# Rapid Dust Formation in Novae: Speed Class vs Grain Formation Timescale


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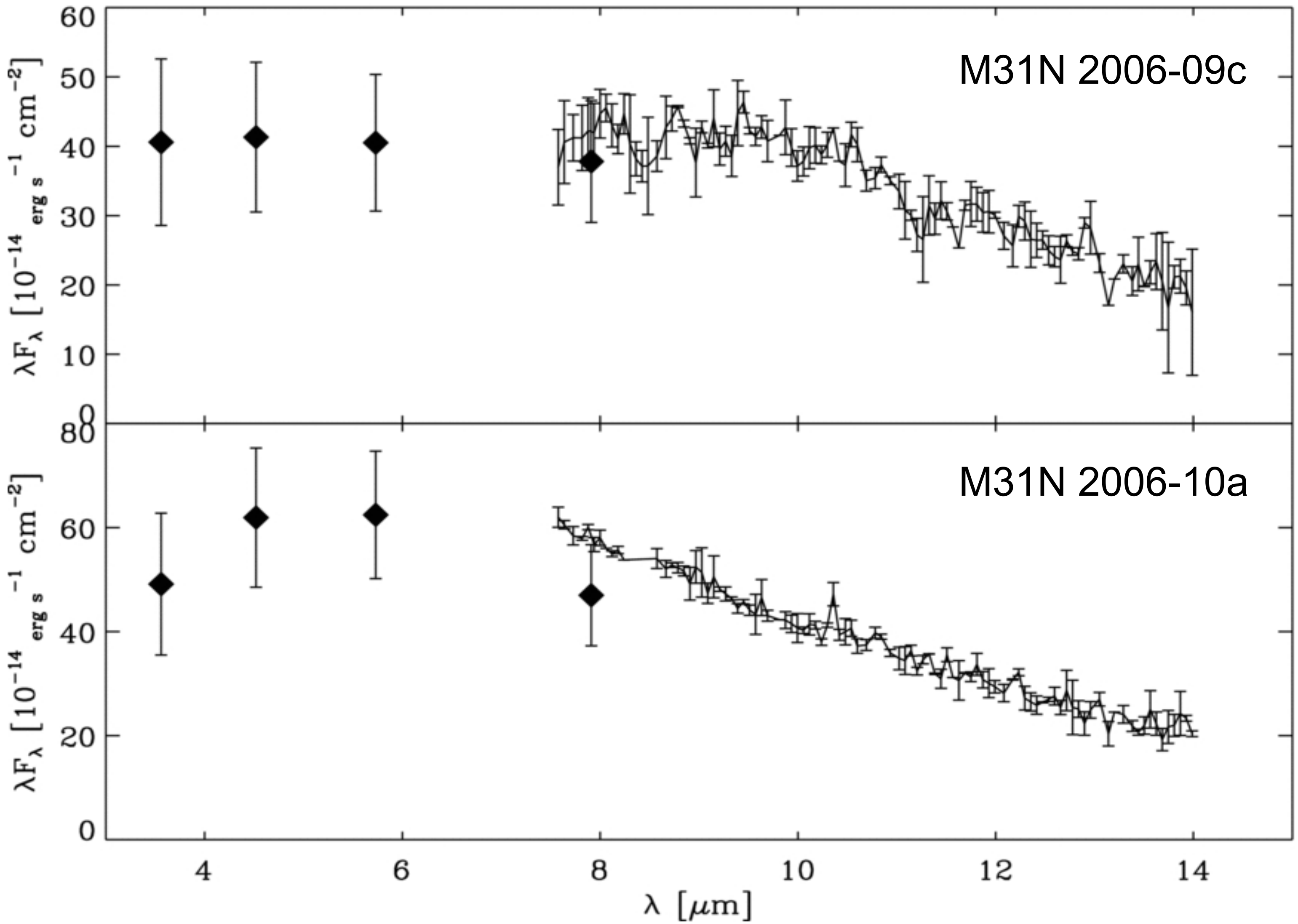
# Outline

- Results from the Spitzer Survey of M31 Novae
- The Simplest Model
- More Refined Modelling
- Results and Conclusions

# Spitzer Survey of M31 Novae
## (Shafter, Bode et al. 2011)

- 10 CNe in M31 observed with IRAC/IRS, 3-7 months after discovery, 8 detected
- Complemented by ground-based observations: optical light curve (2m LT; 0.65m Ondrejov; 0.28m Zlin); spectral type (HET)
- Dust formation detected in M31N 2006-10a; 2007-07f (+ [NeII]12.8um in 2007-11e)
- 2006-10a – no silicate feature, $M_d \sim 2 \times 10^{-6} M_{sun}$ assuming graphite grains

# E.g. IRAC, IRS results



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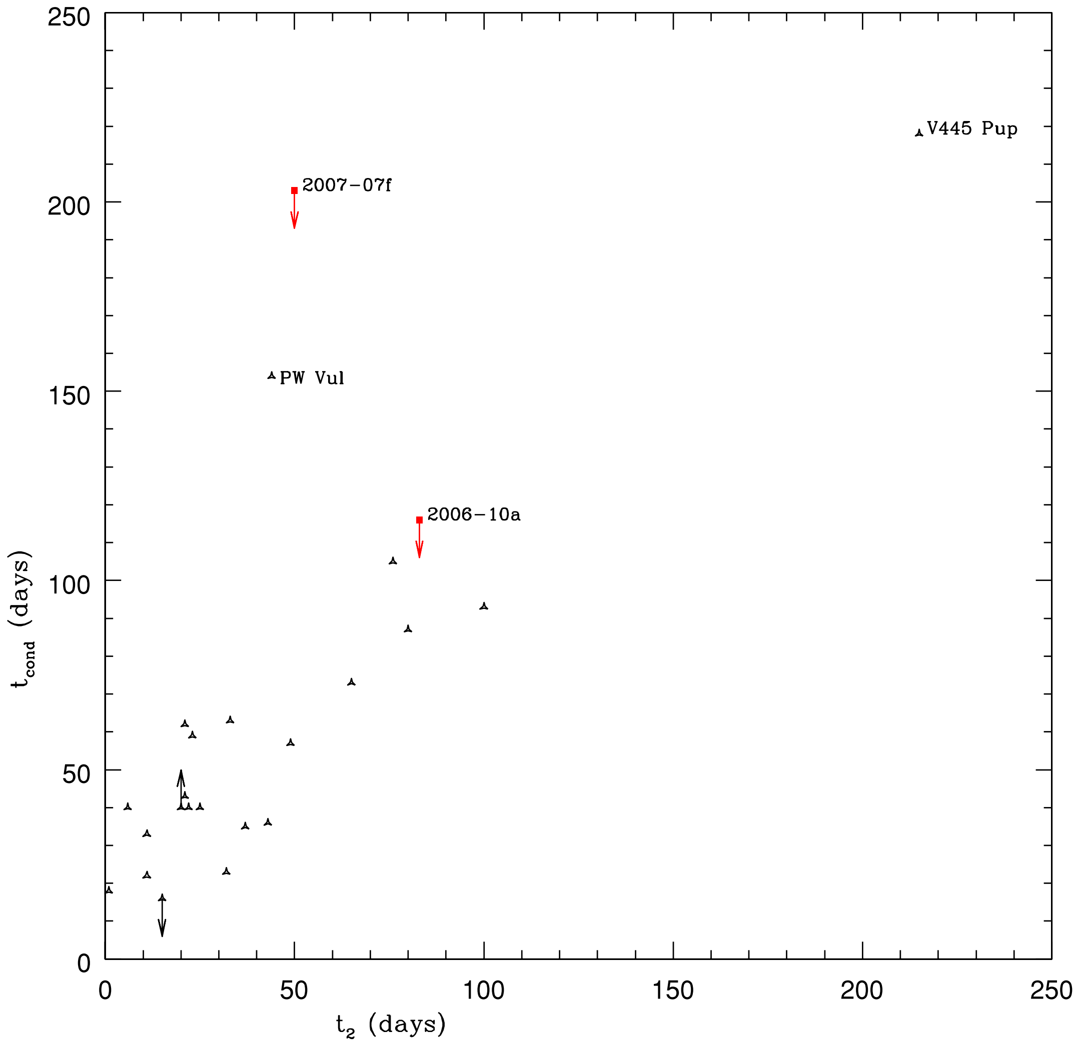
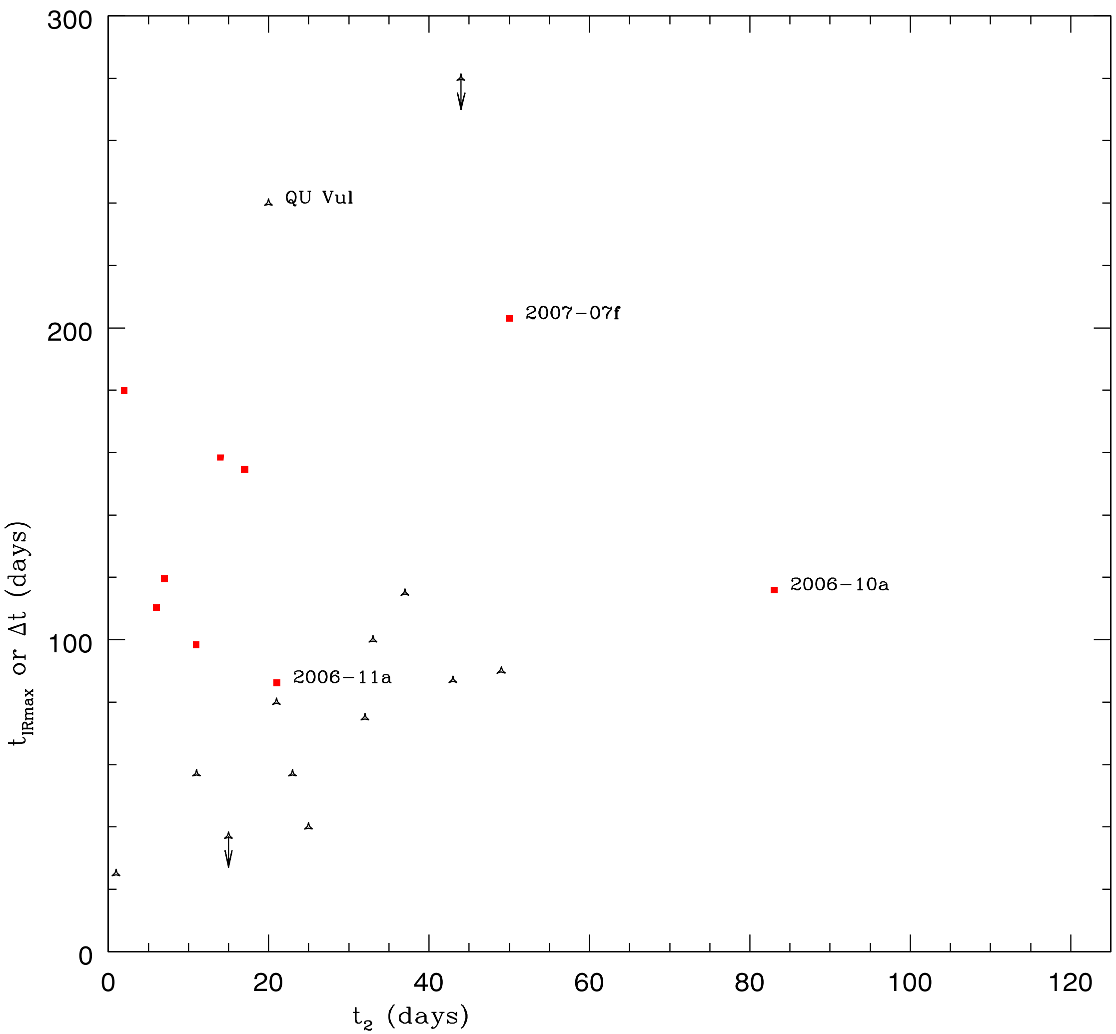
# Comparison to Galactic Novae - condensation time



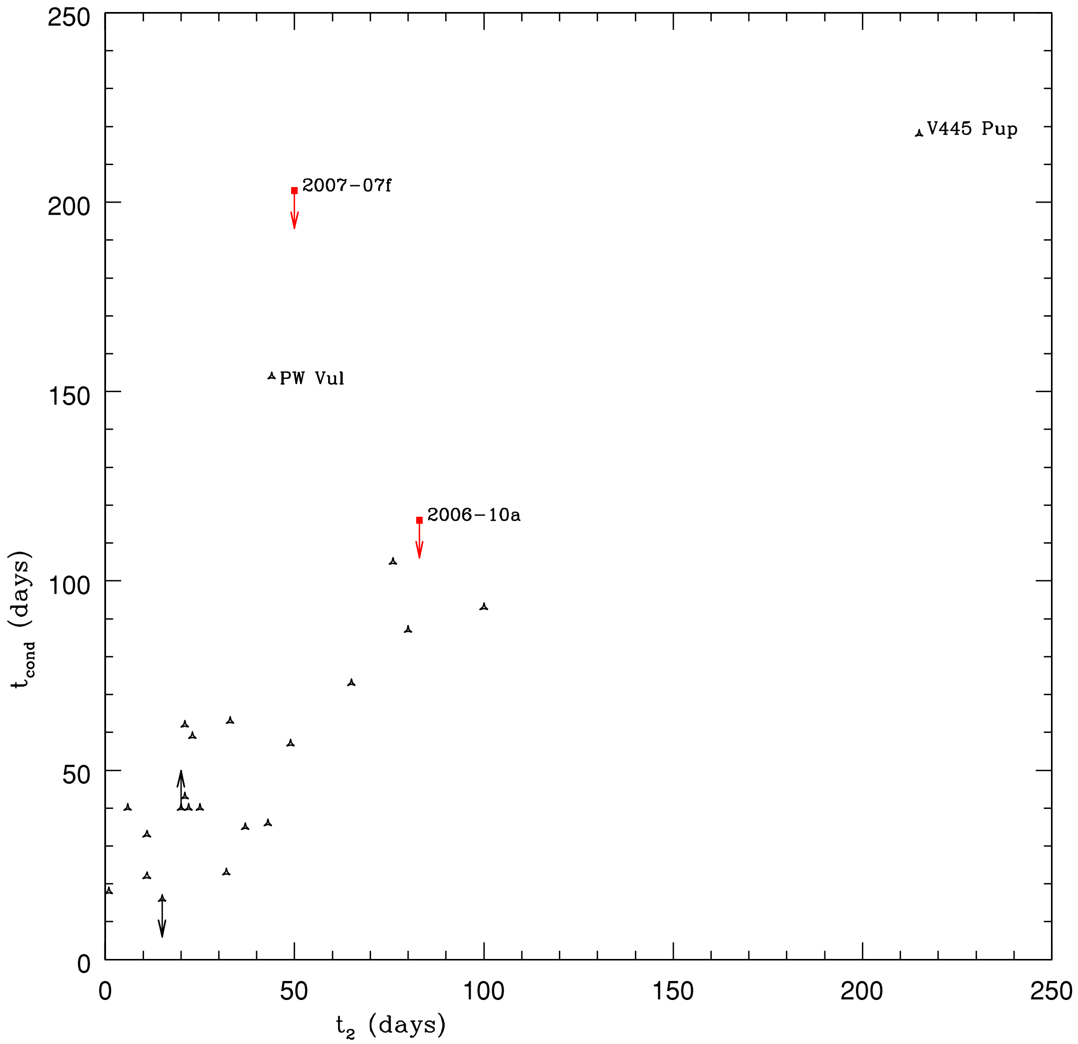

- $t_{cond}$ from Evans & Rawlings (2008); Strope et al. (2010)
- Upper limit for both M31 novae
- Apparent strong correlation (note outliers)

# Time of maximum IR emission




- Also apparent correlation here
- QU Vul – peak of 10um emission
- $t_{cond}$ ~1-3 months after o/b, (mean ~2m; $t_{IRmax}$ ~3m)
- M31 novae observed at 3-7m

# Comparison to Galactic Novae - condensation time

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# Zeroth Order Model

From energy balance:

$$t_{\rm cond} = \left[ \frac{L}{16\pi V_{\rm ej}^2 \sigma T_{\rm cond}^4} \frac{\langle Q_{\rm a} \rangle}{\langle Q_{\rm e} \rangle} \right]^{\frac{1}{2}} \qquad \propto L^{1/2} V_{\rm ej}^{-1}$$

then MMRD (see e.g. Warner 2008; $b_2 \sim 2.5$)

$$2.5 \log L \propto -\log t_2^{b_2} \qquad\qquad L \underset{\sim}{\propto} t_2^{-1}$$

and empirical relationship with ejection velocity

$$\log V_{\rm ej} = 3.57 - 0.5 \log t_2 \qquad\qquad V_{\rm ej} \propto t_2^{-0.5}$$

Thus $t_{\rm cond}$ effectively independent of $t_2$ - including errors in MMRD from Downes & Duerbeck (2000) $t_{\rm cond} \propto t_2^{-0.01 \pm 0.06}$.

# First Order Model

- Grain nucleation and growth in outermost neutral regions
- H absorption cuts off emission incident on forming grains at Lyman limit

Again, from MMRD:

$$M_V = 2.5 \log t_2 - 11$$

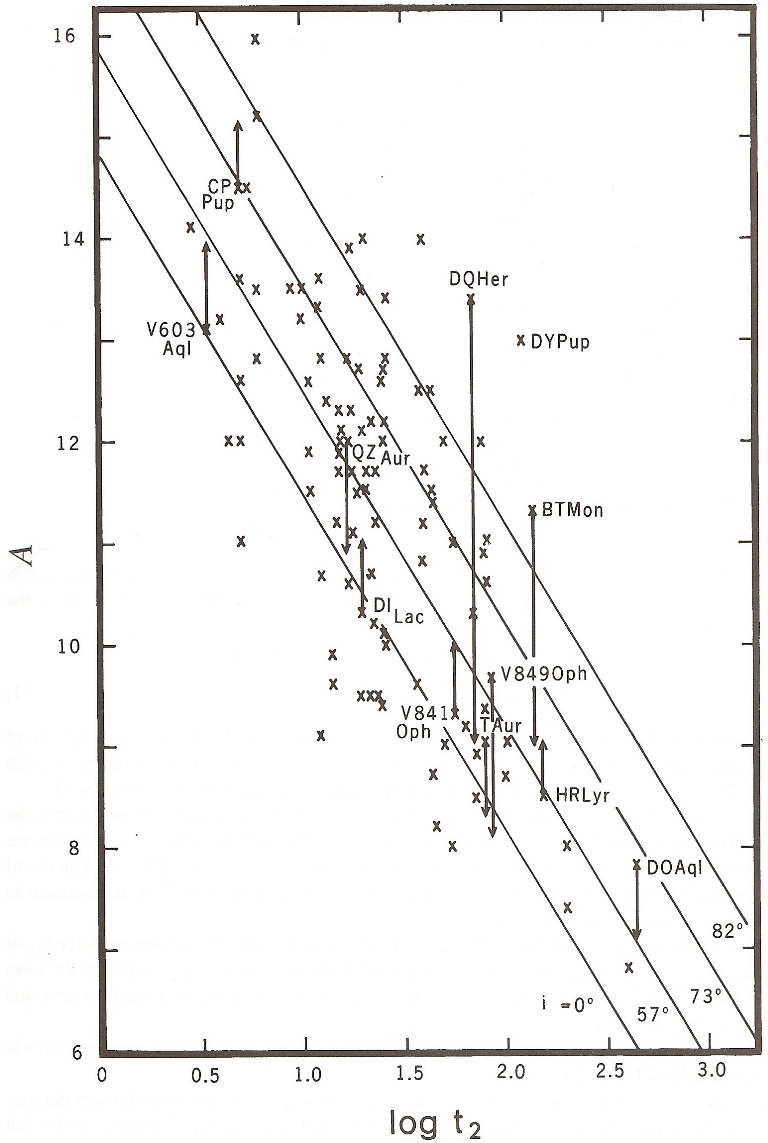
with BC~0 at peak, derive $L_{bol}$ from $t_2$.

Central source continuum evolves according to

$$T_{\rm eff} = T_0 \times 10^{\Delta V/2.5},$$

(Bath & Harkness 1989; $T_0$ = 8000K, Evans et al. 2005)

# Model Optical Light Curves



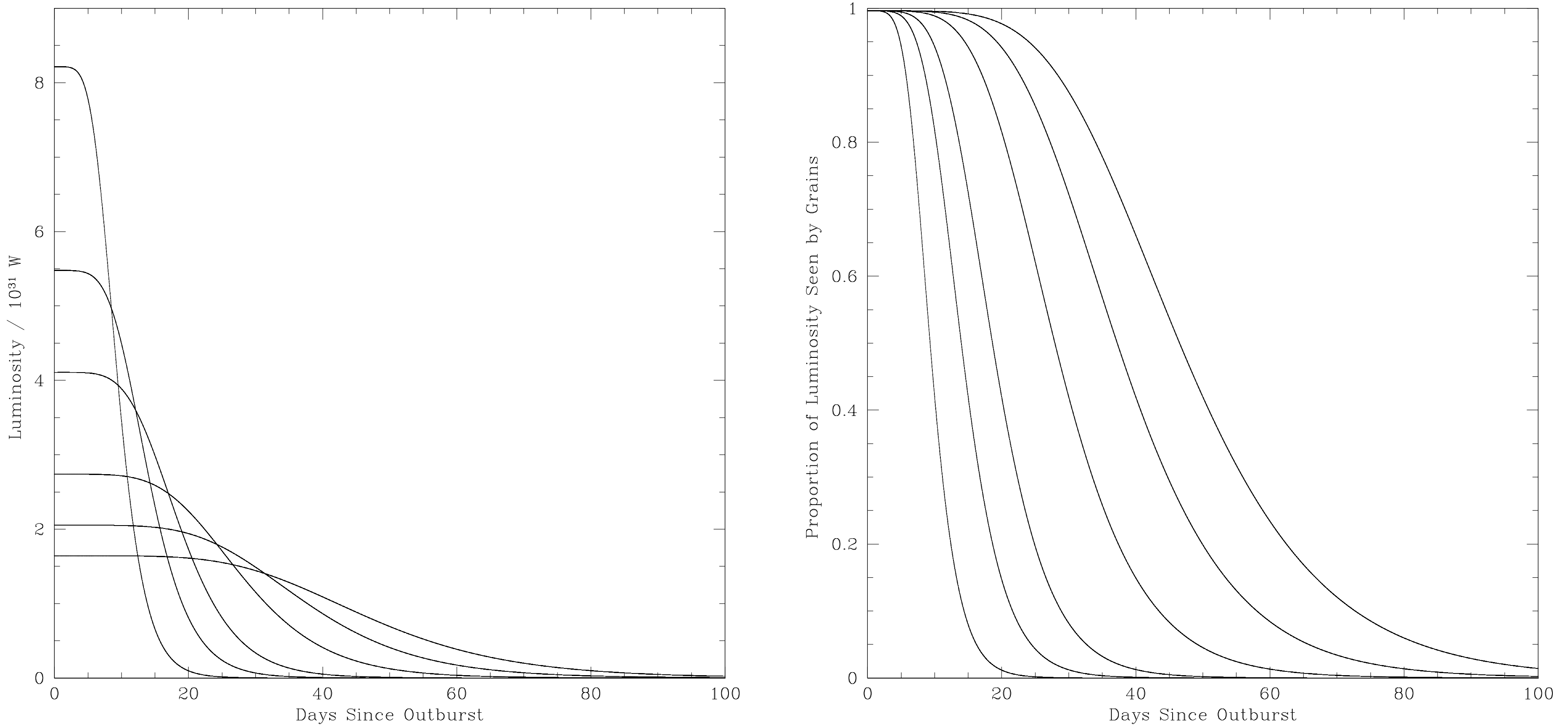

- *A* vs $t_2$ (Warner 1995) and exponential decline

- Unabsorbed luminosity

$$L_{\rm Ly} = 4\pi^2 R^2 \int_{91.2\ {\rm nm}}^{\infty} B_\lambda(T)\,d\lambda$$

where *R* is radius of pseudophotosphere with $T = T_{\rm eff}$

# Resulting Effective Luminosity




$t_2$ = 10, 15, 20, 30, 40, 50 days ($t_2$ = 10 highest luminosity)

# Dust Model

- Nucleation centres $C_8$, *a* ~ 0.26nm (Evans & Rawlings 2008)
- $Q_{abs}$ for graphite and ACH2 (Zubko et al. 1996)calculated for 0.26 < *a* < 5nm

For graphite

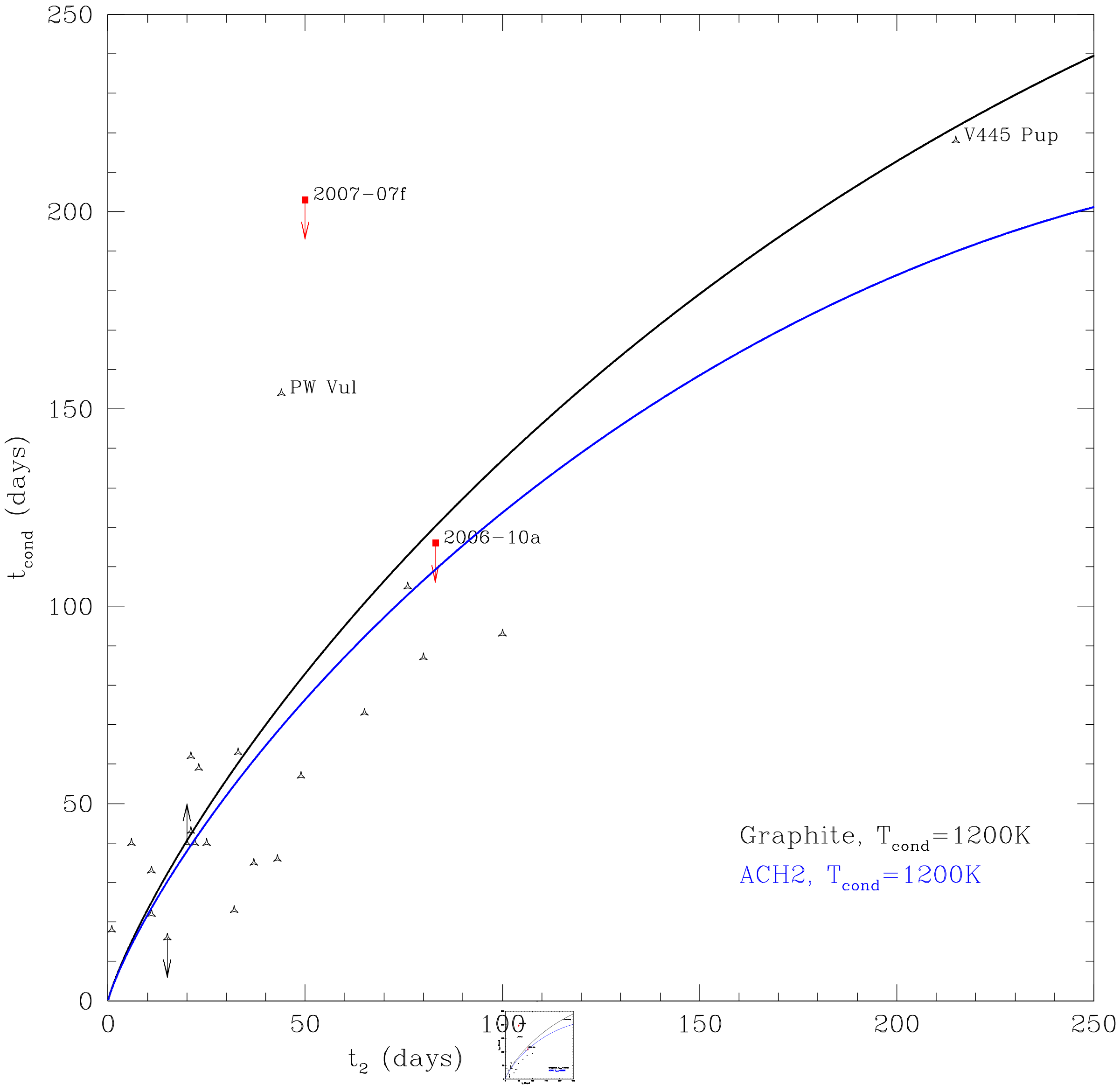
$$\langle Q_\mathrm{e} \rangle \simeq 0.15 a T_d^{1.5}, \; T_\mathrm{d} = \left[ \frac{5 L_\mathrm{bol}}{12 a \sigma^2 T_\mathrm{eff}^4 V_\mathrm{ej}^2 t^2} \int_{91.2\ \mathrm{nm}}^{\infty} B_\lambda(T_\mathrm{eff}) Q_\mathrm{abs}(a,\lambda) d\lambda \right]^{0.18}$$

and ACH2

$$\langle Q_\mathrm{e} \rangle \simeq 400 a T_d^{0.46}, \; T_\mathrm{d} = \left[ \frac{L_\mathrm{bol}}{6400 a \sigma^2 T_\mathrm{eff}^4 V_\mathrm{ej}^2 t^2} \int_{91.2\ \mathrm{nm}}^{\infty} B_\lambda(T_\mathrm{eff}) Q_\mathrm{abs}(a,\lambda) d\lambda \right]^{0.22}$$

Solved numerically for $T_d$ = $T_{cond}$ = 1200K (Evans & Rawlings 2008) to give $t_{cond}$ vs $t_2$

# Results



2007−07f
PW Vul
2006−10a
V445 Pup
Graphite, $T_{cond}$=1200K
ACH2, $T_{cond}$=1200K
$t_{cond}$ (days)
$t_2$ (days)
0
50
100
150
200
250

# Concluding Remarks

- There is a strong correlation of dust condensation timescale with speed class
- The 'first order' model produces surprisingly good agreement with results, despite the simplistic assumptions made
- Refinements would include more realistic spectral energy distributions as seen by nucleation centres, luminosity evolution, etc.
- NIR obs of dust in M31 novae possible with ground-based 8m-class telescopes