Working Group II

Ion Acceleration and Interaction

Participants

Weiqun Gan Gordon Hurford

Karl Ludwig-klein Bob Lin

Alec Mackinnon Mark McConnell

Michael Moser Gerry Share

Albert Shih Gerard Trottet

Valentina Zharkova

Gamma-ray science: the tail the wags the solar dog

Acknowledgements:

Loukas Vlahos: For teaching me how to boil an egg

Hugh Hudson: For believing everything we say about the solar atmosphere

Brian Dennis: For never complaining about our statistical analyses

Gordon Emslie: For blowing my cover as a U.S. Department of Defense employee

Finally: To the band that helped me stay awake while preparing this talk after midnight.

Science Highlights and Puzzles

Properties of accelerated particles at the Sun and in space

Characteristics of the ambient solar plasma

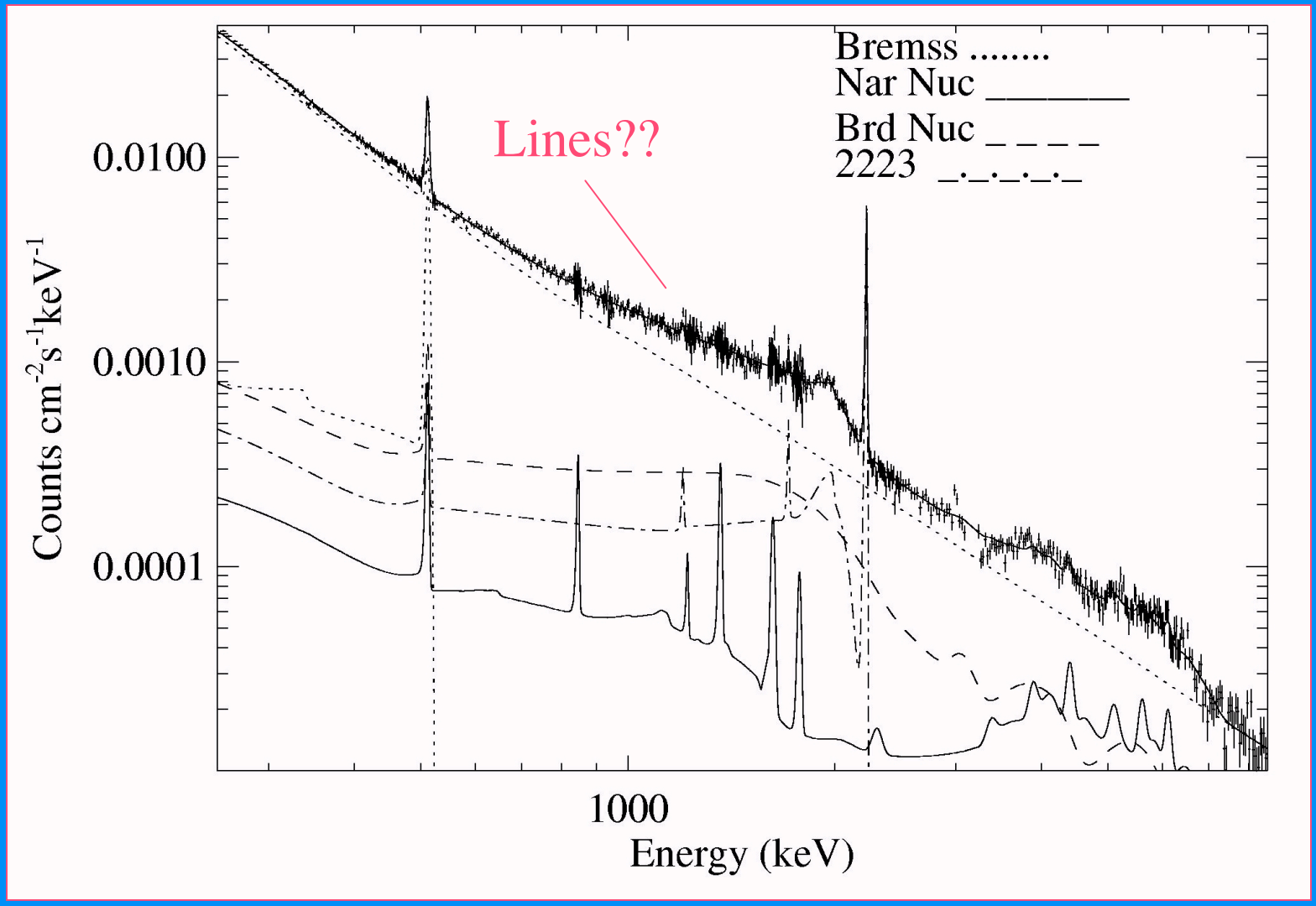
Sites of particle interaction

Hey Man, RHESSI is observing some hard core flares

Or

Where did all the nuclear lines go?

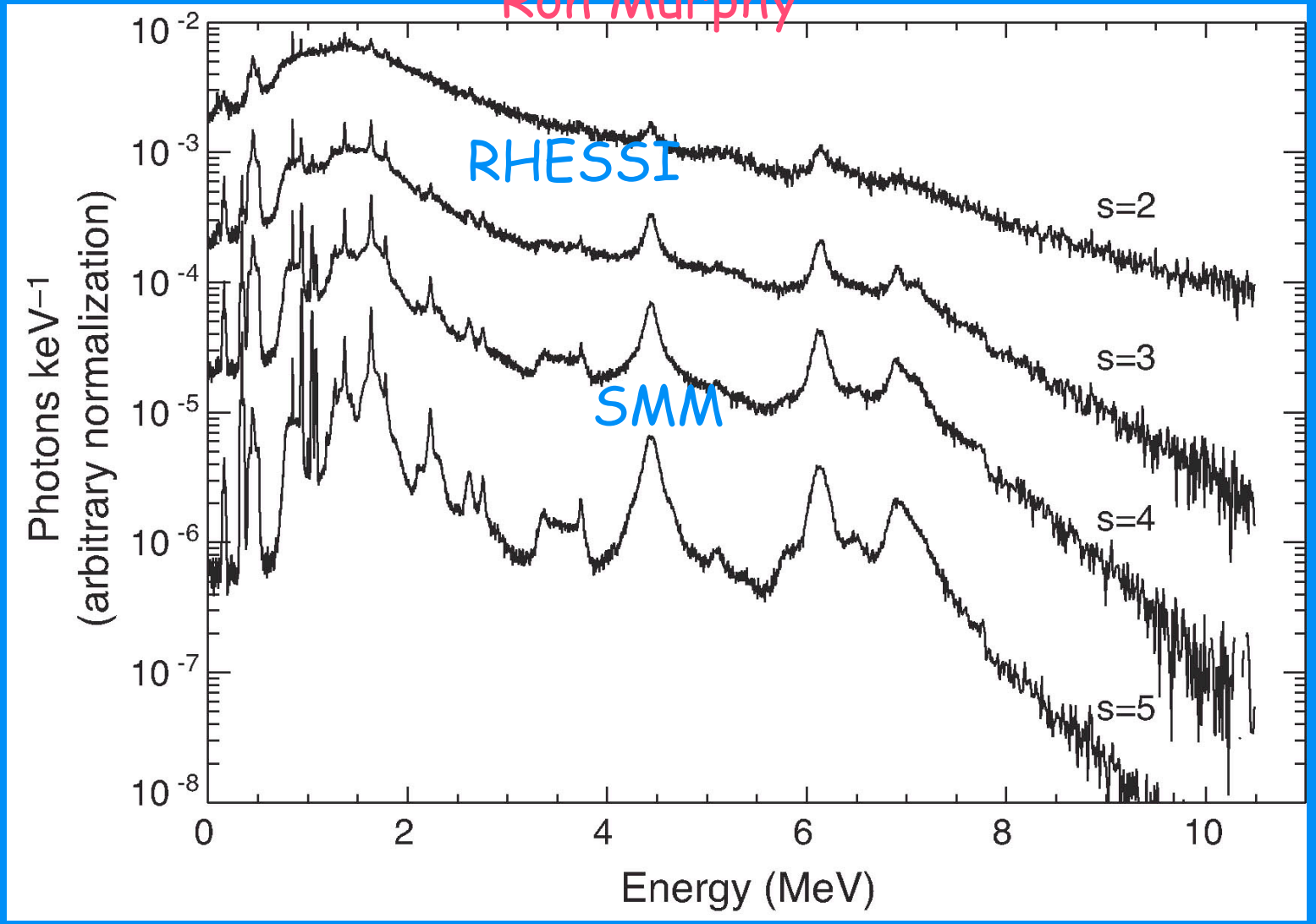
2005 January 20 Gamma Ray Spectrum at Peak



Very hard accelerated particle spectrum, s ~ 2.3, from annihilation and neutron capture line comparison.

Nuclear continuum dominates for hard spectra, masking the discrete lines. Just statistics or something fundamental?

Ron Murphy



Do Spectra of Energetic Particles at Sun and in SEP agree in Well Connected Events? Yes, well maybe.

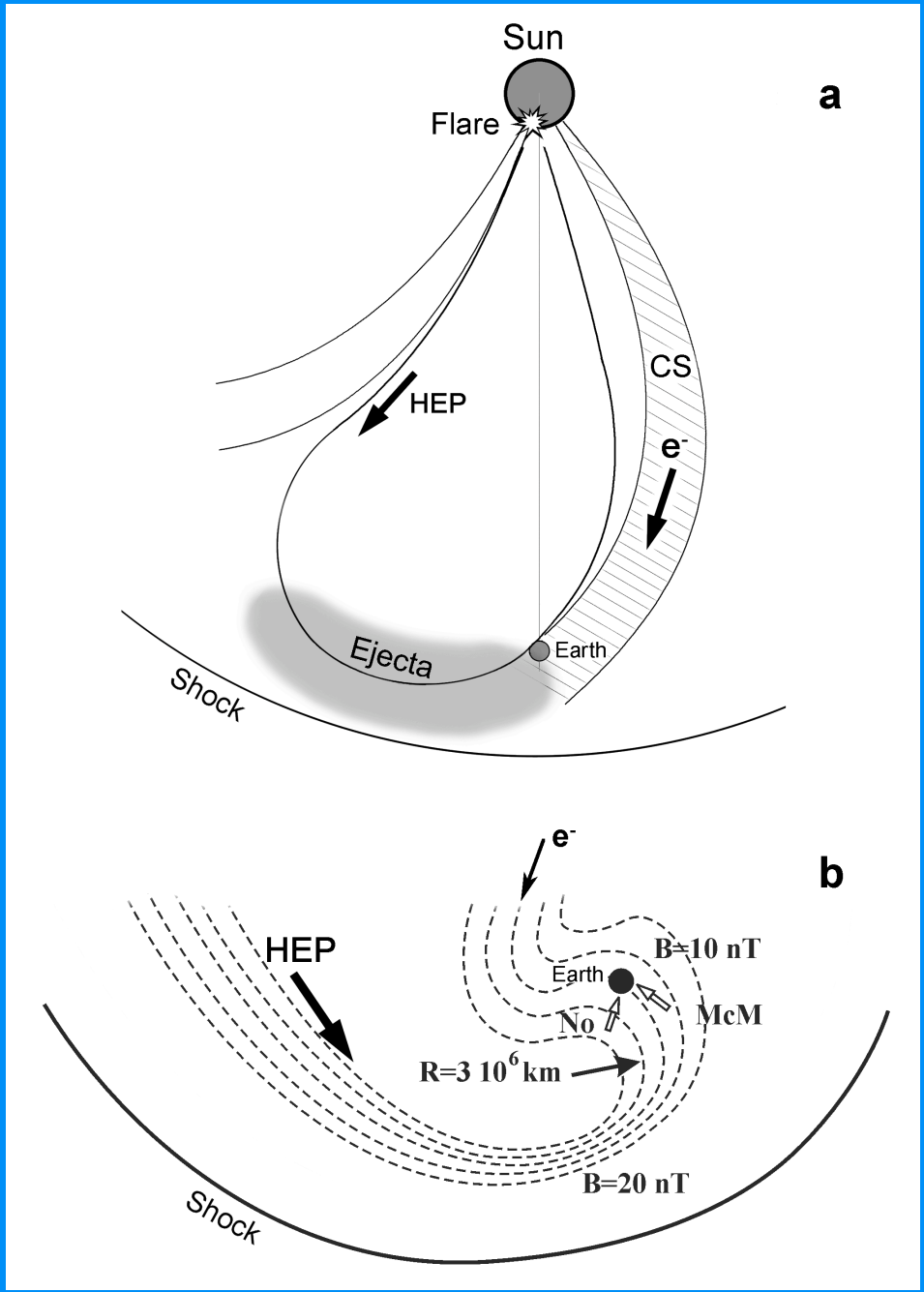
		28 Oct 03 *S16E08*	2 Nov 03 *S15W56*
γ-ray lines	**Energy range**	**γ -ray (SEP)**	**γ-ray (SEP)**
Ne/C+O	**2-20 MeV**	**2.0-3.2 (1.3)**	**1.6-3.2 (1.7)**
e+/C+O	**10-50 MeV**	**2.2-3.3 (2.0)**	**2.3-3.3 (2.8)**
n-capt/C+O	**10-100 MeV**	**2.8-3.8 (2.5)**	**2.8-3.8 (3.0)**

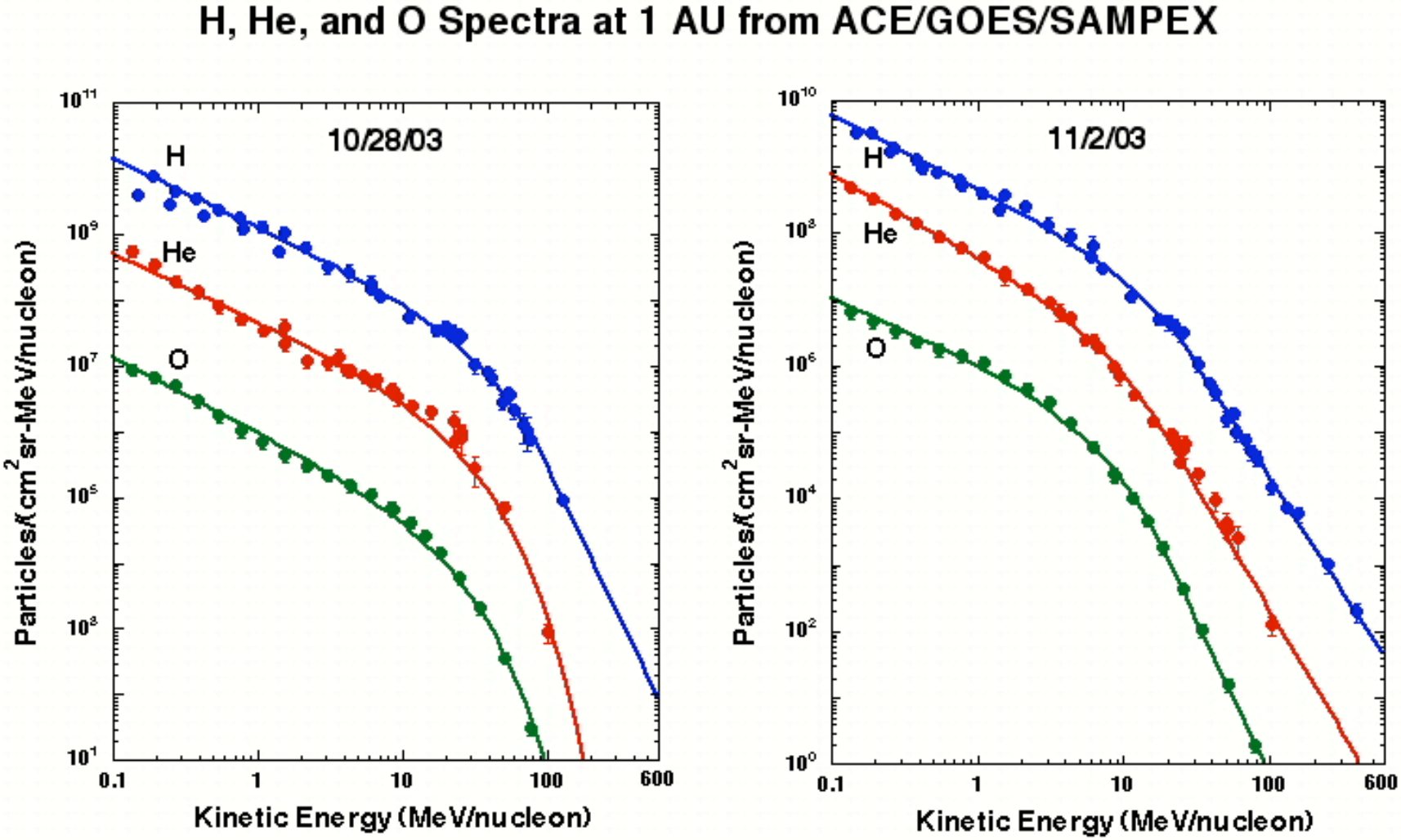
From Bob Lin

But wait a minute!

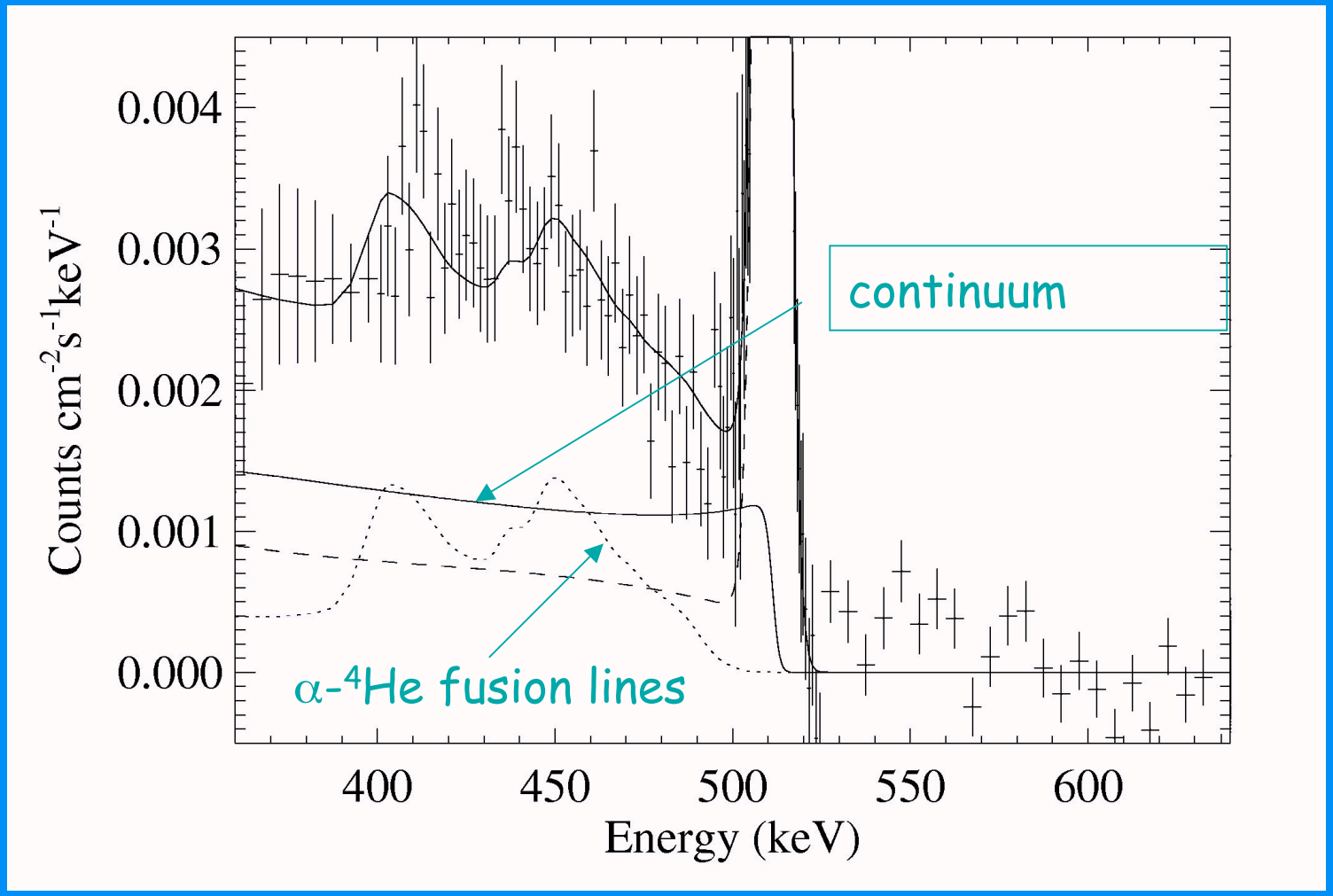
This flare may have been well connected after all. (Karl-Ludwig Klein)

Electrons well connected along undisturbed field line ~1.2 AU and ions well connected along ~2.4 AU field line!!



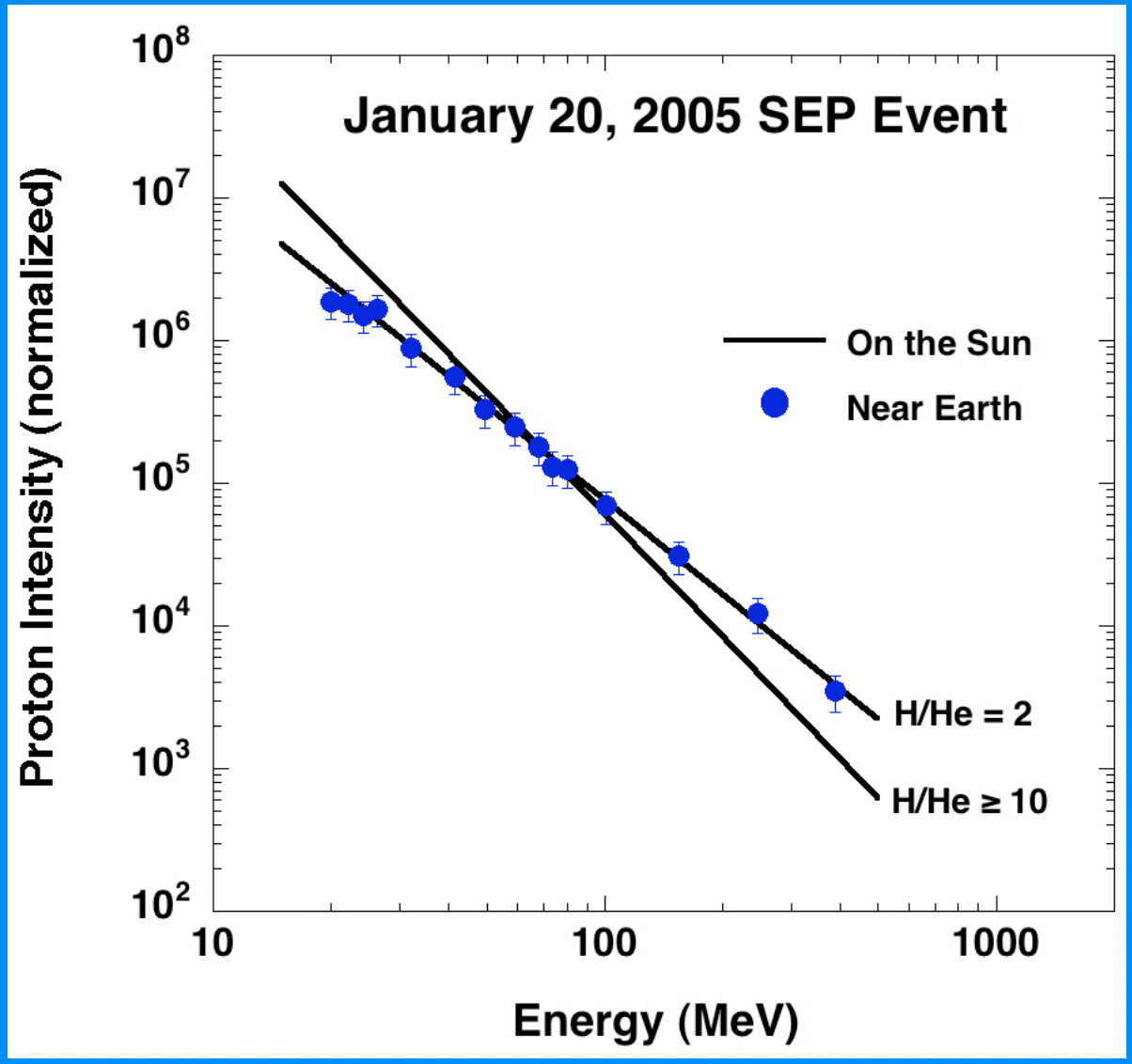


Notice rough agreement in shape between alpha's and proton's and difference in intensity. (Dick Mewaldt)



Why is alpha/proton ratio ~0.3-0.5 at the Sun (even when alpha and proton spectra are decoupled) and only ~0.03 in SEP??

Proton spectra at the Sun and in SEP agree but not α/p ratio? (Mewaldt/Lin)



Who says you can count the number of RHESSI gamma-ray flares on the fingers of your two hands?

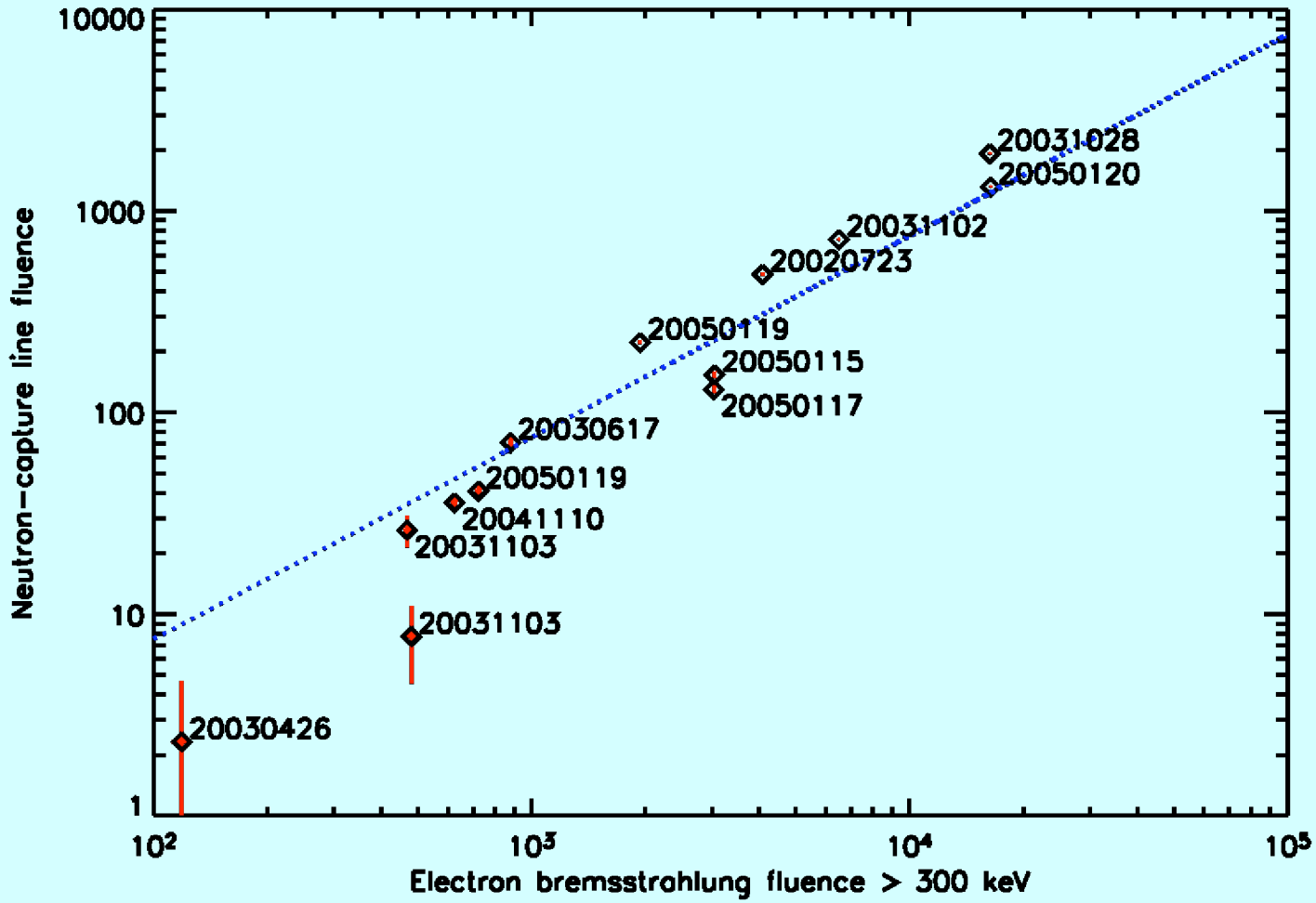
RHESSI Observations

RHESSI Gamma-Ray Flares

Date	GOES Class
2002 July 23	X4.8
2003 June 17	M6.9
2003 October 28	X17
2003 October 29	X10
2003 November 2	X8.3
2003 November 3	X3.9
2004 November 10	X2.5
2005 January 15	X2.6
2005 January 17	X3.8
2005 January 19	X1.3
2005 January 20	X7.1

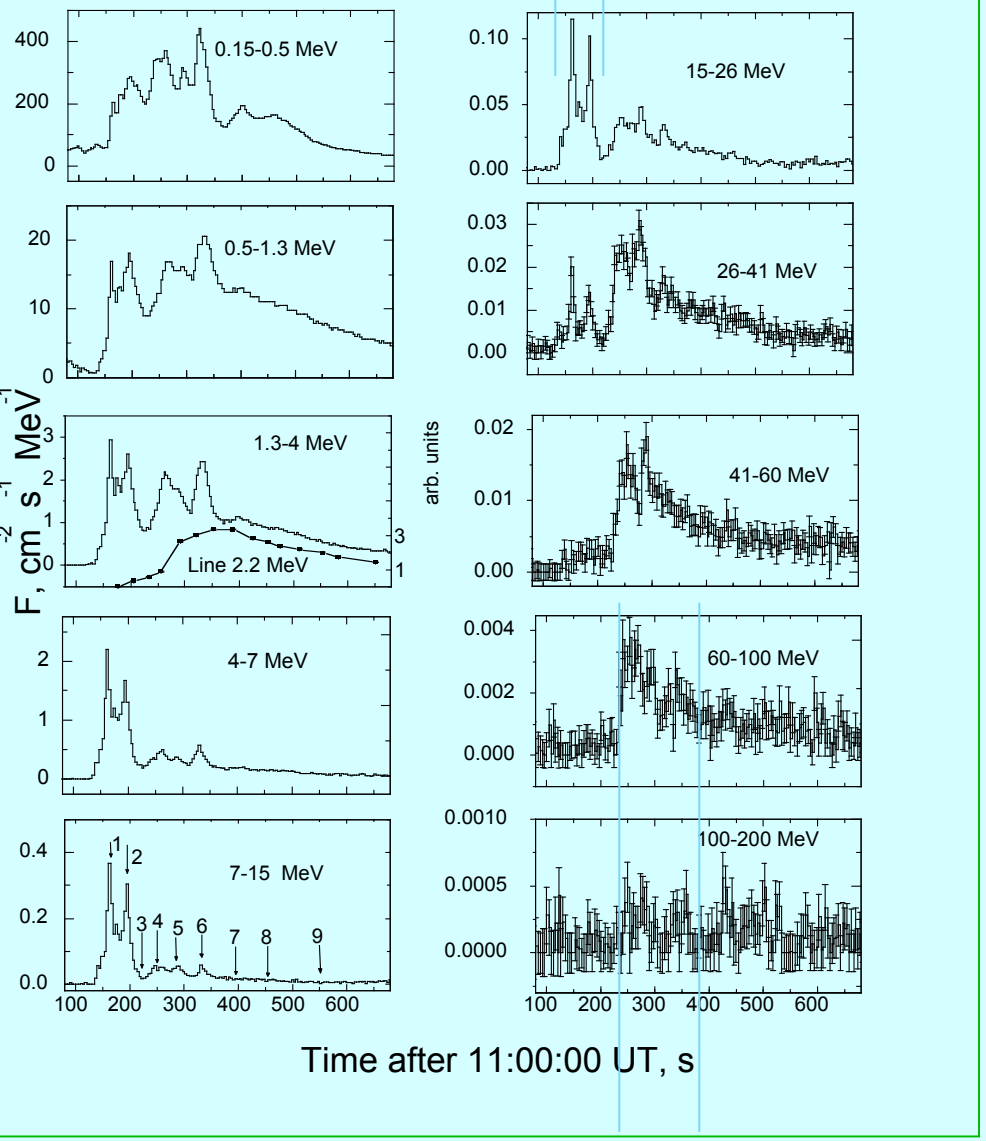
plus at least six flares with high-energy electron bremsstrahlung emission

Albert Shih



Correlation of high-energy electron and ion radiation in RHESSI flares. We know that there is flare to flare differences in the accelerated ion ratio. Also variability within the flare, however. Albert Shih.

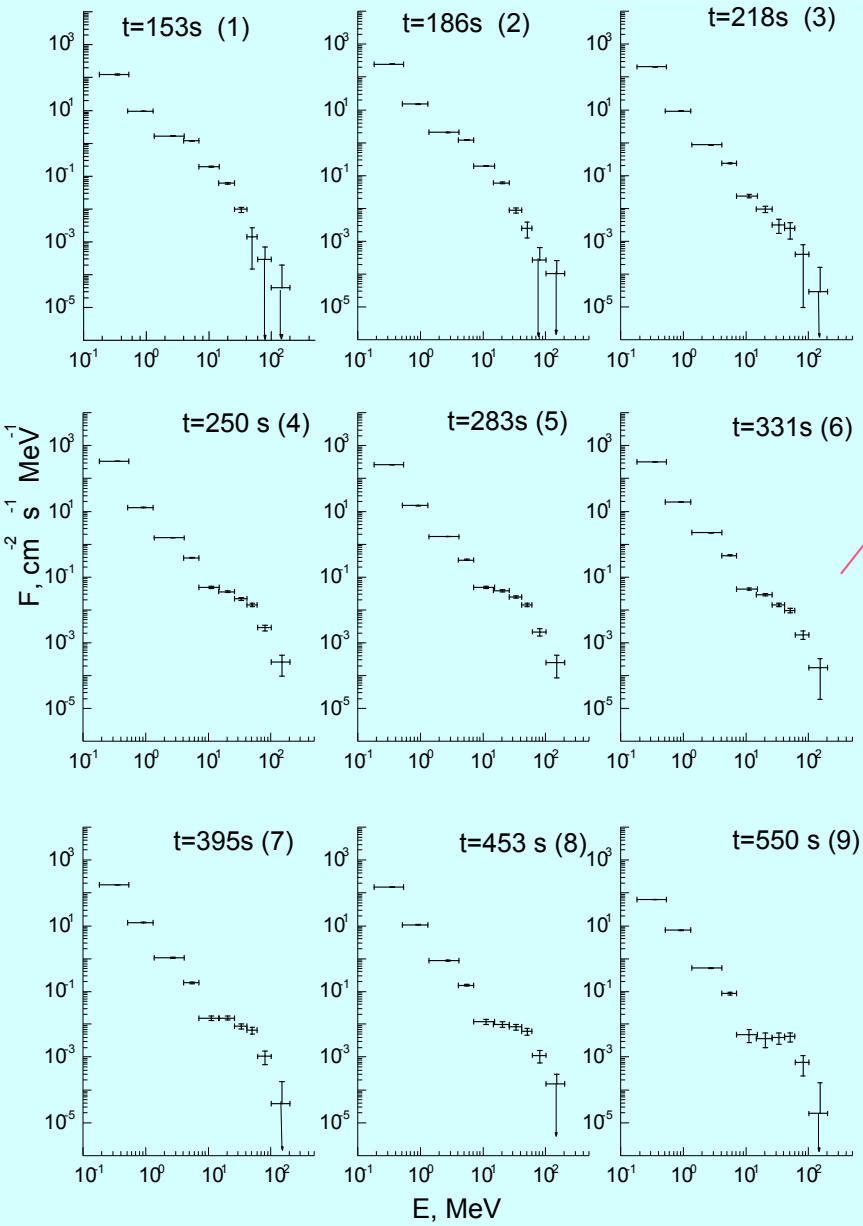
11:02:10 - 11:03:40 Evidence for ~50 MeV electrons



11:04 - 11:06:20 Evidence for pion emission.

2003 October 28 flare -Coronas - >10 MeV e's and p's. Viktoria Kurt.

CORONAS (Viktora Kurt)



Pion Peak?

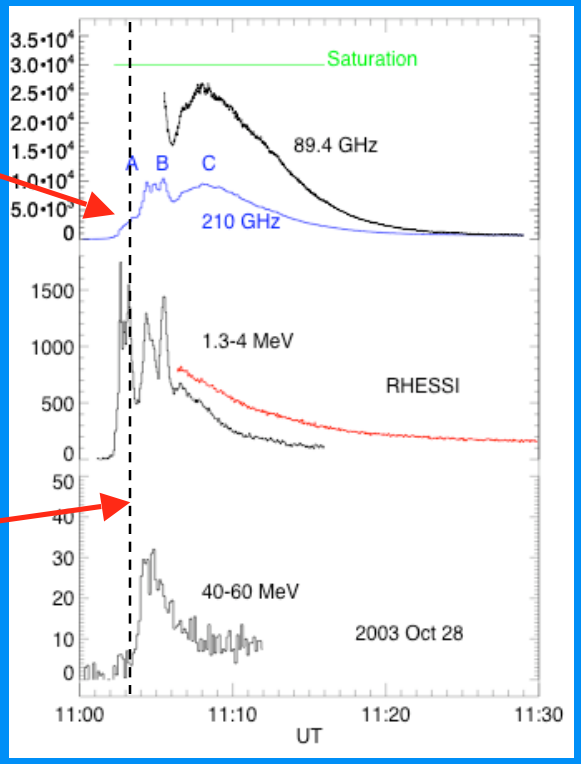
It looks like a pion peak but it appears at too low an energy (calibration/redshift)?

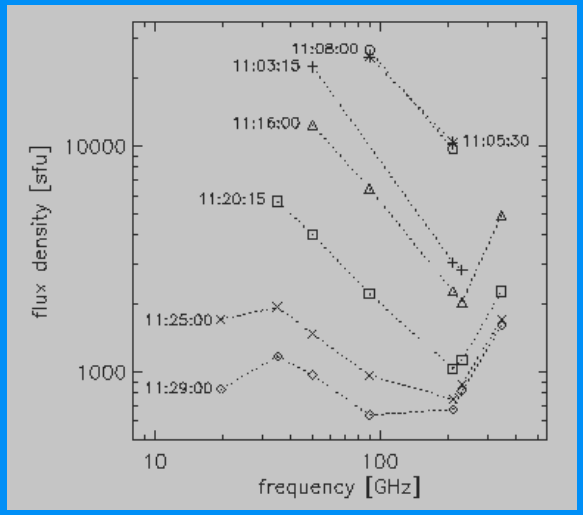
2003 Oct 28

Gs spectr. ↘ 345 GHz

Impulsive burst B at 210 starts when the > 10 MeV GR spectrum hardens

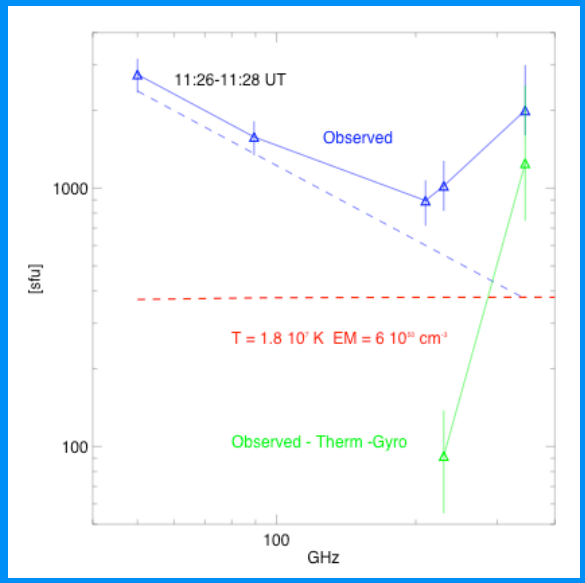
Above 210 GHz The radio spectrum Increases with freq.





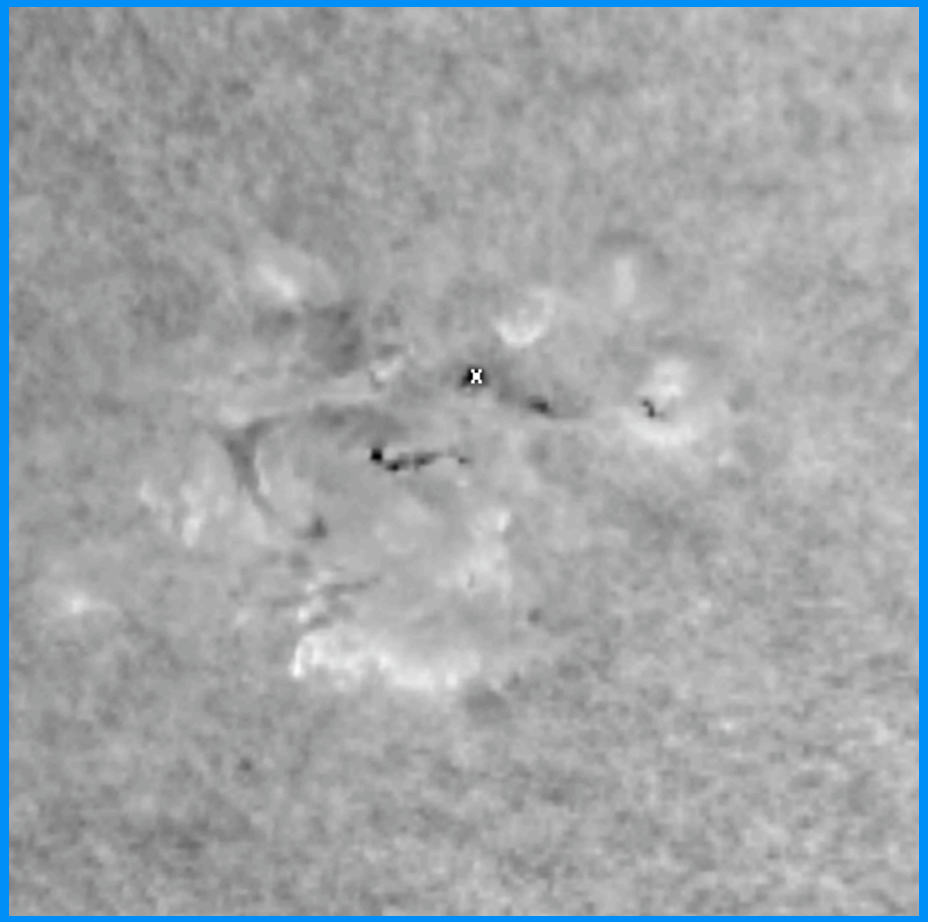
Luethi et al. 2004 A&A

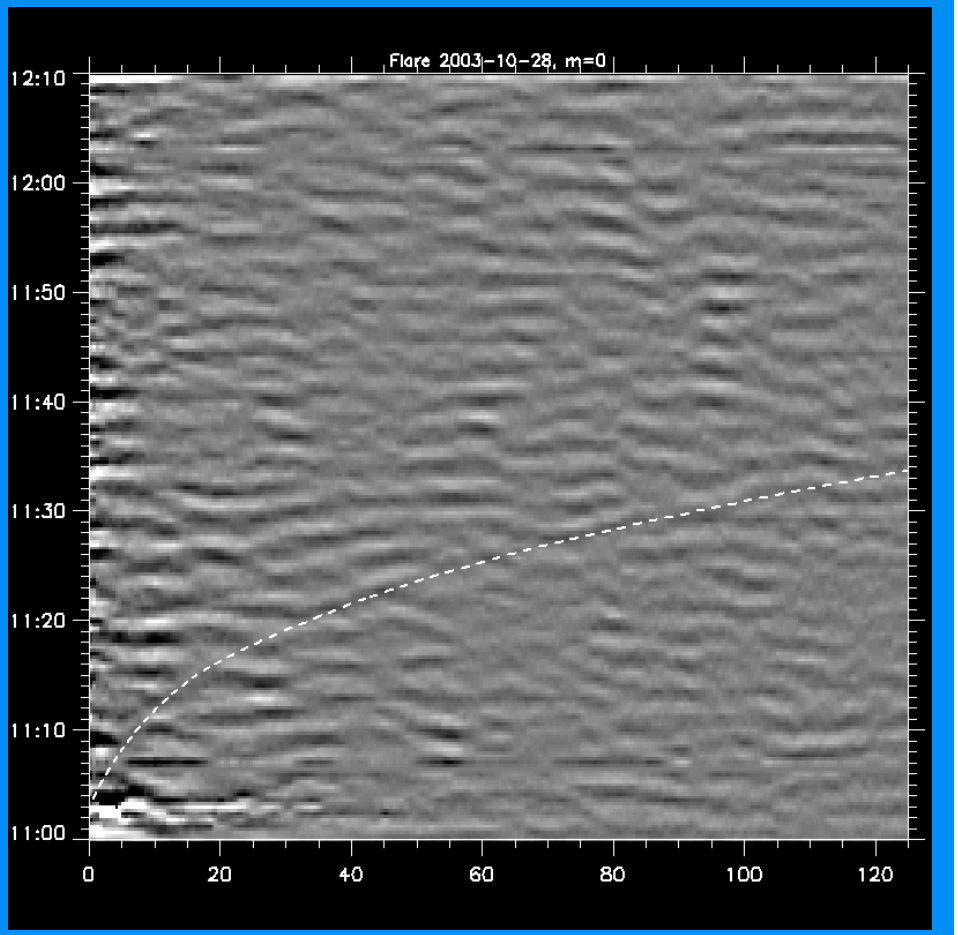
Gs+term (corona) up to ≈ 200 GHz but increasing spect. at higher freq. ?



Trottet et al. 2005

A ray path for a quake from 28/10/03 flare in the Source 5 (left) overlaid onto the time-distance diagram (right)



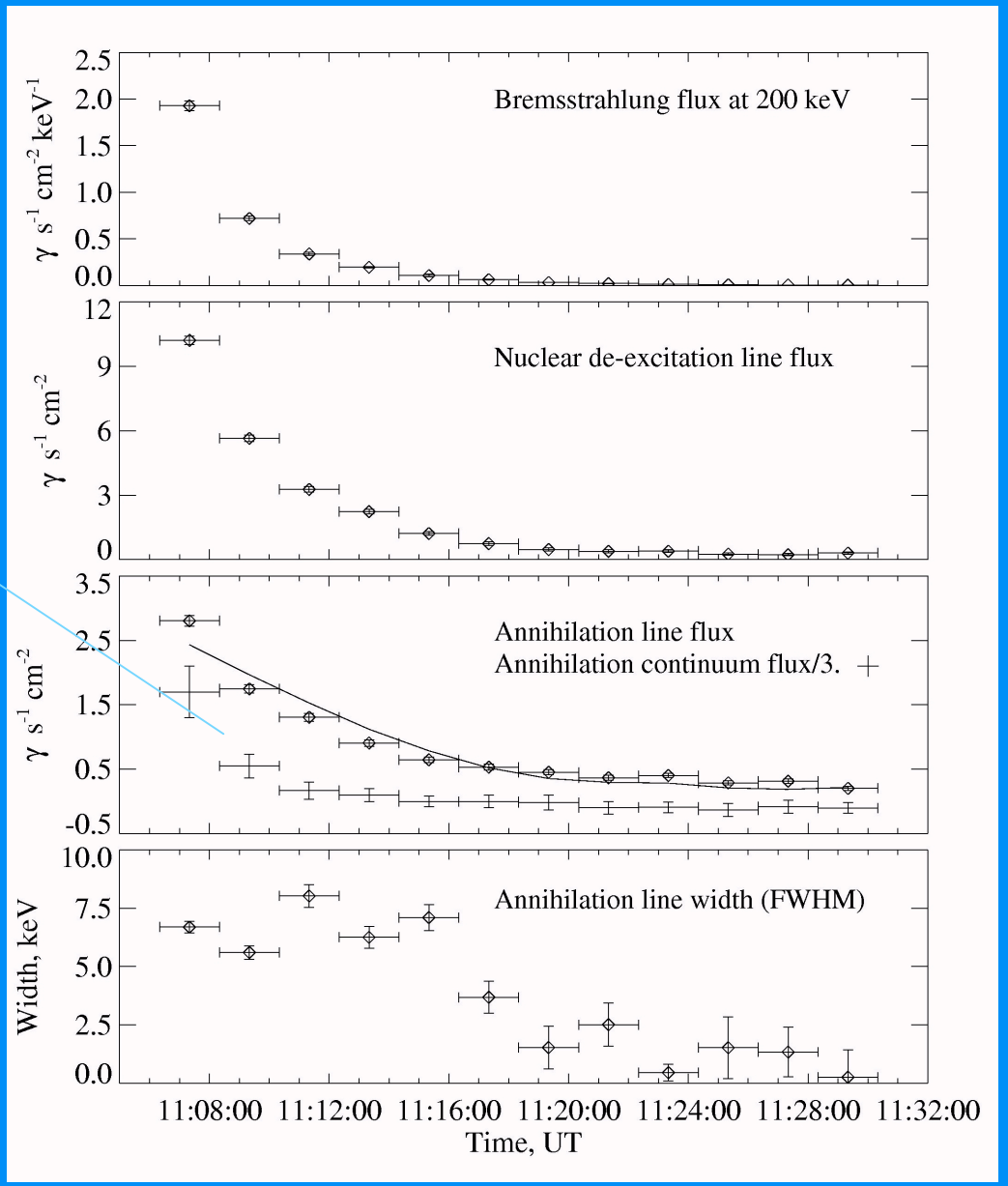


Sure, you would see it without the dashed line. Just ask Valentina.

RHESSI 2003 October 28 Time Histories

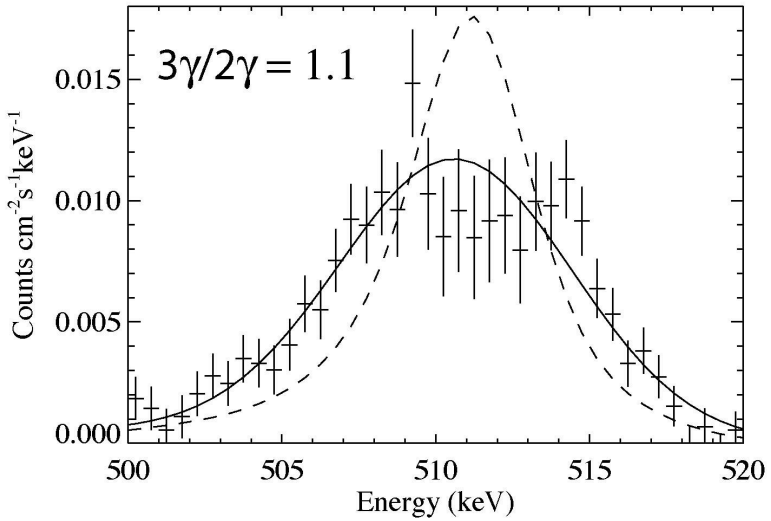
Continuum below the 511 keV line just after impulsive peak also suggests positrons from pion decay.

RHESSI joins the bandwagon for high-energy interactions deep in the chromosphere.

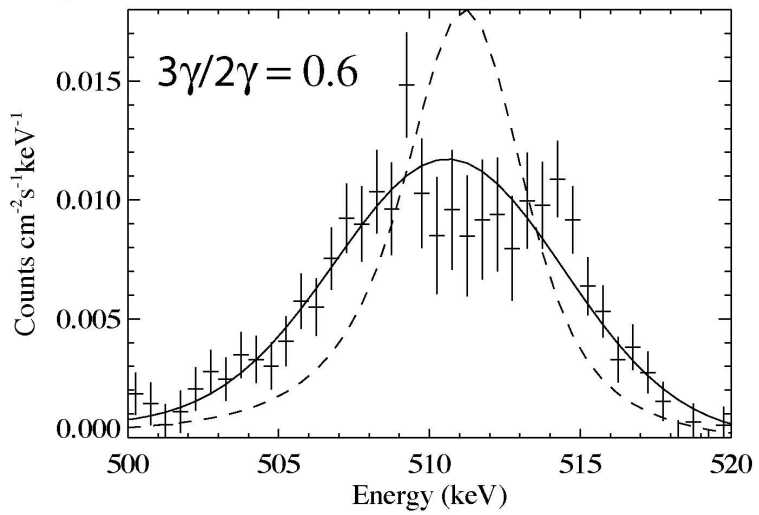


October 28 (broad line)
3rd 2 minutes

Oct. 28, 3rd 2min, 5000K, 5e14, neutral, chi2=154 vs 34.5 Ga



Oct. 28, 3rd 2min, 5000K, 1e15, neutral, chi2=181 vs 34.5 Ga



Annihilation line width appears too broad to be explained by a standard atmosphere. What causes the broad width? High temperature??

measured 3γ/2γ
0.45 ± 0.15
(99% UL = 1)

NO. NO. NO!! says Hugh Hudson. Does this look better Brian?

Upper chromosphere:

_Z: ~20 km

N=6.58E13

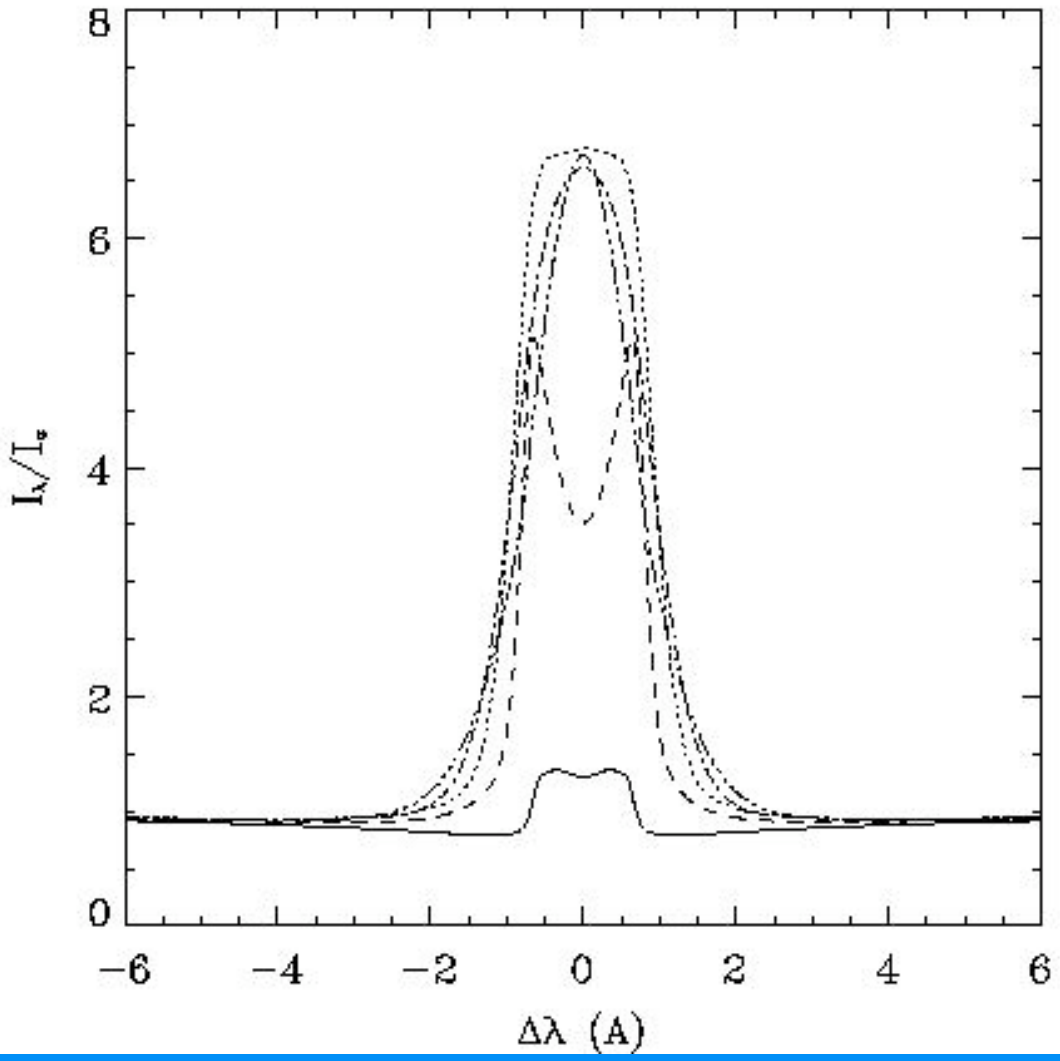
T=8360*[1.0, 2.0, 5.0, 10.0, 20.0]

Line styles:

solid,dashed,dotted,
dash-dotted,
dash-dot-dotted

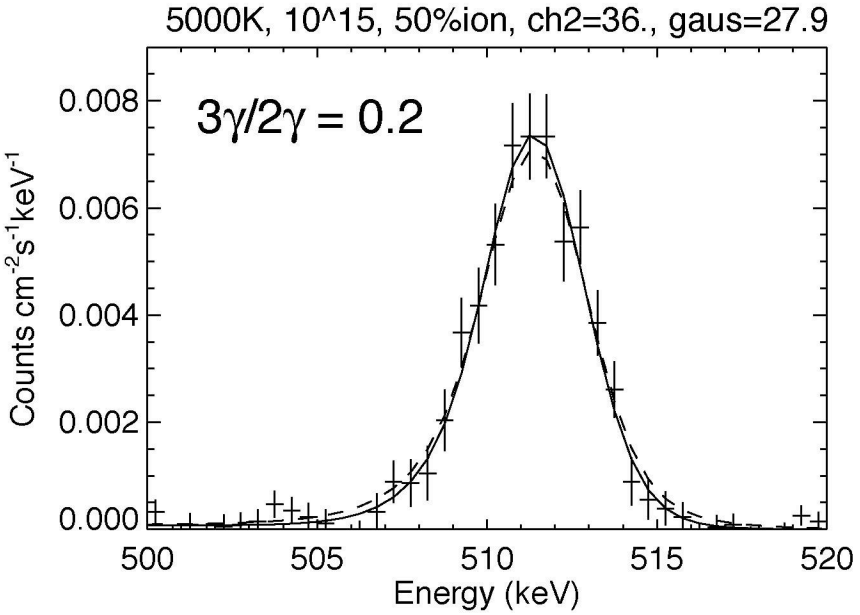
Comment:

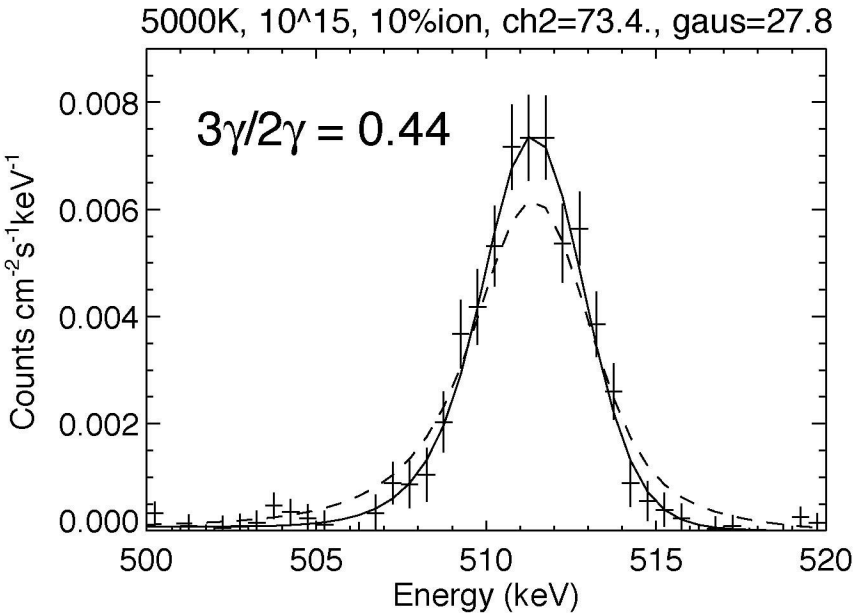
The lines are too strong. From T=8360*5.0 the line seems to be saturated.



Weiqun Gan says H-alpha observations show that temperature can't be too high. Do we have any friends left?

October 28 (narrow line)





measured 3γ/2γ
99% UL = 0.3

All seem happier with the narrow line, even if it requires high ionization. Well maybe not all.

RHESSI 2003 November 2 time histories

Fast rise and falling fluxes following the peak

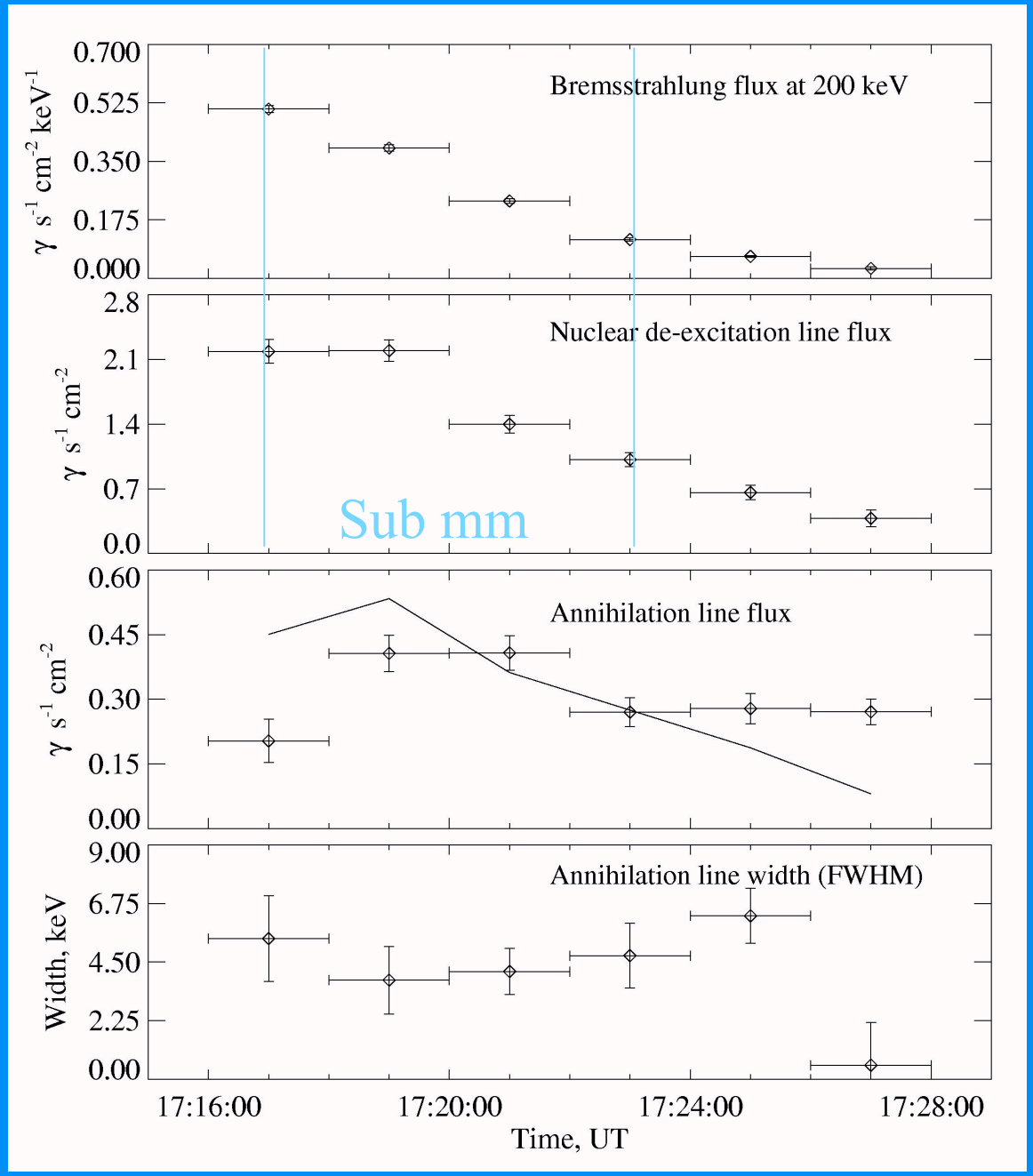
Nuclear/511 keV line flux delayed relative to bremsstrahlung

511-keV flux decay too flat! Origin?

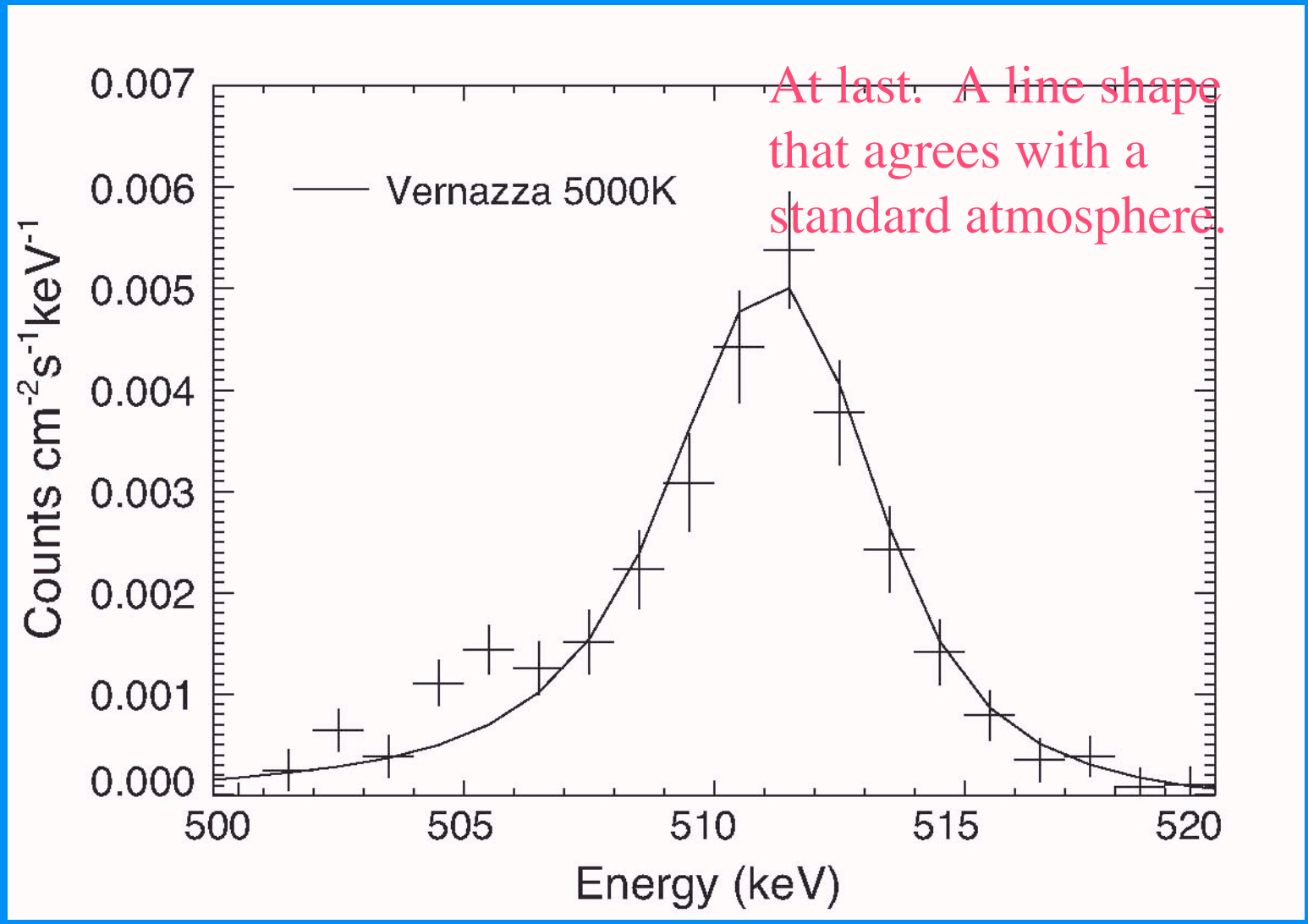
Yet another puzzle!

Wait 'til you see the 2005 January 20 flare.

Sub mm from Adriana Silva.



2005 November 2

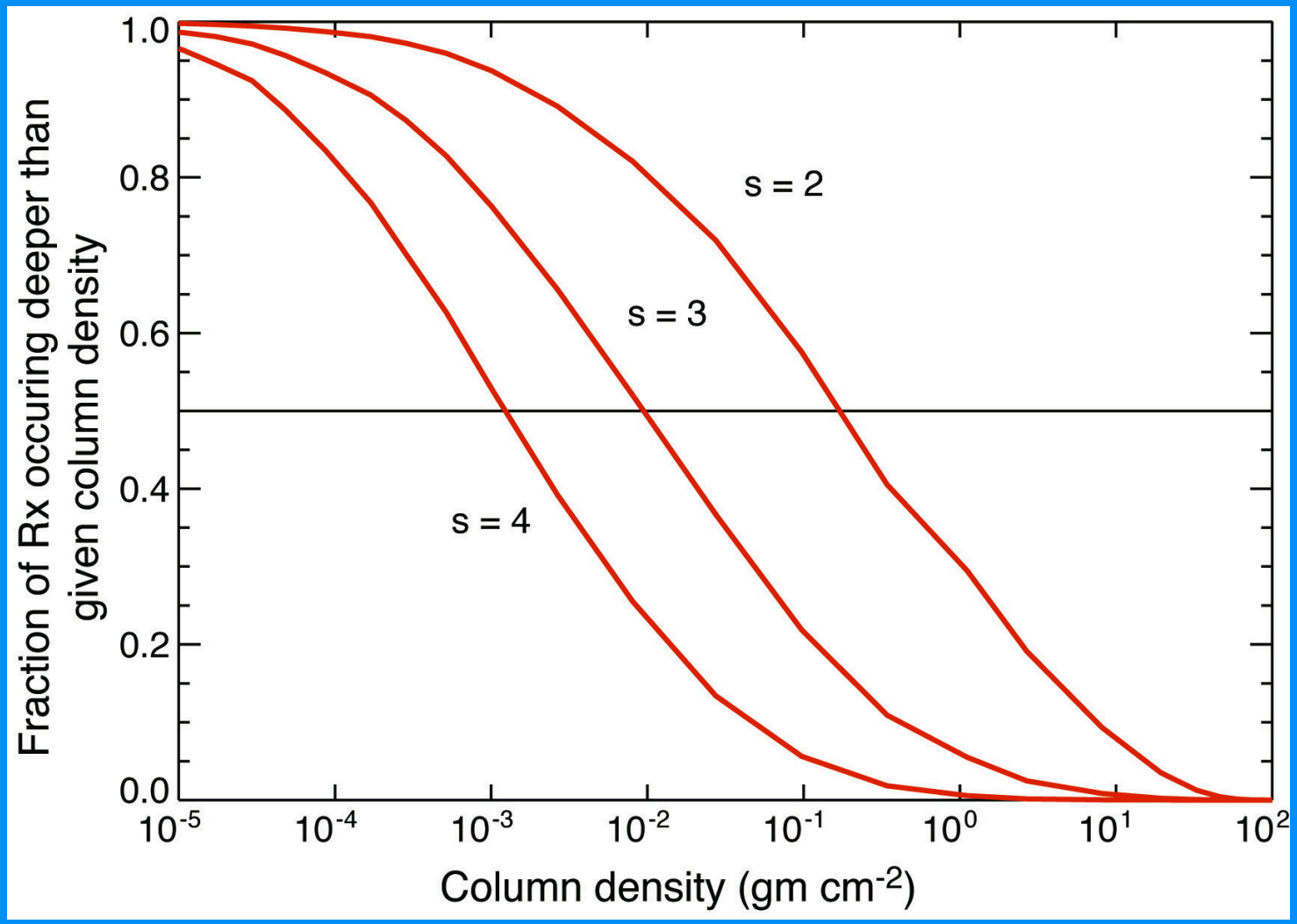


Line width and continuum consistent with annihilation in a quiet solar atmosphere

Can the flaring chromosphere be so dynamic that we can find regions that can appear 'normal', heated to ~300,000 K and cool to 5000K in 2 min. but stay highly ionized?

If you think this caused Lindsay's Working Group problems, ask them what they think about RHESSI observations of a varying (low FIP)/(high FIP) ratio in one-two flares. Top it all off with the SMM/OSSE/RHESSI finding that the average composition where the ions interact appear to look just like the corona.

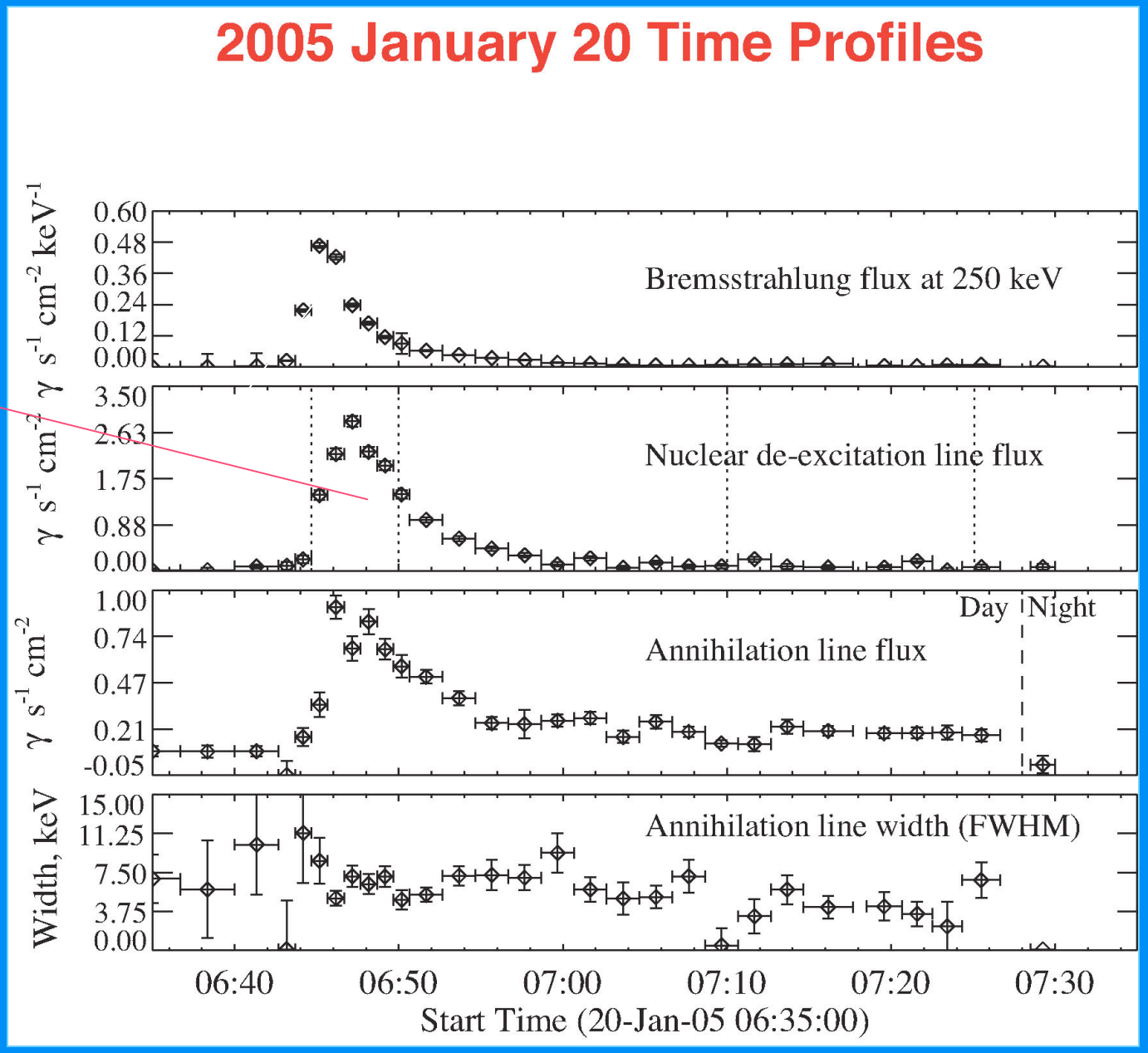
Gerard says if it looks like the corona, tastes like the corona, smells like the corona then it must be the corona.



Wait a minute! Don't we need more column depth for those protons to interact in than we can find in the corona. (Ron Murphy)

You guessed it Coronas observed pion radiation here.

Is the long 511 keV flux tail due to newly revealed radioactive material?

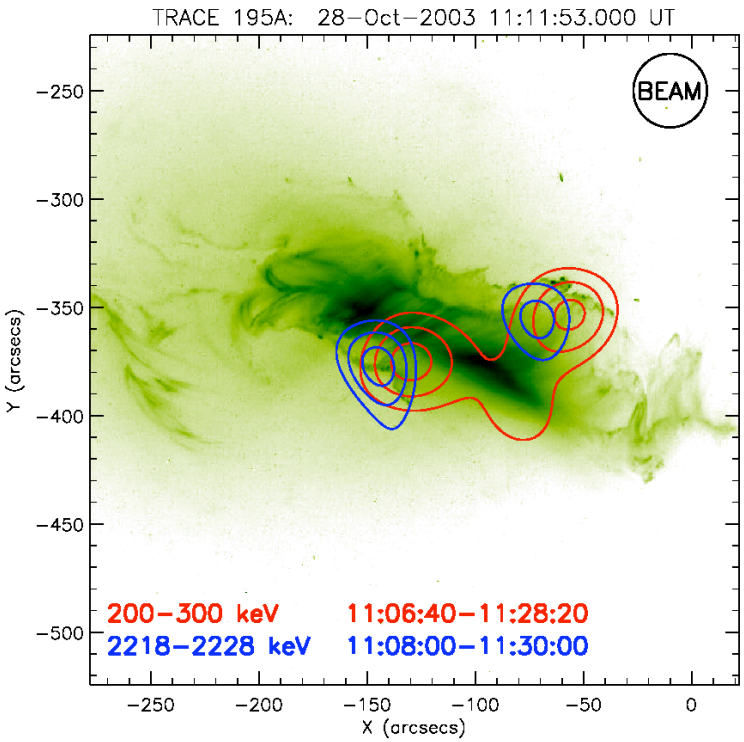


Enough of this spectroscopy stuff. Let's clarify things with some nice images.

No puzzles there. Right!

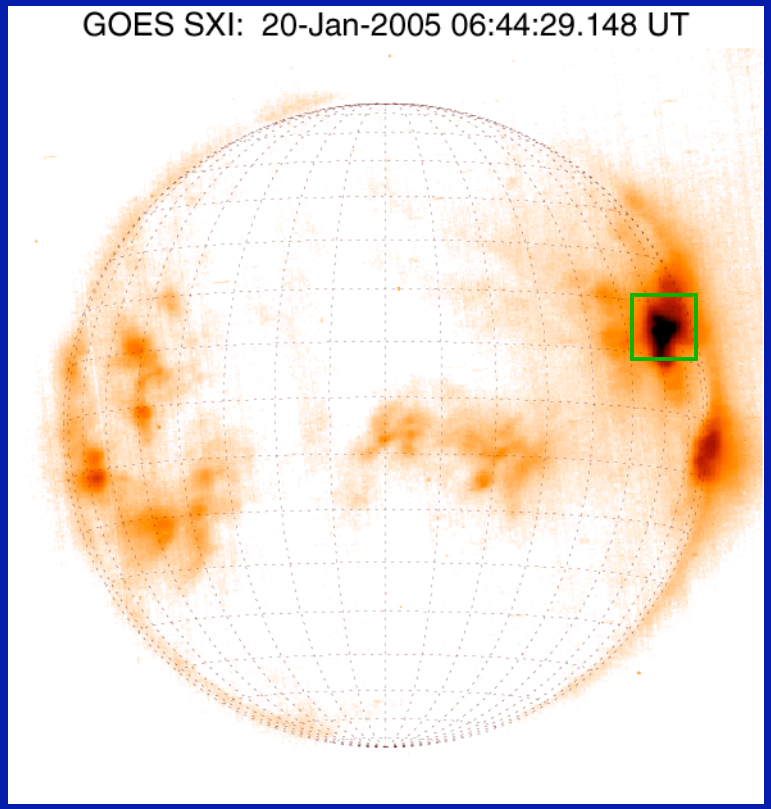
Ok. Explain why the ions and electrons appear to interact in two sets of footpoints separated by ~15 arc sec.

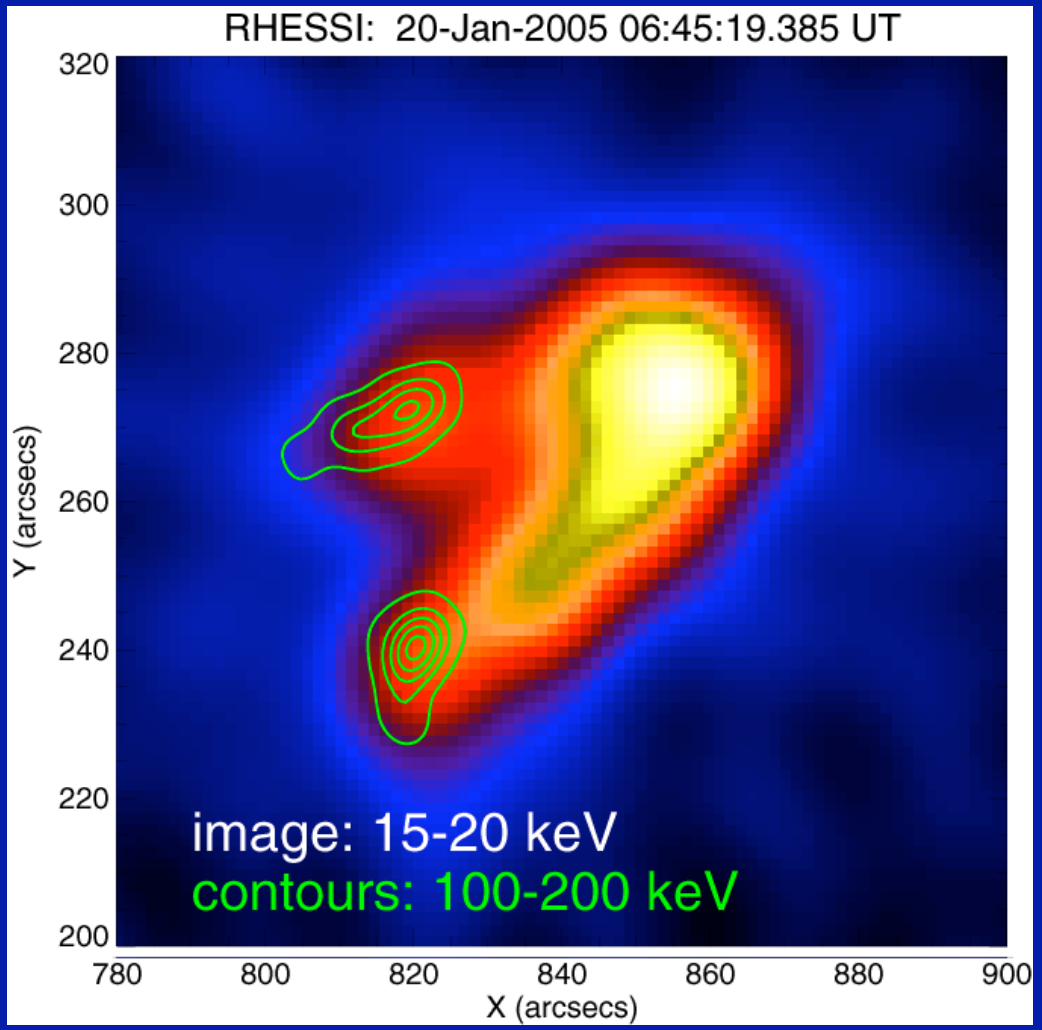
First found in the 2002 July 23 flare (Hurford et al.)



X-ray imaging

RHESSI X-ray imaging during HXR peak:



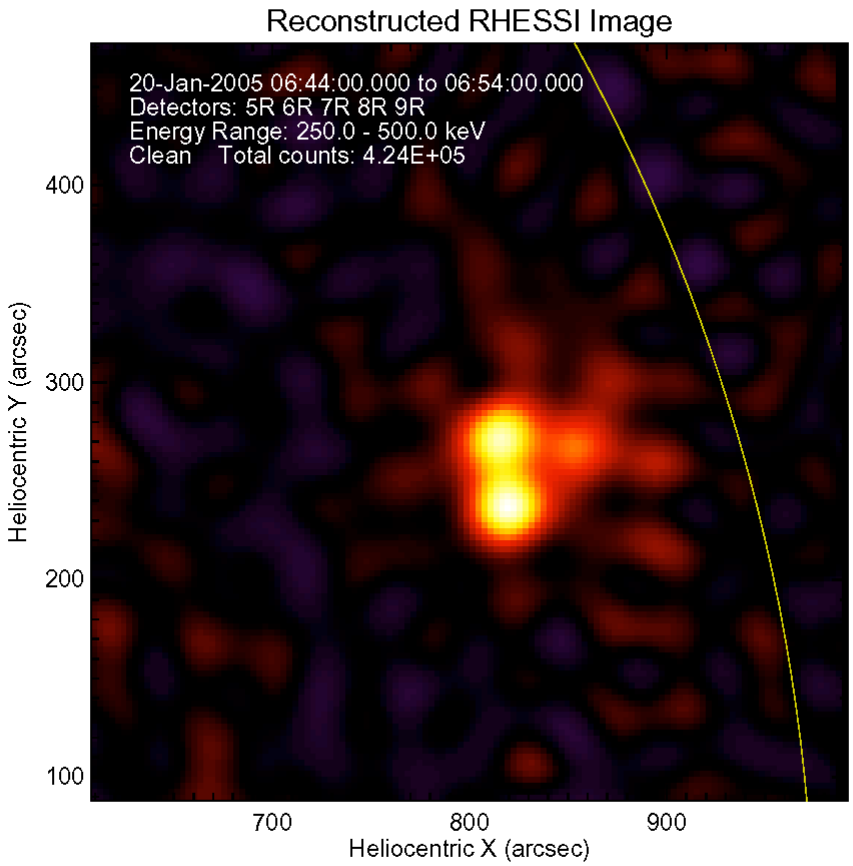


Two ribbon flare with HXR footpoints (contours) with thermal loop (image)

250-500 keV

06:44-06:54

RMCs 5,6,7,8,9



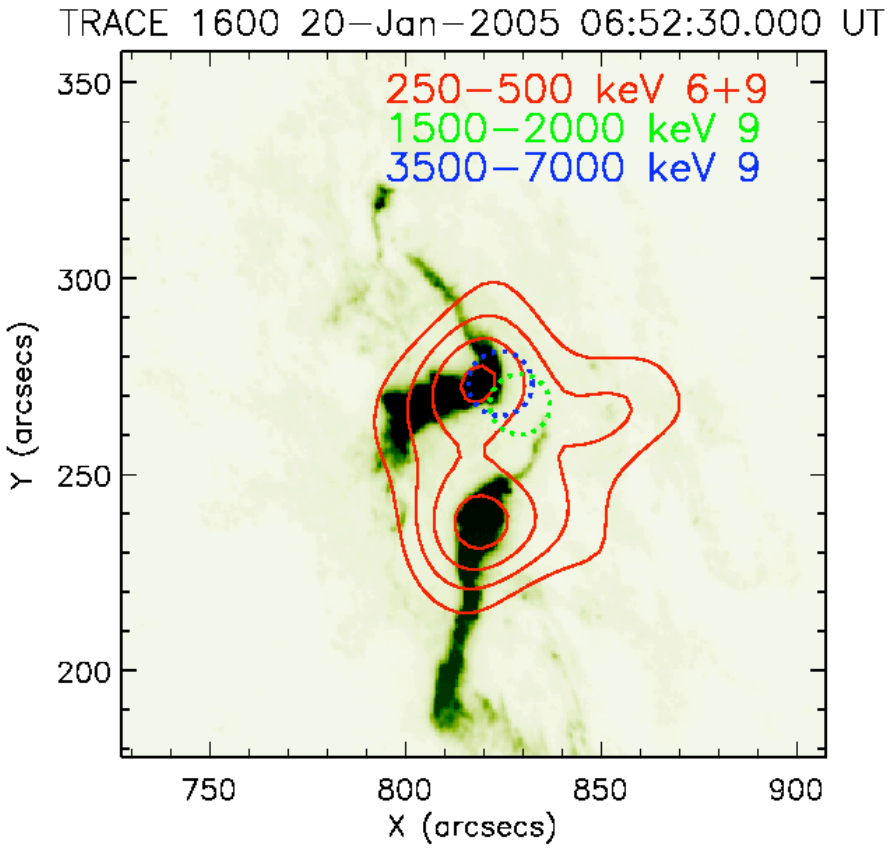
A 250-500 keV coronal source!

It is 12:30 AM and they are playing BeeBopAluma.

I must be seeing things!

Ask Gordon for the explanation. He'll say this wasn't the first time this was seen.

High Energy Overlay



06:44-06:54

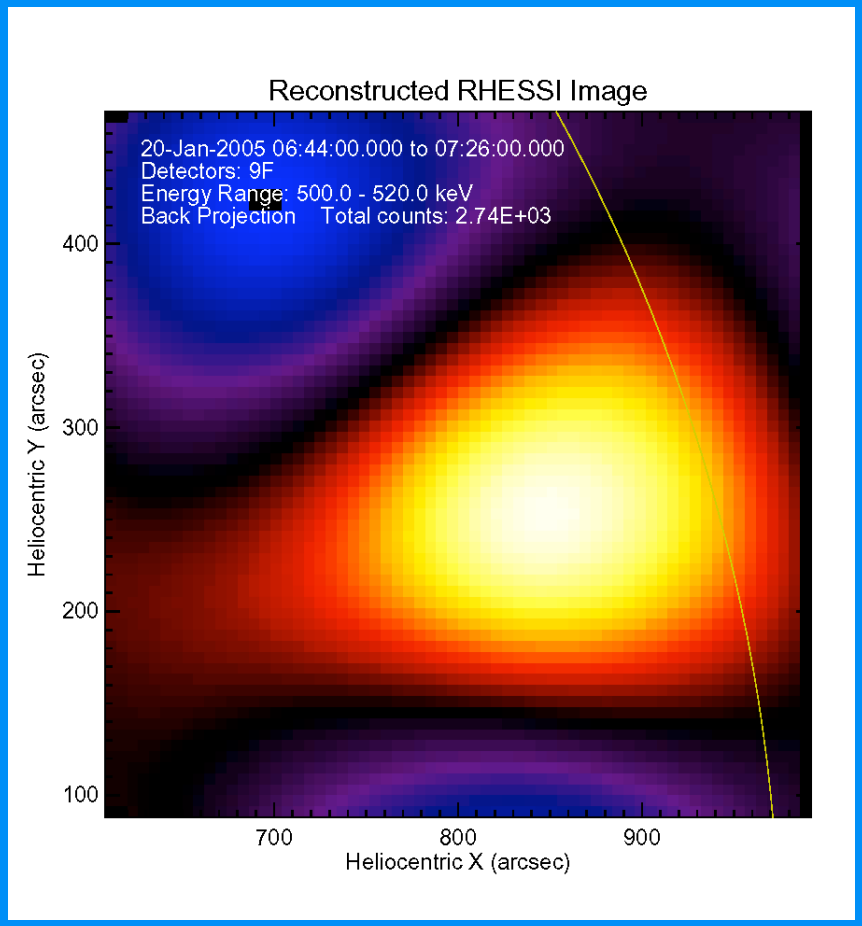
Thanks to Gordon Hurford

And now for the finale! Play it again Sam!!

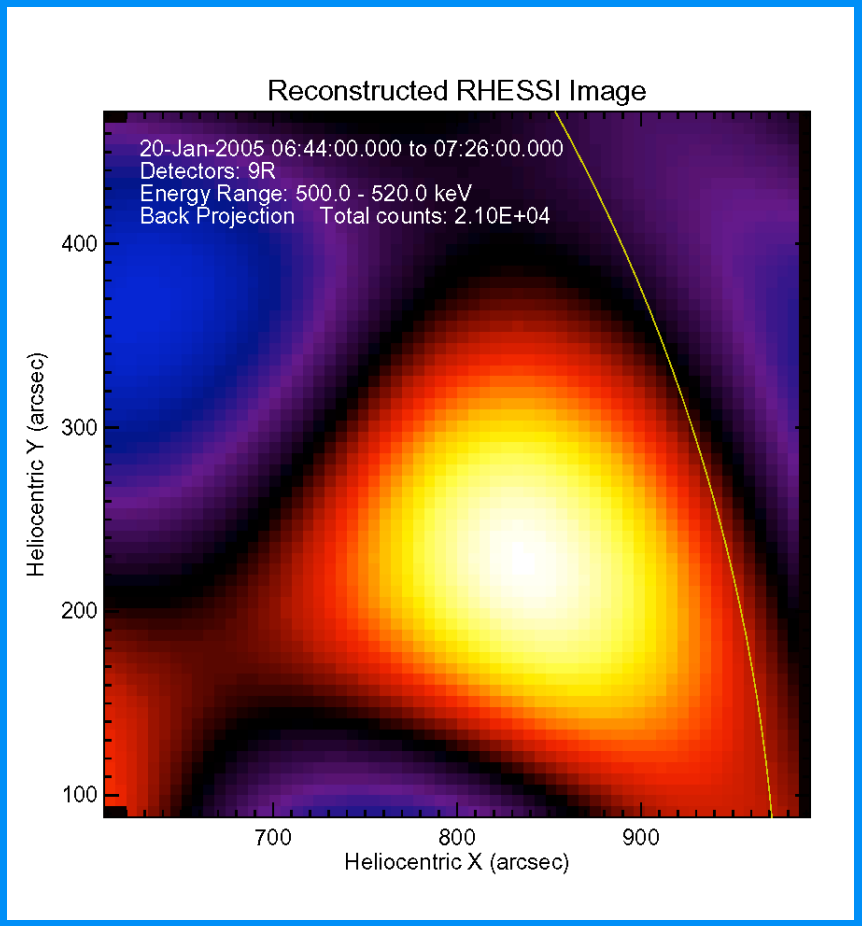
RHESSI images the 511 keV line for the first time!!

Kudos--Gordon (which Gordon?)

Grid 9 mapping 500-520 keV



Front segment



Rear segment

Before you applaud, ask Gordon and Gerry why the number of imaged photons are about 40% of the number found by spectroscopy.

(As I write this, the band has started playing the Charleston. Dance anyone?)