# X-ray study of hot plasma spatial distribution in dwarf novae in quiescence

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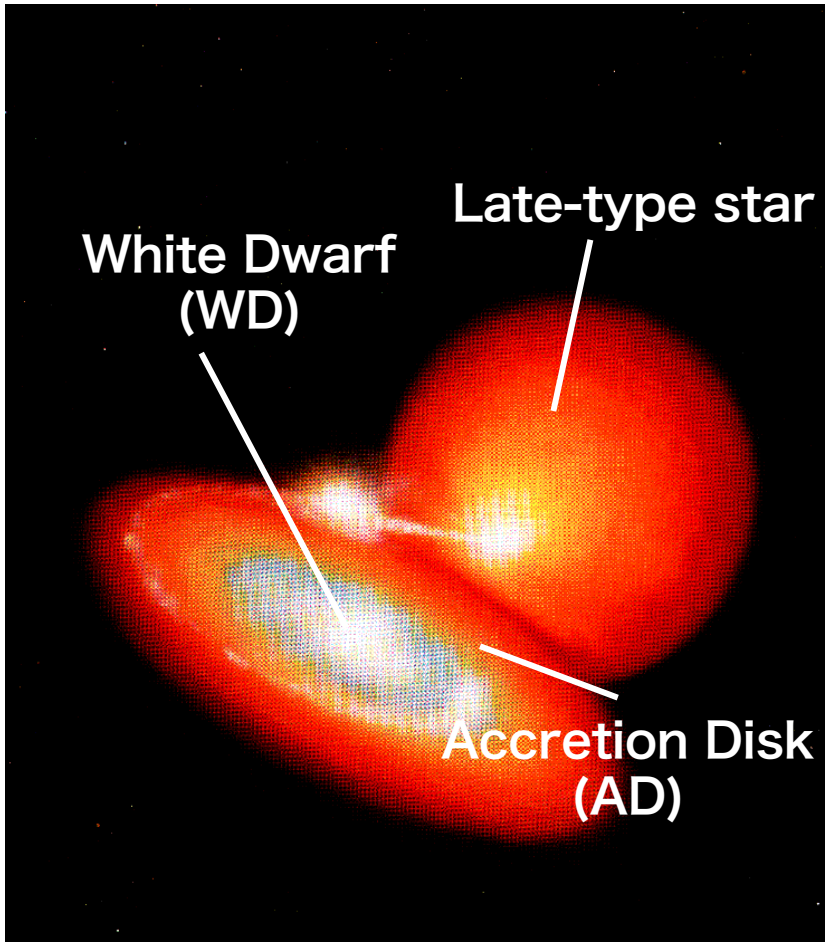
**Takeo et al. 2021a** PASJ, 73, 143 "Spatial distribution of the X-ray-emitting plasma of U Geminorum in quiescence and outburst"

**Takeo et al. 2021b** PASJ, 73, 1418 "Spatial distribution of the X-ray-emitting plasma of SS Cygni in quiescence and outburst"

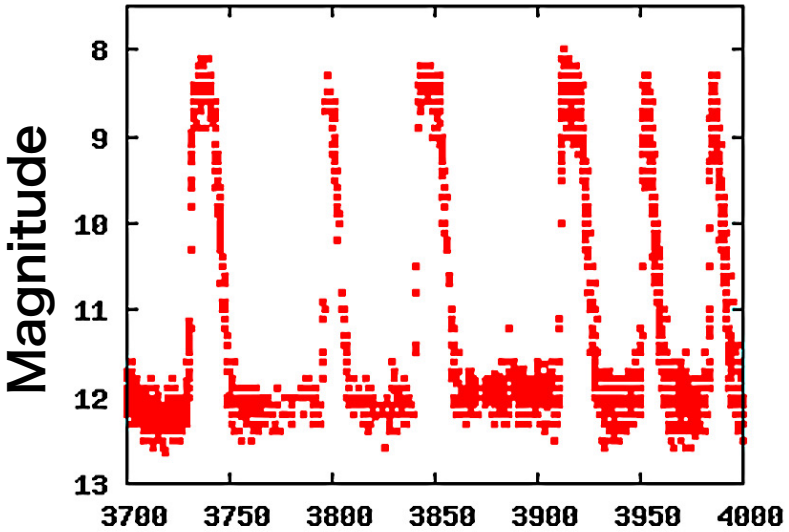
# Introduction




Cataclysmic Variable (CV)
https://www.star.le.ac.uk/%7eopj/nmcv.gif

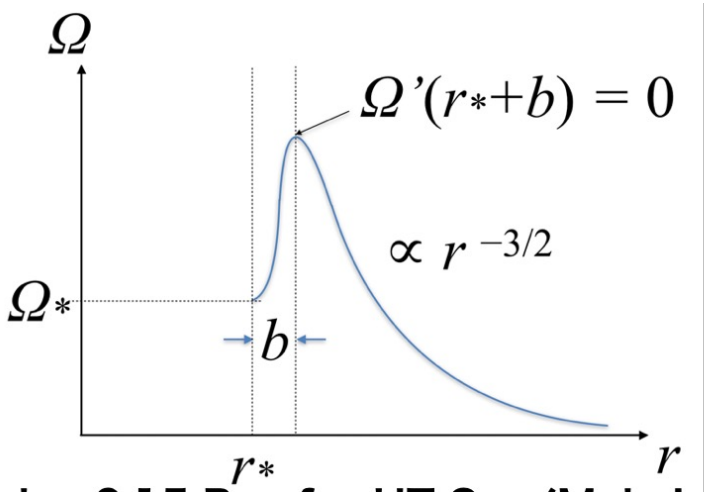
## Dwarf Nova (DN)

DN shows optical outbursts repeatedly with an amplitude of $\Delta m_V$=2–5 and an interval of 10d to decades.

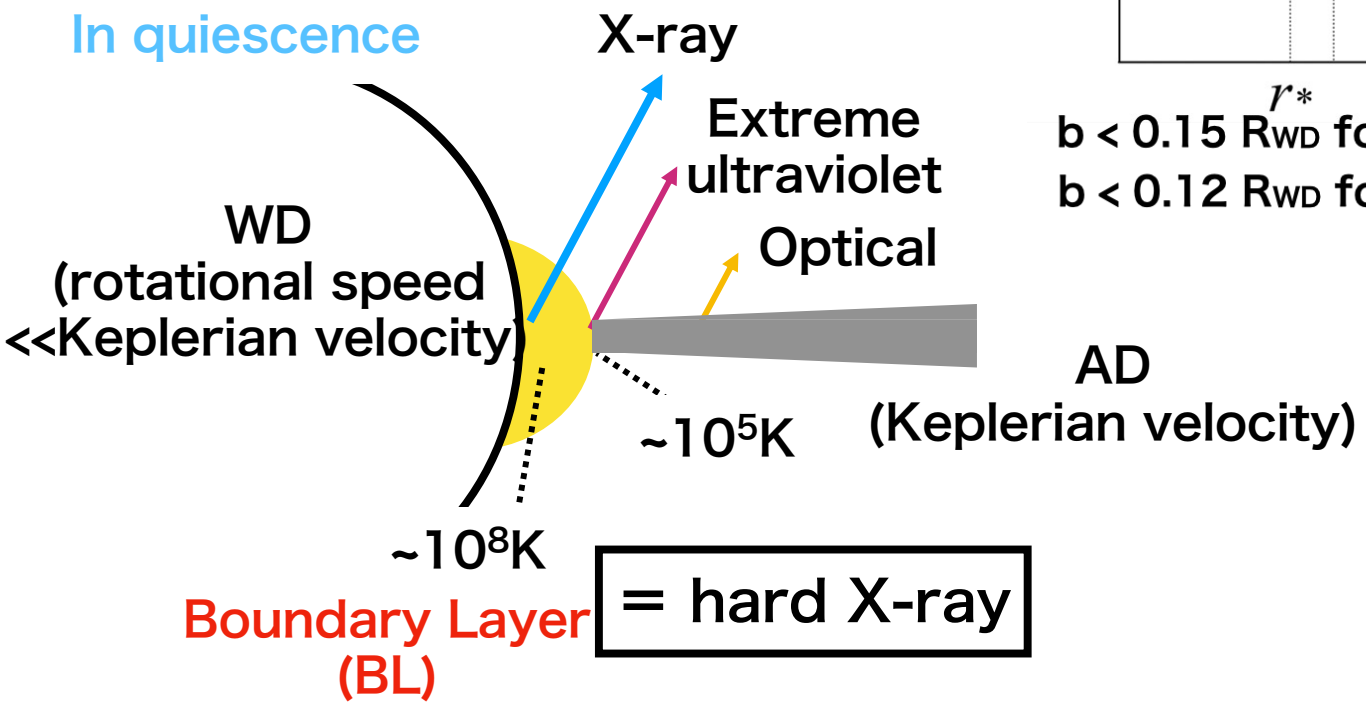



Optical light curve of SS Cyg
https://www.rikanenpyo.jp/kaisetsu/tenmon/tenmon_029.html

# Introduction



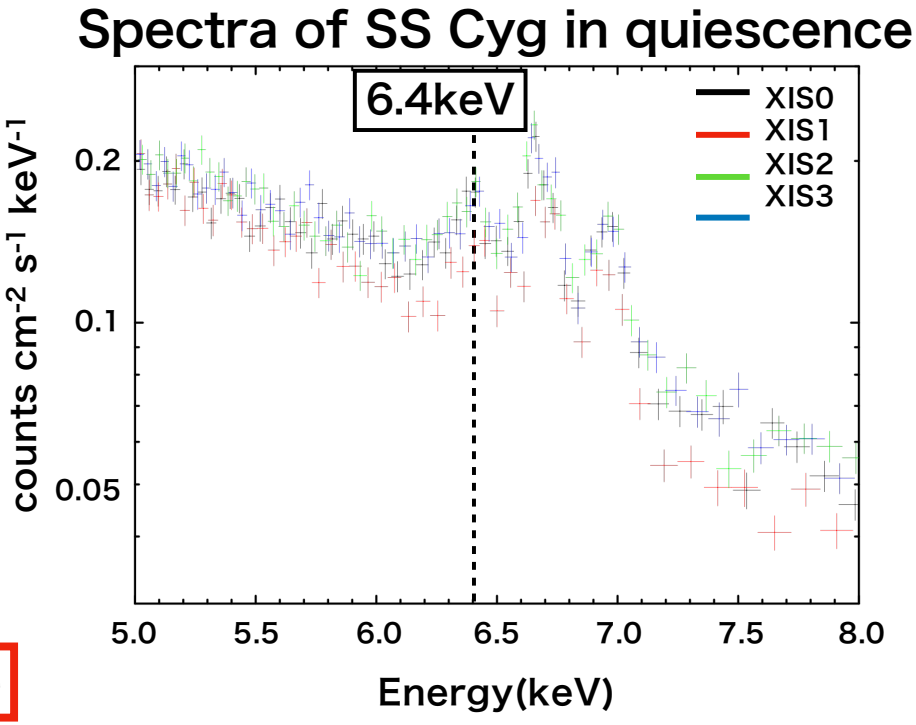

b < 0.15 $R_{WD}$ for HT Cas (Mukai et al. 1997)
b < 0.12 $R_{WD}$ for SS Cyg (Ishida et al. 2009)



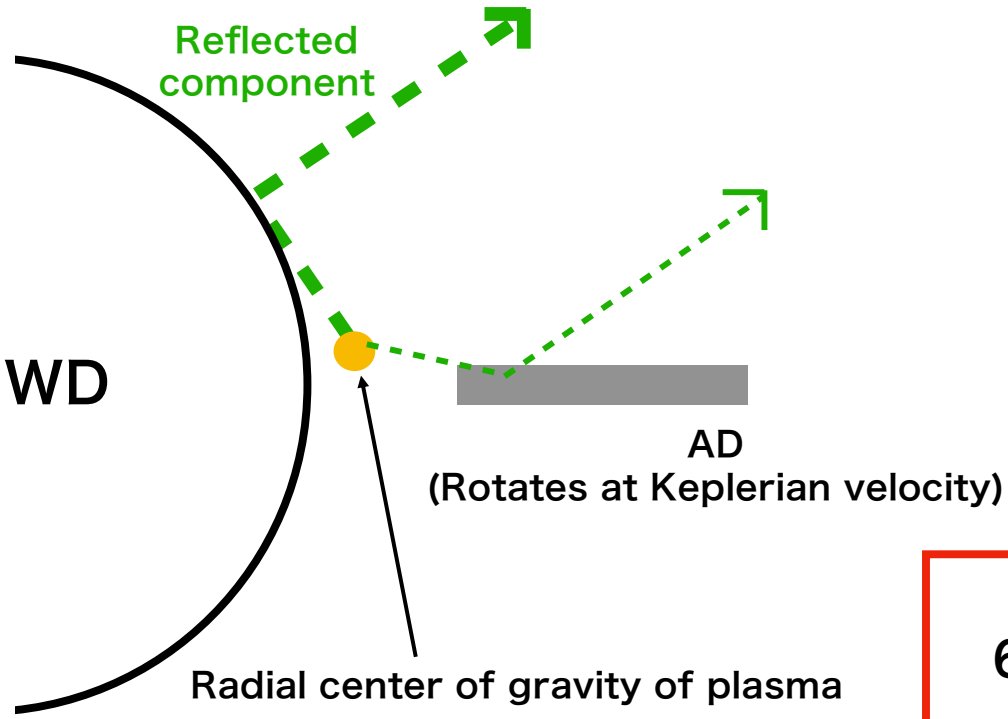

In reality, however, the structure of the BL has not yet been clarified because in the case of DNe where the WD has a weak magnetic field, the AD is formed around the WD, which is a three-dimensional problem if the thickness of the AD is taken into account.

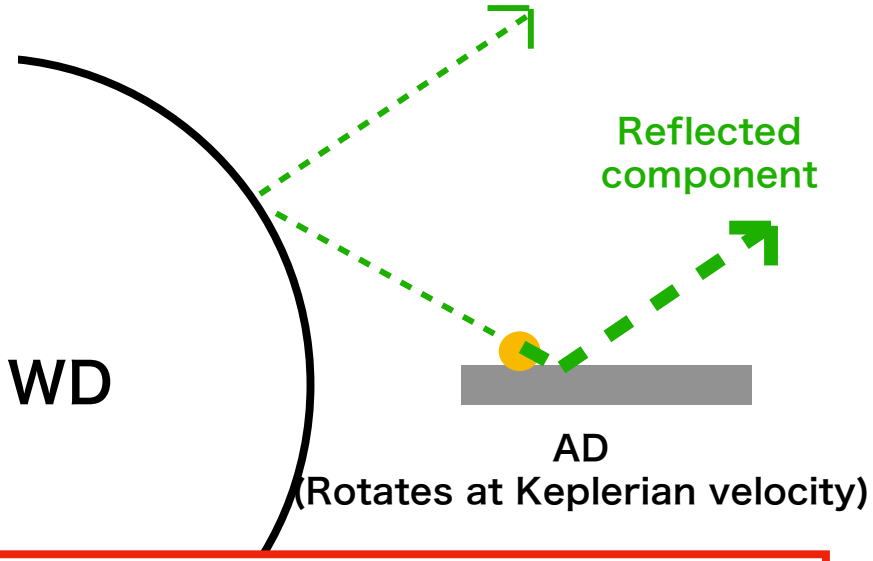
# Introduction

## Iron 6.4 keV fluorescence line
(originating from the cold reflectors such as the WDsurface and the AD)




6.4keV(narrow component) is large



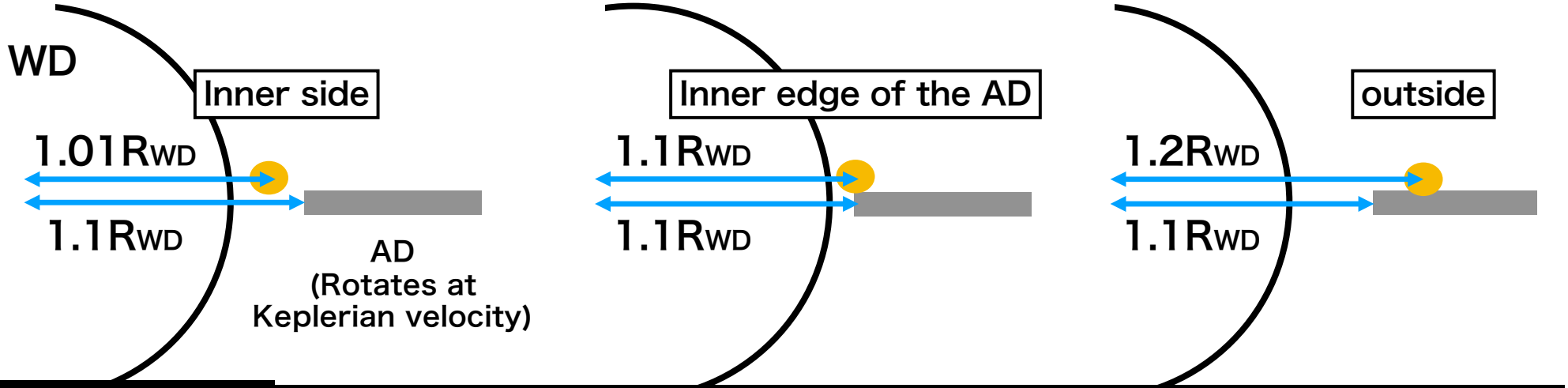



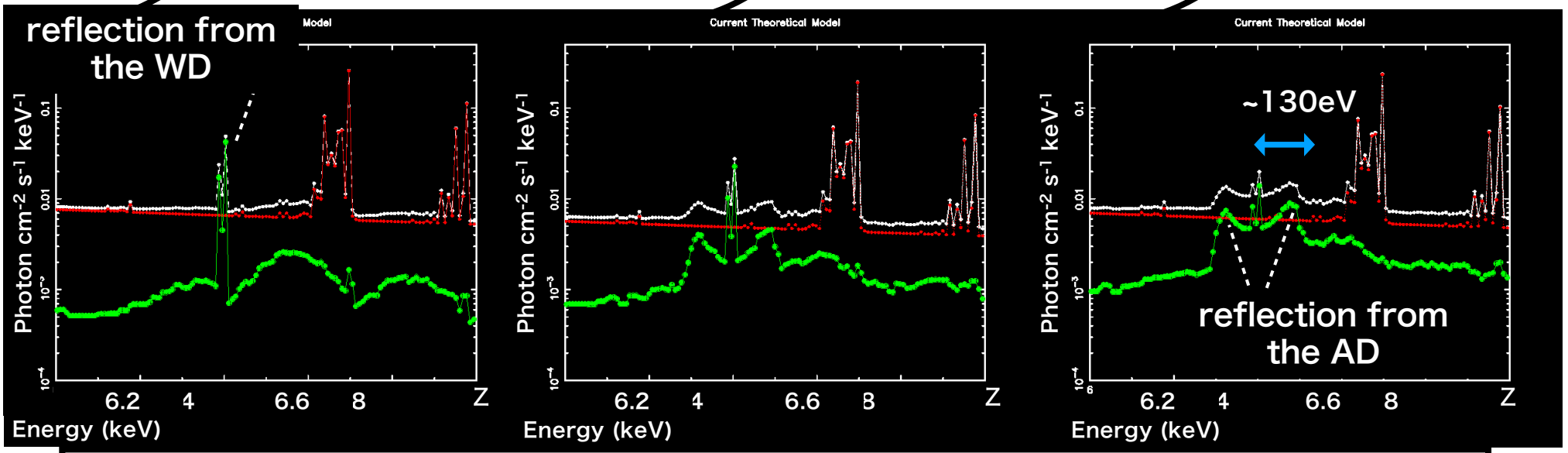

6.4keV(narrow component) & 6.4keV with red-shift and blue-shift(broad component)

# Introduction

<Plasma emission model>
+ <Reflection model>
<Plasma emission model>
<Reflection model>

Iron 6.4 keV fluorescence line
(originating from the cold reflectors such as the WDsurface and the AD)



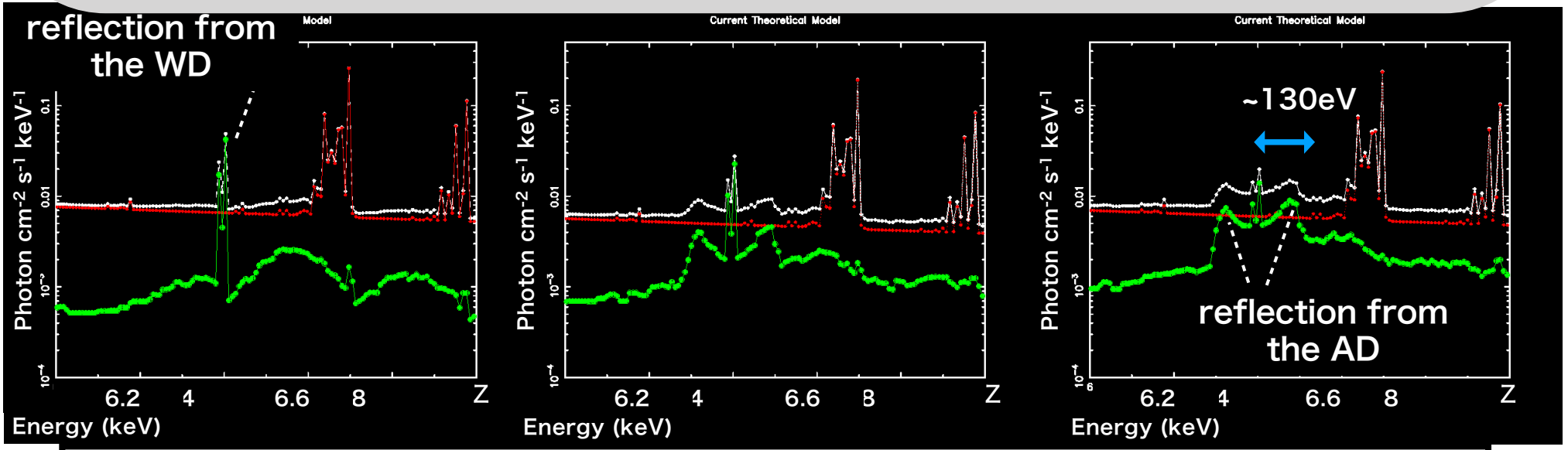

The 6.4 keV line profile is sensitive to the geometry of the hot plasma

# Purpose of this study

Iron 6.4 keV fluorescence line
(originating from the cold reflectors such as the

<Plasma emission model>
+ <Reflection model>
<Plasma emission model>
<Reflection model>

We carried out the spectral simulations of the BL plasma including X-rays reflected off the WD and the AD (Hayashi et al. 2018 MNRAS 474, 1810), and investigated the geometrical relation of the X-ray-emitting hot plasma with respect to the WD and the AD for the Suzaku data of four typical DNe .




The 6.4 keV line profile is sensitive to the geometry of the hot plasma

# Observations

## Suzaku observation log

| Target | State | Observation date | XIS Exposure (ks) | HXD Exposure (ks) | XIS count rate ($s^{-1}$) | HXD count rate ($s^{-1}$) |
|---|---|---|---|---|---|---|
| U Gem | Quiescence | 2012/04/24 | 119.1 | 93.1 | 0.491 ± 0.001 | 0.010 ± 0.002 |
| SS Cyg | Quiescence | 2005/11/02 | 39.5 | 30.0 | 2.928 ± 0.004 | 0.144 ± 0.004 |
| V893 Sco | Quiescence | 2006/08/26 | 18.5 | 15.0 | 3.318 ± 0.014 | 0.015 ± 0.005 |
| Z Cam | transitional state (Use data only during quiescence) | 2009/04/10 | 37.7 | 33.9 | 3.861 ± 0.010 | 0.053 ± 0.003 |

# Analyses

## Models for spectral fitting

The extinction by the interstellar medium + Plasma emission model + Reflection model

multi-temperature thermal plasma model(cevmkl)

$T_{max}$, $\alpha$, $Z_{Fe}$

$$d(EM) \propto (\frac{T}{T_{max}})^{\alpha} d(\log T) \propto (\frac{T}{T_{max}})^{\alpha-1} dT$$

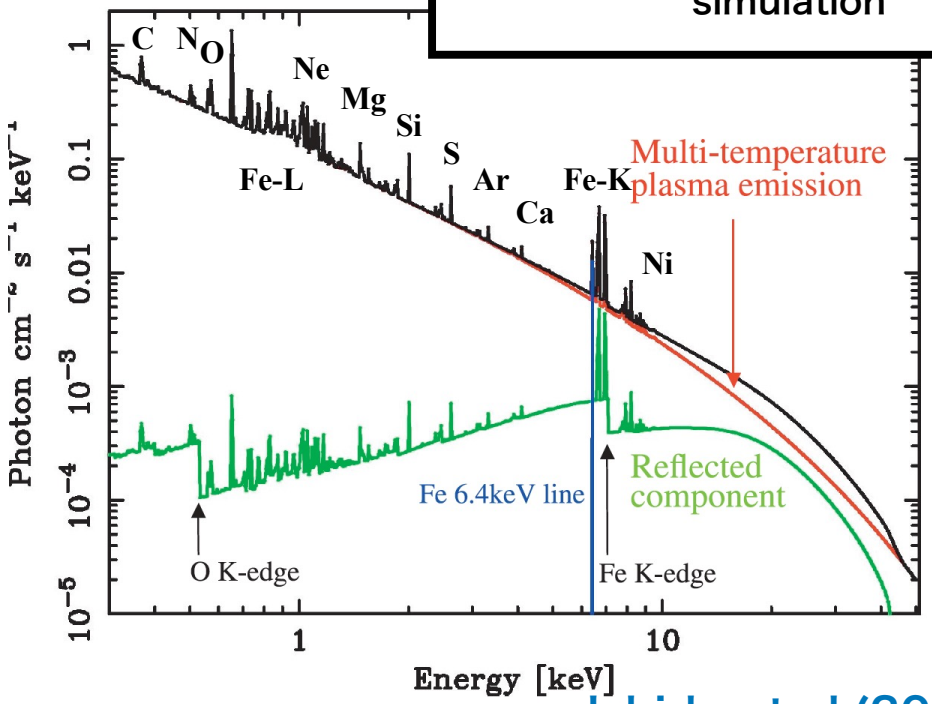
spectral fitting

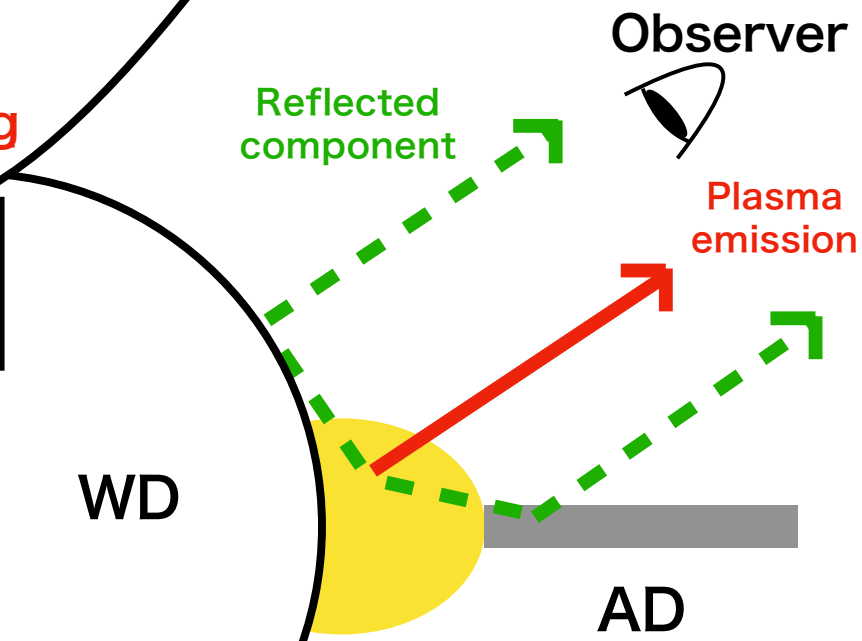
Using the reflection model calculated in the reflection simulation, fit the spectrum

Reflection simulation

Monte Carlo method

Using $T_{max}$, $\alpha$, and $Z_{Fe}$ from the spectral fitting, run the reflection simulation

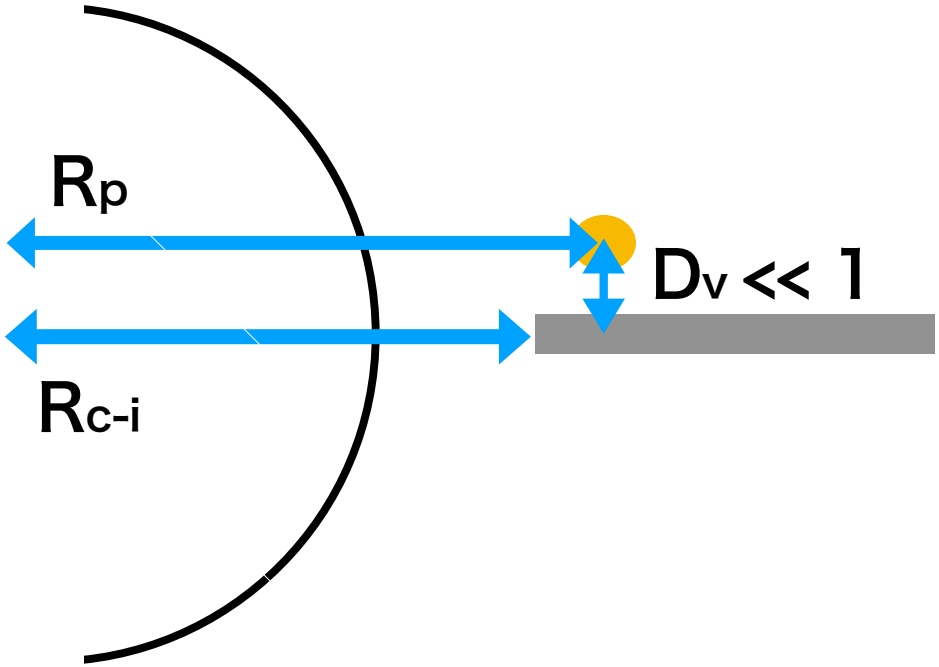


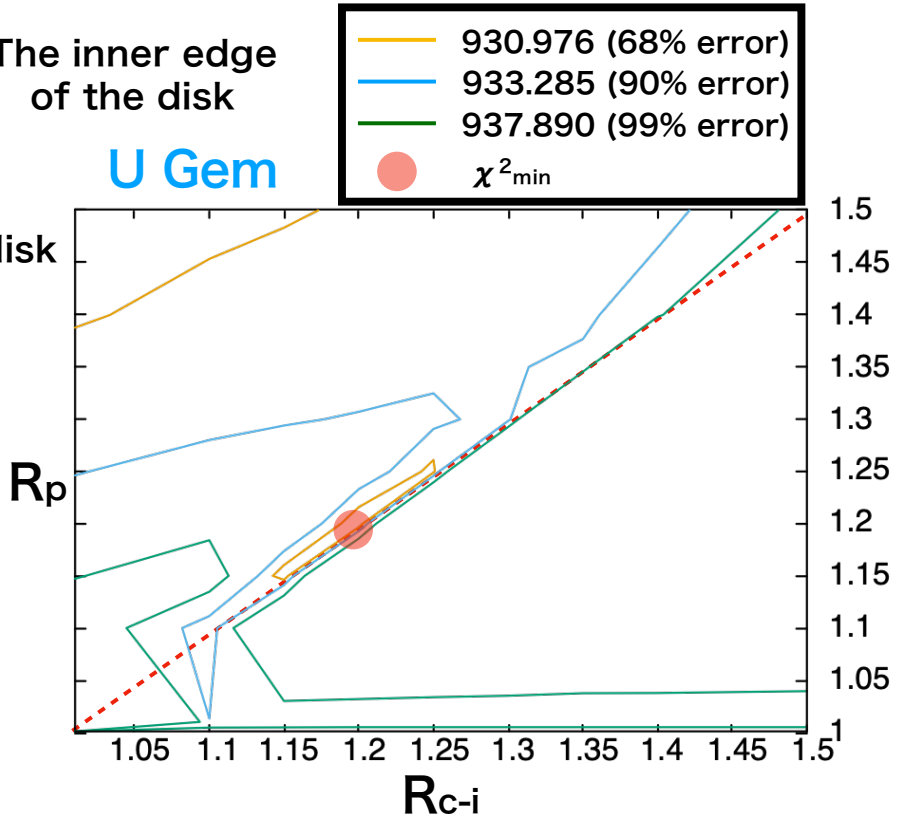




Ishida et al.(2009)

# Analyses

$R_{ci}$ : Distance from the center of WD to inner edge of disk
$R_p$ : Distance from the center of WD to plasma
$D_v$ : Distance from the disk plane to plasma



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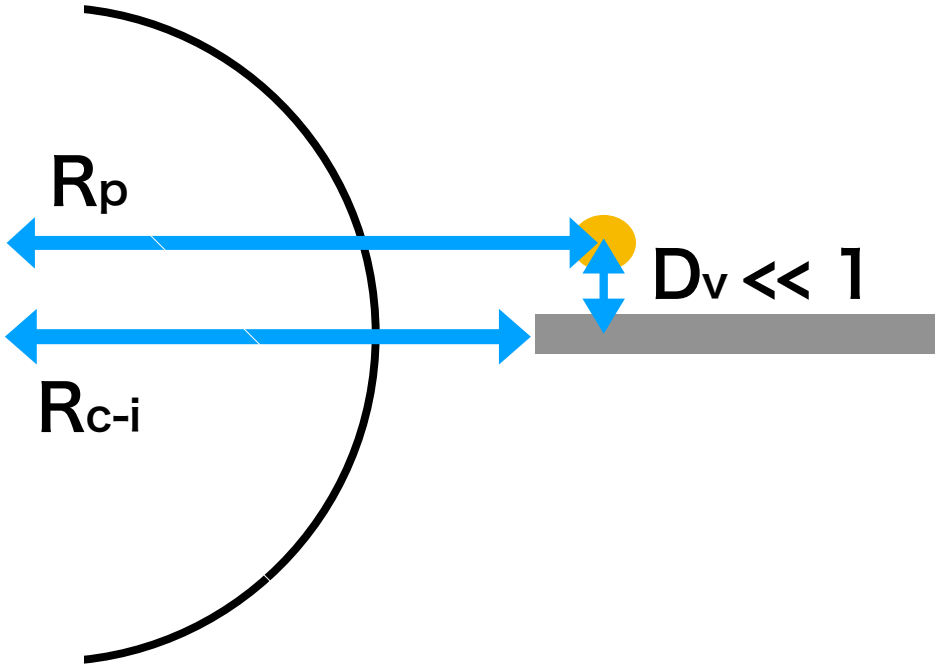


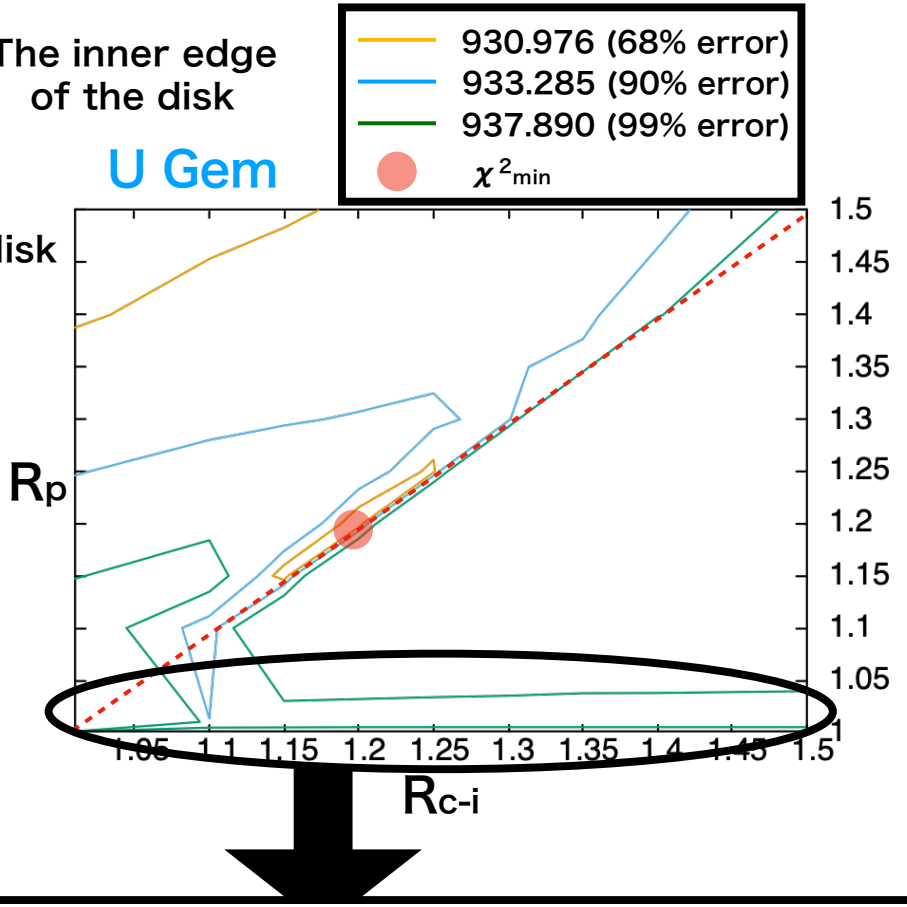


**$R_p$ < $R_{c-i}$**
(The configuration where the plasma is located close to the WD surface)

※$R_{c-i}$ is not constrained at all.

# Analyses

$R_{ci}$ : Distance from the center of WD to inner edge of disk
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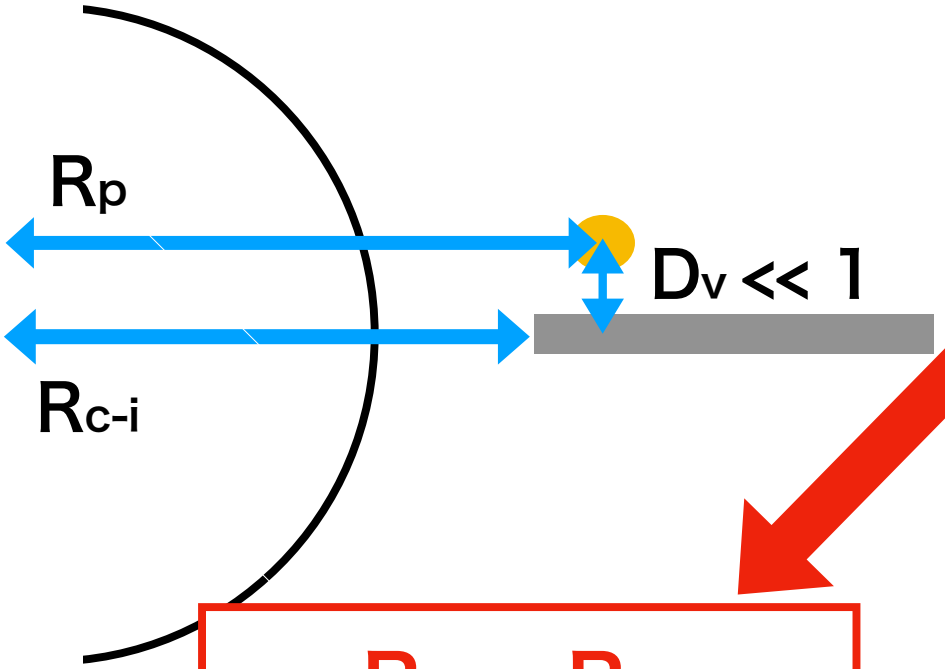
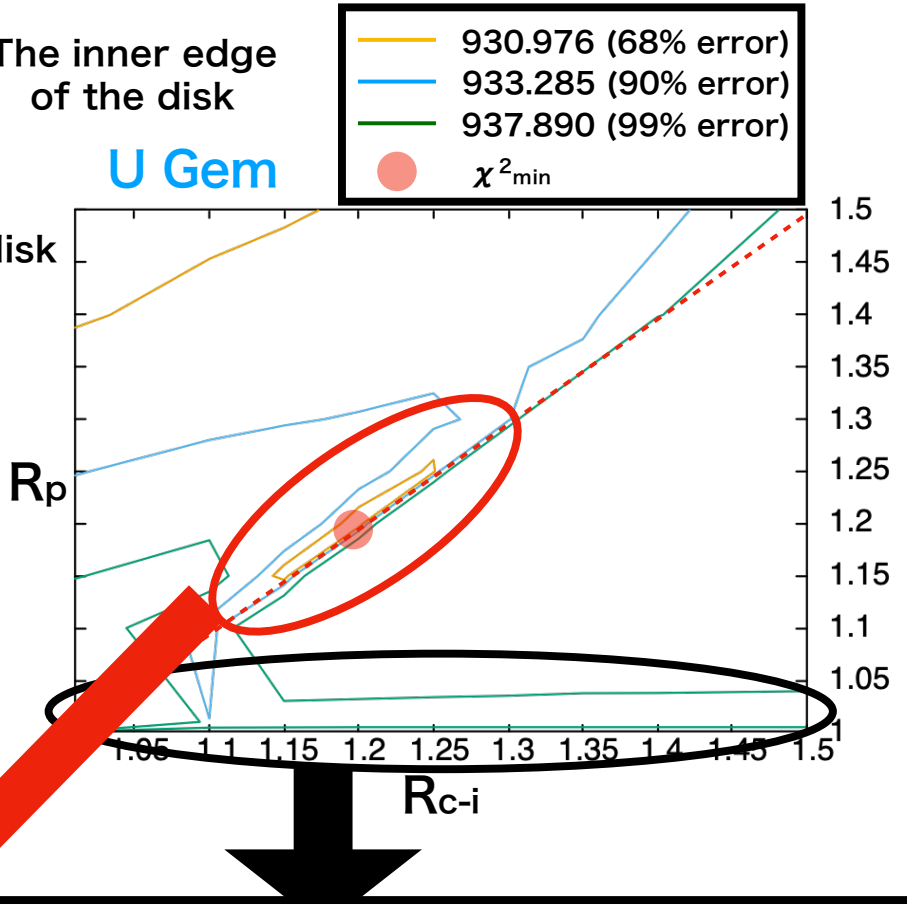
$D_v$ : Distance from the disk plane to plasma




**$R_p = R_{c\text{-}i}$**
(The configuration where the plasma is located just on the inner edge of the disk)

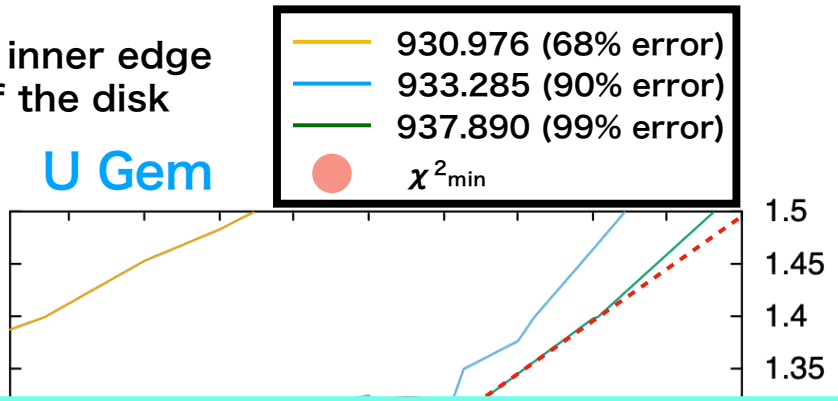



**$R_p < R_{c\text{-}i}$**
(The configuration where the plasma is located close to the WD surface)

※$R_{c\text{-}i}$ is not constrained at all.

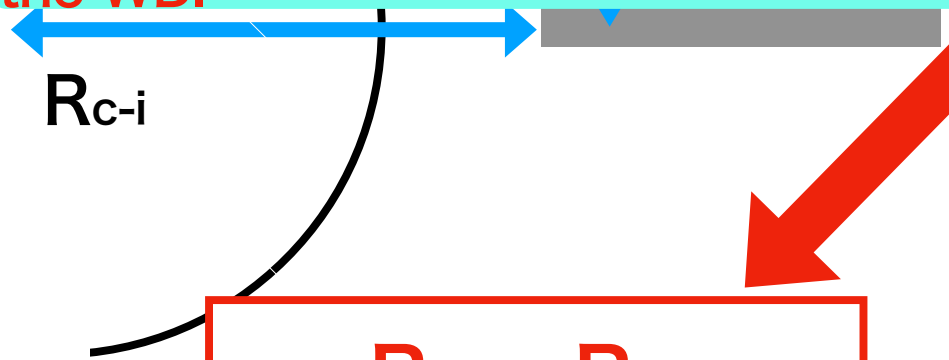
# Analyses

The inner edge of the disk




$R_{ci}$ : Distance from the center of WD to inner edge of disk
$R_p$ : Distance from the center of WD to plasma
$D_v$ : Distance from the disk plane to plasma

However, the scale height (the distance from the center of the WD to the plasma) determined by hydrostatic equilibrium using the maximum plasma temperature (~1.1 $R_{WD}$) is longer than the observed Rp(~1.01 $R_{WD}$). It is unlikely that the plasma is confined in the space such close to the WD.



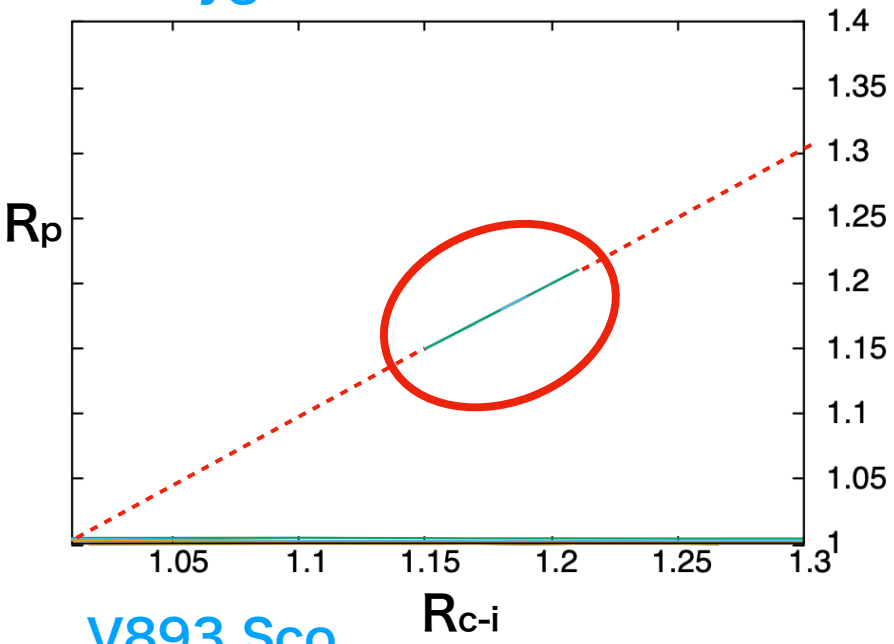

$R_p = R_{c\text{-}i}$
(The configuration where the plasma is located just on the inner edge of the disk)

$R_p < R_{c\text{-}i}$
(The configuration where the plasma is located close to the WD surface)

※$R_{c\text{-}i}$ is not constrained at all.

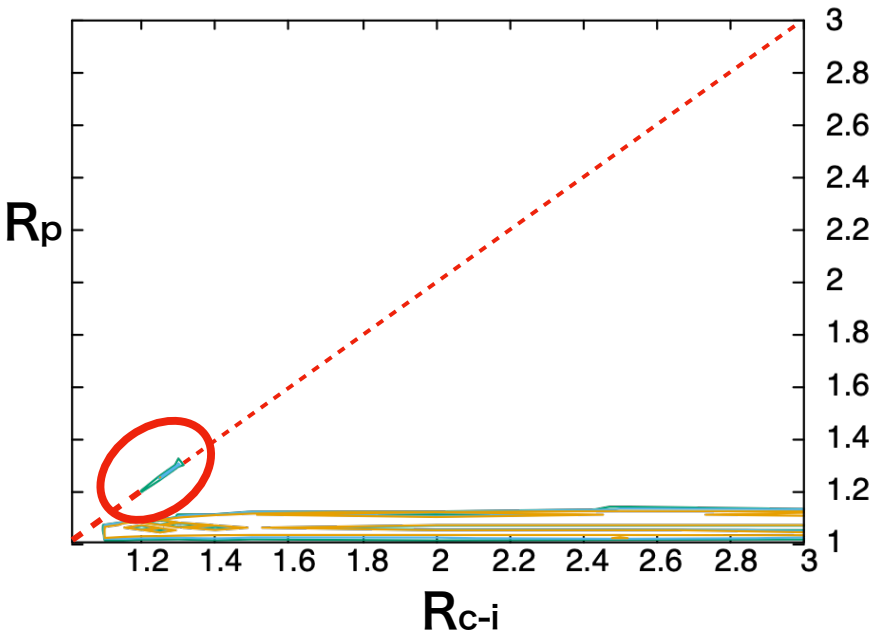
# Analyses

## SS Cyg

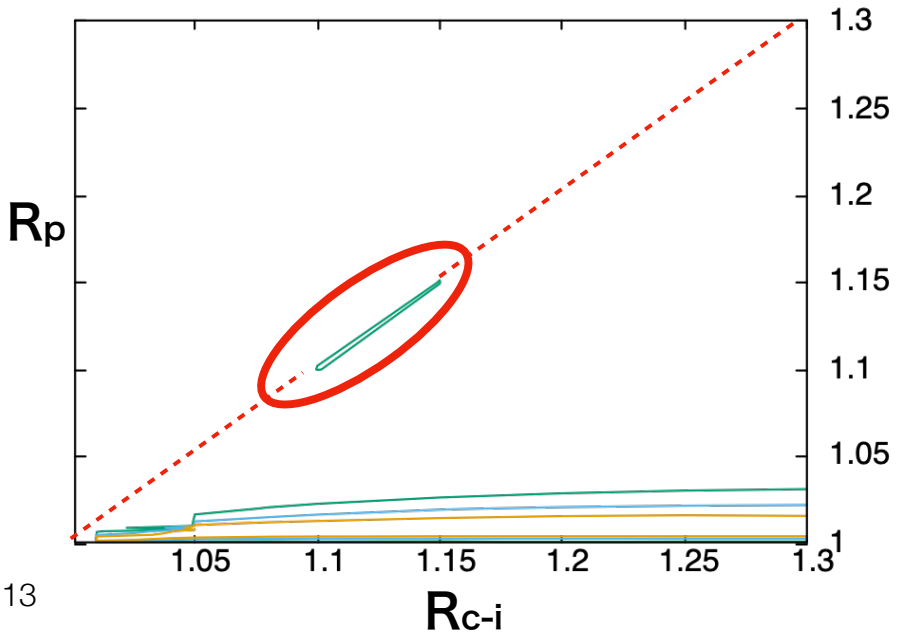



| | $R_p=R_{c-i}$ ($R_{WD}$) |
|---|---|
| U Gem | 1.10-1.40 |
| SS Cyg | 1.15-1.25 |
| V893 Sco | 1.20-1.35 |
| Z Cam | 1.08-1.25 |

## V893 Sco




## Z Cam



# Discussion

**Results of $R_p=R_{c\text{-}i}$**

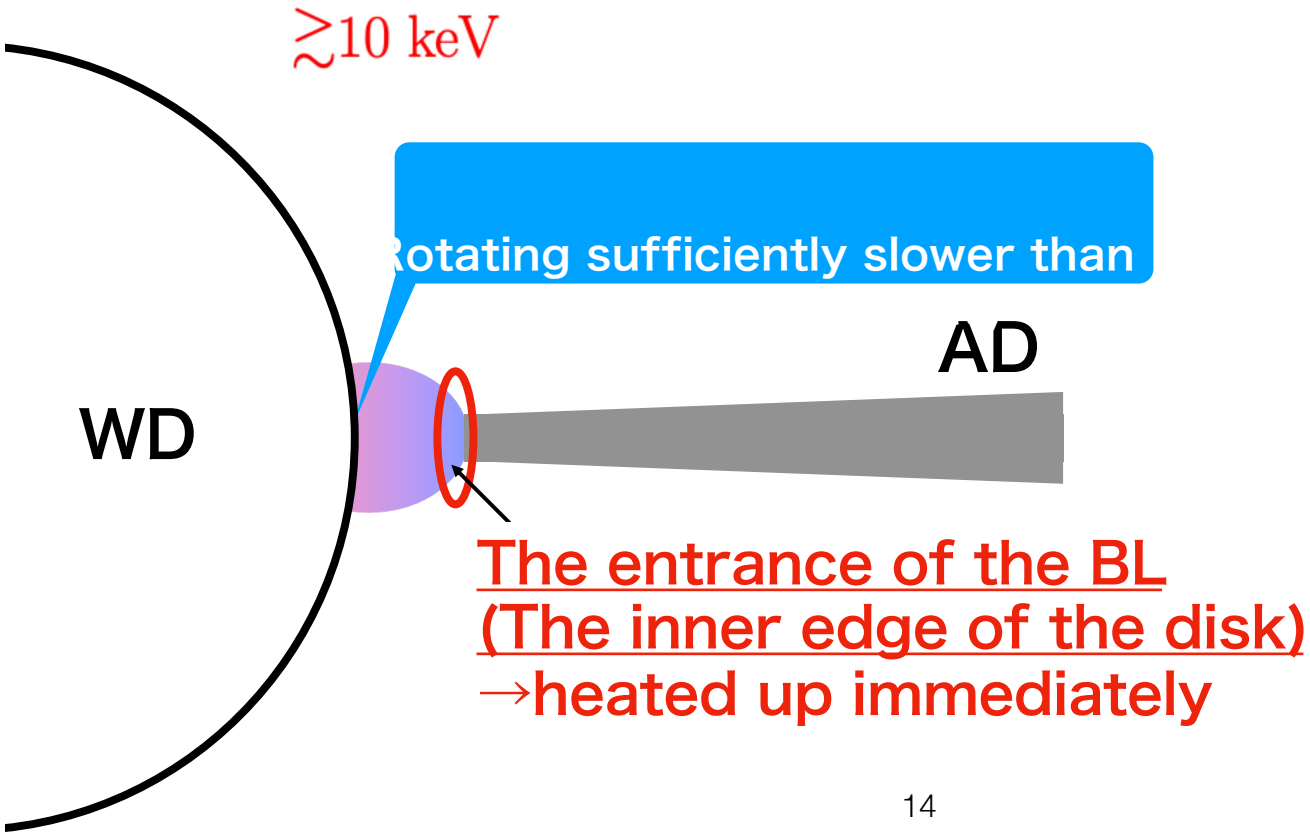
U Gem、SS Cyg、V893 Sco、Z Cam in quiescence

⬇

$R_p=R_{ci}$

The center of gravity of the plasma on the inner edge of the disk

→The plasma is heated up to a high enough temperature to ionize a K-shell electron of Fe immediately after the accreting matter enters the BL.



# Conclusions

—Purpose—
We carried out the spectral simulations of the BL plasma including X-rays reflected off the WD and the AD (Hayashi+18), and investigated the geometrical relation of the X-ray-emitting hot plasma with respect to the WD and the AD for the Suzaku data of four typical DNe .

Similar results common to four objects (U Gem, SS Cyg, V893 Sco, Z Cam)

・The configuration where the plasma is located just on the inner edge of the disk ($R_p=R_{ci}$)

The optically thick AD is truncated before reaching the WD surface and the optically thin hot plasma fills the BL within this radius and the plasma is heated up to a high enough temperature to ionize a K-shell electron of Fe immediately

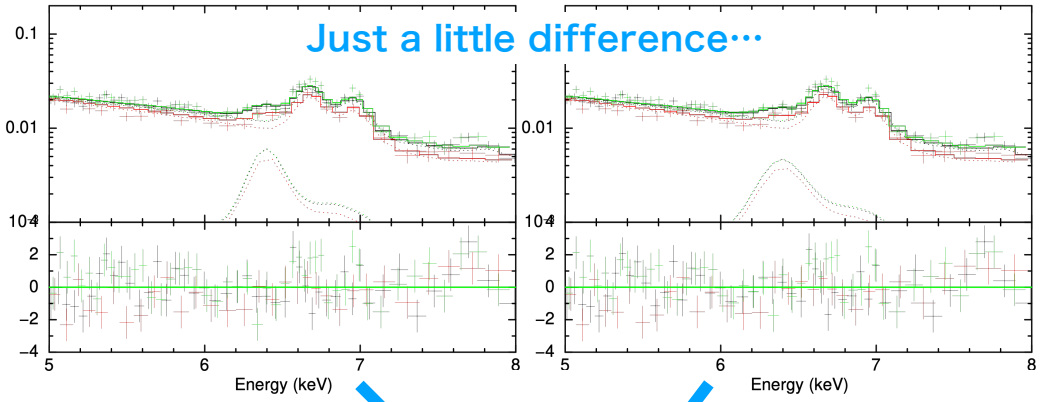
$\gtrsim 10$ keV

# Future prospect

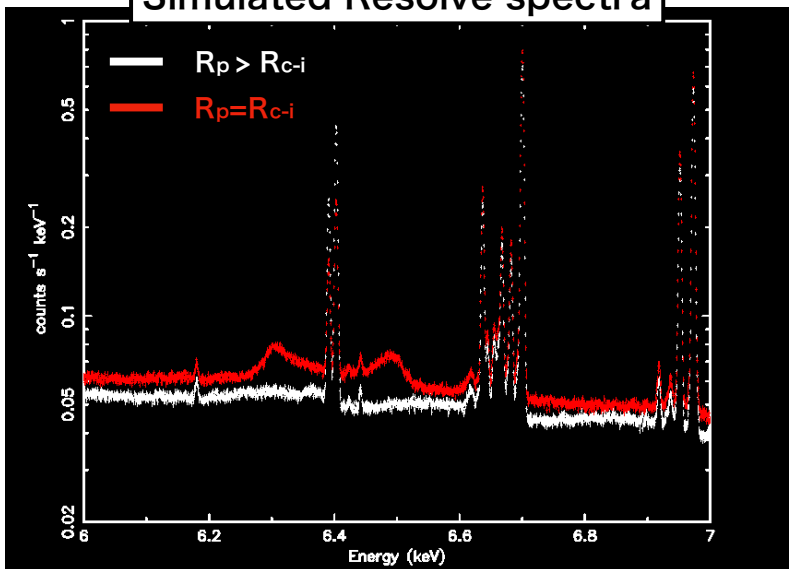
We cannot tell which of the two possible solutions of the plasma configuration because of the limited
energy resolutions of the CCD and the data statistics.

## Analysis results of Suzaku

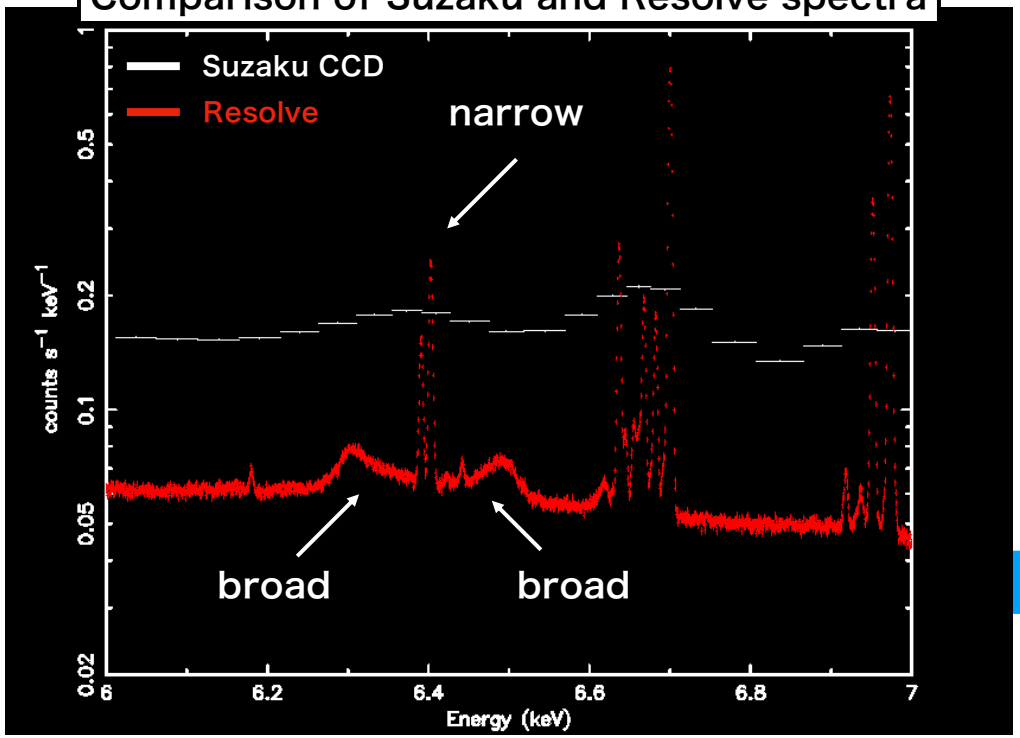
Ex) U Gem $R_p > R_{c\text{-}i}$ Ex) U Gem $R_p = R_{c\text{-}i}$




Simulated Resolve spectra




Comparison of Suzaku and Resolve spectra




narrow and broad components can be precisely resolved with Resolve (energy resolution ~5 eV)