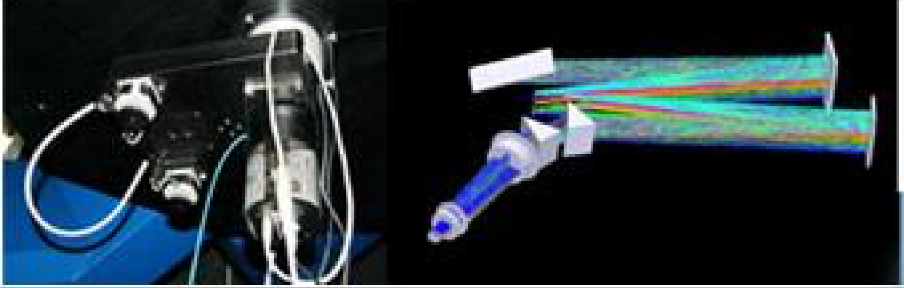


山东大学（威海）
SHANDONG UNIVERSITY, WEIHAI

TDE and other variability in Blazars

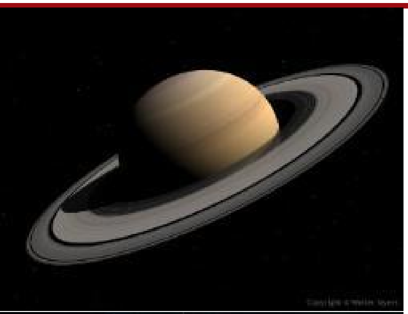
Shaoming Hu

Jingran Xu, Shifeng Huang, Hongxing Yin

Oct 2024 @ Shanghai

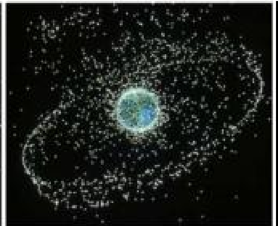
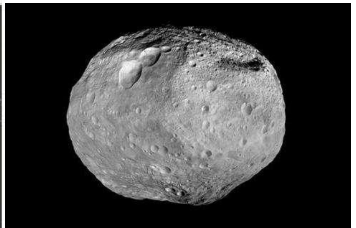
Transient Phenomena and Physical Processes Around Supermassive Black Holes

Outline

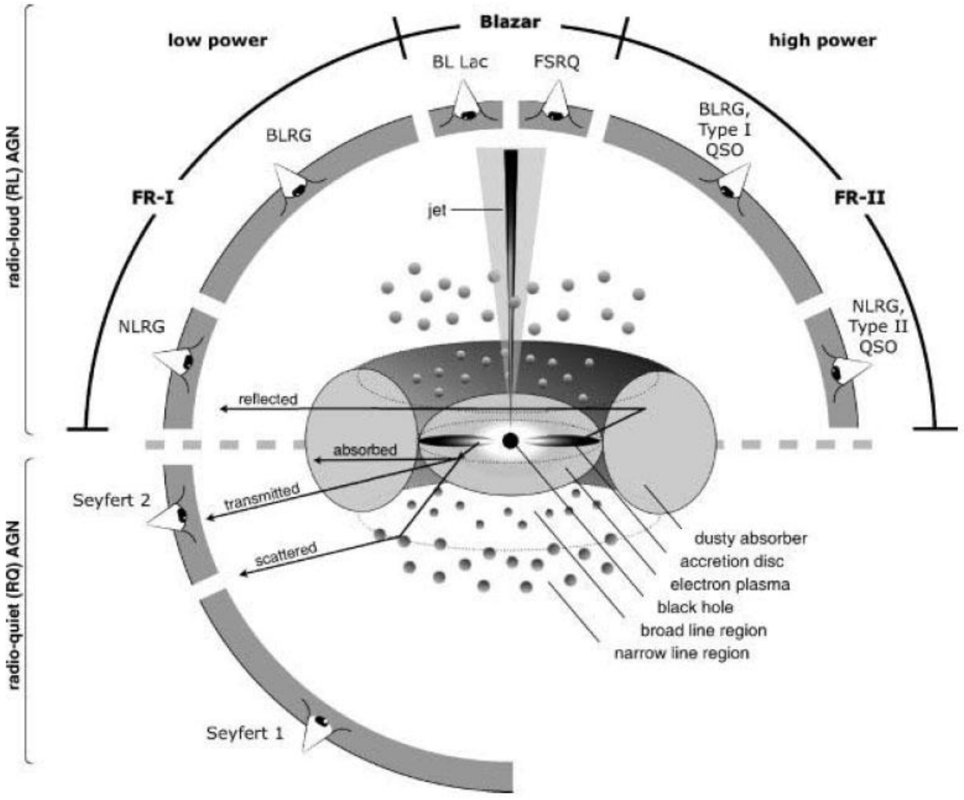


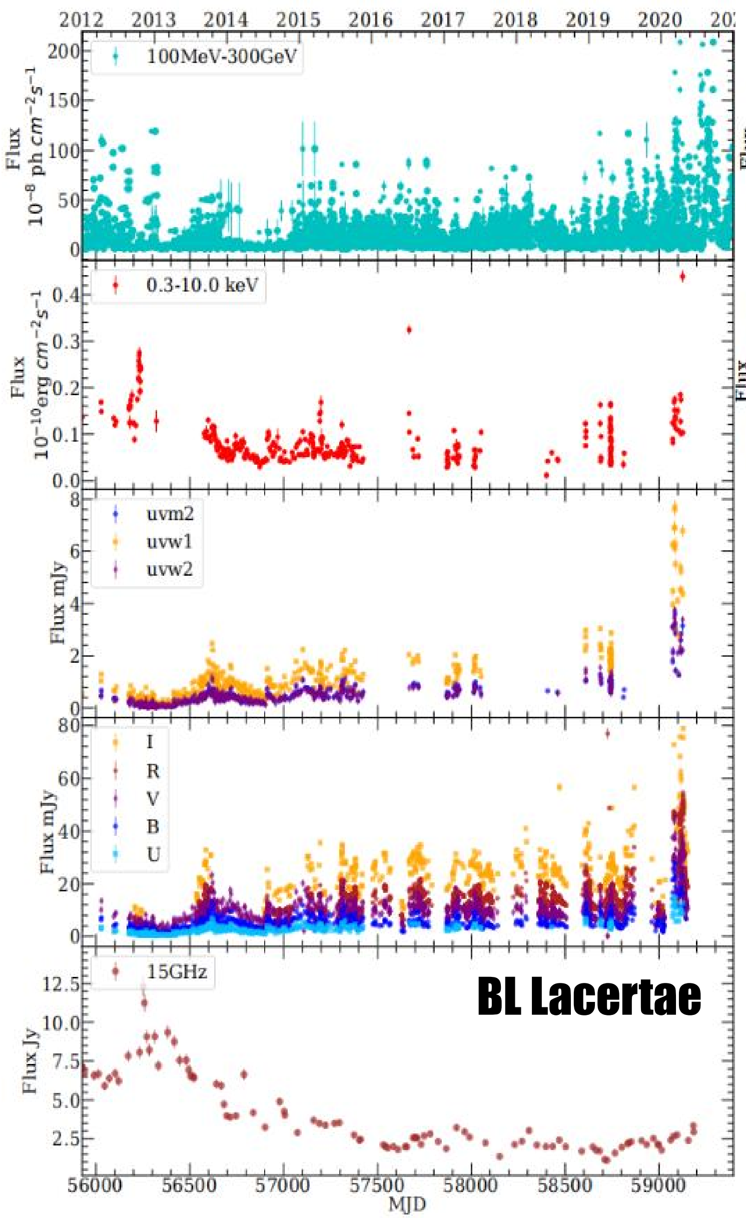

- Variability properties of blazars
- TDE in OJ 287
- Telescopes and Instruments of Shandong University

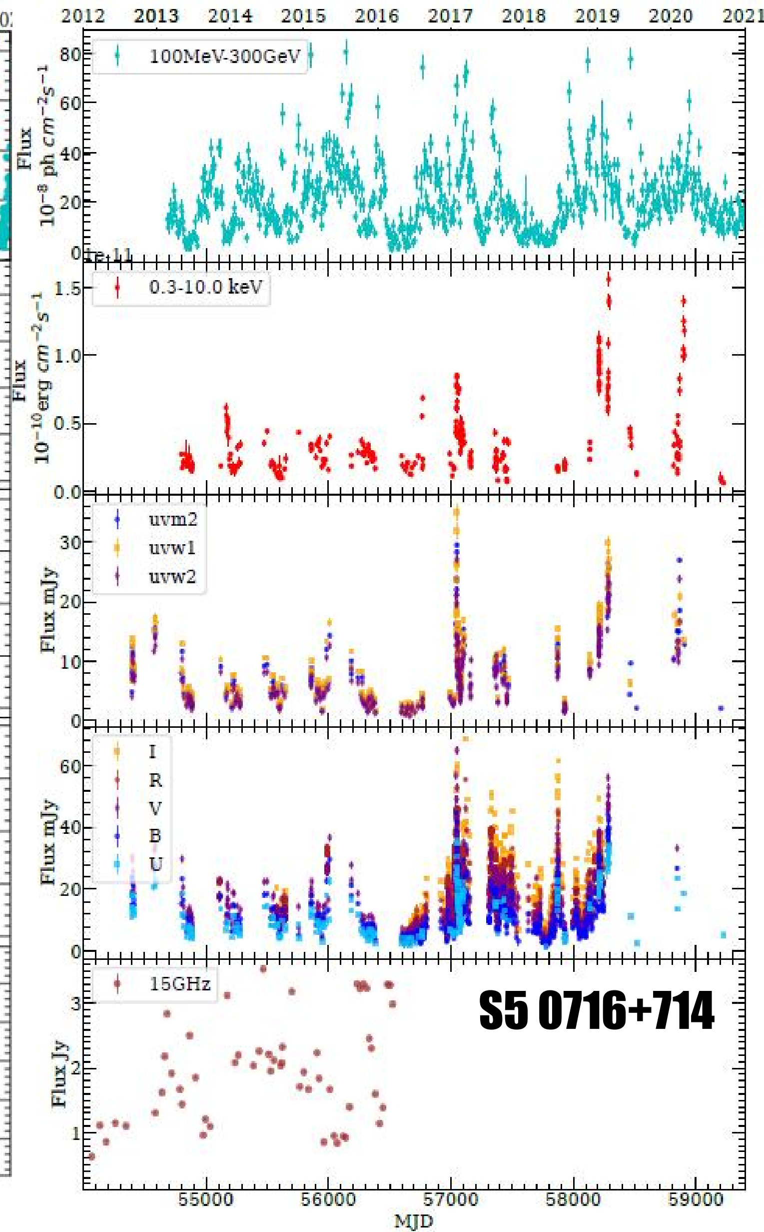


Multiband variability of Blazar



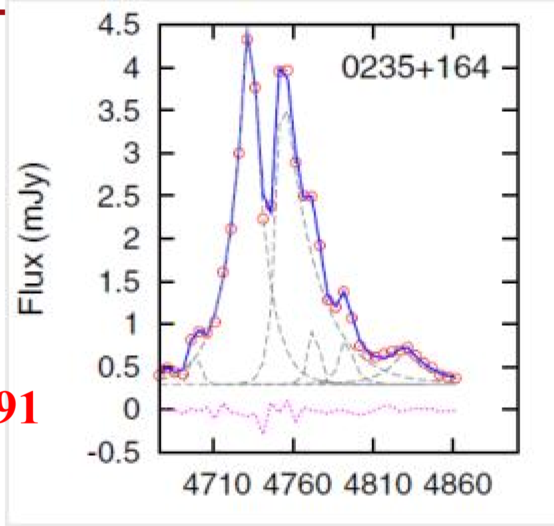




- ➢ What is physical source of the variability?
- ➢ Is there any TDE related variability?

Statistical analysis for blazar flares

The light curves could be decomposed into individual flares using fitting methods.



2012-AJ-749:191

Valtaoja (1999)

$$\Delta S(t) = \begin{cases} \Delta S_{\max} e^{(t-t_{\max})/\tau}, & t < t_{\max} \\ \Delta S_{\max} e^{(t_{\max}-t)/1.3\tau}, & t > t_{\max} \end{cases}$$

Abdo (2010)

$$F(t) = F_c + F_0 \frac{1}{e^{\left(\frac{t_0 - t}{T_r}\right)} + e^{\left(\frac{t - t_0}{T_d}\right)}}$$

Chatterjee (2012)

$$f(t) = f_0 + f_{max} \times \exp[(t - t_0)/T_r], t < t_0$$
$$= f_0 + f_{max} \times \exp[-(t - t_0)/T_d], t > t_0$$

- Flare duration time

$$T \simeq 2(T_r + T_d)$$

- Skewness parameter

$$\xi = \frac{T_d - T_r}{T_d + T_r}$$

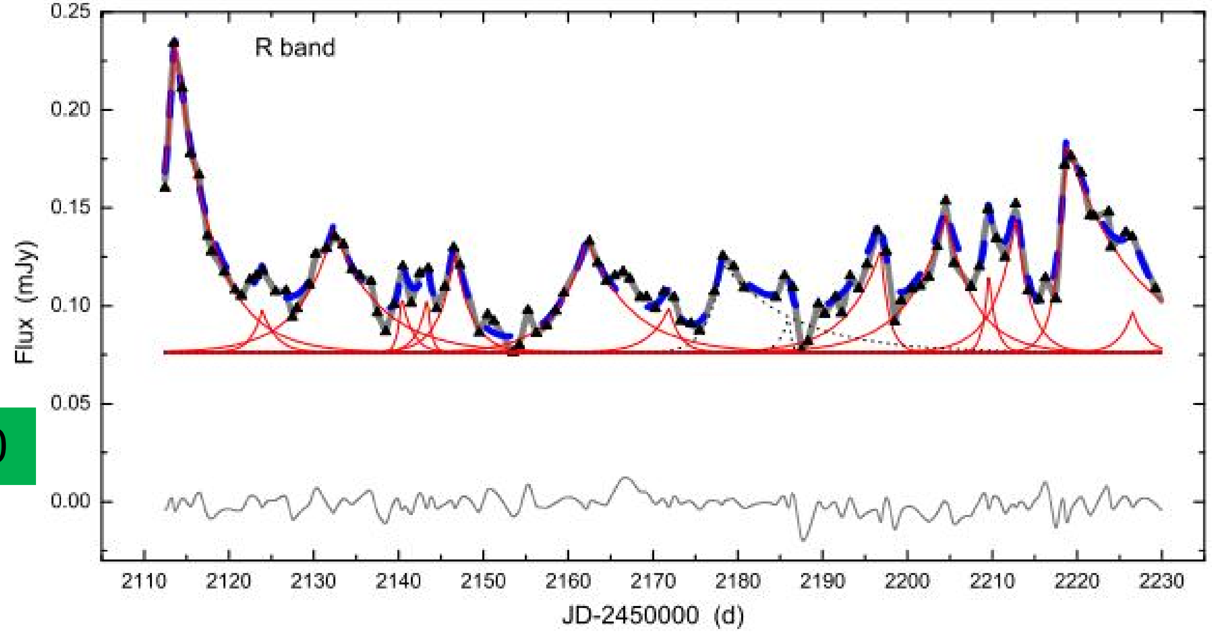
- Amplitude of flare

$$f_{max}$$

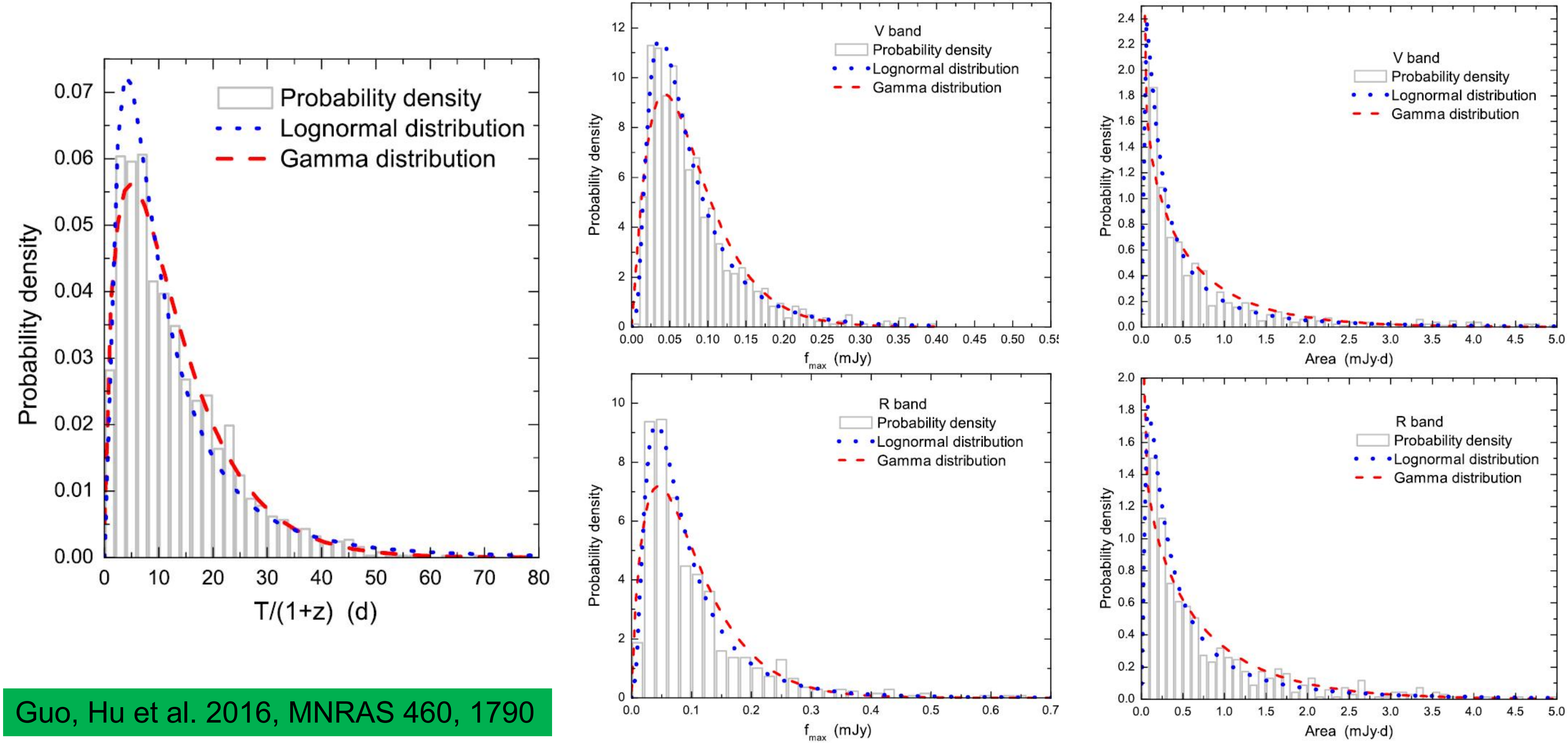
- Energy output

$$Area = \int_{-\infty}^{+\infty} f(t) - f_0 \, dt = f_{max}(t_r + t_d)$$

Guo, Hu et al. 2016, MNRAS 460, 1790

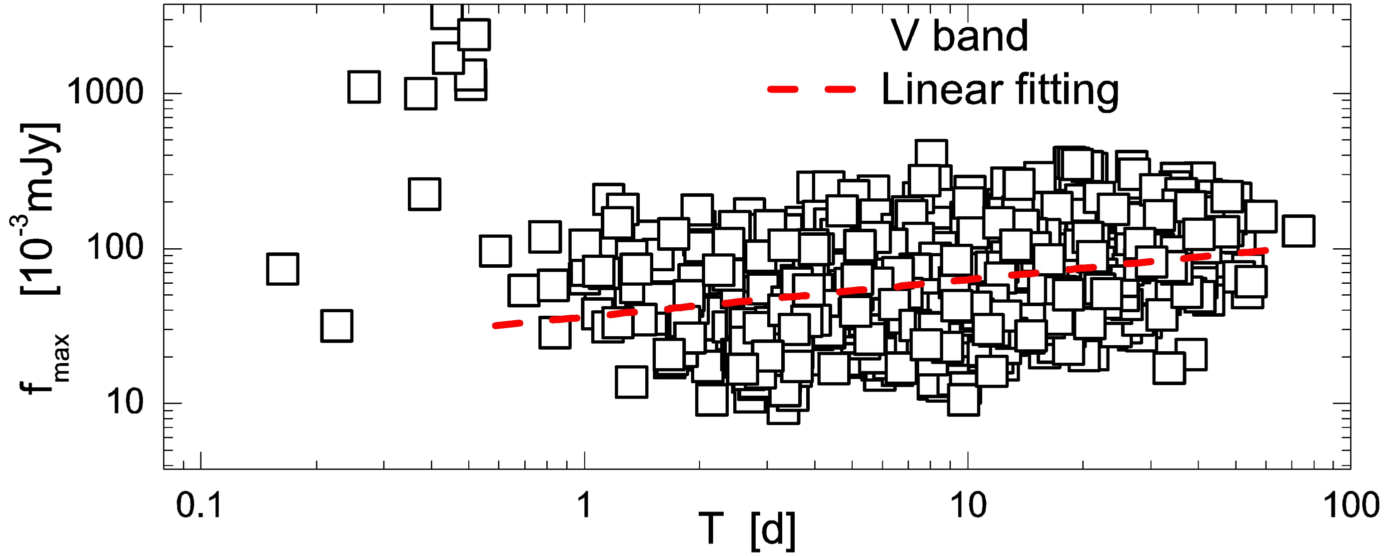


Optical Flares properties of BL Lac

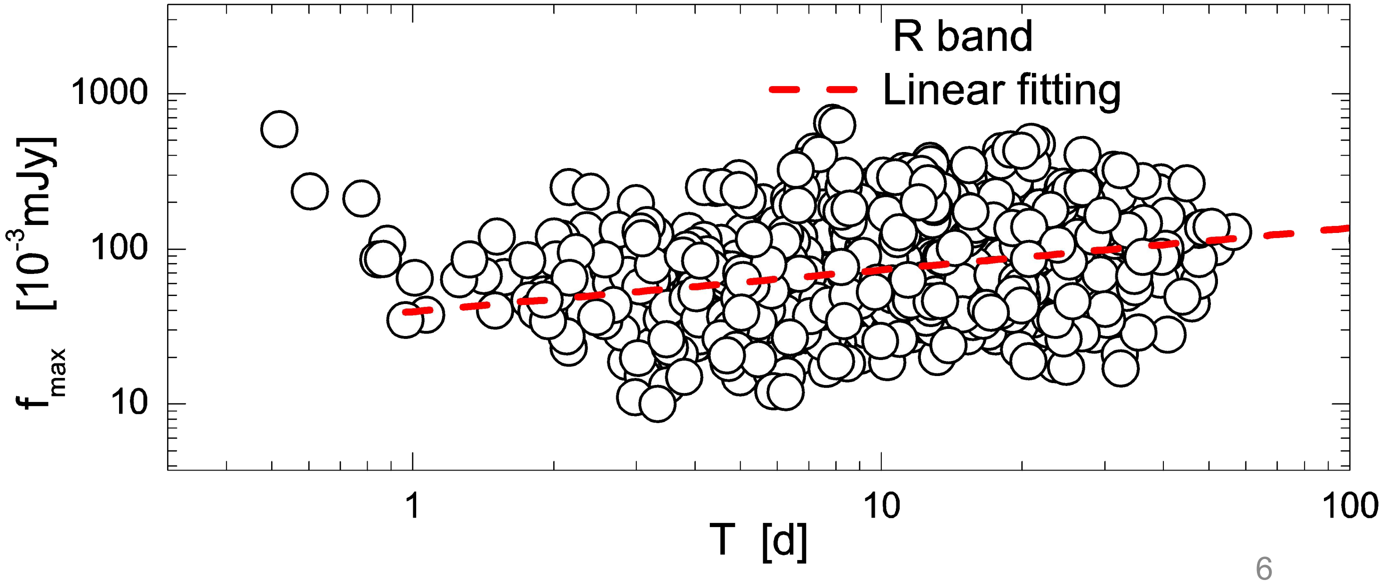


Guo, Hu et al. 2016, MNRAS 460, 1790

Statistical analysis for blazar flares



Seems there are at least two mechanisms of flares



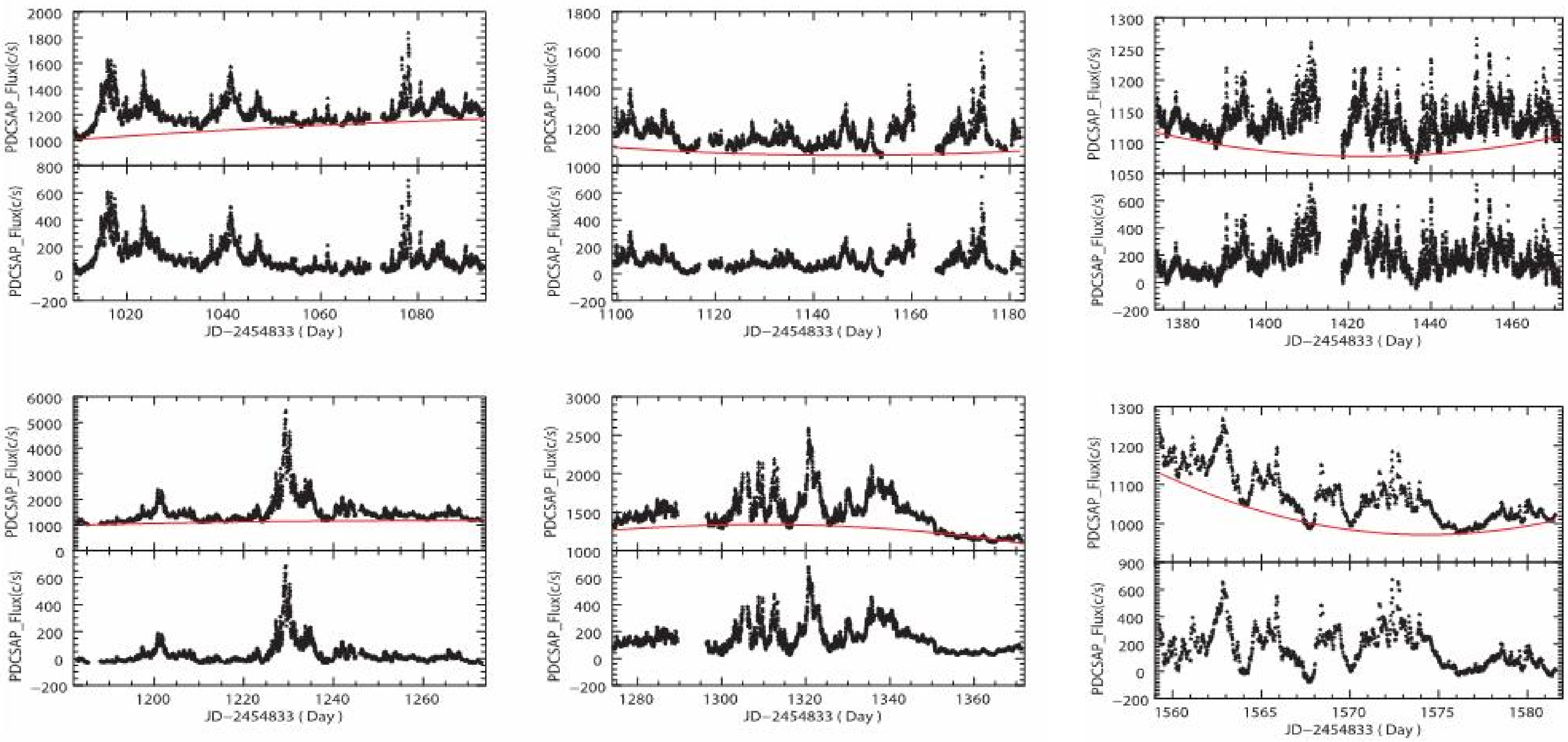
Guo, Hu et al. 2016, MNRAS 460, 1790

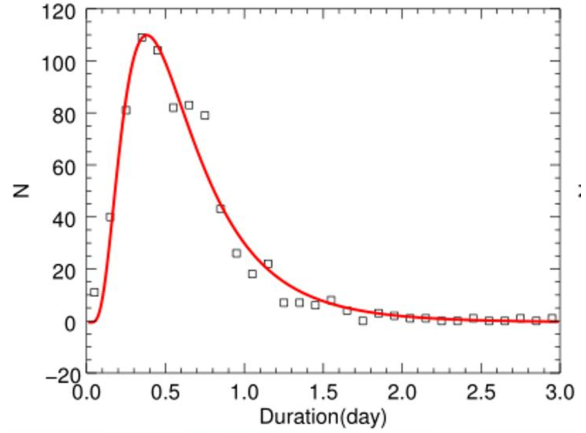
Statistical analysis for blazar flares

Name	Q11	Q12	Q13	Q14	Q15	Q16	Q17
Beginning Date	29-Sep-2011	05-Jan-2012	29-Mar-2012	28-Jun-2012	05-Oct-2012	12-Jan-2013	09-Apr-2013
Ending Date	04-Jan-2012	28-Mar-2012	27-Jun-2012	03-Oct-2012	11-Jan-2013	08-Apr-2013	11-May-2013

W2R 1926 + 42
By Kepler

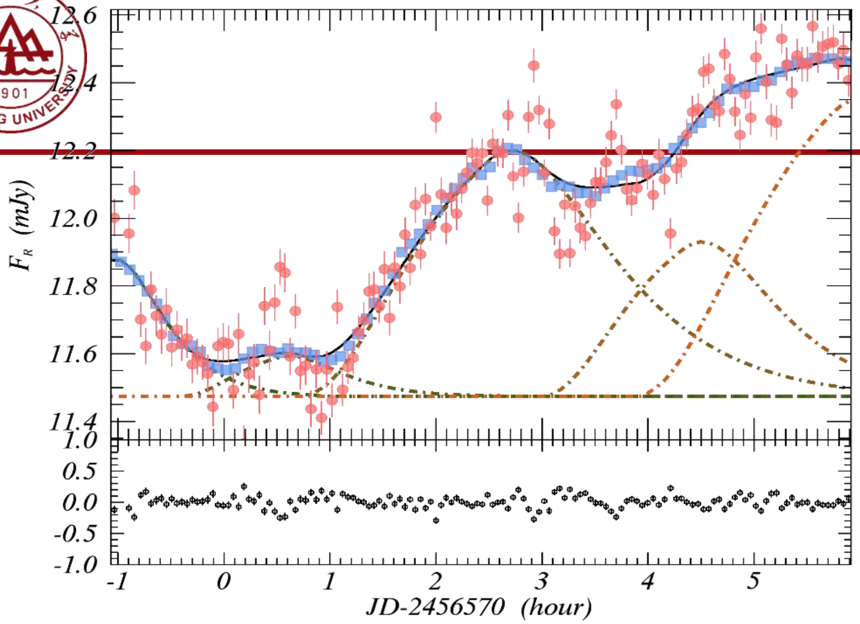
Li, Hu et al. 2018, MNRAS 478, 172

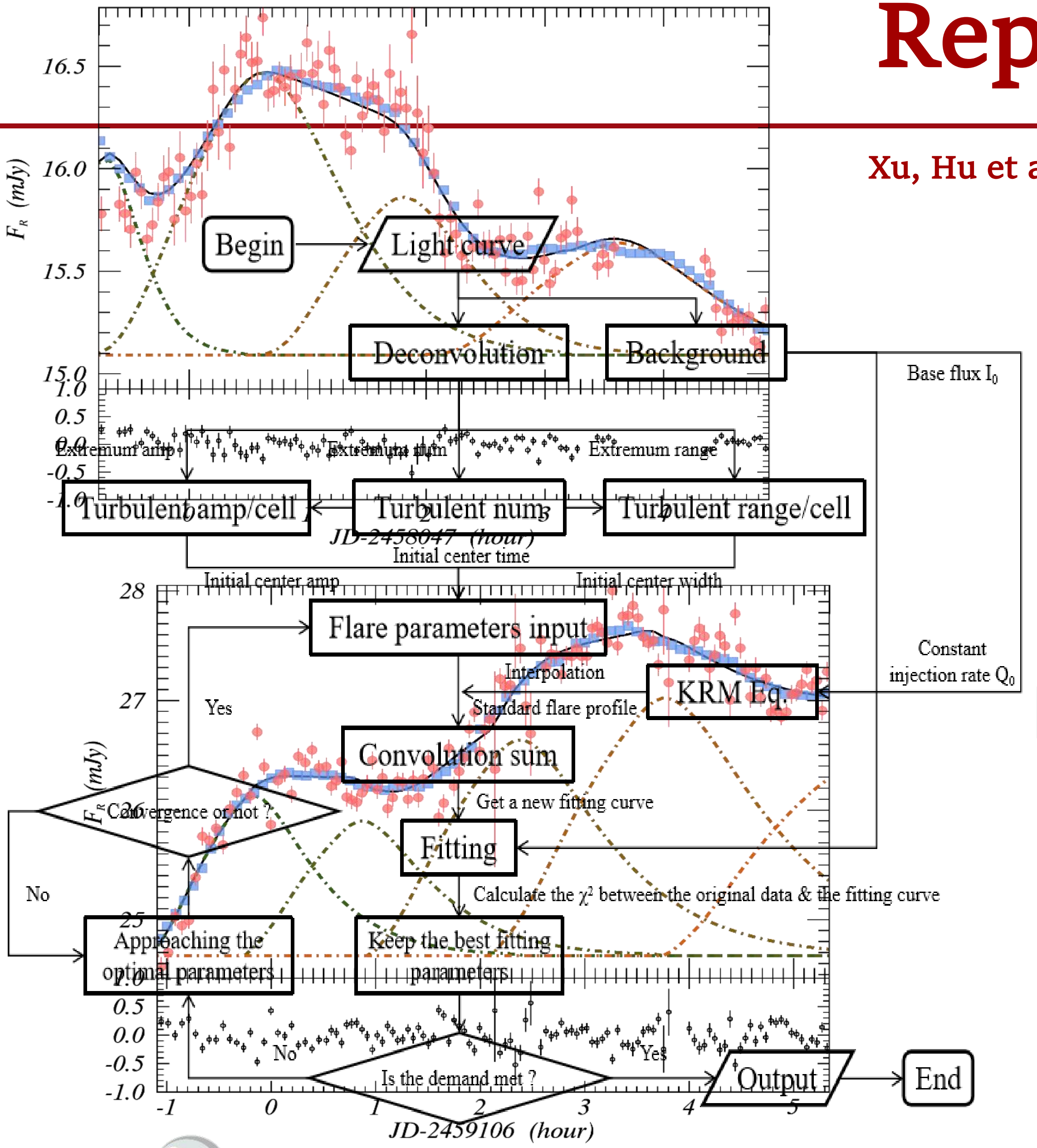


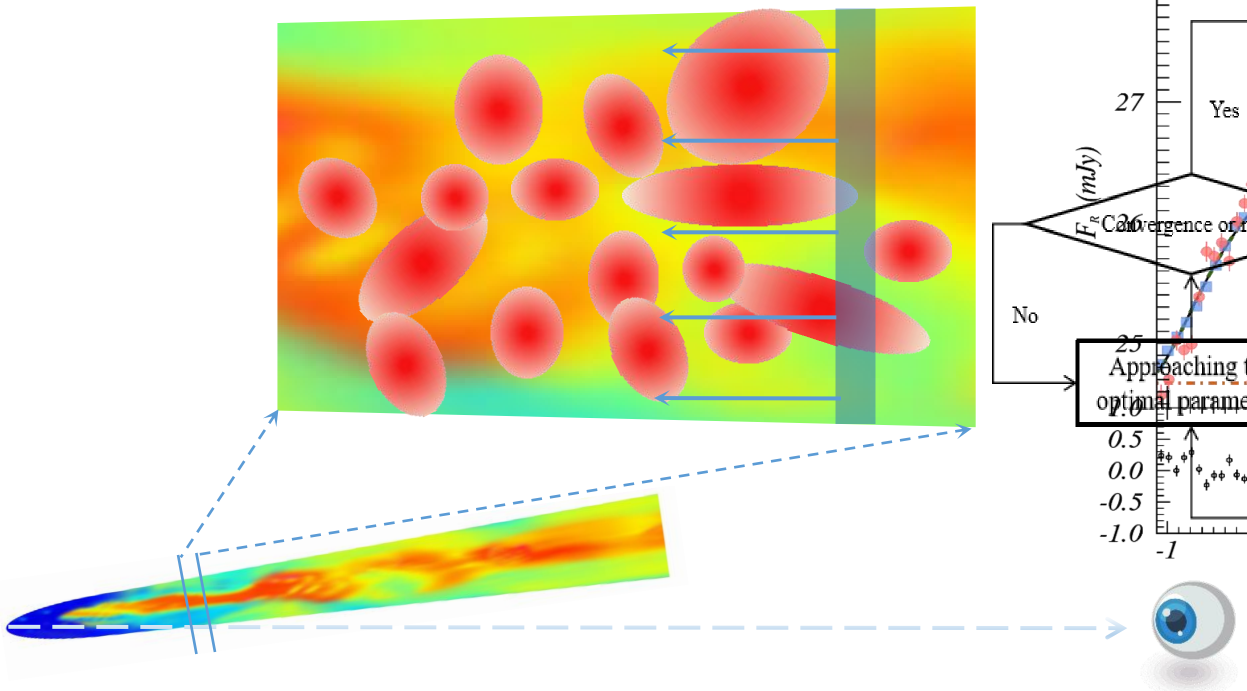


Reproduced

Xu, Hu et al., 2019, ApJ, 884, 92





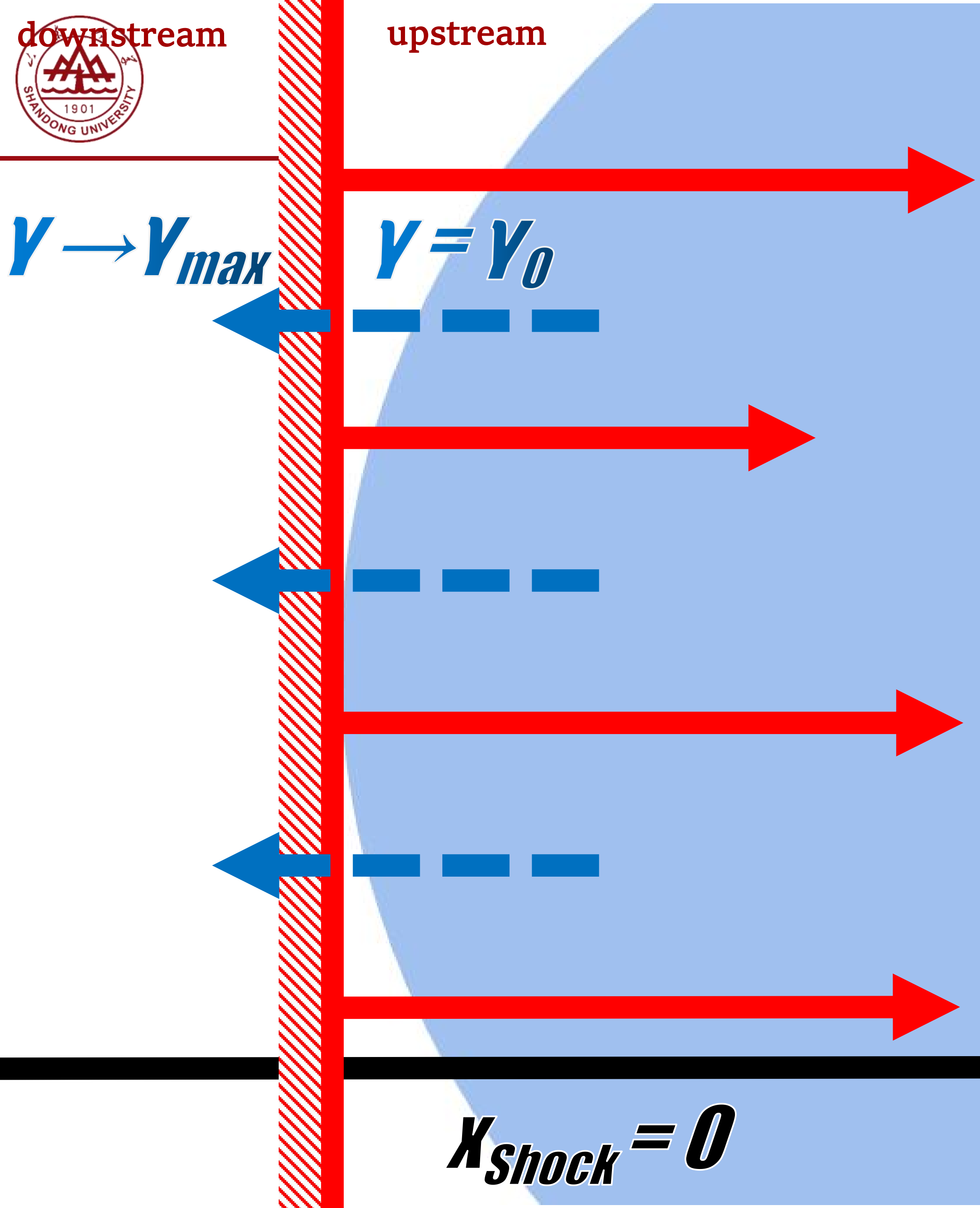


Variability Light Curve

Flare Parameters

Turbulence Parameters

Shock Acceleration



$$\frac{\partial N}{\partial t}+\frac{\partial}{\partial\gamma}\left[\left(\frac{\gamma}{t_{acc}}-\beta_s\gamma^2\right)N\right]+\frac{N}{t_{esc}}=Q\delta(\gamma-\gamma_0)$$

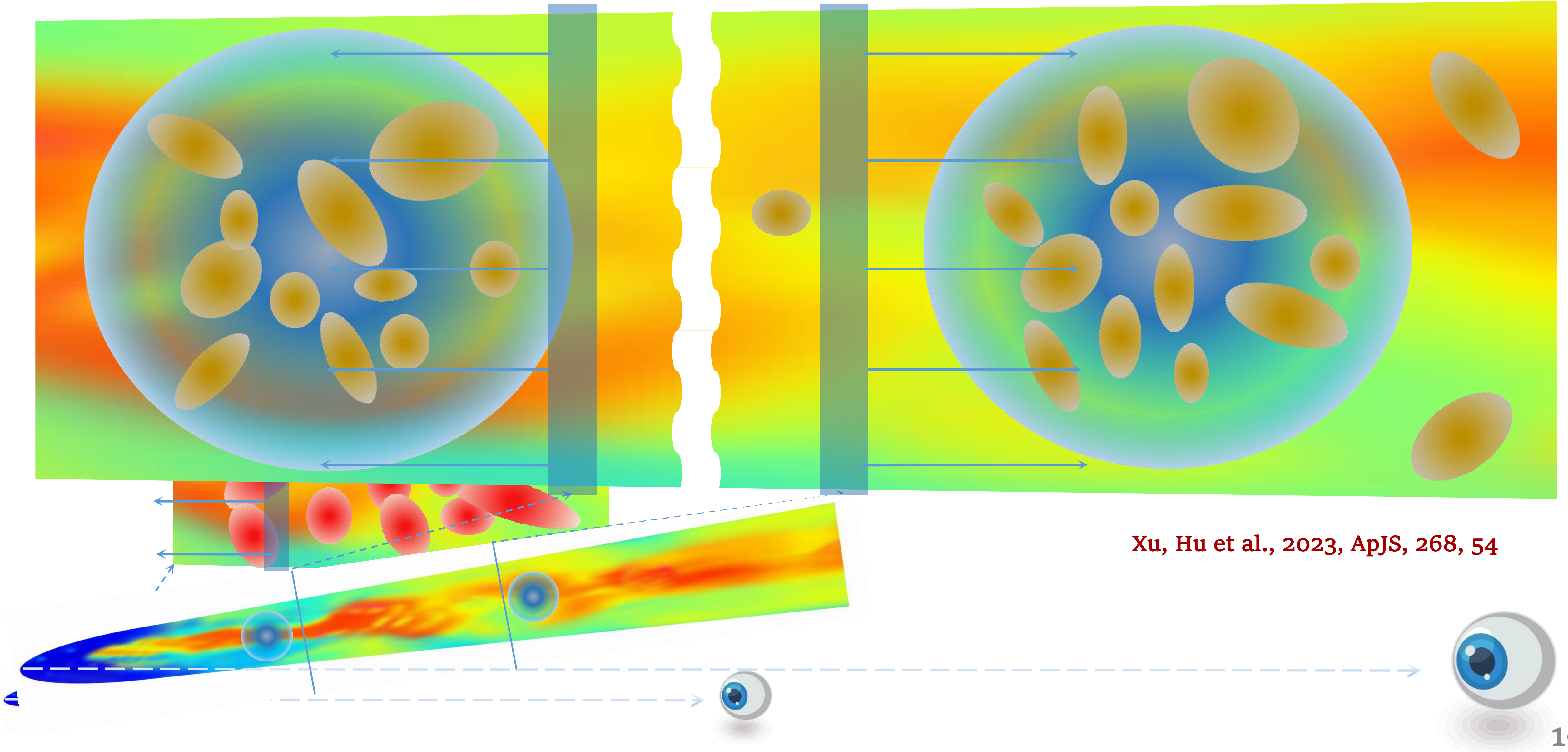
$$\beta_s=\frac{4}{3}\frac{\sigma_T}{m_e c}\left(\frac{B^2}{2\mu_0}\right)$$

$$N(\gamma,t)=a\frac{1}{\gamma^2}\left(\frac{1}{\gamma}-\frac{1}{\gamma_{max}}\right)^{(t_{acc}-t_{esc})/t_{esc}}$$
$$\times\Theta(\gamma-\gamma_0)\Theta(\gamma_1(t)-\gamma)$$

$$a=Q_0 t_{acc}\gamma_0^{t_{acc}/t_{esc}}\left(1-\frac{\gamma_0}{\gamma_{max}}\right)^{-t_{acc}/t_{esc}}$$

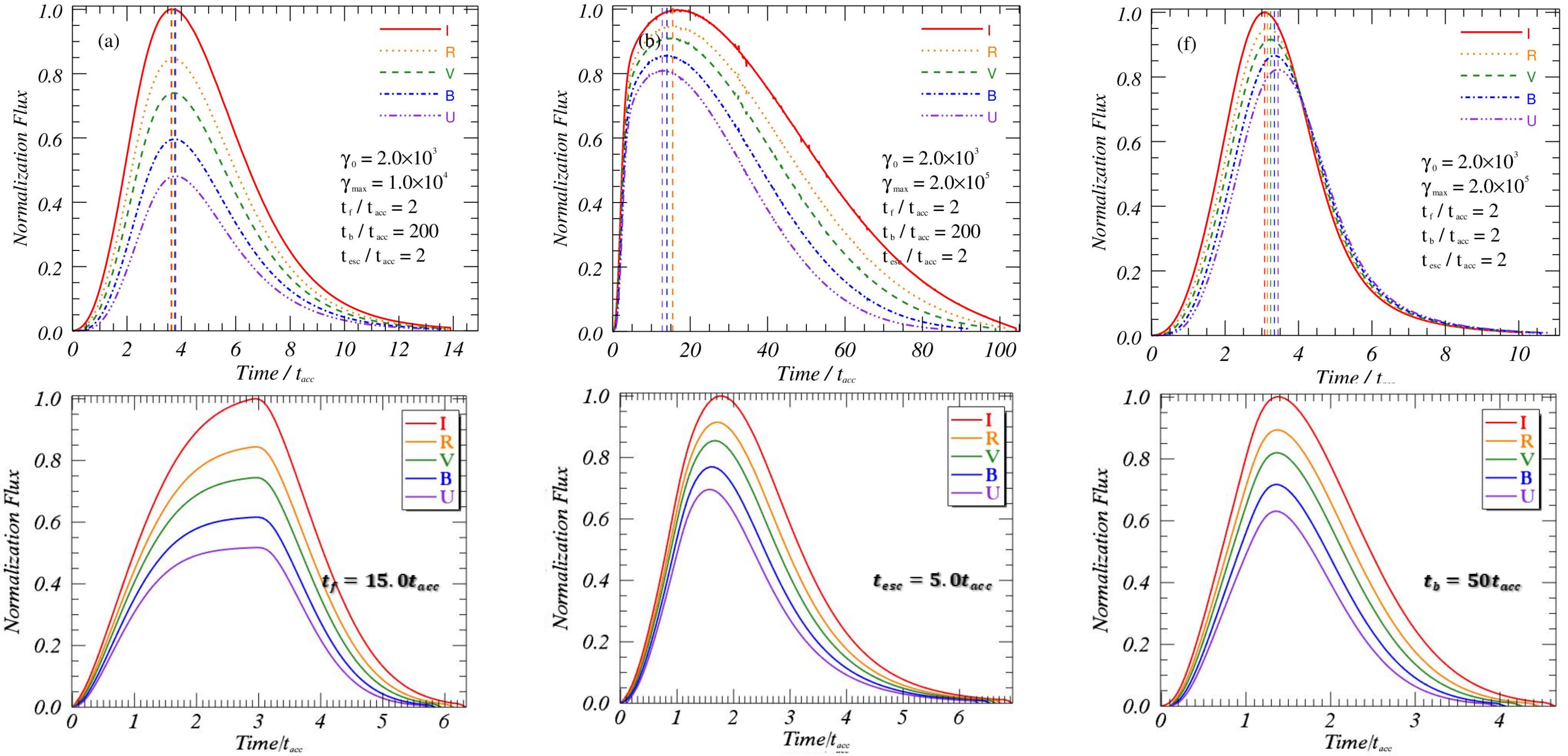
$$\gamma_1(t)=\left(\frac{1}{\gamma_{max}}+\left[\frac{1}{\gamma_0}-\frac{1}{\gamma_{max}}\right]e^{-t/t_{acc}}\right)^{-1}$$

Multi-zone Model

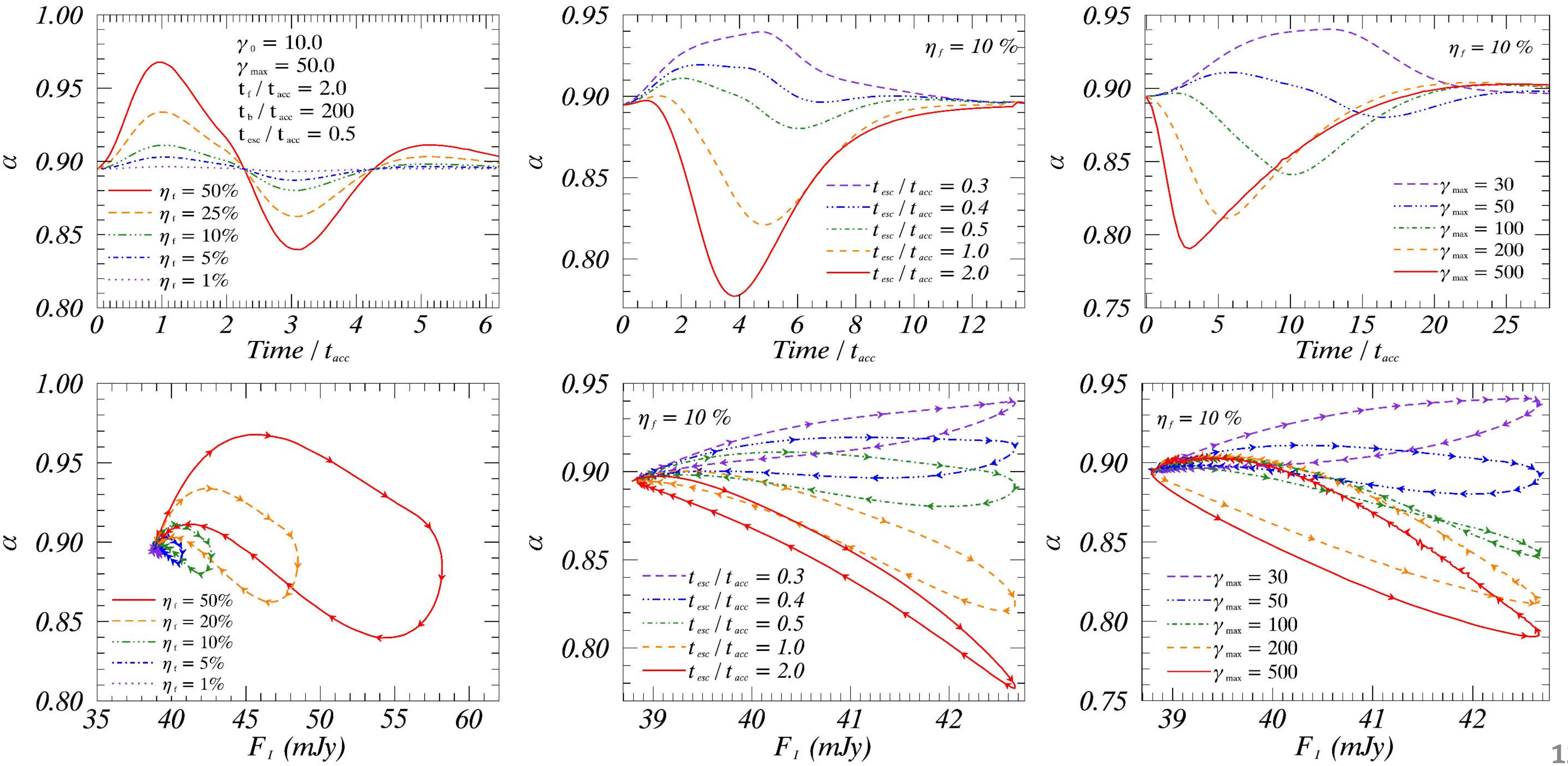


Xu, Hu et al., 2023, ApJS, 268, 54

Flare Simulation

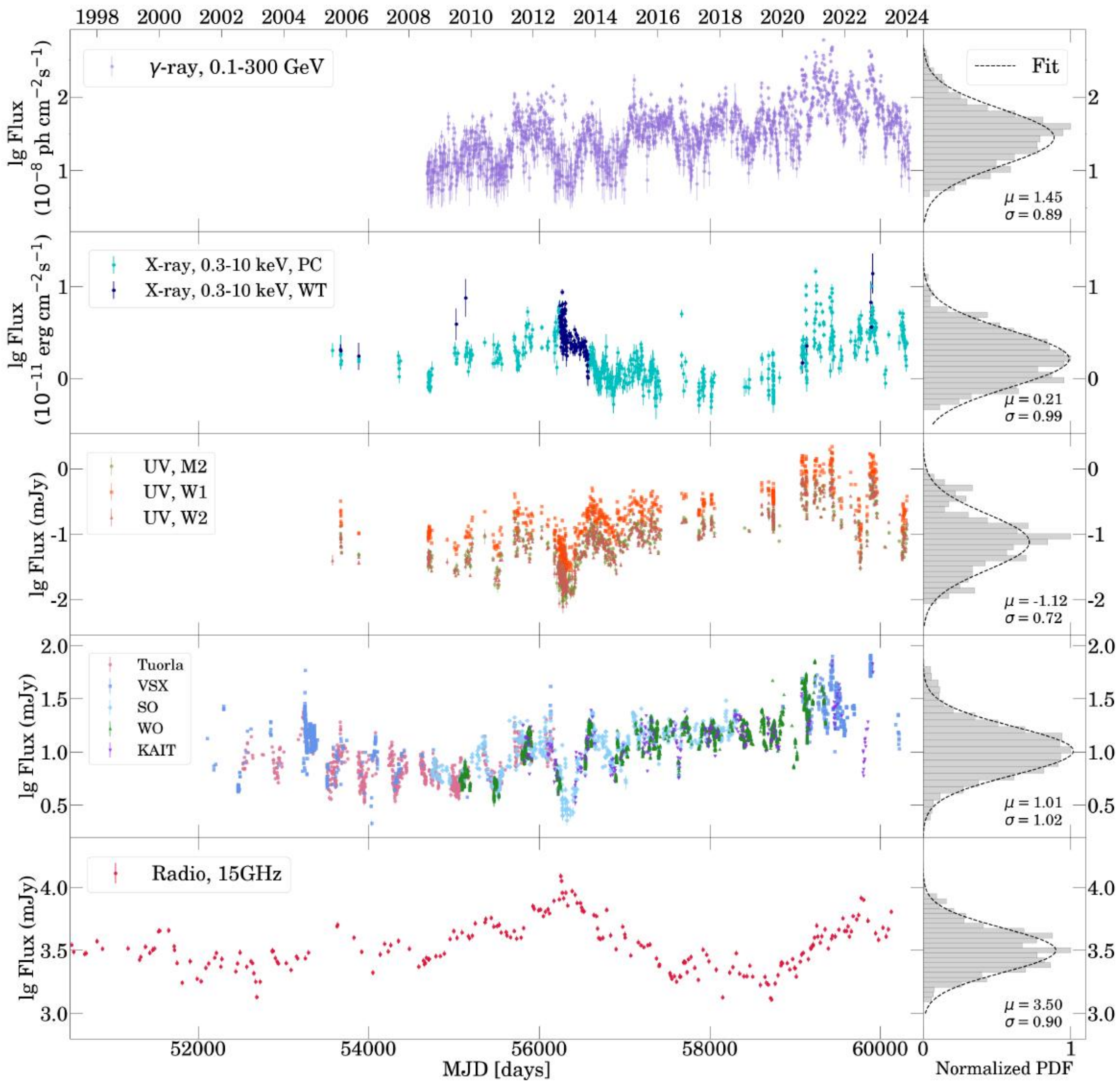


HTD/HID Evolution

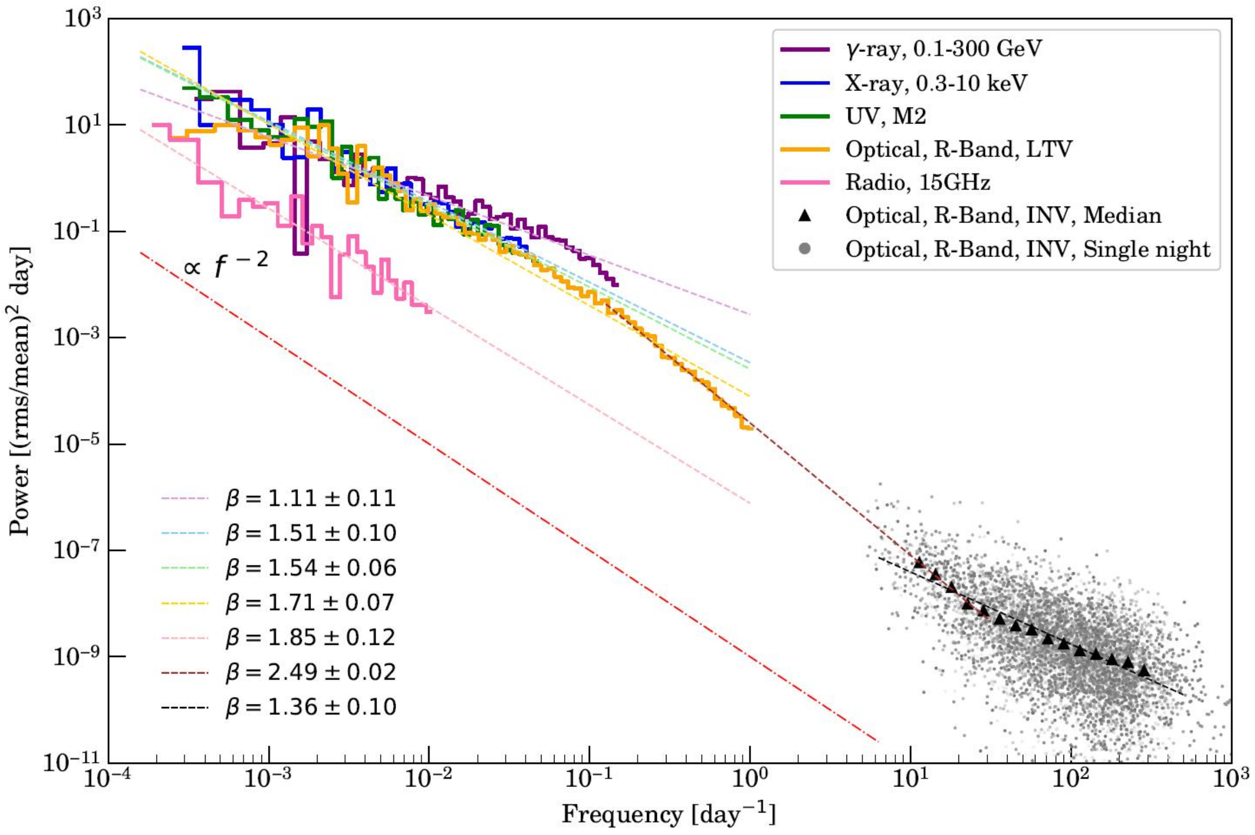


Variability → Power Spectrum

Taking **BL Lacertae** as an example



Classical Method —— DFT

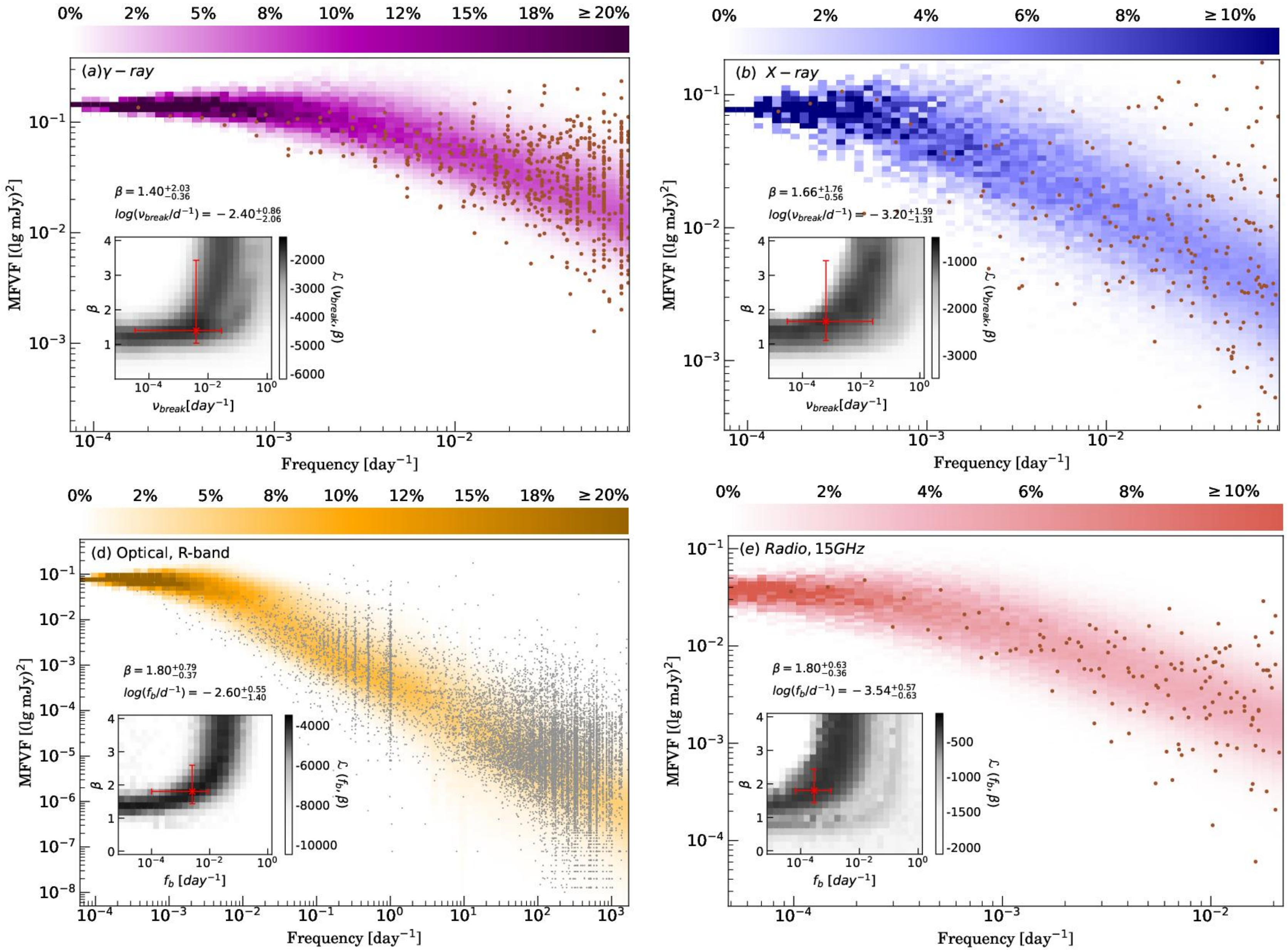


characteristic:

- Power-law index
- Broken Timescale
- Periodicity … …

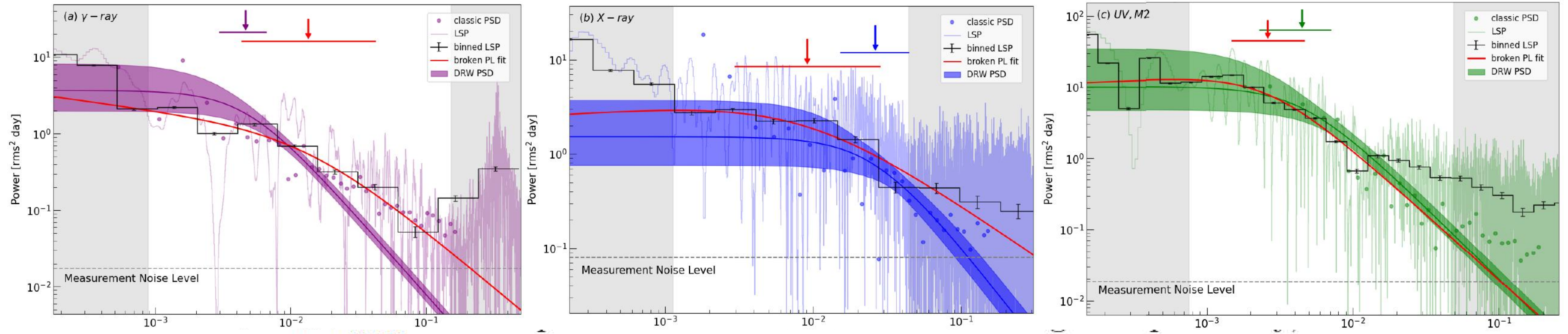
MFVF

Broken Timescale
Power-law index

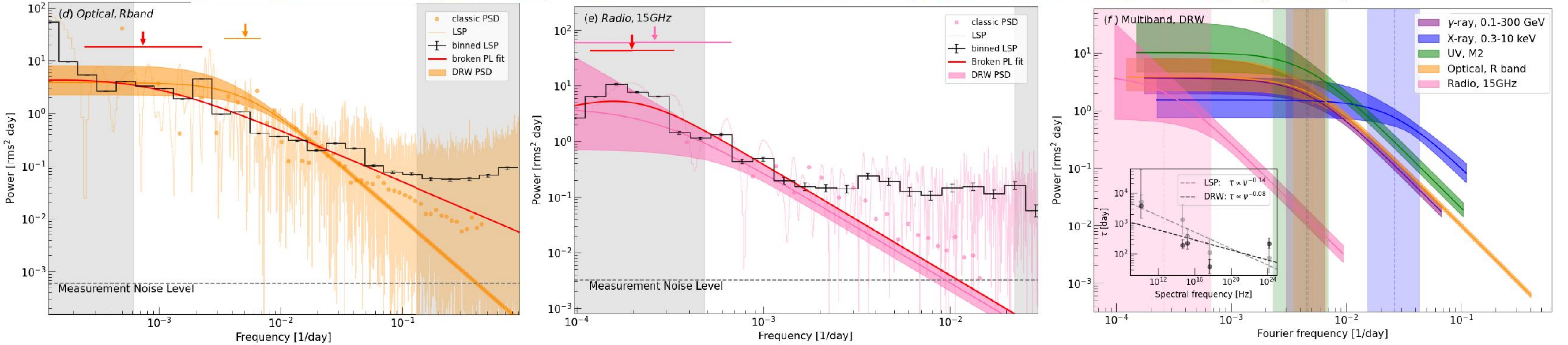


$$\mathcal{L}(\beta, f_{\min}) = \sum_{i=1}^{N} \log p_i(\beta, f_{\min})$$

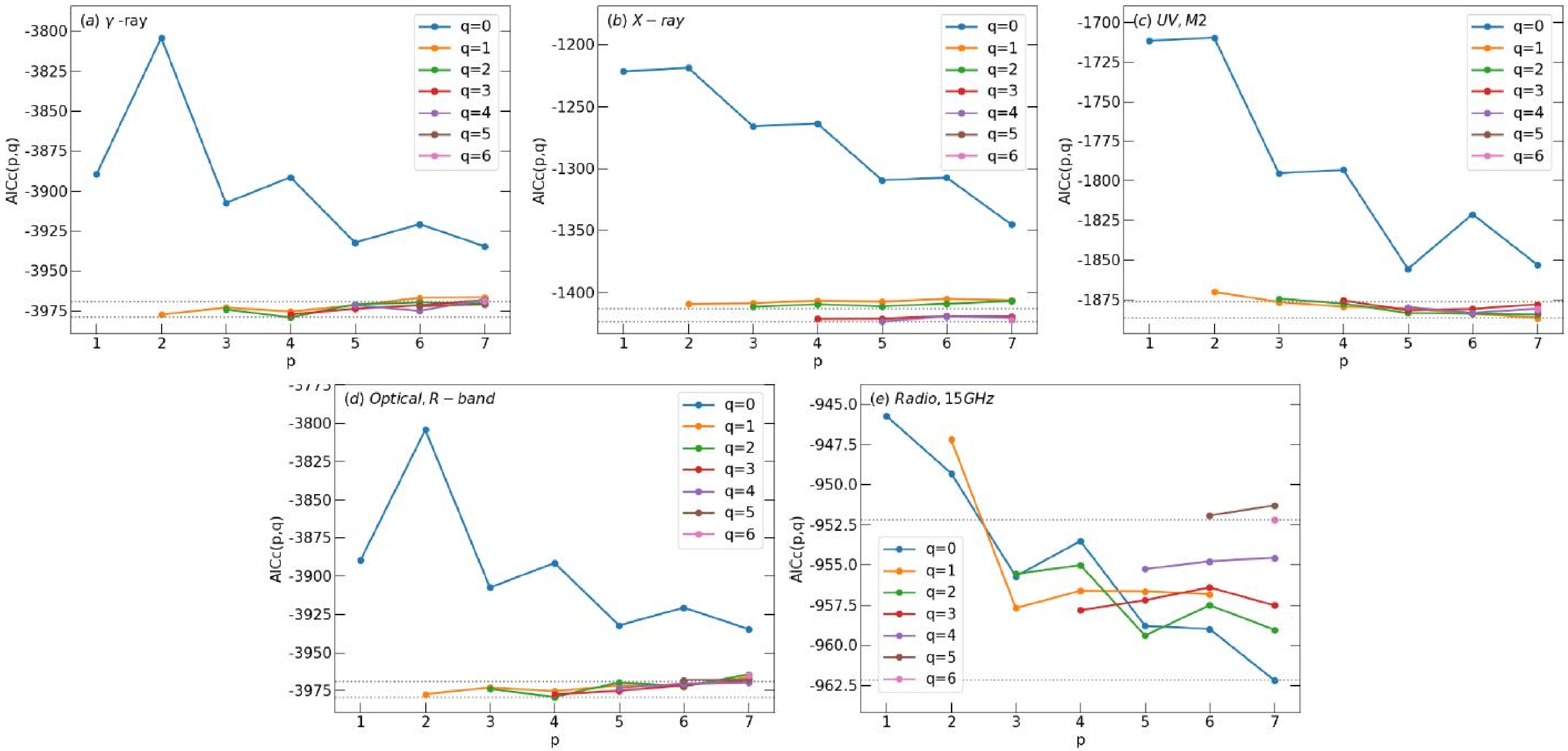
DRW / AR1 / OU



$\tau \propto \lambda^{0.17^{+0.02}_{-0.02}}$ found by MacLeod et al. (2010) and Suberlak et al. (2021).

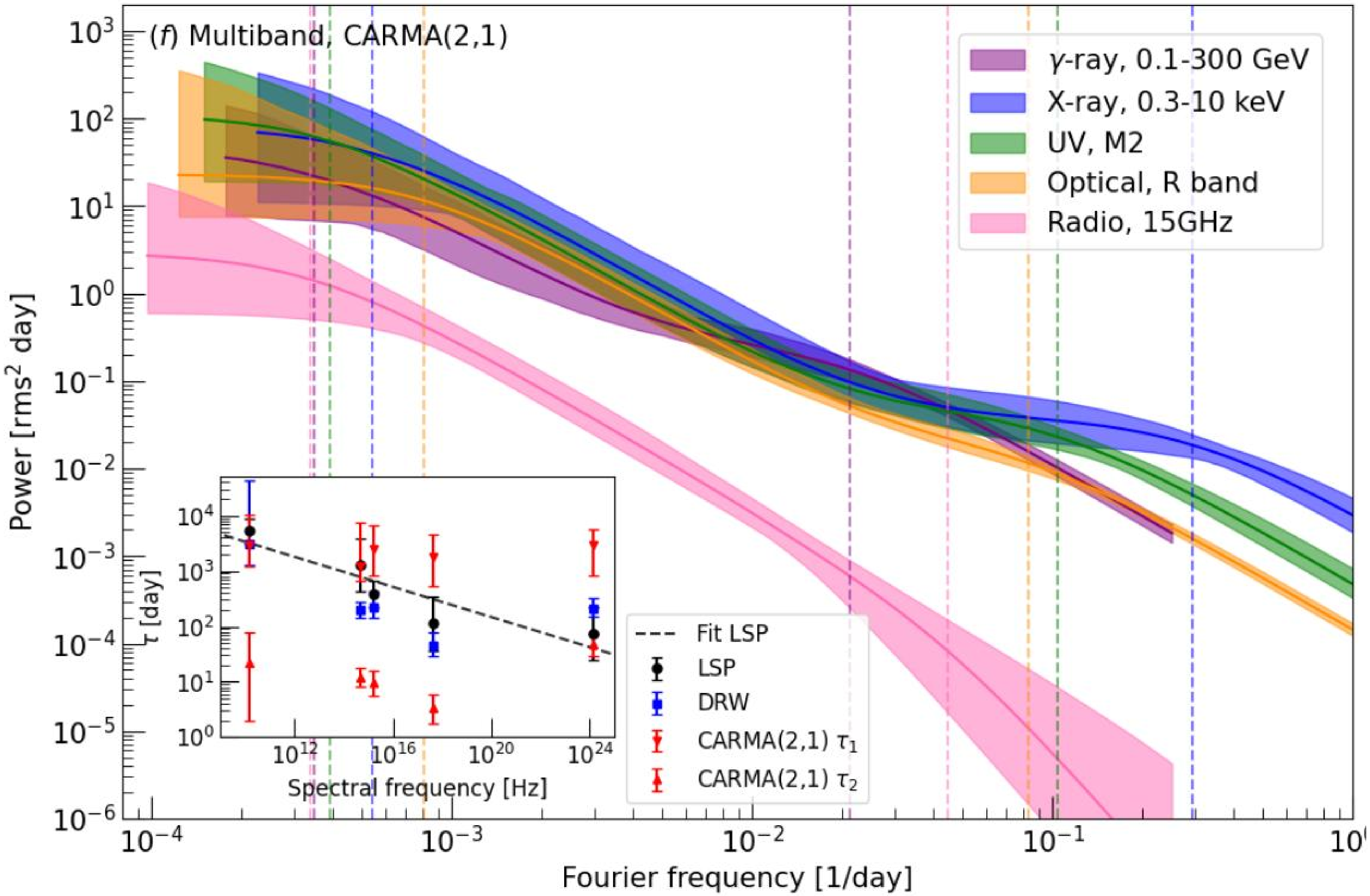


CARMA / Mixed OU



CARMA / Mixed OU

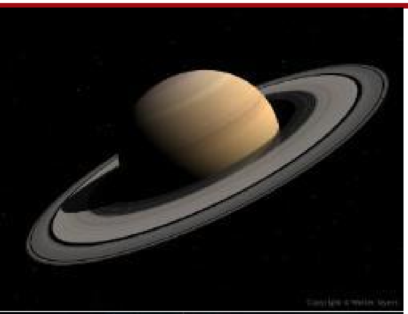
Taking **CARMA(2,1)** as an example



Summary

- The broken power-law model applied to the LSP reveals wavelength-dependent characteristic timescales, whereas the DRW model yields nearly identical timescales across optical, UV, and γ-ray bands. For higher-order CARMA models, the obtained timescales show even greater variability. Variability is better explained by the superposition of multiple stochastic processes;
- The DHO simulations reveal that the characteristic timescales and power spectra are similar in the low-frequency range, while notable differences emerge at high frequencies. We therefore infer that the variability in BL Lacertae is primarily governed by at least two stochastic processes: one that dominates at low frequencies and is weakly dependent on wavelength or even independent of it, and another that dominates at high frequencies and is wavelength-dependent.

Outline




- Variability properties of blazars
- TDE in OJ 287
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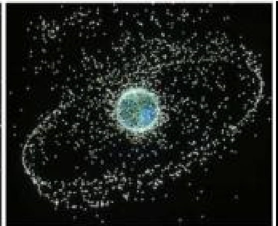
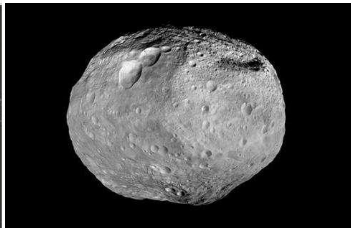
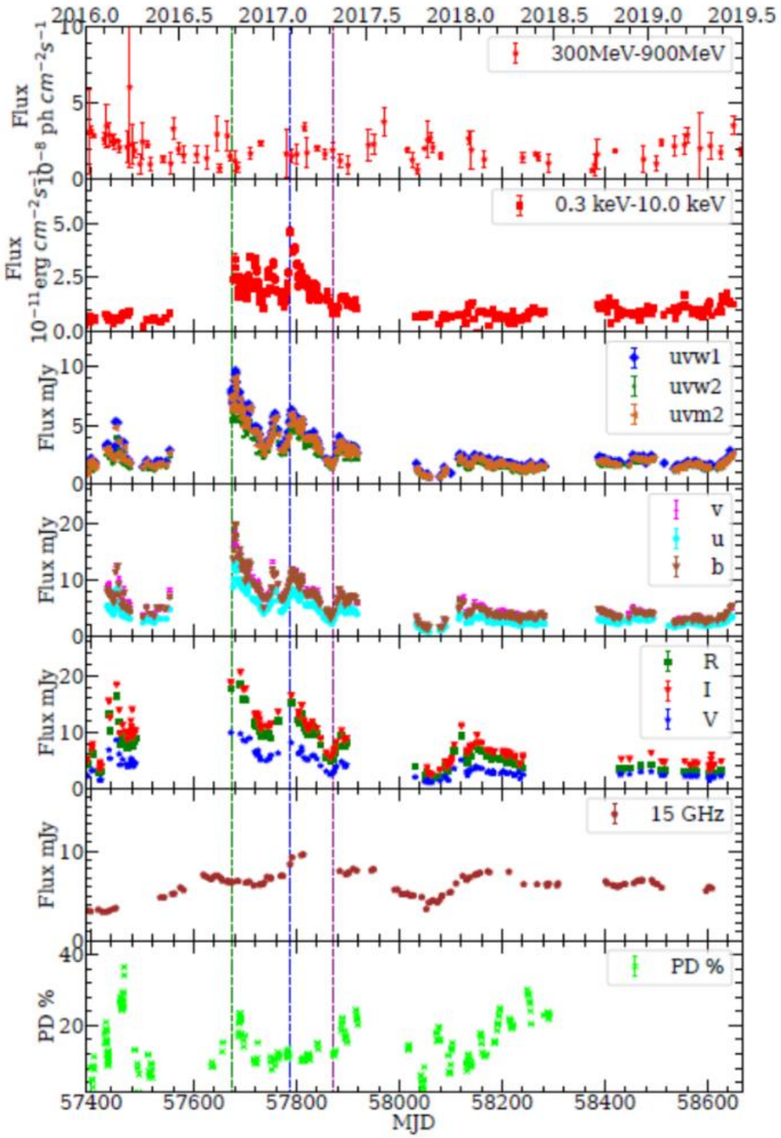
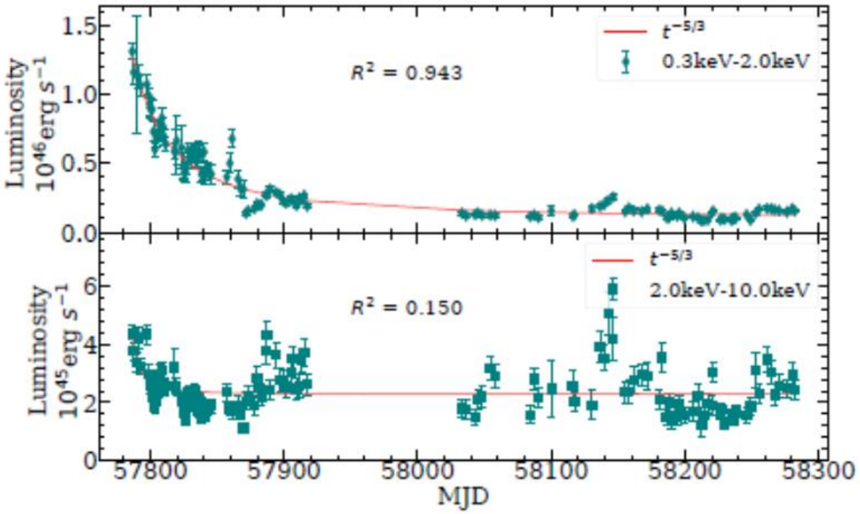
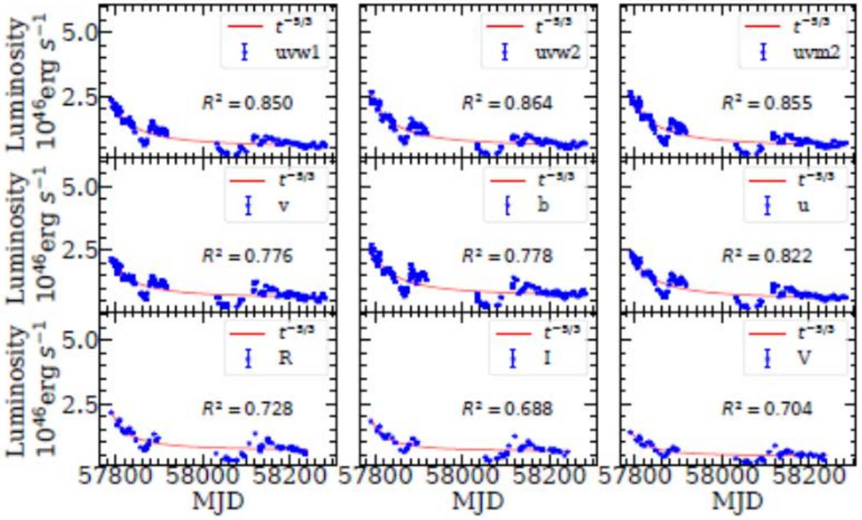



TDE ---the variability of OJ 287 in 2016-2017

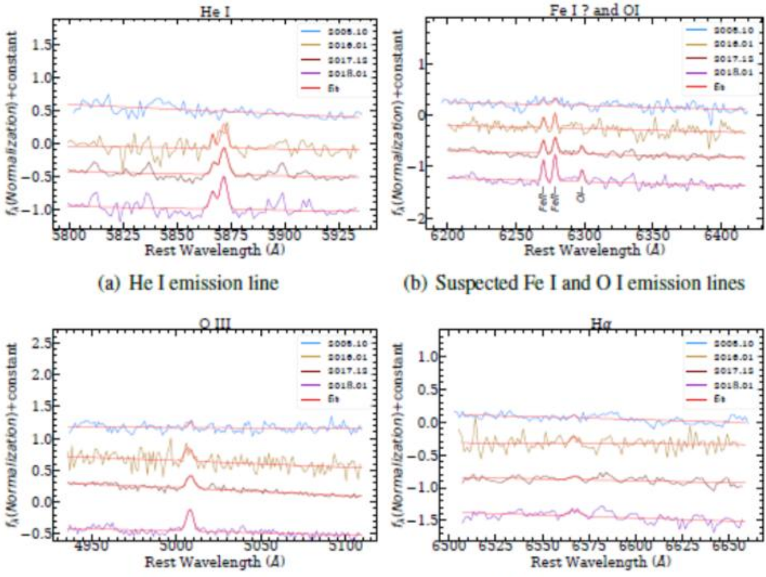




(a) X-ray light curves



(b) UV-optical light curves



(a) He I emission line

(b) Suspected Fe I and O I emission lines

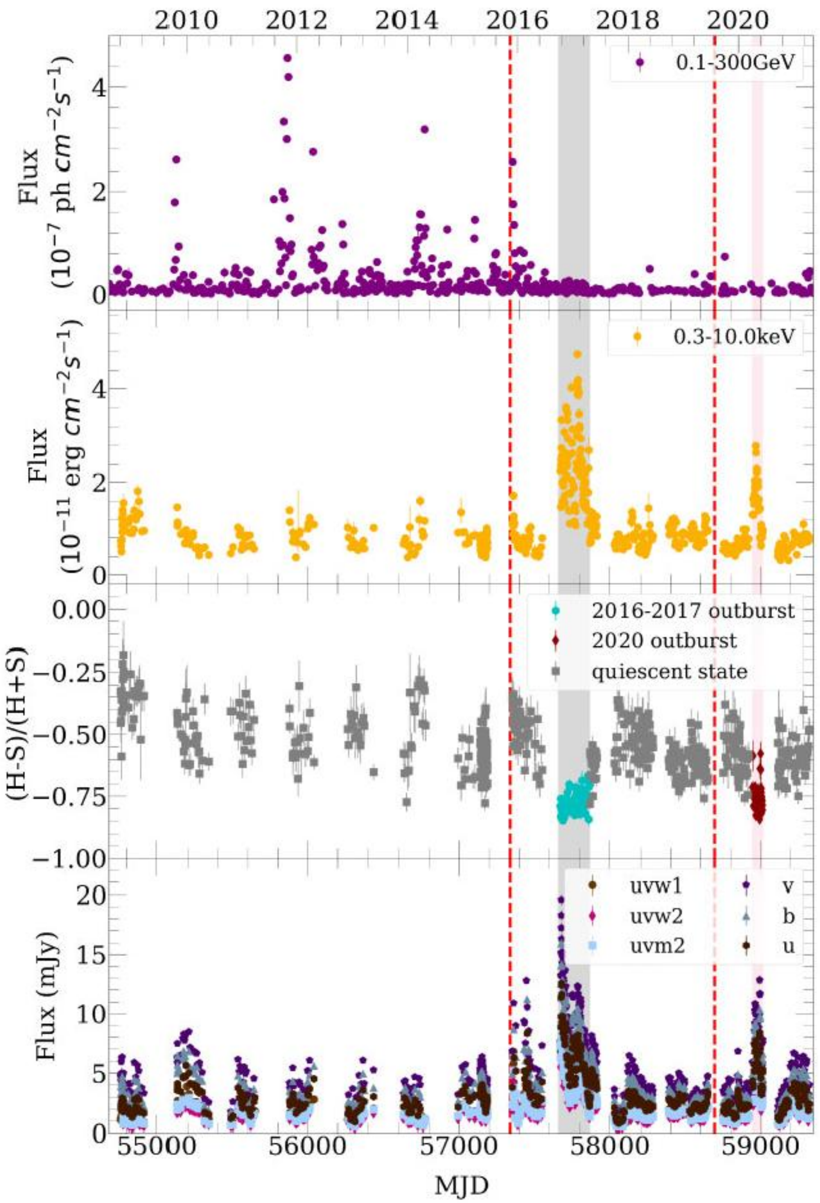
(c) O III emission line

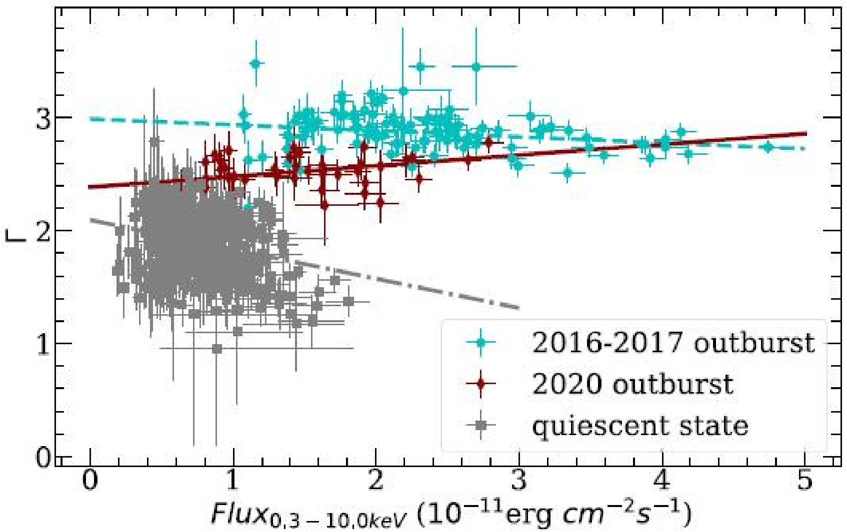
(d) Hα emission line

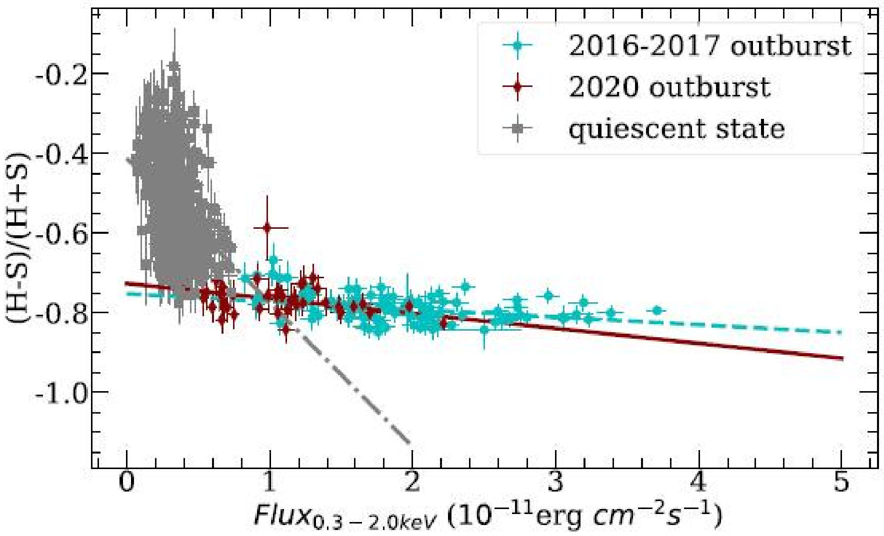
Huang, Hu et al., ApJ, 920, 12 , 2021.

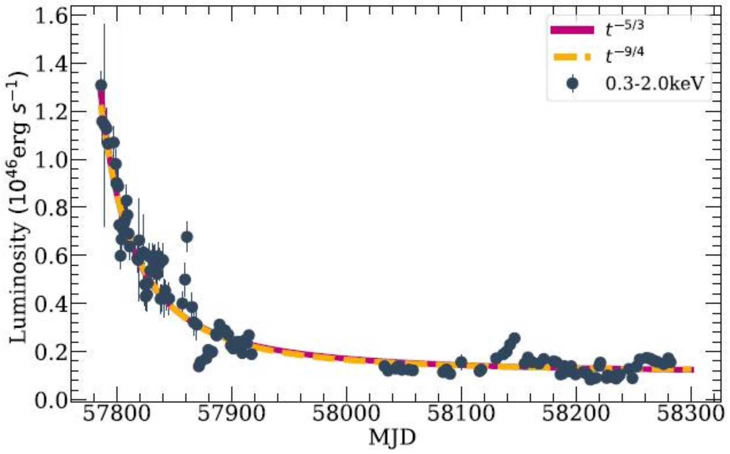
PTDE—Variability of OJ 287 in 2020

Huang, Hu et al., MNRAS, 515, 2778, 2022

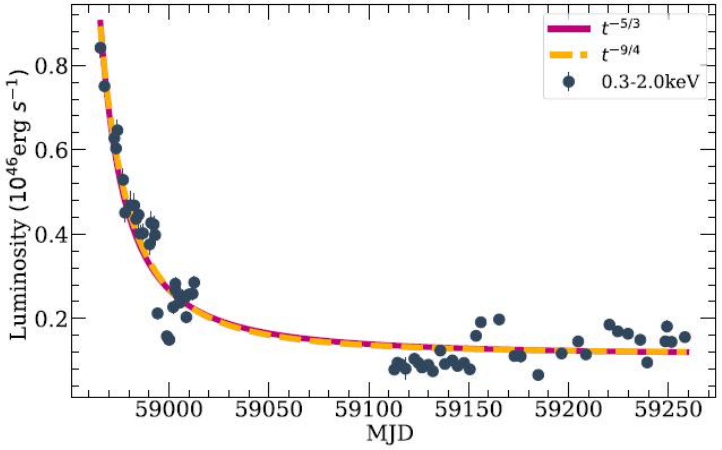






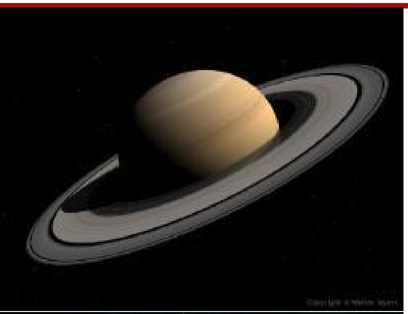


(a) 2016–2017 outburst



(b) 2020 outburst

Outline




- Variability of blazars
- TDE in OJ 287
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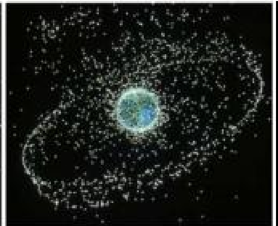
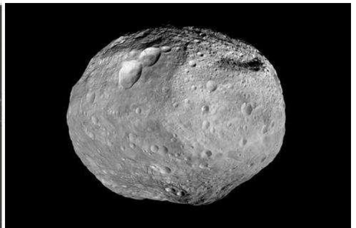



1m Telescope

Optics: classic Cassegrain design, 1000mm optical working diameter, focal ratio: f/8

Mount: equatorial fork mount

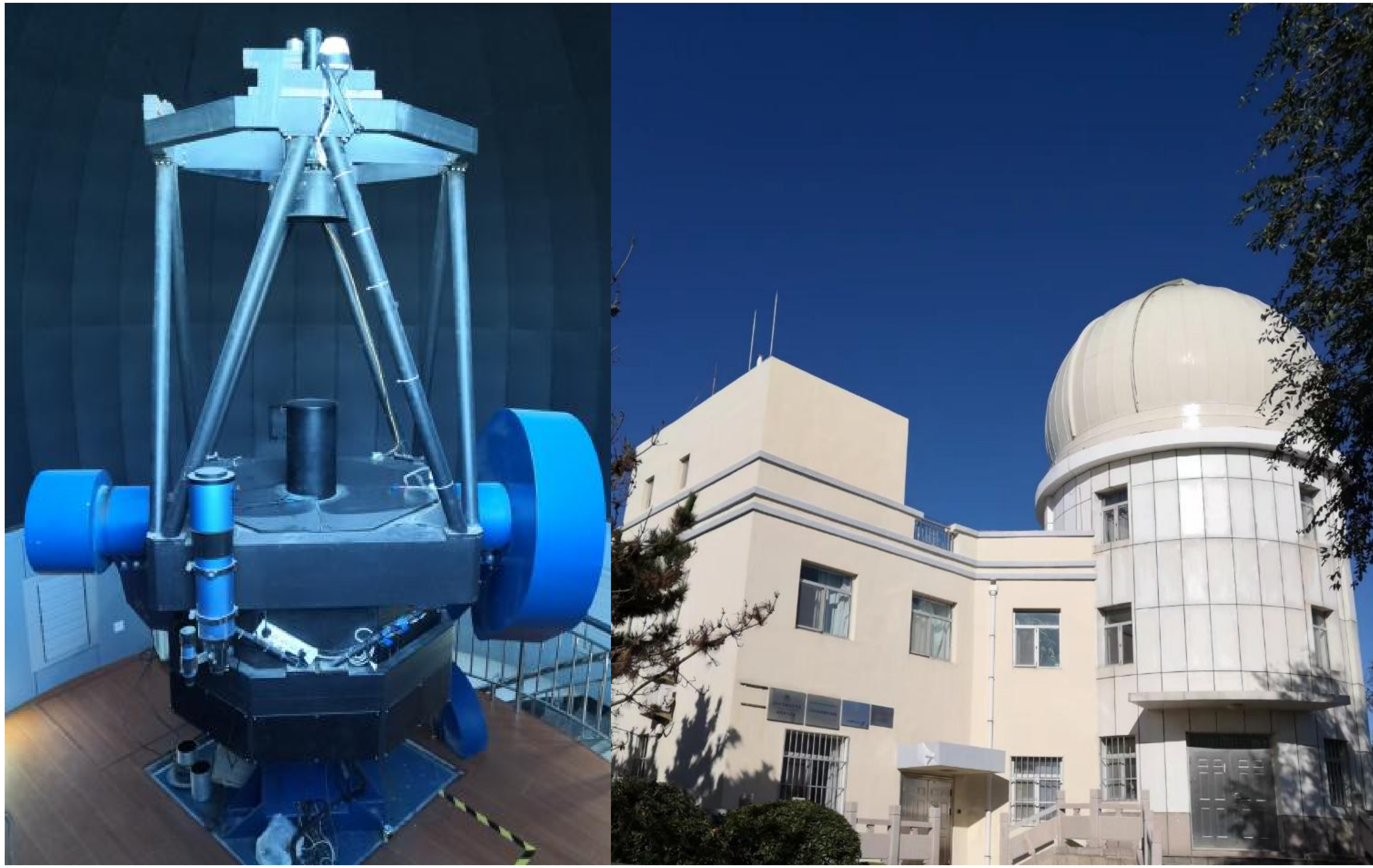
Image quality: 80% Energy in 0.65 arc sec within 15 arc minute FOV

Maximum slew speed is 4 degrees per second in both RA and DEC axis

Pointing accuracy: 5.4 arc sec RMS for 20-90 deg altitude

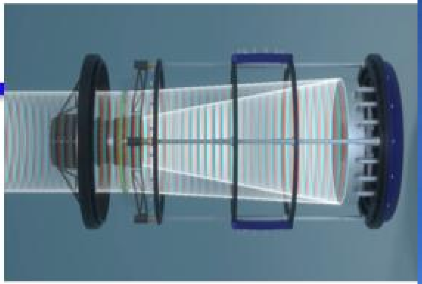
Tracking accuracy: 0.54 arc sec RMS in 10 minutes blind guiding

1m telescope and dome



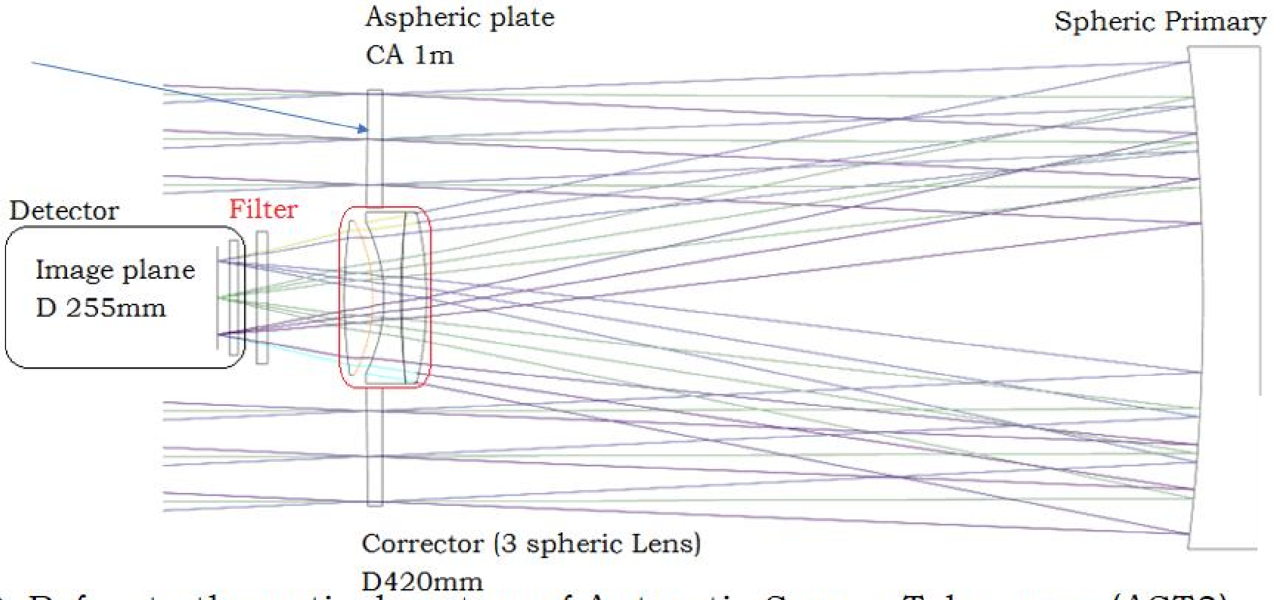
Wide field 1m telescope

Optical design for Sitian Project



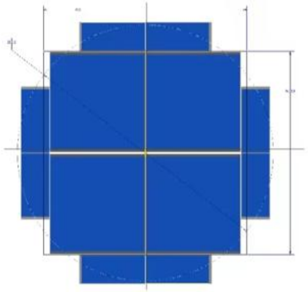
- SITIAN- Prototype optics (Catadioptric)

Aperture 1m; Primary 1.3m; F# 2.06; FOV 5°×5°

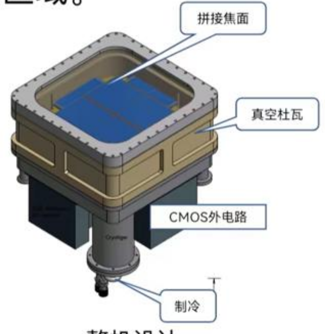


- Refer to the optical system of Antarctic Survey Telescopes (AST3)

- 焦面尺寸为200mm×200mm，采用4片9K×9K、10μm背照式CMOS芯片拼接。
- 焦面四周预留导星和波前传感探测器区域。



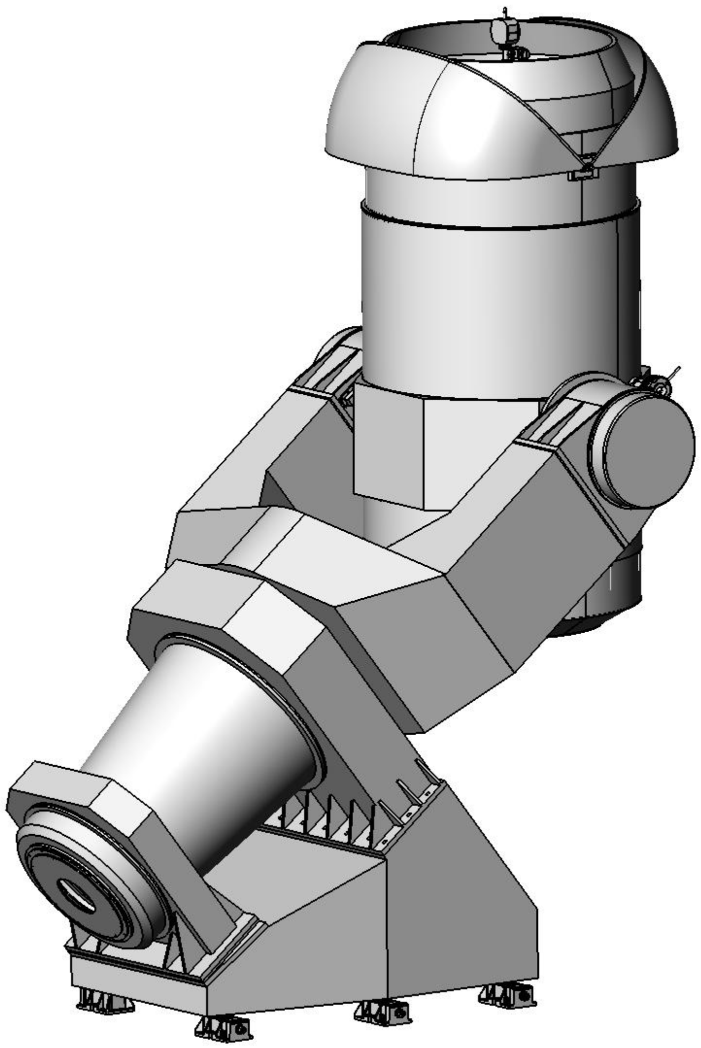
探测器布局

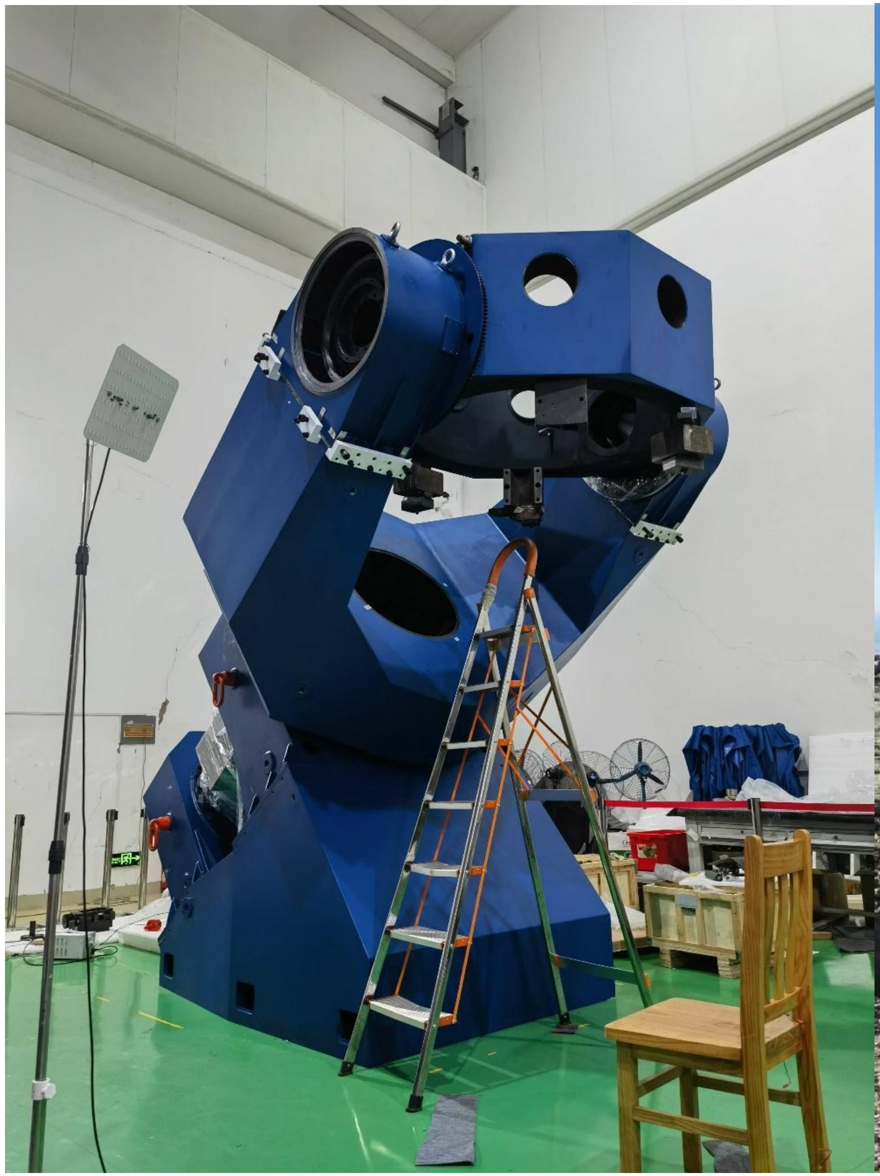


整机设计

For Time domain Astronomy（Varaibility of AGNs, TDEs, Variables, SNs, Exoplanets, GRBs et al.）, Installed in 2024

Progress



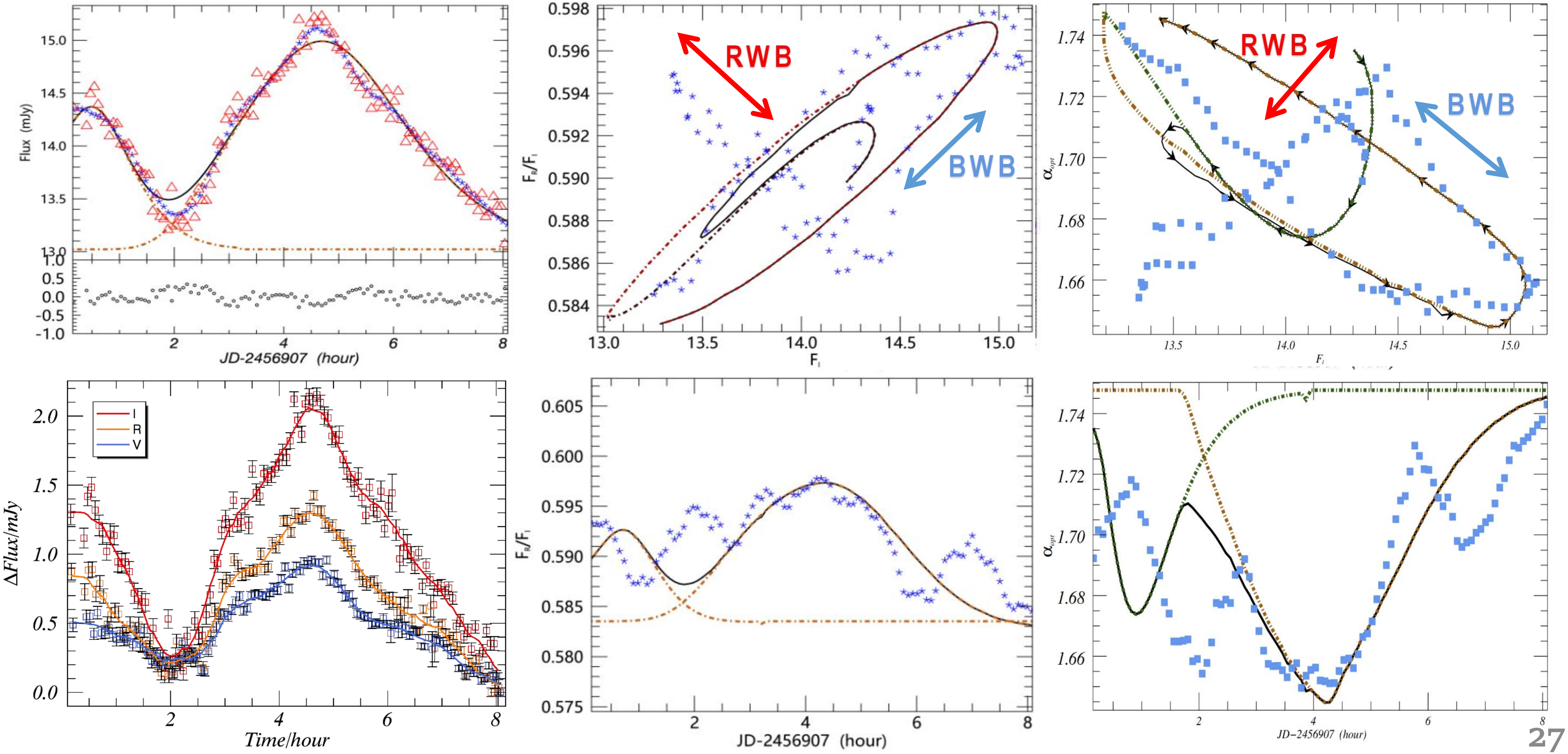


Enroll Staffs and Postdocs in Astronomy

Contact with Shao Ming Hu
Email: husm@sdu.edu.cn

Thank you for your attention!

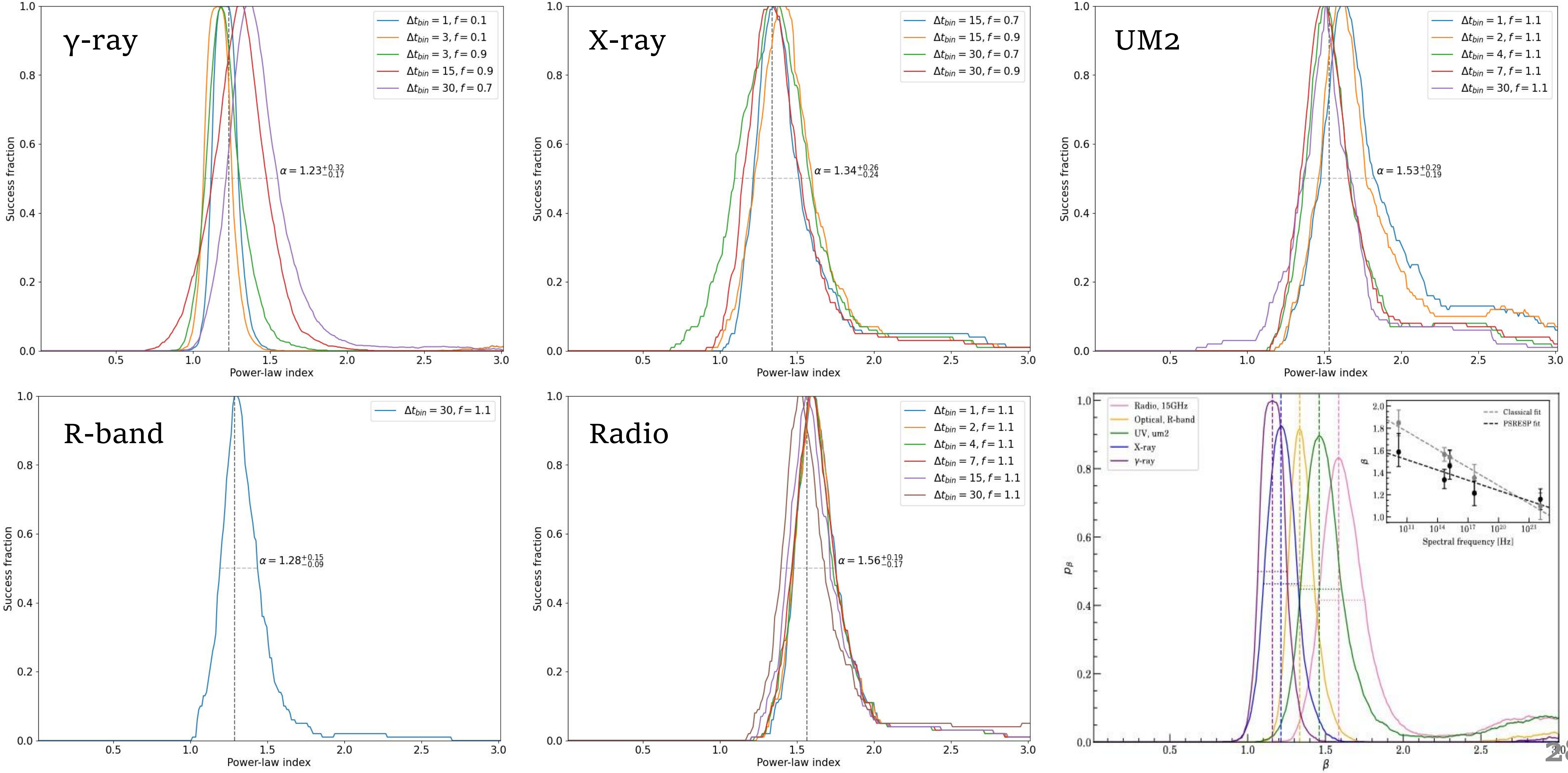
Fitting



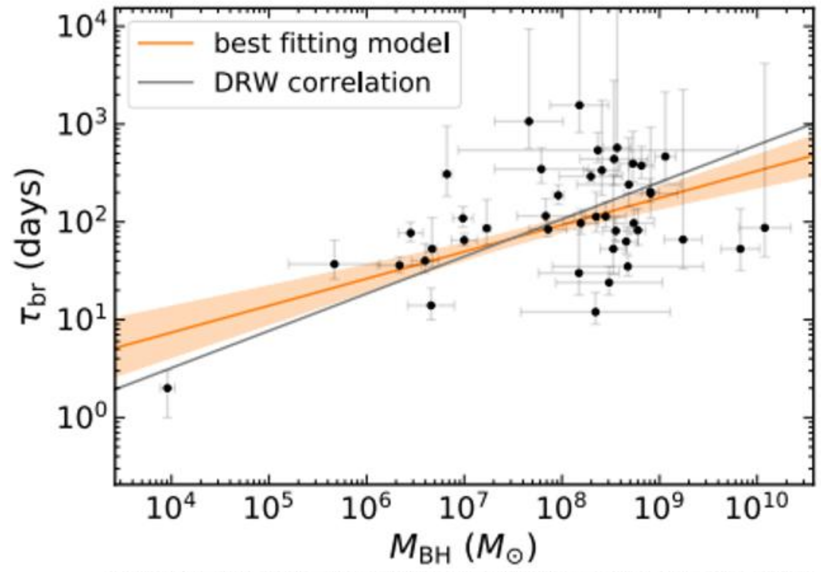
Flux (mJy)
JD-2456907 (hour)
F_R/F_I
F_I
RWB
BWB
α_{opt}
F_i
I
R
V
ΔFlux/mJy
Time/hour
F_R/F_I
JD-2456907 (hour)
α_{opt}
JD−2456907 (hour)

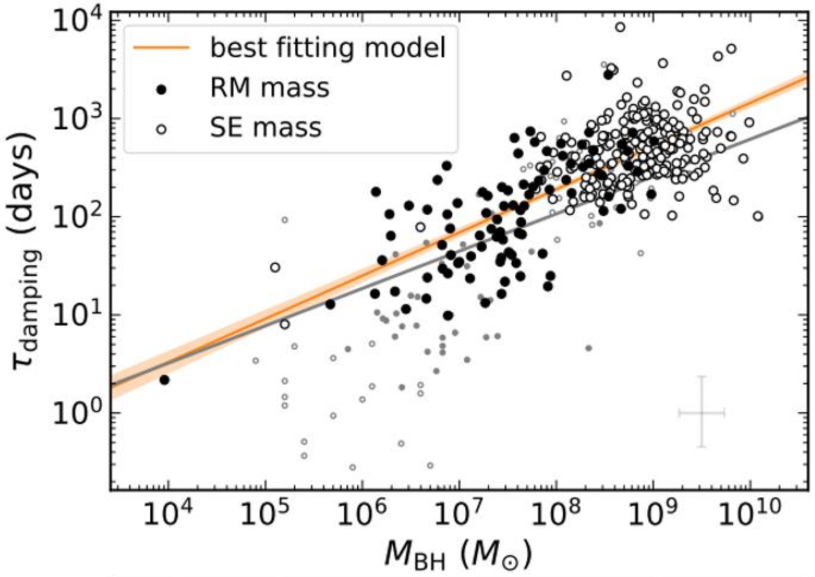
PSRESP

Power-law index



$\tau_{damping}$ - $M_{accretor}$ Relation



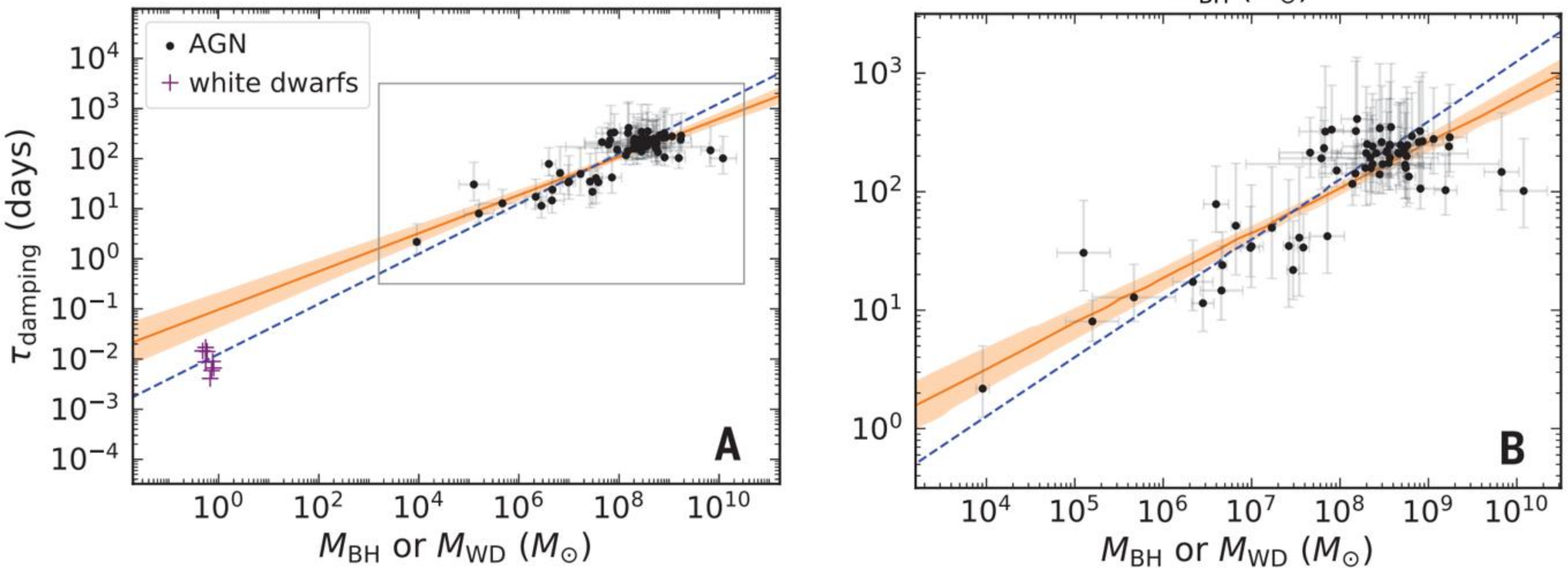


$$\tau_{damping} = 199^{+11}_{-11}\ \text{days} \left(\frac{M_{BH}}{10^8\ M_\odot}\right)^{0.44^{+0.02}_{-0.02}}$$

$$\tau_{damping} \propto \lambda^{0.17}$$

$$R_\lambda \propto M_{BH}^{2/3}, \quad \eta \propto L_{bol}/\dot{M}_{BH} \rightarrow t_{orb},\ t_{th} \propto M_{BH}^{1/2}$$

$$t_{th} \approx (2\pi\alpha)^{-1} t_{orb} = \alpha^{-1} t_{dyn} \approx (H/R)^2 t_{vis}$$



$$\tau_{damping} = 107^{+11}_{-12}\ \text{days} \left(\frac{M_{BH}}{10^8\ M_\odot}\right)^{0.38^{+0.05}_{-0.04}}$$

$$M_{BH} = 10^{7.97^{+0.14}_{-0.14}}\ M_\odot\ (\tau_{damping}/100\ \text{days})^{2.54^{+0.34}_{-0.35}}$$

$$t_{orb} = 100 \left(\frac{M_{BH}}{10^8\ M_\odot}\right)\left(\frac{R}{100\ R_S}\right)^{3/2}\ \text{days}$$

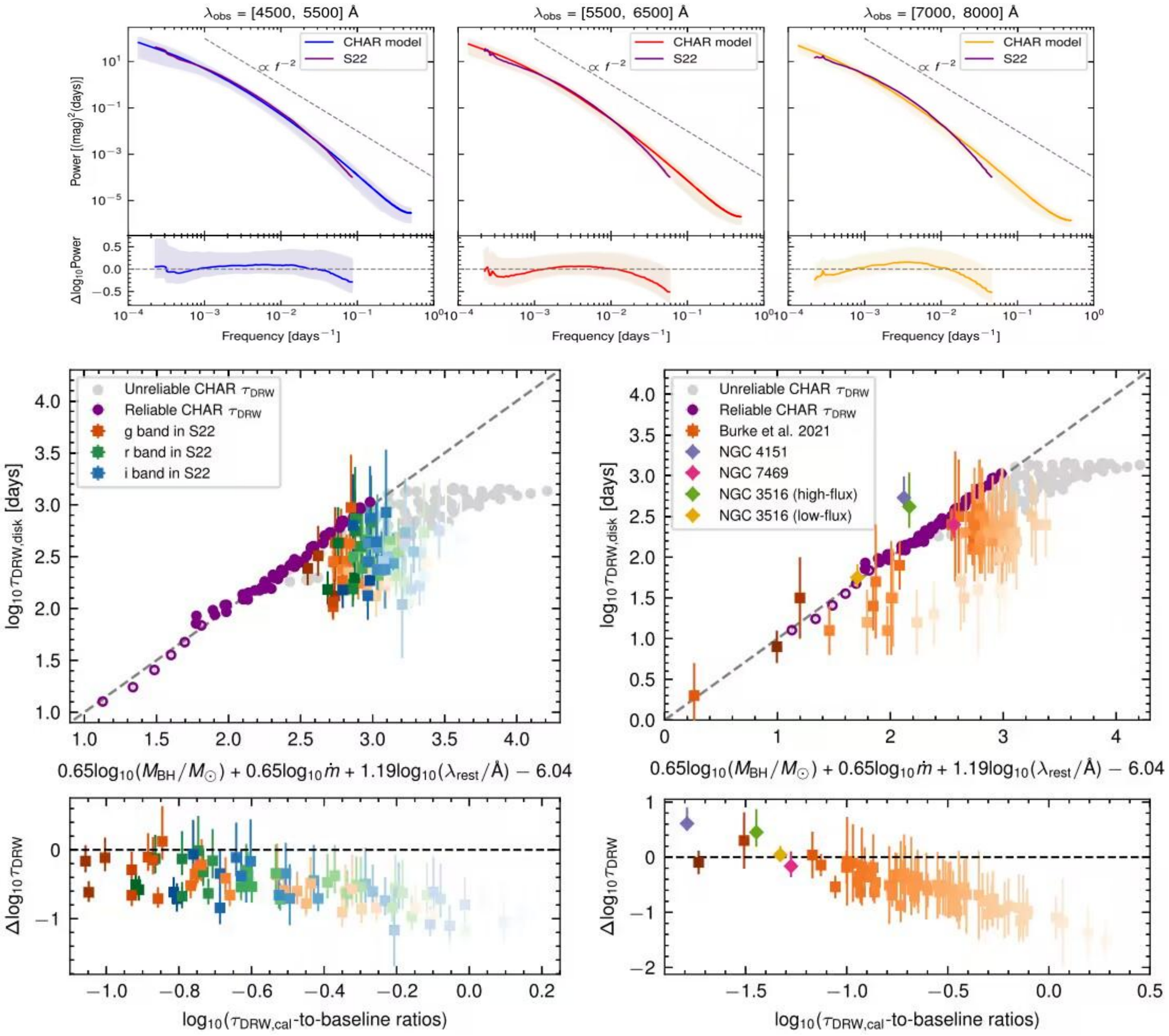
$$t_{th} = 1680 \left(\frac{\alpha}{0.01}\right)^{-1} \times \left(\frac{M_{BH}}{10^8\ M_\odot}\right)\left(\frac{R}{100\ R_S}\right)^{3/2}\ \text{days}$$

Cite from: Burke et al., 2021, Science, 373, 789

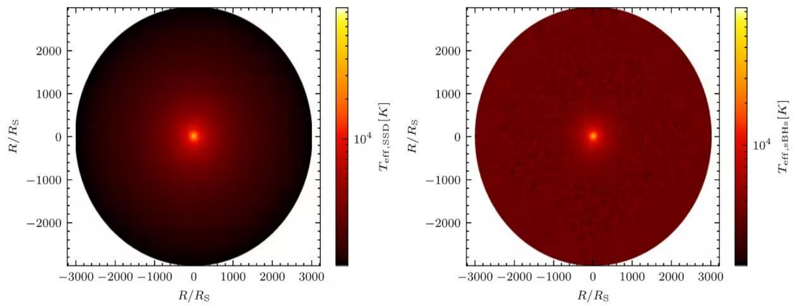
Accretion Disk Model

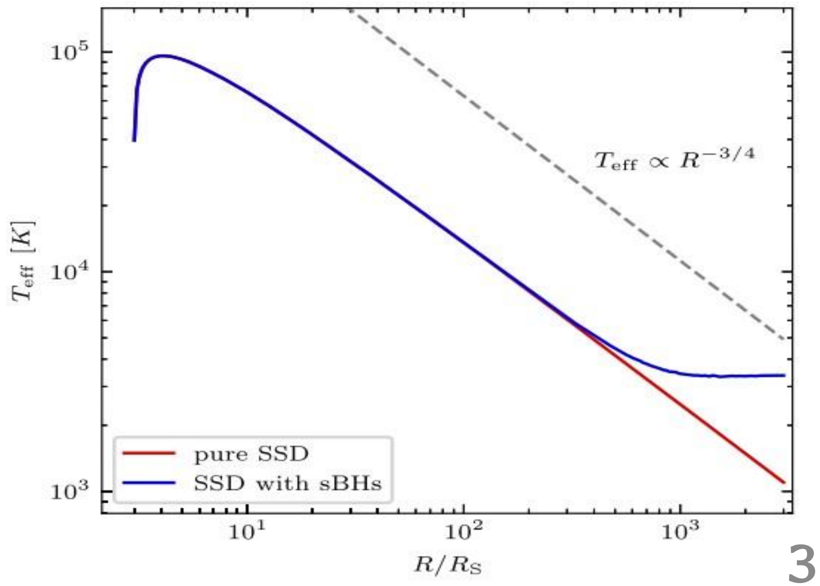
CHAR model

Corona Heated Accretion disk Reprocessing Model



Stellar Black Holes Can "Stretch" Supermassive Black Hole Accretion Disks



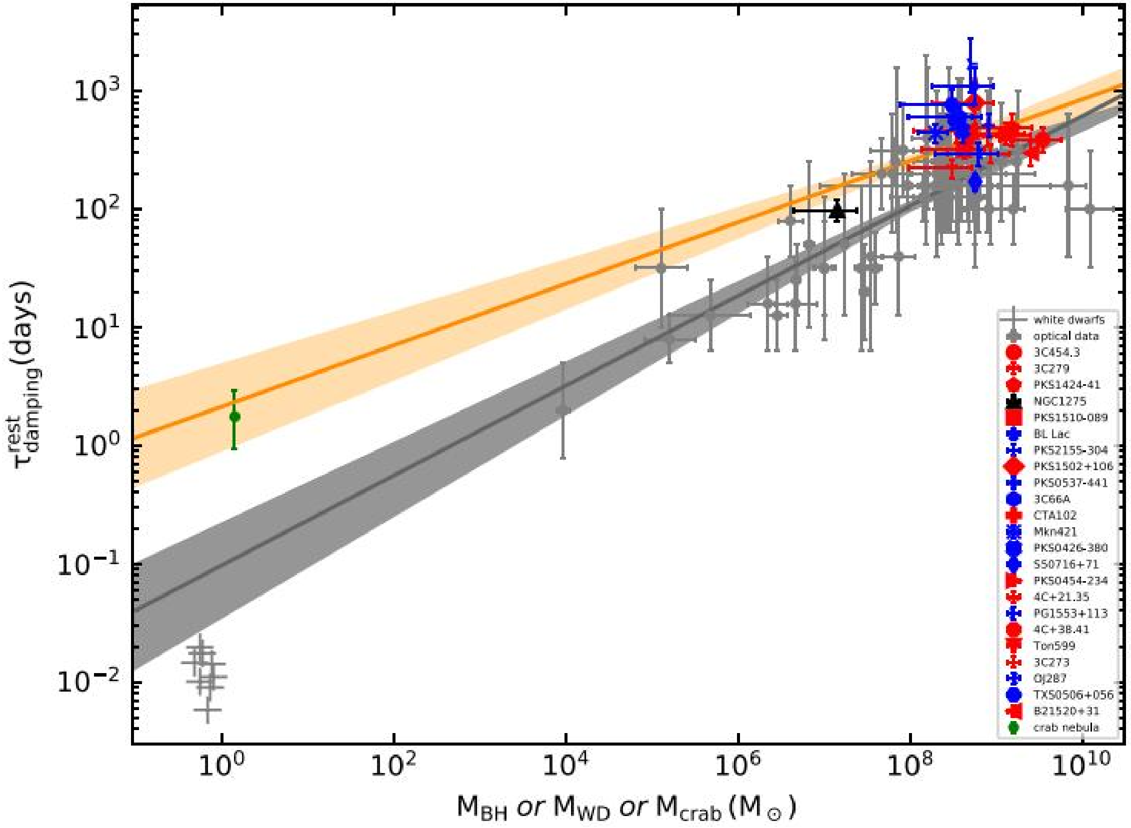


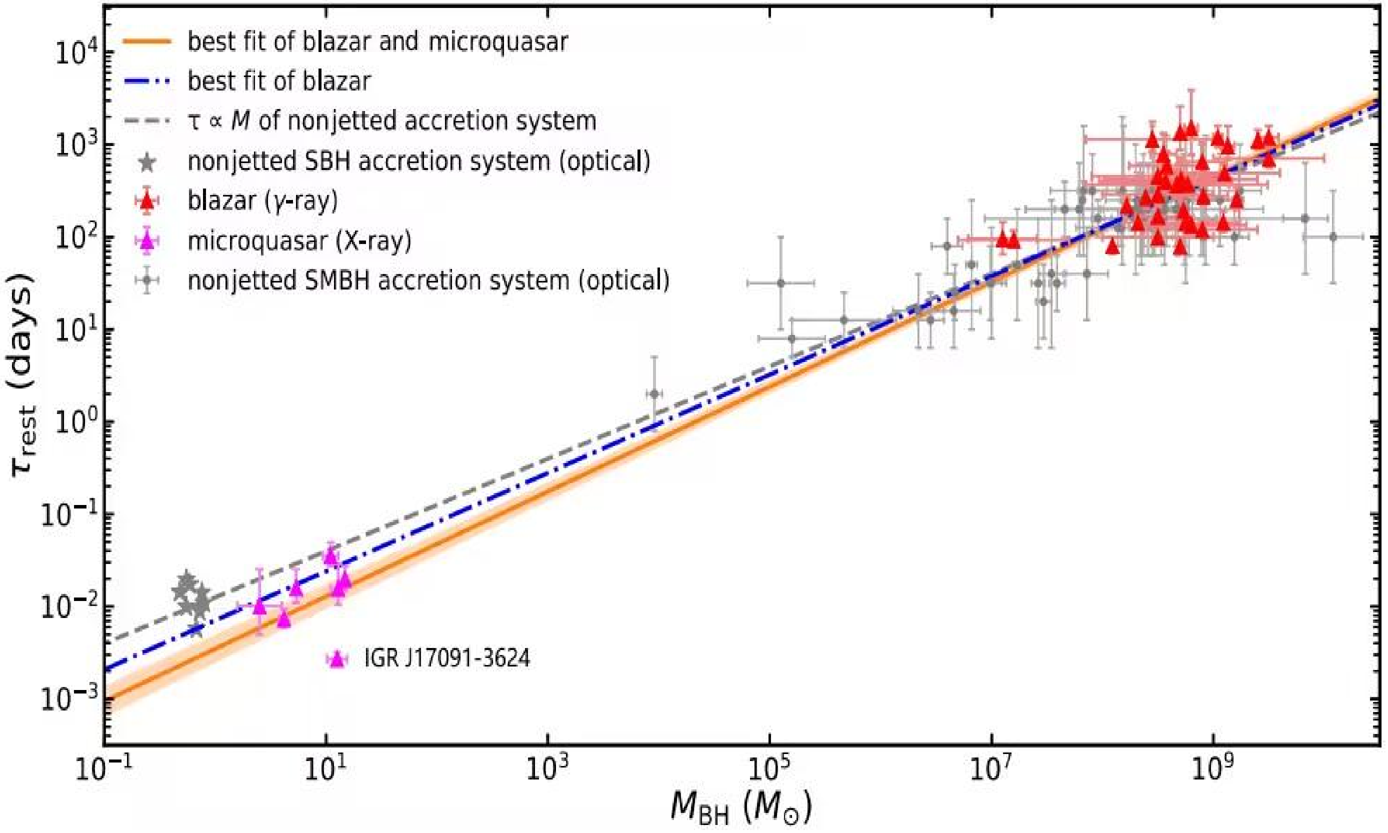
Cite from: Zhou Shuying et al., 2024, ApJ, 966, 8

Cite from: Zhou Shuying et al., 2024, ApJL, 966, L9

Disk-Jet Coupling Model

DRW Model





$$\tau^{rest}_{damping} = 154.22^{+14.76}_{-15.75}\left(\frac{M_{BH}}{10^8 M_\odot}\right)^{0.43^{+0.04}_{-0.04}}$$

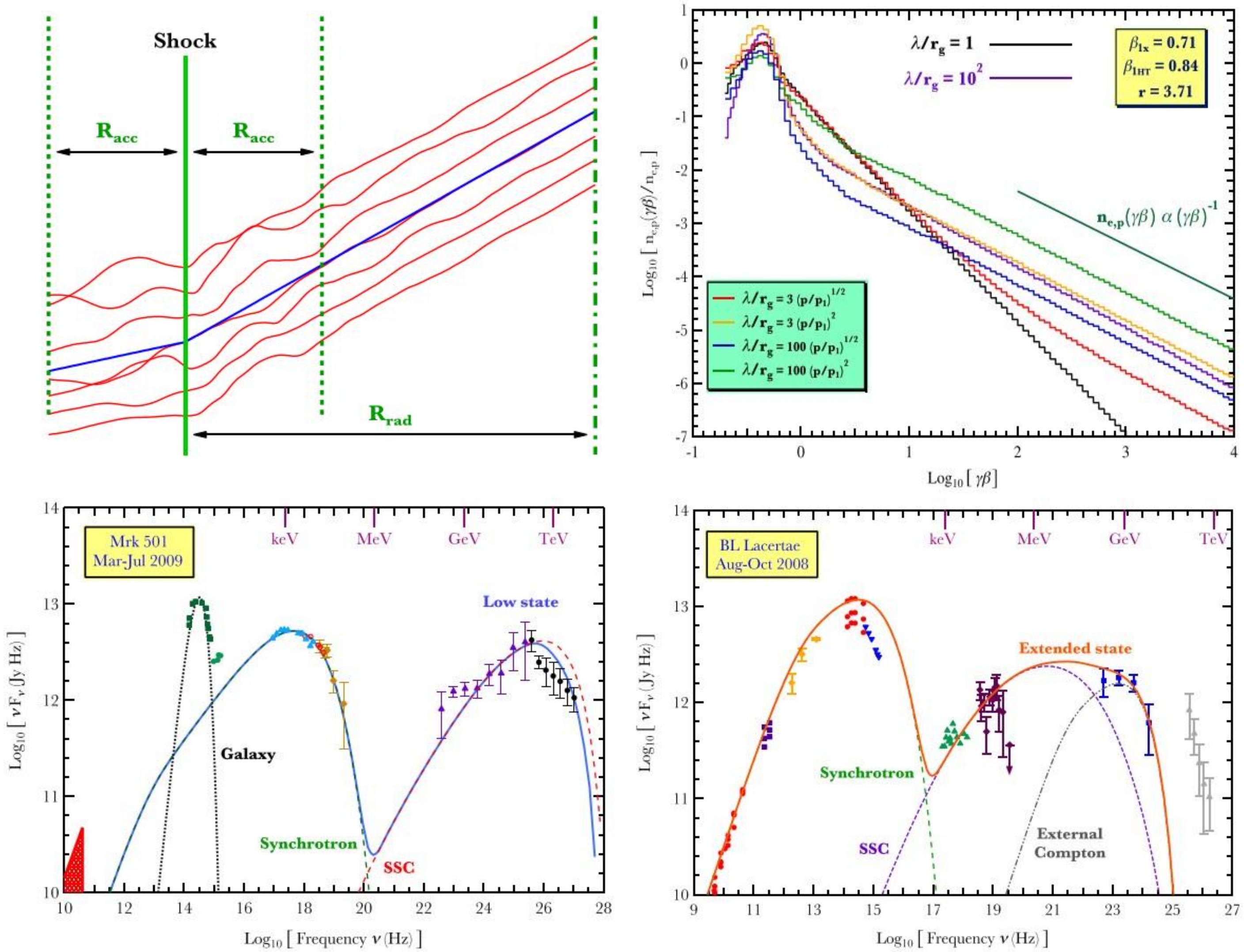
$$\tau_{rest} = 120.47^{+14.84}_{-17.62}\ \text{days}\left(\frac{M_{BH}}{10^8 M_\odot}\right)^{0.57^{+0.02}_{-0.02}}$$

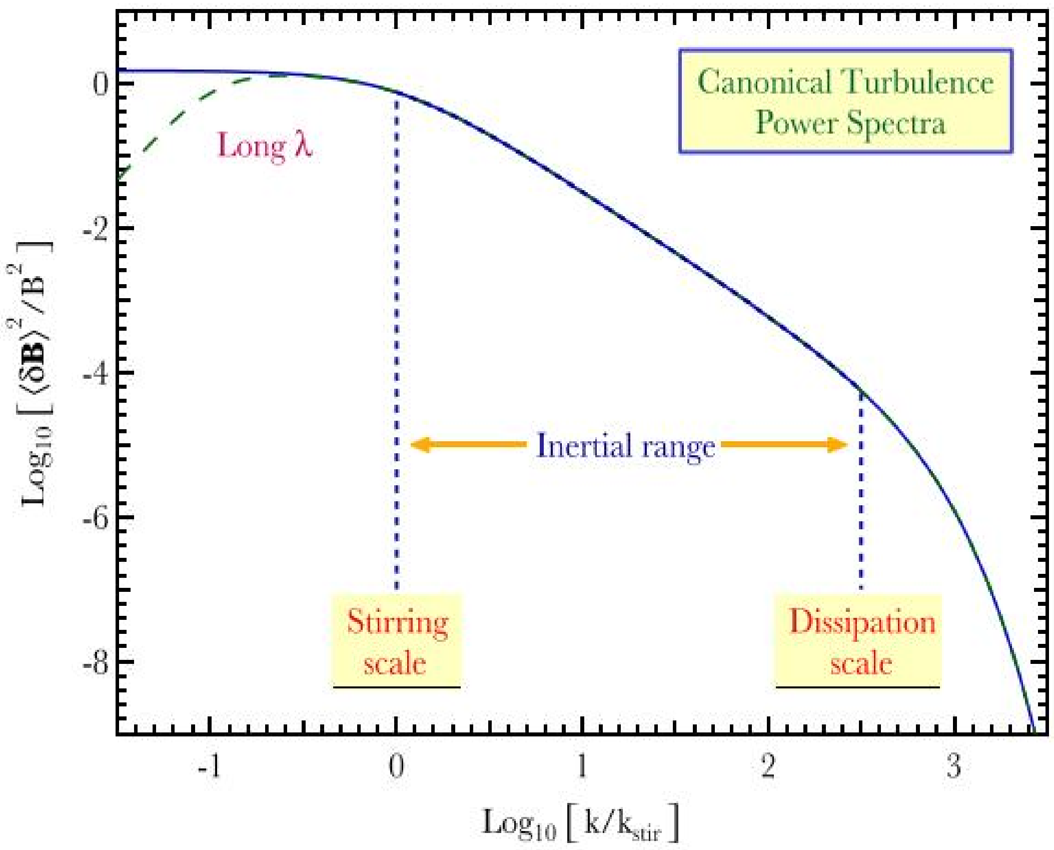
Cite from: Zhang Haiyun et al., 2022, ApJ, 930, 157

Cite from: Zhang Haiyun et al., 2024, ApJL, 967, L18

Turbulence Jet Model

DSA
Diffusive shock acceleration





Cite from: Matthew G. Baring et al., 2017, MNRAS, 464, 4875