Exercise: The Relation between the Brightness
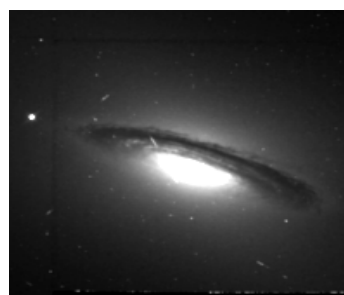# of Supernovae and the Distance to Galaxies

Guide for Teachers

Aim of this educational materials

The supernova explosion is used as a method to measure the distance to far galaxies. Because the supernova explosion is very violent phenomenon, we can easily detect fairly far supernova's appearance. Also, a part of supernova explosion which is called as Type Ia has a feature that the absolute magnitude of maximum brightness becomes the same in any case. The absolute magnitude is known in that type; therefore, by comparing with the apparent magnitude, we can get a clue about measuring the distance to the galaxy in which the supernova was found. This is a method to measure the distance to the cosmologically far galaxies.

In this exercise, 2 sets of materials are prepared. First, calculate some Type Ia supernova's absolute magnitudes and confirm that their values become almost constant. Second, on the assumption that the absolute magnitude of supernovae is already known, by measuring some supernovae's images, calculate distances to galaxies in which supernovae were found.

SN1994d visible   No supernova (by NASA, HST)

Preferable matters to be studied before these exercises

The preferable matters to be studied beforehand are fundamental knowledge about galaxies and supernovae, relation between apparent magnitude and absolute magnitude and how to treat logarithms.

The apparent magnitude of observed star m can be represented by comparison star's magnitude m_0 and photometric value as follows.

$$m = m_0 - 2.5\log\frac{l}{l_0}$$

l_0 : comparison star's photometric value

l : observed star's photometric value

This formula will be needed in the exercise 5-2.

The relation between absolute magnitude *M*, apparent magnitude *m* and distance *r* is as follows.

$$M = m + 5\log\frac{R}{r} \quad \text{······} \quad R = 10\,\text{pc}$$

According to Richardson et al. (2002), the absolute magnitude of Type Ia supernovae's maximum brightness is –19.46.

The distance to a galaxy is mainly calculated from radial velocity *v* by Hubble's Law. As the Hubble constant, we adopted the same value with Richardson et al. which was used when they calculated the absolute magnitude.

$$v = H_0 \times r \quad \text{··············} \quad H_0 = 60\,\text{km/s/Mpc}$$

Outline of the 2 sets of materials
[Set 1] Research on the Relation between Type Ia Supernova's Brightness and Galaxy's Distance - 1

Aim:
Find out that the value of Type Ia supernova's absolute magnitude at maximum brightness becomes around –19.5.

Exercise Plan (an example): 1 hour exercise in the classroom
1. About SN2002bo, from graph of the light curve, read the maximum brightness (magnitude).
2. Calculate the absolute magnitude from the result of 1.
3. By repeating the procedure of 1. and 2., calculate the absolute magnitude of each supernova.
4. Consider about the calculated values.
5. Calculate the distance for an object which distance is unknown. (If there is time.)

An example of the answer to the questions in worksheet:
Question 1 - 3

(See Table 1 in next page.) When reading from the light curve, the variation of individual student's measurement doesn't care. In this calculation, a table of logarithms is needed. It is easy to execute this calculation by using calculator with a function to calculate logarithms or spread sheet software.

Because the number of supernovae is a lot, assign the work to the group composed of 3 or 4 students may be a good way.

Table 1

Galaxy	Distance [Mpc]	Supernova	Apparent magnitude	Calculated magnitude
NGC3190	26.2	SN2002bo	13.6	-18.5
NGC3169	23.0	SN2003cg	14.4	-17.4
NGC5468	47.3	SN2002cr	14.2	-19.2
NGC7678	58.1	SN2002dp	15.0	-18.8
UGC10743	42.8	SN2002er	14.2	-19.0
NGC1309	35.6	SN2002fk	13.2	-19.6
NGC3987	75.8	SN2001V	13.8	-20.6
UGC11725	105.8	SN2001dl	16.2	-18.9
UGC10738	112.0	SN2001cp	15.8	-19.4
UGC1162	185.1	SN2001eh	16.4	-19.9
NGC1448	19.6	SN2001el	12.7	-18.8
UGC5129	67.0	SN2001fe	14.8	-19.3

Mpc: represent one million parsec (pc). The parsec is a unit of distance defined as "a distance corresponding to a stellar parallax of one second".

Question 4

Understand that absolute magnitudes concentrate around –19 magnitude is enough. Taking an average will lead to question 5. An average from above table is –19.2.

Question 5

Calculate the distance from the absolute magnitude of question 4. The value around 75 Mpc will be good enough. If you are planning to execute the exercise "Research on the Relation between Type Ia Supernova's Brightness and Galaxy's Distance 2", this question will be omitted.

[Set 2] Research on the Relation between Type Ia Supernova's Brightness and Galaxy's Distance - 2

Aim:

Find out that the distance to a far galaxy can be measured by Type Ia supernova.

Class Plan (an example): 2 hours exercise in the computer room

1st hour
1. Specify the supernova and the comparison star in the image.
2. Execute photometry of the brightness of the comparison star and the supernova, and record them.
3. Calculate the apparent magnitude from photometric values.

2nd hour
1. Draw the light curve using the calculated apparent magnitude and read the maximum brightness (magnitude).
2. Calculate the distance from the formula for the apparent magnitude and the absolute magnitude at maximum brightness.
3. Consider about calculated values.

An example of the answer to the questions in worksheet:

Question 1

(See Figure 1.) A supernova exists in the dimmed galaxy at center. By adjusting the brightness of the image using the triangle mark of the slide bar, the galaxy will appear more clearly.

Question 2

Either of two comparison stars can be used. Average of both stars will lead more accurate value.

Question 3

Calculation of logarithms is difficult. Use of spread sheet software is a good way. Please use the prepared Excel file.
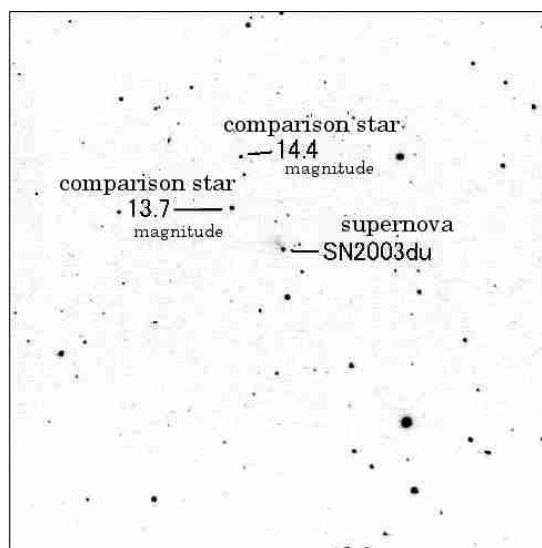

Figure 1

Question 4

When drawing a light curve, light curves of supernovae in exercise 5-1 can be referred. The magnitude at maximum brightness around 13.2 will be good.

Question 5

The value around 30 –35 [Mpc] will be good.
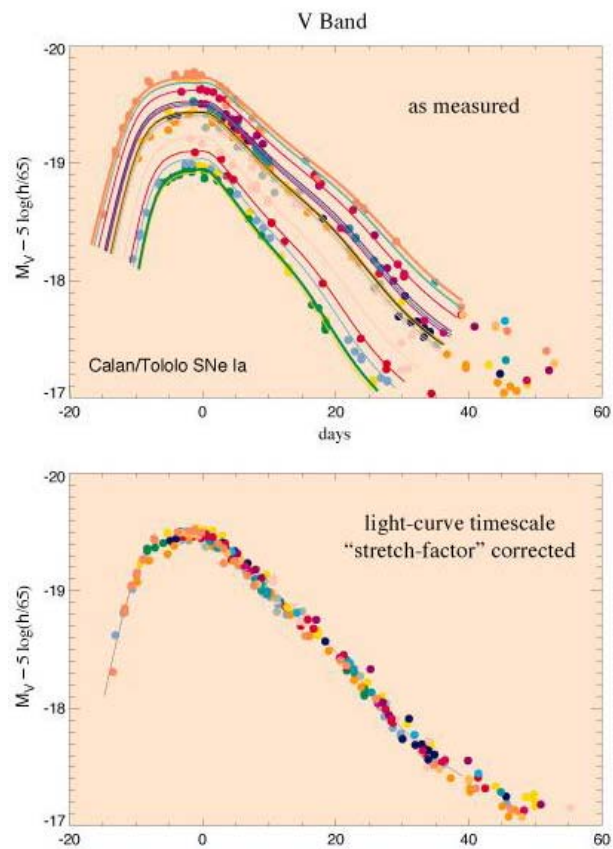

Question 6

This value was calculated from Hubble's Law with the radial velocity 1921[km/s] of the galaxy UGC9391 in which SN2003du was observed.

NOTE: The maximum brightness of supernovae

The maximum brightness of Type Ia supernovae is stable compared with those of other types, but still, show somewhat individuality as Figure 2 (upper panel). To determine the maximum brightness strictly, read the maximum brightness applying the curve fit method at the descending part of the light curve. That's because the maximum brightness will change according to the descending speed of light. In general, slowly descending supernova's maximum brightness becomes more brightened. Considering this fact, the maximum brightness becomes almost –19.5 as Figure 2 (under panel). But, without such corrections, the difference of the maximum magnitude between bright supernova and dark supernova becomes 1 magnitude. This is one of the reasons why student's value doesn't become –19.5 clearly. In this exercise, the individuality will become decrease due to a lot of data and the result will become good value. Therefore, please calculate average without much attention.

One more reason why student's value doesn't approach –19.5 is that the student tends to read the maximum observed point when reading the

(reference; http://www-supernova.lbl.gov/)

Figure 2.

maximum brightness. Guidance of procedure that imagine as drawing a smoothed line first, and then read the maximum value of the line, will lead a good result. As another way, without speaking such procedure, make students consider about values later.

Source of materials:

* Research on the relation between Type Ia supernova's brightness and galaxy's distance – 1
  Light curves of supernovae:
    Supernovae Home Page   http://www.astrosurf.com/snweb/
  Radial velocities of galaxies:
    NAOJ/ADAC, On-line Catalog Service, Galaxy Redshift Catalog
  Images of galaxies:
    NAOJ/ADAC, HST archive
  Absolute magnitude:
    Dean Richardson et al., The Astronomical Journal,123:745-752,2002,Feb

* Research on the relation between Type Ia supernova's brightness and galaxy's distance - 2
  Radial velocities (distance):
    NAOJ/ADAC, On-line Catalog Service, Galaxy Redshift Catalog
  Images of galaxies:
    NAOJ/ADAC, HST archive
  Images of supernovae:
    Courtesy of Mr. Yasuo Sano, Kihara Observatory, Nayoro city

Supplement
 Corresponding to the National Curriculum Guidelines in Japan:
  Senior High School
        Earth Science & Astronomy I
                (2) Composition of Atmosphere, Ocean and Universe
                    Composition of Universe, Galaxy and Universe
        Earth Science & Astronomy II
                (4) Research of Universe, Extension of Universe,
                    Distance and Mass of Celestial Object, Composition of Universe