The Strongly Interacting Binary Scenarios of the enigmatic Supernova iPTF14hls

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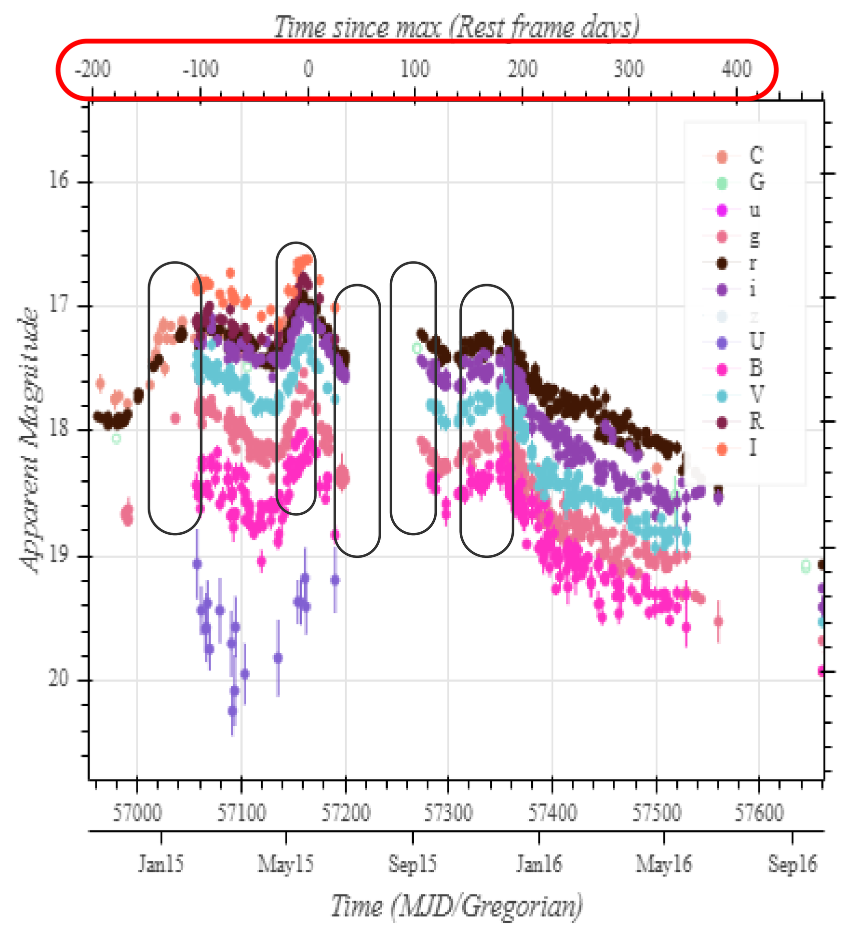
Introduction

Peculiar properties of iPTF14hls:

1. Slow light curve evolution
2. At least 5 peaks in the light curve (see figure on the right)
3. Fast circumstellar matter

iPTF14hls's peculiarity motivated several scenarios, four of which we list in the left column of the table in Abstract & Summary



Arcavi et al. 2017 - Energetic eruptions leading to a peculiar hydrogen-rich explosion of a massive star

Abstract & Summary

Argument: these scenarios are rare cases of **strongly interacting binary systems**

	Prolonged Activity	Critical Ingredient	Required Rare Binary Property	Possible Accompanying Processes
Circum-Stellar Matter (CSM)	Ejecta-CSM collision	Massive equatorial CSM	Interaction to eject equatorial mass	Jets launch by the companion
Magnetar	Rapidly rotating neutron star	Rapidly rotating pre-collapse core	The companion spins-up the core	Accretion disk and jets at explosion
Fallback	Late accretion on to neutron star	Rapidly rotating pre-collapse core	The companion spins-up the core	Accretion disk and jets at explosion
Common Envelope Jets Supernova (CEJSN)	(1) Ejecting a massive envelope and/or (2) late jets	Accretion of mass on to a neutron star inside a red giant star	The neutron star spirals-in down into the companion's core	The neutron star ejects equatorial mass and turns to a magnetar

The Jet to Magnetar Transition

Our Claim: Large amounts of angular momentum require strong binary interaction (see Abstract & Summary table)

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Magnetar activity is preceded by **jets**

AND

Jets' activity in the CEJSN is followed by a **magnetar**

Consider the double magnetar phases scenario proposed by Woosley (2018) that we summarize as:

	Magnetic Filed	Initial Rotational Energy
1st magnetar phase	$B_1 \approx 2\times10^{15}$ G	$E_1 = 2-15\times10^{51}$erg
2nd magnetar phase	$B_2 \approx 4\times10^{13}$ G	$E_2 \approx 0.6\times10^{51}$erg

We examine the possibility to replace the 1st magnetar phase by jets with $\boldsymbol{E_{jets} \approx 8\times10^{51}}$ **erg** ($E_1 - E_2$ average)

Woosley 2018 - Models for the unusual supernova iPTF14hls

Our new scenario: A neutron star (NS) with mass $\boldsymbol{M_{NS} = 1.4 M_\odot}$ and radius $\boldsymbol{R_{NS} = 12\text{km}}$ launches jets with terminal velocity equaling the escape velocity

From this we estimate the following:

Jets mass:

$$M_{jets} = 0.026\left(\frac{E_{jets}}{8\times10^{51}\text{erg}}\right)\left(\frac{R_{NS}}{12\text{km}}\right)\left(\frac{M_{NS}}{1.4M_\odot}\right)^{-1} M_\odot$$

Assumption: the jets carry $\eta \approx 0.1$ times the accreted mass

Accreted mass:

$$M_{acc} = 0.26\left(\frac{\eta}{0.1}\right)^{-1}\left(\frac{E_{jets}}{8\times10^{51}\text{erg}}\right)\left(\frac{R_{NS}}{12\text{km}}\right)\left(\frac{M_{NS}}{1.4M_\odot}\right)^{-1} M_\odot$$

$\boldsymbol{j = \beta\sqrt{GM_{NS}R_{NS}}}$: the specific angular momentum of the accreted mass is a fraction β of the Keplerian value

Neutron star's angular momentum at the end of the accretion

$$J_{acc} = M_{acc}\, j_{acc} \approx 7.72\times10^{48}\beta\left(\frac{\eta}{0.1}\right)^{-1}\left(\frac{E_{jets}}{8\times10^{51}\text{erg}}\right)\left(\frac{R_{NS}}{12\text{km}}\right)^{\frac{3}{2}}\left(\frac{M_{NS}}{1.4M_\odot}\right)^{-\frac{1}{2}} \text{erg s}$$

Requirement: The second phase NS rotational energy: $E_P = 6\times10^{50}$erg, as in Woosley (2018)

$$\beta \approx 0.15\left(\frac{\eta}{0.1}\right)\left(\frac{\alpha}{0.3}\right)^{\frac{1}{2}}\left(\frac{E_{jets}}{8\times10^{51}\text{erg}}\right)^{-1}\left(\frac{E_p}{6\times10^{50}\text{erg}}\right)^{\frac{1}{2}}\left(\frac{R_{NS}}{12\text{km}}\right)^{\frac{3}{2}}\left(\frac{M_{NS}}{1.4M_\odot}\right)$$

$\beta < 1$, the jets carry some angular momentum, making this scenario **consistent**

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Replacing the first magnetar phase with jets is feasible