Infrared Follow-up Observations of Supernovae With Gemini in the Era of Giant Glass

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Upcoming transient surveys LSST and WFIRST will populate new regions of phase space (luminosity, color, and duration), and multi-wavelength follow-up observations will be desired to characterize these targets. Despite significant progress in the SN field over the past few years, however, infrared (IR) observations of SNe remain sparse. In the era of 25-m+ telescopes, Gemini will be optimized to devote time to multi-epoch, multi-wavelength queued follow-up of these new transients. Here I describe some key science topics probed by the next generation of IR observations and how Gemini will play a roll. I conclude with some attention on OCTOCAM, a VIS/IR imager/spectrograph that is part of the current Gemini Instrument Feasibility Study (GIFS).

Interacting, Dusty SNe

SN dust may be newly formed or pre-existing due to progenitor mass-loss and/or eruptions. Either way, the dust characteristics offer important clues regarding the SN progenitor and evolution of dust in the universe. Dust is most commonly observed in Type IIn SNe, named for the narrow emission lines created by a slow-moving, dense, and pre-existing circumstellar medium (CSM).

A growing number other subclasses now also show evidence for significant late-time IR emission from CSM interaction, including SN impostors, SNe IIP, SNe Ibc, SLSNe, and even some SNe Ia (dubbed SNe Ia-CSM). The case of the thermonuclear Type Ia is particularly intriguing because the surrounding CSM suggest that either (a) single-degenerate progenitor scenarios are responsible for these explosions, or (b) the exploding star was not a thermonuclear explosion of a white dwarf at all.

The IR is the most sensitive wavelength to warm dust, but little is actually known about the dust composition and grain sizes. This is mostly due to the rare nature of such SNe, limitations in telescope time, and access to IR instrumentation. As larger telescopes become available, Gemini queue-based observations will offer a prime opportunity to obtain multi-wavelength, multi-epoch observations of these transient events out to large distances and late epochs.

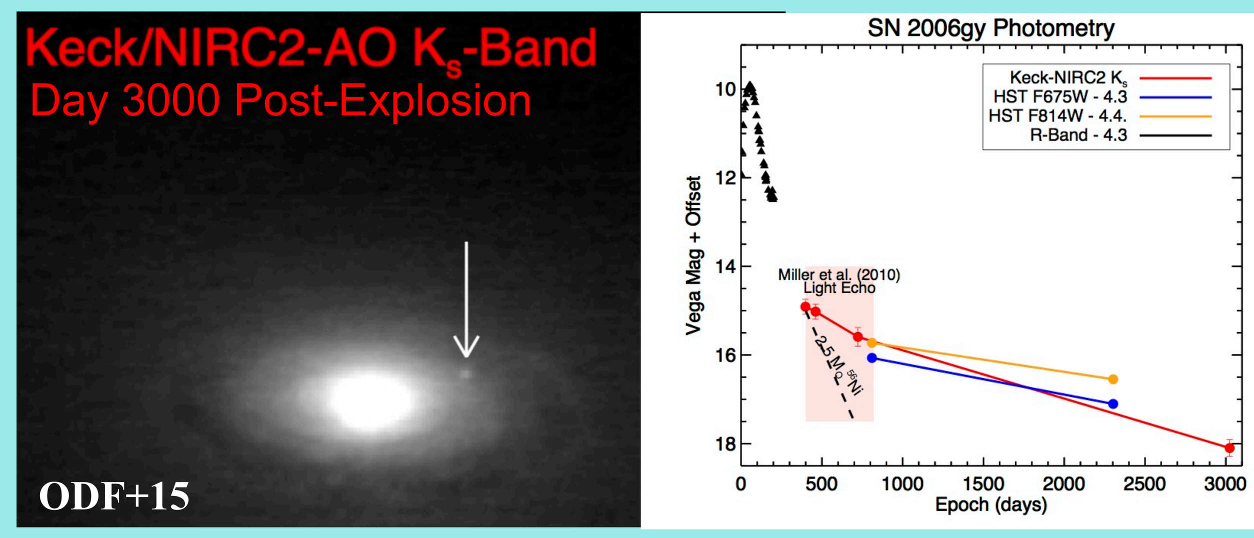


Figure 1: (left) Keck/NIRC2/LGS-AO K'-band image of the Type IIn SN 2006gy obtained on Dec 07, 2014. (right) Keck observations combined with HST optical photometry to form a 3000 day light curve. With only 2 epochs of data past day 1000, these multi-wavelength observations reveal ongoing CSM interaction with a pre-existing dust shell indicative of a massive progenitor star.

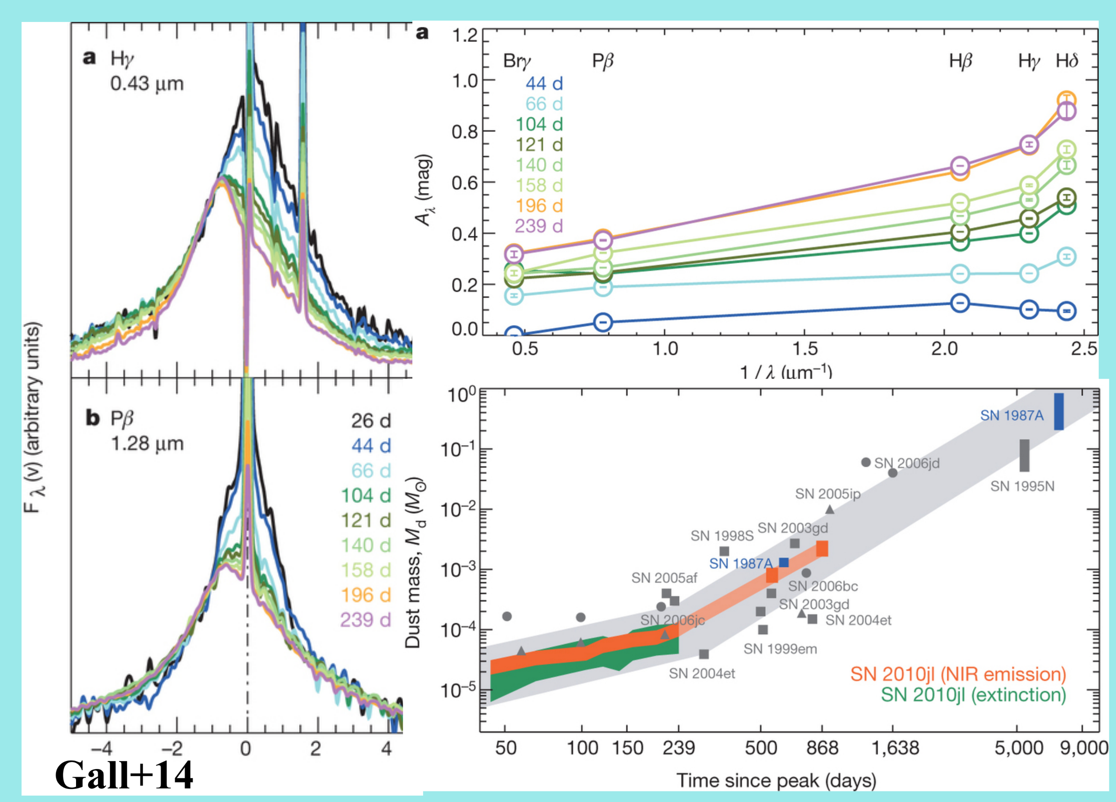


Figure 2: VLT/XSHOOTER simultaneous visible/IR spectra of the Type IIn SN 2010jl. Due to the wavelength coverage, these spectra allowed, for the first time, the ability to measure the extinction curve of the newly formed dust. The grains are sufficiently large (>0.1 micron) to survive the reverse shock and can be considered the missing link in the dust formation timeline of SNe.

IR Hubble Diagram

Type Ia SNe serve as a cornerstone for measurements of dark energy. Recent observations suggest that SNe Ia are likely superior distance indicators in the near-IR since they are less affected by corrections for dimming by dust. A near-IR Hubble diagram will offer the potential to constrain dark energy models. Efforts are already underway to build both low-, intermediate-, and high-redshift near-IR data sets, along with coinciding visible wavelength observations (see Figs. 3 & 4). Gemini/OCTOCAM will easily be able to provide rest-frame visible and near-IR photometry for SNe at redshifts $z > 0.1$.

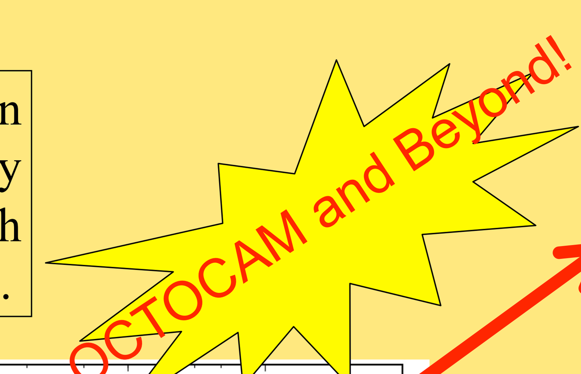


Figure 3: The Reionization And Transients InfraRed (RATIR) Camera, consisting of two visible and two near-IR cameras to offer simultaneous multi-wavelength photometry. Mounted on San Pedro Martir Observatory's 1.5-m robotic telescope in Baja, Mexico, RATIR adds to well-sampled, multi-color light-curves on a nightly basis. Although modest in size, dedicated telescope time can add significantly to the Type Ia IR dataset.

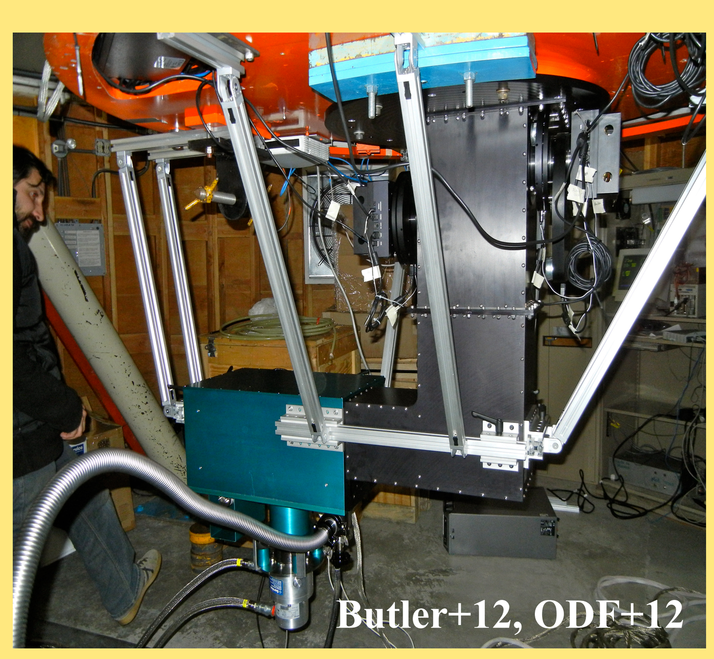
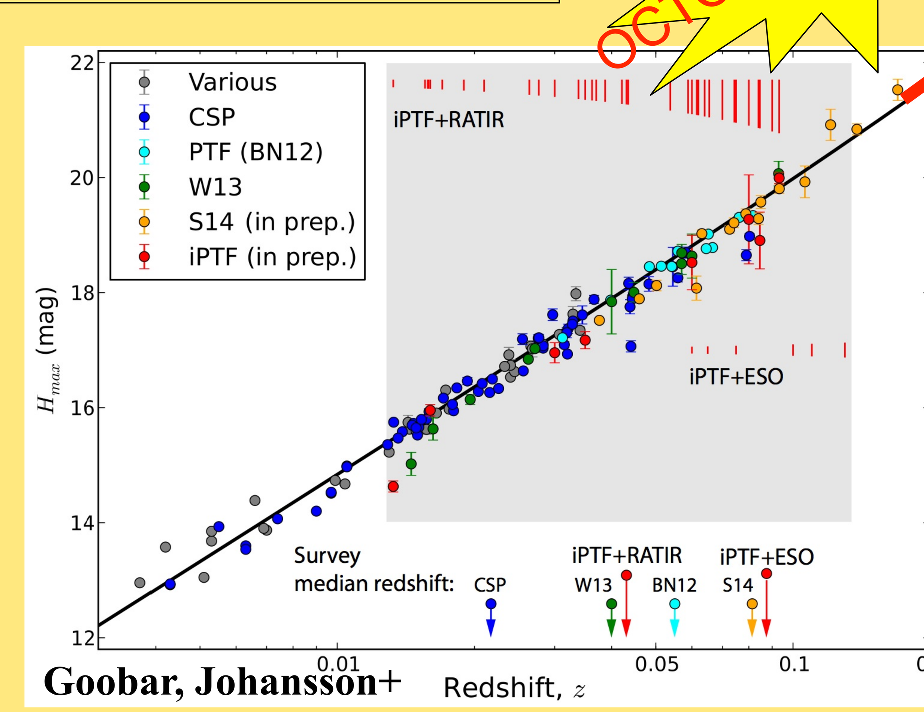


Figure 4: "State of the Art" NIR Hubble diagram showing all published data to date as well as the data in Stanishev et al. in prep. Also indicated in the figure are the redshifts and expected photometric accuracy of our team's 35 (RATIR) + 6 (ESO) iPTF SNe Ia. The HAWKI data offers a dramatic improvement in S/N at z > 0.05. Also shown at the bottom of the panel is the median redshifts of the surveys in the composite NIR Hubble diagram, with the ESO sample covering the most distant sample critical for cosmology.



Gemini/Octocam

OCTOCAM is one of the instruments selected for the Gemini Instrument Feasibility Study (GIFS). Similar to the four-camera RATIR (see above), OCTOCAM has a series of dichroics that allow simultaneous observations across UV/Visible/IR wavelengths on 8 cameras (hence the name). OCTOCAM can be considered a workhorse instrument that optimizes the use of Gemini for broadband single-target observations both for imaging and spectroscopy. Not only will this instrument be ideal for the supernova science discussed above, but it will served as a tool to study the origin and fate in our Universe: It will observe the first generation of stars and their environments through the first gamma-ray bursts at $z > 10$, it will follow the evolution of the Universe throughout cosmological times observing galaxies at all redshifts, it will look for the origin of our solar system in comets, asteroids or transneptunian objects, and advance in the understanding of physics observing extreme phenomena such as magnetars, X-ray binaries, or neutron stars.

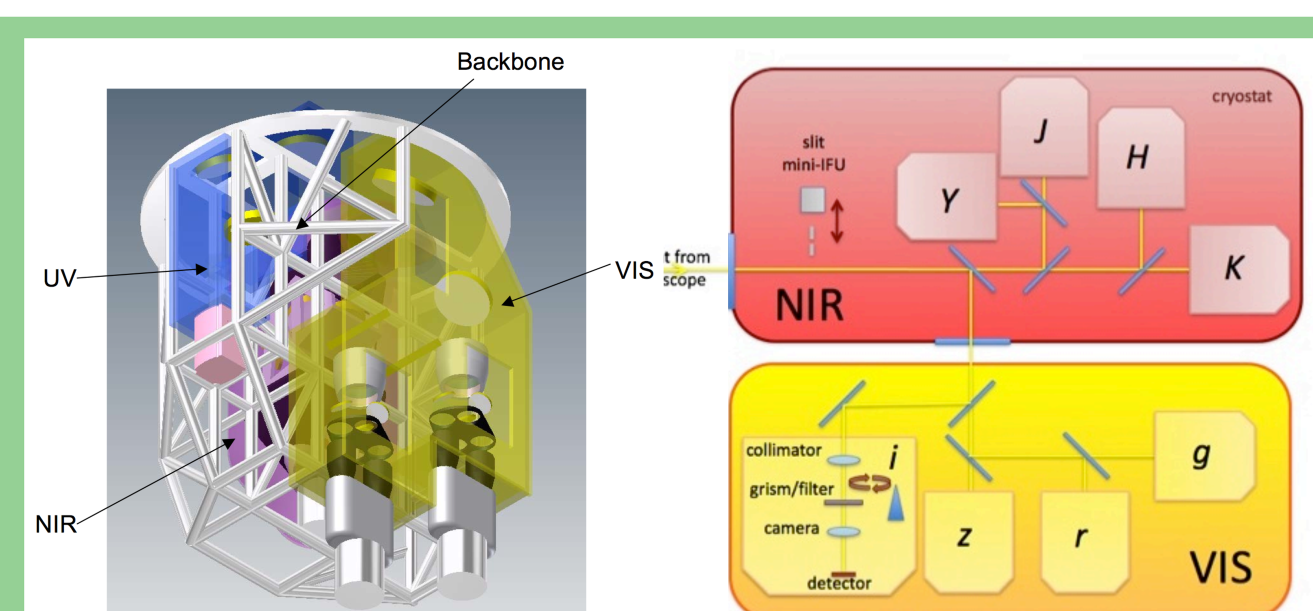


Figure 5: Some early OCTOCAM models of the mechanical and optical design. (Left) Overall instrument layout. The support structure has been designed and optimized using a welded steel truss. As requirements, we impose the possibility to disassemble each of the three optical boxes separately. Lightweight and stiffness are the other design drivers. (right) Schematic optical layout. UV and VIS arms are placed outside the cryostat, which is reserved for the NIR channels (YJHK).

Supernove and Explosive Transient Science

- Pre-SN mass-loss
- Dust formation and characteristics
- Late-time Shock Interaction
- IR Hubble Diagram
- SN Shock Breakout Detection
- Spectropolarimetry of Sne
- GRB Afterglows and Dark Bursts
- High Redshift GRBs and host galaxies
- Kilonovae

*Figure 6: Bullet points summarizing the supernova and other explosive transient science cases for OCTOCAM. In particular, OCTOCAM proposes to offer the following capabilities: multi-band imaging, multi-wavelength spectroscopy, spectropolarimetry, integral field unit spectroscopy, and high time resolution. These features will allow a number of different science cases to be pursued. For a discussion of **all** science cases, see poster by **van der Horst**.*

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