# EVLA Constraints on the Progenitors of Supernovae Type Ia


Laura Chomiuk (Jansky Fellow, Harvard-Smithsonian CfA)

Alicia M. Soderberg (Harvard)

Roger Chevalier (Virginia)

Carles Badenes (Tel Aviv)

Claes Fransson (Stockholm)


Atacama Large Millimeter/submillimeter Array

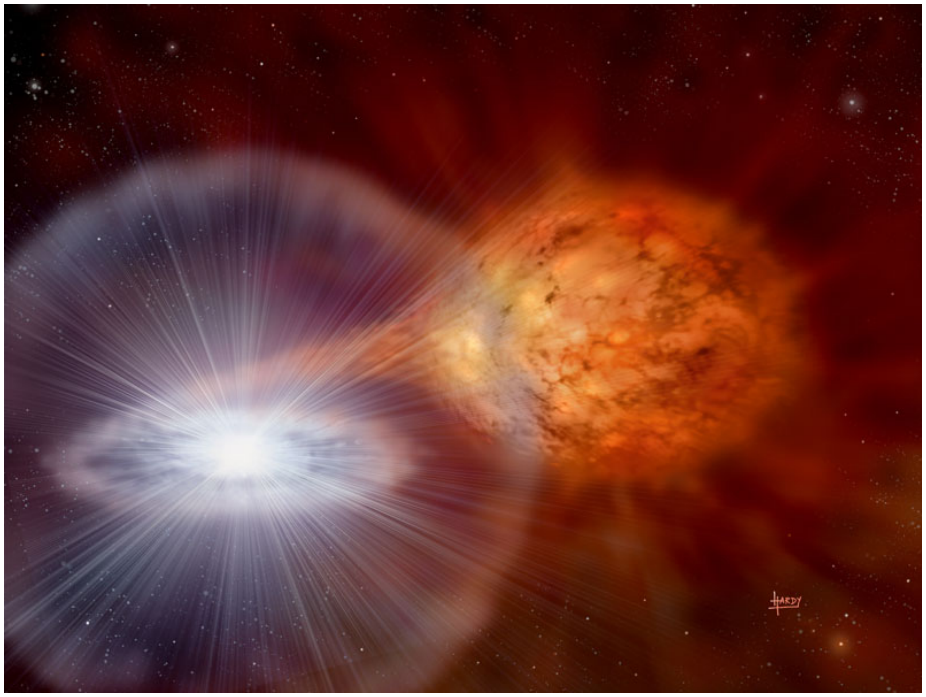
Expanded Very Large Array

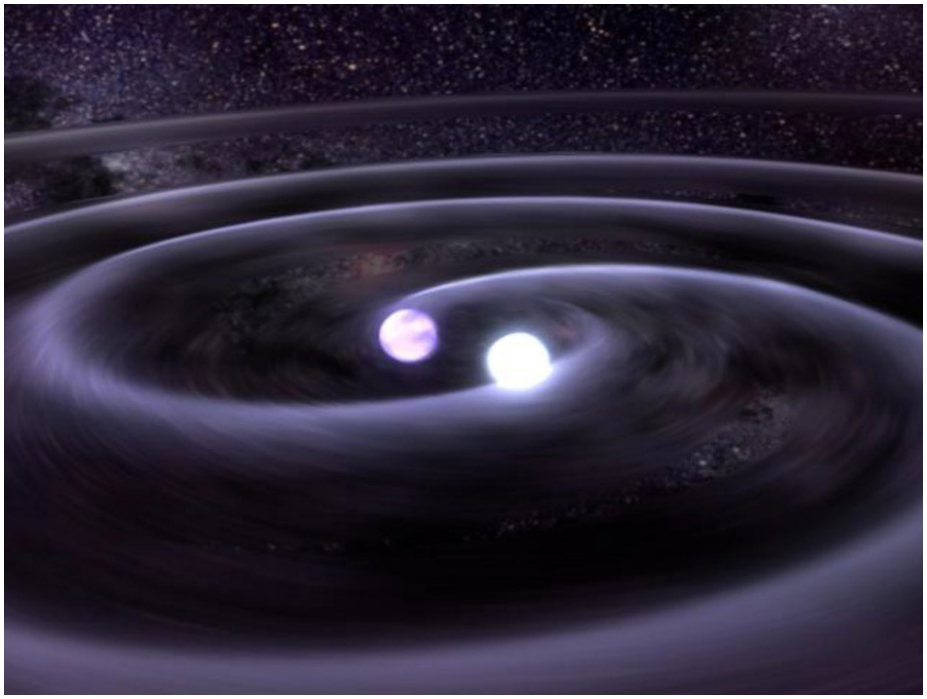
Robert C. Byrd Green Bank Telescope

Very Long Baseline Array

NRAO

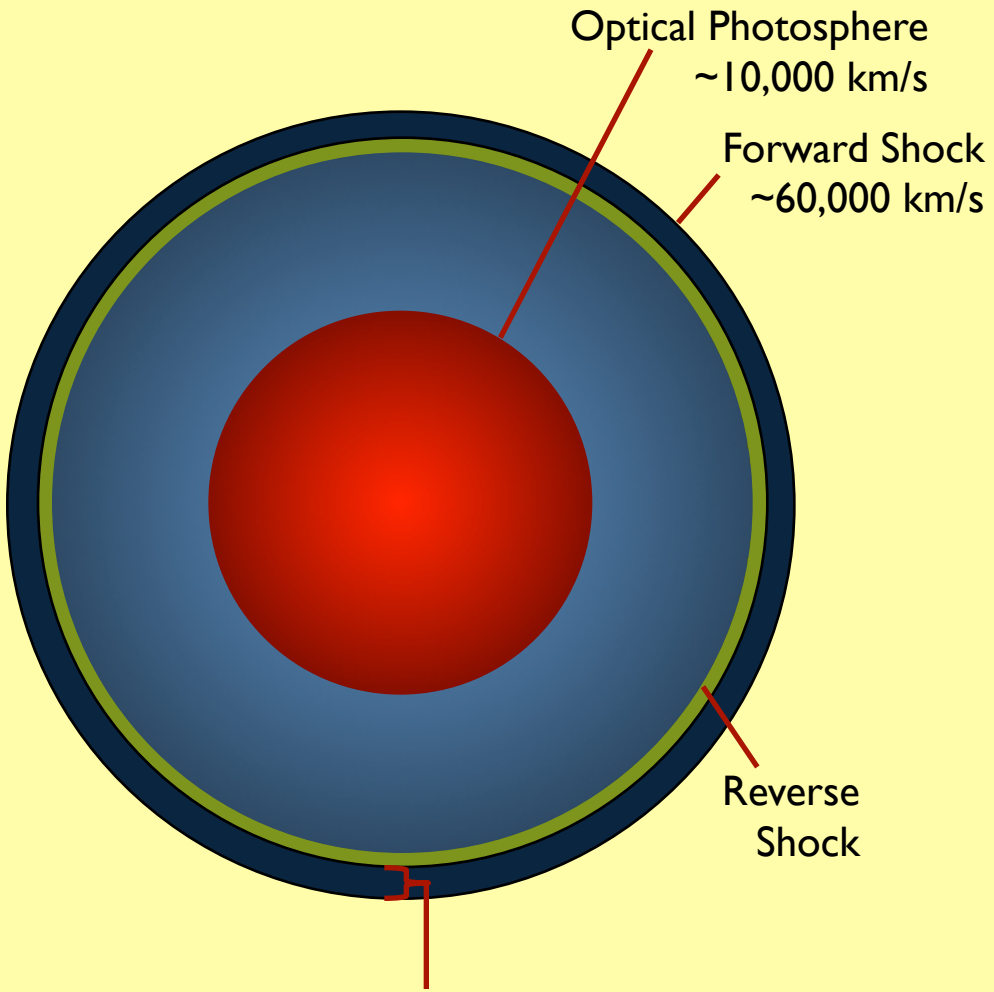
# What are the progenitors of Type Ia supernovae?



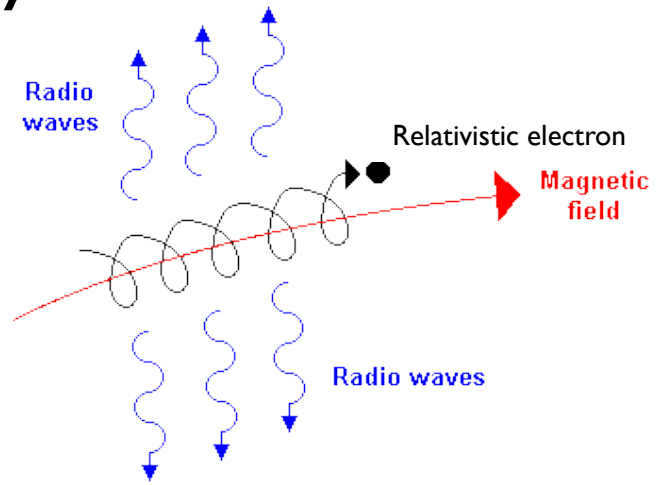


## Single Degenerate or Double Degenerate?

# How does radio trace circumstellar material?




## Synchrotron Emission




Energy densities of magnetic field and relativistic electrons scale with post-shock energy density:

$$U_B \sim U_e \propto \rho_{csm}\ v_s^2$$

$$\boxed{L_{radio} \propto \rho_{csm}^2}$$

# How does radio trace circumstellar material?

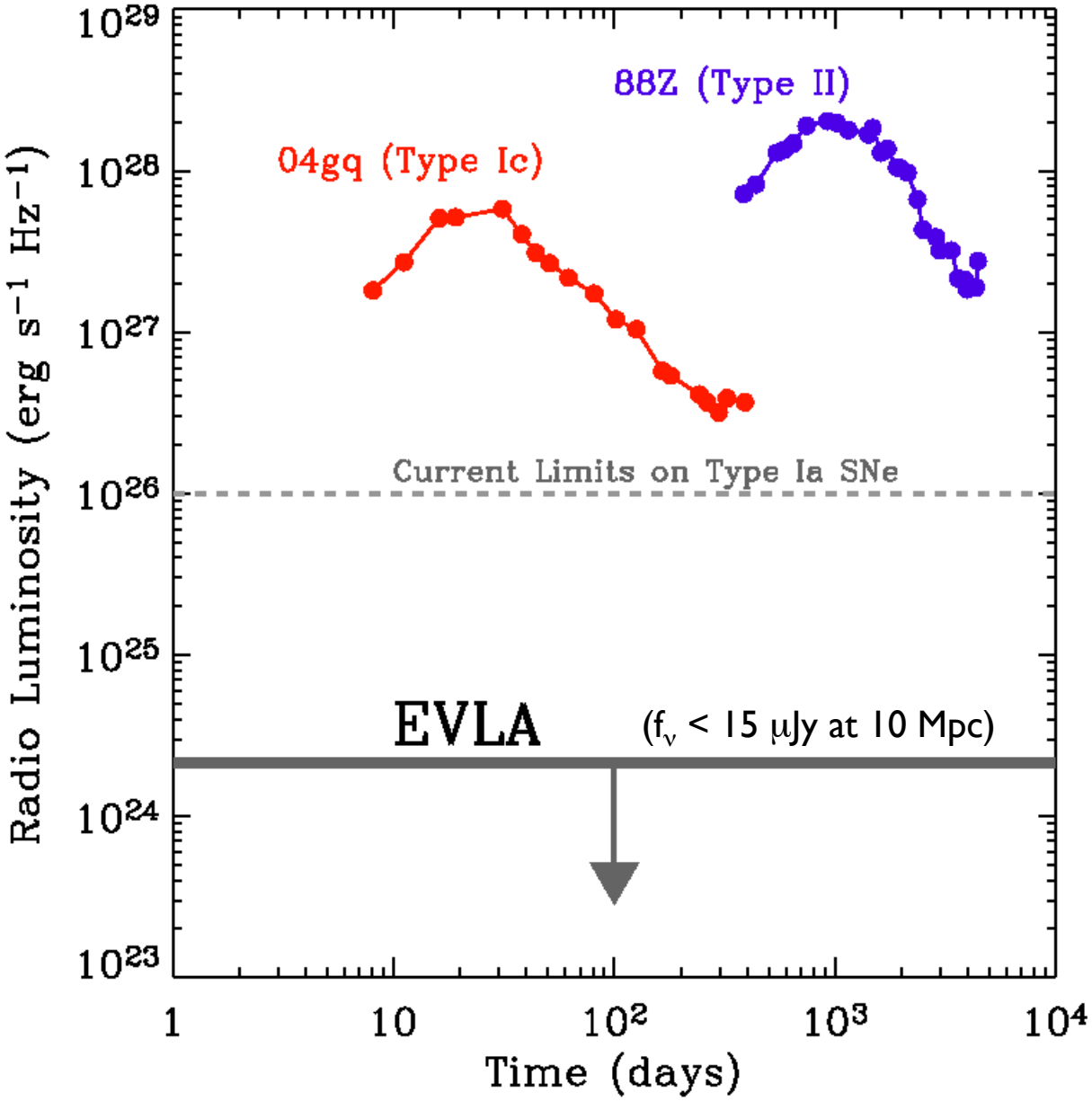

No radio emission has ever been detected from a SN Ia.

Synchrotron Emission

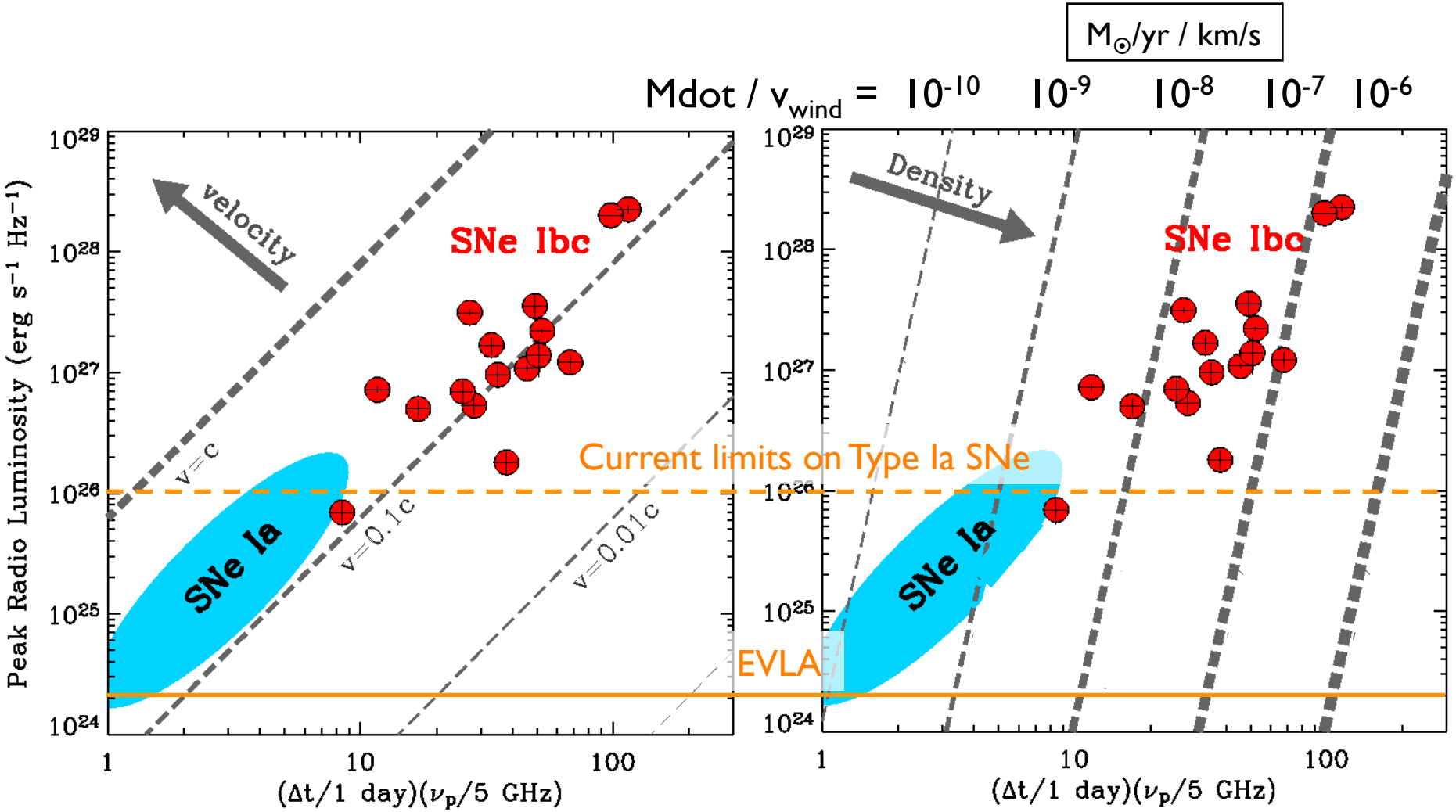

Energy densities of magnetic field and relativistic electrons scale with post-shock energy density:

$$U_B \sim U_e \propto \rho_{csm}\, v_s^2$$

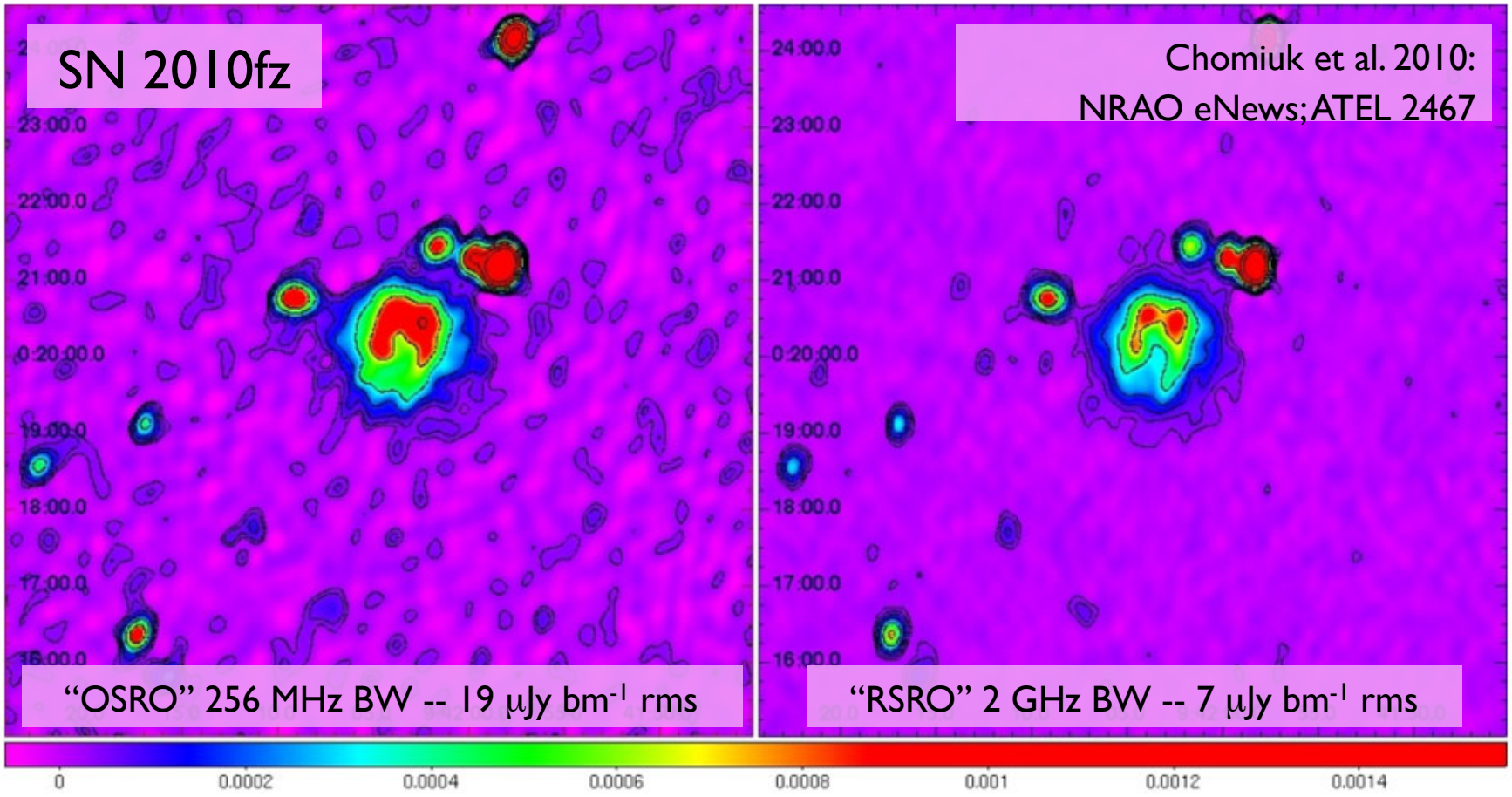
$$\boxed{L_{radio} \propto \rho_{csm}^2}$$


88Z (Type II)
04gq (Type Ic)
Current Limits on Type Ia SNe
EVLA
($f_\nu$ < 15 μJy at 10 Mpc)
Radio Luminosity (erg s$^{-1}$ Hz$^{-1}$)
Time (days)
$10^{29}$
$10^{28}$
$10^{27}$
$10^{26}$
$10^{25}$
$10^{24}$
$10^{23}$
1
10
$10^2$
$10^3$
$10^4$

# We can extend models for SNe Ibc to SNe Ia.

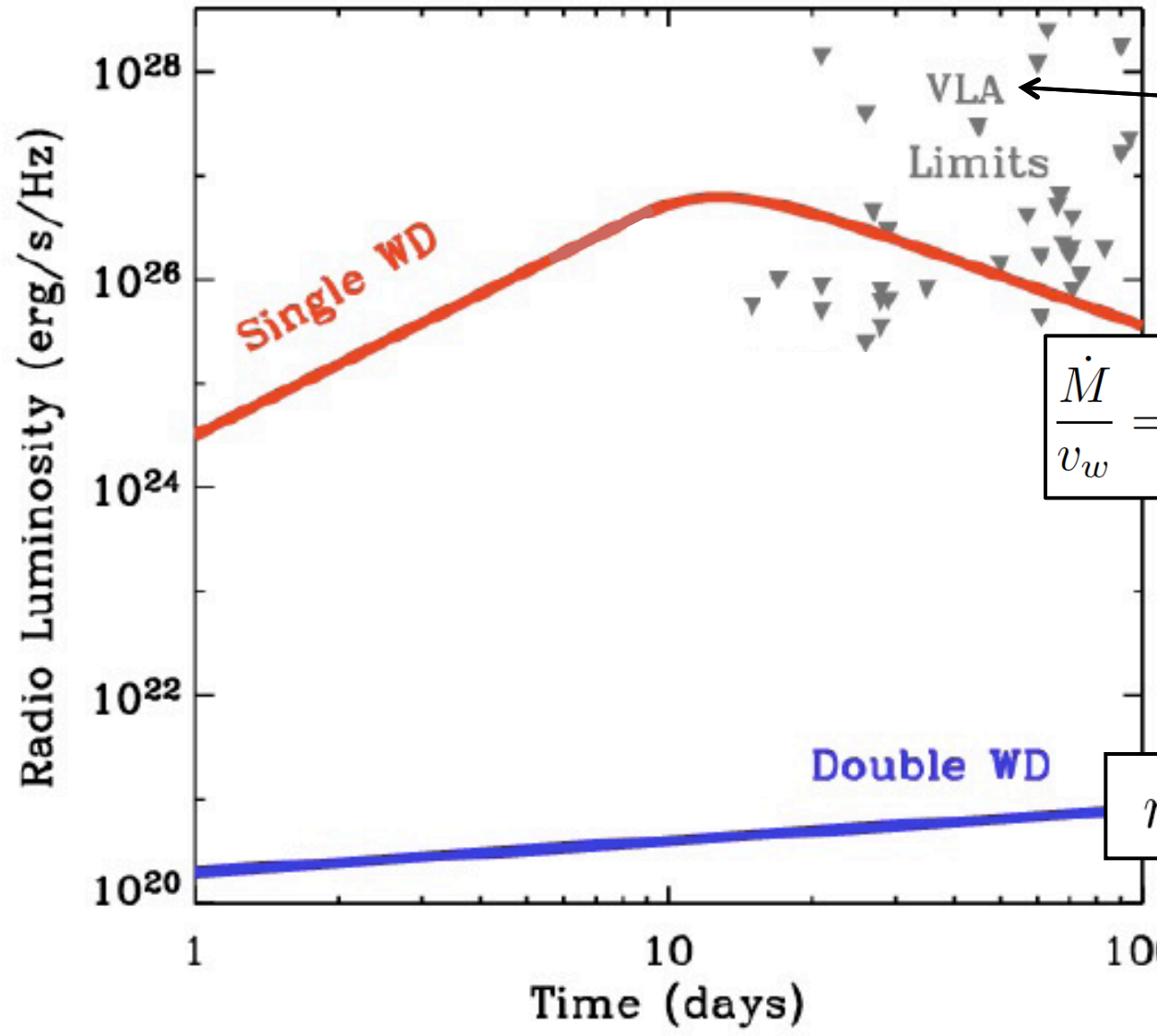


# More bandwidth, More sensitivity




EVLA = A factor of 4.5 increase in S/N over VLA

# VLA Limits




Panagia et al. 2006

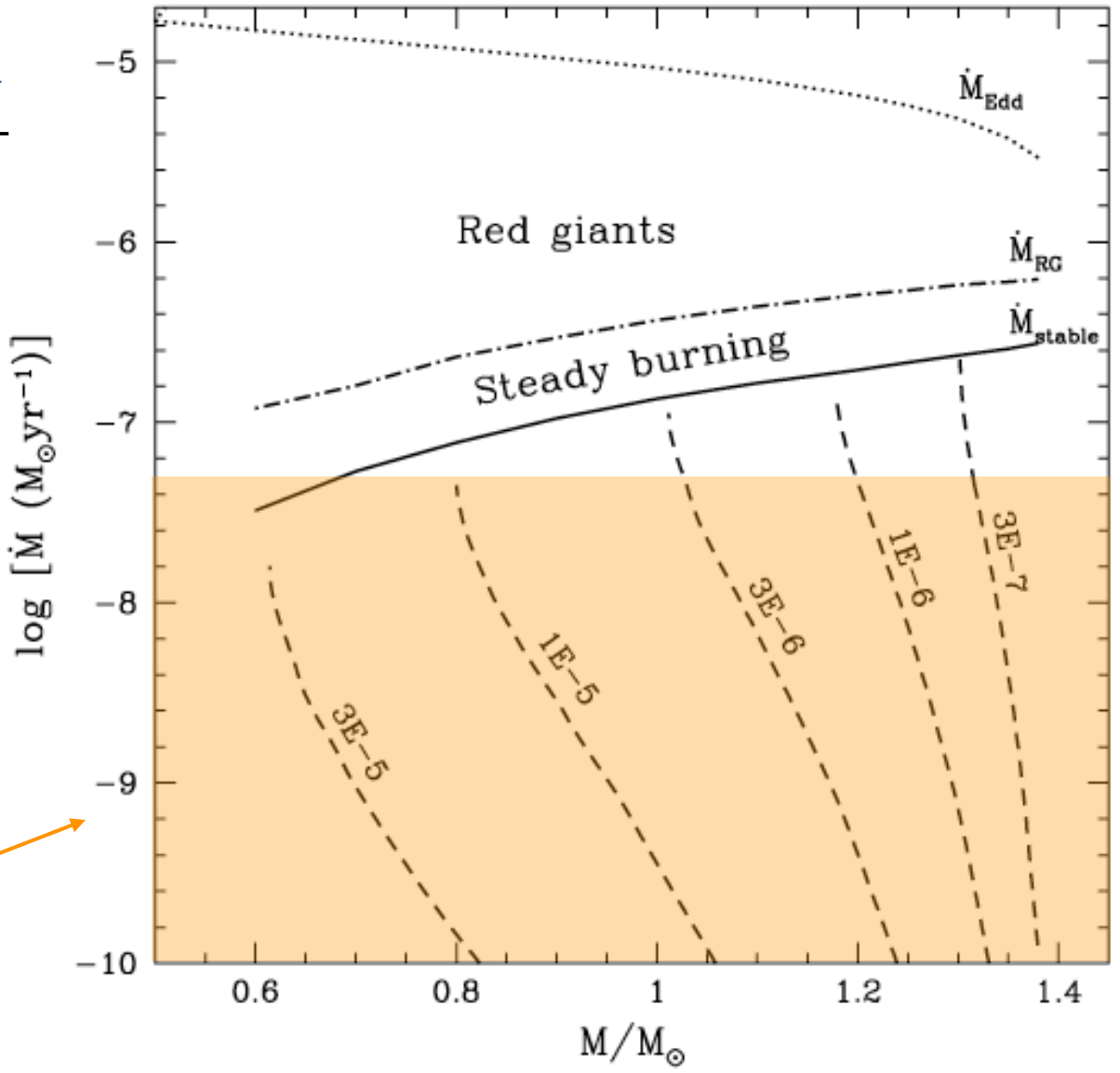
$$\frac{\dot{M}}{v_w} = \frac{10^{-8}}{10} \frac{\mathrm{M}_\odot\ \mathrm{yr}^{-1}}{\mathrm{km\ s}^{-1}}$$

$$n = 1\ \mathrm{cm}^{-3}$$

Nomoto et al. 2007

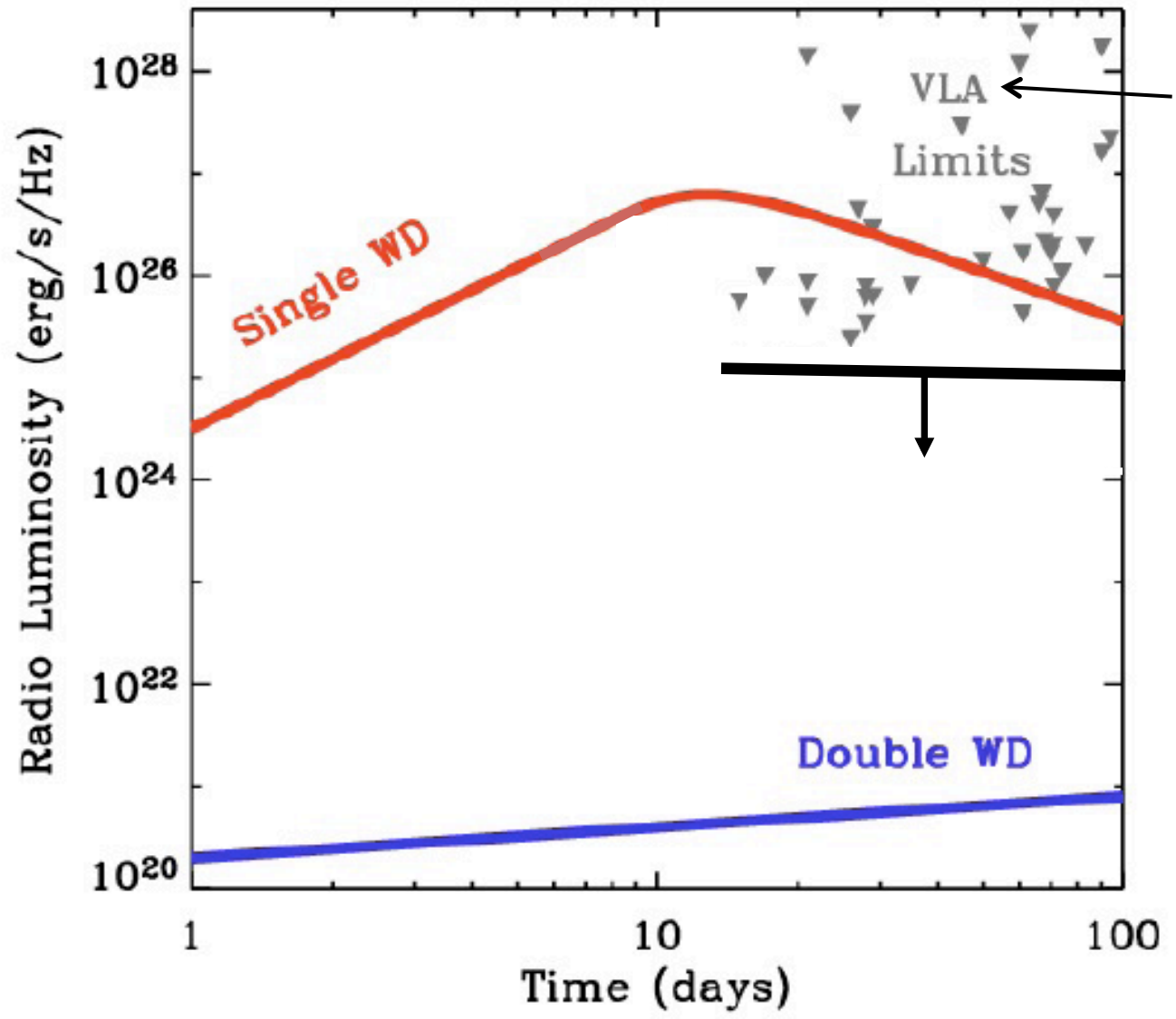
$$\frac{\dot{M}}{v_w} = \frac{10^{-8}}{10} \frac{\mathrm{M}_\odot\ \mathrm{yr}^{-1}}{\mathrm{km\ s}^{-1}}$$

should be relatively conservative




For $v_w$ = 50 km s$^{-1}$

# Stacked VLA Limits

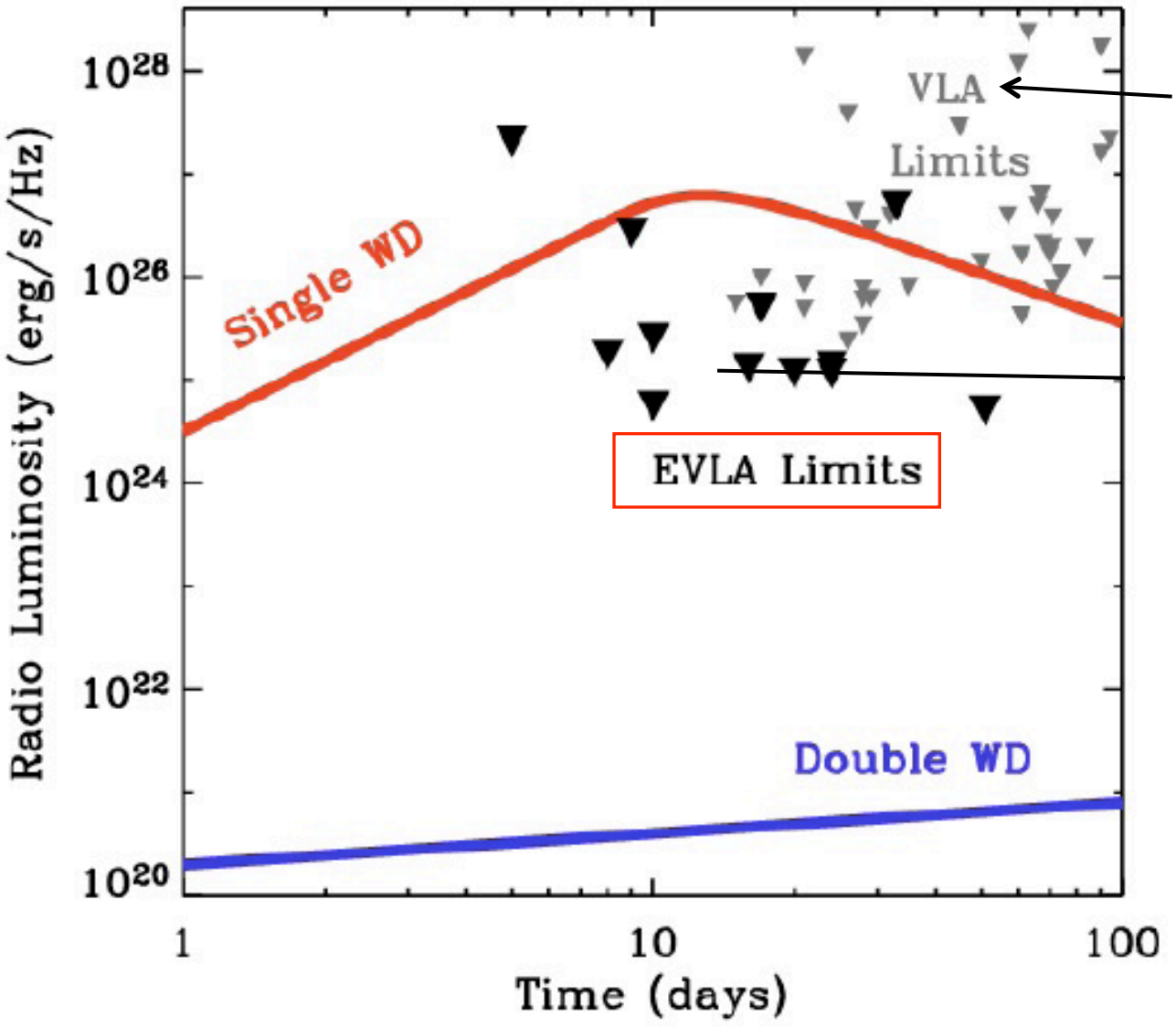



Panagia et al. 2006

Hancock et al. 2011

NRAO

# EVLA Limits




Panagia et al. 2006

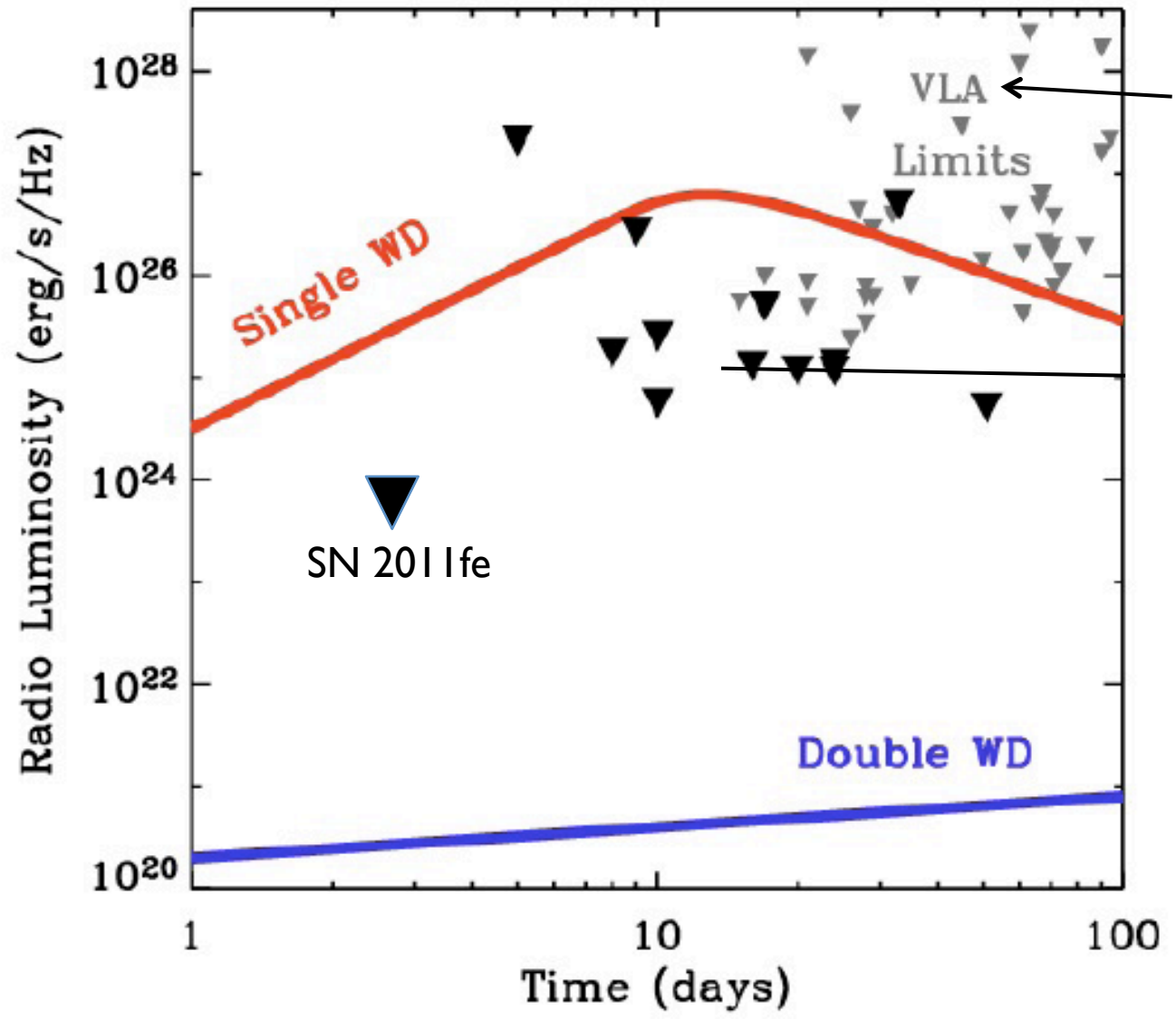
Hancock et al. 2011

# PTF11kly / SN 2011fe

In M101 (d ~ 6.4 Mpc).

Discovered just a day or two after explosion (on Aug 24).

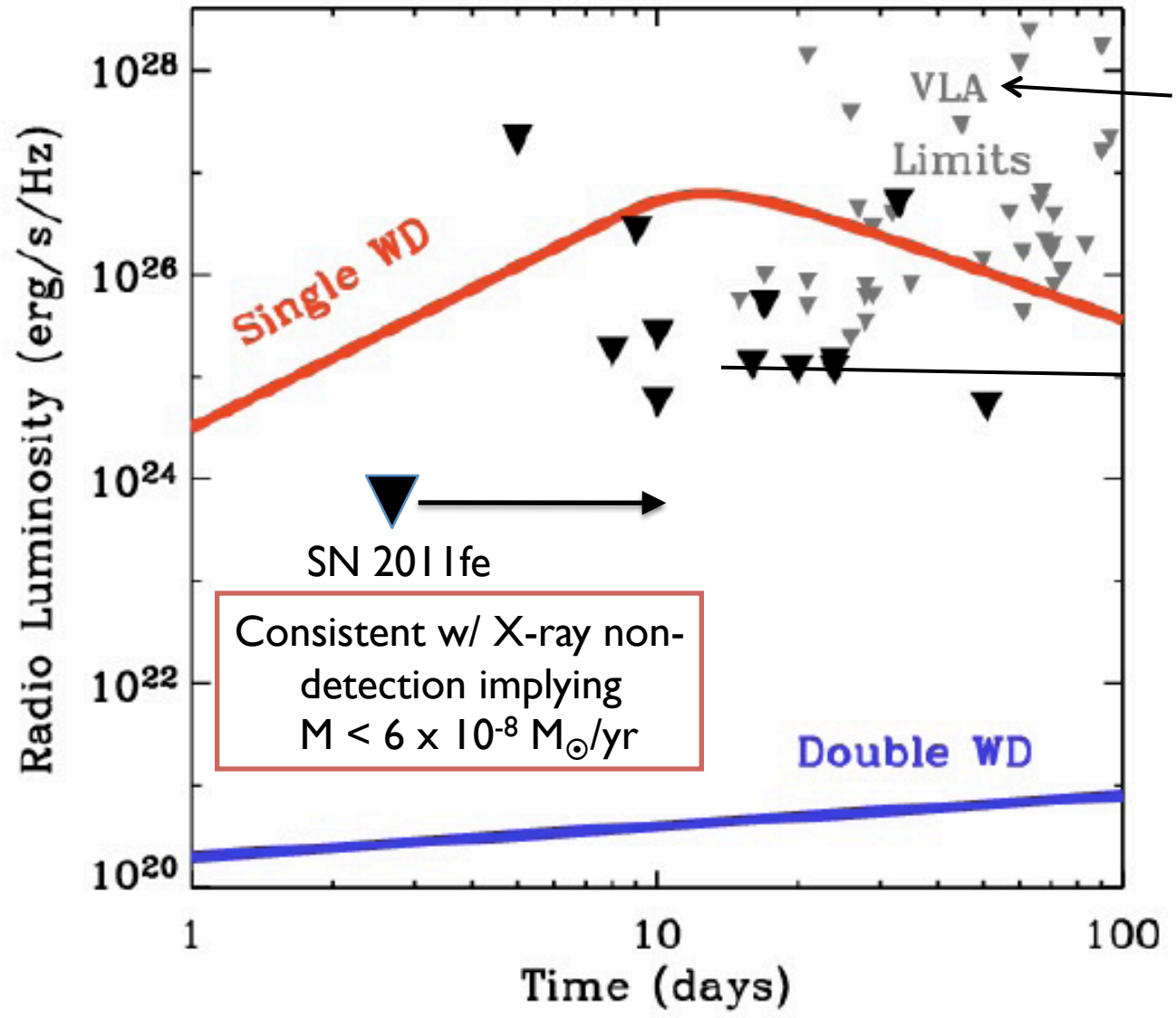
# SN 2011fe with EVLA




Panagia et al. 2006

Hancock et al. 2011

# SN 2011fe with EVLA

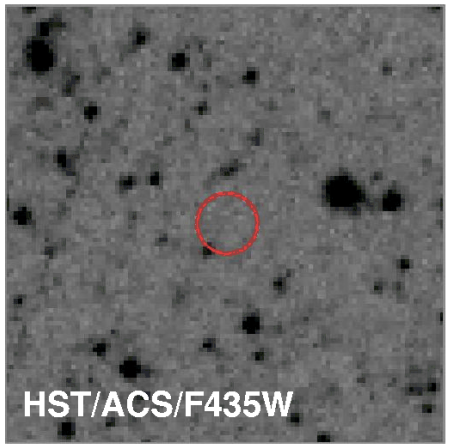


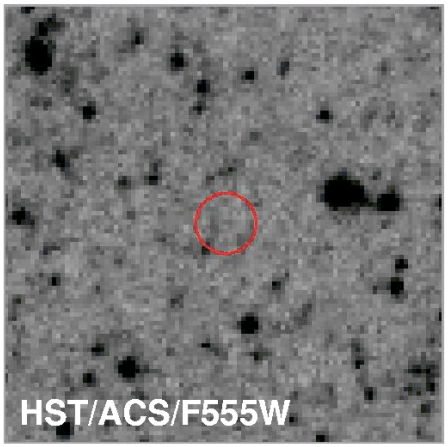

Panagia et al. 2006

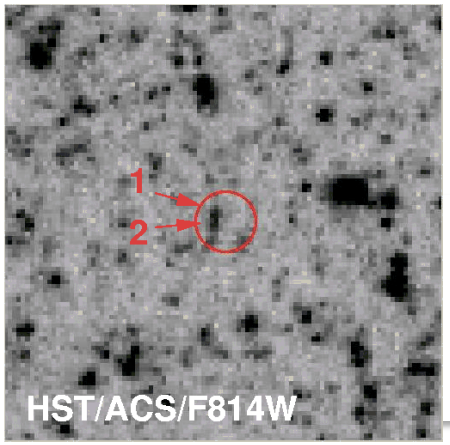
Hancock et al. 2011

NRAO

PTF11kly in M101




## Further Constraints on the Progenitor of SN 2011fe

- HST/ACS archival imaging: two red sources within the 2σ positional error circle, consistent with red giants
  (Li et al. ATels)

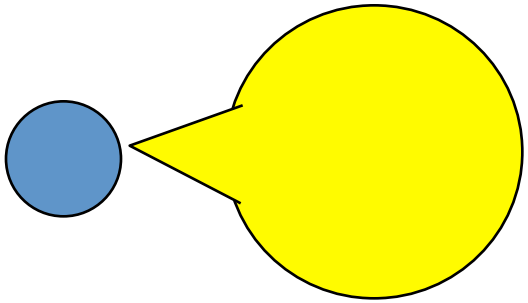
- Deep archival Chandra data imply $L_X < 5 \times 10^{35}$ erg/s, starting to probe the regime of super-soft sources
  (Butler et al., Soderberg et al. ATels)

- Not Nova M101-1997-2 (Shafter & Nelemans ATel)

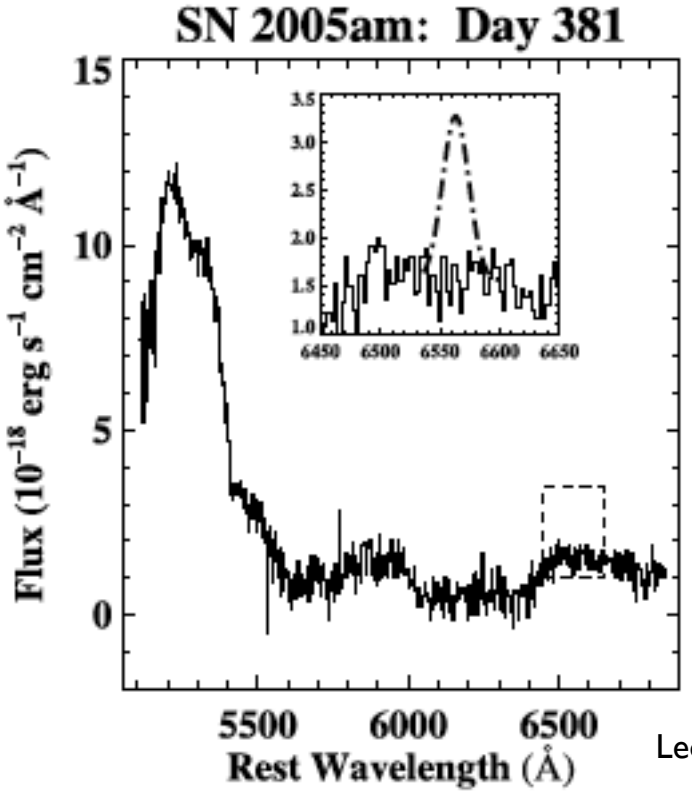
# How are limits on the CSM testing single degenerate models?

- Roche Lobe Accretion from a Main Sequence Star
- Roche Lobe Accretion from a Red Giant
- Wind Accretion from a Red Giant
- Recurrent Novae

# Roche Lobe Accretion From a Main Sequence Companion



No Hα detected in nebular spectra



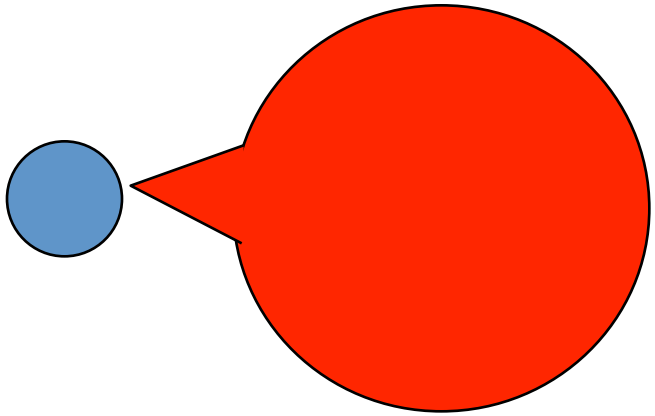

Leonard 2007

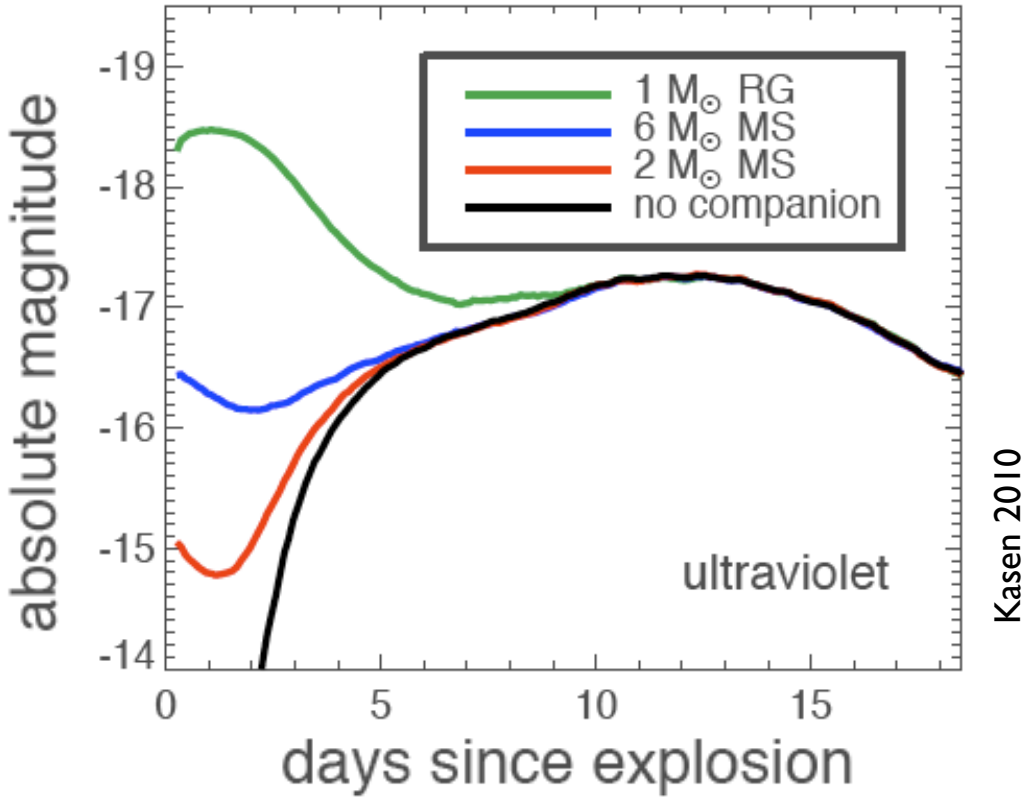
< 0.01 $M_\odot$ stripped from companion (Mattila et al. 2005, Leonard 2007)

Inconsistent with a Roche-Lobe filling MS or RG companion (~1 $M_\odot$; Marietta et al. 2000, Meng et al. 2007)

# No Early Time "Bump" in Light Curves

Roche Lobe Accretion from a Red Giant



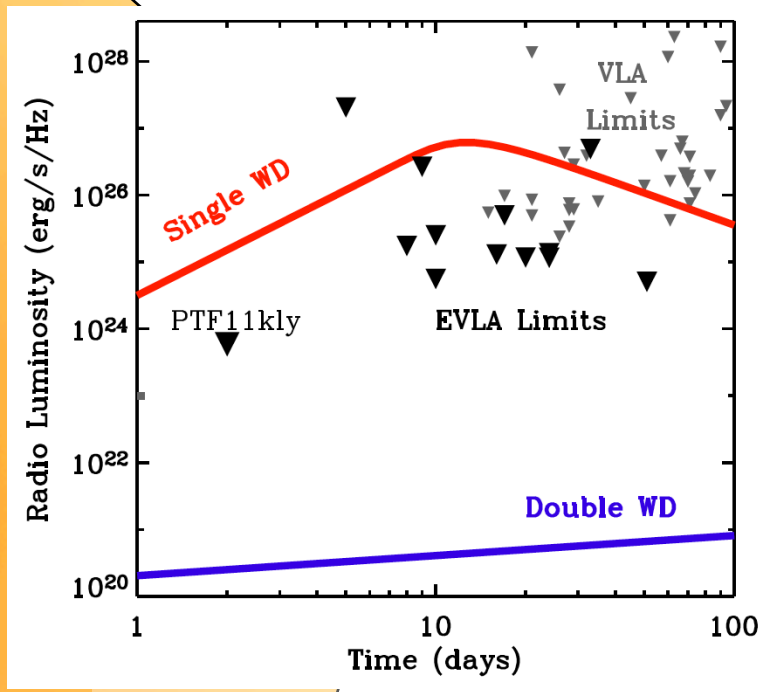



Giants at small separation should be visible in 10% of LCs (Kasen 2010)

< 20% of SNe Ia have ROLF giants as companions (Hayden et al. 2010, Bianco et al. 2011)

Wind Accretion From a Red Giant

No Radio or X-ray Detections




Radio: $\dot{M} < 10^{-8}\ M_\odot/yr$

(Soderberg, Chomiuk, et al., in prep)

X-ray: $\dot{M} < 10^{-5}\ M_\odot/yr$

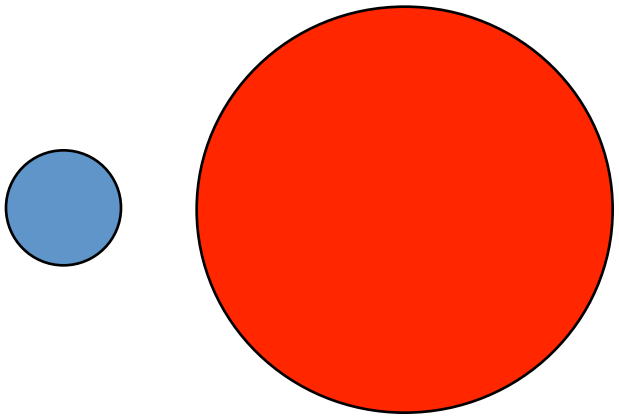
(Immler et al. 2006, Hughes et al. 2007)

H$\alpha$: $\dot{M} < 10^{-5}\ M_\odot/yr$

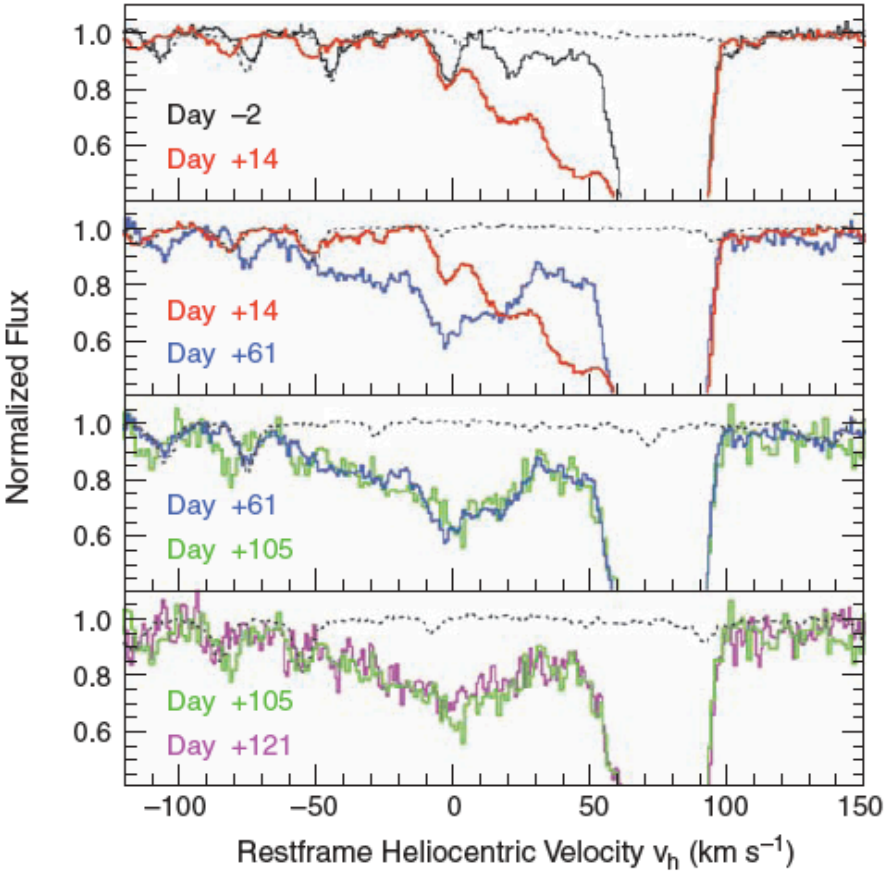
(Mattila et al. 2005)

(For $v_w$ = 10 km/s)

## Recurrent Nova Shells



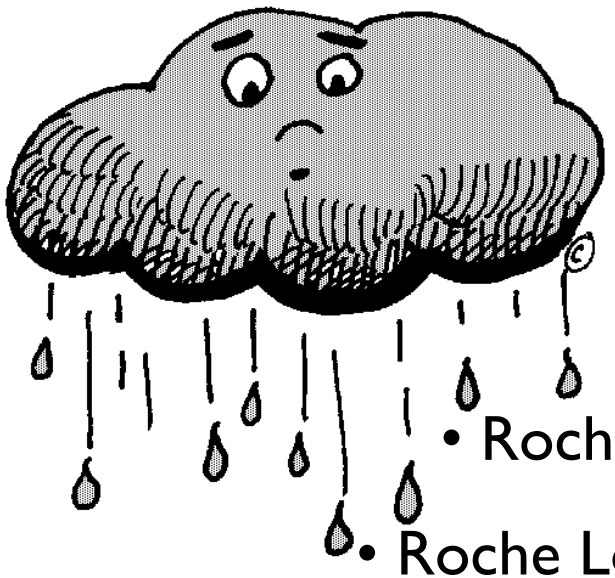
## Na I D Absorption?




Patat et al. 2007; see also Blondin et al. 2009, Simon et al. 2009, Sternberg et al. 2011

There should be associated radio emission some fraction of the time.

# How do constraints on the CSM test single degenerate models?



- Roche Lobe Accretion from a Main Sequence Star
- Roche Lobe Accretion from a Red Giant
- Wind Accretion from a Red Giant
- Recurrent Novae


- Or… maybe there's just a spin-down delay

(Justham 2011, Di Stefano 2011)

# Conclusions

- The EVLA can detect the interaction of SNe Ia with circumstellar material, testing single degenerate models.
- One hour of EVLA time = Two Decades of VLA effort.
- 12 nearby SNe Ia targeted by EVLA so far.
- All non-detections---a significant constraint on symbiotic models. $M < 10^{-8}\ M_{\odot}/yr$
- EVLA could detect recurrent nova shells---but would need to get lucky with the timing.

| Technique | Companion | Accretion Mode | Detection? | Reference |
|---|---|---|---|---|
| Early-Time UV Excess | Red Giant | Roche Lobe | No.<br>< 30 % | Hayden et al. 2010, Bianco et al. 2011 |
| Radio Continuum | Red Giant | Wind | No. | Panagia et al. 2006, Hancock et al. 2011, Soderberg et al. 2011 |
| H alpha Emission | Red Giant/MS | Roche Lobe | No. | Mattila et al. 2005, Leonard et al. 2007 |
| Na D Absorption | Red Giant/MS | Recurrent Nova | Yes. | Patat et al. 2007, Blondin et al. 2009, Simon et al. 2009 |