

Rotational modulation of X-ray emission in Orion Nebula young stars

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E. Flaccomio

(INAF-Osservatorio Astronomico di Palermo)

G. Micela, S. Sciortino, E. D. Feigelson,
W. Herbst, F. Favata, F.R.
Harnden Jr., S.D. Vrtilek



Outline

- Motivation
- Data
- Analysis
- Results
- Conclusions

The motivation:

- What is the origin of X-ray activity in PMS stars? Is it *coronal* activity like on the Sun and MS stars?
- Presence of disks and accretion influences activity:
 - CTTS have lower L_X and L_X/L_{bol} with respect to WTTS
Flaccomio et al. 2003
Preibish et al. 2005
 - Soft X-ray emission from accretion shocks
TW Hydra, Kastner et al. 2002
BP Tau, Schmitt et al. 2005
 - Long star-disk loops probably seen during intense flares
Favata et al. 2005
- It would be nice to actually *resolve* X-ray emission on the stellar surface

Do we see this ?

We might learn something on the spatial distribution of the emitting plasma

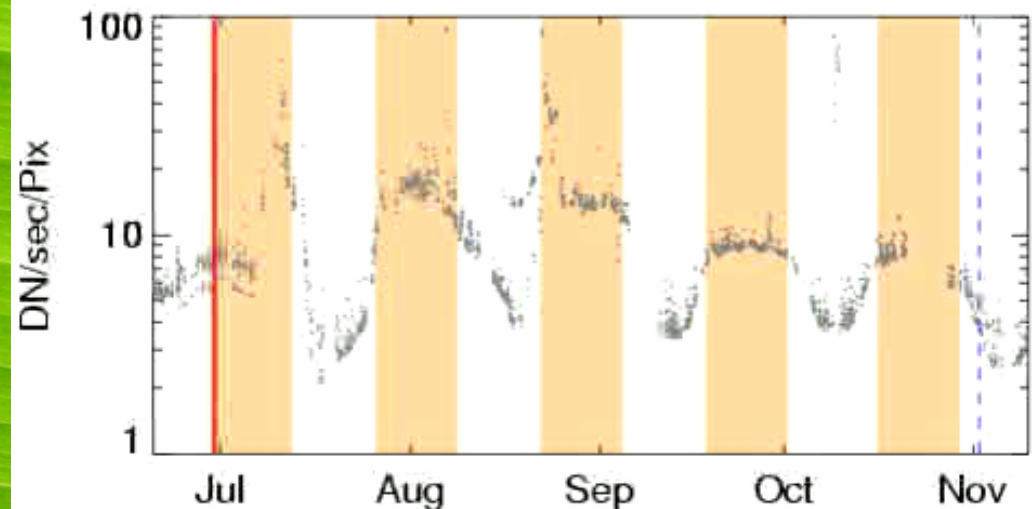
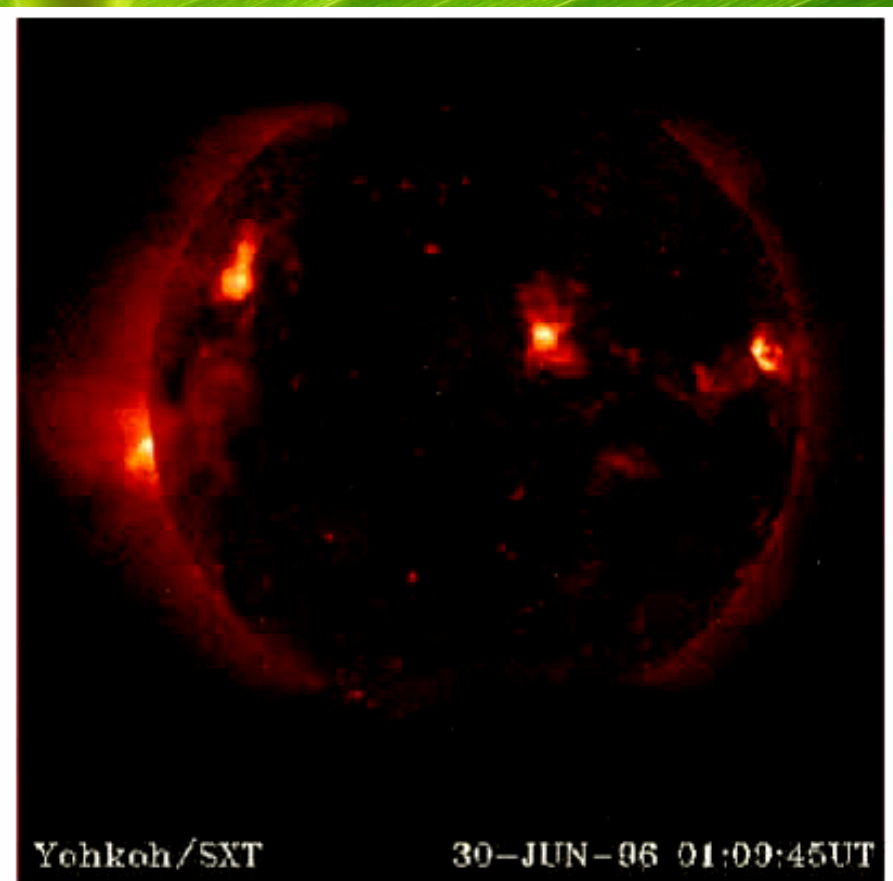
Observations are so far scarce:

- Marino et al. (2003, A&A 407, 63)
VXR 45 - $P = 0.22d$ - G9 ZAMS
- Hussain et al. (2005, ApJ 261, 999)
AB Dor - $P = 0.5d$ - K0 ZAMS
- Guedel et al. (1995, A&A, 301, 201)
EK Dra(?) - $P = 2.7d$ - F8 ZAMS

Why?

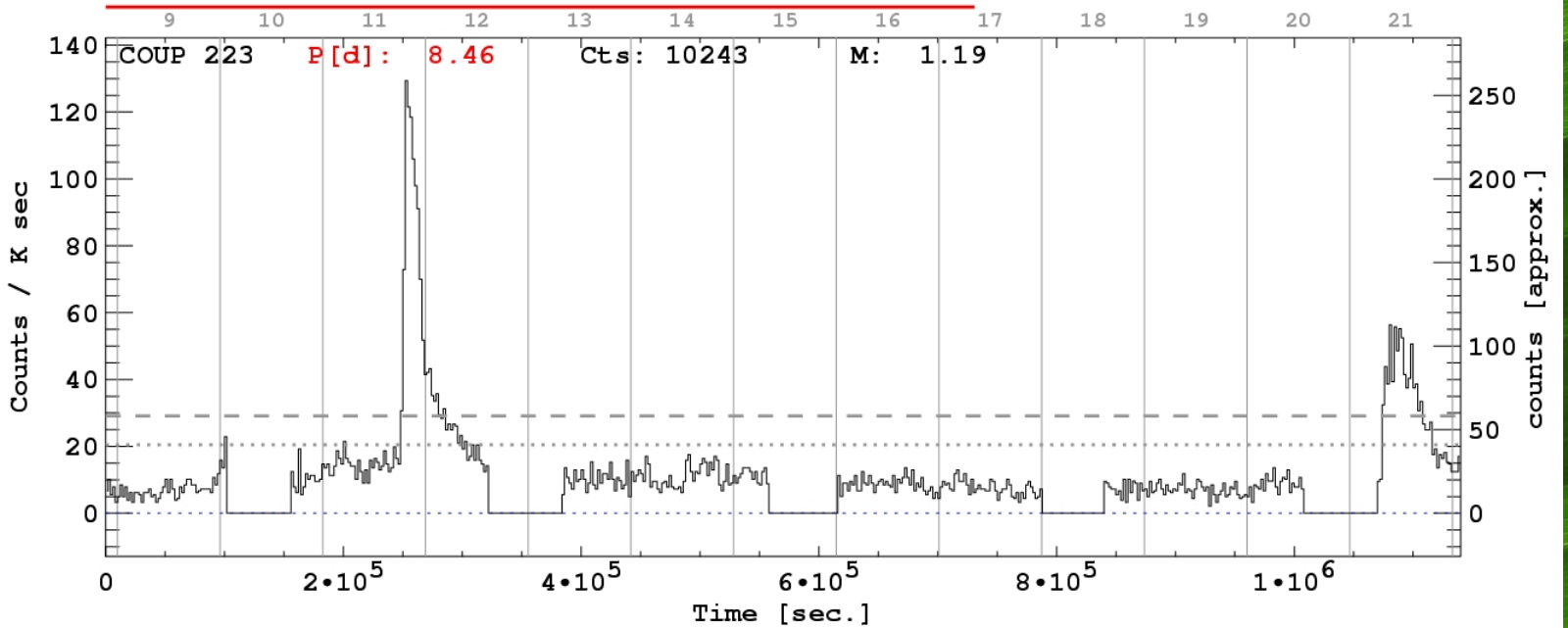
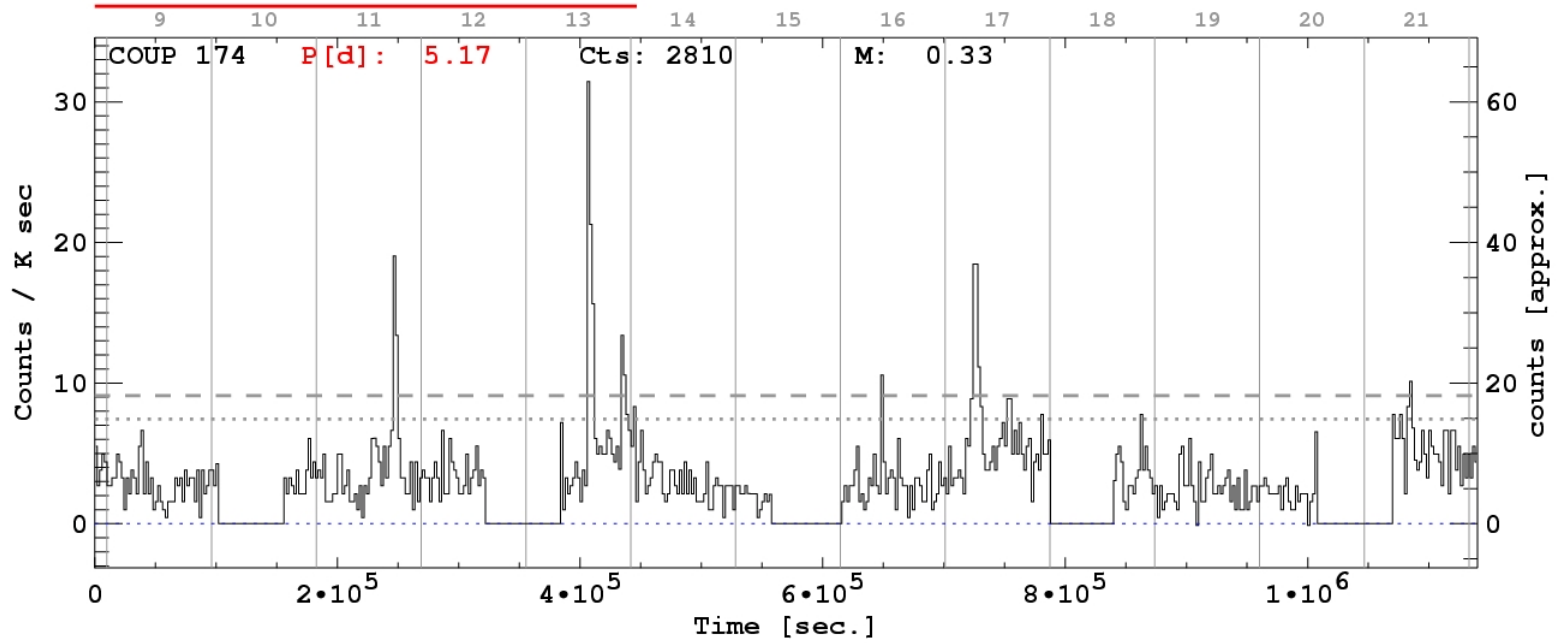
- X-ray observations have been so far too short

COUP is an unique opportunity to study rotational modulation of X-ray emission on a large sample of PMS stars.



The COUP data





Analysis method

➤ Lomb Normalized Periodogram (**LNP**, Scargle, 1982)

False Alarm Probability

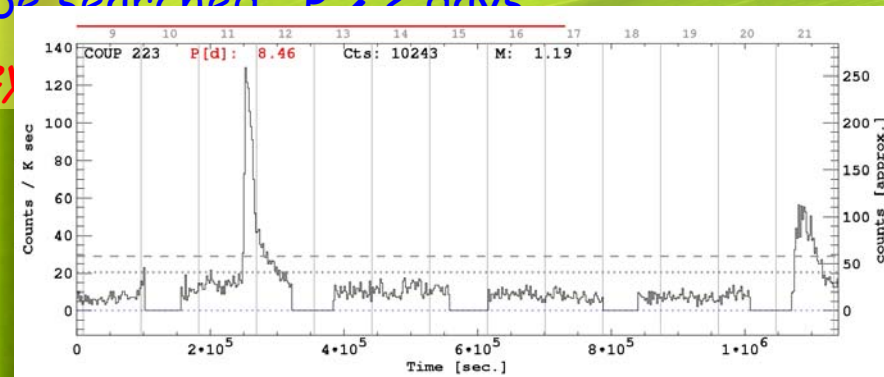
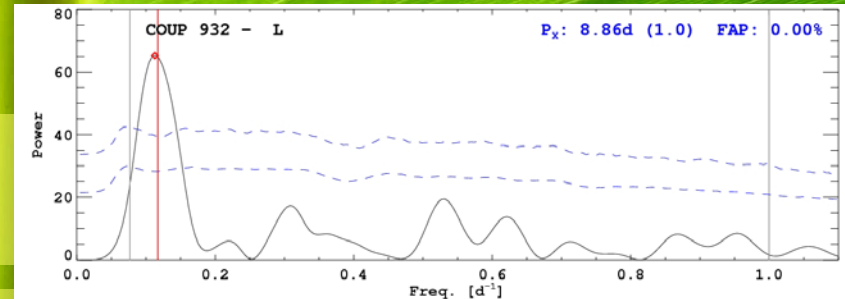
- We take into account *correlated* noise (e.g. flares) with correlation time τ_{corr}
- $\tau_{\text{corr}} = 8$ hours, longer than *most* flare
 - lower limit on the periods that can be searched: $P > 2$ days

FAPs are not accurate, i.e. they

Flare removal

- Trimming above thresholds defined from the count-rate distributions
- Analysis on both filtered and unfiltered light-curves

Not perfect



Search sample

233 COUP sources with :

➤ known rotational period

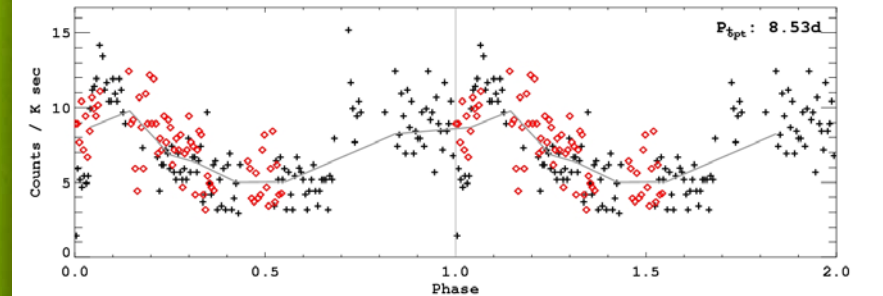
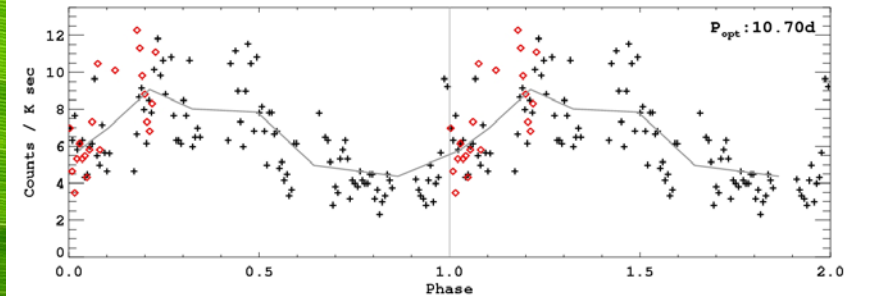
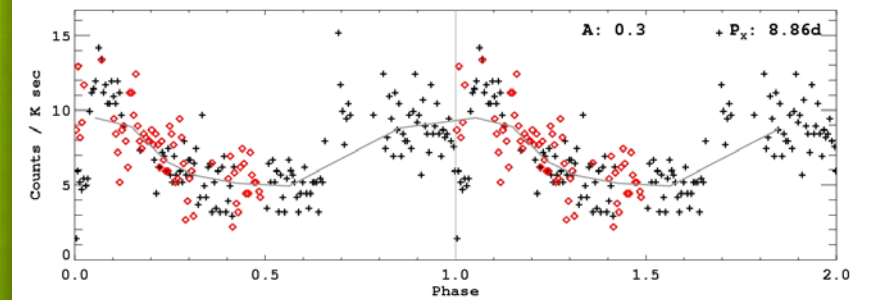
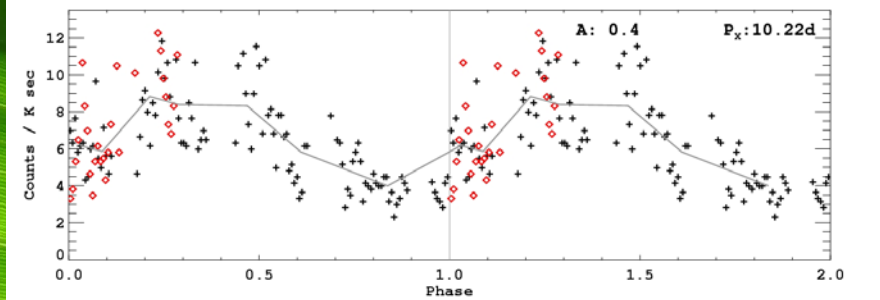
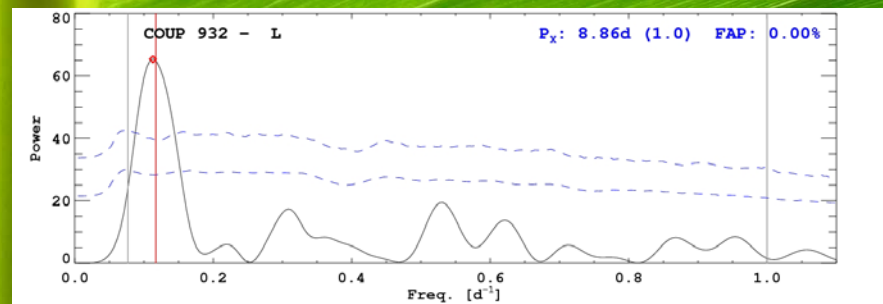
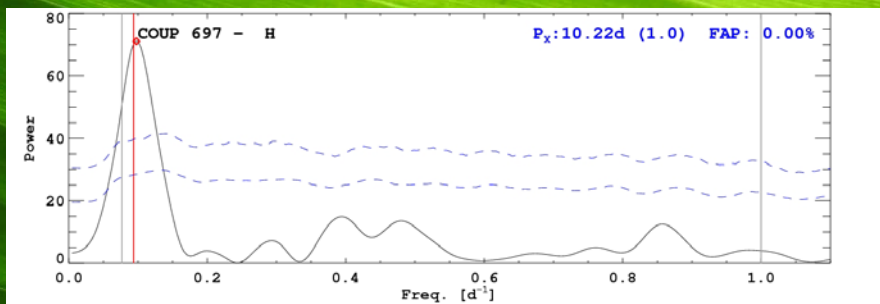
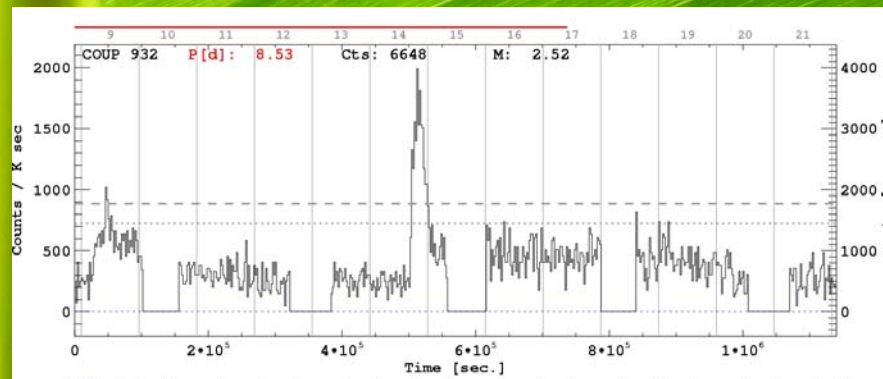
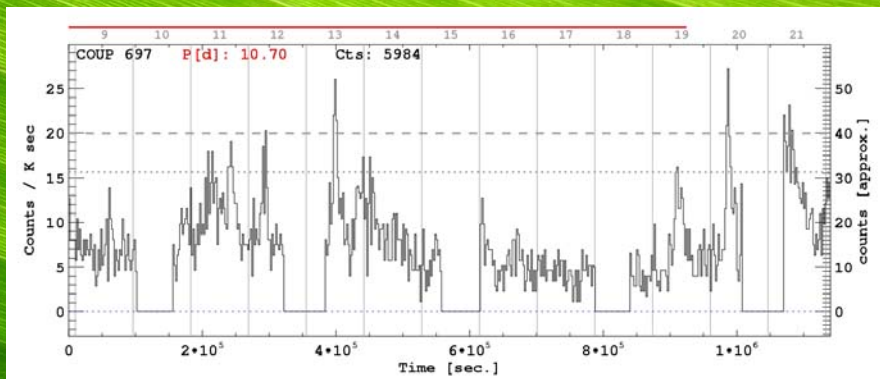
Herbst et al. (2002/2000), Stassun et al. (2000), Carpenter et al. (2002)

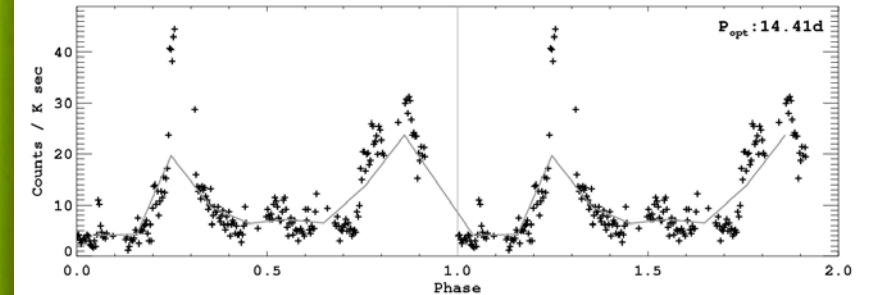
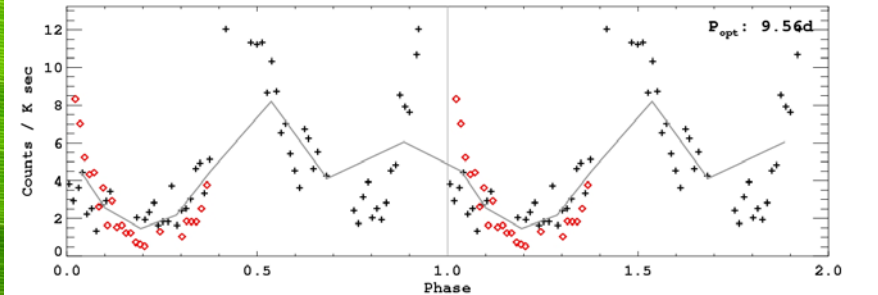
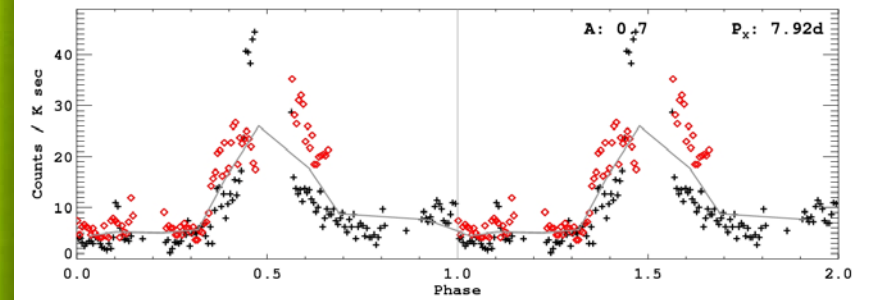
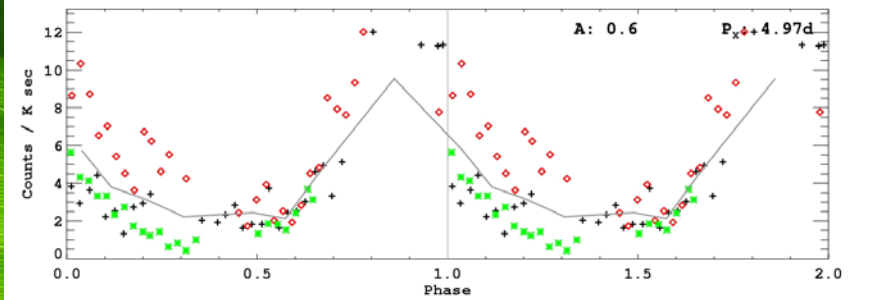
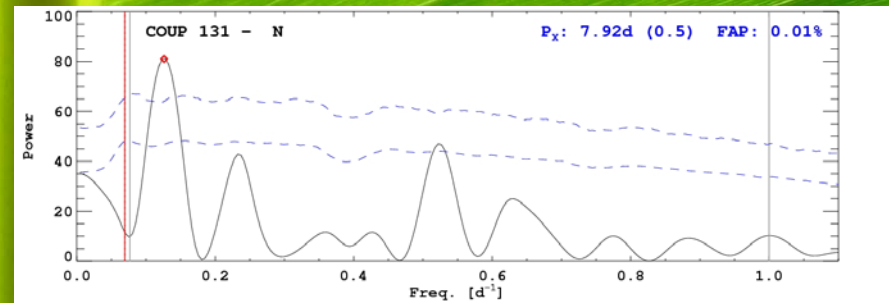
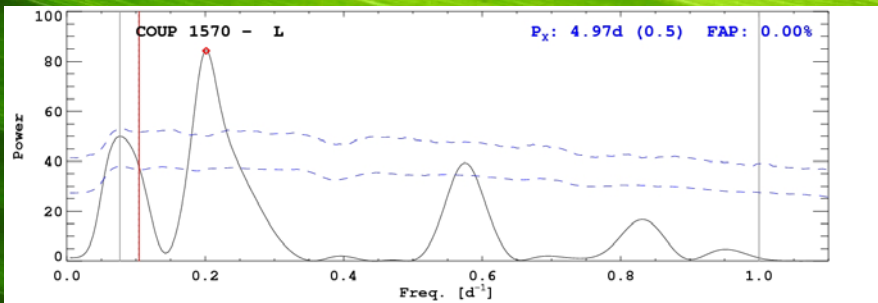
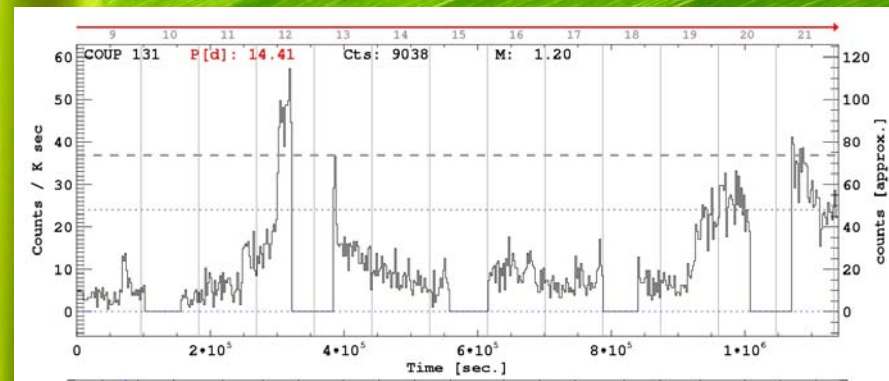
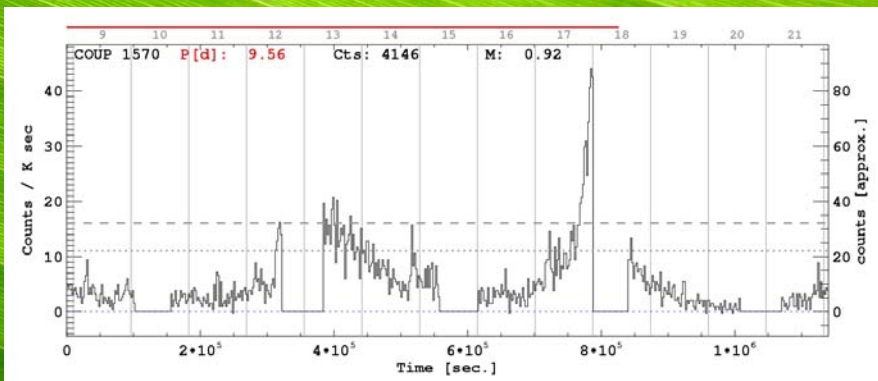
➤ $P_{\text{opt}} > 2$ days

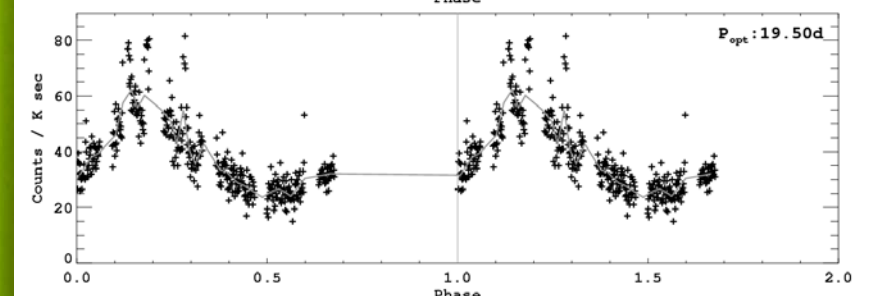
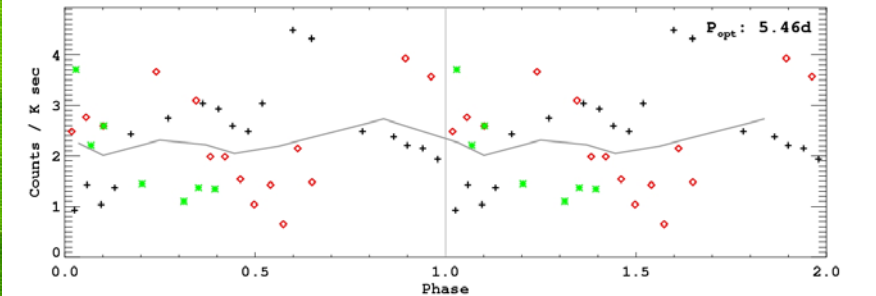
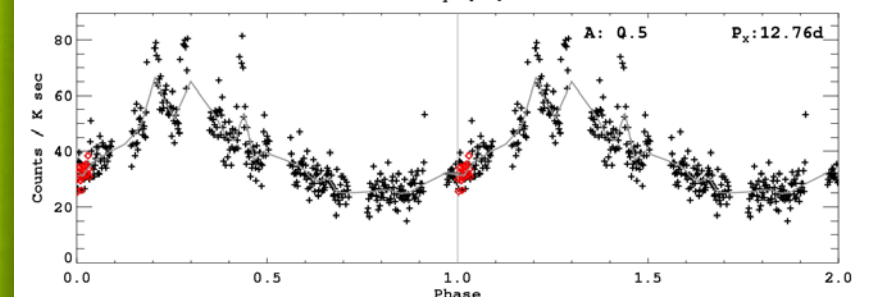
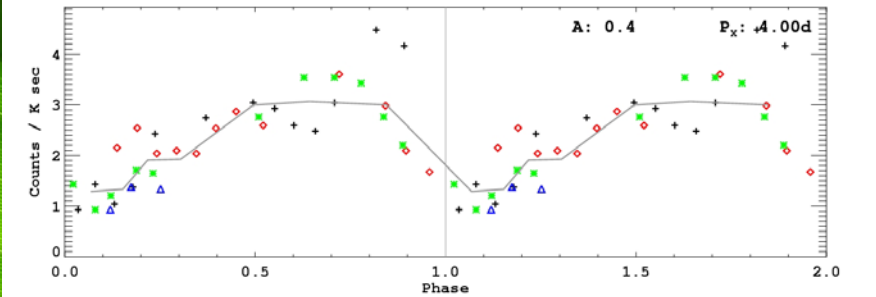
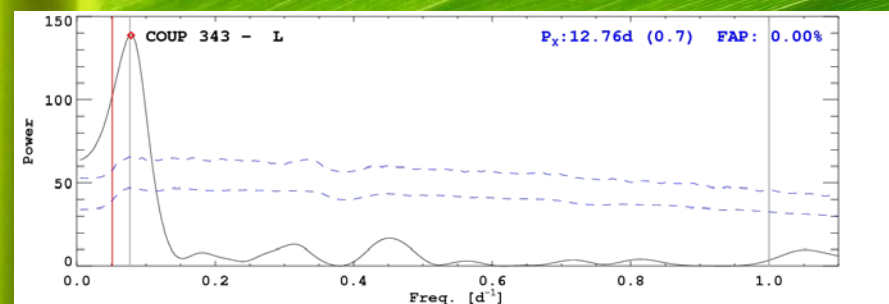
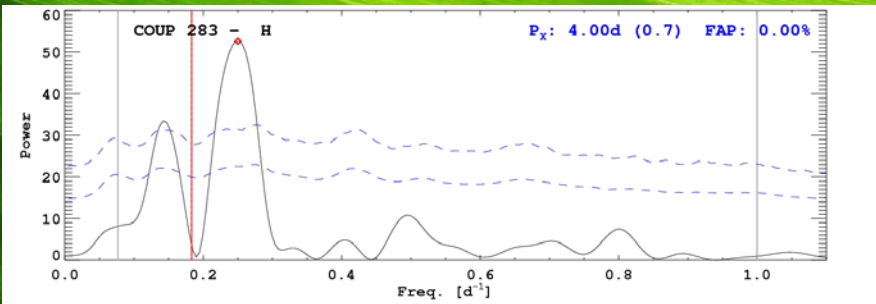
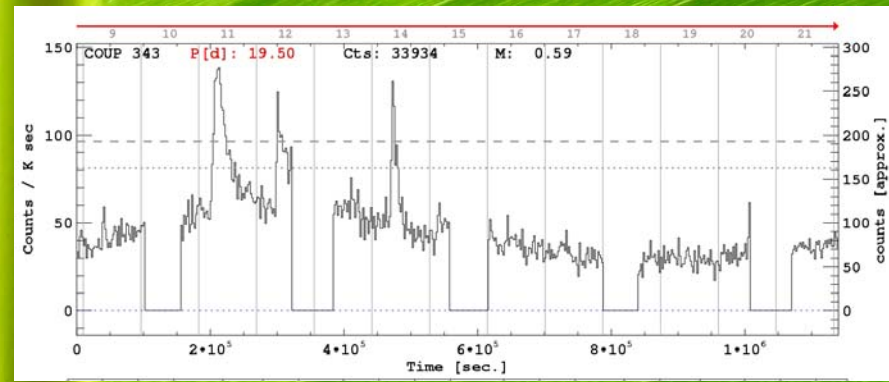
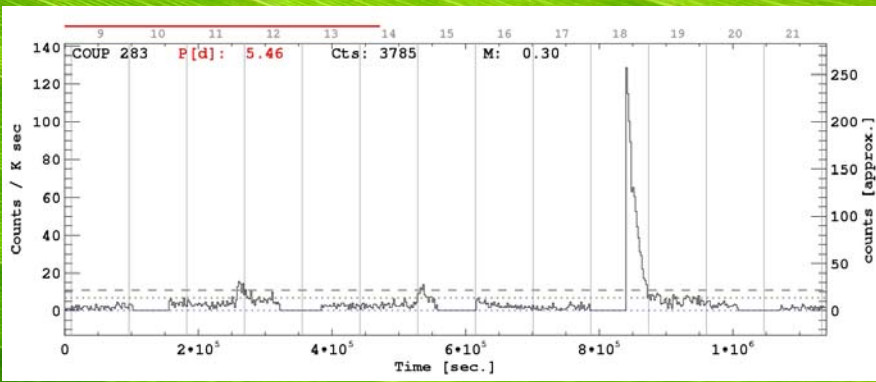
➤ More than 100 detected X-ray photons



Results



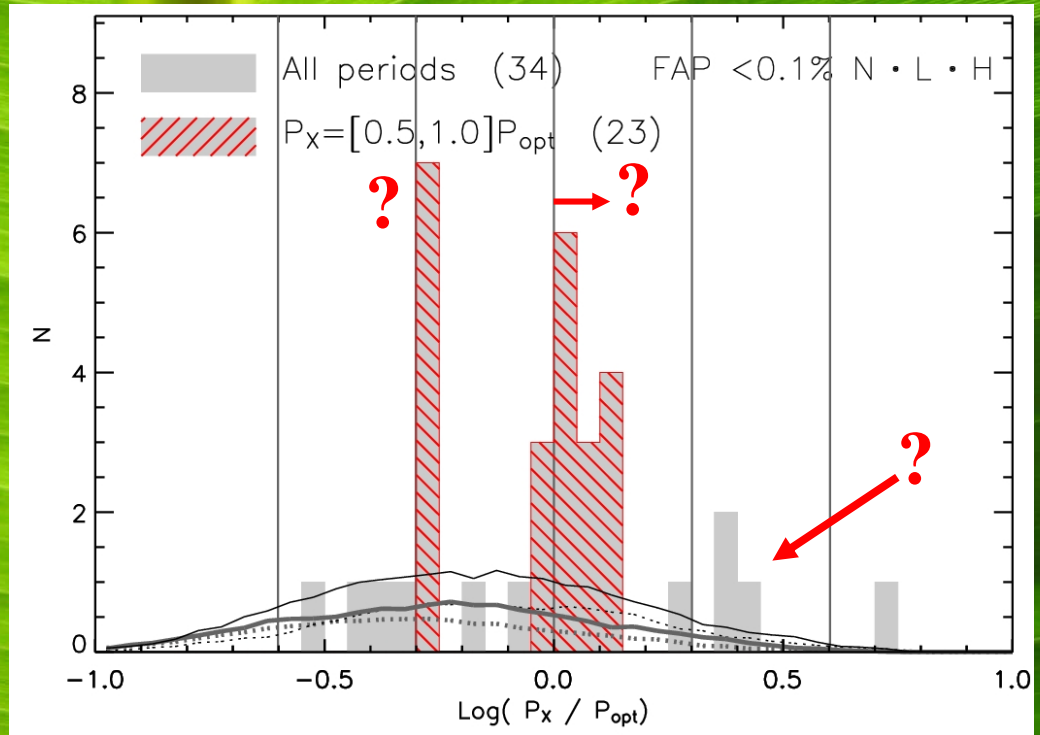
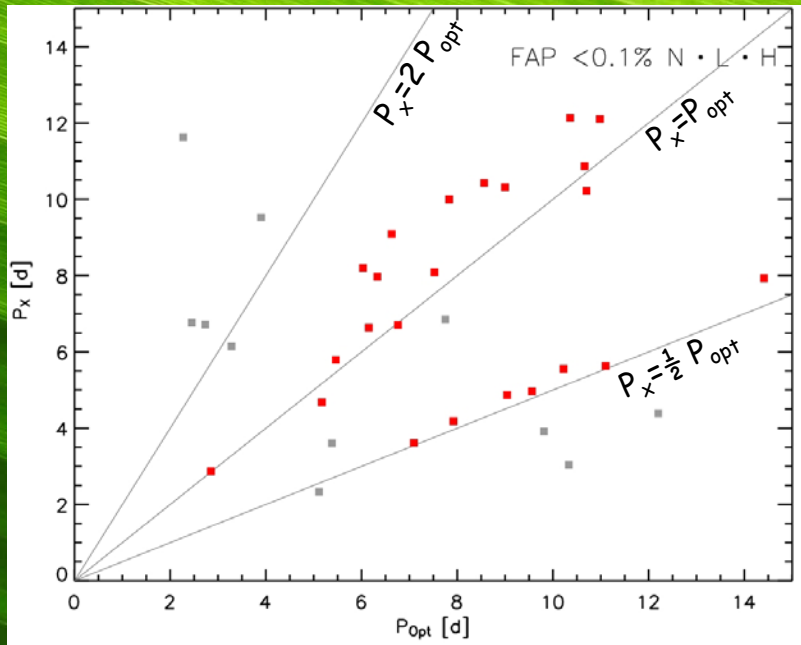






How about the whole
sample?

P_x (FAP < 0.1%) vs. P_{opt}



Simulations of light curves with flares

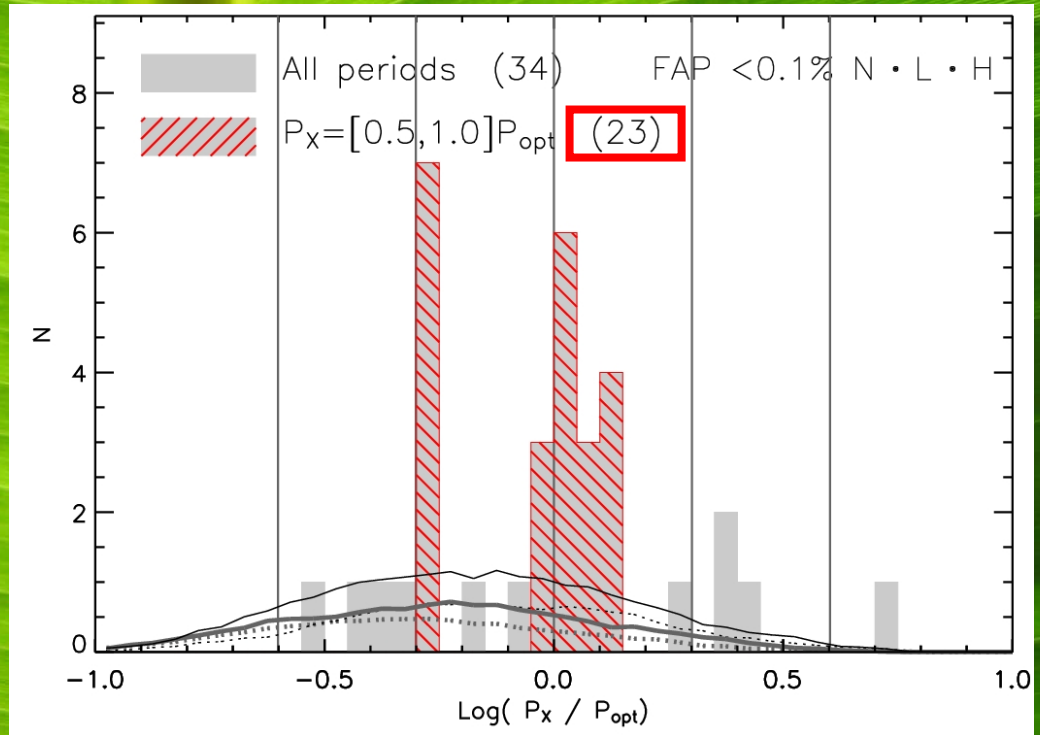
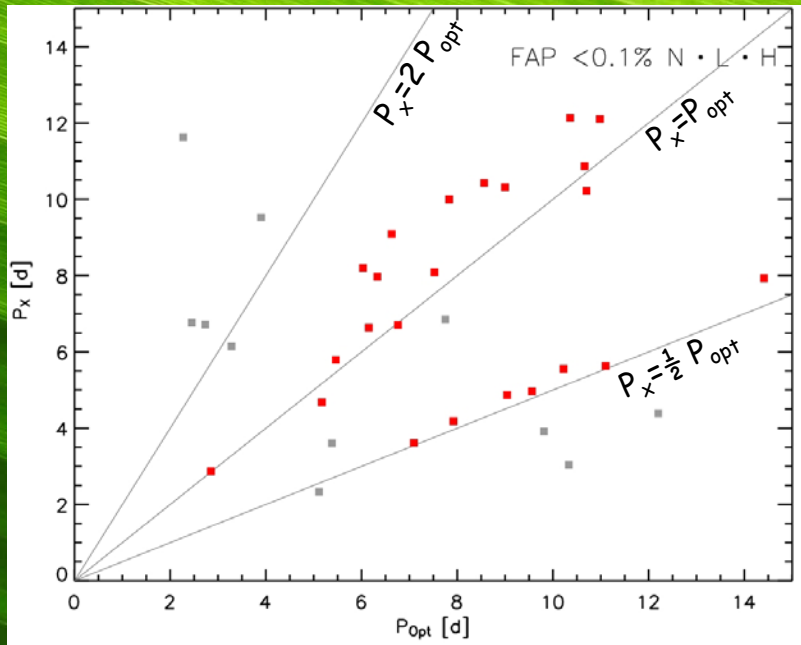
Flares + Modulation

- Single peak at $P_X = P_{\text{opt}}$, with width similar to observed width
- $P_X > P_{\text{opt}}$ *not observed*
- $P_X = \frac{1}{2} P_{\text{opt}}$ *not observed*

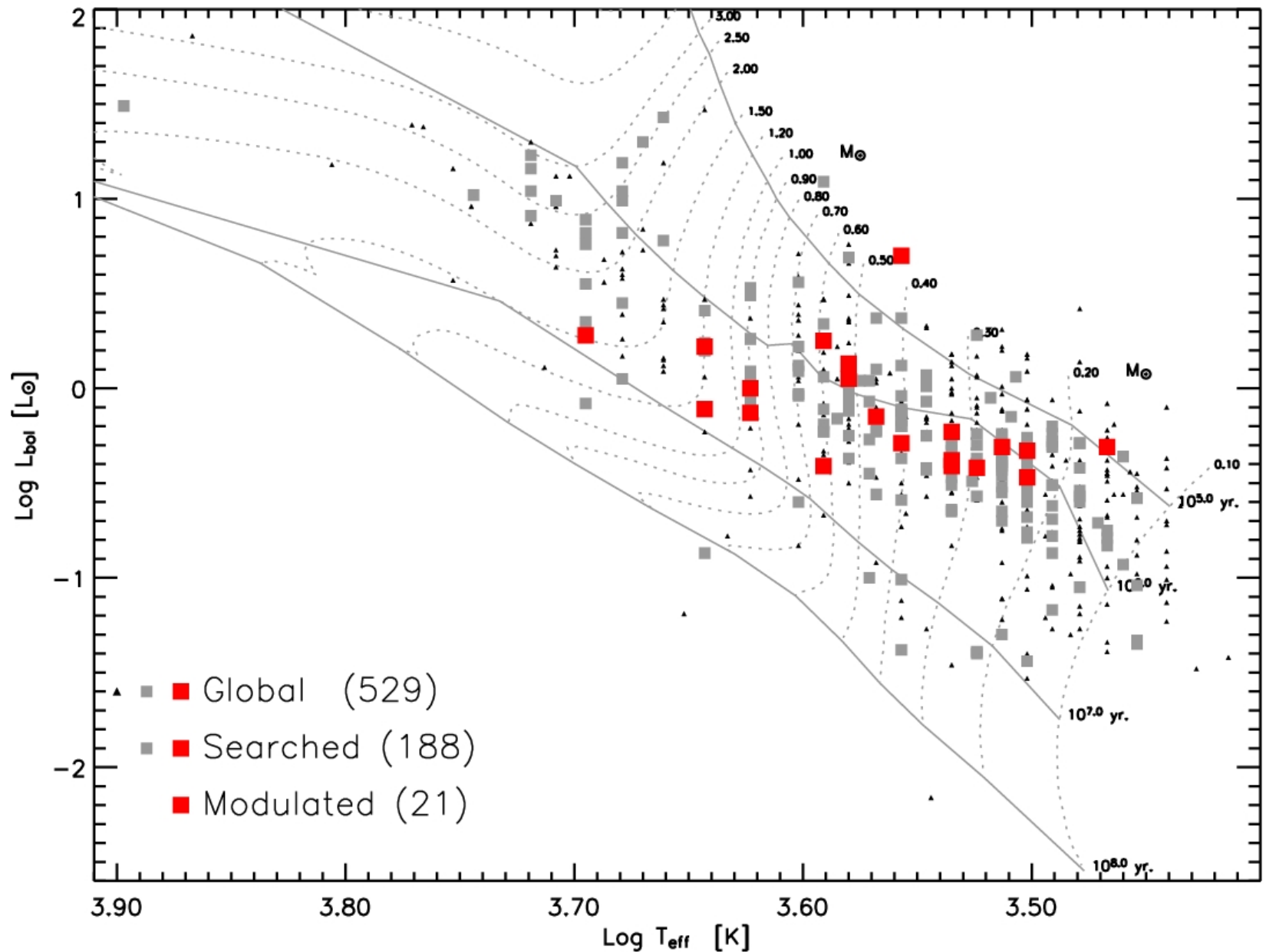
No modulation (just flares)

- Spurious periods are detected:
 - Flares can account for most of the X-ray periods that fall outside the peaks, *i.e. they are likely spurious*

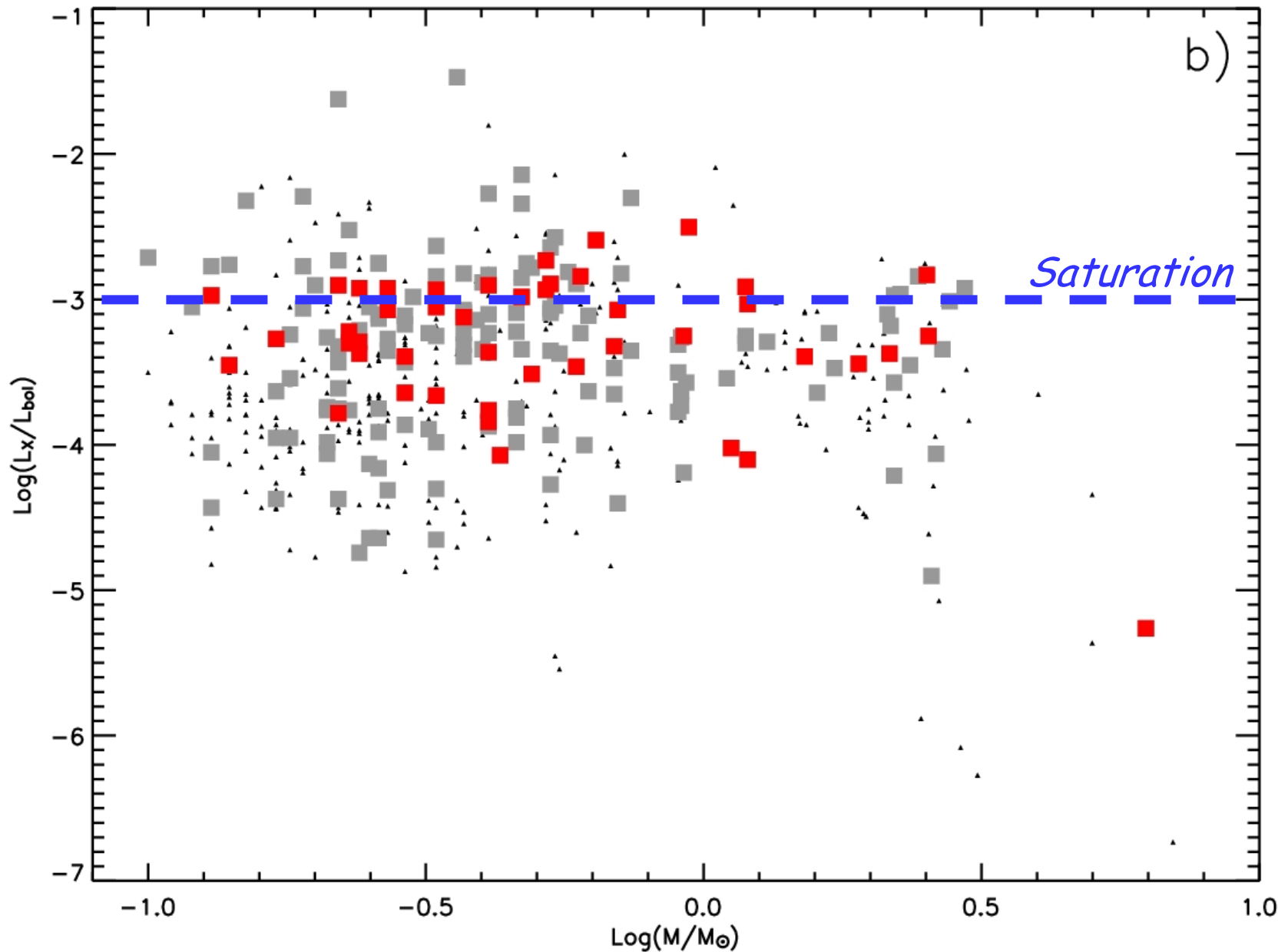
P_x (FAP < 0.1%) vs. P_{opt}



Which stars are modulated? (1)



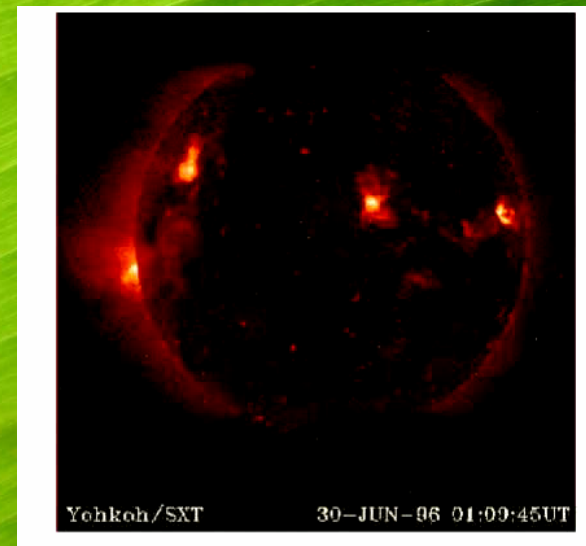
Which stars are modulated? (2)



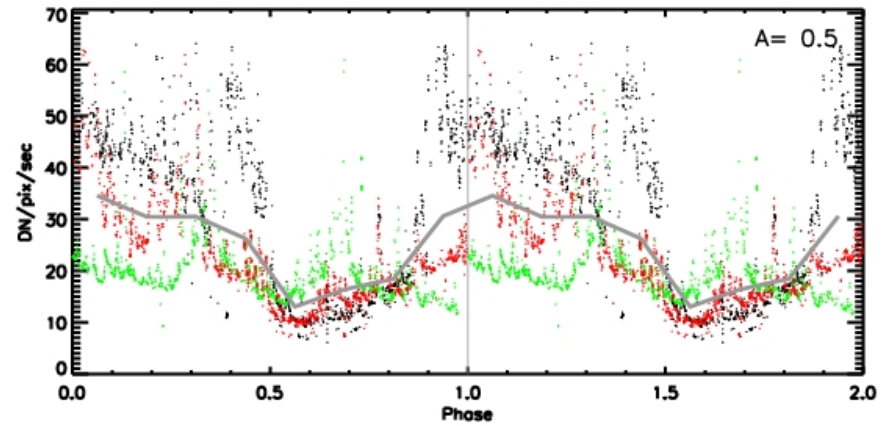
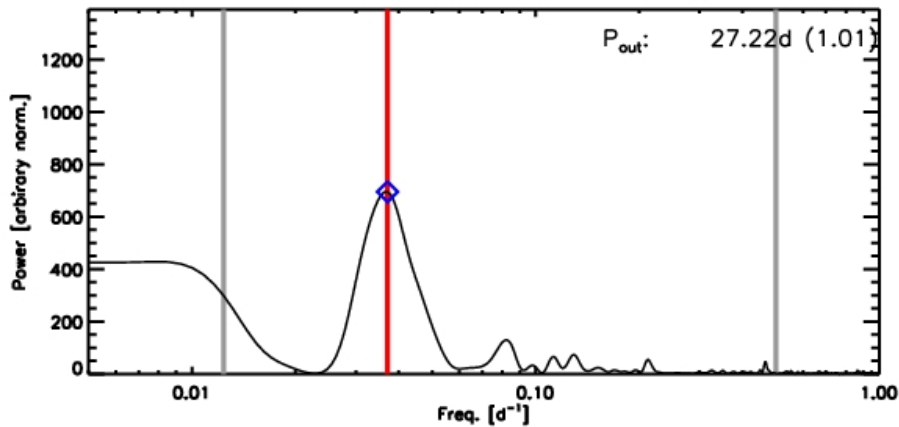
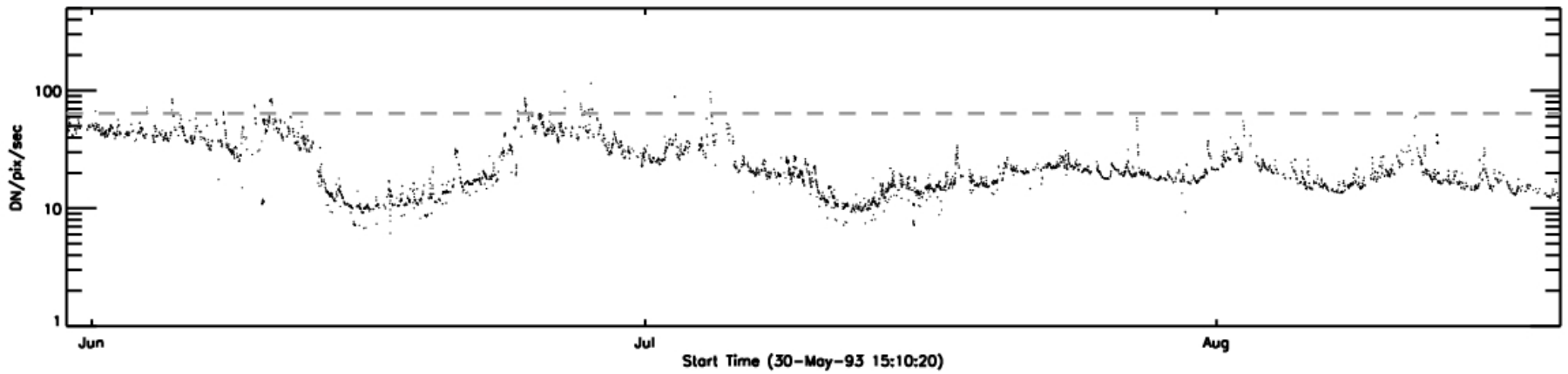
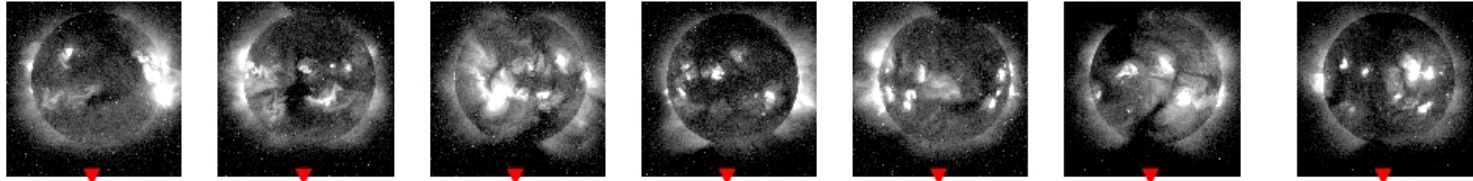
What can we infer on PMS stars?

- X-ray emitting regions are not homogeneously distributed in longitude
 - Amplitudes: 20-70% → factor 2-5 contrast between emispheres
- Dominant X-ray emitting structures must be compact ($< R_*$)
- Modulation is detected in saturated stars (i.e. $L_X / L_{bol} \sim 10^{-3}$).
 - Saturated stars not homogeneously covered with active regions.

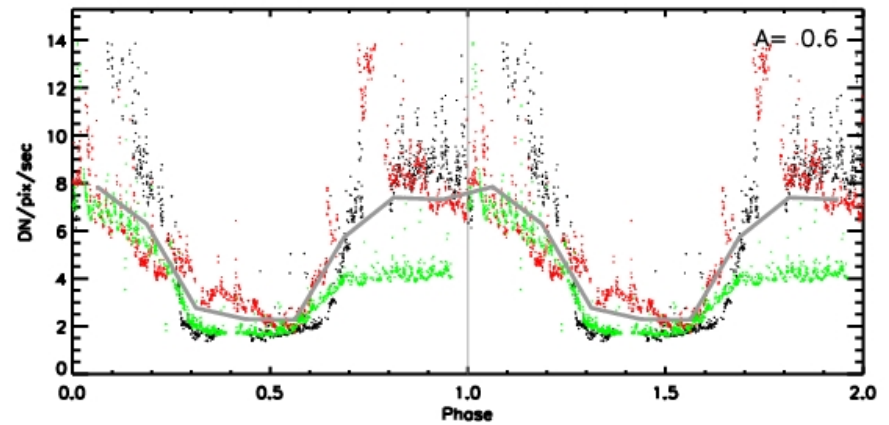
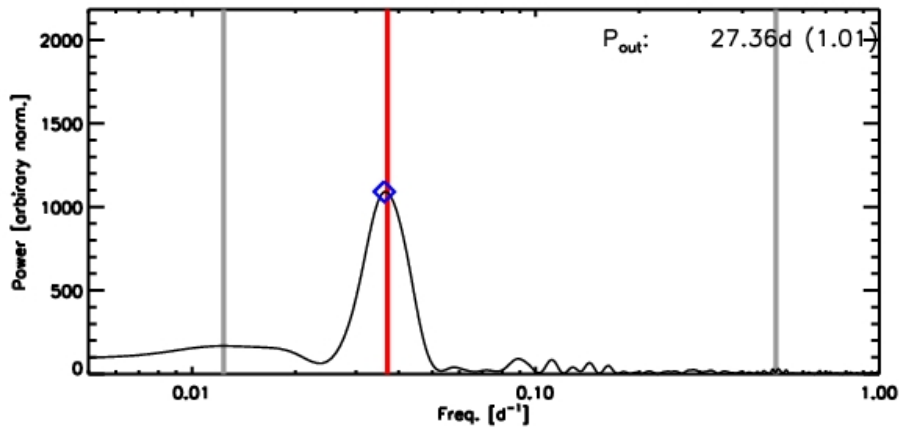
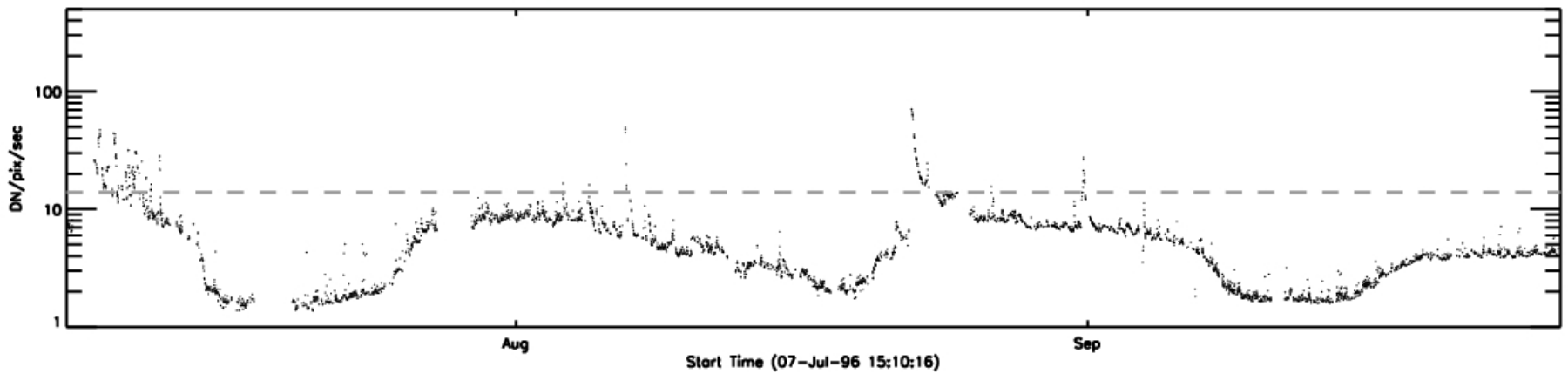
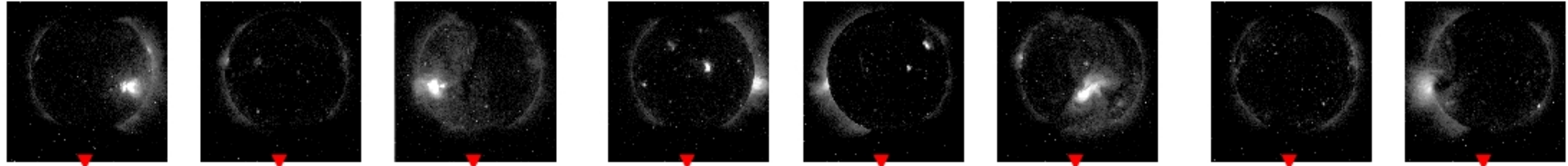
What do they look like ?



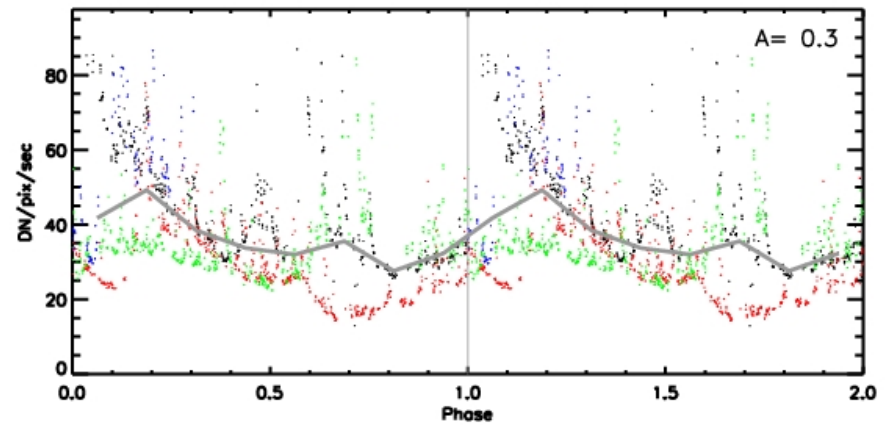
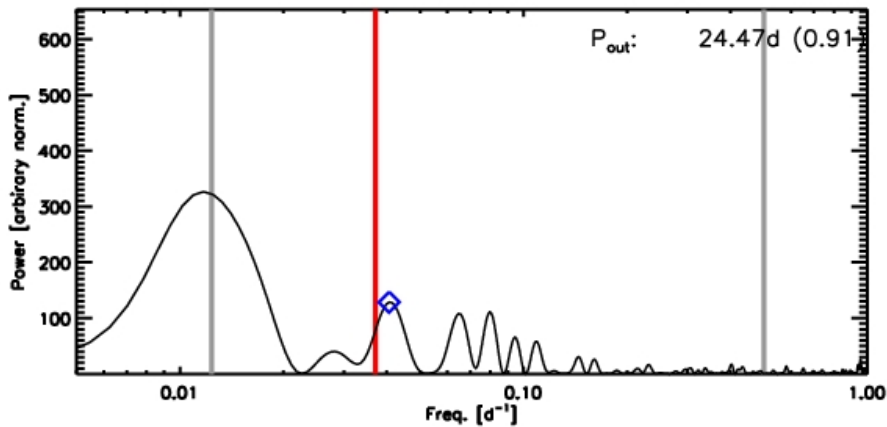
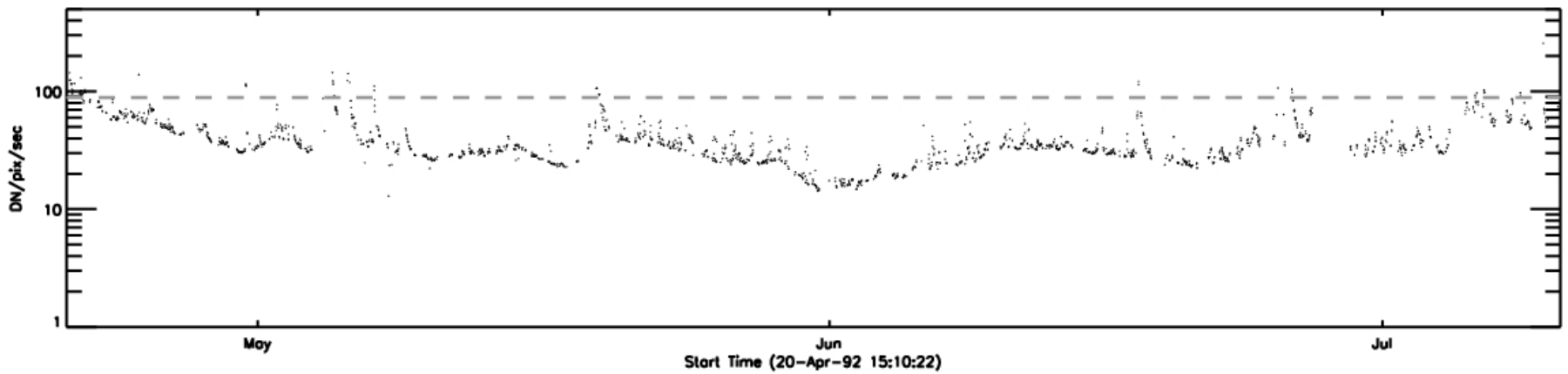
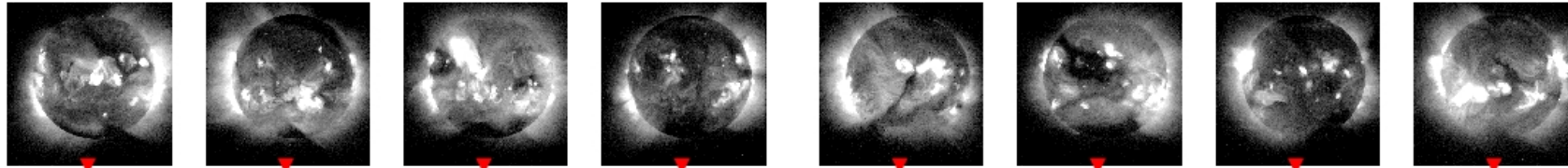
YOHKOH SXT lightcurves -1



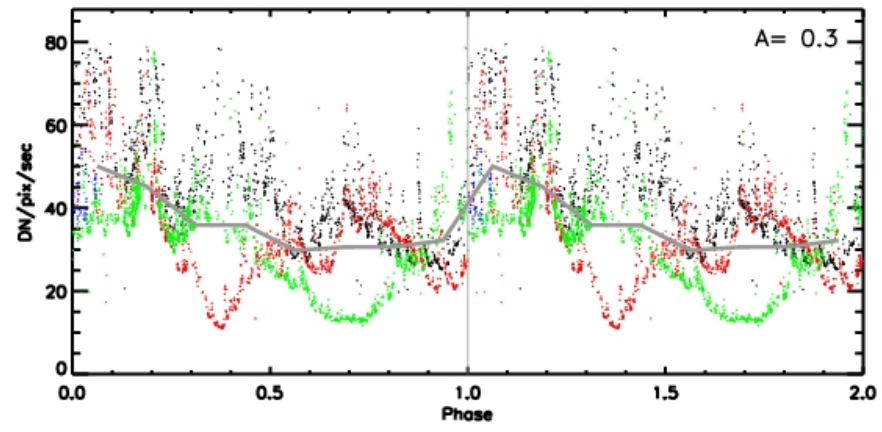
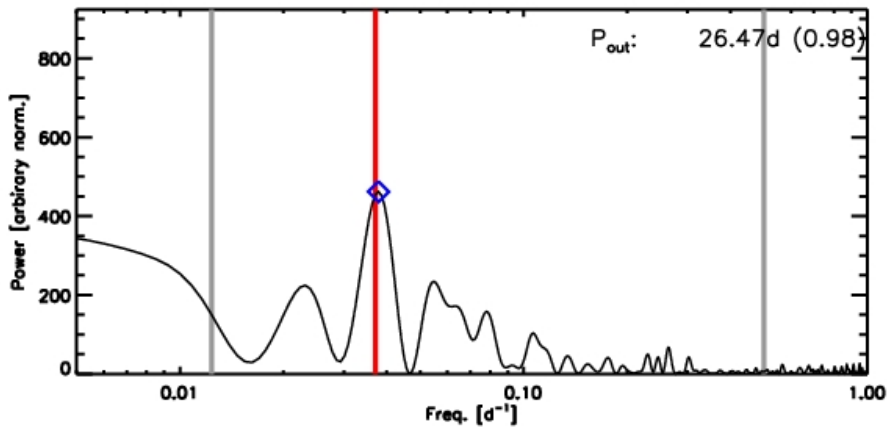
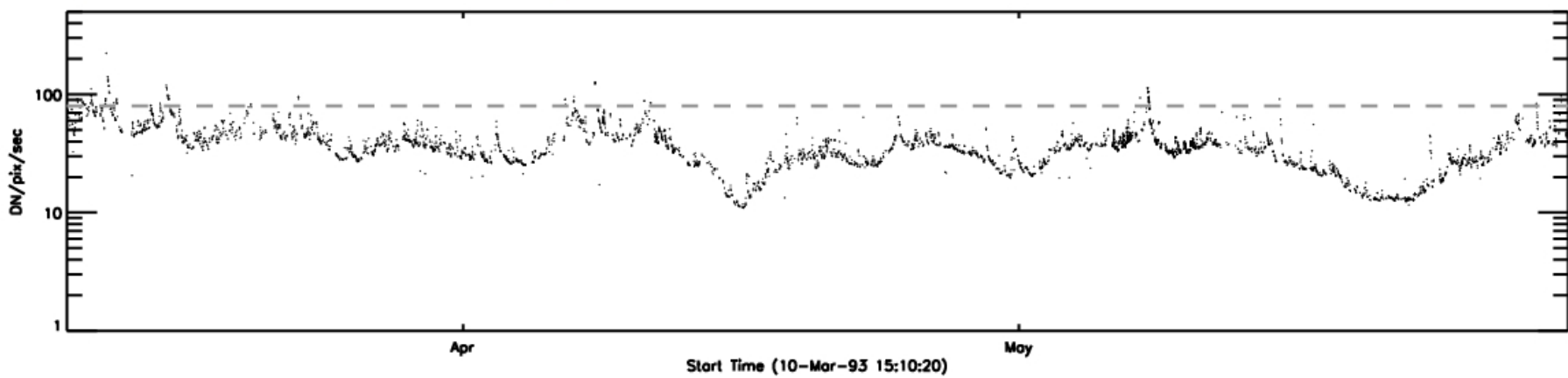
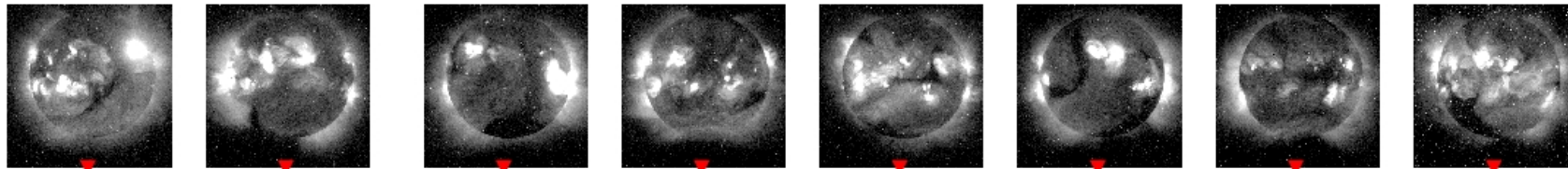
YOHKOH SXT lightcurves -2



YOHKOH SXT lightcurves -3



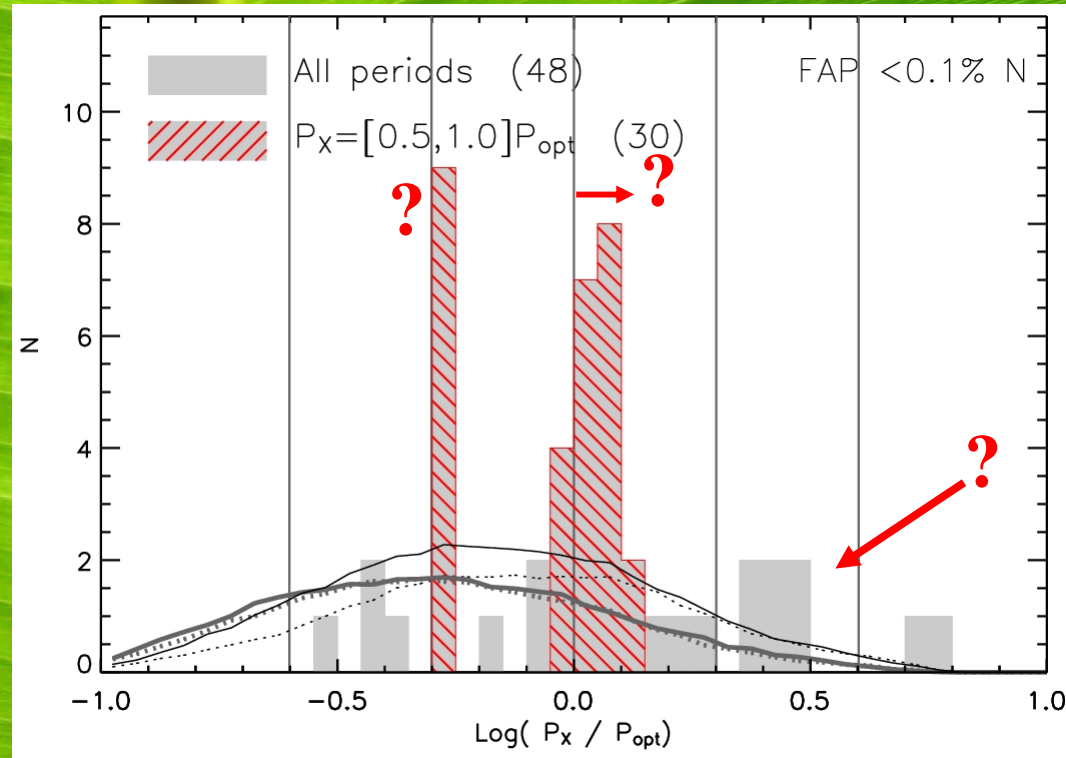
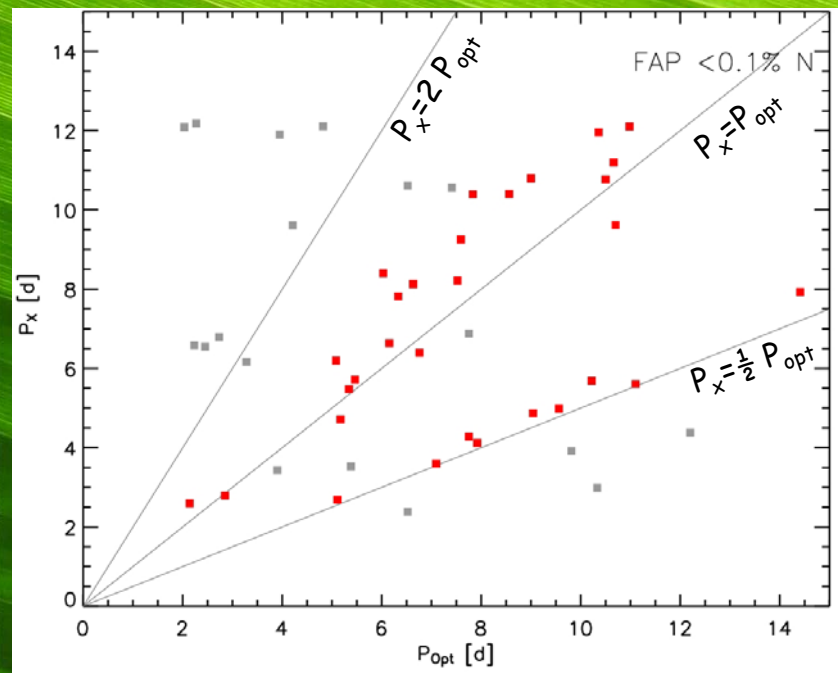
YOHKOH SXT lightcurves -4



Summary & Conclusions

- Rotational modulation of X-ray emission **detected** in > 23 stars (10% of the sample), a huge increase with respect to previous works. Relative amplitudes are 20-70%.
- A significant fraction of the X-ray periods we find are half the optical periods
- X-ray emitting regions are not homogeneously distributed in longitude
- *Dominant* X-ray emitting structures must be compact ($< R_*$)
- Modulation is detected in saturated stars (i.e. $L_X / L_{\text{bol}} \sim 10^{-3}$).
 - Saturated stars not homogeneously covered with active regions.

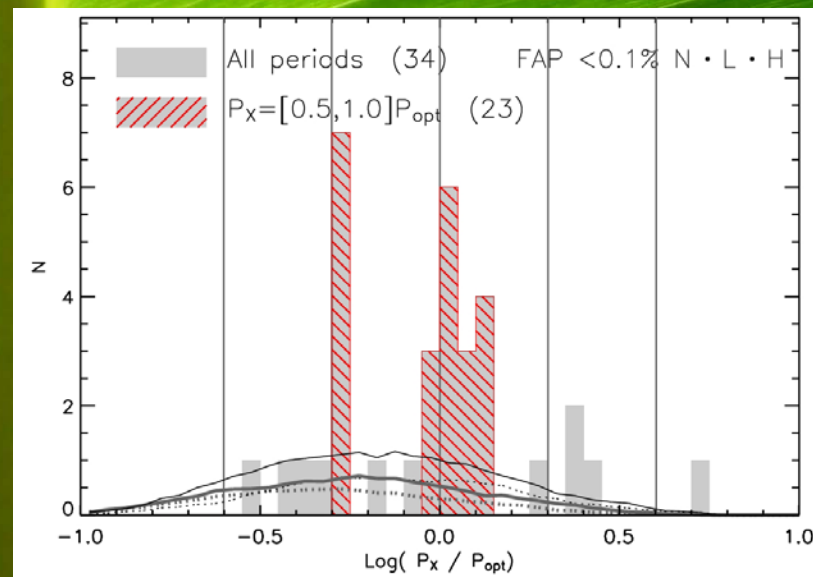
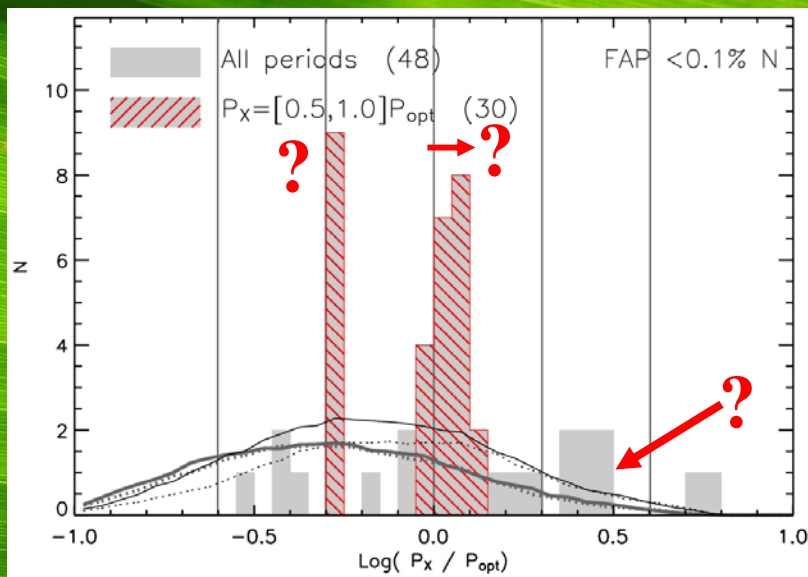
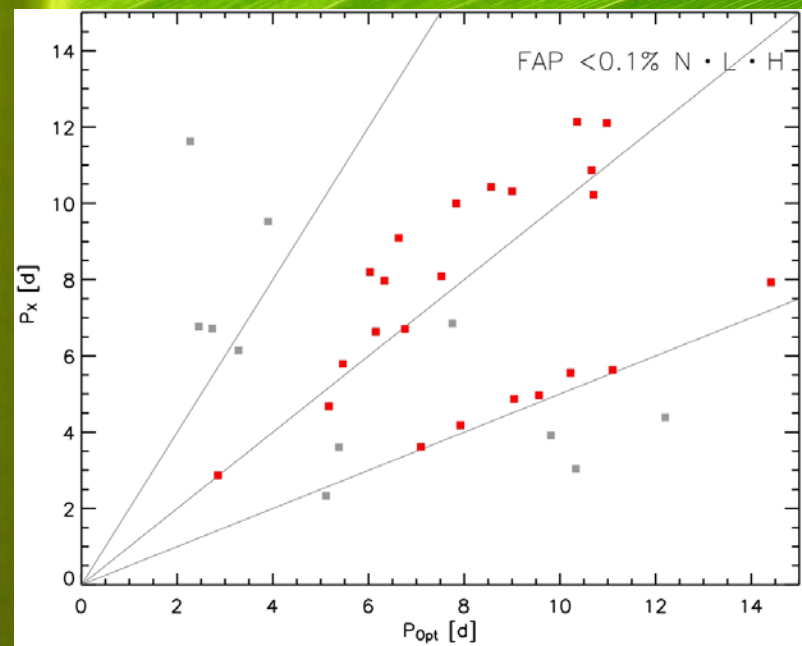
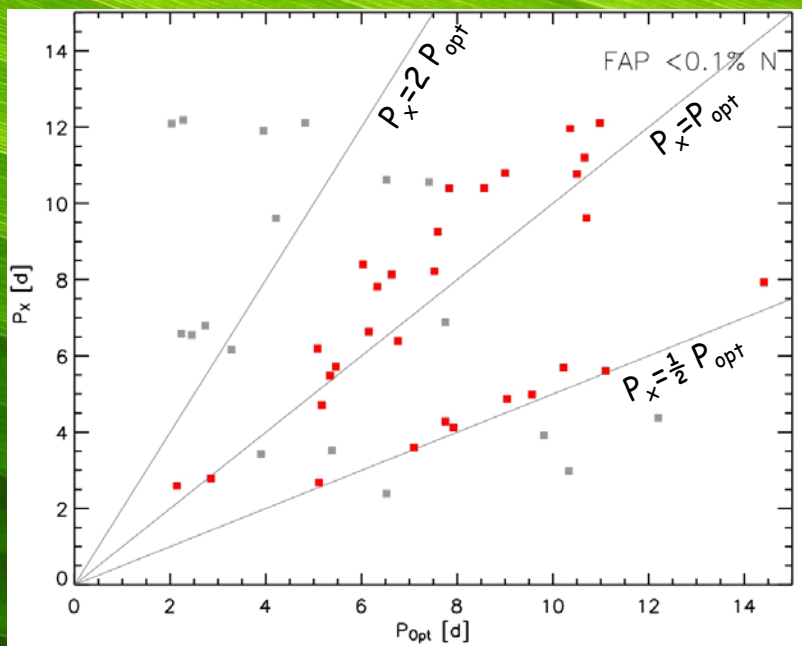
P_x (FAP < 0.1%) vs. P_{opt}



No filter

P_x (FAP < 0.1%) vs. P_{opt}

ALL filter



No filter

P_x (FAP < 0.1%) vs. P_{opt}

ALL filter

