D2P: From Dust to Planets

Summary:

Our CNRS-PICS project aims at coordinating and at supporting the collaborative efforts developed between two groups of the institute of Planetology and Astrophysics of Grenoble in France (IPAG) and the Max Planck Institute for Astronomy of Heidelberg (MPIA), in Germany. Both groups are experts in the field of exo-planet detection and characterization, and disk characterization and modeling. Our goal is to provide support for researchers, post-docs and students exchanges, for the organization of several thematic workshops and one yearly colloquium between Grenoble and Heidelberg over 2013 and 2016. The objectives are to strengthen our common leadership on a competitive international scene. We will prepare the scientific exploitation of upcoming European instruments and we will coordinate our efforts for the instrumental prospective of both institutes in the field of exo-planetalogy and stellar formation.

1. Scientific Project:

1.1 Astrophysical Context

Understanding how exo-planets form, evolve and are structured is one of the biggest challenges of modern astronomy. This major goal is directly connected to the ultimate search for Life over the Horizon 2030. Nevertheless, several steps, (formation, evolution, dynamics, structure and atmosphere), biological (bio-markers) and technical (new technologies developed for next generation of instrumentation), must be carried out in that perspective. We need to understand the initial conditions favorable for planetary formation, how giant and telluric planets are formed and structured, how they evolve and interact as they will dramatically shape the planetary system architecture and therefore the possibility to form telluric planets capable to host Life.

Since the discovery of the first exo-planet around the star 51 Peg (Mayor & Queloz 1995), our understanding of the origin and properties of exo-planets has fundamentally evolved. The existence of hot Jupiters has revealed the premise of an unexpected variety of planetary systems. We know that planetary systems are not rare. Their occurrence actually depends on the host star properties such as the metallicity, the mass or the multiplicity. Multiple planetary systems have been discovered. The atmosphere and the structure of giant irradiated planets have even been probed and studied. Finally, the ultimate performances of current instrumentation led to the discovery of telluric planets, and super-Earths possibly located in the habitable zone (where liquid water is expected to be found on the planet surface). The success of these discoveries relies on the development of theoretical modeling and the use of complementary observing techniques to probe the circumstellar environment. The radial velocity technique is nowadays the most successful one to detect close-in exoplanets at short periods (less than 10 years), with more than 700 exo-planets identified mainly around main-sequence solar-type stars (Udry & Santos 2007). The transit technique is a second method that consists in detecting the

shadow of an exo-planet on its host star, and enables the measurement of exoplanet radii. Combined with radial velocity measurements to derive the mass, the exo-planets density can be measured to study their internal structure. Additional indirect techniques such as micro-lensing and astrometric wobbling offer interesting perspectives for the study of telluric planets and masses determination. However, these techniques are not sensitive to the outer regions of planetary systems. At longer periods (more than ten years), Imaging offers the unique ability to enable fast detection and characterization through the analysis of actual planetary photons. Current instrumentation on very large telescopes is limited to the identification of planets around young stars. Recent discoveries of imaged planets indicate that various formation mechanisms, such as core accretion and disk or core fragmentation, could be actually at work. They offer interesting perspectives for the study of planetary atmosphere and the connection with the proto-planetary disks inside which they are detected (Lagrange et al. 2010). In parallel, vast efforts are devoted to the study of the physics of proto-planetary disks which constrain the initial conditions of planetary formation. Flattened, rotating disks of cool dust and gas extending for tens to hundreds of astronomical units are found around a large fraction of stars shortly after their birth. These disks generally persist for several million years, during which time some material accretes onto the star, some is lost through outflows and photoevaporation, and some condenses into centimeter- and larger-sized bodies or planetesimals. Multi-wavelengths studies (HST, VLT, Spitzer, Herschel, ALMA...) are producing new insights into disk structure, chemistry, and evolution. The study of the dust and gas components, the physical processes of viscous accretion, photoevaporation, grain growth and dust settling, together with dynamical interactions with (sub)stellar companions and/or young planets should help establishing under which conditions young disks can be conducive to the formation of giant and telluric planets (Williams et al. 2011).

1.2 The IPAG and MPIA/Heidelberg Institutes

In that rich scientific context, the institute of Planetology and Astrophysics of Grenoble in France (IPAG) and the Max Planck Institute for Astronomy of Heidelberg (MPIA) have been involved for more than a decade into the development of deep imaging and interferometric instruments dedicated to the observation and the characterization of exoplanets and circumstellar disks. In Grenoble, the Stellar, Substellar and Planetary Formation Group of IPAG gather 40 scientists, experts in the field of disk modeling and observations, as well as exoplanet detection and characterization. They use various techniques from radial velocity to imaging and transit. The group is known for major breakthrough discoveries and the development of dedicated instruments at ESO and CFHT. In Germany, the Planet and Star Formation department of the MPIA-Heidelberg, which consists of approximately 80 scientists, share similar scientific interests and scientific excellence. The scientists study the complicated interplay of physical processes in the interstellar medium, finally leading to the birth of stars and entire planetary systems. They combine multi-wavelength observations from large ground-based telescopes and space-born infrared observatories with large-scale numerical simulations on supercomputers, theoretical models, and dedicated laboratory experiments. Consequently, It is not suprising that several collaborations arose in the past between both institutes for the exploitation of HST, Spitzer, Herschel space missions or ground-based deep imaging and interferometric instruments at ESO observatories (NACO, AMBER, MIDI, PIONIER, PRIMA), and the scientific preparation of upcoming instruments or missions (SPHERE, GRAVITY, MATISSE, NEAT, EPICS...).

1.3 Goals

The scientific project of our application aims at reinforcing and supporting the current collaborations between the two teams at IPAG and MPIA-Heidelberg, experts and leaders in Europe in the field of exoplanet and disk modelling and observations. Our goal is to provide support for researchers, post-docs and students exchanges, for the organization of several thematic workshops and one yearly colloquium between Grenoble and Heidelberg over 2013 and 2016. The objectives are to strengthen our common leadership on a competitive international scene, to prepare the scientific exploitation of upcoming European instruments (SPHERE et VLT, PIONIER, PRIMA, GRAVITY at VLTI), finally to coordinate our efforts for the instrumental prospective of both institutes in the field of exoplanetalogy. Our proposal aims therefore at providing support for two main aspects:

- **Disk observation and simulation.** The first aspect concerns the interferometric and multi-wavelength observations and simulation development dedicated to the study of proto-planetary disks. Collaborations have been developped in the context of the exploitation of the Herchel DUNES, GASPS and DIGIT key programmes, of the AMBER, MIDI, PIONIER and SPHERE guaranteed and open time observations, finally the ALMA call for early science proposals. Numerical codes are already existing (McFOST, RADMC-3D, PRODIMO, GRaTer) and under development to incorporate broader observational constraints and additional physics and chemistry. Key-members involved are J.-C. Augereau, C. Pinte, F. Ménard, J.-P. Berger, F. Malbet and C. Dougados at IPAG and T. Henning, K. Dullemond, J. Olofsson, M. Benisty, J. Bouwman at MPIA. Their work led to several key publications reported in the result sections.

- **Planet search and characterization.** A second aspect concerns the exoplanet search and characterization programmes. It concerns on-going collaborations with the NaCo instrument, including the NaCo large programme (184-0567). Key-members are composed of G. Chauvin, D. Mouillet, J.-L. Beuzit, A.-M. Lagrange at IPAG and T. Henning, M. Feldt, W. Brandner, M. Bonnefoy, B. Biller and C. Mordasini at MPIA. It also concerns the scientific preparation for the SPHERE legacy survey for exoplanets. More than 600 stars will be observed to assess fundamental question regarding the population of giant planets at wide orbits (starting in 2012). Potential collaborations in the context of transit and radial velocity observations will probably emerge, particularly in the context of the new restructuration at IPAG. Finally, this aspect includes also prospects for future instrumental and space missions such as ESA/NEAT, with a science group currently gathering F. Malbet, A.-M. Lagrange, N. Meunier, G. Duvert at IPAG and L. Kaltenegger and C. Mordasini at MPIA.

The CNRS-PICS support will therefore consolidate and officialize these two main collaborative scientific themes between IPAG and MPIA-Heidelberg to ensure an optimal exploitation of upcoming space missions and ground-based instruments for exo-planets and disk study, and help creating new collaborative studies between both institutes.

2. Past Scientific Results:

The Stellar, Substellar and Planetary Formation Group of IPAG and the Planet and Star Formation department of the Max Planck Institute for Astronomy of Heidelberg have

both obtained major breakthrough discoveries in the field of circumstellar disk and exoplanet detection and characterization. In collaboration, they have have both participated in the exploitation of the Spitzer (C2D) and ESA/Herschel key programs (GASPS, DUNES, DEBRIS and DIGIT) for the study of dust and gas in proto-planetary disks which led to various joined publications (Harvey et al. 2012; Goto et al. 2012A, 2012b; Cieza et al. 2011; Olofsson et al. 2010a). Recent efforts have been more recently devoted to the characterization of the planetary formation zone and the inner circumstellar disk using interferometric technics (Benisty et al. 2012, 2011, 2010; Olofsson et al. 2011). The detection of a probable substellar companion shaping the inner gap in the cold disk around T Chamaeleontis could be obtained (Olofsson et al. 2010b; ESO-Press Release, 1106: “Planet formation in action?”). In the context of exoplanet detection and characterization, both teams are collaborating in various observing programs, including the characterization of the young giant planet Beta Pictoris b (Chauvin et al. 2012; Lagrange et al. 2012; Bonnefoy et al. 2011; A&A-Pres Release vol. 528), the NaCo Large programme to search for and characterize planets at wide orbits (Chauvin et al. 2012b; Bonnefoy et al. 2012) and the characterization of circumstellar disks (Lagrange et al. 2012; Thalmann et al. 2011; Buenzli et al. 2010). Finally, both groups are already reinforcing together their expertise (instrumentation, data reduction and analysis, field contamination, planet characterization and population synthesis simulation for statistical interpretation) for the scientific preparation and the exploitation of the SPHERE high contrast imaging instrument that will offer unprecedented capabilities for planet and disk imaging (Wildi et al. 2011; Beuzit et al. 2010; Gillessen et al. 2010).

3. Expected Results over 2013 – 2016:

Over the years 2013-2016, both institutes will be greatly involved into multi-wavelengths observations at various angular scales with NaCo, SPHERE, PIONIER, AMBER, MIDI, MATISSE, GRAVITY, Spitzer, Herschel and ALMA, to study the vertical and radial structures and the dissipation and evolution processes of proto-planetary disks. The synergy of complementary techniques and theoretical modelling developped in common by both insitutes will enable the characterization of the inner part of proto-planetary disks where planetary formation is expected to take place. In the context of exoplanet detection and characterization, much is expected with the upcoming SPHERE instrument developed in collaboration with a European consortium including both IPAG and the MPIA-Heidelberg. Direct images of giant exoplanets will be obtained. Their atmosphere properties will be studied to identify the impact of gravity, metallicity, clouds formation and sedimentation on planetary atmospheres. The SPHERE/NIRSUR survey, by following a systematic appproach, will constrain the occurrence of giant planets at wide orbits and therefore the mechanisms of planetary formation and evolution as a function of the primary star properties (age and mass). The synergy between both institutes will play a key role for the astrophysical exploitation and interpretation of key-European instruments that will benefit the disk and exoplanet community.

4. 2010-2012 joined publications:

(IPAG; MPIA/Heidelberg)

- Pinilla, P.; Benisty, M.; Birnstiel, A. et al. 2012, A&A, accepted: “Ring shaped dust accumulation in transition disks”

- C. Bergfors, W. Brandner, M. Bonnefoy, M. Janson, T. Henning and G. Chauvin, 2012, A&A, accepted: “Near-infrared spectra of four M dwarf binaries”
- Bonnefoy, M., Chauvin, G.; Lagrange, A.-M. et al. 2012, A&A, accepted: “A library of near-infrared integral field spectra of young M-L dwarfs”
- Goto, M.; Carmona, A.; Linz, H.; Stecklum, B.; Henning, Th. et al. 2012, ApJ, 748, 6: “Kinematics of Ionized Gas at 0.01 AU of TW Hya”
- Chauvin, G.; Lagrange, A.-M.; Beust H.; Bonnefoy, M. et al. 2012, A&A, arXiv1202.2655: “Orbital characterization of the beta Pictoris b giant planet”
- Goto, M.; van der Plas, G.; van den Ancker, M.; Dullemond, C. P.; Carmona, A.; Henning, Th. et al. 2012, A&A, 539, 81: ”Warm gas at 50 AU in the disk around Herbig Be star HD 100546”
- Harvey, Paul M.; Henning, Thomas; Ménard, François et al. 2012, ApJ, 744, 1:”A Herschel Search for Cold Dust in Brown Dwarf Disks: First Results”
- Bonnefoy, M.; Lagrange, A.-M.; Boccaletti, A.; Chauvin, G.; Apai, D. et al. 2011, A&A, 528, 15: "High angular resolution detection of beta Pictoris b at 2.18 μm"
- Buenzli, E.; Thalmann, C.; Vigan, A.; Boccaletti, A.; Chauvin, G. et al. 2011, A&A, 524, L1: “Dissecting the Moth: discovery of an off-centered ring in the HD 61005 debris disk with high-resolution imaging”
- Olofsson, J.; Benisty, M.; Augereau, J.-C.; Pinte, C.; Ménard, F. Et al. 2011, A&A, 528, 6: “ Warm dust resolved in the cold disk around T Chamaeleontis with VLTI/AMBER”
- Benisty, M.; Renard, S.; Natta, A.; Berger, J. P. et al. 2011, A&A, 531, 84: “A low optical depth region in the inner disk of the Herbig Ae star HR 5999”
- Tatulli, E.; Benisty, M.; Ménard, F. et al. 2011, A&A, 531, 1: “Constraining the structure of the planet-forming region in the disk of the Herbig Be star HD 100546”
- Oliveira, Isa; Olofsson, Johan; Pontoppidan, Klaus M.; van Dishoeck, Ewine F.; Augereau, Jean-Charles et al. 2011, ApJ, 734, 51: “On the Evolution of Dust Mineralogy, from Protoplanetary Disks to Planetary Systems”
- Cieza, Lucas A.; Olofsson, Johan; Harvey, Paul M.; Pinte, Christophe, Augereau Jean-Charles et al. 2011, ApJ, 741, 25: “Herschel Observations of the T Cha Transition Disk: Constraining the Outer Disk Properties”
- Wildi, François; Beuzit, Jean Luc; Feldt, Markus; Mouillet, David et al. 2011, SPIE, 8151: “The performance of the SPHERE sub-systems in the integration lab”
- Liseau, R.; Eiroa, C.; Fedele, D.; Augereau, J.-C.; Olofsson, G.; et al. 2010, A&A, 518, L132: “Resolving the cold debris disc around a planet-hosting star. PACS photometric imaging observations of q1 Eridani (HD 10647, HR 506)”
- Sturm, B.; Bouwman, J.; Henning, Th.; Evans, N. J.; Acke, B., Augereau, J.C; Maret S. et al. 2010, A&A, 518, 129: "First results of the Herschel key program ``Dust, Ice and Gas In Time'' (DIGIT): Dust and gas spectroscopy of HD 100546”
- Olofsson, J.; Augereau, J.-C.; van Dishoeck, E. F.; Merín, B.; Lahuis, F. et al. 2009, A&A, 507, 327: "C2D Spitzer-IRS spectra of disks around T Tauri stars. IV. Crystalline silicates"
- Malbet F., Leger A., Shao M., Katteneger L., Mordasini C. et al. 2011, Experimental Astronomy, submitted, "High precision astrometry mission for the detection and characterization of nearby habitable planetary systems with the Nearby Earth Astrometric Telescope (NEAT)"
- S. Gillessen, F. Eisenhauer, G. Perrin, W. Brandner, K. Perraut et al. 2010, SPIE, 7734, 33: “ GRAVITY: a four-telescope beam combiner instrument for the VLTI”
- Beuzit, Jean-Luc; Feldt, Markus; Dohlen, Kjetil; Mouillet, David; Puget, Pascal et al. 2010, SPIE, 7014, 41:”SPHERE: a planet finder instrument for the VLT”