



S5 0716+71

Variability across the electromagnetic spectrum during 2003-2004

Luisa Ostorero

(Landessternwarte Heidelberg, Germany)

on behalf of the S5 0716+71 ENIGMA-WEBT collaboration

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

Outline

0716+714 long-term variability during 2003-2004

- Optical and near-infrared light curves
- Colour variations
- Comparison with the historical brightness trend

0716+714 short-term variability:

simultaneous X-ray and optical observations in April 2004

- X-ray variability
- A correlated optical/UV/X-ray flare
- Intra-day SED evolution

Summary

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

0716+714 long-term variability during 2003-2004

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 optical-NIR light curves

Status of the analysis of optical and near-infrared data collected during the extended campaign:

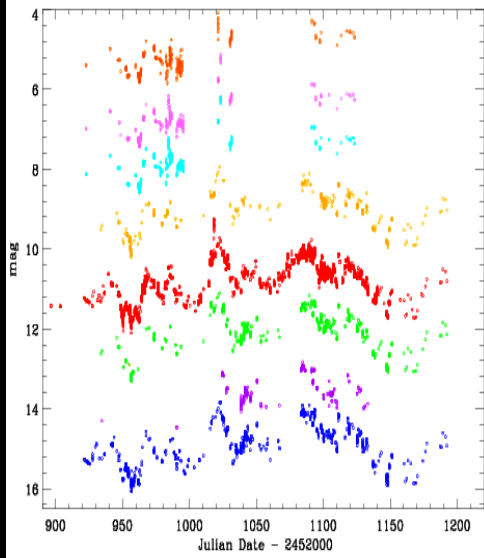
~17000 data from 32 observatories over a period of ~10 months
(October 2003 - July 2004)

- | | |
|---|------------------|
| * photometry : | completed |
| * Calibration run with 3 stars (3,5,6): | completed |
| * color analysis: | work in progress |

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 optical-NIR light curves

Lulin
Yunnan
Sampurnand
Hanle
Mt. Abu
Mt. Maidanak
Abastumani
SAI Crimean
Crimean
Jakokoski
Canakkale
Nyrola
Tuorla
MonteBoo
Catania
Campo Imperatore
Perugia
Heidelberg
Trebur
TIRGO
Torino
Hoher List
Sabadell
Calar Alto
NOT
KVA
WHT
Bell
St. Louis
WIYN
Coyote Hill
Univ. Victoria



K-4.5
H-4.3
J-4.0
I-3.5
R-2.2
V-1.3
U+0.5
B+1.0

outbursts ~ simultaneous at
optical and NIR frequencies

long-term variations of
comparable amplitude in
all the bands

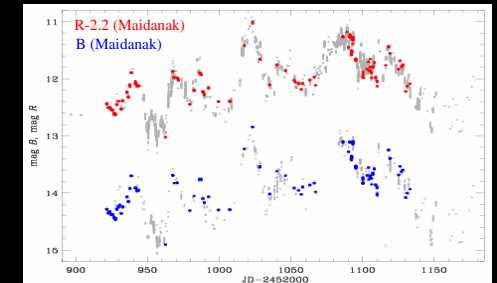
best sampling: B, R

Ostorero et al., in prep.

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 colour variations

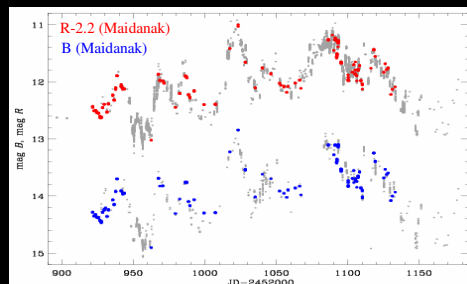
- Big spread in colour indices in the total color data set
⇒ work in progress to reduce inter-instrumental colour offsets
- Selected the best B-R long-term data set:
 - Mt. Maidanak Obs. (Uzbekistan)
 - main light curve features: well sampled (coloured points)
- Computed colour indices by coupling data taken within $\Delta t_{\max} = 5$ min



8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

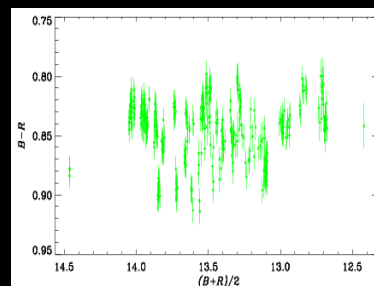
2003-2004 colour variations

- Big spread in colour indices in the total color data set
⇒ work in progress to reduce inter-instrumental colour offsets
- Selected the best B-R long-term data set:
 - Mt. Maidanak Obs. (Uzbekistan)
 - main light curve features: well sampled (coloured points)
- Computed colour indices by coupling data taken within $\Delta t_{\max} = 5$ min



- No correlation between colour and brightness!

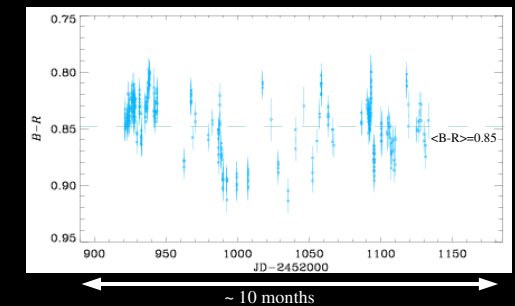
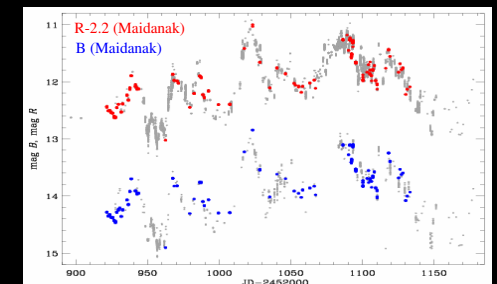
Pearson correlation coefficient
 $r_p = 0.067$
 $P(r > r_p) = 19.3\%$



8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 colour variations

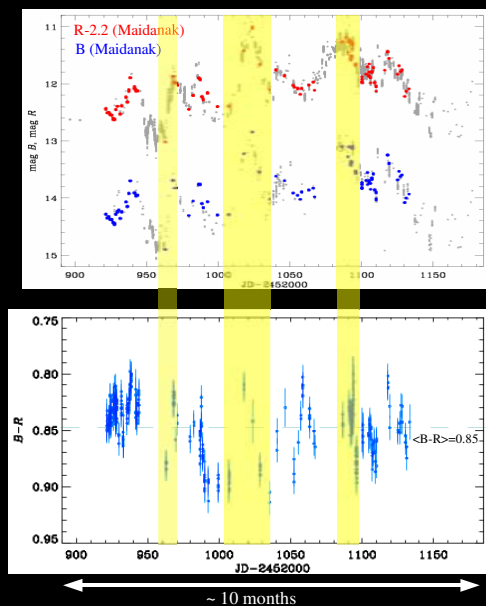
- Big spread in colour indices in the total color data set
⇒ work in progress to reduce inter-instrumental colour offsets
- Selected the best B-R long-term data set:
 - Mt. Maidanak Obs. (Uzbekistan)
 - main light curve features: well sampled (coloured points)
- Computed colour indices by coupling data taken within $\Delta t_{\max} = 5$ min



8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 colour variations

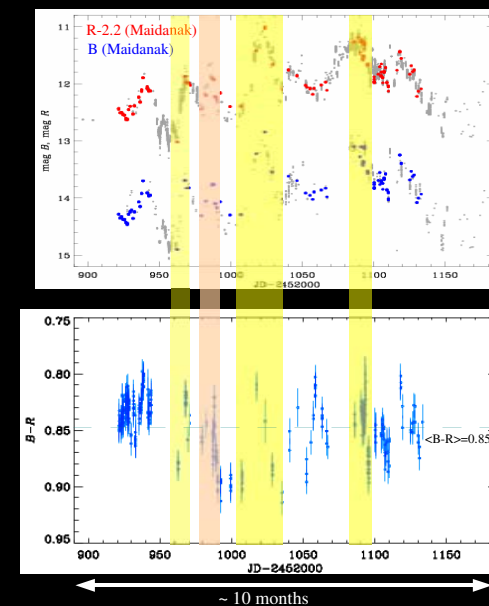
- Big spread in colour indices in the total color data set
 - ⇒ work in progress to reduce inter-instrumental colour offsets
- Selected the best B-R long-term data set:
 - Mt. Maidanak Obs. (Uzbekistan)
 - main light curve features: well sampled (coloured points)
- Computed colour indices by coupling data taken within $\Delta t_{\max} = 5$ min
- Possible association of flux bursts and colour index variations (*flatter-when-brighter*) (agreement with Ghisellini et al. 1997)



8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 colour variations

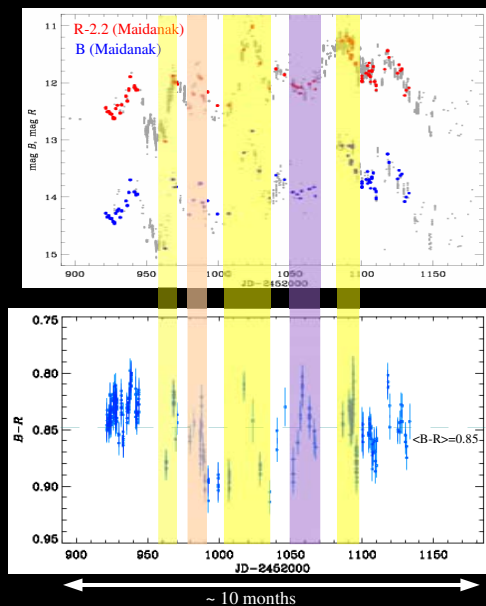
- Big spread in colour indices in the total color data set
 - ⇒ work in progress to reduce inter-instrumental colour offsets
- Selected the best B-R long-term data set:
 - Mt. Maidanak Obs. (Uzbekistan)
 - main light curve features: well sampled (coloured points)
- Computed colour indices by coupling data taken within $\Delta t_{\max} = 5$ min
- Possible association of flux bursts and colour index variations (*flatter-when-brighter*) (agreement with Ghisellini et al. 1997)
- Color variations comparable for bursts of different amplitude
 - >1 mag
 - ~ 0.5 mag



8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 colour variations

- Big spread in colour indices in the total color data set
 - ⇒ work in progress to reduce inter-instrumental colour offsets
- Selected the best B-R long-term data set:
 - Mt. Maidanak Obs. (Uzbekistan)
 - main light curve features: well sampled (coloured points)
- Computed colour indices by coupling data taken within $\Delta t_{\max} = 5$ min
- Possible association of flux bursts and colour index variations (*flatter-when-brighter*) (agreement with Ghisellini et al. 1997)
- Color variations comparable for bursts of different amplitude
 - >1 mag
 - ~ 0.5 mag



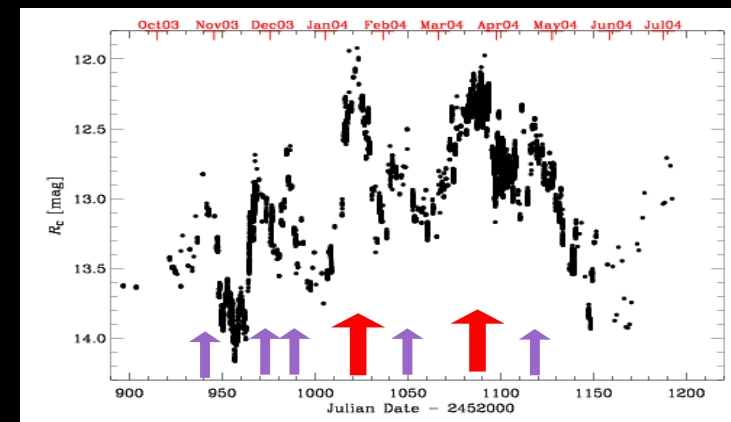
...but also : comparable colour variations without any apparent flux burst!

... Work in progress...

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 optical R-band light curve

- Lulin
- Yunnan
- Sampurnand
- Hanle
- Mt. Maidanak
- Abastumani
- SAI Crimean
- Crimean
- Jakokoski
- Canakkale
- Nyröla
- Tuorla
- MonteBoo
- Perugia
- Heidelberg
- Trebur
- Torino
- Hoher List
- Calar Alto
- KVA
- WHT
- Bell
- St. Louis
- WIYN
- Coyote Hill
- Univ. Victoria



- Several outbursts lasting ~ 2-6 weeks
- 2 biggest outbursts: Jan 2004, Mar-Apr 2004 (~70 days apart)

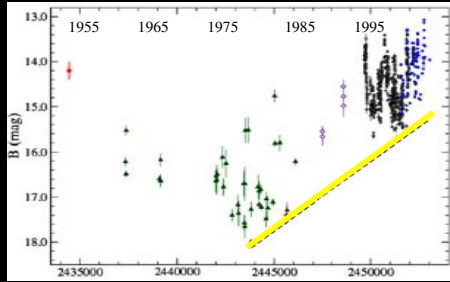
How does this light curve compare to the historical behaviour?

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

1953-2003 optical B-band light curve: historical trend

B-band historical light curve (1953-2003)

from Nesci et al. 2005



- ◆◆◆ 1953-1985: Archival plates (Nesci et al. 2005)
 - ◆ 1994-2001: CCD monitoring (Raiteri et al. 2003)
 - ◆ 2001-2003: CCD monitoring (Nesci et al. 2005)
- long-term trend proposed by Nesci et al. (2005)

Nesci et al. (2005): investigation of the optical long-term (~50 years) behaviour of S5 0716+71 by means of archival plate data:

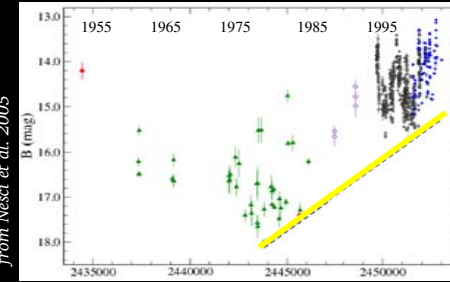
- source active in the past, but much fainter on average
- possible long-term brightening of ~ 0.11 mag/yr from 1975-80 to the present high state

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

1953-2003 optical B-band light curve: historical trend

B-band historical light curve (1953-2003)

from Nesci et al. 2005



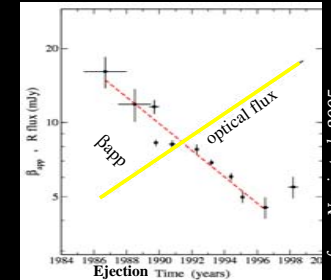
- ◆◆◆ 1953-1985: Archival plates (Nesci et al. 2005)
 - ◆ 1994-2001: CCD monitoring (Raiteri et al. 2003)
 - ◆ 2001-2003: CCD monitoring (Nesci et al. 2005)
- long-term trend proposed by Nesci et al. (2005)

Nesci et al. (2005): investigation of the optical long-term (~50 years) behaviour of S5 0716+71 by means of archival plate data:

- source active in the past, but much fainter on average
- possible long-term brightening of ~ 0.11 mag/yr from 1975-80 to the present high state

Bach et al. (2005): analysis of VLBI monitoring data of 1992-2001
 ⇒ decrease of β_{app} of the jet components with time

- Scenario proposed by Nesci et al. (2005):
 - slowly precessing jet, approaching the l.o.s.
 - $\theta = 5^\circ \rightarrow 0.7^\circ$; $\delta = 15 \rightarrow 22$; $\Gamma = 12-15$
 - prediction: optical dimming phase during the next ~10 years

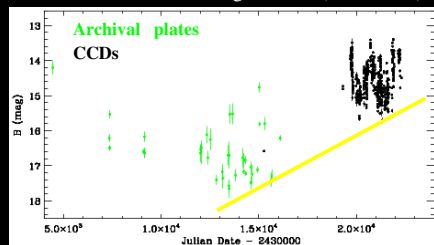


from Nesci et al. 2005

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 optical B-band light curve and historical trend

B-band historical light curve (1953-2003)

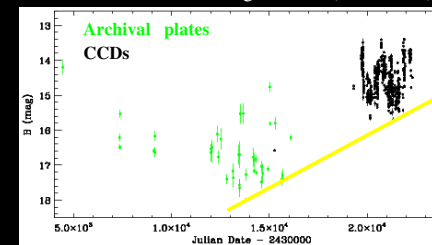


- long-term trend proposed by Nesci et al. (2005)
- ◆ 1953-1985: Archival plates (Nesci et al. 2005)
- ◆ 1994-2001: CCD monitoring (Raiteri et al. 2003)

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

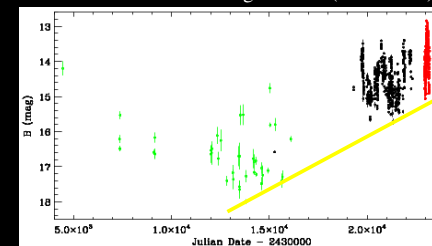
2003-2004 optical B-band light curve and historical trend

B-band historical light curve (1953-2003)



- long-term trend proposed by Nesci et al. (2005)
- ◆ 1953-1985: Archival plates (Nesci et al. 2005)
- ◆ 1994-2001: CCD monitoring (Raiteri et al. 2003)

B-band historical light curve (1953-2004)



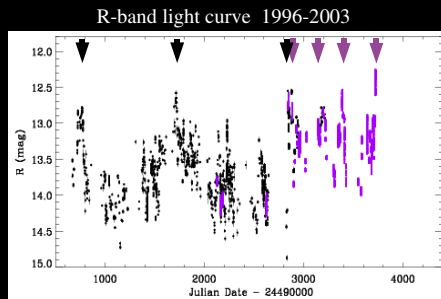
- ◆ 2003-2004: ENIGMA-WEBT campaign (Ostorero et al., in prep.)

two historical outbursts, in agreement with the historical trend

- did we catch the more aligned jet state?

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 optical R-band light curve and historical trend



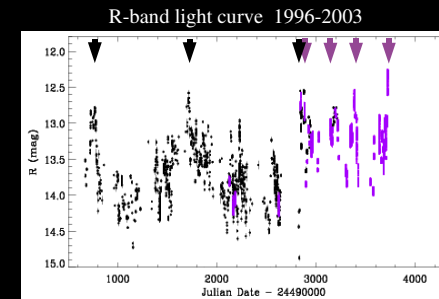
- ◆ Raiteri et al. (2003)
- ◆ Nesci et al. (2005); Montagni et al. (2006)

Variability time scales

1995-2002 : ~ 3.3 yr oscillating trend (Raiteri et al. 2003)
 2002-2003 : ~1 yr outburst frequency (Nesci et al. 2005)
 (3.3 yr - trend disproved)

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

2003-2004 optical R-band light curve and historical trend



- ◆ Raiteri et al. (2003)
- ◆ Nesci et al. (2005); Montagni et al. (2006)

Variability time scales

1995-2002 : ~ 3.3 yr oscillating trend (Raiteri et al. 2003)
 2002-2003 : ~1 yr outburst frequency (Nesci et al. 2005)
 (3.3 yr - trend disproved)

◆ 2003-2004: ENIGMA-WEBT campaign

Two outbursts: r6 and r7
 - r6 (Jan 2004) : ~ 320 days after r5 (March 2003)
 - r7 (Mar-Apr 2004): 70 days after r6

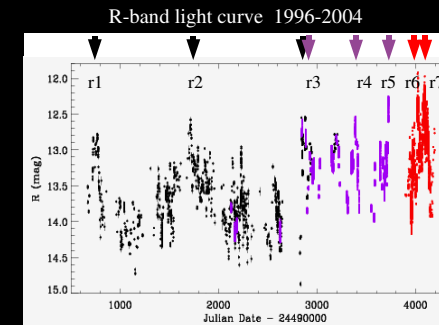
Possible trend of increasing frequency and brightness of the major outbursts

➤ agreement with the increase of the Doppler factor δ due to the alignment of a precessing jet with the l.o.s.

$$F \propto \delta^3(t) \cdot F'$$

$$\frac{dF}{dt} \propto \delta^4(t) \left(\frac{dF'}{dt} \right)$$

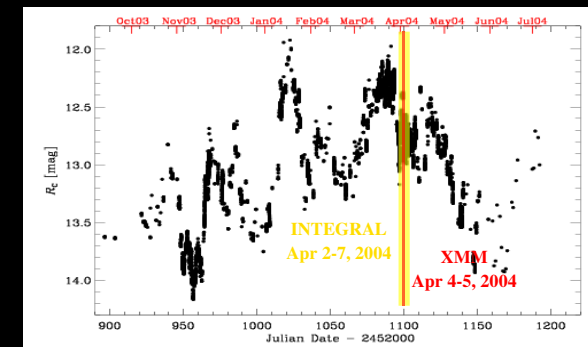
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006



**0716+714 short-term variability:
 simultaneous X-ray and optical observations
 in April 2004**

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM and INTEGRAL ToO observation of April 2004



March-April 2004 optical outburst ⇒ trigger of a combined XMM and INTEGRAL ToO observation
 [Proposals P.L.s: G. Tagliaferri (XMM); E. Pian (INTEGRAL)]

Results: Pian, Foschini, Beckmann, et al. 2005 (INTEGRAL)

Foschini, Tagliaferri, Pian, et al. 2006 (XMM)

Ferrero, Wagner, Enmanoulopoulos, & Ostorero 2006 (XMM)

A&A, 429, 427

A&A, in press; astro-ph/0604600

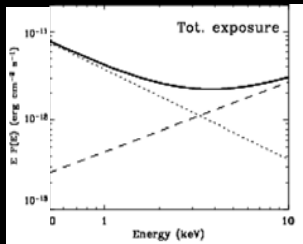
A&A, in press; astro-ph/0607023

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: X-ray spectrum

59 ks observation
PN + MOS data analysis in 0.5-10.0 keV

- broken and double power-law with Galactic absorption:
 - better and simpler parametrization of the data
 - easy interpretation in terms of synchrotron (softer, steeper) and inverse-Compton (harder, flatter) components
- concavity of the spectrum: evident (S5 0716+71: IBL)



ex. PN data – fit values

Γ_1	E_{break} [keV]	Γ_2	$F_{2-10 \text{ keV}}$ [$10^{-12} \text{ erg/cm}^2/\text{s}$]
<i>BROKEN P.L.</i>			
2.83 ± 0.01	$1.91 (+0.1; -0.08)$	$2.06 (+0.05, -0.06)$	$3.83 (+0.11; -0.10)$
<i>DOUBLE P.L. (see fig.)</i>			
3.01 ± 0.05		$1.22 (+0.15, -0.02)$	$3.95 (+0.45; -1.16)$

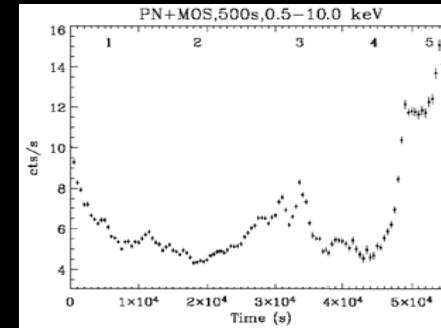
from Ferrero et al. 2006

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

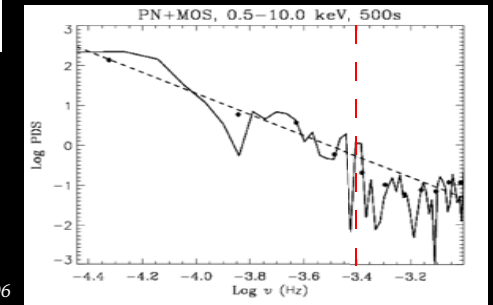
XMM observation: X-ray flux variability

Combined PN+MOS light curve: 0.5-10 keV

Length: 59 ks
Bin size: 500 s



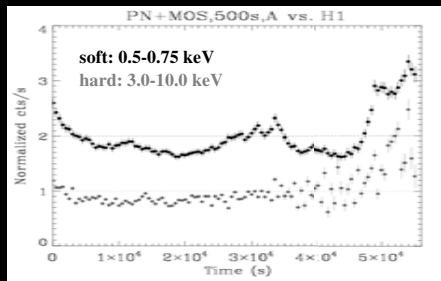
- FVA = $37 \pm 2\%$
 - No characteristic variability time scales
 - PDS slope: $2.64 \pm 0.36 \Rightarrow$ red noise process
 - Shortest time-scale (before noise): 2.5 ks — — —
- [$R < 0.7\delta(1+z)$ l.h. $\sim 25 \cdot 10^{-6} \delta(1+z)$ pc \sim few 100 μ pc



from Ferrero et al. 2006

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: X-ray flux variability

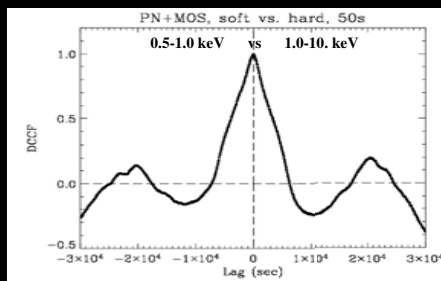


Combined PN+MOS soft and hard light curves

Fractional variability amplitude:
soft band: FVA = $40 \pm 3\%$
hard band: FVA = $27 \pm 1\%$

- more variability in the soft band

from Ferrero et al. 2006



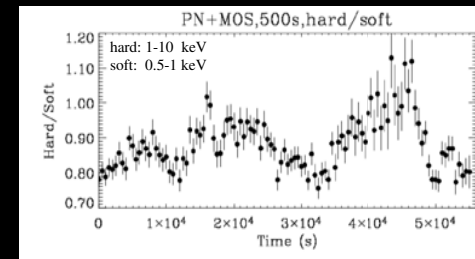
Discrete correlation function: soft vs hard

Bin size = 50 s
DCF peak position: τ_{peak}
(errors on τ_{peak} : simulations; 1000 runs)
negative lags = soft lag

- $\tau_{\text{peak}} = -50_{-75}^{+125}$ s \Rightarrow lags ≥ 100 s not present!

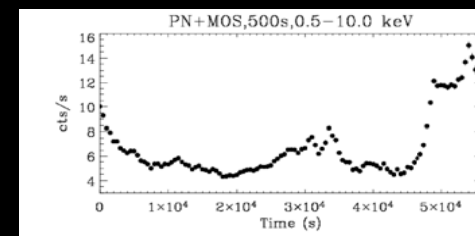
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: X-ray spectral variability



Hardness-ratio vs count-rate light curves
(soft: 0.5-1 keV; hard: 1-10 keV)

- anticorrelation bw HR and flux:
softer-when-brighter behaviour
(opposite to the trend usually observed in HBL)

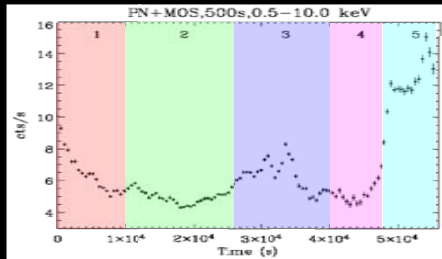


- need of investigating the role of the synchrotron and IC components, possibly time-dependent

from Ferrero et al. 2006

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: time-resolved X-ray spectral analysis



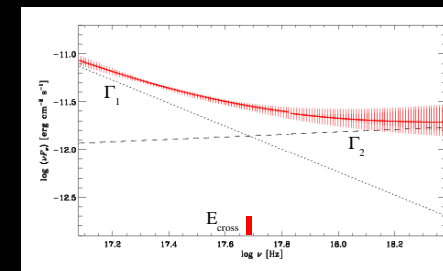
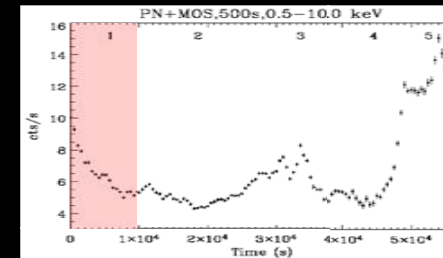
from Ferrero et al. 2006

Time-resolved spectral analysis

- light curve divided in 5 time intervals: compromise between high time resolution and good photon statistics
- spectral analysis with double power-law model repeated for each time interval

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: time-resolved X-ray spectral analysis interval 1



$$\Gamma_1 = 3.20$$

$$\Gamma_2 = 1.87$$

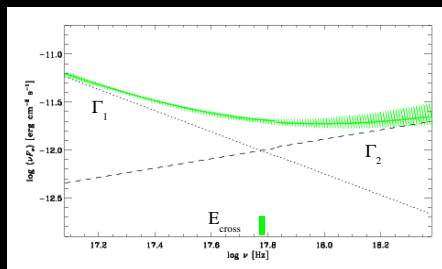
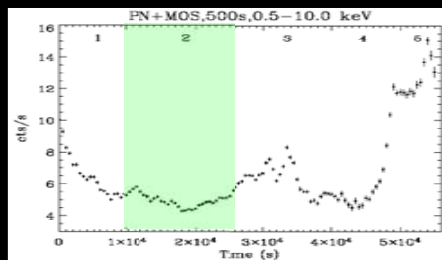
$$E_{\text{cross}} = 2.01 \text{ keV}$$

$$\text{Sinchr. \%} = 58$$

from Ferrero et al. 2006

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: time-resolved X-ray spectral analysis interval 2



$$\Gamma_1 = 3.10$$

$$\Gamma_2 = 1.50$$

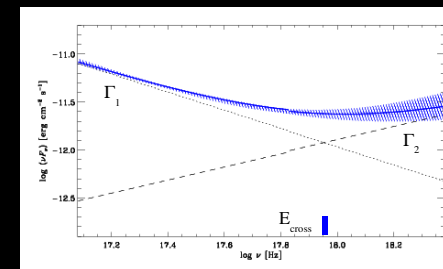
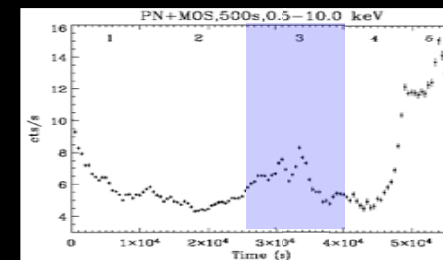
$$E_{\text{cross}} = 2.46 \text{ keV}$$

$$\text{Sinchr. \%} = 62$$

from Ferrero et al. 2006

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: time-resolved X-ray spectral analysis interval 3



$$\Gamma_1 = 2.95$$

$$\Gamma_2 = 1.30$$

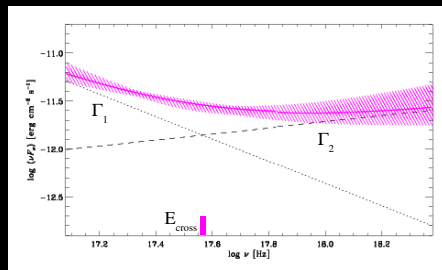
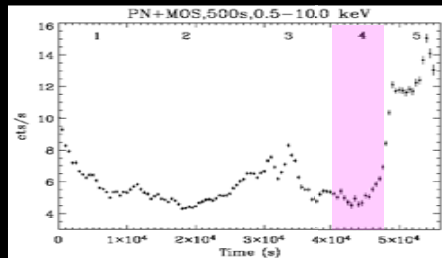
$$E_{\text{cross}} = 3.74 \text{ keV}$$

$$\text{Sinchr. \%} = 72$$

from Ferrero et al. 2006

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: time-resolved X-ray spectral analysis interval 4

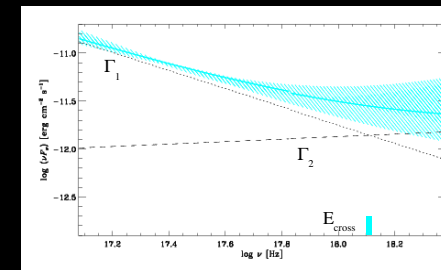
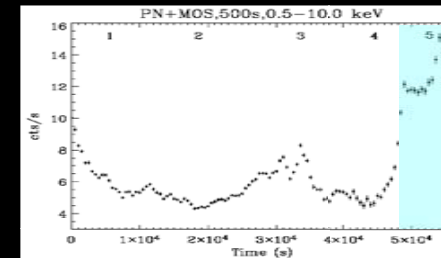


$\Gamma_1 = 3.16$
 $\Gamma_2 = 1.68$
 $E_{\text{cross}} = 1.52 \text{ keV}$
 Synchr. % = 46

from Ferrero et al. 2006

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: time-resolved X-ray spectral analysis interval 5

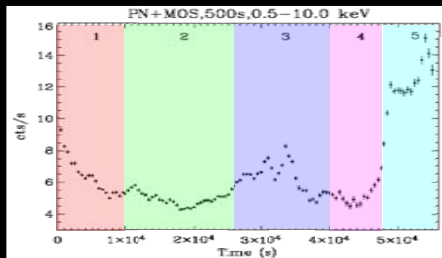


$\Gamma_1 = 2.95$
 $\Gamma_2 = 1.87$
 $E_{\text{cross}} = 5.34 \text{ keV}$
 Synchr. % = 78

from Ferrero et al. 2006

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: time-resolved X-ray spectral analysis



from Ferrero et al. 2006

Time-resolved spectral analysis

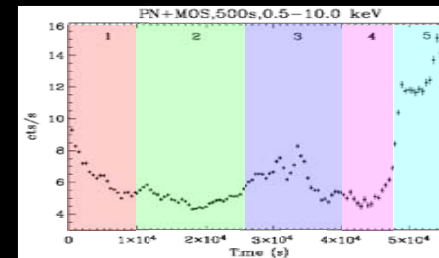
- light curve divided in 5 time intervals: compromise between time resolution and good photon statistics
- spectral analysis with double power-law model repeated for each time interval

Int.	Γ_1	Γ_2	E_{cross} (keV)	F_1 $10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$	F_2 $10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$	Synchr. (%)
1	$3.20^{+0.19}_{-0.16}$	$1.87^{+0.11}_{-0.13}$	2.01	5.99 ± 1.31	4.26 ± 1.60	58
2	$3.10^{+0.09}_{-0.11}$	$1.50^{+0.13}_{-0.12}$	2.46	5.08 ± 1.10	3.15 ± 1.33	62
3	$2.95^{+0.09}_{-0.07}$	$1.30^{+0.26}_{-0.17}$	3.74	7.93 ± 1.49	3.01 ± 1.88	72
4	$3.16^{+0.42}_{-0.26}$	$1.68^{+0.13}_{-0.14}$	1.52	4.28 ± 1.83	4.96 ± 2.04	46
5	$2.95^{+0.28}_{-0.14}$	$1.87^{+0.17}_{-0.02}$	5.34	13.01 ± 4.24	3.76 ± 1.91	78

- stronger soft (synchrotron) dominance during intervals of flaring activity (3, 5)
- significant variability of the hard (IC) component (contrary to previous results)
- soft (synchrotron) components: flatter-when-brighter behaviour (as in HBL); hard (IC) component: complex behaviour
- overall steeper-when-brighter behaviour: due to the flattening of the soft component during flares

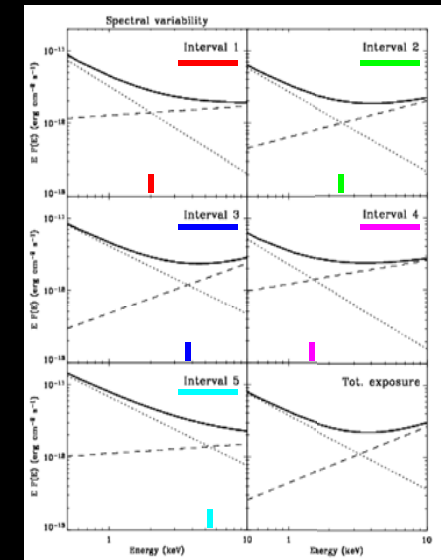
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: time-resolved X-ray spectral analysis



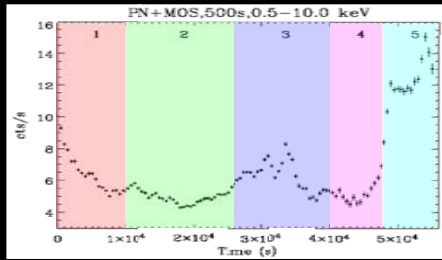
from Ferrero et al. 2006

Int.	Γ_1	Γ_2	E_{cross} (keV)	F_1 $10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$	F_2 $10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$	Synchr. (%)
1	$3.20^{+0.19}_{-0.16}$	$1.87^{+0.11}_{-0.13}$	2.01	5.99 ± 1.31	4.26 ± 1.60	58
2	$3.10^{+0.09}_{-0.11}$	$1.50^{+0.13}_{-0.12}$	2.46	5.08 ± 1.10	3.15 ± 1.33	62
3	$2.95^{+0.09}_{-0.07}$	$1.30^{+0.26}_{-0.17}$	3.74	7.93 ± 1.49	3.01 ± 1.88	72
4	$3.16^{+0.42}_{-0.26}$	$1.68^{+0.13}_{-0.14}$	1.52	4.28 ± 1.83	4.96 ± 2.04	46
5	$2.95^{+0.28}_{-0.14}$	$1.87^{+0.17}_{-0.02}$	5.34	13.01 ± 4.24	3.76 ± 1.91	78



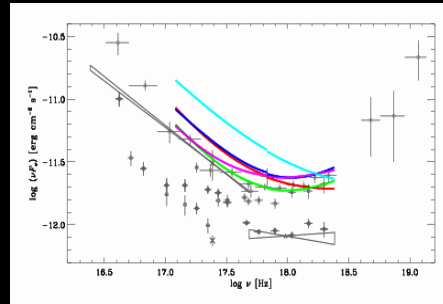
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

XMM observation: time-resolved X-ray spectral analysis



from Ferrero et al. 2006

Int.	Γ_1	Γ_2	E_{cutoff} (keV)	F_1 10^{-12} erg cm $^{-2}$ s $^{-1}$	F_2 10^{-12} erg cm $^{-2}$ s $^{-1}$	Synchr. (%)
1	$3.20^{+0.10}_{-0.16}$	$1.87^{+0.30}_{-0.23}$	2.01	5.99 ± 1.31	4.26 ± 1.60	58
2	$3.10^{+0.09}_{-0.11}$	$1.50^{+0.13}_{-0.12}$	2.46	5.08 ± 1.10	3.15 ± 1.33	62
3	$2.95^{+0.09}_{-0.07}$	$1.30^{+0.26}_{-0.27}$	3.74	7.93 ± 1.49	3.01 ± 1.88	72
4	$3.16^{+0.42}_{-0.26}$	$1.68^{+0.23}_{-0.34}$	1.52	4.28 ± 1.83	4.96 ± 2.04	46
5	$2.95^{+0.28}_{-0.14}$	$1.87^{+0.17}_{-0.02}$	5.34	13.01 ± 4.24	3.76 ± 1.91	78



XMM SEDs superimposed to historical SEDs
(detections by HEAO-A, Einstein, ROSAT, ASCA, BeppoSAX)

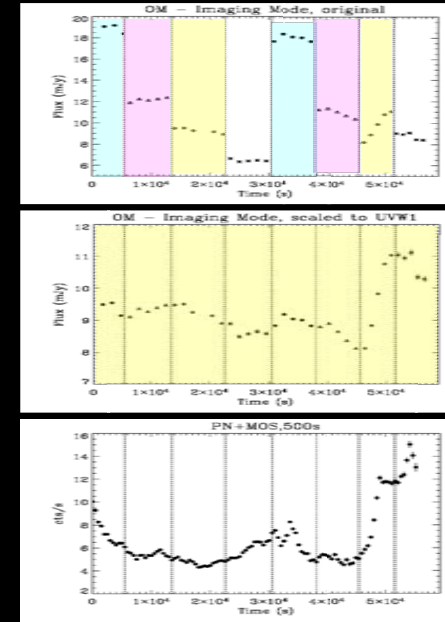
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: XMM "OM" and "PN+MOS" measurements

V
U
UVW1
UVM2

scaling to
UVW1

X-ray
0.5-10 keV



from Ferrero et al. 2006

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

Optical Monitor (OM) data

- imaging mode
- 38 exposures (1000-1200 s)
- V, U, UVW1, UVM2 sequences

- hyp. of power-law spectrum constant over $\Delta t \sim 1$ ks
- spectral indices w.r.t. UVW1
- scaling of V, U, UVM2 to UVW1

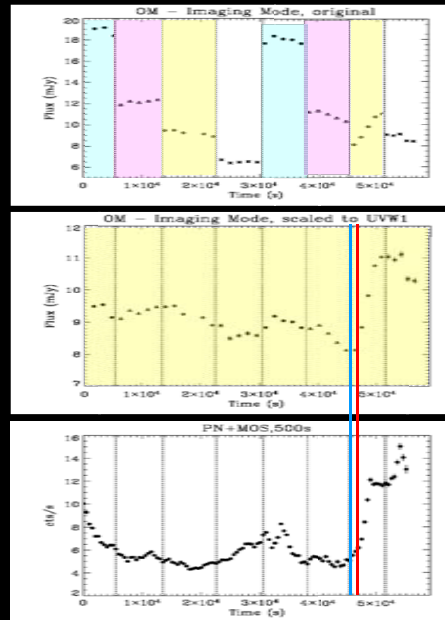
- UV curve \neq X-ray curve apart from the last flare

An optical-UV and X-ray correlated flare: XMM "OM" and "PN+MOS" measurements

V
U
UVW1
UVM2

scaling to
UVW1

X-ray
0.5-10 keV



from Ferrero et al. 2006

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

Optical Monitor (OM) data

- imaging mode
- 38 exposures (1000-1200 s)
- V, U, UVW1, UVM2 sequences

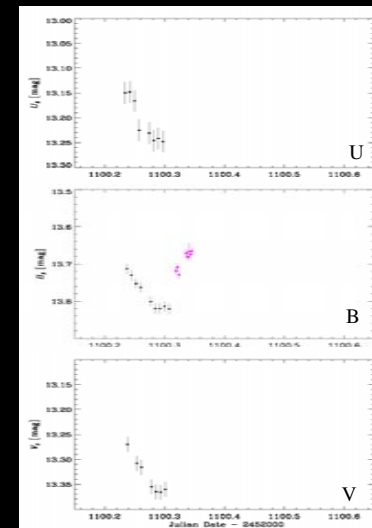
- hyp. of power-law spectrum constant over $\Delta t \sim 1$ ks
- spectral indices w.r.t. UVW1
- scaling of V, U, UVM2 to UVW1

- UV curve \neq X-ray curve apart from the last flare

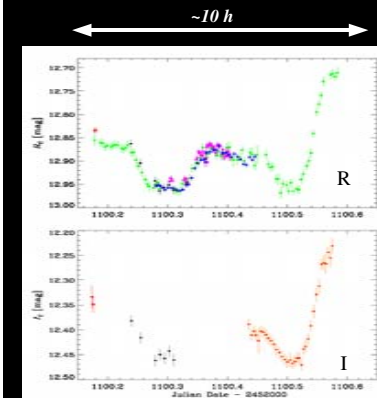
- Possible start of the final X-ray flare ~ 1 ks (~ 17 min) before the start of the UV flare

An optical-UV and X-ray correlated flare: ground-based optical measurements

Ground-based optical observations:



UBVRI data provided by 7 optical observatories who were intensively monitoring the source during the INTEGRAL ToO of Apr. 2-7, 2004 (XMM pointing: not known)



Abastumani
Maidanak
Nyröla
Tuorla
KVA
Sampurnand
Jakokoski

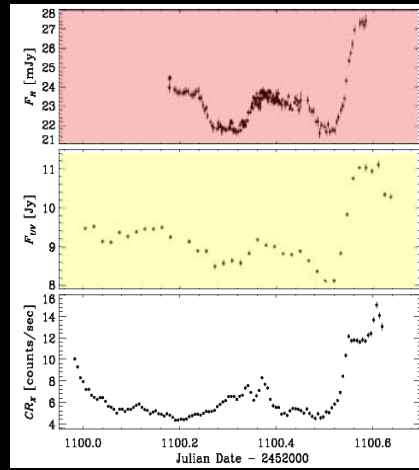
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: ground- and space-based measurements

R-band
(ground-based)

UVW1
(XMM-OM)

X-ray
0.5-10 keV
(XMM, PN+MOS)



- Optical light curve: good match with the UV light curve; only the last flare (achromatic in "R-I") in common with the X-ray light curve

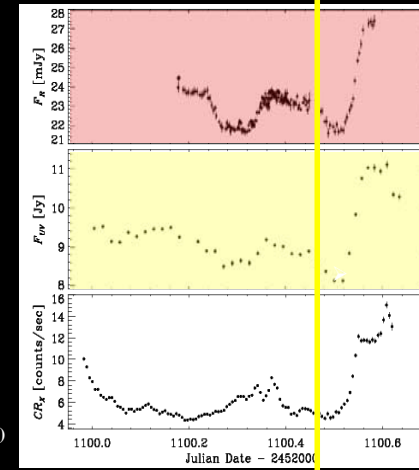
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: ground- and space-based measurements

R-band
(ground-based)

UVW1
(XMM-OM)

X-ray
0.5-10 keV
(XMM, PN+MOS)



- Optical light curve: good match with the UV light curve; only the last flare (achromatic in "R-I") in common with the X-ray light curve

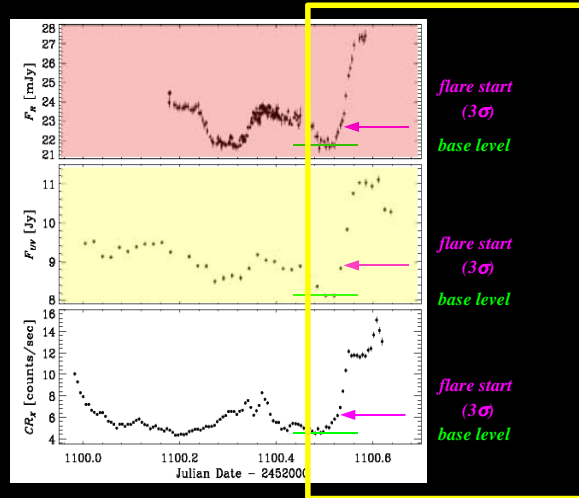
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: ground- and space-based measurements

R-band
(ground-based)

UVW1
(XMM-OM)

X-ray
0.5-10 keV
(XMM, PN+MOS)



- Optical light curve: good match with the UV light curve; only the last flare (achromatic in "R-I") in common with the X-ray light curve

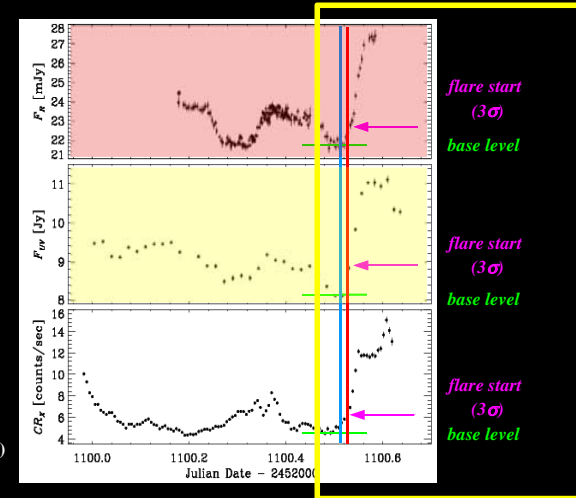
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: ground- and space-based measurements

R-band
(ground-based)

UVW1
(XMM-OM)

X-ray
0.5-10 keV
(XMM, PN+MOS)



- Optical light curve: good match with the UV light curve; only the last flare (achromatic in "R-I") in common with the X-ray light curve
- Possible 1.5 ks delay of the start of the optical (R,I) flare w.r.t. the X-ray flare

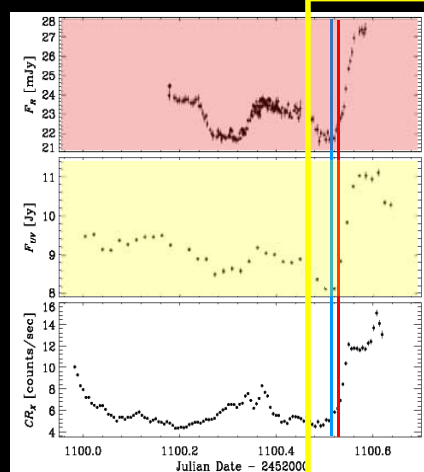
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: ground- and space-based measurements

R-band
(ground-based)

UVW1
(XMM-OM)

X-ray
0.5-10 keV
(XMM, PN+MOS)



- Optical light curve: good match with the UV light curve; only the last flare (achromatic in "R-I") in common with the X-ray light curve
- Possible 1.5 ks delay of the start of the optical (R,I) flare w.r.t. the X-ray flare

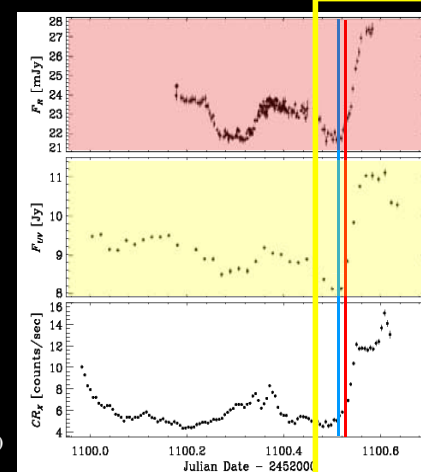
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: ground- and space-based measurements

R-band
(ground-based)

UVW1
(XMM-OM)

X-ray
0.5-10 keV
(XMM, PN+MOS)



- Optical light curve: good match with the UV light curve; only the last flare (achromatic in "R-I") in common with the X-ray light curve
- Possible 1.5 ks delay of the start of the optical (R,I) flare w.r.t. the X-ray flare
- Decreasing flare amplitude from X-ray to optical frequencies

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: light-curve summary



- Overall optical-UV and X-ray light curves:
* different variability patterns on time-scales $\leq \sim 10$ hours

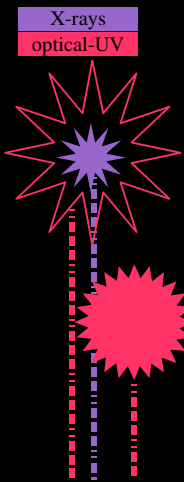
⇒ *short-term optical and X-ray variability likely due to processes taking place in different source regions*

- Strong X-ray flare, synchrotron dominated

- * optical-UV counterpart, strongly contaminating the optical-UV light curves
- * optical counterpart possibly lagging ~ 1.5 ks behind the X-ray flare
- * decreasing flare amplitude from X-ray down to optical frequencies

⇒ *consistency with a cooling-dominated scenario in a source region with size: $R < \sim 2 \text{ l.h.} \cdot \delta(1+z) \sim \text{few } 100 \mu\text{pc} \div \text{mpc}$*
 ⇒ *optical counterpart significant only for X-ray flares exceeding a given luminosity threshold*

- Optical-UV intraday variability
⇒ *more than one component with comparable intensity (in general difficult to disentangle)*

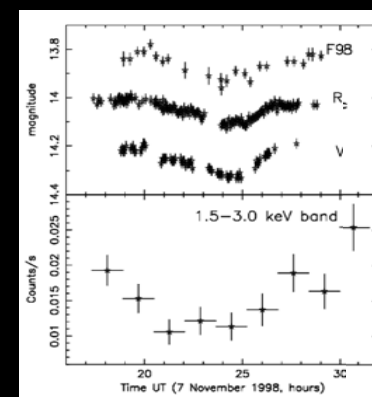


8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: comparison with previous observations

Best example of previous simultaneous intra-day optical and X-ray variability in S5 0716+71:

Nov. 1998 *BeppoSAX* and ground-based R-band observations during a faint optical-X-ray state (Giommi et al. 1999)



from Giommi et al. 1999

R-band optical vs soft-X-rays (1.5-3.0 keV):

- possible 2-3 h lag of optical decay w.r.t. X-ray decay

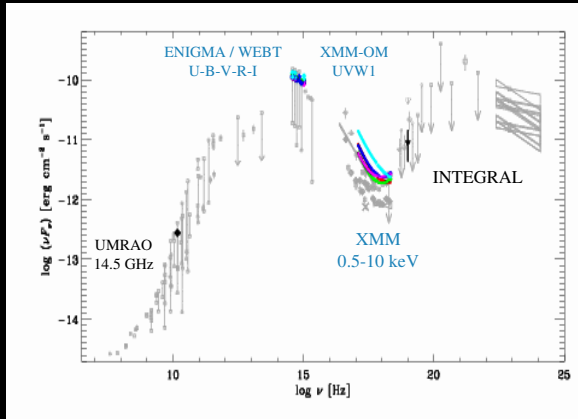
⇒ interpreted as difference in cooling times or geometric effect (electrons diffusing out from an injection region while cooling)
 ⇒ cooling time $< R/c$

- simultaneous optical/X-ray rise at ~ 25 h U.T.

⇒ *the data quality was too poor to establish firm correlations between optical and X-ray variability*

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

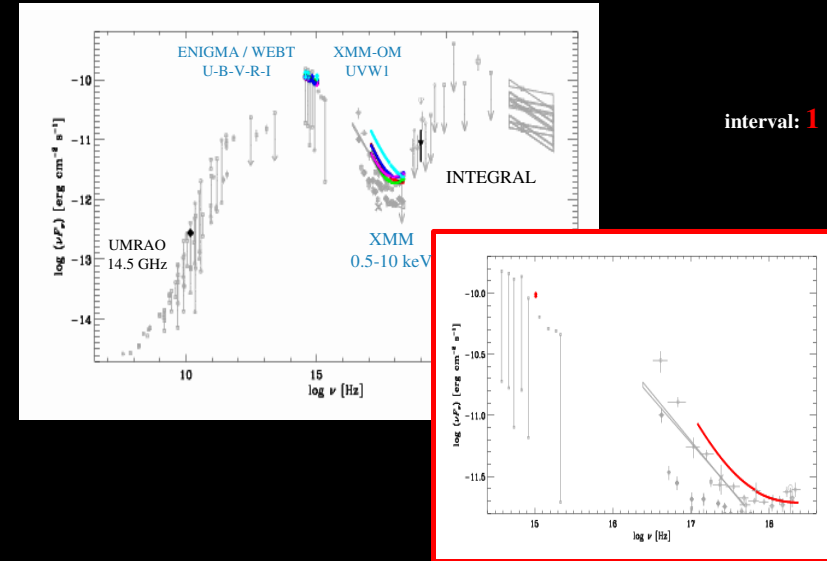
An optical-UV and X-ray correlated flare: broadband SED evolution



The multifrequency data collected during the XMM pointings enable, for the first time, to study the intra-day evolution of the optical-to-X-ray SED...

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

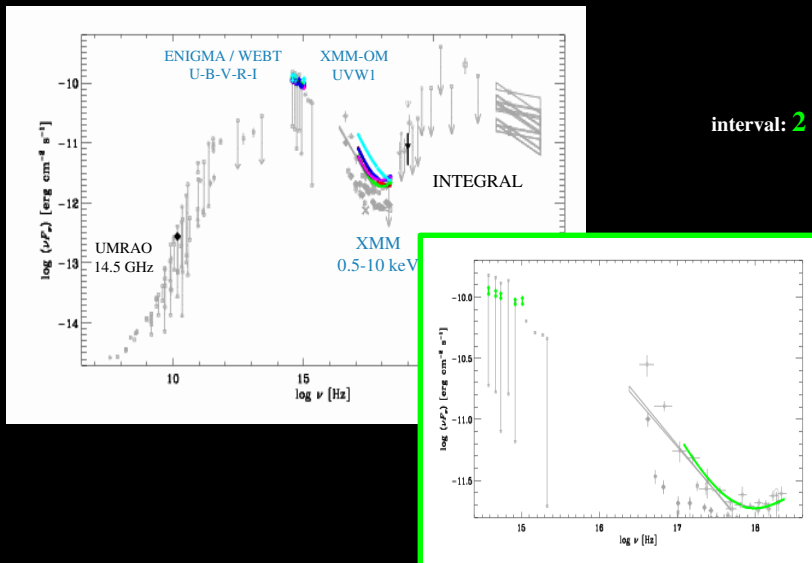
An optical-UV and X-ray correlated flare: broadband SED evolution



interval: 1

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

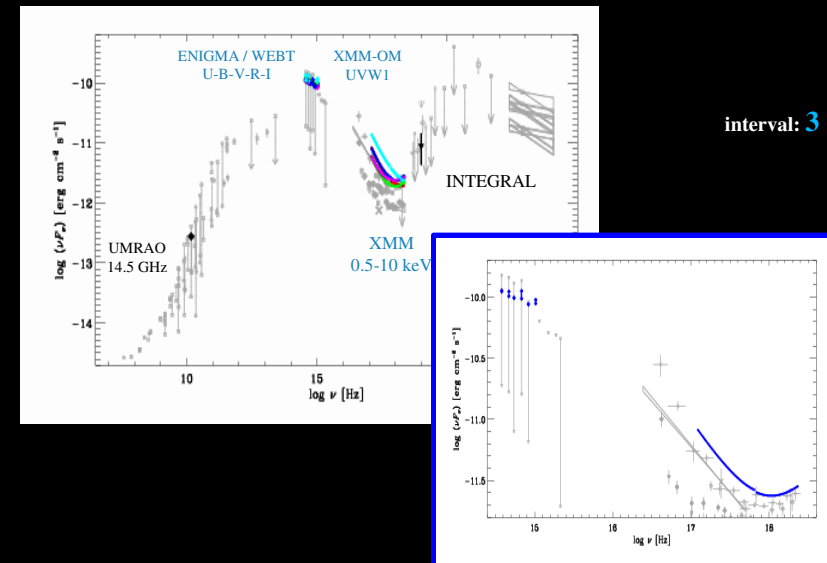
An optical-UV and X-ray correlated flare: broadband SED evolution



interval: 2

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

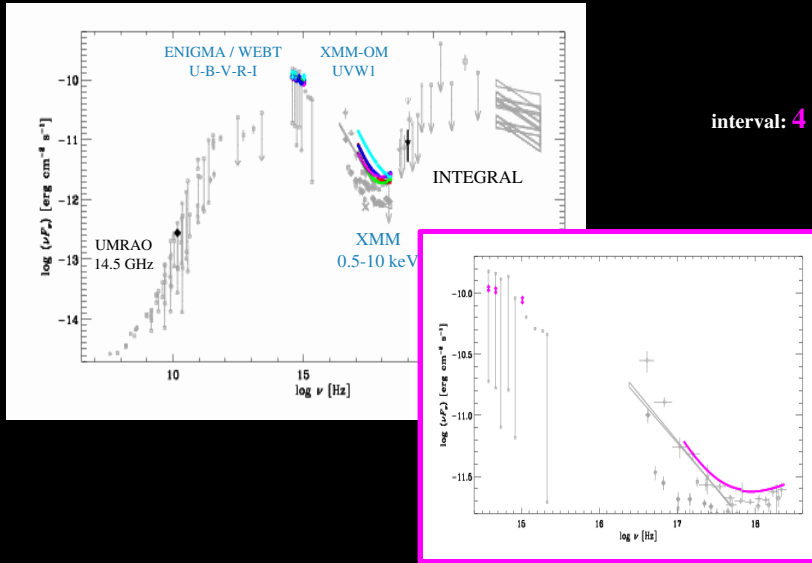
An optical-UV and X-ray correlated flare: broadband SED evolution



interval: 3

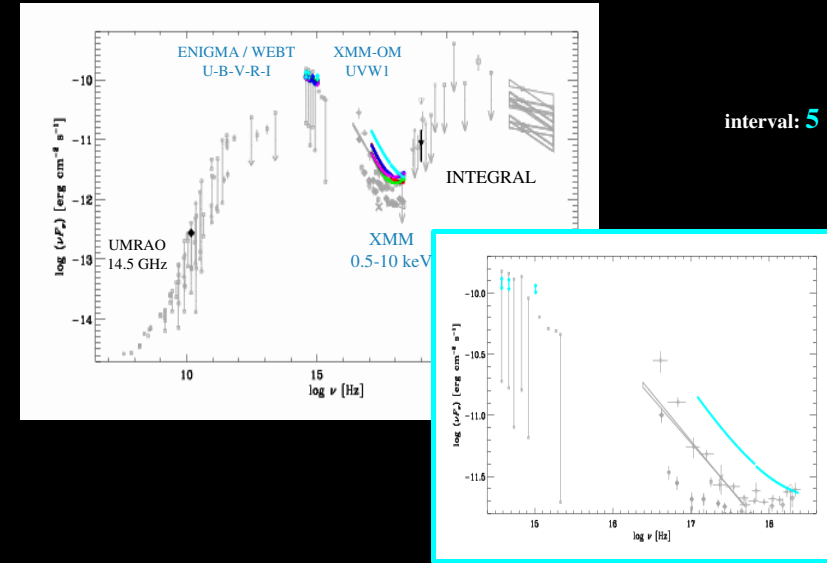
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: broadband SED evolution



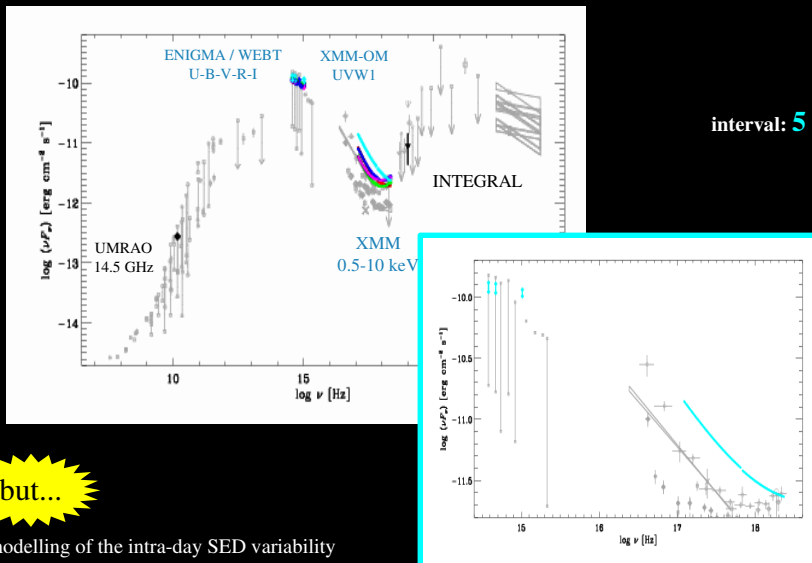
8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: broadband SED evolution



8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

An optical-UV and X-ray correlated flare: broadband SED evolution



but...

... modelling of the intra-day SED variability probably requires more than one source component

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

Summary

0716+714 long-term variability during 2003-2004

- detection of two historical outbursts
 - no correlation between colour and brightness
 - *flatter-when-brighter* chromatism of the main flux bursts
 - confirmation of the long-term brightening of the source discovered by Nesci et al. (2005)
 - confirmation of the increase of the frequency of the major outbursts present in the 2002-2003 dataset by Nesci et al. (2005)
- ⇒ possible time-dependent beaming effect as responsible of the intensification of the activity

0716+714 short-term variability: simultaneous X-ray and optical observations in April 2004

- brightest X-ray state ever detected for this source
- time-resolved spectral analysis: synchrotron dominance during flaring states; significant short-term variability of the IC component
- detection of the optical-UV counterpart of a strong X-ray flare of (possible soft lag ~ 1.5 ks)
- presence of more than one IDV component in the optical light curves
- intra-day optical to X-ray SED evolution: a challenge for the emission models

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006

*Thanks a lot for your attention
and for the collaboration!*

8th ENIGMA Meeting - Espoo (Finland), September 06-08, 2006