

# SoXS-WG7: Gap Transients



Rubina Kotak & Andrea Pastorello

# WG7 - The team

## INAF-OAPd

- Pastorello
- Benetti
- Cappellaro
- Elias-Rosa
- Tartaglia
- Turatto
- (Valerin)

## Belfast

- Smartt

## Aarhus

- Stritzinger

## Turku

- Kotak
- Gutiérrez
- Kankare
- Kuncarayakti
- Mattila
- Nagao
- Williams

## Andres Bello

- Pignata
- (Reguitti)

## ESO

- Anderson

## INAF-OACn

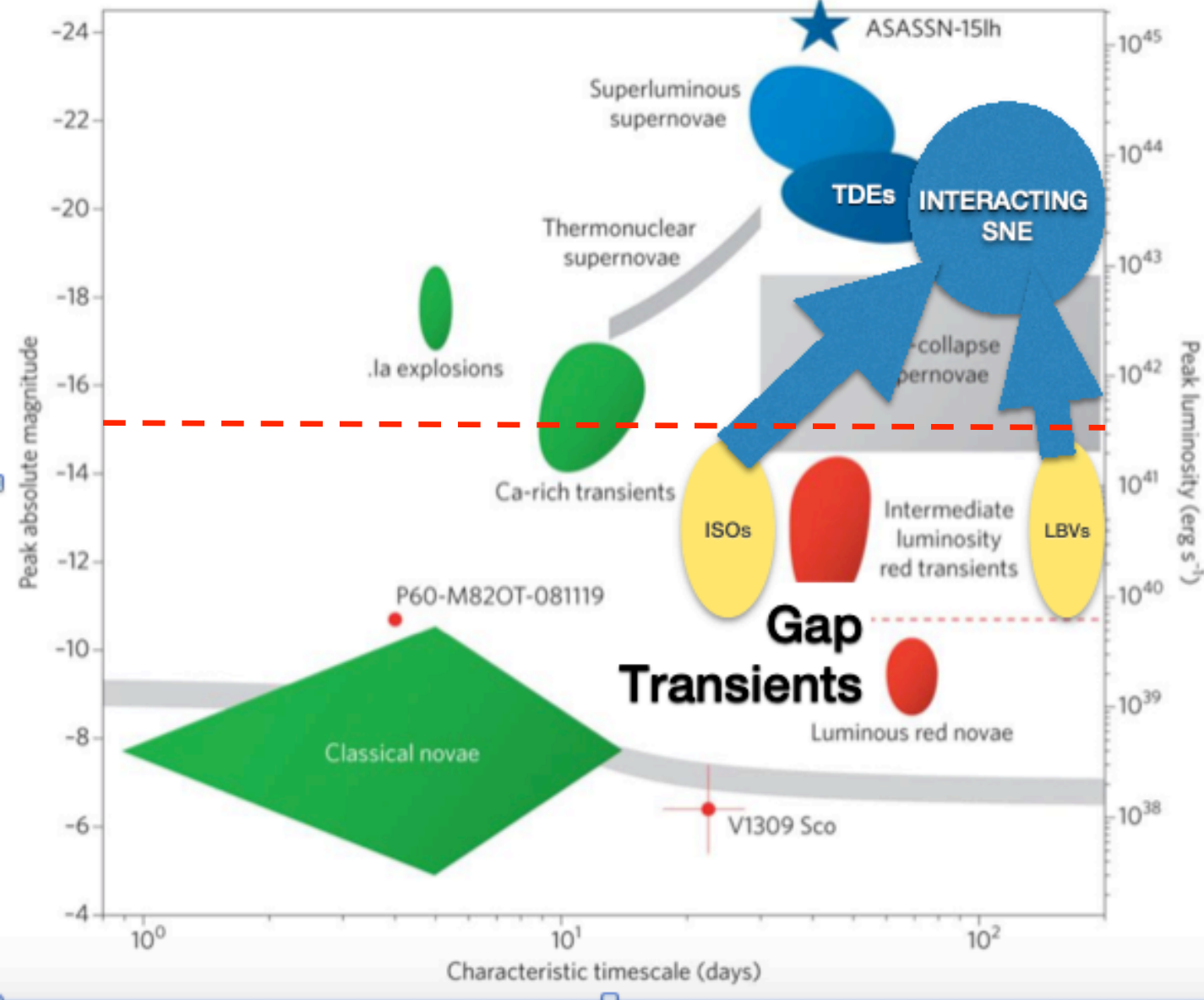
- Botticella
- Della Valle

## INAF-OATs

- Mason



Join us!



Gap transients:  
clearing house for  
many different  
types of transients

$$-8 > M > -15$$

Some linked to  
(bright) interacting  
(CC)SNe



**Luminous Red Novae (LRNe)** - usually yellowish giant-to-hypergiant progenitors (with a large mass range), in Close binaries. Merger events?

**Intermediate-Luminosity Red Transients (ILRTs)** - Dust-embedded 8-15 Msun progenitors. Electron-capture SNe or S-AGB-type outbursts?

**SN impostors** - massive ( $M_{\text{ZAMS}} > 40 \text{ Msun}$ ) progenitors (LBVs, WR...); non-terminal events

**Major LBV eruptions** (Eta-Car, SN 2000ch, SN 2009ip in 2009-2012)  
=> erratic variability with multiple outbursts;  $M_V \sim -11.5$  to  $-14.5$

**Major stellar outbursts** (SN 2007sv, the 2004 precursor of SN 2006jc)  
=> single outburst event;  $M_V \sim -13$  to  $-14$

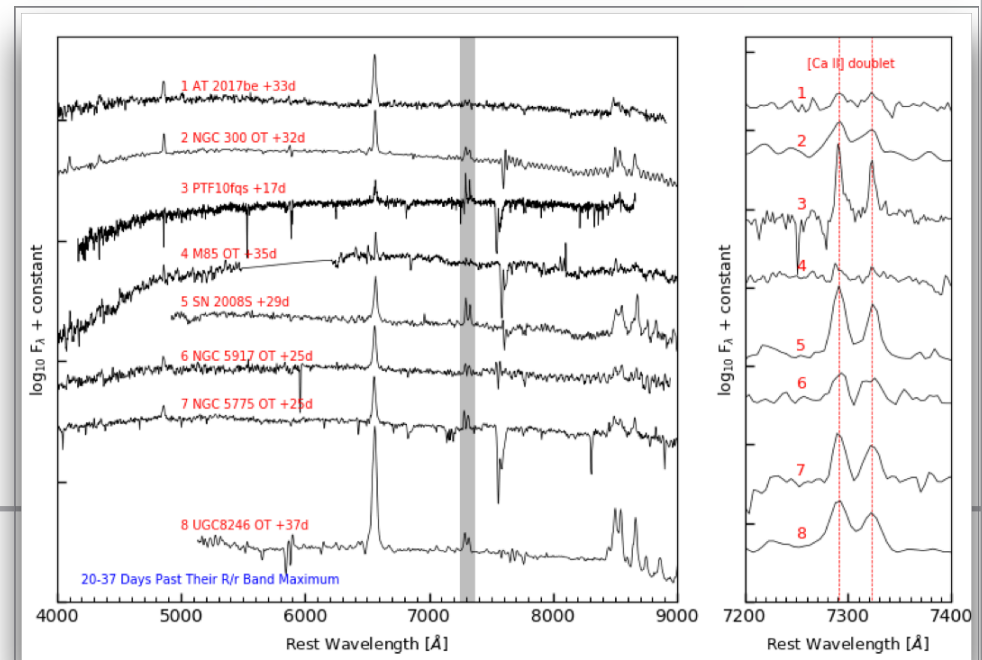
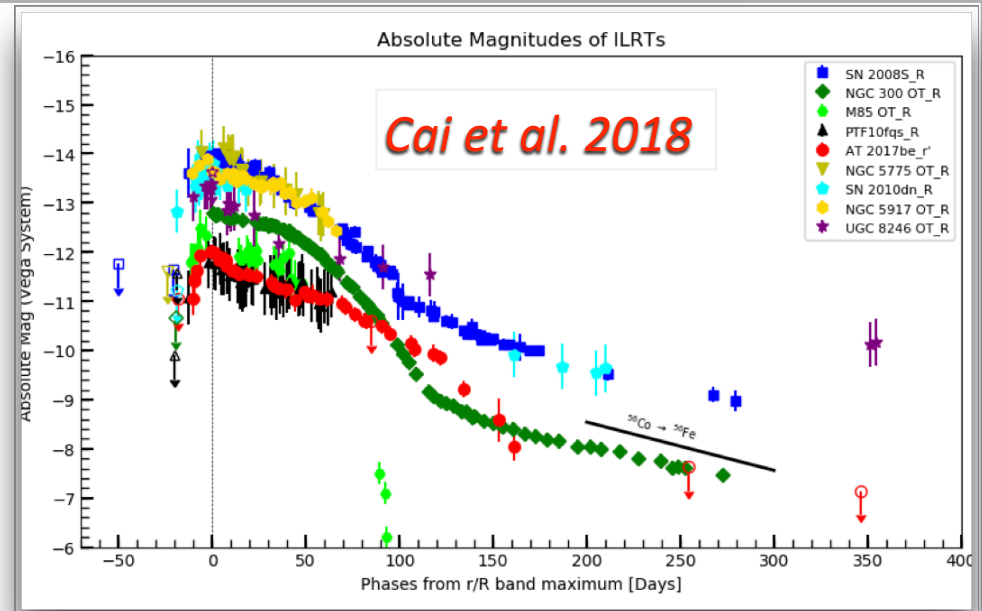
**Extreme S Dor variability** (e.g. R71, M33 Var C, UGC 2773-2009OT1)  
=> quite heterogeneous  $DM < 3 \text{ mag}$ ,  $M_V > -11 \text{ mag}$

**Faint type I SNe** (.Ia, Ca-rich transients, fast & faint SNe) - failed thermonuclear explosions or faint core-collapse (e.g. fall-back SNe)?

**Faint type II SNe** (1997D-like and 1999ga-like events) - Fe core-collapse of 7-8 Msun RSGs or fall-back SNe of  $M > 25 \text{ Msun}$  stars?



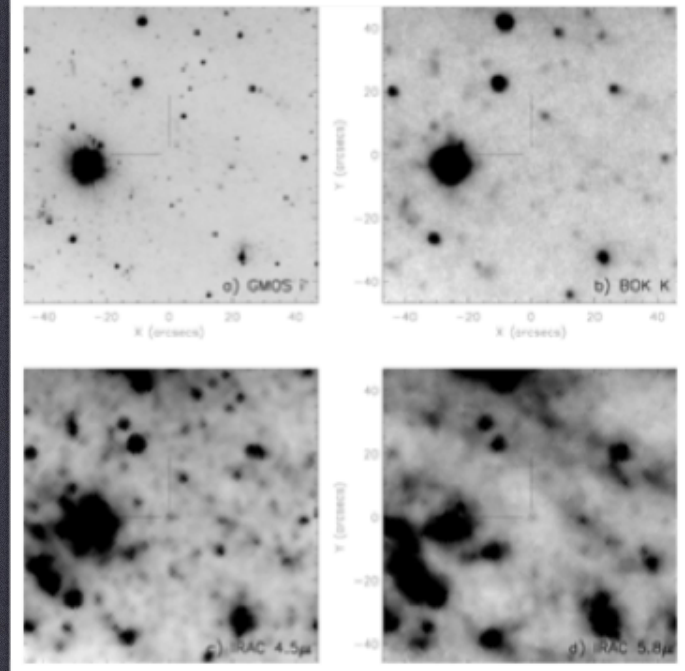
- Peak absolute mag: -12 to -14
- Type IIP or IIL-like light curves
- Late-time decline consistent with  $^{56}\text{Co}$
- Type IIn-like spectra
- [Ca II] near 7300 Å always detected
- Optical spectra never show molecular band signatures
- Quiescent progenitors detected in the mid-IR only; no detection in the optical or near-IR regions



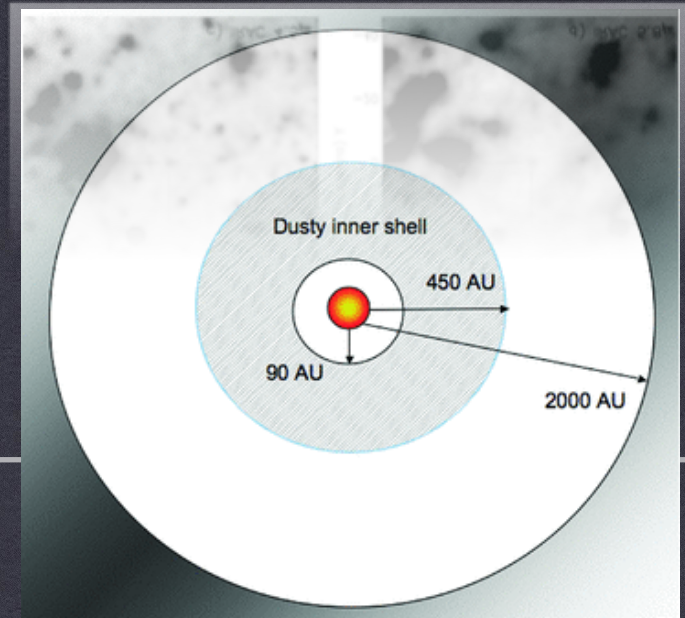
## Intermediate-Luminosity Red Transients (ILRTs)

## 8-15 Msun stars embedded in dusty cocoons

- Outbursts from low-mass LBVs or B[e] hypergiants in a dusty cocoon
- Outbursts due to binary interaction involving a S-AGB
- Electron-capture SNe from S-AGB stars



Botticella+ 2009

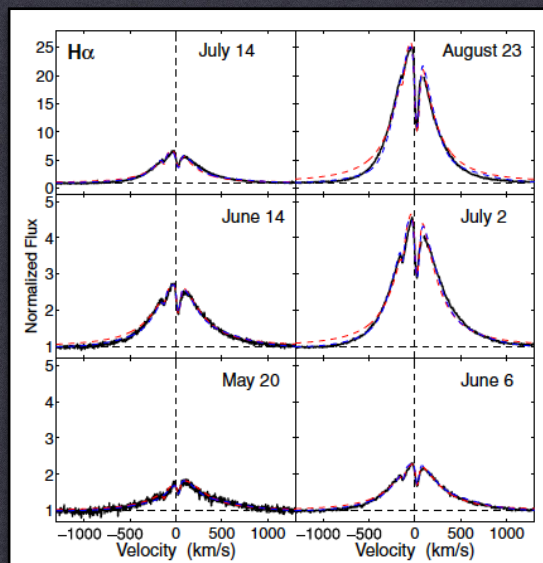


Intermediate-Luminosity  
Red Transients (ILRTs)



## Resolution

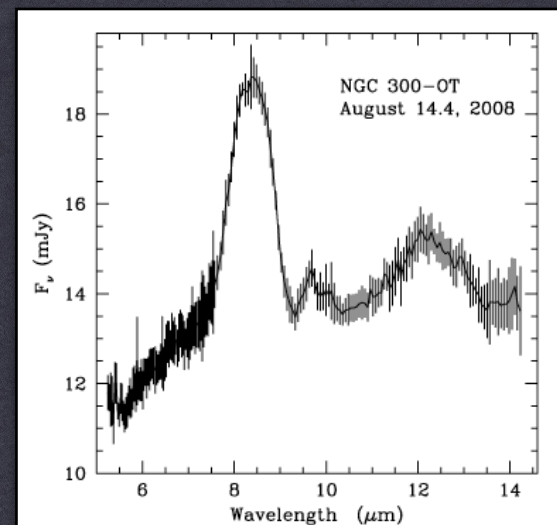
(spectral lines with velocities of a few tens  $\text{km s}^{-1}$ )



*Berger et al. 2009*

Wavelength range:  
SED evolution  
constrains different  
emitting regions  
(transient, light echo,  
dusty environment)

IR monitoring -  
Chemical species (Fe-  
peak lines? molecules?)  
NO NIR spectra are  
available for ILRTs!



*Prieto et al. 2009*

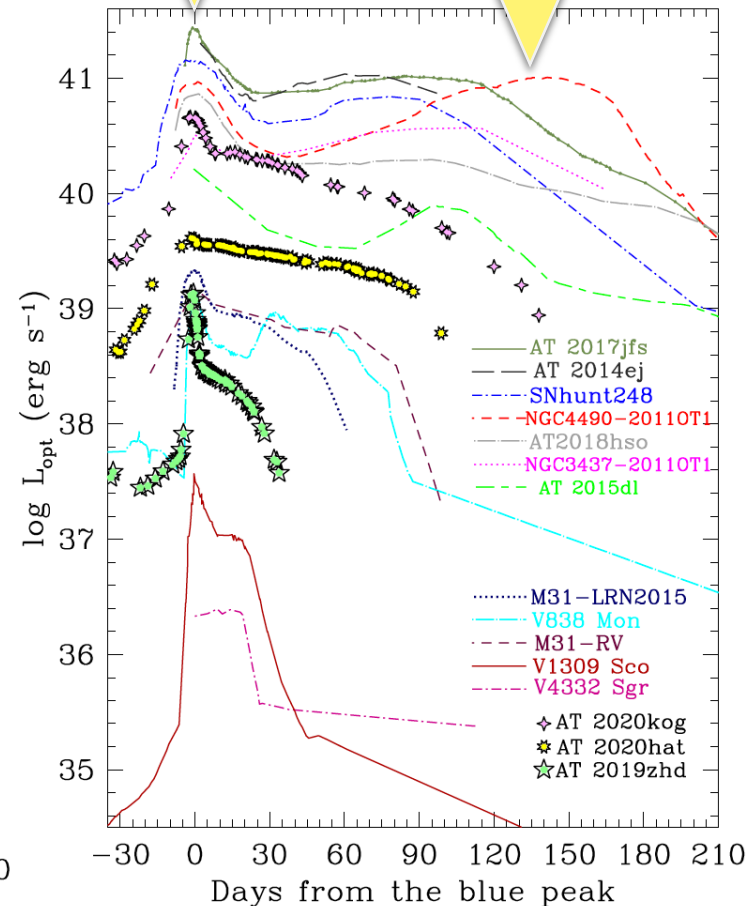
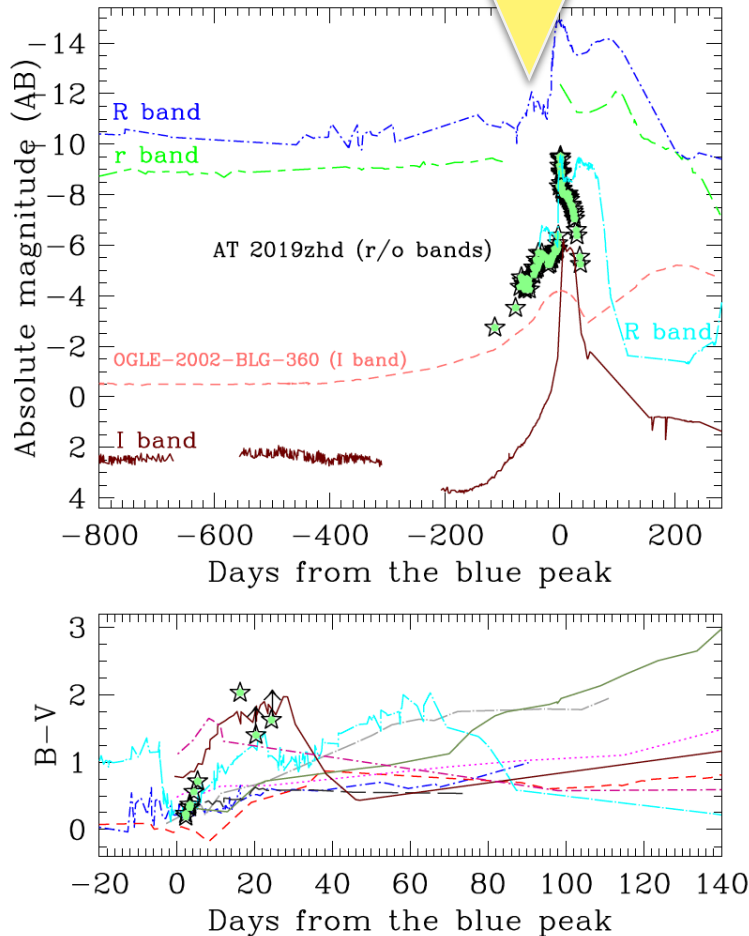
# WHY SOXS?

ILRTS



# Luminous Red Novae

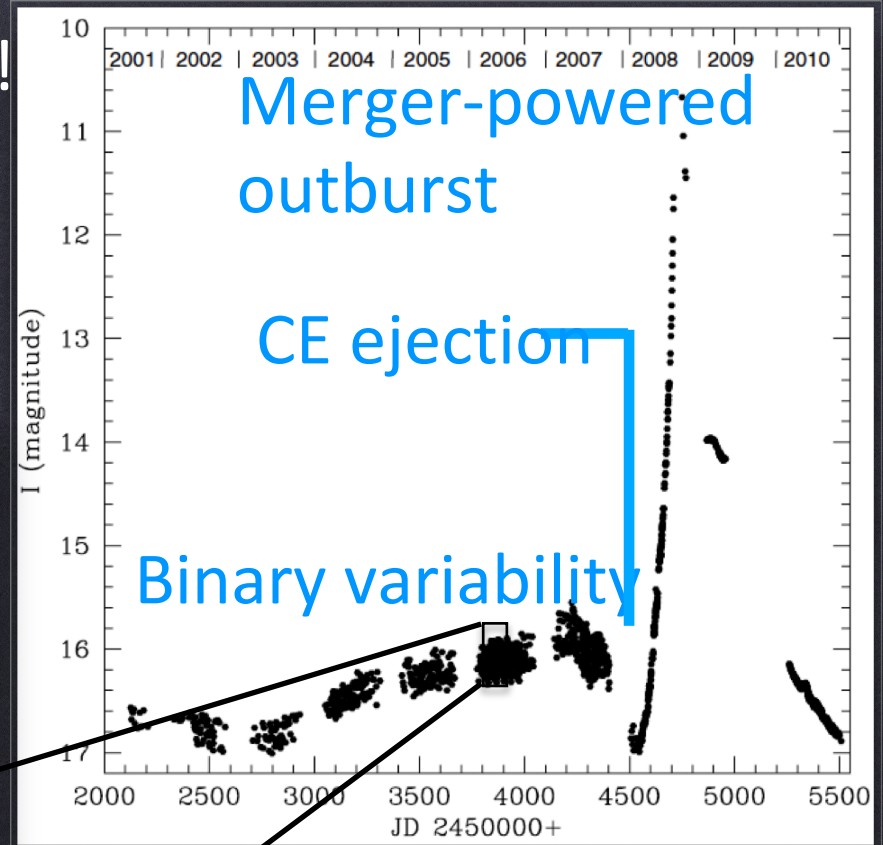
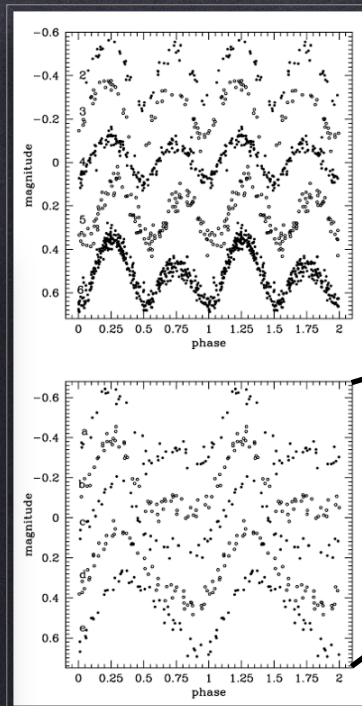
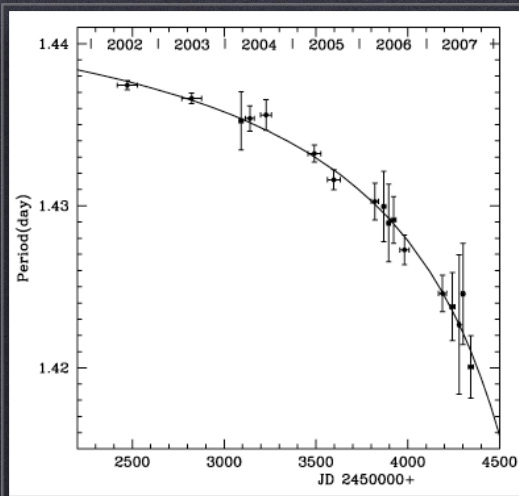
1. Pre-outburst brightening
2. Early short-duration blue peak
3. Late red peak or a plateau





# V1309 Sco: real time merger!

2002-2006

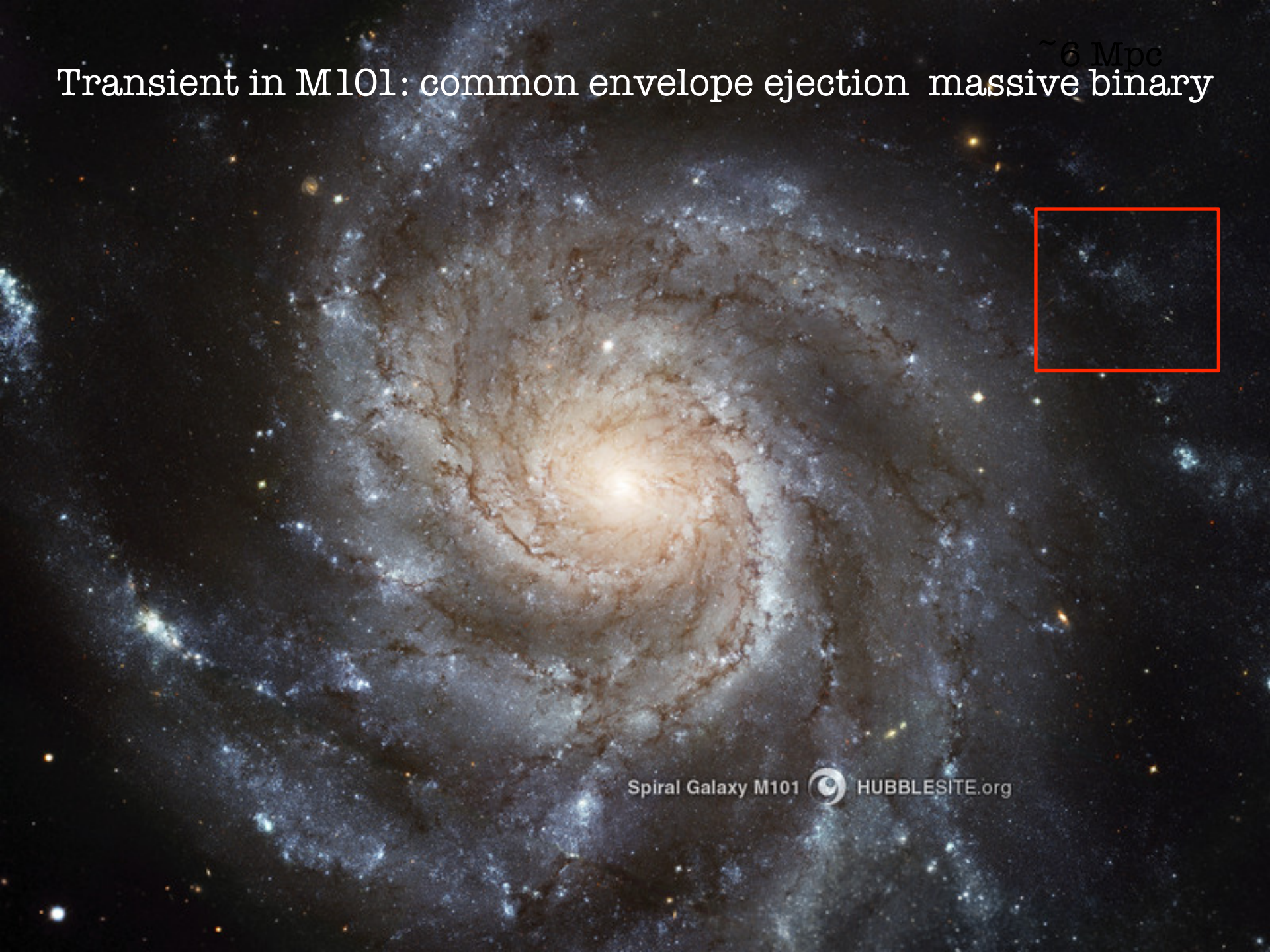


*Tylenda et al. 2011*  
*Mason et al. 2010*

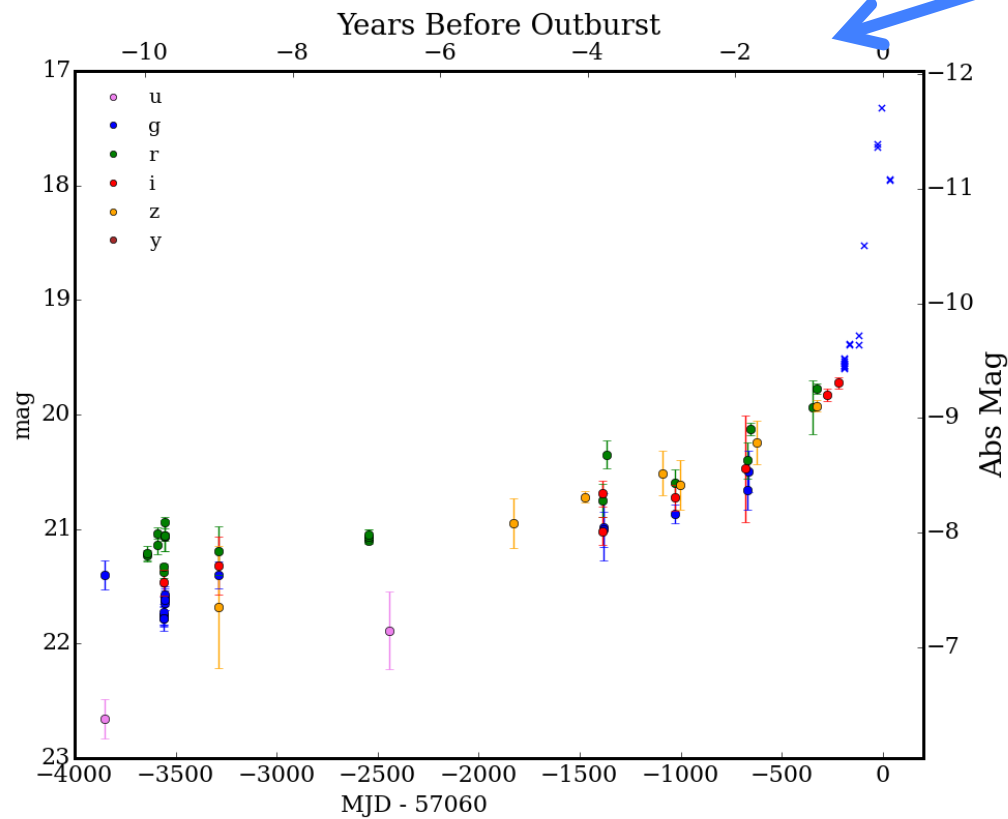
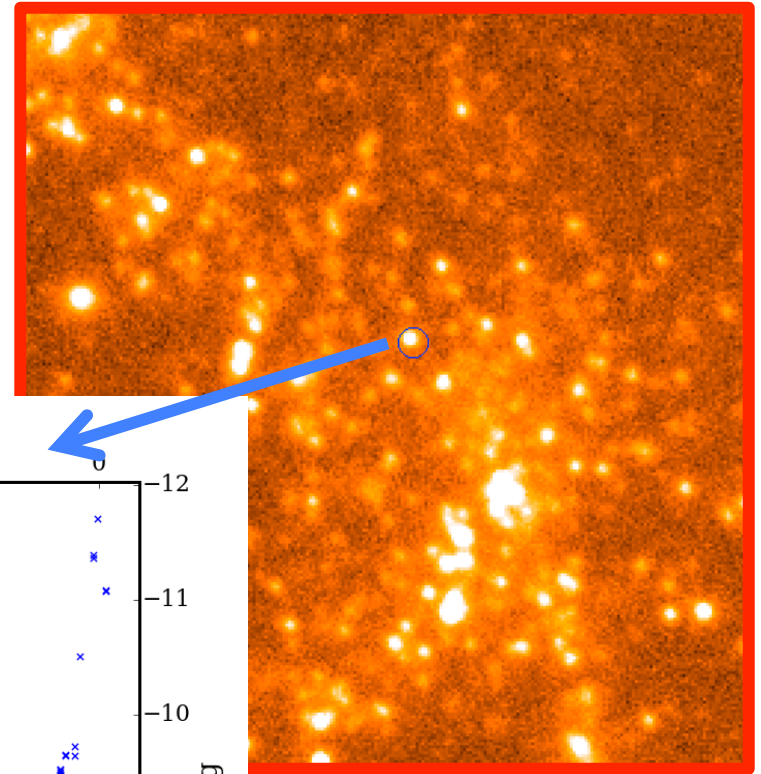
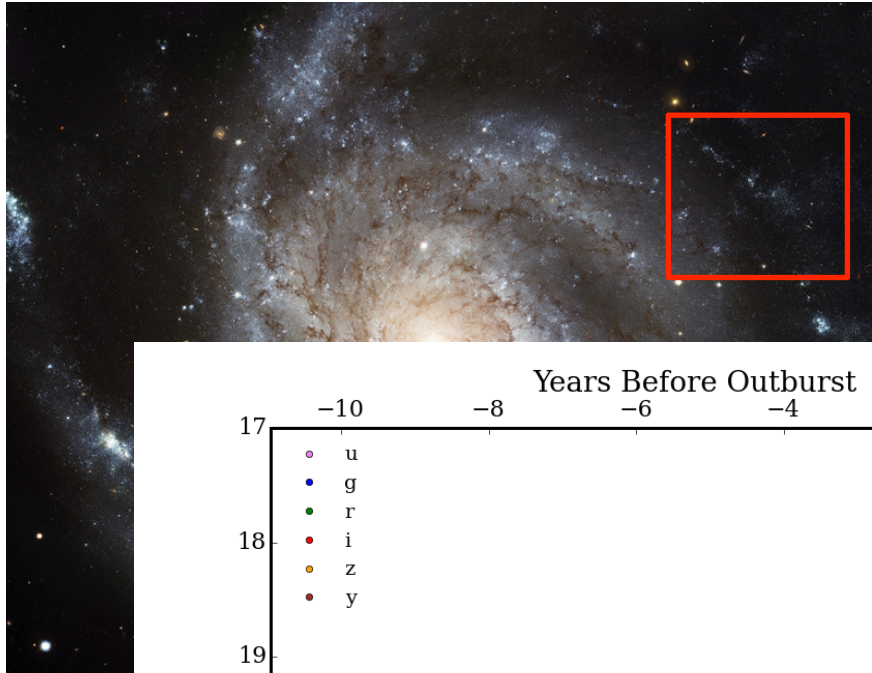
# LRNe



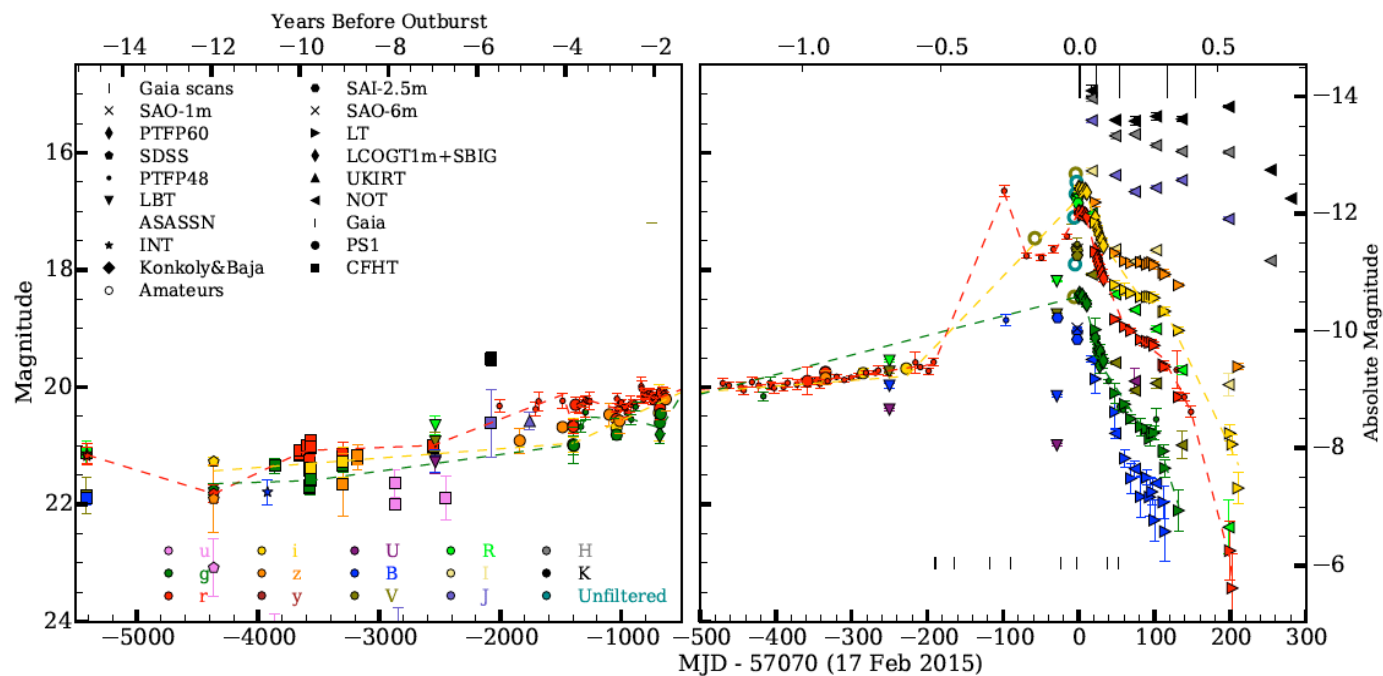
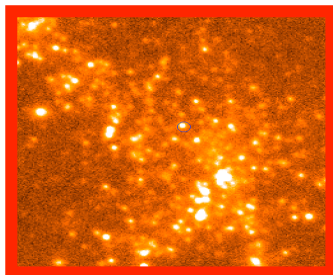
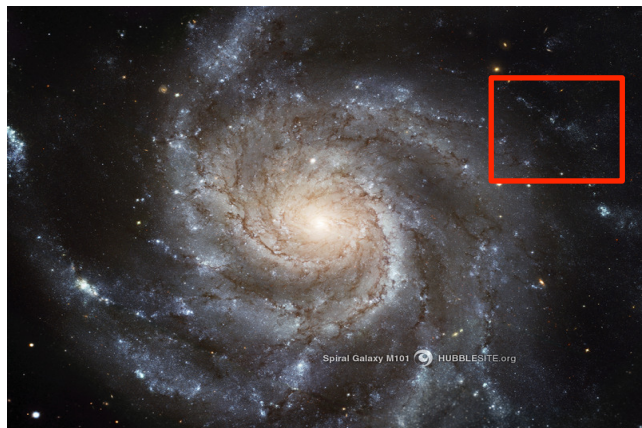
Transient in M101: common envelope ejection massive binary ~6 Mpc







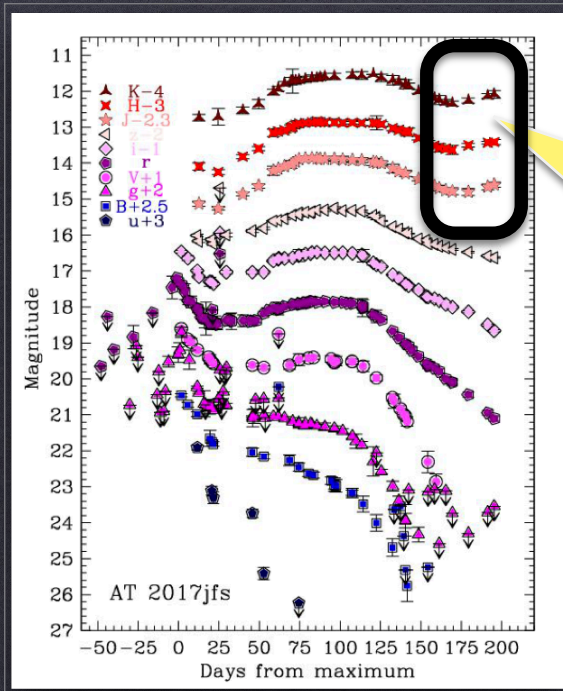
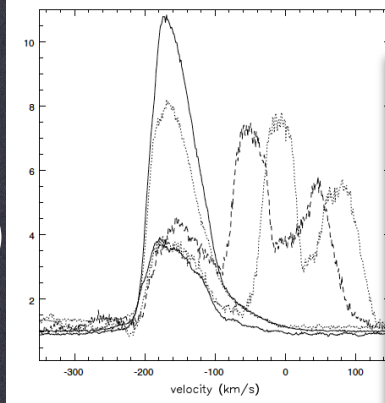
Blagorodnova, RK+ (2017)





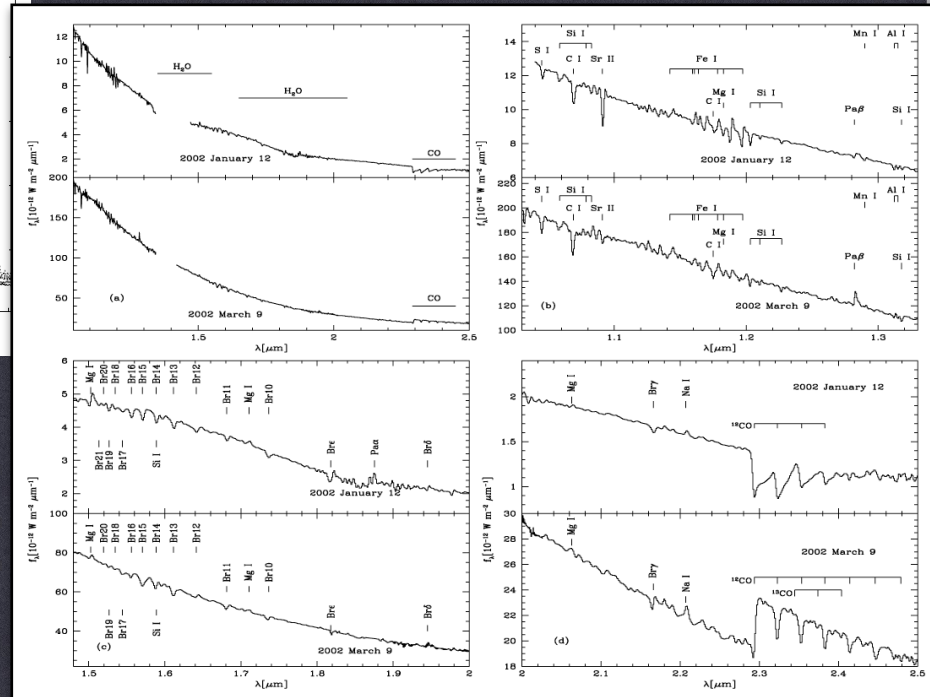
Resolution: line velocity; line profile evolution (precision of a few tens of km/s)

*Mason et al. 2010*



NIR spectra: what's happening here?

*Pastorello+ 2020*



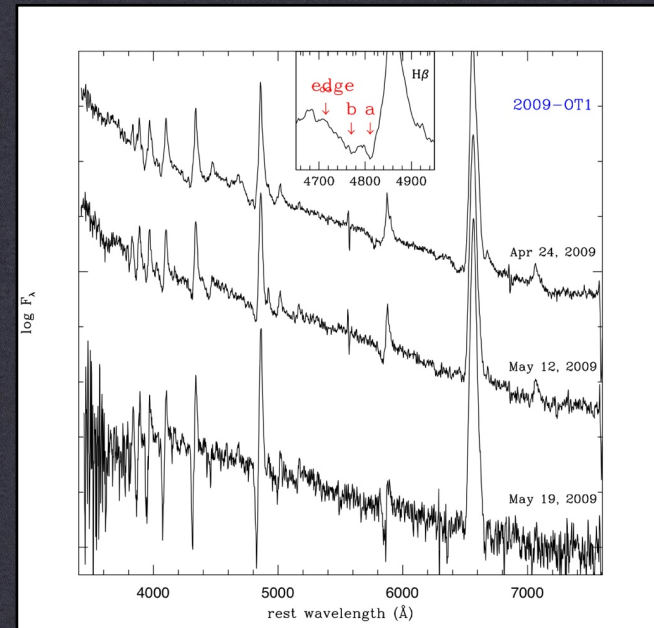
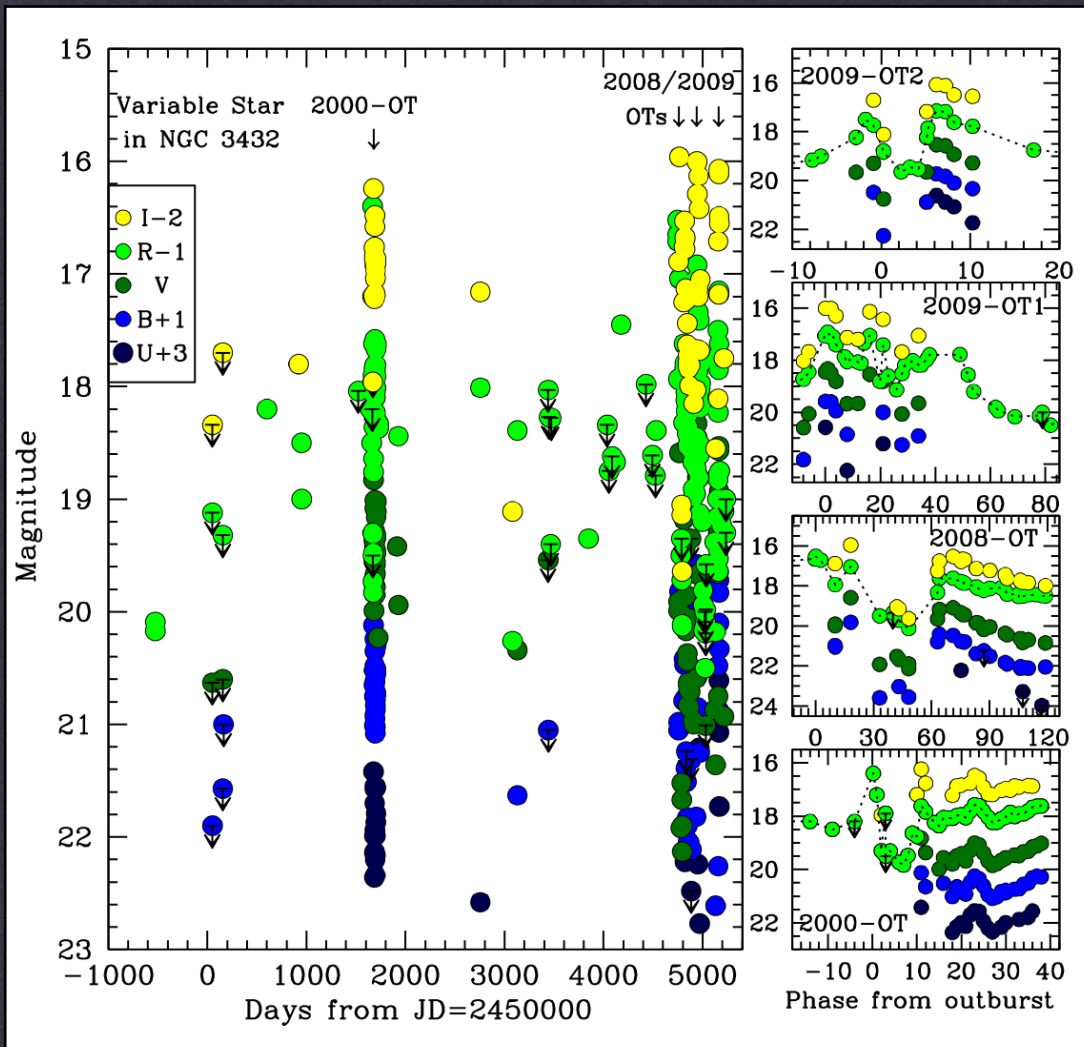
Opt+NIR spectra & good S/N: Late spectral evolution, SED, molecule detection, dust thermal continuum, light echoes

*Rushton+ 2005*

# WHY SOXS?

LRN





*Wagner+ 2004, Pastorello+ 2010*

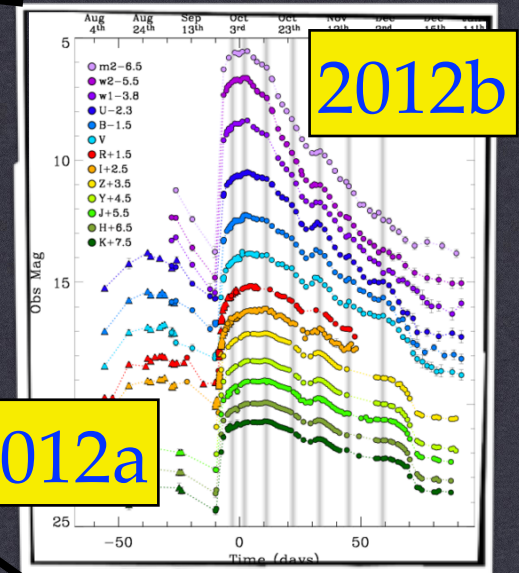
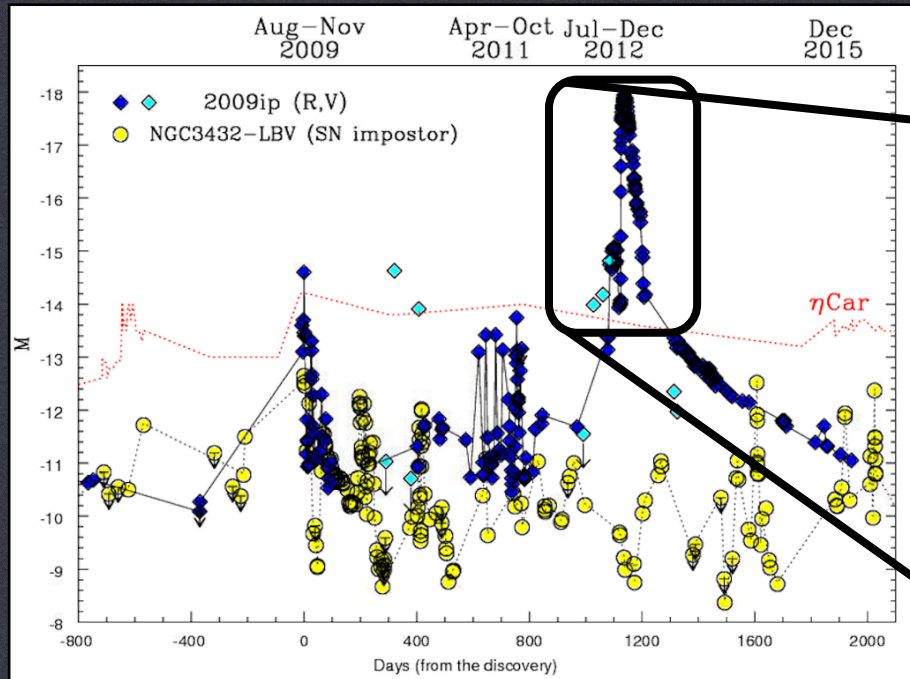
Multiple Outbursts  
of massive LBVs

# SN IMPOSTORS

## LBV GIANT ERUPTIONS



# Outbursts of SN 2009ip: SN / giant outburst / both?

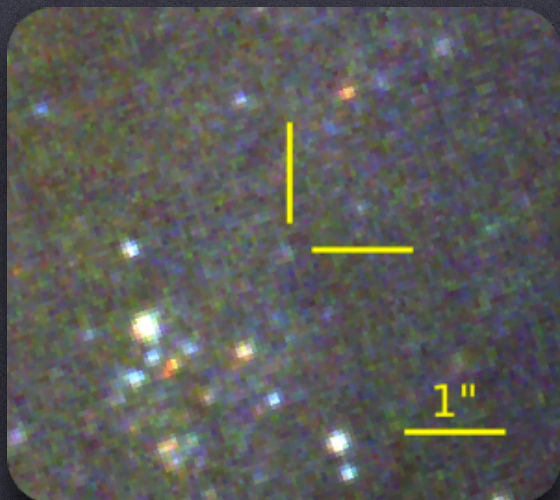


- < mid-2012: repeat outbursts
- Jul. 2012: “outburst” / SN explosion
- Sept. 2012: interaction dominated spectra

**FROM IMPOSTORS TO INTERACTING SNE (MAYBE?!)**

FROM WR OUTBURSTS TO TYPE IIN



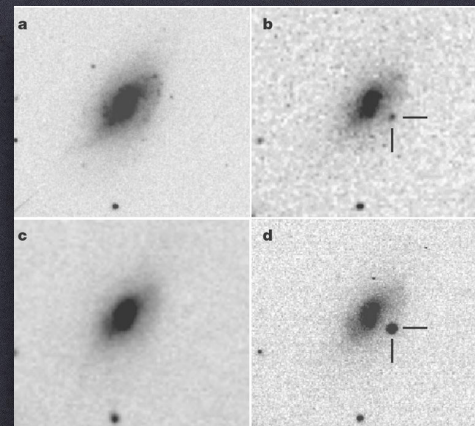


*Maund+ 2016, ApJ, 833, 128*

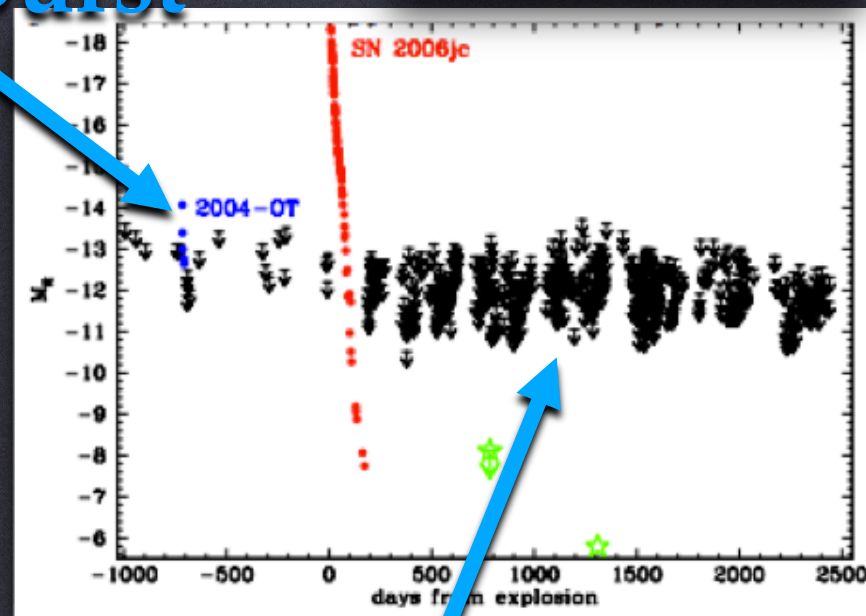
No massive ( $> 8 M_{\odot}$ ) LBV companion!

An LBV-like outburst of a WR or a binary (LBV+WR) system?

Pre-SN outbursts of the first Ibn supernova: 2006jc



2004 burst



A few years of post-explosion monitoring

FROM IMPOSTORS TO INTERACTING SNE

FROM WR OUTBURSTS TO TYPE IBN



- Resolution to resolve very narrow features (a few tens km/s), unblend the different species, and study the line profiles => characterization of the different emitting gas regions.
- Resolution to properly investigate the profile of the interstellar Na ID
- SED coverage, to discriminate multiple temperature components.
- Near-IR coverage, to constrain Fe-peak lines, molecules and dust formation.

Good efficiency of SOXS at blue wavelengths ( $\sim 4000\text{\AA}$ ), to estimate  $T_{\text{BB}}$  at early epochs, and unblend the H/Ca/Fe line forest in the U-to-B region

## WHY SOXS?

SN IMPOSTORS AND INTERACTING SNE

- Rates are not well constrained:
- **ILRTs**: Within  $\sim 15$  Mpc  $\sim$  few / yr  
 $\sim 3$ -5 months of follow-up
- **LRNe**: Mergers of low mass systems relatively common  $\sim 1 / 5$  yrs in Local Group galaxies.  
 $\sim$ heterogeneous evol. 1-6 months (possibly longer in the near IR)
- Should be brighter than  $M_R \sim -12$  (at 10Mpc) to allow reasonable follow-up
- **LBV-GE /ISO**: expect  $\sim 1$ -2 per year, but generally bright  $\Rightarrow$  few tens of Mpc  
generally short-lived, but could be recurrent
- **Very faint “SNe”**: 1-2 over 5yrs (?)  
2-3 months



## Initial time request estimate: 60h / sem

TRANSIENT	OBJECTS PER YR	NO. SPECTRA PER OBJECT	TIME REQUESTED PER SEMESTER
ILRT	3-4	6-8	10h
LRN	4-6	8-10	25h
LBV-GE / OTHER OUTBURST	1	12	15hr
FAINT SNE	<1	8	10hr

- Have grouped some sub-classes together; distinctions only possible once campaign is under way.
- Overlap with several WGs

# Sample sizes

- At the end of 5-yr of SoXS operations, we would aim to have:
  - At least 10 ILOTs
  - At least 10 LRNe
  - A few giant outbursts

Classify all gap transients that are brighter than  $\sim 20$

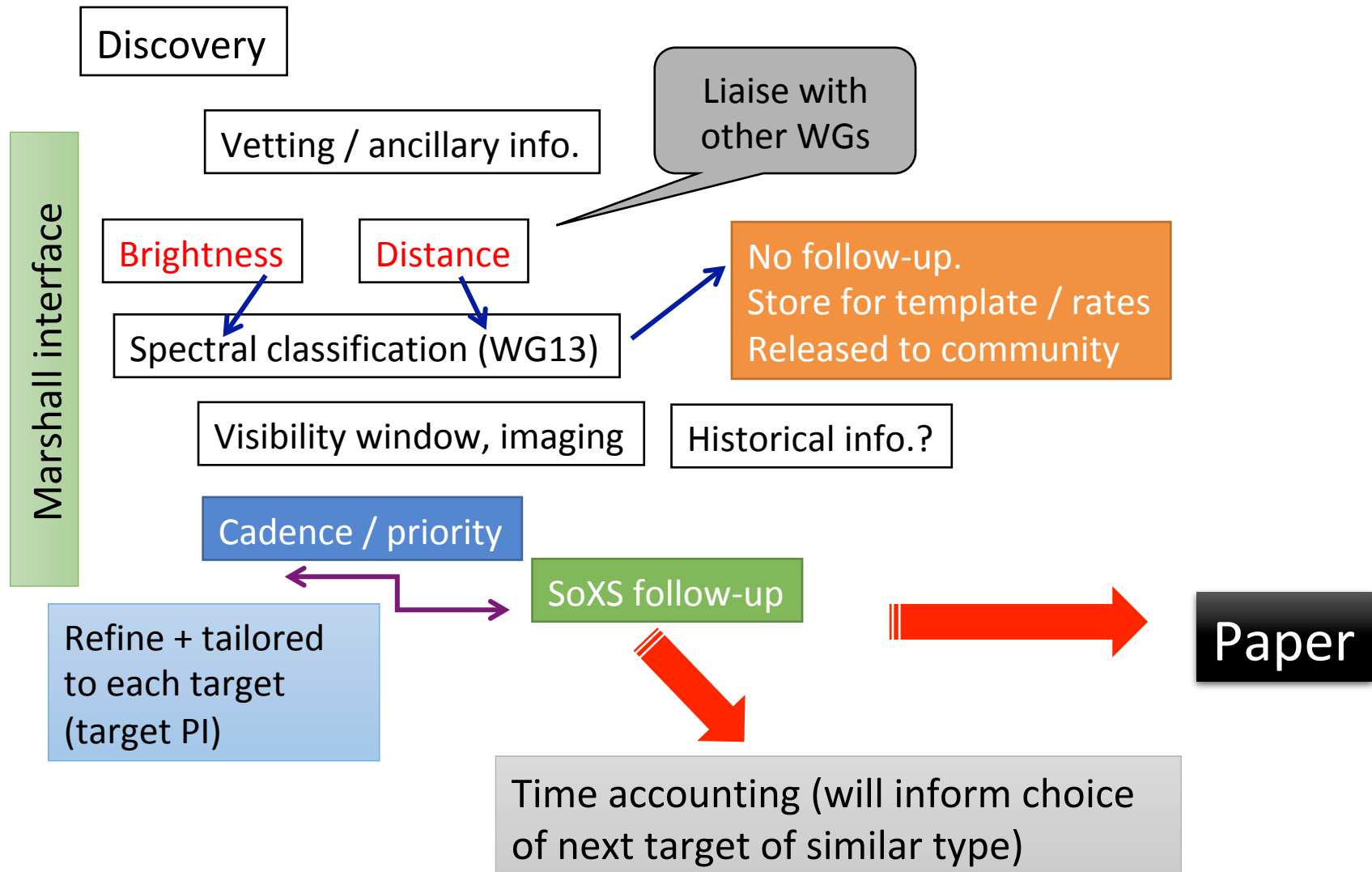
-- will have imaging for these

-- rates

Follow all transients within 20Mpc (not all in WG7)



# Example triggering procedure:



# (Very) Preliminary division of time (not labour)

Current time estimate: 60hr / semester

- Intermediate luminosity transients
- Luminous red novae
- (recurrent) LBVs, other outbursts

General interest across all science areas (ordered): IT, FI, CL-DK-UK

Various time-share configurations possible, spread across science themes within WG7.

Examples (for illustrative purposes only):

- **ILRTs**: IT-75%, FI-20%, other-5% (\*, \*\*)
- **LRNe**: IT-100% or IT-90%, other-10%
- **Outbursts**: IT-80%, FI-10%, other-10%
- **OR** e.g. 1 impostor outburst: FI:90%, other:10%

\* Need to discuss specifics within WG7, but also need to build in some flexibility

\*\* Not accounting for “grey” targets that fall into >1 WGs

→ WG7: 1 proposal for all of the above

→ Monitoring proposals may not fit within GTO (currently considering alternatives)