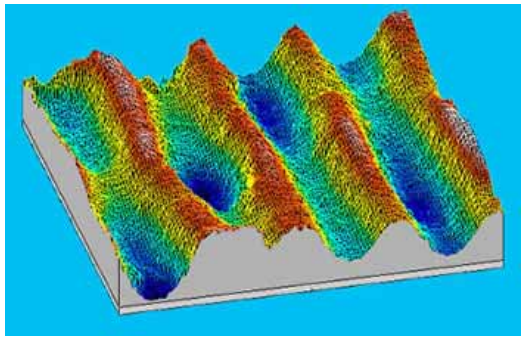
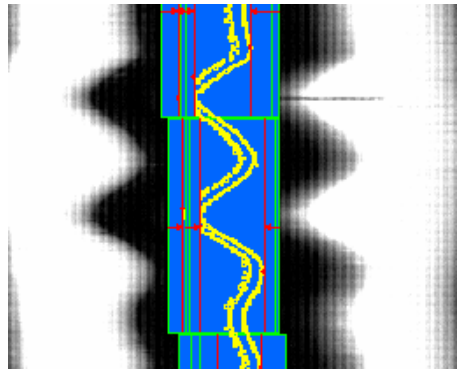
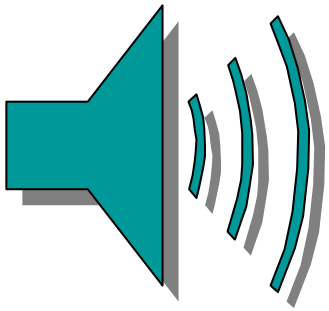




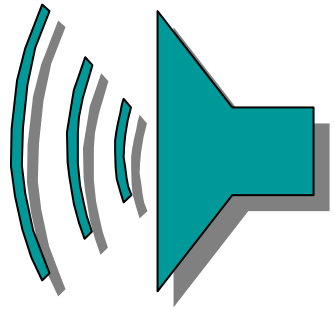
Imaging the Voices of the Past: New Ways to Digitize Historical Sound Recordings

Carl Haber

Lawrence Berkeley National Lab



What is Sound?



- Matter = gas, liquid, and solid
- Matter can be compressed by a force
- Density = stuff / volume
- Sound
  - Compression = increased density
  - Rarefaction = decreased density
  - Sound is energy which travels through matter via periodic compressions and rarefactions
  - Period = pitch
  - Amplitude = loudness
- We experience the sensation of sound when our ears respond to periodic compressions and rarefactions of the atmosphere (or other media).

Sound Recording

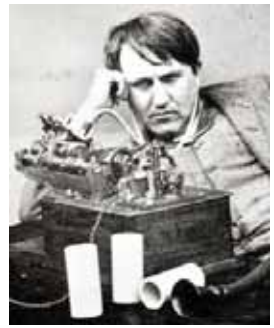
- Sound can be transferred from one material to another
  - Beat a drum
  - Pluck a string
  - Stand near a speaker
  - Speak into a paper cup and feel the bottom vibrate

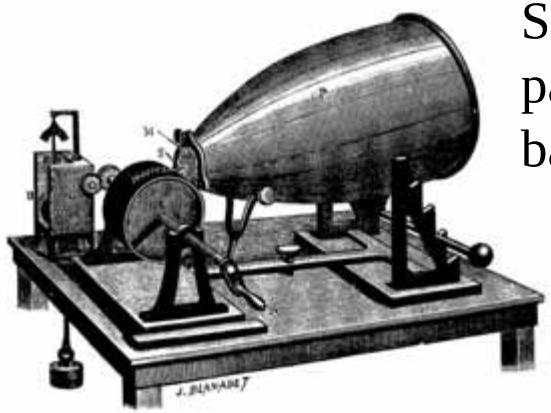
- Sound can be directly recorded by capturing the mechanical effect permanently in material

Inventions

Phonautograph
Leon Scott
1853

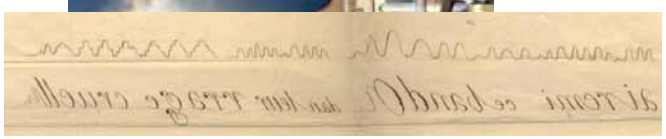
Phonograph
Tom Edison
1877



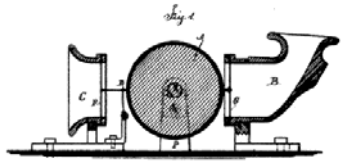


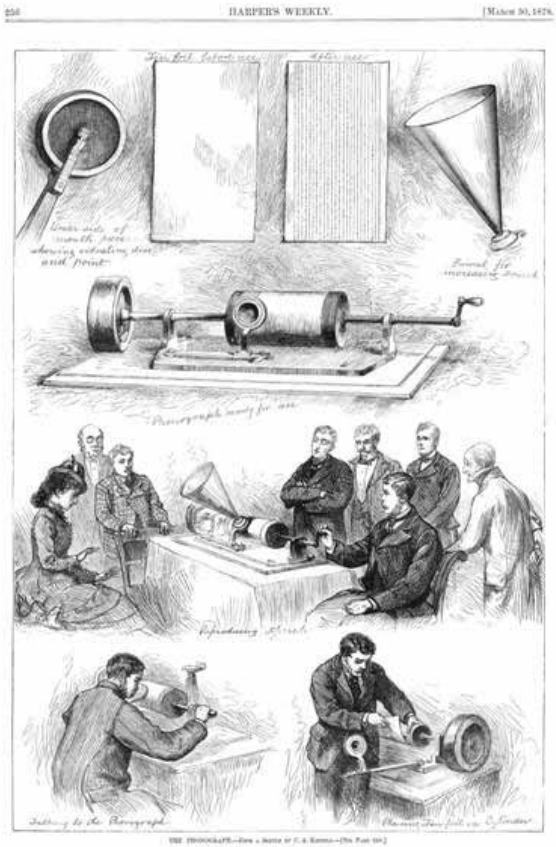
Scott enscribed sound on paper and could not play it back

Edison embossed sound on foil and was therefore the first to reproduce it.



T. A. EDISON.
Phonograph or Speaking Machine.
No. 200,521. Patented Feb. 19, 1878.





History

- Scott's invention was ingenious
- Edison's invention was transformative
- From Edison onwards the technology of sound recording and reproduction has focused on
  - Improved media
  - Fidelity
  - Capacity
  - Access

Recorded Sound is Valuable

- Technical tests and experiments…
- Field recordings of linguistic, cultural, and anthropological materials…
- Primary recordings of key artists
- Field recordings of sources which underlie much of modern music, American and European folk traditions…
- Speeches & spoken words of historical figures, Edison, Churchill, Roosevelt…
- Early radio broadcasts (lacquers)…
- Live performances, events,….
- Public and private dictation and monitoring records, intelligence, Presidential sources,…
- Commercial record releases…










This is a record of our culture

So how much is there?

- American institutions hold some 5 billion items in their collections
- Of these about 45 million are sound recordings
- Of these about 10 million are mechanical
- **National Recording Preservation Act of 2000** "A bill to…maintain and preserve sound recordings and collections of sound recordings that are culturally, historically, or aesthetically significant…, " (Public Law 106-474; H.R.4846).

What's the Problem?

- Archivists want to copy all pre-digital media into modern forms.
- It's a big project.
- Much of it is in unknown condition.
- Some of the materials are damaged or too delicate to "play".

Can science help preserve culture?

- "Preservation Science" supports museums, libraries, and collections through
  - Analysis and processing of materials
  - Dating
  - Imaging and measurement
  - Analysis of images and signals
  - Studying degradation mechanisms
  - Developing information technology tools and resources

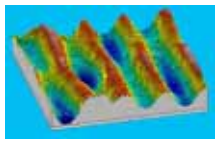
Digital is Forever

Automatic book scanner

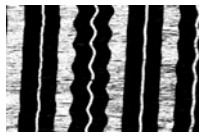
- A key concept for preservation is digitization
- Digital materials can be copied exactly
- Robotic scanning of texts is in wide use at major libraries, Google…
- Unlike texts, digitization of historical sound recordings is often an invasive process-by definition

A Modern Physics Approach to Sound Recordings

- Could we digitize a recording **without contact** to the medium – like robotic text scanning
- Address concerns of the preservation, archival, and research communities:
  - Preservation: Restore or stabilize delicate or damaged media
  - Access: Mass digitization of diverse media, automation
  - Assessment
  - Obsolete formats and legacy playback systems
- Precision optical measurements are widely practiced in the physics research lab



Non-Contact Digital Imaging



- Create a high resolution digital image of entire surface
- Computer plays record (image) with a virtual stylus
- Product
  - Standard digital sound files (ie .wav)
  - High resolution digital images which may be reanalyzed later as well
- Protects samples from further damage
- Repair existing damage through “touch-up”
- Reconstruct broken and delicate records
- Offload aspects of restoration to automated software

A “smart” copying machine for records

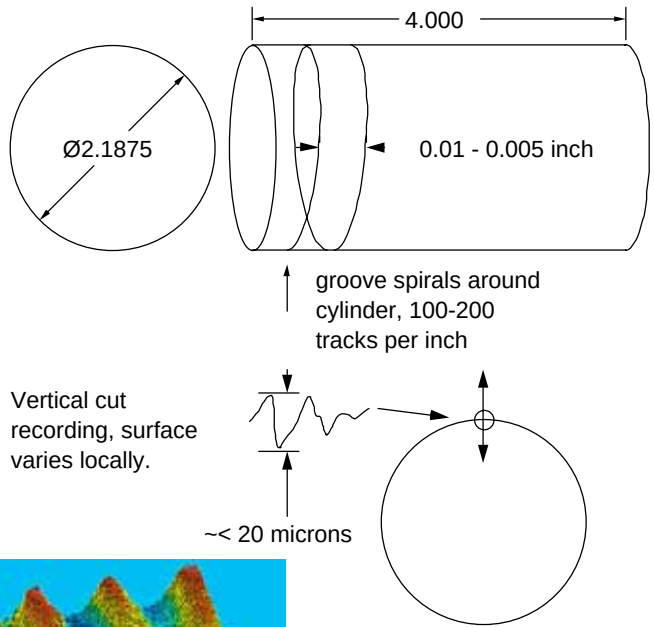
What do we need to know?

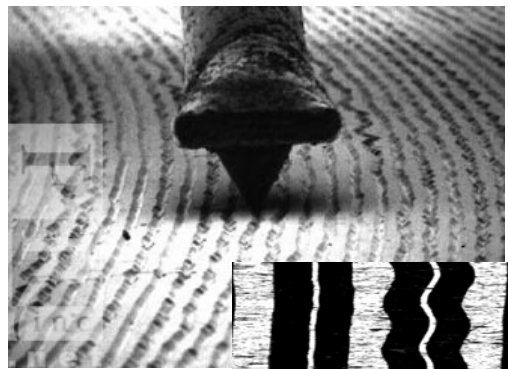
- What do I want to measure and how well?
- What are the right tools?
- How can I interpret the results?
- How do I know if I am doing a good job?
- Is there a future?
- Who will do the work?
- Who will pay for it?

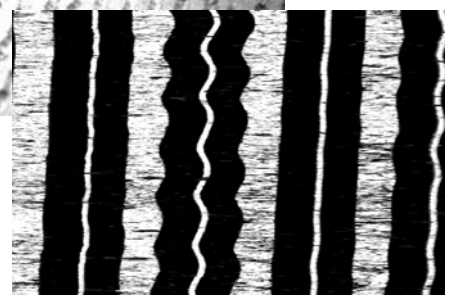
Mechanical Recording Principles

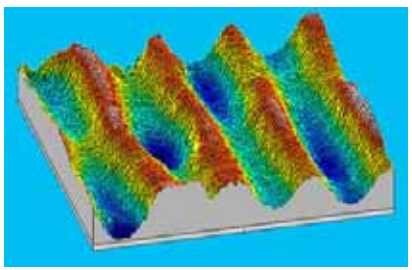
Cylinder: groove varies in depth (Vertical Cut)

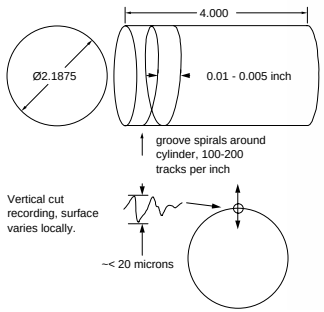
Disc: groove moves from side to side (Lateral Cut)

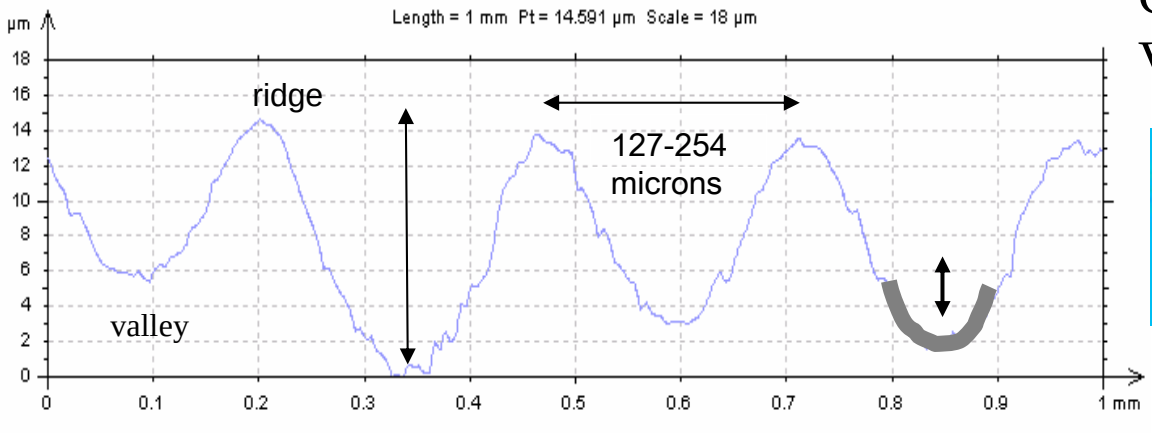




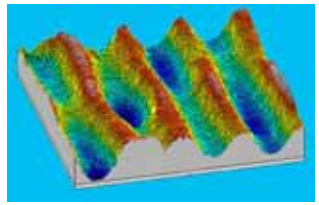




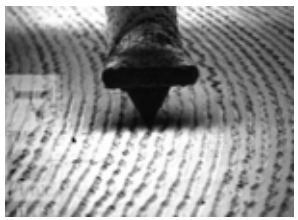


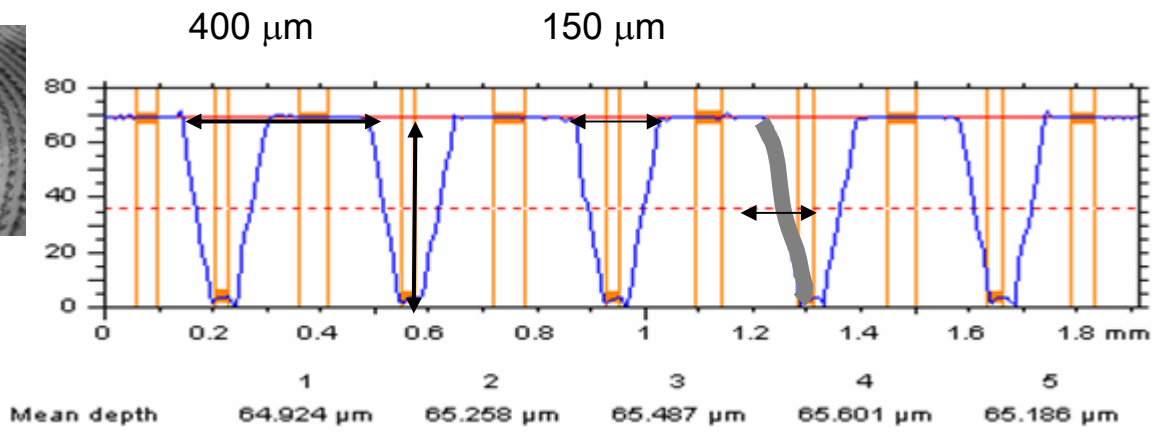


Cylinder surface
Vertical cut

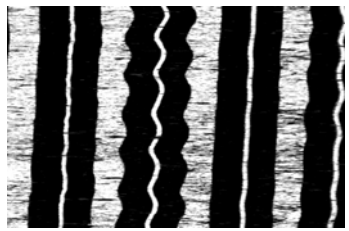


3D image





Disc surface
Lateral cut



2D image

A human hair is 25-50 microns in diameter

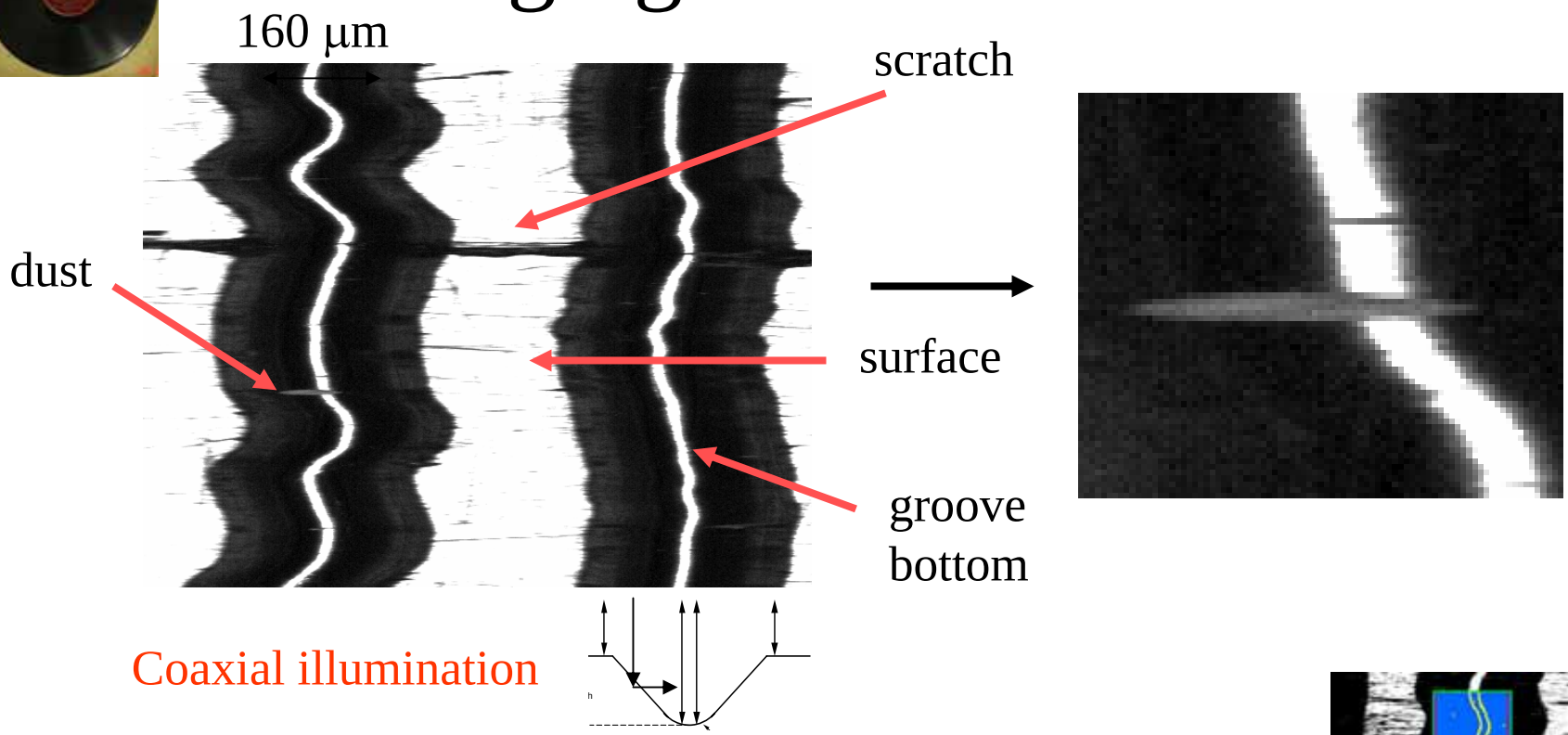
Audio is encoded in micron scale features which are >100 meters long.

The Method

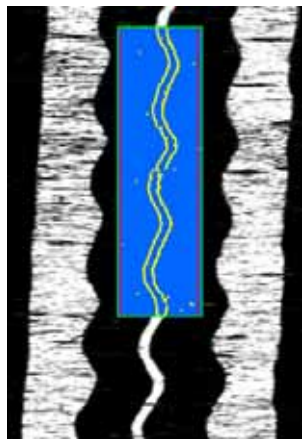
- Digitally image the surface
- Process image to remove defects
- Analyze shape to model stylus motion.
- Sample at standard frequency
- Convert to digital sound format.
- Store results as standard digital sound files (.wav) and high resolution digital images

Digital imaging technology and data processing are improving significantly year after year, fueled by diverse commercial and scientific applications

2D Imaging: Electronic Camera

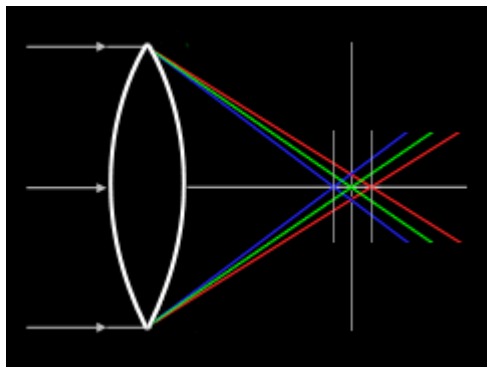


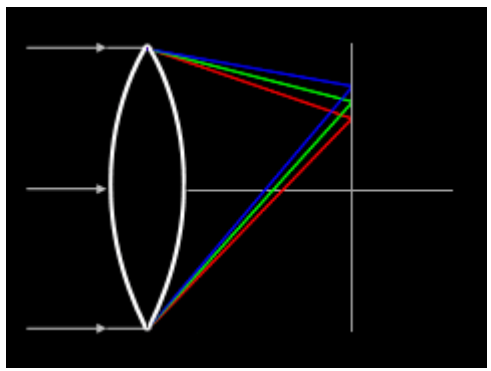
Coaxial illumination



- Suitable for disc with lateral groove
- Require 1 pixel = ~ 1 micron on the disc surface
- High resolution yeilds narrow depth of field, 10 – 20 microns
- High speed cameras allow near “real-time” imaging
- Extract groove information from high contrast edge transitions

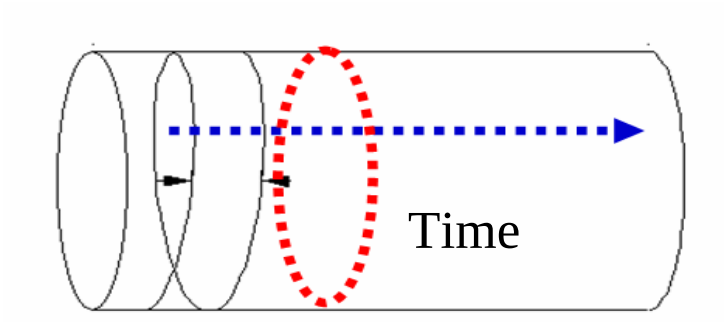
3D Imaging: Chromatic Aberration

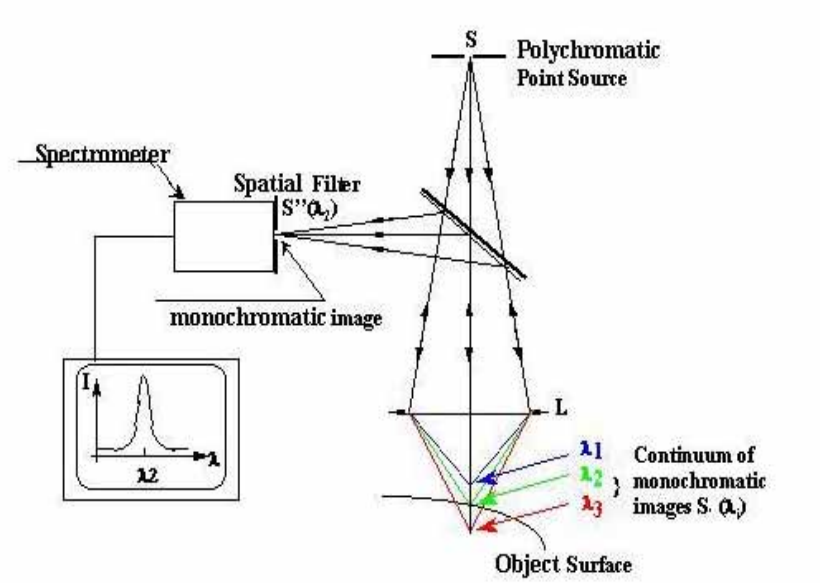


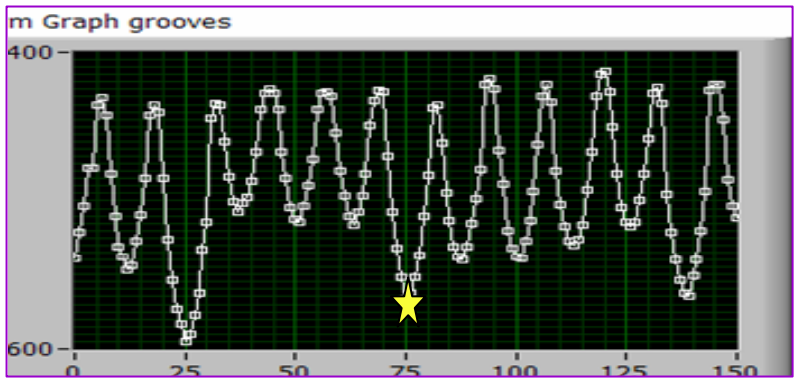


3D Imaging: Confocal Scanning Probe

Required for cylinder with vertical groove modulation.







Depth resolved to ~0.1 micron

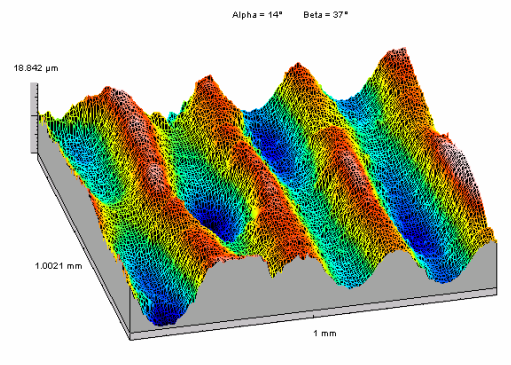
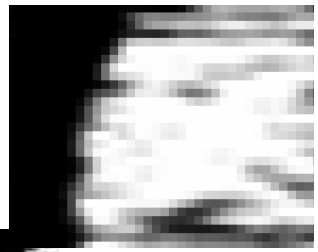
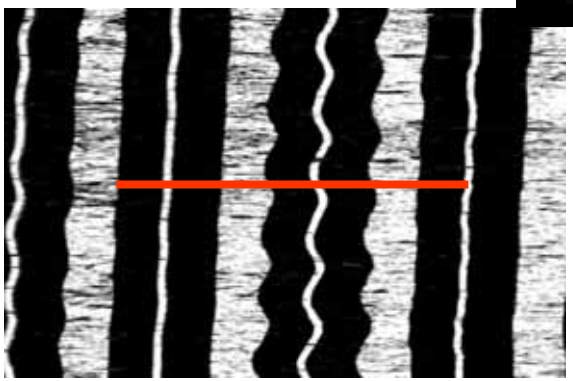
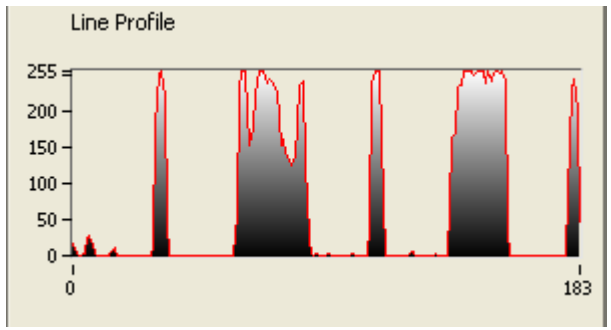


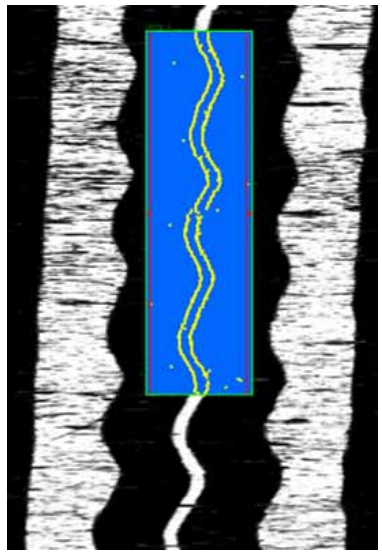
Image Analysis

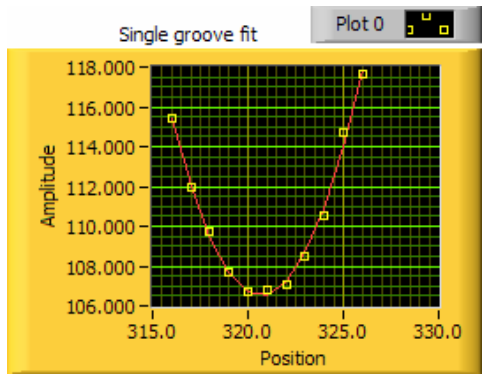
232	22	1	22	10
1	0	0	34	7
255	66	10	11	12
5	67	68	69	70
1	123	233	199	101









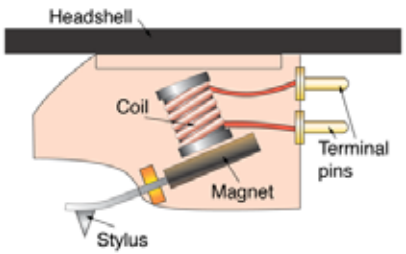


Feature extraction and measurement

Measured width of features provide a natural noise detection and removal tool.

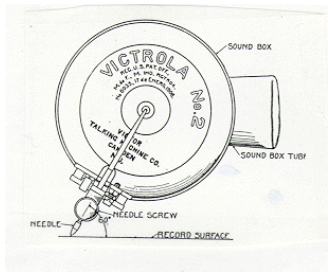
What is the relationship between "groove" and sound?

Electro-magnetic case

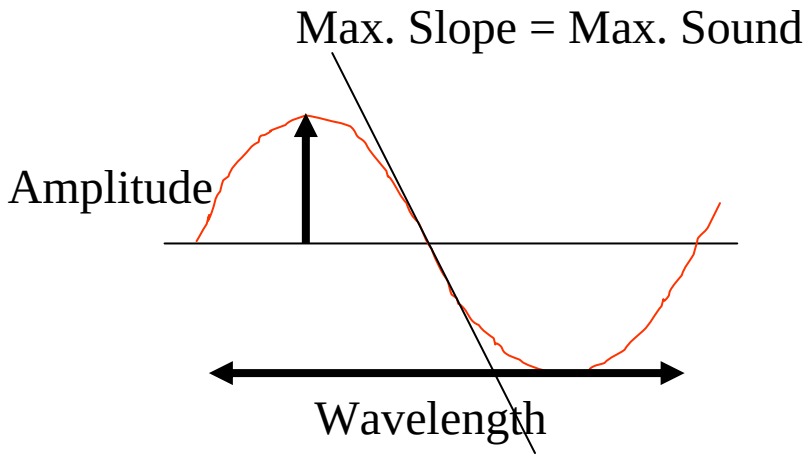


induction

Acoustic case



Diaphragm is over-damped to provide flat response



$$A_p = \frac{v_p}{2\pi f}$$

Sound = Stylus Velocity = Groove Shape Derivative

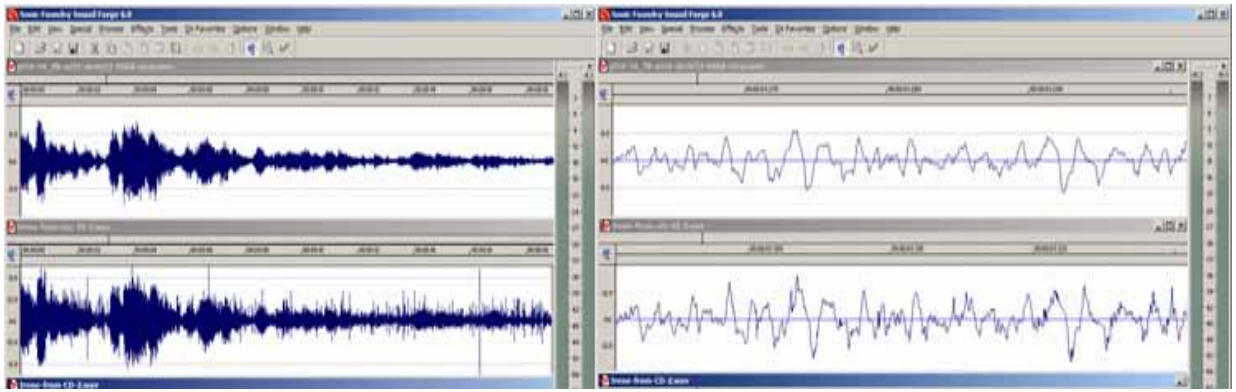
("constant velocity condition")

1st Test: Does this work?

"Goodnight Irene" by H. Ledbetter (Leadbelly) and J.Lomax, performed by The Weavers with Gordon Jenkins and His Orchestra ~1950

optical readout.

mechanical (stylus)

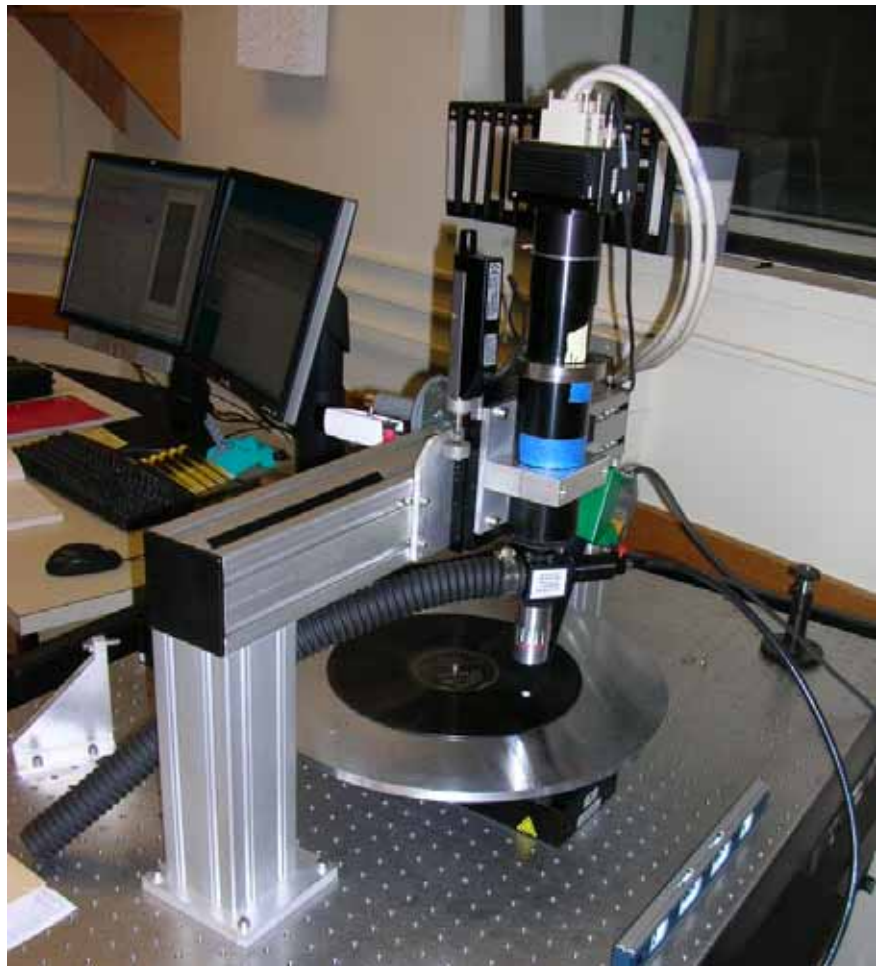


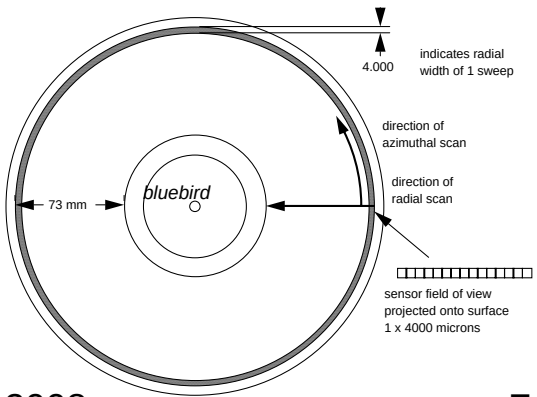
Projects Underway

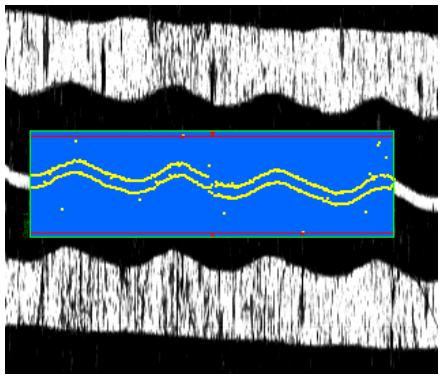
- The Library of Congress and other public custodians of cultural history have seen promise in this approach and supported a research program
- "IRENE": a fast 2D optical scanner for disc records (NEH)
  - Installed 2006 at Library of Congress, evaluation, upgrade
- "3D": develop a fast 3D scanner for cylinders and discs (IMLS)
  - Funded in 2007 and currently under development
- Special Studies: damaged, broken, unplayable, rare

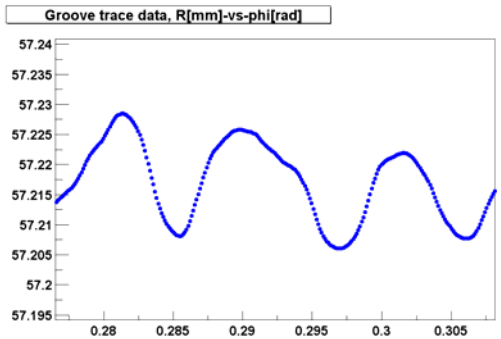
I.R.E.N.E.

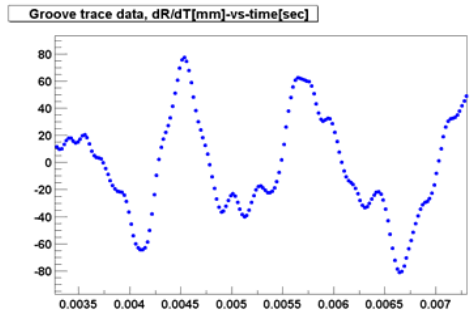
Image, **R**econstruct, **E**rase **N**oise, **E**tc

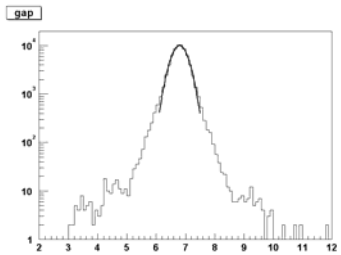








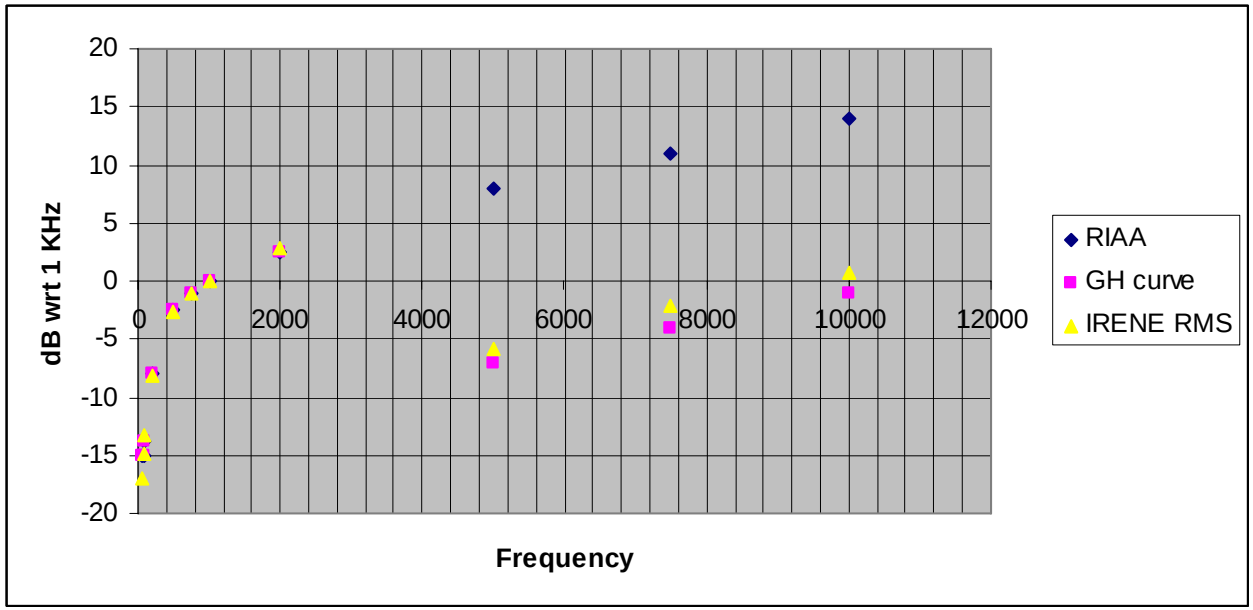


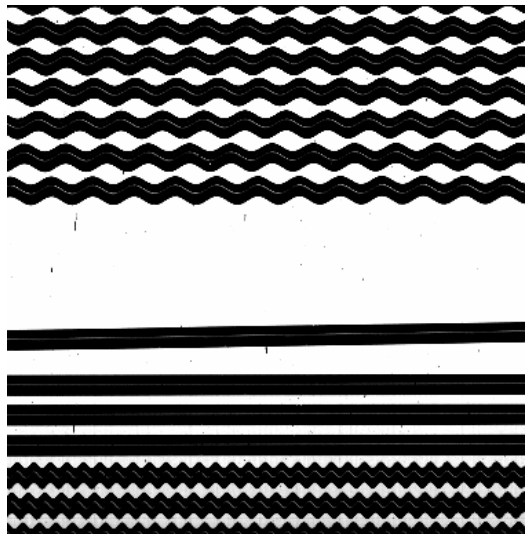


Measure slope at each point (stylus velocity)

Width across groove bottom

Test Discs

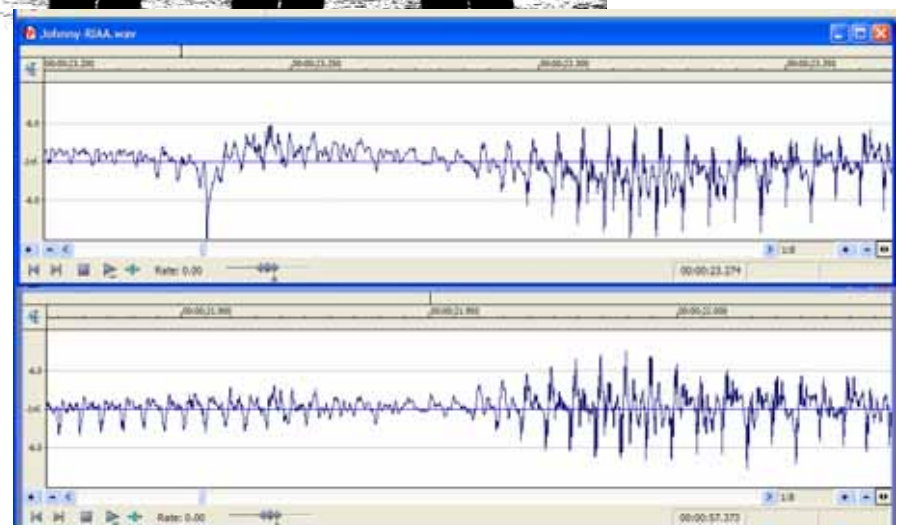




Pristine new acetate disc scanned by IRENE

“Johnny”: Les Paul and Mary Ford

1953 recording, shellac 78 rpm disc is worn and scratched, distorted



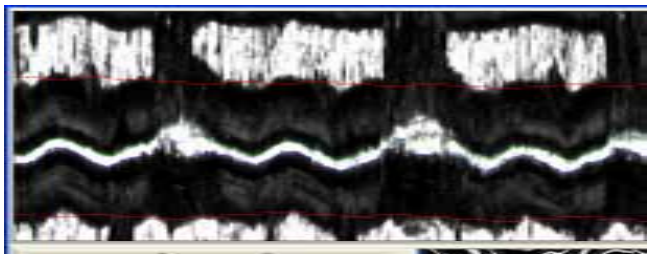
Stylus version has a clear skip due to scratch

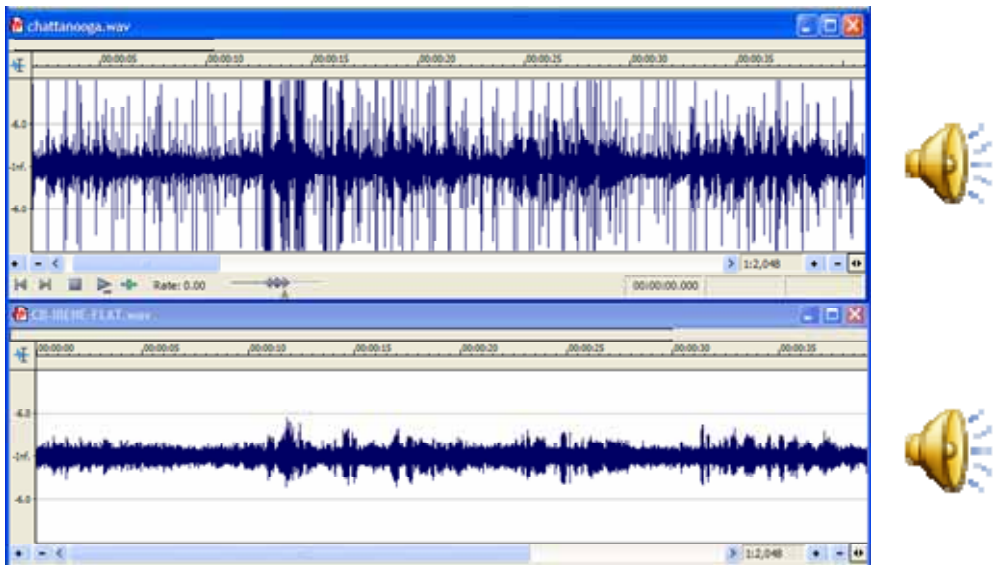
IRENE

Chattanooga Blues 1923

Ida Cox, Paramount 12063

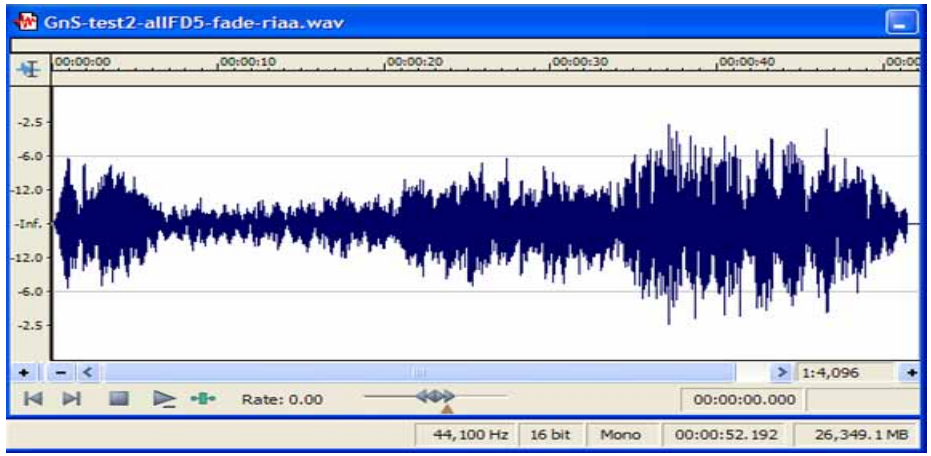
Acoustic recording, heavily worn, cracked, with significant stylus damage and distortion

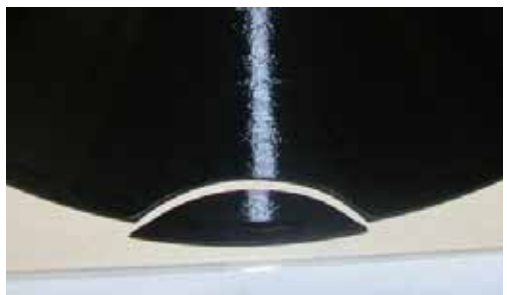


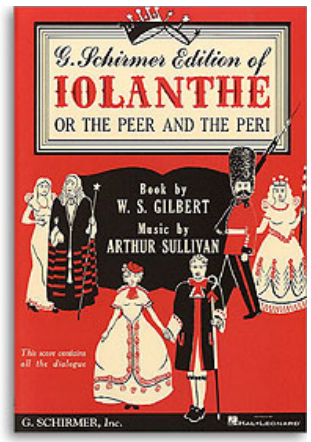


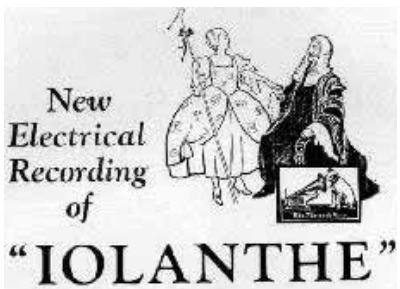
Broken Record

Gilbert and Sullivan “Iolanthe” 1930 Victor 9708



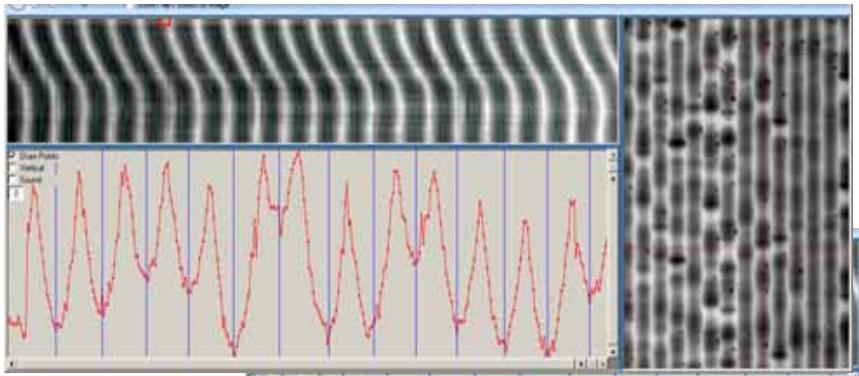




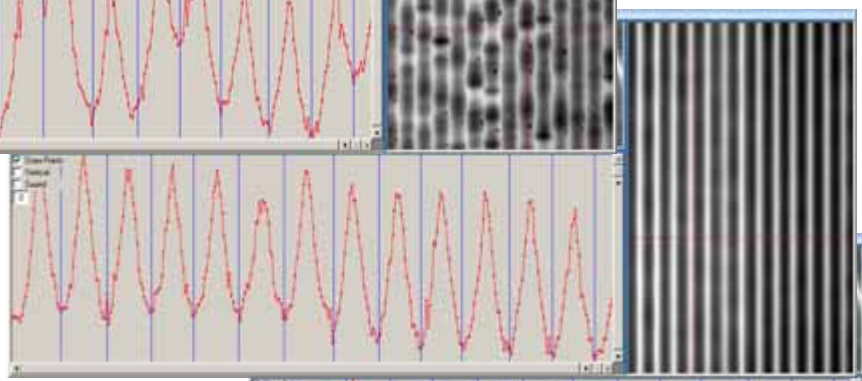


3D Scanner

3D Data Analysis

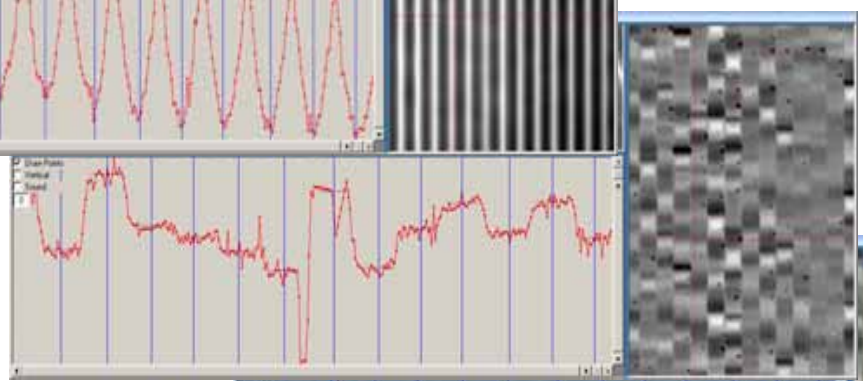


Raw image, greyscale = depth

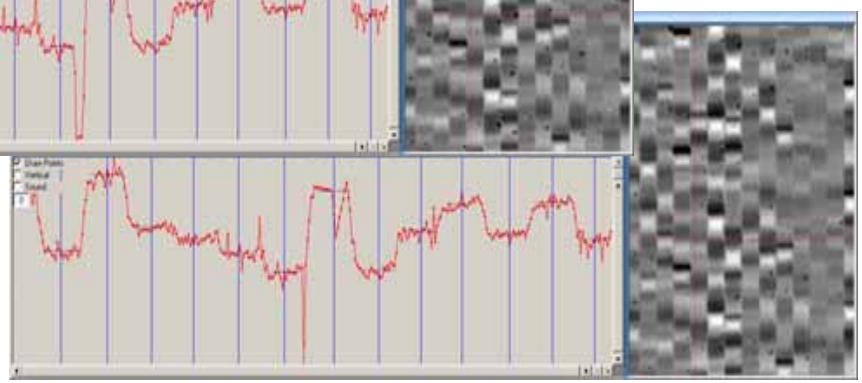


Spatial average to determine local shape

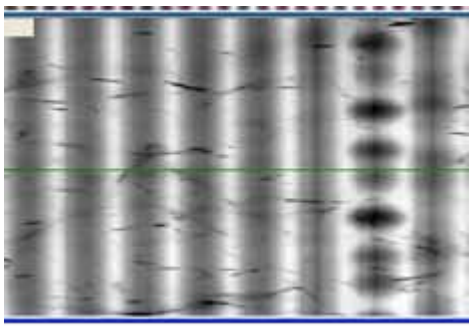
Profile view



Subtract local shape

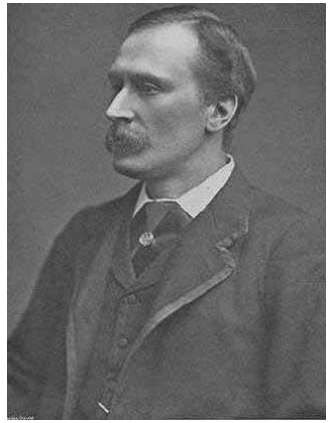


“blobs” removed



Condition assessment

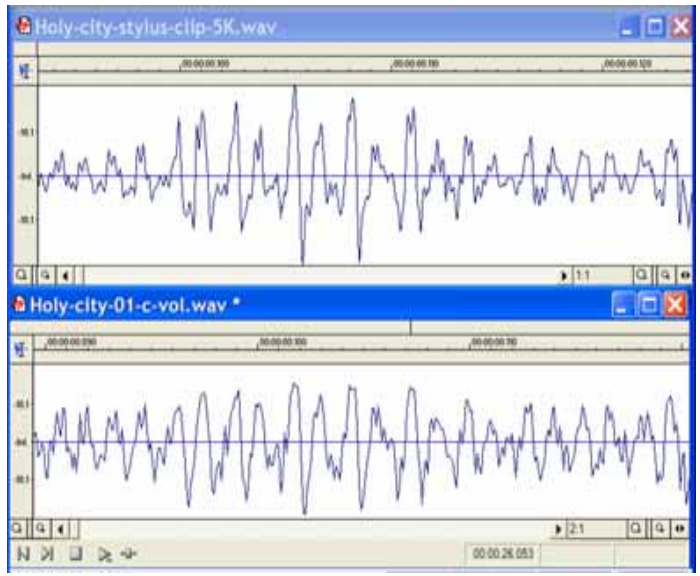
Sound Comparison



- The Holy City, composed by Stephen Adams,

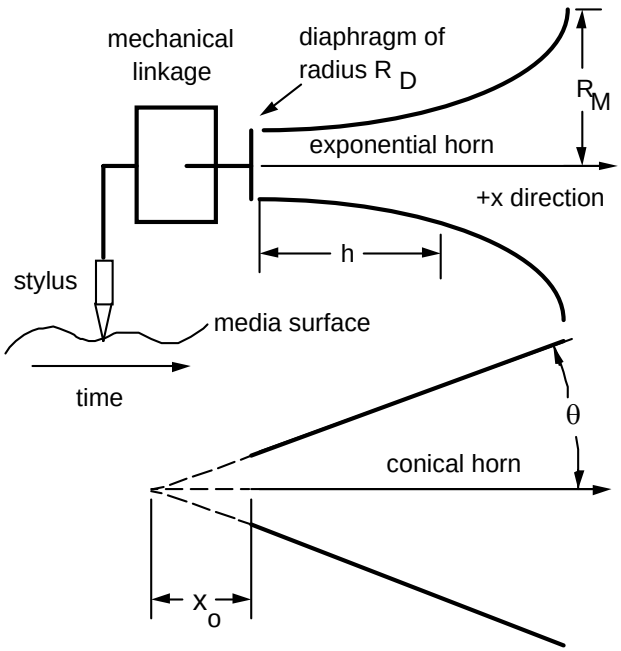
The Edison and Skedden Mixed Quartet, Amberol 1601

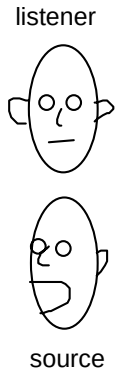
Commercial cellulose release

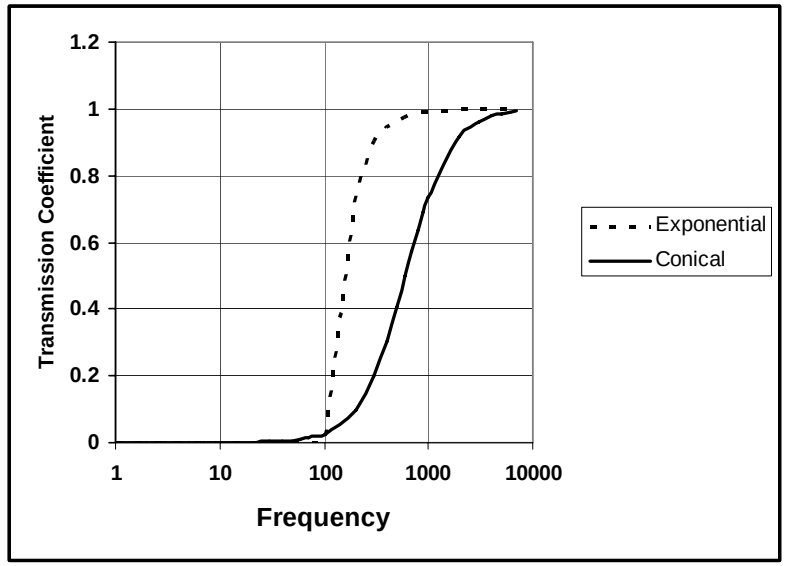


- Stylus
- Optical

Optical + EQ + filter







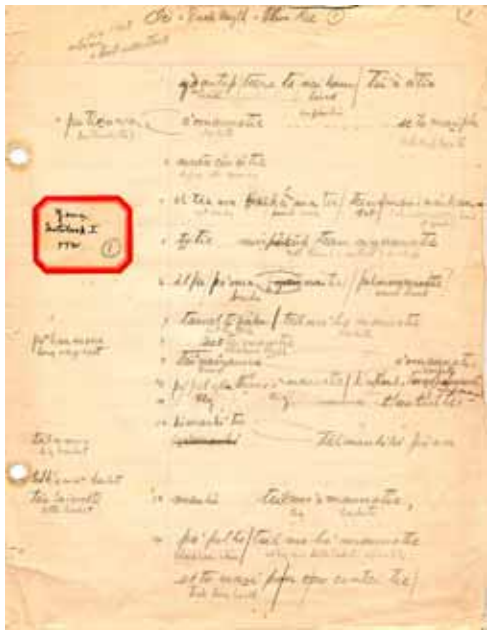
Response of horn and diaphragm at low frequency can modify response and deviations from “constant velocity” characteristic.

Native American Field Recordings

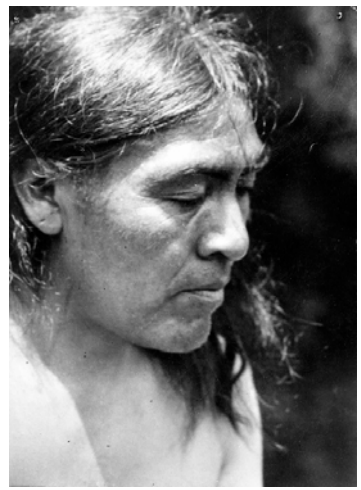
UC Berkeley Collection 3000 cylinders
Ishi Recordings: The Story of Wood Duck

Such collections are a valuable tool for scholars and for language preservation programs

Sam Batwai, Alfred L. Kroeber, and Ishi



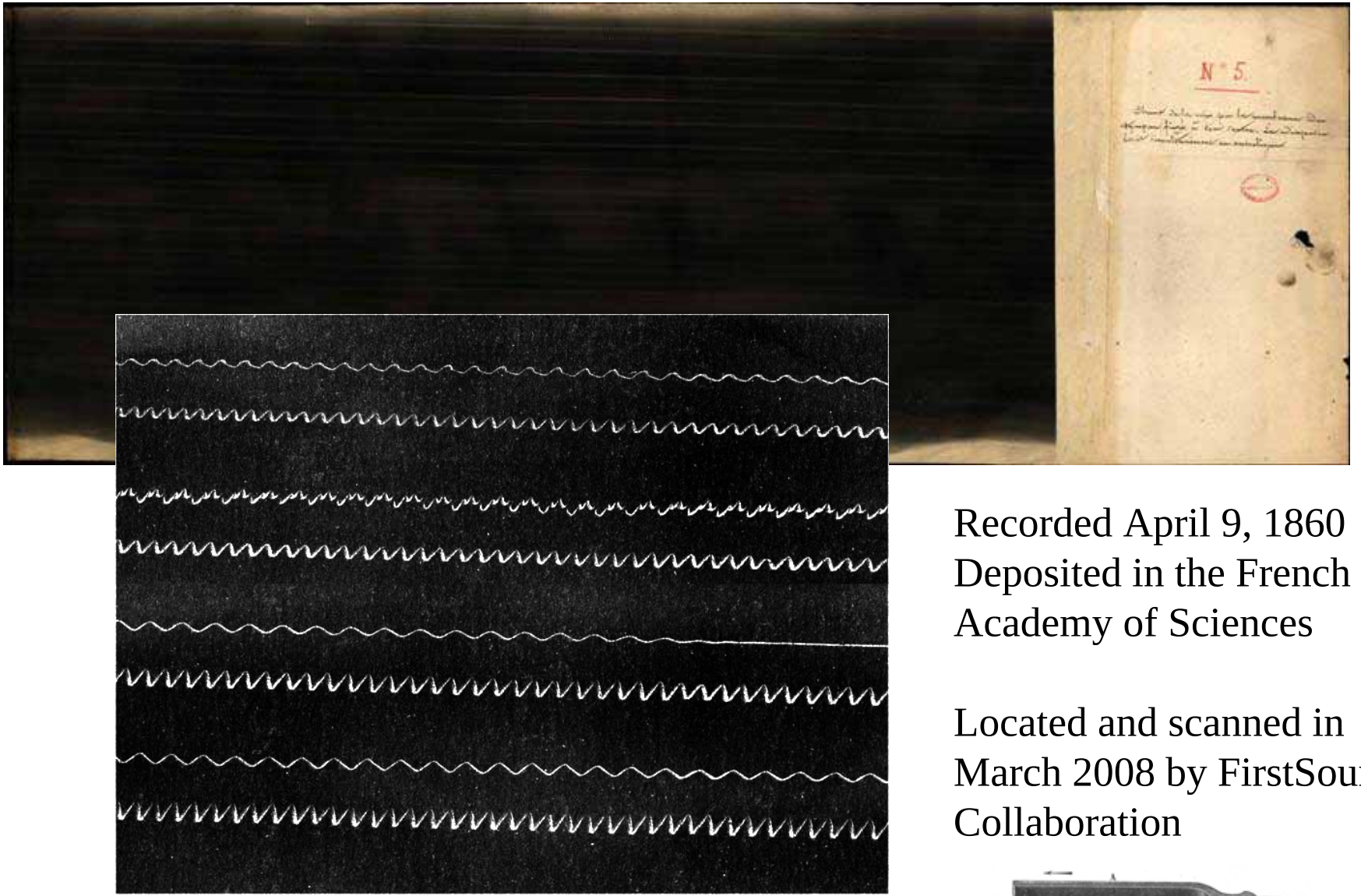
This narrative is ~2.5 hours long and is contained upon 51 wax cylinders



Remember Leon Scott

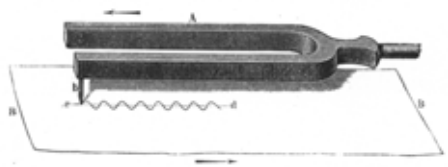
- He built a paper recorder but had no way to reproduce sound.
- Scott deposited the results of his research at the French Academy of Sciences, in Paris. They have remained there, in good condition, for nearly 150 years.
- In 2008 we digitally scanned Scotts paper recordings in Paris and applied the IRENE analysis.

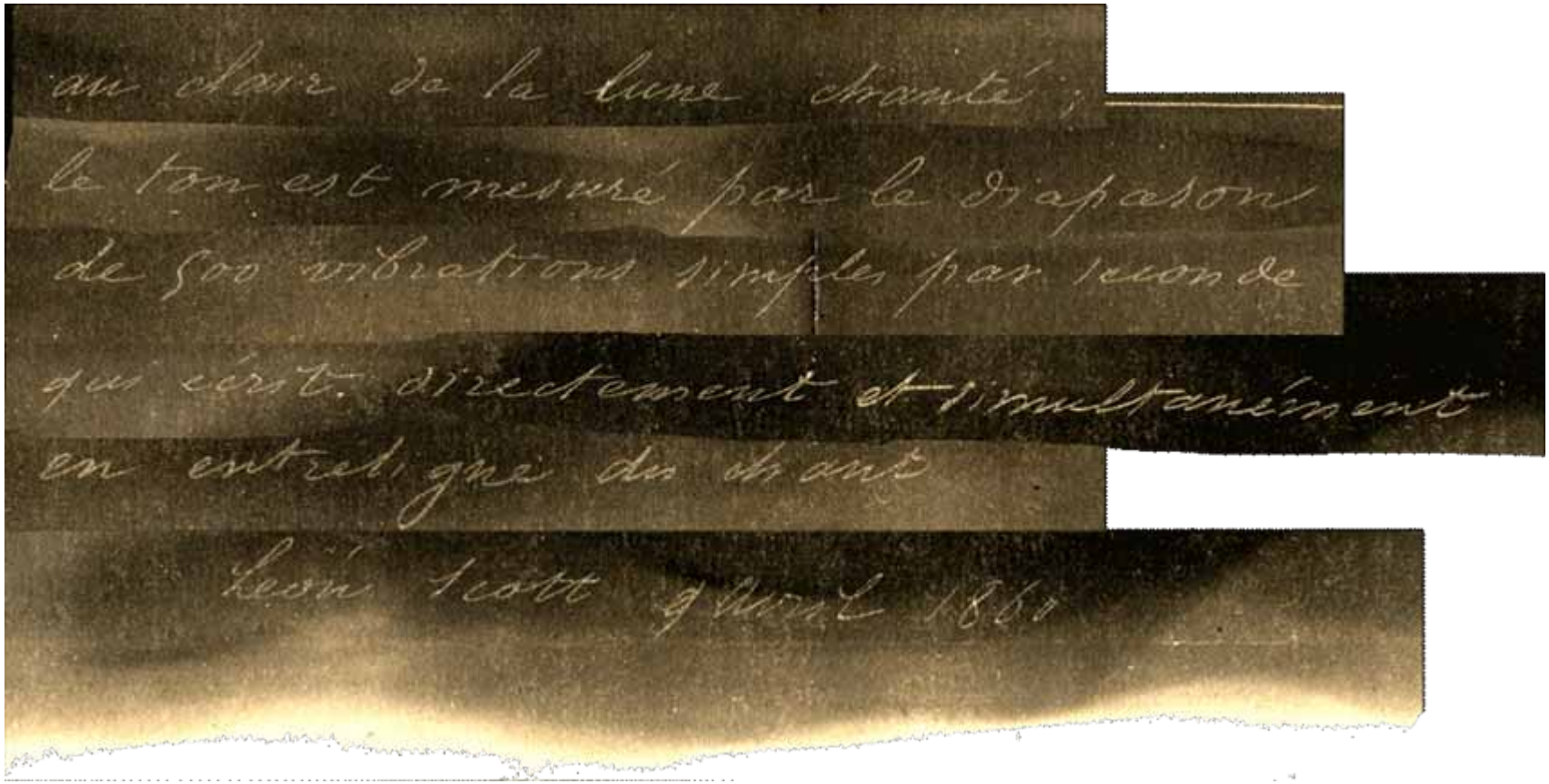
Paper coated with lamp soot (lamp black)



Recorded April 9, 1860
Deposited in the French Academy of Sciences

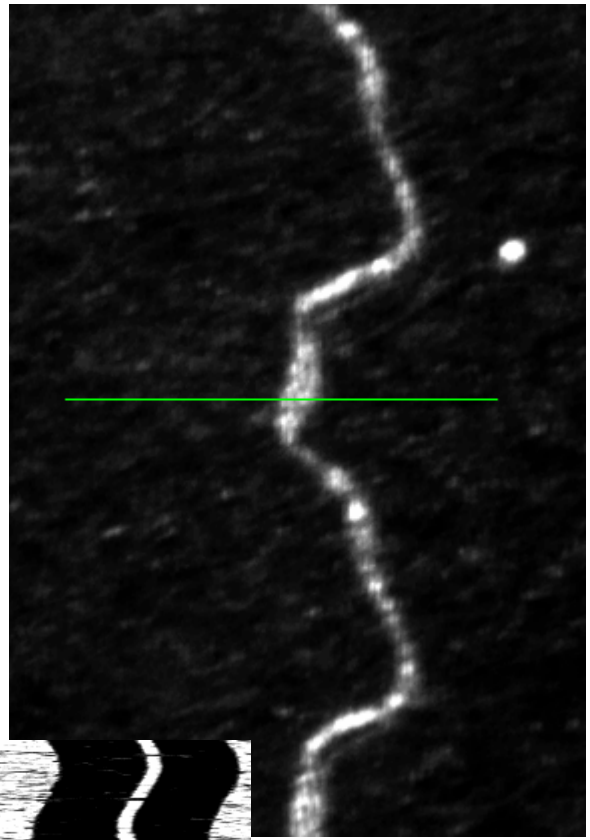
Located and scanned in March 2008 by FirstSounds Collaboration

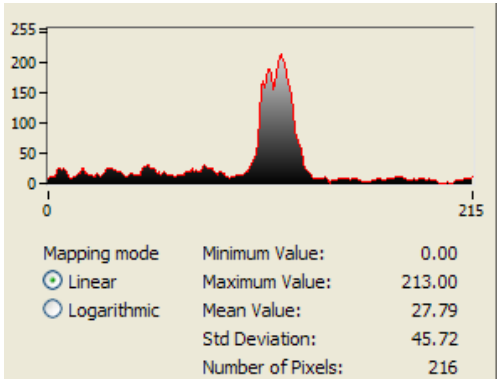


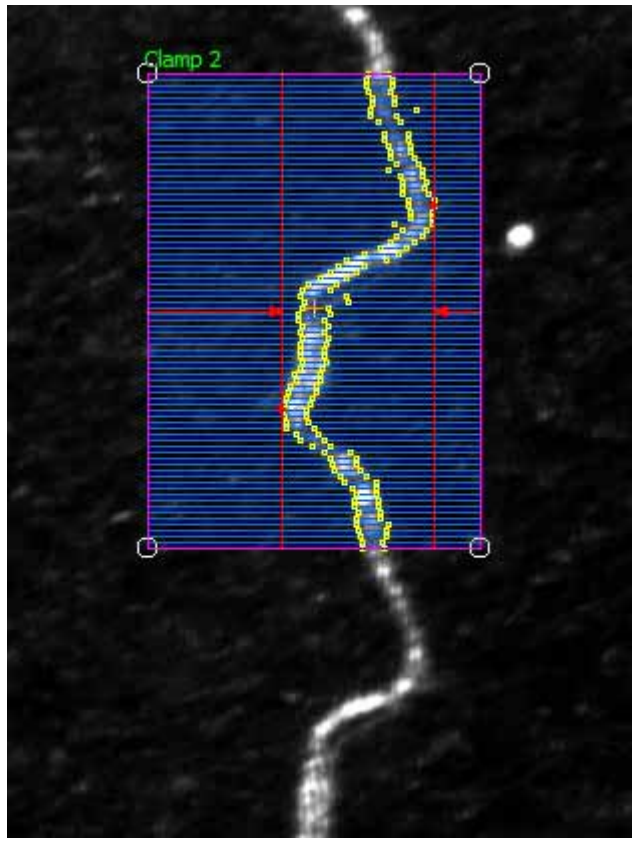


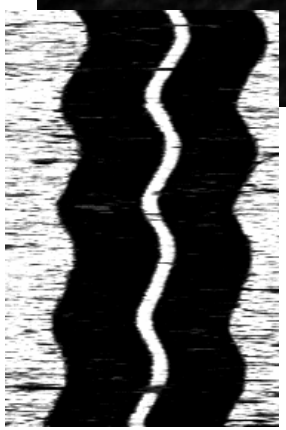
"Au Clair de la Lune" ["By the Light of the Moon"] sung;
"…the pitch is measured by the tuning fork of 500 simple vibrations per second which writes directly and simultaneously in interlinear space of the song"

Léon Scott 9 April 1860

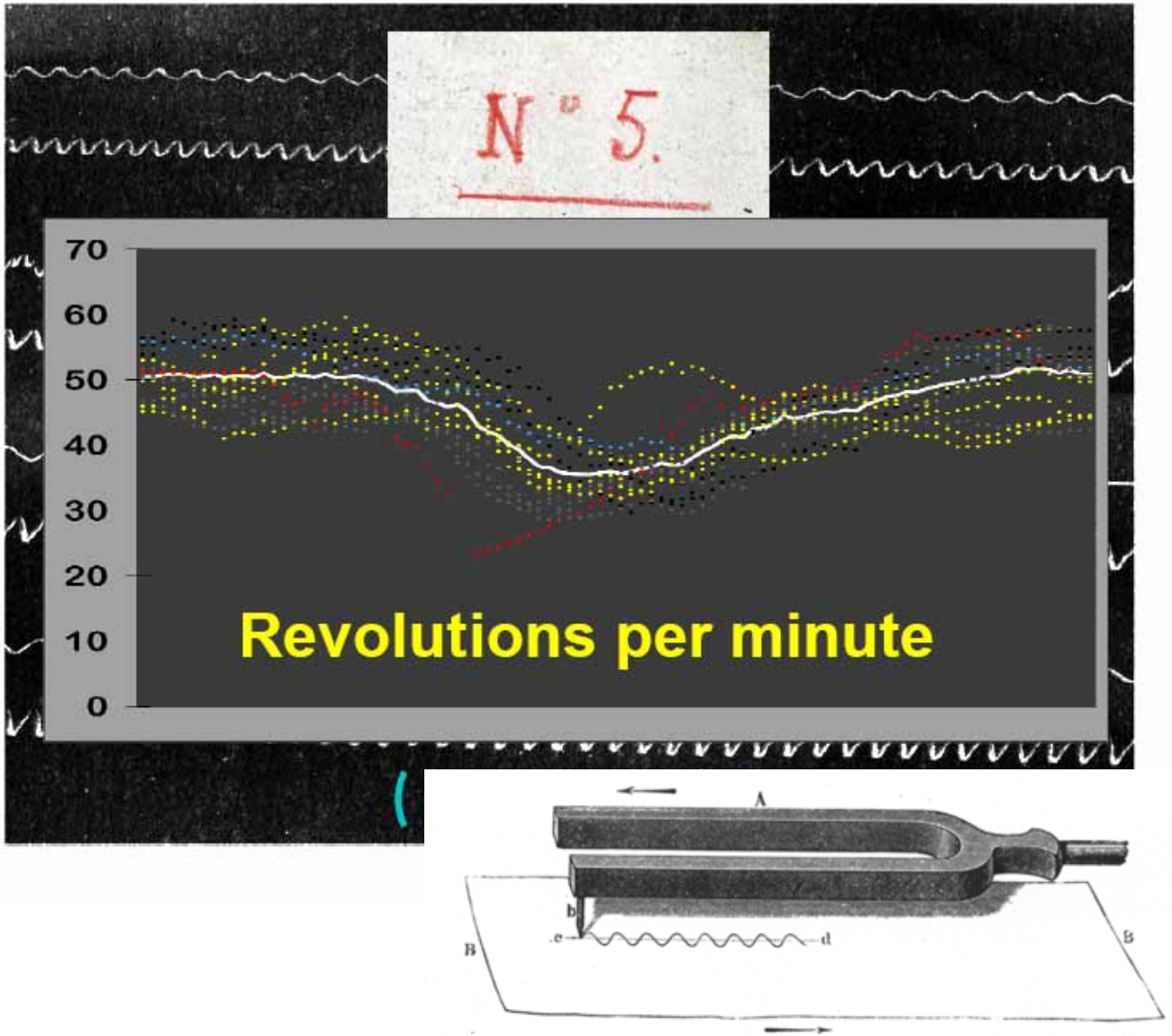








Phonautograms are visually similar to “IRENE” 2D scans and can therefore be processed and analyzed by the same tools…
…albeit with much lower fidelity.


N° 5.
70
60
50
40
30
20
10
0
Revolutions per minute
A
b
c
d
B
B

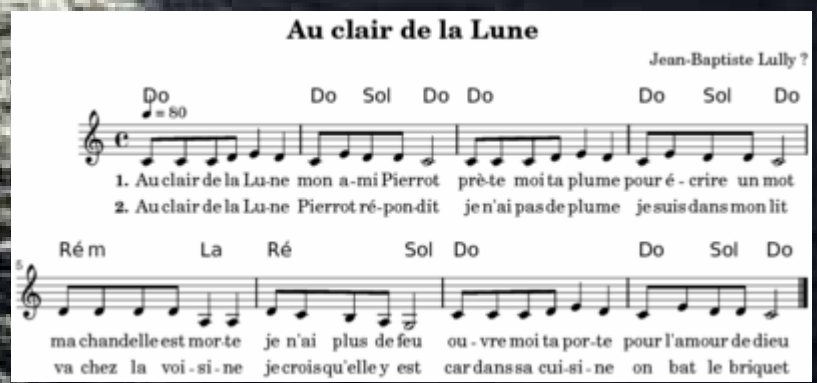
1st example of a sound recording in history

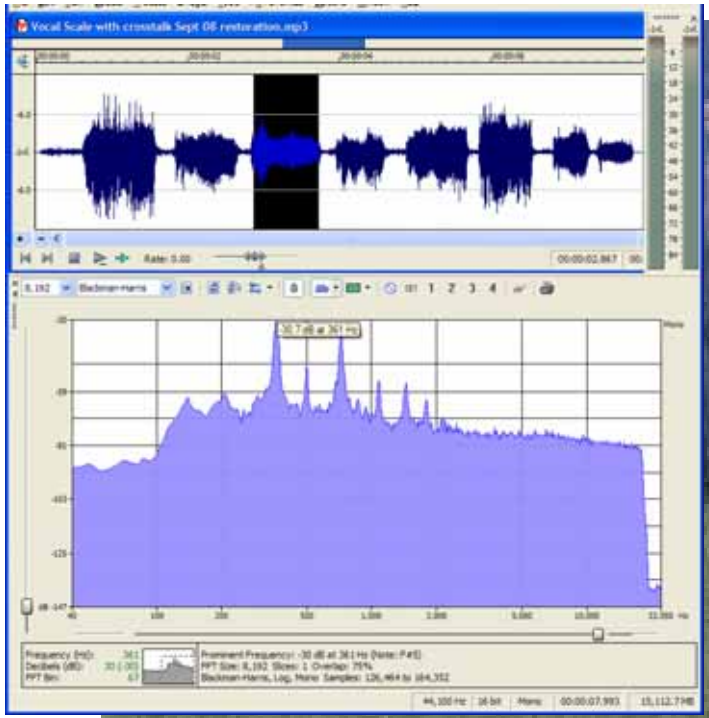
Au clair de la lune, mon ami Pierrot
Prête-moi ta plume, pour écrire un mot.
Ma chandelle est morte, je n'ai plus de feu.
Ouvre-moi ta porte, pour l'amour de Dieu
Au clair de la lune, Pierrot répondit
Je n'ai pas de plume, je suis dans mon lit.
Va chez la voisine, je crois qu'elle y est
Car dans sa cuisine, on bat le briquet.

Under the moonlight, My friend Pierrot
Lend me your pen, So I could write a word
My candle is out, I've no more light
Open your door for me, For God's sake.
Under the moonlight, Pierrot replied,
I've no pen, I'm in my bed.
Go next door, I believe they're in,
For in the kitchen, Someone lit a match.

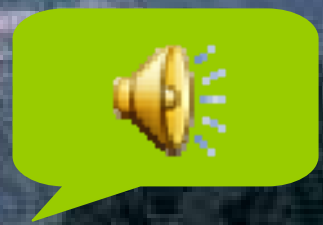
2008

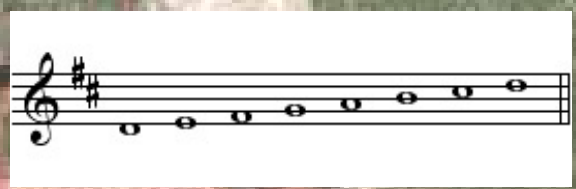
1860





2nd example of a sound recording in history w/ 500 Hz tuning fork crosstalk





Do Re Mi… in D major

Epilogue

- Edison announced in his invention in 1877 to international acclaim.
- Scott complained bitterly, in print, that the original credit was rightfully his.
- Scott died a year later.

What is the future?

Gifted to the nation by David W. Packard, opened in 2007

Who did the work and who paid for it?

Lawrence Berkeley National Lab: Earl Cornell, CH, Vitaliy Fadeyev, Robert Nordmeyer, Jian Jin, Mitch Golden
Library of Congress: Peter Alyea, Larry Appelbaum, Dianne van der Reyden, Elmer Eusman, Eric Hansen
UC Berkeley: Andrew Garrett (Linguistics), Victoria Bradshaw (Phoebe Hearst Museum of Anthropology)
Fantasy Studios: George Horn
First Sounds

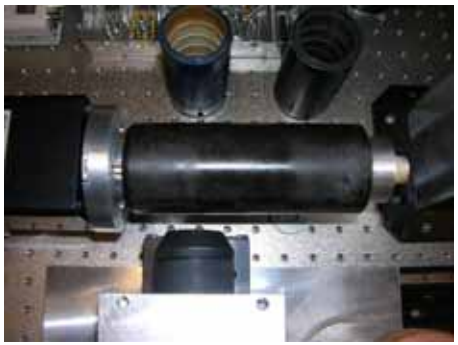
INSTITUTE of Museum and Library SERVICES

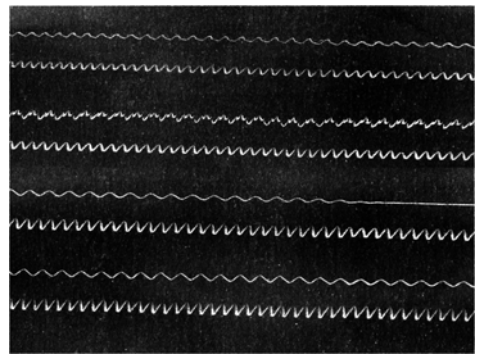
NATIONAL ENDOWMENT FOR THE HUMANITIES

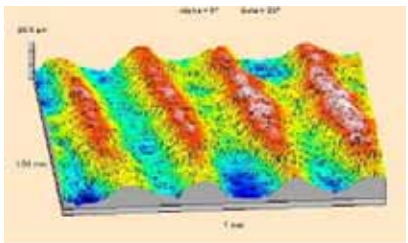
THE ANDREW W. MELLON FOUNDATION

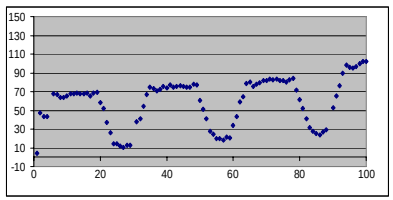
John Simon Guggenheim Memorial Foundation
Fellowships to Assist Research and Artistic Creation

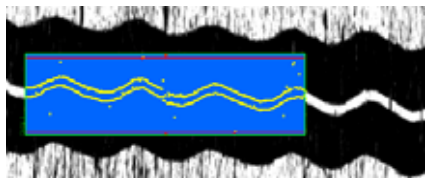
Optical Scanning: A general tool to preserve and create access to recorded sound history











Wax cylinder

Shellac disc

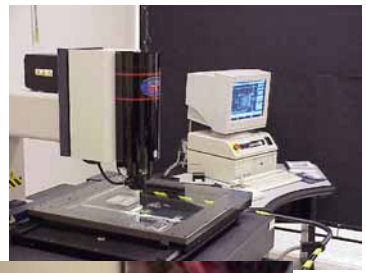
Phonautogram

Web site URL: http://irene.lbl.gov/

V. Fadeyev and C. Haber **J. Audio Eng. Soc**, vol. 51, no. 12, pp. 1172-1185 (2003 Dec.)
V. Fadeyev et al, **J. Audio Eng. Soc**., vol. 53, no.6, pp.485-508 (2005 June).

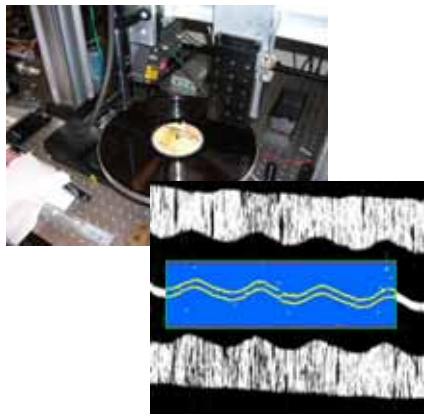
Can I do better in the future?

Basic **2**D concept
demonstration
40 min / 1 sec

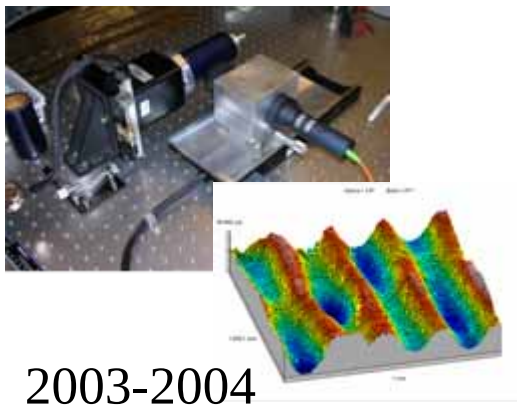


2002

2D disc R&D
4 sec / 1 sec



3D cylinder R&D
20 hr / 1 min



2003-2004

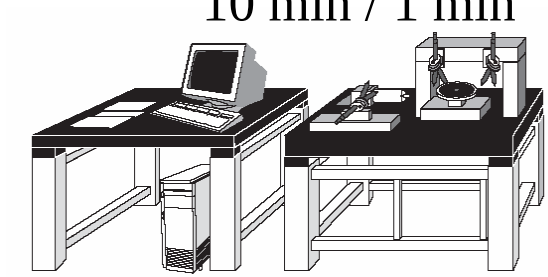
IRENE
System eval

2006-2007

Production
mode discs

2008?

3D System
10 min / 1 min



2008-2009 ?

Pilot
study

Web site: http://irene.lbl.gov/