### How Do Massive Stars Explode?

### Origin of elements



(Hubble Space Telescope)

# Supernova Explosions

Supernova 2007gr in NGC 1058

MT, Kawabata, Maeda, et al. 2008, ApJ, 689, 1191 MT, Kawabata, Maeda, et al. 2009, ApJ, 699, 1119 MT, Kawabata, Yamanaka, et al. 2010, ApJ, in press (arXiv:0908.2057)

Subaru/FOCASV+R

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# **Brief Self-Introduction**

- Masaomi Tanaka (@AI9)
  PhD. 2009 Sep.
  - "M.Tanaka" in astronomical society Masayuki Tanaka (IPMU, @A18), ...
- Research Interests
  - Observational and theoretical astronomy
    - Optical observations of supernovae in external galaxies (Imaging, Spectroscopy, Spectropolarimetry)
    - Radiative transfer simulations



# How Massive Stars End Their Life?

### Core-Collapse Supernova!

- Origin on elements, dynamical effect on the galaxy, origin of cosmic rays, ...
- But, how? core-collapse --> bounce --> ??
  Longstanding mystery (> 50 yrs)
- Recent "state-of-the-arts" numerical simulations
  - Explosion would not succeed in one-dimensional simulations (e.g., Rampp+00; Sumiyoshi+05)



# Unsolved Problems in Astronomy

- Does the activity of the sun affect the earth?
- The structure of the solar system
- How were the planets formed?
- Is our solar system common? (Extrasolar planets)
- How do massive stars explode?
- The life of galaxies
- What is the gamma-ray bursts
- The origin of ultra-high energy cosmic rays
- How was the first galaxy formed?
- What is "dark matter"?
- What is "dark energy"?
- How many dimensions are in the universe?
- Is our universe alone?



太陽と太陽系の"難問" 太陽系はどこまで広がっているか?/生命の材料はどうやってできたのか? など 銀河宇宙の"難問" 銀河はどんな一生をたどるのか?/宇宙で最初の天体はいつ生まれたのか? など 宇宙論の"難問" ダークマターの正体は何か?/宇宙は何次元か?/宇宙は一つたけか? など 著作権保護コンテンツ」

Newton 2008, ed. by Kaifu

# A Hope

- Multi-dimensional simulations
  - Non-spherical explosion may succeed with help of e.g., rotation, magnetic field, or some instabilities



Harikae et al. 2009

Are SNe Really Non-Spherical? --> Extracting Explosion Geometry of SNe from Observations

# Some Quantities

- Velocity ~ 10,000 km/s (from spectroscopy, Doppler shift)
- Time ~ 30 days 1 yr
  (diffusion time <sup>56</sup>Co decay time)
- Radius ~ 2 x 10<sup>15</sup> cm ~ 0.001pc @ 30 days
- Distance ~ 30 Mpc (~10<sup>26</sup>cm)
- Angular size ~ 10<sup>-10</sup> deg (~10<sup>-6</sup> arcsec) (diffraction limit of ~100 km telescope in optical) We cannot resolve the "shape"...



# Power of Polarization (1/2)



# Power of Polarization (2/2)

Zero polarization

Non-zero polarization

Non-zero polarization (at line)

ion

The unique method to explore the "shape" of extragalactic (point source) SNe

# Strategy for SN Spectropolarimetry

- Spectropolarimetry = "Photon-hungry" technique
  - Wavelength resolution (λ/Δλ~600 --> Δv ~500 km/s) polarization accuracy (0.1%)
- SN = transient
  - Fading rate ~I-2mag/50 days

 Need for ToO observation with large telescopes
 < 2-3 weeks after the discovery</li>



 Very small samples so far (only 4 high-quality data for H-deficit core-collapse SNe)

# Description of Polarization

Stokes parameters (for linear polarization)



• Total polarization  $P = (Q^2 + U^2)^{0.5} / I$ 

• Polarization angle  $\theta = 1/2 \operatorname{atan}(U/Q)$ 







# Polarization Spectrum of SN 2007gr



Large polarization at Ca
 = Explosion is not
 spherically symmetric!

 No polarization at O/Na = different distribution between Ca and O/Na

• Continuum polarization? MT et al. 2008, ApJ, 689, 1191

### Interstellar Polarization • P < 9% x E(B-V) Serkowski et al. 1975 magnetic field



(Astrophoto.com)

# Inferred Element Distributions

shock

line of sight

Ca

O, Na

Ca

- O I and Na I: nearly spherical (Pre-exist in the massive stars)
- Call: non-spherical (Synthesized by the explosion + pre-exist)

Example: Bipolar explosion (not unique!!)

# Polarization Spectrum of SN 2009jf



# Polarization of Type la Supernova



Thermonuclear
 explosion of white
 dwarf

 Rotation of the angle is well-known (e.g., Wang et al. 2003)

Type Ia SNe are brighter --> more samples

MT et al. 2010, ApJ, in press (arXiv:0908.2057) MT et al. in prep.

# Thermonuclear Explosion

Rotation of the angle <--> Turbulence...
 (Wang & Wheeler 2008)

#### Thermonuclear Supernova Explosion

model f1



(c) Friedrich Röpke, MPA, 2004

Roepke et al. 2006

Roepke et al. 2004

# What about Core-Collapse SNe?

Core-collapse: spherical or axisymmetric

### Resulting explosion: fully 3D

### Two-axes in collapse?



Mikami et al. 2008



#### Kifonidis et al. 2006

#### 3D instability?



# **Current Status and Future Prospects**

### • Quantitative study

- 3D radiative transfer simulations with polarization
- <u>SN spectropolarimetry with Subaru</u> (PI: MT, Co-I: K. Kawabata, T. Hattori, M. Yamanaka, K. Maeda, et al.)
   --> 3 SNe so far (4 before this program)
  - S09A (I night ToO), S09B (2 nights ToO), SI0A (2 nights ToO), SI0B (submitted)
  - Doubling the number of high-quality samples in 2 yrs
  - Statistical properties with > 10 samples

### Summary: How Massive Stars End Their Life?

Supernova 2007gr in NGC 1058

Ca

Ca

O, Na

2 D)

- From Spectropolarimetric View...
  - The explosion is not spherically symmetric (consistent with other works/expectations/hope)
  - Not even axisymmetric! (NEW with spectropolarimetry)
  - Two axes (c.f. pulsar)?
    Clumps (c.f. thermonuclear explosion)?
  - --> Quantitative study with 3D radiative transfer code