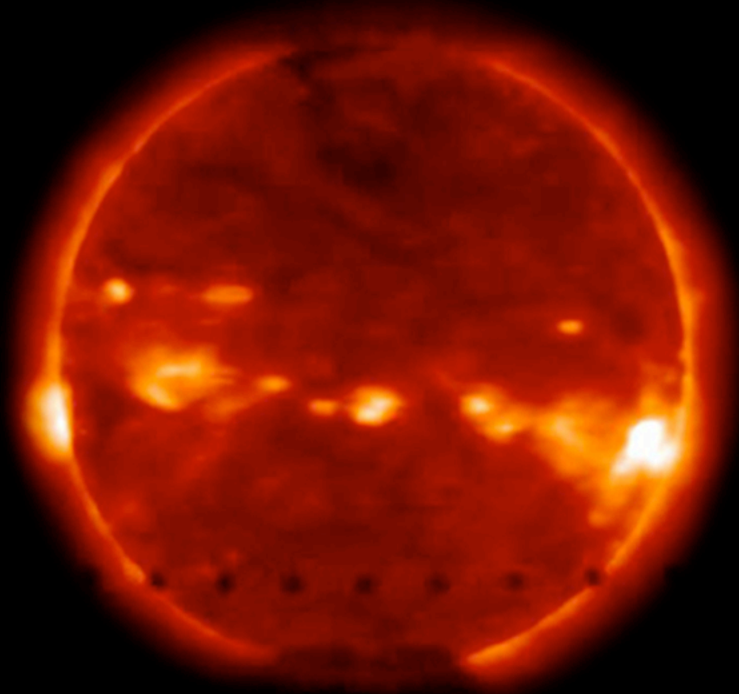
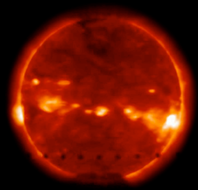
Simulating stellar micro-variability
(for BT2 and other purposes)



S. Aigrain (IoA, Cambridge)
A. Lanza (INAF, Catania)

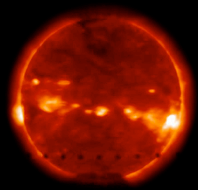
CW8, Toulouse, 25/05/05

Image: GOES-12 / SXI composite of Venus 2004 transit



Until now

- 2 parallel modelling activities
  - *Rotational modulation* model (Lanza et al. 2003, 2004)
  - *Stochastic variations* model (Aigrain et al. 2004)
- Both based on *fits to solar TSI* and extrapolations using *empirical scaling laws*
- Both used in BT1 (Moutou et al. 2005)
- Aims for BT2:
  - Include *colour* information
  - Improve treatment of *short time-scales*
  - *Merge* models



Rotational modulation

(Lanza et al. 2003, 2004, 2005 in prep.)

$$\Delta F(t,\lambda) = \sum_{k;\mu_k>0} \mu_k A_k I_{\rm unp}(\lambda,\mu_k)\left[c_{\rm s}(\lambda) + Q c_{\rm fac}(\lambda,\mu_k)\right]$$

$\Delta F(t,\lambda) =$ disk-integrated relative flux variations

$\mu_k =$ projection factor

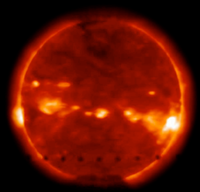
$A_k =$ active region area (as a fraction of stellar disk)

$I_{\rm unp}(\lambda,\mu_k) =$ specific intensity of unperturbed photosphere
(Kurucz model atmospheres + quadratic limb darkening law)

$c_{\rm s}(\lambda) =$ spot contrast factor $= B_\lambda(T_{\rm s})/B_\lambda(T_{\rm unp}) - 1$ (black body approximation)

$c_{\rm fac}(\lambda,\mu_k) =$ facular contrast factor $= c_{\rm f}(\lambda)(1-\mu)$ (brightest at limb)

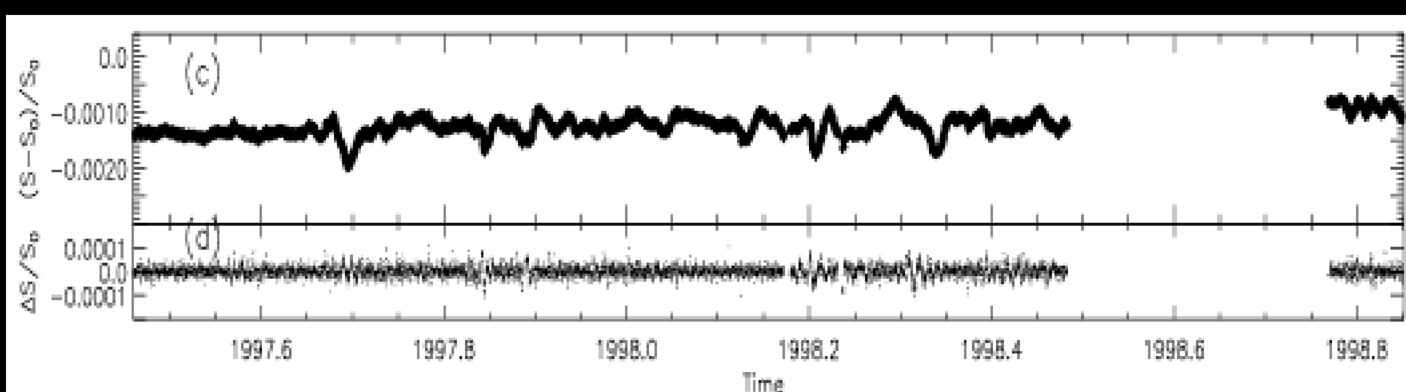
$Q =$ ratio of facular to cool spot area

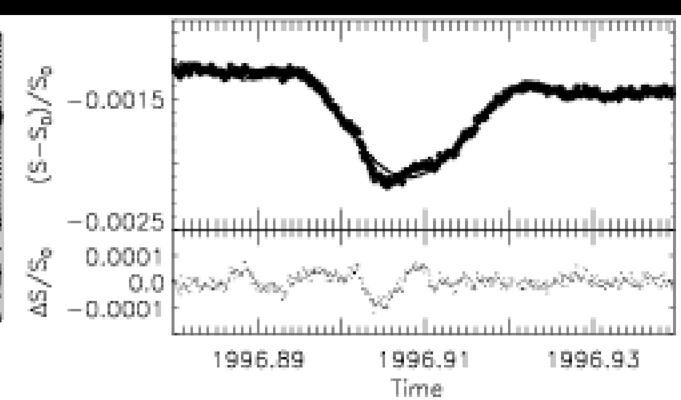


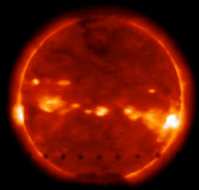
Rotational modulation

(Lanza et al. 2003, 2004, 2005 in prep.)

- Simultaneously fit solar 4-band solar irradiance data from VIRGO:
  - TSI - bolometric and 3 narrow SPM channels (402, 500, 862 nm)
- Use three active regions + uniform background (uniform distribution of small active regions)
- Adjust each region's position and area every 7 days based on 14 days of data
- Residuals 20 to 30 times smaller than solar variations



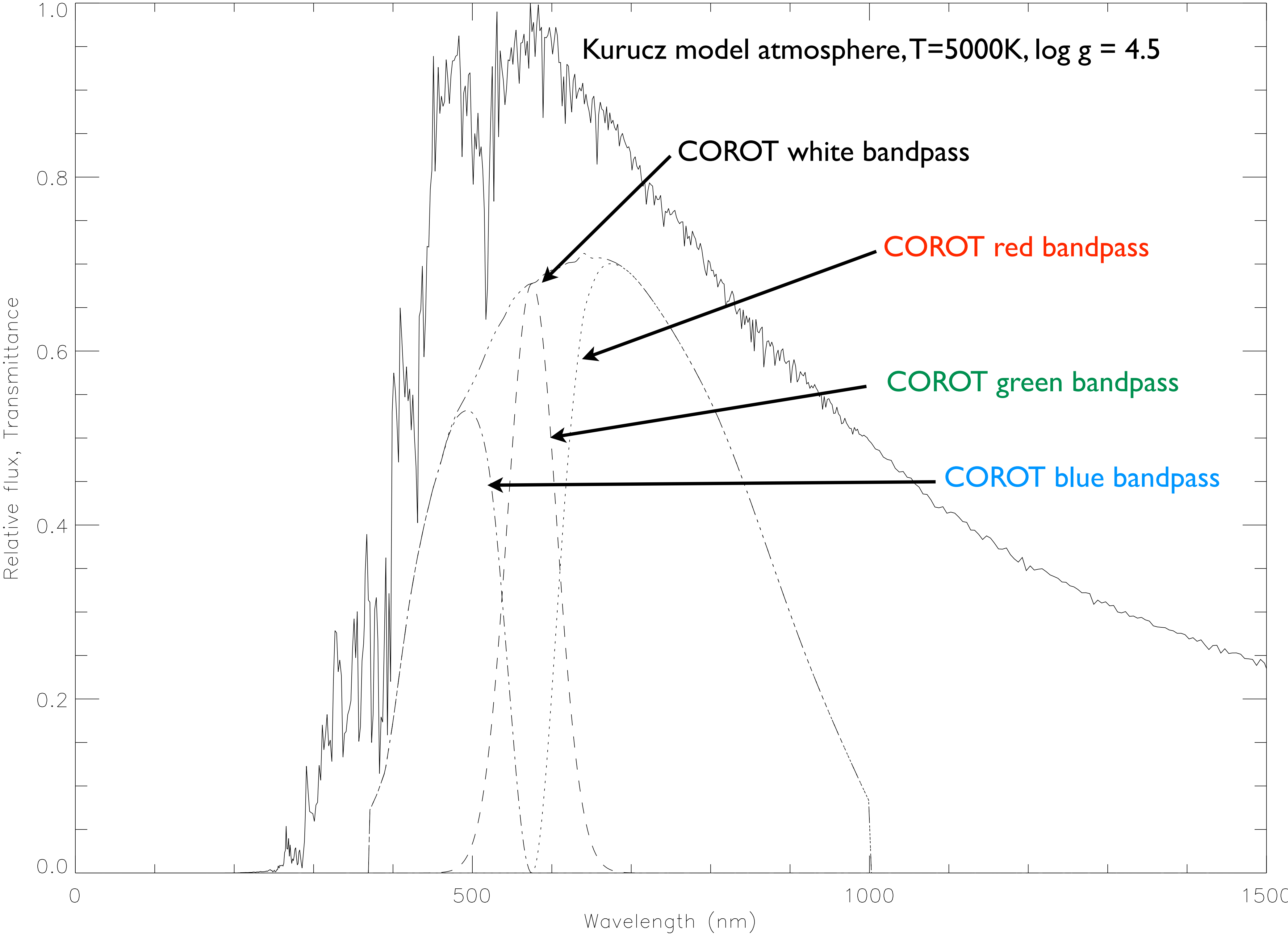




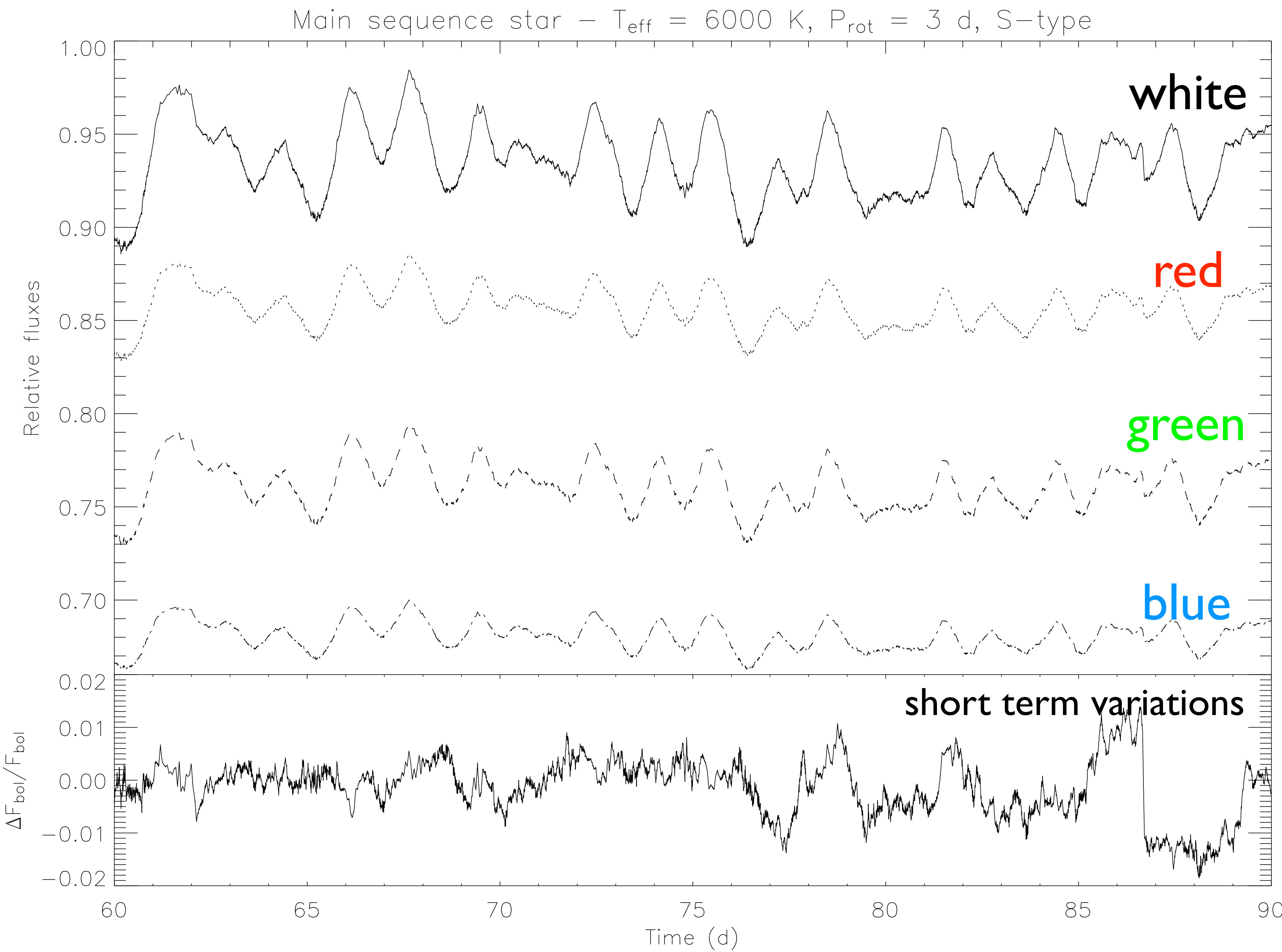
Rotational modulation

(Lanza et al. 2003, 2004, 2005 in prep.)

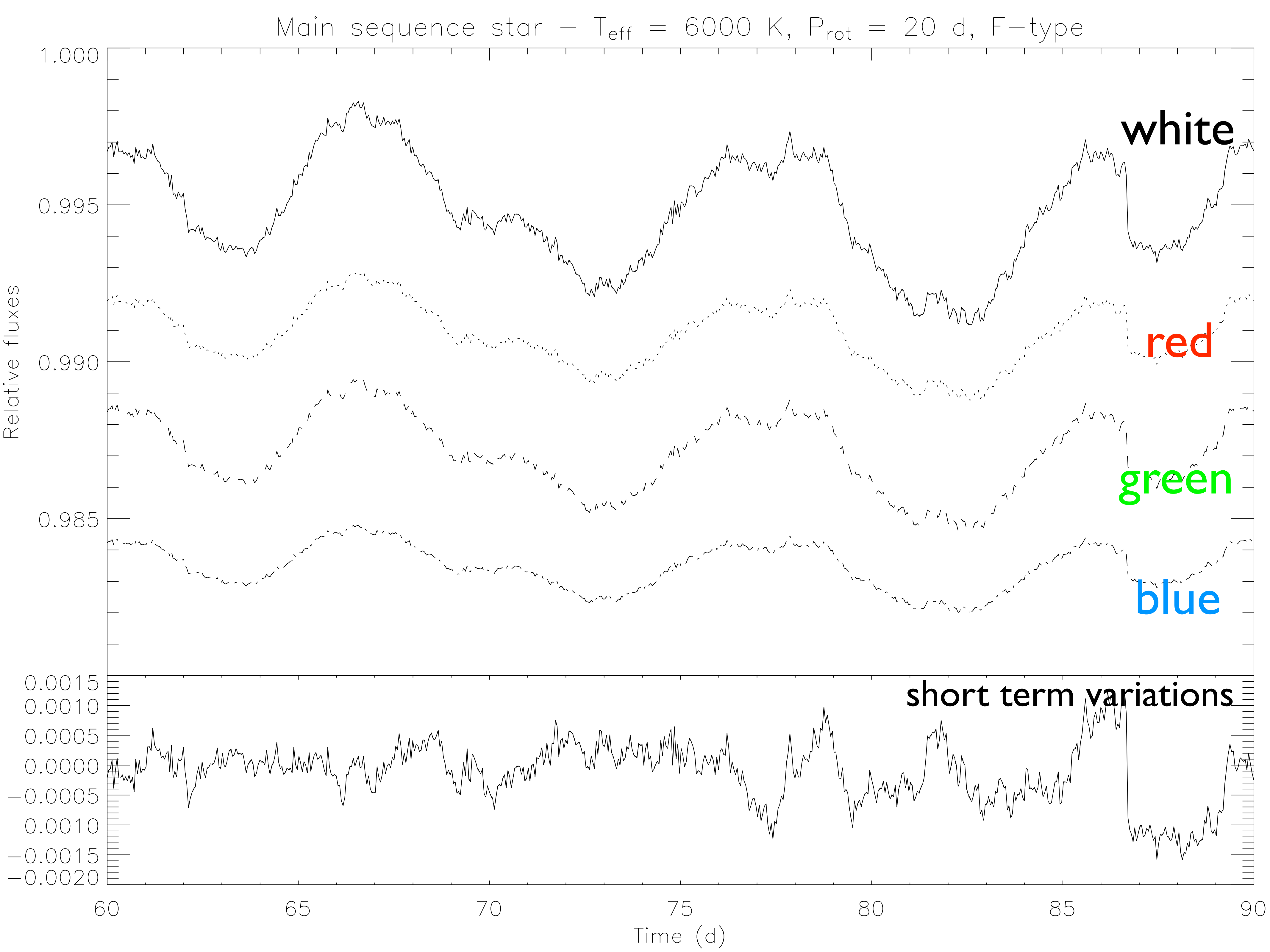
- Extrapolate fit to solar data to simulate light curves for a range of stars
  - P = 3, 10, 20 d
  - T = 4000, 5000, 6000, 7000 K
  - log g = 4.5 cm/s^2, microturbulence 2 km/s, ML / pressure scale height = 1.25
- Scale active regions area with rotation period (Messina et al. 2003) as in BT1
- Multiply all wavelength dependent quantities by bandpass profile and integrate
- Two hypotheses for relative contribution of faculae:
  - Decreases strongly with decreasing rotation period (Chapman et al. 1997, Solanki & Unruh 2004)
  - Constant at Q = 5
- Two options for short term variations:
  - scale residuals of solar fit by 3 times area scaling factor (as in BT1)
  - leave out entirely



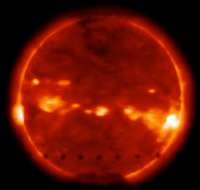
Kurucz model atmosphere, T=5000K, log g = 4.5
COROT white bandpass
COROT red bandpass
COROT green bandpass
COROT blue bandpass
Relative flux, Transmittance
Wavelength (nm)
0.0
0.2
0.4
0.6
0.8
1.0
0
500
1000
1500



Main sequence star − T_{eff} = 6000 K, P_{rot} = 3 d, S−type
white
red
green
blue
short term variations
Relative fluxes
$\Delta F_{bol}/F_{bol}$
Time (d)
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.02
0.01
0.00
−0.01
−0.02
60
65
70
75
80
85
90



Main sequence star − T_{eff} = 6000 K, P_{rot} = 20 d, F−type
white
red
green
blue
short term variations
Relative fluxes
1.000
0.995
0.990
0.985
0.0015
0.0010
0.0005
0.0000
−0.0005
−0.0010
−0.0015
−0.0020
60
65
70
75
80
85
90
Time (d)



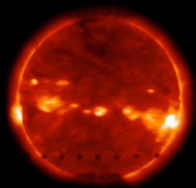
Stochastic variations

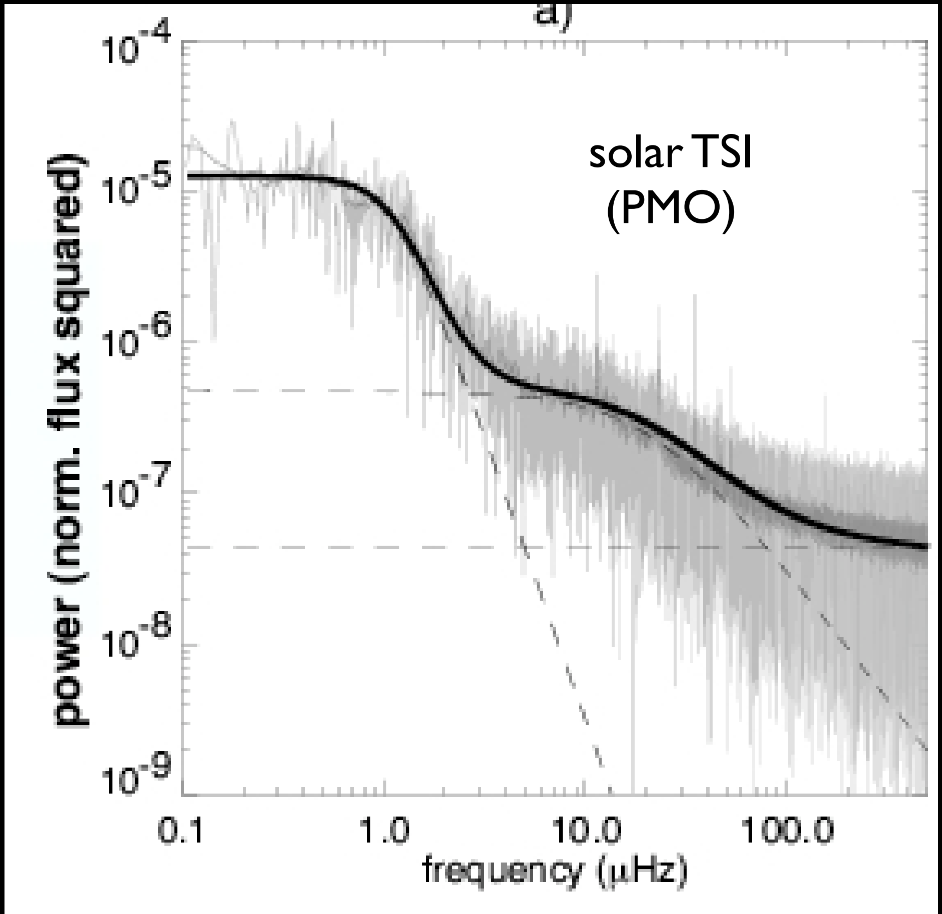
(Aigrain et al. 2004)

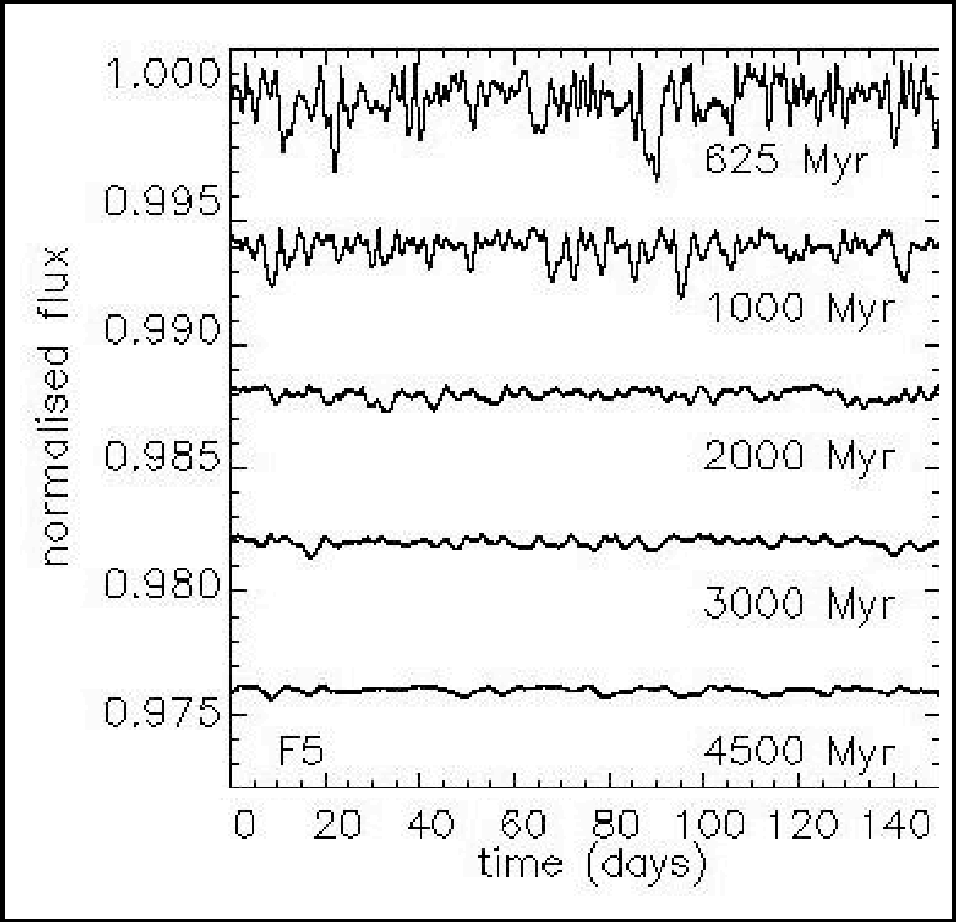
- power spectrum of solar TSI variations often modelled as sum of broken powerlaws (Harvey 1985)
- components = active regions, super-granulation (?), granulation
- follow component's evolution each throughout solar cycle:
  AR amplitude ∝ chromospheric activity
  - scale AR amplitude with age & SpT via P & chromospheric activity (Noyes et al. 1984)
  - scale AR timescale with P for short P
- higher frequency components left as in the Sun
- revert to time domain using randomly generated phase array

Stochastic variations

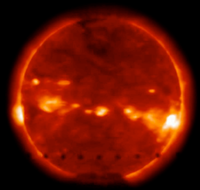
(Aigrain et al. 2004)

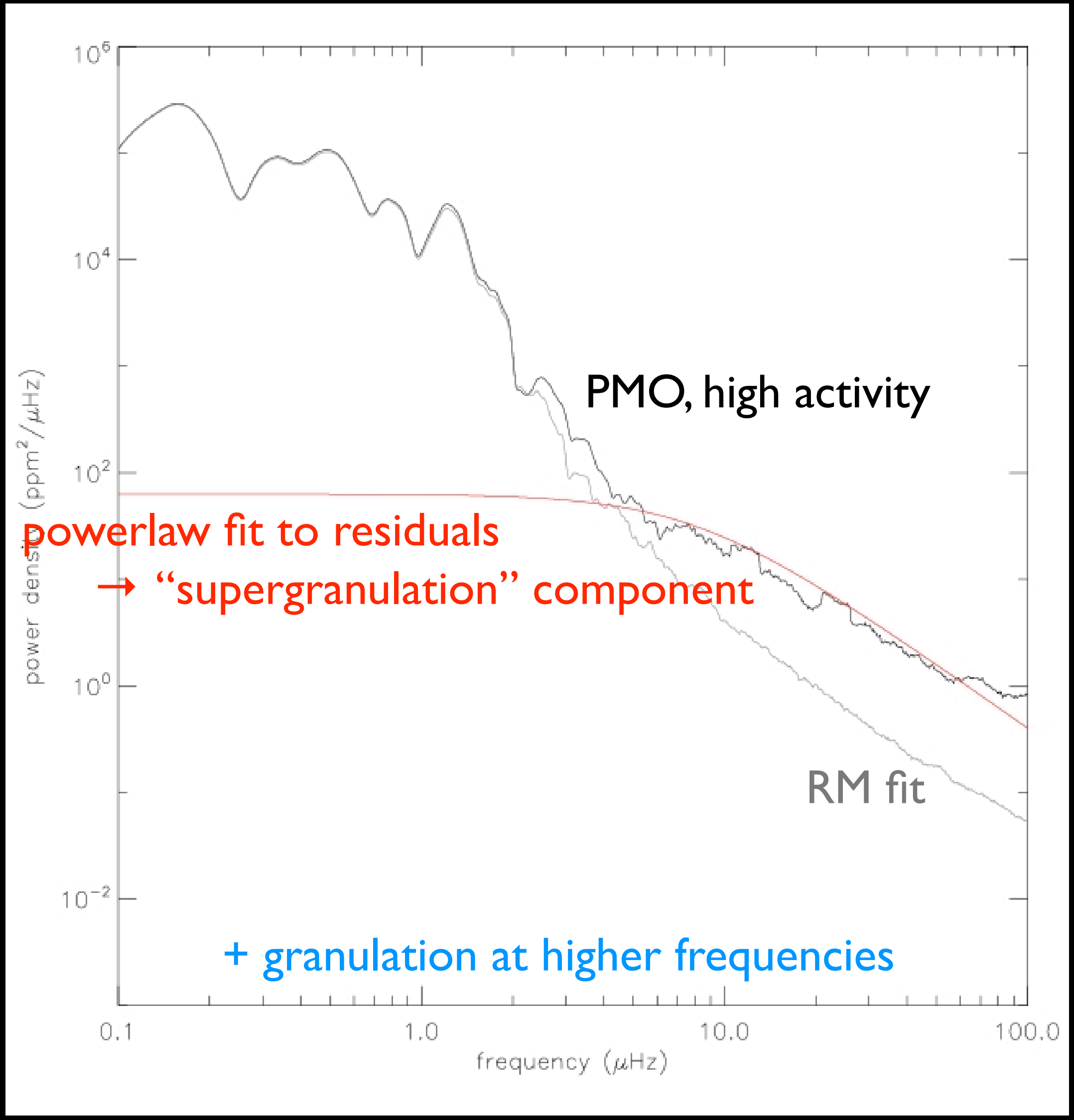




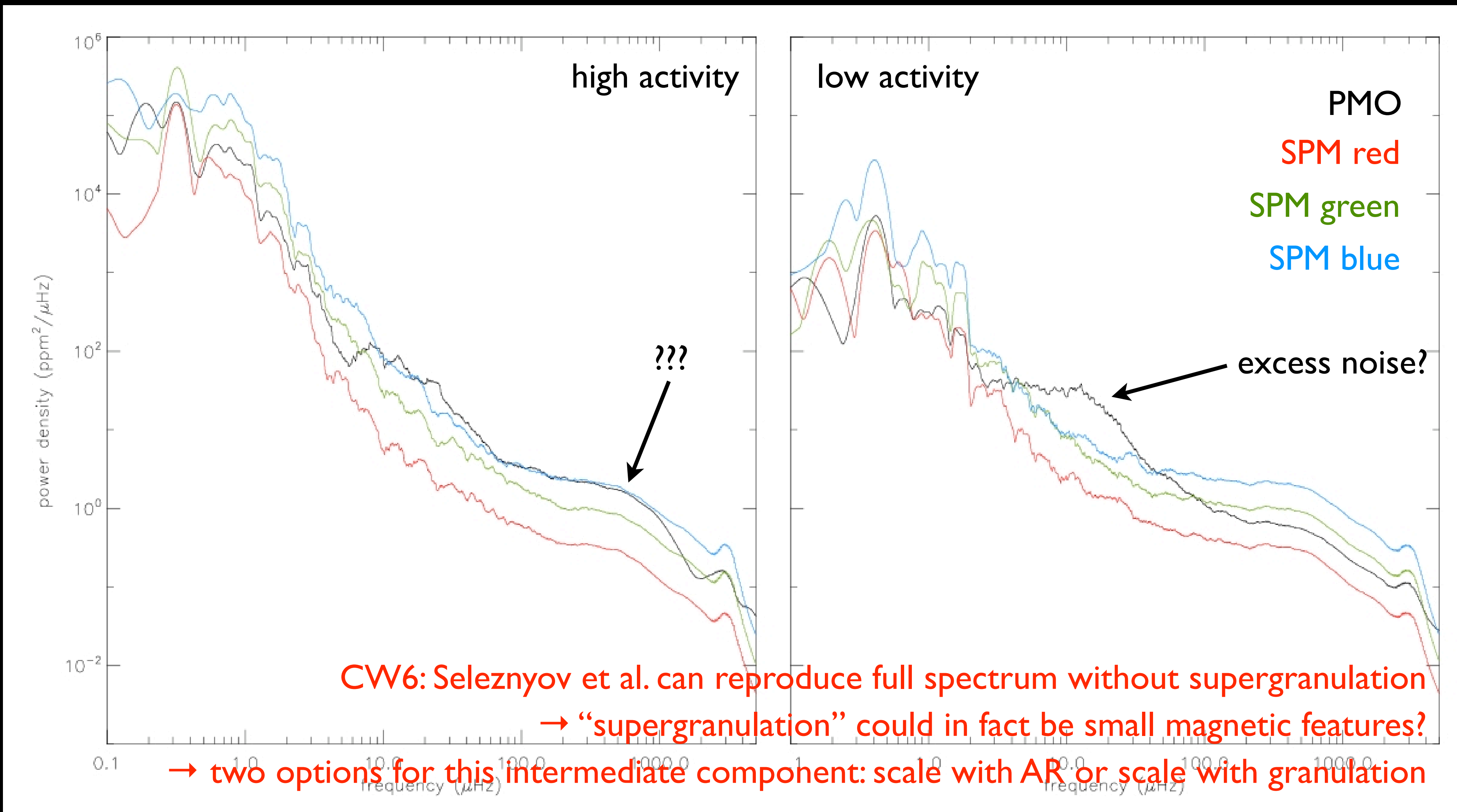


Complementing the RM model





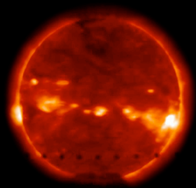
Is it really supergranulation?



CW6: Seleznyov et al. can reproduce full spectrum without supergranulation

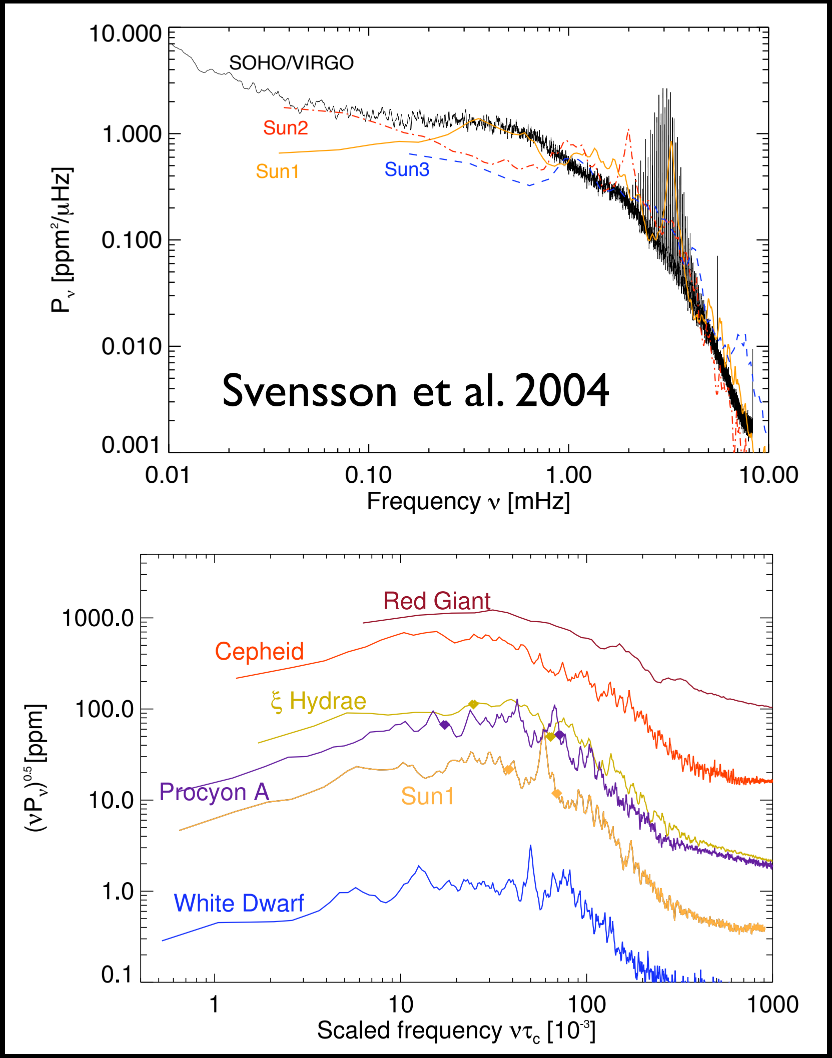
→ “supergranulation” could in fact be small magnetic features?

→ two options for this intermediate component: scale with AR or scale with granulation



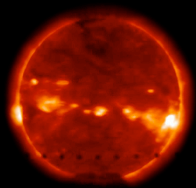
constraints on granulation

- recent modelling (Freytag et al. 2001, Seleznyov et al. at CW6, Svensson et al. 2004)
  - $\log P_{gr} \propto -\frac{1}{2} \log N_{gr} \propto \frac{1}{2} \log X_{gr} \propto -\frac{1}{2} \log g$
  - temperature dependence
  - metallicity dependence
- observational constraints
  - RV: Kjeldsen et al. (1999): $P_{gr}(\alpha\text{Cen, G2V}) \approx P_{gr}(\text{Sun})$
  - WIRE: Bruntt et al. (2005): $P_{gr}(\text{Procyon, F5IV}) \approx 1.8 \pm 0.3 \times P_{gr}(\text{Sun})$
  - MOST: constraints so far elusive

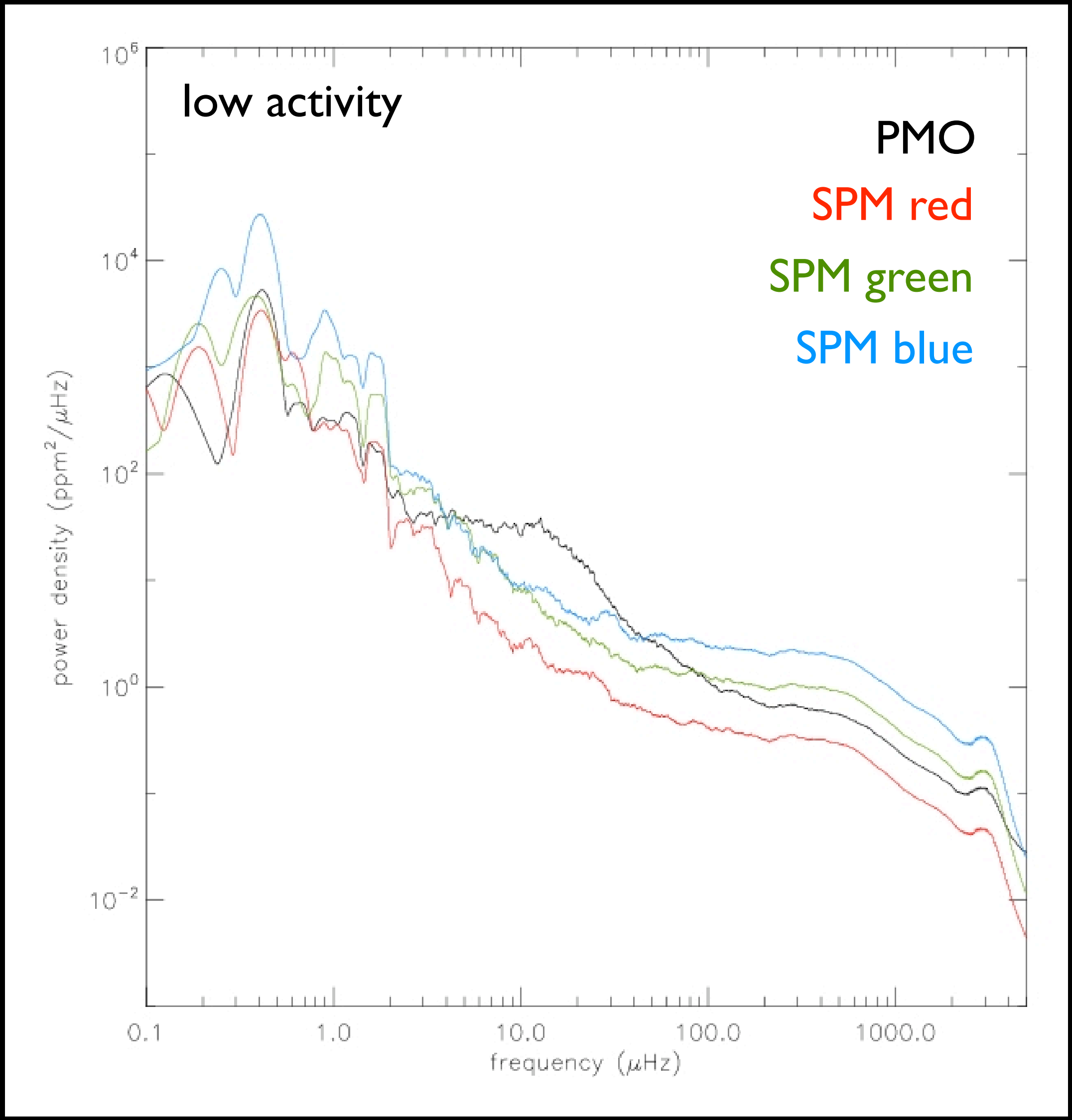


all constraints so far consistent with

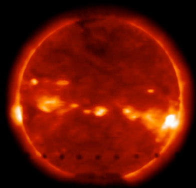
$$P_{\rm gr}^2 \propto -\log g + 3 \log T_{\rm eff}$$



colour versus frequency



- no significant trends with frequency in the relative amplitude of variations between different SPM channels
- colour dependence follows that of low frequency components
- correlation between band passes at all frequencies
- confirmed by work of P. Bordé for wide spectral range



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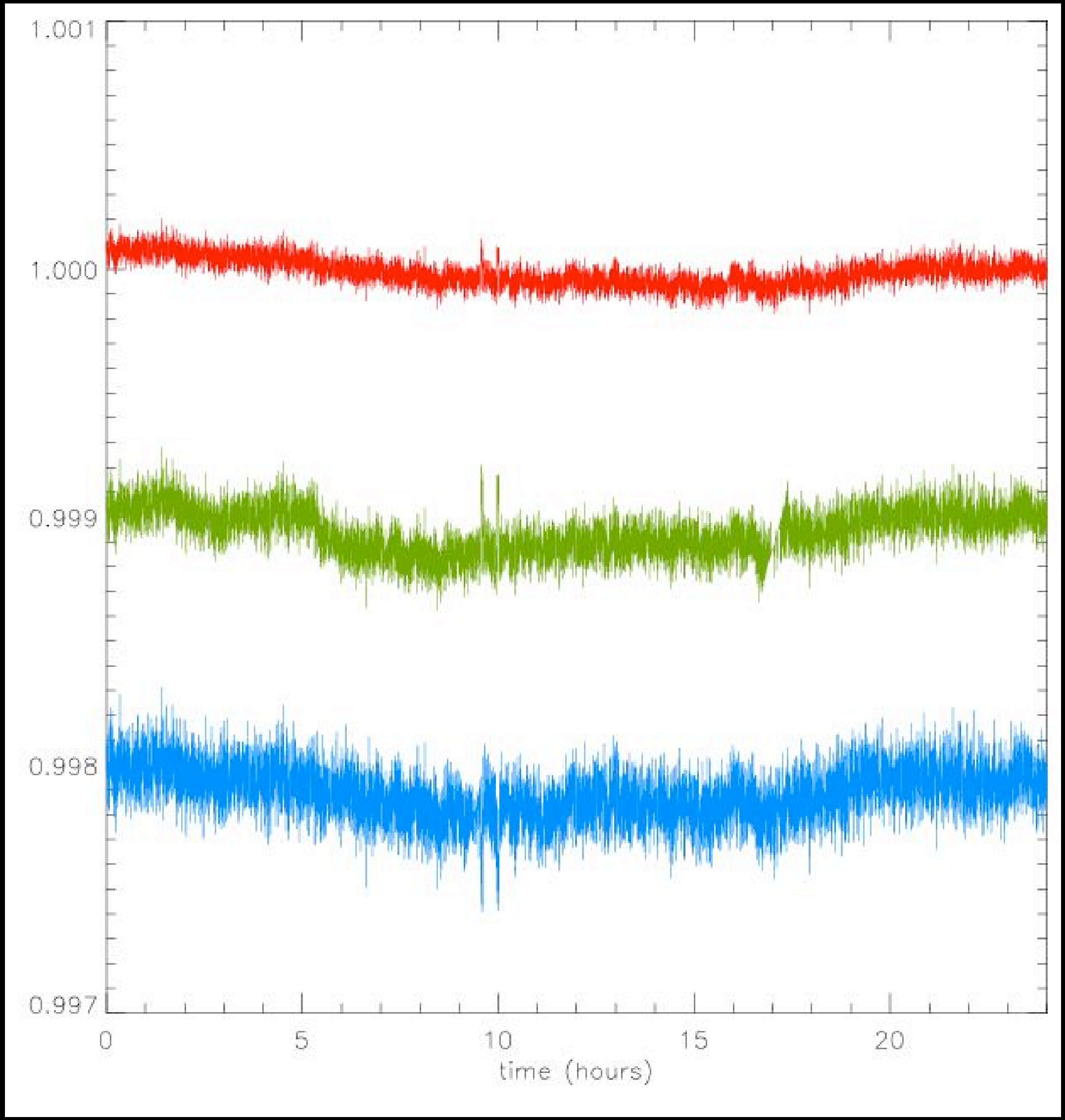

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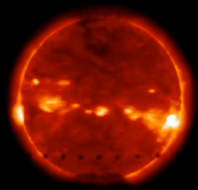
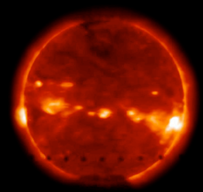
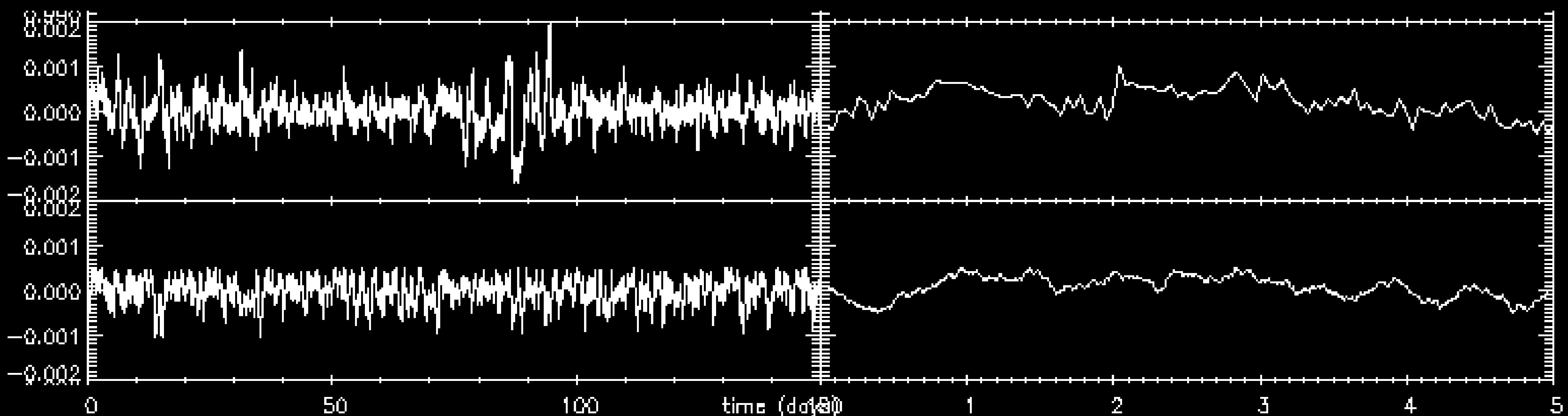


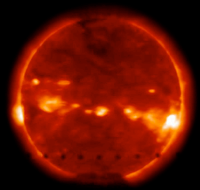
Complementing the RM model

- took the 12 RM only light curves simulated by Nuccio
- measured rms of white light curve cf. solar case (1)
- measured rms of coloured cf. white (2)
- computed amplitude of granulation component from log g and Teff, cf. solar case (3)
- added hours timescale component scaled either as active regions (1) or granulation (3)
- scaled colours following (2)



Complementing the RM model





conclusions

- Colour information has been included
- What constraints are available on high frequency components have been included
- Combined light curves are available
    - → All set to produce light curves for a BT2
- Future work
    - Improve AR component of my model (add gaussian)
    - Improve understanding of "supergranulation" component?
    - check on colour dependence using SORCE data