X-ray Quasi-periodic Pulsations in Solar Flares as Magnetohydrodynamic Oscillations

Claire Foullon

The University of Warwick

In collaboration with:

E. Verwichte, V. M. Nakariakov (Univ. Warwick, UK)

L. Fletcher (Univ. Glasgow, UK)

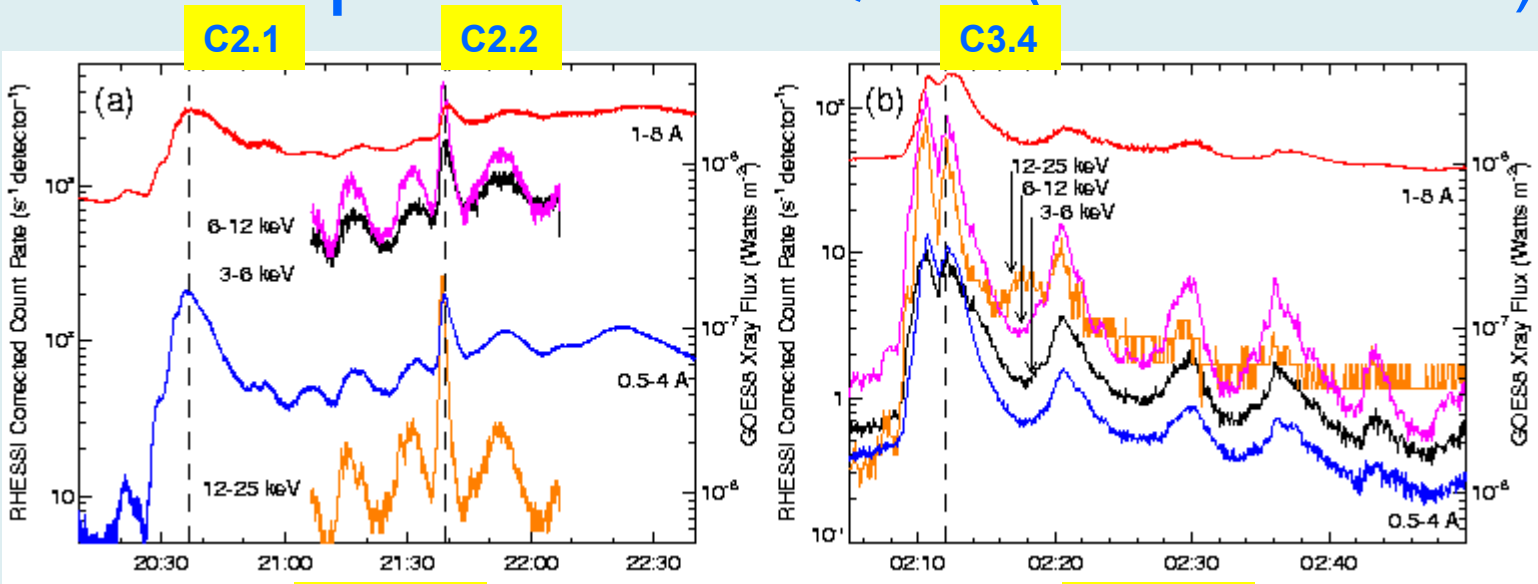
Introduction

Quasi-periodic pulsations (QPP)

- Known since the early 1970s.
- Periods: fractions of sec. - several min.
- Similar phenomena in stellar flares.
- HXIS/SMM (in the 80s) 3.5-5.5 keV images → Long periods (12-29 min) at the foot, or below, large-scale coronal loops.
- SUMER/SOHO: Doppler shifts (7-31 min).
- RHESSI: new observational level.

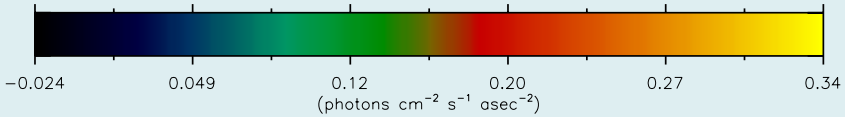
Observations

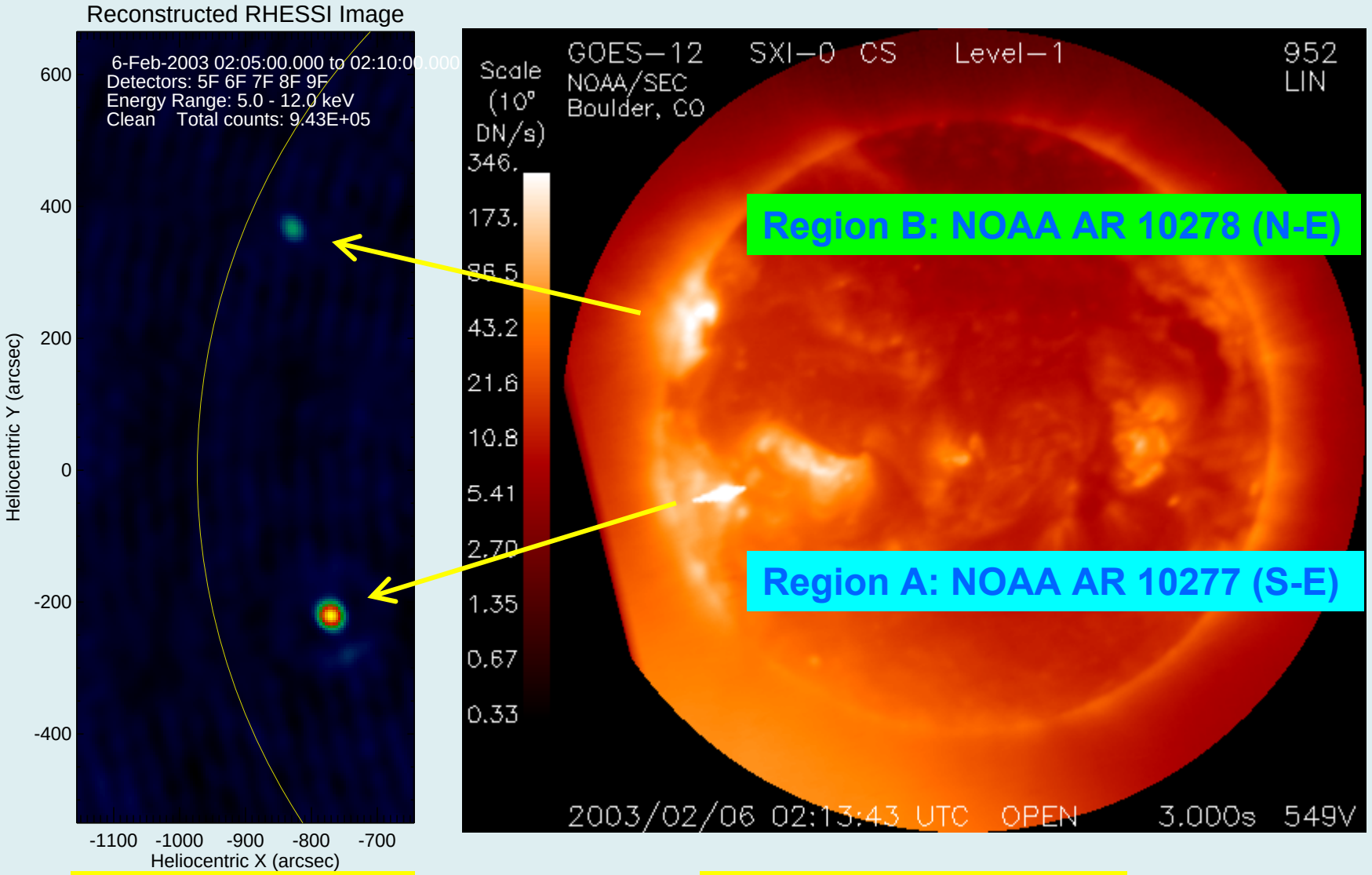
- Two sequences of QPP (Feb. 5-6 2003)



- **Full disk measurements in X-rays: GOES-8 & RHESSI**
- **Energies: 3-25keV, large amplitude, periods: 8-12 min.**

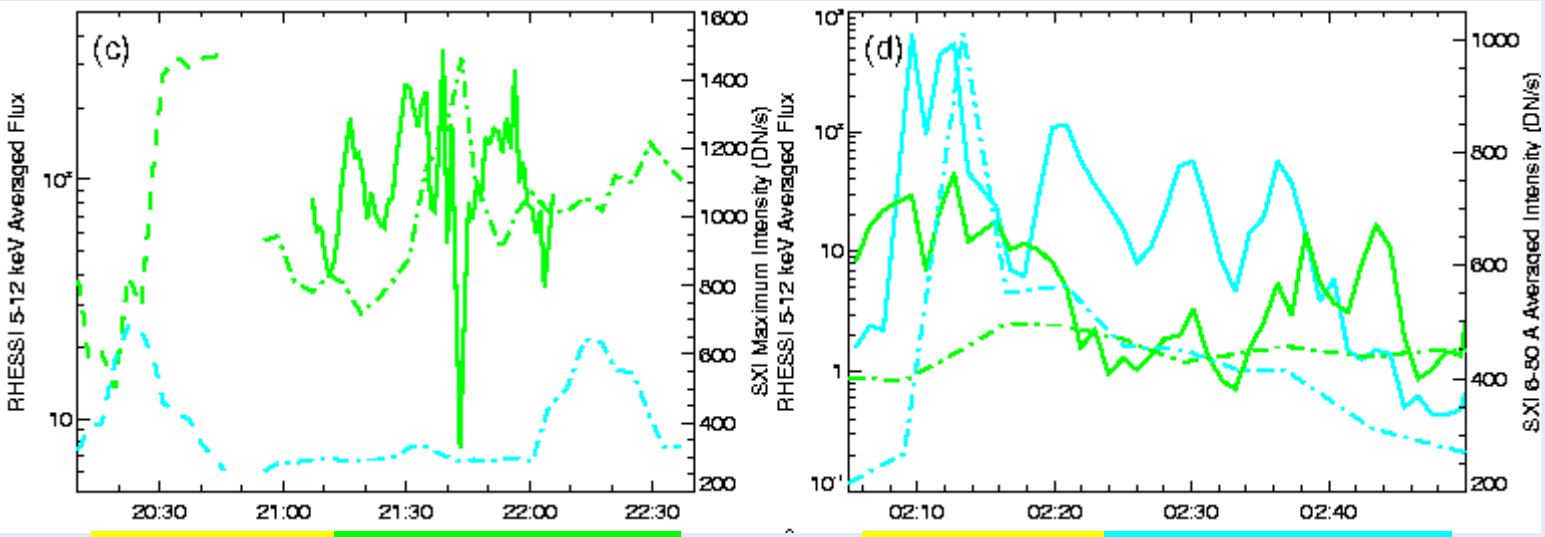
• Two active sources





Observations

- Each QPP from one single site



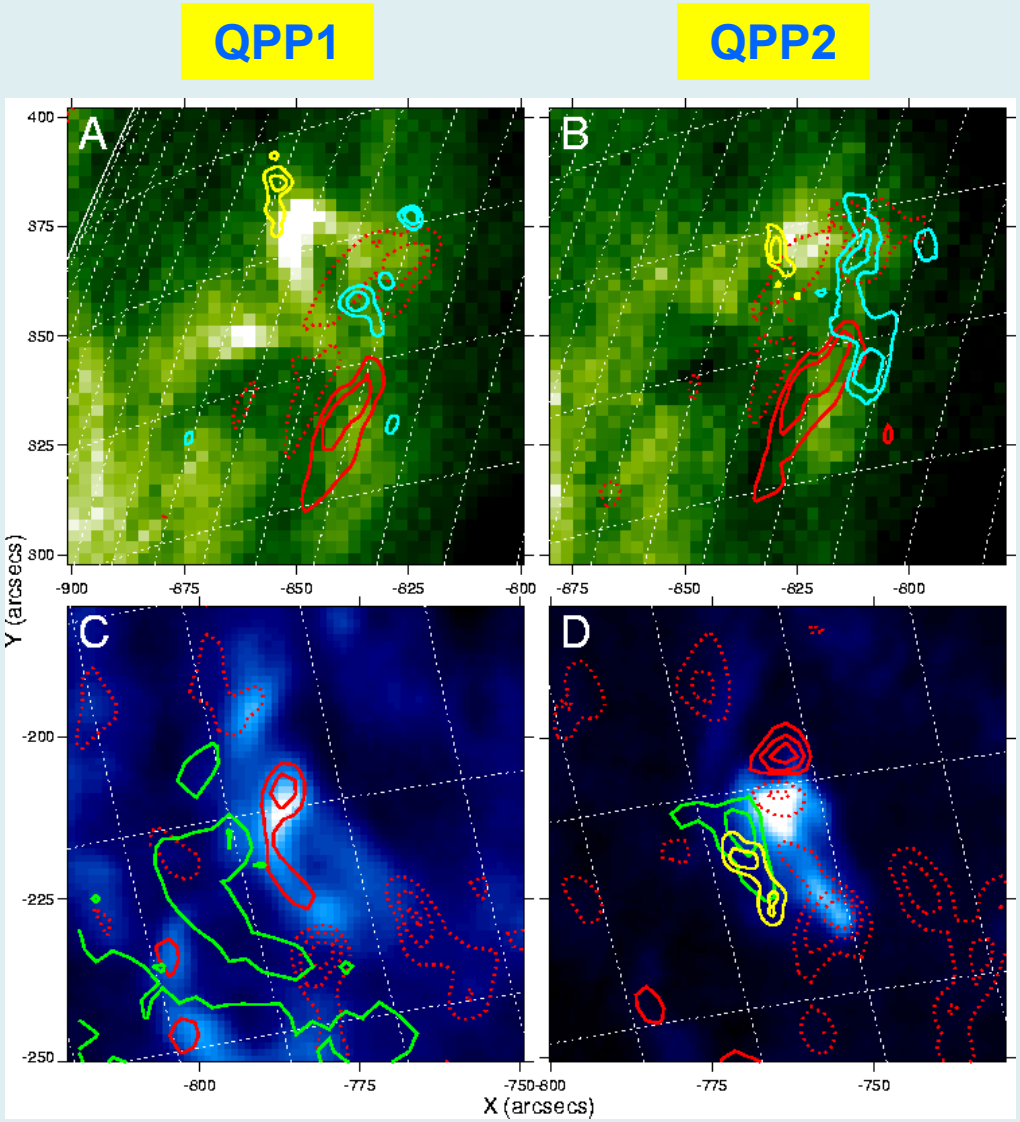
- **Imaging data averaged in region A and region B.**
- **Poor correlation between the two regions, but sympathetic activity.**

— RHESSI 5-12 keV

· – · SXI 6-80Å

- - SXI 6-60Å

• Top of small flaring loop



- **Coalignments of images**

RHESSI 5-12 keV

EIT 195 Å **loop body**

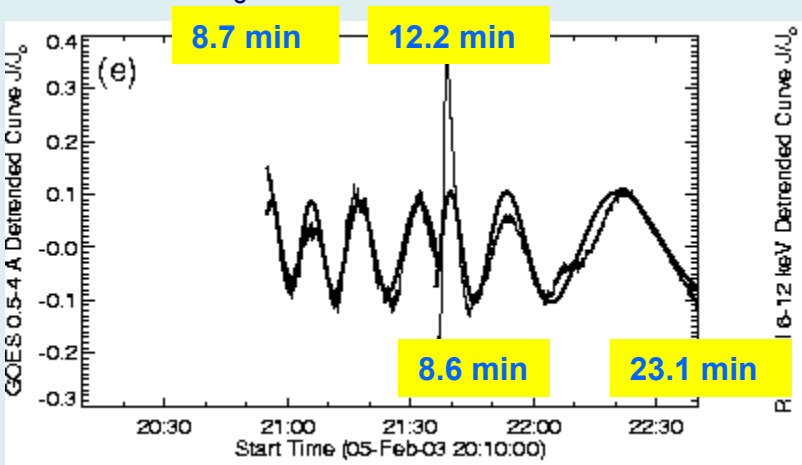
H-alpha **MDI** **footpoint locations**

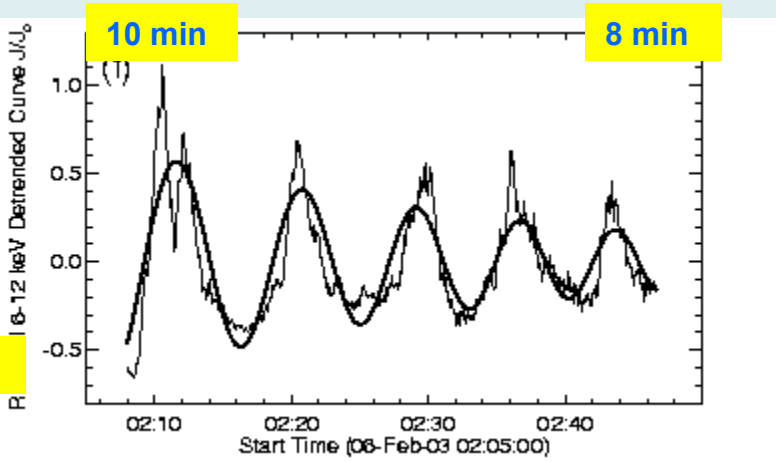
- **Consistent with thermal interpretation ($I(t) \sim n_e^2$).**

Observations

- Similar periodicities (8-12 min)
  - **Define time series J(t)= =√I(t).**
  - **Fit a cosine curve F(t) on detrended curves J/J_0.**

$$F(t) = A\cos\left(\frac{2\pi t}{P_0 + \lambda t} - \varphi\right)\exp\left(-\frac{t}{\tau_d}\right)$$





QPP1

- Monotonic **<u>increase</u>** in P
- No measurable decay ($\tau_d \rightarrow \infty$).

QPP2

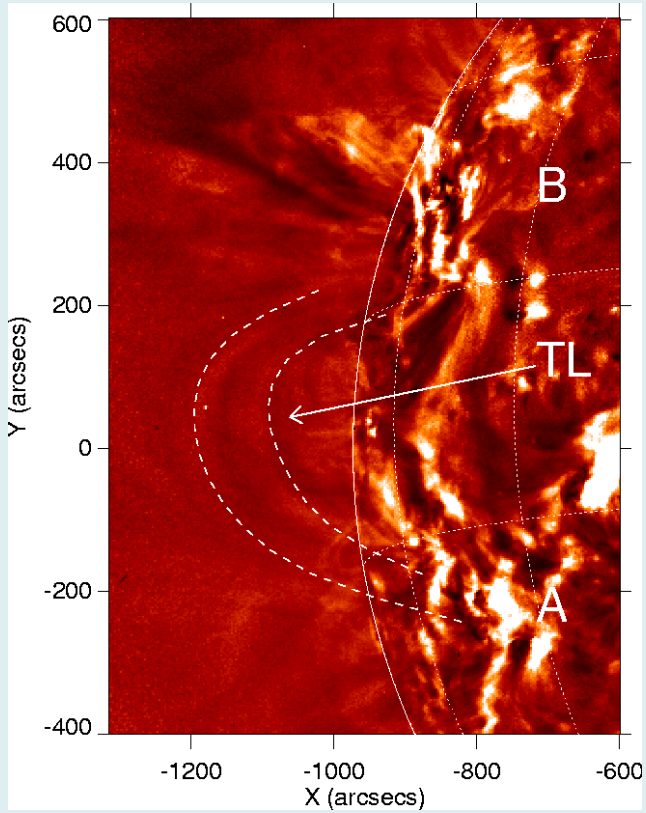
- Monotonic **<u>decrease</u>** in P
- τ_d = 28.4 min~ 2.84 P_0

Discussion

- Possible interpretation: MHD oscillations
  - QPP: periodic pumping, or other energisation, of electrons in the flaring loop, modulated by MHD oscillations (Roberts, Edwin & Benz 1983, 1984).
  - Length-scales of flaring loops too short:
    with L~22 Mm and T~10 MK, largest period sustained (fundamental slow m.a. standing mode) < 100 s
    ($P \approx \alpha L/\sqrt{T}$, with α=13.6, P in s, L in Mm, T in MK).
  - In site A or B, footpoint of a long loop (resonator) is adjacent and may be connected to the smaller flaring loop (external exciter).

Discussion

- Possible MHD resonator: transequatorial loop
  - the **long periods**, explained in terms of MHD oscillation modes of a large-scale loop;
  - the **similarity of periodicities** found at opposite sites;
  - for each QPP, some **aperiodic sympathetic activity** observed in the oppositely located and quieter region;
  - evidence of the **TL in the EUV**.

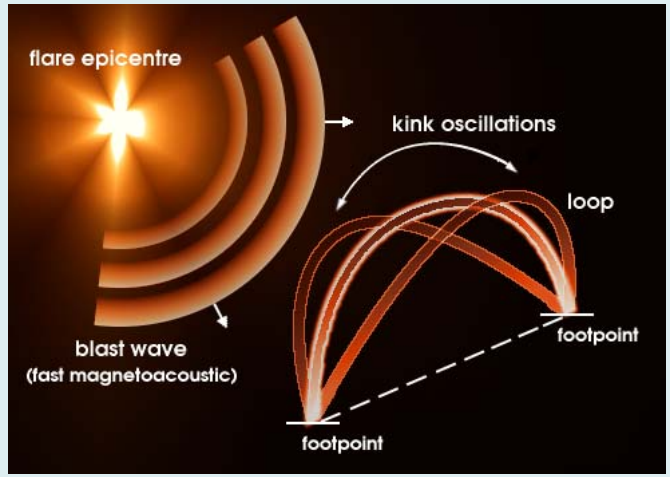


Difference of EIT 195Å images

Discussion

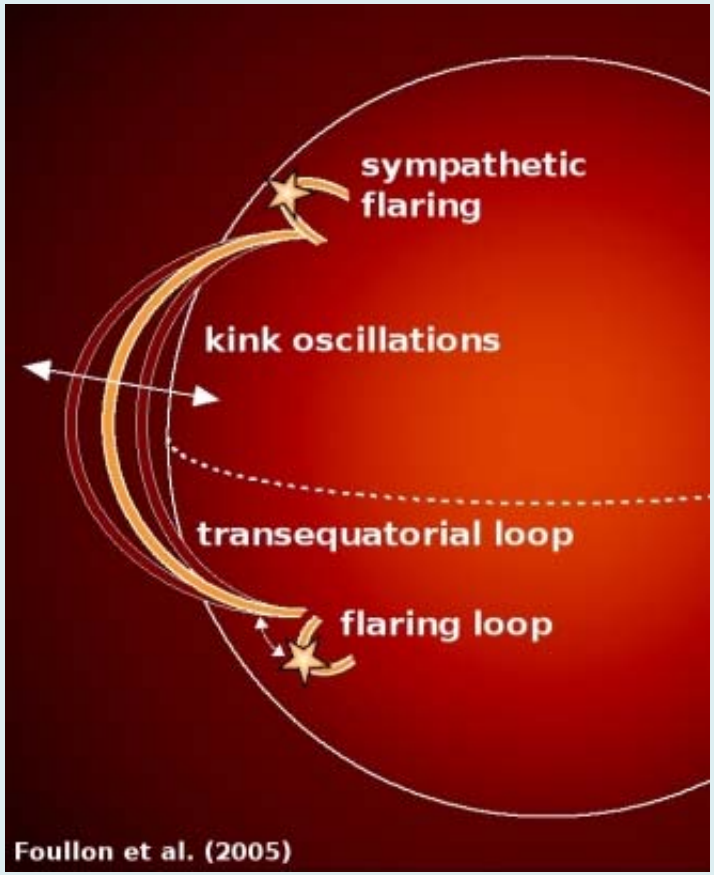
- Most likely candidate: fast m.a. kink mode
  - Consistent with fast magnetoacoustic kink modes observed by TRACE:

    ▪ **Phase speed** V~1400-2500 km/s (V=2L/P, with L~ 500-600 Mm and P~8-12 min)
    ▪ **Weak damping**
    ▪ **Response to a dynamic event** (flare, filament eruption and CME).



Discussion

- Most likely candidate: fast m.a. kink mode



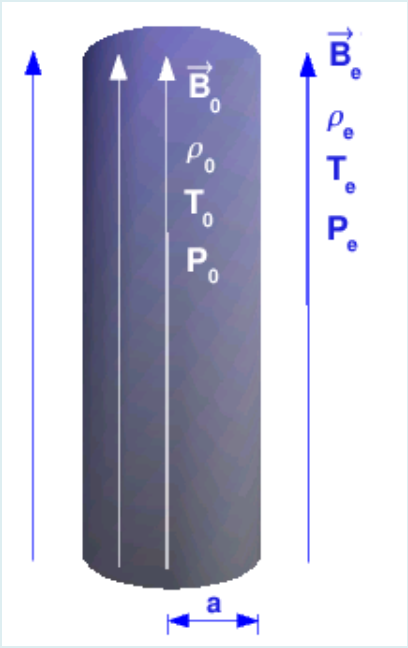
• Perturbs the field lines in the transverse direction

→ may compress the field lines of the flaring loop

→ modulating the particle acceleration process (e.g. magnetic pumping, Brown & Hoyng 1975).

Discussion

- Most likely candidate: fast m.a. kink mode



$$P \sim \frac{2L}{C_k} \sim \frac{\sqrt{2(\rho_0 + \rho_e)\mu_0}}{B_0} L$$

- Monotonic change of the periods accounted for by changes in the coronal environment (B_0, ρ, L)

→ any of these changes associated with large-scale coronal eruption are plausible.

Discussion

- Other possibility: slow standing mode?
  - TL would need to have an unrealistic temperature
  - Possible resonator: medium-size loop (one for each sequence and region).
  - Longitudinal mode → not clear how it could modulate the emission of the smaller flaring loop.
  - Spectroscopic or high-cadence EUV imaging necessary.

Conclusions

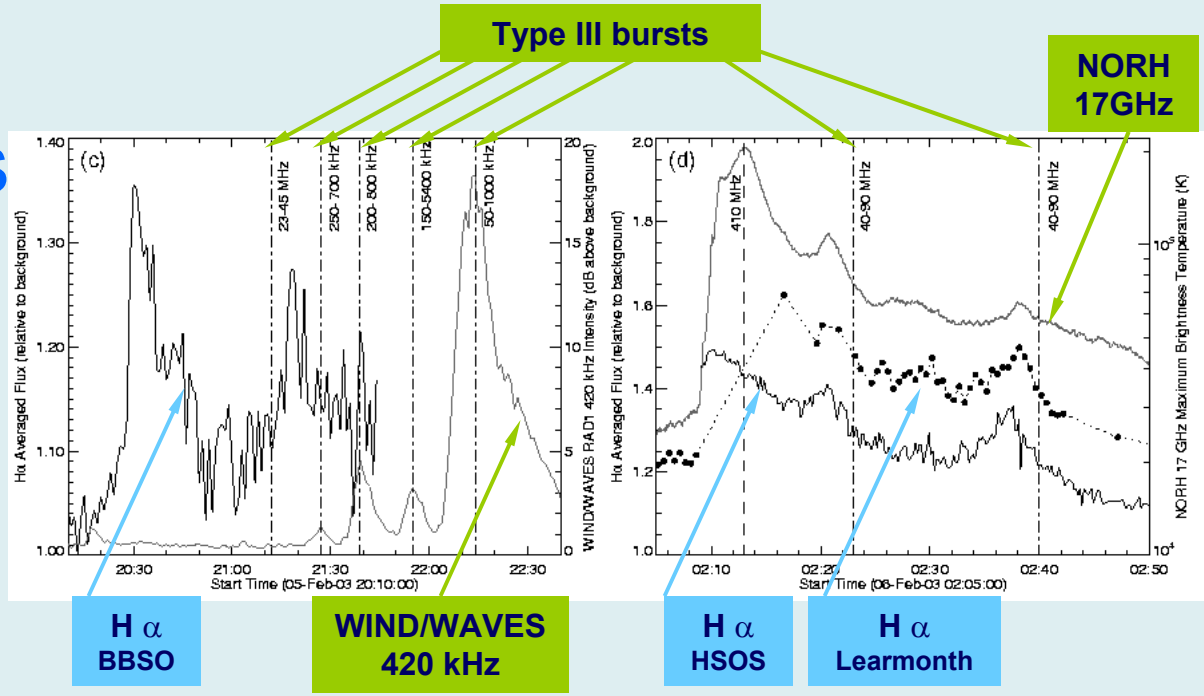
- First observation at high spatial resolution of long-period pulsations with RHESSI.
- QPP: modulations of emission in a small flaring loop due to fast kink MHD waves in a magnetically linked TL.
- Other interpretations cannot be ruled out.
- Potential to provide remote diagnostics if RHESSI studies combined with complementary data (e.g. TRACE, EIS/Solar-B).

Foullon, Verwichte, Nakariakov and Fletcher, 2005, A&A 440, L59

To be continued …

To be continued

- Observations
  - Hα, radio
  - T, EM



- Theory
  - Coupling between large loop oscillations and flaring loop emission.