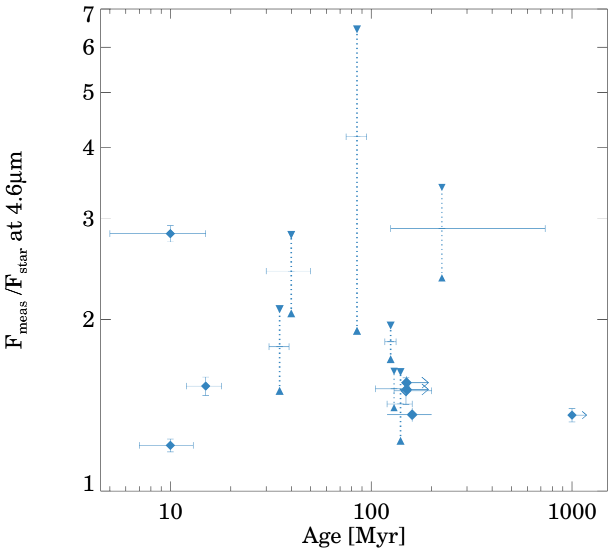

Figure 2: *Ratios of the measured 4.6μm WISE flux densities to stellar photospheric fluxes as a function of ages for the previously known fifteen extreme debris disks (Moór et al. in prep.). Variability level of sources – if they are variable – are shown by vertical dotted lines. Interestingly, the majority of these systems have ages falling between 100 and 300 Myr. This suggests a deviation from the current leading theories that predict a decay in intensity of rocky planet formation after 100 Myr.*

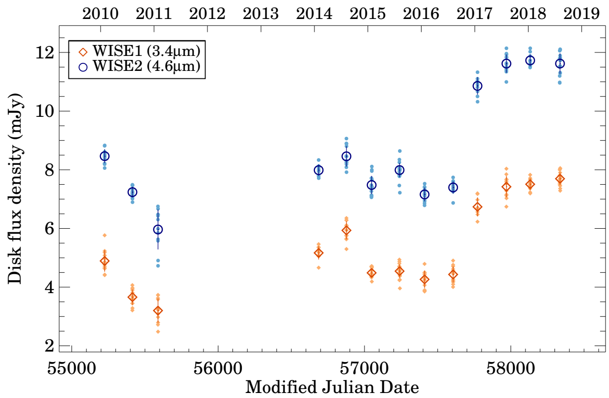

Figure 3: *Variation of disk flux density (the predicted photospheric fluxes have already been subtracted from the measured fluxes) in WISE W1 (3.4μm) and WISE W2 (4.6μm) bands as a function of time for one of our targets, J025411.56+055258.2. Smaller symbols show AllWISE and NEOWISE Reactivation single epoch data that have been gathered from the IRSA database, while larger symbols display the averages of the individual measurements obtained in a given observing window.*

9. Objects to be observed

(Objects to be observed with high priority should be marked in last column)

Designation	α (2000)	δ (2000)	magnitude in spectral range to be observed	priority
J025411.56+055258.2	$02^h\,54^m\,11\overset{s}{.}5$	$+05°\,52'\,59''$	V = 13.8	1
J035449.29-103544.1	$03^h\,54^m\,49\overset{s}{.}3$	$-10°\,35'\,44''$	V = 13.1	2
J052212.57+001334.8	$05^h\,22^m\,12\overset{s}{.}6$	$+00°\,13'\,35''$	V = 12.5	1
J053404.86-004017.2	$05^h\,34^m\,04\overset{s}{.}9$	$-00°\,40'\,17''$	V = 11.6	2
J060917.00-150808.5	$06^h\,09^m\,17\overset{s}{.}0$	$-15°\,08'\,09''$	V = 13.5	1
J065311.53+113256.5	$06^h\,53^m\,11\overset{s}{.}5$	$+11°\,32'\,57''$	V = 12.5	2
J071206.54-475242.3	$07^h\,12^m\,06\overset{s}{.}5$	$-47°\,52'\,42''$	V = 12.8	2
J082623.50-703143.1	$08^h\,26^m\,23\overset{s}{.}5$	$-70°\,31'\,43''$	V = 14.4	1
J082907.83+040810.6	$08^h\,29^m\,07\overset{s}{.}9$	$+04°\,08'\,11''$	V = 12.8	2
J090841.12-394220.2	$09^h\,08^m\,41\overset{s}{.}1$	$-39°\,42'\,20''$	V = 11.3	1
J113757.56-535003.8	$11^h\,37^m\,57\overset{s}{.}6$	$-53°\,50'\,04''$	V = 12.2	1
J145353.47-342127.7	$14^h\,53^m\,53\overset{s}{.}5$	$-34°\,21'\,28''$	V = 13.7	2
J150254.71-141250.4	$15^h\,02^m\,54\overset{s}{.}7$	$-14°\,12'\,50''$	V = 12.7	1
J190056.01-080352.6	$19^h\,00^m\,56\overset{s}{.}0$	$-08°\,03'\,52''$	V = 9.68	2
J204315.23+104335.3	$20^h\,43^m\,15\overset{s}{.}2$	$+10°\,43'\,36''$	V = 12.2	2
J214254.20-395400.0	$21^h\,42^m\,54\overset{s}{.}2$	$-39°\,54'\,00''$	V = 12.8	2
J220116.17-283008.7	$22^h\,01^m\,16\overset{s}{.}2$	$-28°\,30'\,09''$	V = 13.2	1

10. Justification of the amount of observing time requested:

Determination of precise radial velocity and study of lithium abundance requires high resolution spectroscopy. Most of our targets are relatively bright (V<13.0 mag.) and are located in the southern hemisphere making *FEROS* spectrograph ideal for our study.
In this application we propose to observe 18 stars. We plan to use the "object-sky" mode of the instrument with one fiber on the target and the other on the sky for telluric subtraction. To estimate the necessary integration times for our sources we used the FEROS Exposure Time Calculator. In the course of calculations we utilized the following basic settings: Moon phase of 0.5, airmass - 1.5, seeing - $1''.3$, CCD mode - 1×1 (Fast readout, low gain). Generally we require a signal-to-noise ratio of 70 or better at $\sim$6700 Å (for R=48,000). For stars fainter than V=13.2 mag we will bin the obtained spectra to achieve this requirement. The total requested observing time, taking into account the overheads (estimates using the p2ls tool), is 14 hours.

For the same sources we have an accepted proposal in P105, however its completion is uncertain due to the pandemic situation, that is why here we resubmit the complete proposal.

11. Constraints for scheduling observations for this application:

Given the wide range of our target RAs, we have no strict scheduling constrains. We note, however, that the observability of our sample is not identical throughout the offered period. Given the target RA's the best period would be between December 15 and February 20.

12. Observational experience of observer(s) named under 2.3:
(at least one observer must have sufficient experience)

Kossakowski has vast experience observing with HARPS.

13. Observing runs at the ESO 2.2m-telescope (preferably during the last 3 years)
and publications resulting from these

Telescope	instrument	date	hours	success rate	publications
2.2m	FEROS	Apr 2019-Mar 2020	31		[3, 7, 12]
3.6m	HARPS	Apr 2018-Sep 2018	9		[22, 23]
2.2m	FEROS	2018-ongoing	$\sim$460	$\sim$90%	[25], analysis ongoing
2.2m	FEROS	2017	9	100%	Analysis almost finished, paper in prep., PI: AMUELLER
2.2m	FEROS	N/A	many hours	N/A	[8, 11, 16, 17, 18, 19, 20]

14. References for items 8 and 13:

[1] Brahm, R., Jordán, A., & Espinoza, N. 2017, PASP, 129, c4002: *CERES: A Set of Automated Routines for Echelle Spectra*

[2] Brahm, R., et al. 2017, MNRAS, 467, 971: *ZASPE: A Code to Measure Stellar Atmospheric Parameters and their Covariance from Spectra*

[3] Brahm et al. 2019, AJ, 158, 45: *HD 1397b: A Transiting Warm Giant Planet Orbiting A $V = 7.8$ mag Subgiant Star Discovered by TESS*

[4] Canup, R. M. 2004, Icarus, 168, 433: *Simulations of a late lunar-forming impact*

[5] Chambers, J. E. & Wetherill, G. W. 1998, Icarus, 136, 304: *Making the Terrestrial Planets: N-Body Integrations of Planetary Embryos in Three Dimensions*

[6] Cutri, R. M., & et al. 2013, VizieR Online Data Catalog, II/328: *AllWISE Data Release*

[7] Espinoza et al. 2019, arXiv:1903.07694: *HD 213885b: A transiting 1-day-period super-Earth with an Earth-like composition around a bright (V=7.9) star unveiled by TESS*

[8] Fang et al. 2014, A&A 570, 118: *GW Orionis: Inner disk readjustments in a triple system*

[9] Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2018, A&A, 616, A1: *Gaia Data Release 2. Summary of the contents and survey properties*

[10] Genda, H., Kobayashi, H., & Kokubo, E. 2015, ApJ, 810, 136: *Warm Debris Disks Produced by Giant Impacts during Terrestrial Planet Formation*

[11] Kóspál et al. 2014, A&A 561, 61: *Radial velocity variations in the young eruptive star EX Lup*

[12] Kossakowski et al. 2019, MNRAS, 490, 1094: *TOI-150b and TOI-163b: two transiting hot Jupiters, one eccentric and one inflated, revealed by TESS near and at the edge of the JWST CVZ*

[13] Melis, C., et al. 2010, ApJL, 717, L57: *The Age of the HD 15407 System and The Epoch of Final Catastrophic Mass Accretion onto Terrestrial Planets Around Sun-like Stars*

[14] Meng, H. Y. A., et al. 2014, Science, 345, 1032: *Large impacts around a solar-analog star in the era of terrestrial planet formation*

[15] Meng, H. Y. A., et al. 2015, ApJ, 805, 77: *Planetary Collisions Outside the Solar System: Time Domain Characterization of Extreme Debris Disks*

[16] Müller et al. A&A 530, A8: *A young star has reached its rotational limit*

[17] Müller et al. 2011, A&A 535, 3: *HD 144432: A young triple system*

[18] Müller et al. 2013, A&A 556, 3: *Reanalysis of the FEROS observations of HIP 11952*

[19] Setiawan et al. 2007, ApJ 660, 145: *Evidence for a Planetary Companion around a Nearby Young Star*

[20] Setiawan et al. 2008, Nature 451, 38: *A young massive planet in a star-disk system*

[21] Su, K. Y. L., et al. 2019, AJ, 157, 202: *Extreme Debris Disk Variability: Exploring the Diverse Outcomes of Large Asteroid Impacts During the Era of Terrestrial Planet Formation*

[22] Trifonov et al. 2018, RNAAS, 2, 180: *New HARPS and FEROS Observations of GJ 1046*

[23] Wang et al. 2019, AJ, 157, 51:*HD 202772A b: A Transiting Hot Jupiter around a Bright, Mildly Evolved Star in a Visual Binary Discovered by TESS*

[24] Wyatt, M. C. & Jackson, A. P. 2016, Space Science Reviews, 205, 231: *Insights into Planet Formation from Debris Disks. II. Giant Impacts in Extrasolar Planetary Systems*

[25] Zakhozhay et al. 2019, A&A, in prep.: *Radial Velocity Survey for Planets around Young stars (RVSPY)*

Tolerance limits for planned observations:

maximum seeing: 1.5″	**minimum transparency:** 85%	**maximum airmass:** 2.0
photometric conditions: no	**moon: max. phase / ∠ :** 0.7/30°	**min. / max. lag:** 0/- nights