News from the X-Ray to Infrared Transient Sky

Arne Rau (Caltech)
The phase space of optical transients
M85OT2006-1 - a Luminous Red Novae

- Lick Observatory Supernovae Search, Jan 07 2006 at 19.3mag
- 2.3kpc from center of M85
- peak V=-13
- precursor F475W > -4.3 and F850LP > -6.4
- old stellar population (M < 7 Ms)
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M85OT2006-1

(Kulkarni et al., Nature, 2007)
P200/DBSP (Jan 08) and Keck/LRIS (Feb 24)

Hα and Hβ at M85 distance (15Mpc), FWHM = 800+350 km/s

T_{BB} \sim 4600 \text{ K}

A_R < 1 \text{ mag}
M85OT - Late Time Evolution

$L_{t=6\text{month}} = 10^{39} \text{ erg/s}$

$R_{t=6\text{month}} = 20000 \, R_*$

(Rau et al. 2007)
M85OT - Late Time Evolution

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Models - IIP, Stellar Merger, Nova

- **low-luminosity** (<10^{50} erg/s) SN IIP
- narrow Hα lines,
- N_i < 10^{-3} M_\odot, 6-9 M_\odot ejected
- progenitor < 12-15 M_\odot (K-M SG)

**Stellar Merger** (Tylenda & Soker 2006)
- common envelope phase
- low mass progenitor
- similar to V838 Mon

**Extreme Classical Nova** (Shara et al. 2008)
- low mass (0.5 M_\odot), cold (2-4 \times 10^6 K), low M_{acc} (10^{-10} M_\odot/yr)
- massive (10^{-3} \text{--} 5 M_\odot) H-rich envelopes
- massive (10^{-3} M_\odot) low-\nu (100-400 km/s) ejecta – dust/molecule formation
- predicts high-O abundances (as in V838 Mon) and T>10^6 K WD remnant (claimed for M31RV)
Rates, Stellar Population etc

Event rates:

- $0.016 \text{ yr}^{-1} \text{ L}_{\odot}^{-1}$ from known number of events (Ofek et al. 2007) and theory of stellar mergers visible out to $D (r=24) \sim 150 \text{ Mpc (M85OT like)}$ up to 3500 events per year
- identifiable out to $D (r=23) \sim 40 \text{ Mpc (V838 Mon like)}$ up to 70 events per year

Stellar Population:

- eruption mechanism likely independent of stellar age
- M31RV in bulge, V838 Mon in B-star cluster, M85OT (?)

The LRNe Sample:

- M31RV (Rich et al. 1989)
- V4332 Sgr (Martini et al. 1999)
- V838 Mon (Brown et al. 2002)
- M85OT-2006-1 (Kulkarni et al. 2007)
An Extremely Luminous X-ray Outburst
during serendipitous Swift/XRT observation of NGC2770 (27 Mpc)
UVOT counterpart appeared 85min later at U=19.8
Properties of the X-ray Outburst

An Extremely Luminous X-ray Outburst
- Powerlaw best fit ($\Gamma_{\text{peak}}=1.7$, $\Gamma_{400s}=3.2$, $N_H=7 \times 10^{21} \text{ cm}^{-2}$)
- BAT limits consistent with XRT extrapolation
- $L_{x,\text{peak}} = 6 \times 10^{43} \text{ erg s}^{-1}$, $E_x=2 \times 10^{46} \text{ erg}$
- Non-relativistic, shock break-out (thermal below XRT) + bulk Comptonization (powerlaw, soft)
- Outbreak radius $>7 \times 10^{11} \text{ cm}$ --> likely from dense stellar wind lost few hours prior explosion
Optical spectroscopy - it is a Ibc!

- evolution from featureless to broad absorption
- NaI, Hα and SNe abs. = NGC2770
- extinction from Keck/HIRES
- coverage exceeds that of most SNe, including GRB-SNe
- not swamped by an GRB afterglow
Photometric Evolution - Two Components

Early:
- thermal component from cooling of outer stellar envelope after shock
- $R=10^{11}$ cm (WR consistent)
- $T_{ph}=14000$ K, $R_{ph}(t=1)=10^{14}$ cm

Late:
- normal SN Ibc
Implications

Rates
- discovery consistent with CC SNe rate (from XRT coverage of nearby galaxies)
- BAT (mission) non-detection still consistent for events within 20Mpc
- detection possible (sub-threshold experiment)
- but, NGC2770 may be special (3 Ibc in last decade)

Future
- several hundred CC SNe in wide-field survey with XRT-like sensitivity
- unbiased against dust, even at the time of the explosion

Importance
- likely every CC SNe will have shock-breakout
- probe early phases of explosion
- study radius and mass loss (hours before eruption)
- provide crucial temporal triggers for neutrino and gravitational wave detectors
Spectral Evolution (V4332 Sgr)

- $\frac{H\alpha}{H\beta}$ (11 days) = 2.4
- $\frac{H\alpha}{H\beta}$ (97 days) = 17
- $N_e = 10^{8-9} \text{ cm}^{-3}$
- KI, RbI, TiO, ScO emission after 9 years

(Martini et al. 1999)
Open Questions

Observations

- large peak brightness range (-3 to -12)
- single vs multiple outburst
- late time differences (photometric and spectroscopic)
- PCyg lines in all but V4332 Sgr (inverse)
- old (M85OT, M31RV, V4332 Sgr) vs young (V838 Mon) stellar population

Theory

- stellar merger vs massive novae vs faint CCSNe vs ...
Summary

- very small sample of long-lasting transients in brightness gap between novae and supernovae
- low velocity ejecta with strong redward evolution indicating dust condensation
- explosion mechanism independent of stellar population?
- merging stars, unusual bright novae or faint supernovae
- 1 event every $10-50$ years per MW-like galaxy
- $10-10^3$ events with PTF to LSST