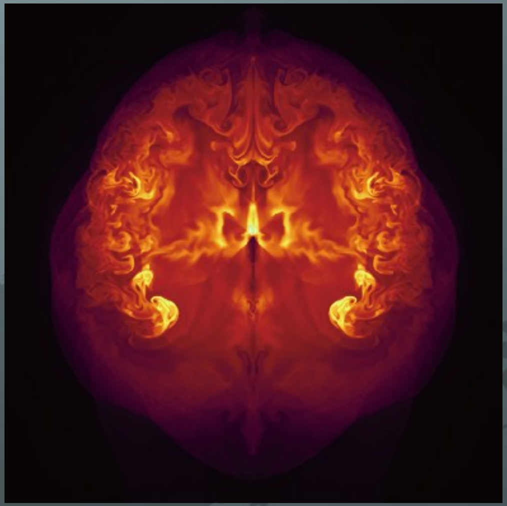
Supernovae and related objects unveiled by TMT

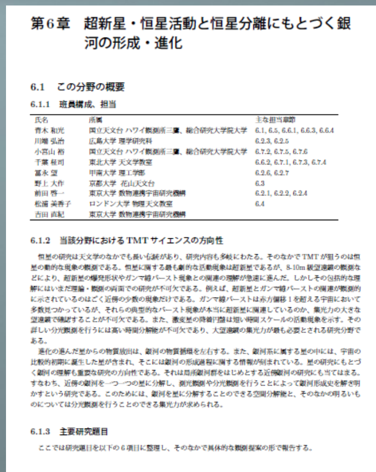
Koji Kawabata (Hiroshima Univ., Japan)



From a Japanese proposal in fields of Stars and Local Galaxies

Pictures: left, Maeda+ 10, right ed. Kodama+

Japanese science proposal for Stars and Local Galaxies fields discussed by sub working group



第6章　超新星・恒星活動と恒星分離にもとづく銀河の形成・進化

6.1　この分野の概要

6.1.1　班員構成、担当

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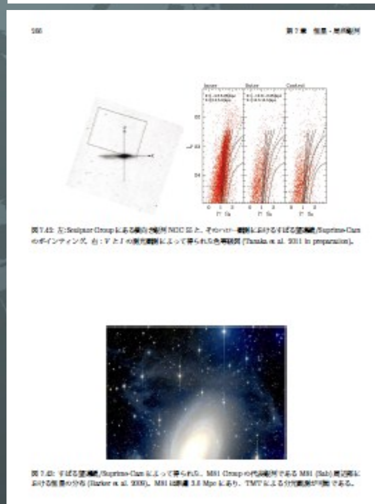
6.1.2　当該分野におけるTMTサイエンスの方向性

6.1.3　主要研究題目



In Stars and Local Galaxies

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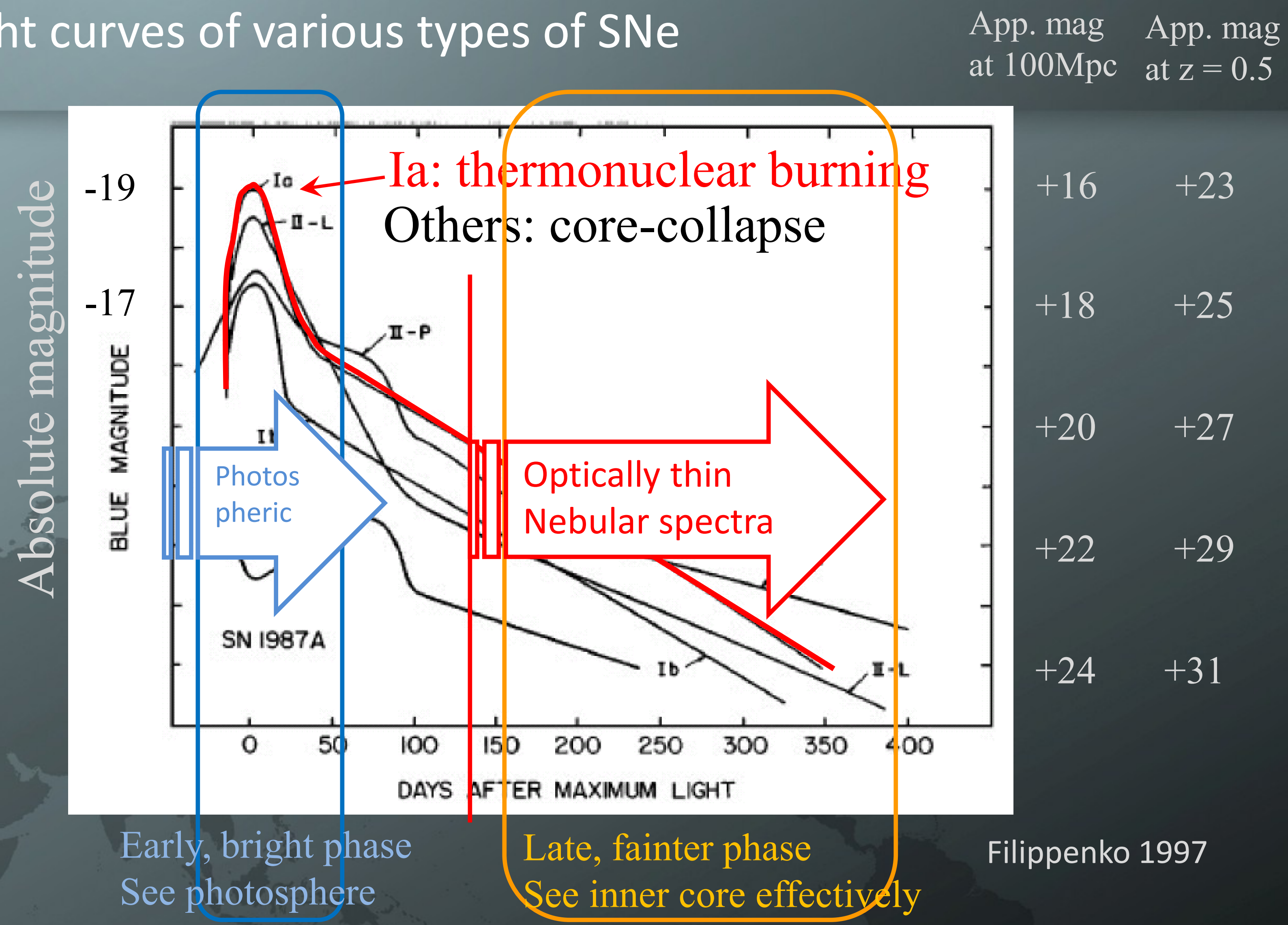
Japanese science white paper for TMT : Edited by Tad Kodama

Main Items of proposal: Stars and Local Galaxies

☺*Trace stellar activity and explosions*
☺*Decipher galaxy formation and evolution via high-res. observation*

- **Supernovae (SNe) and gamma-ray bursts (GRBs)**
- Time variability of stars and binaries
- Stellar evolution and cycles of matter
- 1st and 2nd generation stars
- Formation of local galaxies
- Detailed stellar population in nearby galaxies

Light curves of various types of SNe



Filippenko 1997

⇨ TMT may contribute to late-phase (detailed) obs. for nearby SNe and early-phase obs. for moderately distant SNe

Major problems on SNe

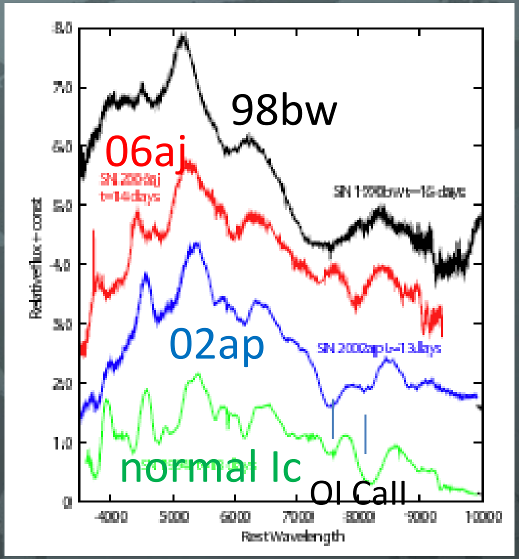
- Explosion mechanism and progenitors
  - Core-collapse (CC) SNe: Outward shock wave, 3D effects
  - Thermonuclear (Type Ia) SNe: Spectroscopic diversity, 3D effects
  - Connection between SNe and GRBs
  - Nature of Faint supernovae/New type explosions
- Nucleosynthesis, products back to ISM (dust, etc.)

Main items on SNe and GRBs in our proposal

- GRBs and SNe: Progenitors of *normal* GRBs
- Geometry of SN explosion
  - Spectroscopic approach
  - Polarimetric approach
- High Spatial Resolution Spectroscopy of Nearby SNe and SNRs
- Faint supernovae
- Supernovae in the High-Redshift Universe

SNe as Progenitors of long GRBs: Introduction

- A part of long GRBs appear associated with energetic SNe Ic
- Spectroscopically confirmed SNe associated with long GRBs
  - SN 1998bw (bright, energetic SN Ic) - GRB 980425 (z=0.0085; X-ray rich; $E_{iso} << E_{typ}$)
  - SN 2003dh (bright energetic SN Ic) – GRB 030329 (z=0.168)
  - SN 2003lw (bright energetic SN Ic) – GRB 031203 (z=0.105; $E_{iso} << E_{typ}$)
  - SN 2006aj (mildly-energetic SN Ic) – GRB 060218 (z=0.033; X-ray flash; $E_{iso} << E_{typ}$)



Spectra of SNe Ic (*hypernovae*)
(Nomoto+ 06)

Massive star

Envelope-stripped
(mass-loss in WR phase / binary interaction)
H,He layers off

Type Ic SN
H,He-deficient
High-vel. ejecta
Forming BH/GRB

Diversity of GRB-SNe: The scenario is universal?

- **Consensus "Long-duration GRBs originate from energetic SNe Ic"?**

However,

Sample SN-GRBs are still few and quite atypical.

- $E_{iso} = 10^{48}\text{-}10^{49}$ erg << $E_{iso,typ}$ ~ 10^{51} erg
- **z < ~0.1 << z_{typ} ~ 1-2 (restricted to nearest GRBs; outlier?)**

Difference between `GRB-associated energetic SNe Ic' (like 98bw) and `non-GRB energetic SNe Ic' (like 03jd). e.g., metalicity of host galaxy (Modiaz+ 08)

Thus, a part of observational facts can be no longer explained only by the simple scenario.

- **Diversity of Progenitors for long-duration GRBs**

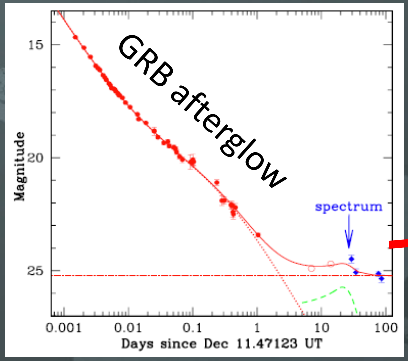
GRB 060505 and GRB 060614 (z <~ 0.1):

Afterglow observed, but SN is too faint (<1/100 of typical luminosity)

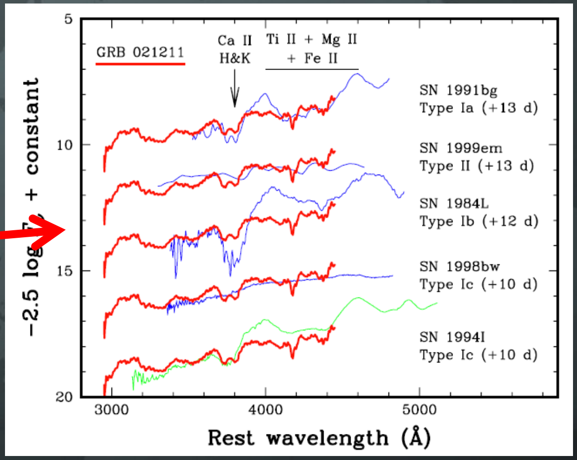
Every nearby long GRB is NOT associated with bright SNe.

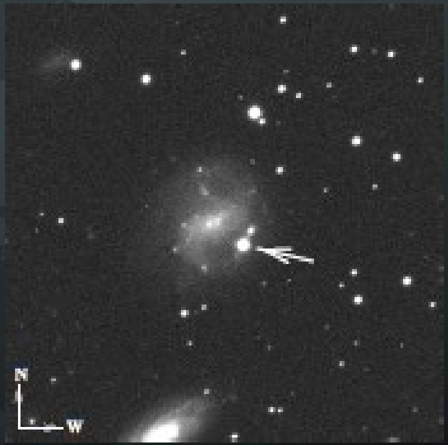
GRBs and SNe: Progenitors of *normal* GRBs: Observation Plan

- With TMT (IRIS/AO and/or WFOS)
  - Optical and NIR Spectroscopy for SN components of GRBs up to z=1-2 at ~1 month from GRB
    - SN 1998bw at z=1: I_{max}=24mag, J_{max}=23mag, H_{max}=23mag
    - S/N~5 with R~1000: Exp time ~1hr in I-band, 3hr in J-band, 5hr in H-band
    - ~5 GRBs/year at z<1
  - AO is so effective to avoid contamination of host galaxy background



Marginal spectroscopy for GRB 021211 (z=1.0; Della Valle+ 04)

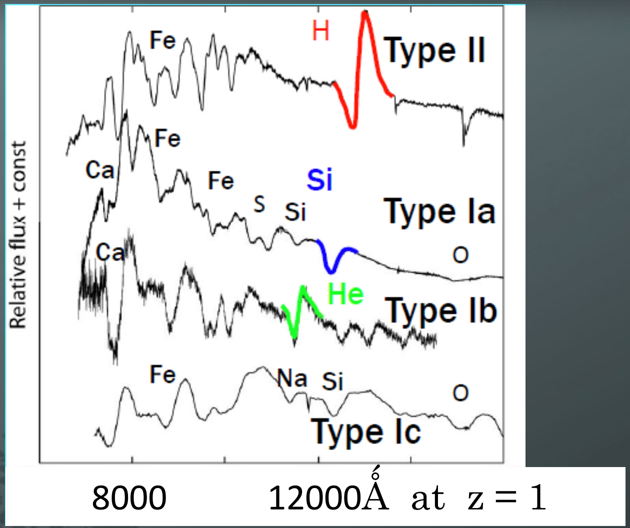




SN 1998bw (Galama+ 98)

GRBs and SNe: Progenitors of *normal* GRBs: Summary

High quality spectra for SN components of *normal* GRBs at $z > 0.1$ (up to ~2) (TMT IRIS/AO, WFOS)



More GRB-associated supernova samples

Clarify connection between GRBs and SNe:
- ✓ Progenitor of GRBs, Physical process of GRB-jet ejection,
- ✓ Massive star evolution…

Geometry of SN explosion: Introduction

Explosion mechanism of SNe (core-collapse/thermonuclear=Ia)

-- Essential, but still unclear

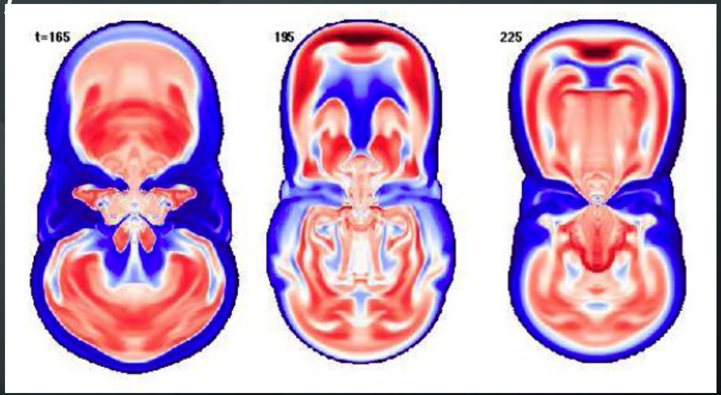
-- Explosion does not occur in simulation (CC; $M_{zams} > 10\text{-}15M_{\odot}$)

-- Diversity in velocity/composition structure (Ia; e.g., Maeda+ 10)

Recently, many studies indicate that **Effects in multi-dimesional structure** can be a key ingredient in the explosion physics.

- ✓ Standing Accretion Shock Instability, SASI (CC)
- ✓ Magnetic field, rotation effect (CC)
- ✓ Off-center ignition (Ia)

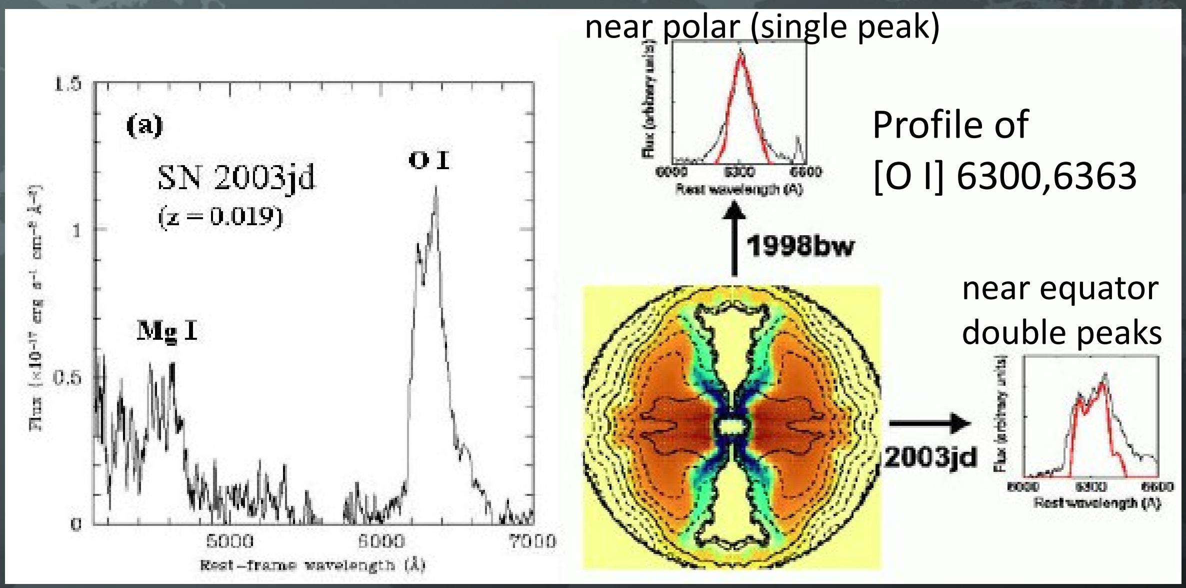
⇨ Non-spherical SN explosion



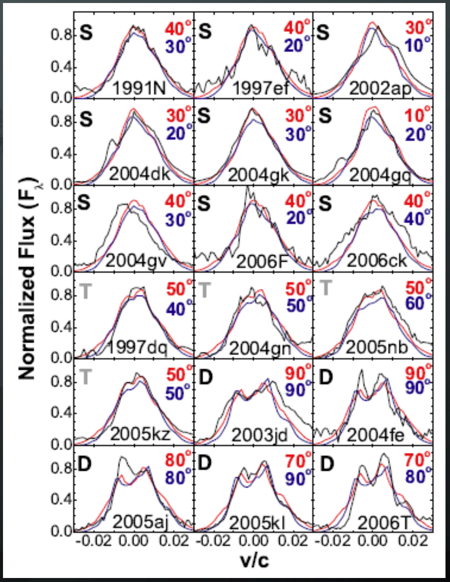
Numerical simulation of SASI (Blondin+ 04)

Geometry of SNe: Spectroscopic approach 1

- Late-phase spectra (>0.5 year): Ejecta becomes optically-thin and line emission brings information at innermost part (composition, expansion velocity).
- 8-10m telescopes are revealing possible general asphericity for envelope-stripped SNe (SNe Ib/Ic).
- [OI]6300,6363 is blend. Mg I]4571 is more useful, but faint



Mazzali+ 05; Maeda+ 08



Maeda+ 08

Geometry of SNe: Spectroscopic approach 2 and Obs. Plan

- For SNe Ia, recent studies pointed the correlation between the velocity dispersion in the early phase and Fe/Ni line velocity in late phase, which can be explained by off-center ignition.

With TMT (IRIS/AO and/or WFOS)

Much larger sample for both CC/Ia.

CC: Explosion mechanism for each type

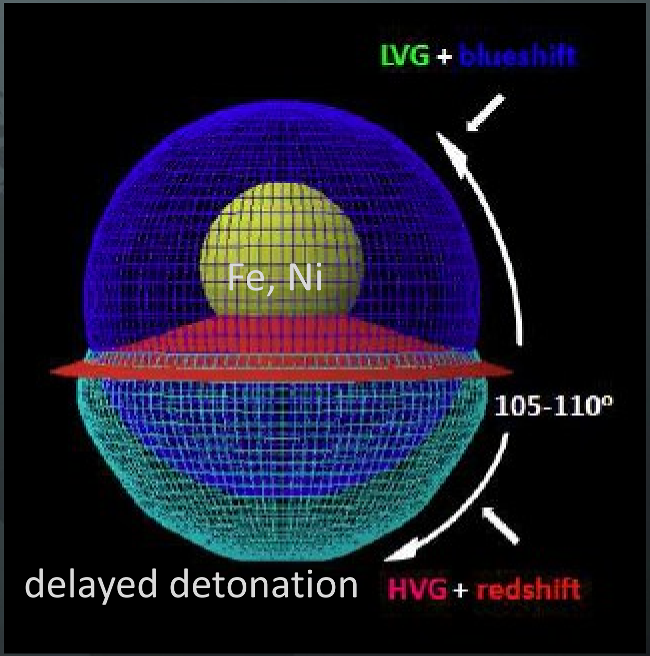
(Type Ic – Ib – IIb – II)

Nearby Ia: Detailed explosion mechanism

from Opt-NIR-MIR spectra

Distant Ia: Difference from nearby SNe Ia,

validity of standard candle (z~0.15)



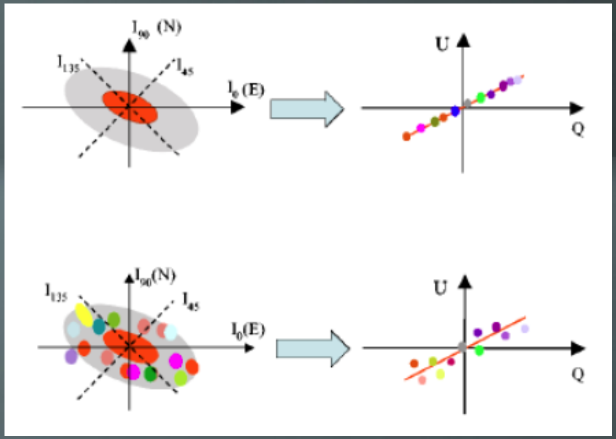
Off-center ignition explosion model (Maeda+ 10)

Geometry of SNe: Polarimetric approach

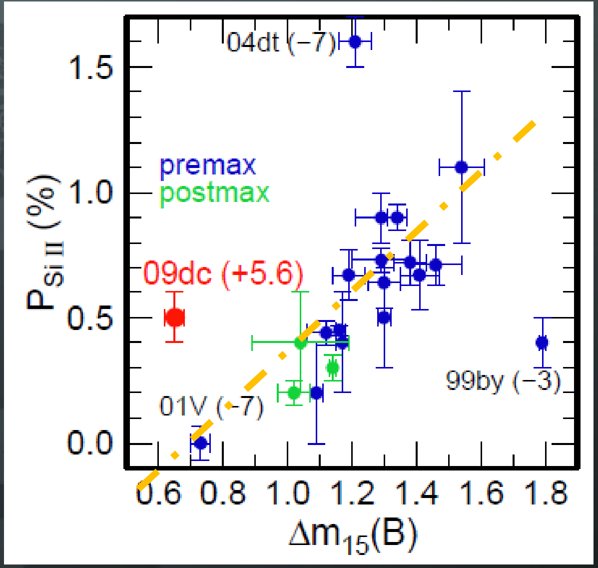
Polarization proves asymmetry of ejecta (photosphere/chemical inhomogeneity) for early, photospheric phase of SNe.

Not only CC SNe but also SNe Ia show large polarization across absorption lines, being different with elements. However, well-observed samples are still lacking.

Polarimetry needs much number of photons (Δp~0.1%) and TMT will be ideal photon collector. But, the problem is no optical and NIR polarimeter being planned for TMT (instrumental polarization of tertially mirror in Nasmyth foci ~4%).



Photospheric asphericity and polarization in QU diagram (Wang & Wheeler 08)



Line polarizatin vs. decline rate of SNe Ia (Tanaka+ 10; Wang+ 08; Leonard+ 05; Chornock&Filippenko 08)

Geometry of SNe: Summary

Late-phase spectroscopy - Emission line profile, velocity
Early-phase spectropolarimetry – Chemical structure
(TMT IRIS/AO, WFOS, possible polarimeter)

3D structure of SN ejecta: Velocity, composition, etc.

⬇

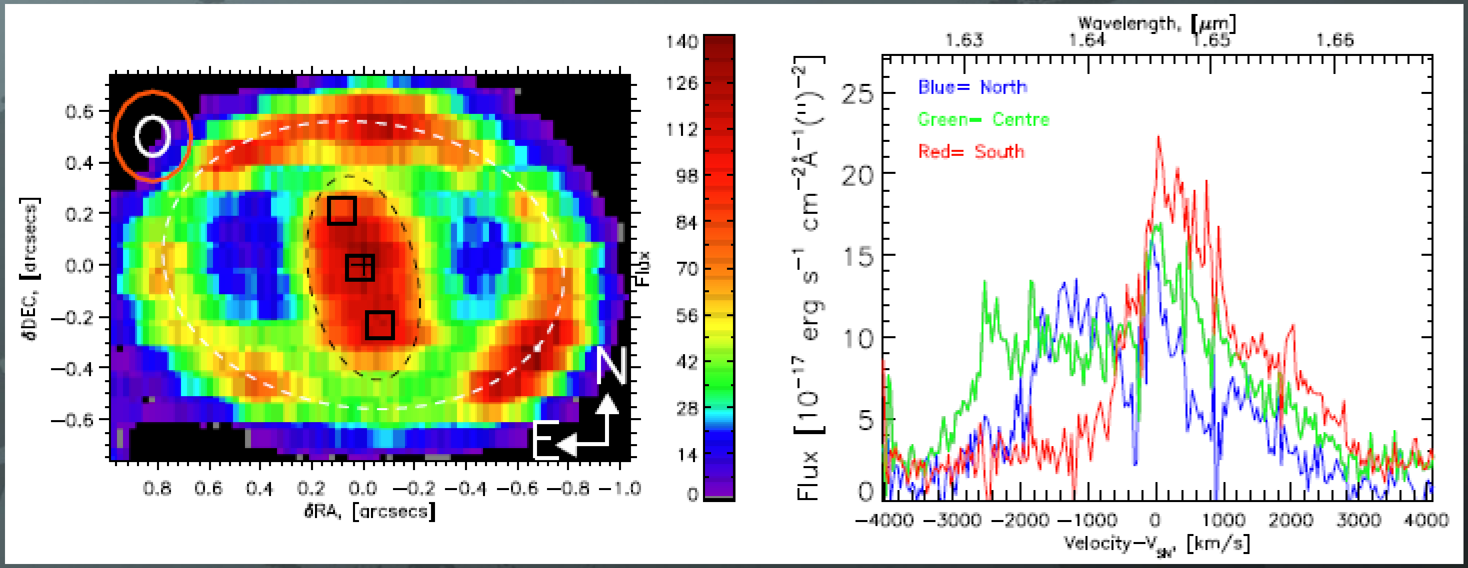
Explosion mechanism and nucleosynthesis:
CC: How outgoing shock wave is produced?
Ia: Is off-center ignition universal? How transition from deflagration to detonation occurs?

Spatial Resolusion Spectroscopy of Nearby SNe and SNRs

SN 1987A – only young SN which has been spatially-resolved

With TMT (IRIS/AO and/or IRMOS/AO)

Spectroscopy of young, nearby ~5-10 SNRs (after 1980 at <10Mpc)



2D spectroscopy of SN 1987A remnant; different asymmetry between central ejecta and circumstellar ring (Kjær+ 10)

Faint supernovae

Suffering from selection effect / Can be a larger population

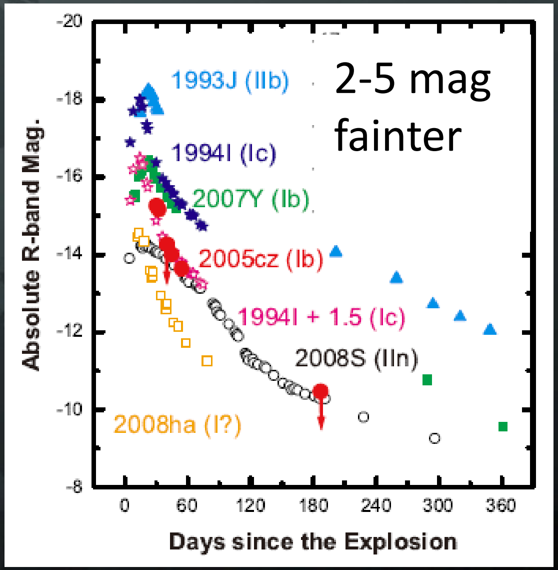
Potential roles for resolving some major problems of SNe

- Ia: SN 2002cx-like, SN 2008ha – incomplete Ia?
- Ib: Ca-rich, O-deficient: helium detonation, or CC of less massive
- IIP: Fall-back to black hole? Less massive core-collapse?

With TMT (WFOS)

Spectroscopy of larger samples of faint SNe

→ From case studies to comprehensive understanding of stellar evolution



Light curves of faint SNe (KK+ 10)

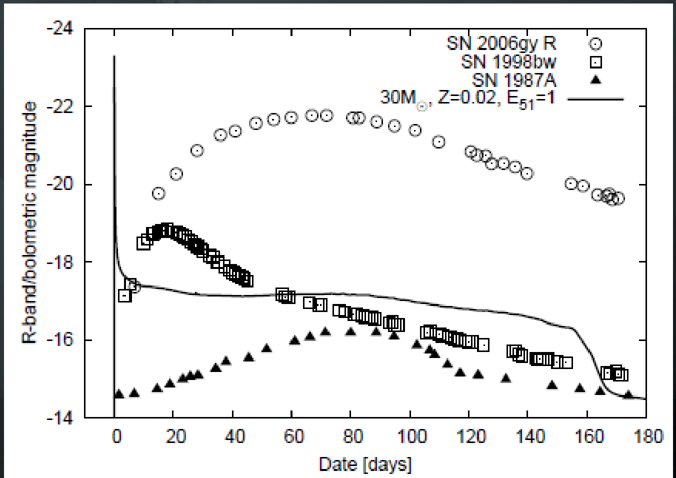
Supernovae in the High-Redshift Universe

Exploring high-z universe, e.g., SFR, from unbiased, individual stars (SFR from galaxy observation may miss faint diffuse galaxies)

- ✓ Bright SN IIn (+SNe IIL, PISN) --- $M_R \sim -22$ mag
- ✓ Shock breakout --- $M_{bol} \leq -23$ mag, easy to observe because $\Delta t/(z+1)$

With TMT (IRIS and/or WFOS)

Spectroscopy of candidates of high-z supernovae found by survey program coordinated with other telescopes (Subaru, LSST, Pan-STARRS,etc)



Light curve of typical SNe at rest frame (Smith+ 07; Patat+ 01; Catchpole+ 87; Tominaga+ 09). The time scale is prolonged by 1/(z+1) for high z SNe.

Conclusion 1/2

- TMT spectroscopy for SNe associated with moderately-distant GRBs and explore progenitors of *normal* GRBs
- TMT spectroscopy (and spectropolarimetry, if possible) for SNe to diagnose 3D structure and explosion engines
- High spatial-resolution spectroscopy of young, nearby SNRs
- Faint supernovae to complete stellar evolution model
- Supernovae in the High-Redshift Universe

Conclusion 2/2

Opt: WFOS (R~500-1000)
NIR: IRIS w/ AO (R~500-2000), IRMOS (R~2000)

Mostly, no multiplicity is required
Polarimetric capability is desirable, if possible

To maximize the opportunity,
Simultaneous wide-band spectroscopy (Opt-NIR),
AO-assisted instruments (red band – NIR) is desirable

→ X-shooter-like instrument at the AO port is ideal (mostly for moderately distant SNe)