木曽シュミットシンポジウム2023 (2023年5月30-31日)

Light-curve Modeling for The Initial Rising Phase of Rapidly-evolving Transients Powered by Continuous Outflow

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Collaborator: Keiichi Maeda (Kyoto Univ.)

reference: KU & Maeda 2020a/b, 2023c

https://ui.adsabs.harvard.edu/abs/2020ApJ...897..156U/abstract

https://ui.adsabs.harvard.edu/abs/2020ApJ...905L...5U/abstract

https://ui.adsabs.harvard.edu/abs/2023MNRAS.521.4598U/abstract

Frontiers in Rapid-Evolving Transients

~2000s: Supernova, Nova…

timescale > 10 days

New Generation Surveys

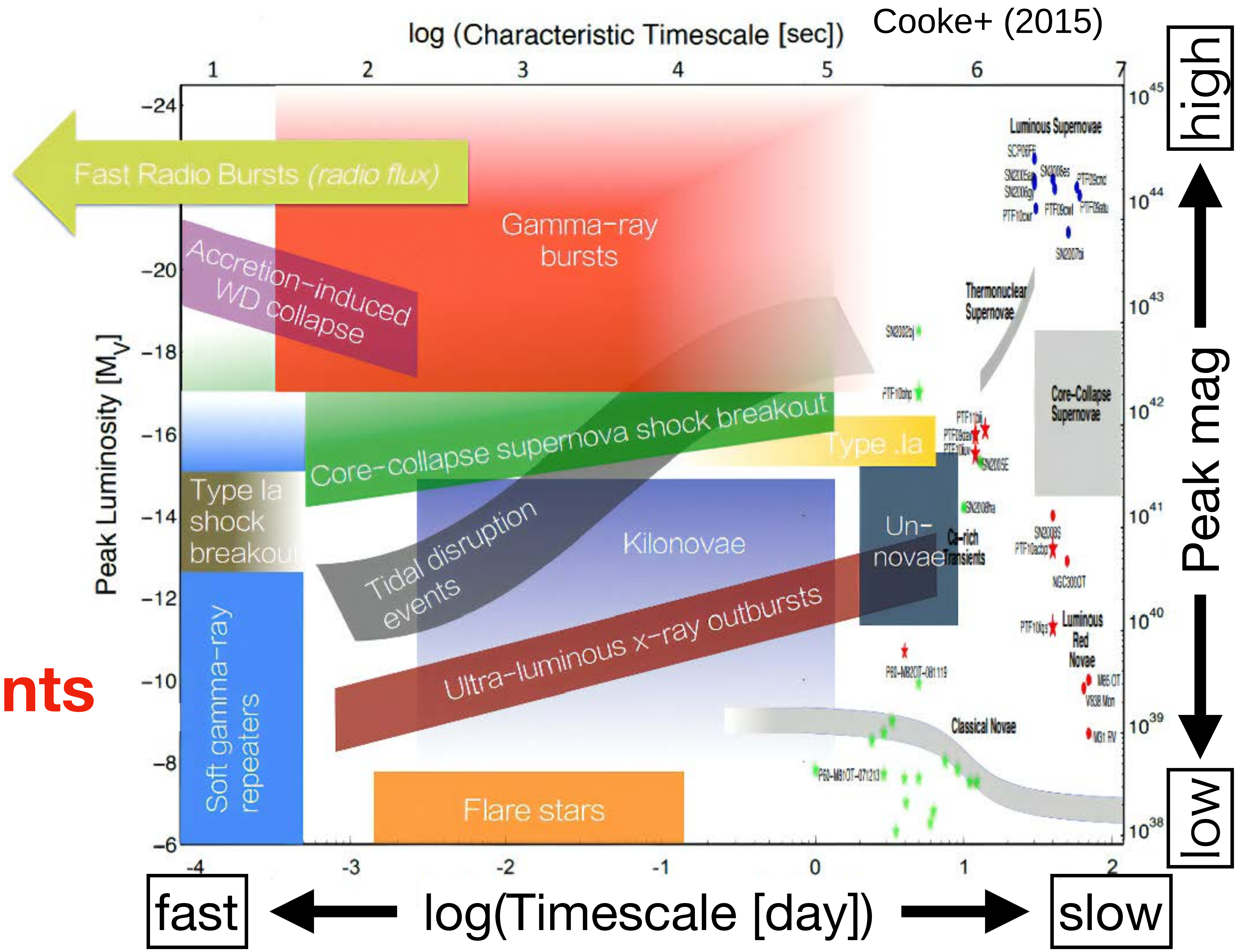
ASAS-SN, Pan-STARRS, Tomo-e Gozen, atlas, ZTF

2010s~: Rapid-Evolving Transients

timescale ~ day

Much more diversity than expected !

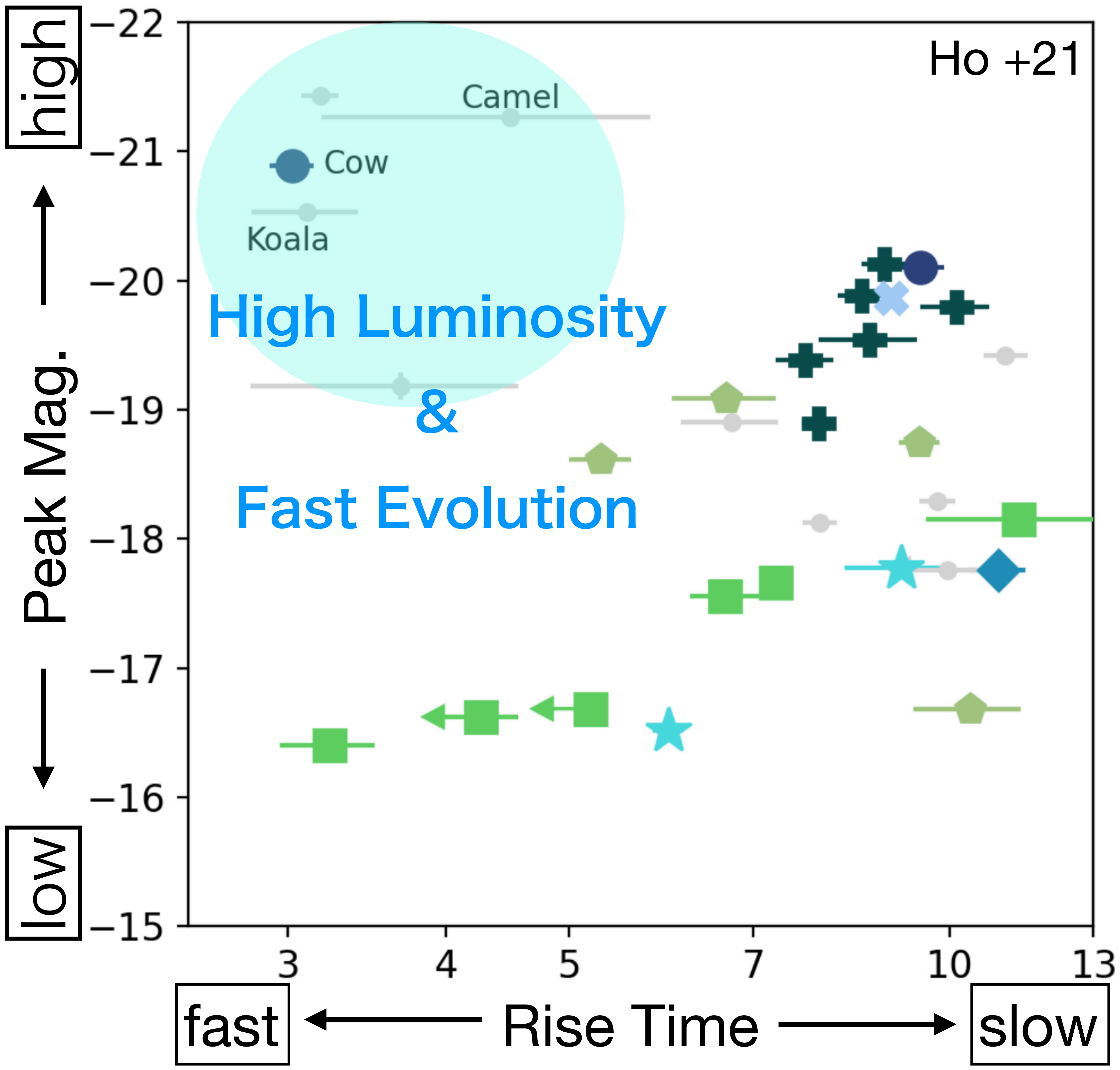
→ New insight for Stellar Evolution

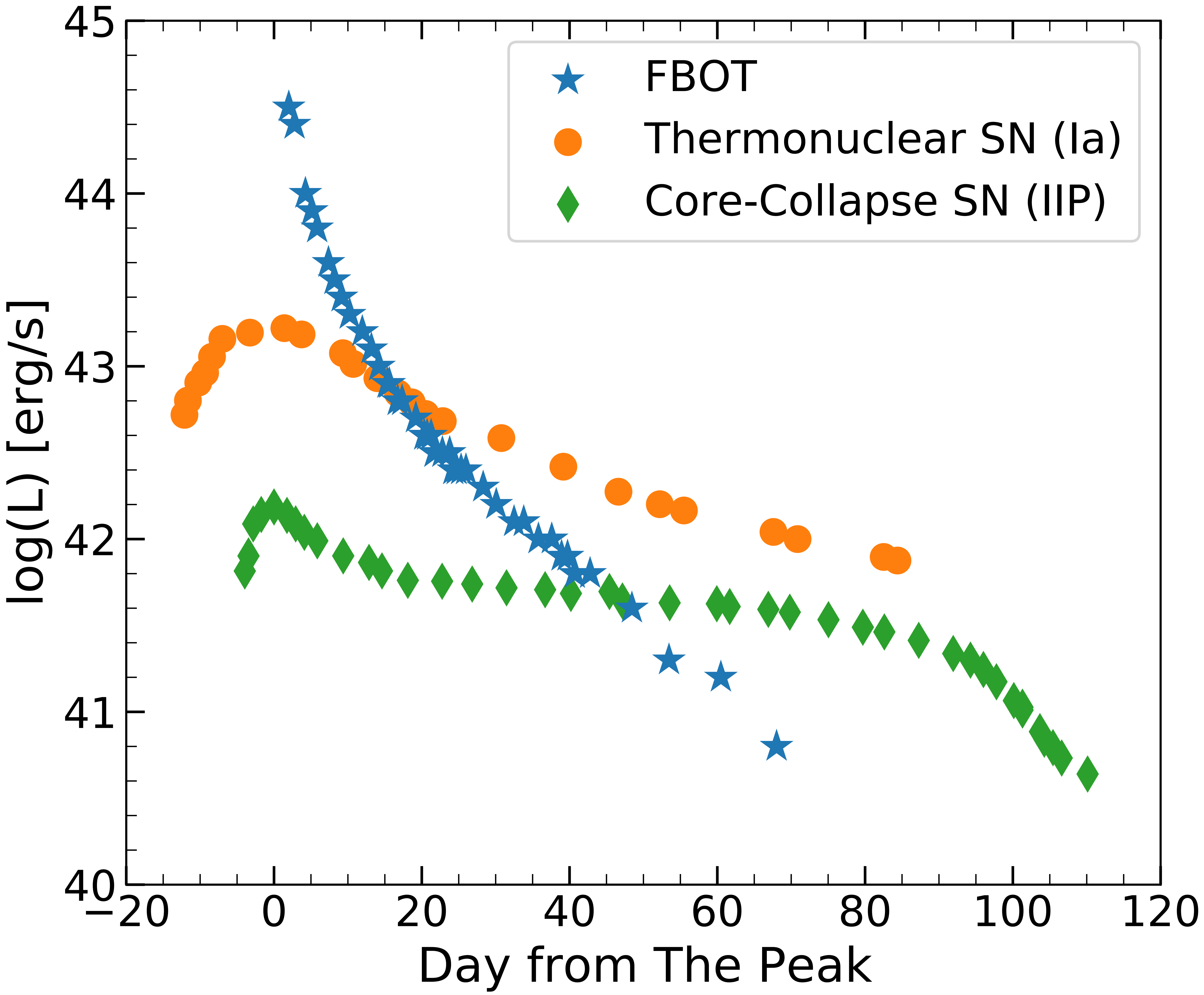


Rapid-Evolving Transients by ZTF

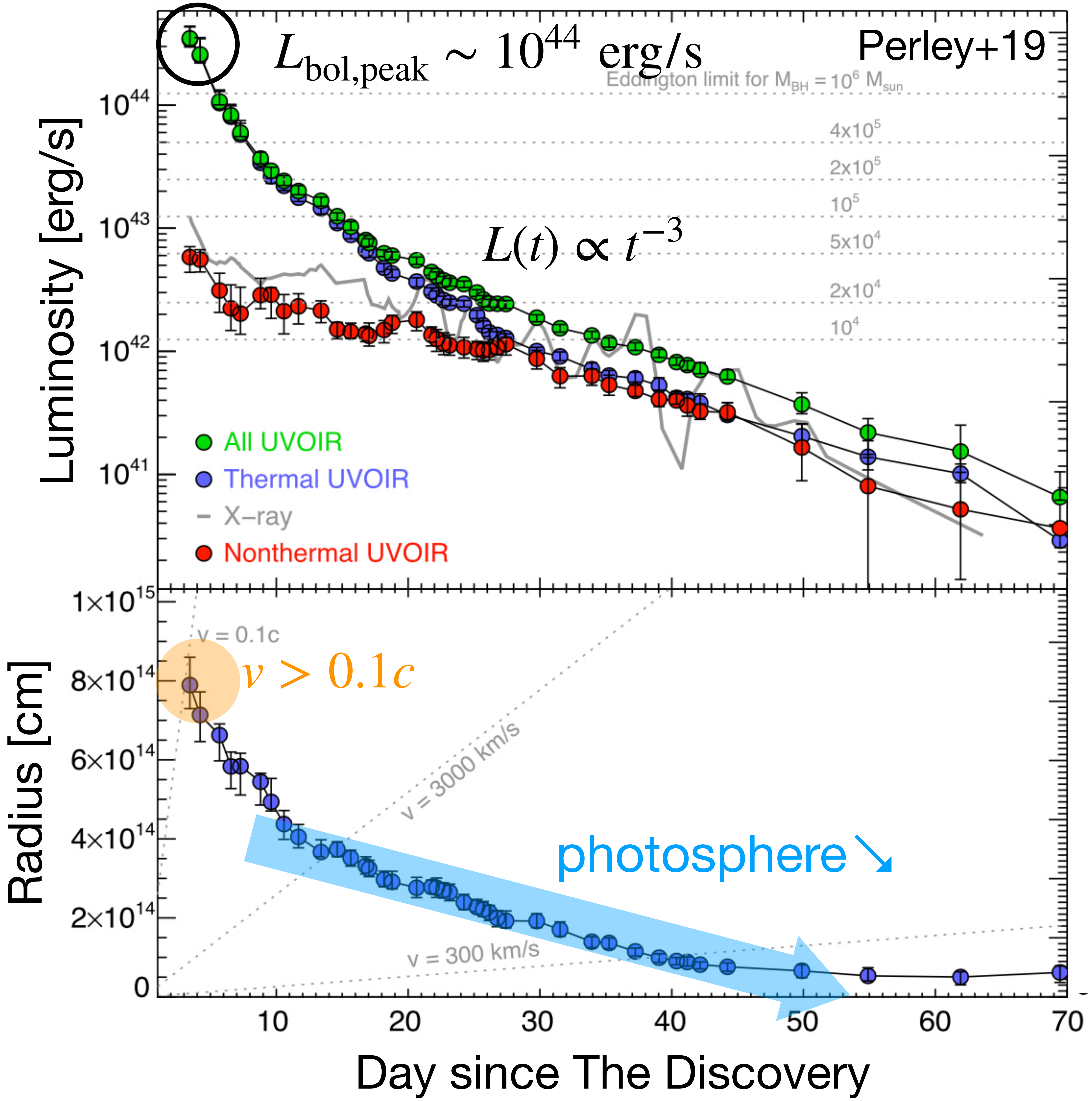
Fast Blue Optical Transients (FBOTs)

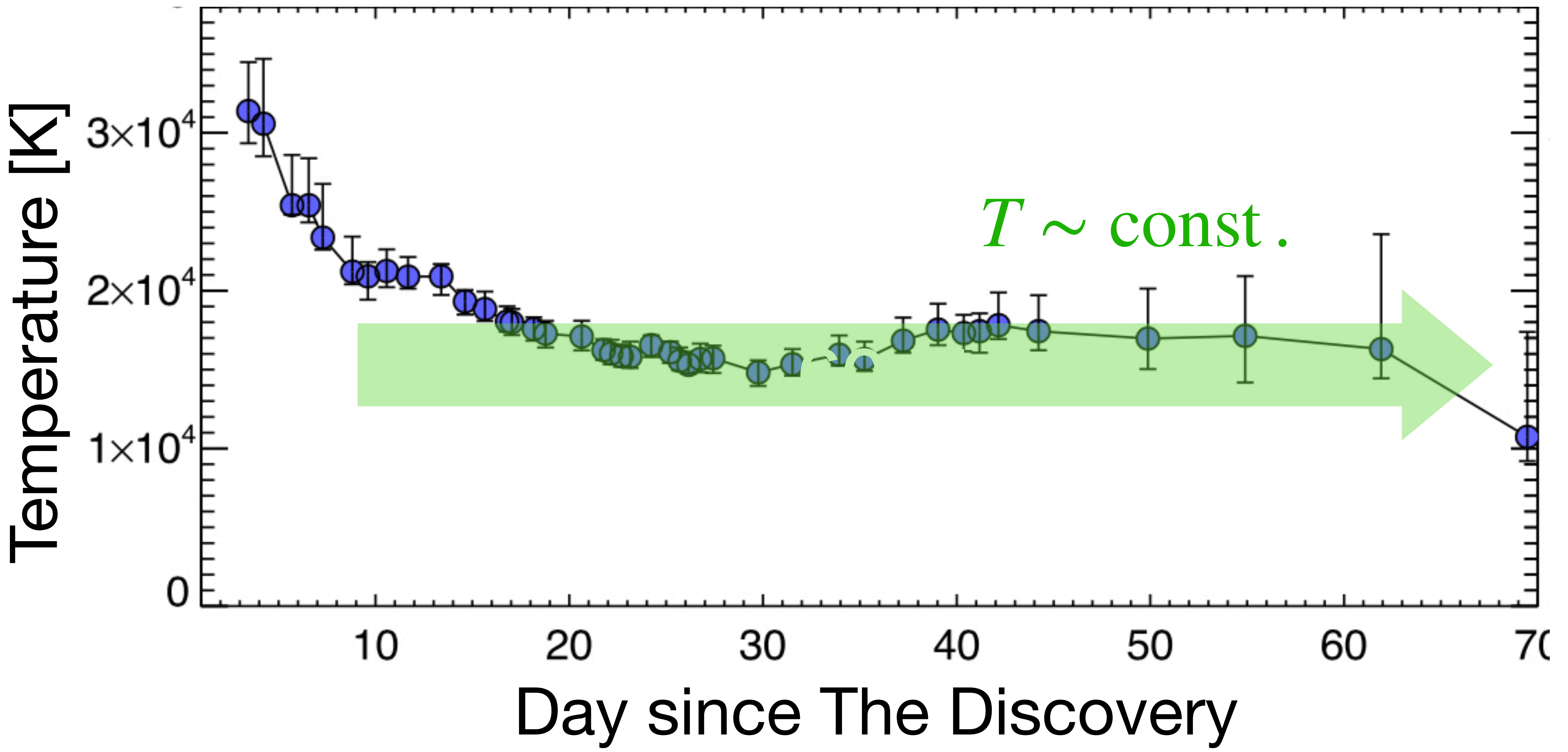
FBOTs : Rapid-Evolving Transients with High Luminosity (M > -20 mag)





A Peculiar Transient AT2018cow





	AT2018cow	supernova
L [erg/s]	10^{44}	10^{42}
v [cm/s]	3×10^9 $(0.1c)$	$\lesssim 10^9$
$R_{\rm ph}$	↘	↗
$T_{\rm ph}$ [K]	$\sim 2 \times 10^4$ (const.)	~ 6000
color	const.	redder
timescale [day]	~ 10	~ 100

Method: Wind-Driven Model

	AT2018cow	supernova
L [erg/s]	10^{44}	10^{42}
v [cm/s]	3×10^9 $(0.1c)$	$\lesssim 10^9$
$R_{\rm ph}$	$\searrow$	$\nearrow$
$T_{\rm ph}$ [K]	$\sim 2 \times 10^4$ (const.)	~ 6000
color	const.	redder
timescale [day]	~ 10	~ 100

SN model

e.g. Homologous expansion: $R = vt$

→ increasing photosphere

→ decreasing temperature

Steady-State-Like Model?

e.g. Wind/Outflow forms photosphere?

This Study

Motivation Which systems can explain the FBOT/AT2018cow?

Assumption **wind-like continuous mass ejection (outflow)**

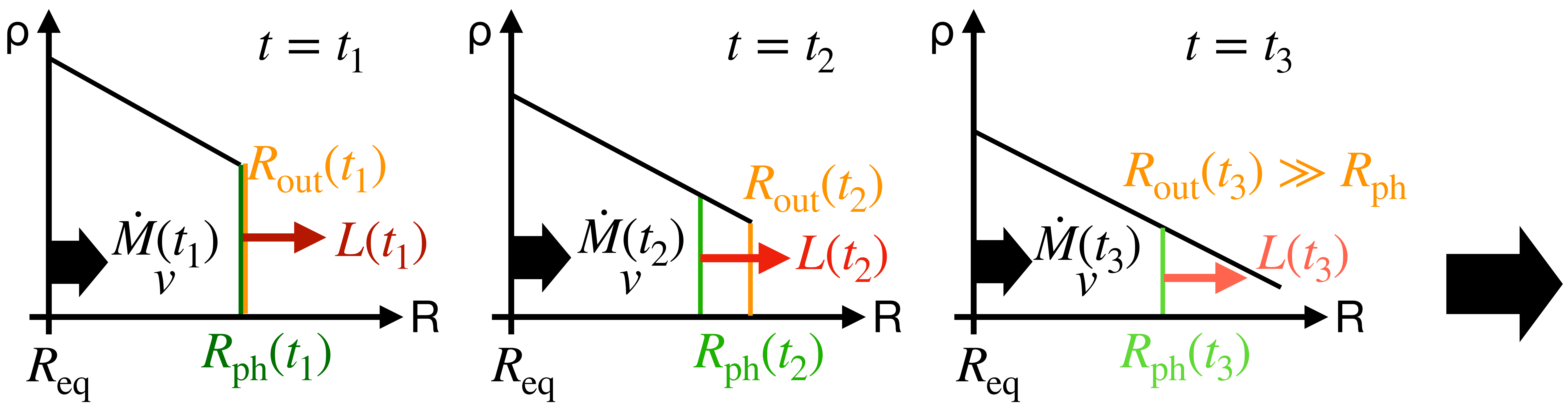
Method We apply a **'Wind-Driven Model'** to FBOT/AT2018cow.

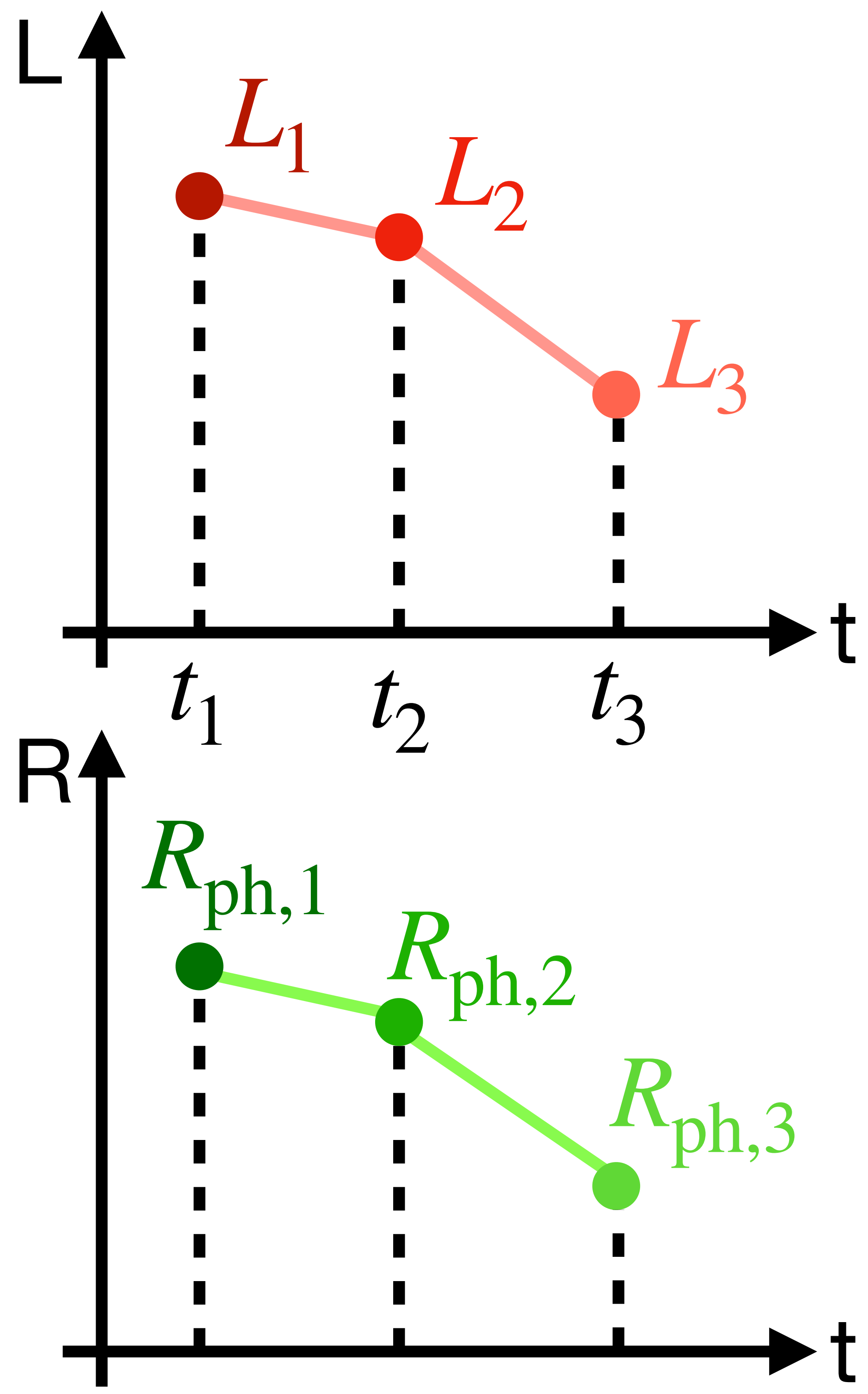
Method: Wind-Driven Model (Set Up)

Wind-Driven Model (KU & Maeda 2020a, b, 2023c)

Assuming **continuous outflows like stellar winds**,
characterized by **mass-loss rate** ($\dot{M}$), **wind velocity** ($v_{\rm wind}$), and **wind-launched radius** ($R_{\rm eq}$).

Observational Properties (L, $T_{\rm ph}$, v, $\cdots$) $\rightleftarrows$ Physical Quantities ($R_{\rm eq}$, $\dot{M}$, $\cdots$)

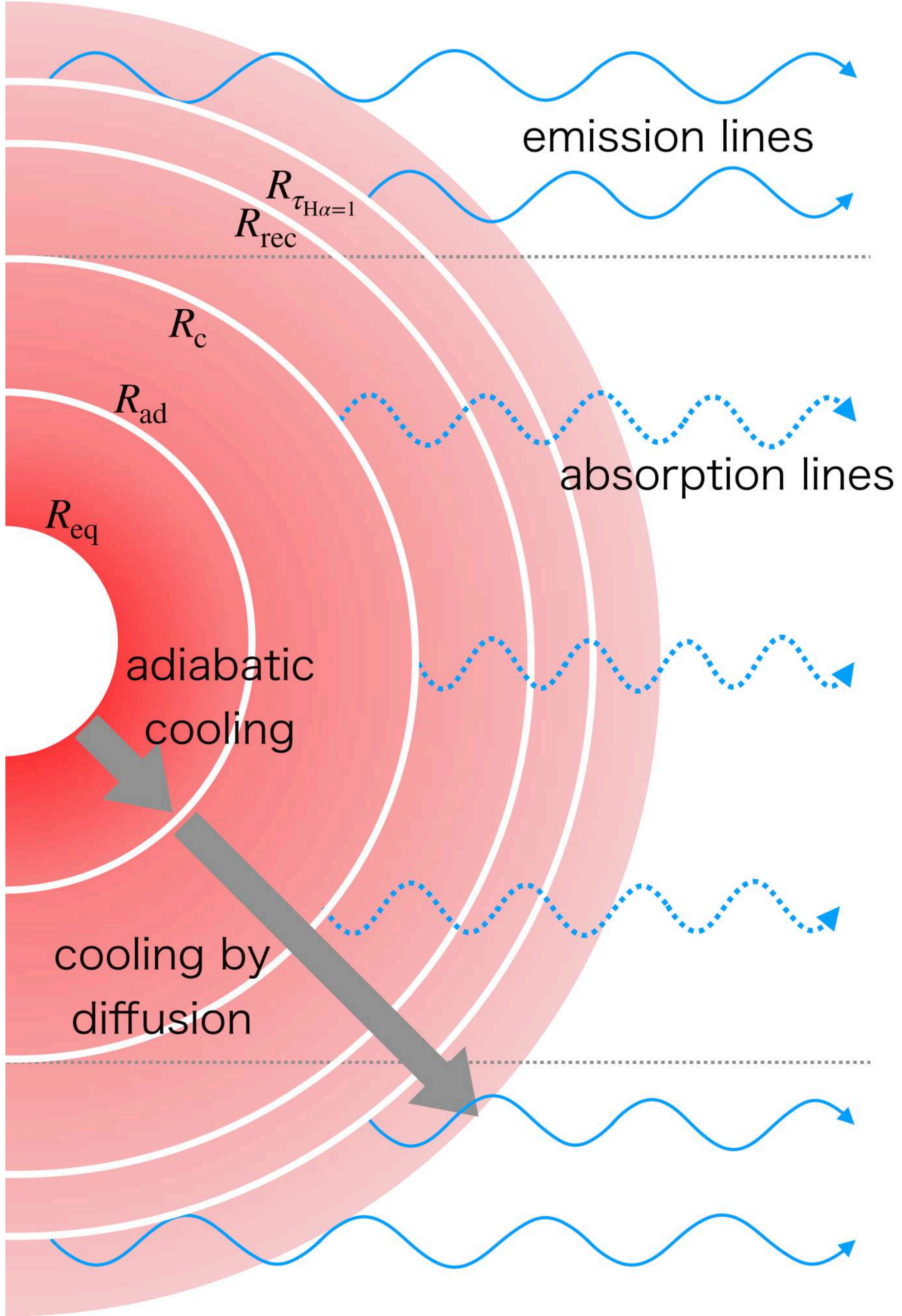




$$R_{\rm out}(t) = R_{\rm eq} + vt$$
$$v(t) = {\rm const}\,.$$

$$\dot{M}(t) = M_0 \left(1 + \frac{t'}{t_0}\right)^{-\beta} \quad \left(t' = t - \frac{r - R_{\rm eq}}{v}\right)$$

Method: Wind-Driven Model (Typical Scale)



@ R_{eq} (equipartition radius): $aT_{\mathrm{eq}}^4 = \frac{1}{2}\rho_{\mathrm{eq}}v^2$

↓ adiabatic cooling $T(r) = T_{\mathrm{eq}}\left(\frac{r}{R_{\mathrm{eq}}}\right)^{-2/3}$

@ R_{ad} (photon trapped radius): $\tau_{\mathrm{s}}(R_{\mathrm{ad}}) = c/v$

↓ diffusion cooling $T(r) = T_{\mathrm{ad}}\left(\frac{r}{R_{\mathrm{ad}}}\right)^{-3/4}$

@ R_c (color radius): $\tau_{\mathrm{eff}}(R_{\mathrm{c}}) = 1$

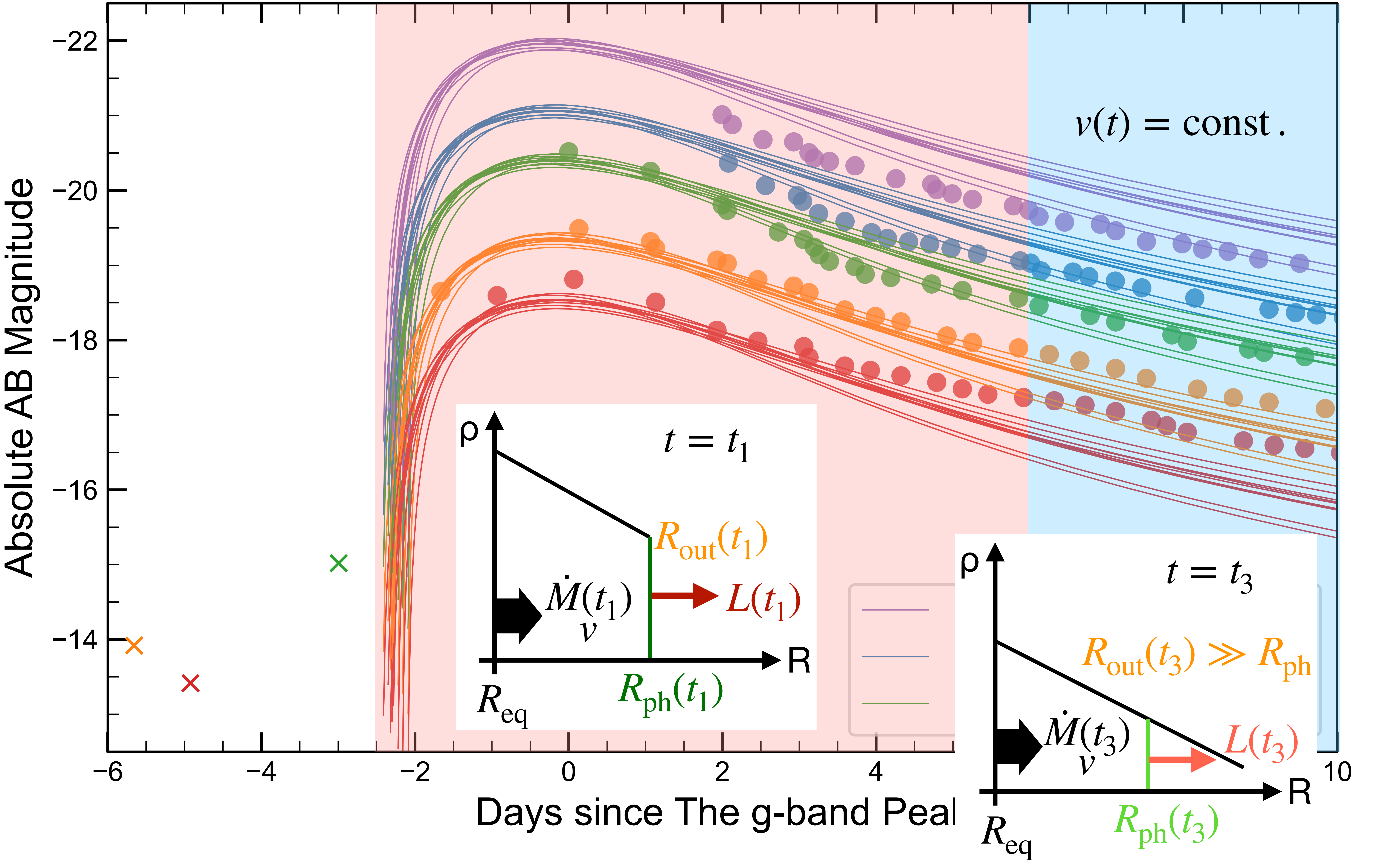
↓ diffusion cooling $T(r) = T_{\mathrm{ad}}\left(\frac{r}{R_{\mathrm{ad}}}\right)^{-3/4}$

@ R_{rec} (recombination radius): $T(R_{\mathrm{rec}}) = 12000,\ 6000\ (\mathrm{K})$

@ $R_{\tau_{\mathrm{H}\alpha}=1}$ (line forming radius): $\tau_{\mathrm{H}\alpha} \approx 1.79 \times 10^{18}\rho \exp\left(-\frac{\Delta E_{1,2}}{kT}\right)\frac{r}{v}$

Results: Application to AT2018cow

$\dot{M}_0 = 35\ [\mathrm{M_\odot/yr}]$
$v = 0.3\ [\mathrm{c}]$
$R_{\mathrm{eq}} = 10^{12-13}\ [\mathrm{cm}]$



Discussion: Central Engine for FBOTs

- eruptive mass ejection: $\dot{M}_0 \sim 30\ [\mathrm{M_\odot/yr}]$
- mass-loss rate index: $\dot{M}(t) \propto t^{-5/3}$

  → **BH-accretion-driven transients?**

- wind-launched radius: $R_{\mathrm{eq}} \sim 10^{13}\ [\mathrm{cm}]$

  → **Red Super Giant (RSG) radius?** or **Tidal Disruption Events**?

- total mass ejection: $M_{\mathrm{total}} \sim 0.2\ [\mathrm{M_\odot}]$
- total kinetic energy: $E_{\mathrm{kin,total}} \sim 10^{52}\ [\mathrm{erg}]$

  → typical gravitational energy at the scale of stellar core?

⬇

Speculation for Central Engine for FBOTs/AT2018cow

(1) Failed Supernovae by Supergiant

(2) Tidal Disruption Events (TDE)

Discussion: Central Engine for FBOTs

(1) Failed Supernova by Supergiant

- Energy Budget (Dexter+ 15)

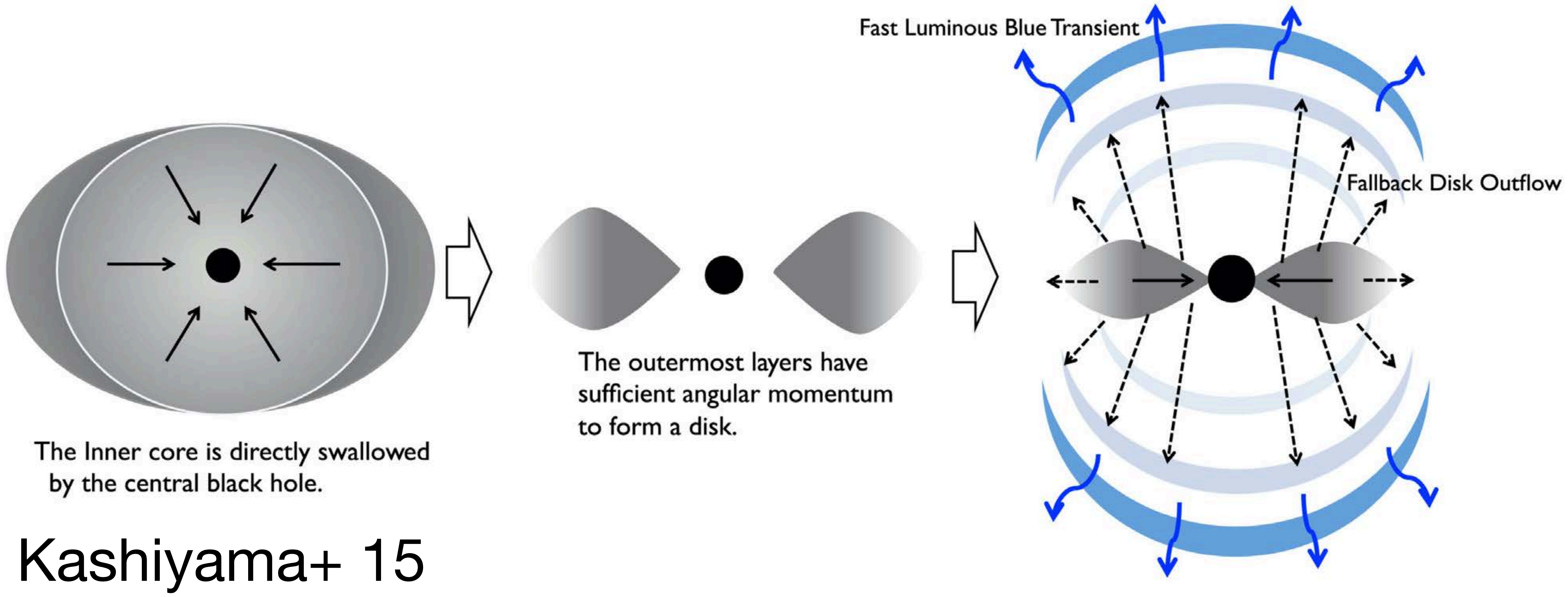
$$E \sim \varepsilon M_{\rm fallback} c^2 \sim 1.8 \times 10^{51}\ [{\rm erg}] \left(\frac{M_{\rm fallback}}{1\ {\rm M_\odot}}\right) \left(\frac{\varepsilon}{10^{-3}}\right)$$

- Ejected Mass (Dexter+ 15)

$$M_{\rm ej} \sim 10^{-3} - 10^{0}\ [{\rm M_\odot}]$$

- Timescale

$$t_{\rm dyn} \approx t_{\rm freefall} \sim 6\ [{\rm days}] \left(\frac{M_{\rm BH}}{30\ {\rm M_\odot}}\right)^{-1/2} \left(\frac{R_{\rm RSG}}{10^{13}\ {\rm cm}}\right)^{3/2}$$



Kashiyama+ 15

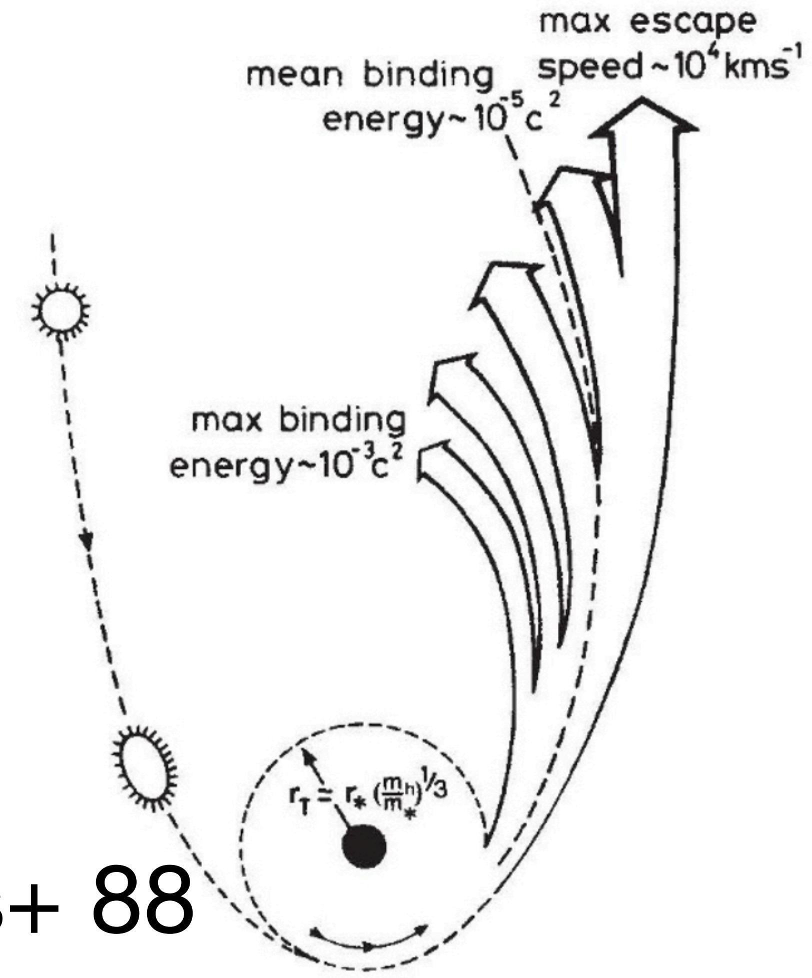
(2) TDE by intermediate mass BH

- Ejected Mass (e.g. Rees+ 88)

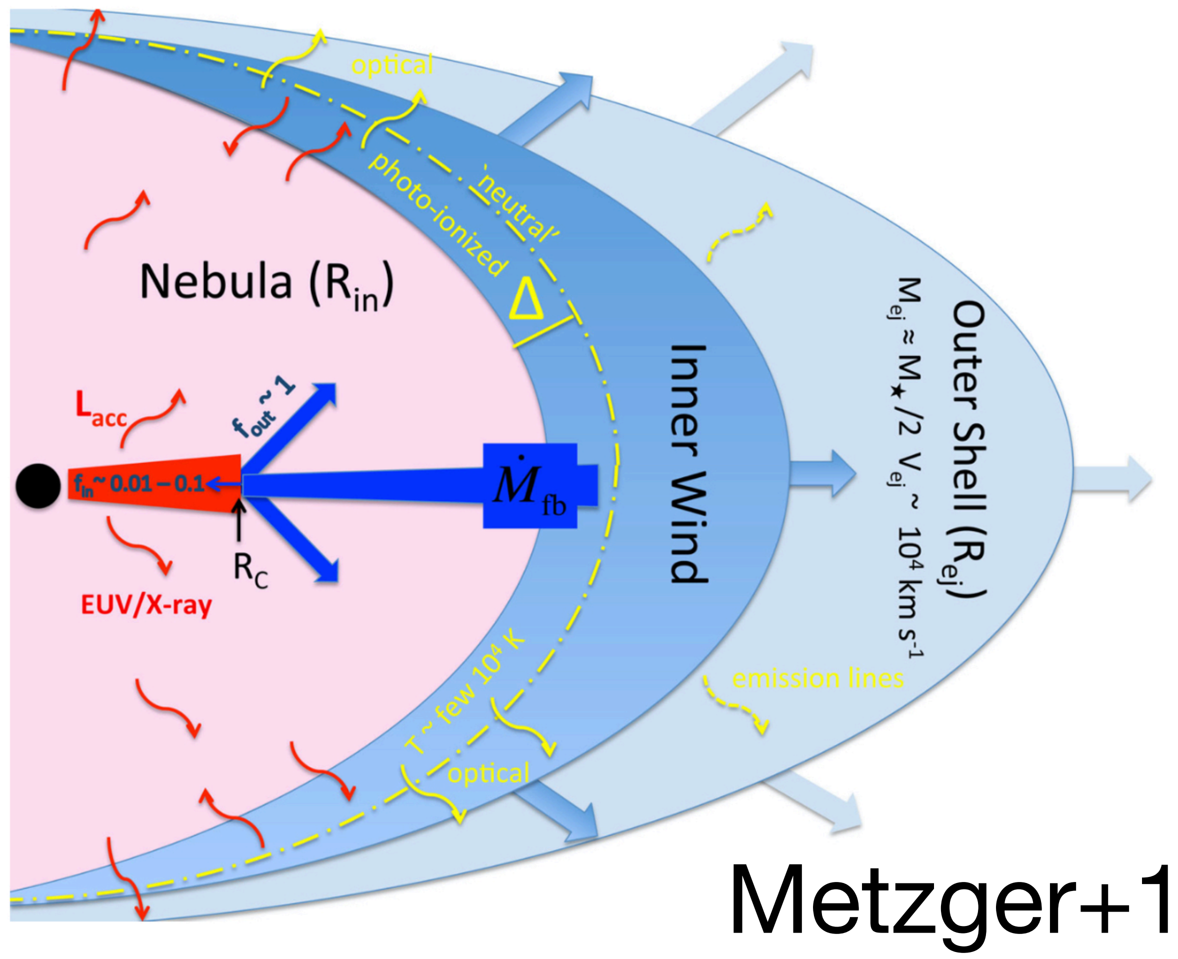
$$M_{\rm ej} \lesssim 0.5\ [{\rm M_\odot}] \left(\frac{M_{\rm star}}{1\ {\rm M_\odot}}\right)$$

- Timescale (e.g., Metzger+16)

$$t_{\rm TDE} \sim 4\ [{\rm days}] \left(\frac{M_{\rm BH}}{10^4\ {\rm M_\odot}}\right)^{1/2} \left(\frac{M_{\rm star}}{1\ {\rm M_\odot}}\right)^{1/5}$$



Rees+ 88



Metzger+16

Discussion: from Tomo-e to Seimei

FBOT @100Mpc

g ~ 16-17 mag @peak

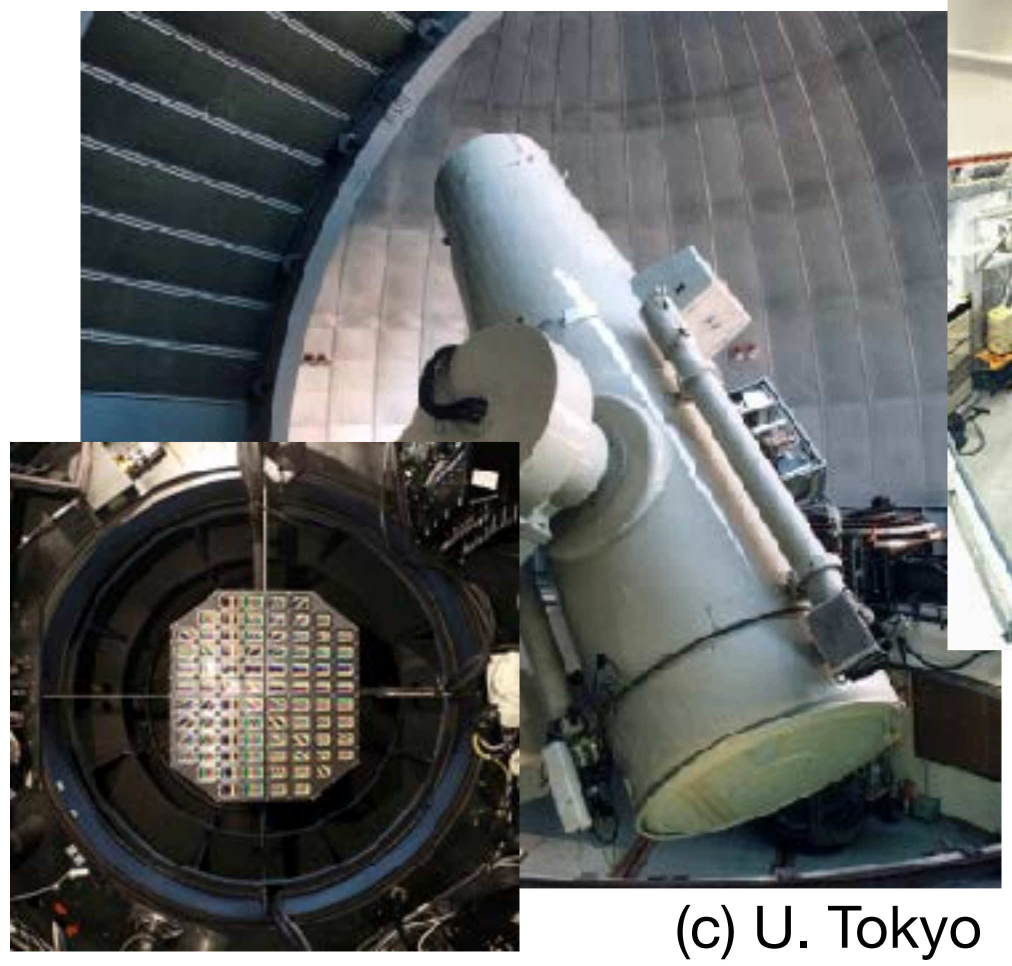
rise time ~ a few days

→ High Cadence (<day) Survey

※ public ZTF survey: ~3 (2) day

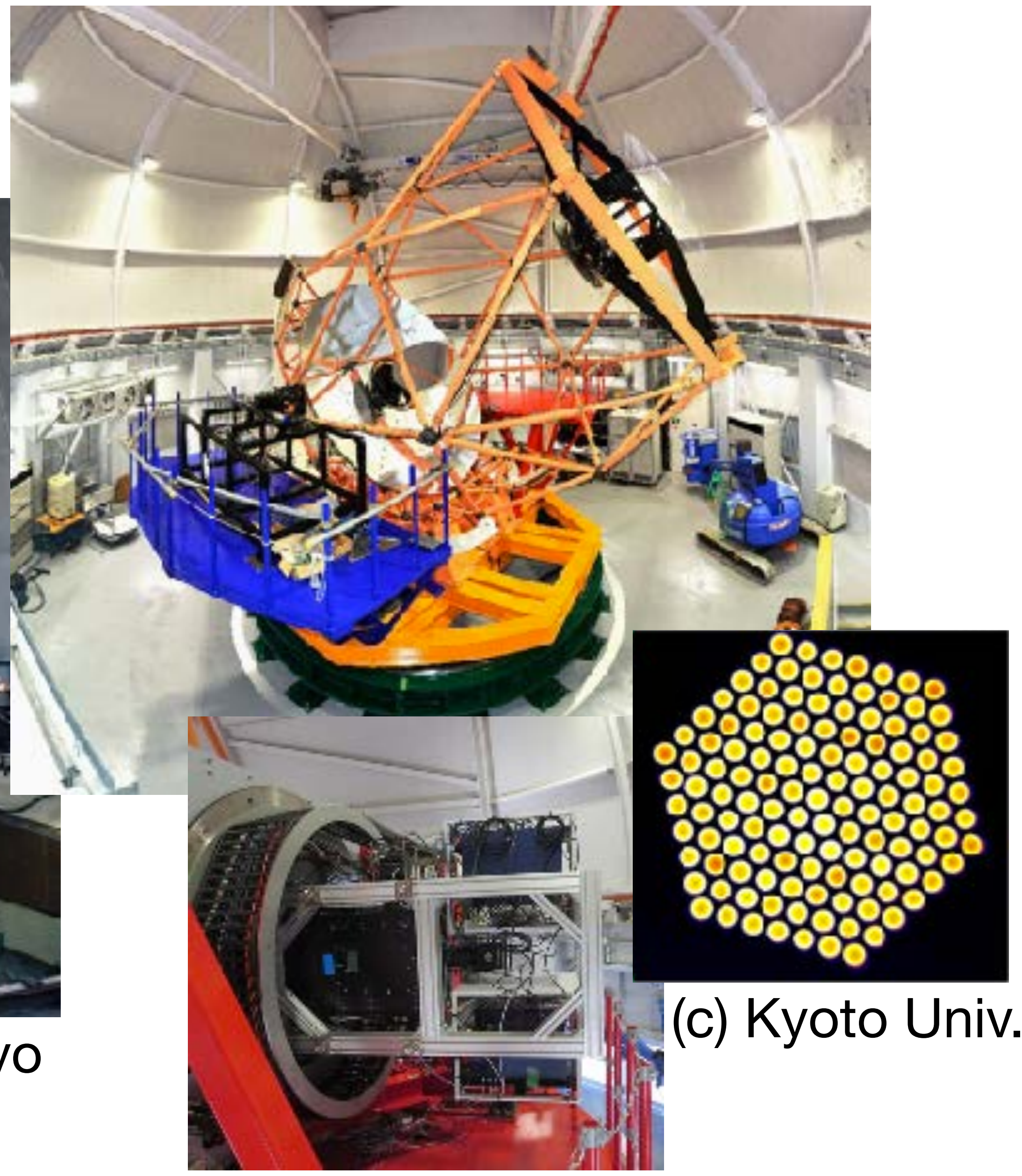
→ Follow-Up Observation

Tomo-e

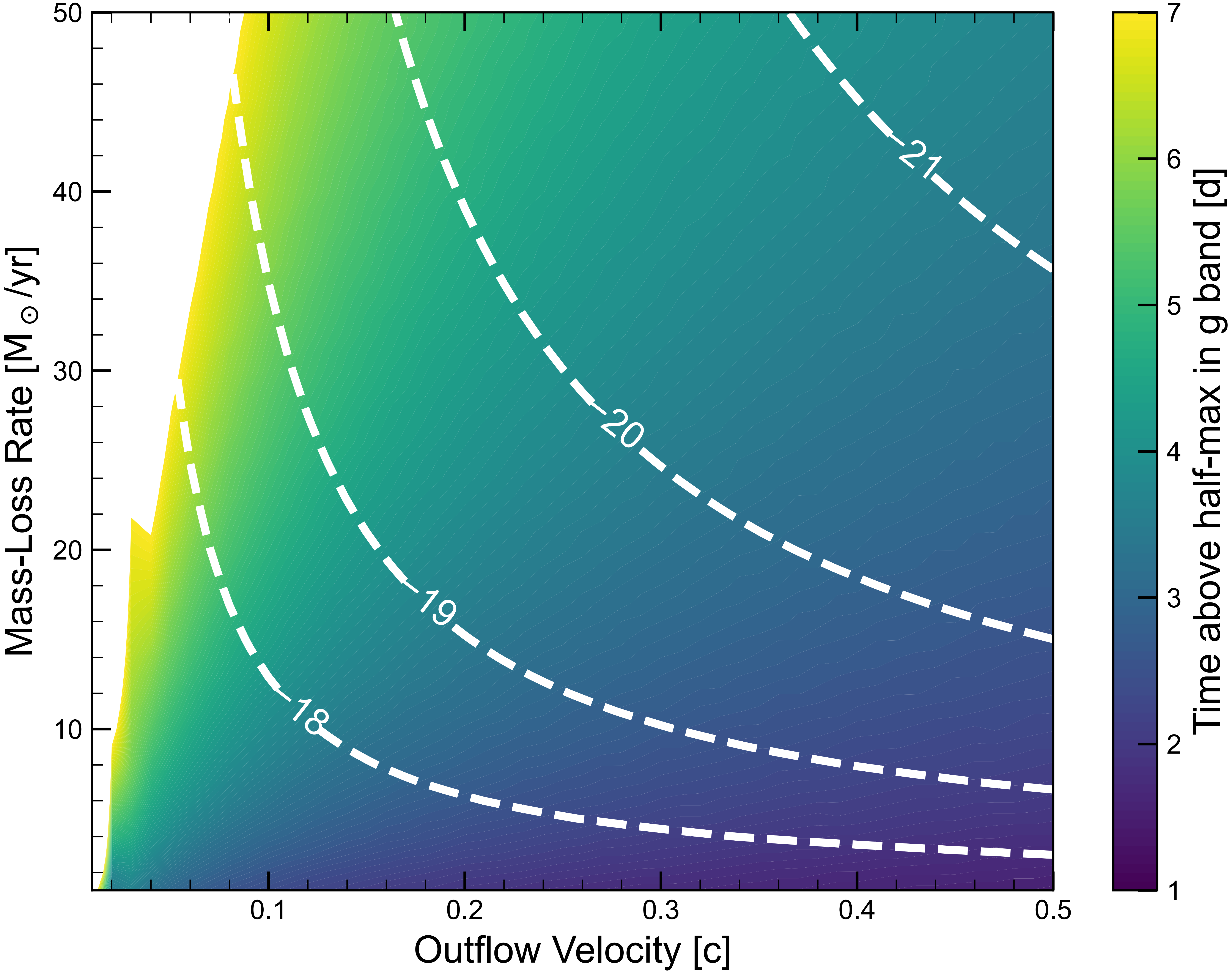


(c) U. Tokyo

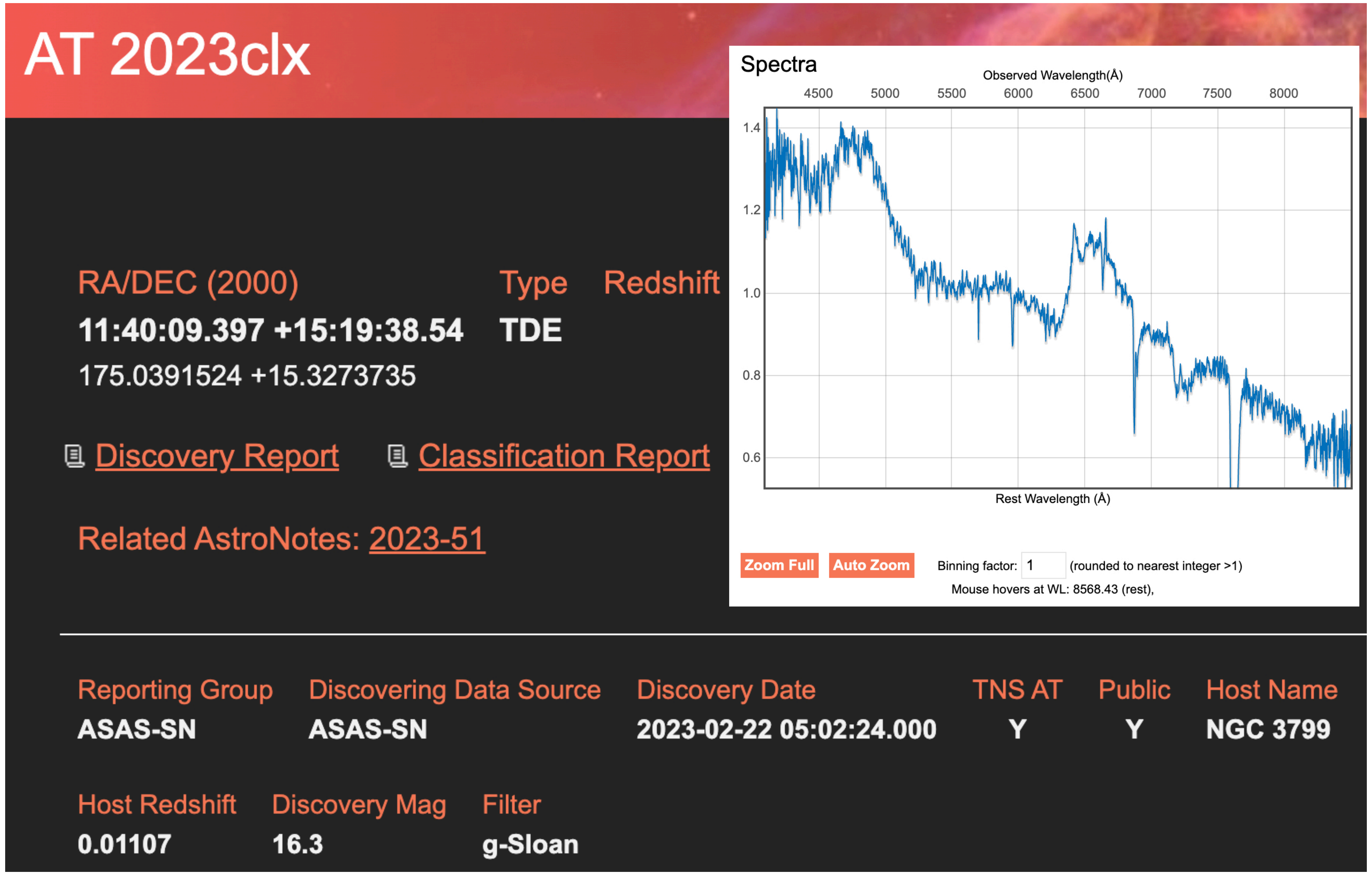
Seimei

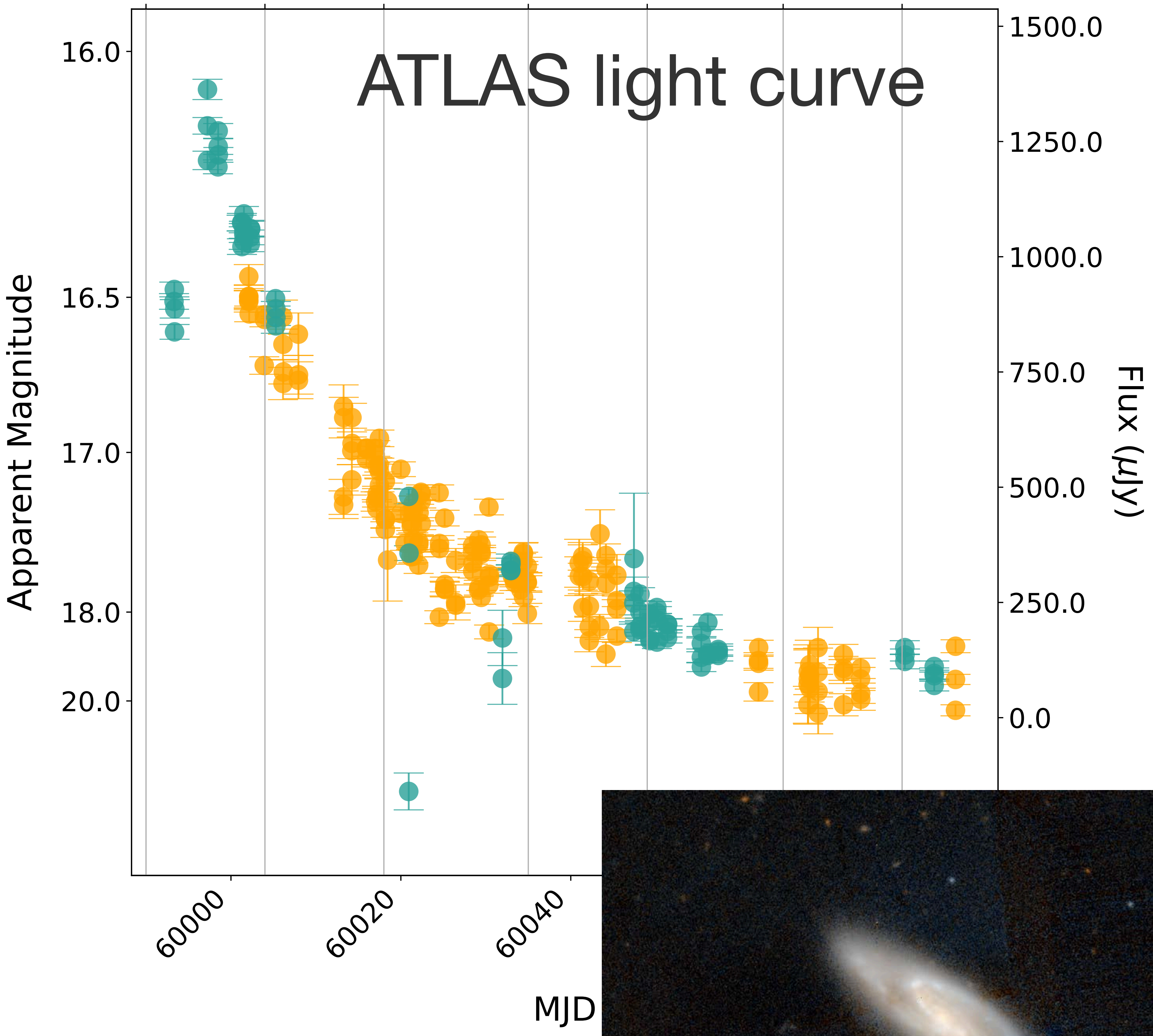


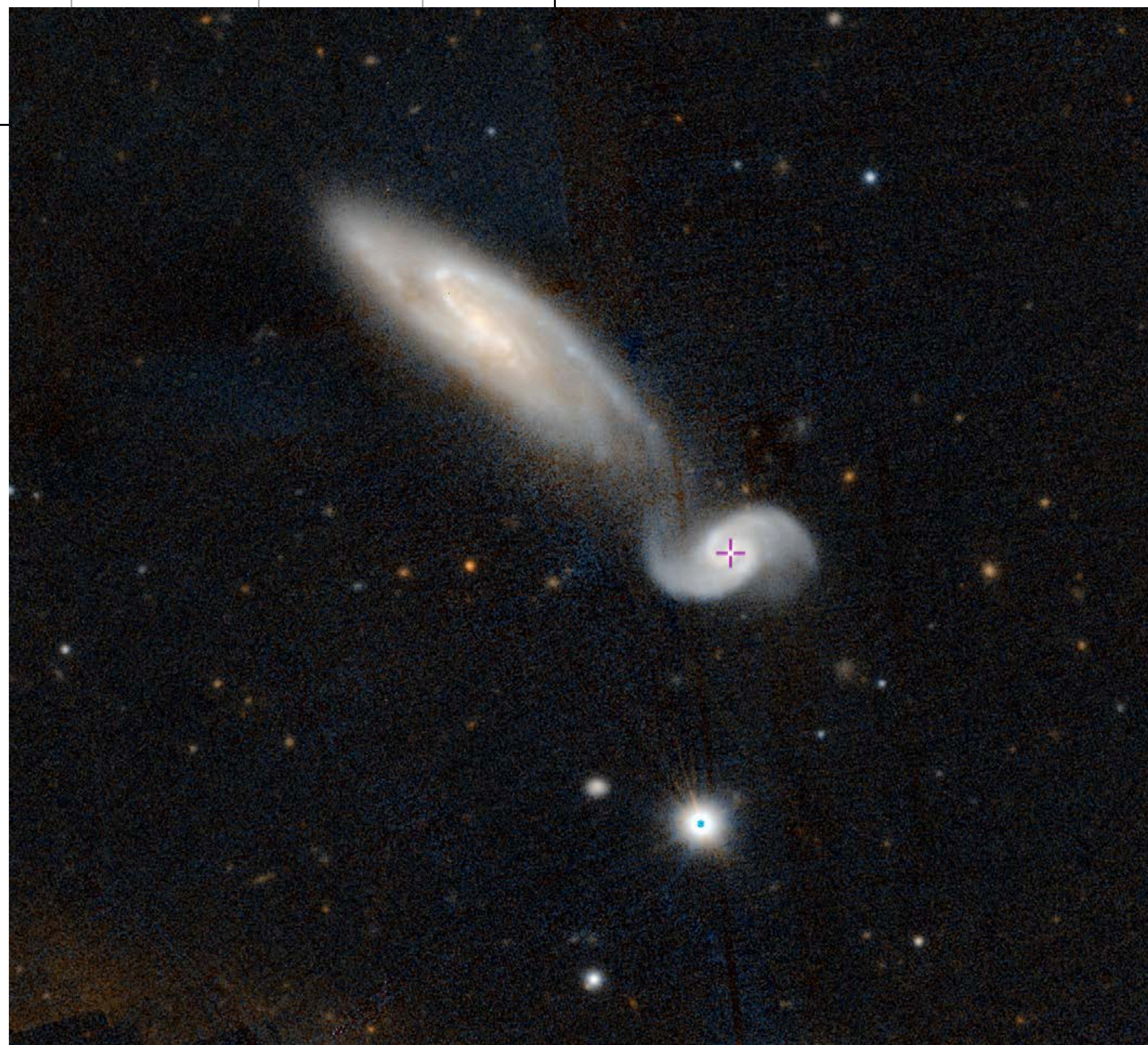
(c) Kyoto Univ.



Further Works: from ASAS-SN to Seimei







- nearby TDE: AT2023clx
- spectral classification with Seimei (Taguchi+2023)
- follow-up observation with Subaru/FOCAS (P.I. Uno / S23A-052)

Further Works: from Tomo-e, via Seimei, to Subaru

- 1 night (0.5 night x 2) left in this semester

Please let me know when you discover nuclear transients !

Schedule for June 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				Jun 01	Jun 02	Jun 03 ○
				SSP IRD S23A-UH015-B2 Williams CHARIS+SCExAO+NGS	S23A-TE166-K Brandt CRS+MEC+SCExAO-NGS S23A-UH015-B2 Williams CHARIS+SCExAO+NGS	SSP IRD S23A-UH015-B2 Williams CHARIS+SCExAO+NGS
Jun 04	Jun 05	Jun 06	Jun 07	Jun 08	Jun 09	Jun 10 ◑
SSP(0.2) --- S23A-059(0.15) Hirano --- SSP(0.15) IRD S23A-085 Lozi VAM+SCExAO+NGS	SSP(0.15) --- S23A-059(0.15) Hirano --- SSP(0.2) IRD S23A-038 Currie CHARIS+SCExAO	S UH G	SSP(0.15) --- S23A-059(0.15)		S23A-TE138-K	S23A-TE138-K
Jun 11	Jun 12	Jun				
S23A-TE138-K Hennawi HSC Queue HSC	S23A-TE138-K Hennawi HSC S23A-TE006-K Verbiscer HSC	S23 Yo HSC S23A-TE006-K Verbiscer HSC	HSC Queue HSC	Queue HSC	HSC Queue HSC	HSC Queue HSC
Jun 18	Jun 19	Jun 20	Jun 21	Jun 22	Jun 23	Jun 24
S23A-TE017-G Hudson HSC Queue HSC	S23A-TE017-G Hudson HSC Queue HSC	S23A-TE017-G Hudson HSC	Queue HSC	S23A-080 Pena Herazo FOCAS	S23A-055 Nishigaki FOCAS S23A-UH013-A4 Do FOCAS	S23A-055 Nishigaki FOCAS S23A-UH013-A4 Do FOCAS
Jun 25 ◐	Jun 26	Jun 27	Jun 28	Jun 29	Jun 30	
Eng	Eng SCExAO	Eng REACH+NGS-AO	SSP IRD	SSP IRD	SSP IRD	

Schedule for July 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
						Jul 01
						SSP IRD Obs MOIRCS
Jul 02 ○	Jul 03	Jul 04	Jul 05	Jul 06	Jul 07	Jul 08
Eng AO188 SSP IRD	Eng IRCS Eng IRD	Obs IRCS+NGS Eng IRD	S23A-059 Hirano IRD SSP	S23A-UH001-S Lucas CHARIS+VAM+SCExAO+NGS	S23A-027 Kanai MOIRCS S23A-038 Currie CHARIS+SCExAO	S23A-027 Kanai MOIRCS SSP IRD
					Jul 14	Jul 15
				o	S23A-UH013-A4 Do FOCAS S23A-080 Pena Herazo FOCAS	S23A-UH013-A4 Do FOCAS S23A-089 Toshikawa FOCAS
					Jul 21	Jul 22
S23A-089 Toshikawa FOCAS	S23A-060 Aoki HDS	Eng PFS+MCS	Eng PFS+MCS	Eng PFS+MCS	Eng PFS+MCS	Eng PFS+MCS
Jul 23	Jul 24 ◐	Jul 25	Jul 26	Jul 27	Jul 28	Jul 29
Eng PFS+MCS	Eng PFS+MCS	Eng PFS+MCS	Eng PFS+MCS	Eng PFS+MCS	SSP IRD SSP IRD	SSP IRD S23A-TE010-K Fitzgerald CRS+SCExAO-NGS
Jul 30	Jul 31					
S23A-067I Narita IRD	SSP IRD Obs MOIRCS					

Summery

Background

- Recently, enigmatic transients; **FBOTs/AT2018cow** have been discovered.
- Supernova-like model cannot explain observational properties of FBOTs.

Motivation

- Which systems can explain the FBOTs/AT2018cow?

Method

- Assuming continuous outflow, we propose a ‘Wind-Driven Model’.

Results

- The ‘Wind-Driven Model’ can explain some observational properties.
- The central engine of FBOTs/AT2018cow may be **Failed SN** or **IMBH TDE**.
- **High cadence surveys** are important to discover FBOTs & related objects.
- **Tomo-e to Seimei (to Subaru)**