
The Formation of Planets:
The Critical First Growth Phase
Proposal for Funding of a
Forschergruppe
Universität Tübingen
Universität Heidelberg
Technische Universität Braunschweig
Universität Münster
Max-Planck-Institut für Astronomie

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Front page image: *"Beyond the Realm of the Giants" by Mark Garlick. This painting gives an artist's impression of Kuiper belt objects in our solar system, which are left-overs from the planet formation era. These icy objects are examples of the "planetesimals" at the center of this Forschergruppe. Since the painting also shows some amounts of dust, this painting also symbolizes the process of formation from dust to planetesimals.*

Planet Formation Witnesses and Probes: Transition Discs

Proposal for Funding of a Forschergruppe

Speaker: B. Ercolano

Co-speaker: C. P. Dullemond

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Project Descriptions

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Project B1:
oss from quantitative spectroscopy of photoevapo

Authors:

PI:	B. Ercolano (LMU)
Co-I:	P. Caselli (MPE), K. Dullemond (Heidelberg), Kley (Tübingen)
Collaborations:	T. Preibisch (LMU), L. Testi (ESO), James Owen (Princeton), E. van Dishoeck (Leiden, MPE), T. Henning (MPIA)

Requested positions: 1 Postdoc

Abstract:

Abstract:
Type 1 TDs are likely discs in an advanced stage of dispersal. The dispersal mechanism of discs is of fundamental importance to planet formation, yet the responsible mechanism is still largely unconstrained. Photoevaporation from the central star is currently a promising avenue to investigate. We aim at building the most up-to-date radiation-hydrodynamical calculations of irradiated discs coupled to photoionisation, chemistry and radiative transfer calculations to allow us for the first time to perform quantitative spectroscopy of disc winds. Comparison with existing observations will allow us to constrain mass loss rates and emission regions of the wind which will pin down the underlying driving disc dispersal mechanism.

1. State of the art and preliminary work

1.1 Scientific Background

Understanding disc dispersal is a key piece in the puzzle of planet formation. Type 1 TDs, which are considered to be objects on the verge of dispersal provide a tight constrain on the underlaying dispersal mechanism. One of the favourite models to drive disc dispersal is photoevaporation by radiation from the central star (e.g. Clarke et al. 2001, Alexander et al. 2006). The exact nature of the driving radiation is however still open to debate. (Extreme and Far) Ultraviolet (UV) radiation as well as X-ray have been shown to be able to drive winds from the disc upper layers (Alexander et al. 2006; Gorti, Hollenbach & Dullemond 2009; Ercolano et al. 2009; Owen et al. 2010) able to disperse the discs in the observed timescales. However both the location and intensity of the wind depend strongly on the driving radiation, with differences of more than two orders of magnitude for mass loss rates predicted by different models. This has profound implications for disc evolution and hence for the formation of planets and their subsequent evolution (e.g. Ercolano & Rosotti 2015).

While the presence of disc winds has been confirmed via the observation of a few km/sec blue-shift in the line profiles of a number of tracers like [NeII] 12.8μm and [OI] 6300 (e.g. Pascucci et al 2007), these lines cannot be used to infer the underlying mass-loss-rate (e.g. Ercolano & Owen 2010, Ercolano & Owen 2016). For example, the intensity and the profile of the [NeII] 12.8μm can be equally well fitted using an EUV (Alexander ???) or an X-ray photoevaporation model (Ercolano & Owen 2010). The problem with the [NeII] line is that the Ne+ formation route can occur both via the removal of a valence electron in the fully-ionised winds driven by EUV radiation, but also by charge exchange of Ne++ with neutral H which is abundant in the quasi-neutral winds driven by X-ray. The problem with the [OI] 6300 line and all other ionic collisionally excited lines considered to date is the strong temperature dependence imposed by the Boltzmann term in the emissivity. This means that these lines are mostly just tracing the hot layer of the wind heated by the EUV radiation and not actually tracing the bulk of the wind where it matters (Ercolano & Owen 2016), hence they cannot be used to infer mass-loss-rates or to constrain the wind driving mechanism.

Mid-infrared observations of molecular lines (e.g. CO) provide a new promising alternative to directly measure disc winds. Indeed recent observations suggest that these lines may be tracing a disc wind which is slow and partially molecular (e.g. Pontoppidan et al. 2011; Brown et al. 2013).

The spectro-astrometric survey of molecular gas in the inner regions of protoplanetary discs using CRIRES, the high-resolution infrared imaging spectrometer on the Very Large Telescope (Pontoppidan et al. 2011), showed that for several sources the astrometric signatures are dominated by gas with strong non-Keplerian (radial) motions. These authors concluded that the non-Keplerian spectro-astrometric signatures are likely indicative of the presence of wide-angle disc winds. More observations of this type are planned after the update of the CRIRES instrument, which is expected to be completed by 2019. Observations with ALMA in molecular lines like e.g. CO J = 2-1 and J = 3-2 emission are also able to trace the presence of a wind (e.g.Klaassen et al. 2013, 2016). Molecular lines are sensitive to the mass loss rates since they sample a significant area of the wind launching regions. However the exploitation of molecular tracers is currently severely hampered by the lack of a suitable hydrodynamic wind model coupled to chemistry and to dust evolution models (which dominate the opacity in the wind) to interpret the observations.

While a number of chemical models exist of the deeper, denser regions of discs, no model is currently available for the optically thinner disc winds. The work of Gorti & Hollenbach (2009), while carrying out detailed chemical calculations extending to the disc atmosphere, used a hydrostatic disc model which was analysed in a 1+1D fashion. Without hydrodynamics no predictions on line profiles can be made.

here add something about why all models lack elements -

also perhaps mention something about the work on single streamlines for magnetic outflows – ewine –

1.2 Preliminary work

We have performed the only existing radiation hydrodynamic calculations of X-ray driven photoevaporative winds to date (Owen et al. 2010, 2011, 2012). We have used these grids to make predictions on the ionised phase of the wind spectra (Ercolano & Owen 2010; Ercolano & Owen

2016), however the parameter space available to date is very limited.

In this project we will significantly expand on this by constructing a library of X-ray wind solutions for an extended grid of X-ray luminosities and stellar masses, covering all observed values. Our previous calculations could only account for the ionised phase of the wind, hence restricting severely predictions of interesting line diagnostic. We will then lift this limitation by perform the first simultaneous chemical calculations in the wind and upper disc atmosphere.

1.3 Project-related publications

[Text]

1.3.1 Articles published or officially accepted by publication outlets with scientific quality assurance; book publications [Text]

1.3.2 Other publications [Text]

1.3.3 Patents

1.3.3.1 Pending

[Text]

1.3.3.2 Issued

[Text]

2. Objectives and work programme

2.1 Anticipated total duration of the project

[Text]

2.2 Objectives

The main aim of this project is together with project B2 to identify new wind tracers and use them to constrain mass loss rates and hence disc dispersal models.

Furthermore an intermediate objective test the X-ray photoevaporation theory by performing a higher parameter space grid blahblah

is this really true? or should this be the aim of B2?? Perhaps look at how this was described in the ERC program?

Perform a quantitative spectroscopic comparison between TDs and primordial disc to provide important constraints on the wind architecture. Type 1 TDs, are particularly interesting as the streamline architecture of their winds and the profiles of the lines that are produced in the wind differ from those of primordial discs. (e.g. Ercolano & Owen 2010). Indeed the lines are expected to be broader and brighter for e.g. inner cavities of a few to 10 AUs.

Test whether Type 2 TDs (large holes, large accretion rates) may result from radiative transfer effects on a tilted inner disc. This idea stems from the recent suggestion (e.g. Marino et al. 2015, Montesino et al. 2016) that some Type 2 TDs may have a tilted inner disc. A tilted inner disc may strongly influence photoevaporation by allowing radiation to reach outer disc regions and may produce the large inner holes of (some) Type 2 TDs. This is certainly a worthwhile new challenge requiring the development of 3D simulations.

the marino and montesino idea must also be included in the intro and also in the background section of this proposal

2.3 Work programme including proposed research methods

2.4 Research Tools

For this project we will need the following tools:

1. A 3D hydrodynamical code which we will modify to include the effects of X-ray irradiation as we did in Owen et al. (2010). For that we will use the Pluto code, for which extensive expertise exists in our team.

2. A 3D photoionisation and chemical code to post-process the wind solutions obtained above. The PI is the author of the MOCASSIN code (Ercolano et al. 2003, 2005, 2008b), which has already been used to calculate the emission line spectra from the ionic phase of X-ray winds (Ercolano & Owen 2010; Ercolano, Owen & Testi 2016, in prep). The code has now been coupled and benchmarked to the KROME code to perform arbitrary chemical calculations (Ercolano & Grassi 2016, in prep) and needs now only the appropriate reduced chemical network, which we will obtain from project B2.

3. A 3D radiative transfer code to post-post-process the hydrodynamical grids from step 1, with the appropriate temperatures and abundances obtained from step 2 to produce emission line intensities and profiles to compare with the existing observations and those gathered and reprocessed in project A1. We will make use of the RadMC code developed and maintained by Prof. Dullemond.

2.5 Research Plan

We have divided the work load into two connected blocks which also have self-contained immediate objectives. Block 1 is already being executed by Dr Picogna, employed on a LMUExcellent initiative grant awarded to B. Ercolano in support of this project (End date November 2017).

quickly describe the blocks

2.5.1 Block 1: Parameter-space investigations of X-ray photoevaporation models. The 3D hydrodynamical code PLUTO is being modified to include the effects of X-ray irradiation (Owen et al. 2010) in order to produce a library of X-ray wind solutions that will be analysed in Block 2 to produce emission line and continuum spectra of the wind. The obtained solutions will be first of all benchmarked against those that are already available for a 0.7 and 0.1 $M_\odot$ central stars (Owen et al. 2010, 2011, 2012). The parameter space will be then significantly extended for the mass of the central star and its X-ray luminosity. With the new

models we will also test the theoretical relations for X-ray photoevaporation predicted by means of semi-analytical models and ab-initio arguments by Owen et al. (2012). While these relations are being widely used in the literature, they have until now never been tested.
As a further step we plan to perform a small set of 3D simulations to explore the effects of asymmetries in the inner disc. We expect to see dramatic effects in the photoevaporation profile and in the wind architecture, which may lead to the formation of large hole TDs. This avenue is never been explored before.

2.5.2 Block 2: Spectral line energy distribution calculations of disc winds.

The MOCASSIN code (Ercolano et al. 2003, 2005, 2008b), which has already been used to calculate the emission line spectra from the ionic phase of X-ray winds (Ercolano & Owen 2010; Ercolano & Owen 2016). The code has now been coupled and benchmarked to the KROME code (Grassi et al., 2014) to perform arbitrary chemical calculations (Ercolano & Grassi 2016, in prep) and needs now only the appropriate reduced chemical network, which we will obtain from B2.

The new KROME-coupled MOCASSIN code will be employed to perform photoionisation and chemical calculations disc wind solutions starting off from the available models of Owen et al. (2010, 2011, 2012) and then moving to the new data obtained in Block 1 (which is already being executed). To this aim, under the guidance of Prof Caselli, an initially very simple network will be included in the MOCASSIN-KROME to perform initial test calculations, which will then be updated when project B2 begins to provide results. As a final step in the post-processing with the help of Prof Dullemond we will perform 3D radiative transfer calculations to produce line intensities and profiles to compare with existing and new observations, which may become available at the time.

all of the above needs to be reviewed - see also if some of it should go into B2 - and also give approximate timelines

2.6 Data handling

A library of models with corresponding profiles for interesting emission lines will be made available online on the public partition of the Research Unit server. This will help the community with the interpretation of upcoming observational datasets.

2.7 Other information

Not Relevant

2.8 Information on scientific and financial involvement of international cooperation partners

Not Relevant

3. Bibliography

[Text]

4. Requested modules/funds

4.1 Basic Module

4.1.1 Funding for Staff We require funding for one Postdoc to work at the LMU in the group of Prof. Ercolano.

4.1.2 Direct Project Costs

4.1.2.1 Equipment up to EUR 10,000, Software and Consumables

Will be provided by the host institution

4.1.2.2 Travel Expenses

Total: 9900 Euro Justification : Each year one national trip (meeting of Astronomical Society, national meetings) and one international trip (conference, visit collaborators). During the course of the PhD 2 one week long visits to our main international collaborator, Dr J. Owen (currently at Princeton University, will move to Imperial College London in 2017).
Cost estimate:

- National trip: 5 overnight stays, train/airfare, conference fee; 1000 Euro (3000 over 3 years).
- International trip: 6 overnight stays, airfare, conference fee; 1500 Euro (4500 over 3 years).
- Visit to/from J. Oweni: airfare, 6 overnight stay 1200 Euro (2400 for 2 visits)

4.1.2.3 Visiting Researchers (excluding Mercator Fellows)

Not Relevant

4.1.2.4 Other Costs

None

4.1.2.5 Project-related publication expenses

We request 770 Euro py (total 2250 Euro) for publication expenses.

4.1.3 Instrumentation None

4.1.3.1 Equipment exceeding EUR 10,000

None

4.1.3.2 Major Instrumentation exceeding EUR 100,000

None

4.2 Module Temporary Position

Not Relevant

4.3 Module Replacement Funding

Not Relevant

4.4 Module Mercator Fellows

Not Relevant

4.5 Module Public Relations Funding

Not Relevant

5. Project requirements

5.1 Employment status information

Barbara Ercolano, Professor at the Ludwig-Maximilians-Universität München (permanent)

5.2 First-time proposal data

Not Relevant

5.3 Composition of the project group

[Text]

5.4 Cooperation with other researchers

5.4.1 Planned cooperation on this project

5.4.1.1 Collaborating researchers for this project within the Research Unit

This project depends on project B2 for the reduced network and on project A2 for the observational input. Furthermore Dr James Owen (Princeton) will be heavily involved in the project.

expand

5.4.1.2 Collaborating researchers for this project outside of the Research Unit

Dr. James Owen, currently at Princeton University, from 2017 at Imperial College London.

Expand above - mention James' contributions to the state of the art and his likely contribution to the project - mention visits

5.4.2 Researchers with whom you have collaborated scientifically within the past three years F. Niederhofer (STSci, USA); M. Hilker (ESO, Garching); N. Bastian (U. Liverpool, UK); M. Guarcello (U. Palermo, Italy); M. Tazzari (U. Cambridge, UK); A. Natta (Florence, Italy); R. Alexander (U. Leicester); D. Hubber (LMU); J. Dale (U. Hertfordshire, UK); C.

Koepferl (LMU); I. Bonnell (U. St. Andrews, UK); A. McLeod (ESO, Garching); D. Boneberg (U. Cambridge, UK); R. Parker (U. Liverpool, UK); R. Wesson (UCL, London, UK); M. Barlow (UCL, London, UK); A. Glassgold (u. Berkeley, USA); C. Manara (ESA, Noordwjik, Netherlands); A. Danekhar (CfA, Harward, USA); Q. Parker (Sidney, Australia); S. Casassus (U. de Chile, Santiago, Chile); I. Pascucci (U. Arizona, USA); A. Bevan (UCL, London, UK).

5.5 Scientific equipment

The group of Prof. Ercolano has two own computer clusters comprising

- 2 CPU Intel Xeon X5650 (Westmere, beginning 2010, 2.66 GHz) 6 cores each 12 cores total (24 virtual) 74 GB ram.
- 4 CPU Intel Xeon E7-4850 (Ivy Bridge, beginning 2014, 2.30 GHz) 12 cores each 48 cores total (96 virtual) 660 GB ram.

Further computational power is provided through the C2PAP facility of the Excellence Cluster to which the group has guaranteed time. This comprises 126 nodes, each node with 2 CPU Intel Xeon E5-2680 (Sandy Bridge, beginning 2012, 2.7 GHz) 8 cores each 16 cores total (32 virtual) 64 GB ram. Note that while the future of the Excellence Cluster Universe is uncertain, the C2PAP facilities will be in any case supported by the LMU.

The Leibniz Rechnung Zentrum (LRZ) is also available to us, where still larger facilities are available with somewhat more constrained and longer queues.

5.6 Project-relevant interests in commercial enterprises

Not Relevant

5.7 Additional information

Not Relevant