Kilonova modelling and GW-EM combined analysis

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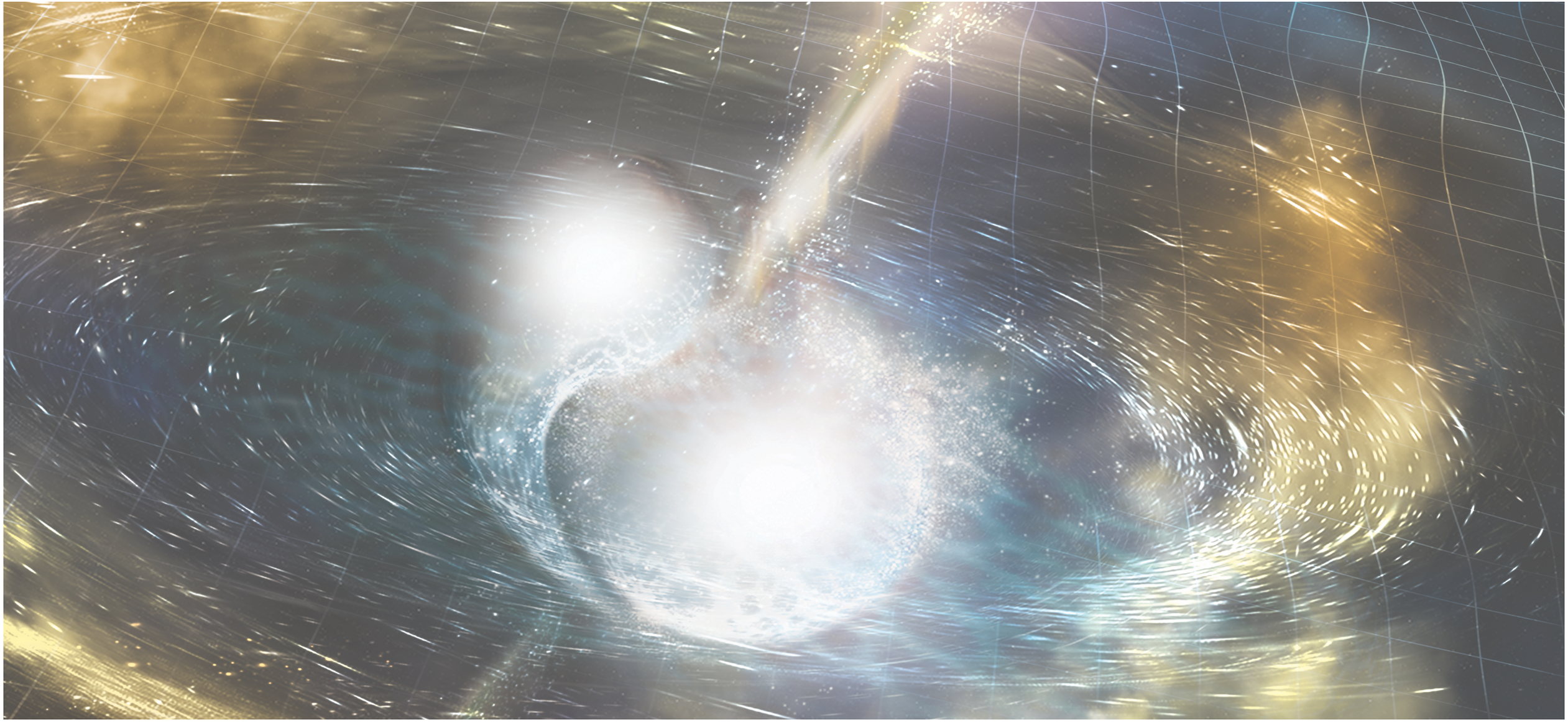
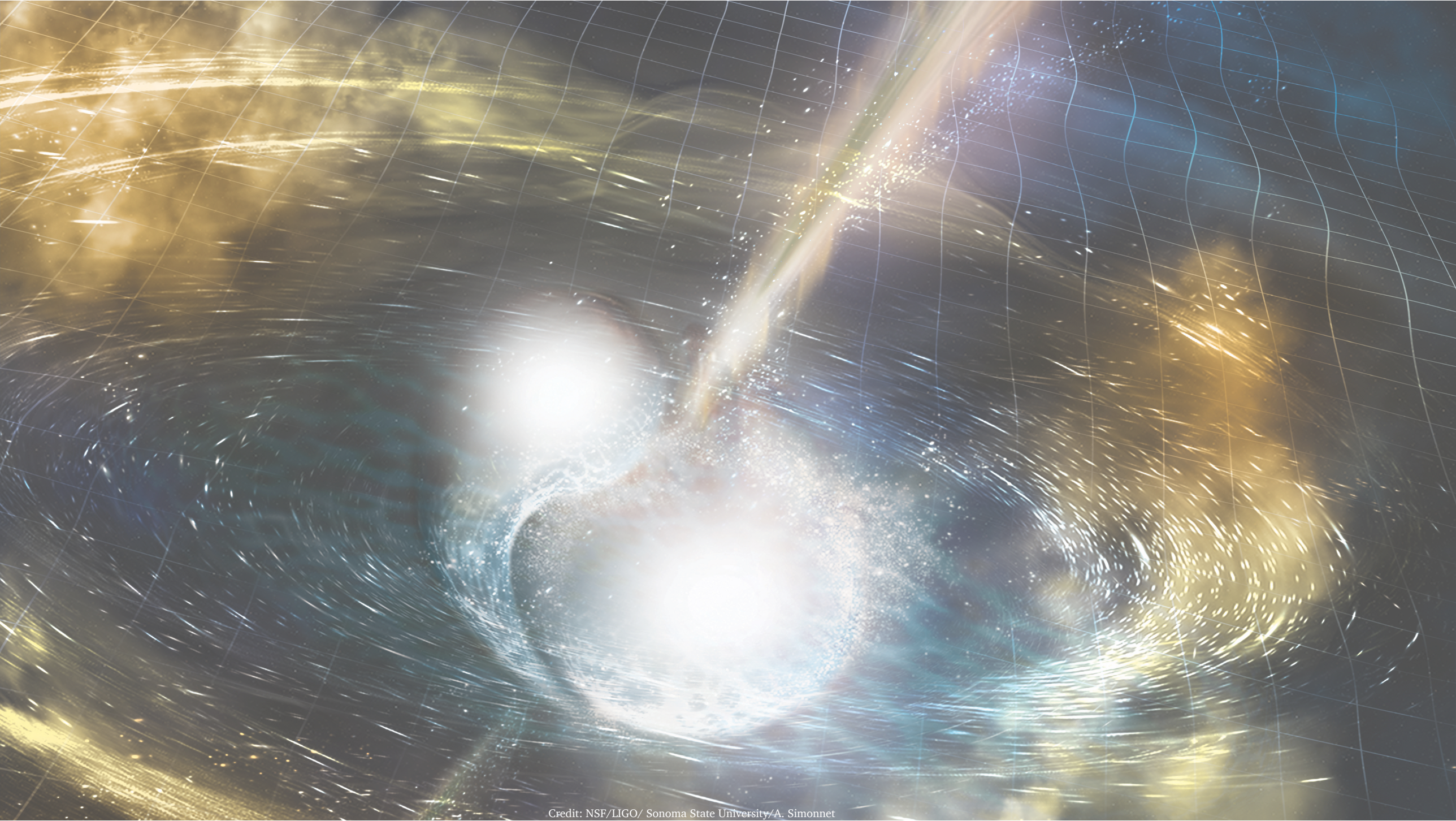
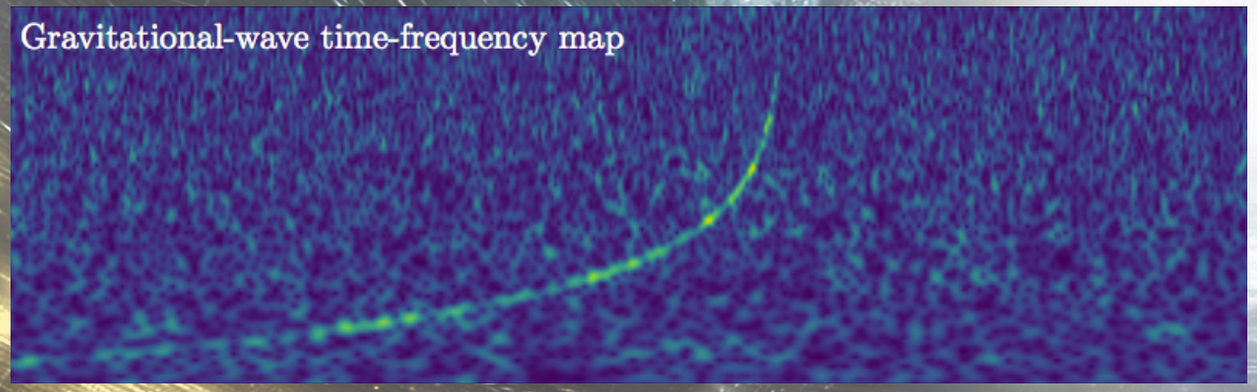
INAF Istituto Nazionale di Astrofisica





Credit: NSF/LIGO/ Sonoma State University/A. Simonnet

Gravitational Waves (GW)



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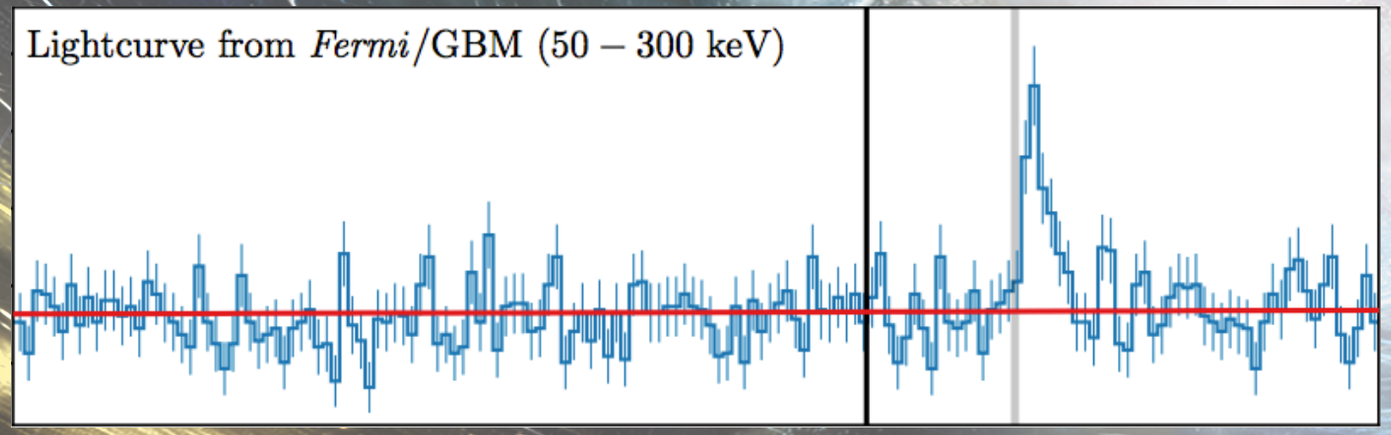
Gravitational Waves (GW)

Gamma-Ray Burst (GRB)



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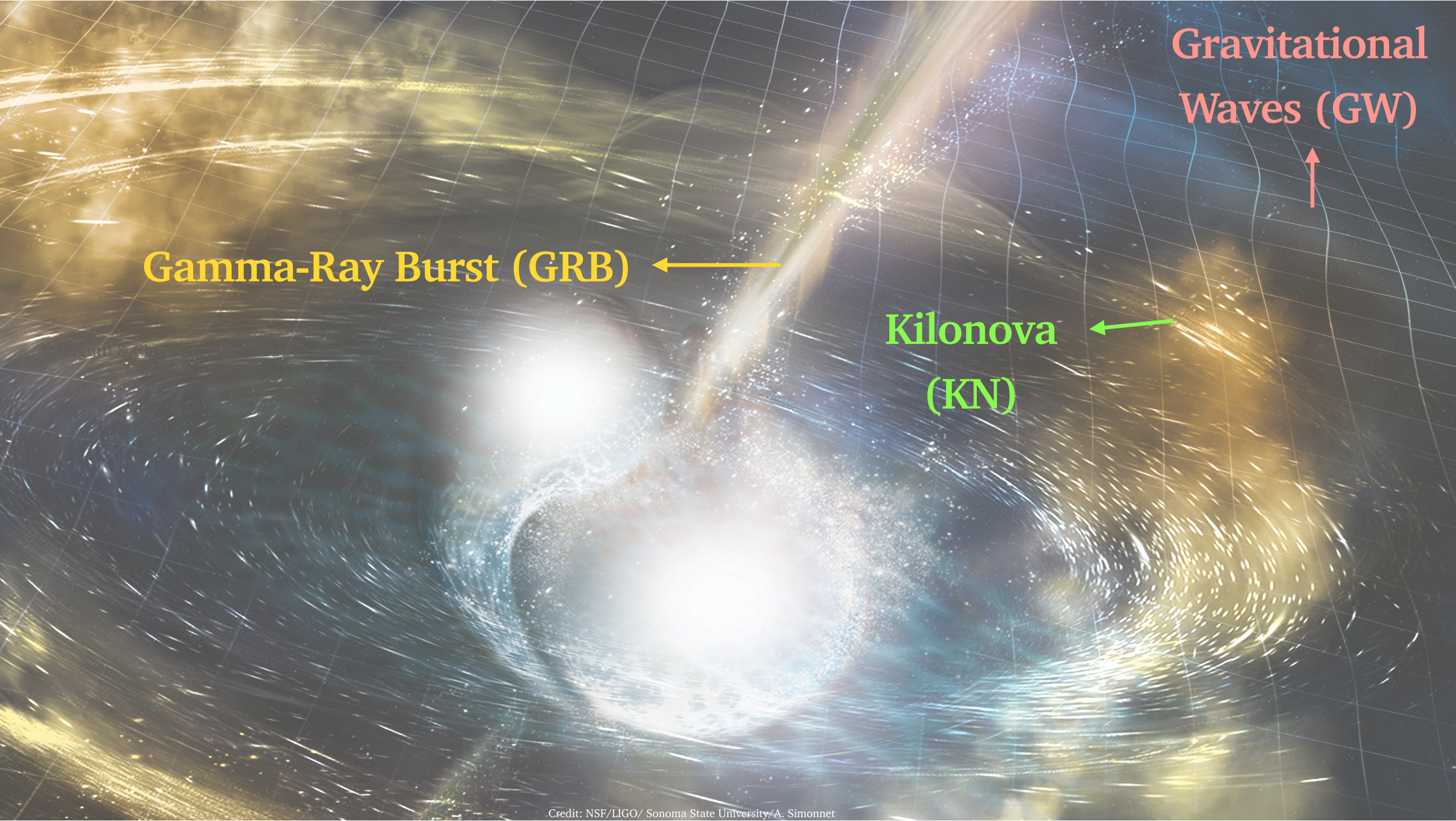

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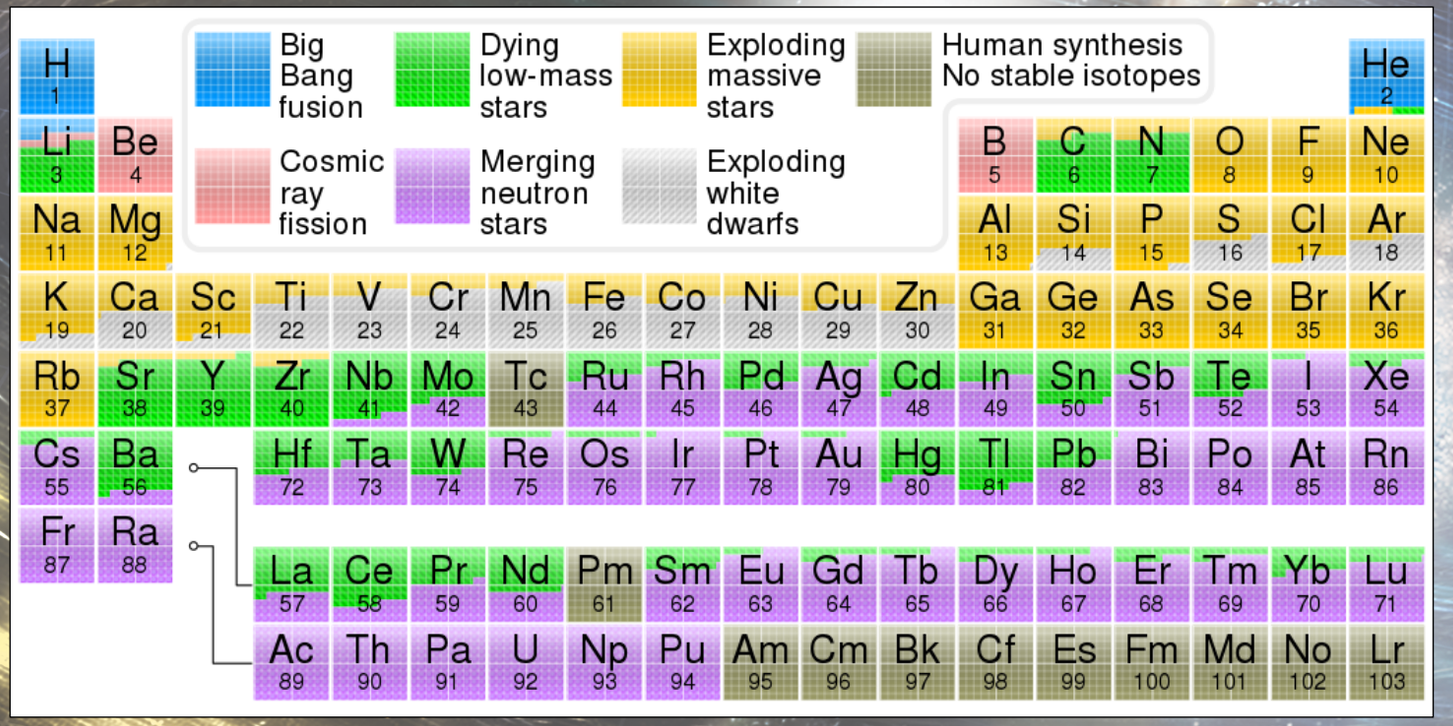
Gravitational Waves (GW)

Gamma-Ray Burst (GRB)

Kilonova (KN)



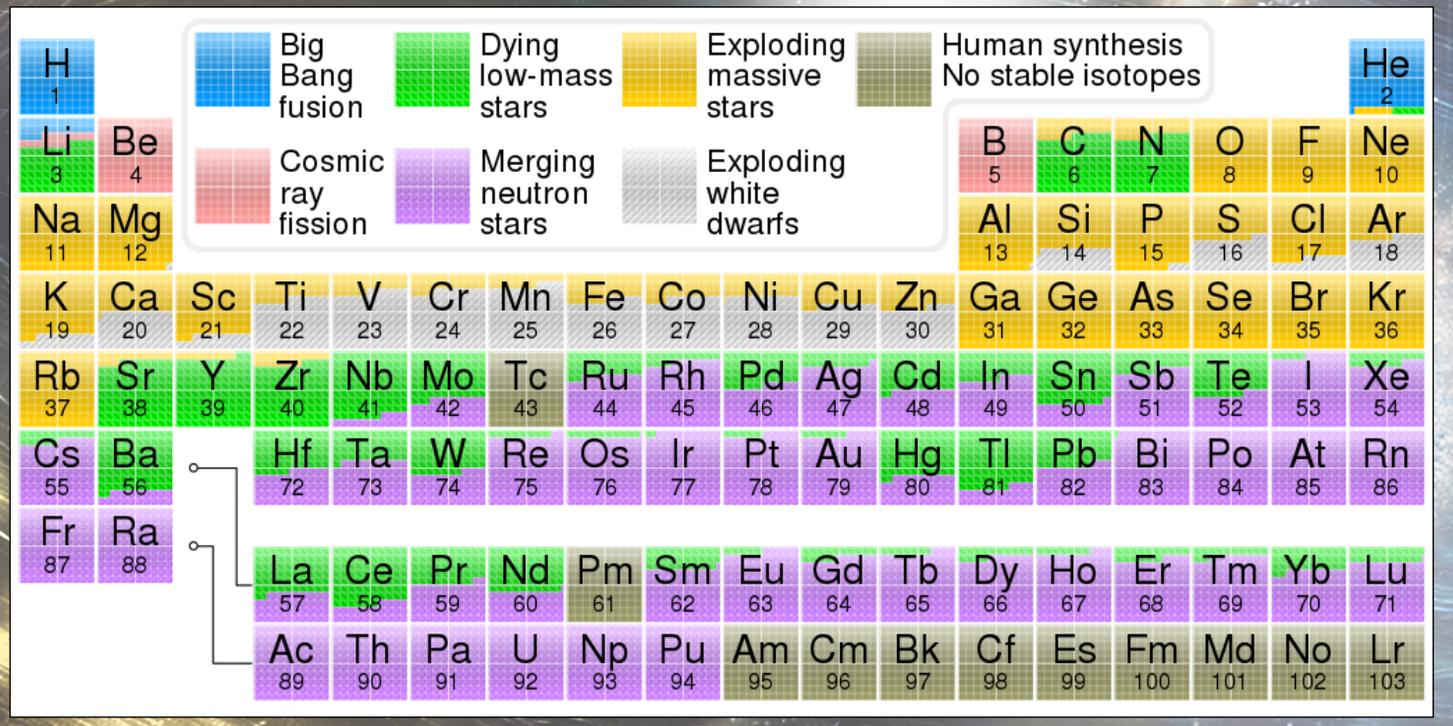
r-process elements

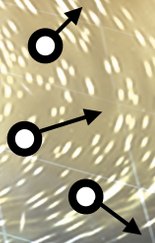
Credit: NSF/LIGO/ Sonoma State University/A. Simonnet

Gravitational Waves (GW)

Gamma-Ray Burst (GRB)

Kilonova (KN)





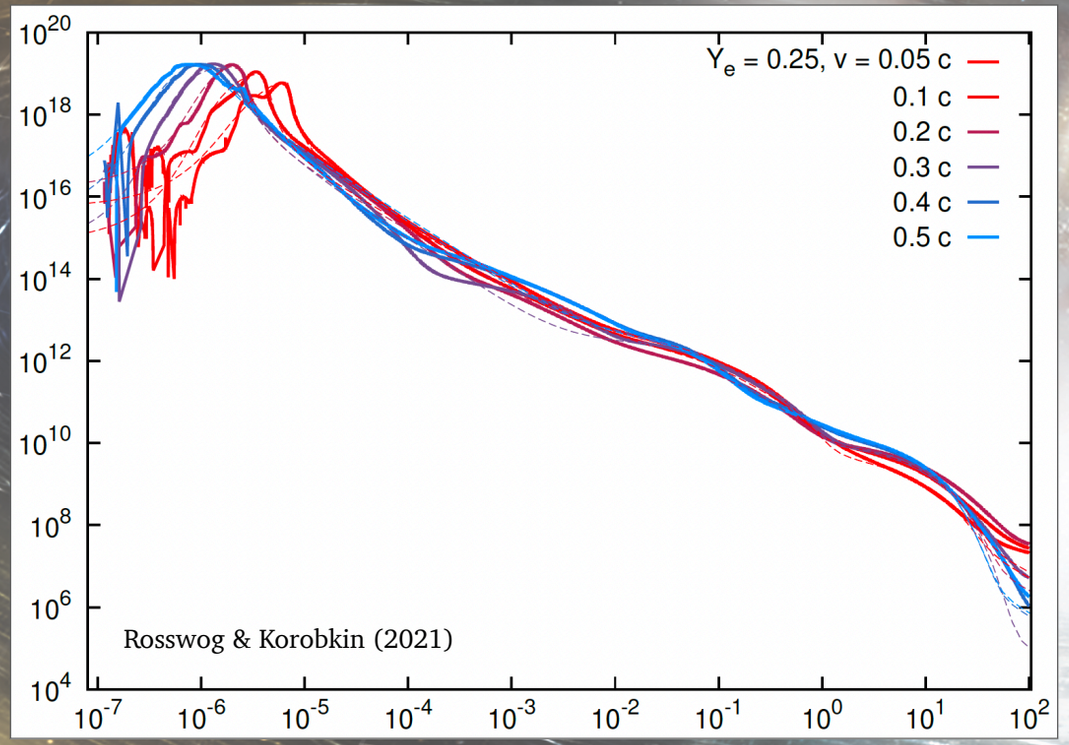
Radioactive decay

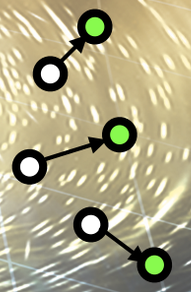
Credit: NSF/LIGO/ Sonoma State University/A. Simonnet

Gravitational Waves (GW)

Gamma-Ray Burst (GRB)

Kilonova (KN)





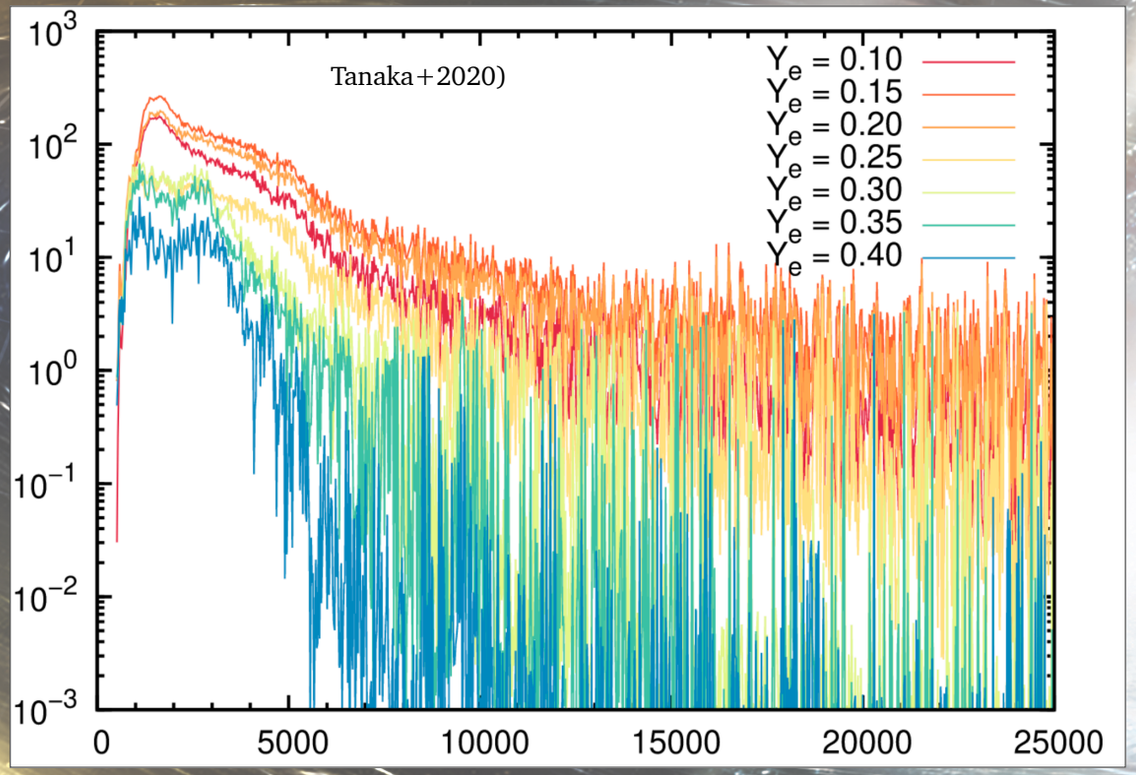
Thermalization of decay products

Credit: NSF/LIGO/ Sonoma State University/A. Simonnet

Gravitational Waves (GW)

Gamma-Ray Burst (GRB)

Kilonova (KN)

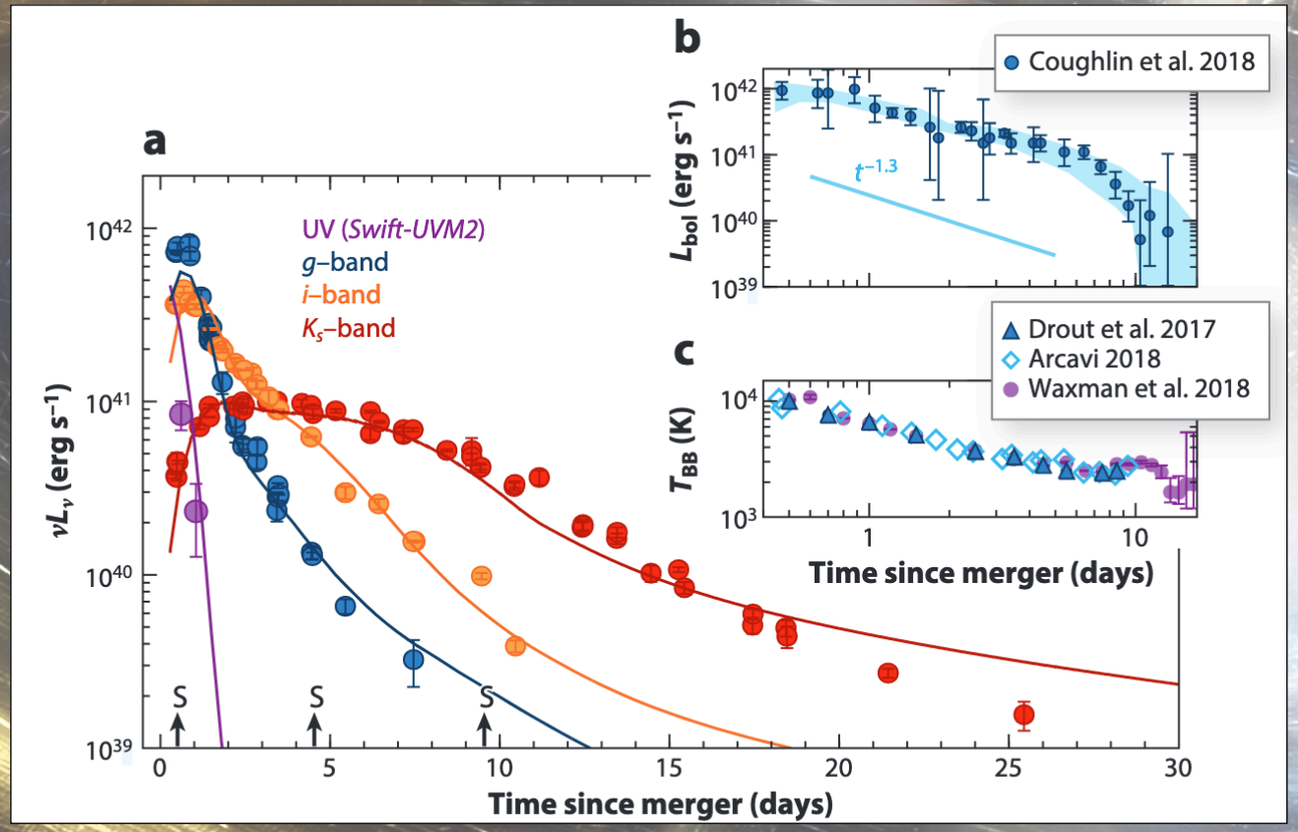


Thermal emission and interaction with matter

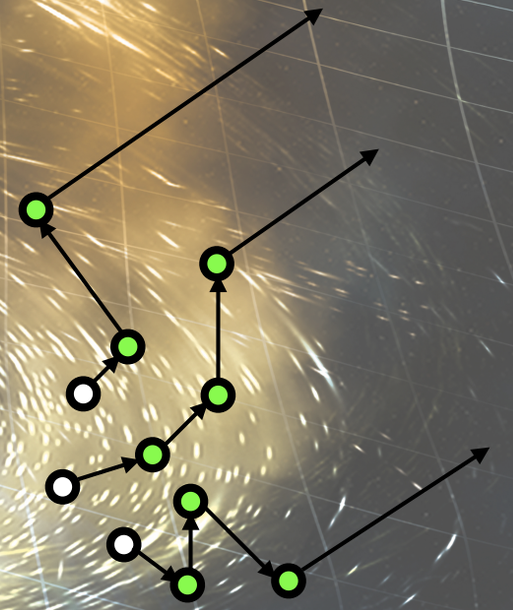
Credit: NSF/LIGO/ Sonoma State University/A. Simonnet

Gravitational Waves (GW)

Gamma-Ray Burst (GRB)



Kilonova (KN)



Kilonova signal

Credit: NSF/LIGO/ Sonoma State University/A. Simonnet

Kilonova modelling with radiative transfer

POSSIS: A 3D Monte Carlo radiative transfer code to model explosive transients

[MB 2019, MNRAS; MB 2023, MNRAS]

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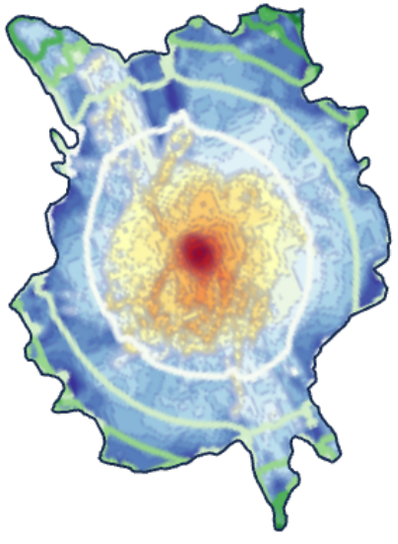
EJECTA MODEL



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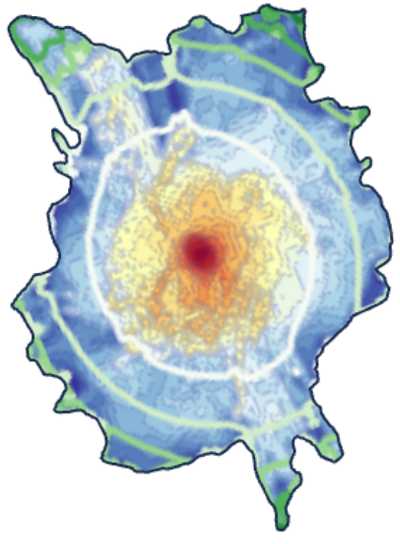

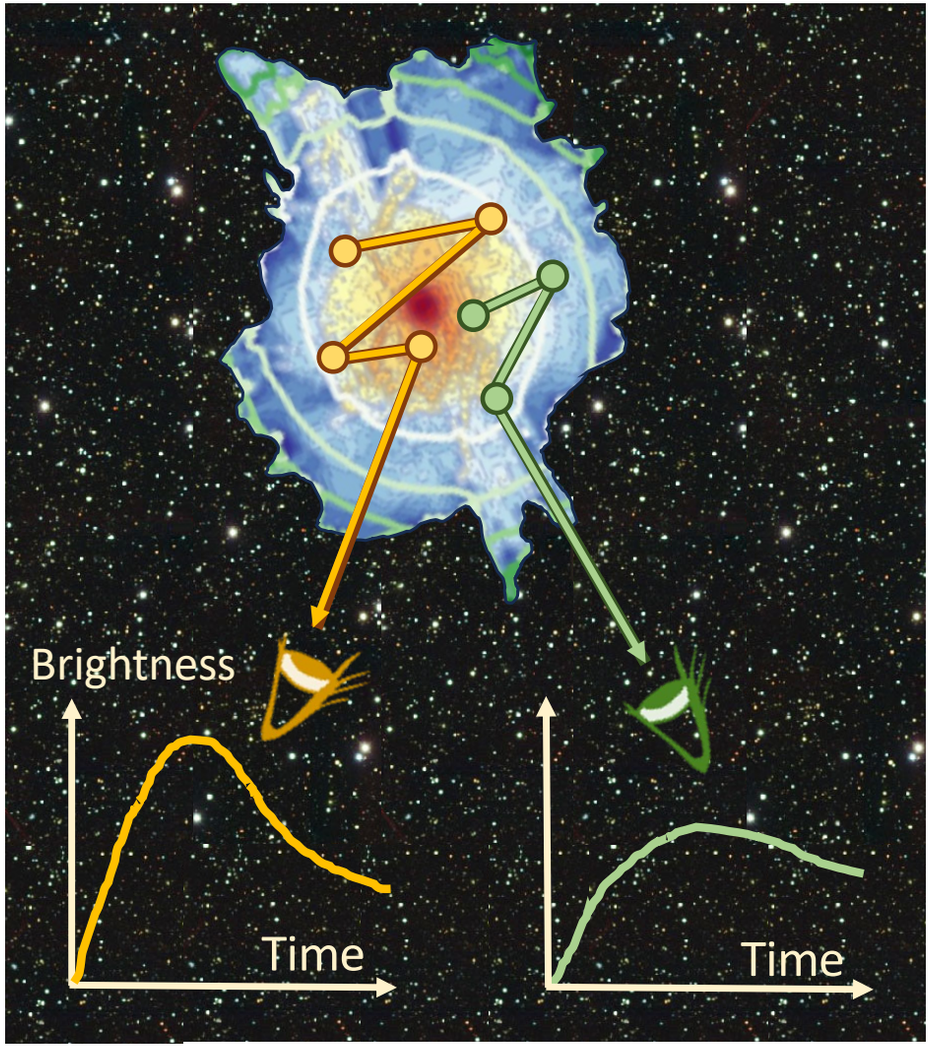

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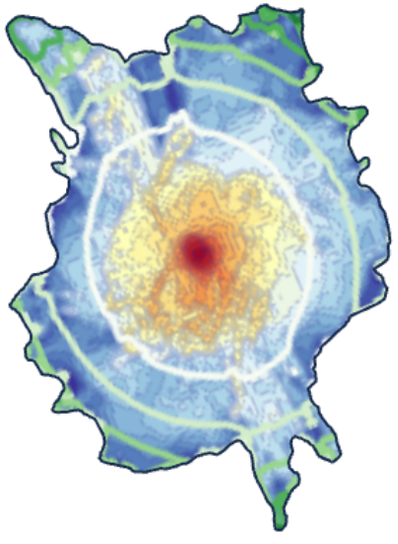
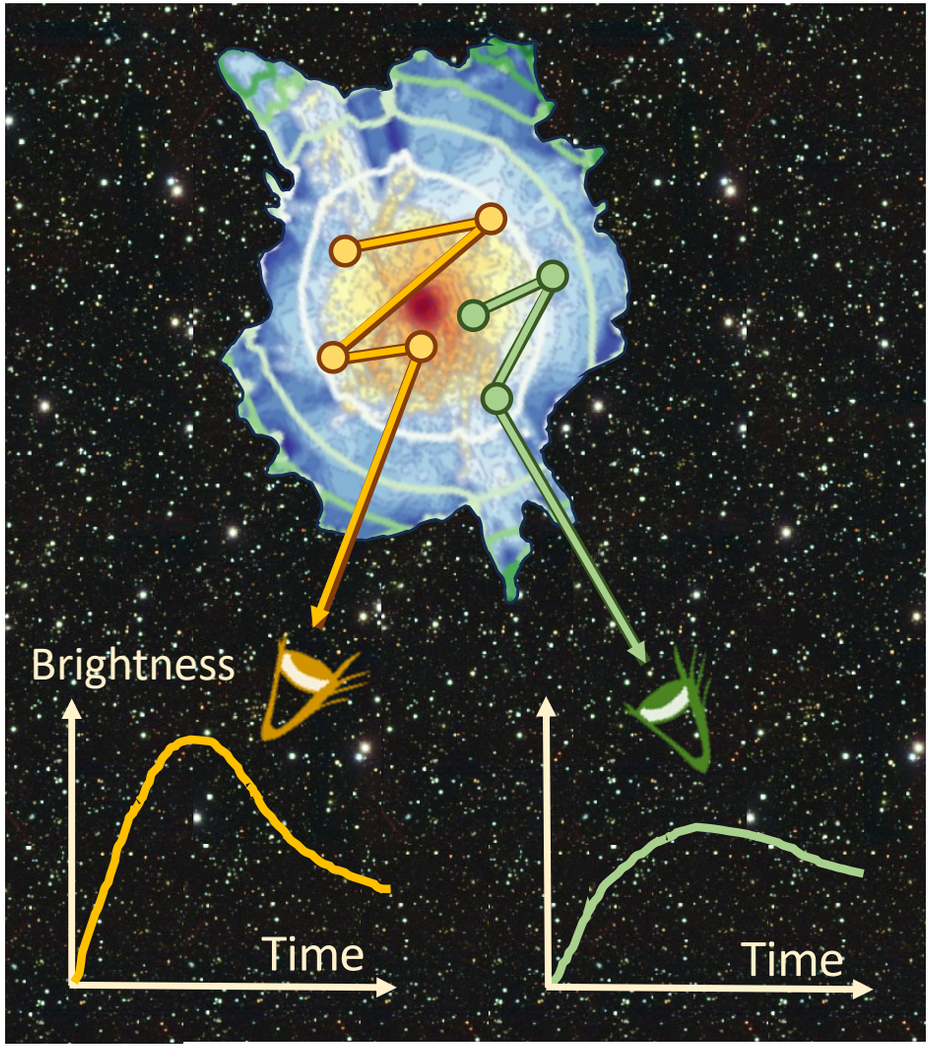
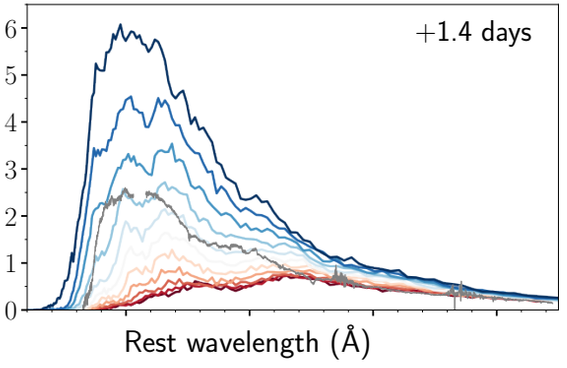




SYNTHETIC OBSERVABLES

Spectral time series



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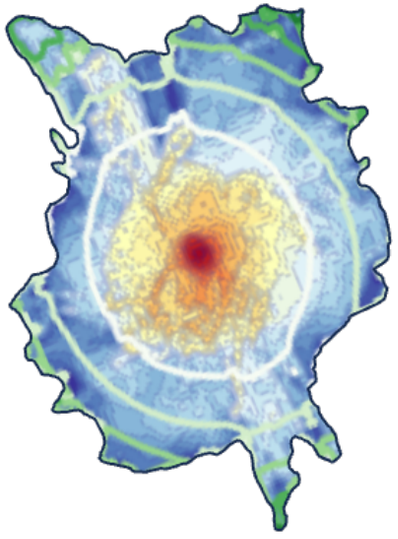

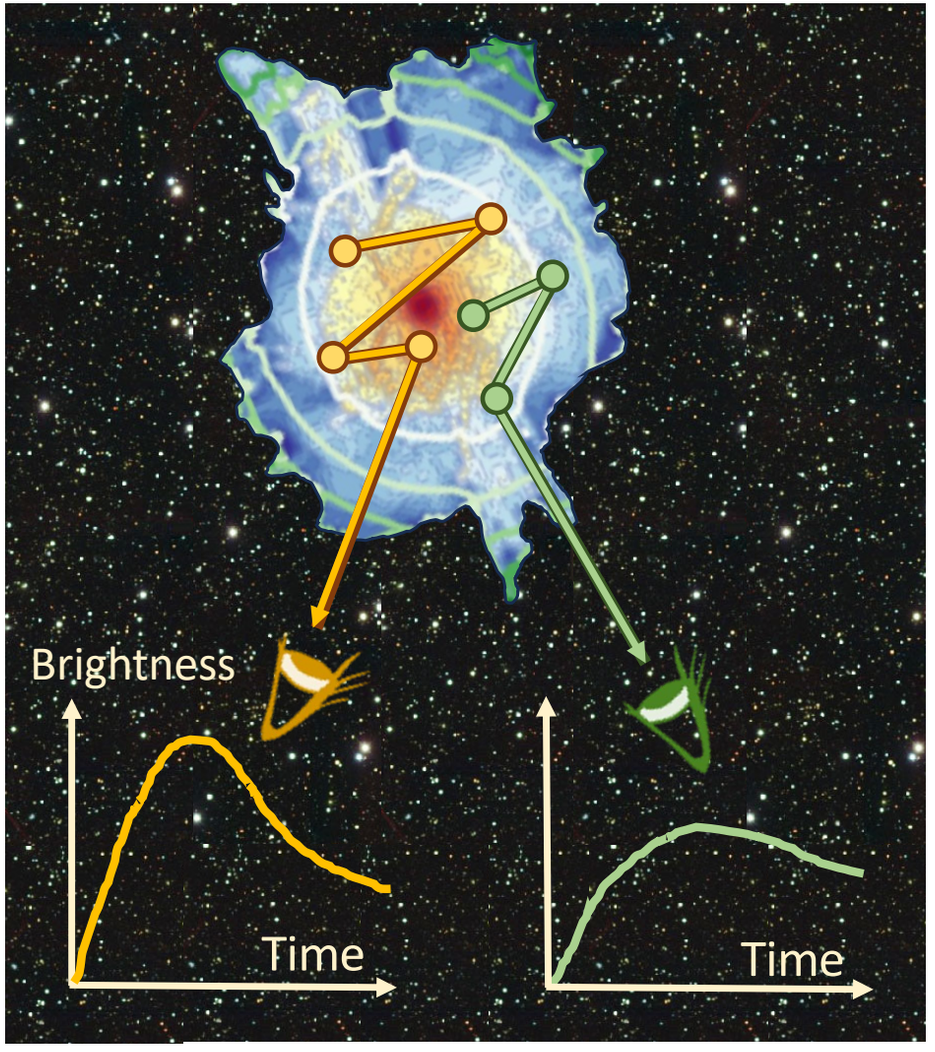

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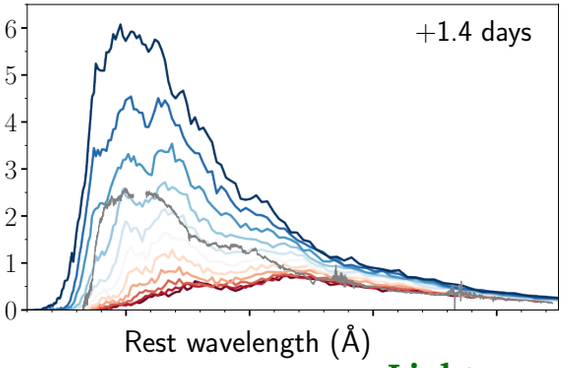
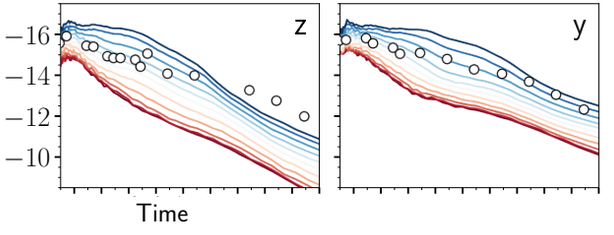


Light curves



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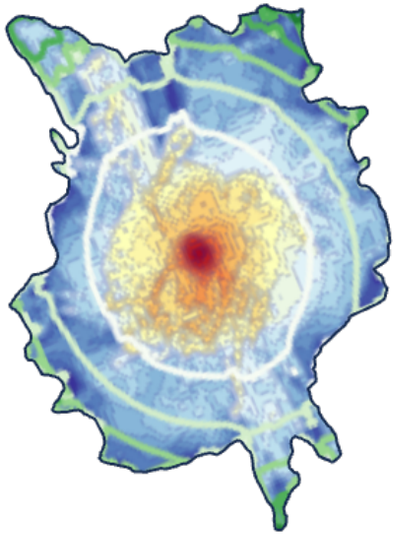

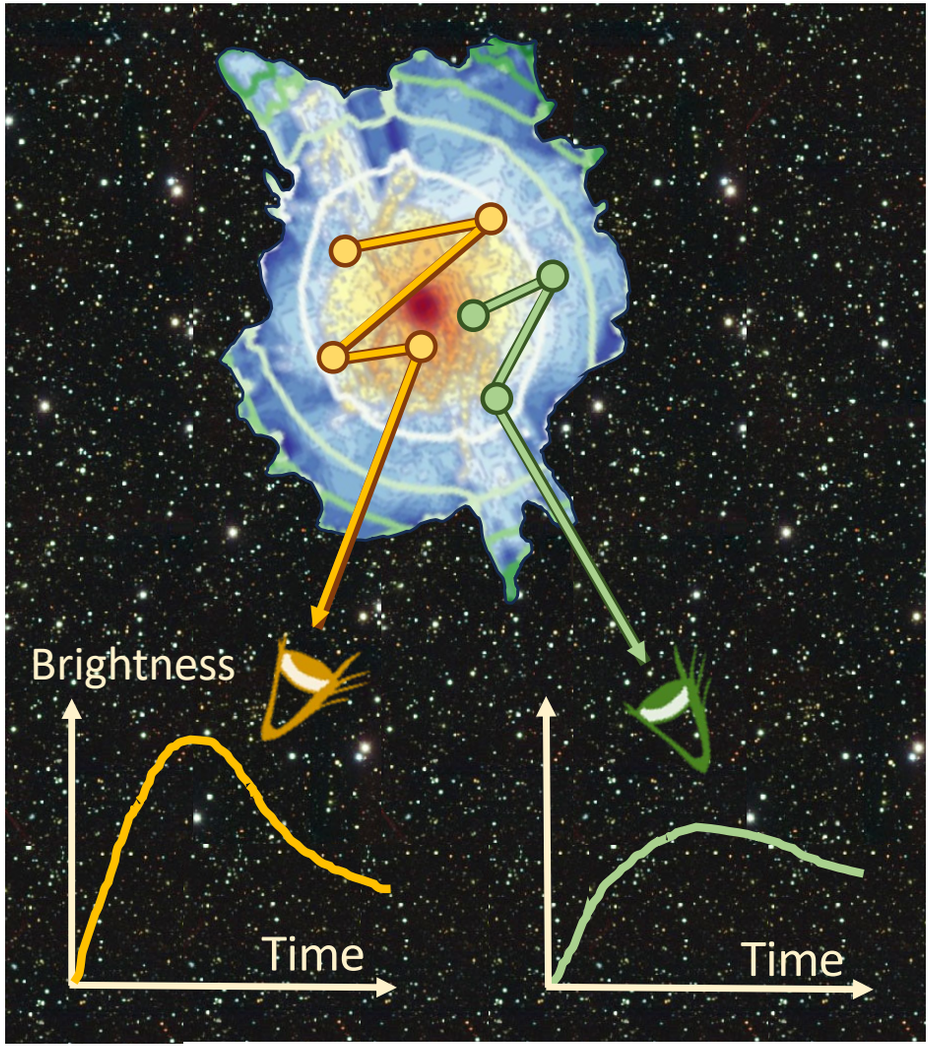

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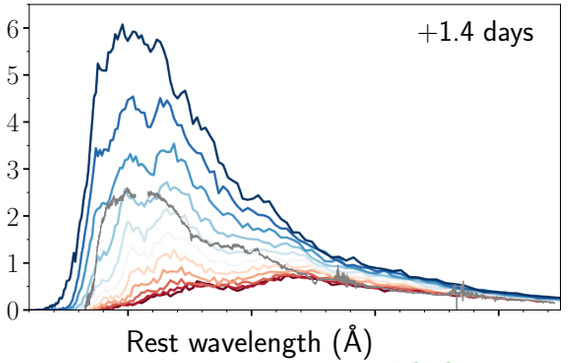

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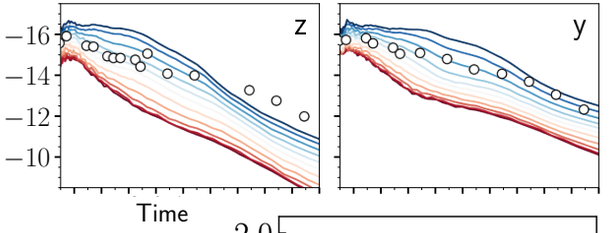
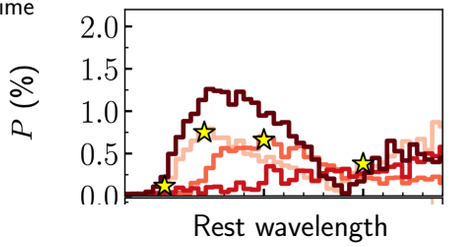


Polarization



[MB+2019, Nature Astronomy] (BNS)
[MB+2021, MNRAS] (BHNS)
[Shrestha, MB+2023, MNRAS] (BNS with jets)

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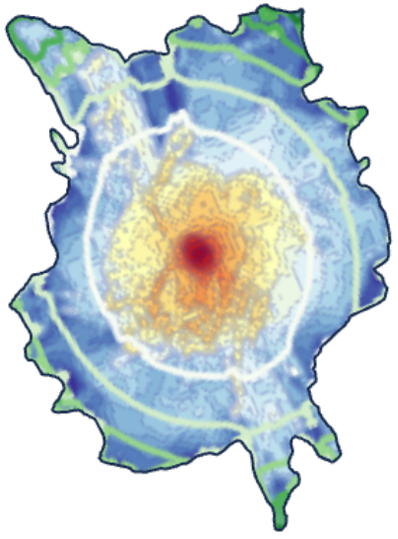

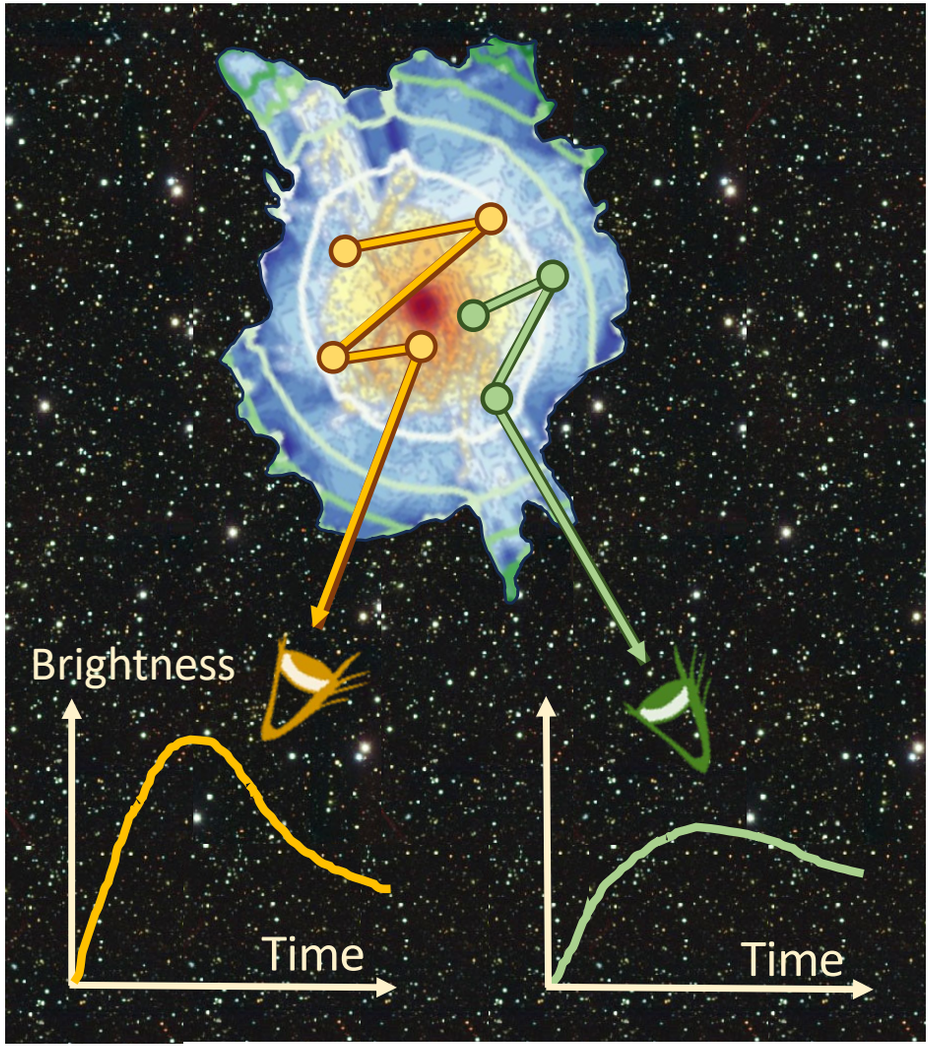

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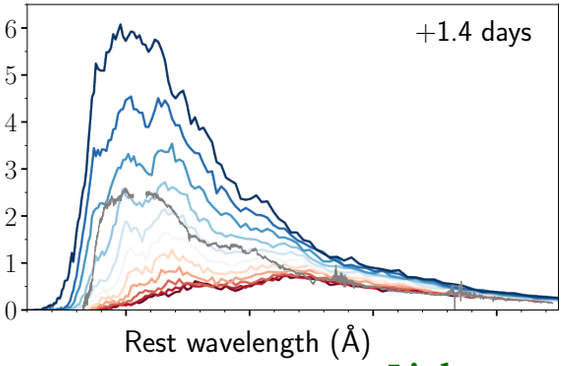

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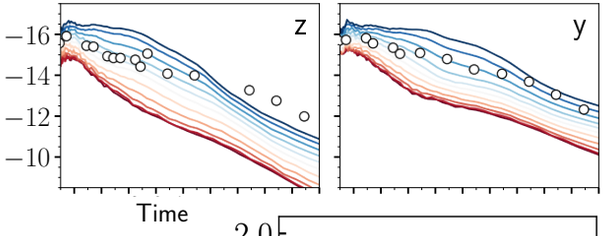

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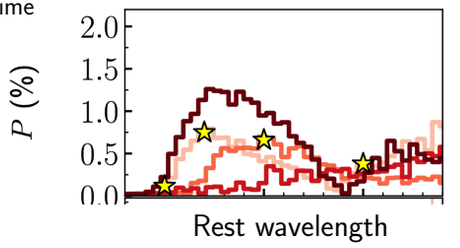


[MB+2019, Nature Astronomy] (BNS)
[MB+2021, MNRAS] (BHNS)
[Shrestha, MB+2023, MNRAS] (BNS with jets)

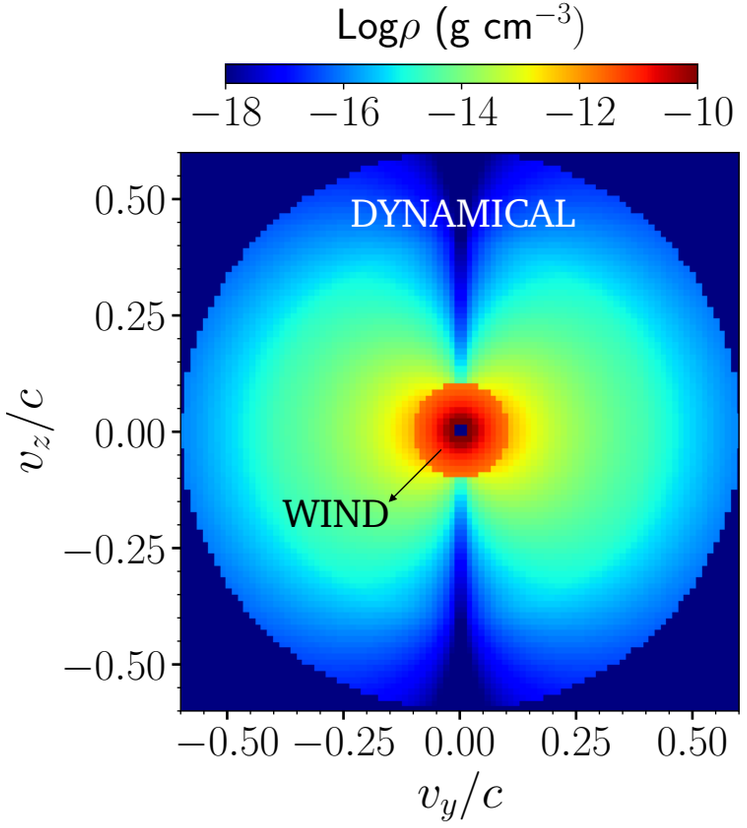
Modelled grids available at
https://bit.ly/possis_models

Kilonova modelling with radiative transfer

Idealised

Large grids of models (∼1000)

Typical runtime/model ∼ 100-500 CPUh



[MB 2023, MNRAS]

Kilonova modelling with radiative transfer

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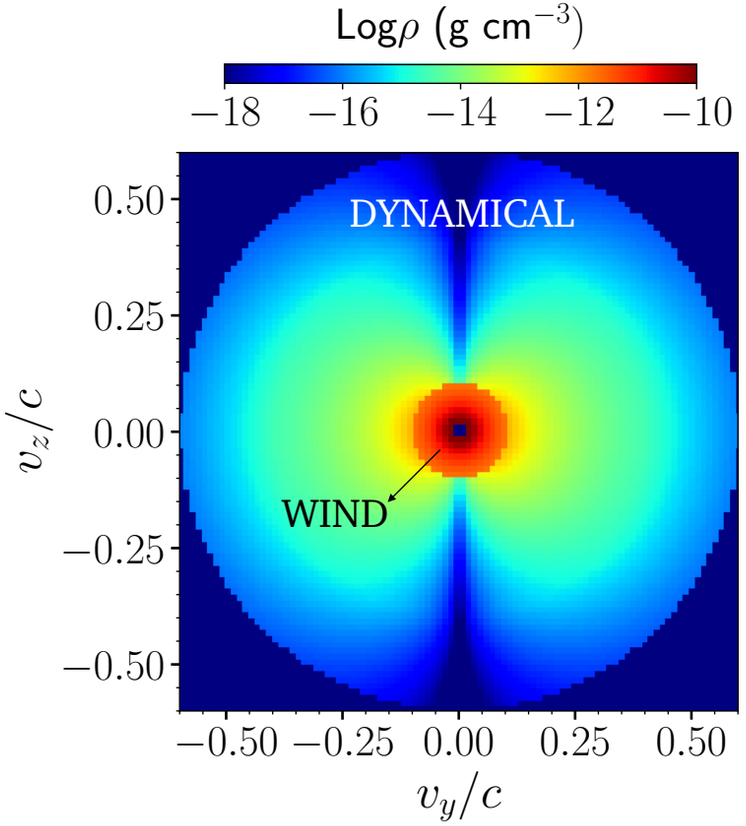
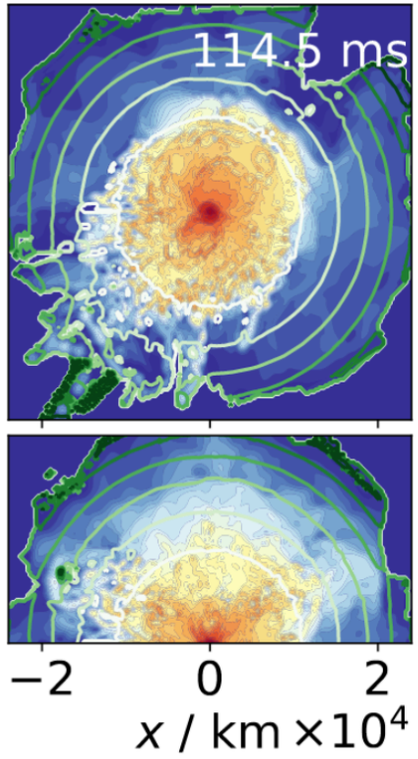


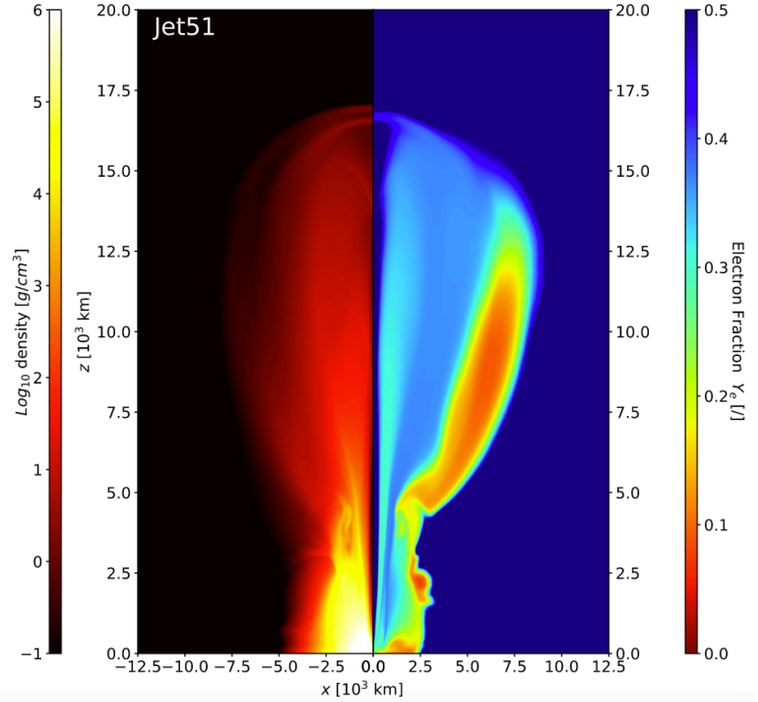
[MB 2023, MNRAS]

Numerical simulations

From numerical-relativity and/or hydrodynamic simulations



[Neuweiler, Dietrich, MB+2023, PRD]



[Nativi, MB+2020, MNRAS]

See also [Markin+2023, PRD; Schianchi+2024, PRD; Markin+2026, PRD; Neuweiler+arXiv:2510.14850; Markin, MB & Dietrich, arXiv:2601.19405]

Kilonova modelling with radiative transfer

[MB 2023, MNRAS]

Kilonova modelling with radiative transfer

Radioactive decay of r-process nuclei

[MB 2023, MNRAS]

Kilonova modelling with radiative transfer

[MB 2023, MNRAS]

Radioactive decay of r-process nuclei

Decay products

$(\nu, \gamma, \alpha, \beta,$ fission fragments)

[1] Nuclear heating rates
How much energy comes from radioactive decay

[2] Thermalisation efficiencies
How much of this energy goes into heating the ejecta

Thermalisation of decay products within the ejecta

Kilonova modelling with radiative transfer

[MB 2023, MNRAS]

Radioactive decay of r-process nuclei

Decay products

$(\nu, \gamma, \alpha, \beta,$ fission fragments)

[1] Nuclear heating rates
How much energy comes from radioactive decay

[2] Thermalisation efficiencies
How much of this energy goes into heating the ejecta

Thermalisation of decay products within the ejecta

nearUV-opt-nearIR photons

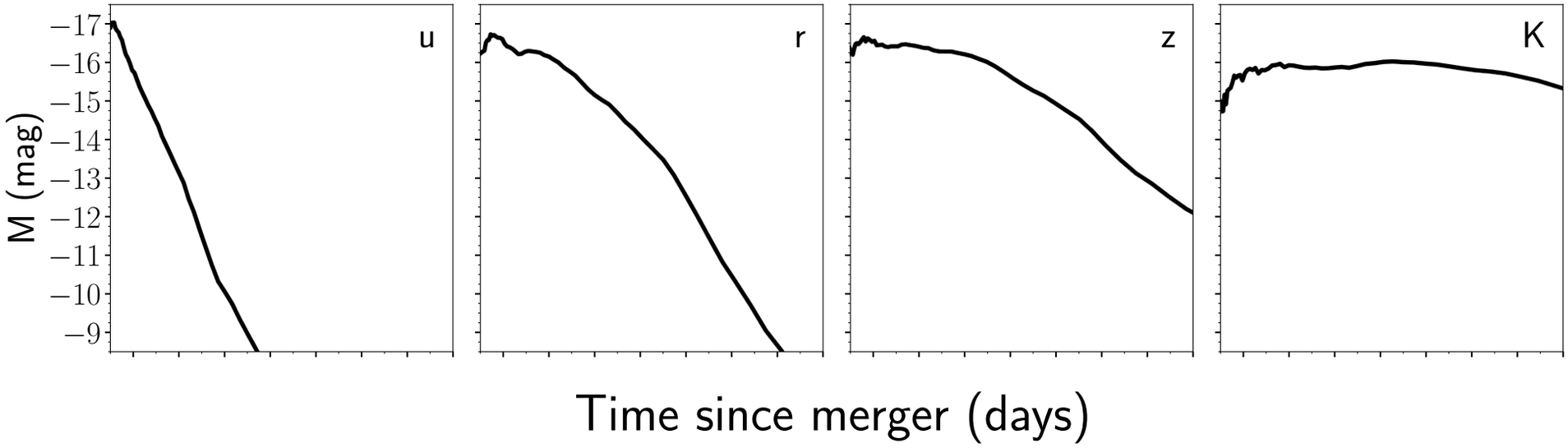
[3] Opacity
How thermal emission is affected by interaction with matter

Kilonova radiation

Kilonova modelling with radiative transfer

GLOBAL vs **LOCAL**

[1] + [2] + [3]



See also [Brethauer, Kasen, Margutti & Chornock 2024, ApJ][Sarin & Rosswog 2024, ApJ] [Jhawar, Wouters, Pang, MB+ 2025, PRD]

Kilonova modelling with radiative transfer

GLOBAL vs **LOCAL**

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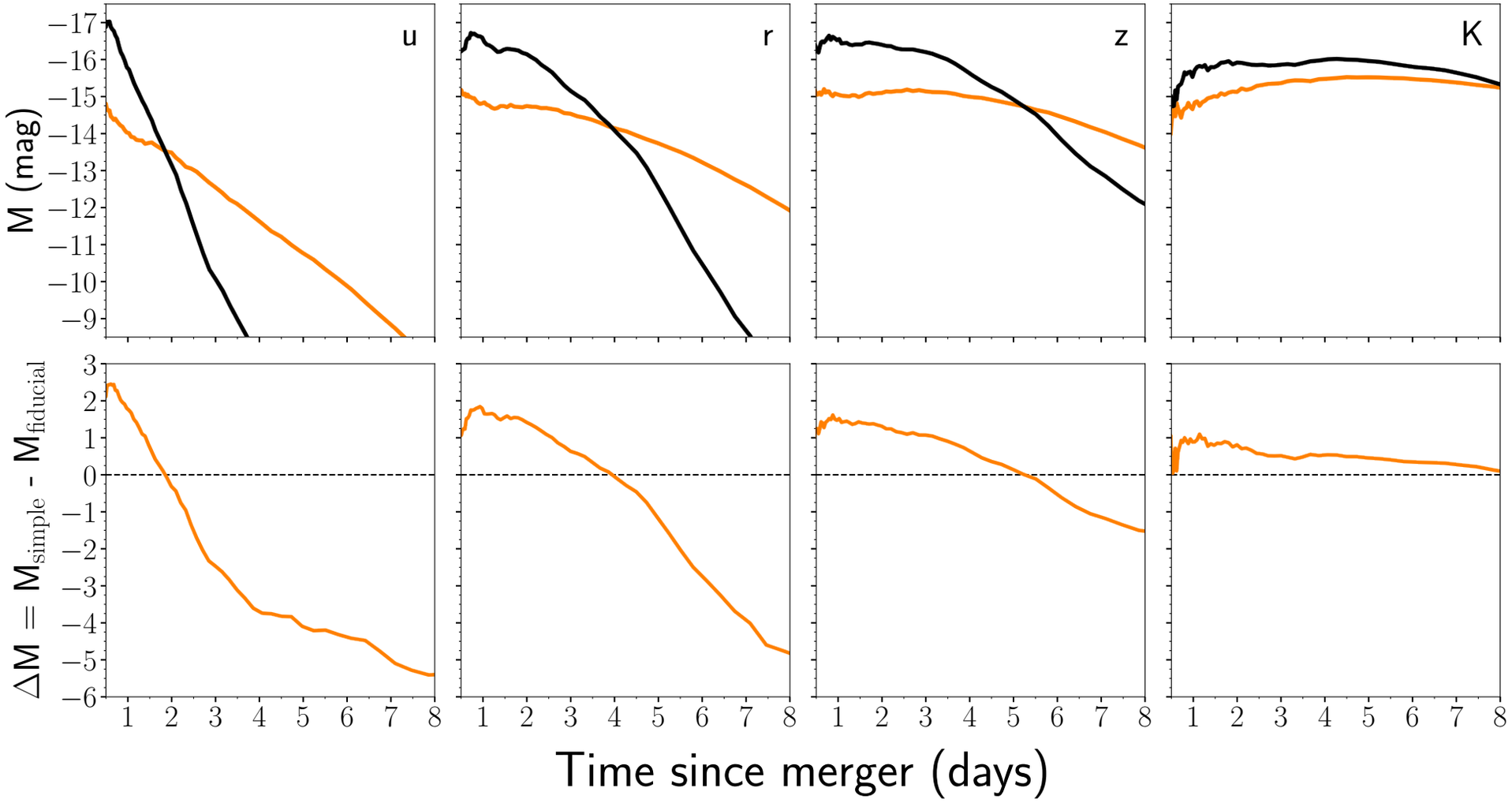


See also [Brethauer, Kasen, Margutti & Chornock 2024, ApJ][Sarin & Rosswog 2024, ApJ] [Jhawar, Wouters, Pang, MB+ 2025, PRD]

Università degli Studi di Ferrara

GW-EM combined analysis

INFN FERRARA Istituto Nazionale di Fisica Nucleare Sezione di Ferrara

INAF Istituto Nazionale di Astrofisica

GW-EM combined analysis

Kilonova grids

Observables for **selected** values of the ejecta parameters

GW-EM combined analysis

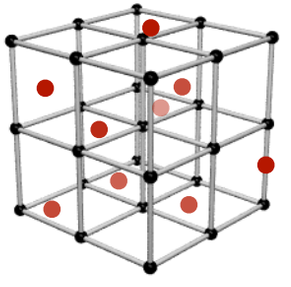
Kilonova grids

Observables for
selected
values of the
ejecta parameters

→

Kilonova emulators

Observables for
arbitrary
values of the
ejecta parameters



GW-EM combined analysis

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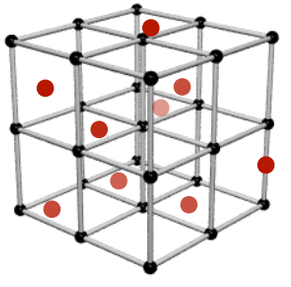
values of the
ejecta parameters



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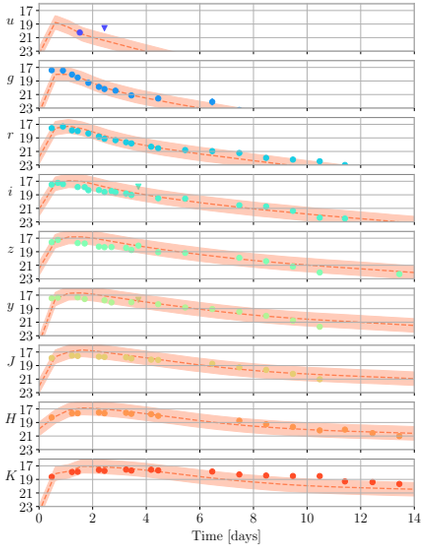
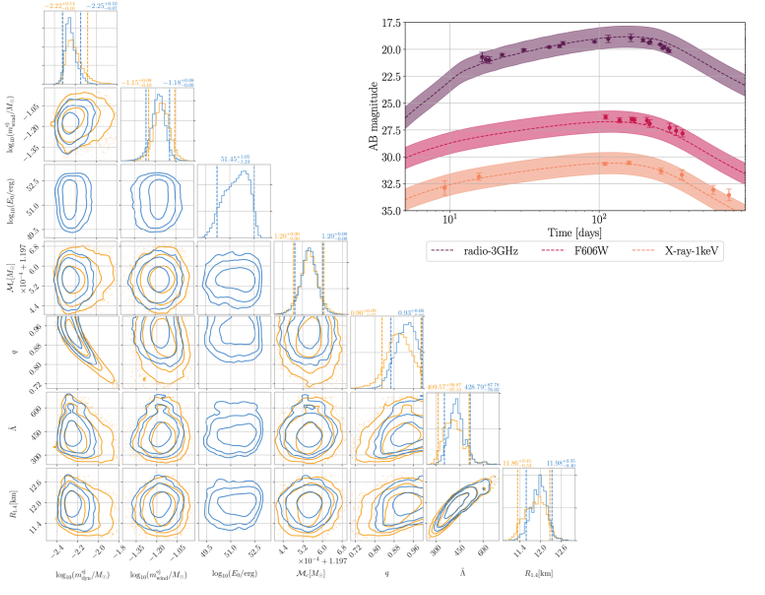
GW+EM fit and parameter inference



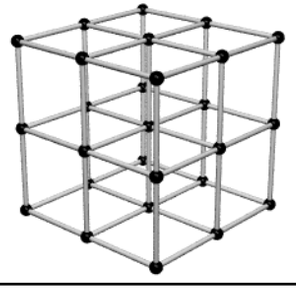


GW-EM combined analysis

P O S S I S

Kilonova grids

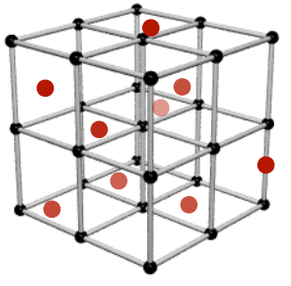
Observables for
selected
values of the
ejecta parameters



→

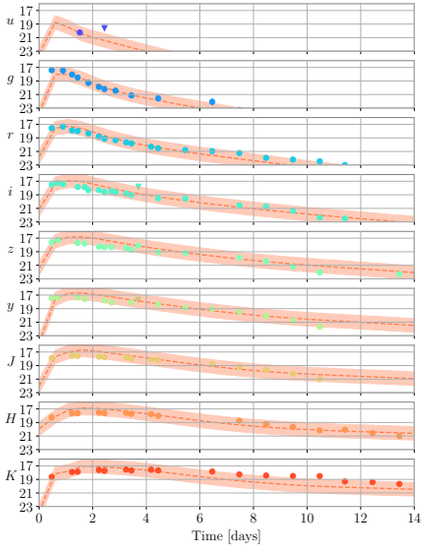
Kilonova emulators

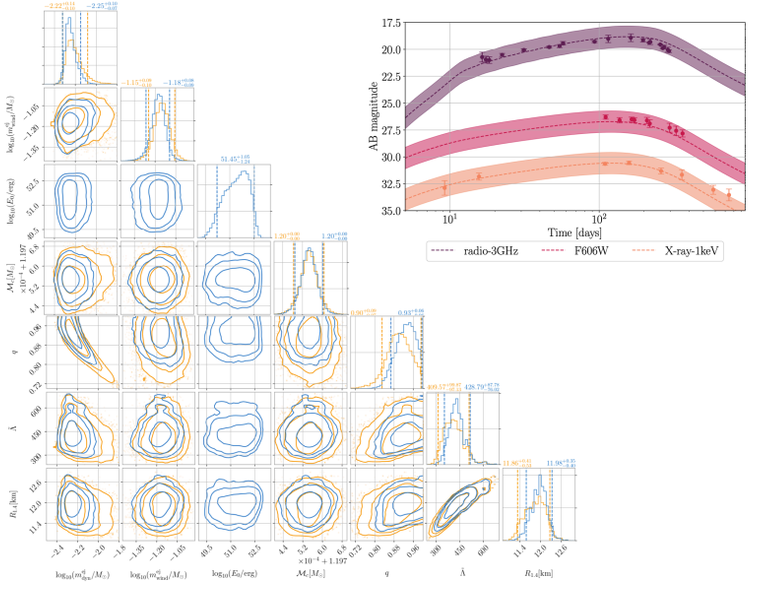
Observables for
arbitrary
values of the
ejecta parameters



→

GW+EM fit and parameter inference





GW-EM combined analysis

NMMA

[Dietrich, Coughlin, Pang, MB+2020, Science]

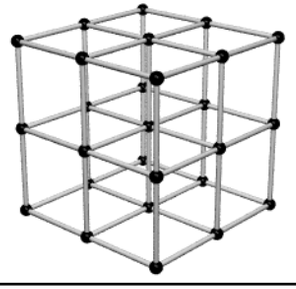
[Pang, Dietrich, Coughlin, MB+2024, Nature Comms.]

[Koehn, Wouters, Pang, MB+2025, A&A]

POSSIS

Kilonova grids

Observables for **selected** values of the ejecta parameters



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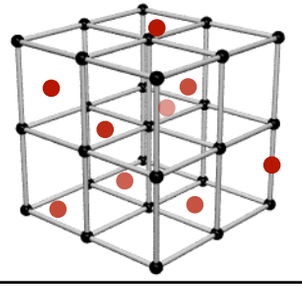
NMMA / FIESTA

Kilonova emulators

Observables for **arbitrary** values of the ejecta parameters



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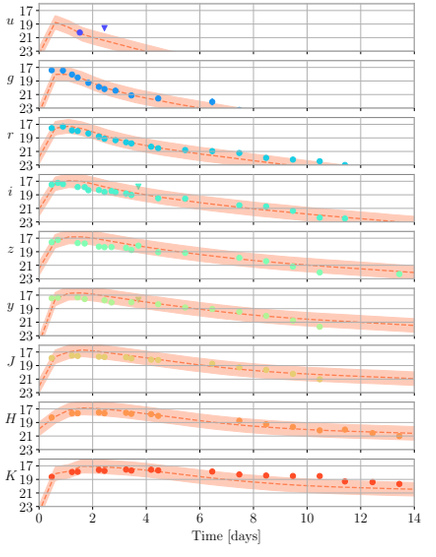
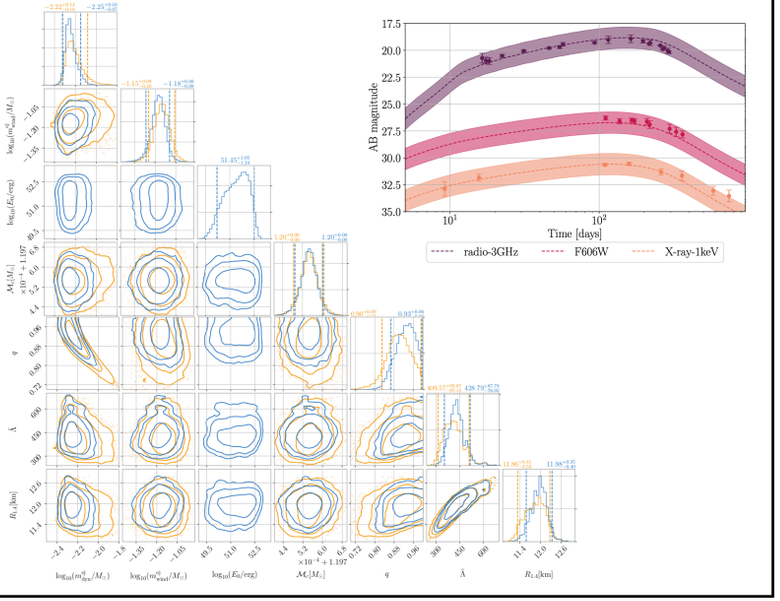
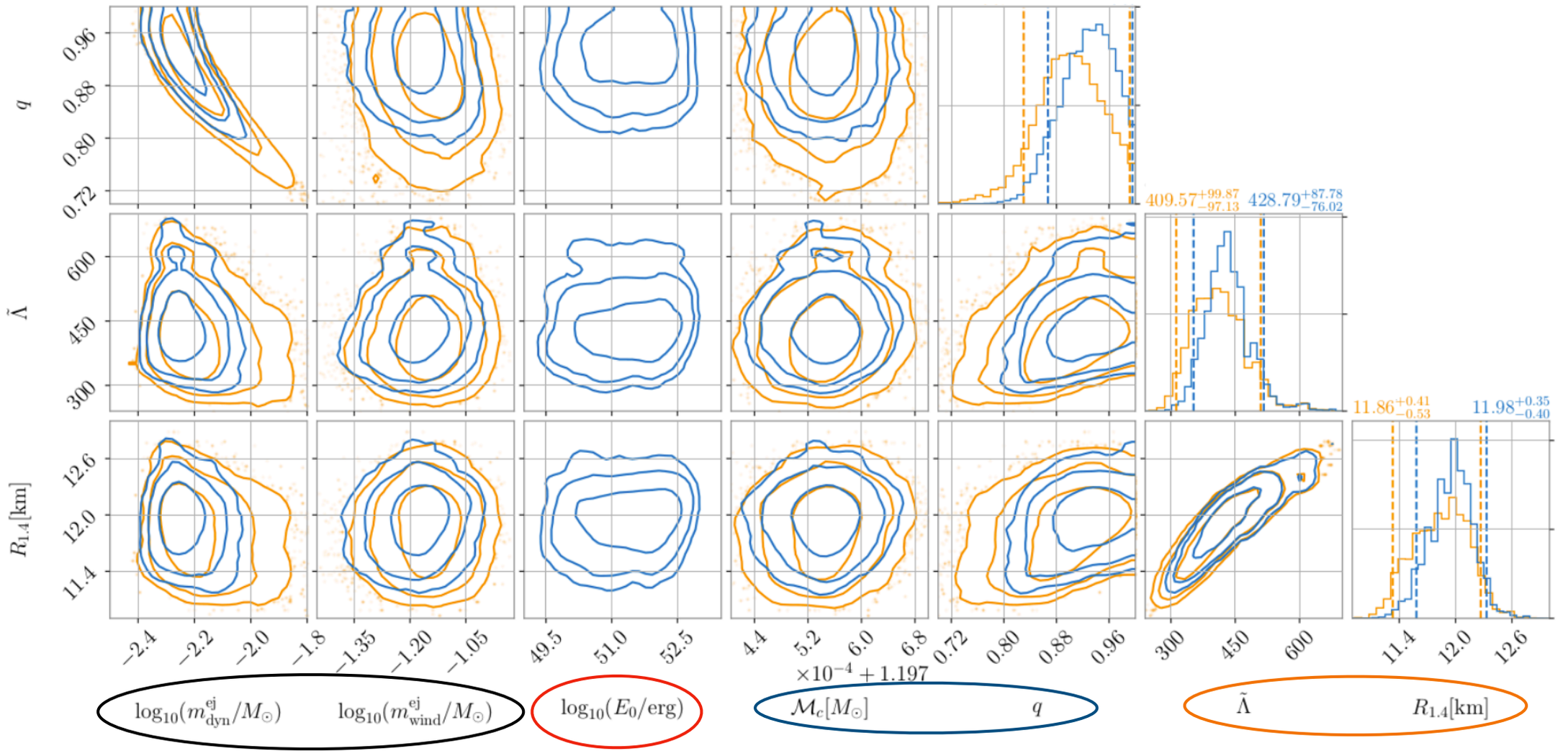
GW+EM fit and parameter inference





GW-EM combined analysis



Ejecta parameters

Energy of the jet

Masses of merging objects

Equation of State

GW-EM combined analysis

NMMA

[Dietrich, Coughlin, Pang, MB+2020, Science]

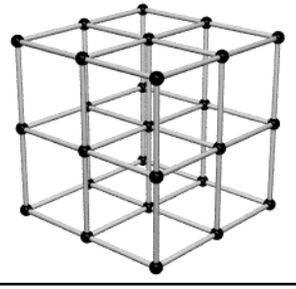
[Pang, Dietrich, Coughlin, MB+2024, Nature Comms.]

[Koehn, Wouters, Pang, MB+2025, A&A]

POSSIS

Kilonova grids

Observables for **selected** values of the ejecta parameters



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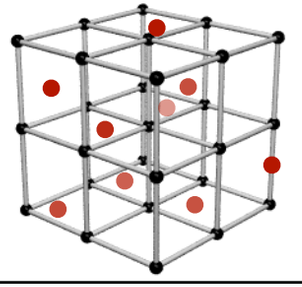
NMMA / FIESTA

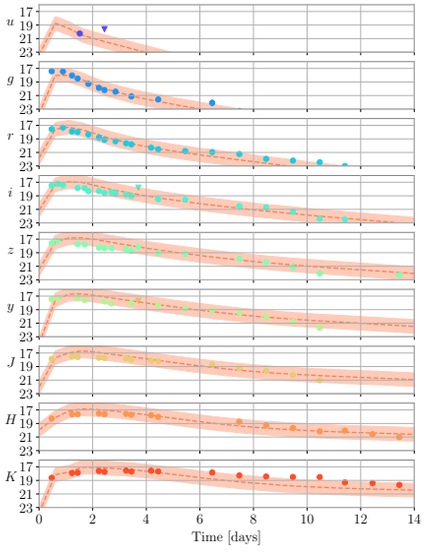
Kilonova emulators

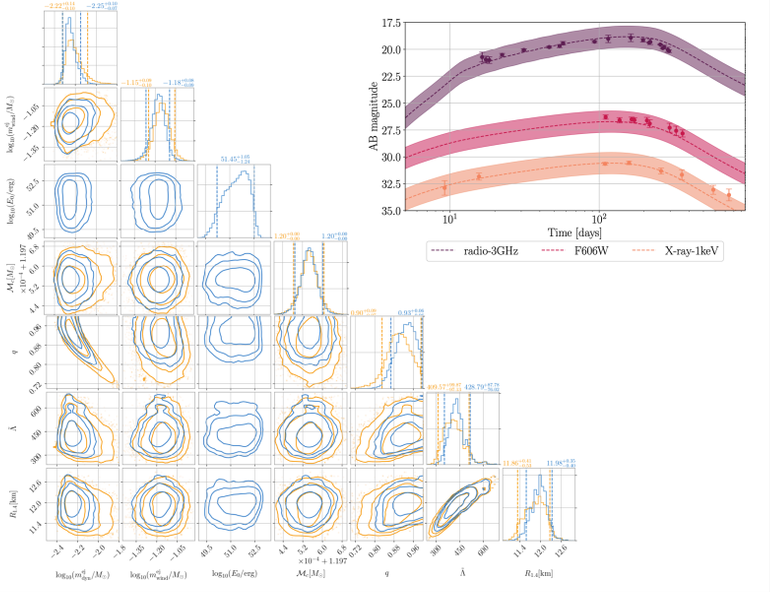
Observables for **arbitrary** values of the ejecta parameters



→

GW+EM fit and parameter inference





Other softwares: MOSFit (Nicholl+2021), Bajes-MMA (Breschi+2021, 2024), GEMMA (Raaijmakers+2021), surrogate_kne (Kedia+2023), Redback (Sarin+2024)

Special Session SS32 2 Jul 2026

Kilonovae: further insights from theory and observations

Aims and scope

This session aims to bring together a diverse range of experts to disseminate knowledge and promote discussion on the interpretation of kilonovae, in an effort to establish what we already (think we) know, summarise what key questions remain unanswered, and determine what can be gleaned from future observations and theoretical models.

The discovery of the first (spectroscopically) confirmed kilonova event by the coincident detection of gravitational waves (GW170817), gamma rays