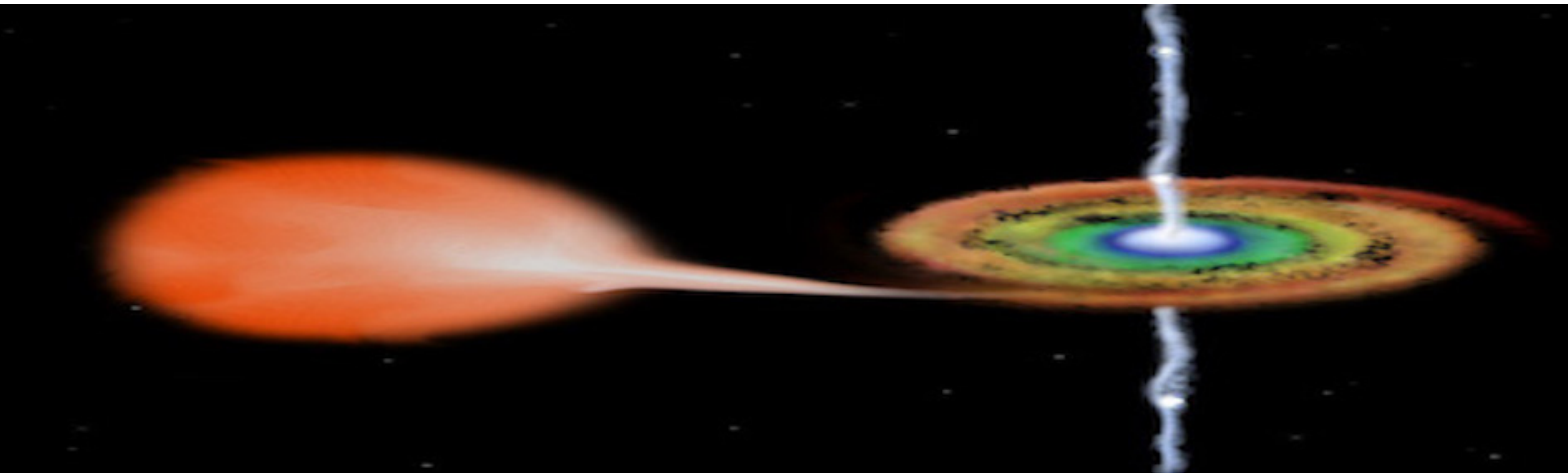
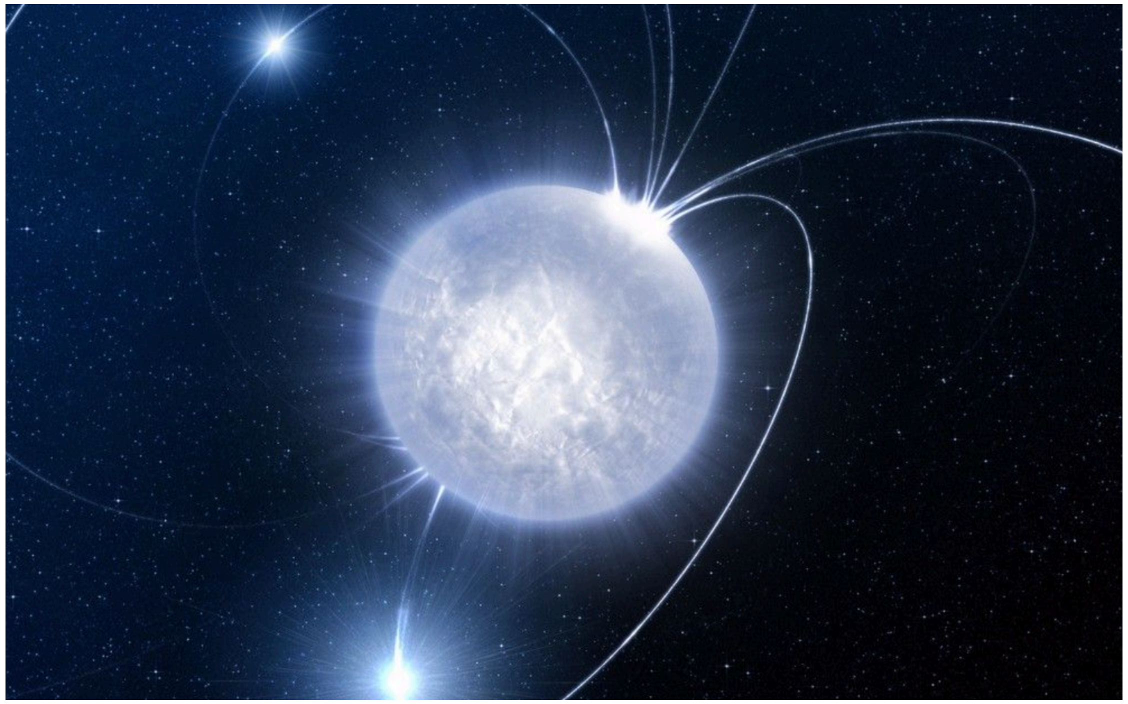
中子星周围热吸积流
的理论研究及其观测检验



乔二林
国家天文台

2022/11/4，国家天文台青年学者学术交流活动

中子星



- 致密天体（复杂的物态）
- 强引力场
- 硬表面
- 磁场
  - ✳ 脉冲星 B～10^{12} G
  - ✳ 毫秒X-射线脉冲星B～10^{8-9} G
  - ✳ 低质量X-射线双星B<10^{8} G

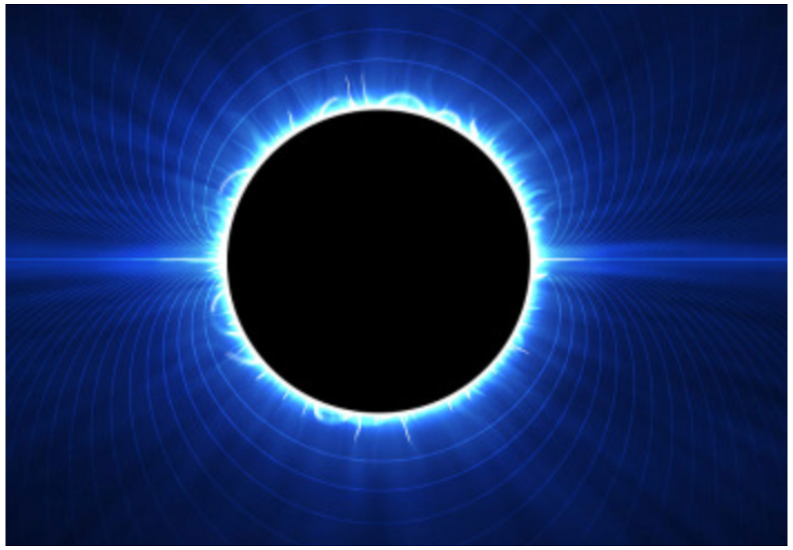
热吸积流

M87（黑洞照片；热吸积流）

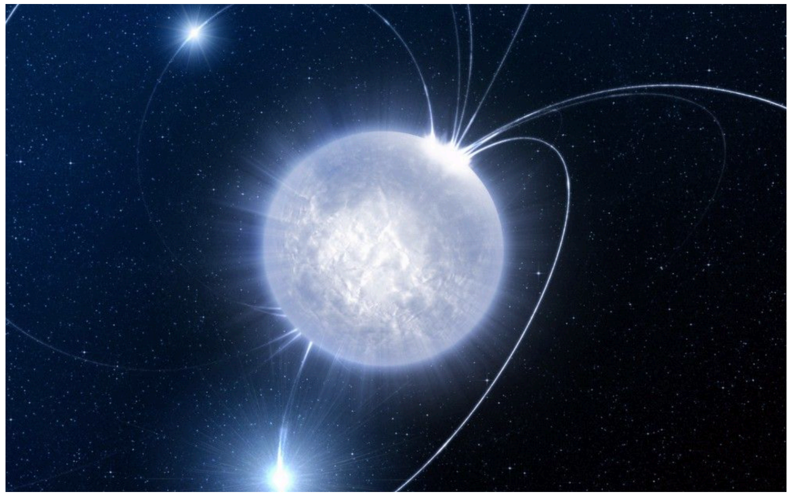
- 热吸积流：Advection Dominated Accretion Flow—ADAF，及其变种
- 温度高，吸积率低
- 辐射效率低：大部分粘滞产生的热被黑洞吞噬（视界面证据之一）
- 主要应用对象：银河系中心、M87以及宁静态黑洞X-射线双星等黑洞吸积系统

中子星周围热吸积流?

黑洞

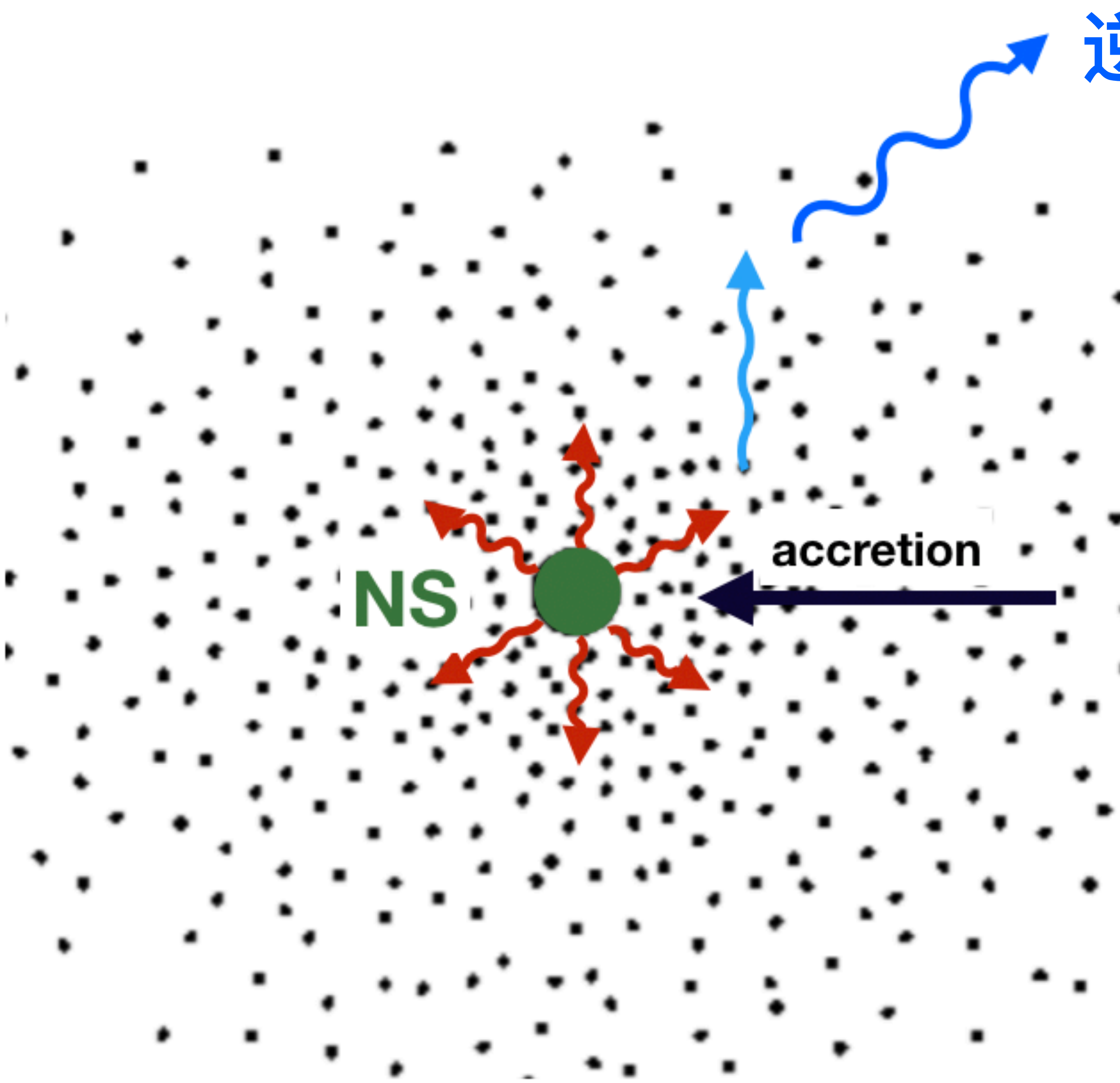


中子星



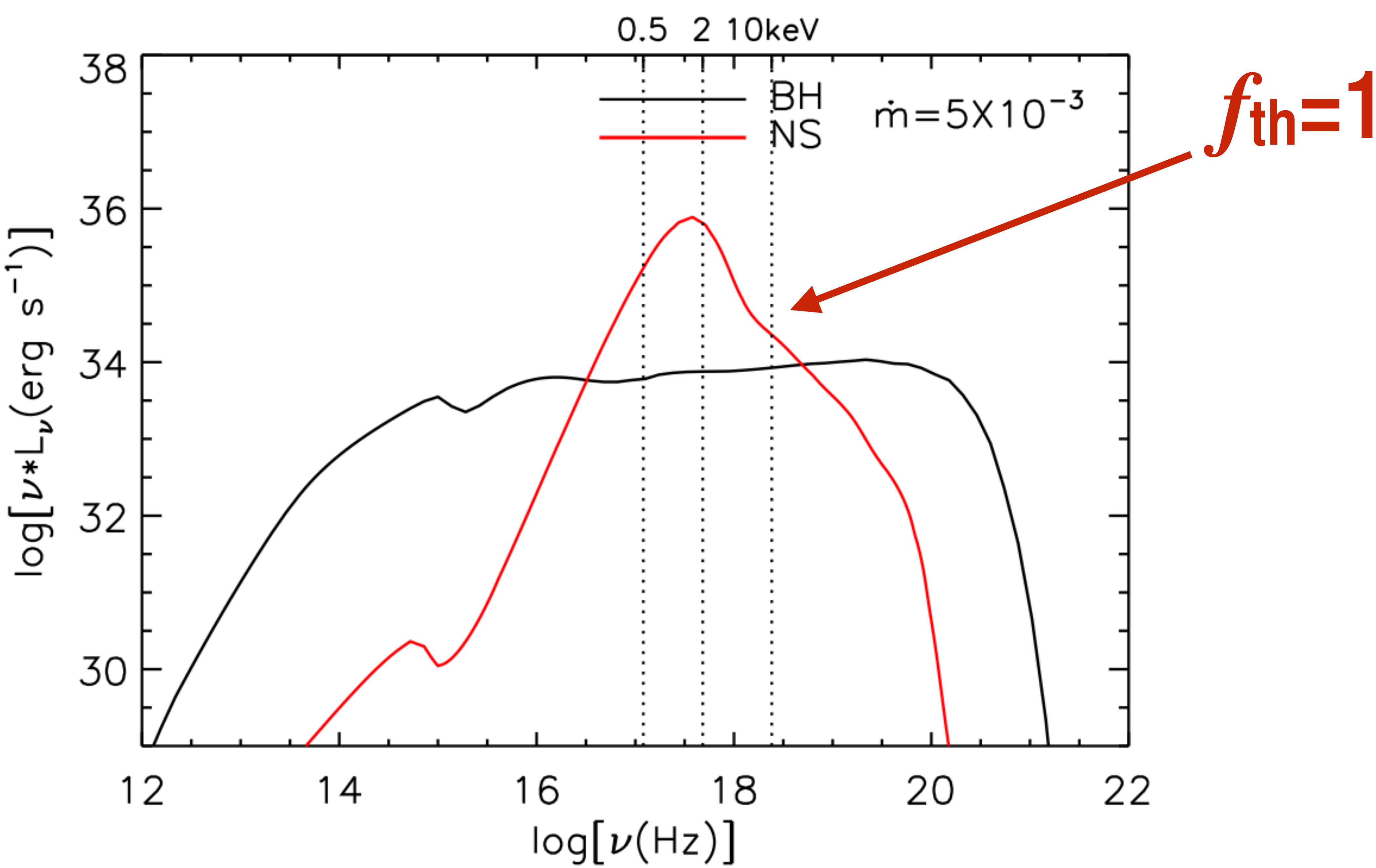
- **研究目的:**
  - 检验中子星硬表面/黑洞视界面造成的不同的观测效应
- **黑洞 VS 中子星**
  - 相似的引力场
  - 视界面 VS 硬表面
  - 磁场弱 VS 低质量X-射线双星: 磁场弱
- **热吸积流**
  - 反馈效应强

中子星对热吸积流的反馈效应



- 中子星硬表面的反馈效应（很复杂，且不清楚）
- 引入热化因子：f_{th}（0–1）描述吸积流和中子星的相互作用

出射谱：中子星 VS 黑洞

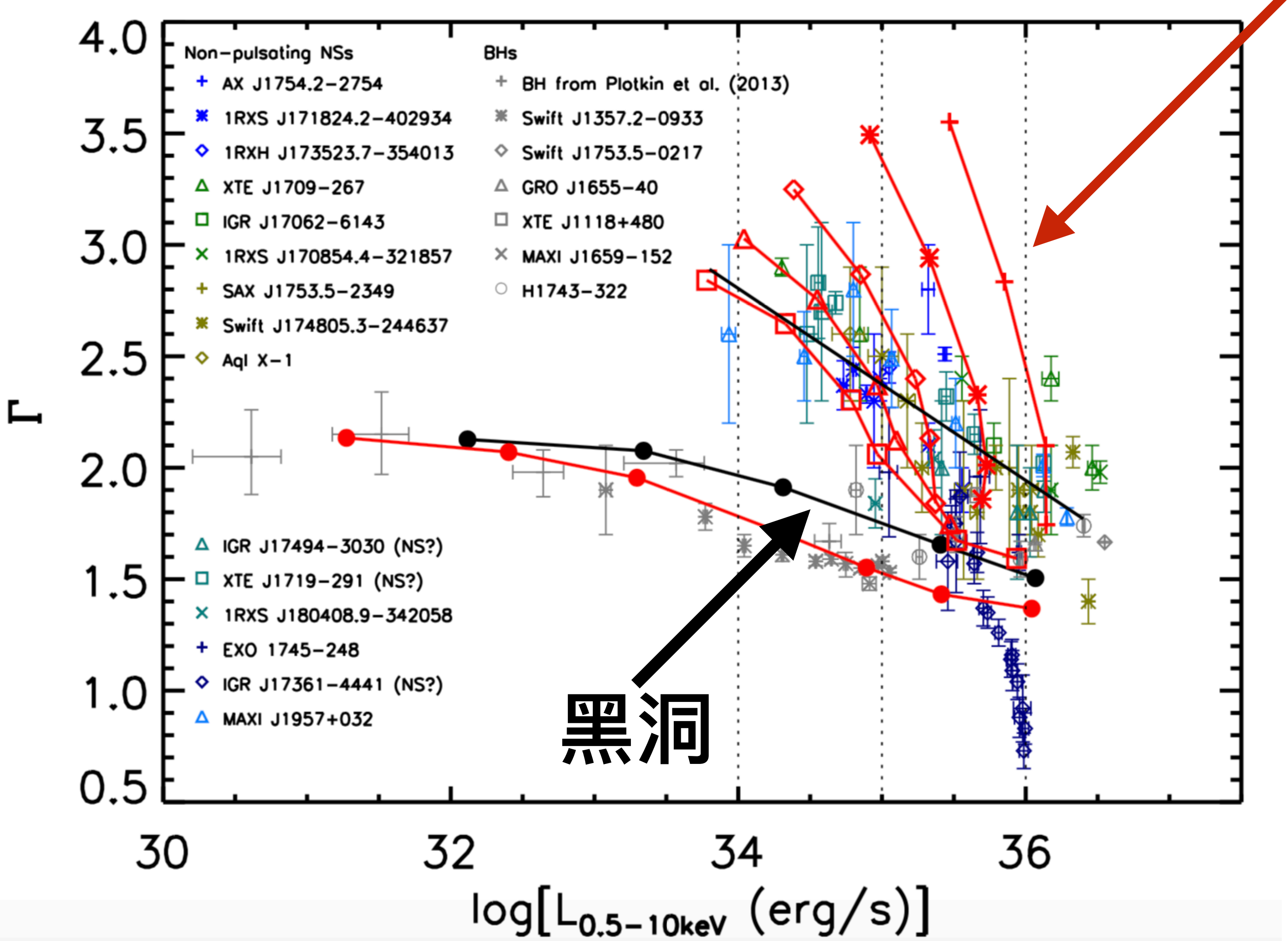


Qiao & Liu 2018, MNRAS, 481, 938

中子星光谱演化（I）

$\Gamma_{0.5-10\mathrm{keV}}$ verus $L_{0.5-10\mathrm{keV}}$

中子星

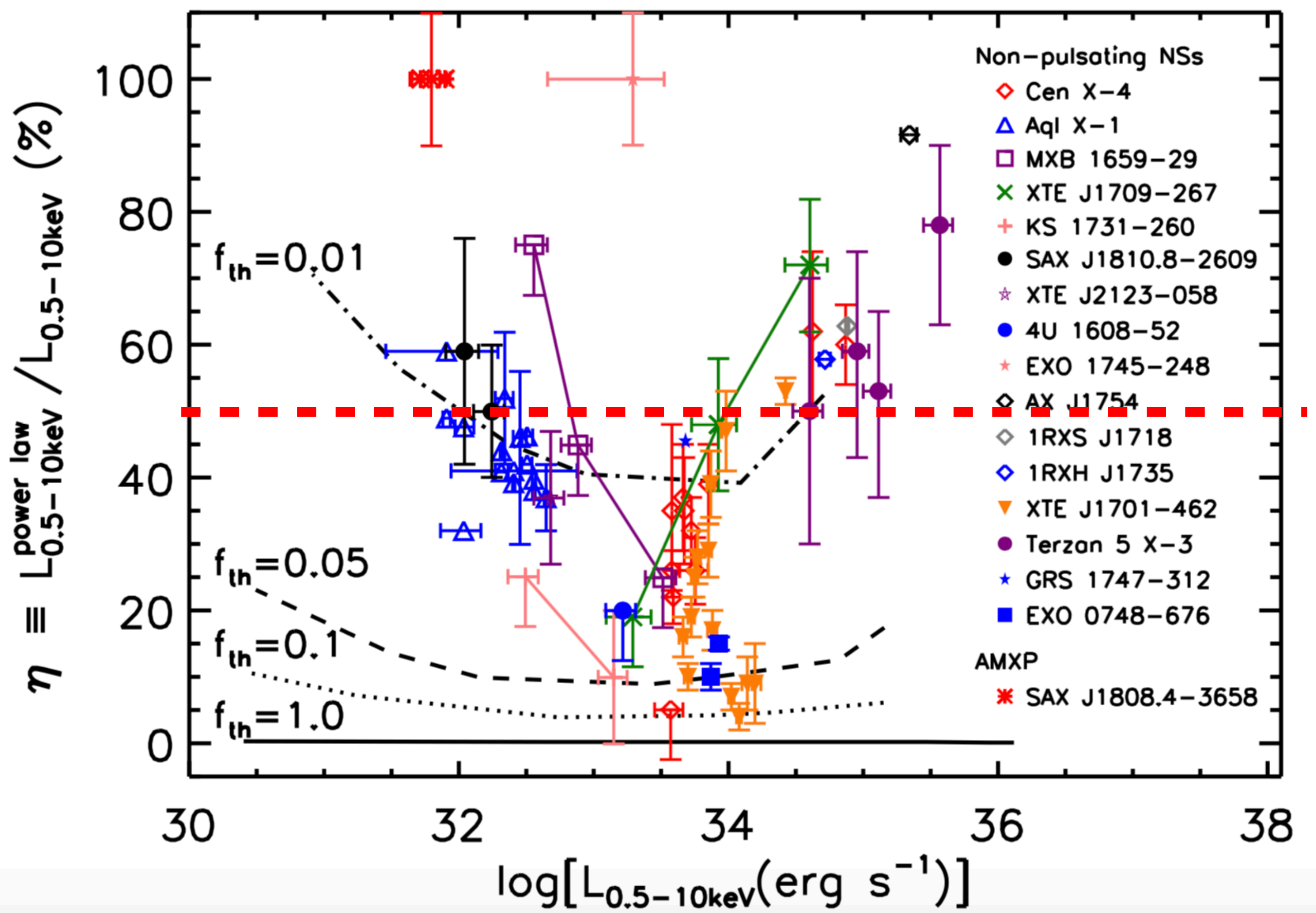


- Swift/XRT数据（分辨率低）
- f_{th} ~0.01 最符合观测

Qiao & Liu 2020a, MNRAS, 496, 2704

中子星光谱演化（II）

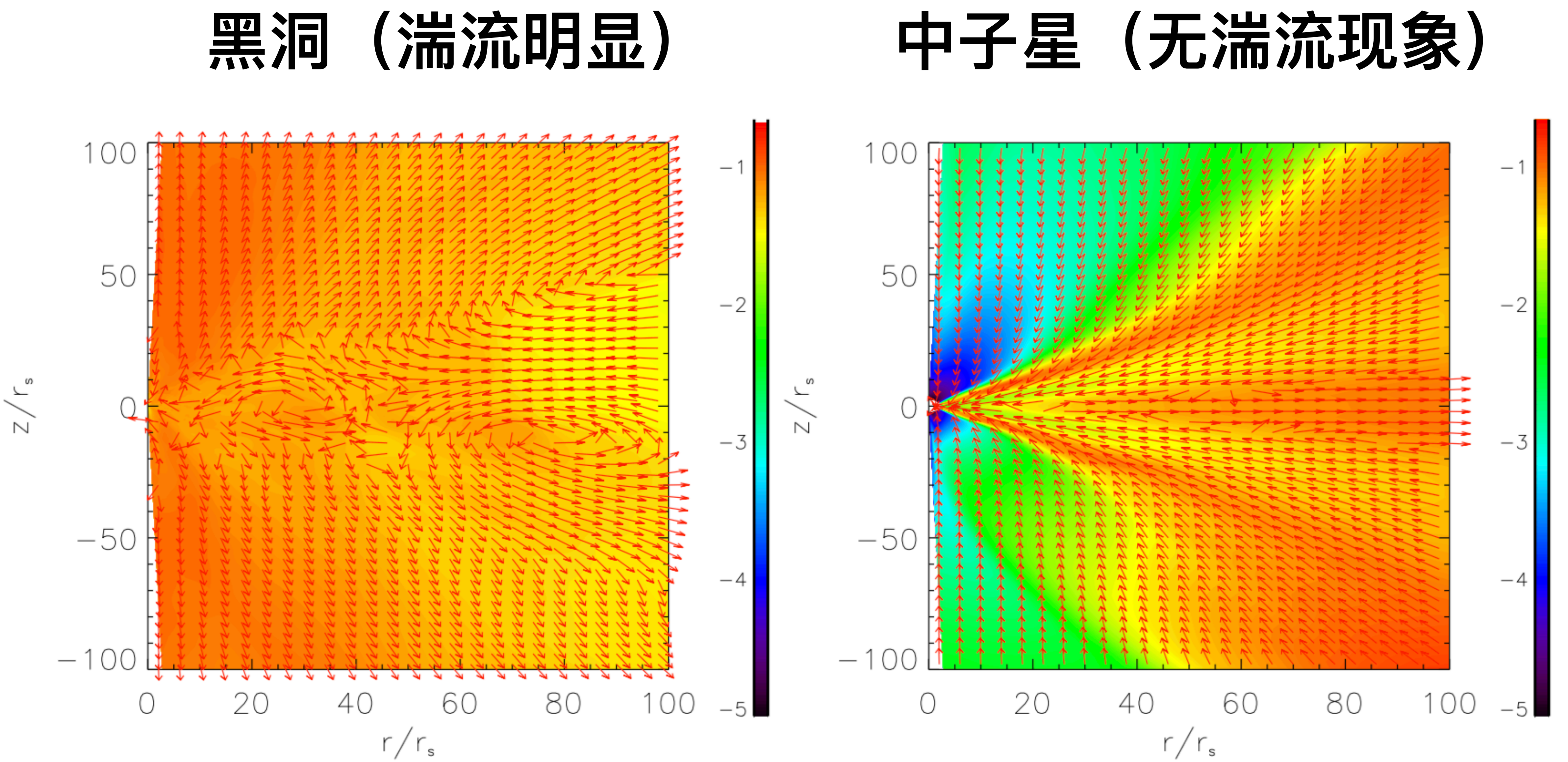
$$\eta = L^{PL}_{0.5-10\mathrm{keV}}/L_{0.5-10\mathrm{keV}} \text{ verus } L_{0.5-10\mathrm{keV}}$$



- **XMM-Newton数据（分辨率高）**
- f_{th}**~0.01 最符合观测**

Qiao & Liu 2020b, MNRAS, 492, 615

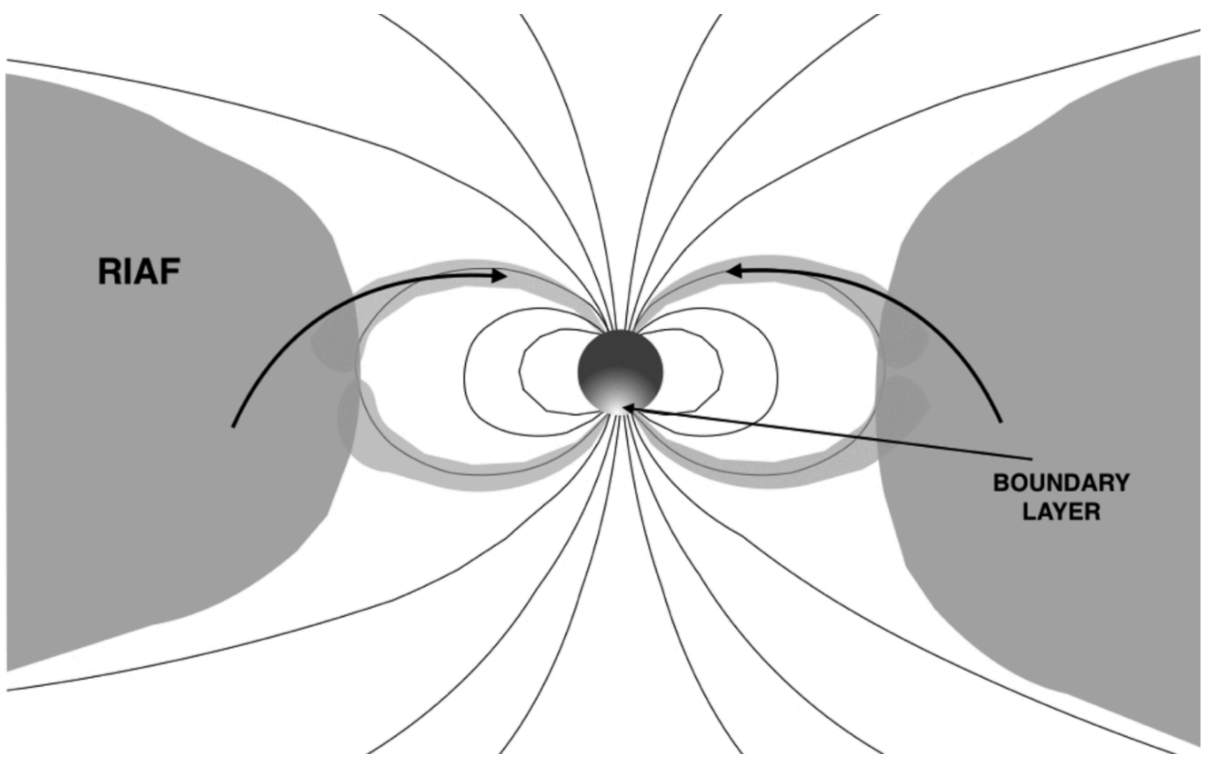
热吸积流辐射流体力学数值模拟研究



Bu, Qiao & Yang 2019, ApJ, 875, 147 (1T)
Bu, Qiao & Yang 2020, ApJ, 890, 116 (2T)

宁静态吸积毫秒X-射线脉冲星形成的新机制

$B \sim 10^{8\text{-}9}$ G



Qiao & Liu 2021, MNRAS, 502, 3870

- 宁静态：$L_X < 10^{35}$ erg/s
- 宁静态AMXP：目前仅3例
- 经典公式低估了吸积率：

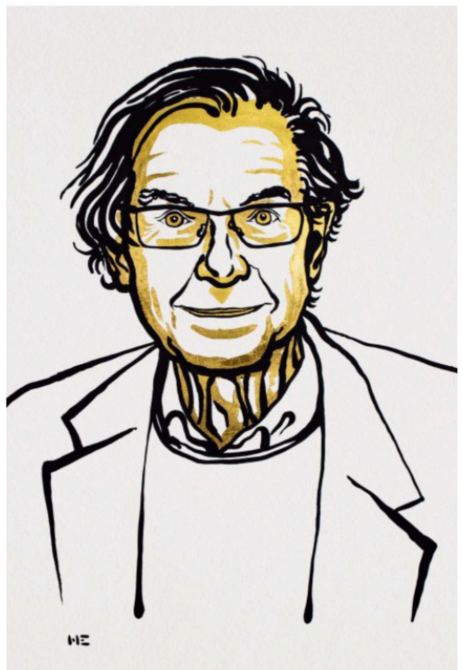
$$\dot{M} = L_X \left(\frac{R_*}{GM}\right)$$

- 我们模型结果：辐射效率低 $f_{th} \sim 0.01$；但是依然高于黑洞吸积系统

总结与讨论

- 建立了弱磁场下中子星的热吸积理论
- 结合最新的观测数据系统研究了NS-LMXBs（硬表面）和BH-LMXBs（视界面）的差异导致的不同观测现象的内在物理原因
- 黑洞和中子星辐射流体力学行为的比较（湍流 VS 无湍流）
- 宁静态毫秒X射线脉冲星（B～10^{8-9} G；弱磁场）形成的新机制
- 未来研究：
  - 大尺度磁场（B～10^{12} G；强磁场）的影响
  - 探索决定相对论喷流性质的关键因素，中子星VS黑洞（自转? 磁场？）

2020年诺贝尔物理学奖：
罗杰·彭罗斯，莱因哈德·根泽尔，安德里亚·格兹



© Nobel Media. Ill. Niklas Elmehed.

Roger Penrose

Prize share: 1/2

© Nobel Media. Ill. Niklas Elmehed.

Reinhard Genzel

Prize share: 1/4

© Nobel Media. Ill. Niklas Elmehed.

Andrea Ghez

Prize share: 1/4

One half awarded to Roger Penrose "for the discovery that black hole formation is a robust prediction of the general theory of relativity", the other half jointly to Reinhard Genzel and Andrea Ghez "for the discovery of a supermassive compact object at the centre of our galaxy."

图片来源：http://www.nobelprize.org

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **514,** 935–942 (2022) https://doi.org/10.1093/mnras/stac1394
Advance Access publication 2022 May 19

$$M = 3.04 \pm 0.06 M_{\odot}$$

X-ray constraint for the unseen companion of V723 Mon: it is a mass-gap black hole rather than binary neutron stars

Yan Li (李彦),[1,2★] Erlin Qiao (乔二林)[3,4] and Rong-Feng Shen (申荣锋)[1,2★]

[1] *School of Physics and Astronomy, Sun Yat-Sen University, Zhuhai 519082, China*
[2] *CSST Science Center for the Guangdong–Hongkong–Macau Greater Bay Area, Sun Yat-Sen University, Zhuhai 519082, China*
[3] *Key Laboratory of Space Astronomy and Technology, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China*
[4] *School of Astronomy and Space Sciences, University of Chinese Academy of Sciences, 19A Yuquan Road, Beijing 100049, China*

Accepted 2022 May 15. Received 2022 April 30; in original form 2022 February 22

ABSTRACT

Recently, the red giant V723 Mon is reported to have an unseen companion with a mass of $3.04 \pm 0.06\,M_{\odot}$, but question remains about whether it is a single (thus the so-called mass-gap) black hole or an inner binary of two more ordinary compact objects (neutron stars or white dwarfs). In this work, we estimate the X-ray emission by considering the wind-fed accretion from V723 Mon on to the compact companion. We analyse three different scenarios of the dark companion, i.e. a single black hole, binary neutron stars, and binary of a neutron star and a white dwarf. We show that the single black hole is the most favoured scenario. We also calculate the synchrotron emission from the bow shock caused by the interaction of the compact companion with the wind. We find that this emission peaks at ∼0.1–1 GHz, with a flux density of ∼1 mJy, which is expected to be detected by observations with higher angular resolution in the future.

Key words: stars: individual: V723 Mon – stars: neutron – radio continuum: general – X-rays: binaries – stars: black holes – accretion, accretion discs.