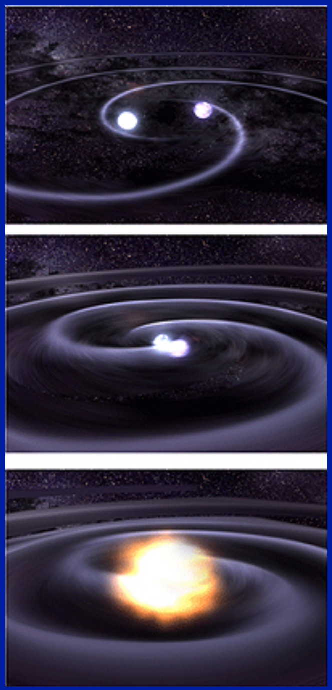
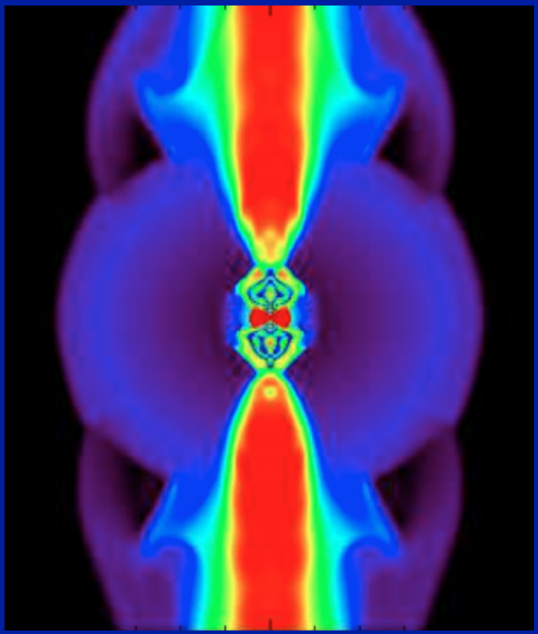
The Central Engines of Short Duration Gamma-Ray Bursts



NS ⇔ NS

NS ⇔ BH



Brian Metzger

Columbia University

In Collaboration with

Edo Berger, Wen-Fai Fong (Harvard), Tony Piro, Dan Perley (Caltech)

Almudena Arcones, Gabriel Martinez-Pinedo (Darmstadt), Todd Thompson (OSU)

Rodrigo Fernandez, Eliot Quataert, Dan Kasen, Geoff Bower (UC Berkeley)

Indrek Vurm, Romain Hascoet, Andrei Beloborodov (Columbia), N. Bucciantini (INAF)

"Gamma-Ray Bursts" November 14, 2013 - YITP, Kyoto, Japan

Neutron Star Binary Mergers

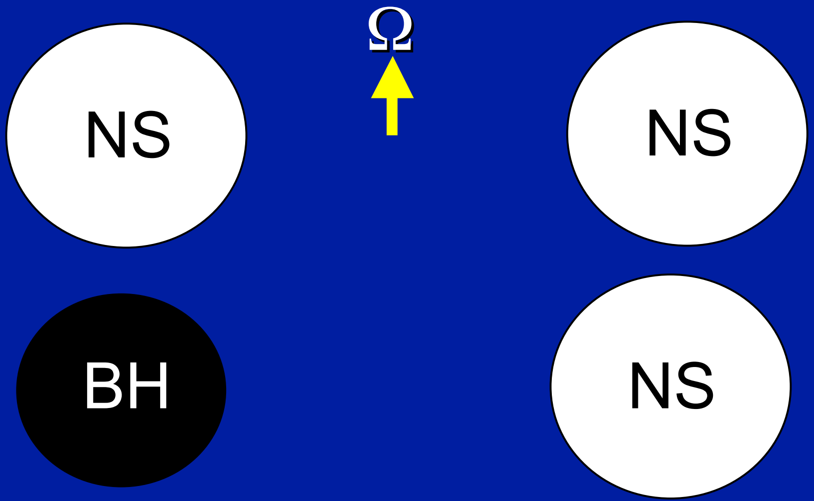
"Advanced" LIGO/Virgo (>2016)

Range ~ 200-500 Mpc

Detection Rate ~ 1-100 yr^{-1}

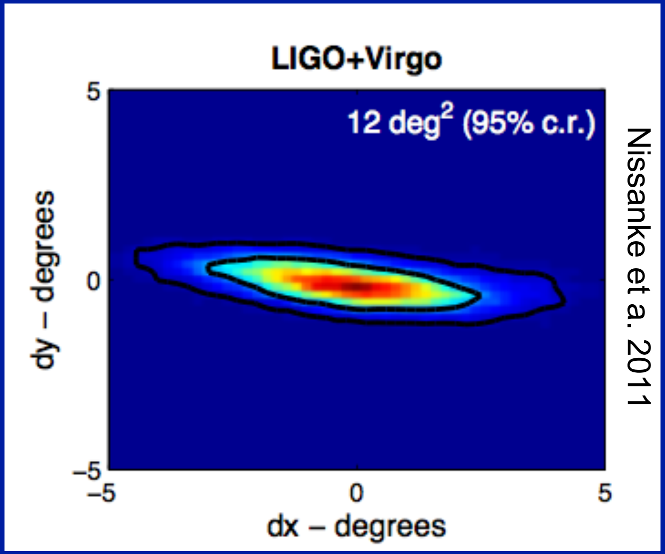
LIGO (North America)

Virgo (Europe)



Sky Error Regions ~ 10-100 deg^2

⇒ ~ 10^3-10^4 galaxies



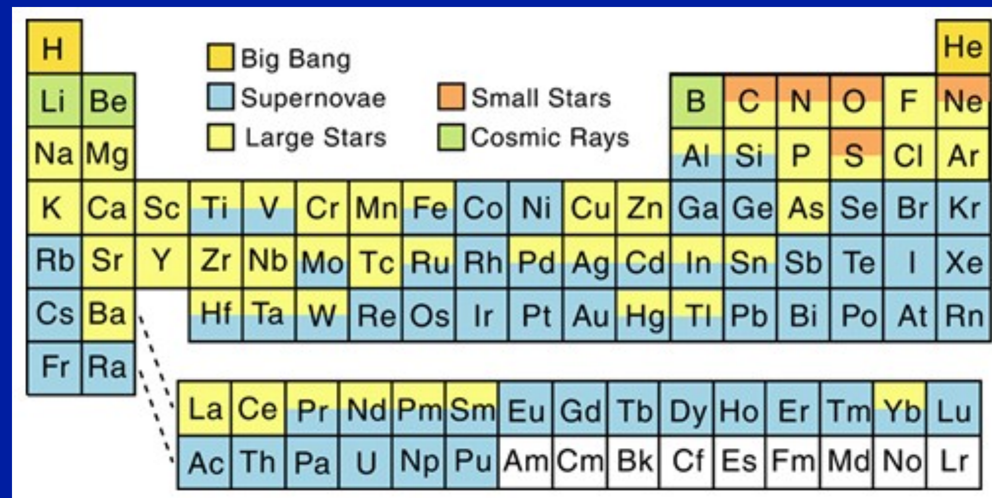
Astrophysical Origin of R-Process Nuclei

Core Collapse Supernovae or NS Binary Mergers?

Galactic r-process rate:

$$\dot{M}_{A>130} \sim 5 \times 10^{-7} M_{\odot}\, \mathrm{yr}^{-1}$$

(Qian et al. 2000)



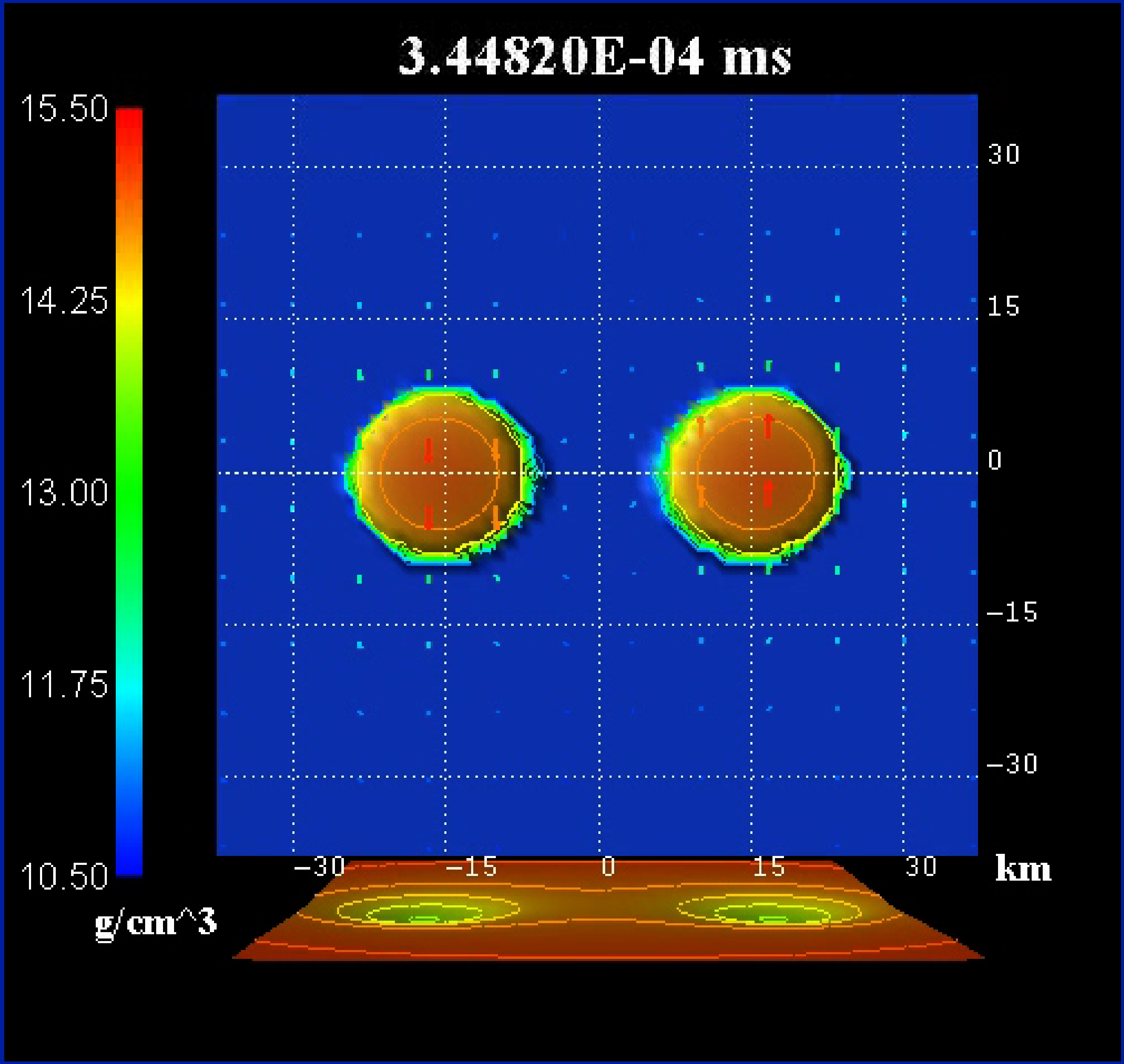
Requires (e.g. Hoffman et al. 1997)

(1) low Y_e (2) high entropy (3) fast expansion

Fraction of r-Process from NS Mergers:

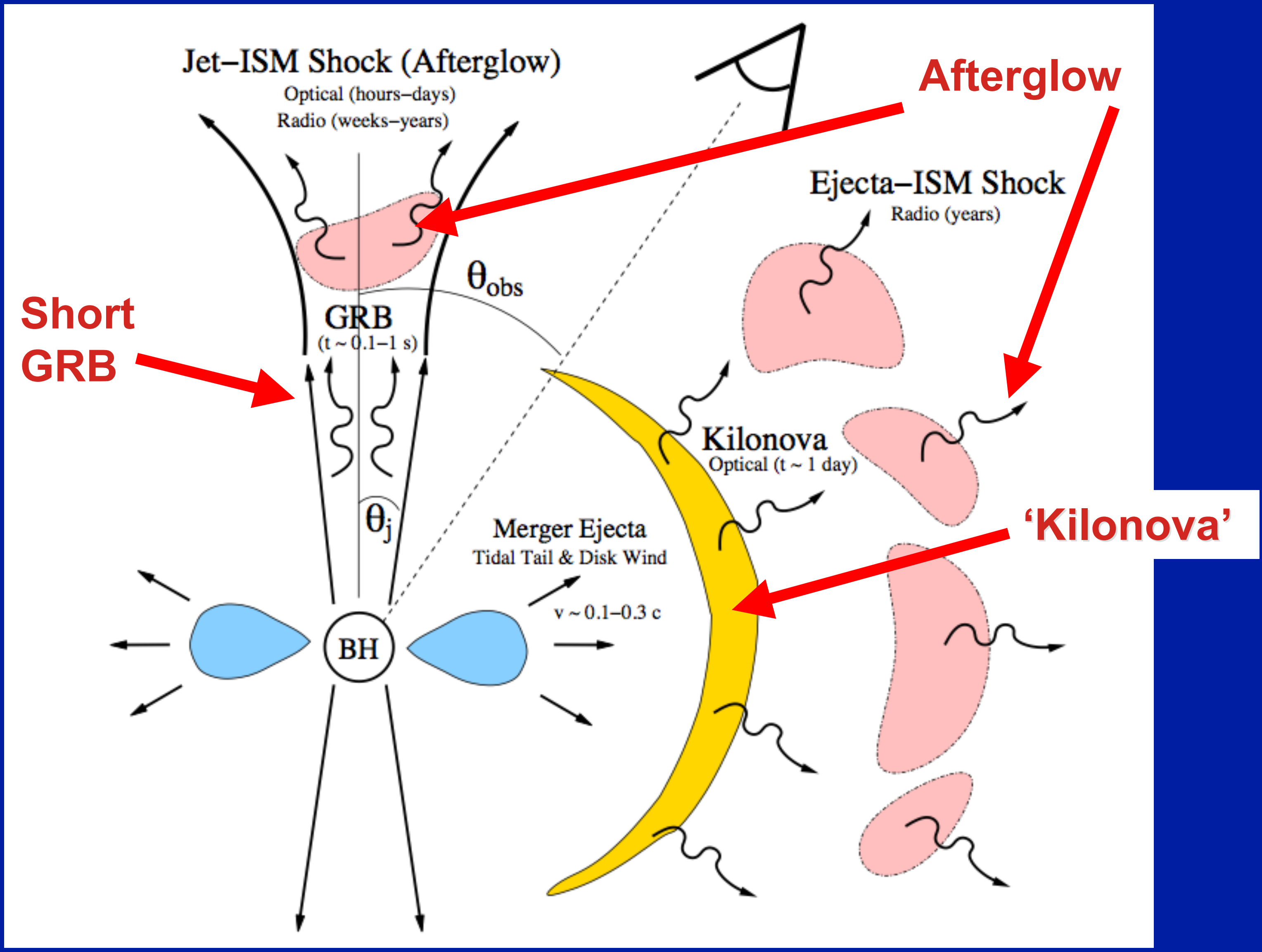
$$f_R \sim \left(\dot{N}_{\mathrm{merge}} \Big/ 10^{-4}\, \mathrm{yr}^{-1} \right) \left(\overline{M}_{\mathrm{ej}} \Big/ 10^{-2} M_{\odot} \right)$$

Numerical Simulation - Two 1.4 $M_{\odot}$ NSs



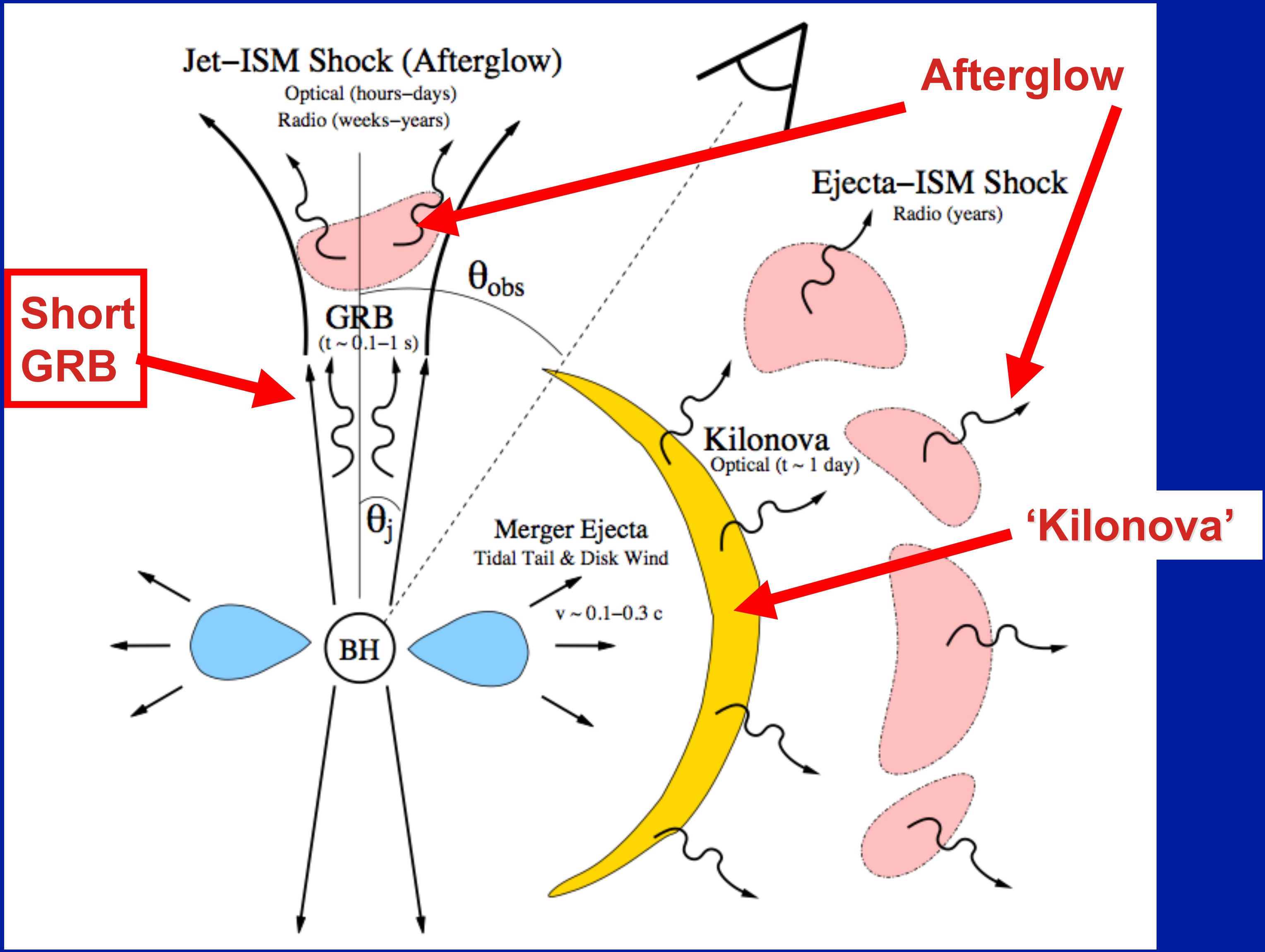
Courtesy M. Shibata (Tokyo U)

Electromagnetic Counterparts of NS-NS/NS-BH Mergers



Metzger & Berger 2012

Electromagnetic Counterparts of NS-NS/NS-BH Mergers



Metzger & Berger 2012

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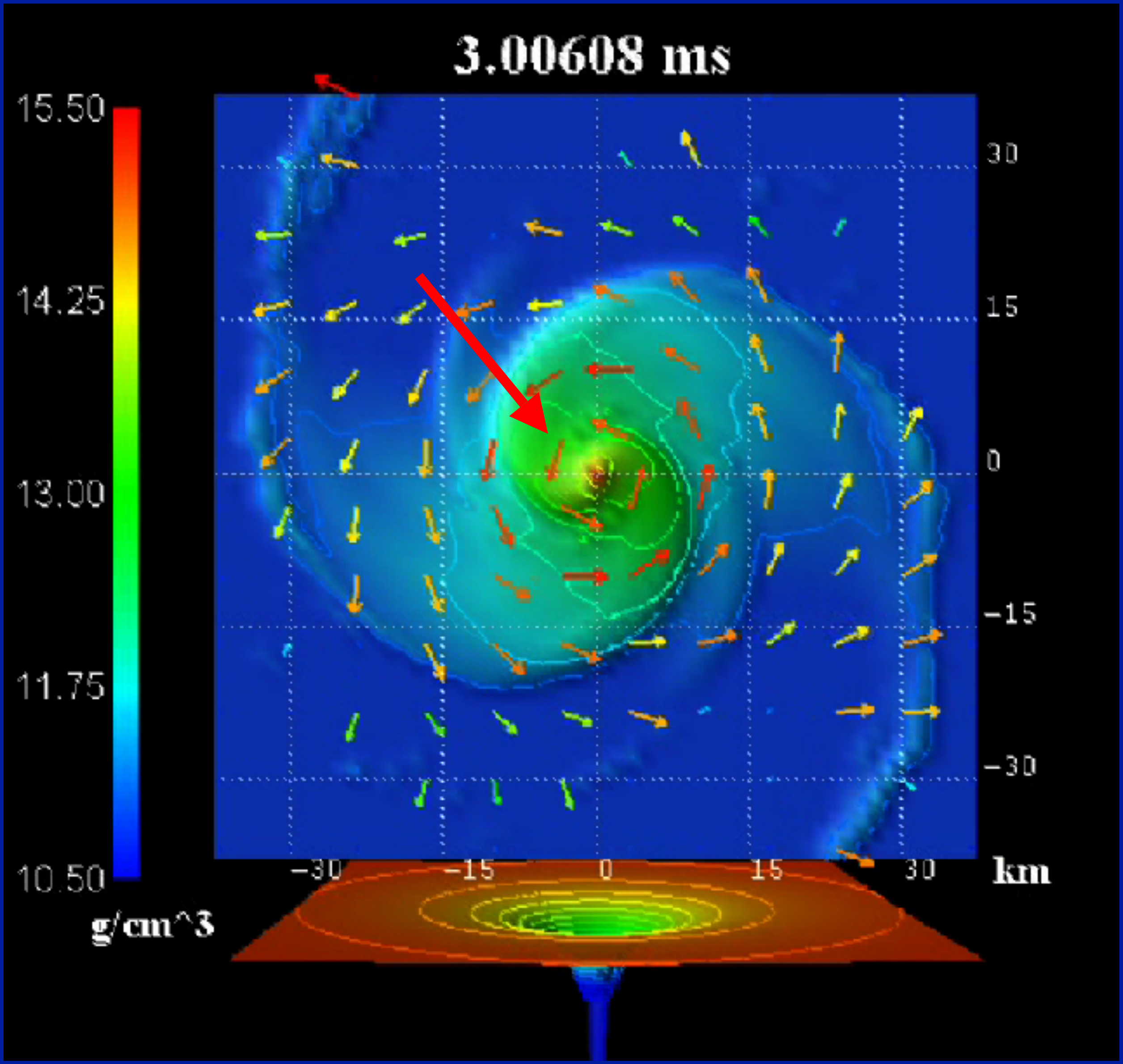
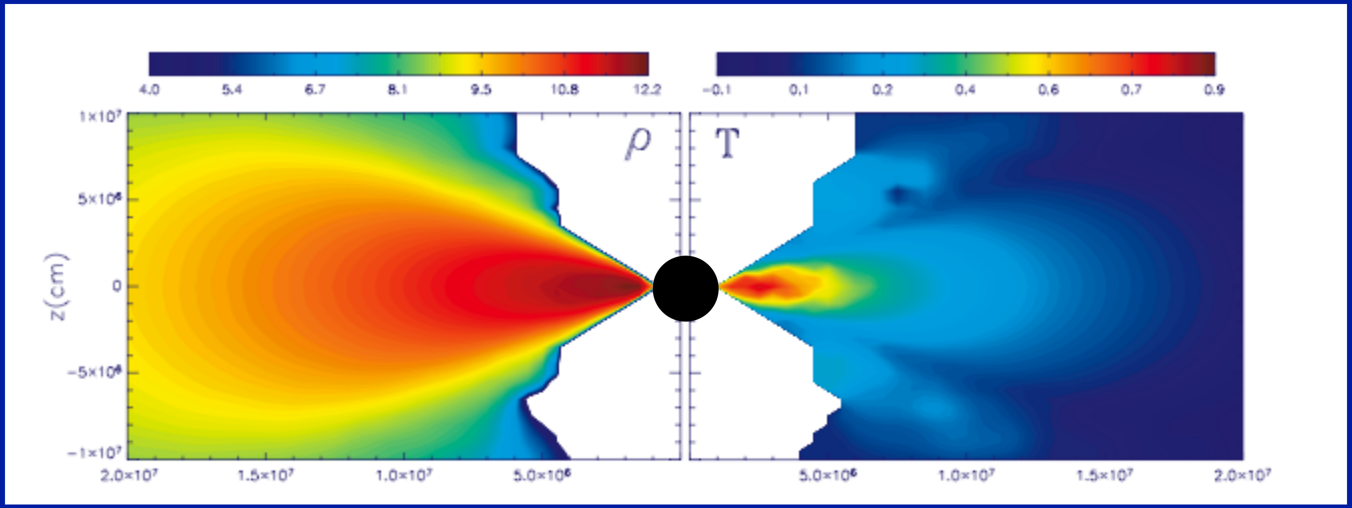


Courtesy M. Shibata (Tokyo U)

Remnant Accretion Disk

(e.g. Ruffert & Janka 1999; Shibata & Taniguchi 2006; Faber et al. 2006; Chawla et al. 2010; Duez et al. 2010; Foucalt 2012; Deaton et al. 2013)



Lee et al. 2004

- Disk **Mass ~0.01 - 0.1 $M_{\odot}$** & **Size ~ 10-100 km**
- Hot (T > MeV) & Dense ($\rho \sim 10^{8}$-10^{12} g cm^{-3})
- Neutrino Cooled: ($\tau_{\nu} \sim$ 0.01-100)
- Equilibrium $e^{+} + n \rightarrow \bar{\nu}_e + p$ vs. $e^{-} + p \rightarrow \nu_e + n$ $\Rightarrow Y_e \sim 0.1$

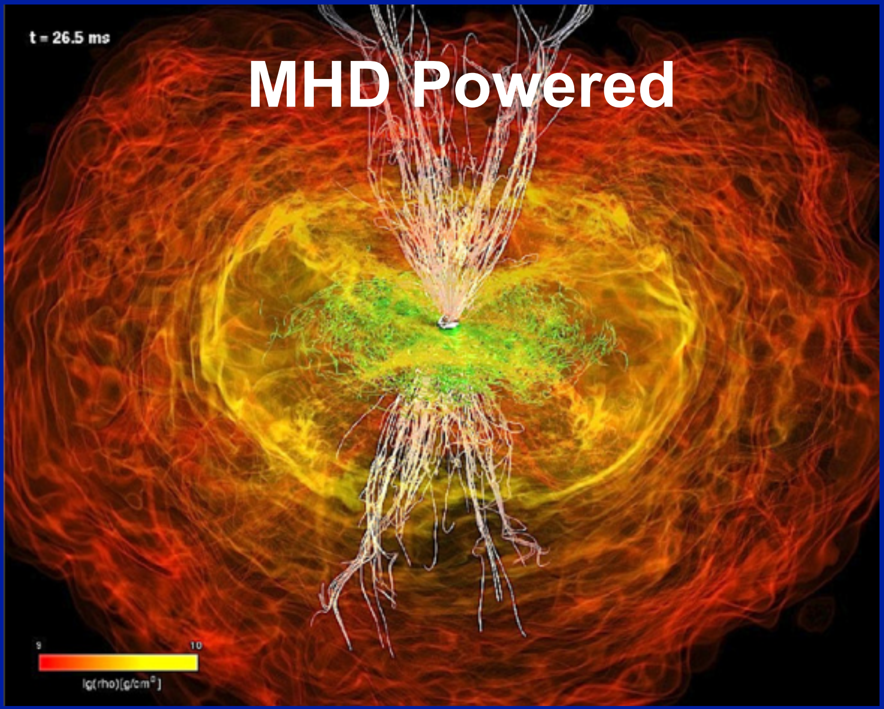
Accretion Rate $\dot{M} \sim 10^{-2} - 10\, M_{\odot}\ \mathrm{s}^{-1}$

$$t_{\mathrm{visc}} \sim 0.1 \left(\frac{M_{\bullet}}{3M_{\odot}}\right)^{1/2} \left(\frac{\alpha}{0.1}\right)^{-1} \left(\frac{R_d}{100\ \mathrm{km}}\right)^{3/2} \left(\frac{H/R}{0.5}\right)^{-2}\ \mathrm{s}$$

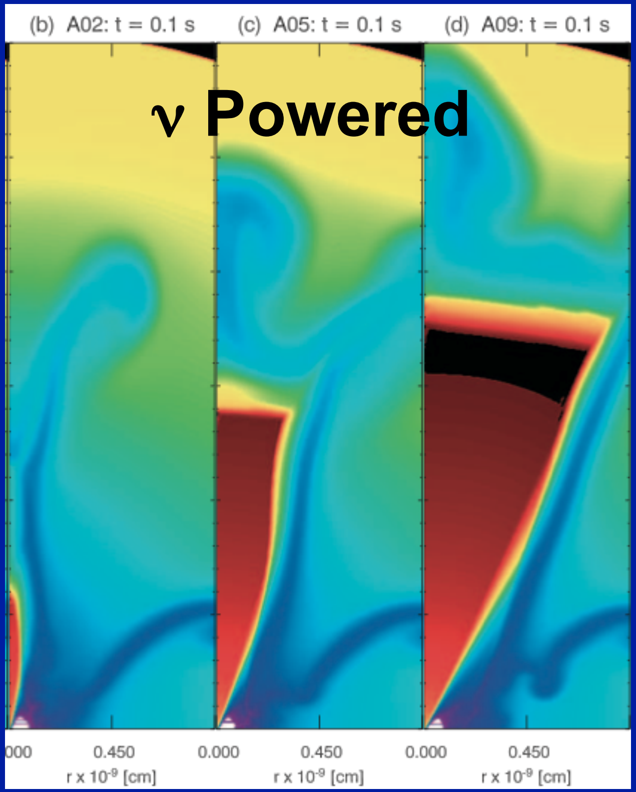
Short GRB Engine?

Relativistic Jets and Short GRBs

Rezzolla et al. 2010



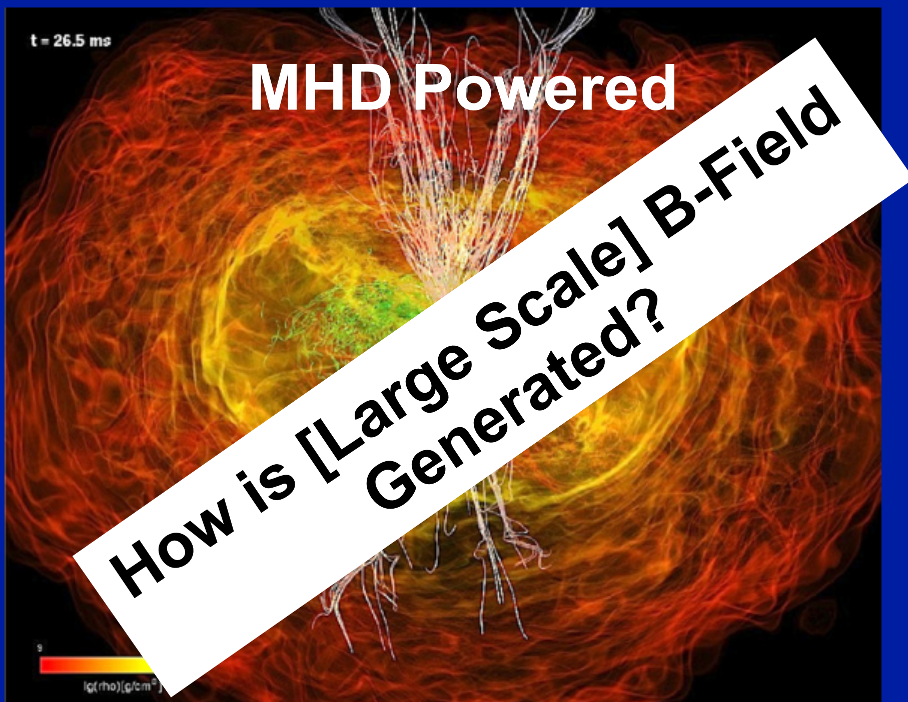
OR



Aloy et al. 2005

Relativistic Jets and Short GRBs

Rezzolla et al. 2010



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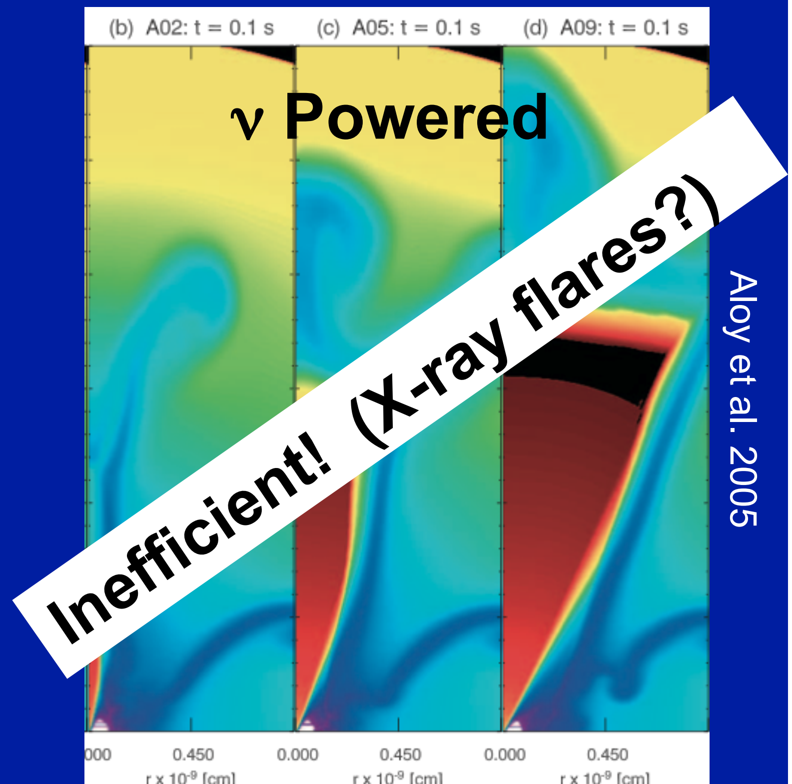
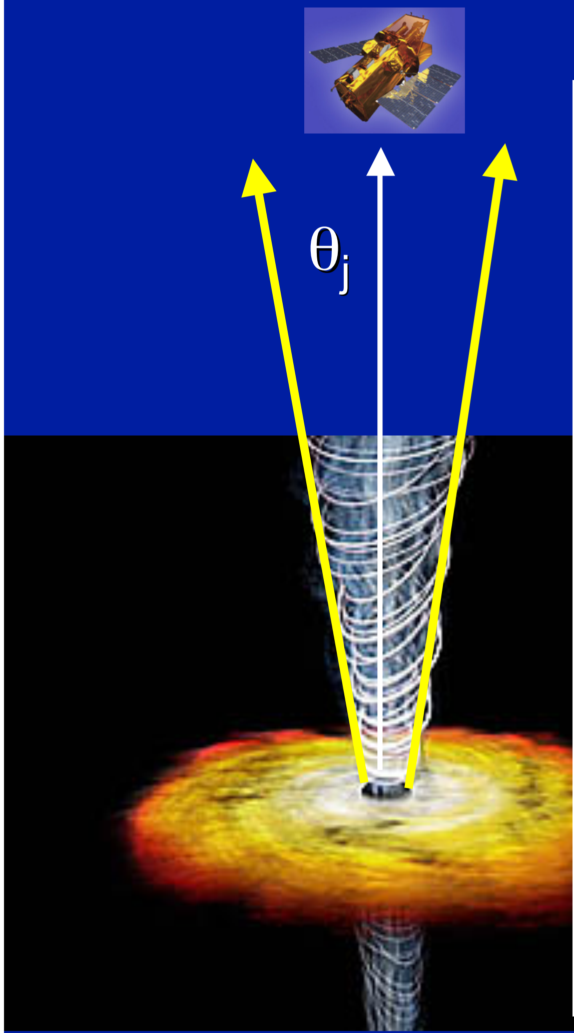
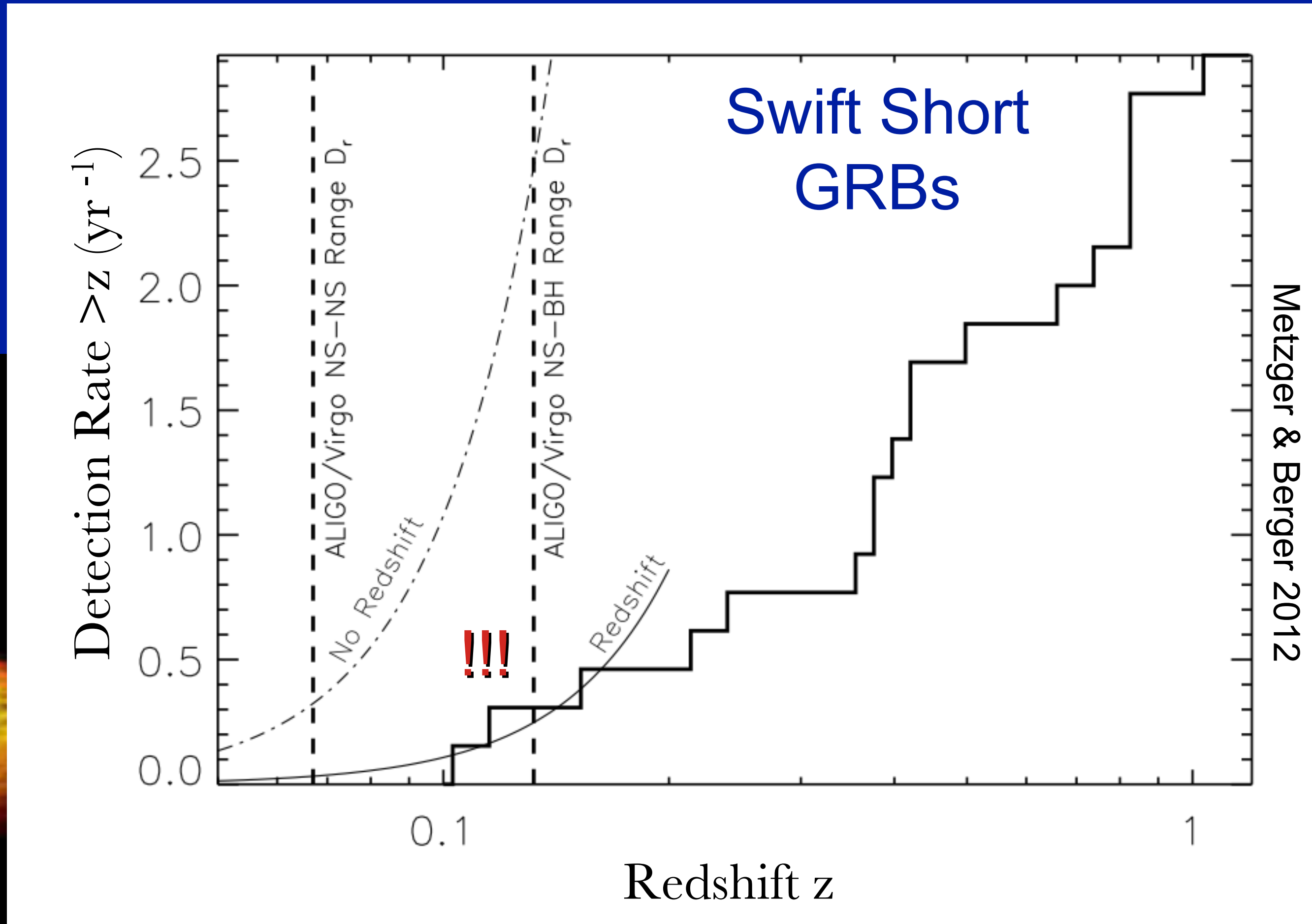


Aloy et al. 2005

Short GRBs Rare within aLIGO/Virgo Volume

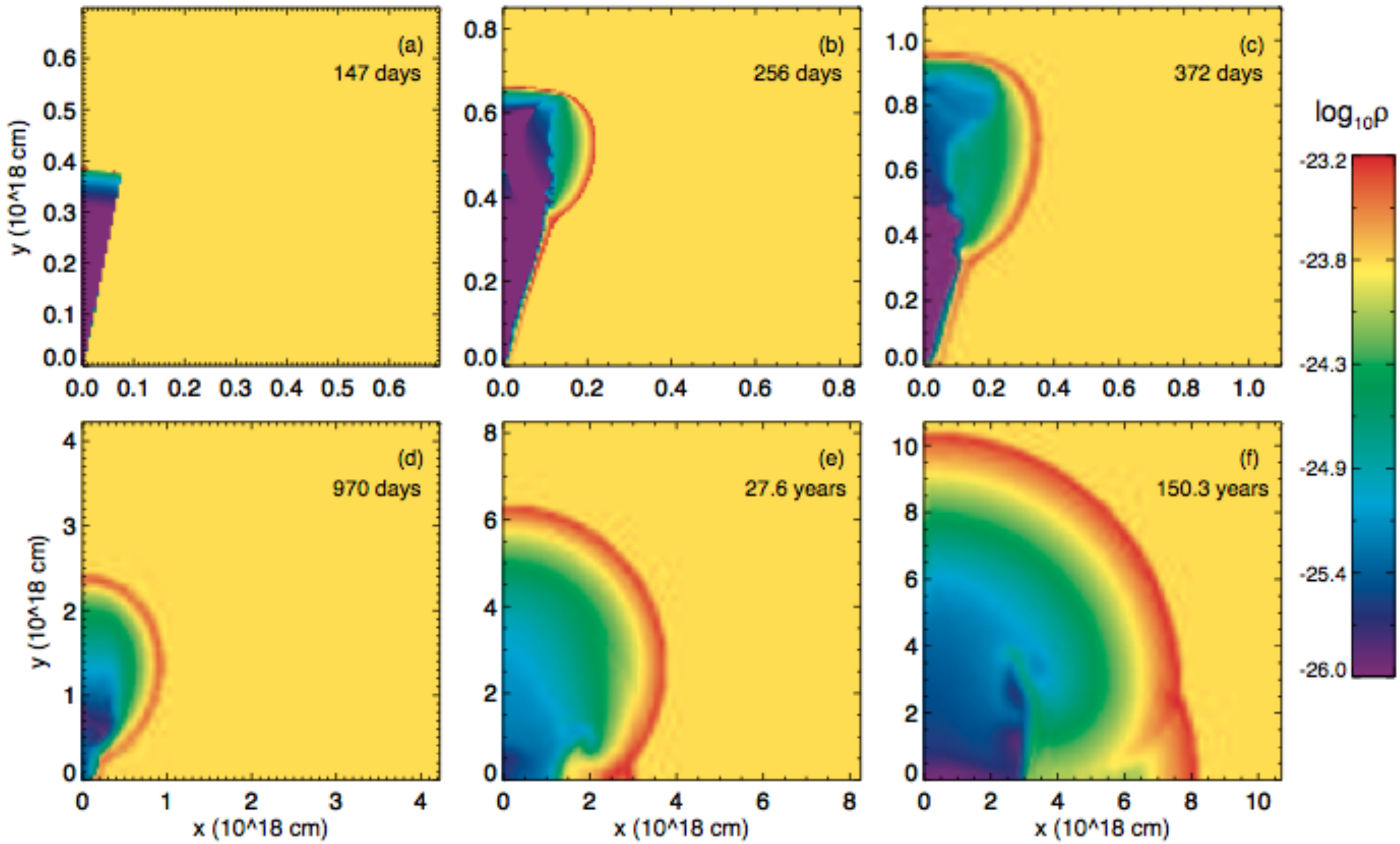




Detectable fraction by all sky γ-ray telescope

$$f_\gamma \sim 3.4 \times \bar{\theta}_j^2 / 2 \sim 0.07 \left(\frac{\bar{\theta}_j}{0.2} \right)^2$$

Relativistic Blastwave



Zhang & MacFadyen 2009

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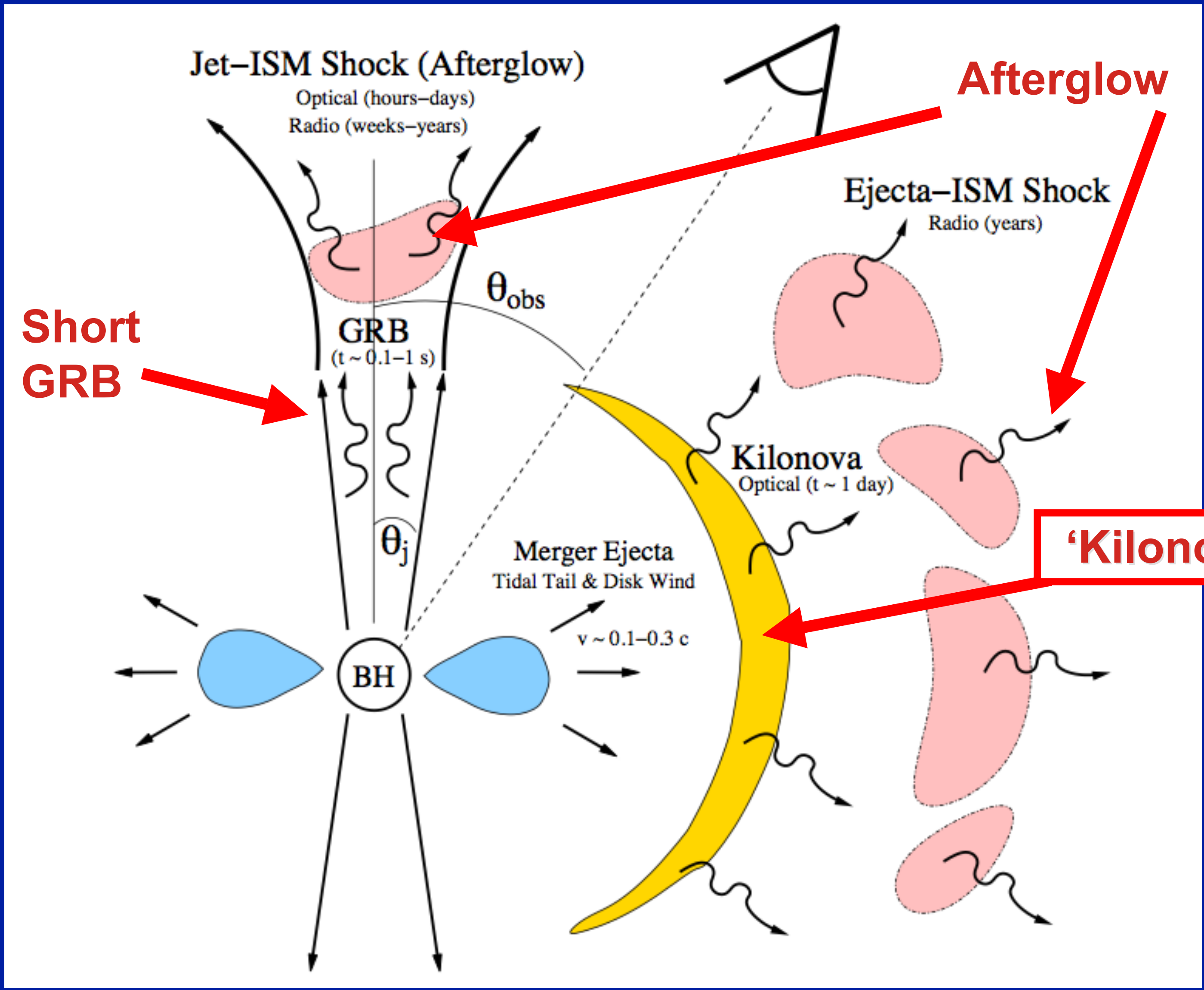
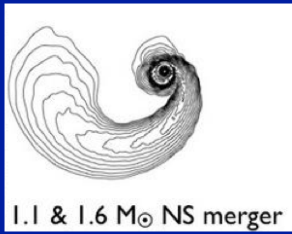


Metzger & Berger 2012



Neutron-Rich Ejecta

Dynamical Tidal Tails

(e.g. Janka et al. 1999; Lee & Kluzniak 1999; Ruffert & Janka 2001; Rosswog et al. 2004; Rosswog 2005; Shibata & Taniguchi 2006; Giacomazzo et al. 2009; Duez et al. 2010; East et al. 2012; Hotokezaka et al. 2013; Bauswein+13)

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APR4-135135	2.0	HMNS	5
APR4-120140	1.8	HMNS	3
APR4-125135	1.8	HMNS	5
APR4-130130	1.8	HMNS	2
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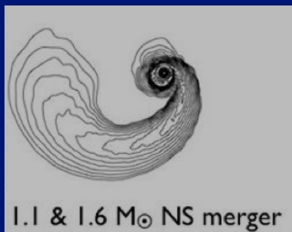
ALF2-120150	1.8	HMNS	5.5
ALF2-125145	1.8	HMNS	3
ALF2-130140	1.8	HMNS → BH	1.5
ALF2-135135	1.8	HMNS → BH	2.5
ALF2-130130	1.8	HMNS	2
H4-130150	1.8	HMNS→BH	3
H4-140140	1.8	HMNS→BH	0.3
H4-120150	1.6	HMNS	4.5
H4-120150	1.8	HMNS	3.5
H4-120150	2.0	HMNS	4
H4-125145	1.8	HMNS	2
H4-130140	1.8	HMNS	0.7
H4-135135	1.6	HMNS→BH	0.7
H4-135135	1.8	HMNS→BH	0.5
H4-135135	2.0	HMNS	0.4
H4-120140	1.8	HMNS	2.5
H4-125135	1.8	HMNS	0.6
H4-130130	1.8	HMNS	0.3
MS1-140140	1.8	MNS	0.6
MS1-120150	1.8	MNS	3.5
MS1-125145	1.8	MNS	1.5
MS1-130140	1.8	MNS	0.6
MS1-135135	1.8	MNS	1.5
MS1-130130	1.8	MNS	1.5

Hotokezaka et al. 2013

Neutron-Rich Ejecta



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APR4-120150	1.6	HMNS	9
APR4-120150	1.8	HMNS	8
APR4-120150	2.0	HMNS	7.5
APR4-125145	1.8	HMNS	7
APR4-130140	1.8	HMNS	8
APR4-135135	1.6	HMNS	11
APR4-135135	1.8	HMNS	7
APR4-135135	2.0	HMNS	5
APR4-120140	1.8	HMNS	3
APR4-125135	1.8	HMNS	5
APR4-130130	1.8	HMNS	2
ALF2-140140	1.8	HMNS→BH	2.5
ALF2-120150	1.8	HMNS	5.5
ALF2-125145	1.8	HMNS	3
ALF2-130140	1.8	HMNS → BH	1.5
ALF2-135135	1.8	HMNS → BH	2.5
ALF2-130130	1.8	HMNS	2
H4-130150	1.8	HMNS→BH	3
H4-140140	1.8	HMNS→BH	0.3
H4-120150	1.6	HMNS	4.5
H4-120150	1.8	HMNS	3.5
H4-120150	2.0	HMNS	4
H4-125145	1.8	HMNS	2
H4-130140	1.8	HMNS	0.7
H4-135135	1.6	HMNS→BH	0.7
H4-135135	1.8	HMNS→BH	0.5
H4-135135	2.0	HMNS	0.4
H4-120140	1.8	HMNS	2.5
H4-125135	1.8	HMNS	0.6
H4-130130	1.8	HMNS	0.3
MS1-140140	1.8	MNS	0.6
MS1-120150	1.8	MNS	3.5
MS1-125145	1.8	MNS	1.5
MS1-130140	1.8	MNS	0.6
MS1-135135	1.8	MNS	1.5
MS1-130130	1.8	MNS	1.5

Hotokezaka et al. 2013

Disk Outflows

Neutrino-Powered (Early)

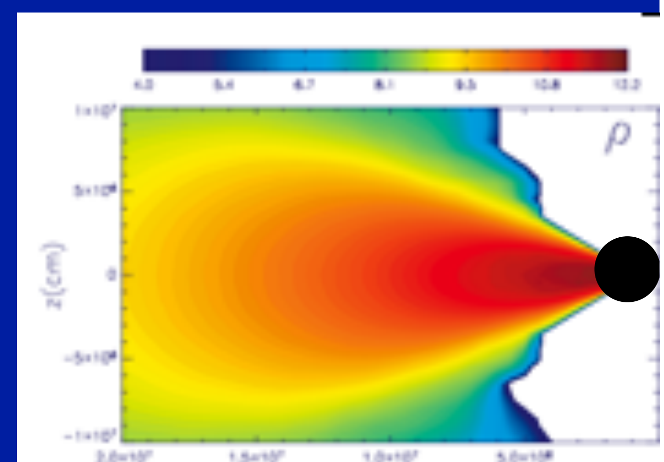
(e.g. McLaughlin & Surman 05; Surman+08; BDM+08; Dessart+09; Wanajo & Janka 12)

Recombination-Powered (Late)

(e.g. Beloborodov 08; BDM+08, 09; Lee+09; Fernandez & BDM 13)

$$Y_e \sim ???$$

$$M_{ej} = f_w M_d \sim 10^{-3} - 10^{-2}\ (f_w/0.1)\ M_{\odot}$$

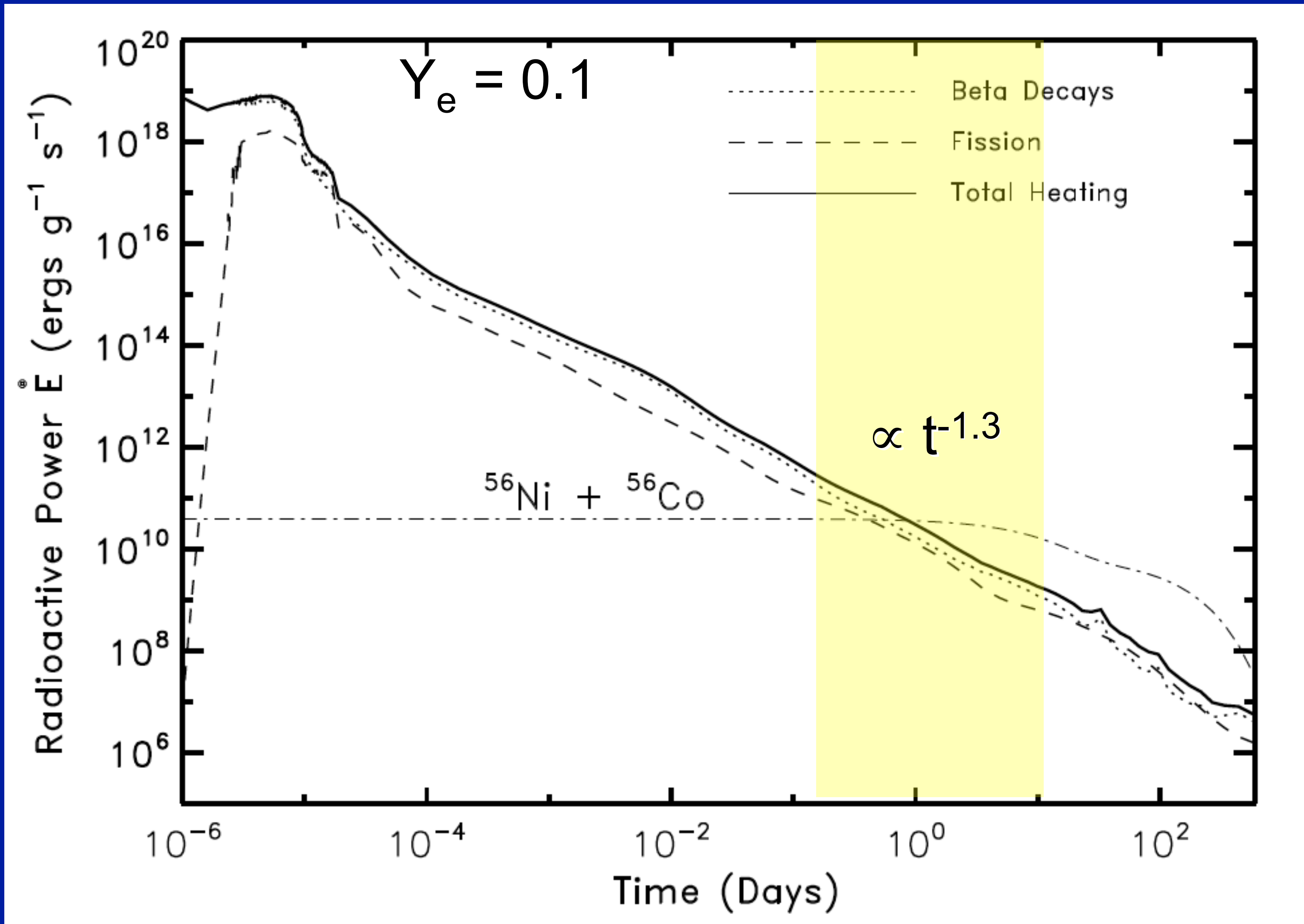


R-Process Network (neutron captures, photo-dissociations, α- and β-decays, fission)

as used in Metzger et al. 2010 (movie courtesy A. Arcones & G. Martinez-Pinedo)

Radioactive Heating of Merger Ejecta

(BDM et al. 2010; Roberts et al. 2011; Goriely et al. 2011; Korobkin et al. 2012; Bauswein et al. 2013)

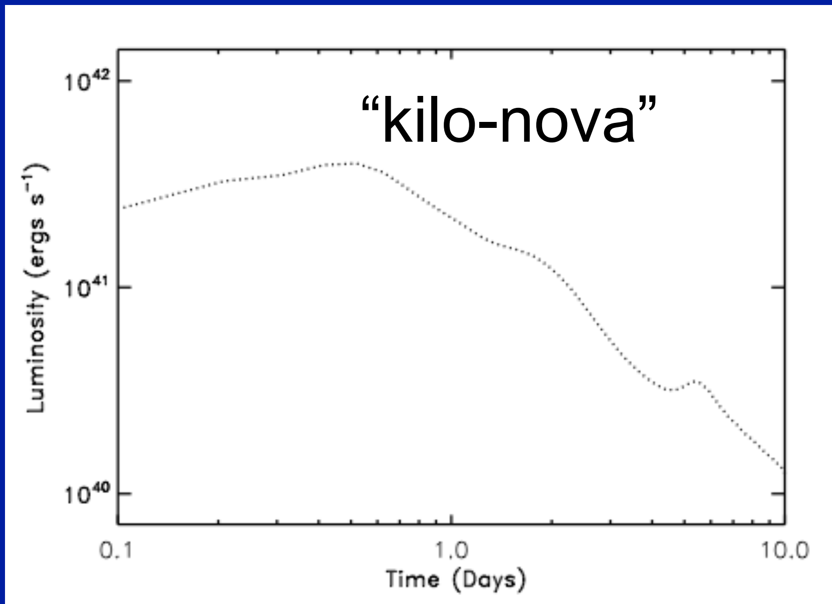


BDM et al. 2010

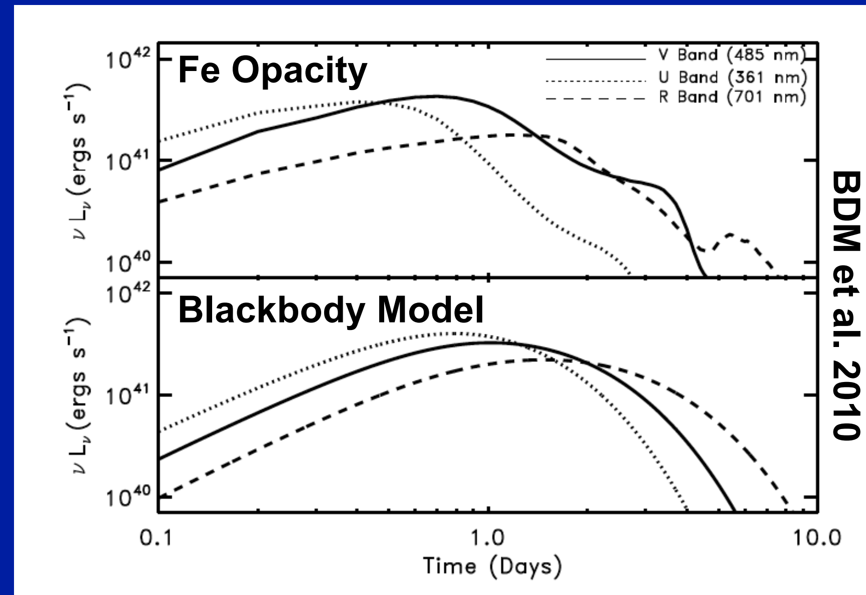
Dominant β-Decays at t ~ 1 day: ^{132,134,135}I, ^{128,129}Sb, ^{129}Te, ^{135}Xe

Relatively insensitive to details (Y_e, expansion history, NSE or not)

Bolometric Luminosity

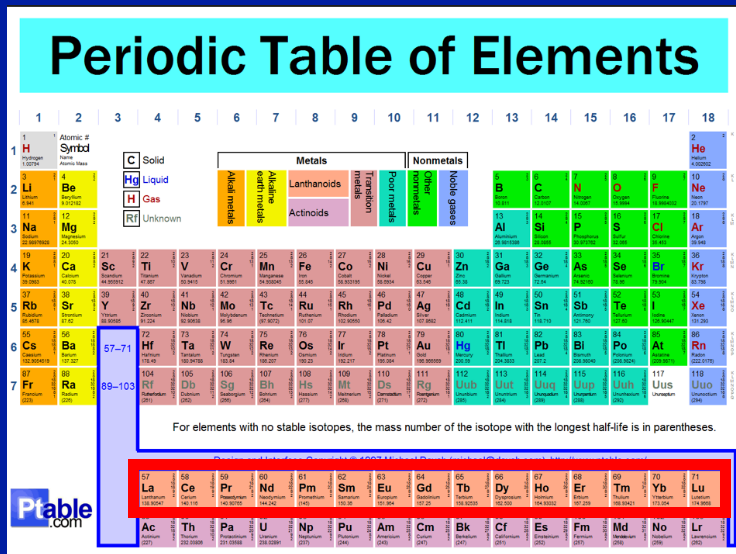


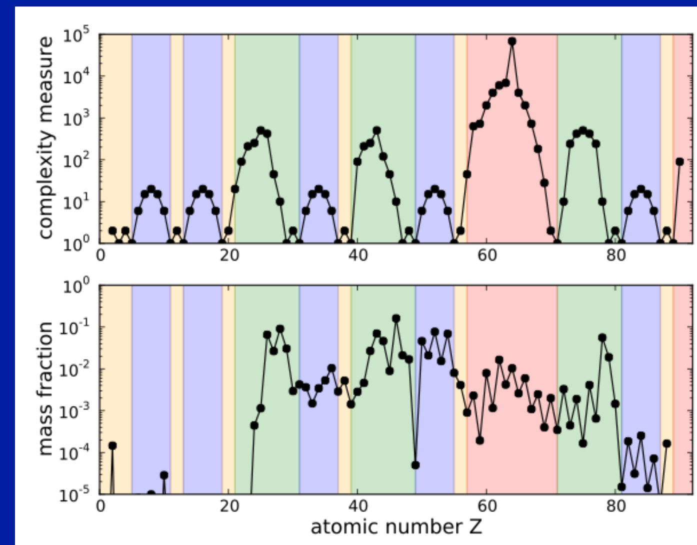
Color Evolution

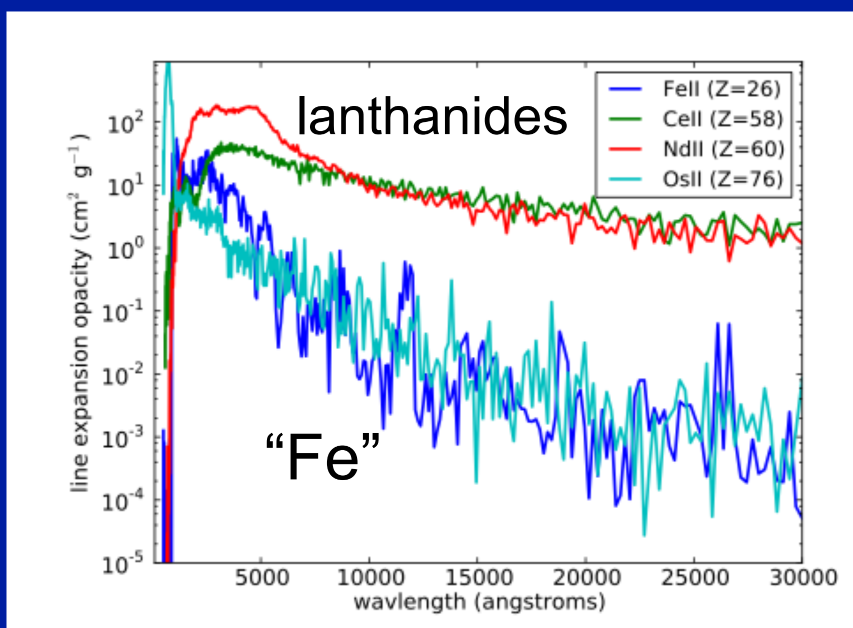


High Opacity of the Lanthanides

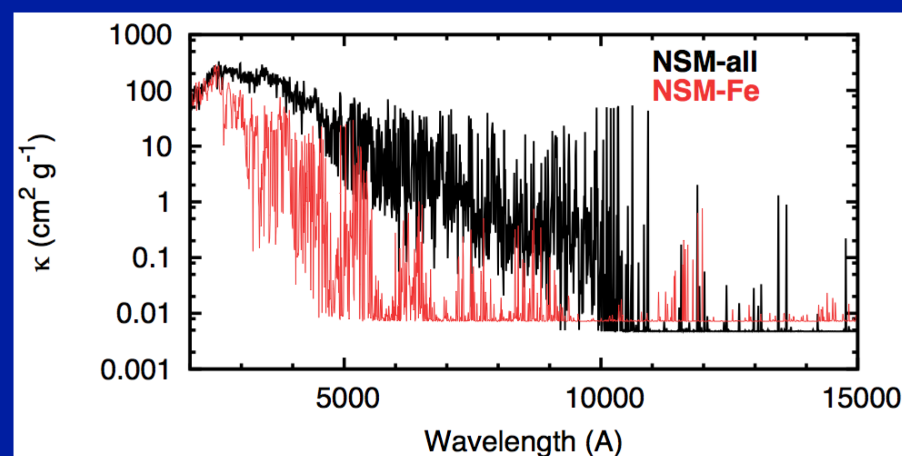
(Kasen et al. 2013; Tanaka & Hotokezaka 2013)







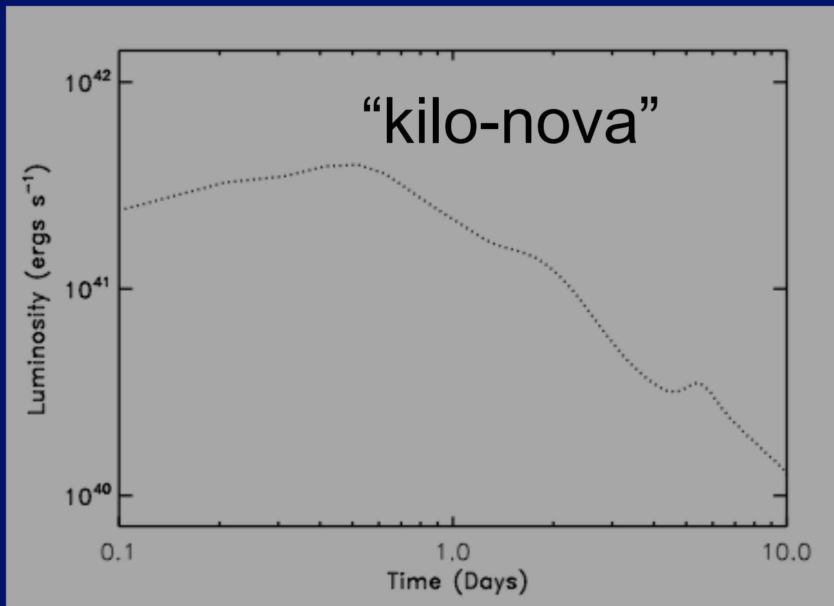
Kasen et al. 2013

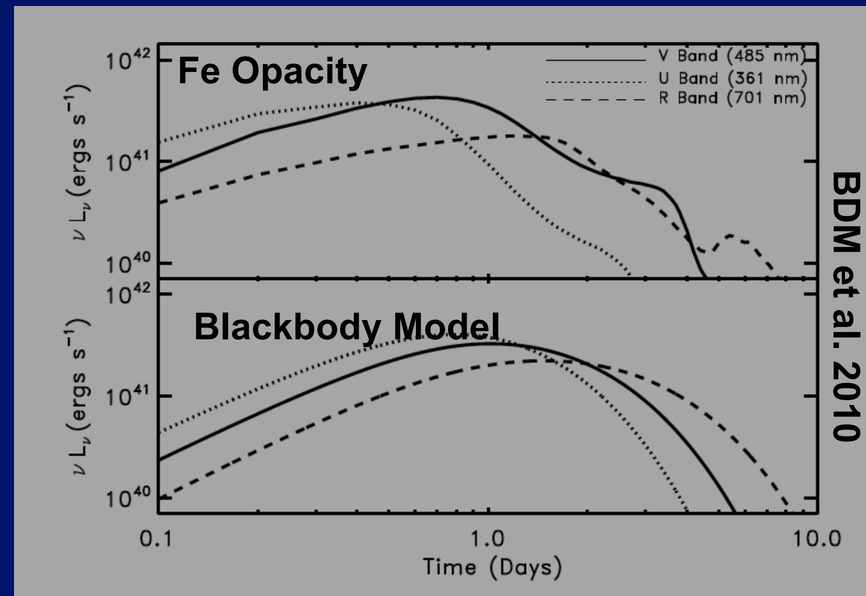


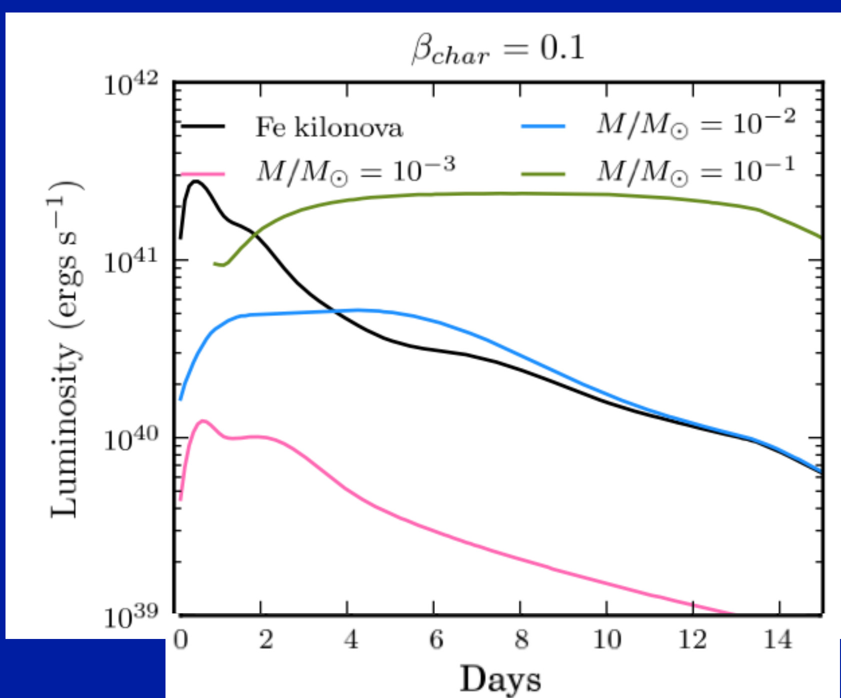
Tanaka & Hotokezaka 2013

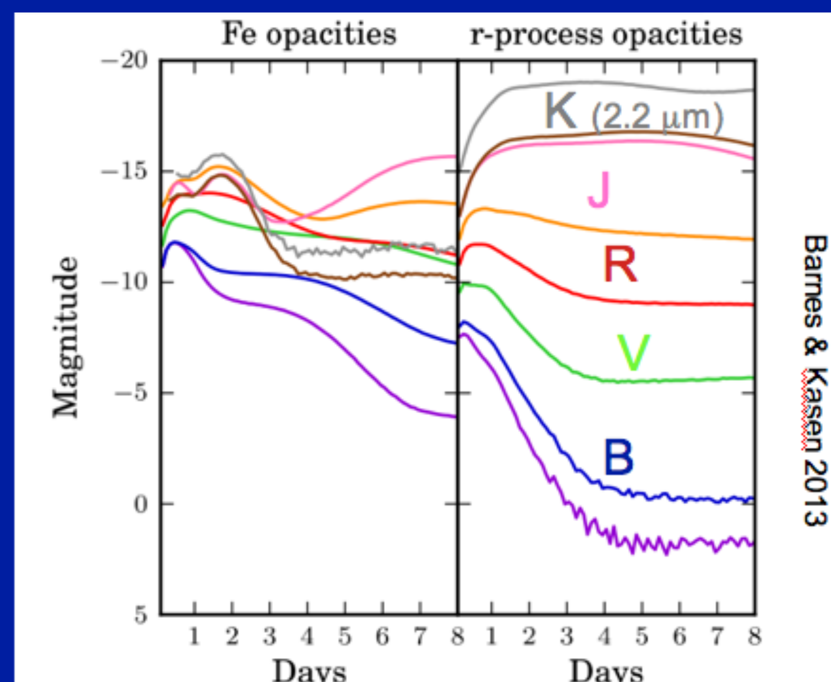
Bolometric Luminosity

Color Evolution









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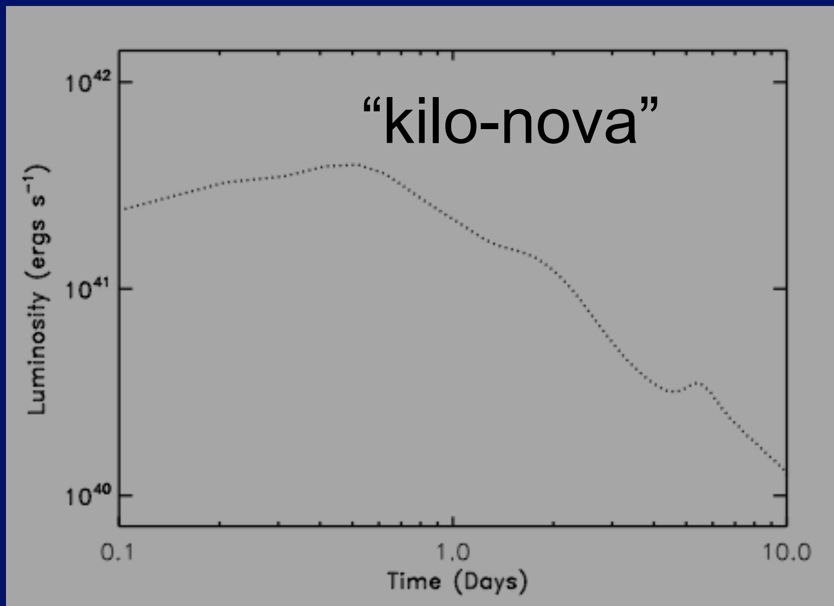

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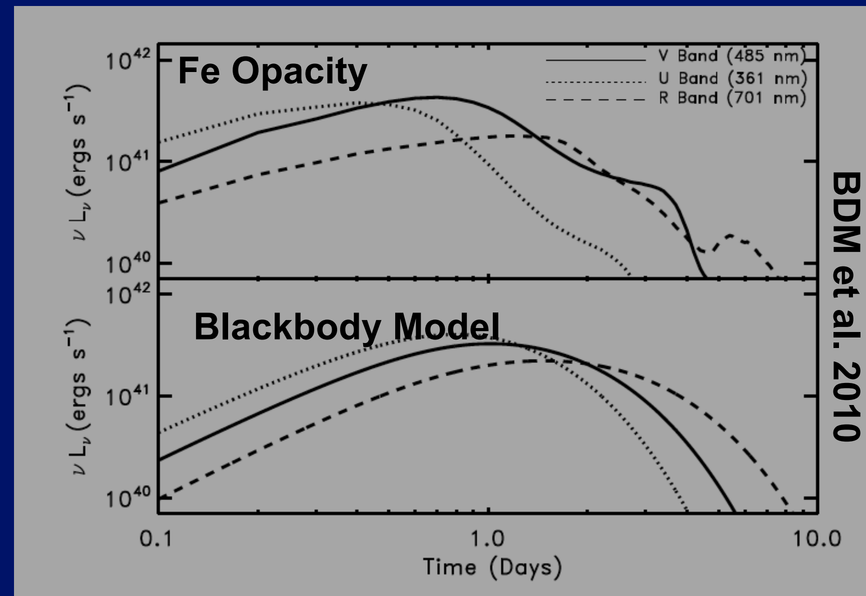

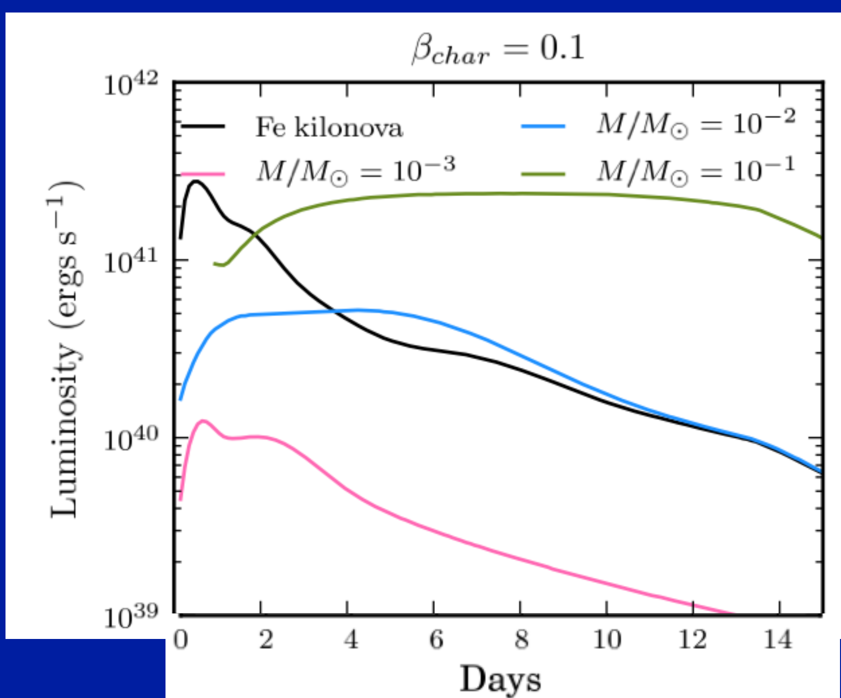

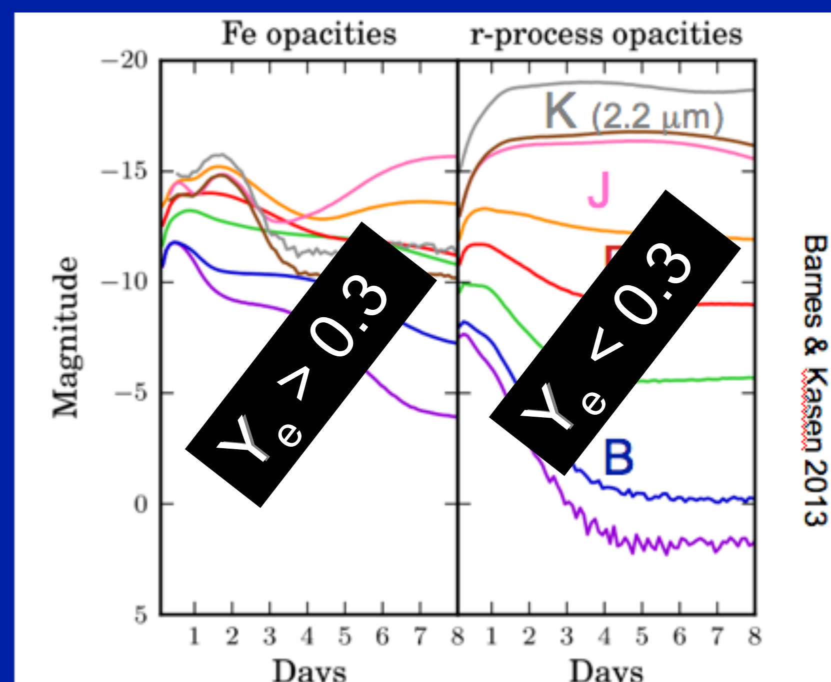

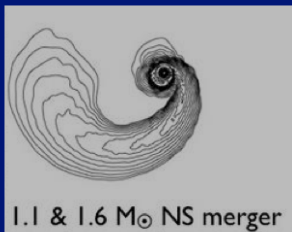

Neutron-Rich Ejecta

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MS1-125145	1.8	MNS	1.5
MS1-130140	1.8	MNS	0.6
MS1-135135	1.8	MNS	1.5
MS1-130130	1.8	MNS	1.5

Hotokezaka et al. 2013

Disk Outflows

Neutrino-Powered (Early)

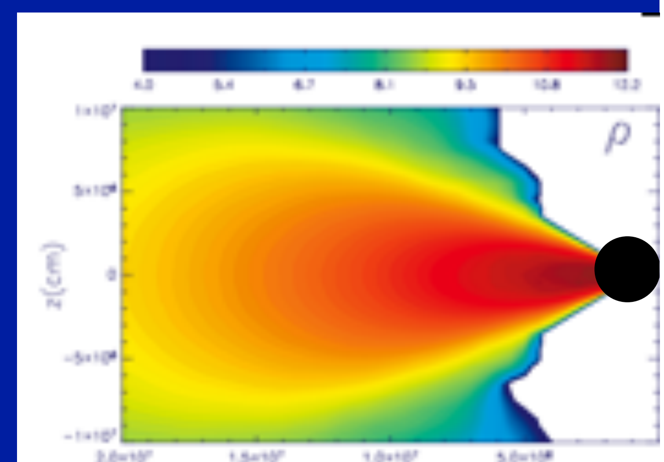
(e.g. McLaughlin & Surman 05; Surman+08; BDM+08; Dessart+09)

Recombination-Powered (Late)

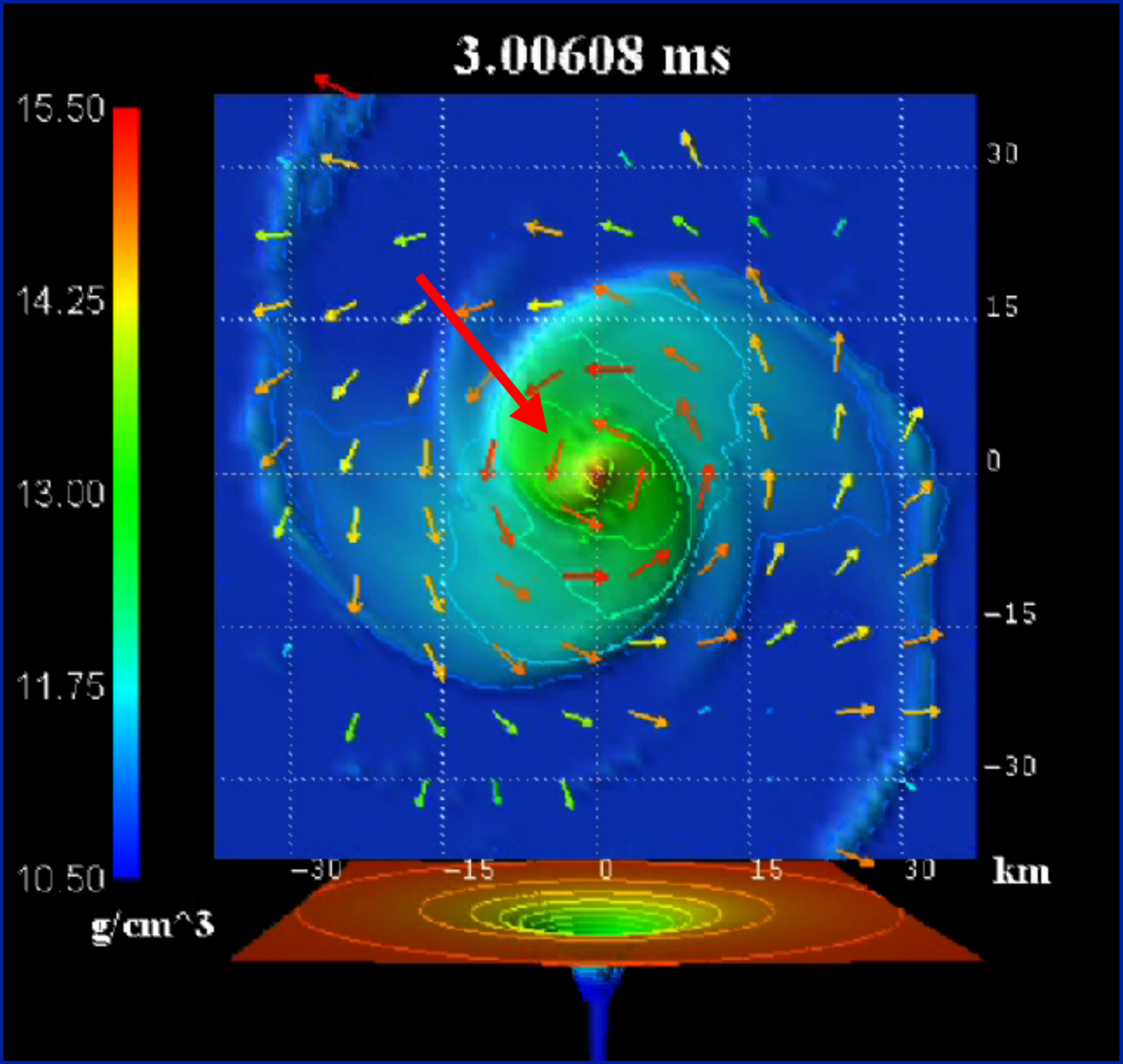
(e.g. Beloborodov 08; BDM+08, 09; Lee+09; Fernandez & BDM 13)

$$Y_e \sim ???$$

$$M_{ej} = f_w M_d \sim 10^{-3}\text{-}10^{-2}\ (f_w/0.1)\ M_{\odot}$$

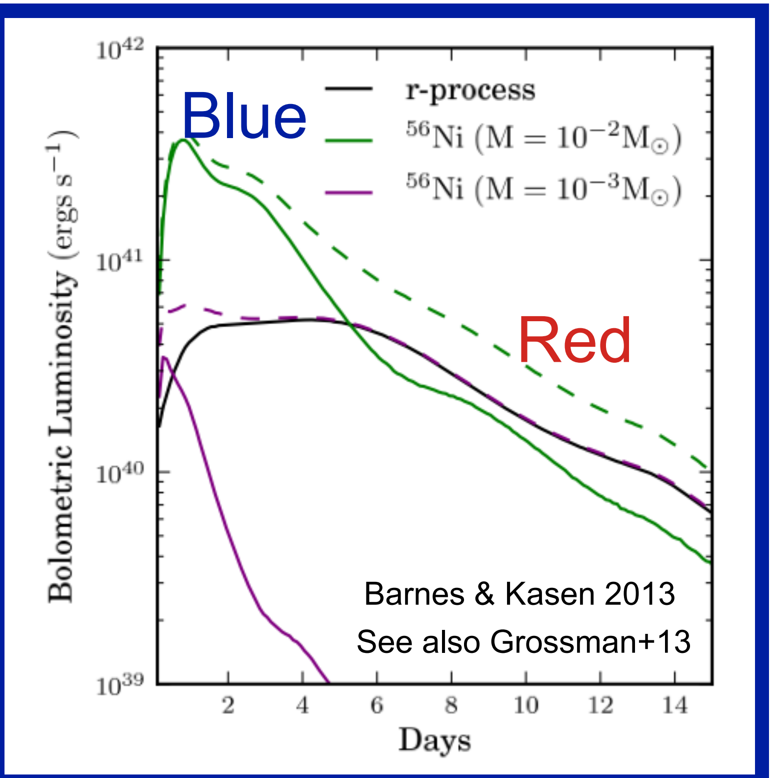


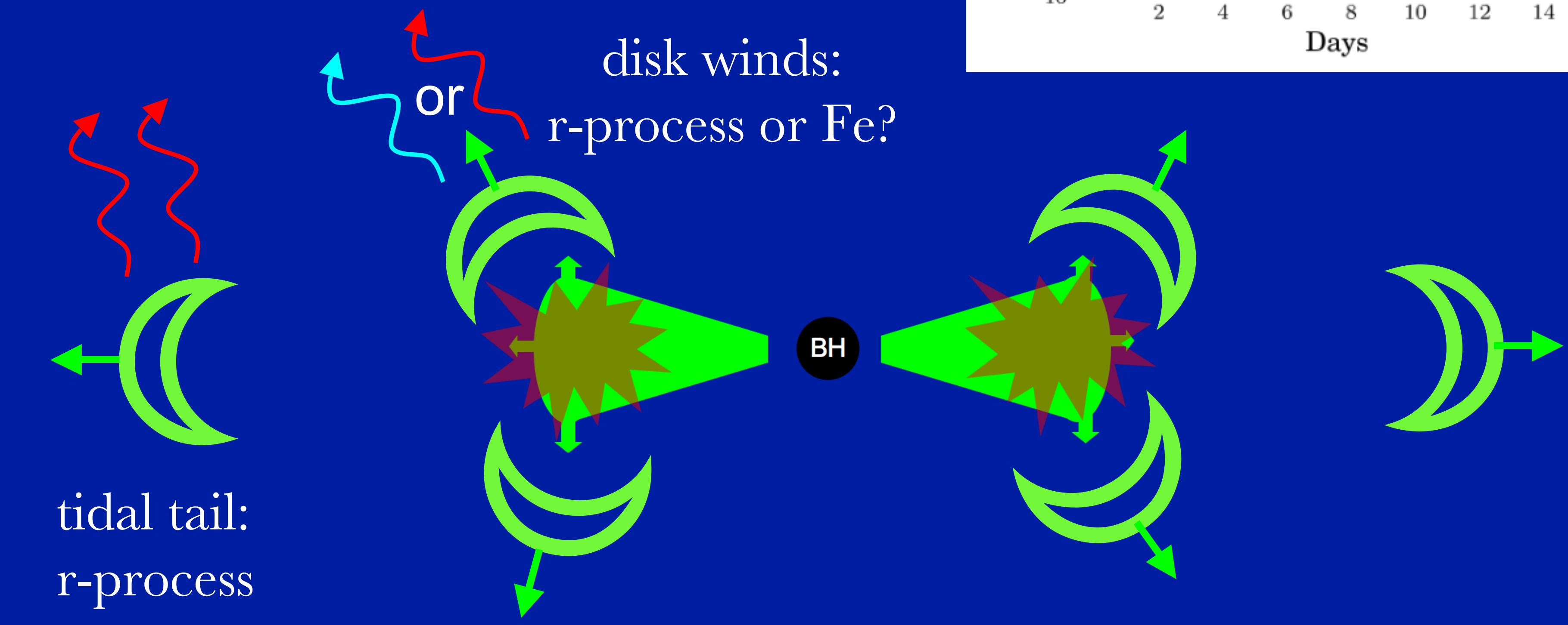
Numerical Simulation - Two 1.4 $M_{\odot}$ NSs



Courtesy M. Shibata (Tokyo U)

Two Component Light Curve





Viscous Evolution of the Remnant Disk

Metzger, Piro & Quataert 2008, 2009

Angular Momentum

$$\frac{\partial \Sigma}{\partial t} = \frac{3}{r}\frac{\partial}{\partial r}\left[r^{1/2}\frac{\partial}{\partial r}\left(\nu \Sigma r^{1/2}\right)\right]$$

Entropy

BH

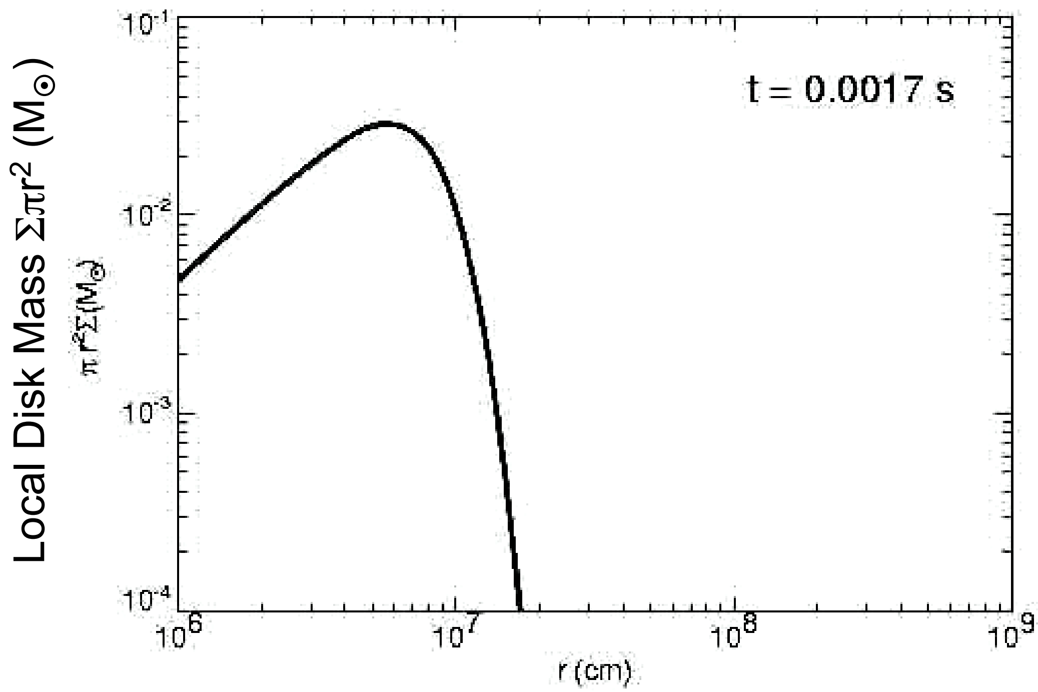
$$T\frac{dS}{dt} = \dot{q}_{visc} - \dot{q}_{\nu}$$

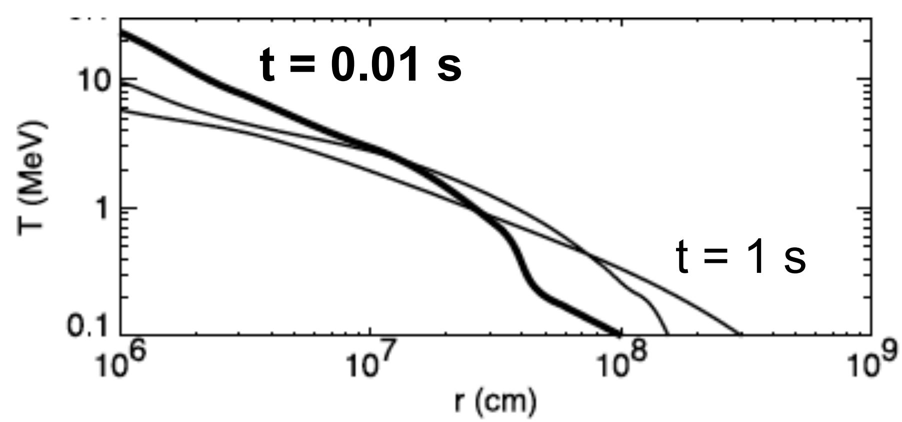
Heating

Cooling

Nuclear Composition

$$\frac{dY_e}{dt} = (\lambda_{e^+ n \rightarrow p\nu} + \lambda_{e^- p \rightarrow n\nu})\left[1 - Y_e - \left(\frac{1 - X_f}{2}\right)\right]$$





Delayed Disk Winds ('Evaporation')

After t ~ 1 seconds, R ~ 300 km & T < 1 MeV

- **Recombination: n + p $\Rightarrow$ He**

  $E_{BIND} \sim GM_{BH}m_n/2R \sim 5$ MeV nucleon^{-1}

  $\Delta E_{NUC} \sim 7$ MeV nucleon^{-1}

- **Thick Disks Marginally Bound**

Delayed Disk Winds ('Evaporation')

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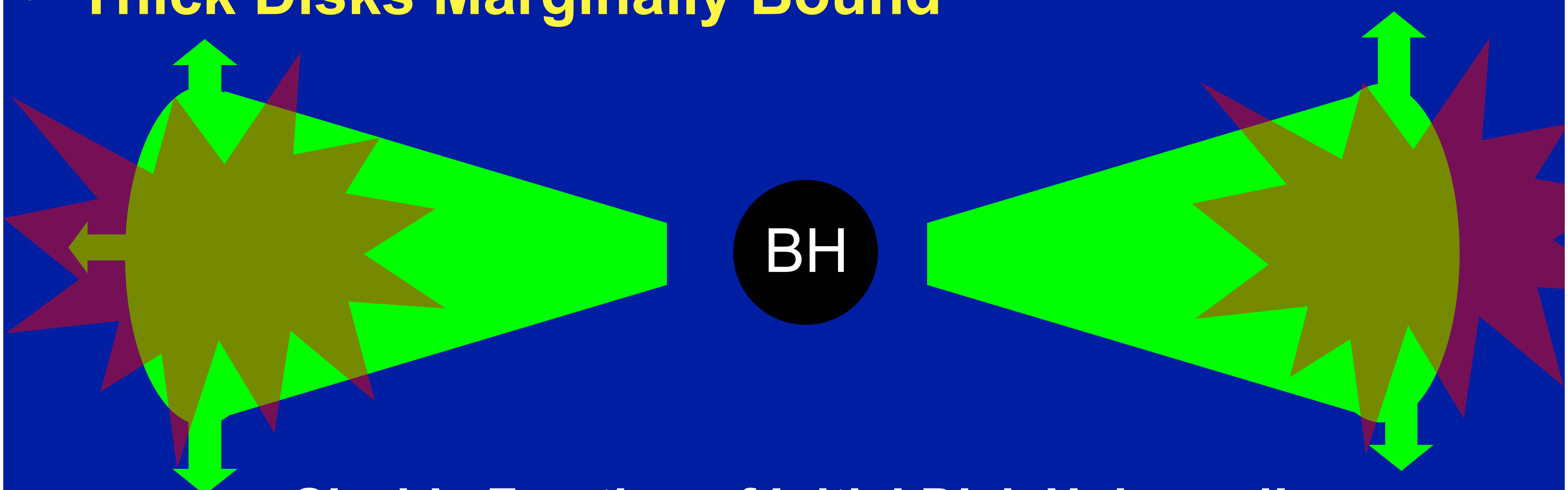
- **Thick Disks Marginally Bound**

} ⇒ **Disk Blows Apart**



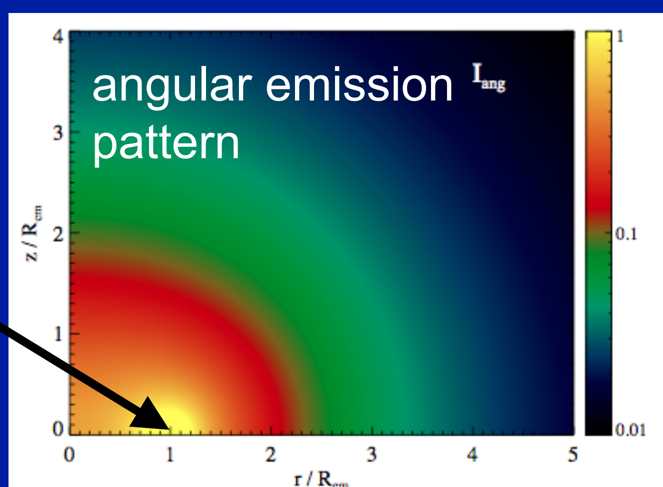
Sizable Fraction of Initial Disk Unbound!

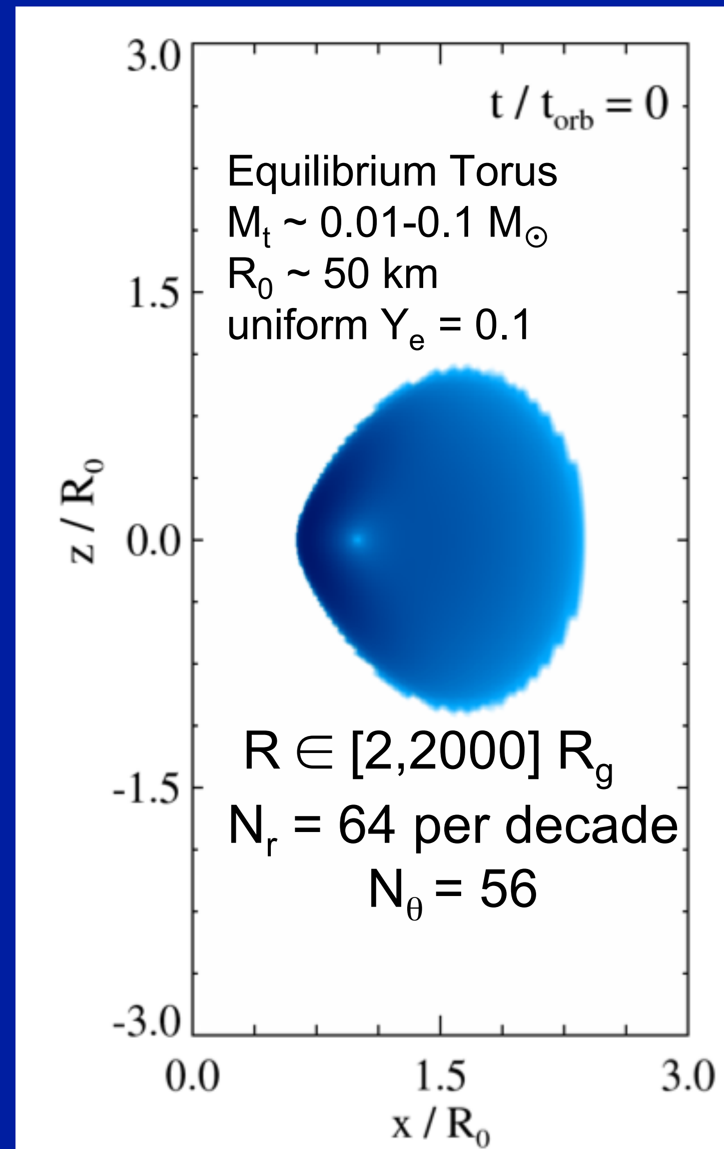
Axisymmetric Torus Evolution

(Fernandez & Metzger 2012, 2013)

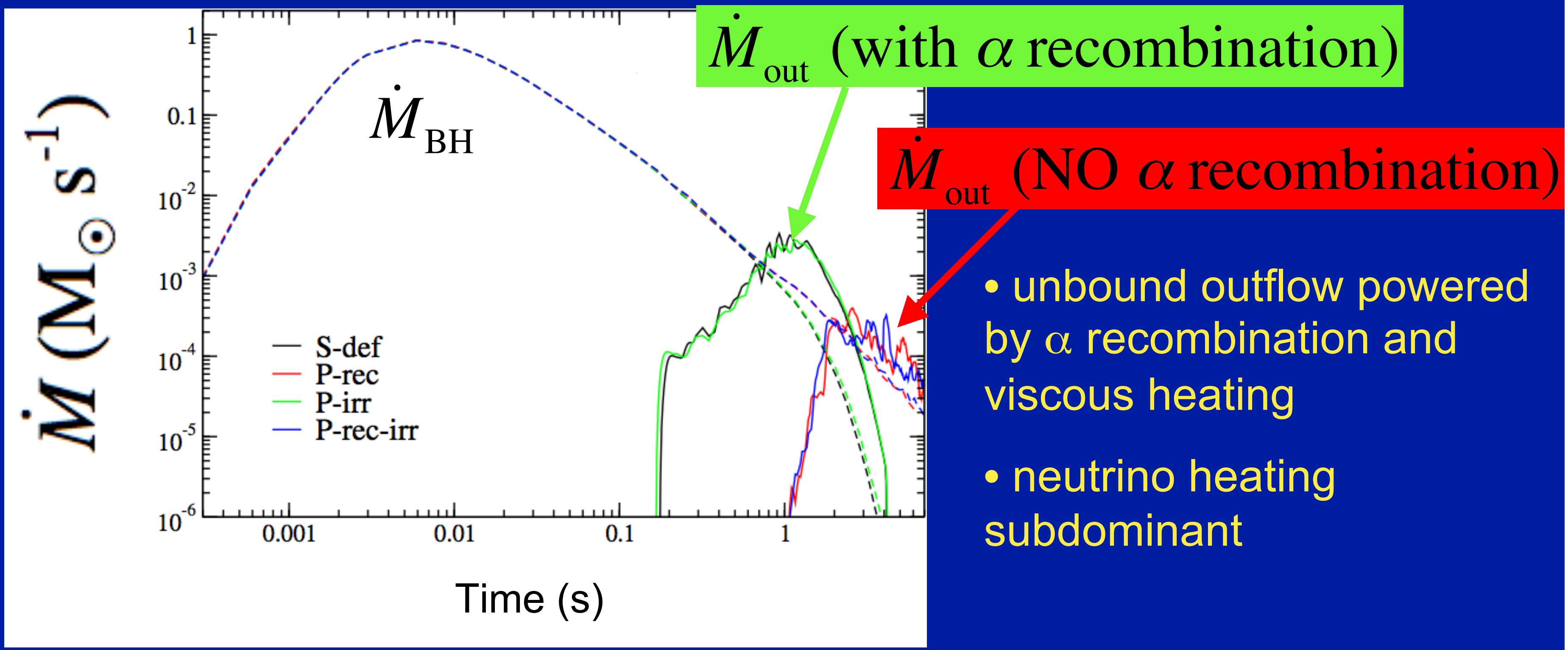
- P-W potential with $M_{BH} = 3,10\ M_\odot$
- hydrodynamic α viscosity
- NSE recombination $2n+2p \Rightarrow {}^4He$
- run-time $\Delta t \sim 1000\text{-}3000\ t_{orb}$
- neutrino self-irradiation: "light bulb" + optical depth corrections:

peak emission



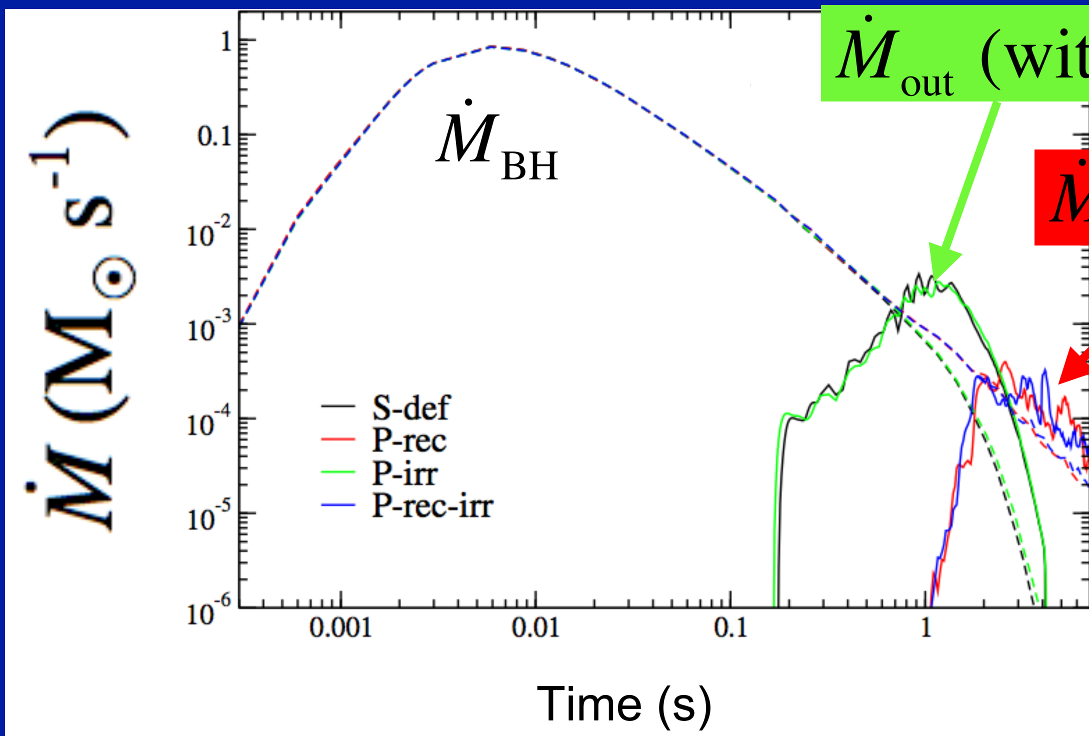


Late Disk Outflows (Evaporation)



- unbound outflow powered by α recombination and viscous heating
- neutrino heating subdominant

Late Disk Outflows (Evaporation)



$\dot{M}_{out}$ (with α recombination)

$\dot{M}_{out}$ (NO α recombination)

- unbound outflow powered by α recombination and viscous heating
- neutrino heating subdominant

Model	M_{t0} ($M_\odot$)	M_{BH}	R_0 (km)	Y_{e0}	s_0 (k_B/b)	α	M_{ej}/M_{acc} (M_{t0}/M_{t0})	$\bar{v}_{r,9}$
S-def	0.03	3	50	0.10	8	0.03	0.10/0.90	2.2
S-m0.01	0.01	3	50	0.10	8	0.03	0.10/0.90	2.2
S-m0.10	0.10						0.11/0.89	2.3
S-R75	0.03	3	75				0.22/0.78	2.2
S-M10		10	150				0.04/0.92	1.8
S-y0.05		3	50	0.05			0.10/0.90	2.2
S-y0.15				0.15			0.10/0.90	2.3
S-s6				0.10	6		0.08/0.91	1.9
S-s10					10		0.12/0.88	2.6
S-v0.01					8	0.01	0.11/0.89	2.5
S-v0.10						0.10	0.13/0.87	2.4

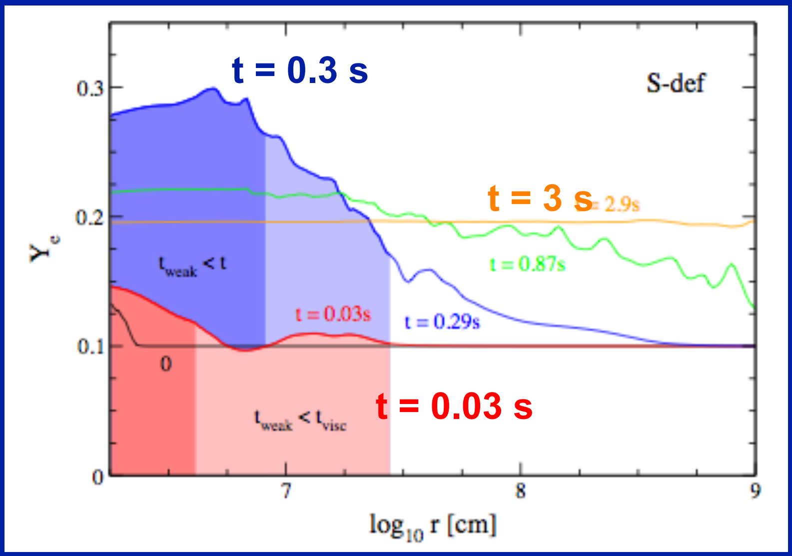
outflow robust

M_{ej} ~ 0.05 - 0.2 M_t

V_{ej} ~ 0.1 c

Outflow Composition

Y_e Freeze Out



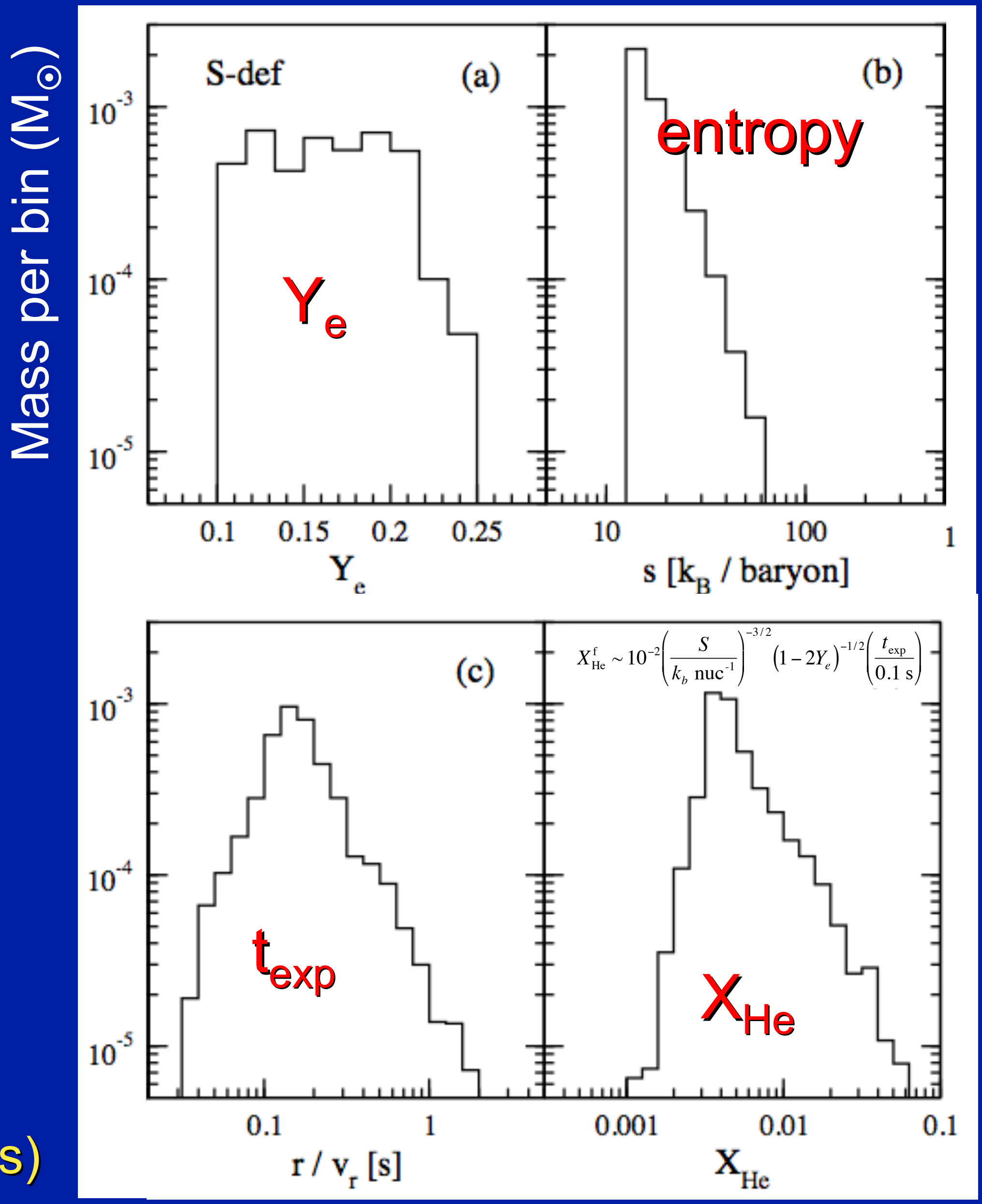
'seed' nuclei form ($T<5\times10^9$ K)

$$^4\mathrm{He}(\alpha n,\gamma)^9\mathrm{Be}(\alpha,\mathrm{n})^{12}\mathrm{C}$$

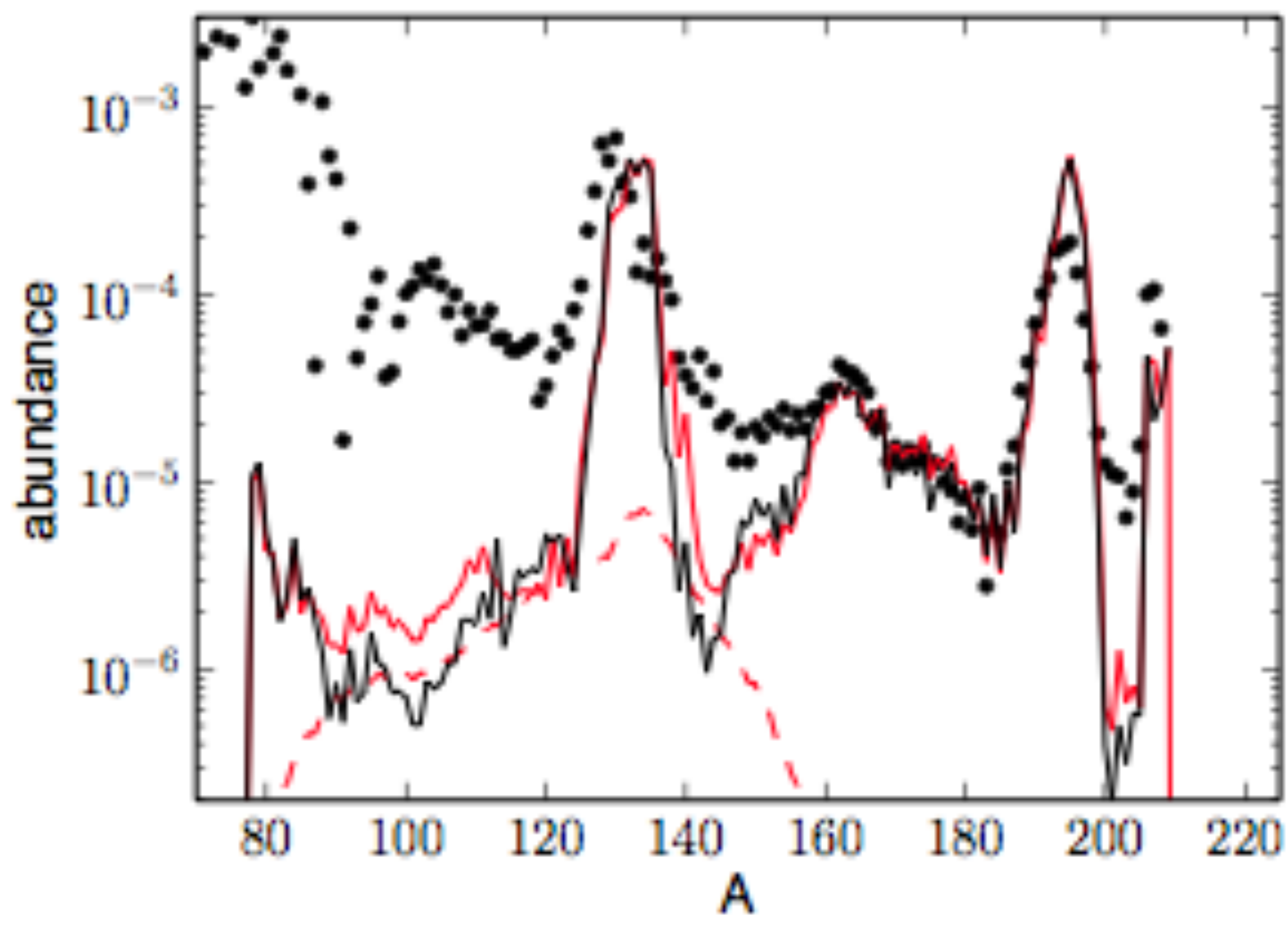
then α-process (Woosley & Hoffman 92)

$$\frac{n}{seed} > 100 \Rightarrow A > 130$$

⇒ r-process (including lanthanides)



Composition (Preliminary)



Implications of Neutron-Rich Outflows

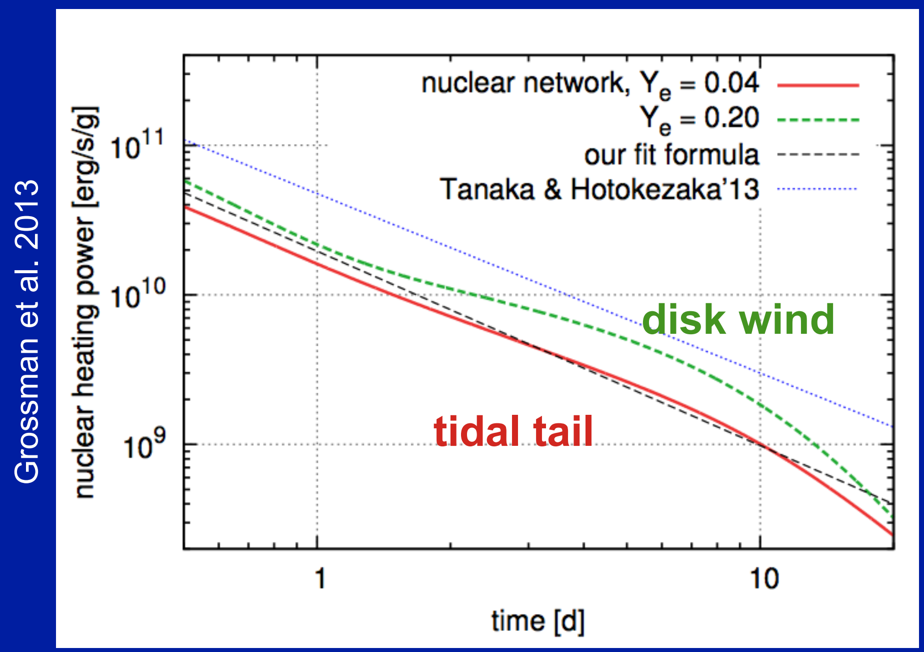
- Robust heavy r-process source (distinct from dynamical ejecta)

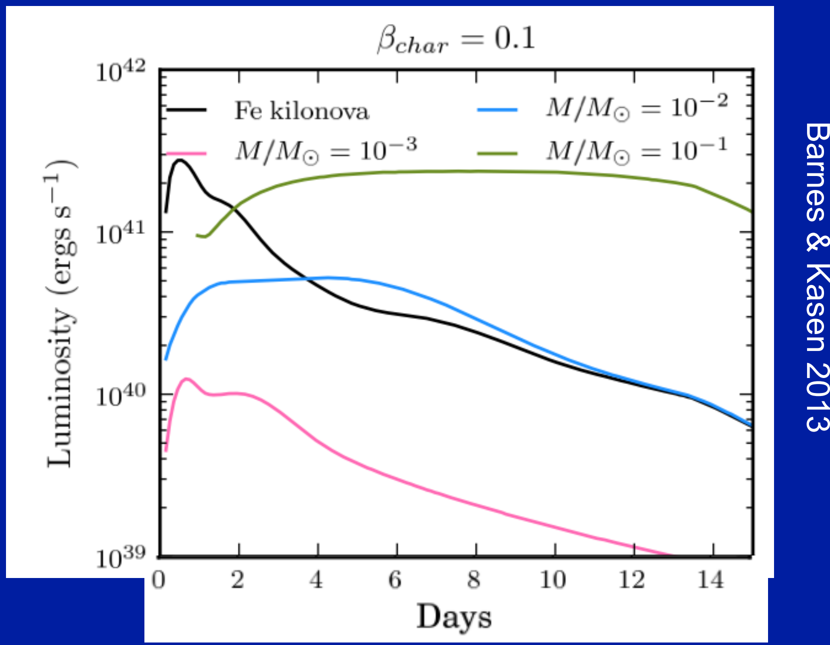
$$\dot{M}_r = 10^{-7} M_\odot \mathrm{yr}^{-1} \left(\frac{\mathcal{R}_{\mathrm{NS}^2}}{10^{-4}\mathrm{yr}^{-1}}\right)\left(\frac{f_{\mathrm{ej}}}{0.1}\right)\left(\frac{\bar{M}_{\mathrm{t}}}{10^{-2} M_\odot}\right)$$

$$\dot{M}^{\mathrm{Galactic}}_{A>130} \sim 5 \times 10^{-7} M_\odot \mathrm{yr}^{-1}$$

(Qian 2000)

- Disk outflow emission hard to distinguish from tidal tail
  - High opacity of lanthanides ⇒ both produce RED and long (~WEEK) kilonova

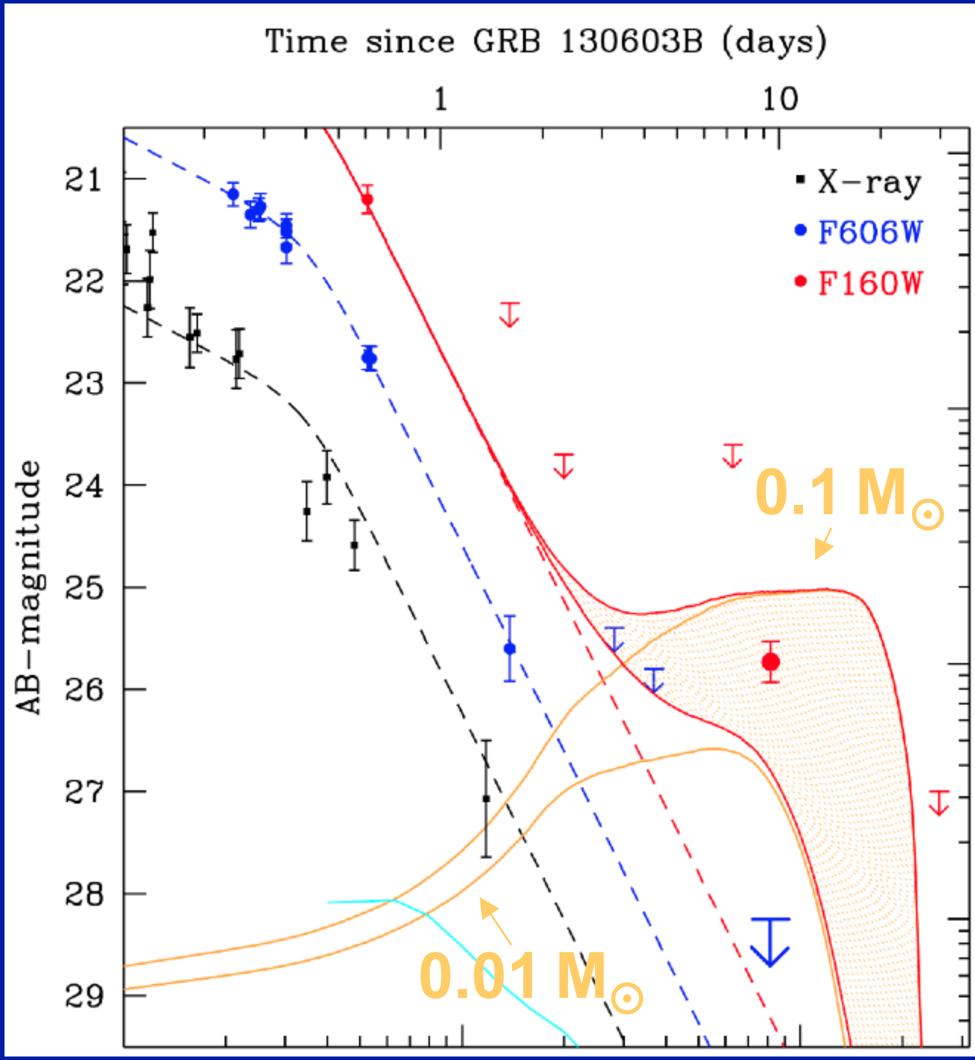




A 'kilonova' associated with the short-duration γ- ray burst GRB 130603B

N. R. Tanvir, A. J. Levan, A. S. Fruchter, J. Hjorth, R. A. Hounsell, K. Wiersema & R. L. Tunnicliffe

(cf. Berger+13; de Ugarte Postigo+13 ; Fong+13)



If true, confirms association of short GRBs and NS-NS mergers

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NATURE | LETTER

N. R. Tanvir, A. J. Levan, A. S. Fruchter, J. Hjorth, R. A. Hounsell, K. Wiersema & R. L. Tunnicliffe

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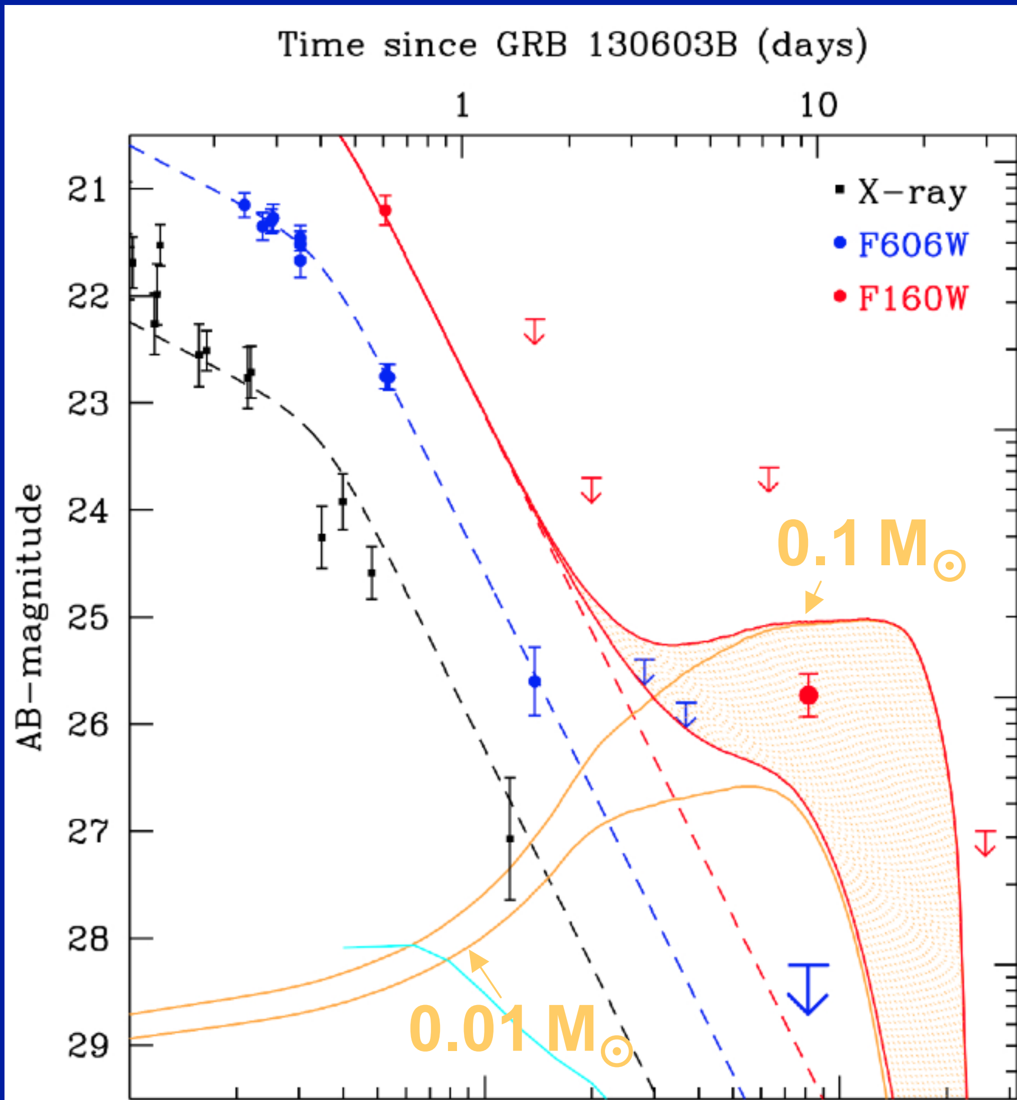


Implications (if true)

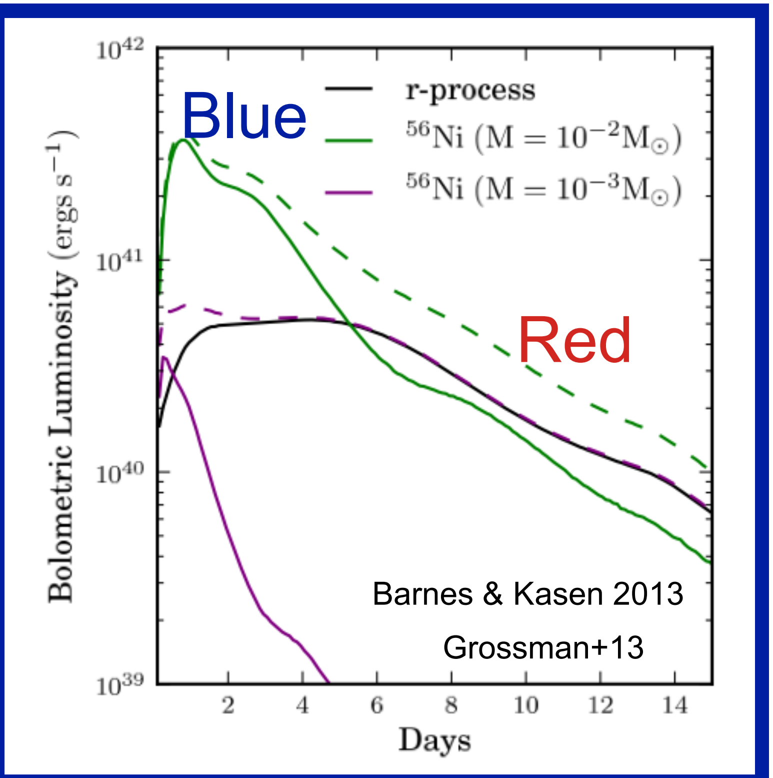
- confirms association of short GRBs with NS mergers
- counterpart would ~21-22 mag at 200 Mpc (detectable with big glass)
- minimum r-process contribution from NS mergers

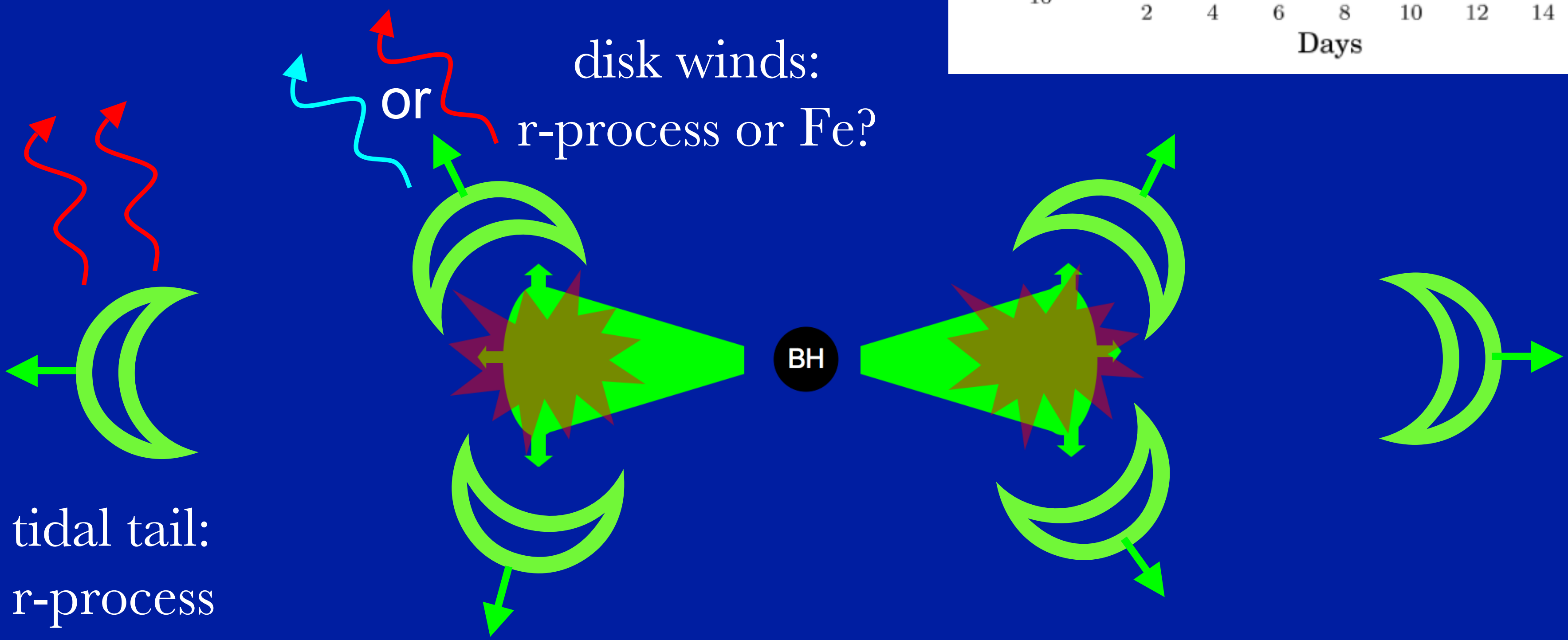
$$\dot{M}_r \sim \frac{R_{SGRB} \times M_{ej}}{n_{gal}}$$

$$\sim \frac{10^{-8}\ \mathrm{Mpc}^{-3}\ \mathrm{yr}^{-1} \times 0.03 M_\odot}{0.03\ \mathrm{gal\ Mpc}^{-3}}$$

$$\sim 10^{-8} M_\odot\ \mathrm{yr}^{-1}\ \mathrm{gal}^{-1} \sim 0.02 \dot{M}_{\mathrm{MW}}$$

Two Component Light Curve





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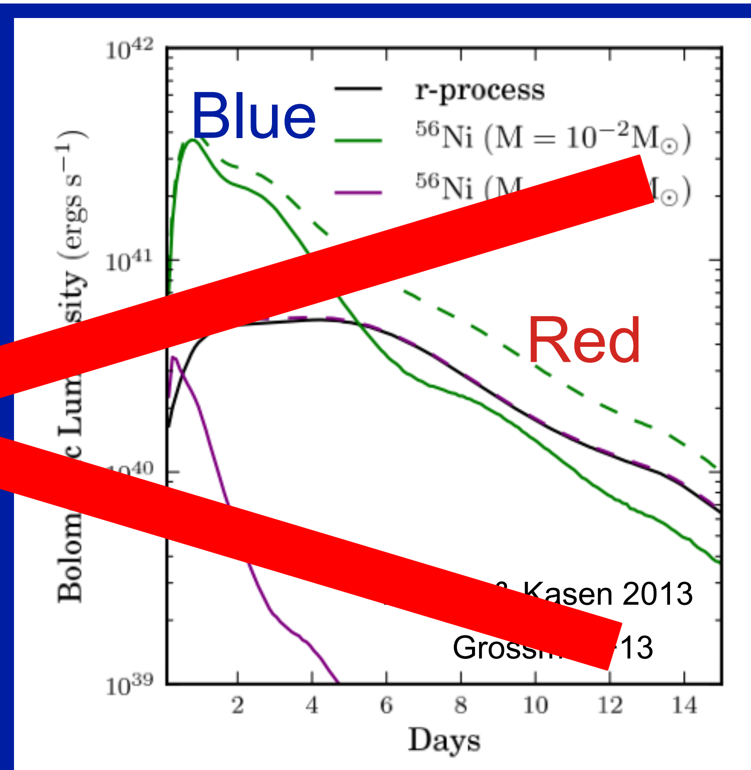

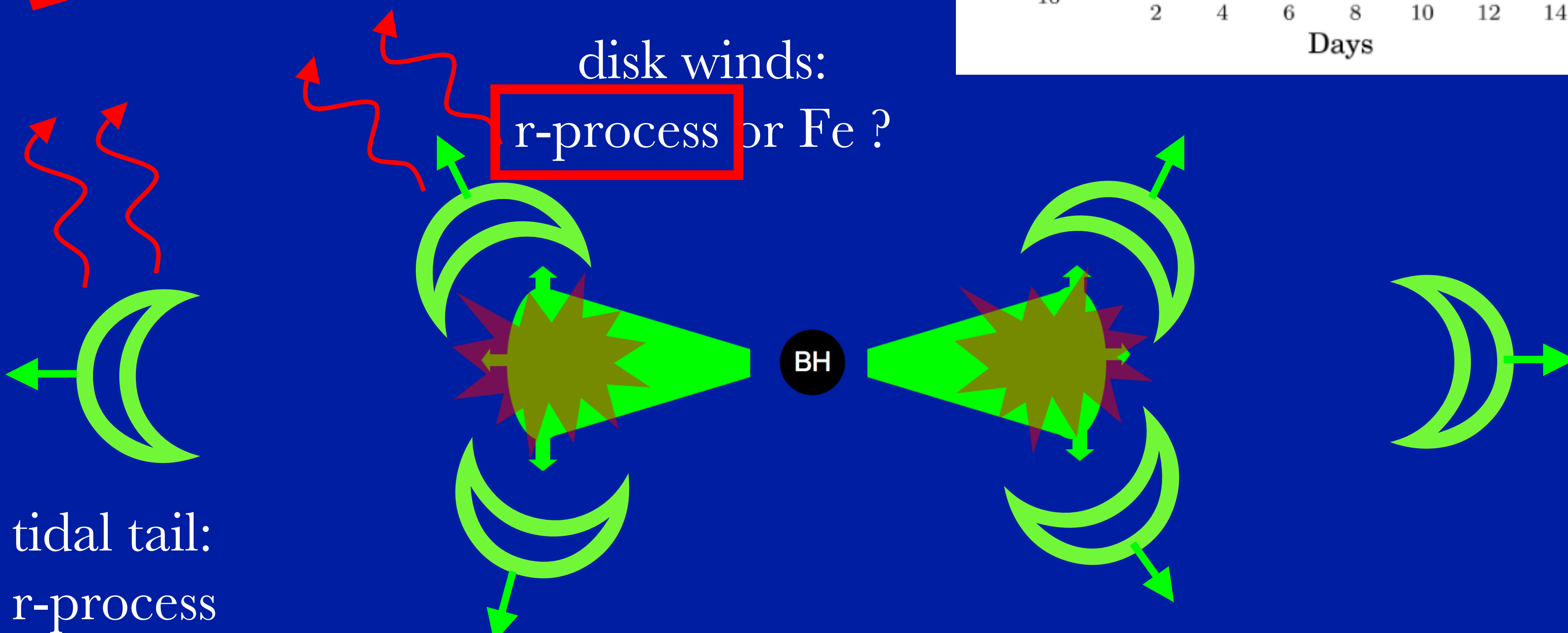

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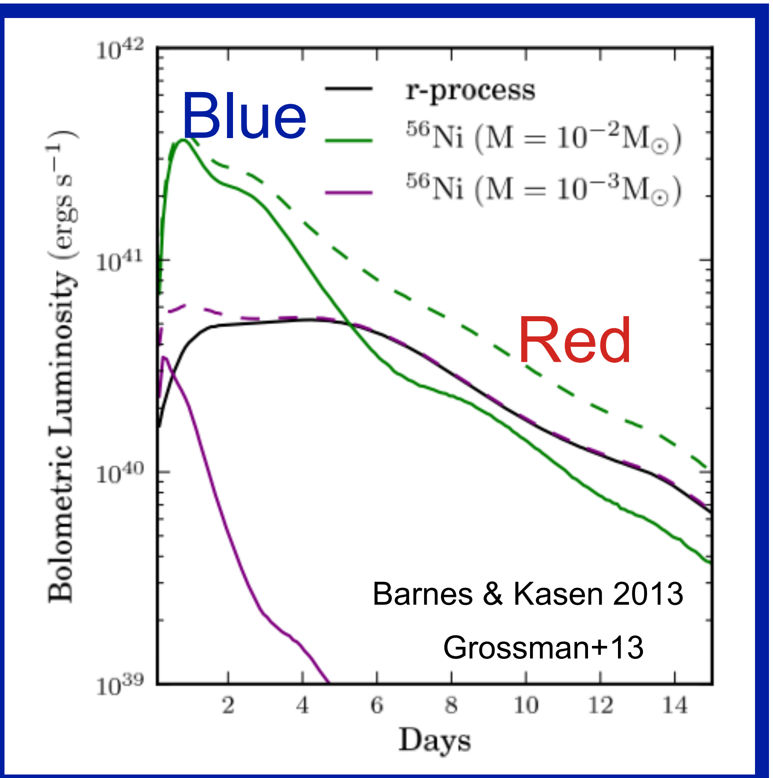

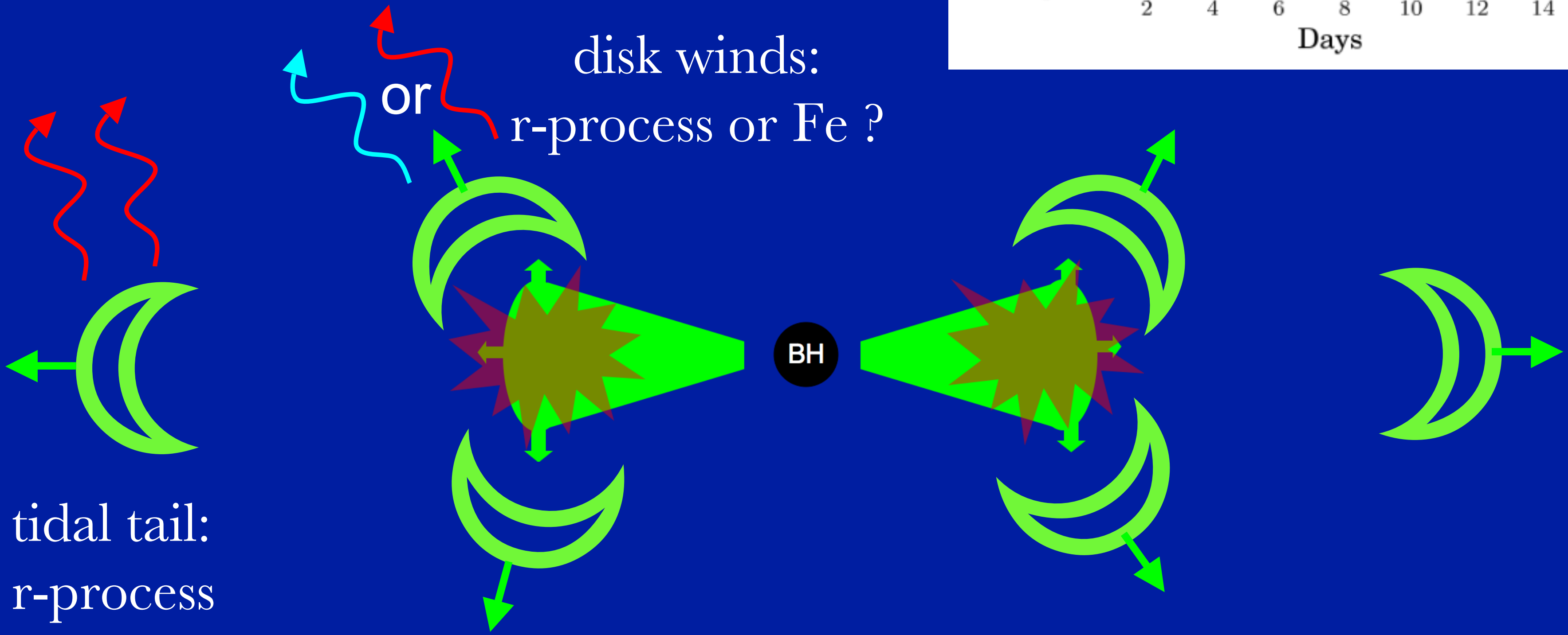

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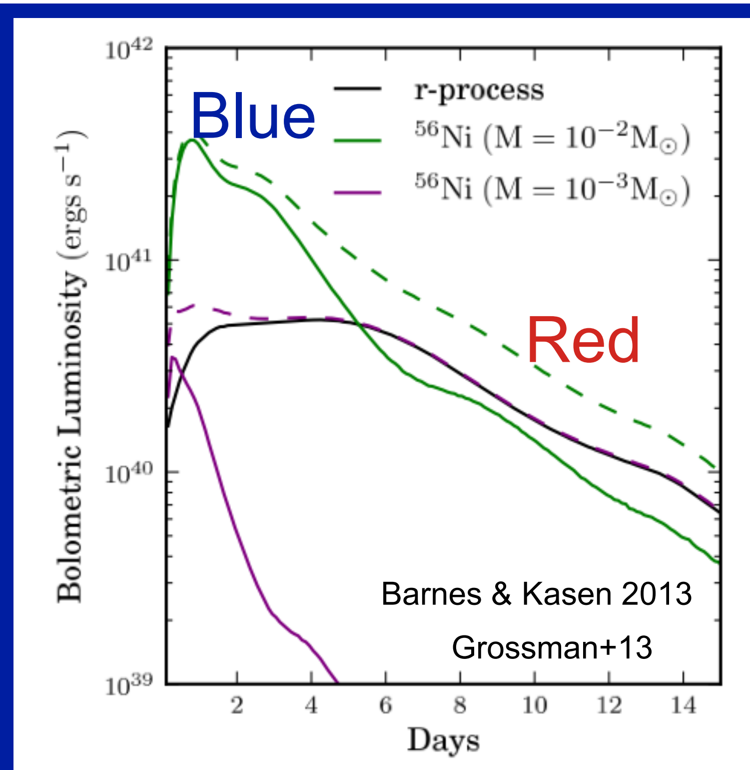
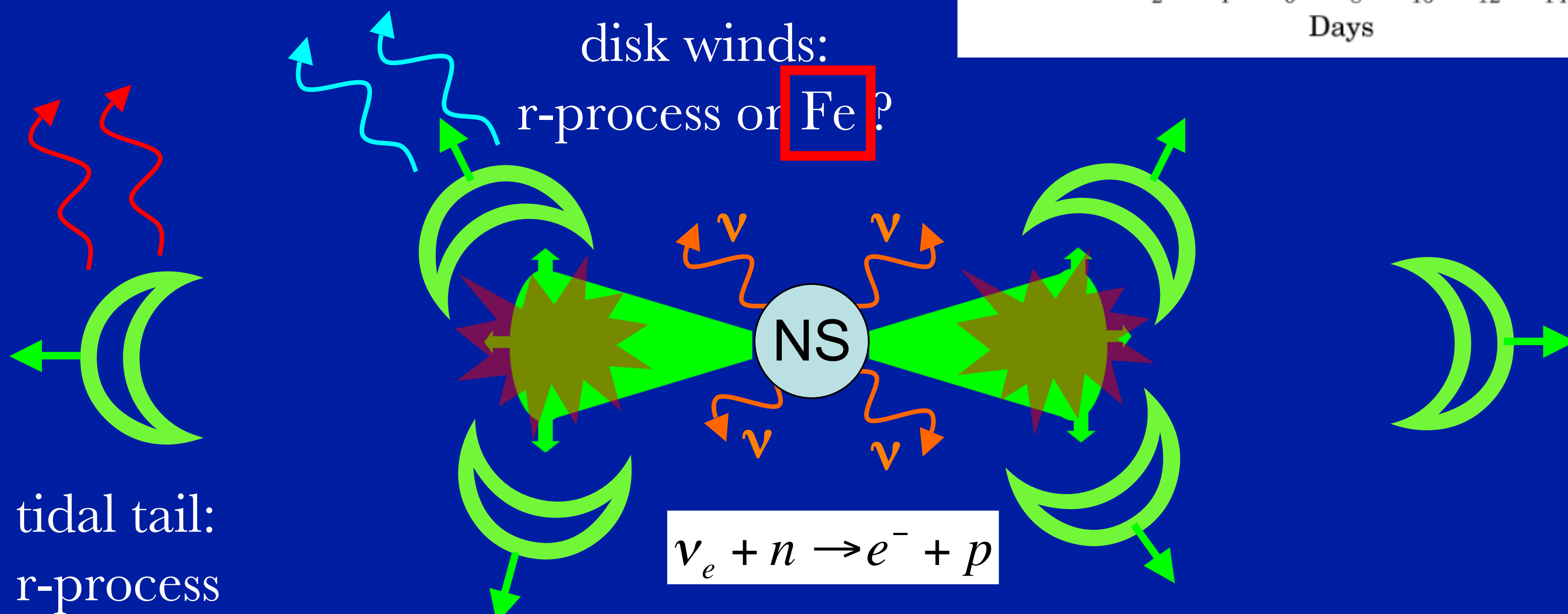
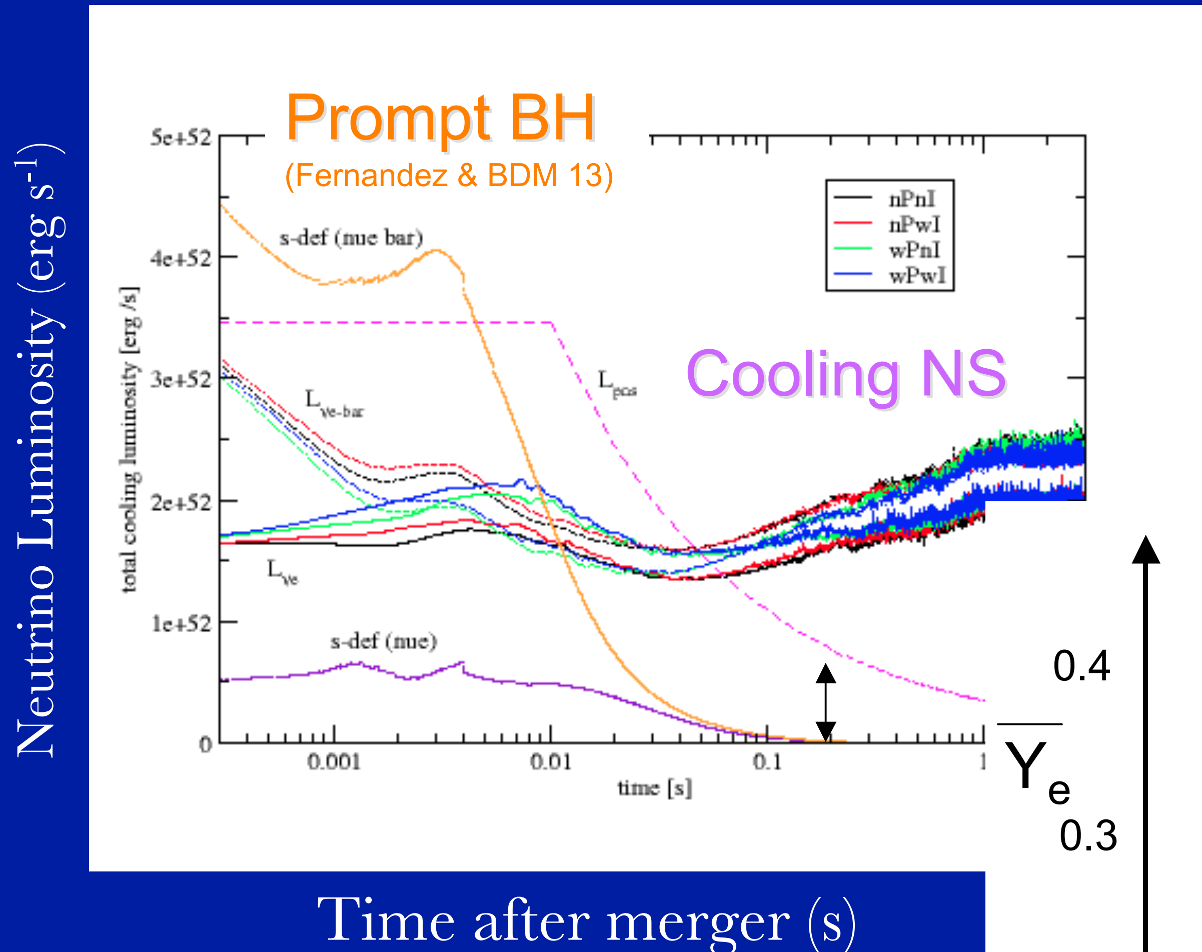
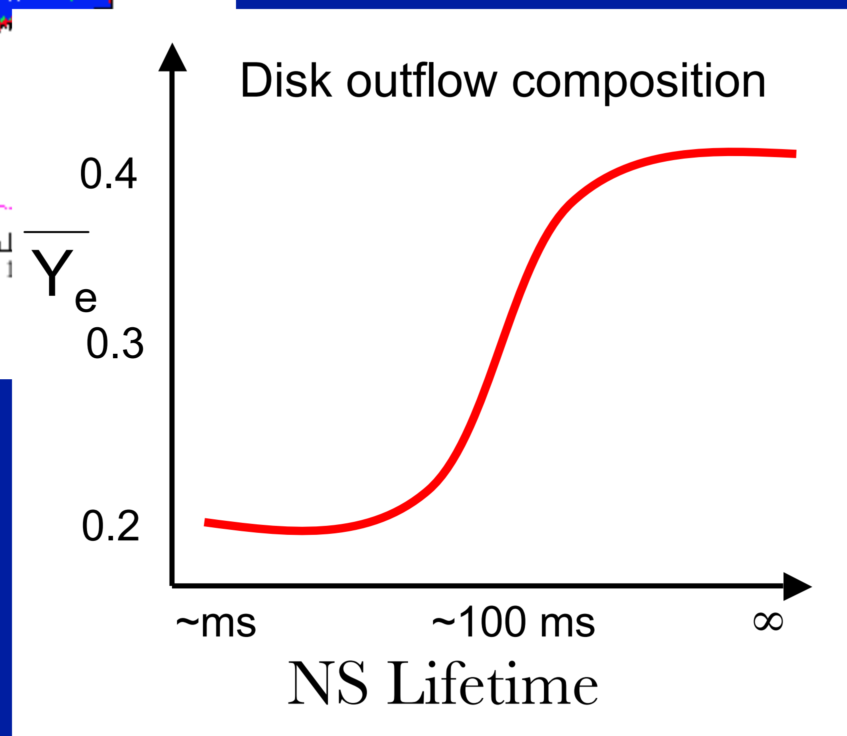




Neutrinos from NS Remnant





See talk by Albino Perego

Indefinitely Stable Neutron Star Remnant?

(e.g. BDM+08; Ozel et al. 2010; Bucciantini et al. 2012; Zhang 13; Giacomazzo & Perna 13; Falcke & Rezzolla 13; Kiziltan 2013)

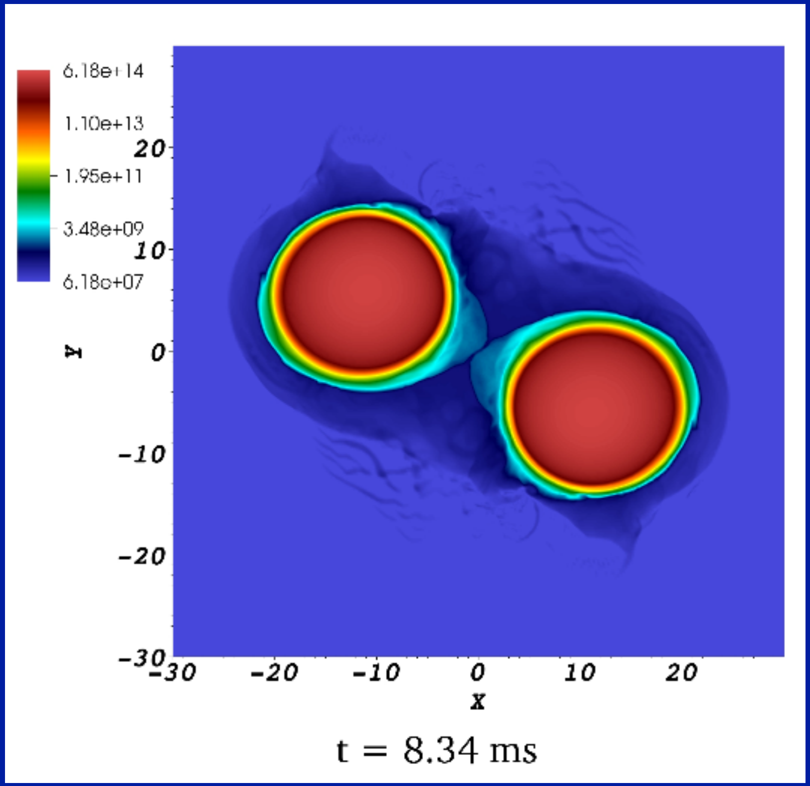
- Requires: low total mass binary, stiff EOS*, and/or mass loss during merger

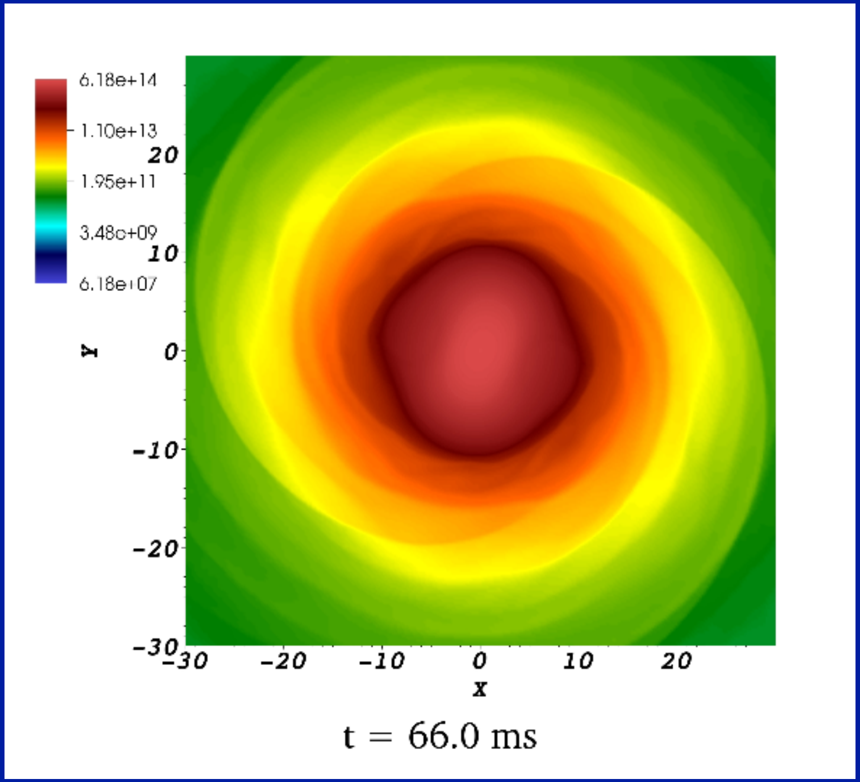
  *supported by recent discovery of $2M_{\odot}$ NS by Demorest et al. 2011

- Rotating near centrifugal break-up with spin period P ~ 1 ms

- Magnetic field amplified by rotational energy ⇒ **“Magnetar” ?**

  (e.g. Thompson & Duncan 92; Price & Rosswog 2006; Zrake & MacFadyen 2013)

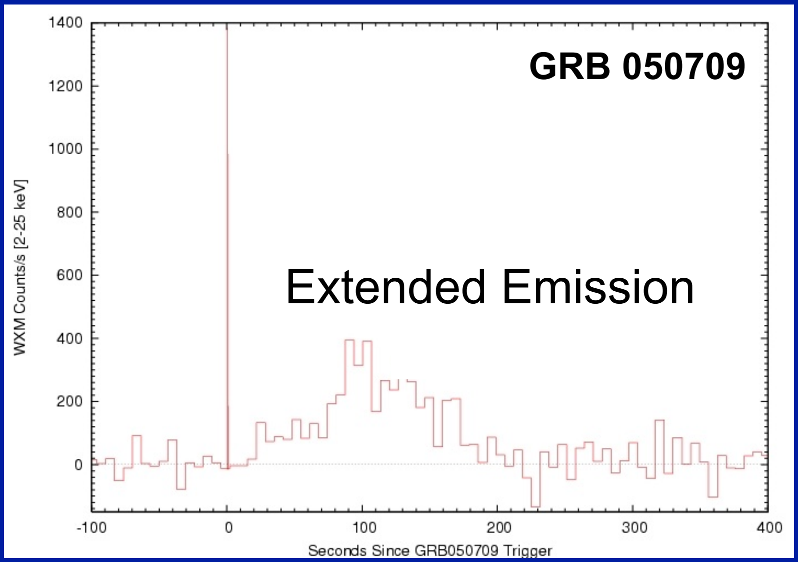


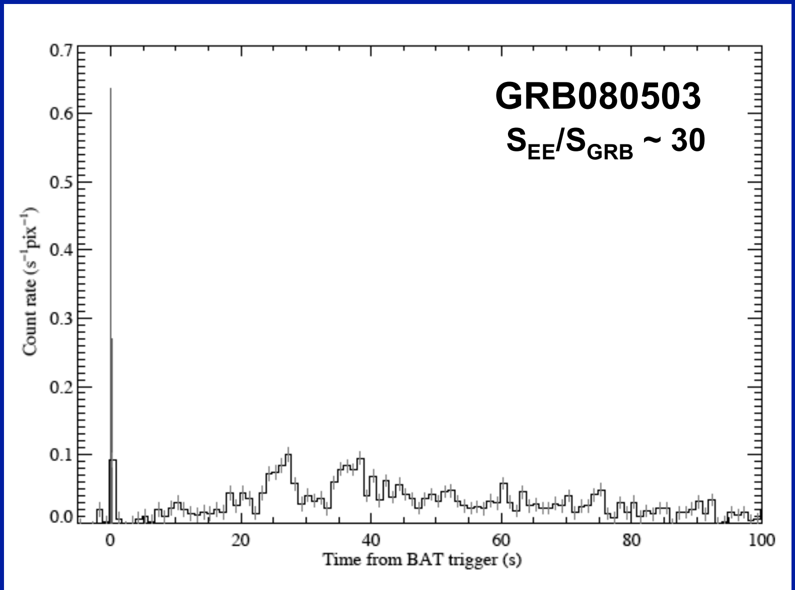


Giacomazzo & Perna 2013

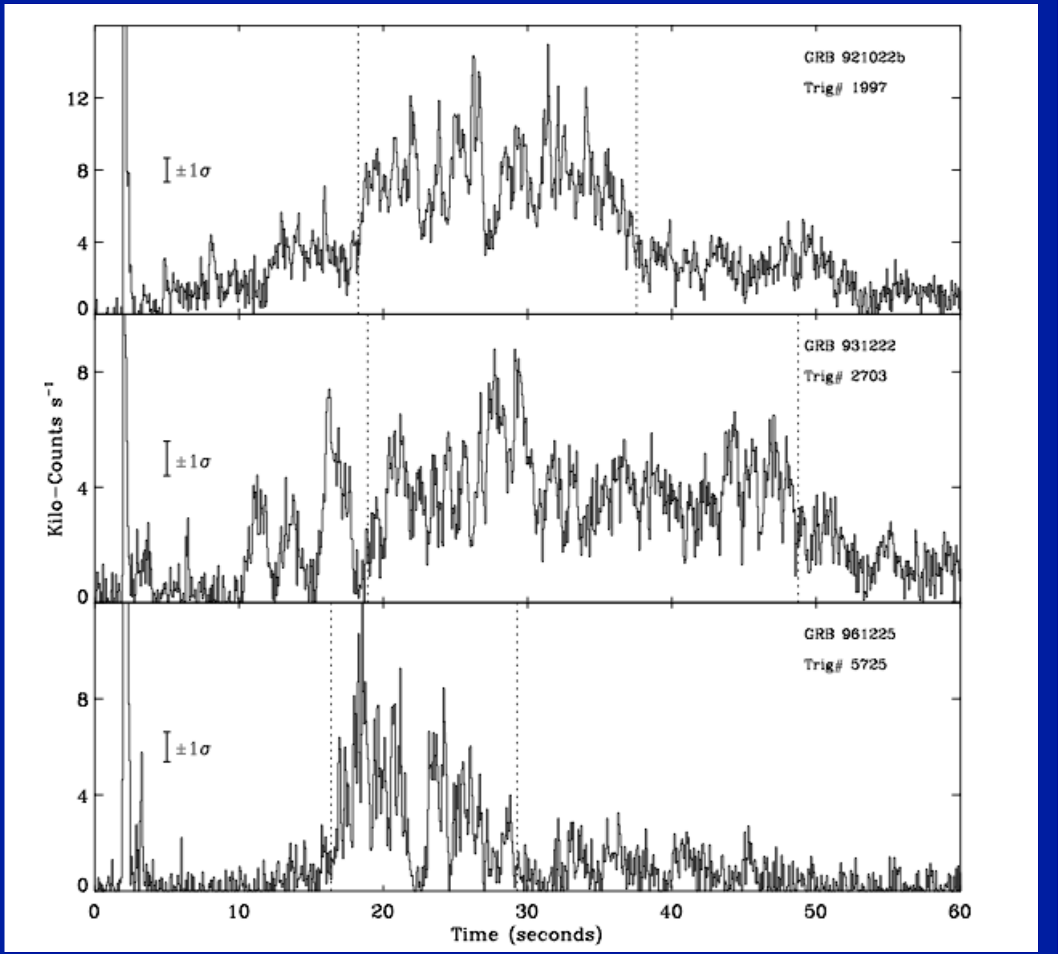
Short GRBs with Extended Emission

- 1/5 Swift Short Bursts have X-ray Tails
- Rapid Variability ⇒ Ongoing Engine Activity
- Energy up to ~30 times Burst Itself!





Perley, BDM et al. 2009

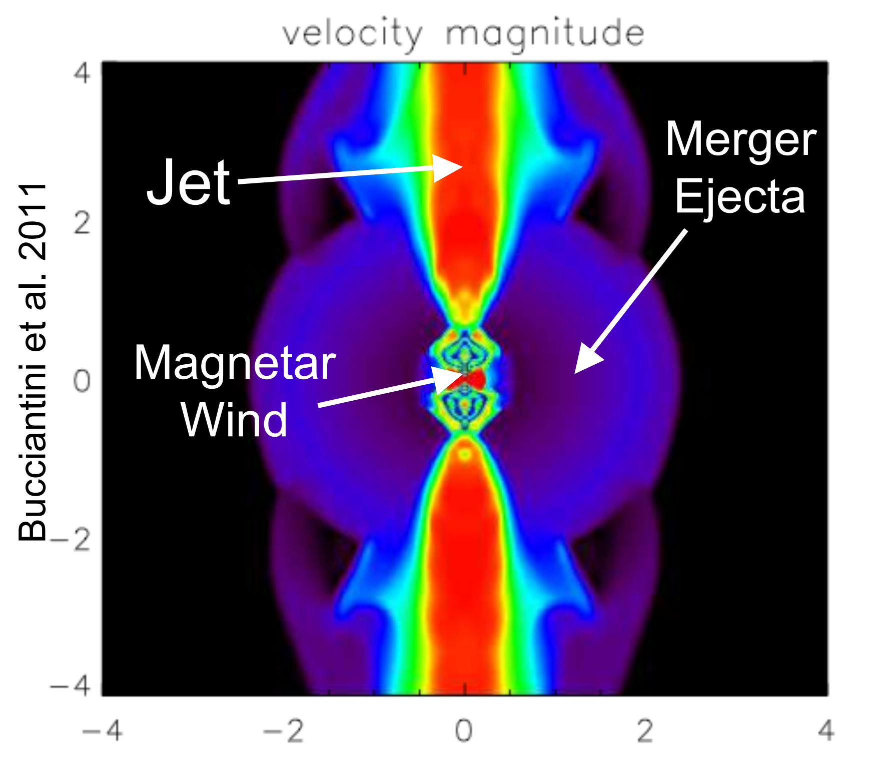


BATSE Examples (Norris & Bonnell 2006)

Magnetar Spin-Down Powered Extended Emission

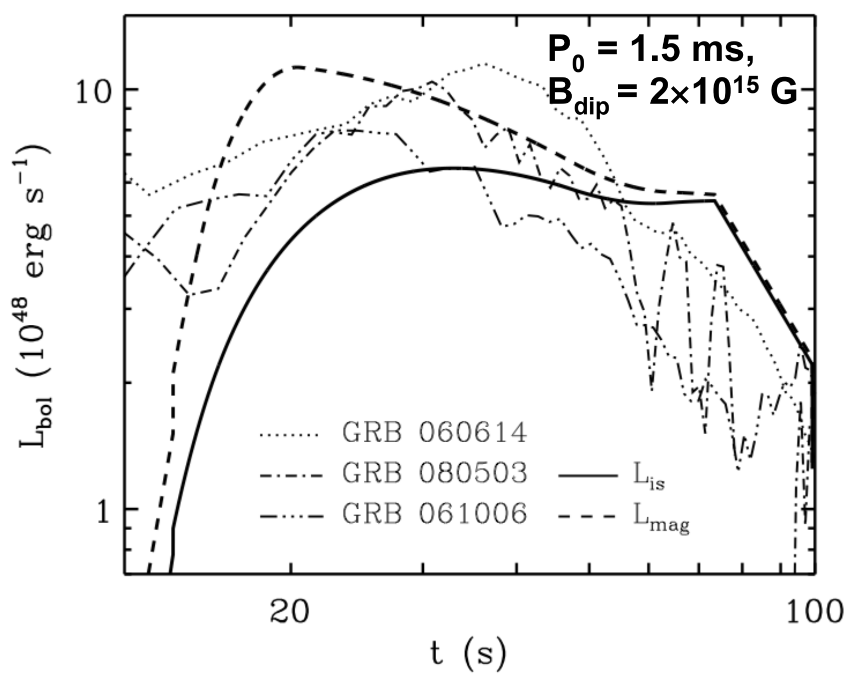
(BDM et al. 2008; Bucciantini, BDM et al. 2012; cf. Gao & Fan 2006)

Magnetar wind confined by merger ejecta



Theoretical Light Curves vs. observed X-ray tails

(magnetar outflow model from Metzger et al. 2011)



Jet may continue to inject energy into forward shock or produce lower level prompt emission

(Zhang & Meszaros 2001; Dall'Osso et al. 2011; Rowlinson et al. 2013; Gompertz et al. 2013)

Millisecond Magnetar Wind Nebula

Metzger & Piro, submitted (see also Yu et al. 2013)

time for jet to escape envelope

$$t_{\rm bo} \approx 0.17\left(\frac{L_{\rm j}}{10^{47}\,{\rm erg\,s^{-1}}}\right)^{-1/3}\left(\frac{\theta}{30^{\circ}}\right)^{4/3}\left(\frac{R_{\rm ej}}{10^{13}\,{\rm cm}}\right)^{2/3}\left(\frac{M_{\rm ej}}{0.01\,M_{\odot}}\right)^{1/3}\,{\rm hr}$$

Bromberg et al. 2011

jet power ∝ pulsar luminosity

$$L_{\rm j} \sim L_{\rm sd} = \frac{\mu^2\Omega^4}{c^3} \underset{t \gg t_{\rm sd}}{\approx} 1.2\times10^{48}\,B_{15}^{-2}t_{\rm hr}^{-2}\,{\rm erg\,s^{-1}}$$

$$\frac{t_{\rm bo}}{t} \sim 0.6\left(\frac{\epsilon_j}{0.5}\right)^{-1/3}\left(\frac{B_{\rm d}}{10^{15}\,{\rm G}}\right)^{2/3}\left(\frac{\theta}{30^{\circ}}\right)^{4/3}\left(\frac{v_{\rm ej}}{c}\right)^{2/3}\left(\frac{M_{\rm ej}}{0.01\,M_{\odot}}\right)^{1/3}\left(\frac{t}{\rm hr}\right)^{1/3}$$

⇒ Jet ‘choked’ behind ejecta at late times

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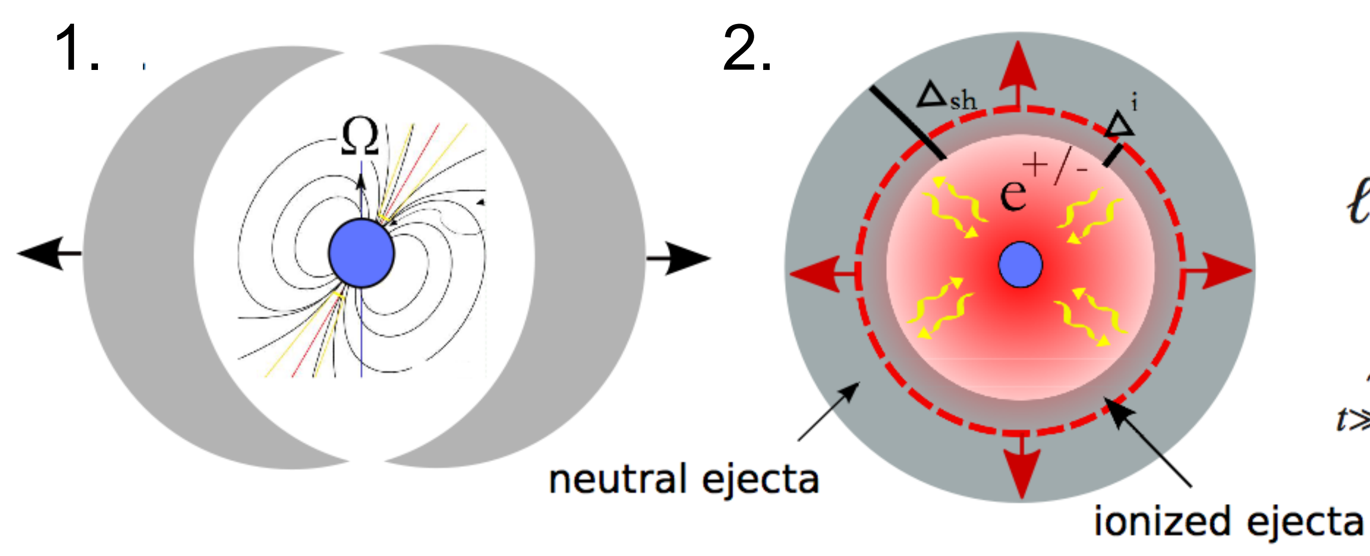
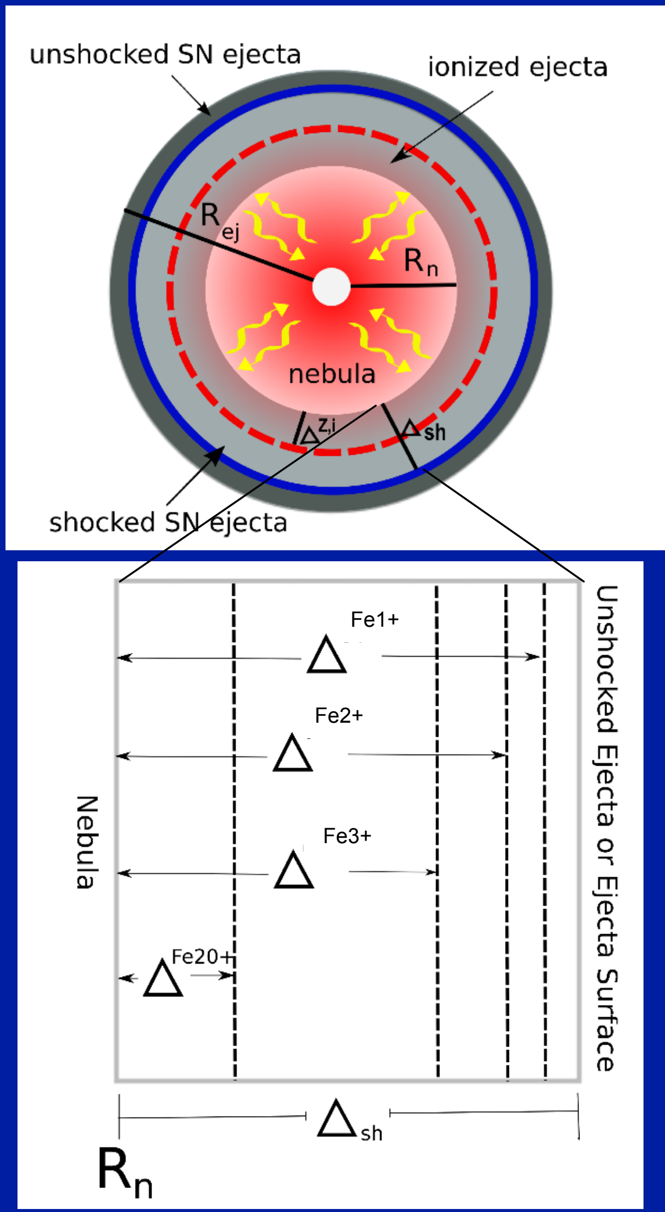


$$\ell \equiv \frac{E_{\rm nth}\sigma_{\rm T}R}{Vm_ec^2} \underset{t\gg t_{\rm sd}}{\sim} 3\times 10^4 B_{15}^{-2} t_{\rm hr}^{-3}$$

Evolution Model for Millisecond Pulsar Wind Nebulae

(BDM, Vurm, Hascoet & Beloborodov 2013; BDM & Piro 2013)



Non-Thermal (UV / X-rays)

Source: cooling $e^{+/-}$ pairs (pulsar)

Sinks: PdV work, absorption by ejecta walls

Thermal Bath (Optical)

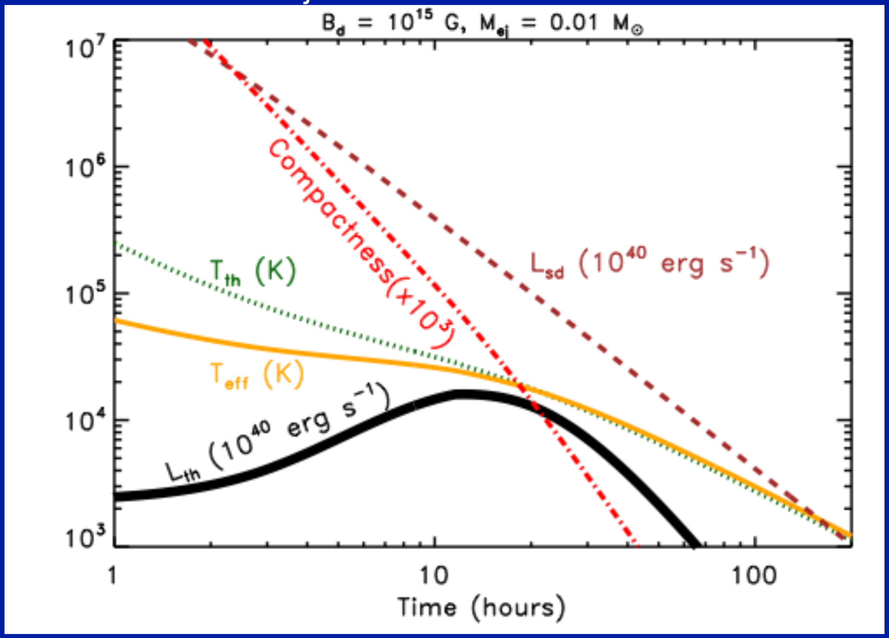
Source: re-emission of X-rays by ejecta walls

Sinks: PdV work, radiative diffusion

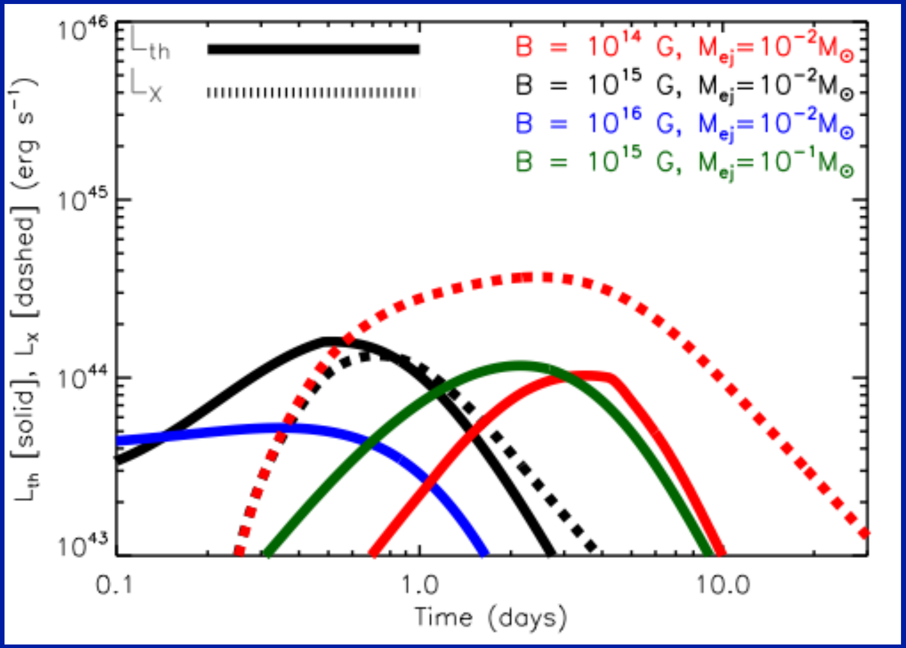
Ejecta Ionization State

- Balance photo-ionization with recombination in ionized layer(s)
- Sets ejecta albedo (thermalization efficiency)

Example ($M_{ej}=10^{-2}\,M_\odot$; $B_d=10^{15}$ G)



Optical [Solid], X-ray [Dashed] Light Curves



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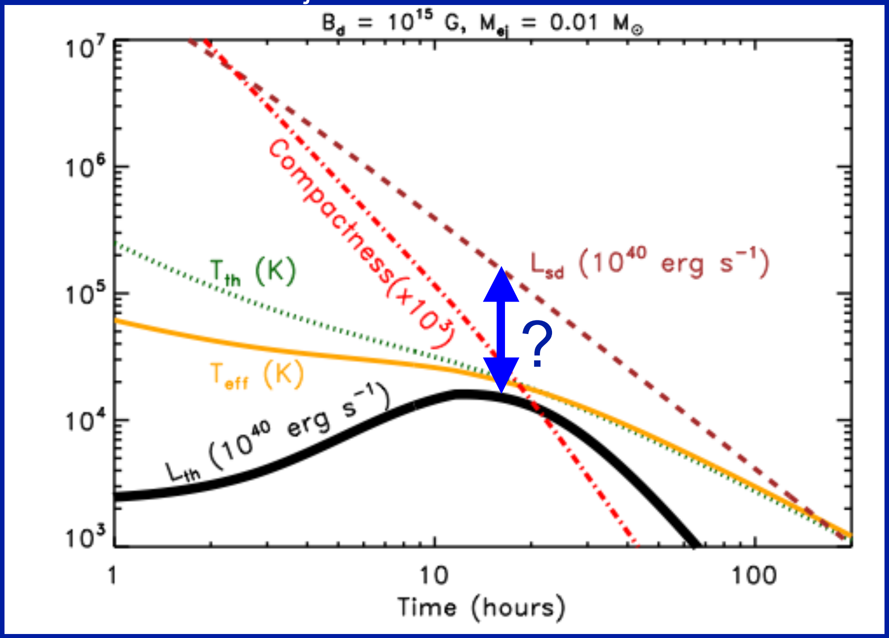

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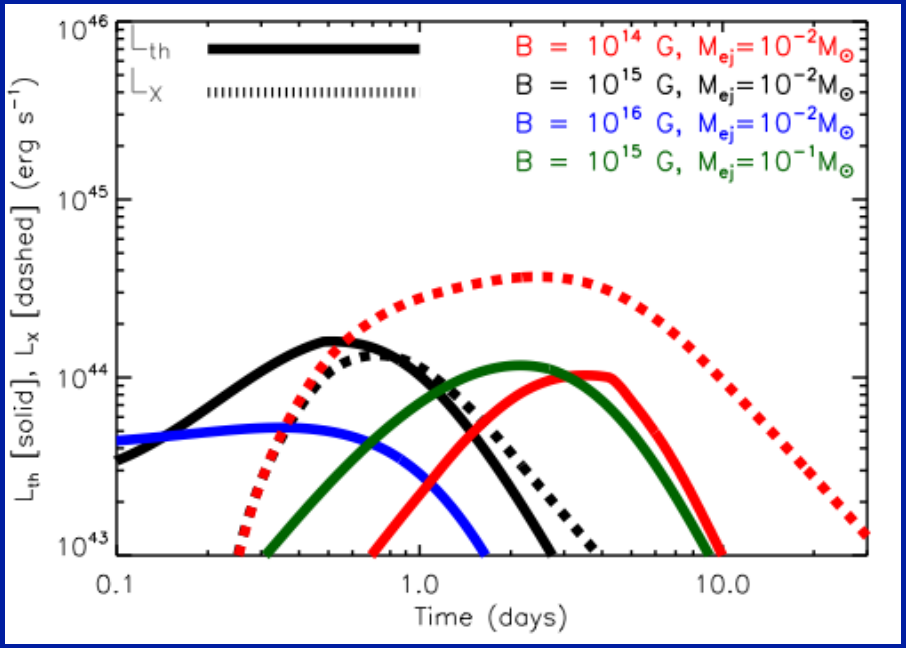

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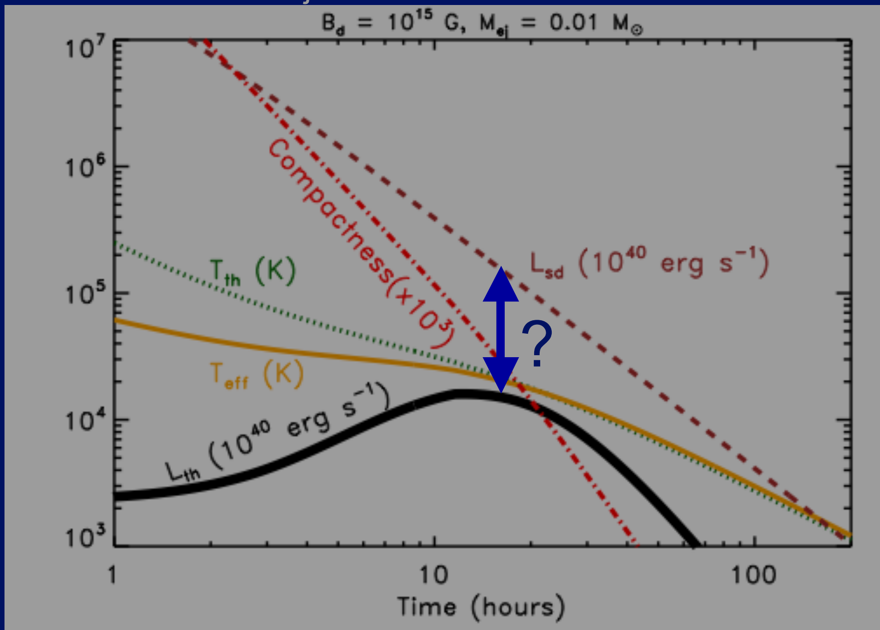

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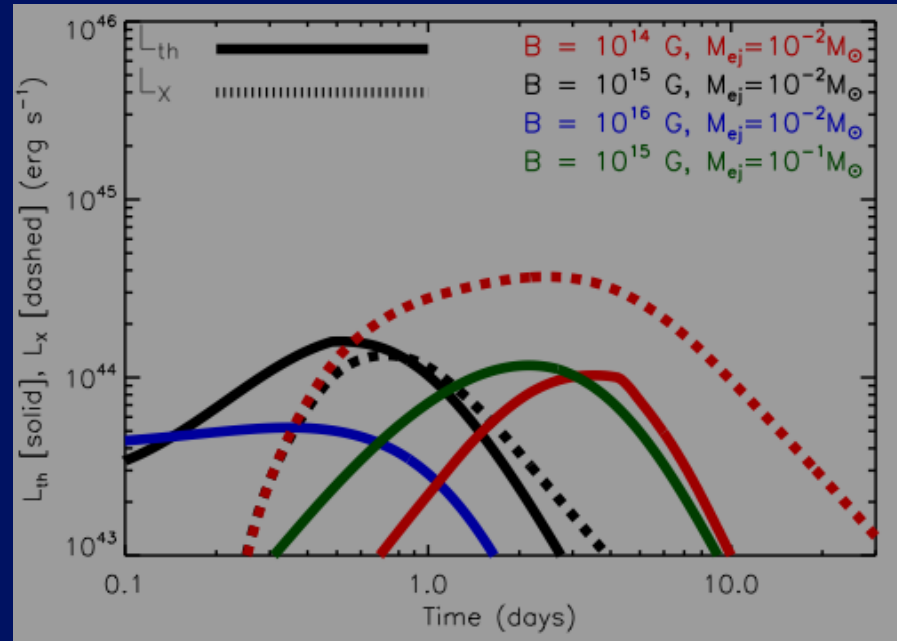
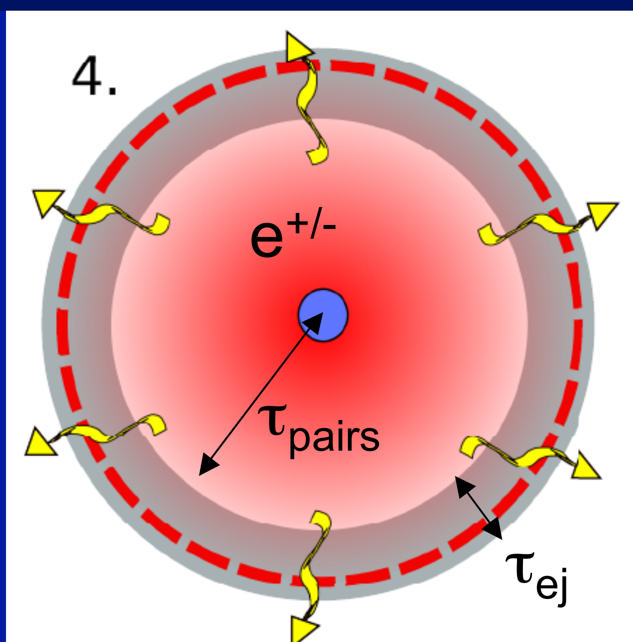




Peak Luminosity

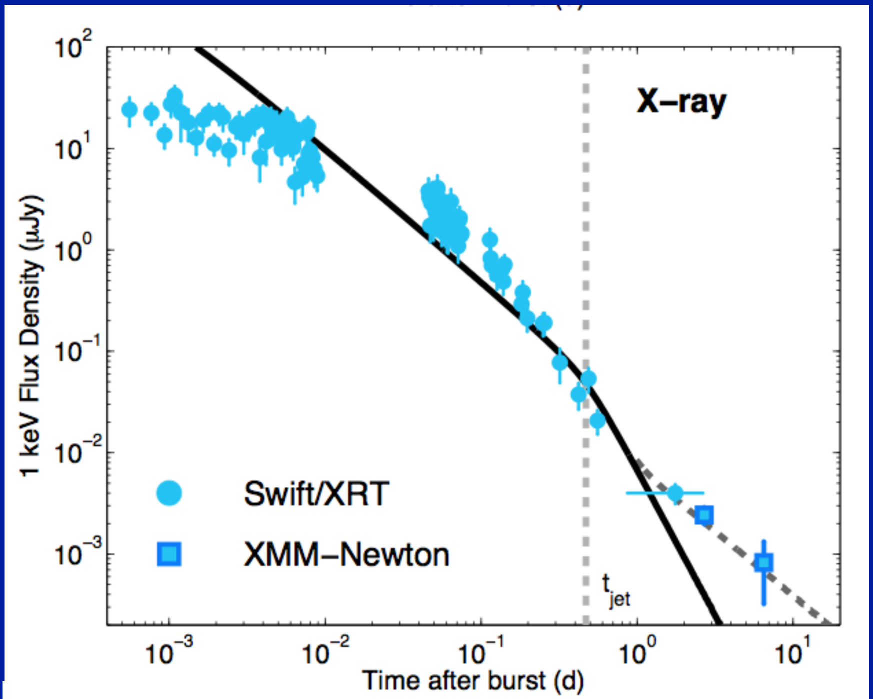
$$L_{\rm opt,peak} \approx \chi^{-3/2} L_{\rm sd}\Big|_{t_{\rm peak}}$$

$$\chi \equiv \frac{\tau_{\rm pairs}}{\tau_{\rm ej}}\Bigg|_{t_{\rm peak}} \approx 2.7\left(\frac{B_{\rm d}}{10^{15}\,{\rm G}}\right)^{-2/3}\left(\frac{M_{\rm ej}}{10^{-2}\,M_\odot}\right)^{-2/3}\left(\frac{v_{\rm ej}}{c}\right)^{5/6}$$

$\chi > 1 \Rightarrow$ X-rays lose most of their energy to P dV work before reaching ejecta walls to be absorbed

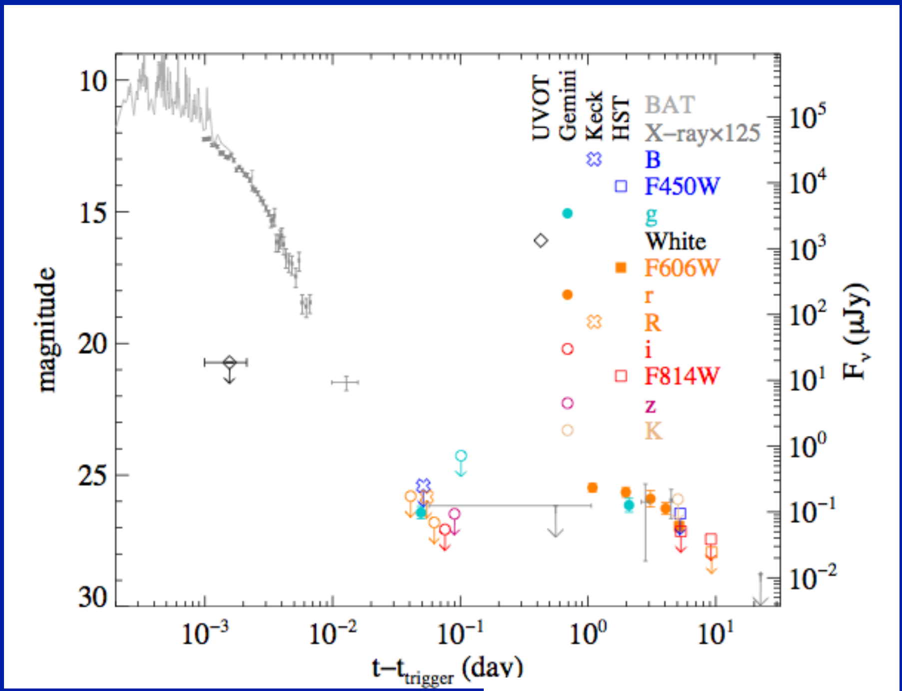
X-ray Excesses in Kilonova Candidates

GRB 130603B



Fong et al. 2013

GRB 080503



Perley et al. 2009

See also Zhang 2013, Gao et al. 2013

Radio constraints on long-lived NS merger remnants

(BDM & Bower 2013)

- Rotational energy

$$E_{\rm rot} = \frac{1}{2} I \Omega^2 \simeq 3 \times 10^{52} {\rm ergs} \left(\frac{P}{1\,{\rm ms}}\right)^{-2}$$

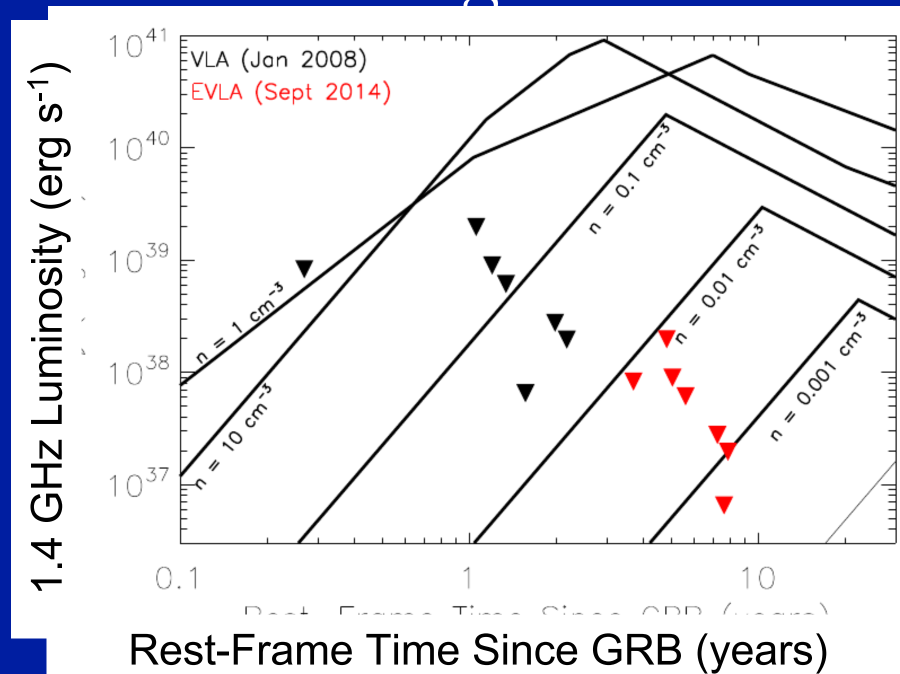
eventually transferred to ISM
⇒ bright radio emission (cf. Gao+13)

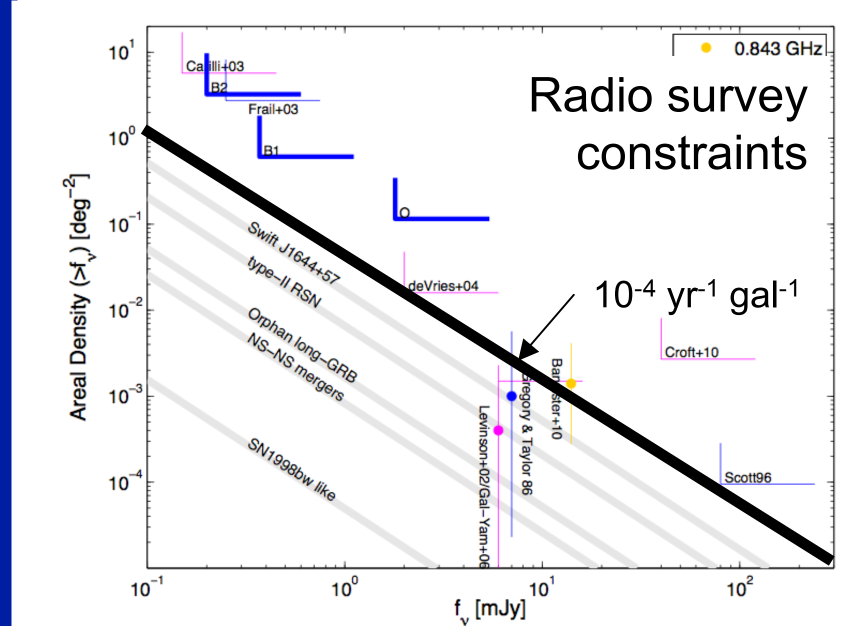
- Observed 7 short GRBs with VLA on timescales ~1-3 years after burst

- NO DETECTIONS ⇒ rules out stable NS remnant in 2 GRBs with known high ISM densities

- Additional JVLA observations *now* much more constraining

- Upcoming radio surveys (e.g. ASKAP) will strongly constrain population of stable NS merger remnants ⇒ indirectly probes EoS





Frail et al. 2012

Timeline of Binary NS Mergers

1.	Chirp enters LIGO Bandpass	t (minus) ~ mins
2.	Last Orbit, Plunge & Dynamical Ejecta	t ~ ms
3.	BH Formation	~ ms - ∞
4.	Accretion of Remnant Disk, Jet Formation (GRB)	~ 0.1-1 s
5.	He-Recombination + Disk Evaporation ⇒ outflow Y_e depends on NS collapse time	~ 0.3-3 s
6.	R-Process in Merger Ejecta	~ few s
7.	Jet from Magnetar (**X-rays**)	~ min (or longer)
8.	Disk Wind Kilonova ⇒ prompt BH formation $Y_e < 0.25$ (NIR, $L \sim 10^{41}$ erg s^{-1}) ⇒ delayed BH formation $Y_e > 0.3$ (Optical, $L \sim 10^{42}$ erg s^{-1}) ⇒ stable magnetar (Optical, $L \sim 10^{44}$ erg s^{-1})	 ~ week ~ day ~ day
9.	Tidal Tail Kilonova (**IR**)	~ week
10.	Ejecta ISM Interaction (**Radio**) ⇒ Much brighter if stable magnetar	~ years

The Structure and Signals of Neutron Stars, from Birth to Death

Workshop: March 10 - April 17, 2014 Conference: March 24 - 28, 2014

- Equation of state of dense matter, including hyperon, kaon and quark degrees of freedom
- Neutrino emission and cooling of compact stars
- Constraints from EM observations
- Gravitational wave sources
- Models for Supernovae and for Gamma Ray Bursts
- Magnetars

organizers:
Fiorella Burgio
Allessandro Drago
Ian Jones
Brian Metzger
Pierre Pizzochero
Anna Watts

Registration Deadline: December 15, 2013

http://indico.cern.ch/e/NS2014