NWU

SA-GAMMA
THE SOUTH AFRICAN GAMMA-RAY
ASTRONOMY PROGRAMME

fermi

Variety of extreme blazars in *AstroSat* view

Pranjupriya Goswami*

Michael Zacharias , Sunil Chandra , Andreas Zech,
Markus Boettcher, Iurii Sushch

North-West University, South Africa
LSW, Universität Heidelberg
South African Astronomical Observatory, Cape Town
LUTH, Observatoire de Paris

*pranjupriya.g@gmail.com

Introduction

A new population of blazars?

- Spectral properties:
- Extreme synchrotron with $E_{p,syn}$ > 1-10 keV
- Extreme Compton with $E_{p,IC}$ > 2-10 TeV, Or both
- Hard X-ray/TeV spectrum (Γ < 1.5 - 1.9)
- **No detected flux variability or flares (?) - 1ES 1218+304**

Why extreme blazars ?

- Challenges the blazar emission/acceleration mechanisms, Extreme accelerators?

- One-zone SSC scenario

  - requiring lower magnetic field (<10 mG) and extremely high values of min. Lorentz factor (> 10^3-10^4)

  Example: 1ES 0229+200, RGB J0710+591, 1ES 1218+304

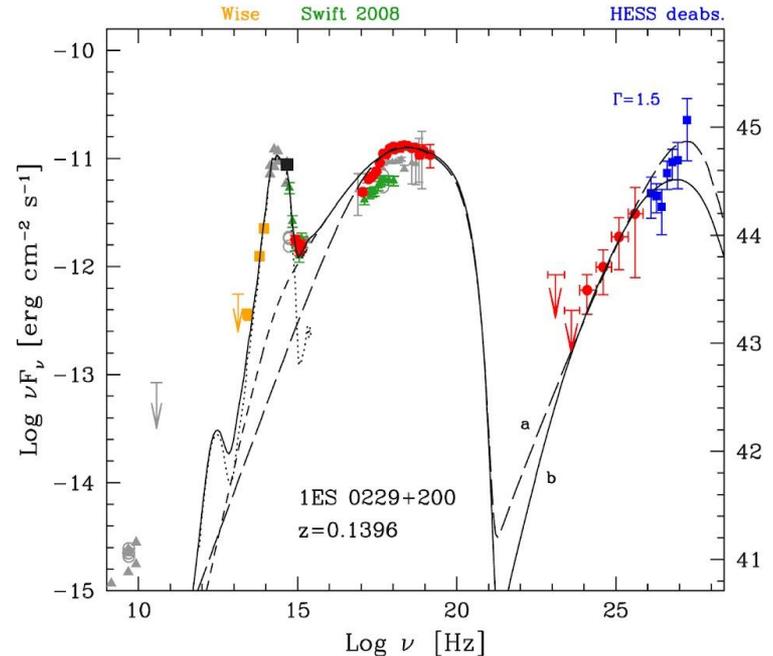 **Kaufmann et al. 2011, Aharonian et al. 2007, Acciari et al. 2010,**

Fig: One Zone SSC modeling of 1ES 0229+200
Costamante et al., 2018

Introduction

A new population of blazars?

- Spectral properties:
- Extreme synchrotron with $E_{p,syn}$ > 1keV
- Extreme Compton with $E_{p,IC}$ > 1 TeV, Or both
- Hard X-ray/TeV spectrum (Γ < 1.9)
- **No detected flux variability or flares (?) - 1ES 1218+304**

Why extreme blazars ?

- Challenges the blazar emission/acceleration mechanisms,
  Extreme accelerators?

- One-zone SSC scenario
  - requiring lower magnetic field (<10 mG) and extremely high values of min. Lorentz factor (> 10^3-10^4)

Aim is to test the viability of various SSC, hadronic scenarios in such extreme conditions
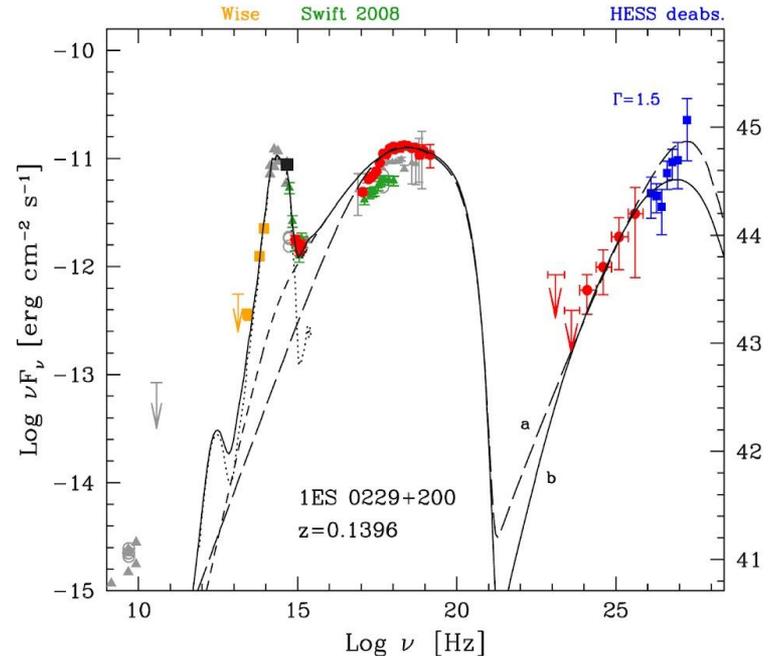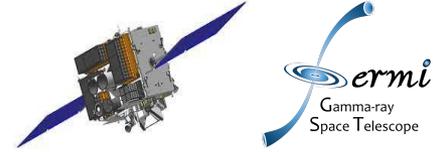
Fig: One Zone SSC modeling of 1ES 0229+200
Costamante et al., 2018

Observations

AstroSat:

- **SXT** : 0.3 - 7 kev, in PC mode;

- **LAXPC**: 3-20 keV

- **UVIT** : 2 FUV filters

Fermi-LAT:

- PASS-8 data

- 0.3-300 GeV energy range

We selected five high energy peaked blazars (HBLs) and the selection is based on the available AstroSat data from our proposed observations

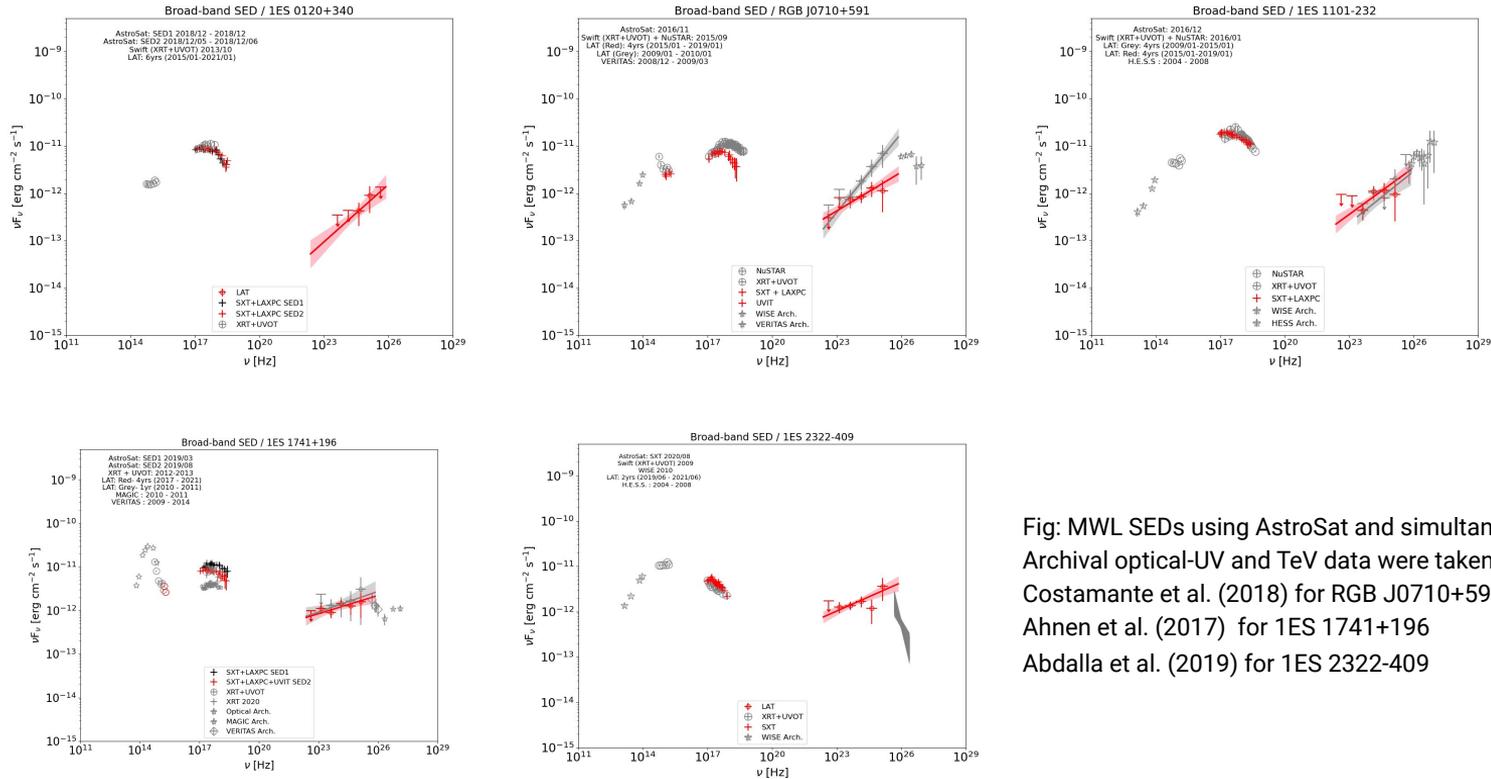|	Source	Observation date (yyyy-mm-dd)	Exposure (SXT) (ks)	State	Contemp. Fermi-LAT
extreme TeV ?	1ES 0120+340	2018-12-01	112.12	S1	6yrs (2015/01-2021/01)
		2018-12-06	20.68	S2	
extreme TeV	RGB J0710+591	2016-11-19	20.25		4yrs (2015/01-2019/01)
	1ES 1101-232	2016-12-28	70.78		4yrs (2015/01-2019/01)
		2019-03-27	33.94	S1	
HBL ?	1ES 1741+196	2019-07-03	33.12	S2	4yrs (2017/01-2021/01)
		2019-08-22	24.8	S3	
HBL	1ES 2322-409	2020-07-03	44.21		2yrs (2019/01-2021/01)

MWL SEDs

Fig: MWL SEDs using AstroSat and simultaneous Fermi-LAT data
Archival optical-UV and TeV data were taken from
Costamante et al. (2018) for RGB J0710+591 and 1ES 1101-232
Ahnen et al. (2017) for 1ES 1741+196
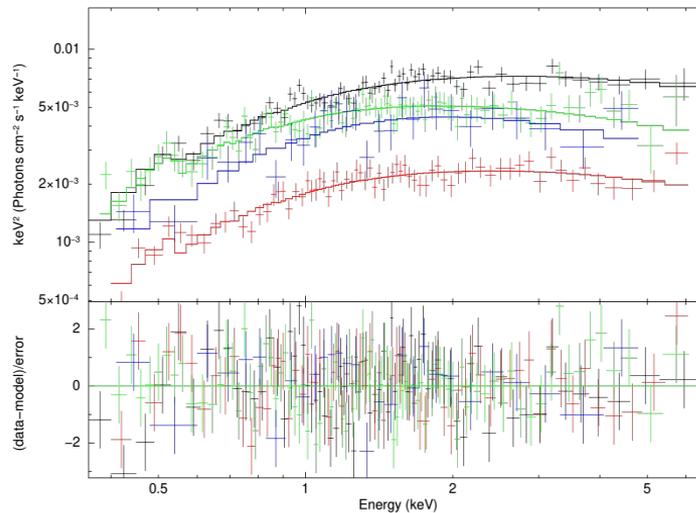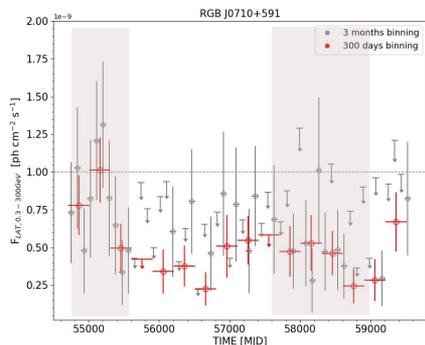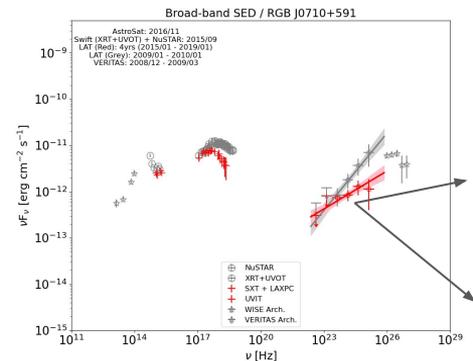Abdalla et al. (2019) for 1ES 2322-409

Variability?

- **X-ray and GeV variability in RGB J0710+591**

Fermi-LAT spectrum

Source	TS	PL Index	Flux (0.3-300 GeV) [ph cm^{-2} s^{-1}]
RGB J0710+591			
2017/01-2021/01	96.6	1.76±0.12	(3.44±0.62) e-10
2009/01-2010/01	138.95	1.44±0.12	(2.43±0.83)e-09

- **Hint of X-ray variability in 1ES 1741+196**

Black, Green: AstroSat 2019
Red : XRT 2012-2013
Blue: XRT 2020

Models considered

- **One zone leptonic (SSC) model**   **Böttcher et al. 2013, ApJ, 768, 54**

➔ Ultrarelativistic e^- (or e^+) population with power-law injection

➔ Cooling due to synchrotron and Compton emission

➔ synchrotron self compton in our case (no contribution from external field considered)

➔ Resulting electron distribution will follow broken power law form

Models considered

- ## One zone leptonic

Böttcher et al. 2013, ApJ, 768, 54
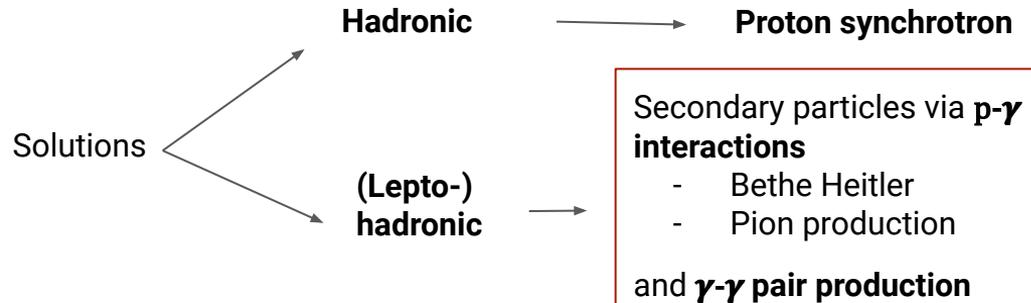
→ Ultrarelativistic e- (or e+) population with power-law injection
→ Cooling due to synchrotron and IC (SSC in our case)

- ## One-zone Hadro-Leptonic code (*OneHaLe*)

Zacharias, M. 2021, Physics, 3, 1098
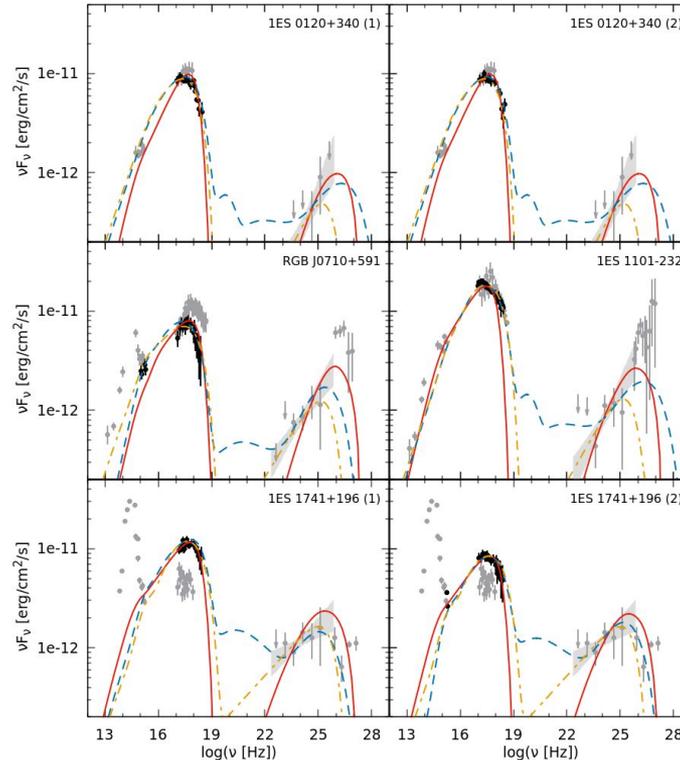**Zacharias, M. et al. 2022, MNRAS, 512,3**

→ Primary injection of protons and electrons in simple power-law form and particles evolved self-consistently

→ Time-dependent

→ Cooling due to : synchrotron (e-, p, pion, muon), inverse Compton, adiabatic, secondary emissions via Bethe Heitler and Pion production

Solutions

Hadronic → **Proton synchrotron**

(Lepto-) hadronic →

Secondary particles via **p-γ interactions**
- Bethe Heitler
- Pion production

and **γ-γ pair production**

ExHaLe-jet (Talk by Michael Zacharias)
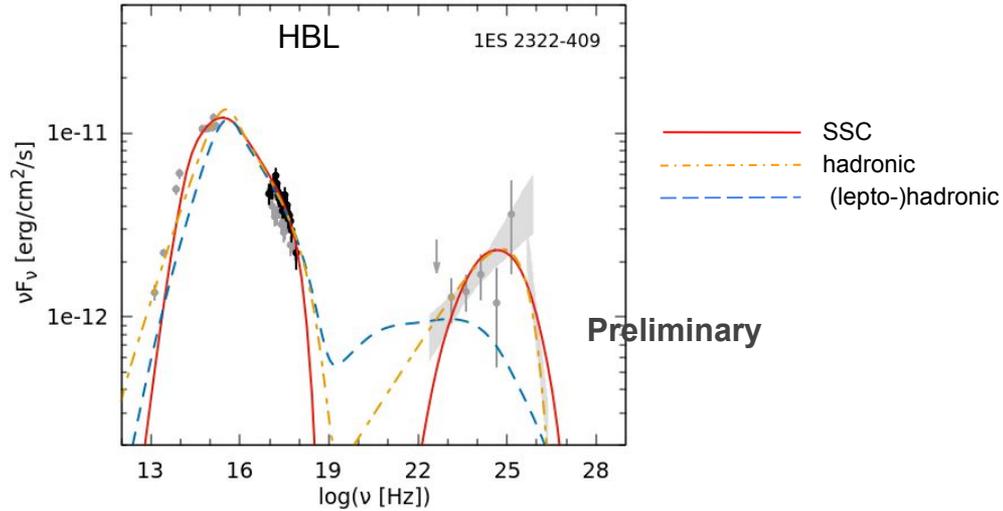
Modeling (preliminary)

eHBLs

SSC
hadronic
(lepto-)hadronic

- Both SSC and (lepto-)hadronic models seem to provide satisfactory representation of the SEDs

- SSC: $\delta = 30$, $B \sim 10 - 35$ mG, $\gamma_{min} \leq 10^3$

- Lepto-hadronic: $\delta = 50$, $B = 1$ G

- Injection spectrum with $\alpha \sim 1.2 - 1.5$

Fig: SED modeling using One Zone SSC and OneHaLe
Credit: Michael Zacharias

Modeling (preliminary)

Fig: SED modeling of the HBL using One Zone SSC and OneHaLe
Credit: Michael Zacharias

- One SSC model seems to provide satisfactory representation of the HBL

- SSC: **δ =30, B = 13 mG**
- Injection spectrum with **α ~ 2.5**

Model

e⁻p co-acceleration code   **Zech and Lemoine (2021)**

Explains the extreme VHE emission,
- Low magnetization
- High min Lorentz factor (γ_{min}) - due to electron preheating at single or multiple shocks

Modification to the standard one-zone SSC:

- Proton population has been added
- PL with exponential cutoff e⁻ population (index=2.2) has been considered

Preheating scenarios:

- Scenario-I : Shock acceleration with high γ_{min}
- Scenario-II : Co-acceleration on mildly relativistic shocks
- Scenario-II : Re-acceleration on a second shock

Application: 5 extreme VHE sources - 1ES 0229+200, 1ES 0347-121, RGB J0710+591, 1ES 1101-232, 1ES 1218+304

Modeling (preliminary)

RGB J0710+591

Acceleration scenario on single shock

- δ=50, B changes from 9.8 to 5 mG
- γ_{min} = 1.8e-3
- L_{jet} = 4.5e44

1ES 1101-232

Re-acceleration scenario on a second shock

- δ=50, B changes from 4.5 to 3 mG
- γ_{min} = 1.8e-3
- L_{jet} = 3.65e44

1ES 0120-232

Re-acceleration scenario on a second shock

- δ=50, B = 4 mG
- γ_{min} = 1.8e-3
- L_{jet} = 2.14e44

Fig: SED modeling using e-p co-acceleration code
Credit: Andreas Zech

Preliminary

CGRaBS J0211+1051

- Flared up on 2011 January 23 in high-energy γ-rays as reported by Fermi/LAT

- Intra night variability in optical observed by MIRO

- Detected to have $\sim$ 21 % degree of polarization with steady position angle at 43° on 2011 January 30.

Chandra et al. (2012, 2014)

In collaboration with: **Sunil Chandra,** Michael Zacharias
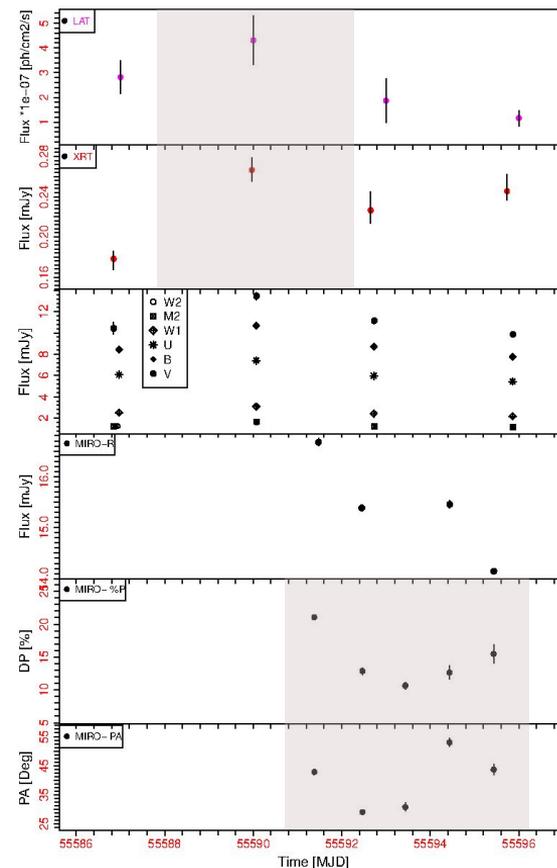**Poster by Sunil Chandra**

Fig: Multi-wavelength light curve of CGRaBSJ0211+1051

X-ray flares detected by XRT in 2011 and 2019

Spectral energy distribution

An ISP source - peaking in optical-UV
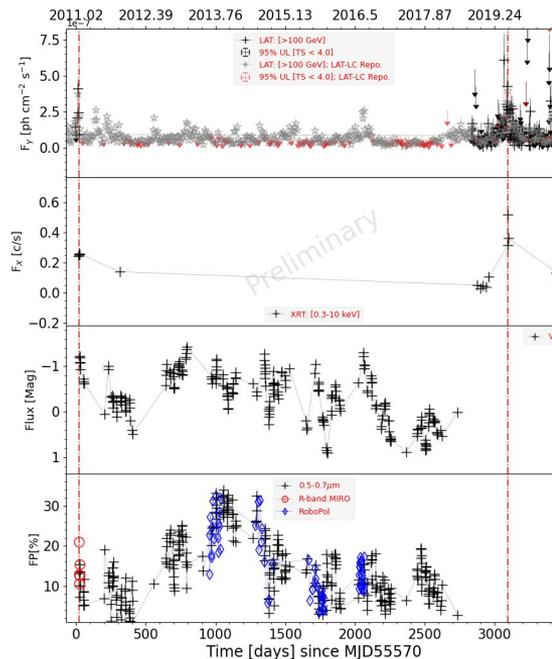

Fig: Multi-wavelength SED of
CGRaBSJ0211+1051

Fig: Multi-wavelength light curve of
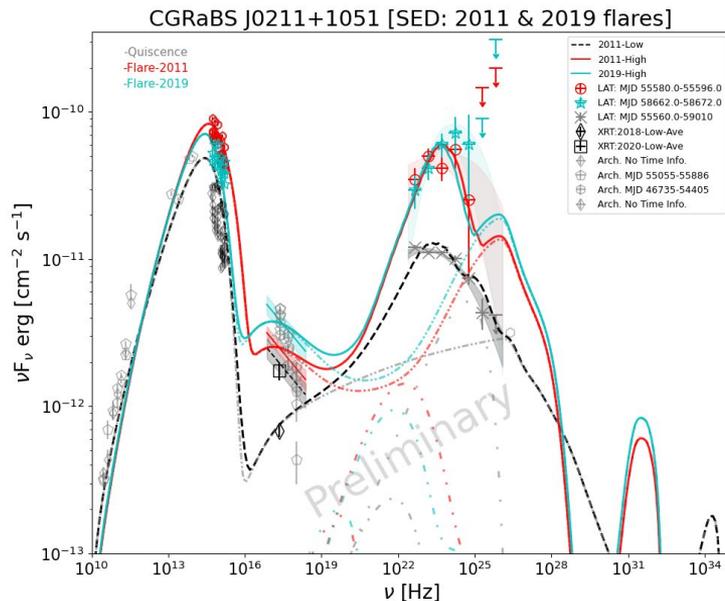CGRaBSJ0211+1051

SED Modeling: *OneHaLe*

Fig: SED modeling using *OneHaLe* code
Credit: Sunil Chandra

- X-ray is not continuation of the UV-optical, indicating separate emission process than synchrotron

- One-Zone SSC not adequate - requiring hadronic component

- *OneHaLe* lepto-hadronic scenario

- Work in progress ..

For details, please visit -
Poster by **Sunil Chandra**
#Contribution ID: 178

Summary

- None of the sources show extreme synchrotron behaviour (syn. peak < 2keV)
- RGBJ0710+591 and 1ES1741+196 show a hint of long term-term variability in X-rays/GeV
- One zone SSC and (lepto-)hadronic models provide reasonably good fit to all the SEDs
- while hadronic models require extreme values of max. proton energy
- e-p co-acceleration code provide satisfactory fit to the extreme VHE sources for RGBJ0710, 1ES1101 and 1ES0120+340
- However, non-simultaneity in the VHE data could be problem
- CGRaBS J0211+1051 - highly variable in optical, peculiar SED - explained by Lepto-(hadronic scenario)
- Work in progress ….