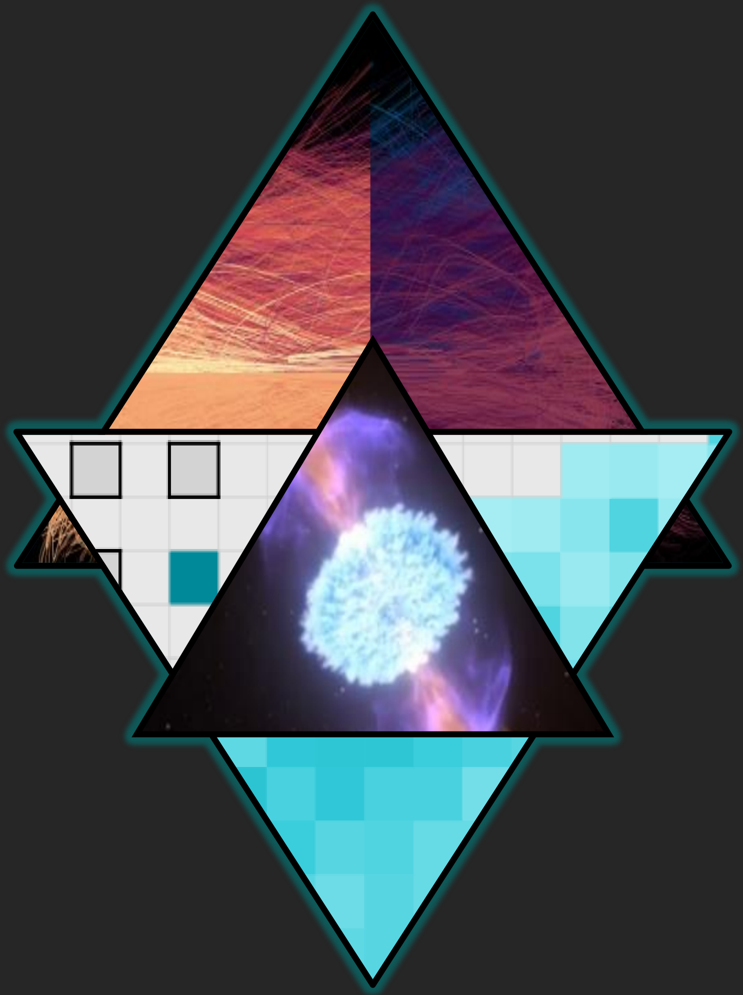
MICRA: Microphysics in Computational Relativistic Astrophysics



Magnetic Field Effects on Nucleosynthesis in Post-Merger Disk Outflows

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FIRE Fission In R-process Elements

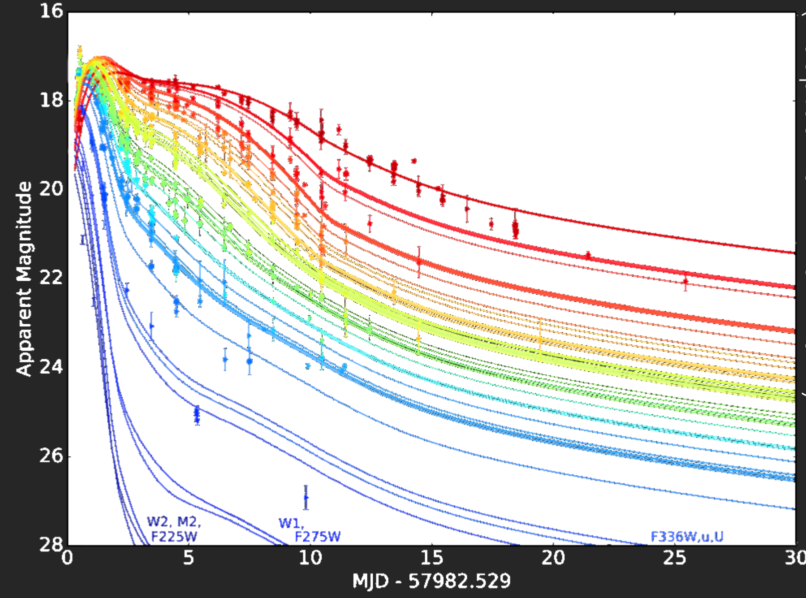
Kilonovae & r-Process

Kilonova (KN): electromagnetic transient event associated with compact object mergers (at least one neutron star).

Important heating mechanism: radioactive decay of r-process nuclei

Kilonovae are the direct consequence of physics that develops over a wide range of time scales.

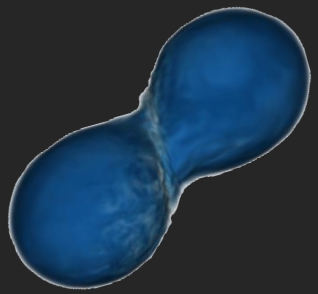
GW170817 Composite



(Adapted from Villar+ 2017)

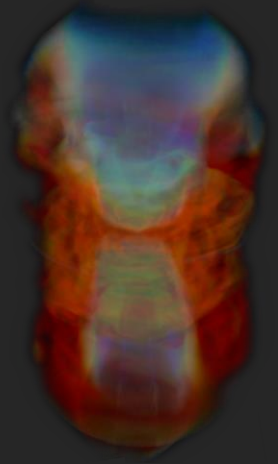
Time Scales

In-Spiral



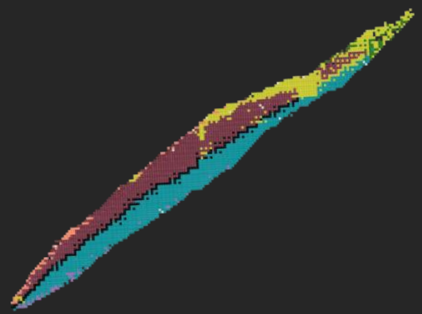
μs - s

Post-Merger Disk



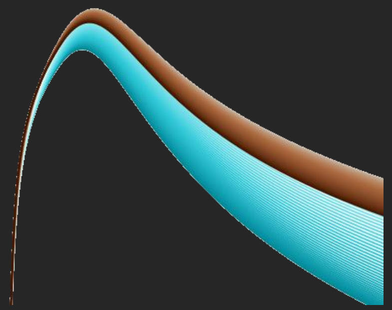
μs - s

Non-Equilibrium Reactions



s - Gyr

Photon Transport



Hours - Weeks

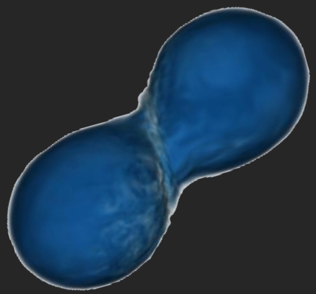
Enrichment

Myr - Gyr

Time Scales (advertisement)

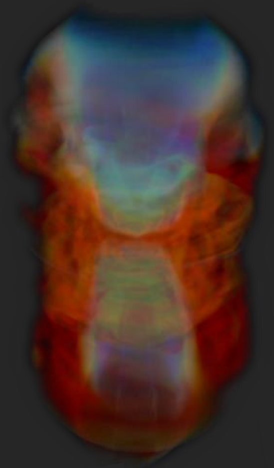
Holmbeck+ 2023: 2304.02125
Lund+ 2023: 2208.06373
Barnes+ 2021: 2010.11182
Zhu+ 2021: 2010.03668

In-Spiral



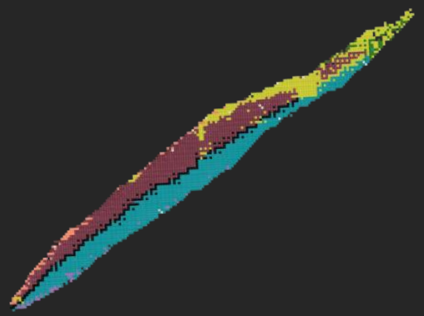
μs - s

Post-Merger Disk



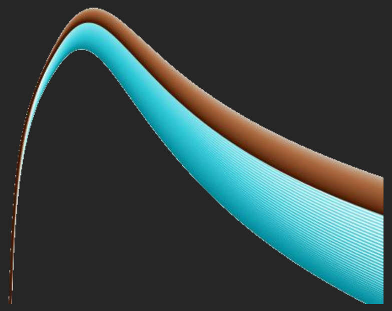
μs - s

Non-Equilibrium Reactions



s - Gyr

Photon Transport



Hours - Weeks

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Myr - Gyr

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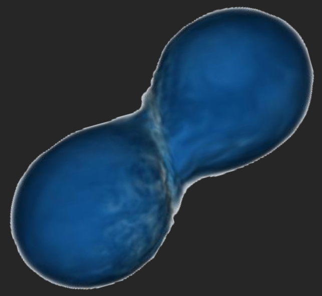
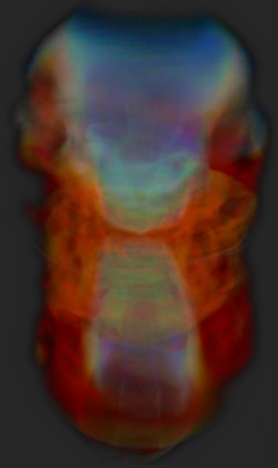
Time Scales

In-Spiral



μs - s

Post-Merger Disk



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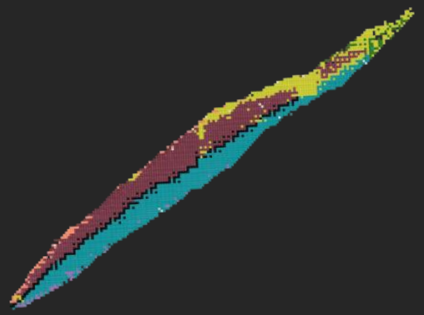

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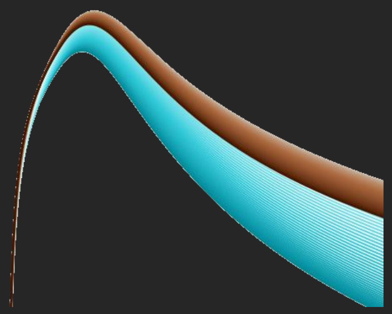
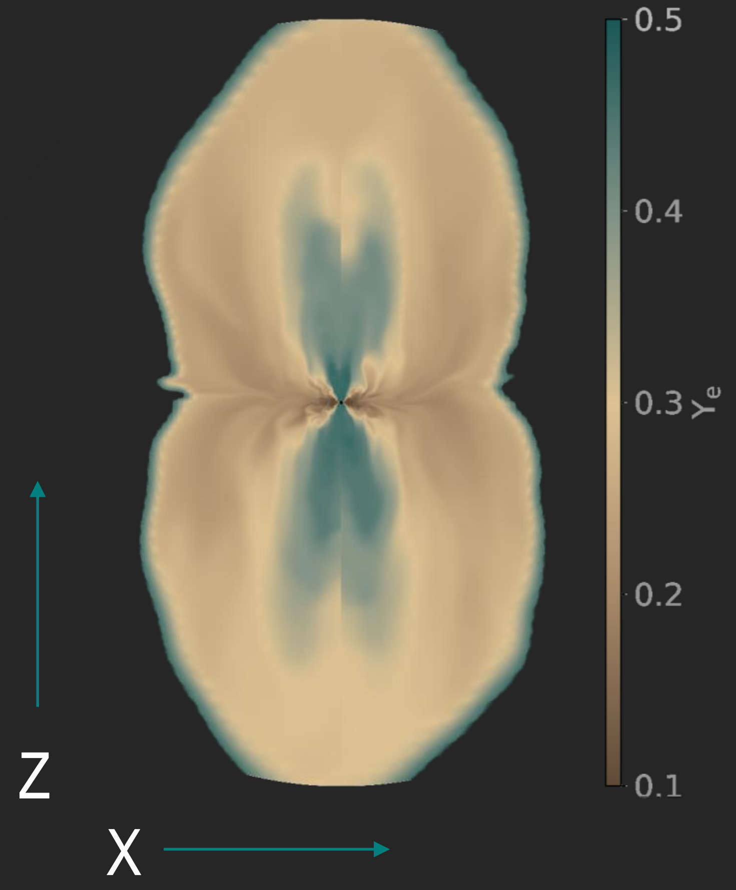


Hours - Weeks

Enrichment

Myr - Gyr

r-Process Site: Post-Merger Disk



Magnetically driven accretion disk forms after merger event

r-Process occurs in different ejection "sites":

- Fast wind driven off material in mid-plane
- Material entrained in semi-relativistic jet
- Slow, viscous disk

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Evolution of Post-Merger Disk

Disk Y_e — depends on — **Neutrino interactions** — **depend on** — Thermodynamic evolution of the disk — depends on — Magnetic fields

Neutrinos in the disk are neither trapped nor free-streaming, therefore neutrino transport is essential

nubhlight performs general relativistic magnetohydrodynamics *with* neutrino transport

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Variable Field Strength

$$\beta = \frac{P_{gas}}{P_{magnetic}}$$

could affect

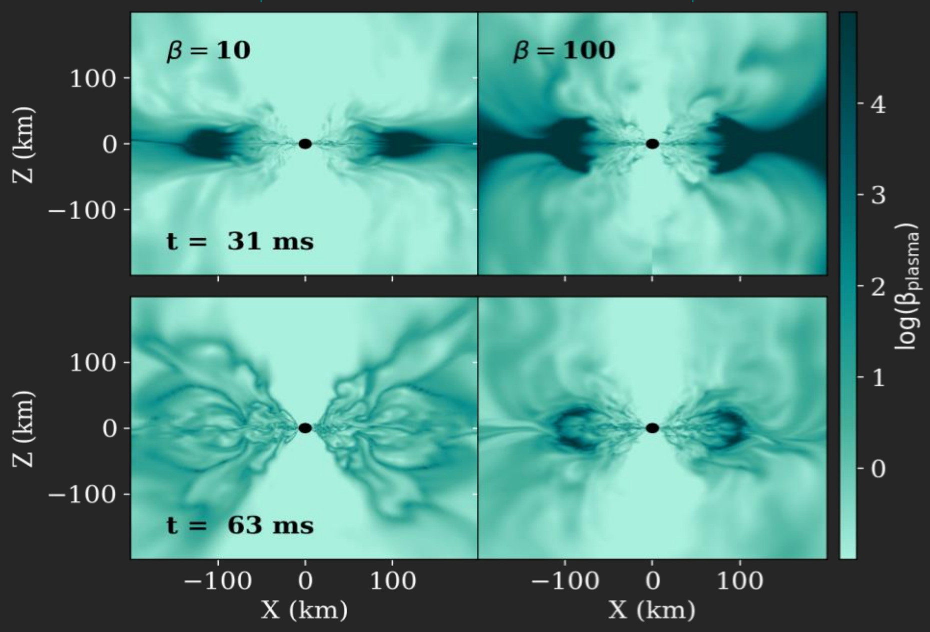
Ejection mechanism

Mass of ejecta

Ejecta velocity

Neutrino evolution timescale

Decreasing initial field strength



Procedure

GRνMHD simulations
with **nubhlight** (Miller + 2019)

produce

Tracers: thermodynamic evolution
(>400,000 total)

for

Nucleosynthesis
with **PRISM** (Mumpower+)

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$N_r \times N_\theta \times N_\phi = 192 \times 128 \times 66$

$M_{disk} = 0.12\ M_\odot$
$M_{BH} = 2.58\ M_\odot$
$Y_e = 0.1$
$a = 0.69$

Simulation time: $10^4\ GM_{BH}/c^3$
(~127 ms)

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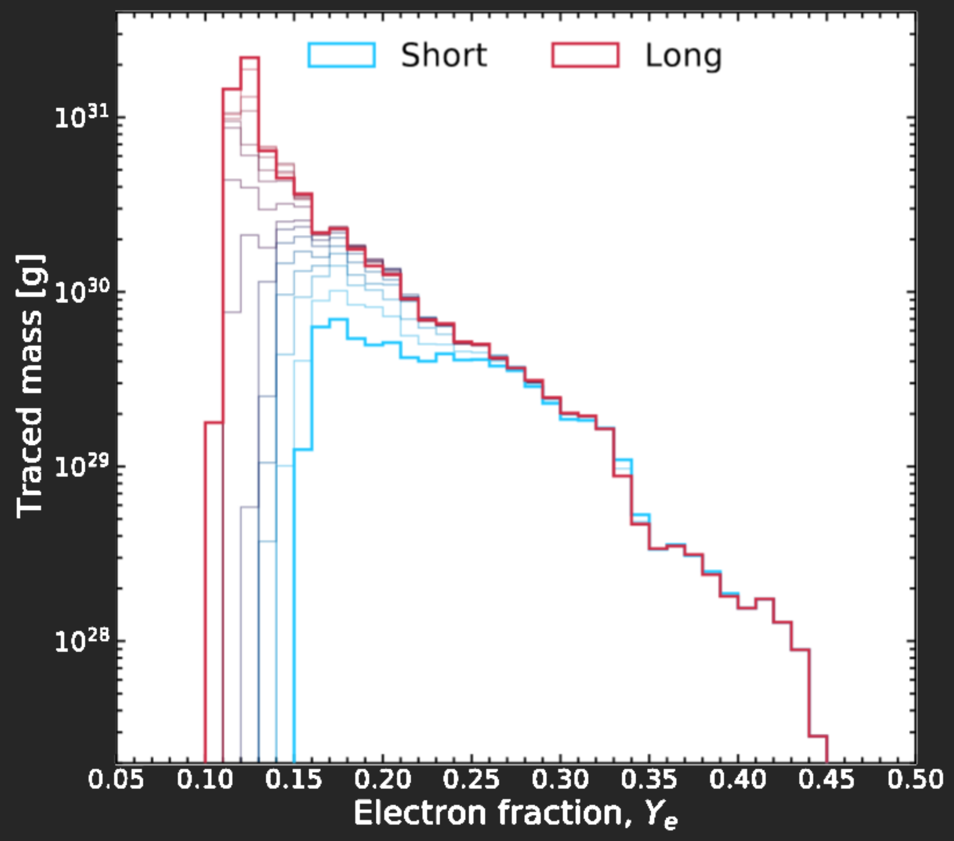
FRDM2012 Mass Model
FRLDM Fission Barrier Heights
Nubase Experimental Data

Abundance Record Time:
1 Gyr

A Note on Simulation Time

Sprouse+ 2023: Coming soon to an arXiv near you!



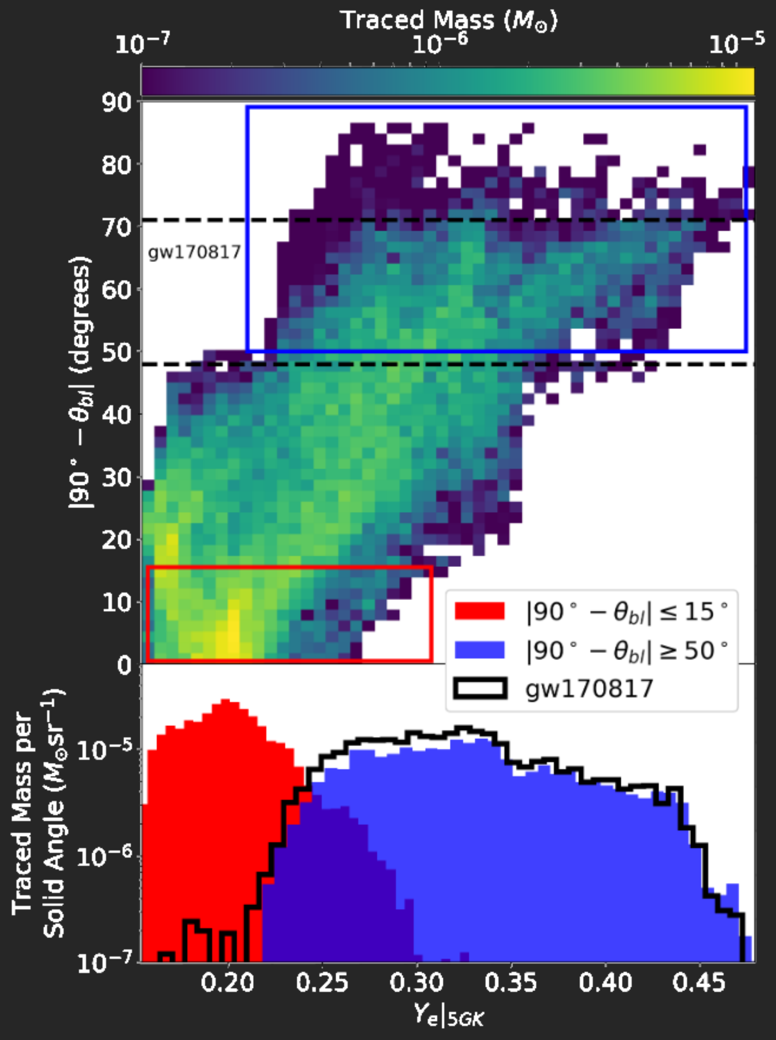
Running GRνMHD simulation out to $10^5\ GM_{BH}/c^3$ (~1.27 s) results in significantly more unbound low-Ye material!

Some Results

Lund+ in prep
Figure: Miller+ 2019

Can lanthanide or actinide production be traced back to a specific region in the disk?

Where does material of a given Ye get ejected?



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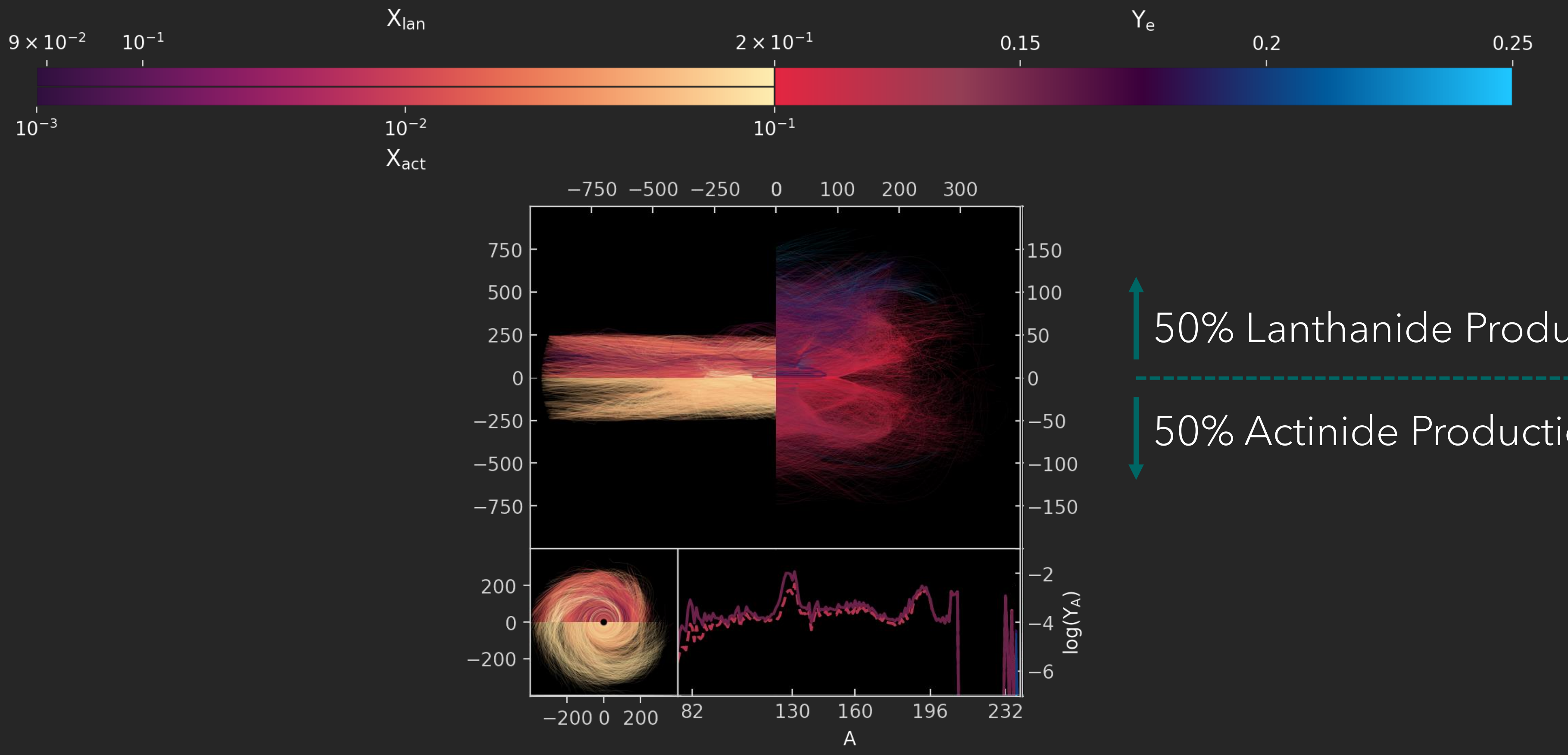
Spatial Trajectories

Lund+ in prep



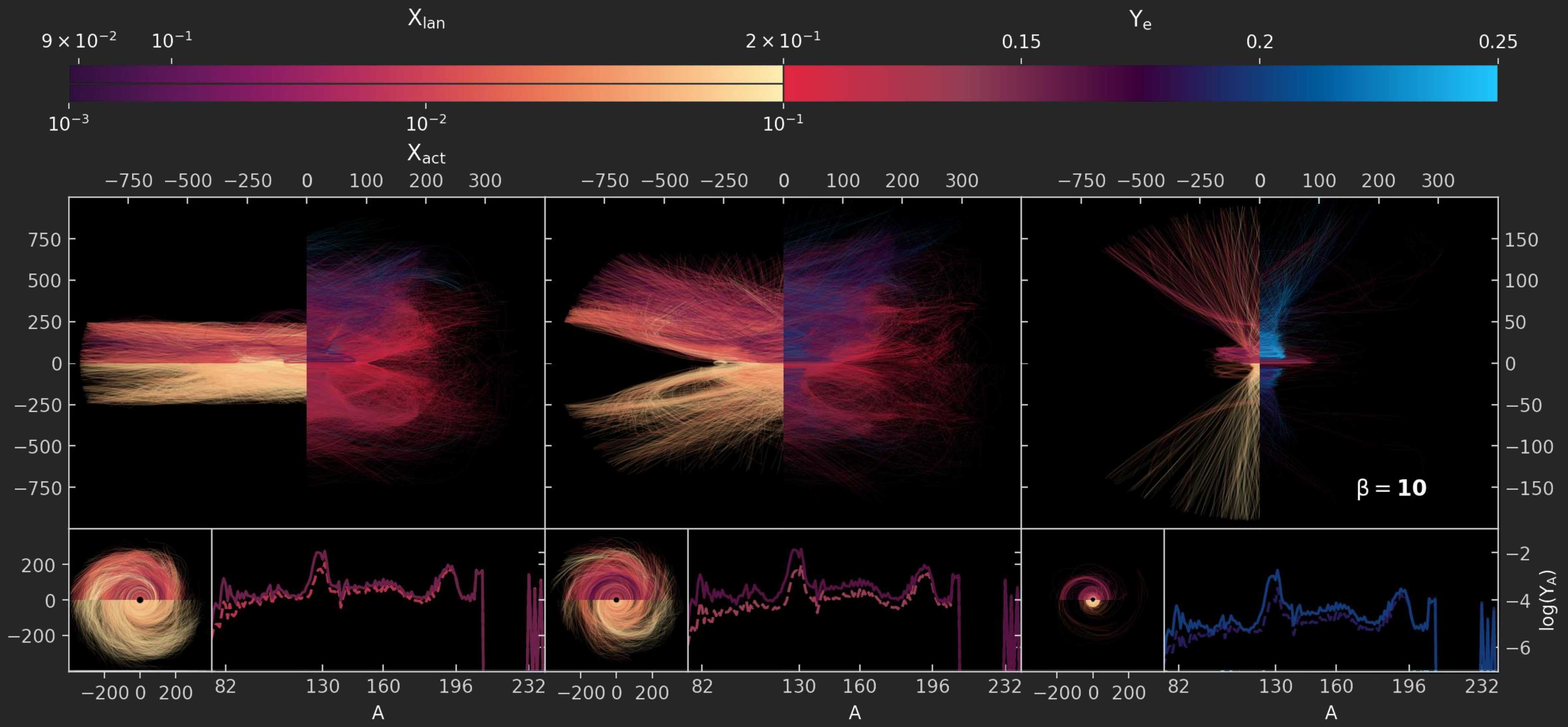
50% Lanthanide Production

50% Actinide Production

Mass Fraction

Electron Fraction

Spatial Trajectories



Polar material capable of producing overall small amounts of actinides, but high mass fraction

High entropy in polar region allows for higher Ye for lanthanide/actinide production

Stronger initial B field yields higher ejecta mass, with higher lanthanide and actinide richness

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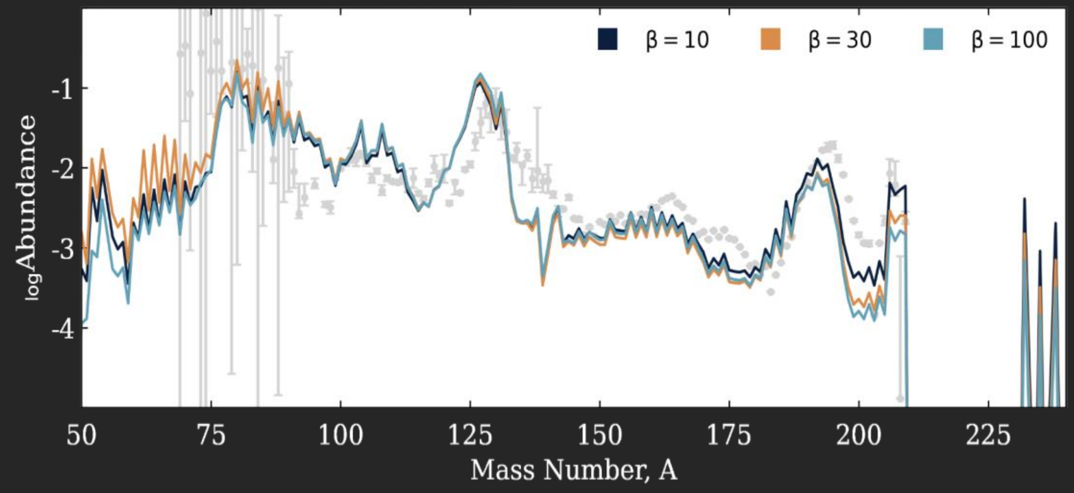
Nucleosynthesis!

(scaled) Abundance patterns at 1 Gyr show some differences, but overall shape quite similar!

Largest differences in actinides, third peak



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Nucleosynthesis!

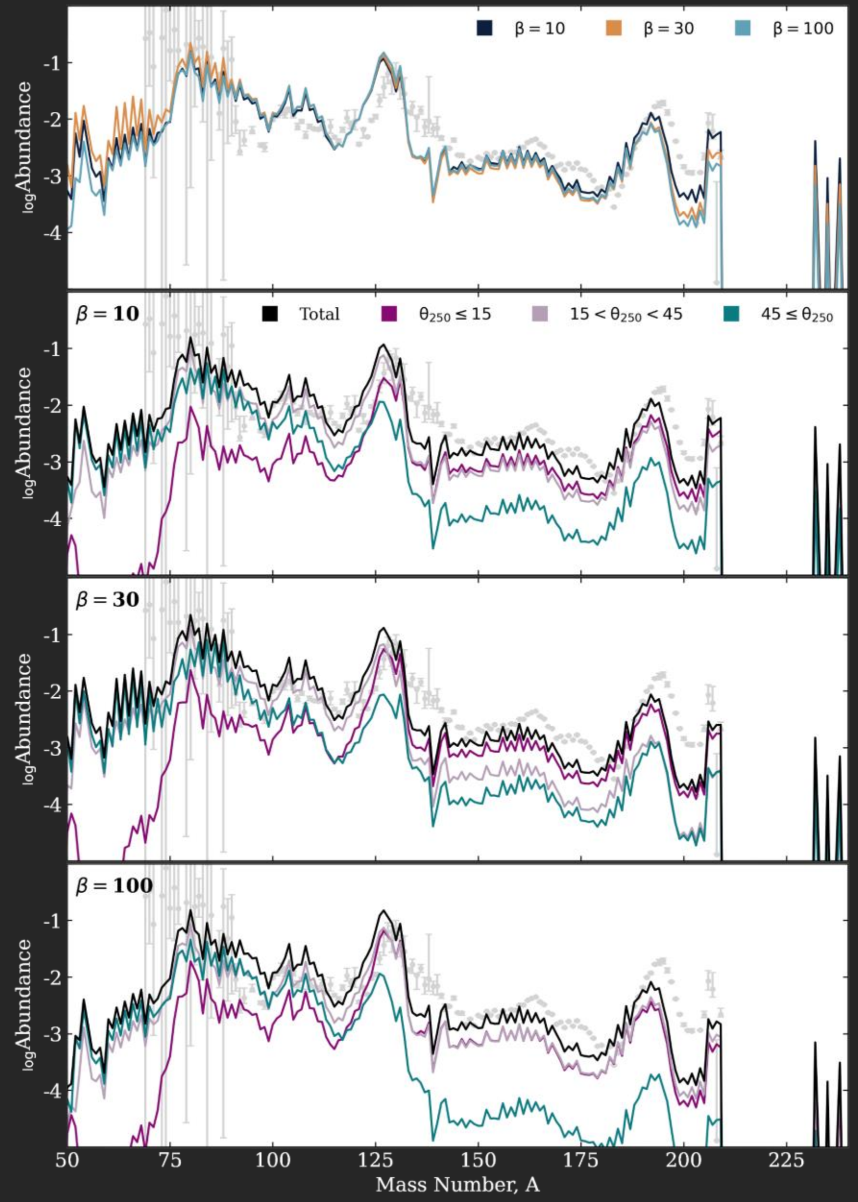
Lund+ in prep

Despite similarity in abundance pattern shape, bulk of material comes from different parts of ejecta, and depends on β.

Proportion of overall pattern from intermediate-angle ejecta: 15 < θ < 45

Larger actinide abundances tend to see larger contribution from intermediate angle material

Efficiency of actinide production sensitive to initial conditions.



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Thank you!