EXORCISM: EXORs optiCal-Infrared Systematic Monitoring

Simone Antoniucci[a], Arkady A. Arkharov[b], Andrea Di Paola[a], Teresa Giannini[a], Makoto Kishimoto[c],
Brian Kloppenborg[c], Valeri M. Larionov[b,d], Gianluca Li Causi[a], Dario Lorenzetti[a], Fabrizio Vitali[a]

a) INAF - Osservatorio Astronomico di Roma, Monte Porzio Catone, Italy; b) Central Astronomical Observatory of Pulkovo, St. Petersburg, Russia; c) Max Planck Institut für Radioastronomie, Bonn, Germany;
d) Astronomical Institute of St. Petersburg University, Russia

1. EXors

EXors are pre-main sequence eruptive stars showing intermittent outbursts (Δmag about 4-5) of short duration (months) superposed on longer (years) quiescence periods. **These bursts**, usually detected in the optical and near-IR bands, **are related to disk accretion events** in which there is a sudden increase of the mass accretion rate by orders of magnitude (e.g. *Hartmann & Kenyon 1996*).

No detailed analysis or modeling of EXor inner disk structure is available, so **the mechanism regulating the outbursts is basically not known**. Reasons are:

i) lack of long-term multi-wavelength monitoring programs of photometric and spectroscopic properties;

ii) only a few studies were able to compare photometry and/or spectroscopy of the outburst and quiescence phase (e.g. *Lorenzetti+ 2009, Sipos+ 2009, Audard+ 2010, Sicilia-Aguilar+ 2012, Juhasz+ 2012*);

iii) absence of high angular resolution observations able to spatially resolve the inner disk of the sources.

Source	L_{bol} ($L_\odot$)	max-min (V mag)	A_V (mag)	Id.
Classical EXors (as defined by *Herbig 1989*)				
UZ Tau E	1.7	11.7 – 15.0	1.5	a
VY Tau	0.7	9.0 – 15.3	0.8	b
DR Tau	1.0 - 5.0	10.5 – 16.0	1.7 – 2.0	c
V1118 Ori	1.4 - 25	12.8 – 17.5	0 - 2	d
NY Ori	…	14.5 – 17.5	0.3	e
V1143 Ori	…	13 - 19	…	f
EX Lup	0.7	8.4 – 13.2	0	g
PV Cep	100	14.6 – 18.0	5 - 7	h
Recently identified (and more embedded) candidate EXors				
V1180 Cas	0.07	15.7 - >21	4.3	A
V512 Per	…	15.9 – 19.0	6 - 15	B
LDN1415	…	14.7 – 18.4	…	C
V2775 Ori	1.9 - 22	11.8 – 16.4	18	D
V1647 Ori	5.2, 2.8-44	14.4 – 20.3	9 - 19	E
GM Cha	1.5	10.6 – 12.7	13	F
OO Ser	4.5 - 26/36	11.4 – 16.1	42	G
V2492 Cyg	20	14.7 – 18/19	6 - 12	H
V2493 Cyg	2.7 - 12	13.6 – 17.0	3.4	I
GM Cep	30/40	12.4 – 14.6	2 - 4	J

2. Project

EXORCISM is a systematic monitoring project we have just started, based on **photometric and spectroscopic observations** at optical and near-IR wavelengths, with the aim to:

- → trace **photometric variations** (monthly basis) → **prompt detection of any possible outburst**
- → trace **spectroscopic variations** (yearly basis, more often in case of outburst)

In parallel to the systematic observations, we are also carrying out a **near-IR and mid-IR interferometric investigation** of the objects in quiescence, which will be replicated in case of any outburst (through ToO and DDT programs): The goals of this part of the program are:

- → modelling of the magnetospheric region and inner/outer disk structure both in quiescence and outburst → trace **structure variations**
- → study outburst **trigger mechanism**

3. Facilities

Systematic monitoring

- AZT24 1m – Campo Imperatore (Italy): ***J H K Imaging + spectroscopy*** *(R ~ 250)*
- TNG (Telescopio Nazionale Galileo) 3.6m – Canary Islands: ***B V R I J H K Imaging + spectroscopy*** *(R ~ 1500)*
- REM (Robotic Telescope) 0.6m – ESO La Silla (Chile): ***B V R I J H K Imaging***
- LX200 0.4m – St. Petersbourg University (Russia): ***U B V (Johnson) R I (Cousin) imaging + polarimetry***.

Interferometry

- VLTI AMBER+MIDI – ESO Paranal (Chile) – ***H K spectro-interferometry*** *(R ~ 1500)* + ***N spectro-interferometry*** *(R ~ 30)*
- CHARA CLIMB – MWO (California) – ***H K interferometry***

4. Our previous results

Data collected by EXORCISM will alllow us to replicate in a systematic and more detailed fashion the investigations performed by our group during the last few years on some EXor objects, here summarized.

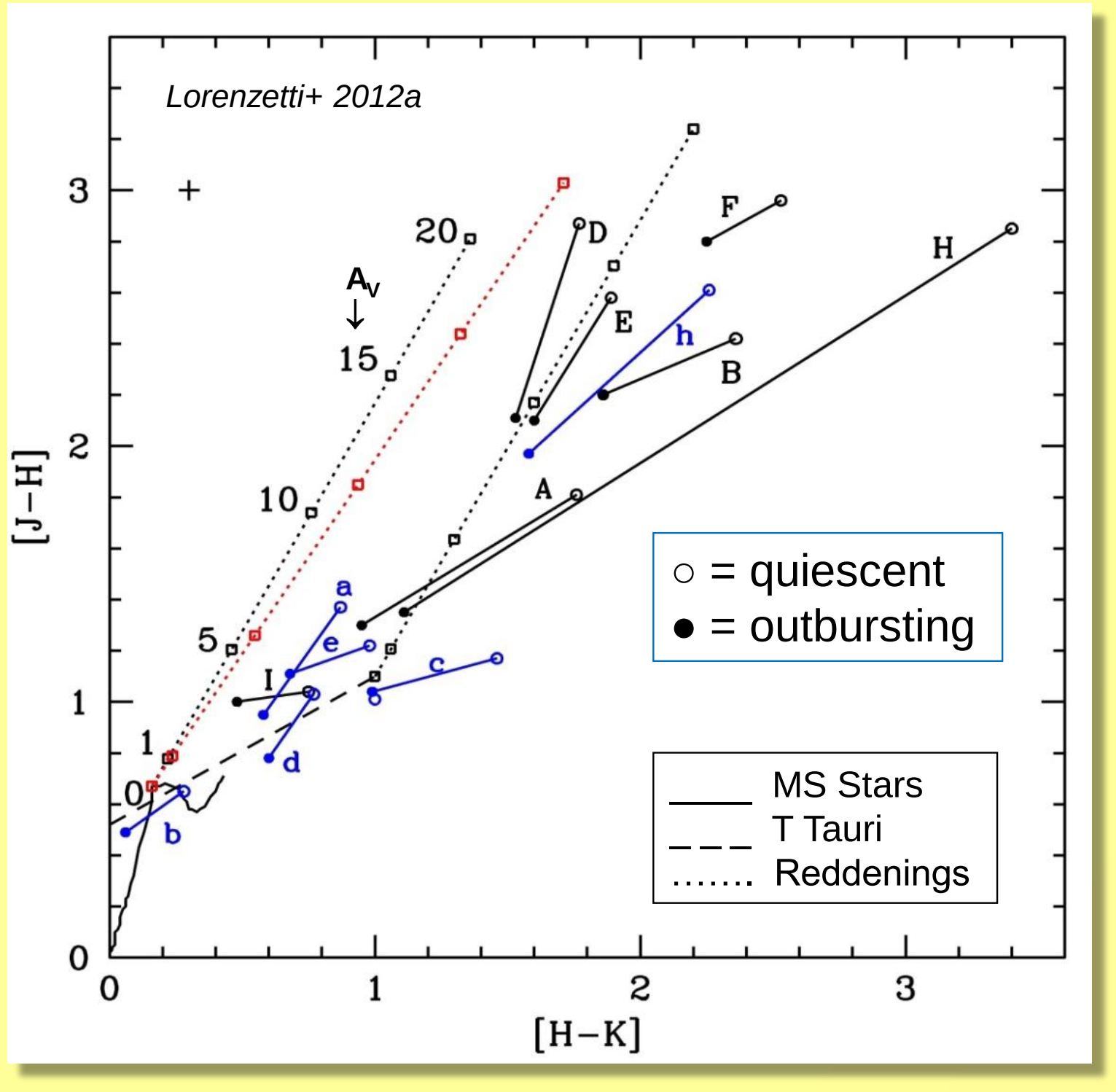

Fig. 1: NIR c-c diagram of EXors (see Table above). In outburst (quiescence) EXors are all bluer (redder).

⇒ **typical variations tend not to follow the extinction vector, so other effects have a role (e.g. disk stratification thickness).**

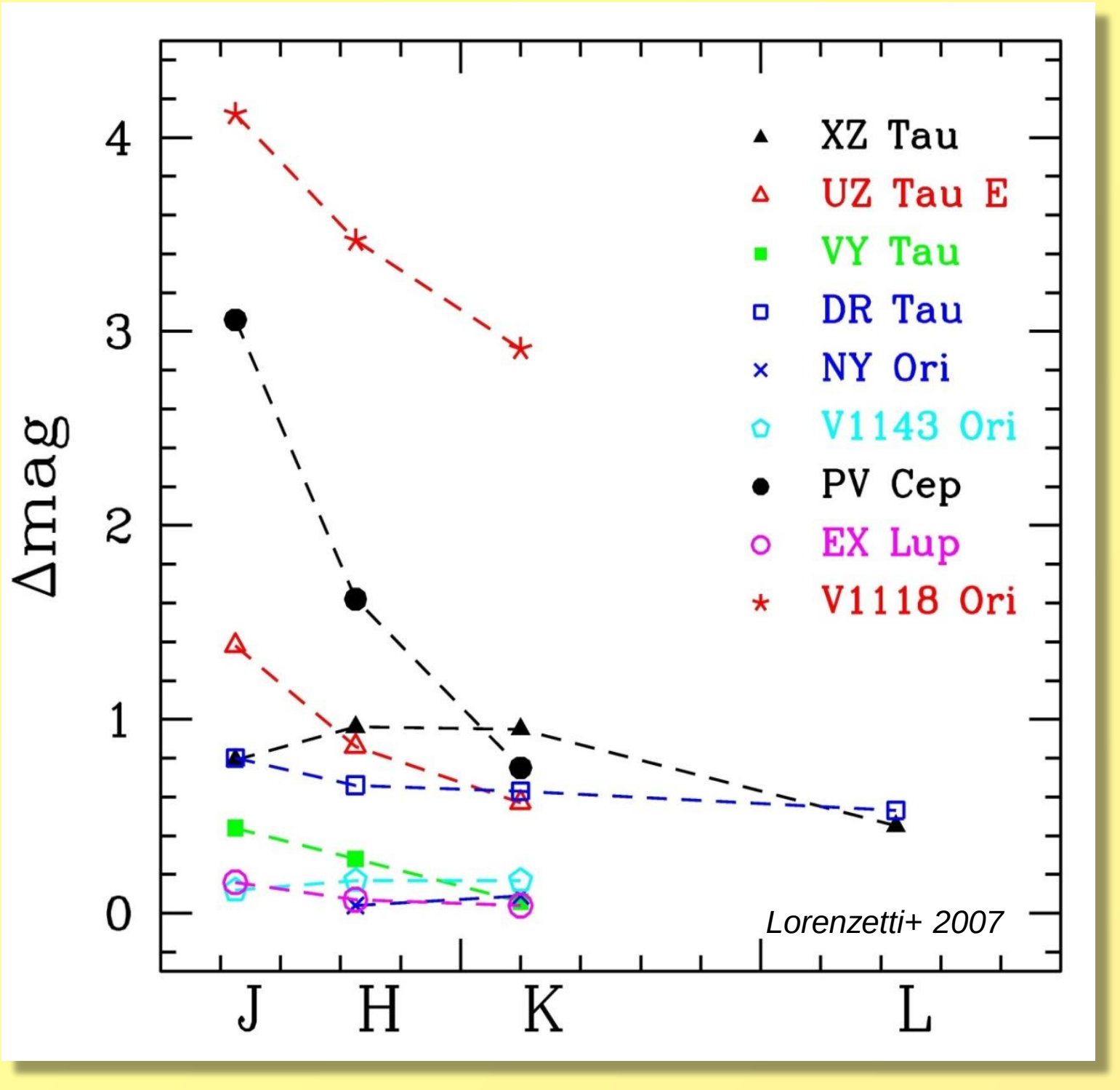

Fig. 2: the amplitude of mag variations tends to decrease at longer wavelengths (at least for larger fluctuations)

⇒ **infalling matter creates a hot spot on the stellar surface that heats different parts of the disk to different temperatures**

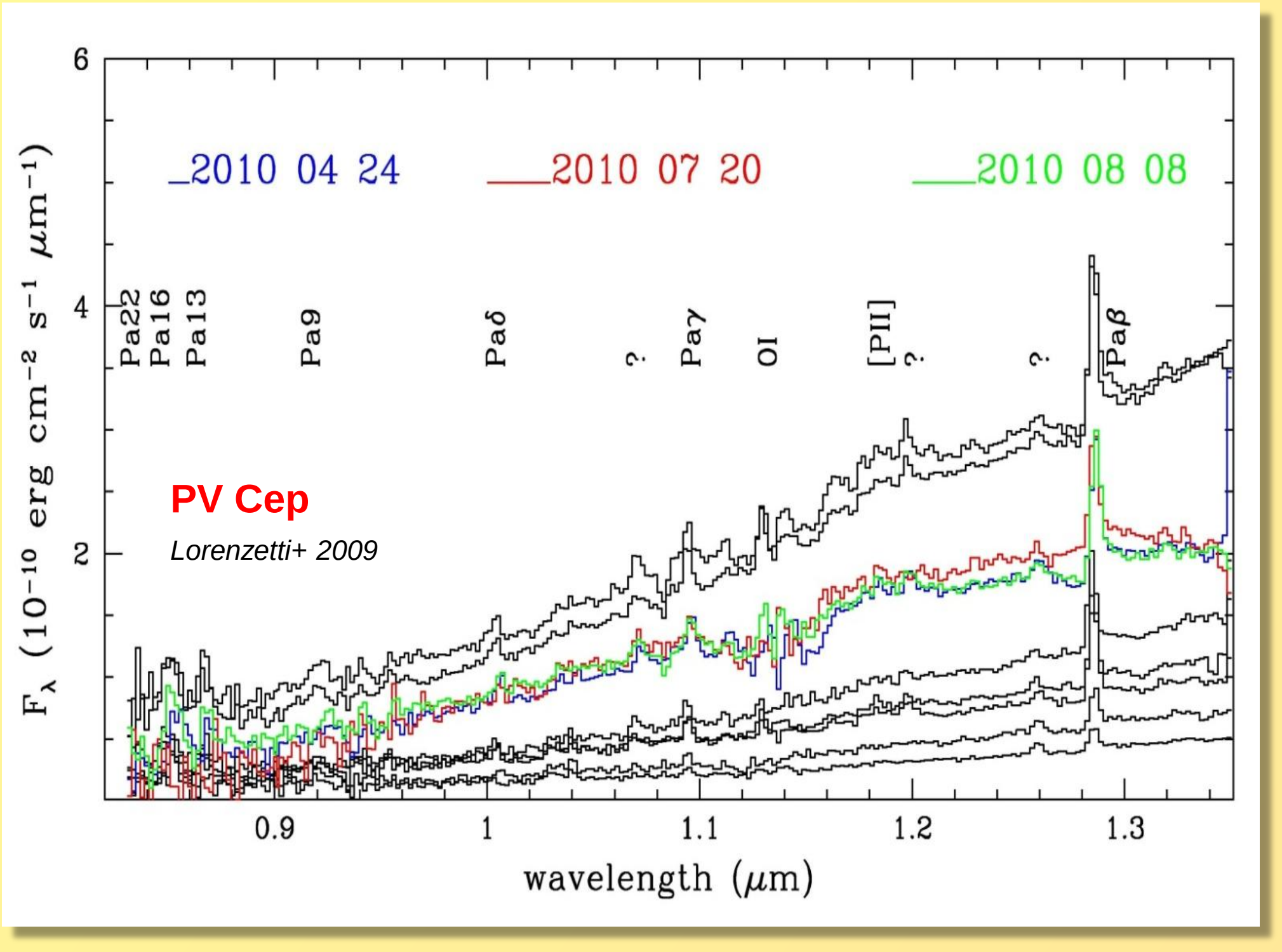

Fig. 3: low resolution (R ~ 250) spectroscopic monitoring of PV Cep in the NIR (0.8 - 2.5μm).

⇒ **EXors spectra show a wide variety of emission features dominated by HI recombination lines.**

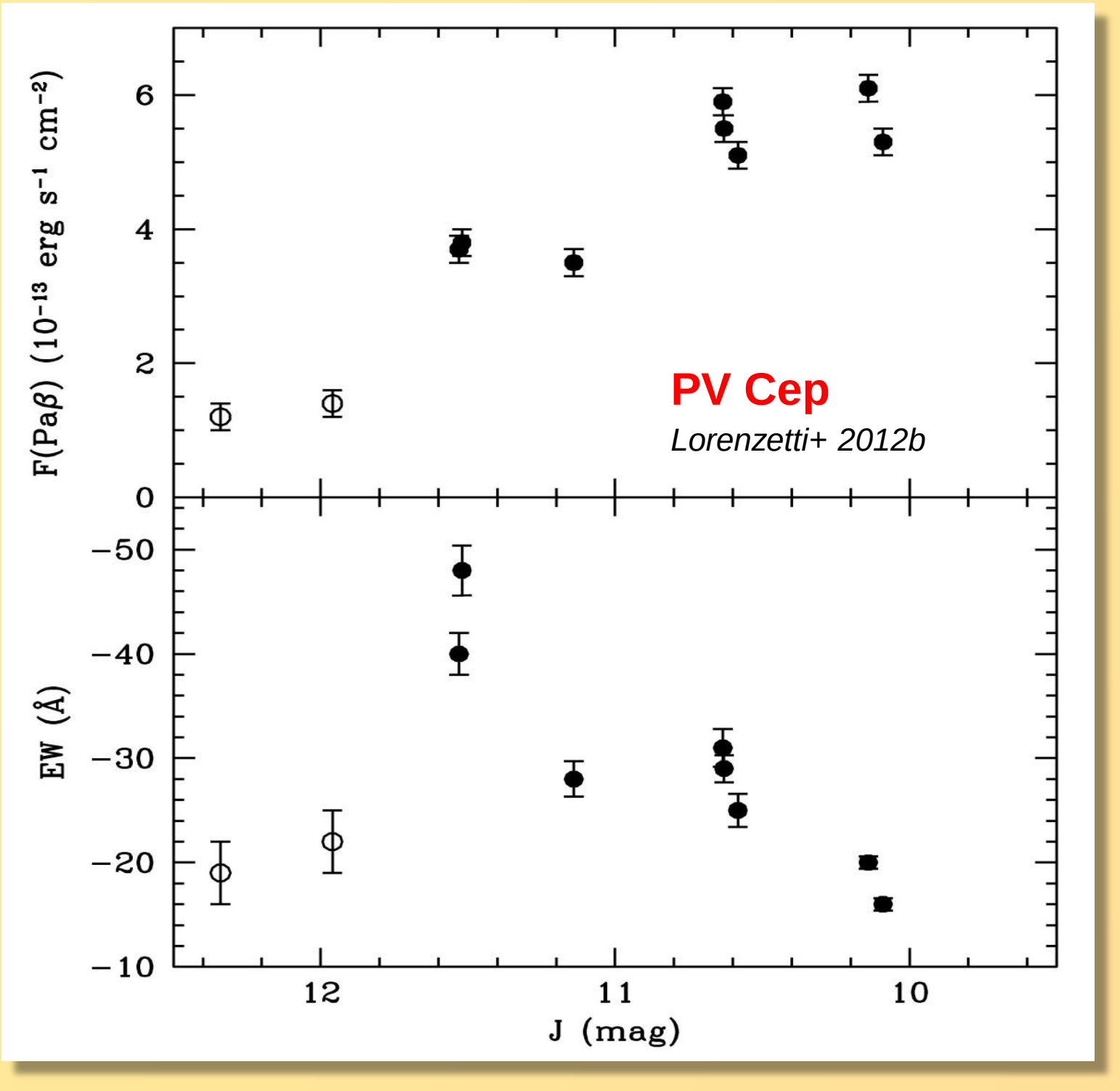

Fig. 4: flux and EW of Paβ in PV Cep: variations seems to be anti-correlated (black points).

⇒ **anti-correlation: increase of J continuum is larger (i.e. faster) than increase of line flux. Since EW is basically unaffected by extinction, varying extinction effects are ruled out.**

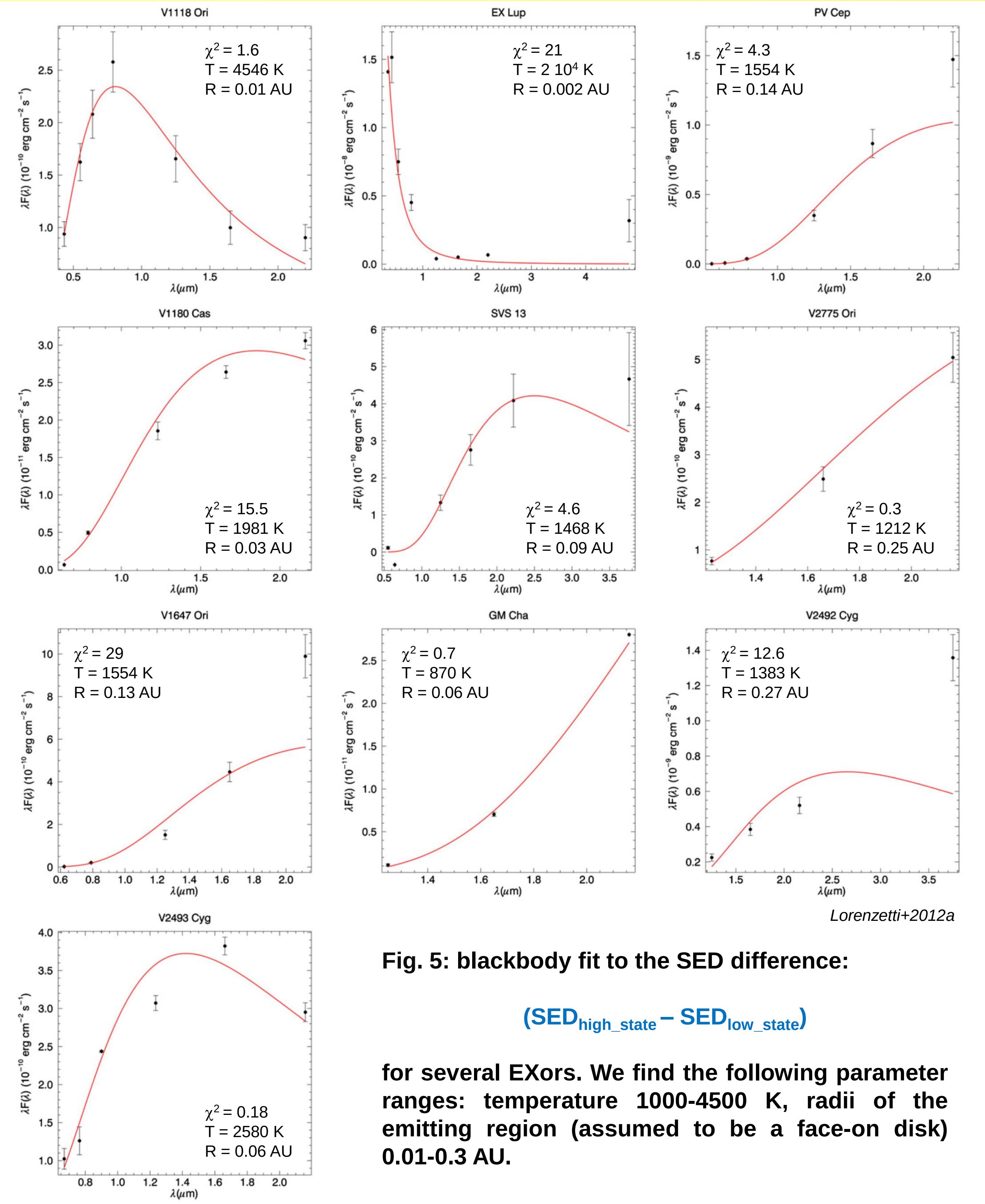

Fig. 5: blackbody fit to the SED difference:

($SED_{high\_state} – SED_{low\_state}$)

for several EXors. We find the following parameter ranges: temperature 1000-4500 K, radii of the emitting region (assumed to be a face-on disk) 0.01-0.3 AU.

- ⇒ ***i.*** **While the SED difference can be well fitted with a single blackbody, it is impossible to fit the data with a pure extinction function.**
- ⇒ ***ii.*** **EXor systems behave as if an additional thermal component appears during the outbursting phase.**
- ⇒ ***iii.*** **Spots persisting up to 50% of the outburst duration, not exceeding 10% of the stellar surface, and with temperatures between 10000-18000 K, are able to account for both the appearance of the additional thermal component and dust sublimation in the inner disk.**

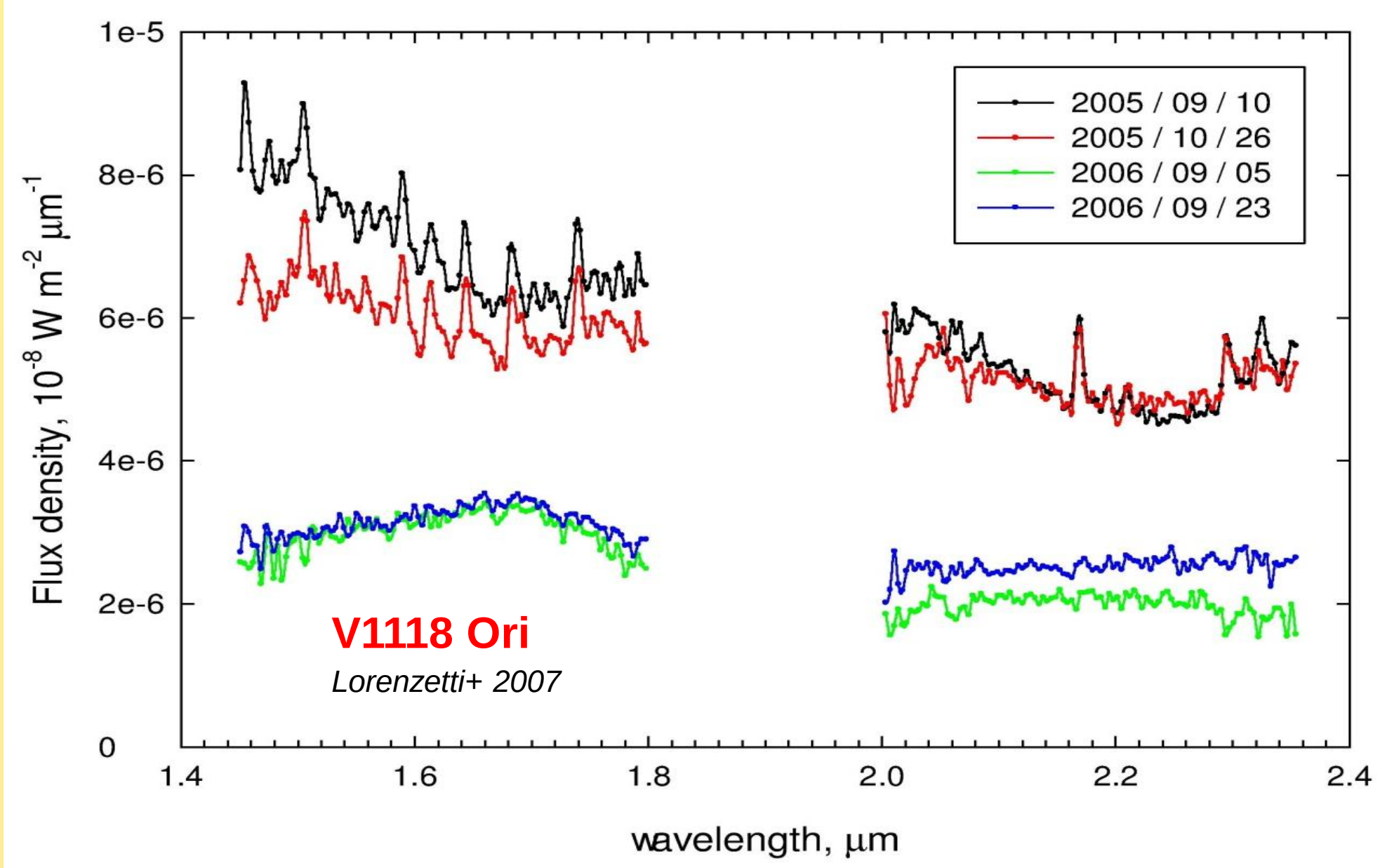

Fig. 6: as continuum fades (and reddens) the spectrum tends to become featureless (Brγ fades by more than a factor of 6): presence of features and continuum excess seem to be correlated.

⇒ **correlation: emission lines are generated by some mechanism strongly related to the accretion onto the central source**

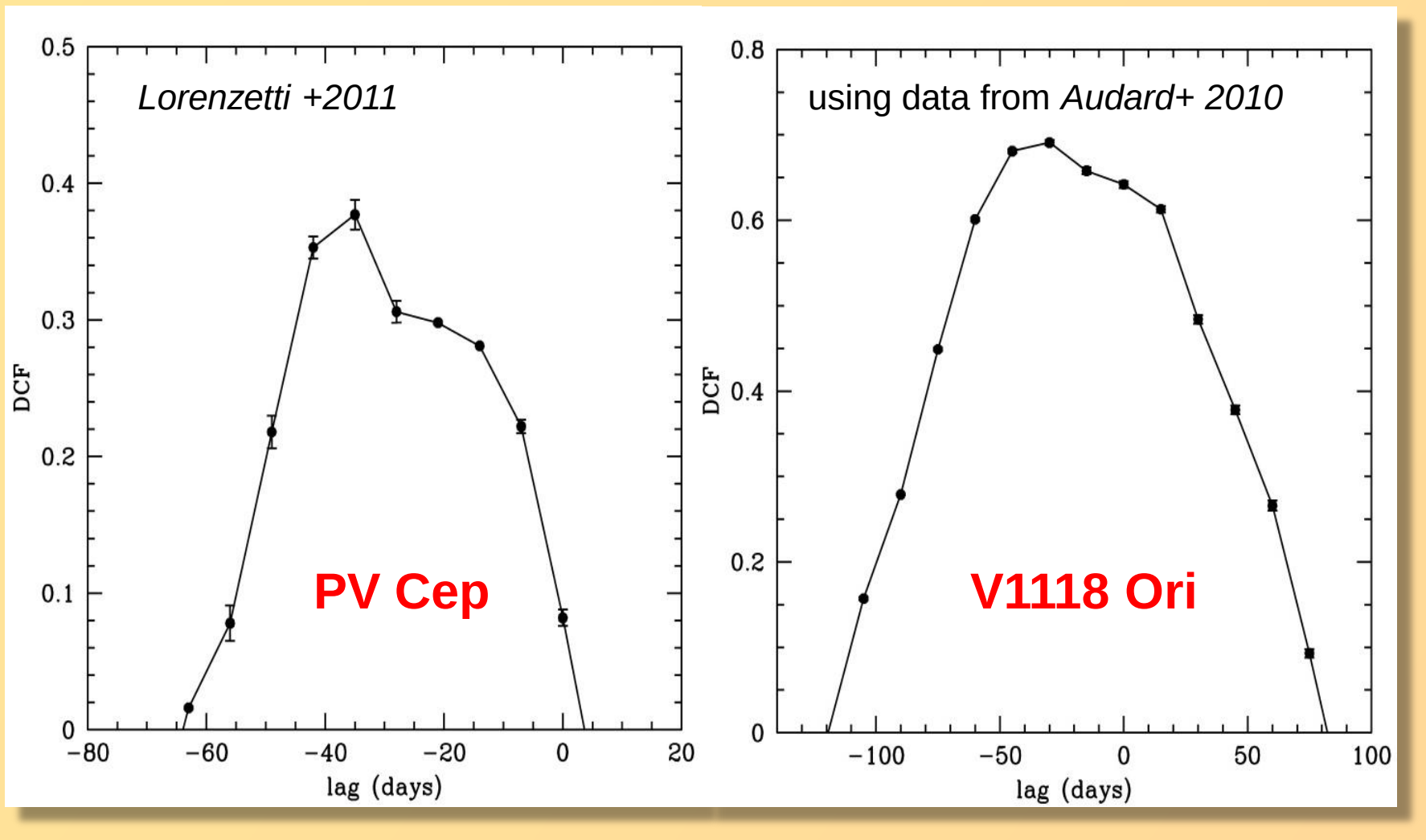

Fig. 7: Discrete Correlation Function (DCF) for R and J light-curves of PV Cep and V1118 Ori. The DCF provides a way to analyse the delay between the two light-curves. In both PV Cep and V1118 Ori variations in J occur about 50 days after those in R

⇒ **evidence of a common mechanism at work: the observed (very similar) lag might be typical of any outbursting (or declining) event.**

5. Interferometric observations

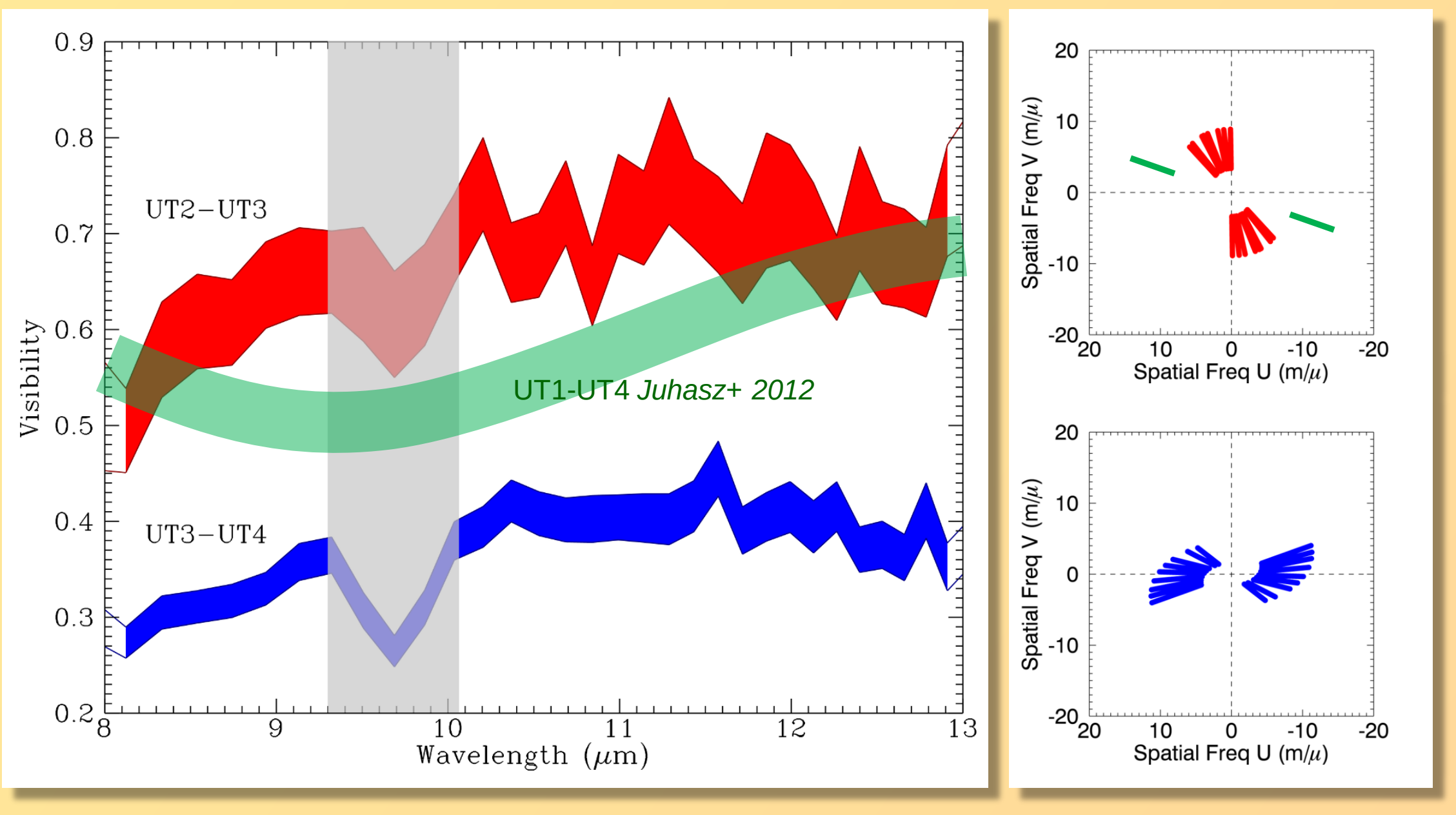

Fig. 8: preliminary results of VLTI/MIDI observations of the prototype EXor source EX Lup, carried out in May 2013, with the target in a quiescent phase after the 2008 outburst (*Jones 2008*). Visibility curves (in red and blue) and relative u-v coverage refer to two different nights of observations with almost perpendicular projected baselines. Atmospheric residuals are grayed out. Previous MIDI visibilities (green) were obtained by *Juhasz+ (2012)* during the 2008 outburst.

⇒ **the disk is resolved on both our baselines and appears to be inclined. Comparison with outburst visibilities suggest a modification of the disk structure between the outburst and quiescence phases. Work in progress!**

REFERENCES
- Antoniucci, Giannini & Lorenzetti 2013, NewAst, 23-24, 98
- Audard, Stringfellow, Güdel et al. 2010, A&A 511, 6
- Hartmann & Kenyon 1996, ARAA ,34, 207
- Herbig 1989, Proc. ESO Workshop on *Low Mass Star Formation and Pre-Main Sequence Objects*, ed. B. Reipurth, p.233
- Jones 2008, CBET, 1217, 1
- Juhasz, Dullemond, van Boekel et al. 2012, ApJ 744,118
- Lorenzetti, Giannini, Larionov et al. 2007, ApJ 665, 1182
- Lorenzetti, Larionov, Giannini et al. 2009, ApJ 693, 1056
- Lorenzetti, Giannini, Larionov et al. 2011, ApJ 732, 69
- Lorenzetti, Antoniucci, Giannini et al. 2012a, ApJ 749, 188
- Lorenzetti, Antoniucci, Giannini et al. 2012b, ApSS 343, 535
- Sipos, Abraham, Acosta-Pulido et al. 2009, A&A 507, 881
- Sicilia-Aguilar , Kospal, Setiawan et al. 2012, A&A, 544,93

simone.antoniucci@oa-roma.inaf.it