

# 类超新星现象可能的X射线辐射特征及其来源

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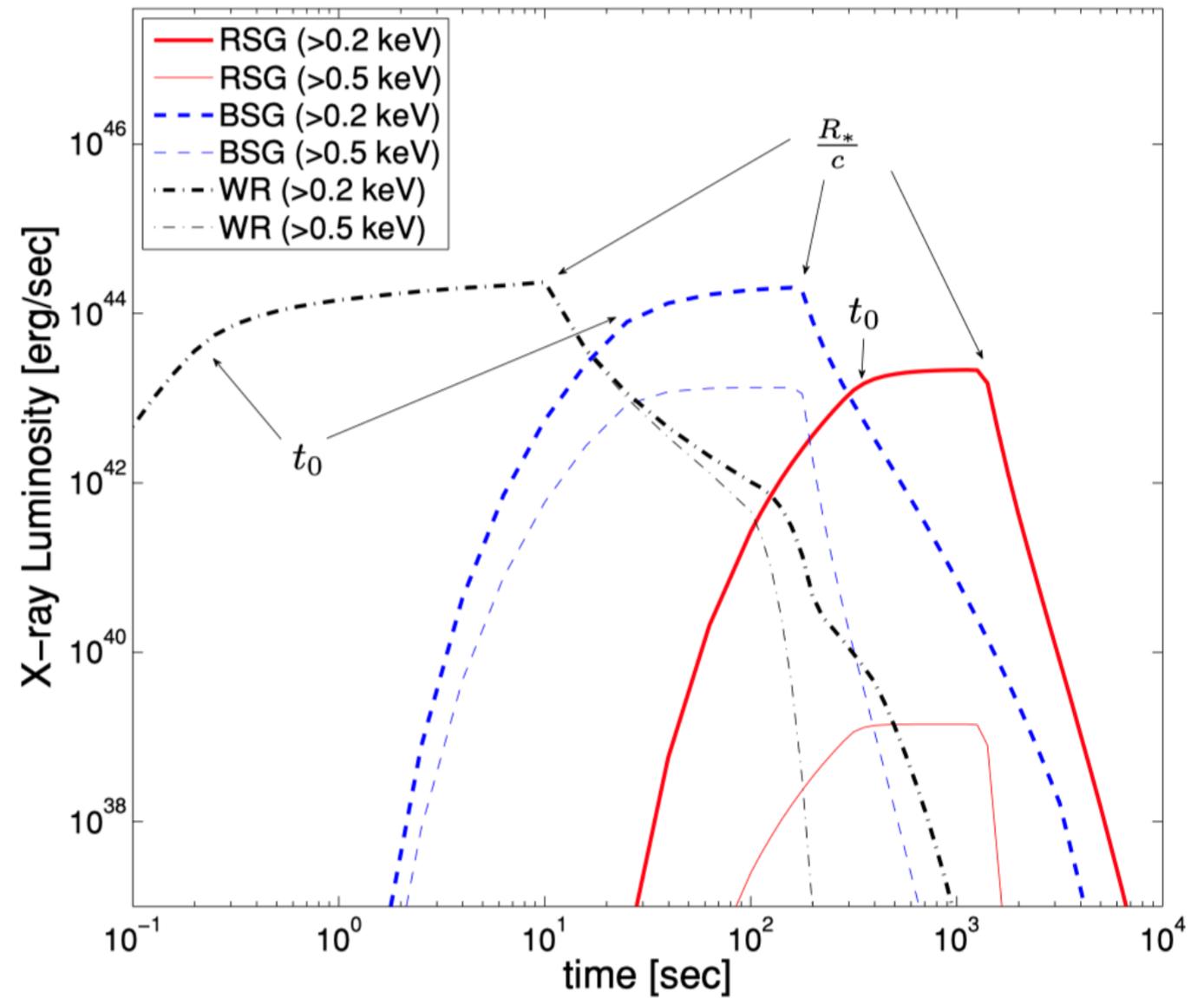
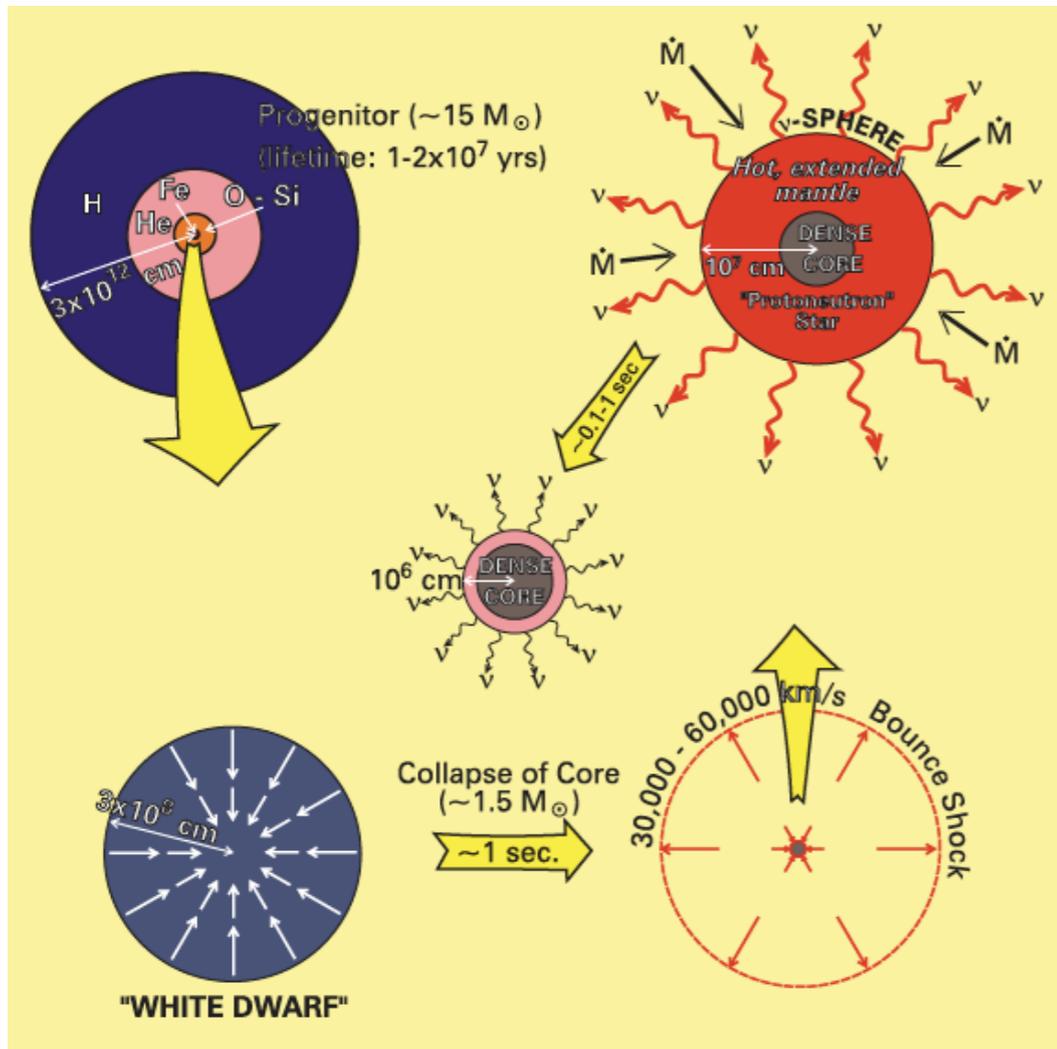


# 超新星激波突破 (激波暴)



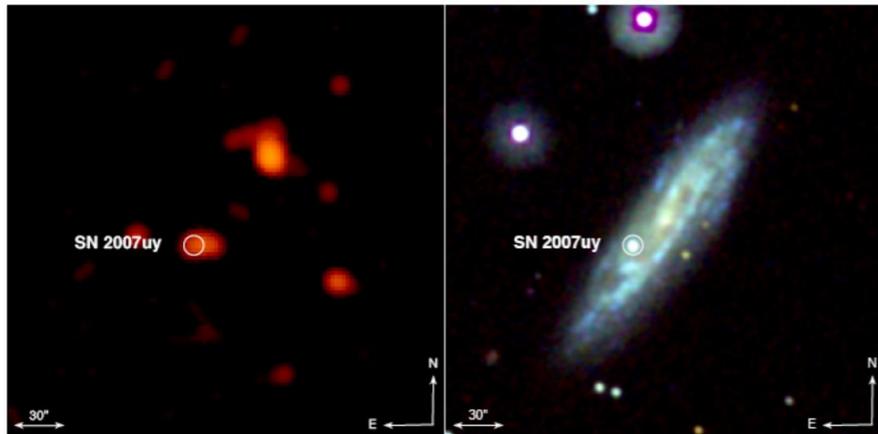


# 核坍缩型超新星爆发和激波突破

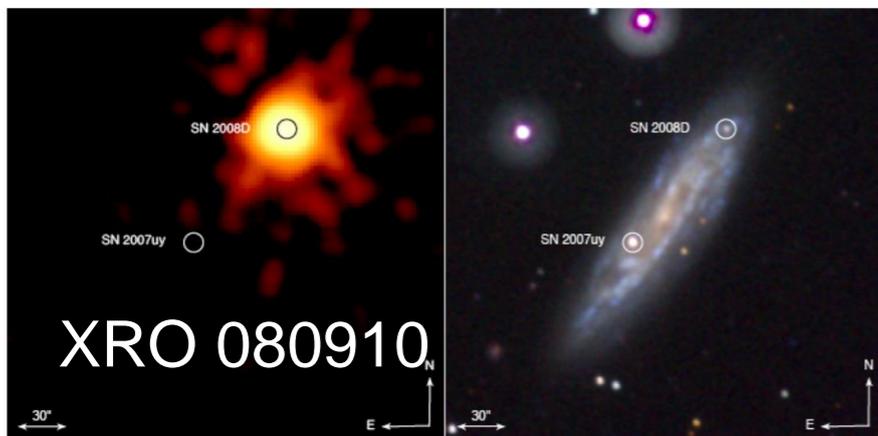


# SN 2008D 激波突破的X射线辐射

2008 Jan 7

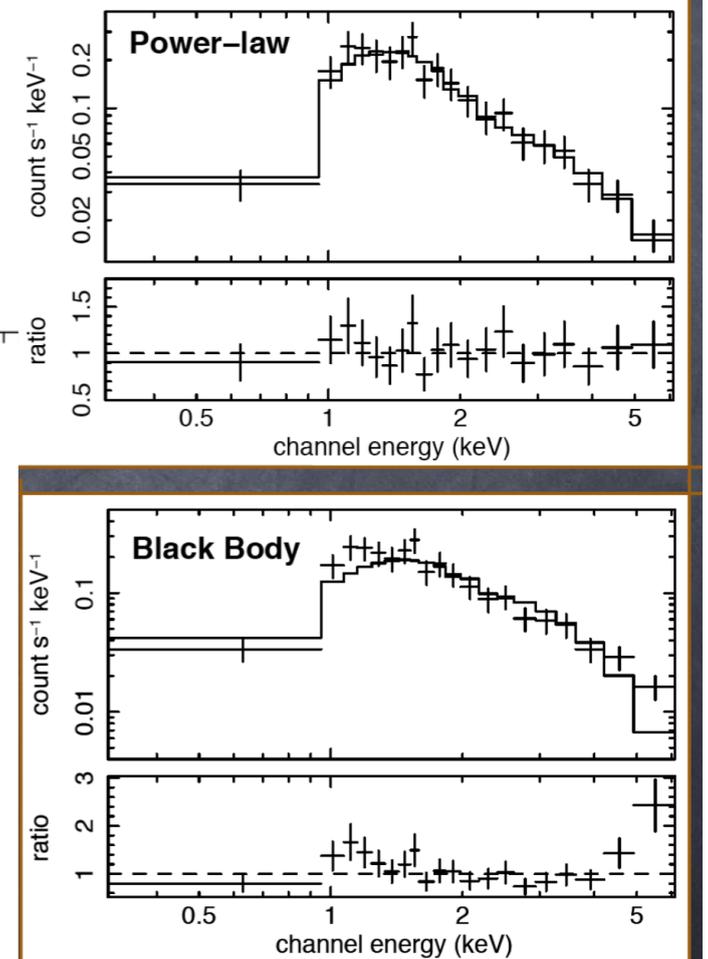
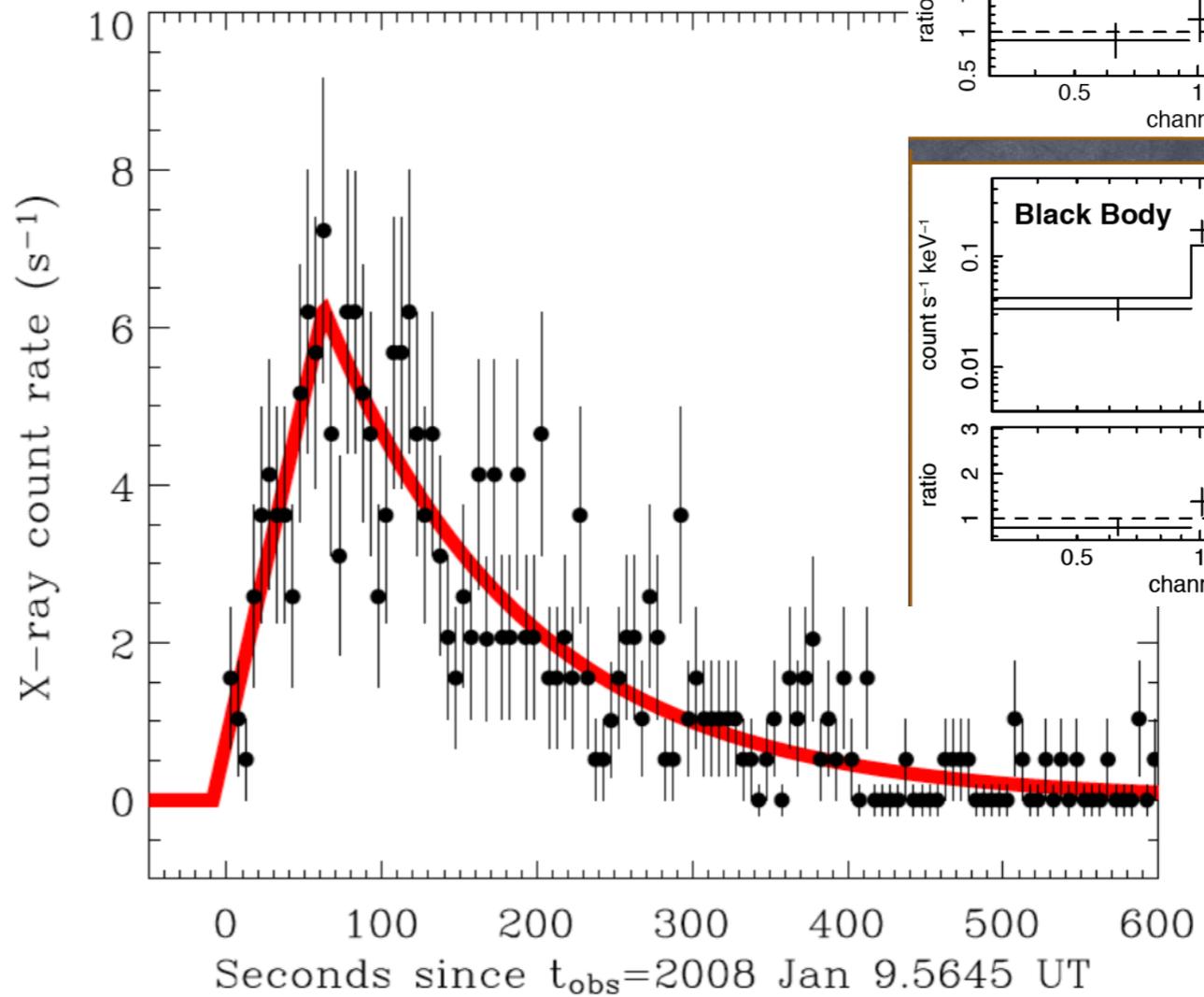


2008 Jan 9

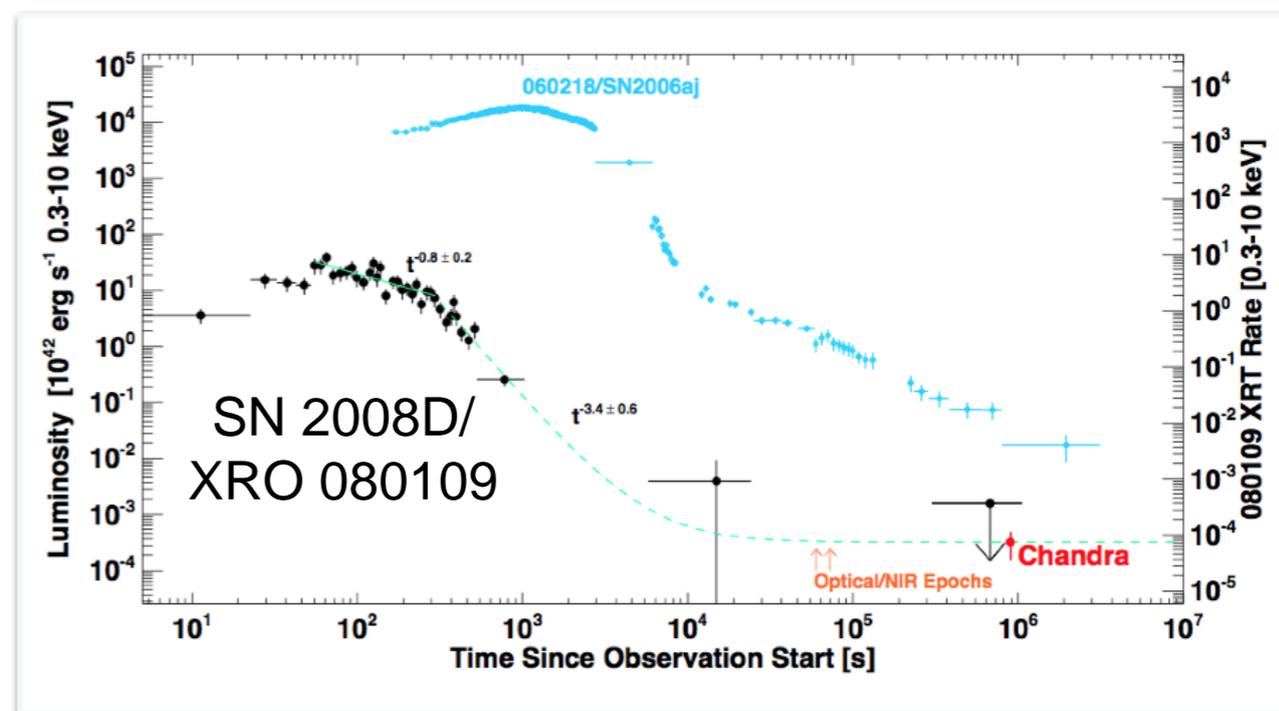
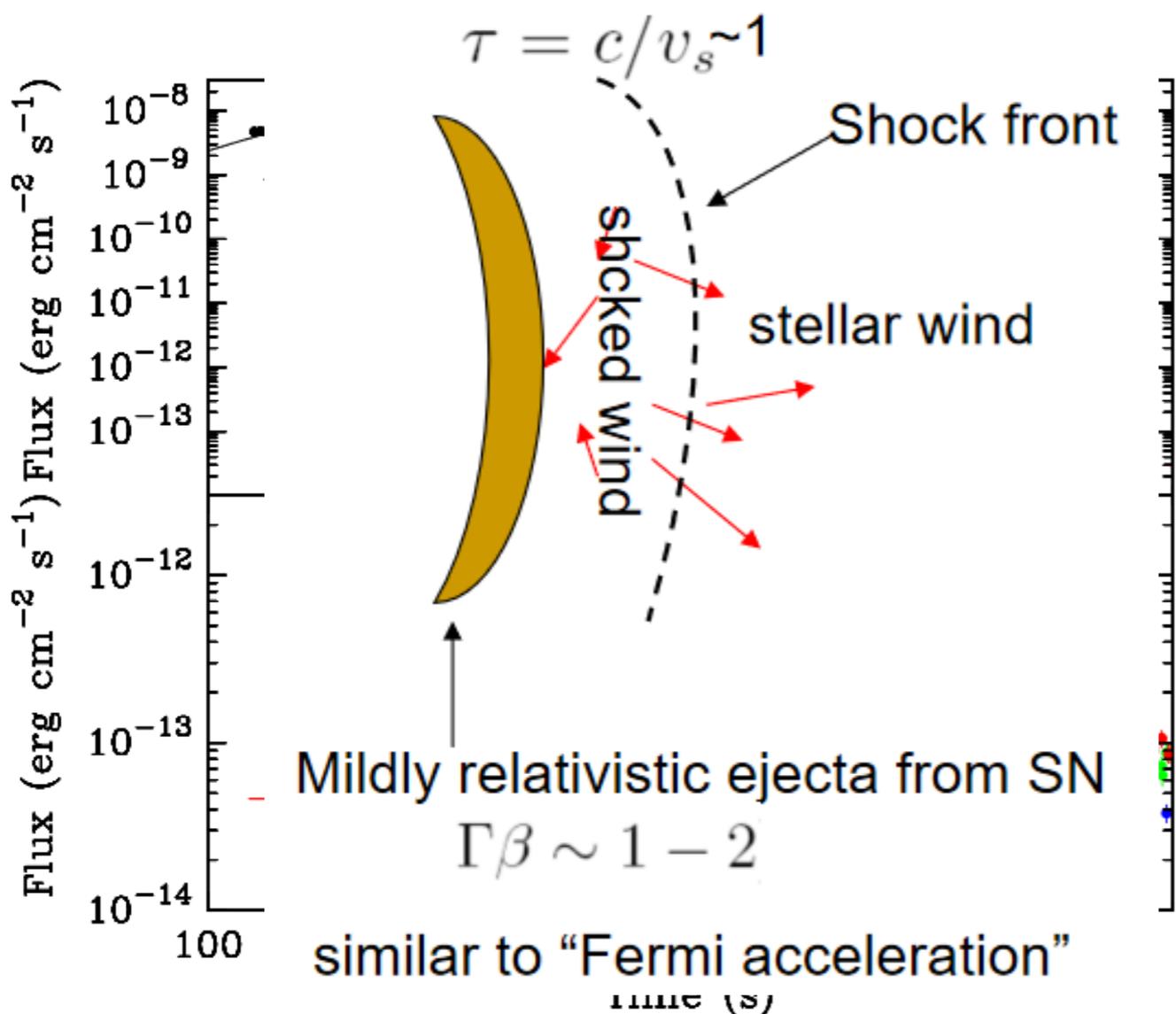


Swift/XRT observation of  
NGC2770(27Mpc)

Soderberg et al. 2008



# 伽马射线暴成协超新星GRB060218/SN 2006AJ



Wang, Li, Waxman & Meszaros 2007

# 统计性质和EP探测率

✧ 12 SN SBO candidates discovered from XMM-Newton archival data (Alp & Larsson 2020)

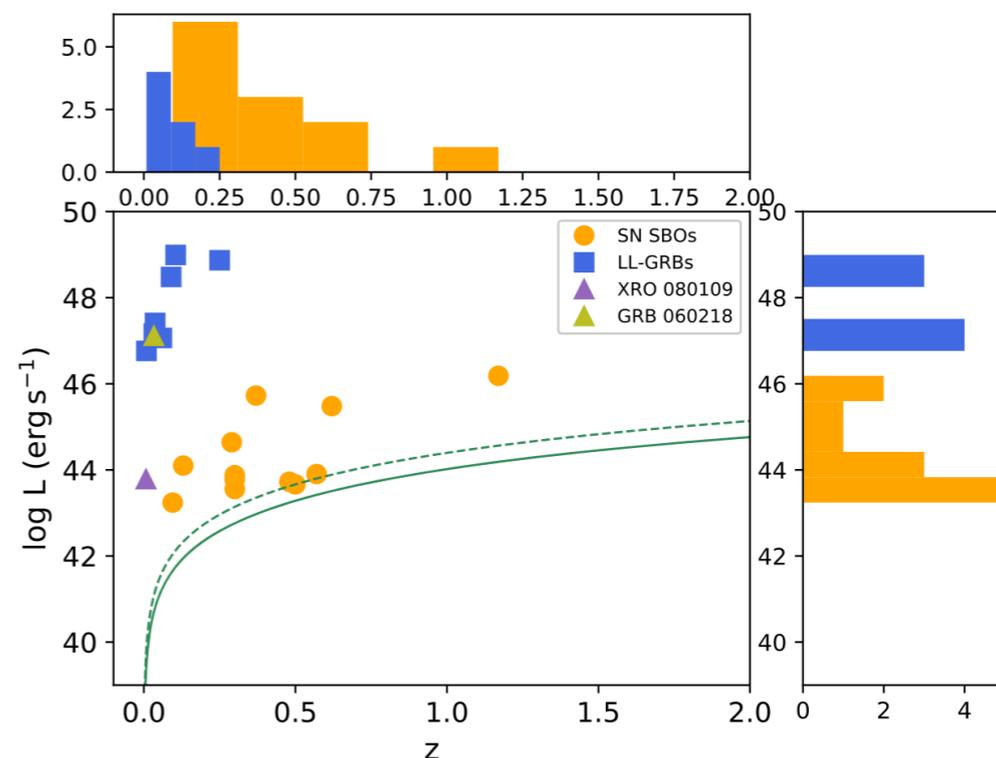
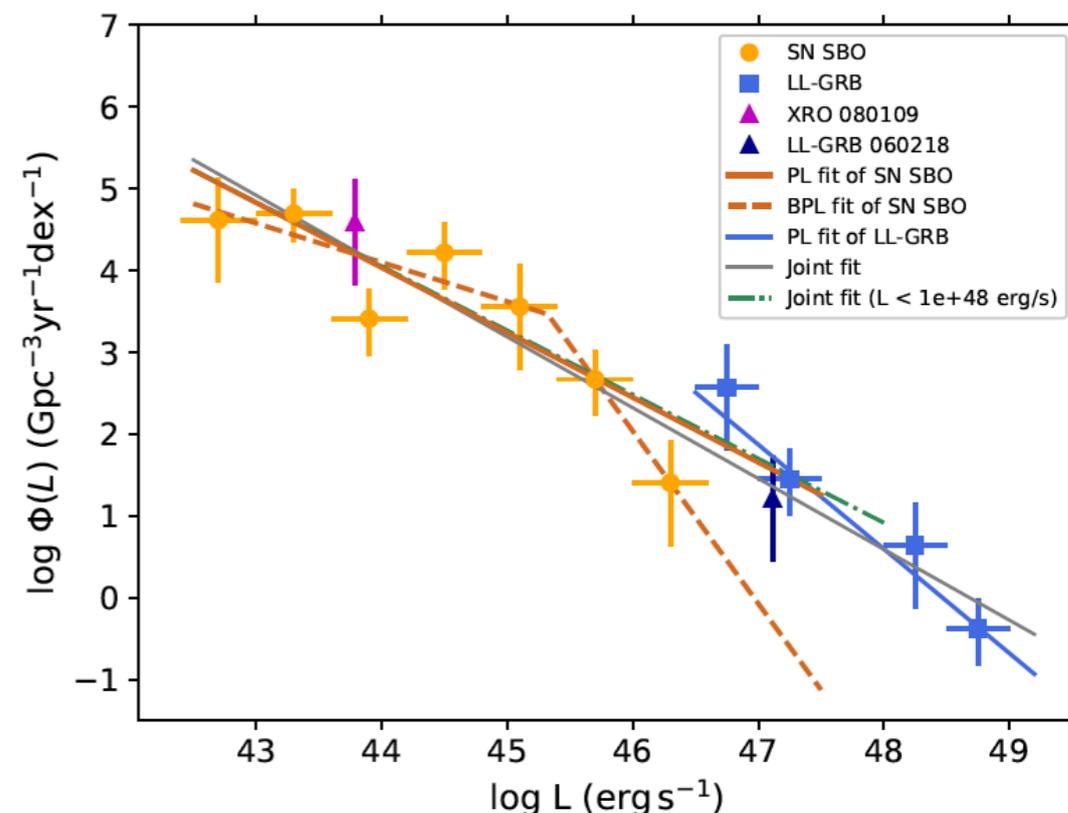
Larsson 2020

✧  $L_{\text{bol}} \sim [10^{43}, 10^{46.5}] \text{ erg s}^{-1}$

✧  $T_{\text{bb}} \sim [0.1, 1] \text{ keV}$

XT	$t_{R/c}$ (s)	$L_{\text{peak}}$ ( $10^{44} \text{ erg s}^{-1}$ )	$E_{\text{SBO}}$ ( $10^{46} \text{ erg}$ )	$R_t$ ( $R_{\odot}$ )
161028	42	$3.39^{+2.40}_{-1.03}$	$0.3^{+0.2}_{-0.1}$	14
151219	90	$32.88^{+53.76}_{-11.00}$	$2.4^{+4.0}_{-0.8}$	24
110621	380	$0.39^{+7.45}_{-0.22}$	$0.5^{+9.5}_{-0.3}$	150
030206	360	$172.47^{+28.72}_{-23.77}$	$79.0^{+13.2}_{-10.9}$	71
070618	70	$48.78^{+17.05}_{-10.68}$	$7.6^{+2.6}_{-1.7}$	22
060207	110	$6.44^{+2.74}_{-2.03}$	$2.2^{+0.9}_{-0.7}$	36
100424	5600	$0.05^{+0.12}_{-0.01}$	$1.0^{+2.6}_{-0.3}$	2136
151128	1800	$1.83^{+56.98}_{-1.08}$	$2.5^{+78.1}_{-1.5}$	524
050925	850	$0.21^{+0.14}_{-0.08}$	$0.3^{+0.2}_{-0.1}$	282
160220	750	$0.51^{+0.23}_{-0.12}$	$0.6^{+0.3}_{-0.2}$	249
140811	1800	$0.93^{+4.64}_{-0.41}$	$2.9^{+14.6}_{-1.3}$	494
040610	3200	$0.32^{+0.09}_{-0.07}$	$1.8^{+0.5}_{-0.4}$	919

Sun et al, 2022, ApJ, 927, 224



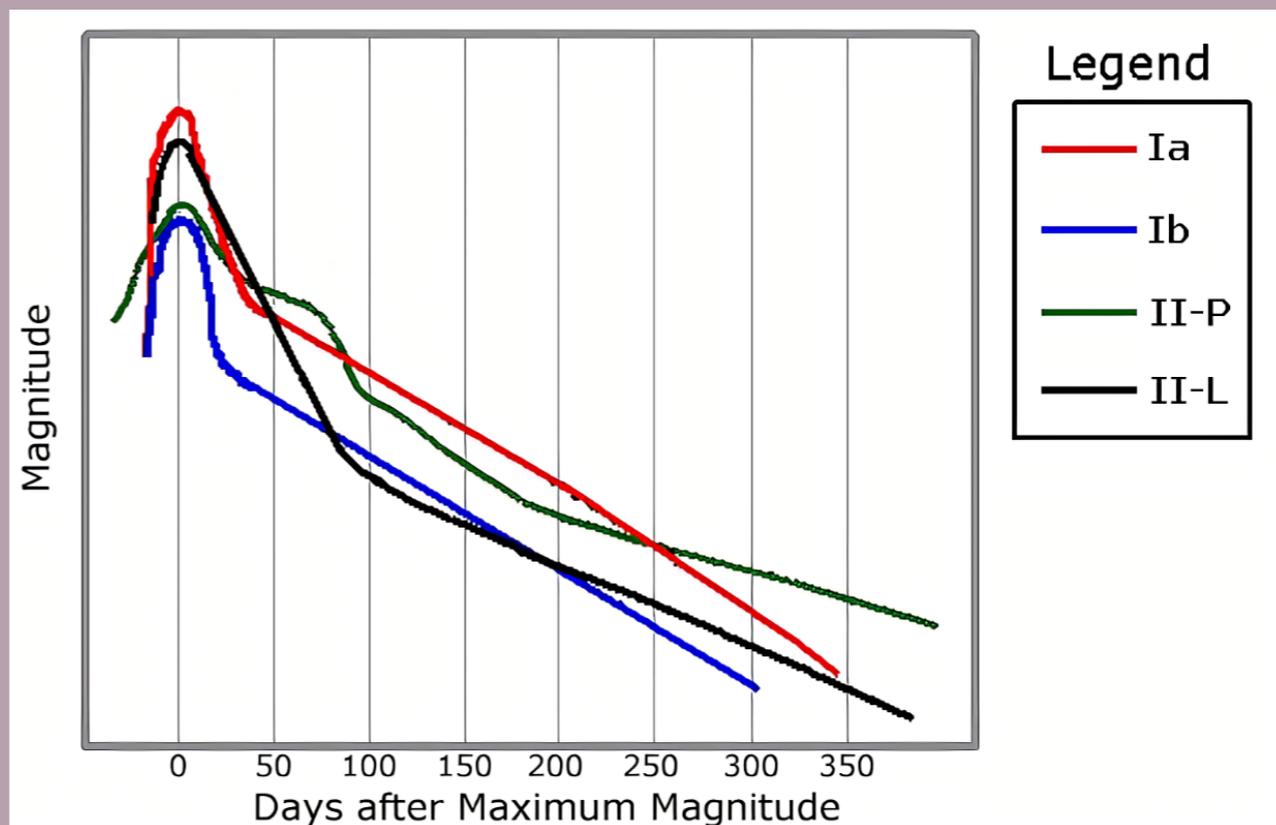
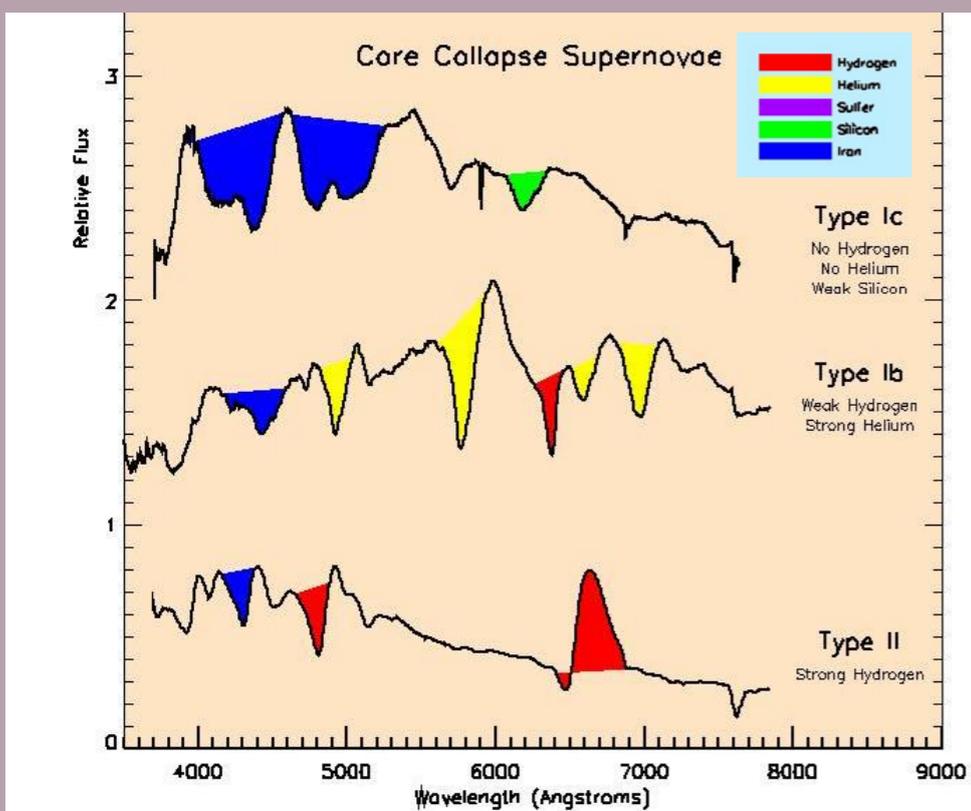
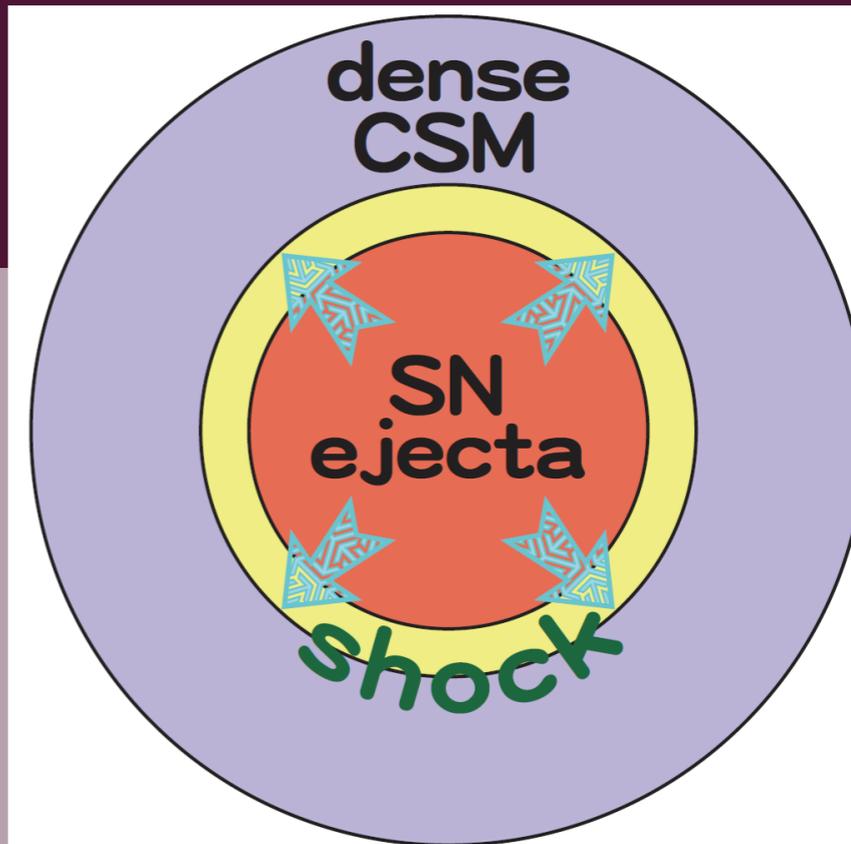
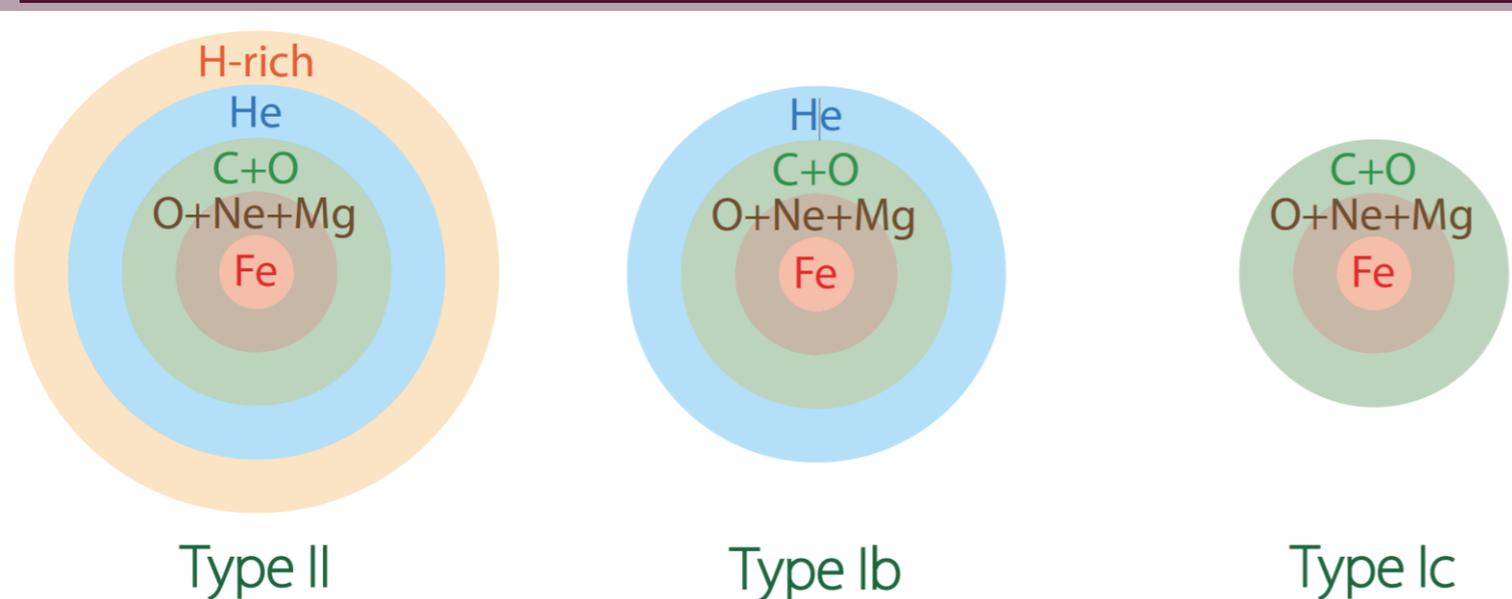
• 预计EP每年能够探测10到几十个超新星激波突破事件



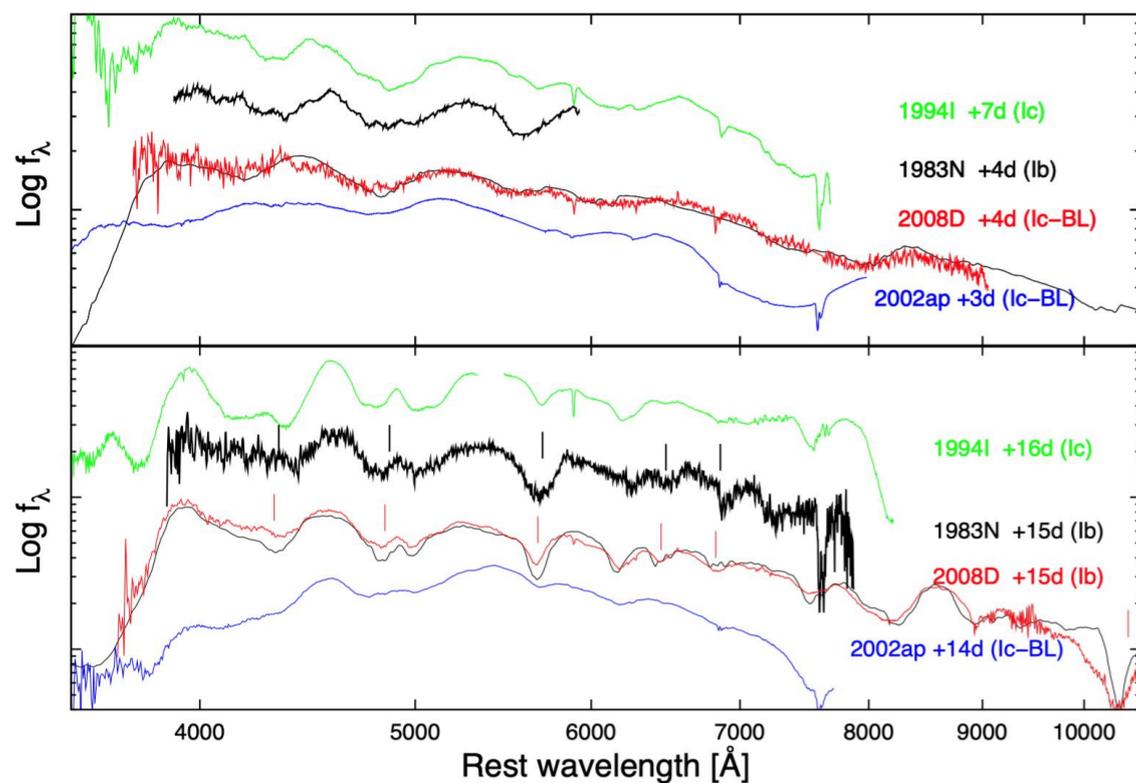
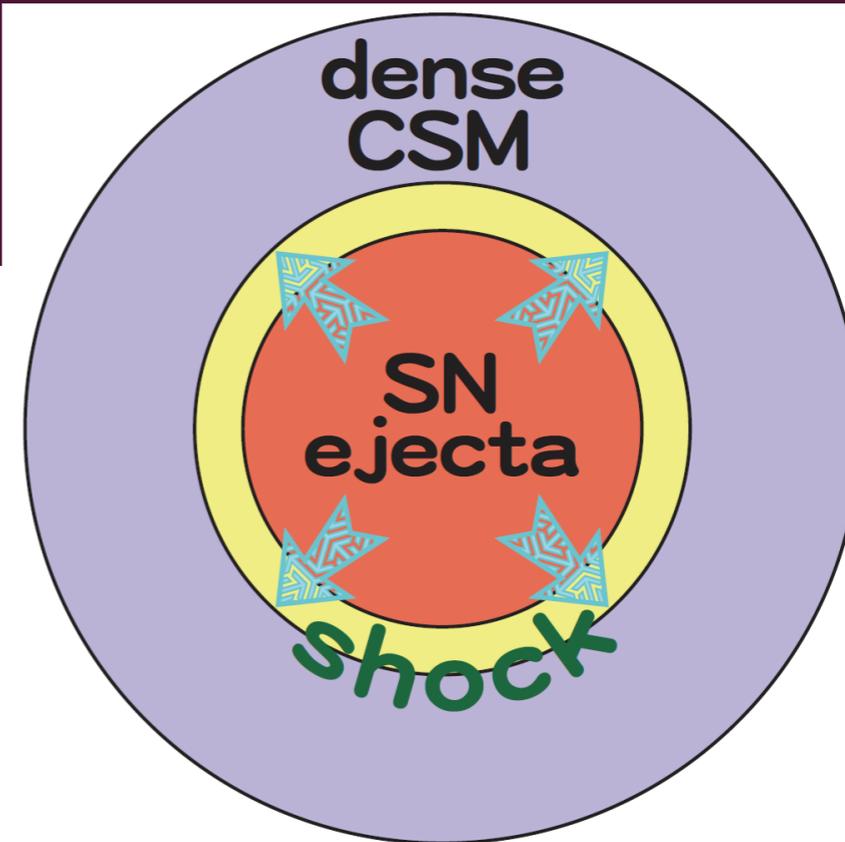
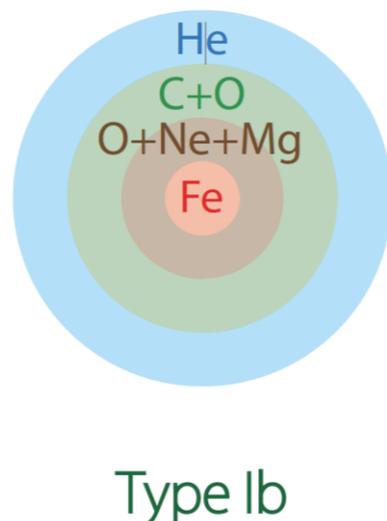
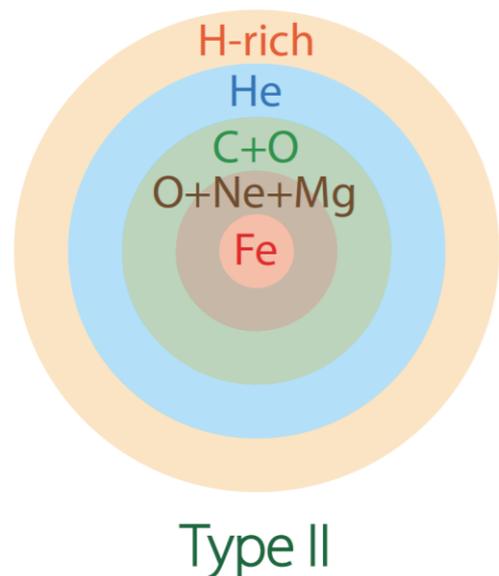
# 相互作用超新星X射线辐射



# 核坍缩型超新星的类型和能源



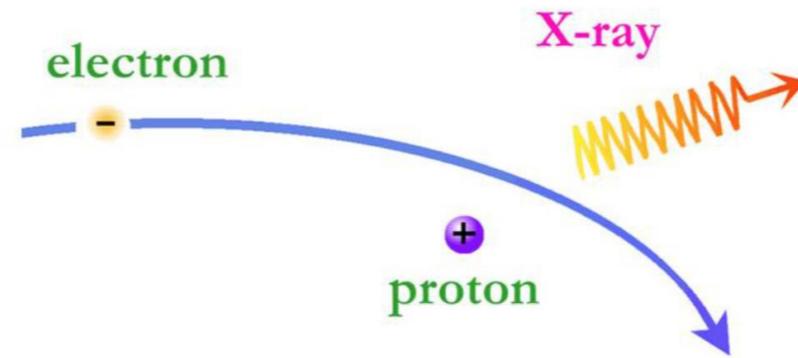
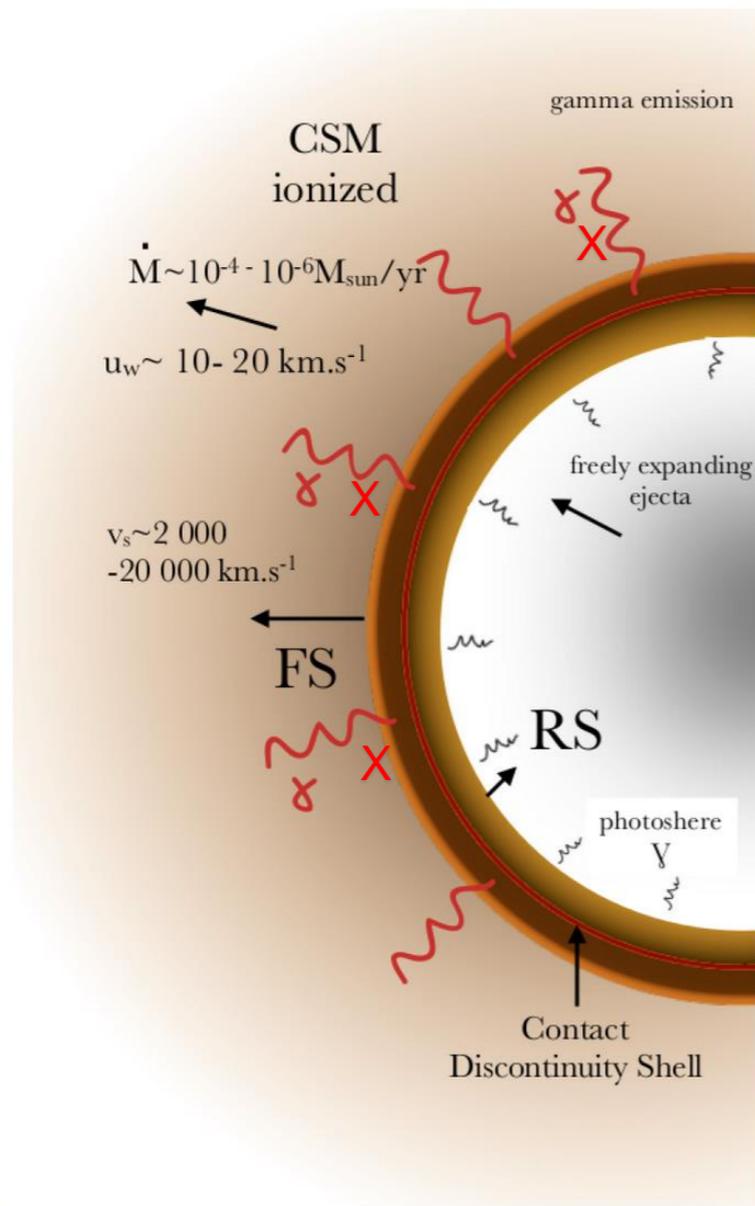
# 核坍缩型超新星的类型和能源



SN 2008D / XRF 080109

开始表现为宽线Ic型超新星的光谱，  
其后转变为窄线Ib型超新星光谱

# 激波相互作用和电子的韧致辐射



$$F_{\nu} \sim \frac{n_e n_H V}{4\pi D^2} T^{1/2} g(E, T) e^{-E/kT}$$

$$L_i \approx 3.0 \times 10^{39} \bar{g}_{\text{ff}} C_n \left( \frac{\dot{M}}{10^{-5} M_{\odot} \text{ yr}^{-1}} \right)^2 \left( \frac{v_{\text{wind}}}{10 \text{ km s}^{-1}} \right)^{-2} \left( \frac{t}{10} \right)^{-1} \text{ erg s}^{-1}$$

# 现有超新星X射线观测

- 目前31颗超新星被多次探测到X射线辐射，主要来自于Chandra、Swift-XRT、XMM-Newton和NuSTAR等望远镜的发现。

- IIIn超新星的X-ray辐射平均明显高于所有其他类型的超新星:

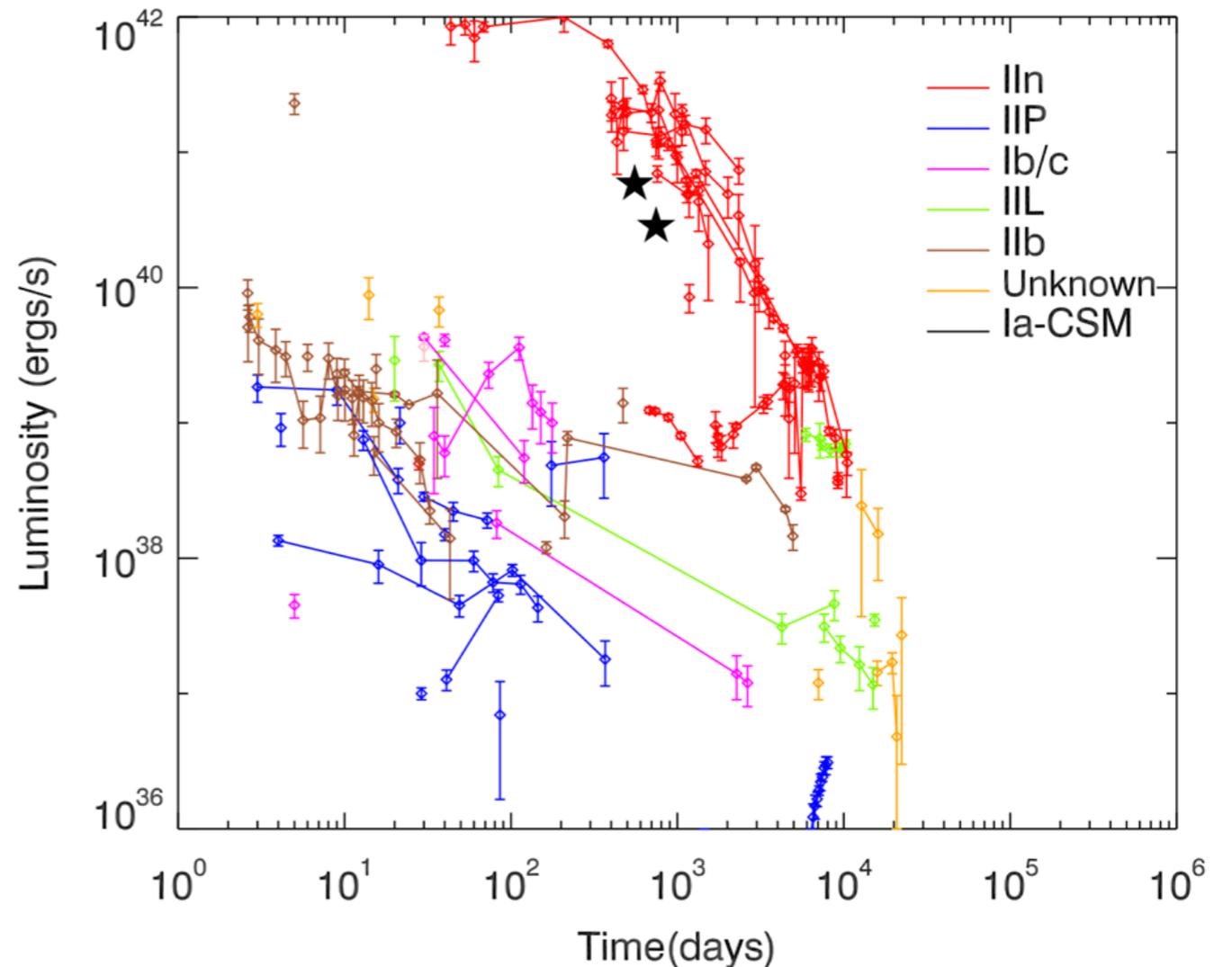
$$L_X \sim 10^{41} - 10^{42} \text{ erg s}^{-1}$$

- 来自其他类型的超新星 (IIL, IIP等) 的X-ray辐射相对较弱:

$$L_X \lesssim 10^{40} \text{ erg s}^{-1}$$

**Table 1**  
The List of 31 SNe for Which Multiple Data Points of X-Ray Luminosities Were Found within the Literature

Supernova	Publication(s)	Band Observed (keV)
1970G	Immler & Kuntz (2005)	0.3–2.0
1978K	Schlegel et al. (2004)	0.5–2.0
1979C	Patnaude et al. (2011)	0.3–2.0
1980K	Schlegel (1995)	0.2–2.4
1986J	Temple et al. (2005)	0.3–2.0



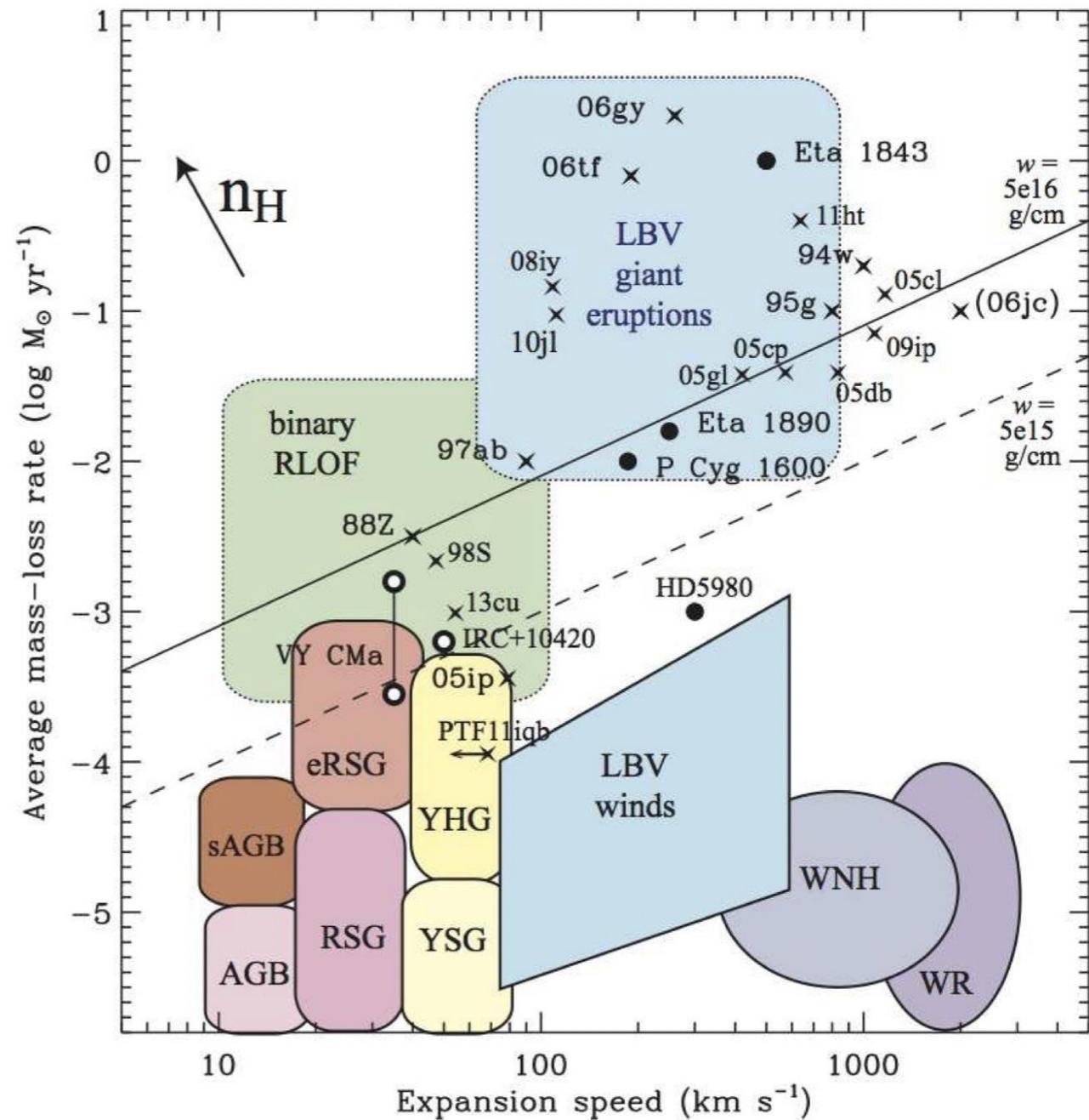
2014C	Brethauer et al. (2022)	0.3–100
2017eaw	Szalai et al. (2019)	0.3–10
2019ehk	Jacobson-Galán et al. (2020)	0.3–10

# IIN型超新星X射线辐射特点

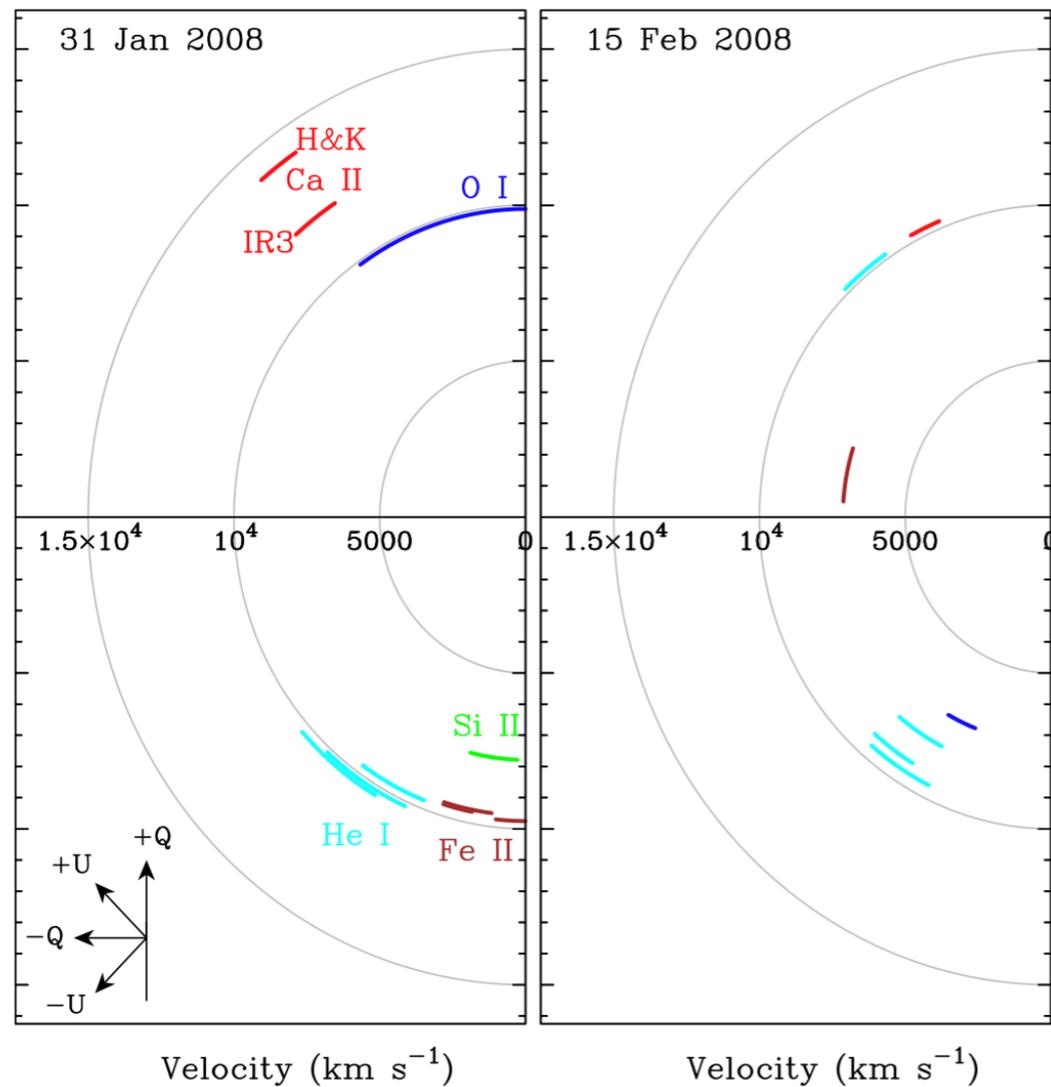
- 在所有超新星中具有最高的X射线光度，并具有相当大的范围
- 光变曲线的形态具有多样性，一般为快速衰减
- 早期光谱显示其辐射温度常常在Chandra和XMM能段之外 ( $>10\text{keV}$ )
- 几年内的中性氢密度  $> 10^{21} \text{ cm}^{-2}$
- 光谱中常具有Fe、Si、S、Mg等超出特征

# 不同前身星系统的星风环境

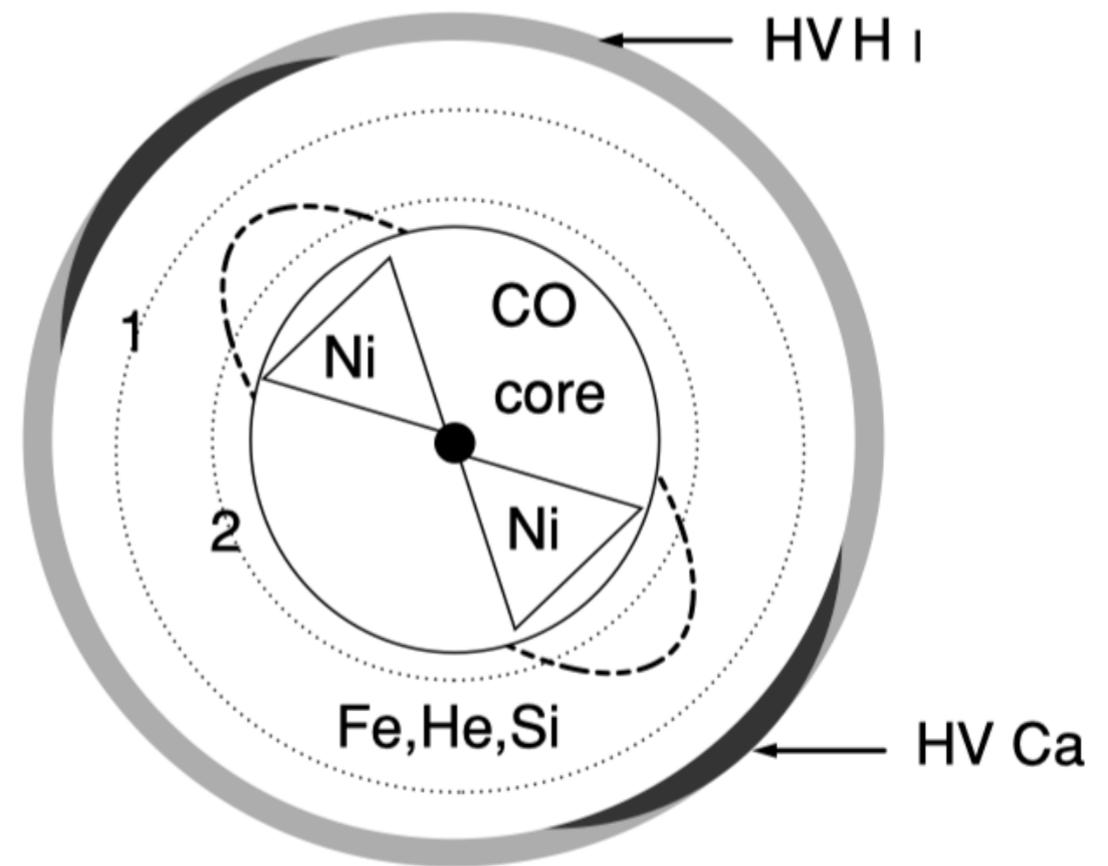
- 大质量恒星  
( $\dot{M} < 0.001 M_{\odot} / \text{yr}$ )
- 双星系统相互作用  
( $\dot{M} < 0.1 M_{\odot} / \text{yr}$ )
- 亮蓝变星的Giant eruptions  
( $\dot{M} < 10 M_{\odot} / \text{yr}$ )



# 各向异性和中心引擎（喷流）



SN 2008D的光学偏振观测

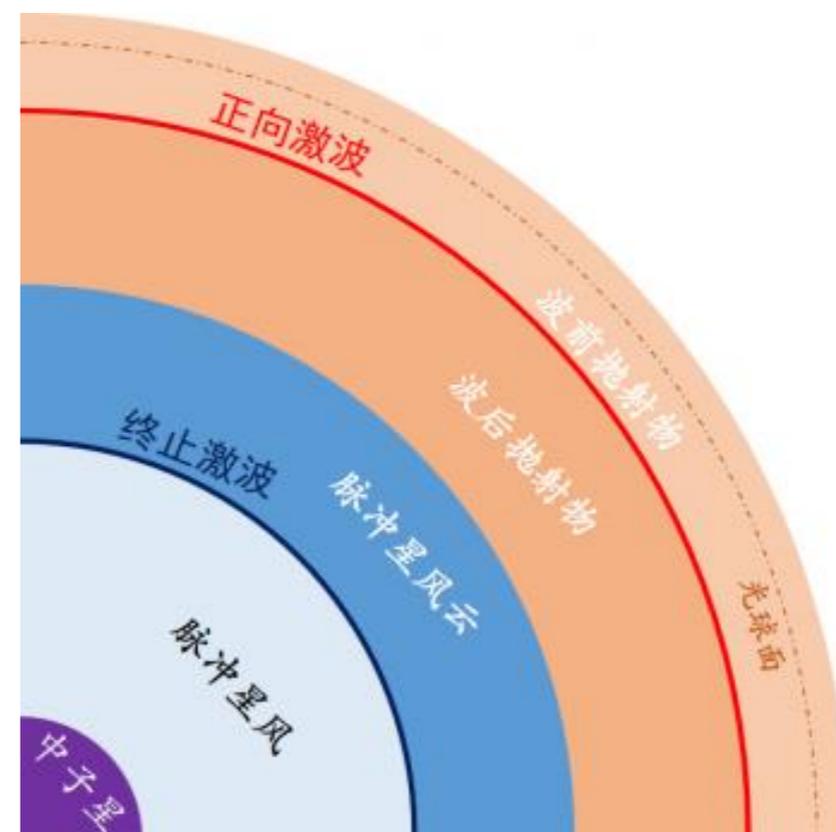
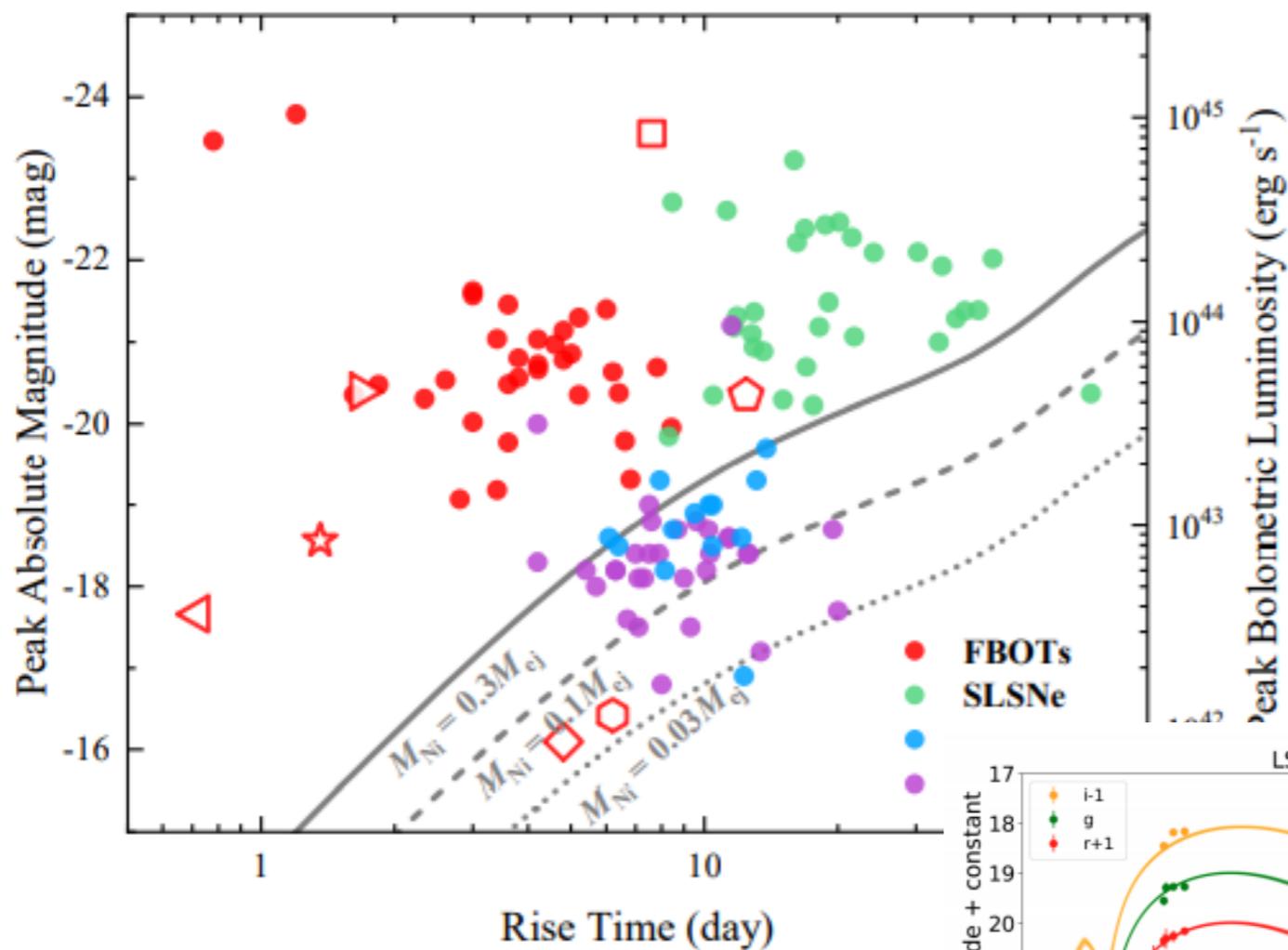


连续谱偏振度非常低，但同时Ca II、He I等谱线偏振度较高，暗示着爆发过程各向异性，因而也存在非球对称激波突破的可能性。

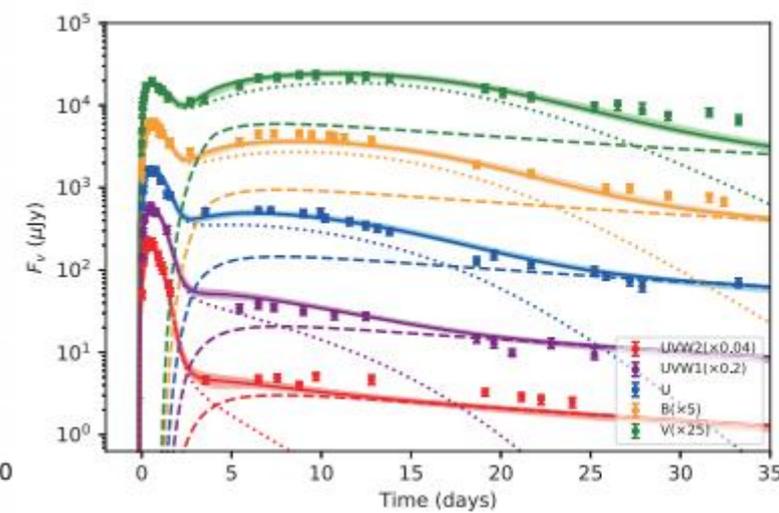
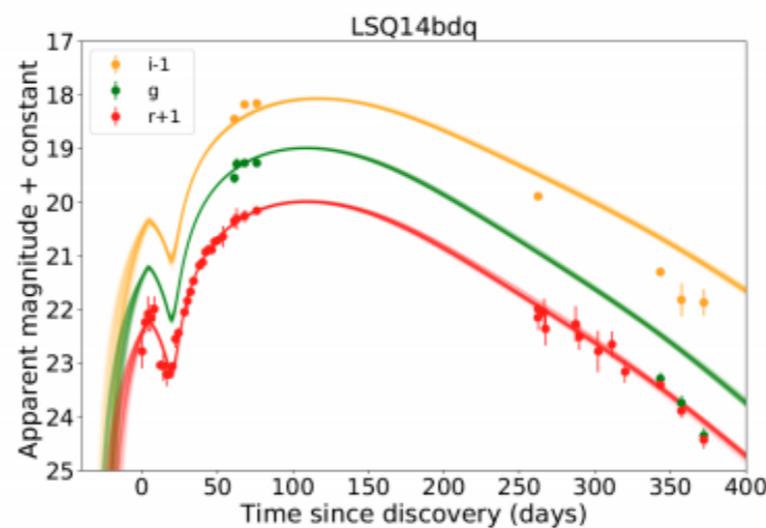


# 超亮超新星和快变蓝色暂现源

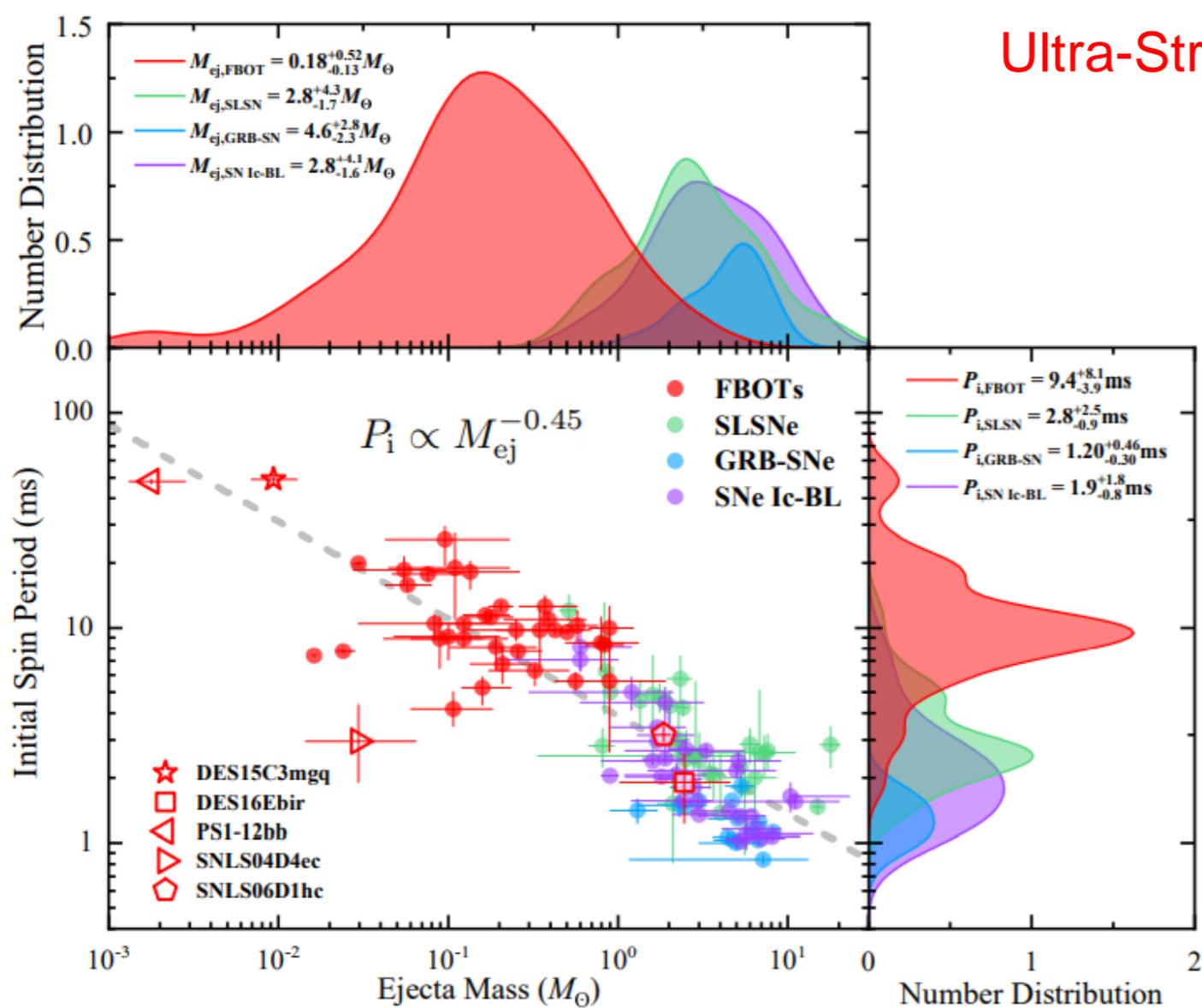
# 超亮超新星 (SLSN) 和快变蓝色暂现源 (FBOT)



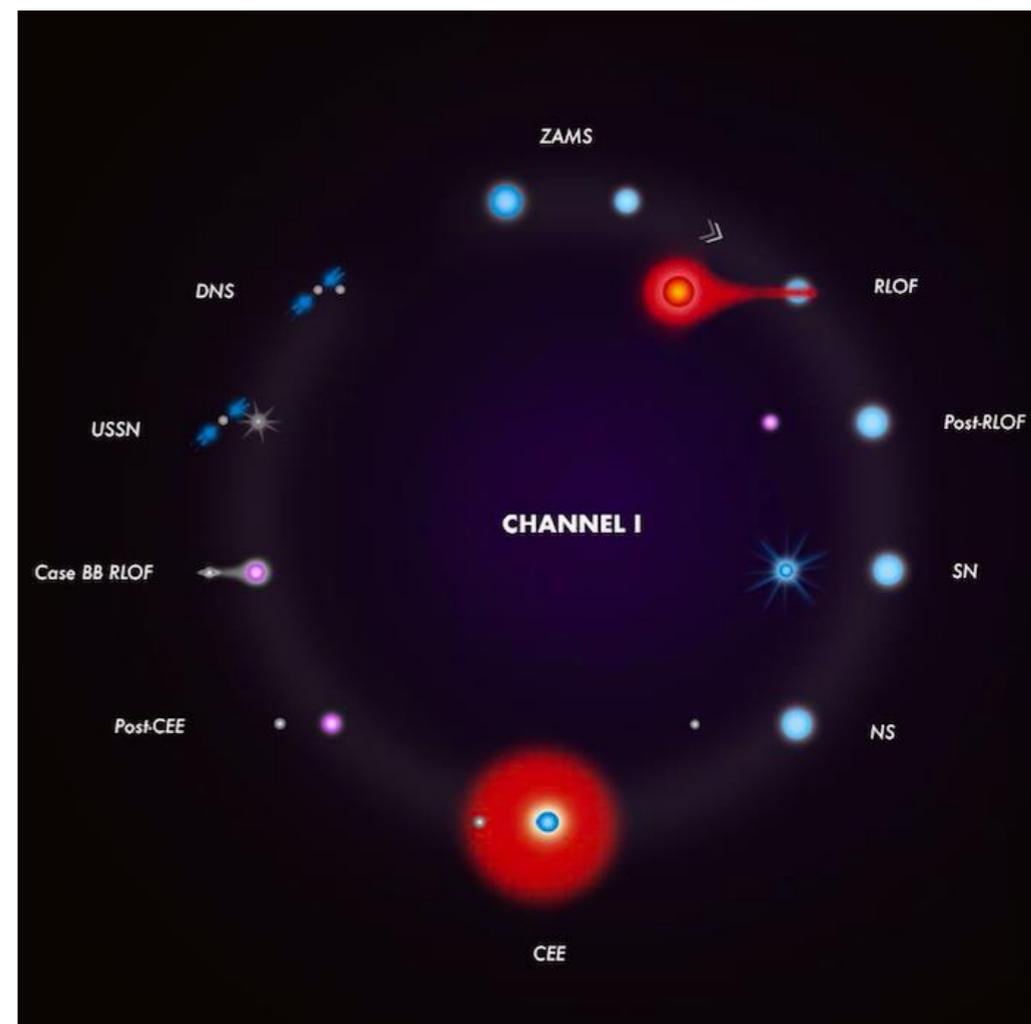
Liu et al. 2022, ApJL, 935, L34



# 统计属性和起源

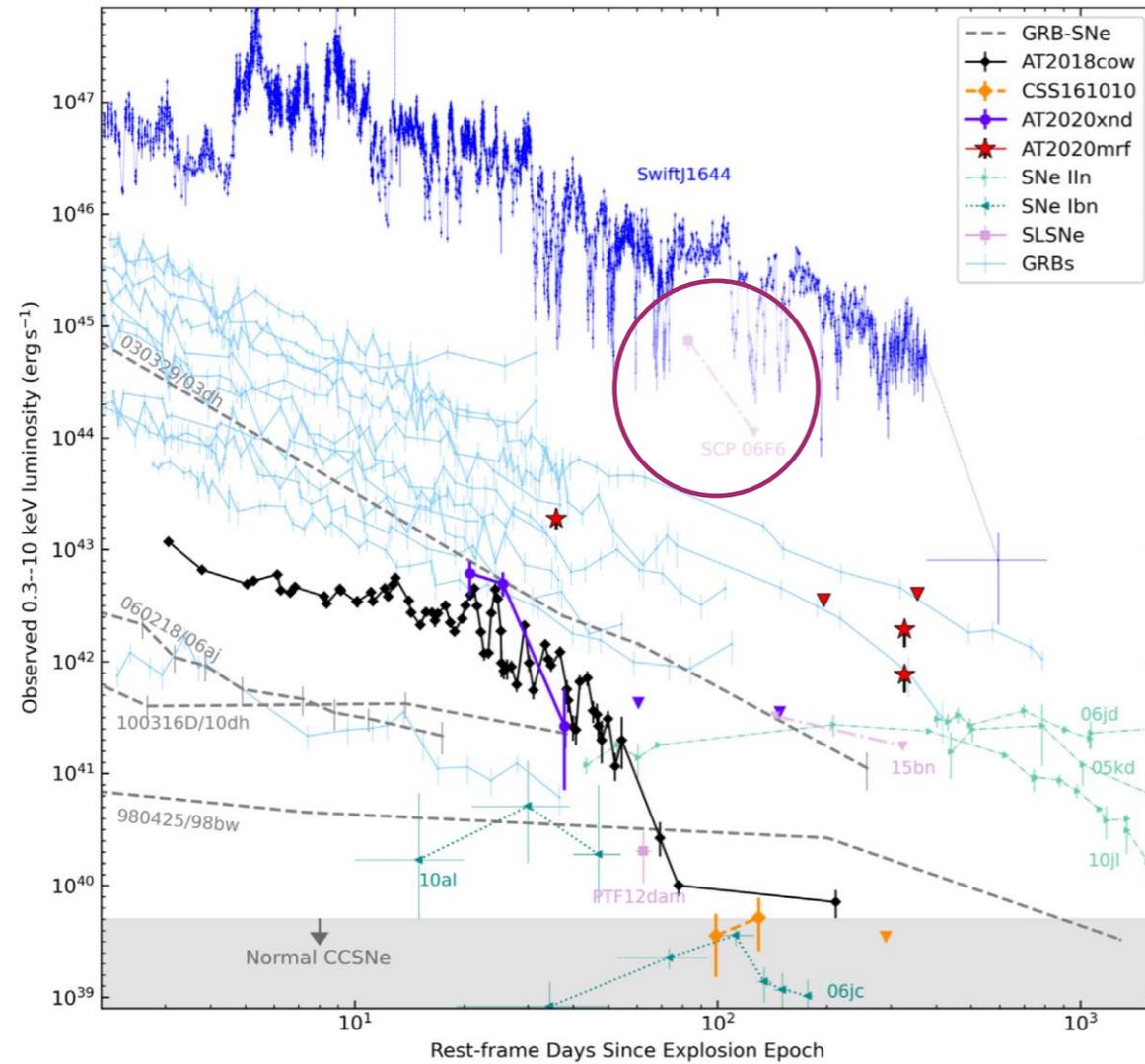


## Ultra-Stripped Supernova in Close Binary



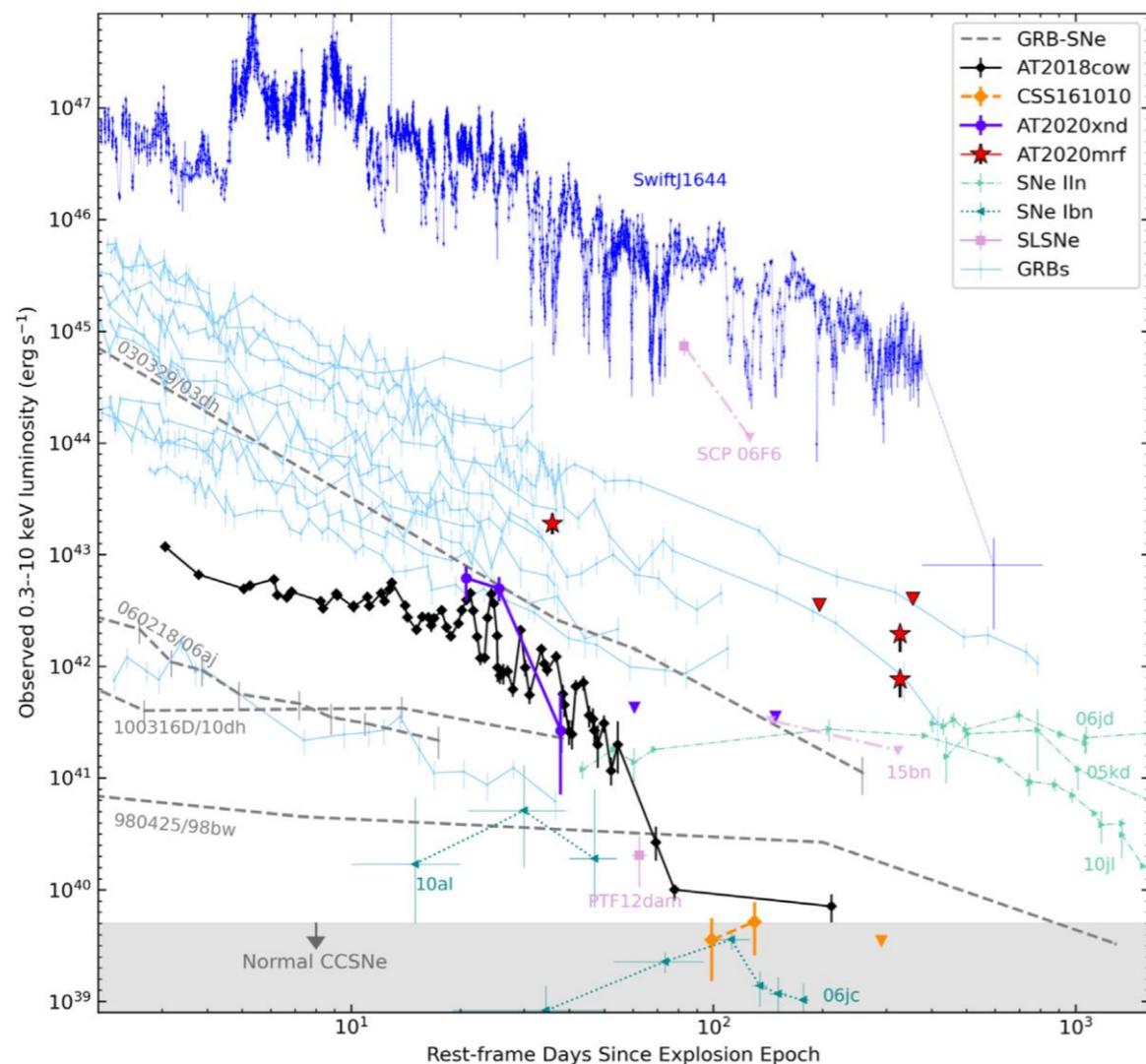
# 超亮超新星X射线观测现状

- 目前只在一例SLSN中发现了X射线辐射

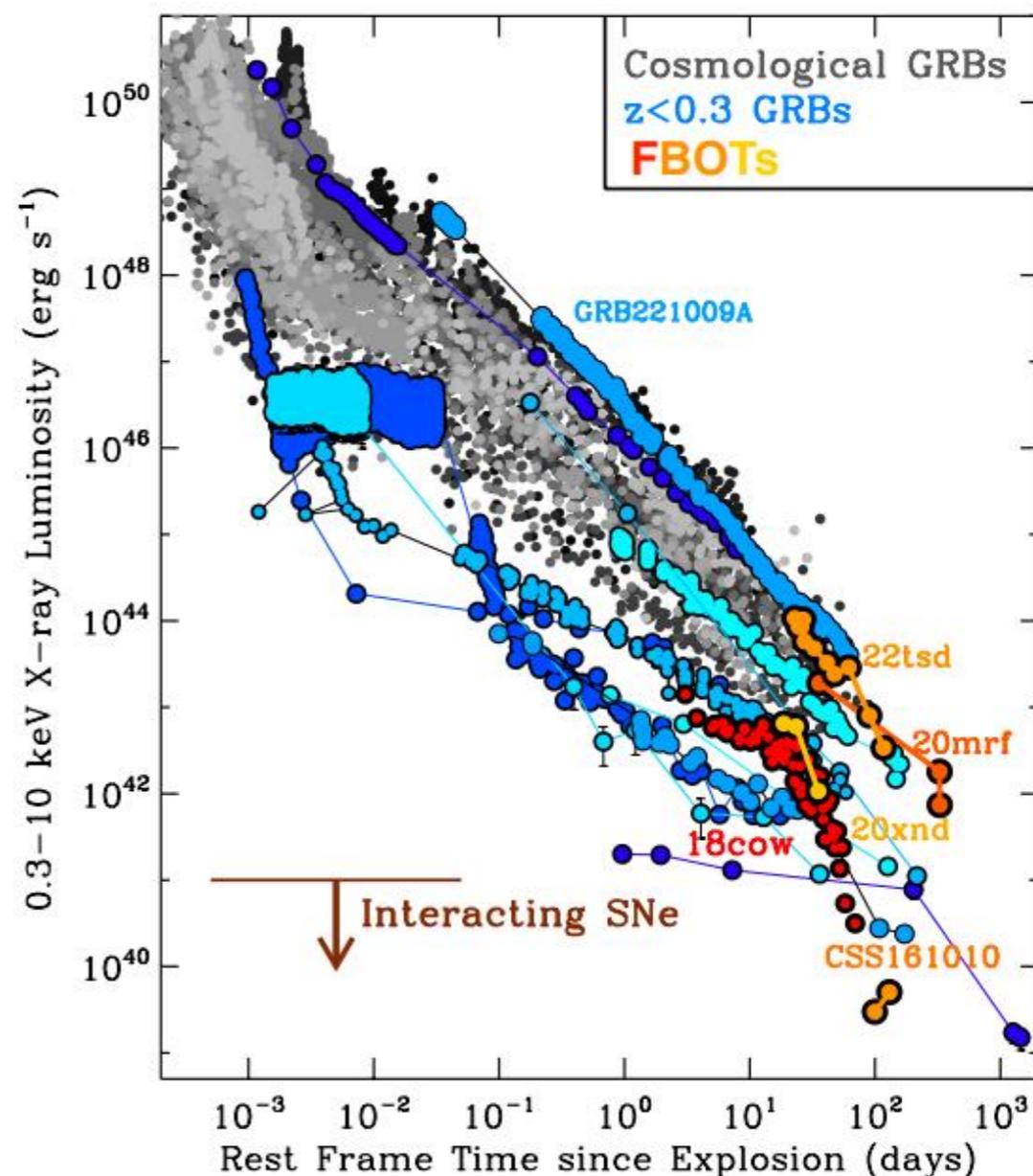


# 快变蓝色暂现源X射线观测现状

- 目前一共发现5例FBOT存在X射线辐射，最具代表性的是AT 2018cow 代表性的



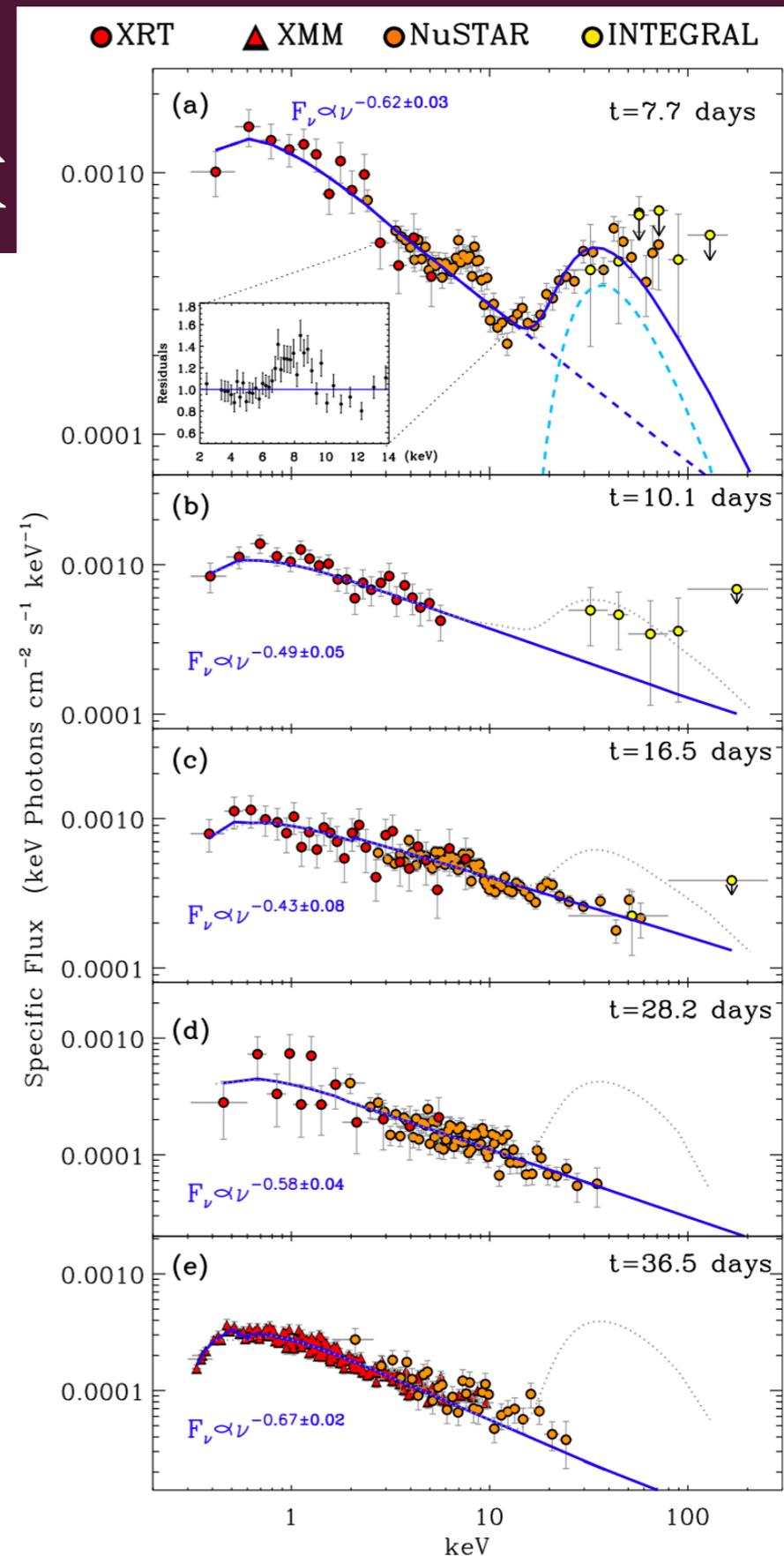
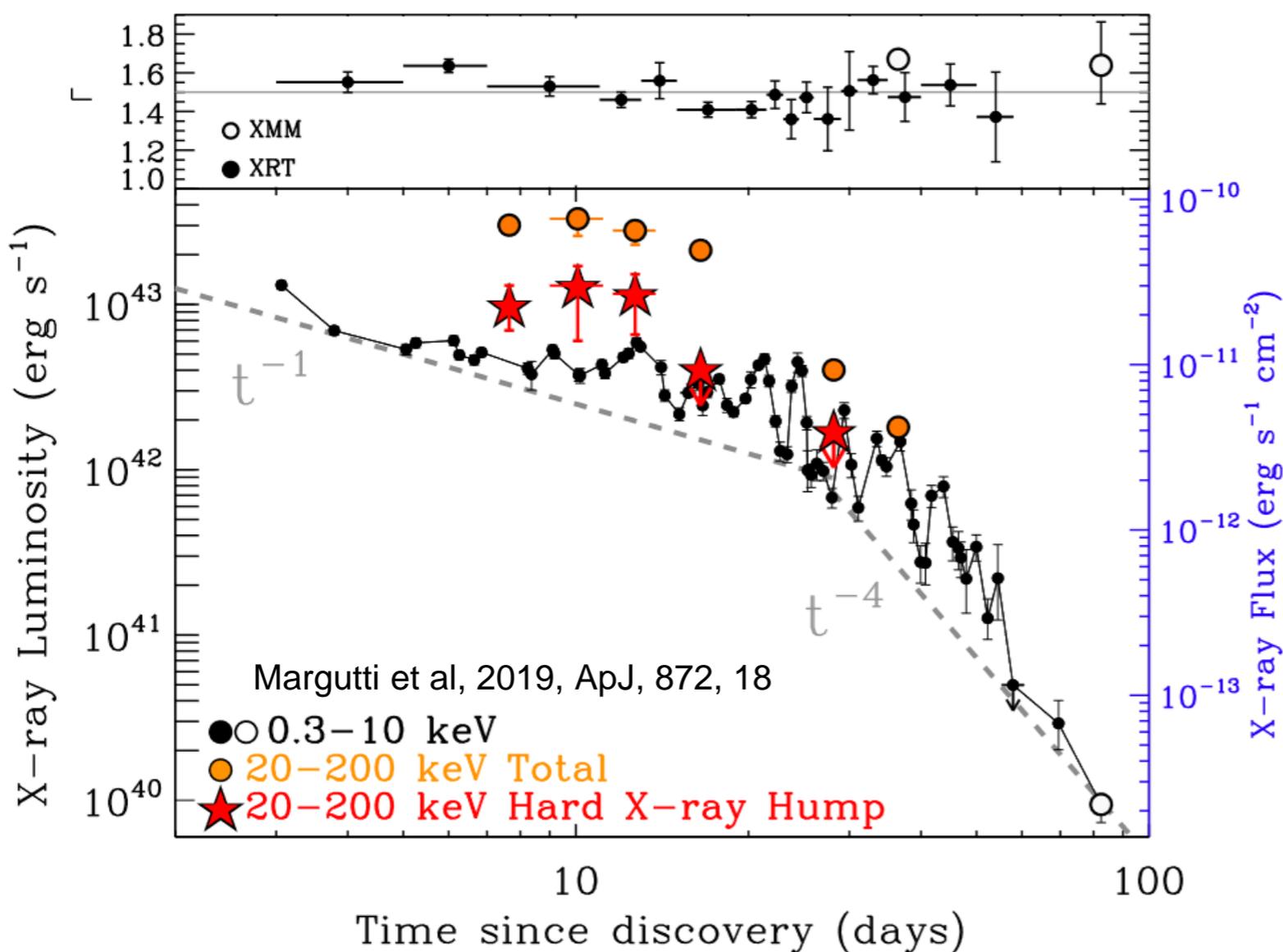
Yao et al, 2022, ApJ, 934, 104



Matthews et al. arxiv: 2306.01114

# 快变蓝色暂现源X射线观测现状

- 目前一共发现5例FBOT存在X射线辐射，最具代表性的是AT 2018cow 代表性的



# EP对FBOT的X-RAY的探测率估计

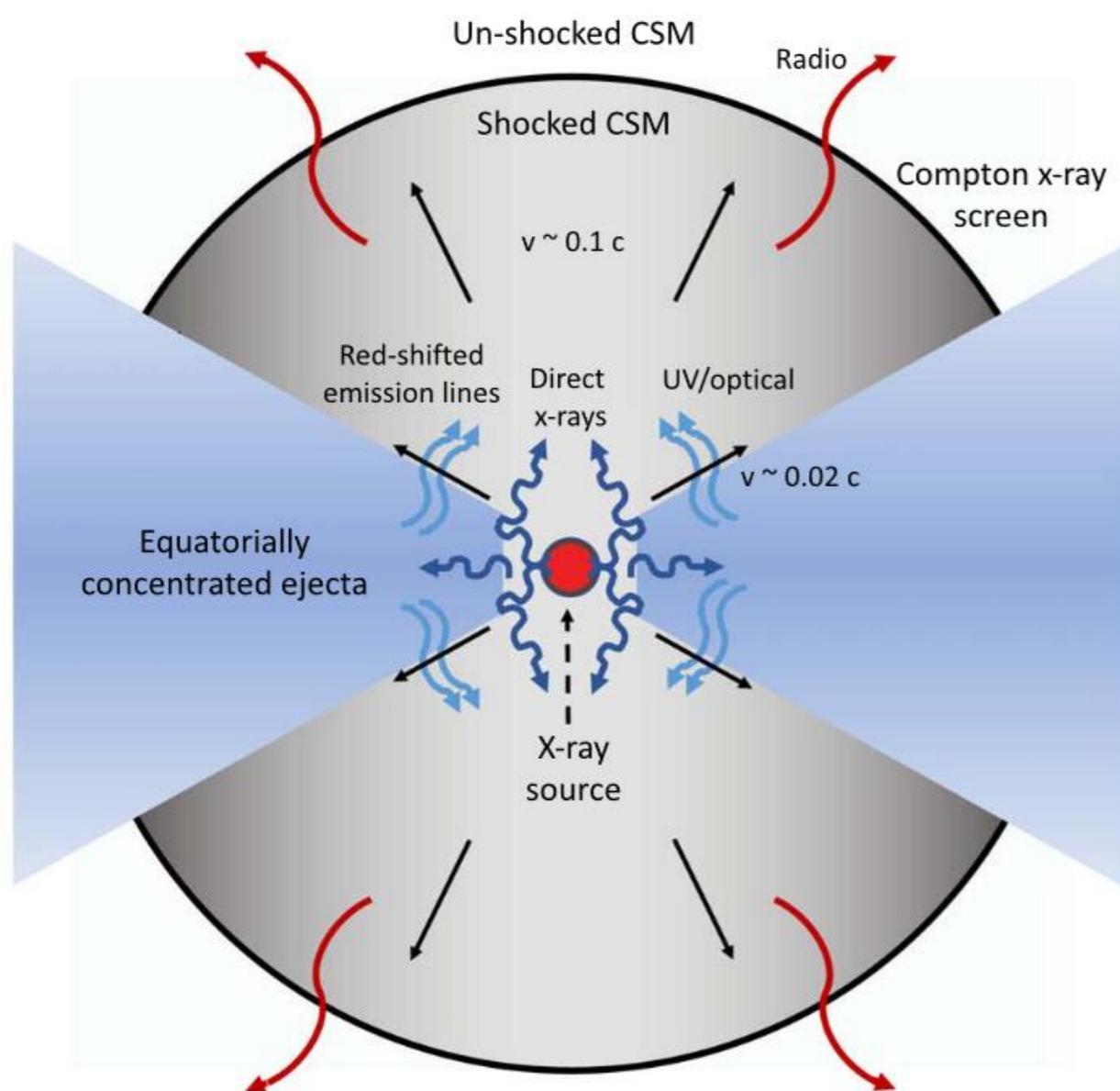
$$\dot{N}_{\text{det}} = \frac{\Omega}{3} D_{\text{max}}^3 \mathcal{R} p_s$$

AT 2018cow-like的事件率  $\mathcal{R} = 2.1 - 420 \text{ Gpc}^{-3} \text{ yr}^{-1}$

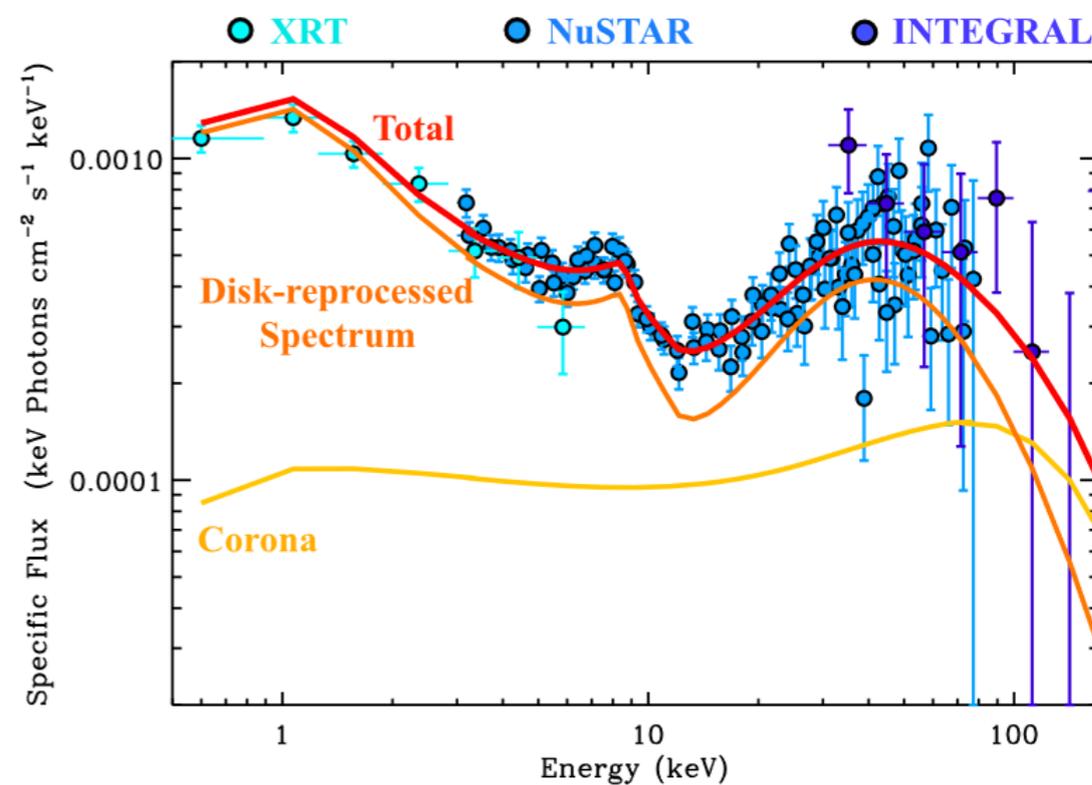
Survey	$f_{-13}$	$D_{\text{max}}$	$\dot{N}_{\text{det}}$ if $\mathcal{R} = 2.1$	$\dot{N}_{\text{det}}$ if $\mathcal{R} = 70$	$\dot{N}_{\text{det}}$ if $\mathcal{R} = 420$
SRG/eROSITA	1.8	373	0.080	2.7	16
		964	1.7	57	340
Einstein Probe	20	112	0.012	0.41	2.5
		289	0.21	7.1	43

**Note.**  $D_{\text{max}}$  is given in Mpc. The values in the first and third rows assume an X-ray light-curve shape similar to AT2018cow. The values in the second and fourth rows assume a conservative light-curve shape similar to AT2020mrf, and therefore the derived  $\dot{N}_{\text{det}}$  should be taken as lower limits.

# AT 2018COW 的X射线辐射特征的理论解释



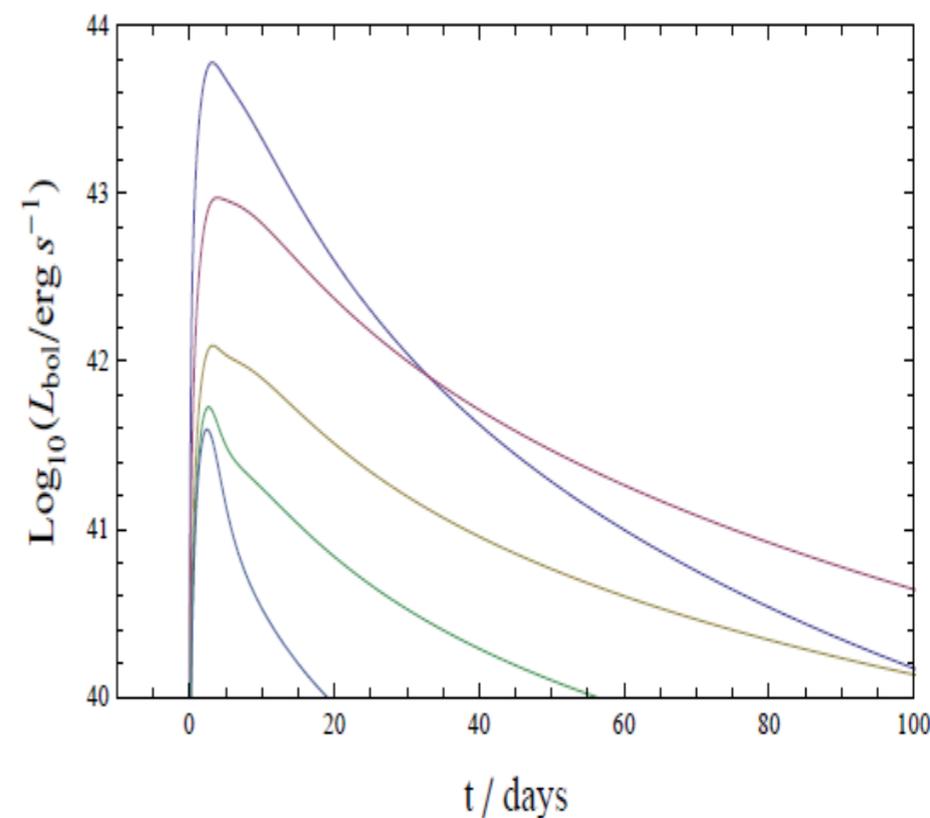
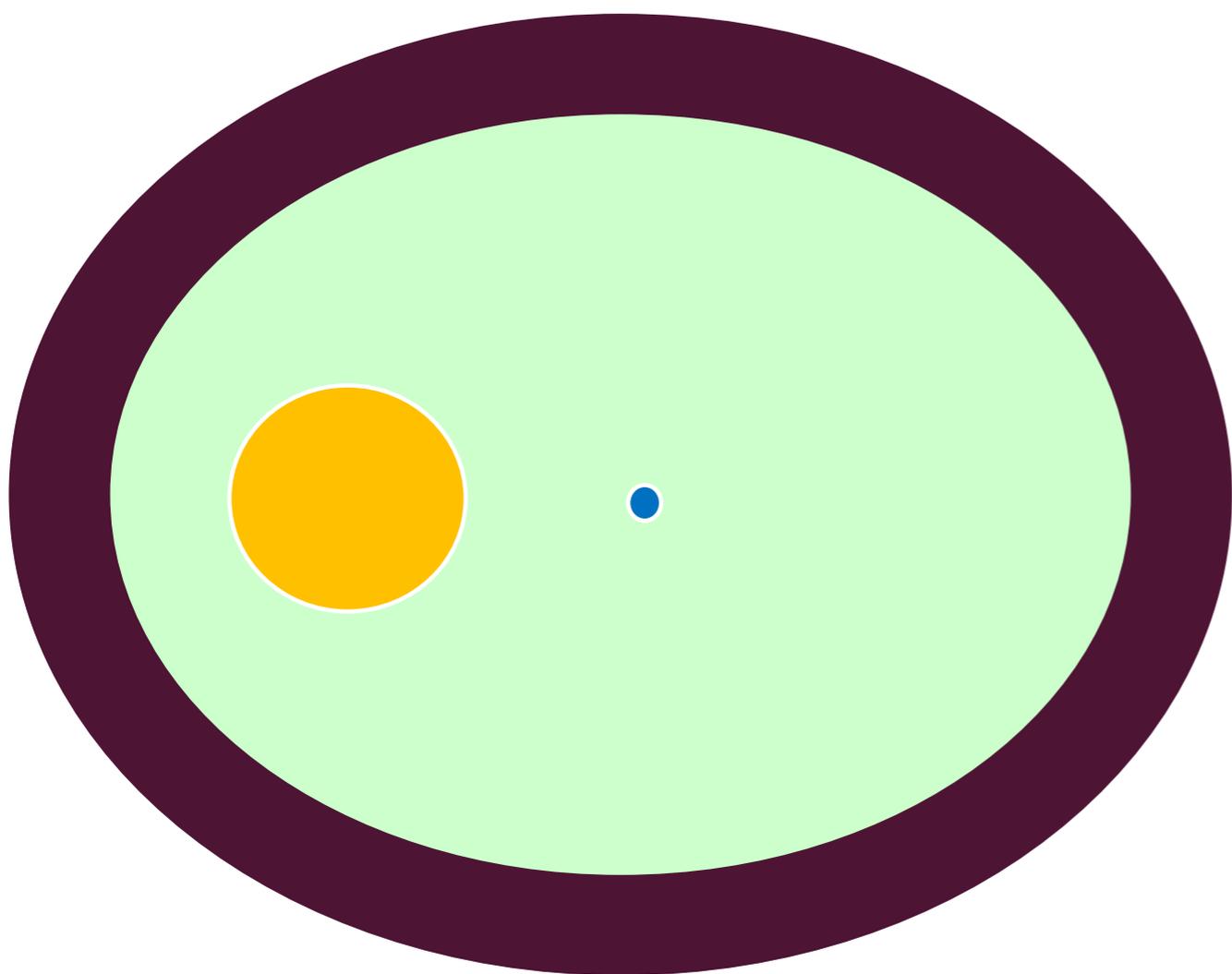
- 各向异性分布的抛射物与致密星周物质相互作用
- 早期宽波段X射线能谱可由康普顿化盘反射模型解释



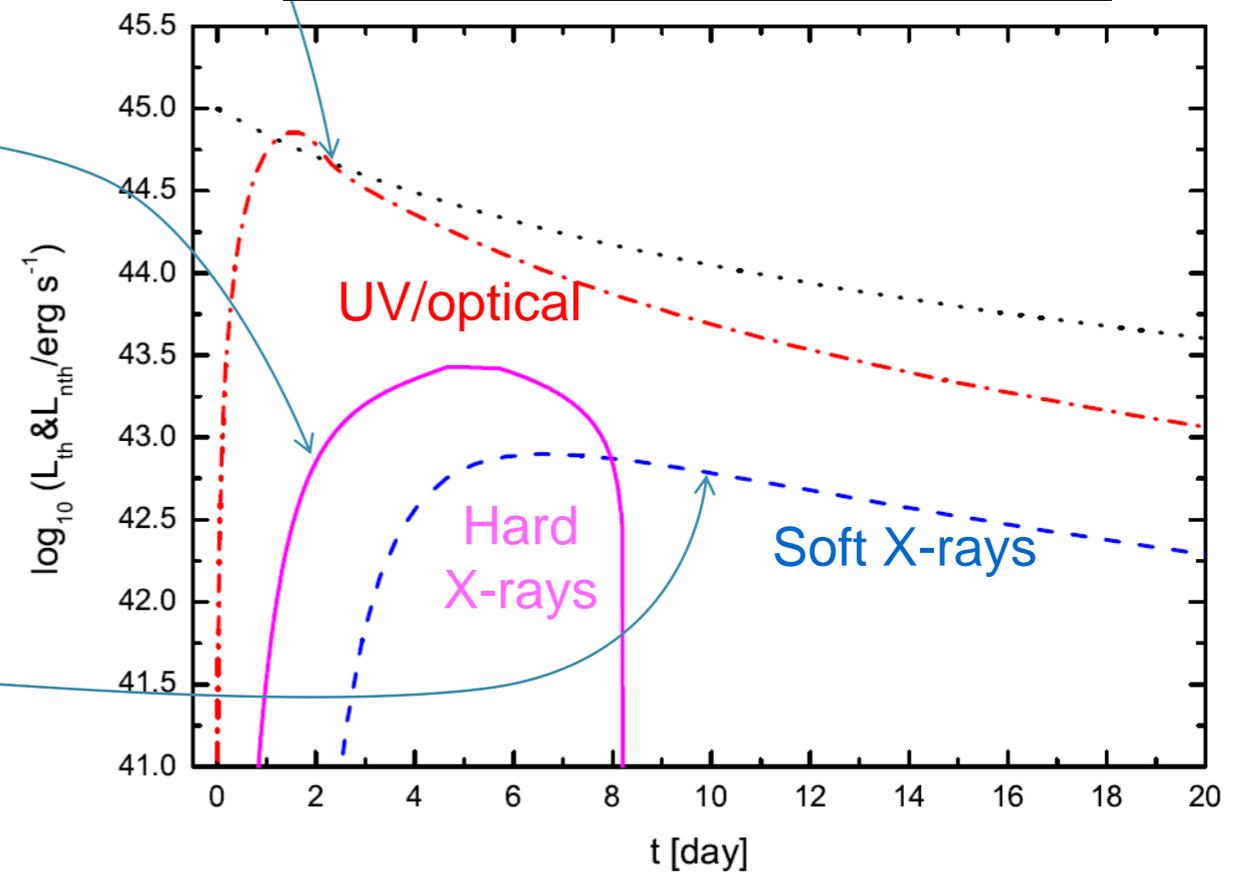
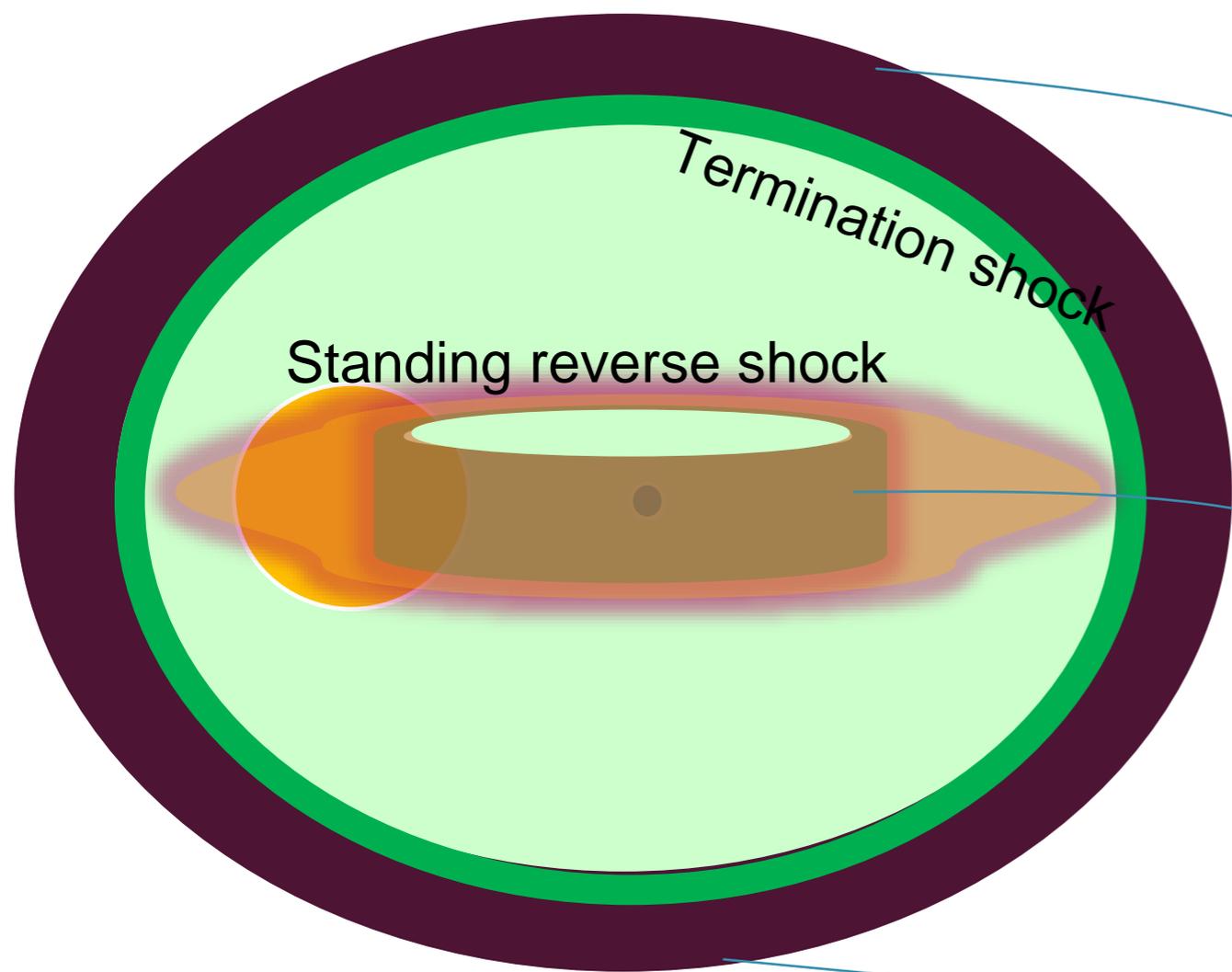


# 白矮星相关爆发过程的X射线辐射

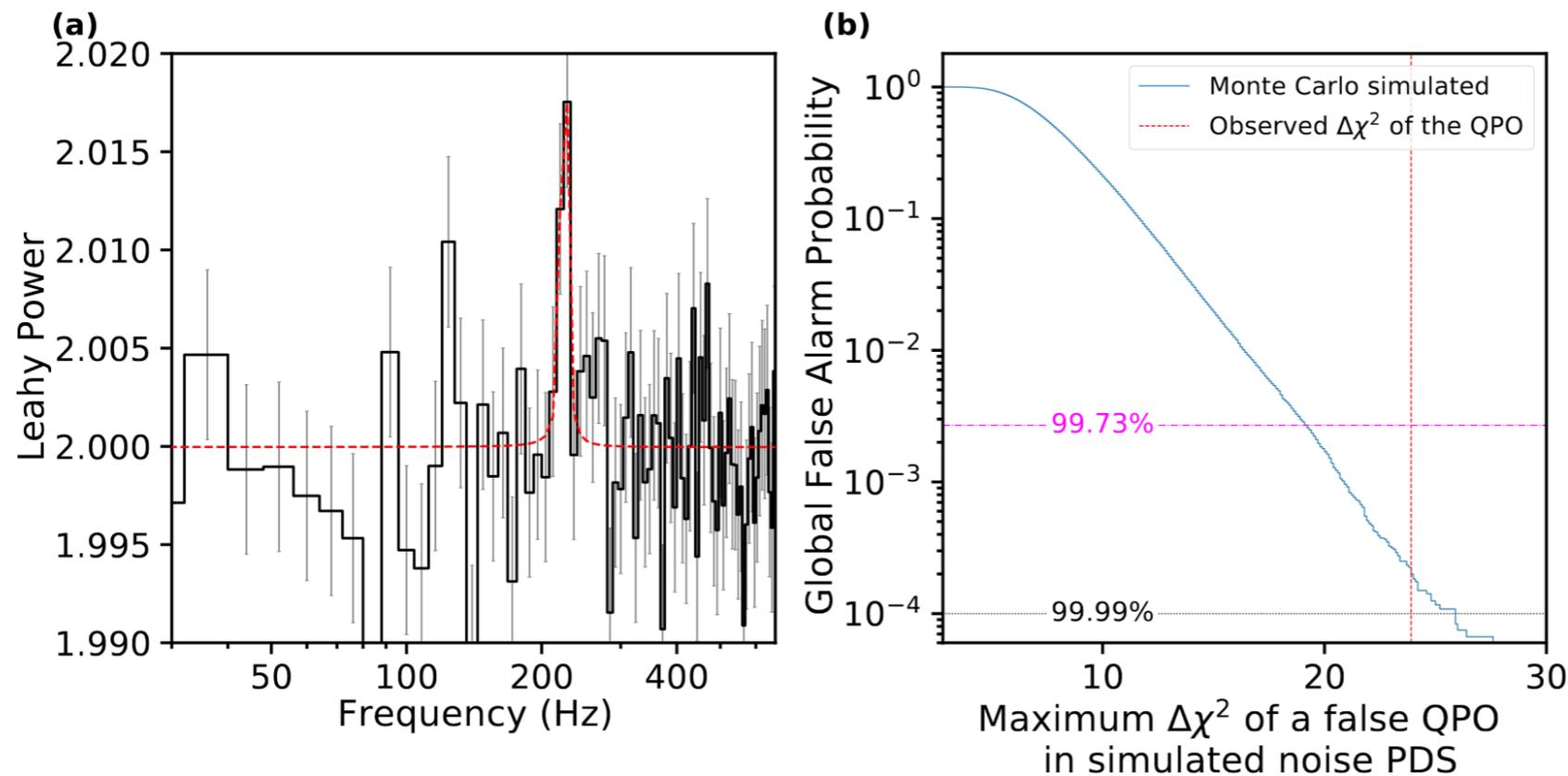
# AT 2018COW 的X射线辐射特征的理论解释



# AT 2018COW 的X射线辐射特征的理论解释



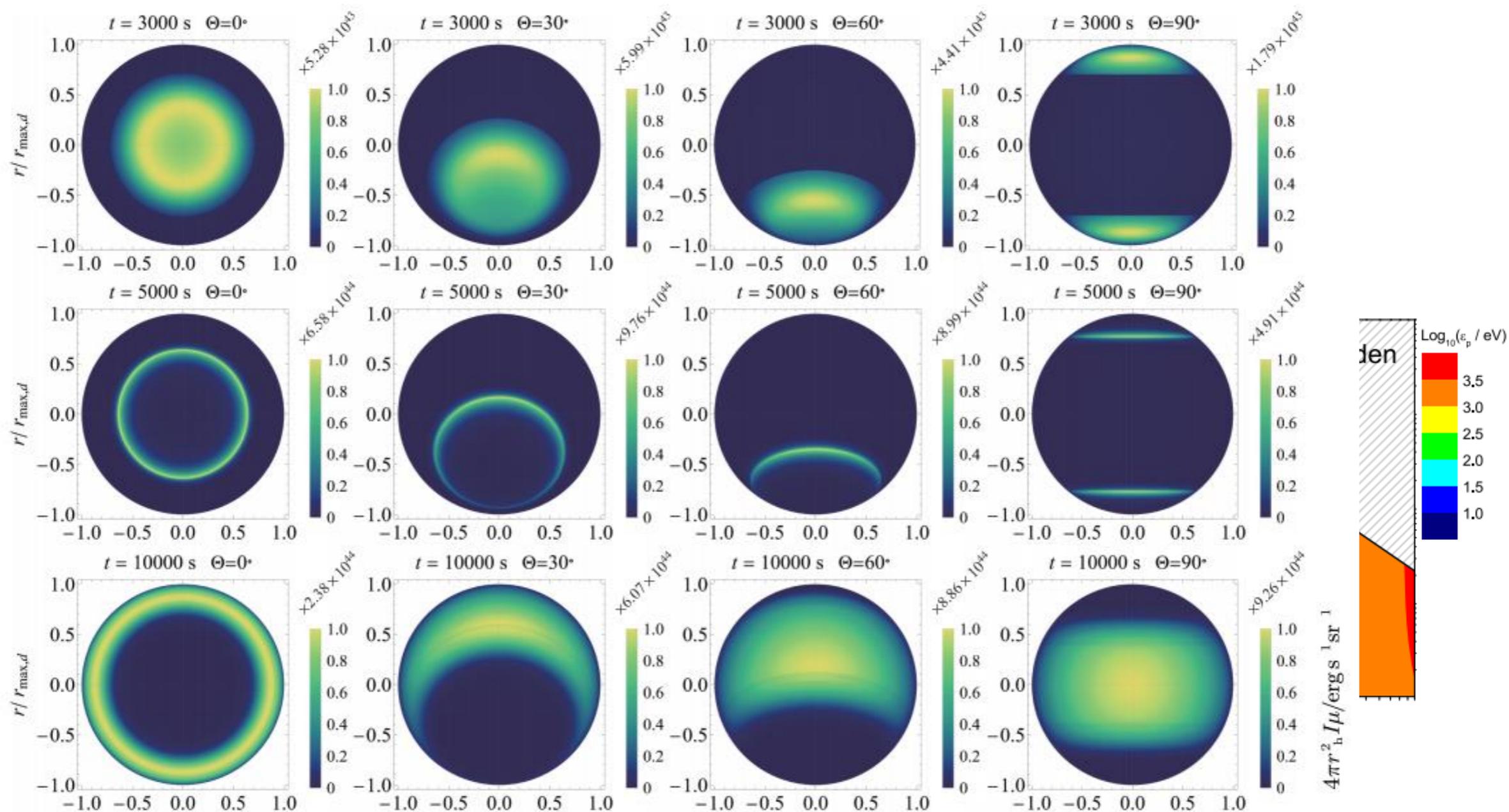
# AT 2018COW 的X射线辐射中的 QPO信号



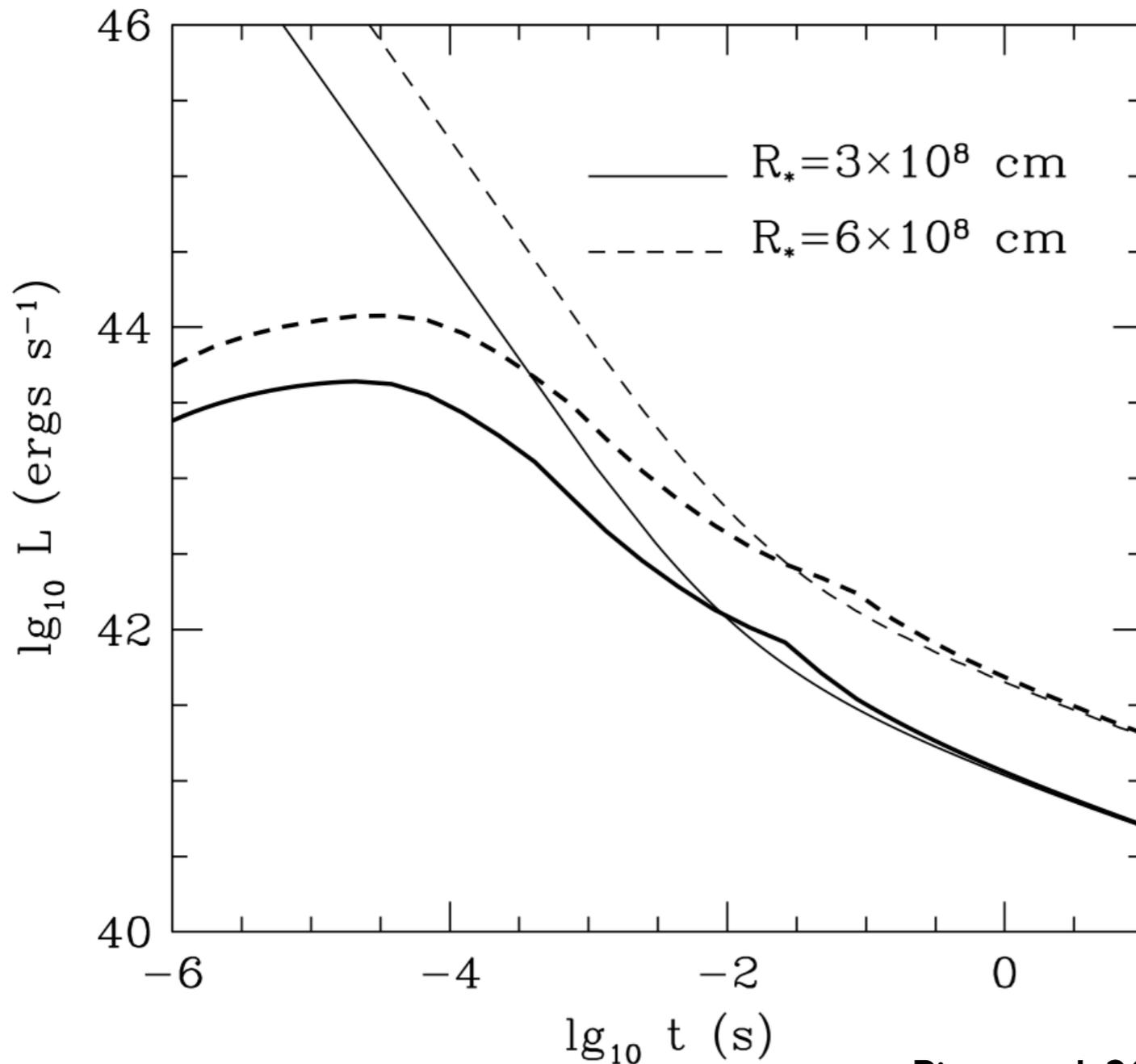
- 224Hz的QPO说明其中  
心存在一个质量小于  
850太阳质量的致密  
天体

Figure 1: (a) Average X-ray PDS of AT2018cow showing evidence for a quasi-periodicity near 224 Hz. This PDS was computed by averaging 105 256-second soft X-ray (0.25-2.5 keV) light curves sampled at 1/2048 s. The resulting PDS was further re-binned by a factor of 2048

# 脉冲星风驱动的激波突破

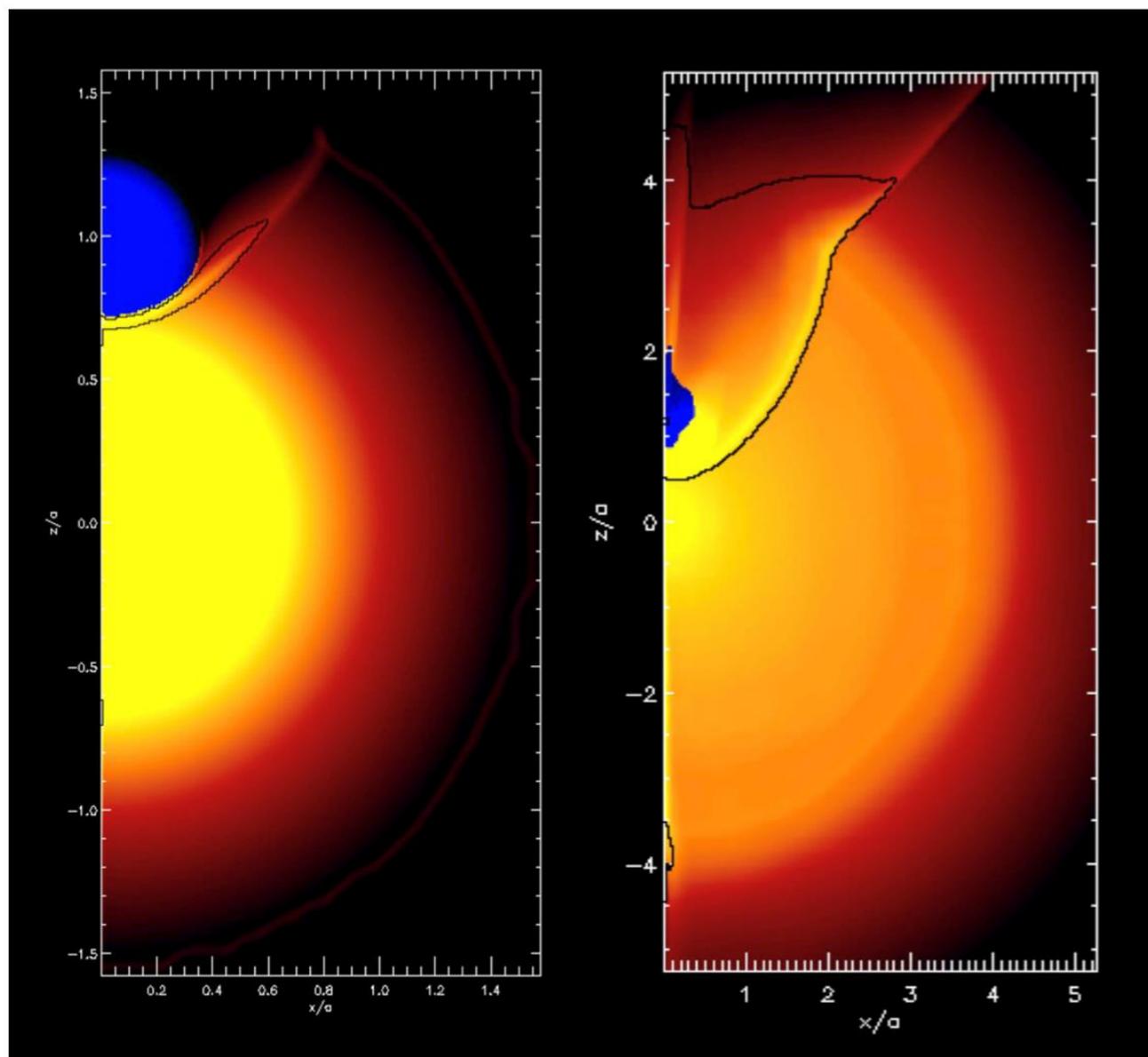


# IA型超新星的激波突破X射线辐射



持续时间 $\sim 0.1\text{s}$ , EP的可探测距离约1Mpc, 5Mpc以内爆发数目不足0.01/Year。

# IA型超新星的相互作用X射线辐射



持续时间  $\sim 1.5$  hr for RG

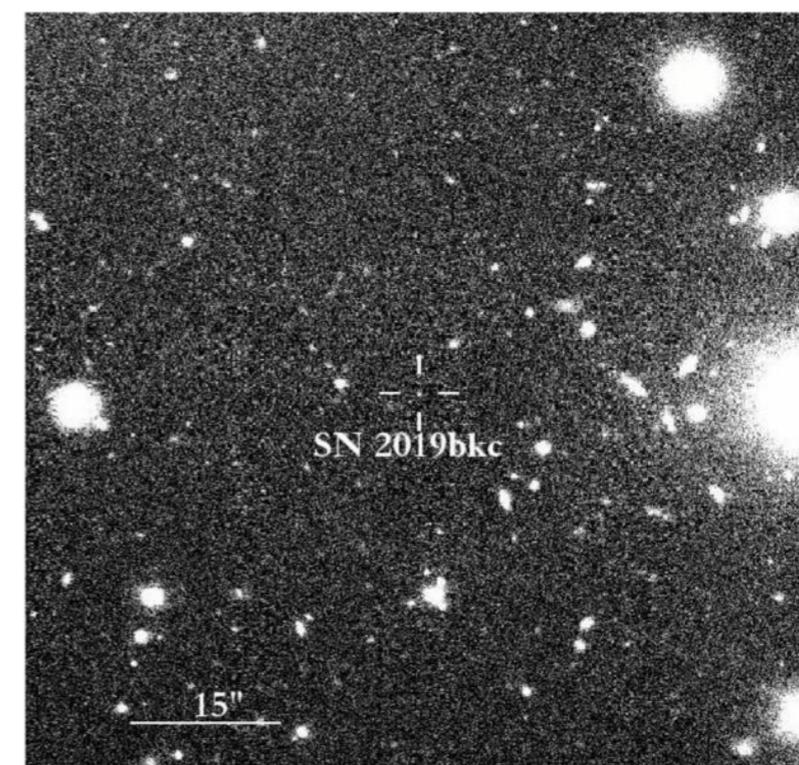
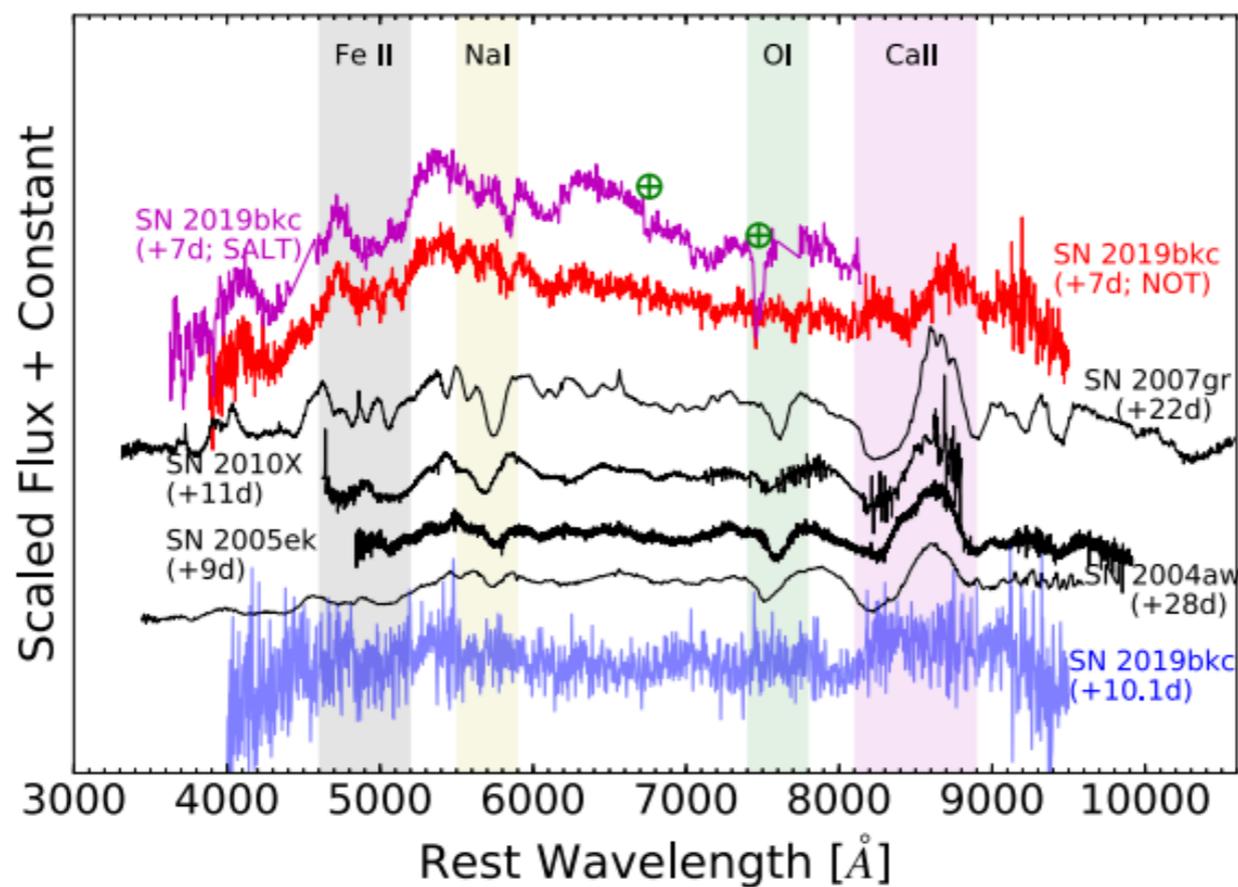
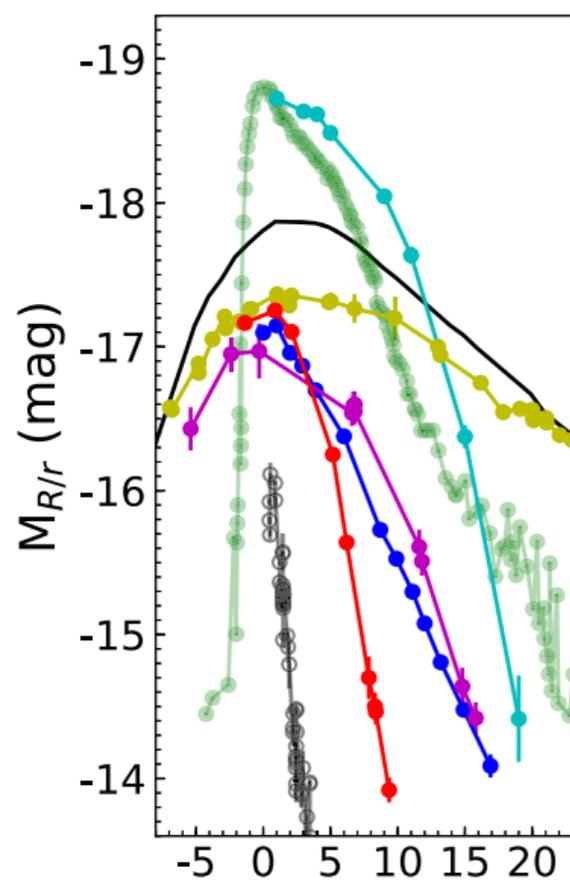
$\sim 5$  min for MS

EP的可探测距离约90

Mpc, 100 Mpc以内SNeIa

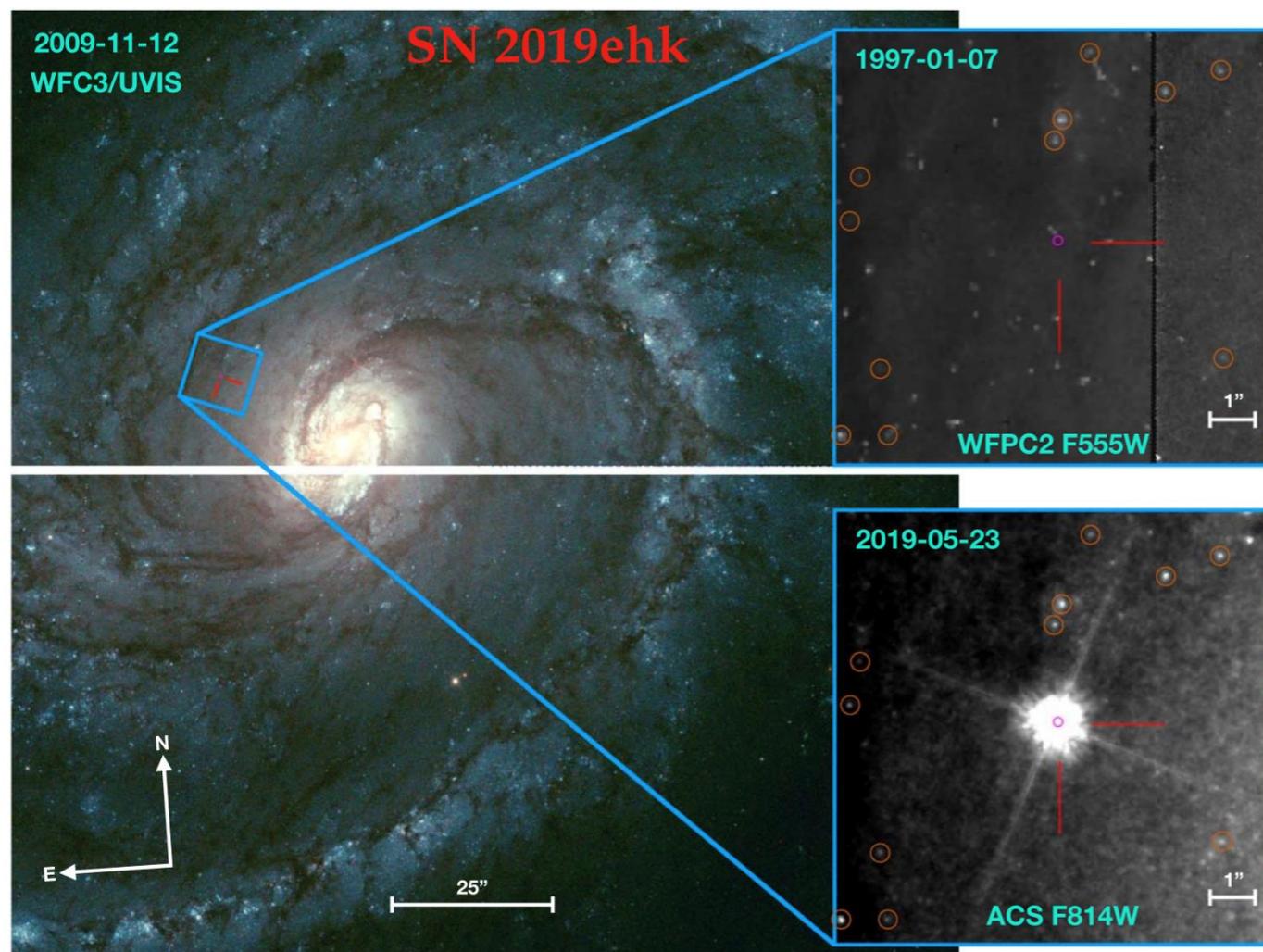
的爆发数目约100/Year。

# 富钙超新星/暂现源



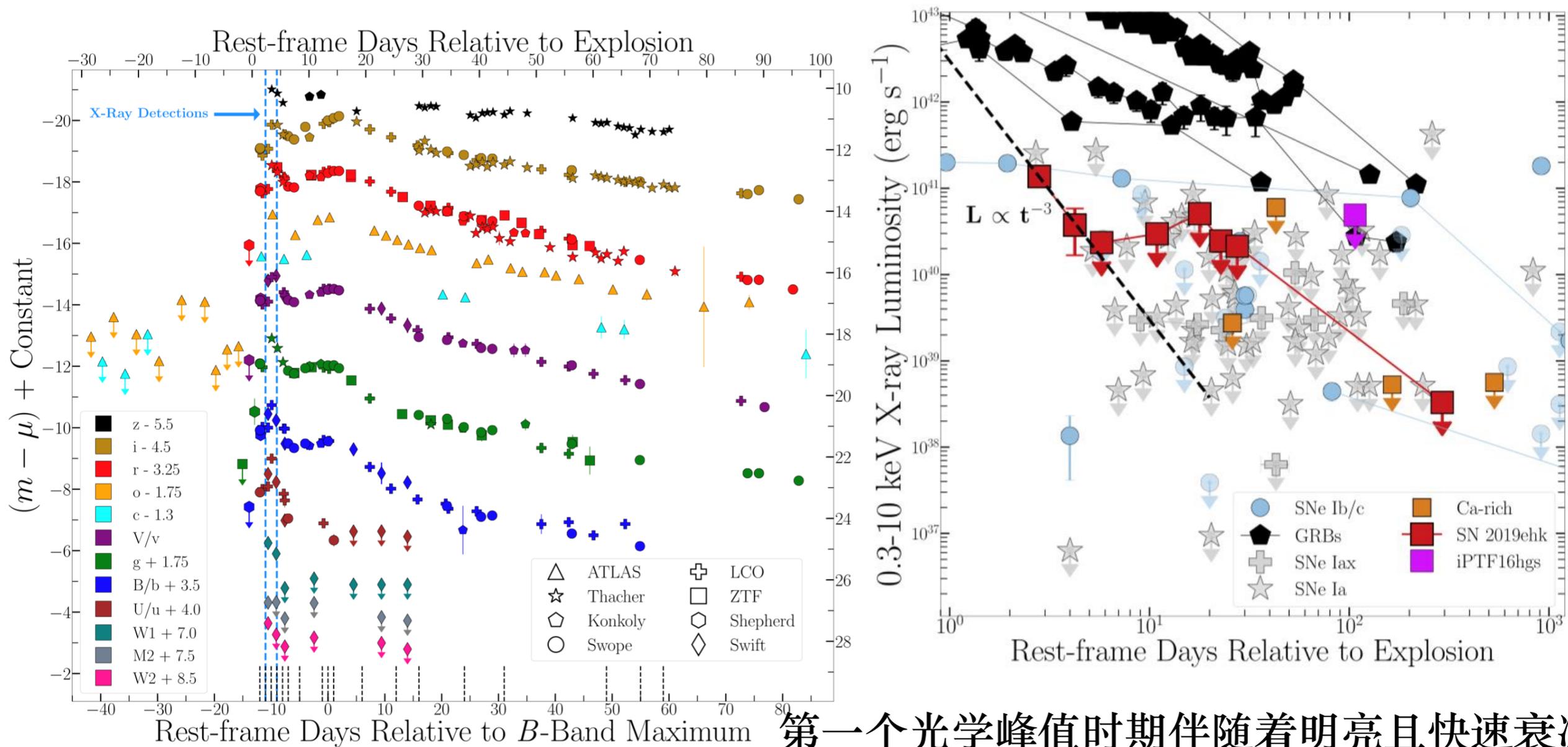
Chen et al. 2020, ApJL, 889, L6

# 富钙超新星/暂现源



SN 2019ehk, 一颗爆发于漩  
涡星系的富钙超新星/暂现  
源。爆发前的HST图像数据  
显示其前身星系统低于  
10Msun, 意味着可能起源于  
低质量的HeCO WD + CO  
WD双星系统。

# 富钙超新星/暂现源的X射线辐射



第一个光学峰值时期伴随着明亮且快速衰减的 X-ray 辐射 ( $L_x \sim 10^{41}$  erg/s,  $L_x \propto t^{-3}$ )。

# 总结：类超新星领域的EP科学目标

- 通过观测超新星激波突破限制前身星属性
- 通过观测超新星相互作用的X射线辐射限制暴周环境
- 检验超亮超新星和快变蓝色暂现源的起源
- 探索白矮星双星系统的相互作用和爆发过程，确定Ia型超新星等爆发现象的物理起源