NBIA Workshop on Radiation Transfer in Astrophysics

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Book of Abstracts

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3D non-LTE radiative transfer in the solar atmosphere

Author: Jorrit Leenaarts[None]

Predictions made by radiation-MHD simulations of the solar atmosphere can be tested by comparing the emergent spectrum to observations. Comparison with observations of the intensity in spectral lines that form in the chromosphere require that non-LTE, non-equilibrium, 3D effects, and partially coherent scattering play important roles. If comparison with the full Stokes vector is required, then also atomic polarization, as well as the Zeeman and Hanle effect need to be considered.
I will present results obtained with the Multi3d radiative transfer code as applied to simulations with Bifrost and Muram that take some of these effects into account. If time permits I will also discuss multigrid methods that can be used to speed up the calculations, and argue for the need of including adaptive mesh refinement in the future.

Interstellar Medium / 32

Measuring turbulence driving in the ISM with NLTE CO modeling

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Measuring the driving mode of turbulence is important for characterizing its role in the ISM. The driving mode of turbulence is parameterized by b, the ratio of the width of the gas density PDF to the turbulent Mach number. b ~ 1/3, 1, and 0.4 correspond to turbulence driving that is purely solenoidal, purely compressive, and a natural mixture of the two, respectively. We use high-resolution (sub-pc) ALMA CO observations of the star-forming region N159E (Papillon Nebula) in the LMC to provide the first measurement of turbulence driving in an extragalactic region. As opposed to earlier studies that only focused on the Milky Way and used LTE modeling of CO emission to derive the density PDF, we use NLTE models and show how LTE can overestimate the column density due to subthermal excitation of CO. We find that the width of the log-normal part of the density PDF is comparable to the supersonic turbulent Mach number, resulting in b ~ 0.9. We speculate that the highly compressive turbulence could have been powered by HI flows that is proposed to have created N159E, which can be confirmed by high resolution HI observations (e.g., using ASKAP or SKA) in the future.

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Modelling Radiation Hydrodynamics with the Variable-Eddington Tensor Method in the FLASH AMR Code

Authors: Shyam Menon[None]; Christoph Federrath[1]; Mark Krumholz[1]; Rolf Kuiper[2]

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The transport of radiation and its dynamical interaction with dusty gas is important for a wide range of applications —from the interior of stars, to kilo-parsec flows onto active galactic nuclei. Modelling these systems requires a self-consistent and accurate treatment of the radiation transport. In this talk, I will present a new time-dependent Radiation-Hydrodynamical (RHD) module with support

for Adaptive Mesh Refinement (AMR) in the FLASH magnetohydrodynamics (MHD) code. I will discuss general difficulties associated with modelling RHD, and various approximations induced to alleviate the complex angular dependencies of radiation transport. Our new method uses the Variable Eddington Tensor (VET) closure approach for modelling the directionality of the radiation flow, based on a ray-tracing step to estimate the Eddington Tensor. I will present standard numerical tests of the algorithm, compare the VET approach with other commonly used methods such as the Flux-Limited-Diffusion and Moment-1 approximations, and discuss applications in star formation and the interstellar medium.

Interstellar Medium / 35

Quokka: A code for two-moment AMR radiation hydrodynamics on GPUs

Author: Benjamin Wibking[1]

[1] *Australian National University*

We present Quokka, a new subcycling-in-time, block-structured adaptive mesh refinement (AMR) radiation hydrodynamics code optimised for graphics processing units (GPUs). Quokka solves the equations of hydrodynamics with the piecewise parabolic method (PPM) in a method-of-lines formulation, and handles radiative transfer via the variable Eddington tensor (VET) radiation moment equations with a local closure. In order to maximise GPU performance, we combine explicit-in-time evolution of the radiation moment equations with the reduced speed-of-light approximation. We show results for a wide range of test problems for hydrodynamics, radiation, and coupled radiation hydrodynamics. On uniform grids in 3D, we achieve a peak of 93 million hydrodynamic updates per second per GPU, and 22 million radiation hydrodynamic updates per second per GPU. For radiation hydrodynamics problems on uniform grids in 3D, our code also scales from 4 GPUs to 256 GPUs with an efficiency of 80 percent. The code is publicly released under an open-source license on GitHub.

Exoplanetary Atmospheres / 36

NLTE effects in the atmosphere of the ultra-hot Jupiter KELT-9b

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Ultra-hot Jupiters (UHJs) have become prime targets for atmospheric characterisation. KELT-9b is the hottest of the known UHJs and both hydrogen Balmer lines and metal line features have been detected in the planetary transmission spectrum. I will show how NLTE effects drive the temperature pressure structure of KELT-9b's atmosphere and that NLTE effects must be taken into account in order to reproduce the observations. I will show how our NLTE models have enabled the direct observational detection of NLTE effects in the atmosphere of KELT-9b at the position of both hydrogen and metal line features. Finally, I will show that the NLTE models further place strong constraints on velocities in the planetary atmosphere.

Accretion Disks / 37

Modelling continuum anisotropy and super Eddington accreting quasar spectra

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Emission from the **Broad-line regions (BLR) in active galaxies** are produced primarily by photoionization processes, driven by the continuum arising from an underlying, complex structure circumscribing the black hole. **Modelling the broad-band spectral energy distribution** (SED) that ionizes these gas-rich BLRs is key to understanding the various radiative processes leading to the emission of emission lines from diverse physical conditions. ***We focus on a long-standing issue of the anisotropic continuum from the very centres (~10-100 Rg) of these active galaxies***. This is a direct consequence of the development of a funnel-like structure in the vicinity of the black hole due to a marked increase in the accretion rates, in addition to the almost standard disk at larger radii.

> **Incorporating the radiation emerging from such a structure in our photoionization modelling, we are successful in replicating the observed emission line intensities, in addition to the remarkable agreement on the location of the BLR with current reverberation mapping estimates.**

This study allows us to locate the super Eddington sources along the main sequence of quasars and constrain the physical conditions of their line-emitting BLR, eventually allowing us to use these fascinating sources to understand better the cosmological state of our Universe.

TIdal Disruption Events / 39

Modeling disks and emissions of tidal disruption events

Author: Jane Dai[1]

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Tidal disruption events, in which stars are torn apart by massive black holes, are ideal laboratories for studying the accretion and emission physics around black holes. In this talk, we will show some of our recent general relativistic magnetohydrodynamic simulations of super-Eddington disks formed in tidal disruptions and their spectra obtained via Monte Carlo radiative transfer codes. We will show how the emissions from tidal disruption events depend on key parameters such as the viewing inclination as well as the accretion rate. These results are useful for understanding the evolution of emissions observed from tidal disruption events.

TIdal Disruption Events / 40

Eccentric tidal disruption event discs around supermassive black holes: dynamics and thermal emission

Authors: John Zanazzi[1]; Gordon Ogilvie[2]

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After the tidal disruption event (TDE) of a star around a supermassive black hole (SMBH), if the stellar debris stream rapidly circularizes and forms a compact disc, the TDE emission is expected to peak in the soft X-ray or far ultraviolet (UV). The fact that many TDE candidates are observed to peak in the near UV and optical has challenged conventional TDE emission models. By idealizing a disc as a nested sequence of elliptical orbits that communicate adiabatically via pressure forces, and are heated by energy dissipated during the circularization of the nearly parabolic debris streams, we investigate the dynamics and thermal emission of highly eccentric TDE discs, including the effect of general-relativistic apsidal precession from the SMBH. We calculate the properties of uniformly precessing, apsidally aligned, and highly eccentric TDE discs, and find highly eccentric disc solutions exist for realistic TDE properties (SMBH and stellar mass, periapsis distance, etc.). Taking into account compressional heating (cooling) near periapsis (apoapsis), we find our idealized eccentric disc model can produce emission consistent with the X-ray and UV/optical luminosities of many optically bright TDE candidates. Our work finds stream-stream collisions are a promising way to power optically bright TDEs.

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Discrete implicit Monte-Carlo (DIMC) scheme for simulating radiative transfer problems

Authors: Shay I. Heizler[1]; Elad Steinberg[1]

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We present a new algorithm for radiative transfer, based on a statistical Monte-Carlo approach, that does not suffer from teleportation effects and yields smooth results. Implicit-Monte-Carlo (IMC) techniques for modelling radiative transfer exist from the 70's. However, in optically thick problems, the basic algorithm suffers from 'teleportation'errors, where the photons propagate faster than the exact physical behavior. One possible solution is to use semi-analog Monte-Carlo (ISMC), that uses two kinds of particles, photons and discrete material particles. This algorithm yields excellent teleportation-free results, however, it also results with nosier solutions due to its discrete nature. We derive a new algorithm, Discrete implicit Monte-Carlo (DIMC) that uses the idea of the two-kind discrete particles and thus, does not suffer from teleportation errors. DIMC implements the IMC discretization and creates new radiation photons each time step. We test the new algorithm in both 1D and 2D problems, and show that it yields smooth, teleportation-free results. We finish in demonstrating the power of the new algorithm in a classic radiative hydrodynamic problem, an opaque radiative shock wave. This new MC algorithm, will enable the astrophysics community to accurately simulate radiative transfer in problems that transition from optically thick to optically thin.

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The origin of TDE emission

Authors: Elad Steinberg[1]; Nicholas Stone[1]

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We present, for the first time, a fully self-consistent radiation hydrodynamic simulation of a realistic tidal disruption event (TDE). TDEs are highly luminous, multiwavelength astrophysical transients that carry great promise for measuring the properties of supermassive black holes, but the complex

physics and large dynamic range of the problem has until now prevented self-consistent simulations with realistic parameters. Using the moving mesh code RICH, we evolve a solar mass star from its (destructive) first passage through the tidal radius of a 10^6 solar mass SMBH, up through the first fallback of debris, and beyond.
We show that the shock heating of the gas as it passes through pericenter is the main luminosity source of the observed early time emission. No efficient circularization is observed, ruling out certain classes of TDE models for "typical" TDE parameters.

Exoplanetary Atmospheres / 49

Improving planetary atmosphere characterization by 3D NLTE modeling of the stellar centre-to-limb effect

Author: Gloria Canocchi[1]

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The center-to-limb variation (CLV) of the stellar lines across the stellar disk is an important effect for planetary transit spectroscopy. Indeed the variation of spectral line profiles when the planet transits different part of the stellar disk can affect the determination of elemental abundances in the planetary atmospheres, as shown by Yan et al. (2017). Accurately modeling the CLV effect of planet-host stars is fundamental to better characterize the planetary transmission spectrum and to correctly detect and measure abundances of atmospheric species.
However, we know that the commonly used 1D plane-parallel LTE atmosphere models fail to reproduce spatially resolved observations of the solar disk. 3D hydrodynamic models and non-LTE line formation is required for an accurate modeling of the CLV effect.
So far, the best studied atomic lines in transit spectroscopy are the Na D lines and the NIR K resonance lines. In this talk I will present new results regarding the modeling of these lines in the Sun using 3D NLTE radiative transfer and discuss possible implications for transit spectroscopy.

Supernovae / 50

Systematic investigation of very early-phase spectra of type Ia supernovae

Author: Mao Ogawa[1]

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It is widely accepted that Type Ia supernovae (SNe Ia) are thermonuclear explosions of a CO white dwarf in a binary system, but it is still unknown how the explosive nucleosynthesis proceeds during the explosion. Thanks to the recent technological development of the transient observations, many supernovae are now detected shortly after the explosion, followed by quick spectroscopic observations. In this study, we focus on very early-phase spectra of SNe Ia and try to constrain the explosion models of SNe Ia. By using one-dimensional Monte Carlo radiation transfer code, TARDIS, we estimate the density and the abundance structure of the outermost ejecta of SNe Ia. Applying the method for a sample of SNe Ia, we systematically investigate whether and how the outermost ejecta structure is different for different subclasses of SNe Ia. In this presentation, we will show the initial results of our investigations, and discuss possible links between the properties of the outermost layers and the explosion models.

Protoplanetary Disks / 51

Hydrogen-line emission from accreting planets: fluxes, line shapes, and a new correlation

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Recent direct evidence for ongoing accretion at gas giants such as PDS 70 b and c and Delorme 1 (AB)b make theoretical models of hydrogen-line emission timely. For the shock at the planet's surface, we present fluxes in the strongest indicators (H alpha, H beta, Pa beta, etc.) using the non-LTE, chemical-kinetics code of Aoyama et al. (2018). We consider the relevant large parameter space in accretion rate, mass, and radius. We show that our correlation between accretion luminosity and line luminosity differs from extrapolations from fits to Young Stellar Objects, which bears on the interpretation of (non-)detections. Also, we study systematically how much the accreting matter can absorb the H alpha radiation. We find that in most cases the gas barely absorbs, but that the increase in extinction with accretion rate eventually leads to a maximum H alpha luminosity. We estimate appropriate dust opacity values, which are found to cover a wide range. Finally, we show that the accreting gas can leave a imprint visible in the line profile at high resolution (R ~ 15'000, like VIS-X), providing complex signatures of the accretion geometry.

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The Multi3D extension for DISPATCH: A task based approach to NLTE radiative transfer

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With next-generation astronomical facilities like WEAVE, 4MOST, and SDSS-V large datasets of high-quality stellar spectra will become available soon. The need for cutting edge 3D non-LTE radiative

transfer codes is clear, but the demand for easy-to-use spectrum synthesis tools is even greater. We aim to provide both by supplying a non-LTE RT module based on the Multi3D code to the recently published DISPATCH framework. The strong scaling capabilities of the DISPATCH framework as well as its already implemented magneto-hydrodynamics (MHD) solvers promise to produce time-dependent non-LTE spectra if combined with Multi3D.

Stellar atmospheres / 53

Modelling the Milky Way's most metal-poor star

Author: Cis Lagae[1]

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Late-type ultra metal-poor stars are thought to be formed from interstellar gas enriched by only one to few supernovae. As such, their elemental abundances and total metal content are important in understanding the limits of star formation in the early universe and the chemical evolution of the Milky Way. In this talk, I will present an updated chemical abundance analysis of the most metal-poor star known to date (SDSS J102915+172927) using new stellar parameters from Gaia DR2 and a tailored 3D atmospheric model, first discussed by Caffau et al. (2011). This work showcases the advantages of state-of-the-art 3D atmospheric models and 3D NLTE radiative transfer compared to commonly used 1D LTE methods. In addition, we are revitalising and expanding the STAGGERgrid of 3D stellar models together with collaborators from Aarhus university. This is especially interesting in the prospect of upcoming large spectroscopic observing campaigns like GALAH, WEAVE, and 4MOST, which will release a wealth of spectroscopic data, including hundreds of thousands of metal-poor stars.

Stellar atmospheres / 55

The handling of radiation transport in 3D simulations of cool giants

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Recent 3D simulations of cool giants and supergiants, specifically the asymptotic giant branch (AGB) and red supergiant (RSG) stars, with the CO5BOLD radiation-hydrodynamics code cover a wider range of stellar parameters and with greater temporal and spatial resolution than before. In these simulations, the hydrodynamical steps were handled straightforwardly with the Roe solver with 1D directional splitting, while particular considerations were needed for the radiation transport scheme. As all the boundaries on the grid are fully open for matter and radiation, and conditions in AGB and RSG stars give rise to turbulent and violent flows, resulting in large fluctuations in local temperature, heat capacity and opacity, radiation transport is handled with a modified short-characteristics scheme. The size of a radiative time step was calculated in relation to the thermal relaxation time of the grids, with an equation adapted from Spiegel (1957). Other simplifications exist to allow for efficient, yet accurate and reliable, radiative transfer in the 3D simulations. The aim of the talk, or poster, would be to highlight the radiation transport scheme being utilised in the CO5BOLD simulations, and present recent analyses on the pulsation properties of the simulated stars and how they relate to their stellar parameters.

Protoplanetary Disks / 56

Multi-fluid Radiation Hydrodynamics of Protoplanets

Author: Leonardo Krapp[1]

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The coupling between multi-species dust dynamics and radiative transfer is crucial for the realistic modeling of cold astrophysical environments such as star-forming regions, protoplanetary disks, and exoplanets atmospheres. At low temperatures, dust distribution plays a primordial role in shaping gas opacity, even when the dust mass fraction is negligible. Thus, in this talk, I will present a framework to perform 3D radiation hydrodynamics simulations with opacity based on self-consistent dust dynamics, in local and non-local thermal equilibrium. I will focus on planet formation and introduce recent 3D numerical simulations performed with the multi-fluid code FARGO3D. In particular, I will showcase the regimes where the opacity of the planet envelope deviates from spherical symmetry. Therefore, the envelope thermodynamics may not be trivially cast in 1D models. This is critical to assess the scope of core accretion theory and explain exoplanet demographics.

Supernovae / 57

Type Ia supernovae from sub-Chandrasekhar-mass white dwarf detonations: The importance of non-LTE

Author: Ken Shen[1]

[1] *UC Berkeley*

The double detonation scenario has recently risen to the forefront of Type Ia supernova (SN Ia) progenitor research. In this channel, a helium-burning detonation on the surface of a sub-Chandrasekhar-mass white dwarf (WD) ignites a secondary carbon-burning core detonation. This scenario has been studied for decades, but it is only in the past year that, for the first time, explosion models with accurate detonation physics and nucleosynthesis have been combined with non-LTE radiation transport calculations, yielding the best match in the literature to the Phillips relation, which forms the basis for the use of SNe Ia as cosmological distance indicators. In this talk, I will describe these improvements and present our generated observables. The success of this scenario in matching observations, as well as other achievements that I will discuss, provide evidence that the double detonation scenario is the mechanism responsible for most SNe Ia.

Protoplanetary Disks / 59

Discontinuous finite element method applied to the 2D radiative transfer problem in axisymmetric circumstellar envelopes

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The study of circumstellar environments at different stages of stellar evolution is of crucial importance. These environments reflect the physical processes in action, from the star formation with the presence of accretion discs to late stages in the evolution, in which strong stellar winds shape the circumstellar envelopes. In order to constrain the models describing them, it is necessary to solve the radiative transfer equation under the assumption of radiative equilibrium. We investigated a

discontinuous finite element method in order to solve the 2D radiative transfer equation, in spherical coordinates, with isotropic scattering and coupled with the radiative equilibrium equation. The study is conducted for the special case of an axisymmetric circumstellar envelope surrounding a star. We implemented this method in a code and tested its accuracy by comparing it with previous 1D (Ivezic & al. 1997) and 2D (Pascucci & al. 2004) benchmarks tests.

Exoplanetary Atmospheres / 60

Probing the upper atmospheres of exoplanets and atmospheric escape with NLTE radiative transfer

Author: Antonija Oklopcic[1]

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The helium line at 1083 nm is one of the strongest spectral features observable in transit spectroscopy of exoplanet atmospheres. As such, it is a powerful diagnostic of upper atmospheres of exoplanets, providing valuable insight into their dynamics and the process of atmospheric escape. Absorption in this line is caused by neutral helium atoms in an excited, metastable state. At low densities and strong irradiation characteristic of upper atmospheres of close-in exoplanets, the population of the helium metastable level is out of local thermodynamic equilibrium. I will discuss the NLTE approach adopted in atmospheric models designed to predict and interpret the growing number of transit observations at 1083 nm.

Exoplanetary Atmospheres / 63

Why does thermodynamic equilibrium matter when measuring transition probabilities?

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High-quality transition probabilities (oscillator strengths, log(gf)) are of vital importance in the analysis of astronomical spectra. Along with spectral line wavelengths and widths, they allow astronomers not only to determine the chemical composition of stellar and exoplanetary atmospheres, but also to gain some insight into their temperature and electron density.

For more than 30 years, the Plasma Spectroscopy Laboratory at the University of Valladolid (Spain) has been developing different techniques for the generation and diagnosis of plasma light sources with which to measure atomic parameters (transition probabilities, Stark widths). Our instrument has a resolving power of 200 000 at 200 nm and is able to measure in the 200-900 nm spectral region.

In this talk, I will explain in a comprehensive manner the different experimental methods available for the measurement of transition probabilities. Each method is chosen according to whether thermodynamic equilibrium on the plasma used as a light source is present or not. The final aim of this presentation is to make the work of experimental plasma spectroscopy more accessible to researchers and astronomers in need of high-quality atomic data and to create a common language that can be used as a foundation upon which to foster future collaborations.

Interstellar Medium / 65

DEATHSTAR - A new hope for accurate mass-loss-rate estimates

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Asymptotic giant branch (AGB) stars are agonising cool giants that lose mass through spectacular stellar winds. The gas and dust ejected through the winds create a chemically-rich expanding envelope around the star, namely the circumstellar envelope (CSE), and eventually enrich the interstellar medium. The mass loss is the most crucial process that determines the fate and the galactic-chemical-enrichment contribution of AGB stars. DEATHSTAR is a large project aimed at improving the accuracy of wind-parameter measurements using high-quality CO observations from ALMA towards the CSEs of nearby AGB stars. These are used as constraints and combined with detailed radiative transfer (RT) modelling of the observed CO to obtain reliable mass-loss-rate (MLR) estimates. Solving the RT through the cool, low density CSE requires a non-LTE approach. We use a Monte-Carlo method that takes into account the geometry, the velocity fields and the heating/cooling properties of the studied gas to obtain its level population. I will give an overview of the current state of the DEATHSTAR project and present the RT outputs, including the better-constrained dust and gas MLRs, the radial kinetic gas and dust temperature in the CSE, and the size of the molecular envelopes in the CSEs of AGB stars.

Supernovae / 66

Radiative transfer simulations for explosive transients

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We use the 3D radiative transfer code ARTIS to predict light curves and spectra for hydrodynamic explosion models. We first present radiative transfer simulations of the 'double detonation'scenario, which is a promising explosion mechanism to explain Type Ia supernovae from sub-Chandrasekhar mass white dwarfs. The synthetic spectra and light curves from our approximate non-LTE calculations (which use a nebular approximation) show a number of discrepancies with observations of SNe Ia, namely that the light curves show colours too red and spectra show strong absorption features due to heavy elements (Ti, Cr and Fe-group) produced during the He shell detonation in the outer layers. ARTIS has recently been extended with the capability to model radiative transfer in full non-LTE. This substantially improves the accuracy of predicted observables, and we discuss improvements in the agreement between models and observations.

We also present ARTIS calculations predicting the kilonova emission from neutron star merger simulations. Many previous kilonova simulations have assumed greatly simplified ejecta structures. We investigate in 3D how the simulated dynamical ejecta component (ejected on timescales of milliseconds) contributes to the resulting kilonova light curve.

Supernovae / 67

Electromagnetic Counterparts of Neutron Star Mergers: Signatures of Heavy r-Process Nucleosynthesis

Author: Andreas Flörs[1]

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It has long since been established that observable actinides in the universe originate from the r-process. In 2017, the electromagnetic counterpart to the gravitational wave detection of two merging neutron stars was observed. From the light curve alone it was possible to characterise two ejecta components: one that contains low-Ye material such as lanthanides and possibly actinides, and a high-Ye component with low lanthanide abundances. The dividing characteristic between the two components is the opacity of the material: lanthanides have a ~100 times higher opacity than iron-group material. The opacity of actinides is expected to be on a similar level as that of the lanthanides, or, possibly, even higher.

To identify specific elements, spectroscopic information is required. However, so far no clear detection of individual lanthanides or actinides has been made in the only observed neutron star merger. A great challenge for spectroscopic modelling of kilonovae is the almost non-existent atomic data currently available for lanthanides and actinides. I will present converged and calibrated atomic structure calculations from Zr to U. I will then use this collection of atomic data to show how we can identify signatures or place constraints on the amount of heavy r-process material synthesized in kilonovae.

Protoplanetary Disks / 68

Dissecting the kinematics of an infalling envelope with modeling of absorption and emission

Author: Yao-Lun Yang[1]

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Infall drives the growth of protostars in terms of their mass as well as the structural and chemical complexities. The rich spectra of molecules best probe the infall kinematics at a wide range of spatial scales and physical environments. Molecular emission highlights the infalling gas as specific patterns in position-velocity diagrams and streamers. Moreover, red-shifted absorption against the continuum due to the cold dense gas falling onto the protostar give an unambiguous evidence of infall. While these features indicate ongoing infall, constraining the underlying kinematics requires forward modeling with non-LTE radiative transfer calculations. In BHR 71, a Class 0 protostar, we have modeled the infalling envelope to reproduce the red-shifted absorption in HCO^{+} and HCN using LIME. While the model reproduces the spectra toward the continuum source, the synthetic spectra disagree with the observations at off-center positions, hinting a stronger rotation at the inner 50 au region compared to our envelope model. I will discuss the success and the shortcoming of our model as well as possible remedies. I will also discuss the comparison of this model to other transitions of HCO+ and emission features to formulate an infalling envelope constrained by multiple tracers at various scales.

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Applicability of LTE to Kilonova Ejecta, and Impact on Opacities

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A binary neutron star merger (BNS) is expected to produce supernova-like radioactively powered transient known as a kilonova (KN), which enters the nebular phase several days after the merger. Modelling of the ejecta in this phase has often been approached under the assumption that local thermodynamic equilibrium (LTE) is applicable. In order to test the validity of this assumption, we compare the excitation structure of elements in the ejecta when assuming LTE, and when using full non-local thermodynamic equilibrium (NLTE) calculations from the spectral synthesis code `SUMO`. We also consider NLTE calculations omitting the radiation field in order to test the importance of radiative transfer in NLTE modelling. From these solutions, we calculate expansion opacities for the ejecta in a time-span of 3 –20 days after merger. I will present the results of this study, focussing on the accuracy of LTE at early times, as well as the importance of including radiative transfer in NLTE modelling.

Stellar atmospheres / 74

Solar atmospheric modelling and diagnostics

Radiation is the dominant energy transport mechanism in the solar atmosphere, and it is therefore important to have a good description of radiative transfer when modelling the solar atmosphere. For modelling purposes, it is only important to capture the radiative cooling/heating and not the details of the spectrum. For diagnostic purposes, we need the detailed spectrum and 3D radiative transfer modelling is necessary, at least for diagnostic lines formed in the outer atmosphere. I will discuss radiative transfer within this context of solar atmospheric modelling (multi-group opacities without and with scattering, non-equilibrium ionization) and diagnostics (3D non-LTE).

Stellar atmospheres / 75

Non-LTE stellar physics and its applications

One of the biggest assumptions in modelling stellar emission has been an assumption of local thermodynamical equilibrium, also known as LTE. While still widely spread, it has been shown to significantly bias results of stellar modelling, for example derived abundances.
In this talk I will focus on what is known as Non-LTE modelling - modelling stellar radiation without assuming LTE.
I will touch on its costs and requirements and will mainly focus on how it changes our understanding of individual stars and stellar populations, within and outside of the Milky Way.

Exoplanetary Atmospheres / 76

The Atmospheres of Exoplanets: Albedos and Phase Curves of Celestial Bodies

The albedo of a celestial body is the fraction of incident starlight reflected by it. The study of the

albedos of Solar System objects is at least a century old, at least in the Western world. As examples: Bond (1861) speculated on the near-unity albedo of Jupiter, while Russell (1916) observed the opposition surge of the Moon near and at full phase. The light of a planet or moon varying with orbital phase is known as its phase curve. Modern astronomical facilities have enabled the measurement of phase curves of reflected light and thermal emission from exoplanets (e.g. Kepler, TESS, CHEOPS, Hubble, Spitzer), which enables the investigation of atmospheric dynamics and aerosols. In the current talk, I will concisely review and discuss historically important work, including seminal contributions by Chandrasekhar (1960), Sobolev (1975) and Hapke (1981). These introductions set the stage for a detailed discussion of our recent work on generalising these classic works to derive closed-form, ab initio solutions for the geometric albedo and reflected light phase curve. This novel theoretical framework is applied to Kepler space telescope data of the hot Jupiter Kepler-7b, where we demonstrate that one may infer fundamental aerosol (single-scattering albedo, scattering asymmetry factor) and atmospheric (geometric albedo, Bond albedo, phase integral) properties from precise photometry alone, thus providing powerful complementary information to spectra. Another case study are the Cassini phase curves of Jupiter, which were measured in the early 2000s by the Cassini space mission but never subjected to Bayesian inference. By inverting the Cassini phase curves, we infer that aerosols in the Jovian atmosphere are large, irregular, polydisperse particles that may be responsible for causing coherent backscattering of sunlight.

Exoplanetary Atmospheres / 77

Along the Line of Sight: Changing Chemical States in Cloud Forming Exoplanet Atmospheres

Author: Dominic Samra[None]

Exoplanet atmospheres provide ideal atmospheric laboratories to explore atmospheres unlike anything in our Solar System. Atmosphere characterisation is also an important tool in understanding exoplanetary system formation and evolution. However, exoplanets are not globally homogeneous, as the light we observe must pass though many diverse regions any observations probe a wide variety of chemical states, for example in transmission spectroscopy. With new instruments like JWST and upcoming missions such as ARIEL, the higher quality observations will demand a detailed understanding of all these regimes. Furthermore, population studies of gas-giant exoplanet atmospheres are beginning to reveal the impacts planetary system parameters and host star properties also have on the atmospheres.

We explore the non-equilibrium formation of clouds, globally, for gas-giant exoplanets with a range of orbital parameters. Crucially, the asymmetries between the dayside and nightside and at the terminators depend on parameters like planetary rotation rate and host star spectral type. However, there is consistently formation of clouds on the nightside of these planets. Whilst the lowest rays pass through regions of chemical-equilibrium, there are also are regions of ionisation of the gas deep in the atmospheres of gas-giant exoplanets, as well as the upper atmosphere on the dayside of ultra-hot Jupiters. Furthermore, the upper atmospheres also have photochemical processes and energetic particle fluxes, which because of the slant geometry of transmission observations will have a large impact on the observed spectra. Differences in irradiation between the dayside and nightside of hot Jupiters leads to large chemical abundance changes, with ammonium and oxonium being key fingerprints for non-thermal ionisation processes. In addition these non-equilibrium process enhance the production of organic molecules on the pathway to producing amino acids such as glycine. This talk endeavours to provide insight as to how these non-equilibrium processes shape an exoplanet atmosphere.

Protoplanetary Disks / 78

Radiation thermo-chemical modeling of planet forming disks

With the advent of high spatial resolution ALMA data and the prospect of JWST data in the near future, we have entered an era where the limitations of simple disk models are becoming clear. The data reveal to us the complex interplay between gas and dust in disks, which happens not only at the level of physics (heating/cooling) and chemistry, but also at the level of radiative transfer. I will discuss in this talk recent advances in radiation thermo-chemical disk modeling and address open issues and directions for improvements both in terms of radiative transfer methods, but also require atomic/molecular data.

Interstellar Medium / 79

Radiative transfer modelling of cold interstellar matter

Radiative transfer modelling is an essential tool in star-forming studies, providing the connection between the complex physical reality within the interstellar medium and the radiation observed from it. Therefore, it is needed both in the analysis of observations and when predictions are made based on numerical simulations.

I will discuss the modelling of spectral lines and the dust emission and scattering, in the context of dense molecular clouds. The non-local nature of the radiative transfer problem, the high optical depths, and the large dynamical range of the models all cause practical challenges. I will examine, how (and if) these can be addressed with the use of hierarchical grids, GPU computing, and specific numerical methods. The examples range from the post-processing of MHD simulations, covering scales of hundreds of parsecs with up to billion volume elements, down to small one-dimensional models at the scale of individual cloud cores. I will also touch on one related problem, how to build a model that matches the observations of an individual object. I will end by discussing some future plans, for example, in the modelling of dust polarisation.

Interstellar Medium / 80

Radiative transfer tools for regions of star and planet formation

Understanding the processes that form stars and planets requires line observations of atoms and molecules at long (infrared and radio) wavelengths. Radiative transfer tools are essential for the step from observed line intensities to physical and chemical conditions such as cloud masses, kinetic temperatures, gas densities, and atomic & molecular abundances. This talk describes existing tools for the physical interpretation of observed line spectra, and outlines which steps are needed to prepare ourselves for the large data streams of upcoming telescope facilities. Special attention is given to the measurement, computation and dissemination of atomic and molecular input data, which are key to reliable estimations of gas properties

Accretion Disks / 81

A polarimetric view of black hole accretion flows and jets

The Event Horizon Telescope is a global effort to construct an
Earth-sized virtual radio telescope array, with the goal to make pictures and movies of two nearby supermassive black holes. A detailed theoretical understanding of black hole accretion is now crucial to interpret these observations. I will review our current efforts to model polarimetric properties of

light produced in synchrotron processes in plasma falling
towards the event horizon. The numerical models are based on general relativistic magnetohydrodynamics simulations so they are capable of capturing the complex dynamics of magnetic fields and their interactions with plasma. It is now
important to understand the polarized radiative transfer in these simulations to correctly predict the observational signatures of the events at the event horizon scales where the accretion disk and jet are connected.

Accretion Disks / 82

[Ca II] emission in the nebular phase: what exactly can it tell us?

Nebular [Ca II] emission can show up in the spectra of just about every type of supernovae (SNe): SNe Type Ia, core collapse SNe and of course the elusive Ca-rich transients. But what this emission can tell us, beyond there being some (how much?) calcium in the ejecta, is not well understood. I will present the early results of ongoing work to quantify this phenomena using NLTE radiative transport methods on simple SN ejecta models. We aim to understand exactly what a [Ca II] emission line can tell us about abundances and when it can dominate a spectrum. Lastly, we relate our findings to the topic of Ca-rich transients in the attempt to answer the question that plagues us all: how rich in calcium are they really?

TIdal Disruption Events / 83

Spectral modeling of flares following tidal disruptions of stars by supermassive black holes

A wealth of spectral data now exists for the flares that follow the tidal disruptions of stars by supermassive black holes, over a wide range of wavelengths. The information encoded in these spectra will be essential to uncovering the dynamical process by which the disruption unfolds and the radiation is generated, which remains intensely debated. However, the theoretical interpretation of these spectra poses substantial theoretical challenges. I will review the available data and the unusual features that arise in these spectra. Then I will review the techniques for theoretical modeling of these spectra, which iteratively combine radiative transfer calculations with non-LTE atomic transition rate equations. These calculations have had some success in addressing coarse-grained features of the data, but I will emphasize the pressing need for new and more detailed models.

Supernovae / 84

Supernovae: Progress and Nightmares

Considerable progress has been made towards modeling supernova (SN) spectra using a variety of codes and techniques. The codes broadly fall into three categories - hydro codes that treat the hydrodynamics but approximate the radiative transfer and the properties of the gas; transfer codes that treat the radiative transfer and gas properties (e.g., temperature, ionization structure) accurately but make simplifying assumptions about the hydrodynamics; and Monte Carlo codes that have varying degrees of accuracy in the treatment of the radiative transfer and the gas properties. Major improvements are required in several areas. The most difficult of these is the consistent treatment of hydrodynamics, radiation transfer and non-LTE state of the gas (in 1D and 3D). At a simpler level more work is needed on time-dependent non-LTE radiative transfer in both 1D and 3D. Density inhomogeneities and abundance inhomogeneities are both important, and their effects can only be approximated in 1D. At nebular times, molecules become important and need to be included. The accuracy of model calculations is also influenced by the availability and accuracy of atomic data.

Supernovae / 85

Non equilibrium effects in Kilonova

A kilonova in the first neutron star merger GW170817 provided us with evidence that the merger ejects a large amount of neutron rich material. Despite the success of the very detailed observations, there remain unanswered questions. Non-LTE modelings of kilonovae likely play key roles to fully understand kilonovae. I will talk about the recent progress in non-LTE kilonova and discuss the implications of the non-LTE effects
to the kilonova in GW170817 as well as to future observations.

Accretion Disks / 86

General Relativistic Radiation Hydrodynamics and Black Hole Accretion

Author: Shane William Davis[1]

[1] *University of Virginia, USA*

I will review methods for solving time-dependent radiation transfer in general relativistic spacetimes and described a new method for treating radiation transfer in a five or six dimensional finite volume approach. I will also describe our efforts to apply direct transfer solutions to simulations of black hole accretion and the driving of accretion disk winds via radiation pressure.

Protoplanetary Disks / 87

Radiative transfer and protostars and disks: an observer's perspective

TIdal Disruption Events / 89

High-energy neutrino emission associated with tidal disruption events

Author: Kimitake Hayasaki[None]

TIdal Disruption Events / 90

First light from tidal disruption events

Author: Clément Bonnerot[None]

When a star comes too close to a supermassive black hole, it gets torn apart by strong tidal forces in a tidal disruption event. The emitted signal represents a powerful probe of these compact objects, the large majority being otherwise starved of gas and therefore undetectable. Exploiting this potential requires a precise characterization of the electromagnetic signatures from these phenomena that can be used to optimally interpret upcoming observations. I will present recent progress towards this goal, which relies on a suite of interlinked simulations to follow for the first time the entire evolution of tidal disruption events.

Supernovae / 91

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92

Along the Line of Sight: Changing Chemical States in Cloud Forming Exoplanet Atmospheres

Exoplanet atmospheres provide ideal atmospheric laboratories to explore atmospheres unlike anything in our Solar System. Atmosphere characterisation is also an important tool in understanding exoplanetary system formation and evolution. However, exoplanets are not globally homogeneous, as the light we observe must pass though many diverse regions any observations probe a wide variety of chemical states, for example in transmission spectroscopy. With new instruments like JWST and upcoming missions such as ARIEL, the higher quality observations will demand a detailed understanding of all these regimes. Furthermore, population studies of gas-giant exoplanet atmospheres are beginning to reveal the impacts planetary system parameters and host star properties also have on the atmospheres.

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TBA

TBA

Stellar atmospheres / 94

Non-LTE impact of Ti I and Ti II on metal-poor type star abundances

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Stellar atmospheres

Title: Non-LTE zinc abundance in different spectral type stars and Galactic [Zn/Fe] trend
Abstract: We present the non-LTE line formation calculations for Zn I-II in stars in a wide range of spectral types. The most accurate atomic data available to date were adopted, namely, quantum mechanical rate coefficients for inelastic collisions with hydrogen atoms and electronic collisions, and laboratory measurements of the oscillator strengths, where available. For the first time we investigated the departures from LTE for the UV Zn I and Zn II lines in very metal poor (VMP) stars. For three VMP reference stars, we found a satisfactory agreement within 0.2 dex between non-LTE abundances from different Zn I and Zn II lines. We determined non-LTE abundances of Zn in a sample of solar vicinity dwarfs in a wide metallicity range, -2.6 < [Fe/H] < 0.2. Metal-poor stars with [Fe/H] < -1 show constant [Zn/Fe] = 0.2, while a spread from 0 to [Zn/Fe] = -0.2 was found at solar metallicity. The diversity of [Zn/Fe] in stars with close to solar metallicity is confirmed from non-LTE analysis of Zn and Fe lines in BAF type stars.