第58卷 第3期 天 文 学 报 Vol.58 No.3
2017年5月 ACTA ASTRONOMICA SINICA May, 2017

doi: 10.15940/j.cnki.0001-5245.2017.03.011 博士学位论文摘要选登

毫秒磁星作为伽玛射线暴中心引擎的研究

王灵俊[†]

(南京大学天文与空间科学学院 南京 210023)

伽玛暴是一种短时标的高能光子爆发现象. 通常把持续时间短于∼ 2 s的暴称为短暴, 长于∼ 2 s的暴称为长暴. 大量观测已经证实, 长暴起源于大质量恒星的塌缩, 因而与超新星成协. 短暴最可能的起源是致密双星并合. 目前, 伽玛暴研究的一个核心问题是确定其中心引擎究竟为黑洞还是中子星. 本文第1章详细阐述了相关进展.

数值模拟发现黑洞可产生相对论喷流, 因而可作为伽玛暴的中心引擎. 然而, 有一些观测特征似乎不能轻易糅合到黑洞模型中去, 如持续数百秒甚至数万秒的X射线平台、短暴的延展辐射、X射线耀发等. 对于这些特征, 最简洁的解释就是它们是由磁星的转动能驱动的. 如果中心引擎为磁星, 快速转动的磁星会向抛射物注入Poynting流. 这种能量注入可使得位于短暴喷流张角之外的观测者观测到来自磁星的电磁辐射信号. 在第2章我们假设来自磁星的Poynting流会很快变成正负电子对主导的极端相对论星风, 该星风受到抛射物阻挡, 形成反向激波. 我们发现, 最近发现的光学暂现源PTF11agg可合理地解释为毫秒磁星驱动的反向激波辐射.

在研究PTF11agg时, 我们没有考虑抛射物对反向激波辐射的吸收, 对抛射物动力学也做了许多简化处理. 在第3章我们对这些问题做了严格处理. 双星并合之后抛射出去的物质是很纯的快中子物质, 在实验室中对这种物质的性质进行研究是非常困难的. 为此我们探讨了通过不同电磁波段的观测来研究其性质的可能性. 我们发现, 在反向激波早期阶段, X射线的不透明度主要来自电子汤姆森散射, 光学波段不透明度主要来自bb (束缚-束缚)跃迁, 而紫外波段的不透明度则很可能来自bf (束缚-自由) 跃迁, 因此将会观测到紫外电离突破.

前两章没有考虑逆康普顿散射对电子冷却的影响. 我们知道, 反向激波中的电子是极端相对论的, 其逆康普顿散射不容忽视, 为此我们在第4章考虑逆康普顿散射过程. 对于同步辐射, 逆康普顿散射会影响同步冷却频率, 使该频率降低. 本章我们计算了由毫秒磁星所驱动的反向激波产生的逆康普顿散射在1–100 GeV能段的流量, 为利用高能望远镜探测并合后产生的毫秒磁星提供了理论依据. 计算发现, 现有的望远镜如Fermi/LAT (Large Area Telescope)、CTA (Cherenkov Telescope Array)可探测到来自∼ 1 Gpc处的毫秒磁星的辐射.

第5章对目前伽玛暴研究领域的热点问题展开了一些讨论, 这些问题的解决无疑将大大推动伽玛暴的研究.

[†]2015-06-15获得博士学位, 导师: 南京大学天文与空间科学学院戴子高教授; wanglj@nao.cas.cn

Millisecond Magnetars as the Central Engine of Gamma-ray Bursts

WANG Ling-jun
(*School of Astronomy and Space Science, Nanjing University, Nanjing 210023*)

The durations of GRBs (gamma-ray bursts) have a bimodal distribution with short-duration GRBs (SGRBs) lasting for less than $\sim$ 2 s and long-duration GRBs (LGRBs) greater than $\sim$ 2 s. A large number of observations indicate that LGRBs originate from the collapses of massive stars and are therefore associated with supernovae (SNe). SGRBs, on the other hand, are believed to be the results of binary compact object mergers. Now the study of GRBs has progressed to the stage of identifing the nature of central engines, i.e., black holes or millisecond magnetars. We elaborate the progress in Chapter 1.

Numerical simulations support the idea of black holes as the central engine of GRBs since the simulations find the formation of jets by black holes. Some observational features, however, cannot be easily integrated into the black hole model, for example, the X-ray plateau lasting for $100-10^4$ s, the extended emission of SGRBs, X-ray flares, etc. The most concise interpretation for these features is that they are powered by rapidly rotating magnetars. If the central engine is a magnetar, it will dissipate its rotational energy by injecting Poynting flux to the ejecta. Such energy injection will enable an observer outside the jet angle of the SGRB to detect the electromagnetic signals. In Chapter 2, we assume that the Poynting flux from the magnetar will quickly transform into the wind dominated by the ultrarelativistic electron-positron, and then a reverse shock will develop when the wind encounters the ejecta. We find that the recently discovered optical transient PTF11agg can be interpreted as synchrotron emission of reverse shock powered by a millisecond magnetar.

In Chapter 3, we consider the absorption of reverse shock emission by the ejecta which is ignored when we study PTF11agg. We also adopt a more realistic dynamics of the blast wave than that adopted in Chapter 2. The ejecta is believed to be pure r-process material which is difficult to study in laboratory. We therefore explore the feasibility to study it by observing the X-ray, UV (ultraviolet), and optical emission obscured by the ejecta. It is found that at early time of the reverse shock emission, the opacity in X-ray band is dominated by elastic scattering of free electrons, the opacity in optical band is dominated by bound-bound transitions, and the opacity in UV band is very likely dominated by bound-free transitions. As a result, the ionization breakout is expected in UV wavelength.

In Chapter 4, we consider the effect of inverse Compton (IC) scattering on the electron cooling that was not taken into account in previous 2 chapters. Because the electrons in reverse shock are ultrarelativistic, it is expected that the IC emission is prominent. The effect of IC on synchrotron emission is to reduce its cooling frequency. To utilize the high-energy telescope to probe the birth of millisecond magnetars, we calculate the IC flux from 1 GeV to 100 GeV. It is found that Fermi/LAT (Large Area Telescope) and CTA (Cherenkov Telescope Array) can detect the IC emission powered by a typical magnetar up to $\sim$ 1 Gpc.

In Chapter 5, we discuss some topics that are on hot debate and the perspective for upcoming years.