



Investigating Spiral Structures in Accretion Disks of
the Novalike Variable, UU
Aqr, through Multicolor Eclipse Observations
多色撮像による食の観測から探る激変星

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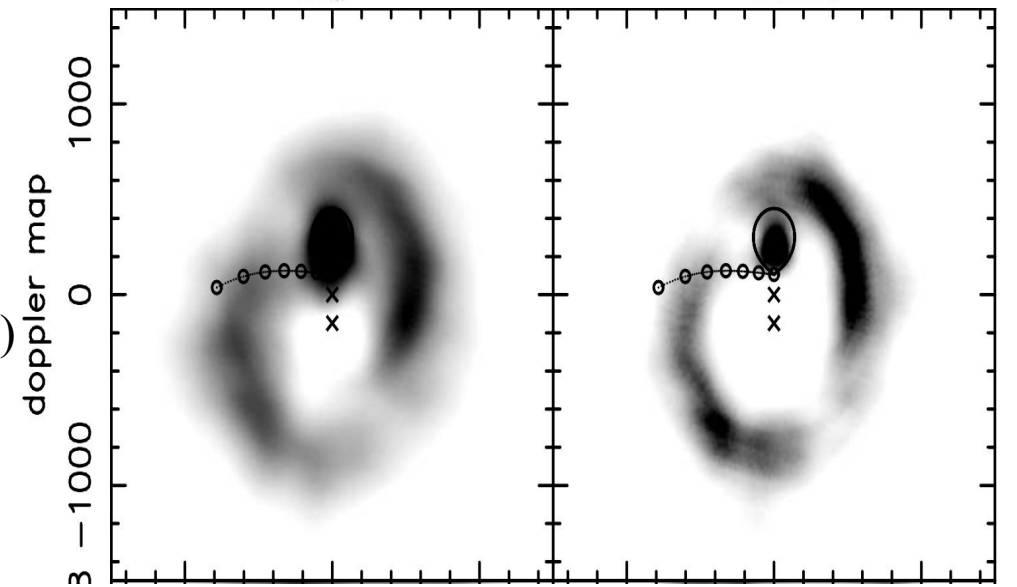
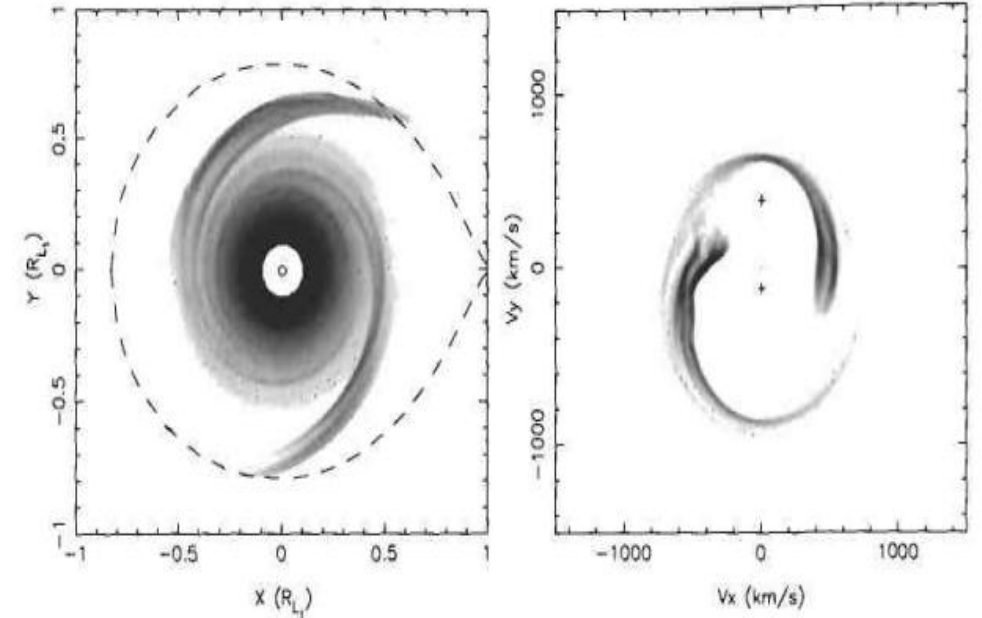
Introduction

- Cataclysmic variables (CVs) : A close binary system consisting of a white dwarf and a low-mass companion star. The companion star fills its Roche lobe and transfers mass to the white dwarf.

Spiral shocks ↔ **transfer angular momentum?**

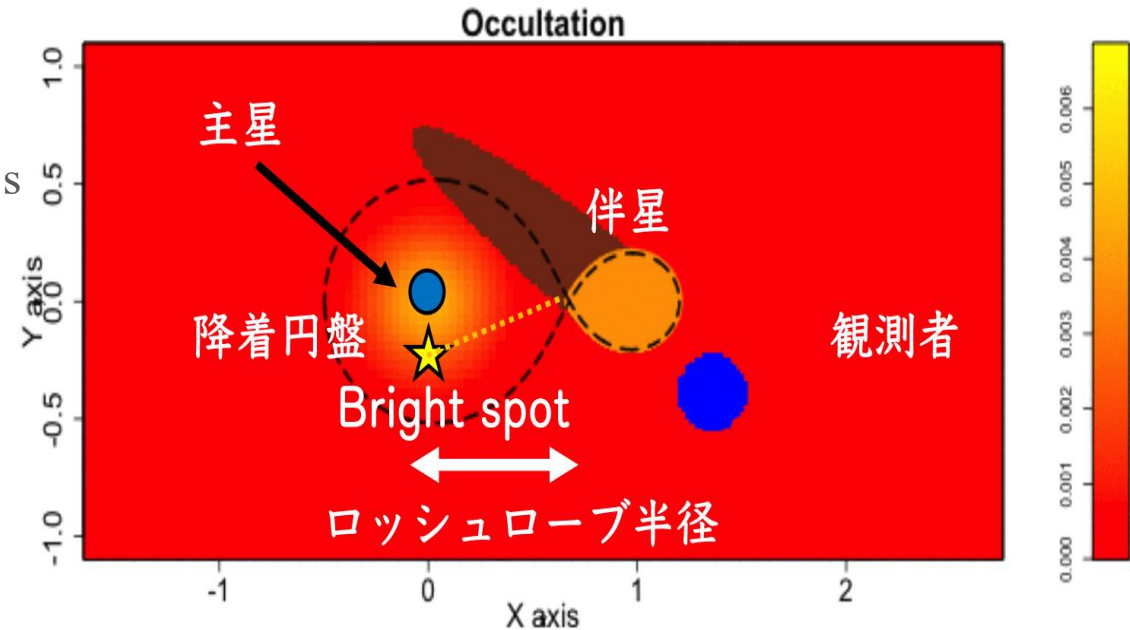
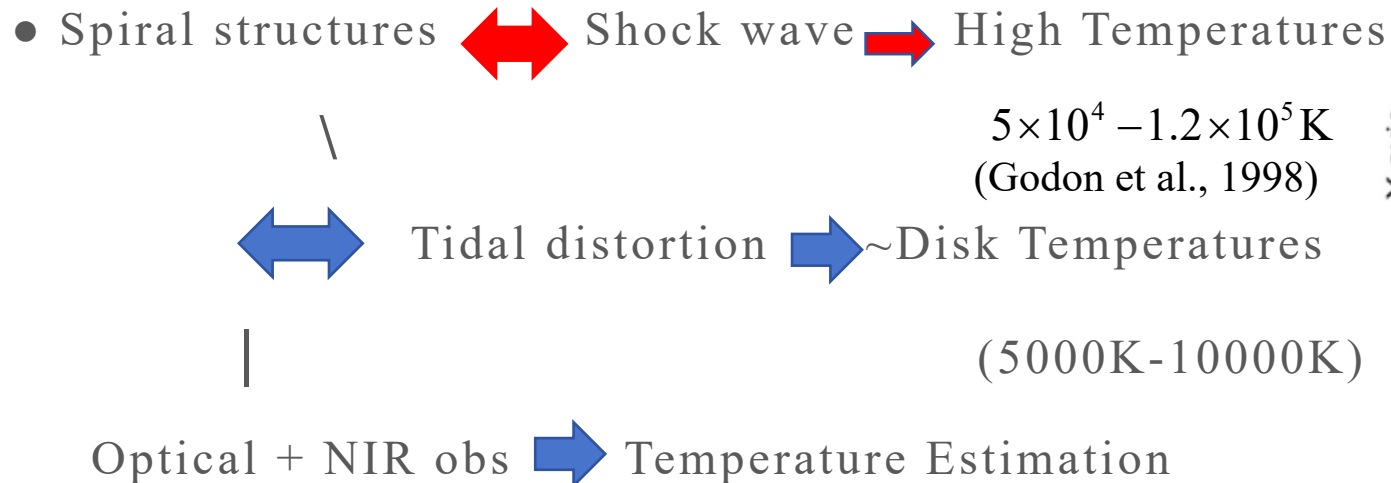
- Simulations(Sawada+86, Spruit+87): Effectively working
- Observations(Steeghs+97): Spiral structure seen in IP Peg

Only structures observed : (Ogilvie+02: may be tidal distortions)



Purpose of this study

- The object of analysis is the eclipse light curve caused by the occultation of the accretion disk by the companion star.
- Confirm whether it is possible to determine the presence of the spiral structure through observation (in the V-band and J-band)?
- How does the spiral structure affect the light curve?



(Shibata et al., 2021)

Model of the eclipse light curve

Parameter (*MCMC*)

T_0 ... Temperature at maximum radius of disk

b ... Temperature factor of spiral structure:

$T_{spiral} = b \cdot T_{disk}$... Spiral structure

Linear component of the out-of-eclipse light curve:

A, B_v, B_j ... $y_{v/j} = Ax + B_{v/j}$

Hyper-parameter

i, q ... inclination, mass ratio

R_{disk} ... Disk radius

$\delta = 100$... Azimuthal angle of spiral

(Relative location shown in right panel)

MCMC: Markov Chain Monte Carlo method

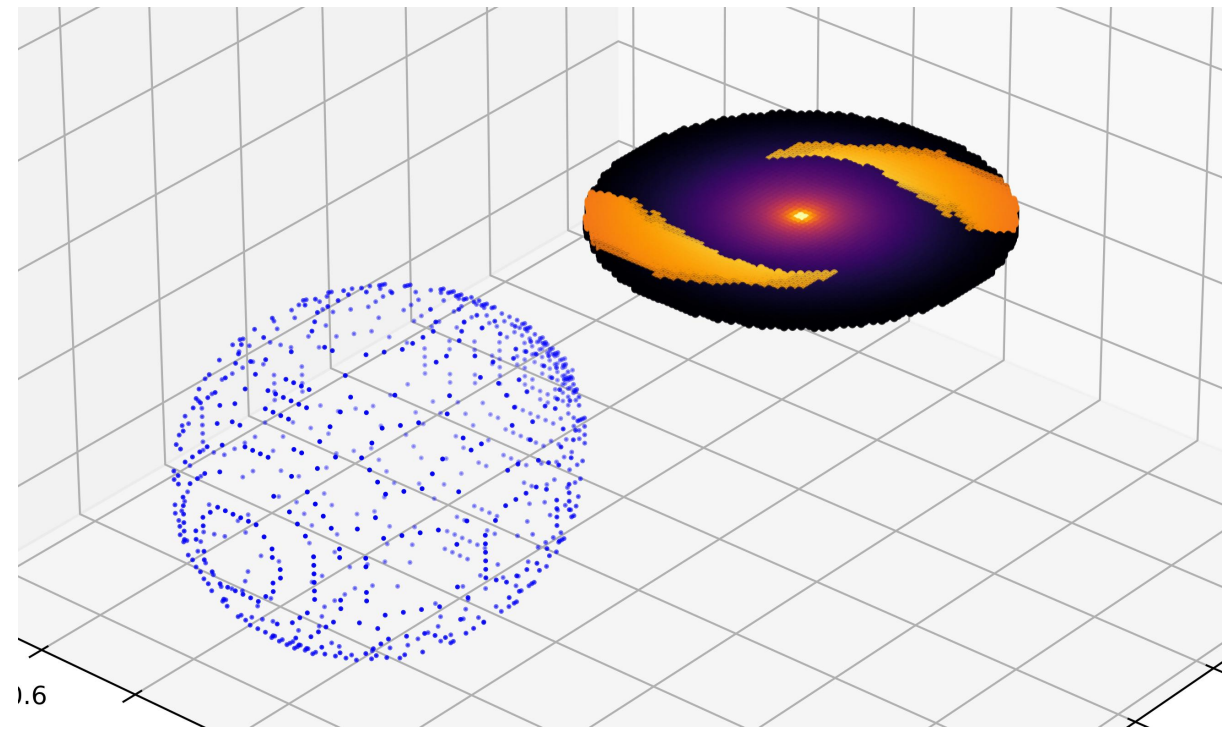
Power law: $T \propto R^{-\alpha}$

$$T_{disk} = T_0 \left(\frac{r}{R_{disk}} \right)^{-\alpha}$$

$\alpha = 3/4$... Standard accretion disk

$b = 8$

$T_0 = 5000K$



Model of the eclipse light curve

- Using this eclipse model, we confirmed that the presence or absence of a spiral pattern produces distinguishable differences in the light curve.
- Furthermore, these differences are observable if the spiral pattern has a sufficiently high temperature. ($T_{\text{spiral}} = 8 \cdot T_{\text{disk}}$)

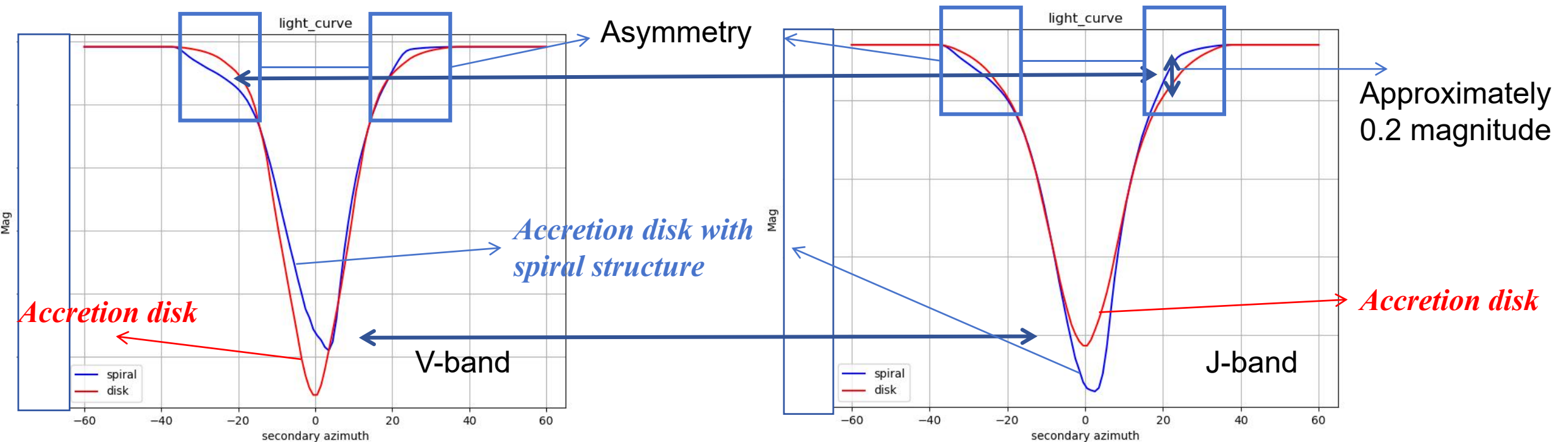
Power law: $T \propto R^{-\alpha}$

$$T_{\text{disk}} = T_0 \left(\frac{r}{R_{\text{disk}}} \right)^{-\alpha}$$

$\alpha = 3 / 4 \dots$ Standard accretion disk

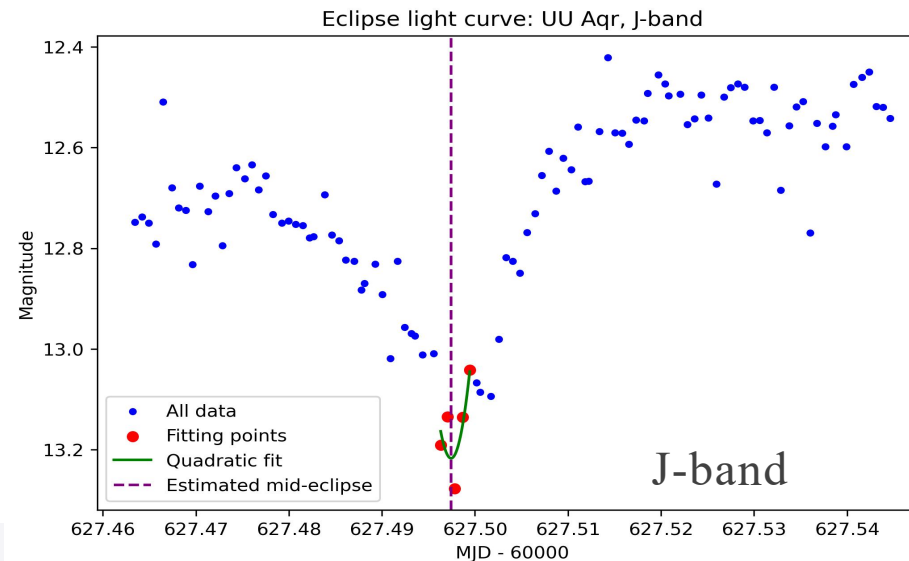
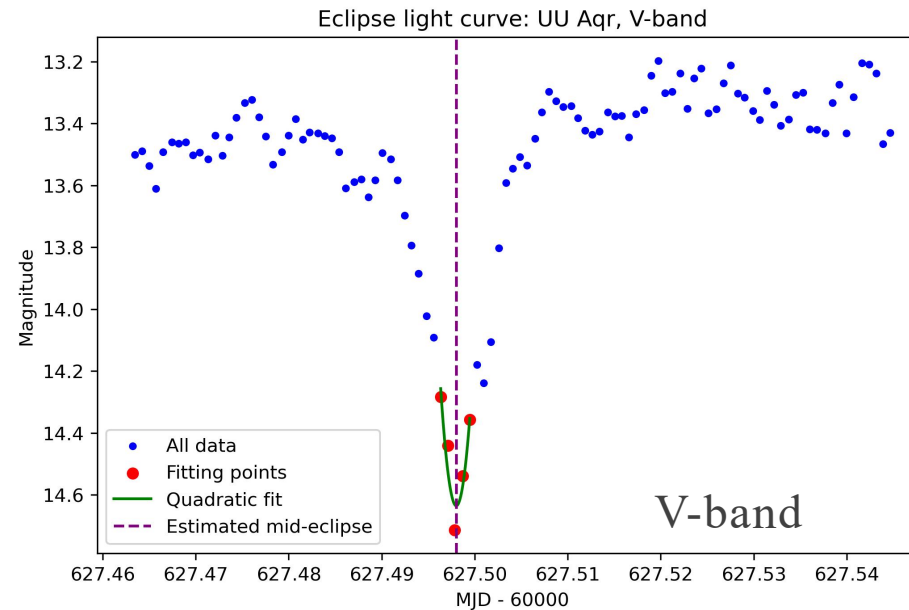
$b = 8$

$T_0 = 5000K$



Analytic object: UU Aqr

- Telescope: Kanata Telescope(1.5-meter Optical and Near-infrared Telescope)
- Detector: Hiroshima Optical and Near-infrared Camera HONIR
- Band: optical: V, infrared: J
- Observation period: 2024/11/13
20:00~22:00



Light Curve Fitting Results (Standard accretion disk model and spiral structure)

Orange line

Standard accretion disk + spiral structure

$$T_0 = 5884.04K (\pm 66.72K)$$

$$T_{spiral} = b \cdot T_{disk} \cdots \text{Spiral structure}$$

$$b = 1.09 (\pm 0.04)$$

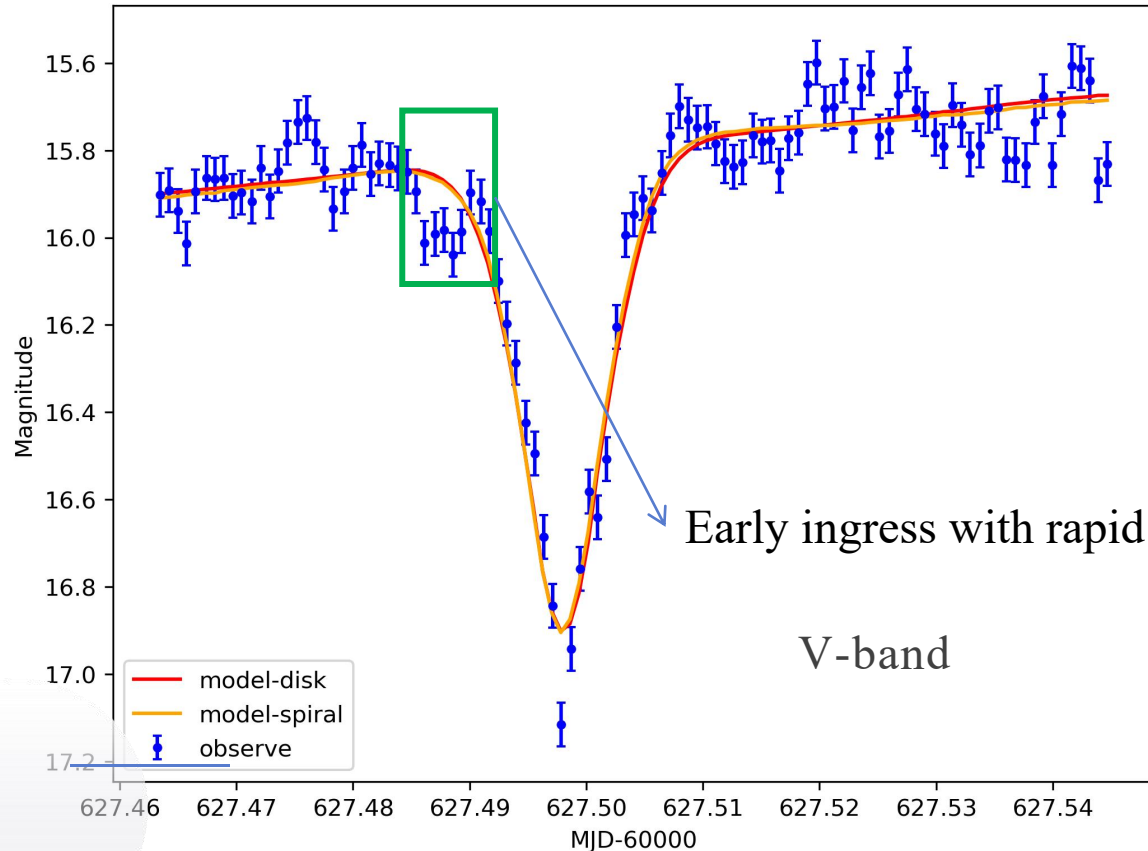
Even with the inclusion of a spiral structure in the accretion disk, its temperature does not differ significantly from that of the disk.

Red line

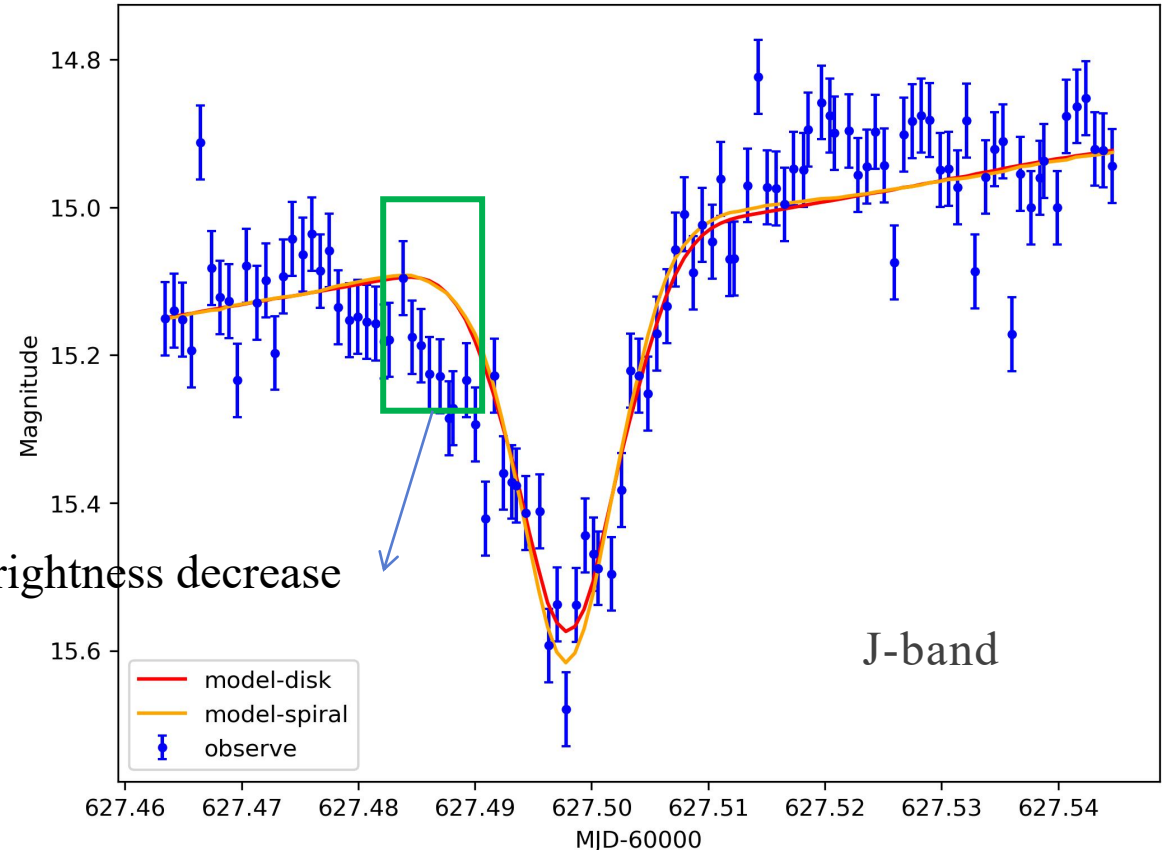
Standard accretion disk model

$$T_0 = 4967.54K (\pm 55.31K)$$

Curve fitting: V-band



Curve fitting: J-band



Light Curve Fitting Results (Disk + Spiral structure + Hypothetical cylindrical emission region)

$$T_0 = 4671.51K (\pm 113.16K)$$

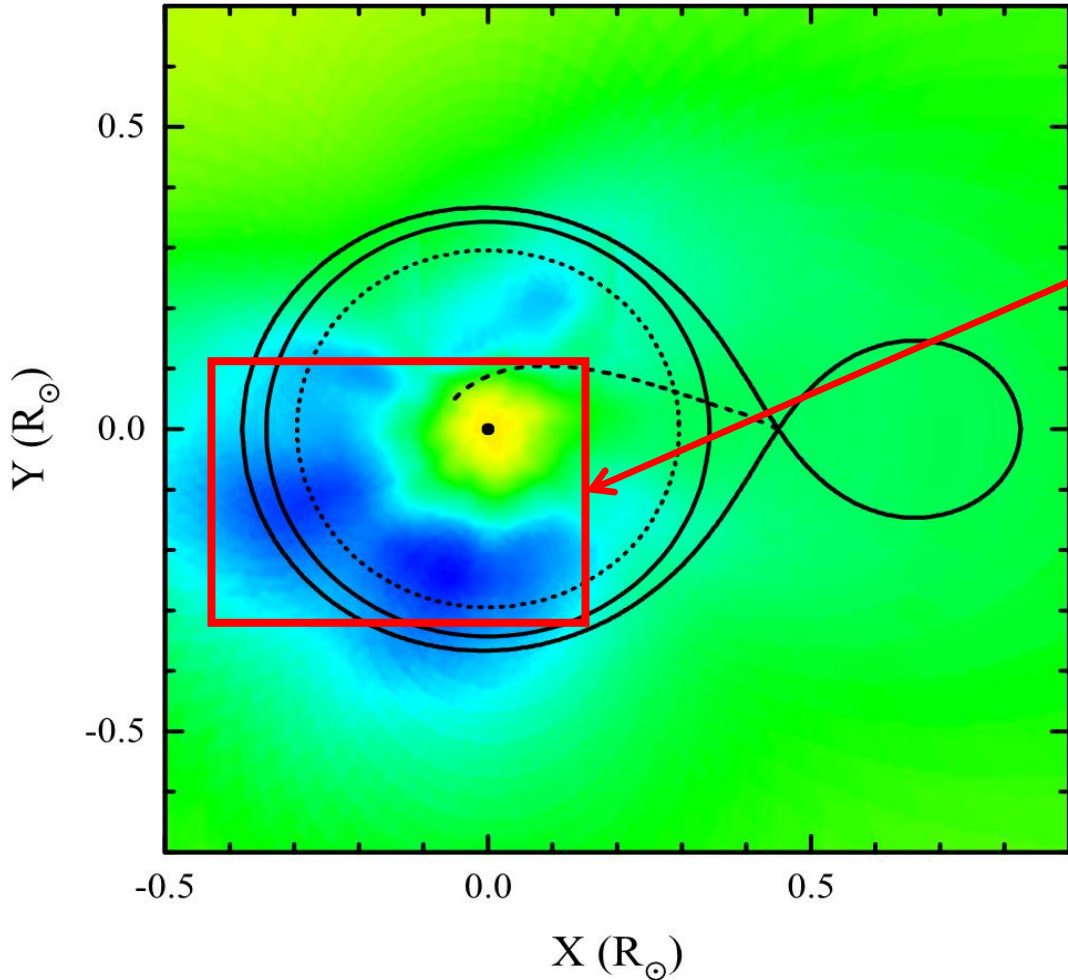
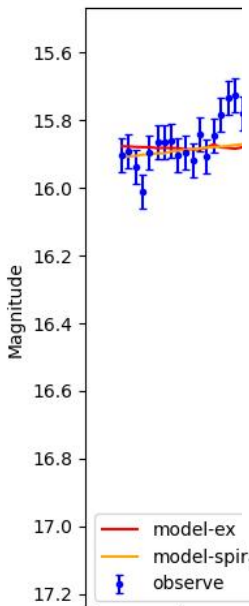
$$T_{spiral} = b \cdot T$$

$$b = 1.18 (\pm 0.05)$$

$$T_{ex} = c \cdot T_{disk}$$

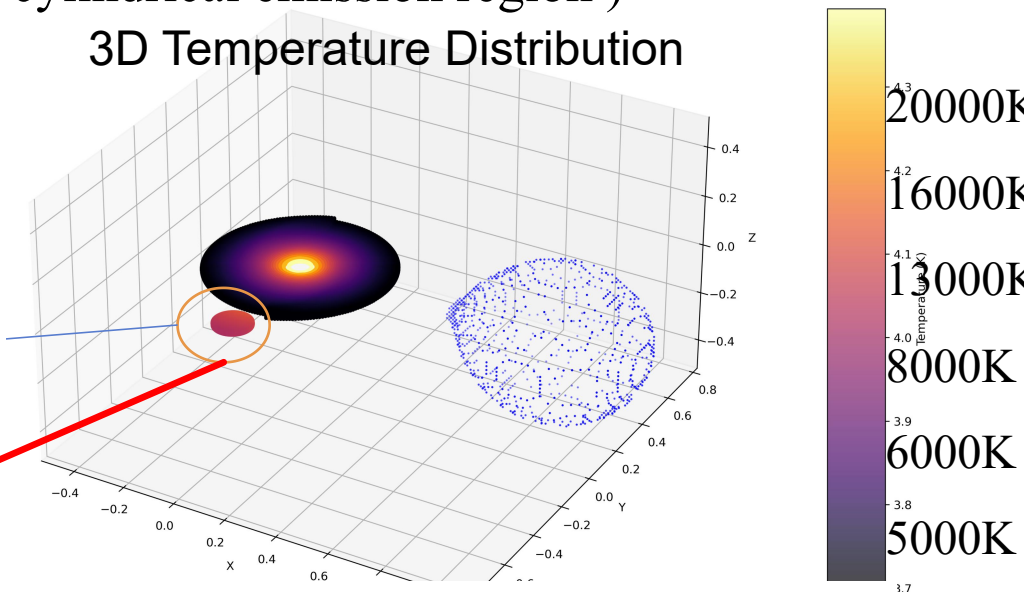
... Hypothetical cylindrical emission region

$$c = 2.53 (\pm 0.15)$$

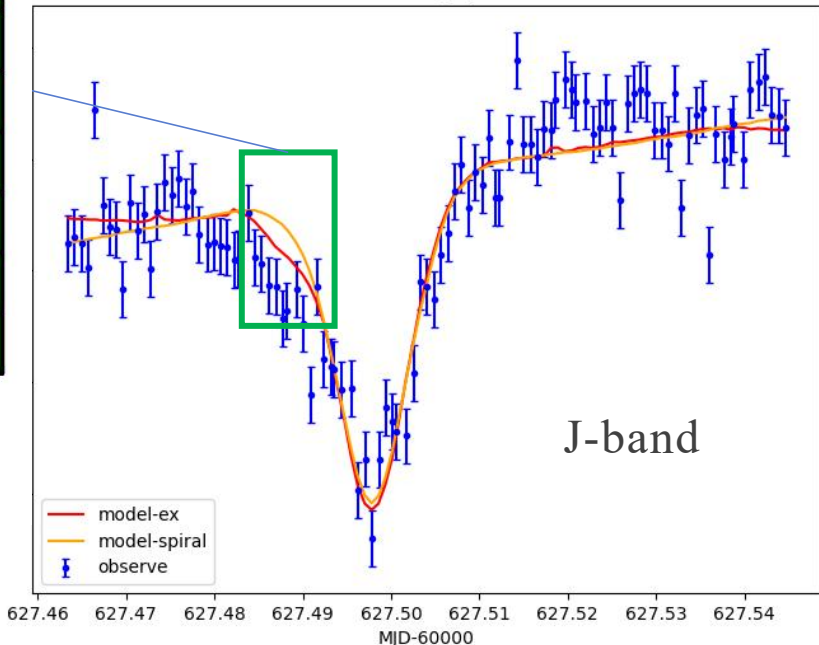


(Neustroev, Zharikov, and Borisov 2016)

3D Temperature Distribution



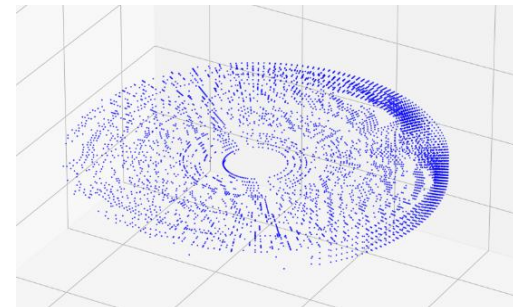
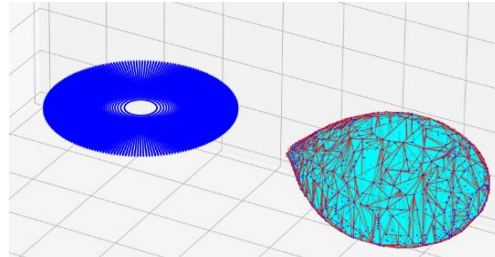
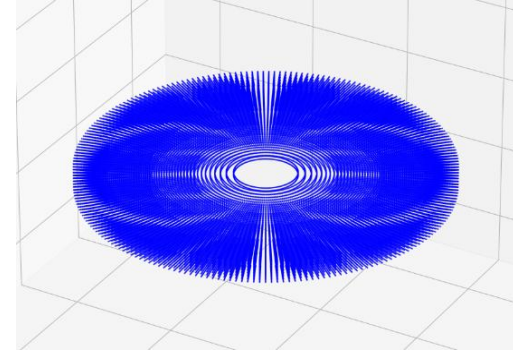
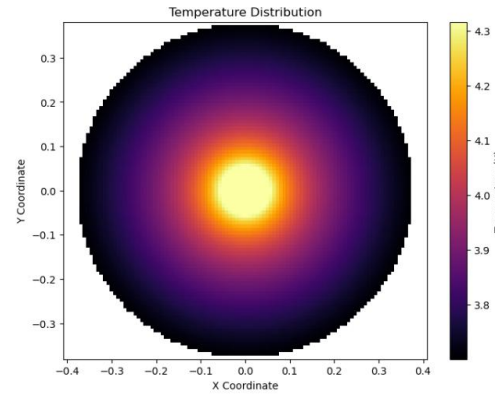
Curve fitting: J-band



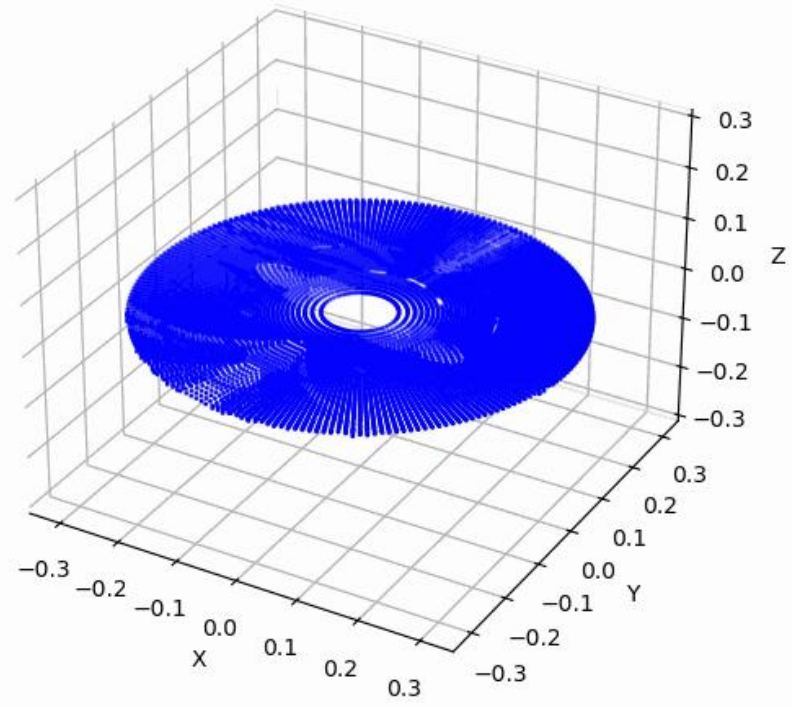
CONCLUSIONS

- I. Shock waves in the accretion disk alter the eclipse light curves in brightness and shape.
 - I. The spiral pattern mainly affects brightness at the start, end, and center of the eclipse.
 - II. The V- and J-band light curves show some asymmetry.
- II. We conducted simultaneous observations of UU Aqr in the V-band and J-band.
- III. The standard disk model alone cannot explain the rapid brightness drop.
 - I. Adding an extra emitting region reproduces the initial rapid decline.
 - II. Our model suggests that the extra emitting region is relatively hot (Temperature $\sim 10000\text{K}$).
 - III. The spiral structure itself remains cool, not supporting the shock hypothesis.

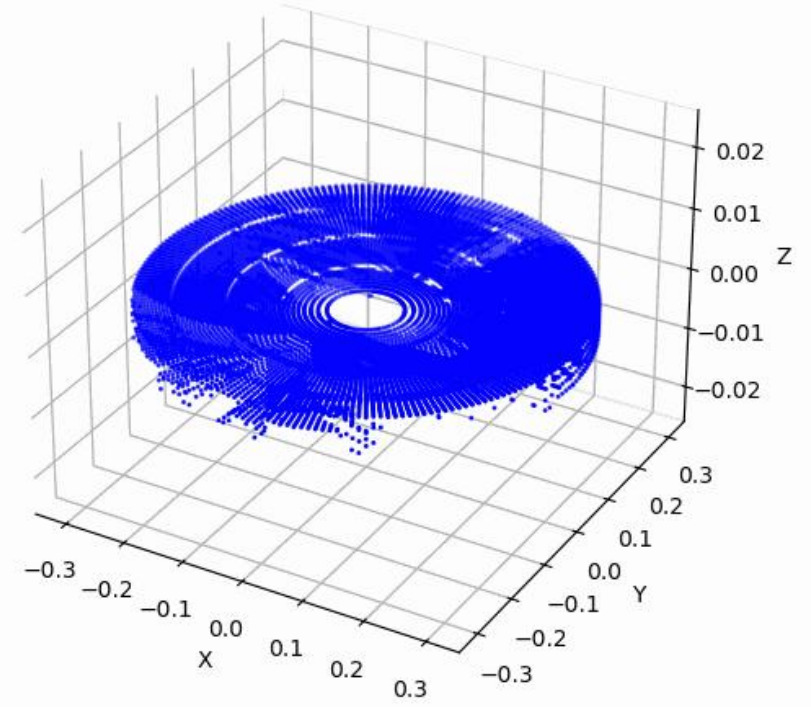
Model



Frame 1/105



Frame 1/105



Construction of the eclipse light curve model

$$z_1 = \max \left(1, \frac{\xi_1}{\sqrt{\left\{ r/R_{disk} - \exp[-\eta(\phi - \delta)] \right\}^2 + \varepsilon^2}} \right) \cdots \text{spiral structure}$$

$$z_2 = \max \left(1, \frac{\xi_2}{\sqrt{\left\{ r/R_{disk} - \exp[-\eta(\phi - \delta - \pi)] \right\}^2 + \varepsilon^2}} \right) \cdots \text{spiral structure}$$

$$h' = h \max(z_1, z_2)$$

h' ... the height of accretion disk surface including the axisymmetric structure

η ... the inverse of the pitch angle of spirals

δ ... the position angle

ξ ... the heights of spirals

$$h = \beta R_{disk} \left(\frac{r}{R_{disk}} \right)^\nu \cdots \text{the height of a standard accretion disk}$$

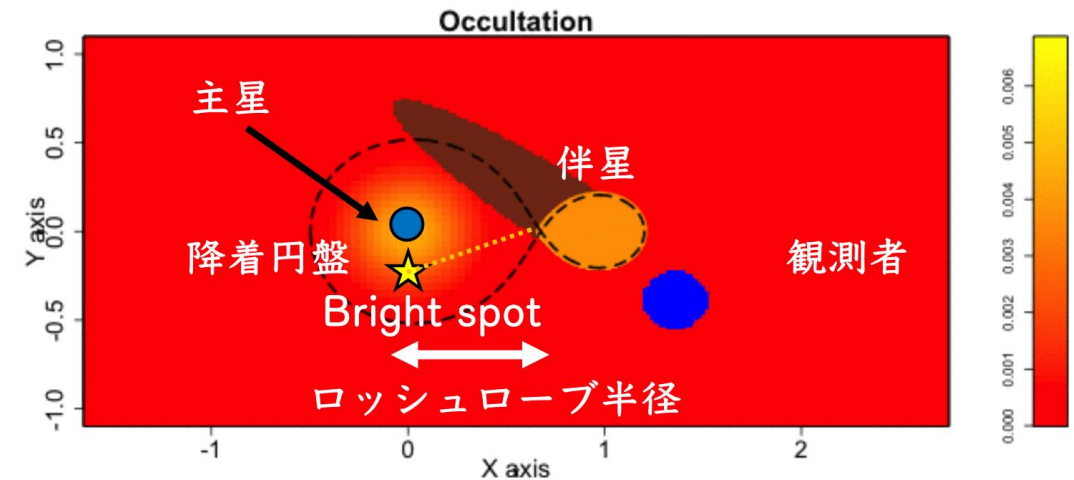
R_{effect} ... the effective radius of the inner critical Roche lobe for WD

h ... the height of the surface from the equatorial plane

r ... the distance on the equatorial plane from the center of the WD

β ... disk thickness

(Hachisu et al., 2004)(Maehara et al., 2007)



(Shibata et al., 2021)

$$\frac{R_{disk}}{a} = \left(\frac{7}{5} \right)^2 (1+q) \left(\frac{R_{L1}}{a} \right)^4 \cdots \text{Lubow-Shu radius}$$

mass ratio ... $q = 0.4$

inclination ... $\theta = 76^\circ$

$a = 1$... dimensionless binary distance

$\beta = 0.01, \nu = 1, \eta = 0.5$

$\xi_1 = \xi_2 = 0.5, \varepsilon = 0.1$