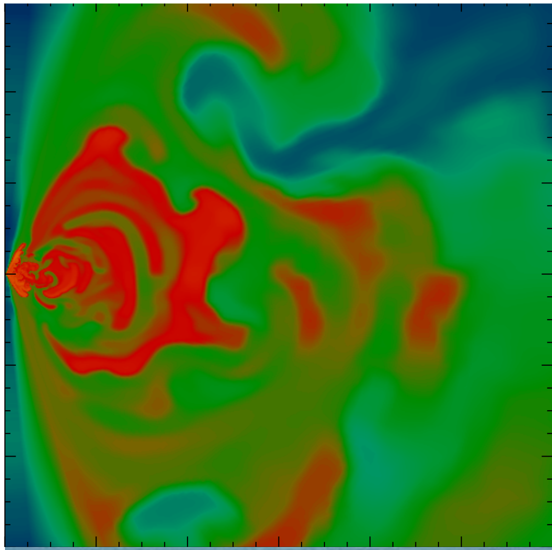
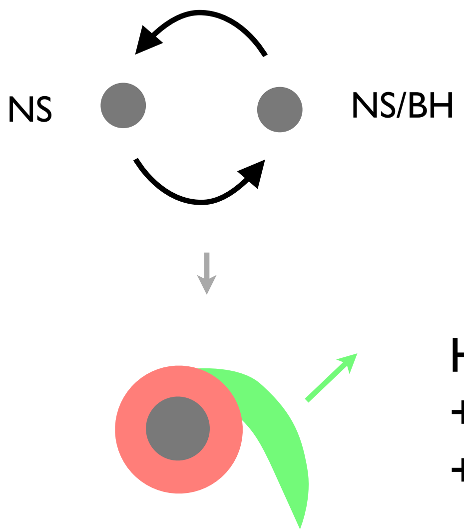
Disk winds from NS merger remnants: EM transients & r-process nucleosynthesis

Rodrigo Fernández
UC Berkeley

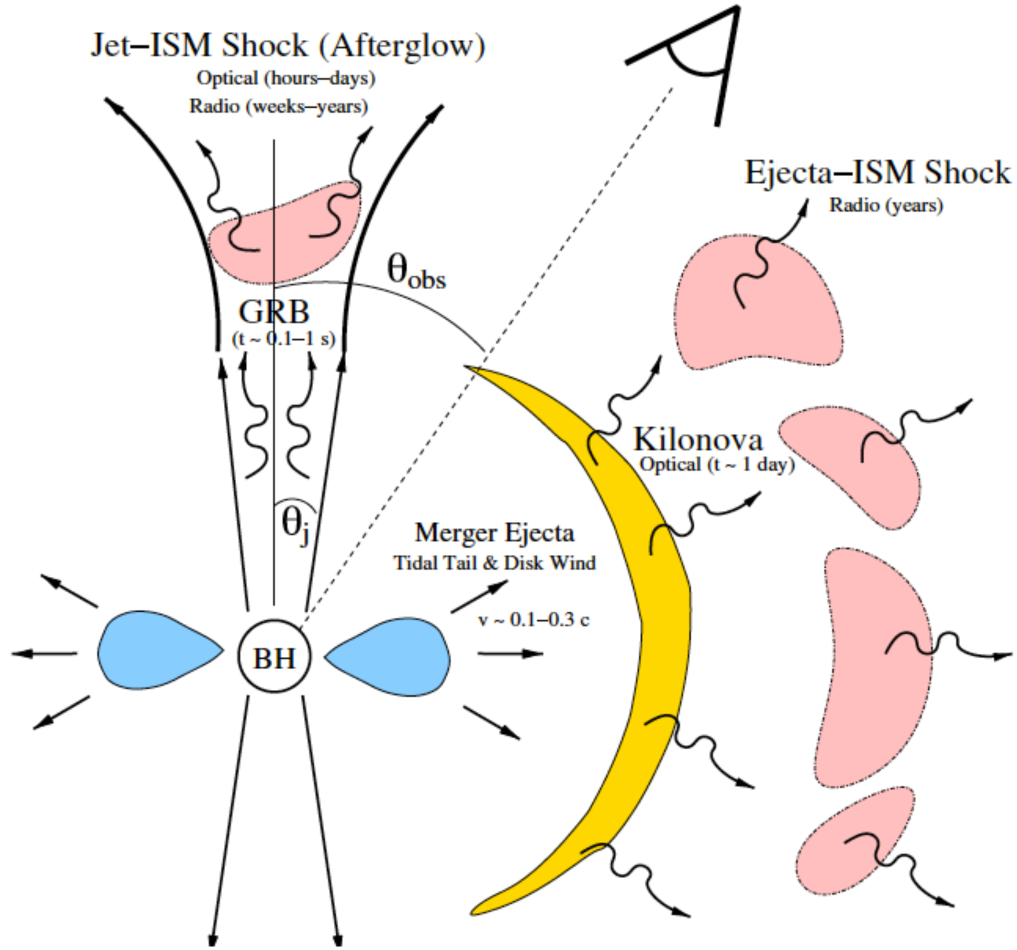
Dan Kasen, Eliot Quataert, & Josiah Schwab (UC Berkeley)
Brian Metzger (Columbia), Stephan Rosswog (Stockholm)



Ejecta from NS Mergers & EM transients



HMNS or BH
+ Disk (this talk)
+ Dynamical Ejecta



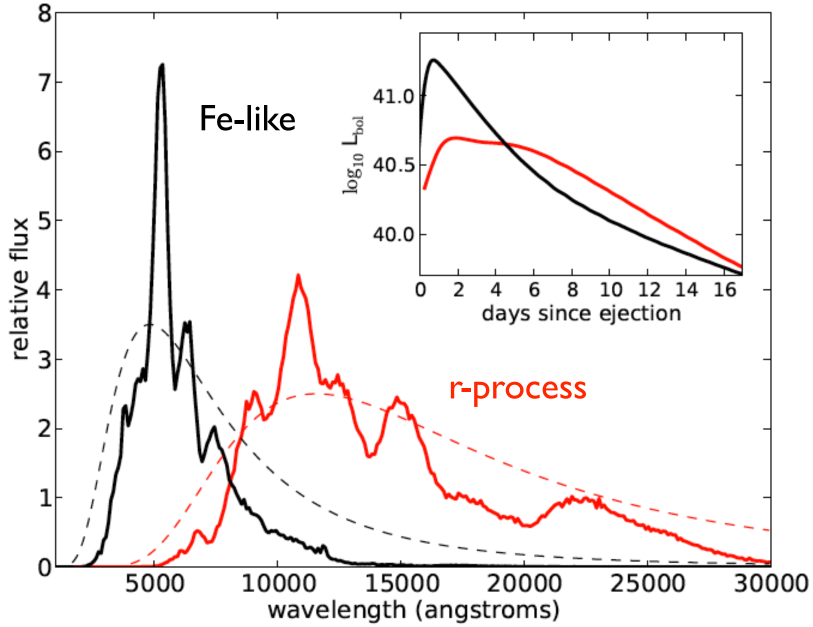
Kilonova: SN-like EM counterpart powered by r-process radioactive heating (non-relativistic ejecta)

Li & Paczynski (1998), Metzger+(2010), Roberts+(2011)

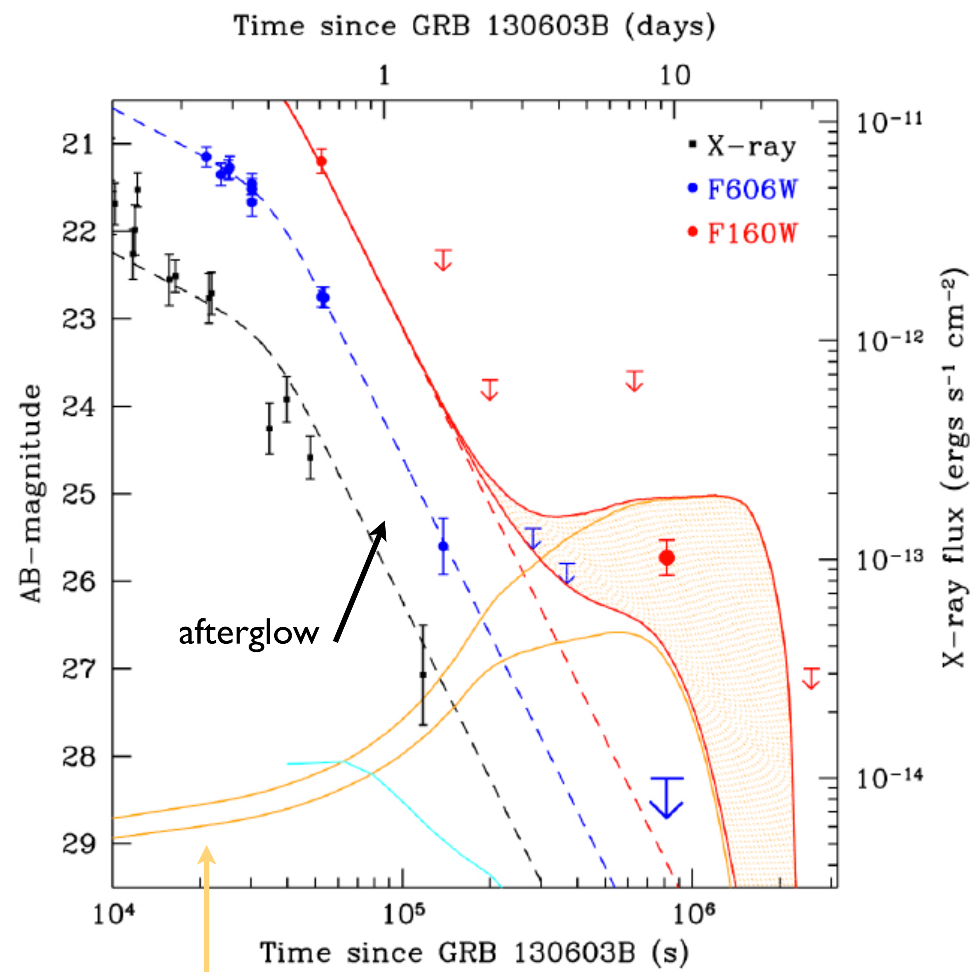
Metzger & Berger (2012)

Importance of composition: optical opacity

Theoretical kilonova spectra & lightcurves:



Kasen+ (2013)

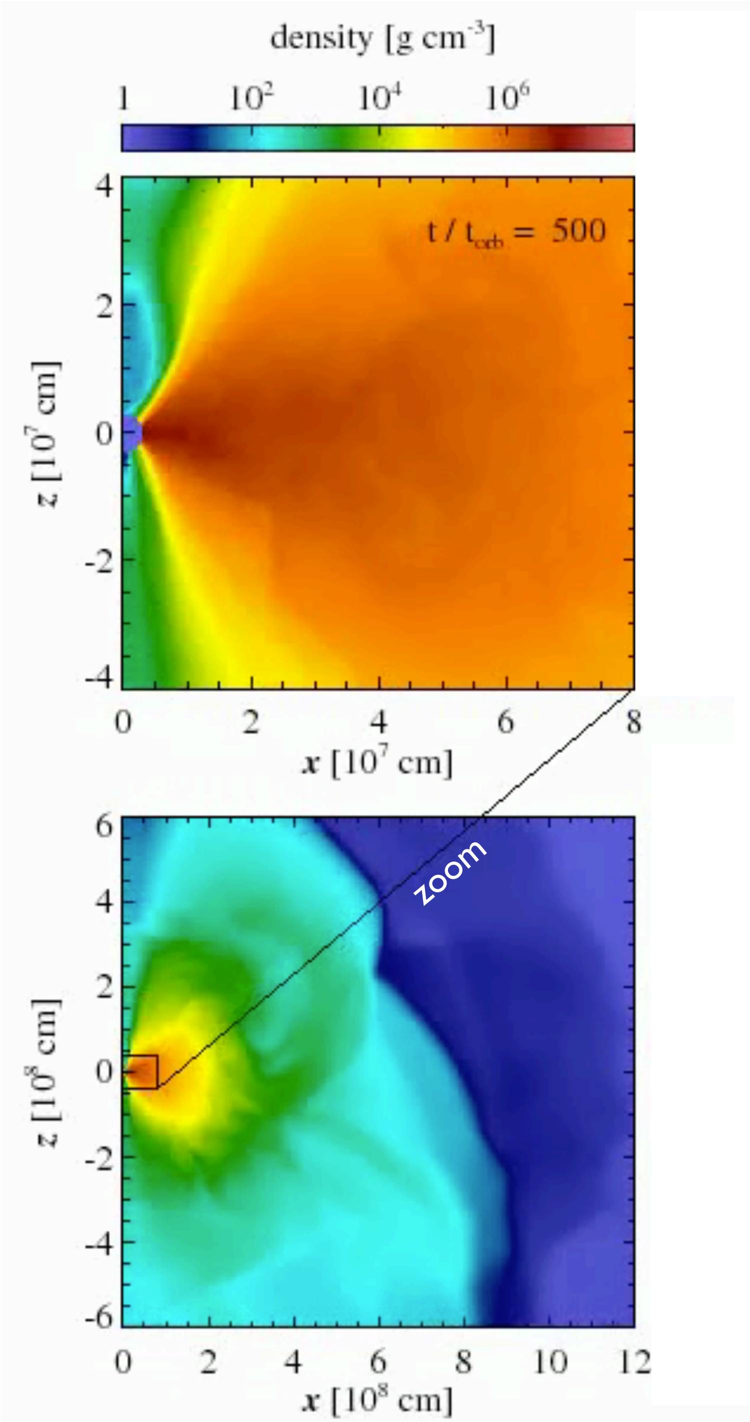


r-process-dominated material generates IR transient

(large number of lines in optical)

Kilonova models
from Barnes & Kasen (2013)
(using dynamical ejecta)

Tanvir+ (2013)
see also Berger+ (2013)



Wind from remnant Accretion Disk

- Neutrino cooling shuts down as disks spreads (temperature decreases)

- Viscous heating & nuclear recombination are unbalanced

- Fraction ~10% of initial disk mass ejected, ~1E-3 to 1E-2 solar masses

- Material is neutron-rich

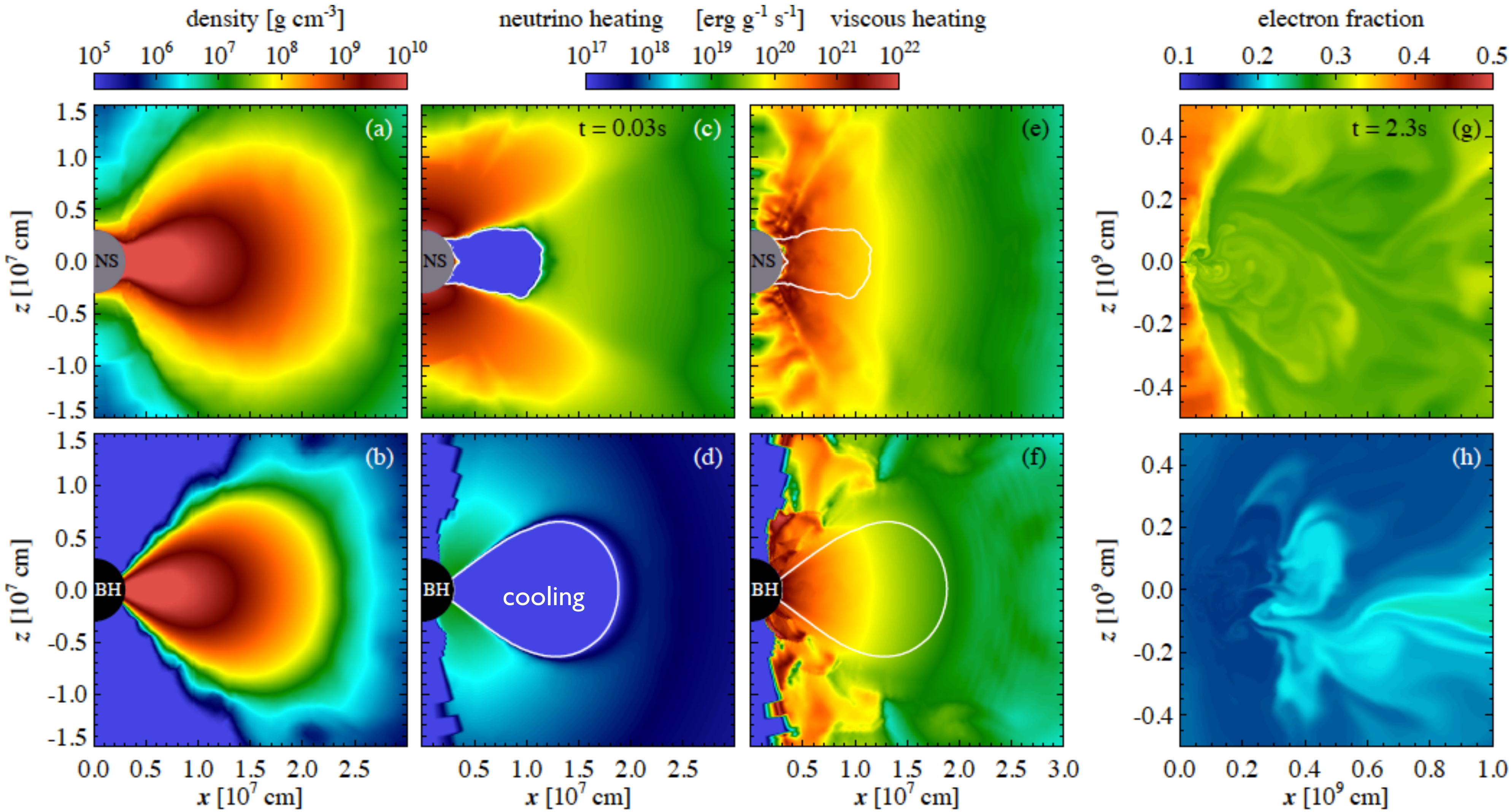
RF & Metzger (2013), MNRAS

see also Metzger+(2008)

Lee+(2009)

Just+(2015)

Hypermassive NS vs. BH

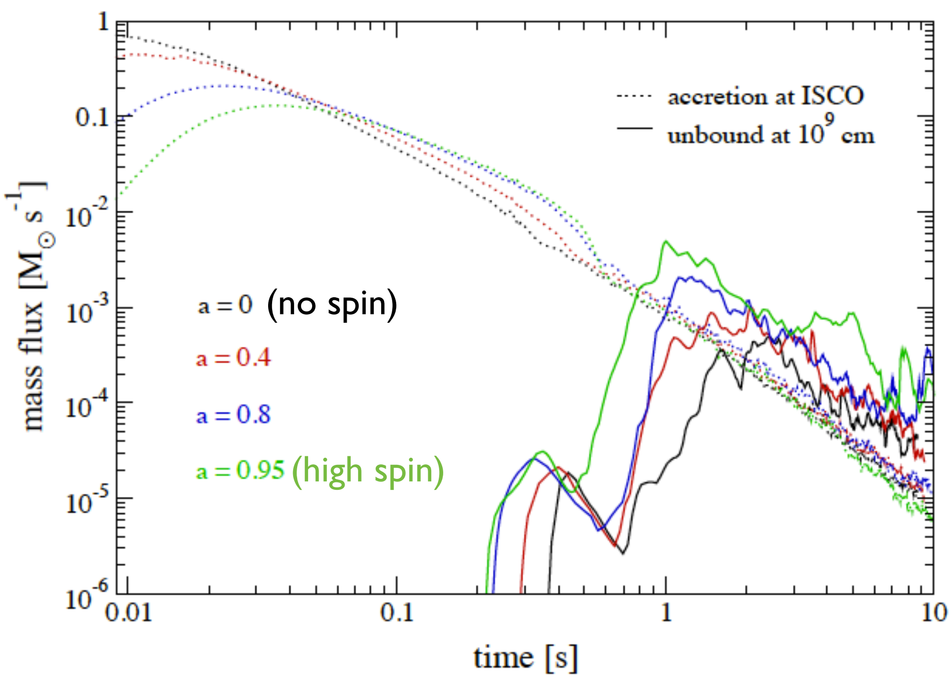


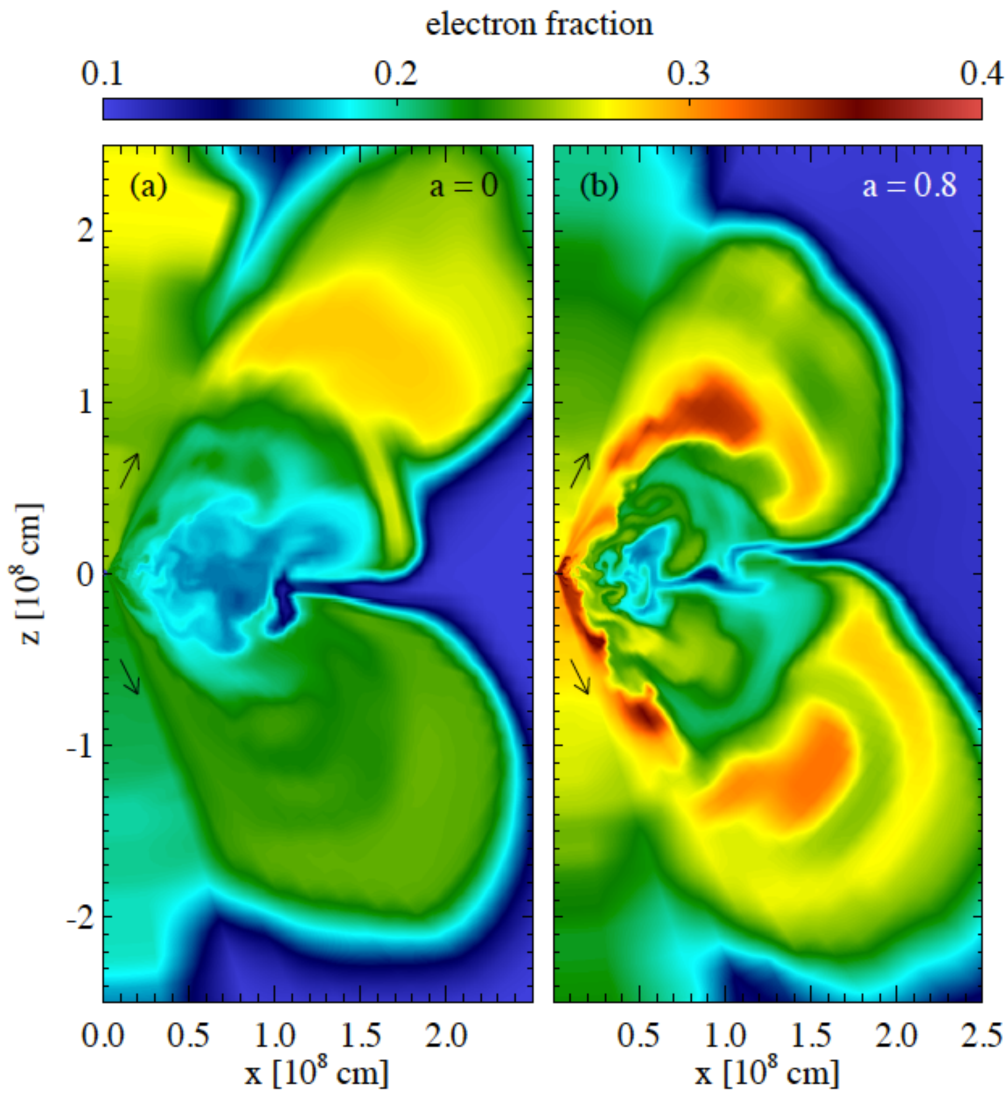
Metzger & RF (2014), MNRAS

see also talk by S. Richers (Y14.16, Tue 2:30pm)

Effect of BH spin on Disk Wind

Mass ejection as a function of time (solid lines):

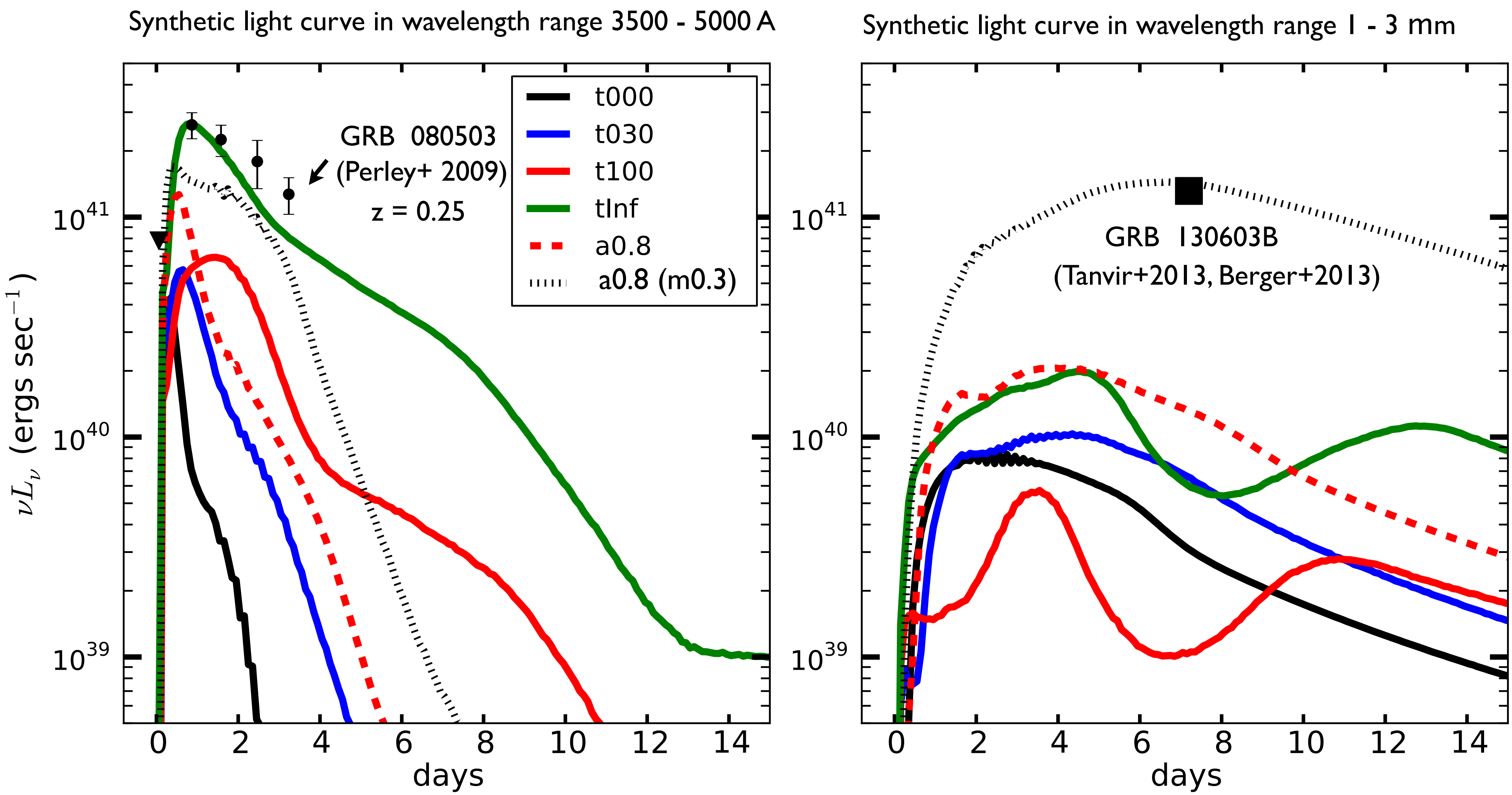




RF, Kasen, Metzger, Quataert (2015), MNRAS

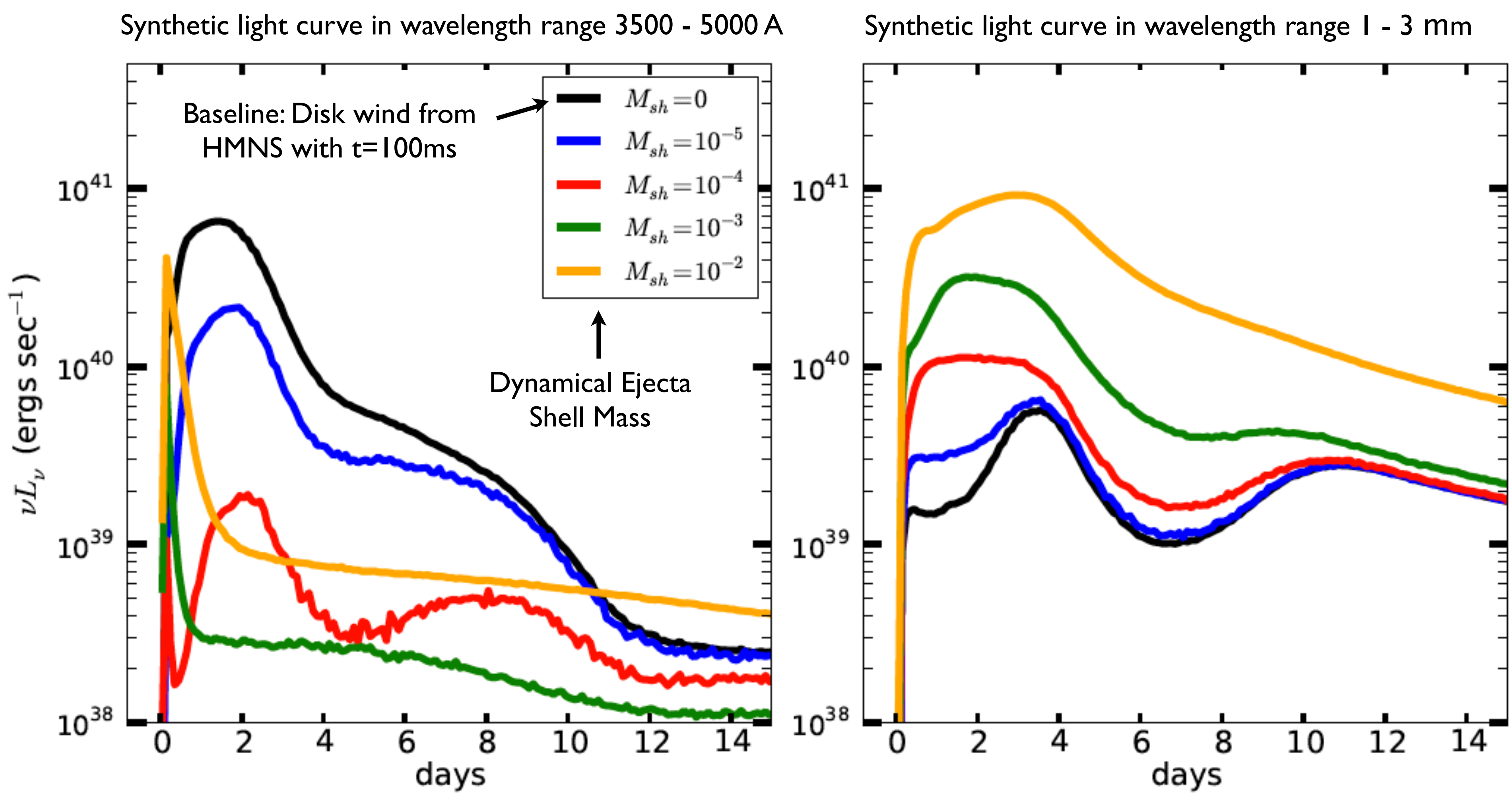
see also Just et al. (2015)

Disk wind contribution to Kilonova



Kasen, RF, & Metzger (2015), MNRAS, arXiv:1411.3726

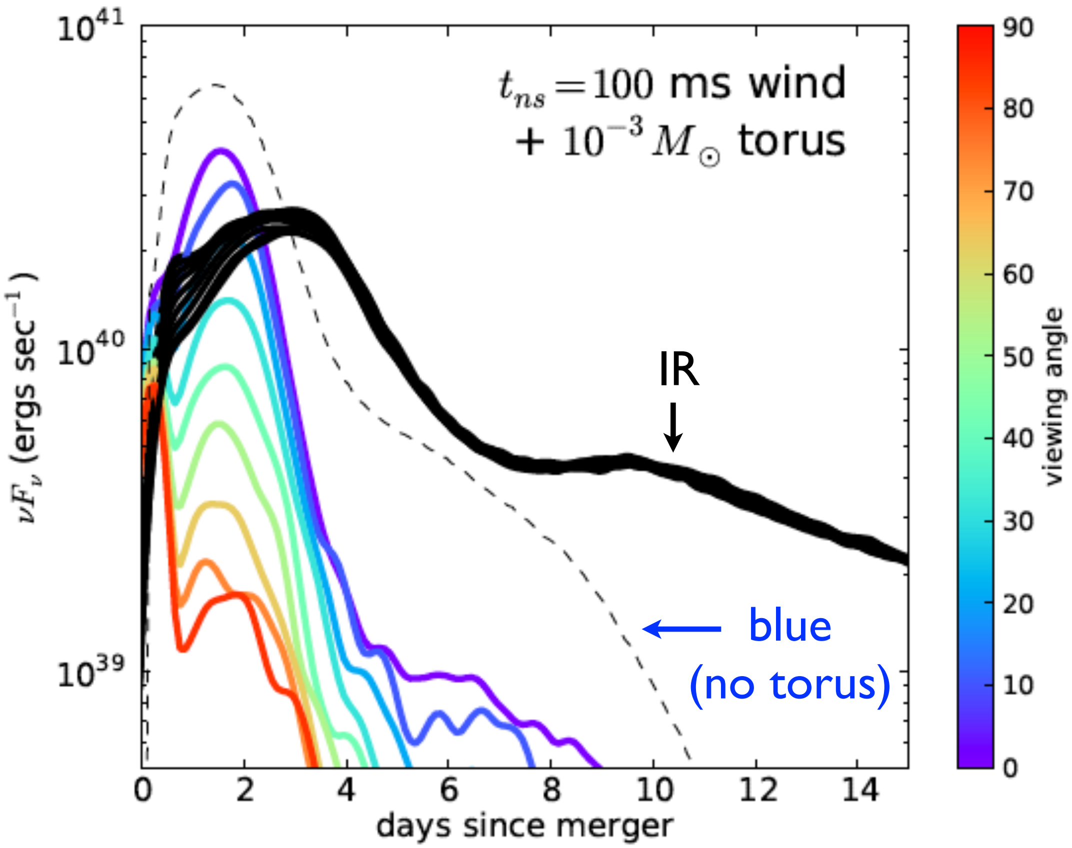
Adding (spherical) dynamical ejecta



Kasen, RF, & Metzger (2015), MNRAS, arXiv:1411.3726

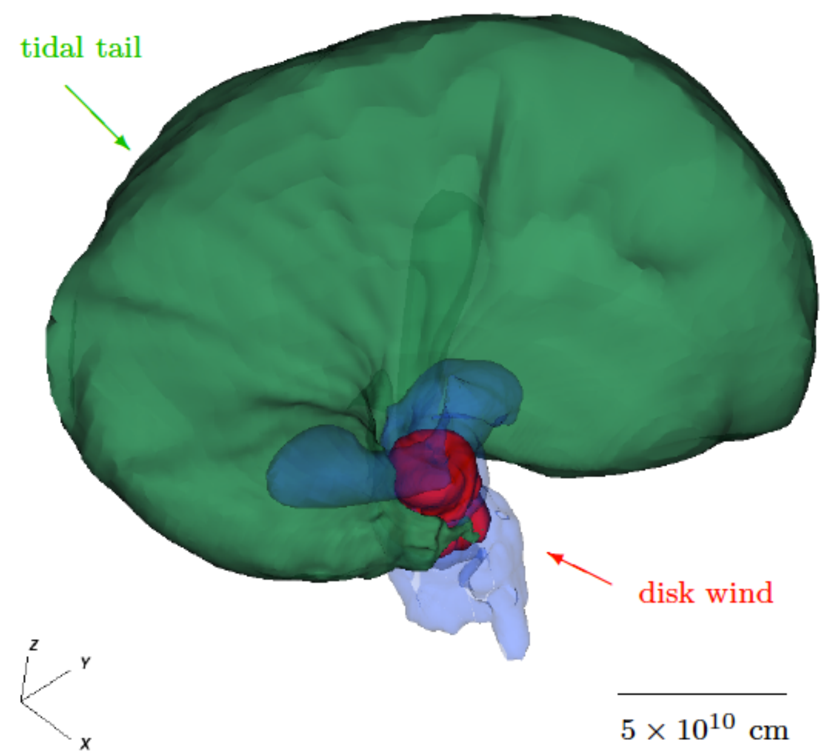
BH-NS mergers: viewing angle dependence

3500 - 5000 A light curve as fn. of viewing angle



Kasen, RF, & Metzger (2015), MNRAS, arXiv:1411.3726

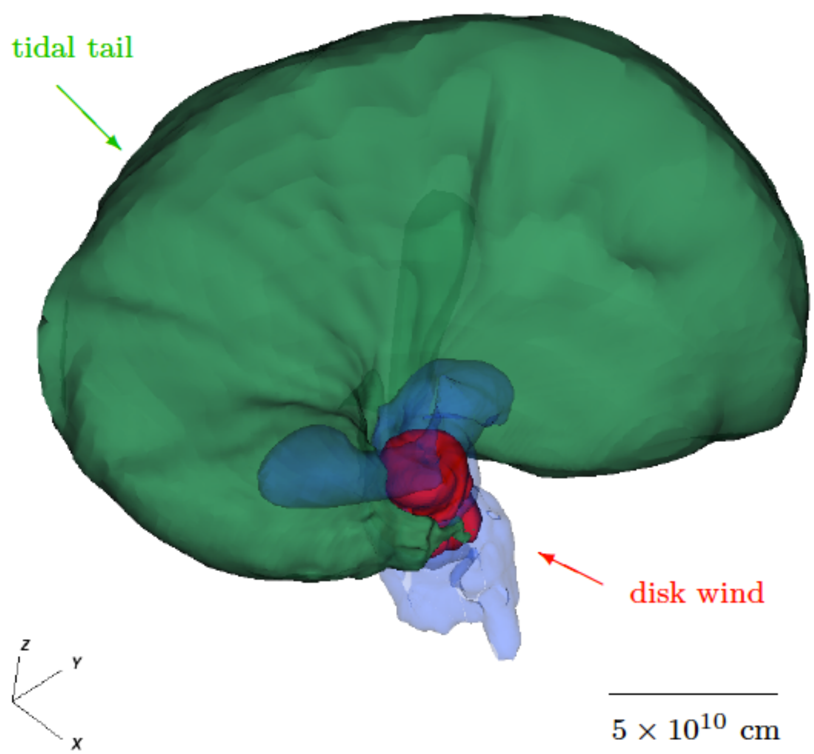
BH-NS merger remnant:



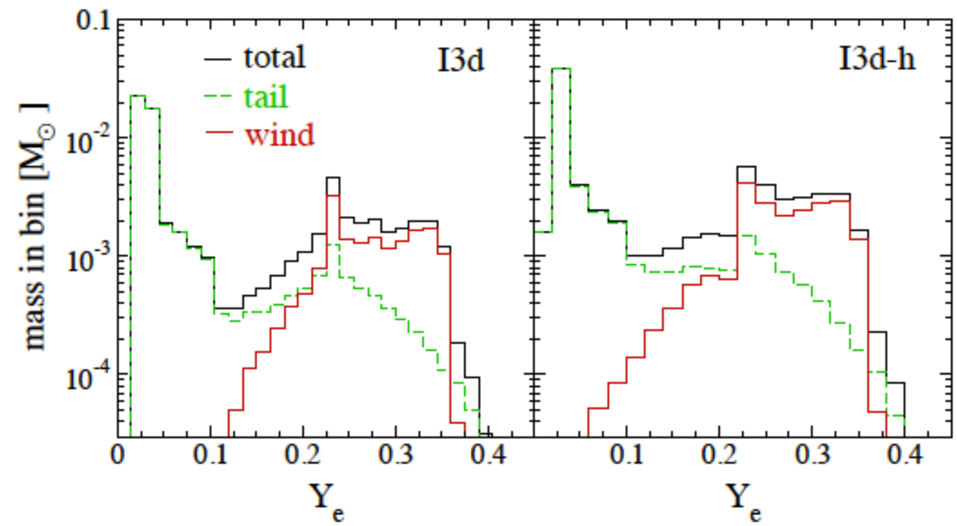
RF, Quataert, Schwab, Kasen & Rosswog (2015) MNRAS

Interplay of disk wind and dynamical ejecta

BH-NS merger remnant:

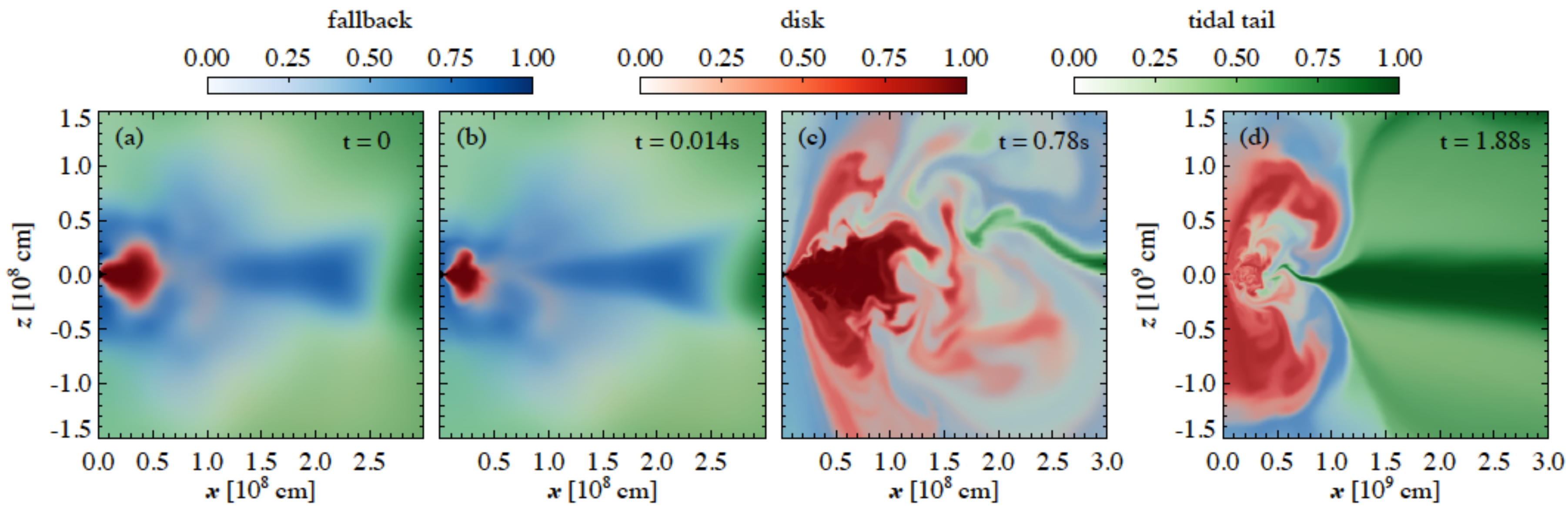


Not much mixing: different velocities

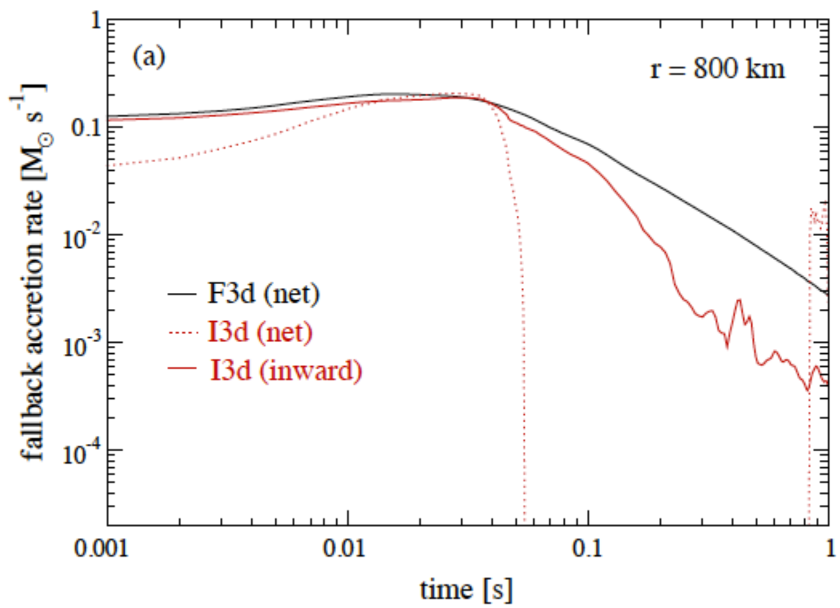


RF, Quataert, Schwab, Kasen & Rosswog (2015)
MNRAS

Interplay of disk wind and dynamical ejecta

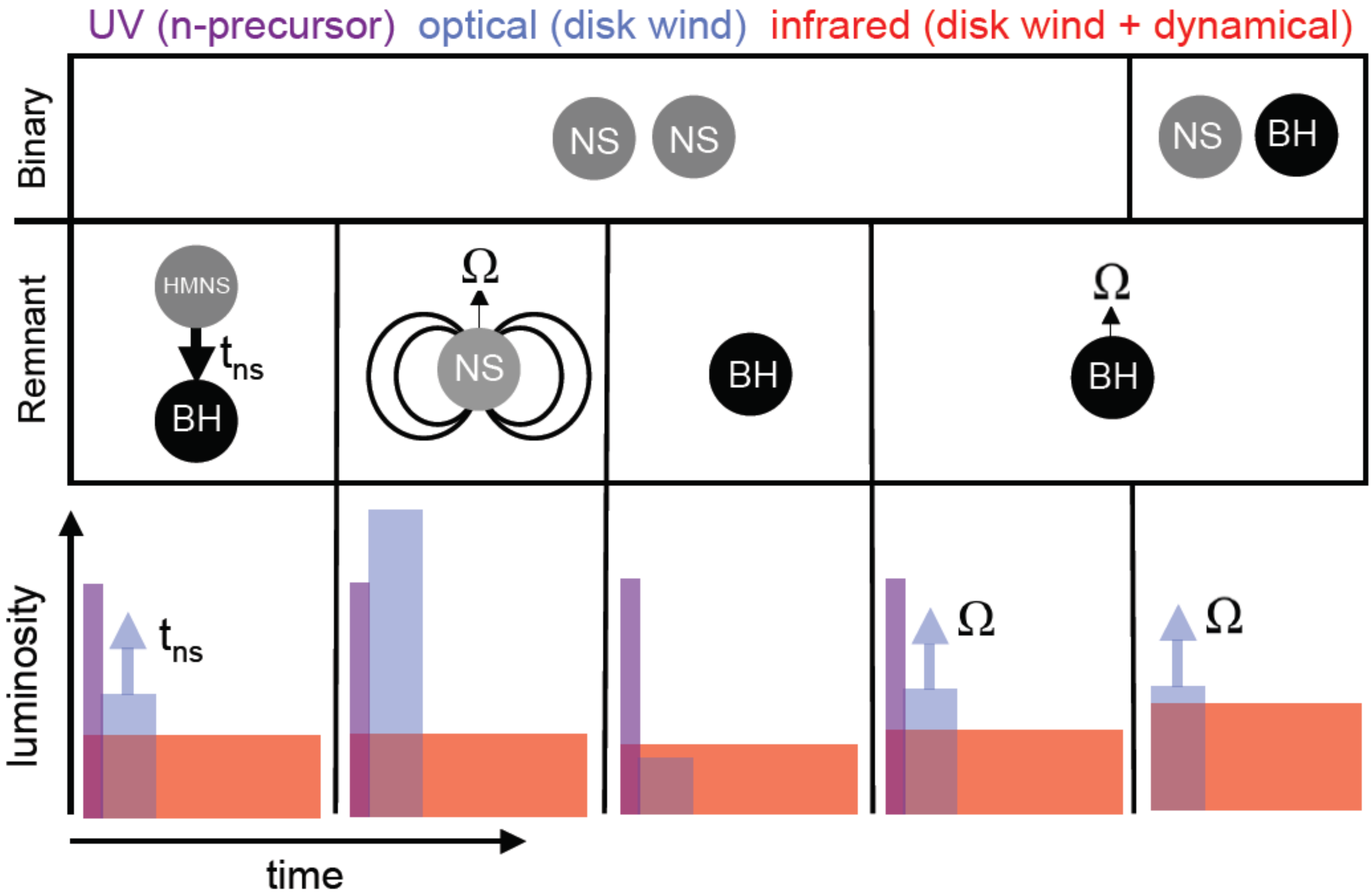


Disk wind can suppress fallback accretion: implications for the late-time emission from GRBs



RF, Quataert, Schwab, Kasen & Rosswog (2015) MNRAS

Diversity of Outcomes & Transients



Kasen, RF, & Metzger (2014), MNRAS, arXiv:1411.3726

Summary

1) Wind from remnant NS-NS & NS-BH merger accretion disk contributes to r-process powered kilonova

2) Higher BH spin or long-lived HMNS leads to more mass ejection with less neutron-rich ejecta: lighter elements & lower optical opacity

Metzger & Fernández (2014), MNRAS

Fernández, Kasen, Metzger, Quataert (2015), MNRAS

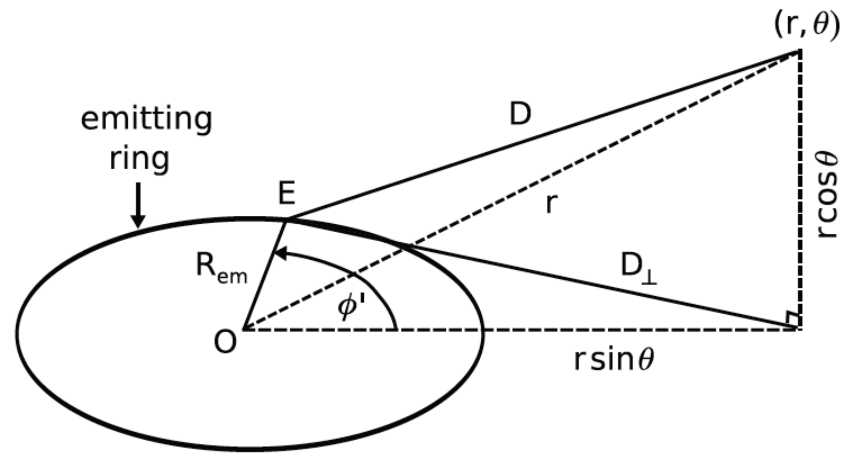
3) Disk wind always contains some blue optical component, importance relative to IR depends on BH spin and/or presence of HMNS.
For NS-BH mergers, importance depends on viewing angle.

Kasen, Fernández & Metzger (2015), MNRAS, arXiv:1411.3726

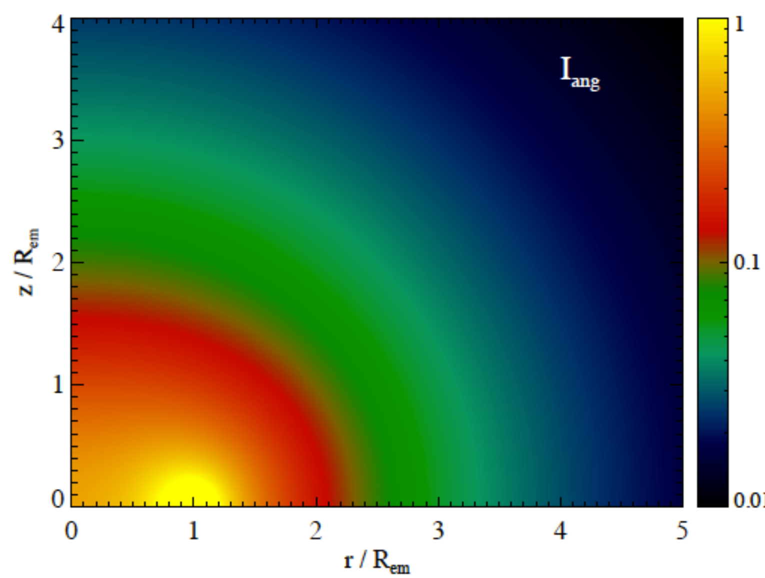
Fernández, Quataert, Schwab, Kasen, Rosswog (2015), MNRAS

Time-Dependent 2D Evolution of remnant disk around BH

- Implemented in FLASH3.2
- Helmholtz EOS with NSE abundances
- Shear viscosity (α -parameterization)
- Charged-current weak interactions: evolution of n/p composition
- Approximate self-irradiation
- Pseudo-Newtonian Potential



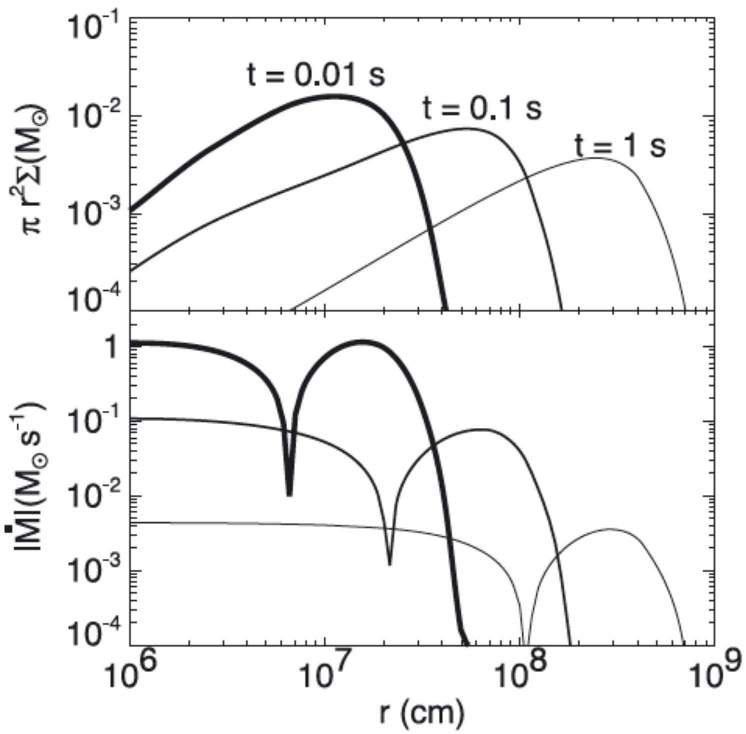
Angular distribution of neutrino irradiation



RF & Metzger (2013), MNRAS

Disk contribution?

Evolution of surface density and accretion rate



Metzger+ (2008)

$$t_{\rm orb} \simeq 3R_{50}^{3/2}M_3^{-1/2}\ {\rm ms}$$

$$t_{\rm visc} \simeq 1\alpha_{0.03}^{-1}R_{50}^{3/2}M_3^{-1/2}\,(H/3R)\ \ {\rm s}$$

$$t_{\rm therm} \simeq \frac{c_s^2}{v_K^2}t_{\rm visc} \lesssim t_{\rm visc}$$

- Disk evolves on timescales long compared to the dynamical (orbital) time, due to viscous processes

- Weak interactions freeze-out as the disk spreads viscously: final Ye

- Gravitationally-unbound outflows driven by:

  - Neutrino heating (on thermal time)

    Ruffert & Janka (1999), Dessart+ (2009), Wanajo & Janka (2012)

  - Viscous heating and nuclear recombination (on viscous time)

    Metzger+ (2008)

$$\frac{E_\alpha}{GM_{\rm BH}/R} \simeq 1R_{600}M_3^{-1}$$

Multi-dimensional evolution of remnant accretion disk

ρ : density
p : pressure
$\mathbf{v}$: velocity
$e_{\rm int}$: int. energy
Y_e : electron frac.

mass conservation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

momentum conservation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla)\mathbf{v} + \frac{1}{\rho}\nabla p = -\nabla \Phi + \frac{1}{\rho}\nabla \cdot \mathbb{T}$$

gas pressure — gravity — angular mom. transport

energy conservation:

$$\frac{De_{\rm int}}{Dt} - \frac{p}{\rho^2}\frac{D\rho}{Dt} = \frac{1}{\rho^2 \nu}\mathbb{T} : \mathbb{T} + Q_{\nu,\rm abs} - Q_{\nu,\rm em}$$

viscous heating — neutrino heating — neutrino cooling

lepton # conservation:

$$\frac{DY_e}{Dt} = \Gamma_{\nu,\rm abs} + \Gamma_{\nu,\rm em}$$

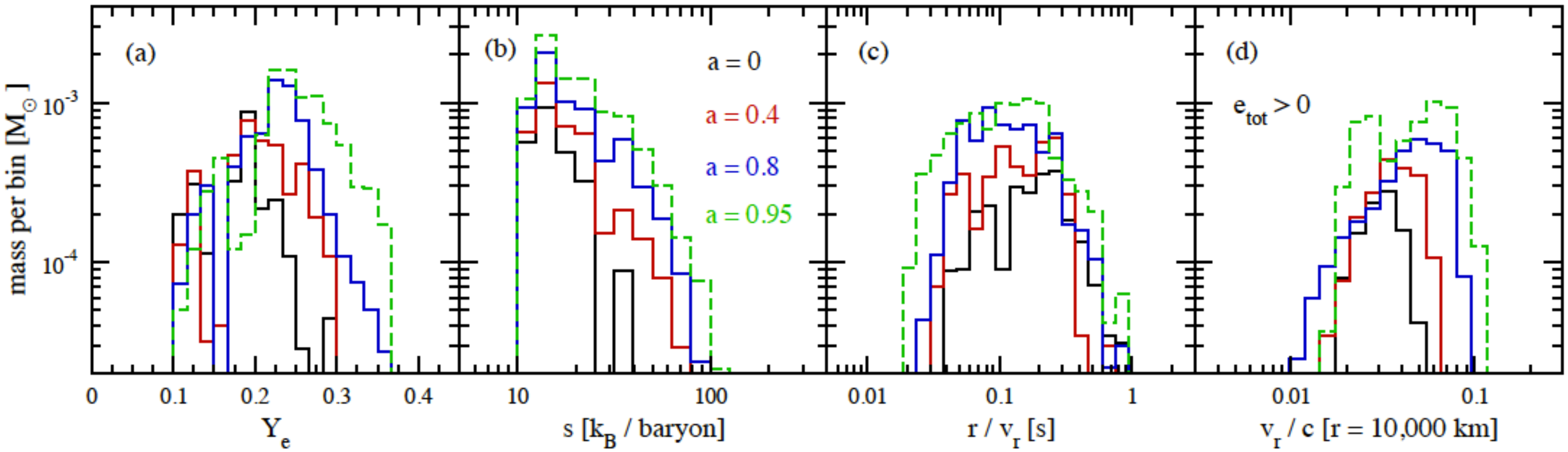
neutrino absorption — neutrino emission

EOS:

$$p = p(\rho, e_{\rm int}, Y_e) \qquad Y_e = \frac{n_e}{n} = \frac{n_e}{\rho/m_n}$$

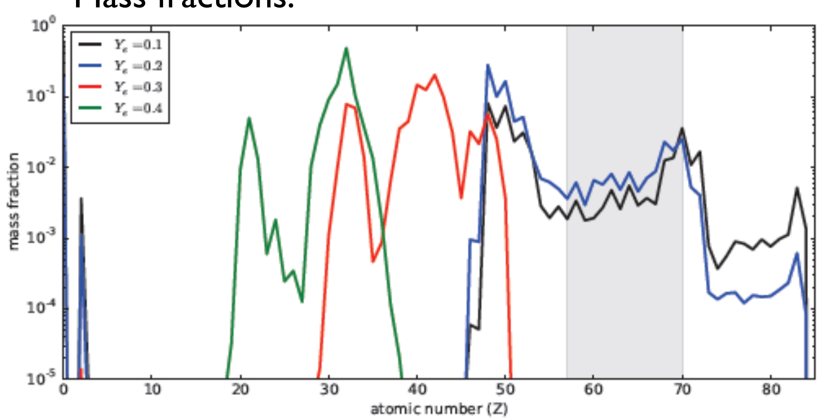
Effect of BH spin on Disk Wind

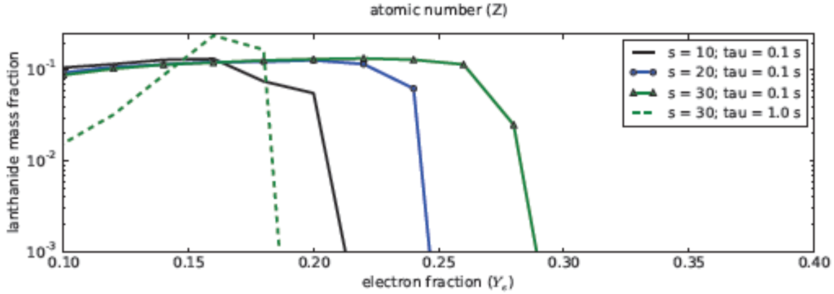
Nucleosynthesis-relevant quantities in the wind:



RF, Kasen, Metzger, Quataert (2015), MNRAS

Mass fractions:





Thermodynamic trajectories with

$$s \sim 20 k_B / \text{ baryon}$$

$$t_{\text{exp}} \sim 0.1 \text{ s}$$

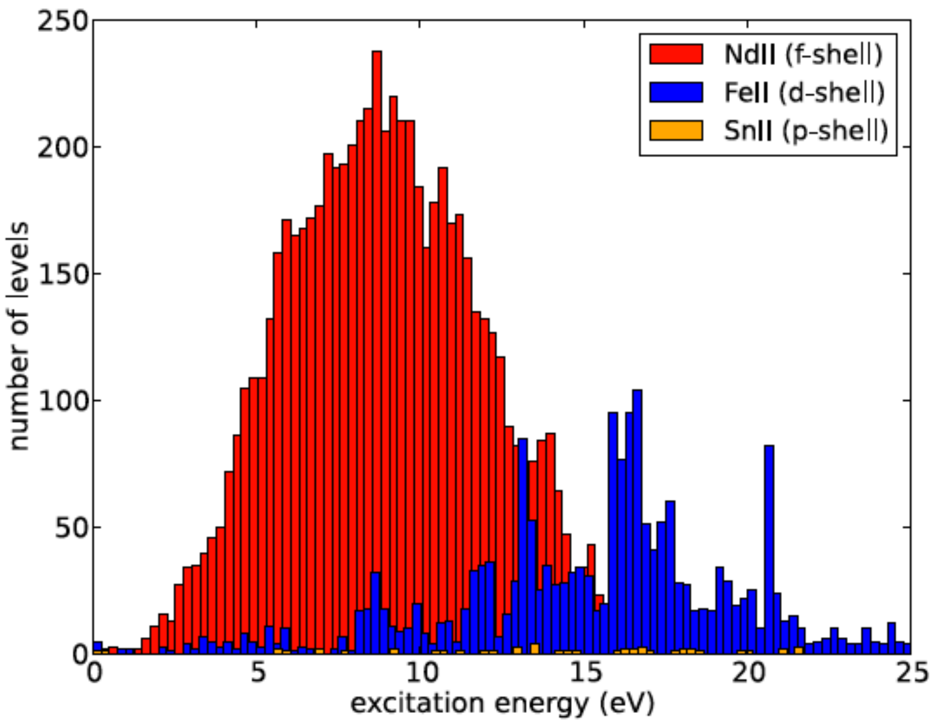
Yield critical Ye for Lanthanide formation:

$$Y_{e,crit} \sim 0.25$$

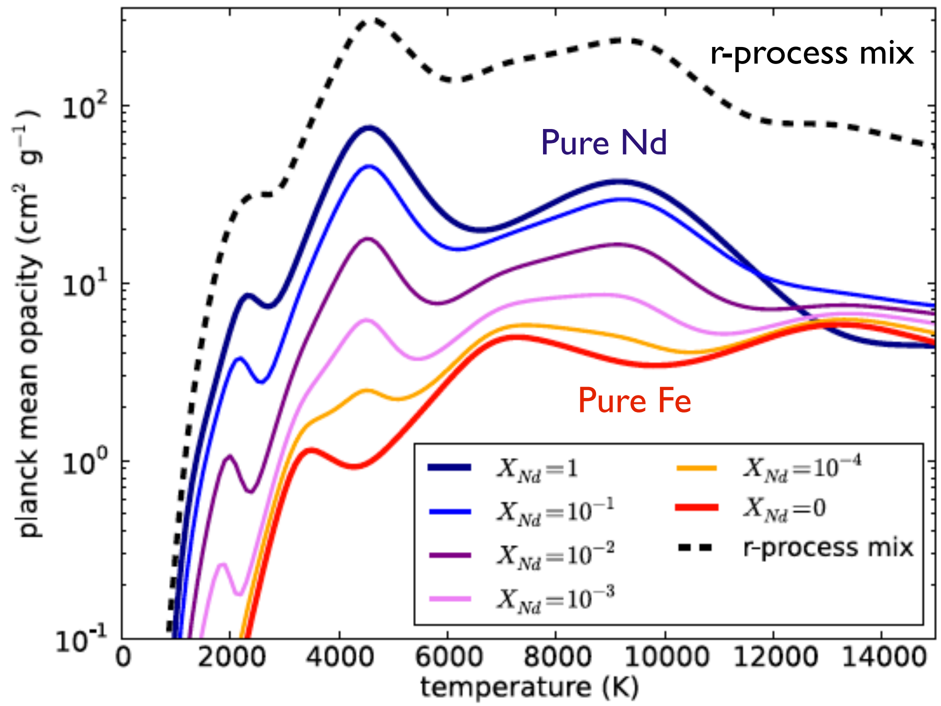
Kasen, RF, & Metzger (2014), arXiv:1411.3726

Opacity of Lanthanides

Lanthanides have many more atomic levels



Much higher opacity than iron



Kasen+ (2013)