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博士学位论文摘要选登

Ia型超新星多样性的观测研究

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通常认为Ia型超新星来自碳氧白矮星的热核爆炸, 利用其光度可标准化的特性进行宇宙学距离测量, 发现宇宙处于加速膨胀状态. 然而Ia型超新星的研究仍存在一些基本问题没有解决. 这些问题和Ia型超新星观测上的多样性密切相关. 通过对处于爆发极早期的Ia型超新星进行观测, 获得前身星系统的残留信息, 是研究观测多样性起源、提高测距精度的关键环节. 我们利用丽江2.4 m望远镜, 从国内外超新星巡天项目发现的近百颗超新星候选体中证认出84颗超新星, 包括一批处于爆发早期的Ia型超新星. 结合国内外多台望远镜的后续监测数据, 发现在现有的分类体系中, 一些Ia型超新星难以被归入已知的光谱和测光亚类, 表明它们可能具有不同的前身星性质或者不同的爆发机制.

下面介绍其中3个有代表性的观测和研究工作:

(1)窄线型的Ia型超新星SN 2012fr: 通过对SN 2012fr的观测和研究, 发现在高光度“浅硅型”Ia型超新星中存在两种不同轮廓的Si II λ 6355吸收, 分别以SN 2012fr以及SN 1991T为代表, 暗示着不同的抛射物结构. 这两类Ia型超新星存在明显不同的观测性质, 比如早期紫外-光学颜色演化以及二次电离铁线的强度. 因此, 建议将类似SN 2012fr的“浅硅型”Ia型超新星归入到一类新型子类, 即窄线型Ia型超新星. 这些窄线型Ia型超新星有着较小的光变曲线下降率、较窄的谱线吸收轮廓以及较年轻的诞生环境. 窄线型Ia型超新星的发现对于减小“浅硅型”Ia型超新星的内部光度弥散, 提高使用这类Ia型超新星开展测距时的精度有着重要意义.

(2)贫钙且明亮的Ia型超新星SN 2011hr: 通过对SN 2011hr的观测和模型分析, 发现这颗极端的类91T型Ia型超新星, 同时又具有类似超钱德拉塞卡极限候选体SN 2007if的光谱性质. 光谱模拟计算表明其超高的光度以及较弱的Si II、Ca II吸收是由于爆炸时前身星物质更为充分地燃烧成铁族物质所致, 进而暗示某些超亮的Ia型超新星仍然可以在钱氏质量极限的理论框架下进行解释.

(3)富碳的Ia型超新星SN 2013dy: SN 2013dy极早期的光变曲线表明其前身星半径在$0.25R_{\odot}$以内, 结合早期光谱中明显的碳、氧吸收, 强有力地证明它的前身星是碳氧白矮星. 后续研究表明: 这颗Ia型超新星观测性质大体正常, 在分类上处于过渡区域, 光学光度较高, 但是近红外光度偏低. 结合SN 2011hr偏高的近红外光度, 我们发现这些光变曲线下降较慢的“浅硅型”Ia型超新星在近红外存在2.0 mag左右的光度弥散, 由此对Ia型超新星近红外光度基本均匀的假设提出了质疑.

这些研究表明Ia型超新星有着非常丰富的多样性, 说明它们的前身星性质以及爆炸机制存在很多差异, 值得我们继续开展观测和理论研究. 而这些研究对于提高超新星测量河外距离的精度来说是必不可少的.

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Observational Study of the Diversity of Type Ia Supernovae

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Type Ia supernovae (SNe Ia) are widely accepted as the results of thermonuclear explosion of carbon-oxygen white dwarfs (C/O WDs). However, the basic mechanism of SNe Ia is still uncertain although it has been used to determine the cosmological parameters. It is related to the observed diversity of SNe Ia tightly. The observations of SNe Ia during the extremely early phase can provide key information about the diversity of SNe Ia, and improve the measurement of their distances. Eighty-four SNe are identified from a sample of around 100 SNe candidates based on their spectral observations with the Lijiang 2.4 m telescope. And the following spectroscopy and photometry observations focus on the SNe Ia at the extremely early phase. Based on these observations, we found that some SNe Ia cannot be well classified in the current spectral and photometrical classification systems, which might indicate complex progenitor systems and explosion mechanisms of SNe Ia.

Three representative SNe Ia will be introduced in following:

(1) Narrow-lined (NL) SN Ia—SN 2012fr: Two different profiles of Si II λ 6355 absorption in the luminous “shallow silicon” (SS) SNe Ia are found. That might imply distinction in the structure of the ejecta. Observational differences in the evolution of the “UV-Optical” color and the strength of second ionized iron also exist. Thus, we suggest a new sub-class SNe Ia for it named as NL which shows similarities as SN 2012fr, e.g., small decline rate of the light curve, narrow absorption profile of the spectra, and young environment of the birth place. It is important to reduce to intrinsic luminosity scatters of SS SNe Ia with NL SNe Ia. Thus, it is essential for the further research of SN Ia cosmology.

(2) Calcium-poor and luminous SN Ia—SN 2011hr: The extreme 91T-like SN Ia 2011hr has some similarities with the super-Chandrasekhar candidate SN 2007if according to their observations and spectral modelling. Spectral modelling suggests that the high luminosity and relatively weak absorption of Si II and Ca II are due to the efficient transformation of the progenitor material into the iron group elements during the explosion. It implies that some over-luminous SNe Ia may arise from a Chandrasekhar-mass white dwarf progenitor, which experienced a more efficient burning process during the explosion.

(3) Cabron-rich SN Ia—SN 2013dy: Its extremely early light curves give an upper limit ($R < 0.25\ R_{\odot}$) of the progenitor radius, and the early spectrum reveals strong C II absorption. These indicate a C/O WD progenitor for this SN. The following observation suggests that it is a fairly normal but transitional SN Ia, bright in optical, but the near infrared (NIR) brightness of SN 2013dy is about 2–3 times lower than usual. There is about 2.0 mag scatter in the NIR luminosities of the SNe Ia with small decline rate. This might challenge the assumption of the NIR luminousity uniformity in the SNe Ia.

These research works indicate complex diversity among the nature of progenitor system and the explosion mechanism of SNe Ia. Understanding the diversity of SNe Ia is essential to improve the study of SNe Ia cosmology.