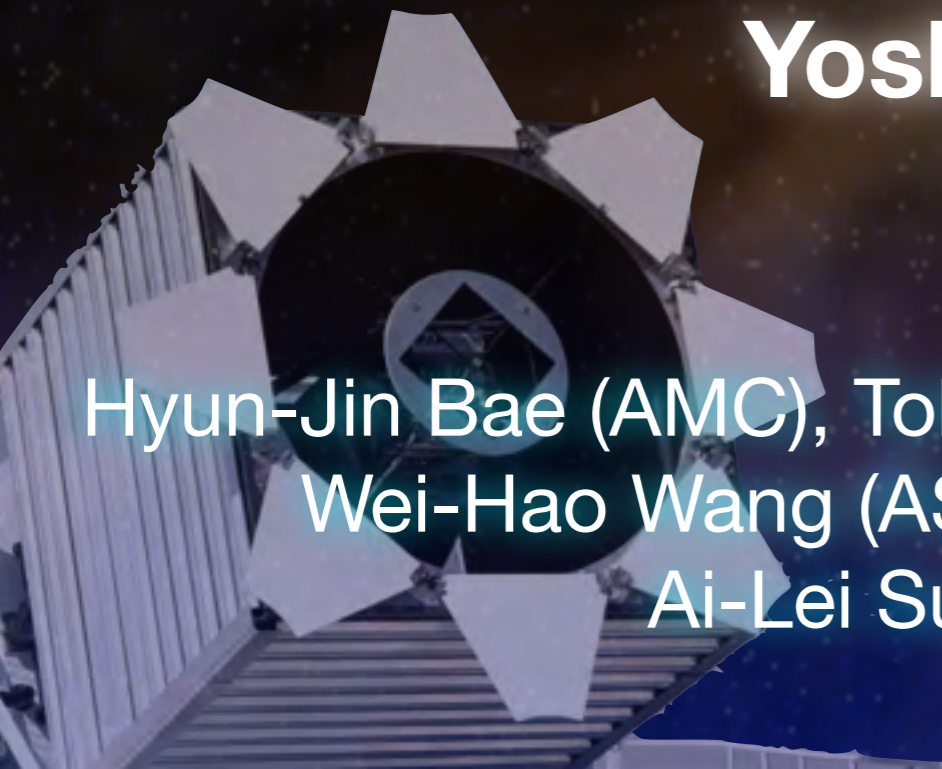


# Ionized Gas Outflows in Infrared-bright Dust-**O**bscured **G**alaxies at $0 < z < 1$

Toba et al. 2017c, ApJ, in press. (arXiv:1710.02525)

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(ASIAA)

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Wei-Hao Wang (ASIAA), Alexander Wagner (Tsukuba Univ.),  
Ai-Lei Sun (JHU), Yu-Yen Chang (ASIAA)



We discovered IR-bright DOGs with strong ionized gas outflow

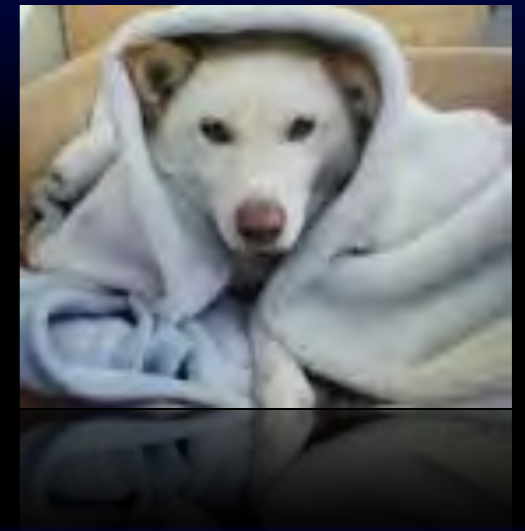
Dogs are obscured by blanket..

狗

σκυλί

hund

cane



anjing

# Introduction

chó

## What are Dust-Obscured Galaxies (DOGs)?

หมา  
dog

개  
chien

कूत्ता

Cão

犬  
собака

# Dust-Obscured Galaxies



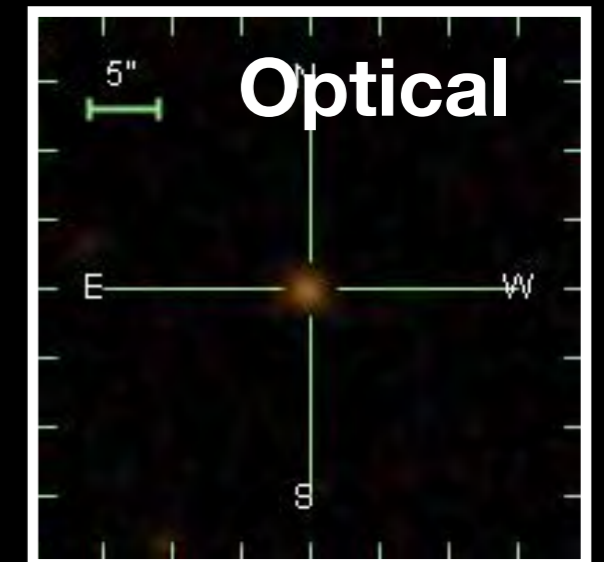
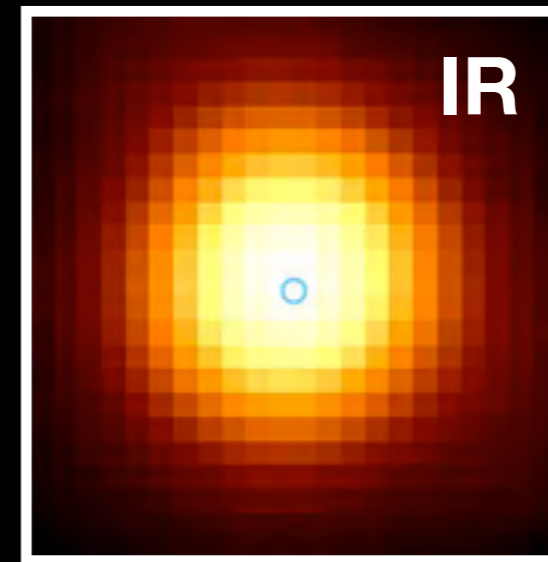
$$i - [22] > 7.0 \text{ (AB mag)}$$

Toba et al. 2015, PASJ, 67, 86

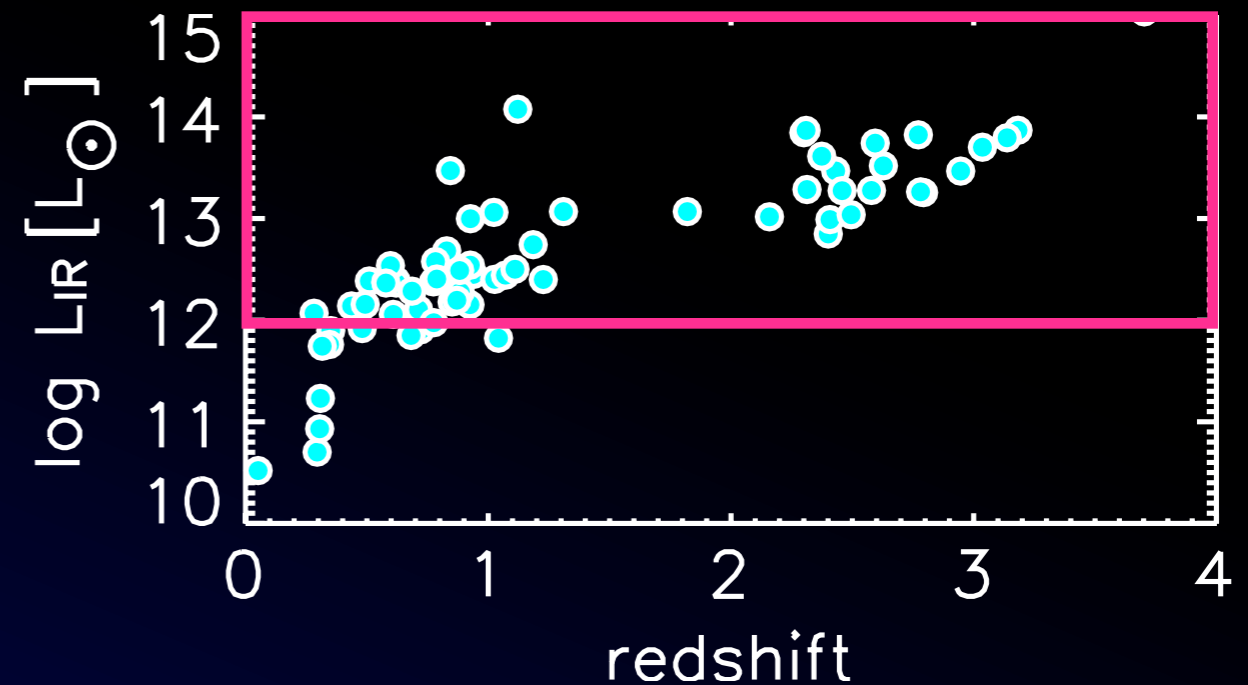
- An optically faint but infrared (IR) bright objects.

~ ULIRGs, HyLIRGs

- Most DOGs are ultra-luminous infrared galaxies (ULIRGs:  $L_{\text{IR}} \geq 10^{12} L_{\text{sun}}$ )
- Some DOGs are hyper-luminous infrared galaxies (HyLIRGs:  $L_{\text{IR}} \geq 10^{13} L_{\text{sun}}$ )



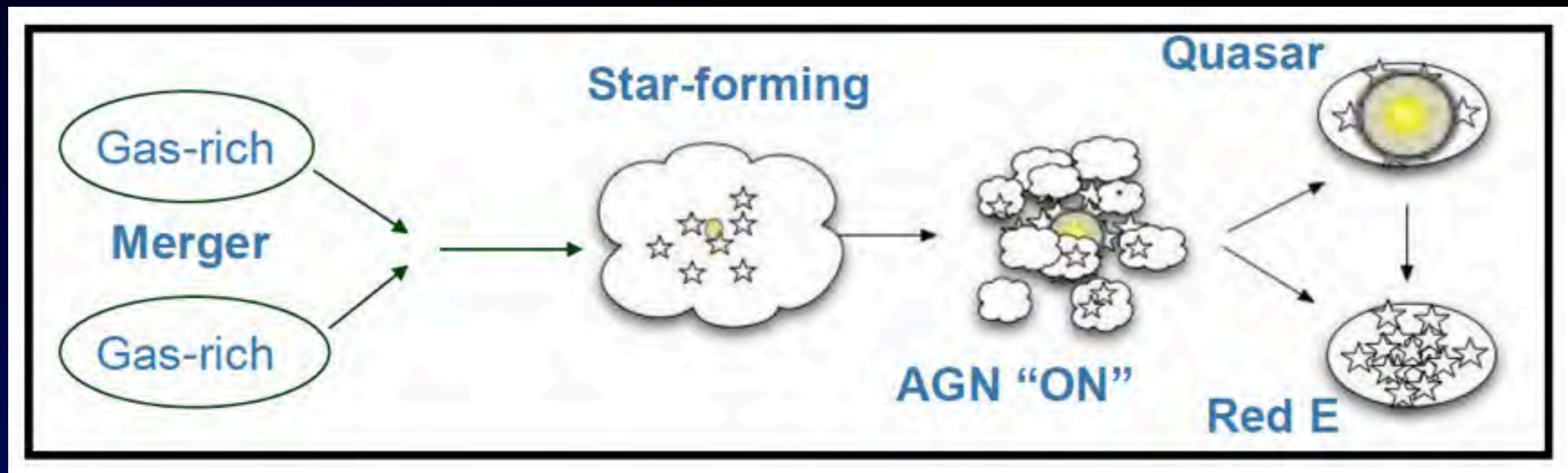
$$F(\text{IR}) > 1000 \times F(\text{optical})$$



Toba & Nagao 2016, ApJ, 820, 46

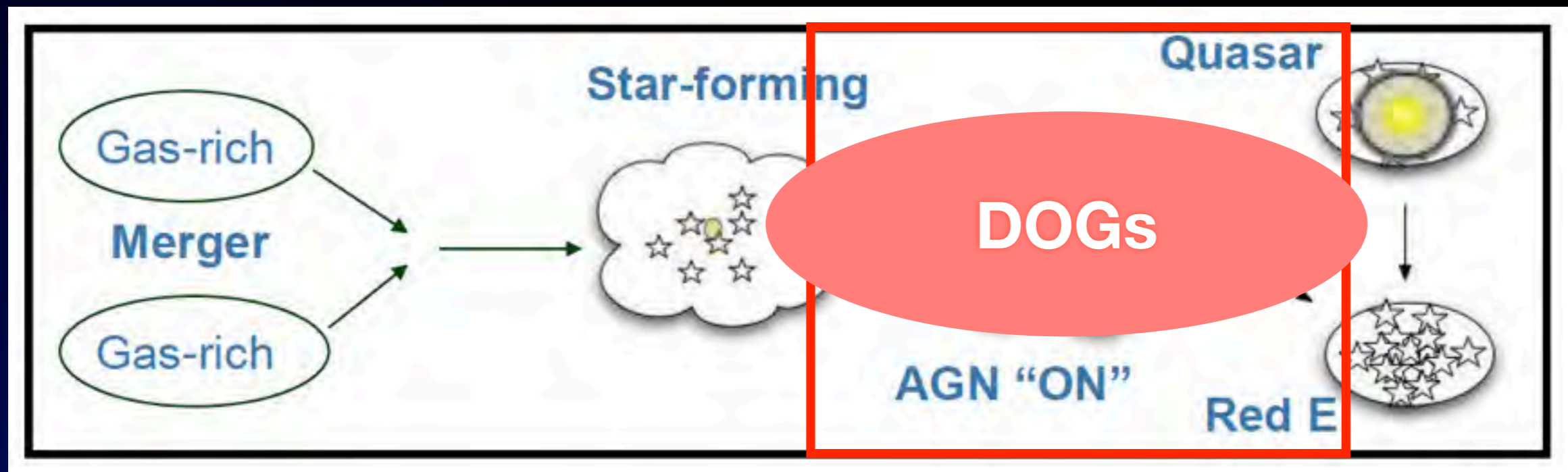
# The importance of IR-bright DOGs

- In the context of major merger scenario, particularly **IR-bright** DOGs ( $F_{\text{MIR}} > 1 \text{ mJy}$ ) may correspond to a maximum phase of AGN activity behind a large amount of dust.
- Some IR-bright DOGs are expected to be a “blowout” phase during the co-evolution.



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# The importance of IR-bright DOGs

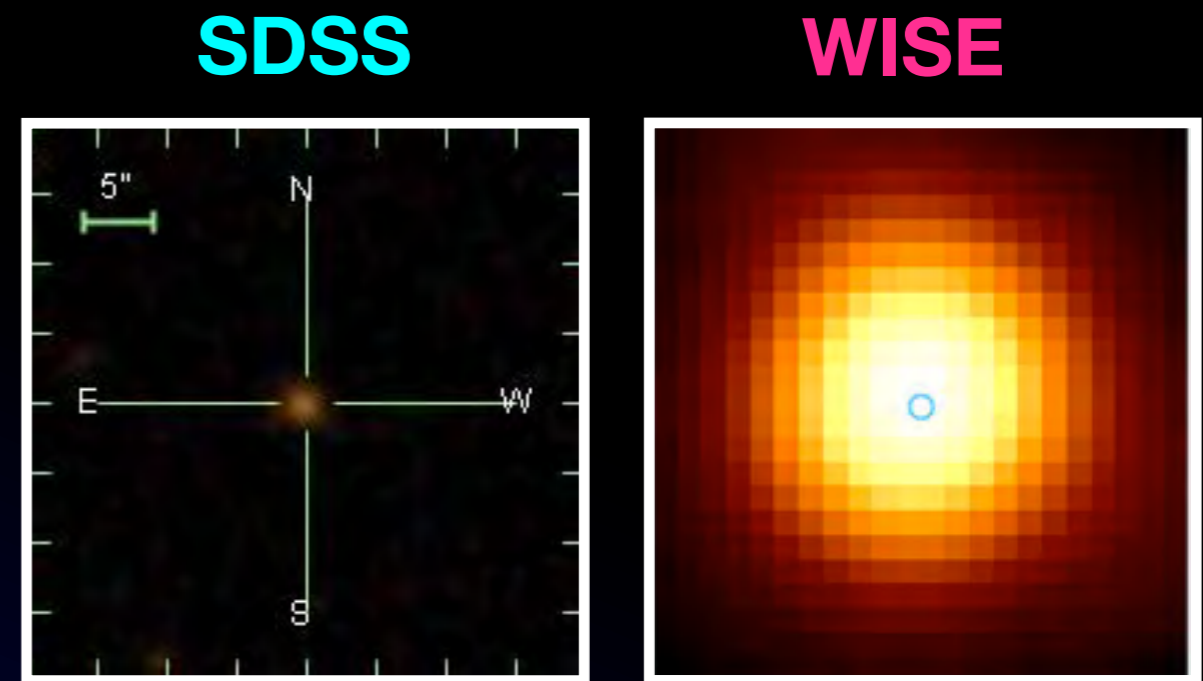
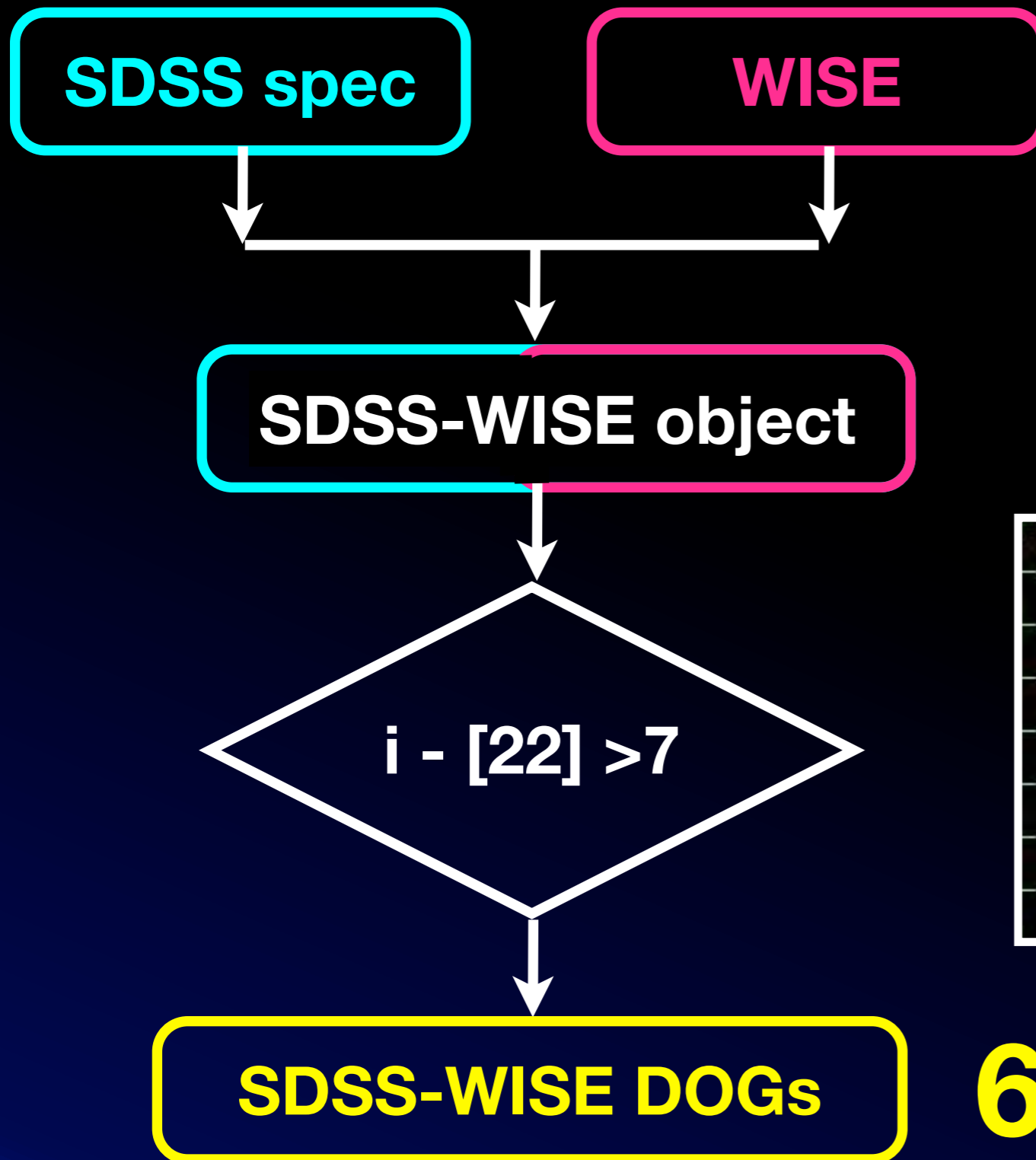
IR-bright DOGs are key population to understanding the co-evolution.

They are a good laboratory to investigate the AGN feedback phenomenon.



# IR-bright DOGs survey with SDSS and WISE

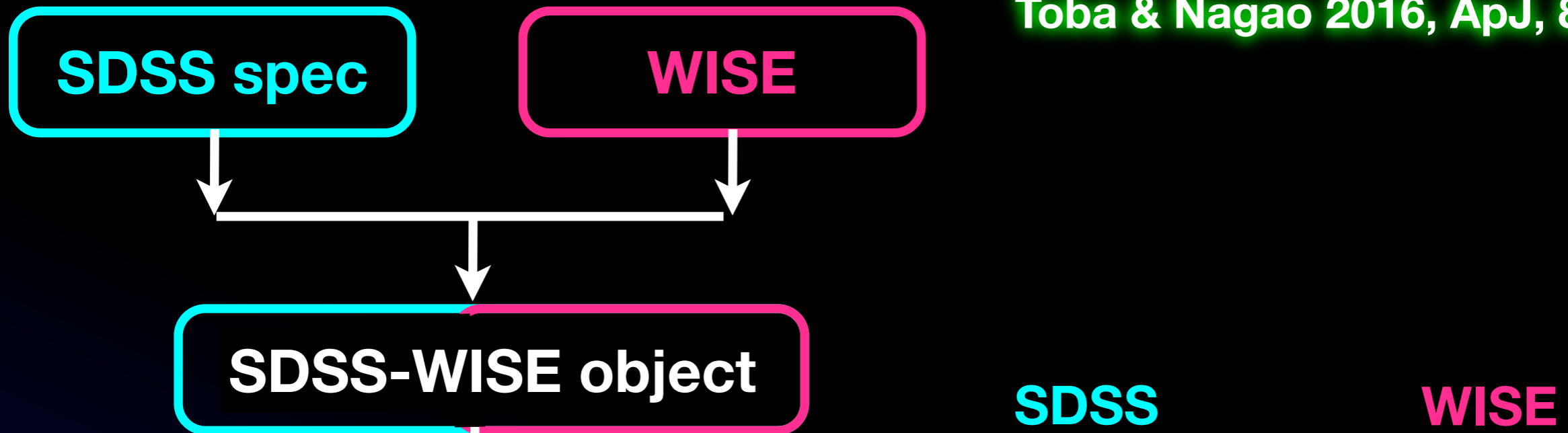
Toba & Nagao 2016, ApJ, 820, 46



**67**

# IR-bright DOGs survey with SDSS and WISE

Toba & Nagao 2016, ApJ, 820, 46

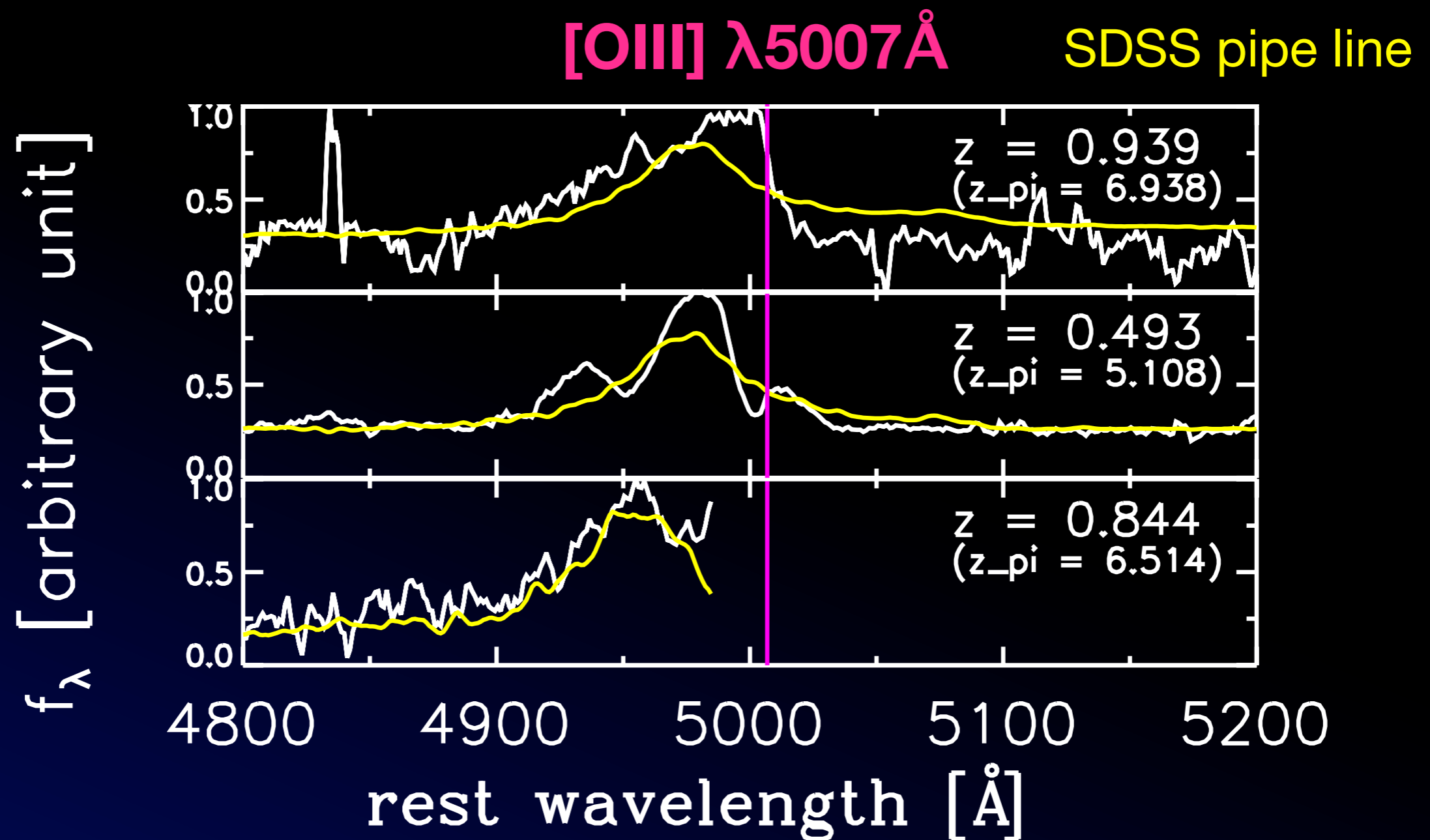


We focus on 32 IR-bright DOGs ( $0 < z < 1$ ) with [OIII] $\lambda$ 5007 line

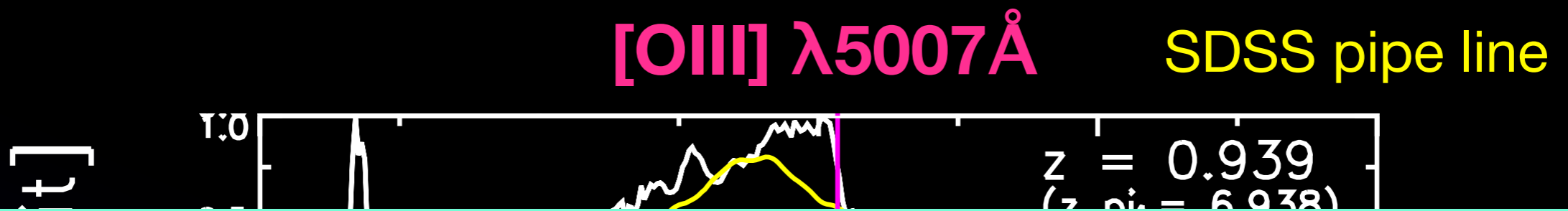




# Broad & blue-shifted [OIII] $\lambda$ 5007Å



**Some objects have broad and blueshifted [OIII] line that is mis-identified as Ly $\alpha$  based on the SDSS pipeline**



**Purpose of this work**

**To investigate the properties of outflowing gas based on a detailed spectral analysis**



*We discovered IR-bright DOGs with strong ionized gas outflow*



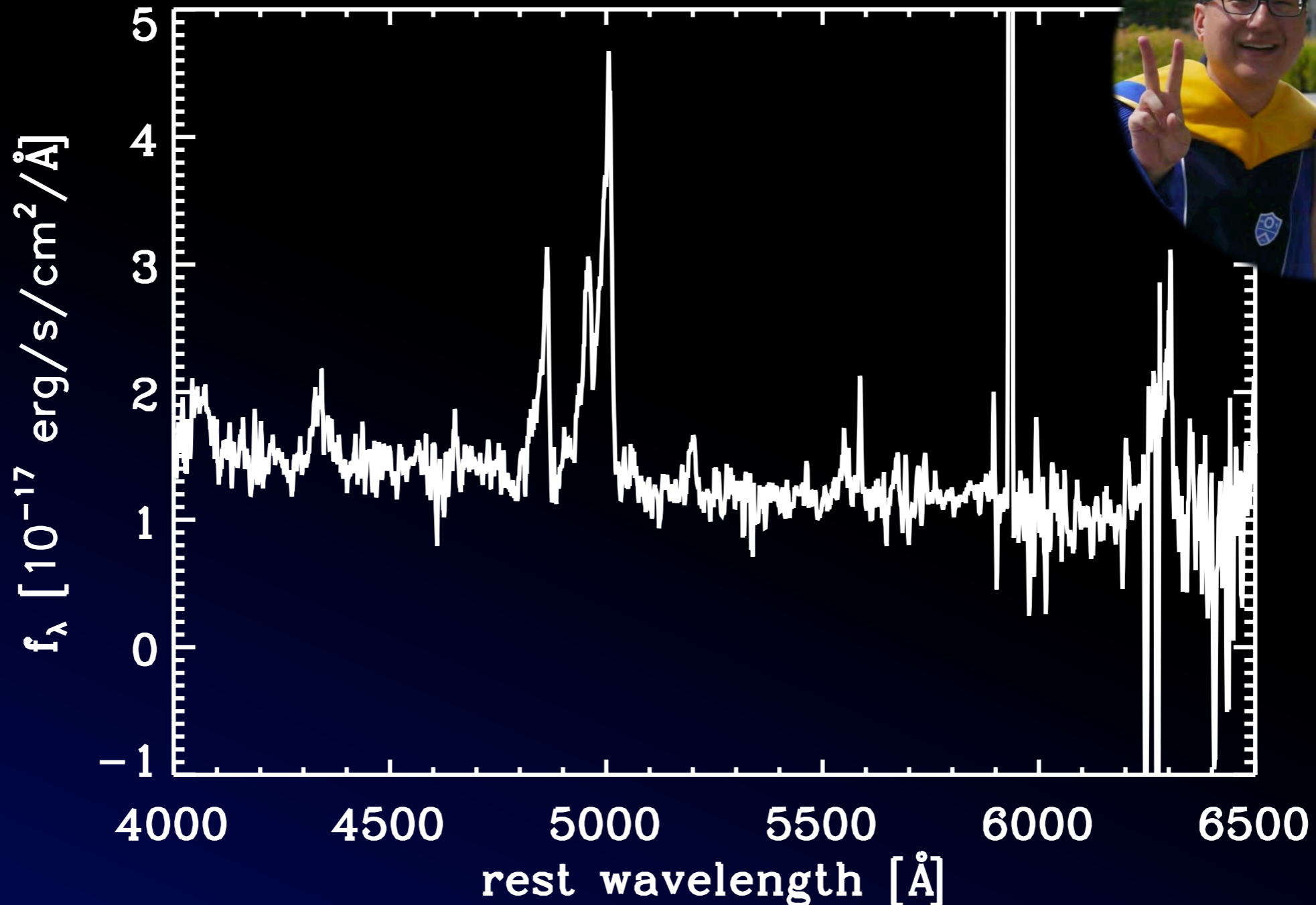
outflowing DOG!?

## Data and Analysis

How do we evaluate a peculiar profile of [OIII] line?

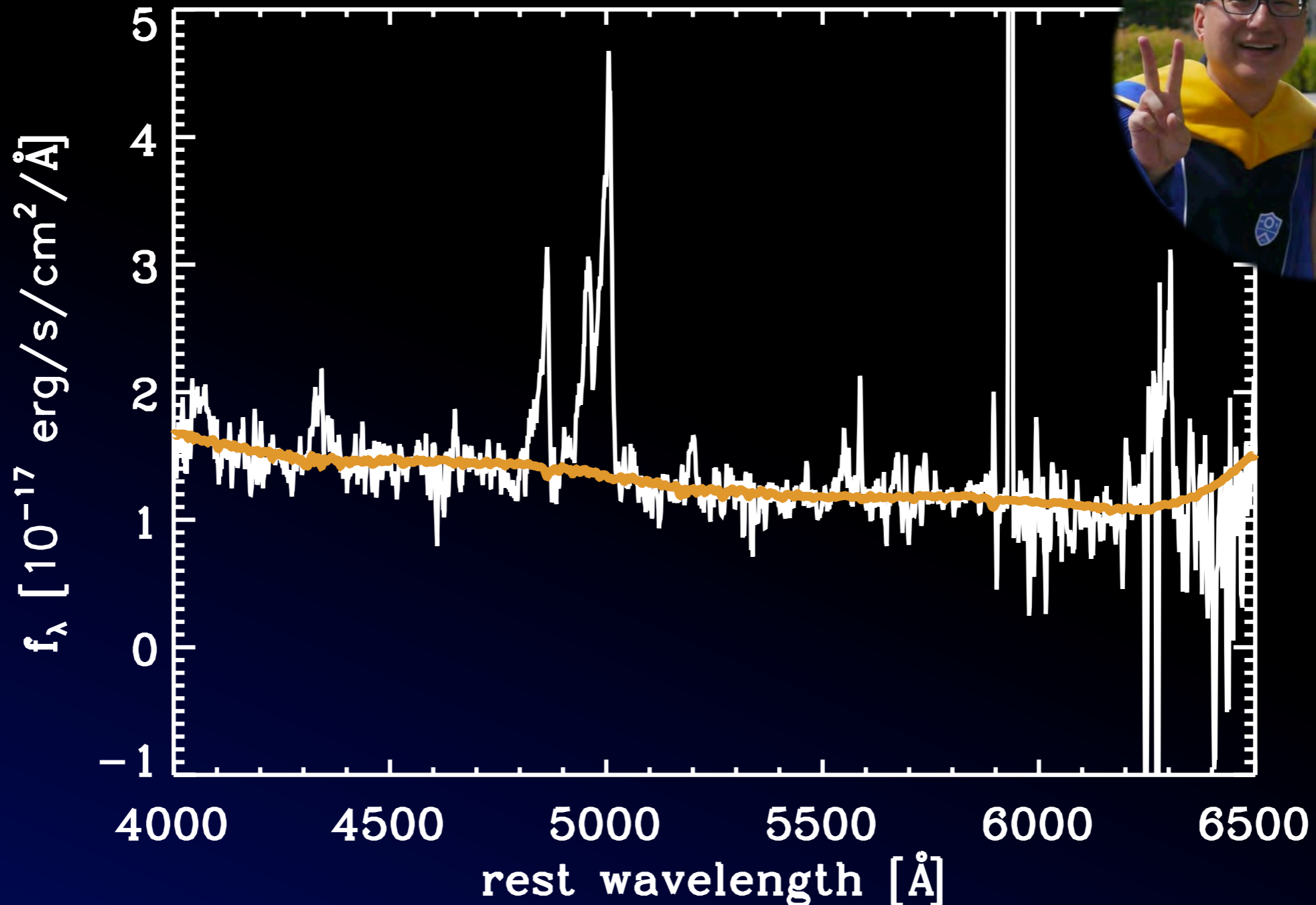
# Spectral analysis

collaborated with  
Dr. Hyun-Jin Bae



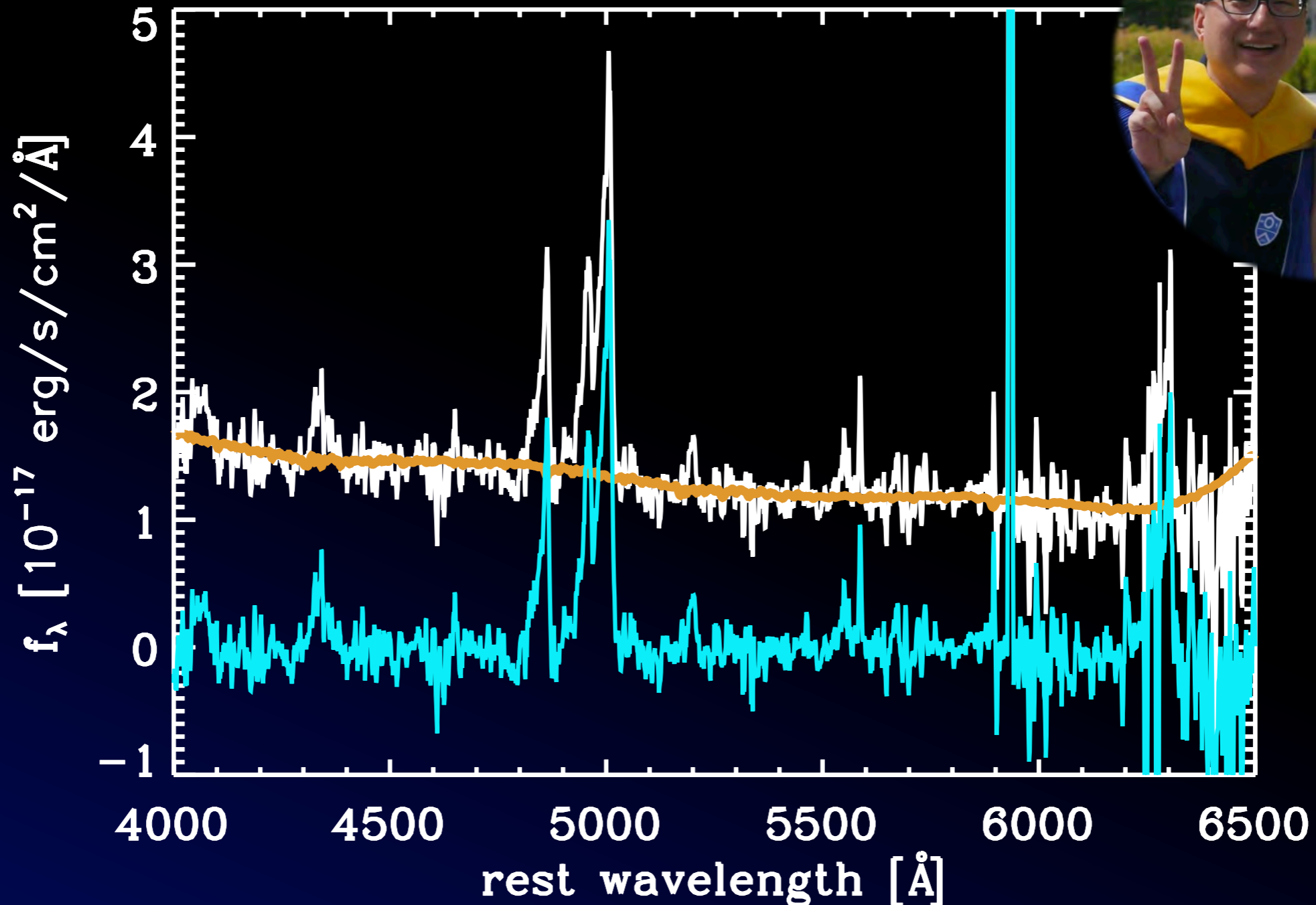
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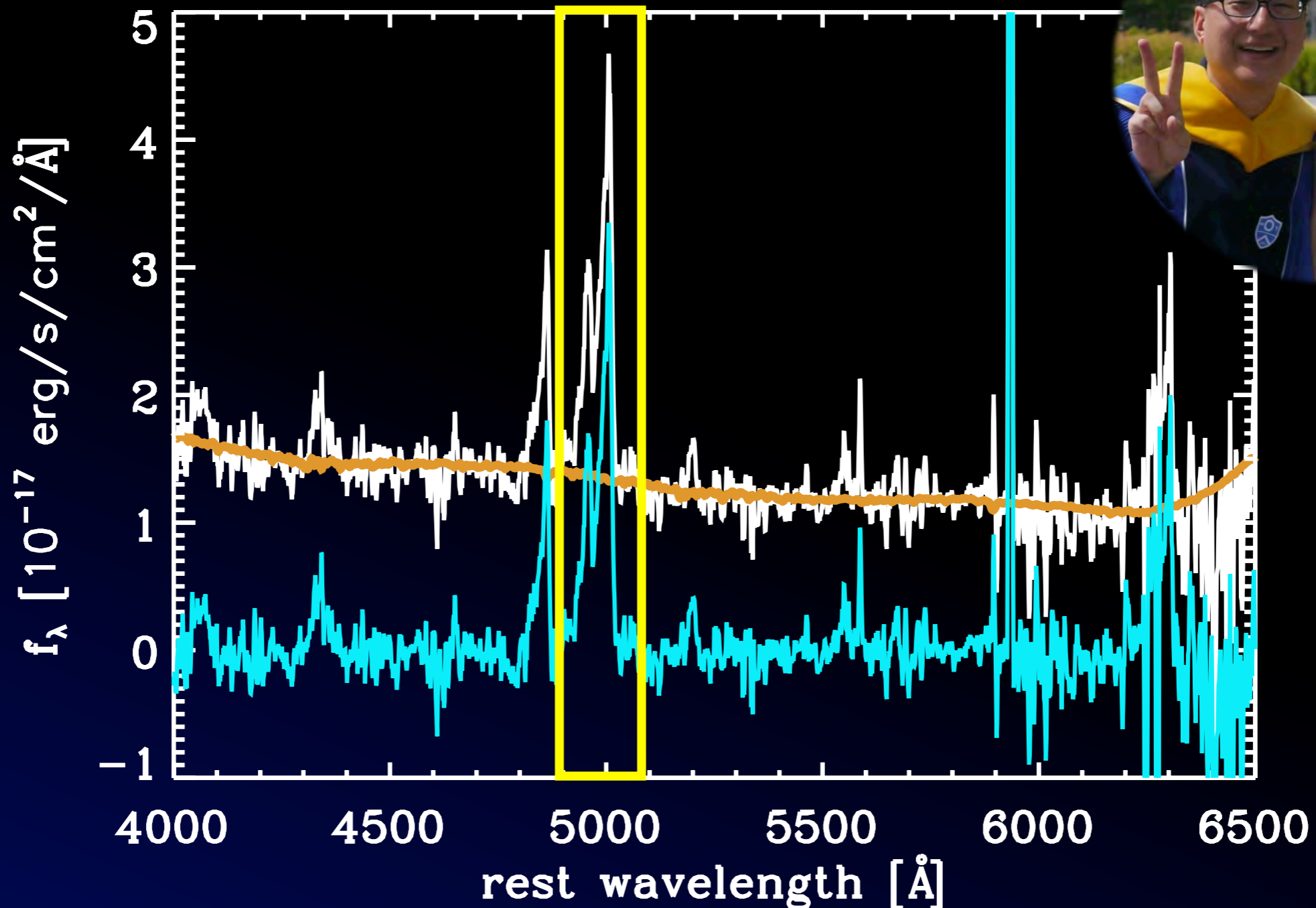
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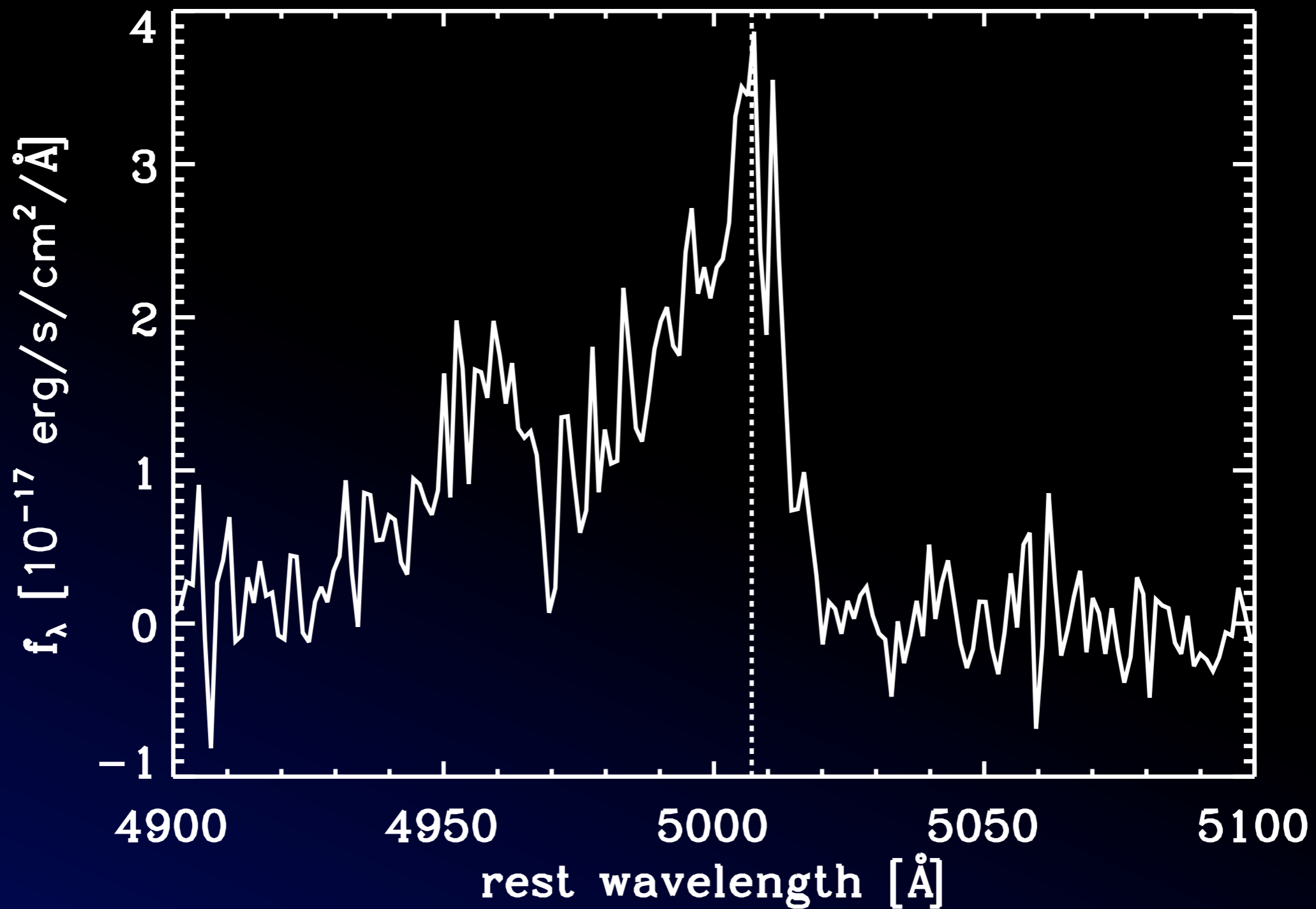


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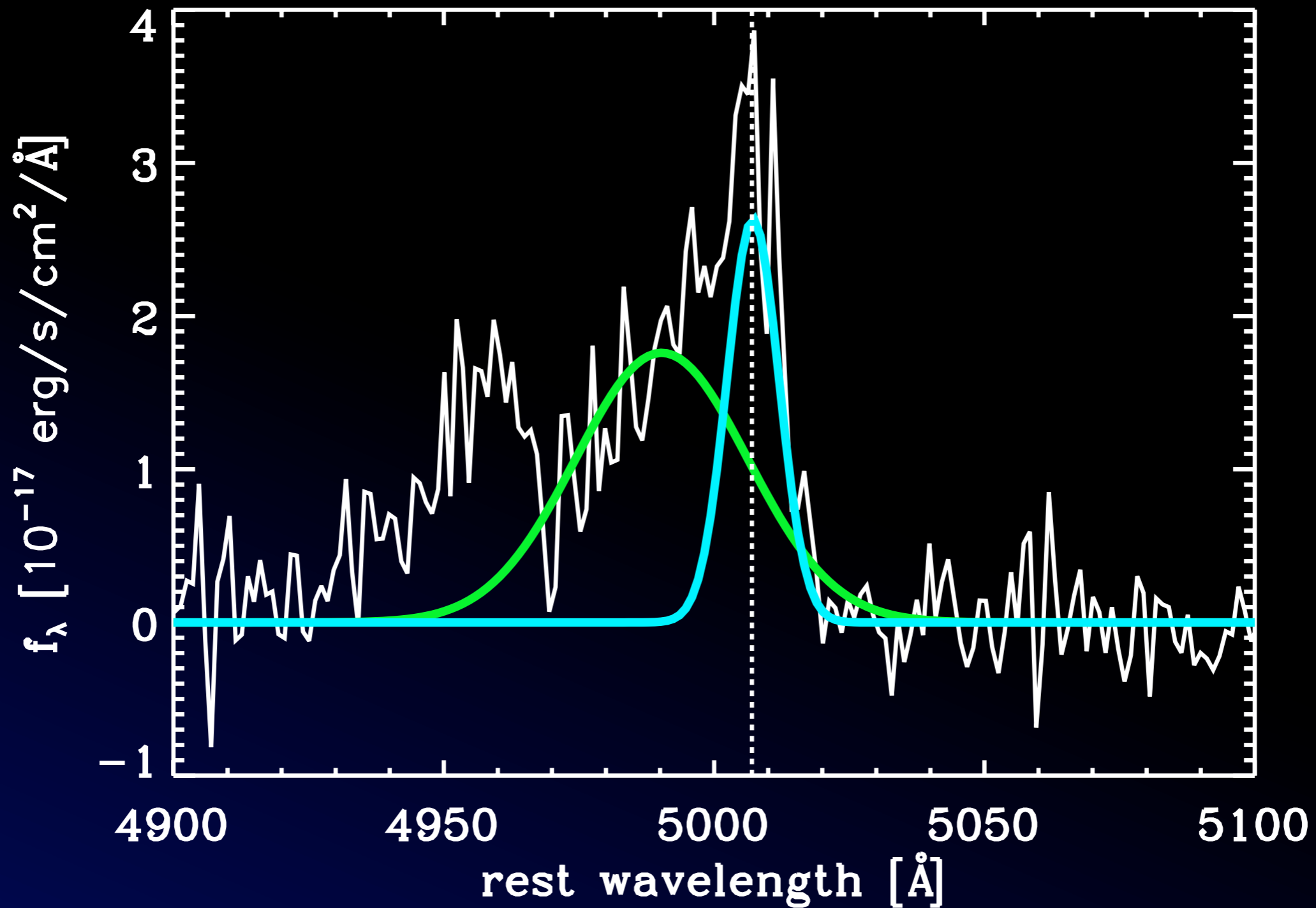


# Spectral analysis

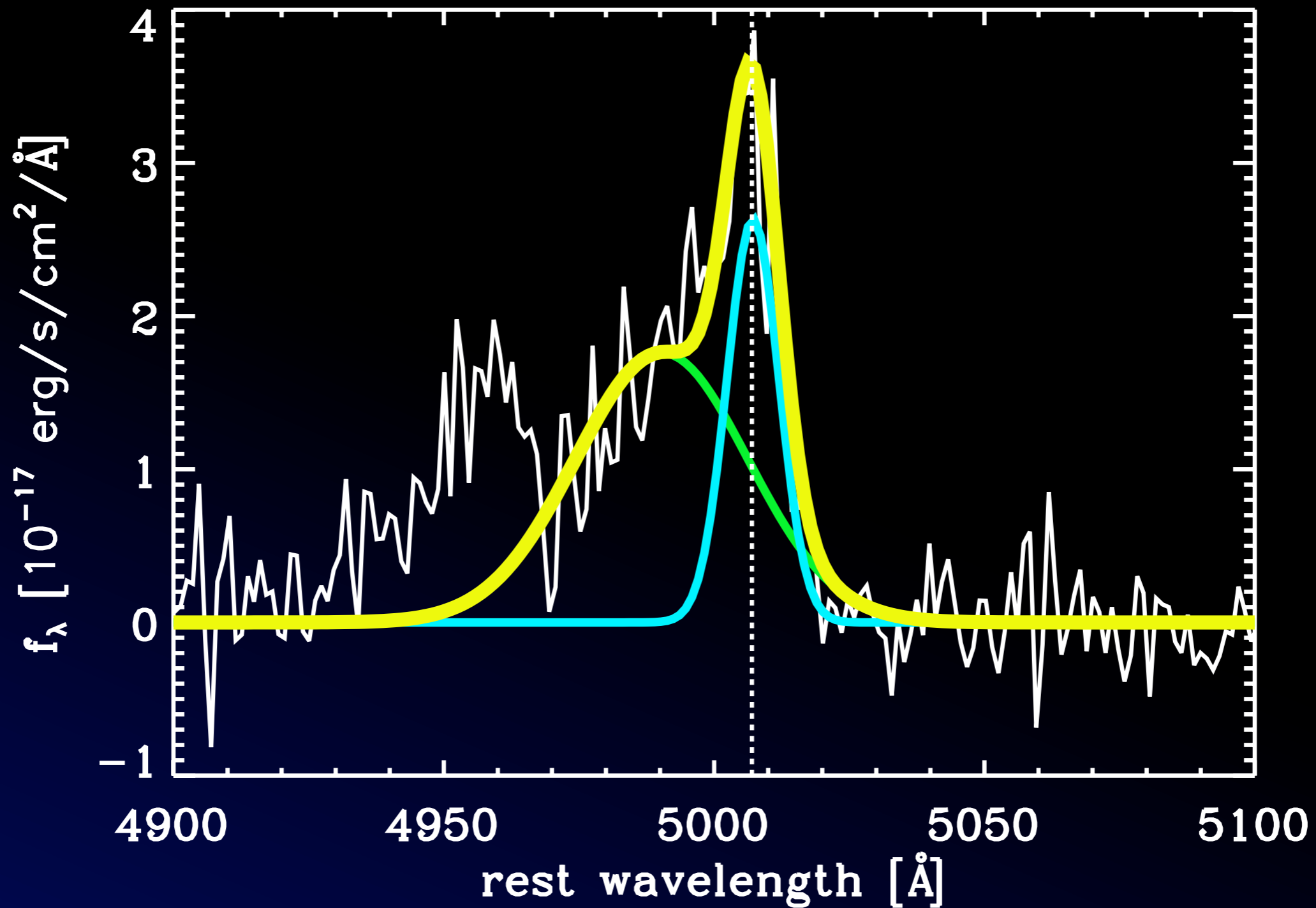




# Spectral analysis



# Spectral analysis



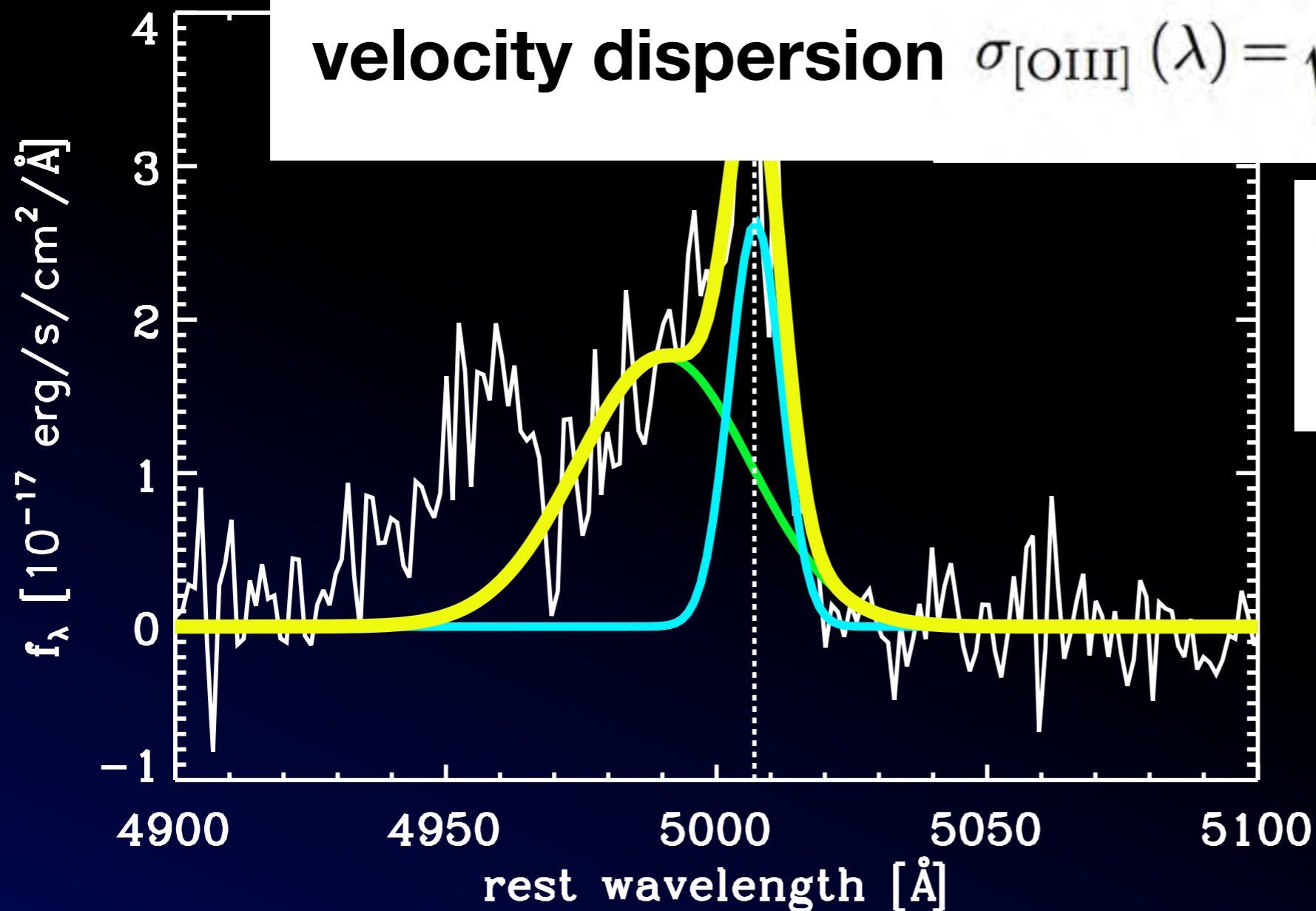
# Spectral analysis

**velocity offset**

$$v_{[\text{OIII}]}(\lambda) = \frac{(\lambda_0 - \lambda_{\text{rest}})c}{\lambda_{\text{rest}}} - v_{\text{sys}}(\lambda)$$

**velocity dispersion**

$$\sigma_{[\text{OIII}]}(\lambda) = \sqrt{\frac{\int \lambda^2 f(\lambda) d\lambda}{\int f(\lambda) d\lambda} - \lambda_0^2}$$



$$\lambda_0 = \frac{\int \lambda f(\lambda) d\lambda}{\int f(\lambda) d\lambda}$$

*We discovered IR-bright DOGs with strong ionized gas outflow*

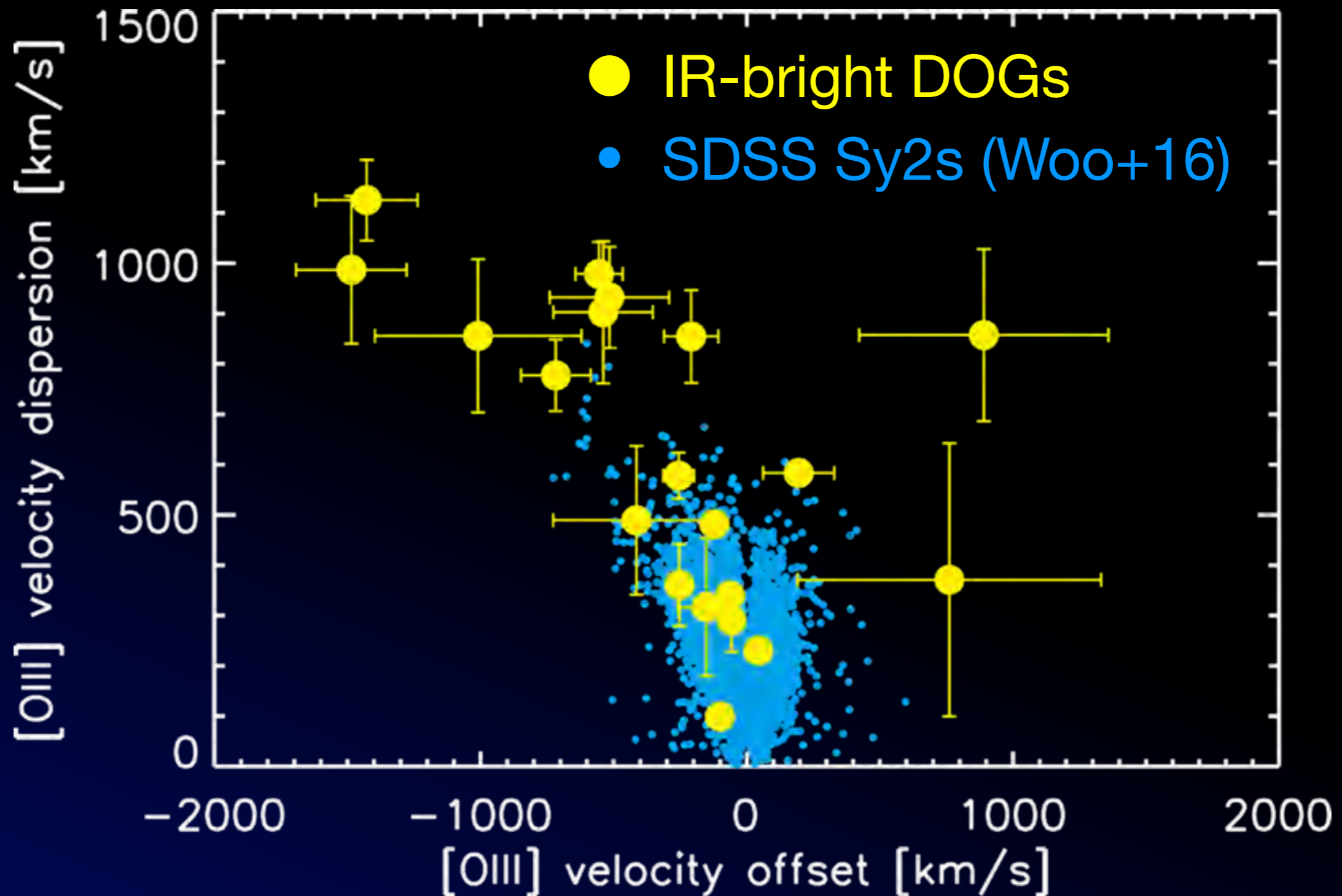


# Results and Discussions

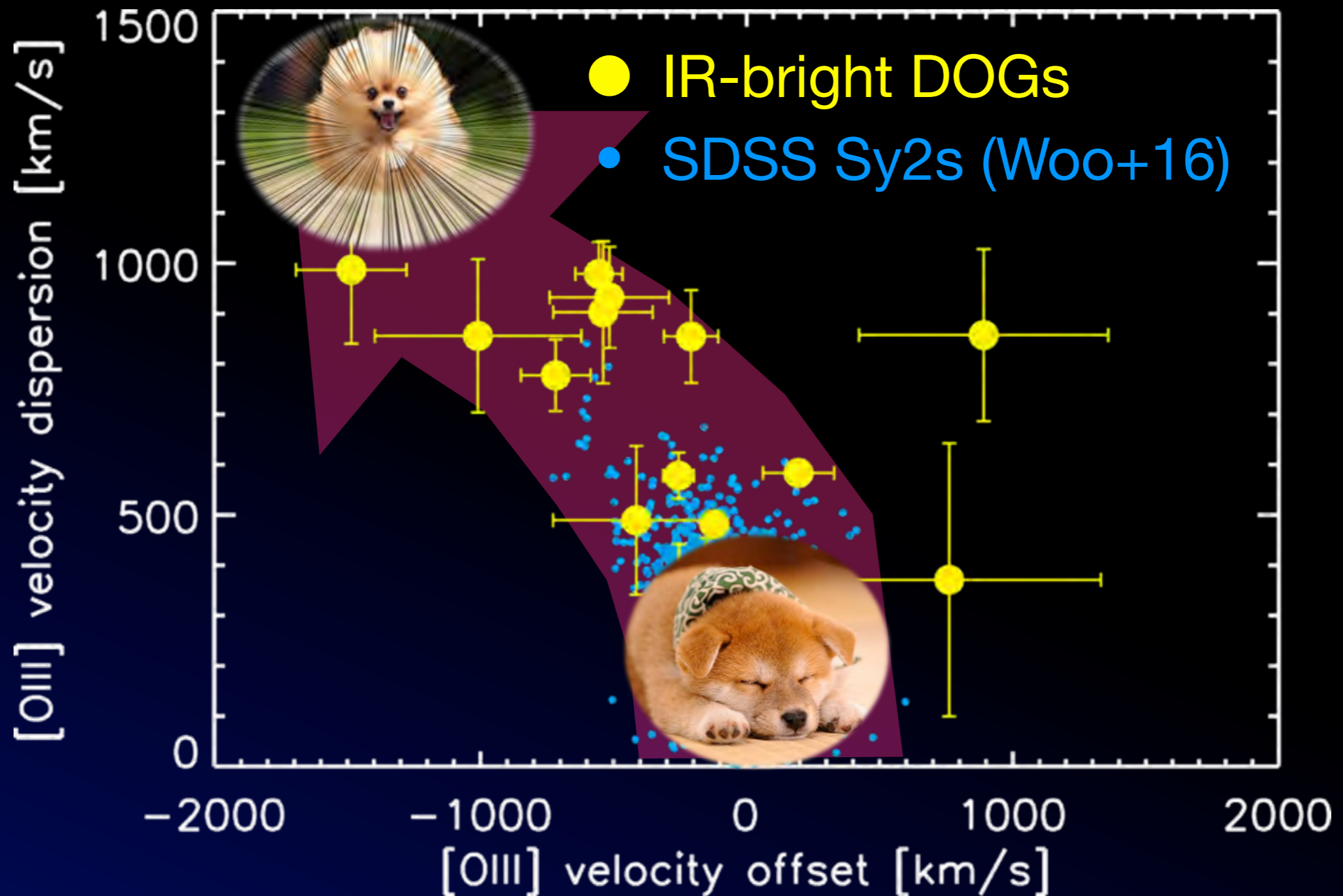
**Comparison of outflow strength between IR-bright DOGs and Sy2s**

**What determines the outflow strength?**

**How about other lines such as  $[OII]\lambda 3727$ ?**

**V**elocity offset — **V**elocity **D**ispersion diagram

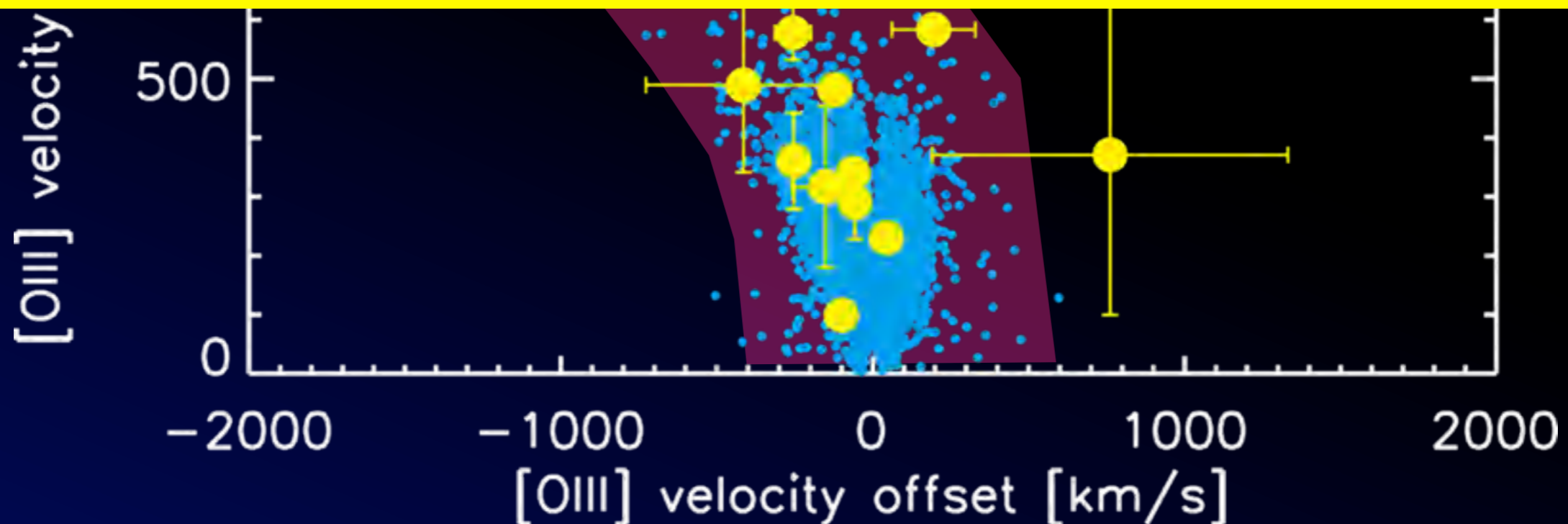
# Velocity offset — Velocity Dispersion diagram

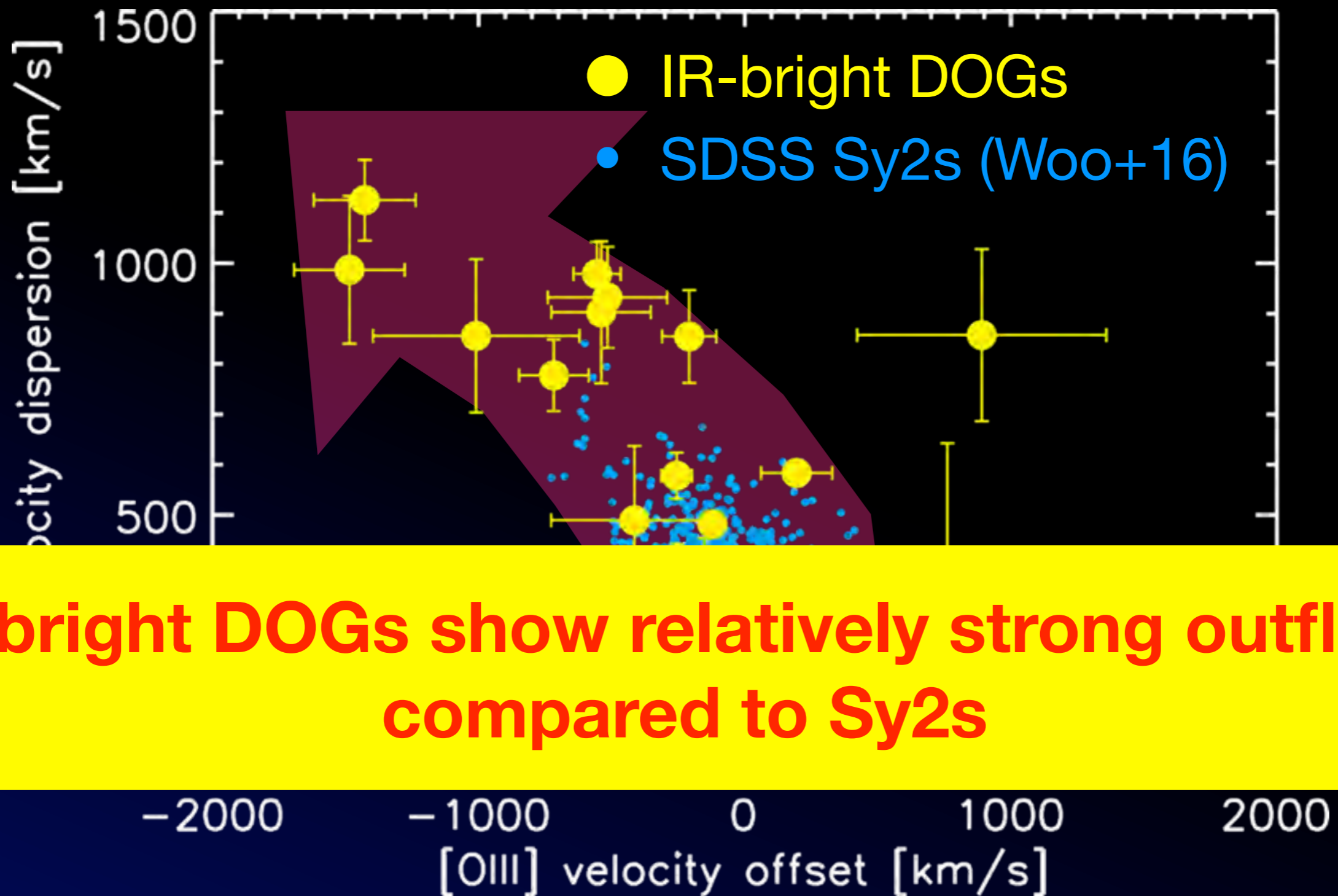


# Velocity offset — Velocity Dispersion diagram



**~75% IR-bright DOGs have  $\sigma[\text{OIII}] > 300$  km/s**



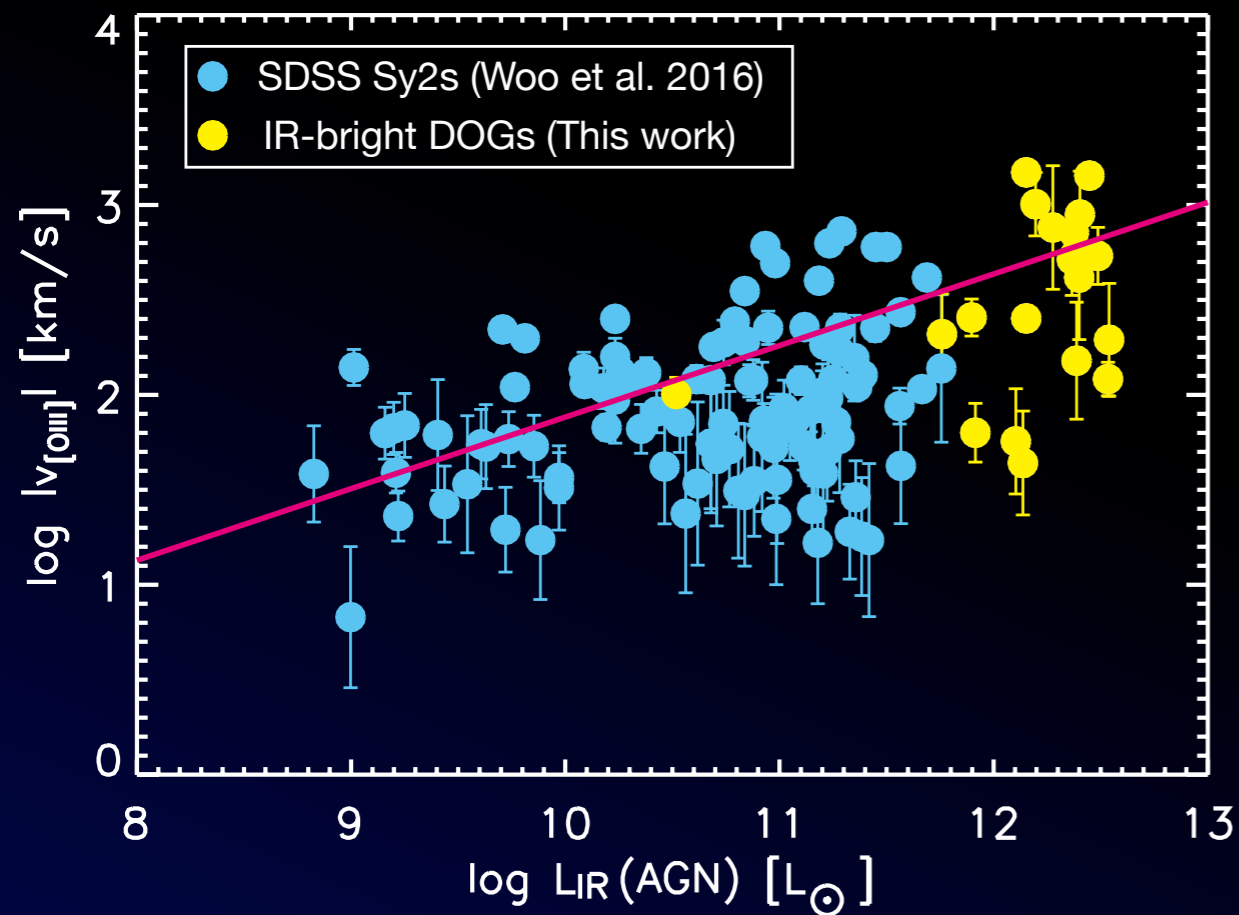
**V**elocity offset — **V**elocity **D**ispersion diagram

**IR-bright DOGs show relatively strong outflows compared to Sy2s**

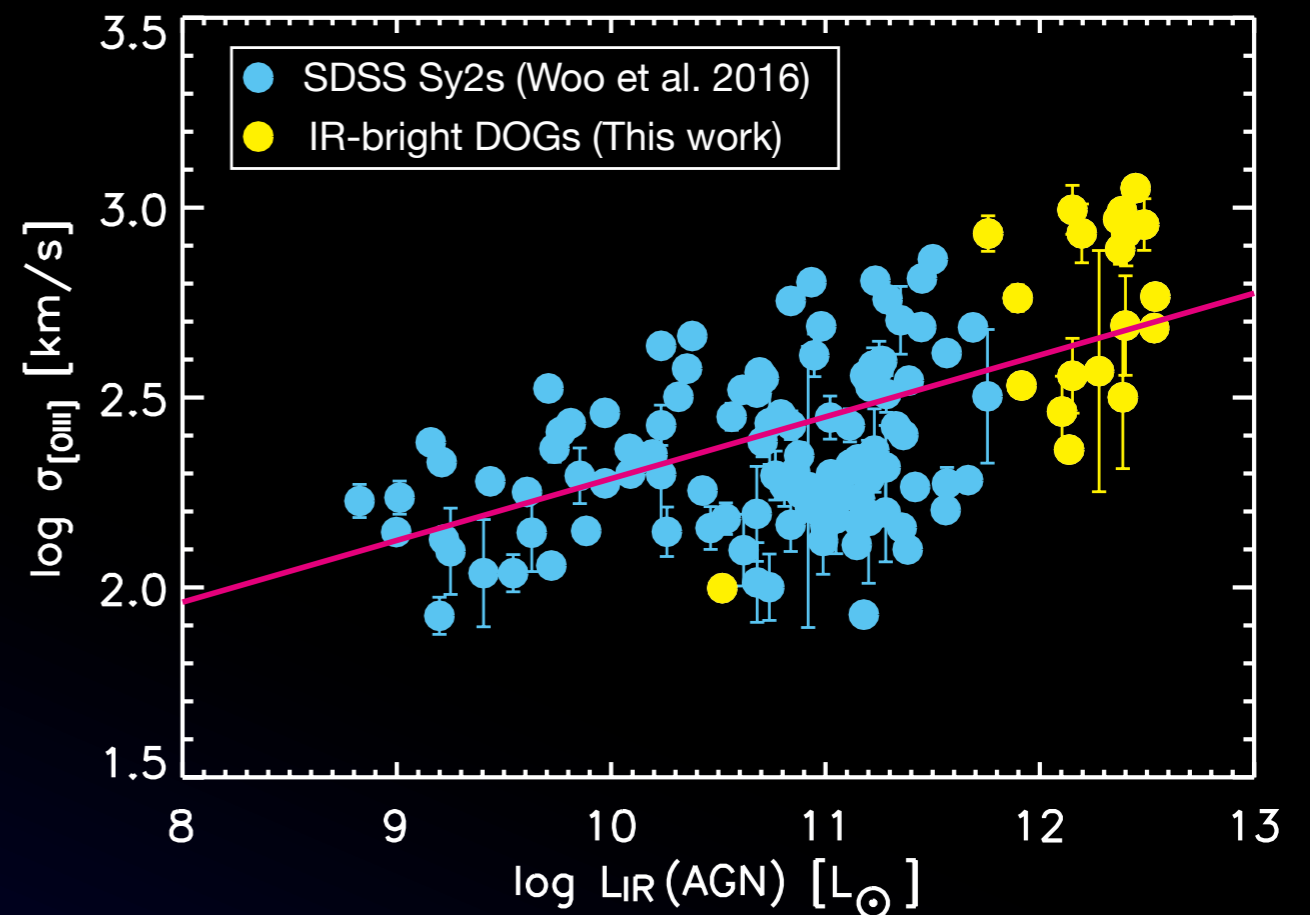


# LIR (AGN) vs. outflow strength

## $V_{[\text{OIII}]}$ vs. $L_{\text{IR}}(\text{AGN})$

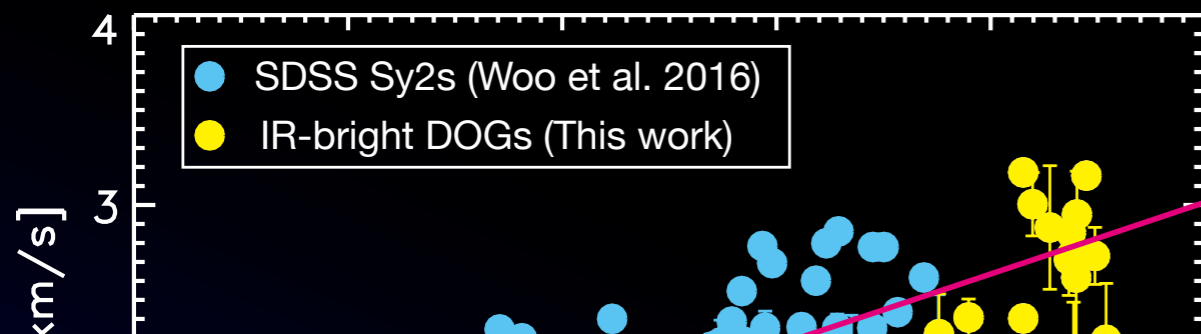


## $\sigma_{[\text{OIII}]}$ vs. $L_{\text{IR}}(\text{AGN})$

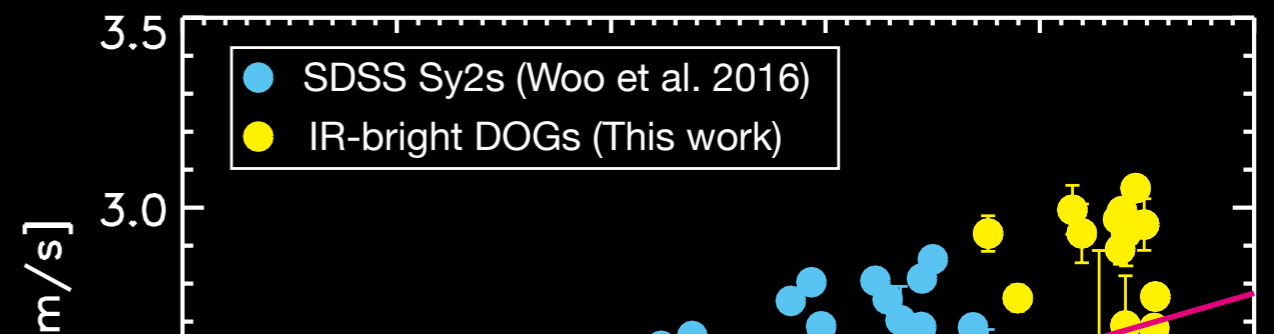


# LIR (AGN) vs. outflow strength

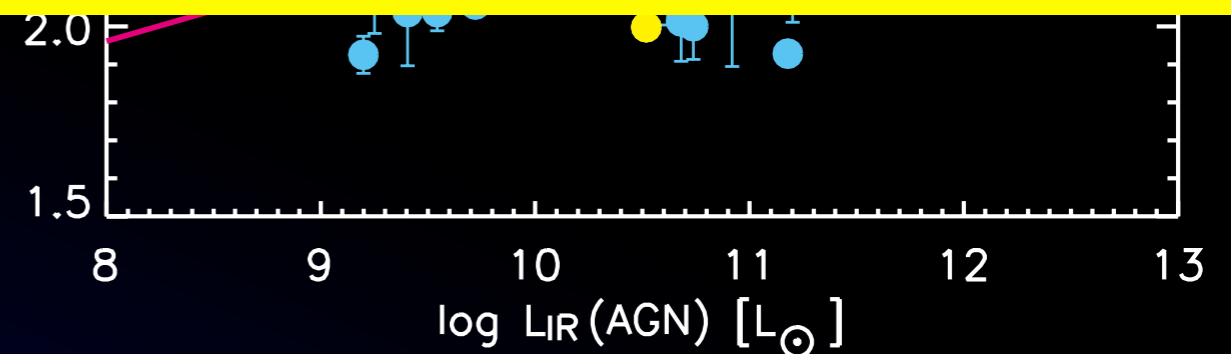
## $V_{[\text{OIII}]}$ vs. $L_{\text{IR}}$ (AGN)



## $\sigma_{[\text{OIII}]}$ vs. $L_{\text{IR}}$ (AGN)



**LIR (AGN) correlates with  $V_{[\text{OIII}]}$  and  $\sigma_{[\text{OIII}]}$**

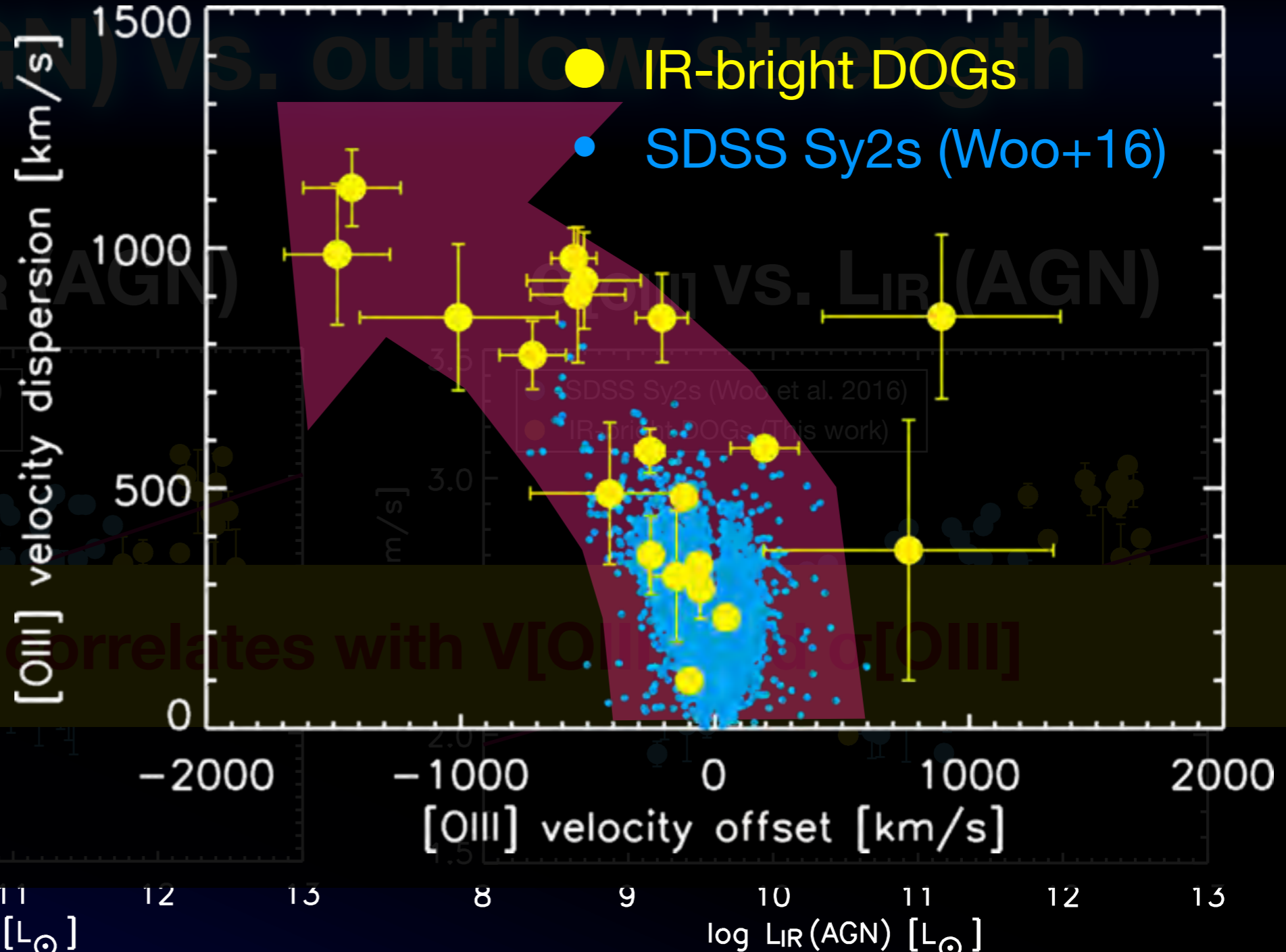


**LIR (AGN)**

**$V_{[OIII]}$  vs.  $L_{IR}$**

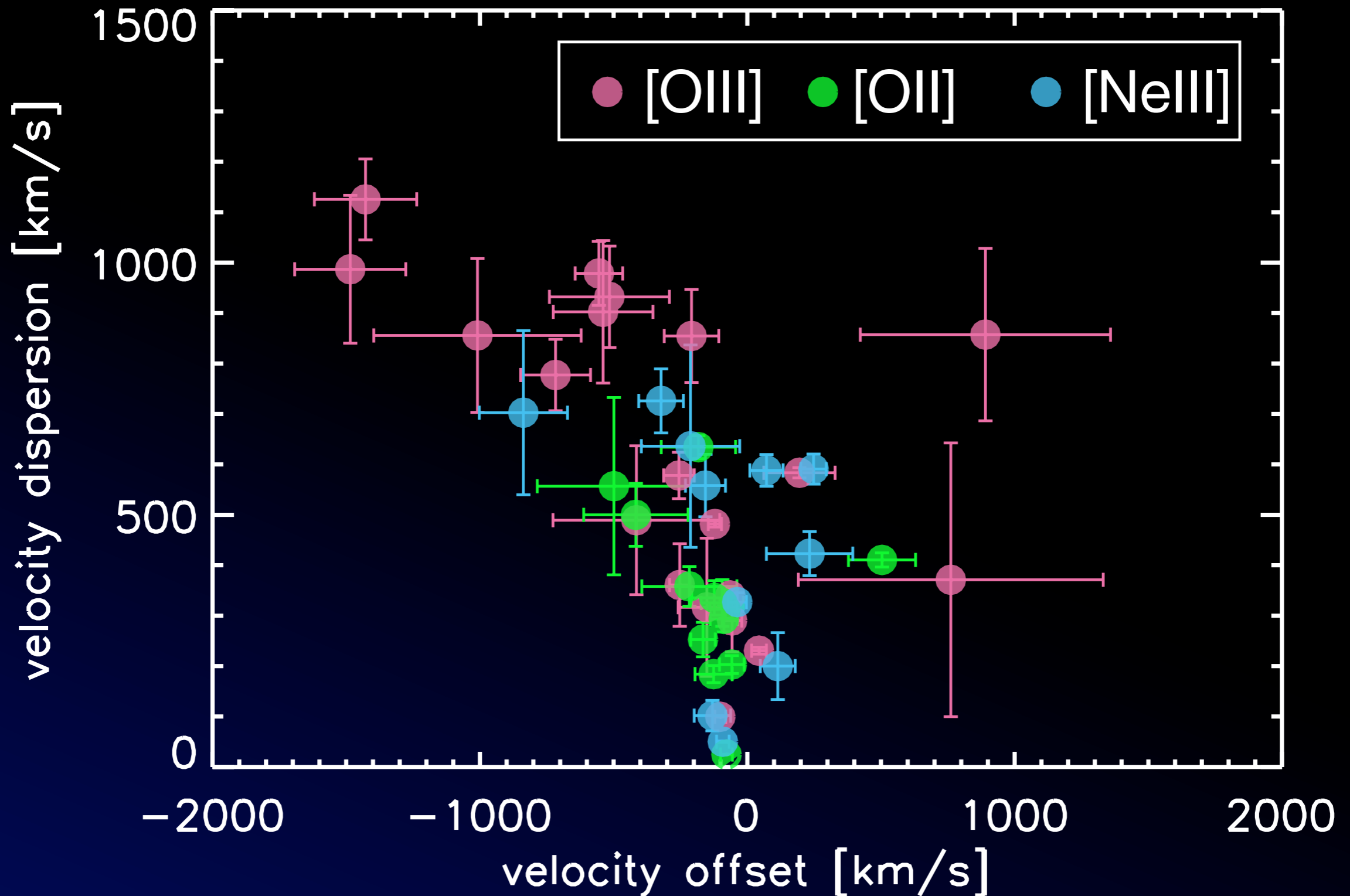


**LIR (AGN)**

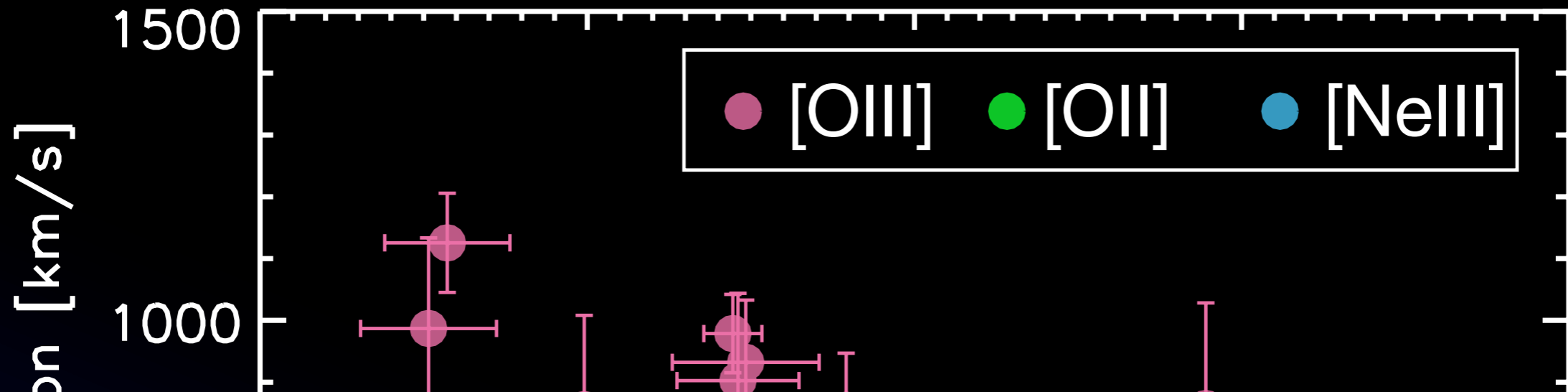


**The systematic offset on the VVD is due to the difference in LIR(AGN)**

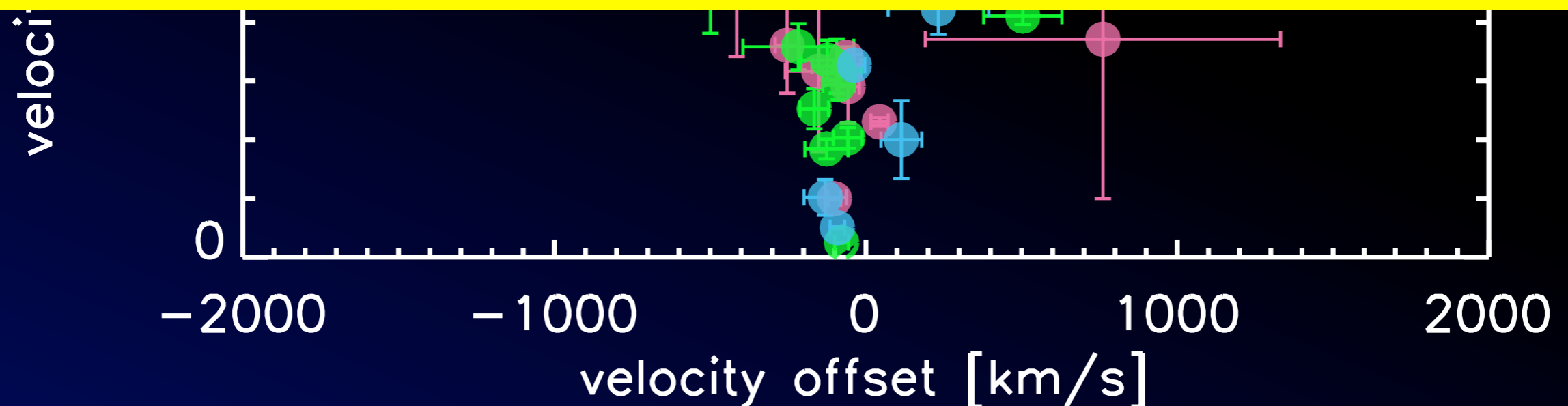
# VVD diagram for other lines



# VVD diagram for other lines



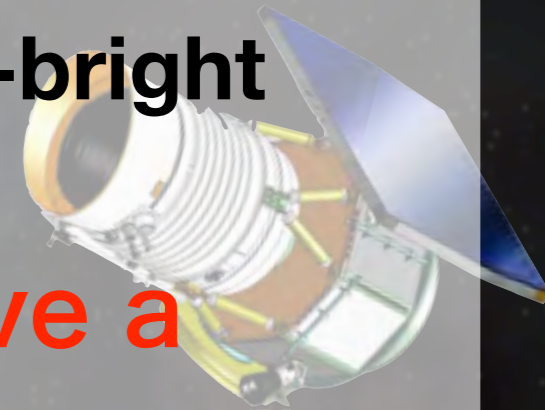
**The highly ionized gas  
tends to show stronger outflows**



# Summary



We investigated ionized gas properties of 32 IR-bright DOGs selected with SDSS and WISE



24/32 (75%) IR-bright DOGs have a strong [OIII] outflow



IR-bright DOGs show relatively strong outflows compared to Sy2s due to the difference in LIR(AGN)



The highly ionized gas tends to show stronger outflows

I ♥ DOGS

