PROCEEDINGS OF SCIENCE

Towards the unified model for rich variety of outburst light curves in compact binary systems

---

Mariko Kimura[a,*]

[a]*Advanced Research Center for Space Science and Technology, College of Science and Engineering, Kanazawa University, Kakuma, Kanazawa, Ishikawa 920-1192, Japan*

E-mail: `mariko-kimura@se.kanazawa-u.ac.jp`

It has been fifty years since the disk instability model was first proposed. Extensive observational and theoretical efforts have been devoted to this field. The physical origin of the instability has been elucidated, the basic outburst behavior of dwarf novae and low-mass X-ray binaries can now be reproduced, and in the field of cataclysmic variables, it once seemed that a unified model for various kinds of transient events and binary evolution had been achieved. However, recent advances in broadband transient surveys have revealed a number of transient events that cannot be explained by existing models, and the study of compact binary systems is entering a new phase. It is therefore necessary to improve the disk instability model and to construct a grand unified model capable of explaining the rich variety of outburst phenomena in compact binary systems. In this article, I review the motivation for organizing the 87th Fujihara Seminar, the history of research on the disk instability model, and what I believe is essential for establishing such a grand unified model.

87th Fujihara SeminarThe 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars (DIM50TH2025)
22-26 September 2025
Tomakomai, Japan

---

[*] Speaker

ISSN 1824-8039. Published by SISSA Medialab.
https://pos.sissa.it/

PoS(DIM50th2025)039

1. Introduction

First, I would like to express my sincere gratitude to all participants in the 87th Fujihara Seminar: the 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars. A group photograph with the names of all participants is shown in Figure 1. Since opportunities to organize such a large international conference probably come only once or twice in my life, I would like to briefly describe how I came to host this workshop. It all started with a conversation with Prof. Osaki. He mentioned that it would be fifty years in 2024 since he had proposed the working model of the disk instability in 1974, and that it would be great to organize a memorial workshop around that time. At that moment, I thought to myself, “Isn’t that something I should do?”

Figure 1: Group photo of all participants in the 87th Fujihara seminar.

It has been more than fifty years since the disk instability model (DIM) was first proposed in 1974 [1], and research on the DIM has made remarkable progress. In the early stages, theoretical studies focused on identifying the source of the instability and reproducing the outburst behavior of compact binary systems. Later, as observational and theoretical research advanced hand in hand, the physical origins of various types of outbursts began to be identified. However, with the rapid development of time-domain and multi-wavelength astronomy in recent years, many new phenomena have been discovered that cannot be explained by existing models. I believe that there is still much unexplored territory in the study of the DIM. If we continue to tackle these unresolved issues one by one, we may eventually reach a comprehensive understanding of the diverse outburst behaviors observed in binary systems.

Many of the renowned researchers who pioneered earlier DIM studies are no longer closely following the latest observational developments. In contrast, younger researchers who have recently entered the field often find themselves overwhelmed by the vast amount of observational data, leaving them little time to develop a deep understanding of the underlying physics. I have long felt the need for a forum where researchers from both groups can come together, exchange ideas, and accelerate progress in this field. Organizing a workshop to celebrate the 50th anniversary of the DIM therefore seemed like an ideal opportunity to realize this goal. I also wished to take this opportunity to express my sincere gratitude to Prof. Osaki, who has been a valued collaborator since 2019.

In the spring of 2024, during the annual meeting of the Astronomical Society of Japan, I discussed the concept of the workshop with Dr. Uemura, Dr. Nogami, and Prof. Osaki, and together we defined its main objectives. At that time, I was pregnant with my second child, and it was therefore decided that the workshop would be held in FY2025. Because we aimed to organize a large-scale international workshop, the idea of applying for the Fujihara Seminar program arose during the discussion, and we agreed to proceed with the application. We selected Hokkaido as the venue, invited Prof. Okazaki to join the Local Organizing Committee (LOC), and began preparing the proposal. Just a few days after giving birth, I submitted the application documents to the Fujihara Foundation from the hospital.

Table 1: List of the SOC members in the 87th Fujihara seminar.

Country	Name	Affiliation
Japan	Mariko Kimura	Kanazawa University
Japan	Yoji Osaki	University of Tokyo
Japan	Shin Mineshige	Kyoto University
UK	Chris Done	University of Durham
France	Jean-Marie Hameury	Strasbourg Observatory
France	Guillaume Dubus	Univ. Grenoble Alpes, CNRS, IPAG
Poland	Bożena Czerny	Center for Theoretical Physics, Polish Academy of Sciences
USA	Stephen H. Lubow	Space Telescope Science Institute
USA	Rebecca G. Martin	University of Nevada

After that, I became busy with childcare and, for a time, almost forgot about the workshop, until late September, when I received the wonderful news that our proposal had been accepted as the 87th Fujihara Seminar. I was both surprised and delighted; it felt like a recognition that DIM research in Japan had reached a world-class level. We then invited Prof. Mineshige and Prof. Kawaguchi to join the LOC and asked several distinguished researchers in the field to serve on the Scientific Organizing Committee (SOC). The SOC members are listed in Table 1. Together, we spent a great deal of time preparing for the event. As a result, I believe that this workshop achieved a very high level of participant satisfaction. I would like to once again express my heartfelt gratitude to all members of the LOC and SOC for their tremendous efforts and support.

On the first day of the workshop, I explained that the purposes of organizing this event were: (1) to better understand the unsolved problems in DIM studies and (2) to identify directions for improving the DIM toward a grand unified model capable of explaining the diverse light curves observed in compact binary systems. I hope that the discussions during the meeting provided valuable insights for young researchers as they continue their work in this field.

In this article, I briefly review the history and recent progress in studies of the DIM in compact binary systems and summarize, from my own perspective, some of the remaining open questions, along with possible approaches to addressing them. I also touch upon the potential applications of the DIM to other types of astrophysical objects. There are two important types of disk instabilities in compact binary systems: the thermal-viscous instability and the radiation-pressure instability.

Because of the limited number of pages and because my research to date has focused mainly on the former, this article primarily discusses the thermal-viscous instability. A comprehensive review of the basic physics of disk instabilities is given in [2].

2. Brief history of the DIM study up to the 2000s

2.1 Discovery of the DIM and dwarf-nova outbursts

The study of the DIM began with the working model presented by Prof. Osaki in [1]. He proposed that gas transferred from the secondary star should accumulate in the disk in order to reproduce the eclipsing light curve of the prototype dwarf nova U Gem. This accumulated material then accretes onto the white dwarf (WD) through an instability triggered within the accretion disk. The source of this instability was identified in the early 1980s as the partial ionization of hydrogen [3, 4]. Since then, many researchers have attempted to reproduce the normal outbursts of dwarf novae (DNe) [5–7]. DNe are a subclass of cataclysmic variables (CVs)—close binary systems consisting of a WD and a low-mass secondary star—in which gas transferred from the secondary star forms an accretion disk around the WD. A more detailed historical overview is provided in [8].

The DIM was not immediately accepted by many researchers; instead, there was intense debate with the previously proposed mass-transfer burst (MTB) model, in which time variations in the mass transferred from the secondary star trigger outbursts [9]. The DIM eventually became widely accepted because no observational evidence for fluctuations in the mass-transfer rate was found, and the physical mechanism that would cause such variations had not been identified. Observations of eclipsing systems have shown that the disk radius expands when an outburst is triggered [10], supporting the DIM. Numerical simulations with a variable disk radius demonstrated that, in the MTB model, the disk radius begins to shrink immediately after the onset of an outburst [11], which is inconsistent with observations. However, it is also believed that fluctuations in the mass-transfer rate are required to explain certain types of light-curve variations in CVs, such as Z Cam-type standstills [12].

2.2 Applications to low-mass X-ray binaries

In the 1990s, the DIM was applied to explain outbursts in low-mass X-ray binaries (LMXBs), which are close binary systems consisting of a black hole or neutron star (the primary) and a low-mass companion star (the secondary). Although it has been suggested that strong X-ray irradiation suppresses the thermal–viscous instability, the irradiation effect is in fact modest, and the DIM remains applicable to accretion disks in LMXBs [13]. Previous numerical simulations have successfully reproduced the characteristic fast-rise and exponential-decay outbursts observed in these systems [14–18].

The behavior of the outer regions of accretion disks in LMXBs does not differ greatly from that of disks in CVs. However, the inner regions are affected by the strong magnetic field and/or strong gravitational field of the primary star, giving rise to characteristics not observed in CVs — such as sub-second variability and dramatic spectral state transitions in X-rays. For further details, see [19–21]. The inner disk in LMXBs can become bright enough during outbursts to trigger the radiation-pressure instability [22]. In such cases, short-term variability with regular patterns on timescales of several minutes to several hours is observed [23, 24]. For the history of the radiation-pressure instability and recent observational results, see [25].

2.3 Discovery of SU UMa stars, developments of the thermal-tidal instability model, and the unified model for DN outbursts

The discovery of superhumps in VW Hyi, an SU UMa-type star, was a major surprise for CV researchers. SU UMa-type stars exhibit not only normal outbursts but also superoutbursts—large-amplitude, long-duration outbursts accompanied by small-amplitude, periodic light modulations known as superhumps. Many theorists attempted to model this behavior. A breakthrough was made by [26], who showed that superhumps arise from a tidal instability that occurs when the disk radius exceeds the 3:1 resonance radius, leading to an eccentric distortion of the accretion disk. The eccentric disk undergoes prograde precession, and tidal dissipation within the disk is periodically enhanced by the orbiting secondary star.

Inspired by this finding, Prof. Osaki proposed the thermal-tidal instability (TTI) model [27]. If the disk is circular, the system undergoes a sequence of normal outbursts. When the tidal instability is triggered, the disk becomes eccentric, and the efficiency of angular-momentum transport due to the tidal torque exerted by the secondary star increases sharply, leading to a superoutburst. In the TTI model, the combination of the thermal instability and the tidal instability gives rise to two types of limit cycles (one in the $\dot{M}$–Σ plane and the other in the $\dot{J}_{\rm tidal}$–$J_{\rm disk}$ plane), allowing superoutbursts and supercycles to be explained naturally.

WZ Sge stars, an extreme subclass of SU UMa stars, exhibit only superoutbursts and are characterized by the appearance of early superhumps in the initial phase of these superoutbursts. Early superhumps are double-peaked light modulations with a period identical to the orbital period. It has been proposed—and is now widely accepted—that outbursts in WZ Sge stars are triggered when the accretion disk expands beyond the 2:1 resonance radius [28]. Early superhumps are thought to arise because part of the disk becomes vertically inflated due to the 2:1 resonance [29, 30] (see also [31] for recent observations).

Through the accumulation of various studies such as those described above, a unified model of outbursts in CVs had been established by the 2000s. Figure 2 presents a schematic illustration of this model. In the diagram of orbital period versus mass-transfer rate, CVs are classified into several subgroups. Because different physical mechanisms operate in each subgroup, their outburst light curves differ accordingly. Since changes in orbital period and mass-transfer rate are closely related to binary evolution, this diagram represents not only a unified model of outbursts but also a unified model of the evolutionary sequence of CVs. In general, as a binary evolves, the secondary star loses mass and the orbital period becomes shorter. Consequently, the mass-transfer rate tends to decrease and the intervals between outbursts become longer. Because the maximum disk radius reached during outbursts becomes progressively larger, additional physical mechanisms—such as the tidal instability and the 2:1 resonance, in addition to the thermal–viscous instability—begin to operate in the disk.

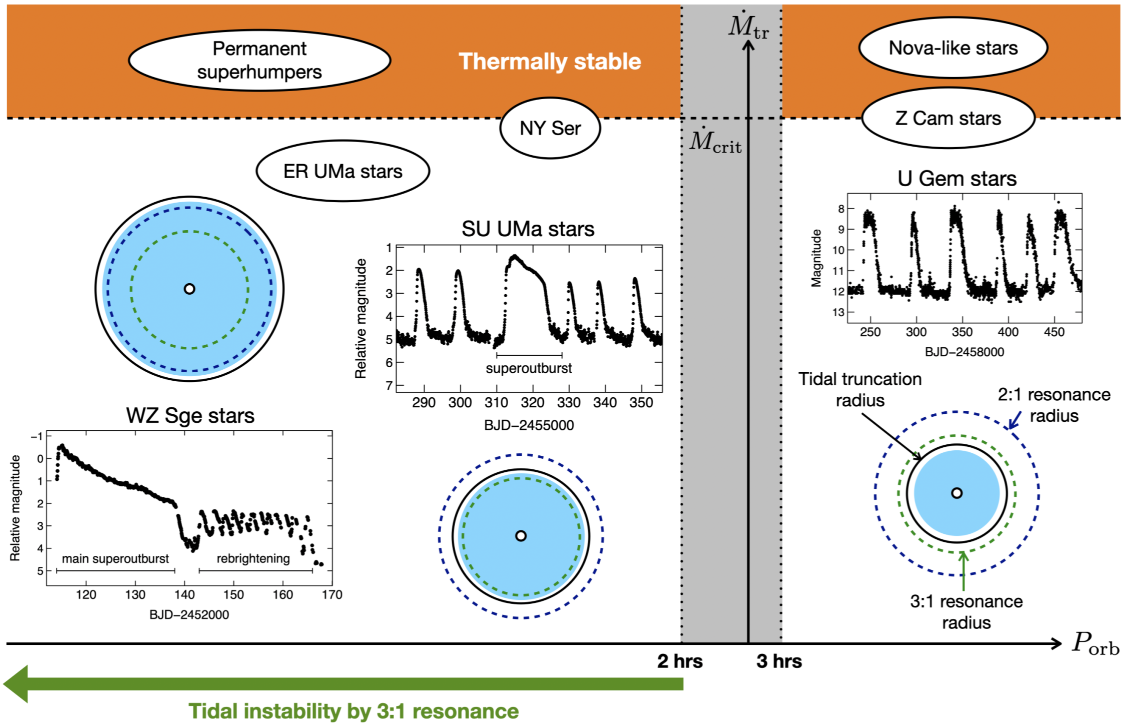

Figure 2: Illustration of the unified model for various kinds of DN outbursts. If the mass transfer rate is below the critical rate, thermal-viscous instability works in the disk. There is a period gap around a few hours, and the tidal instability is usually triggered in the systems below the period gap which show superoutbursts and superhumps.

3. Advances in research since the 2010s accompanying the development of time-domain astronomy

3.1 Detailed studies of time-varying superhumps

By the 2000s, research on the DIM in CVs and XBs appeared to be nearly complete. However, the situation changed dramatically in the 2010s with major advances in observational techniques. Dr. Kato and his collaborators organized a large observational network for variable stars, which included many amateur astronomers, collected a huge amount of light-curve data, and found that superhumps can be classified into three distinct stages: stage A (growing) superhumps with a constant period and increasing amplitudes, stage B superhumps with varying periods and decreasing amplitudes, and stage C superhumps with a short, nearly constant period [32]. The existence of different phases of superhumps had already been predicted by theoretical models [33]. For a comprehensive review of the basic physics of tidally driven eccentric instabilities, see [34]. The *Kepler* satellite also played a major role. The combination of high-time-cadence light curves and statistically sophisticated analysis methods enabled detailed studies of superhumps and provided strong support for the TTI model [35–37].

Dr. Kato and Prof. Osaki noticed that growing (stage A) superhumps represent the full development of eccentricity at the 3:1 resonance radius and developed a new method for estimating the

PoS(DIM50th2025)039

binary mass ratio [38]. Before this work, mass ratios in superhump-bearing systems had typically been underestimated when using the empirical relation between the stage-B superhump period and the mass ratio [39]. The new method provides significantly more accurate estimates and has played an important role in identifying the evolutionary paths of many SU UMa stars. Recent advances in the study of superhumps are reviewed in [40].

3.2 Discovery of dozens of WZ Sge stars

Optical transient surveys such as CRTS, MASTER, ASAS-SN, and ZTF have led to a substantial increase in the number of known WZ Sge–type DNe. Dr. Kato has written a comprehensive review of this subgroup of DNe [41]. It has become clear that there are five distinct types of rebrightenings that occur after the main outburst in WZ Sge stars. Each object shows the same type of rebrightening even if the duration of the main outburst differs [42], implying that rebrightening behavior is closely related to physical properties intrinsic to each individual system.

Rebrightenings are useful tracers of the evolutionary paths of WZ Sge stars. For example, multiple rebrightenings (type B) and double superoutbursts (type E) are observed primarily in period bouncers with very small binary mass ratios—the ultimate evolutionary stage of CVs [43, 44]. Standard models of CV evolution predicted that ~70% of CVs should be period bouncers [45]; however, only a few candidates were identified before the 2010s. A subset of WZ Sge stars is considered to provide the best candidates for period bouncers. The growth rate of the 3:1 resonance decreases with decreasing binary mass ratio. A delay in the full development of the 3:1 resonance until the end of the 2:1 resonance naturally leads to double superoutbursts in period-bouncer candidates. The increased number of known WZ Sge stars has accelerated research on not only accretion physics but also CV evolution. Recent advances in the study of WZ Sge stars are reviewed in [46].

3.3 Recently discovered unusual light variations and long-standing problems

Although advances in observational instruments have driven progress in research, they have also revealed new puzzles, and many long-standing unresolved problems remain. For example, with newly obtained long-term light curves, it has become evident that some nova-like (NL) systems and Z Cam stars exhibit the IW And–type phenomenon: repeated episodes of mid-brightness intervals accompanied by oscillatory variations, terminated by low-amplitude brightenings. For further discussion of this topic, please refer to another article I have written [47]. While the thermal-viscous instability in a tilted disk can account for some aspects of the IW And phenomenon, many objects display behaviors that cannot be explained by this mechanism alone, indicating that further refinement of the proposed model is required.

The outburst behavior of AM CVn stars has also become increasingly well understood thanks to the discovery of new systems by surveys such as ASAS-SN and the *TESS* satellite. AM CVn stars have helium-rich accretion disks, in contrast to the hydrogen-rich disks of normal CVs, and they possess ultrashort orbital periods of 5–65 min. For details of the properties of this subclass of CVs, see [48]. They exhibit peculiar light variations—such as luminosity dips during the superoutburst plateau, outburst events lasting over a year, and outbursts in systems with very low mass-transfer rate. It remains under debate whether these variations can be explained by the DIM alone or whether fluctuations in the mass-transfer rate are required [49–51]. Numerical simulations capable of reproducing such unusual light variations are needed.

Thanks to the contributions of instruments such as MAXI and the *Swift* satellite, the number of known LMXBs has also increased. It has become clear that LMXBs exhibit a wide variety of outburst behaviors. Past observations and modeling efforts have successfully reproduced the most common type of outbursts; however, other features—such as V404 Cyg-type outbursts, secondary maxima during the plateau, and rebrightenings—have not been reproduced by numerical simulations. In particular, a major unresolved problem common to both LMXBs and CVs is the physical origin of rebrightenings. Several working models have been proposed. For example, some researchers have suggested that mass transfer from the secondary is enhanced immediately after the main outburst through irradiation of the secondary star by the disk [52], although such irradiation is unlikely to trigger a significant increase in the mass-transfer rate [53]. Others have proposed that a substantial amount of mass remains outside the 3:1 resonance radius and accretes onto the WD with a delay relative to the main outburst [54]. Another possibility is that the viscosity in the quiescent disk is temporarily enhanced after the main outburst [55]. Repeated reflections of transition waves may also keep the inner disk permanently hot and trigger multiple rebrightenings [56].

Importantly, there is still a significant gap between observationally constrained and theoretically predicted values of the viscosity parameter. The DIM is the only model for which observational data can place meaningful constraints on the viscosity parameter α. Studies of outbursts in CVs suggest that the viscosity parameter in the hot state is in the range 0.1–0.3, while that in the cold state is roughly one-tenth of this value [5, 7]. Large values of α are necessary for the propagation of the 3:1 resonance within the disk [57]. The magnitude of the viscosity also affects the degree of disk warping [58]. Magnetohydrodynamic (MHD) simulations, however, yield $\alpha_{\rm hot}$ values smaller than those required by observations [59]. The source of turbulence in the hot state is the magneto-rotational instability (MRI). However, the MRI does not operate in the quiescent disk, indicating that additional physical mechanisms must be at work. For a comprehensive review of MHD simulations and viscosity parameters, see [60]. It is also a serious problem that the viscosity parameter estimated from X-ray outburst light curves is about an order of magnitude larger than that expected from theoretical studies [61].

3.4 Implications for other accreting systems

Thanks to long-term light curves spanning more than ten years, many changing-look active galactic nuclei (CLAGNs) have been discovered that exhibit light variations on decade-long timescales [62]. Their spectral transitions are similar to those observed in black-hole LMXBs [63]. Although the origin of the changing-look phenomenon is still not well understood, the thermal-viscous instability that operates in compact binary stars is one of the most promising candidates. However, when the DIM is naively applied to AGNs, whose central black holes are a hundred million times more massive than those in black-hole binaries, the predicted variability timescale becomes $\sim 10^5$ years, which is inconsistent with observations. This suggests that key physical processes are still missing, and numerical simulations incorporating additional effects such as X-ray irradiation or variations in the viscosity parameter are urgently needed.

Quasi-periodic eruptions (QPEs), discovered in 2019, are another fascinating phenomenon. QPEs are observed as regular flares from AGNs with a period of roughly ten hours [64]. More recently, QPEs occurring after tidal disruption events (TDEs) have been discovered [65], and it has been suggested that radiation-pressure instability may be responsible for triggering them [66]. A TDE occurs when a star is disrupted by the tidal forces of a supermassive black hole at the center of a galaxy, and the stellar debris produces a luminous flare as it accretes. Thus, research on disk instabilities in compact binary systems is now influencing our understanding of accretion phenomena in systems far more massive than binaries.

4. Necessary steps towards the grand unified model

4.1 Outflows from binary systems

Wind outflows from the accretion disk influence outburst light curves and binary evolution, but they have not yet been incorporated into the current standard DIM. This is the reason why I included a dedicated session on this topic in this workshop. In CVs, radiation pressure is weak, and line-driven winds are considered the primary driving mechanism of disk winds. These winds remove a fraction of mass from the system. Blue-shifted absorption features known as P-Cyg profiles—regarded as the smoking gun of disk winds—are observed in UV and optical spectra of CVs [67–70]. Line-driven winds are typically launched during outbursts. On the other hand, magnetically driven disk winds may be launched in the quiescent state, potentially providing a source of turbulence in the cold disk and triggering mass accretion during quiescence [71].

In the case of LMXBs, disk winds appear in X-ray spectra as highly ionized and blueshifted absorption lines. Such features are mainly observed in the soft state. Unlike in CVs, the outflow rate can be high enough to exceed the accretion rate. When such strong outflows are launched, they are expected to have a significant impact on the outburst light curve. The diversity of LMXB outbursts may indeed be caused by outflows [72]. Several models have been proposed for the driving mechanism of outflows, and recent observations favor thermally driven winds [73]. In this scenario, gas in the outer disk is heated by X-ray irradiation and escapes the system by overcoming gravity. Recent studies have shown that thermal winds can shift the stability boundary of the accretion disk to higher mass-accretion rates, in agreement with the observed distribution of LMXBs in the orbital period versus mass-accretion-rate plane [74]. However, neutral-gas winds that cannot be explained by this mechanism alone have also been observed [75]. To understand their origin, a combination of high-energy-resolution X-ray spectroscopy with XRISM and optical spectroscopy will be useful (see [76] for more on winds in LMXBs).

4.2 Similarity between CVs and XBs, multi-wavelength observations

In the astronomical community, research groups are often separated by category — such as CVs, XBs, and AGNs — and interactions between the CV and XB fields have been limited. However, as mentioned in previous sections, accretion disks in CVs and XBs share common disk instabilities. Because CVs are bright in the optical band, most CV research has been conducted with optical observations. Many CV researchers therefore focus on the accretion physics in the outer disk. By contrast, XBs are bright in X-rays, and studies tend to concentrate on the inner accretion disk and the hot corona. If discussions between researchers in the CV and XB communities can be strengthened, their complementary expertise could be exchanged, potentially leading to breakthroughs in both fields. This is one of the motivations behind organizing this workshop.

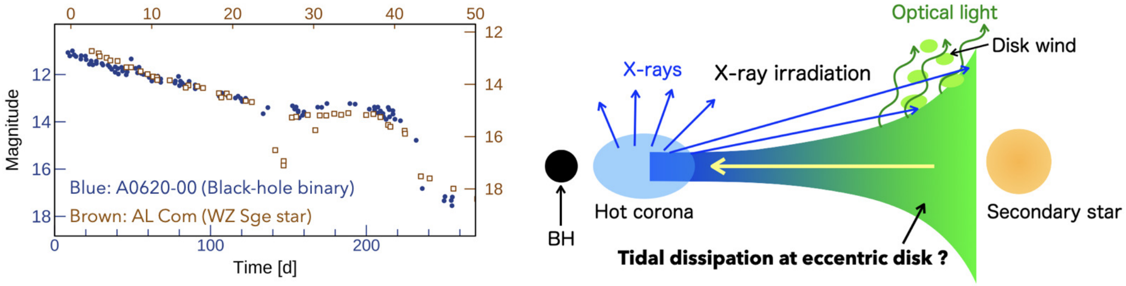

Figure 3: (Left) A superoutburst in AL Com, a WZ Sge star, and an outburst in A0620-00, a BH LMXB. Although the timescale is different, the overall behavior including the rebrightening is similar to each other. (Right) Schematic figure of the half of edge-on accretion disk in a BHB.

For example, the outbursts of black-hole binaries (BHBs) exhibit characteristics that closely resemble those of WZ Sge stars (Figure 3). This similarity is likely attributable to the relatively large black hole mass in BHB systems, which typically results in a small binary mass ratio. Superhumps have long been recognized as a feature observed during BHB outbursts, and recent observations have demonstrated that superhumps in BHBs undergo stage transitions analogous to those seen in CVs [77]. These findings suggest that tidal instability may likewise play a significant role in shaping the outburst behavior of BHBs. Furthermore, during the later phase of an outburst, the UV and optical emission exhibits an excess that cannot be accounted for by standard X-ray irradiation models [78].

Although the binary properties of high-mass X-ray binaries (HMXBs), LMXBs, and CVs differ substantially, many systems share common disk geometries, such as eccentric disks or tilted and/or warped disks. The mechanisms that trigger and sustain disk eccentricity or disk tilt remain poorly understood. Around Be stars, various instabilities associated with disk geometry can arise (see [79] for details). Researchers studying CVs and LMXBs may therefore gain valuable insights from investigations of Be decretion disks. In addition, Be X-ray binaries, a subclass of HMXBs, exhibit type-II outbursts whose origin remains unresolved (see [80] for a general review). Regarding the transition from outburst to quiescence, accretion may be inhibited either by the rapid rotation of the neutron star or by the stellar wind from the Be star, which may suppress accretion onto the neutron star when the surrounding disk is misaligned with respect to the orbital plane (see [81]). It is intriguing to explore the possibility that the DIM is related to these giant outbursts.

Because past research has often been divided by observational wavelength, multi-wavelength observations of the same object can lead to breakthroughs. For example, simultaneous X-ray and optical observations have revealed that X-ray behavior changes with the stage transitions of superhumps in WZ Sge stars [82]. Moreover, by using not only X-ray but also optical light curves to estimate the viscosity parameter, significantly lower estimates were obtained, which are closer to theoretical predictions (Dr. Russell's talk). Although it is difficult to obtain and analyze simultaneously-observed multi-wavelength data, the automatic observational system and modern statistics will help us and extract rich information (see [83]). The recent study by [84] will increase the chances of observing radio jets synchronized with the shrinkage of the inner disk edge in LMXBs.

4.3 Gravitational waves: a new window for CVs and XBs

In 2015, a new observational window into the universe — gravitational waves (GWs) — was opened in astronomy [85]. Since then, a large number of binary black-hole mergers have been detected, and increasing attention has been directed toward understanding how X-ray binaries evolve into GW sources. Because studies of binary evolution ultimately reduce to determining how angular momentum is removed from the system, they are intimately connected to the physics of accretion.

In the case of CVs, it is expected that many compact binaries containing WDs will be discovered by LISA and eLISA, which are scheduled for launch in the 2030s. Indeed, several AM CVn stars and double WD binary systems are regarded as prime candidates for GW sources [86]. Further theoretical development is required to understand how such objects—representing the final stage of CV evolution—are formed (see [87]). Moreover, it will remain essential to identify candidate systems and to determine their binary parameters through conventional optical observations.

5. Summary and future perspectives

Research on the DIM began in the 1970s, and by the 2000s it appeared to have reached a certain degree of convergence. However, with the advent of time-domain astronomy, the number of observable objects has increased dramatically, revealing a variety of phenomena that cannot be accounted for by existing models. Several long-standing unresolved problems have also returned to the forefront. At present, what is required is the construction of a grand unified model capable of comprehensively explaining the diversity of transient events, including these newly discovered phenomena.

Recent observations have not only uncovered an increasing number of unusual light variations that cannot be reproduced by standard models, but have also demonstrated that various physical mechanisms previously excluded from the standard framework are in fact essential for understanding accretion physics. For example, numerical simulations of the DIM that incorporate time-dependent outflows from accretion disks have yet to be performed, and the effects of tidal instability have not been fully taken into account when analyzing observational data or conducting numerical simulations of outbursts in BHBs. Going forward, the DIM will need to be updated by incorporating such newly recognized physical processes, as well as those whose importance has recently been reevaluated. I anticipate that these updated theoretical frameworks will eventually be applied to AGNs and protoplanetary disks, thereby further advancing accretion-disk studies across astrophysics. Unexpected transient events will continue to be discovered by upcoming satellites and telescopes. I am greatly looking forward to focusing on the identification of new phenomena and on developing models to explain them.

References

[1] Y. Osaki, *An accretion model for the outbursts of U Geminorum stars*, *Publ. Astron. Soc. Jpn.* **26** (1974) 429.

[2] S. Mineshige, *Intoroduction: various disk instabilities*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)001.

[3] R. Hōshi, *Accretion model for outbursts of dwarf nova*, *Progress of Theoretical Physics* **61** (1979) 1307.

[4] F. Meyer and E. Meyer-Hofmeister, *On the elusive cause of cataclysmic variable outbursts*, *Astron. Astrophys.* **104** (1981) L10.

[5] S. Mineshige and Y. Osaki, *Disk-instability model for outbursts of dwarf novae. ii full-disk calculations*, *Publ. Astron. Soc. Jpn.* **37** (1985) 1.

[6] J.K. Cannizzo, *The accretion disk limit cycle model: Toward an understanding of the long-term behavior of SS Cygni*, *Astrophys. J.* **419** (1993) 318.

[7] J. Smak, *accretion in cataclysmic binaries. IV – accretion disks in dwarf novae*, *Acta Astron.* **34** (1984) 161.

[8] Y. Osaki, *A brief history of the disk instability model in cataclysmic variable stars*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)002.

[9] G.T. Bath, *Periodicities and disks in dwarf novae*, *Nature Physical Science* **246** (1973) 84.

[10] J. Smak, *eruptive binaries. XI – disk-radius variations in U Gem*, *Acta Astron.* **34** (1984) 93.

[11] S. Ichikawa and Y. Osaki, *Time evolution of the accretion disk radius in a dwarf nova*, *Publ. Astron. Soc. Jpn.* **44** (1992) 15.

[12] J.M. Hameury, *The DIM: original recipe and additional ingredients*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)003.

[13] S. Mineshige, K. Ebisawa, M. Takizawa, Y. Tanaka, K. Hayashida, S. Kitamoto et al., *On x-ray luminosities of the quiescent x-ray novae - gs 2000+25 and gs 2023+338*, *Publ. Astron. Soc. Jpn.* **44** (1992) 117.

[14] S. Mineshige and J.C. Wheeler, *Disk-instability model for soft-x-ray transients containing black holes*, *Astrophys. J.* **343** (1989) 241.

[15] S. Ichikawa, S. Mineshige and T. Kato, *Disk-instability model for black hole transients: Interplay of thermal and tidal instabilities*, *Astrophys. J.* **435** (1994) 748.

[16] K. Menou, J.-M. Hameury, J.-P. Lasota and R. Narayan, *Disc instability models for x-ray transients: evidence for evaporation and low α-viscosity?*, *Mon. Not. R. Astron. Soc.* **314** (2000) 498.

[17] Y. Tanaka and N. Shibazaki, *X-ray novae*, *ARA&A* **34** (1996) 607.

[18] W. Chen, C.R. Shrader and M. Livio, *The properties of x-ray and optical light curves of x-ray novae*, *Astrophys. J.* **491** (1997) 312.

[19] C. Done, *Disc-jet-wind coupling through the disk instability cycle*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)004.

[20] C. Done, M. Gierliński and A. Kubota, *Modelling the behaviour of accretion flows in X-ray binaries. Everything you always wanted to know about accretion but were afraid to ask*, **15** (2007) 1 [0708.0148].

[21] R.A. Remillard and J.E. McClintock, *X-Ray Properties of Black-Hole Binaries*, *ARA&A* **44** (2006) 49 [astro-ph/0606352].

[22] A. Janiuk and B. Czerny, *On different types of instabilities in black hole accretion discs: implications for X-ray binaries and active galactic nuclei*, *Mon. Not. R. Astron. Soc.* **414** (2011) 2186.

[23] R. Fender and T. Belloni, *GRS 1915+105 and the disc-jet coupling in accreting black hole systems*, *ARA&A* **42** (2004) 317.

[24] D. Altamirano, T. Belloni, M. Linares, M. van der Klis, R. Wijnands, P.A. Curran et al., *The faint "heartbeats" of IGR J17091−3624: An exceptional black hole candidate*, *Astrophys. J., Lett.* **742** (2011) L17.

[25] A. Janiuk, *Radiation pressure instability: from heart-beat states in black hole binary systems to Quasars and Changing-Look AGN*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)006.

[26] R. Whitehurst, *Numerical simulations of accretion disks. i - superhumps - a tidal phenomenon of accretion disks*, *Mon. Not. R. Astron. Soc.* **232** (1988) 35.

[27] Y. Osaki, *A model for the superoutburst phenomenon of SU Ursae Majoris stars*, *Publ. Astron. Soc. Jpn.* **41** (1989) 1005.

[28] Y. Osaki and F. Meyer, *Early humps in WZ Sge stars*, *Astron. Astrophys.* **383** (2002) 574.

[29] H. Maehara, I. Hachisu and K. Nakajima, *Photometric observation and numerical simulation of early superhumps in BC Ursae Majoris during the 2003 superoutburst*, *Publ. Astron. Soc. Jpn.* **59** (2007) 227.

[30] M. Uemura, T. Kato, T. Ohshima and H. Maehara, *Reconstruction of the structure of accretion disks in dwarf novae from the multi-band light curves of early superhumps*, *Publ. Astron. Soc. Jpn.* **64** (2012) 92.

[31] R. Sazaki and M. Uemura, *The evolution of the asymmetric disk structure of WZ Sge-type dwarf novae*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)015.

[32] T. Kato, A. Imada, M. Uemura, D. Nogami, H. Maehara, R. Ishioka et al., *Survey of period variations of superhumps in SU UMa-type dwarf novae*, *Publ. Astron. Soc. Jpn.* **61** (2009) S395.

[33] S.H. Lubow, *a model for tidally driven eccentric instabilities in fluid disks*, *Astrophys. J.* **381** (1991) 259.

[34] S. Lubow, *The Eccentric Disk Model for Superhumps*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)011.

[35] T. Kato and M. Uemura, *Period analysis using the Least Absolute Shrinkage and Selection Operator (Lasso)*, *PASJ* **64** (2012) 122.

[36] Y. Osaki and T. Kato, *the cause of the superoutburst in SU UMa stars is finally revealed by Kepler light curve of V1504 Cygni*, *Publ. Astron. Soc. Jpn.* **65** (2013) 50.

[37] Y. Osaki and T. Kato, *study of superoutbursts and superhumps in SU UMa stars by the Kepler light curves of V344 Lyrae and V1504 Cygni*, *Publ. Astron. Soc. Jpn.* **65** (2013) 95.

[38] T. Kato and Y. Osaki, *new method to estimate binary mass ratios by using superhumps*, *Publ. Astron. Soc. Jpn.* **65** (2013) 115.

[39] J. Patterson, J. Kemp, D.A. Harvey, R.E. Fried, R. Rea, B. Monard et al., *Superhumps in cataclysmic binaries. XXV.* q_{crit}*,* $\epsilon(q)$*, and mass-radius*, *Publ. Astron. Soc. Pac.* **117** (2005) 1204.

[40] D. Nogami, *Superhumps and their Relation to the Disk Instaibility Model*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)010.

[41] T. Kato, *WZ Sge-type dwarf novae*, *Publ. Astron. Soc. Jpn.* **67** (2015) 108 [`1507.07659`].

[42] M. Kimura, T. Kato, A. Imada, K. Ikuta, K. Isogai, P.A. Dubovsky et al., *Unexpected superoutburst and rebrightening of AL Comae Berenices in 2015*, *Publ. Astron. Soc. Jpn.* **68** (2016) L2 [`1511.06596`].

[43] M. Kimura, K. Isogai, T. Kato, A. Imada, N. Kojiguchi, Y. Sugiura et al., *ASASSN-15jd: WZ Sge-type star with intermediate superoutburst between single and double ones*, *Publ. Astron. Soc. Jpn.* **68** (2016) 55 [`1604.06344`].

[44] M. Kimura, K. Isogai, T. Kato, K. Taguchi, Y. Wakamatsu, F.-J. Hambsch et al., *ASASSN-16dt and ASASSN-16hg: Promising candidate period bouncers*, *Publ. Astron. Soc. Jpn.* **70** (2018) 47 [`1803.03179`].

[45] U. Kolb, *A model for the intrinsic population of cataclysmic variables*, *Astron. Astrophys.* **271** (1993) 149.

[46] Y. Tampo, *WZ Sge-type dwarf novae: an extreme laboratory in cataclysmic variables*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)014.

[47] M. Kimura, *Could the thermal instability in the tilted disk be responsible for IW And phenomenon ?*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)012.

[48] G. Ramsay, *Outbursts in ultra-compact AM CVn binaries*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)017.

[49] K. Isogai, T. Kato, T. Ohshima, K. Kasai, A. Oksanen, K. Masumoto et al., *Superoutburst of CR Bootis: Estimation of mass ratio of a typical AM CVn star by stage A superhumps*, *Publ. Astron. Soc. Jpn.* **68** (2016) 64 [`1605.05408`].

[50] L.E. Rivera Sandoval, C.O. Heinke, J.M. Hameury, Y. Cavecchi, T. Vanmunster, T. Tordai et al., *The Fast Evolving, Tremendous Blue Superoutburst in ASASSN-21au Reveals a Dichotomy in the Outbursts of Long-period AM CVns*, *Astrophys. J.* **926** (2022) 10 [`2107.11006`].

[51] N. Kojiguchi, K. Isogai, Y. Tampo, T. Kato, R. Ohnishi, A. Imada et al., *First-ever discovery of a superoutburst in GP Comae Berenices buried in archival data*, *Publ. Astron. Soc. Jpn.* **77** (2025) 1126.

[52] J. Patterson, G. Masi, M.W. Richmond, B. Martin, E. Beshore, D.R. Skillman et al., *The 2001 superoutburst of wz sagittae*, *Publ. Astron. Soc. Pac.* **114** (2002) 721.

[53] Y. Osaki and F. Meyer, *Enhanced mass transfer during dwarf nova outbursts by irradiation of the secondary?*, *Astron. Astrophys.* **428** (2004) L17.

[54] C. Hellier, *On echo outbursts and er uma supercycles in su uma-type cataclysmic variables*, *Publ. Astron. Soc. Pac.* **113** (2001) 469.

[55] Y. Osaki, F. Meyer and E. Meyer-Hofmeister, *Repetitive rebrightening of EG Cancri: Evidence for viscosity decay in the quiescent disk?*, *Astron. Astrophys.* **370** (2001) 488.

[56] F. Meyer and E. Meyer-Hofmeister, *SU UMa stars: Rebrightenings after superoutburst*, *Publ. Astron. Soc. Jpn.* **67** (2015) 52.

[57] M. Ohana, Y.-F. Jiang, O. Blaes and B. Oyang, *Simulations of Eccentricity Growth in Compact Binary Accretion Disks with Magnetohydrodynamic Turbulence*, *Astrophys. J.* **979** (2025) 128 [`2411.15325`].

[58] C. Nixon and A. King, *Warp Propagation in Astrophysical Discs*, in *Astrophysical Black Holes, Lecture Notes in Physics, Volume 905. ISBN 978-3-319-19415-8. Springer International Publishing Switzerland, 2016, p. 45*, F. Haardt, V. Gorini, U. Moschella, A. Treves and M. Colpi, eds., vol. 905, p. 45 (2016), DOI.

[59] S. Hirose, O. Blaes, J.H. Krolik, M.S.B. Coleman and T. Sano, *Convection causes enhanced magnetic turbulence in accretion disks in outburst*, *Astrophys. J.* **787** (2014) 1.

[60] S. Hirose, *Thermal equilibrium curves of accretion disks driven by magneto-rotational instability*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)025.

[61] B. Tetarenko, G. Dubus, J.-P. Lasota, C. Heinke and G. Sivakoff, *Understanding X-ray irradiation in low-mass X-ray binaries directly from their light-curves*, *Mon. Not. R. Astron. Soc.* **480** (2018) 2 [1807.01360].

[62] M.J. Graham, N.P. Ross, D. Stern, A.J. Drake, B. McKernan, K.E.S. Ford et al., *Understanding extreme quasar optical variability with CRTS - II. Changing-state quasars*, *Mon. Not. R. Astron. Soc.* **491** (2020) 4925 [1905.02262].

[63] H. Noda and C. Done, *Explaining changing-look AGN with state transition triggered by rapid mass accretion rate drop*, *Mon. Not. R. Astron. Soc.* **480** (2018) 3898 [1805.07873].

[64] G. Miniutti, R.D. Saxton, M. Giustini, K.D. Alexander, R.P. Fender, I. Heywood et al., *Nine-hour X-ray quasi-periodic eruptions from a low-mass black hole galactic nucleus*, *Nature* **573** (2019) 381 [1909.04693].

[65] M. Nicholl, D.R. Pasham, A. Mummery, M. Guolo, K. Gendreau, G.C. Dewangan et al., *Quasi-periodic X-ray eruptions years after a nearby tidal disruption event*, *Nature* **634** (2024) 804 [2409.02181].

[66] X. Pan, S.-L. Li, X. Cao, G. Miniutti and M. Gu, *A Disk Instability Model for the Quasi-periodic Eruptions of GSN 069*, *Astrophys. J., Lett.* **928** (2022) L18 [2203.12137].

[67] F.V. Hessman, *The spectrum of ss cygni during a dwarf nova eruption*, *Astrophys. J.* **300** (1986) 794.

[68] R.K. Prinja, F.A. Ringwald, R.A. Wade and C. Knigge, *HST ultraviolet observations of rapid variability in the accretion-disc wind of BZ Cam*, *Mon. Not. R. Astron. Soc.* **312** (2000) 316.

[69] C. Knigge, J.A. Woods and J.E. Drew, *The application of Monte Carlo methods to the synthesis of spectral line profiles arising from accretion disc winds*, *Mon. Not. R. Astron. Soc.* **273** (1995) 225.

[70] Y. Tampo, C. Knigge, K.S. Long, J.H. Matthews and N.C. Segura, *A disc wind origin for the optical spectra of dwarf novae in outburst*, *Mon. Not. R. Astron. Soc.* **532** (2024) 1199 [2406.14396].

[71] N. Scepi, G. Lesur, G. Dubus and M. Flock, *Turbulent and wind-driven accretion in dwarf novae threaded by a large-scale magnetic field*, *Astron. Astrophys.* **620** (2018) A49 [1809.09131].

[72] B.E. Tetarenko, G. Dubus, G. Marcel, C. Done and M. Clavel, *Thermally driven disc winds as a mechanism for X-ray irradiation heating in black hole X-ray binaries: the case study of GX339-4*, *Mon. Not. R. Astron. Soc.* **495** (2020) 3666 [`2005.06378`].

[73] M. Shidatsu, C. Done and Y. Ueda, *An Optically Thick Disk Wind in GRO J1655-40?*, *Astrophys. J.* **823** (2016) 159 [`1604.04346`].

[74] G. Dubus, C. Done, B.E. Tetarenko and J.-M. Hameury, *The impact of thermal winds on the outburst lightcurves of black hole X-ray binaries*, *Astron. Astrophys.* **632** (2019) A40 [`1909.13601`].

[75] T. Muñoz-Darias, J. Casares, D. Mata Sánchez, R.P. Fender, M. Armas Padilla, M. Linares et al., *Regulation of black-hole accretion by a disk wind during a violent outburst of V404 Cygni*, *Nature* **534** (2016) 75 [`1605.02358`].

[76] M. Shidatsu, *X-ray Spectroscopy of Disk Winds in X-ray Binaries*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)032.

[77] K. Niijima, M. Kimura, Y. Wakamatsu, T. Kato, D. Nogami, K. Isogai et al., *Optical Variability Correlated with X-ray Spectral Transition in the Black-Hole Transient ASASSN-18ey = MAXI J1820+070*, *arXiv e-prints* (2021) arXiv:2107.03681 [`2107.03681`].

[78] M. Kimura and C. Done, *Evolution of X-ray irradiation during the 1999-2000 outburst of the black hole binary XTE J1859 + 226*, *Mon. Not. R. Astron. Soc.* **482** (2019) 626 [`1808.02944`].

[79] R. Martin, *Instabilities in Be star decretion discs*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)021.

[80] P. Reig, *Taxonomy of High Mass X-ray binaries from a historical perspective*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)023.

[81] A. Okazaki, *Wind-driven ablation of accretion disks as a mechanism for state transitions in Be/X-ray binaries*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)024.

[82] V.V. Neustroev, K.L. Page, E. Kuulkers, J.P. Osborne, A.P. Beardmore, C. Knigge et al., *Superhumps linked to X-ray emission. The superoutbursts of SSS J122221.7-311525 and GW Lib*, *Astron. Astrophys.* **611** (2018) A13 [`1712.03515`].

[83] M. Uemura, *Modeling the Unseen: Inference and Reconstruction in Accretion Disk Physics*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)036.

[84] T. Kawaguchi, *Conditions for Jet Launching Unveiled via Multiple Ejections in XTE J1859+226*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)037.

[85] B.P. Abbott, R. Abbott, T.D. Abbott, M.R. Abernathy, F. Acernese, K. Ackley et al., *Observation of Gravitational Waves from a Binary Black Hole Merger*, *Physical Review Letters* **116** (2016) 061102 [`1602.03837`].

[86] S. Scaringi, K. Breivik, T.B. Littenberg, C. Knigge, P.J. Groot and M. Veresvarska, *Cataclysmic variables are a key population of gravitational wave sources for LISA*, *Mon. Not. R. Astron. Soc.* **525** (2023) L50 [`2307.02553`].

[87] L. McNeill, *Finite temperature dependent criteria for stable mass transfer for AMCVn binaries*, in *proceedings of "87th Fujihara Seminar: The 50th Anniversary Workshop of the Disk Instability Model in Compact Binary Stars"* PoS(DIM50TH2025)046.