

Hot onsets at radio wavelengths

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Synopsis: Flare precursors begin at high temperatures (~10 MK), the “Hot Onsets” (2021MNRAS.501.1273H) as seen by GOES.

(1) What do radio wavelengths show?

(2) Can we use this information for prediction?

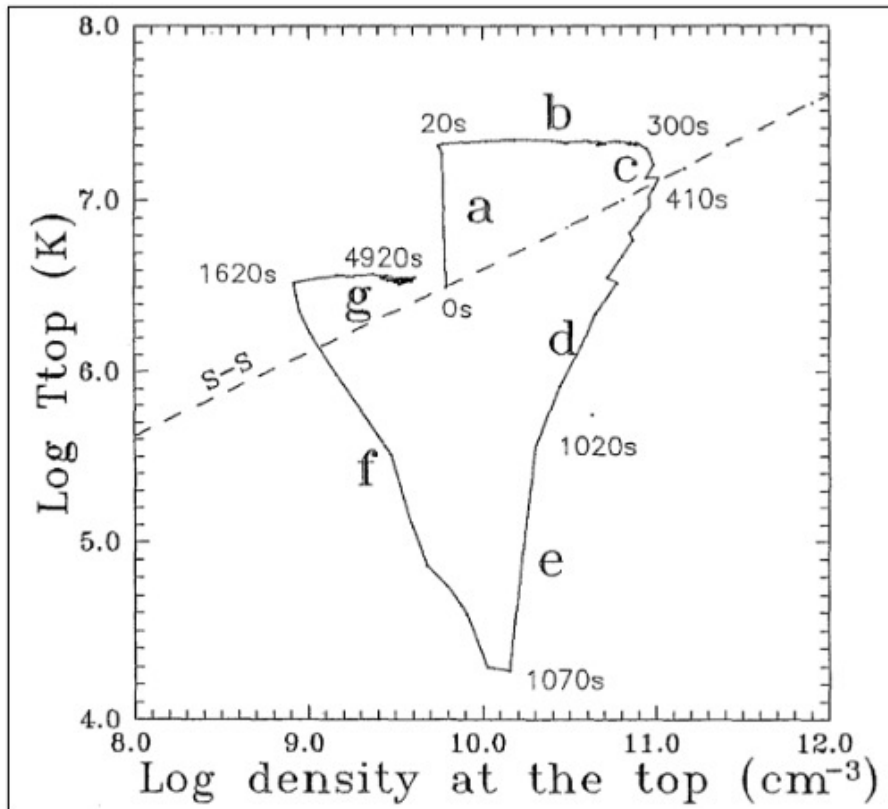
Flare precursor phenomena

- Expansion of magnetic field
- Filament activation
- Pre-event flare events
- Dm spike bursts
- Preflare EUV dimmings
- “Turbulent” line broadening
- Thermal gyroresonance (Van Hoven & Hurford 1984)
- ...
- ***HOPE (Hot Onset Precursor Event) (Hudson et al. 2021)***

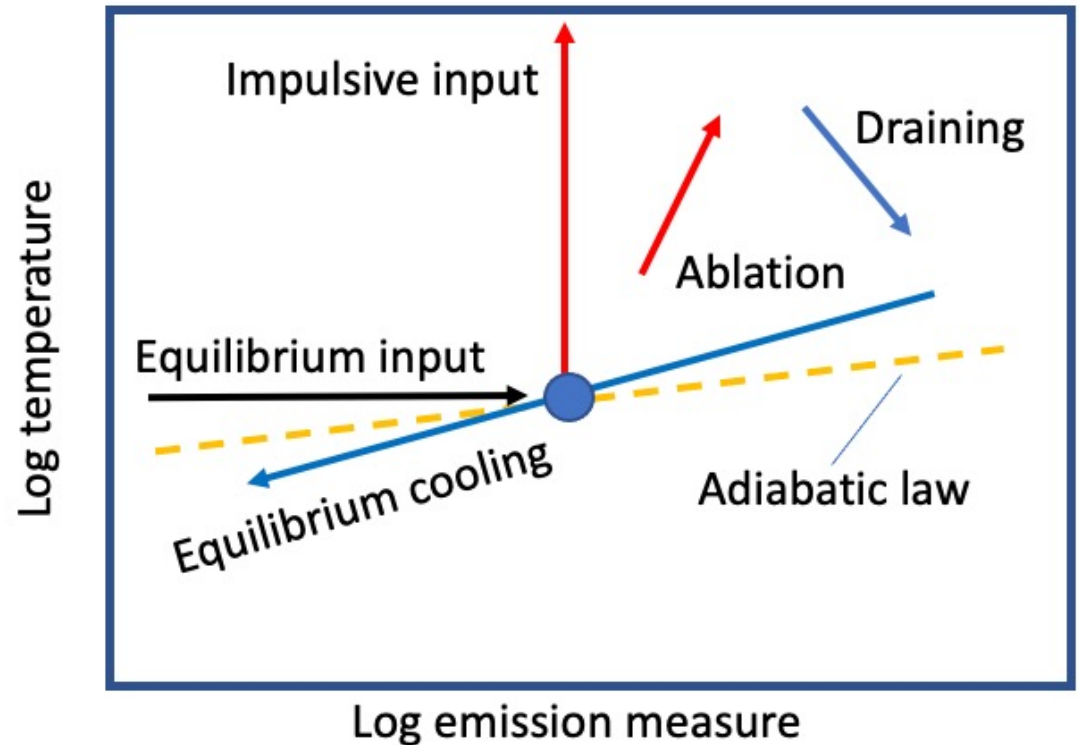
HOPE and the “horizontal branch”

- “Hot onsets” for solar flares recently recognized:
 - GOES (T, EM) data show the initial flare to be hot already
 - The hot onset phase precedes the impulsive phase and is not described by standard theories
- The observational characteristic in Sun-as-a-star data is a “horizontal branch” in the (T, EM) diagram *preceding* the Neupertian clockwise loop
- The HOPE indicates hot plasma that might have a **gyroresonance** precursor signature in strong fields

No-HOPE behavior (the Neupert effect)



Barbara Sylwester original (1996)

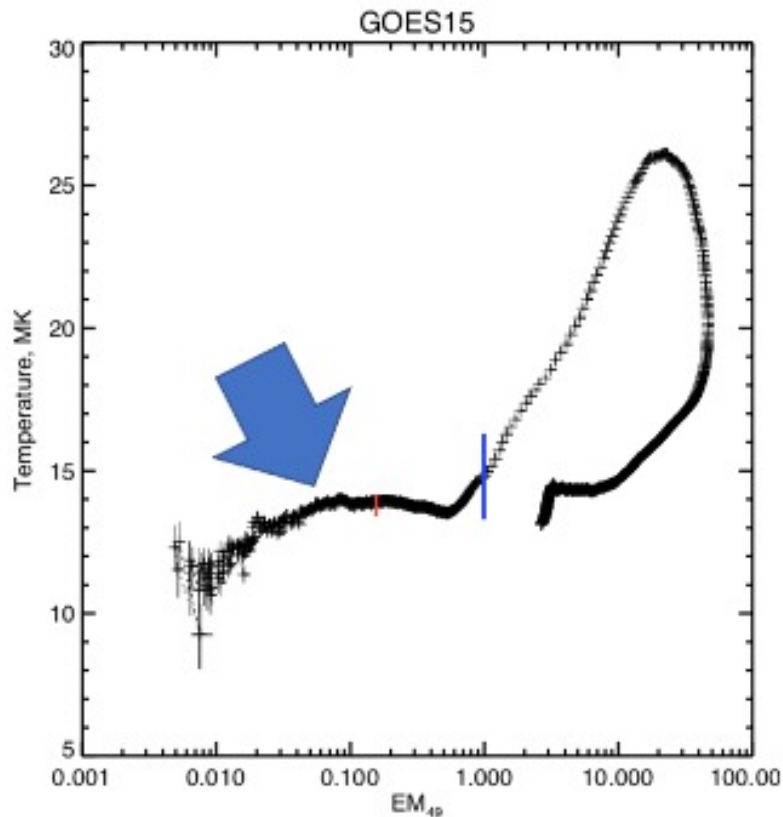
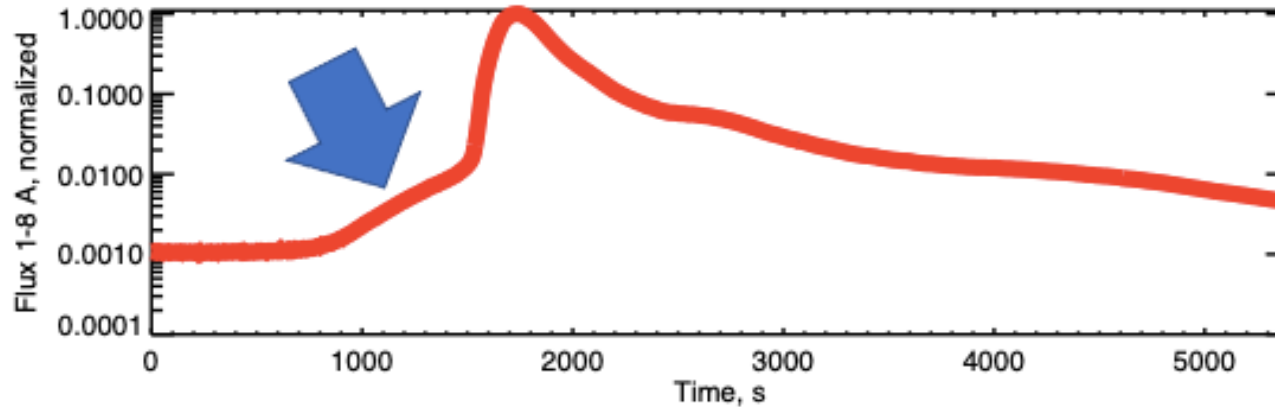


Explanations...

About HOPEs

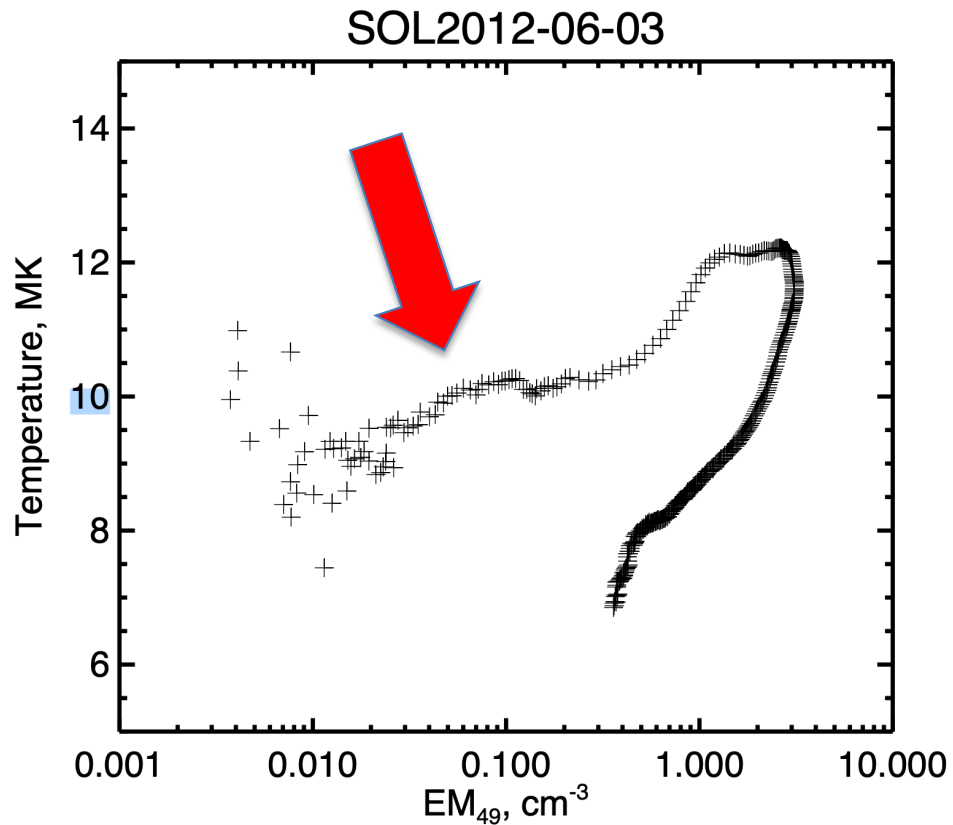
- Virtually every flare shows this behavior
- The initial temperatures (the “horizontal branch”) tend to be at 10-15 MK
- The HOPE precedes the hard X-ray “impulsive phase” (Kane) and represents different plasma physics
- It is not “pre-heating”; we can’t measure dT/dt
- It is not the Neupert effect

A “Slow HOPE”

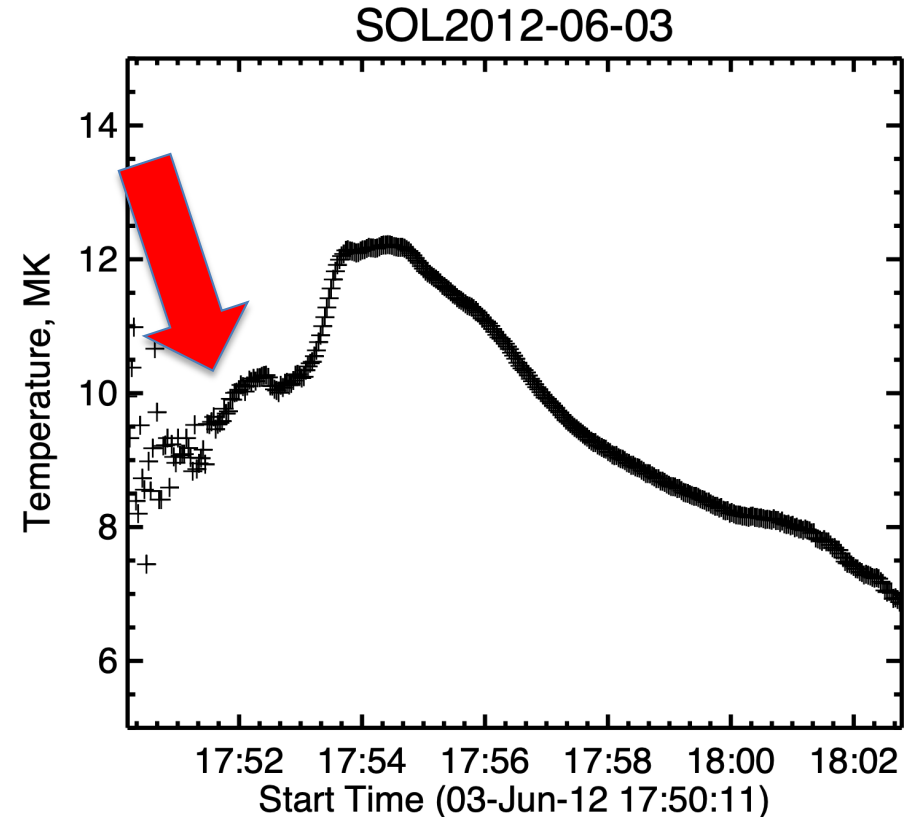


- SOL2011-08-09 (X6.9) has a HOPE lasting for minutes
- The GOES T vs. GOES EM “loopde loop” plot has an apparently smooth horizontal branch.

HOPes at radio wavelengths

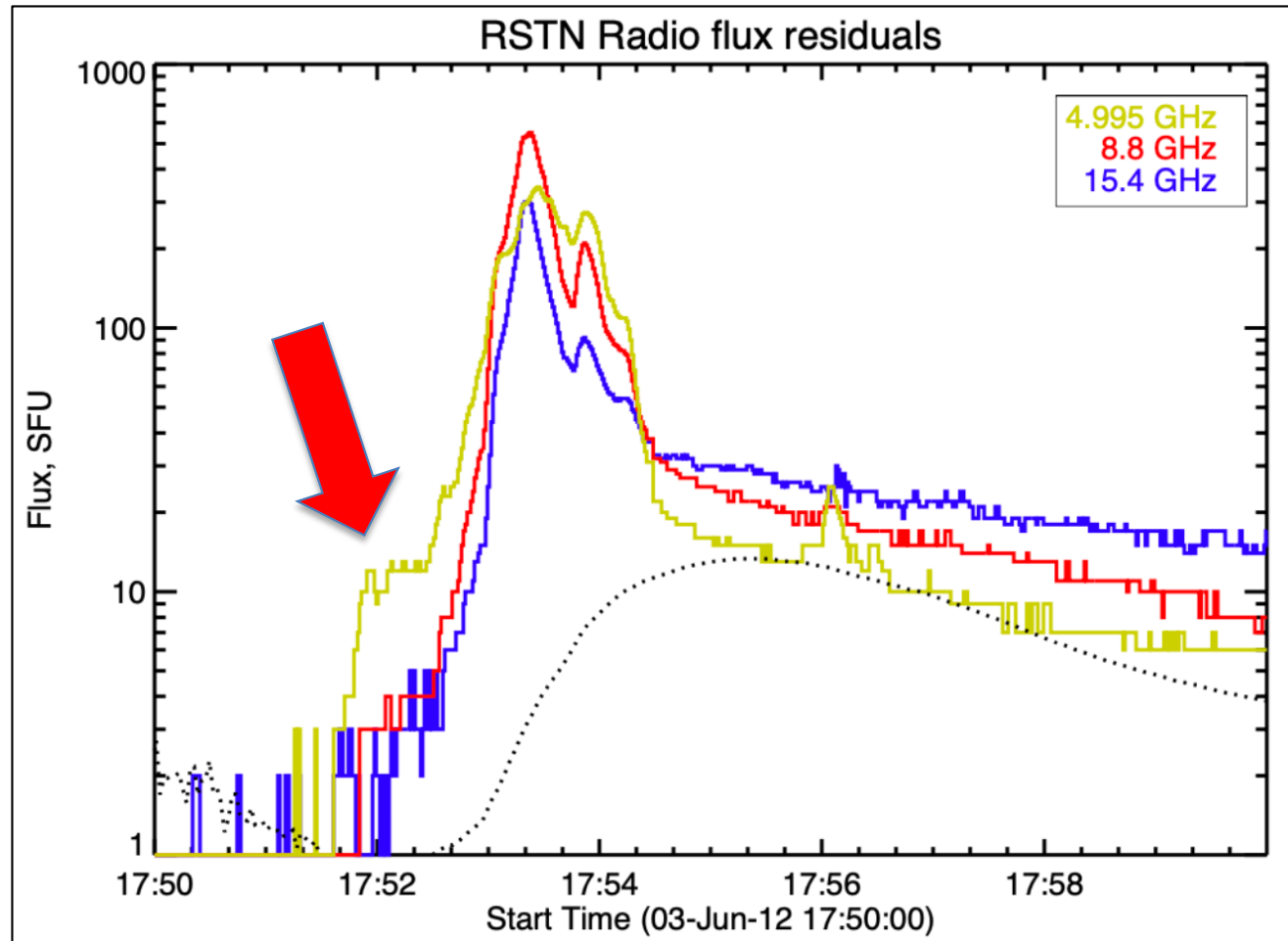


Correlation plot, GOES T vs EM
- Horizontal branch
- Neupert loop



Timeseries plot, GOES T vs time

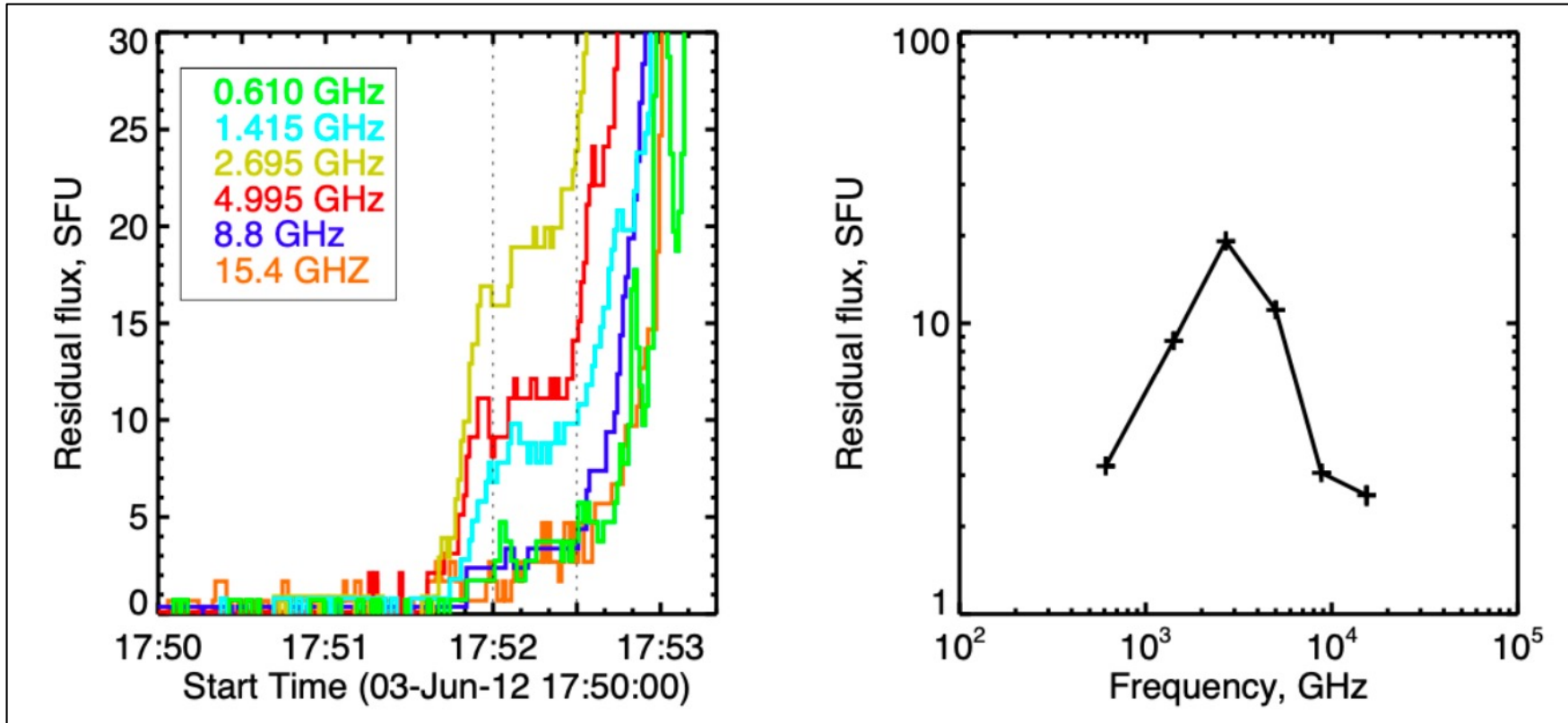
HOPEs at radio wavelengths



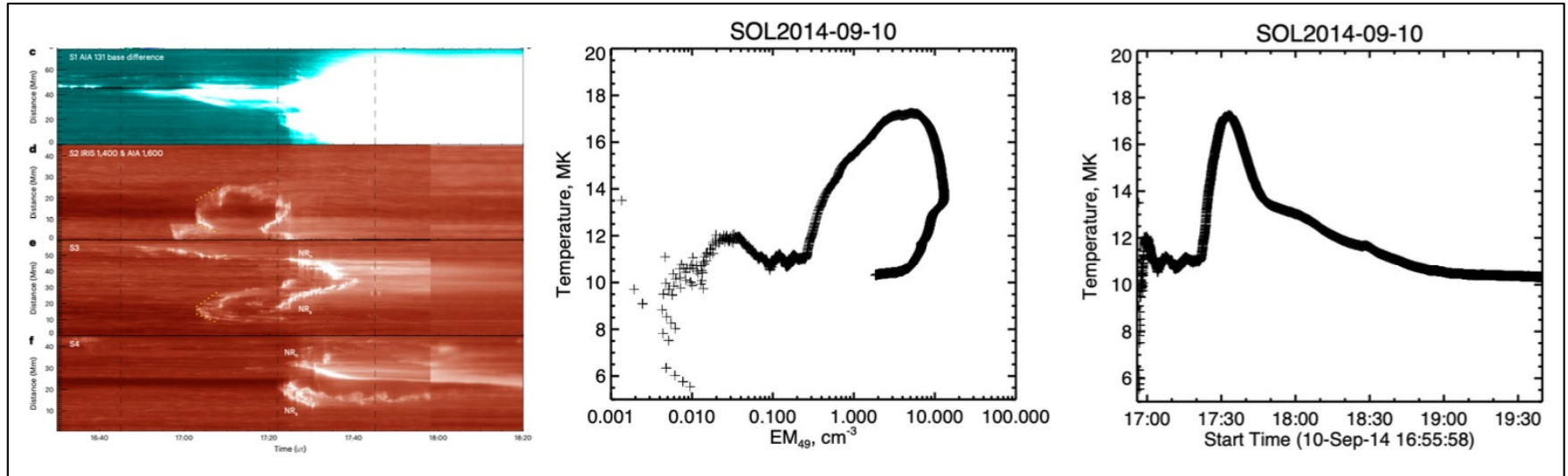
HOPE clearly detectable in RSTN data

- Far above free-free level
- High-frequency cutoff

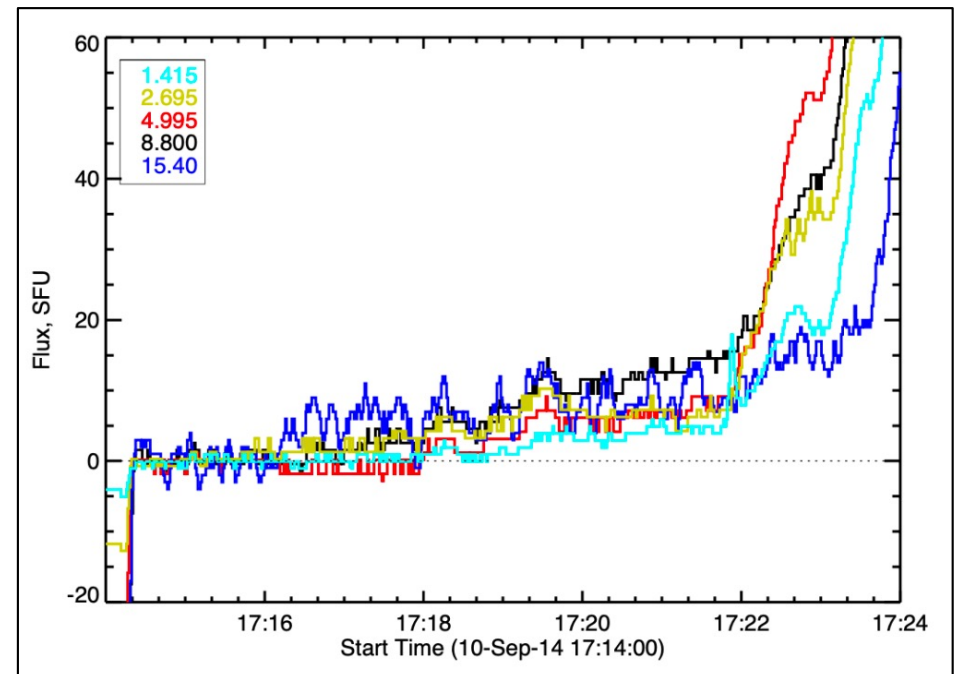
RSTN spectrum



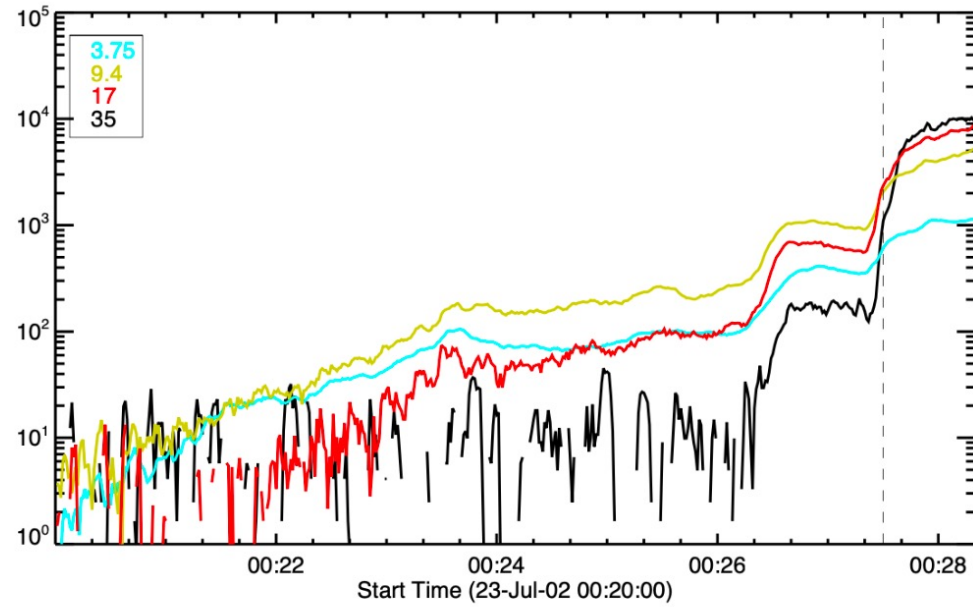
Another example



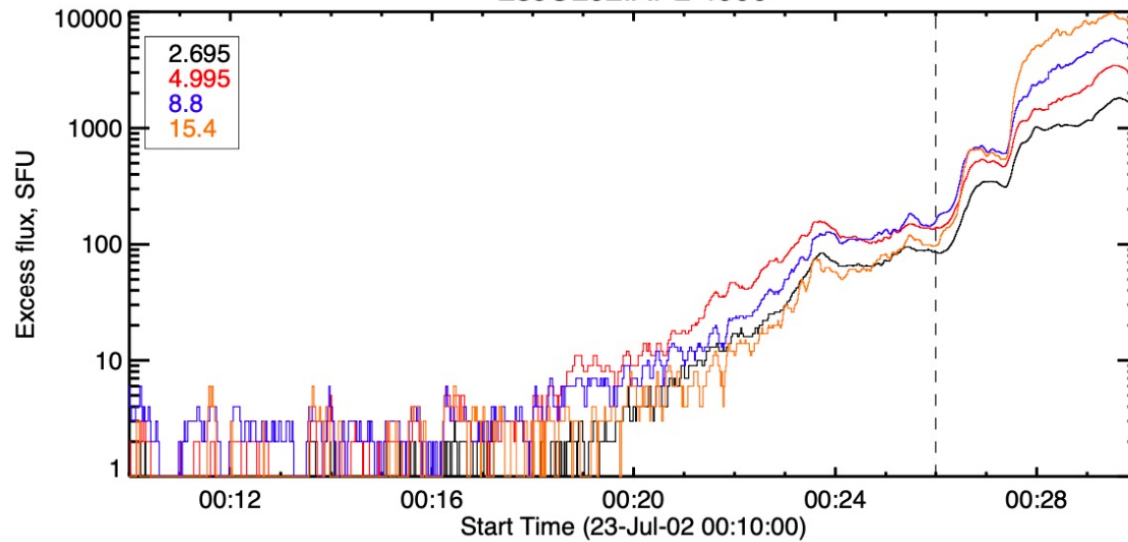
- SOL2014-09-10 IRIS observations (Gou et al., 2023)
 - note precursor dimming
- RSTN possibly to 15.4 GHz
- But this X1.8 flare is still marginal via RSTN



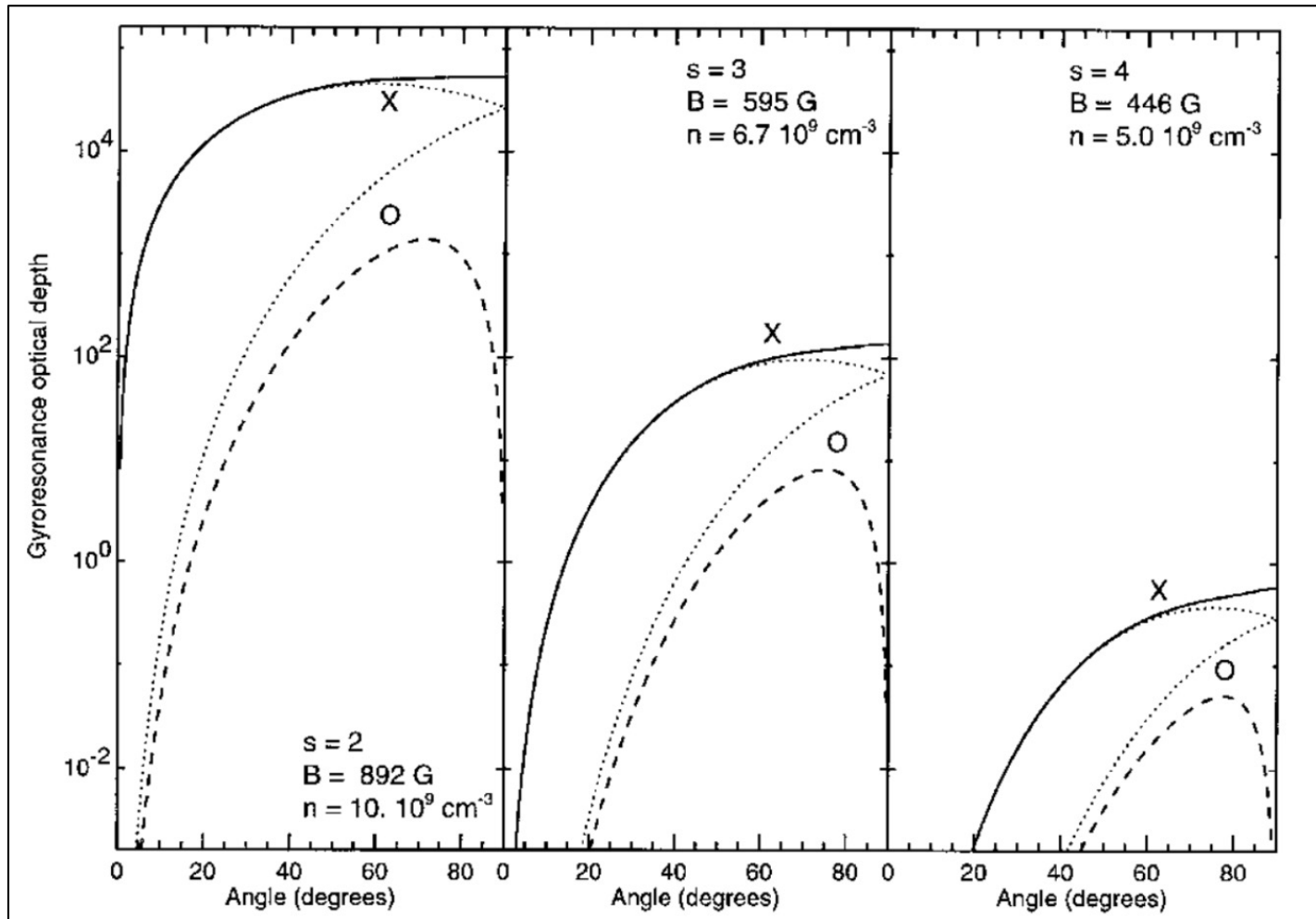
SOL2002-07-23 with NoRP



23JUL02.APL 4000

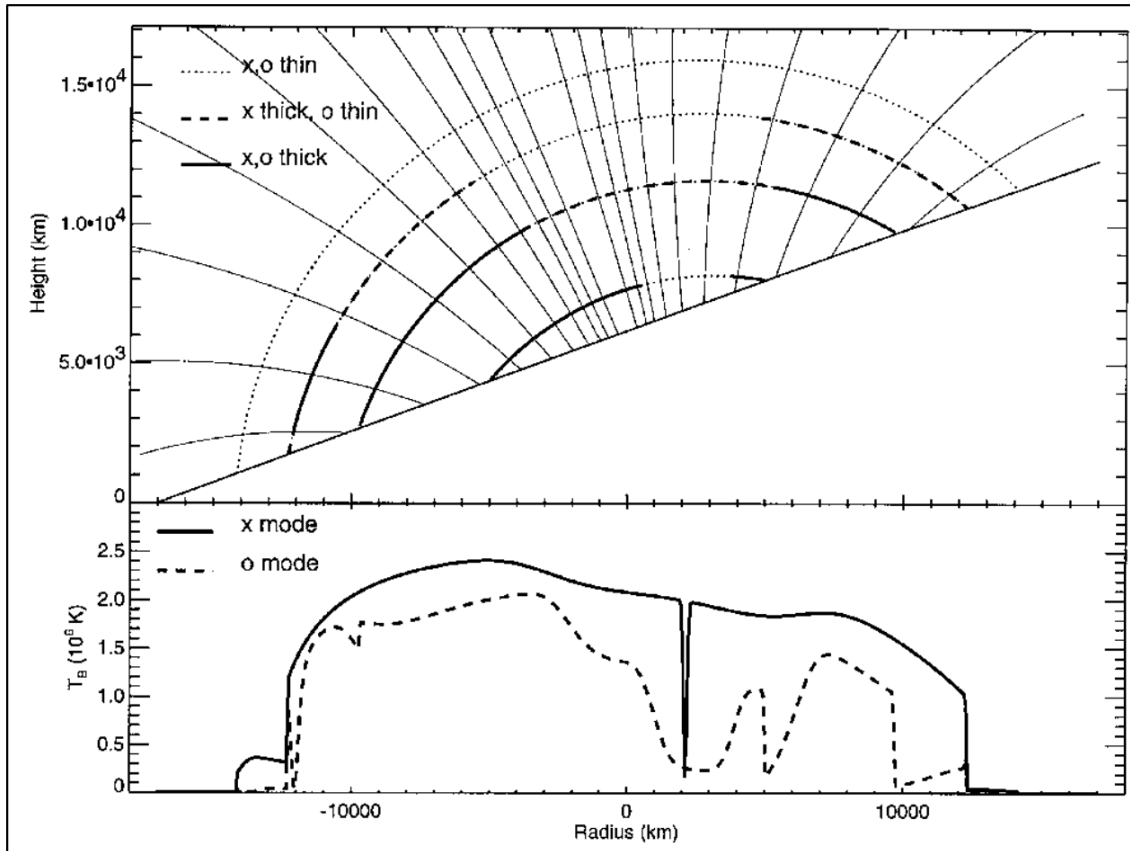


Gyroresonance theory I



White & Kundu 1997

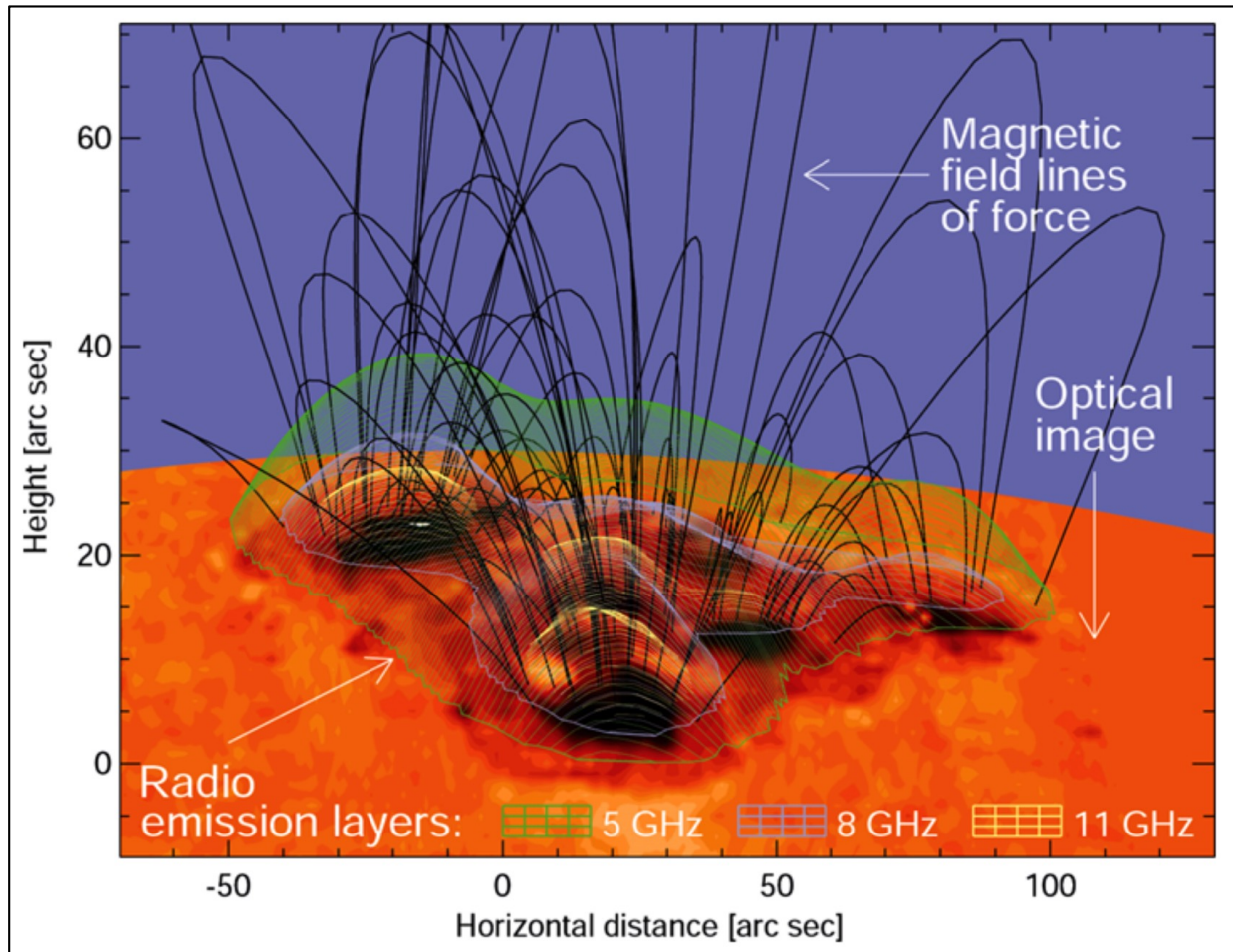
Gyroresonance theory 2



- Simplest possible model, but great complexity
- We would like to study this in HOPEs, where we know [T, EM] vs space and time
- Serious messiness in the opacity calculation, but great opportunities await

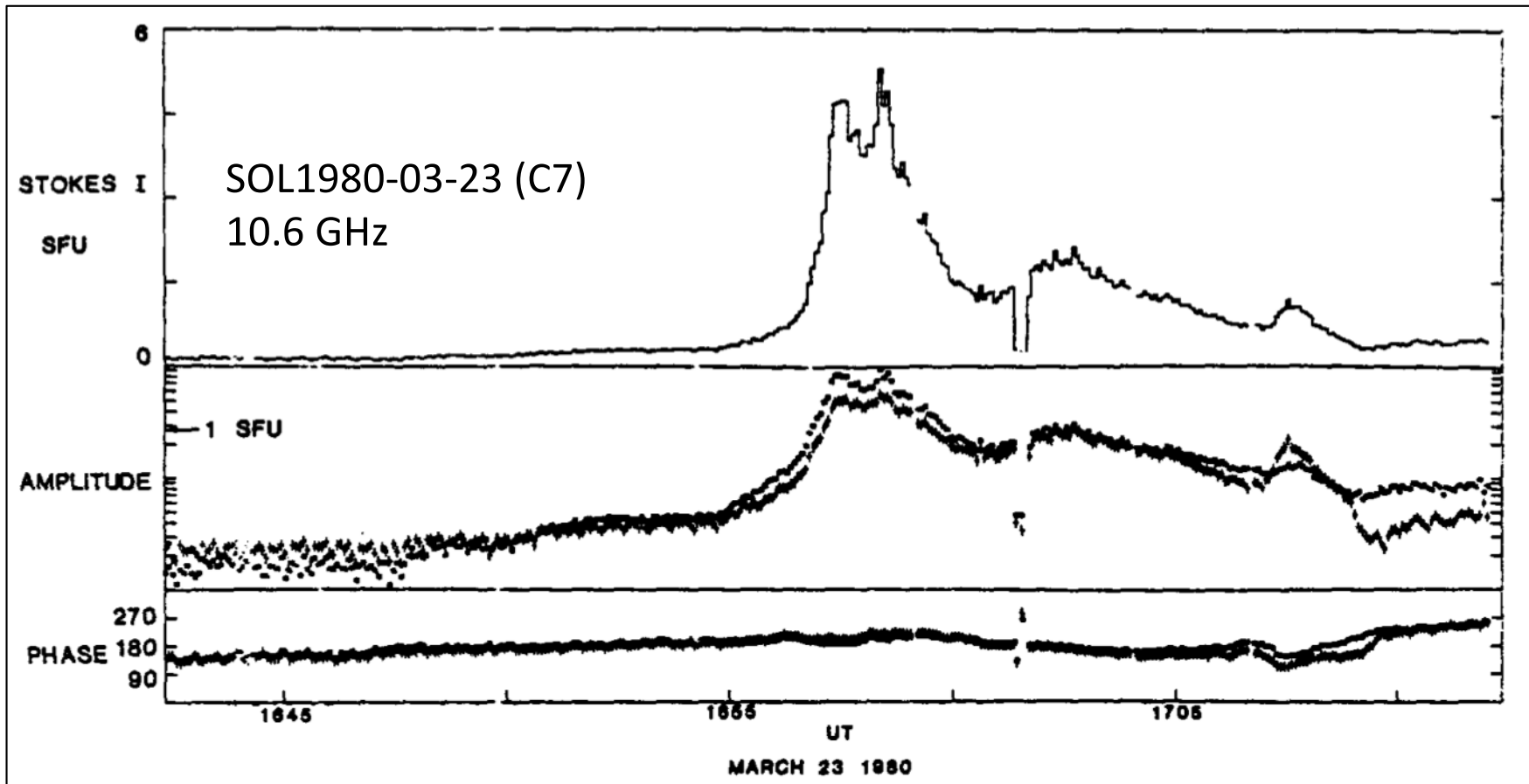
White & Kundu 1997

Gyroresonance spherical cow



Apologies to the artist, but this iconic figure shows a model with smooth features. The field may be smooth, but X-ray images show the AR/flare density to be highly structured – hence so is the gyroresonance opacity.

Some rHOPE history



Van Hoven & Hurford (1984)

- Interferometer sensitivity (better than 1 SFU!)
- Circular polarization diagnostics

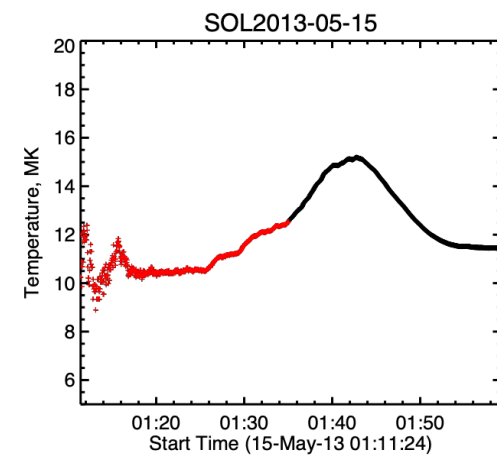
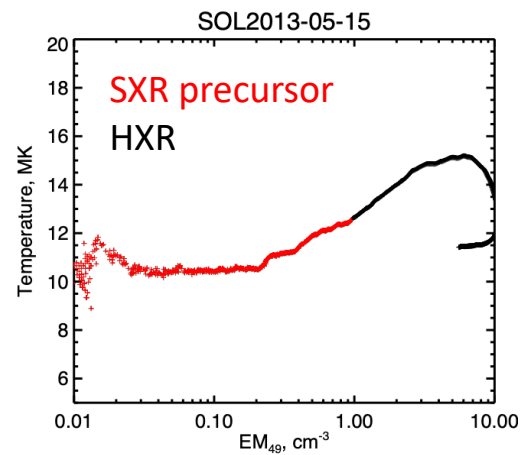
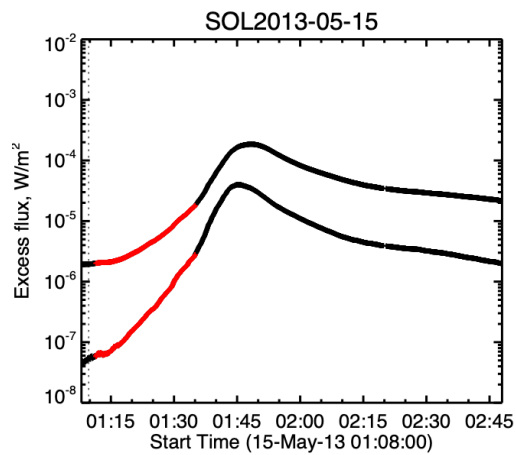
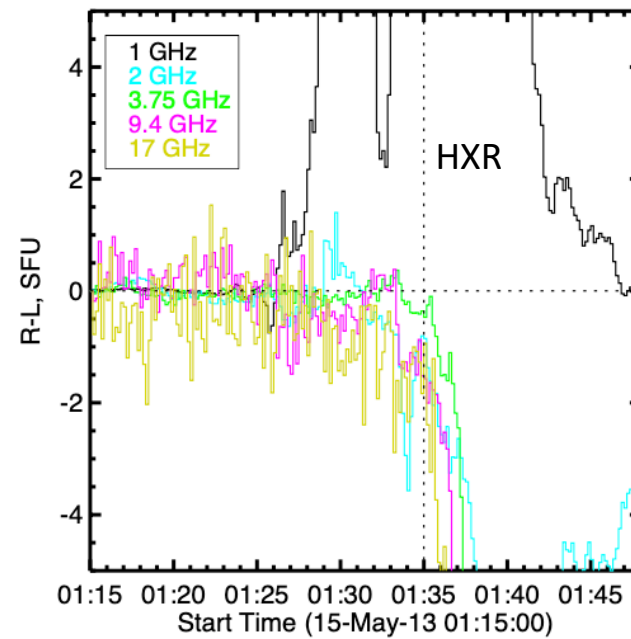
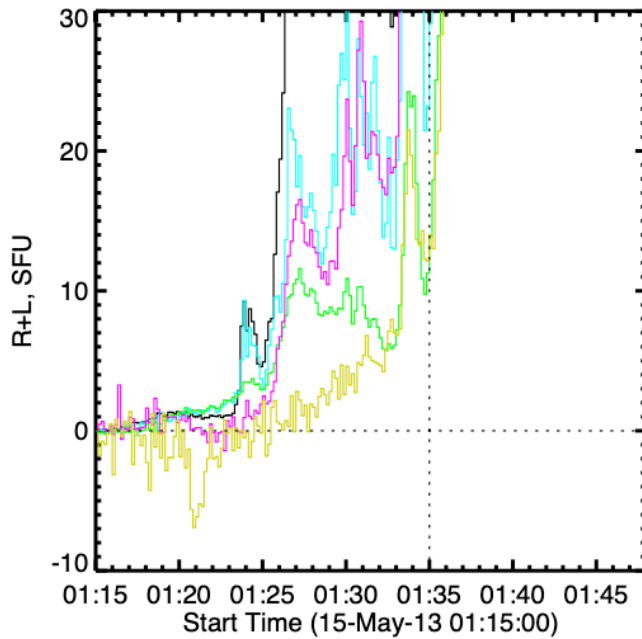
Urgency in flare “prediction”

- HOPE (SXR) alone doesn't predict flare class
- The radio HOPE sources could be different, with gyroresonance showing strong **B**
- Such a handle could help to the flare rocketeers to anticipate a good event

Survey of NoRP data: all X-class flares with *Fermi* HXR coverage

						1	2	4	9	17	GHz
SOL2011-02-15T01:56	X2.2	01:47:00	01:44:00	-	2	-	-	3	-	-	SFU
SOL2011-03-09T23:23	X1.5	23:19:00	23:17:00	-	-	7	13	2			
SOL2011-09-06T22:20	X2.1	22:16:00	22:12:00	1	2	-	-	-			
SOL2011-09-07T22:38	X1.8	22:35:20	22:33:00	-	-	-	2	-			
SOL2012-03-05T04:09	X1.1			chaos in all bands!							
SOL2012-10-23T03:17	X1.8	03:15:00	03:10:00	-	-	-	2	25			
SOL2013-05-14T01:11	X3.2	01:00:00		no rHOPE							
SOL2013-05-15T01:48	X1.2	01:32:30	01:27:30	25	20	11	16	-			
SOL2013-10-28T02:03	X1.0			no rHOPE							
SOL2014-02-25T00:49	X4.9	00:41:00	00:36:00	-	-	2	-	-			
SOL2014-10-19T05:03	X1.1	04:18:00	04:10:00	2	4	7	15	15			
SOL2015-05-05T22:11	X2.7	22:07:00		no rHOPE							
SOL2022-04-17T03:34	X1.1	03:22:30		no rHOPE							
SOL2023-01-06T00:57	X1.2	00:55:00		no rHOPE							

NoRP event SOL2013-05-15



Survey Conclusions

- rHOPE signatures do exist in the NoRP data
- In our X-class sample, 4/13 hits
- The flux levels far exceed free-free levels predicted by the HOPE SXR
- There may be strong time variability
- Circular polarization is not strong

Recommendations

- Extend the NoRP sample to M class
- Compare image relationships to spots
- Use EOVSAs or other imaging spectroscopy
 - The rHOPE fluxes are weak, and imaging may reduce the background fluctuations
 - The details of the spectrum will be highly important diagnostically

Conclusions

- rHOPE is fairly common in major events, but not universal
- The rHOPE alone don't anticipate flares
- The events are well worth studying with GX Simulator software even so