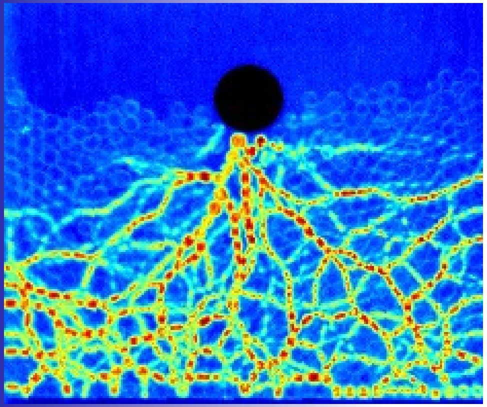
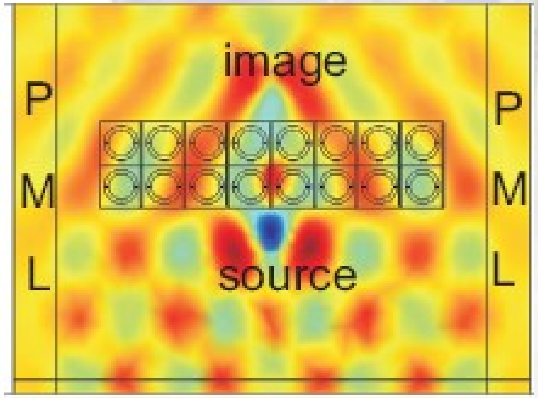
Hot Topics in Physical Acoustics





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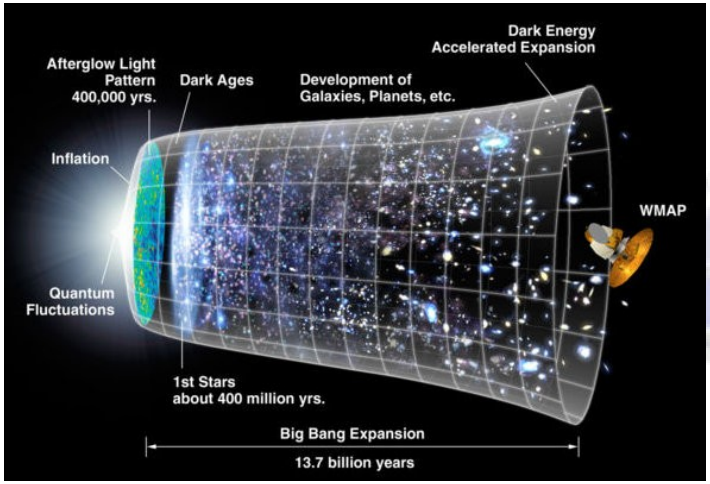


ASA Fall Meeting
November 12, 2008

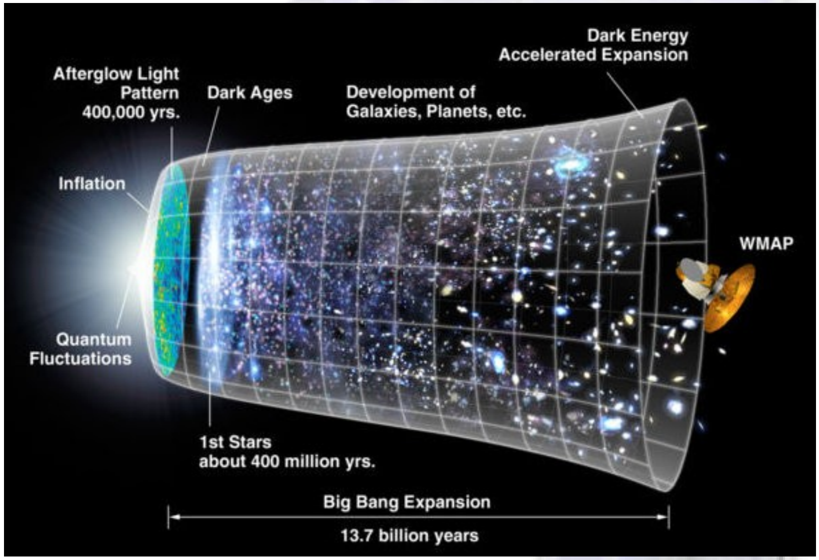
Outline

- **Sound waves in the early universe**
  - Nature of sound in a hot plasma
  - Acoustic imprint in the microwave background
  - Connections to dark energy and matter
- **Acoustics and slip-stick friction**
  - A table top model fault zone
  - The role of transient elastic waves
  - Connections to earthquake triggering
- **Acoustic Metamaterials**
  - Generalized wave phenomenon
  - Coherent scattering effects:
    negative index of refraction, band gaps
  - Applications: acoustic lenses, filters, cloaking

Sound waves in the early universe

- After Inflation phase (0 – 380k yrs)
- Baryonic (n,p) matter was fully ionized
- Acoustic waves driven by **radiation** pressure

  - Momentum transfer between photons and free electrons
  - **Source:** small, early (quantum?) fluctuations in photon density
    ⇉ radiation pressure gradients
    ⇉ propagating sound waves.



Courtesy of NASA/WMAP Science Team

Reference: Eisenstein and Bennett, *Physics Today*, p. 44-50,April 2008

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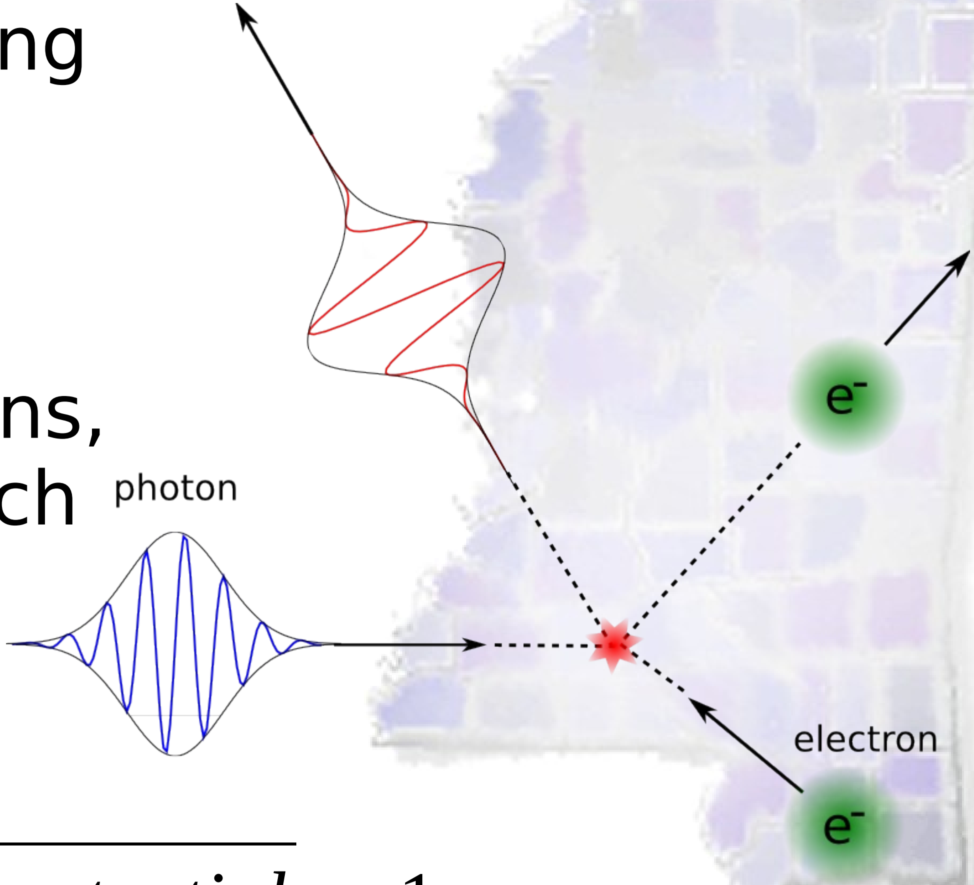
Radiation Pressure

- Compton scattering

$$p_\gamma = \frac{h}{\lambda}$$

- Analogous to molecular collisions, BUT inertia is much lower



- Speed of sound

$$v = \sqrt{\frac{\textit{restoring potential}}{\textit{inertial property}}} = \frac{1}{\sqrt{3}}c$$

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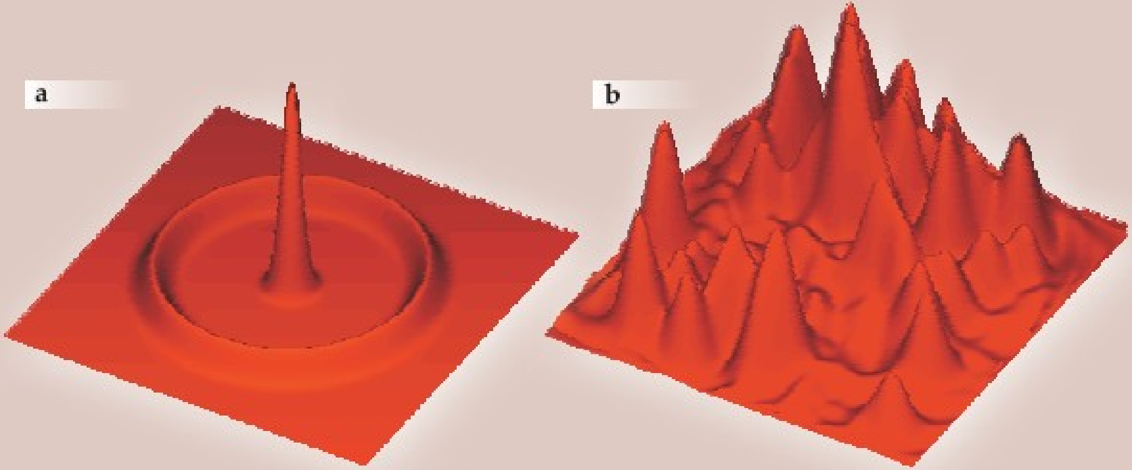
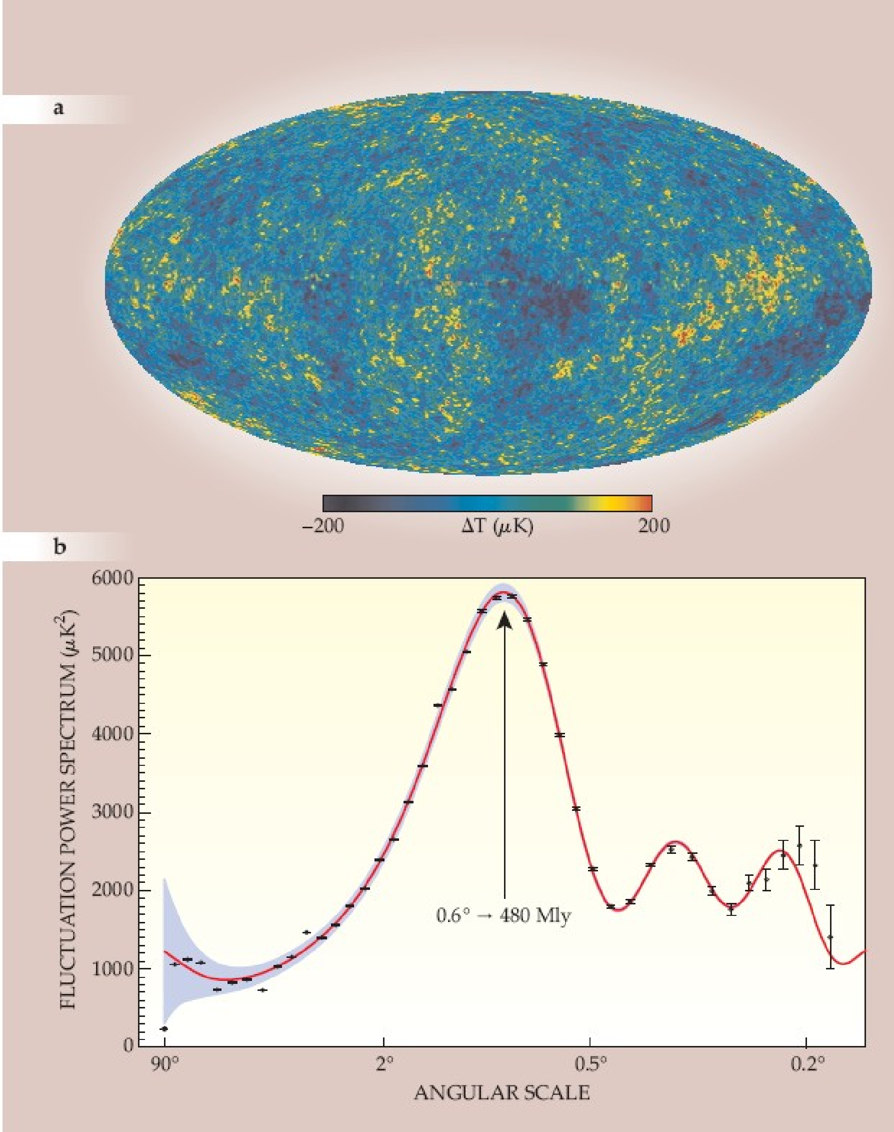
The end of the acoustic era

- At Recombination (~380k years), free electrons dropped by 10^4
- As the restoring potential vanished, the pressure distribution was frozen in time.
- Pattern is still reflected by anisotropies in the cosmic microwave background.



Eisenstein and Bennett, Physics Today, April 2008

Wilkinson Microwave Anisotropy Probe



Eisenstein and Bennett, Physics Today, April 2008

- Pressure map of sound field at Recombination
- Average microwave background: T~2.725K with small variations.
- Power spectrum versus angular size in the sky shows harmonic peaks.
- First peak (480 Mly - acoustic scale) corresponds to distance a sound wave traveled during inflation.
- Predicted by Andrei Sakharov (1965)

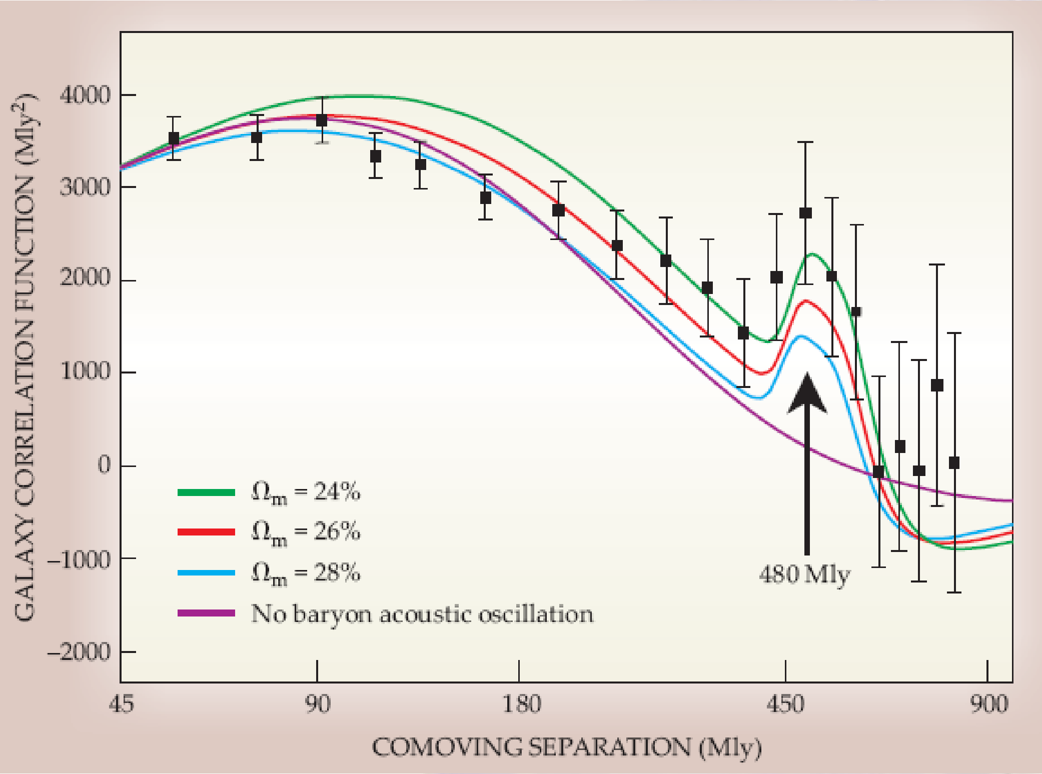
Wilkinson Microwave Anisotropy Probe

- Video from NASA WMAP Science Team
- Illustrates relation of primordial acoustic waves to anisotropy map.
- Animation Link
  [map.gsfc.nasa.gov/media/030658/index.html]

Sound waves and dark matter

- Anisotropy lead to clustering of matter (galaxy clusters)
- Baryon acoustic oscillation peak
- Cosmological model fits help determine ratio of baryonic to dark matter

  $\Omega \sim 1{:}5$



Eisenstein and Bennett, Physics Today, April 2008

Dark matter:

unknown structure, immune to light, *but* has mass.

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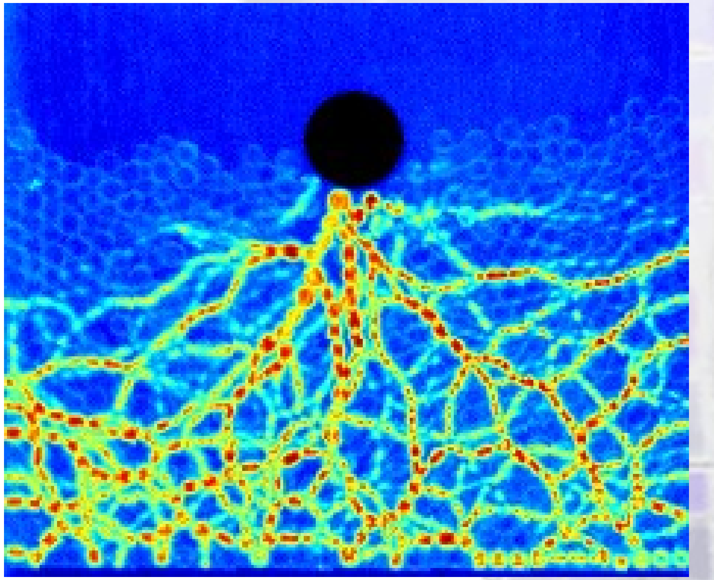
Acoustics and slip-stick friction

> "Friction is a very complicated matter ... and in view of all the work that has been done on it, it is surprising that more understanding of this phenomenon has not come about."
>
> --Richard Feynman, ~1965

- Slip-stick friction plays a vital role in earthquake fault dynamics
- Granular interface produces unexpected dynamics.



Force chains in granular media

courtesy of Behringer, Duke Univ.

The importance of earthquake science

San Andreas Fault
courtesy of USGS

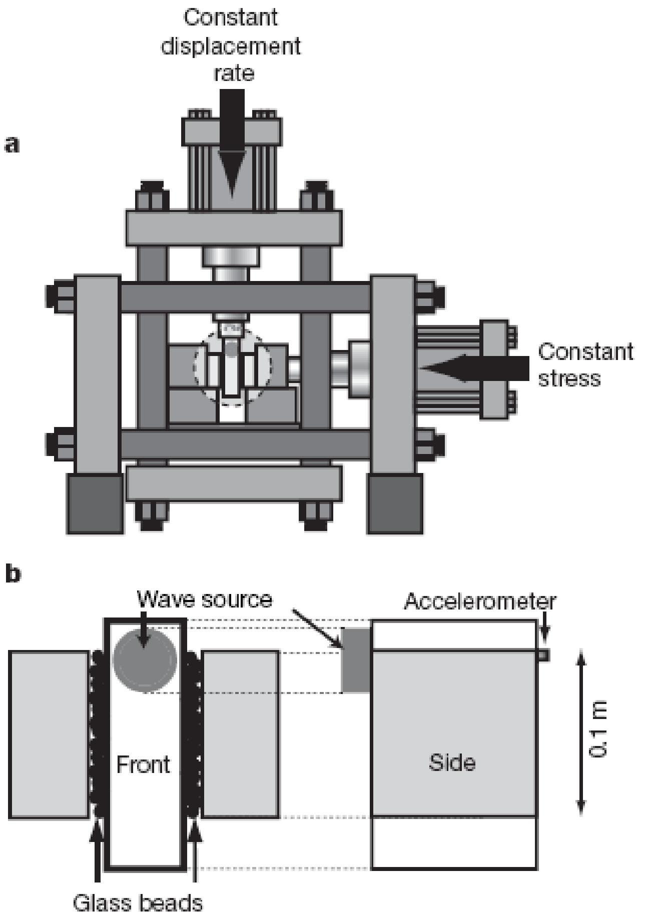
Sichuan Province, China 2008
courtesy of Time.com

San Francisco 1906
courtesy of Library of Congress

Fault on a table top

P.A. Johnson, et al.,*Nature Letters* **451** (3), 57-61, Jan 2008

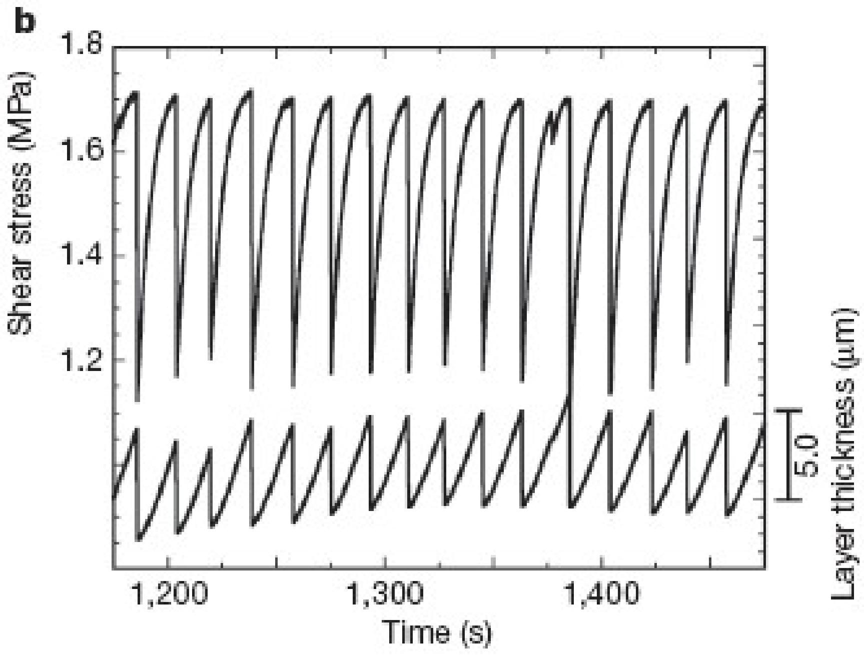
- Laboratory models allow for precise control and repetition
- Shear model with glass bead interface (125μm)
- Transducer introduces transient acoustic pulses (1 – 20 kHz)
- Acoustic stress ~1% of static transverse stress
- Block displacement rate ~ 5μm/s



courtesy of Nature Letters, 2008

Behavior without vibration

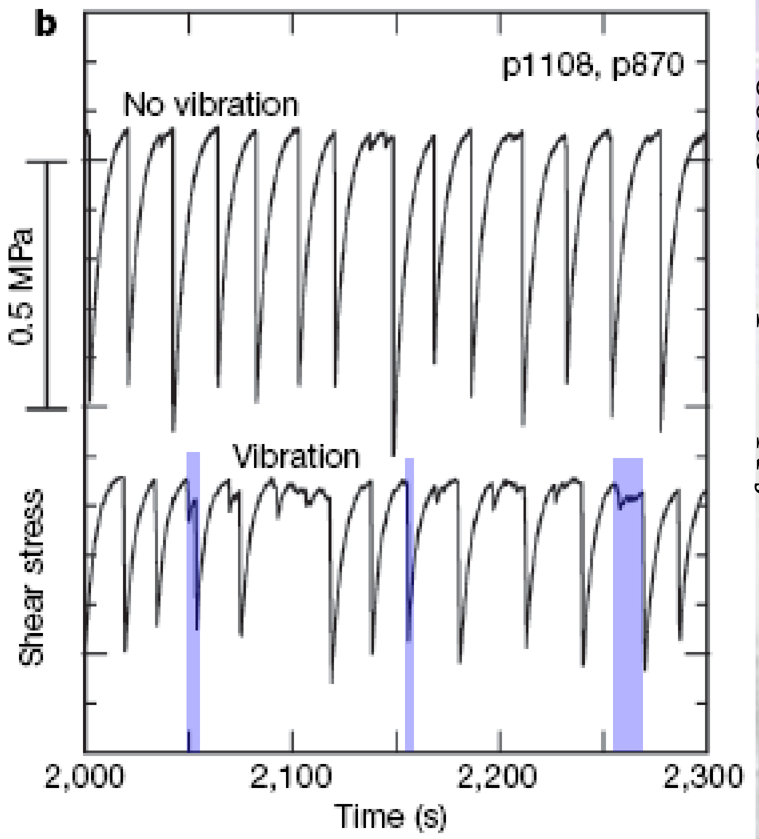
- Stress patterns very regular with period ~250 seconds
- Stress drops of 30%
- Thickness of bead layer varies with slips
- Periodic smaller events



courtesy of Nature Letters, 2008

Three observations with vibrations

- Acoustic waves disrupt the slip-stick period
- Acoustic waves trigger immediate and *delayed* small magnitude events
- Strain memory is *maintained* through successive large magnitude slip-sticks
- No effects for acoustic stresses < 1% of static stress.



Shaded regions are locations and durations of introduced vibrations

courtesy of Nature Letters, 2008

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negative index of refreaction, band gaps
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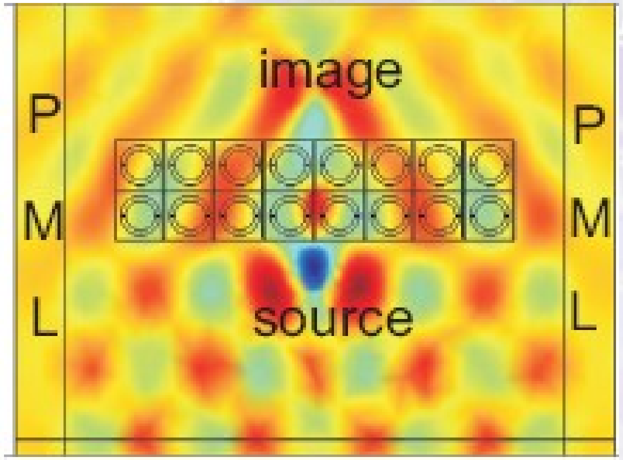
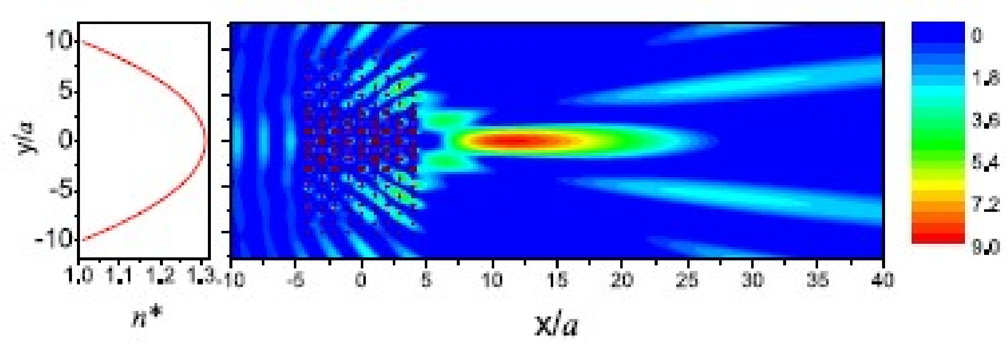
Acoustic Metamaterials

Guenneau, et al.,*New Journal of Physics* **11** 399 (2007)

- A new world for acoustic engineers is opening up!
- Dispersion relations can be tuned and enriched by embedding arrays of geometric objects.



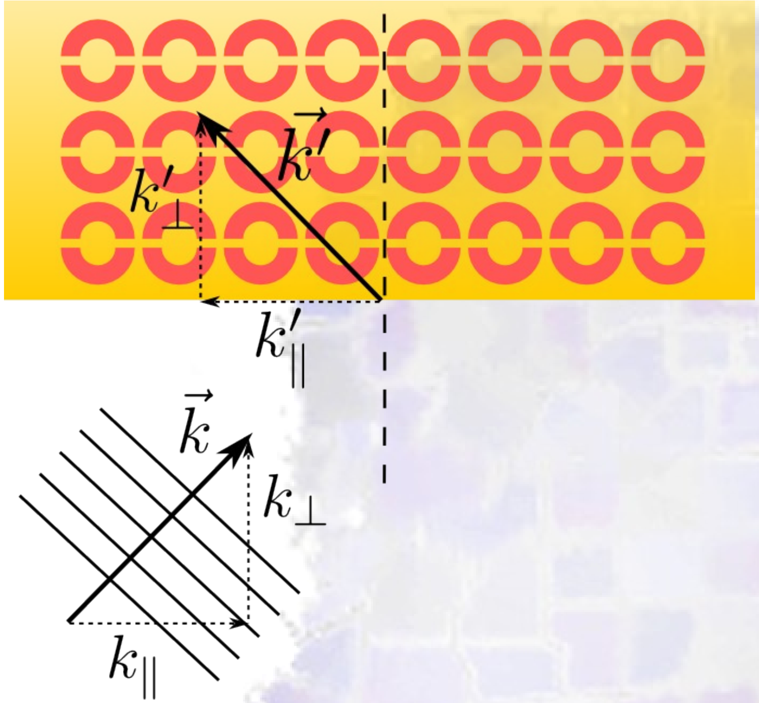
- Novel effects: negative index of refraction and band gaps ⇉ acoustic trapping, flat acoustic lenses, filters



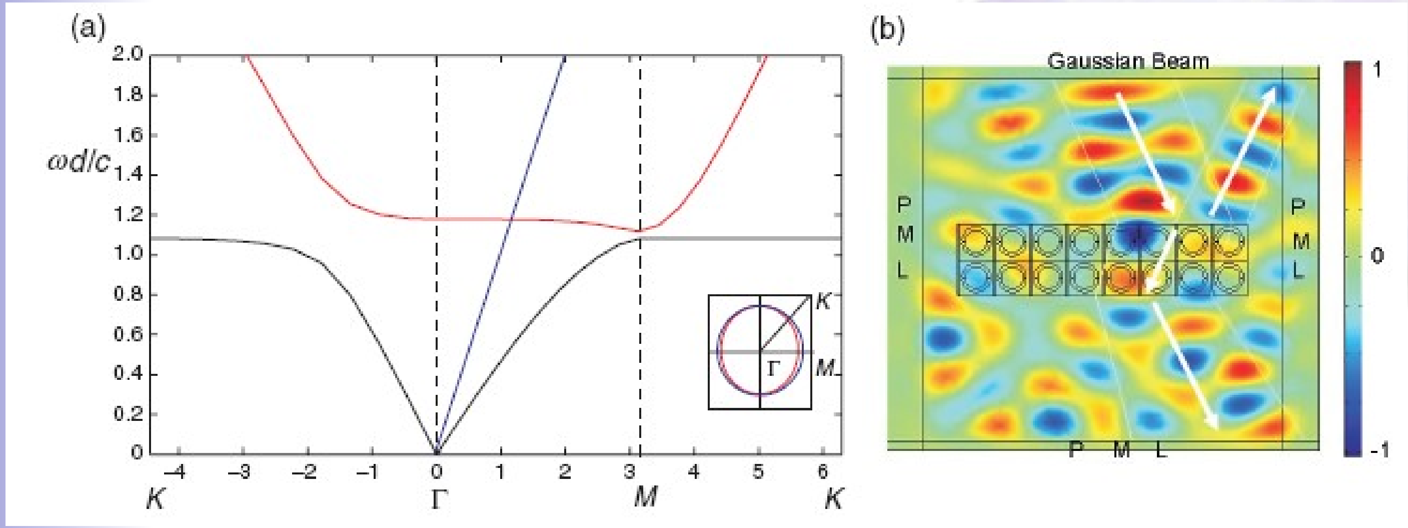
Torrent, et al.,
New Journal of Physics
9 323 (2007)

Negative index of refraction

- Parallel component of incident wave vector reverses direction
- NRAM: negative refraction acoustic material.
- Applications: superlens, open resonator.



Guenneau, et al.

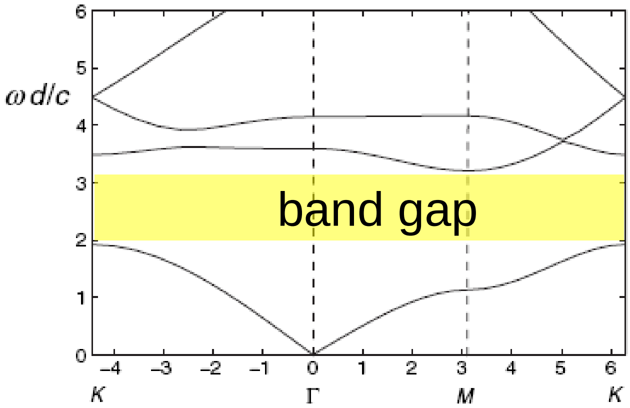


Band gaps

R. Martínez-Sala, *Nature* **378**, 241 (1995)
Artist: Eusebio Sempere

- First experimentally observed by Martínez-Sala, et al. in a periodic array to steel tubes. Strong attenuation ~1670 Hz.
- Due to resonances of scattered waves between structures.

- **Parameters:** geometry, periodicity, symmetry, defects
- **Applications:** filters and isolators, acoustic traps and waveguides.



Guenneau, et al. (2007)

Conclusions

- Physical acoustics continues to increasingly contribute to a wide variety of fundamental science and technology fields.
- The topics presented here represent a small portion of ground breaking and far reaching acoustics research.
- Further advances in cross-disciplinary fields will require wider collaborations for physical acousticians.

    ⇉ New opportunities!

A few references

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