Solar and stellar flares: Observations, modeling and synergies

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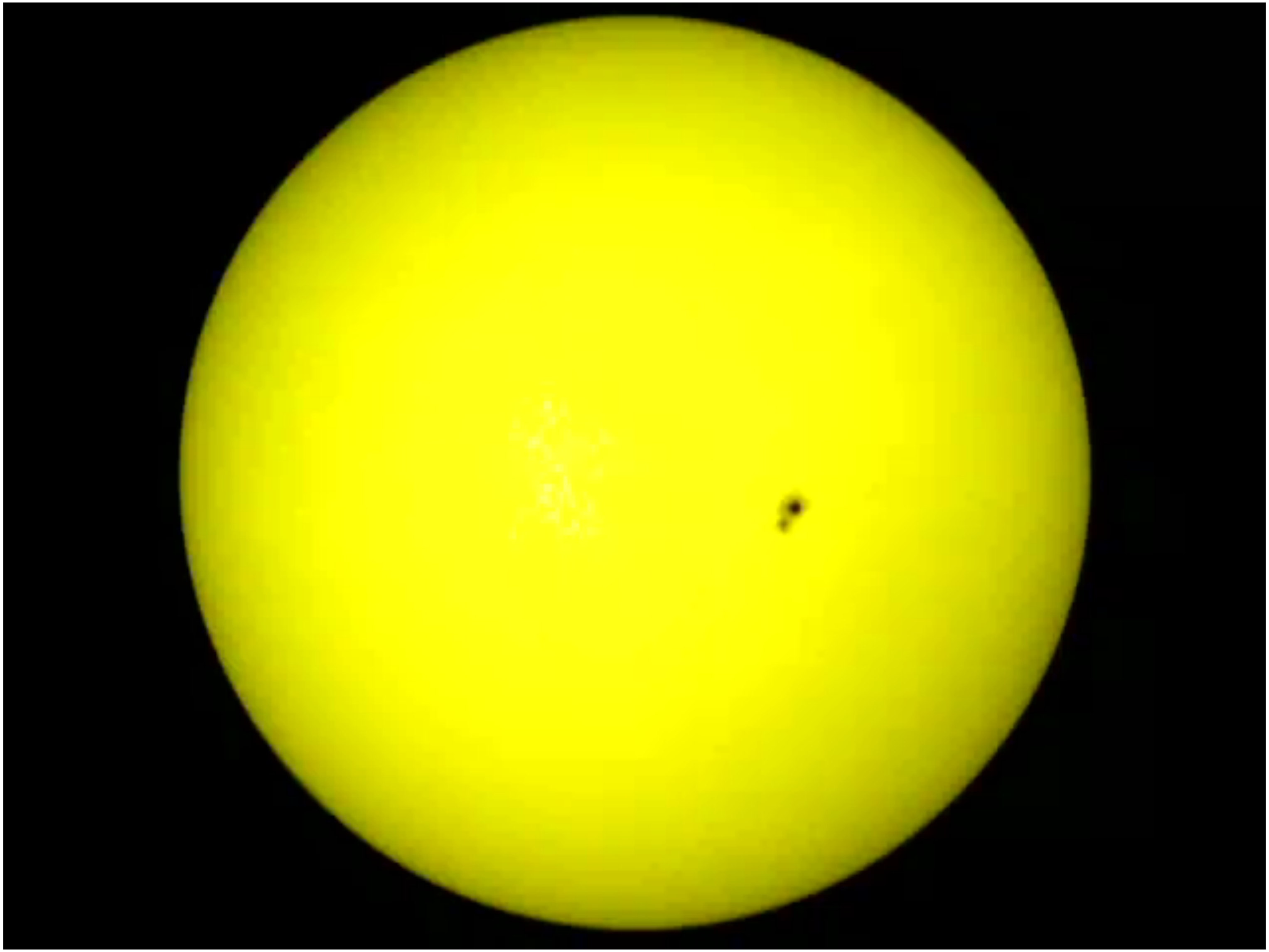
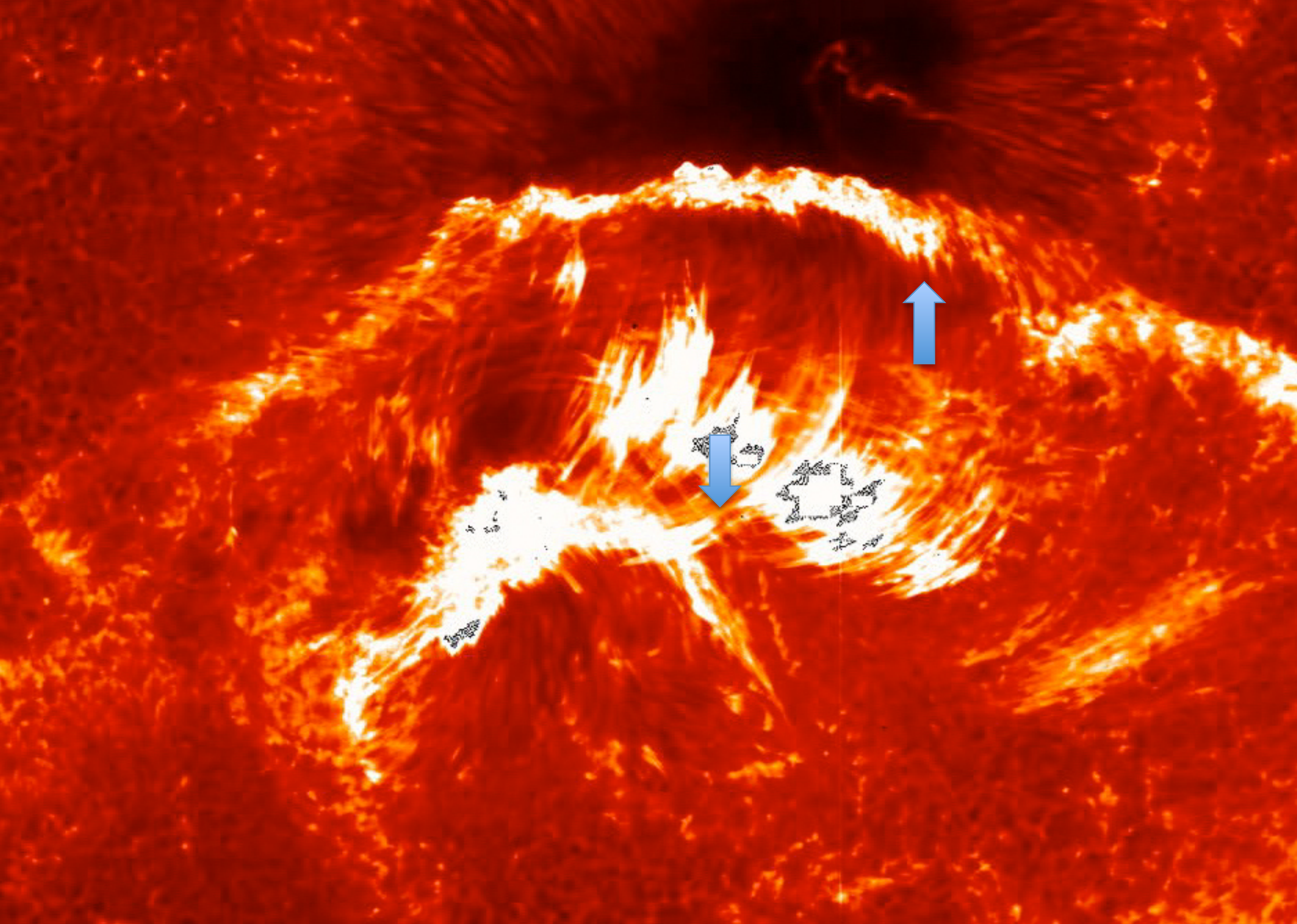
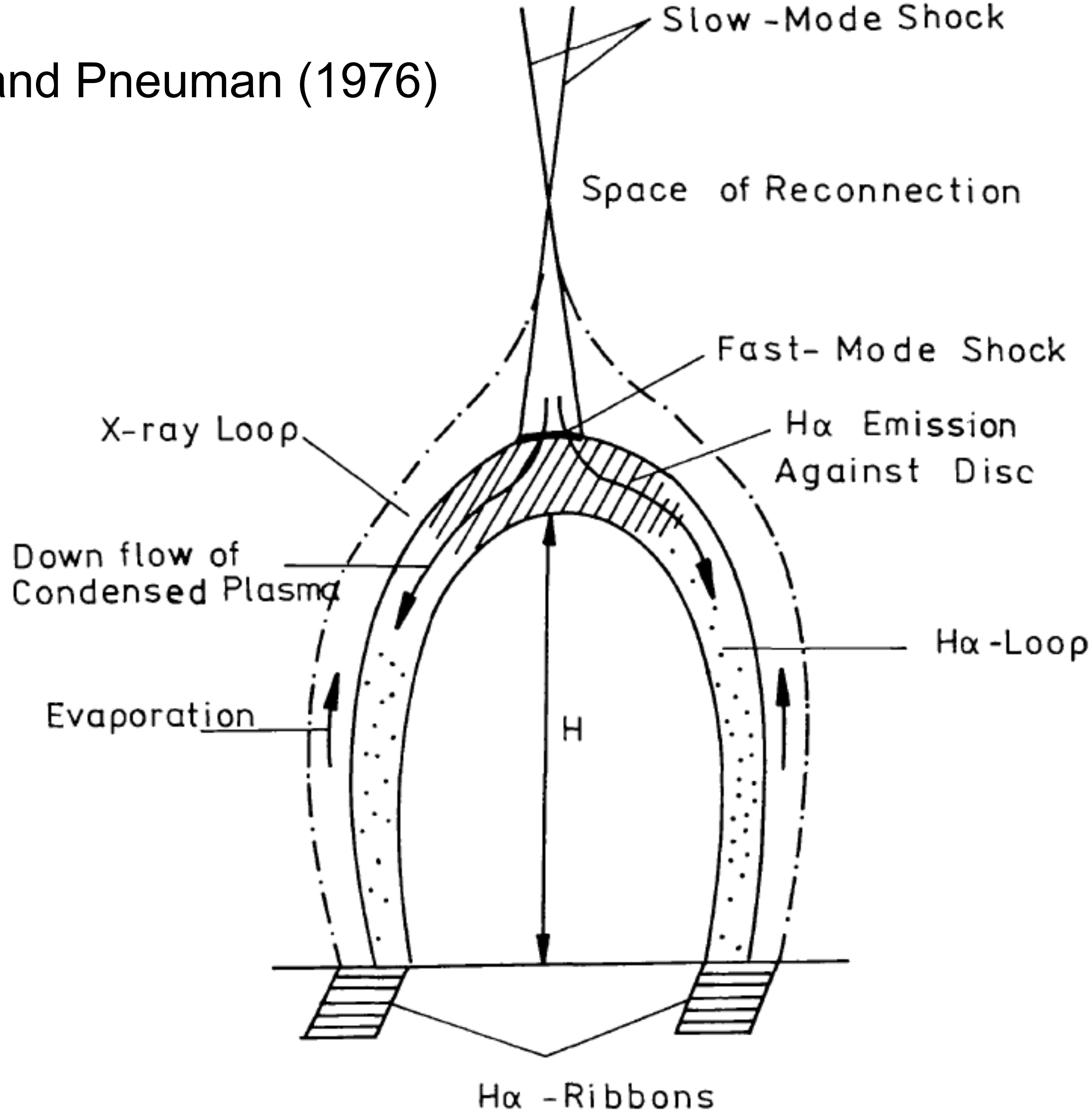
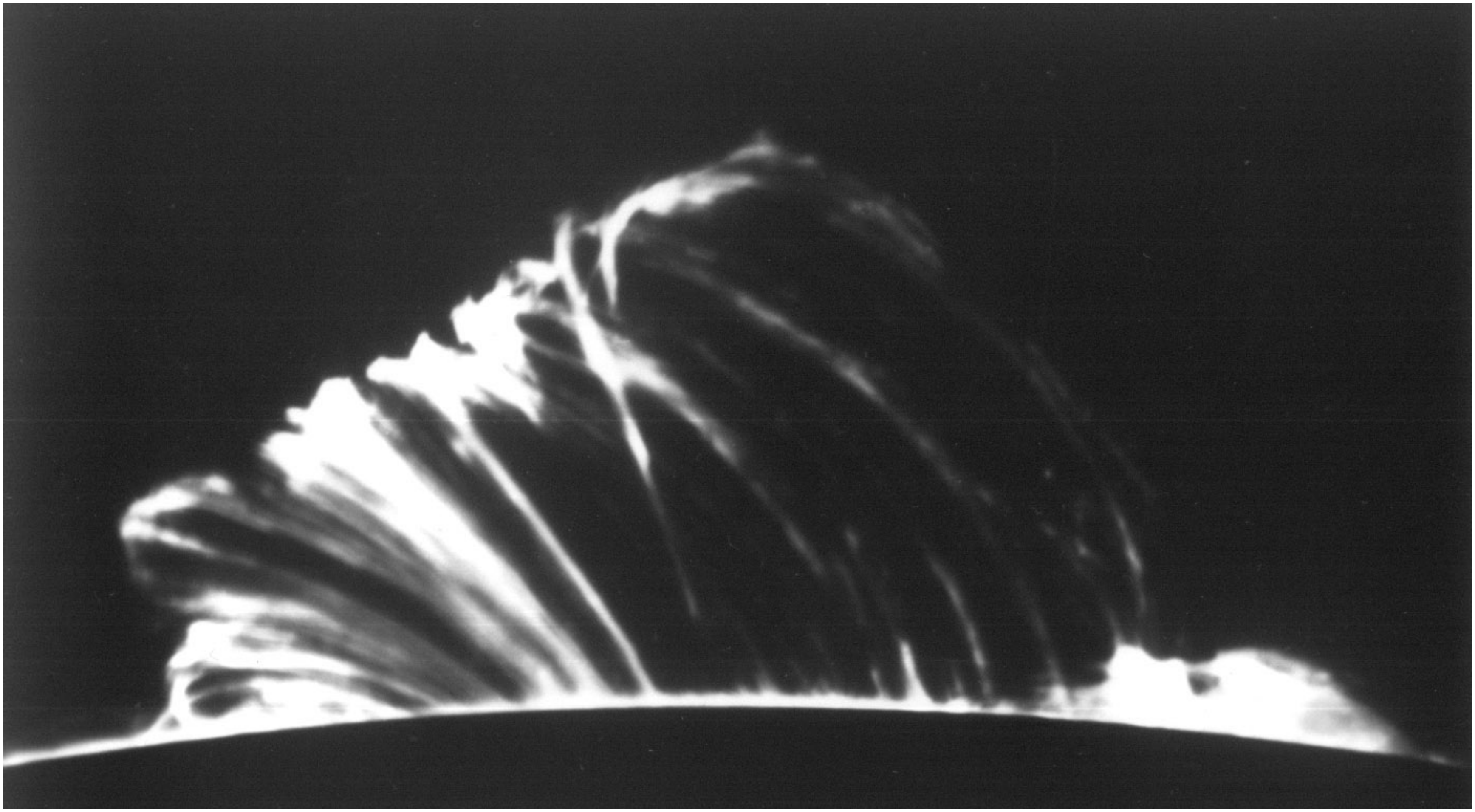


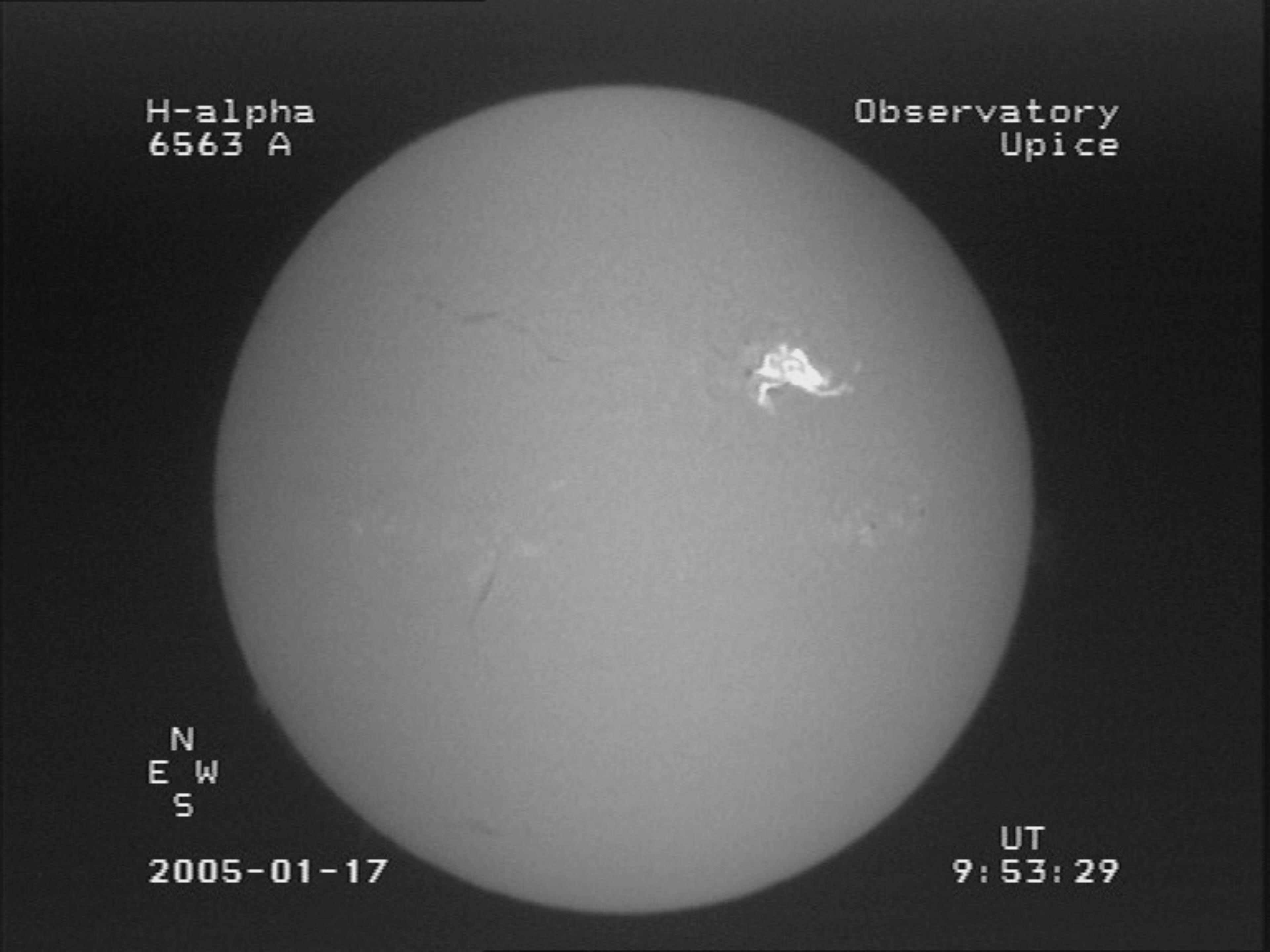


Kopp and Pneuman (1976)

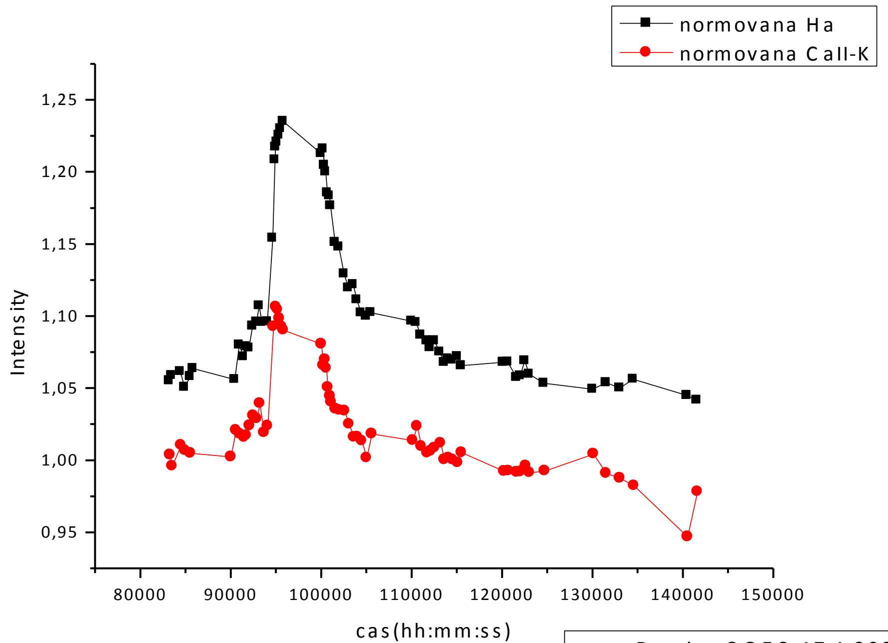


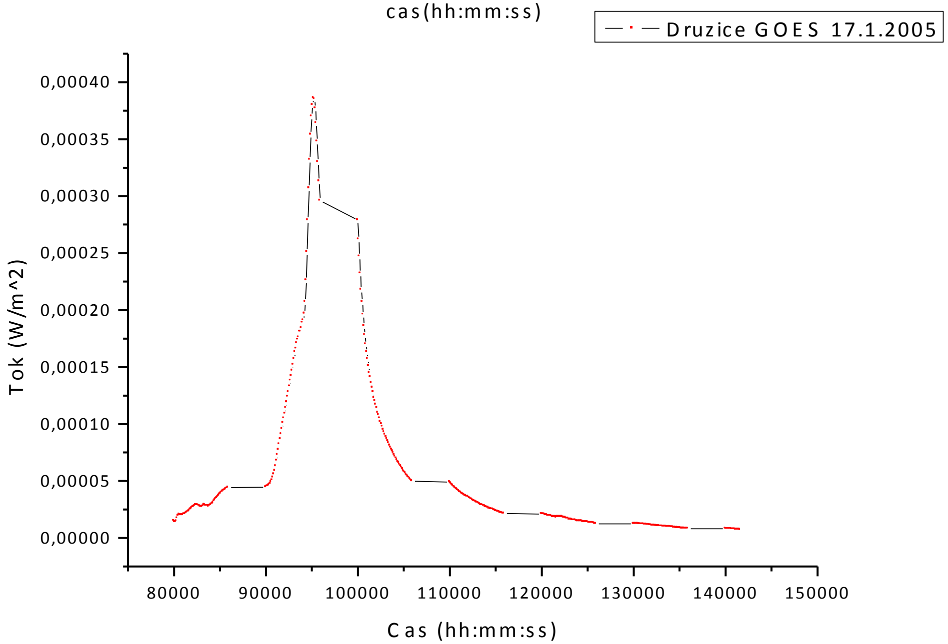
Hα loops (Wroclaw observatory)



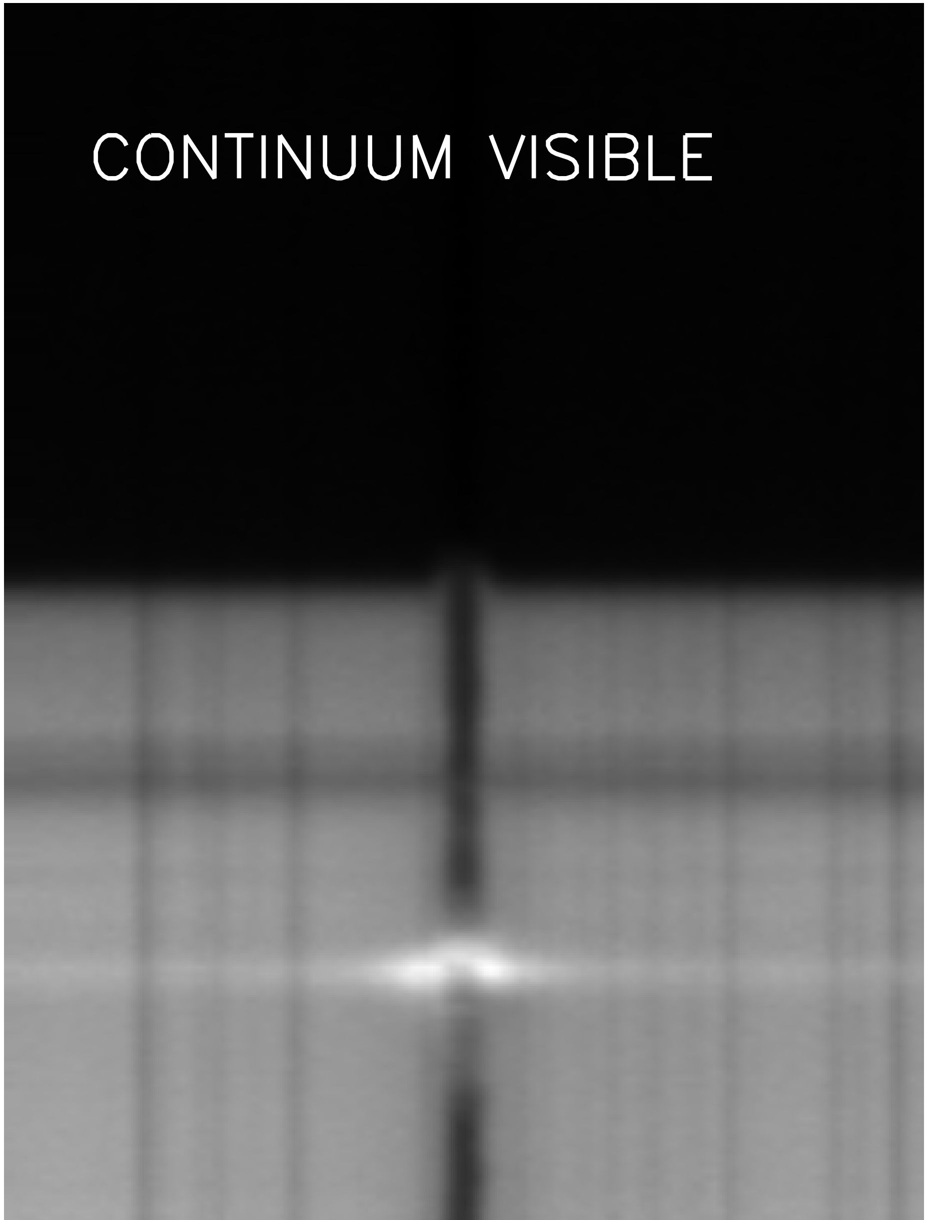

H-alpha
6563 A
Observatory
Upice
N
E W
S
2005-01-17
UT
9:53:29


CaII-K
3934 A
Observatory
Upice
N
E W
S
2005-01-17
UT
9:52:17

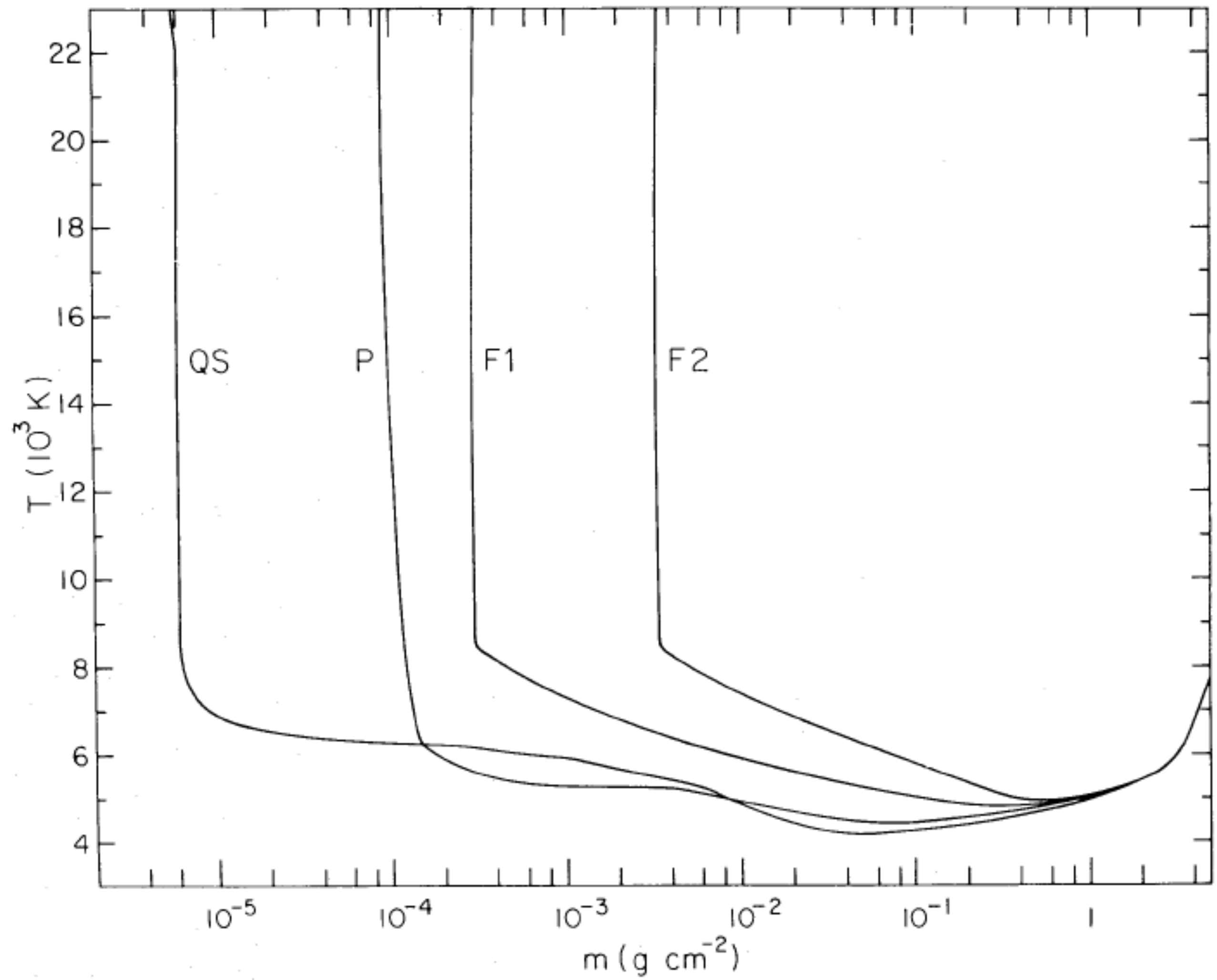

normovana Ha
normovana CaII-K
Intensity
1,25
1,20
1,15
1,10
1,05
1,00
0,95
80000
90000
100000
110000
120000
130000
140000
150000
cas(hh:mm:ss)

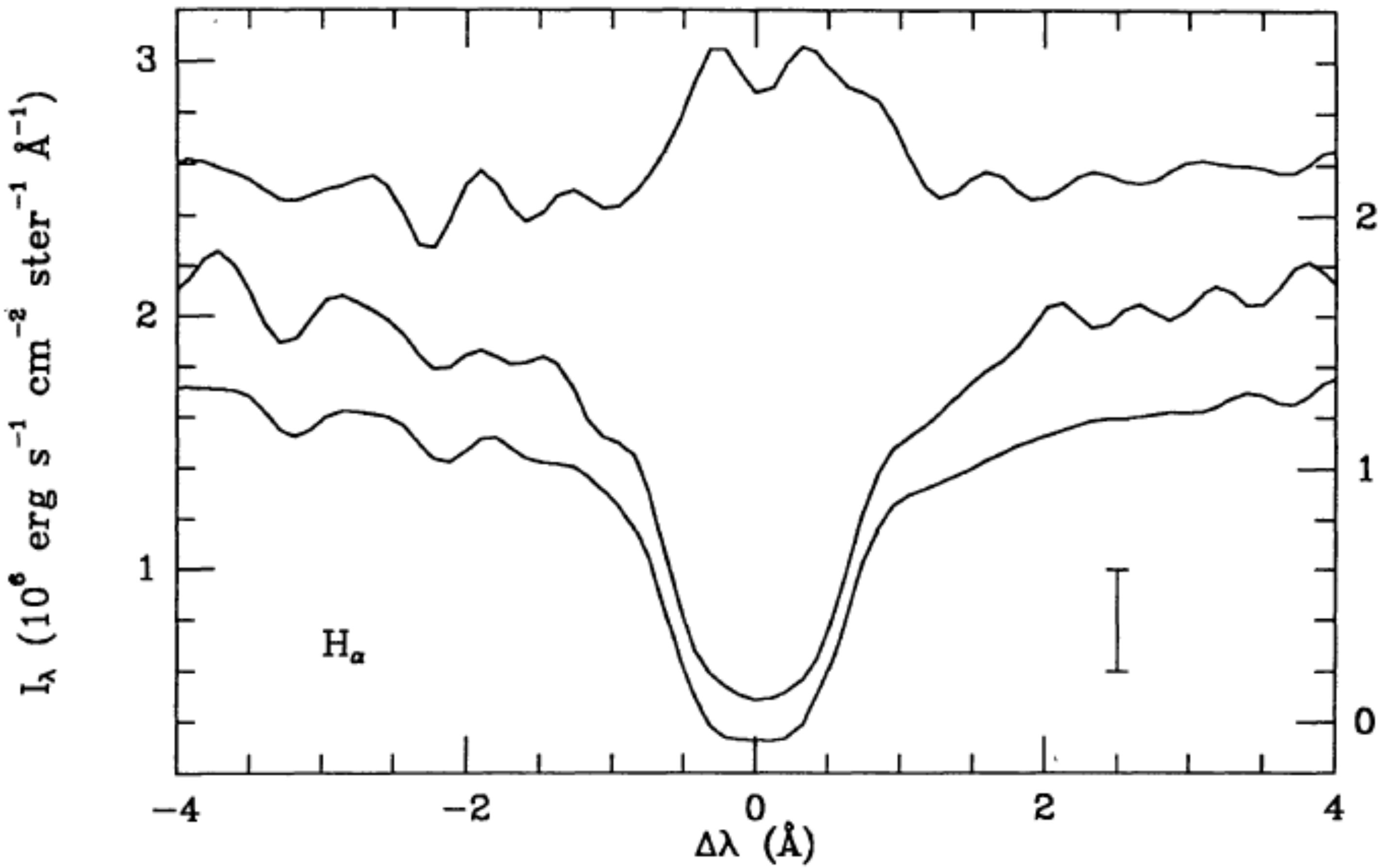

Druzice GOES 17.1.2005
Tok (W/m^2)
0,00040
0,00035
0,00030
0,00025
0,00020
0,00015
0,00010
0,00005
0,00000
80000
90000
100000
110000
120000
130000
140000
150000
Cas (hh:mm:ss)

White-light X-flare (Coimbra)
August 9, 2011



Semi-empirical models of Machado et al. (1980)

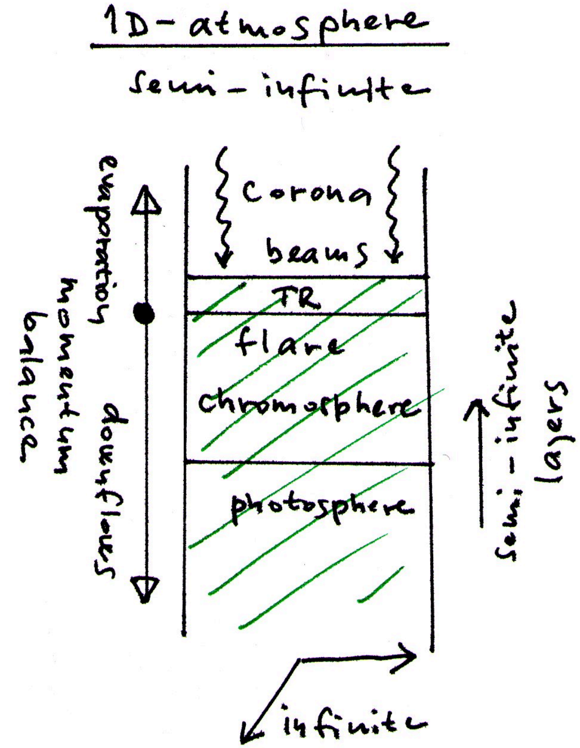


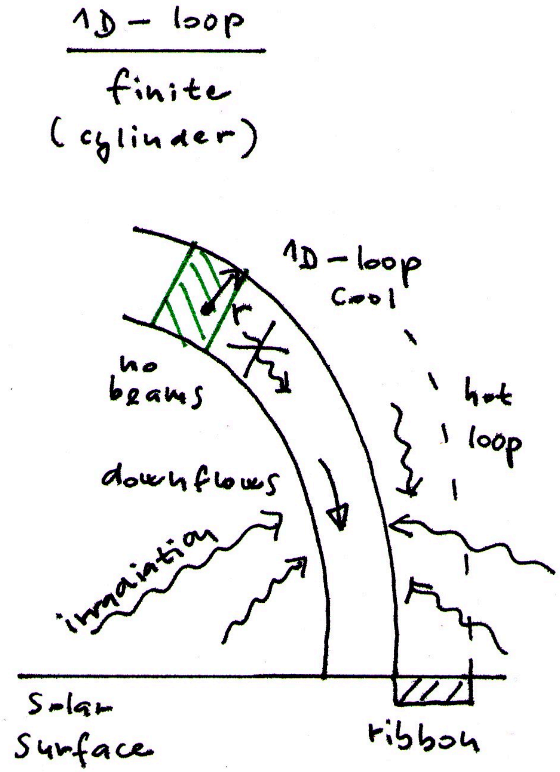


3
2
1
2
1
0
I_λ (10^6 erg s^{-1} cm^{-2} ster^{-1} Å^{-1})
H_α
−4
−2
0
2
4
Δλ (Å)

ribbons vs. loops (cool)

(cartoon)





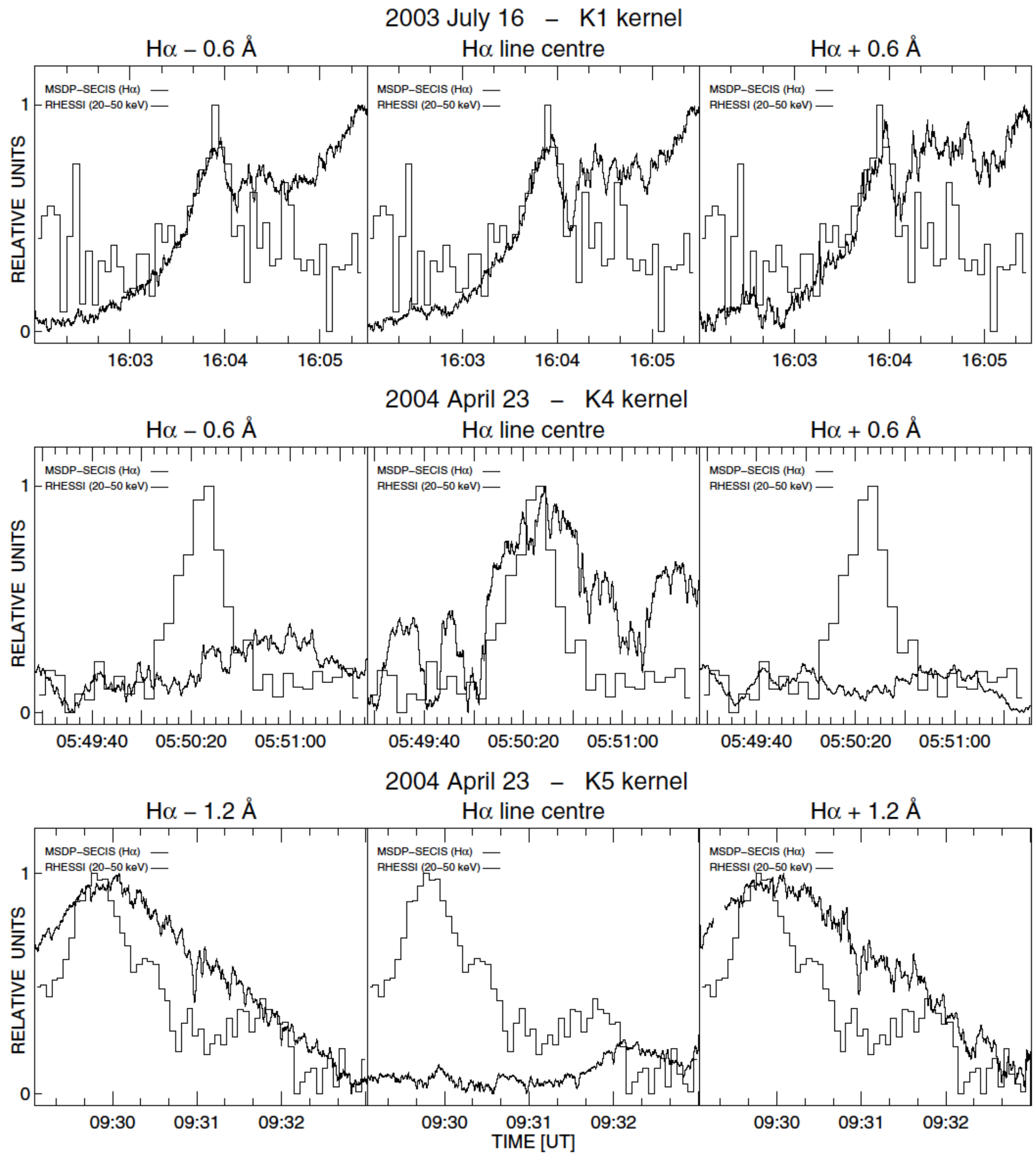
ribbons

loops

radiation transport

vertically (irradiation from corona)

radially (irradiation from corona + surface)



Radziszewski et. (2007, 2011)

Set of 1D plane-parallel equations of RHD

The plane-parallel equations of radiation hydrodynamics are the equations of mass conservation,

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho v}{\partial z} = 0 , \quad (1)$$

momentum conservation,

$$\frac{\partial \rho v}{\partial t} + \frac{\partial \rho v^2}{\partial z} + \frac{\partial}{\partial z}(p + q_v) + \rho g = 0 , \quad (2)$$

and internal energy conservation,

$$\frac{\partial \rho e}{\partial t} + \frac{\partial \rho v e}{\partial z} + (p + q_v)\frac{\partial v}{\partial z} + \frac{\partial}{\partial z}(F_c + F_r) - Q = 0 , \quad (3)$$

along with the level population equation

$$\frac{\partial n_i}{\partial t} + \frac{\partial n_i v}{\partial z} - \left(\sum_{j \neq i}^{N'} n_j P_{ji} - n_i \sum_{j \neq i}^{N'} P_{ij}\right) = 0 , \quad (4)$$

and the equation of radiative transfer

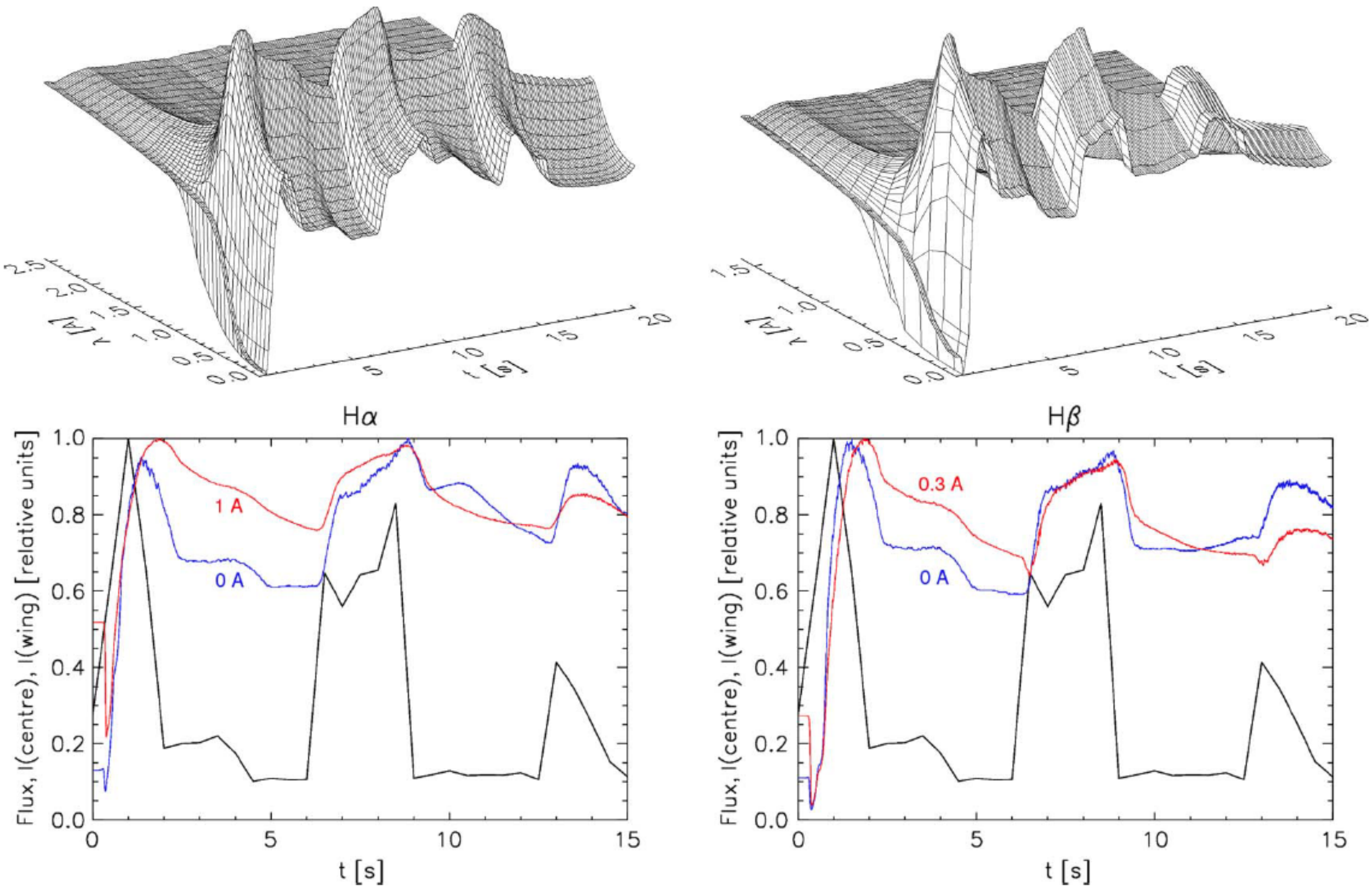
$$\mu \frac{\partial I_{\nu\mu}}{\partial z} = \eta_{\nu\mu} - \chi_{\nu\mu} I_{\nu\mu} . \quad (5)$$

- **RHD codes:**
- **RADYN (Oslo, UW)**
- **HYBRID (Ondrejov)**

beam heating

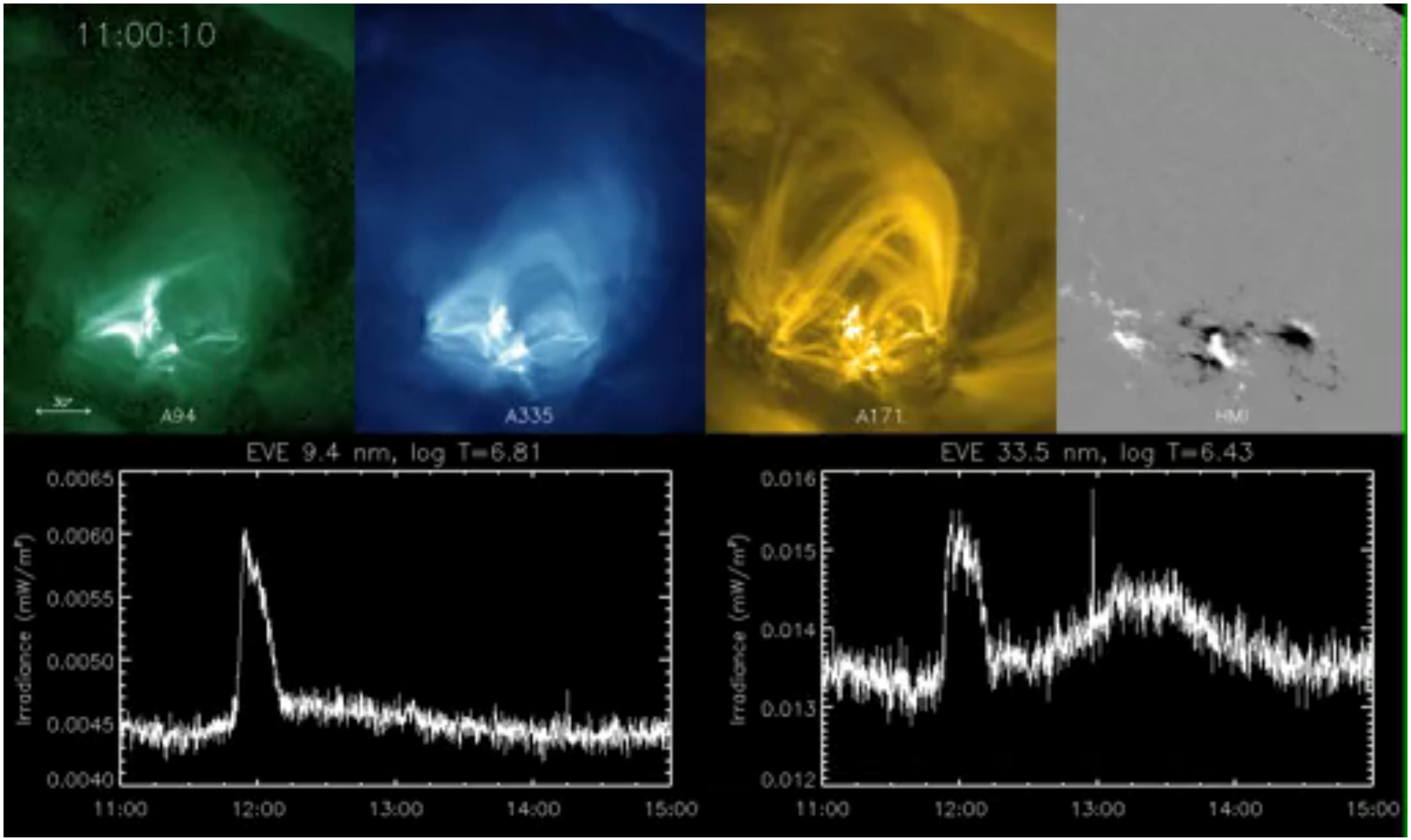
non-thermal coll. rates

Simulations with the HYBRID code



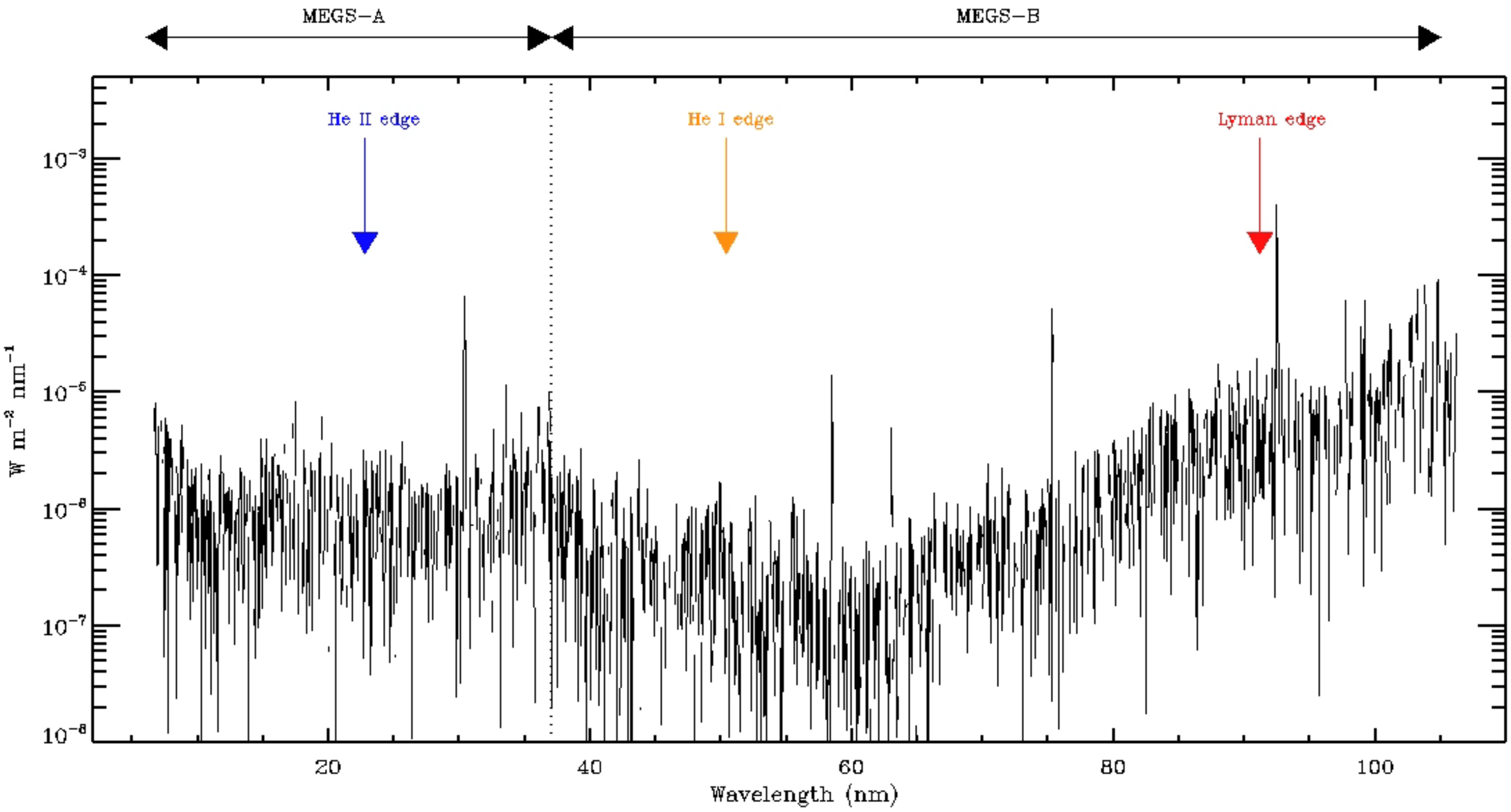
Varady et al. (2010)

EVE flare spectrum in SDO/AIA channels



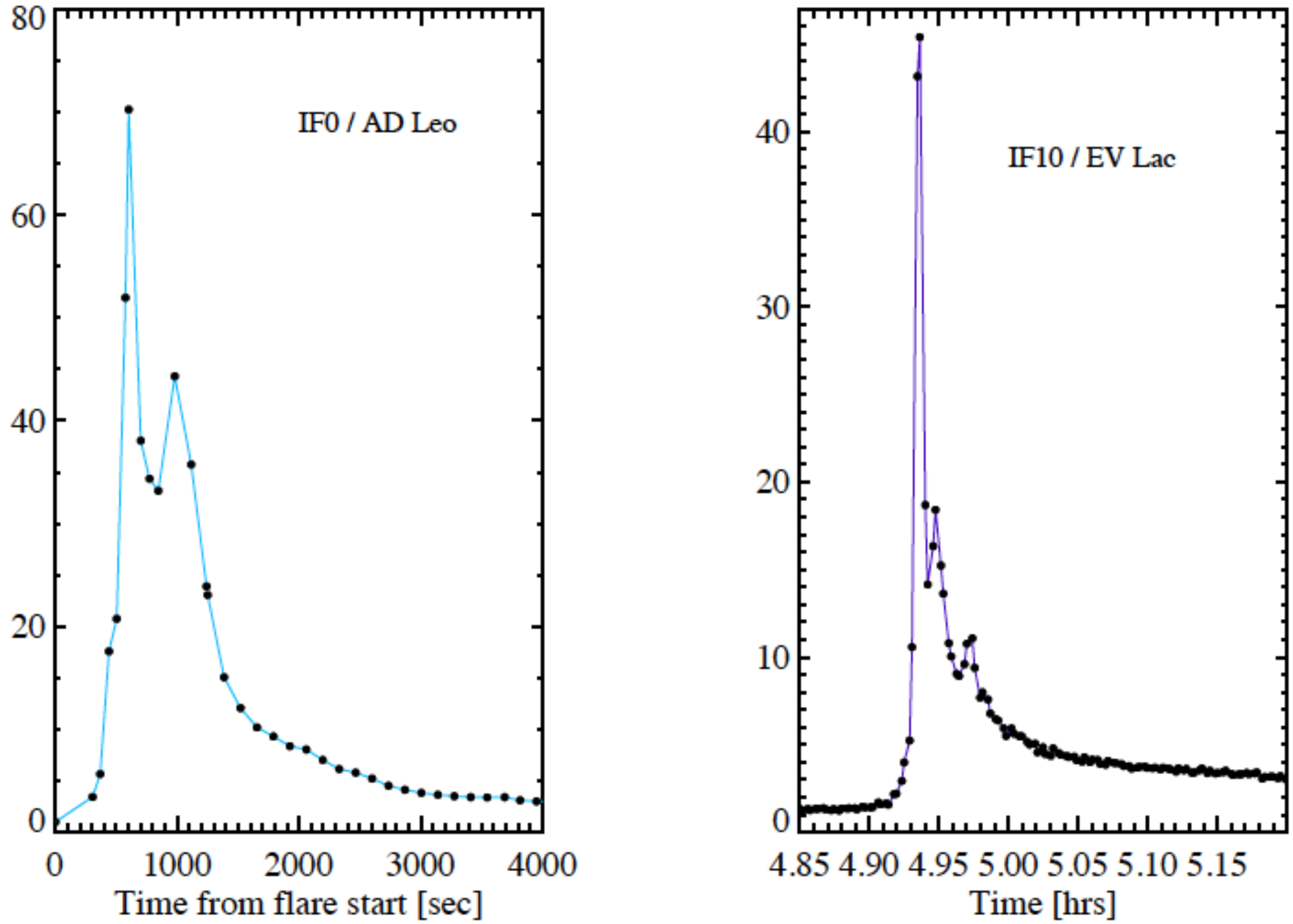
SDO/EVE: total solar irradiance (Sun-as-a-star)

15 Feb 2011 X-class flare (difference spectrum)



dMe flare stars

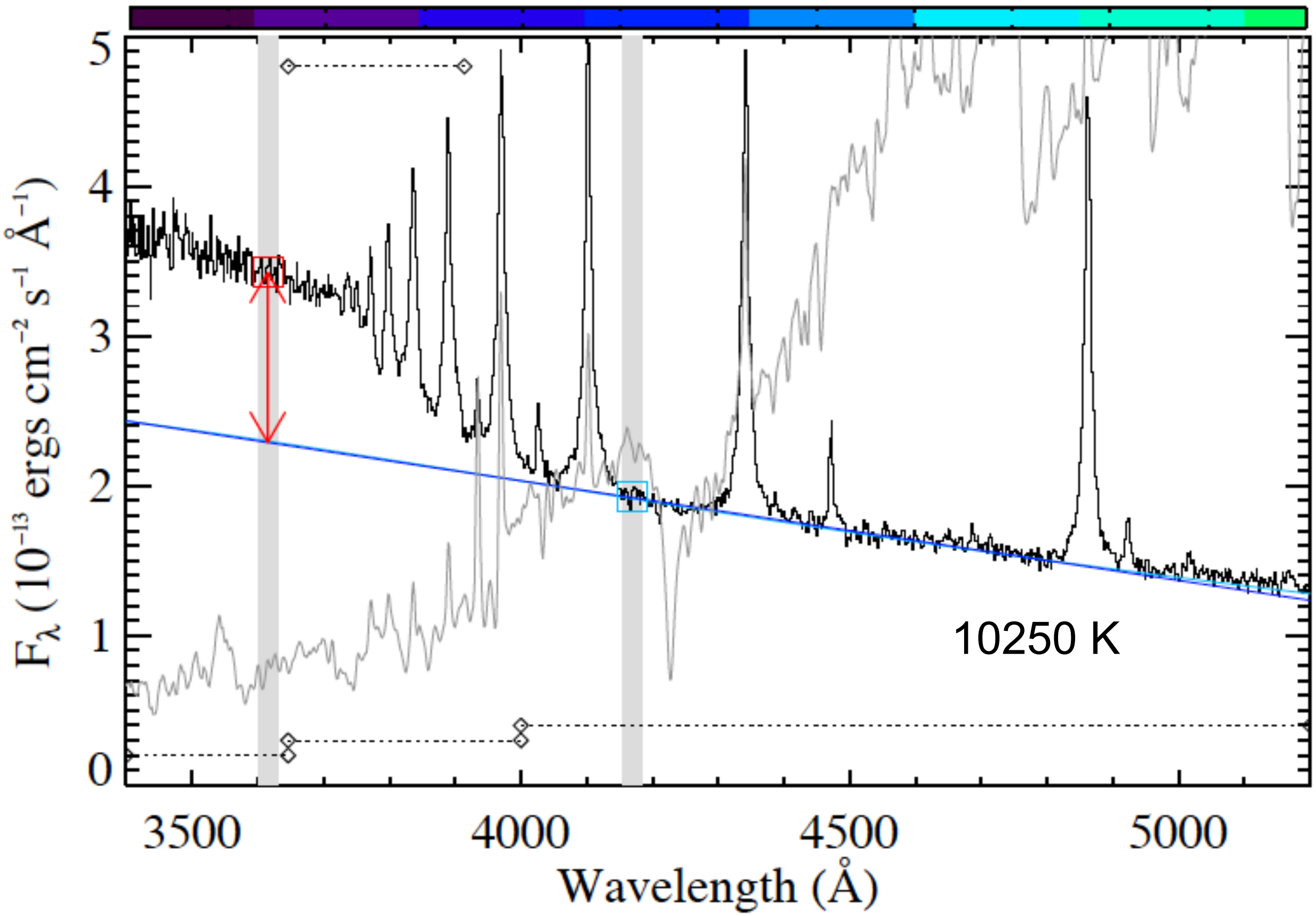
Name	Spectral type	Position (ep=J2000)	Fluxes (mag)
EV Lac	M4.5Ve	Ra = 22 46 49.7317 Dec = +44 20 02.3569	U = 13,000 B = 11,450 V = 10,090
YZ CMi	M4.5Ve	Ra = 07 44 40.17401 Dec = +03 33 08.8350	U = 13,761 B = 12,831 V = 11,225
AD Leo	M4.5Ve	Ra = 10 19 36.277 Dec = +19 52 12.06	U = 12,000 B = 10,970 V = 9,430
V711 Tau		Ra = 03 36 47,3 Dec = +00 35 15,9	B = 6,800 V = 5,905
V773 Tau (HD 283447)		Ra = 04 14 12.92168 Dec = +28 12 12.2960	U = 13,160 B = 11,800 V = 10,700



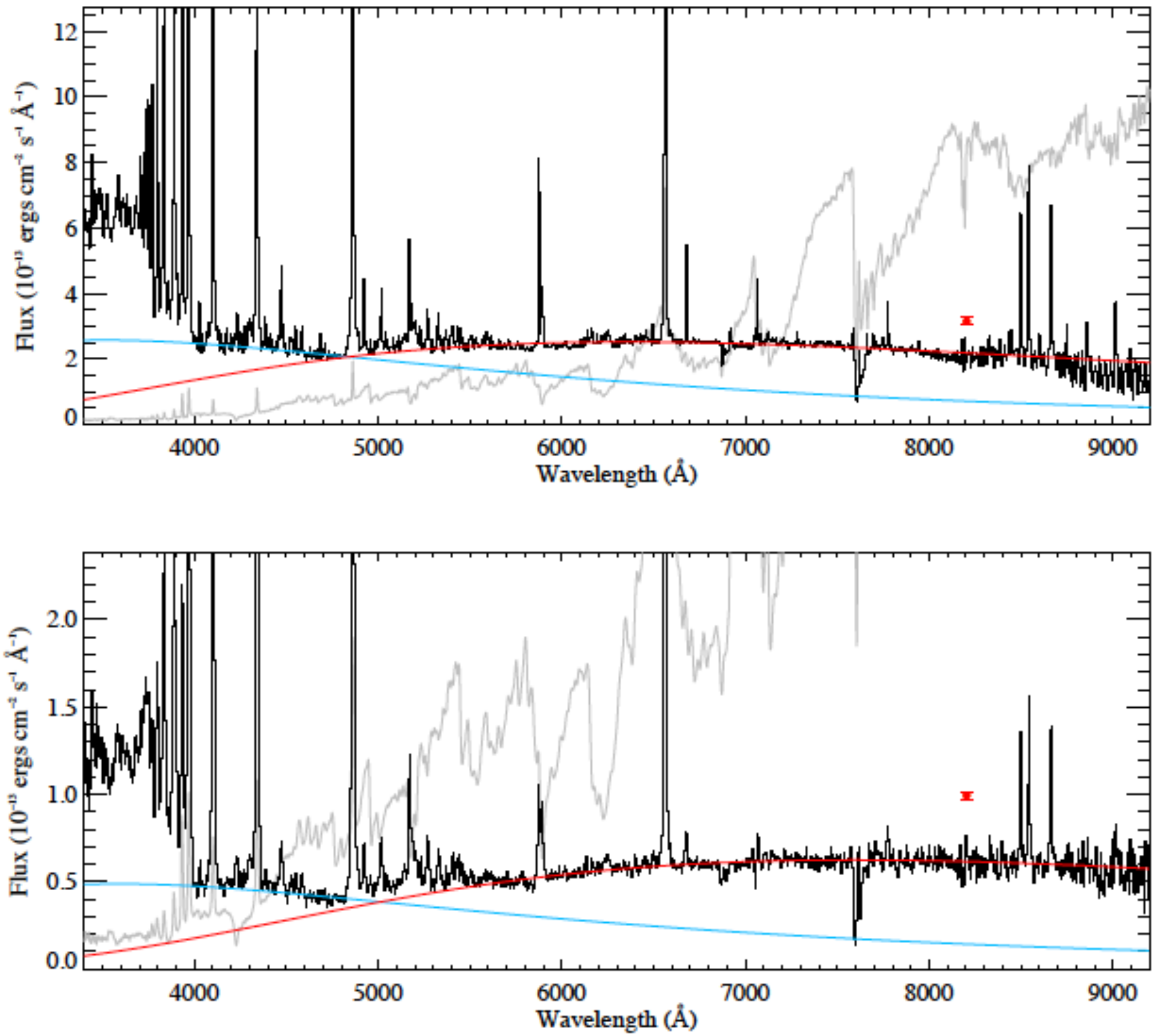
A. Kowalski (2012) – PhD thesis

APO – 3.5m telescope

AD Leo

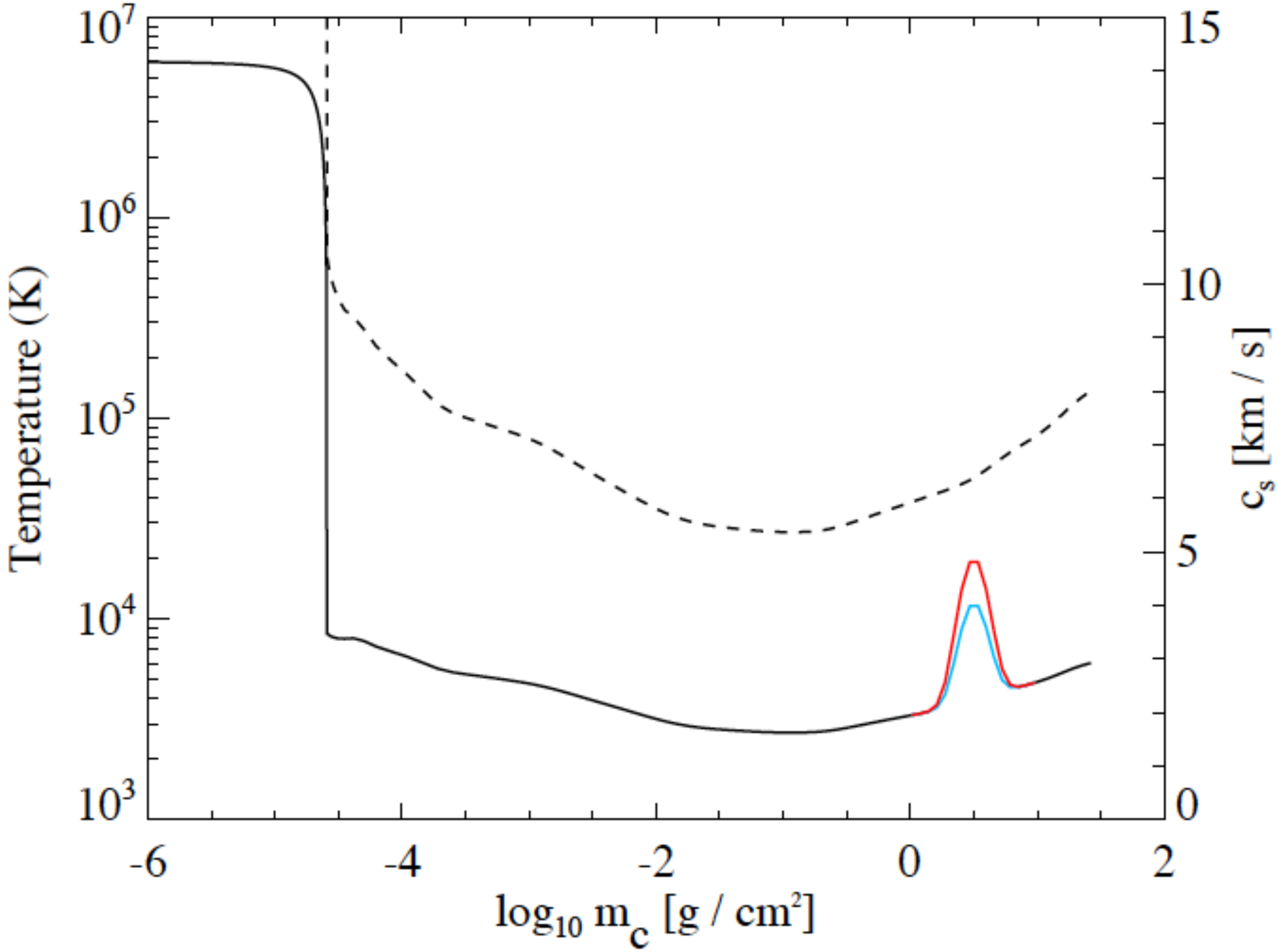


Kowalski (2012)

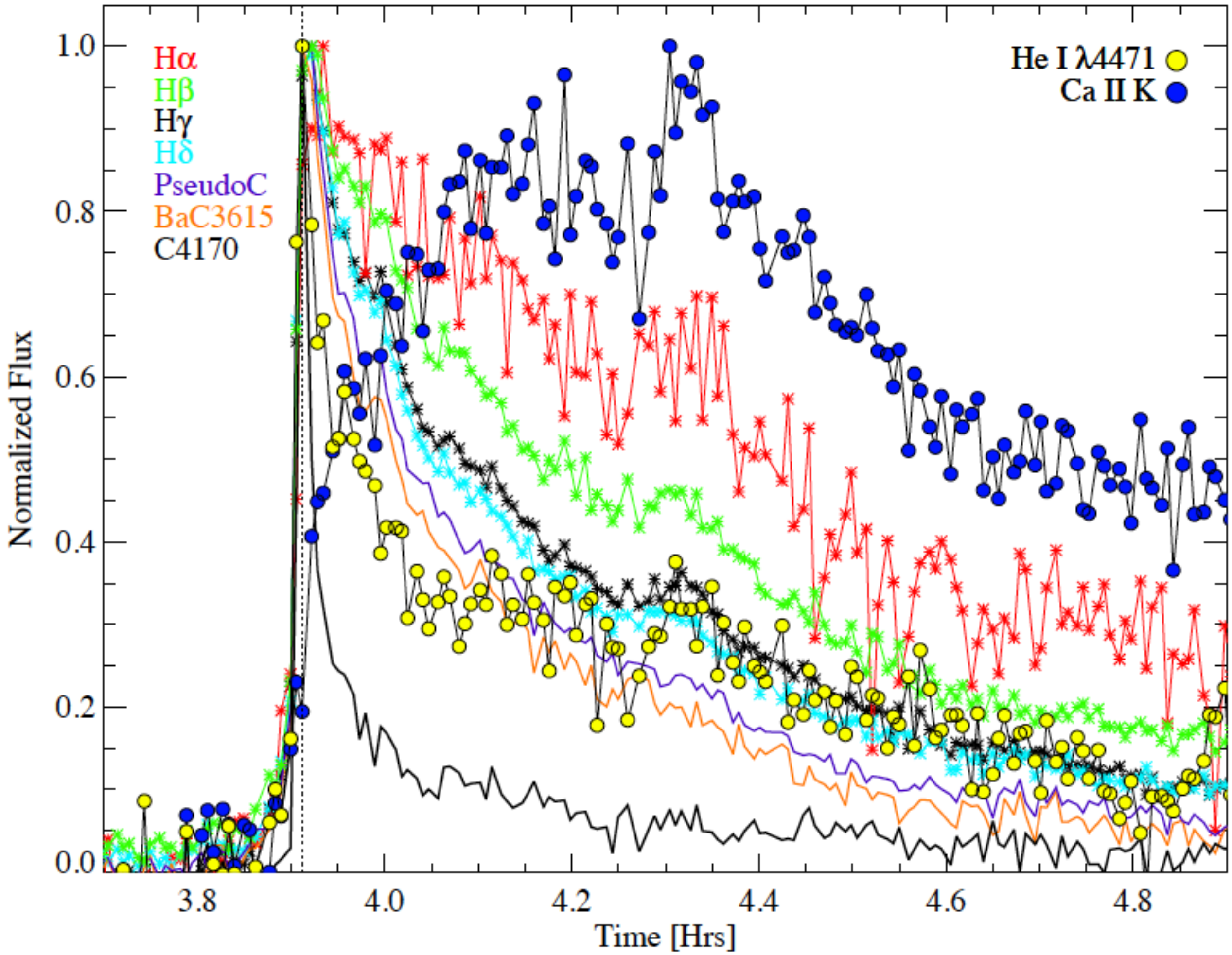


Flux (10^−15 ergs cm^−2 s^−1 Å^−1)
Wavelength (Å)
Flux (10^−15 ergs cm^−2 s^−1 Å^−1)
Wavelength (Å)

‘Hot-spot’ model of the WL continuum (Kowalski 2012)

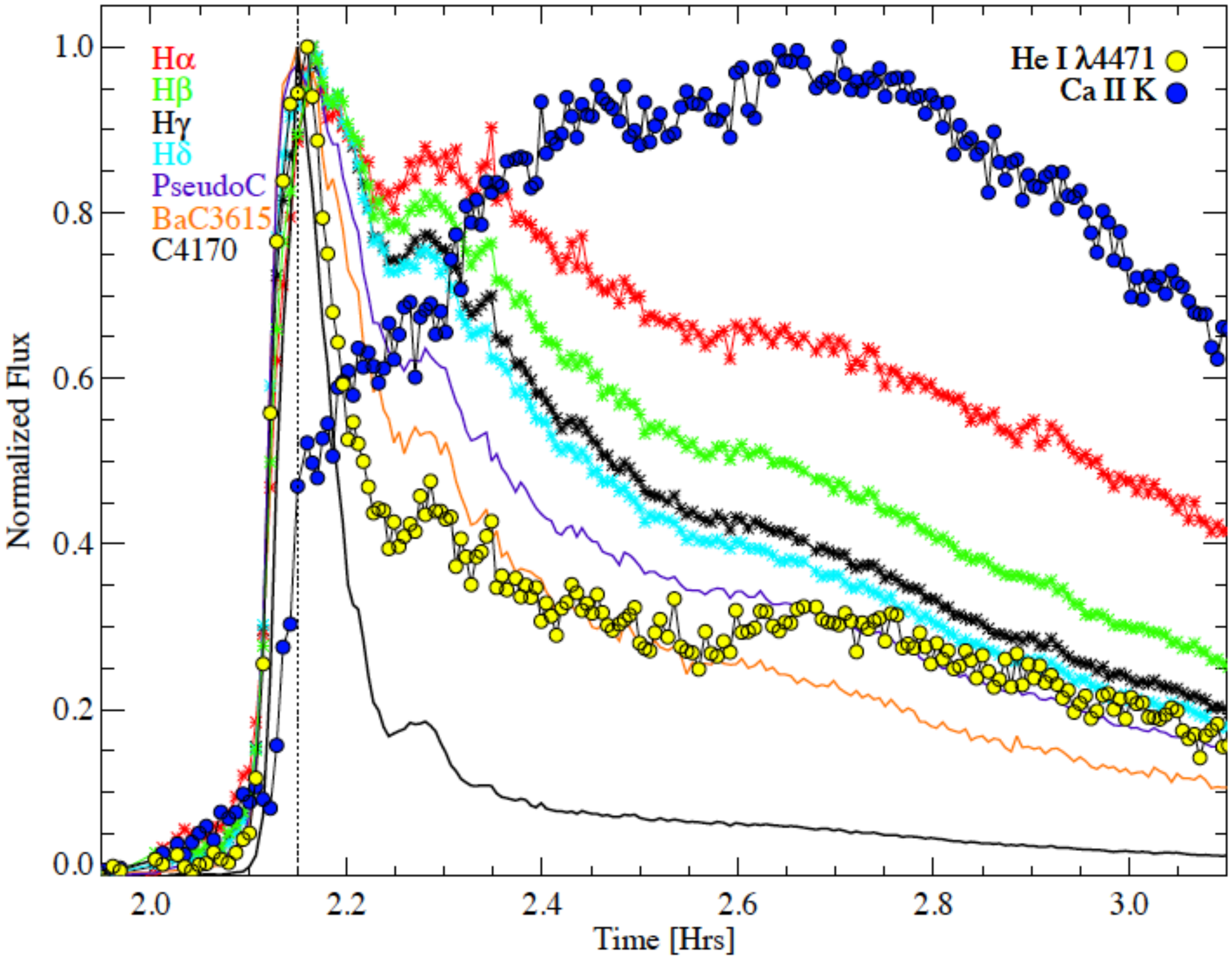


AD Leo

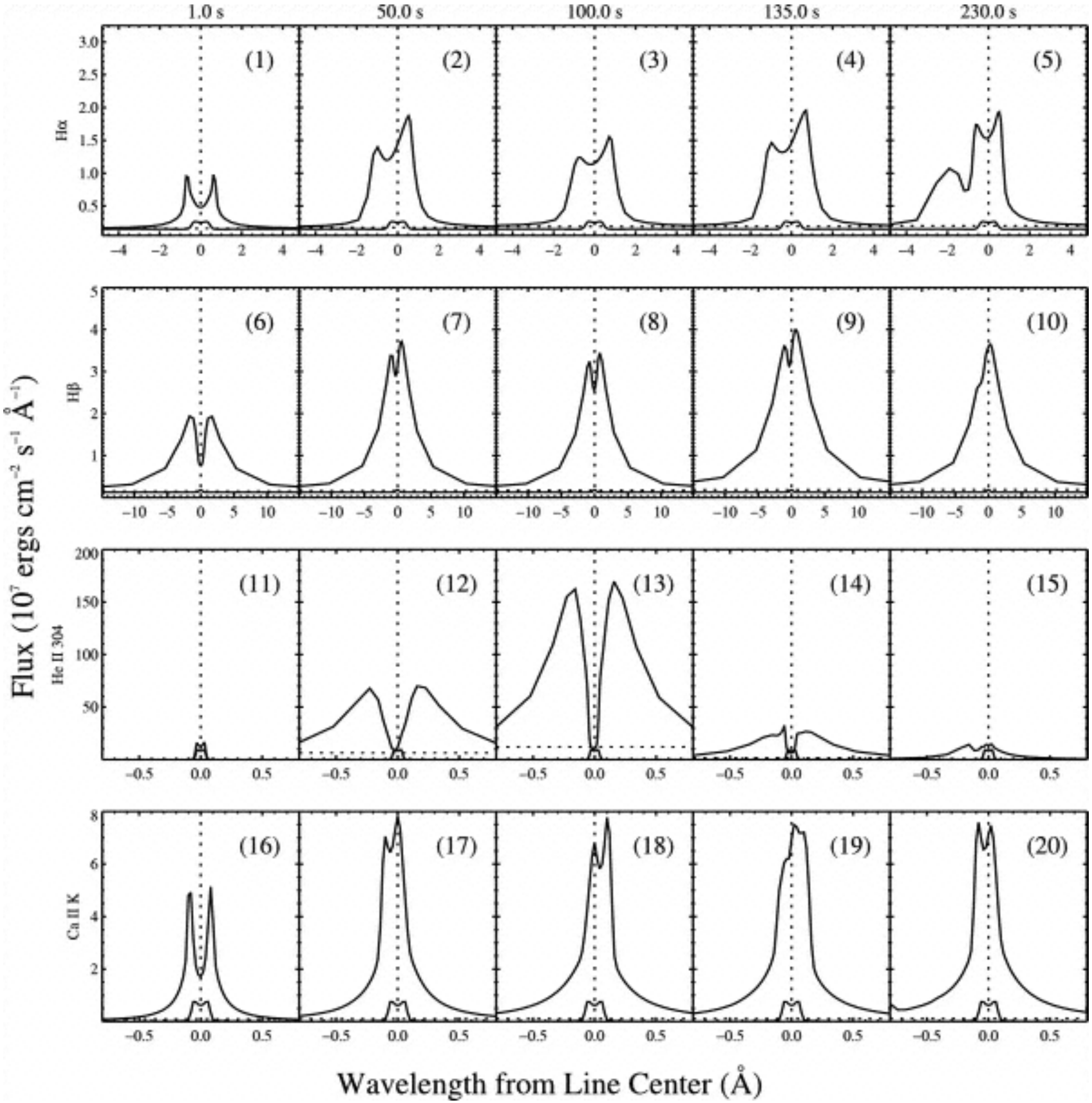


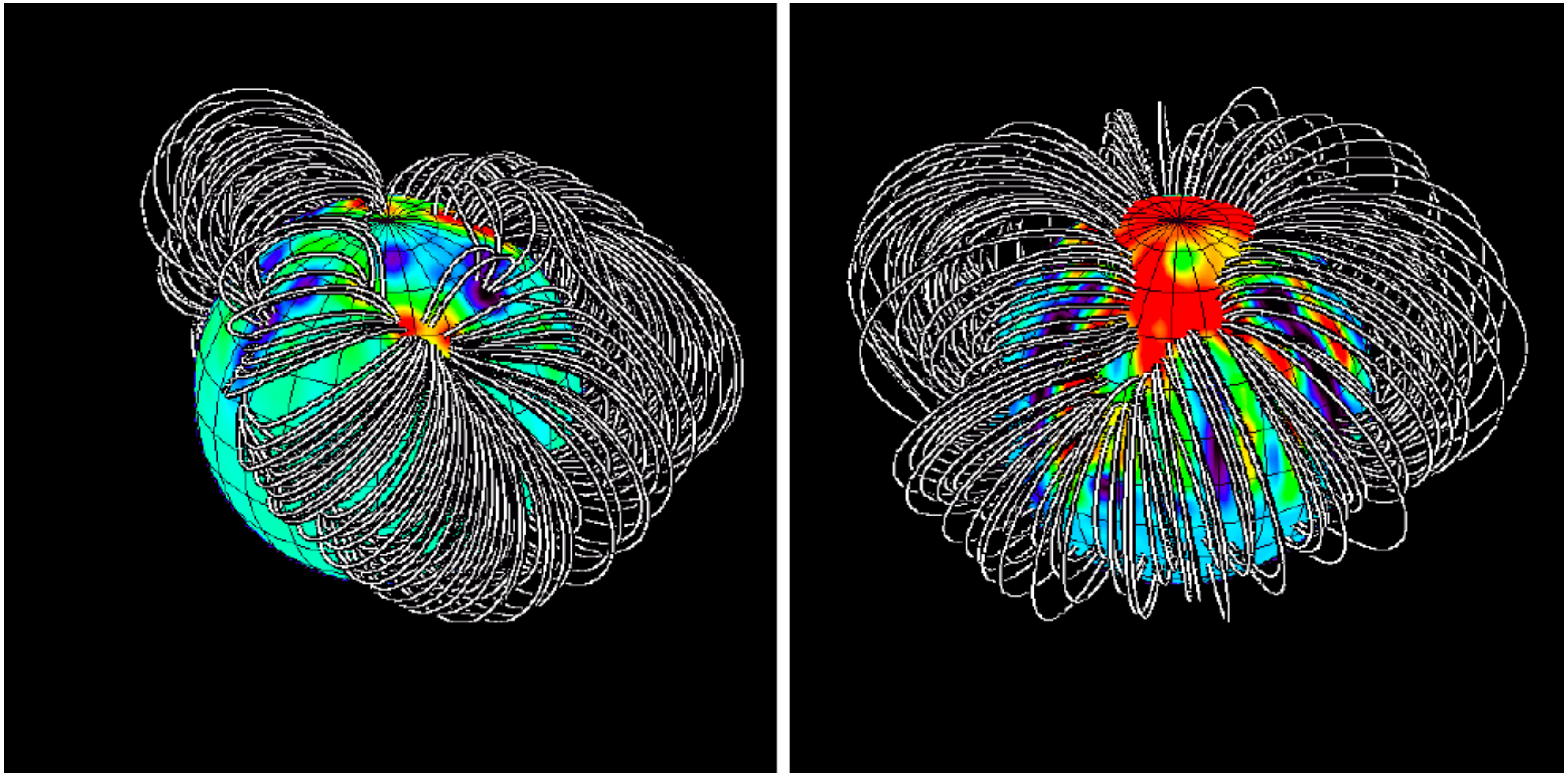
Hα
Hβ
Hγ
Hδ
PseudoC
BaC3615
C4170
He I λ4471
Ca II K
Normalized Flux
Time [Hrs]
0.0
0.2
0.4
0.6
0.8
1.0
3.8
4.0
4.2
4.4
4.6
4.8

YZ CMi



Hα
Hβ
Hγ
Hδ
PseudoC
BaC3615
C4170
He I λ4471
Ca II K
Normalized Flux
Time [Hrs]
0.0
0.2
0.4
0.6
0.8
1.0
2.0
2.2
2.4
2.6
2.8
3.0


1.0 s
50.0 s
100.0 s
135.0 s
230.0 s
Hα
Hβ
He II 304
Ca II K
Flux (10^7 ergs cm^-2 s^-1 Å^-1)
Wavelength from Line Center (Å)
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
(11)
(12)
(13)
(14)
(15)
(16)
(17)
(18)
(19)
(20)



Ondřejov Observatory 2-m Telescope

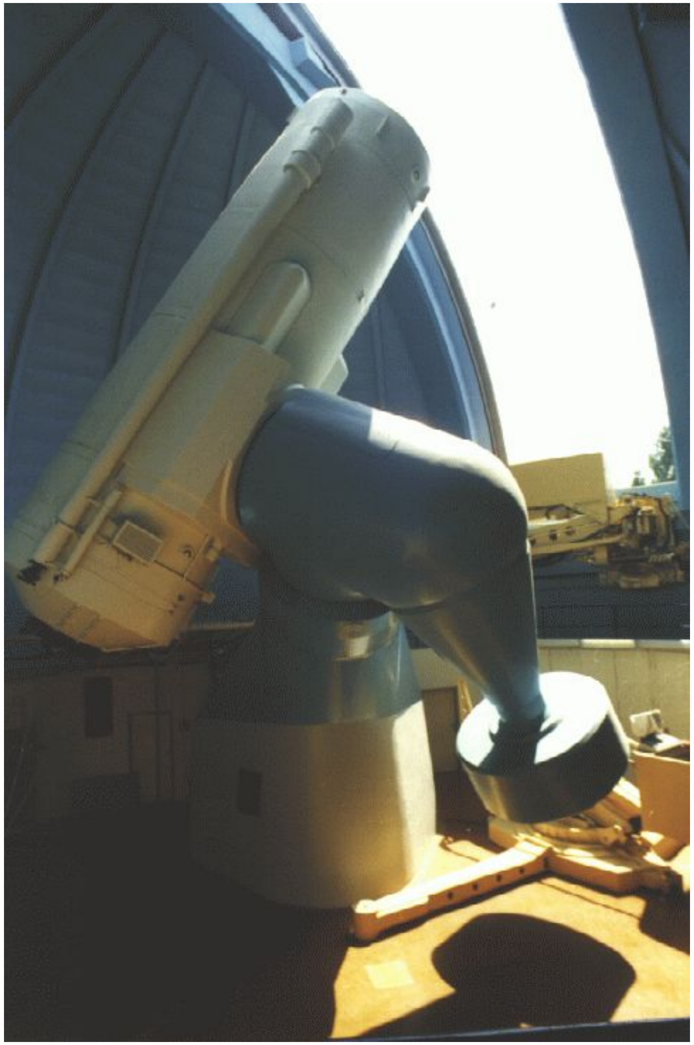
- The 2-meter telescope is in operation since 1967.
- Two cameras:

  400 mm (low dispersion)

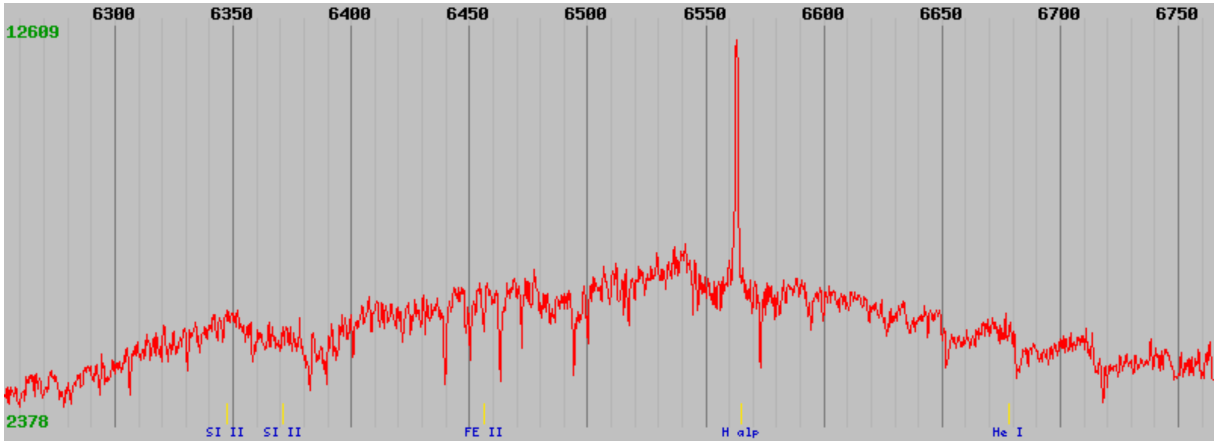
  700 mm (medium dispersion)
- Spectral region 4000Å - 7000Å

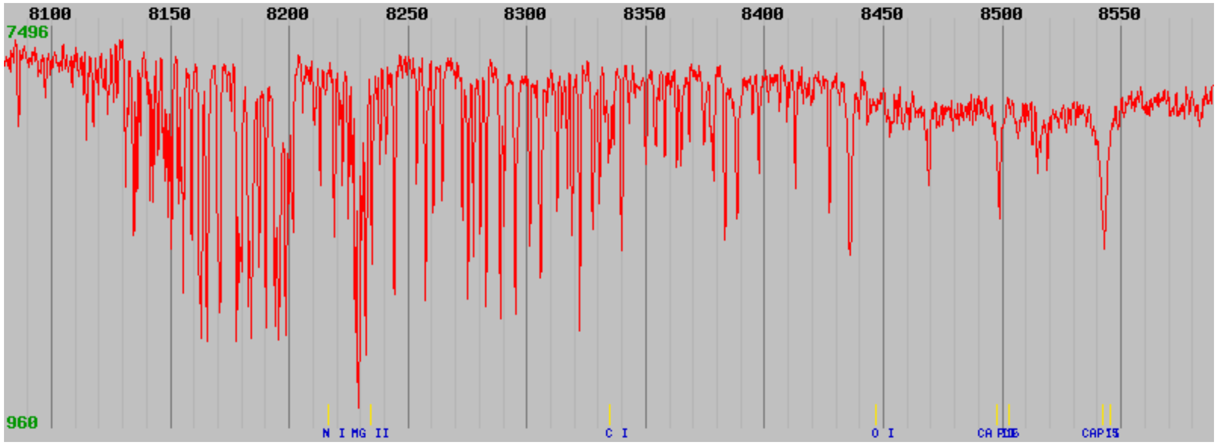
- Telescope parameters:

Primary mirror:	Diameter:	2m
Focal length:	Primary:	9m
	Cassegrain:	29.16m
	coudé:	63.5m
Mounting:	Equatorial	

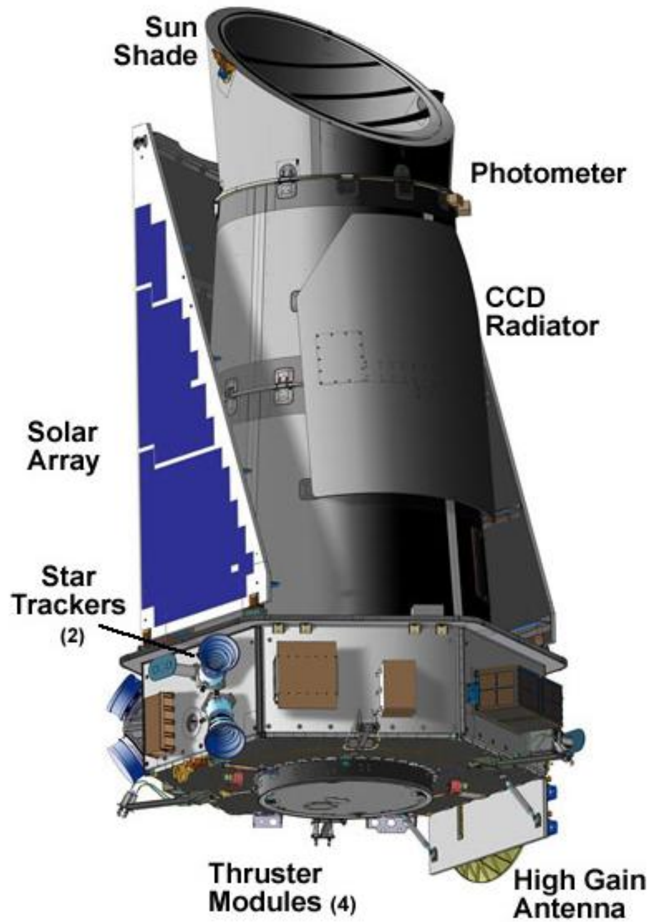


Quiescent spectra of V1054 Oph
Ondrejov 2m telescope

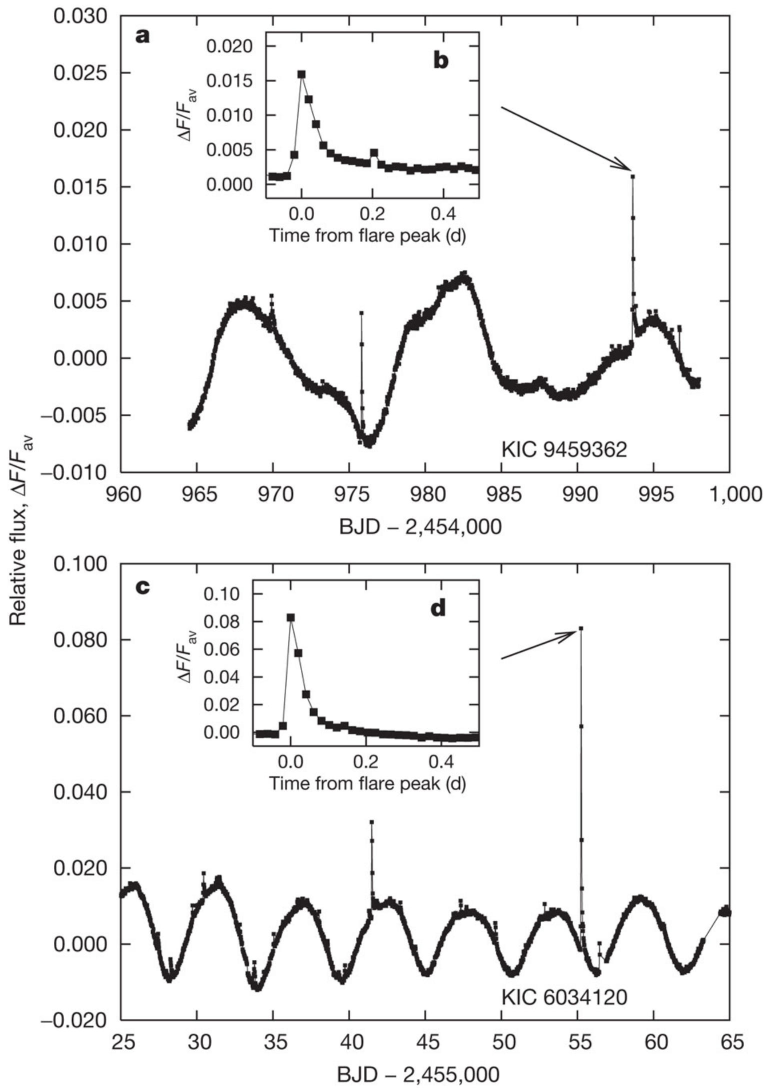




NASA Kepler Mission



Kepler discovery of super flares on solar-type stars



Light curves for different lines

- **CaII K peaks tens of minutes behind other lines and continua**
- **This was not observed on the Sun**
- **Can be effect of a mixture of ribbons and loops**
- **1D RHD simulations provide only vertical view of the ribbons, not any side view of the bright loops**
- **dMe stars are cool (T_{eff} much lower than solar), but exhibit quiescent emission in some lines like hydrogen Hα and CaII**

Further systematic observations of flares on M-dwarf and solar-type stars are required, followed by fully 3D simulations of the flare evolution.

But even 1D simulations were not yet quantitatively compared to current high-resolution and high-cadence spectral observations of solar and stellar flares !