Flares in Time-Domain Surveys

A splinter session convened in Uppsala, Sweden on 07 June 2016 at Cool Stars 19

Science Organizing Committee: Adam Kowalski (University of Maryland/NASA GSFC), Suzanne Hawley (University of Washington), James Davenport (Western Washington University), Arkadiusz Berlicki (University of Wroclaw), Gianna Cauzzi (INAF), Lyndsay Fletcher (University of Glasgow), Petr Heinzel (Academy of Sciences of the Czech Republic)

Presenters: James Davenport (Western Washington University), Yuta Notsu (Kyoto University), Parke Loyd (University of Colorado), Juan Carlos Martinez Oliveros (University of California, Berkeley), Chloe Pugh (University of Warwick), Petr Heinzel (Academy of Sciences of the Czech Republic), Sarah Jane Schmidt (Leibniz Institute for Astrophysics Potsdam), Subhajeet Karmakar (Aryabhatta Research Institute of Observational Sciences), John Pye (University of Leicester), Arkadiusz Berlicki (University of Wroclaw), Ettore Flaccomio (INAF - Osservatorio Astronomico di Palermo), Suzanne Hawley (University of Washington)

Scientific Motivation

The goal of this splinter session was to identify outstanding questions in solar and stellar flare physics that can be addressed in novel ways using the large volume of flare observations in past, current, and future surveys.

Stellar flares are often the dominant source of transient variability in time-domain surveys. Critical aspects of the flare paradigm and dynamo mechanism have been revealed by serendipitous observations in recent large scale surveys (e.g. Kepler, SDSS). Discoveries such as flare rates from inactive stars and “superflares” from field G dwarfs have been enabled by surveys with long monitoring baselines and/or large spatial extents that reveal very rare events. Several existing surveys (e.g., Galex, MEarth, PTF, PanSTARRS, WASP) also offer rich samples of flaring sources. Gaia, TESS, ZTF, and LSST, will open additional new avenues for stellar flare research in the future, such as determining flare rates over cosmic time, the maximum energy of flares, and flare impacts on planet habitability and biomarker detection.

It is also an exciting time for solar flare research, with enormous databases from full-disk monitoring satellites such as SOHO and SDO, a new emphasis on the importance of solar chromospheric emission during flares (e.g. F-CHROMA), and the upcoming capabilities of the DKIST. Solar physicists have been at the forefront of analyzing large volumes of high time resolution data for decades, which can inform stellar flare investigations, and improve the standard solar flare model. The connection between flare activity and the underlying magnetic field seen on the Sun can also constrain stellar flare models. However, many important aspects of solar flares are not yet well-characterized observationally, in particular the spectral energy distribution of white-light emission that constitutes the majority of radiated energy. The wealth of data from these surveys will better determine the role of solar flares in generating our own space weather, and have implications for the severity and conditions that characterize stellar space weather.

Our splinter consisted of both invited and contributed talks, and a round table discussion moderated by members of the SOC. This splinter session was timely because many existing solar and stellar surveys have not been fully utilized, and new projects such as Gaia and the DKIST will soon provide enormous amounts of public data on the transient sky and the Sun that can be mined for flare studies.

Splinter Session Talks and Discussion

The session featured stimulating talks on a wide range of topics in flare research and was well-attended by Cool Stars participants from solar and stellar flare research fields. We engaged in active discussion during the round table and proposed the development of a website that would function as a portal for techniques and methods for analyzing flare data from time-domain surveys. If anyone would like to participate in the development of this web portal, please contact Adam Kowalski at adam.f.kowalski@gmail.com.

The speaker presentations were recorded and posted to YouTube:

- Session 1: https://www.youtube.com/watch?v=3SDwC7tTCSQ
- Session 2: https://www.youtube.com/watch?v=lcW7JrlxQ2o

PDF copies of the talks are contained at the end of this document.

Session 1:

- Invited | James Davenport, The Kepler Catalog of Stellar Flares
- Contributed | Yuta Notsu, Superflares on solar-type stars found from Kepler data
- Contributed | Parke Loyd, FUV Emission Line Flares on M and K Dwarfs in the MUSCLES Survey
- Invited | Juan Carlos Martinez Oliveros, SDO/HMI White-light flares and their associated manifestations
- Contributed | Chloe Pugh, Quasi-Periodic Pulsations in Stellar Flares
- Contributed | Petr Heinzel, On the behavior of light curves of solar and stellar flares

Session 2:

- Invited | Sarah Jane Schmidt, Finding the Largest Flares on Ultracool Dwarfs with ASAS-SN
- Contributed | Subhajeet Karmakar, X-ray Superflares on CC Eri
- Contributed | John Pye, The frequency of dM-star X-ray flares from a large-scale XMM-Newton sample
- Invited | Arkadiusz Berlicki, F-CHROMA project: Observations and modelling of solar flare chromospheres
- Contributed | Ettore Flaccomio, A multi-wavelength view of magnetic flaring from PMS stars
- Contributed | Suzanne Hawley, Recovering Flares in LSST

The Kepler View of Stellar Flares

James R. A. Davenport
@jradavenport

NSF Postdoctoral Fellow
Western Washington University

WESTERN
WASHINGTON UNIVERSITY

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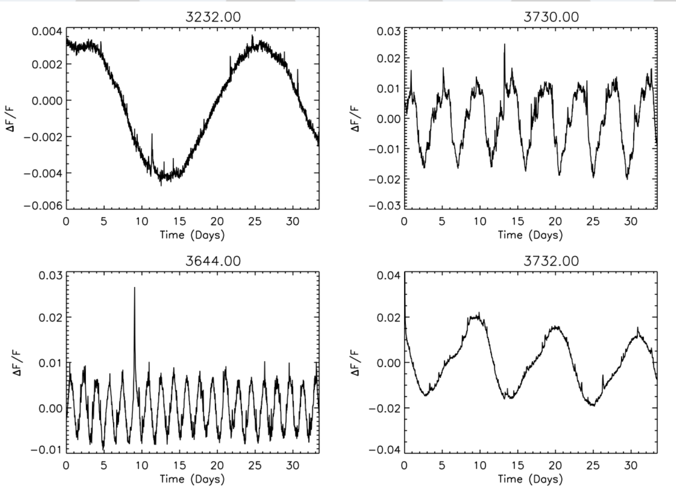
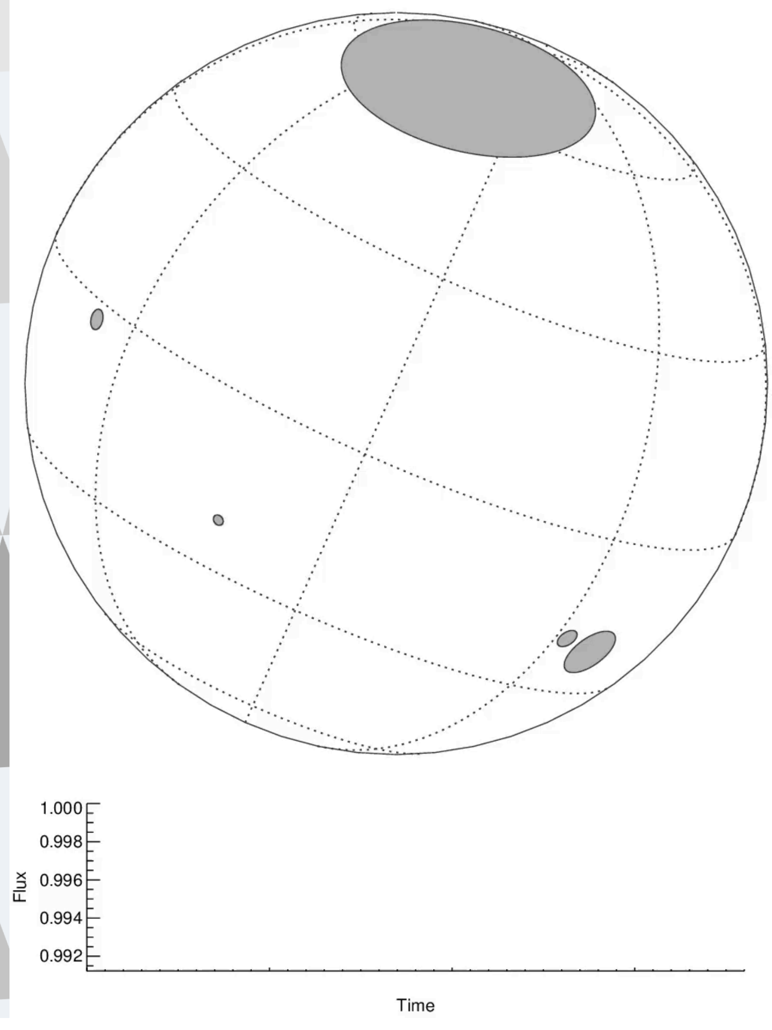
Limited information from *Kepler* light curves…



Walkowicz+ (2011)



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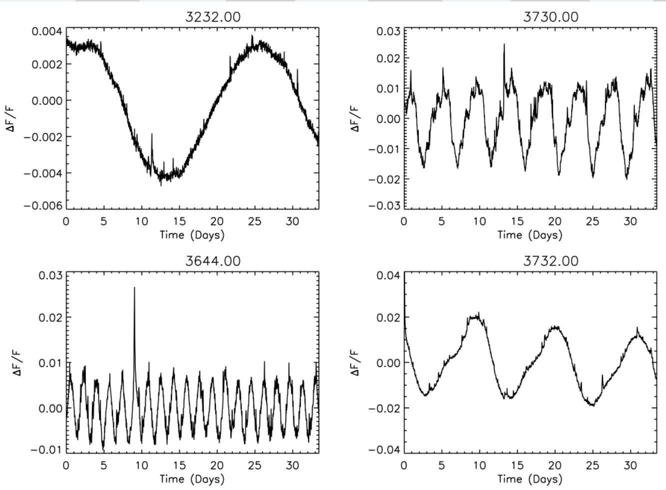

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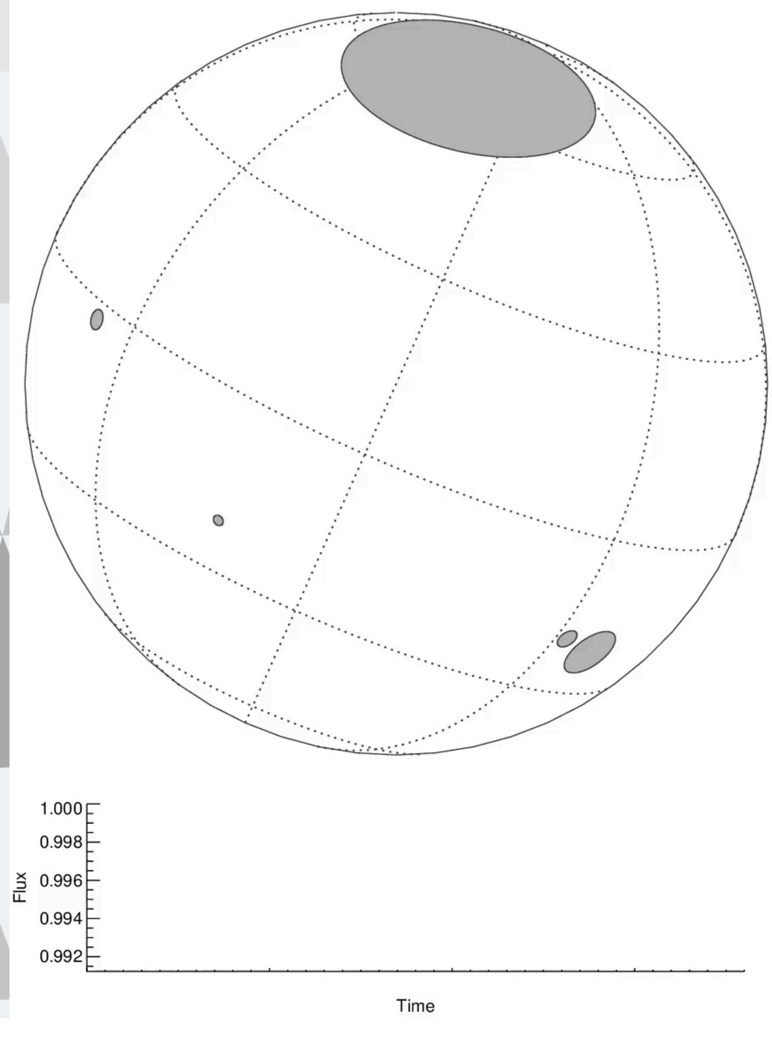

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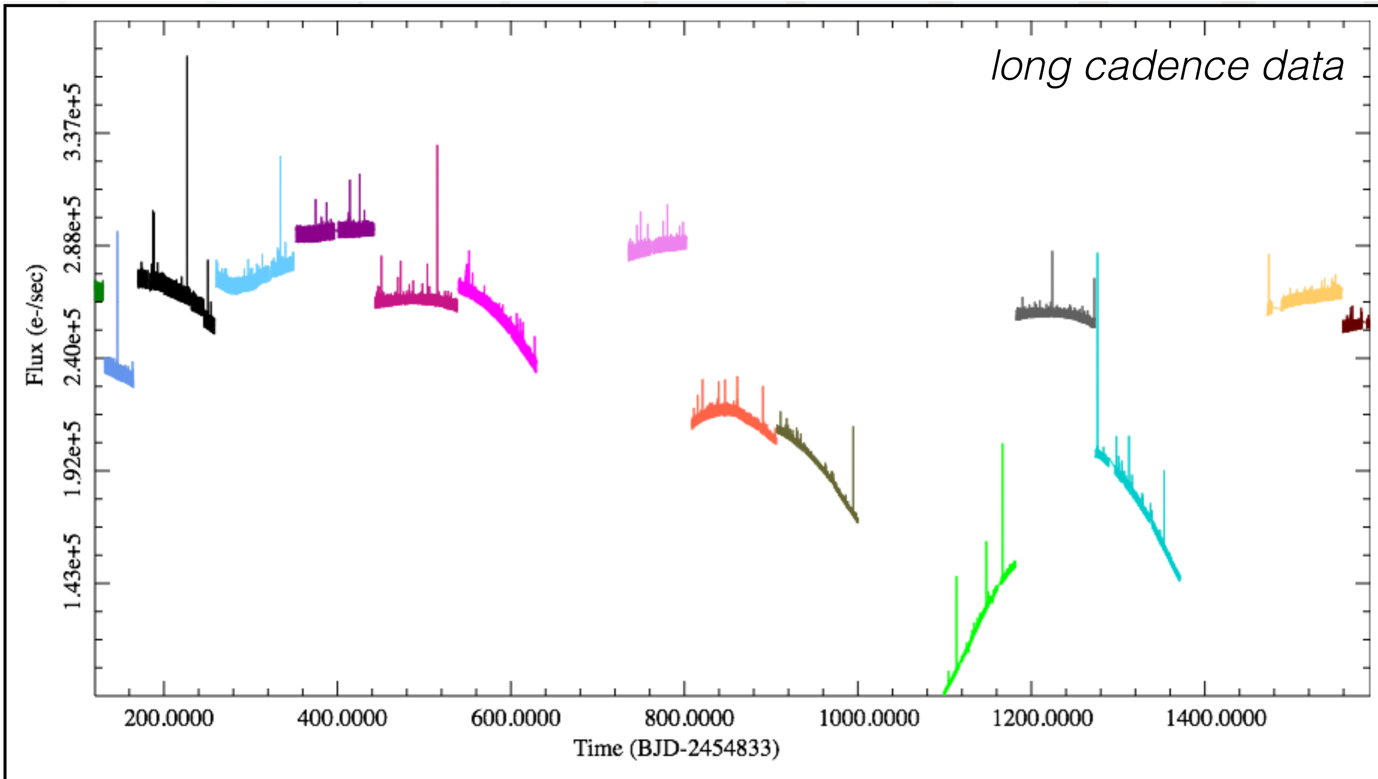

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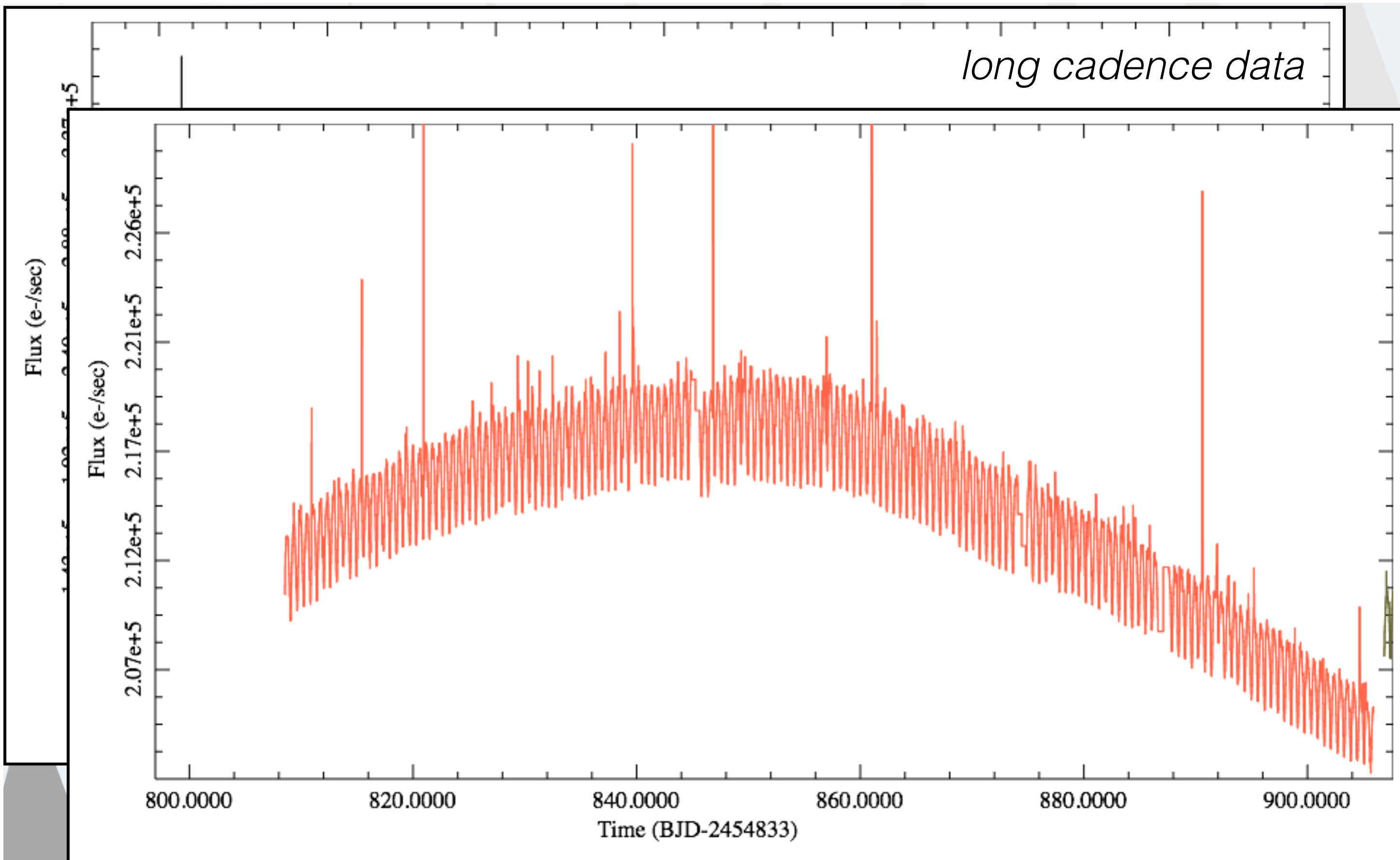
long cadence data
Flux (e-/sec)
Flux (e-/sec)
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2.21e+5
2.17e+5
2.12e+5
2.07e+5
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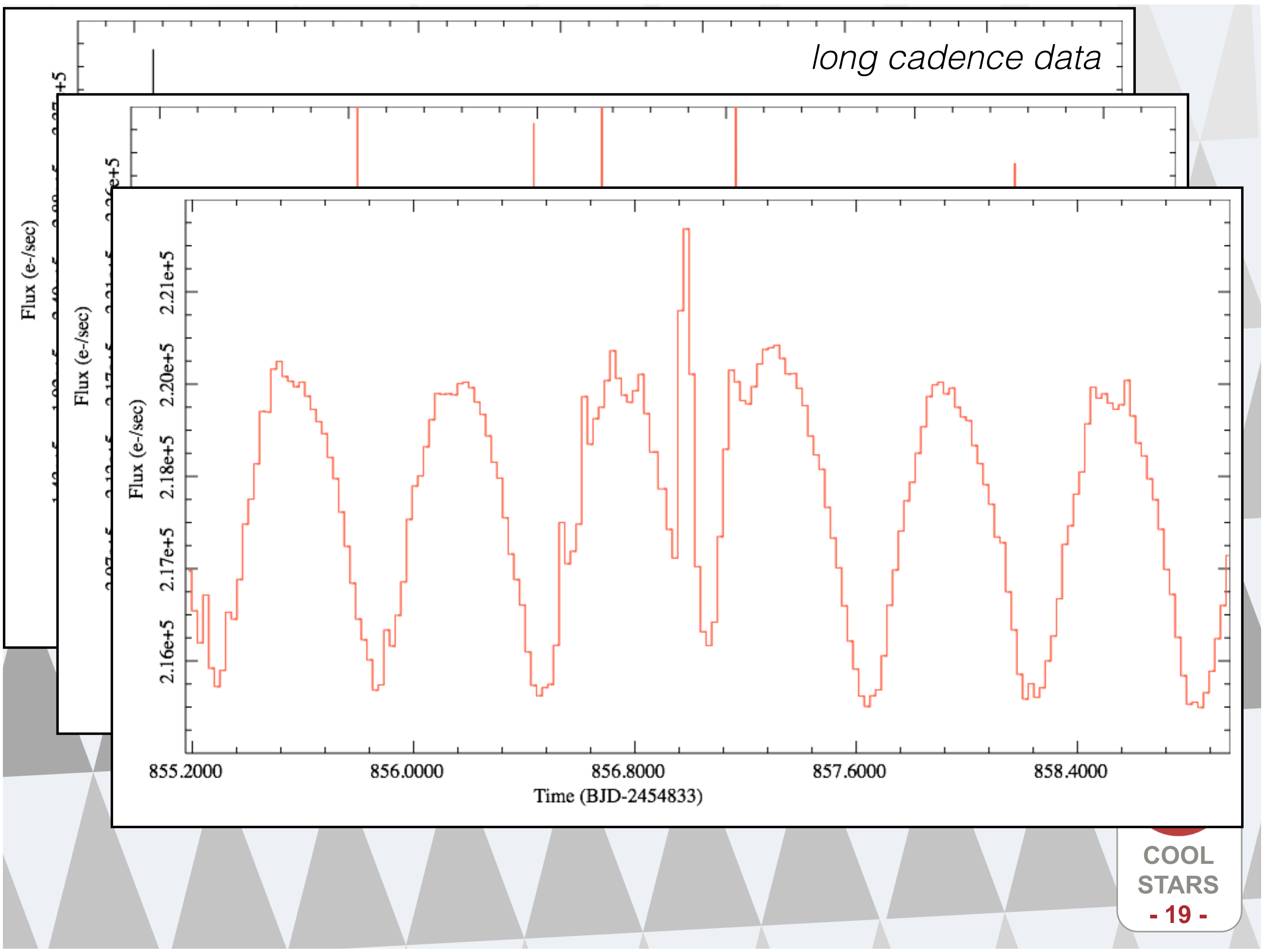
860.0000
880.0000
900.0000
Time (BJD-2454833)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Time (BJD-2454833)
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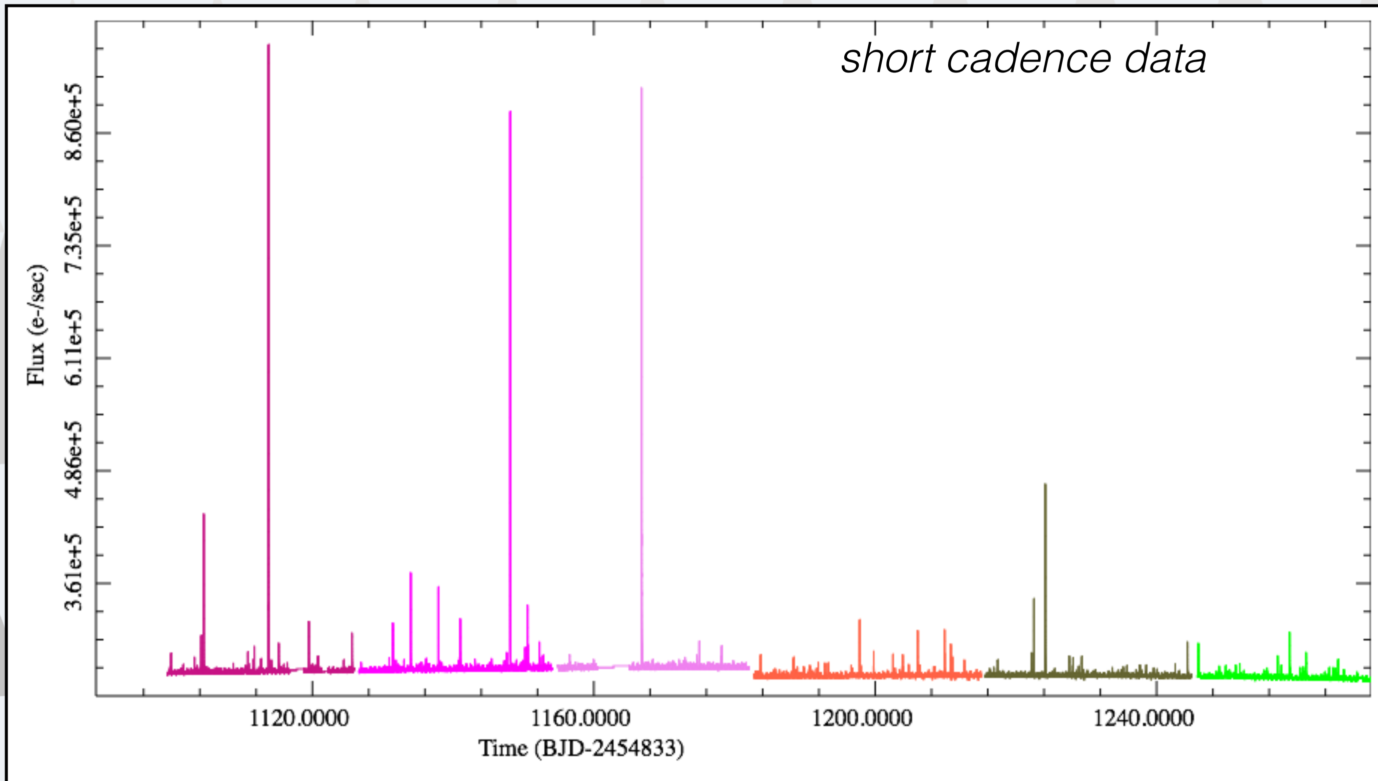
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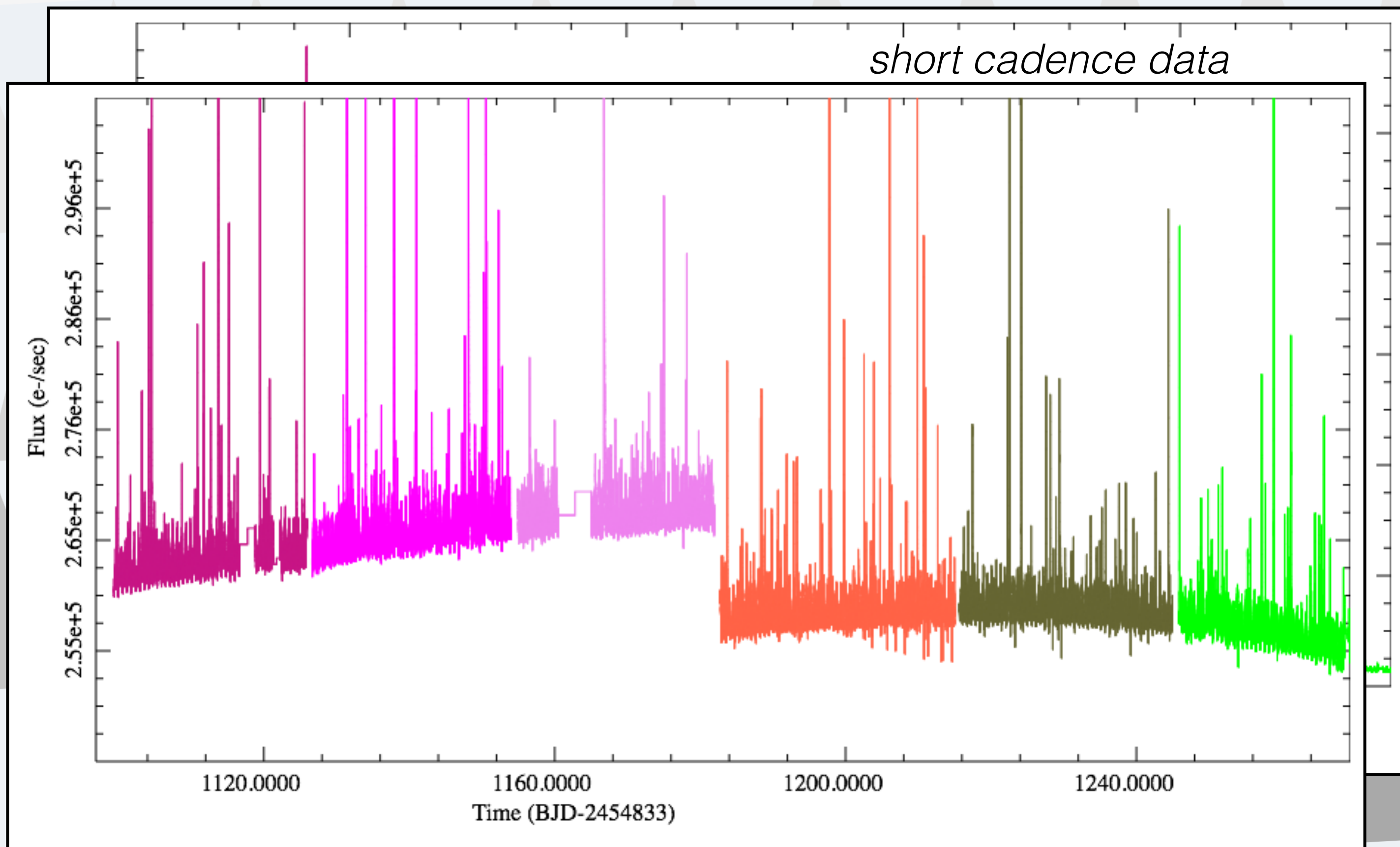
Time (BJD-2454833)



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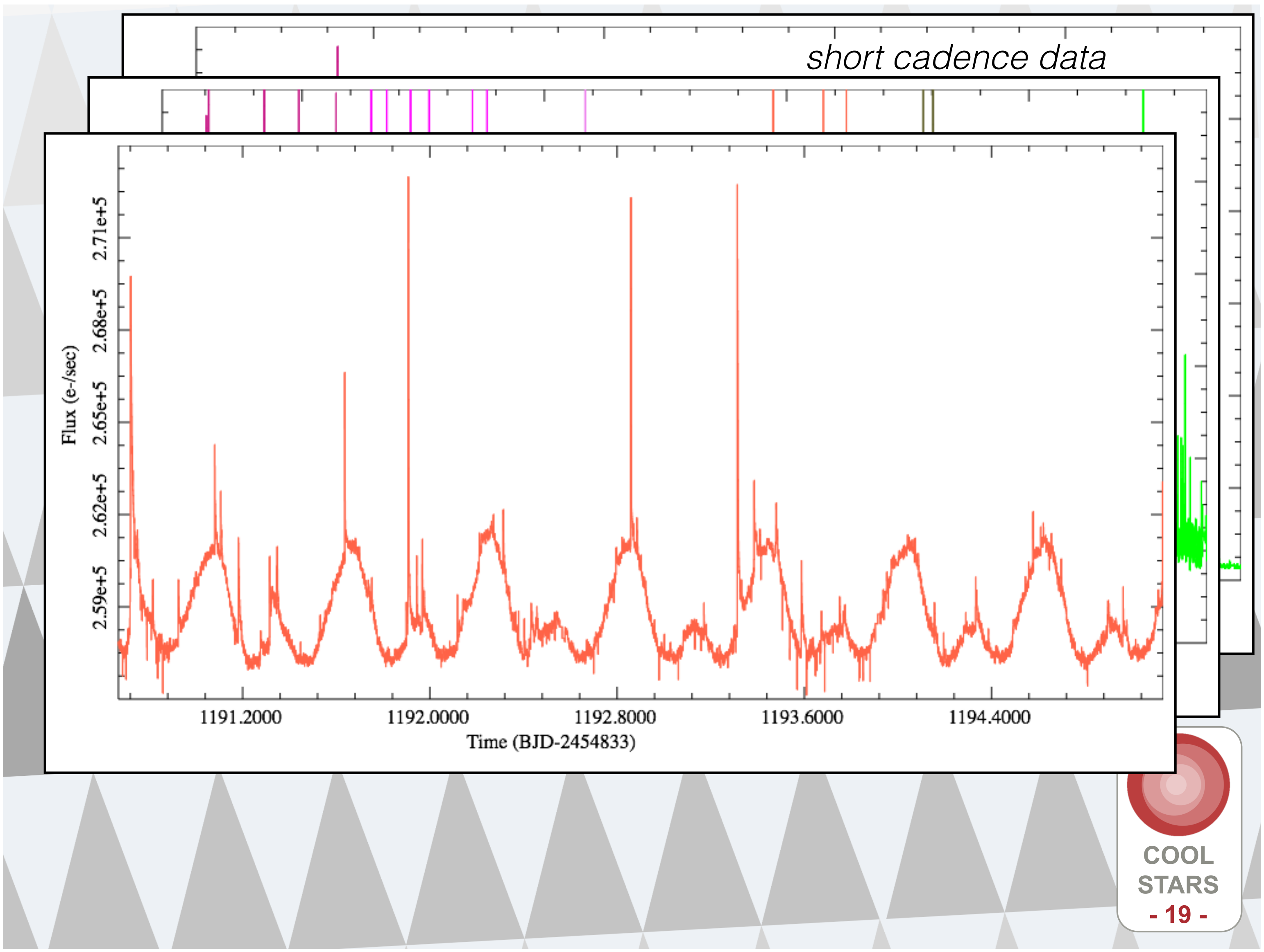
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2.65e+5
2.68e+5
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Time (BJD-2454833)
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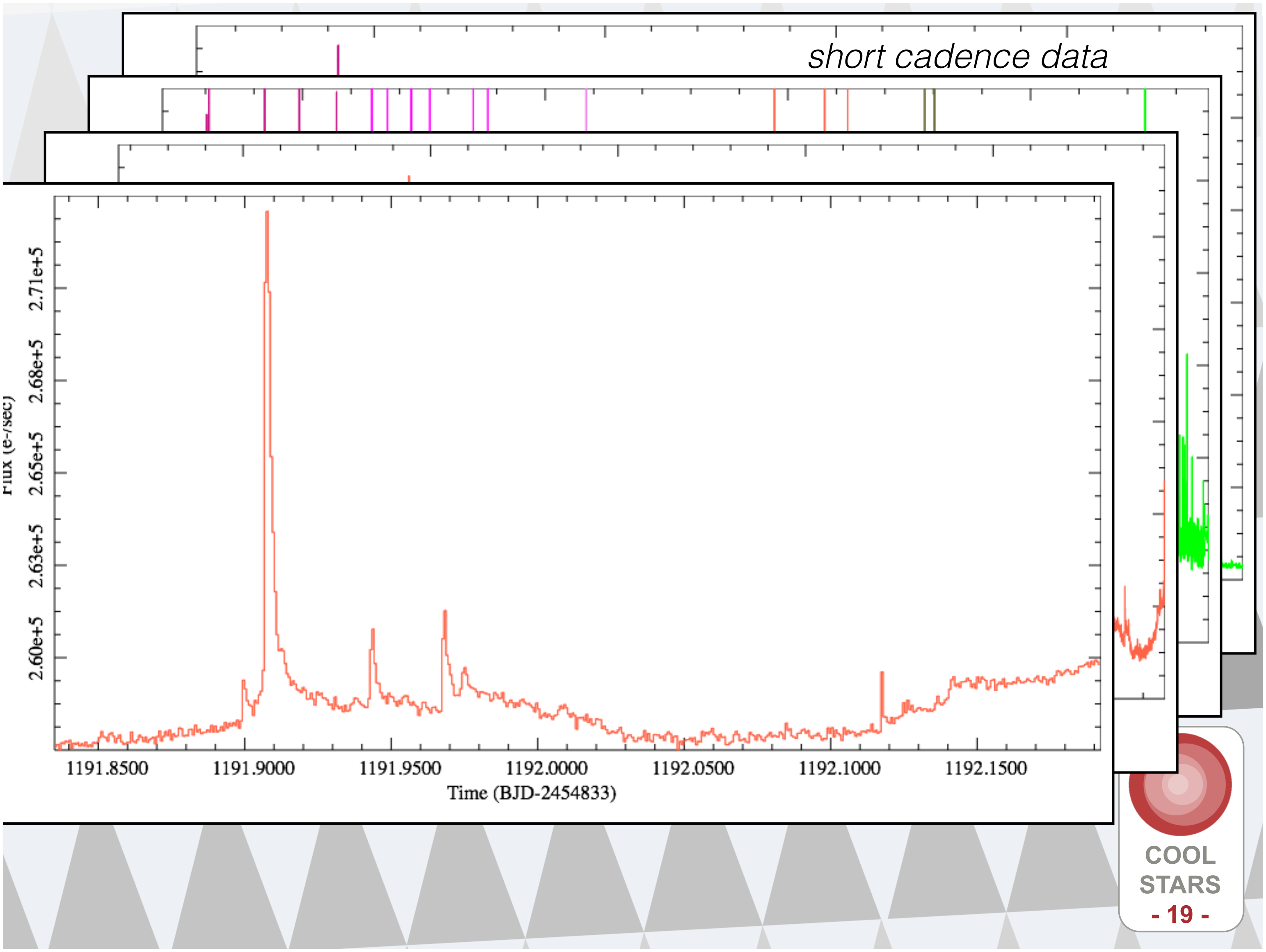
- 19 -


short cadence data
Flux (e-/sec)
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2.65e+5
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1191.9500
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Time (BJD-2454833)
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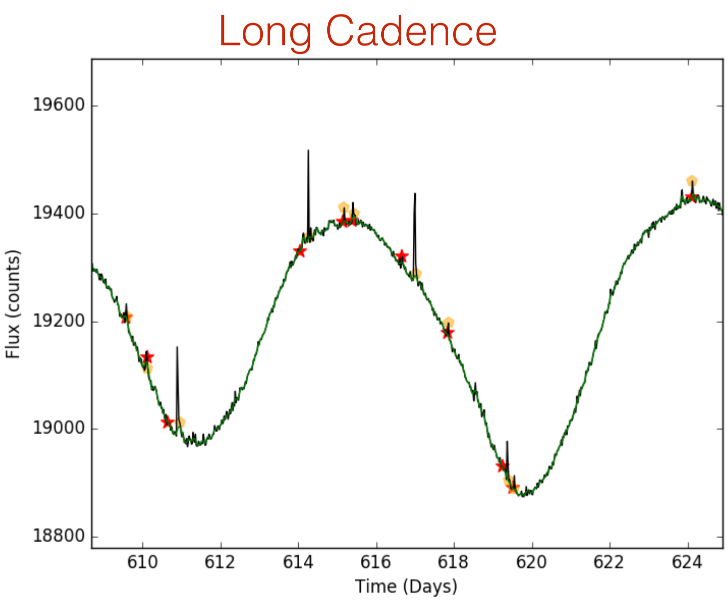
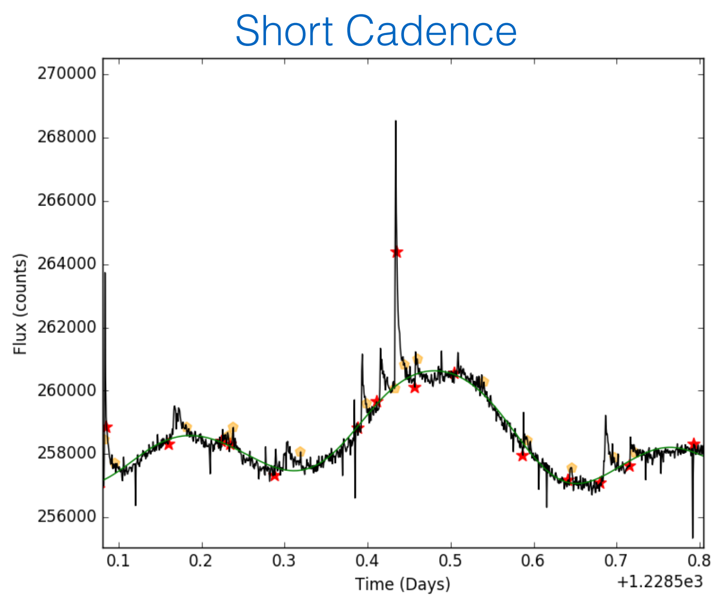
Analyze All Long & Short Cadence Data





3144487 individual light curve files
207617 unique targets

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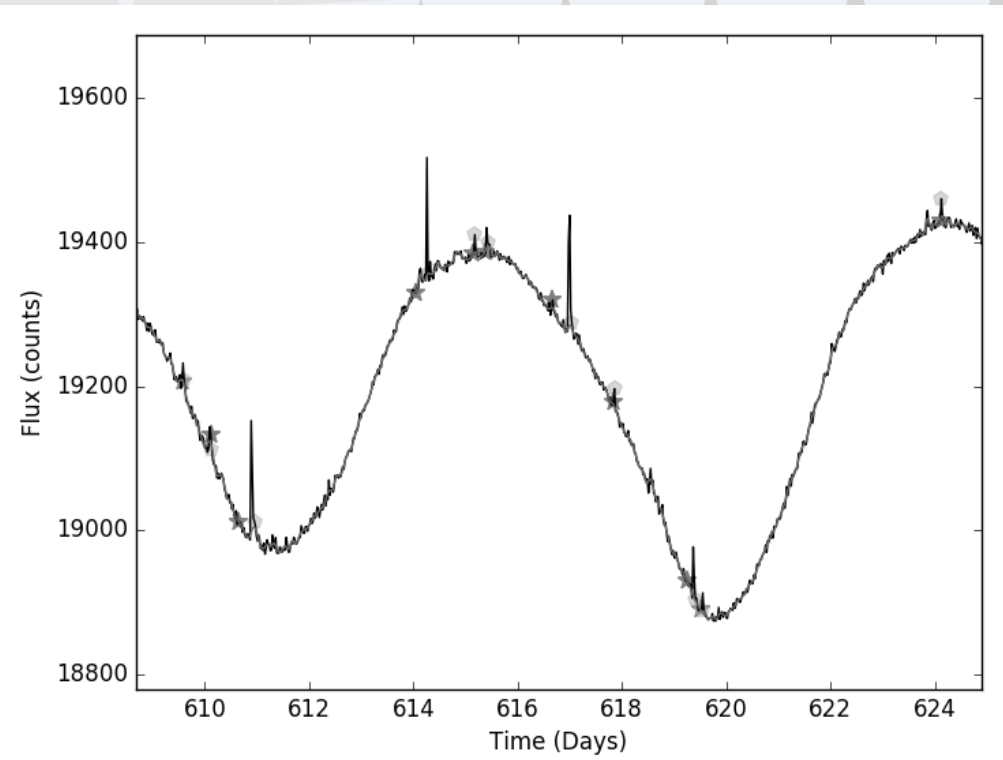
Artificial Flare Injection Tests:
Determine sample completeness!



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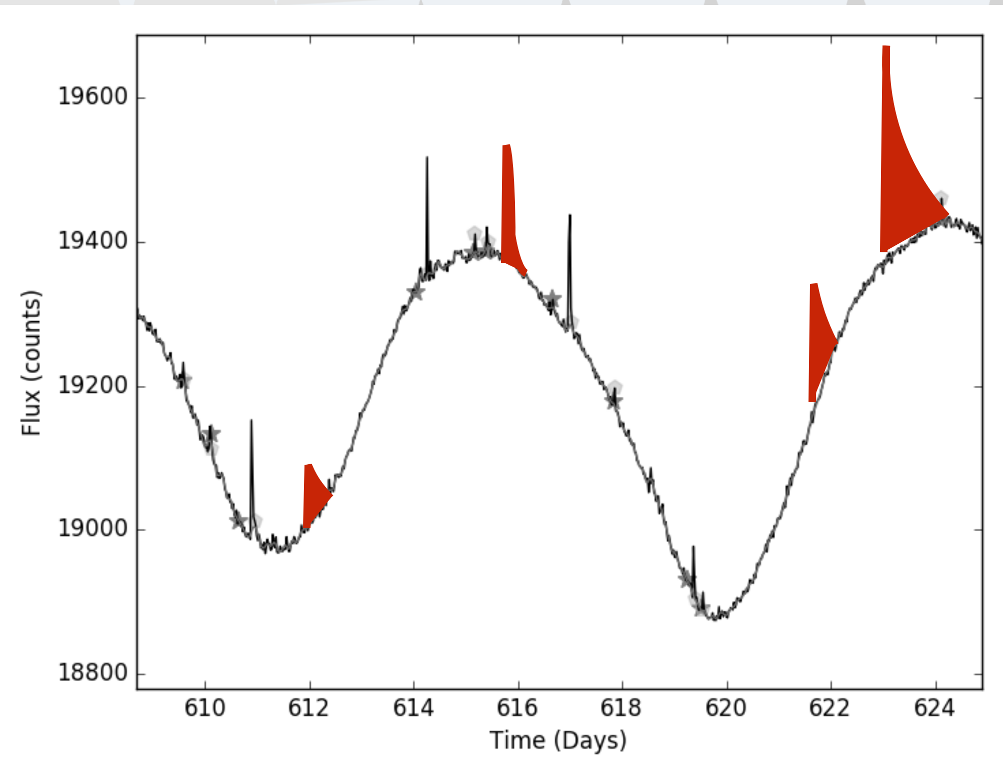
Artificial Flare Injection Tests:
Determine sample completeness!



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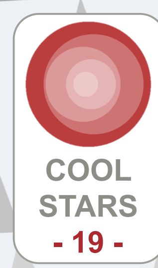

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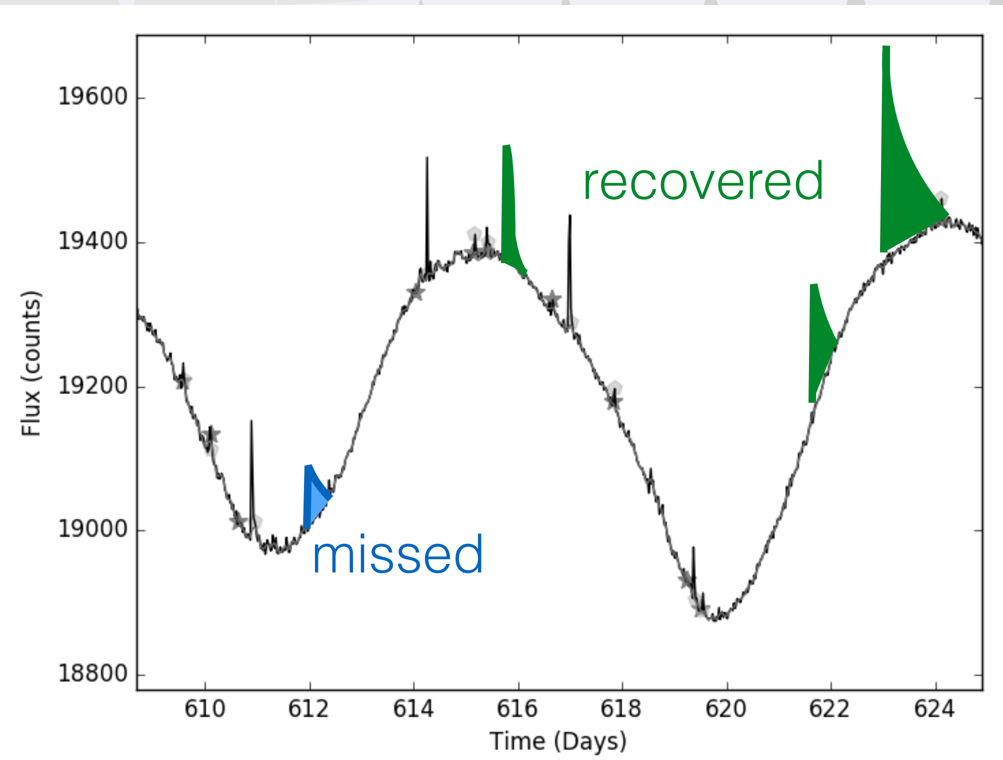
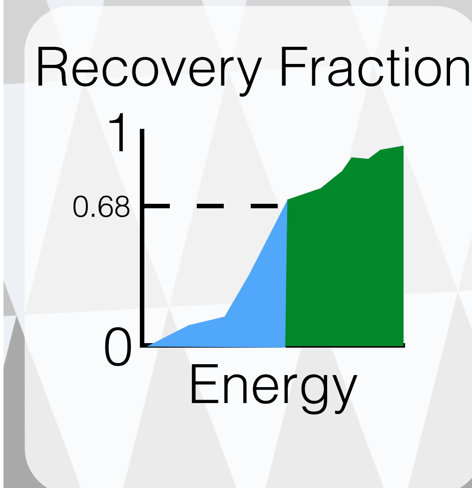
Determine sample completeness!





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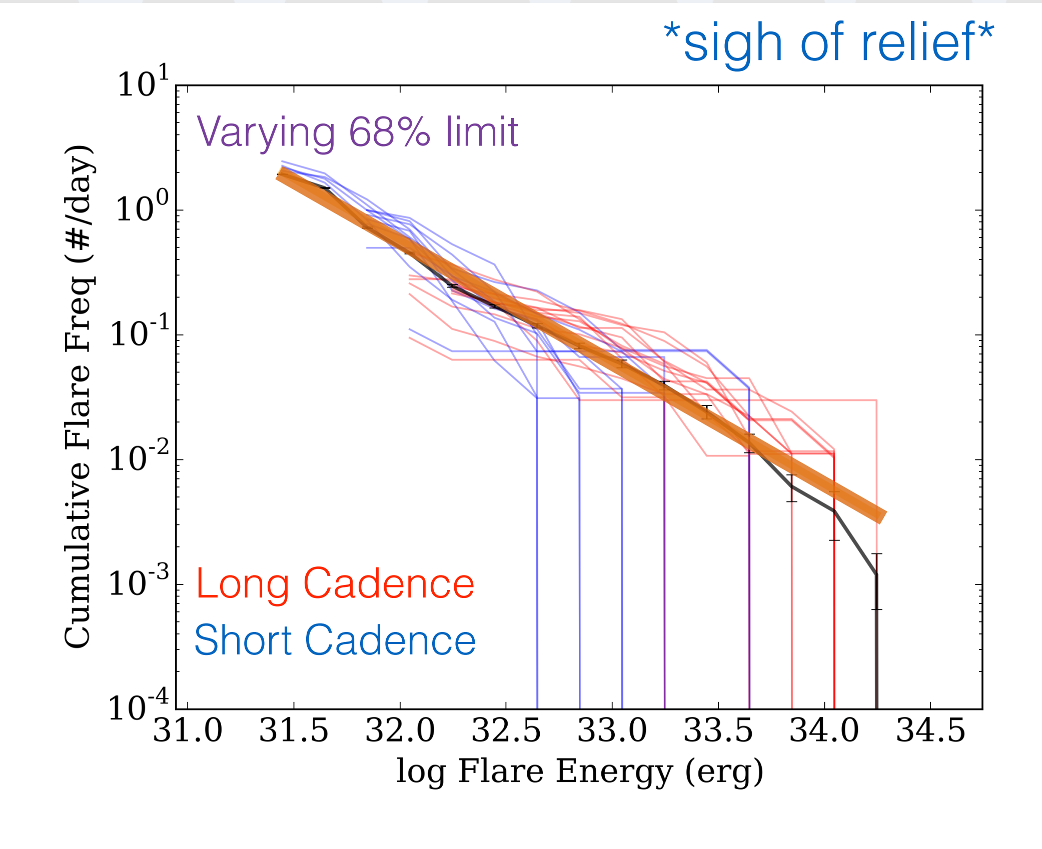
Results

Require 100 flare candidates total
Require 10 flare candidates above 68% threshold

4041 flare stars
1.4M "flare candidates"

Flare Frequency Distribution - Power law



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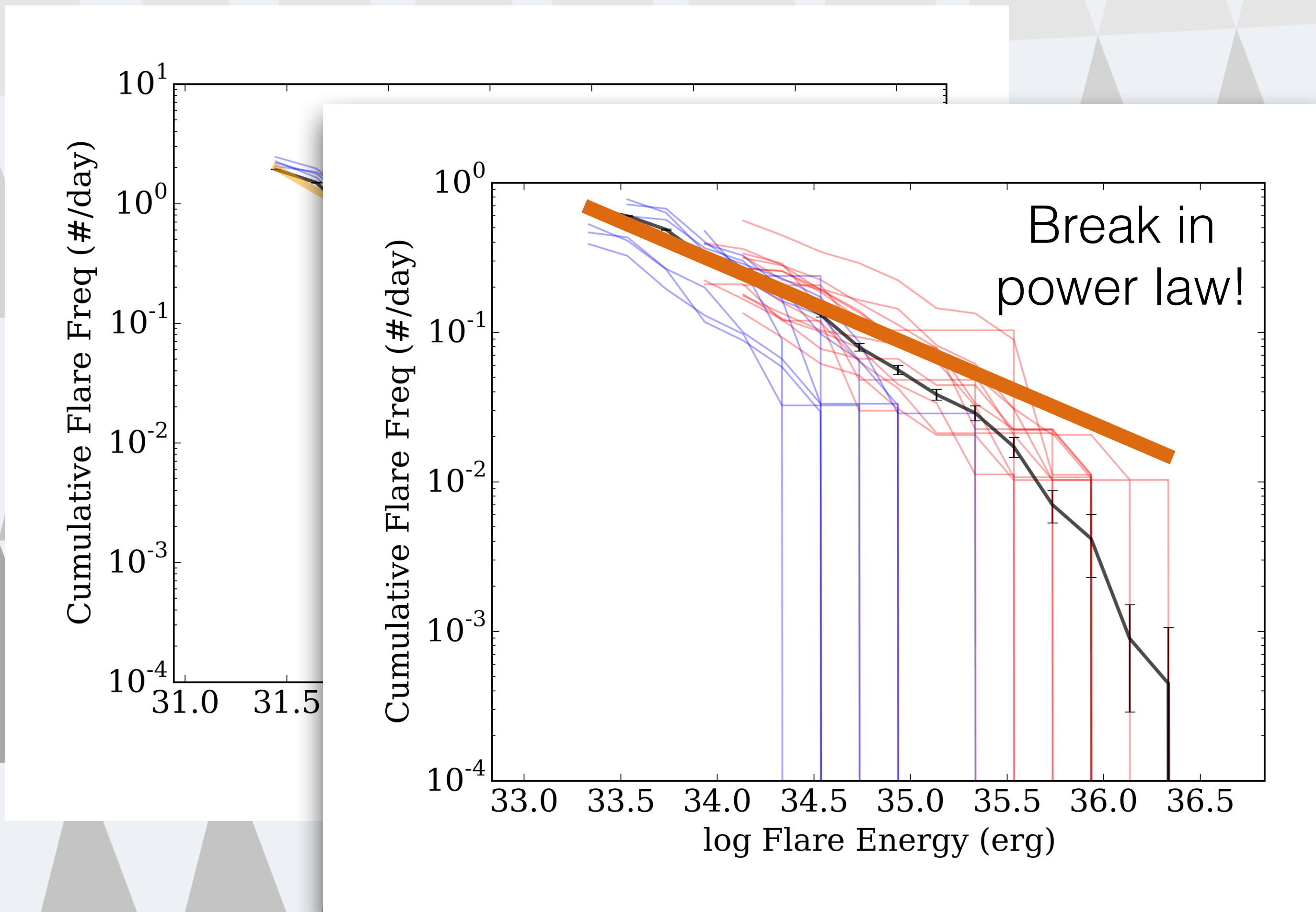
Flare Frequency Distribution - Power law



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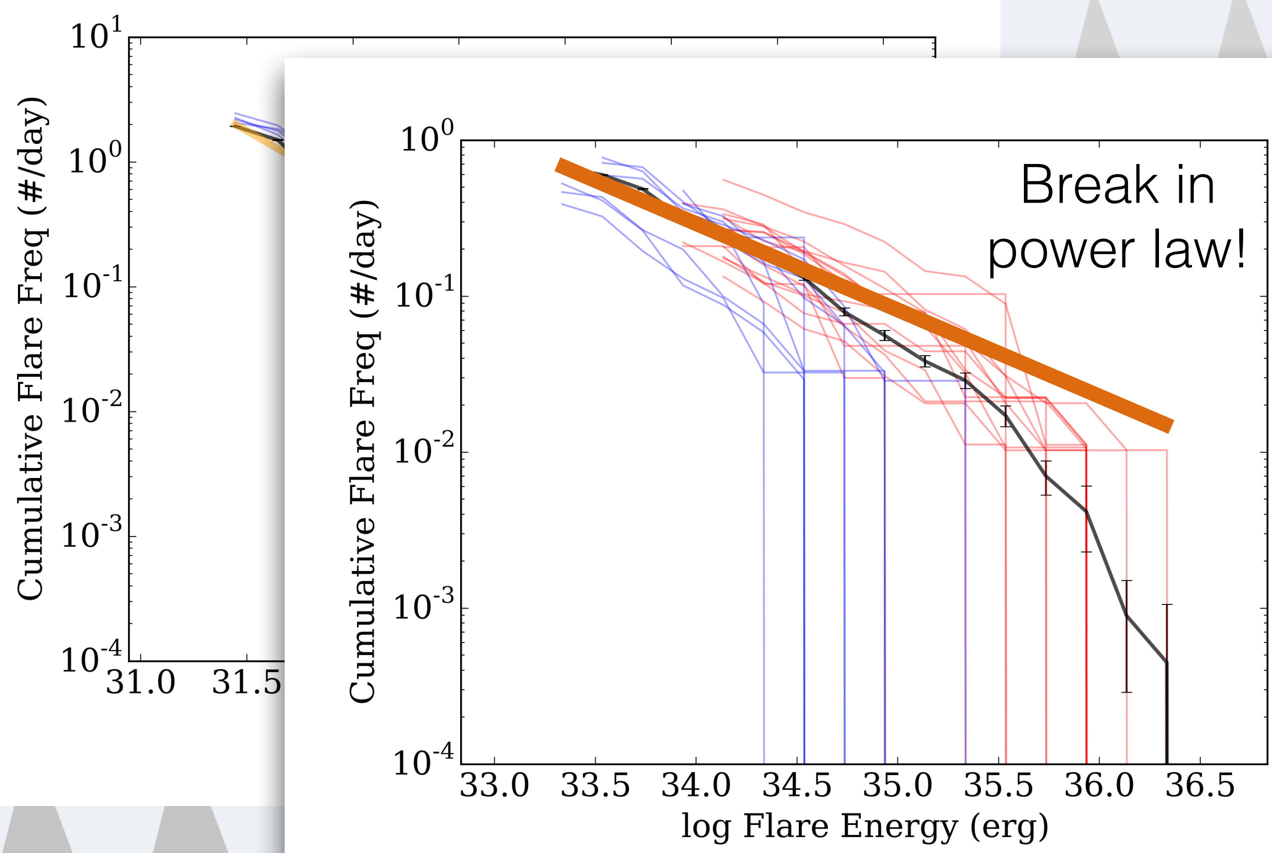
Flare Frequency Distribution - Power law



Go chat with Dave Soderblom for more about this star!

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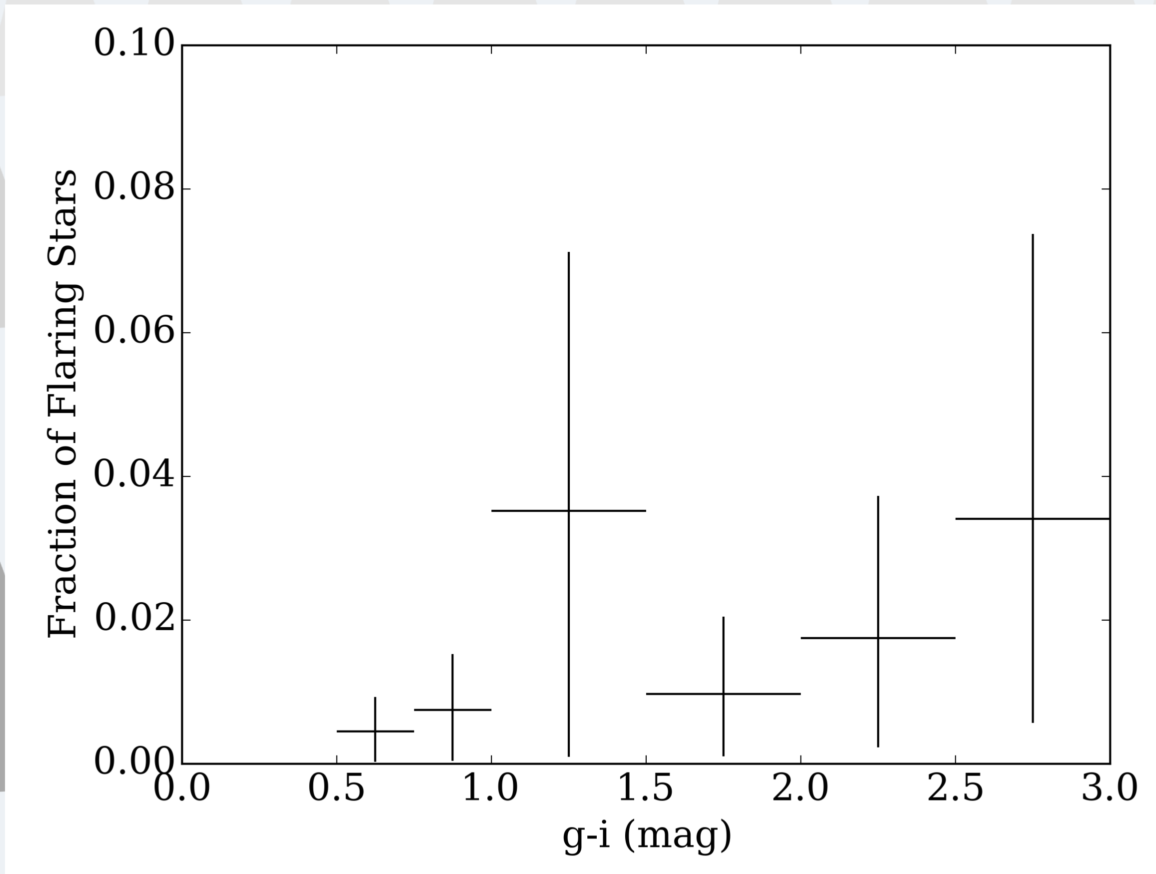
M dwarfs flare the most (*phew*)



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Combine flares with rotation!

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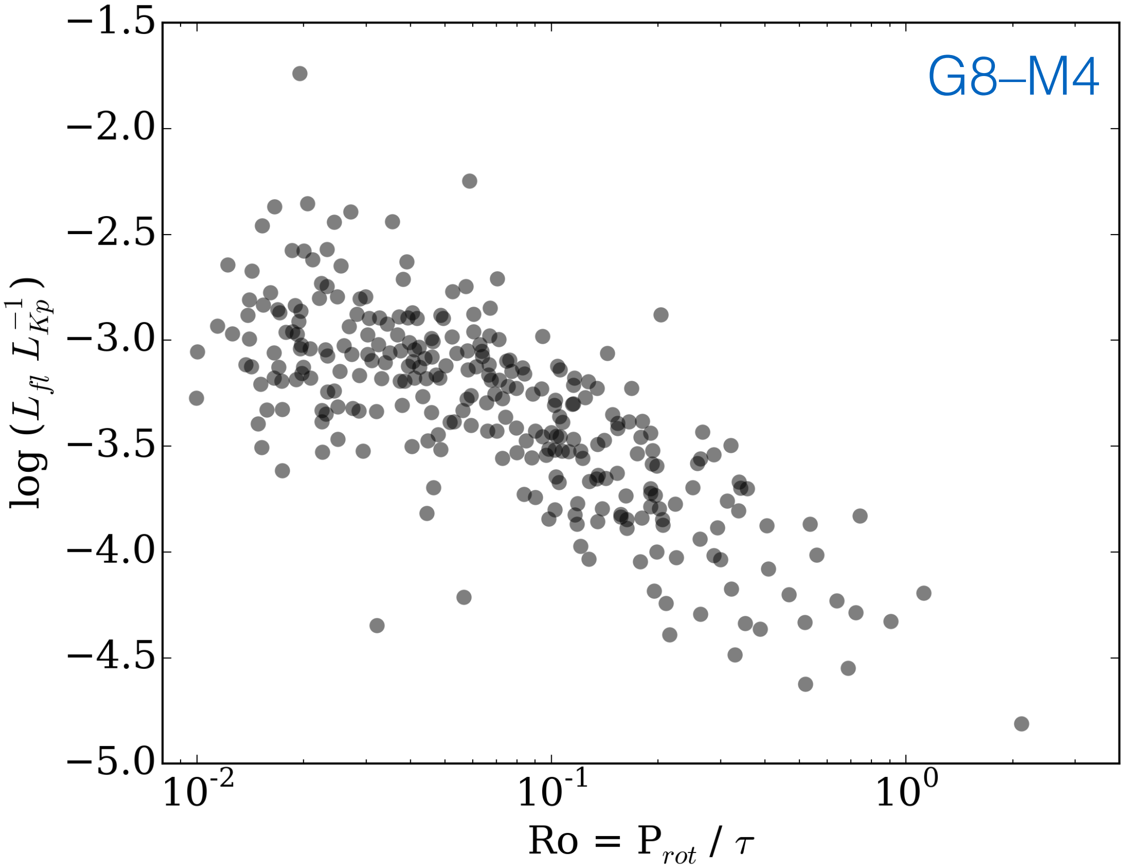
Flare Activity vs. Rossby Number



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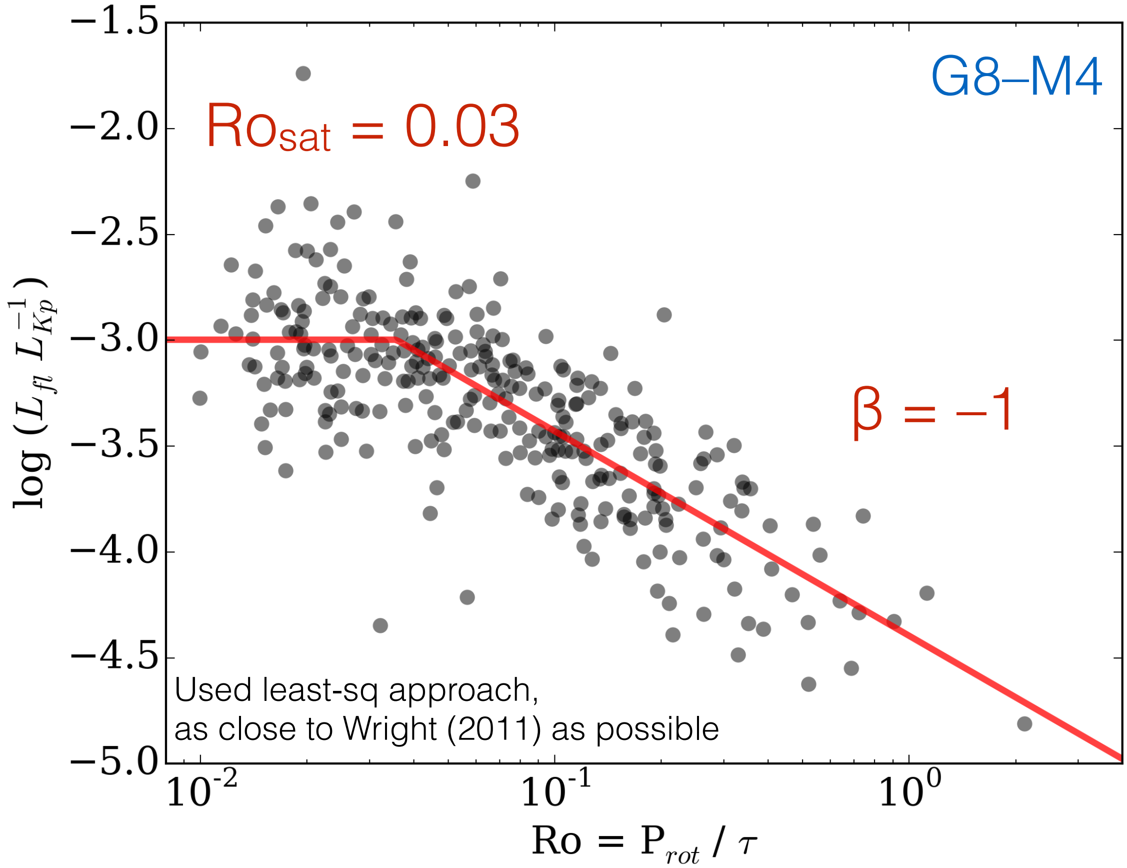
Flare Activity vs. Rossby Number



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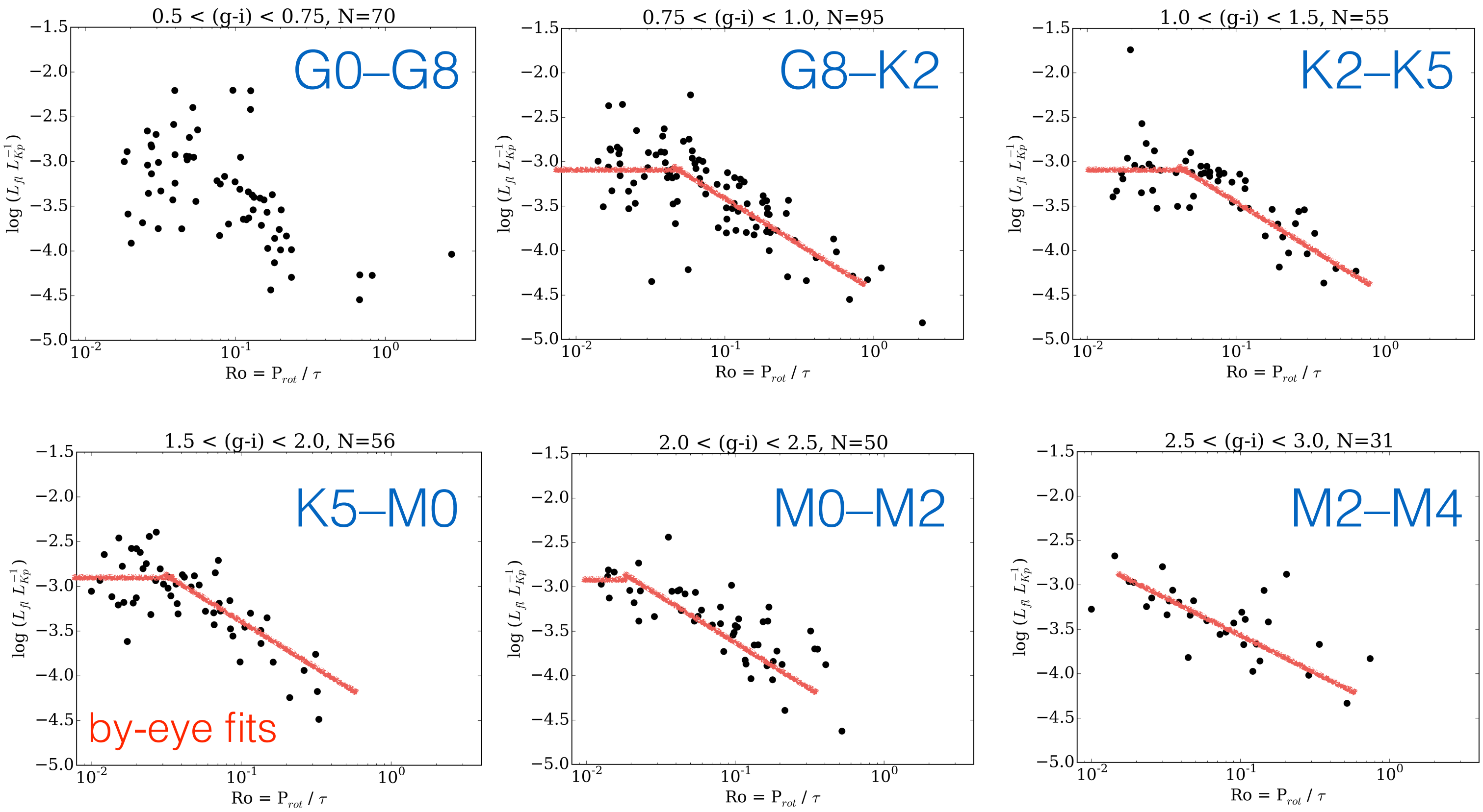

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The Future

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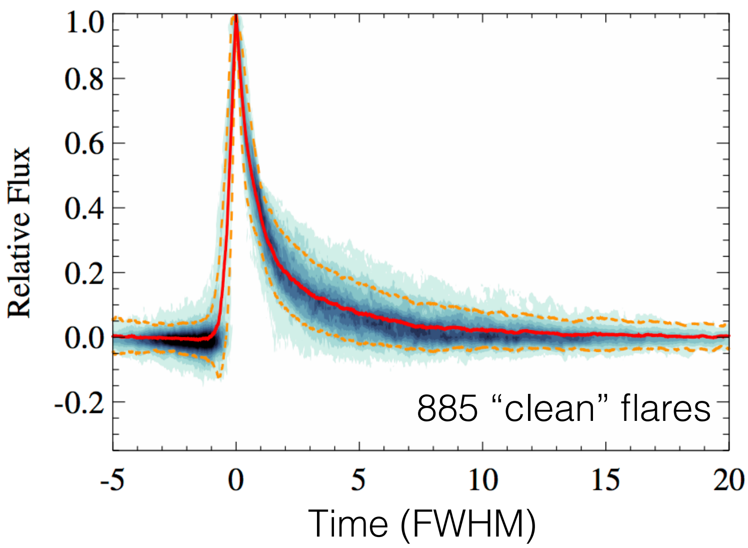
Understanding Flare Morphology

Davenport et al. (2014)



- Is this shape universal?
- Trends with Spectral Type?

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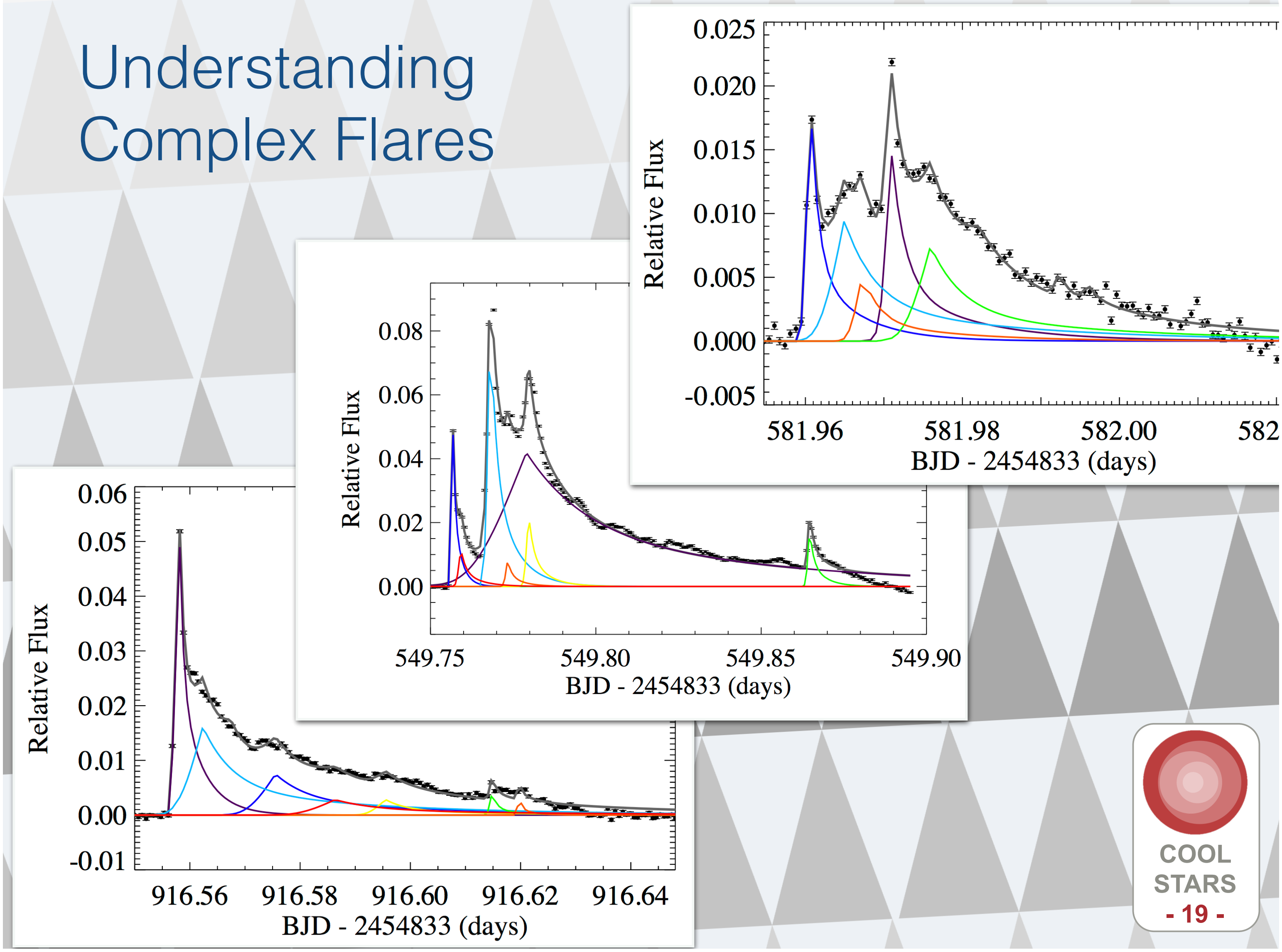
Understanding Complex Flares



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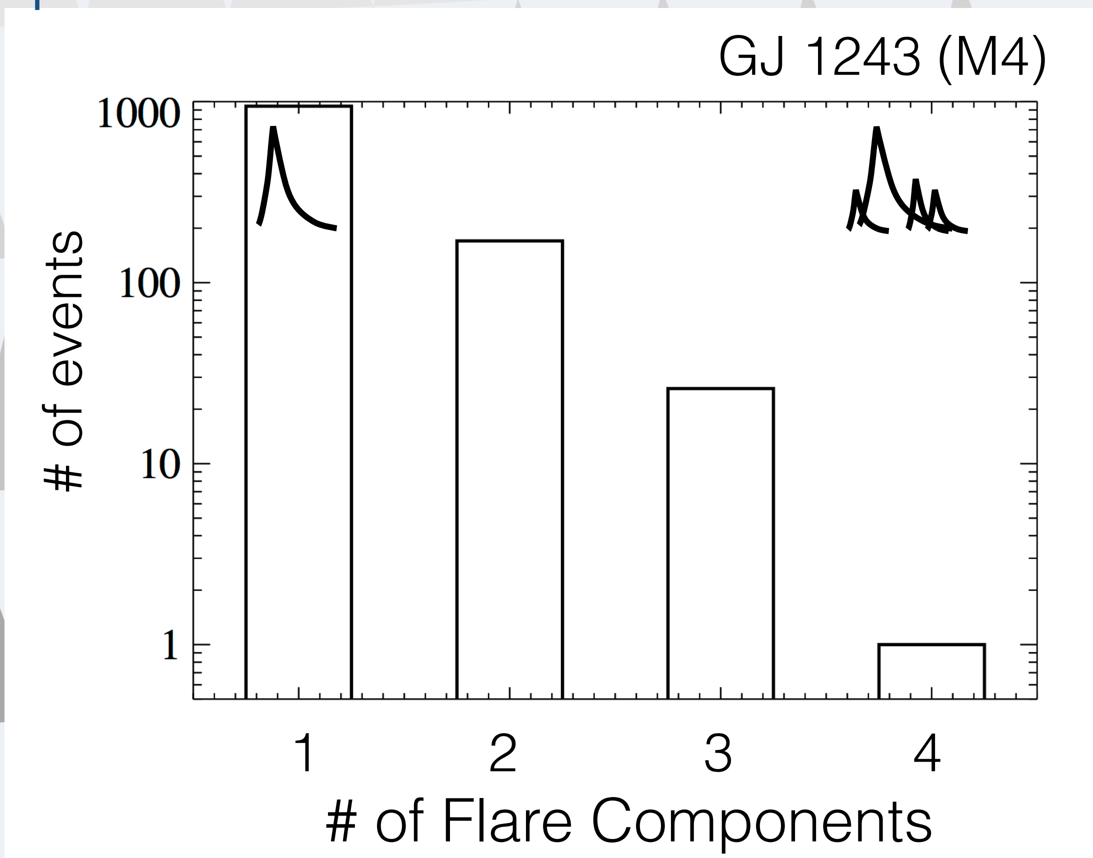
Understanding Complex Flares



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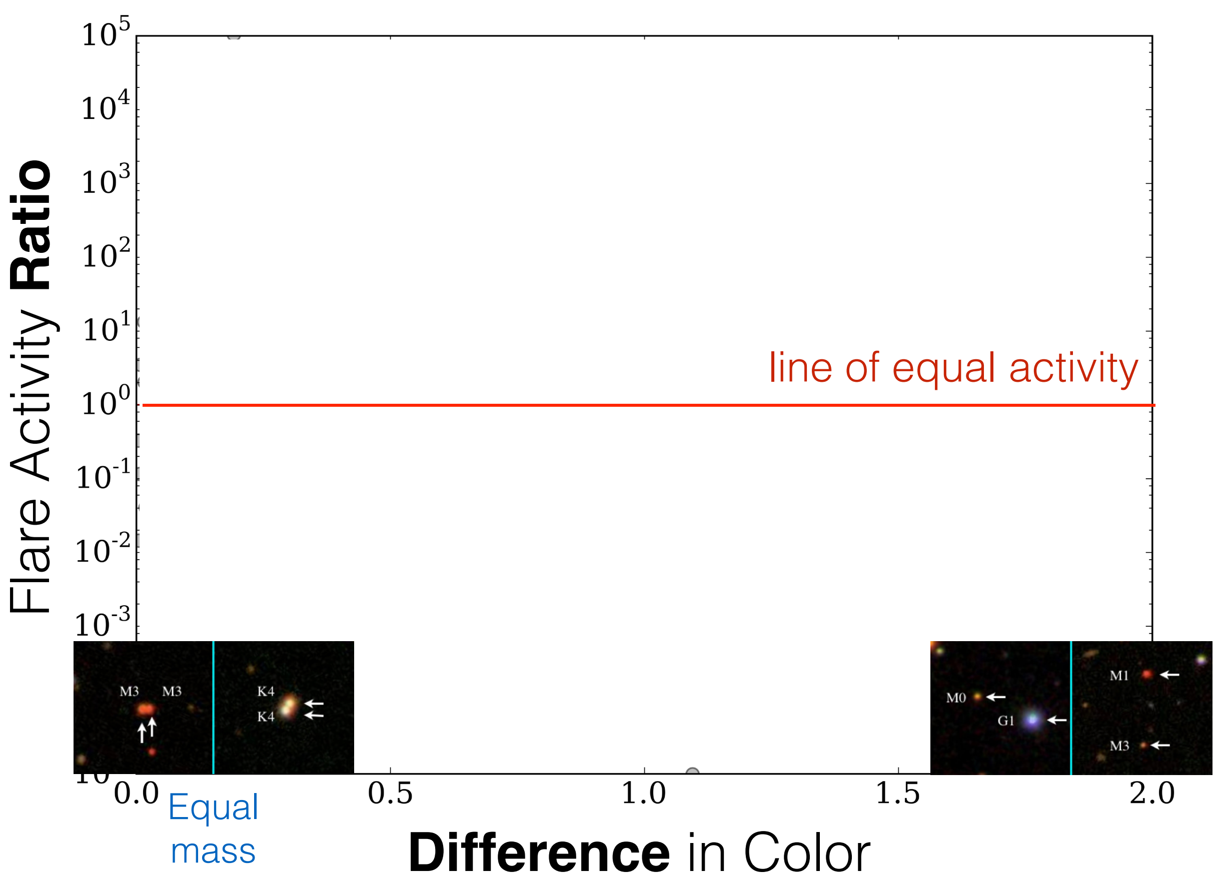
Flare activity with Wide Binaries



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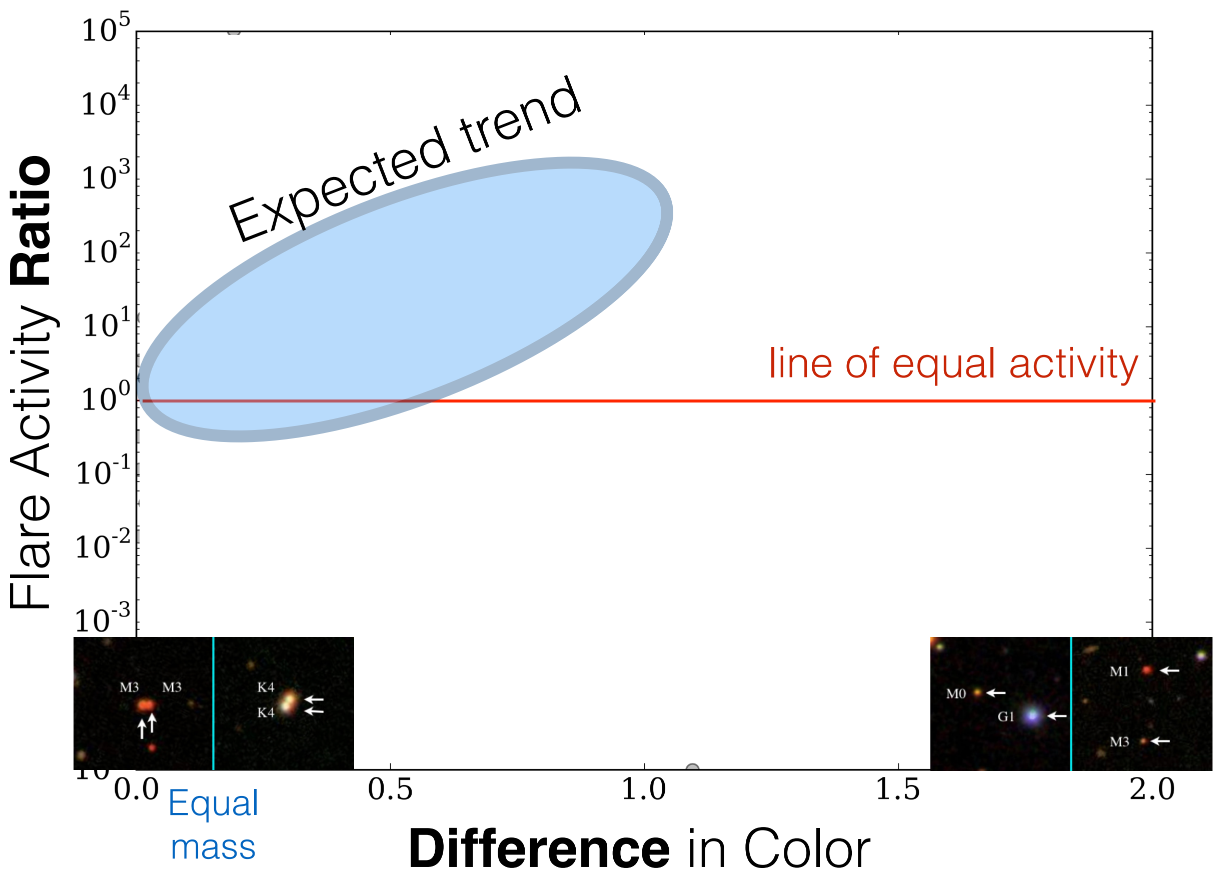
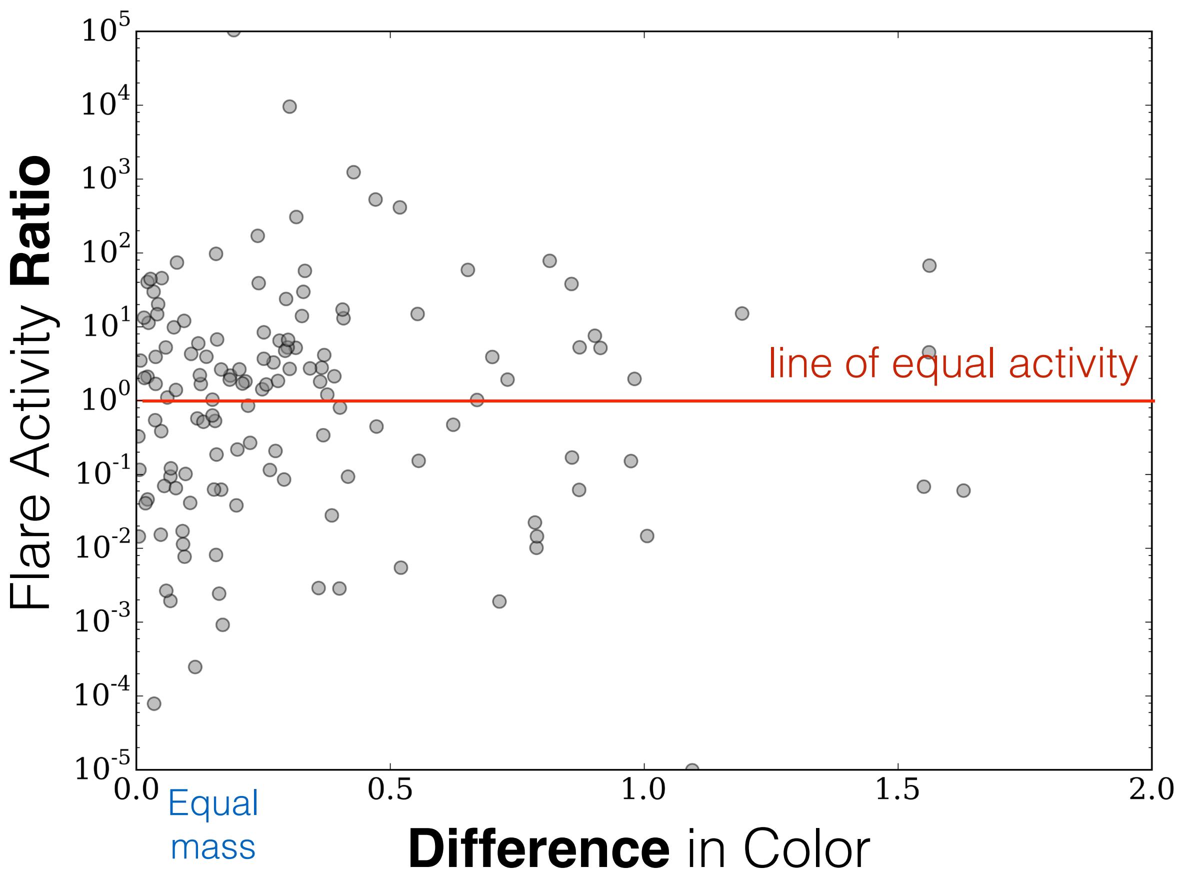
Flare activity with Wide Binaries



Flare activity with Wide Binaries



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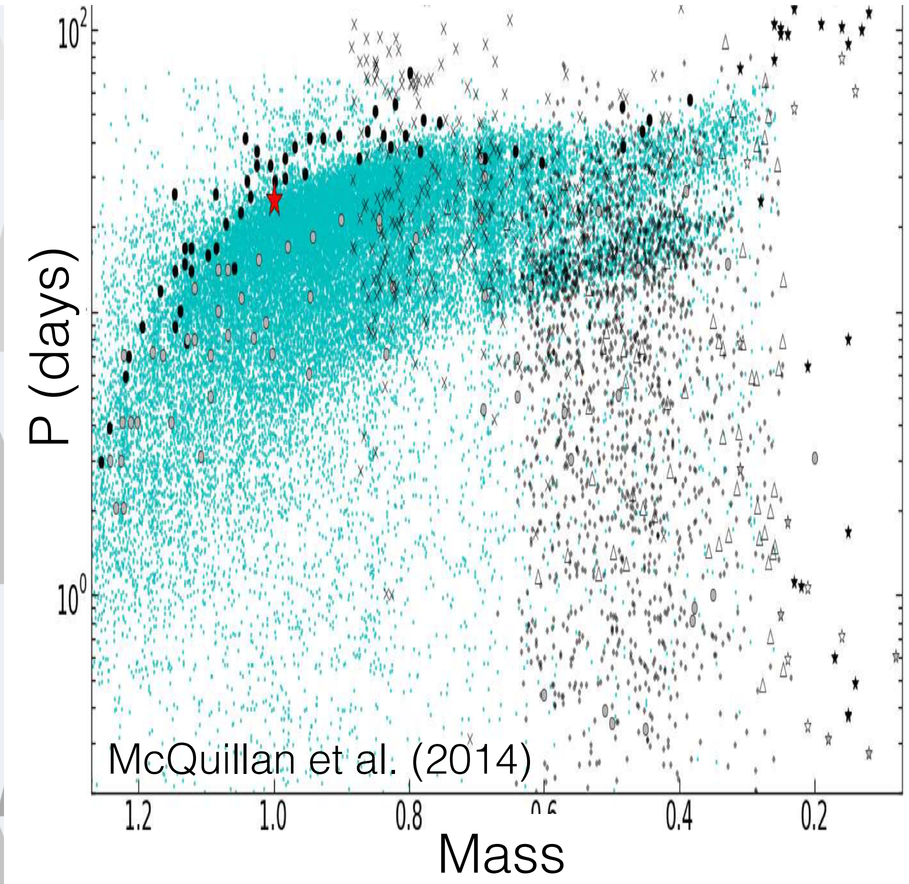
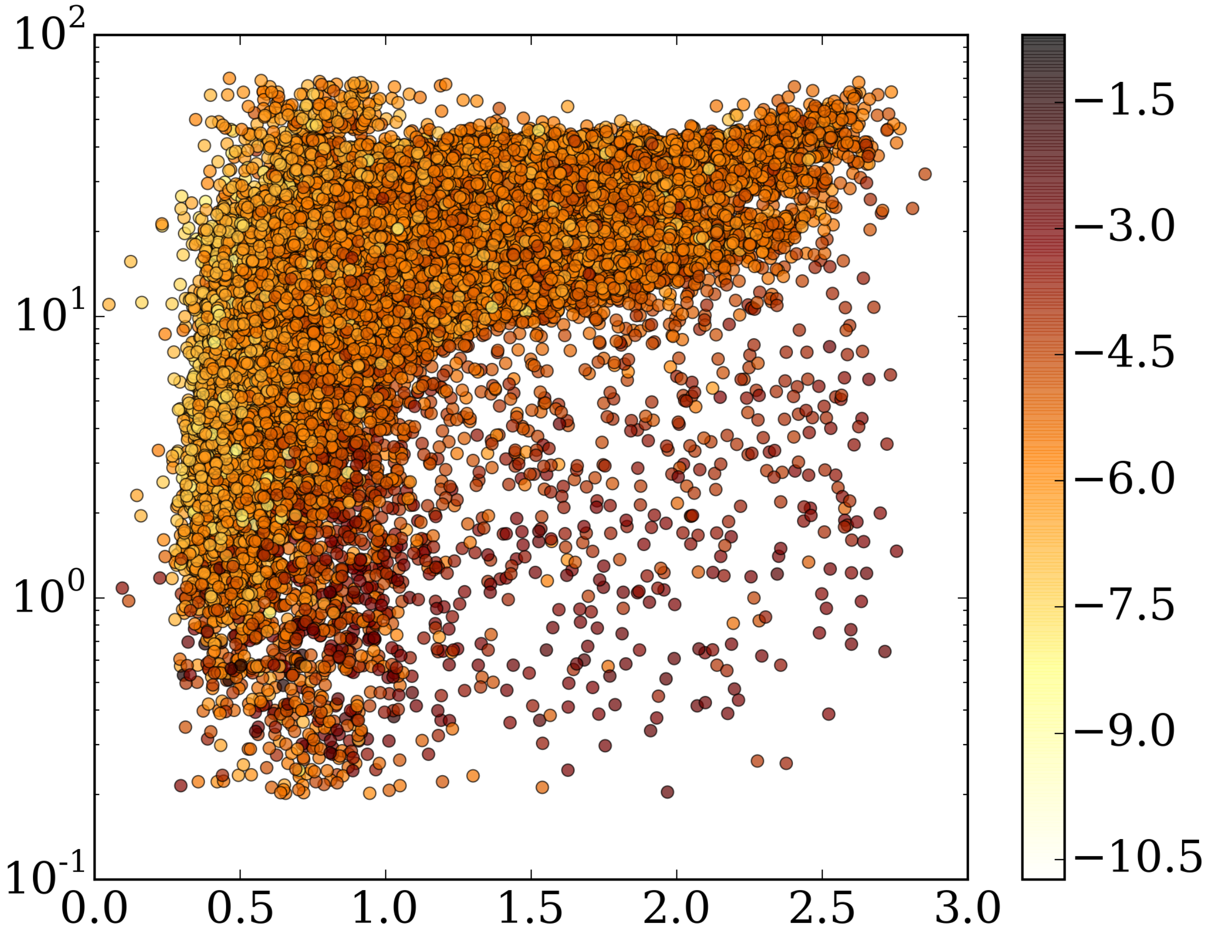
“Gyrochronology”: ages from rotation



Stellar Ages from Flares: "magnetochronology"



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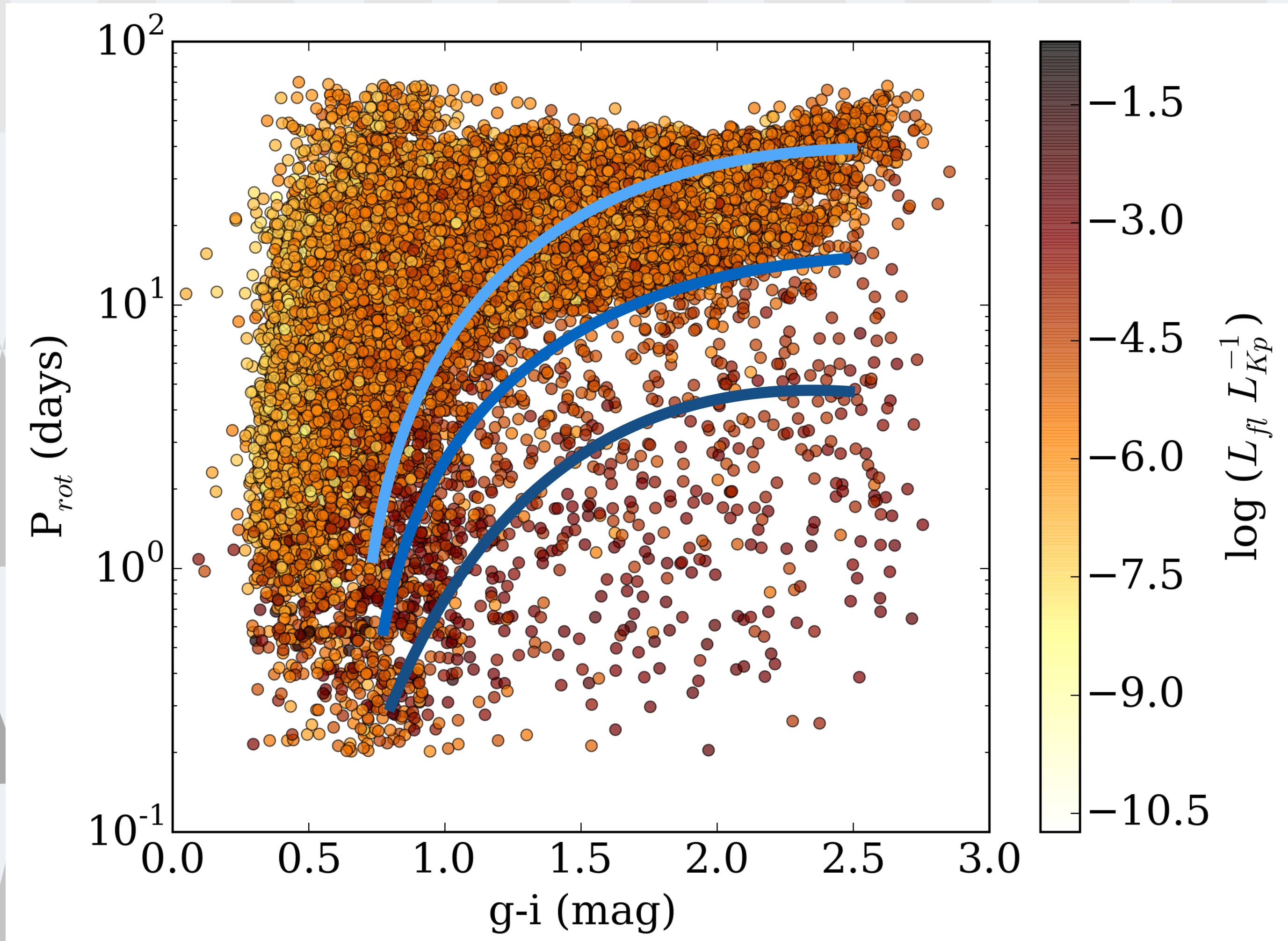
Stellar Ages from Flares: "magnetochronology"



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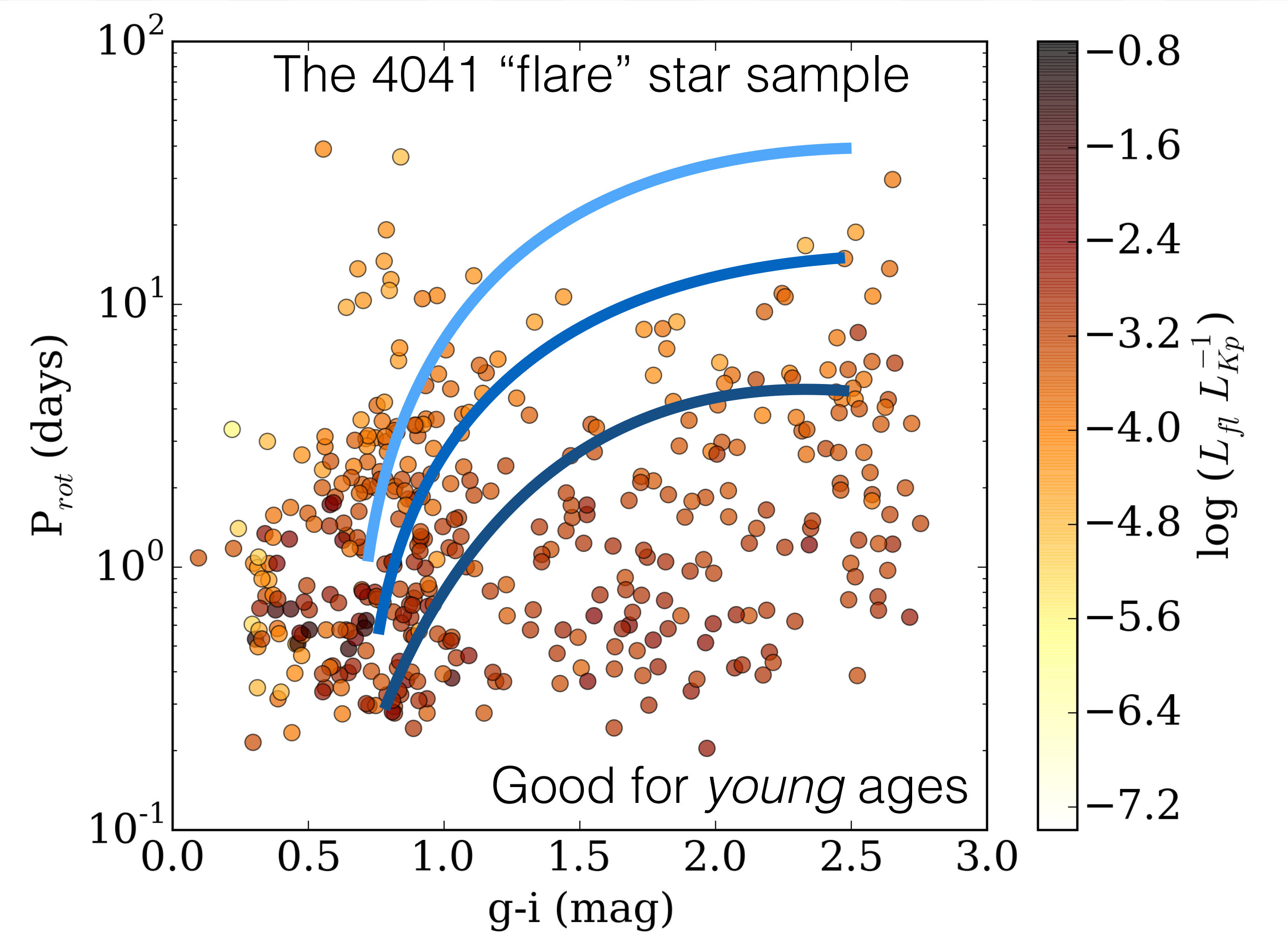
Stellar Ages from Flares: “magnetochronology”



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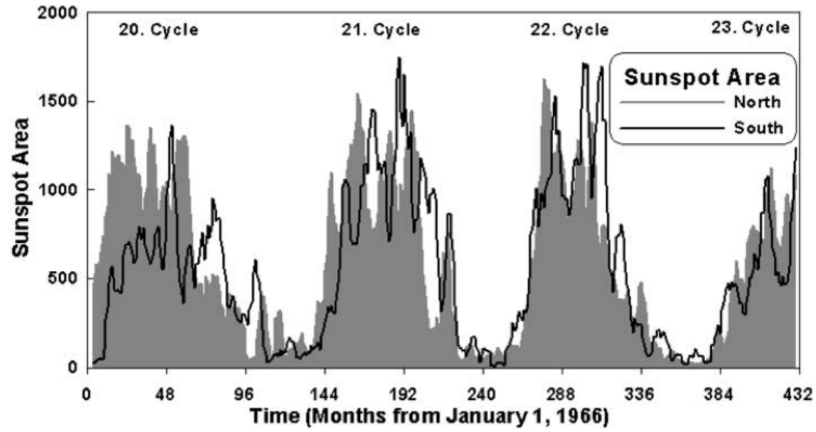
Activity Cycles

A. Özgüç, et al. (2003), SoPh



See also S-index, Ca II H&K, TSI, etc…

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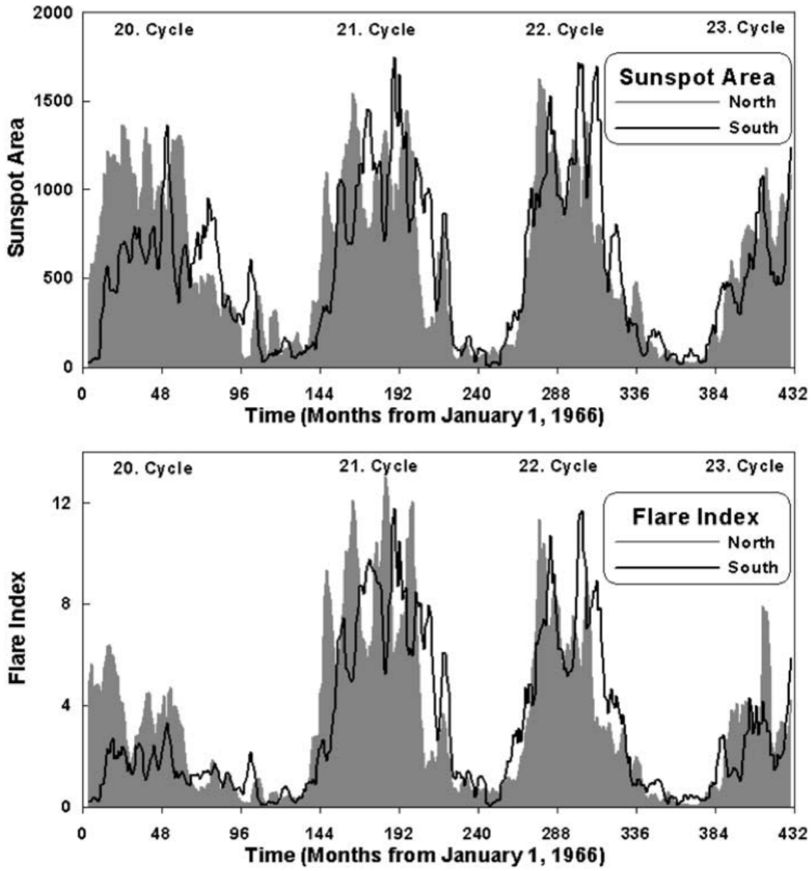
Activity Cycles

A. Özgüç, et al. (2003), SoPh



See also S-index, Ca II H&K, TSI, etc…

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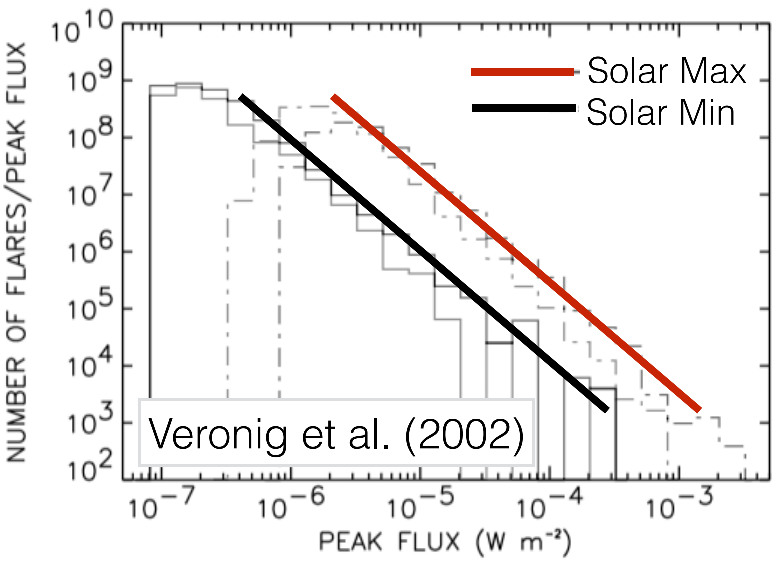
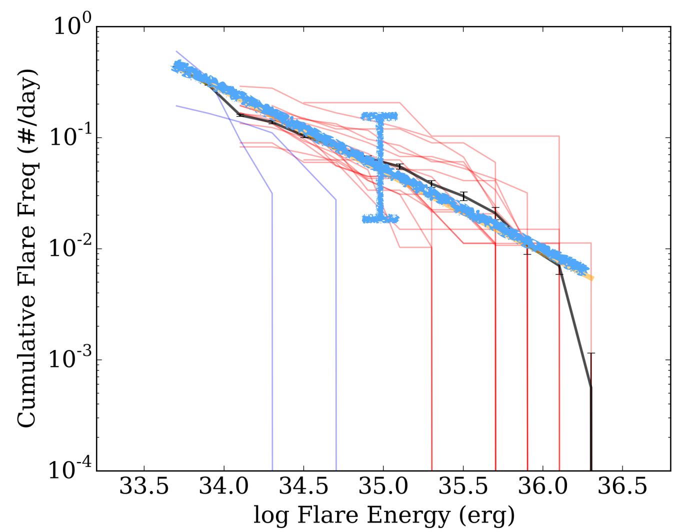
Activity Cycles from Flares

Flare rate varies by an **order of magnitude** between active/quiet Sun!





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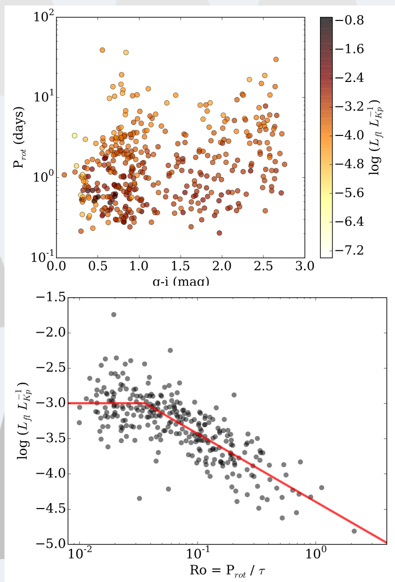
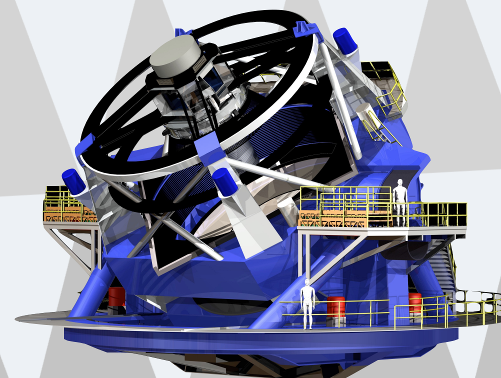
Flares in Future Surveys



LSST



see S. Hawley's talk this afternoon

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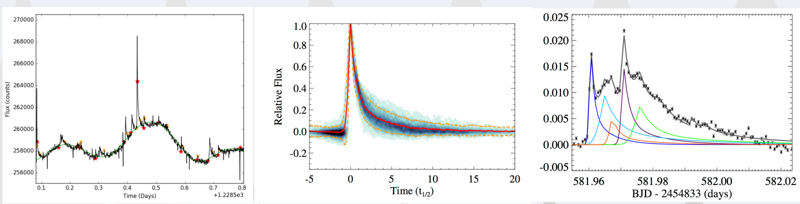
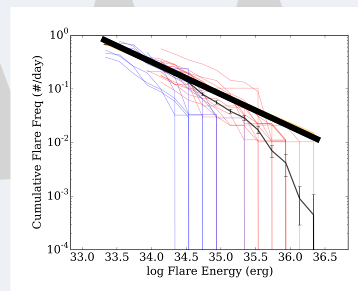


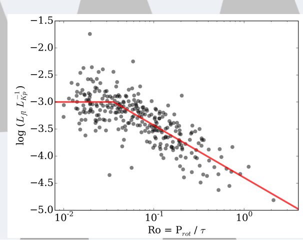
Summary

Poster #87

- Analyzed all Kepler light curves
- Artificial flare injection tests!
- Sample of 1.4M flares
- from 4041 stars



- Flare rates and energy distributions
- Breaks in power law



- Evolution with Rossby number
- Saturation regime
- **Flares now useful metric for magnetic activity level**

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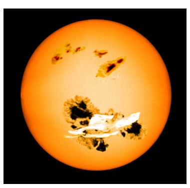
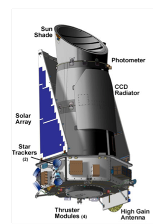
A Cool Stars 19 Splinter Session
“Flares in Time-Domain Surveys”
2016 June 07th @ Uppsala, Sweden

Superflares on solar-type stars found from Kepler data



Yuta Notsu

(Kyoto University, Japan)



H.Maehara (NAOJ), S. Honda (U. Hyogo), T. Shibayama (Nagoya U.)
S. Notsu, K. Namekata, D. Nogami, K. Shibata (Kyoto U.)

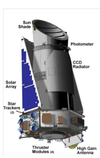
For the details, see also our posters (No.117&118) !!

Reference:

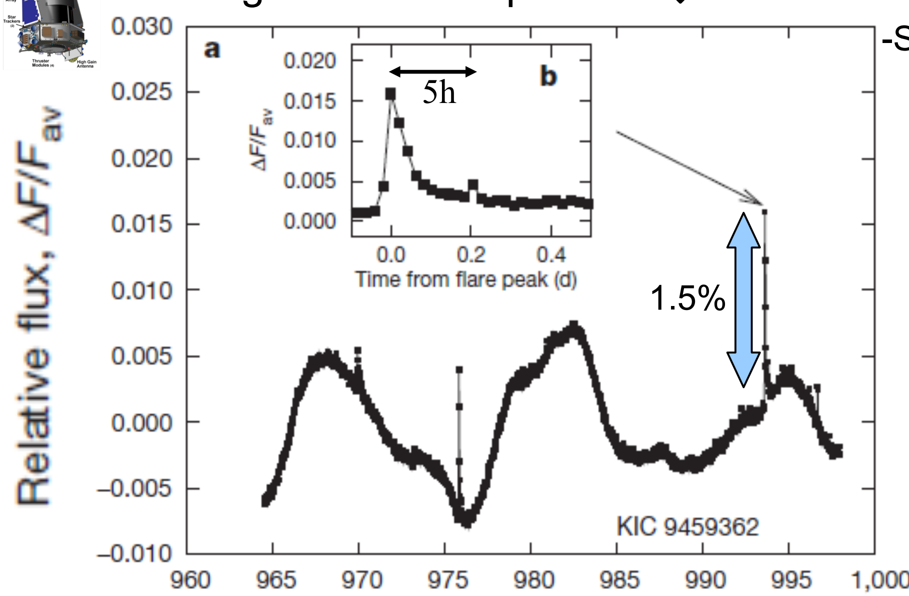
Maehara et al. 2012, Nature, 485, 478
Shibayama et al. 2013, ApJS, 209, 5
Notsu et al. 2013, ApJ, 771, 127
Maehara et al. 2015, Ep&S, 67, 59
Notsu et al. 2015a, PASJ, 67, 32
Notsu et al. 2015b, PASJ, 67, 33

Discoveries of superflares with *Kepler* data

We discovered many (>1000) superflares ($10^{33} \sim 10^{36}$erg: $10 \sim 10^4$ times more energetic than the largest solar flares) on many (~300) solar-type (G-type main sequence) stars.



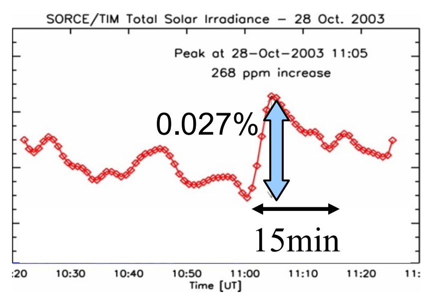
Lightcurve of superflare ↓



Maehara et al. (2012)

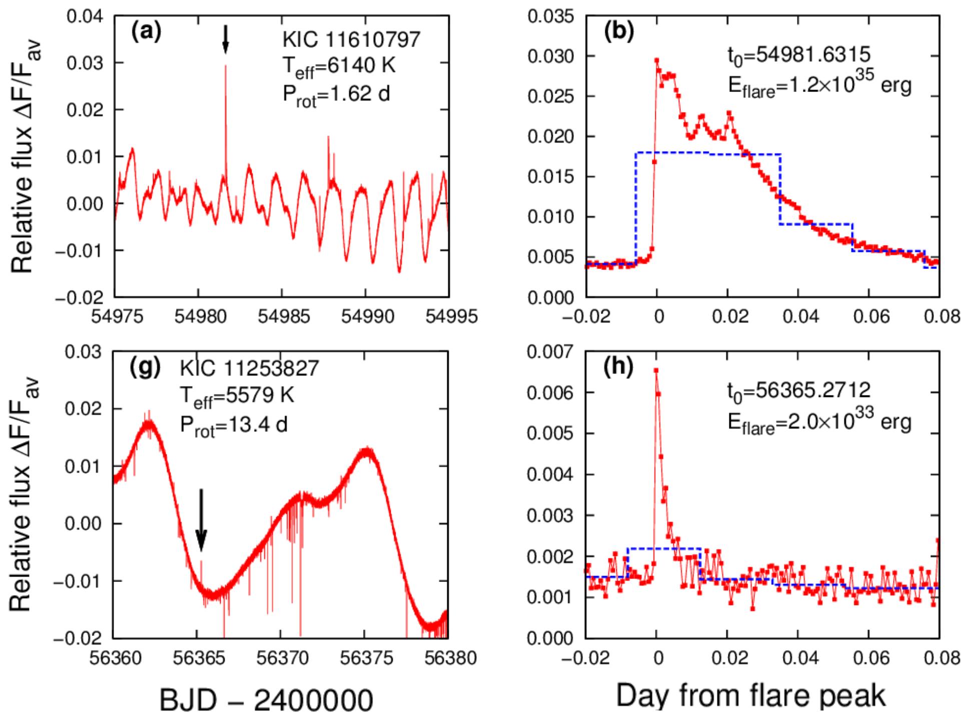
[Data]
-Long (30-min) cadence data
Shibayama+2013 (~90,000 stars)
~500 days
-Short (1-min) cadence data
Maehara+2015 (~1,400 stars)
~all data

Cf. Example of large solar flares (Solar brightness variation)



Kopp et al. (2005)

Superflares (30min & 1min cadence data)



Maehara +2015 EPS

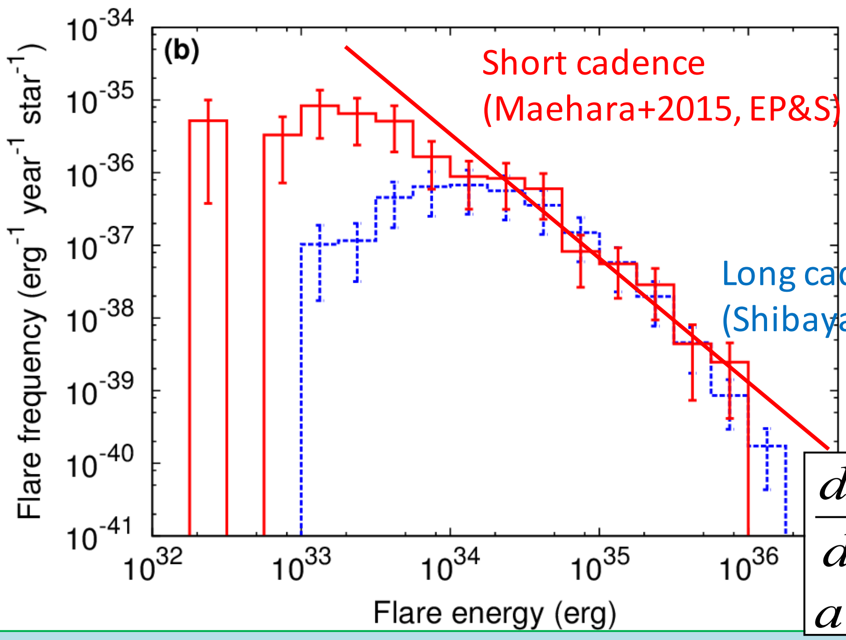
- Long (30-min) cadence data: 1547 superflares on 279 solar-type stars.
- Short (1-min) cadence data : 189 superflares on 23 solar-type stars.

Flare amplitude: 1.3×10^{-3} ~ 8.5×10^{-2}

Bolometric energy: 2×10^{32} ~ 2×10^{36} erg

Flare frequency distribution

- The frequency distribution can be represented by a power-law distribution (power-law index: -1.8 ~ -1.5)
  - similar to that of solar flares

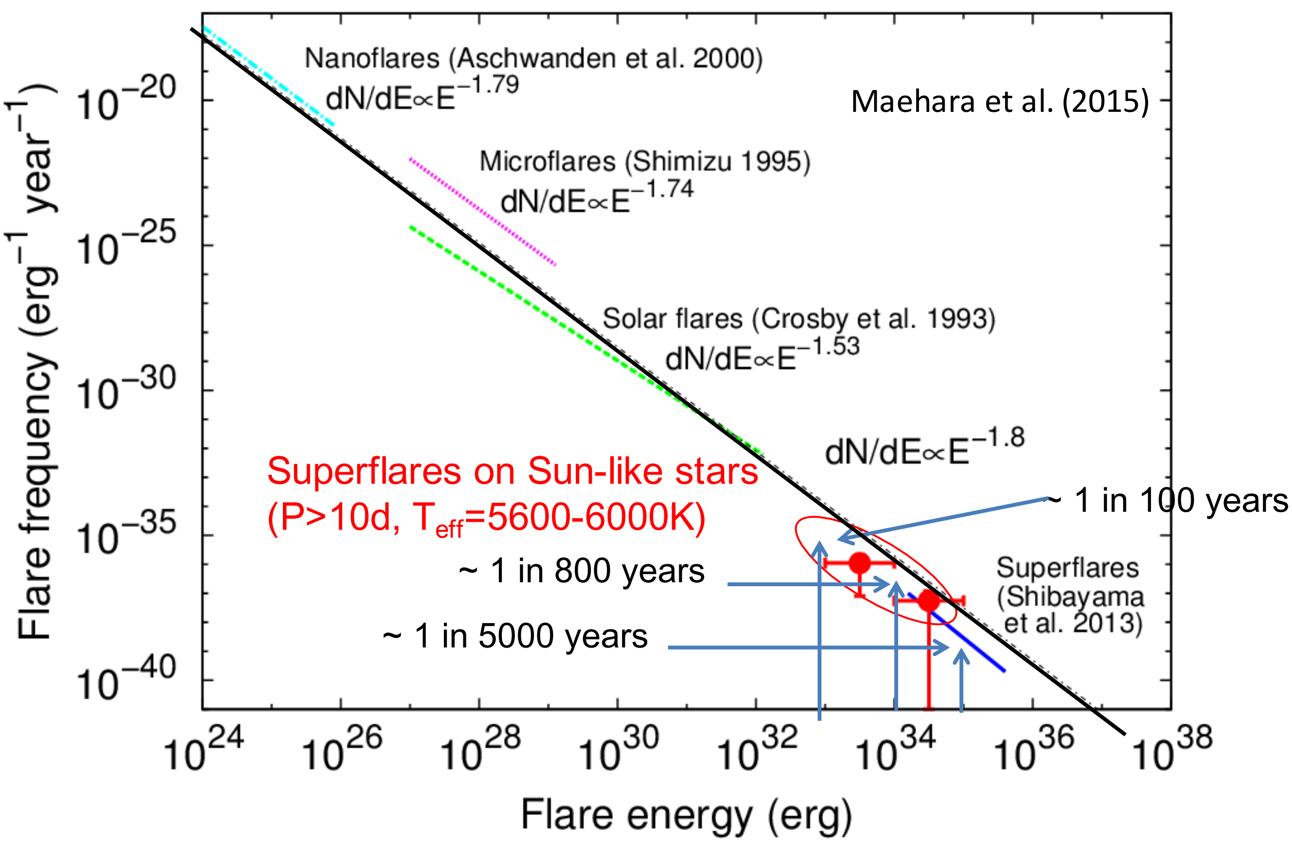


$$\frac{dN}{dE} \quad E^{a}$$

$$a \quad 1.5 \pm 0.2$$

※Flare frequency = $\frac{Number\ of\ superflares}{(number\ of\ stars) \times (length\ of\ observation\ period) \times (bin\ width)}$

Flare frequency vs. flare energy



Can large starspots explain the brightness variation?

Many superflare stars show quasi-periodic brightness variations.

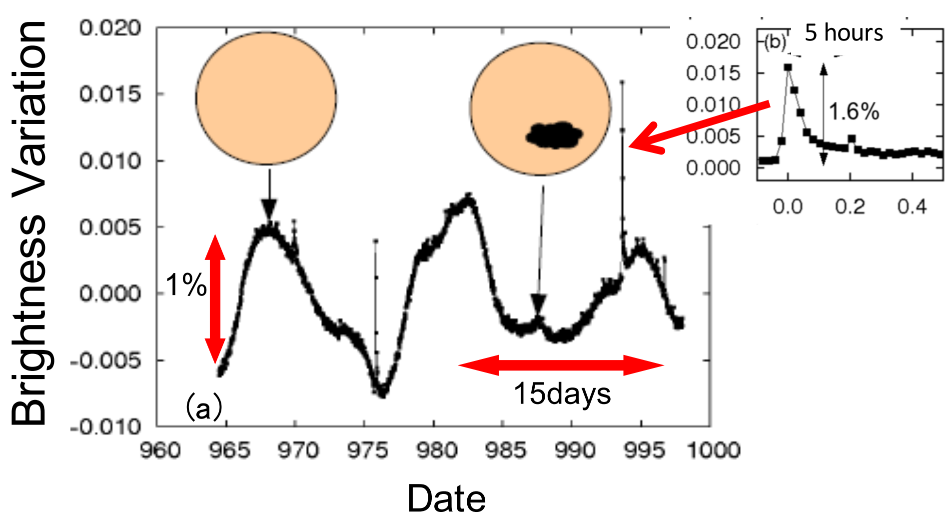
Rotation of a star with large starspots!?

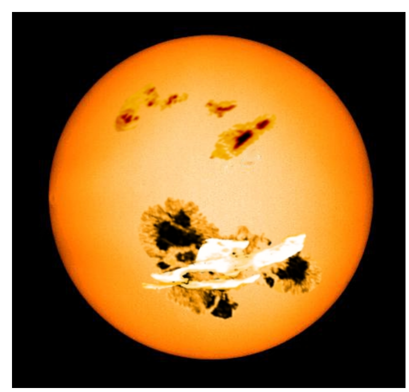
Amplitude ≒ starspot coverage

Notsu Y. et al. (2013)

Amplitude: Much larger than the effect of the rotation of the Sun with sunspots

Sun:0.01～0.1%, Superflare stars : 0.1～10%





Artificial Image of a superflare star

Flare energy vs. area of starspots

- Flare energy is consistent with the magnetic energy stored around the starspots.

⇒Large starspots are necessary.

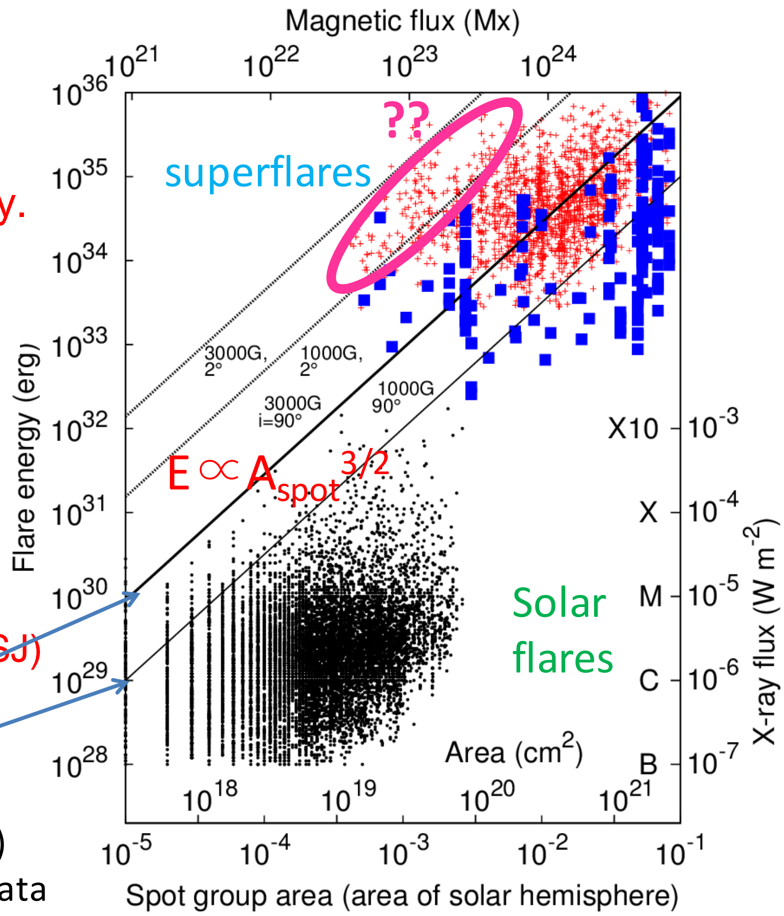
$$E_{\rm flare} \approx f E_{\rm mag} \approx f \frac{B^2 L^3}{8\pi} \approx f \frac{B^2}{8\pi} A_{\rm spot}^{3/2}$$

- Flares above the line may occur on the stars with low-inclination angle (or stars with polar spots?)

cf. Spectroscopic studies (Our Poster & Notsu+2015b PASJ)

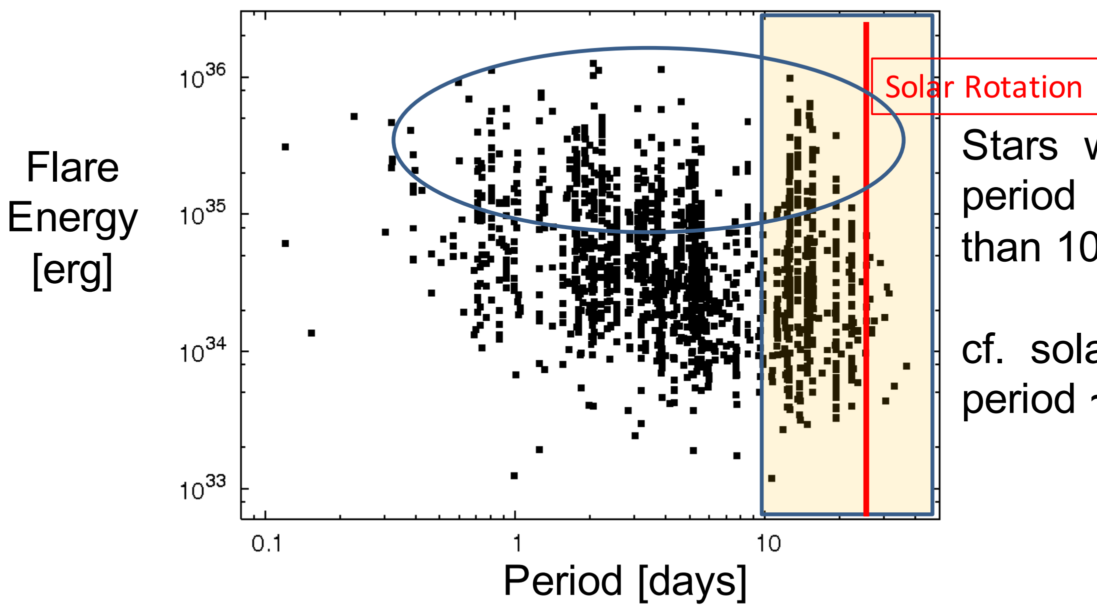
f=0.1, B=3000G

f=0.1, B=1000G



Notsu et al. (2013)
+ short cadence data

Flare energy vs. rotation period



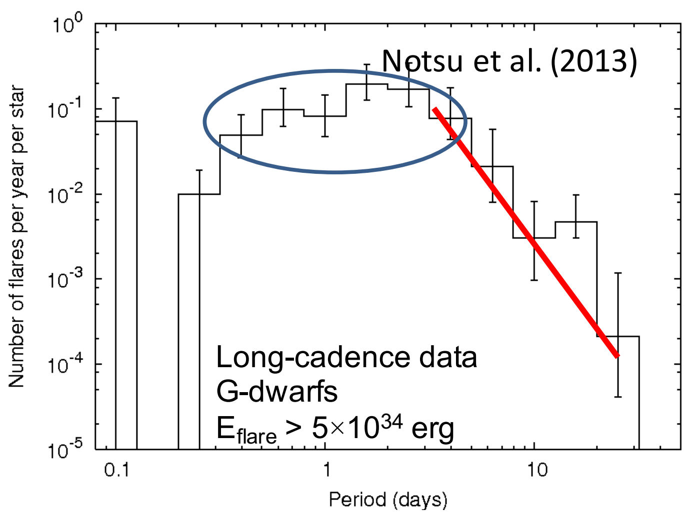
Stars with period longer than 10 days

cf. solar rot period ~ 25days

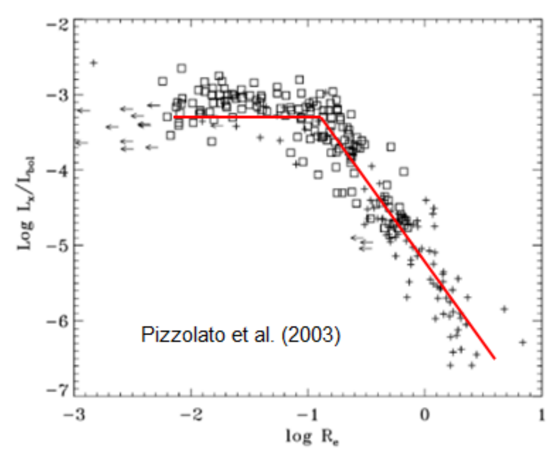
- The energy of the largest flares observed in a given period bin does **not** have a clear correlation with the rotation period.
  - Magnetic energy stored near the spots does not have a strong dependence on the rotation period.
  - Superflares may occur on the slowly-rotating stars.

Flare frequency vs. rotation period

- The frequency of superflares decreases as the rotation period increases (P>2-3days).
  - The frequency of superflares shows the "saturation" for a period range < 3 days.
    → similar to the relation between Lx vs. Ro.



L_X/L_{bol} vs. Rossby number



(Ro = P_rot / t_conv)

Summary

- ○ We discovered many (>1000) superflares on many (~300) solar-type (G-type main sequence) stars.

- ○ Frequency distribution of superflares
  - – power-law function (index: ~ -1.8)
    - • The power-law distributions of superflares on Sun-like stars and that of solar flares are roughly on the same line (E=10^{24}-10^{36} erg)

- ○Superflares vs. stellar properties
  - – Maximum superflare energy :

    Correlation with ○Area of starspots ×rotation period
  - – Flare frequency depends on the rotation period.

⇒Slowly rotating stars like the Sun can have superflares!?
Important factor is an existence of large starspots.

For the details, see also our posters (No.117&118) !!

FUV Emission Line Flares on M and K Dwarfs in the MUSCLES Survey

Cool Stars 19

Parke Loyd

University of Colorado

UV Collaborators: Kevin France *(MUSCLES PI)*, Allison Youngblood, Christian Schneider, Alex Brown and the MUSCLES Team

Flares Influence Atmospheres, Life

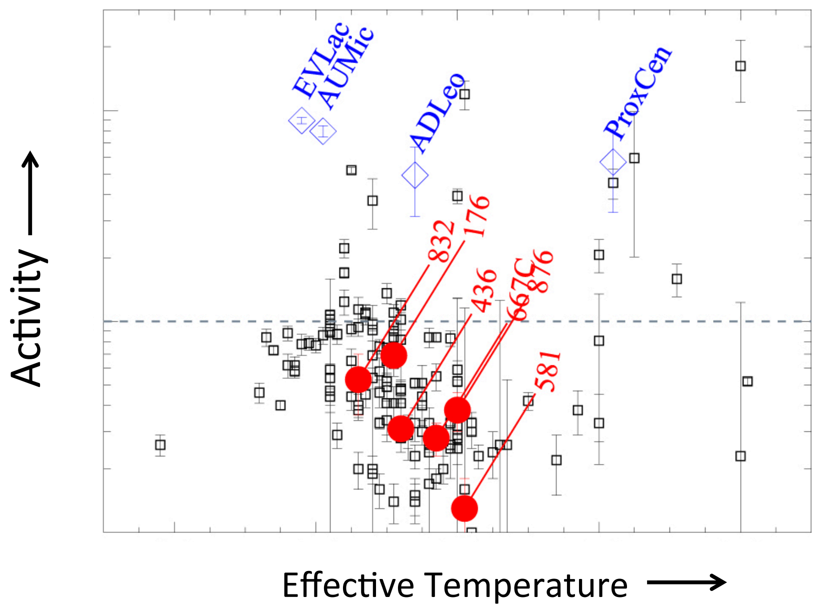
Lammer et al. 2007 (AsBio 7:185): "…Earth-like exoplanets that have no, or weak, magnetic moments may lose tens to hundreds of bars of atmospheric pressure, or even their whole atmospheres due to the CME-induced O ion pick up…"

Segura et al. 2010 (AsBio 10:751): "When the action of protons [released during a flare] is included, the ozone depletion reaches a maximum of 94% two years after the flare for a planet with no magnetic field."

Airapetian et al. 2016 (NGEO 9:452): Flares on the young sun could "initiate reactions converting molecular nitrogen, carbon dioxide and methane to the potent greenhouse gas nitrous oxide as well as hydrogen cyanide, an essential compound for life."

A Gap in Our Knowledge of Low-mass Stars

Total Observed Time by *HST*



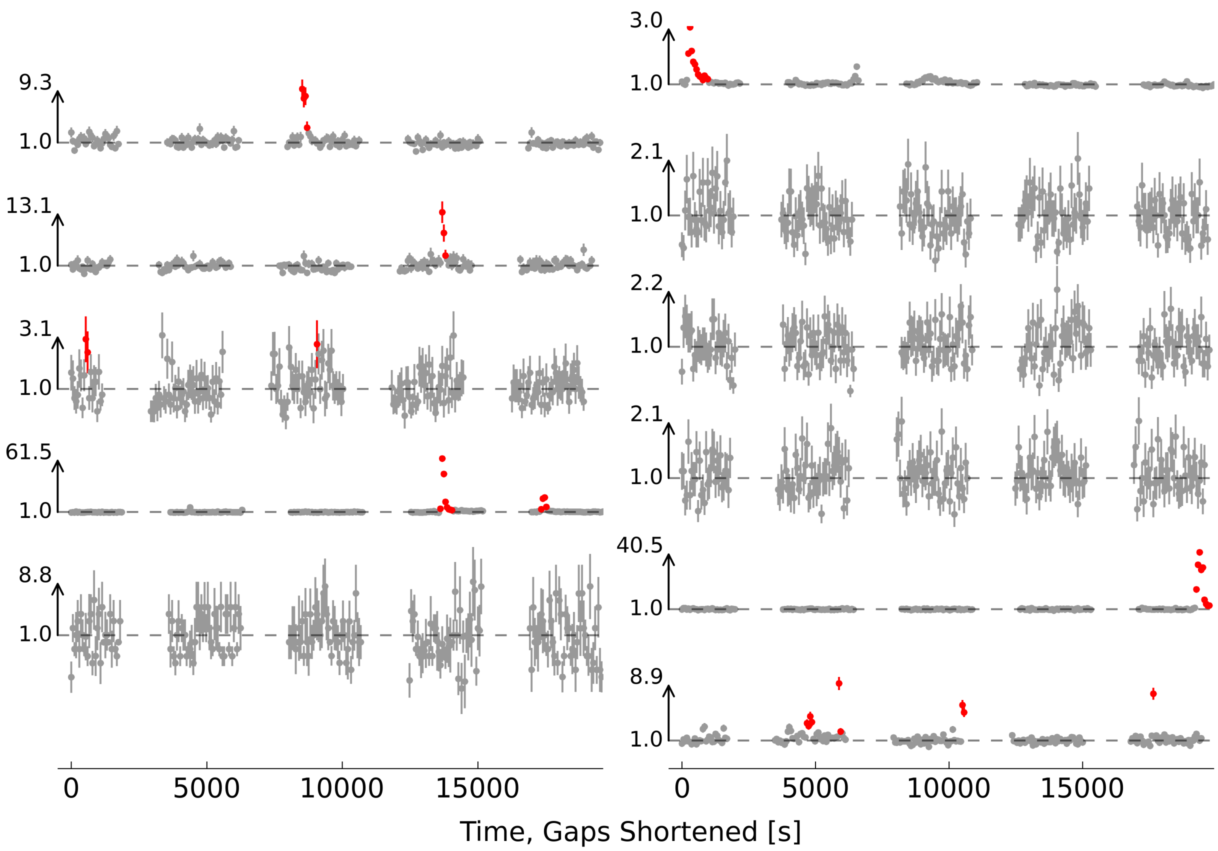
44 h

~~3 h~~

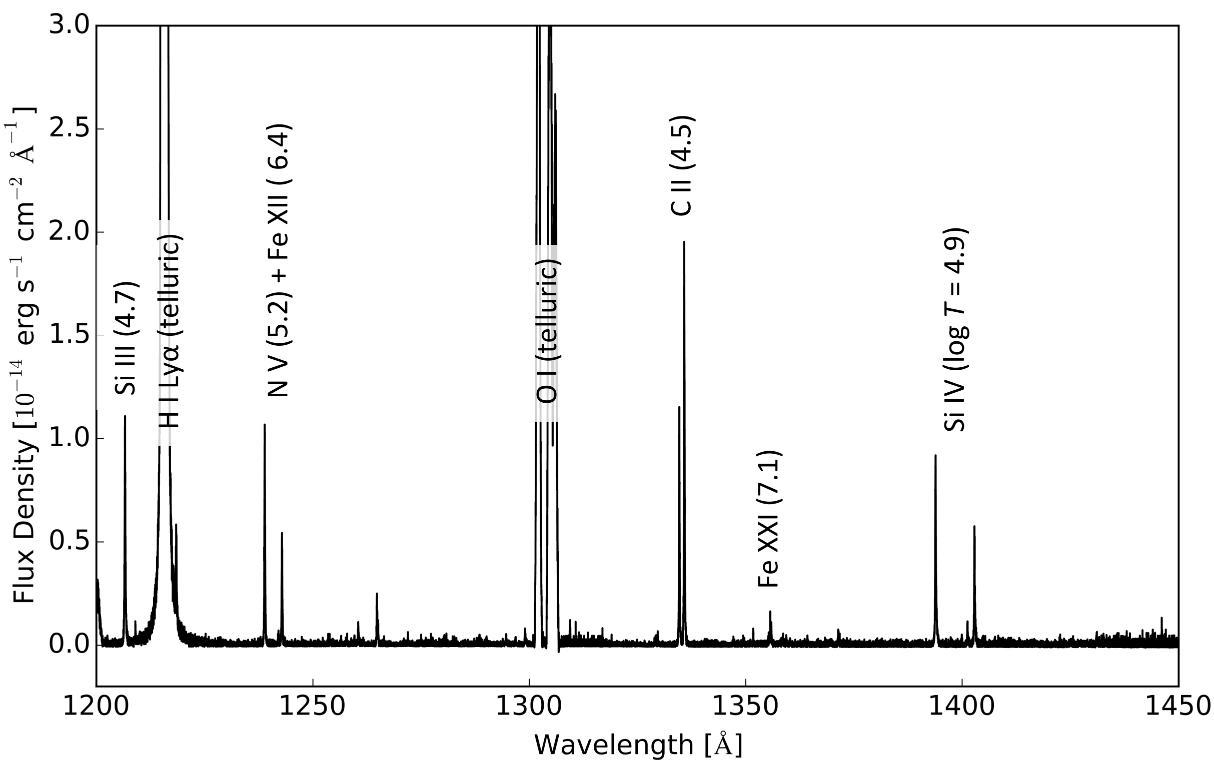
46 h

Rauscher & Marcy 2006, PASP 118:617

The MUSCLES FUV Time Series



Spectral Coverage in the FUV

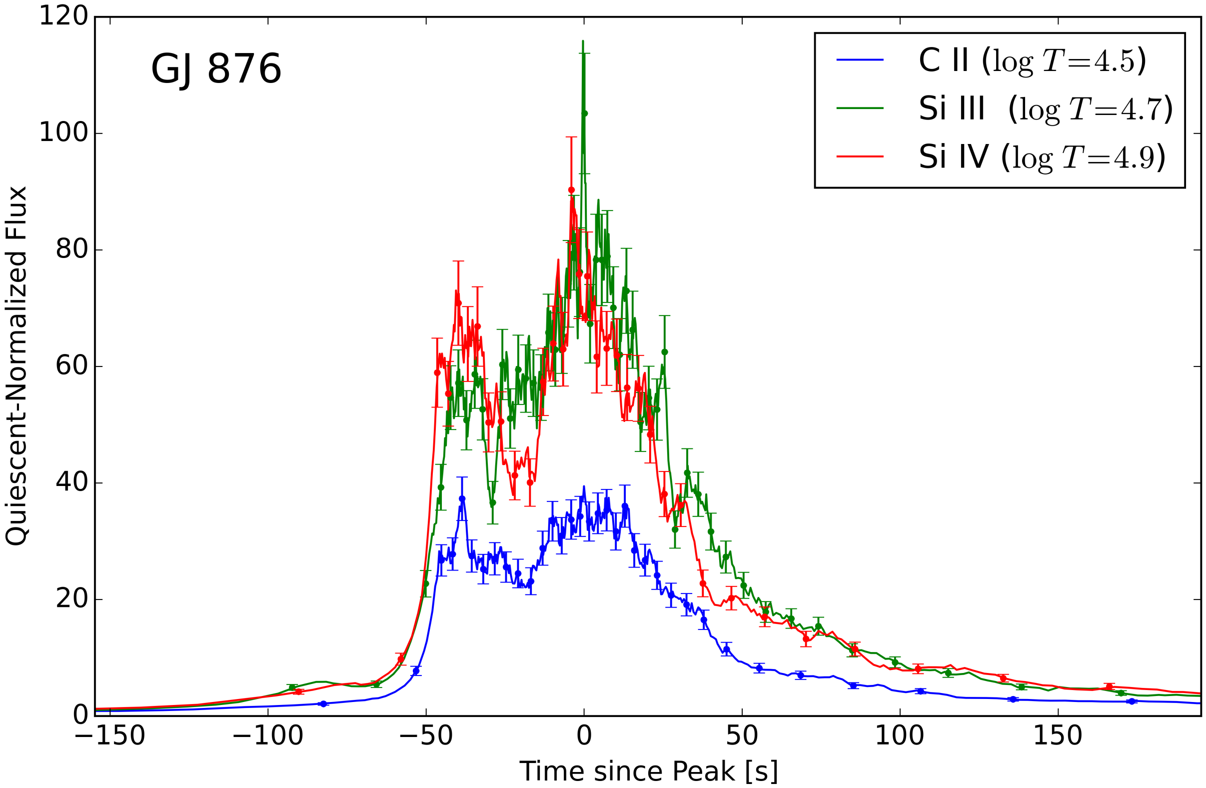


(t, λ) recorded for each photon collected in

3.5 h/star × 11 stars

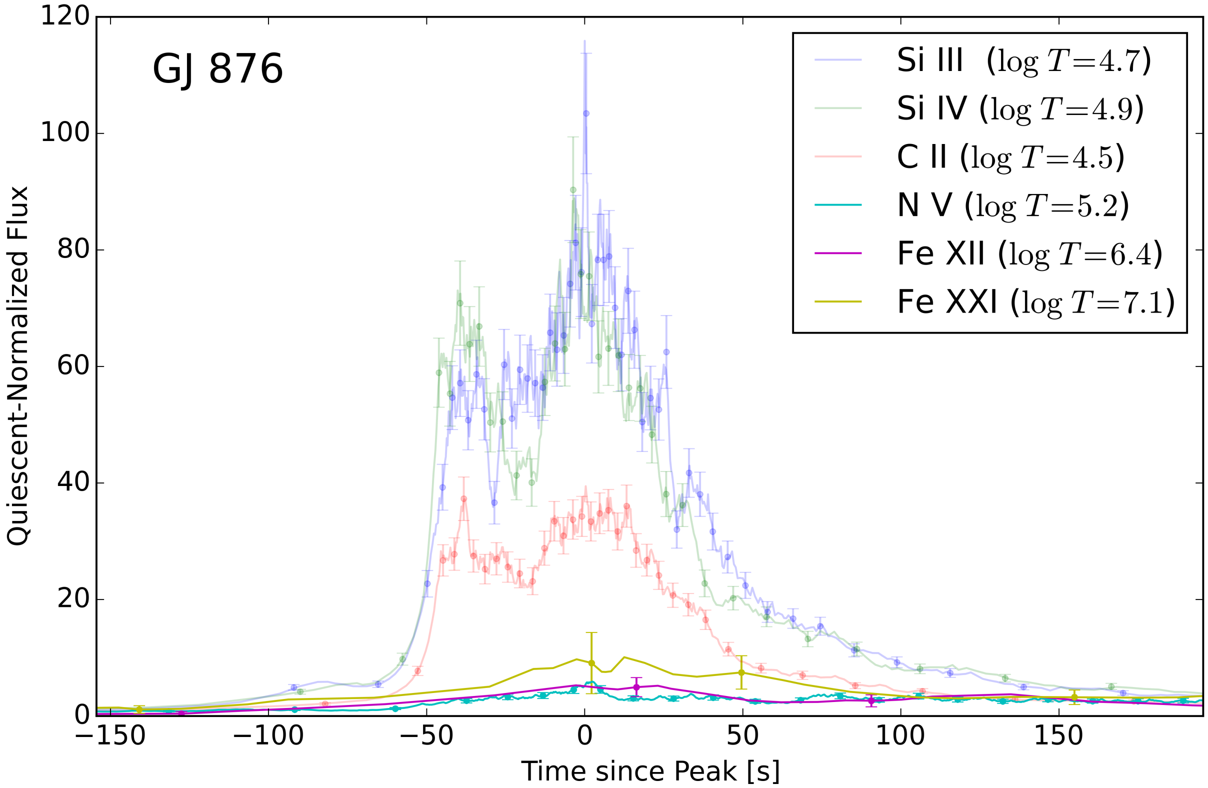
FUV Flare Morphology

Transition region lines show an impulsive, strong response.



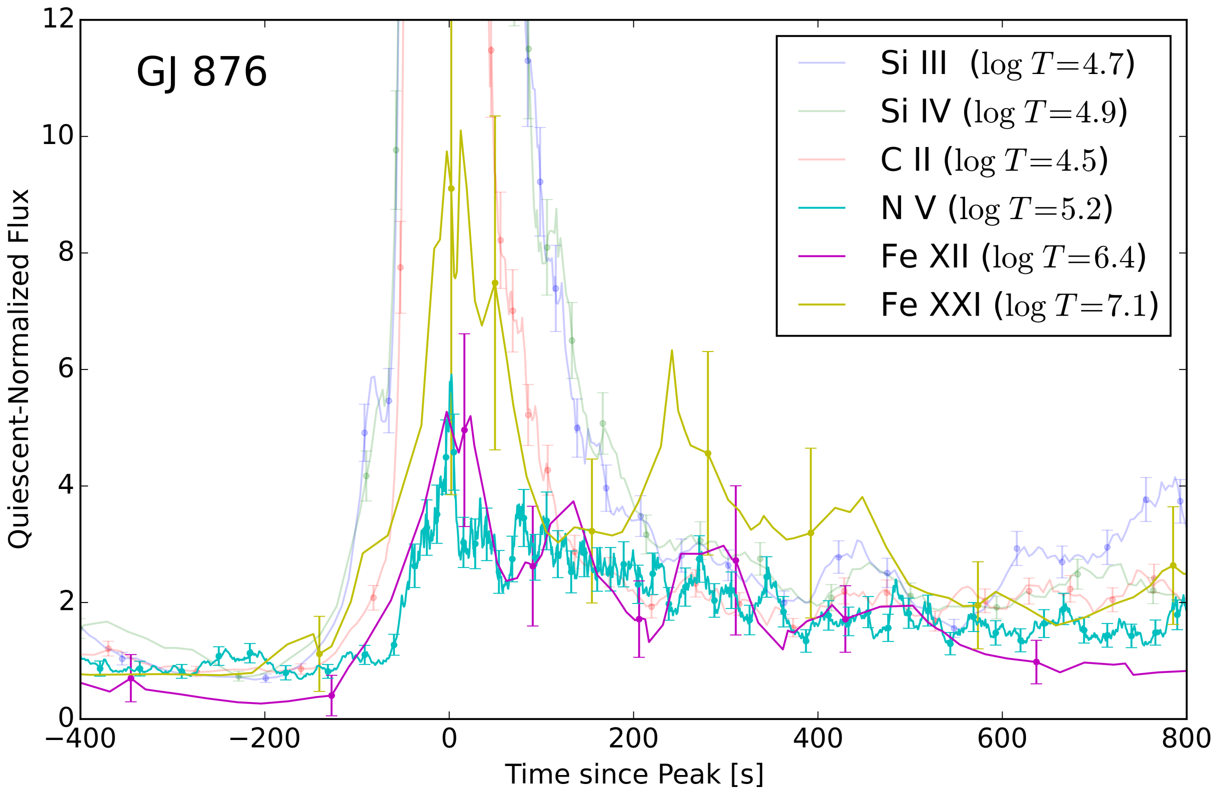
FUV Flare Morphology

Coronal lines and N V show weaker response, gradual decay.

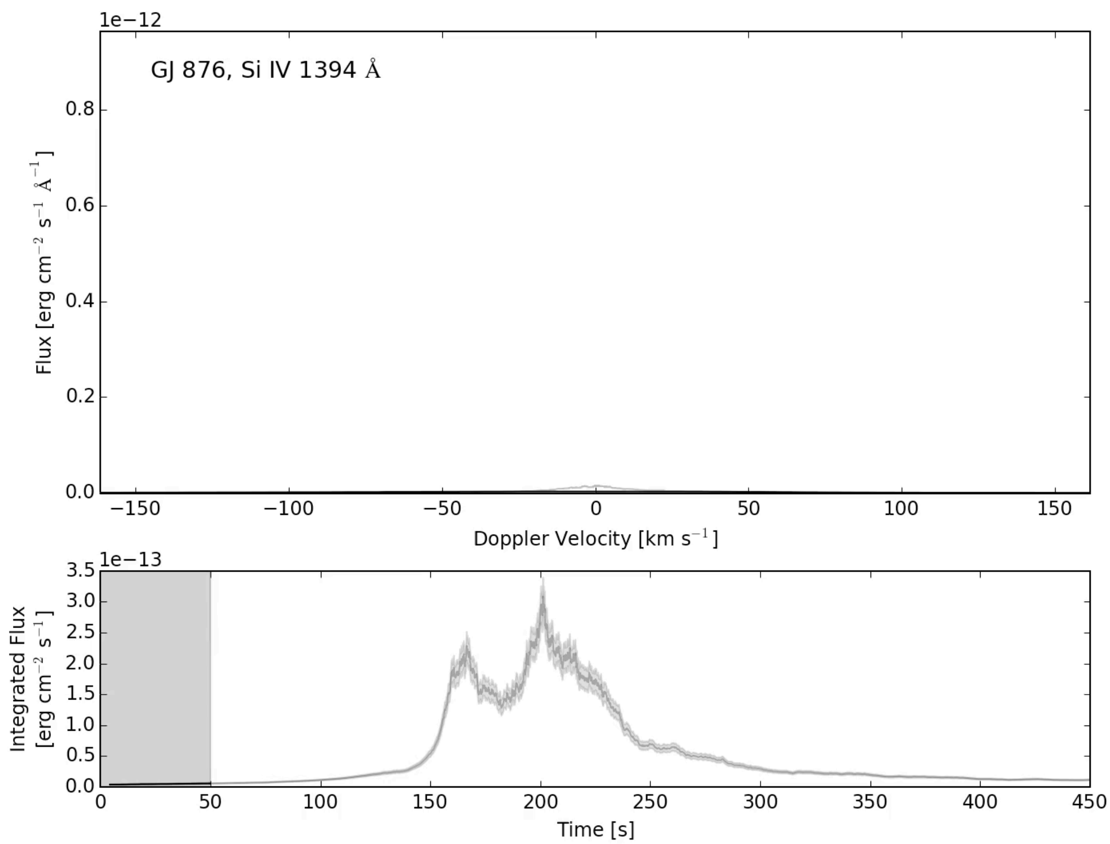


FUV Flare Morphology

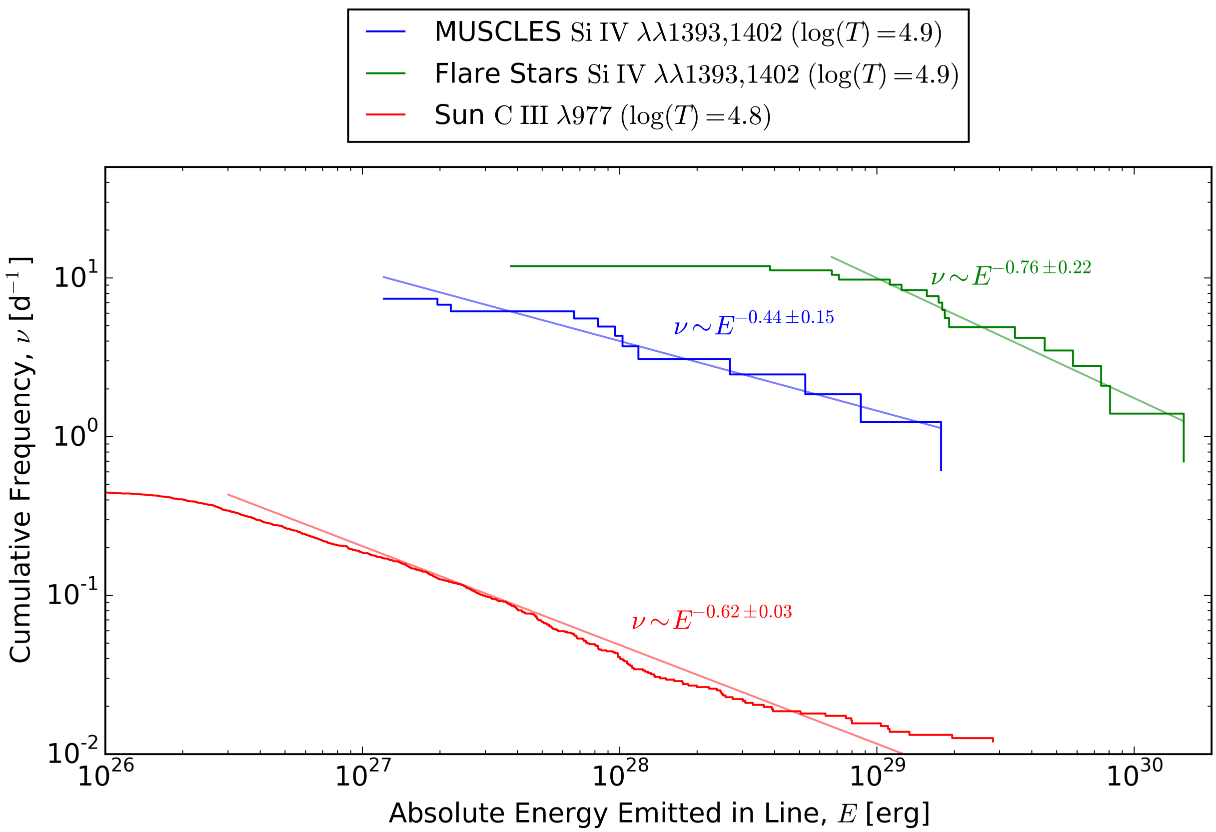
Coronal lines and N V show weaker response, gradual decay.



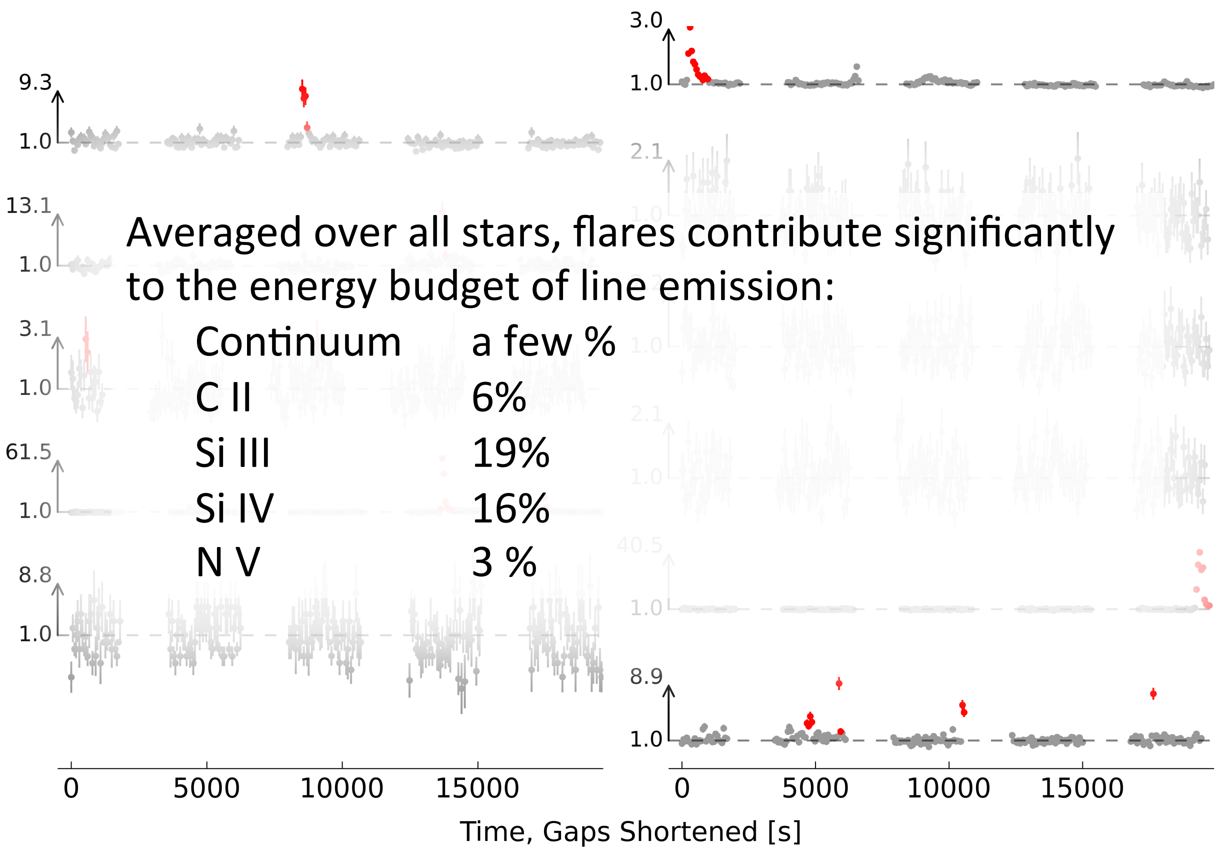
A Flare in Velocity and Time



The MUSCLES Flare Power Law



The MUSCLES FUV Time Series



Averaged over all stars, flares contribute significantly to the energy budget of line emission:

Continuum	a few %
C II	6%
Si III	19%
Si IV	16%
N V	3 %

Conclusions

MUSCLES provides **40 h** of **FUV data** on **7 M** and **4 K stars**

- Transition region flares are common on inactive M and K stars.
- Coolest 3 lines, C II, Si III, Si IV show impulsive, strong flare enhancements. Hottest 3 lines, N V, Fe XII, and Fe XXI, show weaker response, longer decay.
- These stars have a power-frequency distribution with slope statistically consistent with the Sun and flare stars.
- Averaged over all stars, flares contribute 1-20% to FUV line emission energy budgets.

Open questions…

- Do strong UV flares always produce a coronal (Fe XII, Fe XXI, X-ray) response?
- Do these flares correspond to particle events?
- What is the impact of *frequent* UV flares on chemistry and escape in planetary atmospheres?

SDO/HMI White-light flares and Their Associated Manifestations

Juan Carlos Martínez Oliveros, Hugh Hudson
and Säm Krucker

Space Sciences Laboratory, UC Berkeley, Berkeley,
University of Glasgow, Glasgow
University of Applied Sciences and Arts
Northwestern Switzerland

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WL and HXR emissions

- White-light continuum is usually associated with the impulsive phase of a solar flare.
- The association of white-light continuum with the impulsive phase of a solar flare has long been known, and cited as an indication that high-energy nonthermal particles have penetrated deep into the lower solar atmosphere (Najita & Orrall 1970; Švestka 1970)
- The association with particle acceleration has always suggested >10 keV electrons in particular (Hudson 1972; Rust & Hegwer 1975; Hudson et al. 1992; Neidig & Kane 1993).
- These particles can be observed indirectly via their hard X-ray bremsstrahlung emission (Peterson & Winckler 1959).
- The bremsstrahlung signature may also result from acceleration directly in the lower atmosphere, rather than in the corona (Fletcher & Hudson 2008).
- Other possible is that the WLF is produce by backwarming.

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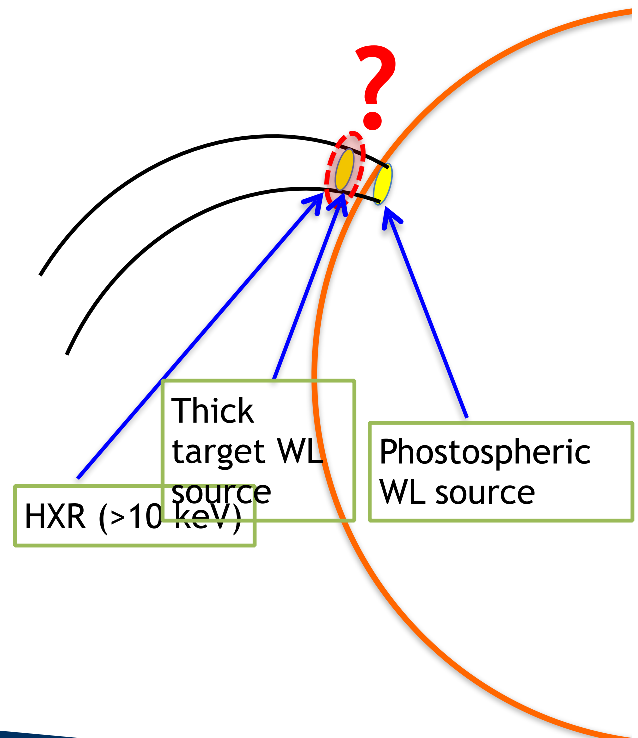
WL and HXR emissions

Where the white light emission is generated?

- One possibility is that the WL emission and the HXRs associated with it are generated in the chromosphere.
- The WL photospheric signatures could be generated by radiative recombination or by backwarming.



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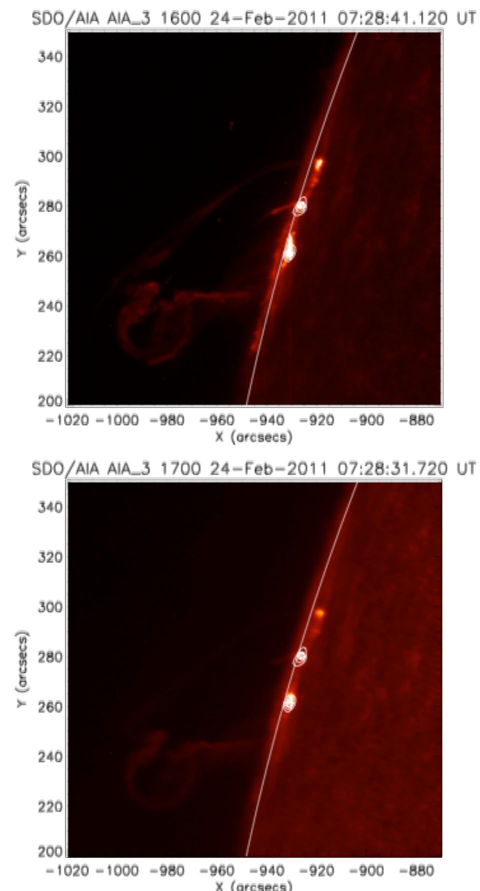
The 24 February 2011 event

•This flare was a GOES M3.5 event hosted by NOAA active region 11163.

•The flare occurred close to the East limb, but not so far as to occult the footpoints.

•Both hard X-rays and white light appear to lie significantly on the front side of the limb.

•In figure the white contours indicate visible light emission.



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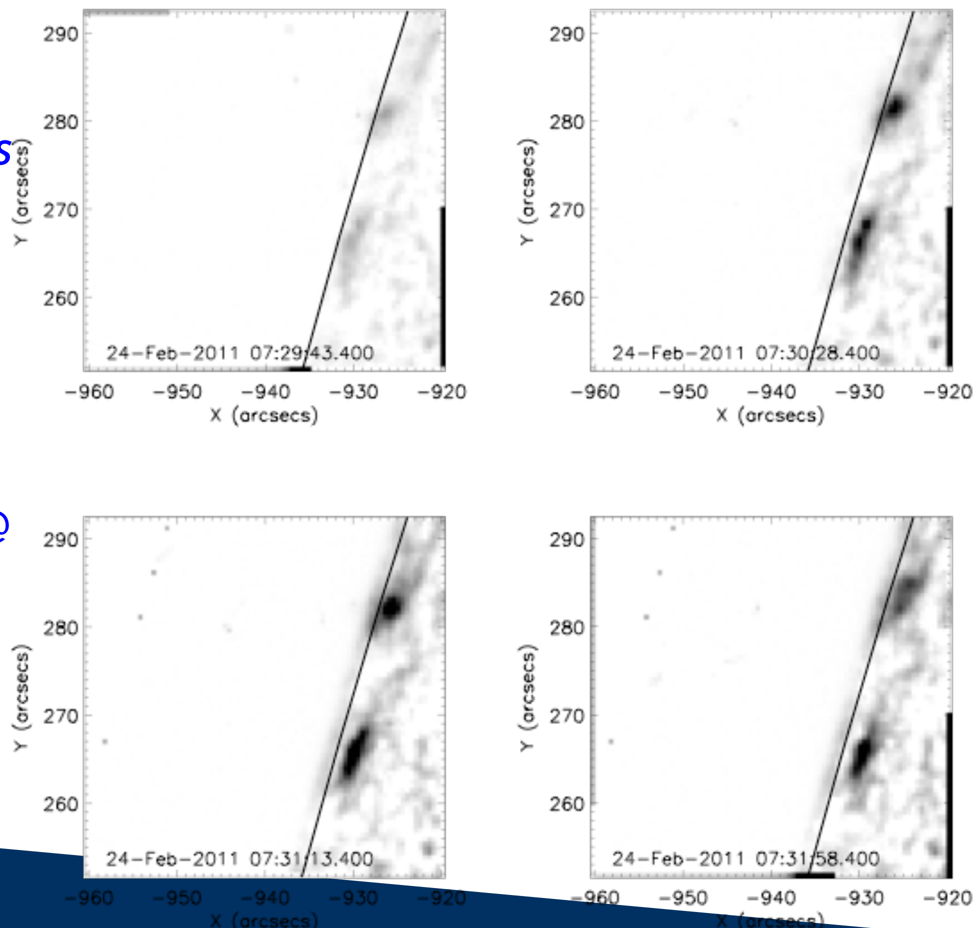
•SDO/HMI *(base difference images @ 6173 A shown here)*

•RHESSI HXR 30-80keV

•STEREO-B EUVI @ 195Å



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Heights of HXR and WL sources

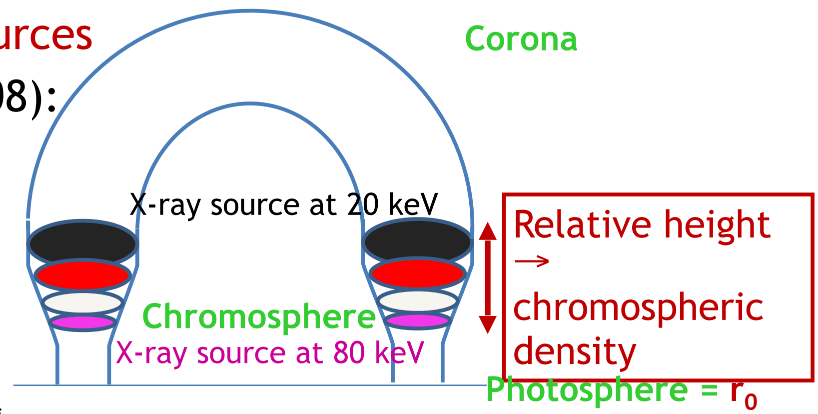
Method (Kontar et al. 2008):

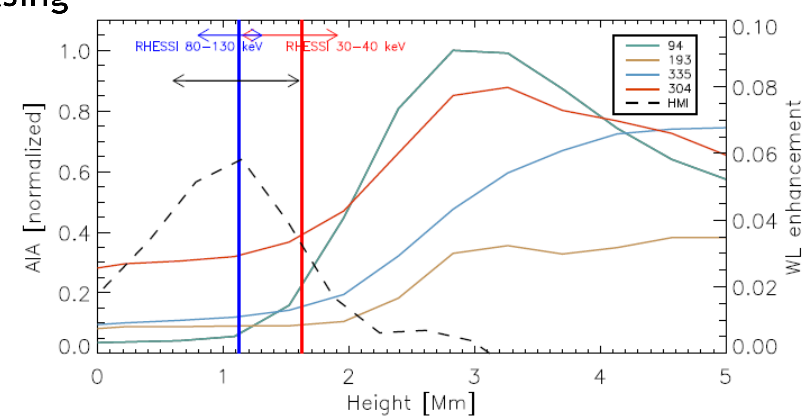
$$n(h = r - r_0) = n_0 \exp\left(\frac{-(r - r_0)}{h_0}\right),$$

Fixed at photospheric density n_0

- Key assumption: Traditional thick target
- fit exponentially increasing density model to HXR source positions

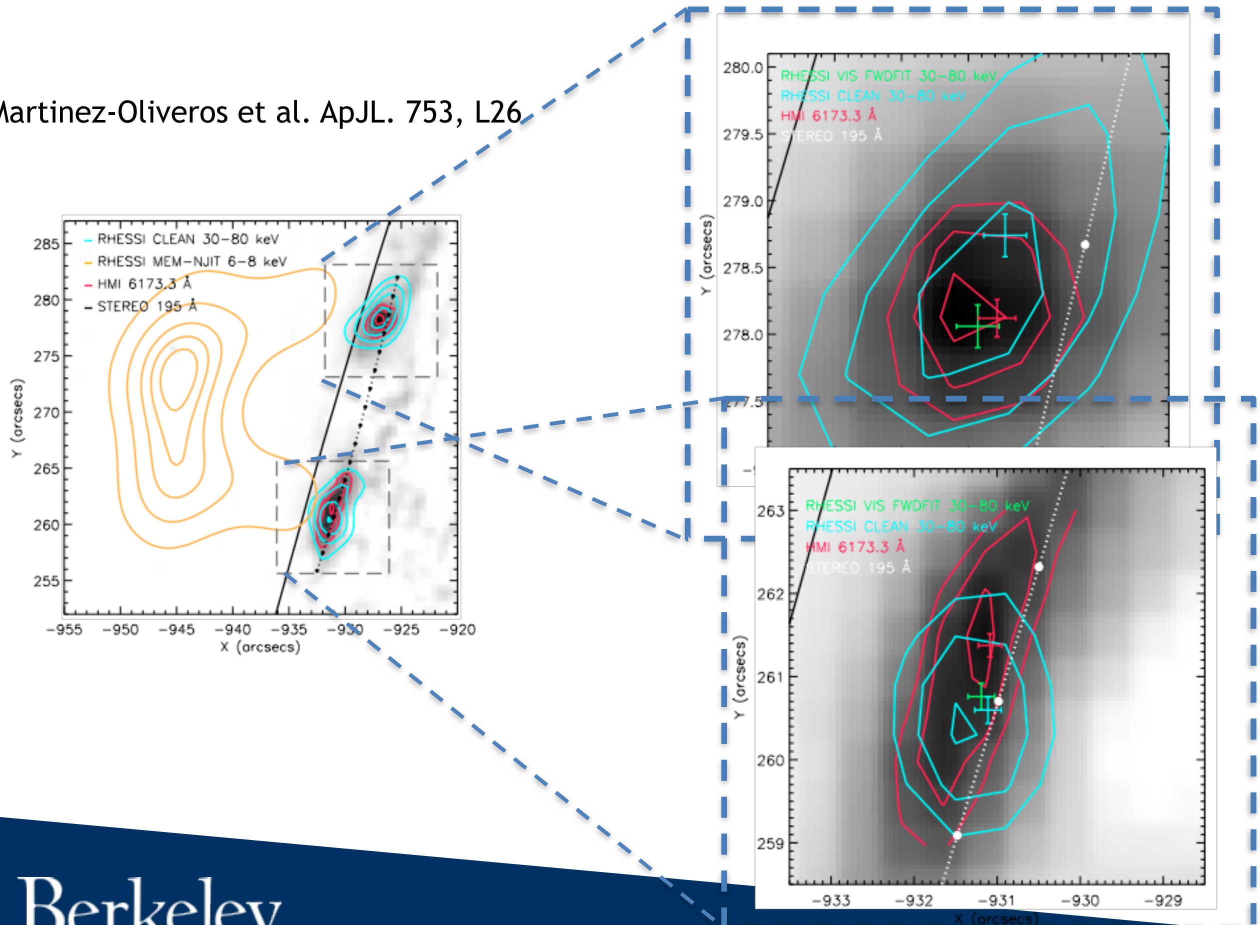
→ scale height h_0 and reference height r_0





Battaglia and Kontar (2011)

Martinez-Oliveros et al. ApJL. 753, L26



Some considerations

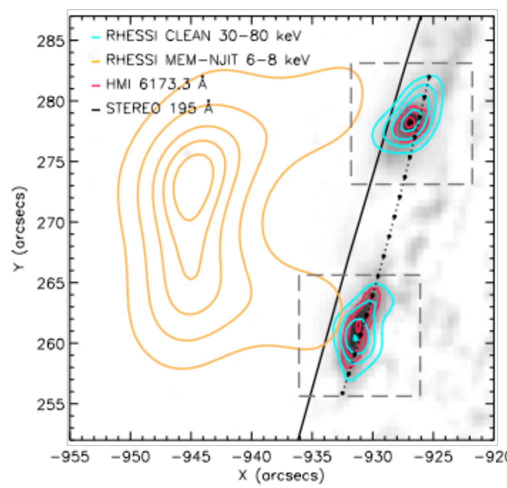
Consideration: Extreme care with metrology and systematic error is needed to draw conclusions at sub-arc sec image scales.

• For the position of the white-light continuum sources, we have used the full-disk HMI image as a reference, fitting its limb via a standard inflection-point method.

•We adopt the limb correction described by Brown & Christensen-Dalsgaard (1998) to relate this measurement to the height of the photosphere ($R_\odot$).

• The mean of their two methods gives 498km for the altitude separation, and we adopt 18km to represent the uncertainty of this number.

Martinez-Oliveros et al. ApJL. 753, L26



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Some considerations

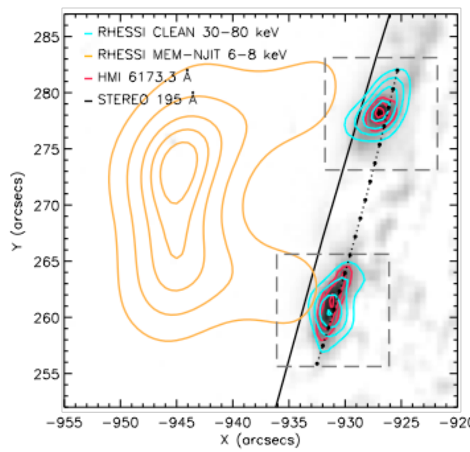
- We determined the locations of the HXR sources by using the RHESSI visibilities-based forward fitting procedure.

- We used a single 45s, 30-80 keV energy interval images and for simplicity and assumed a circular Gaussian model for each of the two bright sources.

- These positions have statistical errors ≈0.16”. Systematic errors in these positions come only from the RHESSI telescope metrology.

- Also, we characterized the source positions via the distribution of CLEAN component sources, showing excellent consistency for the source centroids.

Martinez-Oliveros et al. ApJL. 753, L26



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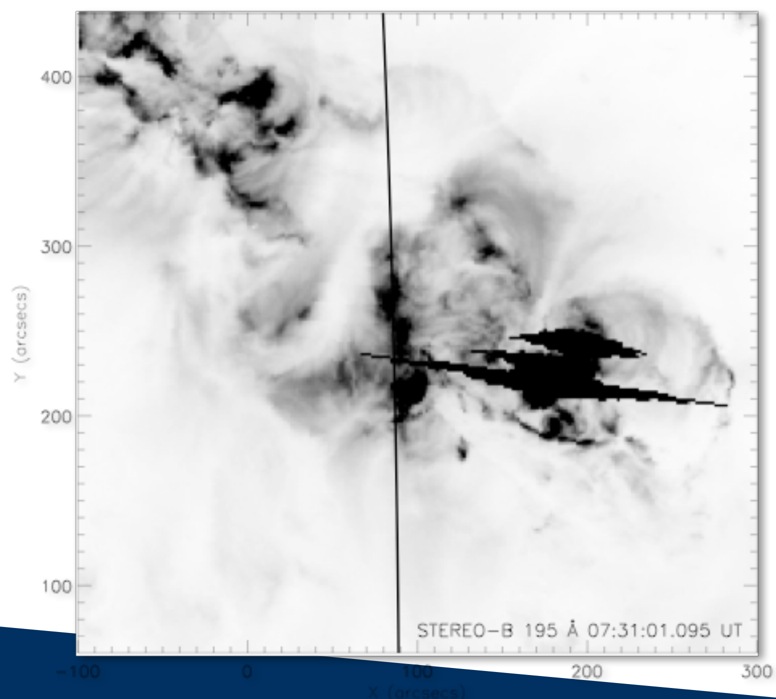
STEREO observations

- This flare was well observed, near disk center, by STEREO-B, near quadrature (space-craft helio-longitude −94.5°).
- One EUV (195 A) image was taken during the integration time of the WL.
- The STEREO-B observations prove that the flare was not occulted.

Martinez-Oliveros et al. ApJL. 753, L26



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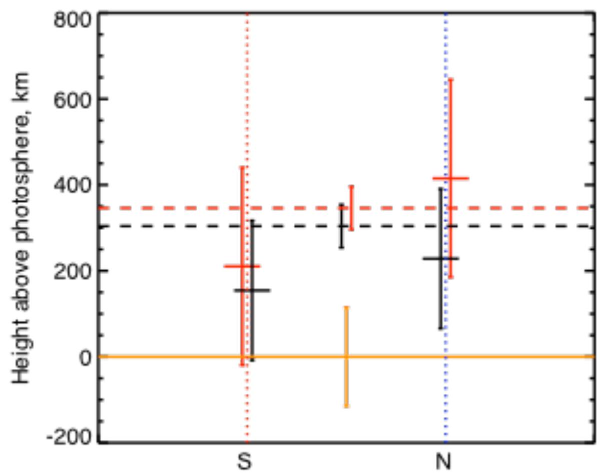
Source height

- The proximity of the flare to the limb, means that we can compare its central distance to the projected position of the photosphere, at the flare's heliographic location, to estimate the absolute source height.
- Surprisingly, our estimates lie close to (if not below) the projected heights of optical depth unity for both 40 keV hard X-rays and for optical continuum at 8673Å.
- They also lie well below the expected penetration depth of the ~50-keV electrons needed to produce the hard X-rays.
- The dominant source of error is our uncertainty in the STEREO flare position, due to the detector saturation.



The two dashed lines show the τ = 1 points for Compton scattering opacity (red) and a scaled optical opacity (black). Martinez-Oliveros et al. ApJL. 753, L26

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The Catalog: First Results

We have analyzed so far data from the years 2011 to 2013. Soon we will have results for 2014.

Total number of flares: 229

Total number of white-light flares detected: 79

Total of off-limb events: 16

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HXR and WL sources are co-spatial

Krucker et al. (2015) studied 3 flares finding:

- *The HXR and WL sources seem to be co-spatial.*
- *The WL and HXR source are generated at lower heights than predicted by models.*

Table 1. Parameters of the WL (617.3 nm) and HXR (30-100 keV) footpoints (values of the stronger footpoint (cf. Figure 5) are shown in bold)

	2012-07-19	2012-11-20	2013-05-13
HMI time	05:21:40.7	12:39:26.5	02:12:37.8
GOES flare class	M7.7	M1.7	X1.7
Location[a] of N ribbon (best guess[b])	**+0.7°**	**-0.5°**	-1.0°
Projection effect[c] N (best guess[b])	**51 km**	**27 km**	105 km
Location of N ribbon (conservative[b])	**+2.2° to -1.4°**	**-0.1° to -1.3°**	+1.2° to -2.2°
Projection effect N (conservative[b])	**<500 km**	**<180 km**	<500 km
Location of S ribbon (best guess[b])	-1.0°	−0.6°	**-1.2°**
Projection effect S (best guess[b])	104 km	39 km	**150 km**
Location of S ribbon (conservative[b])	+0.5° to -1.8°	-0.1° to -1.3°	**+2.4° to -4.1°**
Projection effect S (conservative[b])	<340 km	< 180 km	**<1800 km**
WL altitude	**824±70 km**	**799±70 km**	**810±70 km**
WL radial extent (FWHM)	**~862 km**	**~652 km**	**~839 km**
HXR altitude	**946±103 km**	**746±51 km**	**722±140 km**

[a]positive values corresponds to on disk location, negative to location behind the limb.

[b]estimated from STEREO observations

[c]Projection effect gives the distance the observed altitude appears lower than the actual altitude due to the deviation of the source location away from the limb (cf. Figure 1).

Krucker et al. (2015)

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HXR and WL sources are co-spatial

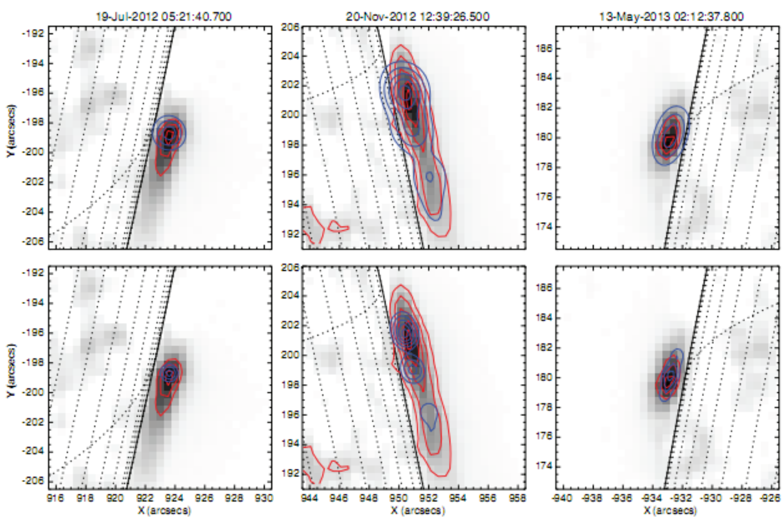

Fig. 5.— Zoomed view (15″×15″) around the stronger flare ribbon shown in Figure 3: The top row shows RHESSI CLEAN images reconstructed with the nominal highest resolution of 2.3″ FHNW. The RHESSI images shown below are reconstructed with an artificially reduced point spread function of 1.1″ FHMW to roughly match the resolution of the HMI images. The same contours are shown for the RHESSI (blue) and HMI (red) images at 50, 70, 90 % (for the more complex flare ribbon of the November 20 flare additional levels at 10 and 30% are shown).

Krucker et al. (2015)

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HXR and WL sources are co-spatial

Kuhar et al. studied 43 M- and X-class flares and finding that in general the WL and HXR are co-spatial.

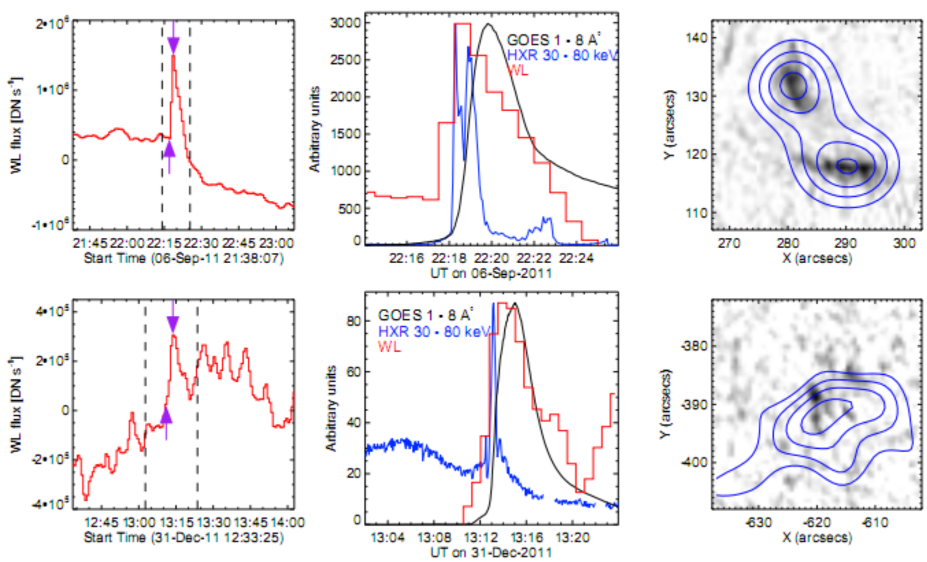
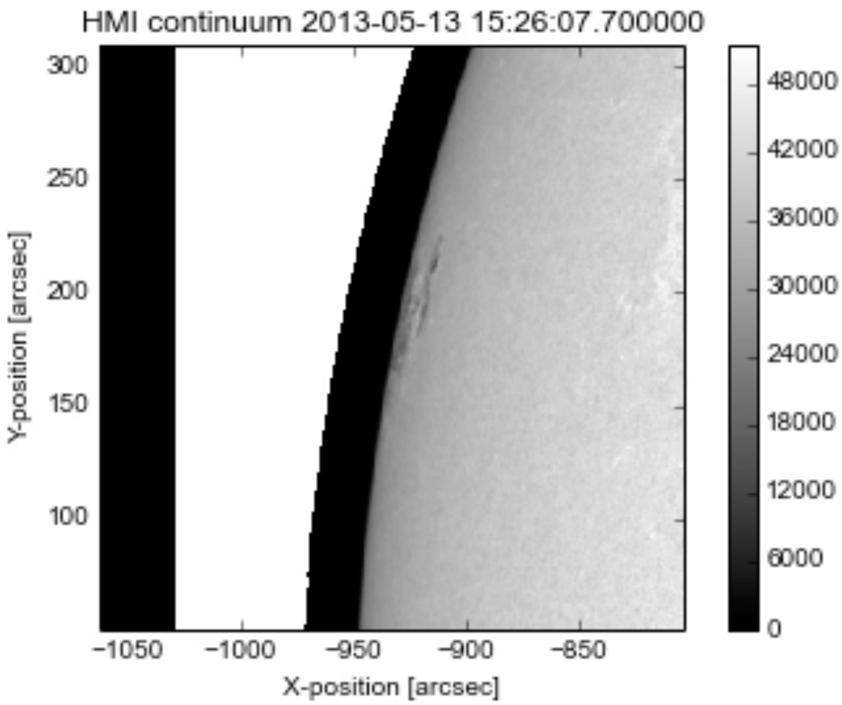
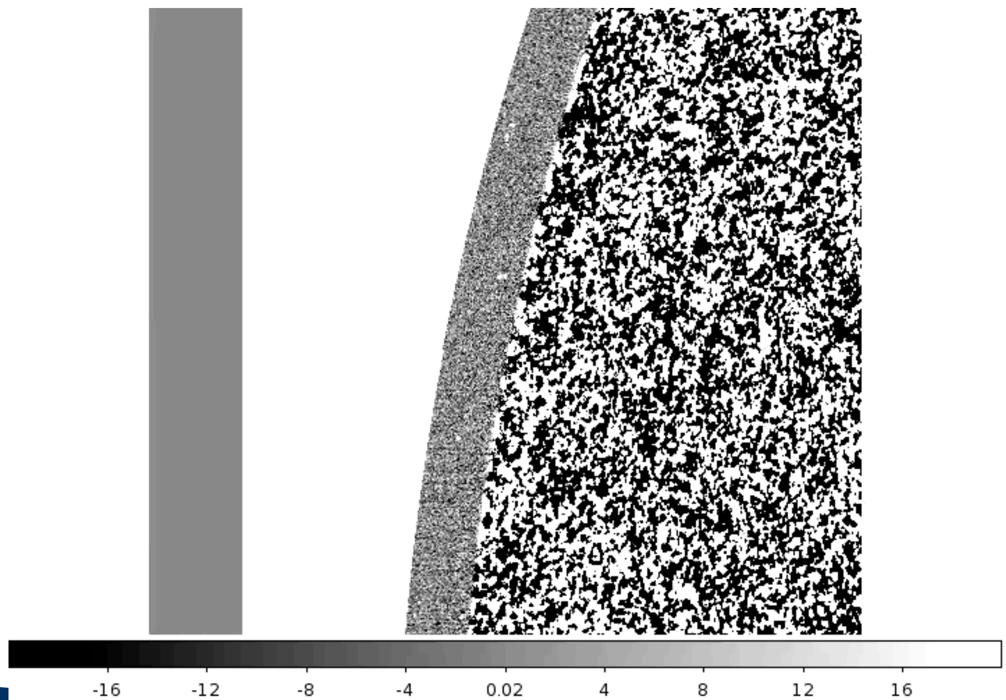


FIG. 1.— Time profiles and images of an intense (SOL2011-09-06 (X2.1)) and a weak (SOL2011-12-31 (M2.4)) event in our sample: Left panels show the WL emission (calculated inside the 30% countour of HXR emission) time profiles for a long time span around the time of peak emission to compare the increase due to the flare relative to the fluctuations of the non-flaring active region. The vertical lines indicate time ranges used in the plots in the central panels, while the purple arrows indicate peak- and pre-flare frames used for the analysis. Central plots show WL flux in red, HXR flux at 30 – 80 keV in blue and GOES flux at 1 – 8 Å in black. Right panels show pre-flare subtracted images of events in HMI with RHESSI contours of 30%, 50%, 70% and 90% of the maximum emission in the 30 – 80 keV CLEAN-image overplotted in blue.

The Catalog: First Results



The Catalog: First Results



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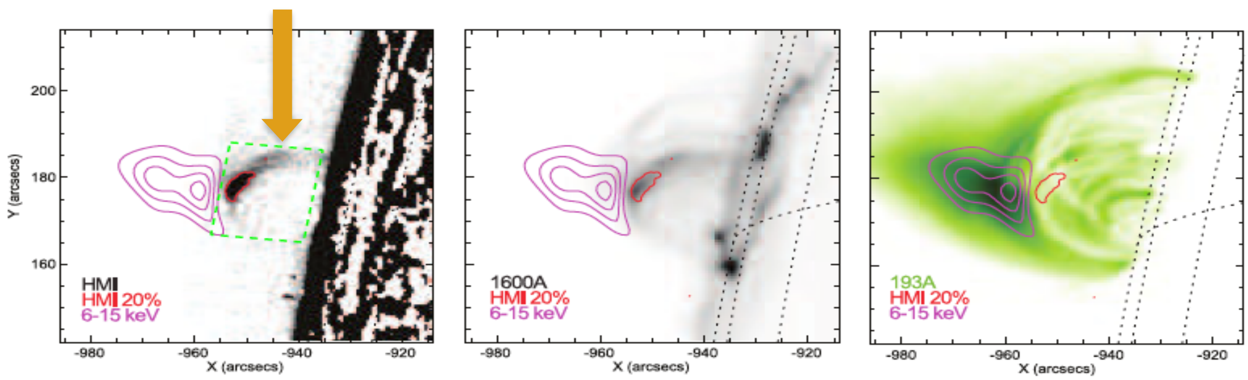
SOL2013-05-13T16:00



HMI, AIA, and RHESSI view of SOL2013-05-13T16:00

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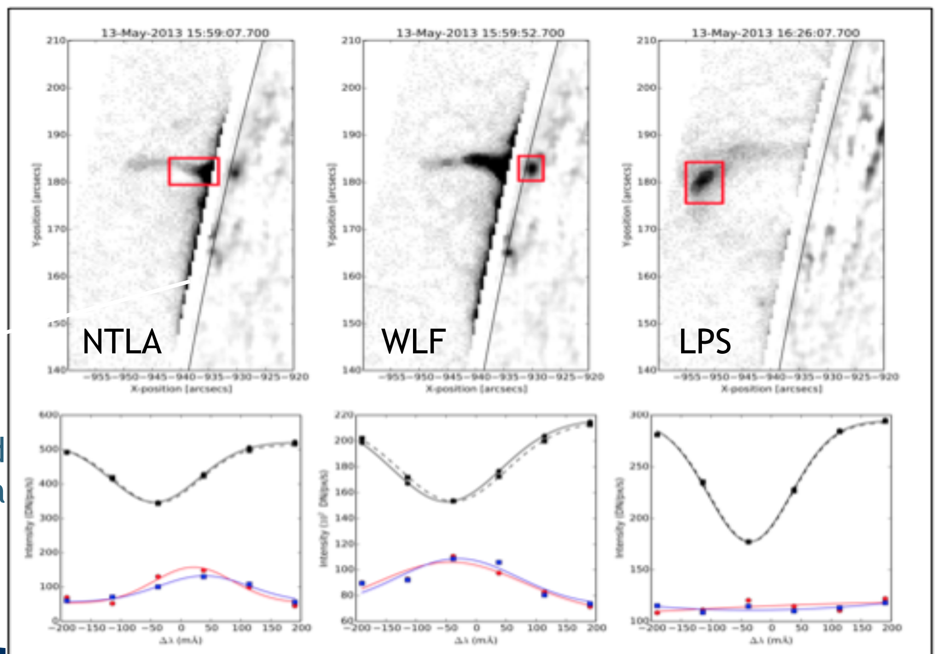
SOL2013-05-13T16:00

Difference images

80x

Background spectra

spectra



Martinez-Oliveros et al., 2014

Berkeley
UNIVERSITY OF CALIFORNIA

Conclusions

• Do all flares have white-light emission? From these initial results it seems like not, but why? The reason is instrumental? Some recent results seems to point that this is the case.

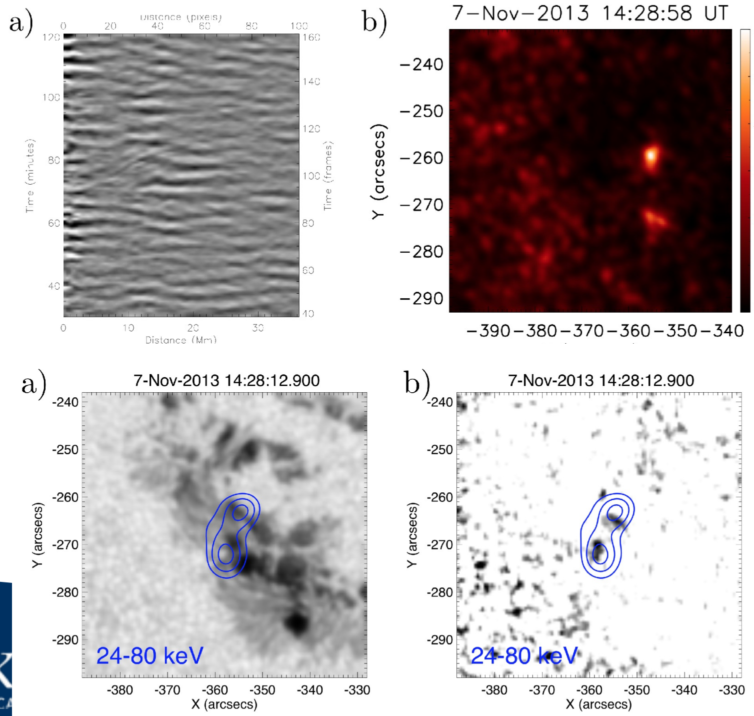
• Results of the comparison between HXR and WL emissions suggest that the HXR and WL sources are co-spatial (Martinez Oliveros et al. ,2012 and Krucker et al., 2015).

• The uncertainty in the measurements can be improved by using other HXR imaging algorithms (PIXON, Forward Fit?)

• The flare continuum, since Carrington's day, remains the most important flare property because it is so energetic. Puzzles remain and observational capabilities should improve.

Motivation II

- Are all sunquakes associated to a white–light flare?



From Buitrago-Casas et.al 2015

Motivation II

- We started to study a large sample of white-light flares
- Buitrago-Casas et.al. used a subset of this flare list to study the statistical correlation between white-light flares and sunquakes. For the selected flares they found a high correlation.

		Transient	
		0	1
WL	1	0	28
	0	34	13

$\phi = 0.70$

		SQ	
		0	1
WL	1	14	14
	0	47	0

$\phi = 0.62$

		HOLO	
		0	1
WL	1	9	19
	0	47	0

$\phi = 0.75$

It is hard to find white-light flares! These study demonstrated the necessity to develop new imaging algorithms.

We found that SDO/HMI can be used to study of limb sources!

Quasi-Periodic Pulsations in Stellar Flares: Kepler Observations

Chloë E. Pugh

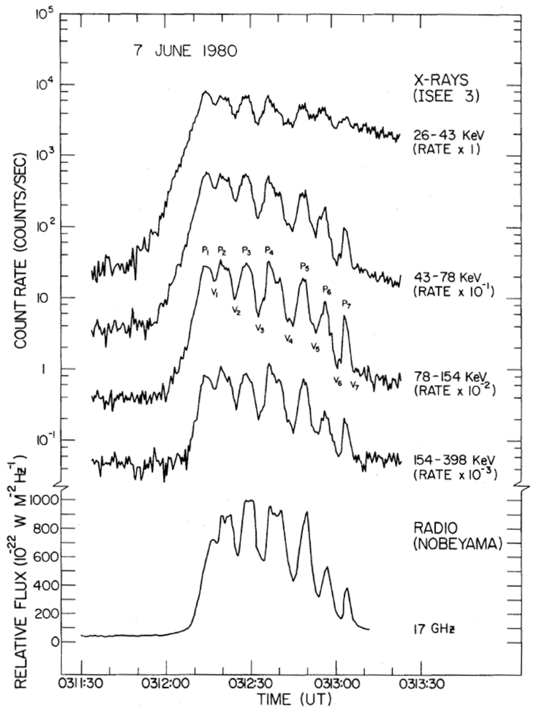
Supervisors:
Prof Valery M. Nakariakov, Dr Anne-Marie Broomhall

WARWICK
THE UNIVERSITY OF WARWICK

European Research Council
Established by the European Commission

Quasi-periodic pulsations (QPPs)

- Time-variations of the intensity of light emitted by a flare (usually in the decay phase)
- QPPs in solar flares can be used to deduce physical parameters of the flaring region (e.g. Nakariakov & Melnikov, 2009)
- QPPs in stellar flares provide evidence that the underlying physics is similar to that in solar flares

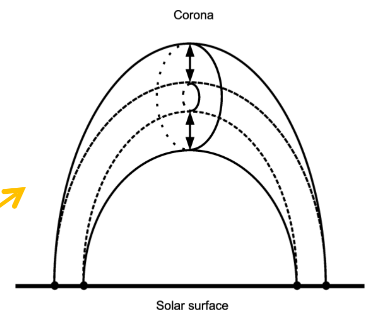


The Seven Sisters Flare, observed by Kane et al. (1983)

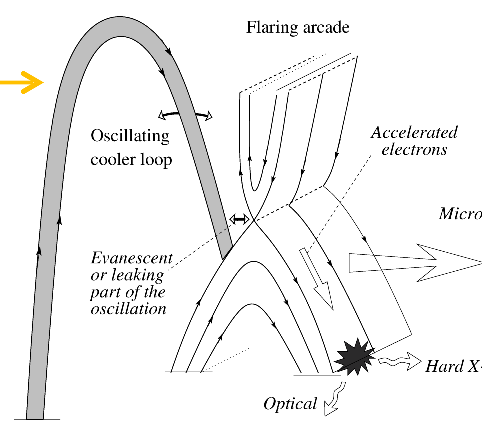
Quasi-periodic pulsations

Two groups of possible mechanisms:

- Magnetohydrodynamic (MHD) oscillations …
  - ..of the flaring structure
  - ..of a nearby structure
- Load/unload or ‘magnetic dripping’ mechanisms of energy release (periodically induced reconnection)



Pascoe et al., 2007



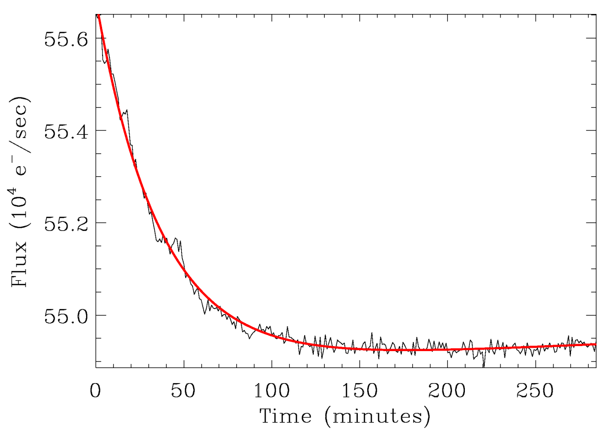
Nakariakov et al., 2006

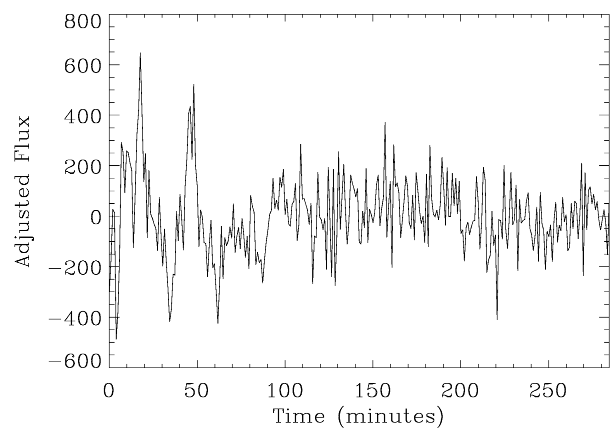
Example of observations

- Left: Kepler flare decay light curve, fitted with an exponential decay function

$$I(t) = Ae^{-Bt} + Ct + D$$

- Right: with the fit subtracted, to emphasise short-term variability

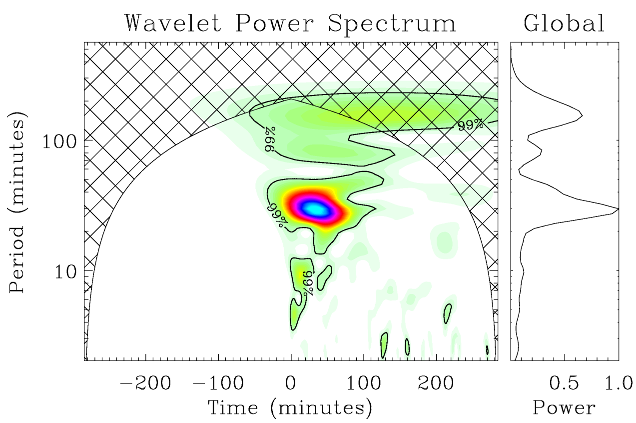


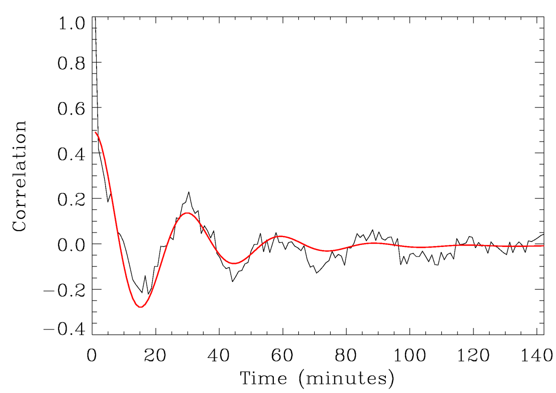


Example of observations

- Left: performing a wavelet transform to highlight oscillations
- Right: performing an autocorrelation to reduce noise
- A decaying cosine wave fits the autocorrelation function well

$$I(t) = Ae^{-Bt}\cos\left(\frac{2\pi}{P}t + \phi\right)$$



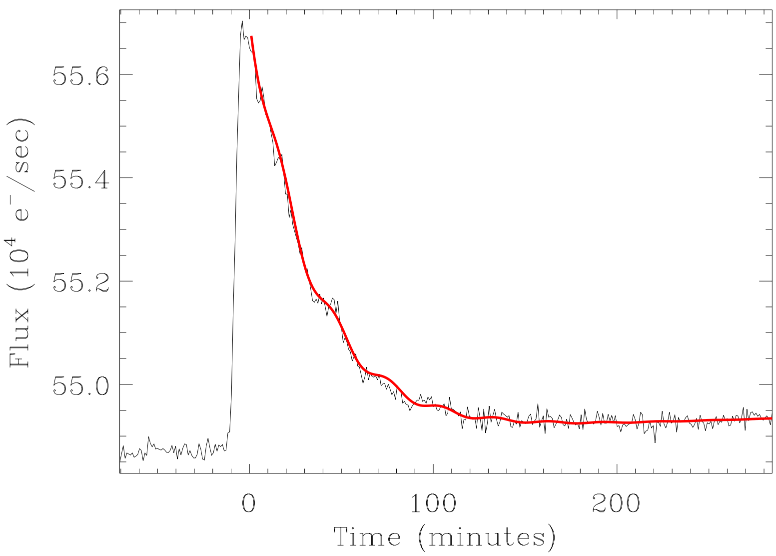


Example of observations

- Result of least squares fit

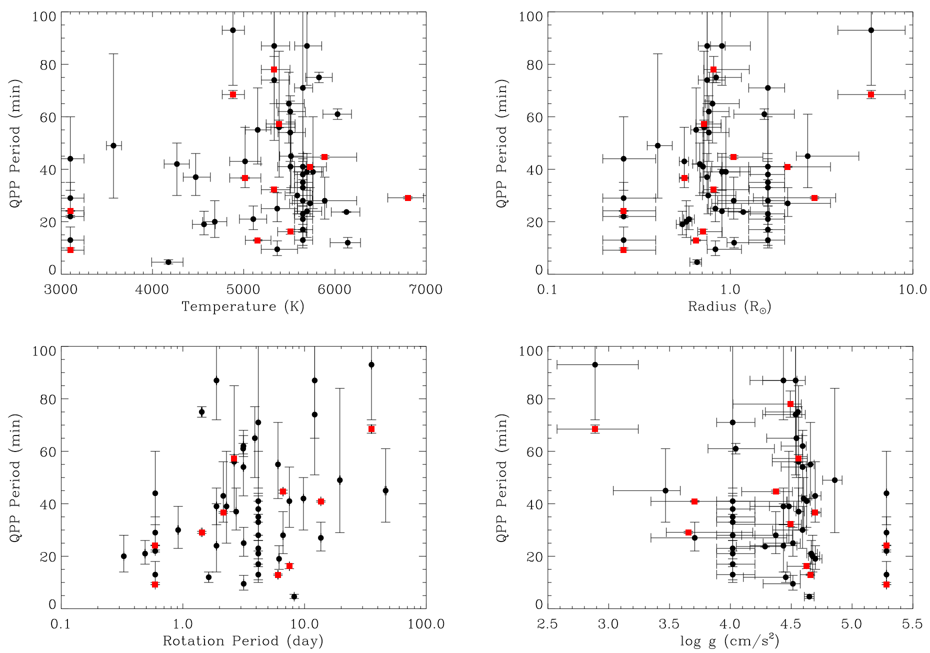
$$F(t) = A_0 \exp\left(-t/t_0\right) + B_0 t + C + A \exp\left(\frac{-(t-B)}{\tau_e}\right)\cos\left(\frac{2\pi}{P}t + \phi\right)$$

- Period = 29.1 ± 0.4 min



Statistical analysis

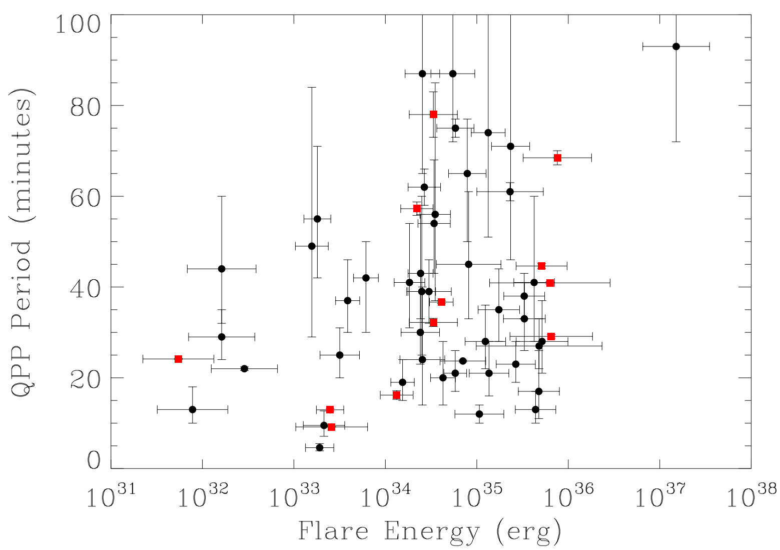
- No correlation of QPP period with global stellar parameters → implies local phenomenon



Pugh, Armstrong, Nakariakov & Broomhall, 2016, MNRAS, 459, 3659

Statistical analysis

- No correlation of QPP period with flare energy → consistent with QPPs in solar flares



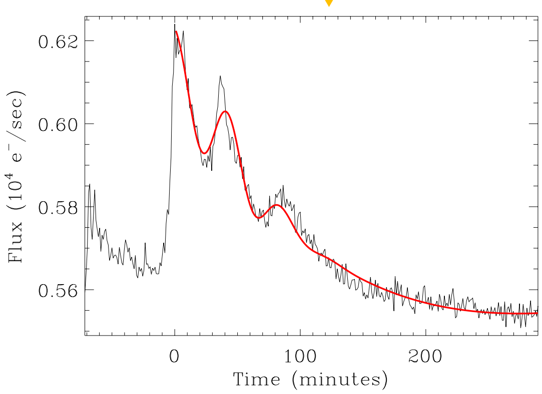
Statistical analysis

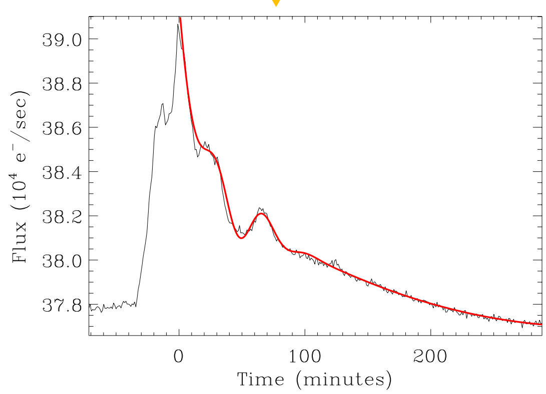
- Example of exponentially damped vs Gaussian modulated oscillations:

$$F(t) = A_0 \exp\left(-t/t_0\right) + B_0 t + C + A\exp\left(\frac{-(t-B)}{\tau_e}\right)\cos\left(\frac{2\pi}{P}t+\phi\right)$$

or

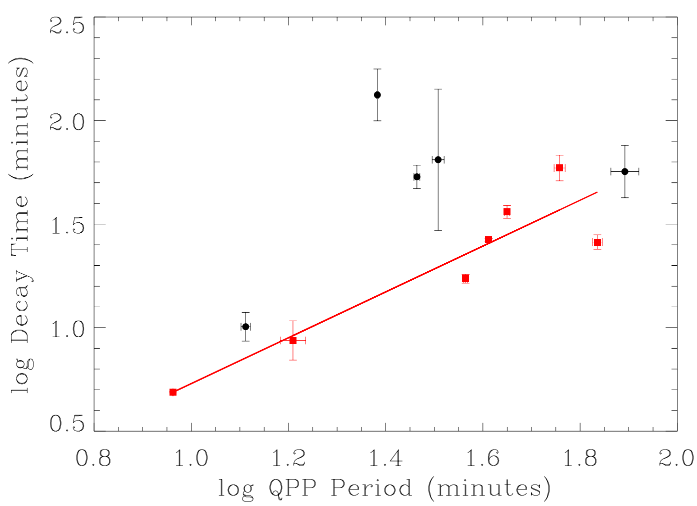
$$F(t) = A_0 \exp\left(-t/t_0\right) + B_0 t + C + A\exp\left(\frac{-(t-B)^2}{2\tau_g^2}\right)\cos\left(\frac{2\pi}{P}t+\phi\right)$$





Statistical analysis

- QPP period is correlated with QPP decay time → consistent with MHD wave theory



- For exp decay time vs period, correlation coefficients are not statistically significant → need a bigger sample
- For Gaussian decay time vs period, there is a significant correlation. We obtain the relationship:

$$\log \tau_g = (1.11 \pm 0.01)\log P - (0.38 \pm 0.01)$$

Statistical analysis

$$\log \tau_g = (1.11 \pm 0.01) \log P - (0.38 \pm 0.01)$$

- is close to:

$$\tau \propto P$$

- In solar theory and coronal loop observations, this corresponds to damping due to resonant absorption for kink waves (Ofman & Aschwanden 2002), or thermal conduction for longitudinal waves (Ofman & Wang 2002)
- NB. Different density contrasts between coronal loop and surrounding plasma result in the different damping profiles (exp or Gaussian) (Pascoe et al. 2016)

Summary

- Using Kepler data to study QPPs in stellar flares
- Many QPP flares found in the short cadence data, albeit a small fraction of the total number of flares
- QPPs in stellar flares seem to be consistent with QPPs in solar flares
- A subset of the QPP flares with stable decaying oscillations are consistent with MHD wave theory

Finding the Largest Flares on Ultracool Dwarfs with ASAS-SN

Sarah Jane Schmidt
Leibniz Institute for Astrophysics Potsdam (AIP)

June 7, 2016
Flares in Time-Domain Surveys
Cool Stars 19

AIP

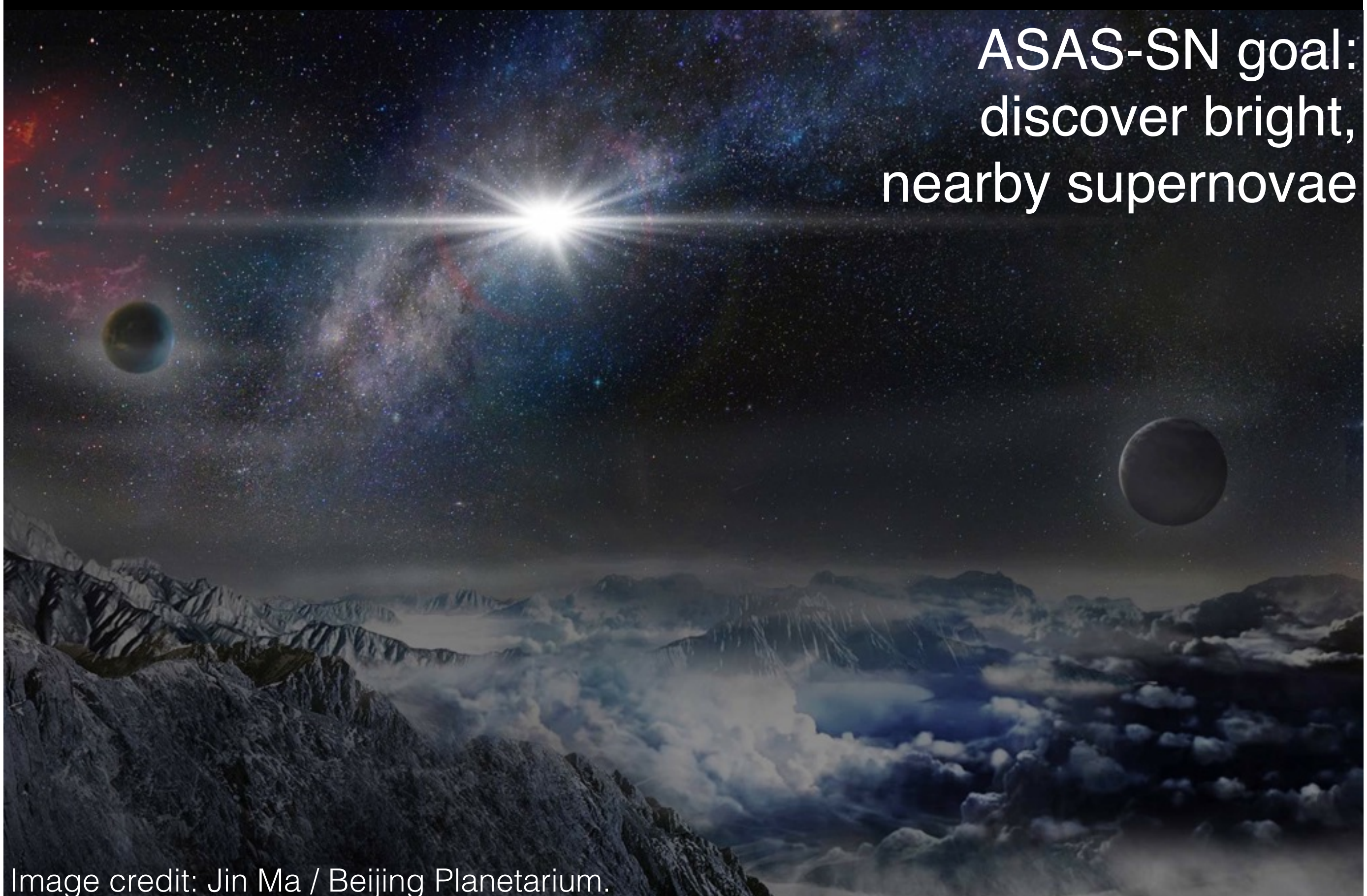
ASAS-SN

All-Sky Automated Survey for SuperNovae

B. J. Shappee (Carnegie), K. Z. Stanek (OSU),
J. L. Prieto (UDP; MAS), T. W.-S. Holoien (OSU)

C. S. Kochanek, J. Brown, A. B. Danilet, G. Simonian, U. Basu, J. F. Beacom, T. A. Thompson (OSU);
D. Bersier (LJMU); Subo Dong, Ping Chen (KIAA-PKU); M. Stritzinger (Aarhus University);
L. Chomiuk, J. Strader (MSU) ; R. Margutti (NYU); P. R. Wozniak (LANL); E. Falco (CfA);
N. Morrell (Carnegie Observatories); J. Brimacombe (Coral Towers Observatory);
G. Pojmanski (Warsaw University); Andres Jordan (Universidad Católica)

D. C. Bardalez Gagliuffi (UCSD),
J. Gagné (Carnegie DTM)


ASAS-SN goal:
discover bright,
nearby supernovae
Image credit: Jin Ma / Beijing Planetarium.

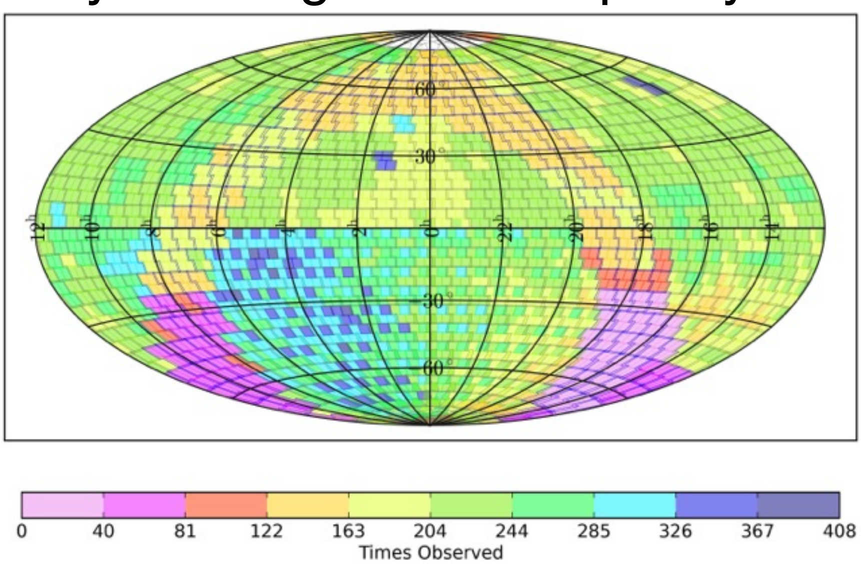
ASAS-SN

image: Mark Elphik

image: Jon De Vera

ASAS-SN

sky coverage over the past year



from: http://www.astronomy.ohio-state.edu/~assassin/index.shtml

first data in 2013

one observation every two days

three 100s V-band images

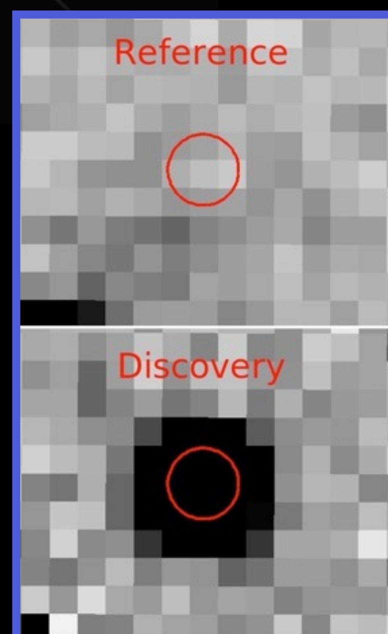
V~9 to 17

ASAS-SN

Data are examined daily

Large events are found and classified by image subtraction

Remarkable events are posted online



flares detected in ASAS-SN

What do we hope to learn
about these flares?

total flare energy
physical conditions
frequency

flares detected in ASAS-SN

$\Delta V = -9$
on an
M8

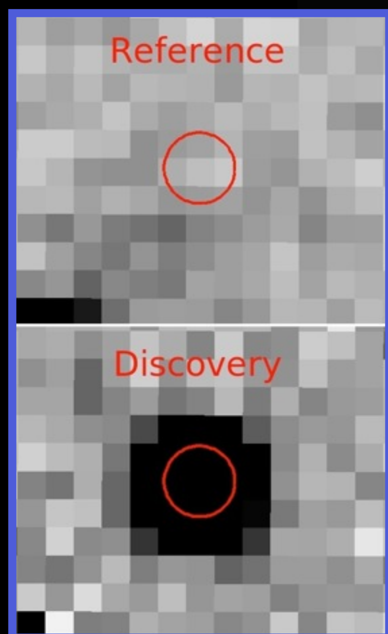
Schmidt+ (2014)

$\Delta V = -11$
on an
L0

Schmidt+ (2016, submitted)

see poster #52

flares detected in ASAS-SN



flares detected in ASAS-SN

survey photometry

rough spectral type, distance, quiescent magnitude

photometric relations (e.g., Dupuy & Liu 2012, Dieterich+ 2014)

flares detected in ASAS-SN

survey photometry

rough spectral type, distance, quiescent magnitude

photometric relations (e.g., Dupuy & Liu 2012, Dieterich+ 2014)

ASASSN-16ae: Discovery of an Extreme (Delta V ~ 10 mag) Flare on an Ultracool Dwarf Star

ATel #8553; ***B. J. Shappee (Hubble Fellow, Carnegie Observatories), K. Z. Stanek (Ohio State), S. Schmidt (Leibniz Institute for Astrophysics - Potsdam), T. W.-S. Holoien, J. S. Brown, C. S. Kochanek, D. Godoy-Rivera, U. Basu (Ohio State), J. L. Prieto (Diego Portales; MAS), D. Bersier (LJMU), Subo Dong, Ping Chen (KIAA-PKU), J. Brimacombe (Coral Towers Observatory)***
*on **15 Jan 2016; 23:14 UT***
Credential Certification: Benjamin Shappee (bshappee@obs.carnegiescience.edu)

Subjects: Optical, Transient

Referred to by ATel #: 8803

Tweet | Recommend 18

During the ongoing All Sky Automated Survey for SuperNovae (ASAS-SN or "Assassin"), using data from the quadruple 14-cm "Brutus" telescope in Haleakala, Hawaii, we discovered a new transient source:

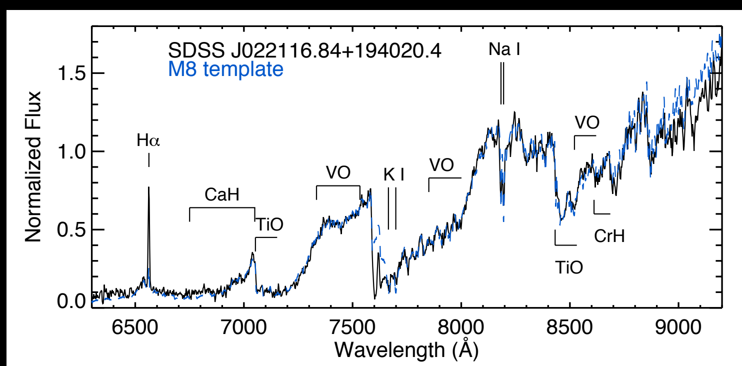
flares detected in ASAS-SN

survey photometry → rough spectral type, distance, quiescent magnitude

photometric relations (e.g., Dupuy & Liu 2012, Dieterich+ 2014)

optical and near-infrared spectroscopy → spectral type, quiescent activity, radial velocity, age/metallicity

templates + standards (e.g., Cruz+ 2016; Schmidt+ 2014)



flares detected in ASAS-SN

survey photometry → rough spectral type, distance, quiescent magnitude

photometric relations (e.g., Dupuy & Liu 2012, Dieterich+ 2014)

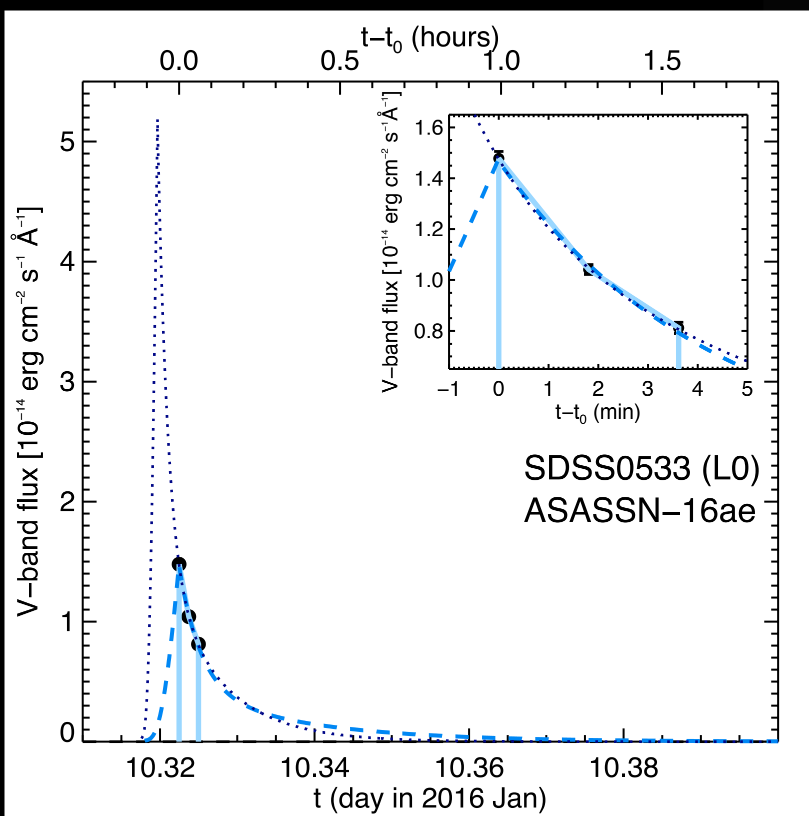
optical and near-infrared spectroscopy → spectral type, quiescent activity, radial velocity, age/metallicity

templates + standards (e.g., Cruz+ 2016; Schmidt+ 2014)

sparse flare lightcurve → estimated total V-band flare energy

empirical lightcurve models (e.g., Davenport+ 2014)

flares detected in ASAS-SN



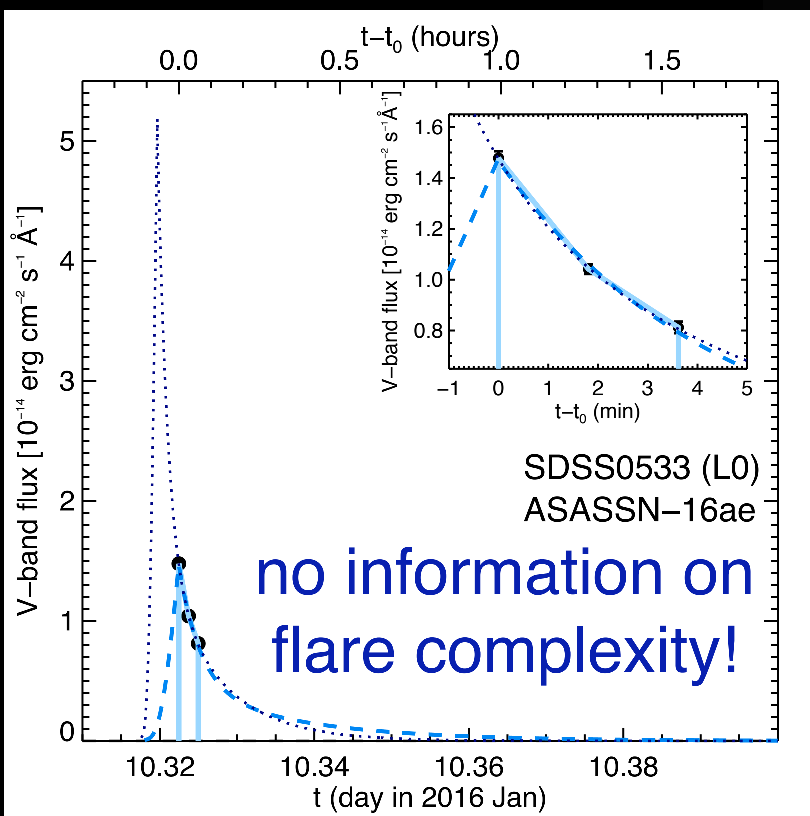
$E_V = 1 \times 10^{33}$ erg

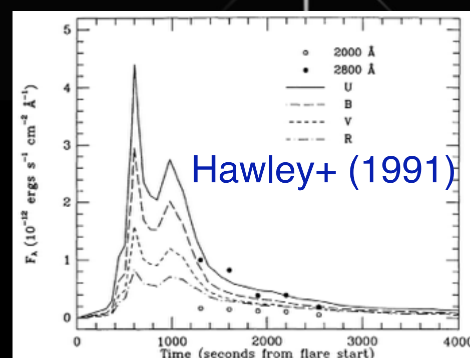
$E_V = 5 \times 10^{33}$ erg

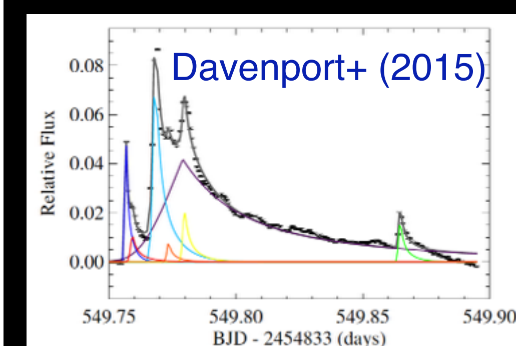
$E_V = 8 \times 10^{33}$ erg

Davenport+ (2015); Schmidt+ (2016)

flares detected in ASAS-SN







Davenport+ (2015); Schmidt+ (2016)

flares detected in ASAS-SN

survey photometry → rough spectral type, distance, quiescent magnitude

photometric relations (e.g., Dupuy & Liu 2012, Dieterich+ 2014)

optical and near-infrared spectroscopy → spectral type, quiescent activity, radial velocity, age/metallicity

templates + standards (e.g., Cruz+ 2016; Schmidt+ 2014)

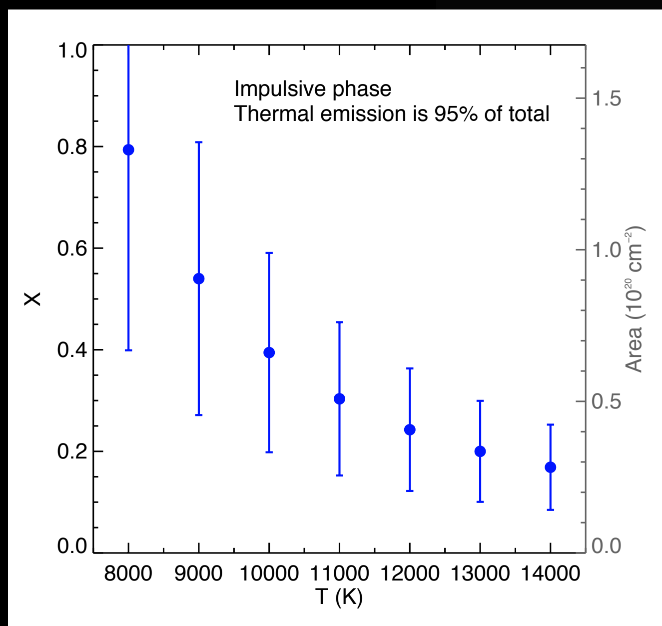
sparse flare lightcurve → estimated total V-band flare energy

empirical lightcurve models (e.g., Davenport+ 2014)

peak brightness → range of flare temperatures and filling factors

detailed energetics (e.g., Hawley+ 2003; Kowalski+ 2013)

flares detected in ASAS-SN



peak brightness

range of flare temperatures and filling factors

detailed energetics (e.g., Hawley+ 2003; Kowalski+ 2013)

those two bright flares
may look like this!

image: Casey Reed/NASA
based on X-ray flare on
EV Lac from Osten+ (2010)

flares detected in ASAS-SN

survey photometry → rough spectral type, distance, quiescent magnitude

photometric relations (e.g., Dupuy & Liu 2012, Dieterich+ 2014)

optical and near-infrared spectroscopy → spectral type, quiescent activity, radial velocity, age/metallicity

templates + standards (e.g., Cruz+ 2016; Schmidt+ 2014)

sparse flare lightcurve → estimated total V-band flare energy

empirical lightcurve models (e.g., Davenport+ 2014)

peak brightness → range of flare temperatures and filling factors

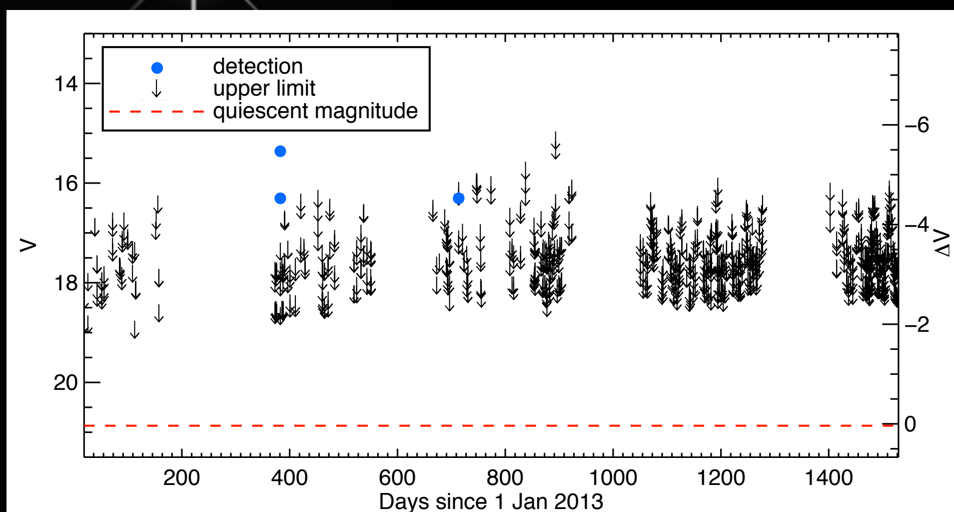
detailed energetics (e.g., Hawley+ 2003; Kowalski+ 2013)

ASAS-SN flare frequency

~25 flares with notifications → follow-up spectroscopy

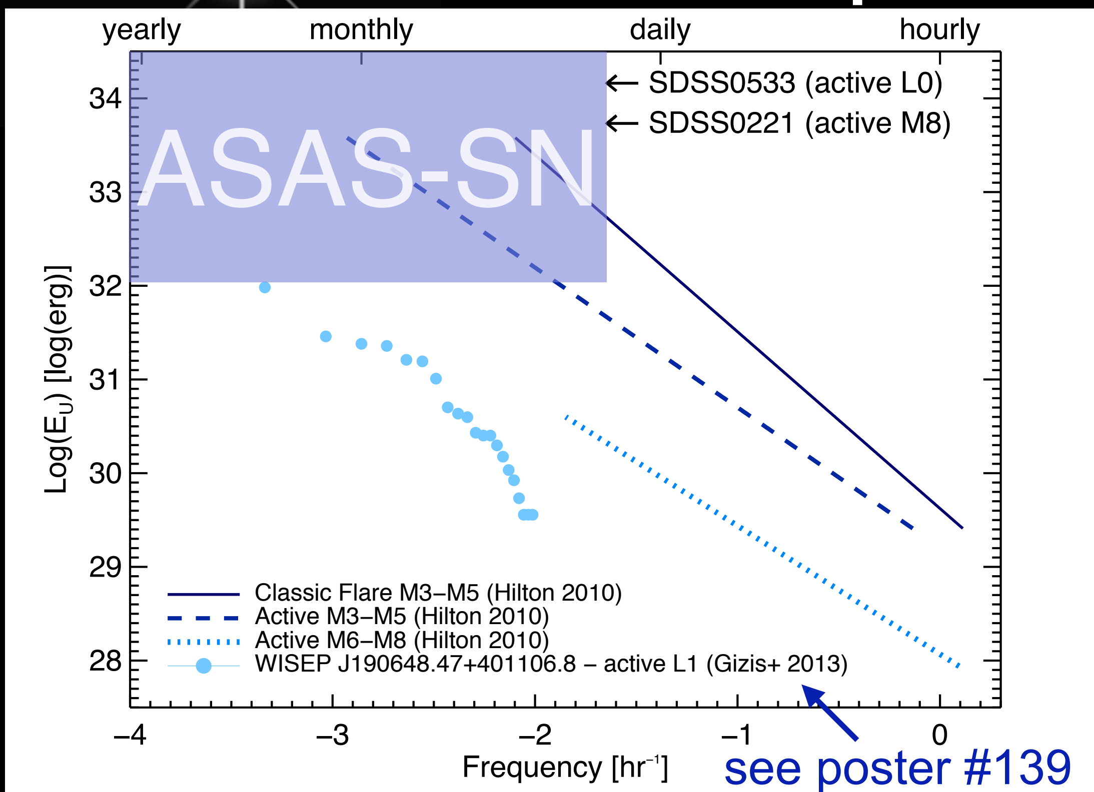
~5000 SDSS ultracool dwarfs → search for smaller flares

ASAS-SN flare frequency



search for smaller flares ← ~5000 SDSS ultracool dwarfs

ASAS-SN flare frequency



based on Lacy+ (1976); Hawley+ (2015)

Getting meaningful information from sparse data is only possible when we can rely on detailed previous observations.

X-ray Superflares on CC Eri

Subhajeet Karmakar
&
Jeewan C. Pandey

Aryabhatta Research Institute of Observational Sciences (*ARIES*)
Nainital, India
E-mail - subhajeet@aries.res.in

Superflare detction: CC Eri

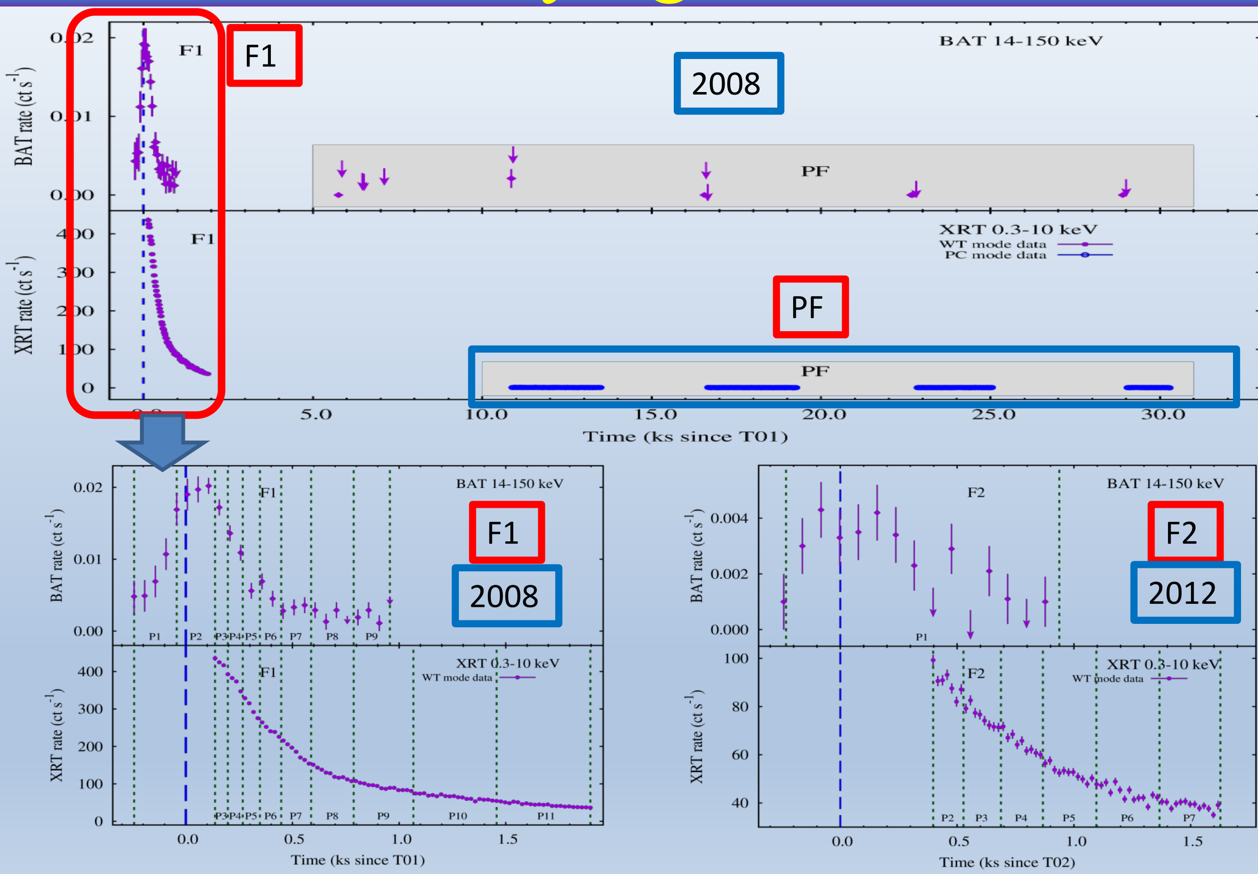
- ***Two CC Eri Superflares:***
  - ***Flare F1:*** ***2008 October 16 UT 11:22:52***
  - ***Flare F2:*** ***2012 February 24 UT 19:05:44***
- ***Known Facts about CC Eri:***

CC Eri	K7.5V—M3V spectroscopic binary
V	8.865 mag
Distance	(11.51 ± 0.11 pc)
Photometric Period	1.56 days

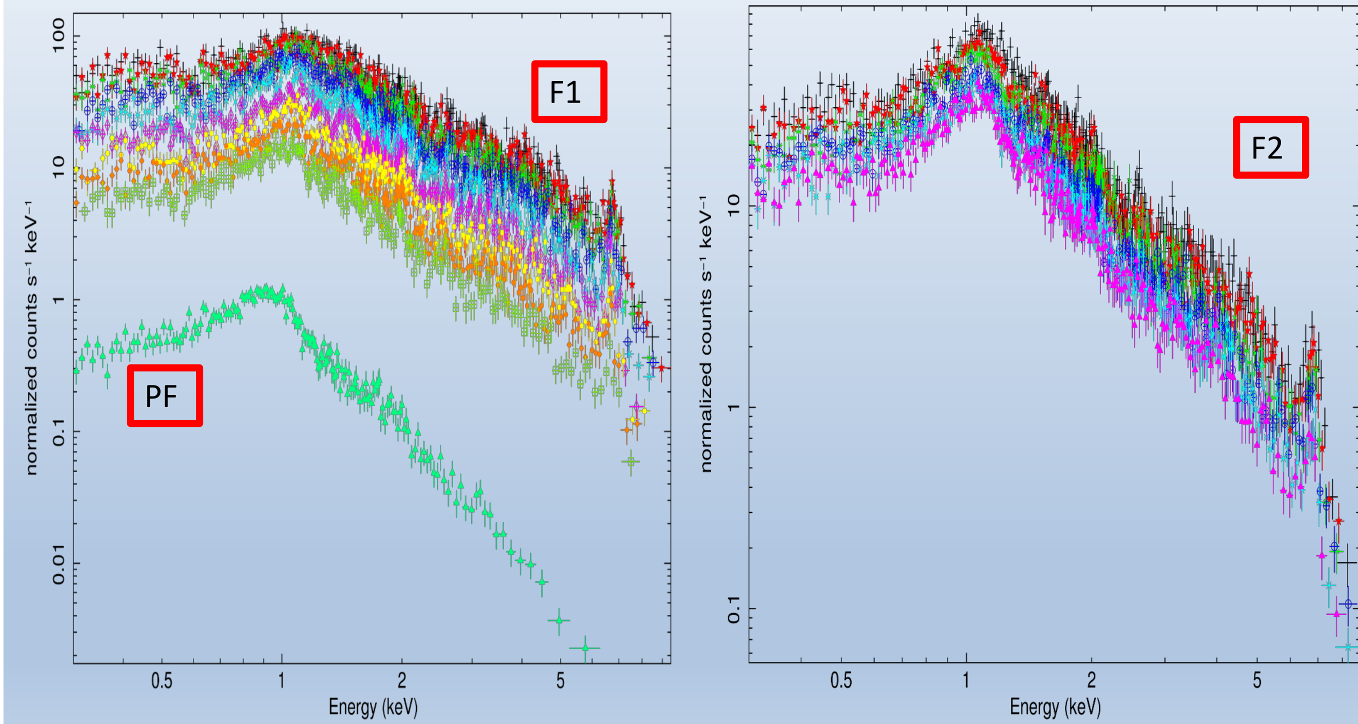
- ***SWIFT Satellite*:**
  - Hard X-ray (14-150 keV) -> Burst Alert Telescope (BAT)
  - Soft X-ray (0.3-10 keV) -> X-ray Telescope (XRT)

Data Reduction is done with standard packages available in ***ftools***
(*http://heasarc.gsfc.nasa.gov/docs/software.html*)

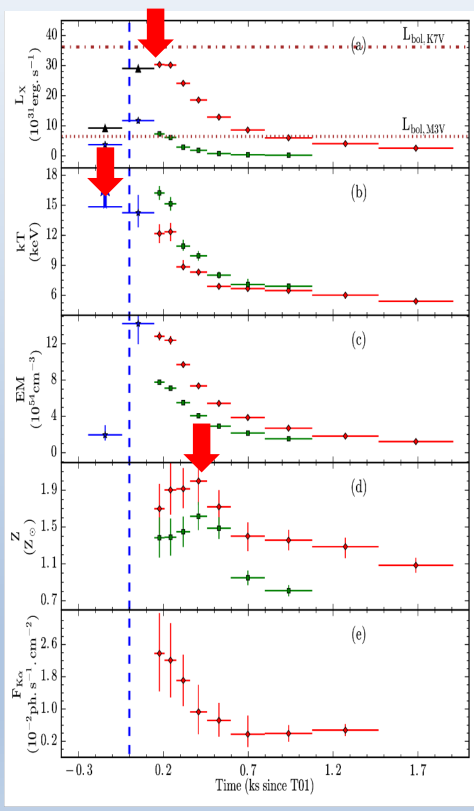
X-ray light curves

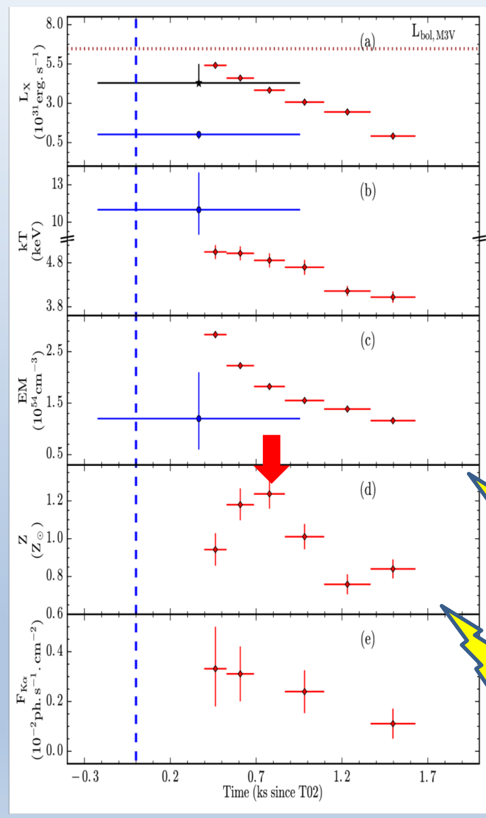


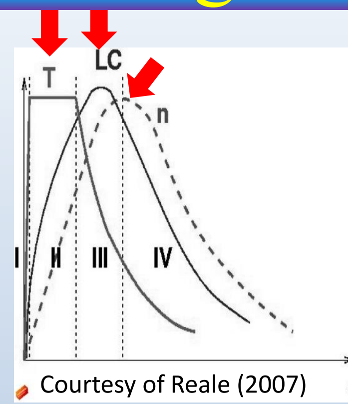
X-ray spectra

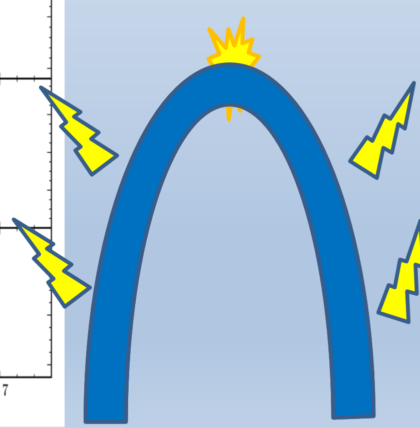


Hydrodynamic loop modeling









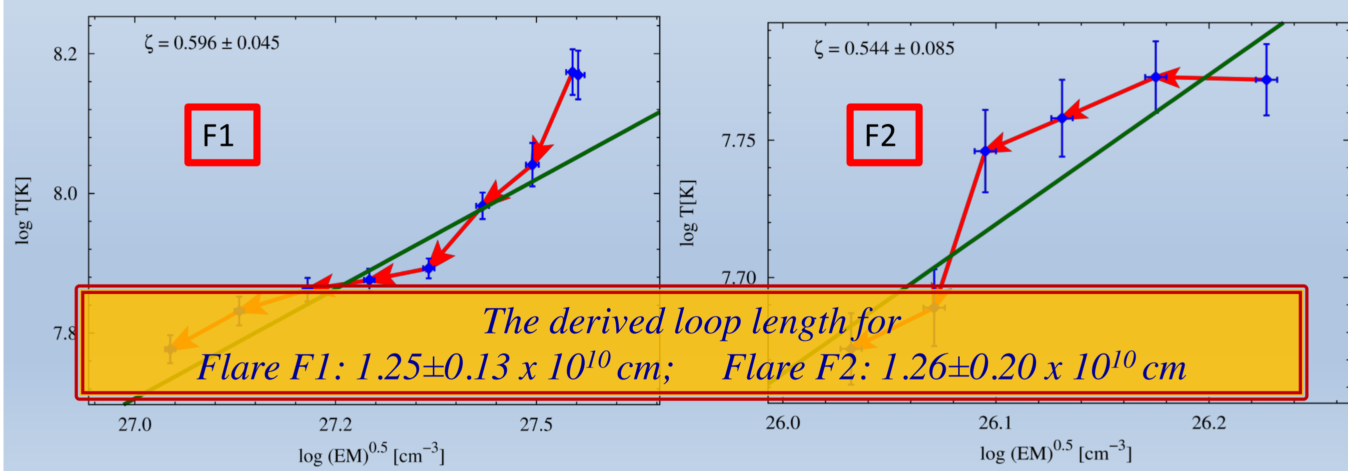
Hydrodynamic loop modeling

The Slope (ζ) of log (T) vs. log (EM)$^{0.5}$ = Diagnostic of presence of heating (*Sylwester et al. 1993* for Solar flares)

For ***Stellar flare***, *Reale 1997* derived the formula of semi-loop length

$$L = \frac{\tau_{\rm lc}\sqrt{T_{\rm pk}}}{3.7\times10^{-4}\ F(\zeta)} \qquad F(\zeta) = \frac{c_a}{\zeta - \zeta_a} + q_a$$

For *Swift* XRT *Osten et al. 2010* calibrated the values of constants.



The derived loop length for
Flare F1: 1.25±0.13 x 10^{10} cm; Flare F2: 1.26±0.20 x 10^{10} cm

Loop Parameters

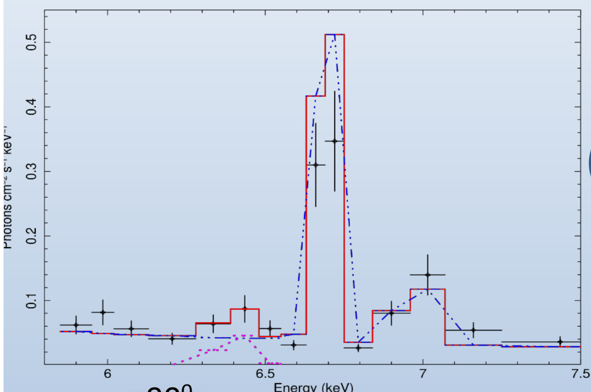
Parameters	Flare F1	Flare F2
Peak Temperature (T_{max})	342 MK	119 MK
Peak Emission Measure (EM)	12.82 x 10^{54} cm^{-3}	2.83 x 10^{54} cm^{-3}
Loop Length (L)	*1.25±0.13 x 10^{10} cm*	*1.26±0.20 x 10^{10} cm*
Assuming Constant cross-section RTV loop: [Rosner et al. 1978]		
Peak Pressure p (α T_{max}^3/L)	1.2 x 10^6 dyne cm^{-2}	4.8 x 10^4 dyne cm^{-2}
Peak Plasma Density ($n_e = p/2kT_{max}$)	12 x 10^{12} cm^{-3}	1.48 x 10^{12} cm^{-3}
Loop Volume V = EM . $(n_e)^{-2}$	0.84 x 10^{29} cm^3	12.94 x 10^{29} cm^3
Total Energy released $E_{X,tot}$	>2.1 x 10^{35} erg	>1.5 x 10^{35} cm^3
Loop Magnetic field B = $\sqrt{8\pi p}$	~5.4 kG	~1.1kG

+ Flare Location on Stellar Disk

Detection of 6.4 keV Fe Kα line

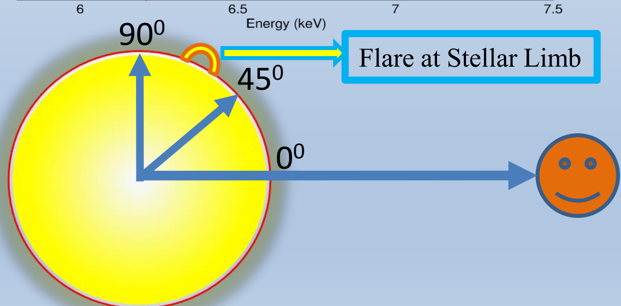
- Iron Kα line is generally attributed to a fluorescent process of photospheric iron.

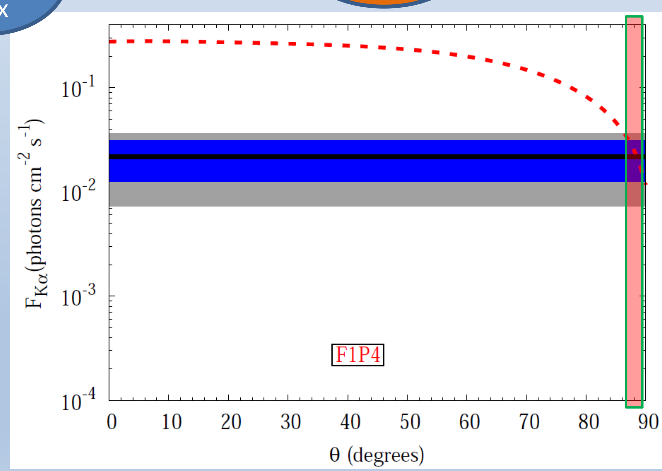
[Solar Flares] : Bai (1979) & *[Stellar Flares] : Drake, Ercolano & Swartz (2008)*



$F_{K\alpha} = f(\theta) * \Gamma(T, h) * F_{7.11}$ photons cm−2

- Iron Kα line Flux
- fluorescent efficiency.
- Flux above 7.11 keV ← XRT+BAT





The derived astrocentric angle of Flare F1: ~88.2^0

Summary

- The **maximum temperature** of Flare F1 and F2 was found to be ***342 MK and 119 MK***.

- **The size of a flaring loop** on CC Eri was inferred to be ***1.25 × 10^{10} cm (F1) and 1.26 × 10^{10} cm (F2) .***

- **The magnetic field of flaring loop** of CC Eri was derived to be ***~5.4 kG and ~1.1kG.***

- The flare F1 was found to be ***located near the limb*** (astrocentric angle = 88.2^0).

Thank You

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The frequency of dM-star X-ray flares from a large-scale XMM-Newton sample

John Pye & Simon Rosen

University of Leicester, Department of Physics & Astronomy

& the EXTraS team
(www.extras-fp7.eu/)

eXTraS

Content

- Introduction to the survey & the data

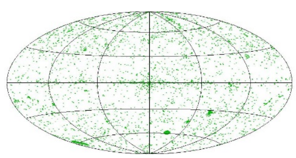
- Results: flare emitted-energy distribution & comparison with other flare surveys

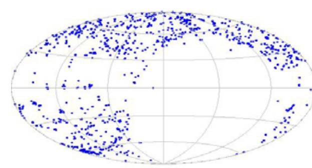
- Summary & future work

Introduction to the red-star X-ray flare survey

- Aim: extensive and uniform survey of dM-star cool-star X-ray flares
  - Complements & extends XMM/Tycho (mainly F – K) survey, Pye+15
  - *Initial, preliminary results reported here*
- Based on cross-correlation of **3XMM-DR5 X-ray** serendipitous source catalogue [~400k sources] (Rosen+16) and **SDSS MoVeRS red-star** (K, M, L) catalogue [~9M stars] (Theissen+16)

X-ray: 3XMM-DR5 catalogue (Rosen+16)





Optical/IR: MoVeRS catalogue (Theissen+16)

- Study **XMM target stars** & **stars observed serendipitously** in XMM field of view
- **Primary aims are for XMM serendipitously-observed stars**: provide (within certain caveats) an 'unbiased' flare sample
- 3XMM + MoVeRS → ~2000 matches → ~200 stars with X-ray light-curves → **31 flares from 24 stars** (including 1 target star)

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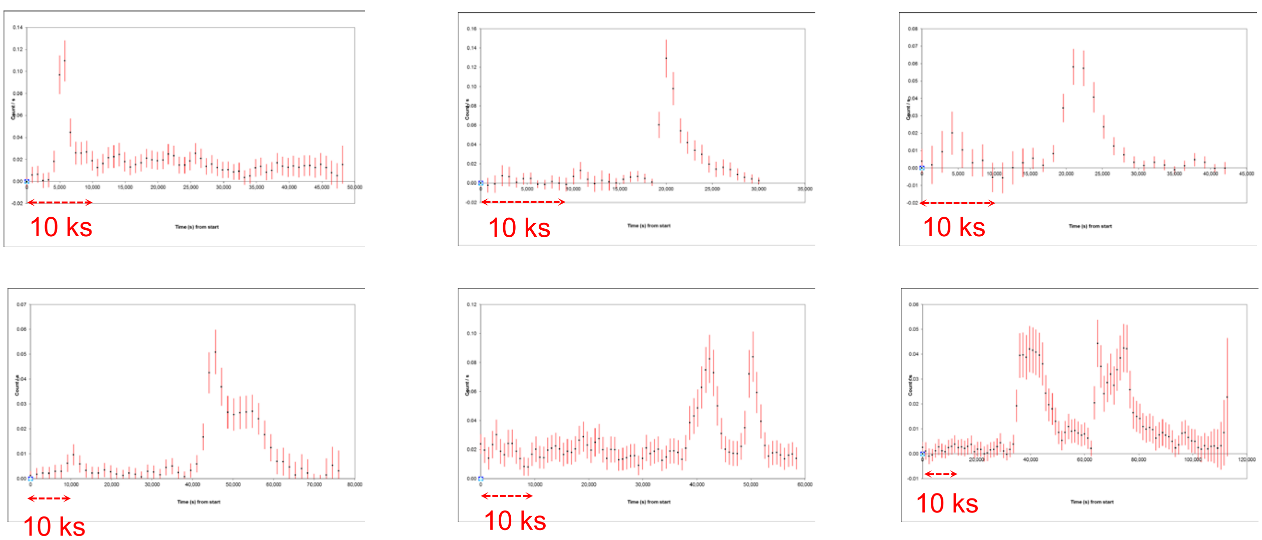
Results – 1: Example X-ray light-curves

- 31 X-ray flares from 24 stars (including 1 target star)



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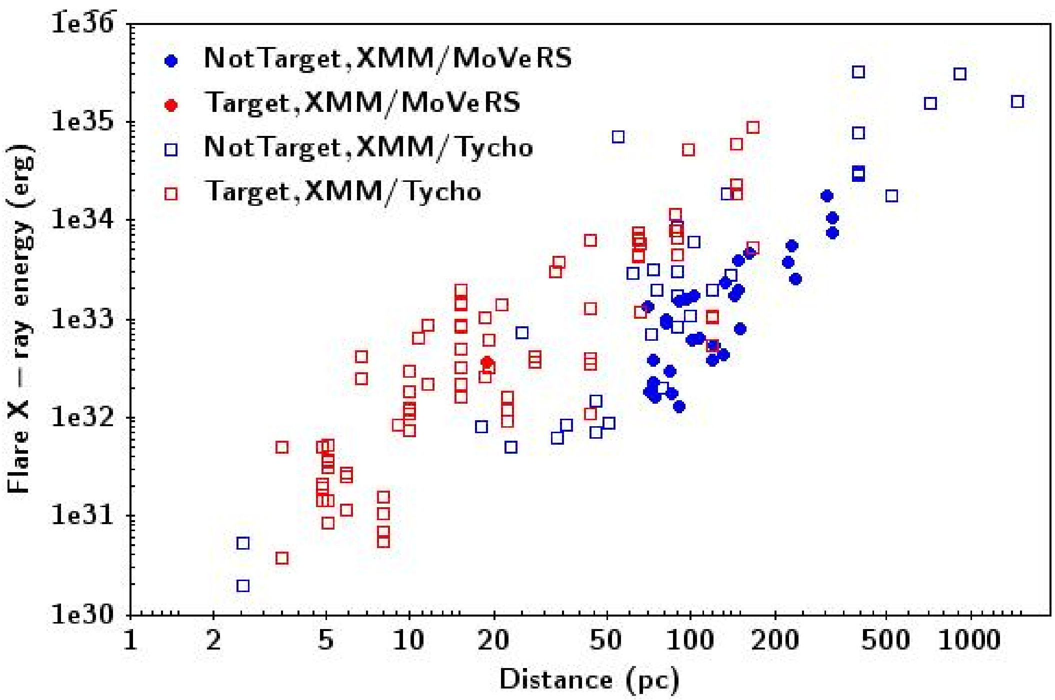
Results – 2:
Flare X-ray energy v stellar distance



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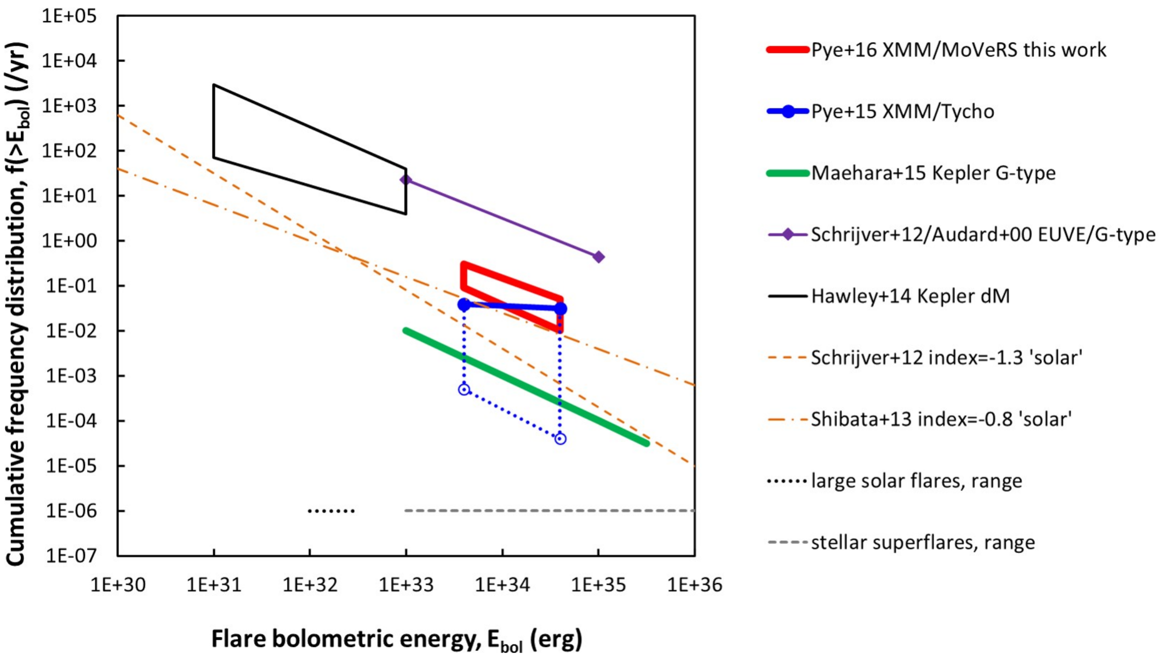
Results – 3: Flare emitted-energy distribution



- Cumulative flare emitted-energy distribution (**E_{bol}**) distribution, **$F(> E_{bol})$**
- *NB. Preliminary analysis; no corrections for coverage, completeness etc yet performed*

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Summary & future work

- Summary:
  - 3XMM / MoVeRS → 31 flares from 24 stars
  - Extensive, unbiased (with respect to flare activity) survey of red-star X-ray flares and flare rates
  - Extending previous stellar X-ray survey work (XMM/Tycho) to later spectral types
- Future:
  - Utilise the data products of the EXTraS time-variability project (EU-FP7; PI: Andrea De Luca/INAF) – http://www.extras-fp7.eu/
  - Corrections for sky coverage, volume completeness …
  - Use other dM-star optical/IR surveys
  - Detailed characterisation of at least some of the stars (optical followup …)

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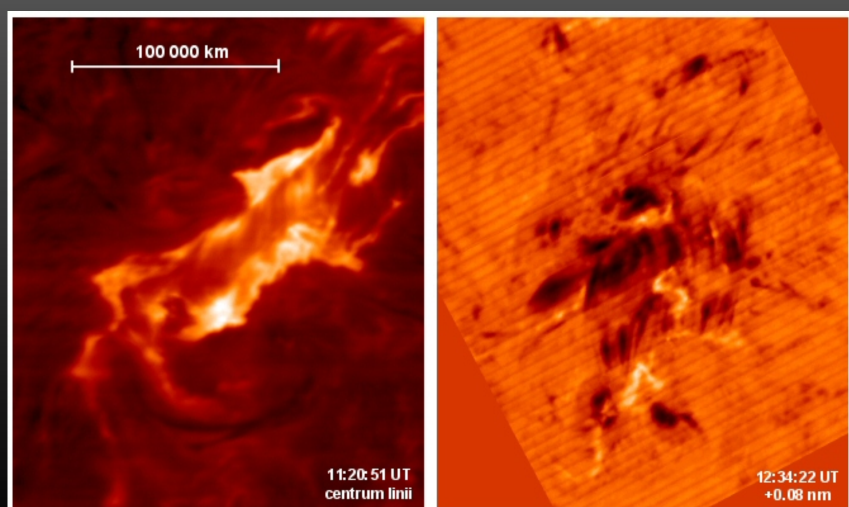
F-CHROMA project:
Observations and modeling of solar flare chromospheres

A. Berlicki[1,2] and the F-CHROMA consortium

[1] Astronomical Institute, University of Wroclaw, Poland
[2] Astronomical Institute, Academy of Sciences, Ondřejov, Czech Republic

F-CHROMA



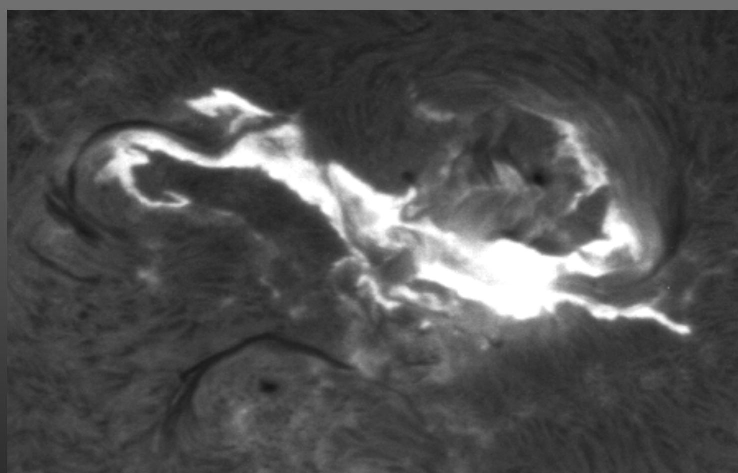
COOL STARS 19
06-10 June 2016 Uppsala, Sweden

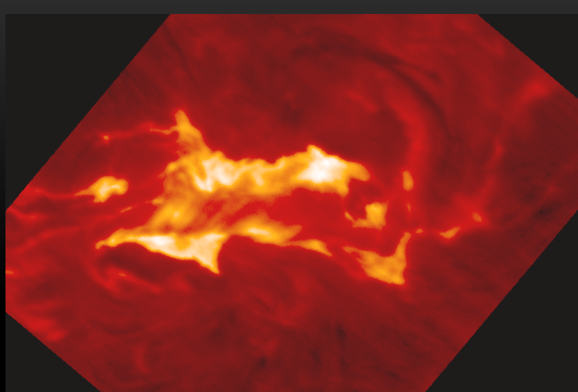
Uniwersytet Wrocławski

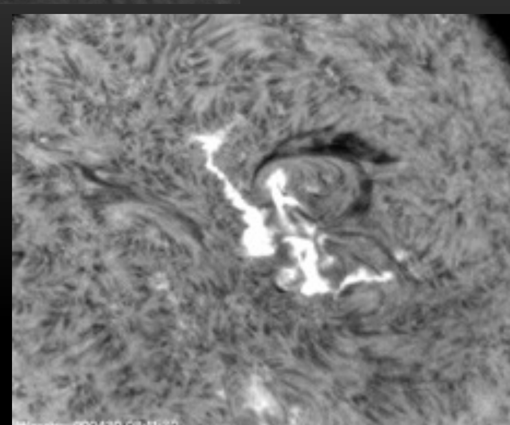
asu
Astronomical Institute
of the Czech Academy of Sciences

F-CHROMA: http://www.fchroma.org/

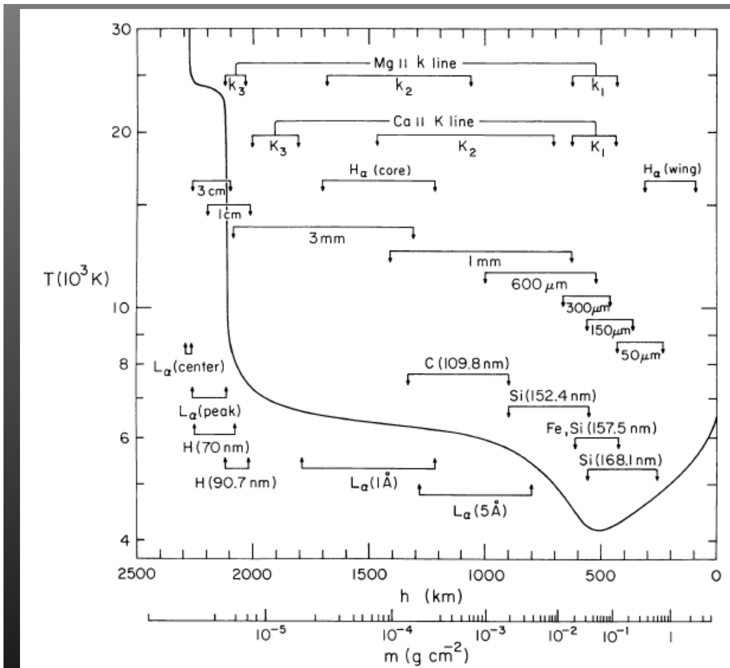
Chromospheric flares



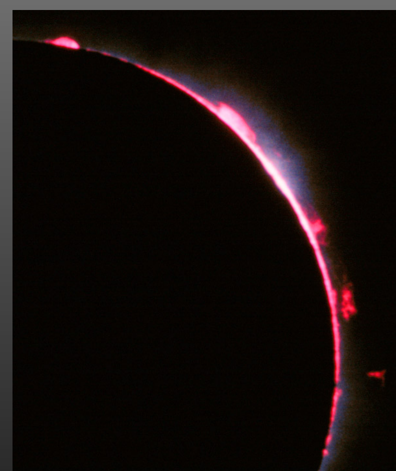


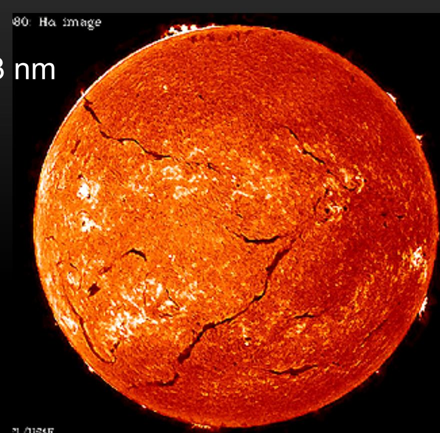


What is solar chromosphere



Quiet Sun model VAL-C (now C7)

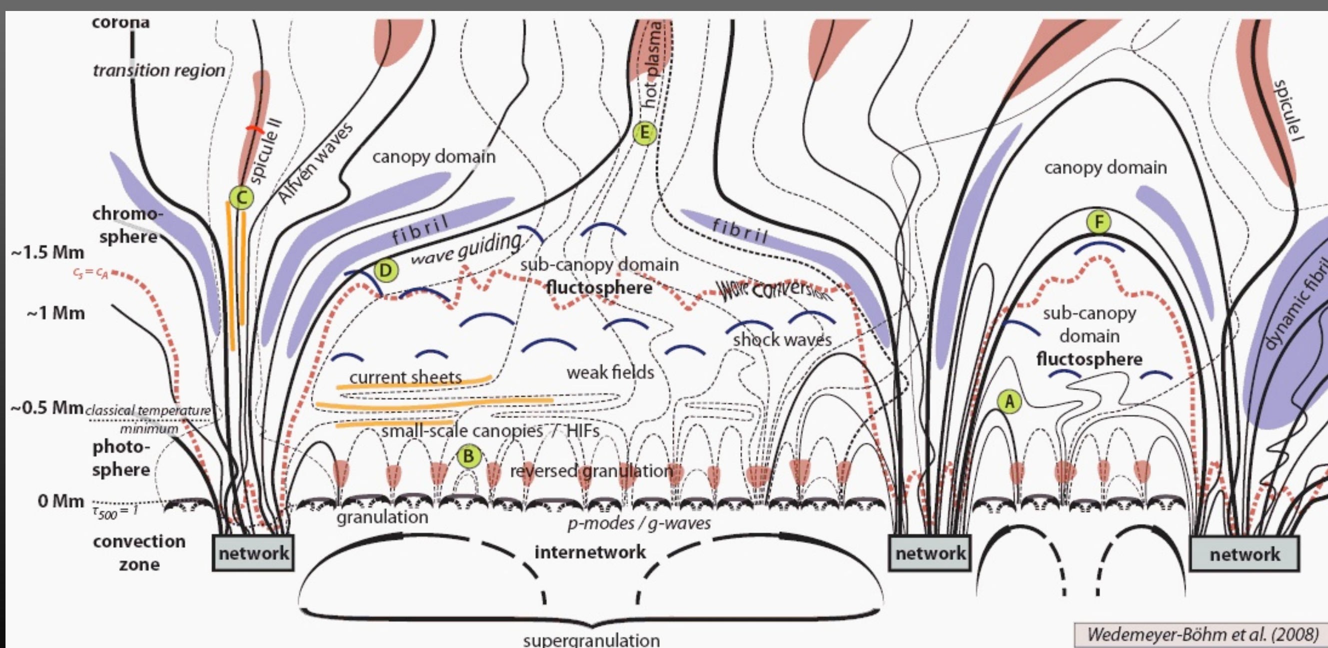


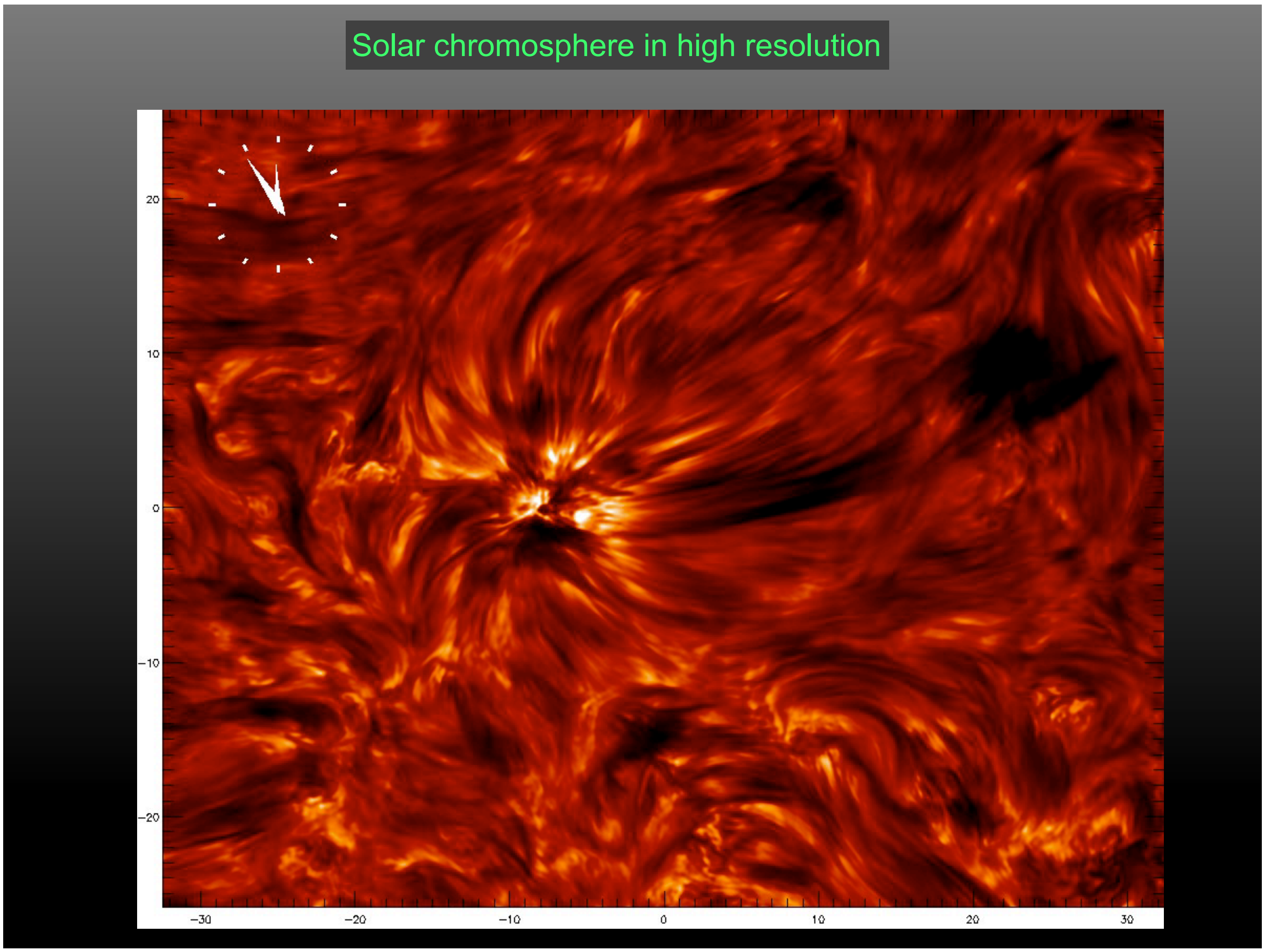


Hα 656.3 nm

He II 30.4 nm

Solar chromosphere – complicated structure

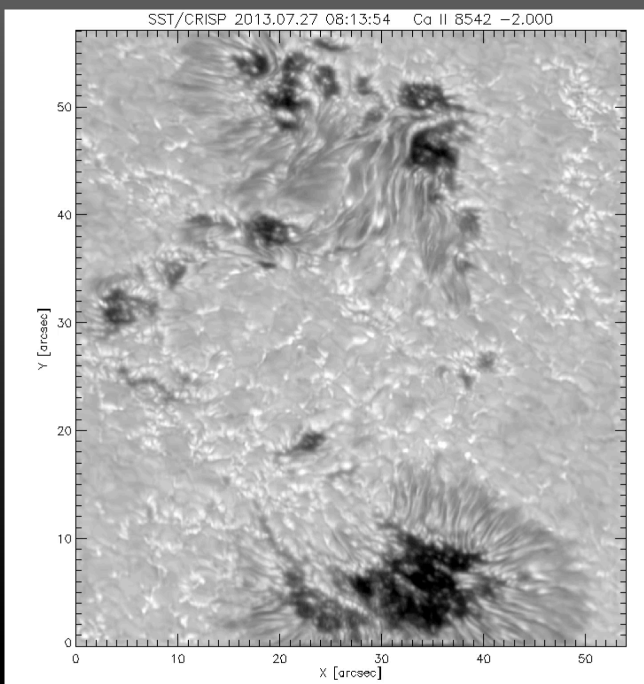


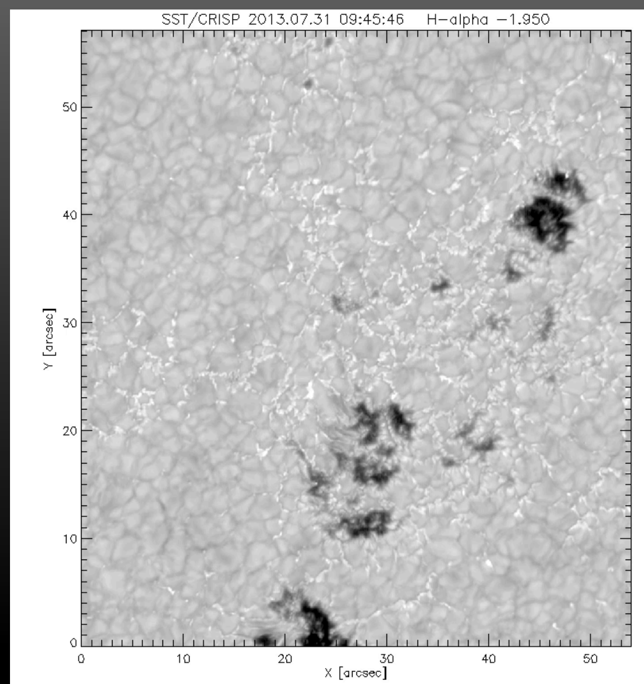


Solar chromosphere in high resolution
20
10
0
−10
−20
−30
−20
−10
0
10
20
30

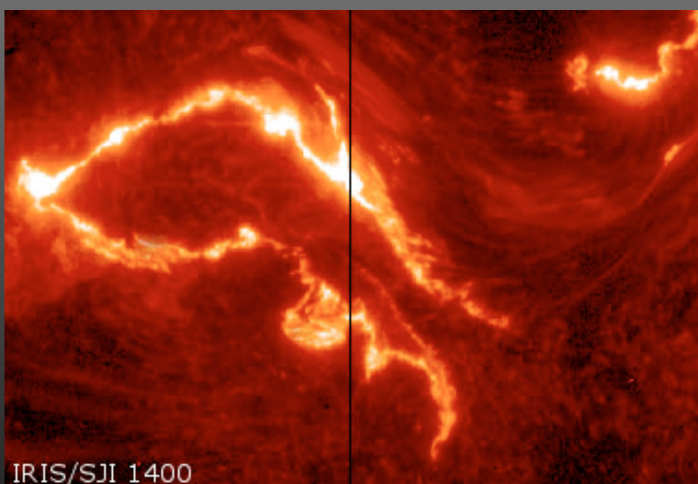
SST/CRISP observations – AR (Ca II 854.2 nm and H I (Hα) 656.3 nm)

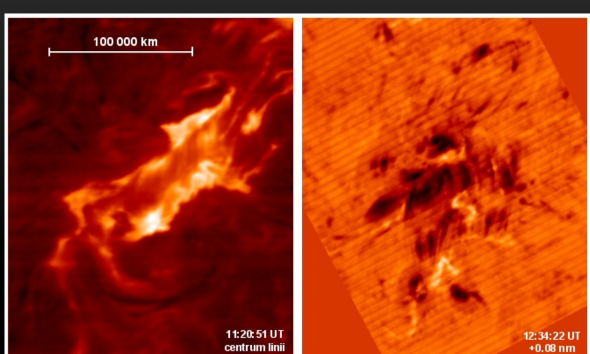
Scan through the line profile

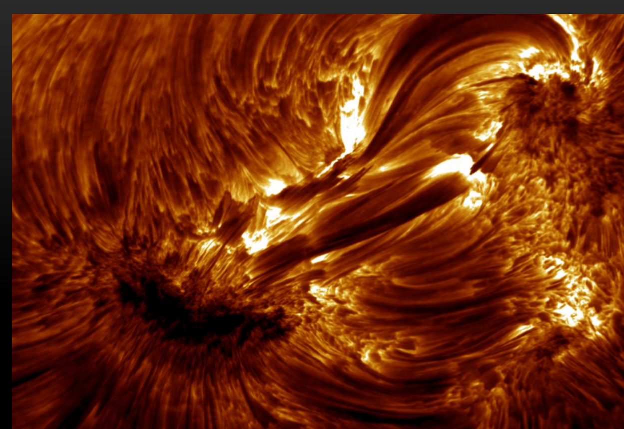




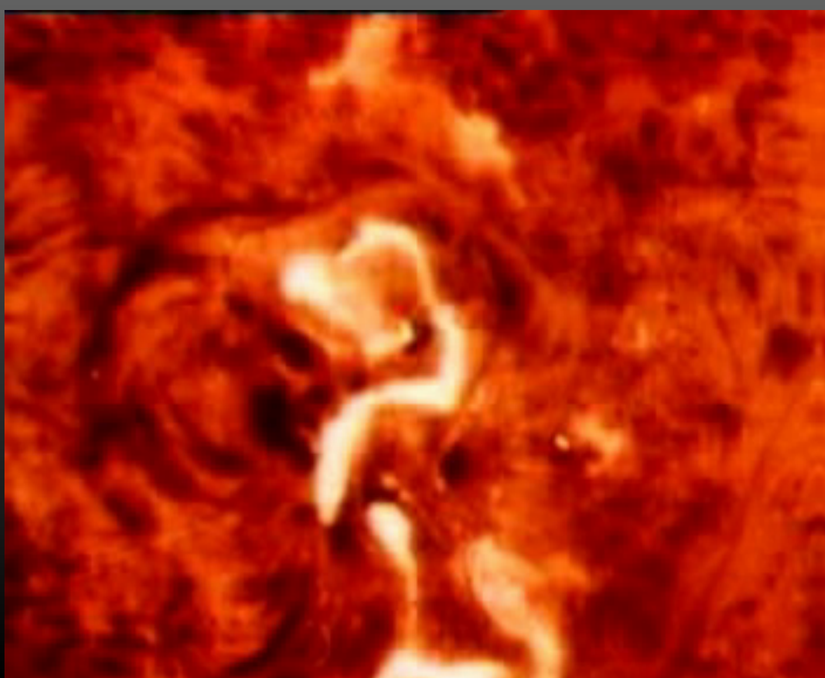
Chromosphere and solar flares are observed with narrow-band tunable filters

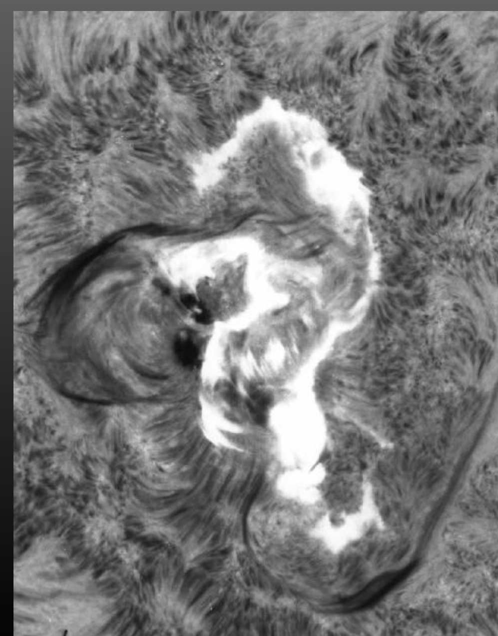






Ground base observations of chromospheric flare (Hα line) – atmospheric turbulence

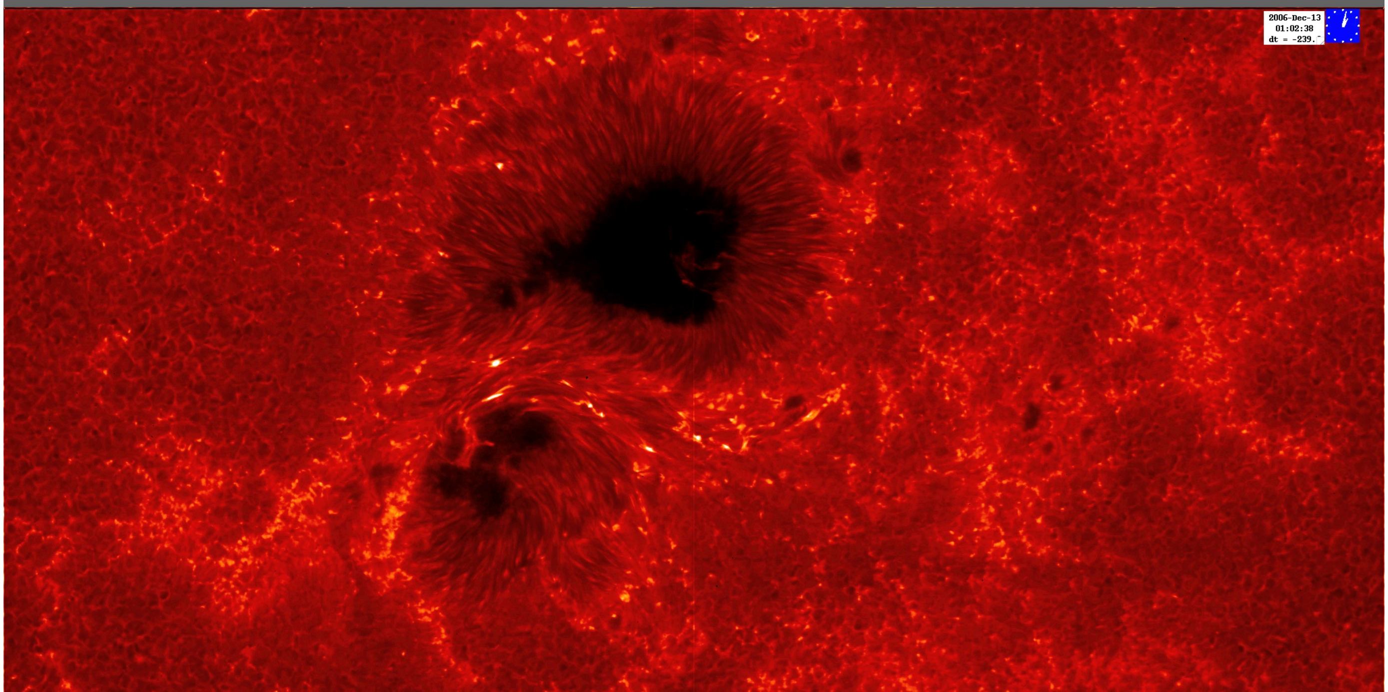




Bialkow Observatory, University of Wroclaw, PL

Space data – no influence of turbulence

Example of solar flare in the chromosphere
(Hinode/SOT, 13 Dec 2006)



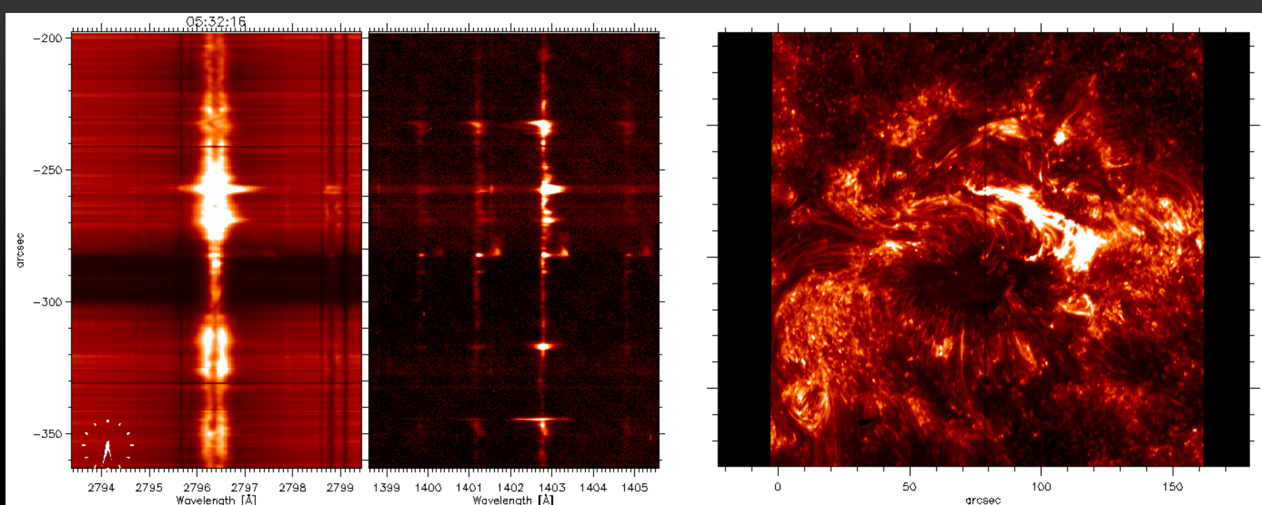
Modeling of chromospheric flares

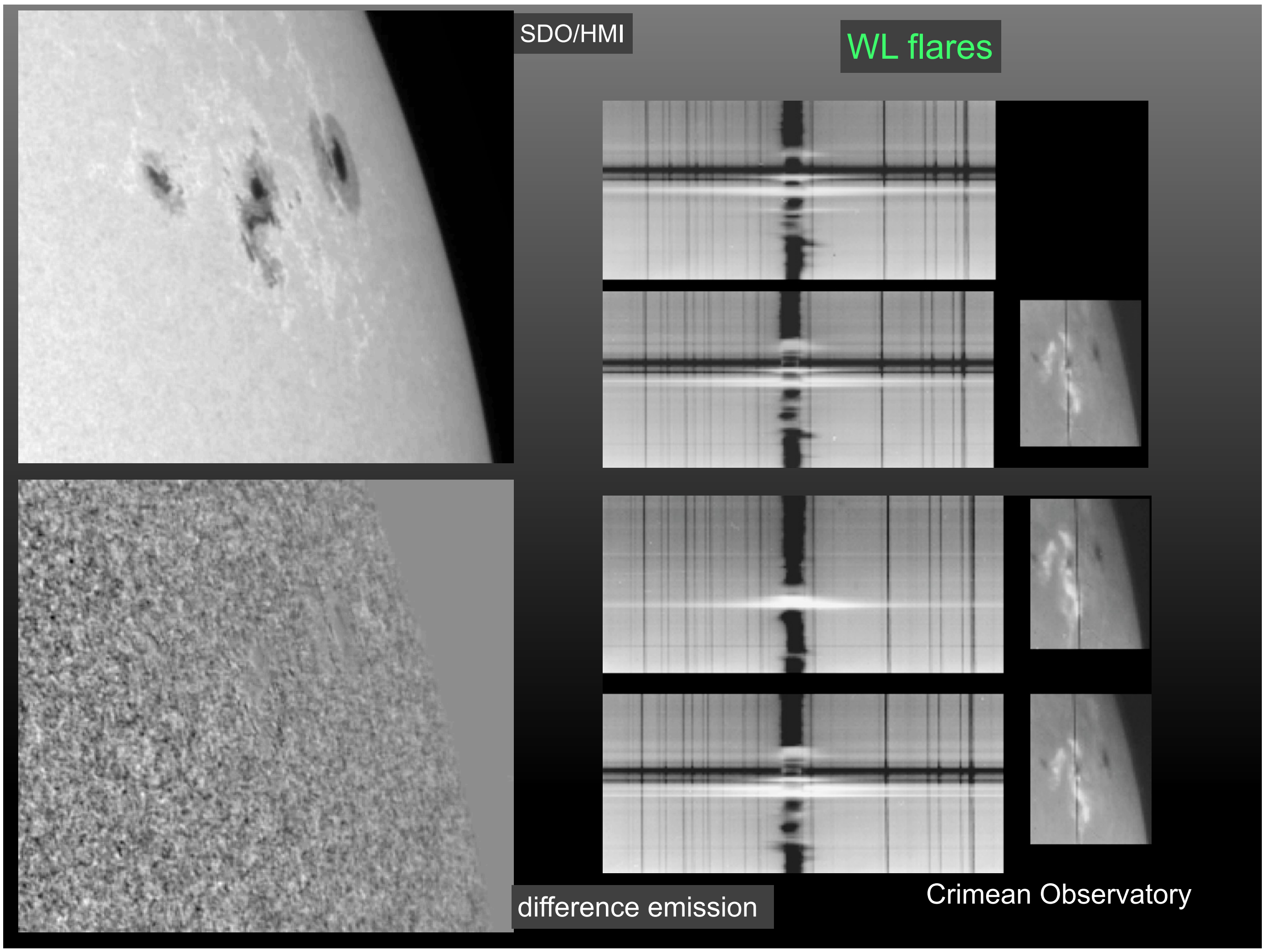
Spectroscopic data are the main source of information about physical conditions in flaring plasma

Such data can be simulated by static and time-dependent flare models

Some outstanding problems:

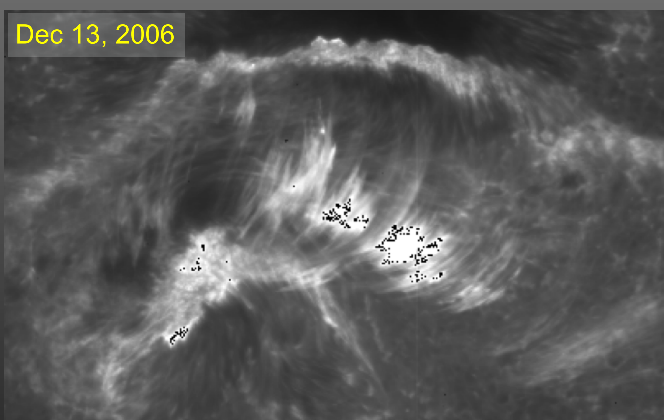
- ✓ time dependent modeling of solar flares
- ✓ heating mechanisms of flaring plasma, and its emission
- ✓ mechanisms of WL emissions of flares
- ✓ long duration brightening of Hα ribbons
- ✓ velocity field in flaring ribbons – chromospheric evaporation, flare cool loops
- ✓ flare models above sunspots

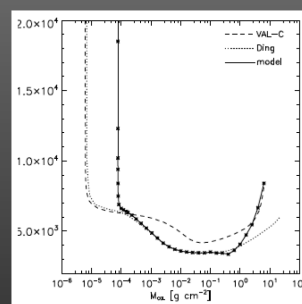


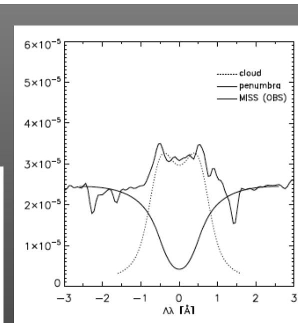

SDO/HMI
WL flares
difference emission
Crimean Observatory

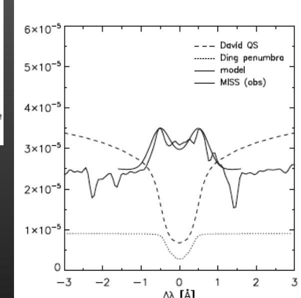
Modeling of the flare observed above sunspots
(Berlicki, Heinzel, Schmieder, Li, A&A, 490, 315 (2008))

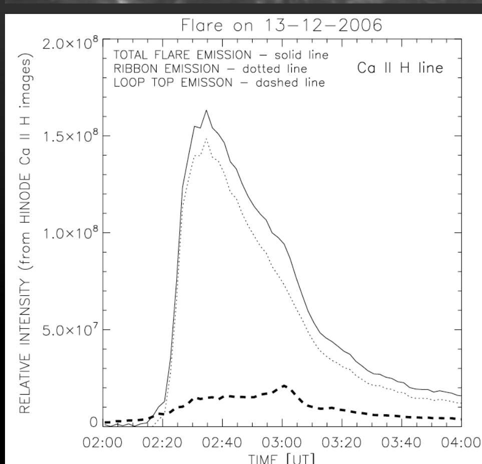
NLTE modeling









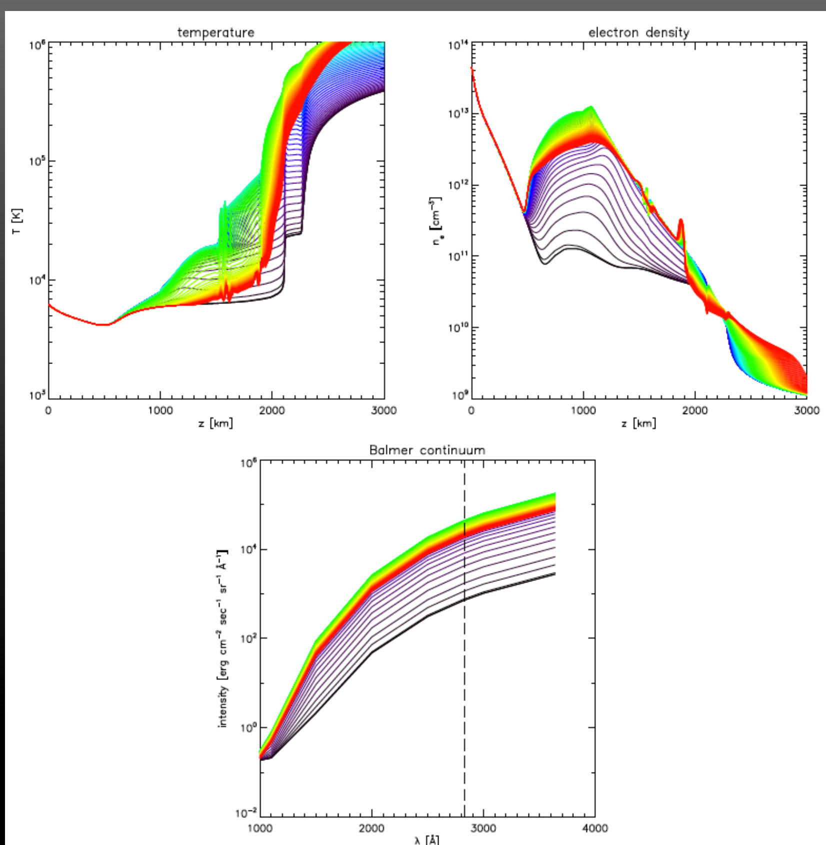


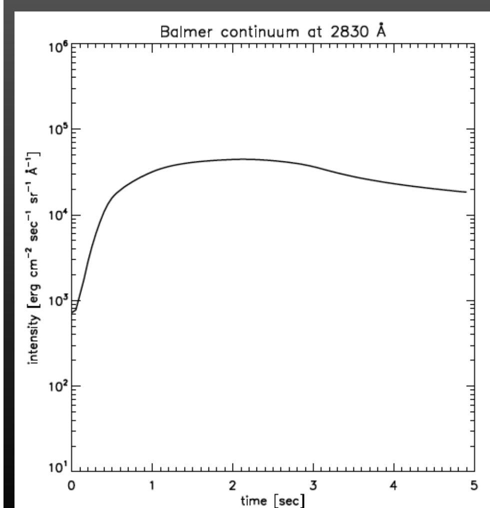
The flare emission comes from low-lying loops located above the penumbra

Flare loops can significantly contributed to the total flare emission – it is important e.g. in the modelling of stellar flares. In cool M stars the contribution form loops can be dominant.

Example of time dependent modeling of flares – FLARIX code

P. Heinzel, J. Kasparova, M. Varady, M. Karlicky, et al., arXiv:1602.00016 (Proceedings IAU Symposium No. 320)

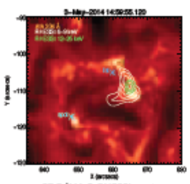




F-CHROMA
Flare Chromospheres: Observations, Models and Archives

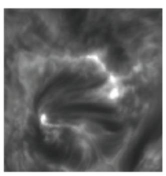
F-CHROMA
http://www.fchroma.org

New flare data:

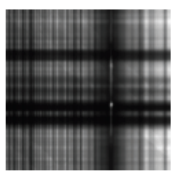


SDO/AIA & RHESSI contours

We are pro-actively running campaigns to obtain more co-ordinated ground-and space-based flare observations. E.g. recent observations have obtained high resolution optical spectroscopy of a B-class flare



DST/IBIS Hα core image

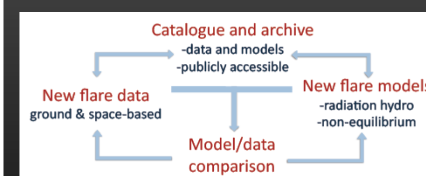


DST/HSG Ca II spectrum from the ribbons. (lower brightening from smaller ribbon)

New flare models:

Flares include many linked processes: energy transport and deposition, rapid heating and plasma expansion, turbulence, wave-particle interactions, non-equilibrium excitation and ionisation. Existing radiative-hydrodynamics and spectral synthesis methods will be improved and exploited, e.g.:

- Test runs of the radiation-hydrodynamics codes RADYN and HYDRAD with different input parameters to assess what most affects output observables.
- Synthesis of visible (Hα, Ca II) and UV (Mg II, C II) spectral lines in realistic flare scenarios.
- Improved treatment of non-equilibrium processes included in existing codes

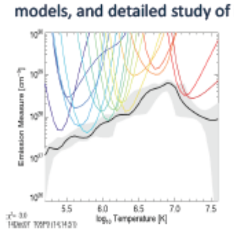


Model-data comparison:

A robust methodology for the interpretation of multi-wavelength data will start from forward modeling.

Application to real, temporally and spatially resolved data will provide feedback to the modeling in terms of input parameters and important physics.

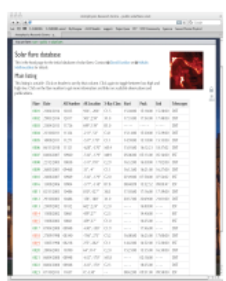
This requires a systematic examination of grids of models, and detailed study of individual flares.



Left: A multi-wavelength observable: the slope of the emission measure distribution, determined from EUV observations of a flare chromospheric footpoint, is a diagnostic of energy transport

Catalogue & Archive:

Flares with comprehensive ground-and space-based coverage are extremely precious.



F-CHROMA will create an archive and catalogue of well-observed GBO flares, with links to space-based data.

The output of flare simulations will also be made available, with analysis tools, to increase community flare research.

F-CHROMA

Flare Chromospheres: Observations, Models and Archives

F-CHROMA solar flares catalogue (around 470 flares)

F-CHROMA
http://www.fchroma.org

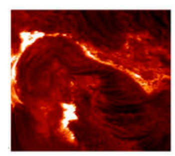
https://star.pst.qub.ac.uk/wiki/doku.php/public/solarflares/start

Astrophysics Research Centre

School of Mathematics and Physics

Solar flare database

F-CHROMA



This is the head page for the initial database of solar flares that have been observed with ground-based facilities.

An asterisk in the first column denotes that data for this flare is available.

Contact David Kuridze or Mihalis Mathioudakis for details.

In some cases you can download formatted data for a flare - these are available on our WebDAV service.

This database has been prepared by the F-CHROMA consortium. The F-CHROMA project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 606862.

Main listing

This listing is *sortable*. Click on header to sort by that column. Click again to toggle between low-high and high-low. Click on the flare number to get more information and links on available observations and publications. A brief description of the instruments used to acquire the data are given here: Ground-based instruments, Space-based instruments.

Flare	Date	AR Number	AR Location[1]	X-Ray Class	Start	Peak	End	Telescopes
Flare 0065*	25/09/1997	08088	S28 E02	C7.2	11:40:00	11:49:00	11:55:00	MSDP/LC
Flare 0066*	02/05/1998	08210	S17 W15	C5.4	04:48:00	05:00:00	05:21:00	MSDP/LC
Flare 208*	02/05/1998	08210	S17W24	X1.1	13:31:00	13:42:00	13:51:00	OT
Flare 0018	13/05/1998	08218	275″-282″	C1.1	14:42:00	14:52:00	15:20:00	SST
Flare 209*	27/05/1998	08226	N18W66	C1.8	06:05:00	06:11:00	06:20:00	OT
Flare 210*	27/05/1998	08224	N18W66	C5.8	11:06:00	11:18:00	11:30:00	OT
Flare 211*	27/05/1998	08226	N18W91	C7.5	13:30:00	13:35:00	14:50:00	OT
Flare 212*	28/05/1998	08226	N18W80	C1.2	06:18:00	06:23:00	06:26:00	OT

F-CHROMA

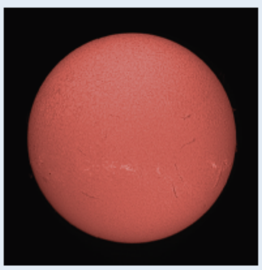
Flare Chromospheres: Observations, Models and Archives

F-CHROMA
http://www.fchroma.org

One of the purpose of the F-CHROMA project is a dissemination of the results of our studies and solar physics in general and involving amateur astronomers in solar flares observations and data analysis (WP8).

Dissemination:

In addition to web and social media presence, we will involve the amateur astronomer community in 'Pro-Am' co-ordinated flare observing campaigns. This recognises that high quality solar observations can be obtained by amateurs.

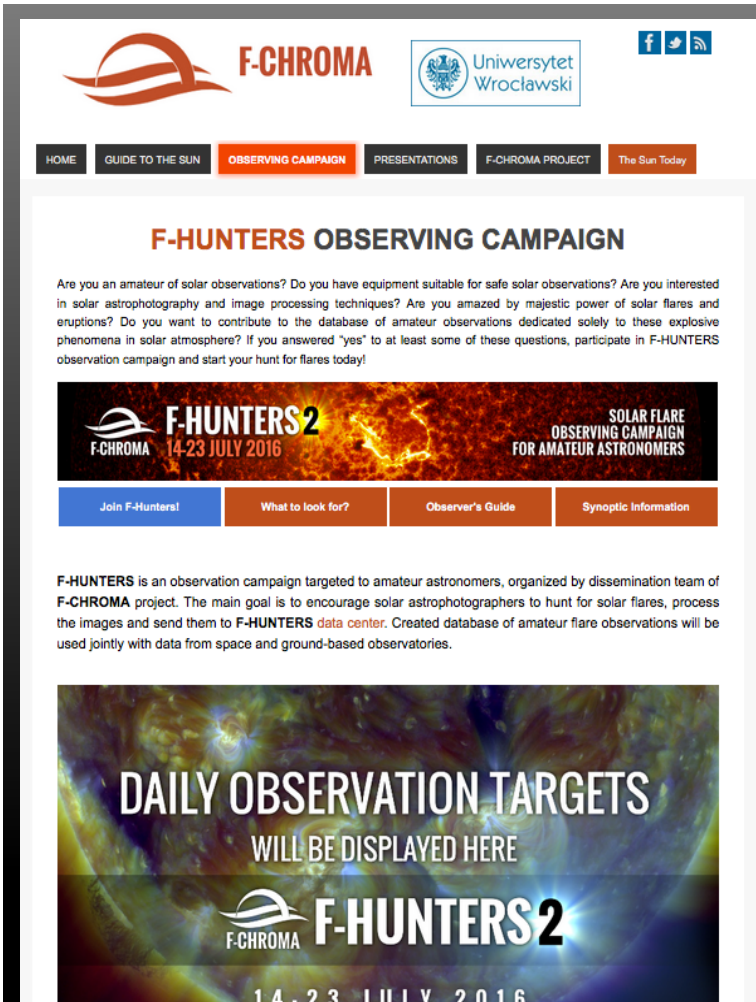


Why the amateur astronomers can be helpful?

1) There are many amateur astronomers scattered through the World so the probability of catching flares by them is higher. Besides, it is more probable to observe the flares from very beginning;

2) Their telescopes/cameras has higher field-of-view so they can observe larger areas of the solar surface thus also increasing the probability of the flare detection;

3) Professional telescopes often works in very narrow spectral ranges, e.g. in the chromospheric lines, or even their parts. Such data obviously contains many information about plasma parameters. However, also the broad-band images or spectra, which include the continuum flare emission, can provide an interesting information about the radiative processes in flaring chromospheres. Such data can be provided by amateurs – they can use cheap solar filters or Mylar foil to observe broad-band white-light emission of flares


F-CHROMA
Uniwersytet Wrocławski
HOME | GUIDE TO THE SUN | OBSERVING CAMPAIGN | PRESENTATIONS | F-CHROMA PROJECT | The Sun Today

F-HUNTERS OBSERVING CAMPAIGN

Are you an amateur of solar observations? Do you have equipment suitable for safe solar observations? Are you interested in solar astrophotography and image processing techniques? Are you amazed by majestic power of solar flares and eruptions? Do you want to contribute to the database of amateur observations dedicated solely to these explosive phenomena in solar atmosphere? If you answered "yes" to at least some of these questions, participate in F-HUNTERS observation campaign and start your hunt for flares today!

Join F-Hunters! | What to look for? | Observer's Guide | Synoptic Information

F-HUNTERS is an observation campaign targeted to amateur astronomers, organized by dissemination team of **F-CHROMA** project. The main goal is to encourage solar astrophotographers to hunt for solar flares, process the images and send them to **F-HUNTERS** data center. Created database of amateur flare observations will be used jointly with data from space and ground-based observatories.

F-CHROMA for amateurs:
http://fchroma.astro.uni.wroc.pl/

Informations about observing campaigns and tutorials for amateurs.

F-HUNTERS #1: 19-27 Sep 2015

F-HUNTERS #2: 14-23 Jul 2016

Advices for amateur astronomers, manuals

We invite all for cooperation !

Subscription


Join F-Hunters!
What to look for?
OBSERVER'S GUIDE
Synoptic Information
F-CHROMA OBSERVING GUIDE
NOTE. conducting observations of the Sun one should always keep in mind that solar observations of any kind are potentially dangerous and could cause a high risk of severe inures. One should applied extraordinary safety measures and precautions in order to avoid eye damages leading even to complete and unrecoverable blindness! All observers of the Sun in visual domain should strictly follow general safety rules stated below.
You should keep in mind and observe following rules:
• never look straight on the Sun without appropriate and reliable eye protection – you could become blind instantly.
• never look straight on the Sun through any telescope, binoculars or any other optical device, even if they are fitted with some not tested and not certified "solar filters" or "dimmers". Direct telescopic observations of the Sun could be made by well trained observers only, applying appropriate and tested instruments.
• even if you are an experienced observer of the Sun, always check your instruments before the observations, putting a special attention on a selection and installation of the right filters and light attenuators.
SAFETY GUIDE
PROJECTION METHOD
SOLAR FILTERS
HOW TO OBSERVE FOR F-CHROMA?
INTRODUCTION TO SOLAR PHOTOGRAPHY
ASTROPHOTOGRAPHY FOR SCIENCE: GUIDELINES
DSLR TUTORIAL
CAMERA TUTORIAL
http://fchroma.astro.uni.wroc.pl
http://fchroma.astro.uni.wroc.pl
F-CHROMA
F-HUNTERS
DAY 5
IRIS POINTING
TARGET INFORMATION FOR F-HUNTERS OBSERVERS
DATE 23 SEP 2015
TIME (UT) 11:42-16:44* / ALL DAY**
TARGET AR 12420
* Hours of IRIS observation time.
** Flare observations from all day are requested.
SDO/HMI CONTINUUM
GONG H-alpha
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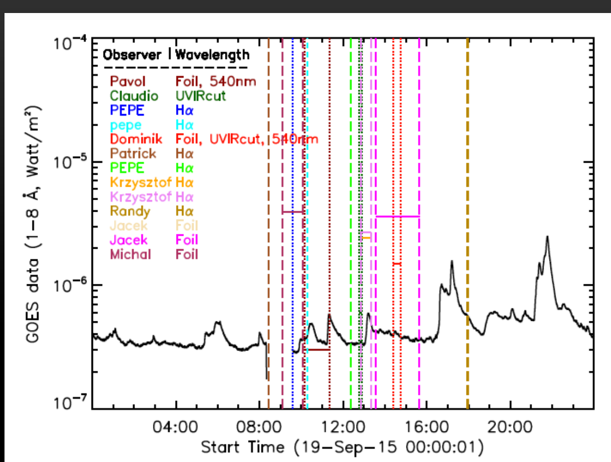
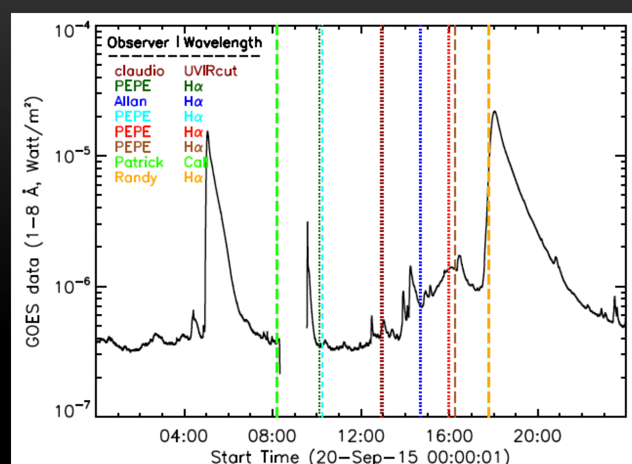
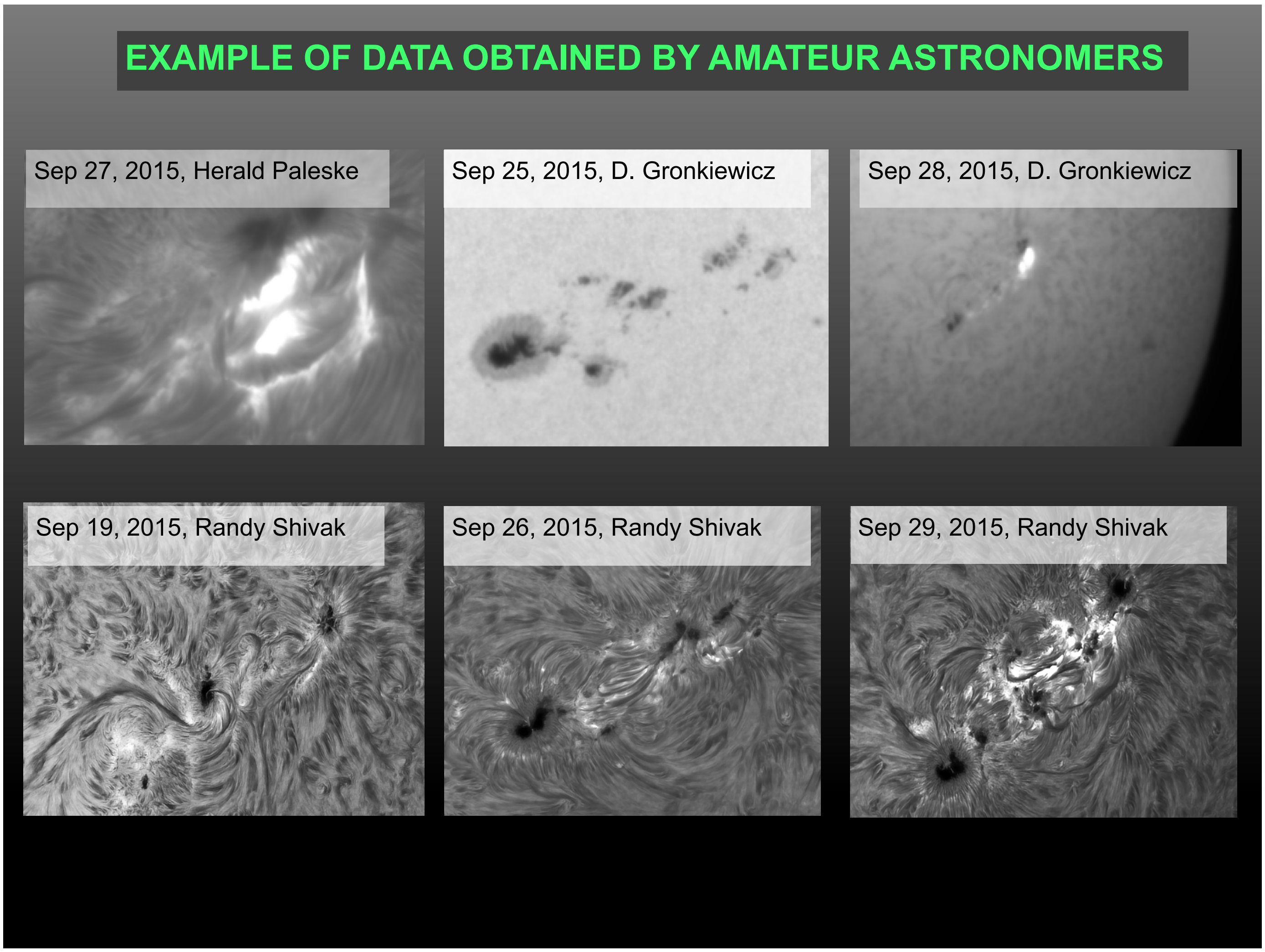
AR 12420

Results of F-HUNTERS#1 flares observing campaign






EXAMPLE OF DATA OBTAINED BY AMATEUR ASTRONOMERS
Sep 27, 2015, Herald Paleske
Sep 25, 2015, D. Gronkiewicz
Sep 28, 2015, D. Gronkiewicz
Sep 19, 2015, Randy Shivak
Sep 26, 2015, Randy Shivak
Sep 29, 2015, Randy Shivak


https://www.facebook.com/fchroma
https://twitter.com/fchroma
F-HUNTERS 2
F-CHROMA
fchroma.astro.uni.wroc.pl
SOLAR FLARE OBSERVING CAMPAIGN
FOR AMATEUR ASTRONOMERS
14-23 JULY 2016
http://fchroma.astro.uni.wroc.pl
http://www.fchroma.org/
F-CHROMA

THANK YOU

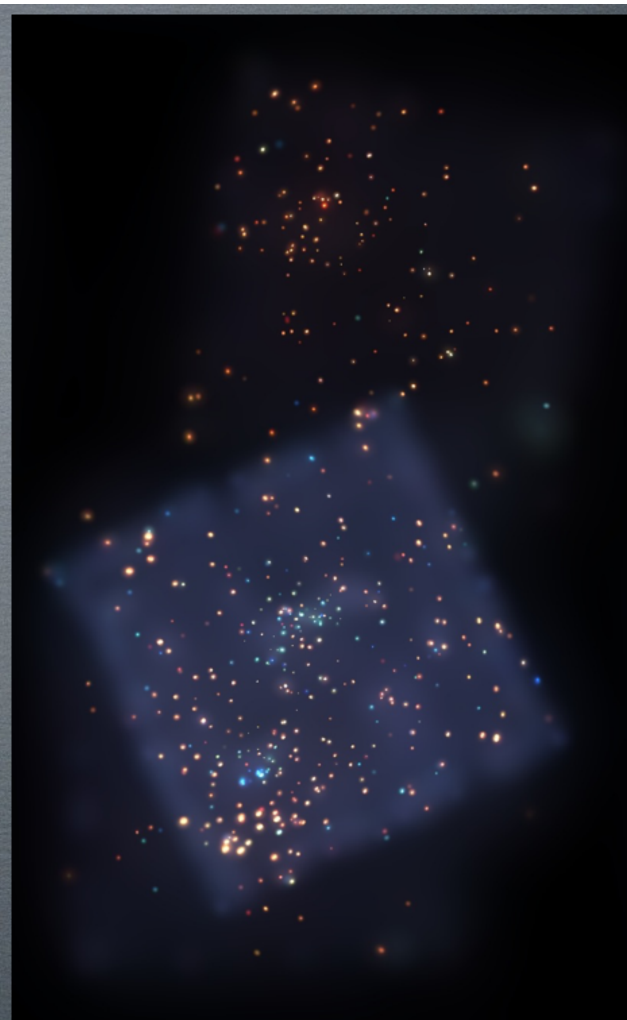
This project has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 606862 (F-CHROMA)

F-CHROMA

A multi-wavelength view of magnetic flaring from PMS stars

E. Flaccomio

and the CSI-NGC2264 collaboration



X-ray emission from PMS stars

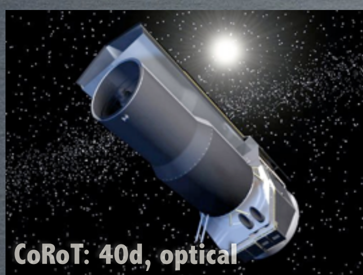
- 10-1000 times brighter than MS stars
- Emission from coronae and accretion shocks
- X-rays heat and ionize circumstellar disks, influencing its evolution
    - Photo-evaporation and dispersal
    - Disk viscosity through MRI - accretion

Flares, higher energies and particles, probably relevant

- Much more energetic than on the Sun, at least in X-rays
- Duration up to >1d
- Some from long loops, connecting the star with the inner disk (debated)

- Optical observations very scarce (e.g. Fernandez et al, 2004; Koen, 2015), **no simultaneous optical/X-ray observations.** Also no mIR observations (?)
- IR/optical/X-ray observations: heating of the inner disk?

The Coordinated Synoptic Investigation of NGC 2264 (CSI 2264)

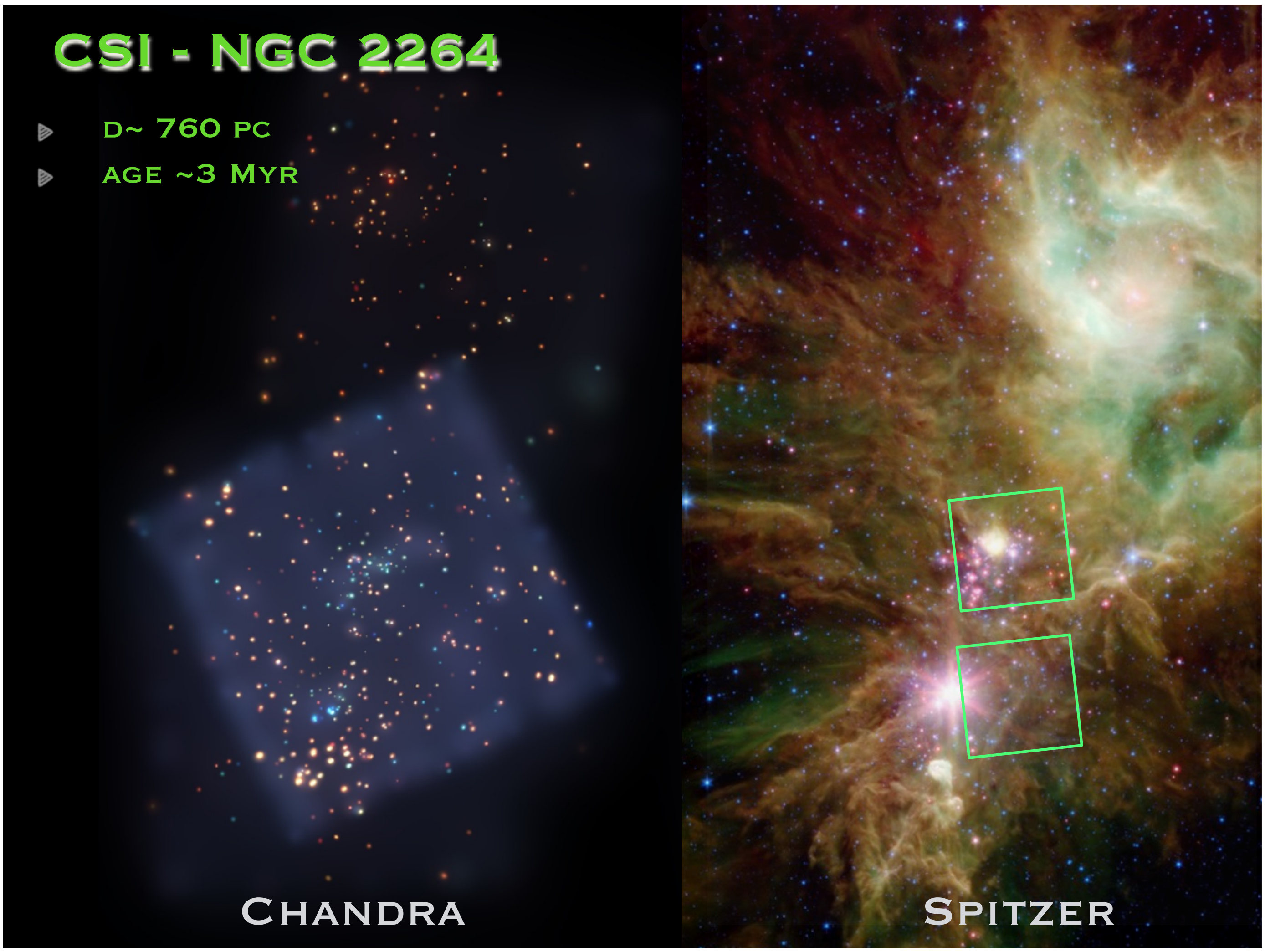


\+ Ground-based monitoring
U-K bands: ~3 months

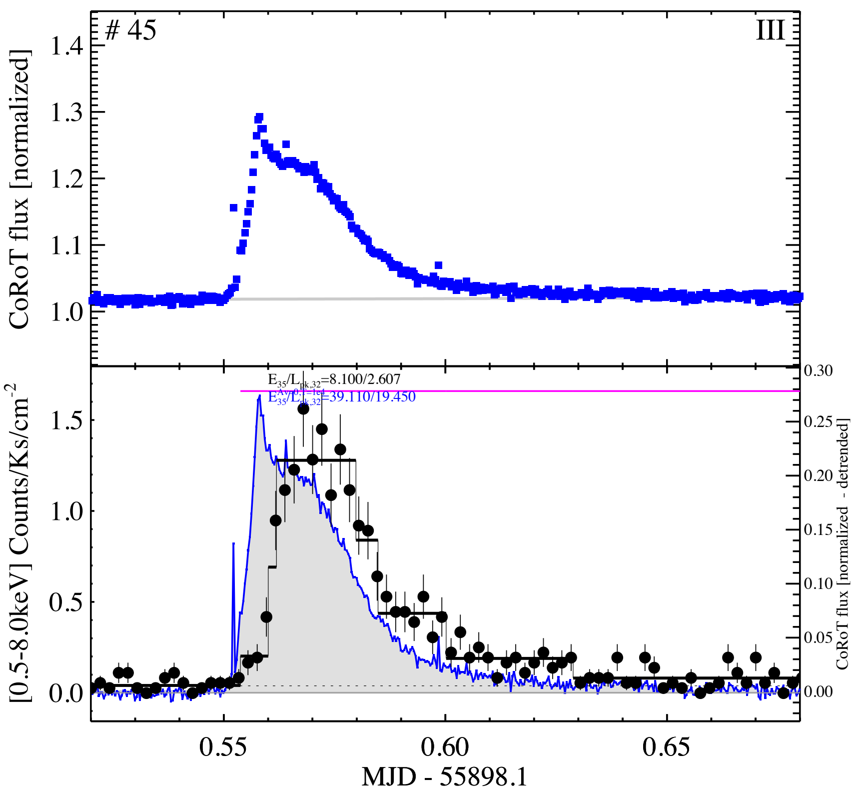
Spitzer PI: John Stauffer
Chandra/CoRoT PI: Giuseppina Micela

Ann Marie Cody, Jérôme Bouvier, Konstanze Zwintz, Ettore Flaccomio, Mario Guarcello, Peter Plavchan, Kevin Covey, Lynne Hillenbrand, Fabio Favata, Rob Gutermuth, Barbara Whitney, John Carpenter, Franck Marchis, Amy McQuillan, Joe Hora, María Morales Calderon, Sylvia Alencar, Suzanne Aigrain, William Herbst, Luisa Rebull, Gabor Furesz, Paula Teixeira, Laura Affer, Neal Turner, David Barrado, Hervé Buoy, Laura Venuti, Inseok Song, Fred Vrba, Jorge Lillo Box, Sean Carey, Susan Terebey, Jon Holtzmann, Ed Gillen, Alan Watson

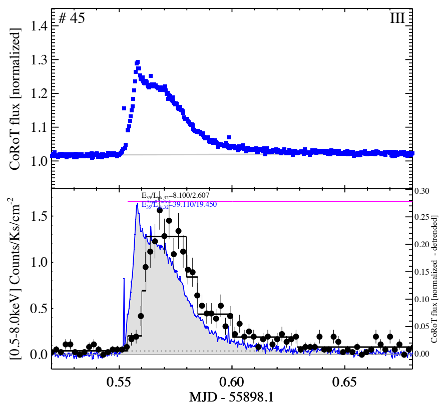
Stauffer et al. (2016)	*CSI 2264: Characterizing Young Stars in NGC 2264 with Stochastically Varying Light Curves*
Sousa et al. (2016)	*CSI 2264: Accretion process in classical T Tauri stars in the young cluster NGC 2264*
McGinnis et al. (2015)	*CSI 2264: Probing the inner disks of AA Tauri-like systems in NGC 2264*
Stauffer et al. (2015)	*CSI 2264: Characterizing Young Stars in NGC 2264 With Short-Duration Periodic Flux Dips in Their Light Curves*
Stauffer et al. (2015)	*CSI 2264: Characterizing Accretion-burst Dominated Light Curves for Young Stars in NGC 2264*
Cody et al. (2015)	*CSI 2264: Simultaneous Optical and Infrared Light Curves of Young Disk-bearing Stars in NGC 2264 with CoRoT and Spitzer—Evidence for Multiple Origins of Variability*

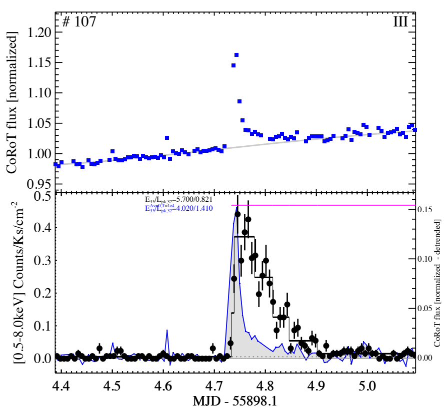

CSI - NGC 2264
D~ 760 PC
AGE ~3 MYR
CHANDRA
SPITZER

Typical Examples

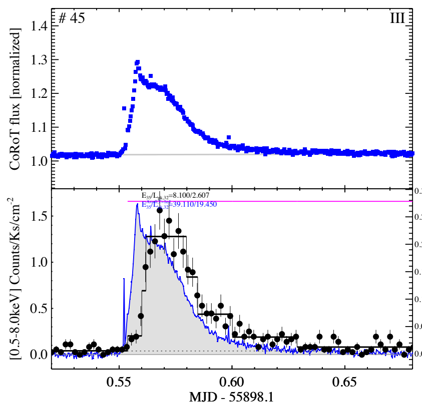


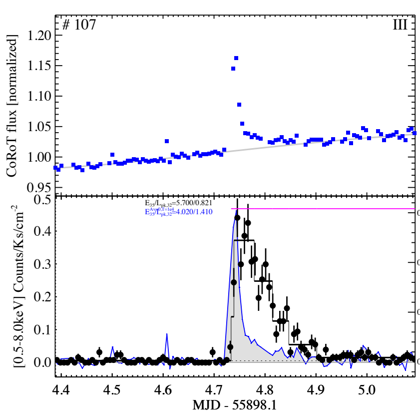
Typical Examples

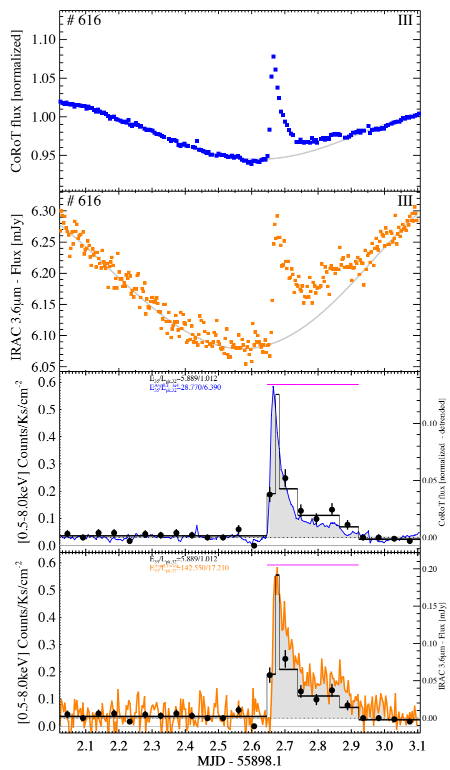




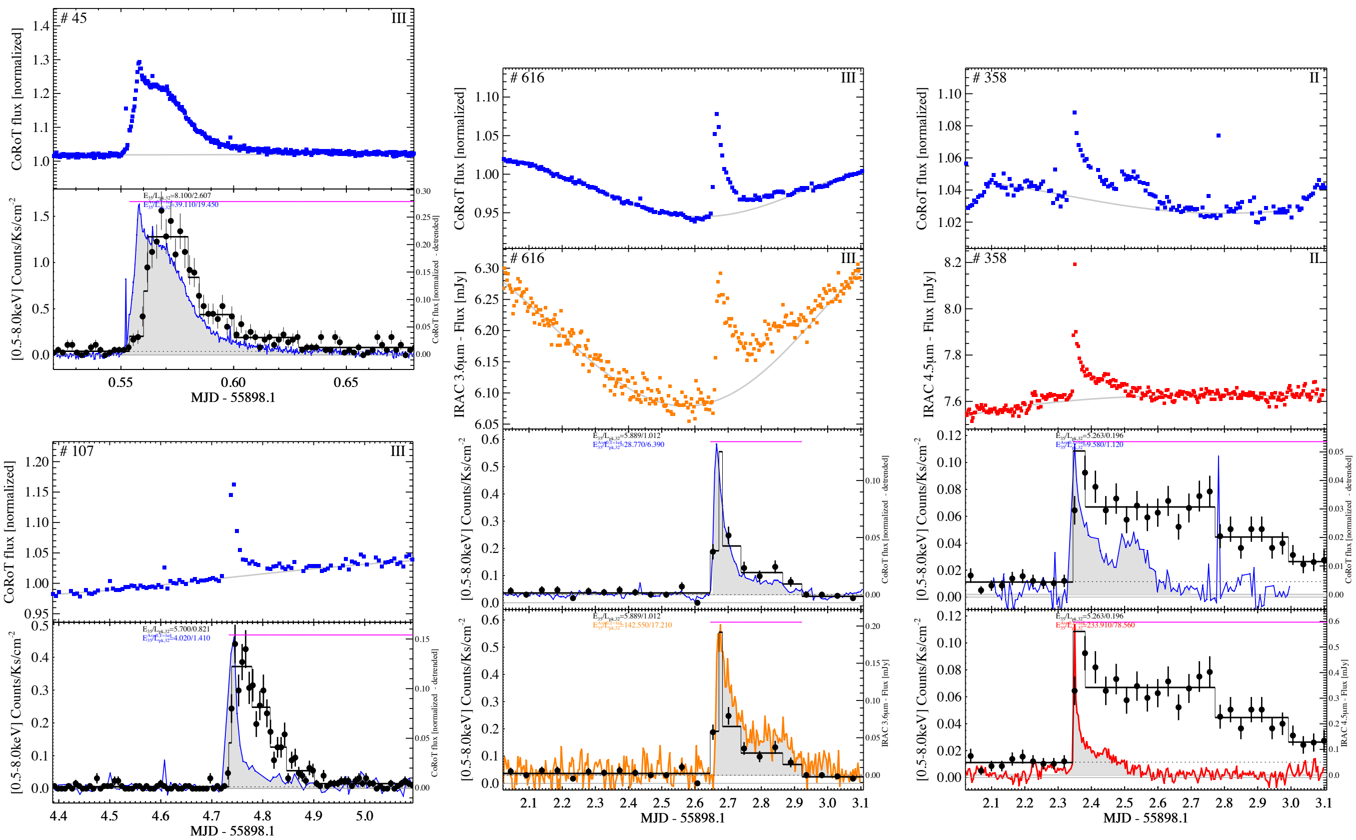
Typical Examples



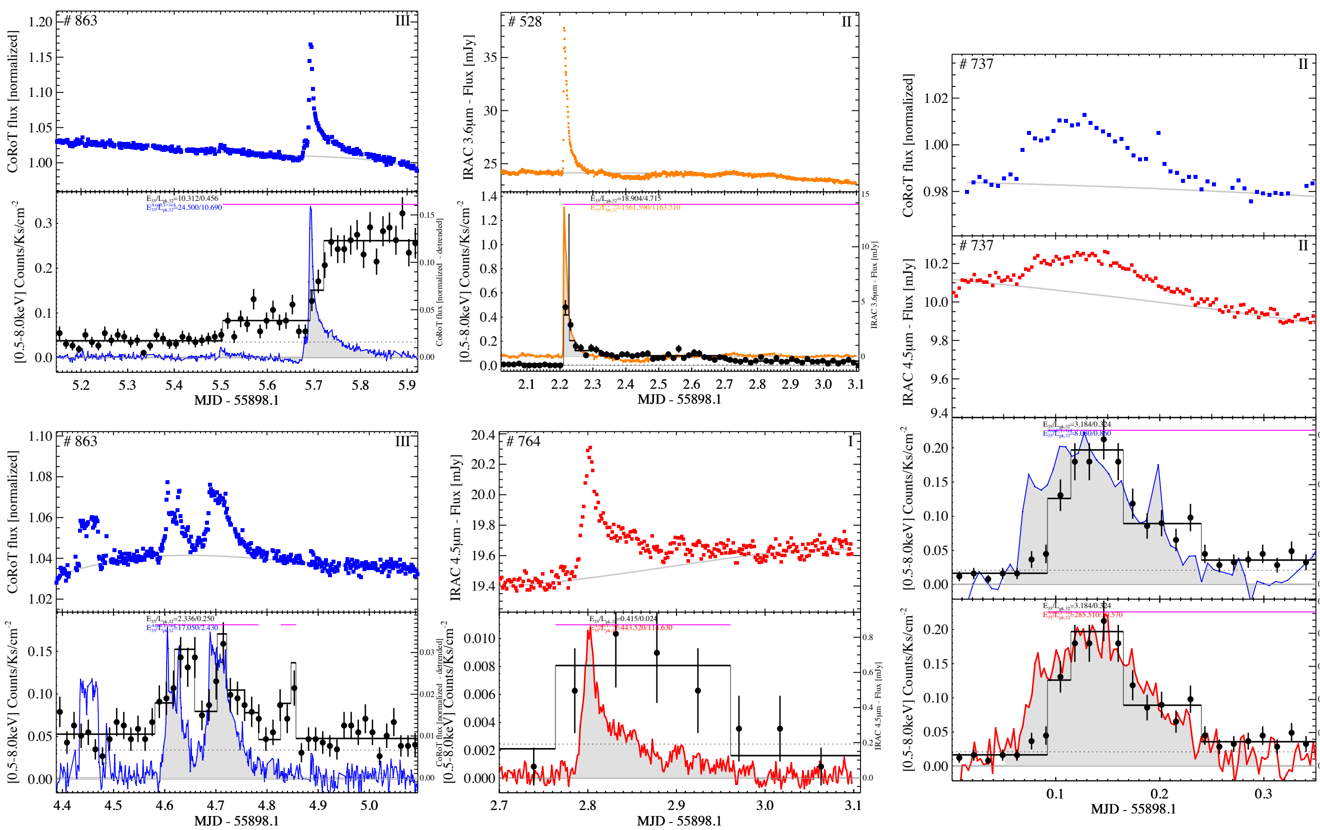




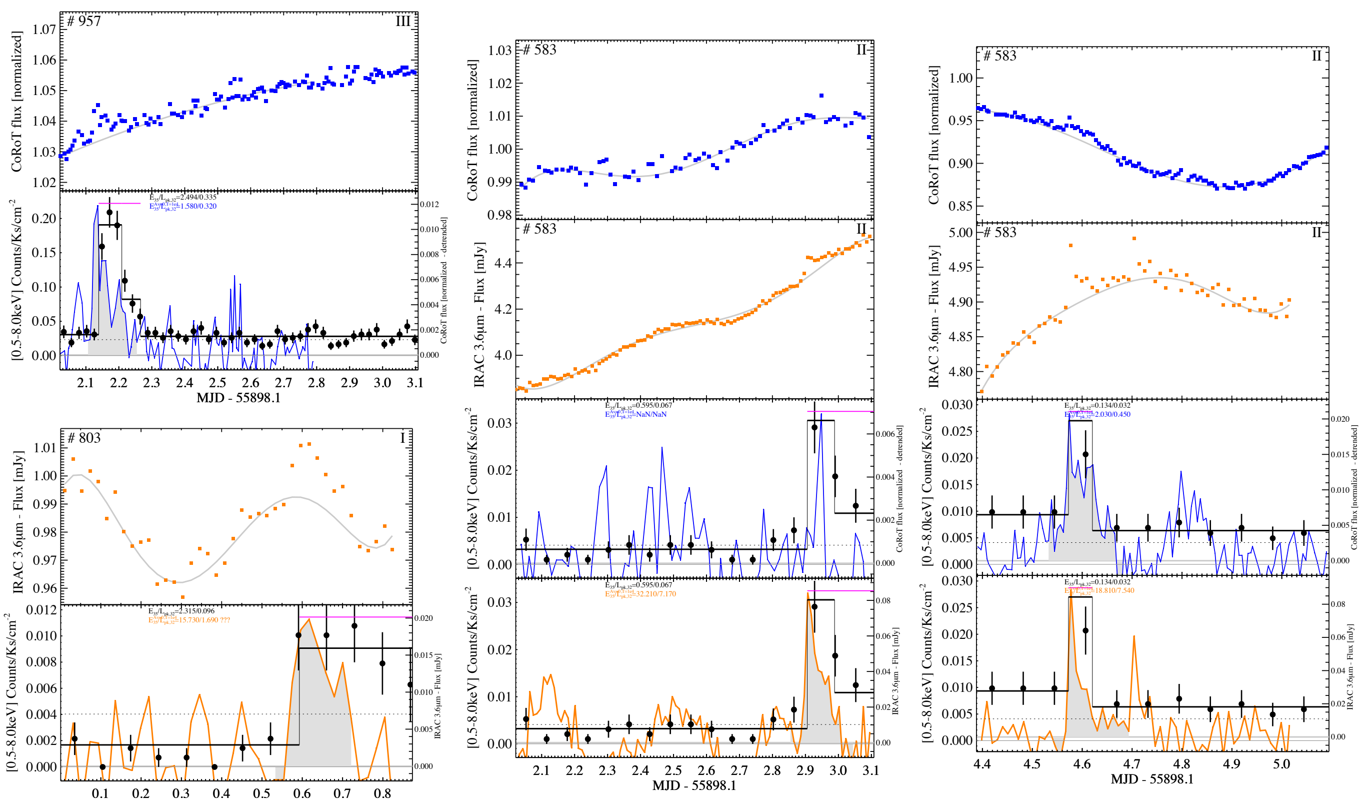
Typical Examples



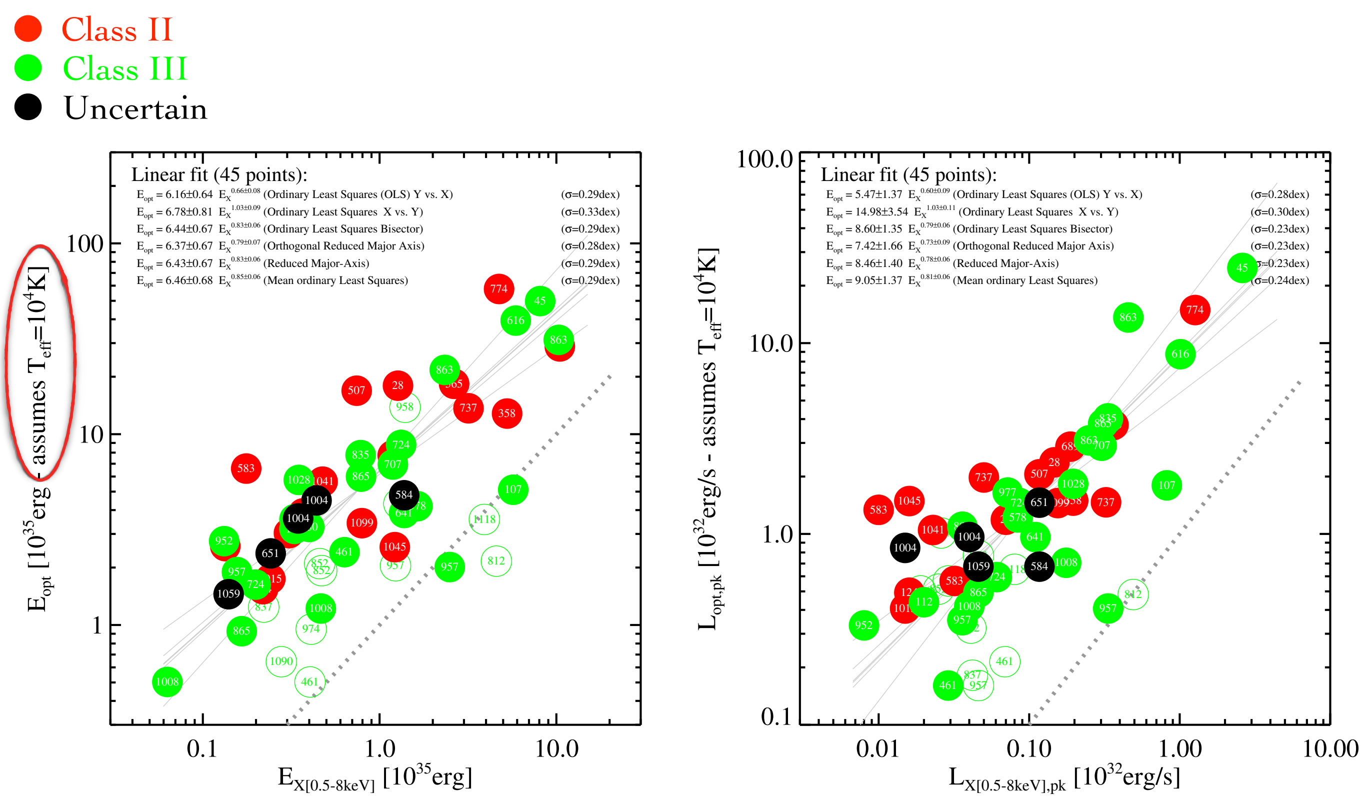
More typical examples



More examples

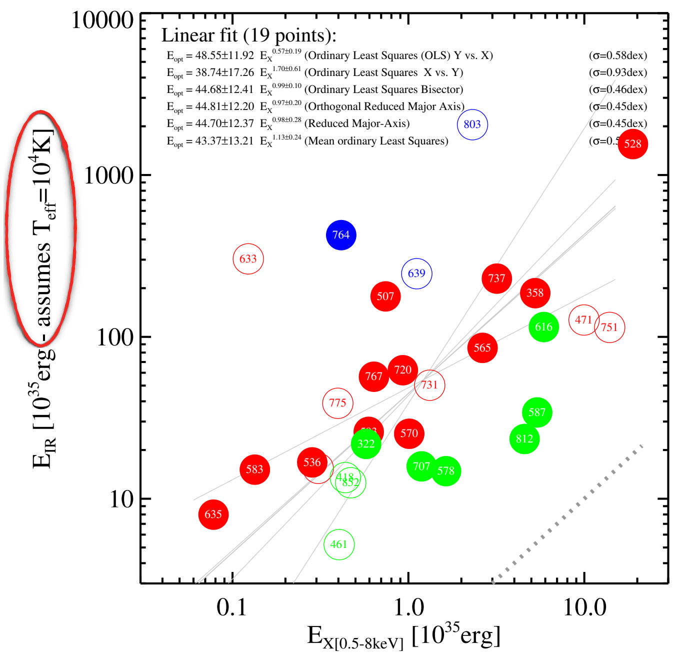


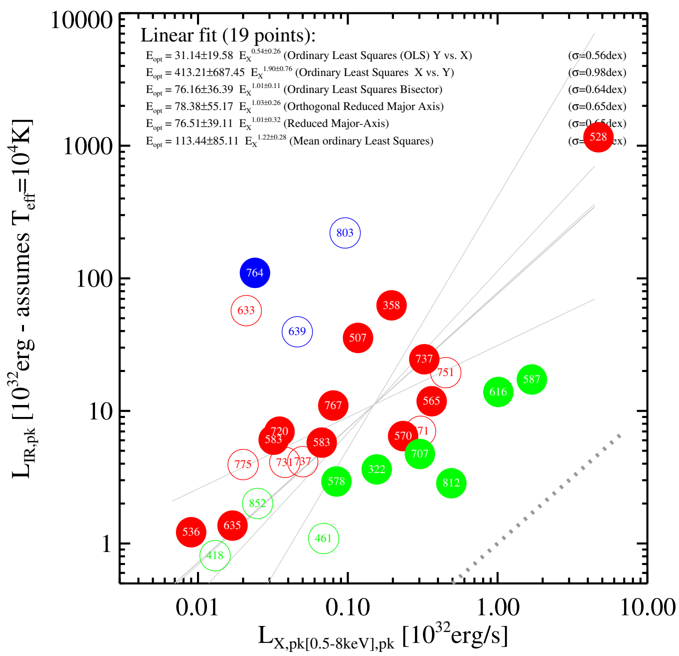
Optical vs. X-ray: energies and peak luminosities



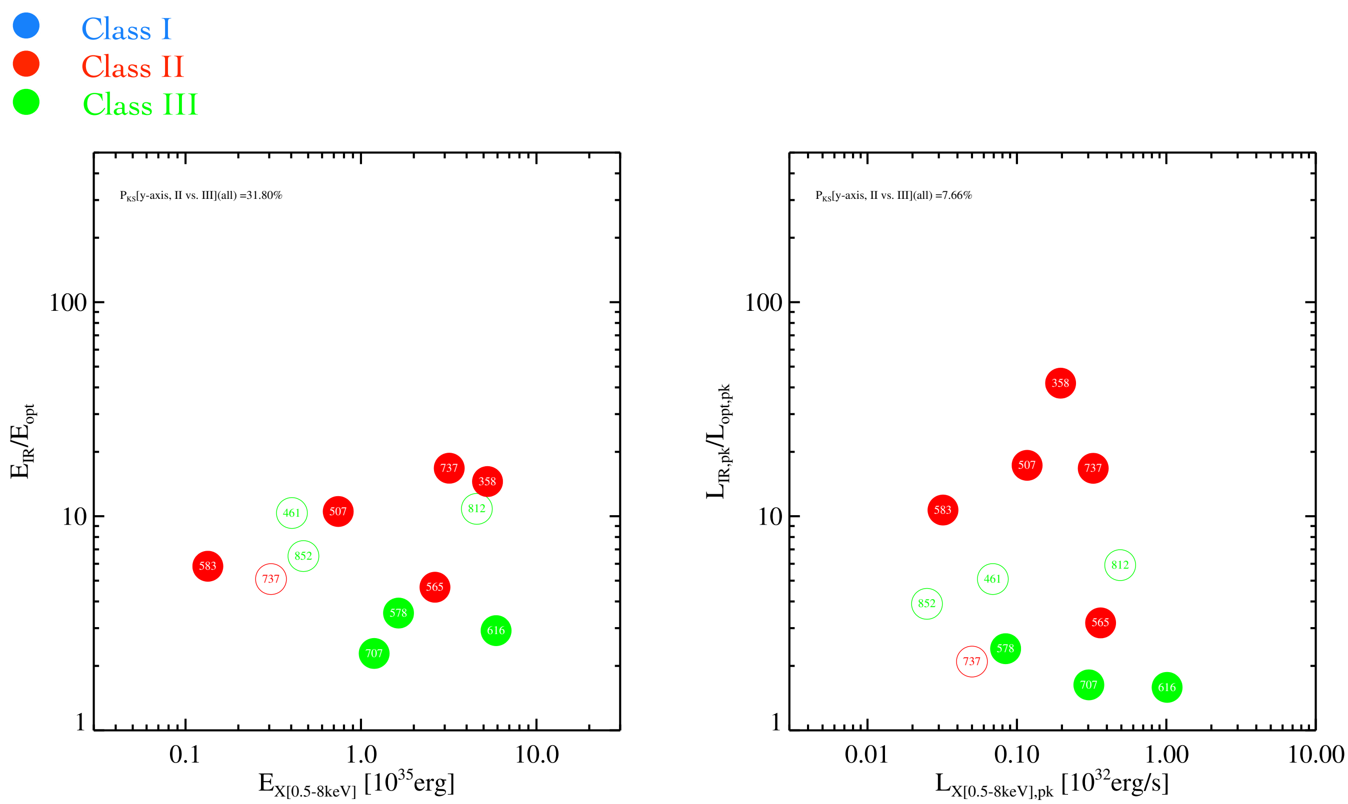
mIR vs. X-ray: energies and peak luminosities

- Class I
- Class II
- Class III

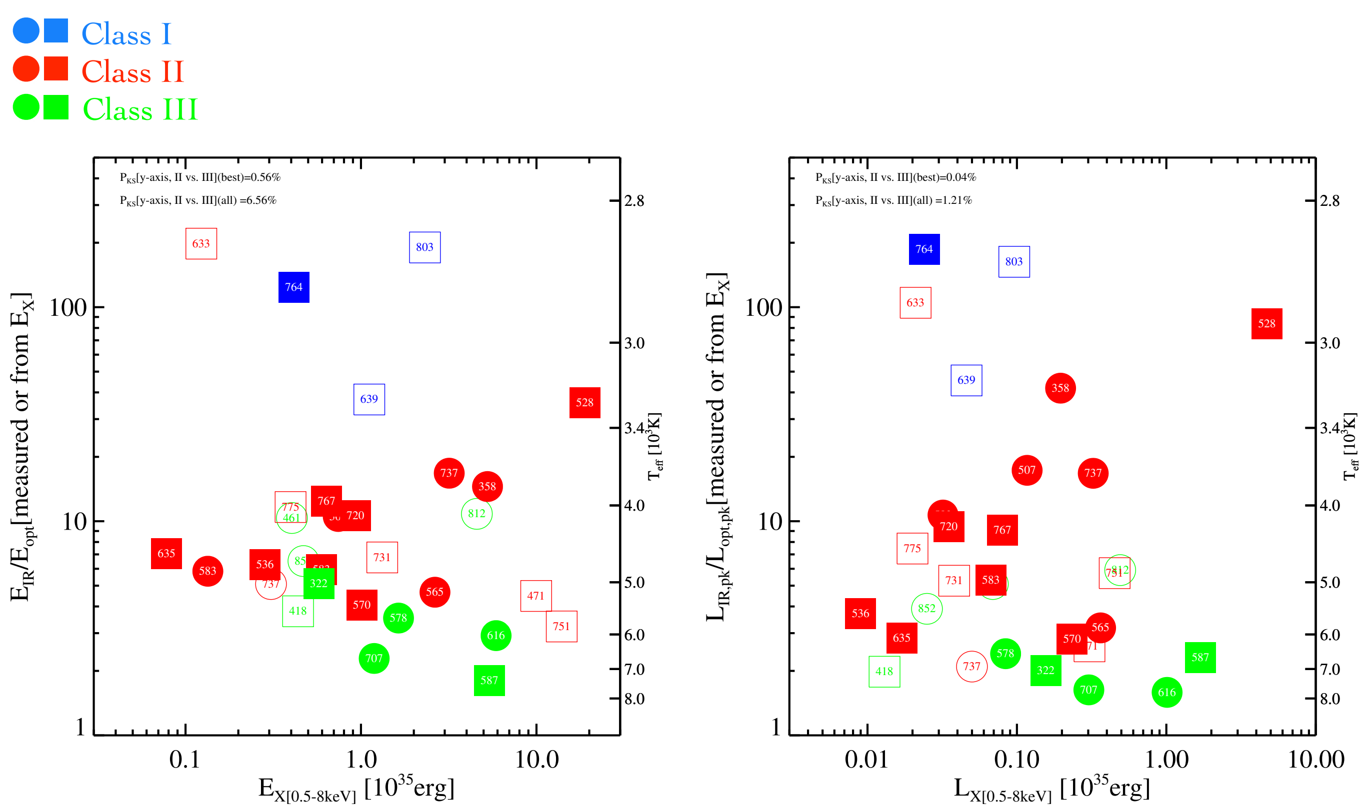




IR/Optical vs. X-ray



IR/Optical vs. X-ray



Conclusions

- Emitted energies up to ~5 dex higher than for the brightest solar flares (total observing time <2yr): Solar flares not necessarily a good model

- The energy emitted in the optical and X-ray bands are tightly correlated, with a small scatter

- Strong IR excesses for flares in stars with circumstellar disks: likely the direct response (heating) of the inner disk to the optical/X-ray flare

Recovering Flares in Sparsely Sampled LSST Light Curves

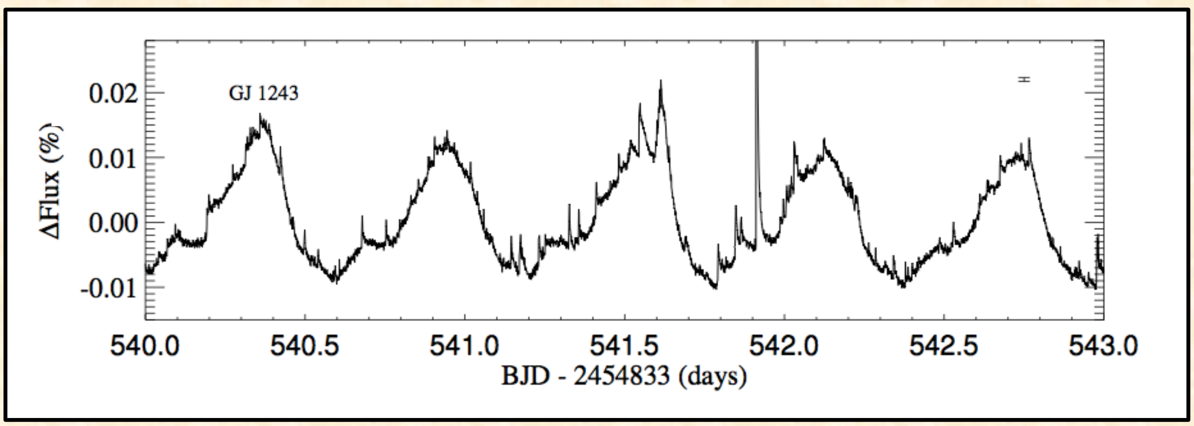
From Stars Study Group report for the NOAO/LSST Workshop on US OIR followup capabilities needed in the LSST Era

Suzanne Hawley, University of Washington
Ruth Angus, Oxford University
Derek Buzasi, Florida Gulf Coast University
Jim Davenport, Western Washington University
Mark Giampapa, National Solar Observatory
Vinay Kashyap and Soren Meibom,
Harvard-Smithsonian Center for Astrophysics

Properties of LSST Data

- Survey entire southern sky (to Dec = +5-10) approx. once every 3 days
- Most data taken in redder filters (rizy) but some in u and g
- Precision is < 0.01 mag from r=16-24
- Data obtained as two consecutive 15 sec exposures, combined into one data point

-- ISSUE: this 3 day light curve (from GJ 1243, an active dM4e in Kepler field) would be sampled approximately once
-- THUS: flares will be single point outliers in the LSST light curves
-- BUT: don't want to flag starspot variations

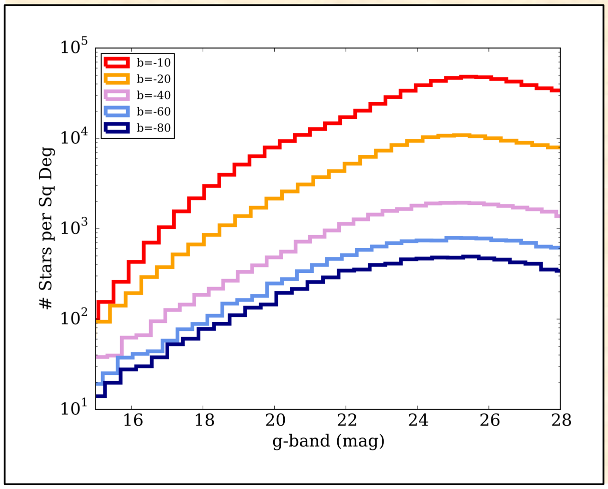


Simulate Galactic fields with TRILEGAL

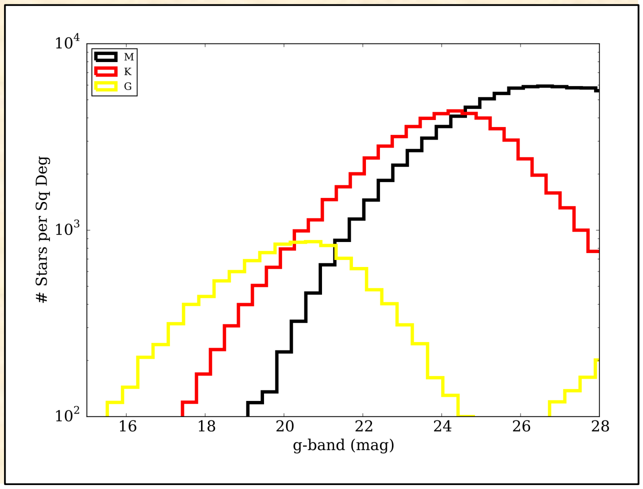
5 different latitudes (-10 to -80)

model data include age, T_{eff}, distance, ugriz magnitudes for each star

stars/sq deg at different latitudes



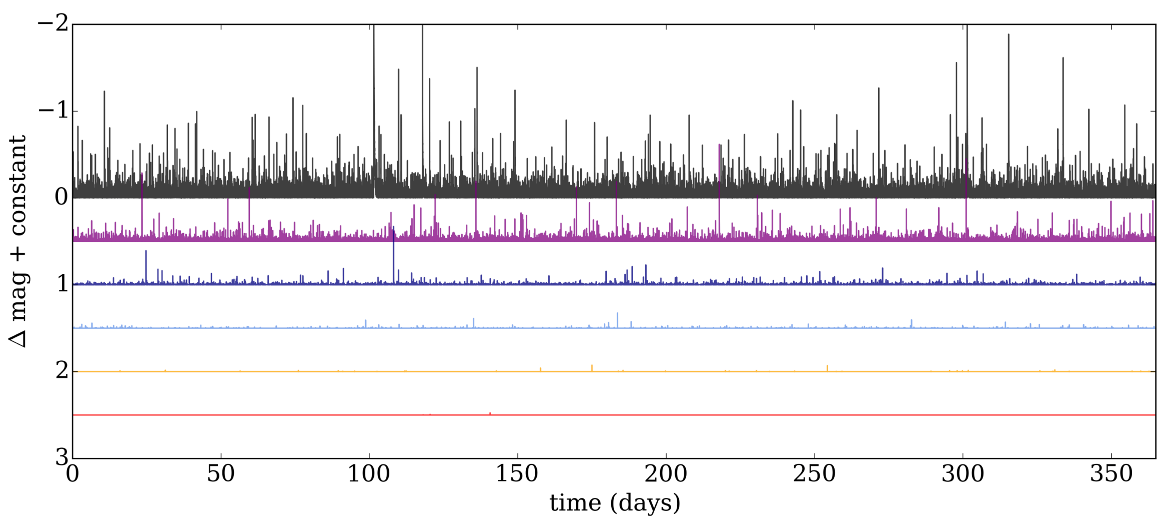
stars/sq deg at different spectral type



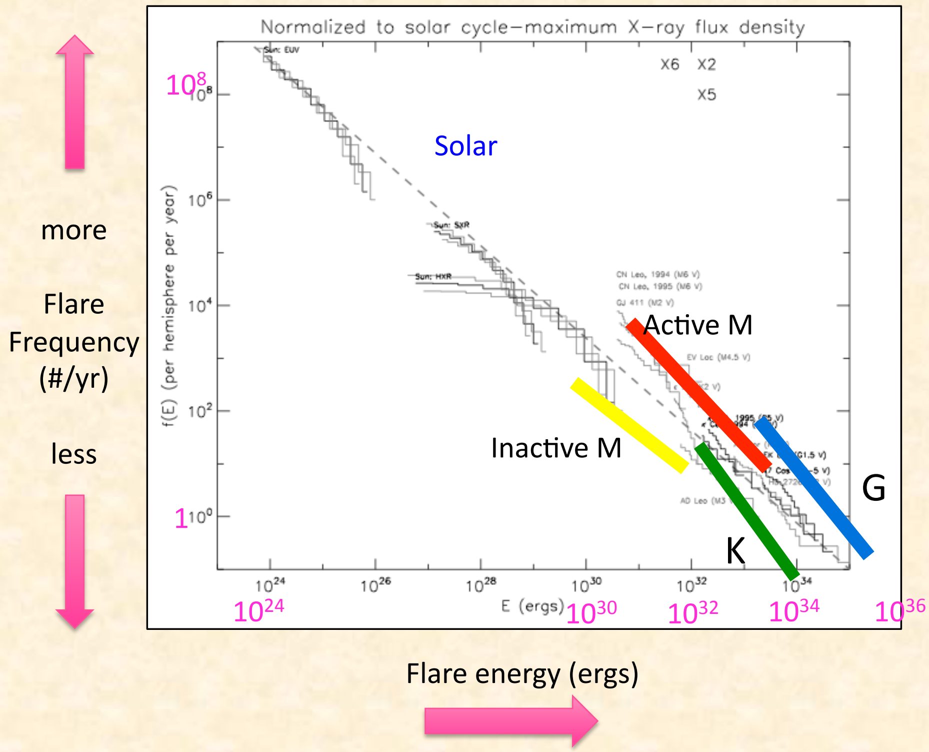
Simulated Flare Light Curves

Kepler data to define flare shape

Flare frequency distributions use power law, depends on age and spectral type



Solar/stellar flare frequencies (Schrijver 2012) depend on age and T_{eff}

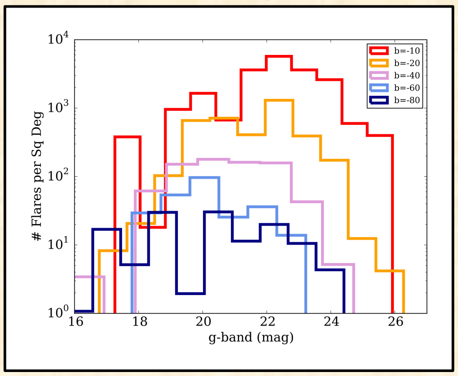


LSST flare simulations

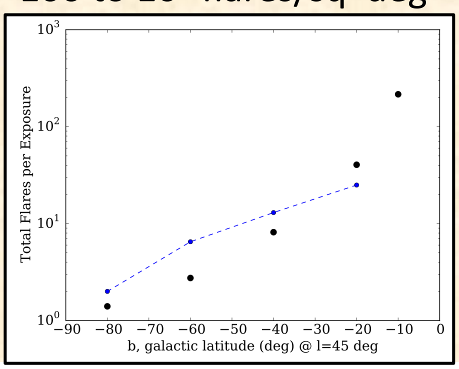
- Generate light curve for each star in test field
- Sample with LSST cadence
- Flares identified as 0.1 magnitude (10 sigma) excursions from median magnitude of the light curve
- Find number of flares recovered at each latitude, and which stars they occurred on

Flare recovery from LSST simulations

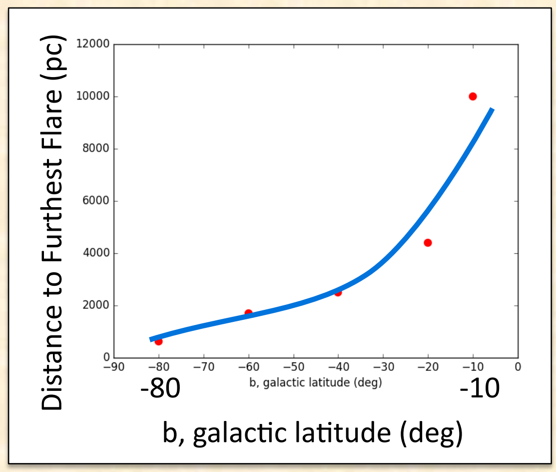
Most flares at g-band < 24



100 to 10^4 flares/sq deg



At low latitude see flares out to 10 kpc!



LSST Flare Simulation Results

• 100 – 10^4 flares/sq deg (depends on latitude)
• recover flares out to 10kpc. Sampling different populations
• 97% of stars with recovered flares are M dwarfs (G and K field stars are typically too old, also show < 0.1 magnitude excursions)
• Very few stars are undetected in quiescence and seen only when flaring. Most stars have g<24
• G dwarf "superflares" likely occur only a few times a year in a typical LSST field – but if seen would require immediate followup!

Report available soon (also includes rotation, activity cycles, open clusters):

http://www.noao.edu/meetings/lsst-oir-study/