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	April 2022
Received	

APPLICATION FOR OBSERVING TIME

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

1. Telescope: 2.2-m [X]

2.1 Applicant

Dr. Thomas **Henning**	Max-Planck-Institut für Astronomie
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2.2 Collaborators

S. Marino / A. Kospal, D. Kossakowski	University of Cambridge / MPIA
name(s)	institute(s)
A. Muller, M. Schlecker / P. Abraham, A. Moor	MPIA / Konkoly Observatory
name(s)	institute(s)

2.3 Observers

	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 : **Age diagnostic of newly discovered extreme debris systems**

Abstract : The peculiarly dust-rich, warm 'Extreme debris disks (EDDs)' are likely formed in a recent giant collisional event occured in the inner disk. Such events may be related either to the formation of rocky planets (in young systems) or to a late rearrangement of the planetary system due to some dynamical instability (in old systems). Here we propose to use the *FEROS* spectrograph to obtain high-resolution optical spectra of the host stars of 8 EDD systems newly discovered by our group and determine their main stellar properties and ages. The obtained age information will allow us to assess which of the above scenarios can explain their origin, and together with the data of previously known extreme debris systems we can explore which mechanism is more common in the development of this phenomenon.

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

5. Brightness range of objects to be observed: from 11.6 to 12.9 R-mag

6. Number of hours:

applied for			already awarded	still needed
7.3			14	none
no restriction	grey	dark		

7. Optimum date range for the observations: .... 15.06.22 – 30.09.22
Usable range in local sideral time LST: .... 05:00h – 23:00h

Astrophysical context

The past decades have seen the discovery of 18 Sun-like (FGK-type) stars that are surrounded by unusual debris disks. They exhibit high dust temperature of >300 K, very high fractional luminosity of $\frac{L_{\rm dust}}{L_*} > 0.01$, and strong mid-IR solid state features, implying the presence of small, submicron-sized dust particles ([15, 16]). Mid-IR photometric monitoring revealed that most of these so called *extreme debris disks* (EDDs) display significant variability on monthly to yearly timescales ([23]). These properties cannot be explained by the steady state collisional evolution of an in situ planetesimal belt (an analog of our asteroid belt) but instead point to a recent dust production event – likely associated to a giant collision – in the terrestrial zone ([10]). In younger systems these disks are likely associated with the final chaotic growth of rocky planets (e.g. [13]), that are thought to be occured by collisions among planetary embryos emerged from the protoplanetary disk ([5]). Traces of such giant impacts can be found on most terrestrial planets in our Solar System ([27]). The most well-known example is the Earth-Moon system, whose formation was likely associated with such an event ([4]). However, the majority (∼60%) of the currently known EDDs are older than 100 Myr ([16, 14]), by which time the intensity of the rocky planet formation processes may significantly decay ([21], Figure 1). Thus, some of the latter disks may rather be linked to the rearrangement of a planetary system following a late dynamical instability ([16]), e.g. analogous to the hypothesized Late Heavy Bombardment in our solar system ([26]).

Immediate aim

Aimed at constructing a comprehensive list of EDDs around Sun-like stars (F5-K7 type), our group discovered 36 new EDDs (see *Previous work*). In order to assess the origin of these disks, it is necessary to know the properties of their host stars, in particular their age. To this end, here we propose to continue our successful use of the *FEROS* spectrograph at the MPG/ESO 2.2m telescope to obtain high-resolution optical spectra of EDD host stars. Using these data we will 1) measure the strength of the lithium line at 6708 Å, one of the best age indicators for the given spectral type range, 2) determine effective temperature, surface gravity, and metallicity of the stars, and 3) measure their projected rotational and radial velocities (RV). For age dating, the lithium method will be combined with other diagnostics that are based on gyrochronology, isochrone fitting, and kinematic properties of the stars. Based on the results we will be able to assess which formation scenario explains the different disks. Using the new database of EDDs we will also examine how the level of EDDs' mid-IR variability depends on the age and other properties of the host stars.

In a previous observing run (see *Previous work*), we have already obtained *FEROS* spectra for 16 newly discovered EDDs located at $\delta < 25°$. In the current project, observations are requested for 8 additional objects (4 G- and 4 K-type stars) that could not be observed earlier.

Previous work

Using a combined data set, based on the WISE mid-infrared photometric (AllWISE, [6]) and Gaia EDR3 astrometric ([9]) catalogues, we identified 36 new EDDs. All of these newly discovered warm, dust-rich disks surround F5-K7 type main-sequence stars that are within 400 pc. Out of this sample, 24 objects are located at declinations south of +25°. In the framework of project 0106.A-9012 (PI: Sebastian Marino) we were granted 14 hours of *FEROS* time to observe 16 among these targets, that were visible from La Silla in the given period. Interestingly, in this new sample we found an even higher proportion of objects older than 100 Myr (13/16) and there are three systems that are at least as old as our solar system. This suggests that late instabilities may play an even greater role in the formation of EDDs that was previously thought.

Layout of observations

We request a total of 7.3 hours to observe 8 stars hosting EDDs using the *FEROS* spectrograph. 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 EDR3 catalogue we will determine the stars' kinematic properties. 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), and stellar kinematics.

Strategic importance for MPIA

Study of planetary systems is a strategic research line of the MPIA. Extreme debris disks are the best signposts of recent large collisonal events which are thought to be linked to the formation of rocky planets around young stars or to late instabilities in mature planetary systems. Our proposed project will provide significant observational constraints on the formation of such disks around Sun-like stars thereby supporting a better understanding the birth and evolution of planetary systems.

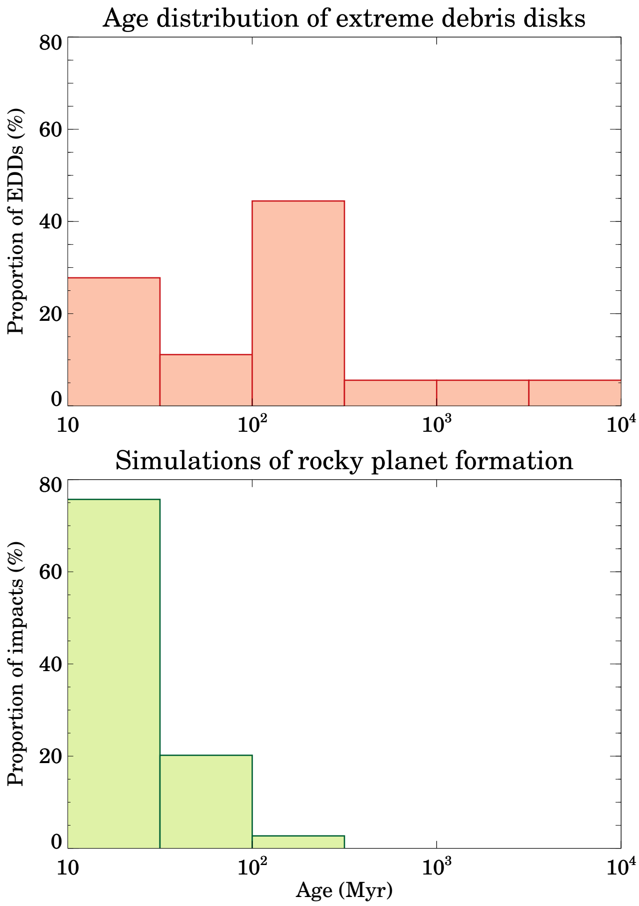

Figure 1: *Top panel - Age distribution of 18 extreme debris disks discovered prior to our study (the data were taken from [16, 14]). Bottom panel - Age distribution of giant collisional events based on numerical simulations of rocky planet formation ([21]). These simulations predict that the majority of giant impacts happen within 100 Myr, mostly in the first 20 Myr, which is in good agreement with observations from the Solar System. However, only a third of the stars in the EDD sample are younger than 100 Myr, the majority of these systems are older than this age. The observed difference in age distributions suggests that some other mechanisms, which is activated later in the systems' evolution, may also be involved in the formation of EDDs.*

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
Name	h^{h} m^{m} s^{s}.fract s	d° $''$ $"''$	mag	priority
J033348.59-073553.6	$03^{\mathrm{h}}\,33^{\mathrm{m}}\,48\overset{\mathrm{s}}{.}6$	$-07^{\circ}\,35'\,54''$	R = 12.1	2
J041517.28+051910.2	$04^{\mathrm{h}}\,15^{\mathrm{m}}\,17\overset{\mathrm{s}}{.}3$	$+05^{\circ}\,19'\,11''$	R = 12.5	2
J072028.10-552703.0	$07^{\mathrm{h}}\,20^{\mathrm{m}}\,28\overset{\mathrm{s}}{.}1$	$-55^{\circ}\,27'\,03''$	R = 12.9	2
J131338.96-193804.5	$13^{\mathrm{h}}\,13^{\mathrm{m}}\,39\overset{\mathrm{s}}{.}0$	$-19^{\circ}\,38'\,05''$	R = 12.3	1
J165502.73-594903.3	$16^{\mathrm{h}}\,55^{\mathrm{m}}\,02\overset{\mathrm{s}}{.}7$	$-59^{\circ}\,49'\,03''$	R = 12.1	1
J204315.23+104335.3	$20^{\mathrm{h}}\,43^{\mathrm{m}}\,15\overset{\mathrm{s}}{.}2$	$+10^{\circ}\,43'\,36''$	R = 11.6	1
J214254.20-395400.0	$21^{\mathrm{h}}\,42^{\mathrm{m}}\,54\overset{\mathrm{s}}{.}2$	$-39^{\circ}\,54'\,00''$	R = 12.5	2
J220116.17-283008.7	$22^{\mathrm{h}}\,01^{\mathrm{m}}\,16\overset{\mathrm{s}}{.}2$	$-28^{\circ}\,30'\,09''$	R = 12.8	1

10. **Justification of the amount of observing time requested:**

Determination of precise radial velocity and study of lithium abundance requires high resolution spectroscopy making *FEROS* spectrograph ideal for our study.
In this application we propose to observe 8 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). The total requested observing time, including 10 mins per target for overhead, is 7.3 hours.

11. **Constraints for scheduling observations for this application:**

Given the wide range of our target RAs, we have no strict scheduling constrains.

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-telscope (preferably during the last 3 years) and publications resulting from these**

Telescope	instrument	date	hours	success rate	publications
2.2m	FEROS	2021-Feb	14		Analysis finished, paper in prep., (PI: S. Marino)
2.2m	FEROS	Apr 2019-Mar 2020	31		[3, 7, 12]
2.2m	FEROS	2018-ongoing	~460	~90%	[28], analysis ongoing
2.2m	FEROS	2017	9	100%	Analysis almost finished, paper in prep., (PI: A. Müller)
2.2m	FEROS	N/A	many hours	N/A	[8, 11, 17, 18, 19, 20, 22]

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] Jackson, A. P. & Wyatt, M. C. 2012, MNRAS, 425, 657: *Debris from terrestrial planet formation: the Moon-forming collision*

[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] Melis, C., et al. 2021, arXiv:2104.06448: *Highly structured inner planetary system debris around the intermediate age Sun-like star TYC 8830 410 1*

[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] Moór, A., et al. 2021, ApJ, 910, 27: *A New Sample of Warm Extreme Debris Disks from the ALLWISE Catalog*

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

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

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

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

[21] Quintana et al. 2016, ApJ 821, 126: *The Frequency of Giant Impacts on Earth-like Worlds*

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

[23] 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*

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

[25] 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*

[26] Wyatt, M. C. et al. 2007, ApJ, 658, 569: *Transience of Hot Dust around Sun-like Stars*

[27] 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*

[28] 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