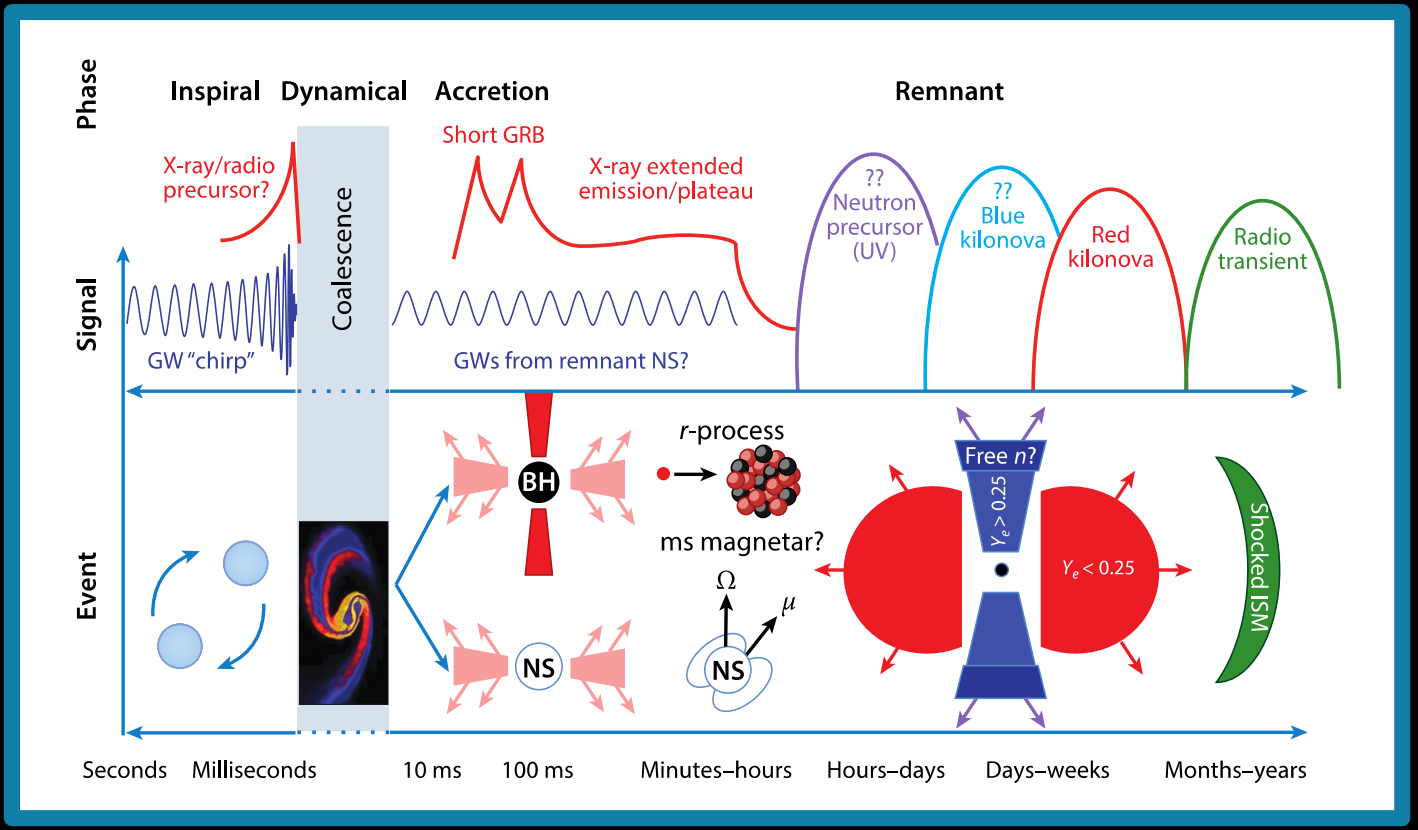
The Multi-D Effects of Jets on Neutron Star Merger Light Curves

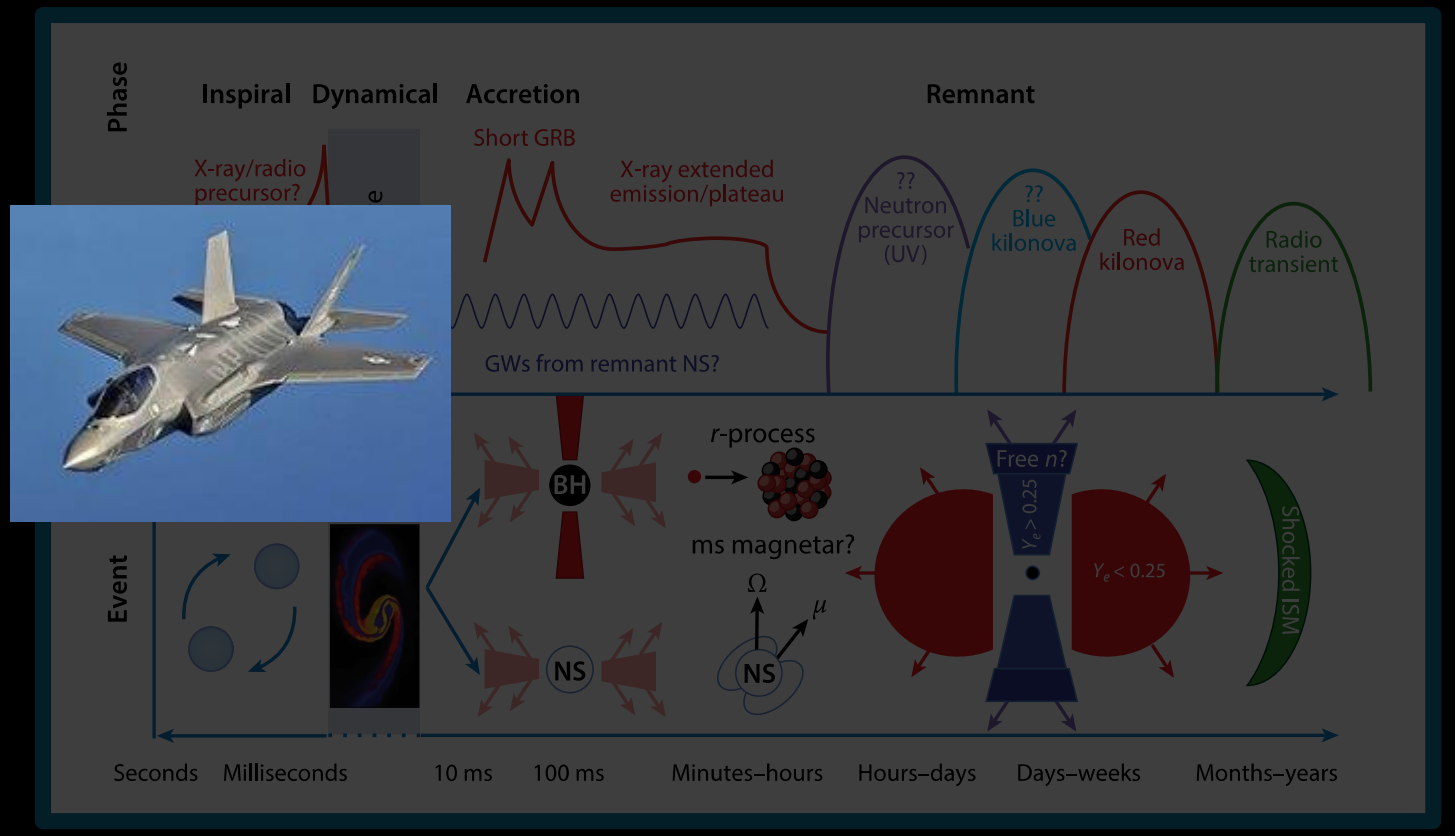
Hannah Klion (UC Berkeley), Paul Duffell (Harvard CFA), Eliot Quataert (UC Berkeley), Daniel Kasen (UC Berkeley, LBNL)

Neutron star mergers are multimessenger events



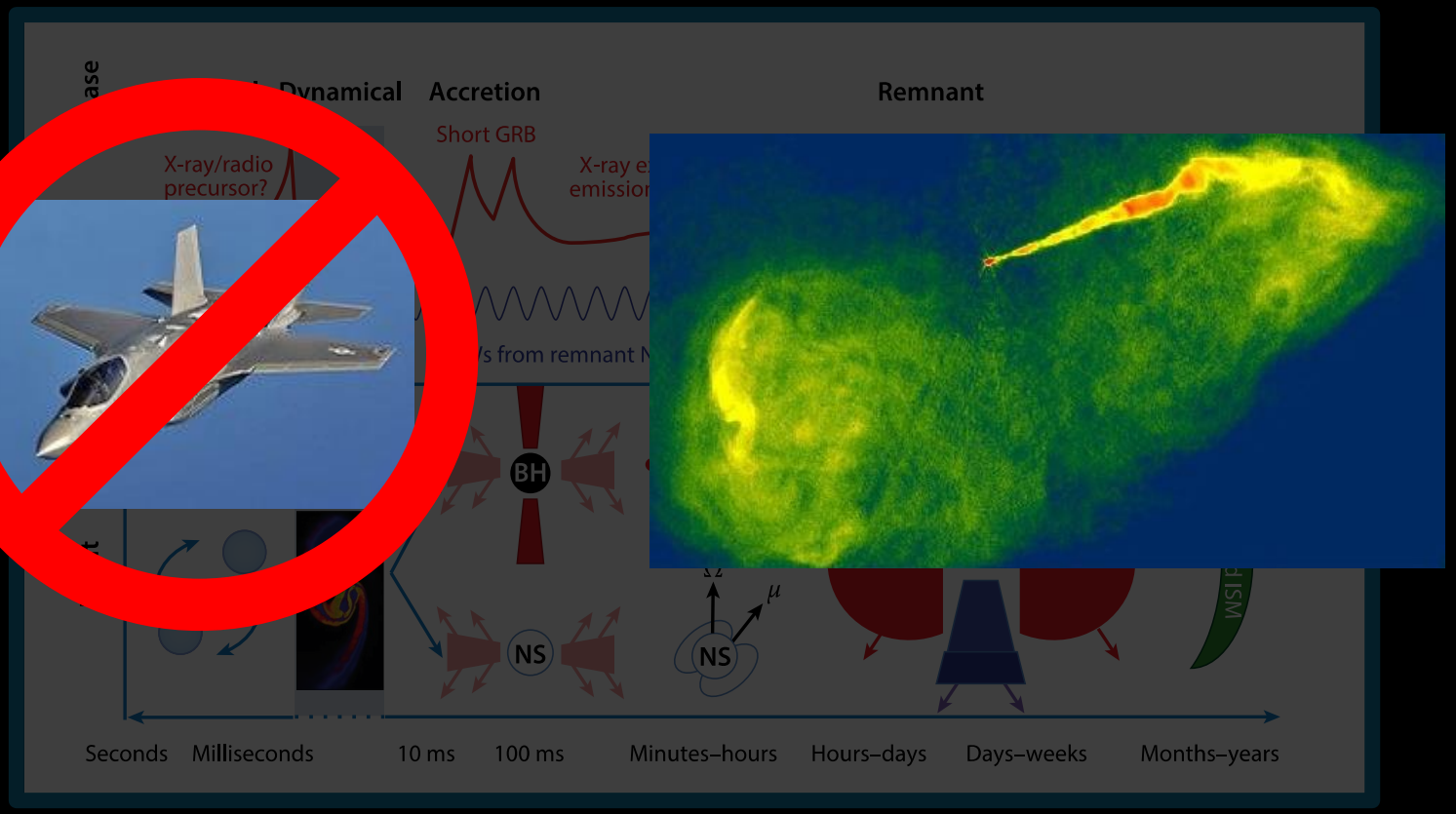
Fernández & Metzger '16

Neutron star mergers are multimessenger events



Fernández & Metzger ‘16

Neutron star mergers are multimessenger events

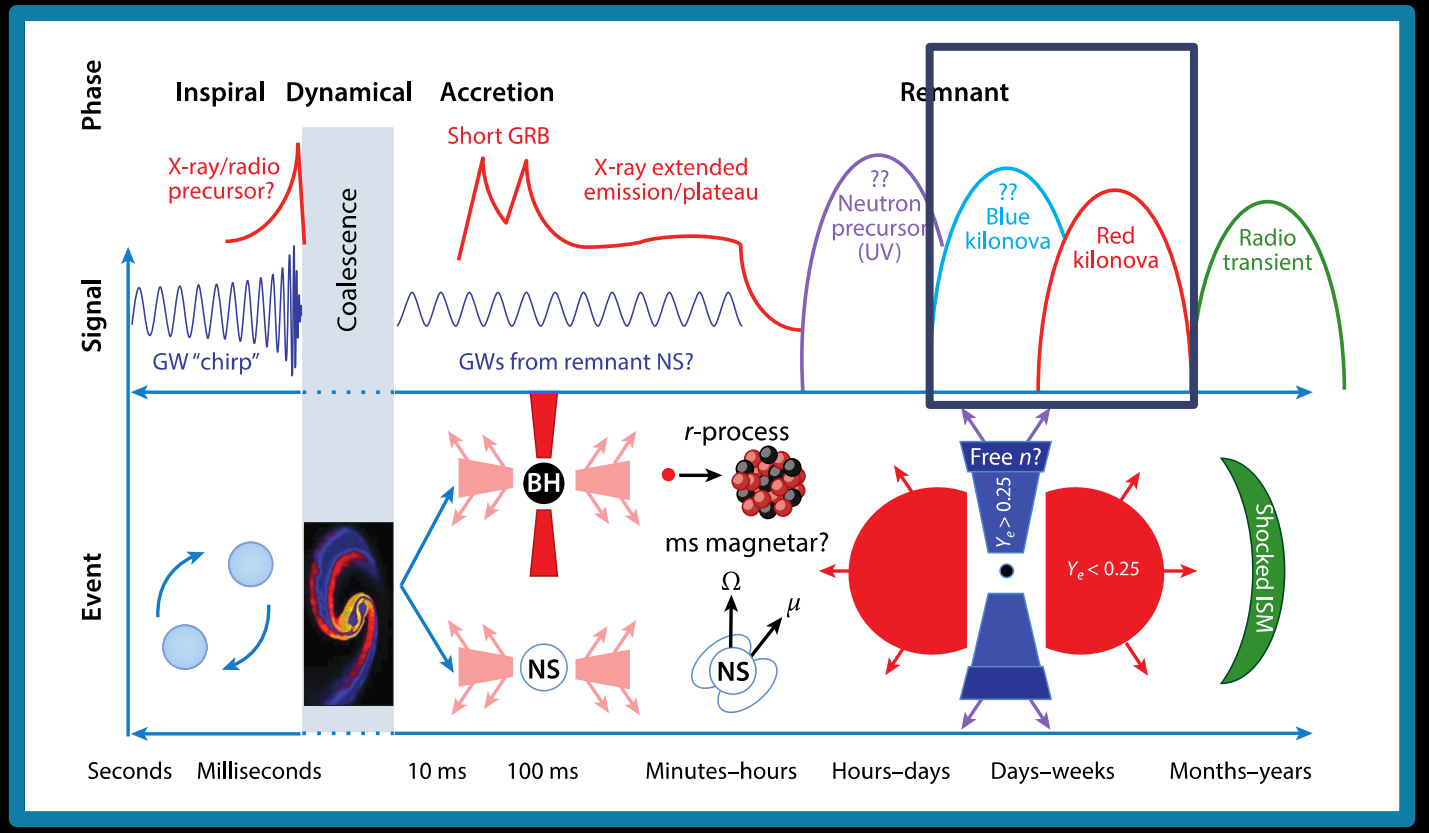


Fernández & Metzger ‘16

Neutron star mergers are multimessenger events

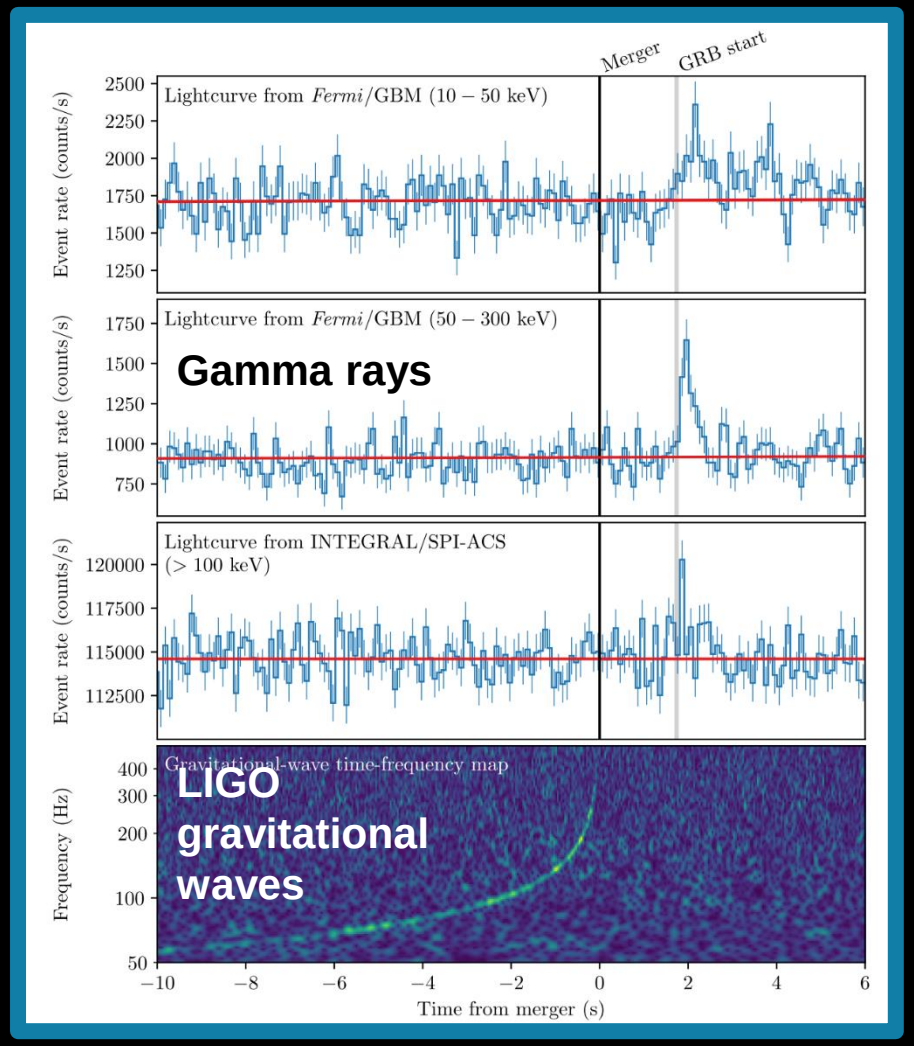
radioactive
UVOIR transient

“kilonova” or “macronova”

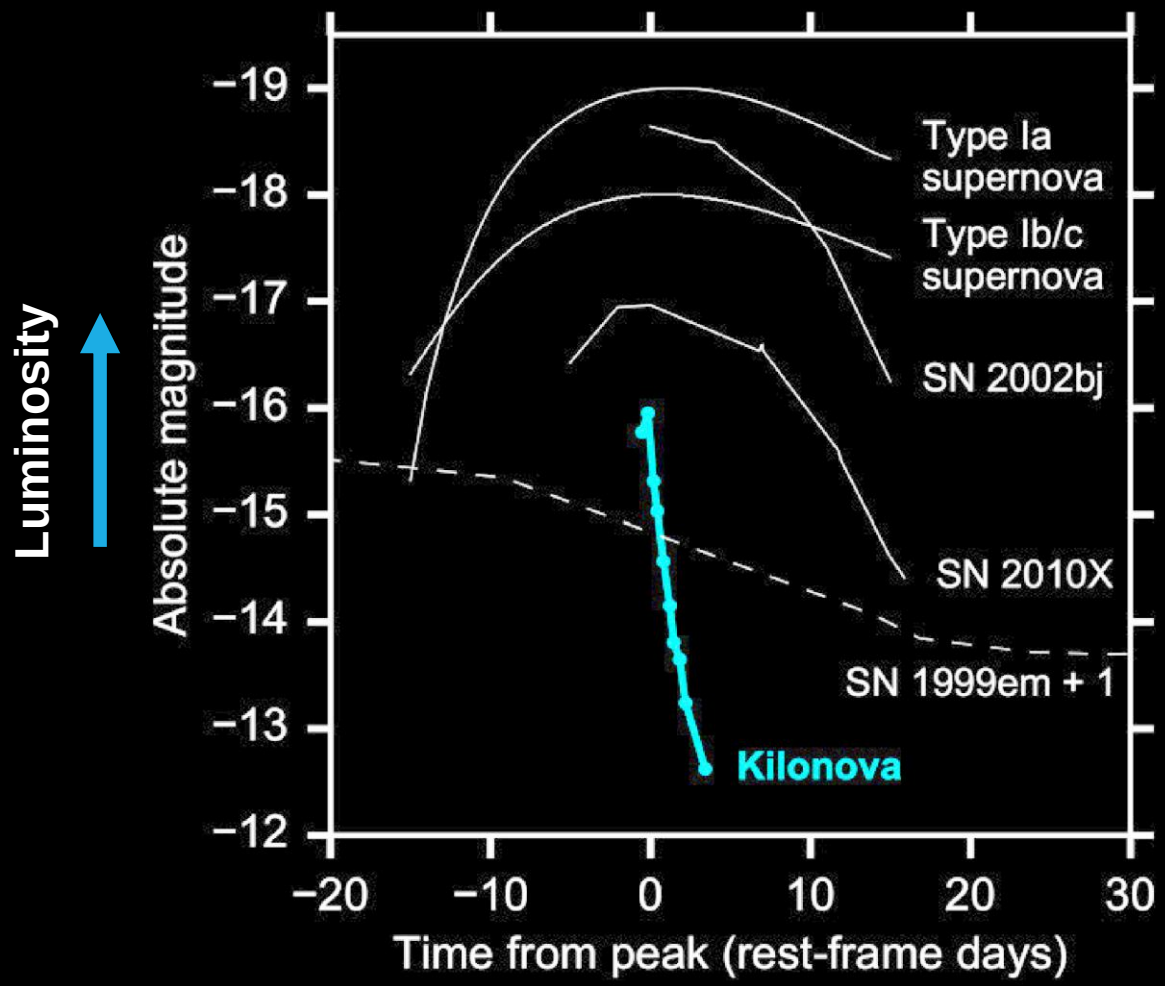


Fernández & Metzger ‘16

GW170817 / AT2017gfo: An Unusual Transient



Abbott + ‘17



Arcavi + ’17

What next?

What kind of diversity can we expect to see in subsequent kilonovae?

What next?

What are the effects of different viewing angles?

Focusing on **shock-heating** due to a prompt jet
and **changes to density structure**

Two of the Possible Sources of Heating

Shock heating from a jet

(incl. Kasliwal+'17, Piro & Kollmeier'17)

~seconds

10^{49} - 10^{50} erg

Radioactive decay of nucleosynthesis products

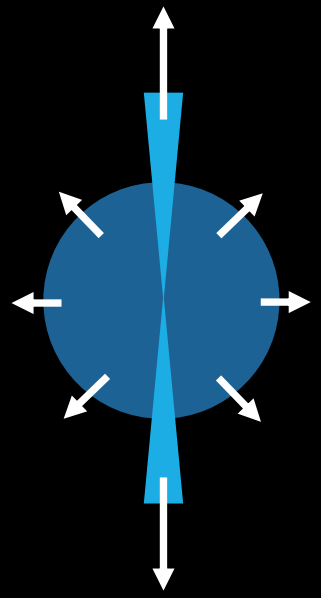
(incl. Metzger+'10)

~seconds to days

10^{50} erg

Approach

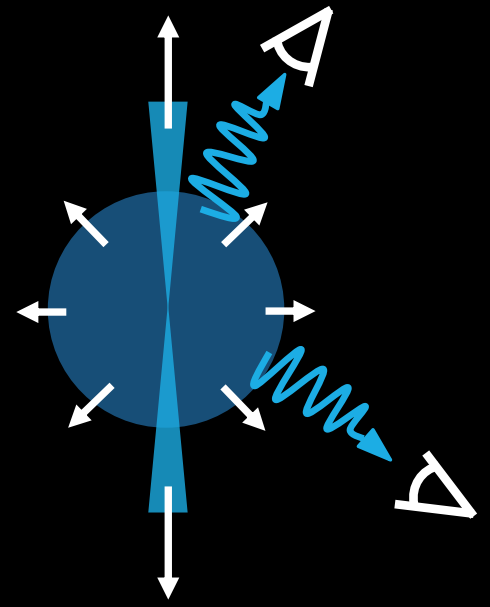
t ~ 10 ms to t ~ 100 s



adiabatic expansion

r-process heating
(Metzger+'10, Lippuner & Roberts '15)

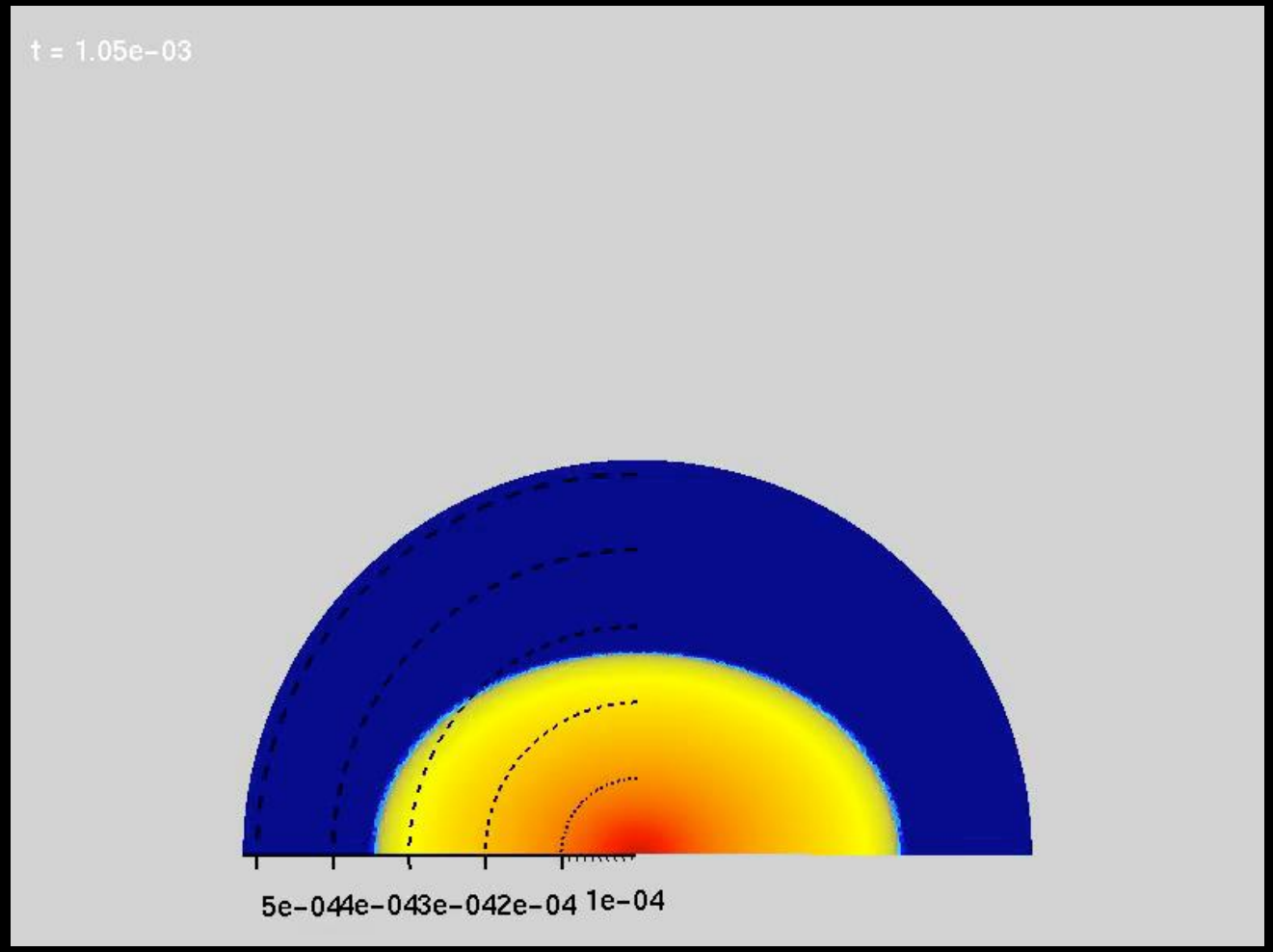
t ~15 min to t ~ 10 days



2D relativistic hydrodynamic simulation (in JET) of jet interacting with expanding outflow
(Duffell + (incl **Klion**) '18)

2D Monte Carlo radiation transport simulations with Sedona

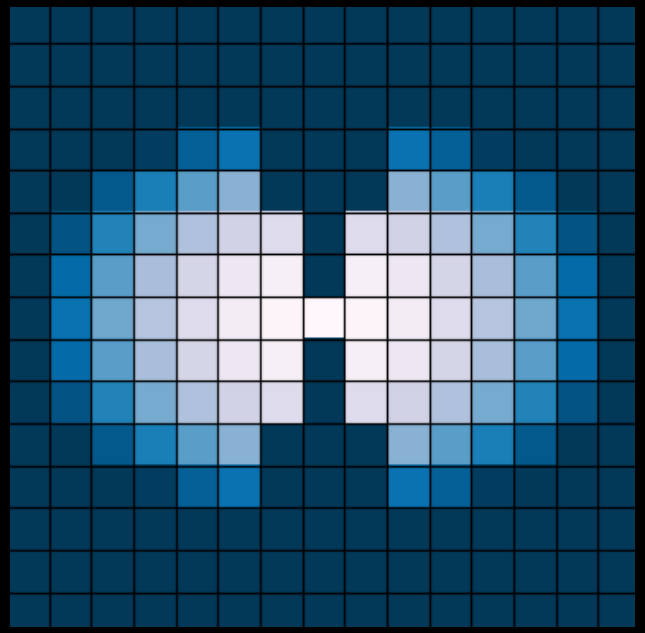
Jet-Ejecta Hydrodynamic Simulations



Sedona: Parallel Multi-D Monte Carlo Radiation Transport Code (Kasen + ’06, update in prep.)

Sedona: Parallel Multi-D Monte Carlo Radiation Transport Code

Background gas

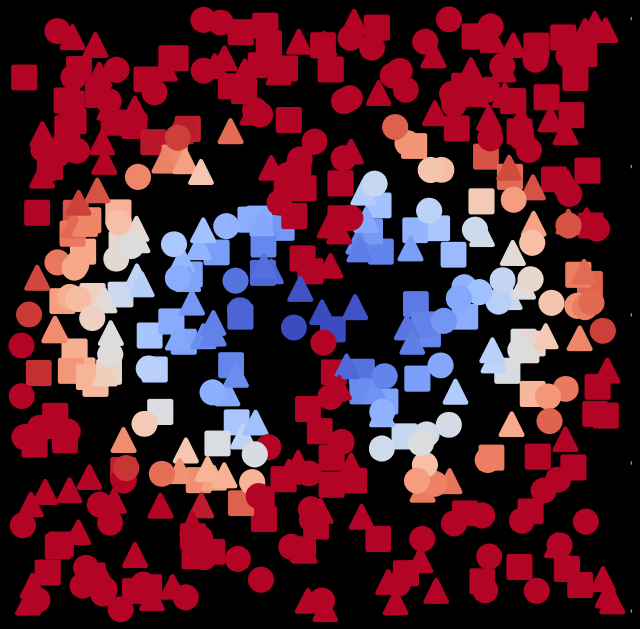


@ each cell

- Opacity
- Temperature
- Composition
- Radiation field

+

Particles



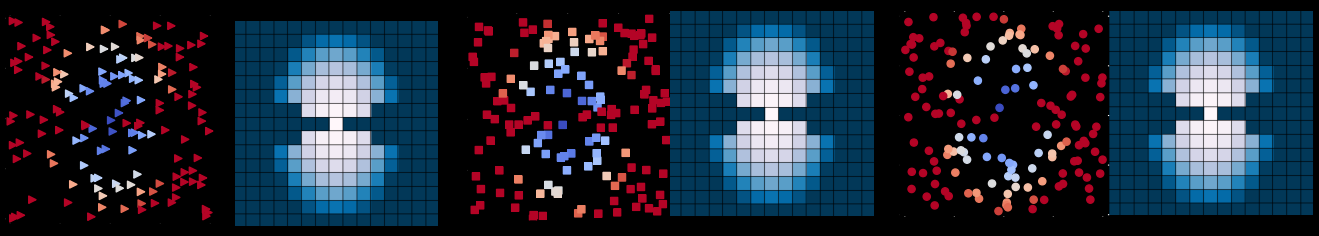
for each particle

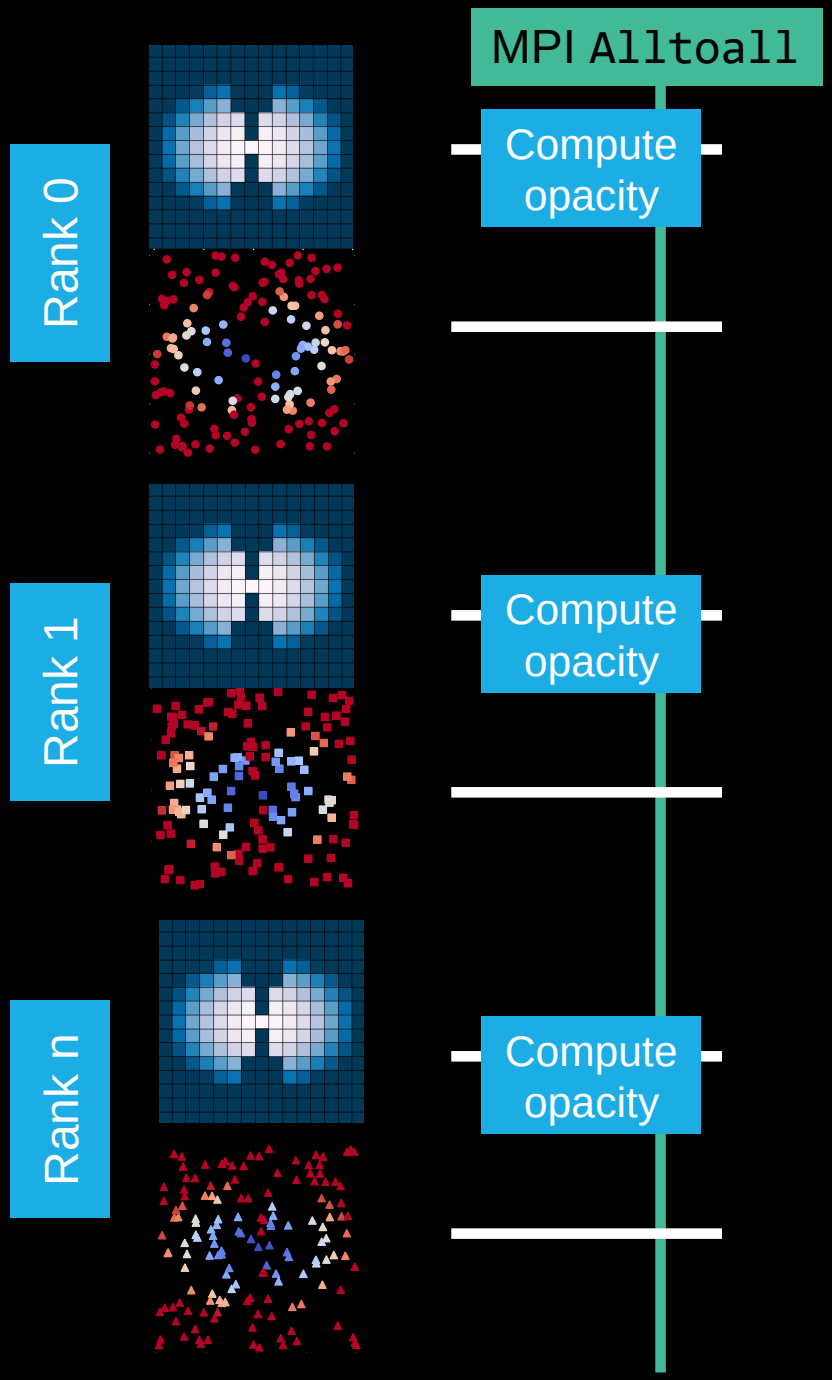
- Photon frequency
- Total energy
- Direction

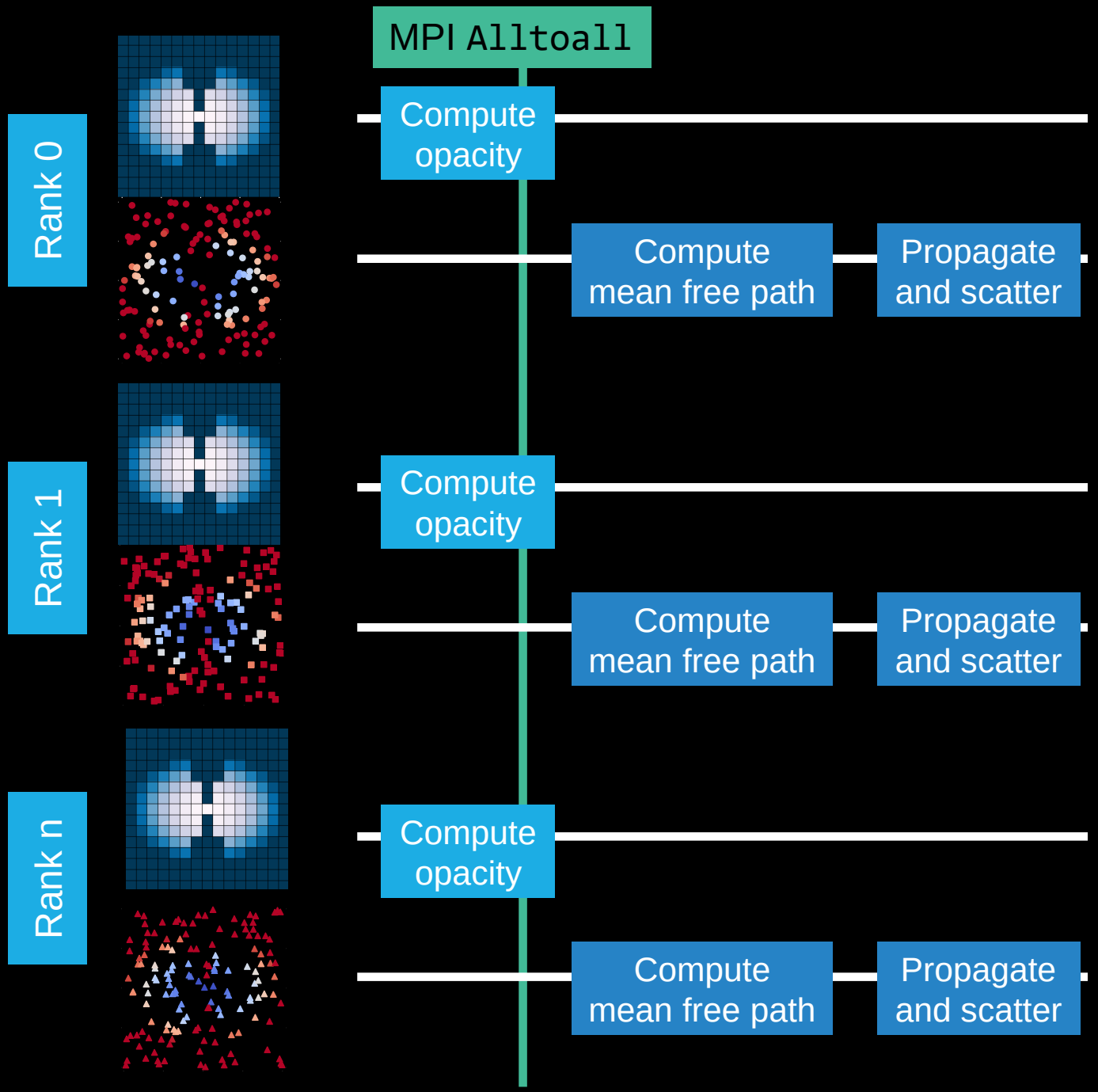
Rank n

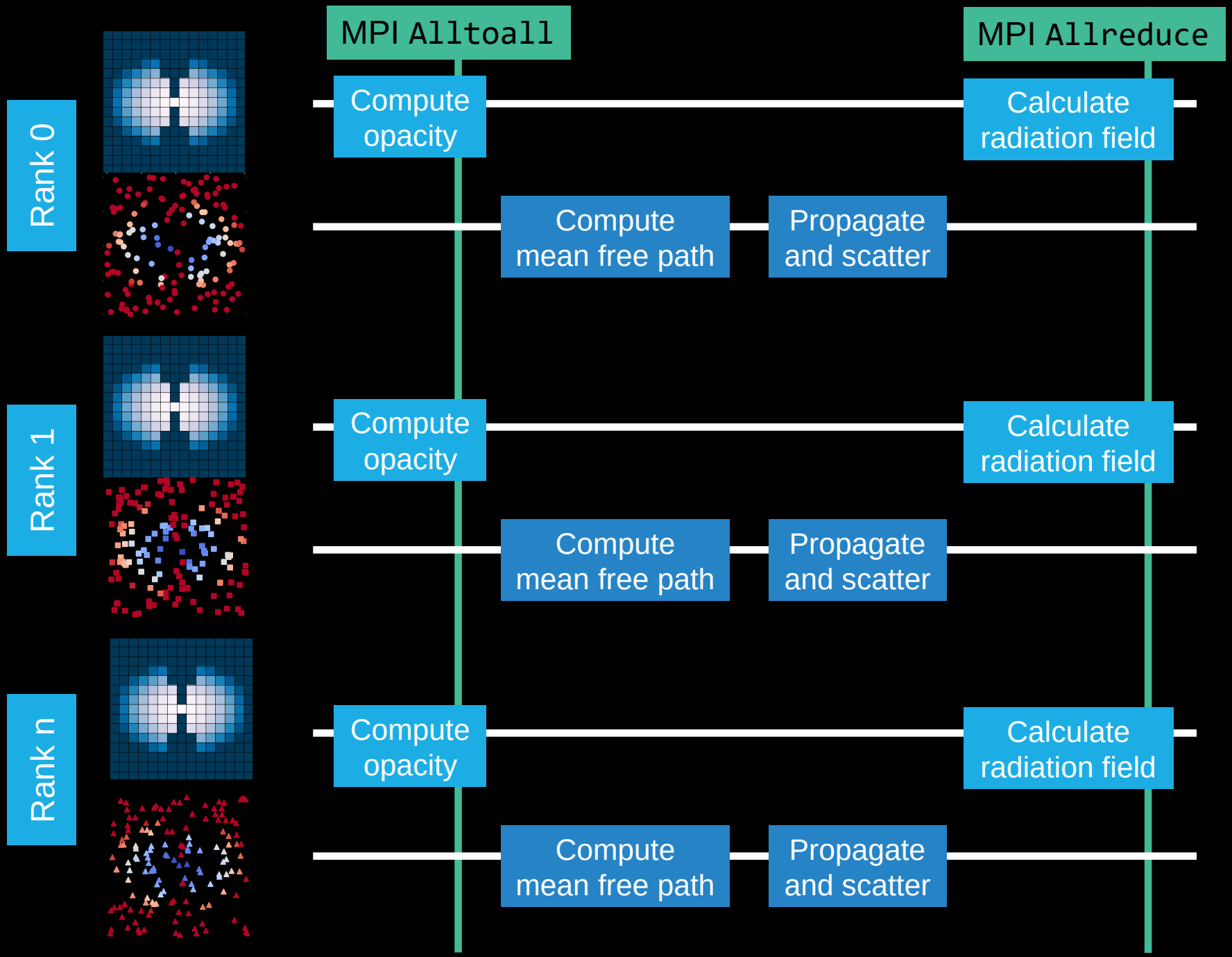
Rank 1

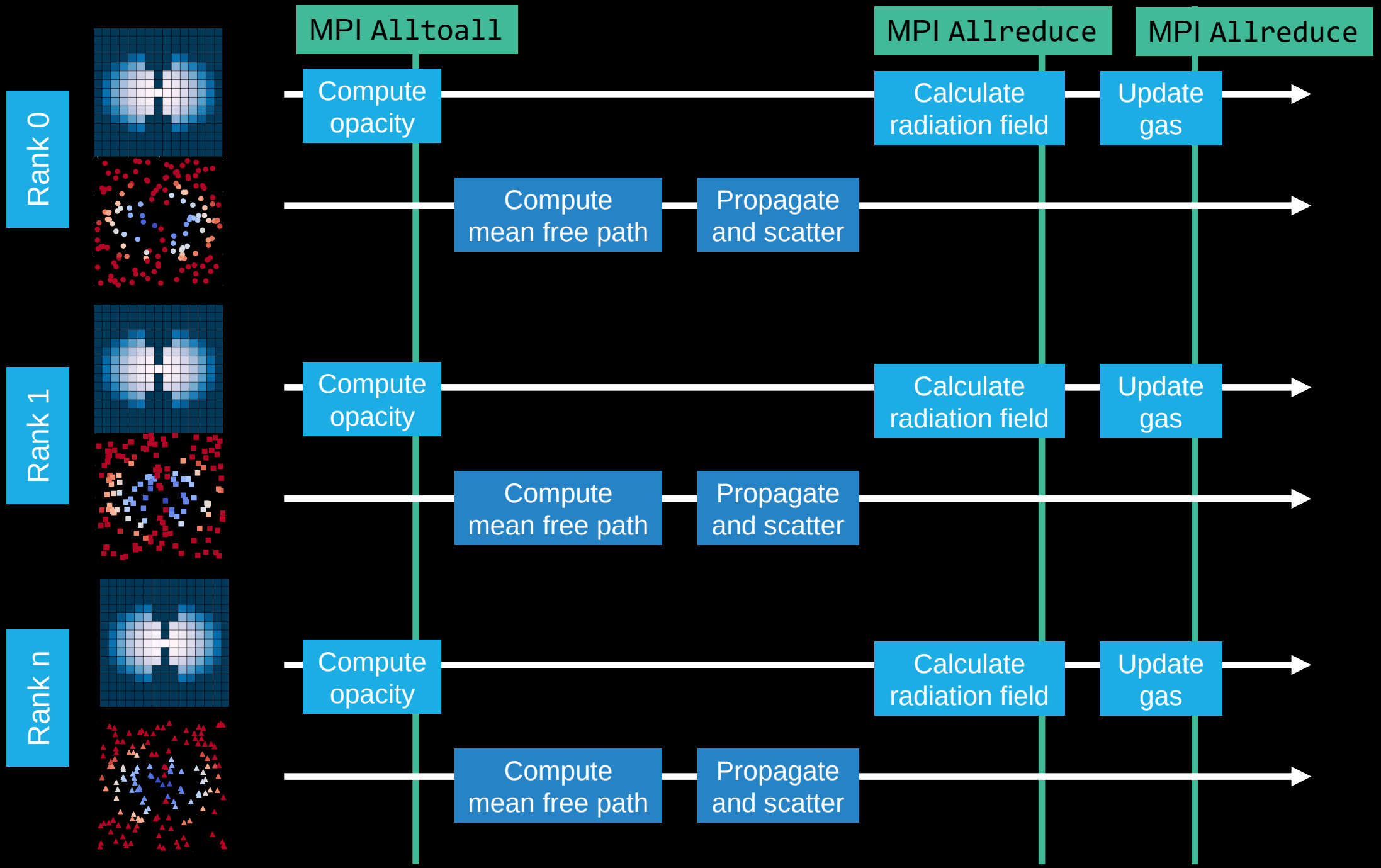
Rank 0

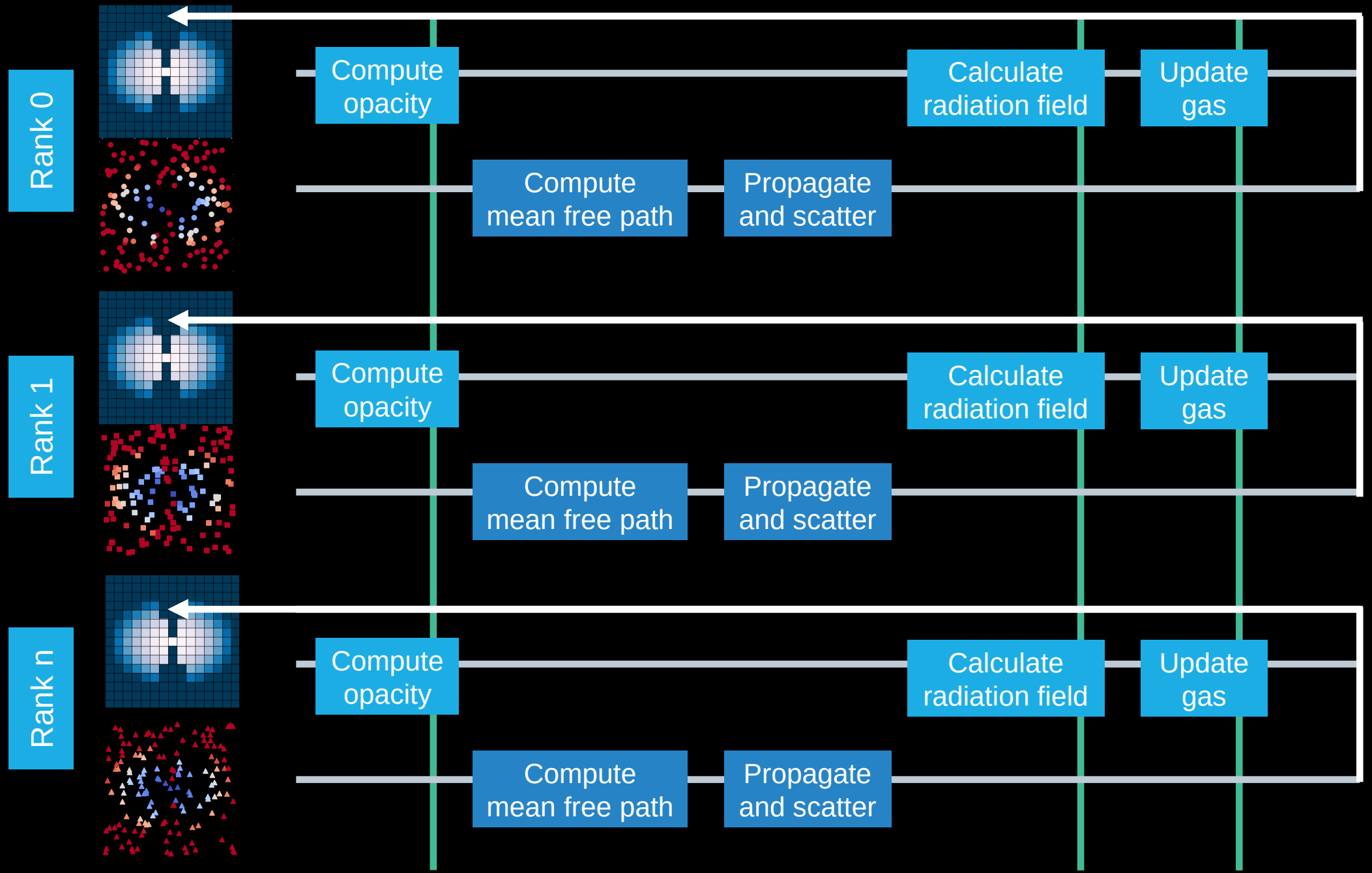



MPI Alltoall
Rank 0
Rank 1
Rank n
Compute opacity
Compute opacity
Compute opacity


MPI Alltoall
Rank 0
Compute opacity
Compute mean free path
Propagate and scatter
Rank 1
Compute opacity
Compute mean free path
Propagate and scatter
Rank n
Compute opacity
Compute mean free path
Propagate and scatter


MPI Alltoall
MPI Allreduce
Rank 0
Rank 1
Rank n
Compute opacity
Calculate radiation field
Compute mean free path
Propagate and scatter
Compute opacity
Calculate radiation field
Compute mean free path
Propagate and scatter
Compute opacity
Calculate radiation field
Compute mean free path
Propagate and scatter

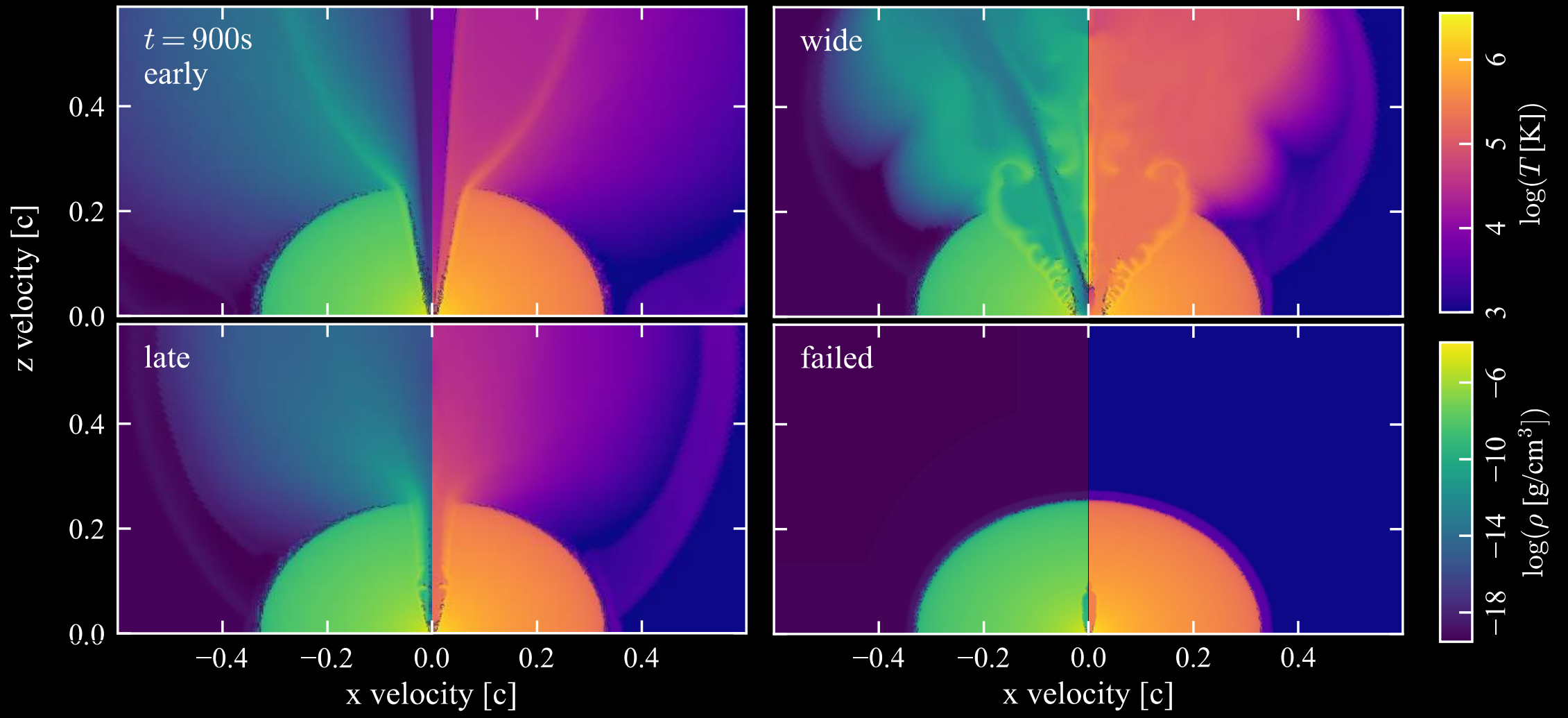

MPI Alltoall
MPI Allreduce
MPI Allreduce
Rank 0
Rank 1
Rank n
Compute opacity
Compute mean free path
Propagate and scatter
Calculate radiation field
Update gas
Compute opacity
Compute mean free path
Propagate and scatter
Calculate radiation field
Update gas
Compute opacity
Compute mean free path
Propagate and scatter
Calculate radiation field
Update gas


Rank 0
Compute opacity
Calculate radiation field
Update gas
Compute mean free path
Propagate and scatter
Rank 1
Compute opacity
Calculate radiation field
Update gas
Compute mean free path
Propagate and scatter
Rank n
Compute opacity
Calculate radiation field
Update gas
Compute mean free path
Propagate and scatter

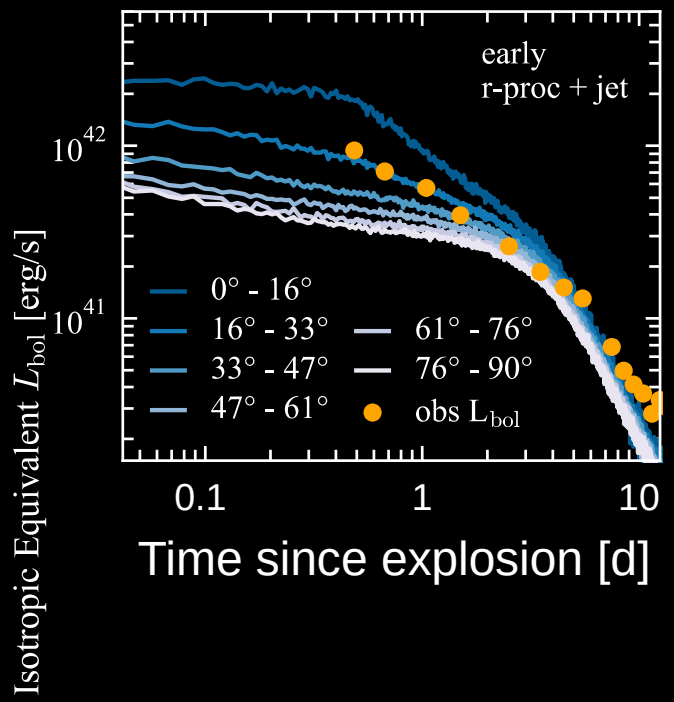
Recent and Ongoing Development

- Added capability to checkpoint and restart simulations (including saving and restarting the state of the random number generators)
- Added doubly diffusive Monte Carlo transport (with frequency-dependent opacity!)
- Parallelize everything in OpenMP
- Move towards GPUs

Input Models + r-process

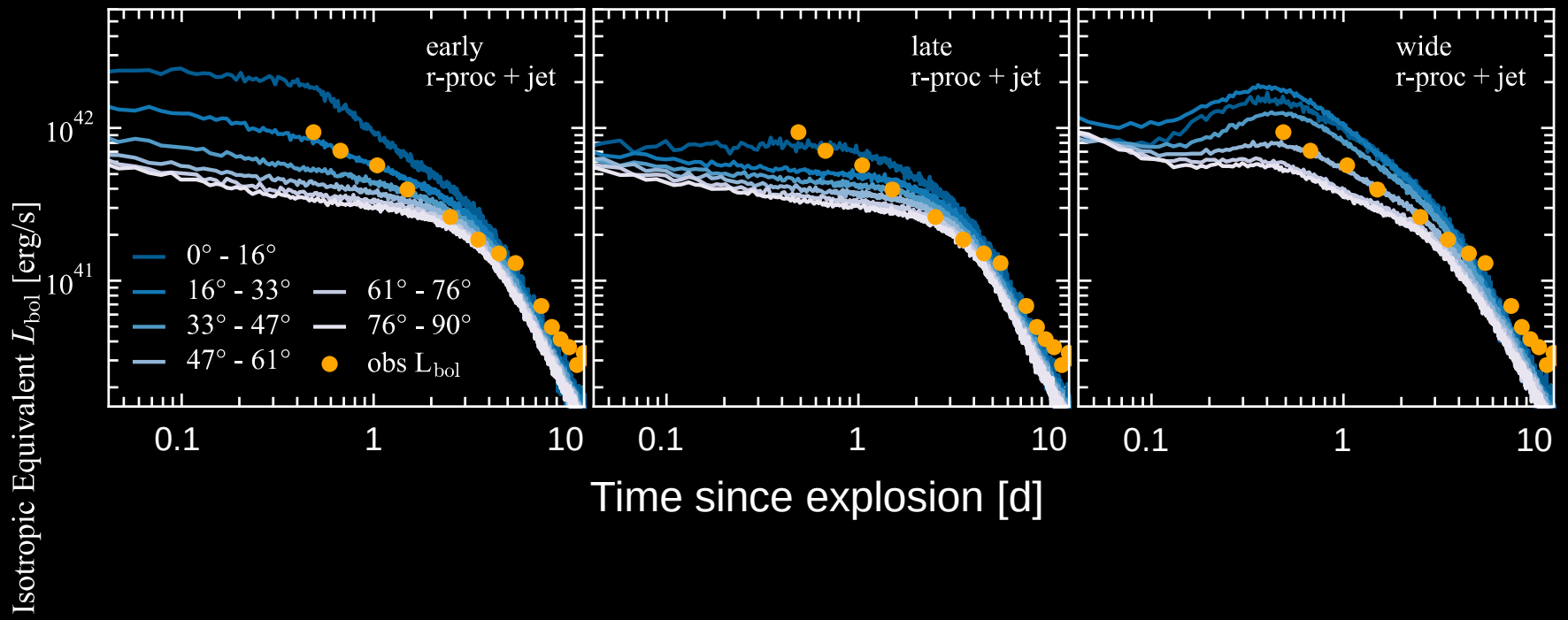


Light curves are brighter along pole than on equator



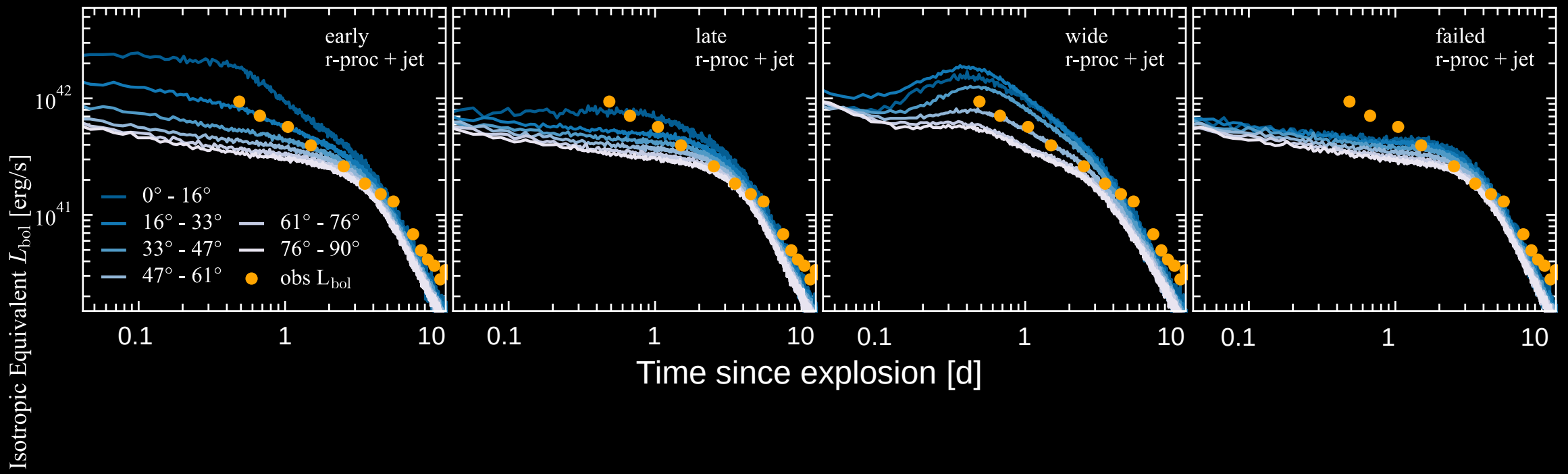
obs L_{bol} from Drout + ‘17

Amount of brightening along jet correlates with how much jet affects density distribution



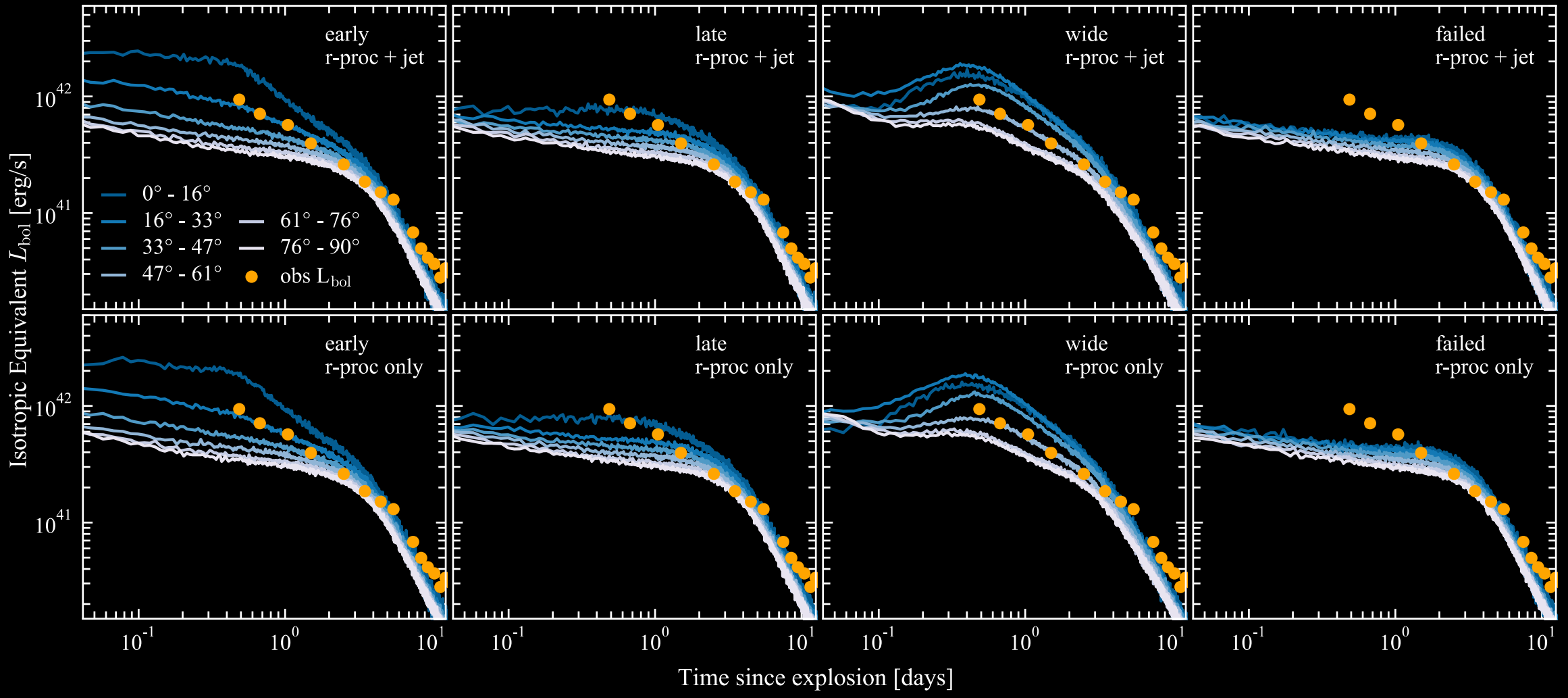
obs L_{bol} from Drout + ‘17

Equatorial light curves match failed jet case



obs L_{bol} from Drout + ‘17

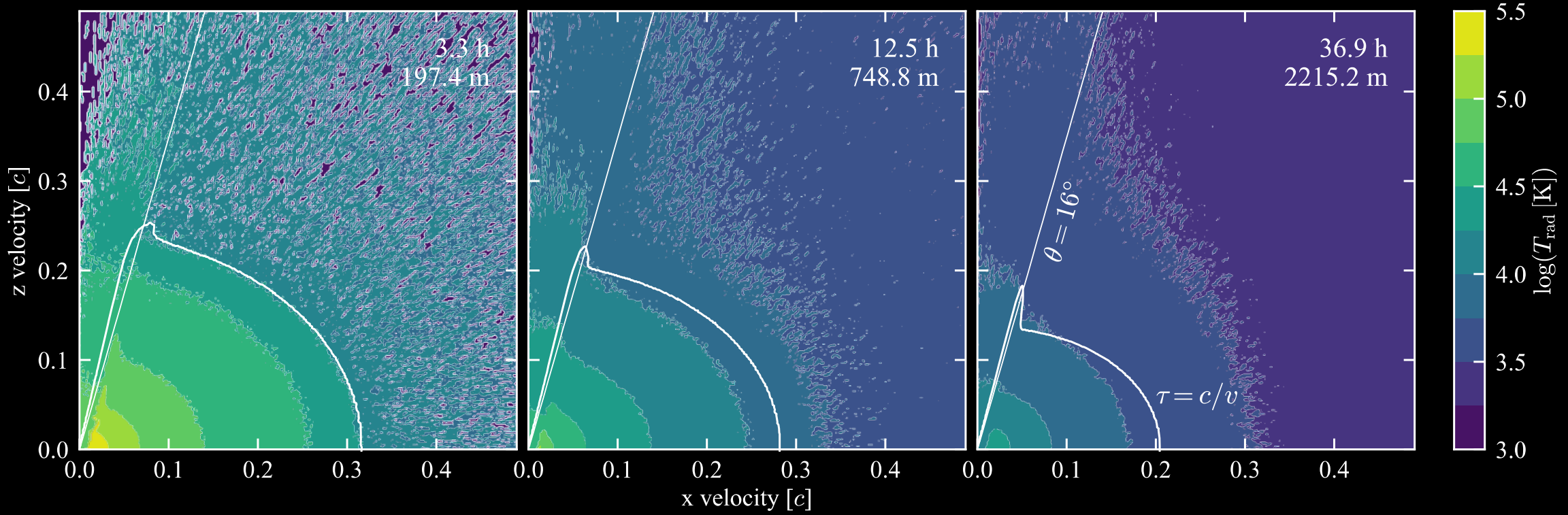
Jet shock heating does not affect light curves



obs L_{bol} from Drout + ‘17

HK + ’19, in prep

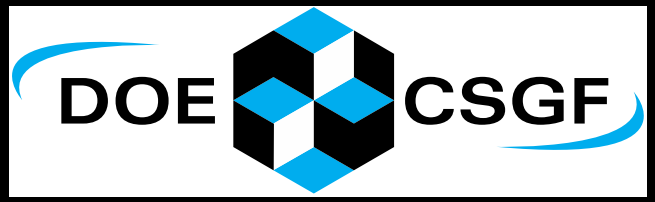
Temperature is higher along jet axis due to emission from hot central ejecta



Summary

- Sedona is a multi-dimensional Monte Carlo radiation transport code
- Unlikely that light curve is dominated by shock heating from a jet
- r-process heating greatly exceeds shock heating
- Jet changes the structure of the ejecta, giving viewing-angle effects that depend on jet energy and opening angle
- Jet-affected viewing angles are brighter and possibly somewhat bluer

Thank you



University of California
BERKELEY
Department of
ASTRONOMY

Eliot Quataert, Dan Kasen, Paul Duffell, Abigail Polin, David Khatami, Chelsea Harris, Peter Nugent

OAK RIDGE
National Laboratory

Bronson Messer, Tom Papatheodore, Austin Harris, Judy Hill, Jim Hack