OBSERVING THE NEXT GALACTIC SUPERNOVA

SCOTT M. ADAMS[1], C.S. KOCHANEK[1,2], JOHN F. BEACOM[1,2,3], MARK R. VAGINS[4,5], & K.Z. STANEK[1,2]

Draft version November 1, 2013

ABSTRACT

No supernova in the Milky Way has been observed since the invention of the optical telescope, instruments for other wavelengths, neutrino detectors, or gravitational wave observatories. It would be a tragedy to miss the opportunity to fully characterize the next one. To aid preparations for its observations, we model the distance, extinction, and magnitude probability distributions of a successful Galactic core-collapse supernova (ccSN), its shock breakout radiation, and its massive star progenitor. We find, at very high probability ($\simeq 100\%$), that the next Galactic supernova will easily be detectable in the near-IR and that near-IR photometry of the progenitor star very likely ($\simeq 92\%$) already exists in the 2MASS survey. Most ccSNe (98%) will be easily observed in the optical, but a significant fraction (43%) will lack observations of the progenitor due to a combination of survey sensitivity and confusion. If neutrino detection experiments can quickly disseminate a likely position ($\sim 3°$), we show that a modestly priced IR camera system can probably detect the shock breakout radiation pulse even in daytime (64% for the cheapest design). Neutrino experiments should seriously consider adding such systems, both for their scientific return and as an added and internal layer of protection against false triggers. We find that shock breakouts from failed ccSNe of red supergiants may be more observable than those of successful SNe due to their lower radiation temperatures. We review the process by which neutrinos from a Galactic core-collapse supernova would be detected and announced. We provide new information on the EGADS system and its potential for providing instant neutrino alerts. We also discuss the distance, extinction, and magnitude probability distributions for the next Galactic Type Ia supernova. Based on our modeled observability, we find a Galactic core-collapse supernova rate of $3.2^{+7.3}_{-2.6}$ per century and a Galactic Type Ia supernova rate of $1.4^{+1.4}_{-0.8}$ per century for a total Galactic supernova rate of $4.6^{+7.4}_{-2.7}$ per century is needed to account for the SNe observed over the last millennium, which implies a Galactic star formation rate of $3.6^{+8.3}_{-3.0}$ $M_\odot$ yr^{-1}.

Schematic view of the problem

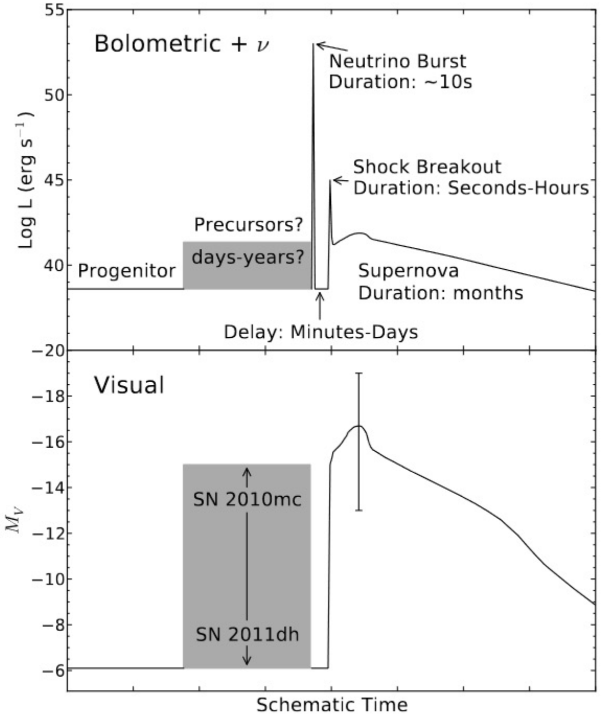


Fig.1

2. MODELS

More about galactic models (dust/star distributions) than about SN models

- Density distributions of dust and SN progenitors:

$$\rho = A e^{-R/R_d} e^{-|z|/H}$$

	dust	ccSN	SNIa
R_d (kpc)	2.9	2.9	2.4
H (pc)	100	100	800

various possible normalization for the dust : ''SIMPLE'' : A_v = 30 to the Galactic Center

- Distribution in distance and absorption

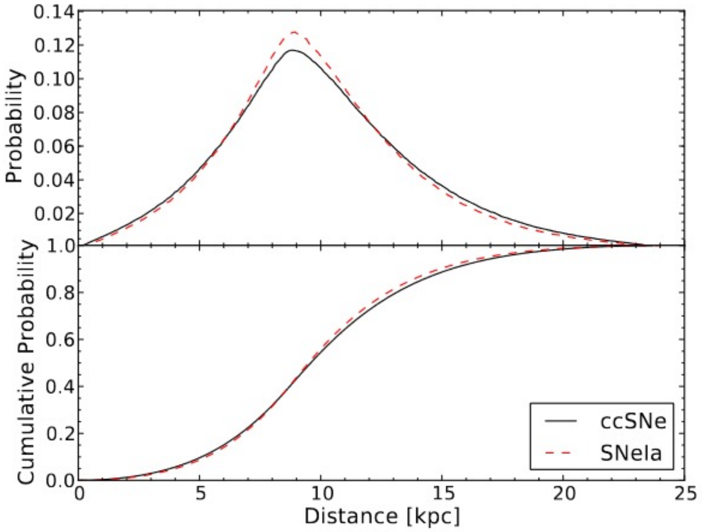


Fig.2

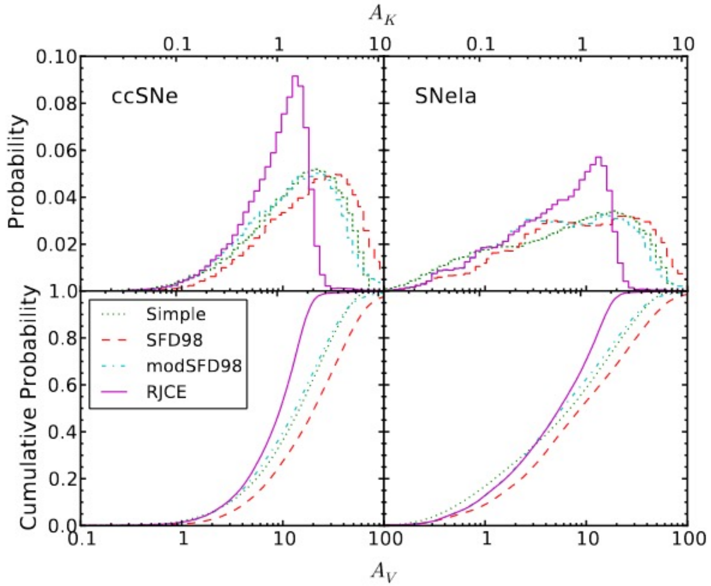


Fig.3

$\longrightarrow$ distribution in mag. primarily controlled by extinction, not by distance

3. RESULTS

From the distribution in distance and absorption →

Distribution in apparent magnitude

CCSNe

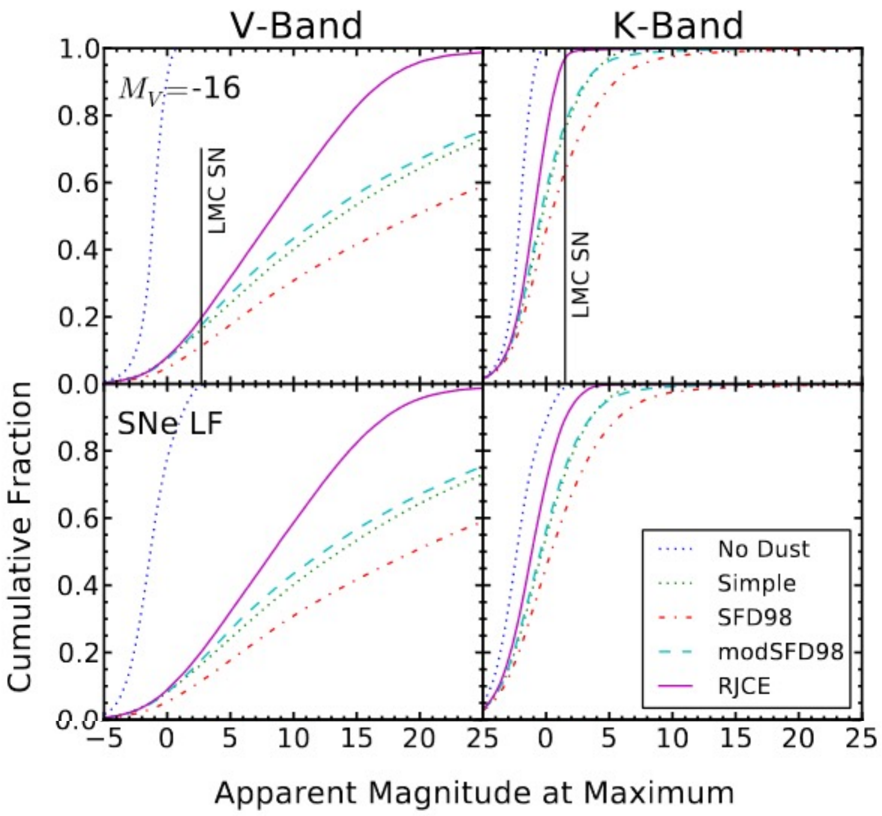


Fig.5

82% with $m_V < 15$; ~ 1/3 with $m_V < 5$

SN Ia

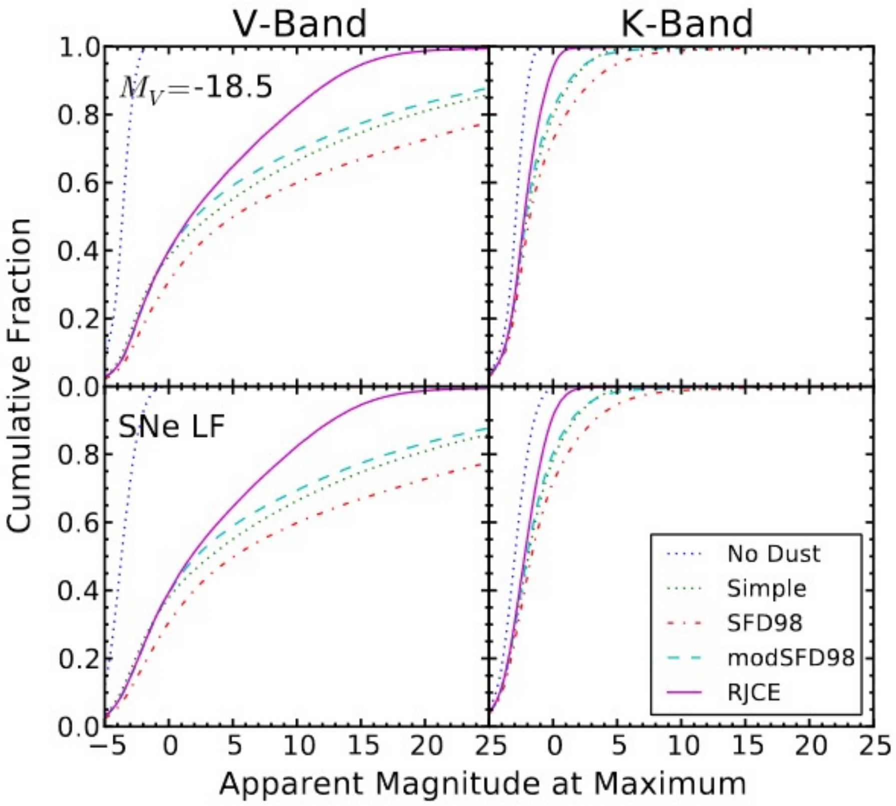


Fig.6

92% with $m_V < 13.5$; ~ 1/2 with $m_V < 5$

Progenitor luminosity function

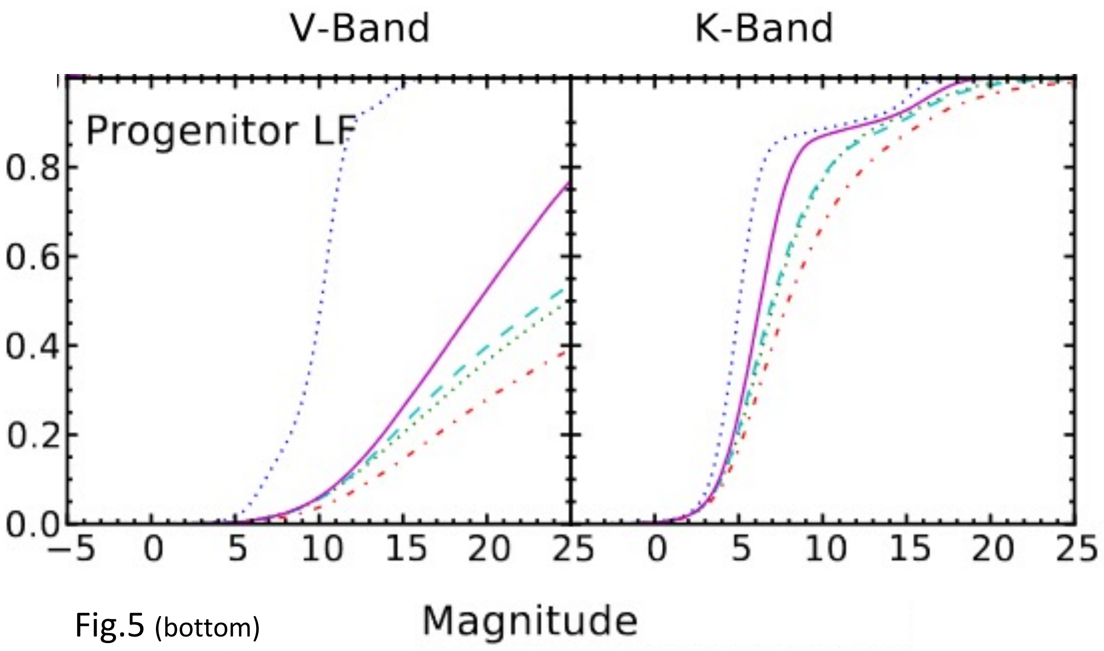


Fig.5 (bottom)

Intrinsic LF coupled to extinction models

Reasonable chance to identify the progenitor in archival plates (especially 2MASS)

Shock breakout

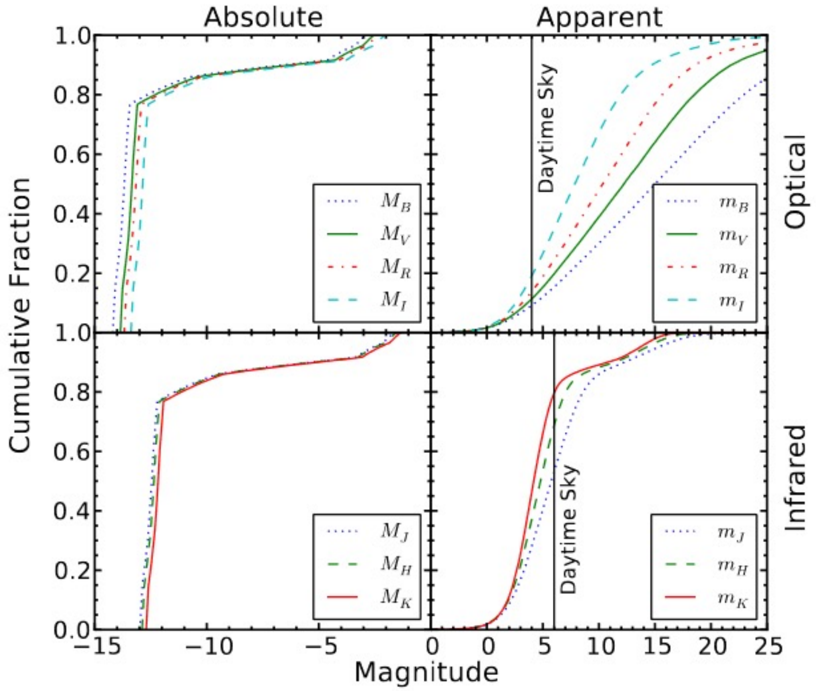


Fig.4

$$T_{\rm eff} \sim 1.24 \times 10^6 {\rm K} \left(\frac{M_\star}{M_\odot}\right)^{0.046} \left(\frac{M_{\rm ej}}{10 M_\odot}\right)^{-0.114} \times \left(\frac{R}{50 R_\odot}\right)^{-0.48}$$

$$L \sim 1.66 \times 10^{45} {\rm erg/s} \left(\frac{M_\star}{10 M_\odot}\right)^{0.126} \left(\frac{M_{\rm ej}}{10 M_\odot}\right)^{-0.816} \times \left(\frac{R}{50 R_\odot}\right)^{-0.22}$$

Confusion: probability of having a source brighter than the SN at a given distance

ccSNe

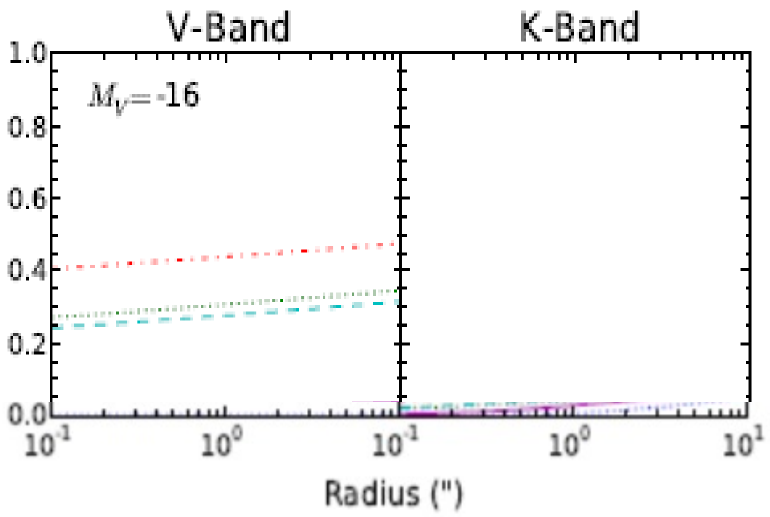


Fig.7

SN Ia

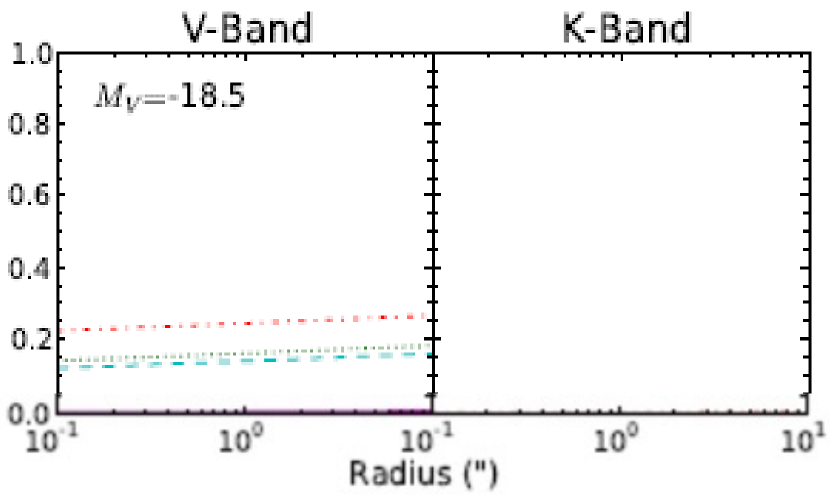


Fig.8

- Supernova:
  - moderate risk of confusion in the visible
  - no confusion in the infrared
- Progenitor:
  - larger risk of confusion in the visible: 50 – 60%
  - no risk in the infrared → progenitor already present in 2MASS survey !

The galactic SN rate

- very uncertain: magnitude distribution from the model $\leftrightarrow$ historical supernovae
- accuracy limited by the small number of historical SNe: only 5 (1006, 1054, 1181, 1572, 1604)
- sample of historical SNe assumed to be complete to a limiting visual magnitude of -2 (or 0)

$\rightarrow$ ccSNe rate: $3.4^{+7.8}_{-2.8}$ $(2.8^{+3.7}_{-1.8})$ per century or one every 30 years (9 to 170 years)

SN Ia rate: $1.4^{+1.4}_{-0.8}$ $\left(0.8^{+0.8}_{-0.5}\right)$ per century or one every 70 years (36 to 170 years)

Neutrinos (ccSNe)

Binding energy of the newly formed compact object : $\sim 10^{53}$ erg (six flavors ν_ε, ν_μ, ν_τ and their antiparticles, $E_\nu \sim$ tens of MeV)

Mainly detected via $\bar{\nu}_e + \mathrm{p} \rightarrow e^+ + \mathrm{n}$ (10^4 $\bar{\nu}_e$ expected in Super-Kamiokande for an event at the Milky Way center !)

(12 for SN 1987A in Kamiokande)

$\rightarrow$ $\bar{\nu}_e$ neutrino light curve and spectrum

direction lost ; rough estimate of the distance from number of events

Other detection channel: neutrino-electron scattering (all flavors; a few hundreds of events expected in Super-K)

forward scattering within 10° $\rightarrow$ direction to the source **within a few degrees**

A delicate question: avoid a false alarm/risk to miss an historical event

Neutrino Alerts

SNEWS: SuperNova Early Warning System

Super-Kamiokande, IceCube, Borexino, LargeVolumeDetector (LVD)

$\longrightarrow$ agreement on the criteria to announce a detection (too severe?)

Super-Kamiokande

Only experiment with localization (a few-degree) capability: time and duration of the ν burst, number of ν above 7 MeV, sky location

SURGE (Supernova Urgent Response Group of Experts)

$\longrightarrow$ release in about one hour (could be too long for the shock breakout signal?)

EGADS: Evaluating Gadolinium's Action on Detector Systems

Adding a small quantity of gadolinium chloride or sulfate to water: test in progress with a 200-ton water tank (1% of Super-K)

$\longrightarrow$ detection of the neutron in coincidence with the positron: $\bar{\nu}_e + \mathrm{p} \rightarrow e^+ + \mathrm{n}$ followed by $\mathrm{n} + \mathrm{Ga}^{157} \longrightarrow \mathrm{Ga}^{158} + \gamma$

robust detection possible within one second !

This would guarantee the detection of the shock breakout

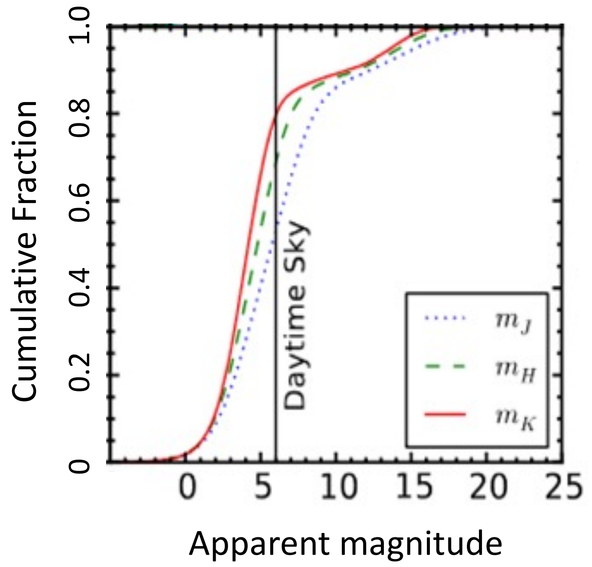
Instrumentation for shock breakout detection

Shock breakout peaks in far UV/X but search more effective in near-IR due to galactic extinction (thermal spectrum assumed)

Design proposed for an IR camera: 86 mm aperture, 300 mm focal length

3x2.5 degree field of view

Detection of the shock breakout signal possible even during daytime



WAIT AND SEE !