Simulating Kilonova Spectra with Detailed Atomic Opacities

Gerrit Leck

17th Rußbach School on Nuclear Astrophysics

14th March 2022

TECHNISCHE
UNIVERSITÄT
DARMSTADT

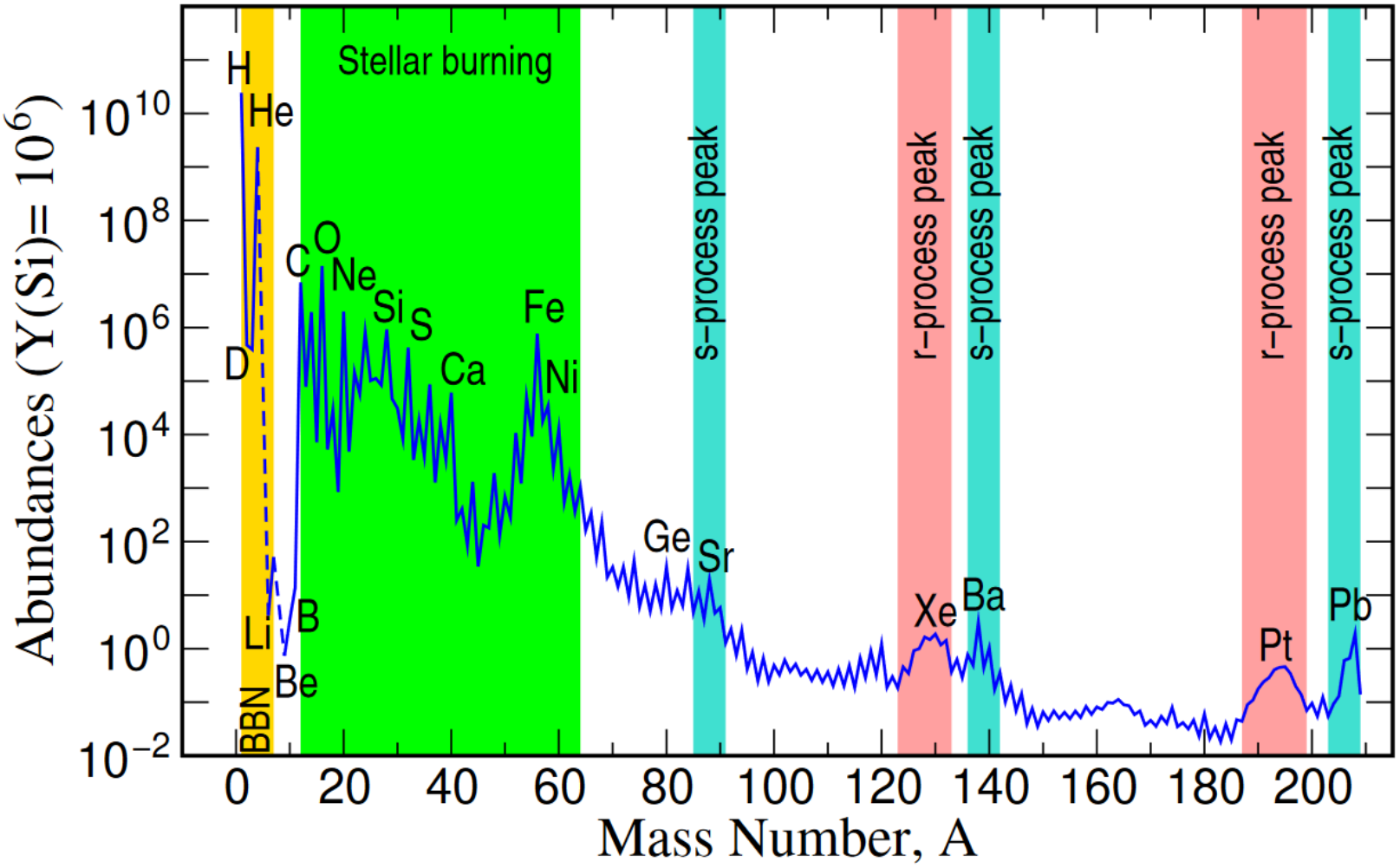
GSI Helmholtzzentrum für Schwerionenforschung GmbH

Outline

- Motivation
- Neutron Star Mergers & r-Process
- The Kilonova AT2017gfo
- Simulation Tools & Required Data

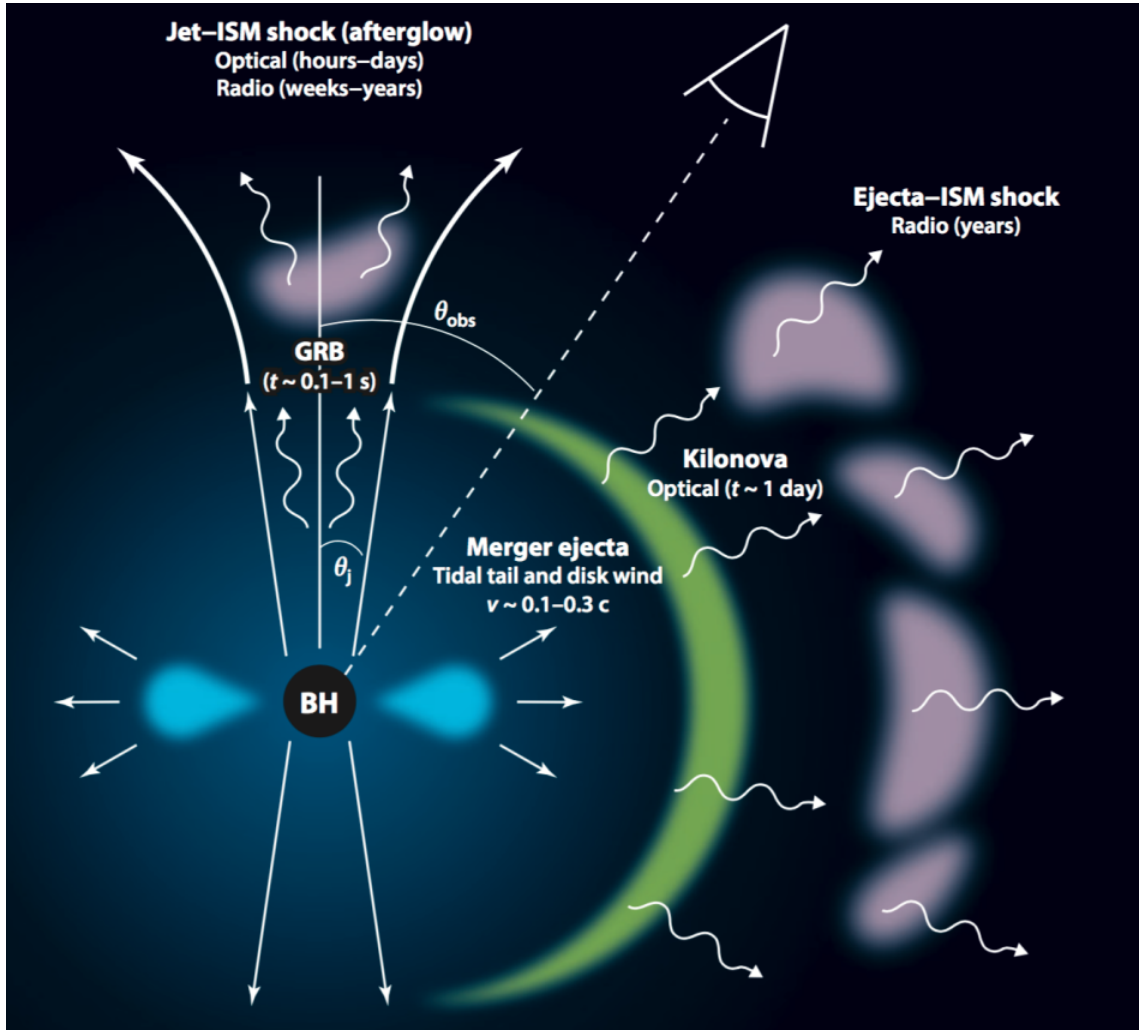
Motivation

- What is the origin of heavy elements?



Cowan et al., 2021

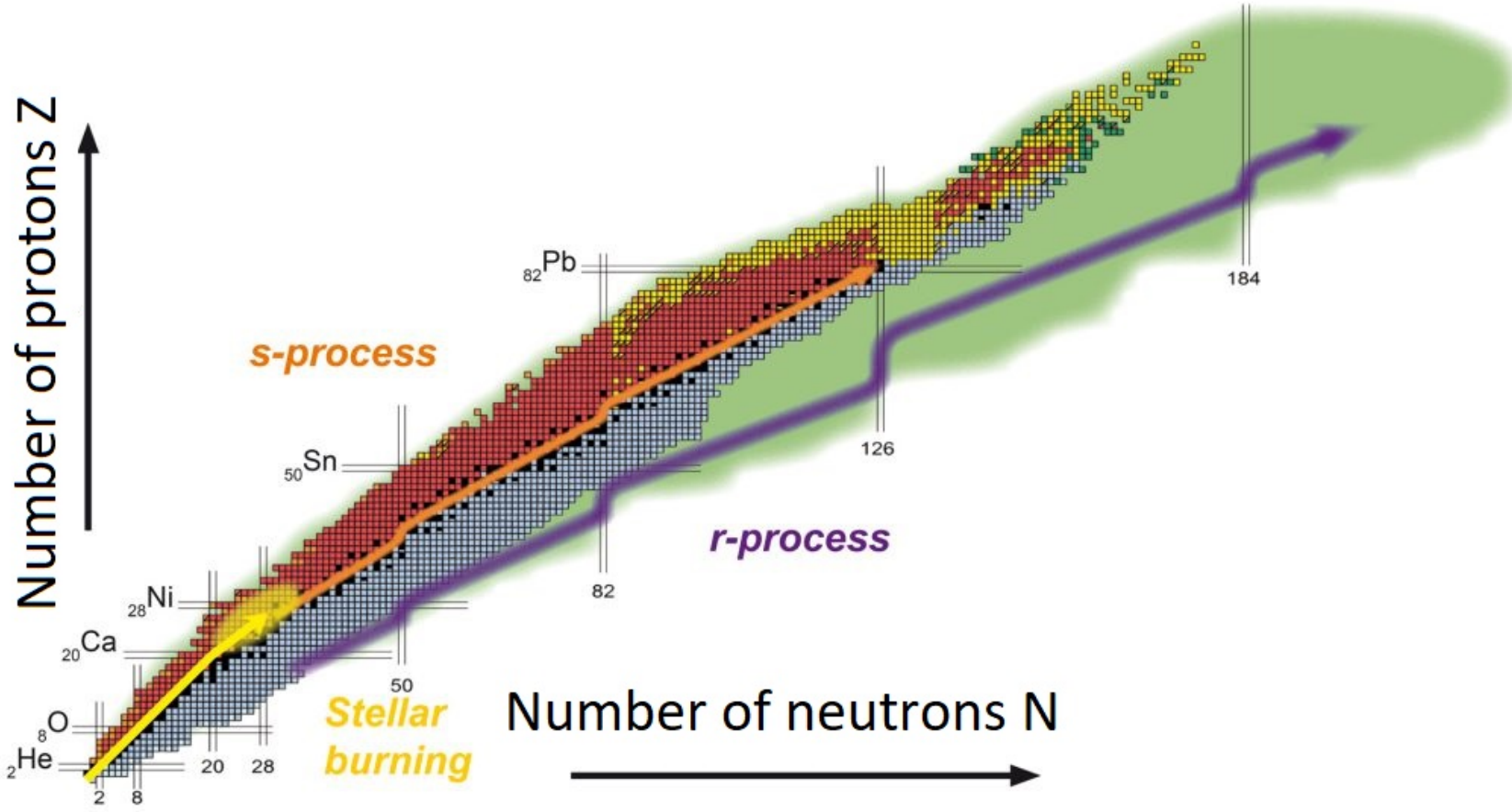
Neutron Star Merger Ejecta



Metzger, 2019

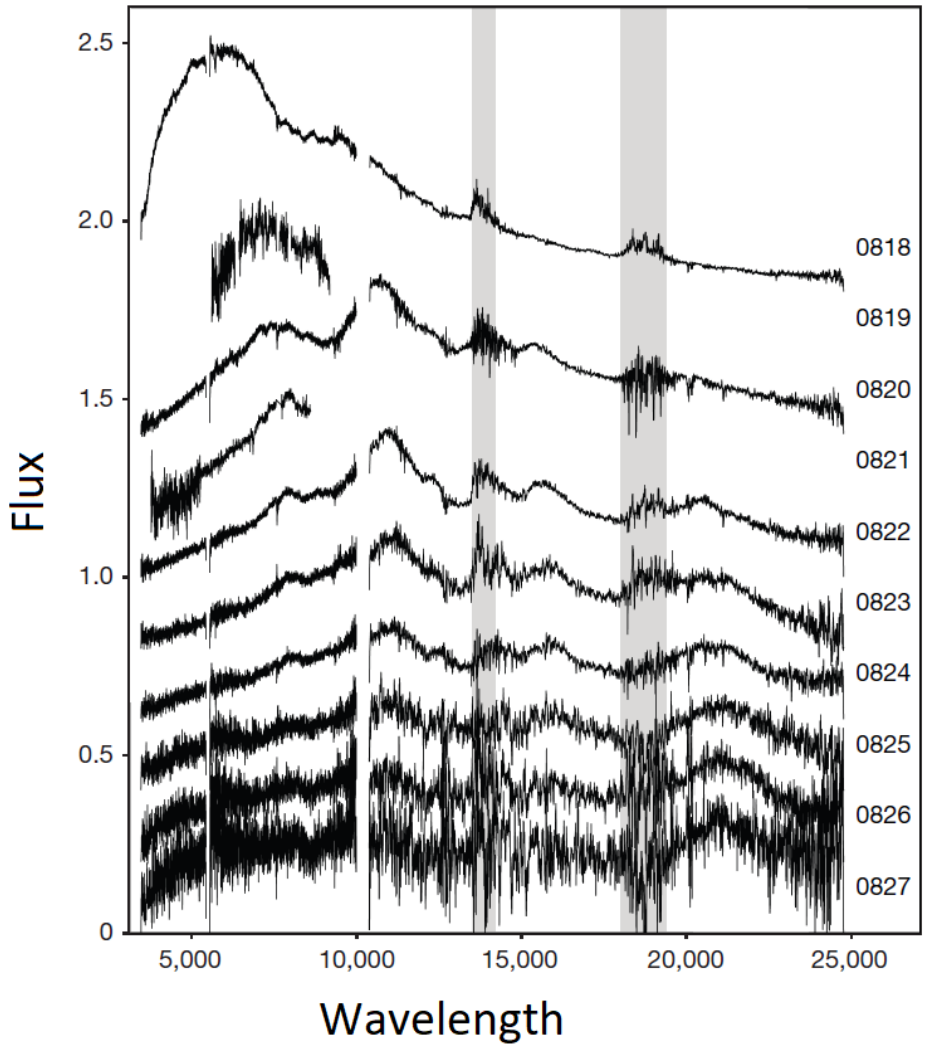
- ejecta masses: $M_{\rm ej} \sim 10^{-3} - 10^{-2}\,{\rm M}_\odot$

The R-Process



- radioactive decay over timescales $\sim$ d of an ensemble of nuclei
- decay energy heats plasma $\rightarrow$ thermal radiation

The Kilonova AT2017gfo



Pian et al., 2017

- Watson et al., 2019: identification of Sr II

Nuclear Network and Atomic Structure Calculations

1. Detailed Composition $\rightarrow$ GSI network code

$$\frac{\mathrm{d}\vec{Y}}{\mathrm{d}t} = \underbrace{\vec{f}\left(\vec{Y}(t), t\right)}_{\text{decays etc., one-body, two-body}}$$

2. Atomic Structure Calculations $\rightarrow$ FAC

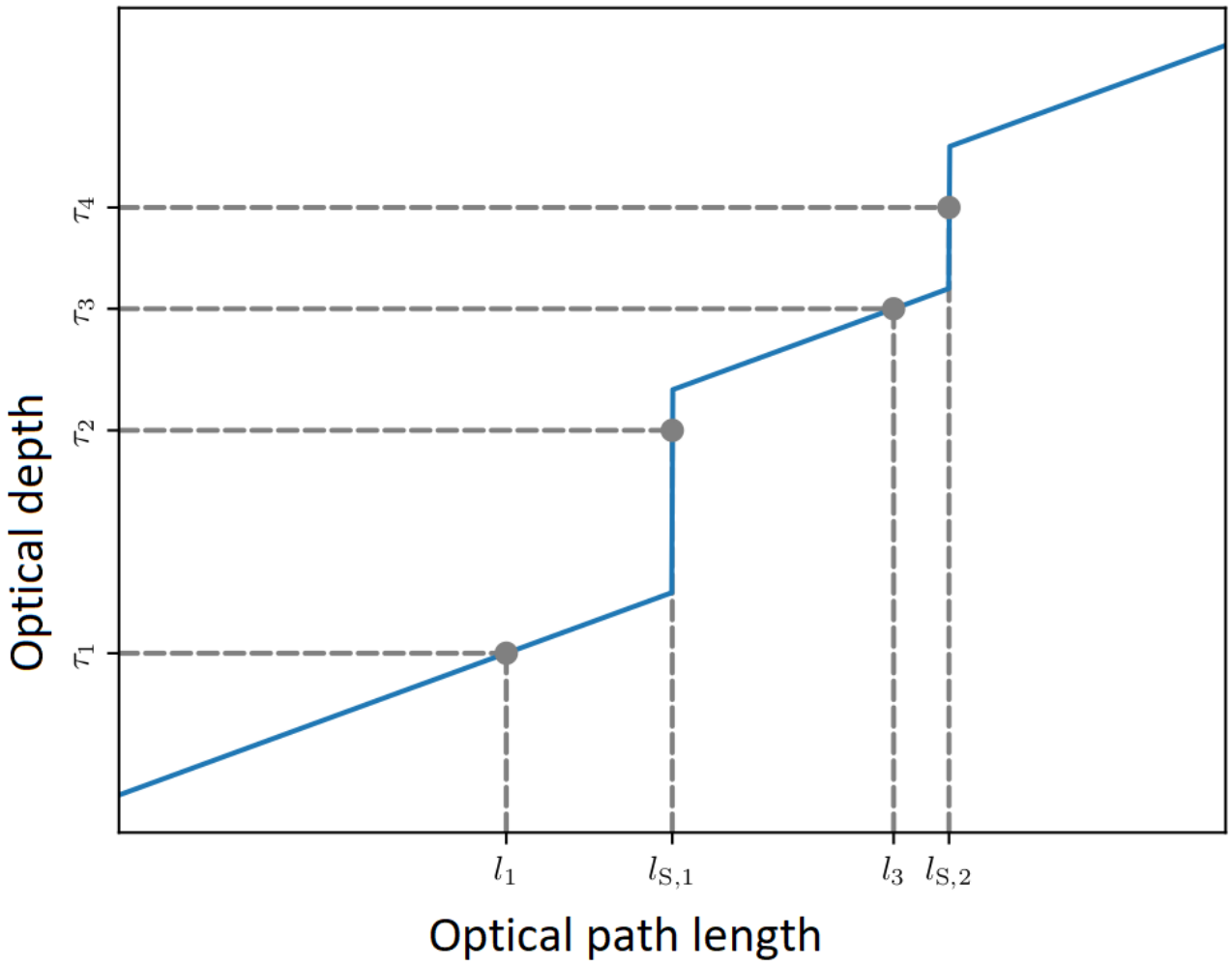
- calculate atomic structure and transitions (λ_l, f_l)
- problem: relativistic many-electron system

$$\Psi = \sum_{\underline{k}} c_{\underline{k}} \Psi^{\mathrm{SD}}_{\underline{k}}$$

- collaboration with Lisbon Atomic Theory Group

Sobolev Approximation

- full interaction within a single point
- optical depth: $\tau := \int \rho \kappa \mathrm{d}s$

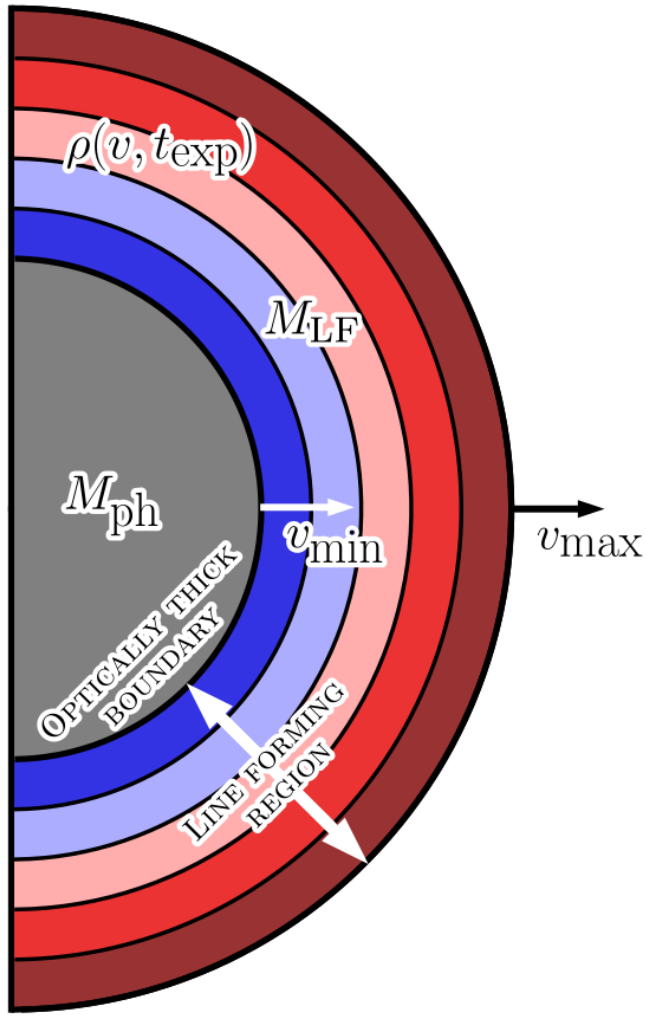


Noebauer et al., 2019

TARDIS

3 Spectral Modeling: TARDIS

- 1D Monte-Carlo radiative transfer code
- expanding medium with Sobolev approximation
- *advantage*: computation timescale of minutes



Gillanders et al., 2022

Summary

- aim: find spectral features of r-process elements
- main impact on spectra: bound-bound atomic transitions
- we need:
  - compositions on timescales of interest
  - *detailed atomic data*
- 1D-MCRT simulations with TARDIS
  $\rightarrow$ systematic parameter studies