Seeing Voices: Using Light to Restore and Preserve Early Recorded Sound

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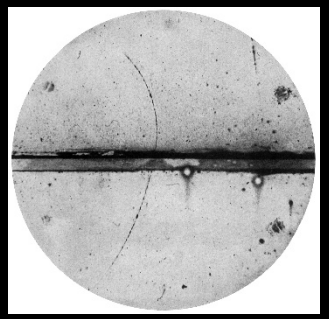
Pictures as Scientific Tools

This pin is radioactive.

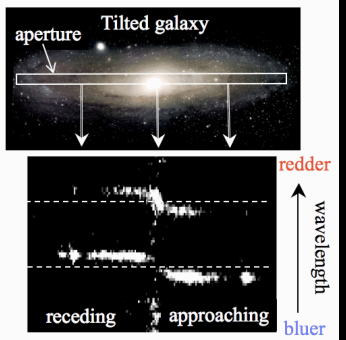
Antimatter exists



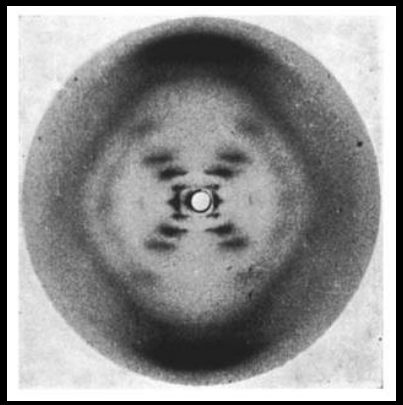
Unification of forces

Dark Matter

Vera Rubin measuring galaxy rotation curves (~1970)

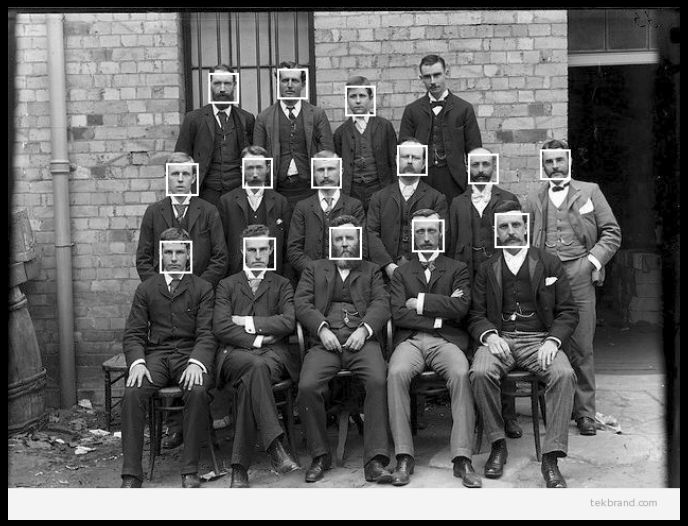


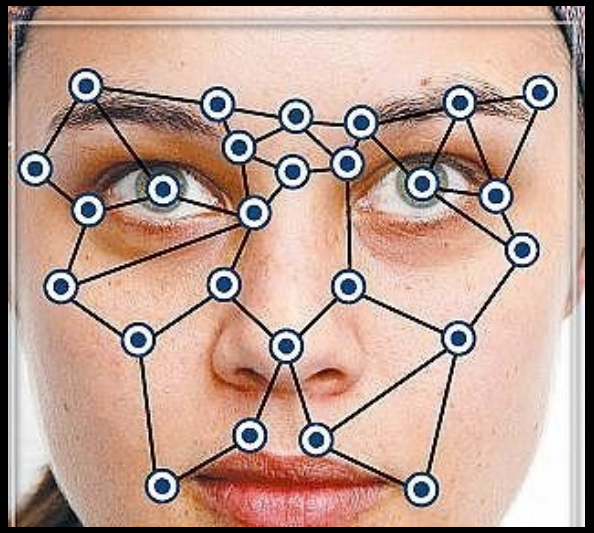
Resulting spectrum of light within aperture



DNA Structure

Pattern Recognition / Metrology

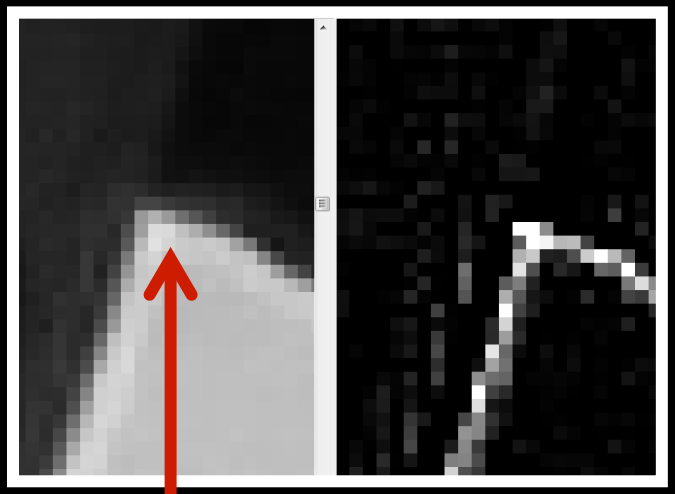




- Digital imaging: pictures become tables of numbers
- These can be mathematically manipulated, leading to precision measurement of features
- Automation and machine learning

Digital Image Processing

A powerful method to extract precision information from images

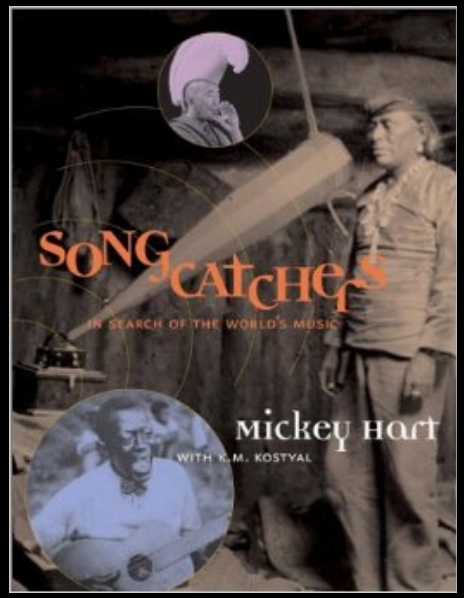


A	B	C
D	E	F
G	H	I

Let N_i be the signal in cell i, dN/dx = E - D

E* = 8E – A – B – C – D – F – G – H - I

Forum on Public Radio, 2000

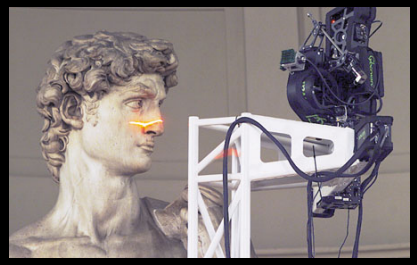


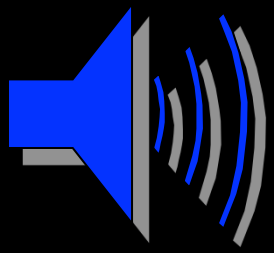
- Sound recordings are of great historical value.
- There are a lot of them, ie. @ the Library of Congress.
- They are sometimes damaged, delicate, endangered
- They are in a wide variety of formats
- We do not maintain all the old playback systems
- J. Audio Eng. Soc., 49 7/8, 2001 July/August

Could we turn a sound recording into a picture?

Three Narratives

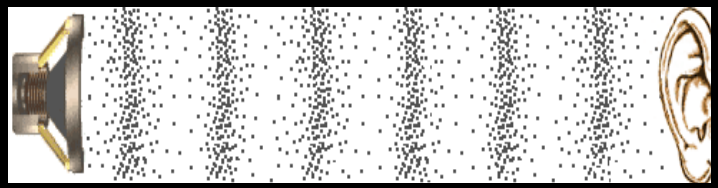
1. The application of quantitative methods to the humanities.
2. Culture and history, as represented in recorded sound, and the challenges of preservation, access, and restoration.
3. A window on the 19th century, the heroic period of invention, when the *analog and digital concepts*, which underlie our information based world, were first explored.

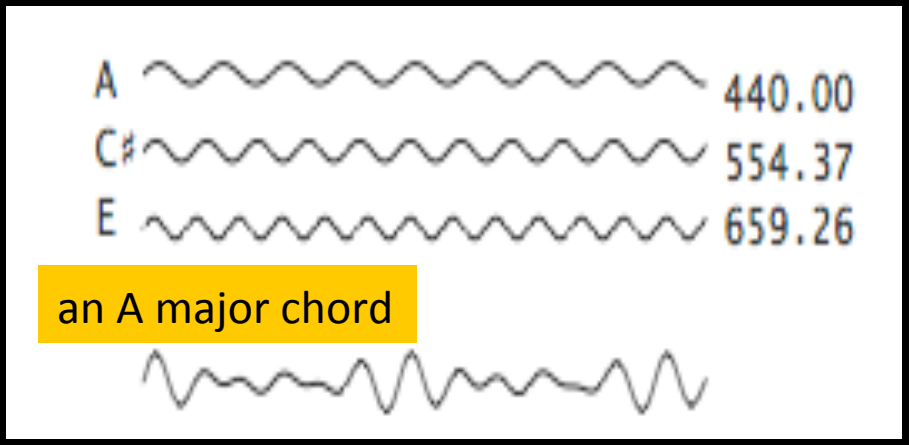




What is sound?

- Sound is a propagating periodic compression and rarefaction of matter (wave)
  - Pitch/tone = period
  - Volume = amplitude
- Sound can be transferred





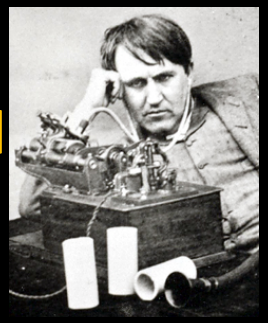
Complex sounds viewed as the sum of pure tones.

Mathematically, a waveform: Amplitude vs Time

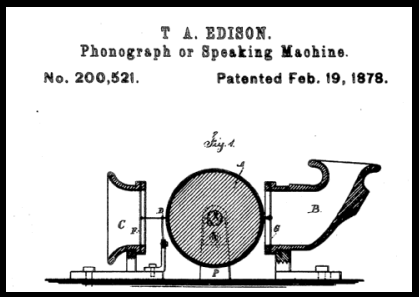
Sound Recording

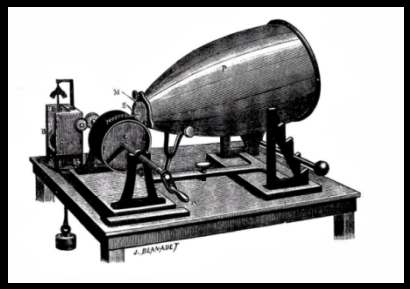
Transfer the mechanical effect to a soft material

Phonautograph
Leon Scott
1853-60



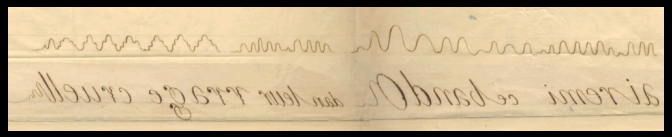
Phonograph
Thomas Edison
1877

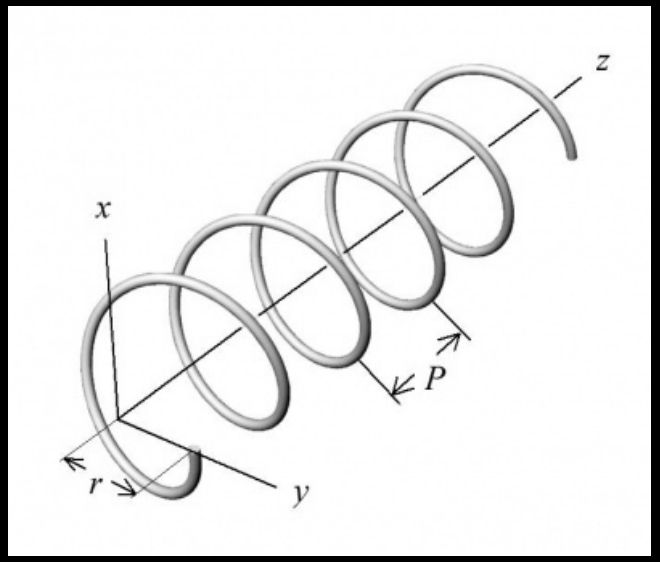


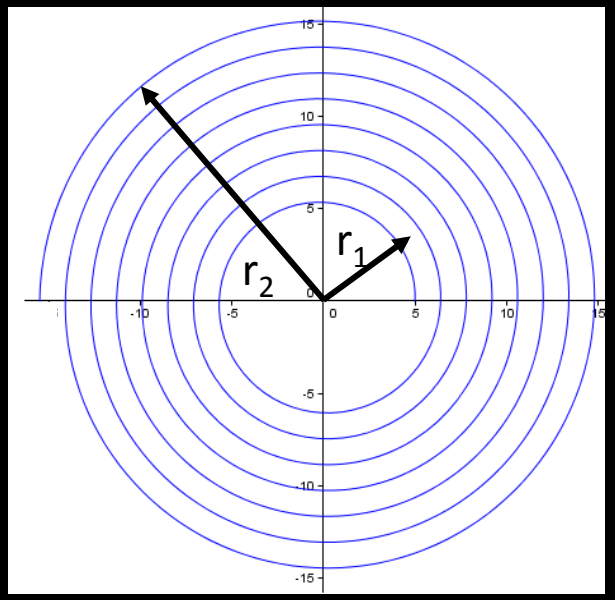


Scott **enscribed** sound on paper and could not play it back

Edison **embossed** sound on foil and was first to reproduce it by reversing the process.





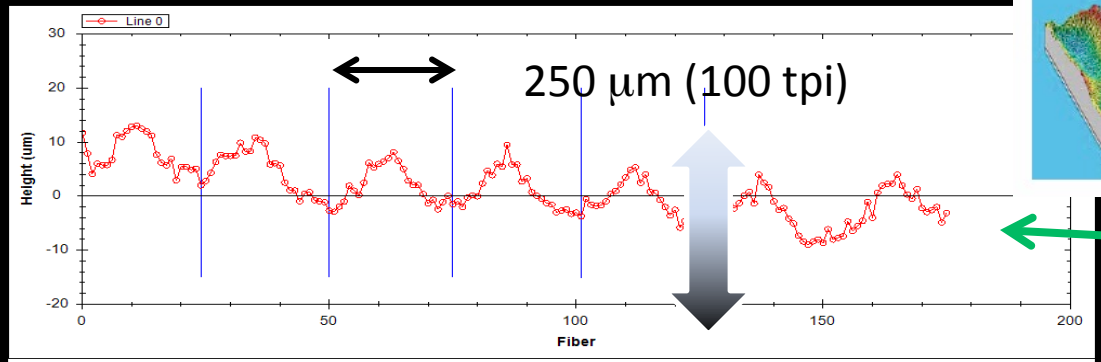


Helix

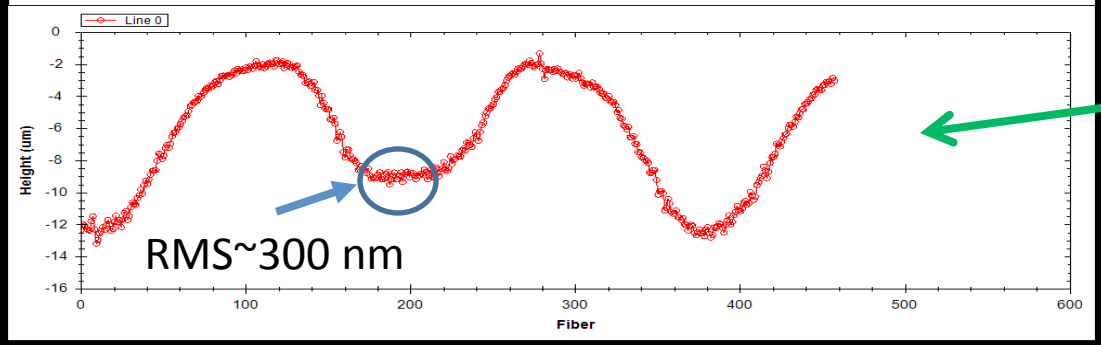
Archimedes' Spiral

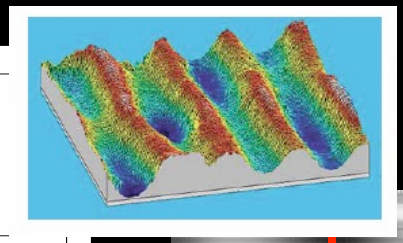
Time=position along the curve

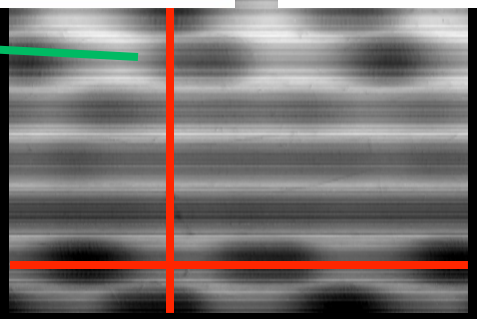
Amplitude= radial deviation from the perfect curve



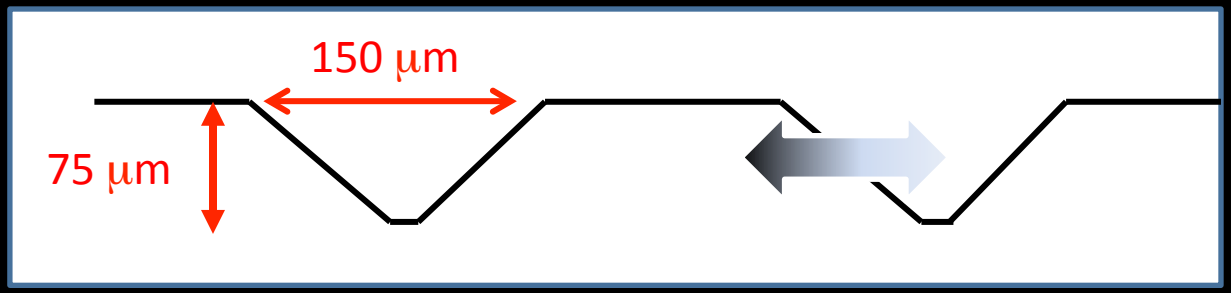
10 µm



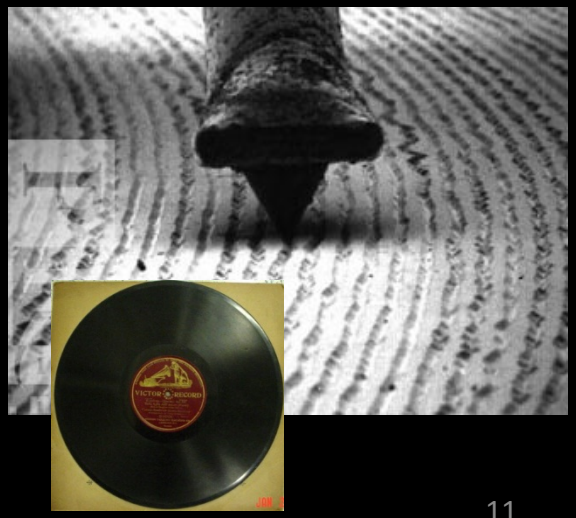




A **vertical** cylinder record

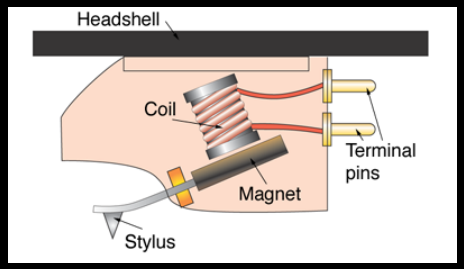


A **lateral (side-to-side)** disc record

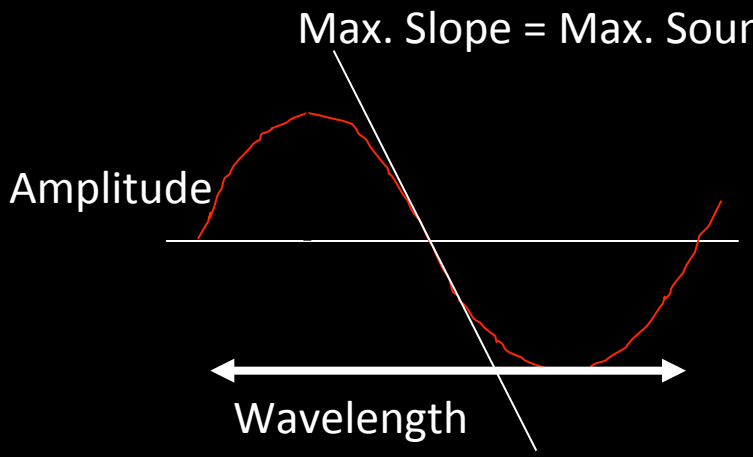


What is the relationship between "groove" and sound?

Electro-magnetic case



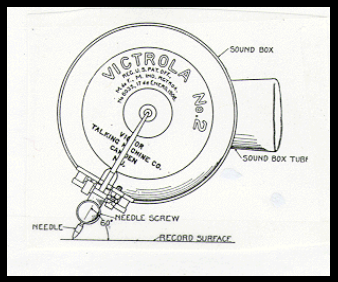
Induction



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

p=peak

Acoustic case



Diaphragm is over-damped to provide flat response

Sound = Stylus Velocity

("constant velocity condition")

Extracted audio = derivative of groove profile
A local effect.

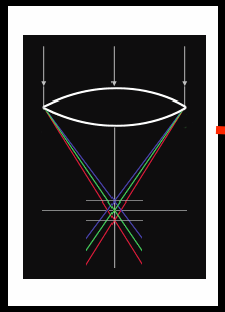
A Non-invasive Restoration

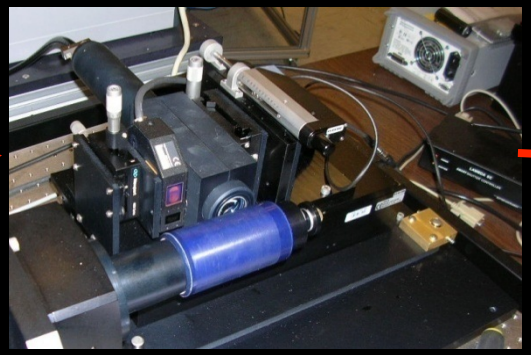
- Could we optically digitize a recording without contact to the material and create a sufficiently detailed image?
- Could we then write a computer program to process the image and recover the sound?
- Address concerns of archivists and conservators….
  - Preservation: Restore or stabilize delicate or damaged media
  - Access: Mass digitization of diverse media using automation
  - Assessment the condition
  - Escape the need to have legacy playback systems
- In 2003 start a systematic study in collaboration* with the Library of Congress

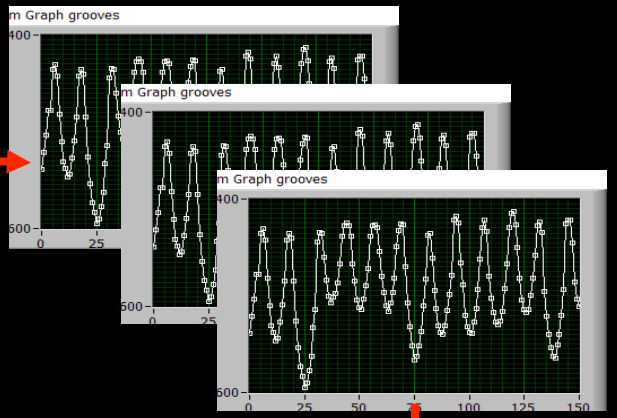
*(CH, V.Fadeyev, E.Cornell, P. Alyea)

Basic Process

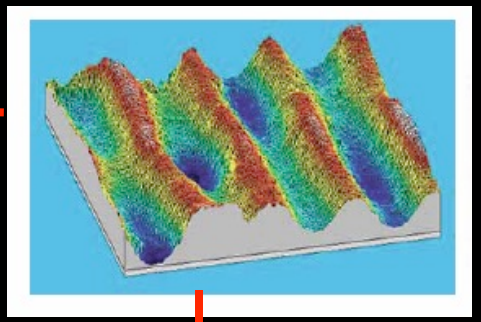
High resolution optical probe…creates a series of depth/intensity profiles of the surface





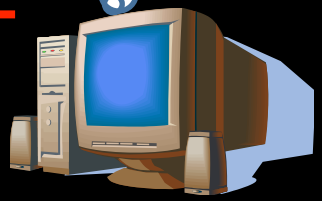


These are merged into a surface map

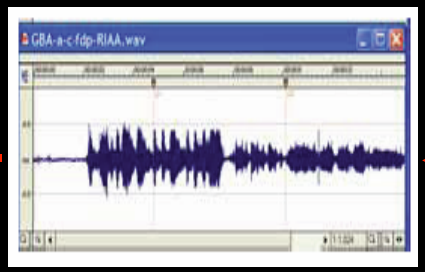


Map is archived

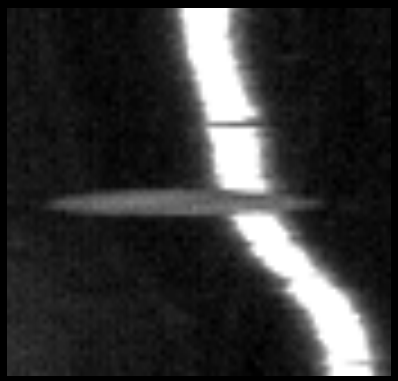
Calculate the motion of a virtual needle, apply optional restoration

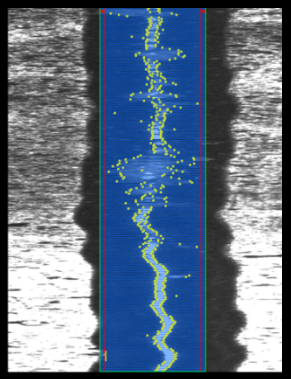


Create audio waveform

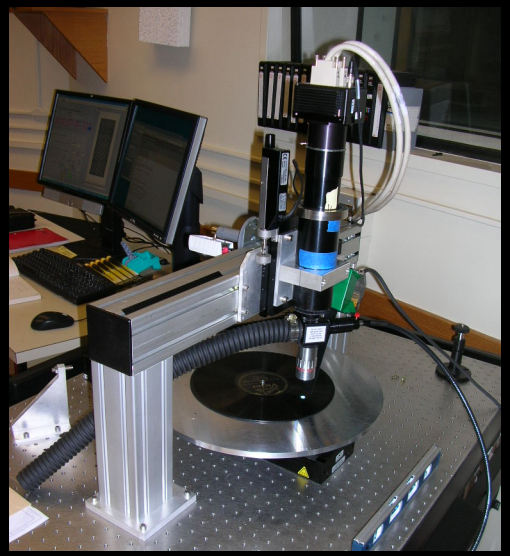


2D Imaging for Lateral Grooves



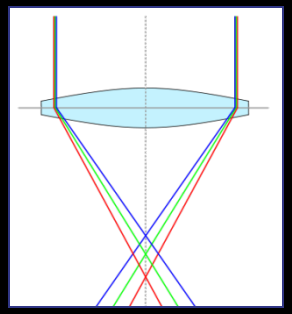


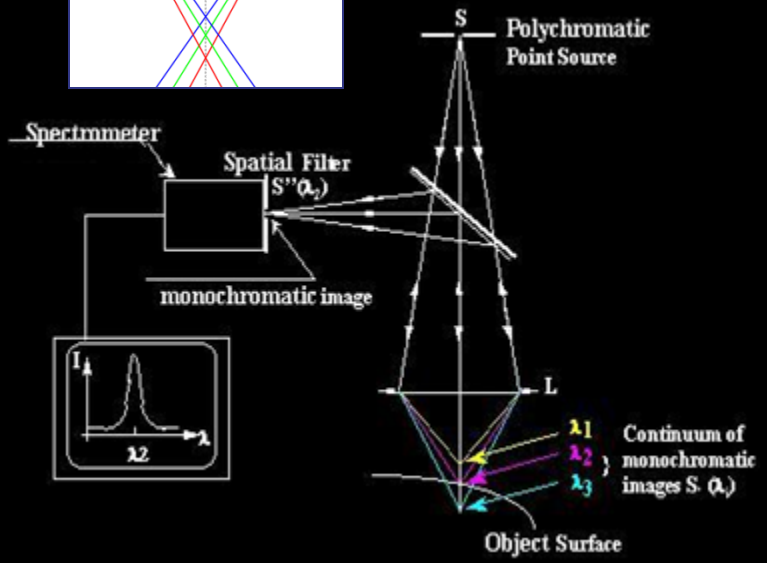
Coaxial illumination

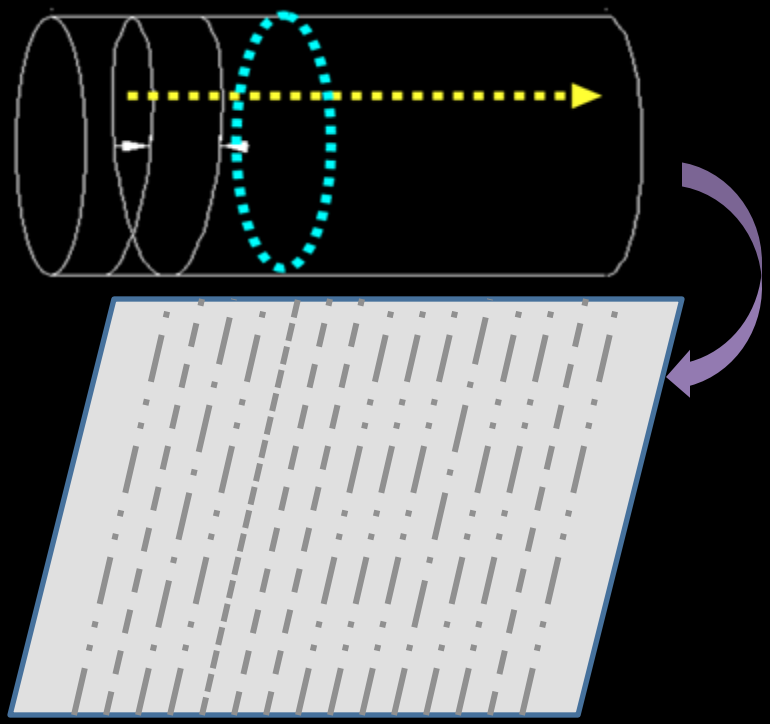


- Require 1 pixel = ~ 1 micron on the disc surface
- Multi-100KHz sampling
- Depth of field, 10 – 20 microns: active focus control
- High speed cameras allow near “real-time” imaging
- Extract groove information from high contrast edge transitions

3D Imaging: Confocal Microscope



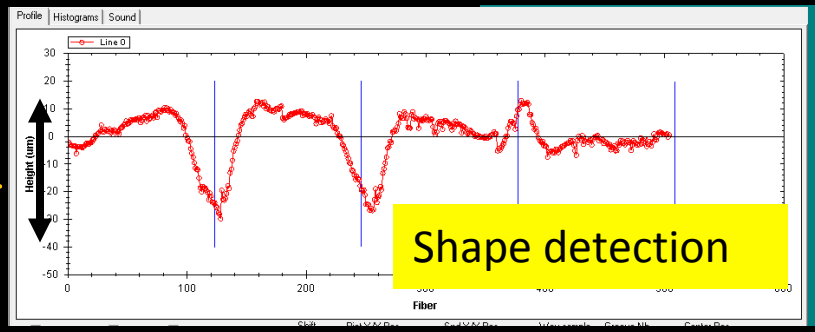


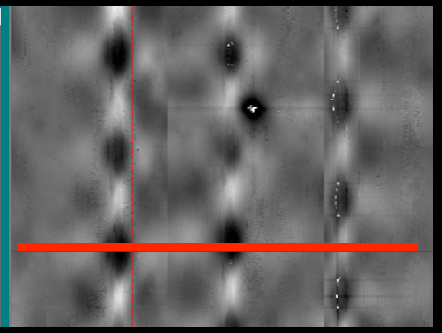


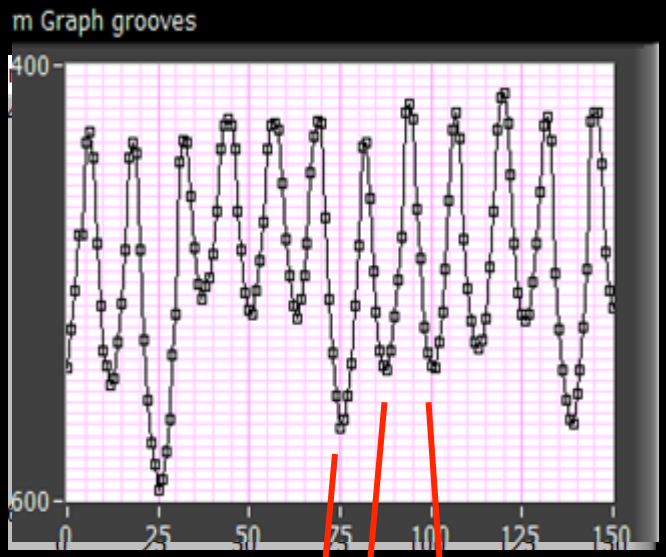
Vertical resolution ~50-100 nm/pt

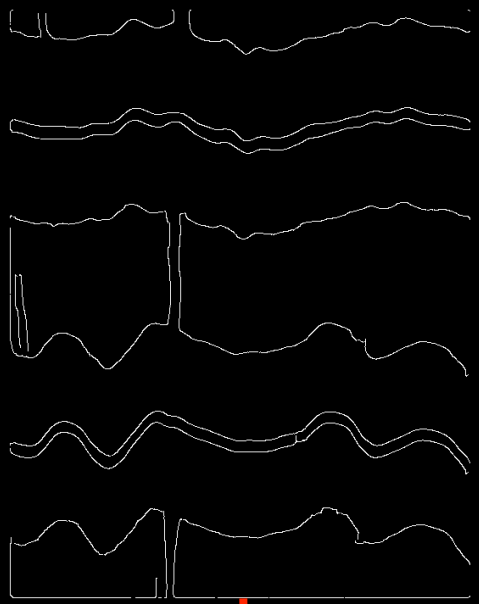
Depth determined by averaging

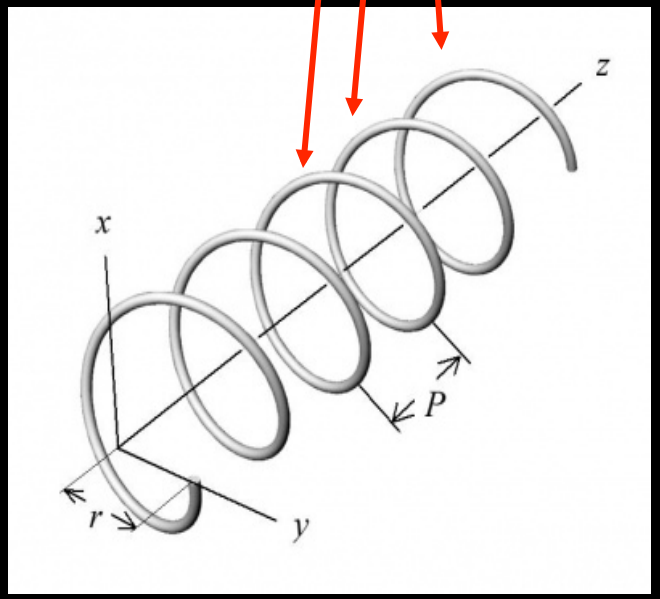
50 μm

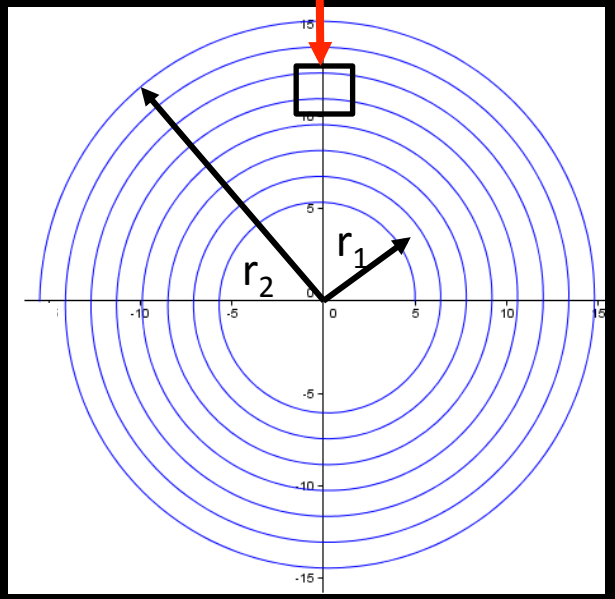





m Graph grooves
400
600
0
25
50
75
100
125
150



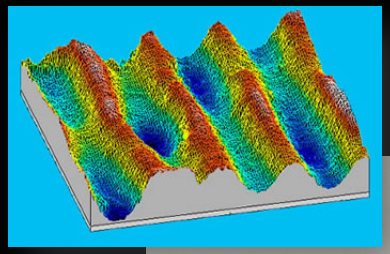

z
x
P
r
y

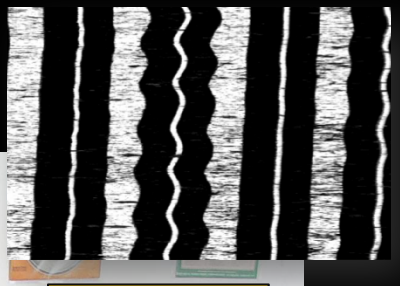

r1
r2

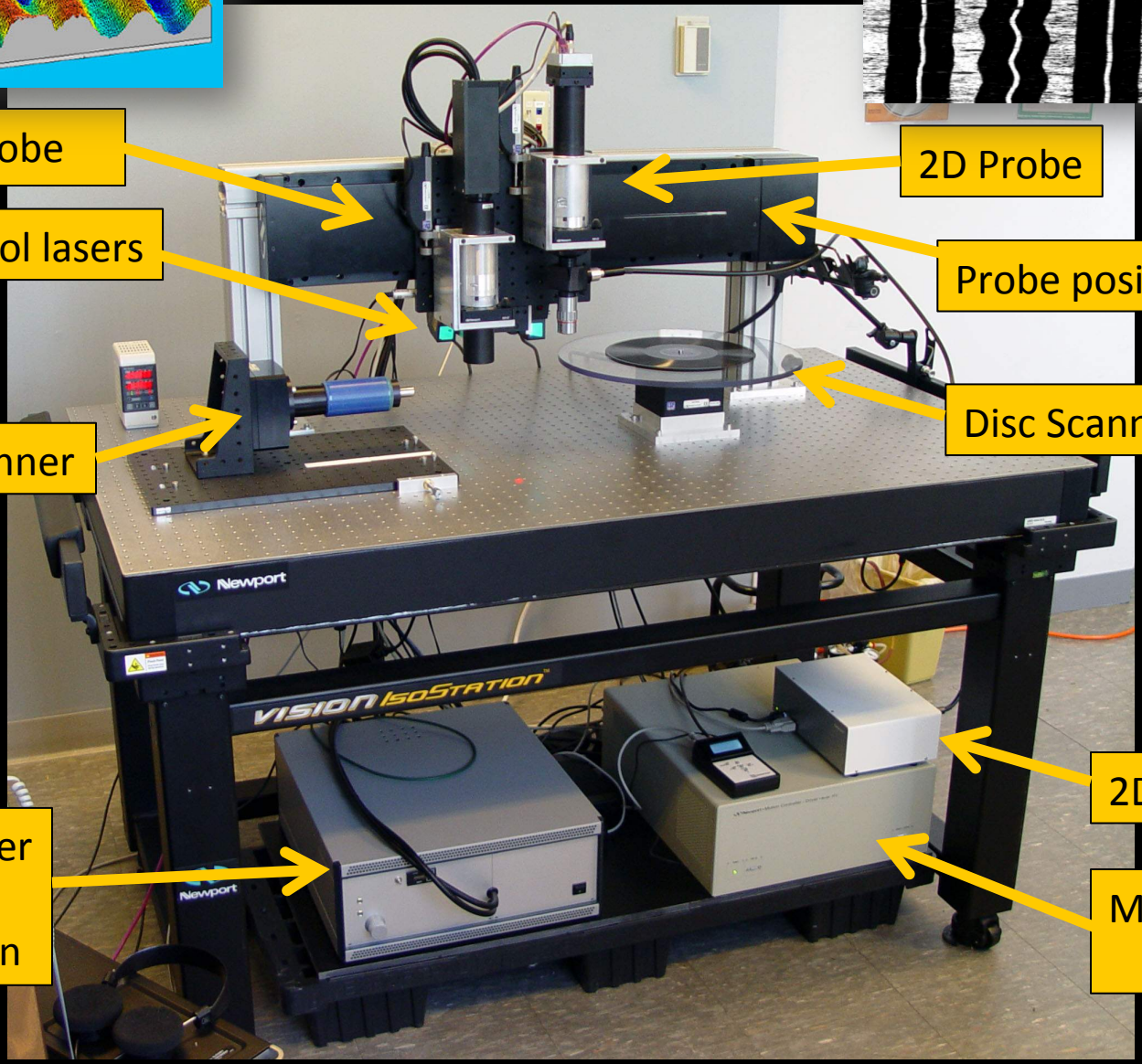
Technical Issues

- Specifications
- Focus control, depth of field
- Vibration isolation
- Illumination
  - Brightness
  - Stability
- Motion control
- Alignment and calibration
- Data acquisition and logging
- Data analysis

IRENE







3D Probe

2D Probe

Focus control lasers

Probe position stage

Cylinder Scanner

Disc Scanner

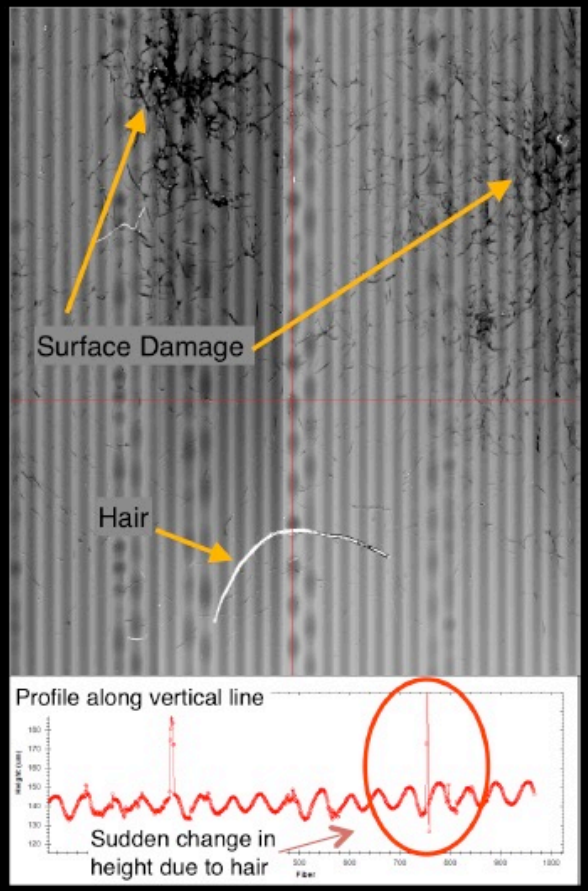
2D illumination

3D Controller and illumination

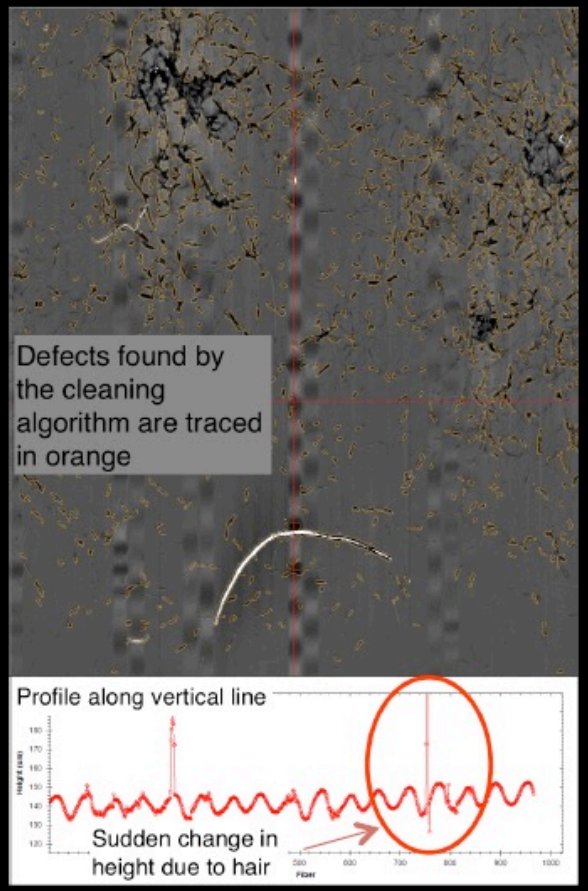
Motion control CPU

Optical Scans: An inclusive data set

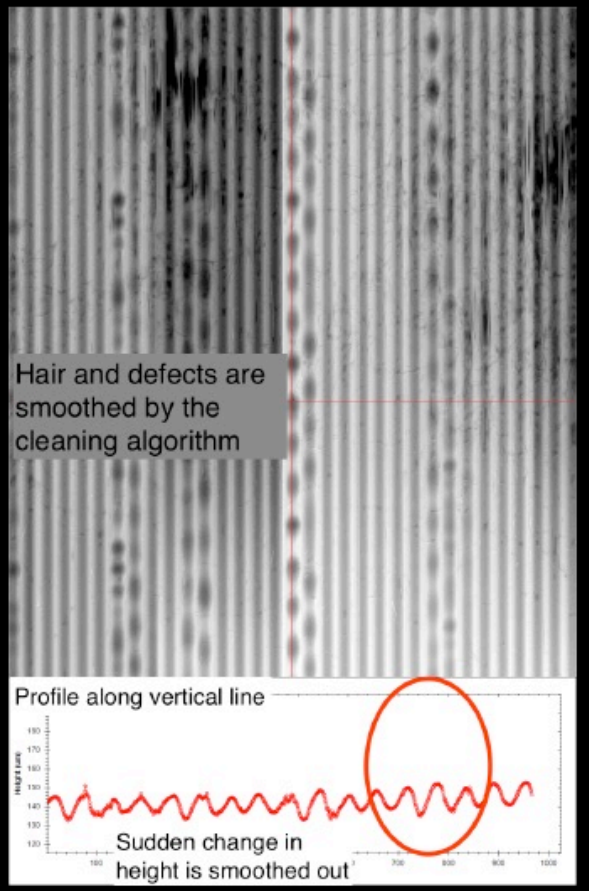
3D depth image: darker = deeper



Raw data



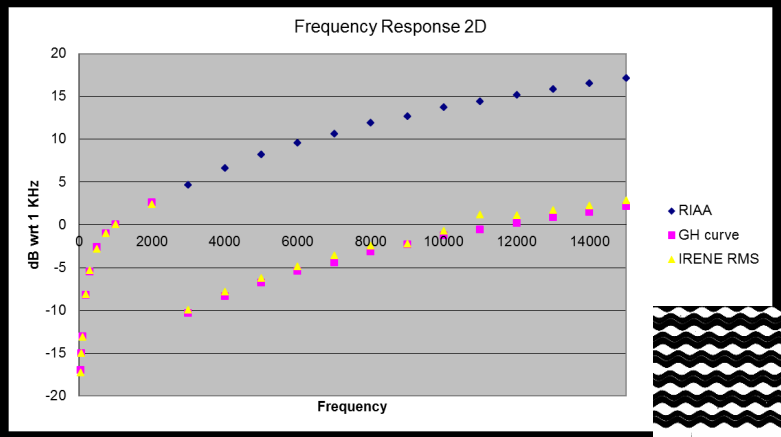
Processed to emphasize structures and locate defects



Cleaned data

Examples

Cracked wax cylinder 1906, fortune teller



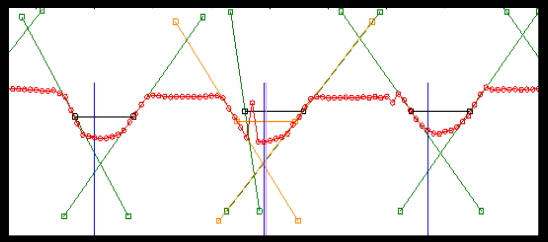
Contemporary lacquer cut disc

"You will soon go to a ball or large gathering and meet a new friend.
A sincere friend seeks to help you in matters of importance to you.
Your troubles can be avoided by changing your attitude towards them…."

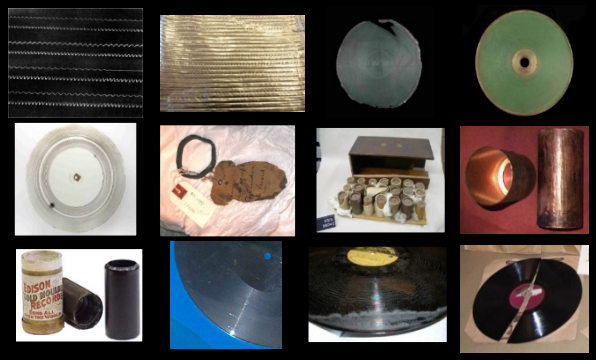
Better or Worse?

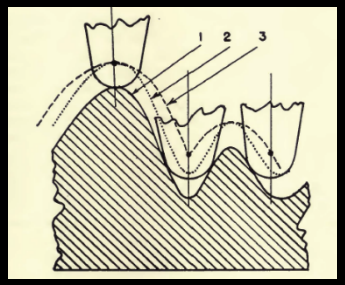
- There is no single answer
- The optical approach may render a whole range of “unplayable” materials playable
  - Delicate and damaged materials are better imaged
  - Wax, lacquer/acetate, other archaic materials
- On shellac disc recordings, in good condition, the traditional methods still work somewhat better
- But optical/numerical methods introduce a variety of new elements which can provide additional advantages
  - Can lead to better noise reduction/restoration

What are the advantages?



Data driven





No dynamics

Non-invasive

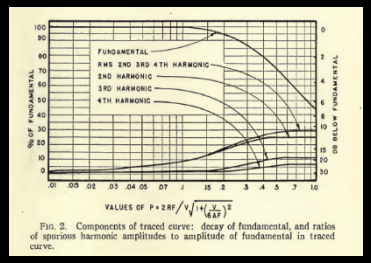
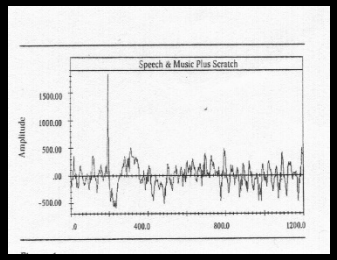
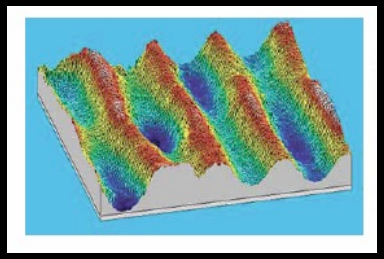


FIG. 2. Components of traced curve: decay of fundamental, and ratios of spurious harmonic amplitudes to amplitude of fundamental in traced curve.



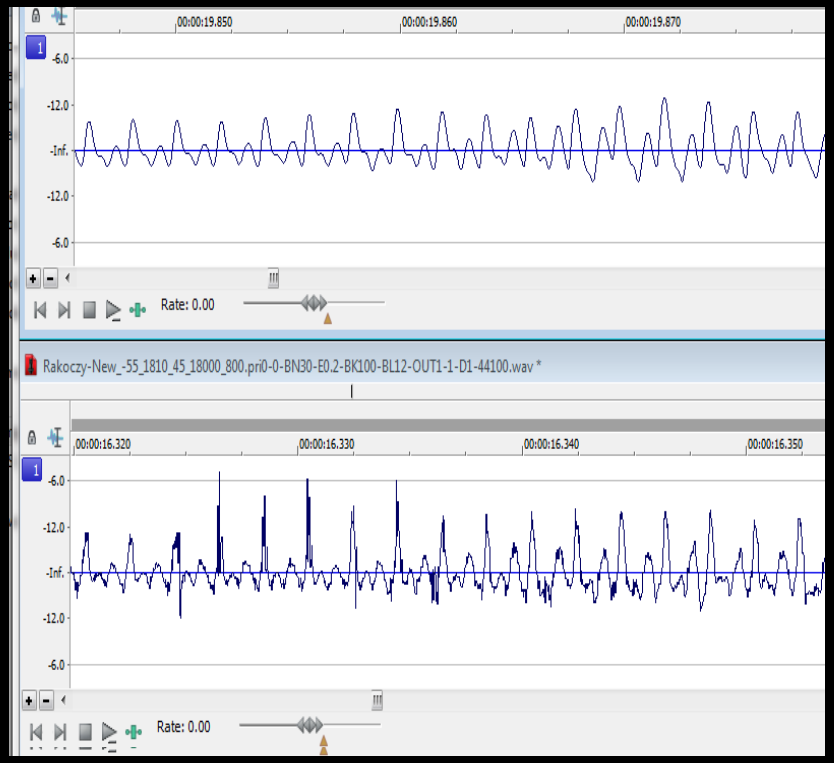
3D Vertical Cut Example

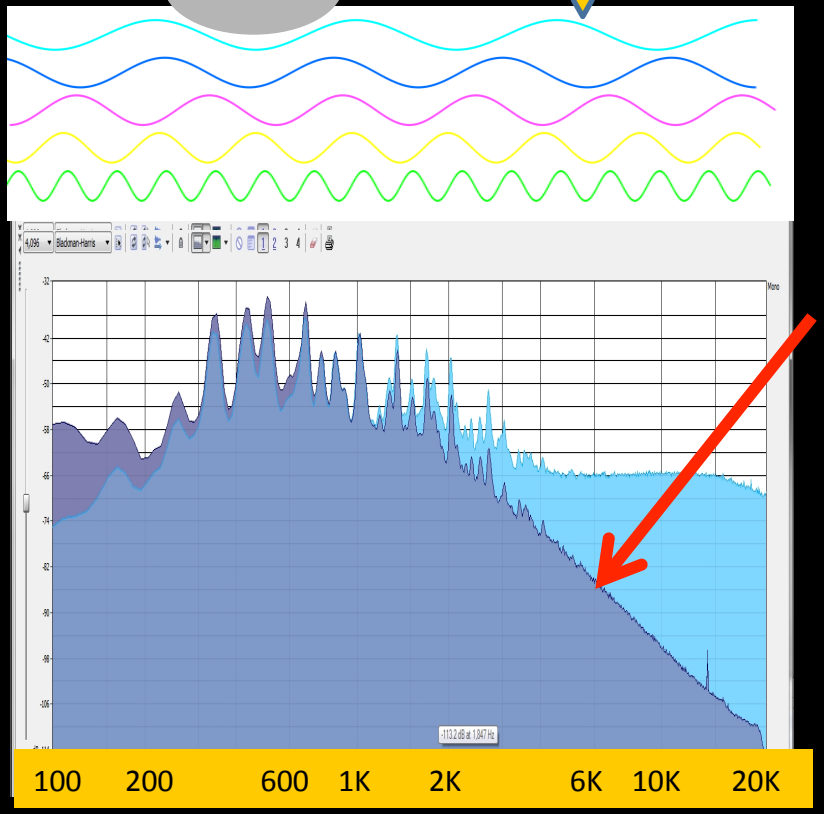


Rakoczy March
2 min. molded cylinder

stylus

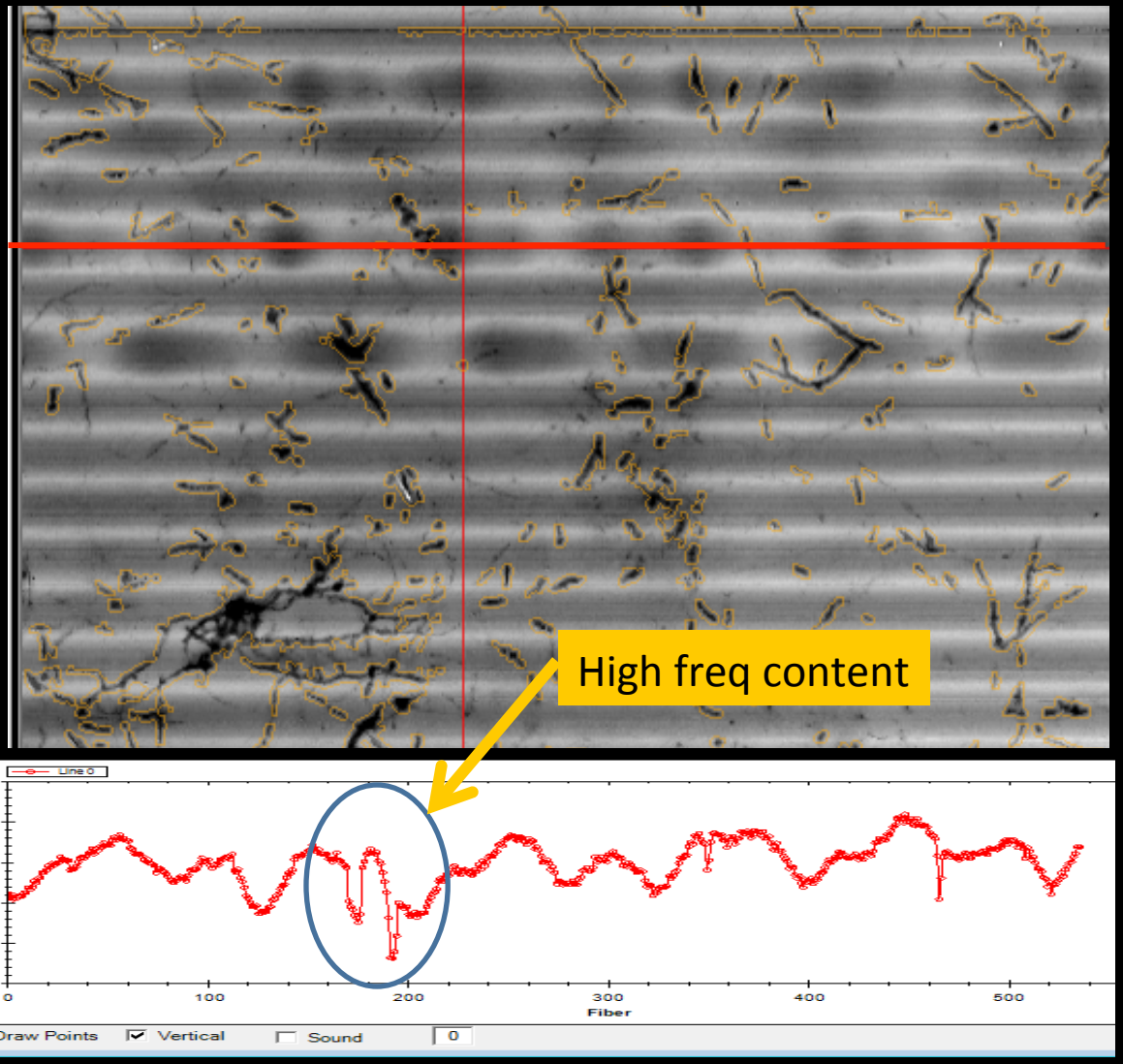
optical





Stylus size effects (tracing/scanning loss) – attenuation at higher frequencies

High Freq = Noise Reduction

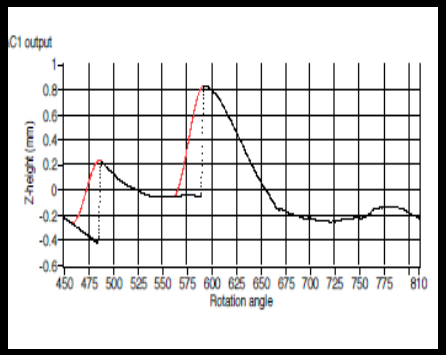


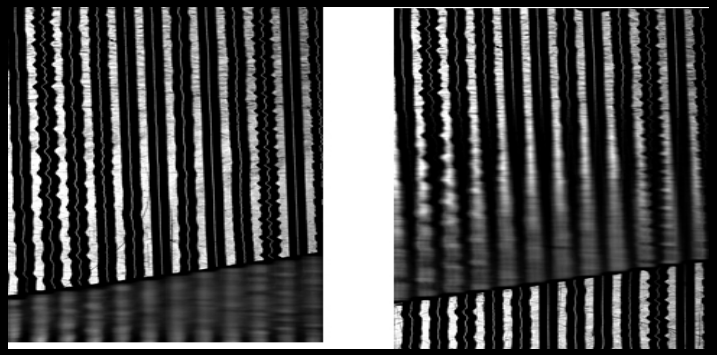
Stylus playback

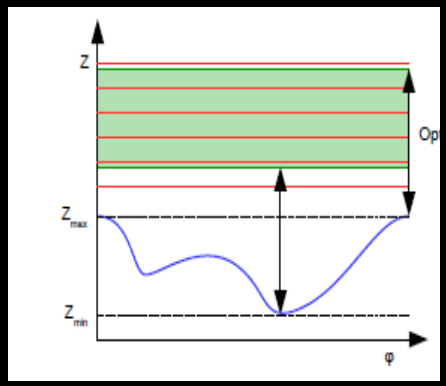
Optical version

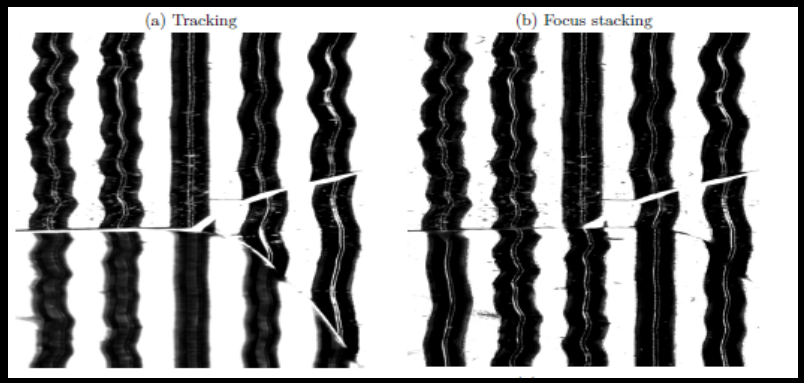
UC Berkeley
Hearst Museum
"Ishi" recordings
1911 wax cylinder

Broken Media









- Key issue is displacement
- Narrow depth of field requires focus control or merging
- Groove linking and use of constraints

Applications and Projects

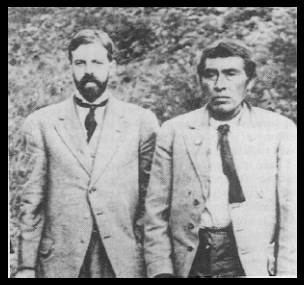
- Partnership with the Library of Congress is ongoing and has grown into further collaboration with many other institutions.
- Tools to process large collections, workflow, diverse materials
  - Faster and robust hardware and software
  - Since 2015: **Northeast Document Conservation Center**, near Boston**,** provides optical scanning service.
  - At risk items
- The history of a technology
  - Have now rendered playable examples of all historic milestones in pre-1895 development of recorded sound
- Pilot projects and major initiatives to digitize important collections

Field Recordings

- 1890: recording adopted as tool for ethnographic research
- Many tens-of-thousands of unique recordings worldwide,
- These require dedicated and systematic transfer projects

Jesse Fewkes

Alfred Kroeber



Frances Densmore

Milman Parry

Mary Haas

John Harrington

Melville Jacobs

Franz Boas

Pilot Digitization Studies

- 2011-2012: 20 (Boas) +60 (Kroeber) cylinders (of 3000) transferred by Maryrose Barrios and Nicolas Scozzaro (UCB physics students)
- 20/week, developed measurement and analysis parameters, database
- Presented at 2012 Breath of Life
- 2014: Tunica and Wiyot collections

irene.lbl.gov/Hearst_Study/Hearst_Final.php

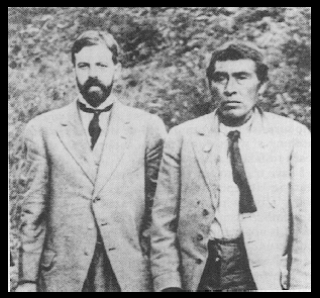
Google | LBNL Central Login Fa... | Suggested Sites | The Crowden School | Indico [Upgrades for H... | Wikipedia, the free enc... | 7-Day Forecast for Lati... | Most Visited | Getting Started | Web Slice Gallery

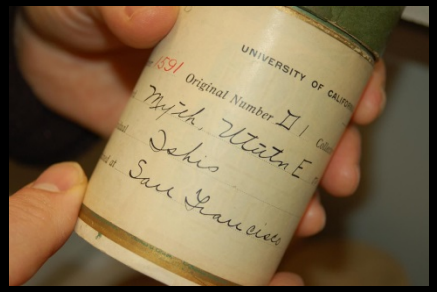
Full Length Scans of Hearst Museum Cylinders

Cylinder	Origin	Year	Content	Condition	Raw Audio File	Filtered Audio File
14-0015	Monterey Ohlone Maria Viviena Soto	1902	Bears Dancing Song	Moderate	0015-full_raw.wav	0015-full_hardM.wav
14-0016	Monterey Ohlone Maria Viviena Soto	1902	Lazy Womans Song, Rabbit and Hare Song, Bears Dancing Song	Moderate	0016-full_raw.wav	0016-full_hardM.wav
14-0017	Monterey Ohlone; [Jancinta Gonzales Mari	1902	Myth of Coyote; Song; Gambling song	Moderate	0017-full_raw.wav	0017-full_hardM.wav
14-0018	Monterey Ohlone; Maria Viviena Soto	1902	a.Esselen Deer Dancing b. Gambling Song	Moderate	0018-full_raw.wav	0018-full_hardM.wav
14-0019	Monterey Ohlone; Maria Viviena Soto	1902	Dancing Song	Moderate	0019-full_raw.wav	0019-full_hardM.wav
14-0020	Monterey Ohlone; Maria Viviena Soto	1902	Song of Blind Man; Dancing Song; Song	Good	0020-full_raw.wav	0020-full_hardM.wav
14-0021	Monterey Ohlone; Maria Viviena Soto	1902	Womens Love Song; Purisimenos Dancing Song	Good	0021-full_raw.wav	0021-full_hardM.wav
14-0022	Monterey Ohlone; Maria Viviena Soto	1902	Purisimenos Dancing Song; Dancing Song	Moderate	0022-full_raw.wav	0022-full_2_3khzrolloff_montery.wav
14-0023	Monterey Ohlone; Maria Viviena Soto	1902	Gambling Song; Dancing Song	Moderate	0023-full_raw.wav	0023-full_2_3
14-0024	Monterey Ohlone; Maria Viviena Soto	1902	Dancing Song of Colorado Indians; Dancing Song; Dancing Song	Moderate	0024-full_raw.wav	0024-full_har
14-0025	Monterey Ohlone; Maria Viviena Soto	1902	Dancing Song; Dancing Song of Coyote; Dancing Song to Bring a Man Home; Charm Song for Death or Sickness	Moderate	0025-full_raw.wav	0025-full_har
14-0271	Yurok; Domingo	1906	Deerskin Song	Poor/Moderate	271-full_raw.wav	271-full_2_75
14-0272	Yurok; Domingo	1906	Deerskin Song	Poor/Moderate	0272-full_raw.wav	0272-full_har
14-0275	Yurok; Domingo	1906	Jump Dance Song	Moderate	0275-full_raw.wav	0275-full_har
14-0276	Yurok; Domingo	1906	Jump Dance Song	Moderate	0276-full_raw.wav	0276-full_har
14-0279	Yurok; Domingo	1906	Brush Dance Song	Moderate	0279-full_raw.wav	0279-full_har
14-0280	Yurok; Domingo	1906	Brush Dance Song	Moderate	0280-full_raw.wav	0280-full_har
14-0282	Yurok; Domingo	1906	Brush Dance Song	Moderate	0282-full_raw.wav	0282-full_har
14-0289	Yurok; Domingo	1906	Gambling Song (w/ drum)	Moderate	0289-full_raw.wav	0289-full_har
14-0290	Yurok; Domingo	1906	Gambling Song (w/ drum)	Moderate	0290-full_raw.wav	0290-full_har
14-0292	Yurok; Domingo	1906	Gambling Song (w/ drum)	Moderate	0292-full_raw.wav	0292-full_har
14-0417	SE Pomo; Tom Johnson	1906	Turva xe (Acorn Song)	Moderate	0417-full_raw.wav	0417-full_har
14-0418	SE Pomo; Tom Johnson	1906	Turva xe (Acorn Song)	Poor	0418-full_raw.wav	0418-full_har
14-0419	SE Pomo; Tom Johnson	1906	Hintil xe (Dance Song)	Moderate	0419-full_raw.wav	0419-full_har
14-0420	SE Pomo; Tom Johnson	1906	Batses xe (Love Song)	Moderate	0420-full_raw.wav	0420-full_har
14-0421	SE Pomo; Tom Johnson	1906	Bastes xe (Love Song)	Moderate	0421-full_raw.wav	0421-full_har
14-0423	SE Pomo; Tom Johnson	1906	Bastes xe (Love Song)	Moderate	0423-full_raw.wav	0423-full_har

UC Berkeley Cylinder Project

Linguistic and ethnographic sound recordings from early twentieth-century California: Optical scanning, digitization, and access





Department of Linguistics

Phoebe Hearst Museum of Anthropology

UC Libraries

Lawrence Berkeley National Lab

3 year project ongoing to scan UCB collection of ~3000 cylinders

Multiple Cylinder System

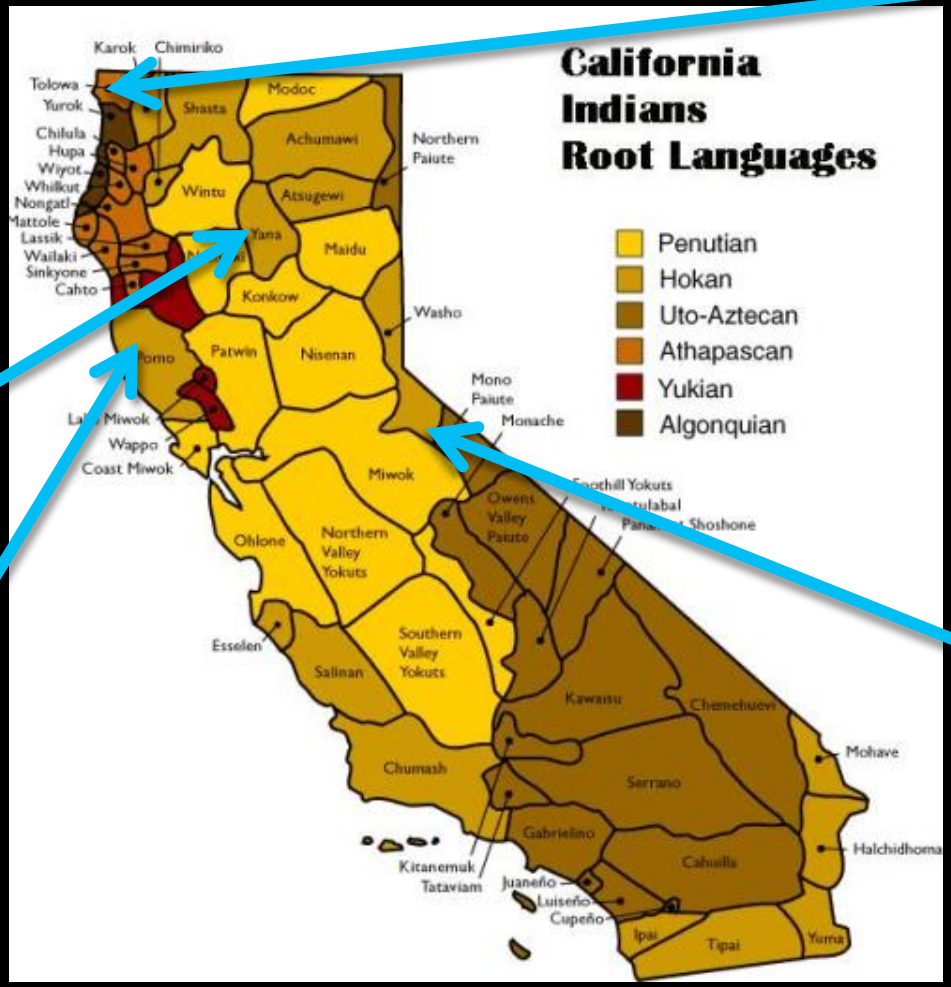
- Can handle 1-5 cylinders simultaneously
- Software and control framework
- >2500 cylinders scanned to date

California Language Survey

Yahi – Ishi Recordings

"Wood Duck" Story

Pomo – Acorn Song



Yurok

Gambling Song

Central Sierra Miwok

Giant's Song

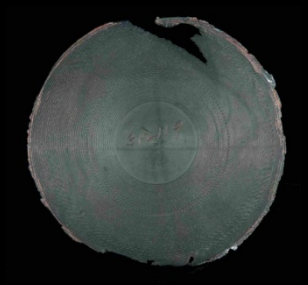
Aluminum Discs

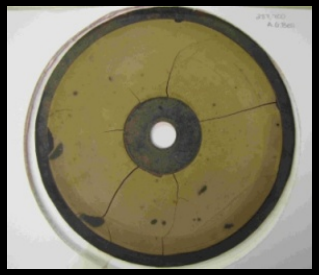
- Mid 1920's- 1930's, improved material for field recording
- Shallow irregular embossed grooves
- Harvard's Milman Parry Collection of Oral Literature

Parry's analysis of South Slavic oral song led to the view that the epic poems were orally transmitted

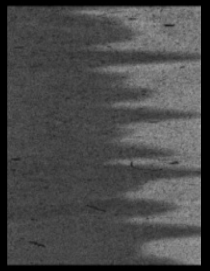
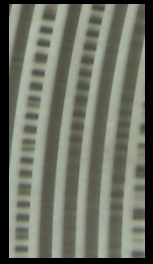
AG Bell and Sound Recording

- In 1880 Alexander Graham Bell established the Volta Laboratory in Washington, D.C., to conduct signals research.
- He formed an association with chemist (and cousin) Chichester Bell and instrument builder Charles Sumner Tainter.
- The associates experimented with an astounding variety of materials and formats, many patents leading to the wax cylinder as the best choice.
- All materials and notes are in the Smithsonian Institution (>400 recordings).





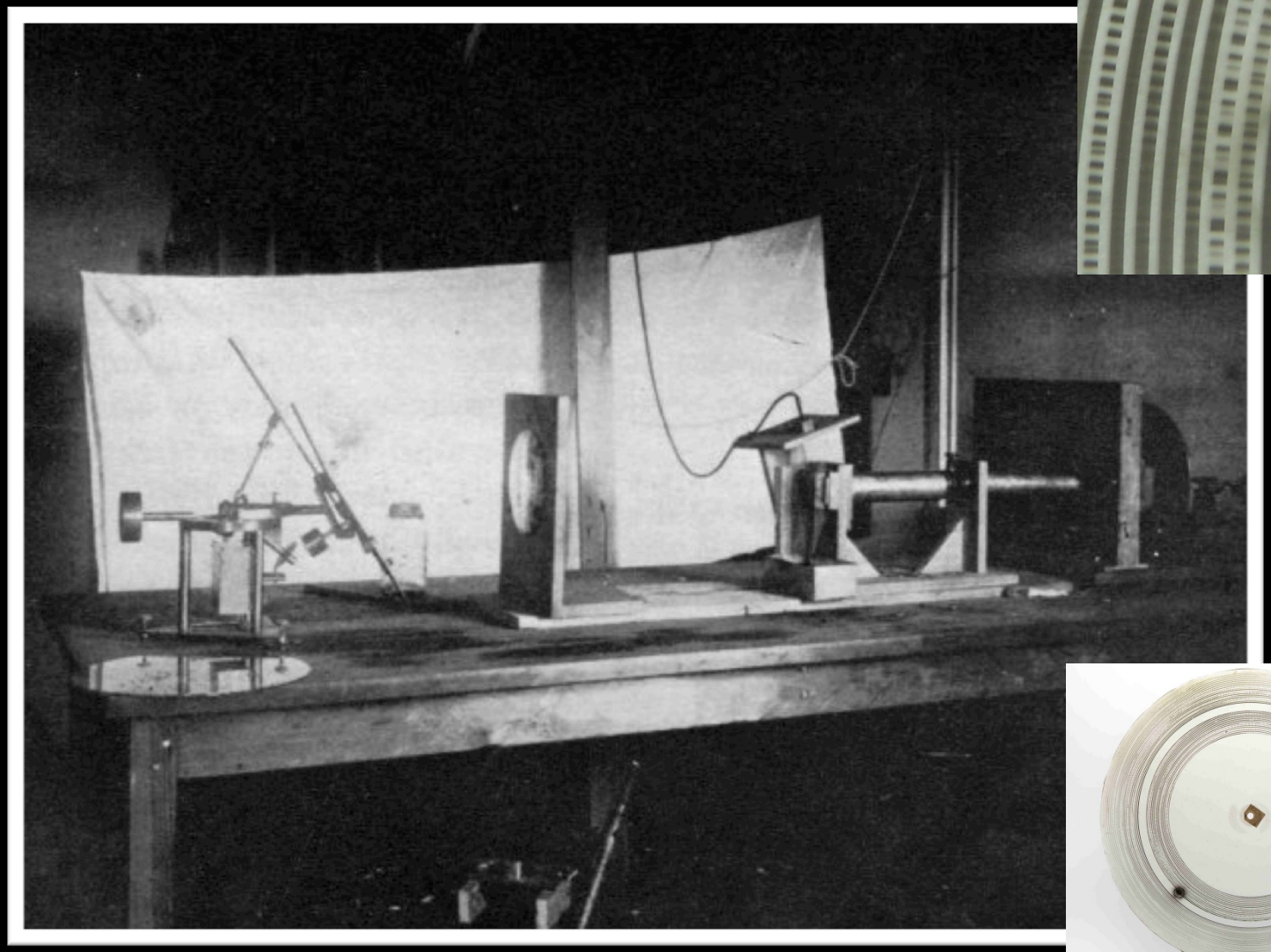


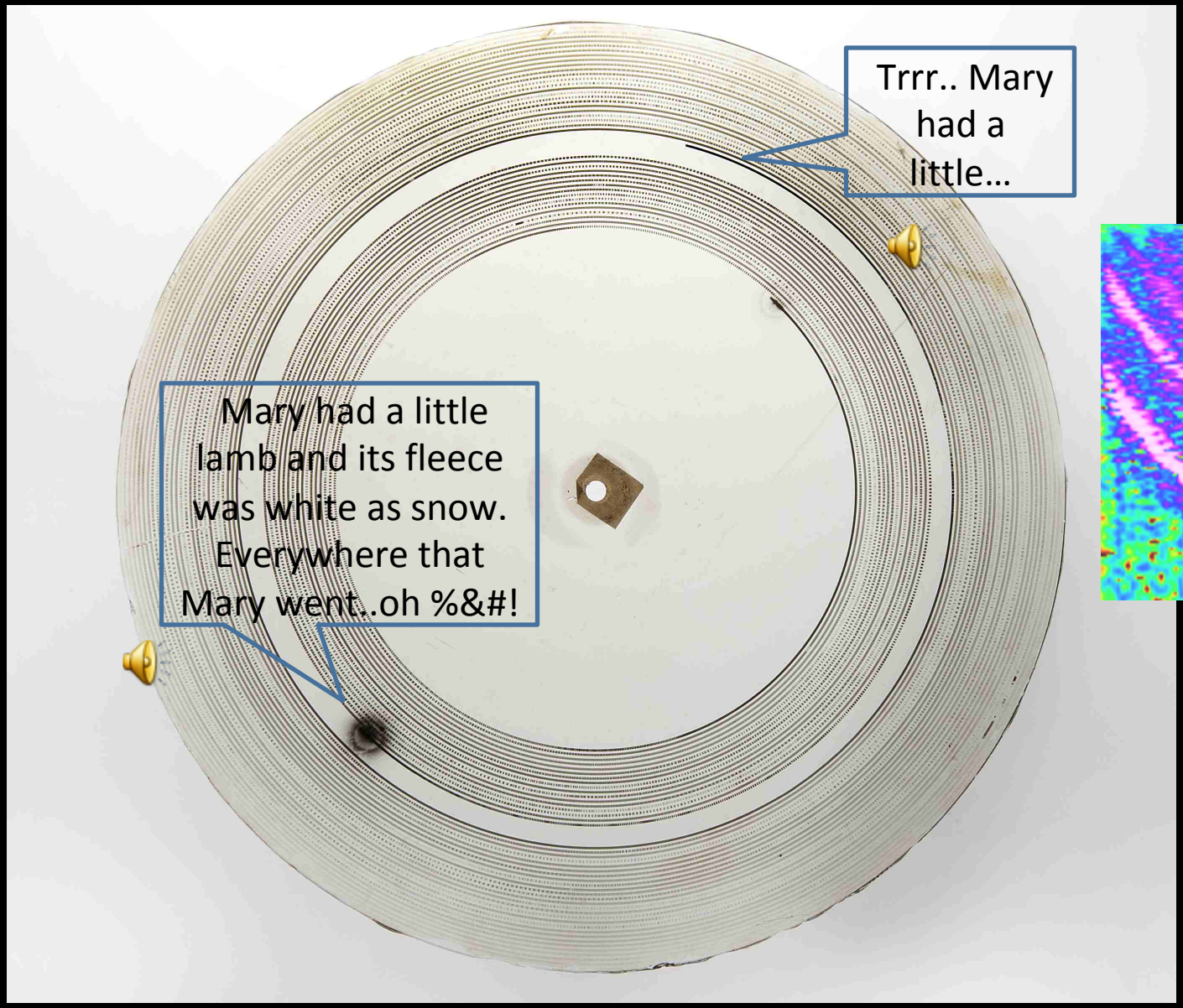




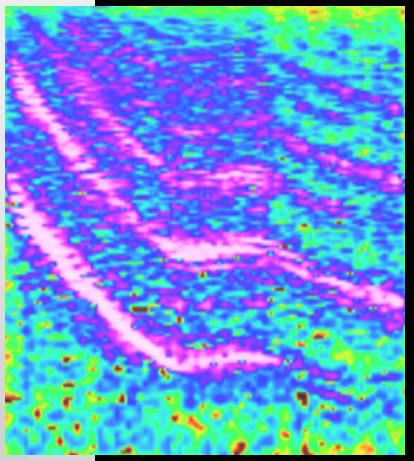
Uniquely identified recording of AG Bell himself: "hear my voice"

"This record has been made by Alexander Graham Bell, in the presence of Dr. Chichester A. Bell, on the 15th of April, Eighteen hundred and eighty five, at the Volta Laboratory, 1221 Connecticut Ave, Washington, DC, in witness whereof, hear my voice, Alexander Graham Bell"

Bell Optical Recorder (1884-5)

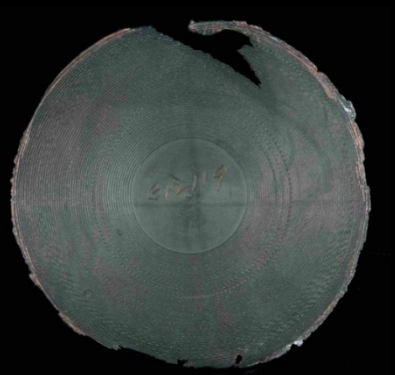


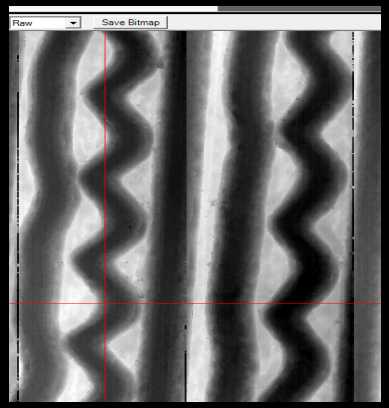

Trrr.. Mary had a little…
Mary had a little lamb and its fleece was white as snow. Everywhere that Mary went..oh %&#!

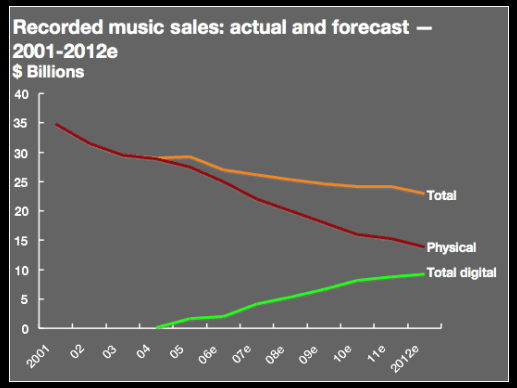


Electroformed Copper “Stamper” (1881)

perhaps the oldest example of a lateral cut disc record!







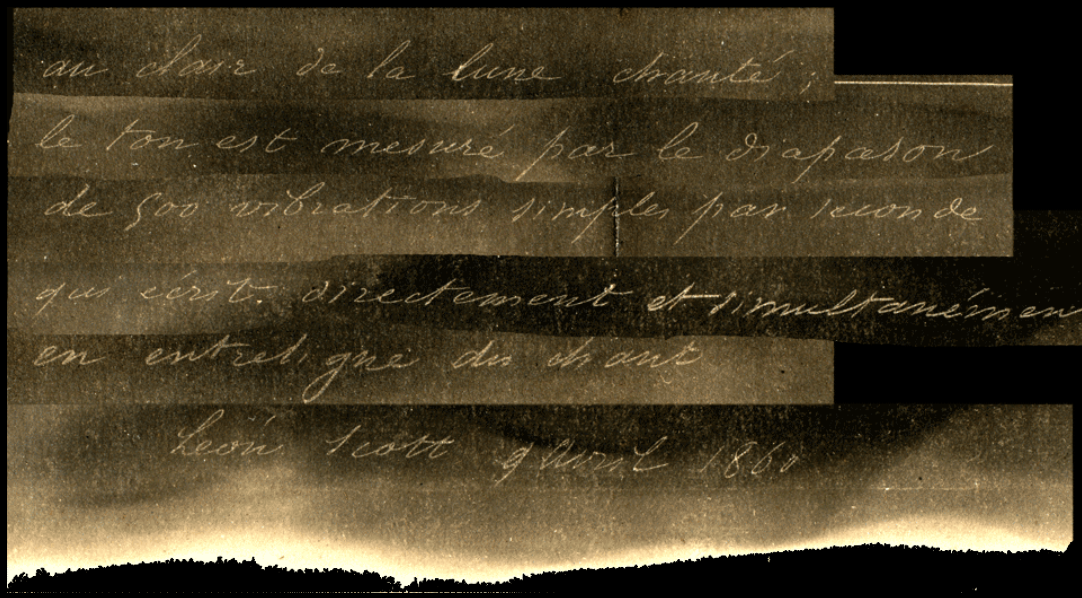
Trrrrrr 1 2 3 4 5 6 trrrr trrrrr

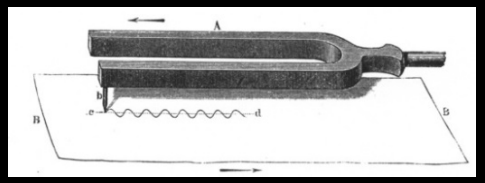
Charles Sumner Tainter, Home Notes Oct. 17, 1881

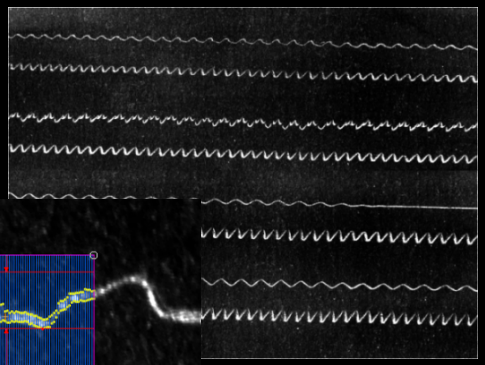
“Our object is to use the copper electro-type for the purpose of forming records or phonograms in other substances by stamping, or printing, and to use these stamped copies for reproducing the sounds originally recorded in the composition.

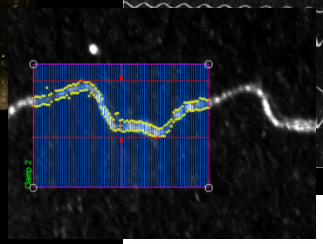
In this way a piece of music, for instance, can be recorded once, and any number of copies made from this original record, and the music reproduced from any each of the copies.”

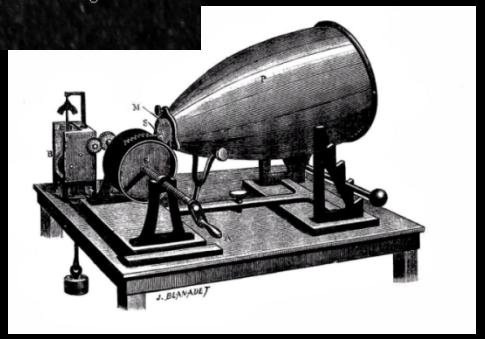
1860 Phonautograph: E. Leon Scott de Martinville











2008 1860

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

*w. FirstSounds

Future Directions

- Major transfer projects – Berkeley + several under discussion
- Additional systems at sites internationally
- Further development of tools and software
- Development of physical modeling methods
- Proposed study to consider standard practice
- Development of a user/developer community
- Open sourcing the code

What if ?

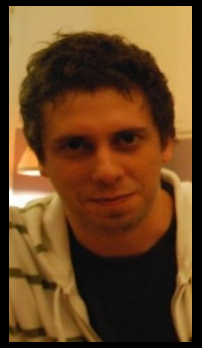
- Sound recording in the 19th century utilizes technology and methods which could have been applied much earlier.
- Could Leonardo Da Vinci (1452-1519) have invented it?
- Da Vinci believed poetry and music were inferior to sculpture and painting because, (hearing is) *"less noble than sight, in that as it is born it dies and its death is as swift as its birth". (from "Treatise on Painting")*
- If only he had considered the *possibility* of recording…

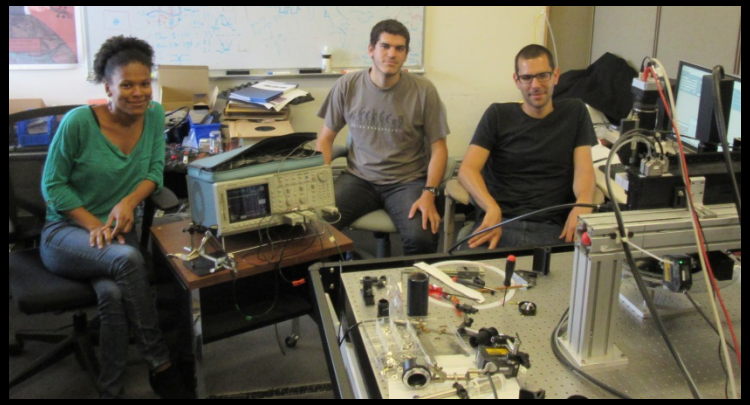
Optical Scanning Collaboration and Support

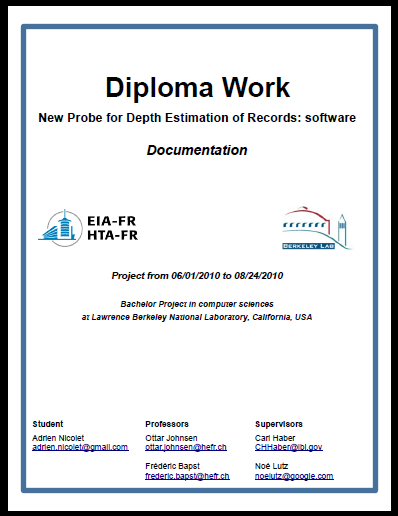
Lawrence Berkeley National Lab (Earl Cornell)
The Library of Congress (Peter Alyea)
Univ. of Appl. Sciences, Fribourg, Switzerland (Ottar Johnsen)
The Smithsonian Institution (Carlene Stephens, Shari Stout)

& **>40 students!**

Students







Diploma Work

New Probe for Depth Estimation of Records: software

Documentation

EIA-FR
HTA-FR

Project from 06/01/2010 to 08/24/2010

Bachelor Project in computer sciences
at Lawrence Berkeley National Laboratory, California, USA

Student	Professors	Supervisors
Adrien Nicolet adrien.nicolet@gmail.com	Ottar Johnsen ottar.johnsen@heft.ch	Carl Haber CHHaber@lbl.gov
	Frédéric Bapst frederic.bapst@heft.ch	Noé Lutz noelutz@google.com

- ~30 undergrad internships
- ~15 thesis students from University of Applied Science Fribourg, Switzerland
- Subjects: Physics, EE, ME. CS, Anthropology, Art History
- Students have participated in design, measurements, data analysis, coding.
- Way to expose students in STEM to problems in preservation/conservation

Conclusions

- Today's digital technology provides a window on the entire early period of sound recording and its rich research, artistic, historical, and commercial legacies.
- "Our ultimate audience is posterity" (B.Vielette NEDCC)
- More info?

http://irene.lbl.gov

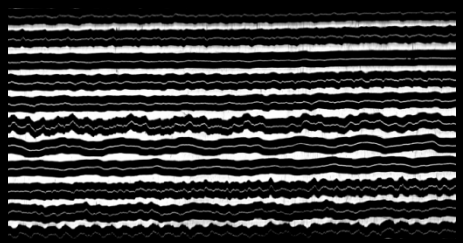
and links there-in…

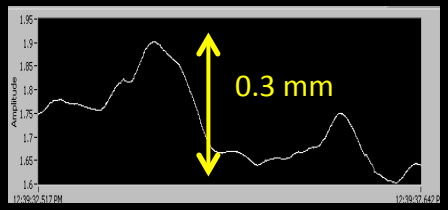
http://bio16p.lbl.gov/PAHMA.html

and the National Recording Preservation Board

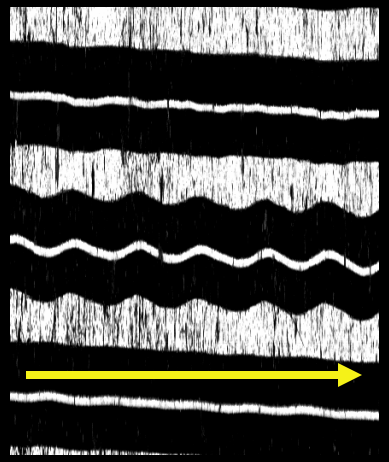
http://www.loc.gov/rr/record/nrpb/

Backup

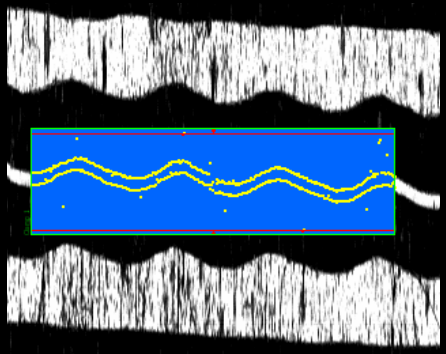




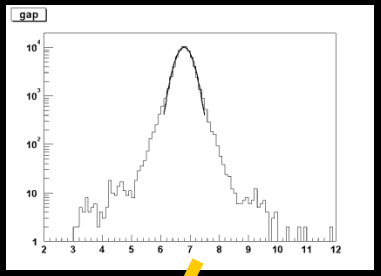
Active focus control



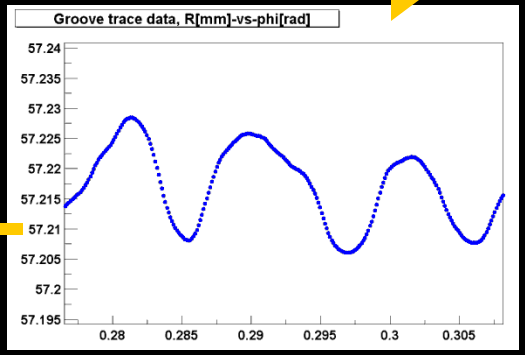
Time
Pixels = 104 KHz

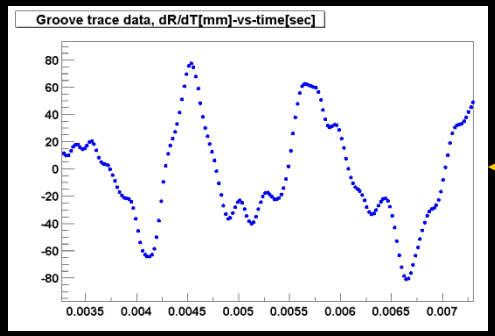


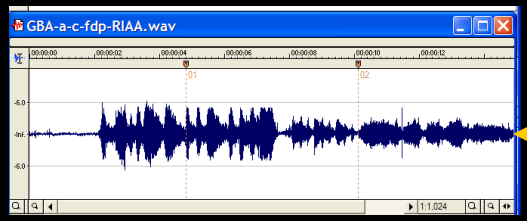
Width across
groove bottom



Measure slope
at each point
(stylus velocity)







Average
Filter using width cut