Curriculum Vitae[1] of Pawel Artymowicz

(i) Personal Data and Contact Information

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(ii) Academic Degrees

1996: Habilitation[2] from Warsaw University, Poland

1994: Docent degree[3] from Stockholm University, Sweden

1990: Ph.D. in Astronomy with distinction from N. Copernicus Astronomical Center of the Polish Academy of Sciences, Warsaw, Poland. (Thesis "Density waves and ultraharmonic resonances in galaxies", written at STScI.)

1985: M.Sc. in Astronomy from Dept. of Physics, Warsaw University, Warsaw, Poland

(iii) Education and Employment

from 2005: Professor of Physics and Astrophysics (tenure), University of Toronto, Toronto, Canada

2003–2005: Assoc. Professor w/tenure, Stockholm Observatory, Stockholm U., Sweden

1997–2003: Senior Researcher (Assoc. Prof.) at Stockholm Observatory, Stockholm U., Sweden

1993–1997: Asst. Professor, Stockholm Observatory

1990–1993: NASA Hubble Fellow, Lick Observatory, Univ. of California, Santa Cruz, CA

1990–1993: Member of the Center for Star Formation Studies (Berkeley–NASA-Ames–Santa Cruz consortium)

1986–1990: Graduate Student Research Asst. at Space Telescope Science Institute and Special Graduate Student at The Johns Hopkins University, Baltimore, MD

[1]Last updated Apr. 2011

[2]The highest Polish post-PhD academic degree.

[3]The highest Swedish post-PhD academic degree.

1984–1986: Research Assistant, Warsaw University Observatory and N. Copernicus Astronomical Center of the Polish Academy of Science, Warsaw, Poland

1980–1985: Undergraduate, Dept. of Physics, Warsaw University, Poland

(iv) Main Areas of Interest Fluid dynamics. Dynamics, formation and evolution of solar and extrasolar systems, β Pictoris–type disks (theory and observations). Binary star formation. Accretion disks. Active galactic nuclei. Engineering and aerodynamics. Aviation.

(v) Teaching Experience

2000–2011: Supervised 4 graduate students, 2 PhD and 4 M.Sc. theses (awarded)
2006-2011: Origin of Planetary Systems, Galactic Dynamics, graduate courses (5), Dept. Astron. & Astroph., U of T
2005-2011: Stellar and Planetary Astrophysics, Galactic and Extragalactic Astrophysics, 2nd and 3rd year undergraduate courses (12), UTSC
1994–2004: 20 undergraduate and graduate courses on Planetary Systems, and Galactic Dynamics, Astron. Dept., Stockholm U.
1995: Star Formation and Cosmogony, graduate course in Astronomy Dept., Stockholm Univ.

(vi) Editorial Work

Co-editor of IAU Symposium No. 202 *Planetary Systems in the Universe: Observation, Formation and Evolution*.
1998–2001 Editor (Extrasolar Systems), *Planetary and Space Science* (Pergamon Press).

(vii) Technical Skills

Lectured on programming already when everything was measured in Kilo, not Giga or Tera. Written large CFD and Mte Carlo, parallel simulations. In 1999–2005 designed, built and maintained parallel supercomputers: Hydra (8 nodes), Antares (20 nodes in 2002, and 38 in 2005, Astrogrid (2005). Designed, built and used GPU-based supercomputers using CUDA C and CUDA Fortran, 2008–2011.

(viii) Professional Societies

International Astron. Union, American Astron. Society, Polish Astron. Society.

(ix) Main Awards and Grants • 2005-: DPES and Connault Startup Grants at U of T (CND $90k + $10k)
• 2005-2013: NSERC Discovery Grant ”The origin and early evolution of planetary systems” (total CND $200k)
• 2003-2005: Coordinator of the European Union INTAS program ”Waves and perturbers in disks: the origin of T Tauri star variability”, 5 institutes in 4 countries. (US $80k grant)
• 2002-2005: Docent stipend from Stockholm U. (US$10k), supercomputer grants (SNAC).
• 2002–2005: Leader of the Stockholm node of the European Union network ”The Origin of Planetary Systems” (US$ 170k grant, including a postdoc position)
• 2002–2005: Research support grants (ca. US$200k) for the Planetary System Formation group at Stockholm Observatory from VR (Swedish Science Council), incl. one postdoc position and US$50k for computer equipment.
• 2001–2003: NASA Origins of Solar Systems Program grant (Co-investigator with S. Lubow, M. Bate, and J. Pringle; ca. US$140k)
• 2000-2004: Invited by the Physics/Chemistry Nobel Committee to nominate Nobel Prize candidates
• 1999–2001: Postdoctoral fellowship grant from NFR (Swedish Natural Science Research Council) for Taku Takeuchi (US$95k)
• 1997: Research grant “Physics of Binary Star Formation” from the Anna-Greta and Holger Crafoord Foundation, awarded by the Royal Swedish Academy of Sciences (US$10k)

• 1997–2000: STINT[4] grant ($200k) for scientific exchange program between the Astronomy Departments of Stockholm University and University of California, Santa Cruz, CA
• 1997–1999: NASA Origins grant "Properties of Planet-Forming Protostellar Disks"
(Co-investigator with S. Lubow, STScI, and J. Pringle, Cambridge U.; ca. US$130k)
• 1996–1997: The STINT grant for Visiting Scientist Eric Pantin (US$80k)
• 1996: Letter of Commendation from the Editorial Board of *Icarus*
• 1994–2001: Continuous research support grants from NFR (ca. US$100k)
• 1990–1993: Hubble Fellowship, awarded by the Space Telescope Science Institute, NASA-funded (US$140k)
• 1984: Award for Young Astronomers, Polish Astronomical Society

(x) Scientific Activities (1996–2006) NOT UPDATED

• Held **Visiting Fellowships**, up to 3 months, at numerous institutes, including Service d'Astrophysique in Saclay (France); University of Grenoble (France); Space Telescope Sci. Inst. in Baltimore (MD); UCSC/Lick Observatory in Santa Cruz (CA), and UCSB/Kavli Inst. Theor. Physics (CA).

• Presented **contributed papers** at numerous international meetings, and gave **24 invited review talks** at the following major conferences:
Planetary Formation in the Binary Environment, Stony Brook (1996);
Planetary systems - the long view, Blois, France (1997);
Non-linear Phenomena in Accretion Disks around Black Holes, Reykjavik (1997);
IAU General Assembly, Kyoto (1997);
Extrasolar planets: Modeling, detection and observation, Lisbon (1998);
Planets outside the solar system series of lectures at NATO ASI, Cargese, Corsica (1998);
Protostars and Planets IV conference, Santa Barbara (1998);
Theories of Exoplanets workshop, Santa Barbara (1998);
IAU Coll. 172 *The impact of modern dynamics in astronomy*, Namur, Belgium (1998);
Minor Bodies in the Outer Solar System, Garching, Germany (1998);
From Dust to Terrestrial Planets, workshop, Bern, Switzerland (1999);
VLT Inauguration Symp. *From Extrasolar Planets to Brown Dwarfs*, Antofagasta, Chile (1999);
DARWIN and Astronomy conference, Stockholm (1999);
IAU Symposium 200 *The Formation of Binary Stars*, Potsdam, Germany (2000);
Joint Discussion on *The Transneptunian Population*, General Assembly of IAU, Manchester, UK (2000);
Planetary Systems in the Universe, General Assembly of IAU & Symp. 202, Manchester, UK (2000);
Annual Meeting of the Div. of Dynamical Astronomy of AAS, Houston, TX (2001);
Debris Disks and the Formation of Planets, Gillett Symposium, Tucson, AZ, (2002);
Astrophysical Tides: Effects in solar and extrasolar systems, IAU Coll. 189, Nanjing, China (2002);
Disks and planets workshop, Nice, France (2003);
Planetary Timescales H. White conference, Canberra, Australia (2004);
Planet Formation: Terrestrial and Extrasolar, KITP Program "Planets", Santa Barbara, CA (2004);
Dust Disks and the Formation, Evolution and Detection of Habitable Planets, San Diego, CA (2004);
Astrobiology and the origins of life, McMaster Univ., Hamilton, Canada (2005).

• Served on **14 Scientific Organizing Committees** for:
VLT Inauguration Symposium (1999); Div. of Planet. Sci. of AAS meeting in Padova, Italy (1999); IAU Symp. 200 in Potsdam, Germany (2000); Joint Discussion No. 4 and the IAU Symp. 202 at the GA of IAU (2000), the 2002 Nanjing (China) IAU Coll. 189 *Astrophysical tides: the effects in the solar and exoplanetary systems*; the NASA/CIW conference *Scientific Frontiers in Research on Extrasolar Planets* in Washington, DC (2002); Ringberg Meeting of Euro-Astronomers, Germany (2003); *Debris disks and the formation of planets* symposium, Tucson (2002), **Convener** of session *Extra-solar planets and planet formation* at the 2000 General Assembly of European Geophys. Union in Nice, FR; *Session chair* and organizer at Gordon Res.

[4] Swedish Foundation for International Cooperation in Research and Higher Education.

Conf., Rhode Island (2003); *Numerics of Disk-Planet Interaction*, Stockholm (2004), Ringberg Workshop on *Planet Formation*, Germany (2005); INTAS workshop *Cyclic variability of PMS objects*, Stockholm (2005).

• Regularly **refereed papers** submitted to international astronomical journals (ApJ, A&A, AJ, MNRAS, Icarus, Science, Planet. Space Sci., Ap. Sp. Sci., Earth Pl. Sci., PASJ), and grant proposals for science foundations: NSF and NASA (USA), KBN (Poland).

• adisor to Solar System and Planetary Studies sub-committee of the Canadian Astronomical Society (CASCA).

• Served on **9 Ph.D. examination committees** at the Universities of Stockholm, Uppsala, Gothenburg, Paris, Grenoble, Toruń, and at Monash University in Melbourne; a **habilitation committee** in Grenoble, and a **selection committe** for Assoc. Professorship at the Niels Bohr Institute in Copenhagen.

• Served as **Responsible Scientist** of the 4-yr STINT-financed, Stockholm Observatory-Lick Observatory/UCSC scientific exchange program.

• Served as **Coordinator** of the 3-year INTAS EU network ”Perturbers and density waves in accretion disks” with 5 institutes in Sweden, Germany, Russia, and Ukraine.

• **Directed** an 8-person research group [5] at Stockholm Observatory, working on theory of the origin of planetary systems: 2 postdocs, 3 graduate students, and 2-3 M.Sc. students.

• Led the **Stockholm node** of the European Research and Training Network ”The Origin of Planetary Systems” (2003–2006), comprising about 35 researchers from 10 European institutes in 7 countries.

(xi) Public Outreach and Media (NOT UPDATED)

Artymowicz enjoys giving popular talks, and created a popular web presentation at *www.yahoo.com ≫ Science ≫ Astronomy ≫ Extrasolar Planets ≫ Planetary systems and their changing theories.*

His work was selected for press release at the AAS convention in Pittsburgh, PA (1995), discussed by James Glanz in *Science* editorials (in 1995 and 1997), in New Scientist (2003), by G. Marcy and P. Butler in the Sky & Telescope (March 1998), in Science News (Aug. 1998) by Ron Cowen, and in *Forskning och Framsteg* (2000) by Jens Ergon. Major Polish and Swedish dailies *Gazeta Wyborcza* and *Dagens Nyheter*, as well as the British *Economist*, published in 1998–2004 interviews and/or stories on extrasolar planets featuring Artymowicz. He appeared on the Swedish TV science program NOVA (2000), and the Japanese NHK Co. production “Space Millenium” (TV program and book, 2001). Swedish magazine Popular Astronomi published in 2002 a profile of Artymowicz’s research. The attractiveness of the subject, together with this publicity, helped Artymowicz recruit young researchers to his group (e.g., A. Jeneskog from Uppsala U. became an M.Sc. student after reading a 1998 issue of Scientific American on exoplanets with references to Artymowicz’s work.)

(xii) Impact and Competitiveness

Artymowicz wrote many outstanding papers gathering large number of citations. In early 2011 he was the 1st author of 42 major papers cited in ADS/Harvard database. He has 2700 citations, or about 30 citations per paper. In 1998–2001 Artymowicz was the third most cited astronomer in Sweden. His research was rated ”excellent and a clear highlight of the Observatory’s program” by an International Evaluation Committee on Astronomy and Astrophysics in Sweden (Oct. 2000)[6].

Artymowicz was offered a visiting professorship at the U. of Rochester, NY (1993), and ranked first among: 100 applicants for a postdoc at the University of Maryland (1993), 70 applicants for asst. prof. in Stockholm (1993), 300 applicants for tenure-track at Vanderbilt U., Nashville, TN (1996), and 40 applicants for Senior Resercher position in Stockholm (1997). In 2001–2002 he was ranked 1st in searches for faculty positions at LASP/Univ. of Colorado, Boulder, and MIT Dept. of Earth and Atm. Sci; in 2004 he was offered tenured positions at the Australian National University in Canberra, and at the University of Toronto.

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[5] www.astro.su.se/˜pawel/systems.html

[6] http://www.astro.su.se/˜pawel/eval2000.html

(xiii) Other Interests

Flying single-engine, complex airplanes across North America; aerobatics, designing and building experimental airplane systems. Mountain biking on Lake Tahoe trails. Diving (Australia, the Bahamas). Skating (Stockholm archipelago). Skiing (Arapahoe Basin). Discovering fractals[7]. Investigating the Smolensk catastrophe (PLF 101, 2010).

[7] http://www.astro.su.se/˜pawel/iii/fractal.html

(xiv) Previous and Current Research – Narrative (NOT UPDATED) [8]

Pre-doctoral work and Ph.D. thesis

• *From binary quarks to binary stars and planets*

As an undergraduate I was interested in elementary particle physics; I spent the summer of 1982 at the e^+e^- collider DESY (Deutsches Elektronen-Synchrotron) in Hamburg. I wrote a paper on quarkonium [3]. I also studied double star formation, and in 1983 reported the results at a NATO Adv. Study Institute in Cambridge, UK (cf. [1],[2]). This work became the core of my M.Sc thesis[9]. Later I turned to disks and solar system formation. I used the Jacobi constant to analyze in detail the growth of a planetary embryo in the planetesimal disk, and found the effective width of the 'feeding zone' and the planetary mass at which its early runaway growth stage ends due to the non-linear increase of the Hill sphere radius [4] (a.k.a. "isolation mass").

• *Getting to know β Pictoris*

At STScI I met Francesco Paresce and Chris Burrows, and started image processing and theoretical interpretation of the observations of β Pic. Our analysis [6] gave much new information on its dusty disk and became a standard reference in the field. Using a simple but flexible parametrization of dust distribution, which is still in use in dusty disk modeling, we realized that the thickness of the observed disk increases with radius. Through maximum entropy technique we reconstructed (using IR data) the coronographically blocked portions of the disk, and have found that the β Pic grains are highly reflective. That indicated either a slightly contaminated ice or semi-transparent silicates such as Mg-rich olivine. (The high albedo stirred some controversy in 1988, settled 4 years later when such materials were discovered around β Pic .) I have also studied the dynamics of β Pic grains for a wide range of realistic grain compositions [5], and concluded that radiation pressure removes sub-micron sized grains, which explains the disk's nearly grey scattering. In [7],[8] and [10] we explored the nature and evolutionary status of β Pic. As one of the first, we found evidence that β Pic is a nearby extrasolar analog of the early solar system, much more evolutionary advanced than a protoplanetary nebula, and that its dust is rapidly destroyed and replenished.

• *Galactic Ph.D. thesis (1990)*

Under the guidance of Steve Lubow and the formal supervision by Wojtek Dziembowski, I wrote at STScI and defended in Warsaw the thesis on the dynamics of ultraharmonic resonances in galactic disks ([9],[11],[13]). At these resonances, located between the Lindblad and the corotational resonances, non-linear effects lead to the excitation of 4-armed features (inter-arms) and a strong local damping of the main 2-armed density wave. Both effects have been detected (e.g., Elmegreen, Elmegreen & Seiden, 1989, ApJ, 343, 602). Ultraharmonic resonances may play a key role in the stability of the spiral structure in some spirals, by damping the growth of global m=2 modes. While working on the paper [13] with Steve Lubow I had a chance to gain a deep insight into the Lindblad resonances (cf. below).

Post-PhD Research (1990–2004)

• *Binary star formation*

With Cathy Clarke, Steve Lubow, and Jim Pringle, I have co-discovered the phenomenon of a rapid growth of (initially small) eccentricity of a binary system embedded in an extended protostellar gas disk ([12],[14]). The forming binary star can undergo a significant orbital evolution before the disk dispersal. This may explain

[8] Bracketed numbers refer to my Bibliography, attached.

[9] A decade later, in his Ph.D. thesis at Cambridge, Matthew Bate recomputed this problem using better techniques and obtained similar results, and recently Ochi et al. (2004) revisited the problem again.

some features in the distribution of orbital elements (size and eccentricity) of the pre-main-sequence (PMS) and main-sequence binaries (cf. Mathieu, R.D., 1994, ARA&A, 32, 645) [12],[15].

In collaboration with Lubow I have studied the resonant and tidal interactions of a binary with a disk. This theory predicts the creation of a gap around a binary, with the size depending on the binary separation, mass ratio and (the previously neglected) eccentricity [22], and has since been used to interpret and even predict observations. We thus have shifted emphasis in binary–disk interaction theories from the simpler circular orbit case to the more realistic eccentric case.

But a true change of paradigm first happened after I realized that, rather than being impermeable to gas, as was believed at the time, a gap around the secondary component may support gas streamers transporting mass at a rate ($\dot{M}$) similar to the unperturbed $\dot{M}$ through the surrounding accretion disks. That is, gas may flow as efficiently as if the secondary was not there. That helped resolve a riddle of the resupply mechanism and the ubiquity of small circumstellar disks in PMS binaries.

We tackled the problem of circumbinary gaps, and the long-term evolution of PMS binaries in ([27],[28], [30],[35],[36]). From the SPH numerical simulations, and my still only partially published grid-based PPM models, it followed that the specific time variability of flow, seen in the spectra of eccentric binary systems, can be used as a fine diagnostic tool in the study of the orbital parameters of the binary (which may be difficult to obtain otherwise, e.g., in unresolved or long-period binaries). The theory has been successfully applied to several prominent PMS binary systems such as GG Tau, DQ Tau, AK Sco and others. GG Tau is a long-period binary with poorly known, but significant, historic variability, and a suggestion of gas streamers from imaging. Periodic flares of DQ Tau, a short-period spectroscopic, classical T Tauri binary, turned out consistent photometrically and spectroscopically with our predictions. Additional evidence for gas streaming through the gap was later found in the IR spectral energy distributions of classical T Tau stars, accretion luminosity of the IR companions to PMS stars, etc.

Gas flows through gaps may also be relevant to binary supermassive black holes in AGNs [41], and to some post-AGB stars [27]. Steve Lubow and I have written a chapter in the *Protostars and Planets IV* book [49] (cf. also [55]), reviewing the theoretical and observational aspects of disk-binary interaction.

• *Lindblad and corotational resonances, mass transfer through gaps, and the exoplanets*

In the formation of planets, three parameters play a crucial role: a, e, and m (planet's mass). AT UCSC, I set out to calculate the early evolution of these three parameters during the nebular phase of planet formation. I developed a post-Goldreich-Tremaine'an, generalized theory of Lindblad resonances [16]. These resonances are intimately connected with emission of spiral waves, opening gaps by planets, planet migration in disks, and either damping or growth of orbital eccentricity. The non-WKB nature of my theory allowed the first analytical description of the so-called torque cutoff at high azimuthal harmonic numbers. This allowed an analytical estimation of eccentricity damping of planetesimals in the solar nebula [17]. Too small to open a gap, such bodies suffer a rapid decay of the orbital eccentricity (faster than due to gas drag or nebular lifetime).

The results of the generalized Lindblad resonance theory were soon incorporated into theories of disk response to planets (Takeuchi, Miyama, and Lin, 1996), and the protoplanet migration theory of Ward (1997) (cf. also Ward and Hahn's review in *Protostars and Planets IV*, 2000). Migration is a key process in planet formation. It is widely thought be responsible for the existence of 'hot Jupiters'.

The process of gas streaming through disk gaps is relevant to the origin of 'superplanets' (having large m). We have proposed that such planets form via continued accretion from the standard protoplanetary disk onto Jupiter-sized planets ([27],[38],[40],[42]–[44]). (In contrast, the standard Lin-Papaloizou theory predicted that accretion stops at about 1 Jupiter mass, when the disk gap opens). Our colleagues have confirmed the presence and magnitude of the gas flows through the gap, using independent hydrocodes (Kley 1999, in MNRAS; Bryden et al. 1999, in ApJ).

As to the origin of the eccentricities of exoplanets, several possibilities exist for exciting e (as described, for instance, in [38],[40],[42]), such as: stellar and mutual planetary perturbations, disk-planet interaction and disk instabilities. My work concerned the disk-planet scenario, as the only one naturally explaining a (weak) observed correlation of planet mass with eccentricity and, what is perhaps more important, the only one capable of *reducing* the eccentricities excited by any of the above-mentioned interactions in the solar-like low-eccentricity systems[10]. In 1992 I have noted in [15] that, for a typical disk representing a minimum mass solar nebula, there is a crossover mass (equal roughly to 10 Jupiter masses for α-disks with $\alpha \sim 10^{-2}$; less for less viscous disks), below which the disk-planet interaction damps e, and above which e increases. The jury is still out on which of the eccentricity driving mechanisms is statistically dominant. There is increasing evidence that the disk-planet and the N-body interactions may, in fact, both be required for producing the observed diversity of orbital parameters of solar and extrasolar planets [51].

I am currently developing sophisticated multi-dimensional, variable- or multi-grid (adaptive mesh) gas-dynamical models of disk-planet interaction, using methods such as PPM (Piecewise Parabolic Method). A fresh look at the mechanisms of migration, including the previously underappreciated role of mass transfer near the planet and the associated corotational torques/resonances is given in [60]–[62]. I have co-discovered a rapid migration mode (type III) in sufficiently massive protoplanetary disks. I study the conditions under which migration stops (which depends on disk density distribution), allowing giant planet's survival. Type III migration is a largely uncharted but probably crucial territory for exploration. With R. Edgar,we find that rapid migration of a giant plane my save the pre-existing terrestrial protoplanets from destruction [64].

• *Active galactic nuclei*

With Doug Lin (UCSC) and Joe Wampler (ESO, Garching) we have sought a better theoretical understanding of active galactic nuclei (AGN), in particular of the interaction of field stars with disks around massive black holes in quasars and AGN. We have calculated ([18], [19]) the trapping rate of stars from the host galaxy's nucleus in gaseous disks or cloud assemblages. The physics of trapping involves the usual supersonic gas drag and the resonant excitation of bending and density waves in the gas. I have formulated a generalized theory of bending and density wave generation in astrophysical disks [20], quantifying the trapping time. The trapped stars provide seeds for rapid accretion of gas. This leads to the emergence of short-lived massive main sequence stars, which eventually contaminate the disk with heavy elements. The rate of metallicity enrichment by seeded star formation is remarkably model-independent, and can explain super-solar metallicities in quasars and AGN. The stellar-mass compact remnants of supernovae can be re-trapped, grow, and exchange angular momentum with the gaseous disk, which may give rise to effective viscosity parameter α of order unity [21].

I have reviewed the evolution of supermassive binary black holes in merging galaxies in [41]. While this subject is still somewhat elusive observationally, dynamically it resembles the physics of binary star interaction with disks. Interaction with the gas disk can drive the evolution of a massive black hole pair, tightening it sufficiently for an eventual gravitational-wave assisted merger. During the tightening, interesting activity patterns may be produced (quasi-periodic variability of sources, like in the blazar OJ 287; wiggly, spiral-like jets of radio galaxies and AGNs, double emission lines).

• *Vega-type systems and Beta Pictoris*

I have done work on diverse aspects of the Vega-type systems and their most prominent member β Pic ([23],-[24],[29],[31]–[34],[36],[37],[39]). I have summarized the knowledge and important remaining puzzles, such as the origin of disk asymmetries in β Pic, in Annual Review [33], and later co-authored a review chapter in *Protostars and Planets IV* [50]. My interests ranged from the physics and mineralogy of dust, evolutionary time scales for the observable disk, and disk polarization, to observational constraints on gaseous refractory species, lower limit on dust:gas ratio, etc. I have participated as co-investigator with C. Burrows, M. Clampin, and E. Pantin and others, in observational programs using HST and ESO telescopes, mostly providing the modeling and interpretation. I collaborated with Sally Heap's group at GSFC on the STIS imaging of β Pic [56].

[10] Levison, Lissauer, and Duncan 1999, in their down-top accumulation models of the outer solar system, vividly illustrated the need for an efficient damping mechanism.

In a paper with Clampin [36], we studied the nature-vs.-nurture question in the origin of the Vega among the candidates phenomenon (strong IR excess, plus other features, cf. [50]). We have found serious problems with the two standard "sandblasting" theories invoking the influence of ISM ('nurture') on pre-existing circumstellar dust. We calculated that the internal evolution (i.e. 'nature') is responsible for the dusty disks around normal main-sequence stars.

I developed theoretically new 'rules of conduct' for extrasolar dust disks. For example, I proposed that radiation-driven dust avalanches occur in gas-poor disks, a process which becomes exponentially important (and self-limiting) for dust coverage factors approaching that of β Pic. This implies that there should be no gas-free disks with a dust coverage factor (measured by bolometric to IR luminosity ratio) much larger than in β Pic. More 'dusty' systems would necessarily be gas-rich, to prevent strong dust avalanches, due to strong drag forces. In [32], I confirmed empirically the dichotomy of dustiness: indeed there were two distinct subsets of Vega-type systems (gas-rich, young, very dusty systems, and on the other hand the Vega-systems proper: gas-poor, and optically thin β Pic analogs). The ISO data also detect this dichotomy.

I proposed an interpretation of the surprising outer rings of dust surrounding many few-million year old stars with dusty disks, the so-called old PMS systems or 'transitional' disks such as HR 4796A and HD 141596 [51]. Superficially resembling gaps dynamically cleared in disks by planets or brown dwarfs, these spectacular structures are more likely connected with the rapid *outward* migration of dust in gas-containing, optically thin dust disks subject to radiation pressure from the central star, studied by Takeuchi and myself in [52]–[53]. In order to make a convincing case for exoplanets, observers need to look for the more specific, nonaxisymmetric, disk structures such as spiral shocks and density waves in disks. Striking rings, and even nonaxisymmetric quasi-spiral features such as those seen with the Hubble Space Telescope recently, can be due to das-dust coupling and collisional avalanches, as we have found with Grigorieva [66]!

With Skånby-Mansour [67] I have also proposed to use the HST/STIS-observed vertical structure of the edge-on disk of β Pic to theoretically determine the upper limit of about 0.1 Earth masses of gas in that system. This work was motivated by the urgent need to resolve a dichotomy in several lines of observational work suggesting either low (like we computed) or high (60 Earth masses) quantity of gas in the disk.

With Jeneskog, we explored the models of β Pic system as a remnant of a recent flyby of a field star. These million-particle calculations[11] contradict some of the conclusions recently reached by Kalas and Larwood (2000), using an oversimplified model of the physics involved. We do not believe any *recent* encounter could have taken place.

• *N-body dynamics of planetary systems*

With Doug Lin and Rosemary Mardling, I studied in 2000 the dynamics of Υ Andromedae, the first multiplanetary system among the candidates discovered in radial velocity surveys (Butler, Marcy, Fisher et al. 1999). I performed extensive direct N-body simulations of the two outermost planets in a timespan of 2 Gyr, with the innermost planet averaged into the Gauss ring around the star. In [54], in sharp contrast to some earlier papers on that subject, we found large, acceptable, parameter space regions guaranteeing long-term stability of Υ And. Our work raised questions about the origin of one highly unusual property of the system: the masses and orbital eccentricities of the three planets all increase with semi-major axis. Such a correlation is unlikely to be due to the purely N-body interaction of the present planets.

• *Books on Astrophysics of the Solar Systems*

I have written a 540-page book *Astrophysics of Solar Systems*, dealing with the solar, and the then-known extrasolar planetary systems [26]. It appeared in 1995 (in Polish) as the closing volume in a series of three upper undergraduate and/or graduate, modern astrophysics textbooks. It has received favorable journal reviews, and has been used at the Warsaw and Stockholm Universities.

With Peter Bodenheimer (UCSC) we have started to write for Springer-Verlag a somewhat similar new book [57], this time devoted largely to the extrasolar planetary systems.

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[11] Jeneskog's B.Sc. thesis (2001) can be downloaded from http://www.astro.su.se/˜pawel/systems.html

Bibliography of Pawel Artymowicz

Refereed publications are marked with **ref**; *Invited reviews are marked with* **inv**, *and books with* book. *Bulletin abstracts are omitted.*

[1] Artymowicz, P., 1983, **A model of accretion onto a binary system**, Postępy Astron., 31, 17

[2]**ref** Artymowicz, P., 1983, **The role of accretion in binary star formation**, Acta Astr., 33, 233

[3]**ref** Artymowicz, P., 1984, **Toponium properties in the Coulomb-linear potential**, Acta Phys. Pol., B16, 361

[4]**ref** Artymowicz, P., 1987, **Self-regulating protoplanet growth**, Icarus, 70, 303

[5]**ref** Artymowicz, P., 1988, **Radiation pressure forces on particles in the Beta Pictoris system**, ApJ Lett., 335, L79

[6]**ref** Artymowicz, P., C. Burrows, & F. Paresce, 1989, **The structure of the Beta Pictoris circumstellar disk from combined IRAS and coronographic observations**, ApJ, 337, 494

[7] Artymowicz, P., 1989, **The β Pictoris disc: a planetary rather than a protoplanetary one**, in *Dynamics of Astrophysical Discs*, Ed. J. A. Sellwood, Cambridge Univ. Press, p. 43

[8] Paresce, F., and Artymowicz, P., 1989, **On the nature of the Beta Pictoris circumstellar nebula**, in *Structure and Dynamics of the Interstellar Medium*, Eds. G. Tenorio-Tagle, M. Moles, and J. Melnick. Lecture Notes in Physics No. 130, Springer-Verlag, Heidelberg, p.221

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