Modelling the Spectral Energy Distributions and Multi-Wavelength Polarisation of Blazars

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***Virtual* HEASA 2021**
13-17 September

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Image Credit: NASA/JPL-Caltech

Collaborators

- Southern African Large Telescope (SALT) - Robert Stobie Spectrograph (RSS):
  - Proposal “Observing the Transient Universe”; PI: David A. H. Buckley;
  - Data reduction: Brian van Soelen and Richard J. Britto, with help from Ken Nordsieck. Justin Cooper double-checked data reduction.

- Las Cumbres Observatory (LCO) network of telescopes:
  - PI of the proposal: Brian van Soelen;
  - Data reduction: Brian van Soelen and Johannes P. Marais

- Archival data: NED, WISE and GALEX webpages, collected by Markus Böttcher and Richard Britto.

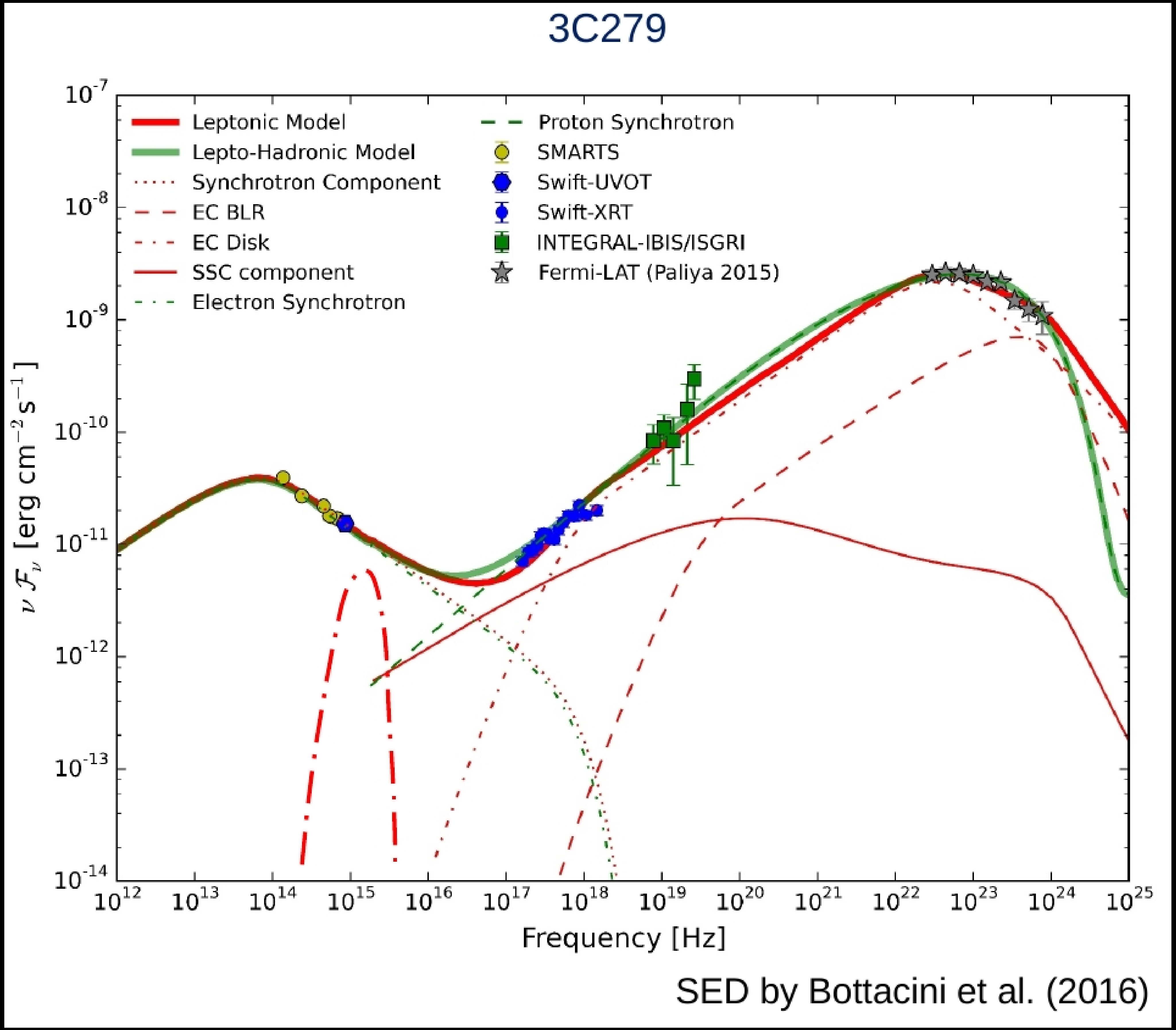
- Swift-XRT: Abe Falcone and Amanpreet Kaur

- Fermi-LAT: Richard J. Britto, for the Fermi-LAT Collaboration

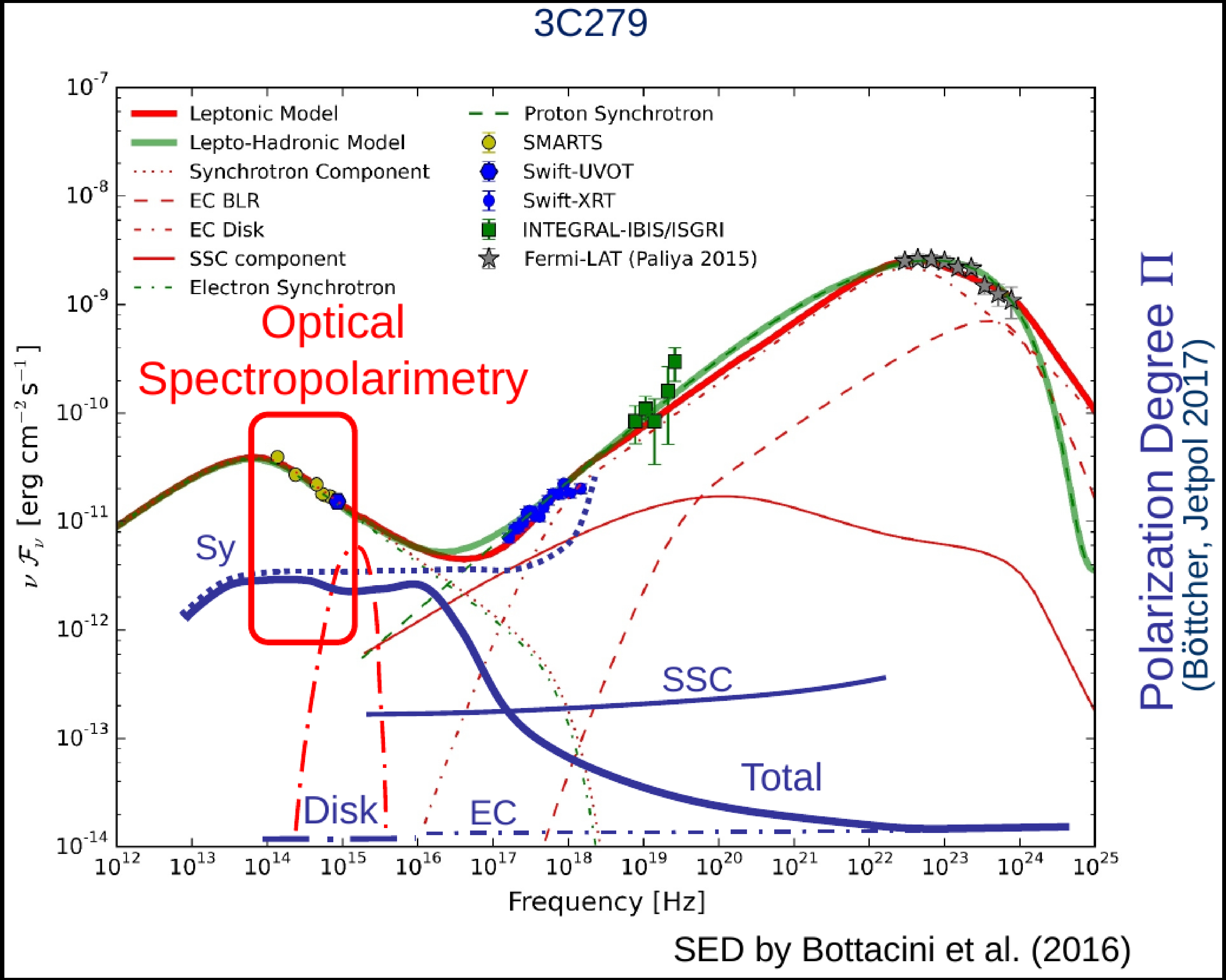
- Modelling multi-wavelength spectral energy distribution (SED) and multi-wavelength polarisation: Hester Schutte, Markus Böttcher and Haocheng Zhang

- SpUpNIC spectrum: Andry Rajoelimanana

Introduction: The Spectral Energy Distribution (SED)



Introduction: The Multi-Wavelength Polarisation



AIM

Constructing a model that simultaneously fits the spectral energy distributions (SEDs) and multi-wavelength polarisation of blazars. This presentation discusses a fit that was applied to the optical-UV regime and further X-ray through gamma-ray studies from the fit results.

Image Credit: DESY, Science Communication Lab

MODEL SETUP

Low-Energy Components

ELECTRON DISTRIBUTION

Broken power-law with exponential cut-off

SHAKURA AND SUNYAEV (1973) ACCRETION DISK

Assuming a thin disk (L_d <0.3 L_{Edd}) and non-rotating BH.

The peak of the accretion disk component corresponds to the maximum disk temperature at the inner disk radius:

$$\nu^{disk}(T^{max}) \propto M_{BH}^{-1/4}$$

BLR EMISSION LINES

- Approximated by Gaussians.
- Flux heights (independent of the continuum flux) relative to each other (Francis et al., 1991).

SYNCHROTRON POLARISATION

According to Rybicki and Lightman (1979):

$$\Pi^{sy} = F_B \cdot \frac{\langle G(x) \rangle}{\langle F(x) \rangle}$$

$$\langle G(x) \rangle = \int N_e(\gamma)\, x(\gamma)\, K_{2/3}(x(\gamma))\, d\gamma$$

$$\langle F(x) \rangle = \int N_e(\gamma)\, x(\gamma) \int_{x(\gamma)}^{\infty} K_{5/3}(x(\xi))\, d\xi\, d\gamma .$$

TOTAL LOW-ENERGY POLARISATION

$$\Pi^{total} = \frac{\Pi^{sy} \cdot F^{sy}}{F^{sy} + F^{disk} + F^{em.lines}}$$

MODEL SETUP

High-Energy Components

INVERSE COMPTON RADIATION (Böttcher et al., 2012):

$$j_{\nu}^{head-on}(\epsilon_s, \Omega_s) \alpha \int_1^{\infty} d\gamma\, n_e(\gamma) \int_{4\pi} d\Omega_{ph} \int_0^{\infty} d\epsilon\, n_{ph}(\epsilon, \Omega_{ph}) \frac{d\sigma_C}{d\epsilon_s}$$

BLR SEED PHOTONS (Böttcher et al., 2013):

Modelled as an isotropic thermal photon field in the AGN rest frame.

ACCRETION DISK PHOTON DISTRIBUTION (Böttcher et al., 1997):

$$n_{ph}(\epsilon, \Omega_{ph}) = \frac{\epsilon^2}{\epsilon^{*2}} n_{ph}^{*}(\epsilon^{*}, \Omega_{ph}^{*}),$$

dependent on disk intensity and angle at which photon travels from disk.

EC emission is expected to be unpolarised due to the approximate azimuthal symmetry and unpolarised target photons.

SSC:

Radiation: Isotropic photon distribution from synchrotron emission.

Polarisation (Bonometto and Saggion, 1973):

$$\Pi_{\omega}^{SSC} = \frac{P_{\omega}^{SSC,\perp} - P_{\omega}^{SSC,\parallel}}{P_{\omega}^{SSC,\perp} + P_{\omega}^{SSC,\parallel}}$$

TOTAL HIGH-ENERGY POLARIZATION (Zhang and Böttcher, 2013):

$$\Pi_{\omega}^{total} = \frac{\Pi_{\omega}^{SSC} \cdot F_{\omega}^{SSC}}{F_{\omega}^{SSC} + F_{\omega}^{EC}}$$

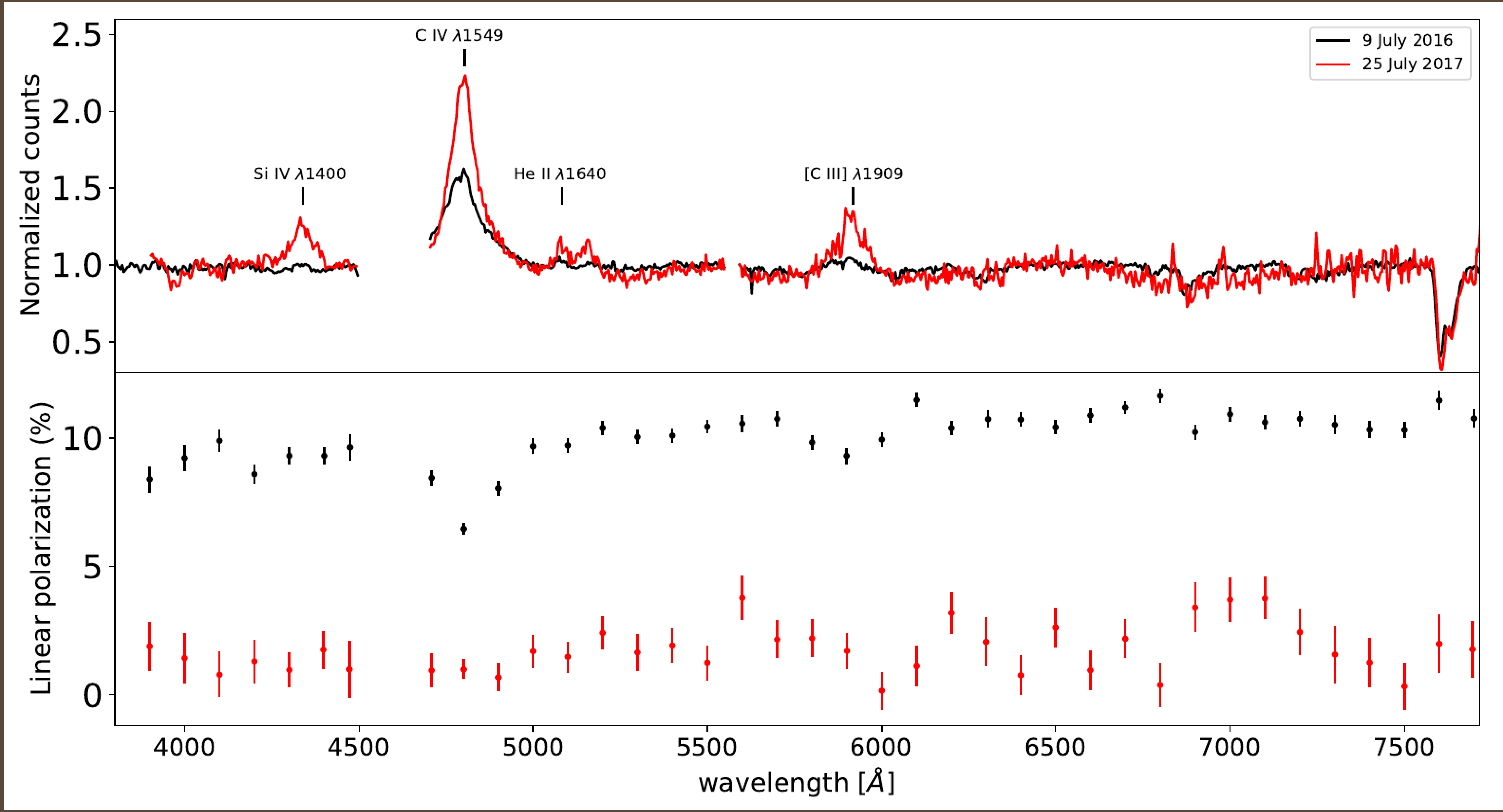
OBSERVATIONS

Spectropolarimetry and spectroscopy observations of blazars conducted by the Southern African Large Telescope (SALT) ToO Program "Observing the Transient Universe"
(PI: D.A.H. Buckley)

- 20 blazars observed (16 FSRQ, 3 BL Lacs, 1 BCU)
- redshifts of 0.1 to 2.1
- Multi-epoch observations for 10 blazars
- Polarisation degrees of 0 to ~ 30 %

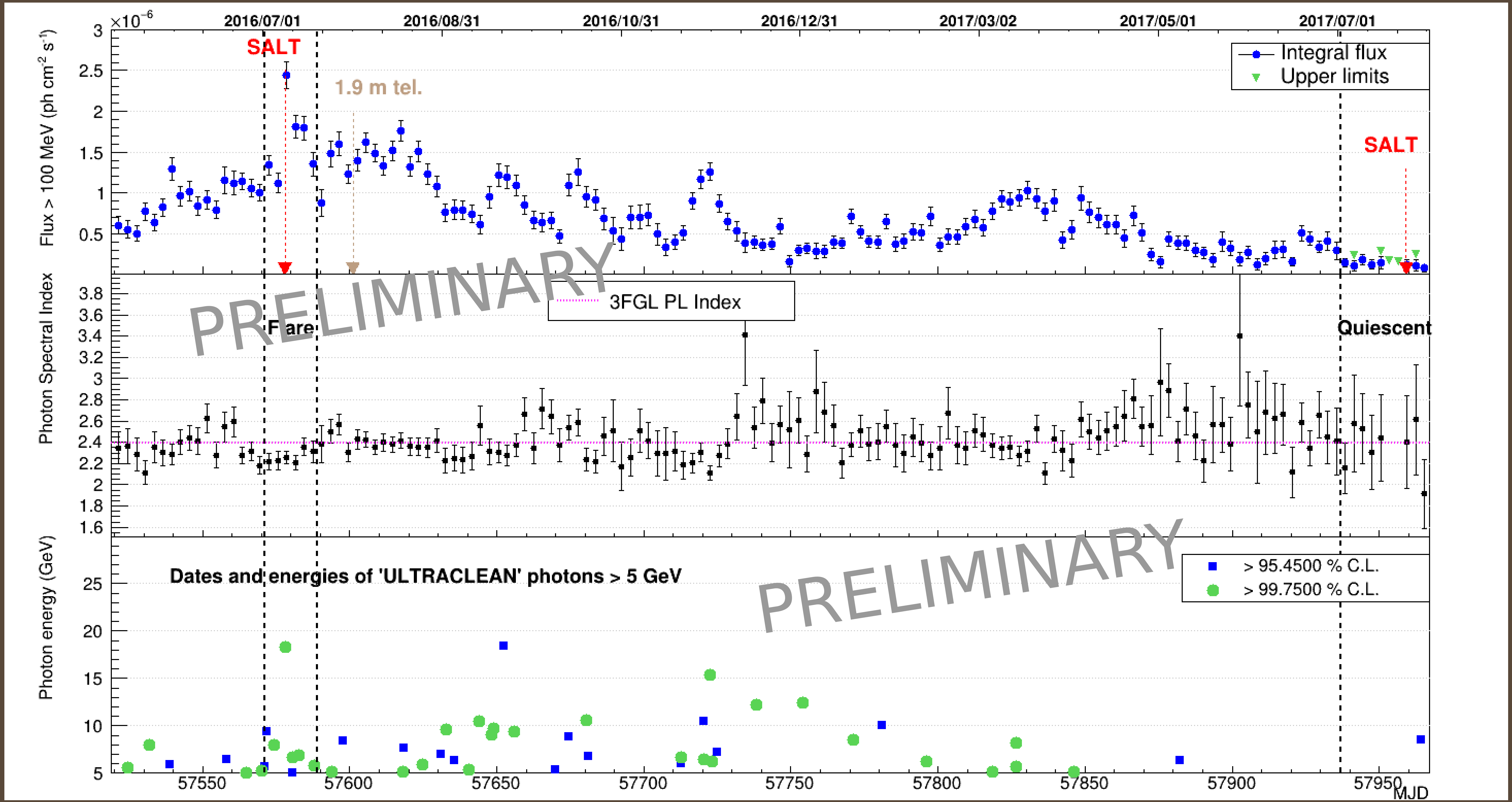
OBSERVATIONS | *Spectropolarimetry and spectroscopy observations of blazars conducted by SALT ToO Program "Observing the Transient Universe" (PI: D.A.H. Buckley)*

4C+01.02



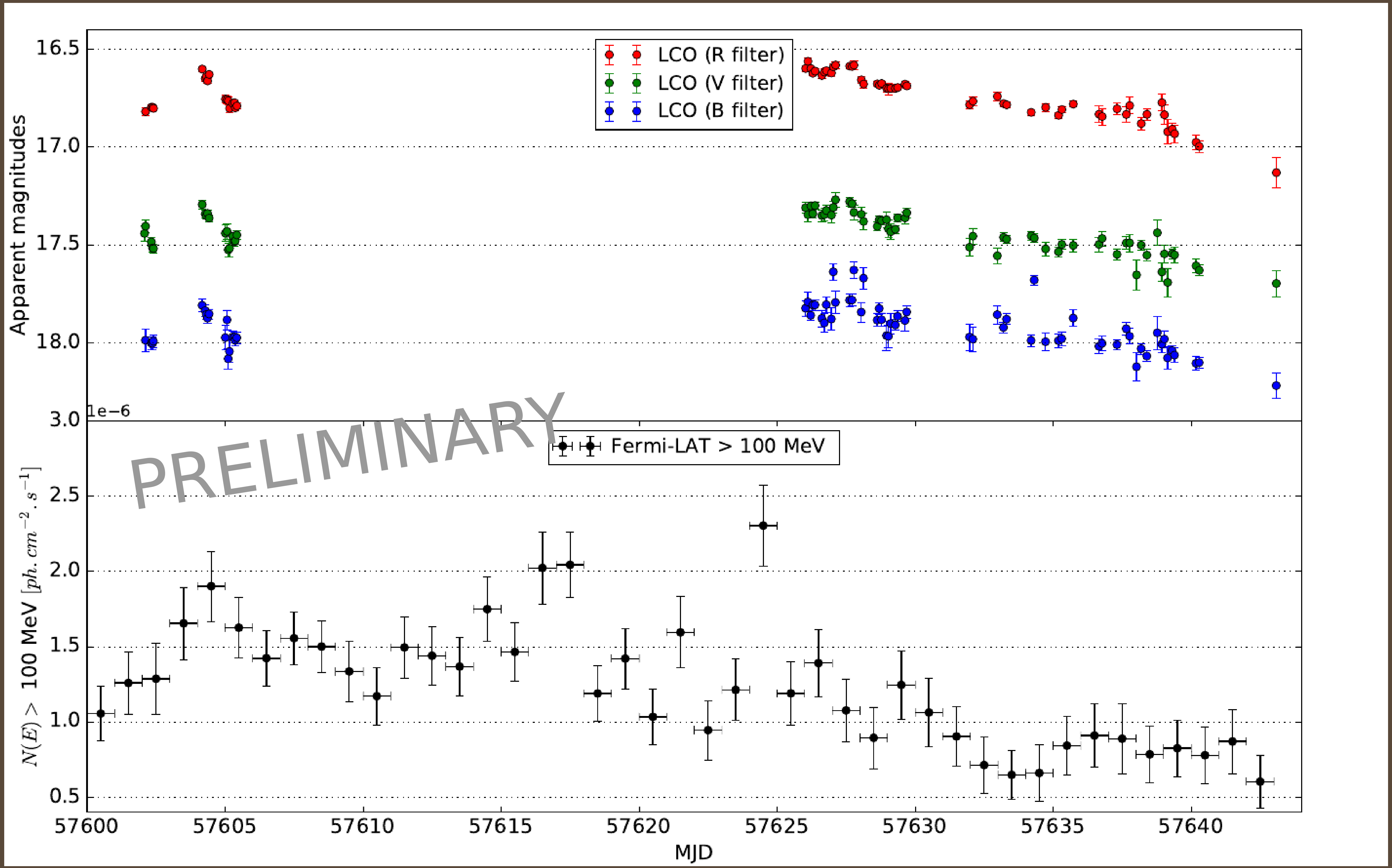
OBSERVATIONS | Fermi-*LAT* Light-curves

4C+01.02



Analysed Fermi-LAT data from 2016 May to 2017 October.

OBSERVATIONS | Las Cumbres Observatory (LCO) (PI: B. van Soelen)



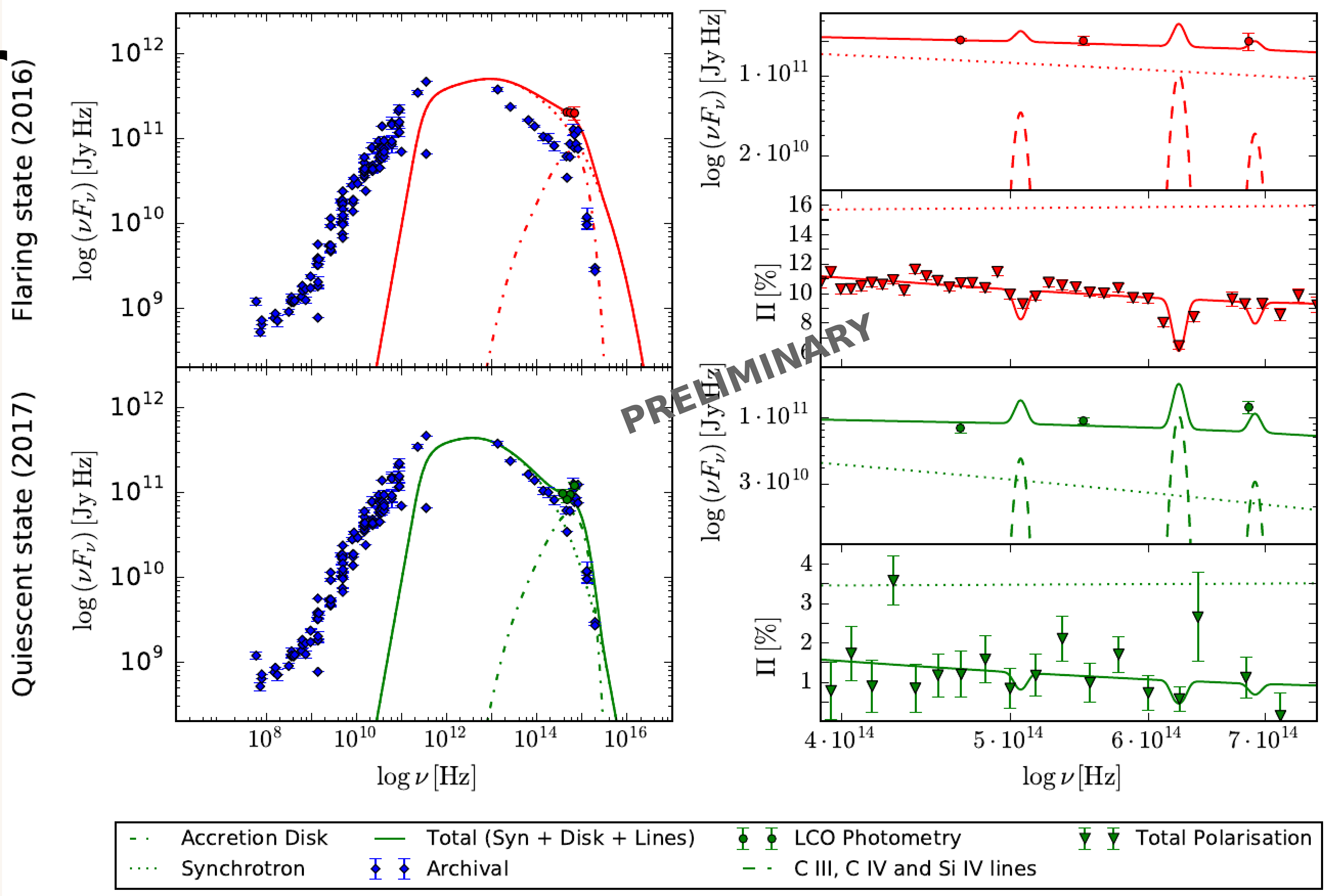
Photometric observations by LCO were conducted in the B, V and R bands on 2016 August 2, and in the B, V, R, and I bands on 2017 July 28.

Results for 4C+01.02

B =0.82 G Γ = 15	Flaring state (2016)	Quiescent state (2017)
M_{BH} (M_{sun})	3 x 10^{9}	3 x 10^{9}
L_d (erg/s)	4.5 x 10^{46}	3.7 x 10^{46}
F_B	0.19	0.04
$(X^2/n)_{pol}$	2.88	1.46

Estimating M_{BH} based on the C IV line width and continuum luminosity (Park et al., 2017):

$$M_{BH} = (7.7 \times 10^{8})^{+2.2 \times 10^{9}}_{-5.4 \times 10^{8}} M_{sun}$$



Flaring (red) and quiescent state (green) low-energy SED bump and spectropolarimetry fit.

Schutte et al. in prep. under review

Comparison to Previous Work

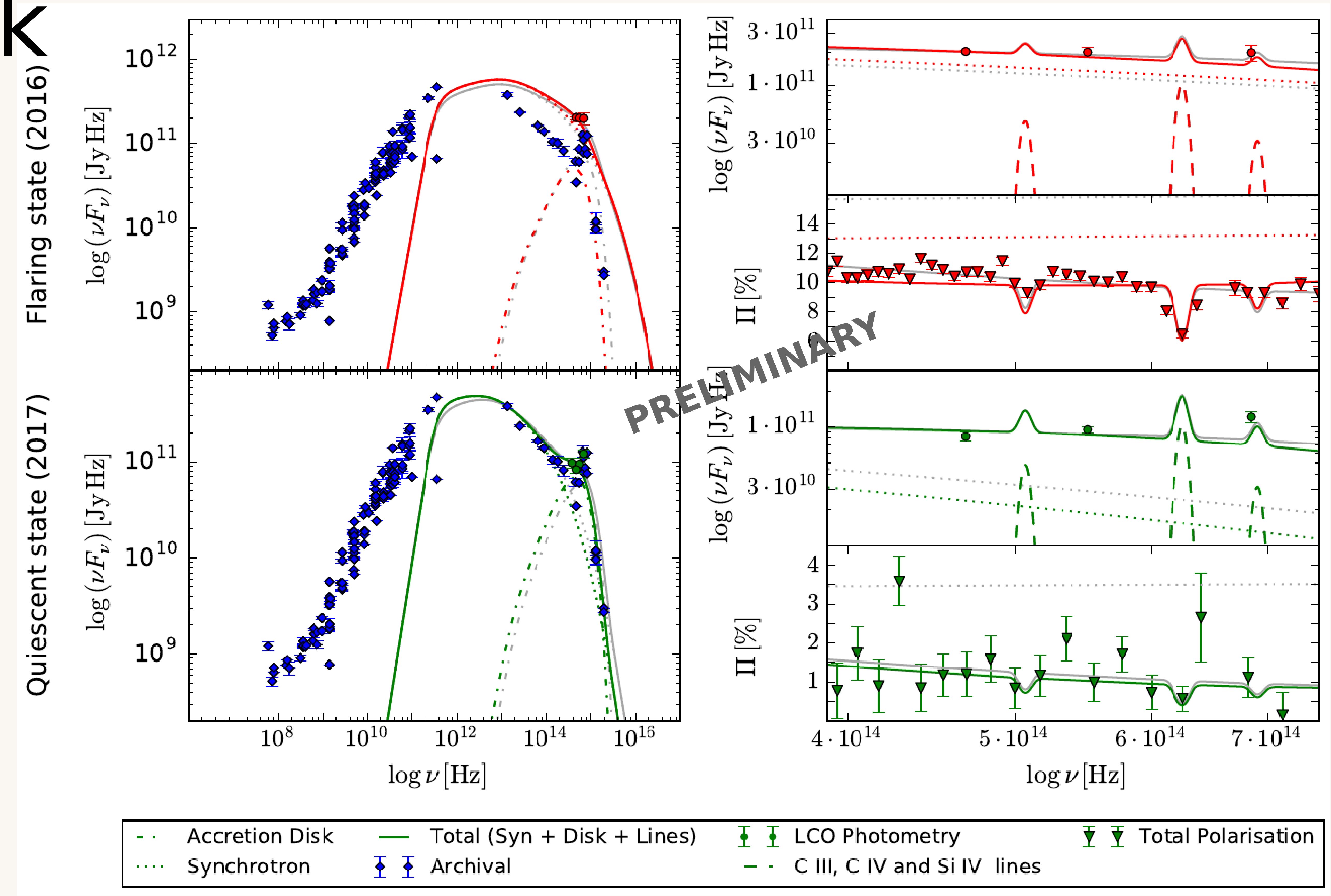
	Flaring state (2016)	Comparison M_{BH}
M_{BH} (M_{sun})	3 x 10^9	5 x 10^9
L_d (erg/s)	4.5 x 10^{46}	3.2 x 10^{46}
F_B	0.19	0.16
$(X^2/n)_{pol}$	2.88	6.91

	Quiescent state (2017)	Comparison M_{BH}
M_{BH} (M_{sun})	3 x 10^9	5 x 10^9
L_d (erg/s)	3.7 x 10^{46}	4.4 x 10^{46}
F_B	0.04	0.05
$(X^2/n)_{pol}$	1.46	1.54

Estimating M_{BH} based on the C IV line width and continuum luminosity (Park et al., 2017):

$$M_{BH} = (7.7 \times 10^8)^{+2.2\times10^9}_{-5.4\times10^8} M_{sun}$$

Ghisellini et al. (2011) and Paliya et al. (2017): M_{BH} = 5 x 10^9 M_{sun}



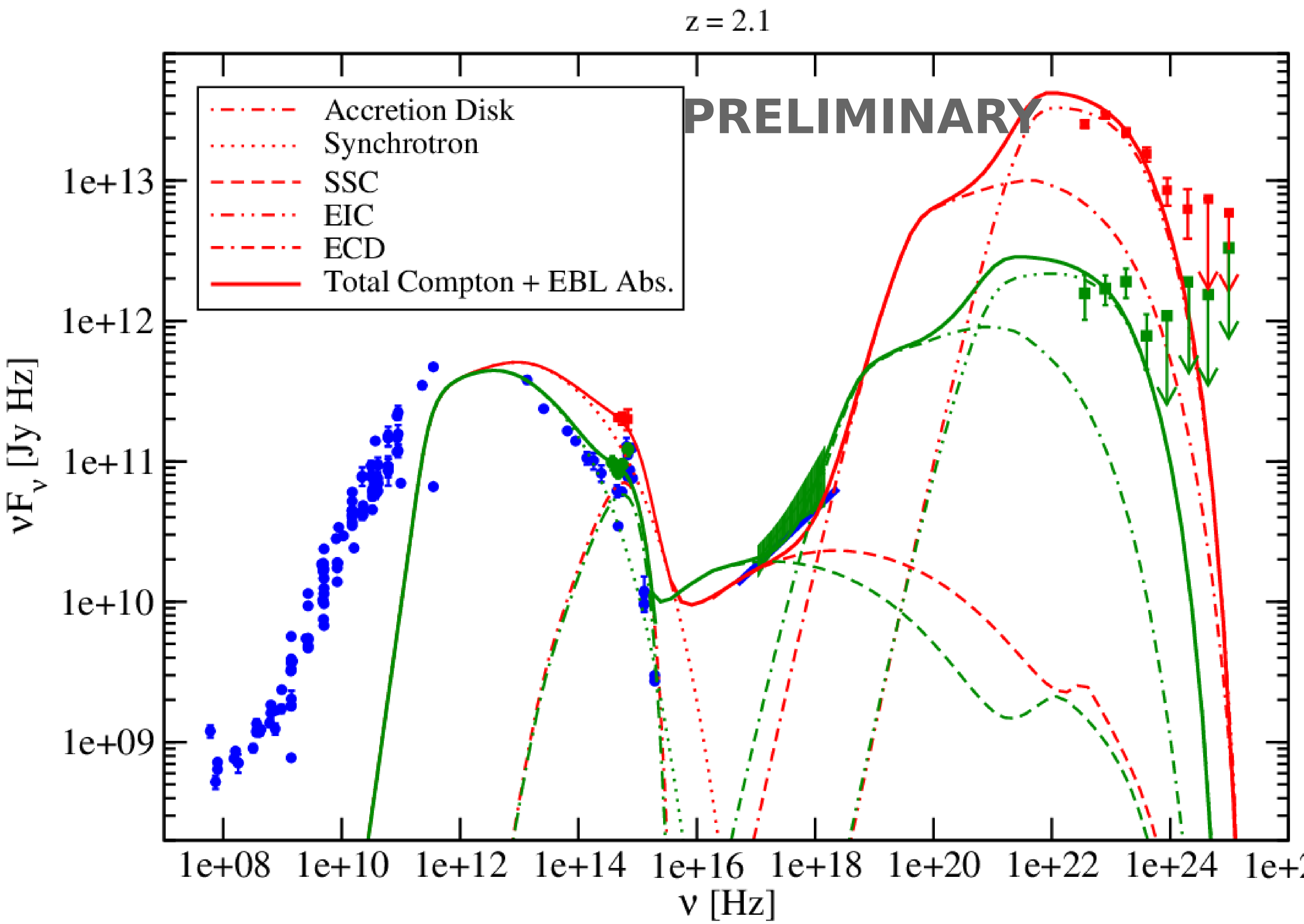
4C+01.02

Contemporaneous observations, SED and polarisation of flaring state during 2016 (green) and quiescent state during 2016 (red). Archival data are shown in blue.

Broad-band SED

Modelled with the code of Böttcher et al. (2013).

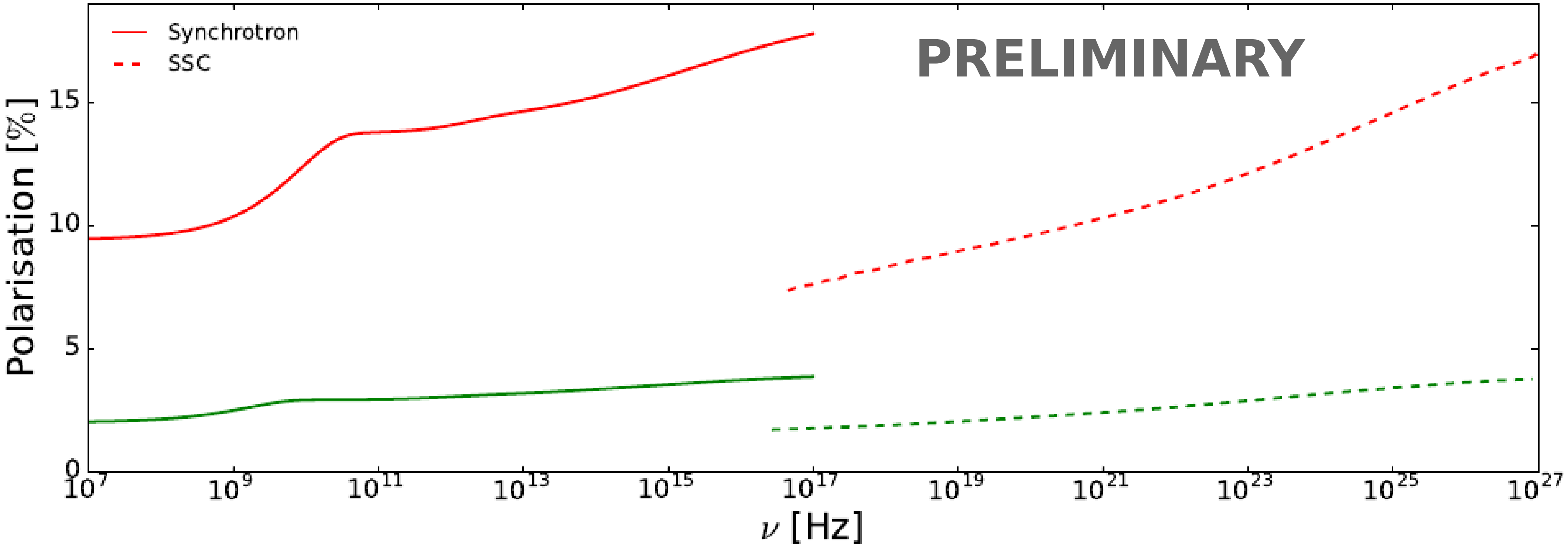
	Flaring state (2016)	Quiescent state (2017)
Parameters Obtained with Fit:		
Minimum gamma γ_{min}	54.8	24.5
Gamma break γ_b	7.27×10^2	4.90×10^2
Critical gamma γ_c	3.00×10^3	1.51×10^3
Electron spectral indices p_1, p_2	2.62, 2.99	2.60, 3.01
High Energy Components Input:		
Kinetic luminosity in jet e^-'s [erg/s]	3.2×10^{45}	6.0×10^{45}
Emission region height z_0 [pc]	0.15	0.3
Emission region radius R_{em} [cm]	3×10^{17}	3×10^{17}
Observation angle $\theta_{obs} = 1/\Gamma$ [$^\circ$]	3.5	3.5
External radiation field energy density [erg/cm^3]	9.0×10^{-3}	5.5×10^{-4}
External radiation field T^{BB} [K]	5×10^4	5×10^4



Fermi-LAT: 2016 Jul 2–Jul 20 (Flare) and 2017 Jul 3 – Aug 2 (Quiescent). *Swift*-XRT: 2 August 2017 (Quiescent)

Multi-Wavelength Polarisation

SSC polarisation with the code of Zhang and Böttcher (2013).



SUMMARY AND CONCLUSIONS

A model was constructed that simultaneously fits the low-energy SED and polarisation (synchrotron + accretion disk) components in the optical-UV regime by use of SALT spectropolarimetry and co-ordinated observations.

For 4C+01.02, the black hole mass was constrained to 3 x 10^9 M_{sun} by including SED and polarisation observations compared to previous work by Ghisellini et al. (2011) and Paliya et al. (2017) who only included SED observations and obtained it as 5 x 10^9 M_{sun}.

Constraining the scaling factor F_B parametrising the degree of order of the magnetic field (includes dependency on line of sight), enables us to predict SSC polarisation and, thereby, the total high-energy polarisation.

OUTLOOK

Hadronic model components

Proton synchrotron and pair synchrotron components.

Modelling future polarisation observations

From IXPE (launch data: 17 November 2021) and AMEGO. Understanding the high energy polarisation mechanisms could help us to distinguish between leptonic and hadronic models.

Studying further blazar sources

With SALT spectropolarimetry and co-ordinated multi-wavelength (archival, *Swift*, *Fermi*-LAT) observations.

Thank you!

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