Max-Planck-Institut für extraterrestrische Physik

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INTEGRAL and multiwavelength observations of the blazar Mrk 421 during an active phase

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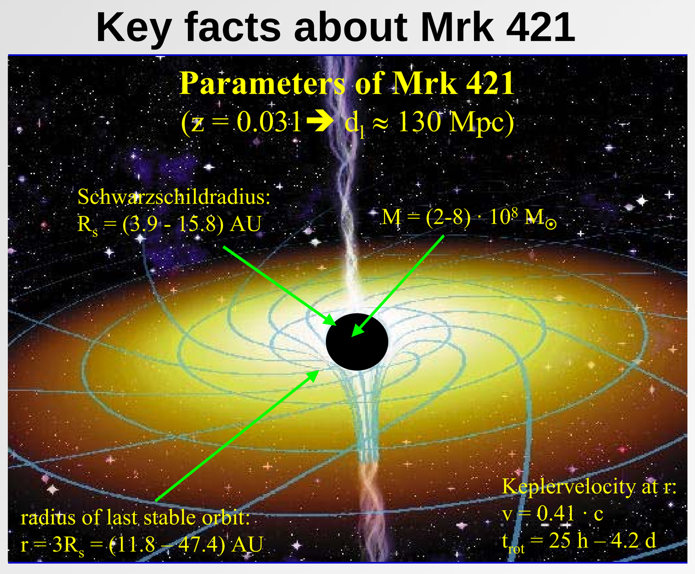
Abstract

A ToO observation of the TeV-emitting blazar Mrk 421 with INTEGRAL was triggered in June 2006 by an increase of the RXTE count rate to more than 30 milliCrab. The source was then observed with all INTEGRAL instruments with the exception of the spectrometer SPI for a total exposure of 829 ks. During this time several outbursts were observed by IBIS and JEM-X. Multiwavelength observations were immediately triggered and the source was observed at radio, optical and X-ray wavelengths up to TeV energies. The data obtained during these observations are analysed with respect to spectral evolution and correlated variability. Preliminary results of the analysis are presented in this poster.

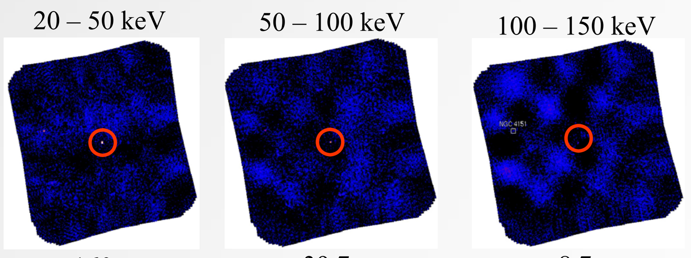
Introduction

Mrk 421 was the 1st AGN detected at TeV energies
Characteristic properties of blazars:
- **radio-loud sources**
- **polarization at radio and optical wavelengths**
- **show strong variability at all wavelengths**
- **non-thermal emission processes**
- **emission along a relativistic jet showing 2 emission components:**
  - **Synchrotron emission at low energies (<~100 keV)**
  - **inverse Compton scattering of low-energetic photons at high energies (>~ 100 keV)**

Key facts about Mrk 421



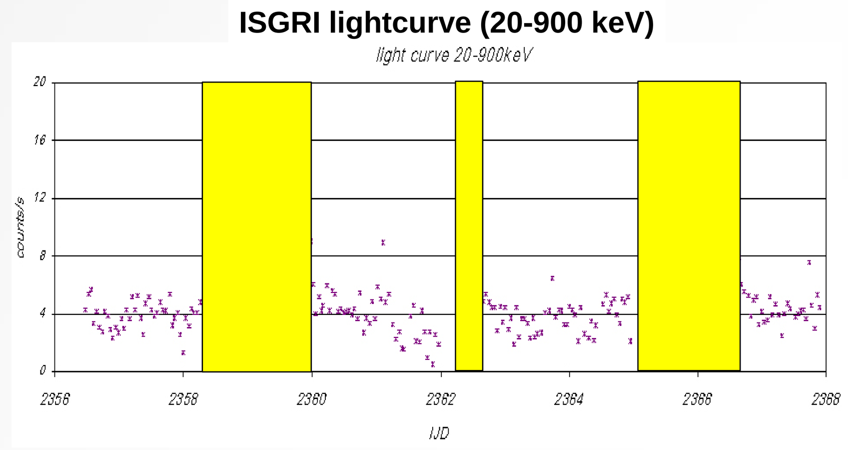
Detection of Mrk 421 with IBIS-ISGRI



Observation with INTEGRAL

An INTEGRAL ToO proposal by Lichti et al. was triggered when Mrk 421 became active (> 30 mCrab measured by RXTE) in April 2006. INTEGRAL then observed Mrk 421 from June 14 – June 25 with a total exposure of 829 ks with the instruments OMC, JEM-X and IBIS (SPI unfortunately was switched off because of annealing). Mrk 421 was detected by all 3 instruments with a high significance. Multiwavelength observations at all wavelengths were initiated and preliminary results of these observations are presented here.

ISGRI lightcurve (20-900 keV)



Observations:
- **4 strong flares were observed**
- **the quiescent intensity is nearly constant**

The time interval was split into phases with a quiescent (white regions) and an active (yellow regions) emission.

The data were collected accordingly and spectra in the two emission states were studied and compared.

Spectral Analysis

Different spectral models were fitted to the quiescent and active fluxes:

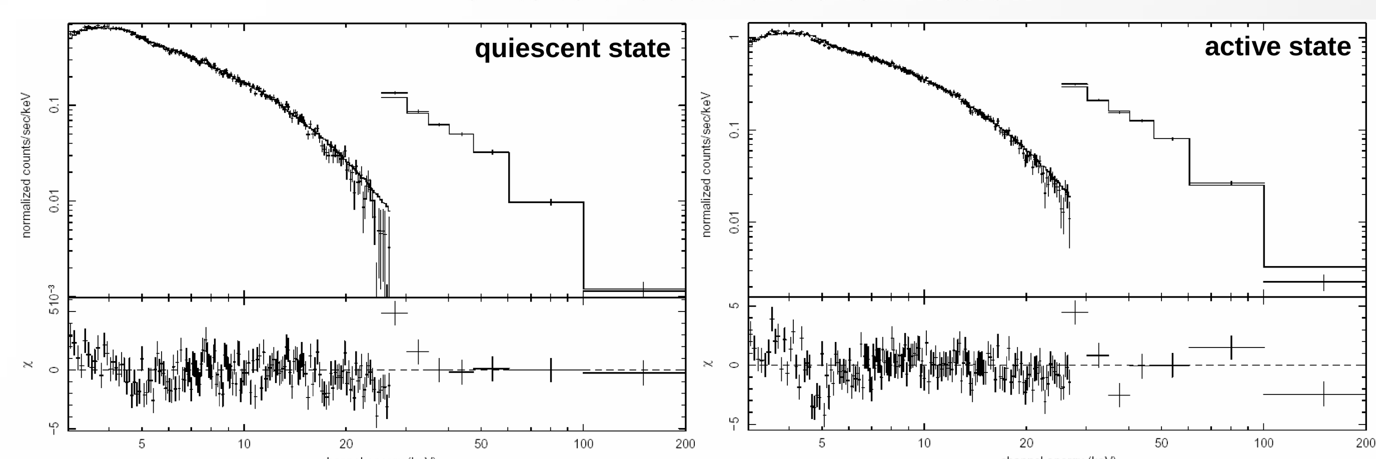
Model fits to the data of the quiescent state

Model	χ^2_{red}	A	α	β	E_c
Powerlaw (PL)	2.17	0.378 ± 0.004	2.318 ± 0.006	-	-
Joint PL	1.85	(9.3± 3) 10^{-6}	2.298 ± 0.007	6.5 ± 1.0	149 ± 11
[redacted]					
Band model	2.2	(2.8 ± 5) 10^{-5}	2 ± 0.2	2.32 ± 0.01	13 ± 2
PL with exp. cutoff	2.17	0.355 ± 0.006	2.27 ± 0.01	-	311 ± 77
Comptonized ST	1.95	0.353 ± 0.005	-	-	-
Comptonized TT	2.65	0.27 ± 0.4	-	-	-

Model fits to the data of the active state

Model	χ^2_{red}	A	α	β	E_c
Powerlaw (PL)	3.67	0.53 ± 0.005	2.164 ± 0.004	-	-
Joint PL	1.85	(9.9 ± 3) 10^{-6}	2.298 ± 0.007	6.65 ± 1.1	145 ± 10
[redacted]					
Band model	3.85	(9 ± 7) 10^{-5}	1.81 ± 0.09	2.20 ± 0.02	23 ± 3
PL with exp. cutoff	2.36	0.53 ± 0.005	2.04 ± 0.01	-	132 ± 0.3
Comptonized ST	1.92	3.6 ± 0.09	-	-	-
Comptonized TT	2.4	0.2 ± 0.25	-	-	-

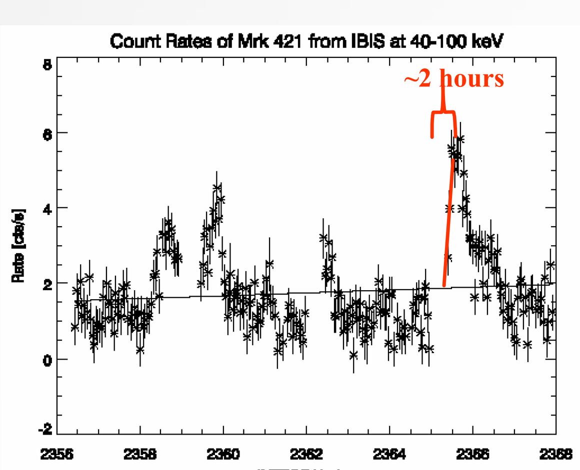
Broken powerlaw gave best fit results with a reduced χ^2 of ~1.9
The fits to the data are shown below



Results of the spectral analysis:

1. **a broken powerlaw fits in both cases the data best**
2. **interestingly the spectral parameters do not change significantly**
3. **in the energy range of the measurements (3-200 keV) only a decline is observed**
   - ⇨ **the maximum of the νF_ν spectrum is below 3 keV (BeppoSAX measured values up to 5.5 keV; Massaro et al., A&A 413, 489, 2004)**
   - ⇨ **the minimum of the νF_ν spectrum is above 200 keV**
4. **the break energy E_b has a value of ~43 keV**
5. **a slight spectral hardening at X-rays is observed**

Timing Analysis



Shortest variability time scale: ~2 hours
➔ size of emission region

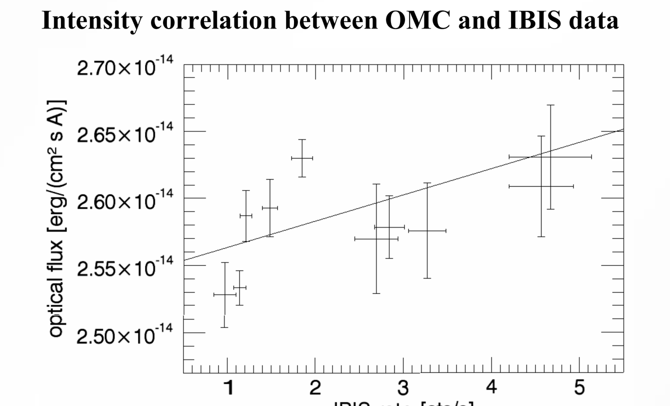
$$l \le \frac{c \cdot t_{flare} \cdot \delta}{1+z}$$

δ = Doppler factor (≅ 10)
z = 0.031 (redshift)
c = speed of light

$l < 2.1 \cdot 10^{15}$ cm = ~140 AU

From the smallest flaring time scale measured at TeV energies an emission region <3.6 AU was derived.

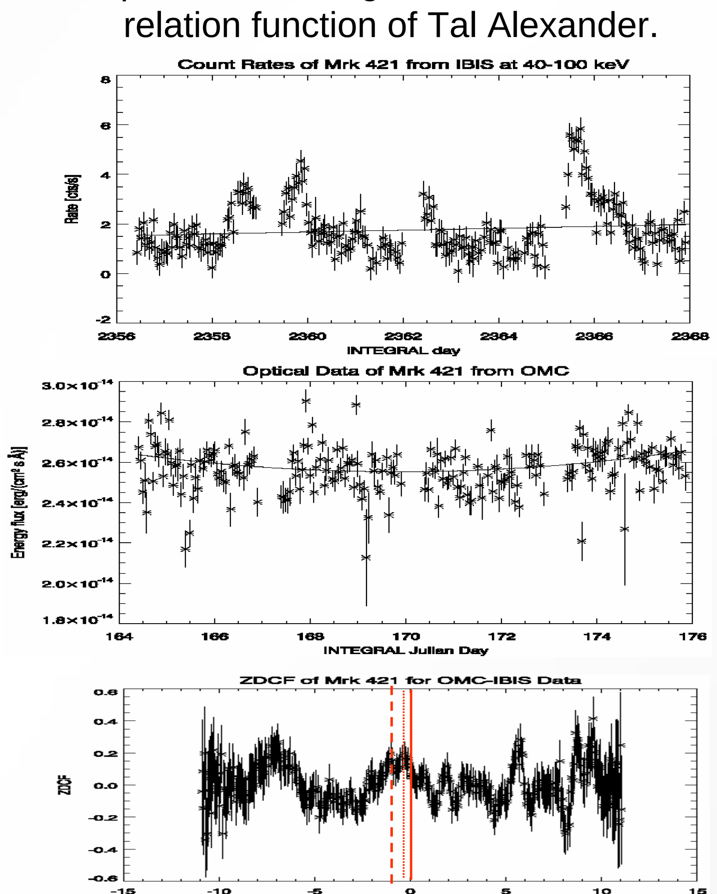
Intensity correlation between OMC and IBIS data



The optical flux is slightly correlated with the X-ray rate!
$F_{OMC} = 2.5\cdot10^{-14} + 1.96\cdot10^{-16} \cdot R_{IBIS}$

Time Lags

Search for time lags between X-ray and optical data using the Z discrete-correlation function of Tal Alexander.



Two peaks at negative time lags are identified:
τ_1 = -8.75 hours — The IBIS lightcurve lags
τ_2 = -24 hours — the OMC lightcurve

Calculation of magnetic field from measured time lag τ at 2 different frequencies ν_1 and ν_0:

$$B = 300 \cdot \left(\frac{1+z}{\nu_1 \cdot \delta}\right)^{\frac{1}{3}} \cdot \left(\frac{1-\sqrt{\nu_1/\nu_0}}{\tau}\right)^{\frac{2}{3}} G$$

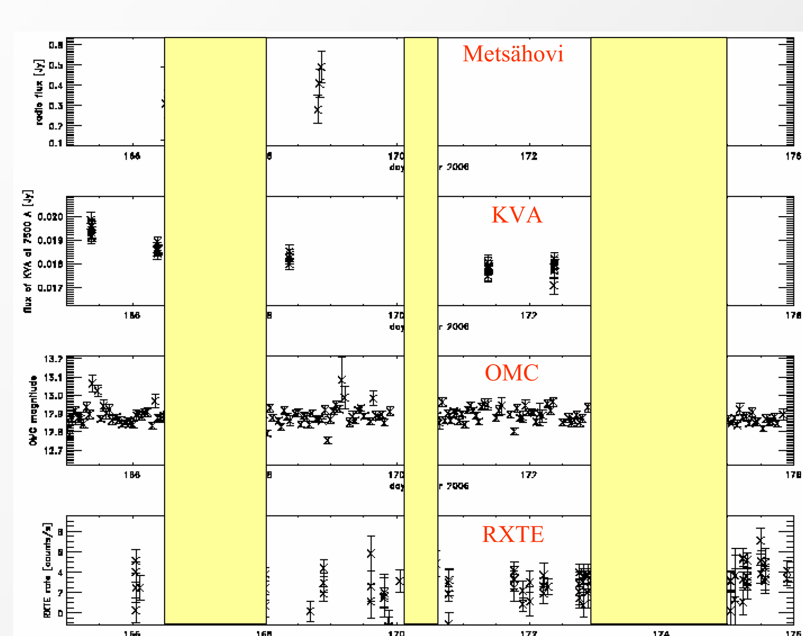
τ [s]	B [G]
31500	0.8
86400	0.41

Sembay at al. (Ap. J. **574**, 634, 2002) derived a lower limit for B of 4.7 G!

Multiwavelength Observations

Multiwavelength observations were initiated and in addition to INTEGRAL the source was observed at
- radiowavelengths (Metsähovi & VLBA radiotelescopes)
- optical wavelengths (KVA & OMC telescopes)
- X-rays (RXTE)
- TeV energies (Whipple, MAGIC)

Some of the obtained lightcurves are shown below



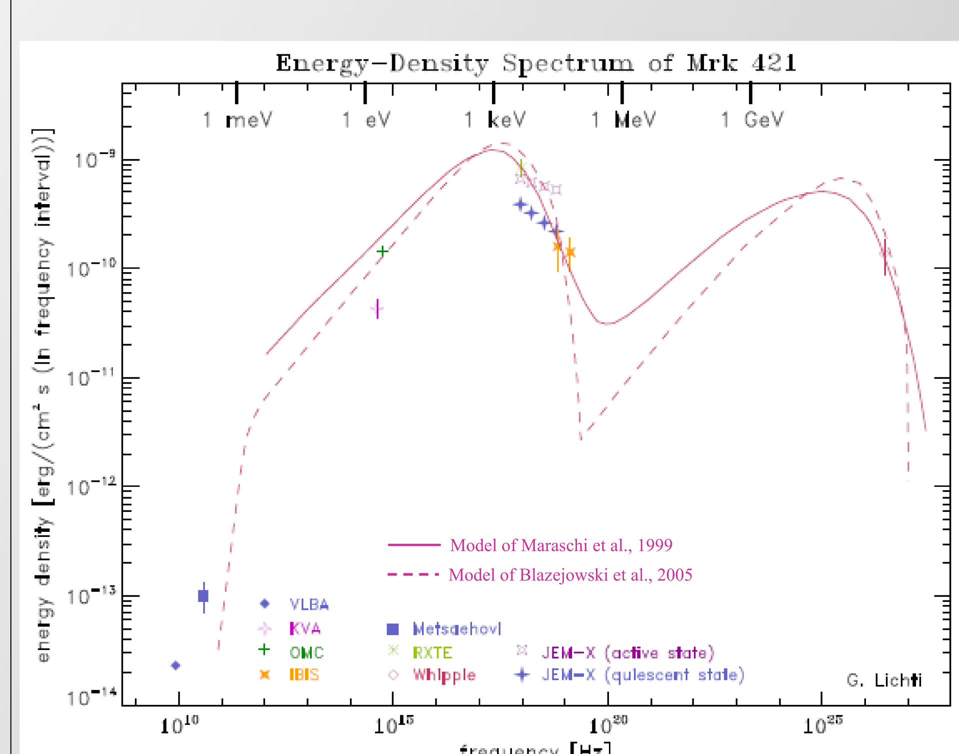
One striking fact is obvious: during the times when JEM-X & IBIS saw flares in the X-rays no intensity increases are seen at lower energies!

Literature:

Blazejowski et al., Ap. J. **630**, 130, 2005
Maraschi et al., Ap. J. **526**, L81, 1999
Massaro et al., A&A **413**, 489,2004
Sembay et al., Ap. J. **574**, 634, 2002

Multiwavelength Spectrum νFν

The collected data points were averaged over the observation time span and are plotted in an energy-density spectrum (νF_ν spectrum). They are compared with 2 theoretical models from Maraschi et al. (1999) and Blazejowski et al. (2005) which were normalized to the IBIS data. Only the JEM-X data are shown in addition for the quiescent and active state.



The following conclusions can be drawn:
- the models fits the RXTE, IBIS and Whipple data reasonably well
- at optical & radiowavelengths the Maraschi model predicts higher energy densities than observed
- the JEM-X spectrum does not match the models very well (however this requires confirmation!)
- the peak energy is around 1 keV
- the minimum energy is around 500 keV

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