Searching for Failed Supernovae:

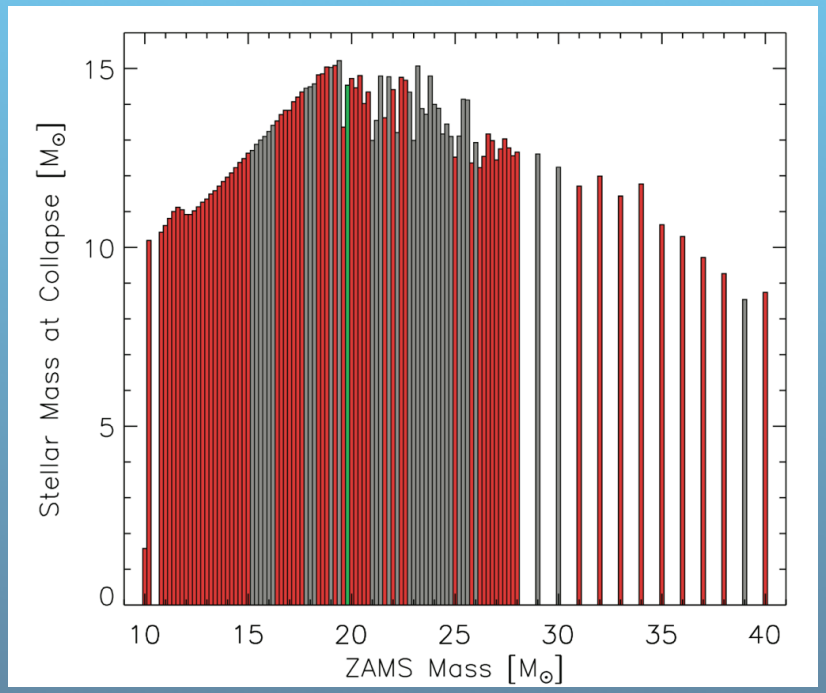
Looking for Vanishing Supergiants with the LBT

Jill Gerke

The Ohio State University
Advisor: Chris Kochanek

Collaborators: Kris Stanek, Dorota Szczygiel, Jose Luis Prieto

How do Massive Stars Die?



Ugliano et al. (2012)

Supernova!

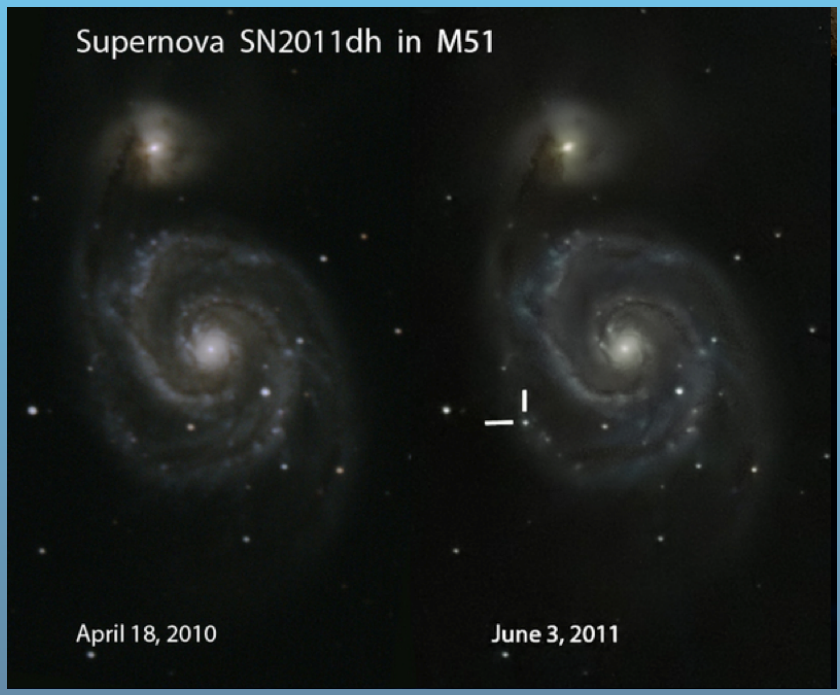
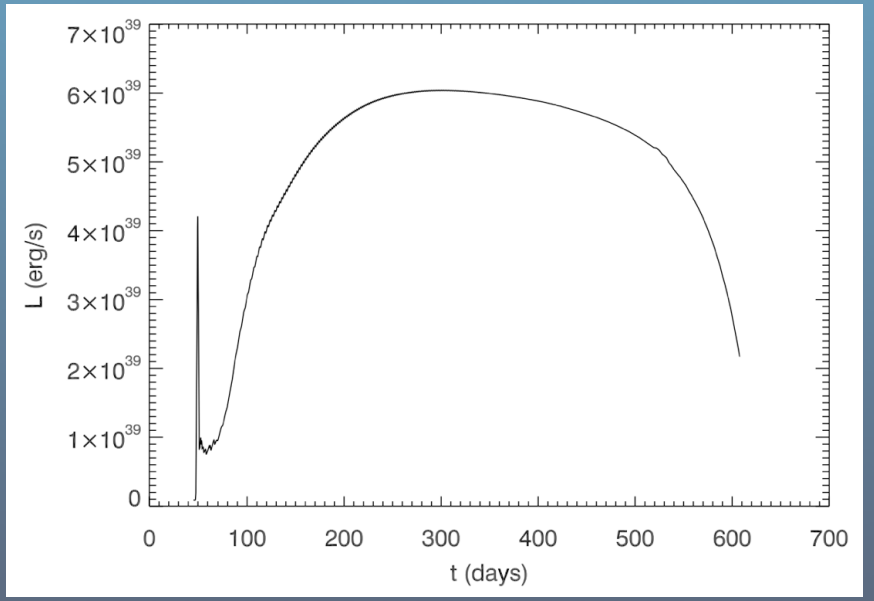


Image credit: D. Szczygiel

- There seems to be a lack of M ≳ 20$M_\odot$ SN Progenitors (Kochanek et al. 2008). More specifically, an absence of ~18-25$M_\odot$ red supergiants (Smartt 2009)
- Theory finds that M~20$M_\odot$ stars are harder to explode (O'Connor & Ott 2011; Ugliano et al. 2012)

Effects of Collapse: Loss of Envelope

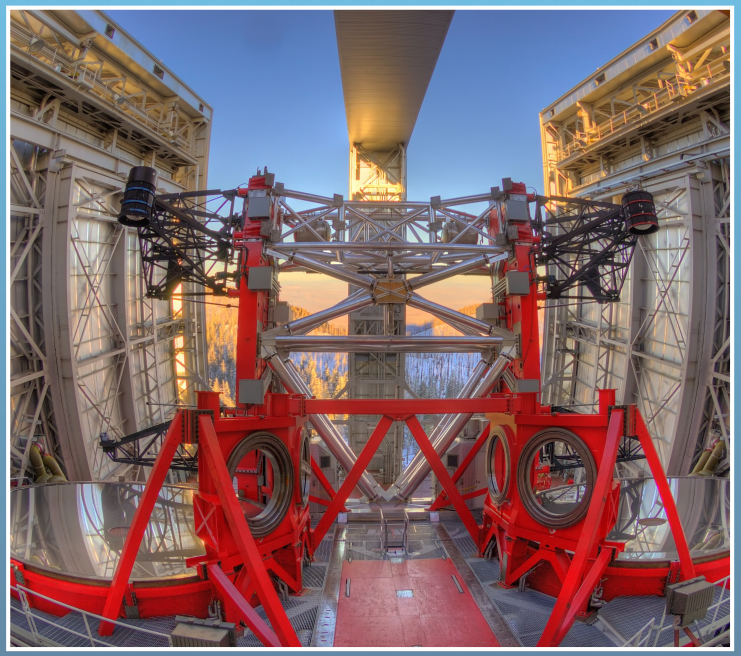
- Lovegrove & Woosley (2013) explored what would happen as a consequence of mass-loss due to neutrino emission during core collapse (also see Nadyozhin1980). It was found that the stellar envelope can be lost when a massive star experiences
  - rapid loss of 0.2-0.5$M_\odot$ from the core
  - results in a low energy SN (~10^{47} erg) and the loss of most of the hydrogen envelope
- With this loss of the envelope, having SN fail in the16.5$M_\odot \lesssim M \lesssim$ 25$M_\odot$ range naturally explains the compact remnant mass function (Kochanek 2014)



Lovegrove & Woosley 2013

LBT Survey About Nothing

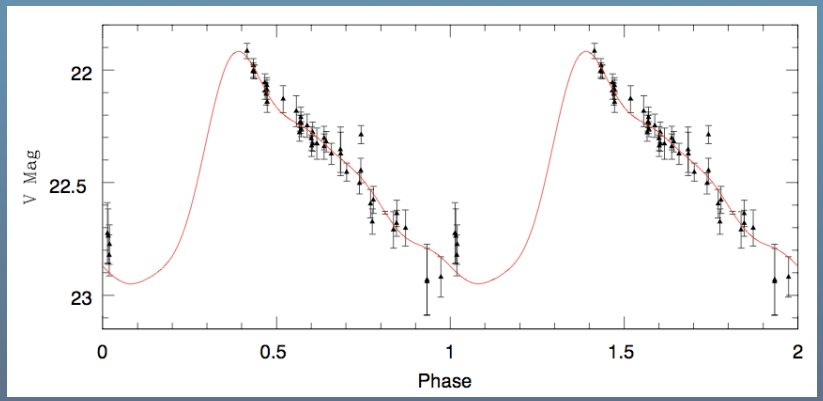
- Monitoring 25 galaxies within 10 Mpc for 5 years
  - 10^6 supergiants
  - Combined SN rate of ~1 per year

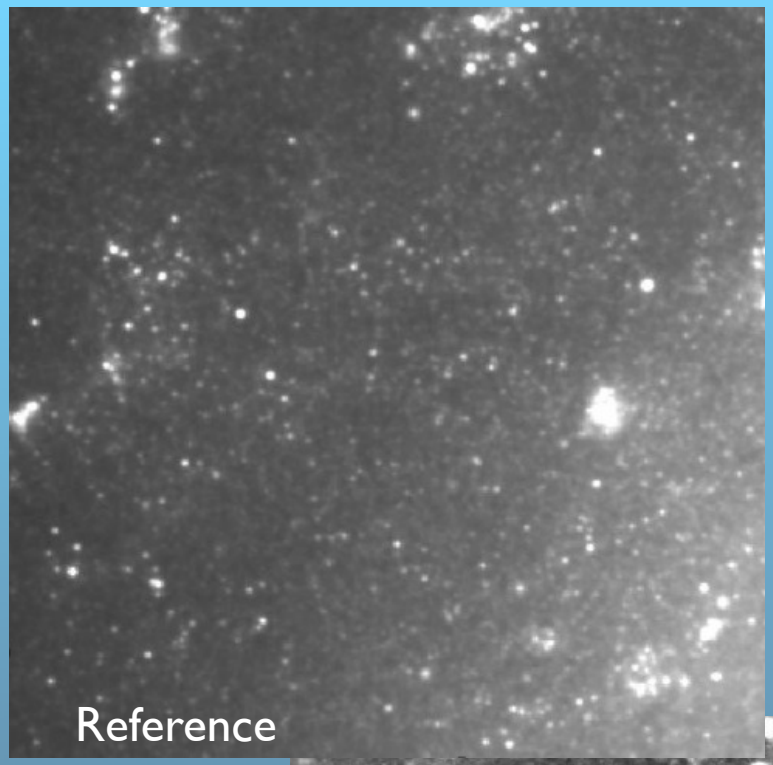


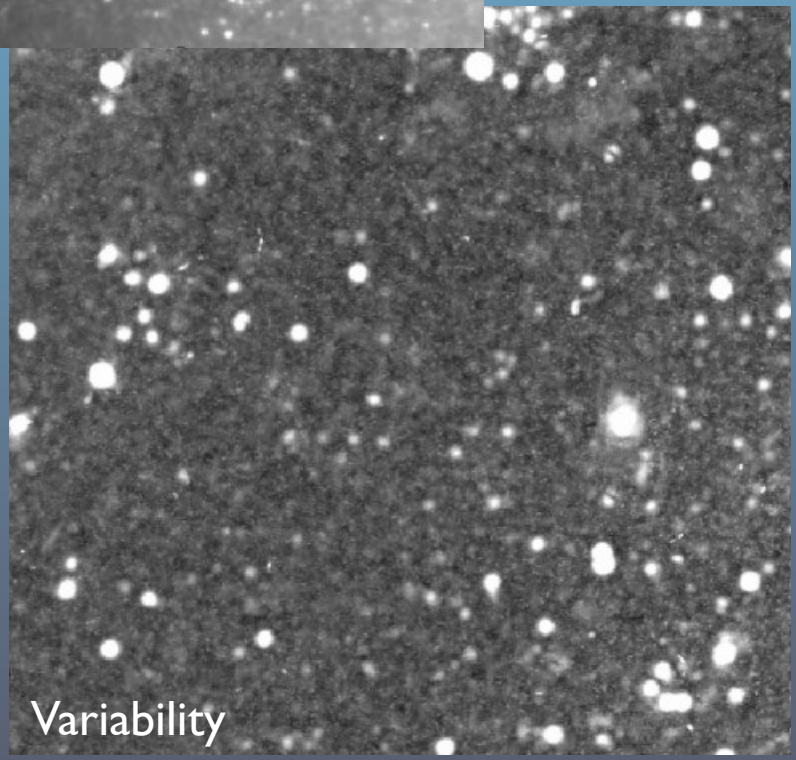
- Data is taken with the LBCs
  - Blue side: UBV bands
  - Red side: R band
- Observation cadence
  - Typically twice per year
  - Cycling galaxies through a period of more intensive monitoring

Method

- ISIS image subtraction (Alard 2000)
- Differential photometry
  - Reduced crowding





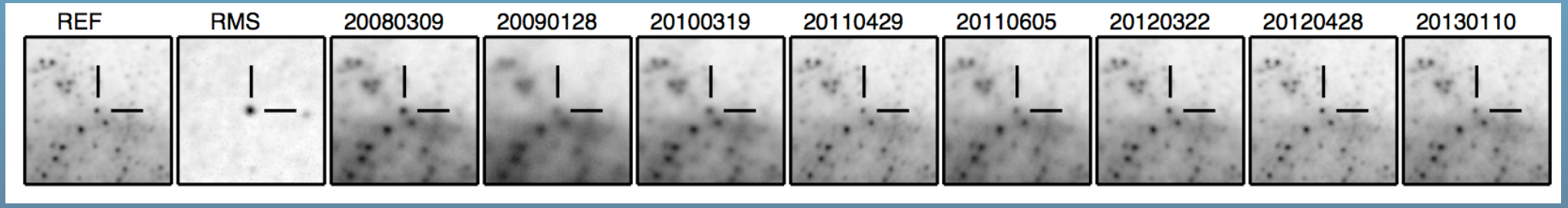


30 day Cepheid, which corresponds to ~6$M_\odot$ evolved star (Gerke et al. 2011)

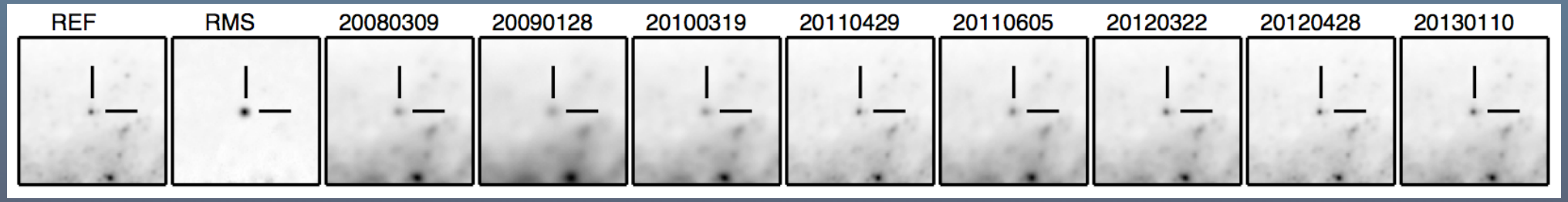
Candidate Selection

- Examine all sources that change by $|\nu L_\nu| \geq 10^4 L_\odot$ from start to end

  - Fading $|\nu L_\nu| = 1.2 \times 10^4 L_\odot$

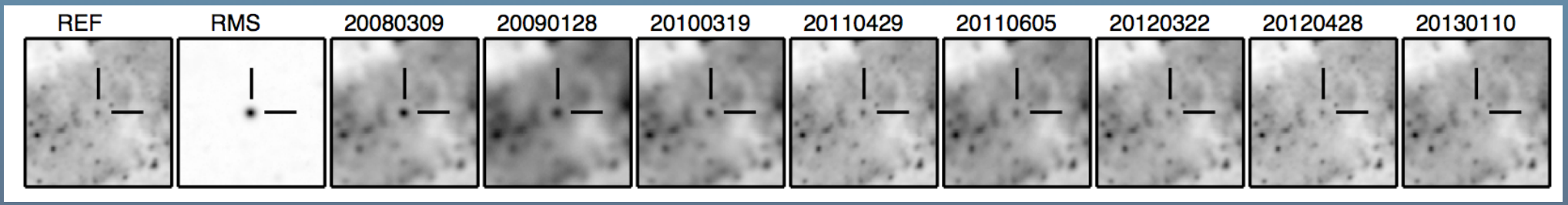


  - Brightening $|\nu L_\nu| = 4.1 \times 10^4 L_\odot$



Candidate Selection 2

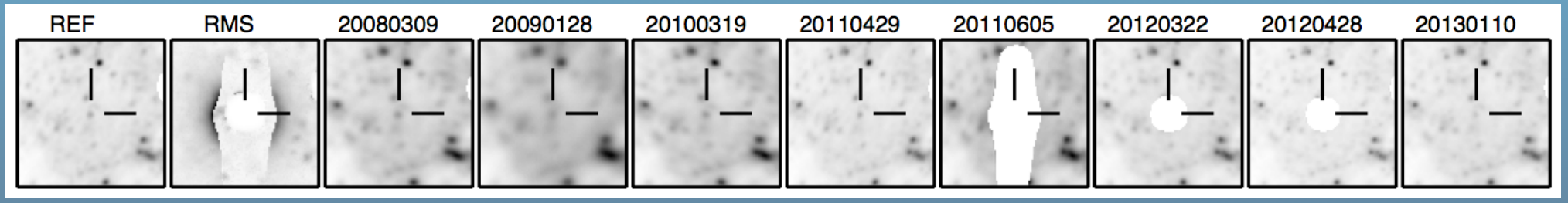
- Examine all sources that have $\nu L_\nu \geq 10^5 L_\odot$ for a period of time then show a decrease in luminosity below that limit
- Examine all sources that show ΔL change of $\nu L_\nu \geq 10^5 L_\odot$ at any time
  - fading $|\nu L_\nu| = 1.0 \times 10^5 L_\odot$



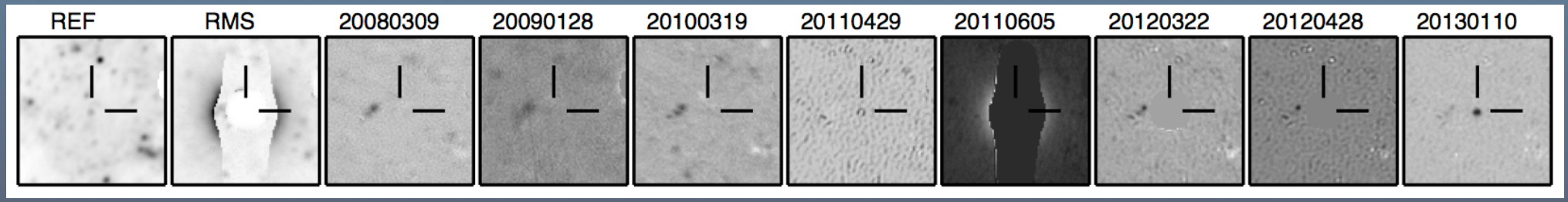
SN 2011dh

- We detect the death of this star independent of the SN transient
- Fading $|\nu L_\nu| = 2.4\times10^4 L_\odot$ ($3.7\times10^4 L_\odot$ as of June 2013)

R band: regular images



R band: subtracted images

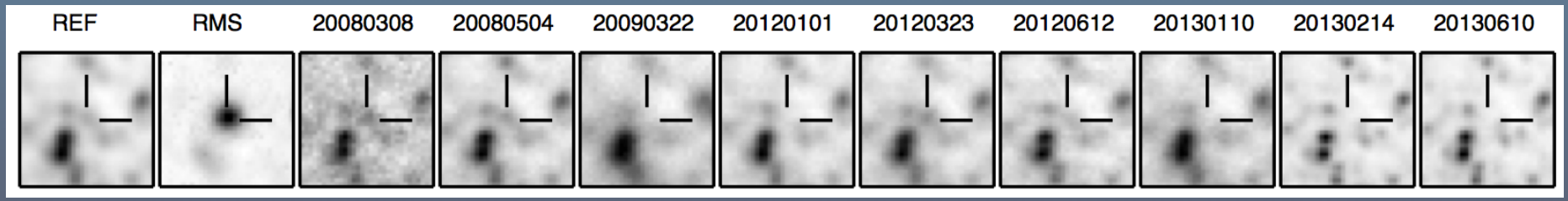


Processing the Candidates

- Using the described criteria, we determine a list of candidates
- If PSF photometry of last images matches ISIS photometry the candidate is considered securely detected and not a failed SN
- If photometry does not match we visually inspect the candidate
- Current State:
  - Almost all galaxies are calibrated and a candidate list has been produced.
  - We are eye checking the candidates when necessary, using the different photometric bands to help in ambiguous cases

Current Candidates

- The average galaxy:
  - 4.05% of galaxy is masked
  - There are 100 round1 candidates
  - There are 7 round 2 candidates
  - There is ~1 round 3 candidate
- 16 galaxies, 110 round 2 candidates, 13 round 3 candidates
- Example Round 3 candidate:



What is the Failed SN rate?

Normal SN rate: $R_{sn} \simeq 1$ per year

Survey baseline: 4 years with 2 observed ccSNe

Expected Number of Failed SN: $N_{fs} = (1\text{-}f_{fs}) \times N_{sn}$

If we find no viable candidates at this point in the survey, our limit on the failed SN rate is $f_{fs} \lesssim 54\%$ at 90% confidence limit.

Future Limits:

If the failed SN rate is $f_{fs} \simeq$ 10%, 20% or 30%, a 9 year survey, with an expected sample of 7 successful ccSNe, has a 54%, 83% and 95% probability of success.

Summary and Future

- It is possible that a significant number of massive stars end their lives as failed supernova
- Our "Survey About Nothing" has been monitoring ~10^6 supergiants with the Large Binocular Telescope over the past 4-5 years.
- The "Survey About Nothing" is also creating a catalog of SN progenitors and enables many other studies.
- This first analysis of the data will place limits on the Failed Supernova rate of $f_{fs} \lesssim 54\%$ the SN rate at 90% confidence.
- We will continue the survey and with more time will be able to improve upon these limits.