

# Yang Yang (杨阳) | Curriculum Vitae

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PhD Candidate, expected to graduate in March 2017

*"Those that do, often achieve; and those that walk, often arrive. ( 晏子曰: “婴闻之, 为者常成, 行者常至。婴非有异于常人也。常为而不置, 常行而不休者, 故难及也? )*  
*” – 晏子春秋*

## Education

**School of Astronomy & Space Science**

*PhD Candidate of Astronomy*

**Nanjing University**

*2010 Sep – 2017 March*

**Information Science and Technology College**

*Bachelor of Computer Science*

**Dalian Maritime University**

*2006 Sep – 2010 June*

## Other Research Experience

**2014 April – Oct: Queen's University**, Canada, Research Student

**2012 Winter: National Radio Astronomy Observatory**, Socorro, NM, Research Student

## Conference Talks

**2015 July: Present Status of NGC4594 and NGC5085 in CHANGES**

Bonn 2015 CHANG-ES workshop, Bonn, Germany

**2015 June: Deep VLA Observations of M31\* and M32\*: Whisper of the Hidden Monster**

Meeting of Black Hole and Accretion and AGN feedback, Shanghai, China

**2014 Junly: LLAGN in Sombrero Galaxy**

Kingston 2014 CHANG-ES workshop, Kingston, Canada

**2014 Jan: Deep VLA Observations of M31\* and M32\*: Whisper of the Hidden Monster**

Chinese Radio Astronomy and Technology colloquium, Xiamen, China

**2013 Oct: Deep VLA Observations of M31\* and M32\*: Whisper of the Hidden Monster**

Chinese Astronomical Society, Suzhou, China

## Programming Skills

Mastered in **IDL** programming languages and **CASA** (the Common Astronomy Software Applica-

tions package).

Finished ~100 hr EVLA data processing.

## Awards

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**2015:** Nanjing University Excellent PhD Candidates Innovation Program, Plan B.

**2012:** Nanjing University Zhengzhiwei Enterprise Scholarship

**2006:** Dalian Maritime University Scholarship, Third Prize.

**2009:** Dalian Maritime University Scholarship, Third Prize.

## Publications

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Publications.....

**2015:** **Yang, Yang**; Li, Zhiyuan; Sjouwerman, Loránt O.; Wang, Q. Daniel; Gu, Qiusheng; Kraft, Ralph P.; Yuan, Feng, *DETECTION OF A COMPACT NUCLEAR RADIO SOURCE IN THE LOCAL GROUP ELLIPTICAL GALAXY M32*. 2015, **ApJ Letters**, **807**, L19

Submitted and in Preparation.....

**2017:** **Yang Yang**, Zhiyuan Li, Lorant O. Sjouwerman, Feng Yuan, Zhi-Qiang Shen, *VERY LARGE ARRAY MULTI-BAND MONITORING OBSERVATIONS OF M31\**, submitted to ApJ

**2017:** **Yang Yang**, Zhiyuan Li, Judith Irwin, et al., *A VLA STUDY OF JET FEEDBACK IN M104*, in preparation

## Accepted Observing Proposals

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**2015:** VLA proposal, Observation time 22 hr, **Yang Yang** Zhiyuan Li, Judith Irwin, Q. Daniel Wang., "A high-resolution follow-up study of radio jets in CHANG-ES galaxies" **(PI)**

**2015:** VLA proposal, Observation time 6 hr, Lorant Sjouwerman, Zhiyuan Li, **Yang Yang**., "The ADAF-Jet Paradigm in the Quiescent Nucleus of M32" **(Co-I)**

**2015:** VLBA proposal, Observation time 28 hr, Zhiyuan Li, Lorant Sjouwerman, Zhi-qiang Shen, **Yang Yang**. "Dissecting the compact radio emission from the nucleus of M31 with VLBA" **(Co-I)**

## PhD Thesis

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**Title:** 低光度活动星系核的射电干涉阵观测研究 (*A Radio Study of Nearby Low-luminosity Active Galactic Nuclei with Interferometric Observations*)

**Supervisors:** Prof. Zhiyuan Li

**Abstract:** 超大质量黑洞的吸积与反馈活动是天体物理中重要的物理过程。超大质量黑洞作为活动星系核的引擎，通过吸积周围的物质将引力能转换为辐射能，通过喷流、外流或者风的形式向星际介质反馈机械能。寄主星系和其中心黑洞无时无刻不进行着相互作用共同演化。因此，了

解黑洞的吸积和反馈的物理过程是了解星系的形成与演化中重要的一环。但目前对超大质量黑洞的吸积和反馈的物理过程并不清楚，这也一直是天体物理中的关键问题。近几十年来，对于超大质量黑洞的观测取得了很大进展，例如：通过近邻星系的巡天发现低光度活动星系核在近邻活动星系核的样本中占有很大的比例；在这些低光度活动星系核中常常能观测到核区致密的 X 射线和射电辐射；以及发现这些源常常在多波段存在光变。根据黑洞的观测性质（多波段观测结果组成的宽带能谱分布，磁场等），人们逐步建立了黑洞吸积在辐射模式和喷流史瓦西模式下不同的理论框架。然而，这一框架中依旧有很多关键问题没有得到解决，例如：是否超大质量黑洞的射电辐射总有喷流的贡献，或者是否喷流的辐射主导着黑洞在射电波段的辐射？是否喷流进行的方向会在演化中发生变化？以及在黑洞附近产生耀变的物理意义是什么？

本论文通过对距离很近的三个星系 M 31, M 32 和 M 104 中心的低光度活动星系核的高分辨率的射电干涉阵的观测，讨论了以下两个问题：1) 吸积极不活跃的超大质量黑洞的射电辐射性质；2) 盘星系中喷流对星际介质的能量反馈。对这两个问题的研究可以给理论模型更多实际例子上的限制，从而进一步了解黑洞活动的物理过程。

第二章中，我们通过使用 Karl G. Jansky Very Large Array (JVLA) 甚大阵射电干涉仪对 M 31\* 进行了多历元的多波段的 pc 尺度的观测。我们分析了这些连续谱观测的结果，首次在 10, 15 和 20 GHz 频率探测到致密的射电核，并且看到在 6 GHz 的图像中的致密的射电核周围存在沿着不同方向的延展结构。在 2011 到 2012 年间多次的观测，看到了 M 31\* 的流量在 6 GHz 频率的流量变化，最短变化时标在 6 小时内出现了近 40% 的变化幅度，说明光变可能来自  $\sim 20$  个史瓦西半径处。通过我们在多频率的观测结果，我们建立了 6 到 20 GHz 的谱能量分布，拟合 ( $S_\nu \propto \alpha$ ) 得到谱指数  $\alpha \sim -0.45$ ，并由此推断射电辐射很可能是由喷流主导的。

第三章中，M 32 作为本星系群中的一个椭圆星系，其中心的超大质量黑洞是最近的超大的质量黑洞之一。我们利用 JVLA 干涉阵第一次探测到位于 M 32 星系核中心的一个致密射电源。这个射电源在中心频率 6.6 GHz 的流量密度是  $\sim 47.3 \pm 6.1 \mu\text{Jy}$ 。我们讨论了这个射电源起源的可能性，认为它起源于超大质量黑洞的射电辐射。同时我们利用 Chandra 和 XMM-Newton 的 X 射线数据研究了这个超大质量黑洞的 X 射线辐射性质。

第四章中，M 104 (NGC 4594) 是一个大质量的早型旋涡星系，也被称作草帽星系，在其中心存在一个原型的低光度活动星系核。我们使用 JVLA 对 M 104 在多波段进行了不同分辨率的连续谱观测以获得其喷流在不同物理尺度的特征。通过分析认为 M 104 的 kpc 尺度的延展很可能来自 pc 尺度的射电喷流。并且发现 kpc 尺度喷流的方向与 pc 尺度喷流的方向有差异，暗示了喷流在传播过程中发生偏折，或者不同尺度的喷流产生自中心黑洞的不同活跃期；我们通过定量测量了 kpc 尺度喷流的磁压，发现其与星际热气体的压强相当，暗示了喷流在传播过程中的机械功对气体注入了可观的能量。

第五章中，我们主要介绍了对本论文工作的总结以及展望。

(Supermassive Black Holes (SMBH), as the central engine of Active Galactic Nuclei (AGNs), play an important role in galaxy evolution. This accretion powered system influences ambient medium by radiation and mechanical energy output carried by jets, outflows, and/or winds. As shown by

multi-wavelength surveys of the local universe, the formation and evolution of host galaxies are related to the growth/activity of the central SMBH. However, as one of the keystones of modern astrophysics, the accretion and feedback processes are still unclear. Surveys of nearby galaxies reveal that low-luminosity AGNs (LLAGNs) are found in a large fraction of galactic nuclei, and a radio core is pervasive in those LLAGNs. Those surveys also reveal flux variations in the LLAGNs, and provide observational support for the SMBH accretion model. However, there are still lots of key questions to be answered: do the jets dominate the radio emission from SMBHs? Are there any changes in the direction of the jets that will evolve in the evolution? What is the origin of the flares close to the central SMBH?

In this thesis, I will try to answer some of these questions by analyzing the high-resolution radio interferometric observations toward three special low-luminosity AGNs: M31, M32, and M104, and emphasize: 1. the physical properties of the radio emission from low-luminosity AGNs; 2. The energy feedback of the jet in edge-on galaxies. We studied the properties of the radio emission from low-activity SMBHs, aiming to constrain the low-activity SMBH model and understand corresponding accretion and feedback processes.

In Chapter 2, the “Andromeda” galaxy (M31) hosts one of the nearest low-luminosity active galactic nuclei (LLAGNs). We investigated its radio properties using deep, parsec-scale, quasi-simultaneous, multi-frequency (6, 8.5, 10, 15 and 20 GHz) Karl G. Jansky Very Large Array (JVLA) continuums observations and archival data from the historical Very Large Array. We firstly detected a radio compact core at 10, 15 and 20 GHz, and the presence of the extended structure emanating from the core at 6 GHz. We also reported its flux has a milder fluctuate at 6 GHz, and the variability interval appears random from day to month. Based on the multi-frequency observations, we built the spectral energy distribution (SED) from 6 to 20 GHz to obtain a spectral index  $\alpha \sim -0.45$  ( $S_\nu \propto \alpha$ ) and discussed whether the radio emission is dominated by the part of the jet further away from the SMBH.

In Chapter 3, the Local Group compact elliptical galaxy M32 hosts one of the nearest candidate super-massive black holes (SMBHs), which has a previously suggested X-ray counter- part. Based on sensitive observations taken with the Karl G. Jansky Very Large Array (VLA), we detect for the first time a compact radio source coincident with the nucleus of M32, which exhibits an integrated flux density of  $\sim 47.3 \pm 6.1$  Jy at 6.6 GHz. We discuss several possibilities for the nature of this source, favoring an origin of the long-sought radio emission from the central SMBH, for which we also revisit the X-ray properties based on recently acquired Chandra and XMM-Newton data. Our VLA observations also discover radio emission from three previously known optical planetary nebulae in the inner region of M32.

In Chapter 4, M104 (NGC 4594) is a massive early-type spiral galaxies, also known as Sombrero galaxies, there is a SMBH. We used JVLA to observe the continuous of M104 at different resolu-

tions in multi-band. It was shown that the kpc-scale extended structure in M104 is likely to come from the pc-scale jet. We found that the direction of the kpc-scale radio structure is significantly different from that of the pc-scale jet, It suggests that the jet is deflected during the evolution process or that the jet of different scales arise from different active periods of the center black hole. The magnetic pressure of the kpc-scale jet was found to be comparable to that of the interstellar hot gas, implying that the mechanical work of the jet transport a considerable amount of energy into the gas.

In Chapter 5, I provide a summary and discuss directions for future work.)

**Keywords:** 超大质量黑洞 ; 射电干涉 ; 低光度活动星系核 ; 喷流 ; M 31 ; M 32 ; M 104

(Super-Massive Black Holes, Radio Interferometry, Low-luminosity AGNs, Jet, M 31, M 32, M 104)