Radiation-hydrodynamic modeling of supernova shock breakout in multi-dimension

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Collaborators: Keiichi Maeda (Kyoto U), Toshikazu Shigeyama (RESCEU)

Reference: Suzuki, Maeda, and Shigeyama (2016), ApJ 825, 92

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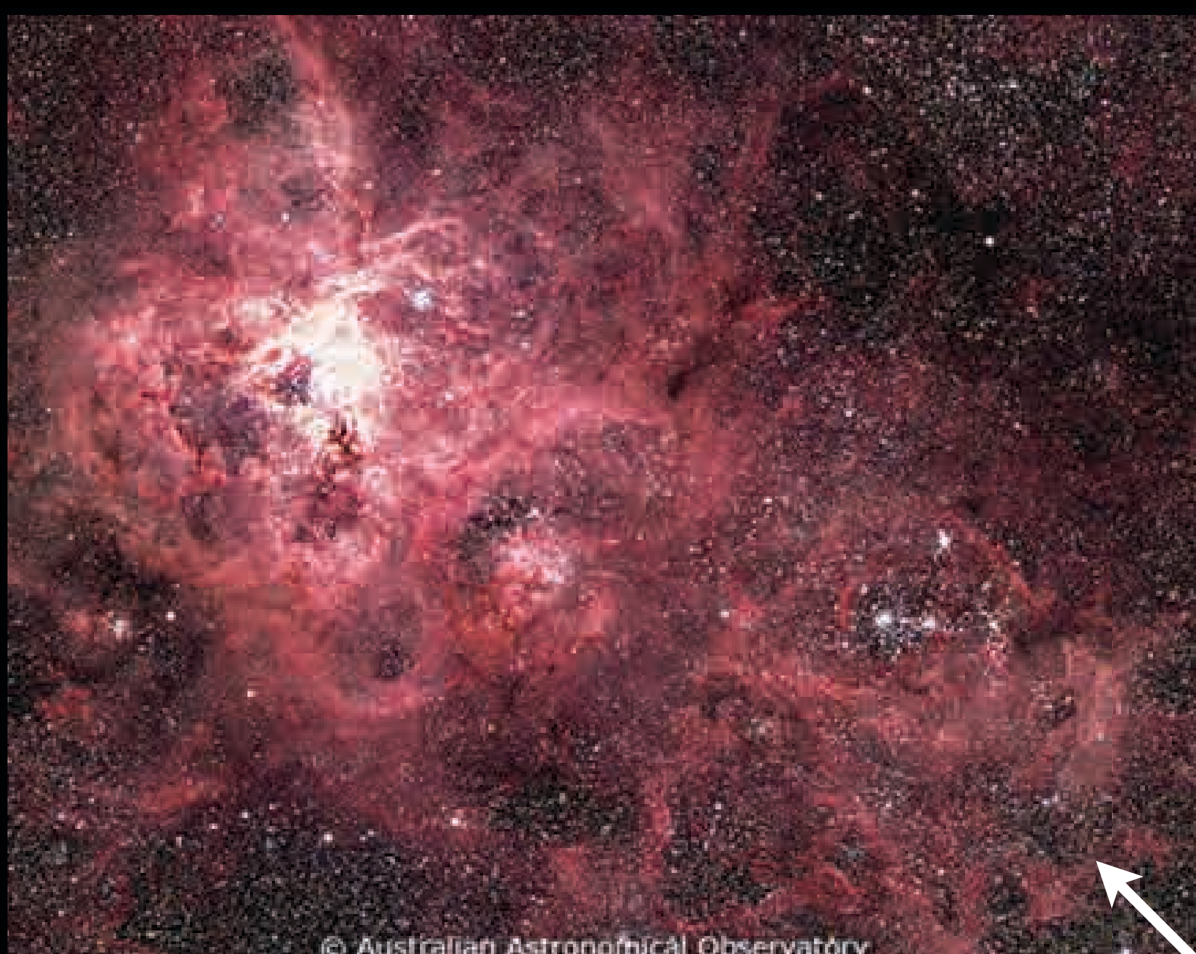
Outline

- ➡ Introduction
- ➡ Shock Propagation in Massive stars
- ➡ 2D radiation-hydrodynamic simulations of SN shock breakout
- ➡ Summary

Supernovae

- ➡ sudden emergence of bright point source
- ➡ stellar death



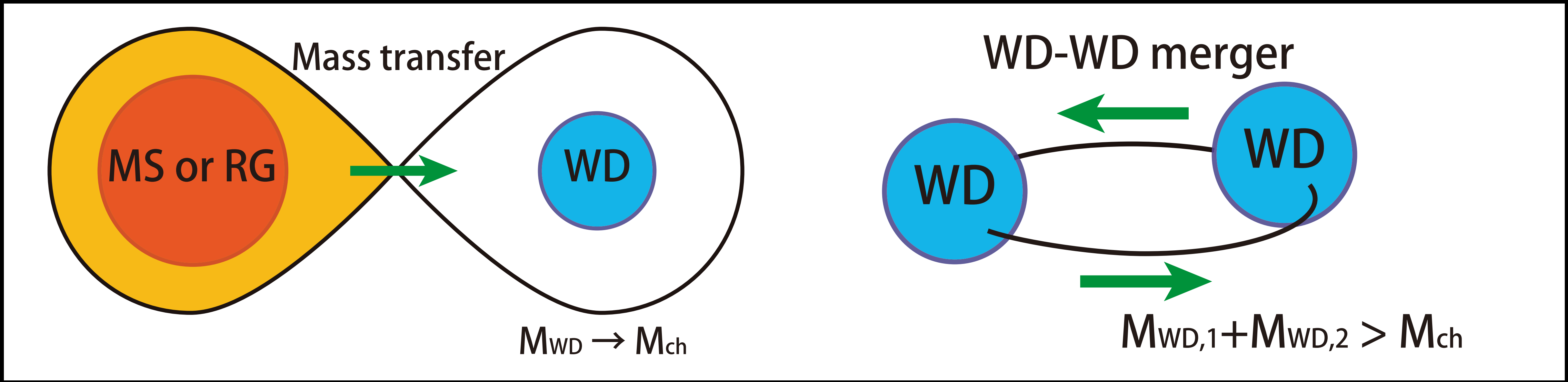
1984

1987

Supernovae

- ➡ sudden emergence of bright point source
- ➡ stellar death
- ➡ classifications based on spectra and light curves: Ia,Ib,Ic, II-P, II-L, IIn
- ➡ classifications based on progenitors: thermonuclear explosions of WDs, gravitational collapse of massive stars

type Ia



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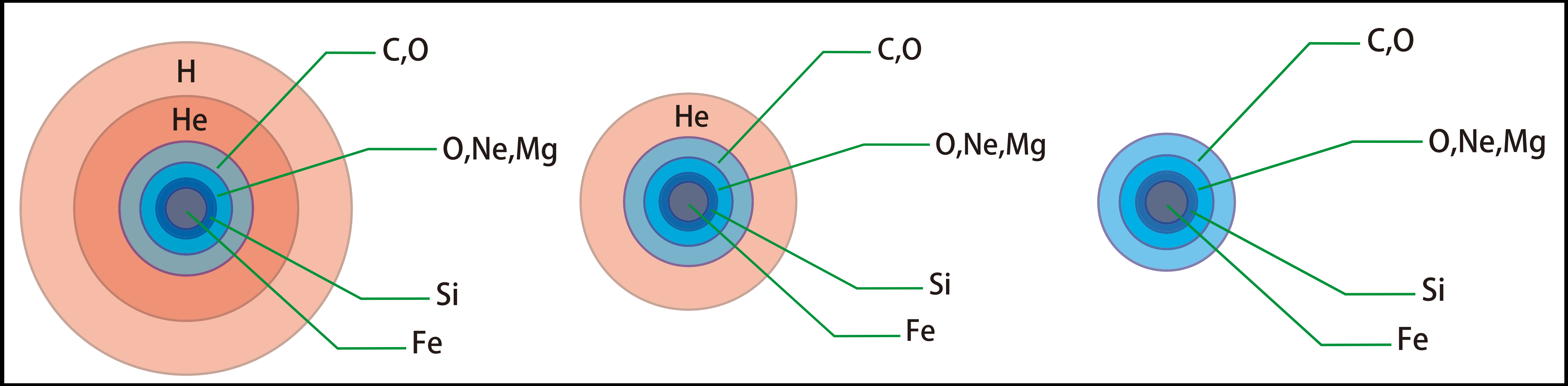
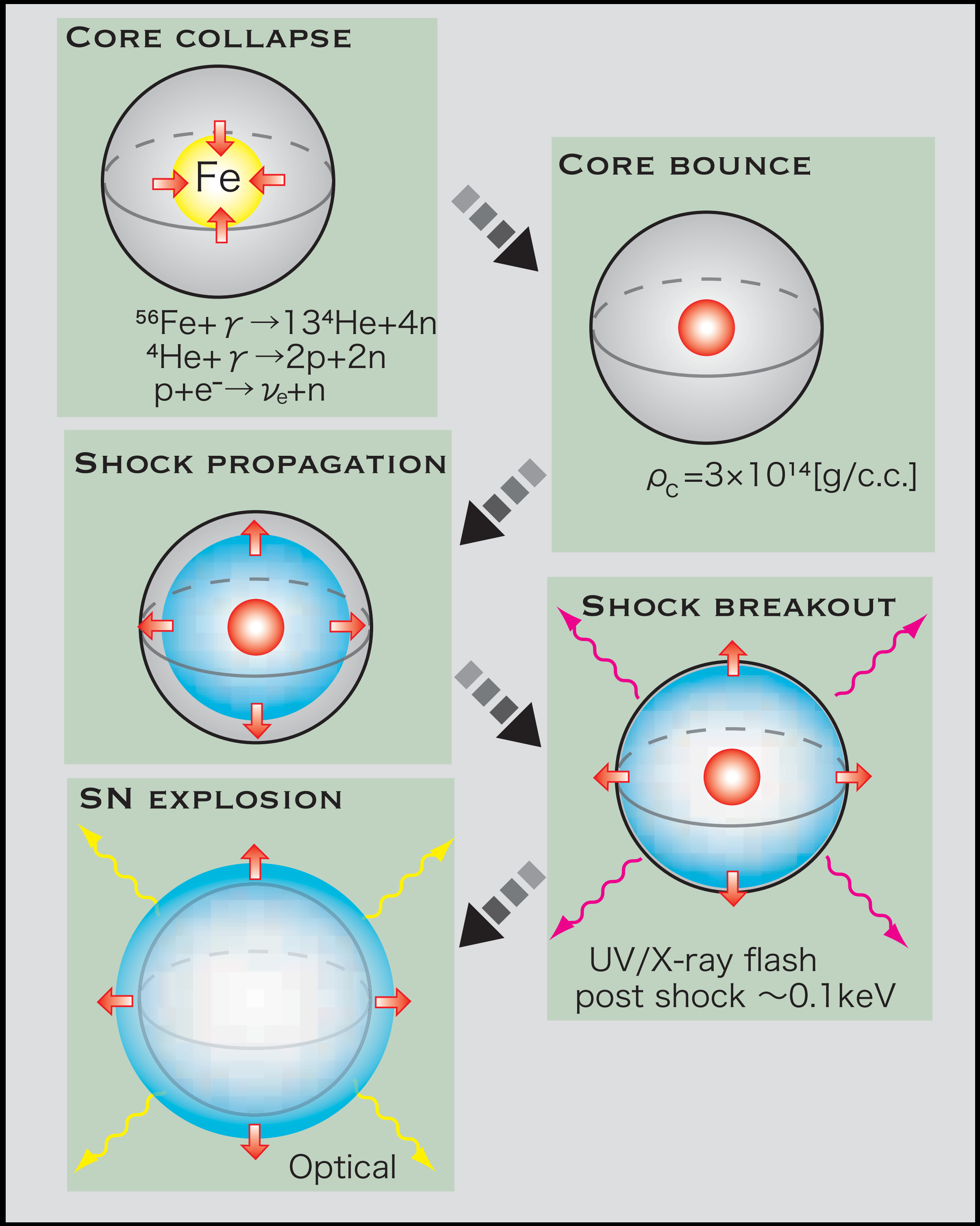
➡ **my main focus in today's talk**

type II **type Ib** **type Ic**



Core-collapse supernova

- ➡ gravitational collapse of the iron core having grown in a massive star
- ➡ core bounce,neutronization
- ➡ blast wave propagation powered by neutrino emission from proto-neutron star
- ➡ shock emergence from the surface
- ➡ expanding ejecta



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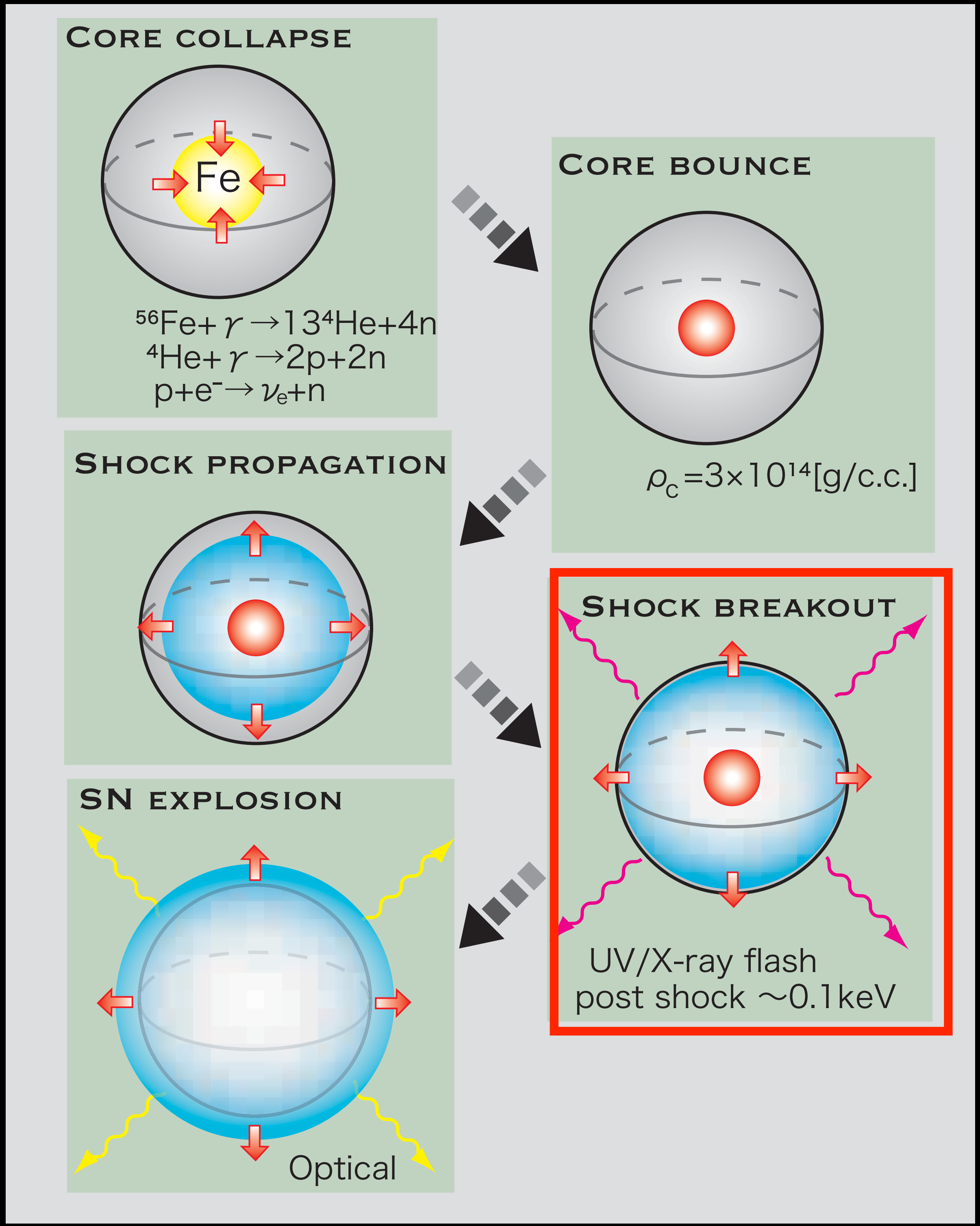


SN shock breakout

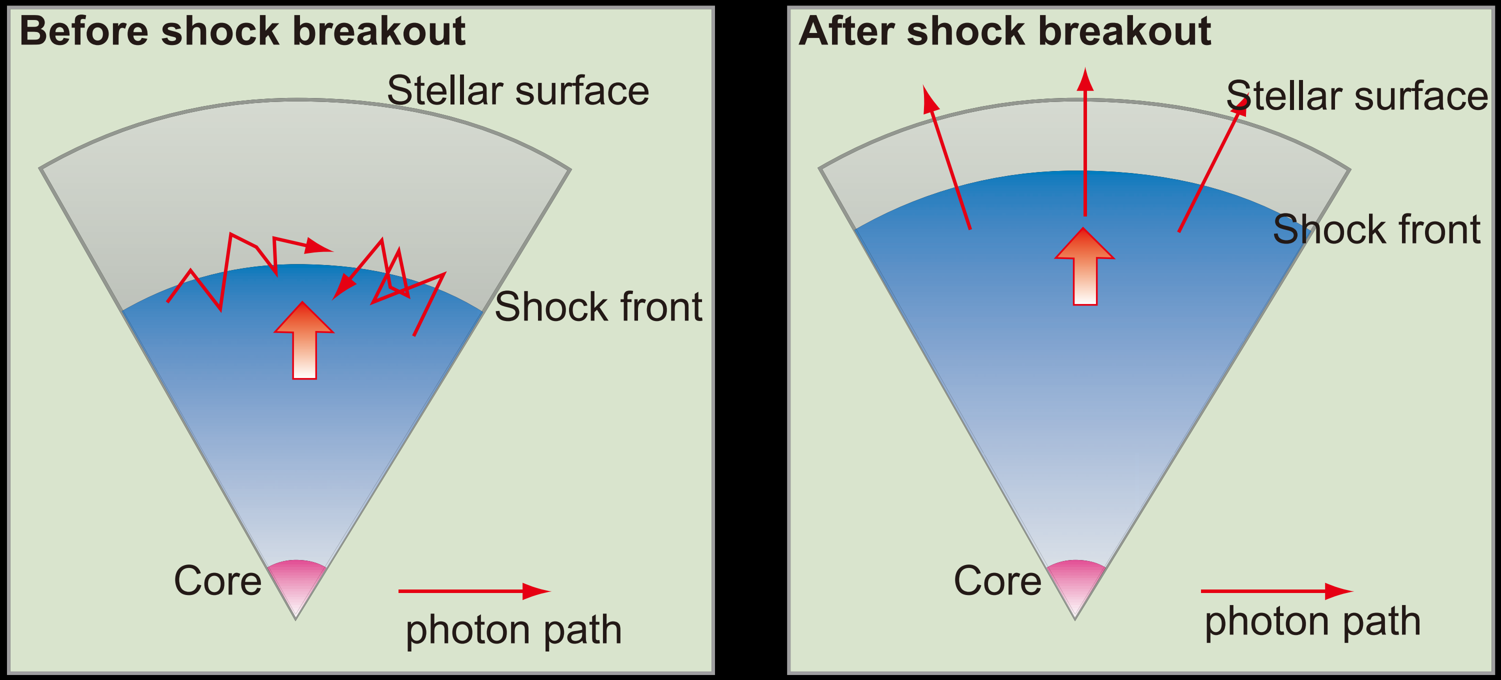
- ➡ UV/X-ray flash associated with the birth of an SN explosion
- ➡ It occurs when the strong shock having been generated at the iron core emerges from the stellar surface
- ➡ We can observe the SN through EM only after shock breakout

photon diffusion velocity $V_{diff} = c/\tau$

shock velocity V_s

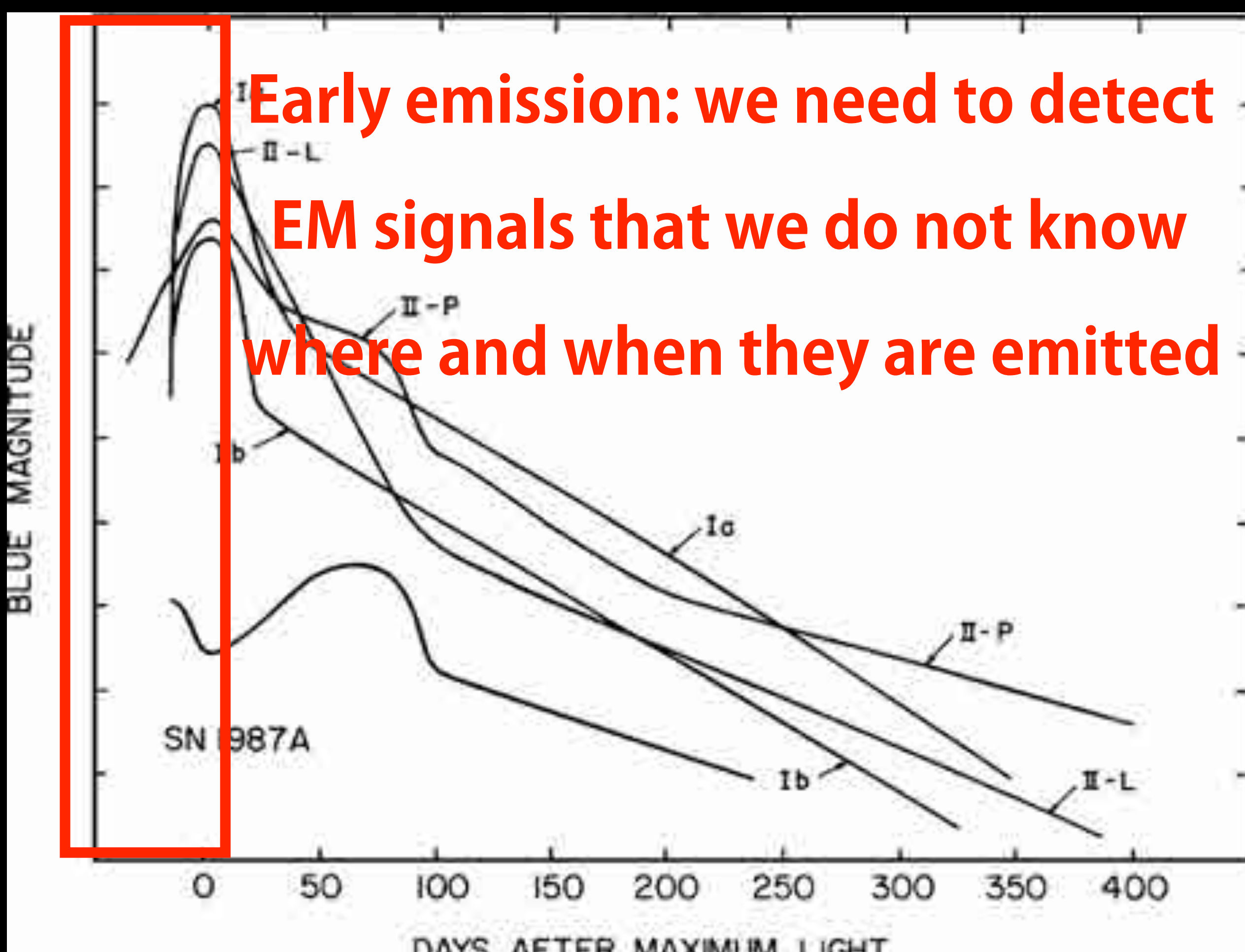
breakout condition $c/\tau > V_s$

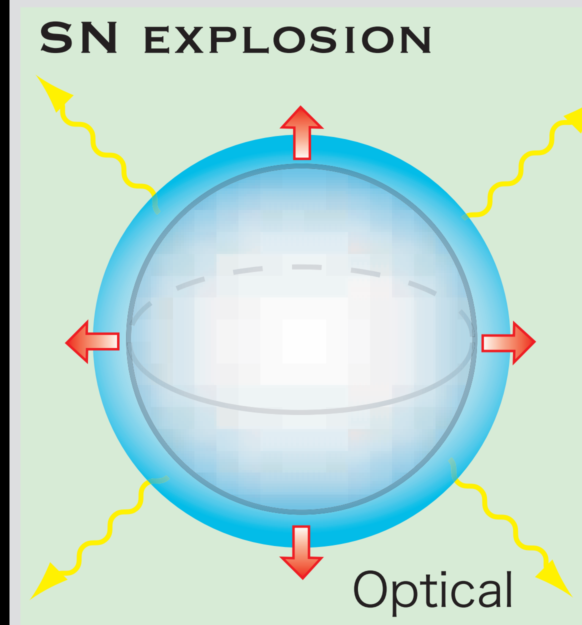
temperature $T_{br} \sim 10^6 [K] \sim 0.1 [keV]$



Core-collapse supernova

➡ Traditionally, optical observations probe the ejecta dynamics, amount of synthesized radioactive ^{56}Ni(energy source), abundance, etc





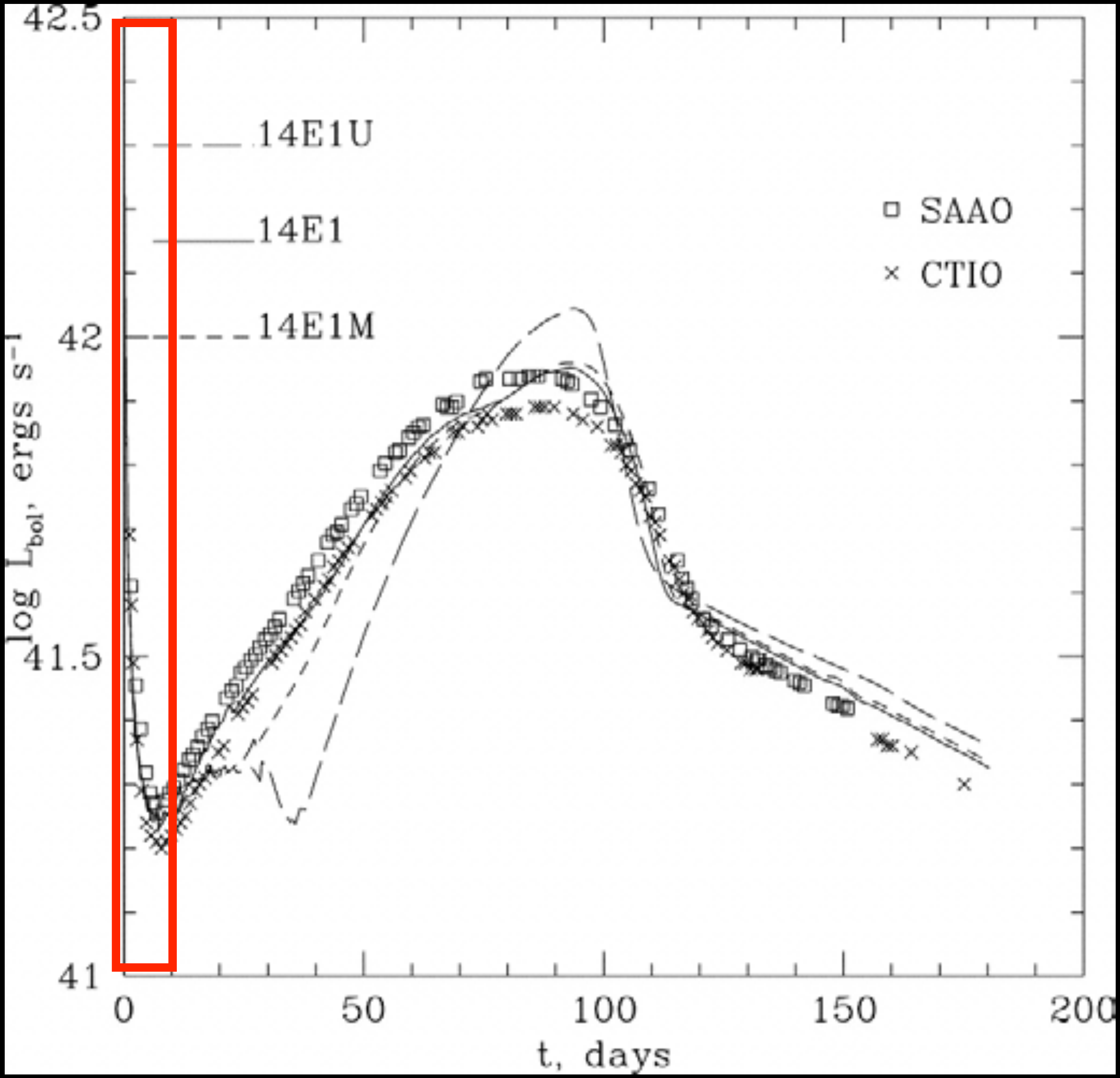
light curves
spectra
polarimetry

explosion energy
ejecta mass
chemical composition
explosion geometry

SN 1987A

- most famous SNe @ magellanic cloud
- type II-peculiar (under-luminous event)
- decay phase of the breakout emission could be detected.
- recombination lines from ions with high ionization potentials: gas photoionized by breakout emission(UV flash)

Blinnikov+(2000)



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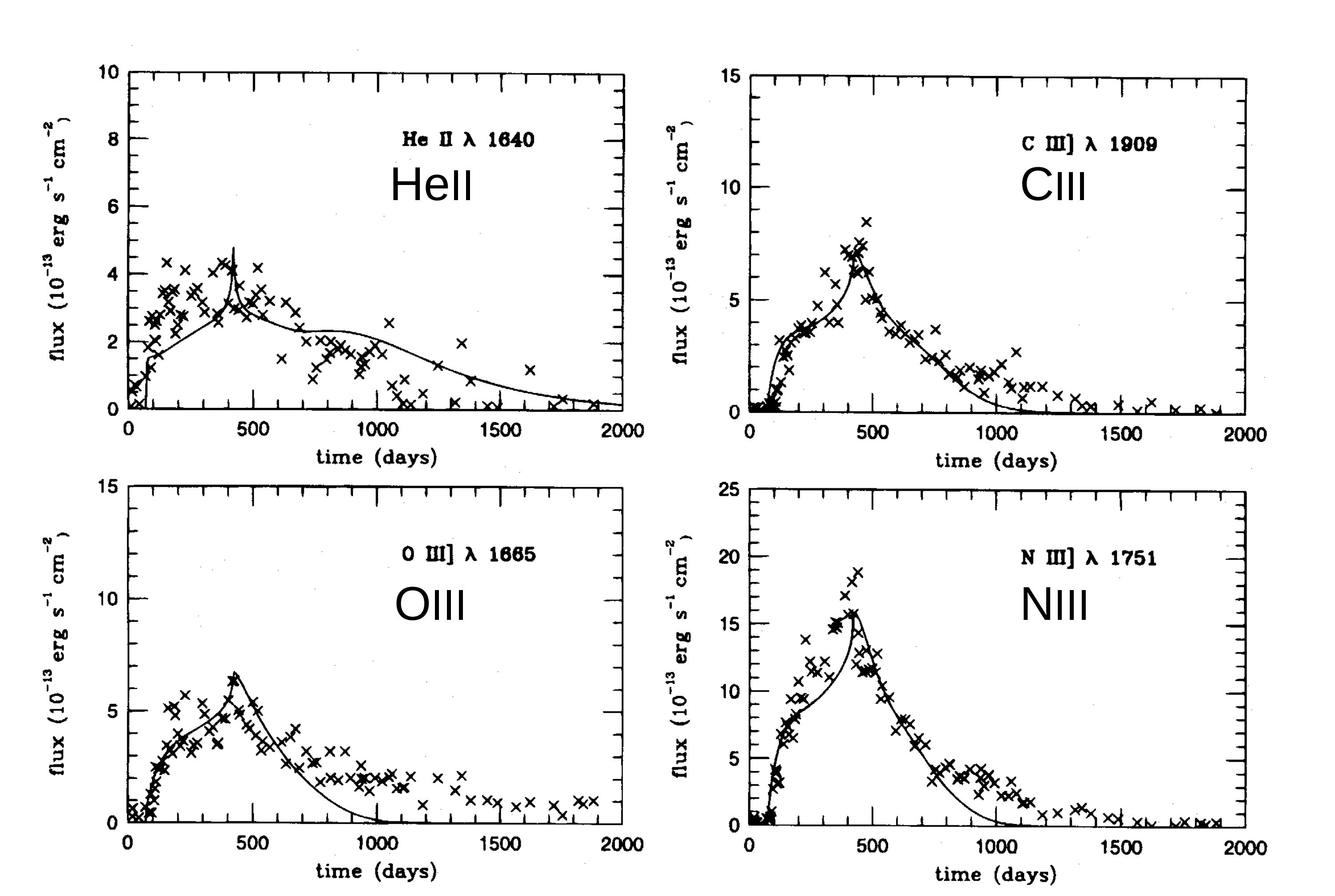
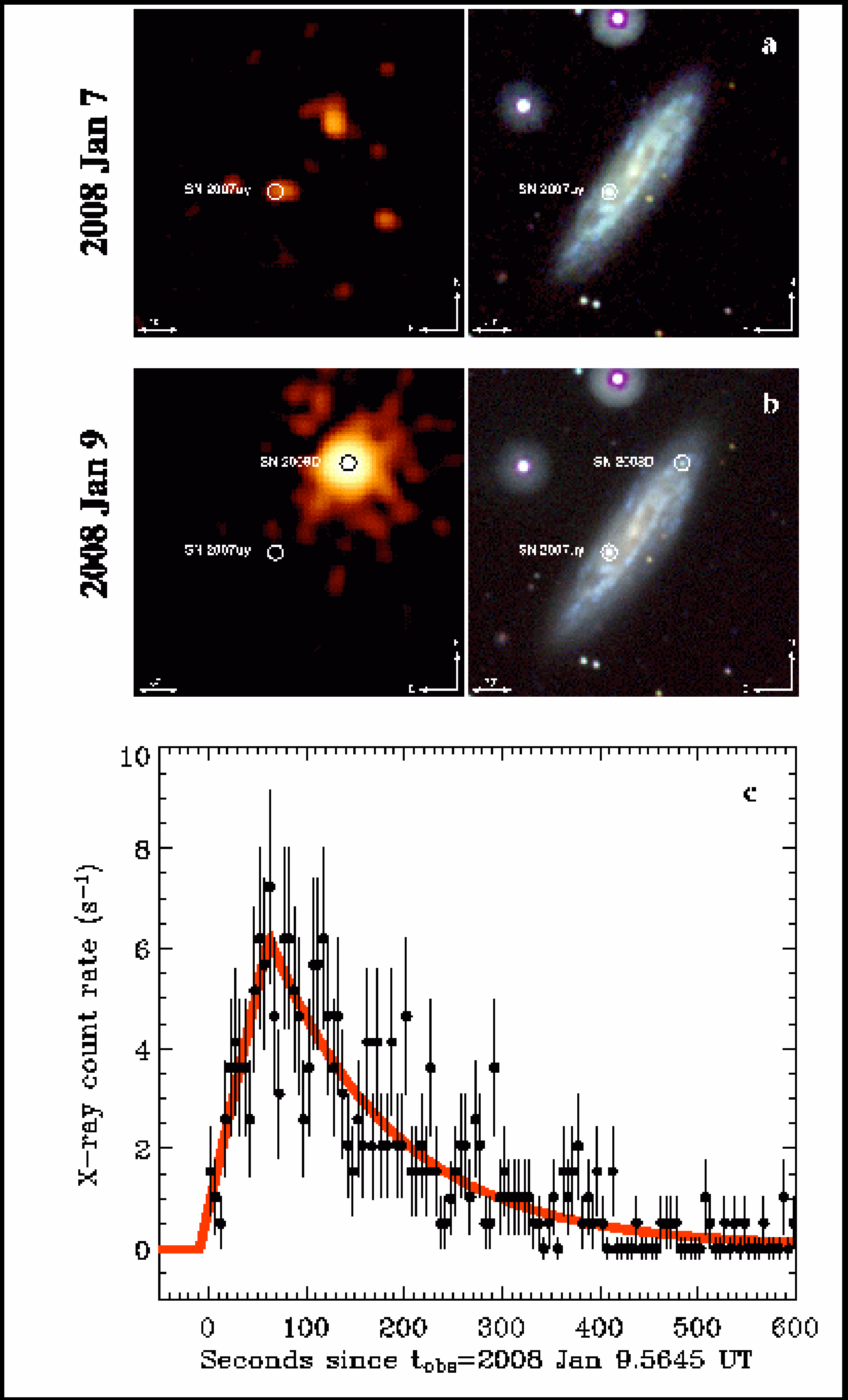
narrow emission line from CSM around SN 1987A Lundqvist&Fransson(1996)



XRF 080109/SN 2008D

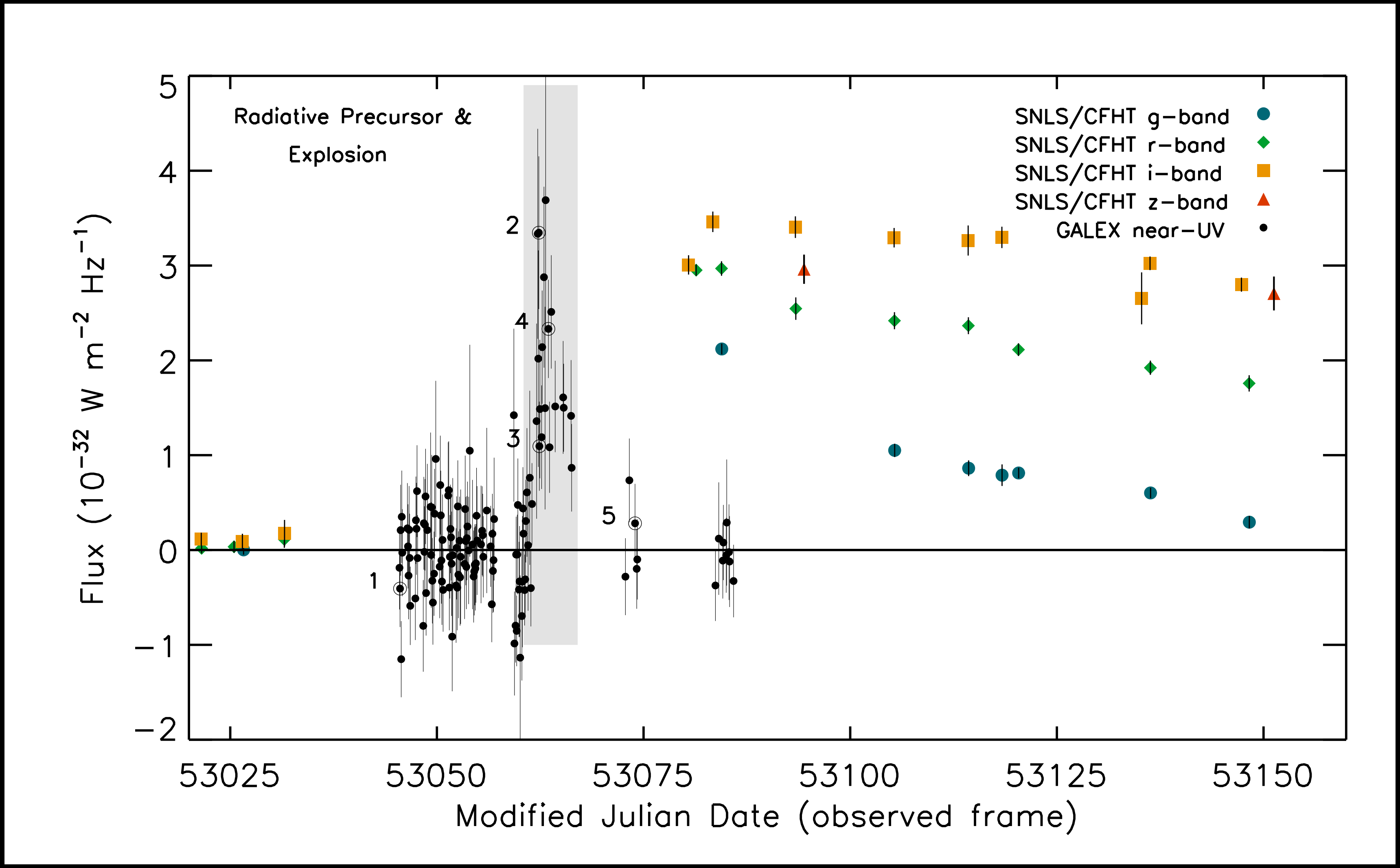
Soderberg+(2008)

- ➡ SN Ib @NGC2770 D=27Mpc
- ➡ On Jan 9, 2008, Swift satellite serendipitously observed an X-ray flash associated with the birth of the SN
- ➡ Lx~ a few×10^{43} erg/s, duration~ 200-300 sec, Ex~10^{46} erg
- ➡ The origin of the X-ray emission is still unclear (breakout from a dense CSM?)



SNLS-04D2DC

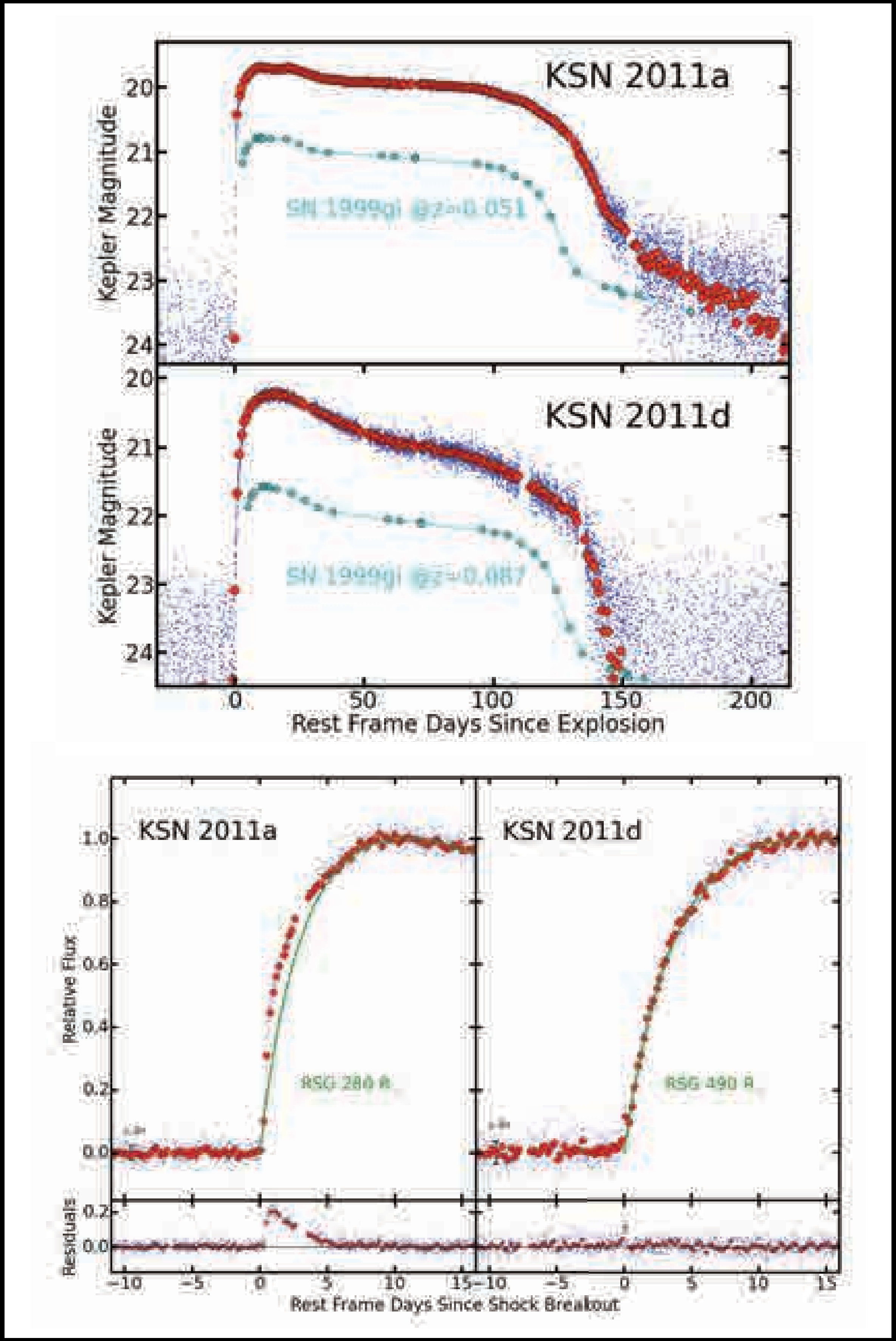
- Supernova Legacy Survey
- coincidence in time and position of an UV flash and a SN (@z=0.1854): GALEX satellite archival data



Schawinski+(2008)

KSN 2011a

- ➡ Kepler space telescope 30min (1800s) cadence observations
- ➡ They identified several SN candidates
- ➡ KSN 2011a initially showed a bump superposed on the theoretical LC



Garnavich+(2016)

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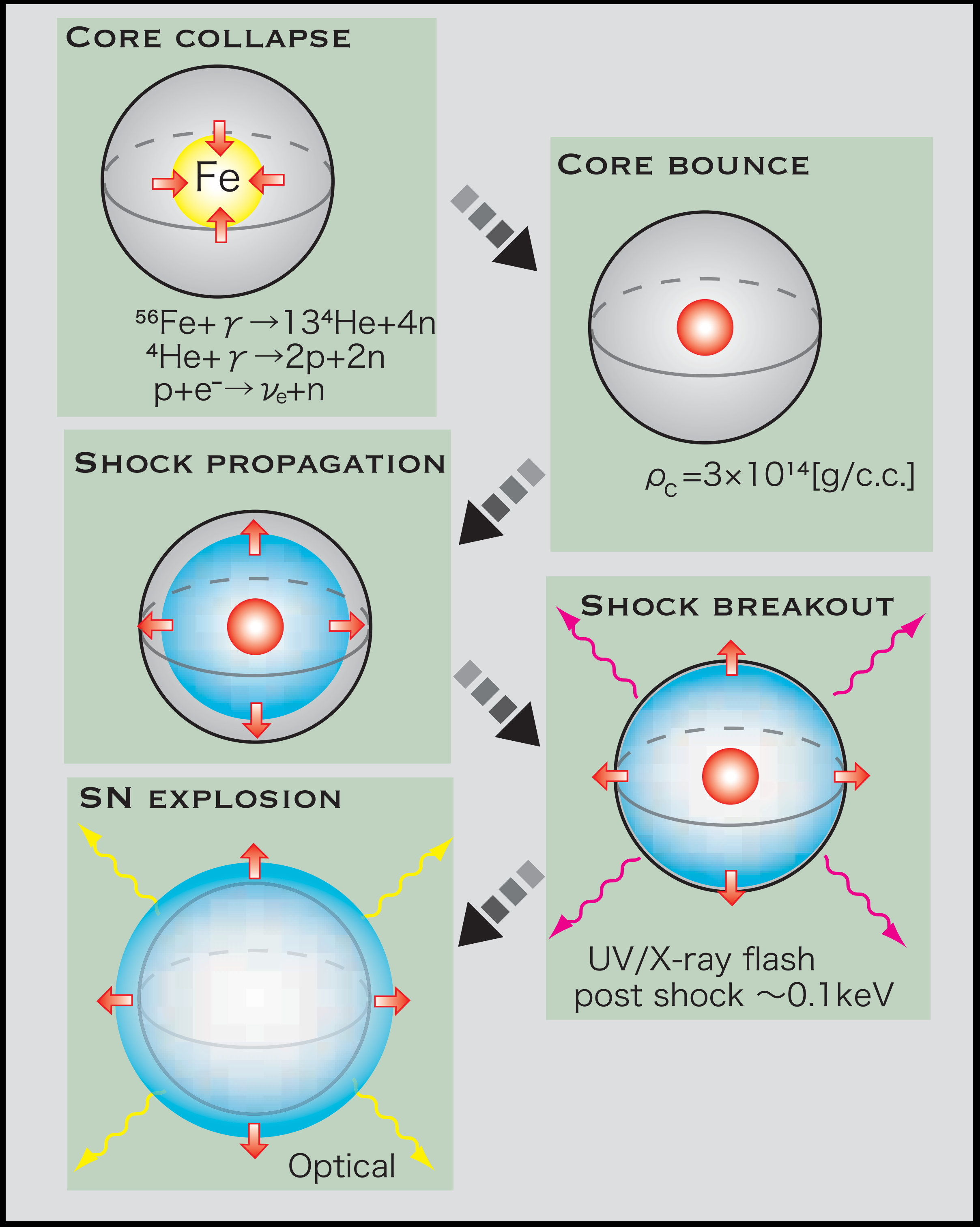
Theoretical works on SN shock breakout

- ➡ **pioneering works:** Colgate (1974), Klein&Chevalier(1976), Falk (1978), Imshennik and Nadyozhin(1988), Matzner&McKee(1999)
- ➡ **steady shock structure:** Weaver(1976),Katz+(2010),Budnik+(2010)
- ➡ **analytical**: Naker&Sari(2010,2011),Rabinak&Waxman(2012),
- ➡ **1D RHD**: Ensmann&Burrows(1992), Tominaga+(2009), Sapir+(2011,2013)
- ➡ **multi-D HD**: Suzuki&Shigeyama(2010),Couch+(2011), Ro&Matzner(2013), Matzner+(2013)
- ➡ **wind breakout**: Arcavi+(2011), Chevalier&Irwin(2011), Moriya&Tominaga(2011), Ofek+(2011), Svirsky+(2012),
- ➡ **1D SR-RHD**: Tolstov+(2013)

How bright shock breakout emission could be for a given stellar structure and explosion energy?

Shock propagation in massive star

- ➡ SN **shock breakout: emission from a hot gas in the downstream of a blast wave.**
- ➡ Its energy source is originally the explosion energy. The shock kinetic energy is converted the thermal energy of gas at the outermost layer of the star.
- ➡ How much thermal energy the shock can deposit into the outermost layer of the star.
- ➡ Matzner&McKee (1999)



Shock propagation in massive star

- ➡ stellar density structure: ρ(r)
- ➡ The shock velocity Vs is expressed as a function of r or ρ
- ➡ find the shock velocity V_{br} and density ρ_{br} satisfying the breakout condition $V_s = c/\tau$
- ➡ internal energy density $e_{int} \sim \rho_{br} V_{br}^2$,
- ➡ temperature $T \sim (e_{int}/a_r)^{1/4}$
- ➡ internal energy, diffusion time, etc

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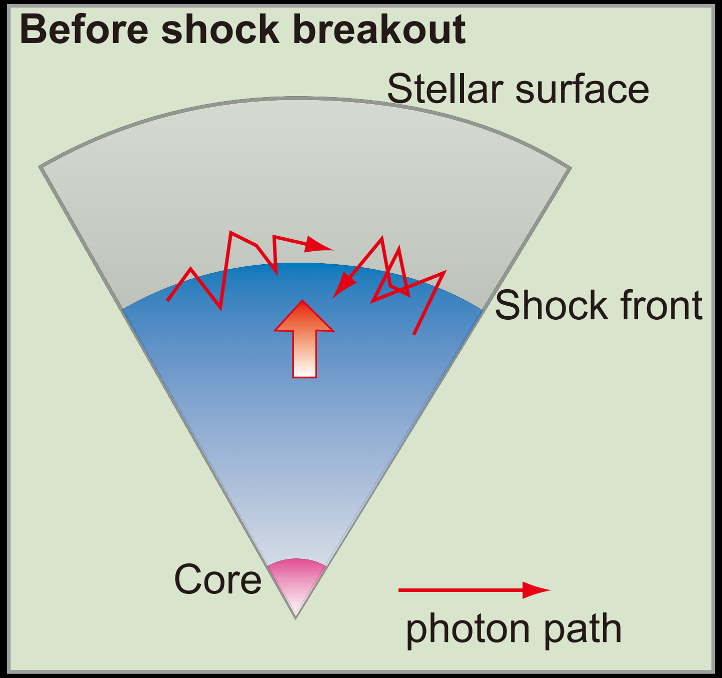
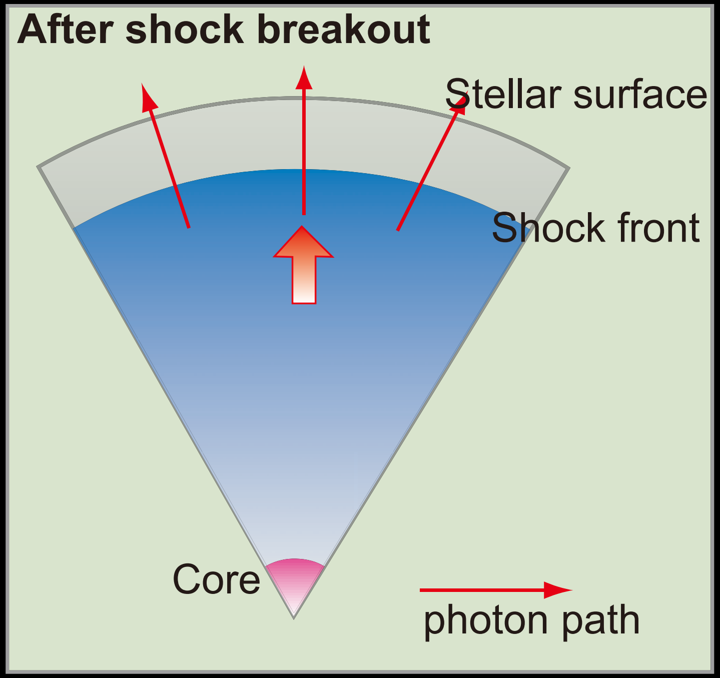
shock velocity Vs

breakout condition $c/\tau > V_s$

temperature $T_{br} \sim 10^6$[K]~0.1[keV]





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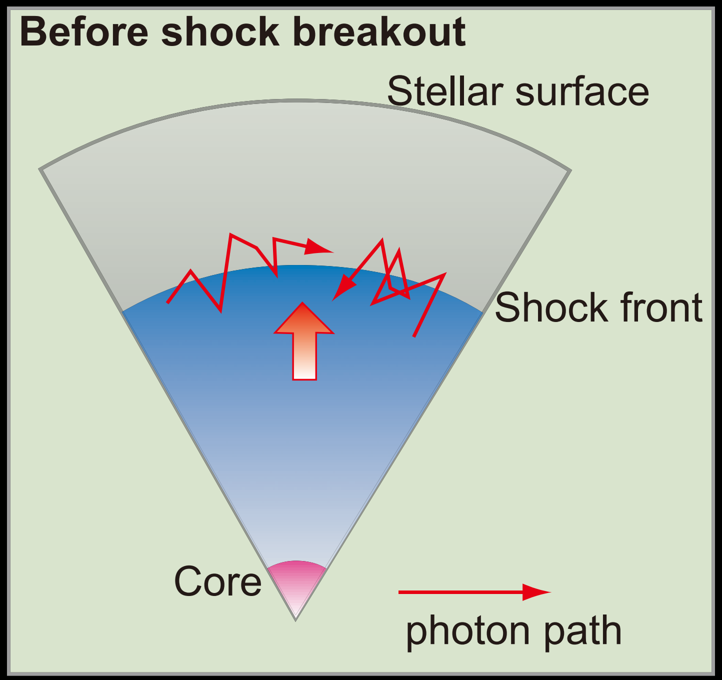
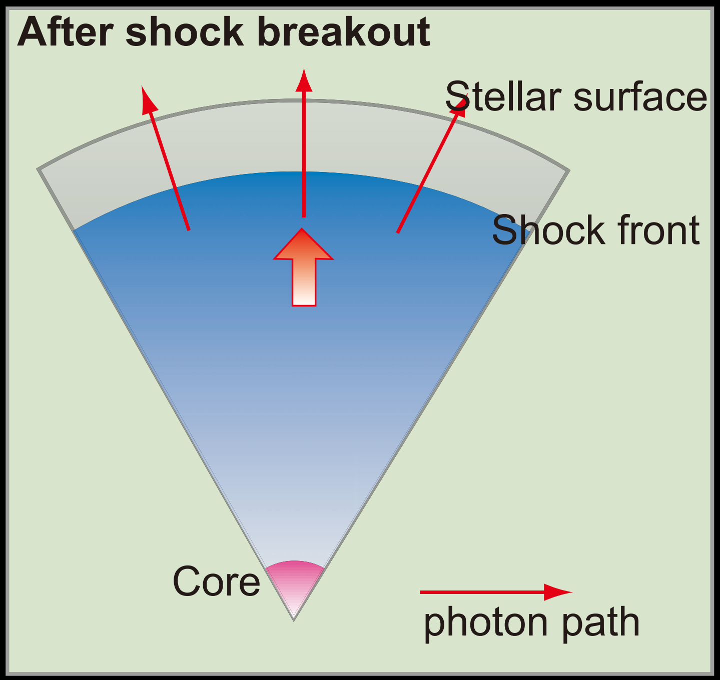
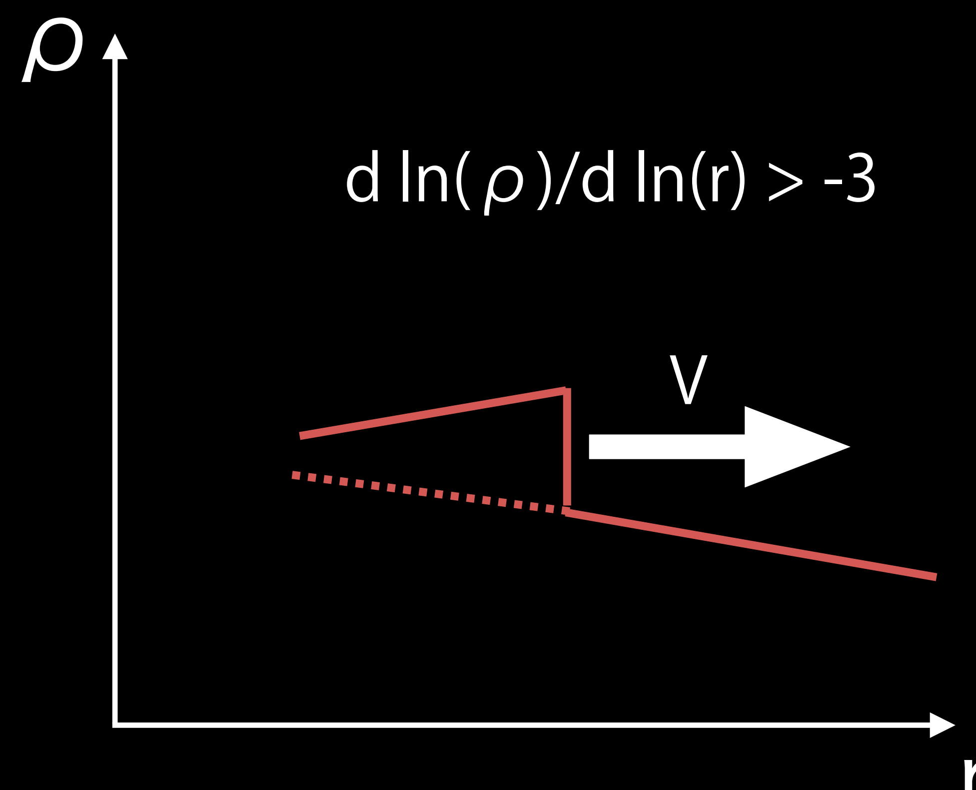
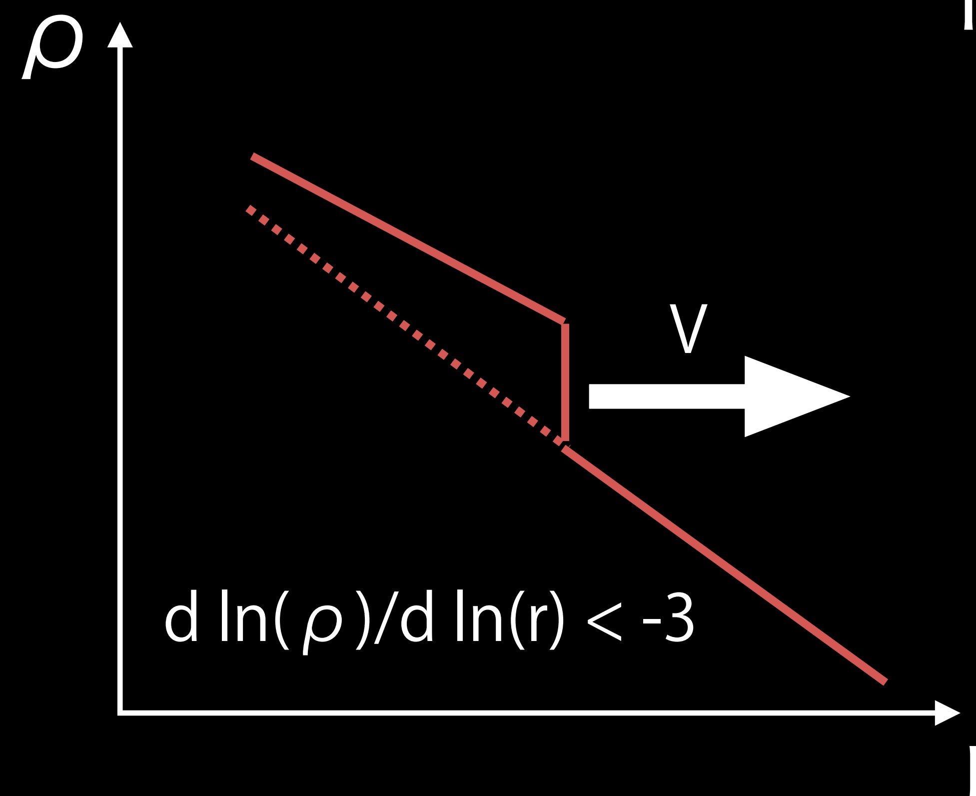




Shock propagation in massive star

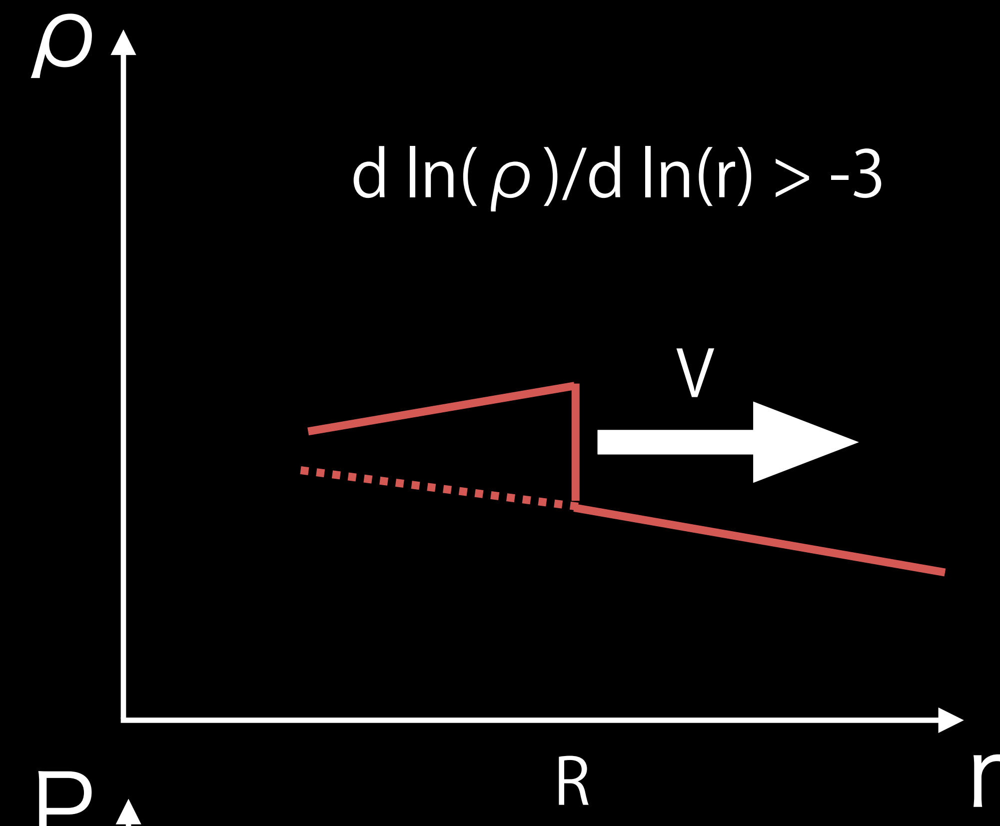
- ➡ Two modes of shock propagation in massive star: decelerating shock and accelerating shock
- ➡ $d\ln(\rho)/d\ln(r) > -3$: ρr^3 is an increasing function of r. The shock accumulate more mass as it propagates. decelerating shock
- ➡ $d\ln(\rho)/d\ln(r) < -3$: ρr^3 is an decreasing function of r. The shock kinetic energy is transferred to smaller and smaller mass. accelerating shock

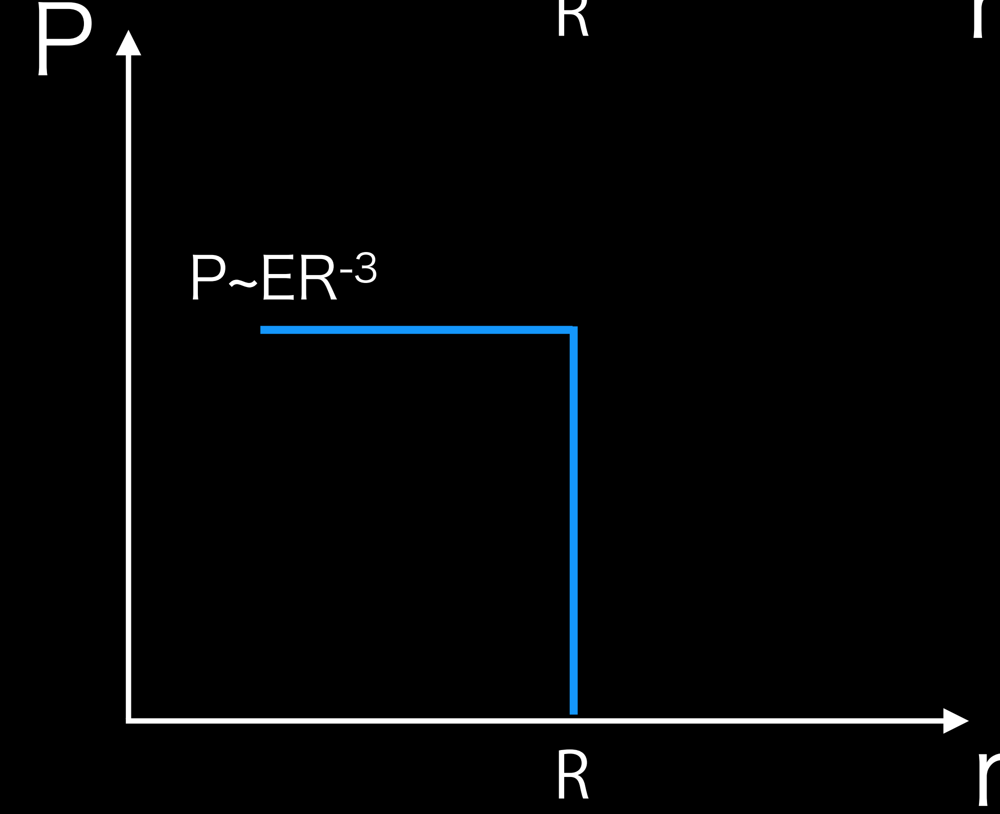




Decelerating shock: Sedov-type solution

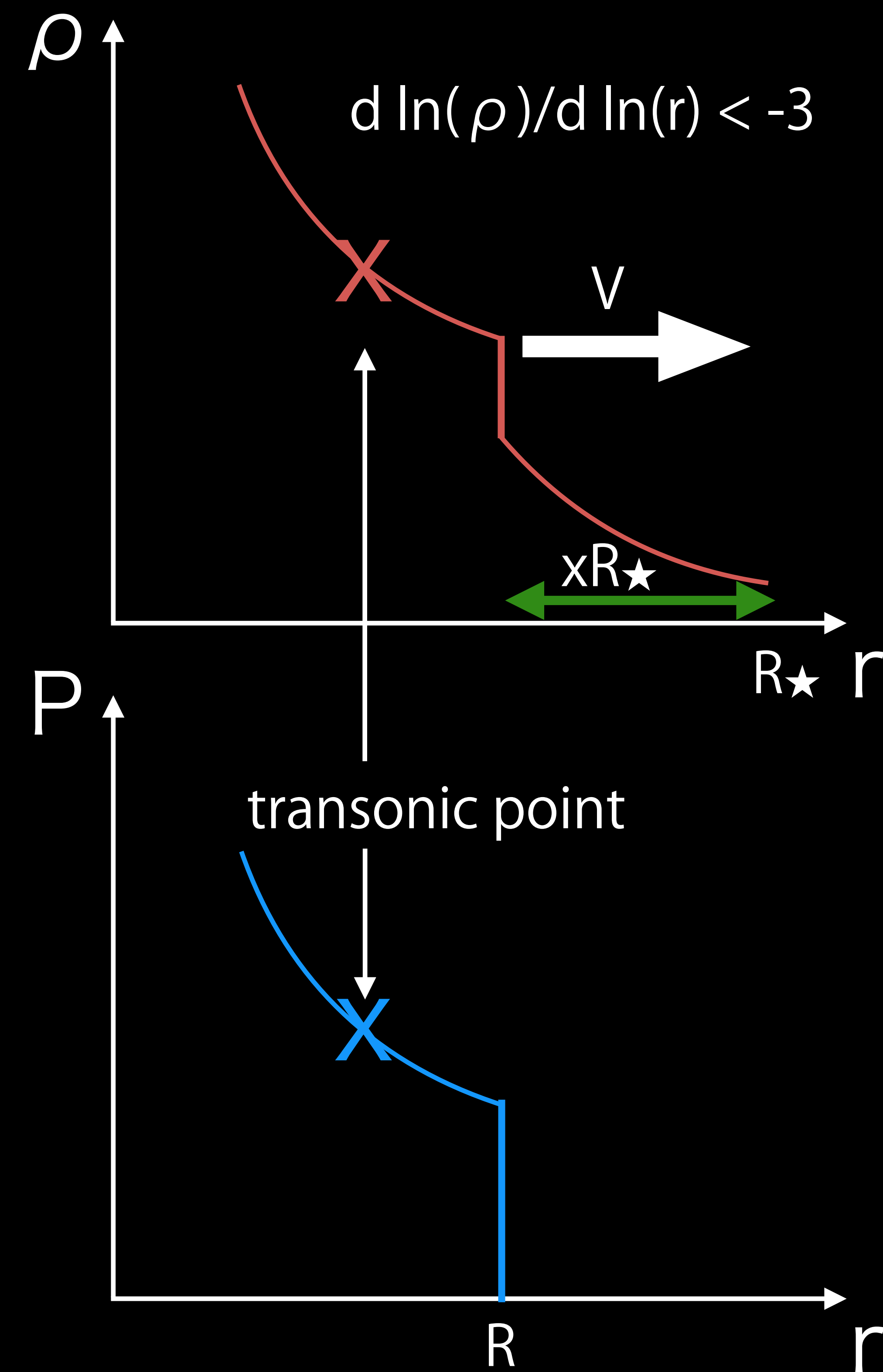
- ➡ Sedov-type solution: power-law: $\rho \sim r^{-n}$
- ➡ shock radius R, shock velocity V=dR/dt ~ R/t
- ➡ $\rho V^2 \sim P \rightarrow R^{-n}(R/t)^2 \propto ER^{-3} \rightarrow R \propto t^{2/(5-n)}$
- ➡ $V \propto t^{(n-3)/(5-n)}$: decelerating shock when n<3
- ➡ $M(R) \propto R^{3-n} \rightarrow M(R)V^2 \propto$ Const.
- ➡ $PR^3 \sim$ Const.
- ➡ $M(R)V^2 \sim$ a fraction of explosion energy E
- ➡ The shock speed is given by $\mathbf{V_s \sim [E/M(R)]^{1/2}}$





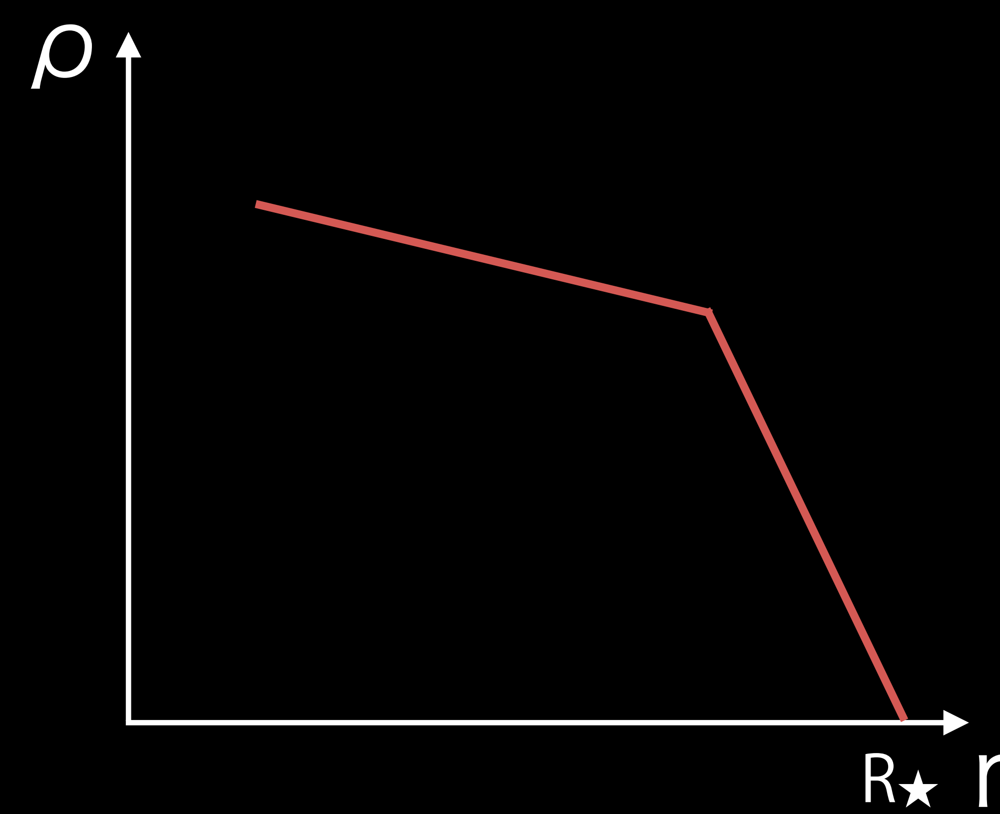
Accelerating shock: Sakurai's self-similar solution

- Sakurai(1960)
- distance from the surface: $x=(R_\star-r)/R_\star$
- $\rho \propto x^n$: plane-parallel atmosphere
- This treatment is justified for polytropic stellar envelopes ($P \propto \rho^{1+1/n}$), n=1.5 for a convective envelope and n=3.0 for a radiative envelope
- For a strong shock, shock speed follows $\mathbf{V_s} \propto \boldsymbol{\rho}^{-\beta}$, ($\beta$~0.19 for n=1.5, 3.0)



Shock propagation in massive star

- ➡ Mazner&McKee(1999)
- ➡ **$V_s = [E/M(r)]^{1/2} \times [\rho(r)/\rho_\star]^{-\beta}$** works well with $\beta \sim 0.19$.
- ➡ This behaves as Sedov-like in a shallow density gradient, while it grows in a power-law fashion in a steep density gradient.
- ➡ find V_{br} and ρ_{br} and estimate some quantities



post-shock temperature	thermal energy	diffusion time scale

RSG

$$T_{se} = 5.55 \times 10^5 \left(\frac{\kappa}{0.34\ \mathrm{cm^2\ g^{-1}}}\right)^{-0.10} \left(\frac{\rho_1}{\rho_*}\right)^{0.070} \times \left(\frac{E_{in}}{10^{51}\ \mathrm{ergs}}\right)^{0.20} \left(\frac{M_{ej}}{10\ M_\odot}\right)^{-0.052} \times \left(\frac{R_*}{500\ R_\odot}\right)^{-0.54} \mathrm{K} \quad \left(n = \frac{3}{2}\right),$$

$$E_{se} = 1.7 \times 10^{48} \left(\frac{\kappa}{0.34\ \mathrm{cm^2\ g^{-1}}}\right)^{-0.87} \left(\frac{\rho_1}{\rho_*}\right)^{-0.086} \times \left(\frac{E_{in}}{10^{51}\ \mathrm{ergs}}\right)^{0.56} \left(\frac{M_{ej}}{10\ M_\odot}\right)^{-0.44} \times \left(\frac{R_*}{500\ R_\odot}\right)^{1.74} \mathrm{ergs} \quad \left(n = \frac{3}{2}\right),$$

$$t_{se} = 790 \left(\frac{\kappa}{0.34\ \mathrm{cm^2\ g^{-1}}}\right)^{-0.58} \left(\frac{\rho_1}{\rho_*}\right)^{-0.28} \times \left(\frac{E_{in}}{10^{51}\ \mathrm{ergs}}\right)^{-0.79} \left(\frac{M_{ej}}{10\ M_\odot}\right)^{0.21} \times \left(\frac{R_*}{500\ R_\odot}\right)^{2.16} \mathrm{s} \quad \left(n = \frac{3}{2}\right),$$

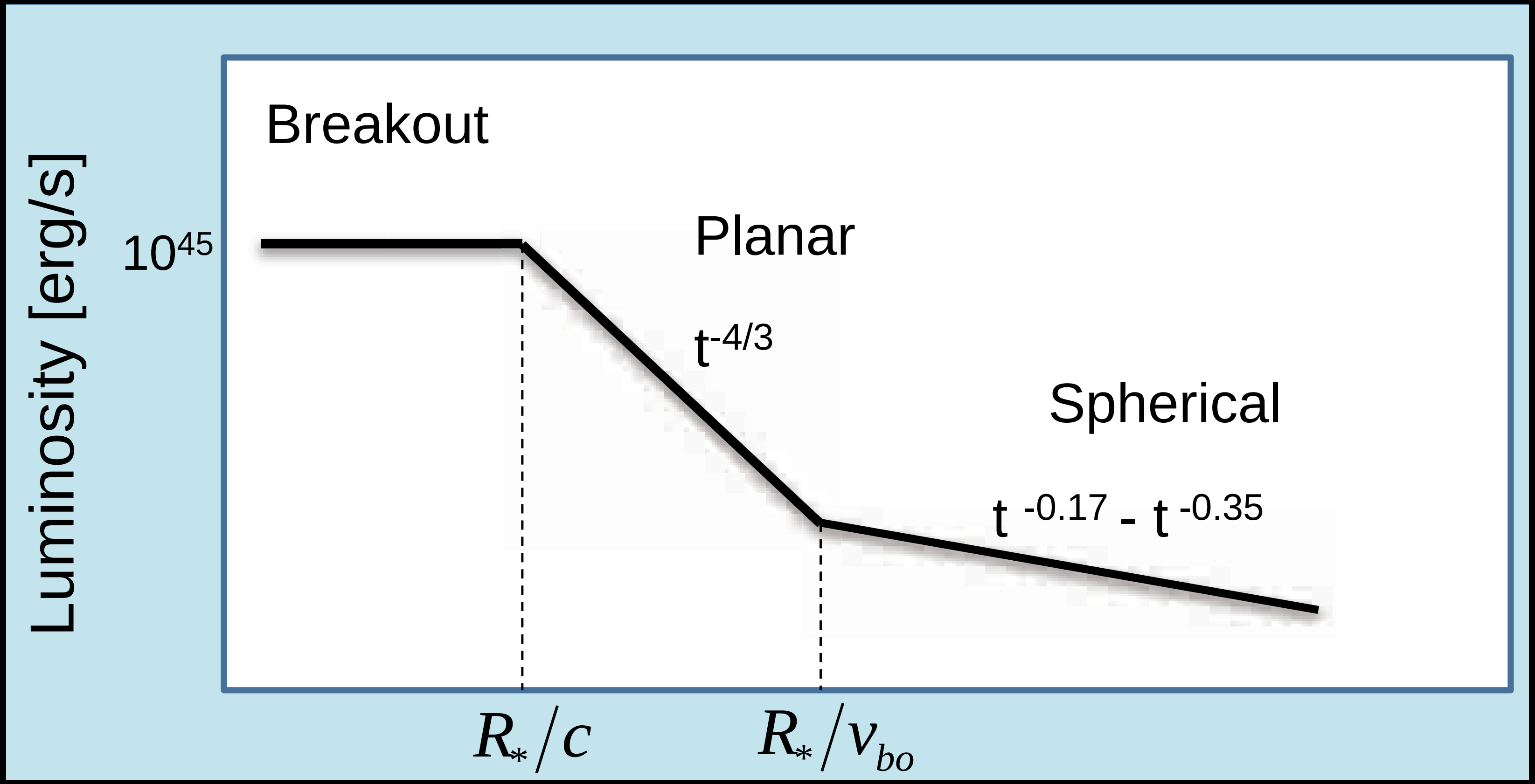
BSG

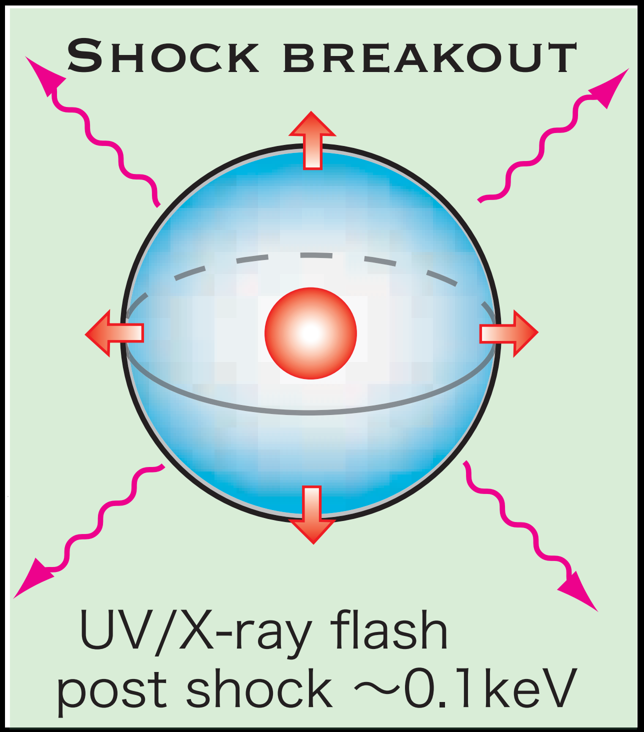
$$T_{se} = 1.31 \times 10^6 \left(\frac{\kappa}{0.34\ \mathrm{cm^2\ g^{-1}}}\right)^{-0.14} \left(\frac{\rho_1}{\rho_*}\right)^{0.046} \times \left(\frac{E_{in}}{10^{51}\ \mathrm{ergs}}\right)^{0.18} \left(\frac{M_{ej}}{10\ M_\odot}\right)^{-0.068} \times \left(\frac{R_*}{50\ R_\odot}\right)^{-0.48} \mathrm{K} \quad (n = 3)\,.$$

$$E_{se} = 7.6 \times 10^{46} \left(\frac{\kappa}{0.34\ \mathrm{cm^2\ g^{-1}}}\right)^{-0.84} \left(\frac{\rho_1}{\rho_*}\right)^{-0.054} \times \left(\frac{E_{in}}{10^{51}\ \mathrm{ergs}}\right)^{0.58} \left(\frac{M_{ej}}{10\ M_\odot}\right)^{-0.42} \times \left(\frac{R_*}{50\ R_\odot}\right)^{1.68} \mathrm{ergs} \quad (n = 3)\,.$$

$$t_{se} = 40 \left(\frac{\kappa}{0.34\ \mathrm{cm^2\ g^{-1}}}\right)^{-0.45} \left(\frac{\rho_1}{\rho_*}\right)^{-0.18} \times \left(\frac{E_{in}}{10^{51}\ \mathrm{ergs}}\right)^{-0.72} \left(\frac{M_{ej}}{10\ M_\odot}\right)^{0.27} \times \left(\frac{R_*}{50\ R_\odot}\right)^{1.90} \mathrm{s} \quad (n = 3)\,.$$

Shock breakout light curves





light crossing time for stellar radius

traveling time of ejecta for stellar radius

Nakar&Sari(2010)

What determines tie time scale?

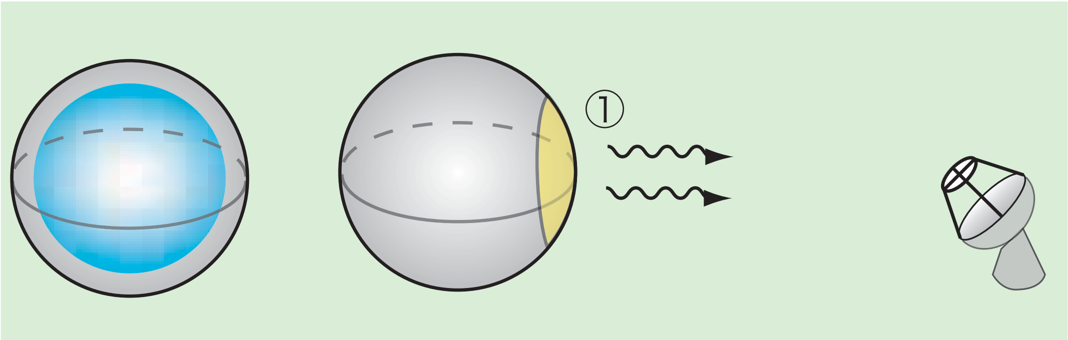
➡ The diffusion time scale is the time scale releasing photons

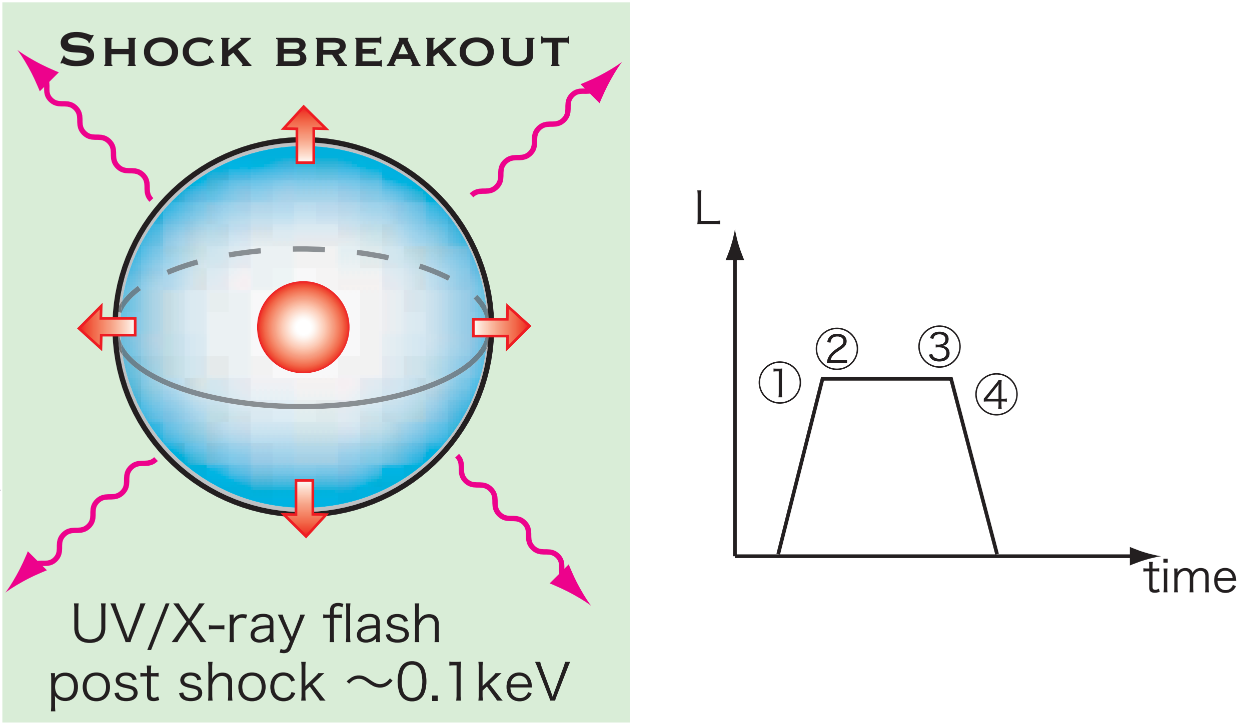
≠ the time scale during which we observe the photons

➡ The emission is “smeared out” within the time scale of R★/c

Shock breakout light curves

➡ Shock breakout occurs at every point of the surface at the same time





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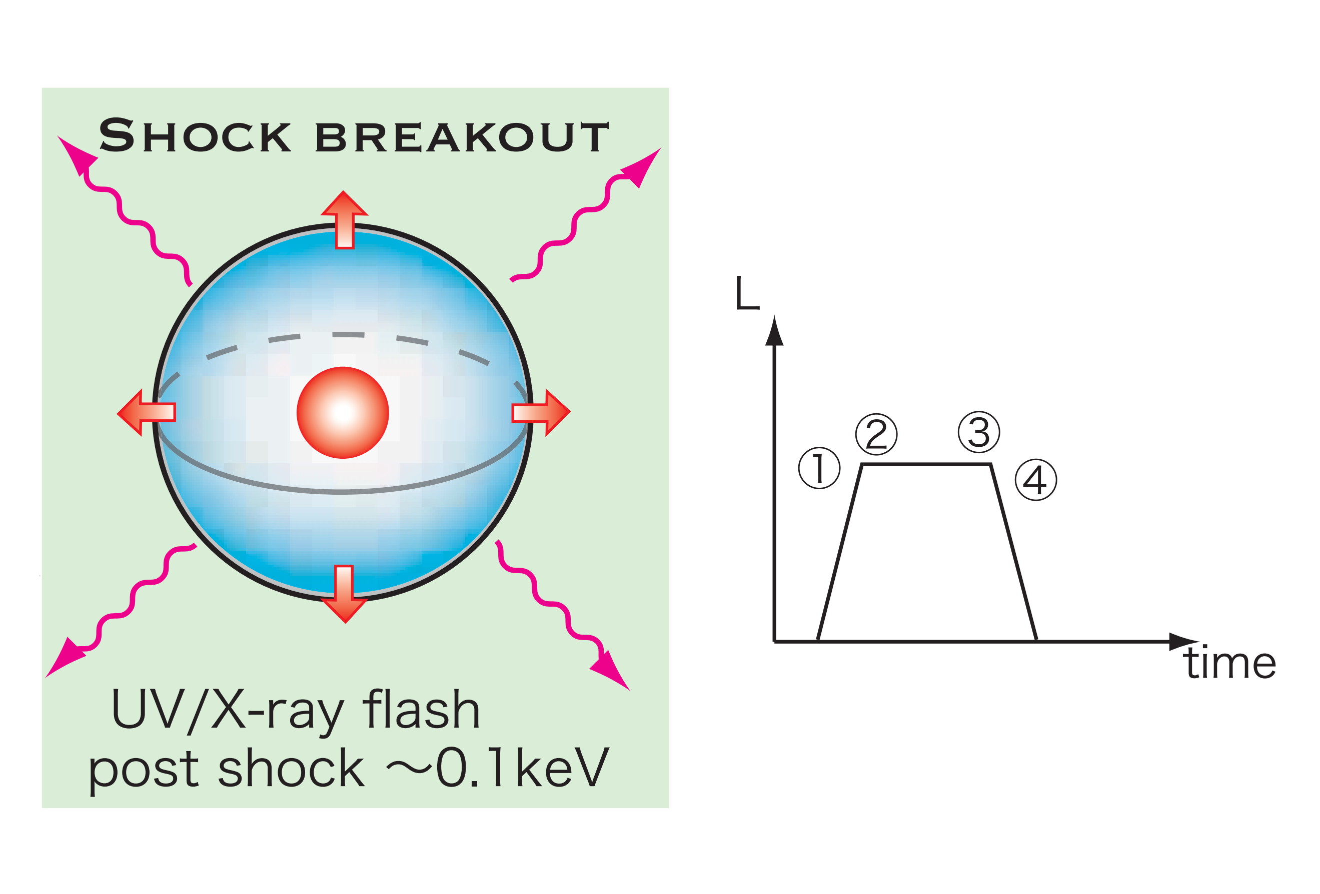

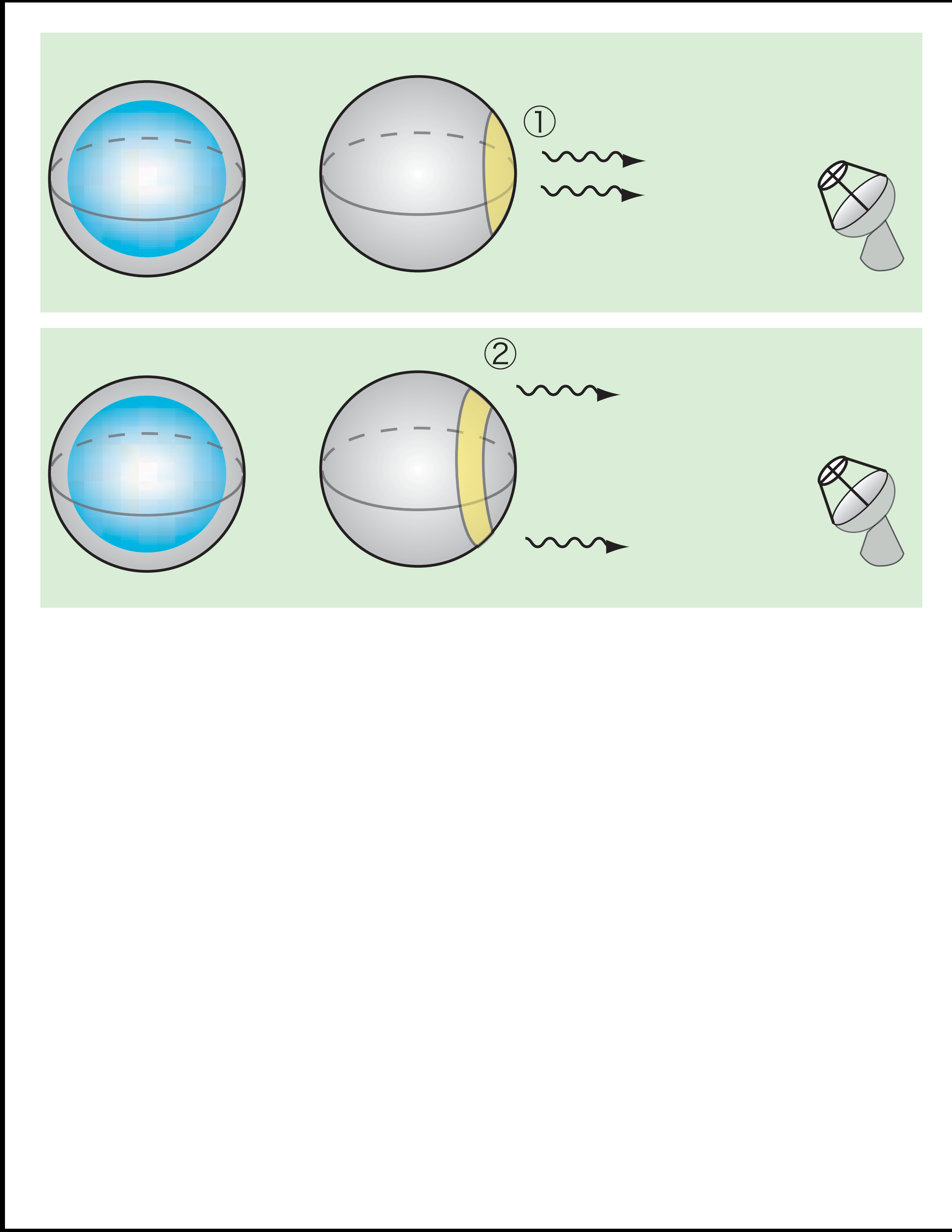

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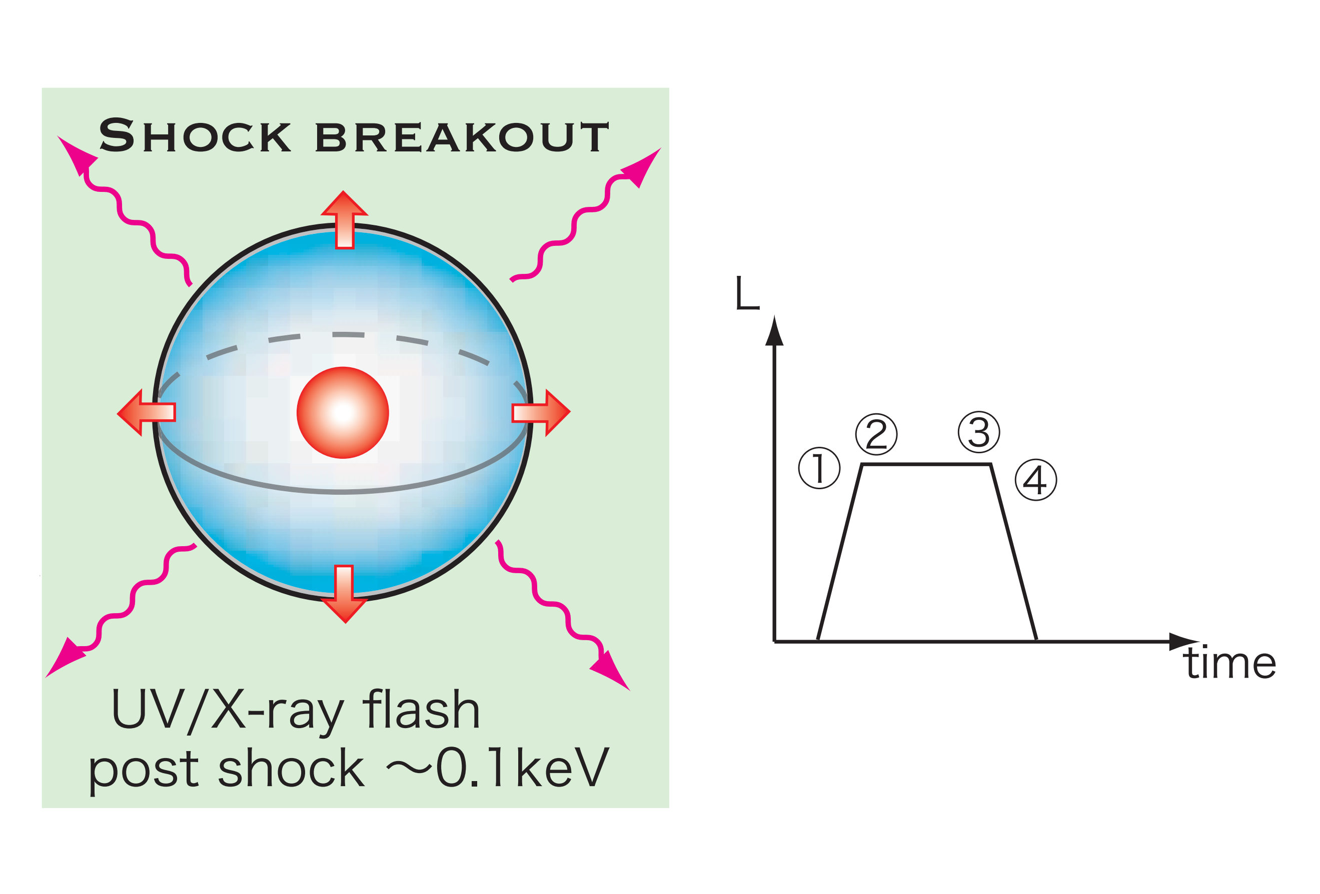

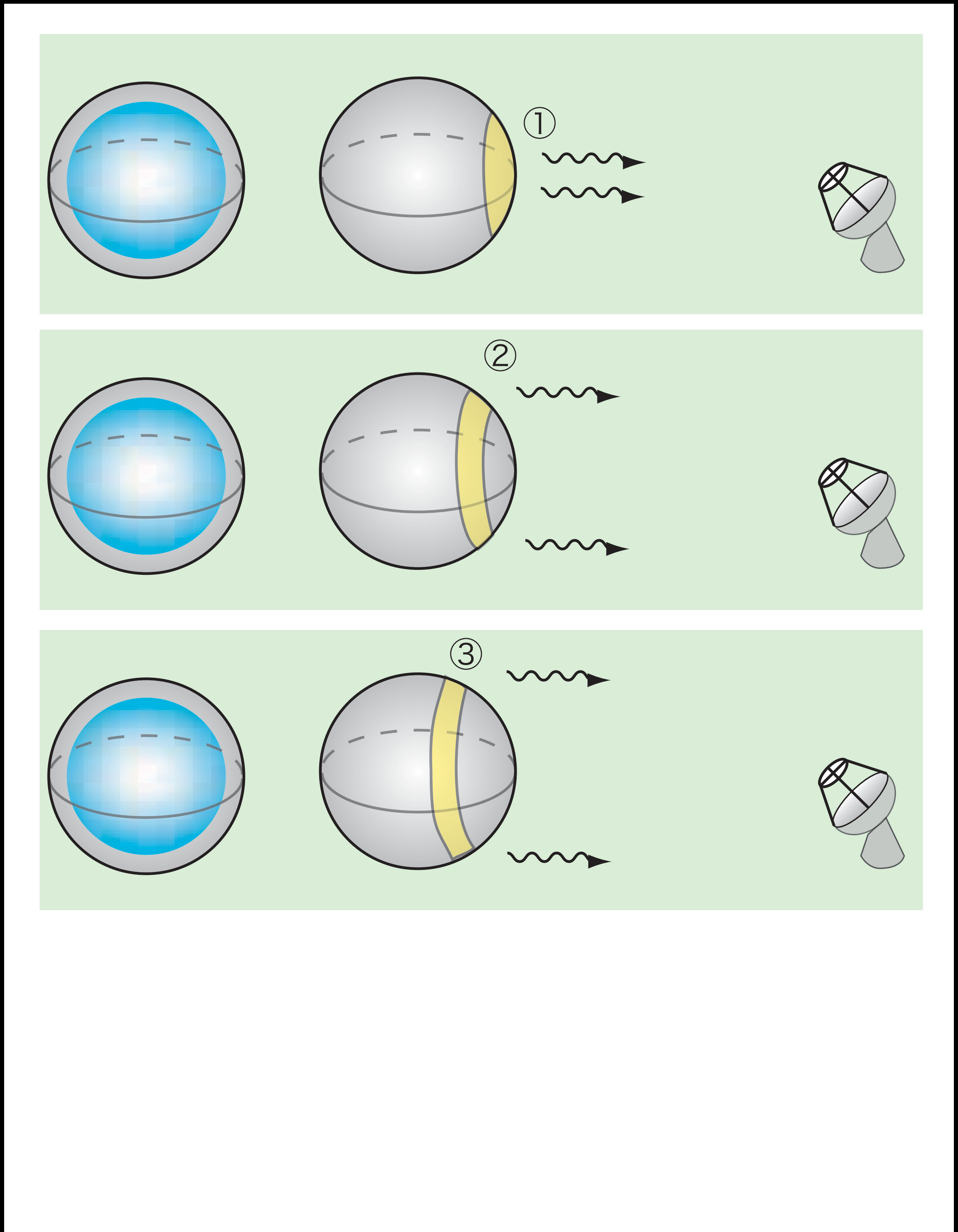

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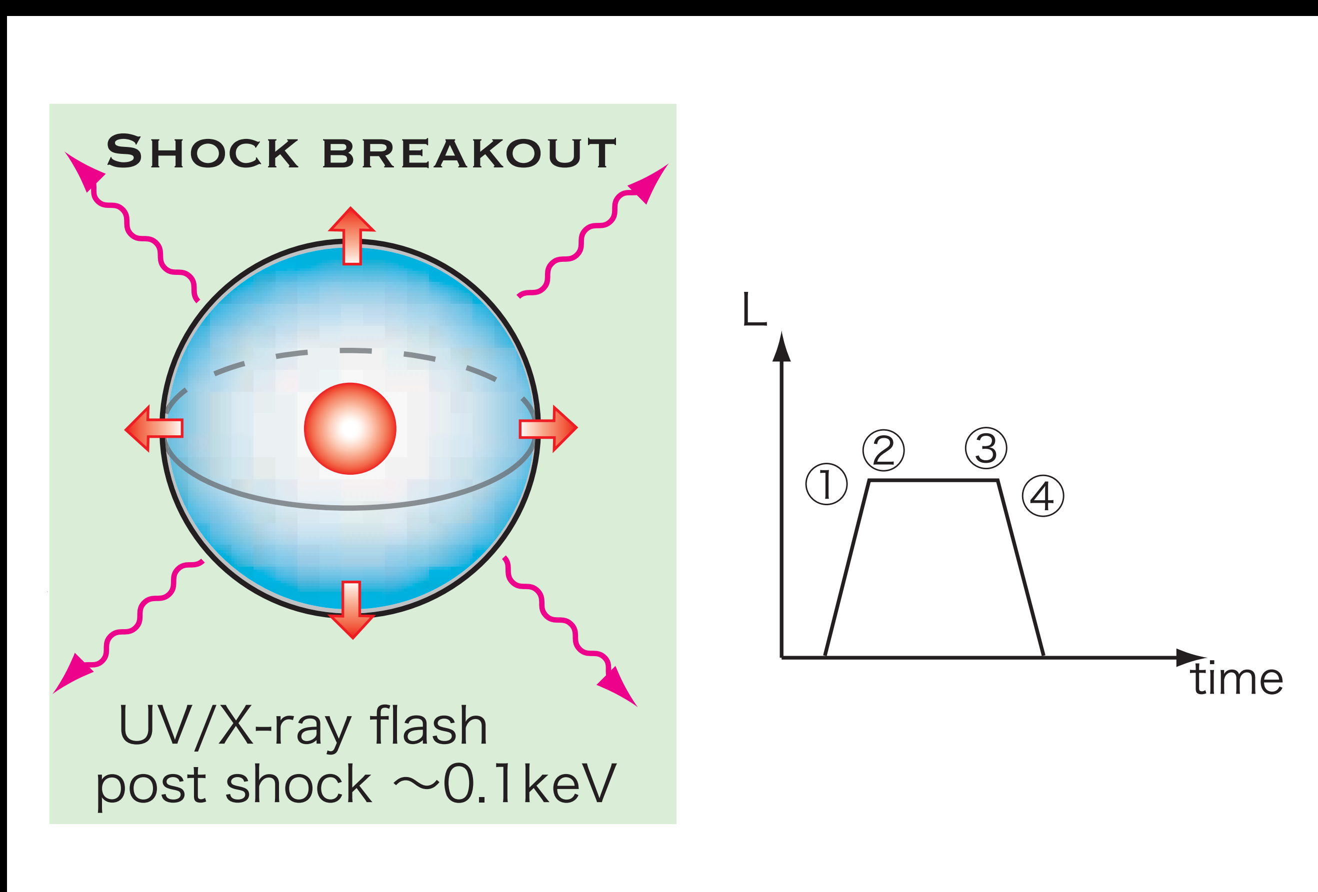

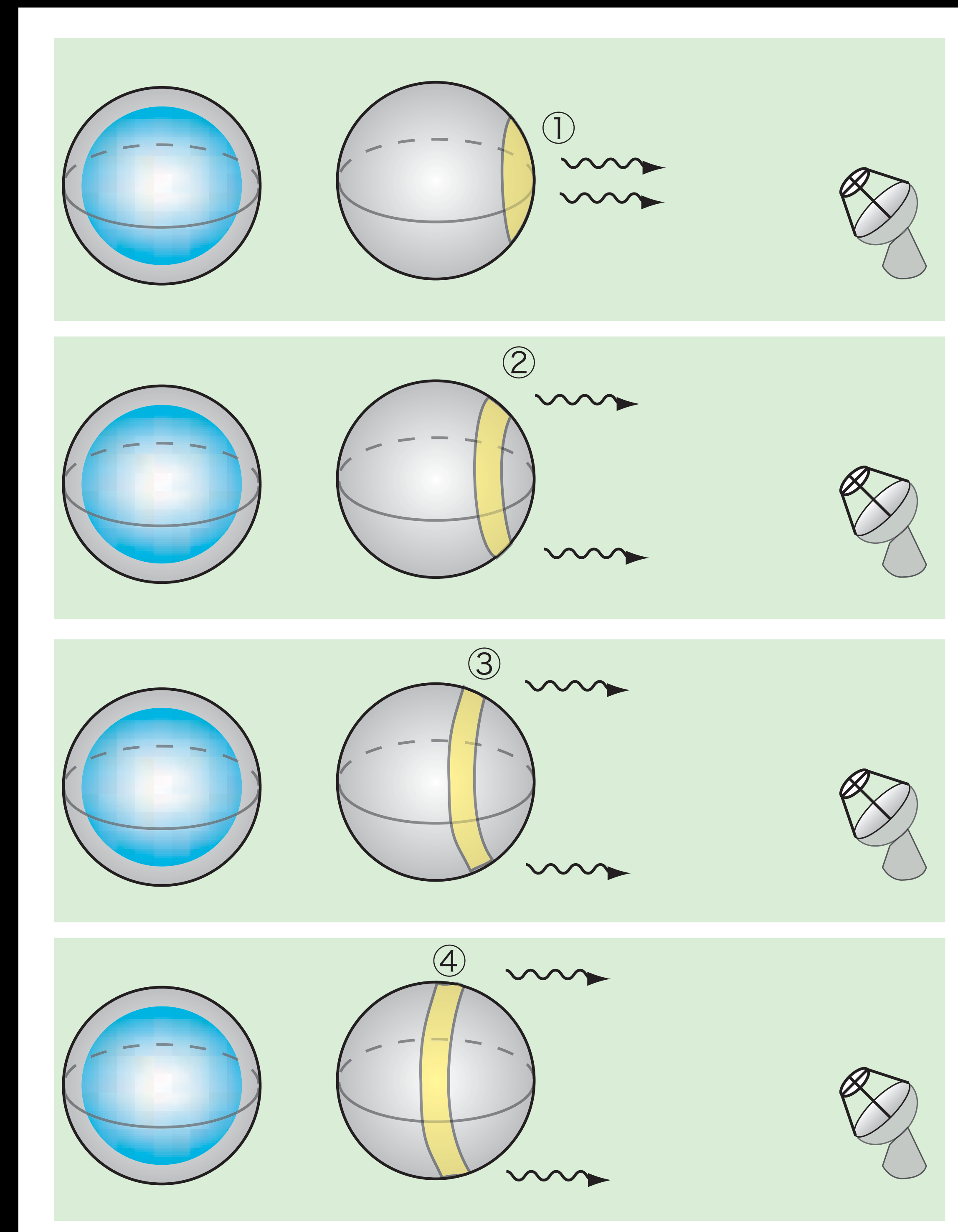

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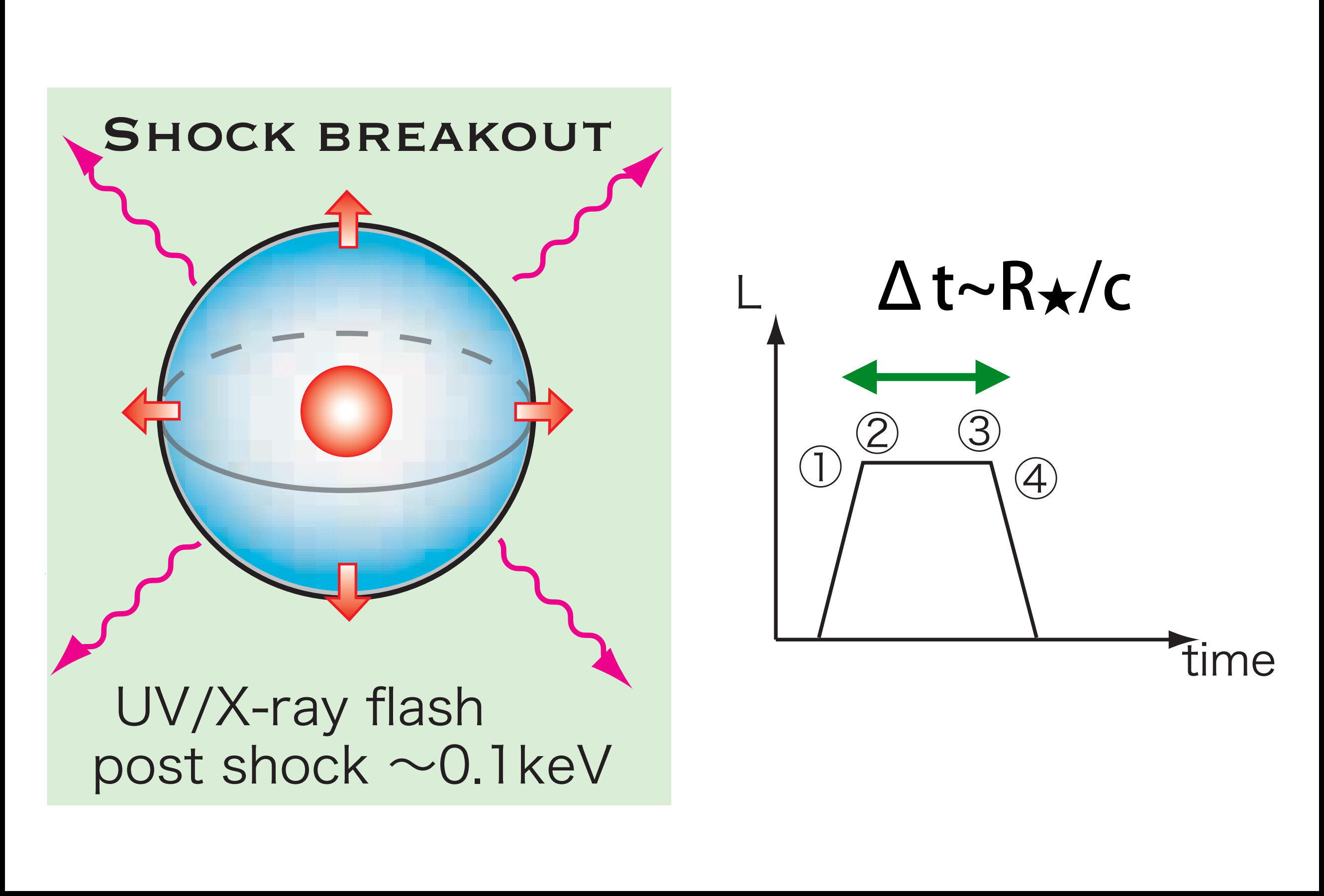

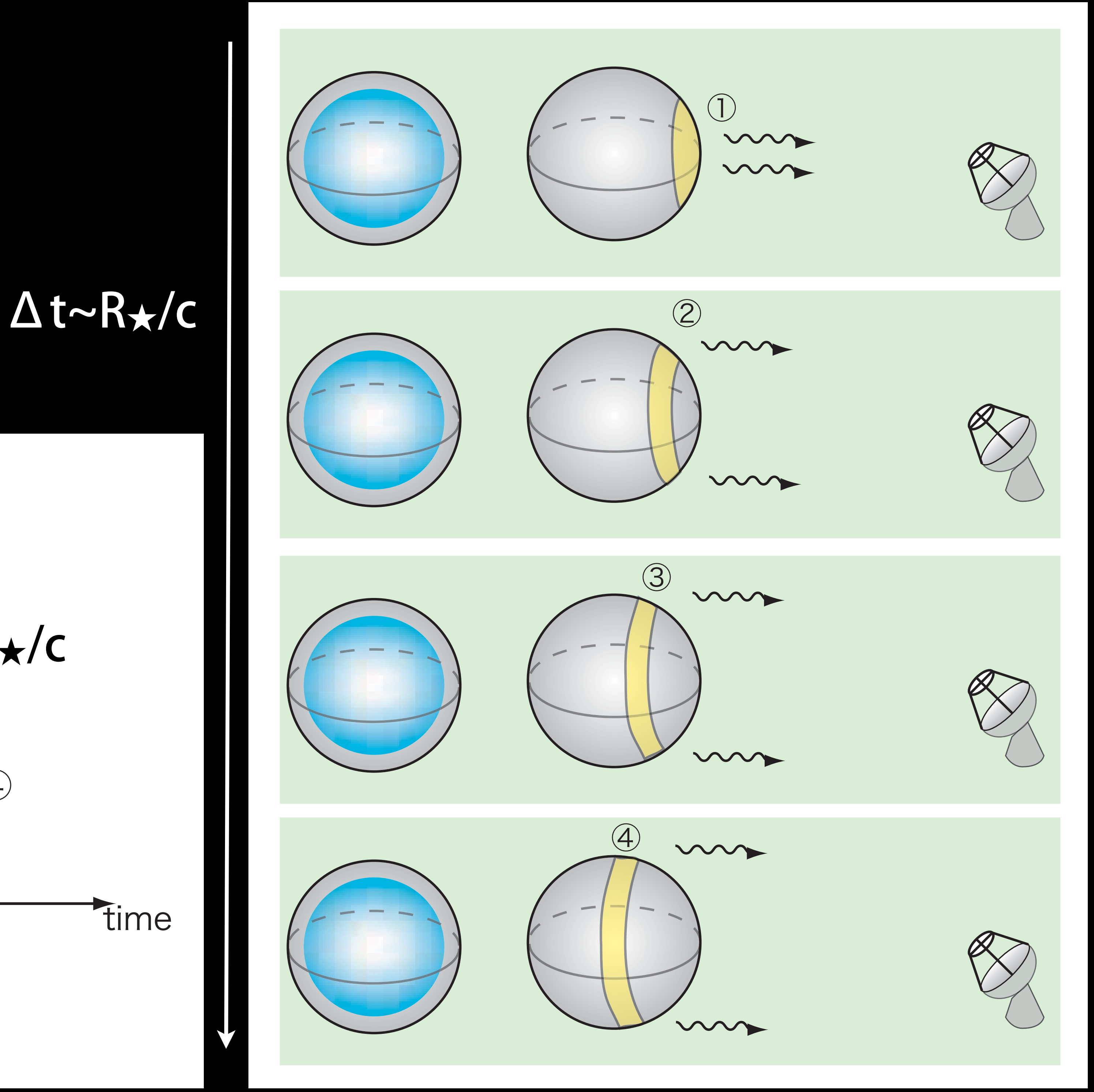

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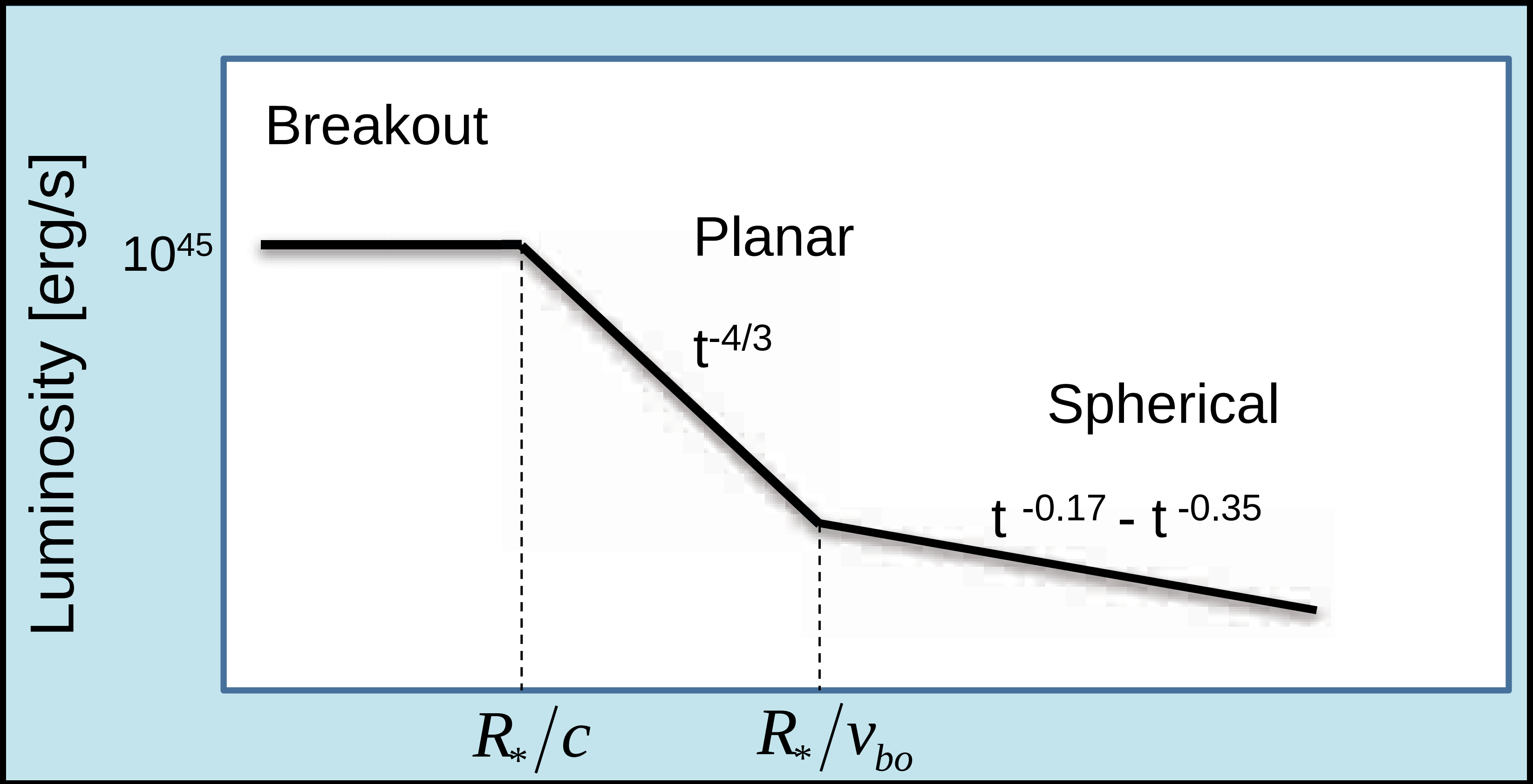
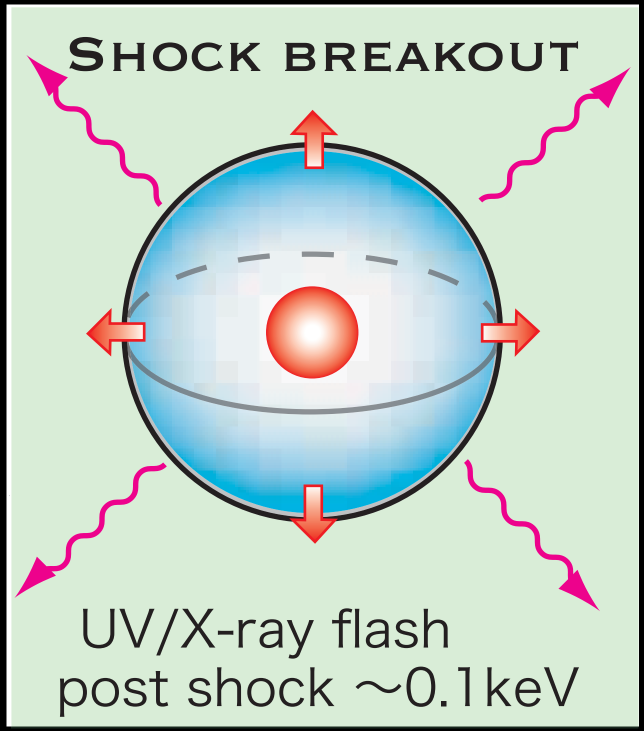
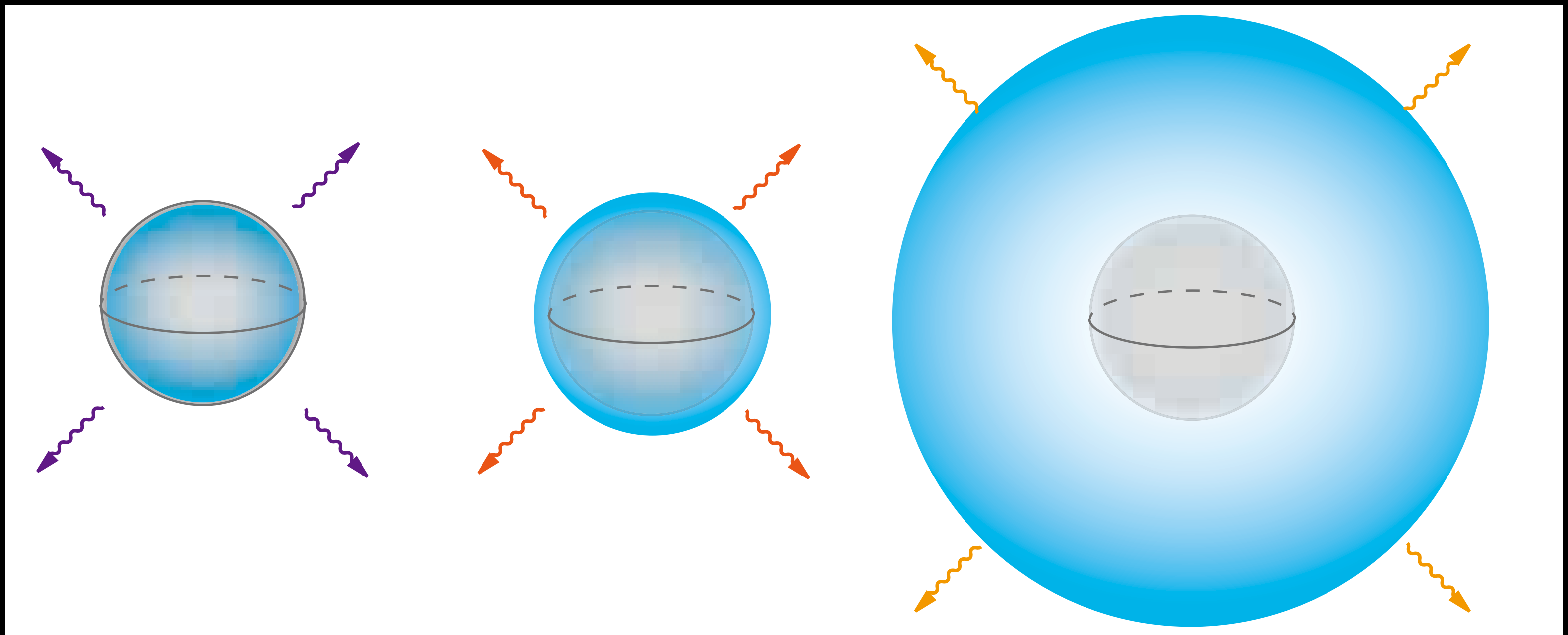




light crossing time for stellar radius

traveling time of ejecta for stellar radius

Nakar&Sari(2010)



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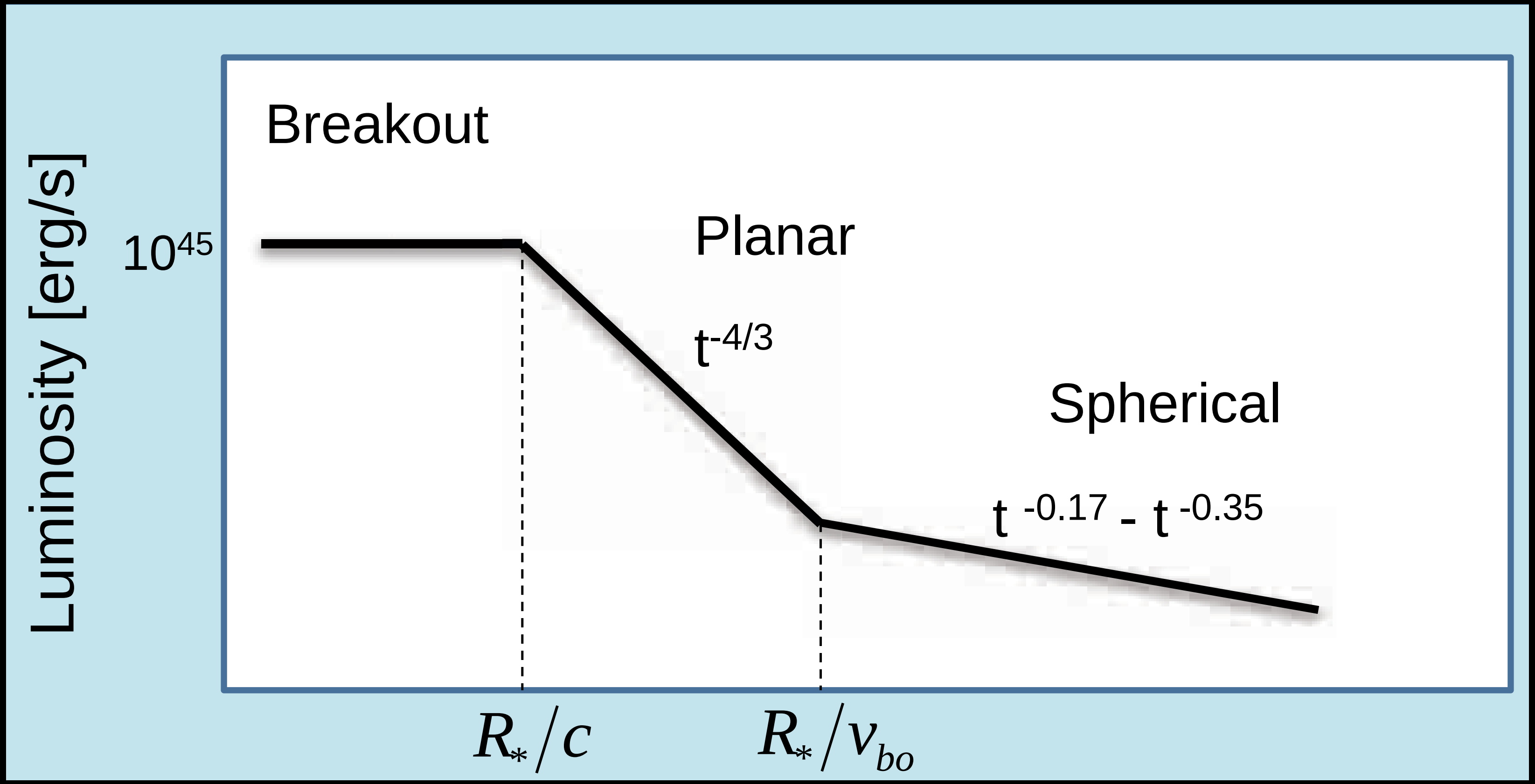

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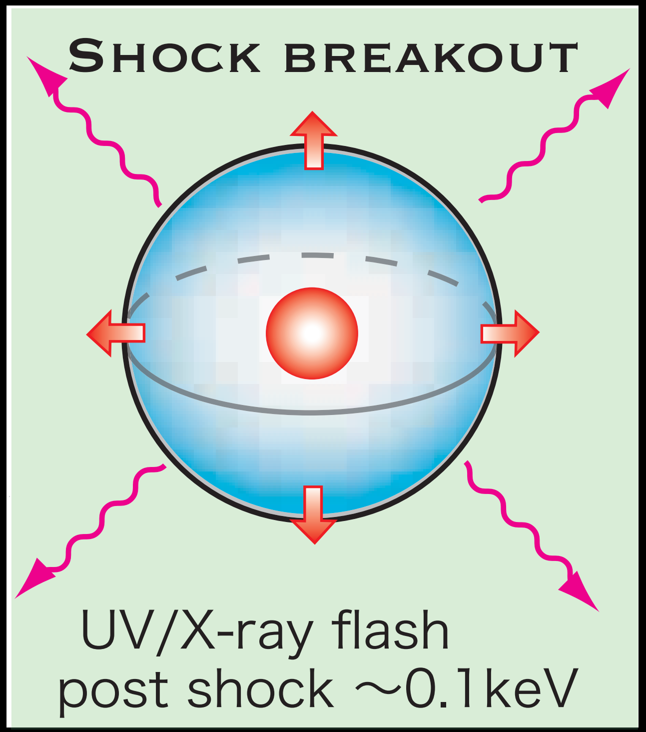


Nakar&Sari(2010)

	R★	R★/c	R★/v
WR	~10^{11}cm	3 sec	10-20 sec
BSG	~3×10^{12}cm	100 sec	15 min
RSG	~3×10^{13}cm	15 min	2-3 hr

Outline

- ➡ Introduction
- ➡ Shock Propagation in Massive stars
- ➡ 2D radiation-hydrodynamic simulations of SN shock breakout
- ➡ Summary

Theoretical works on SN shock breakout

- ➡ **pioneering works:** Colgate (1974), Klein & Chevalier(1976), Falk (1978), Imshennik & Nadyozhin(1988), Matzner & McKee(1999)
- ➡ **steady shock structure:** Weaver(1976),Katz+(2010,2012),Budnik+(2010)
- ➡ **analytical**: Naker & Sari(2010,2012),Rabinak & Waxman(2012),
- ➡ **1D RHD**: Ensmann&Burrows(1992), Tominaga+(2009), Sapir+(2011,2013,2014)
- ➡ **multi-D HD**: Suzuki&Shigeyama(2010),Couch+(2011), Ro & Matzner(2013), Matzner +(2013)
- ➡ **wind breakout**: Balberg & Loeb(2011),Arcavi+(2011), Chevalier & Irwin(2011), Moriya +(2011,2015), Ofek+(2011), Ginzburg & Balberg(2012,2014), Svirsky+(2012,2014),
- ➡ **1D SR-RHD**: Tolstov+(2013)

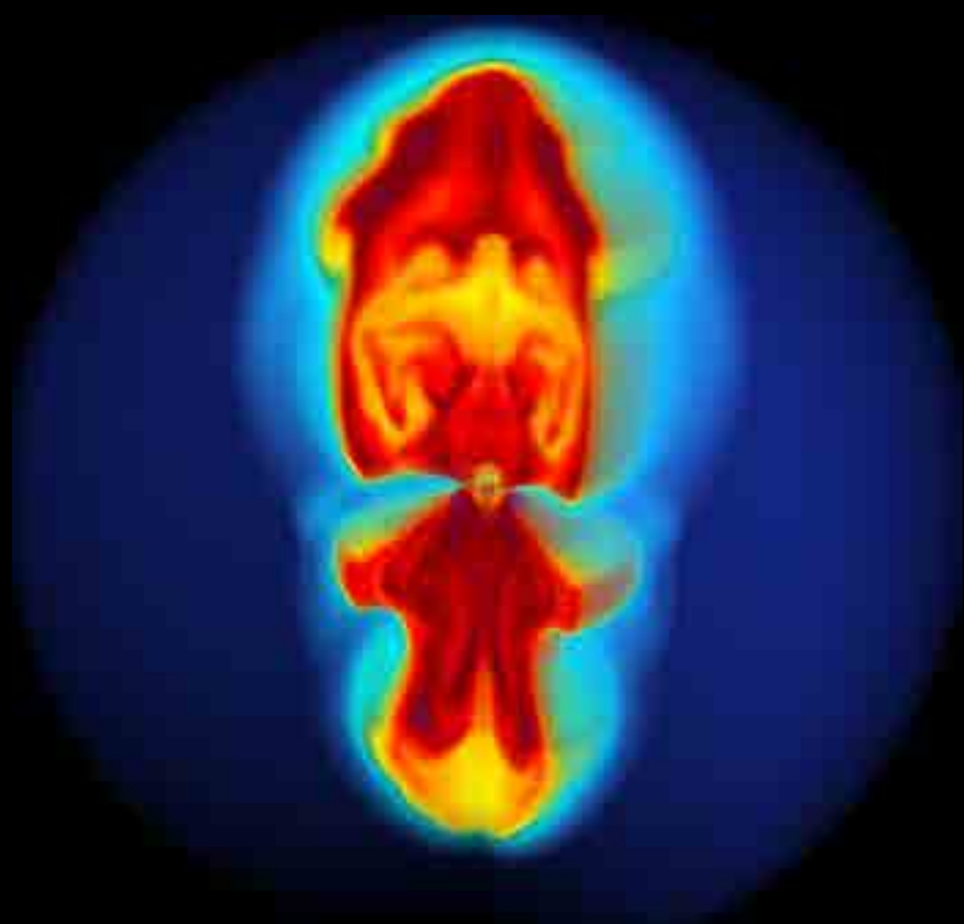
Most of them assume spherical symmetry

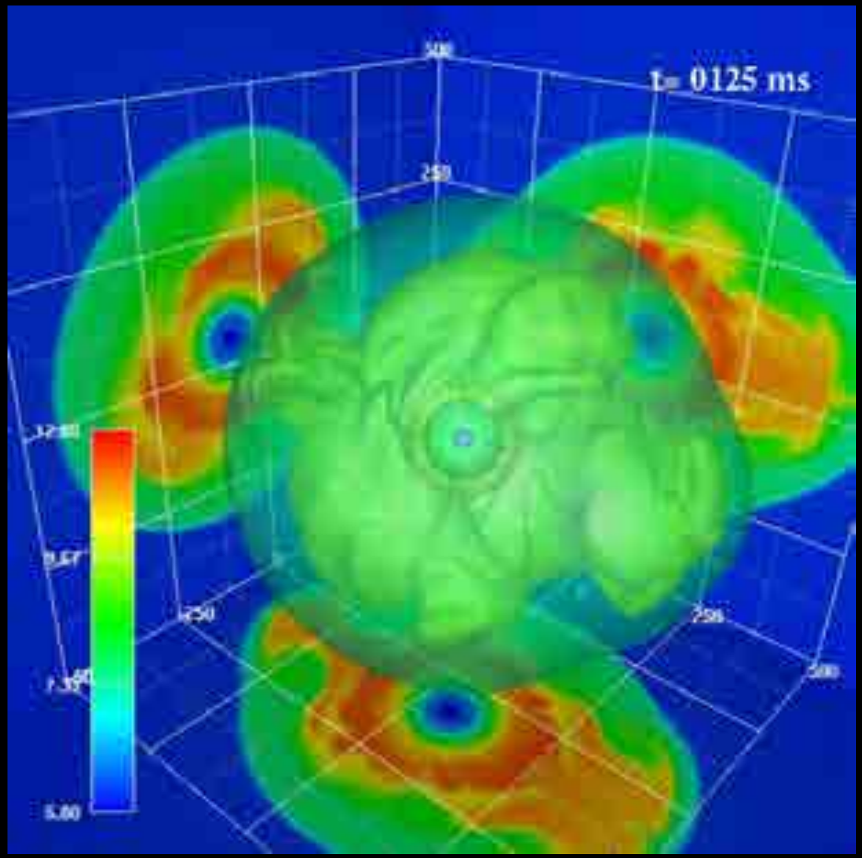
Asymmetry in CCSN

➡ deviation from spherical symmetry is a key to understanding successful core-collapse supernova explosions

SASI?

Marek&Janka (2008)

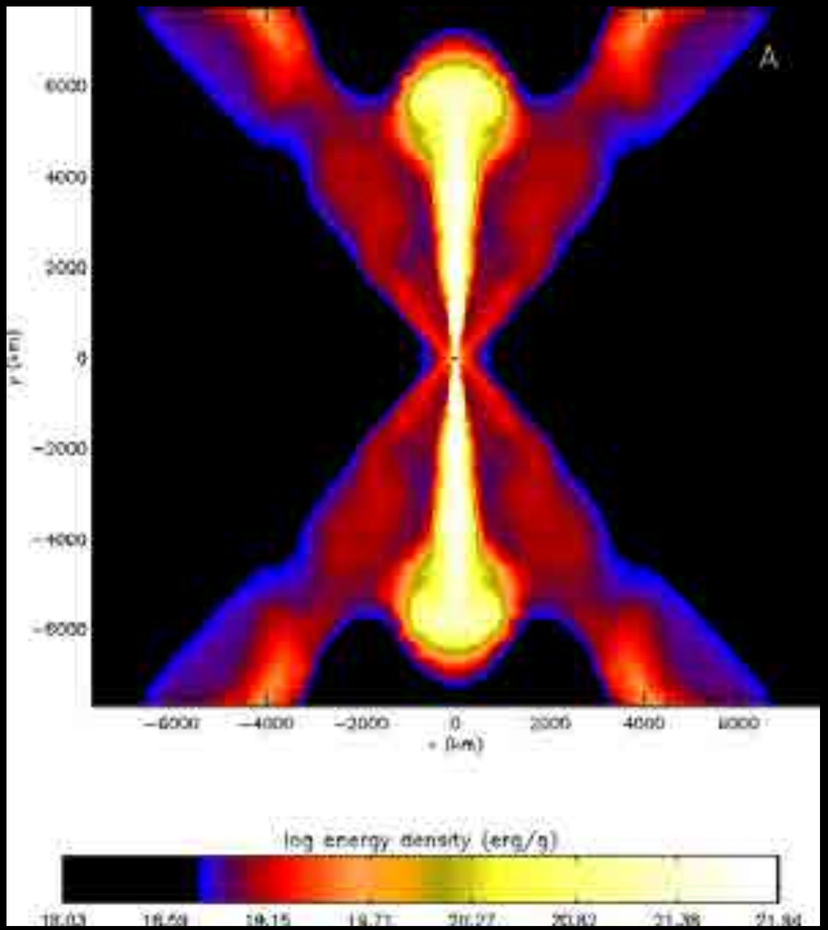




Takiwaki+ (2012)

Convection?

Jet?



MacFadyen&Woosley (1999)

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- ➡ **1D SR-RHD**: Tolstov+(2013)

Most of them assume spherical symmetry

→ toward multi-D SR-RHD

Radiation Hydrodynamics code

➡ Moment equations written in “mixed frame”

$$\frac{\partial I_\nu(t,\boldsymbol{x},\boldsymbol{l})}{\partial t} + (\boldsymbol{l}\cdot\nabla) I_\nu(t,\boldsymbol{x},\boldsymbol{l}) = \eta_\nu + \int g(\nu,\boldsymbol{l};\nu'\boldsymbol{l}')\rho\sigma_\nu I_{\nu'}(t,\boldsymbol{x},\boldsymbol{l}')d\nu' d\Omega' - \rho(\kappa_\nu+\sigma_\nu)I_\nu(t,\boldsymbol{x},\boldsymbol{l})$$

Transfer equation

$$E_{\mathrm{r}}(t,\boldsymbol{x}) = \int E_{\mathrm{r},\nu}(t,\boldsymbol{x})d\nu = \int I_\nu(t,\boldsymbol{x},\boldsymbol{l})d\nu d\Omega$$

$$F_{\mathrm{r}}^i(t,\boldsymbol{x}) = \int F_{\mathrm{r},\nu}^i(t,\boldsymbol{x})d\nu = \int l^i I_\nu(t,\boldsymbol{x},\boldsymbol{l})d\nu d\Omega$$

$$P_{\mathrm{r}}^{ij}(t,\boldsymbol{x}) = \int P_{\mathrm{r},\nu}^{ij}(t,\boldsymbol{x})d\nu = \int l^i l^j I_\nu(t,\boldsymbol{x},\boldsymbol{l})d\nu d\Omega$$

Moment equations

$$\frac{\partial E_{\mathrm{r}}}{\partial t} + \frac{\partial F_{\mathrm{r}}^i}{\partial x^i} = \rho_0\kappa_0(a_{\mathrm{r}}T_{g0}^4 - E_{\mathrm{r}}) + \rho_0\kappa_0\beta_j F_{\mathrm{r}}^j - \rho_0\sigma_0\beta_j F_{\mathrm{r}}^i$$

$$\frac{\partial F_{\mathrm{r}}^i}{\partial t} + \frac{\partial P_{\mathrm{r}}^{ij}}{\partial x^j} = \rho_0\kappa_0 a_{\mathrm{r}}T_{g0}^4\beta^i + \rho_0\sigma_0 E_{\mathrm{r}}\beta^i - \rho_0(\kappa_0+\sigma_0)(F_{\mathrm{r}}^i - \beta_j P_{\mathrm{r}}^{ij})$$

➡ advection term: HLL

➡ source term: implicit method

M1 Closure relation

$$P_{\mathrm{r}}^{ij} = D^{ij}E_{\mathrm{r}}, \quad D^{ij} = \frac{1-\chi}{2}\delta^{ij} + \frac{3-\chi}{2}n^i n_j$$

$$n^i = \frac{F_{\mathrm{r}}^i}{\sqrt{F_{\mathrm{r}}^i F_{\mathrm{r},i}}}, \quad f^i = \frac{F_{\mathrm{r}}^i}{E_{\mathrm{r}}}, \quad \chi = \frac{3+4f^i f_i}{5+2\sqrt{4-3f^i f_i}}$$

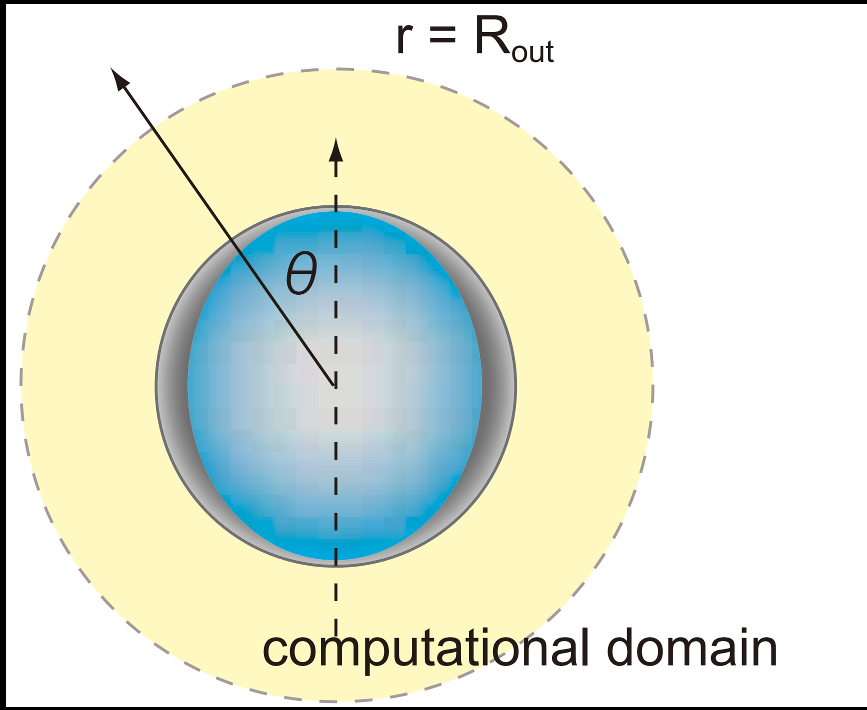
Livermore (1984)

see, Takahashi+,Takahashi&Ohsuga(2013a,b), AS, Maeda, &Shigeyama(2016)

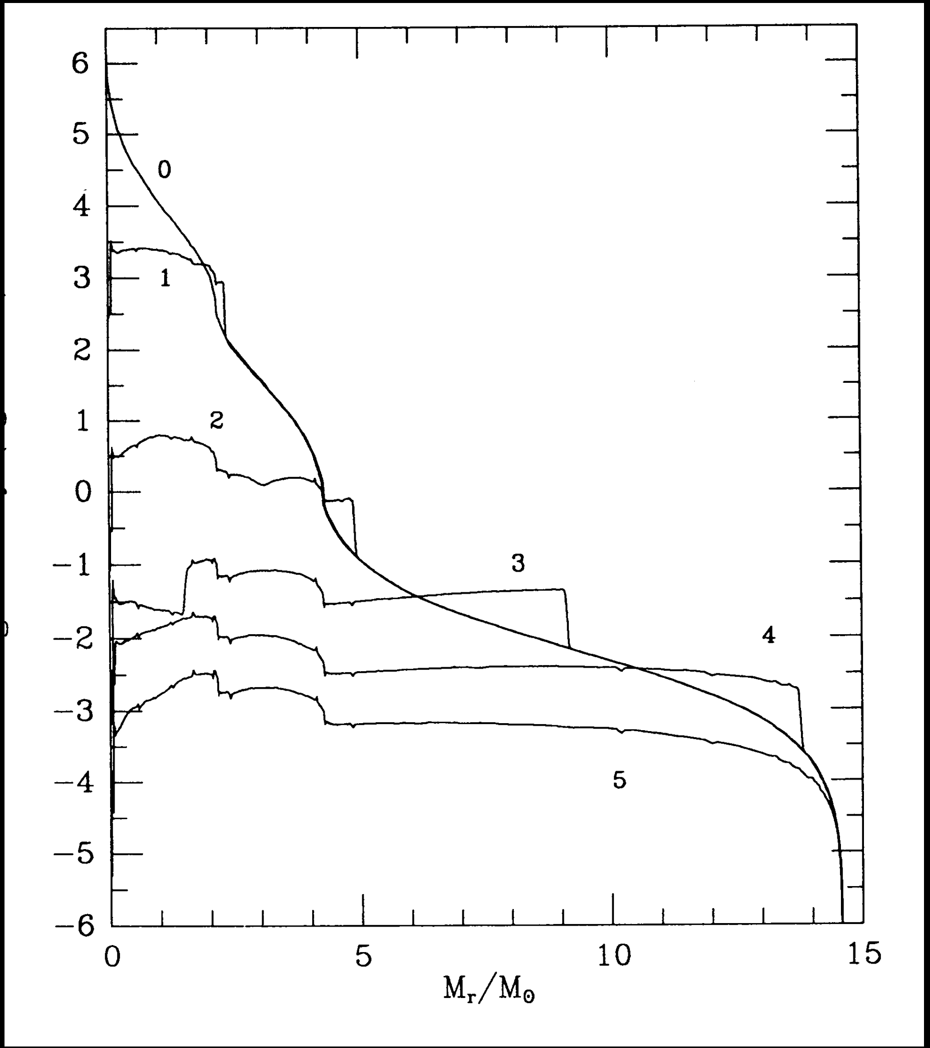
Shock breakout with spherical symmetry

- ➡ 2D RHD simulations, 4096x512 mesh on 512 core
- ➡ 1987A progenitor: BSG with $R_\star=50R_\odot$, $M_\star=14.6M_\odot$ (Nomoto&Hashimoto 1988, Shigeyama&Nomoto 1990)
- ➡ $3\times10^8\mathrm{cm} \leqq r \leqq 4R_\star$, $0 \leqq \theta \leqq \pi$
- ➡ energy injection: $E_{exp}=10^{51}$[erg], $t_{exp}=0.1$[s]
- ➡ asphericity: parameter "a"

$$dE_{int}/dt \propto E_{exp}/t_{exp}[1+a\cos(2\theta)]$$



Shigeyama&Nomoto(1990)

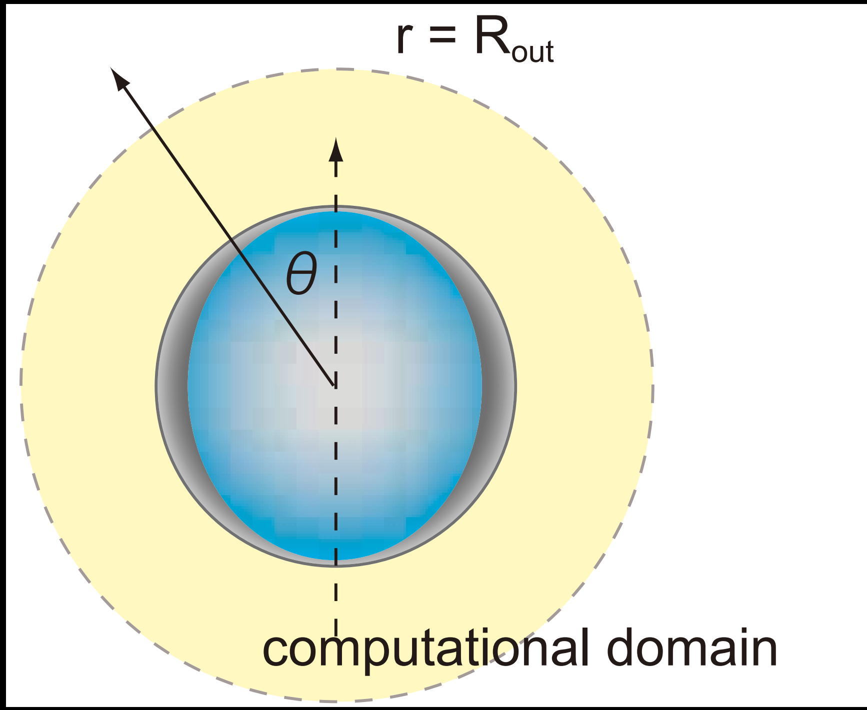


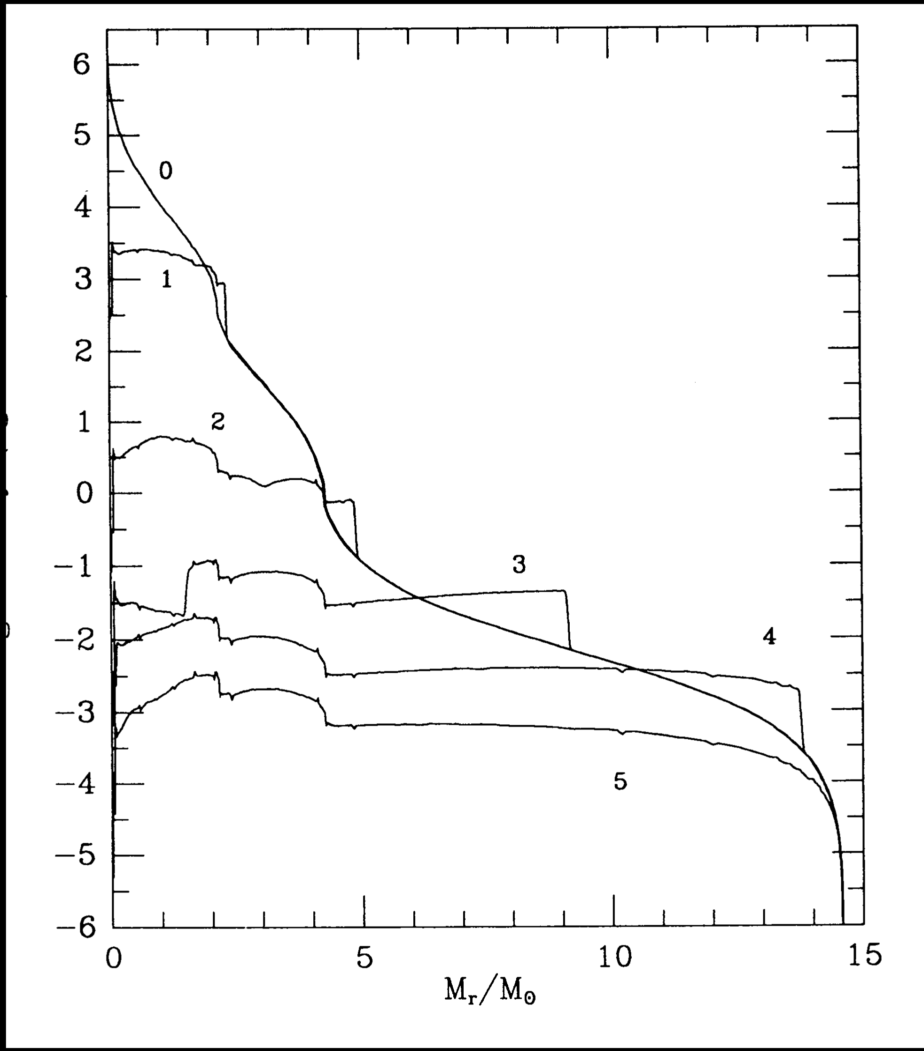
Shock breakout with spherical symmetry

- ➡ fully ionized gas in the stellar envelope with X=0.565, Y=0.430, Z=0.05
- ➡ absorption and emission: free-free
- ➡ scattering: e^- scattering $\kappa = 0.2(1+X)$ [cm^2/g]

Shigeyama&Nomoto(1990)

$dE_{int}/dt \propto E_{exp}/t_{exp}[1+a\cos(2\theta)]$

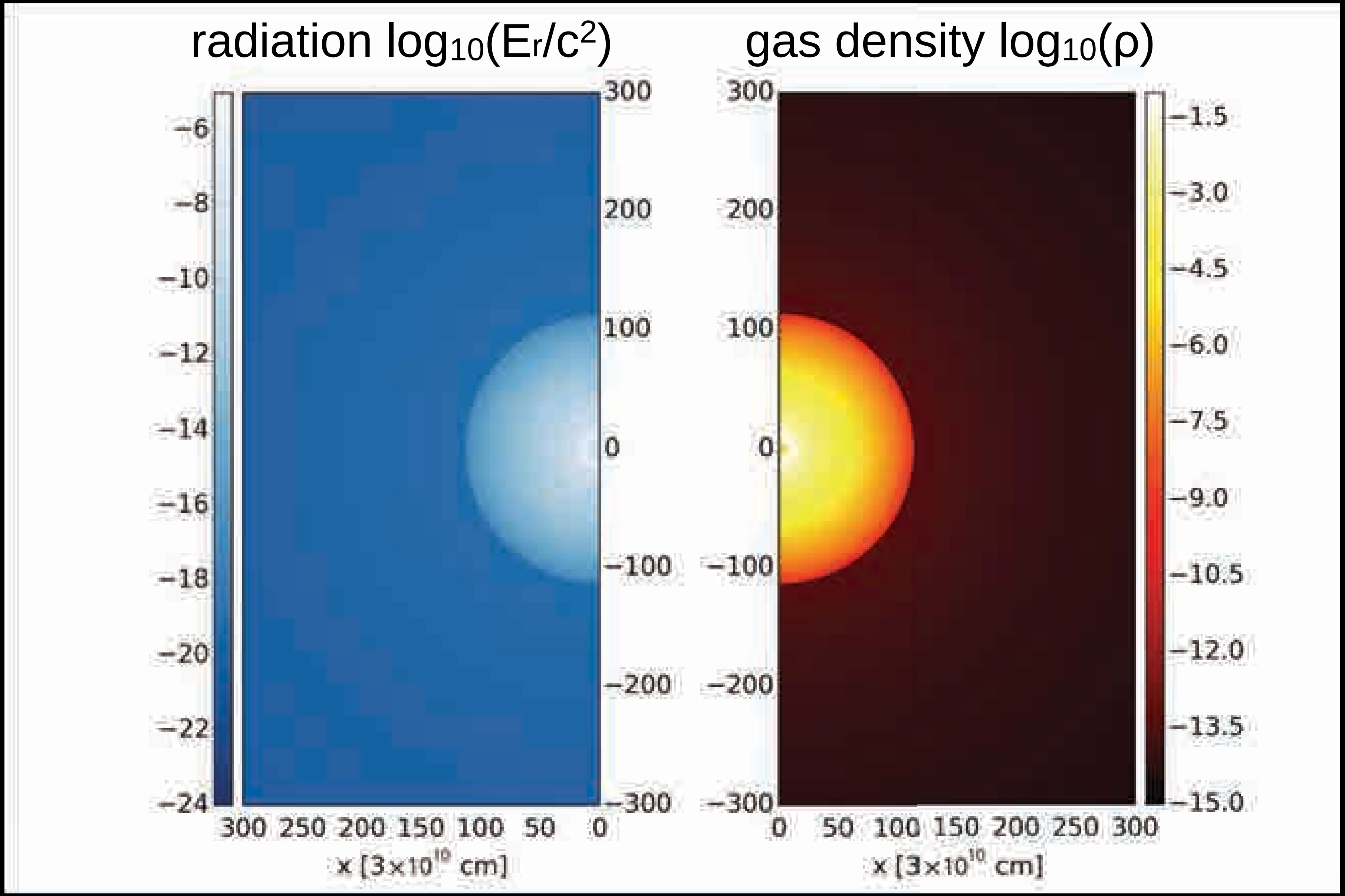




Shock breakout with spherical symmetry

- ➡ 1987A progenitor: BSG with $R_\star = 50R_\odot$, $M_\star = 14.6M_\odot$
- ➡ spherical case: a=0 $dE/dt \propto E_{exp}/t_{exp}[1+a\cos(2\theta)]$

t= 1000 s
after core-collapse



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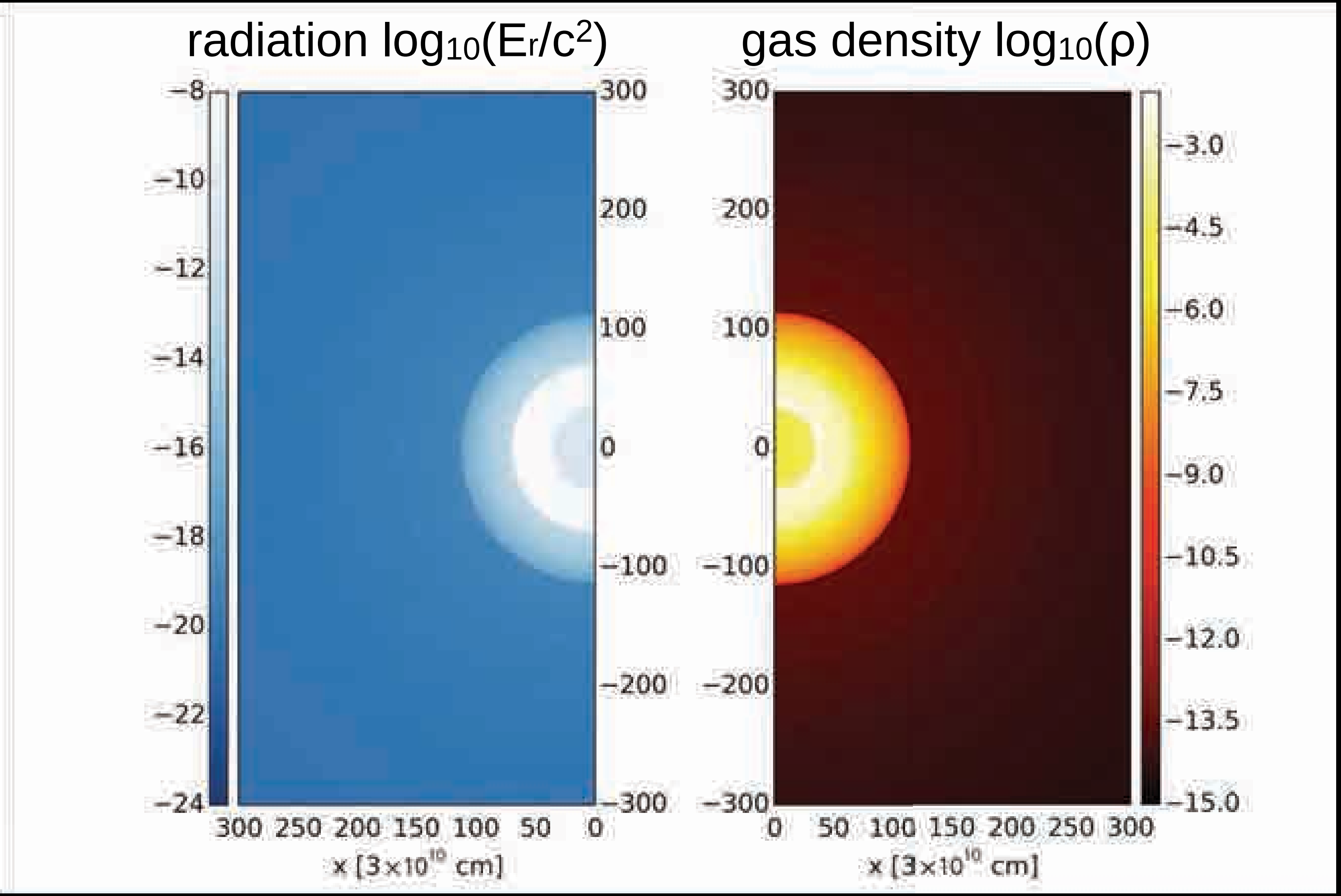
from t= 5000 s
to t= 7000 s
after core-collapse

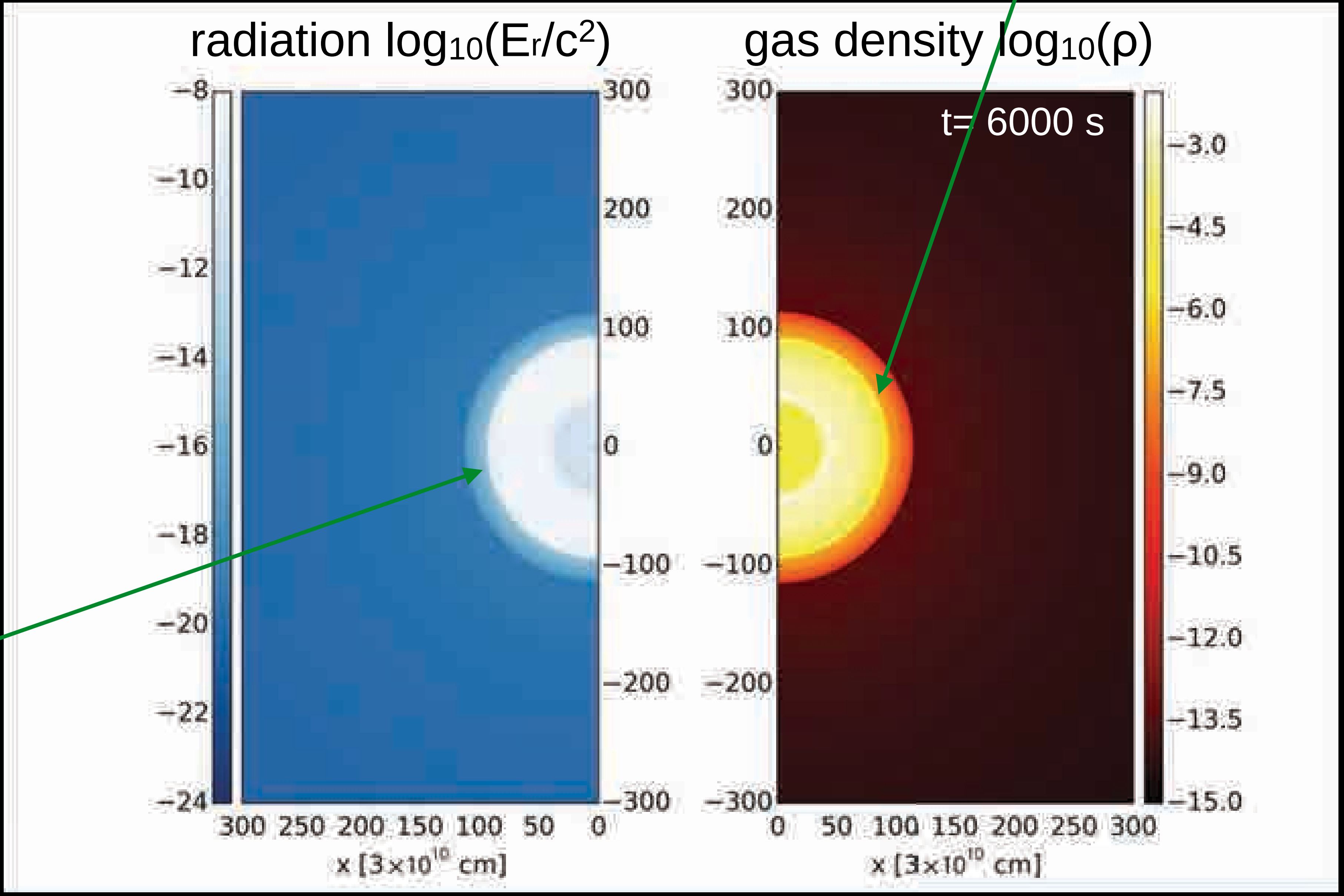


Shock breakout with spherical symmetry

➡ 1987A progenitor: BSG with $R_\star=50R_\odot$, $M_\star=14.6M_\odot$

➡ spherical case: a=0 $dE/dt \propto E_{exp}/t_{exp}[1+a\cos(2\theta)]$

optical depth is too large
for photons in the shocked region



Photons are “trapped”
in the shocked region

Shock breakout with spherical symmetry

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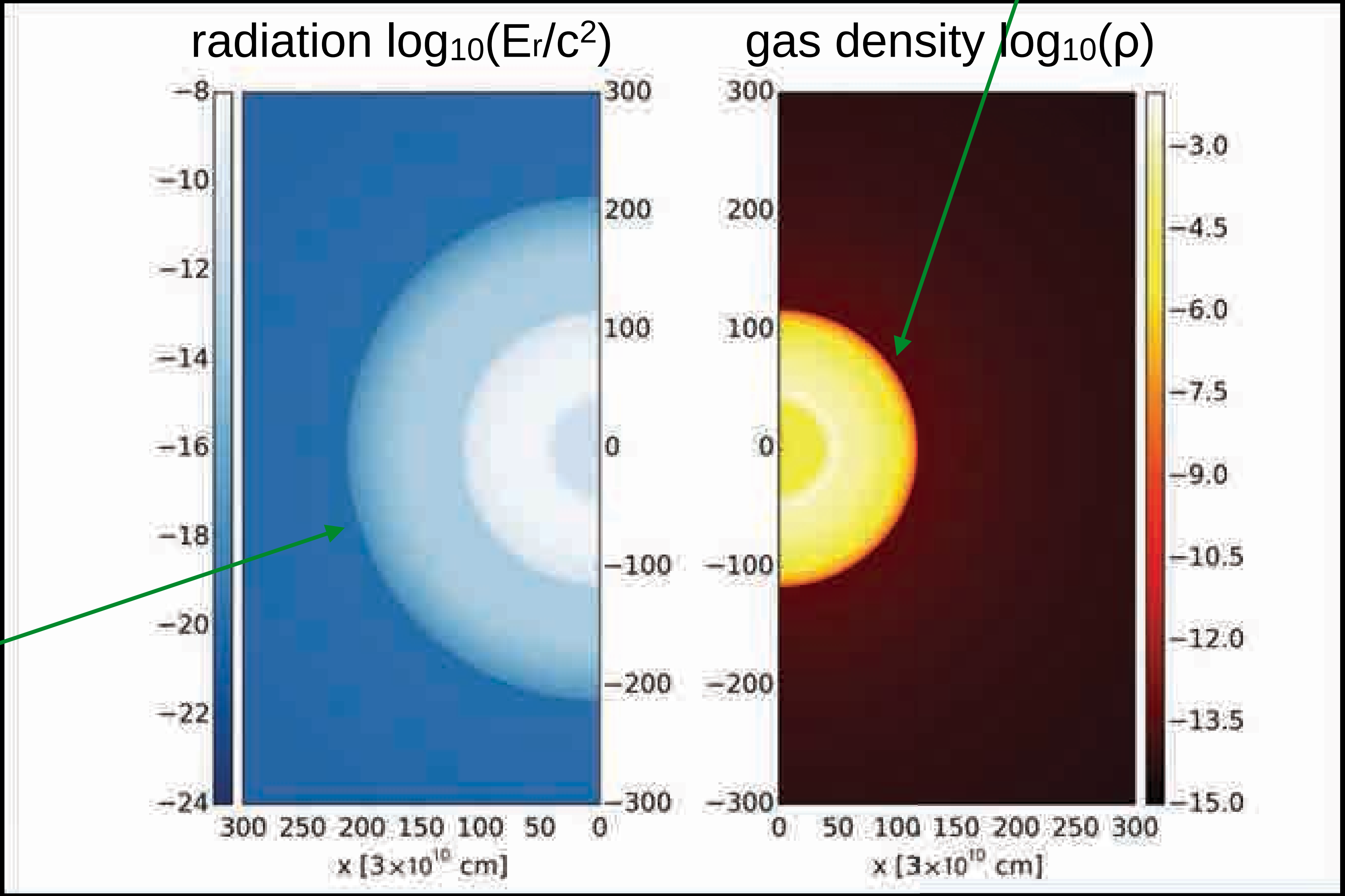
- ➡ spherical case: a=0 $dE/dt \propto E_{exp}/t_{exp}[1+a\cos(2\theta)]$

Now, optical depth is sufficiently small



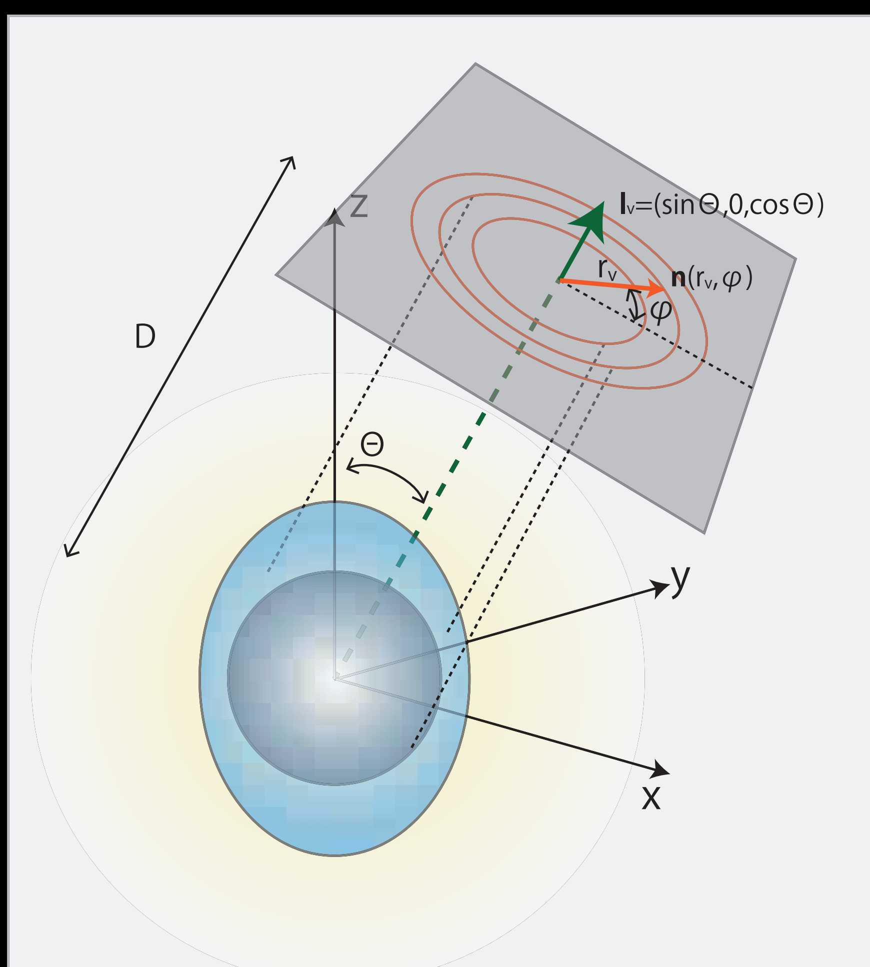
Photons having been in the shocked region can freely travel at c

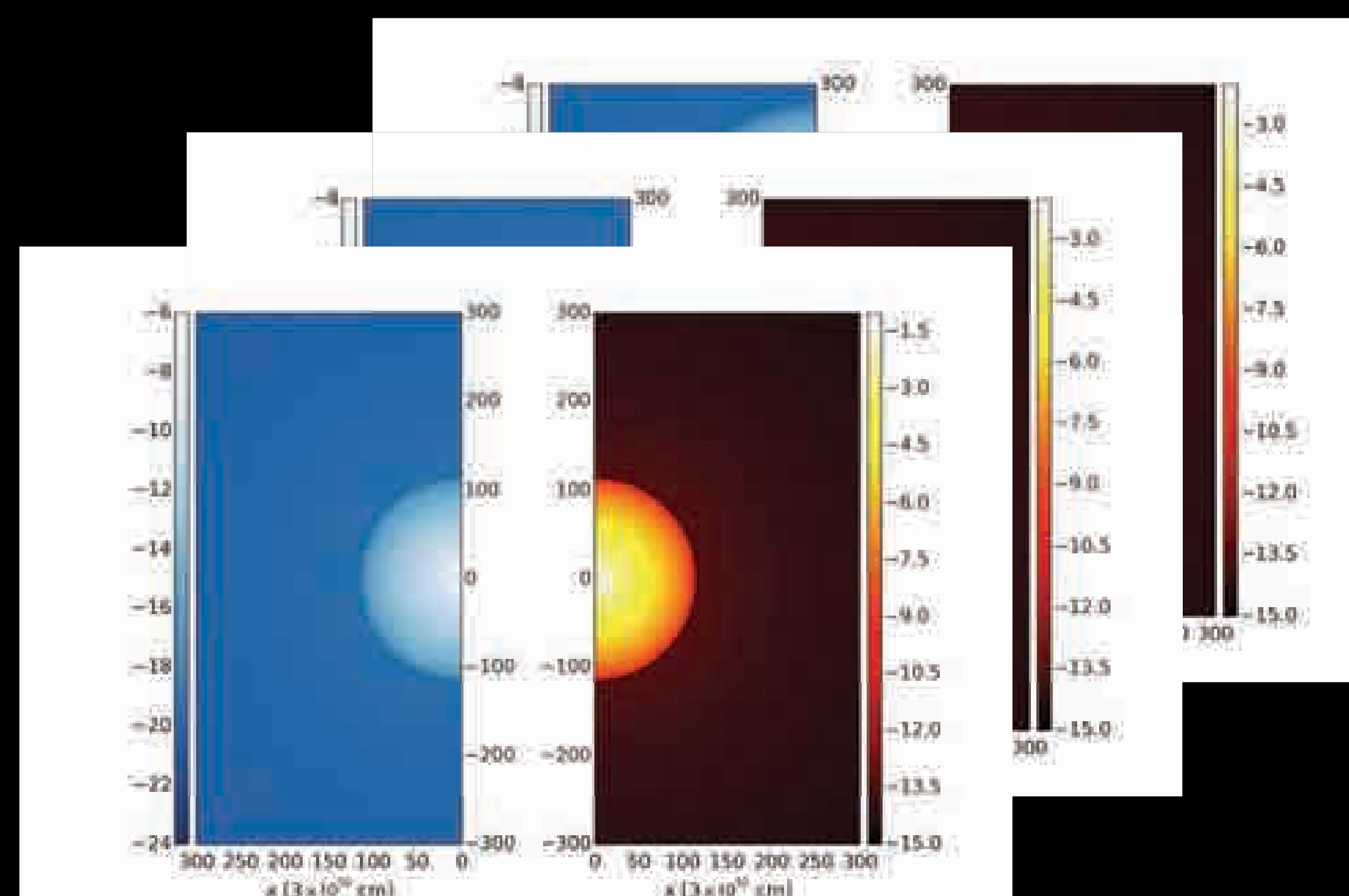
Light curve calculation: ray-tracing

- ➡ observer seeing the event with a viewing angle Θ
- ➡ Transfer equation is integrated along rays using snapshots of a RHD simulation

Transfer equation along a ray (frequency-integrated)

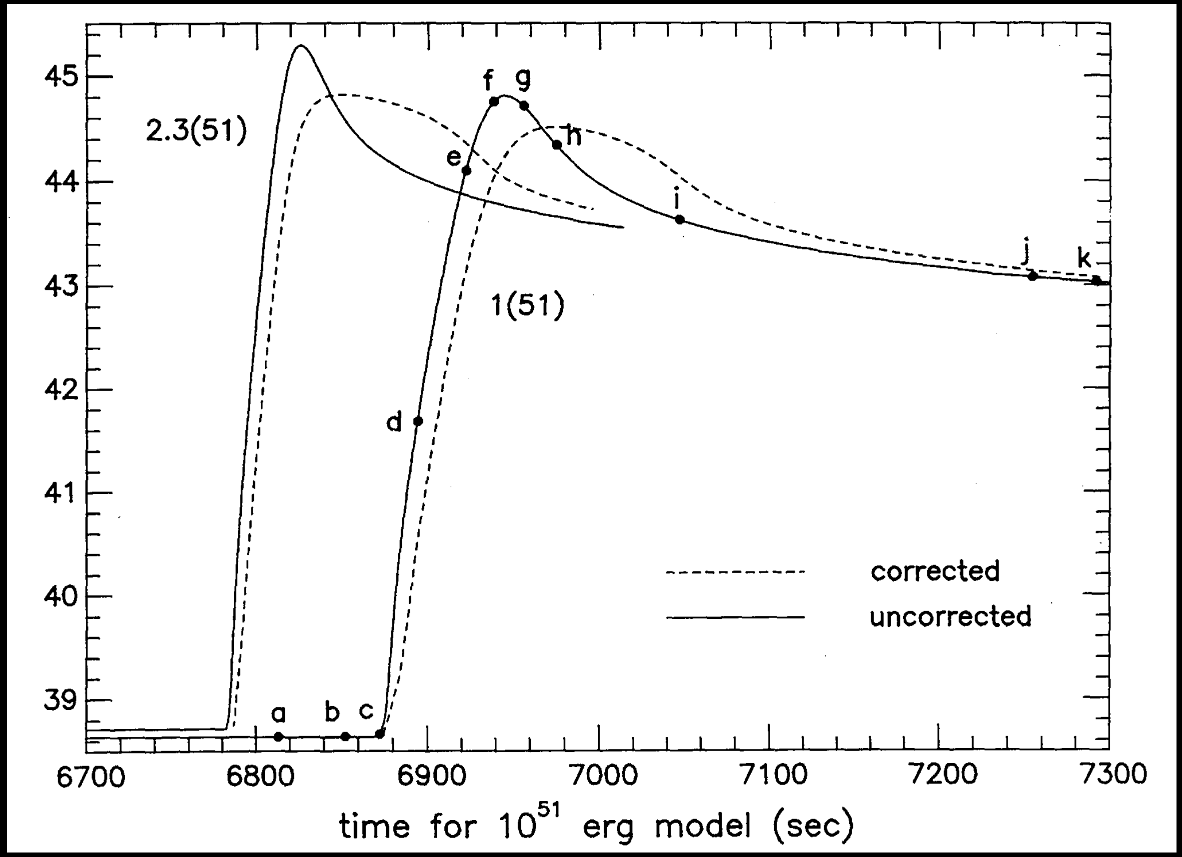
$$\frac{\partial I}{\partial t} + (\boldsymbol{l}\cdot\nabla)I = \mathcal{D}^{-1}\alpha'\left(\mathcal{D}^4\frac{\sigma_{\rm SB}T_{\rm g}^4}{\pi} - I\right) + \mathcal{D}^{-1}\sigma'\left(\mathcal{D}^4\frac{E'_{\rm r}}{4\pi} - I\right)$$



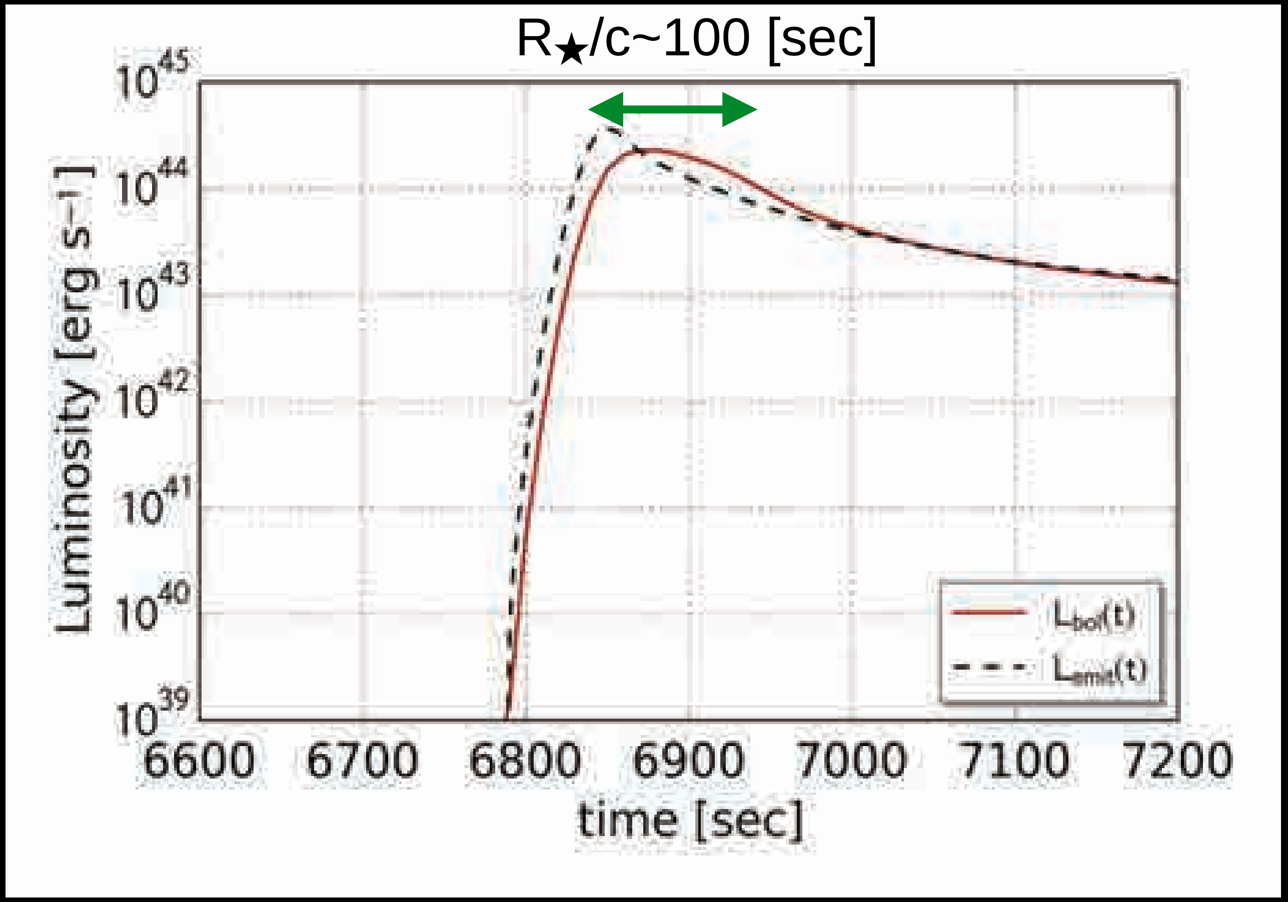


Light curve calculation: spherical

- LC consistent with 1D RHD calculations by Shigeyama+(1988), Ensmann&Burrows(1992) for SN 1987A (dotted line)
- peak luminosity = 2.3×10^{44} [erg s^{-1}], consistent within a factor of 2
- initial bright phase: $\Delta t \sim R_\star/c \sim 100$ [sec]



1D spherical model by Ensmann&Burrows(1992)



Our 2D spherical model

Light curve calculation: spherical

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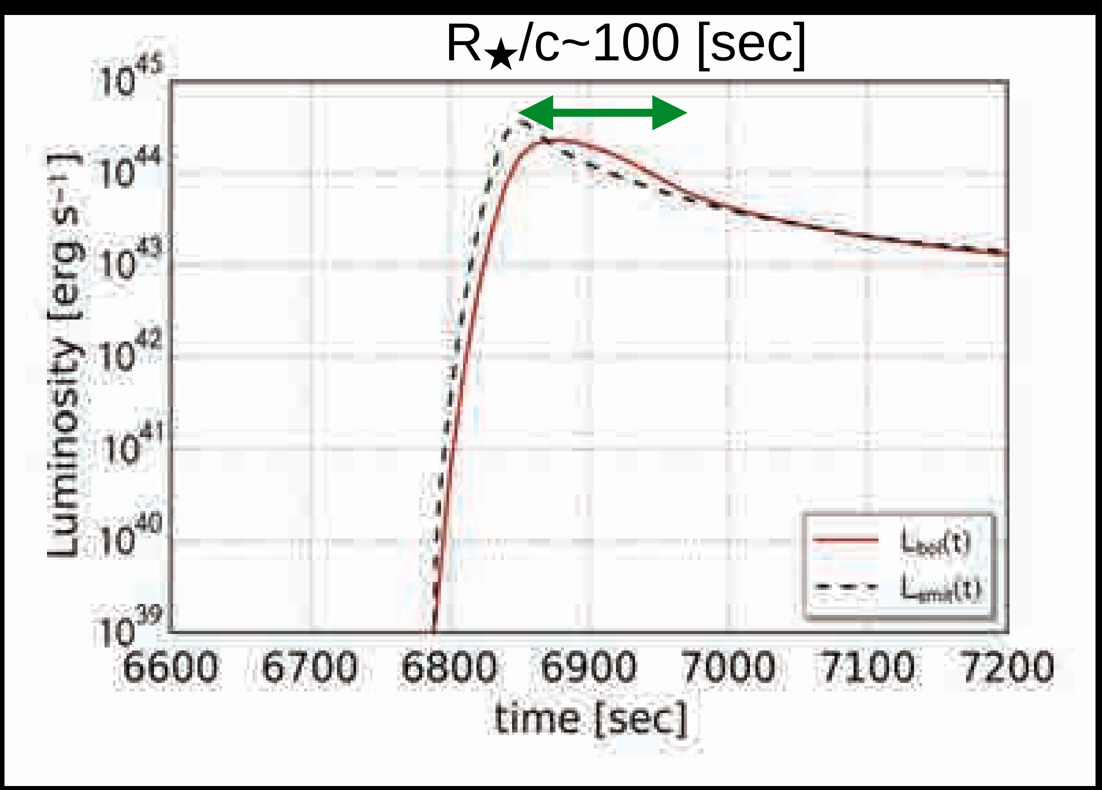
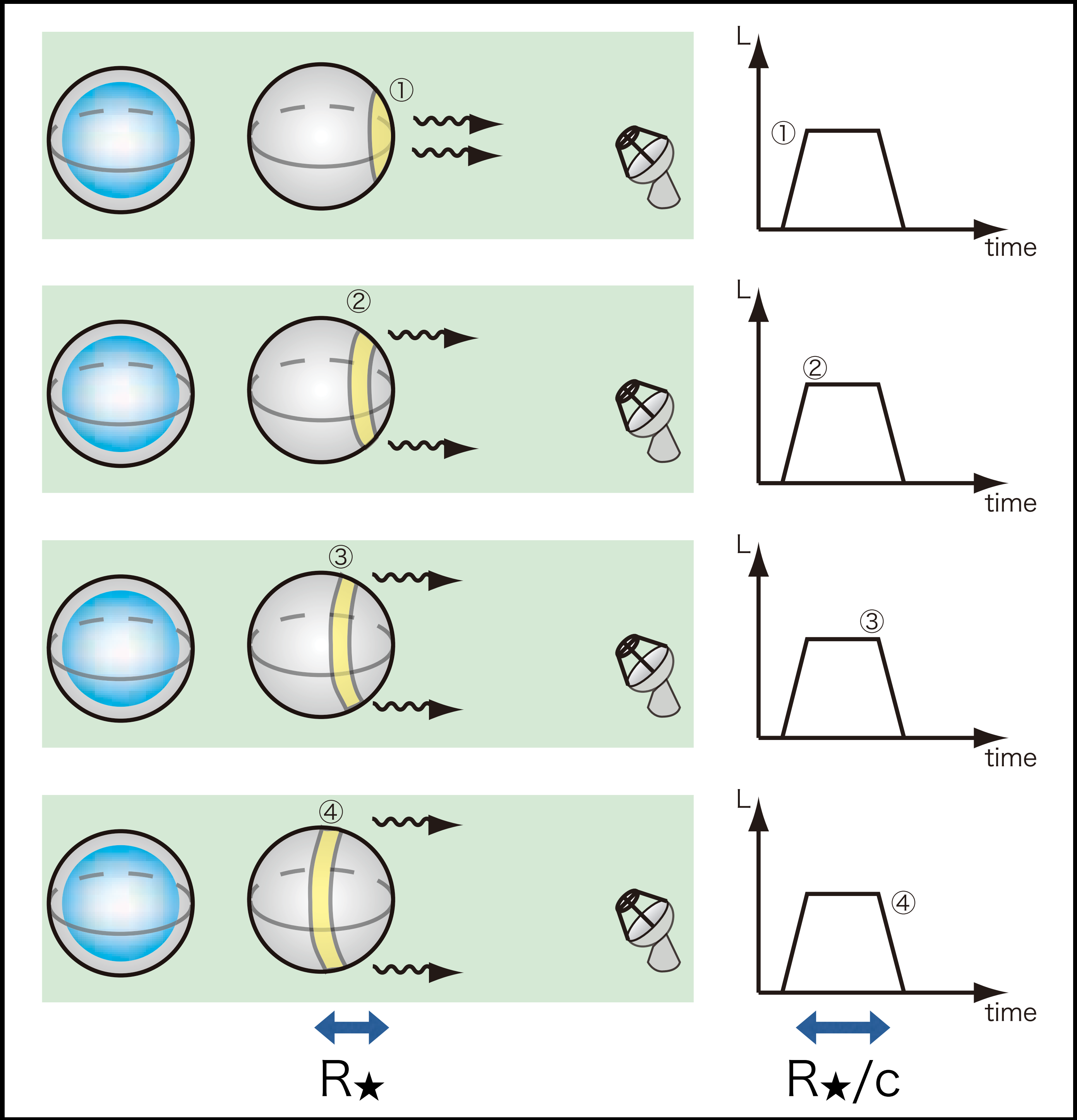
- ➡ initial bright phase: $\Delta t \sim R_\star/c \sim 100$ [sec]



Our 2D spherical model

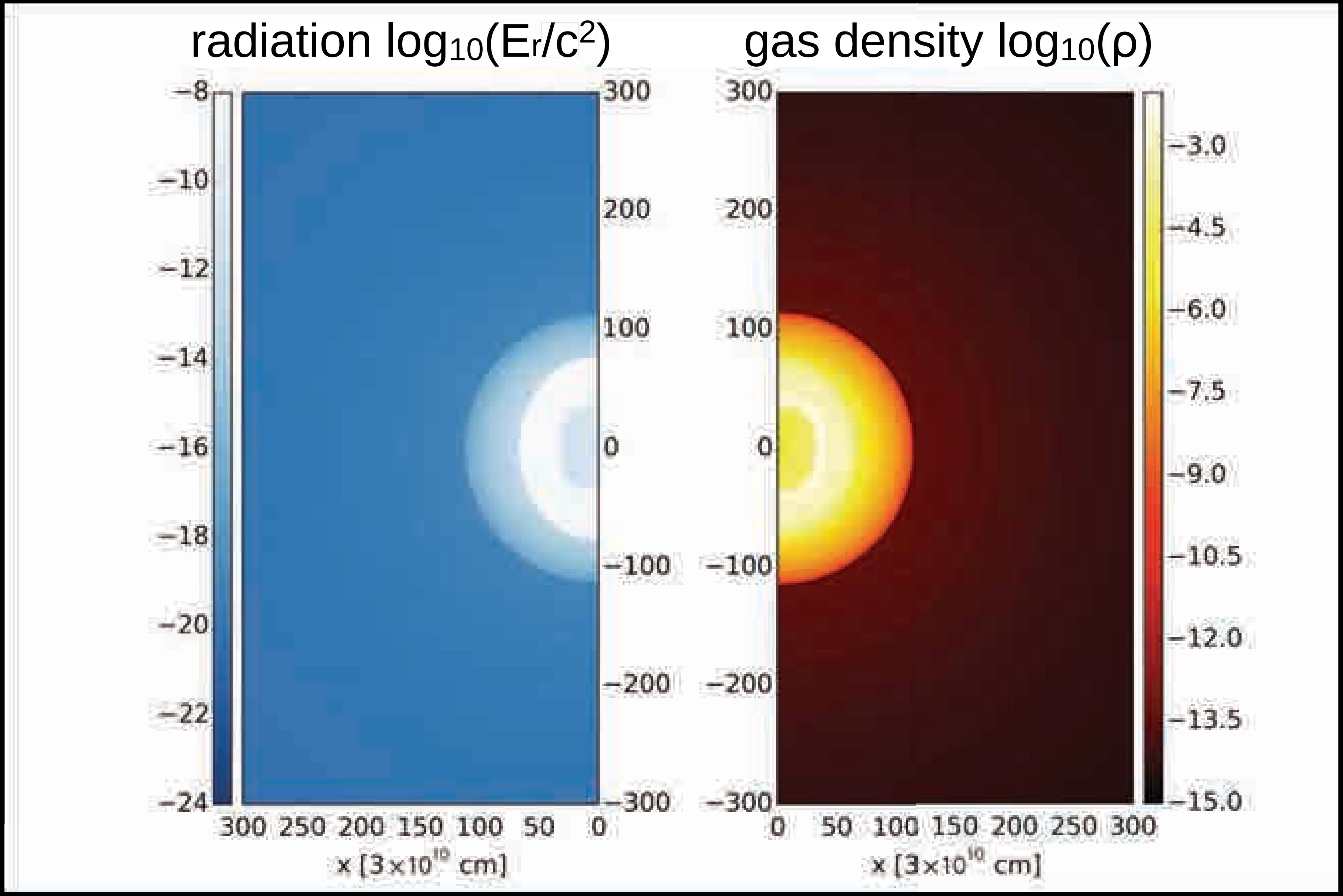


Shock breakout in 2D

➡ 1987A progenitor: BSG with $R_\star=50R_\odot$, $M_\star=14.6M_\odot$

➡ spherical case: a=0.5 $dE/dt \propto E_{exp}/t_{exp}[1+a\cos(2\theta)]$

from t= 5000 s
to t= 7000 s
after core-collapse



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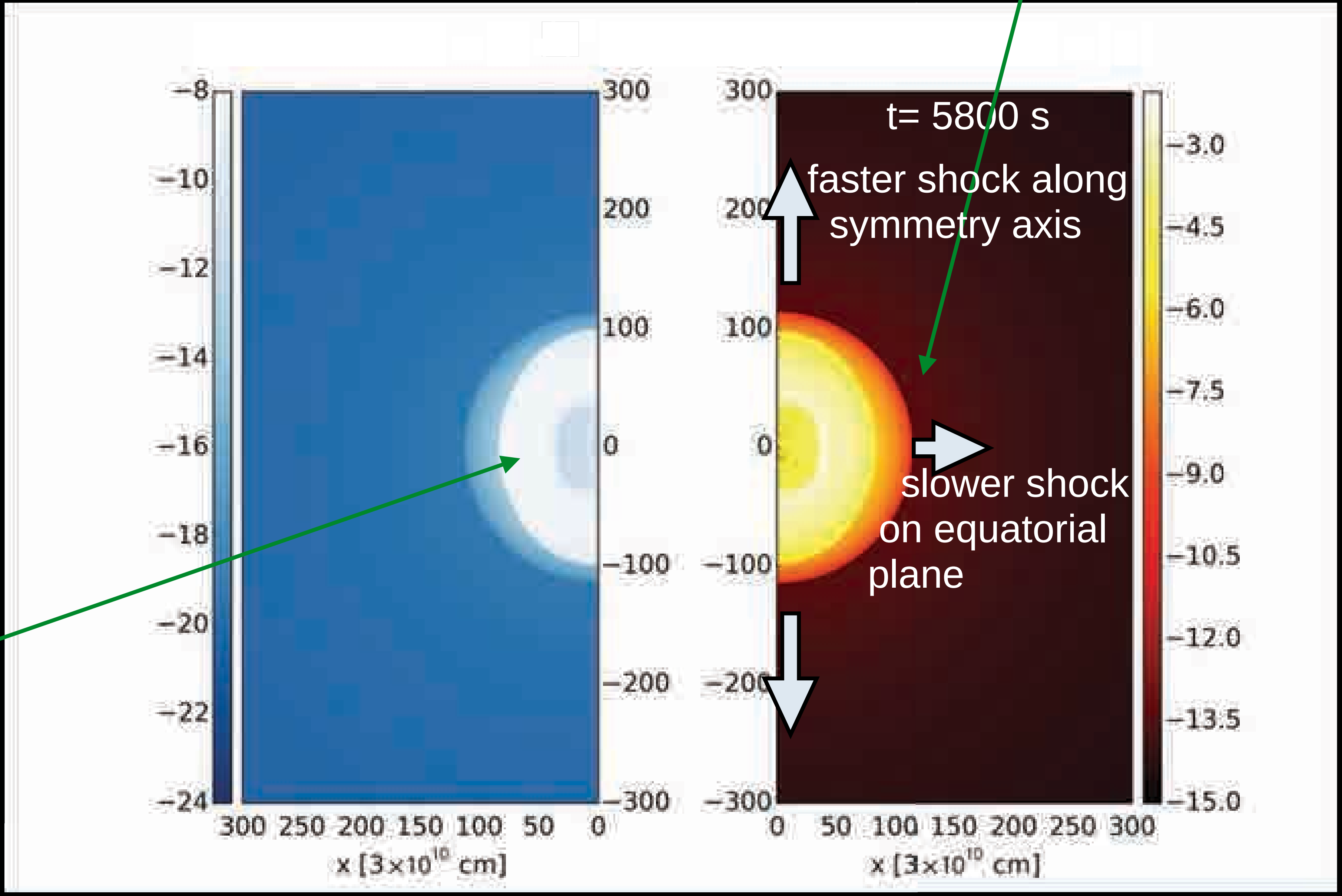

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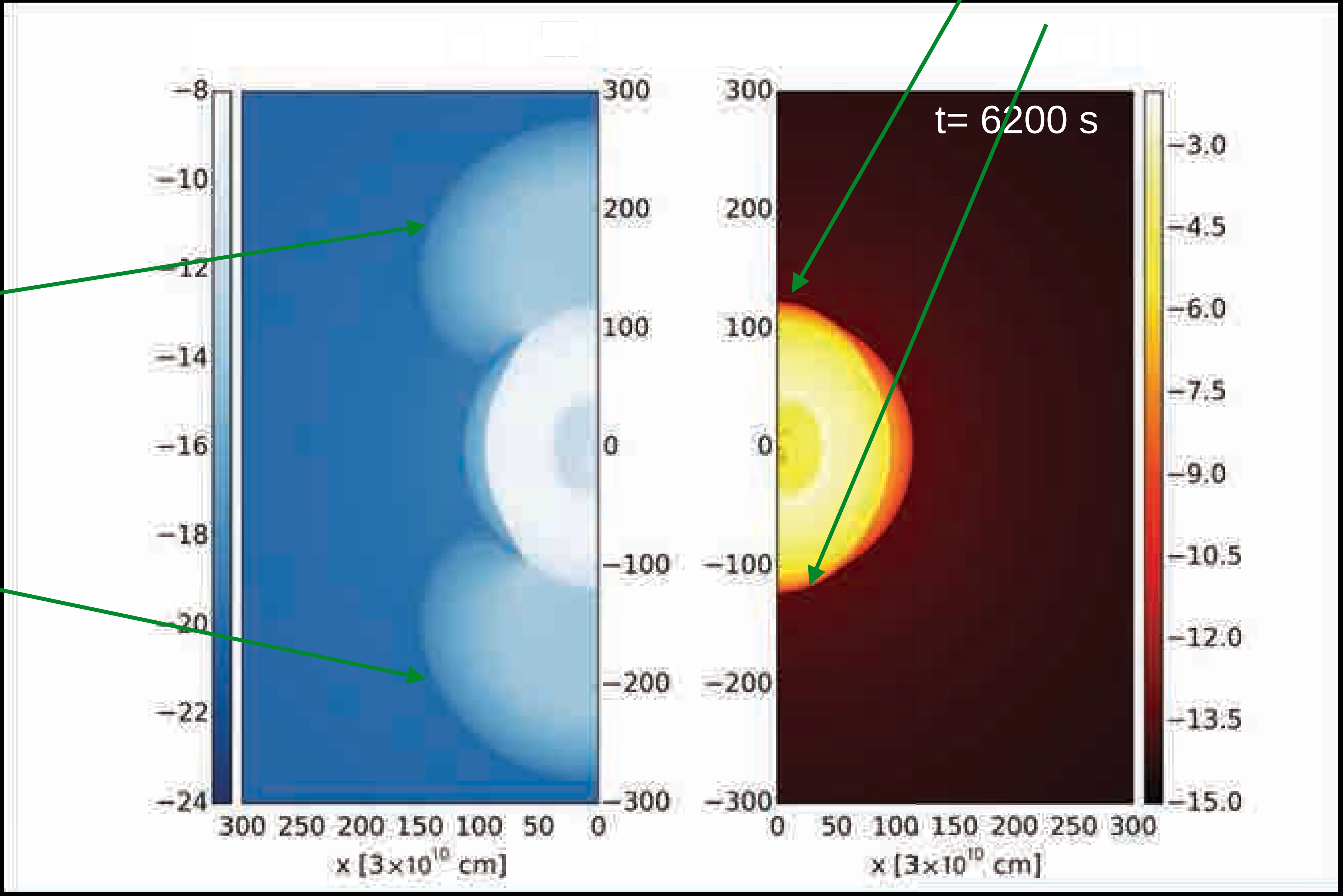
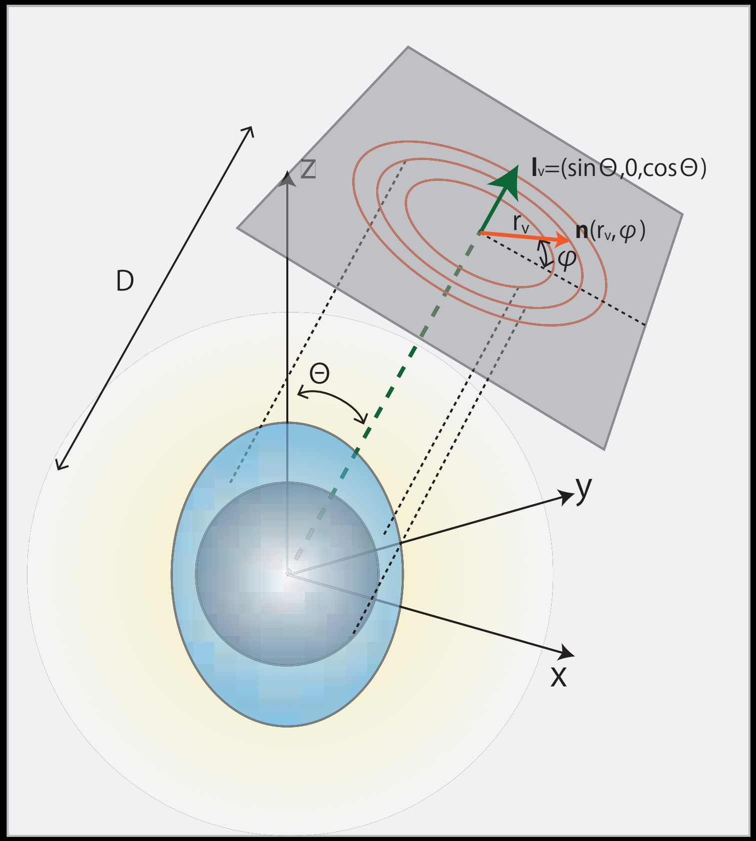
Shocked gas emerge from polar region at first

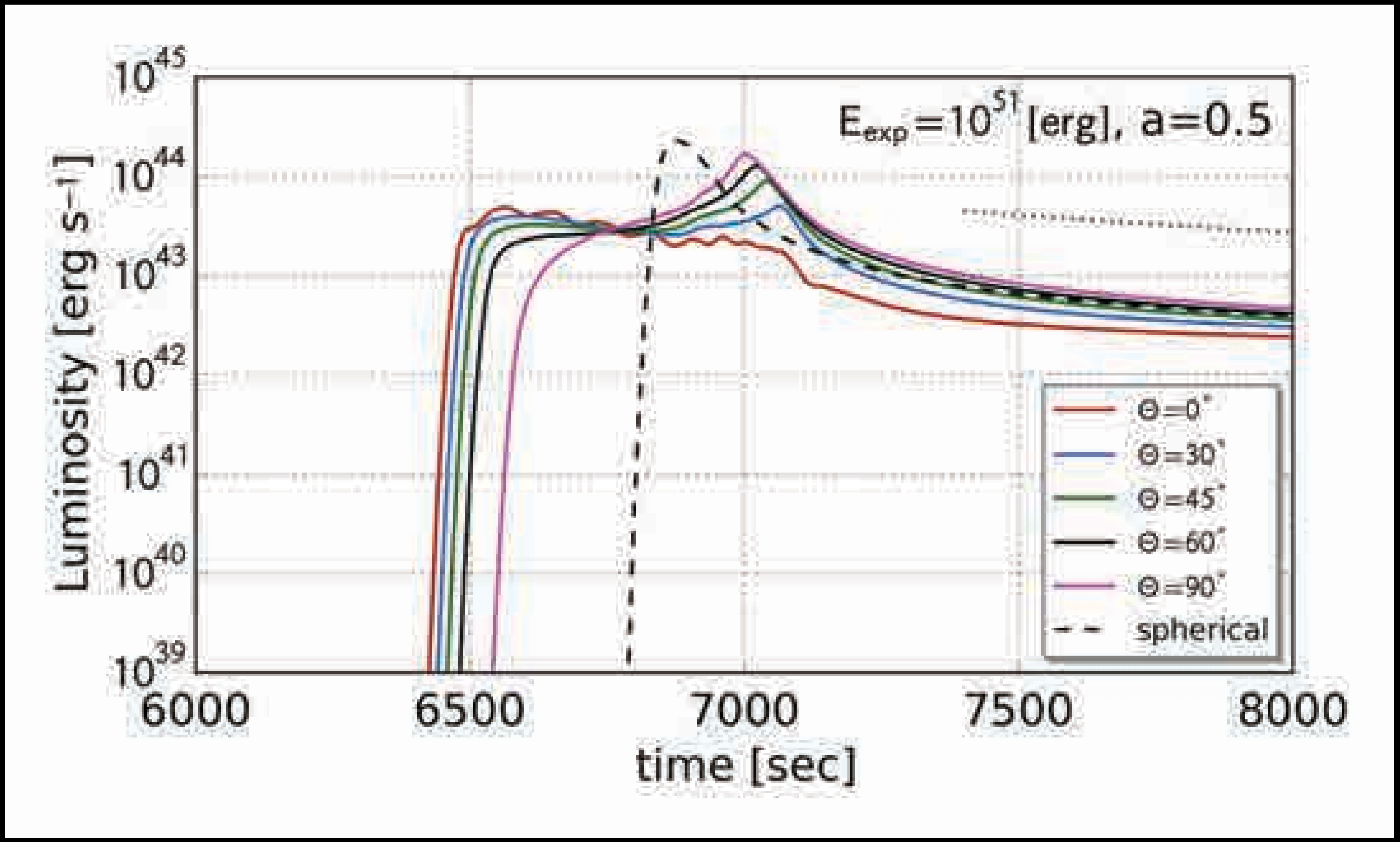
Photons are efficiently emitted from shocks having emerged from the surface



Light curve calculation: aspherical

- ➡ wide variety of light curves depending on the viewing angle, reflecting the geometry of the shock wave
- ➡ under-luminous, long-lasting emission ~ 500-600 sec
- ➡ emission after the initial phase is similar to spherical case





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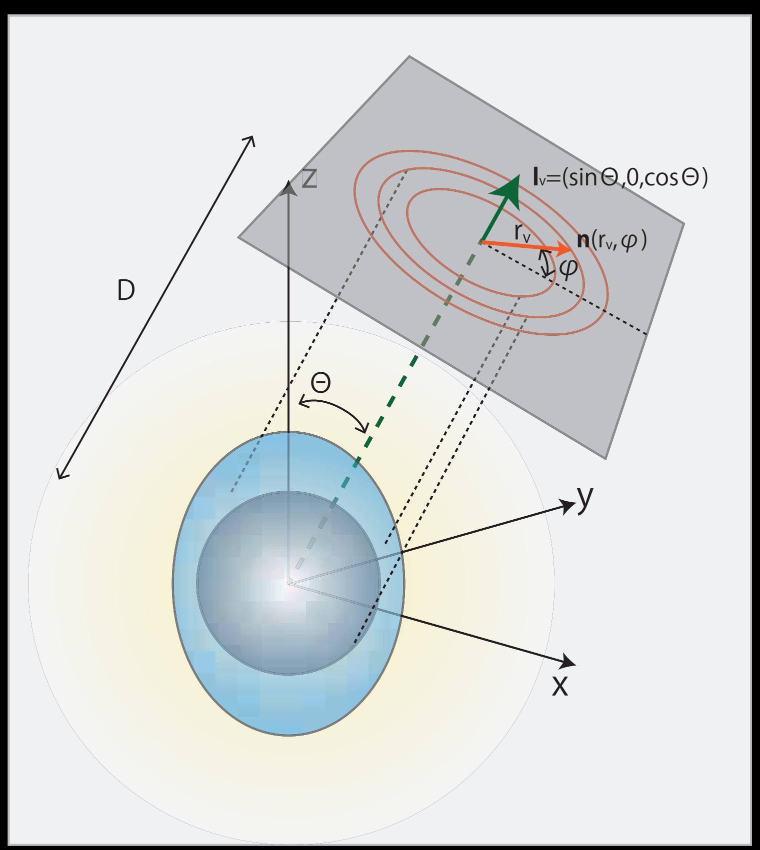

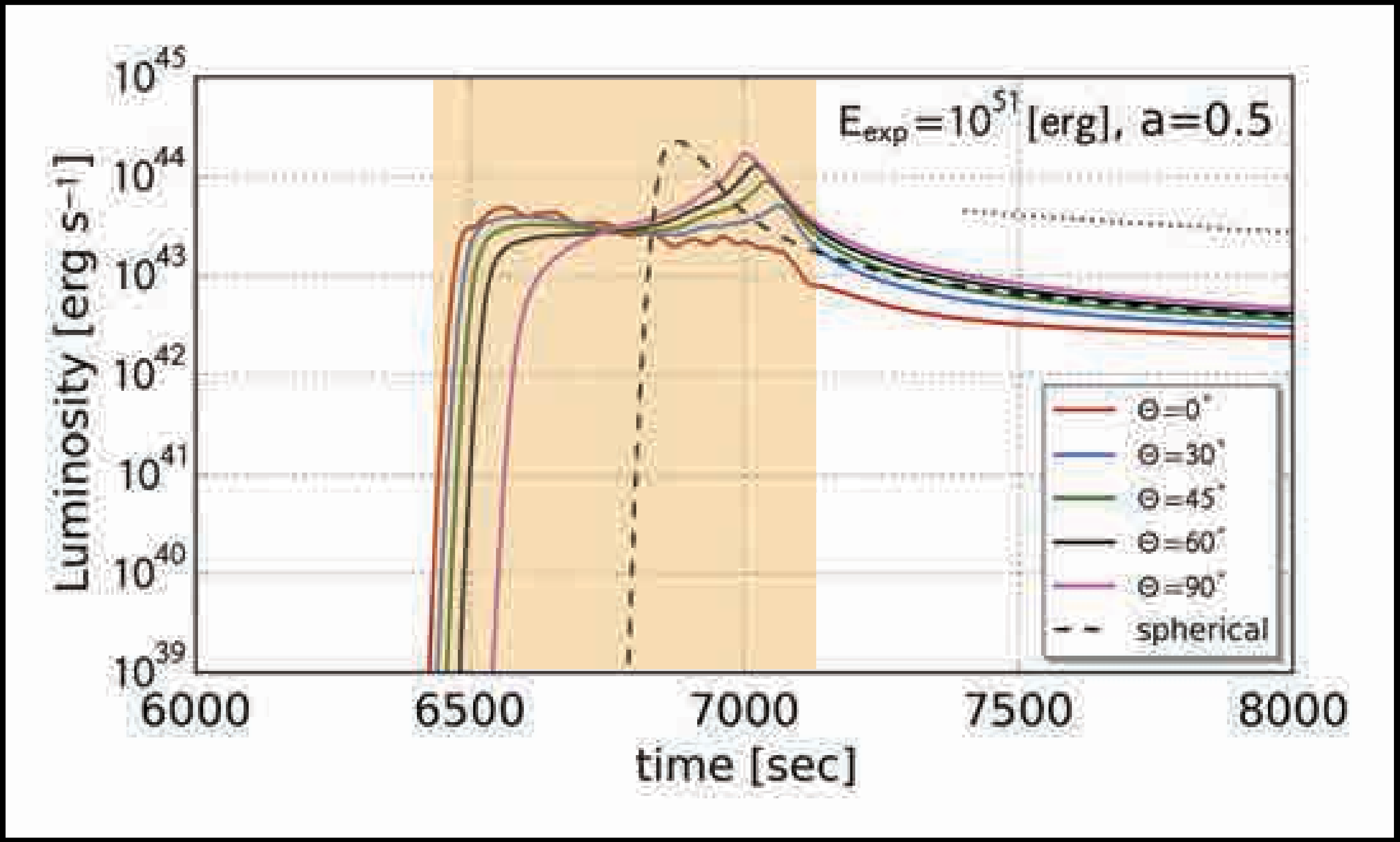

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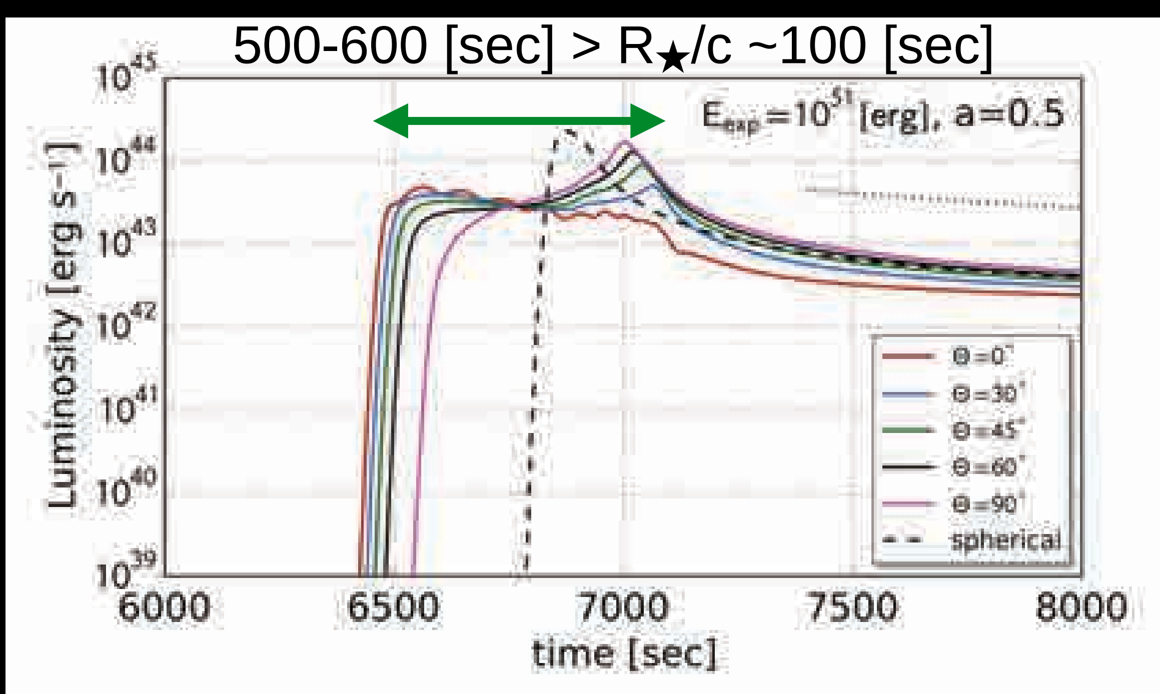

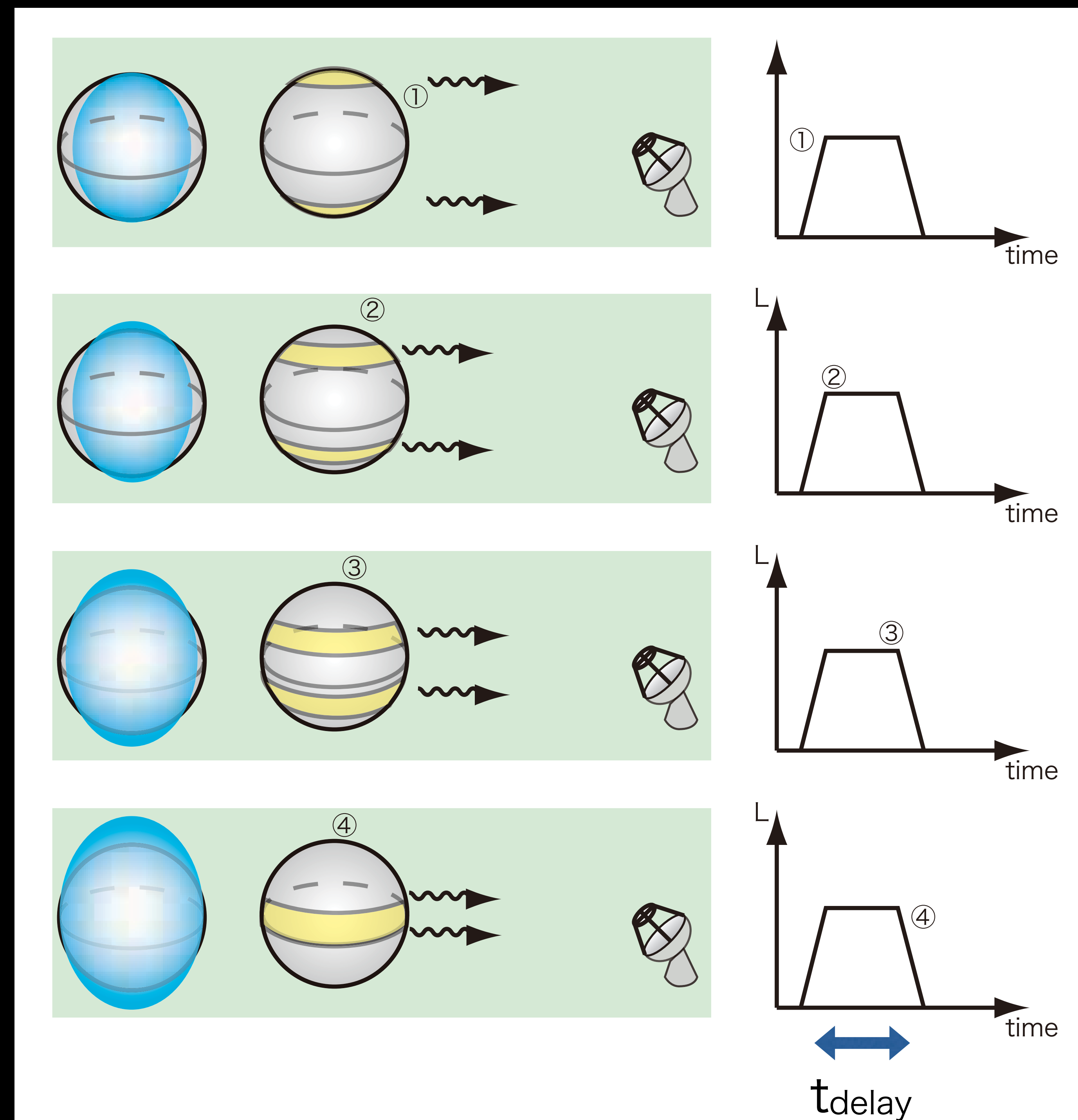

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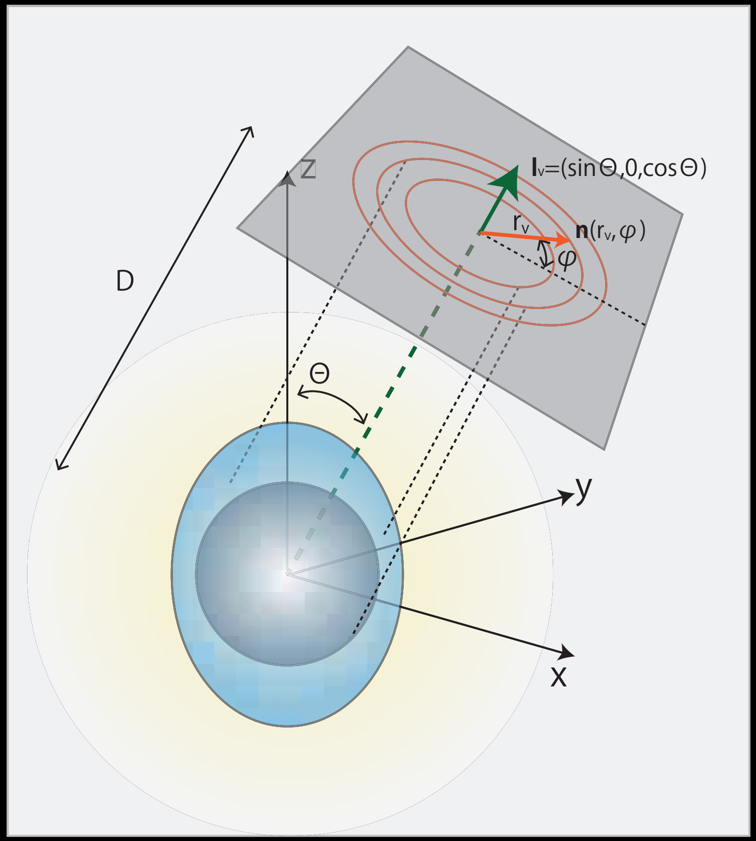
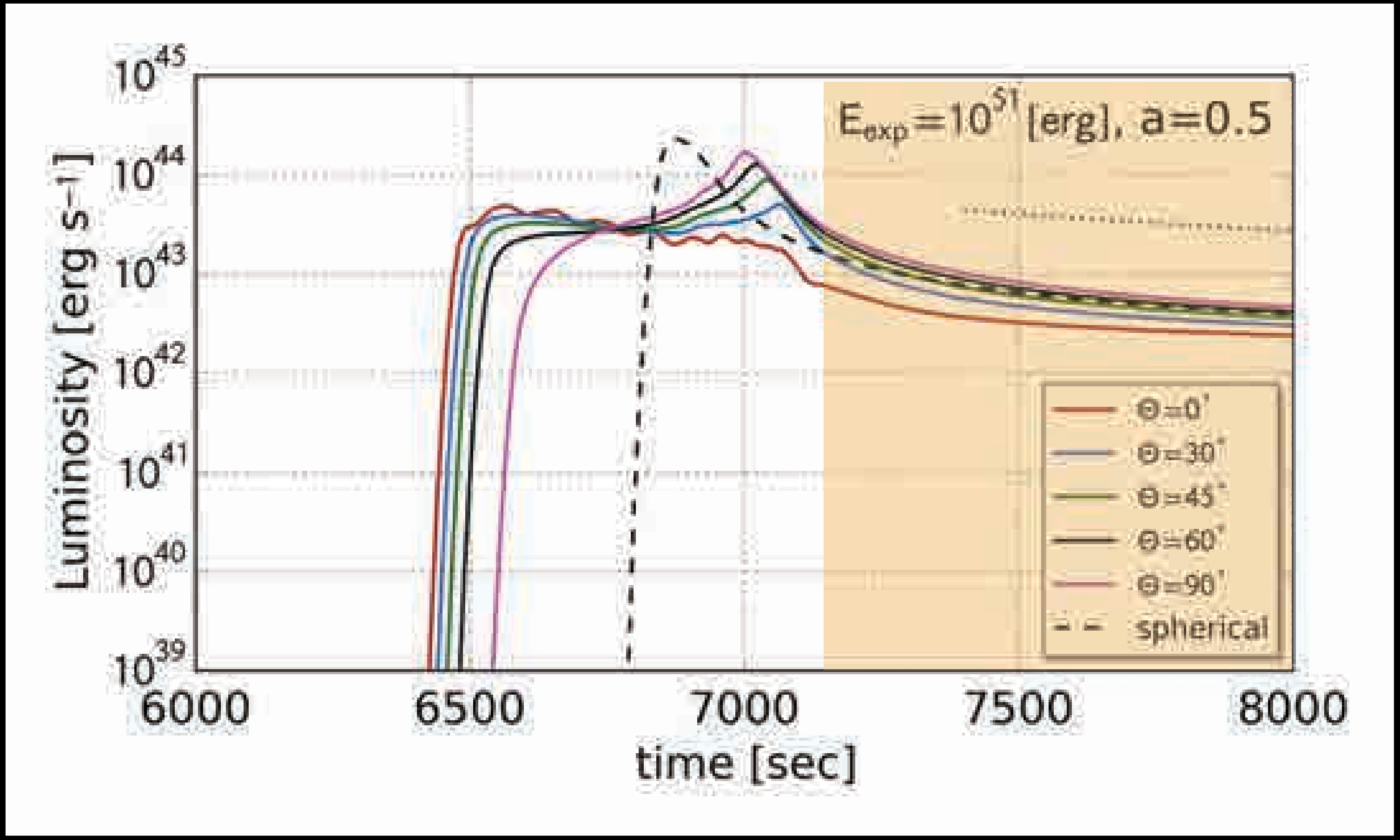
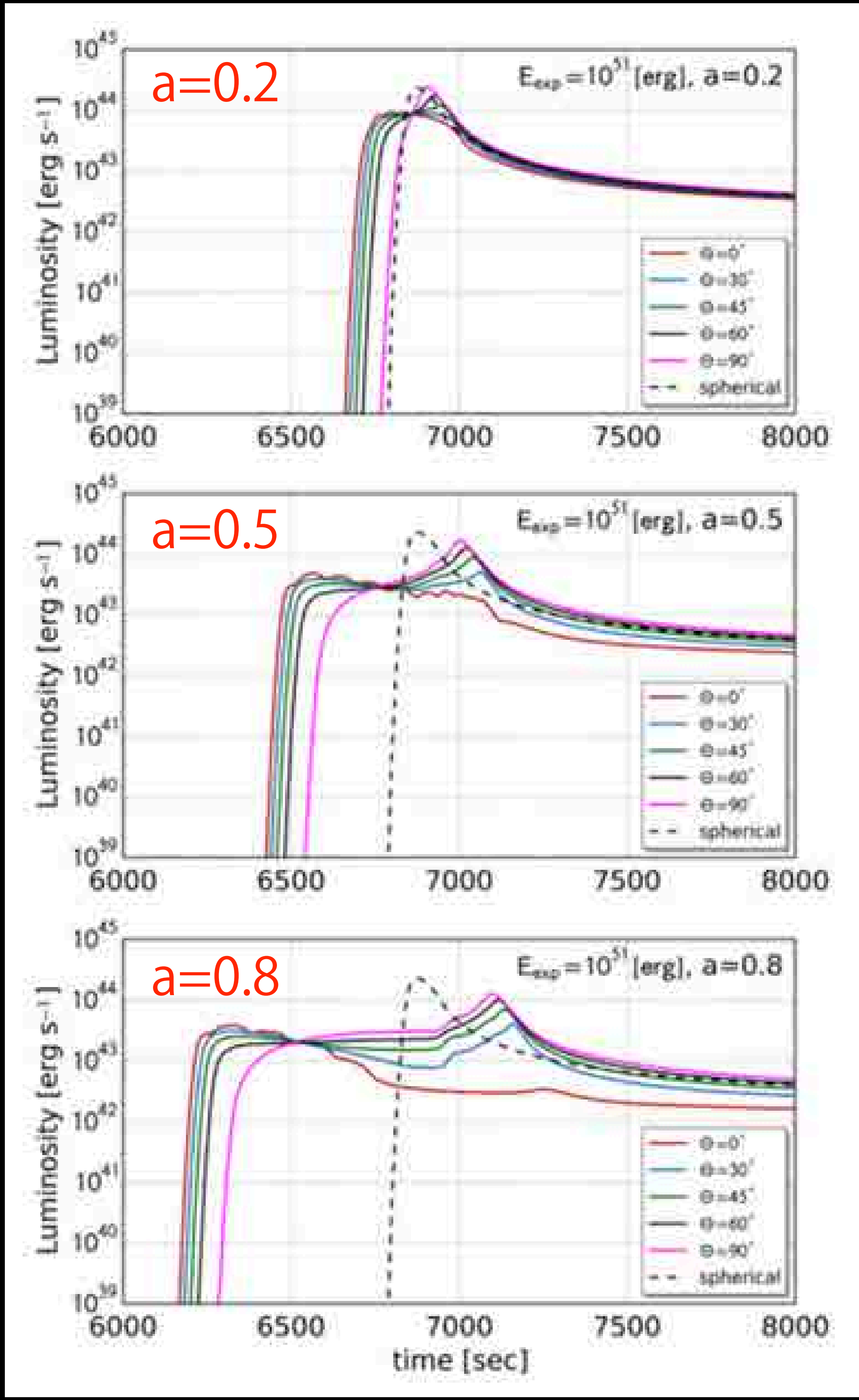




Dependence on asphericity

$dE/dt \propto E_{exp}/t_{exp}[1+a\cos(2\theta)]$

- Basically, larger a lead to larger deviation from the spherical case
- Bolometric light curves of SN shock breakout can be a tracer of aspherical energy deposition at the core of a massive star.



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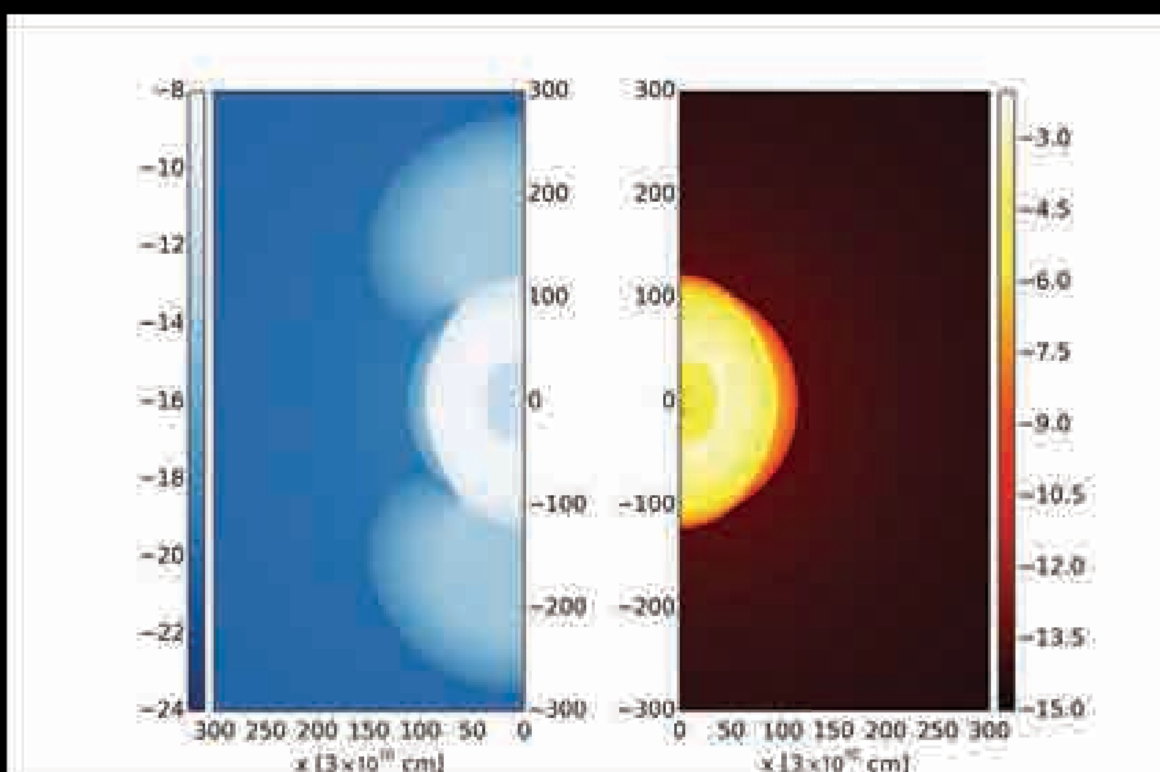
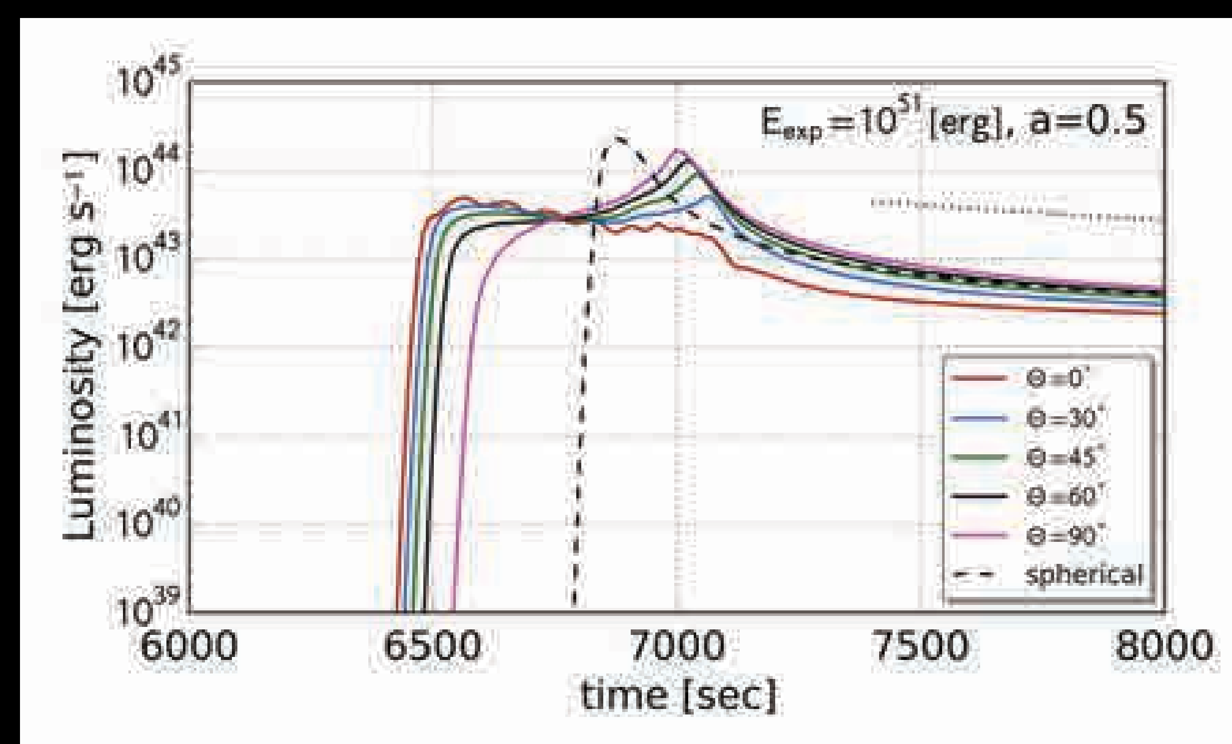
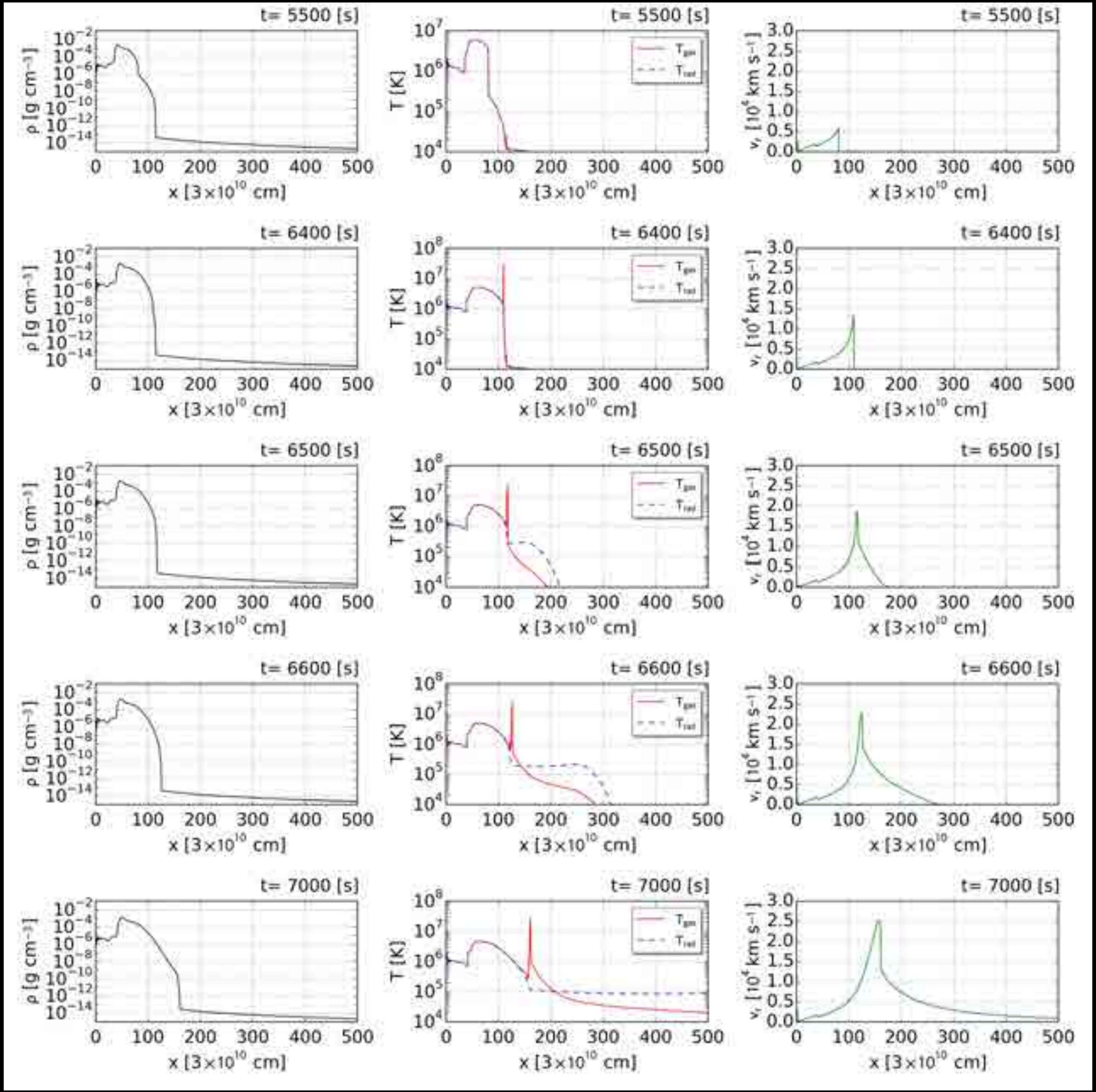
SN Shock breakout as a unique probe

- ➡ increasing number of detections
- ➡ LCs are characterized by $R_\star/c$ for spherical case and t_{delay} for aspherical cases.
- ➡ information on the progenitor radius, energetics, and asphericity
- ➡ multi-D SR-RHD simulations are ongoing,
- ➡ future works: different explosion geometry, progenitor dependence

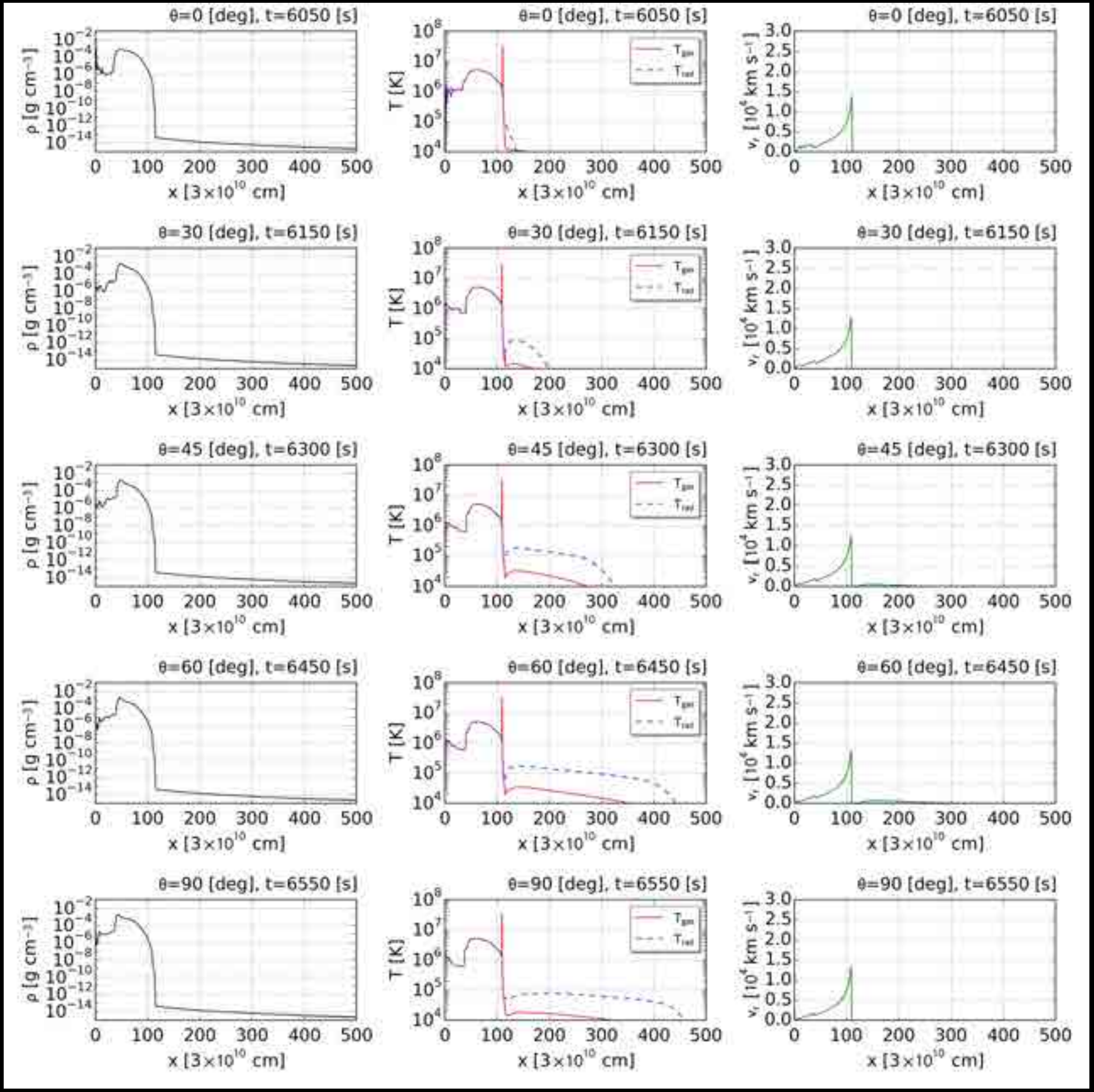




Shock breakout with spherical symmetry

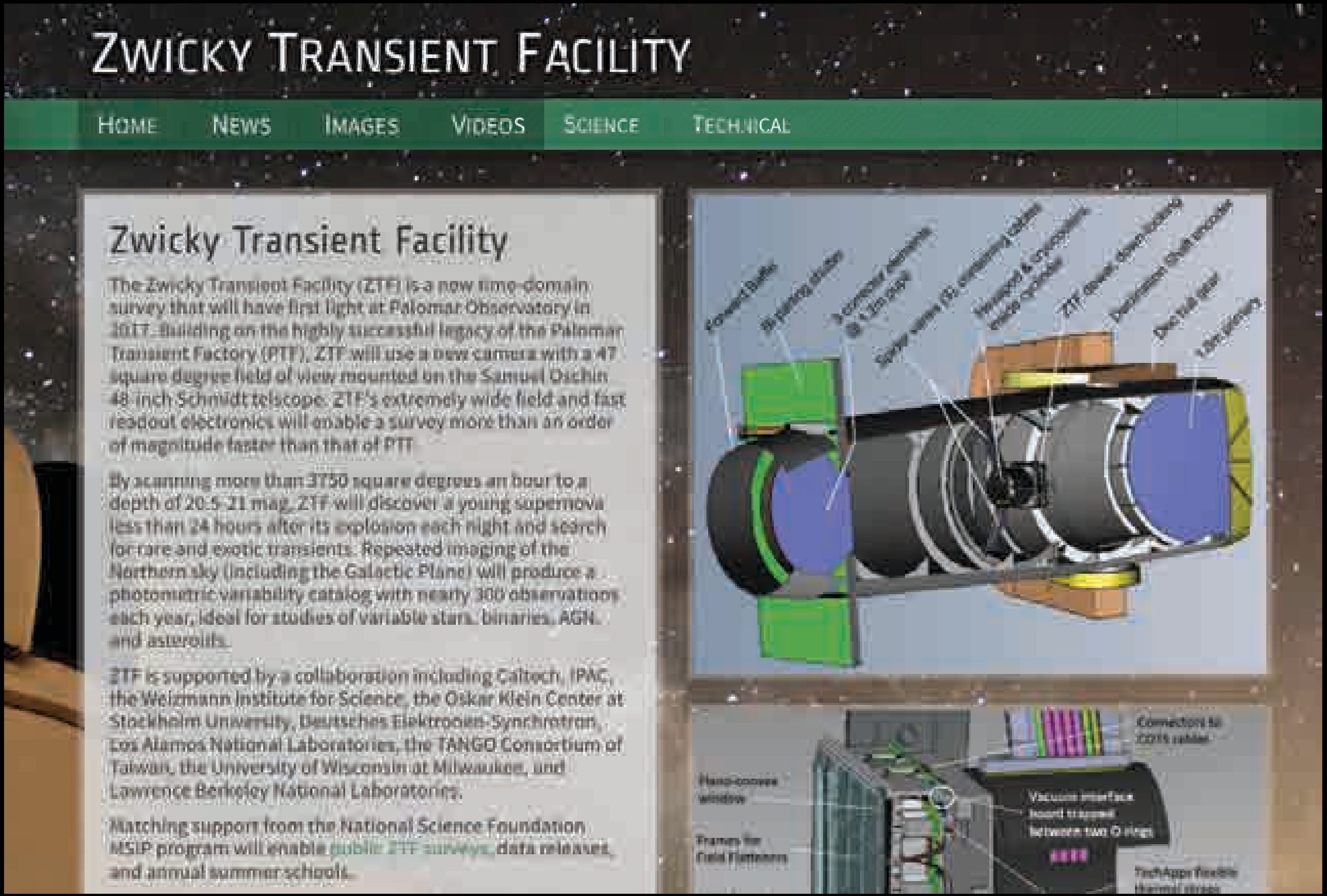


Shock breakout in 2D



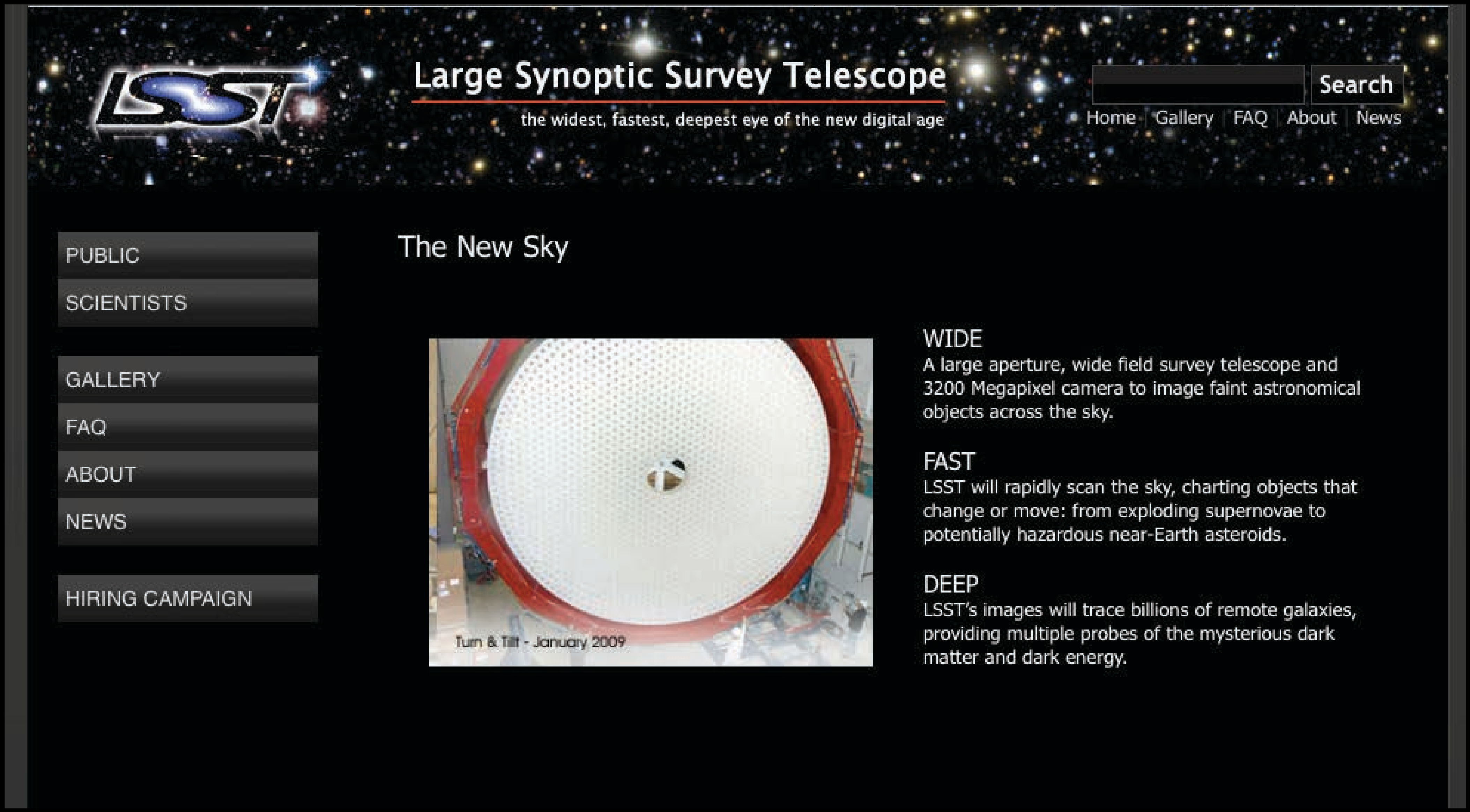
Current and upcoming projects

- Zwicky Transient Facility (ZTF)
- PTF,iPTF → ZTF
- PI: S. Kulkarni (Caltech)
- 3760 deg^2/hr
- arXiv: 1410.8185
- 2017-



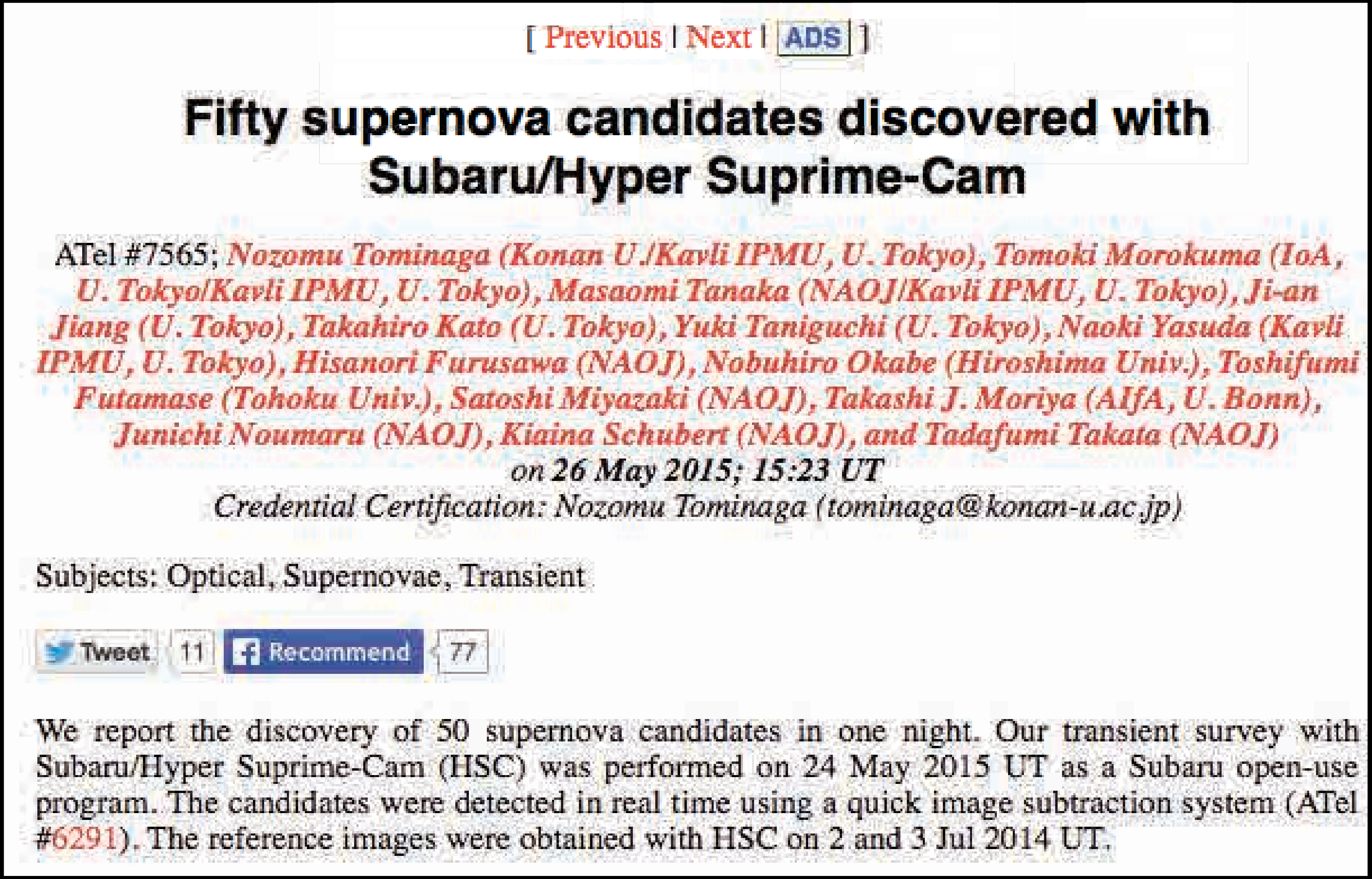
Current and upcoming projects

- Large Synoptic Survey Telescope (LSST)
- 8.4m telescope observing in optical-IR
- FOV: 9.6 deg^2
- Site: Chile
- 2020-



Current and upcoming projects

- Hyper Suprime-Cam on Subaru telescope
- diameter: 8.2m, FOV:1.77 deg^2
- 50 SN candidates in 1 night on 24 May 2015



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Fifty supernova candidates discovered with Subaru/Hyper Suprime-Cam

ATel #7565; *Nozomu Tominaga (Konan U./Kavli IPMU, U. Tokyo), Tomoki Morokuma (IoA, U. Tokyo/Kavli IPMU, U. Tokyo), Masaomi Tanaka (NAOJ/Kavli IPMU, U. Tokyo), Ji-an Jiang (U. Tokyo), Takahiro Kato (U. Tokyo), Yuki Taniguchi (U. Tokyo), Naoki Yasuda (Kavli IPMU, U. Tokyo), Hisanori Furusawa (NAOJ), Nobuhiro Okabe (Hiroshima Univ.), Toshifumi Futamase (Tohoku Univ.), Satoshi Miyazaki (NAOJ), Takashi J. Moriya (AIfA, U. Bonn), Junichi Noumaru (NAOJ), Kiaina Schubert (NAOJ), and Tadafumi Takata (NAOJ)*
on ***26 May 2015; 15:23 UT***
Credential Certification: Nozomu Tominaga (tominaga@konan-u.ac.jp)

Subjects: Optical, Supernovae, Transient

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We report the discovery of 50 supernova candidates in one night. Our transient survey with Subaru/Hyper Suprime-Cam (HSC) was performed on 24 May 2015 UT as a Subaru open-use program. The candidates were detected in real time using a quick image subtraction system (ATel #6291). The reference images were obtained with HSC on 2 and 3 Jul 2014 UT.

Current and upcoming projects

- Ultraviolet Transient Astronomy Satellite (ULTRASAT)
- mini-satellite carrying a telescope with an large FOV observing in UV
- Israeli/US collaboration, Weizmann institute (PI: E. Waxman)-Caltech (PI: S. Kulkarni)
- wavelength: 2200-2800 Å
- FOV: 210 deg^2
- 2020 or 2021-

Thank you for your attention