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Systematic calculations of Electron-Impact Excitation of Lanthanides for Collision-Radiative Modelling

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KILONOVAE and r-PROCESS

When two neutron stars merge, we detect gravitational waves as well as an electromagnetic transient counterpart: kilonova. **R-process** nucleosynthesis may take place, leading to the creation of heavy nuclei such as **lanthanides** and **actinides** [1].

LTE modelling:

→ Level populations follow Maxwell Boltzmann distribution;

→ Bolometric light curves can be reasonably approximated using grey opacities.

NLTE modelling [2]:

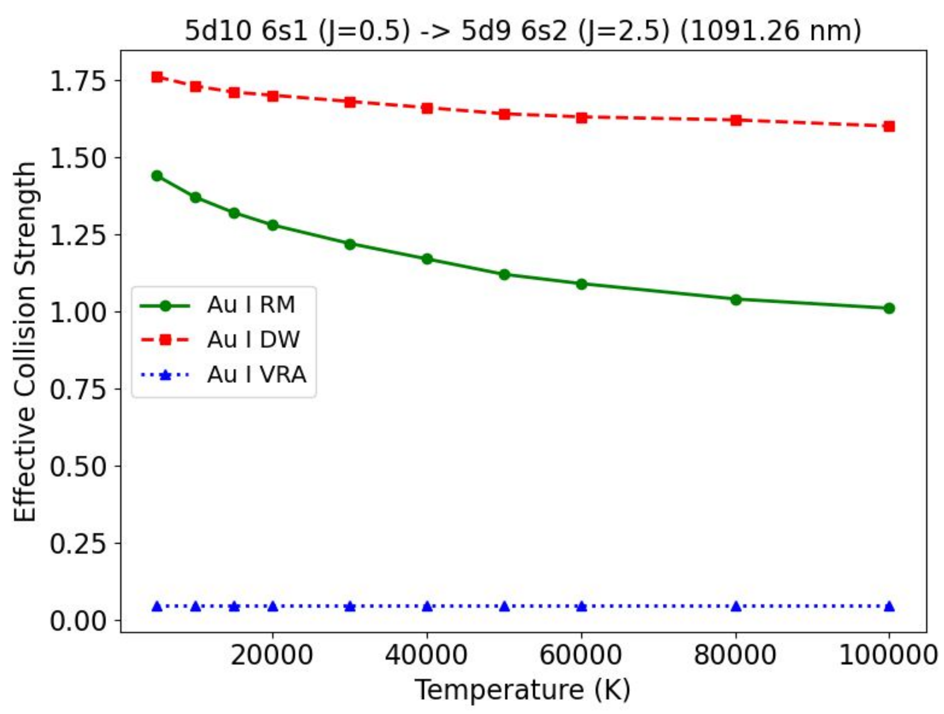
→ Lower densities of the ejecta require a **full solution for the rate equations**;

→ A more extensive set of atomic data is required, for example, Electron-Impact Excitation (EIE) cross-sections.

DISTORTED WAVE, R-MATRIX and VRA

Van Regemorter and Axelrod (VRA) approximation tends to underestimate effective collision strengths and, consequently, level populations. EIE calculations were performed using **Distorted Wave (DW)** package in **FAC** [3] and compared with **R-matrix** calculations [4] and with **VRA**.

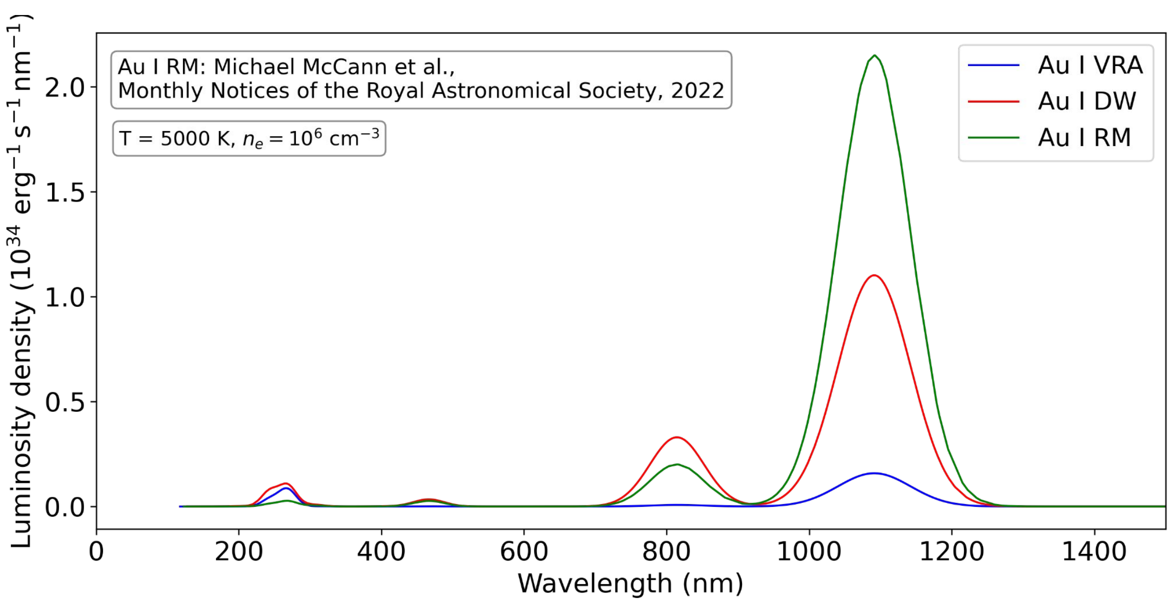
→ Although DW does not include resonances, because the **scattering matrix is non-unitarized**, it tends to **overestimate the background** contribution.



LUMINOSITIES BENCHMARK

→ **VRA underestimates the populations of low energy states**, leading to lower luminosity predictions for the most intense lines.

→ Differences to R-Matrix calculations are likely due to **lack of resonances** and **overestimation of background** → possibility for improvement.



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LINE LUMINOSITIES

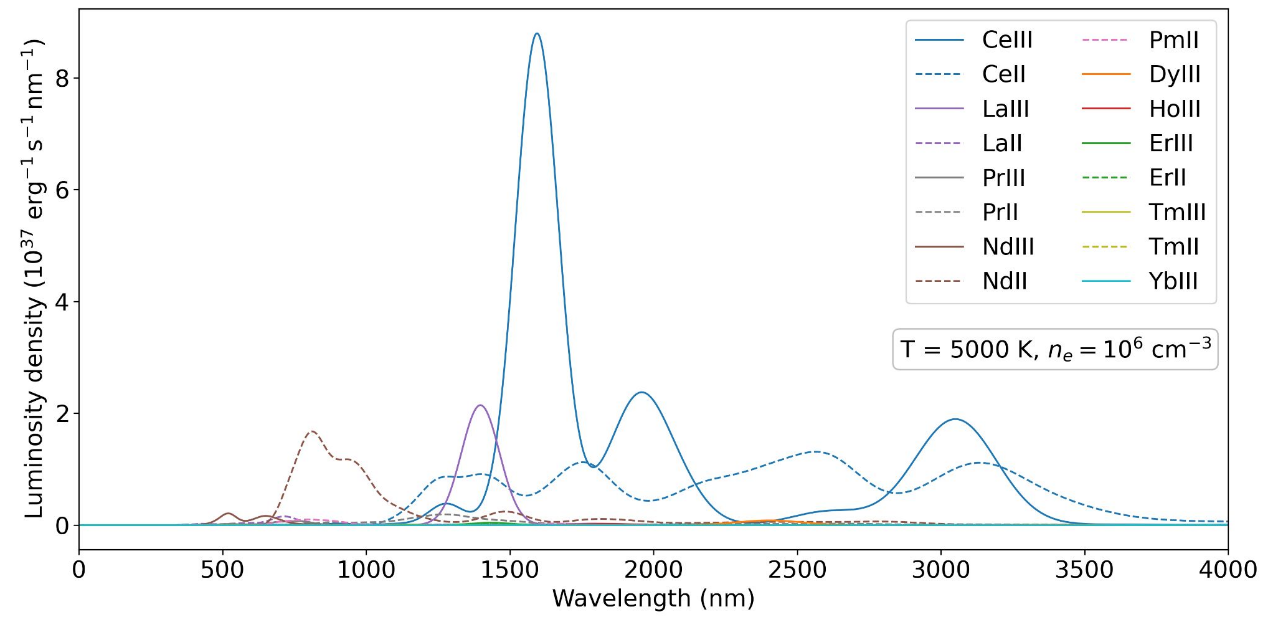
Line luminosities and Photon Emissivity Coefficients (PECs) were calculated, the last one using **COLRADPY** [5], a collision-radiative solver. For abundances, we made use of Gillanders et al. [6].

$$\mathrm{PEC}_{j\to i} = \frac{N_j A_{j\to i}}{n_e} \qquad L_{j\to i} = \frac{hc}{\lambda_{j\to i}} \frac{n_e \mathrm{PEC}_{j\to i}}{\sum_i N_i} \frac{M_{\mathrm{ion}}}{m_{\mathrm{ion}}}$$

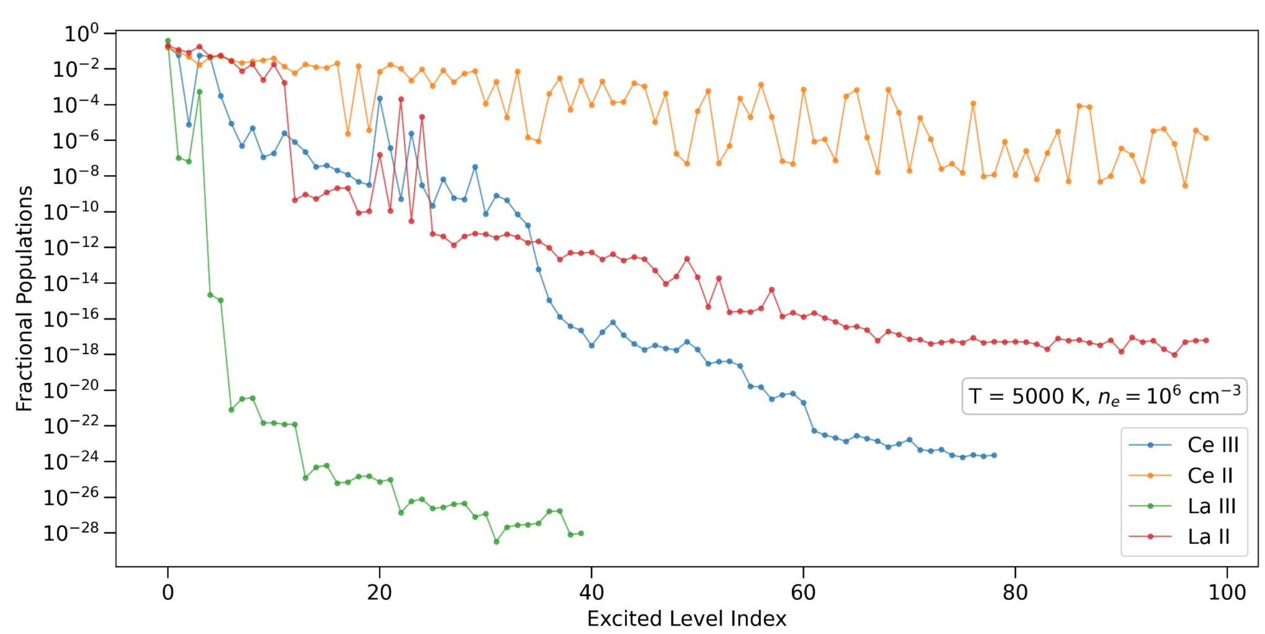
LANTHANIDE SIGNATURES WITH EIE

→ The plasma is assumed to be optical thin → self-absorption effects are neglected → greater contribution from forbidden transitions is expected within a more robust model.

→ Atomic data was calculated using a **potential optimization** procedure [7] and the energy levels were **calibrated** [8].



→ Level populations are concentrated in the lowest-energy levels.



CONCLUSIONS

→ **Few levels significantly populated**: incorporating a large atomic dataset in radiative transfer codes may not be necessary.

→ **DW** calculations can provide **better estimates to effective collisional strengths and level populations than VRA**, and at a much lower computational cost when compared to R-Matrix.

→ Although DW does not include resonances, because the **scattering matrix is not unitary**, it tends to **overestimate the background**.

→ Impact of **inclusion of resonances** in DW presented in R. Ferreira da Silva oral presentation.

REFERENCES

[1] Cowan, John J. et al., Rev. Mod. Phys, 2021.
[2] Pognan, Q. et al., MNRAS, 2022.
[3] Gu, M. F., Can. J. Phys., 2008.
[4] McCann, M. et al., MNRAS, 2022.
[5] Johnson, C.A., Nucl. Mater. Energy, 2019.
[6] Gillanders, J. H. et al., MNRAS, 2022.
[7] Ferreira da Silva, R. et al., PRA, 2025.
[8] Flörs, A. et al., *arXiv preprint*, 2025. Submitted in PRD.