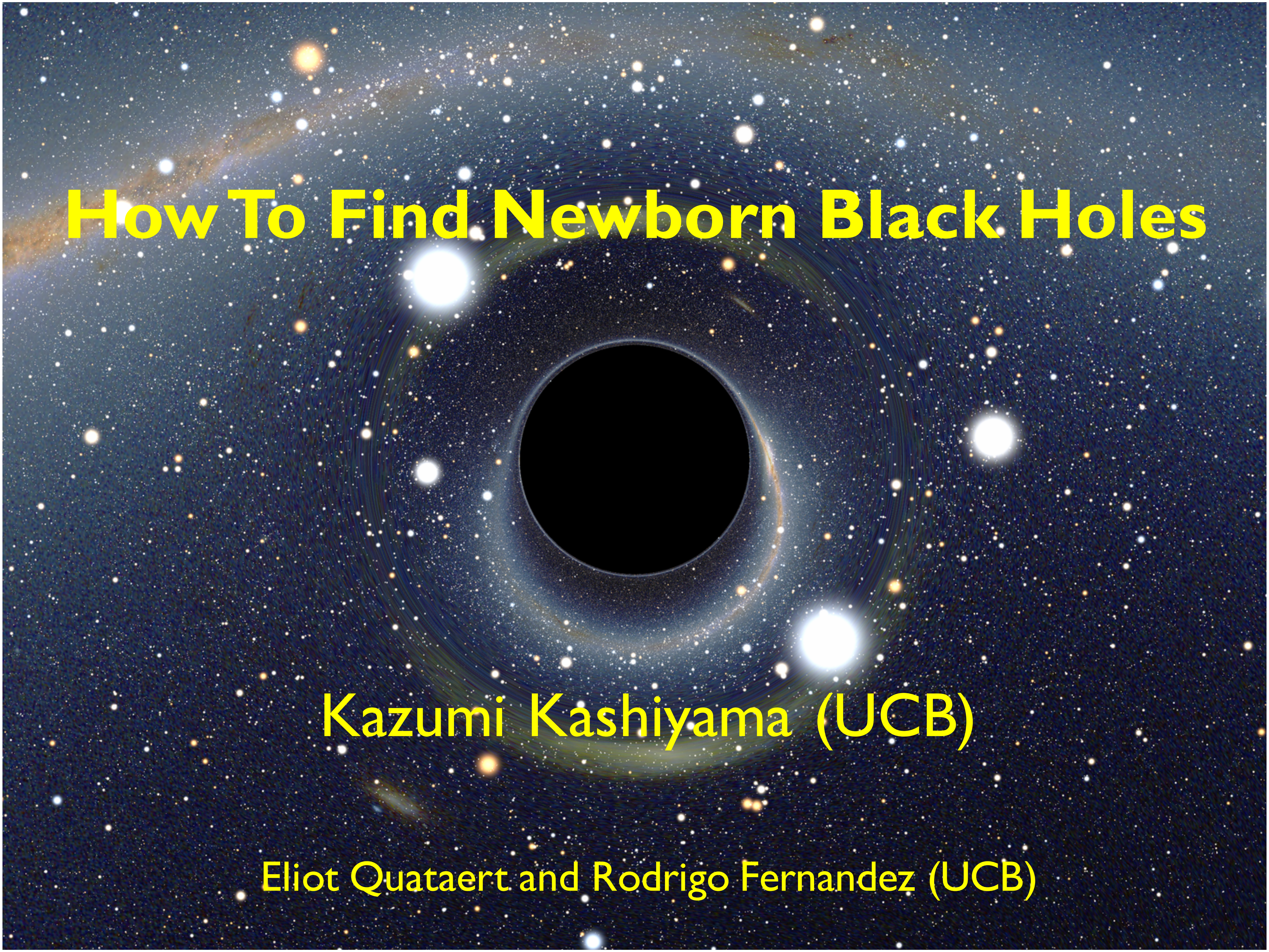
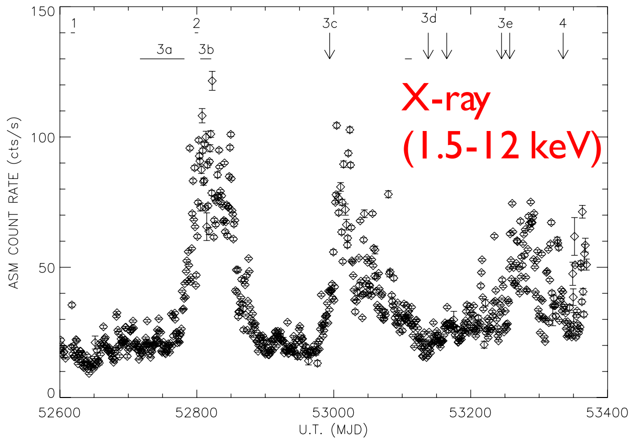


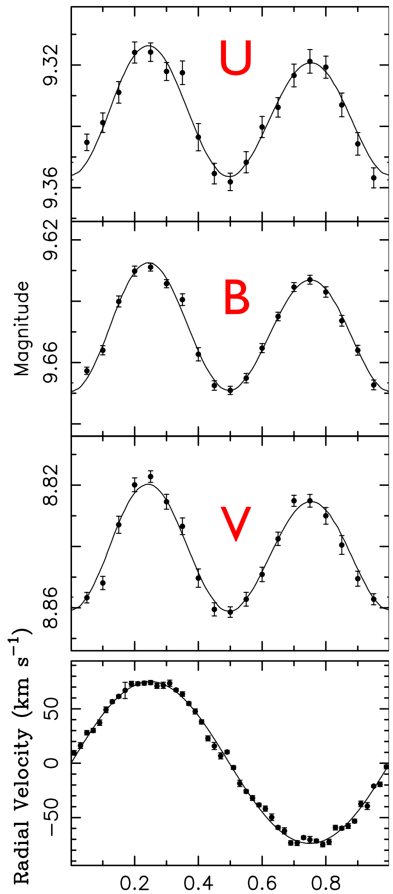
How To Find Newborn Black Holes

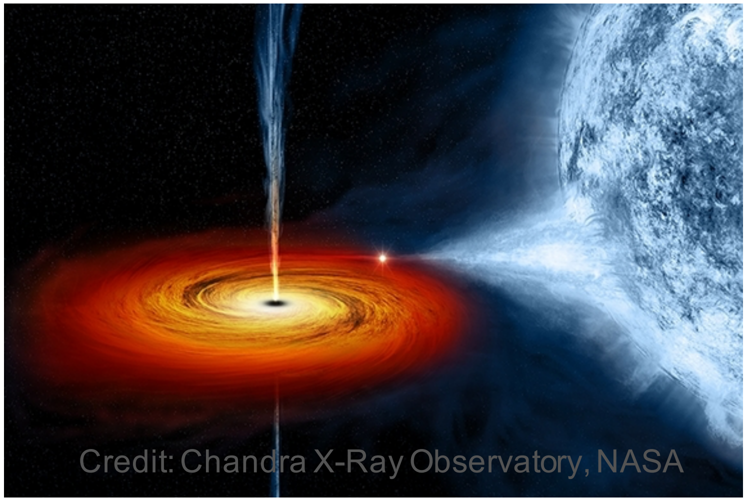
Kazumi Kashiyama (UCB)

Eliot Quataert and Rodrigo Fernandez (UCB)

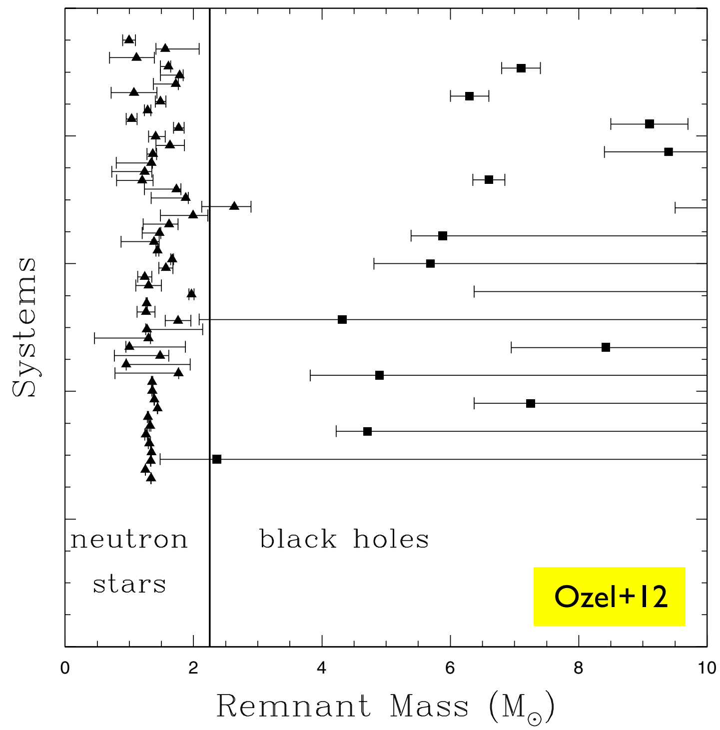
Stellar-Mass Black Holes



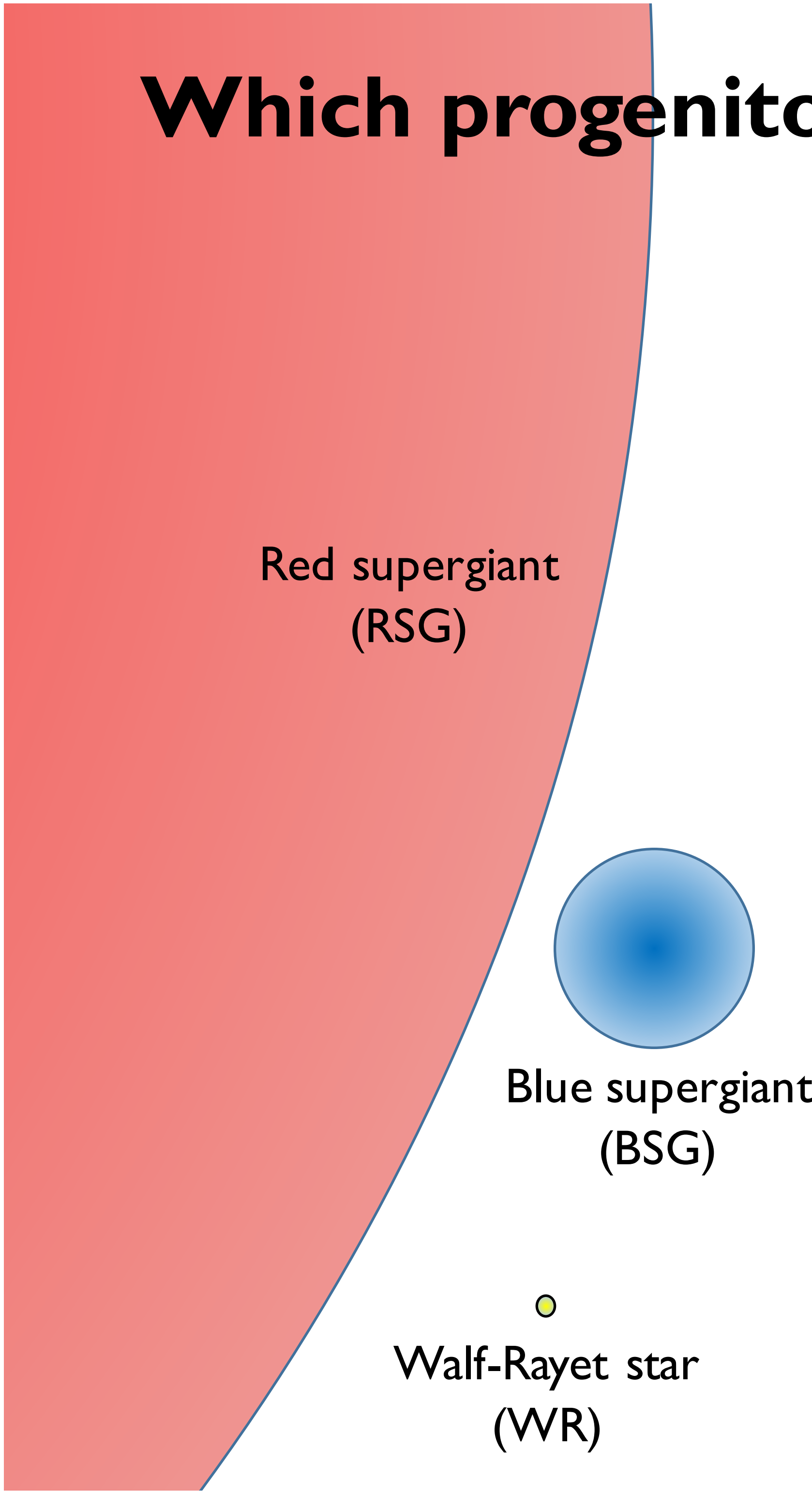




$$f(m_1) \equiv \frac{m_1 \sin^3 i}{(1+q)^2} = \frac{P_{orb} V_2^2}{2\pi G}$$



Which progenitors produce BHs not NSs?

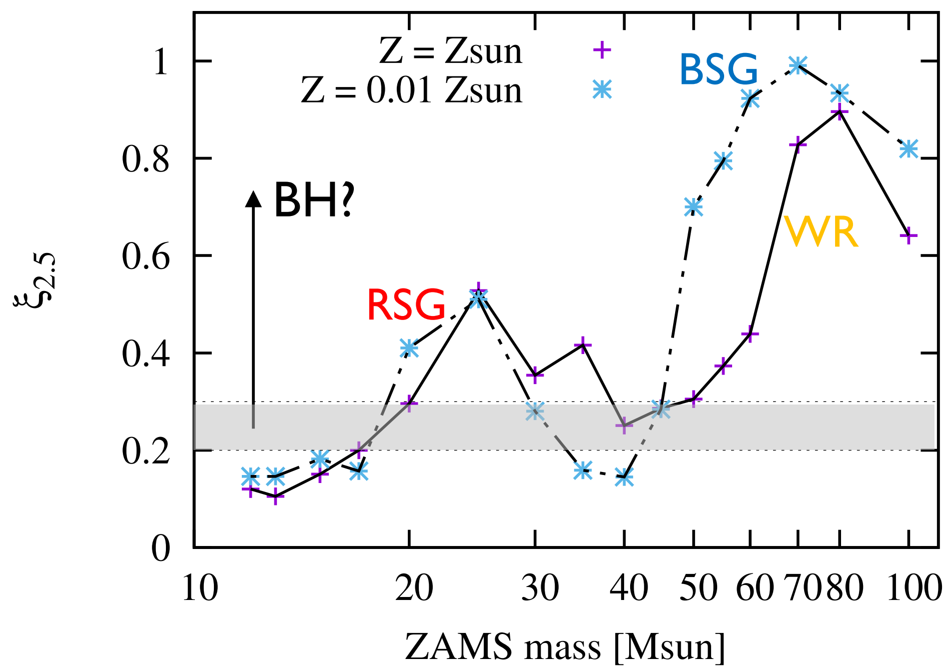


Supernova shock is stalled or not?
How much material fallback on protoNS?

The key will be inner density structure within

$$r \sim 1000 \text{ km}, Mr \sim 2\text{-}3\ M_{\odot}$$

O'Connor & Ott 2011; Ugliano et al. 2012;
Horiuchi et al. 2014; Pejcha & Thompson 2015



All types of massive star can form BHs.

What is observational signature?

Stellar type (RSG, BSG, or WR)

*

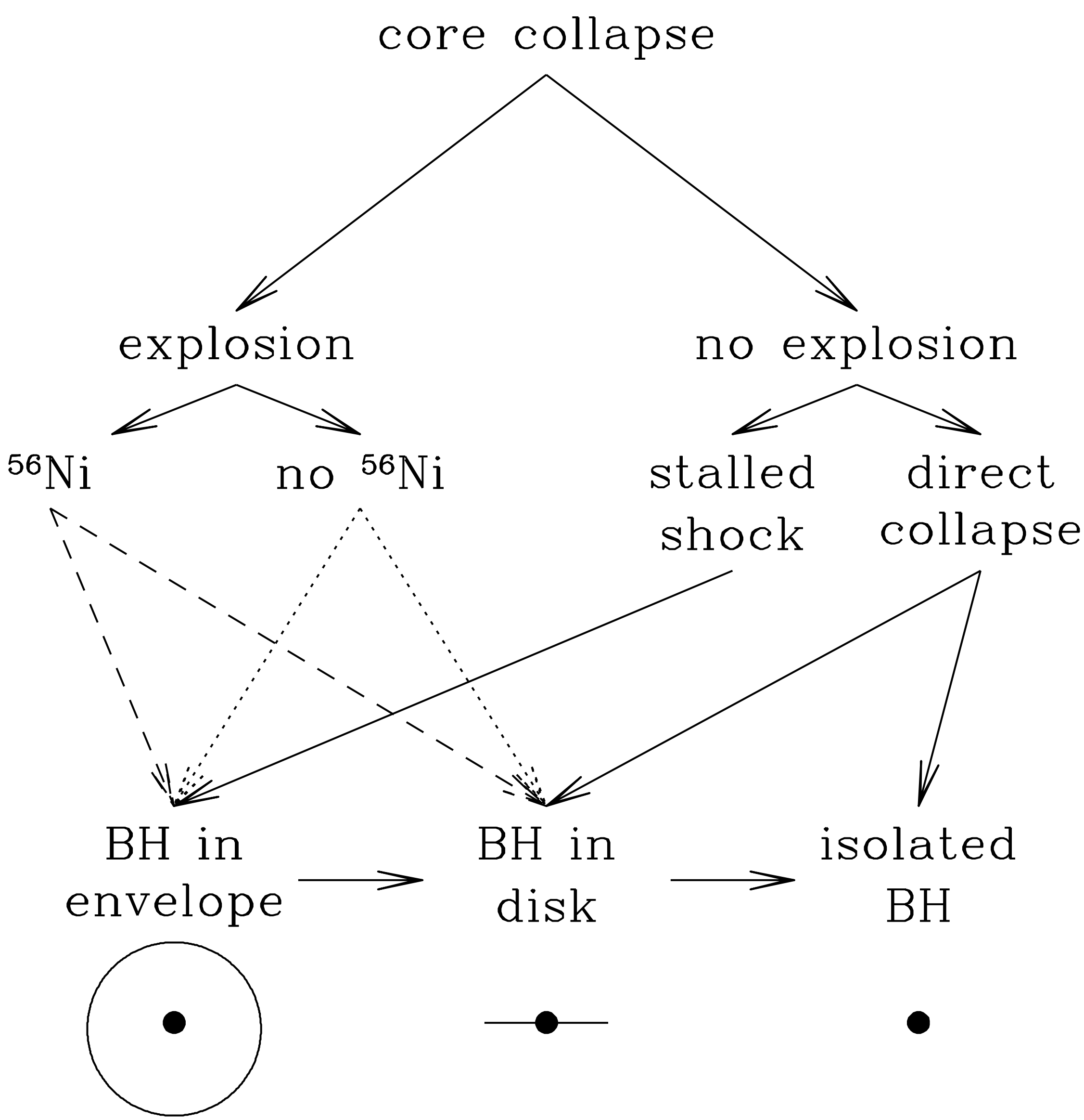
Rotation profile (disk or not)

*

Magnetic field (jet or not)

Possible Outcomes in a BH Formation

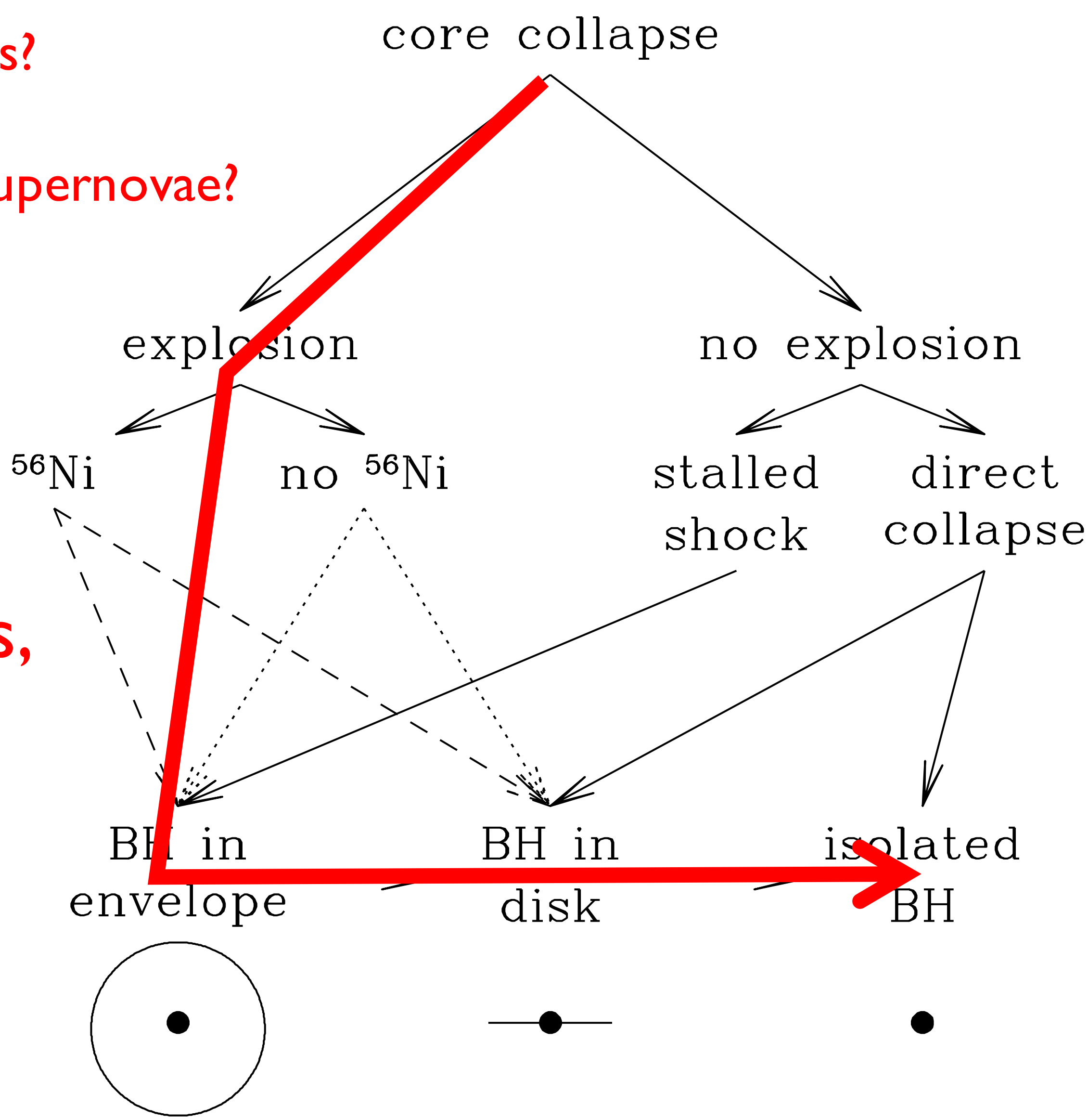
Kochanek+08



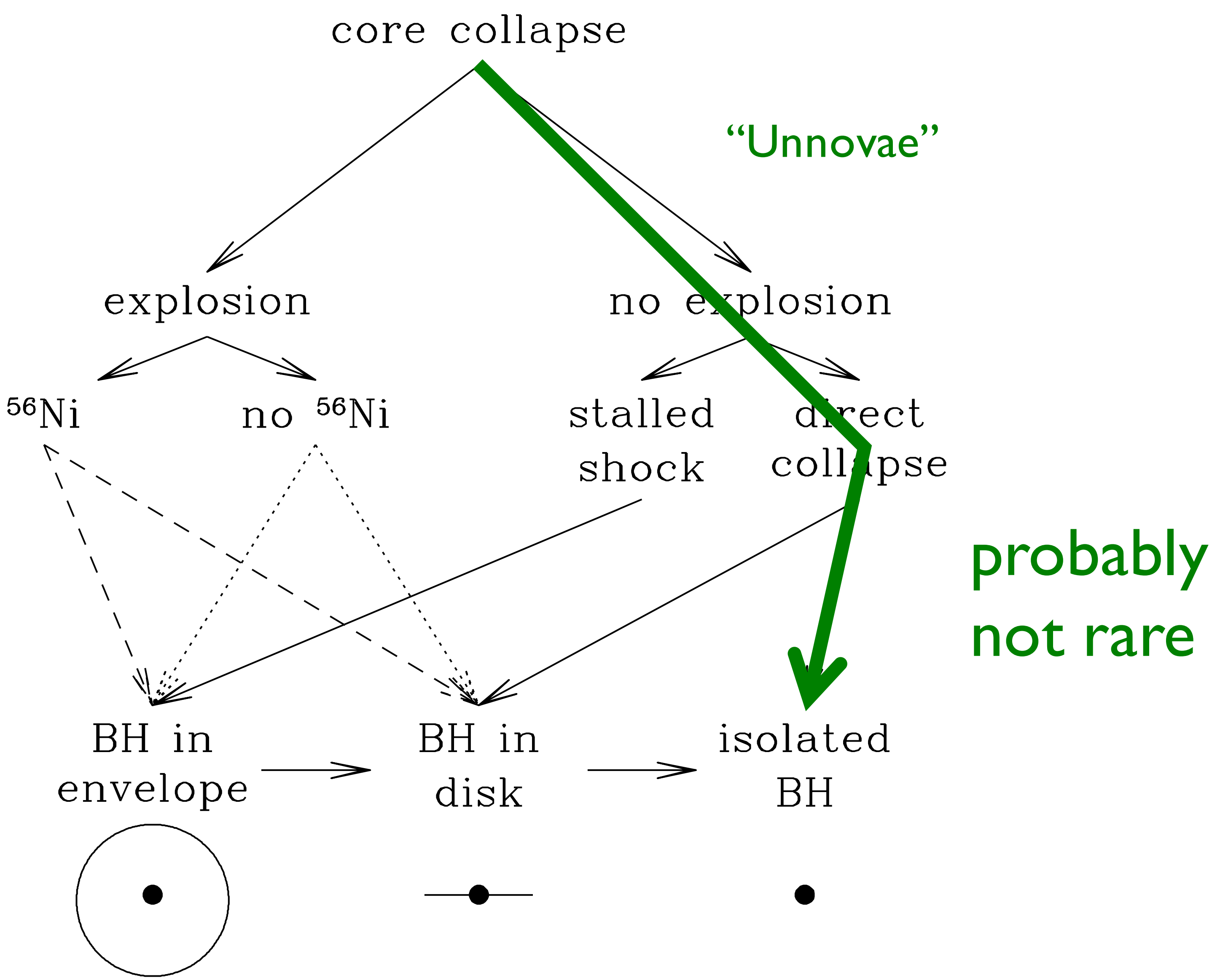
Possible Outcomes in a BH Formation

Gamma-ray bursts?
Hypernovae?
Super-luminous supernovae?

luminous,
but rare



Possible Outcomes in a BH Formation

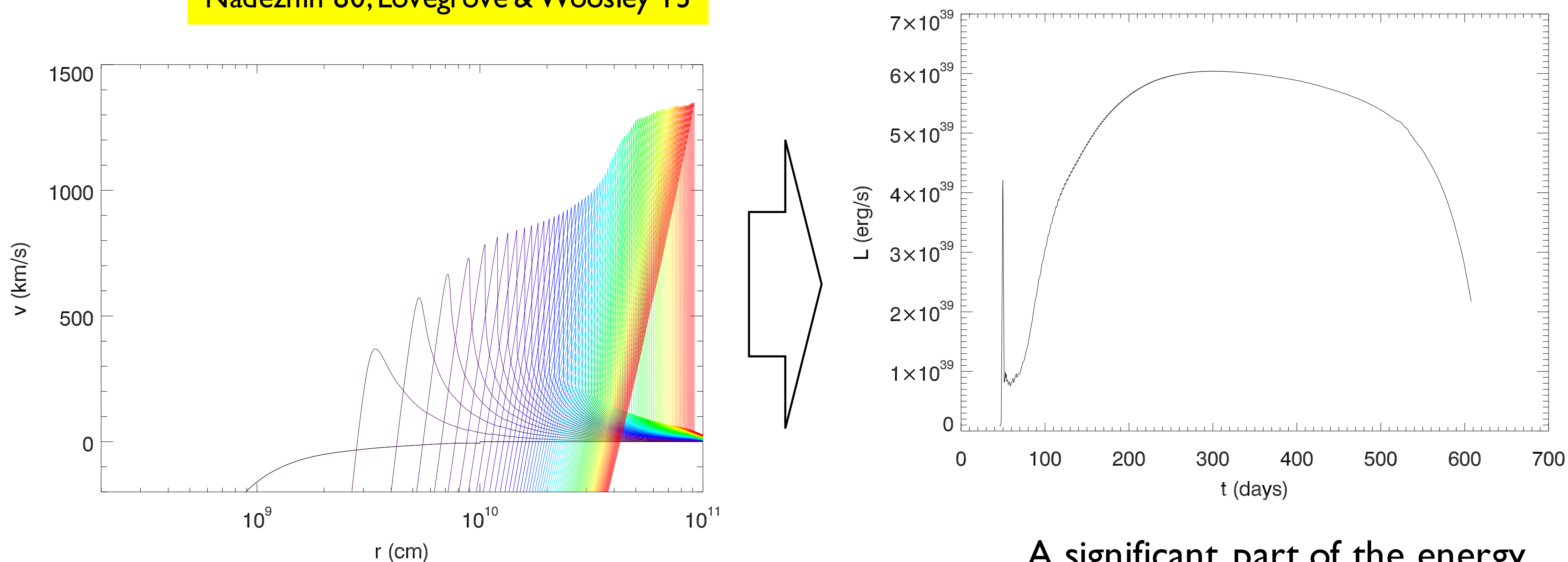


Very low energy supernovae from neutrino mass loss

Even if the SN shock is stalled,
a weak shock can be driven by
neutrino mass loss of the PNS.

Nadezhin 80, Lovegrove & Woosley 13

"Luminous red novae"



A significant part of the energy comes from H recombination.

$$E_{\rm sh} \sim 10^{47\text{-}48}\ \mathrm{erg}$$

$\gtrsim$ Bind. E of H envelope of RSG

$$T \sim 3000\ \mathrm{K}$$

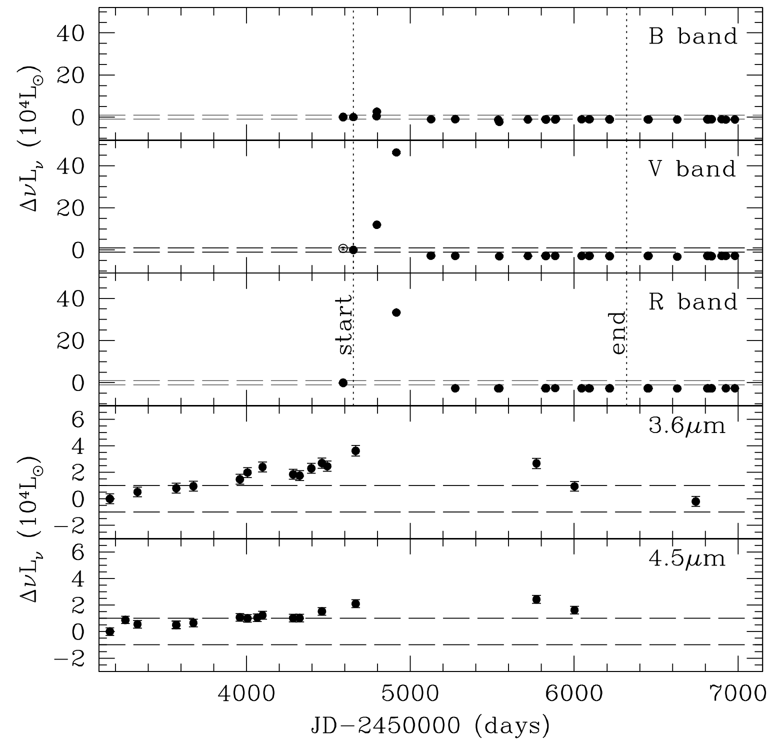
Searching for vanishing supergiants

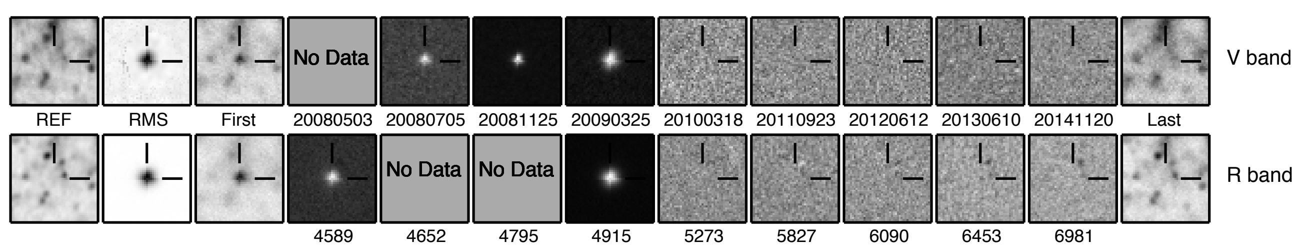
- Monitoring ~10^6 RSGs in ~25 Gal. within ~10 Mpc with ~0.5 yr cadence for ~5 yrs using the Large Binocular Telescope
- Examine sources with

$$\Delta(\nu L_\nu) \geq 10^4 L_\odot$$

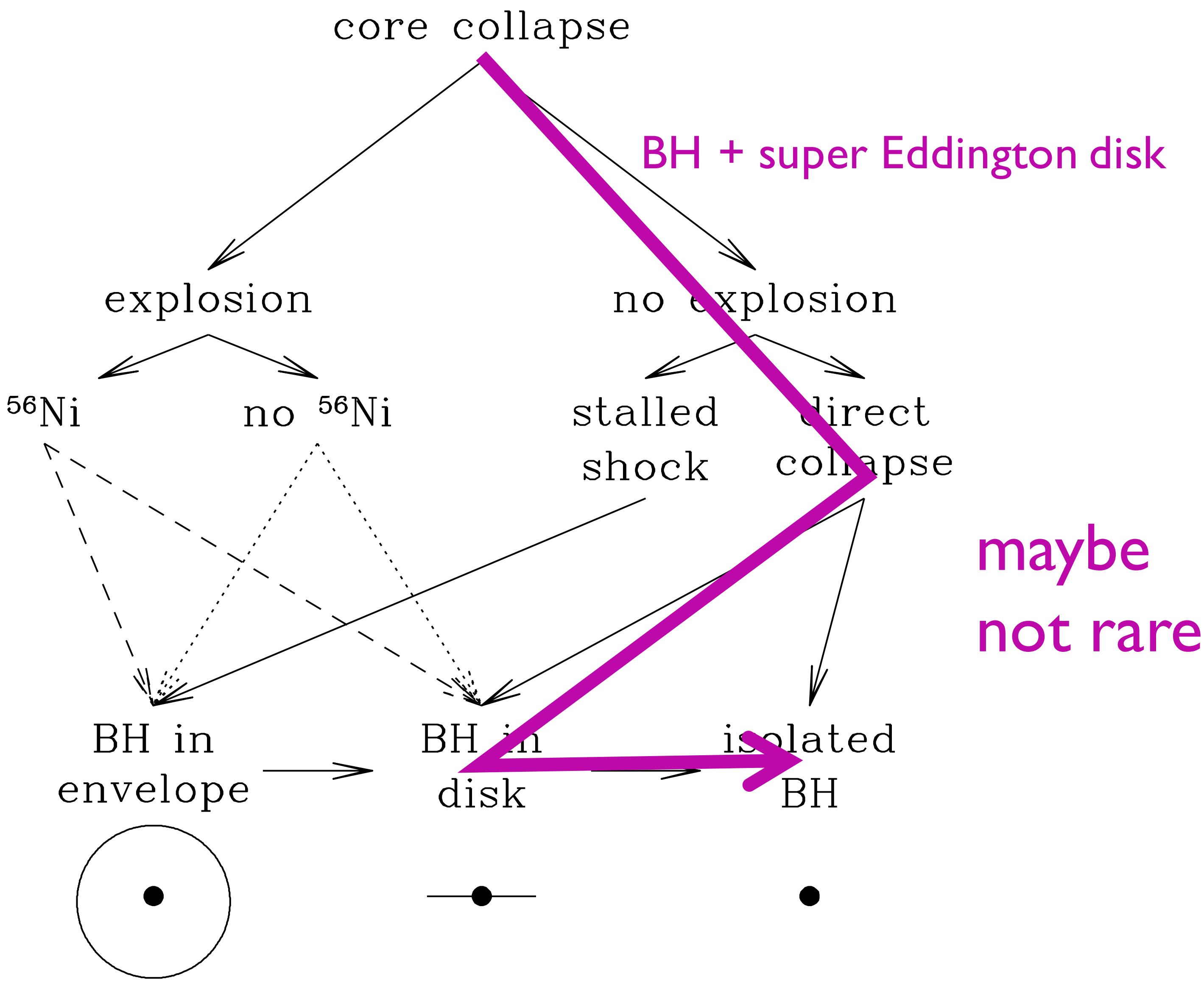
- 3 core collapse supernovae
- 1 candidate of vanishing RSG
- Continuous obs. will give meaningful constraints on failed SN rate.

Kochanek+08, Gerke+15





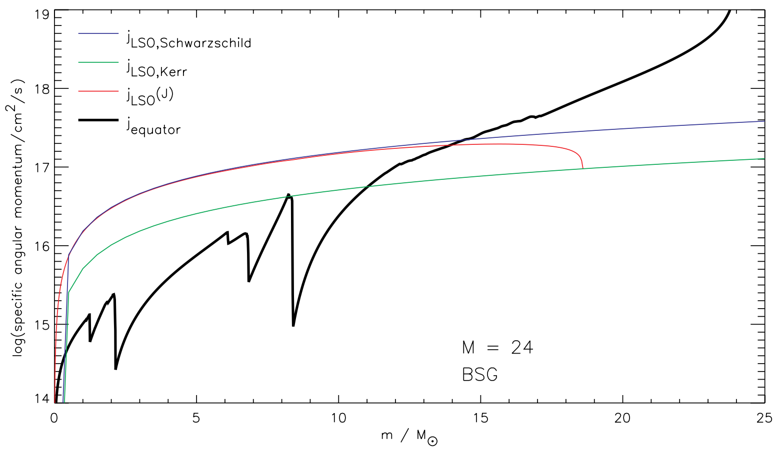
Possible Outcomes in a BH Formation

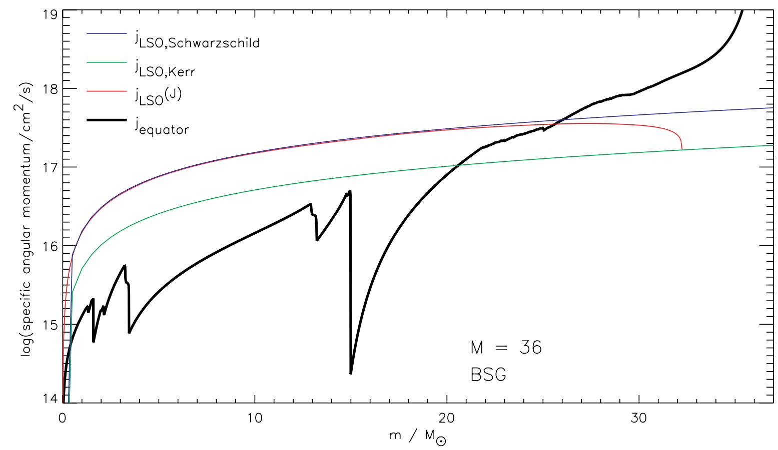


Fall back disk may be ubiquitous

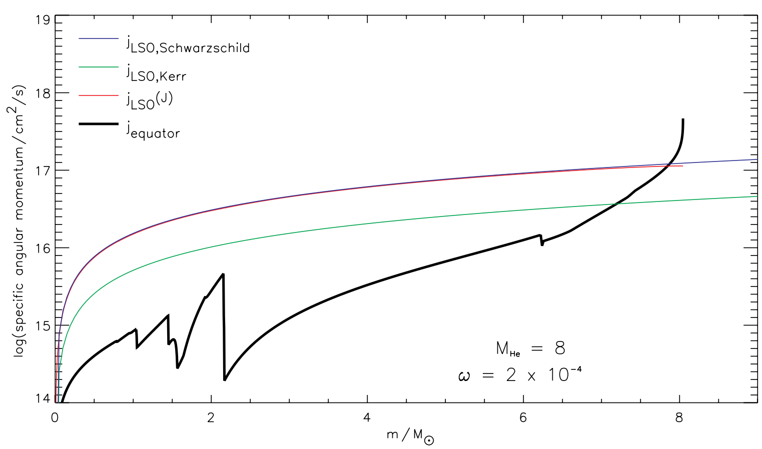
Woosley & Heger 12, Perna+14

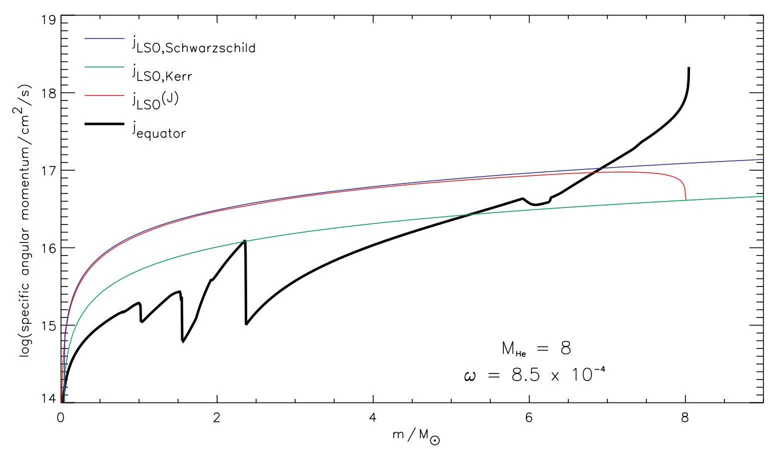
BSG





WR
in binary





Outer layers of up to ~ a few $M_\odot$ can "naturally" have sufficient j

Then, what will happen?

$\dot{M}_{\rm d} \approx M_{\rm d}/t_{\rm acc}$, or

$$\dot{M}_{\rm d} \sim 3\times10^{-5}\ {\rm M_\odot\ s^{-1}} \times \left(\frac{M_{\rm d}}{1\ M_\odot}\right)\left(\frac{R_*}{10^{12}\ {\rm cm}}\right)^{-3/2}\left(\frac{M_{\rm BH}}{10\ M_\odot}\right)^{1/2}, \gg \dot{M}_{\rm Edd} = 4\pi G M_{\rm BH}/c\kappa \sim 10^{-15}\ M_\odot\ {\rm s^{-1}}\ (\kappa/0.2\ {\rm cm^2\ g^{-1}})^{-1}(M_{\rm BH}/10M_\odot)$$

where $t_{\rm acc} \approx \pi({R_*}^3/8GM_{\rm BH})^{1/2}$, or

$$t_{\rm acc} \sim 3\times10^4\ {\rm s}\left(\frac{R_*}{10^{12}\ {\rm cm}}\right)^{3/2}\left(\frac{M_{\rm BH}}{10\ M_\odot}\right)^{-1/2}$$

Super-Eddington accretion!

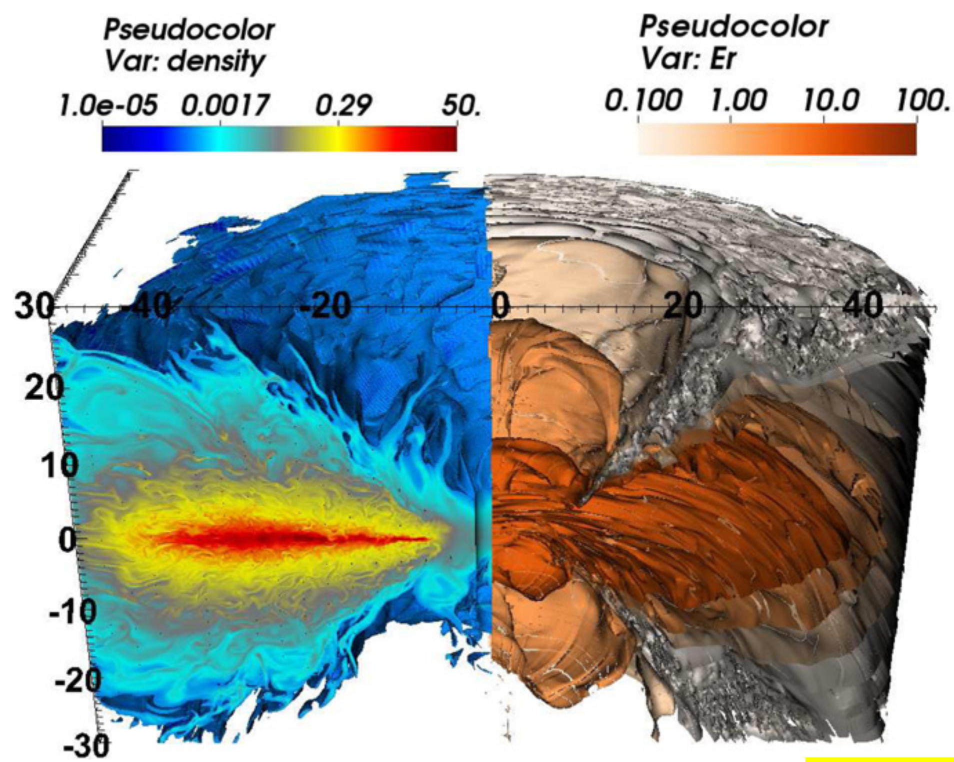
Outflows!

$\bar{v}_{\rm out} \approx (2GM_{\rm BH}/r_0)^{1/2}$, or

$$\bar{v}_{\rm out} \sim 1\times10^{10}\ {\rm cm\ s^{-1}}\left(\frac{f_r}{10}\right)^{-1/2}.$$

$T_0 \approx (\dot{M}_{\rm out} v_{\rm out}/8\pi a r_0^2)^{1/4}$, or

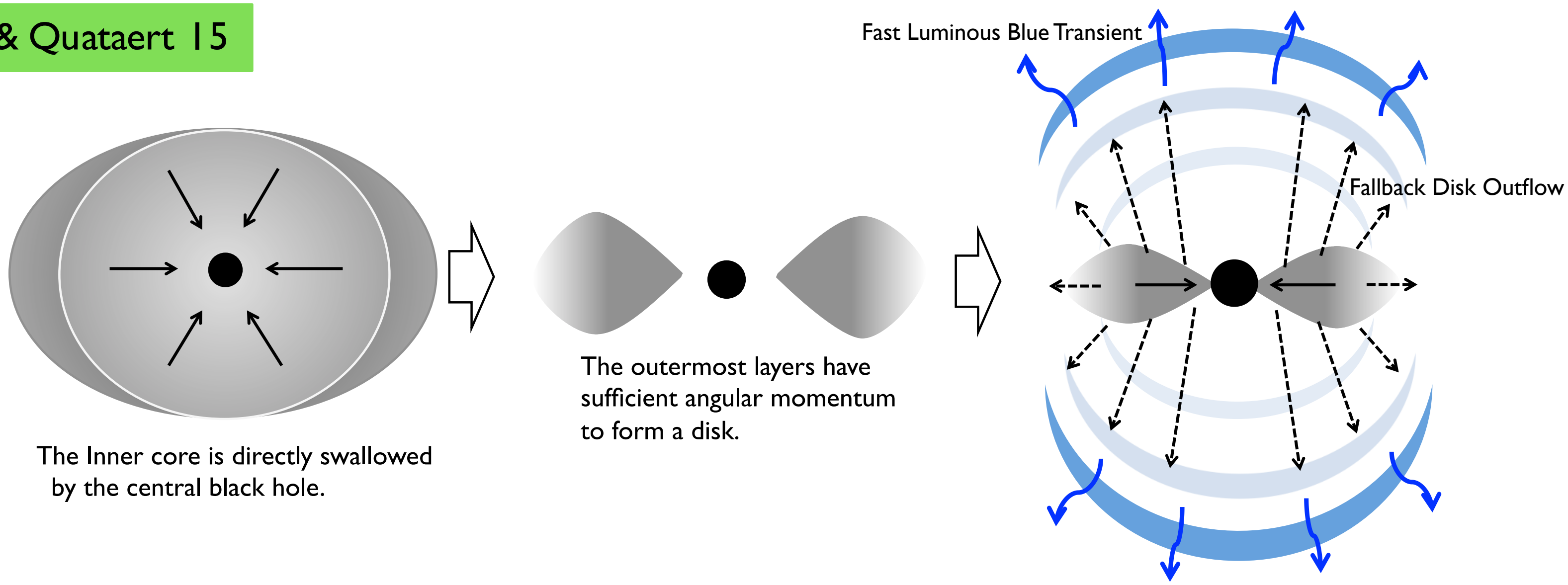
$$T_0 \sim 8\times10^8\ {\rm K}\left(\frac{f_r}{10}\right)^{-5/8}\left(\frac{f_{\dot{M}}}{0.1}\right)^{1/4} \times\left(\frac{M_{\rm d}}{1\ M_\odot}\right)^{1/4}\left(\frac{R_*}{10^{12}\ {\rm cm}}\right)^{-3/8}\left(\frac{M_{\rm BH}}{10\ M_\odot}\right)^{-3/8}.$$

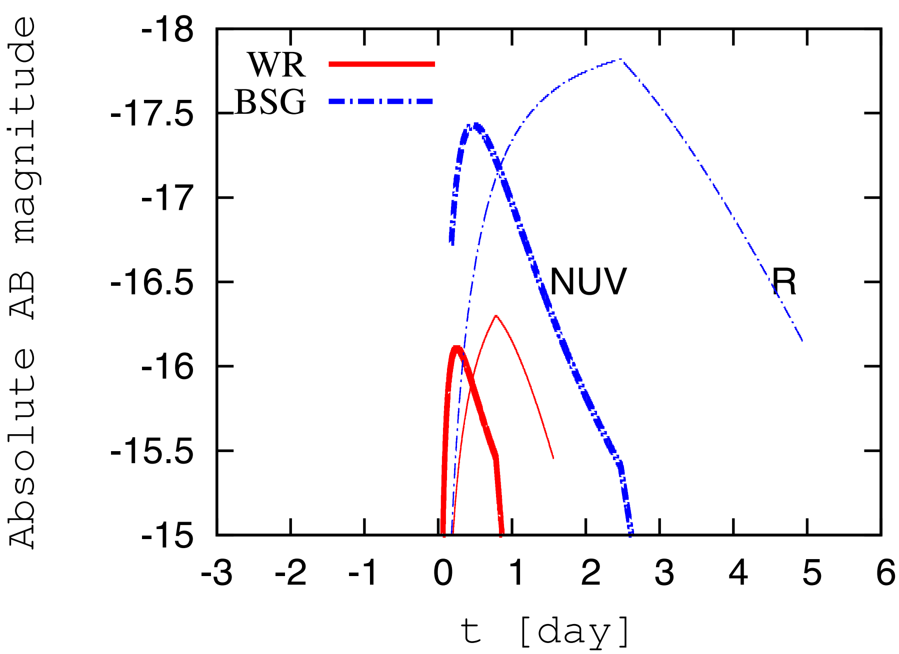


Jiang+14

Fast Luminous Blue Transients

KK & Quataert 15

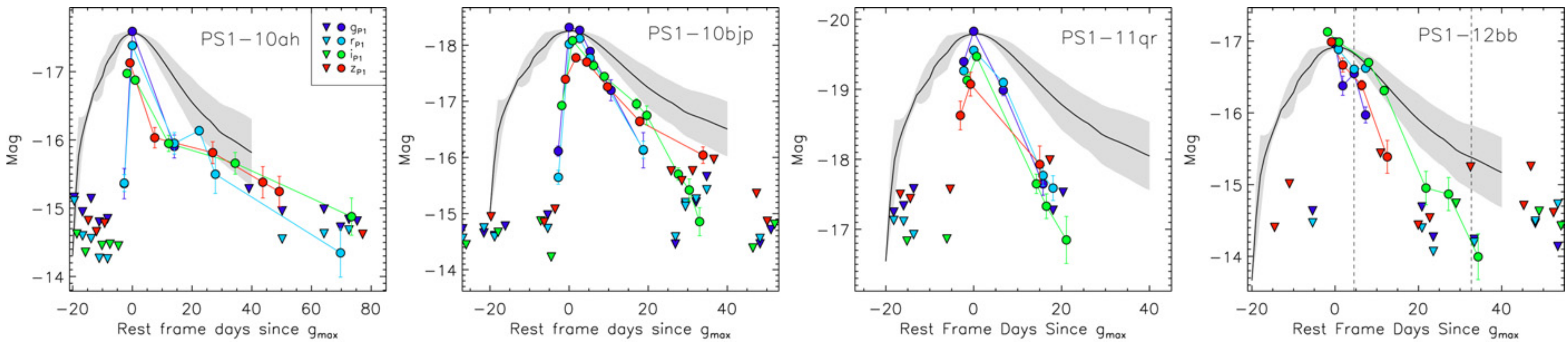




- ✓ t_{emi} ~ Days to 10 days
- ✓ L_{bol} ~ $10^{41\text{-}43}$ erg s^{-1}
- ✓ blue continua with T ~10^4 K

The PS1-MDS Transients

Pan-STARRS1 Medium Deep Survey (PS1-MDS) for Rapidly Evolving and Luminous Transients Drout+14



- ✓ $t_{1/2}$ < 12 day --- rapidly evolving than any SN type
- ✓ L_{peak} ~ $10^{42\text{-}43}$ erg s^{-1} --- luminous as bright SNe
- ✓ T_{peak} ~ a few 10^4 K --- blue
- ✓ No line blanketing --- not powered by the radioactive decay
- ✓ Host Gal. = star forming Gal. --- related to massive stars
- ✓ Event rate ~ 4-7 % of core-collapse SN --- not rare

Summary and Discussion

How to find newborn black holes

- Vanishing supergiants
- Luminous red novae
- Fast blue transients
  - ✓a day to 10 day depending on progenitor structure
  - ✓$L_{bol} \sim 10^{41-43}$ erg s^{-1}
  - ✓Blue continua with $T \sim 10^4$ K
  - ✓The PS1-MDS transients are from WRs and BSGs?
  - ✓may not be rare (~5% of CCSNe).
- Multi-Messenger Approach
  - ✓Radio
  - ✓Gravitational wave

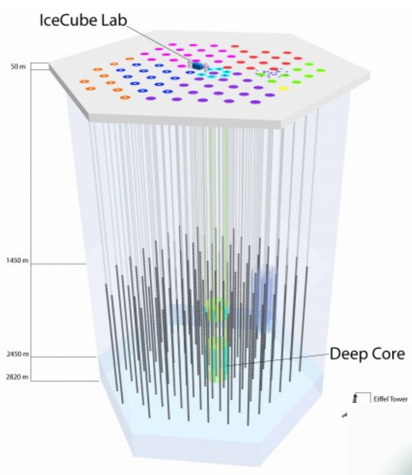
Back up

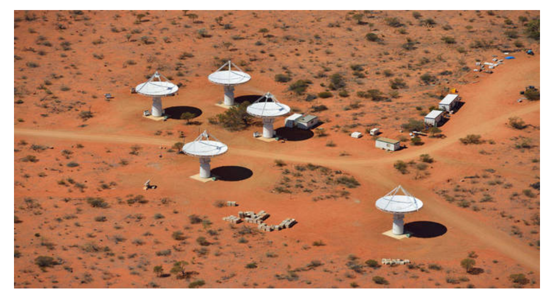
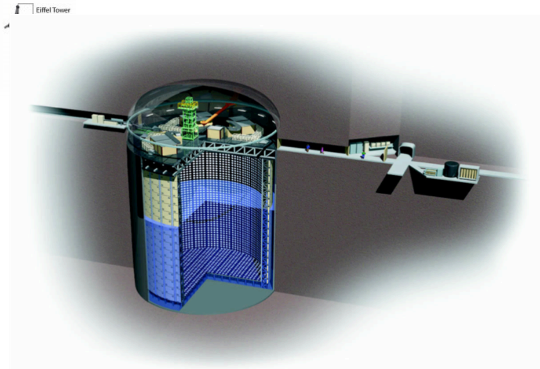
Now is the good timing









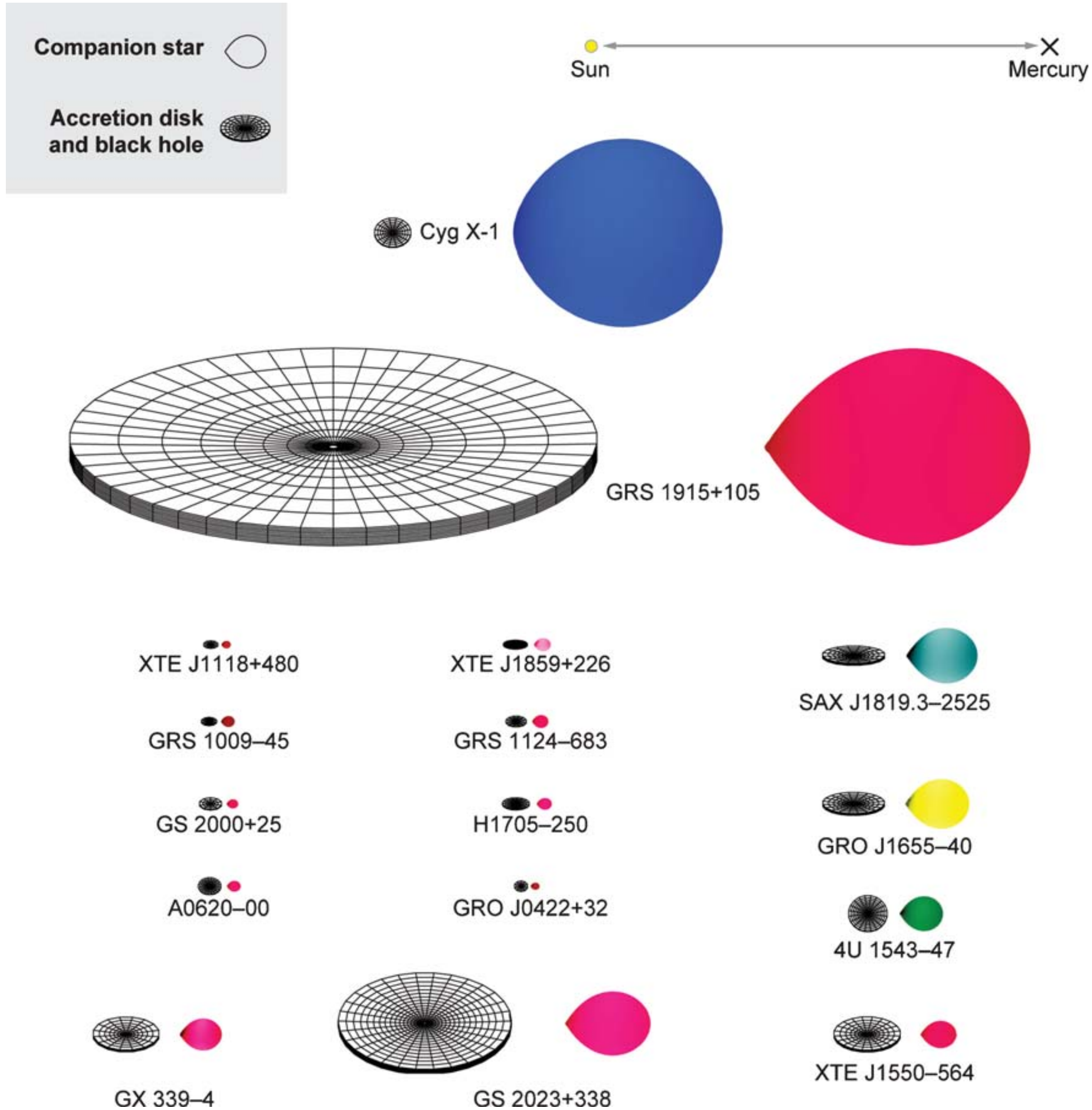
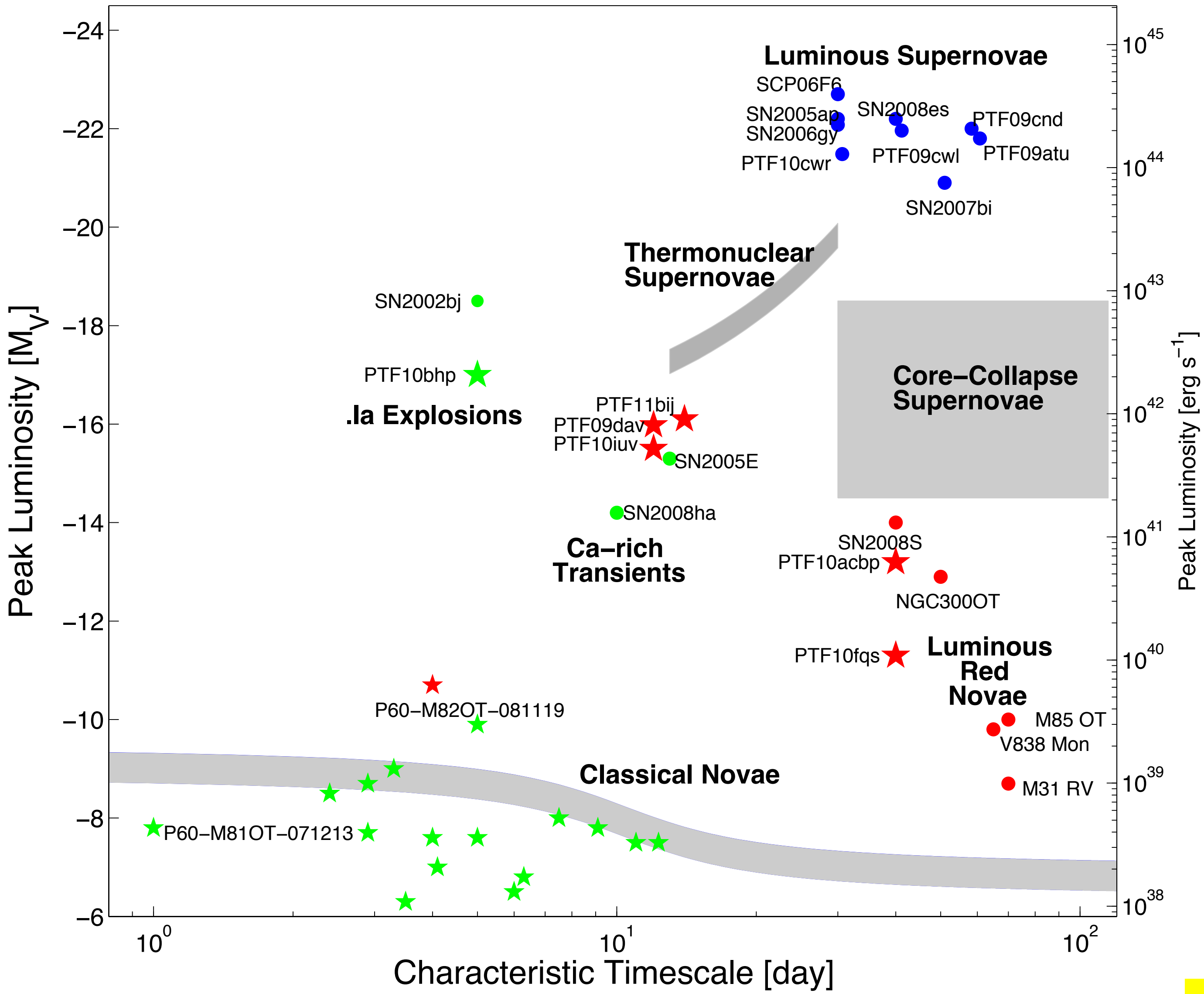



Figure 1

Scale drawings of 16 black-hole binaries in the Milky Way (courtesy of J. Orosz). The Sun–Mercury distance (0.4 AU) is shown at the top. The estimated binary inclination is indicated by the tilt of the accretion disk. The color of the companion star roughly indicates its surface temperature.

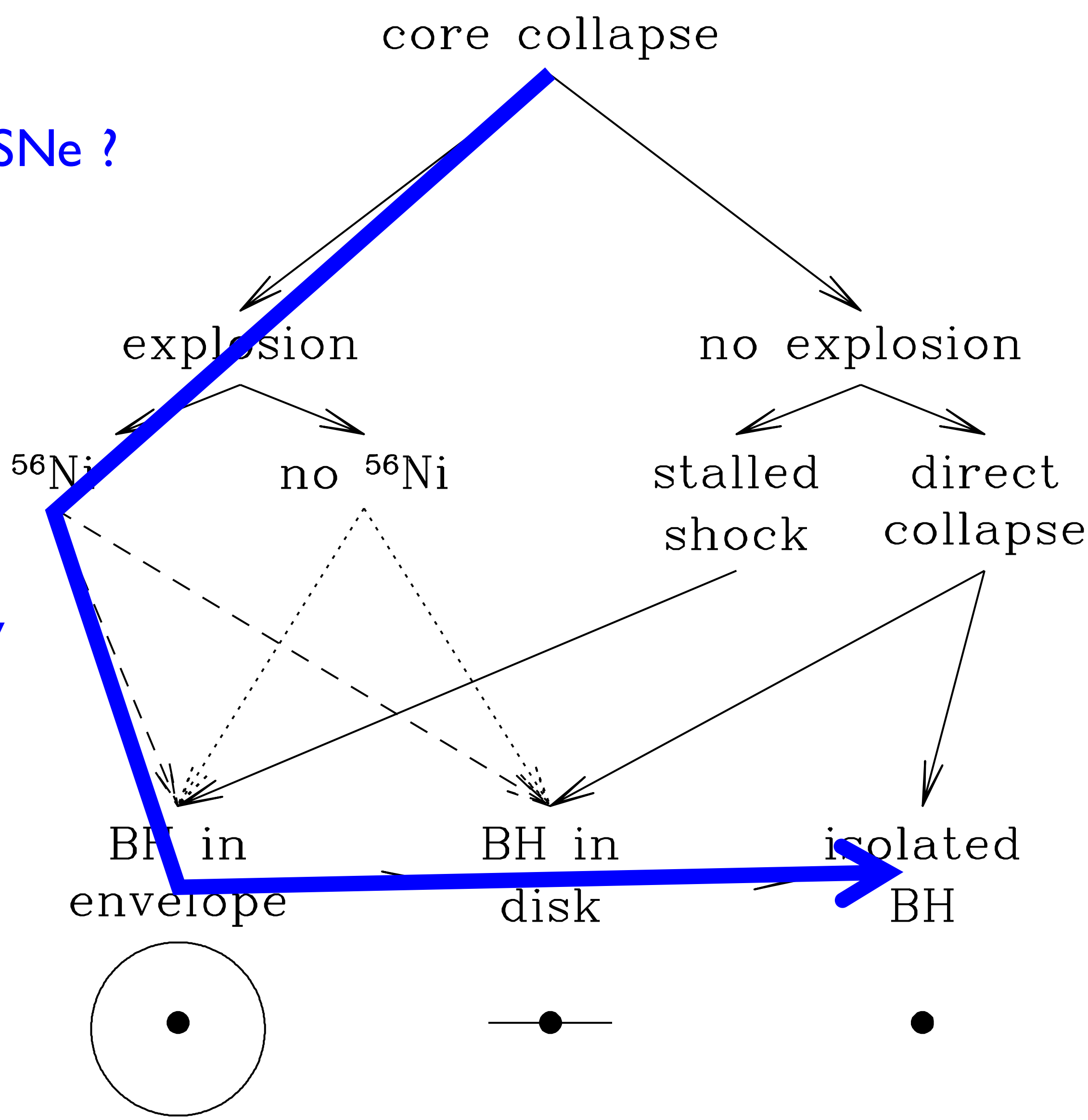
Optical Transients



Kasliwal 11

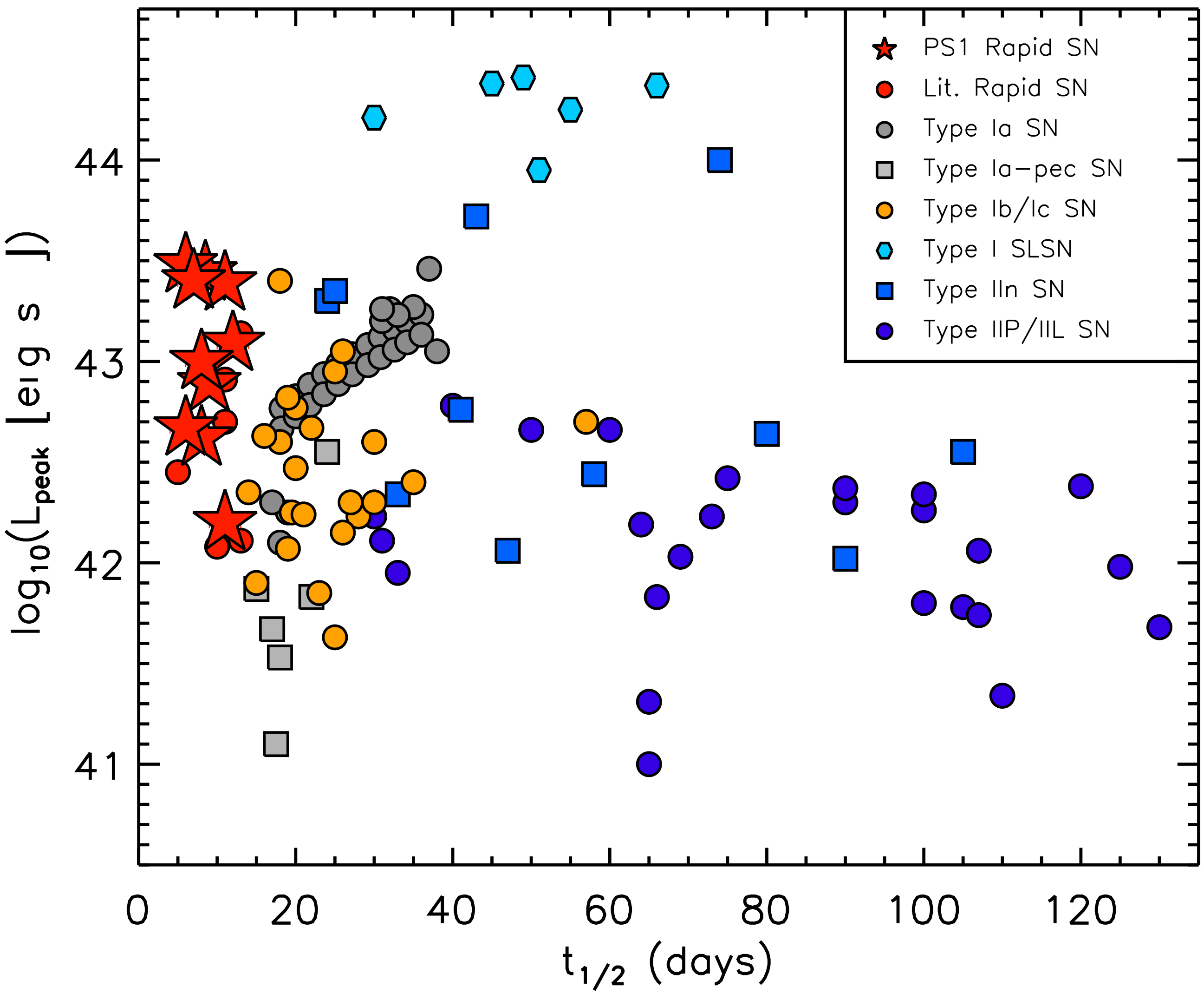
Possible Outcomes in a BH Formation

Dimer class of SNe ?
(e.g., 1987A)



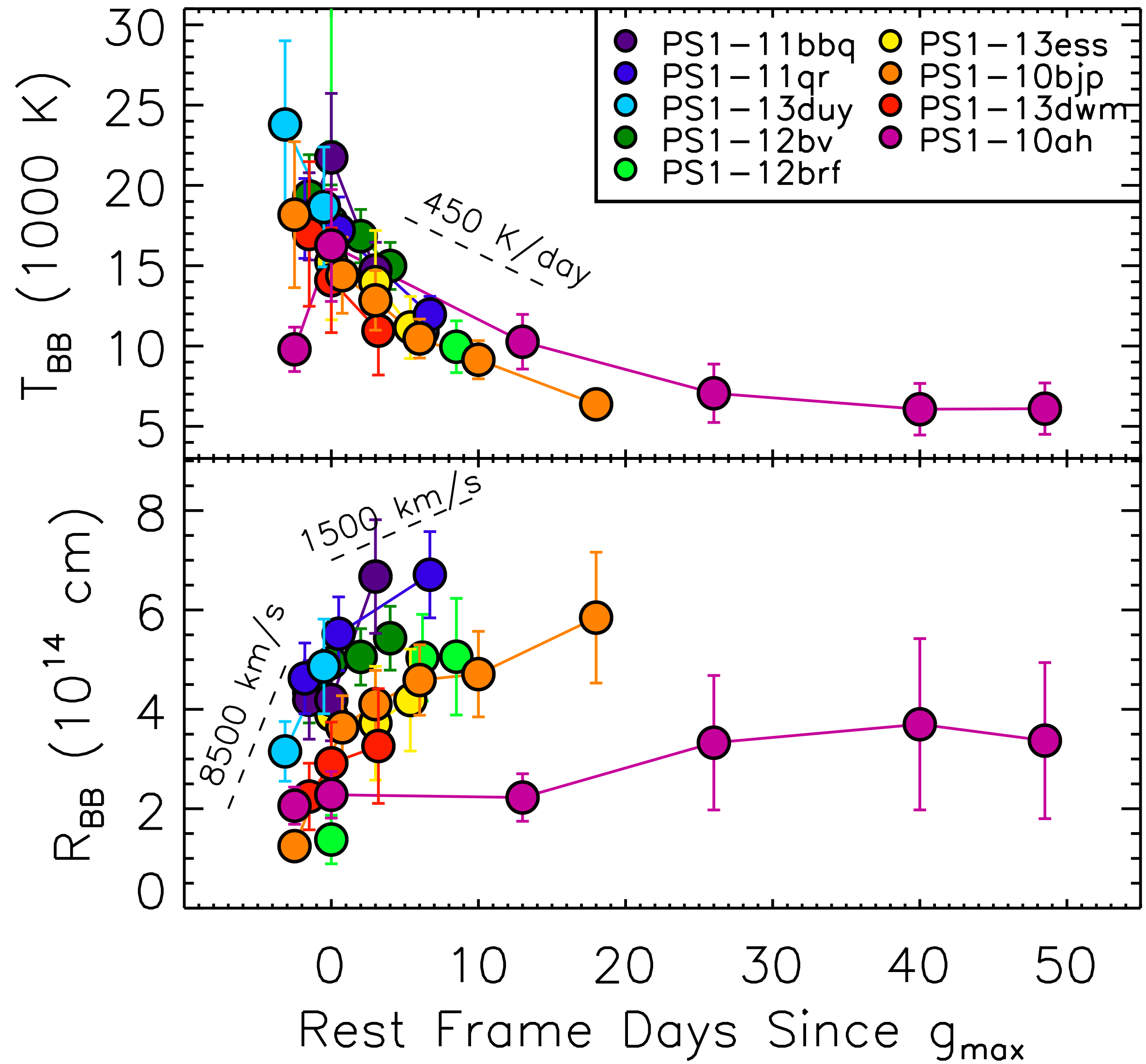
probably not rare

The PS1-MDS Transients



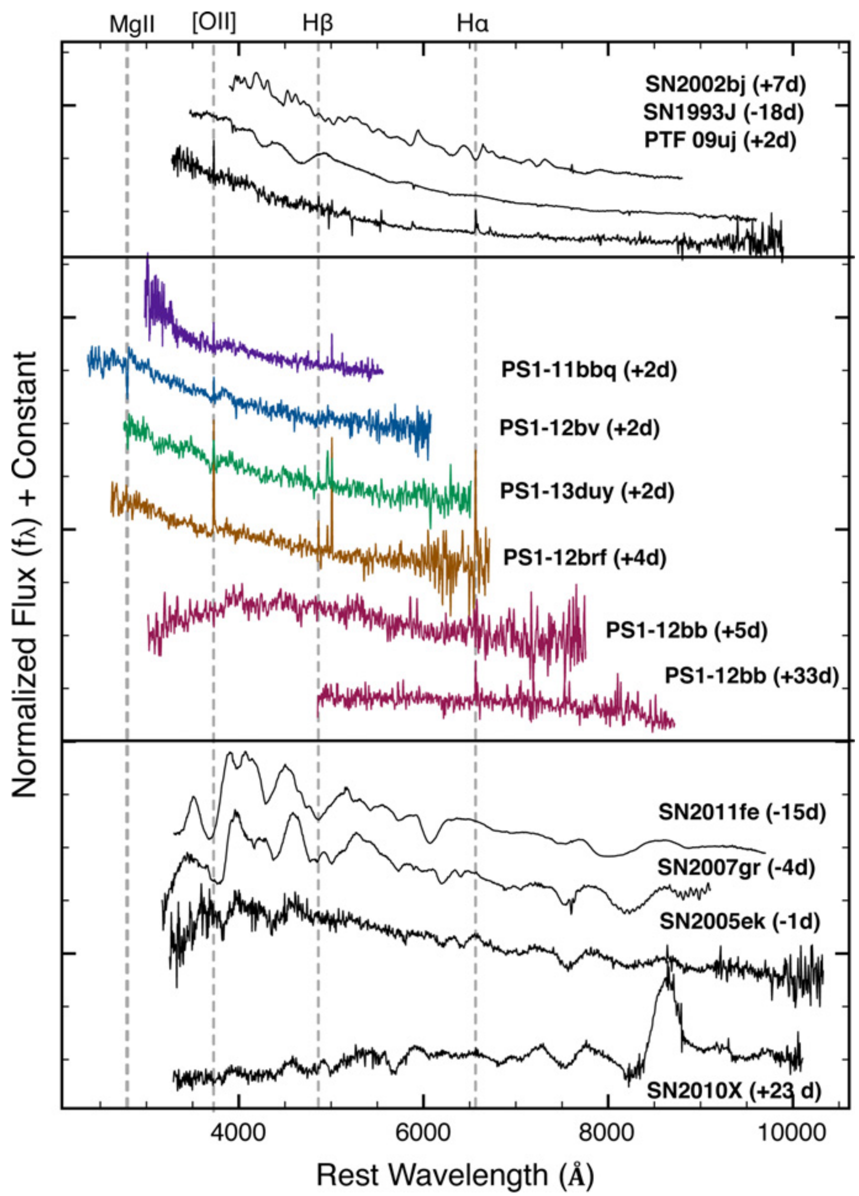
Drout+14

The PS1-MDS Transients



Drout+14

The PS1-MDS Transients

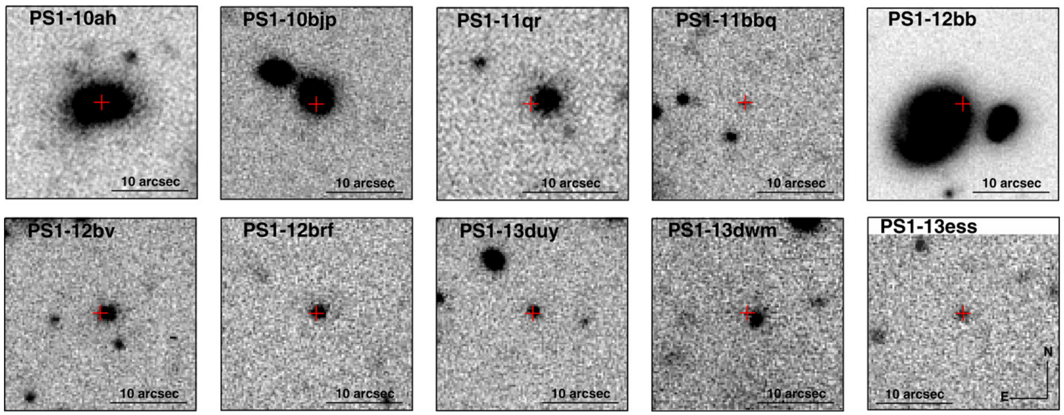


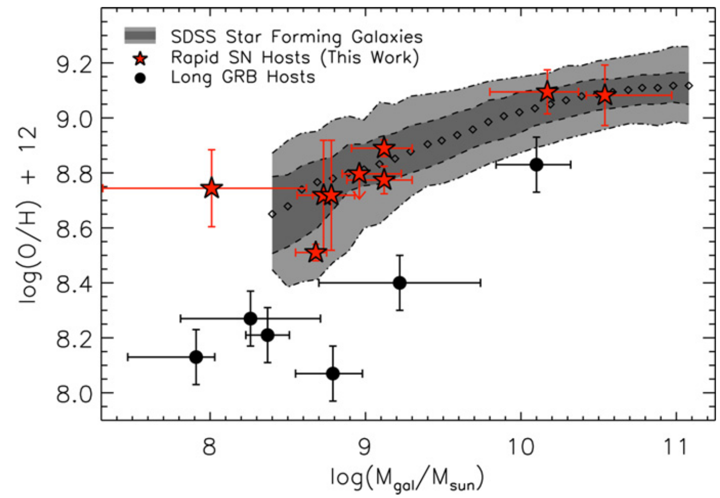
Blue Continua

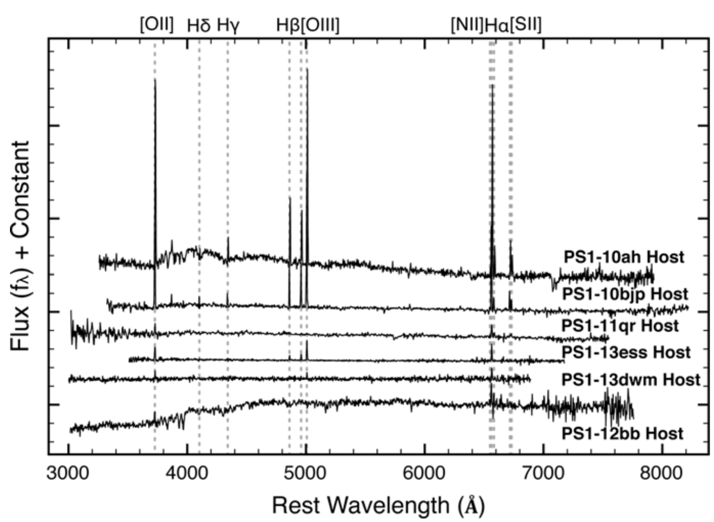
No Line Blanketing

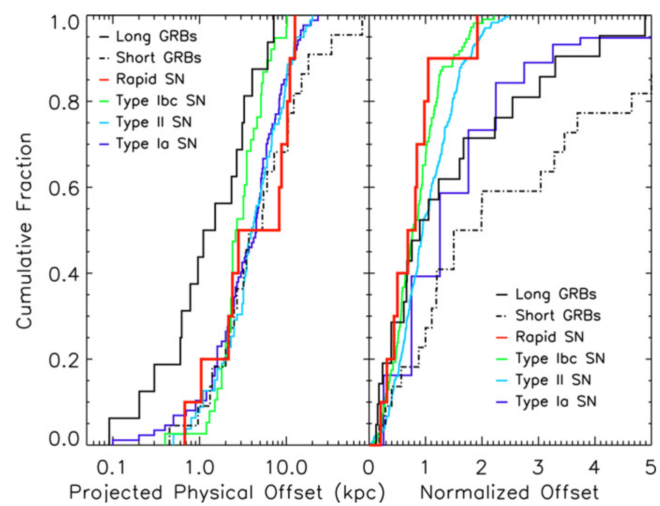
Drout+14

The PS1-MDS Transients





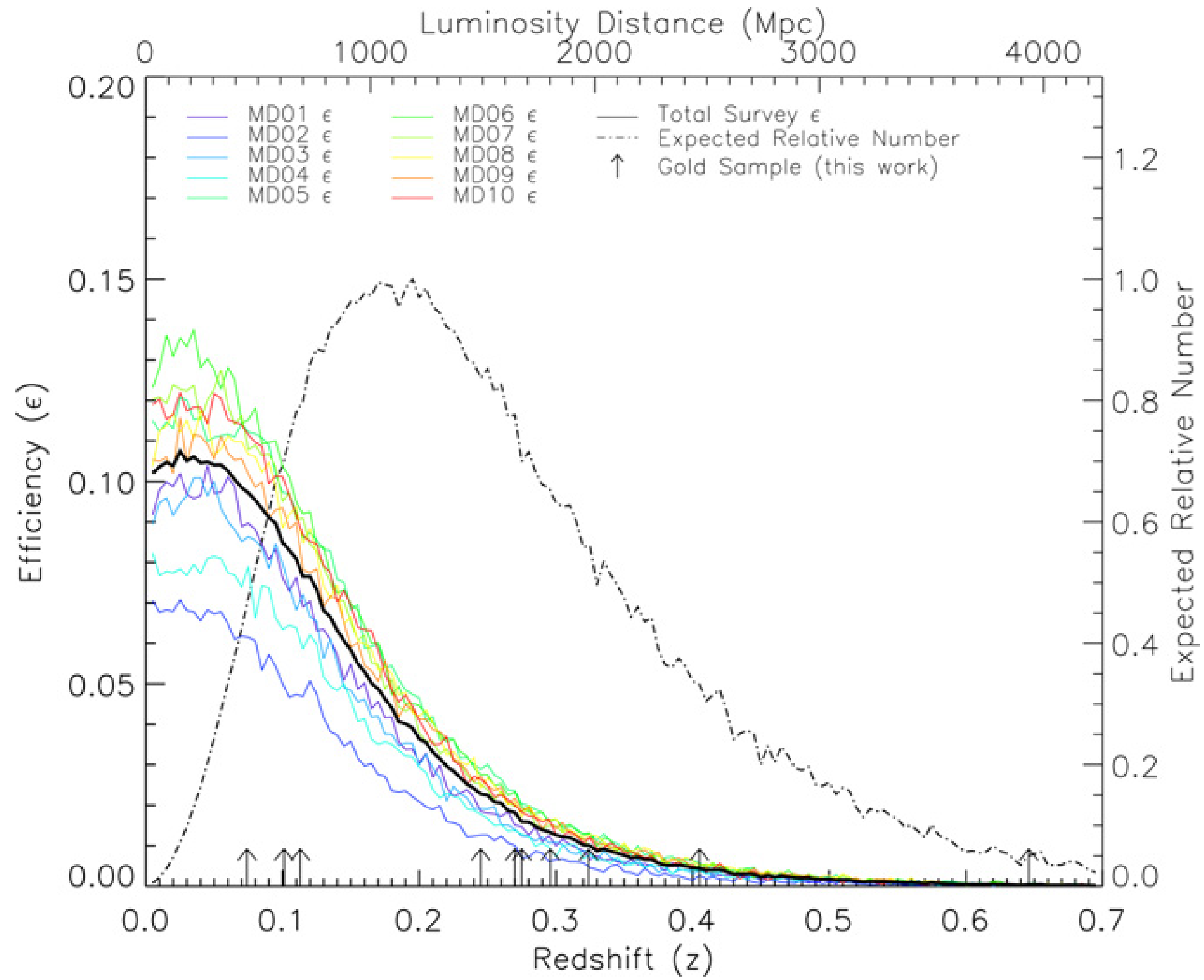




Host Gal. = SF Gal.

Drout+14

The PS1-MDS Transients



4%-7% of CCSN@z =0.2

Drout+14