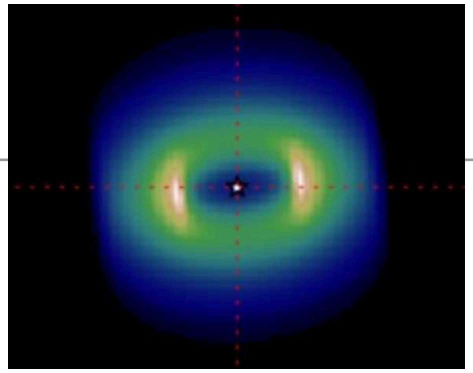
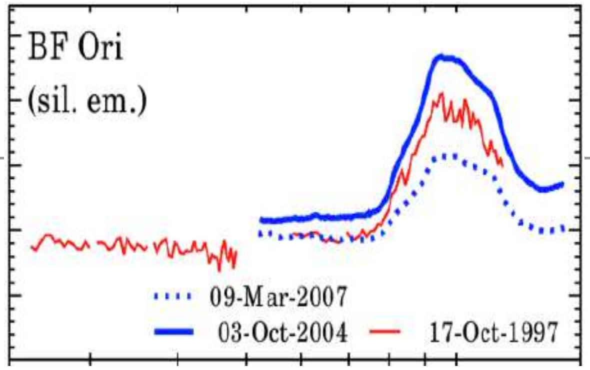
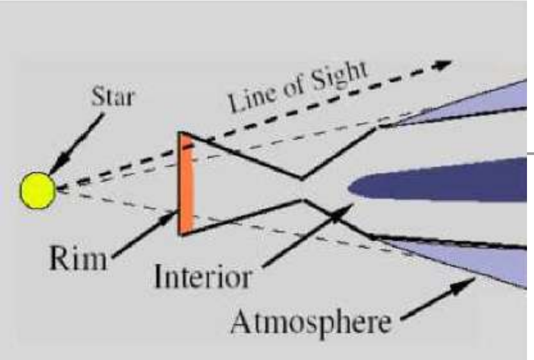
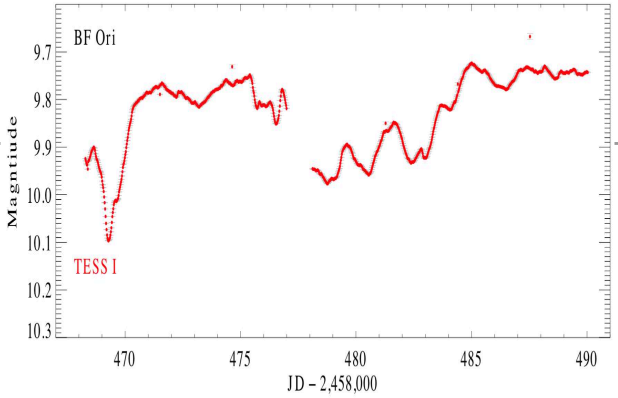
Time-variability and disk geometry in Herbig Ae stars: a simultaneous optical - infrared study of the UXor phenomenon









Péter Ábrahám

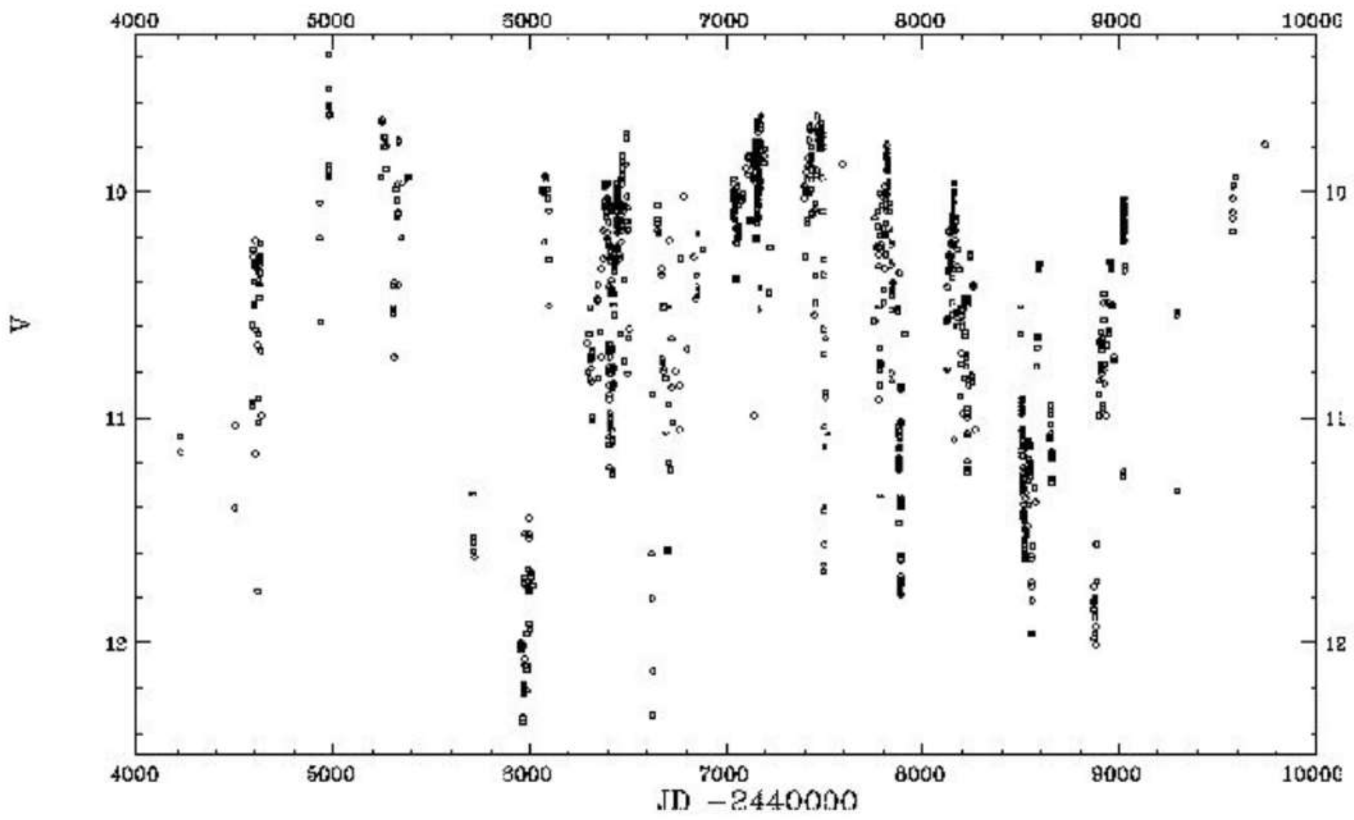
Róbert Szakáts, Ágnes Kóspál
Konkoly Observatory

Research Centre for Astronomy and Earth Sciences
Budapest, Hungary

The UX Ori type stars and related topics, St. Petersburg, 2019 October 1st

Optical variability of Young Stellar Objects

- YSOs are well-known about their optical and near-infrared variability. Three main classes of variability (Herbst et al. 1994):
- **Type I** - Cool spots: similar to sunspots, rotating for a few periods
- **Type II** - Hot spots or zones: variable veiling continuum arising in small transient hot regions where accretion energy is dissipated (periodic or irregular). Mainly later spectral type.
- **Type III** - Variable obscuration. Mainly earlier spectral type. Most studied type is the *UXor phenomenon:* protocometary clouds or protocomets (Grady et al. 2000), hydrodynamic fluctuation in the disk surface (Bertout 2000), puffed-up inner rim (Dullemond et al. 2003)

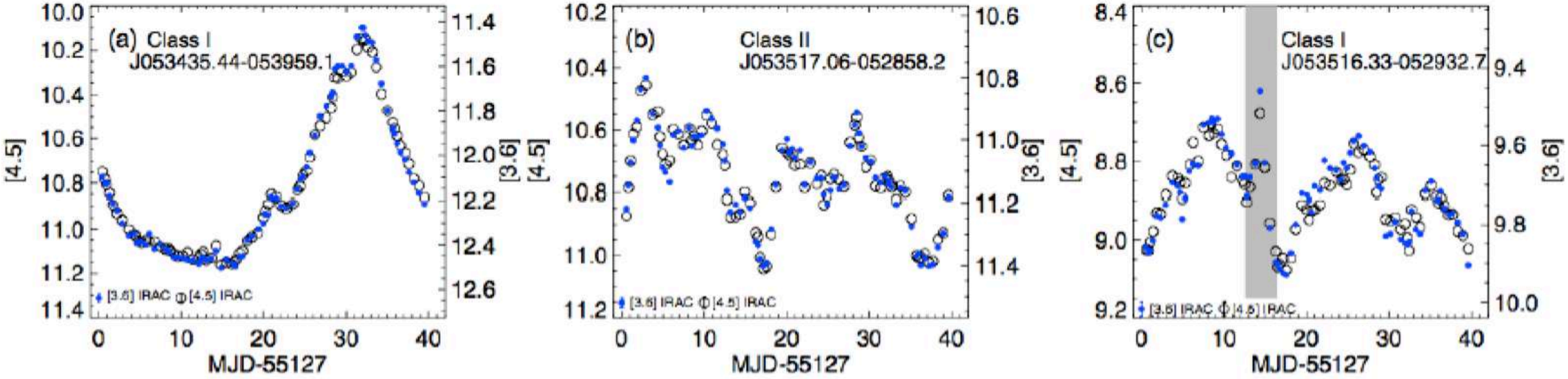


Light curve of UX Ori

Type II-III are related to the disk!

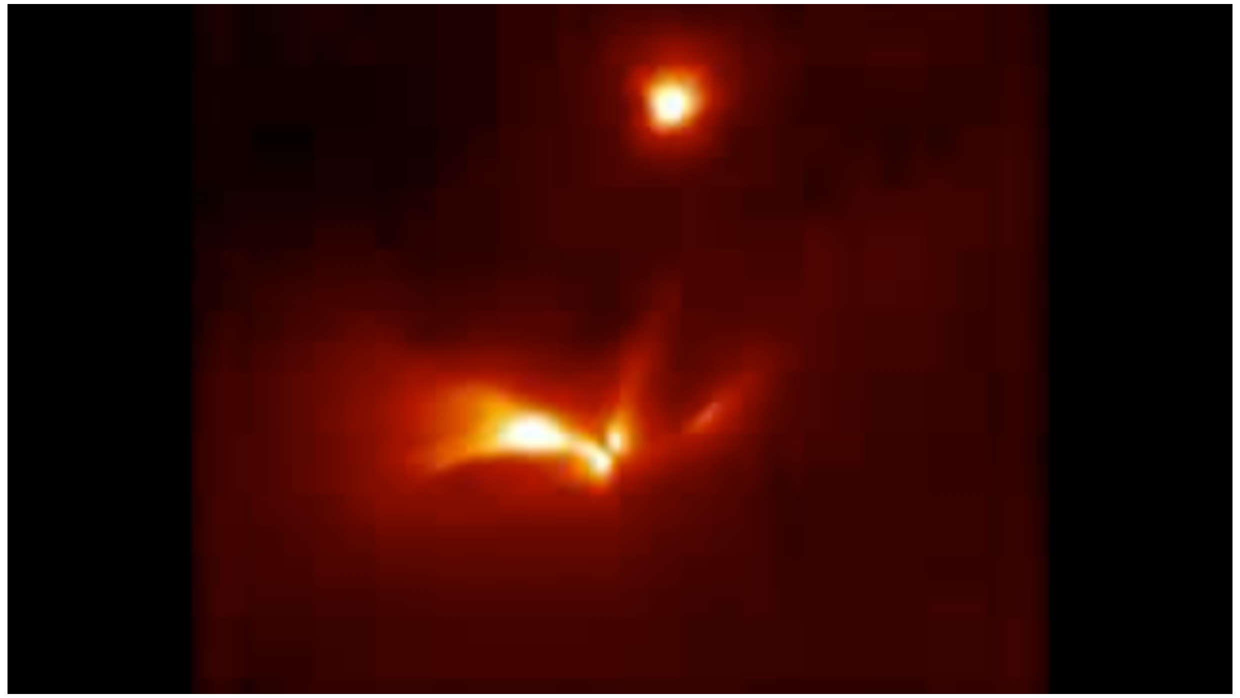
Variability at thermal infrared wavelengths

- Infrared disk emission was long assumed to be constant (but eruptive stars)
- IRAS variability flag showed definite changes (Prusti & Mitskevich 1994)
- Recent mid-infrared photometric studies: a large fraction of YSOs are variable in the thermal infrared (70-80% of YSOs are variable above the 0.1 mag level, e.g. Barsony et al. 2005, Morales-Calderón et al., 2009, Luhman et al., 2010)

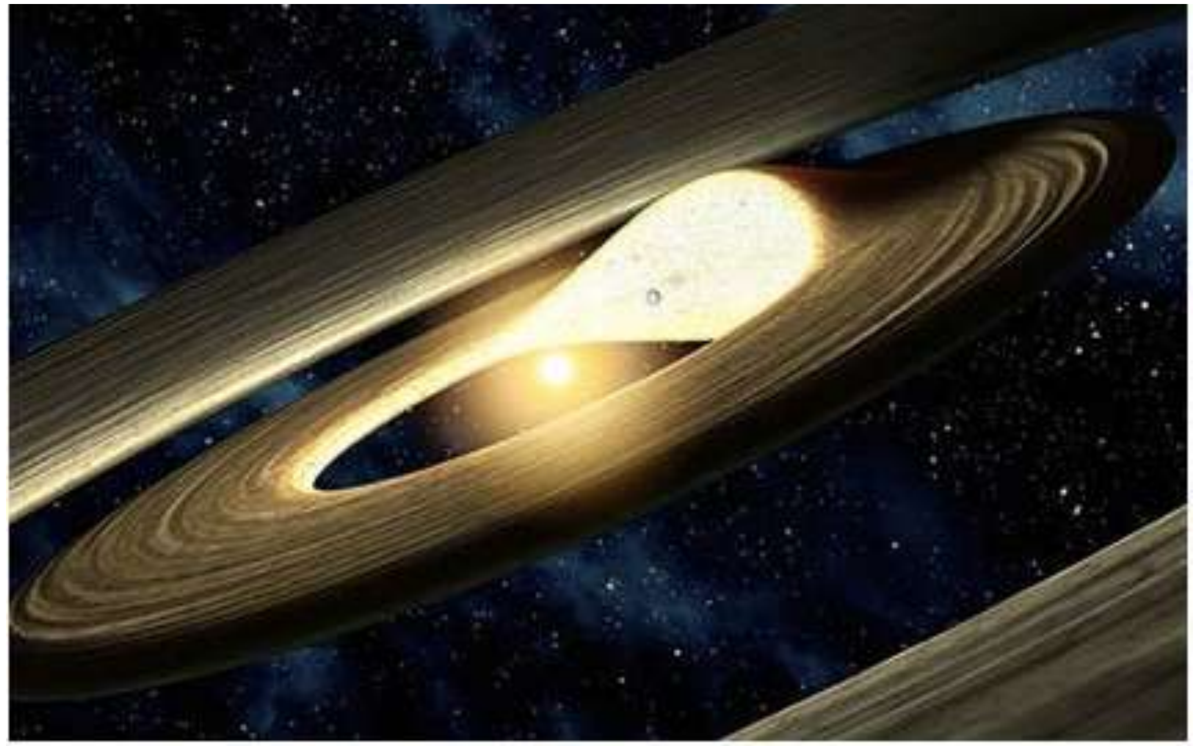


Morales-Calderón et al. (2011)

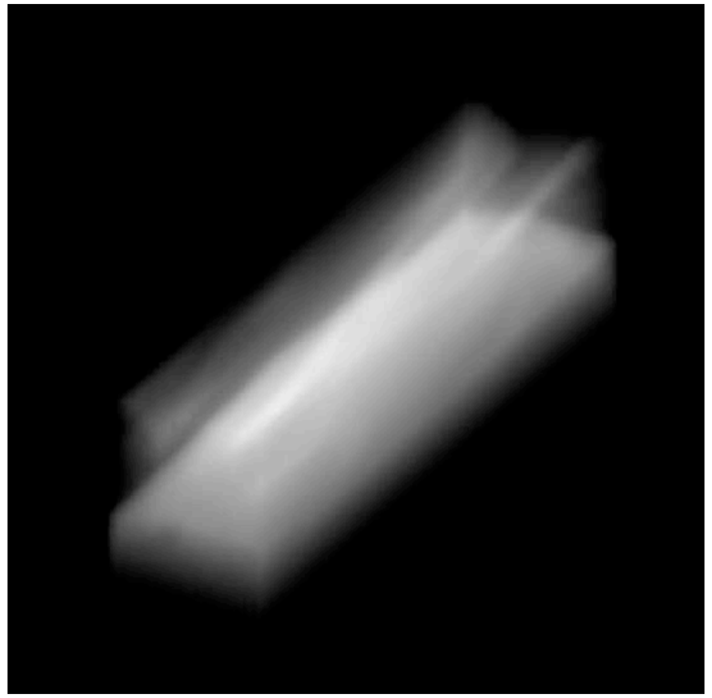
Observable disk changes in the infrared



Light echo around a protostar (Muzerolle et al. Nature, 2013, Balog et al. 2014)



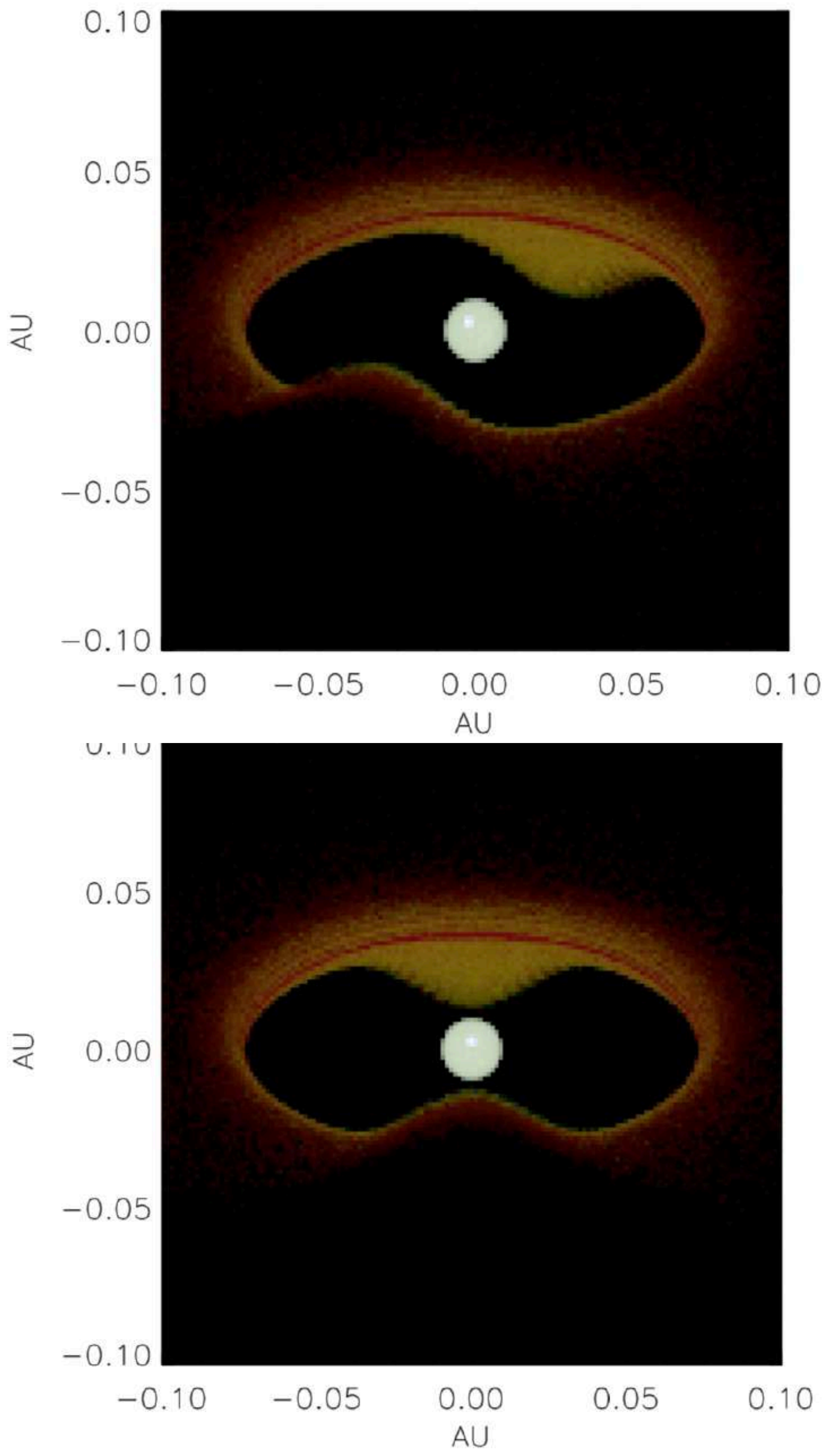
Warp in the disk of LRLL 31 (Muzerolle et al. 2009)



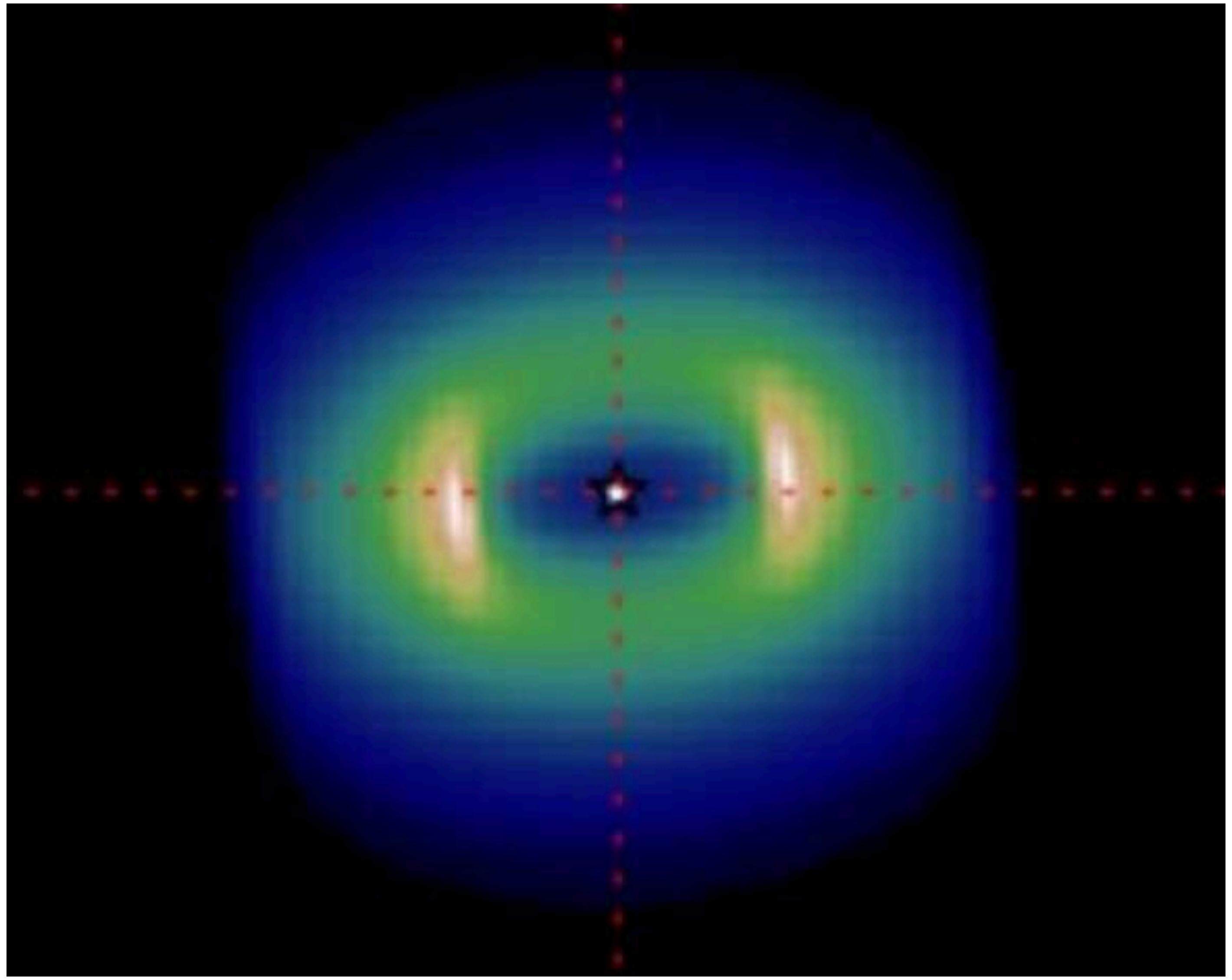
Dust clouds lifted up by turbulent motions the disk atmosphere (Turner et al. 2010)

Dimmings caused by orbiting dust structures (RZ Psc, credit: ISRO)

Radiative transfer models of light variations

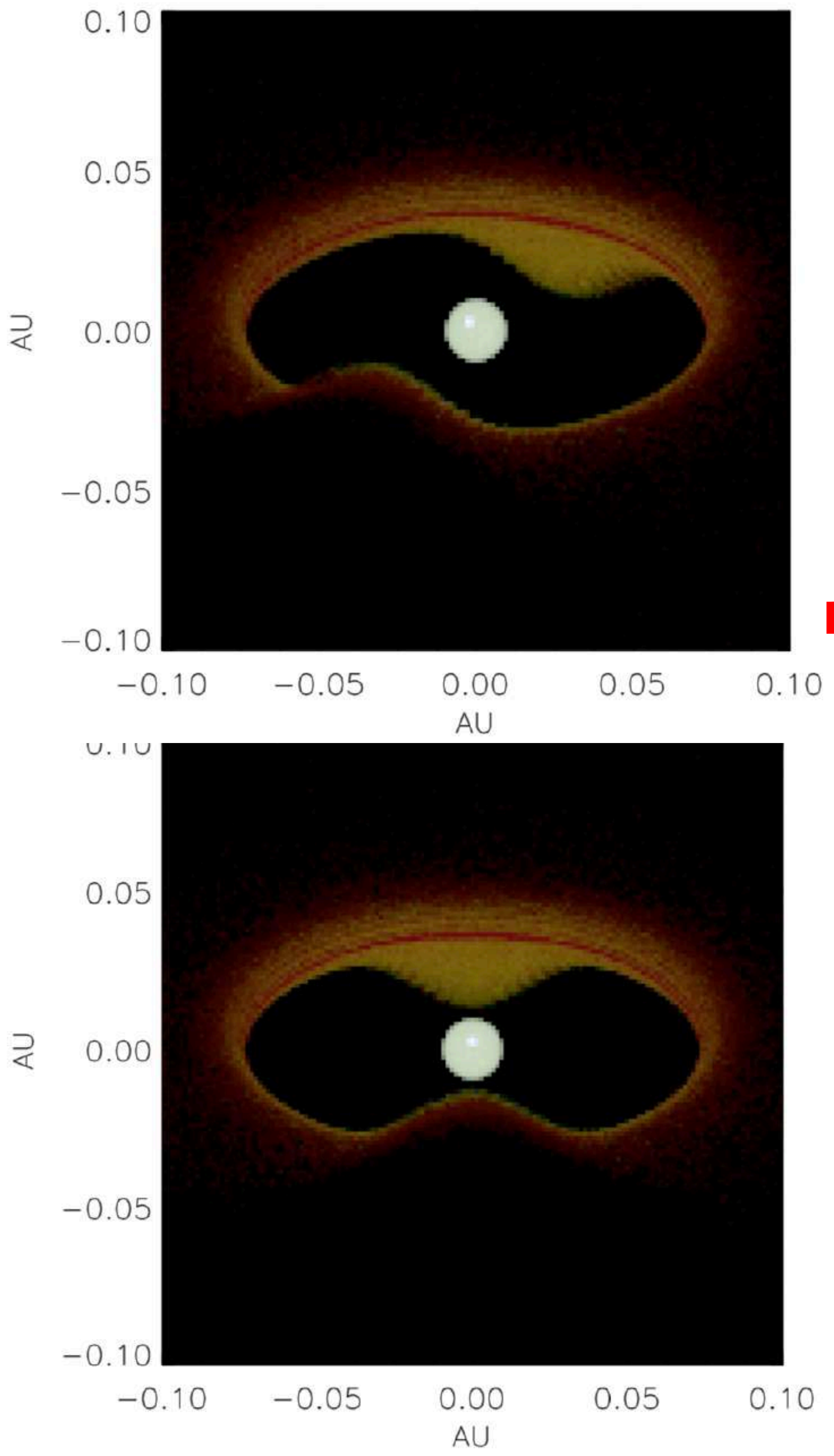


Kesseli et al. (2016)



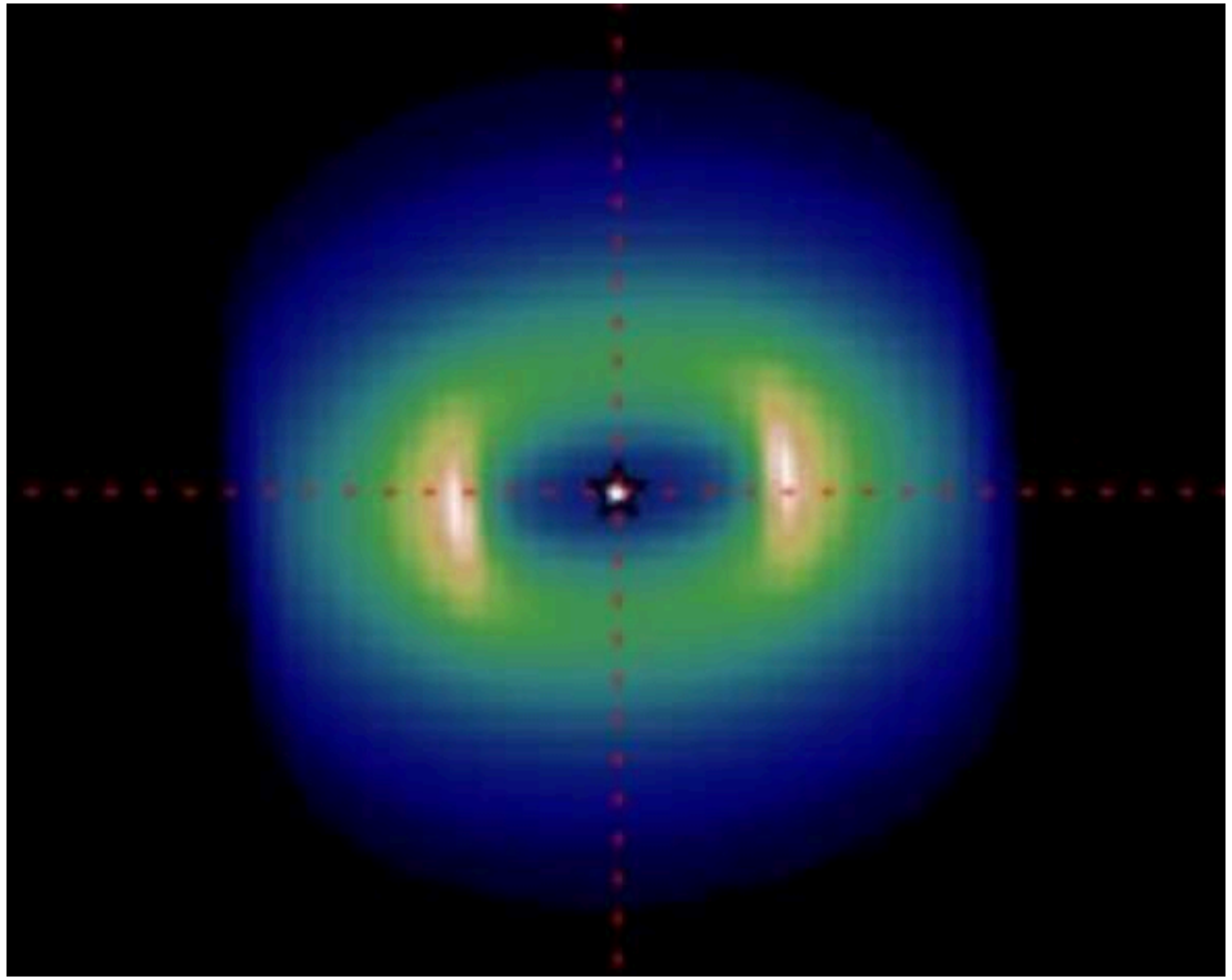
Schwore et al. (2017)

Radiative transfer models of light variations



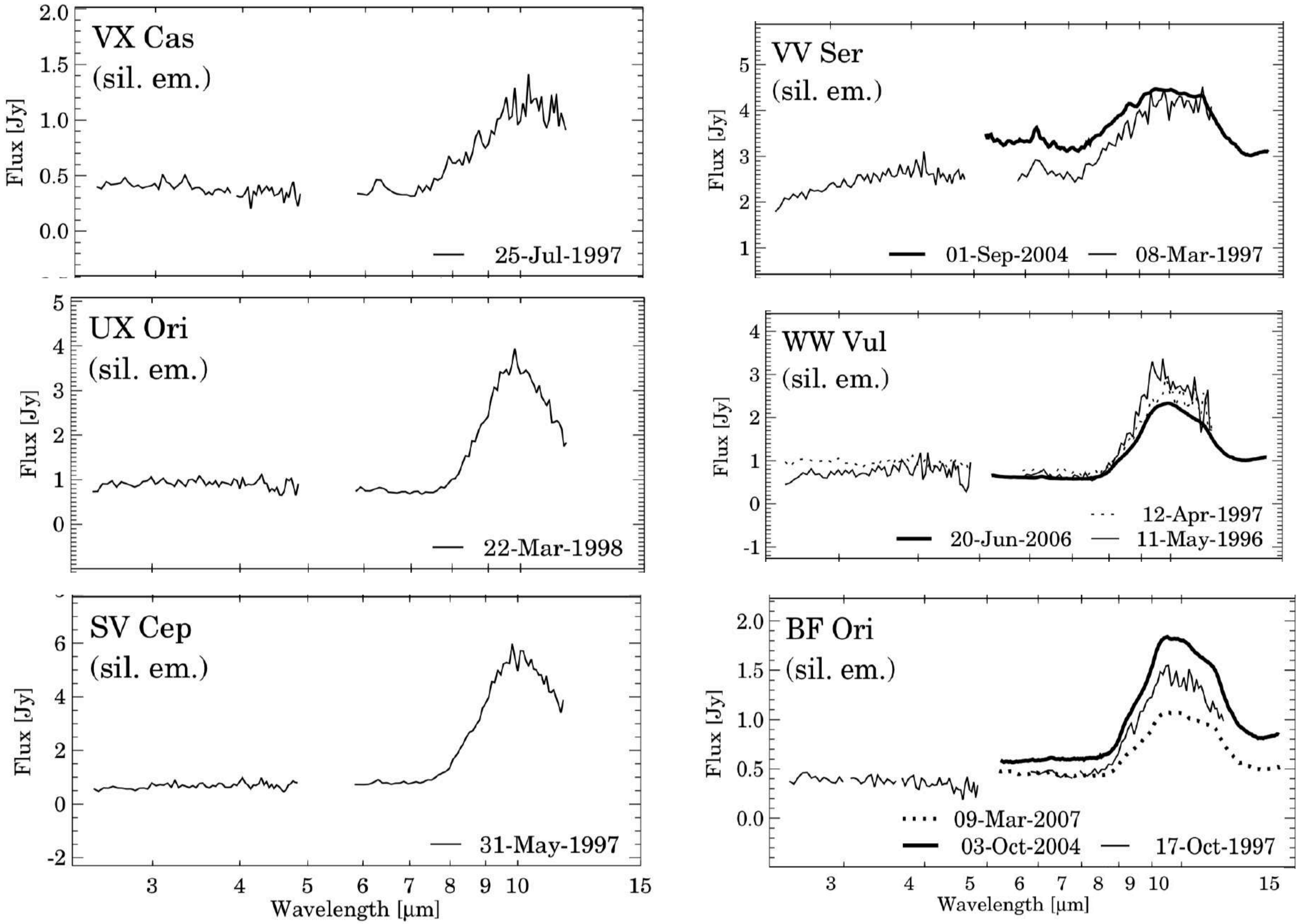
1au

Kesseli et al. (2016)



Schwore et al. (2017)

Konkoly mid-infrared spectral variability atlas (Kóspál+ 2012)



Mid-infrared spectroscopy from ISO and Spitzer

Seven well-known Uxors in the sample

Strong silicate feature variability detected

The Konkolyvar program (2009-10)

A 14-day quasi-simultaneous monitoring program with daily cadence, in 2009 Sep-Nov.

UX Ori type targets: BF Ori, RR Tau, SV Cep, VV Ser, UX Ori, V517 Cyg, VX Cas, WW Vul

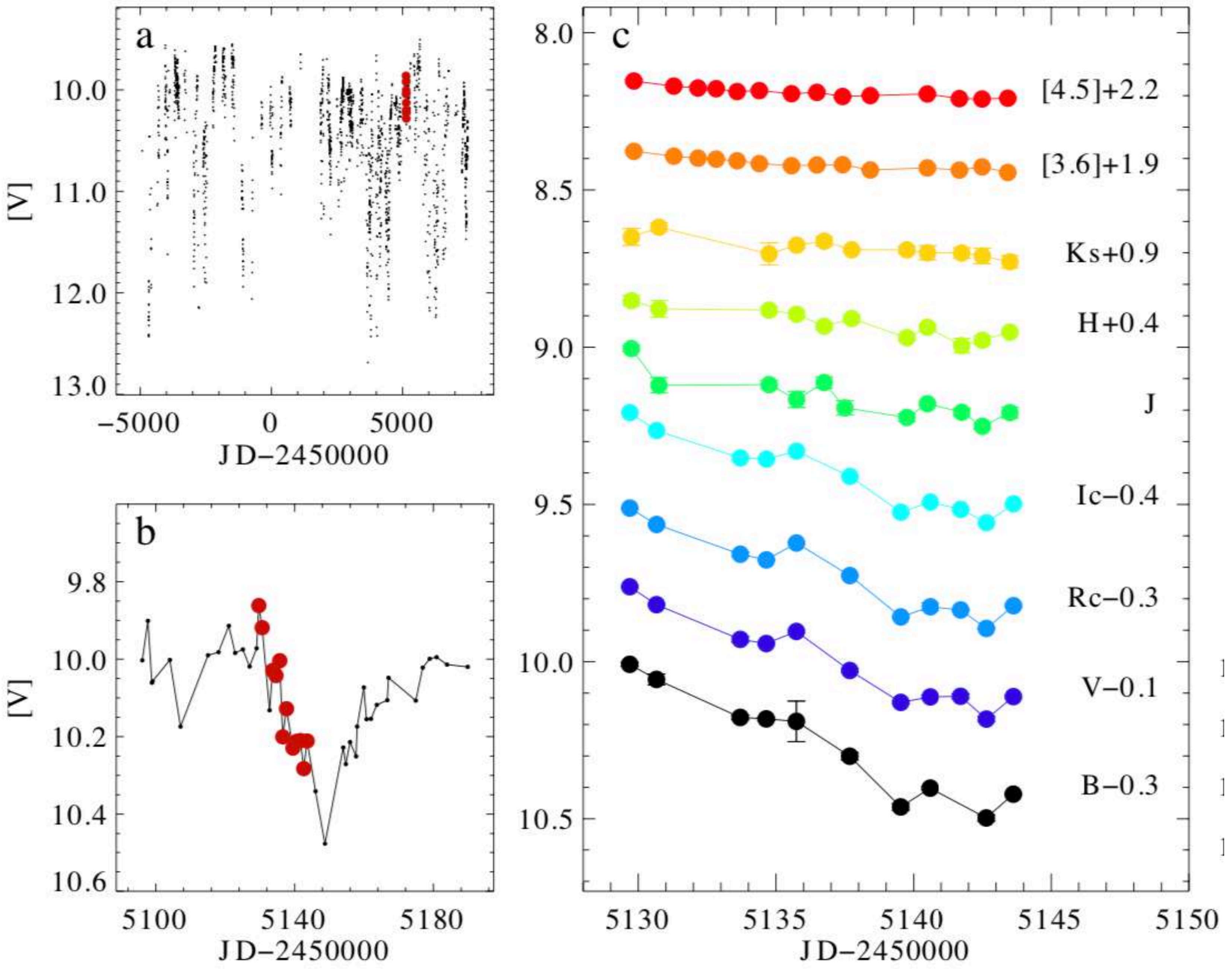
Observations:

- Optical BVRI: Piszkéstető Obs. (Hungary), Teide Obs. (Spain);
- Near-IR JHK: Teide Obs. (Spain);
- Mid-IR 3.6 and 4.5 μm: Spitzer Space Telescope (NASA)

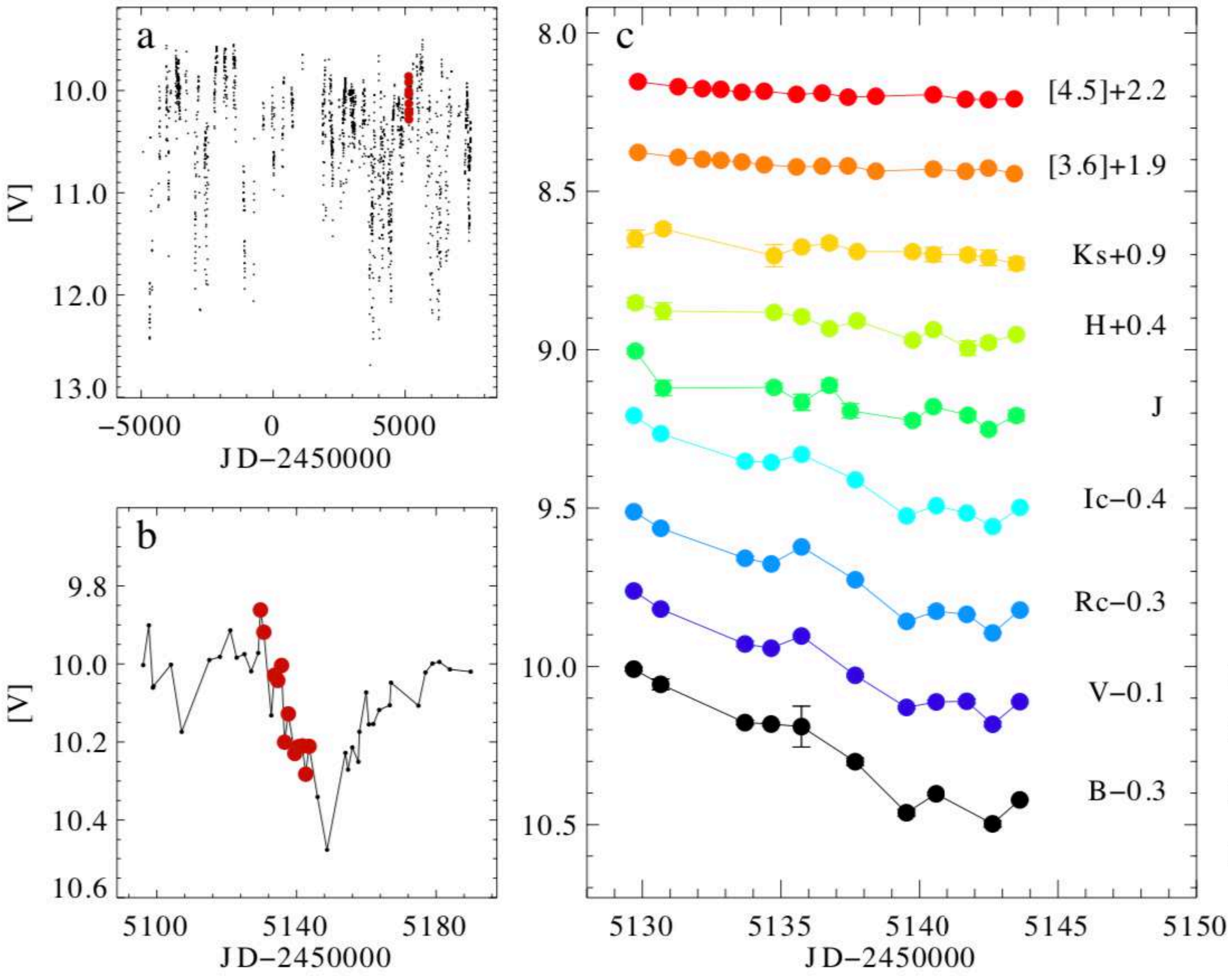
Schmidt telescope, Konkoly Observatory

Spitzer Space Telescope (Credit: NASA)

BF Ori

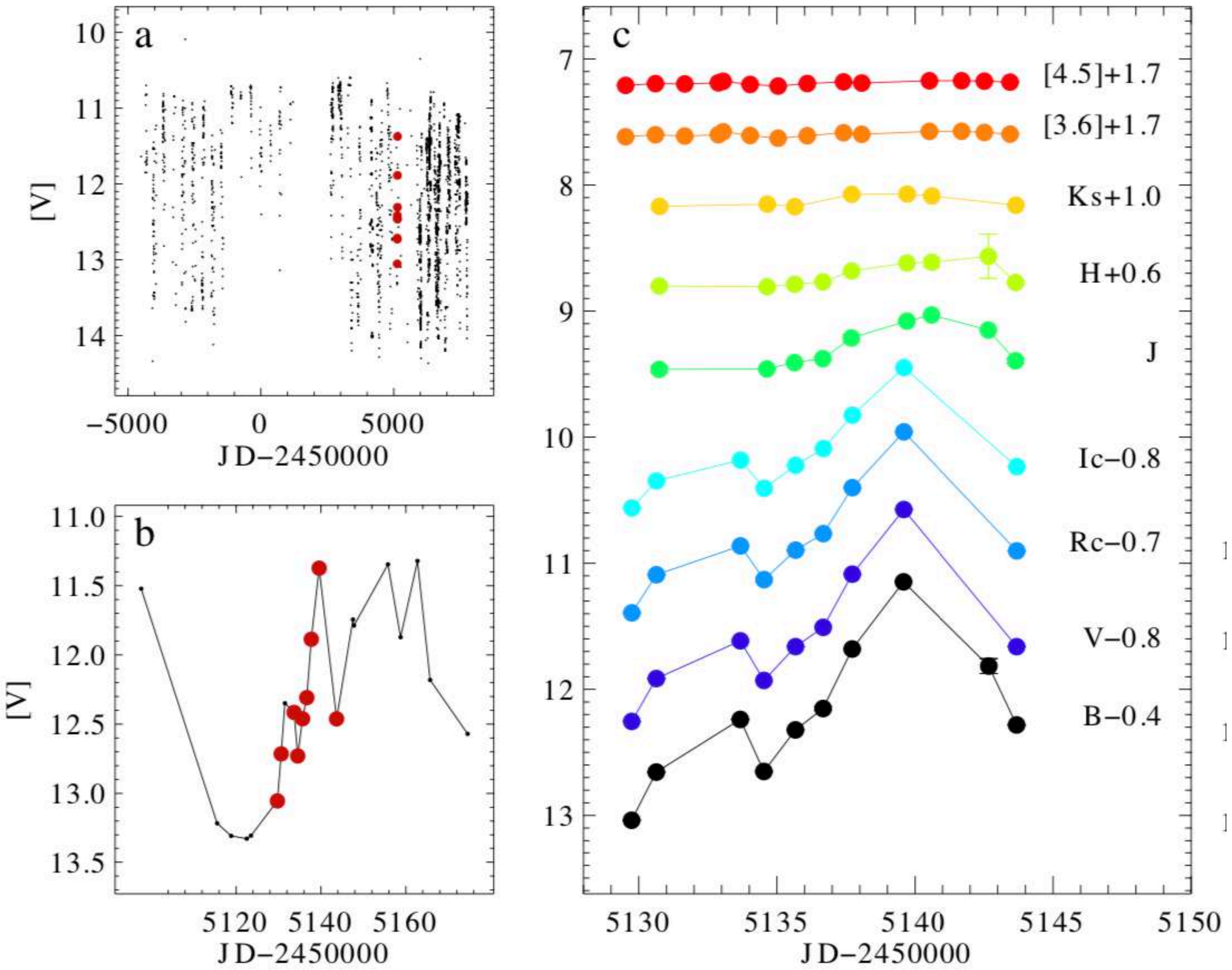


BF Ori



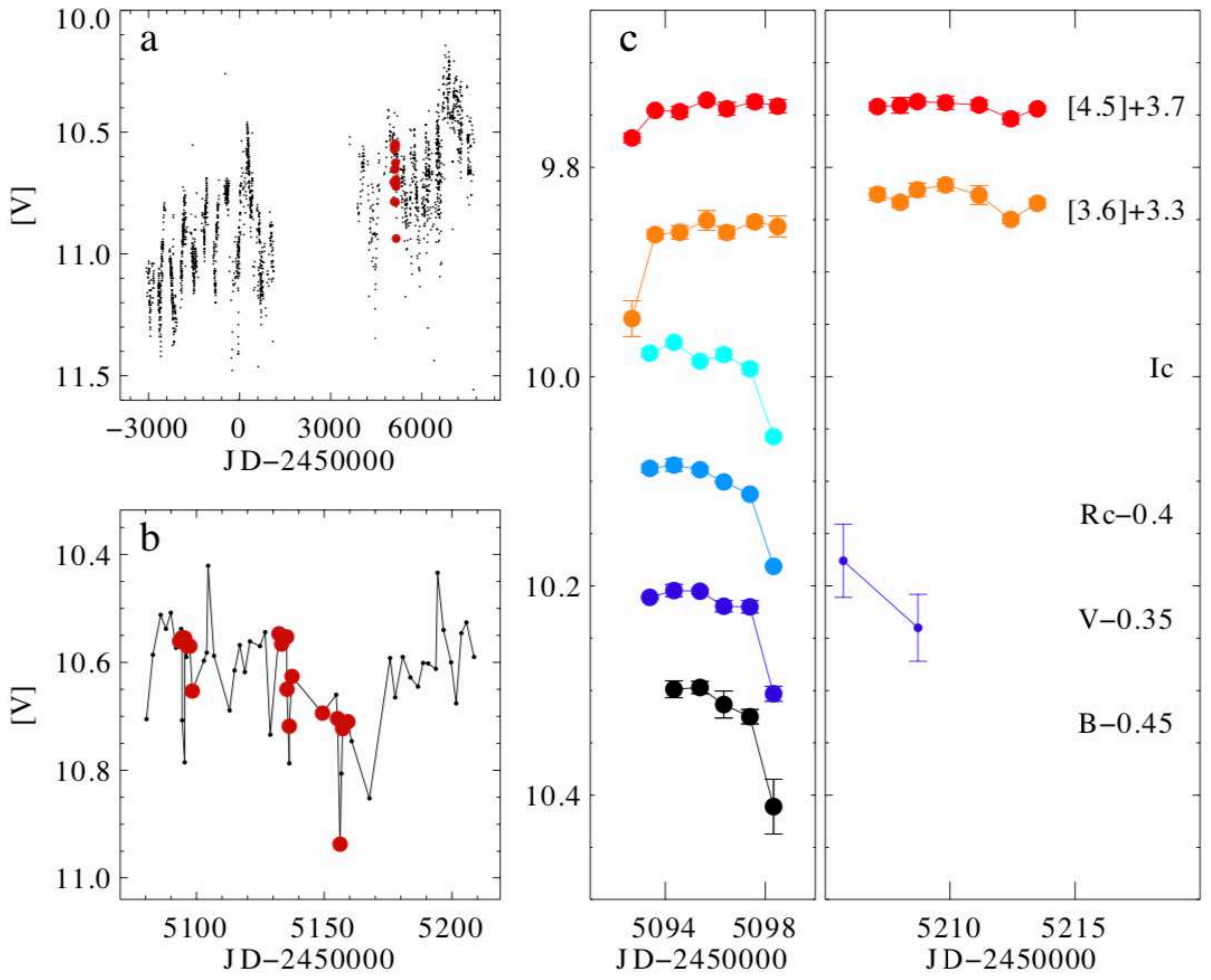
a
b
c
[V]
JD−2450000
[4.5]+2.2
[3.6]+1.9
Ks+0.9
H+0.4
J
Ic−0.4
Rc−0.3
V−0.1
B−0.3

RR Tau

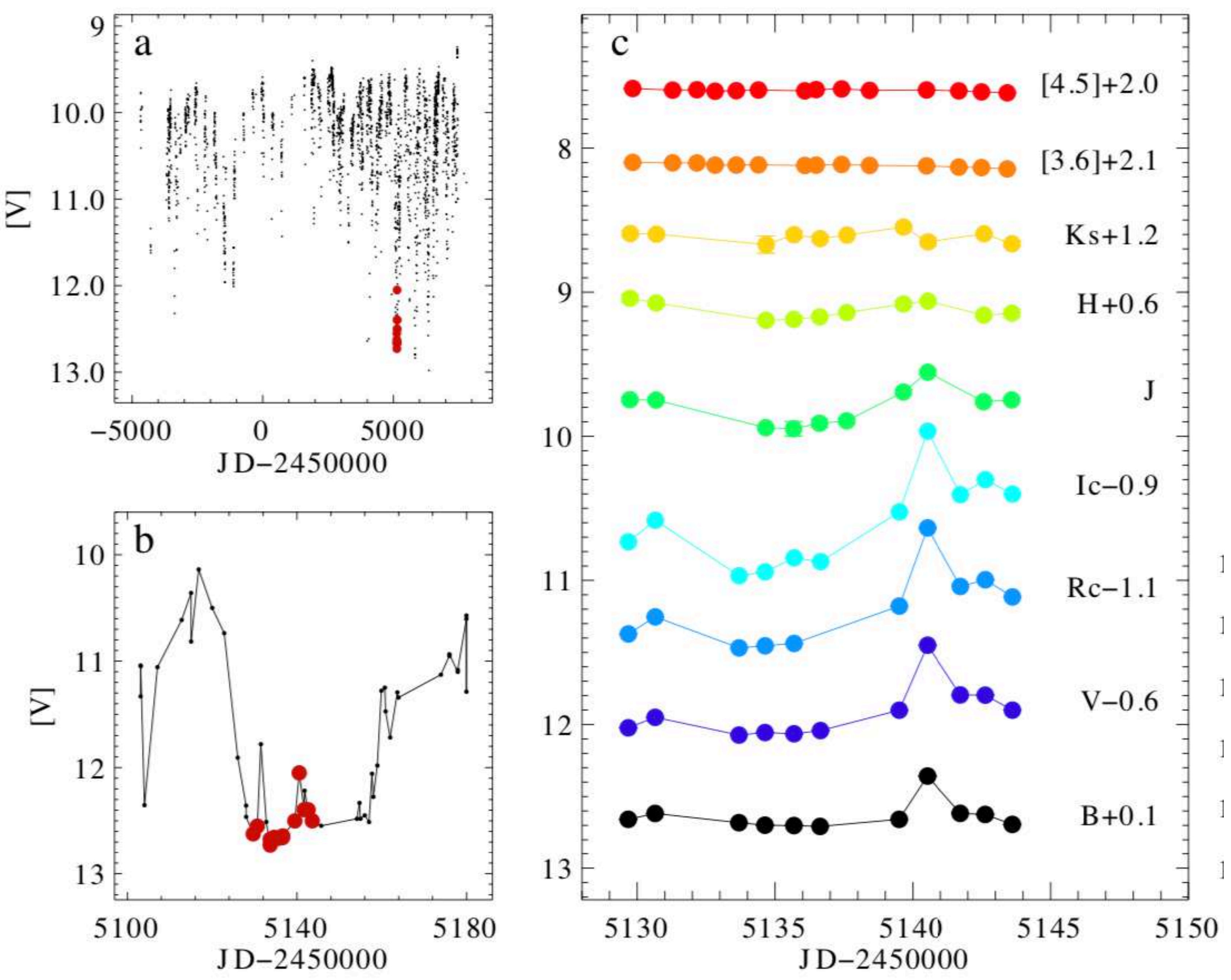


a
b
c
[V]
JD−2450000
[4.5]+1.7
[3.6]+1.7
Ks+1.0
H+0.6
J
Ic−0.8
Rc−0.7
V−0.8
B−0.4

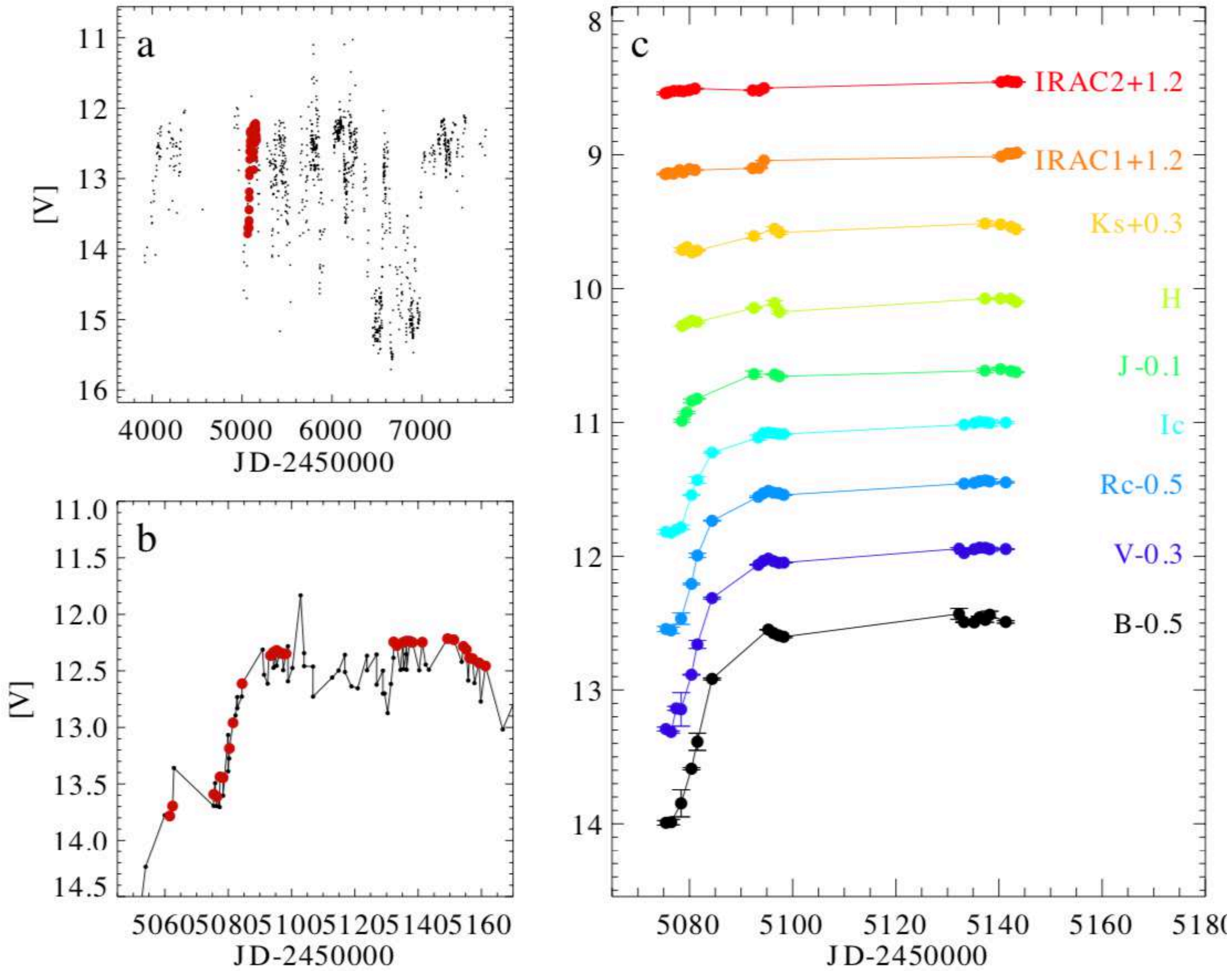
SV Cep


a
b
c
[V]
JD−2450000
[4.5]+3.7
[3.6]+3.3
Ic
Rc−0.4
V−0.35
B−0.45

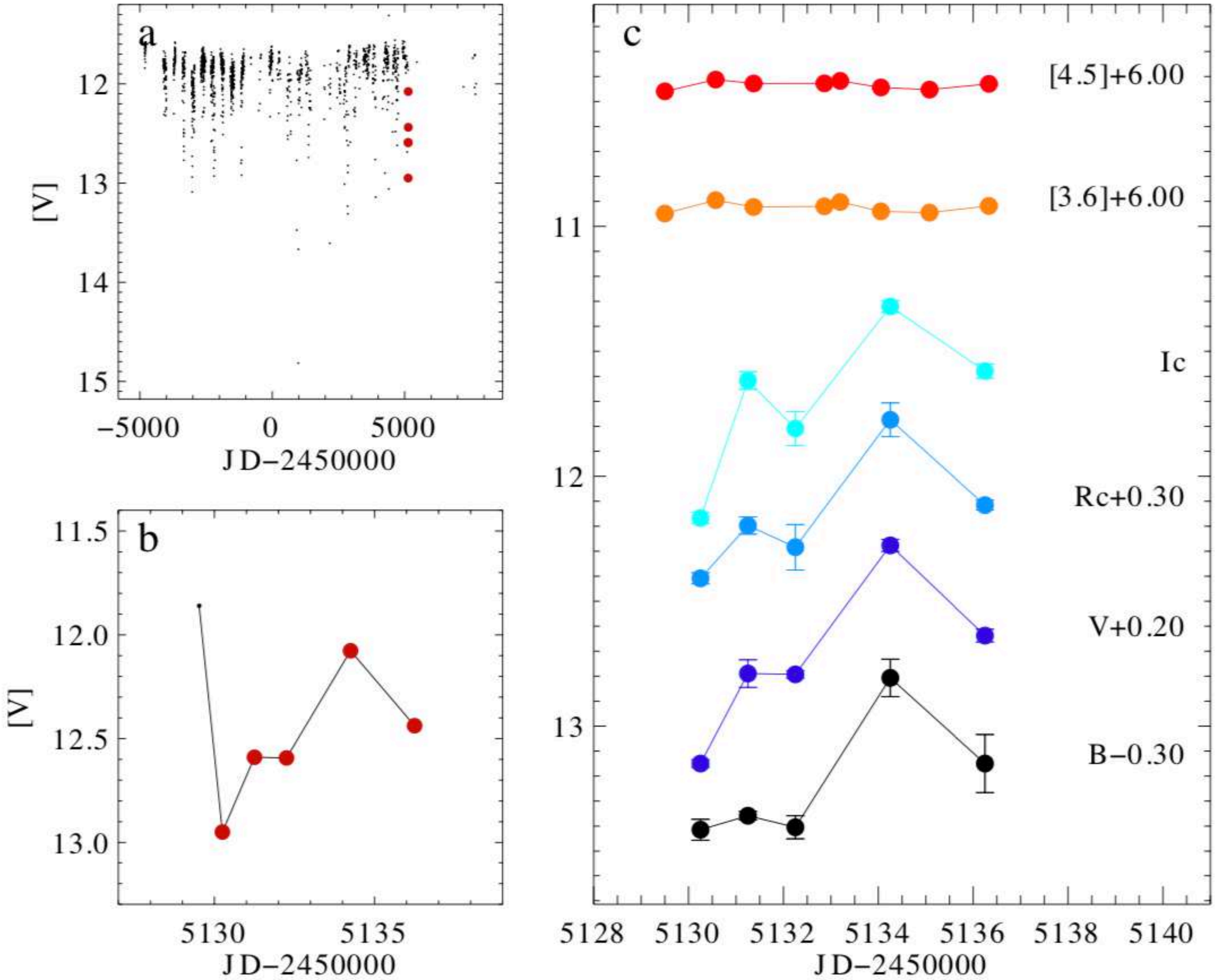
UX Ori


a
b
c
[V]
JD−2450000
[4.5]+2.0
[3.6]+2.1
Ks+1.2
H+0.6
J
Ic−0.9
Rc−1.1
V−0.6
B+0.1

V517 Cyg

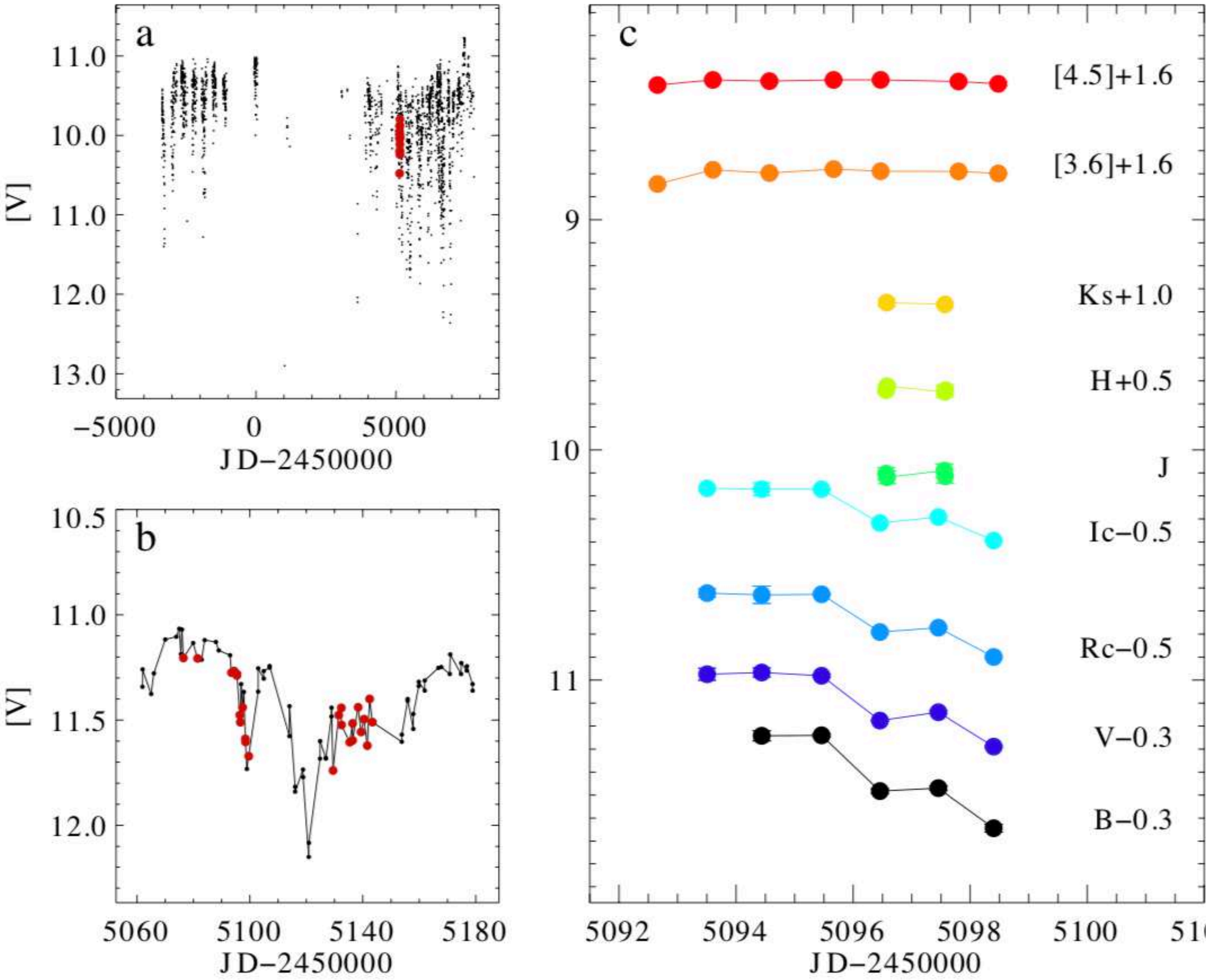


VV Ser

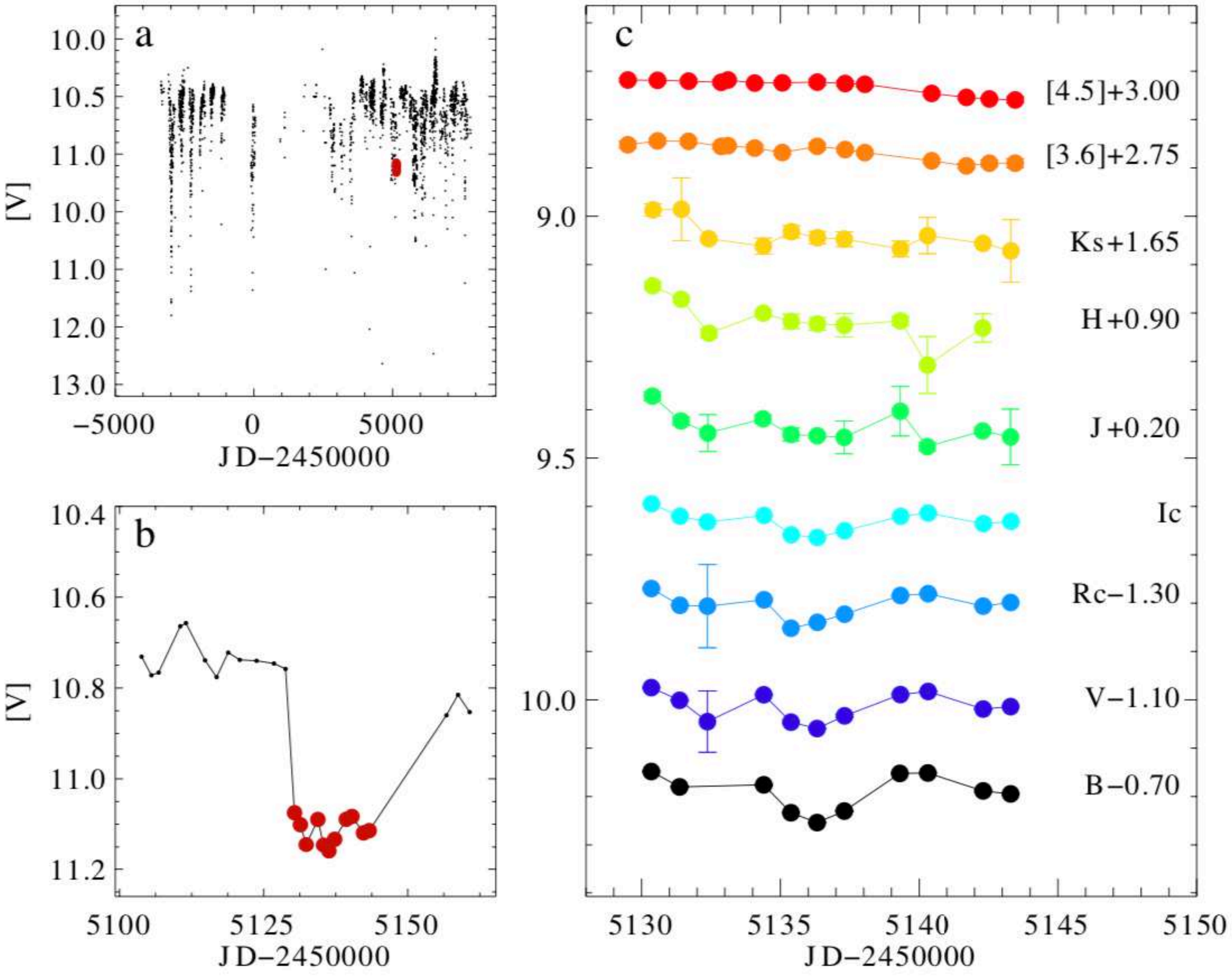


VX Cas

WW Vul

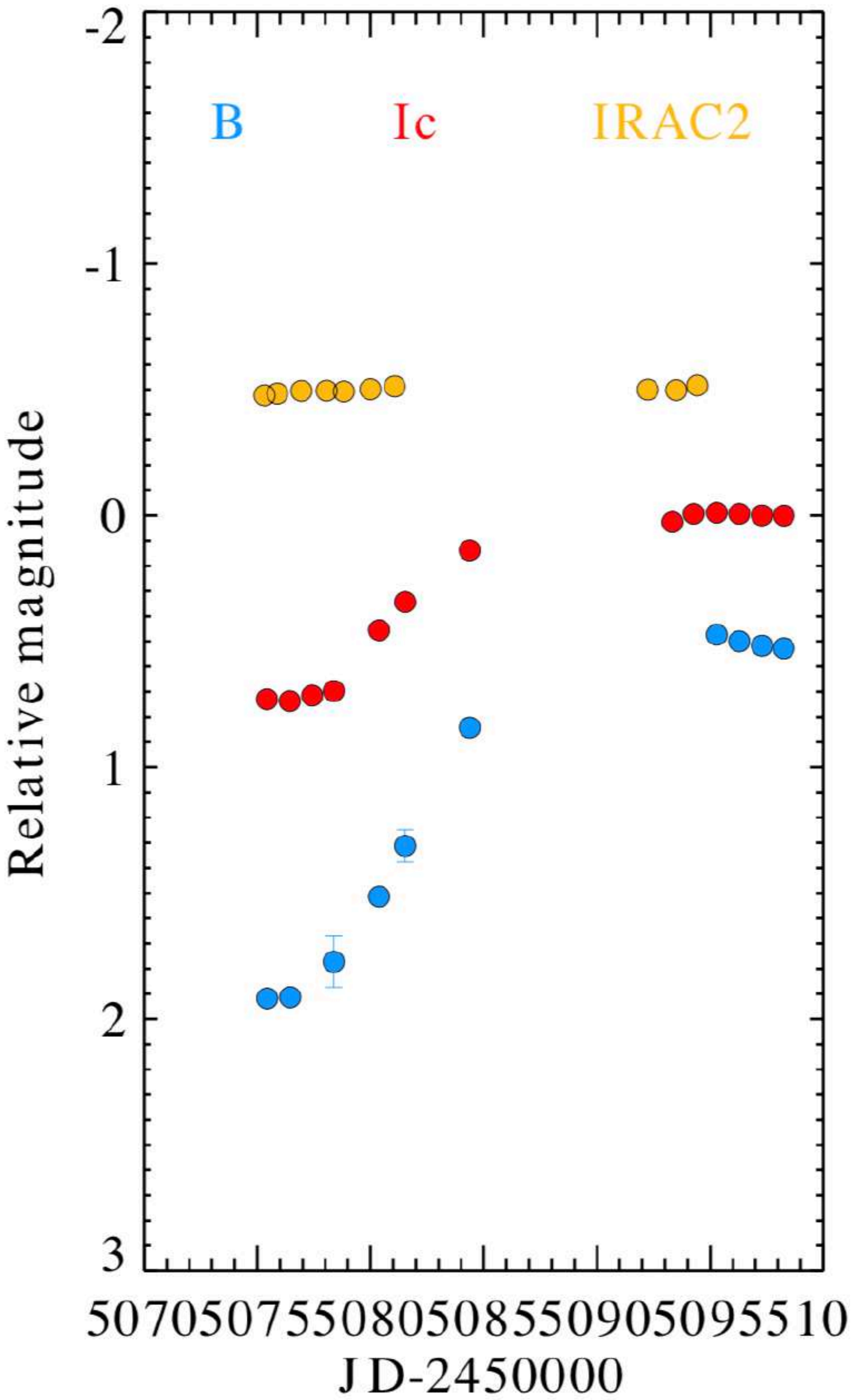


a
[V]
JD−2450000
b
c
[4.5]+1.6
[3.6]+1.6
Ks+1.0
H+0.5
J
Ic−0.5
Rc−0.5
V−0.3
B−0.3

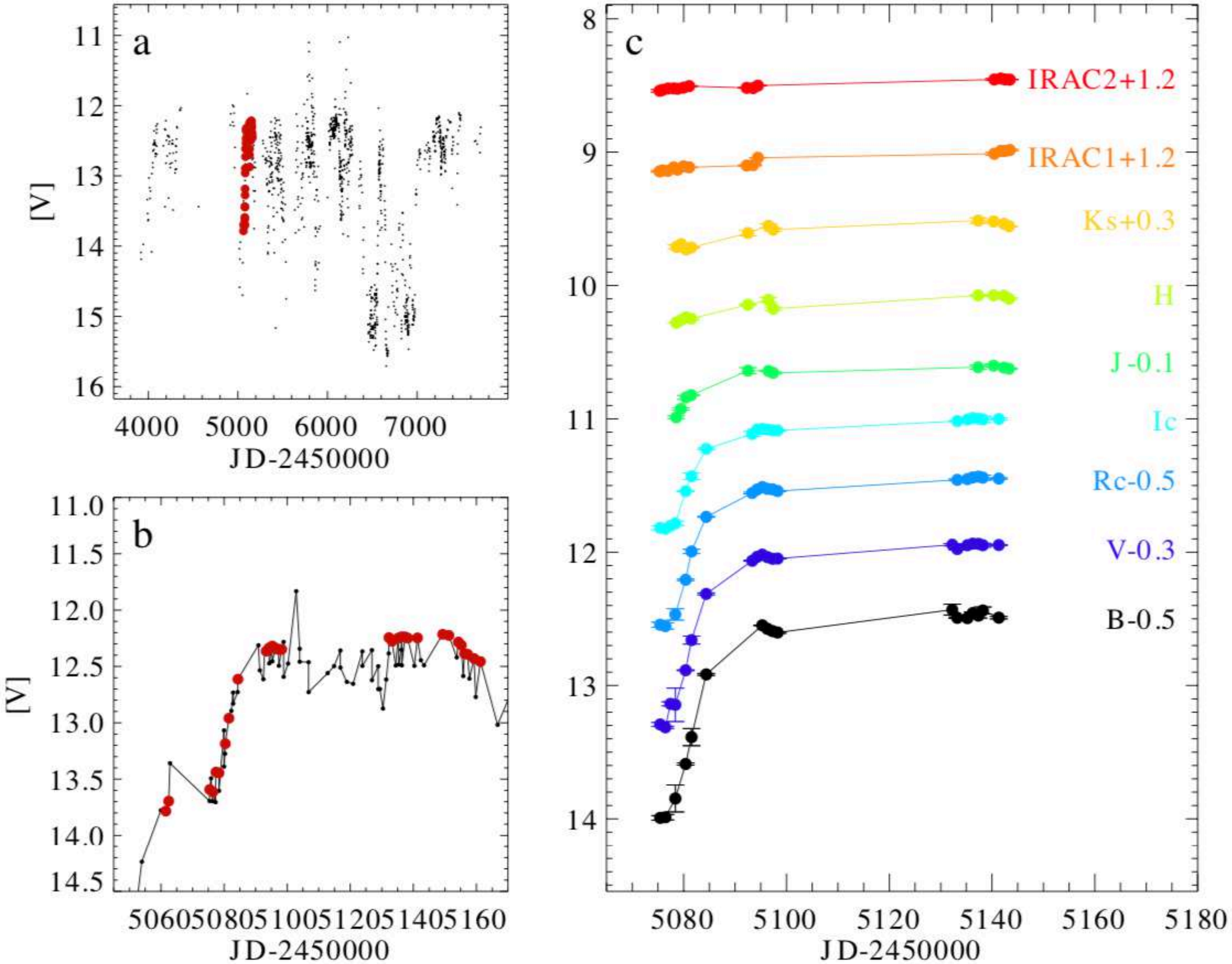


a
[V]
JD−2450000
b
c
[4.5]+3.00
[3.6]+2.75
Ks+1.65
H+0.90
J+0.20
Ic
Rc−1.30
V−1.10
B−0.70

V517 Cyg

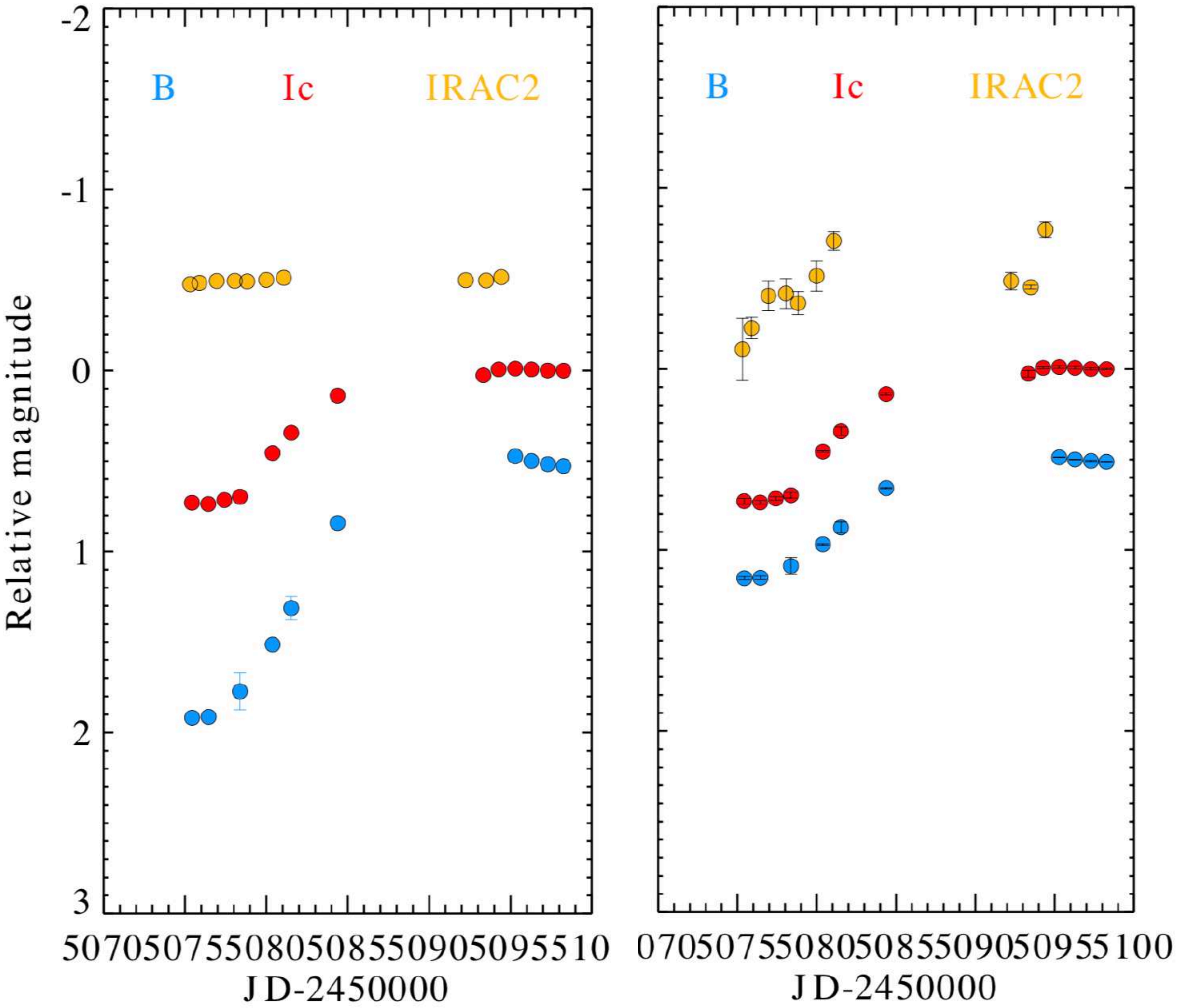


-2
-1
0
1
2
3
B
Ic
IRAC2
Relative magnitude
507050755080508550905095510
JD-2450000

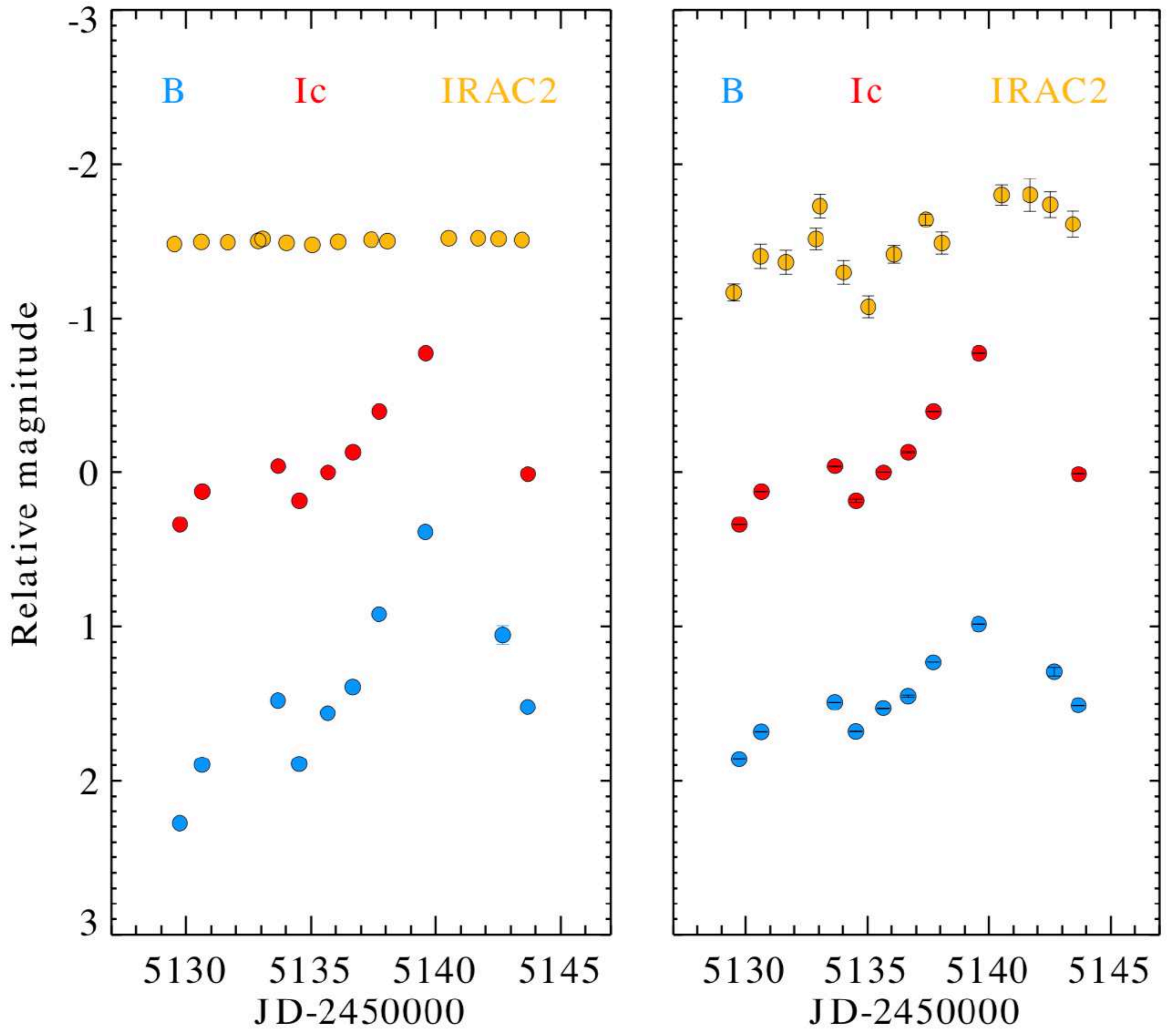


a
[V]
11
12
13
14
15
16
4000
5000
6000
7000
JD-2450000
b
[V]
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
506050805100512051405160
JD-2450000
c
8
9
10
11
12
13
14
IRAC2+1.2
IRAC1+1.2
Ks+0.3
H
J-0.1
Ic
Rc-0.5
V-0.3
B-0.5
5080
5100
5120
5140
5160
5180
JD-2450000

V517 Cyg

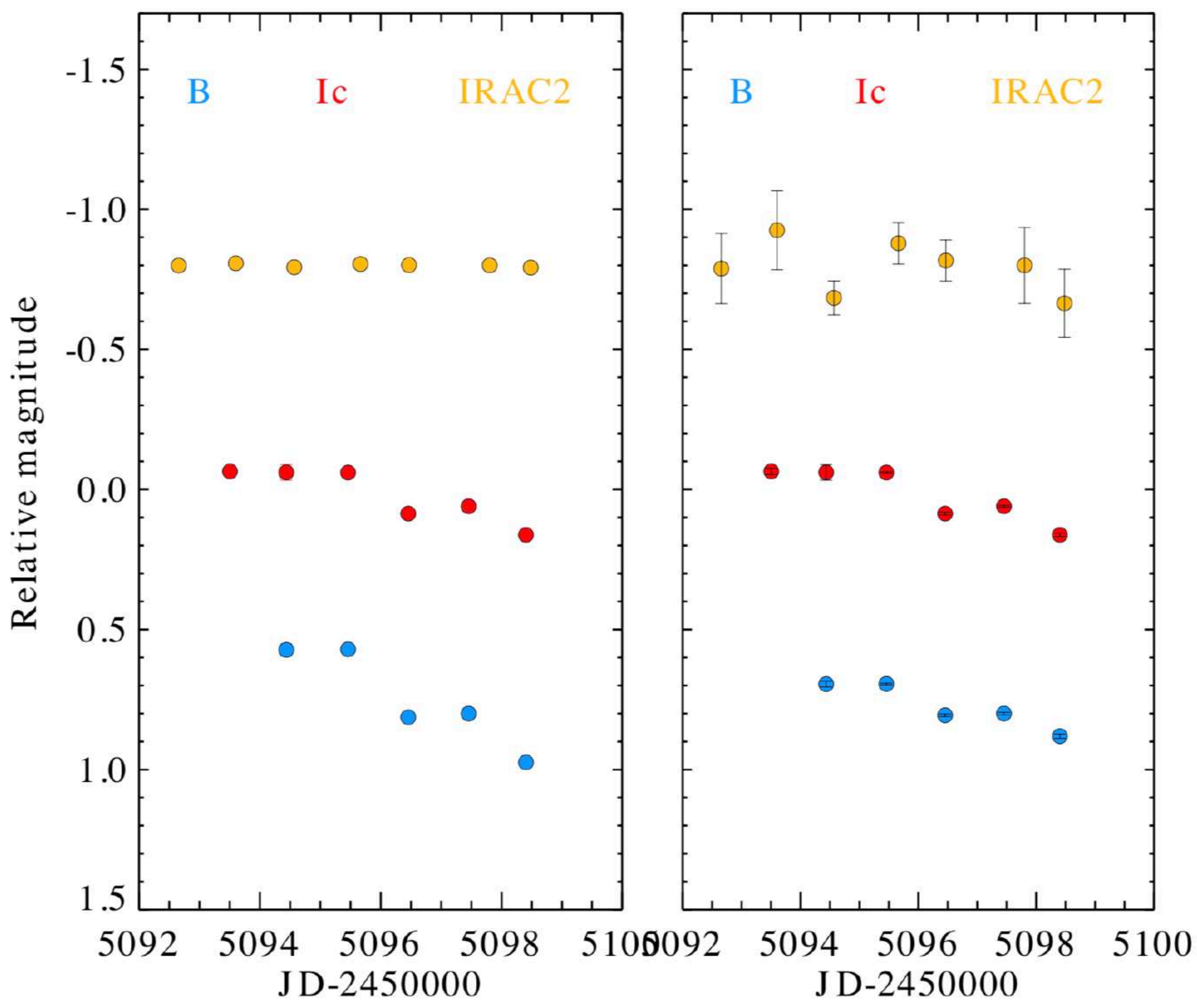

B
Ic
IRAC2
B
Ic
IRAC2
Relative magnitude
-2
-1
0
1
2
3
JD-2450000
JD-2450000

RR Tau



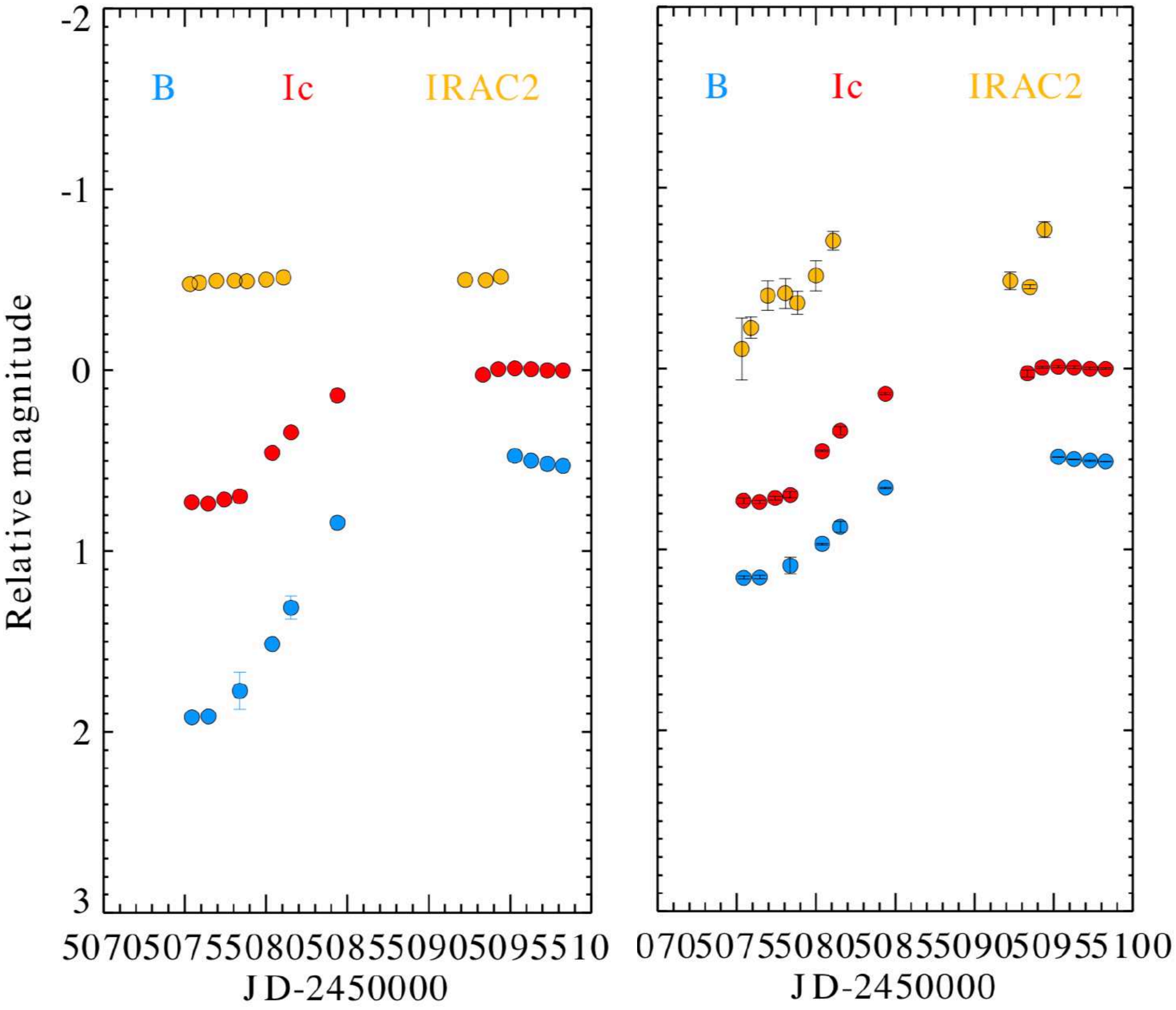
B
Ic
IRAC2
Relative magnitude
JD-2450000

VX Cas



B
Ic
IRAC2
Relative magnitude
JD-2450000

V517 Cyg



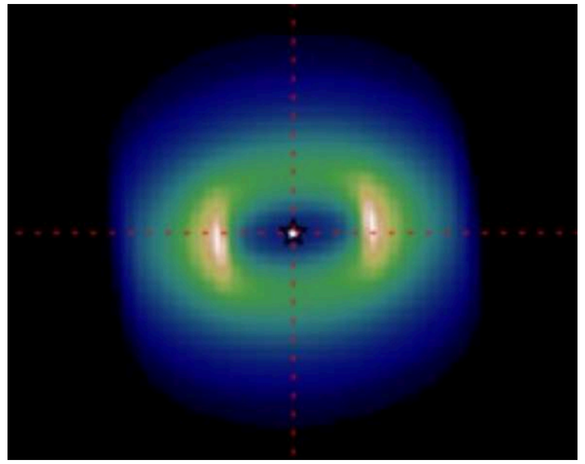
Scaling multiband light curves to match the amplitude of Ic, assuming pure extinction.

After scaling, B, Ic and 4.5 micron light curves run parallel

A homogeneous extinction of the star and the inner disk

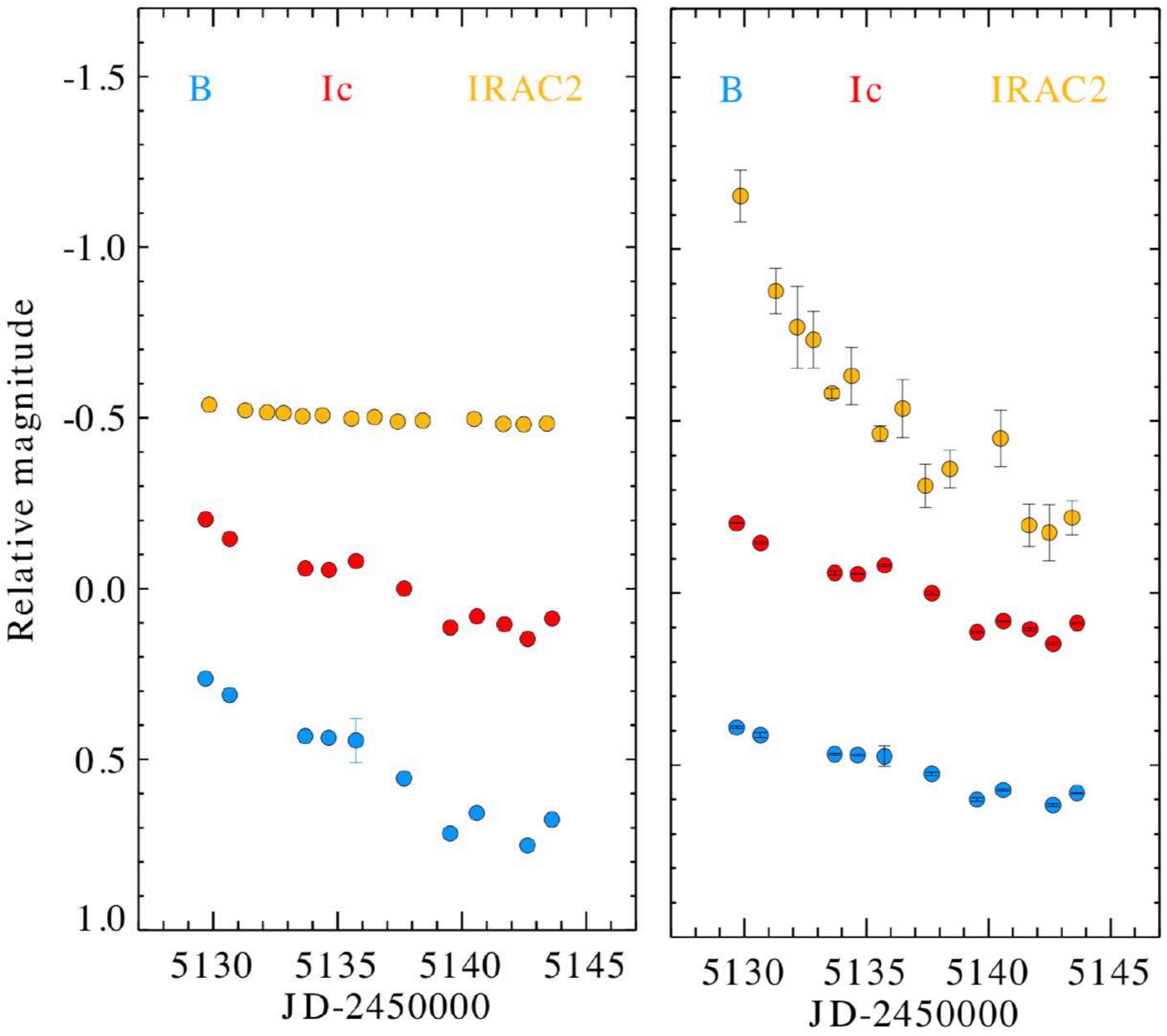
Two similar cases: RR Tau, VX Cas

3/5 fading events are pure extinction

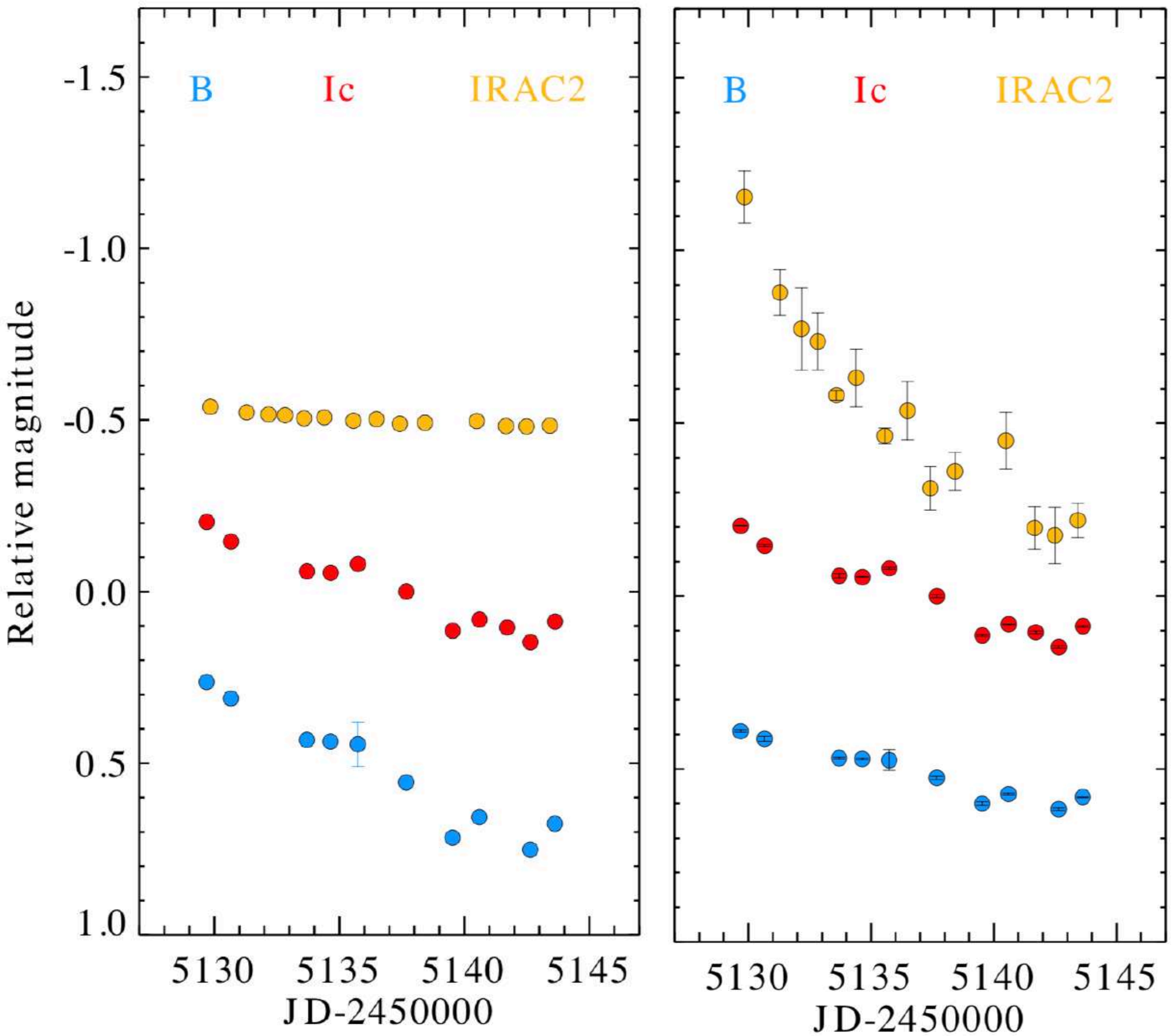


1 au

BF Ori

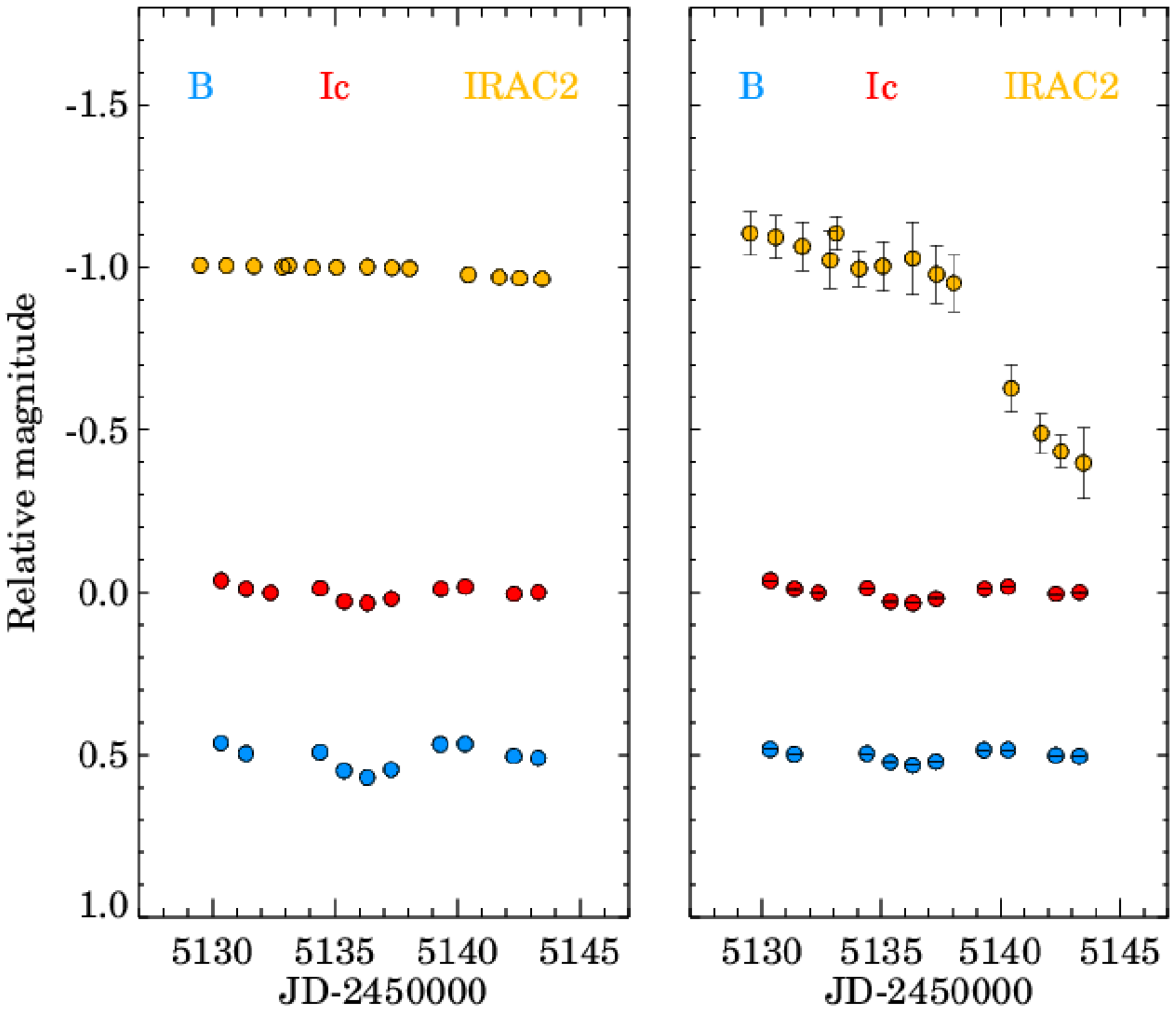

B
Ic
IRAC2
-1.5
-1.0
-0.5
0.0
0.5
1.0
Relative magnitude
5130
5135
5140
5145
JD-2450000
B
Ic
IRAC2
5130
5135
5140
5145
JD-2450000

BF Ori



B
Ic
IRAC2
Relative magnitude
-1.5
-1.0
-0.5
0.0
0.5
1.0
5130
5135
5140
5145
JD-2450000

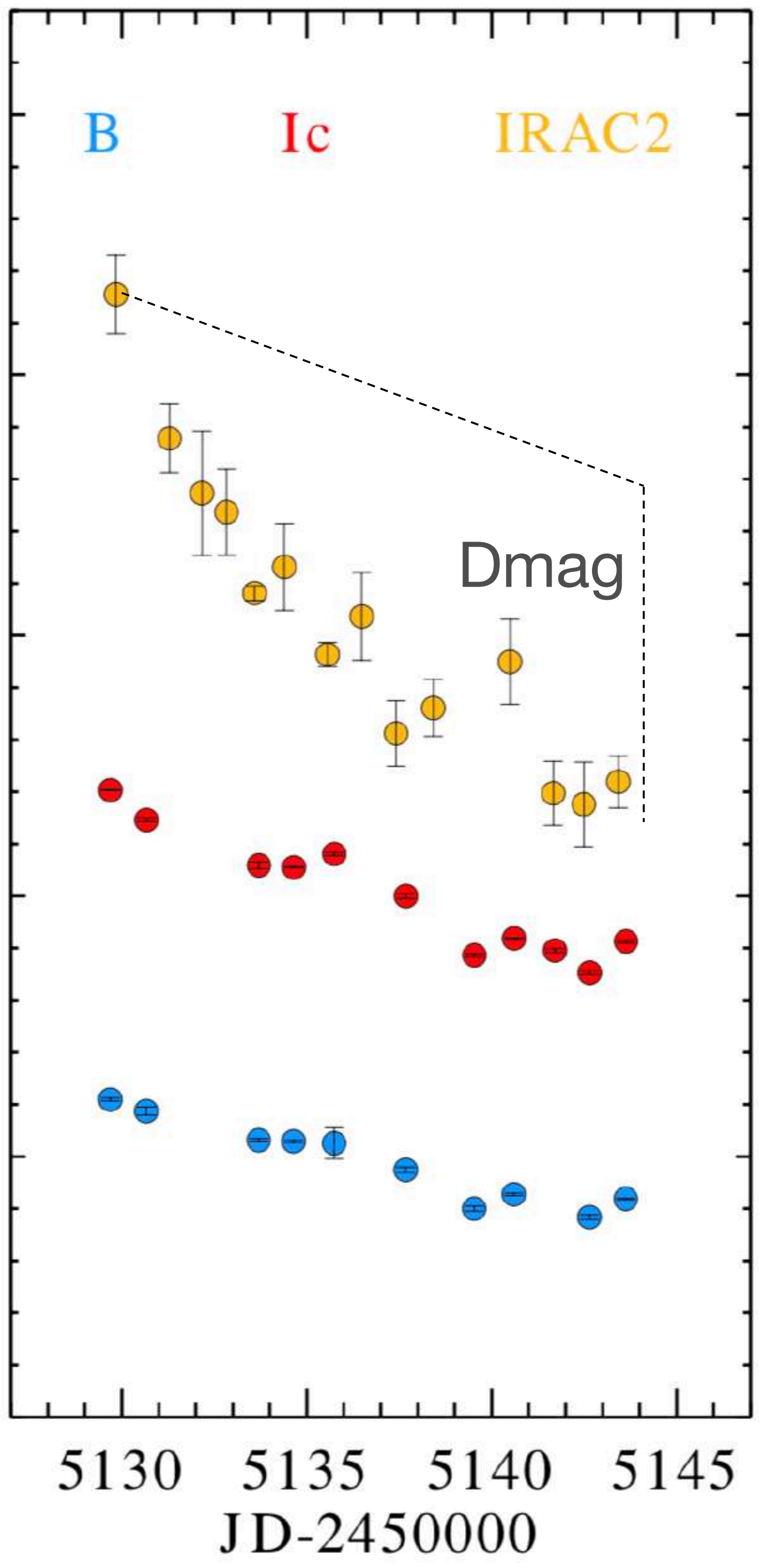
WW Vul



B
Ic
IRAC2
Relative magnitude
-1.5
-1.0
-0.5
0.0
0.5
1.0
5130
5135
5140
5145
JD-2450000

BF Ori

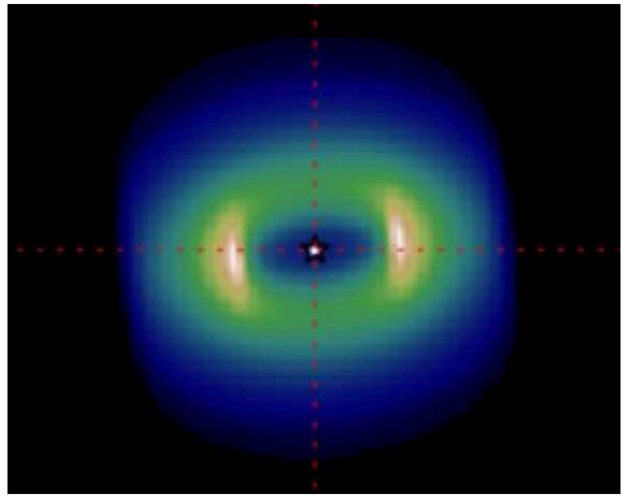
WW Vul

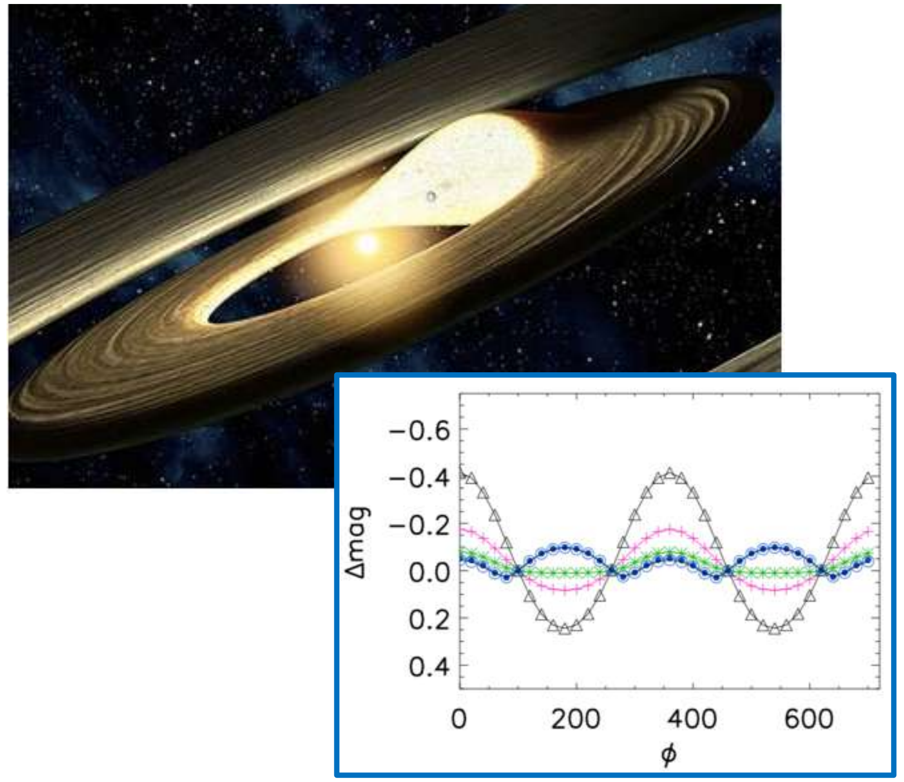


BF Ori: simultaneous optical-infrared fading: patchy obscuring clump, clear to the star?

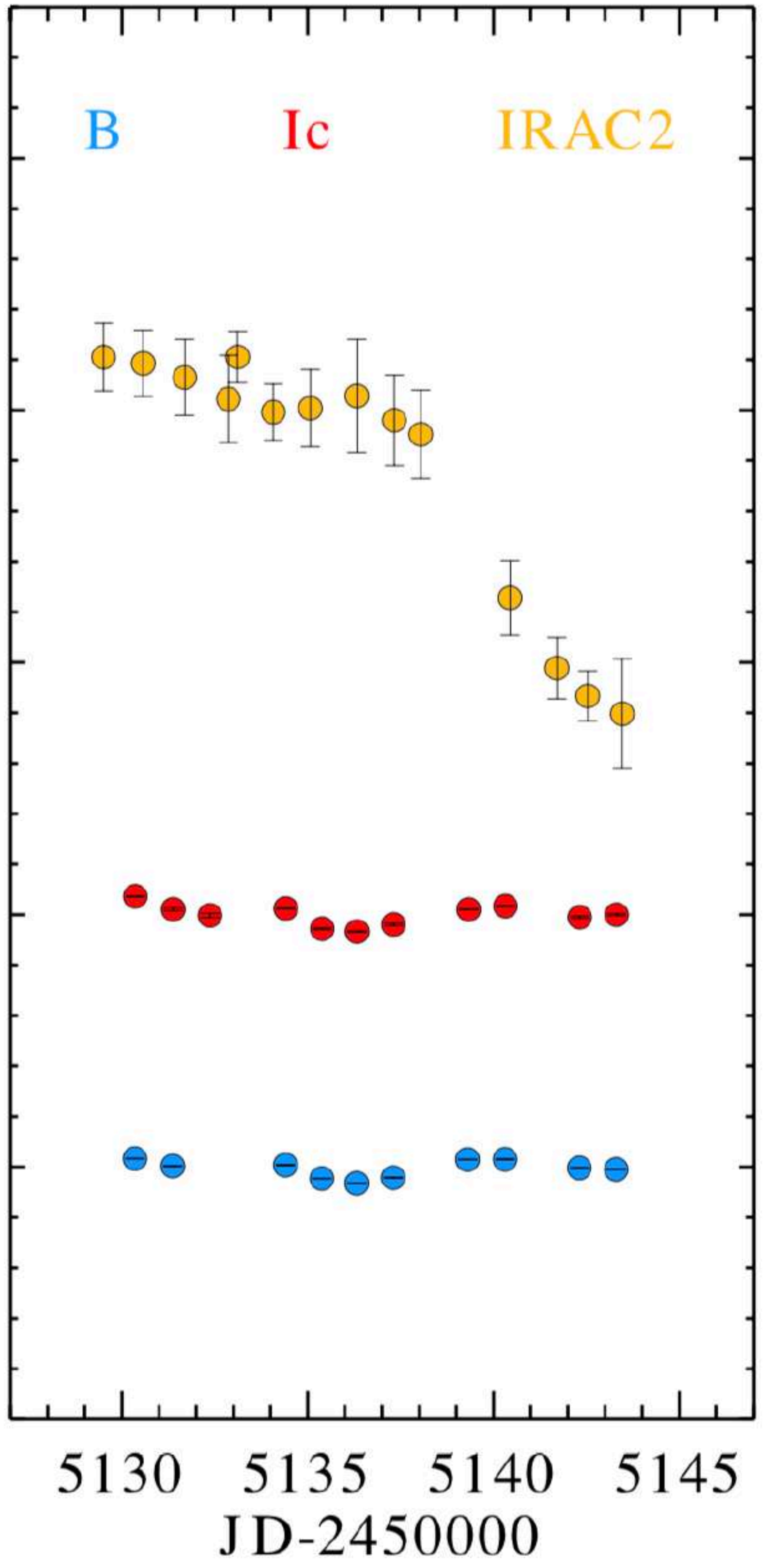
WW Vul: no eclipse in the optical: rotation of a bright disk area?

2/5 fadings are complex events

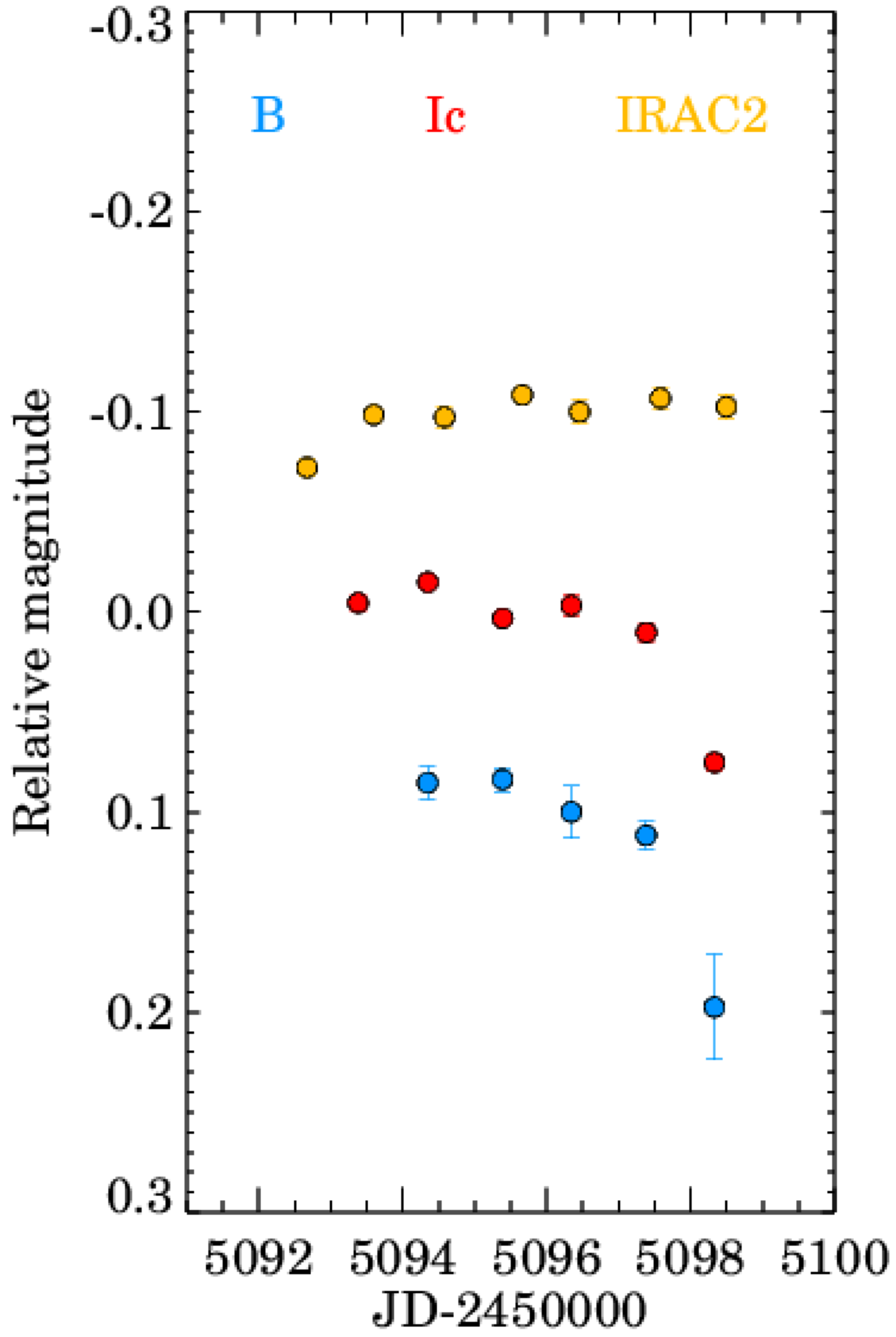




Kesseli et al. (2016)

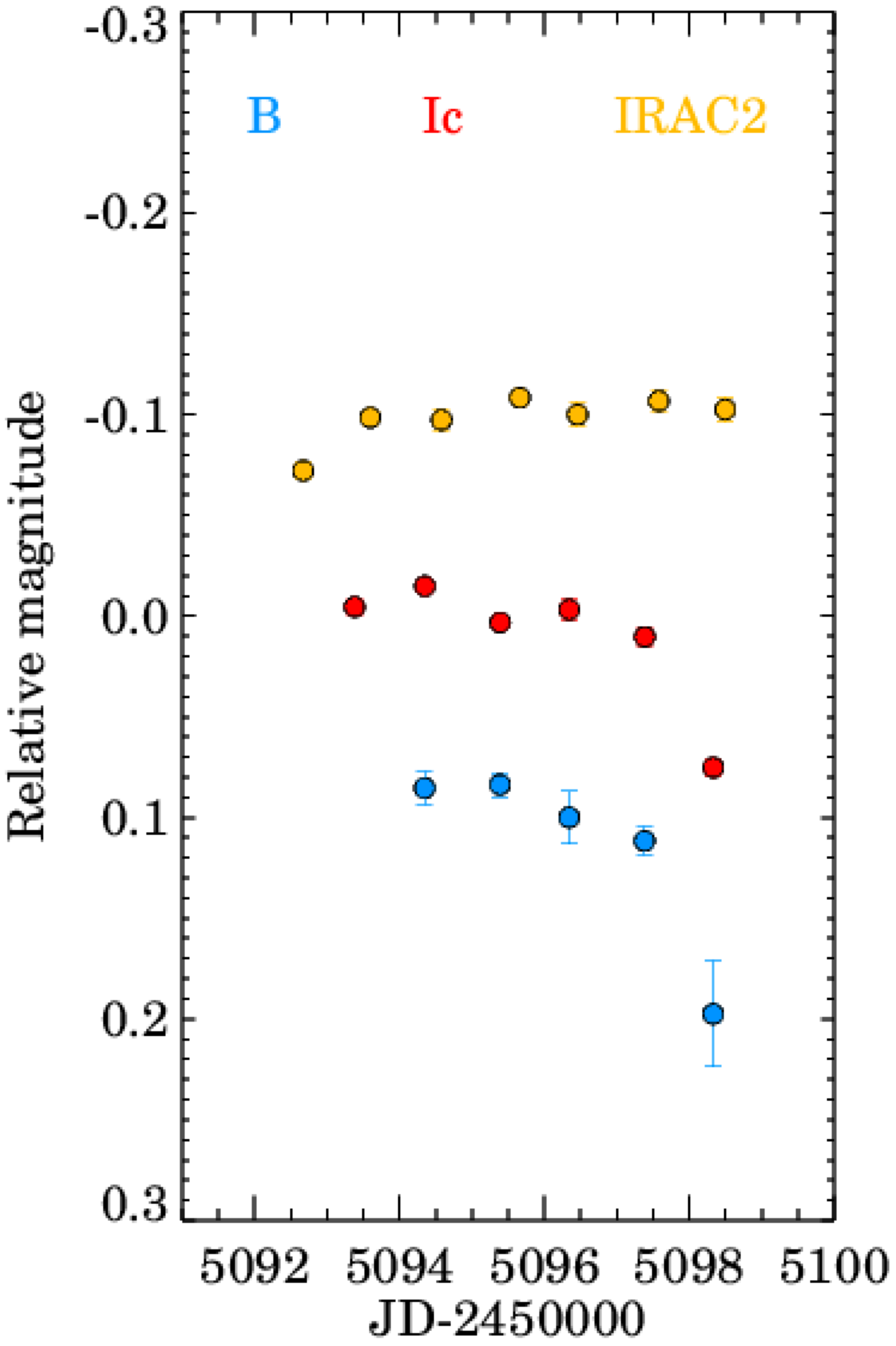


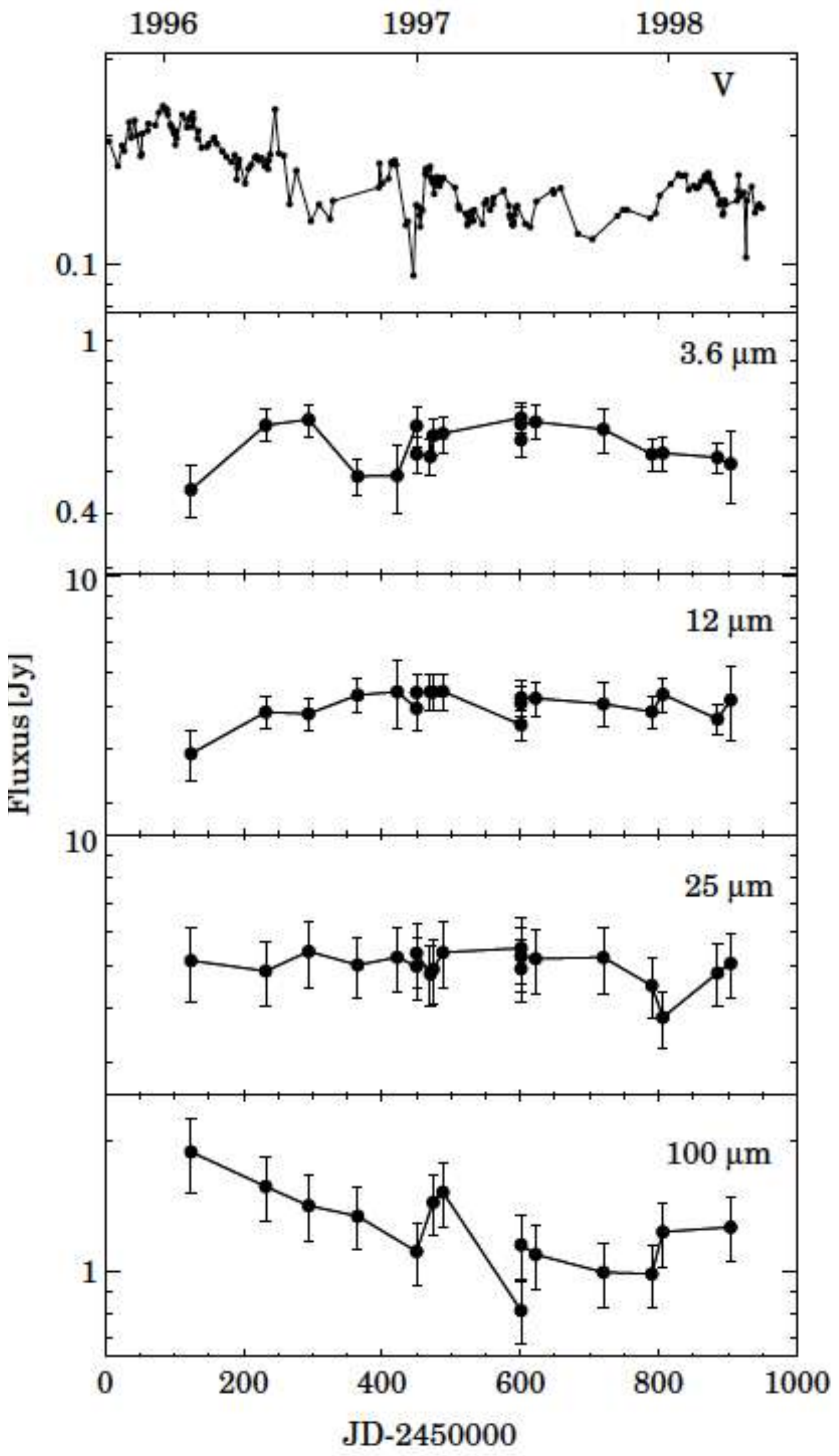
SV Cep



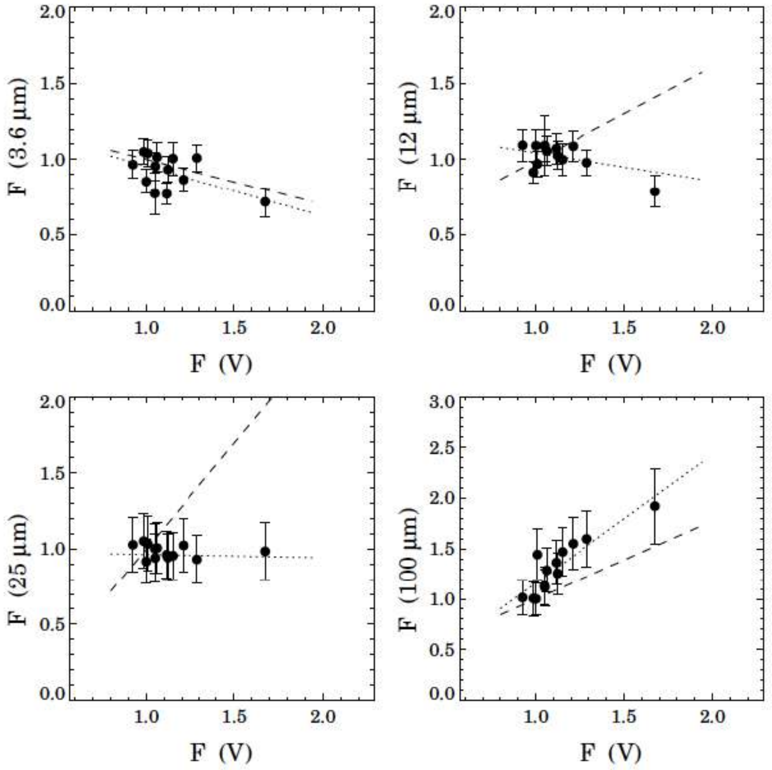
B
Ic
IRAC2
Relative magnitude
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
5092
5094
5096
5098
5100
JD-2450000

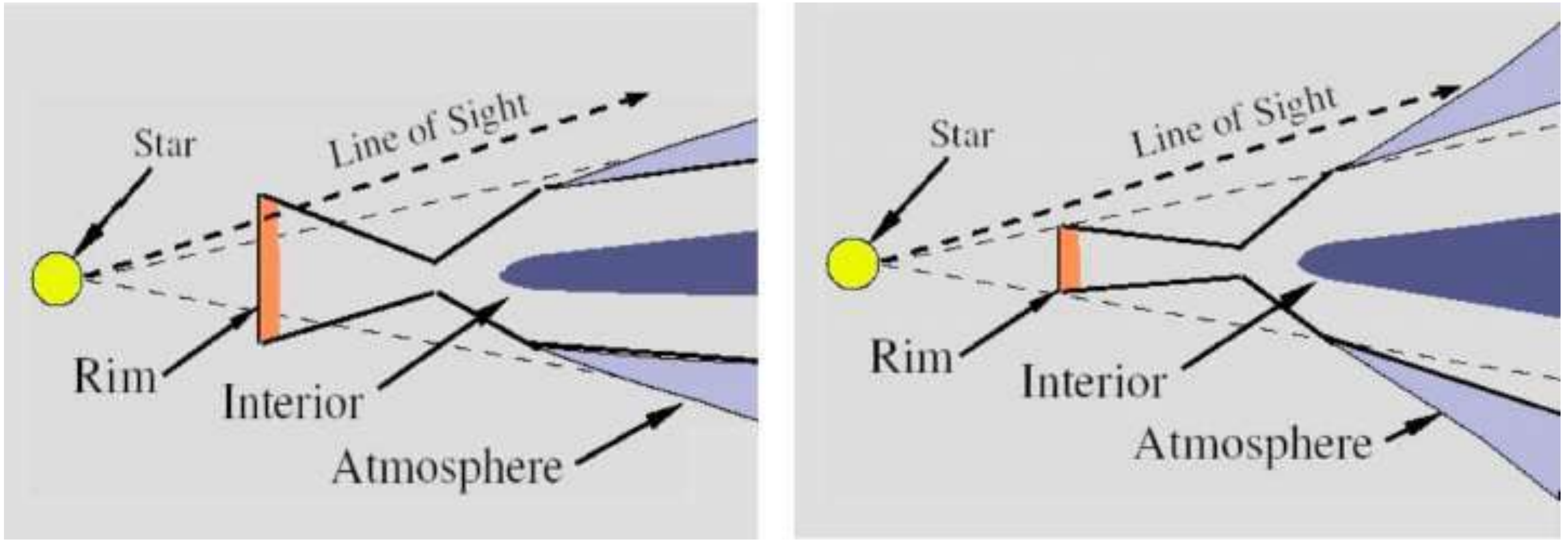
SV Cep





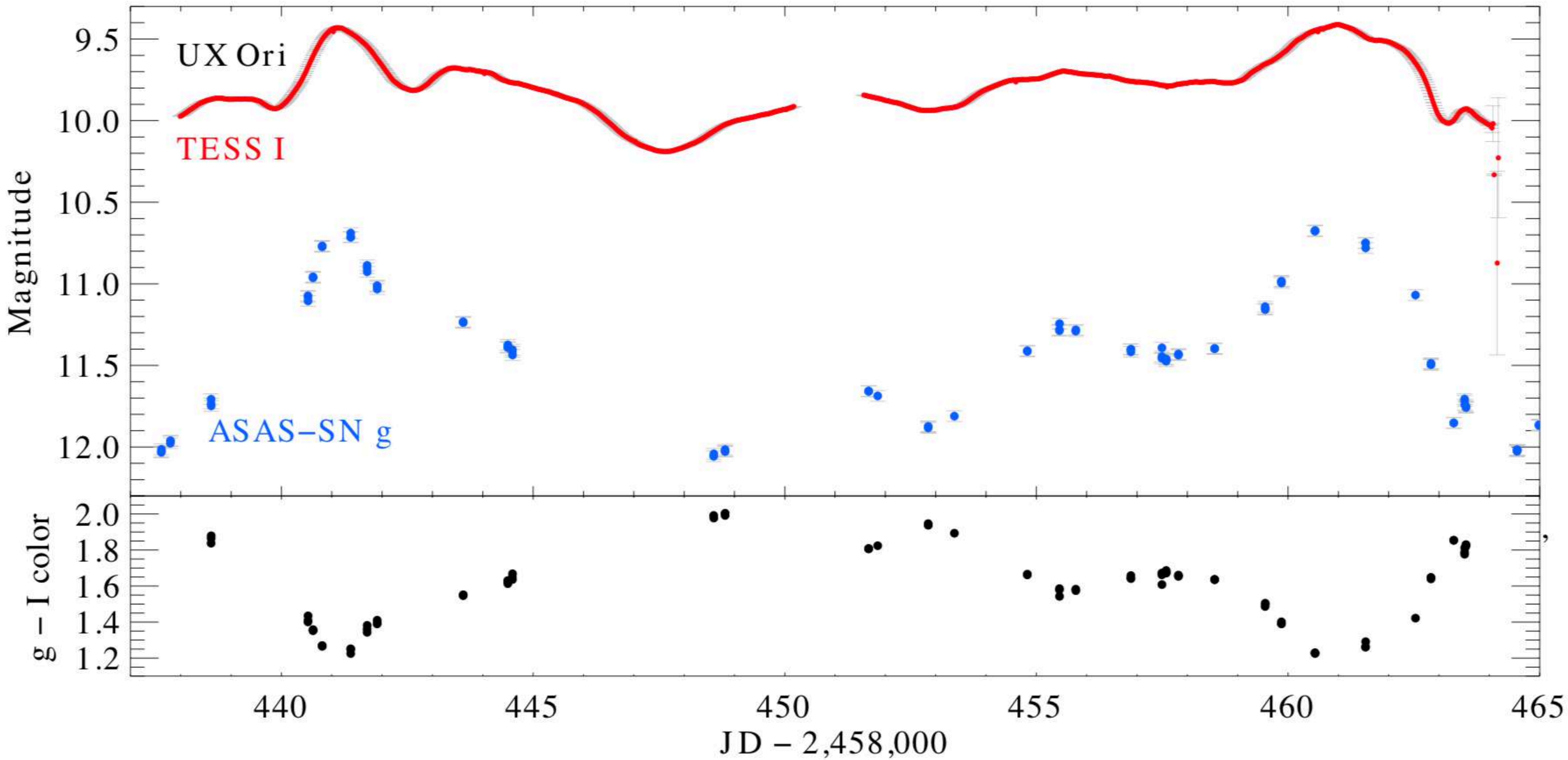
- B9-A0-type star
- ISOPHOT data
- Long-term variability
- Optical-MIR anticorr.
- Optical-FIR corr.
- Optical change: Av
- RT modeling: changing inner rim





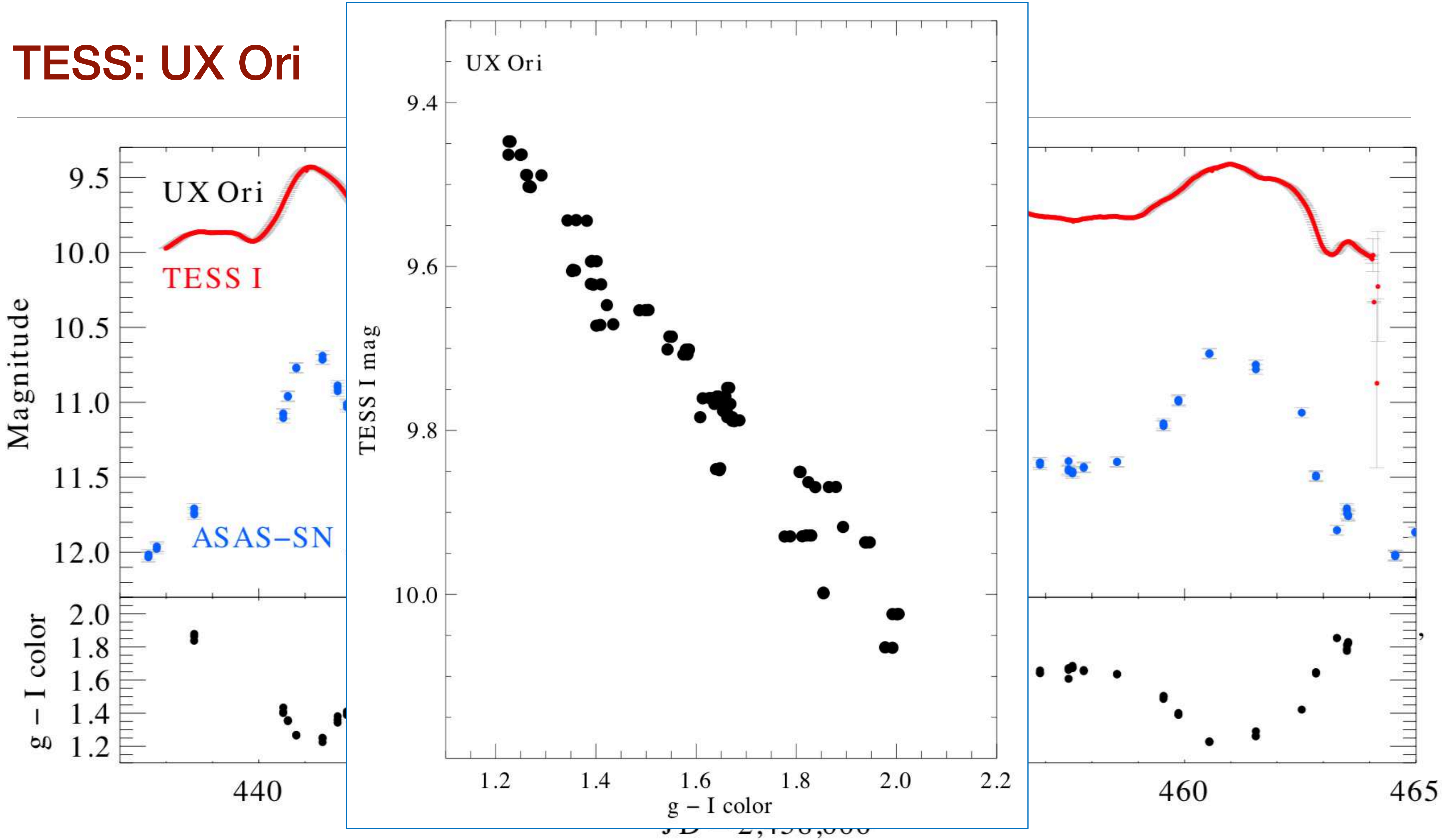
(Juhász, Prusti, Ábrahám, Dullemond 2008)

TESS: UX Ori

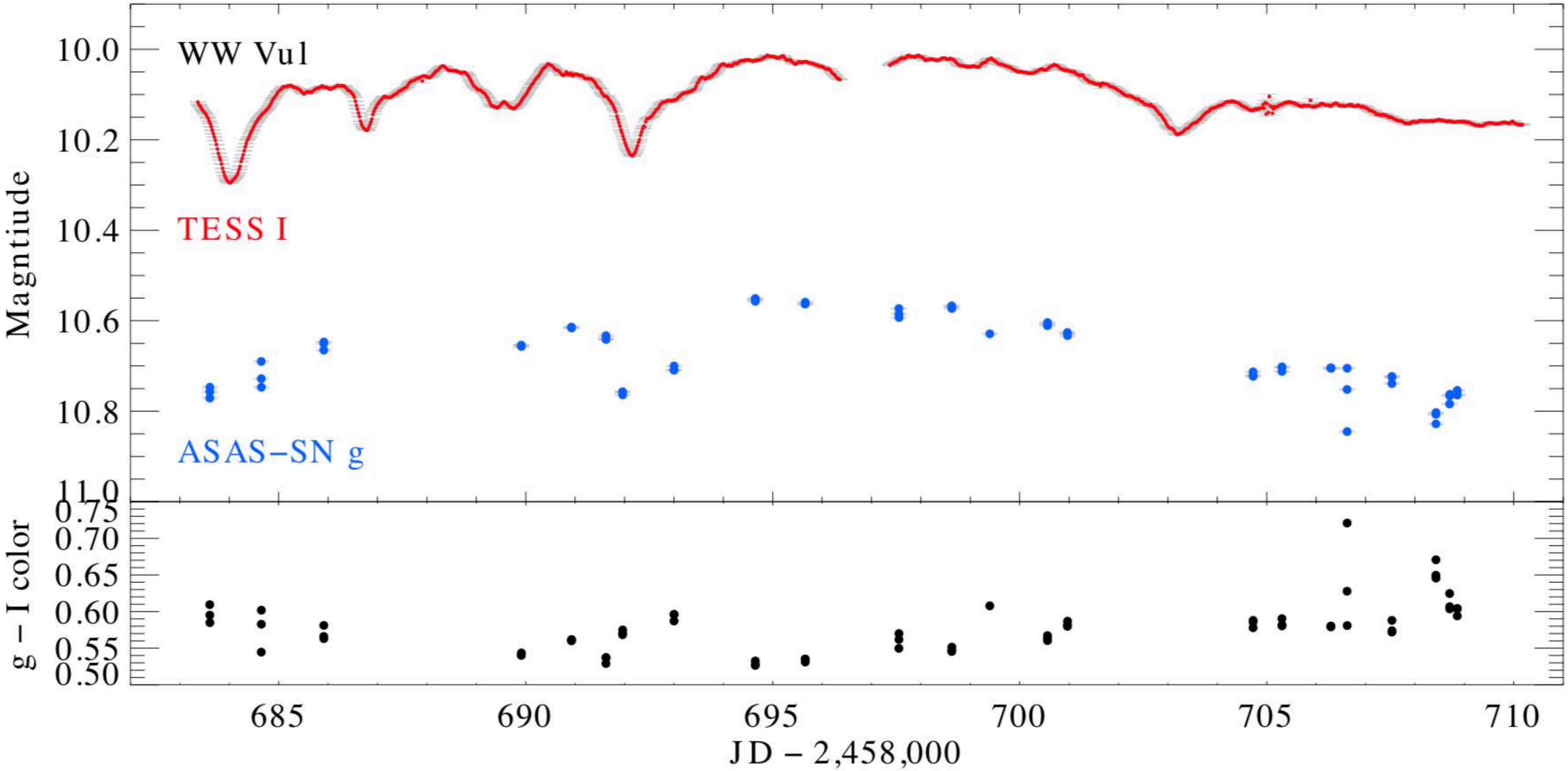


UX Ori
TESS I
ASAS−SN g
Magnitude
9.5
10.0
10.5
11.0
11.5
12.0
g − I color
2.0
1.8
1.6
1.4
1.2
440
445
450
455
460
465
JD − 2,458,000

TESS: UX Ori

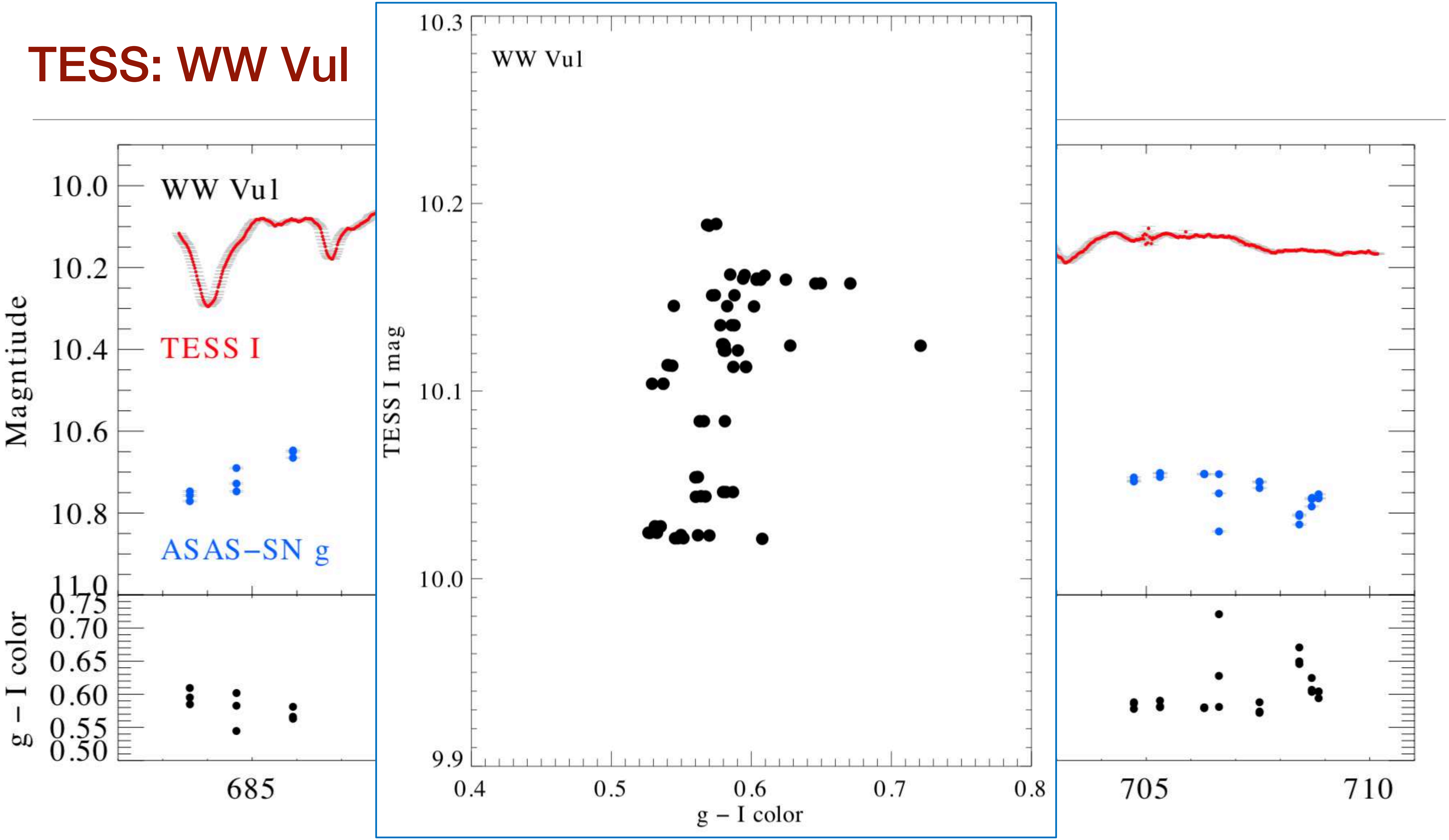

UX Ori
TESS I
ASAS–SN
Magnitude
9.5
10.0
10.5
11.0
11.5
12.0
g – I color
2.0
1.8
1.6
1.4
1.2
440
460
465
UX Ori
TESS I mag
9.4
9.6
9.8
10.0
g – I color
1.2
1.4
1.6
1.8
2.0
2.2

TESS: WW Vul



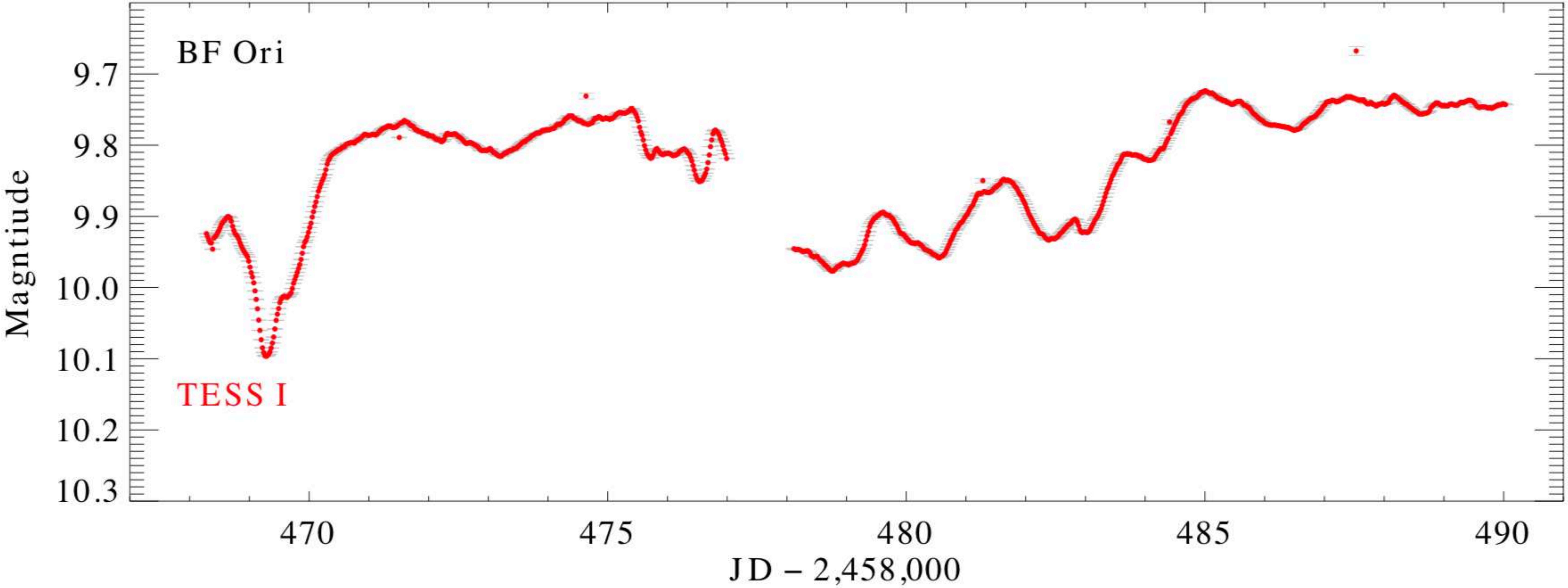
WW Vul
TESS I
ASAS−SN g
Magntiude
10.0
10.2
10.4
10.6
10.8
11.0
g − I color
0.75
0.70
0.65
0.60
0.55
0.50
685
690
695
700
705
710
JD − 2,458,000

TESS: WW Vul



WW Vul
TESS I
ASAS−SN g
Magntiude
g − I color
685
705
710
10.0
10.2
10.4
10.6
10.8
11.0
0.75
0.70
0.65
0.60
0.55
0.50
WW Vul
TESS I mag
g − I color
10.3
10.2
10.1
10.0
9.9
0.4
0.5
0.6
0.7
0.8

TESS: BF Ori


BF Ori
TESS I
Magntiude
9.7
9.8
9.9
10.0
10.1
10.2
10.3
470
475
480
485
490
JD – 2,458,000

Summary

UX Ori type stars exhibit strong variability in the mid-infrared

Variations of the 10 micrometer silicate emission feature (Kóspál+ 2012)

We monitored 8 Uxors in 2009, and detected 5 dimming events

In 3/5 cases pure extinction with a single Av explains the light curves

In 2/5 cases optical and infrared flux evolution differ, more complex explanations

The already known anti-correlation between optical and mid-infrared fluxes of SV Cep were detected

TESS will provide superior optical photometry for our sources

Thanks for your attention!