Semi-analytic modeling of Kilonovae

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September 28, 2022

TECHNISCHE UNIVERSITÄT DARMSTADT

SFB 1245

The Kilonova

Thermal emission powered by decay of r-process nuclei

Reviews on the topic: Metzger Living Rev., Fernández & Metzger (2015)

The Kilonova

Thermal emission powered by decay of r-process nuclei

Scenario: NSNS and NSBH mergers

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Model characterization

Di usive semi-analytic formula + thin layers correction

Out ow hypothesis:

- Homologous expansion
- Optical thickness
- Radiation domination
- Quick decay energy re-processing

Model variables: M_{ej} , v_{ej} ,

Starting point:
First two frequency-integrated moments of RT equation in comoving frame, $O(v=c)$ ...

Derivation: Wollaeger et al. (2017)

Anisotropic multi-component framework:

Perego et al. (2017)

Model characterization

Photosphere computation! Two contributions to total luminosity: $L(t) = L_{thick}(t) + L_{thin}(t)$

Full model description: Camilletti et al. (2022), Ricigliano et al. (in preparation)

Model characterization

Photosphere computation ! Two contributions to total luminosity: $L(t) = L_{thick}(t) + L_{thin}(t)$

$$L_{thick}(t) = \frac{M_{thick}(t)}{M_{ej}} A_0 \sum_{n=1}^{1} (\;\; 1)^{n+1} n \;\;\; _n(t)$$

with $\;_n(t)$ obtained from solving:

$$ ^0_n(t) + \frac{t}{B_0} (n^2 \;\; ^2) \;\; _n(t) = C_0 \frac{(\;\; 1)^{n+1}}{n} t^{\;1}$$

! convergence for 500 basis components

Full model description: Camilletti et al. (2022), Ricigliano et al. (in preparation)

Model characterization

Photosphere computation $\rightarrow$ Two contributions to total luminosity: $L(t) = L_{thick}(t) + L_{thin}(t)$

$$L_{thin}(t) = \sum_{i: r > R_{ph}} \epsilon_{th,i}(t)\, \dot{\epsilon}_r(t)\, dM_i$$

$\dot{\epsilon}_r(t)$ radioactive heating rate

$\epsilon_{th}(\ )$ thermalization efficiency
Barnes et al. (2016)

Full model description: Camilletti et al. (2022), Ricigliano et al. (in preparation)

Model ingredients: heating rates and opacities

Nuclear reaction networkSkyNet calculations
Perego et al. (2022), Wu et al. (2022)

! Heating t formula: $\_r(t) = At$

with $A; \; = f(Y_e; s; \;)$

Model ingredients: heating rates and opacities

Nuclear reaction network SkyNet calculations
Perego et al. (2022), Wu et al. (2022)

Systematic atomic structure HULLAC calculations
Tanaka et al. (2020)

! Heating t formula: $_r(t) = At$

with $A; \; = f(Y_e; s; \;)$

! Planck mean opacities: $= \;(Y_e)$

GW190425: synthetic magnitudes

GRHD BNS simulations
Camilletti et al. (2022)

Dynamic ejecta:

- anisotropic
- $M_{\rm dyn}$ 10^{6} 10^{4} M
- $v_{\rm dyn}$ 0:2 0:3 c
- $Y_{\rm e;dyn}$ 0:10 0:25

Disk wind:

- isotropic
- $M_{\rm wind}$ 10^{4} 10^{2} M
- $v_{\rm wind}$ 0:06 c
- $_{\rm wind}$ 5 $\mathrm{cm}^2\mathrm{g}^{1}$

Distance: 130 Mpc

Camilletti et al. (2022)

Overview

Model achievements:

- Accuracy improved from radiative transfer
- Sensitivity to initial ejecta thermodynamic conditions

Code advantages:

- Runtime < 1 s
- Open to non-trivial ejecta profiles

Applications:

- Bayesian statistical analysis
- Event target (e.g. GW170817)