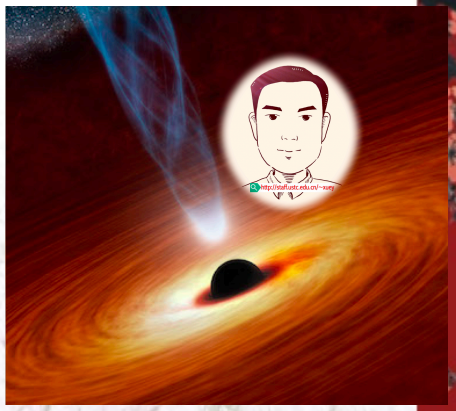
UV/Opt. Stochastic Variability as a Probe of Quasar Physics

Yongquan Xue (薛永泉)

Department of Astronomy
University of Science and Technology of China
http://staff.ustc.edu.cn/~xuey



Mapping Central Regions of Active Galactic Nuclei @ Guilin @ 2019/09/23

Outline

- Why do we study AGN variability?
- What have we done recently?
  - Tales centered around quasar UV/optical variability
- What are the take-home messages?

Outline

- Why do we study AGN variability?
- What have we done recently?
  - Tales centered around quasar UV/optical variability
- What are the take-home messages?

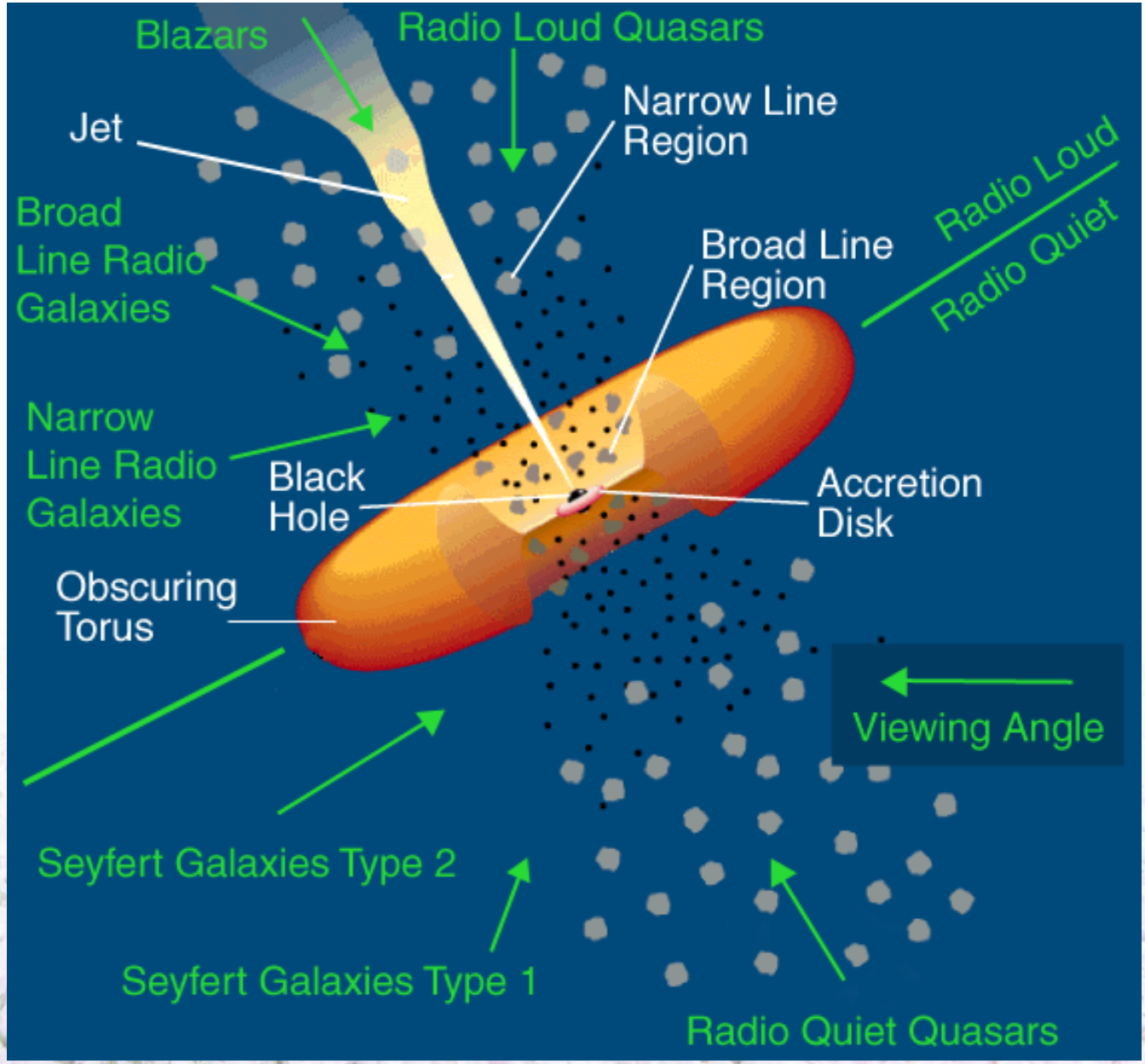
Active galactic nuclei (AGNs)

(University of Warwick, retrieved from bordermail.com.au)

AGN variability,
AGN physics,
AGN feedback,
co-evolution,
etc.

- Tremendous amounts of energy from the center of a galaxy
- Excess emission across almost all wavelengthes
- Accretion of mass onto SMBH (~1E6-1E10 Msun)
- Most luminous persistent sources of electromagnetic radiation

Orientation-based unified models for AGNs

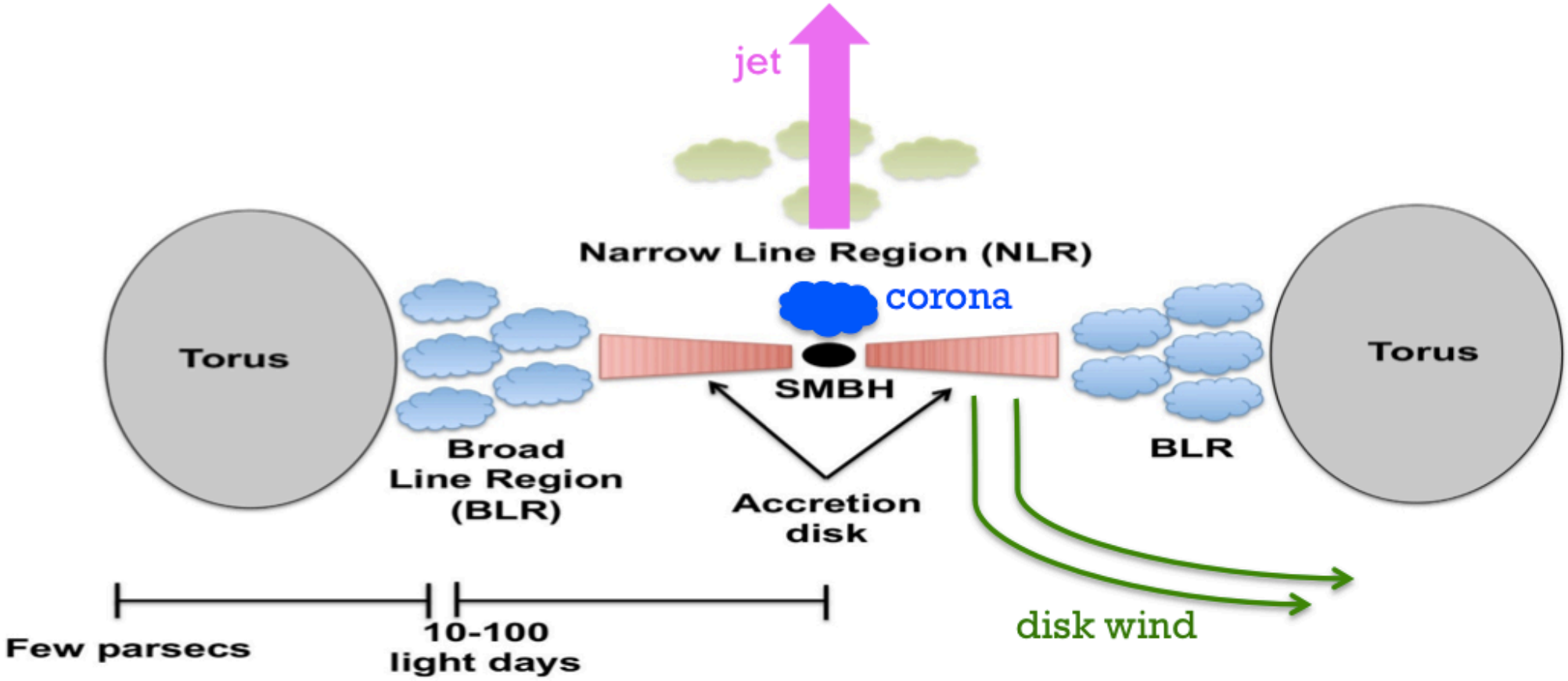


(NASA)

many components

physical driver for AGN variety?

AGN components

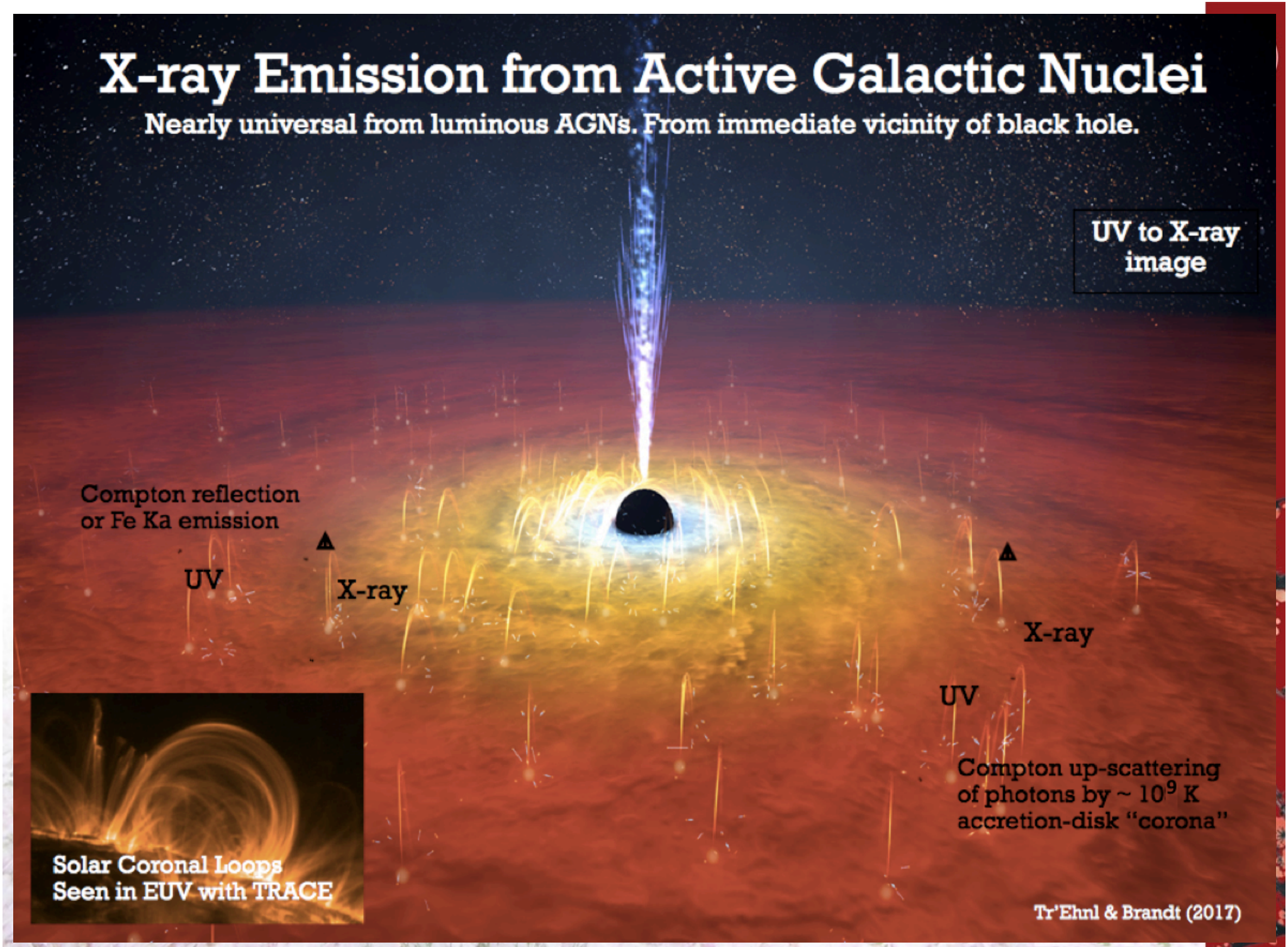


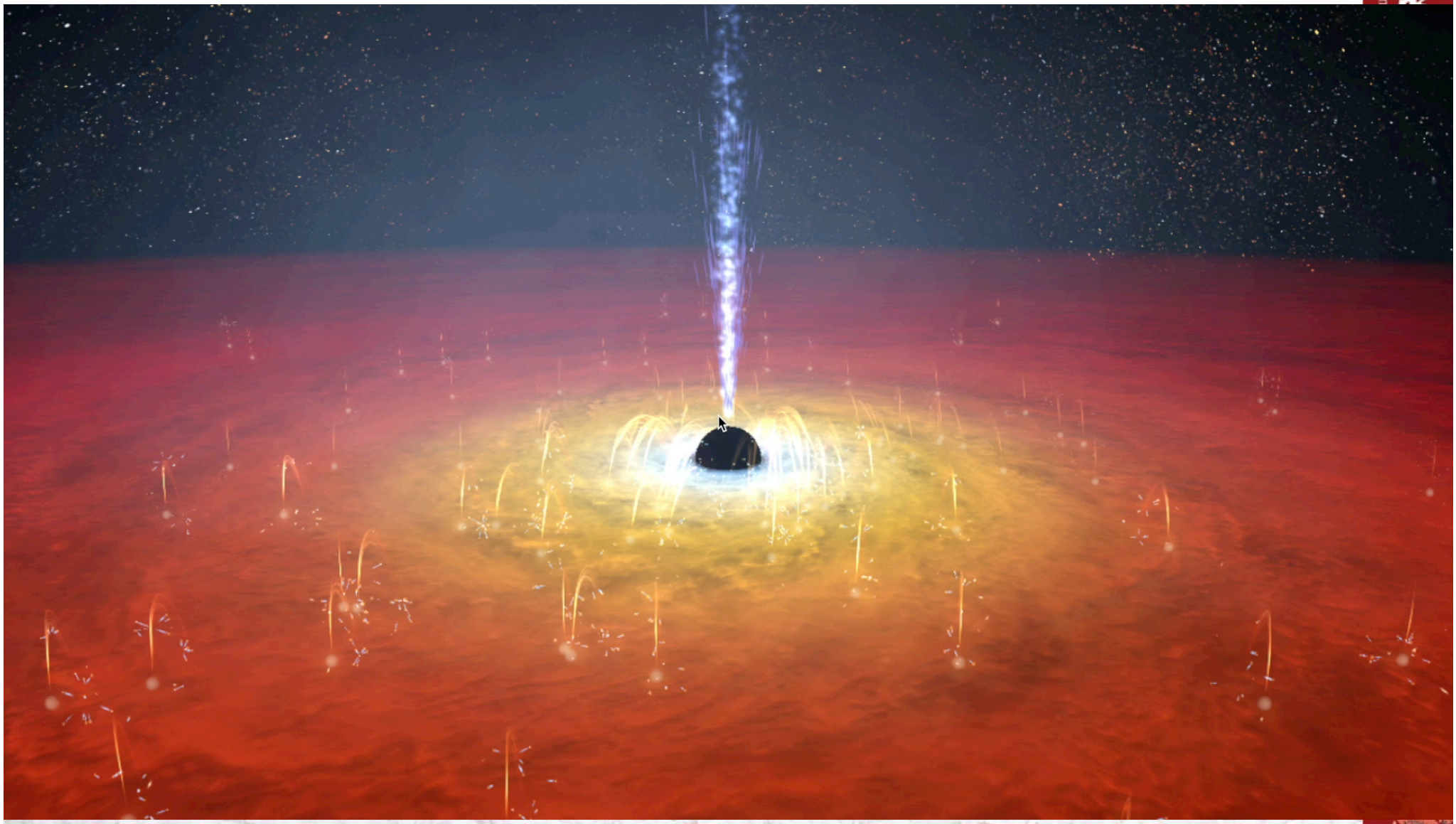
(based on cartoon by C. Ricci)

central engine → significant variability occurring in almost all components

X-ray Emission from Active Galactic Nuclei

Nearly universal from luminous AGNs. From immediate vicinity of black hole.





dynamic engine: variability

Variability: a defining and ubiquitous AGN feature

- Valuable for probing AGN physical properties, e.g.:

  - minimum variability timescale (light-crossing time) → physical size

  - reverberation-mapping → size estimates of various components (e.g., BLR)

  - changes in absorption → properties of obscuring wind and gas

  - PSD properties (e.g., break freq.) correlated to BH properties (e.g., Mbh, Mdot)

  - significant variability as an effective AGN selection technique

  - variability observations constrain emission processes and models

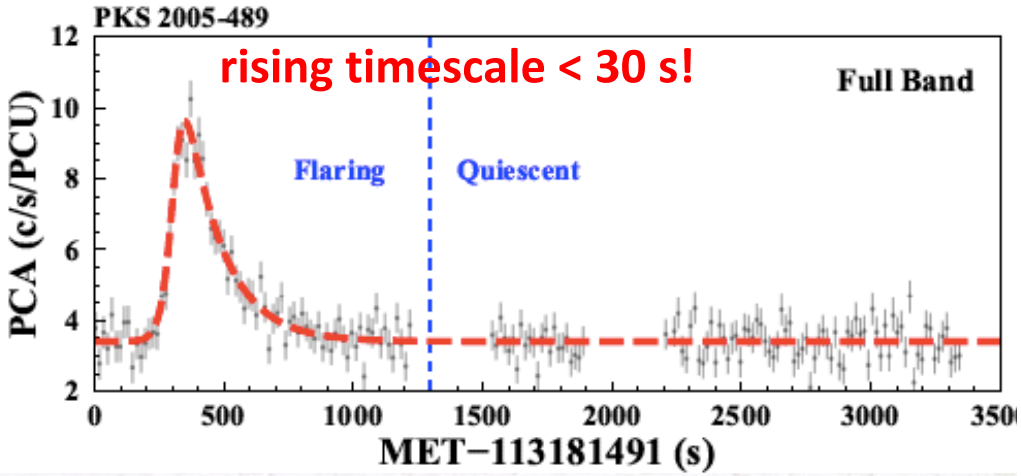
  - long-term variability constrain low-frequency PSD

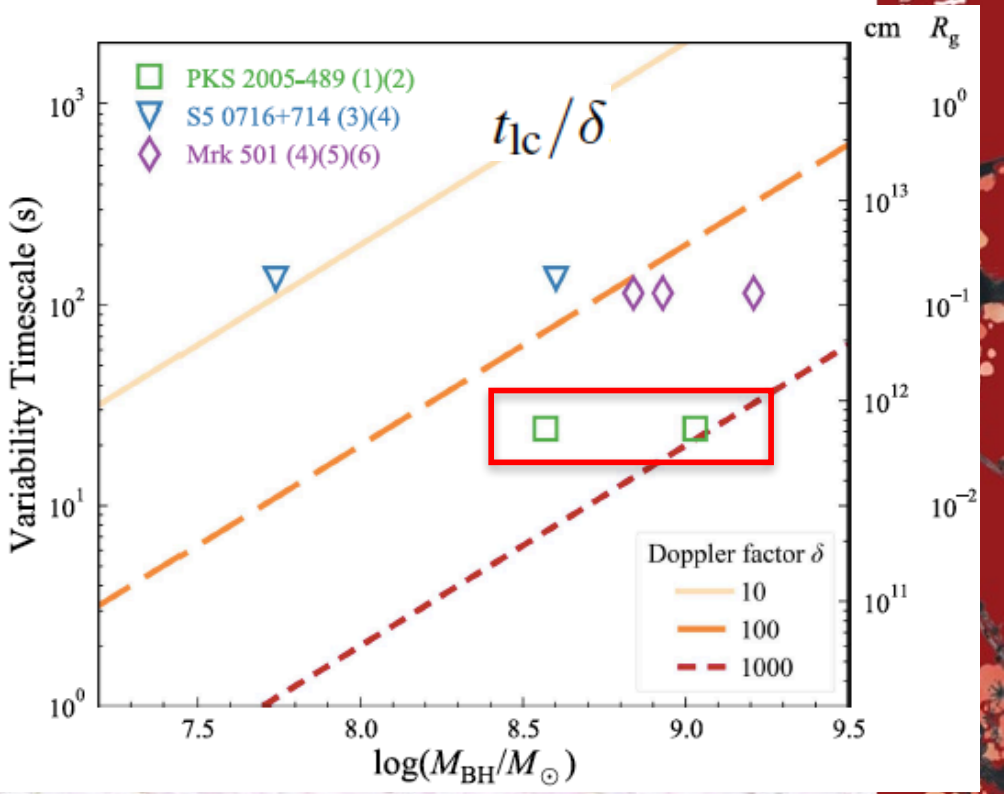
(Xue 2017)

Variability: a defining and ubiquitous AGN feature

- Valuable for probing AGN physical properties, e.g.:

  - minimum variability timescale (light-crossing time) → max. physical size of emission region





SMBH size is not a hard lower limit on the physical size of the flaring emission region

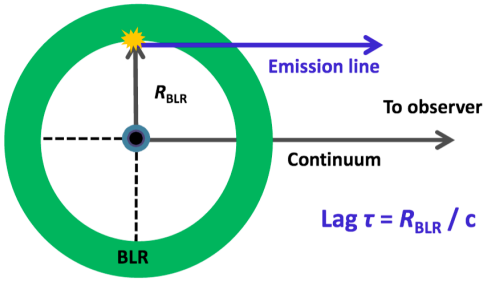
Shifu Zhu

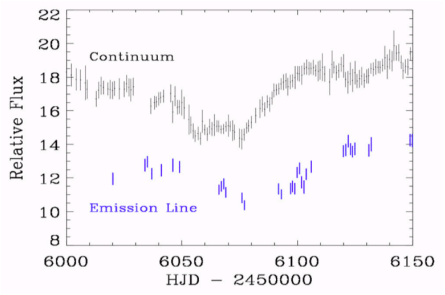
(Zhu, Xue et al. 2018)

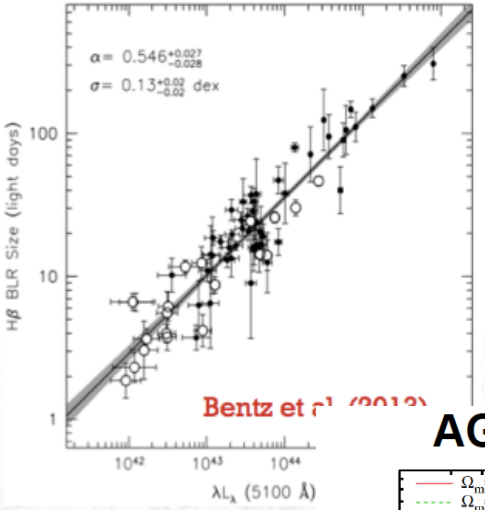
Variability: a defining and ubiquitous AGN feature

- Valuable for probing AGN physical properties, e.g.:

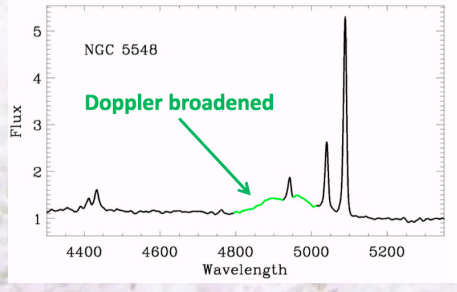
  - reverberation-mapping → size estimates of various components (e.g., BLR)







$R_{BLR} \sim L^{1/2}$



BH Mass Estimate

$M_{BH} \approx f\, R_{BLR}\, \sigma^2 / G$

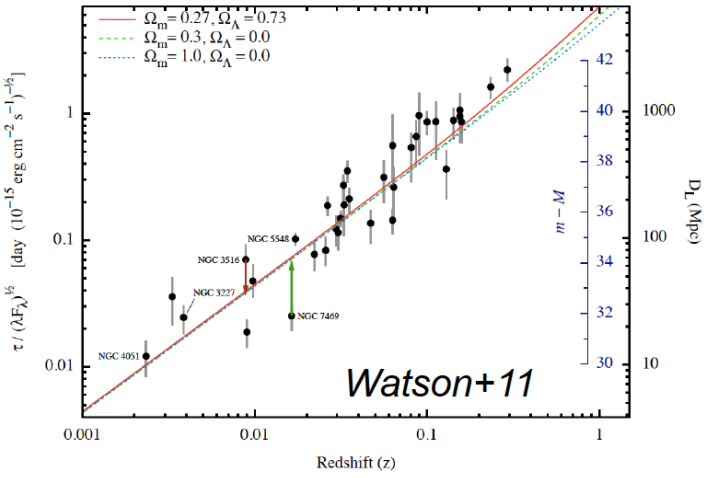
$R_{BLR} = c\,\tau$

Line Width σ = velocity dispersion

f, "form factor": BLR inclination + kinematics

(Courtesy of Liuyi Pei)

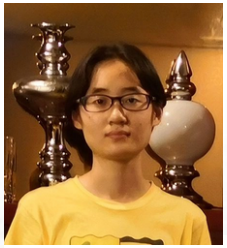
AGN Standard Candles



Variability: a defining and ubiquitous AGN feature

- Valuable for probing AGN physical properties, e.g.:

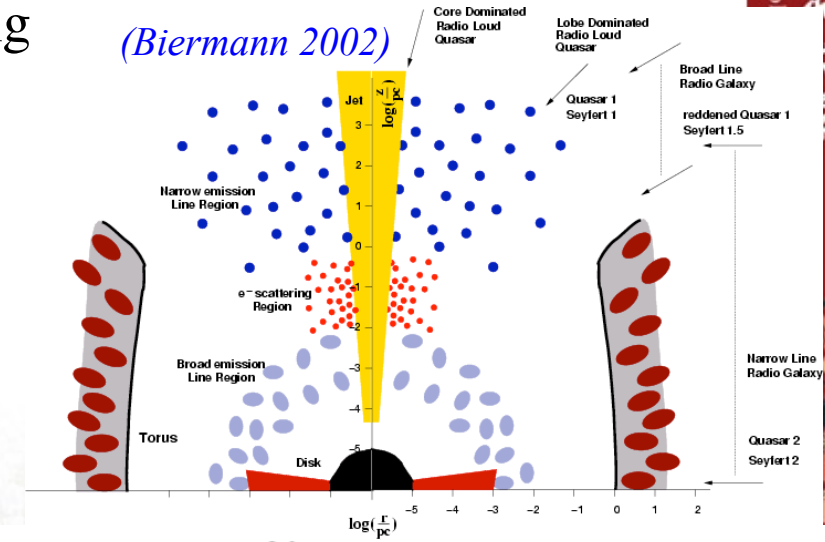
  - changes in absorption → properties of obscuring wind, gas, and dust

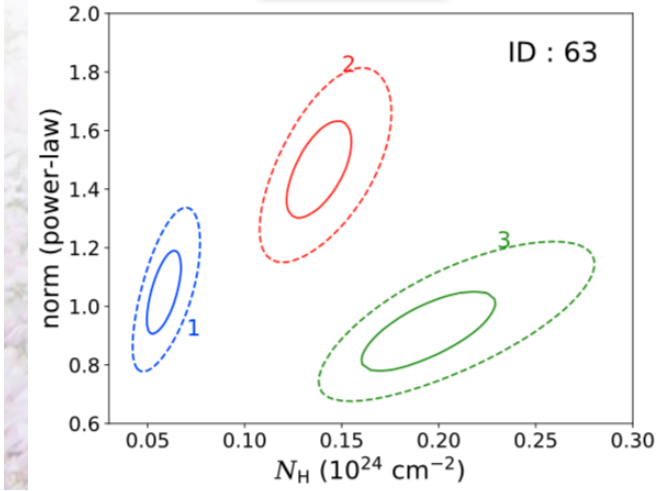


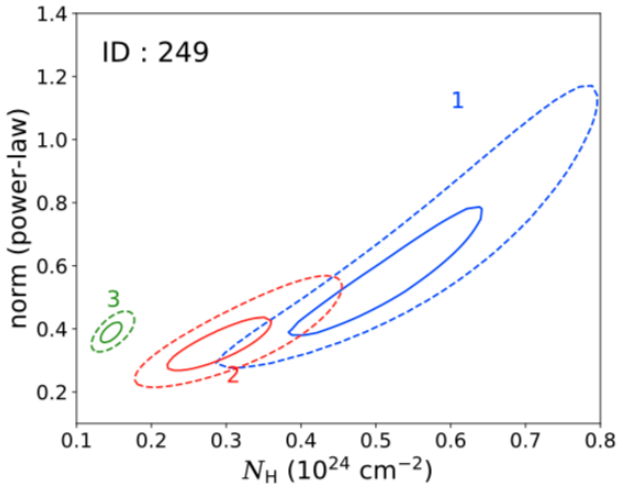
Junyao Li

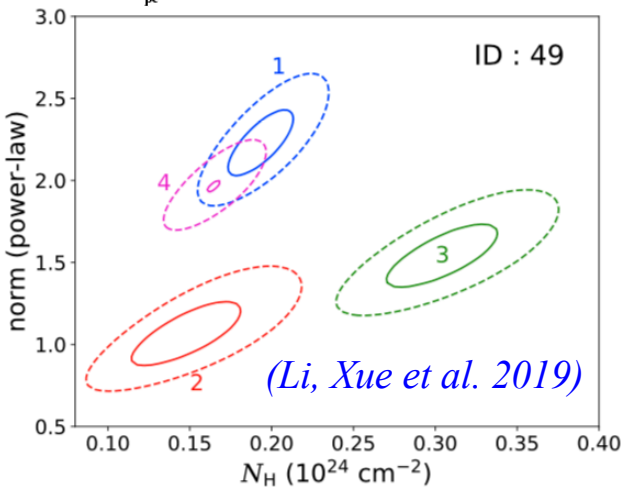
(Proga et al. 1998)

(Biermann 2002)





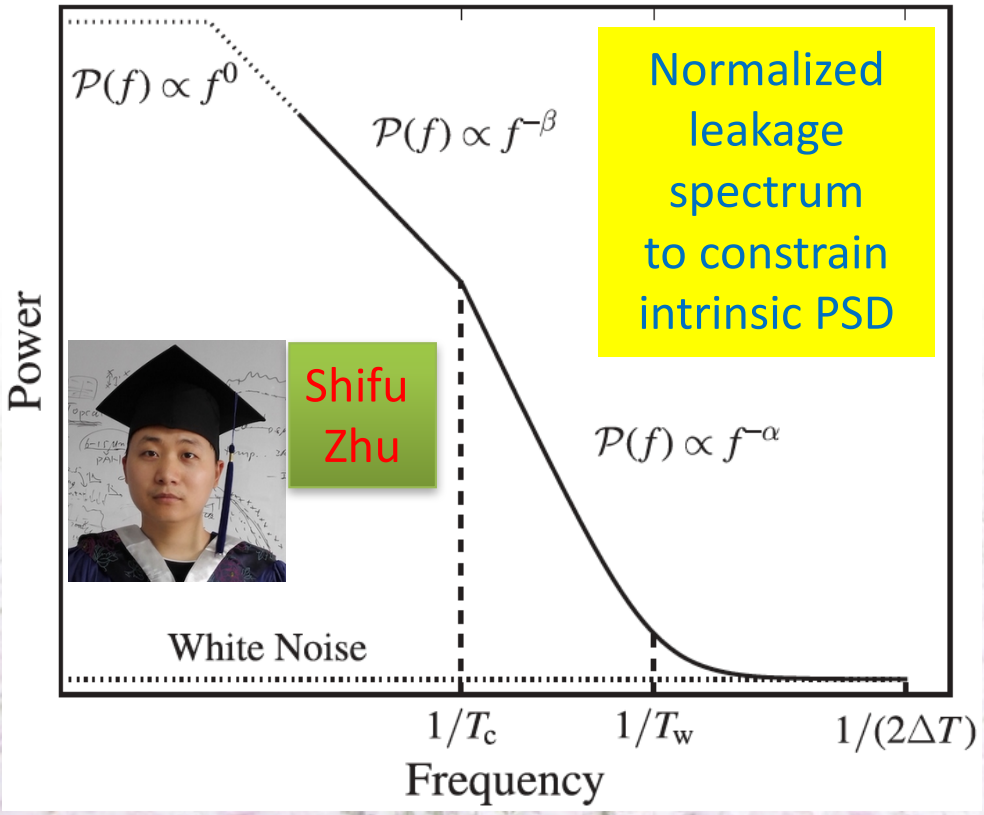




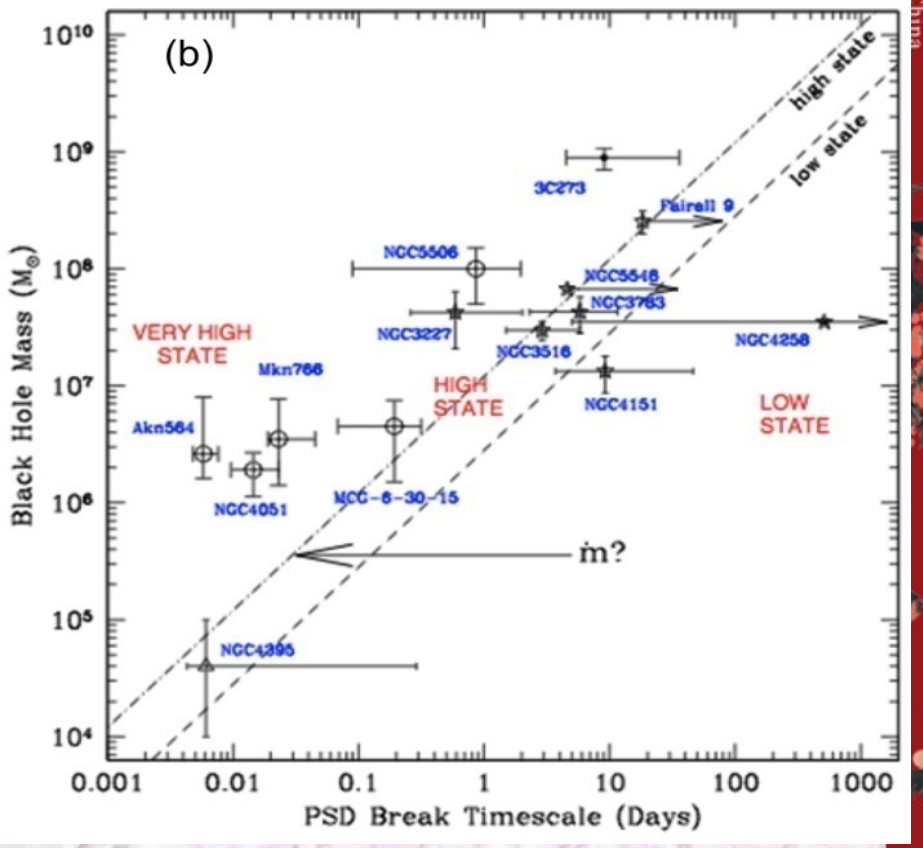
Variability: a defining and ubiquitous AGN feature

- Valuable for probing AGN physical properties, e.g.:

  - PSD properties (e.g., break freq.) correlated to BH properties (e.g., Mbh, Mdot)



(Zhu & Xue 2016)



(McHardy et al. 2005)

Variability: a defining and ubiquitous AGN feature

- Valuable for probing AGN physical properties, e.g.:

  - significant variability as an effective AGN selection technique

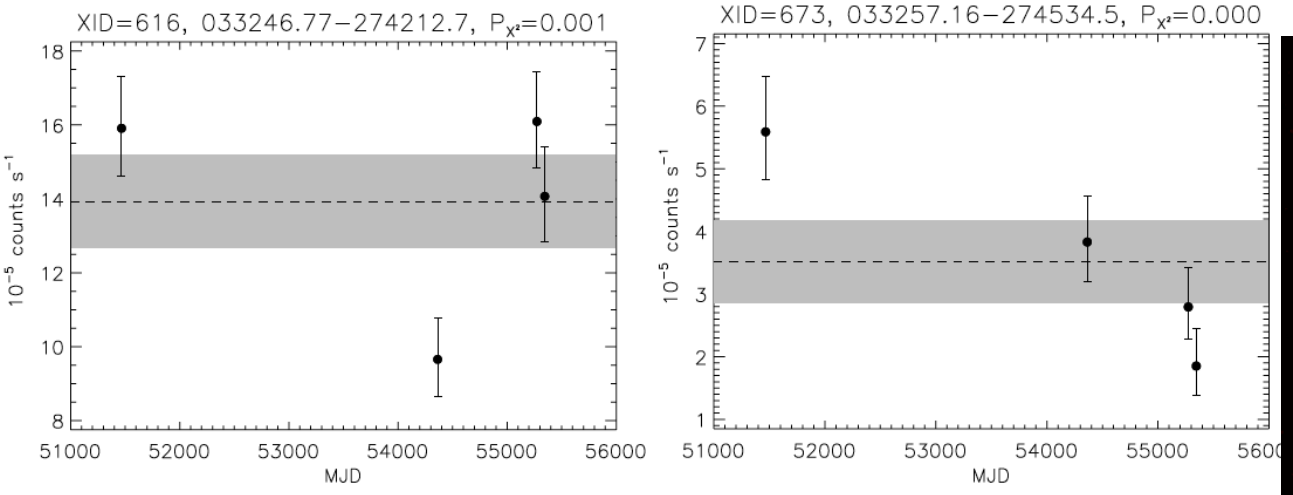
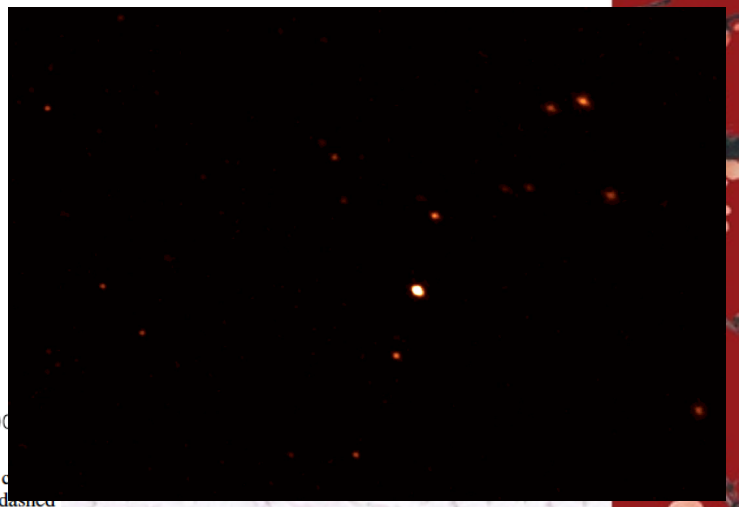


Figure 3. Light curves for six representative CDF-S sources classified as galaxies that exhibit significant variability. Full-band (0.5–8 keV, observed frame) c have been grouped into the four epochs and asymmetric errors on the count rates were calculated via Gehrels (1986). The mean count rate is overplotted as a dashed line, and the error on the mean is shown as the gray shaded area. Each plot lists the P_{X2} values and source names.

(Young, Brandt, Xue et al. 2012)

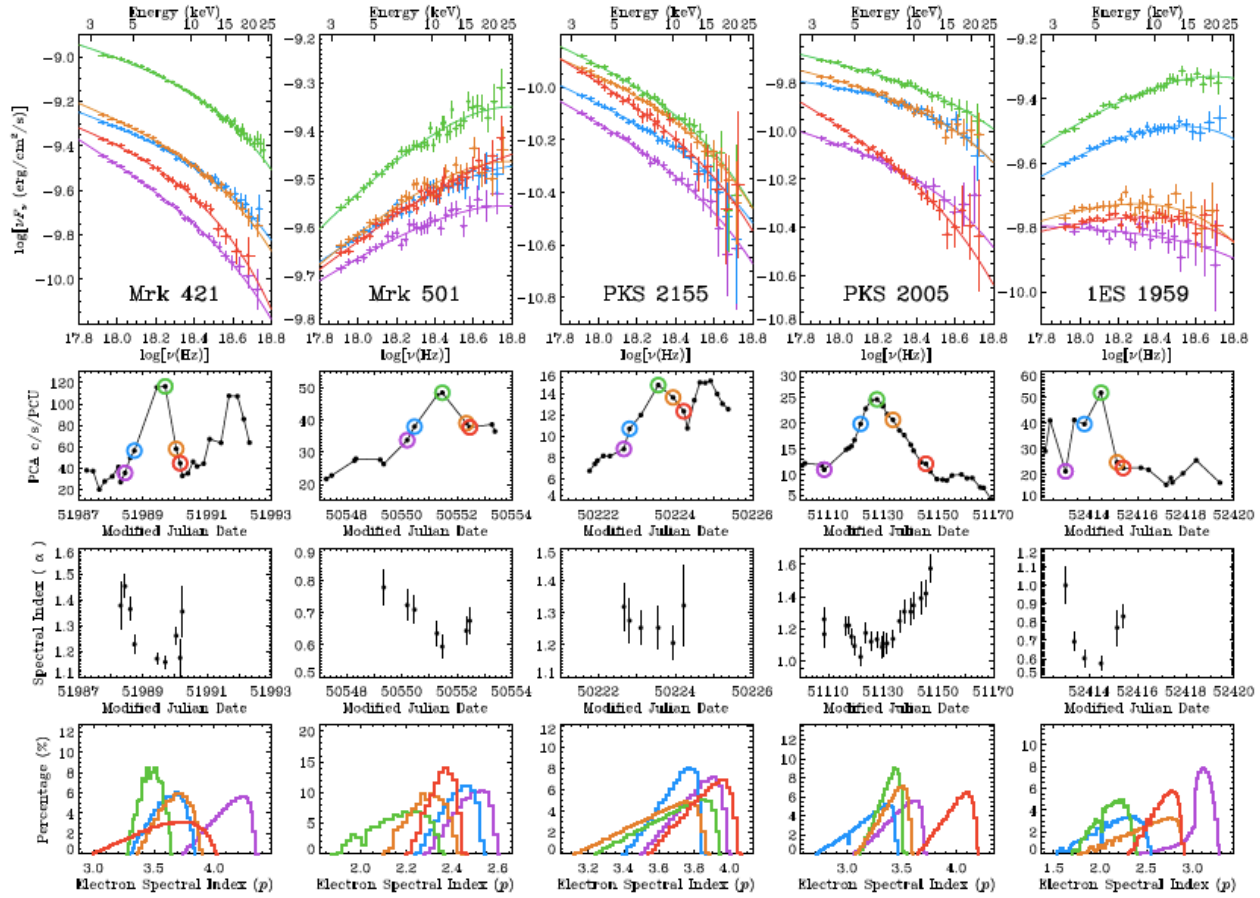


(Courtesy of G. Yang)

Variability: a defining and ubiquitous AGN feature

- Valuable for probing AGN physical properties, e.g.:

  - variability observations constrain emission processes and models



Yijun Wang

X-ray spectral variability of TeV blazars

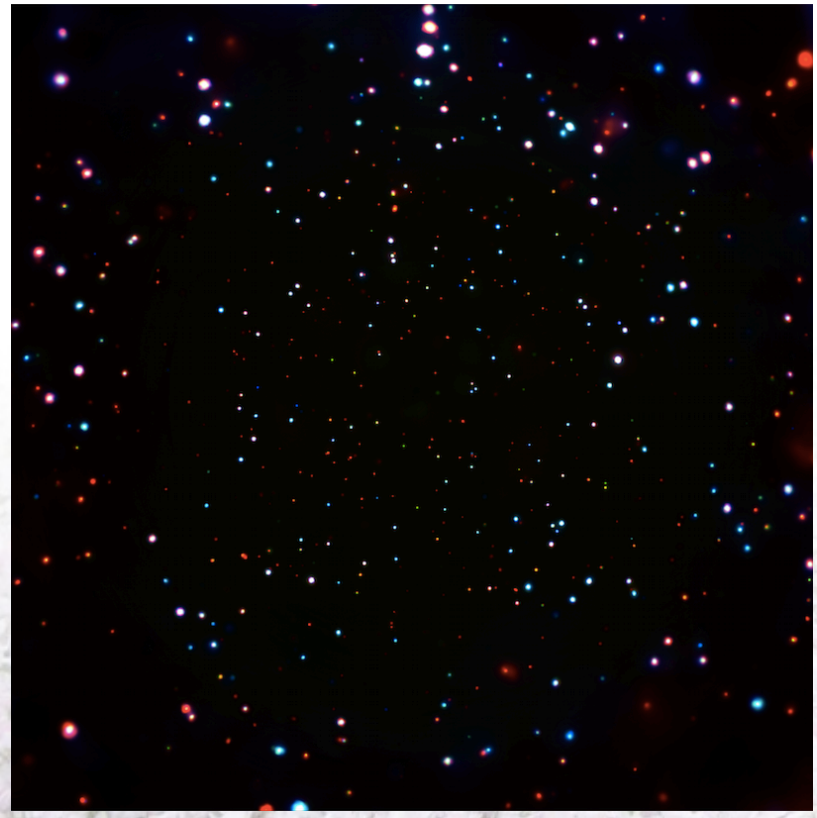
(Wang, Xue et al. 2018)

中国科学技术大学
University of Science and Technology of China

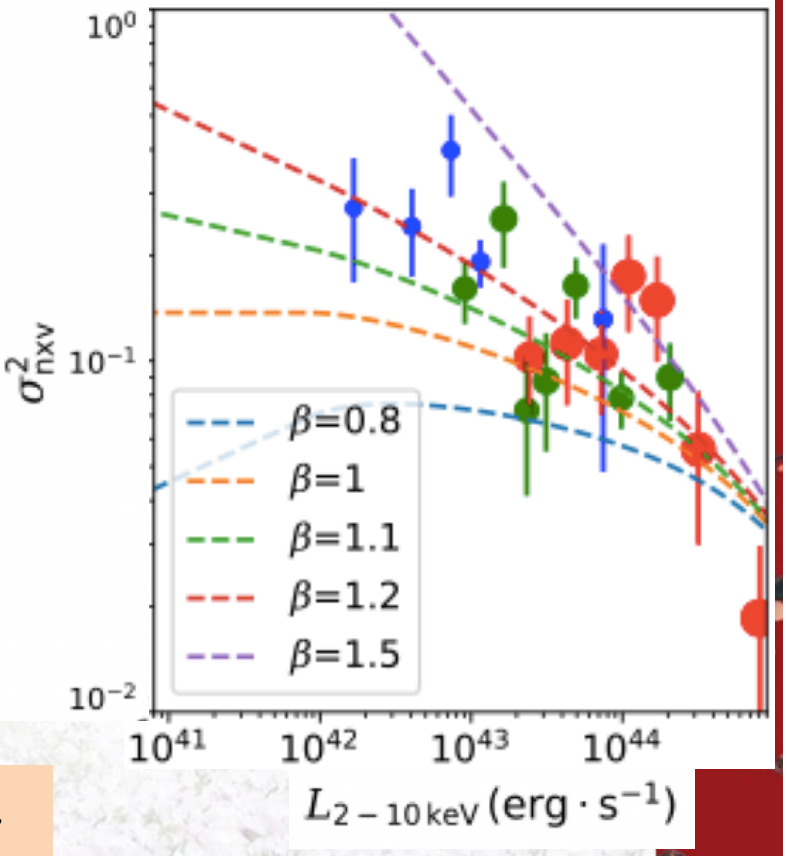
Variability: a defining and ubiquitous AGN feature

- Valuable for probing AGN physical properties, e.g.:

  - long-term variability constrain low-frequency PSD



(7Ms CDF-S: Luo, Brandt, Xue et al. 2017)



β~1.2-1.3 vs. commonly assumed β~1:

(Zheng, Xue et al. 2017)

Xuechen Zheng

Outline

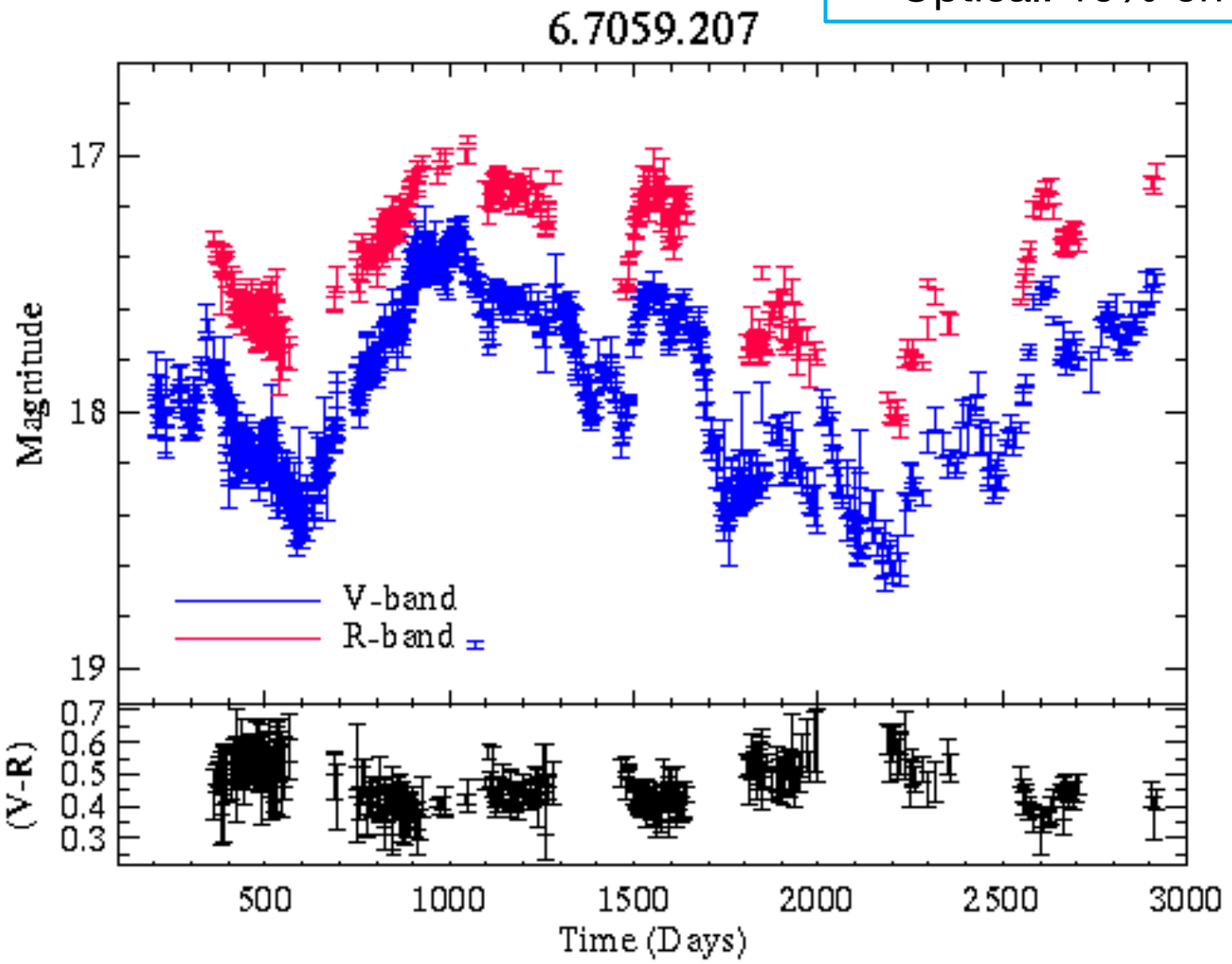
- Why do we study AGN variability?
- What have we done recently?
  - Tales centered around quasar UV/optical variability
- What are the take-home messages?

Dr. → Prof.

Mouyuan Sun

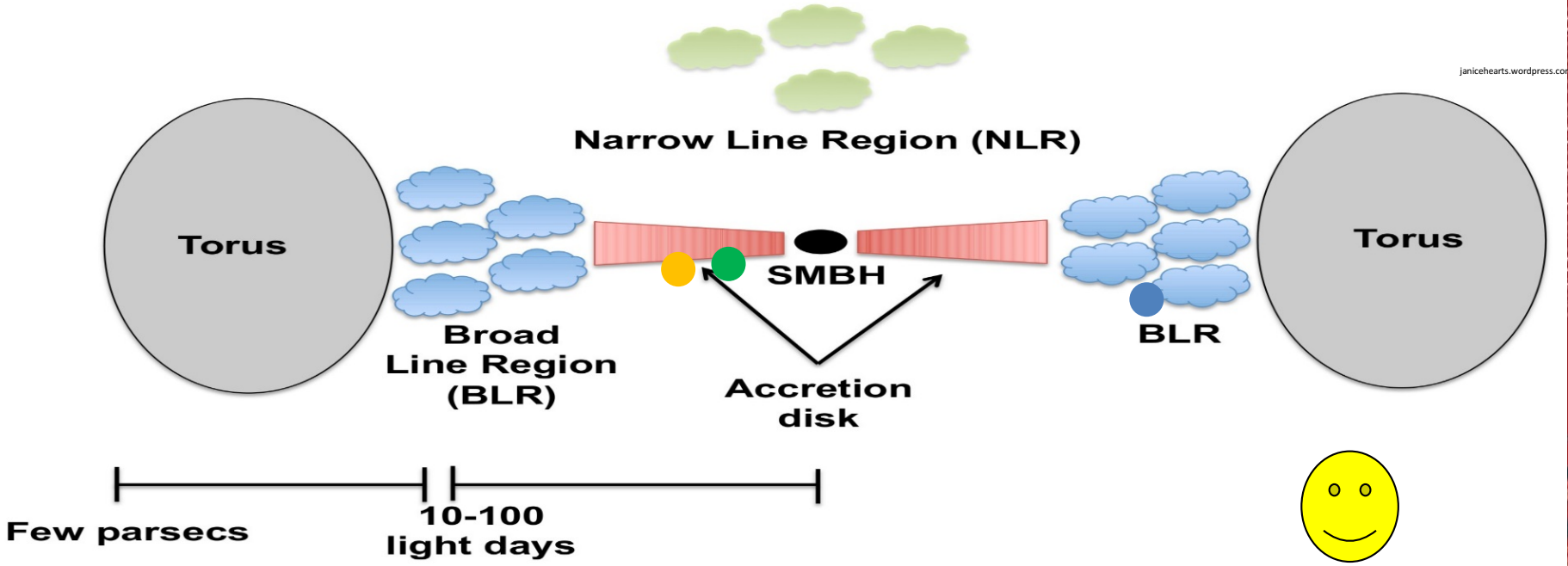
AGNs are flickering...

- Aperiodic luminosity variations
- Amplitude decreases wavelength
- Optical: 10% on timescales of years



http://www.astro.yale.edu/mgeha/MACHO/6.7059.207.html

Small variability, big wisdom



$R_{BLR} \sim L^{1/2}$

Estimating Black Hole Masses

Can estimate black-hole masses following the virial theorem:

$$M_{BH} = \frac{f c \tau \Delta V^2}{G}$$

Where f is a factor that includes (unknown) BLR geometry and inclination.

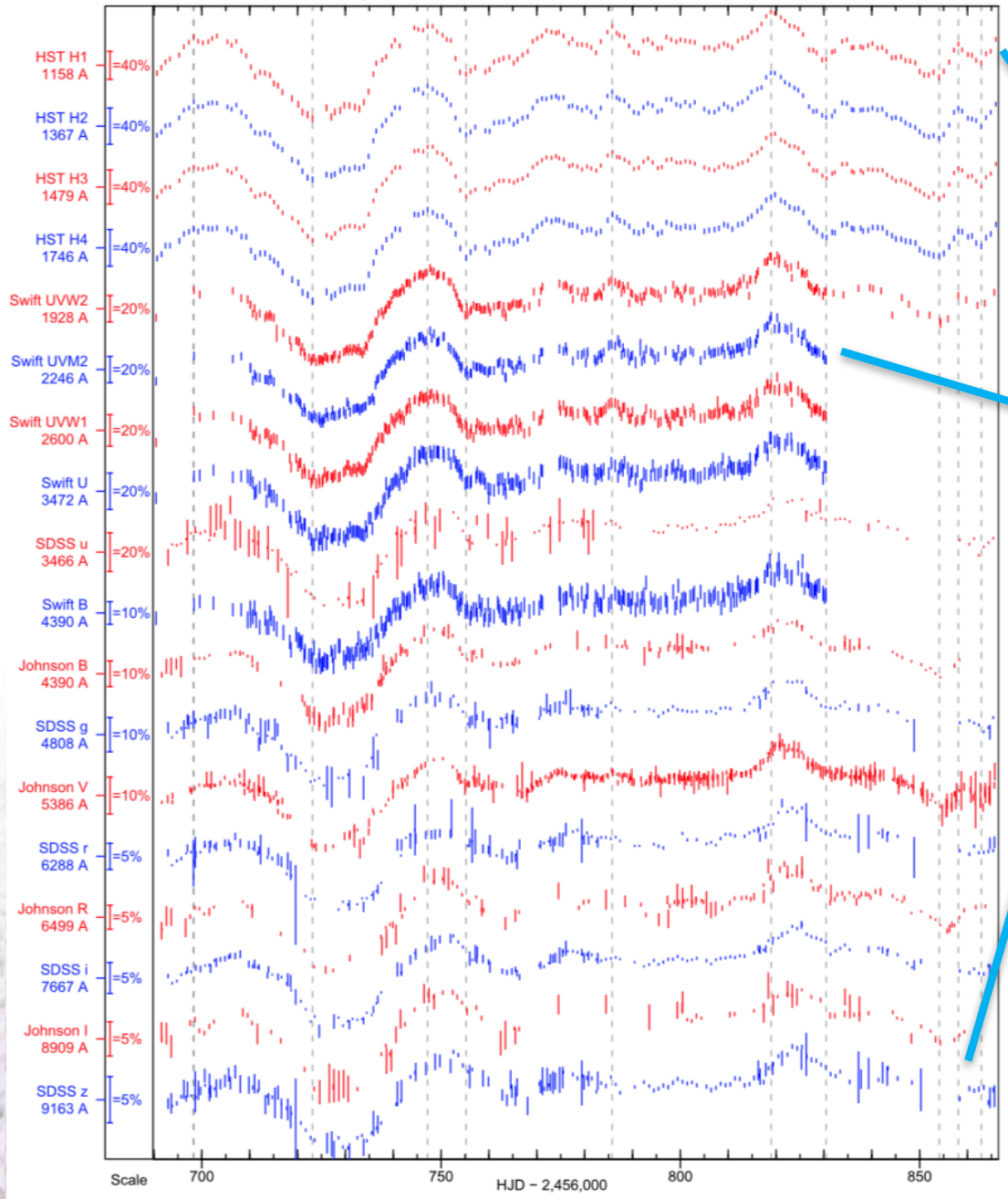
Single-Epoch Masses

Can combine the R_{BLR}-L relation with the virial theorem to estimate single-epoch masses. For example…

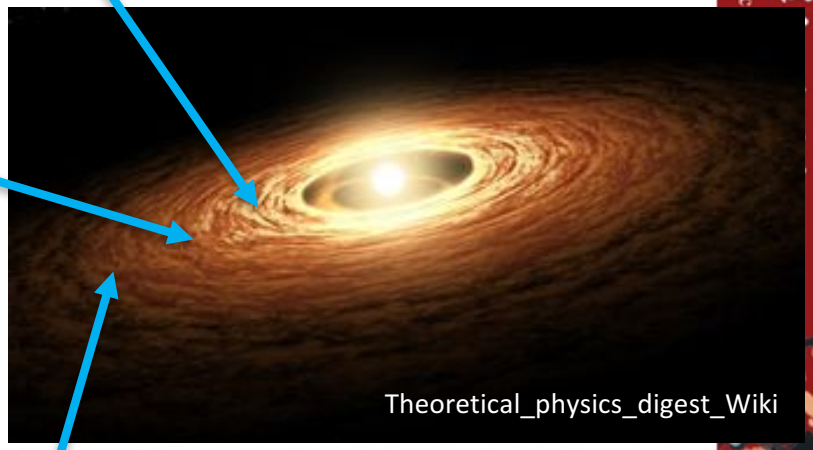
$$\frac{M_{BH}}{10^6\ M_\odot} = 4.35 \left[\frac{\nu L_\nu(5100\ \text{Å})}{10^{44}\ \text{ergs s}^{-1}}\right]^{0.7} \left[\frac{\text{FWHM(H}\beta)}{10^3\ \text{km s}^{-1}}\right]^2$$

AGN Accretion Disk Sizes

AGN STORM; Fausnaugh+16



Reprocessing scenario: continuum RM (cf. Edelson's talk, Chelouche's talk)

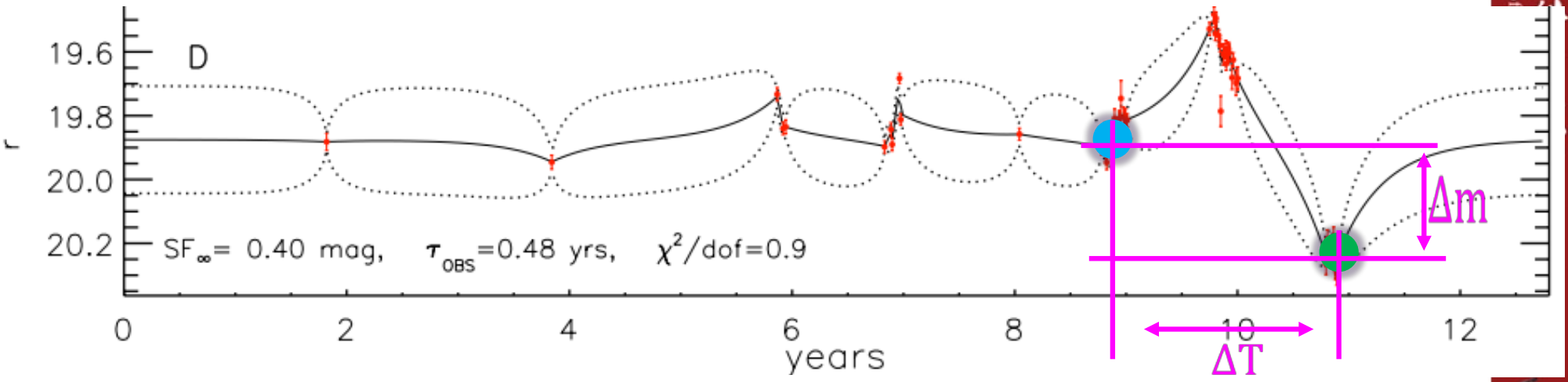


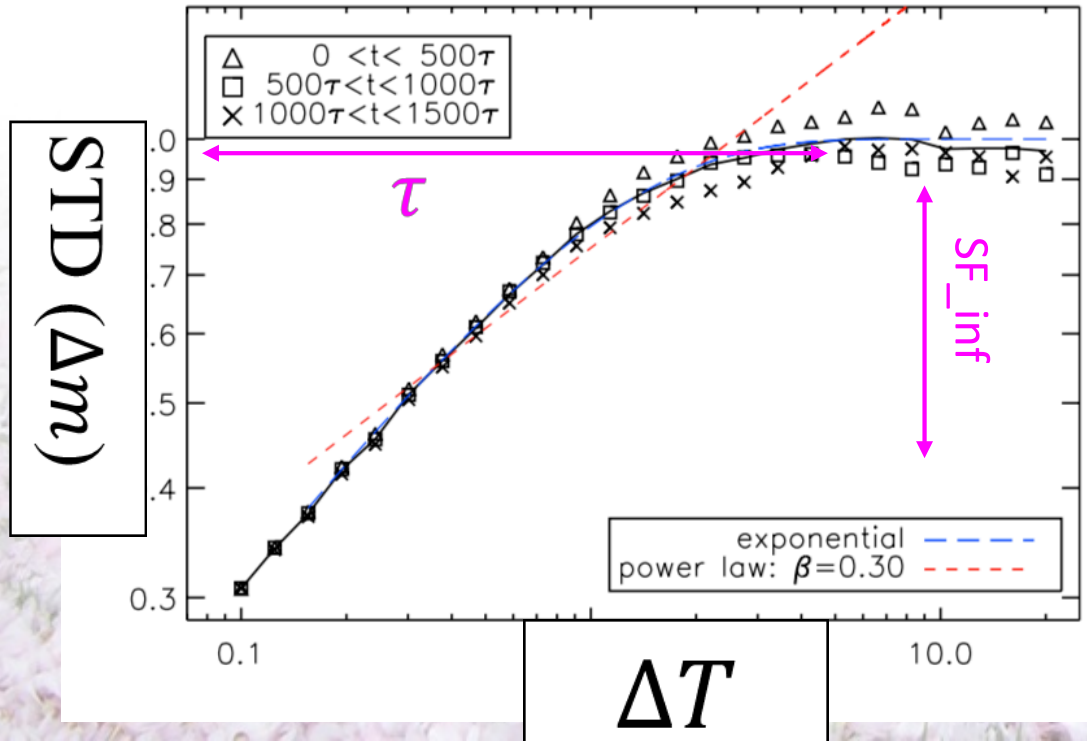
Disk temperature decreases with increasing radius

Time lags indicate the disk sizes

Measuring stochastic variability

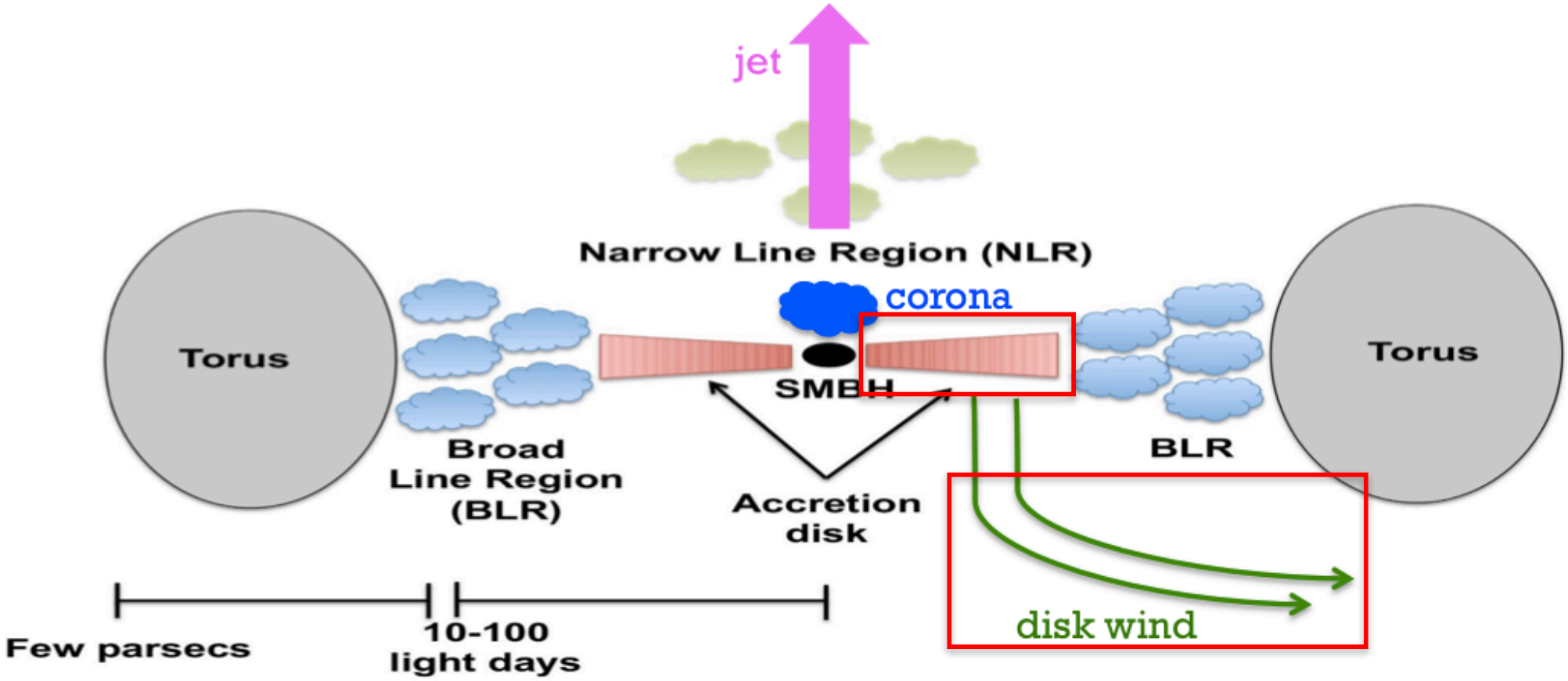
Macleod+10





The most popular model is the DRW. This model has two parameters: tau and SF_inf in structure function

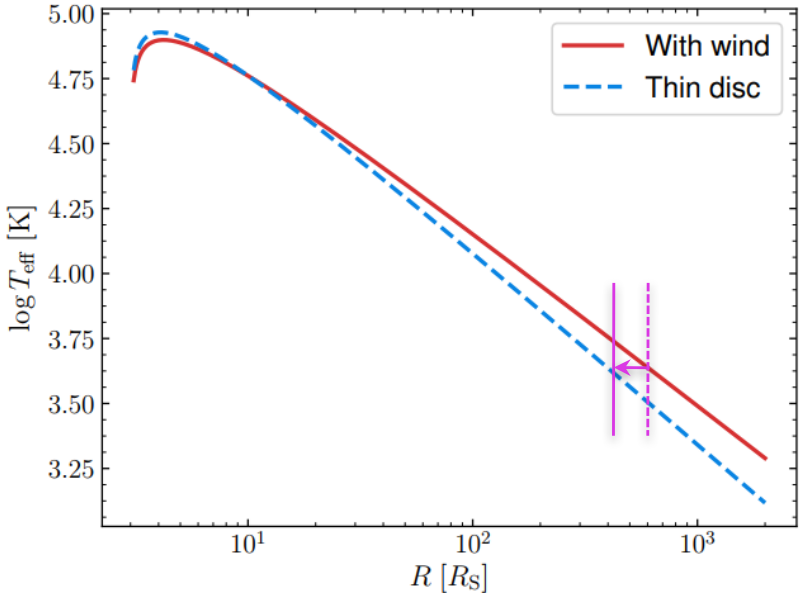
AGN components



(based on cartoon by C. Ricci)

Winds can 'blow up' AGN accretion disc sizes

(cf. Dai's talk)

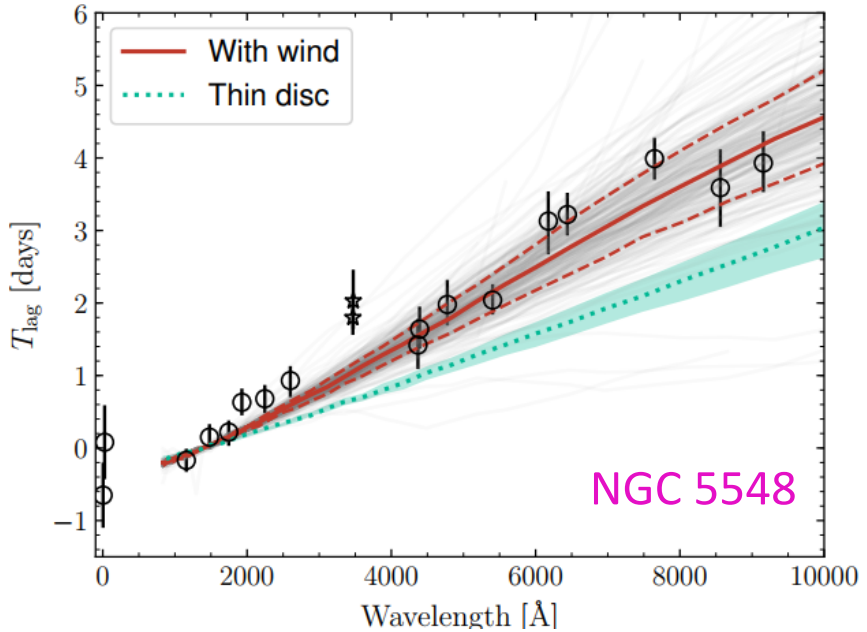


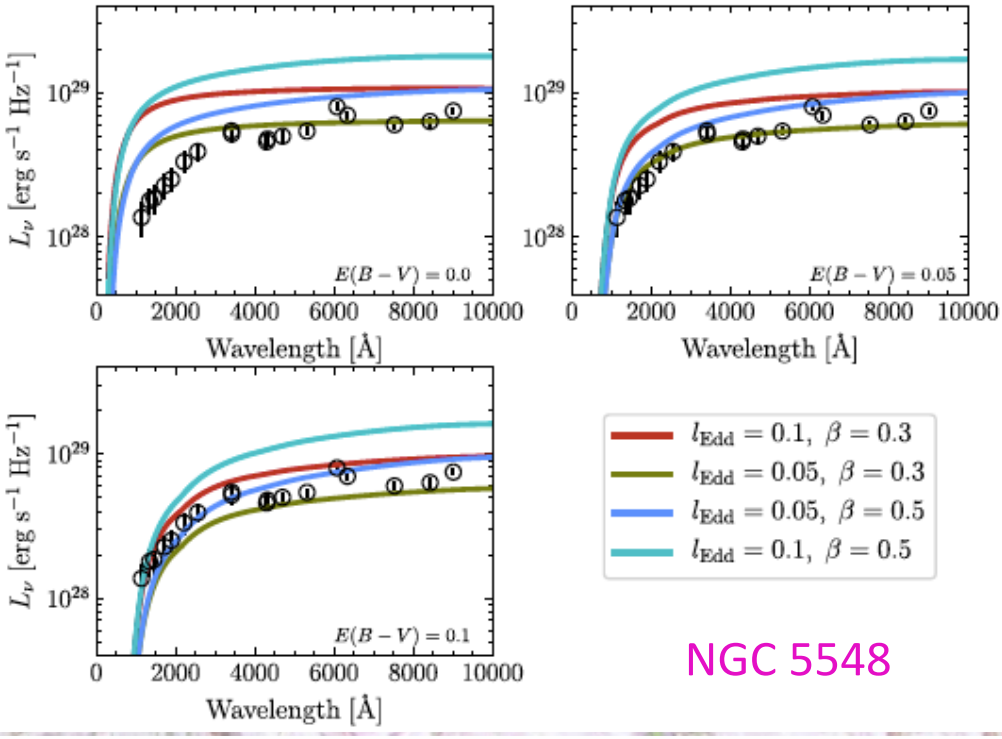
$$\dot{M} = \dot{M}_0 r^{\beta}$$

$$T_{\rm eff} = \left\{ \frac{3GM_{\rm BH}\dot{M}_0(1-\sqrt{3r_{\rm in}/r})}{8\pi\sigma R_S^3} \right\}^{\frac{1}{4}} r^{\frac{\beta-3}{4}}$$

The wind mass rate is ~ 0.6 Msun per year; this is consistent with the observed mass rate.

(Sun, Xue +2019)

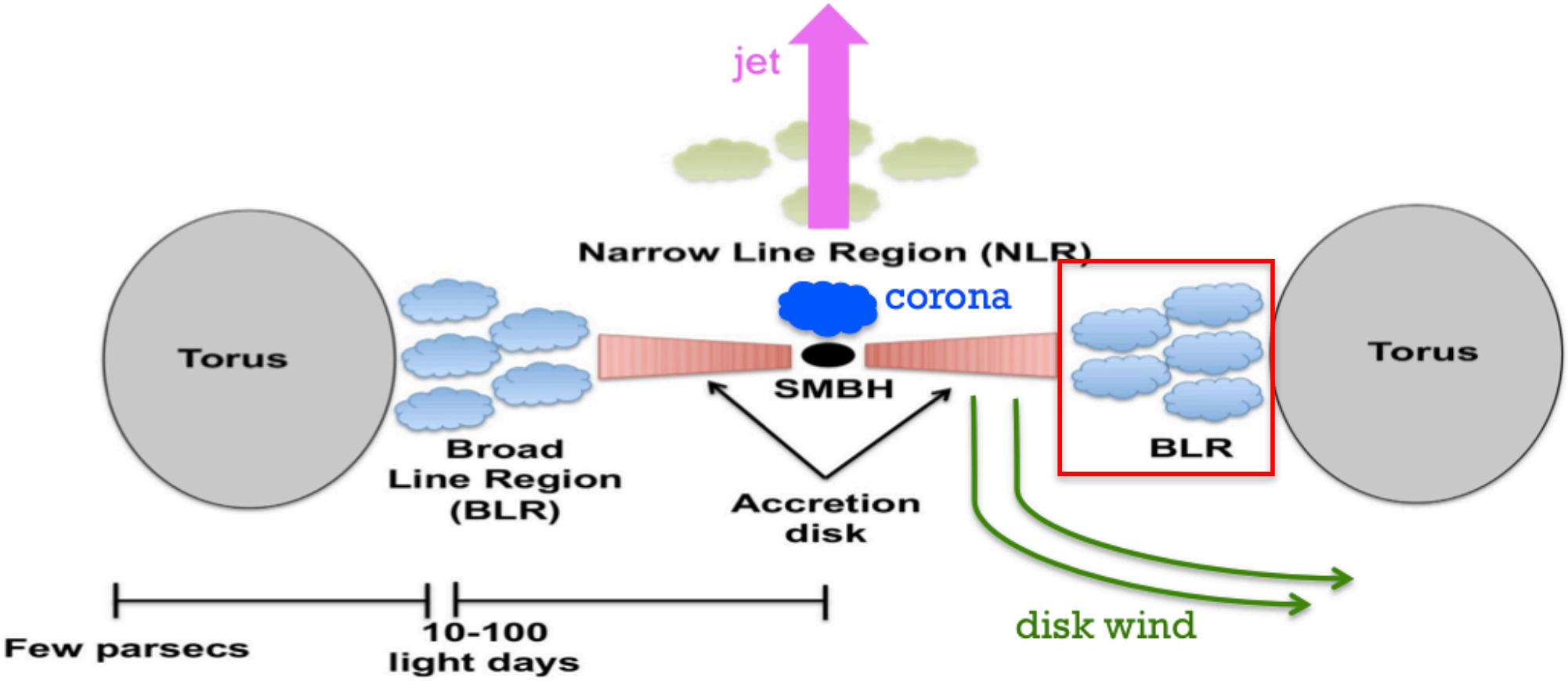




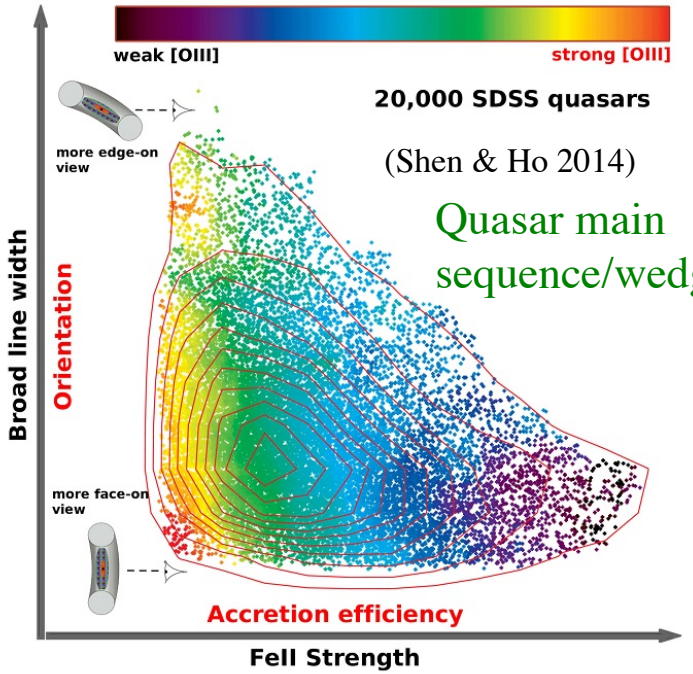
- A windy disk model explains larger-than-usual disk sizes
- Also explains UV-to-NIR SEDs
- Helps understand accretion disks and RM results

(Sun, Xue +2019)

AGN components



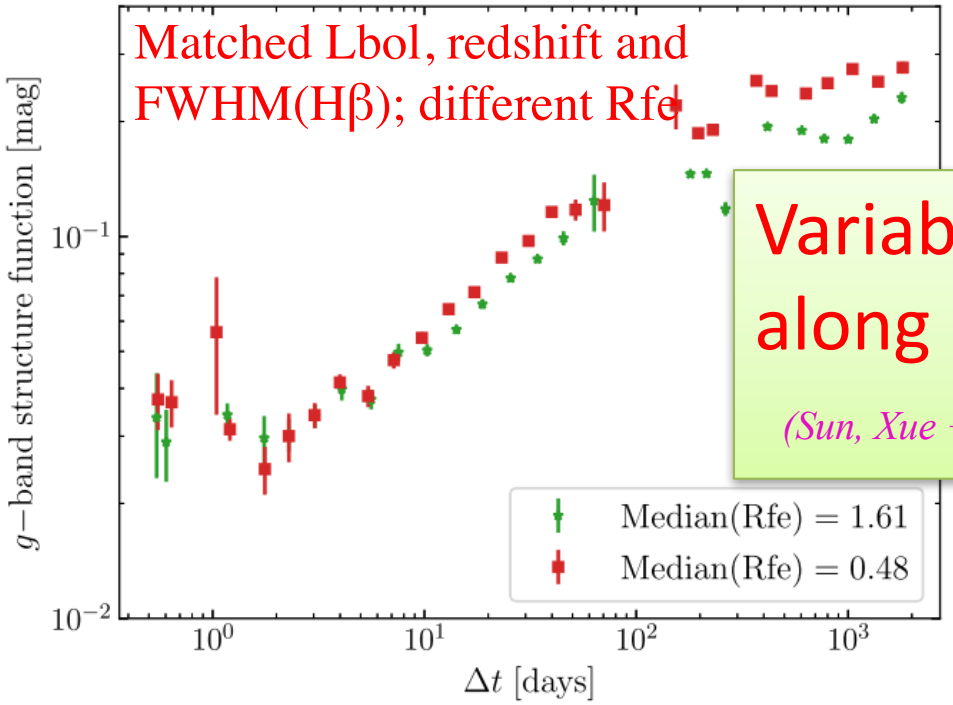
(based on cartoon by C. Ricci)



(Shen & Ho 2014)

Quasar main sequence/wedge

$$\log M_{BH,obs} = p_1 + \log L + 2\log FWHM$$

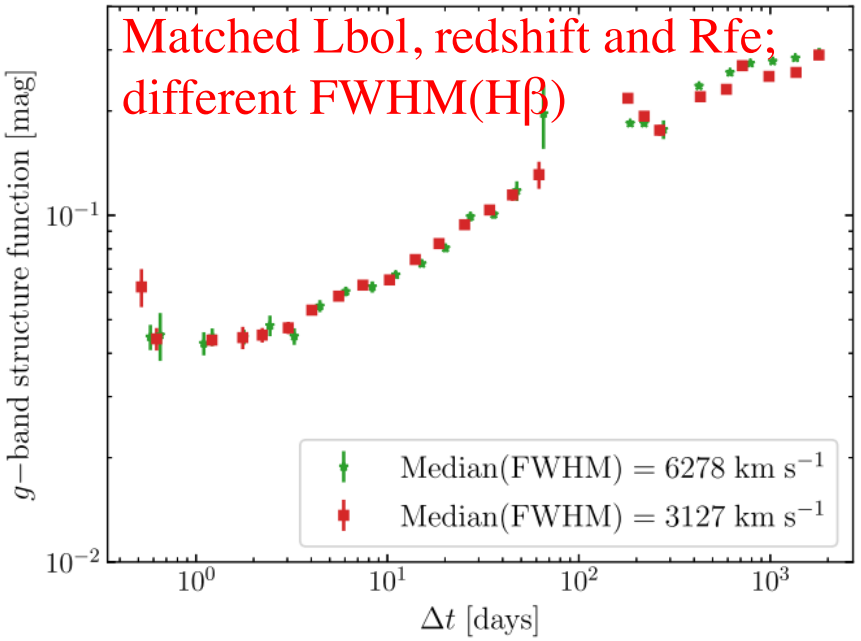


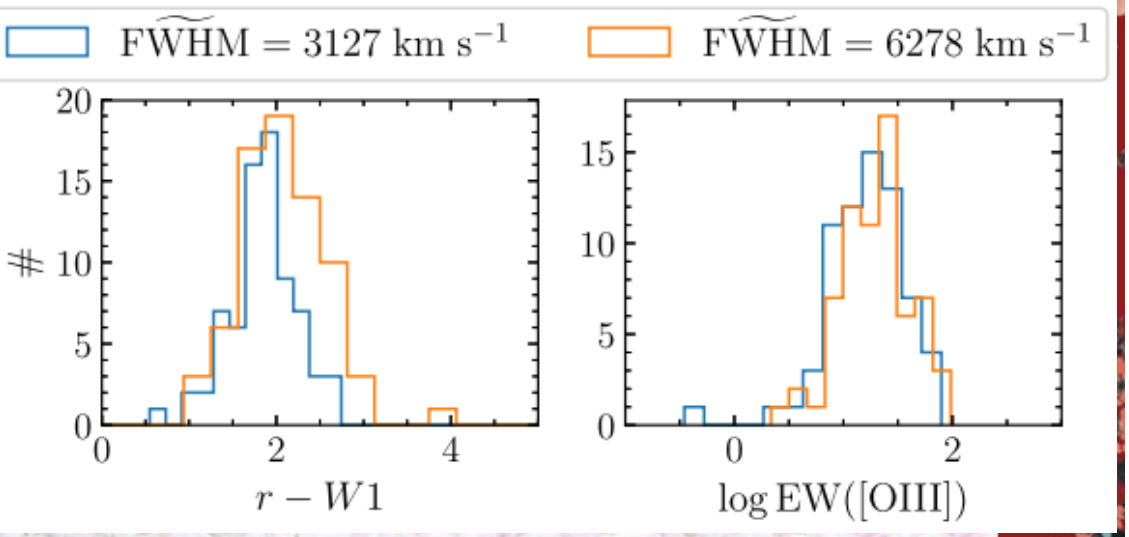
Variability along MS

(Sun, Xue +2018a)

SDSS Stripe 82 quasars

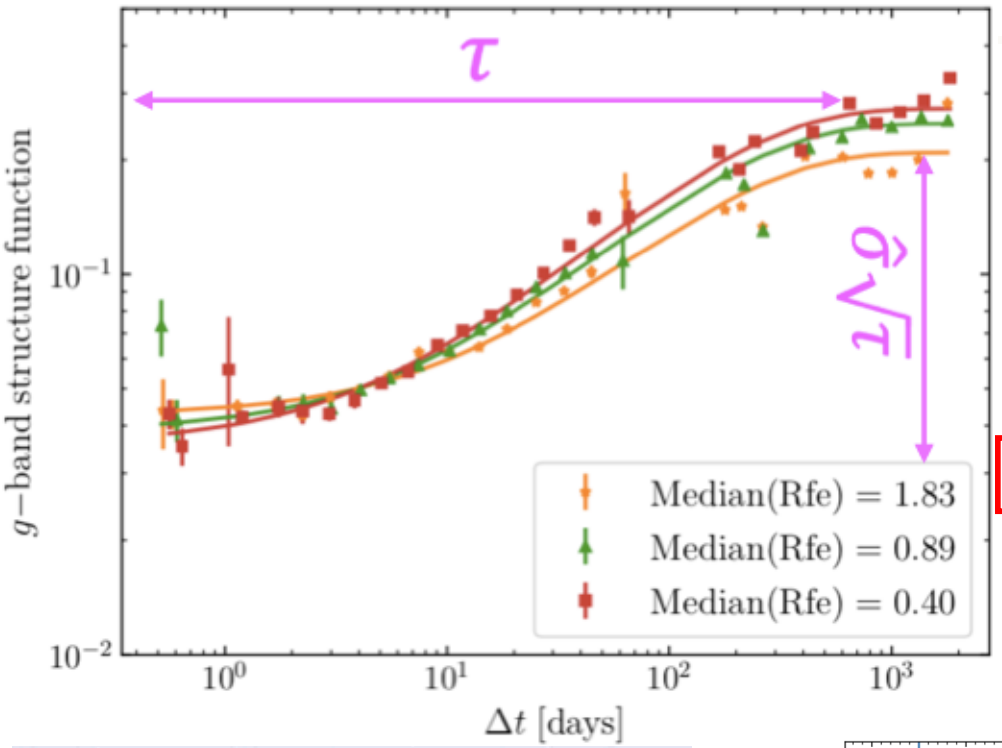
Consistent with Shen & Ho+14:
- Rfe indicates Eddington ratio





- FWHM scatter reflects orientation

We should explore variability as a function of Lbol and Rfe



$$\log \tau = 2.49 + 0.5(\log L_{\rm bol} - 45.5)$$

Luminosity-distance independent

$$\log \hat{\sigma} = -1.788\text{–}0.26(\log L_{\rm bol} - 45.50) - 0.08 R_{\rm Fe\,II}$$

Variability measure

$SF(\Delta t) = \sqrt{(\pi/2)\langle|\Delta m(\Delta t)|\rangle^2 - \langle\sigma^2\rangle}$

$SF(\Delta t) = \sqrt{\langle(\Delta m(\Delta t))^2\rangle - \langle\sigma^2\rangle}$

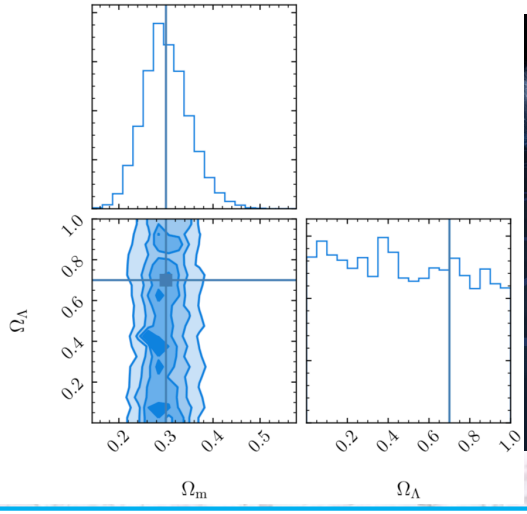
where $\Delta m(\Delta t) = m(t_1) - m(t_2)$

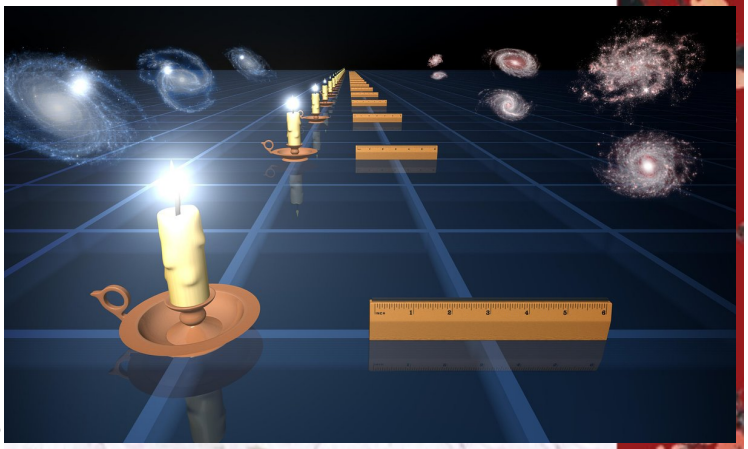
A robust measure for irregularly spaced data

$$SF(\Delta t|\tau, \hat{\sigma}) = \hat{\sigma}\sqrt{\tau(1 - \exp(-\Delta t/\tau))}$$

$\hat{\sigma}$: short-term variability amplitude

τ: characteristic timescale





AGN short-term variability as "standard candle"?!

(Sun, Xue +2018a)

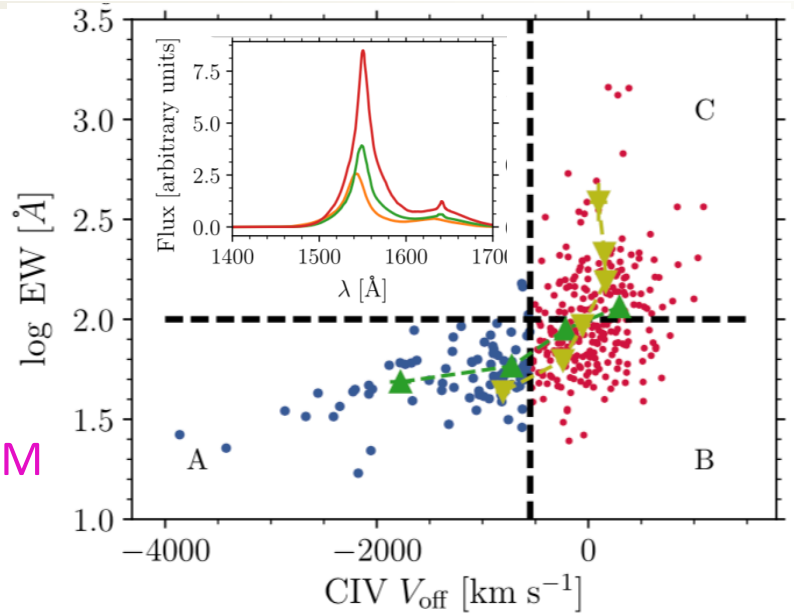
- Further evidence: quasar diversity largely determined by orientation (FWHM) and Eddington ratio (Rfe)
- BLR is disk-like (FWHM depends on orientation)
- Iron strength (Rfe) controls quasar variability (why?!)
- AGN short-term variability as a potential standard candle

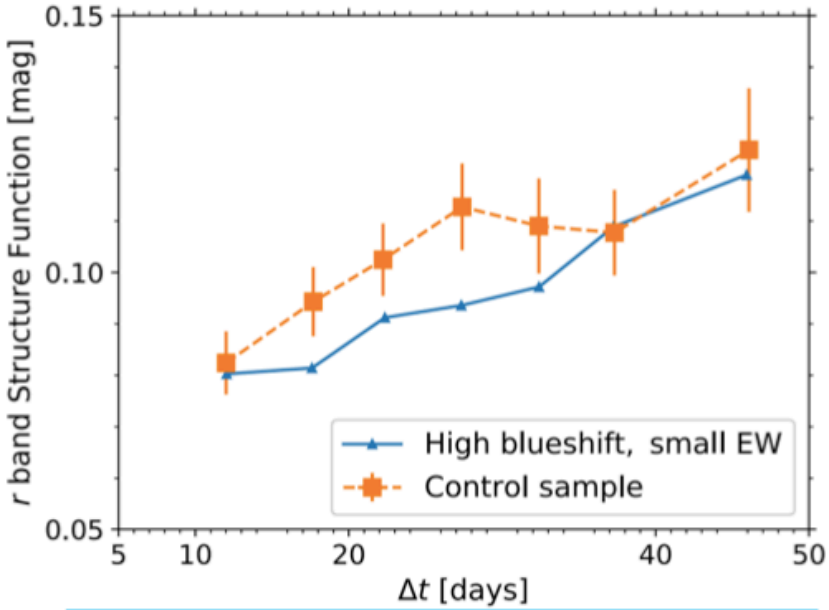
(Sun, Xue +2018a)

High-z: CIV (Mbh)

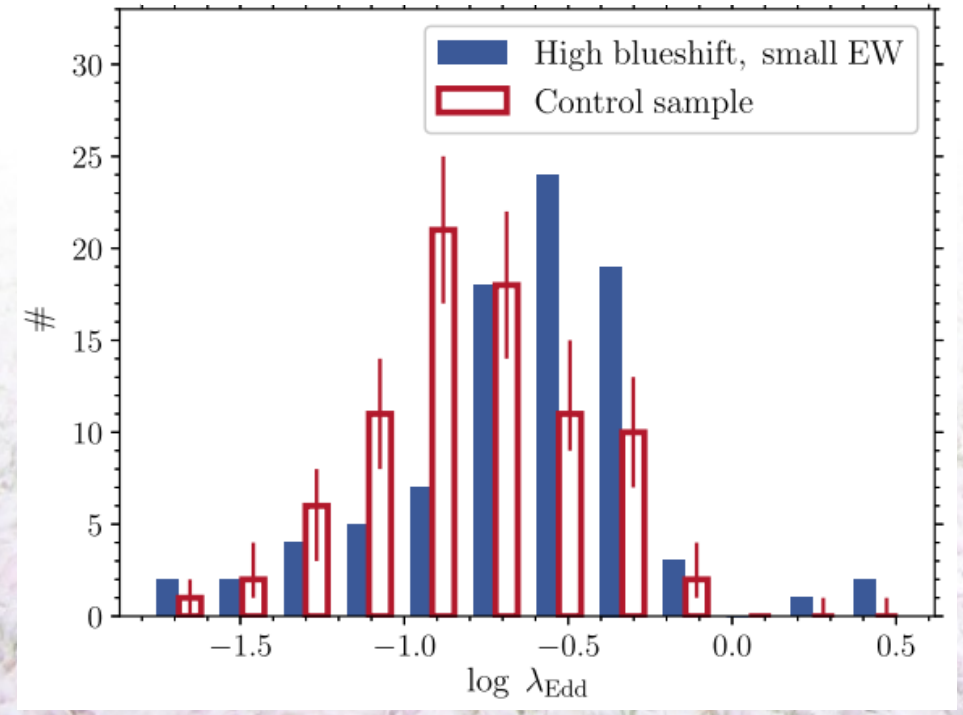
(Sun, Xue +2018b)

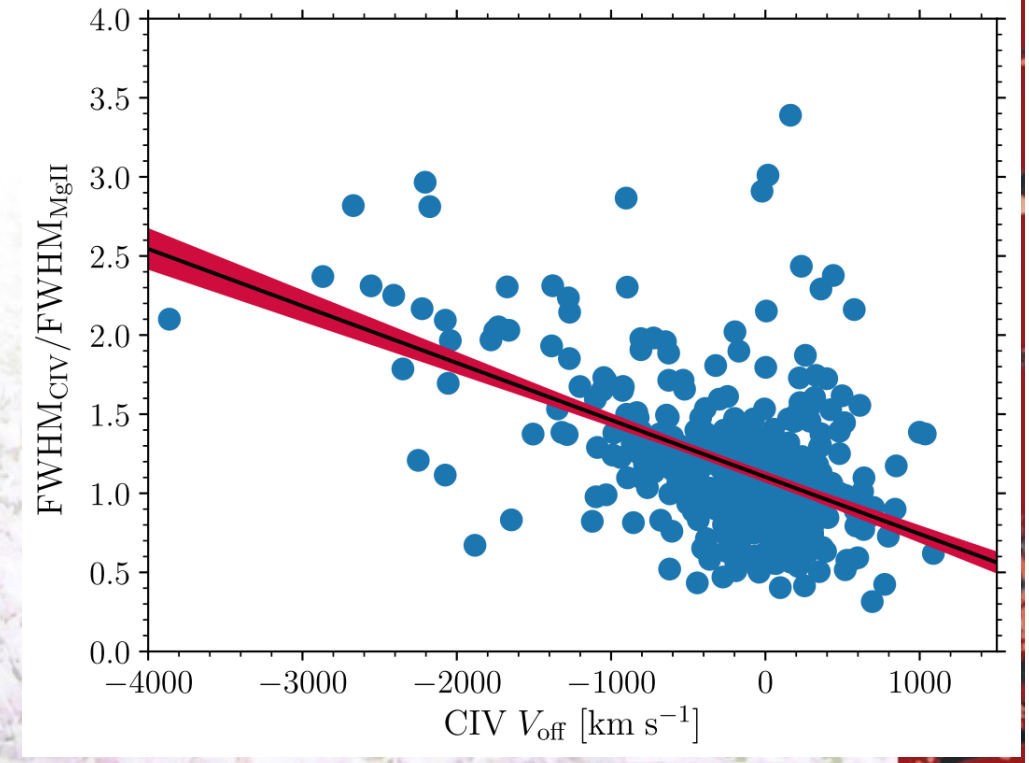
SDSS-RM





Inconsistent with the orientation scenario. High blueshift CIV sources are intrinsically less active!!!





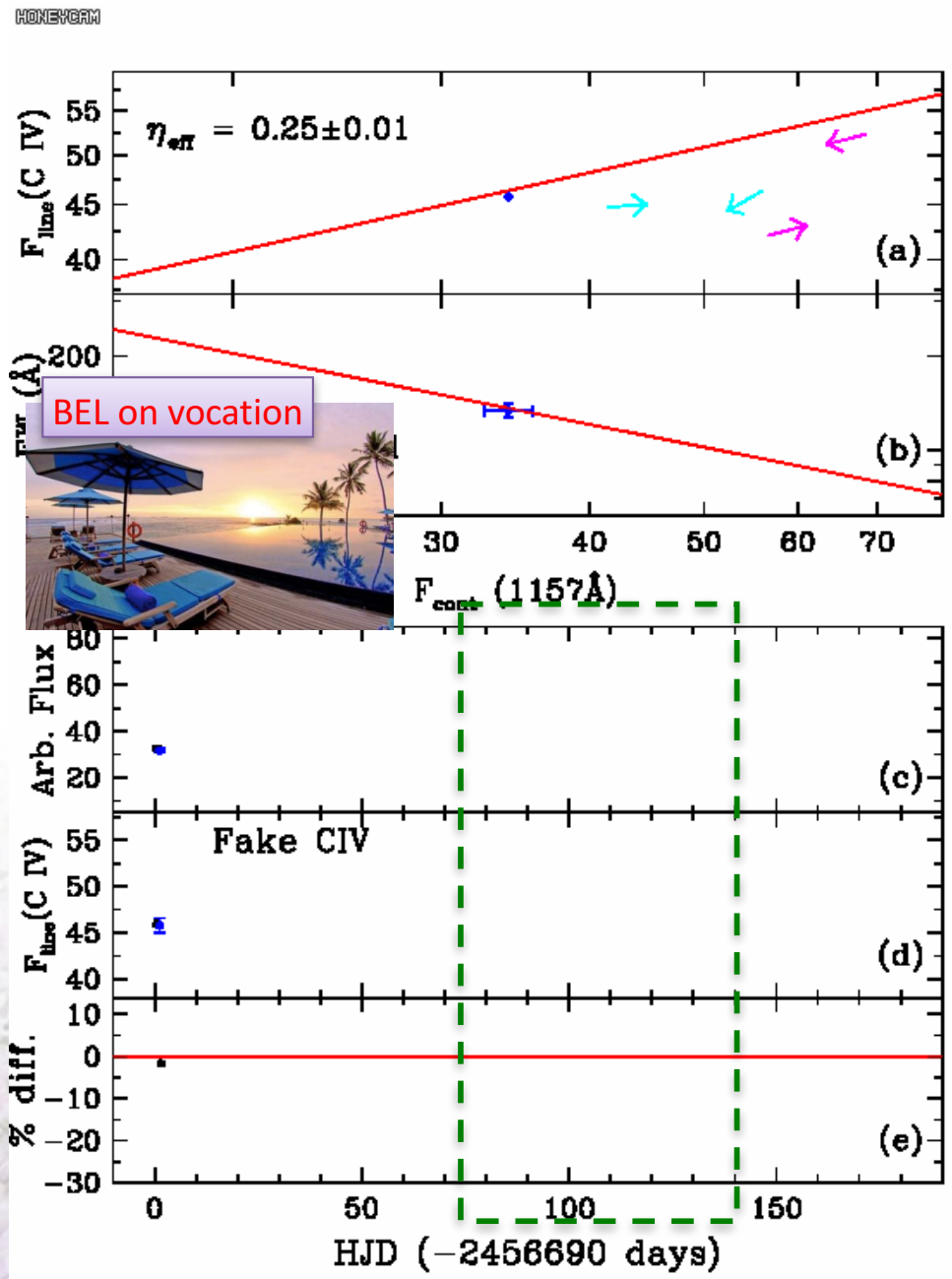
University of Science and Technology of China 中国科学技术大学

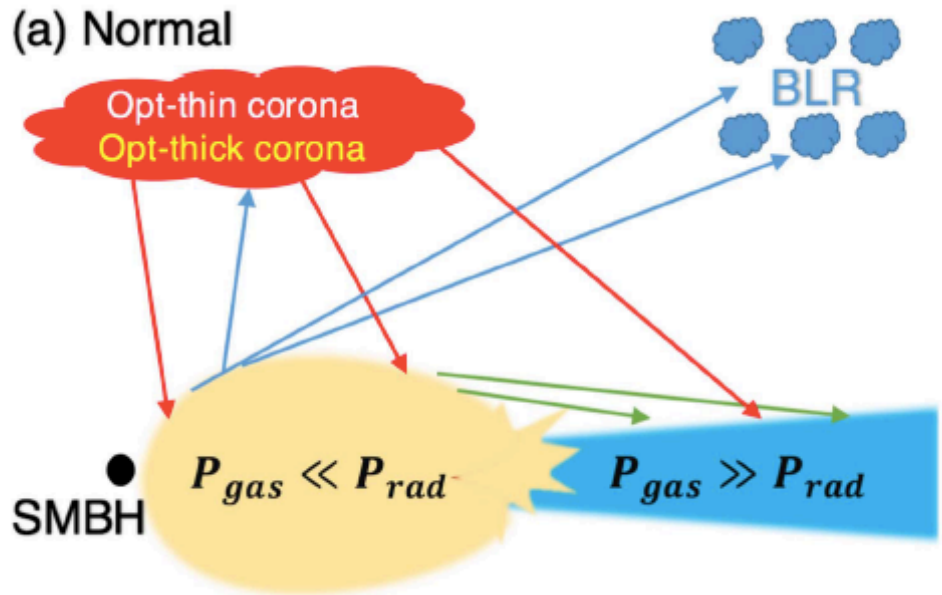
- Non-virial motions for high-ionization lines (e.g., CIV)
- High-blueshift quasars tend to have smaller EWs
- High-blueshift quasars tend to have larger Eddington ratios
- High-blueshift quasars tend to be intrinsically less active
- CIV Mbh estimator might be used after being corrected

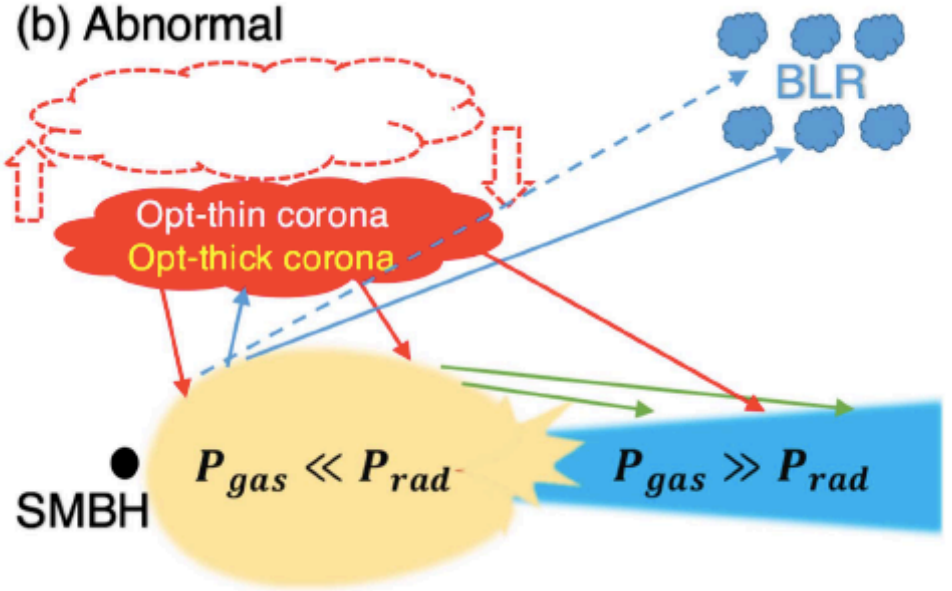
(Sun, Xue +2018b)

A Falling Corona Model for the Anomalous Behavior of the Broad Emission Lines in NGC 5548

(Sun, Xue +2018c)







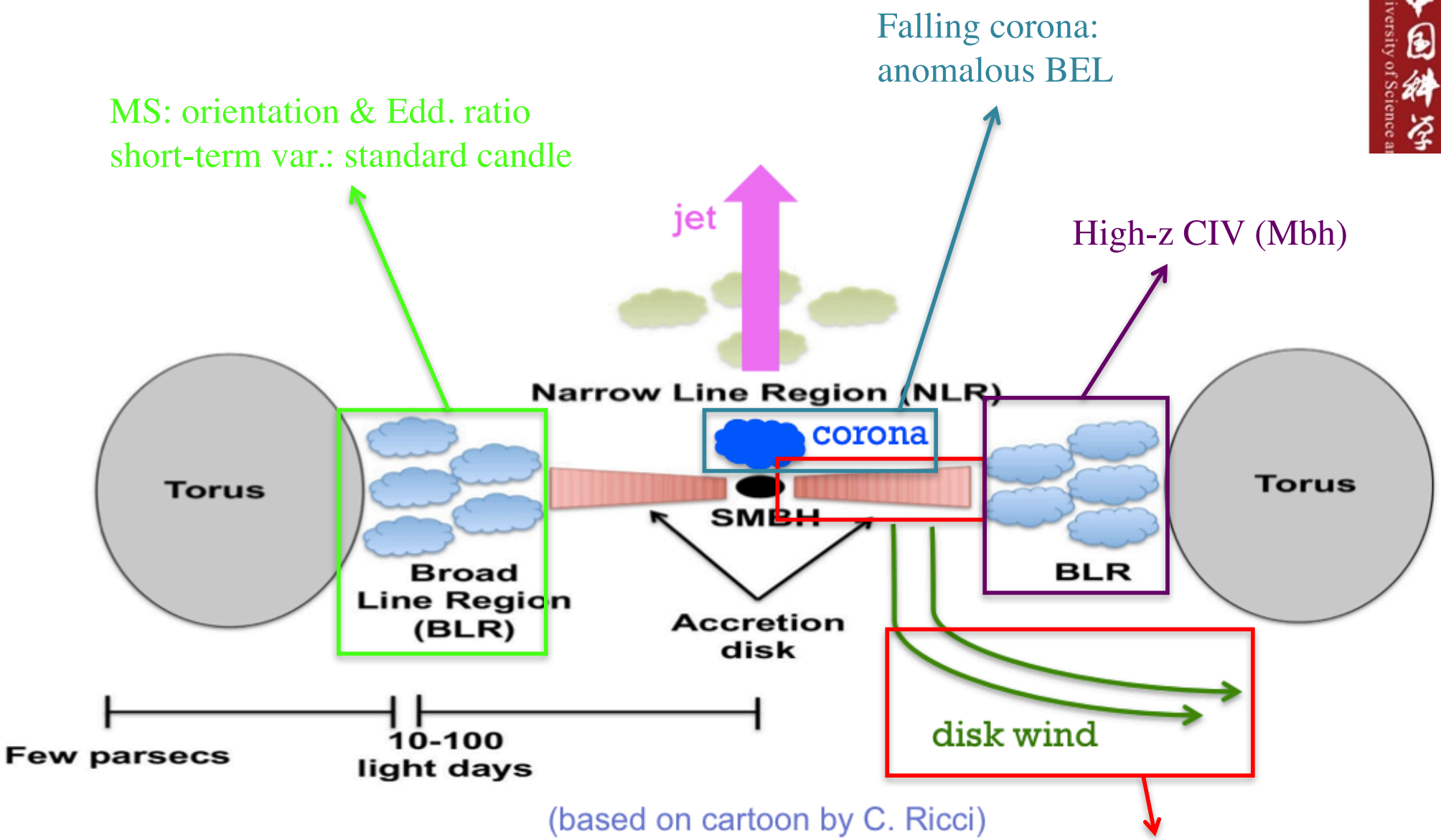
- A falling corona model for the anomalous BEL behavior
- Help understand RM results
- Can even predict another anomalous BEL behavior

(Sun, Xue +2018c)

Outline

- Why do we study AGN variability?
- What have we done recently?
  - Tales centered around quasar UV/optical variability
- What are the take-home messages?

Some take-home messages :)



Variability studies vital for probing AGN physics:

- Windy disks → blow up AGN disk sizes
  (Sun, Xue +2019, MNRAS, 482, 2788)
- Orientation & Edd. ratio → MS; short-term var. → standard candle
  (Sun, Xue +2018a, ApJ, 866, 74)
- High blueshifts → larger Edd. ratios; corrected CIV → high-z Mbh
  (Sun, Xue +2018b, ApJ, 854, 128)
- Falling corona → anomalous BEL behavior
  (Sun, Xue +2018c, ApJ, 857, 86)


Mouyuan Sun


Mouyuan Sun


Mouyuan Sun


Mouyuan Sun

Thank you very much!