SALT Spectropolarimetry and Self-Consistent SED and Polarization Modeling of Blazars

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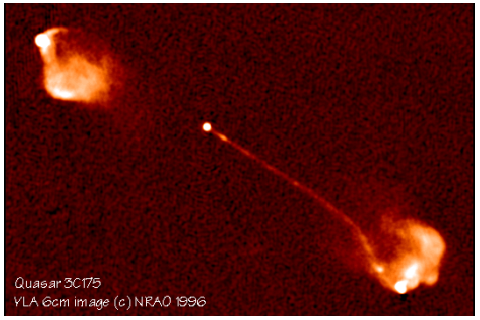

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Brian van Soelen, Richard J. Britto[1],

Johannes P. Marais (UFS)

David Buckley (SAAO)

[1]For the Fermi-LAT Collaboration

Supported by the South African Research Chairs Initiative (SARChI) of the Department of Science and Technology and the National Research Foundation of South Africa.

NRF National Research Foundation

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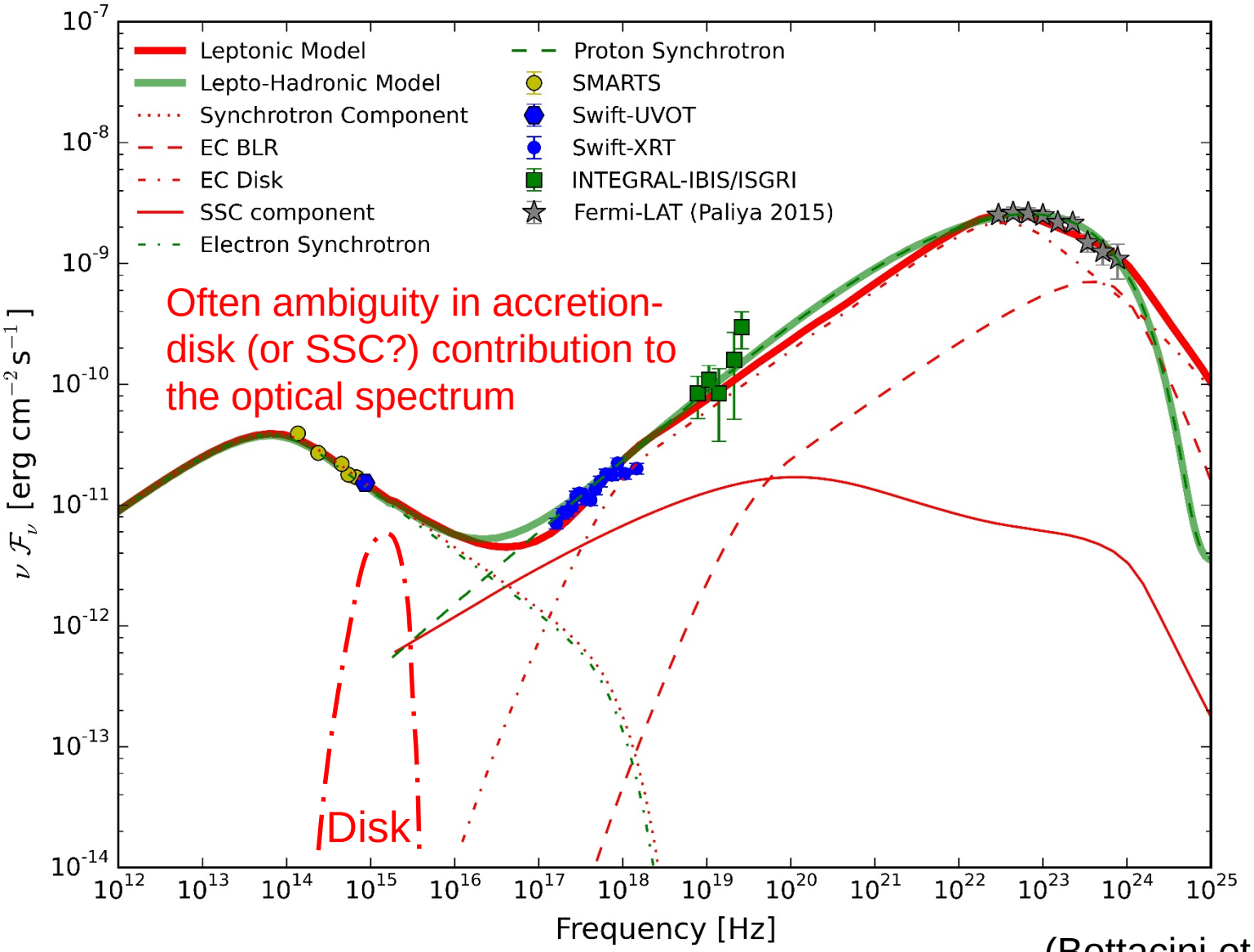
Multiwavelength SEDs

3C279



(Bottacini et al. 2016)

Synchrotron Polarization

For synchrotron radiation from a power-law distribution of electrons with ne (γ) ~ γ^{-p} $\rightarrow$ $F_\nu \sim \nu^{-\alpha}$ with $\alpha = (p-1)/2$

$$\Pi_{PL}^{sy} = f_{B,order} \frac{p+1}{p+7/3} = f_{B,order} \frac{\alpha+1}{\alpha+5/3}$$

p = 2 $\rightarrow$ $\Pi = f_{B,order} * 69\ \%$

p = 3 $\rightarrow$ $\Pi = f_{B,order} * 75\ \%$

Compton Polarization

Compton cross section is polarization-dependent:

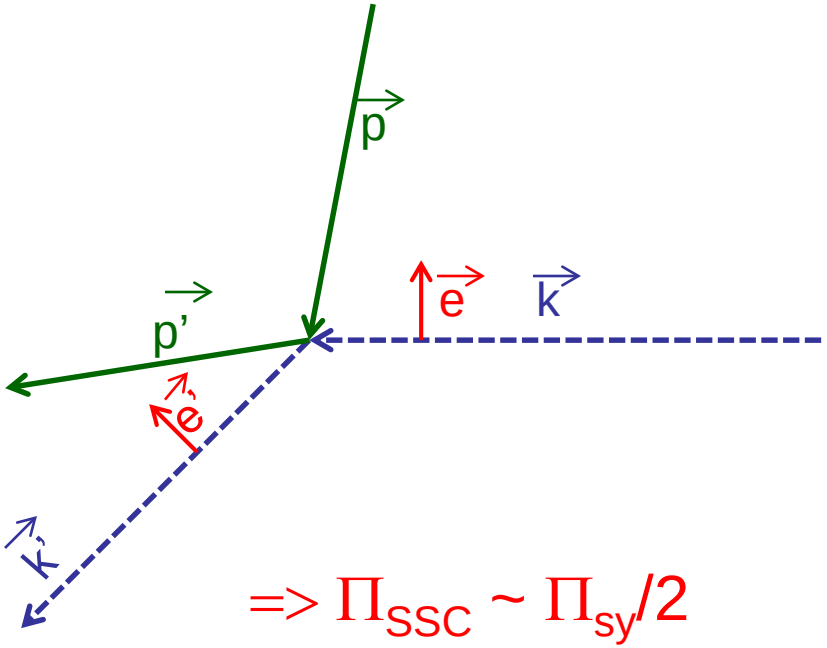
$$\frac{d\sigma}{d\Omega} = \frac{r_0^2}{4}\left(\frac{\epsilon'}{\epsilon}\right)^2\left(\frac{\epsilon}{\epsilon'}+\frac{\epsilon'}{\epsilon}-2+4\left[\vec{e}\cdot\vec{e}'\right]^2\right)$$

$\varepsilon = h\nu/(m_e c^2)$:

Thomson regime: $\varepsilon \approx \varepsilon'$
$\Rightarrow d\sigma/d\Omega = 0$ if $\vec{e}\cdot\vec{e}' = 0$

$\Rightarrow$ Scattering preferentially in the plane perpendicular to $\vec{e}$.

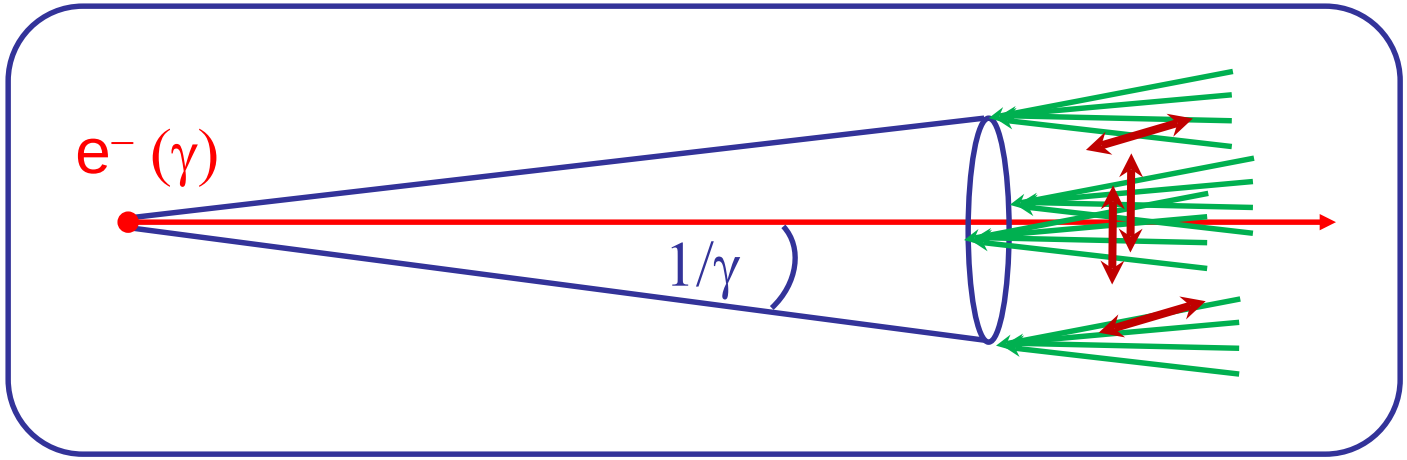
Preferred polarization direction is preserved; polarization degree reduced to ~ ½ of target-photon polarization.



$\Rightarrow \Pi_{SSC} \sim \Pi_{sy}/2$

External-Compton Scattering

- External Compton only relevant for scattering by relativistic electrons
- Relativistic aberration => approx. axisymmetric rad. field in co-moving frame of e^-



=> External-Compton emission ~ **Unpolarized:**

Multiwavelength Polarization

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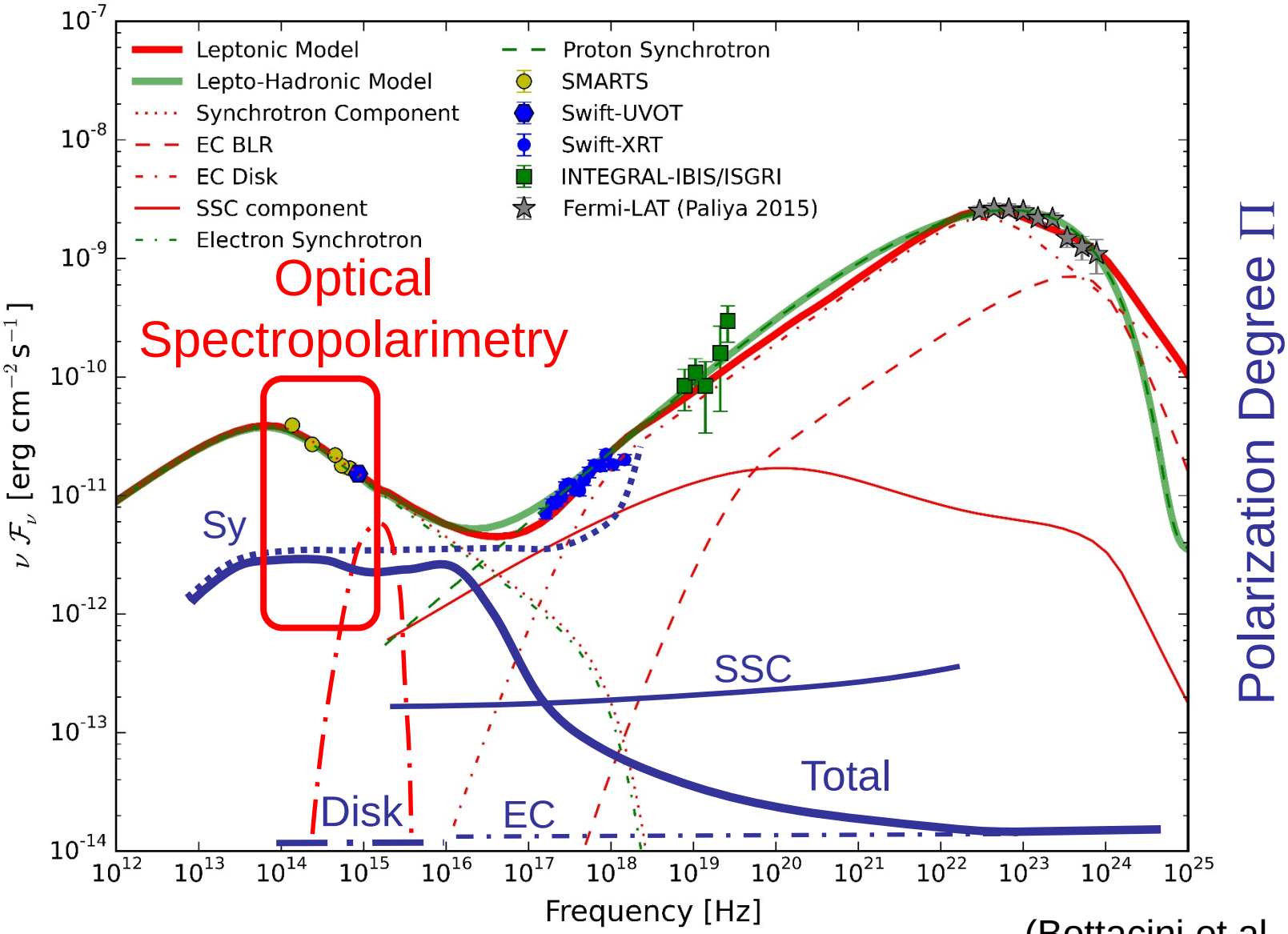
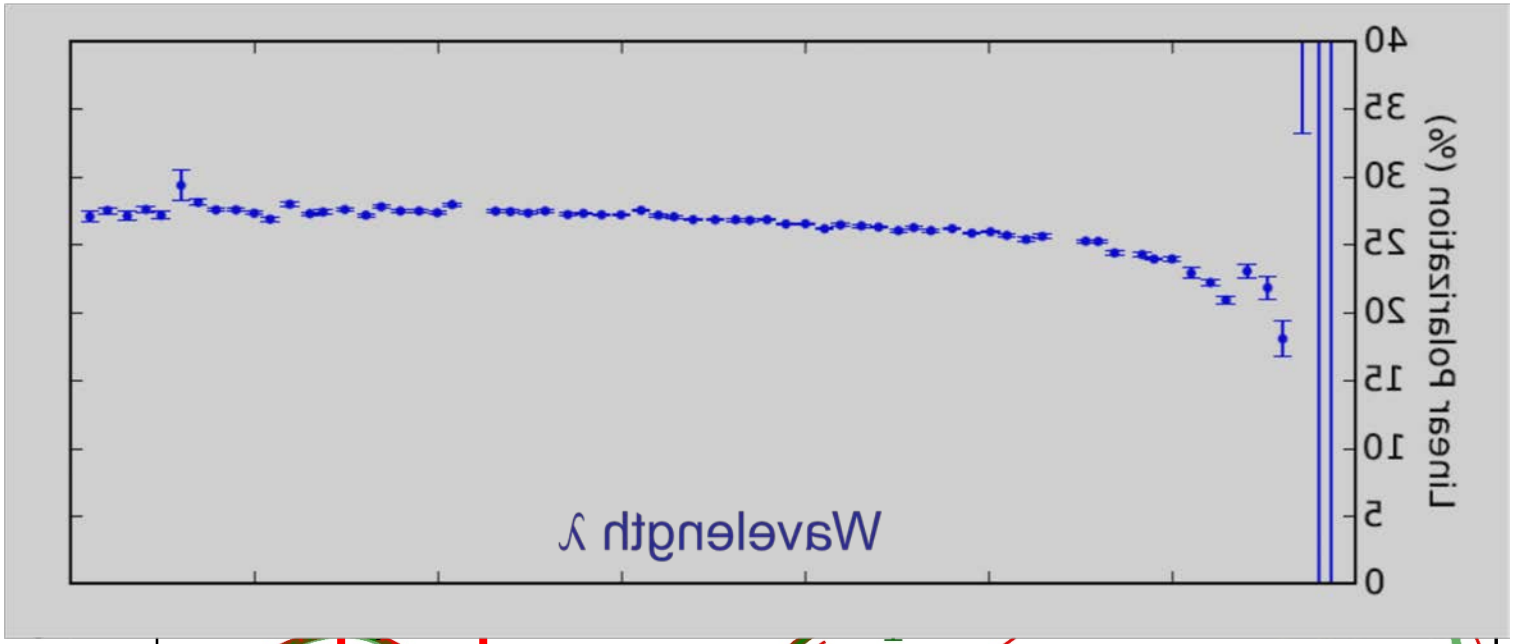
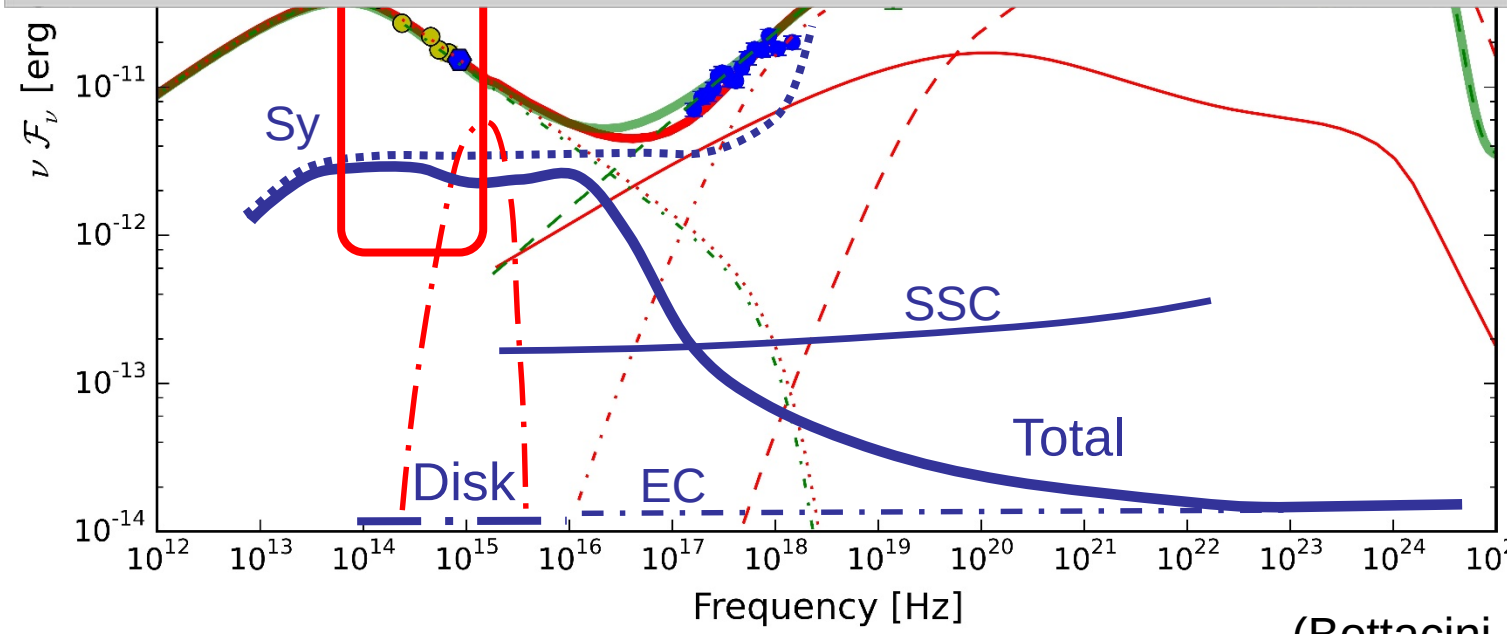


(Bottacini et al. 2016)

Multiwavelength Polarization

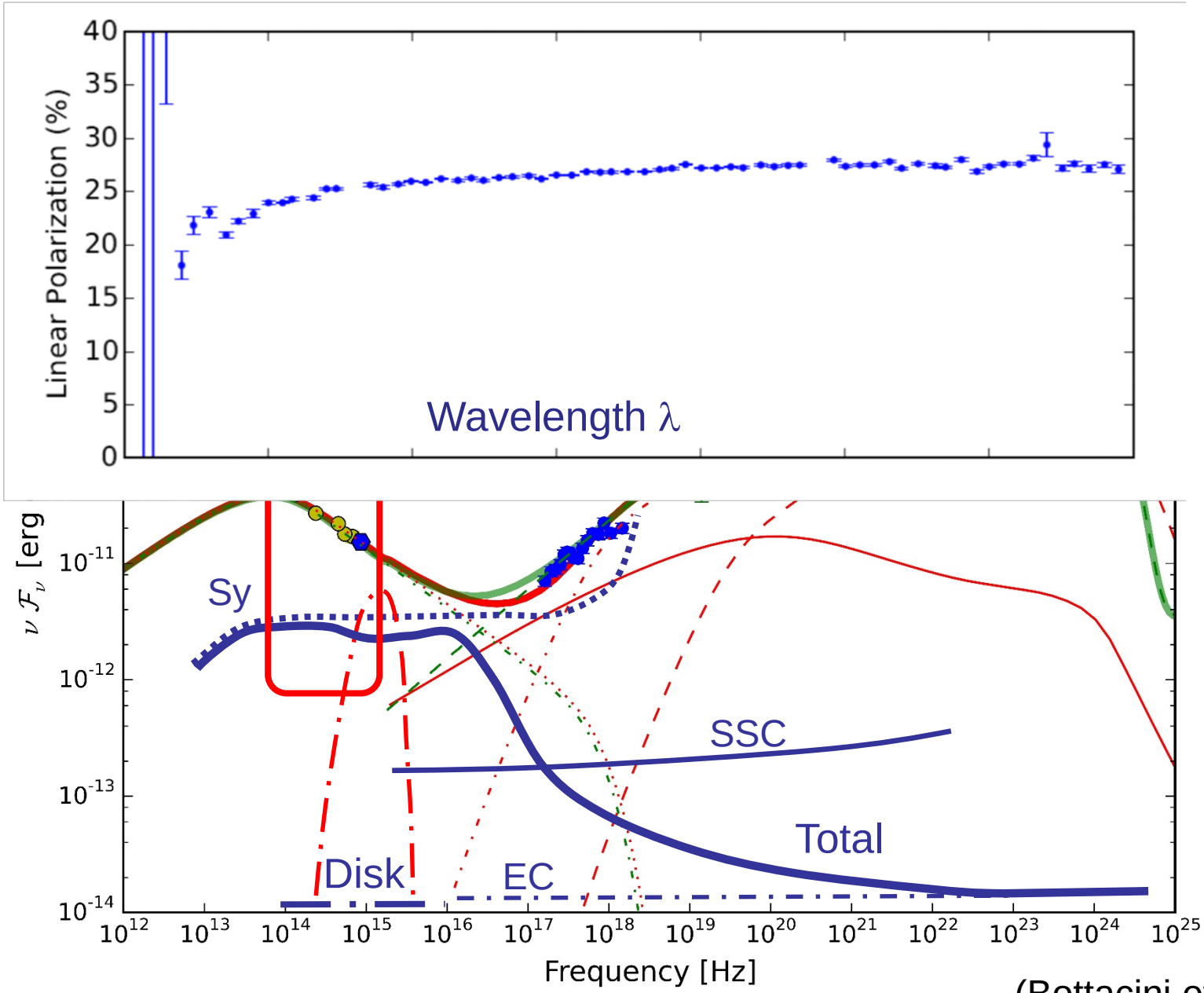




Polarization Degree Π

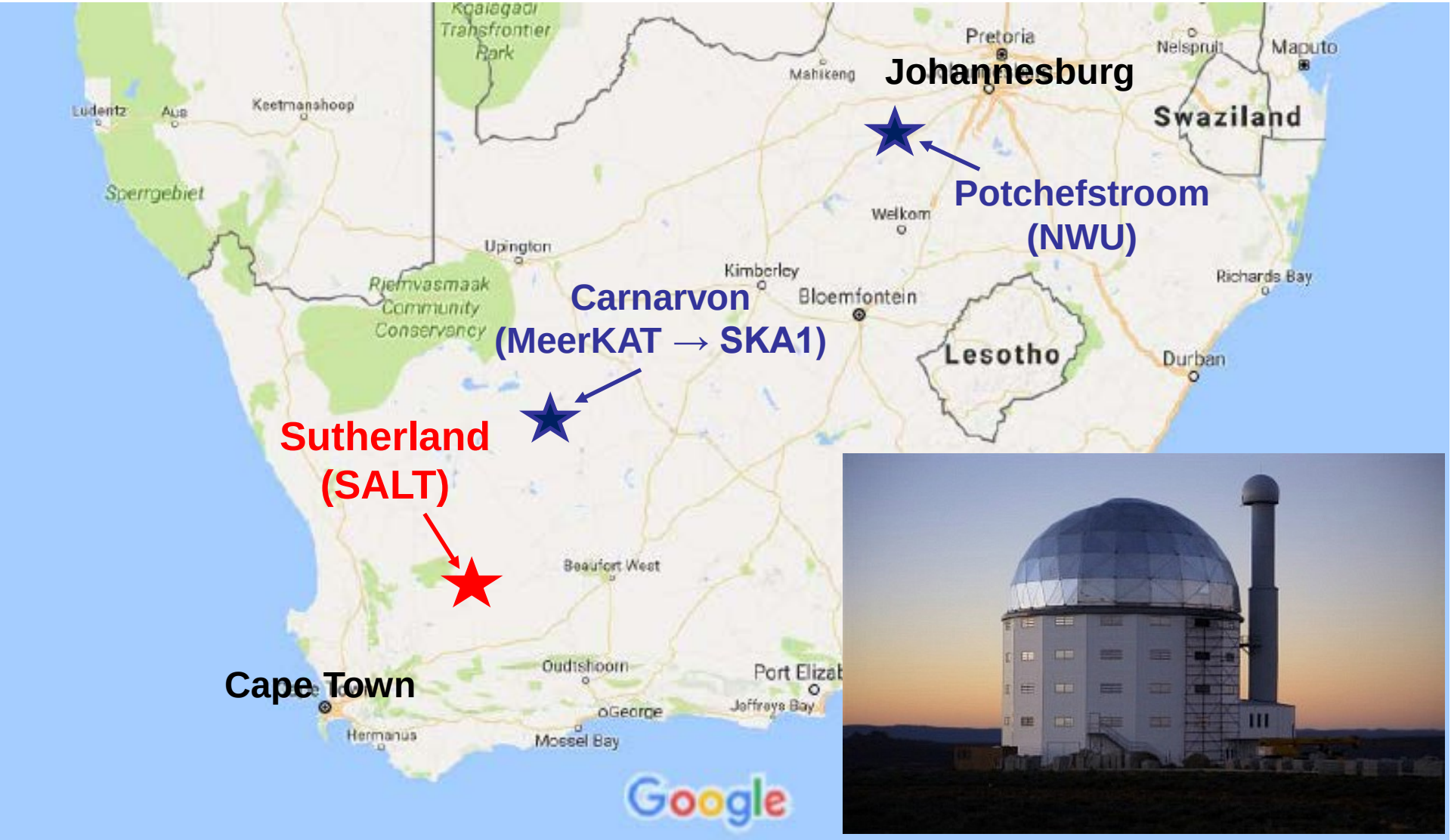
(Bottacini et al. 2016)

Multiwavelength Polarization



(Bottacini et al. 2016)

The Southern African Large Telescope (SALT)



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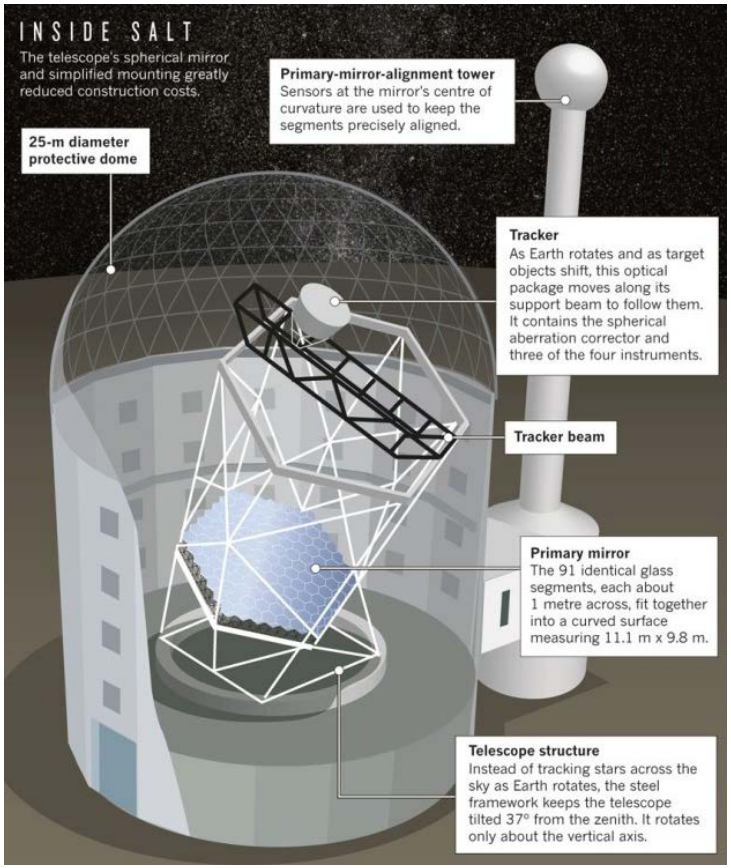


- 11m fixed-altitude telescope (largest single optical telescope in the southern hemisphere)
- Funded by international consortium (SA, USA, Germany, Poland, India, UK, New Zealand)
- Robert-Stobie Spectrograph (RSS): Low – medium resolution (R ~ 5000 – 9000) spectrograph with polarimetry capabilities

SALT Large Programme: Spectroscopy / Spectropolarimetry Follow-up of High-Energy Transients

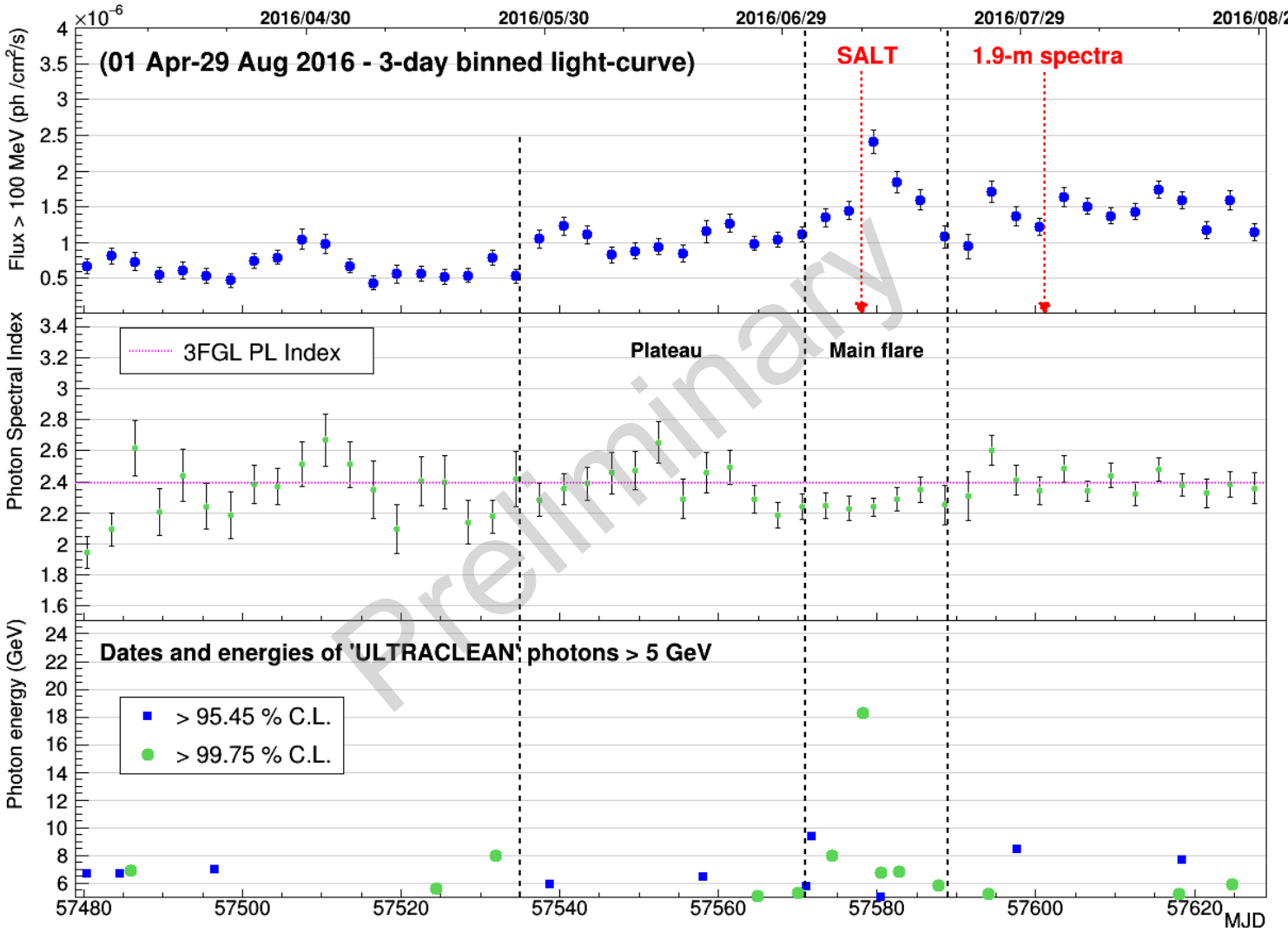
(PI: D. Buckley [SAAO])

Spectropolarimetry Observations of Flaring Blazars

Blazar	Type	Redshift	Obs. dates	Grating	Waveplate pattern	Exposure	% polarisation
PKS 2023-07	FSRQ	$z = 1.4$	15 Apr 2016	PG 300	LINEAR-HI	2400 s	25–27
PKS 1510-089	FSRQ	$z = 0.36$	01 Jun 2016	PG 300	LINEAR-HI	2400 s	
4C +01.02	FSRQ	$z = 2.10$	08 Jul 2016	PG 300	LINEAR	2400 s	9–11
			27 Nov 2016	PG 300	LINEAR	2400 s	~ 6
			28 Nov 2016	PG 300	LINEAR	2400 s	8–10
			29 Nov 2016	PG 300	LINEAR	2400 s	8–10
PKS 0907-023	FSRQ	$z = 0.96$	19 Jan 2017	PG 300	LINEAR	2400 s	0–4
PKS 0426-380	BLL	$z = 1.11$	21 Jan 2017	PG 300	LINEAR	2400 s	10–11
			20 Feb 2017	PG 300	LINEAR	2400 s	11–12
PKS 0447-439	BLL	$z = 0.10$	21 Feb 2017	PG 900	LINEAR	480 s	5–6
3C 279	FSRQ	$z = 0.54$	28 Mar 2017	PG 900	LINEAR	480 s	12–14
			31 Mar 2017	PG 900	LINEAR	480 s	8–10
			17 May 2017	PG 300/900	LINEAR	720 s/720 s	
			21 May 2017	PG 300	LINEAR	1200 s	20–22

Example: 4C +01.02 (PKS B0106+013)

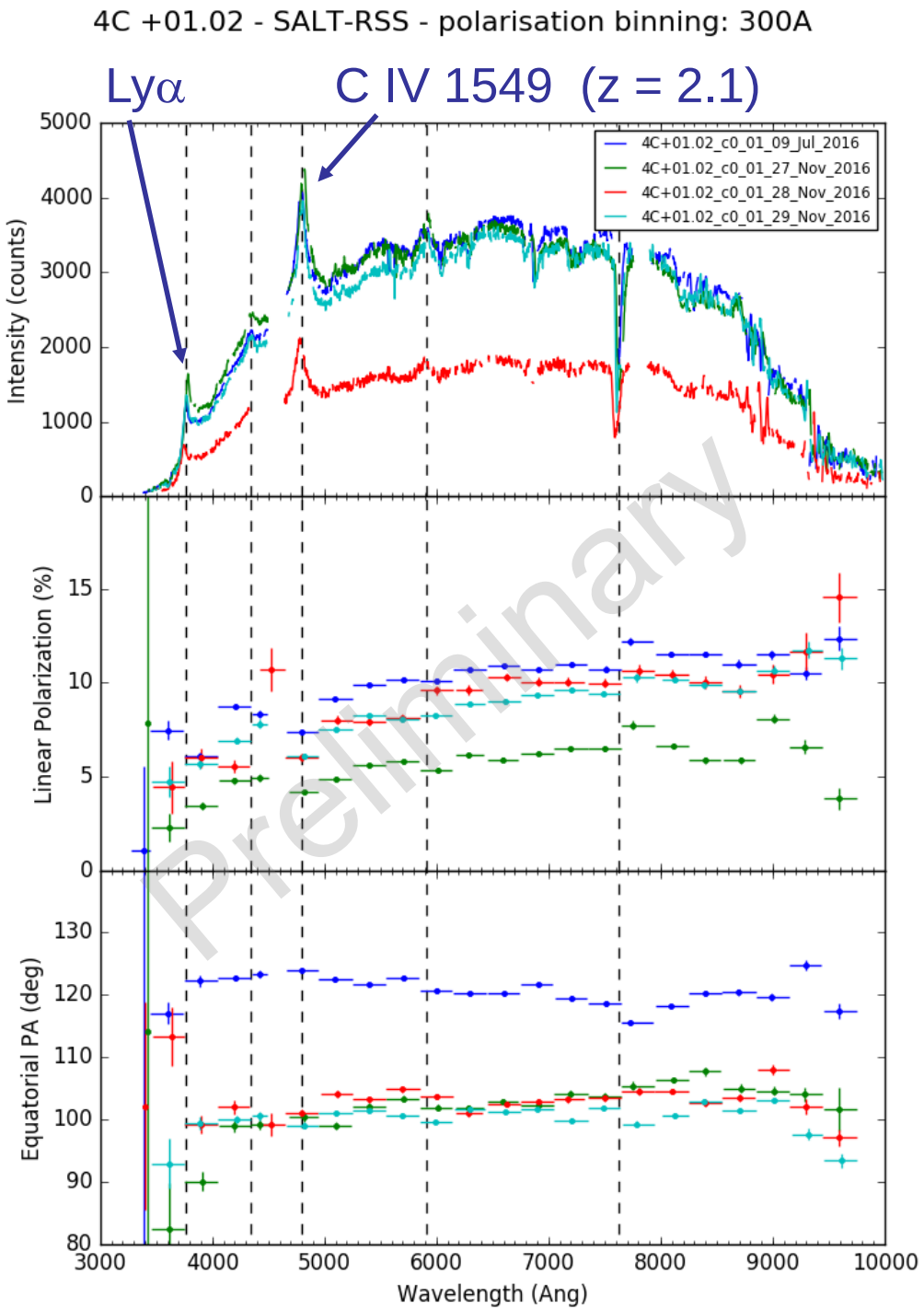
- FSRQ at z = 2.1
- Large γ-ray flare in July 2016
- SALT spectropol. obs. in July and Nov. 2016



(R. J. Britto)

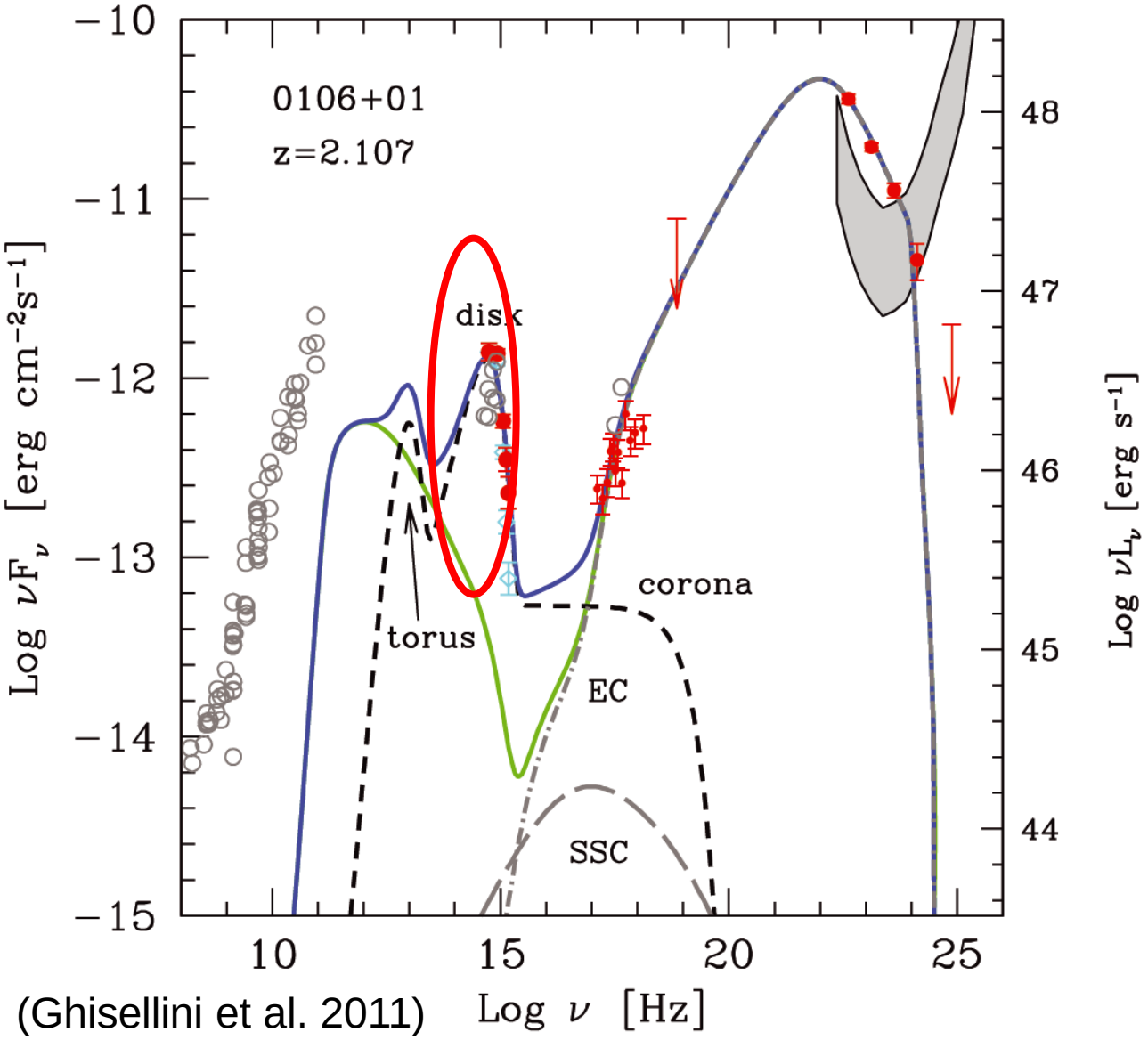
4C +01.02
(PKS B0106+013)

- Significant (and time-variable) optical polarization
- Decreasing towards shorter wavelength
  => Addition of unpolarized component (accretion disk).



(B. v. Soelen, R. J. Britto)

4C +01.02



(Ghisellini et al. 2011)

Previous SED modeling (Ghisellini et al. 2011)

- Would predict unpolarized optical emission!

$\Gamma = 14$

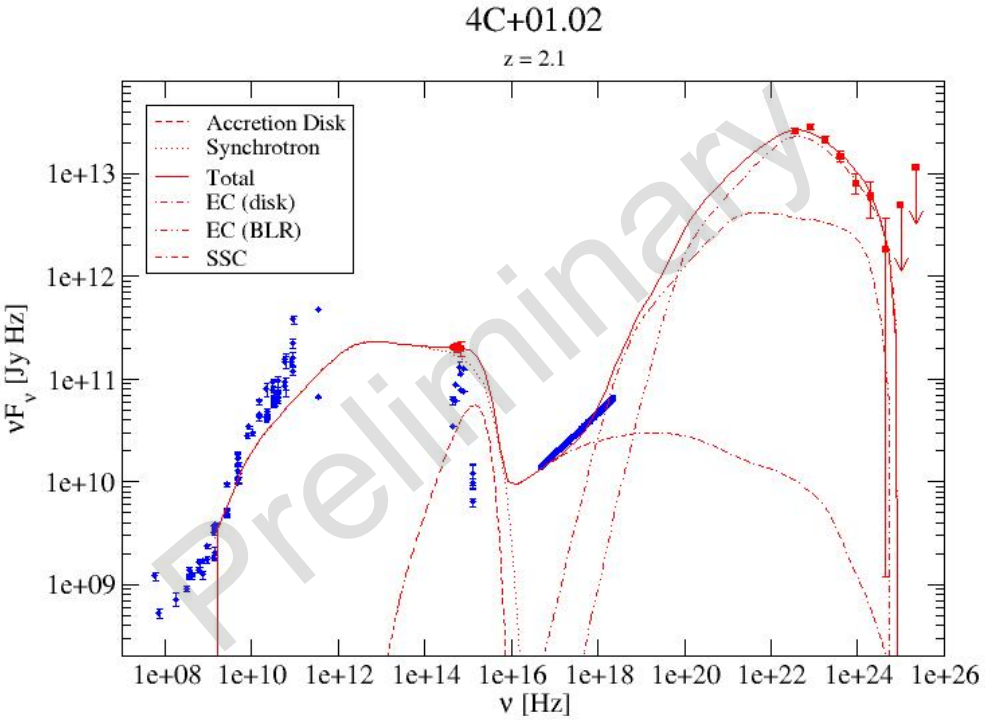
$M_{BH} = 5 \times 10^9 M_0$

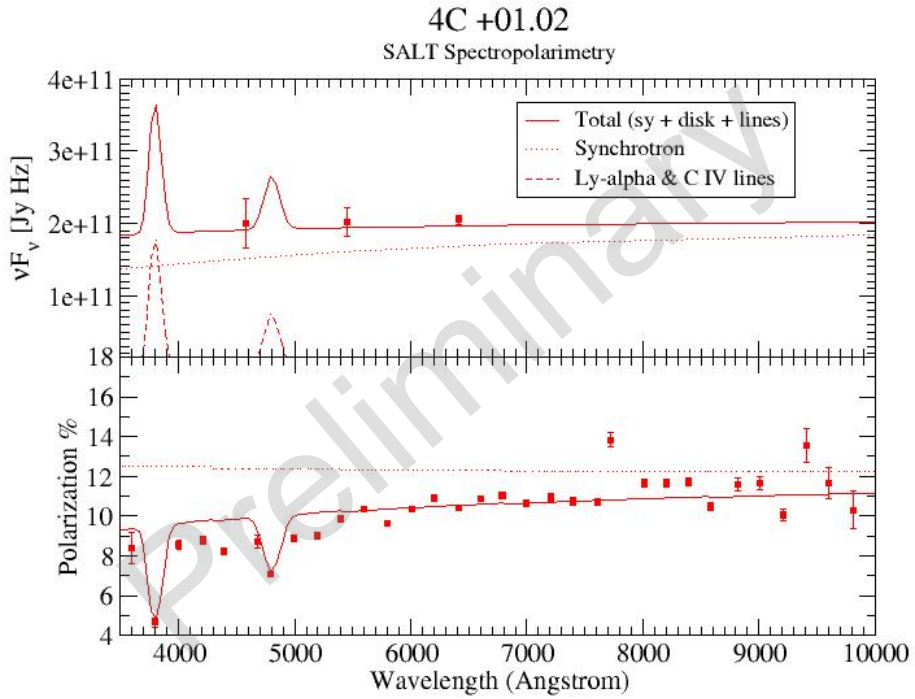
$L_d = 7.5 \times 10^{46}$ erg/s

$L_B/L_e = 15$

4C +01.02

Quasi-simultaneous SED + spectropolarimetry modeling:





$\Gamma = 25$

$M_{BH} = 10^9\ M_0$

$L_d = L_{Edd}$

$f_{B,order} = 0.16$

$L_B/L_e = 0.46$

$M_{BH} = 5 \times 10^9\ M_0$ would produce too cold disk -> fails to produce frequency-dependence of polarization.

Summary

1. Successful SALT Large Programme for spectroscopy / spectropolarimetry follow-up of transients
2. 7 flaring blazars followed-up in 2016/2017
3. Spectropolarimetry allows one to disentangle different radiation components (synchrotron vs. disk vs. SSC)
4. 4C+01.02 (z = 2.1) successfully modelled with synchrotron-dominated optical emission; small disk contribution at the blue end. Constrain BH mass to ~ 10^9 M_0

Supported by the South African Research Chairs Initiative (SARChI) of the Department of Science and Technology and the National Research Foundation of South Africa.

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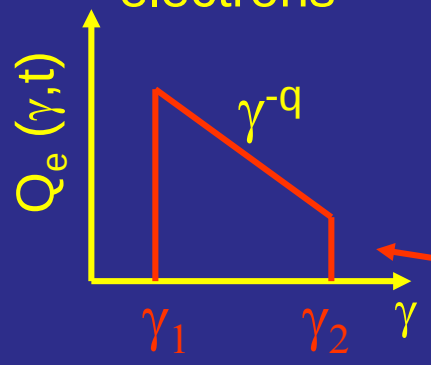
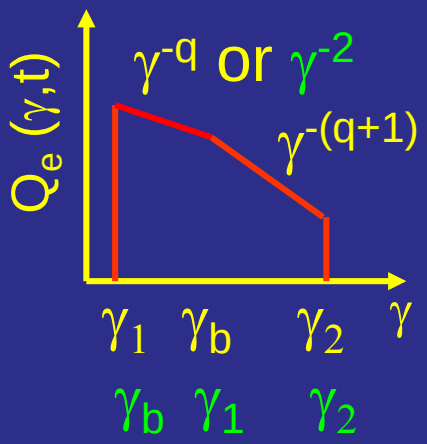
Leptonic Blazar Model

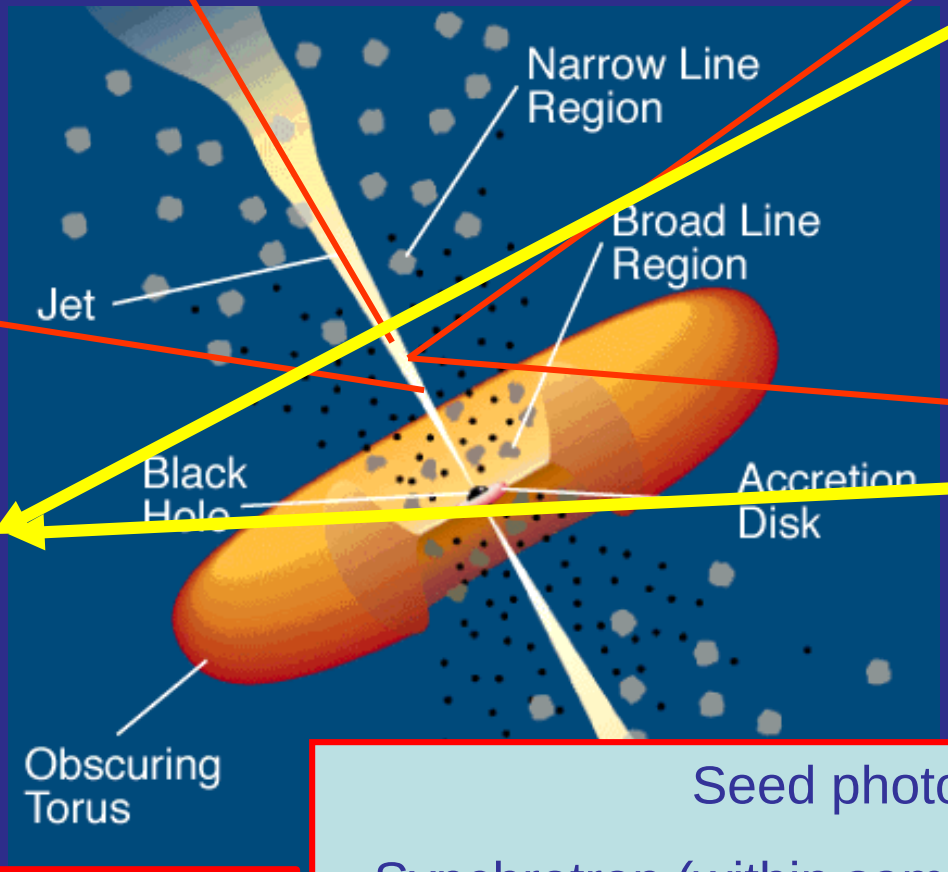
Injection, acceleration of ultrarelativistic electrons



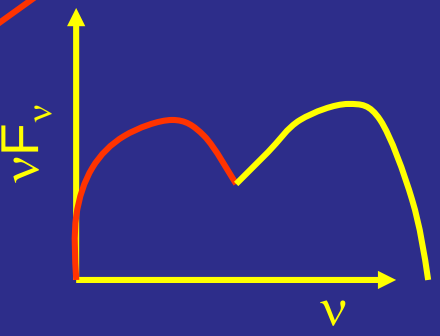
Radiative cooling ↔ escape =>



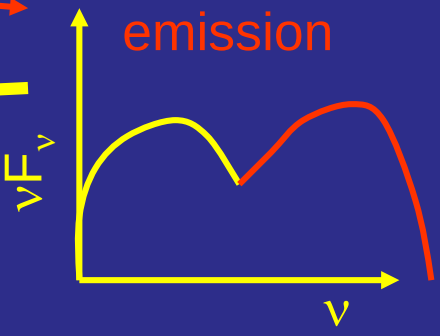
Relativistic jet outflow with $\Gamma \approx 10$



Synchrotron emission



Compton emission



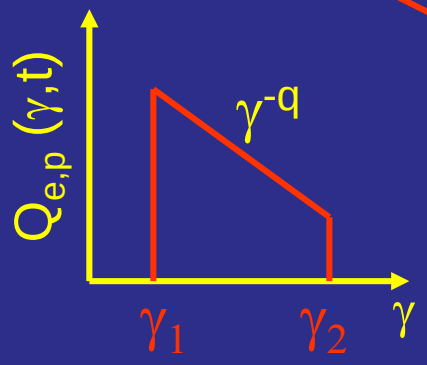
γ_b:
$\tau_{cool}(\gamma_b) = \tau_{esc}$

Seed photons:

Synchrotron (within same region [SSC] or slower/faster earlier/later emission regions [decel. jet]), Accr. Disk, BLR, dust torus (EC)

Hadronic Blazar Models

Injection, acceleration of ultrarelativistic electrons and protons



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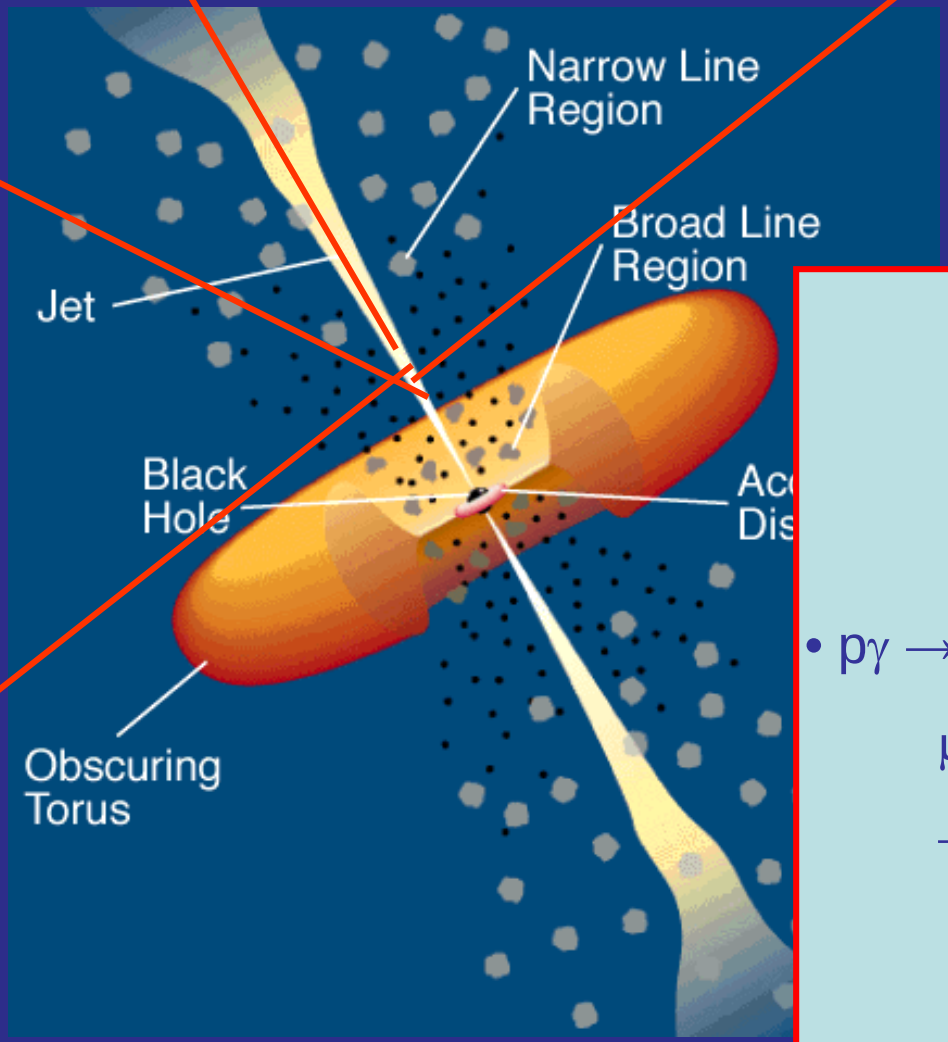
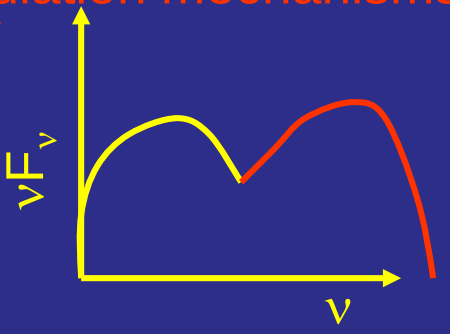
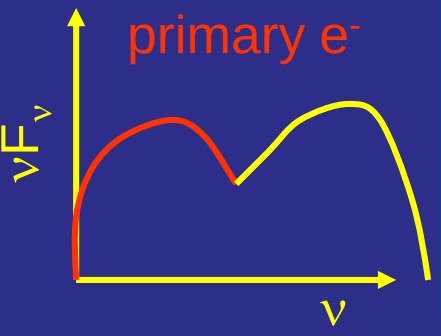


Proton-induced radiation mechanisms



Synchrotron emission of primary e^-



- Proton synchrotron
- $p\gamma \rightarrow p\pi^0$
  $\pi^0 \rightarrow 2\gamma$
- $p\gamma \rightarrow n\pi^+$; $\pi^+ \rightarrow \mu^+\nu_\mu$
  $\mu^+ \rightarrow e^+\nu_e\overline{\nu}_\mu$
  → secondary μ-, e-synchrotron
- Cascades …