Combined radio and X-ray diagnostics of acceleration regions

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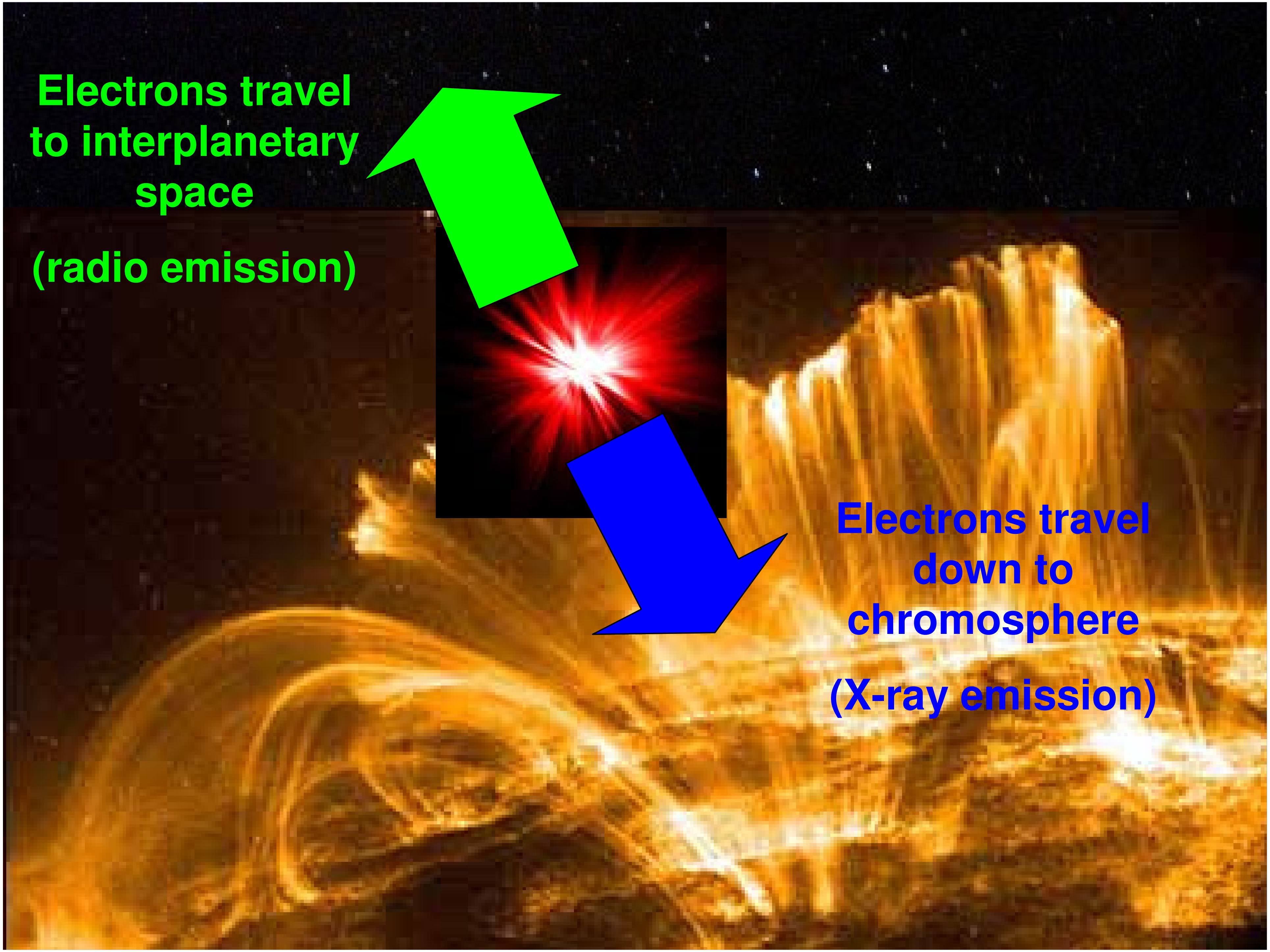


Electrons travel to interplanetary space

(radio emission)

Electrons travel down to chromosphere

(X-ray emission)

Basic Concept

- Assume a common acceleration region for upward and downward propagating energetic electron beams (e.g. Ashwanden et al 1995)
- Use the radio data from type III emission and X-ray data from HXR emission to constrain parameters of upward electron beams
- Estimate parameters regarding the common acceleration region.

Basic Concept

Almost all flares > C5 are associated with some form of coherent radio emission (Benz et al 2005,2007)

Correlated HXR and type III events are found to be fractionally more intense with smaller spectral indices and higher starting frequencies (Kane 1981, Hamilton et al 1990)

The temporal correlation between HXR pulses and type III starting frequencies has been found statistically to be ≤ 0.1 s (Aschwanden et al. 1995)

Upward and downward electron beam spectral indices and densities have been found to be correlated for prompt events (Krucker et al 2007)

Basic Concept

Consider an electron cloud with size **d**, spectral index α located at initial acceleration site **x=0** described by:

$$f_0(x,v,t=0) = g_0(v)\exp\left(\frac{-|x|}{d}\right) \qquad g_0(v) \sim v^{-\alpha}$$

Langmuir waves are generated when their growth rate is larger than the background Maxwellian plasma collisional absorption.

$$\gamma = \frac{\pi\omega_{pe}}{n} v^2 \frac{\partial f}{\partial v} > 2\nu_c \qquad \nu_c = \frac{\omega_{pe}^2 e^2}{m_e v_{Te}^3} \ln\Lambda$$

Basic Concept

At times t>0 the electron beam will become unstable as fast particles outpace slower particles.

$$f_0(x,v,t) = g_0(v)\exp\left(\frac{-\left|x-vt\right|}{d}\right)$$

The growth rate of the Langmuir waves becomes

$$\gamma = \frac{\pi\omega_{pe}}{n} v^2 f(x,v,t)\left(\frac{t}{d} - \frac{\alpha}{v}\right)$$

Langmuir waves are expected to grow at distance

$\mathbf{x = h_{typeIII} - h_{acceleration}}$

Basic Concept

Langmuir waves are expected to grow at distance **x = h**

Langmuir waves are expected to grow at distance **x =** $\mathbf{h_{typeIII} – h_{acceleration.}}$ We can constrain **x** from the growth rate for Langmuir waves

$$x = d\left(\alpha + \frac{2\nu_c n}{\pi\omega_{pe}} v g_0(v)^{-1}\right)$$

The collisional absorption is small so we can derive the simple ralationship

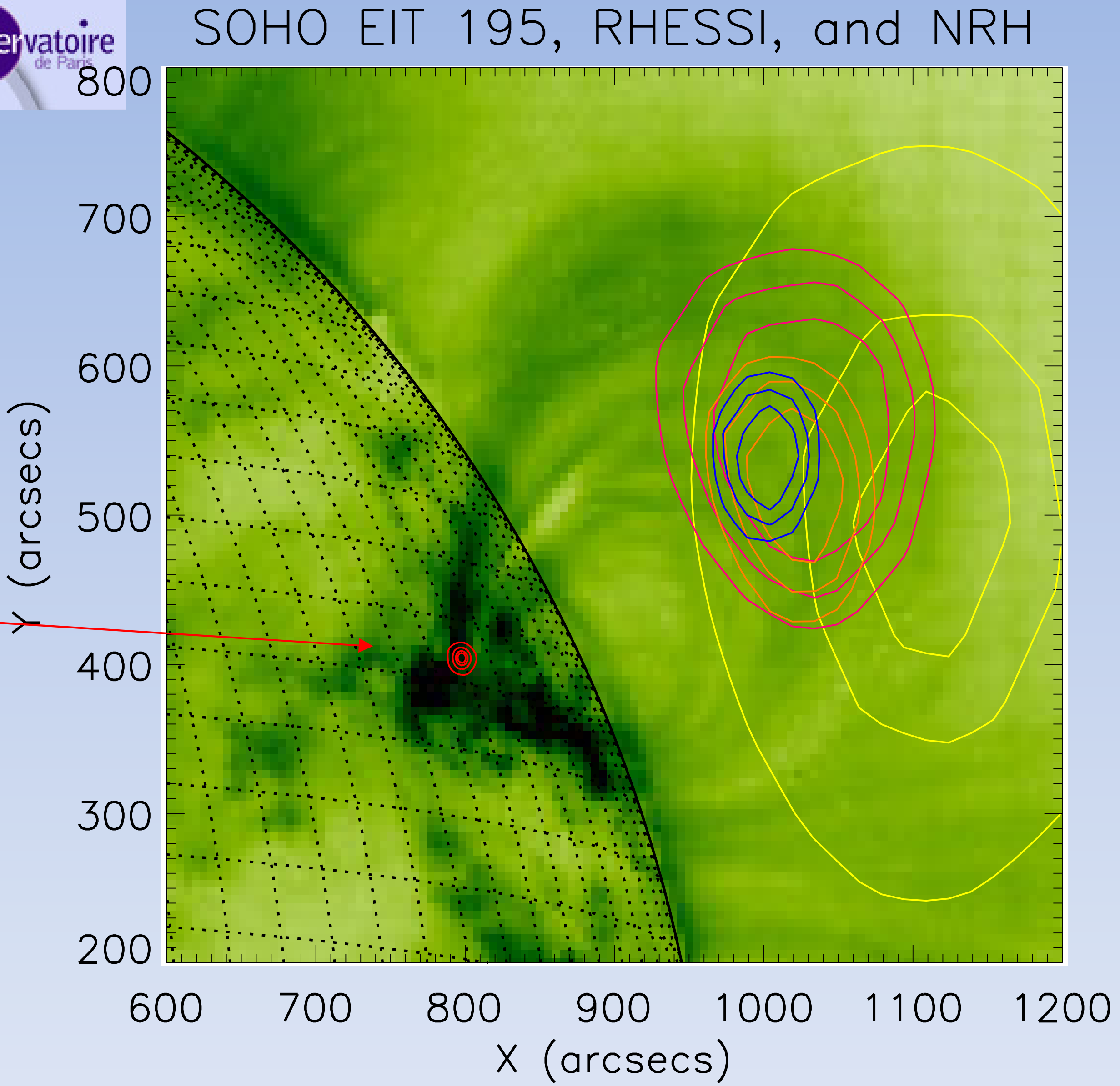
$$h_{typeIII} = d\alpha + h_{acceleration}$$

April 15th 2002 Solar Flare.

Background is SOHO/EIT 195

Small Red contours are RHESSI 15-30 kev

Coloured Contours are NRH 432 MHz Blue to 164 MHz Yellow



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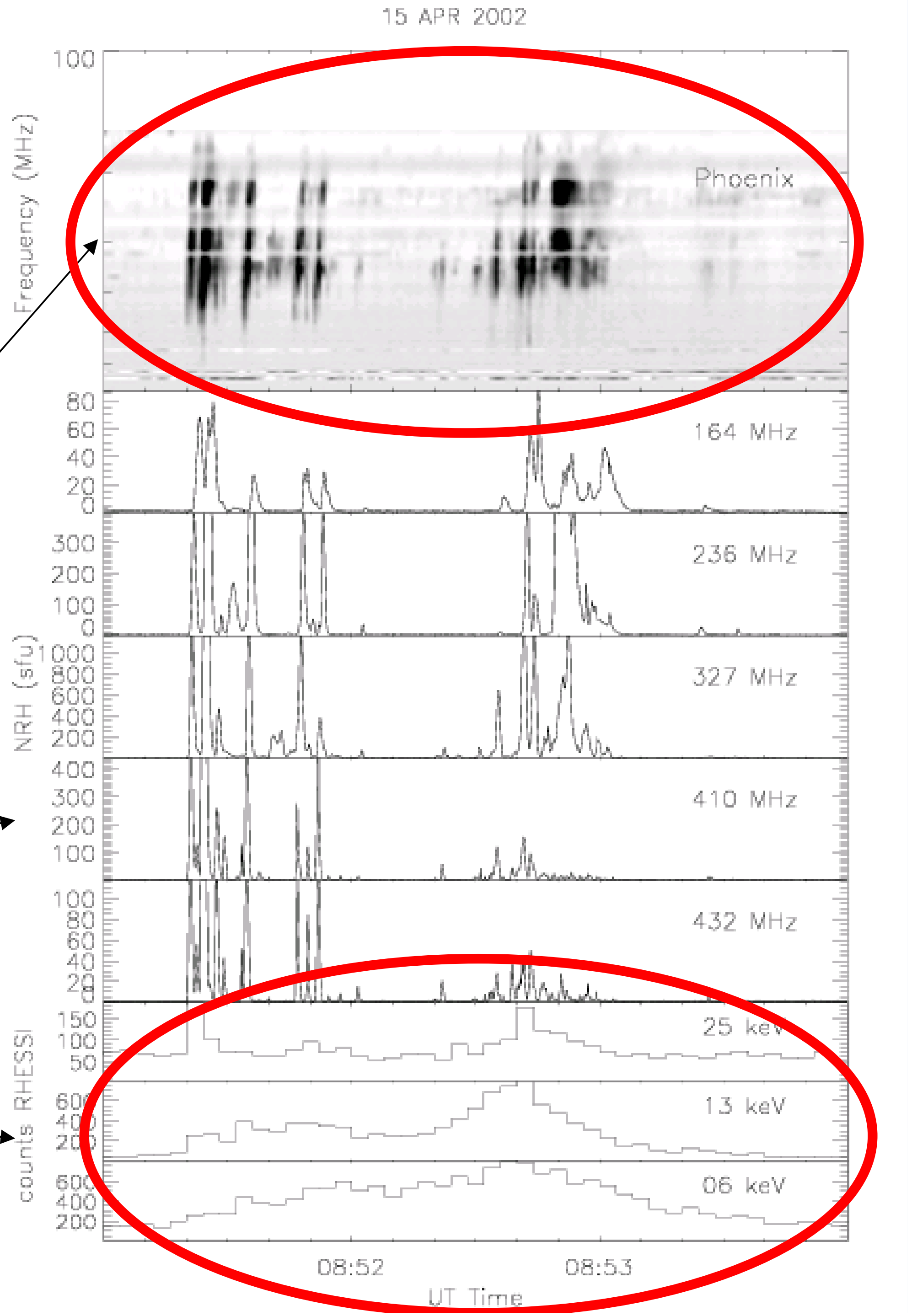


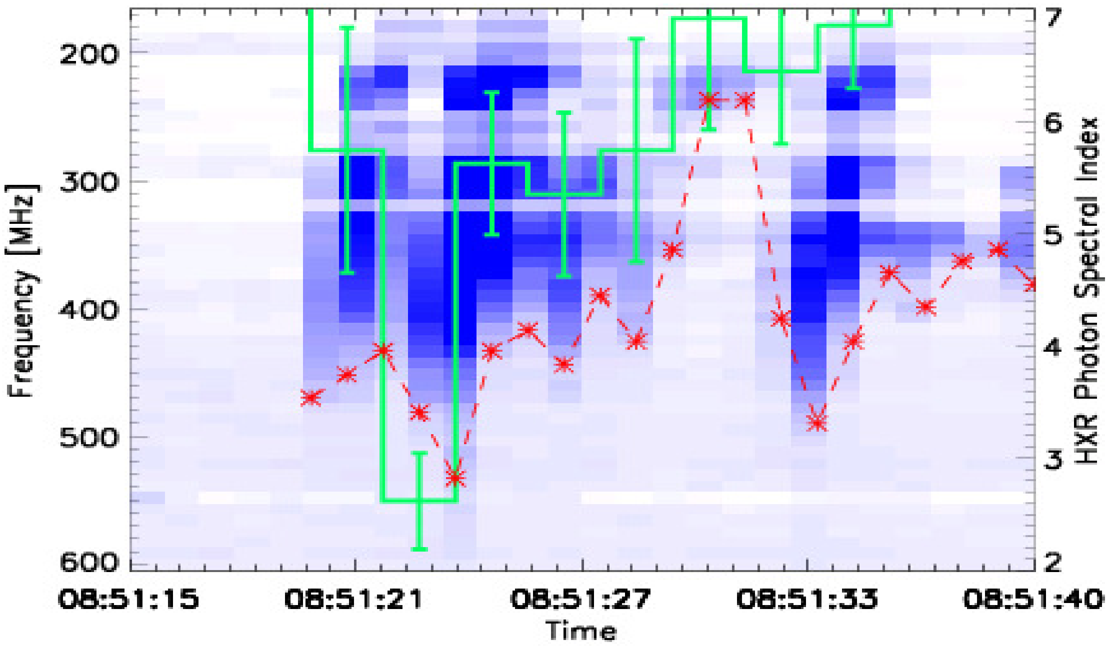
TOP: Phoenix-2 spectral radio data from 700 – 100 MHz

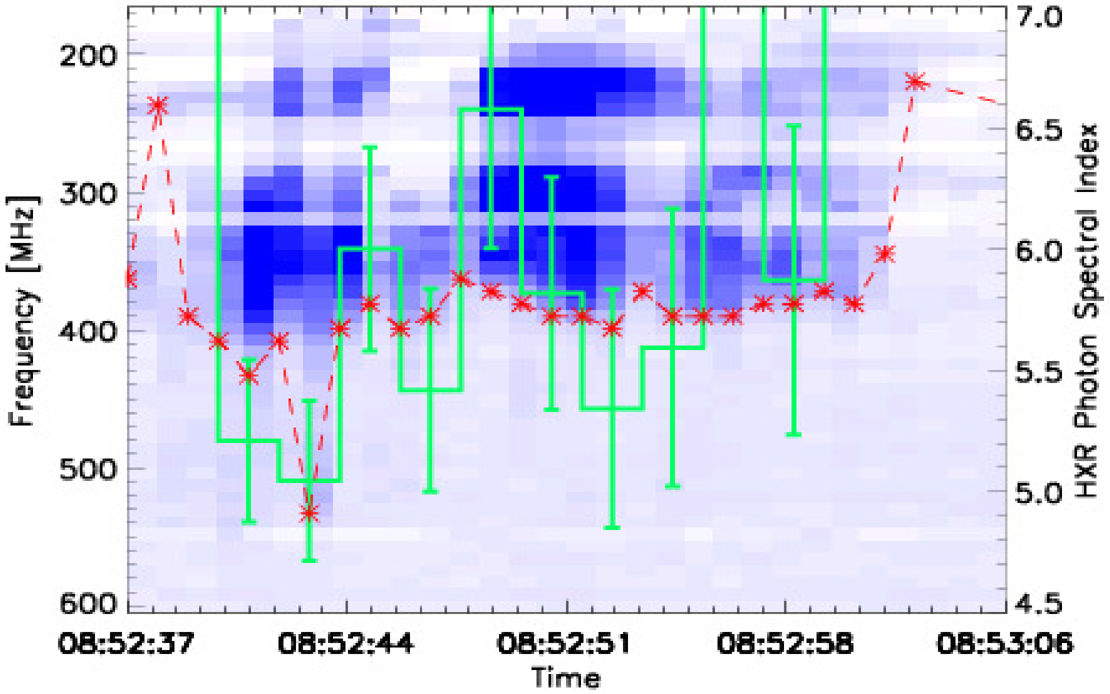
MIDDLE: NRH radio flux from 432 – 164 MHz

BOTTOM: Rhessi HXR flux at 25, 13, 6 keV

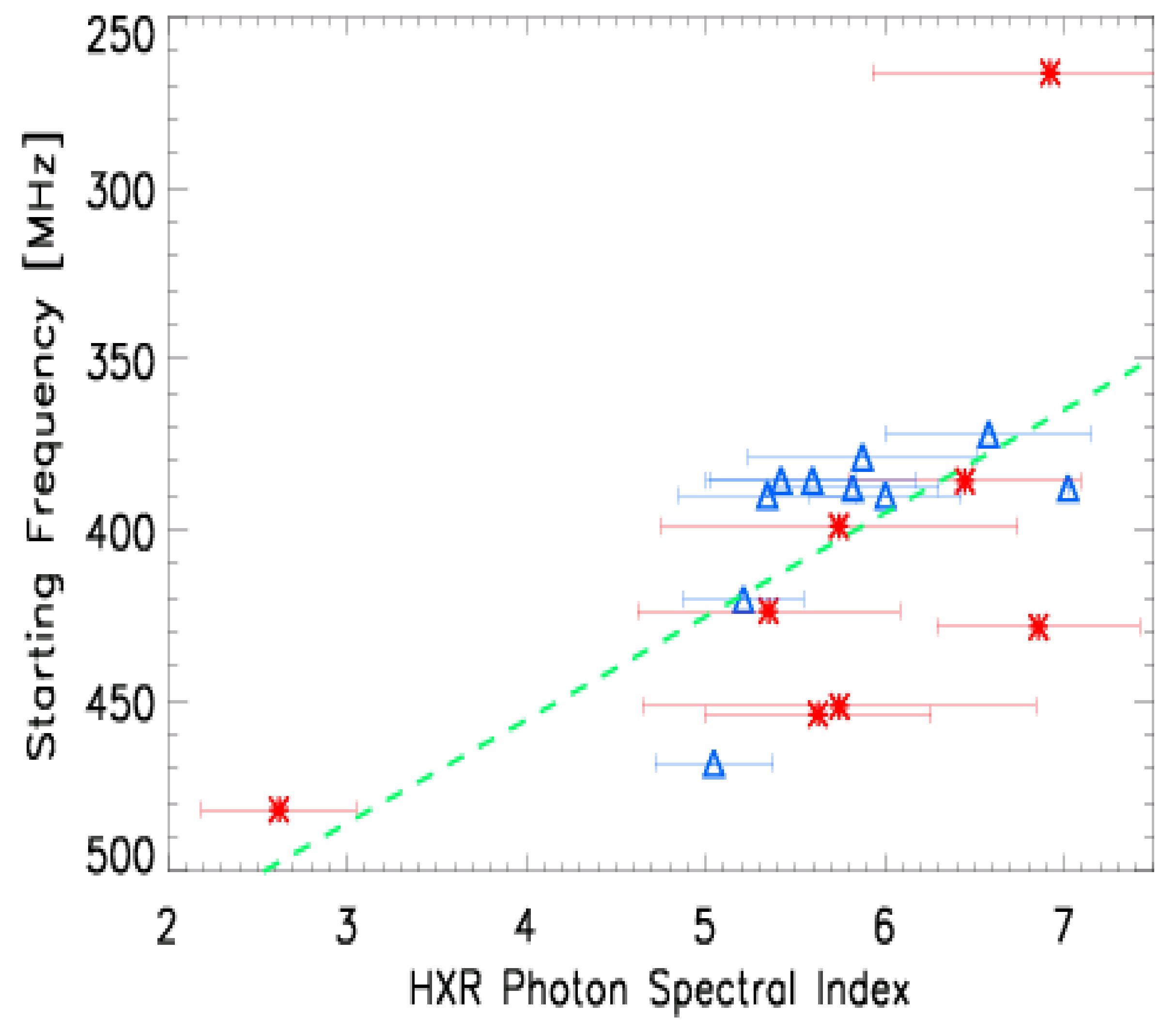
Take the spectral index of HXR every 2 seconds

Take the starting frequency of radio emission with criteria of 2x the quiet background level





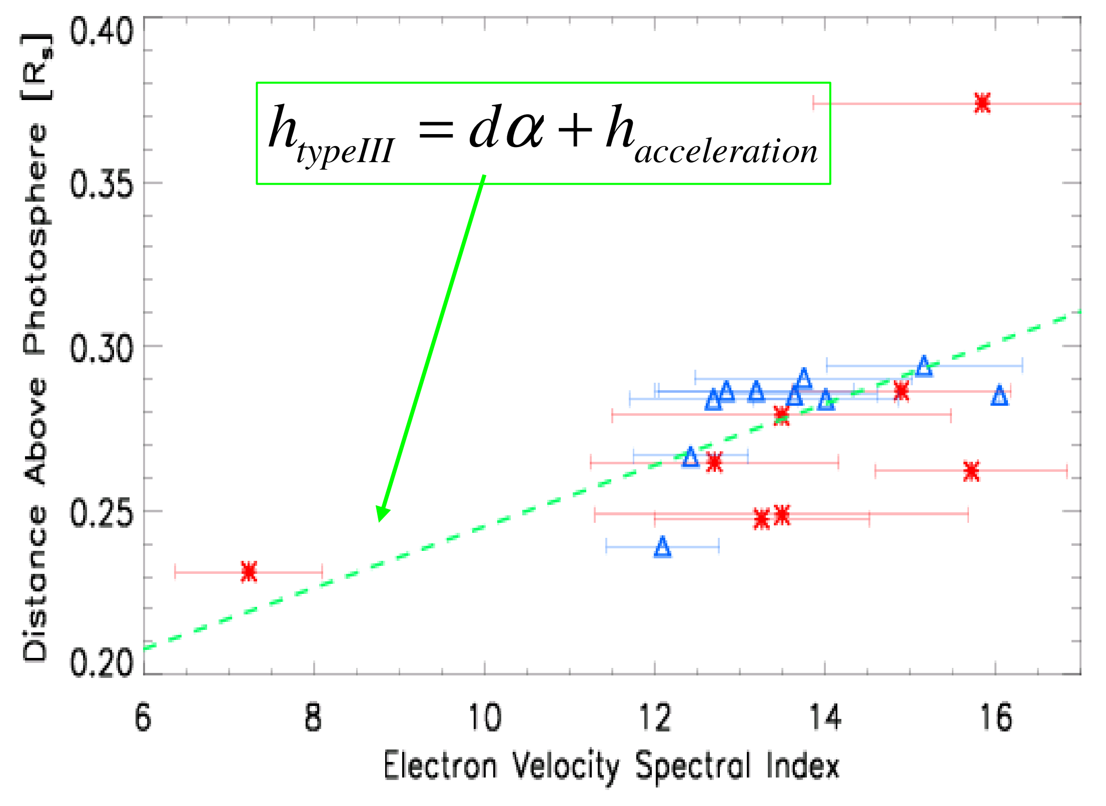
Starting Freq vs Photon Spectral Index



Scatter plot of the starting frequency vs the photon spectral index

Points correlate with a coefficient of -0.62

Starting Dist vs Electron Spectral Index



Assume an exponential electron density model for the solar corona (Paesold et al 2001).

Assume the thick target model to get the electron spectral index from the photon spectral index.

d = 6.5 ± 2.2 Mm **$h_{acceleration}$ = 106 ± 30 Mm**

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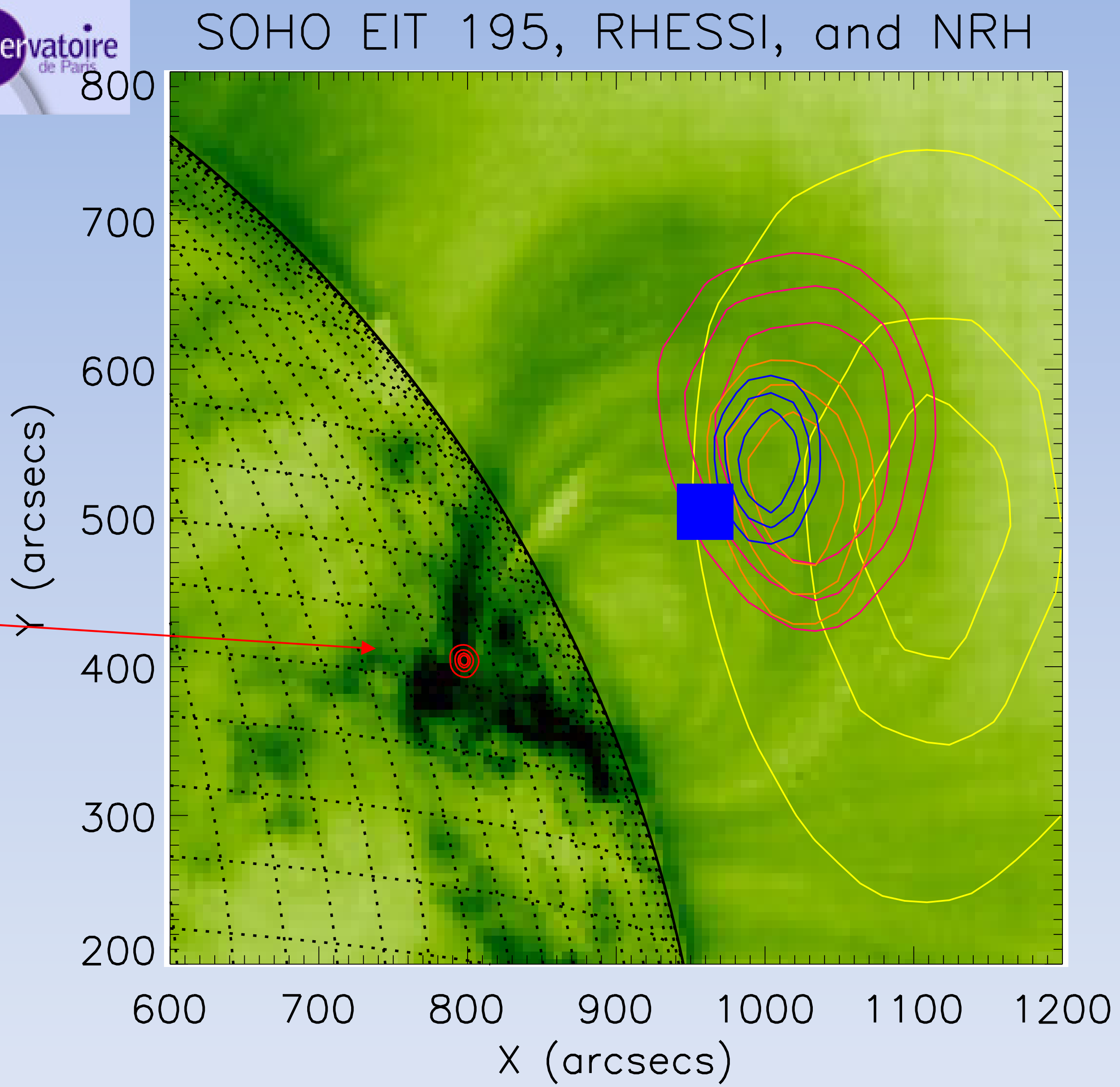


Simulation Initial Conditions

The initial electron beam (at time=0) is dependent on position (as a Gaussian) and velocity (as a power-law)

$$f(v,x,t=0)=g_0(v)\exp\left(\frac{-|x|}{d}\right)$$

$$g_o(v)=n_{beam}\frac{(\alpha-1)}{v_{\min}}\left(\frac{v_{\min}}{v}\right)^{\alpha} \qquad v_{\min}\le v\le v_o$$

The initial, thermal spectral energy density is:

$$W(v,x,t)=\frac{k_b T_e}{4\pi^2}\frac{\omega_{pe}^2}{v^2}\log\left(\frac{v}{v_t}\right)$$

One Dimensional QL equations

One dimensional quasilinear equations (e.g. Drummond and Pines, 1962) describing the kinetics of energetic electrons and Langmuir waves (Kontar, 2001) (Reid and Kontar 2010 submitted ApJ)

$$\frac{\partial F}{\partial t}+v\frac{\partial F}{\partial x}+\frac{2v}{r}F=\frac{4\pi^2e^2}{m^2}\frac{\partial}{\partial v}\left(\frac{W}{v}\frac{\partial F}{\partial v}\right)+\gamma_{cp}\frac{d}{dv}\left(\frac{F}{v^2}\right)\qquad \omega_{pe}=kv$$

$$\frac{\partial W}{\partial t}+\frac{v^2}{L}\frac{\partial W}{\partial v}+\frac{3v_{Te}^2}{v}\frac{\partial W}{\partial x}=\frac{\pi\omega_{pe}}{n_e}v^2W\frac{\partial F}{\partial v}-(\gamma_{cw}+\gamma_L)W+\gamma_s vF\log\left(\frac{v}{v_t}\right)$$

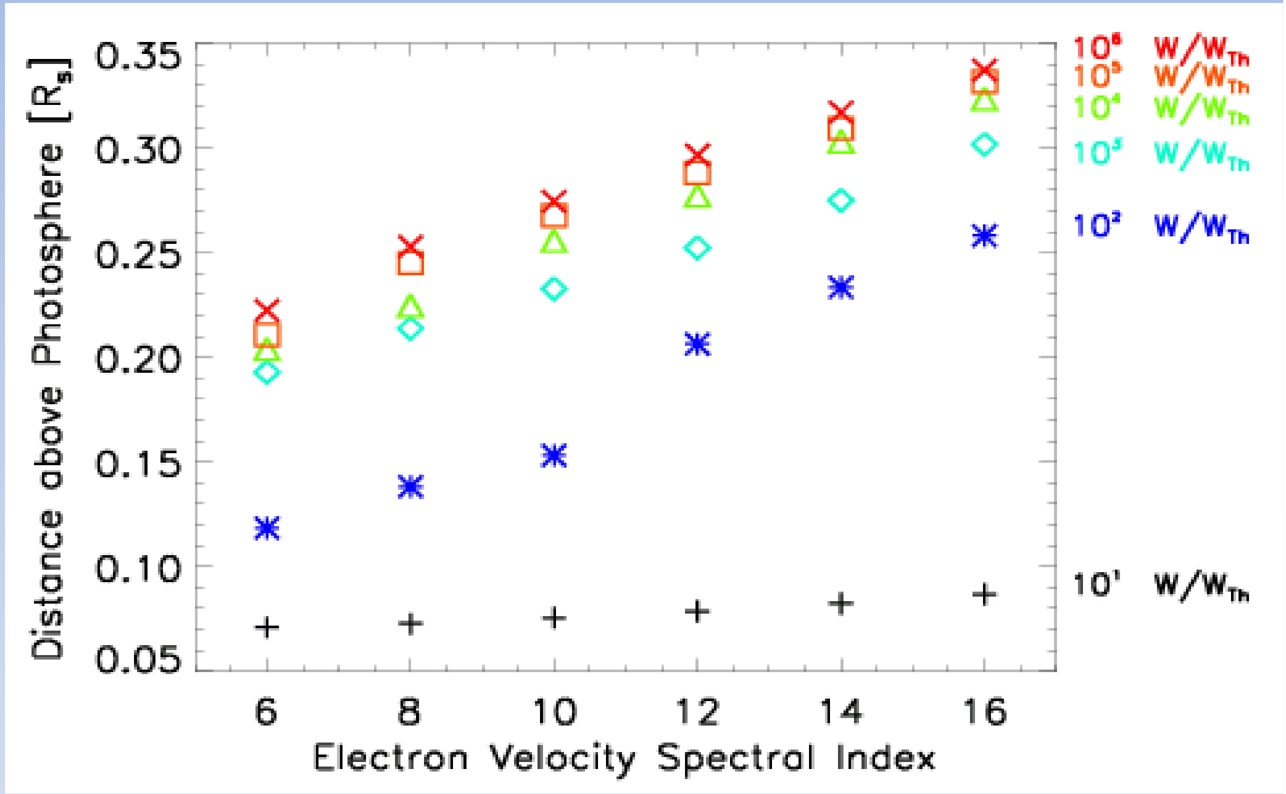
Wave Generation and Absorption

Spontaneous Emission

Sample Simulation

Assume Langmuir waves are induced at a certain level above the thermal background W/W$_{Th}$

A linear fit recovers the value for h$_{acceleration}$ and d



$$\boxed{h_{typeIII} = d\alpha + h_{acceleration}}$$

10^5 W/W$_{Th}$ gives the best fit

d = 8.13 ± 0.39 Mm

h$_{acceleration}$ = 102 ± 4 Mm

Conclusion

- Combined analysis of HXR and radio observations provided reasonable insight into the acceleration region height and size.
- Numerical simulations validated the results and shows the main starting height dependence comes from the spectral index and acceleration region size.