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**THE NATURAL TRUMPET
AND ITS VIRTUAL SOUND**

L. Tronchin (), A. Farina (**), A. Cocchi*

(*) DIENCA – CIARM, Viale Risorgimento, 2
40136 Bologna (Italy) - <http://ciarm.ing.unibo.it>

(**) Industrial Engineering Department.,
University of Parma, Via delle Scienze 181/A,
43100 Parma (Italy) - <http://pcfarina.eng.unipr.it>



The mainframe:

- A) Virtual reconstruction of the sound quality of musical instruments.

Violins, trumpets, flutes

- B) Virtual reconstruction of spaces for music and speech.



Theatres, churches , auditoria

Introduction and Goals

- ◆ Restoration → cultural heritage
- ◆ Storage → museums
- ◆ Sound and music: “visualisation” and “auralisation”.
- ◆ Multimediality and acoustics: could they live together?

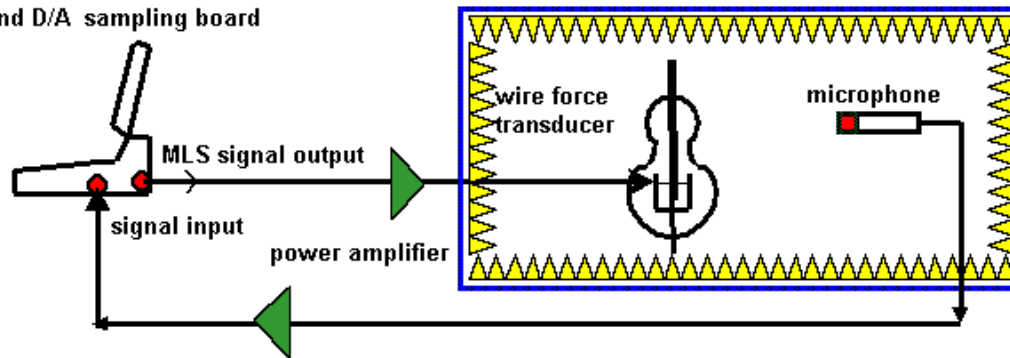
Previous experiments:

→ Evaluation of sound quality of sound chests in different violins

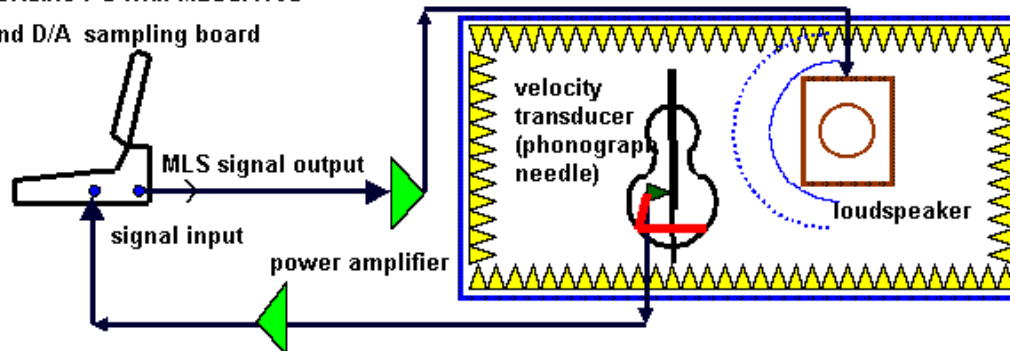
- Measurements of IR (force  pressure)
on the bridge
- Calculation of inverse filter
- Recordings in anechoic chamber
- Deconvolution: $\text{rec} * \text{F.I.R.}$ (getting “dry” music)
- Convolution  virtual sound

The violins (*ISMA95, JNMR97*)

Portable PC with MLSSA A/D
and D/A sampling board



Portable PC with MLSSA A/D
and D/A sampling board



Direct (up) and reciprocal (down) method of measurements

The Trumpets

→ Modern trumpets

- ◆ Vincent Bach
- ◆ Yamaha
- ◆ Yamaha custom

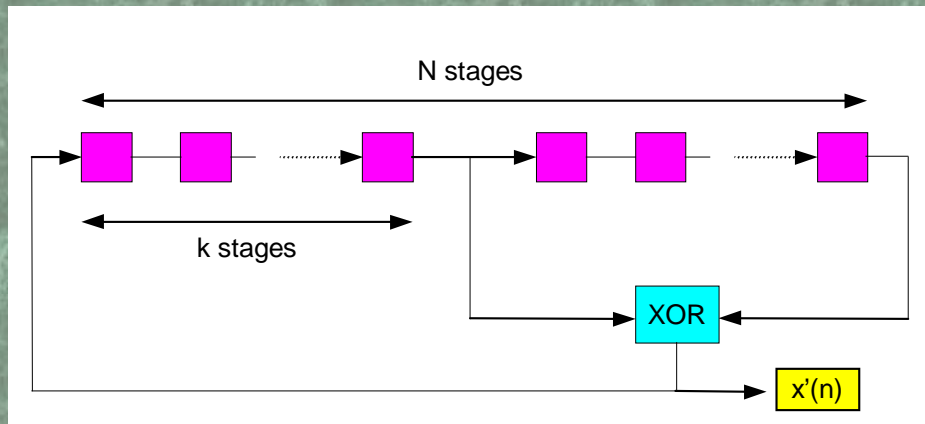
→ Baroque age trumpets

- ◆ Natural
- ◆ Hunting

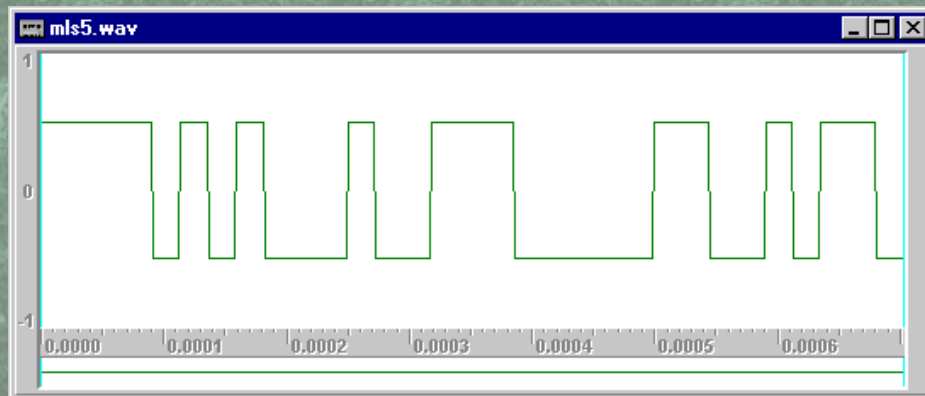
Virtual trumpet reconstruction

- The impulse response (mouthpiece -> radiated field) characterizing different instruments are measured
- A music piece is played on one instrument, and recorded in anechoic environment
- The impulse response of this instrument is inverted
- The anechoic recording is deconvolved by convolution with the inverse filter
- The deconvolved recording is used as the starting point for subsequent reconvolutions with the IRs of the different instruments

Measurement method #1: MLS



Shift register of order N



Binary Maximum
Length sequence of
order $N=5$

MLS Method: Impulse Response deconvolution

Untitled.ses* - Cool Edit Pro

File Edit View Insert Transform Options Help

Master: 0.0

Track 1

Track 2

542169

Begin End Length
Sel 542169 0
View 0 542169 542170

Stopped 48000 · 16-bit · Stereo 2099831 13865.61 MB free

Deconvolve Multiple MLS Sequenc... X

Input Data

MLS Order 15 B

N. of measurements 1

N. of sequences / measurement 16

N. of first sequences to skip 1

Output Results

N. of samples for each sequence 32767

N. of samples to skip 0

Scale each response separately

Remove DC component

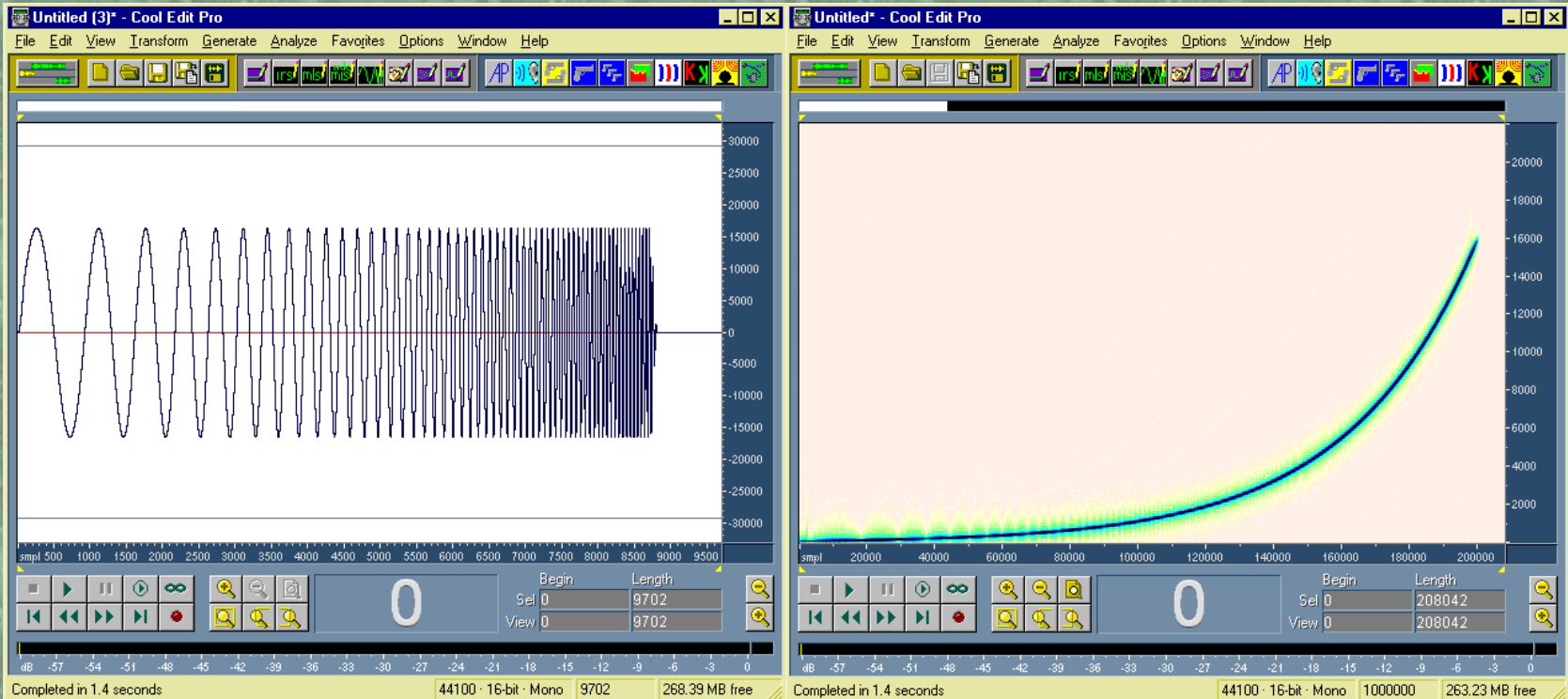
User: Angelo Farina

Reg. key: *****

OK Cancel Help

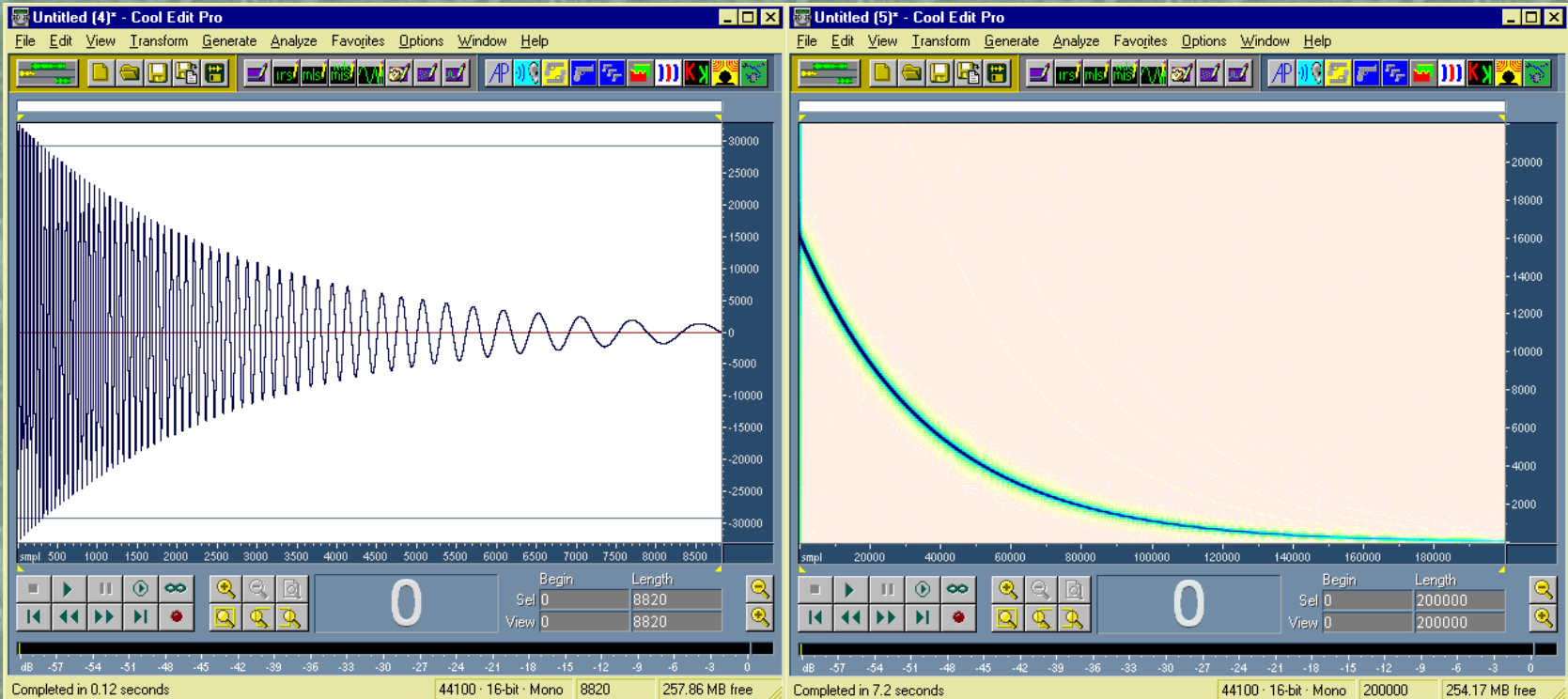
- [CoolEditPro](#) is employed for simultaneous playback and recording – thereafter, a special plug-in is invoked for deconvolving the impulse response

Measurements method #2: exponential sweep



The test signal is a sine sweep:
the frequency exponentially increases with time

Sweep method: impulse response deconvolution



- The impulse response is recovered by convolving the system's response with a proper inverse filter, obtained by the time-reversal mirror of the excitation signal, with a 6dB/octave equalization

Measurements on first trumpet



Conforzi-Callegari natural trumpet
(a tonal copy of the "Wilhelm Magnus Ehe I" model, XVII century)

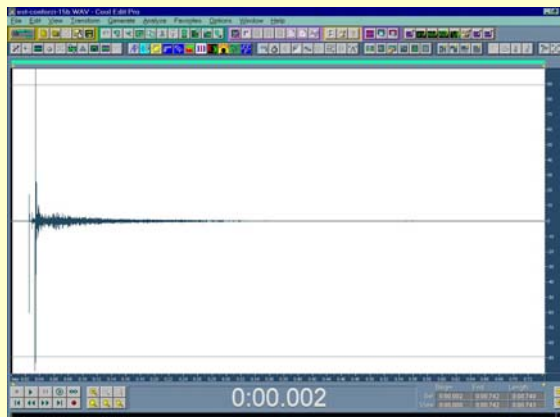
Measurements on second trumpet



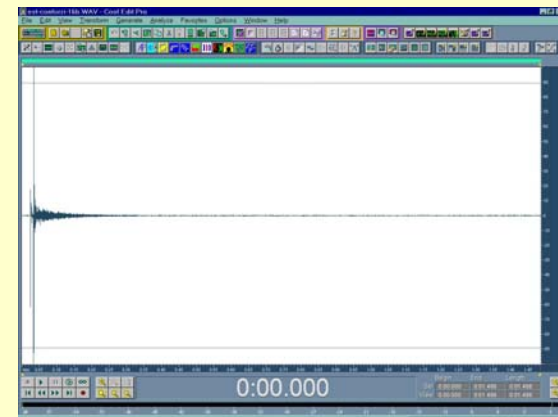
Hunting-trumpet Meinl&Lauber

Results of the measurements

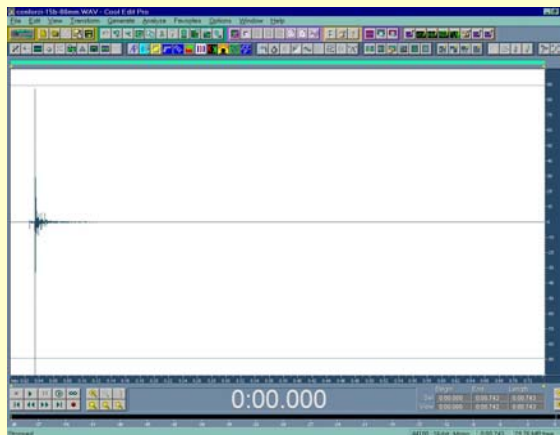
C.C. - MLS 15B



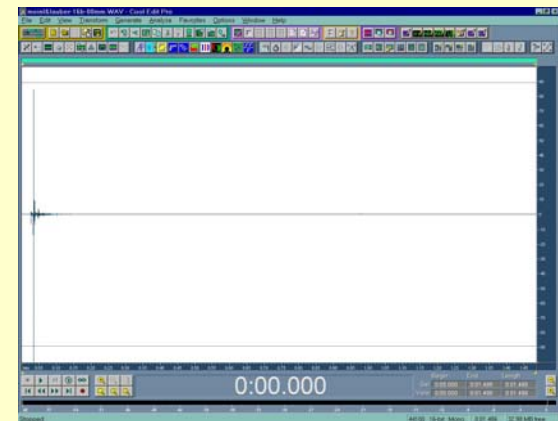
C.C. -
exponential
sweep



ML - MLS 15B



ML -
Exponential
sweep



Computation of inverse filters with the Kirkeby (Farina) method

The original response $h(t)$ is first FFT transformed:

$$C(\omega) = \text{FFT}[h(t)] \quad (1)$$

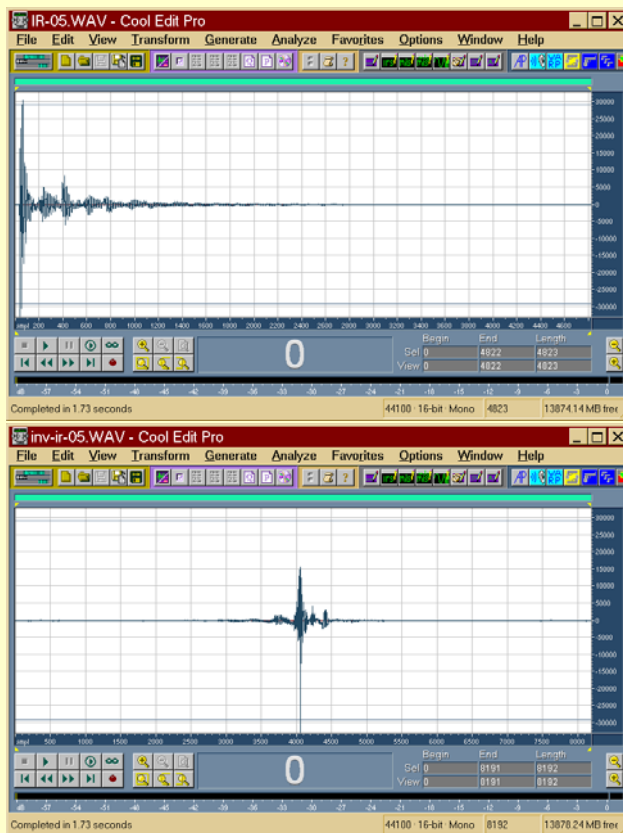
Then the complex spectrum C is inverted:

$$C_{\text{inv}}(\omega) = \frac{\text{Conj}[C(\omega)]}{\text{Conj}[C(\omega)] \cdot C(\omega) + \varepsilon(\omega)} \quad (2)$$

And the result is back-transformed to time domain

$$h_{\text{inv}}(t) = \text{IFFT}[C_{\text{inv}}(\omega)] \quad (3)$$

The measurements of IR and FIR



IR measurements:



- Maximum length sequence
- Exponential sine sweep

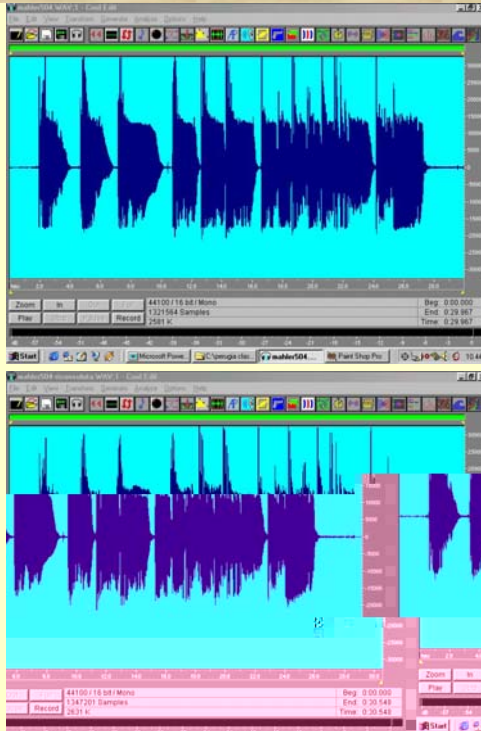
Inverse Filter calculation:



- Toeplitz technique (Morjoupolous 1985)
- Kirkeby technique (Kirkeby, Farina 1998)

The reconstruction of sound

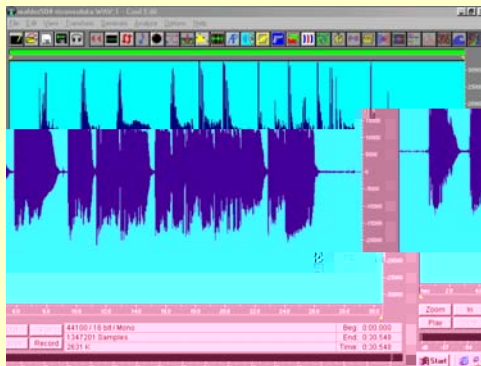
A



B



C



D



A-original (Conforzi-Callegari)
C-reconvolved (as A)

B-dry (deconvolved)
D-with IR of hunting-trumpet

Conclusions and remarks:



- The measurement of IR is feasible in trumpets – the sweep method is better than MLS
- The computation of inverse filter is better with Kirkeby-Farina method
- The measurements could be improved with smaller microphones (1/4”)

Future developments

- As the new sweep measurement method also characterizes the not-linear response of the instrument, a multiple order convolution will be employed for attempting the virtual recreation of the harmonic distortion.
- The reciprocity method will be attempted (as already done on violins)
- A subjective listening experiment will be started, for trying to understand the connection between measurable objective parameters and the perceived musical quality

Internet references

- CIARM site on musical acoustics:

[HTTP://www.ciarm.ing.unibo.it](http://www.ciarm.ing.unibo.it)

- Aurora site (software plug-ins for measurements and convolution):

[HTTP://www.ramsete.com/aurora](http://www.ramsete.com/aurora) (info)

[FTP://pcangelo.ramsete.com/aurora](ftp://pcangelo.ramsete.com/aurora) (download)