Project C2: Gone with the wind: Dust entrainment in photoevaporative winds

Authors:
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Requested positions: 1PhD student

Abstract:

The search for the smoking gun of disc dispersal via photoevaporative winds, which destroy discs via the formation of Type 1 TDs, has until now failed to identify suitable tracers. Quantitative spectroscopy of YSOs to search for blue-shifted emission lines produced in the wind relies on an accurate characterisation of the thermochemical properties of the winds. A central ingredients for the chemical calculations is the dust content of the wind as micron sized grains provide the dominant opacity channel in the far-ultraviolet, furthermore small particles are important players in the temperature balance of the gas via the photoelectric process.

We will use realistic radiation-hydrodynamic models of photoevaporative winds coupled to dust evolution models for the underlying grain distribution in the disc, to calculate the dust entrainment in winds to feed to chemical models. The observability of the continuum emission due to the dust grains in winds from edge-on discs, a potential new diagnostic, will be estimated both for Herbig Ae stars and for their fainter T-Tauri counterparts.

1. State of the art and preliminary work

The dispersal of protoplanetary discs plays a crucial role in the planet formation process, and leads to the formation of Type 1 TDs. While photoevaporation from the central star has been proposed as the dominant disc-dispersal mechanism around low-mass stars (e.g. Clarke et 2001), to date only tentative evidence exists of a wind detection, via blue-shifted forbidden line emission of mostly NeII and OI (e.g. Hartigan, Edwards & Ghandour 1995; Alexander 2008; Pascucci & Sterzik 2009; Schisano, Ercolano & Guedel 2010; Ercolano & Owen 2010, 2016). These lines can only probe the wind on very local scales and they cannot be inverted to obtain mass loss rates, which are crucial to pin down the dominating mechanism which drives the disc photoevaporative wind (i.e. EUV, FUV or X-ray - or a combination). Different driving mechanism induce more or less vigorous mass loss at different disc radii, which can have dramatic effect on planet formation, both at the times of planetesimal assembly and for the later dynamical evolution of planet(esimal)s (e.g. Ercolano & Rosotti 2015).

Owen, Ercolano & Clarke (2011b) demonstrated that in the case of Herbig Ae/Be stars an EUV-driven wind, the wind selectively entrains grains of different sizes at different radii resulting in a dust population that varies spatially and increases with height above the disc at radii larger than about 10 AU. At near infrared wavelengths this variable grain population produces a 'wingnut' morphology which may have already been observed in the case of PDS 144N (Perrin et al. 2006). The work of Owen et al. (2011b) could not however reproduce the colour gradient of the observations, which show redder emission at larger heights above the disc. Possibly, the problem was due to the fact that the synthetic images were dominated by emission from the smallest grains entrained in the flow. Grain growth, neglected in the Owen et al. (2011b) calculations in the disc is a natural solution to the colour problem, which needs to be taken into account in future simulations.

While it is currently not clear if the PDS 144N observation can be explained by dust entrainment in a photoevaporative wind, the work of Owen, Ercolano & Clarke (2011b) has clearly demonstrated that a significant amount of small grains (which dominate the opacity in the FUV) do populate disc winds, hence playing an important part in the chemistry there and at the base of the flow.

1.1 Dust-entrainment in winds: modelling strategies

1.1.1 Analytical approach

Describe approach used in Owen, Ercolano & Clarke 2011b

–why can we decouple photoevaporation calculations from dust entrainment calculation and why is it necessary to do so for our aims

– discuss shortcomings of current models: The Owen, Ercolano & Clarke (2011b) calculation are limited to the EUV-case only and do not include dust-evolution in the underlying disc, for these reasons their applicability to models aiming at quantitative spectroscopy of disc winds is rather limited.

1.1.2 Numerical approach

Dust could be modeled self-consistently in the radiation hydrodynamical simulations -

– mention if this could be done in B1 – Giovanni??? 2 fluid approach or particle approach? – should we do that for selected cases?

– Recently Hutchison et al. (2016a, b) have employed SPH .... blahblahblah

– describe briefly technique and most important results

– describe why we do not wish to use sph for our models

1.2 Grain sizes and abundances at the base of the wind

There are basically two approaches - to zeroth order one can use 1d dust evolution models to set the abundance and size distribution at the base of the flow. For that it is enough to use Birnstiel, Klahr & Ercolano 2012.

– describe what this paper does

A more sofisticated approach is to use 2d models which resolve the vertical abundance and size distribution of the grains.

– describe such a model – what is the state of the art on this? –

– is the development of a 2d model the object of the C1 project?

– how likely it is that one could also find some kind of parameterisation that could be easily coupled to the grian entrainment calculations?

In this project we aim to determine the dust content of photoevaporative winds for the EUV and X-ray case for a range of stellar, disc and wind parameters, using realistic descriptions for grain growth in the underlying disc.

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

36 months

2.2 Objectives

In this project we aim to determine the dust content of photoevaporative winds for the EUV and X-ray case for a range of stellar, disc and wind parameters, using realistic descriptions for grain growth in the underlying disc.

This will allow us to :

1. Build a dust model for photoevaporative winds to be used in chemical calculations.
2. Estimate the observability and observation characteristics of the dust phase in photoevaporative winds.

2.3 Work programme including proposed research methods

In this project we will use the analytical approach described in Section 1.1.1 coupled to models for the evolution of dust grains in the disc in order to efficiently produce dust entrainment models for the complete set of X-ray photoevaporation wind solutions calculated in project B1.

The work will be carried out by a PhD student co-supervised by Prof. Ercolano (LMU) and Prof. Birnstiel (LMU), who will provide guidance, respectively, on the dust entrainment calculations and the coupling with the dust evolution models for the underlying disc.

2.4 Research Tools

For this project we will need the following tools:

1. Photoevaporative wind solutions for EUV-driven models for T-Tauri and Herbig stars. These are available in the literature (e.g. Font et al. ???) .

2. Photoevaporative wind solutions for X-ray photoevaporated models. These will be provided from project B1.

3. Parameterised dust growth models in one dimension. These are available in the literature (Birnstiel, Klahr & Ercolano, 2012)

4. Two-dimensional dust evolution results from project C1.

5. A 3D radiative transfer code to post-postprocess the wind models with the calculated grain populations. We will make use of the RadMC code developed and maintained by Prof. Dullemond (e.g. REF?????).

2.5 Research Plan

The project will proceed in stages of increasing complexity. We will start by setting up a framework that can be benchmarked against available calculations and progressively adding new elements, as they become available from other sub-projects. The plan has been designed to fit a PhD student, who will have the opportunity to develop a new theoretical model as well as acquainting her/himself with standard numerical techniques (e.g. radiation-hydrodynamics, dust evolution models, radiative transfer).

The most important science product from this project is the set of grain models developed for the X-ray driven wind. These are needed by project B2 for the chemical calculations, as the dust grains dominating the opacities in the FUV are not equally distributed in the wind (see e.g. Owen, Ercolano & Clarke, 2011b, Hutchison et al. 2016ab) and they thus affect the chemistry in the wind differently in different parts.

2.5.1 Months 1-12

The student will start by producing wind solution for the EUV case from the work of Font et al. (2004), which may be applicable to Herbig stars. She/he will then proceed to calculate the dust distribution in the wind, under simplifying assumptions for the underlying dust distributions as in Owen et al (2011b). In brief, streamlines from the base of the flow to the edge of the grid will be computed and along each of them, the force balance between the drag force, gravity and the centrifugal force will be calculated. A positive net force on a grain along the streamline will indicate that the grain is entrained.

Once dust abundance and size distributions have been obtained for the wind, radiative transfer calculations will be performed to produce synthetic continuum observations at several disc inclinations. These first models will be benchmarked against the solutions of Owen et al. (2011b).

After the benchmarking tests, the framework will be applied, for the first time to the X-ray phtoevaporation case. For testing purposes the student may at first make use of the existing wind solutions of Owen et al. (2010, 2011, 2012), until new wind solutions become available form sub-project B1. This step will probably however be skipped as the new wind models for the X-ray case are already being calculated by Dr Picogna, who is employed to do the preparatory work from project B1. It is therefore likely that an initial set of high resolution new X-ray wind solution will already be available to the student right from the start of the project.

2.5.2 Months 13-24

The student will then be in a position to significantly improve on this work by considering more realistic grain abundances and size distributions for the underlying disc. She/He will first couple the grain entrainment calculations to of simple prescriptions of dust evolution (e.g. Birnstiel, Klahr & Ercolano 2012) obtained from the one-dimensional models of REF?????.

At a later stage the models will use the results from the two-dimensional calculations of dust evolution carried out in project C1.

– will we also get prescriptions from these???

– if not how can these be coupled???

2.5.3 Months 25-36

In the last year the whole machinery will be in place. The student will now be able apply it to a wide parameter space of disc winds, performing radiative transfer calculations of the obtained structures to compare with available observations or to make observability predictions which may guide future observing proposals. We will join forces with expert collaborators on scattered light observations (e.g. Prof. Henning) to plan new proposals, however we note that failure to obtain new observations does not preclude the main aims of this projects to be achieved.

If time allows, the student will collaborate with Dr Picogna (B1) to produce full hydrodynamical simulations of disc winds, where the dust component in the disc and wind is treated as particles (e.g. Picogna & Kley 2016). These calculations, which are computationally very expensive will be useful as a comparison to the simpler methods previously developed by the student in the project.

2.6 Data handling

The model data-grids will be made available on the Research Unit dedicated server for use within the team.

Furthermore we will provide a set of diagnostic models to guide observers in the wider community on the public partition of the server.

Til can we also provide perhaps other useful data from the dust models?

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 PhD student to be supervised at the LMU jointly by Prof. Birnstiel and 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)
Tilmann Birnstiel, 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

Expand below - include the researchers that are linked to the various projects
The project will use the wind models calculated in project B1 and then feed back the dust model to the same project (B1) and to the reduced chemical network tests of project B2. Dust evolution calculations from C1 will also be used. Observational constraints will be obtained in collaboration with experts working on project A1 and stellar properties to guide the models from project A2.

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 longer queues. It is unlikely that we will need to use these.

5.6 Project-relevant interests in commercial enterprises

Not Relevant

5.7 Additional information

Not Relevant