

# Recent Developments in Solar Quake Studies

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# Outline

- 1 Introduction
- 2 Survey
- 3 Multiwavelength Analysis
  - 29 Oct 2003
  - 16 Jul 2004
- 4 Conclusions

# Brief History

The first "sun quake" was discovered by [Kosovichev & Zharkova \(1998\)](#).

Sun quakes are expanding ring-like waves  
excited by solar flares and observed on the Sun surface.

[Kosovichev & Zharkova \(1998\)](#): time-distance diagrams to recognise sun quakes

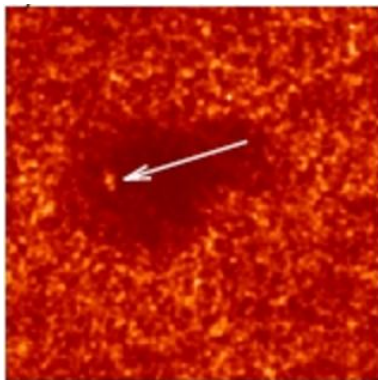
Computational helioseismic holography - ([Donea & Lindsey 1999, 2005](#))

[Fisher, Canfield and McClymont \(1985\)](#) modelled wave generation in chromosphere as a result of sudden thick target heating of the upper chromosphere by high energy particles. [Kosovichev and Zharkova \(1998\)](#) source of seismic emission from flares

Comparisons by [Donea & Lindsey \(2005\)](#) between holographic signatures and impulsive HXR signatures from RHESSI strongly reinforced this proposition.

Following [Donea & Lindsey \(2005\)](#) exhaustive helioseismic survey of all X- and large M-class flares

# Computational Helioseismic Holography

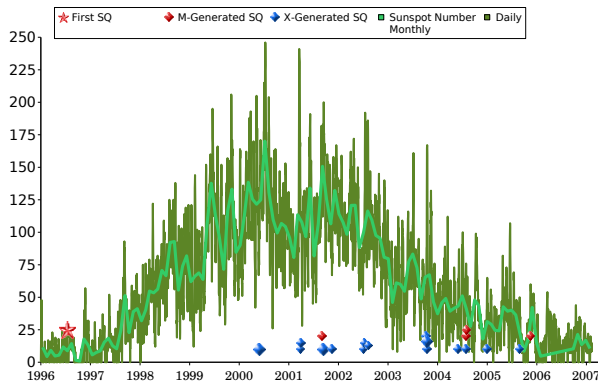


(Donea & Lindsey, 2005)

Egression Power Snapshot  
of the [2003 Oct 29, X10](#)  
flare

- representation of the  
acoustic field at flare  
maximum reconstructed  
from outgoing ripples from  
14 to 60 Mm from the site  
of the flare between 30 and  
60 minutes after the  
impulsive phase of the flare

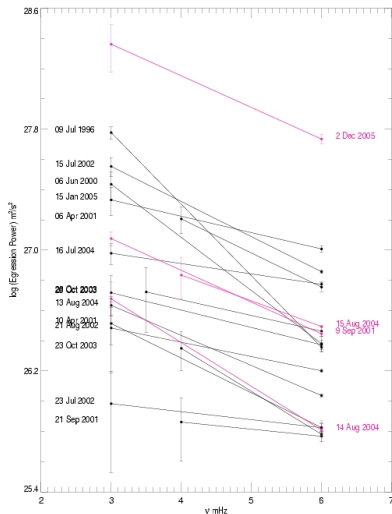
# High Seismicity in S.C. 23



- 13 X-class generated sun quakes
- 4 M-class generated sun quakes

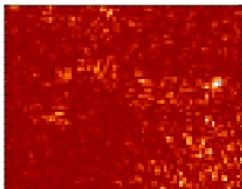
| Year | Month | Day | AR                   | LO    | BO    | Begin (UT) | Max (UT) | End (UT) | Type  | Observations   | Proton Event | White Flare | SQ Begin (UT) | SQ Max (UT) | SQ End (UT) | Seismic Energies 3 mHz (erg) | Seismic Energies 6 mHz (erg) | GOES Xray (f/m <sup>2</sup> ) |
|------|-------|-----|----------------------|-------|-------|------------|----------|----------|-------|--|--------------|-------------|---------------|-------------|-------------|------------------------------|------------------------------|-------------------------------|
| 1996 | 7     | 9   | <a href="#">7978</a> | 248.5 | -10.5 | 09:01      | 09:12    | 09:49    | X 2.6 | <i>First sunquake discovered by Kosovichev; its acoustic source detected by A.C.Donca &amp; C. Linsday</i> | -            |             | 09:01         | 09:13       | 09:19       | 7.50E+27                     | 8.90E+26                     | 7.30E-02                      |
| 1997 | 11    | 4   | <a href="#">8100</a> | -     | -     | 05:52      | 05:58    | 06:02    | X 2.1 | No data  | X            |             | -             | -           | -           | -                            | -                            | 5.60E-02                      |
| 1997 | 11    | 6   | <a href="#">8100</a> | -     | -     | 11 49      | 11 55    | 12 01    | X 9.4 | 9R centred on another AR   | X            |             | -             | -           | -           | -                            | -                            | 3.60E-01                      |
| 1997 | 11    | 27  | <a href="#">8113</a> | -     | -     | 12 59      | 13 17    | 13 20    | X 2.6 | Not enough data  | -            |             | -             | -           | -           | -                            | -                            | 7.00E-02                      |
| 1998 | 4     | 23  | -                    | -     | -     | 05 35      | 05 55    | 06 23    | X 1.2 | -  | -            |             | -             | -           | -           | -                            | -                            | 2.40E-01                      |
| 1998 | 4     | 27  | <a href="#">8210</a> |       |       | 08 55      | 09 20    | 09 38    | X 1   | No data  | X            |             | -             | -           | -           | -                            | -                            | 1.60E-01                      |
| 1998 | 5     | 2   | <a href="#">8210</a> | 135   | -16   | 13 31      | 13 42    | 13 51    | X 1.1 | Negative   | -            |             | -             | -           | -           | -                            | -                            | 6.70E-02                      |
| 1998 | 5     | 6   | <a href="#">8210</a> | -     | -     | 07 58      | 08 09    | 08 20    | X 2.7 | No data  | X            |             | -             | -           | -           | -                            | -                            | 2.10E-01                      |
| 1998 | 8     | 17  | -                    | -     | -     | 21 10      | 21 20    | 21 30    | X 1.2 | -  | -            |             | -             | -           | -           | -                            | -                            | 9.30E-02                      |
| 1998 | 8     | 18  | <a href="#">8307</a> | -     | -     | 08 14      | 08 24    | 08 32    | X 2.8 | No data  | -            |             | -             | -           | -           | -                            | -                            | 1.70E-01                      |

# Acoustic Hardness Power Spectrum

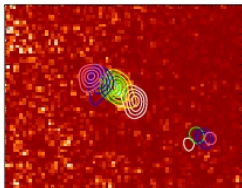
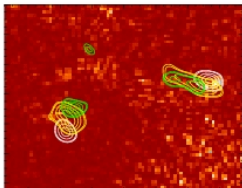
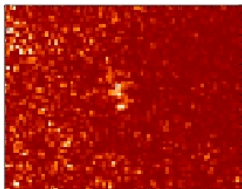


# RHESSI Hard X-Ray Signatures

28 Oct 2003



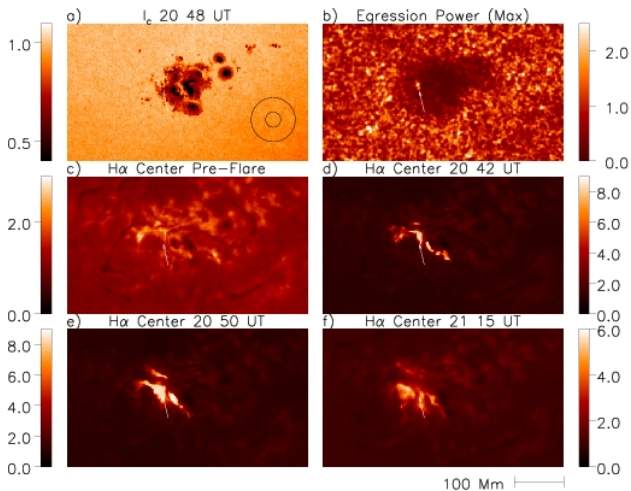
29 Oct 2003



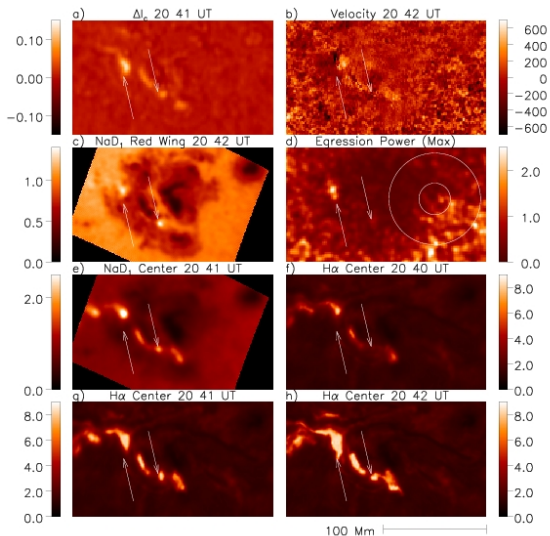
Donea & Lindsey  
(2005): elongated  
kernel structure of  
the acoustic  
signature  $\leftrightarrow$  rapid  
motion of the HXR  
source



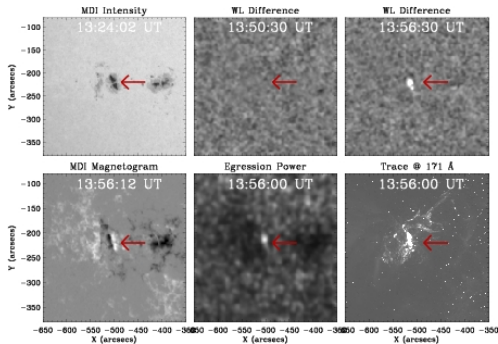
# H $\alpha$ Observations



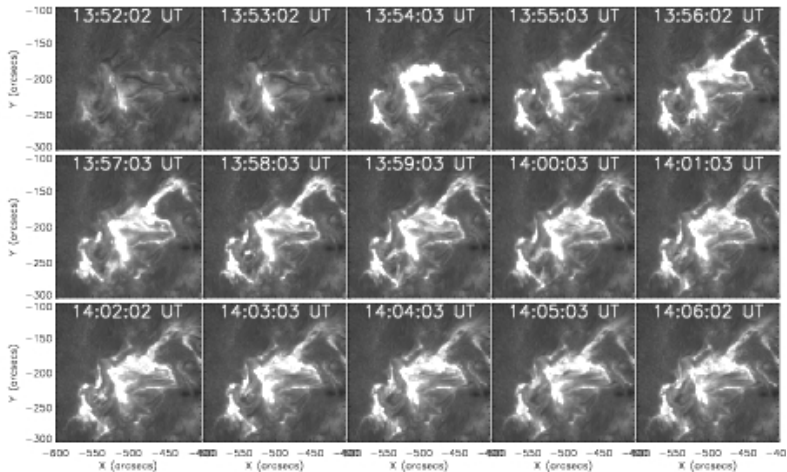
# H $\alpha$ & NaD<sub>1</sub> Observations



# Observations of the 16 July 2004 Flare



# H $\alpha$ Observations



# Conclusions (?)

- **H $\alpha$  signatures encompass seismic signatures**
- 3-D structure of seismically active regions
- Multiwavelength analysis
- coincidence with sudden continuum emission => heating of the chromosphere
- physical modeling of flare acoustic emission

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Thank you!