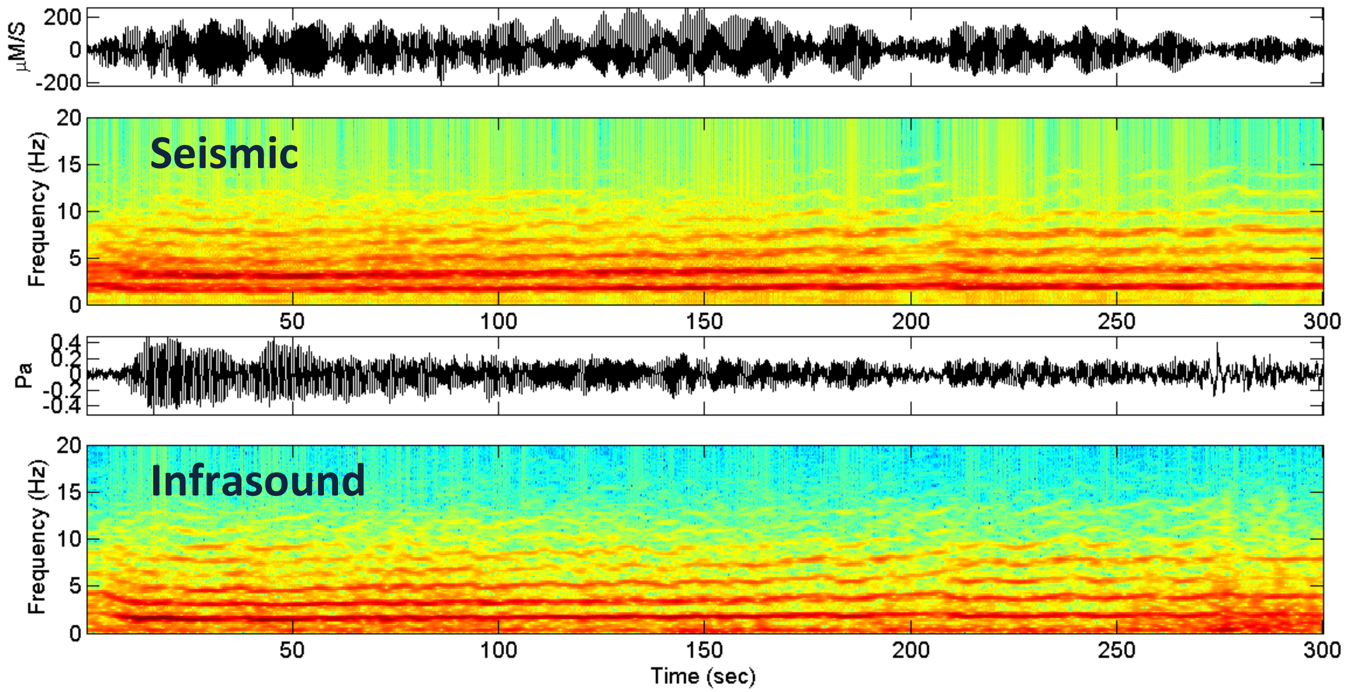
Seismo-acoustic harmonic tremor (SAHT): Moving beyond the 'wow' factor



John Lyons

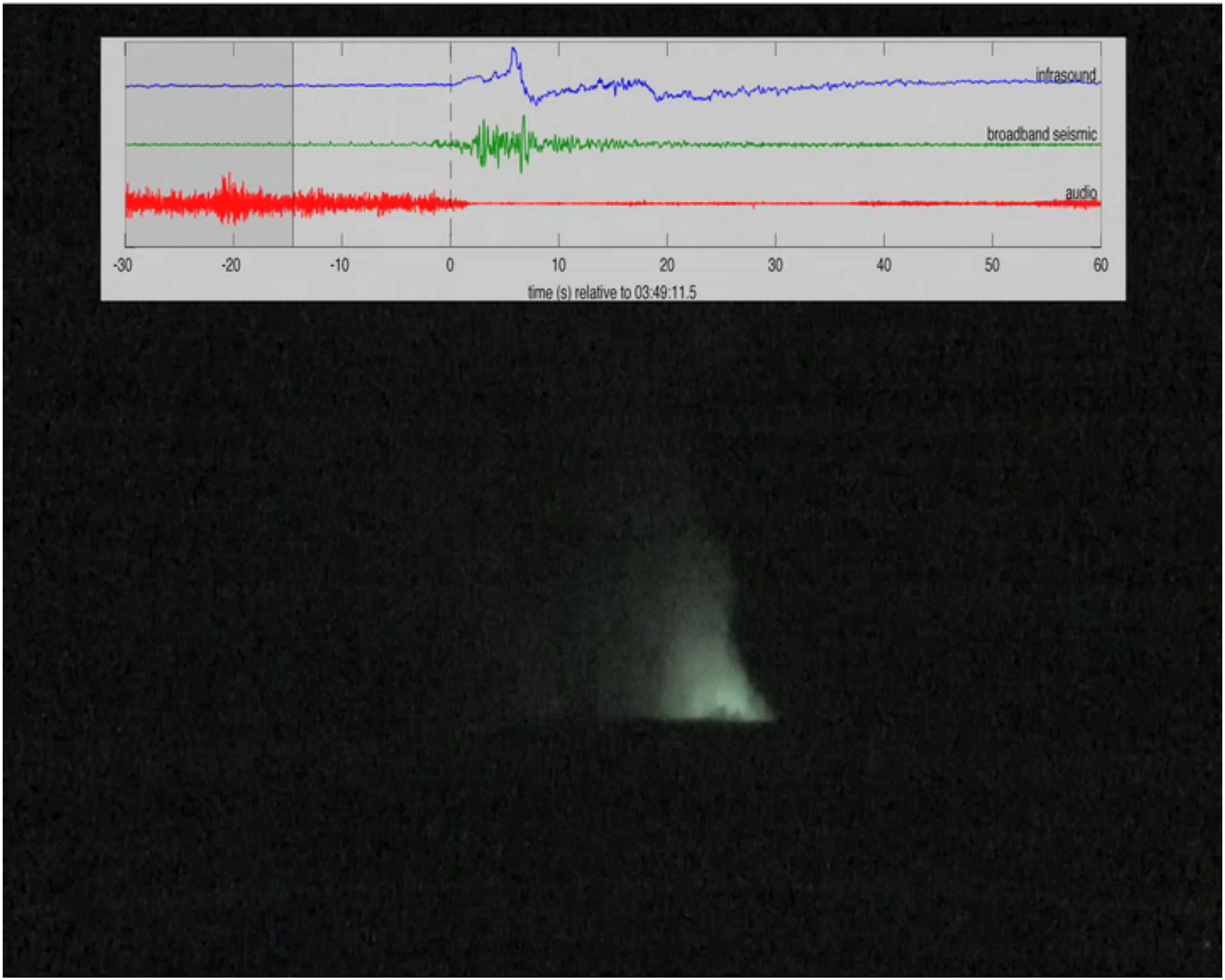
U.S. Geological Survey, Alaska Volcano Observatory

IAVCEI 2013 – Infrasound Workshop

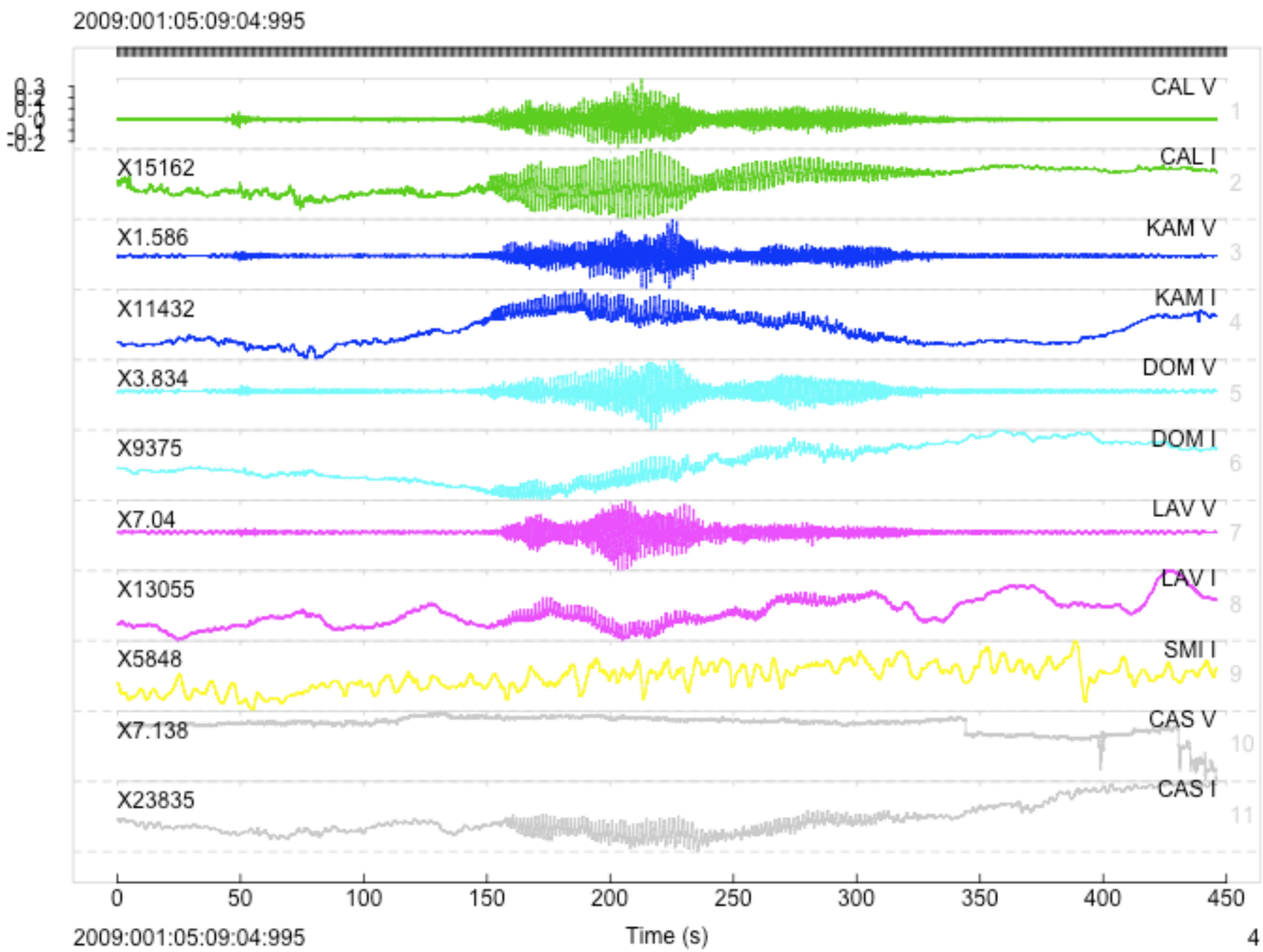
USGS science for a changing world

IAVCEI


Santiaguito volcano, Guatemala


infrasound
broadband seismic
audio
-30
-20
-10
0
10
20
30
40
50
60
time (s) relative to 03:49:11.5

Santiaguito SAHT - 2009



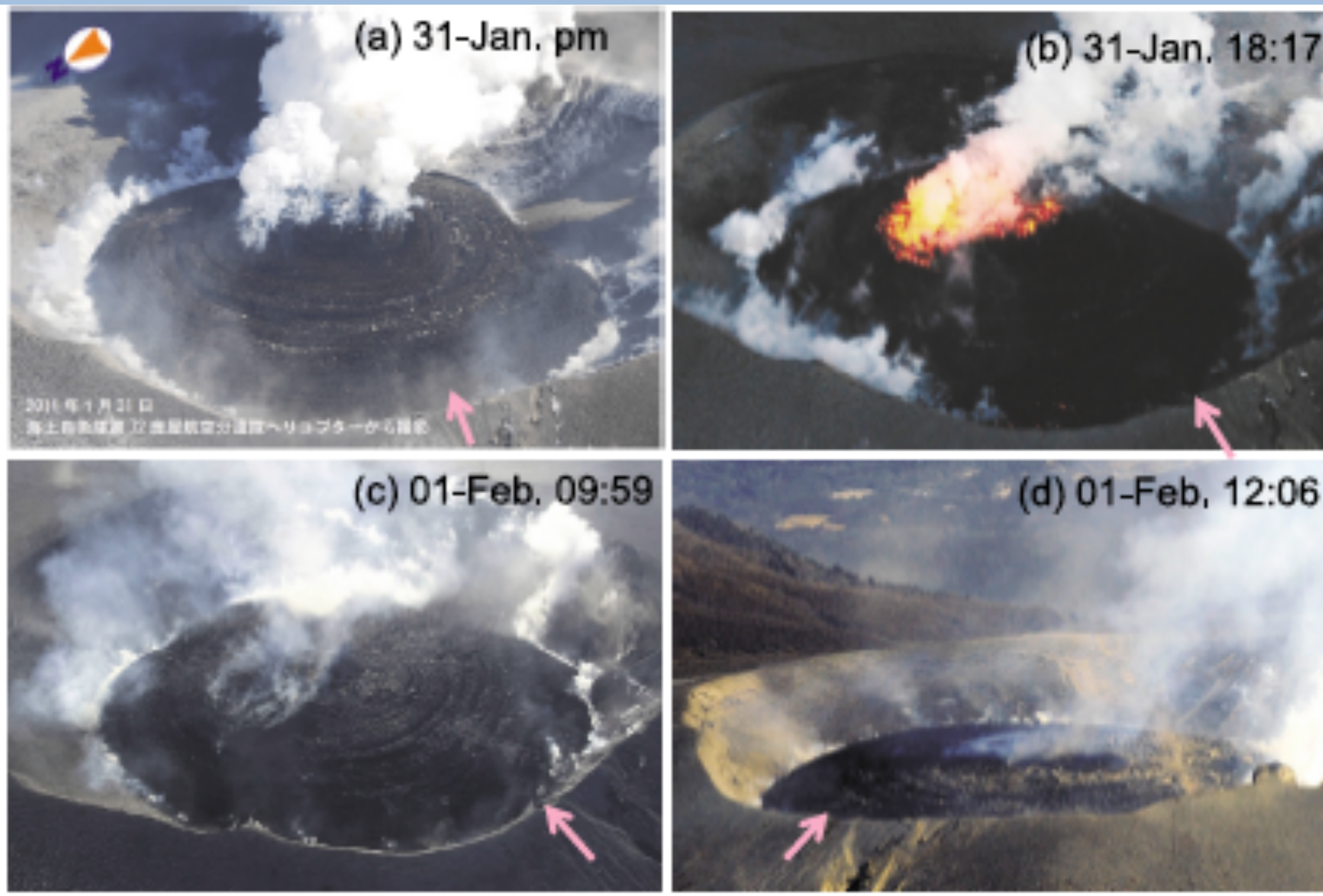
Seismo-acoustic harmonic tremor (SAHT): Moving beyond the ‘wow’ factor

- SAHT is a complex signal generated by the non-linear interaction of multiphase fluids, solid rock, and the atmosphere
  - Not easy to model!
  - Direct sampling and observations very limited
  - Self-sustaining oscillations, and possibly self-induced *(e.g., Kurita et al., IAVCEI 2013)*
  - Many non-unique solutions; no unifying model

So what’s to be done?

- High-quality observations *(e.g., Johnson et al., 2009; Ichihara et al., 2013)*
- Careful, clever data processing *(e.g., De Lauro et al., 2011; Lees and Ruiz, 2008)*
- Analogue experiments *(e.g., Divoux et al., 2009; Lyons et al., 2013)*
- New conceptual models *(e.g., Jellinek and Bercovici, 2011; Lesage et al, 2006)*

Shinmoe-dake Harmonic Tremor:
Combining high-quality observations and analogue modeling

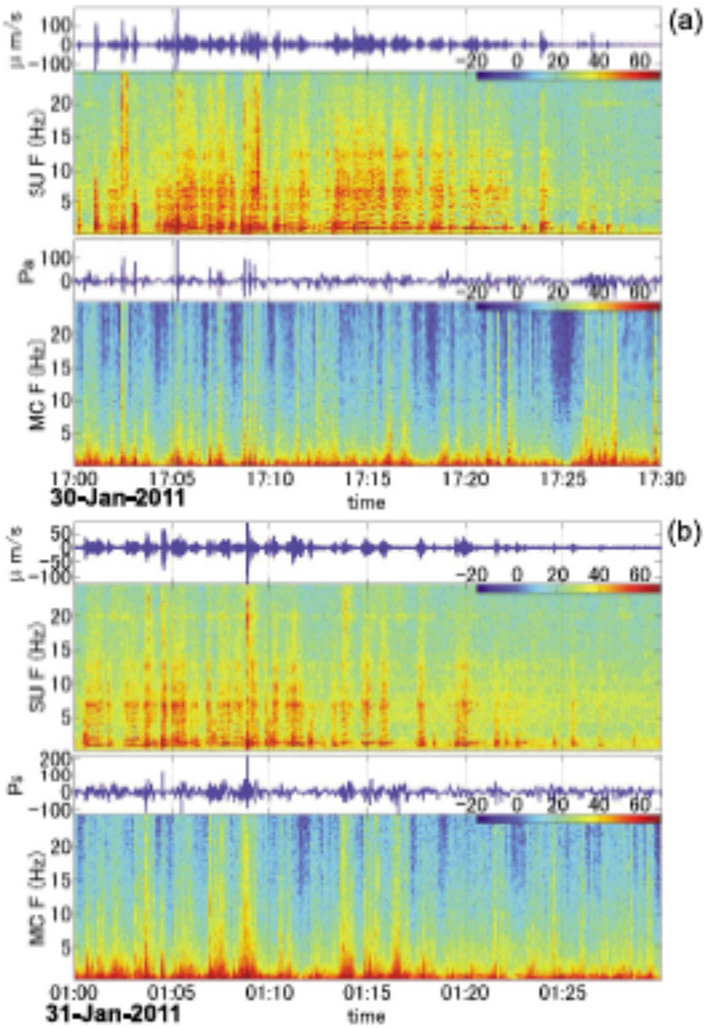


Ichihara et al., 2013

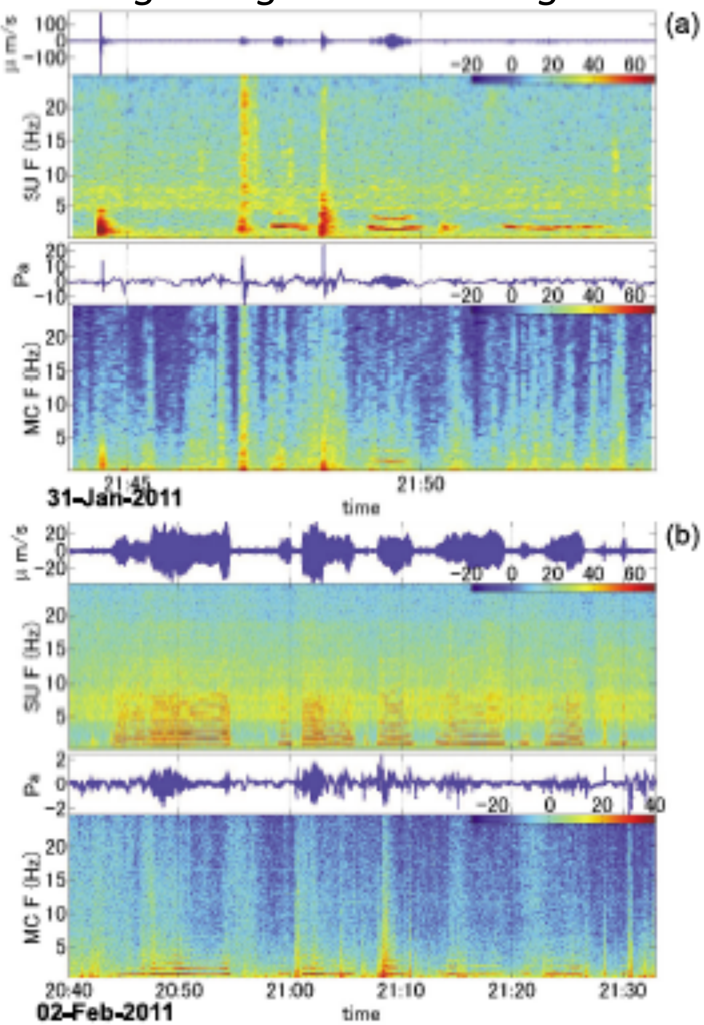
- Change in tremor signals from SHT-only to SAHT observed in 2011 as eruption transitioned from effusive to explosive

Shinmoe-dake Harmonic Tremor:
Combining high-quality observations and analogue modeling

Final stage of lava effusion – SHT only

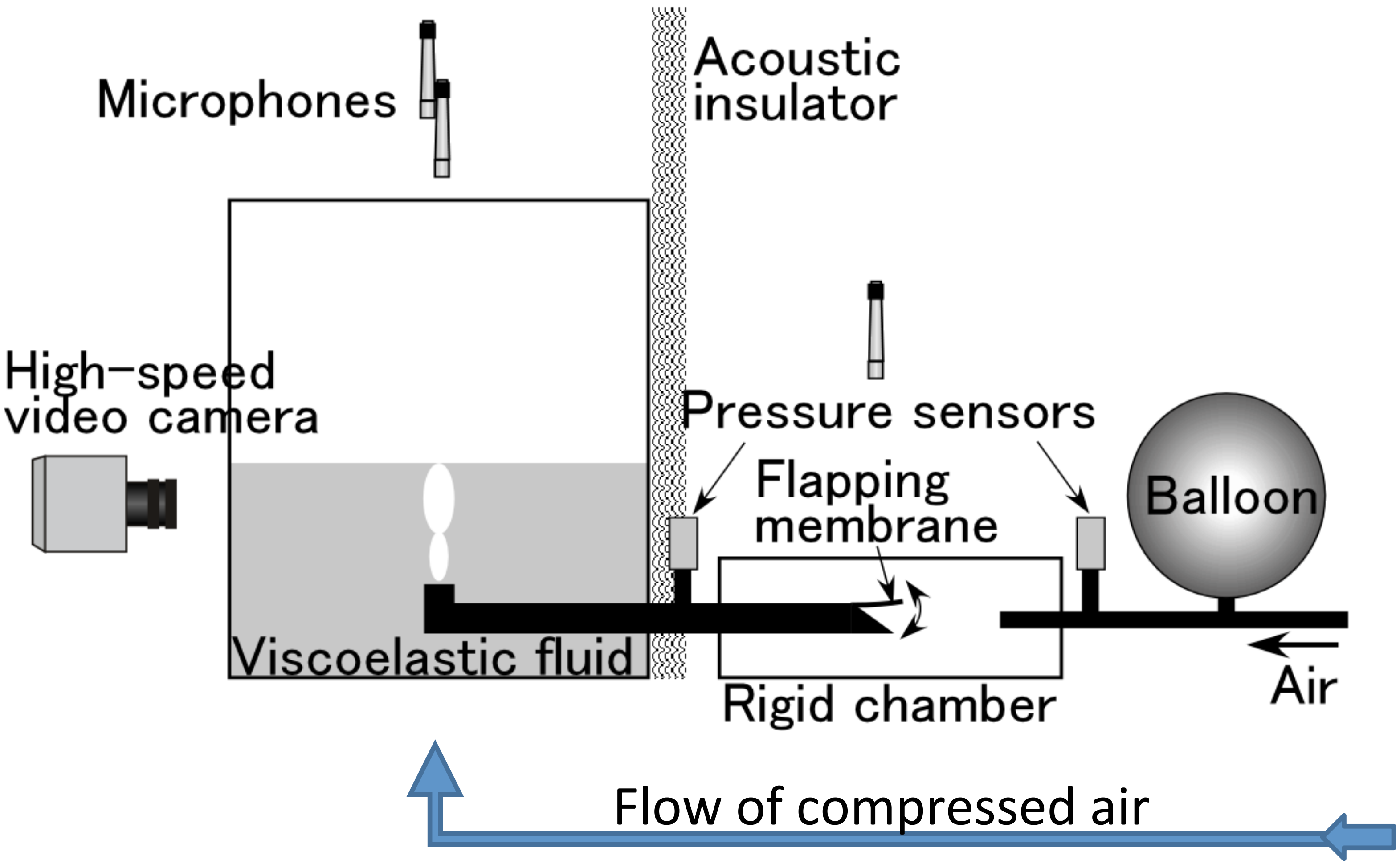


Effusion stops and explosive Degassing and SAHT begins



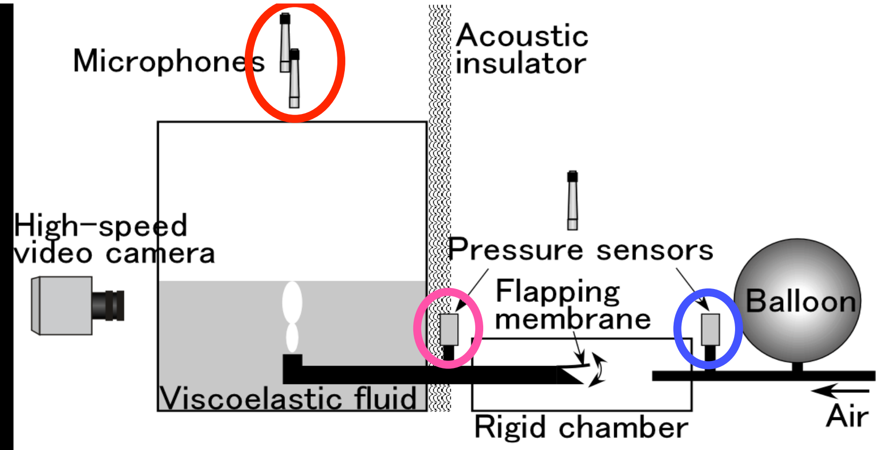
Experimental set-up

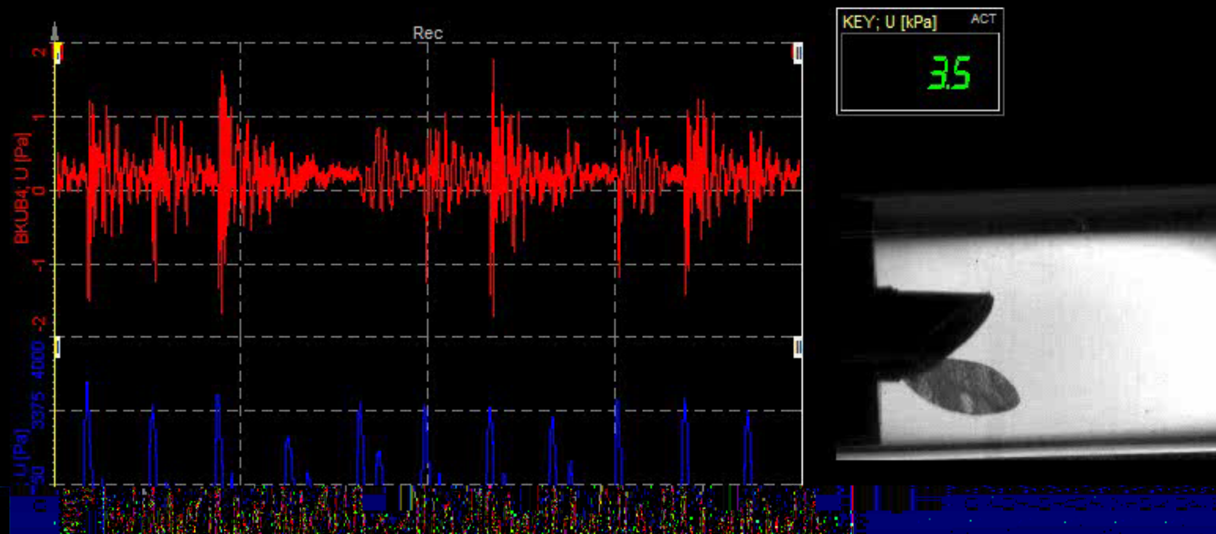
- Meter-scale apparatus built in the lab at ERI, University of Tokyo



Lyons et al., 2013

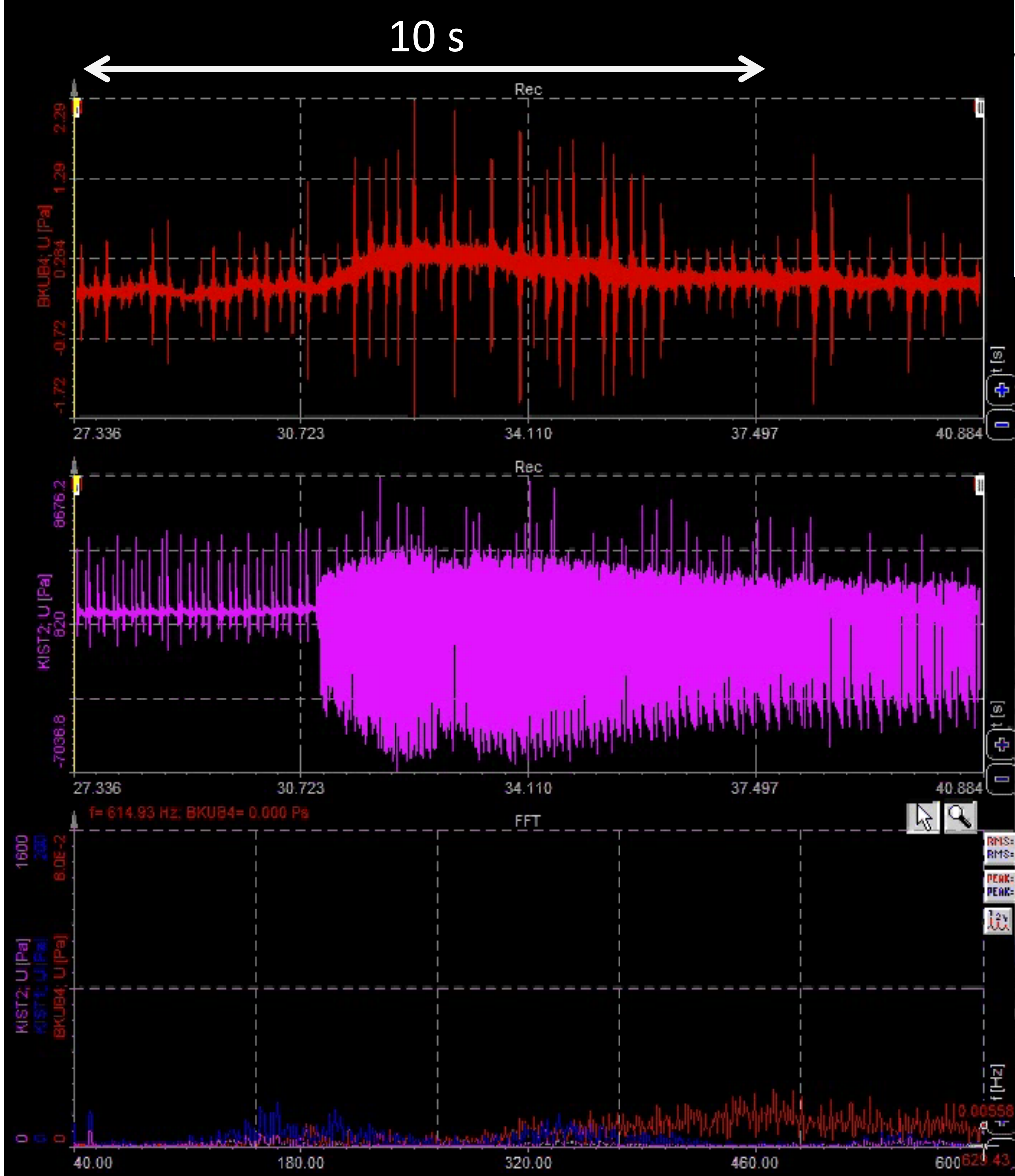
Flapping membrane

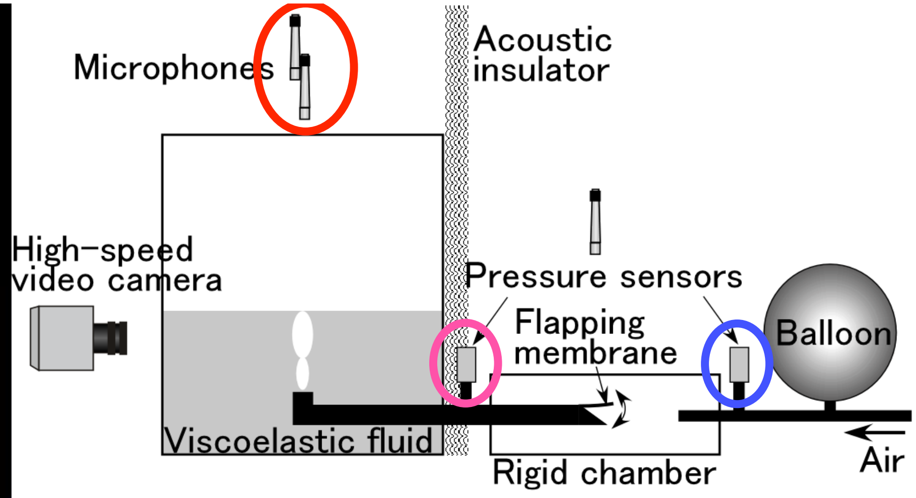


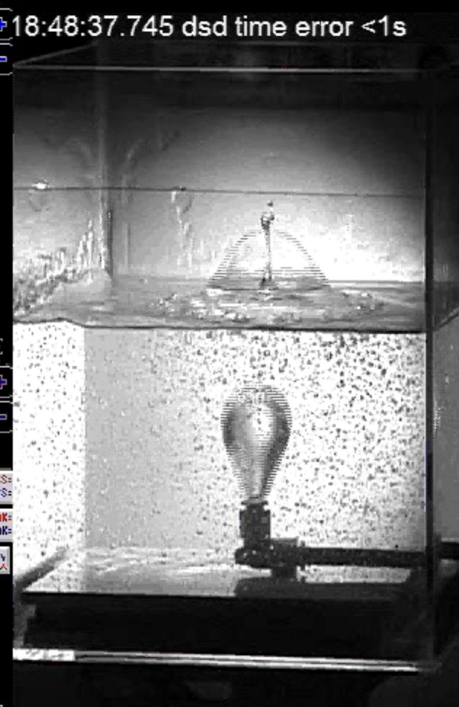


- Membrane flapping at ~58 Hz
- High-speed video of membrane (top)
- Digital video of fluid in tank (bottom)
- 1/500x actual speed
- 0.2 s elapsed time

Lowest viscosity gel

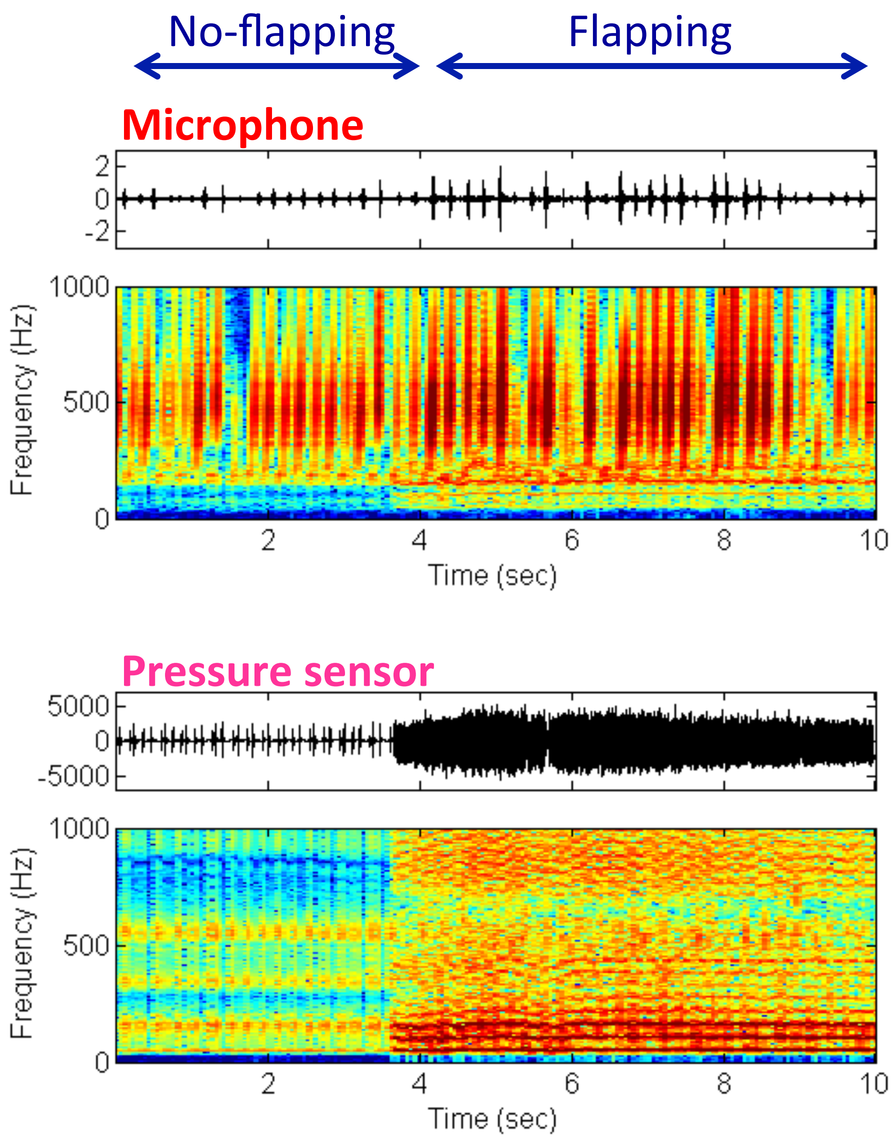


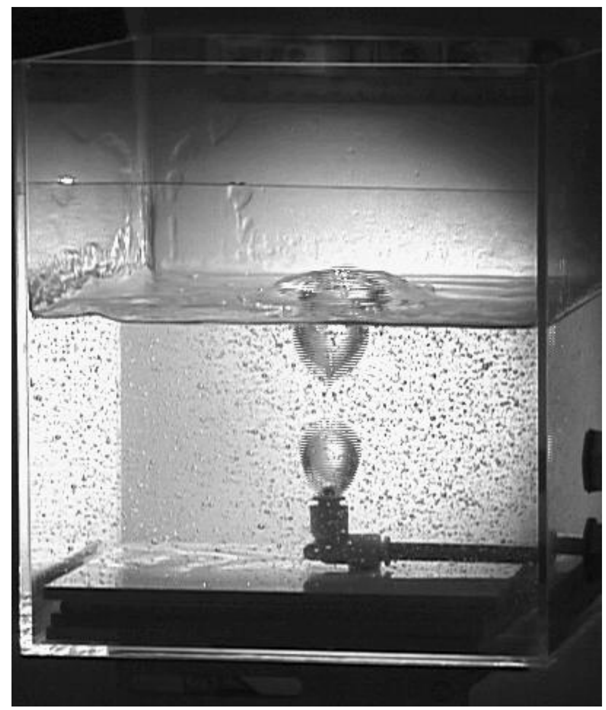




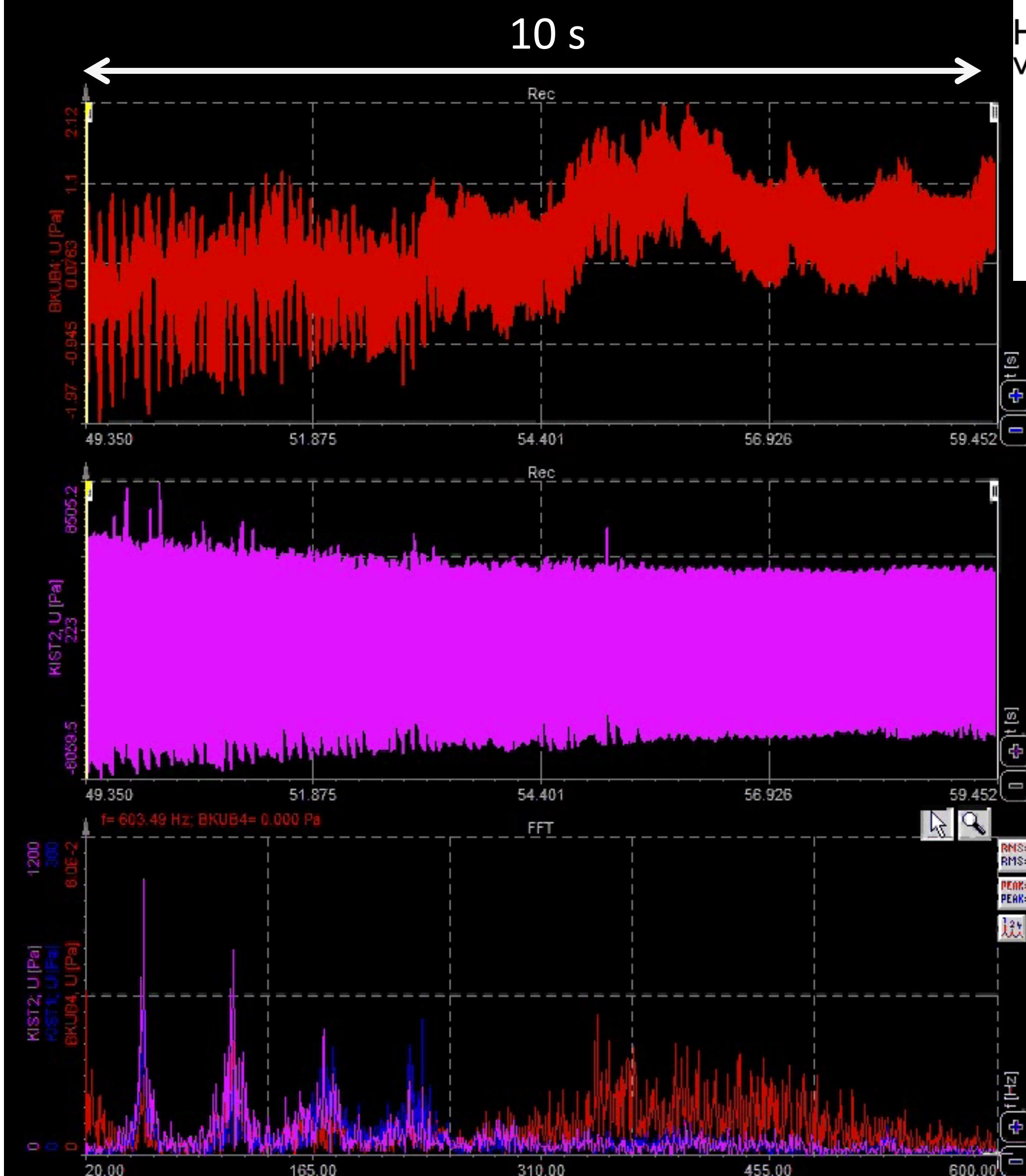
- 1 – 4 s no flapping of membrane
- 4 – 10 s membrane flapping
- 1/2x actual speed
- 40 – 600 Hz in bottom panel FFT

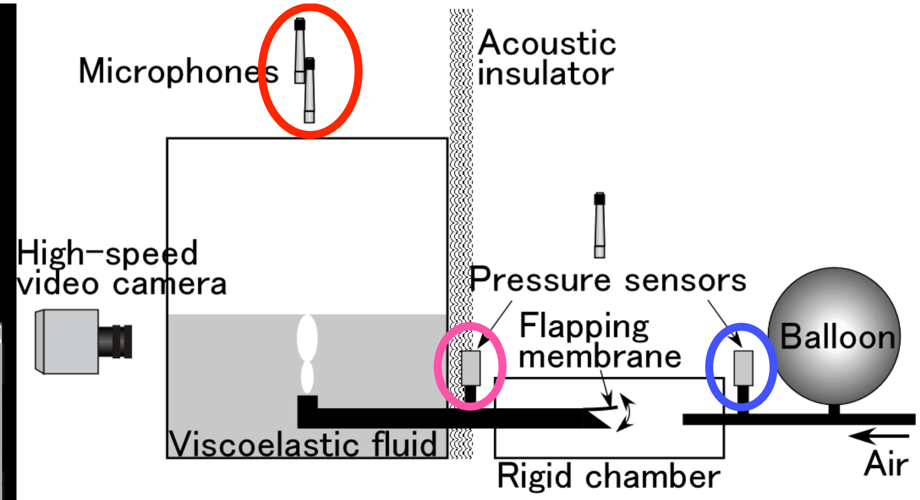
Lowest viscosity gel – bubbling regime





Highest viscosity gel

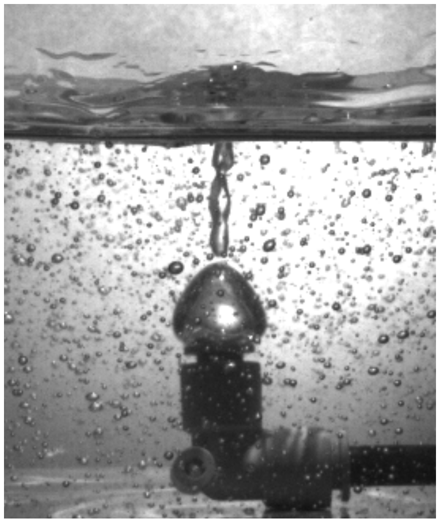




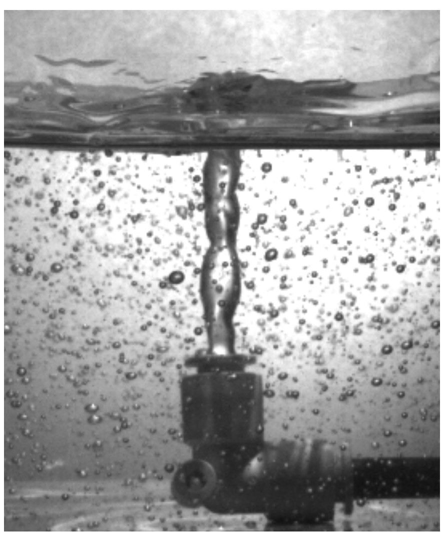
- Continuous flapping of membrane
- 0 – 4 s unsteady bubbling
- 4 – 10 s development of open conduit
- 1/2x actual speed
- 40 – 600 Hz in bottom panel FFT

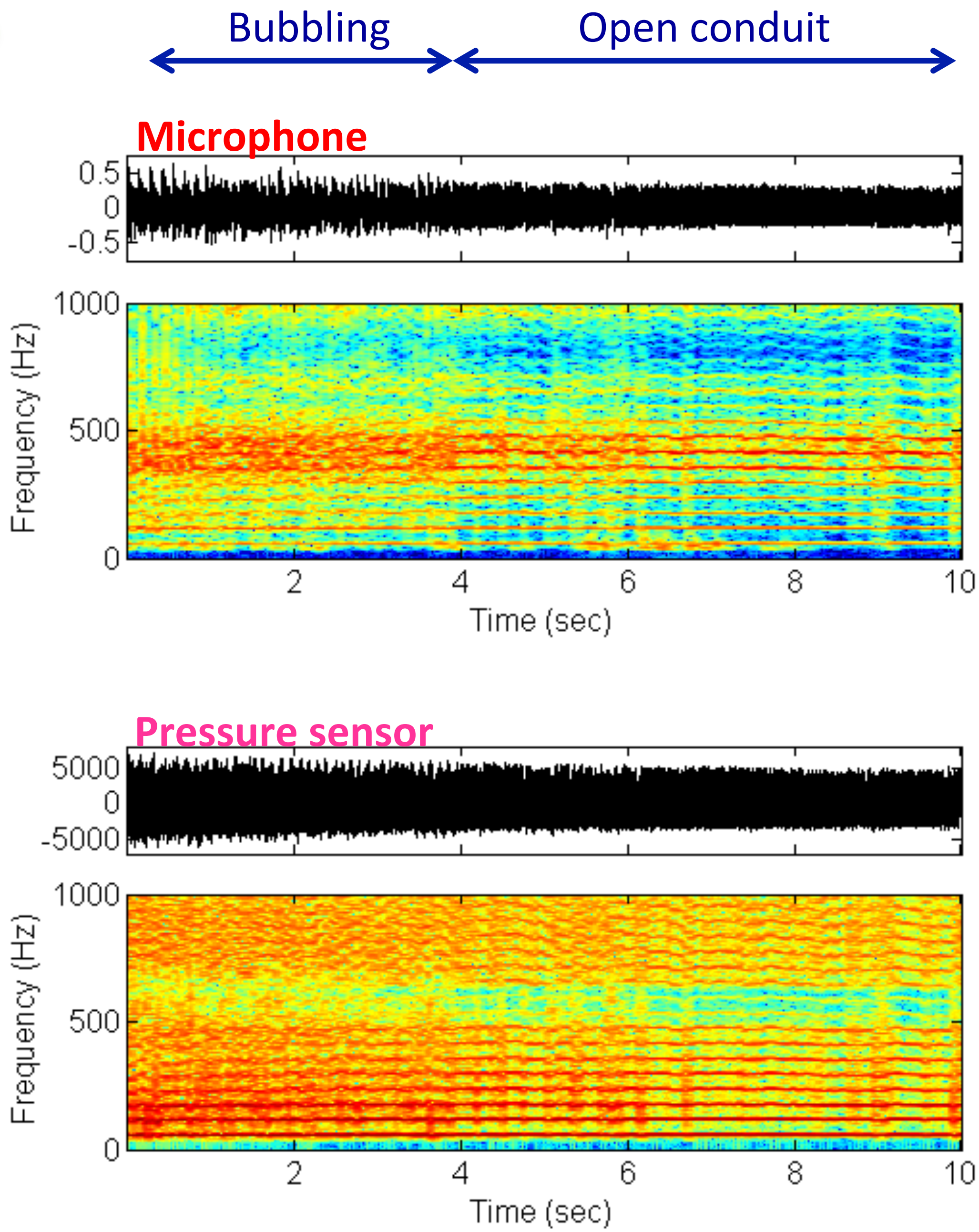
Highest viscosity gel

Bubbling



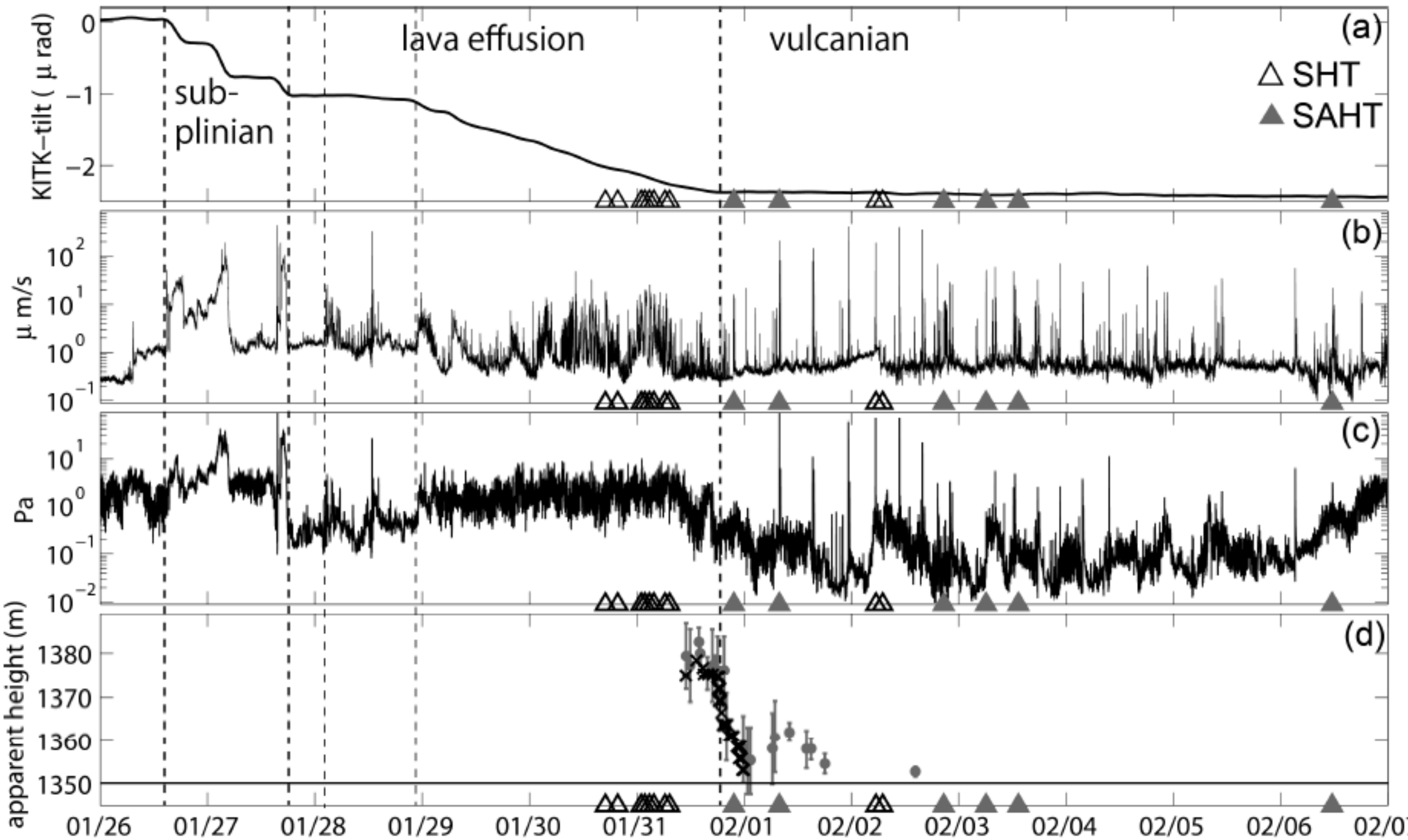
Open conduit





Shinmoe-dake Harmonic Tremor:
Combining high-quality observations and analogue modeling

- Multi-parameter observations + lab results = more robust interpretation of SAHT source, and explanation of observed change in activity

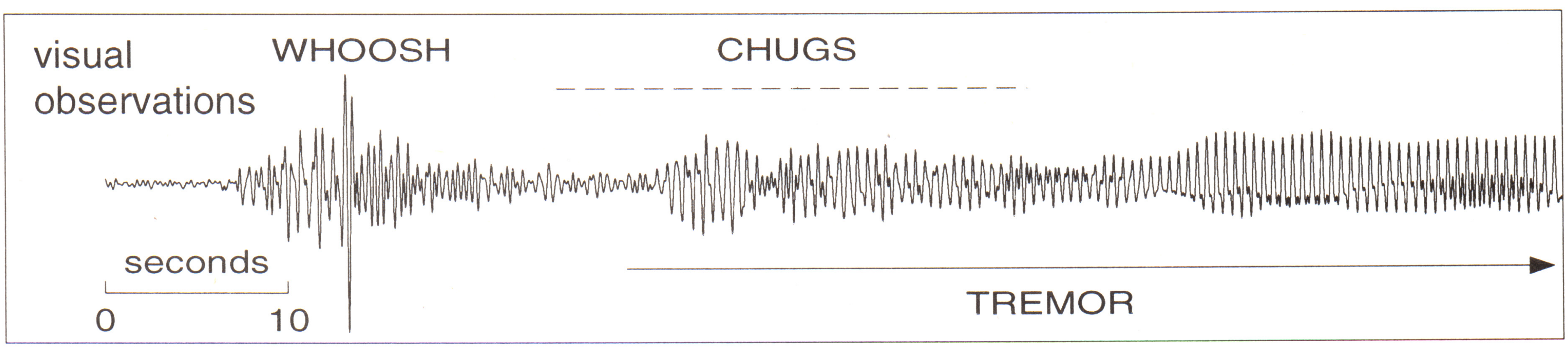


Chugging: A special case of seismo-acoustic harmonic tremor

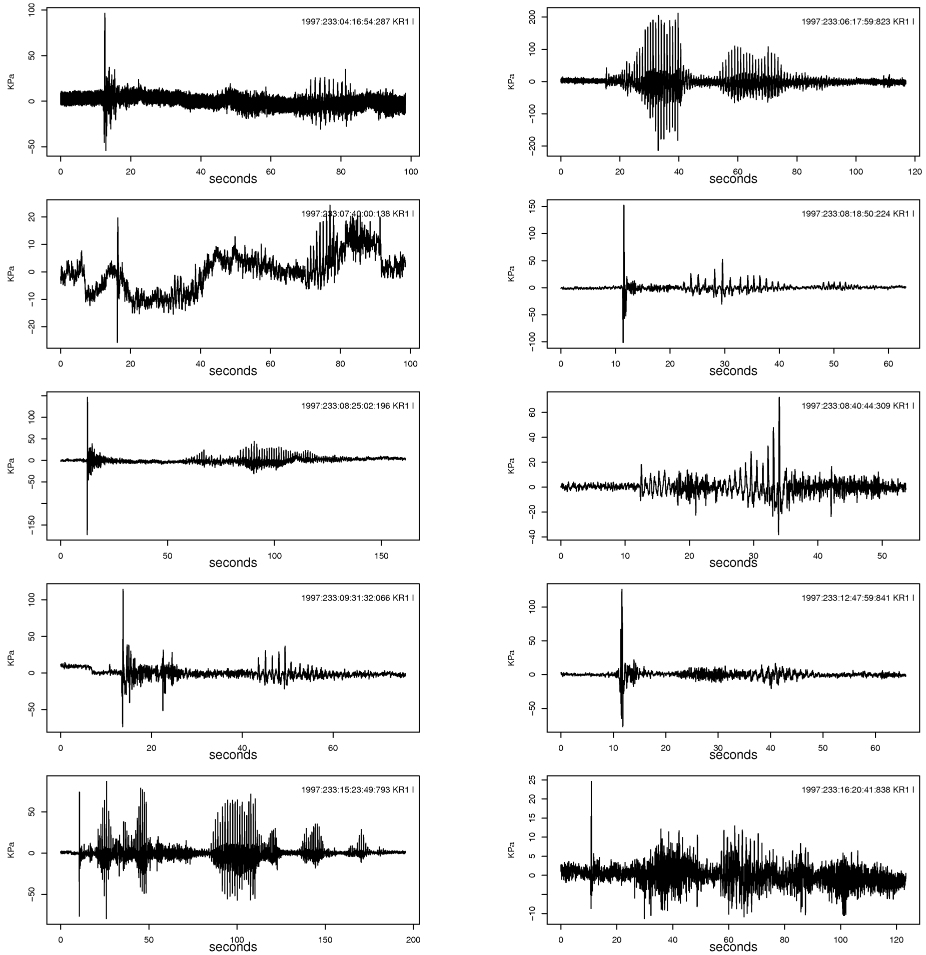
- Examples:
  - Arenal (Benoit & McNutt, 1997; Garces, 1998; Hagerty et al. 2000)
  - Karmysky (Johnson & Lees, 1999; Lees et al. 2004)
  - Sangay (Johnson & Lees, 1999; Lees & Ruiz, 2008)
  - Reventador (Lees et al., 2008)
  - Tungurahua (Ruiz et al., 2005)
  - Fuego (Lyons et al., 2009)

- 'Chugs' are often audible

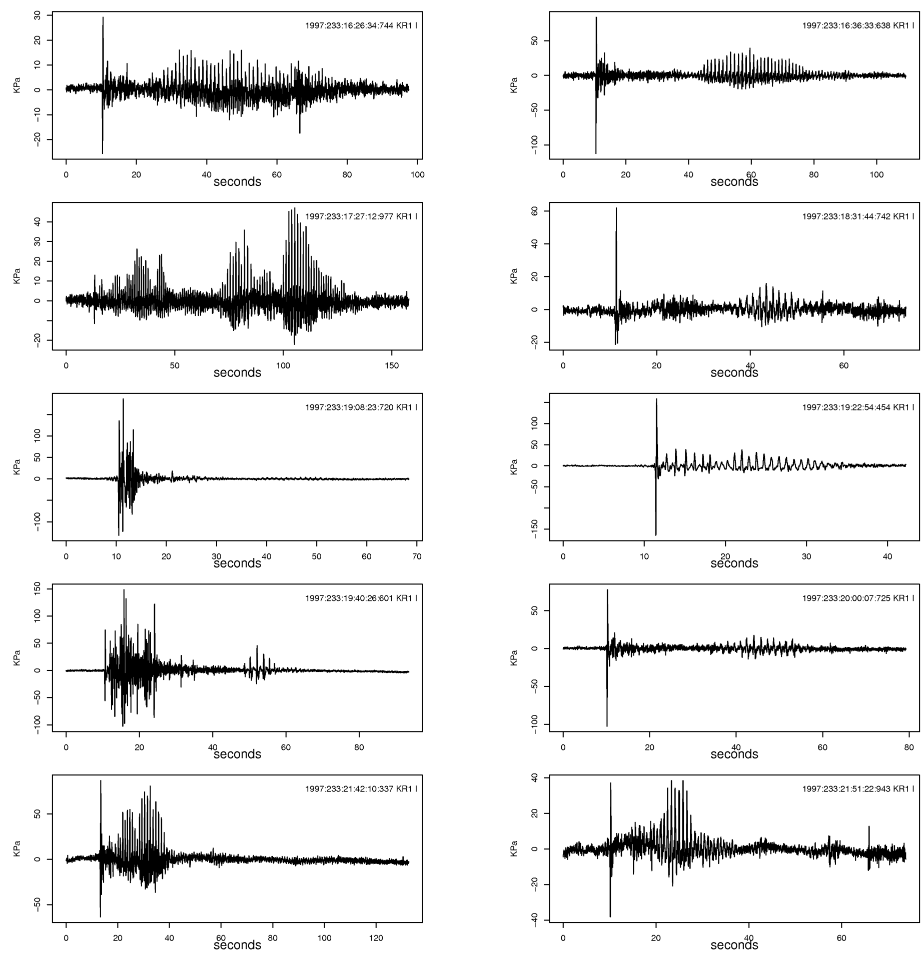
BENOIT AND MCNUTT: CONSTRAINTS ON SOURCE PROCESSES OF VOLCANIC TREMOR



Chugging studies: Combining high-quality data and novel data processing techniques to SAHT at Karymsky and Sangay volcanoes

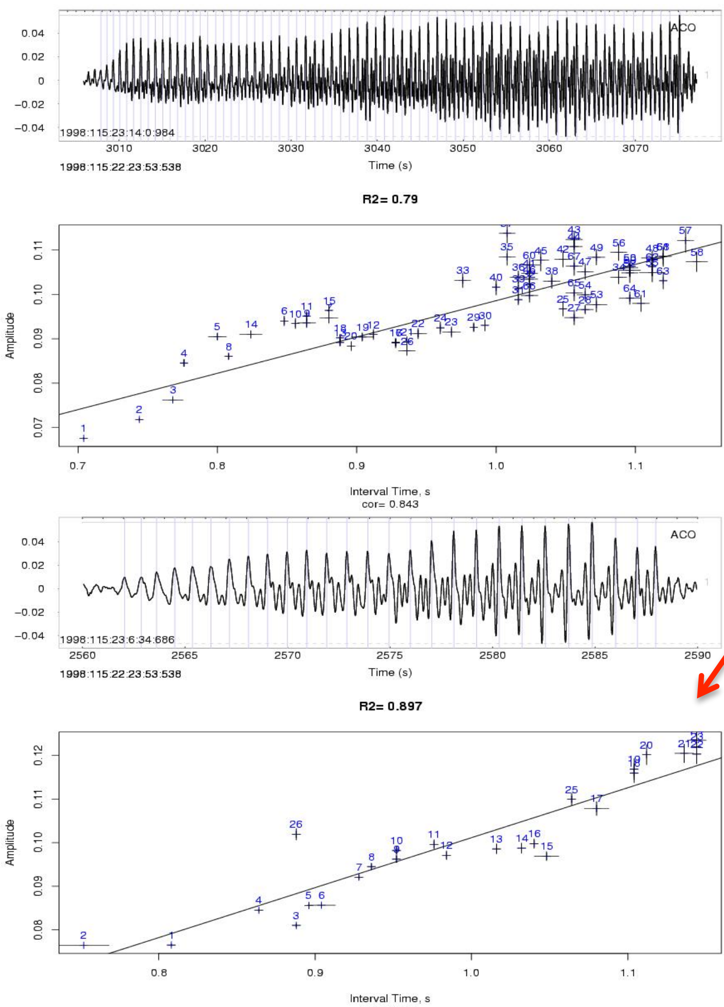


While there are similarities between these chugging sequences, there is also considerable variability.



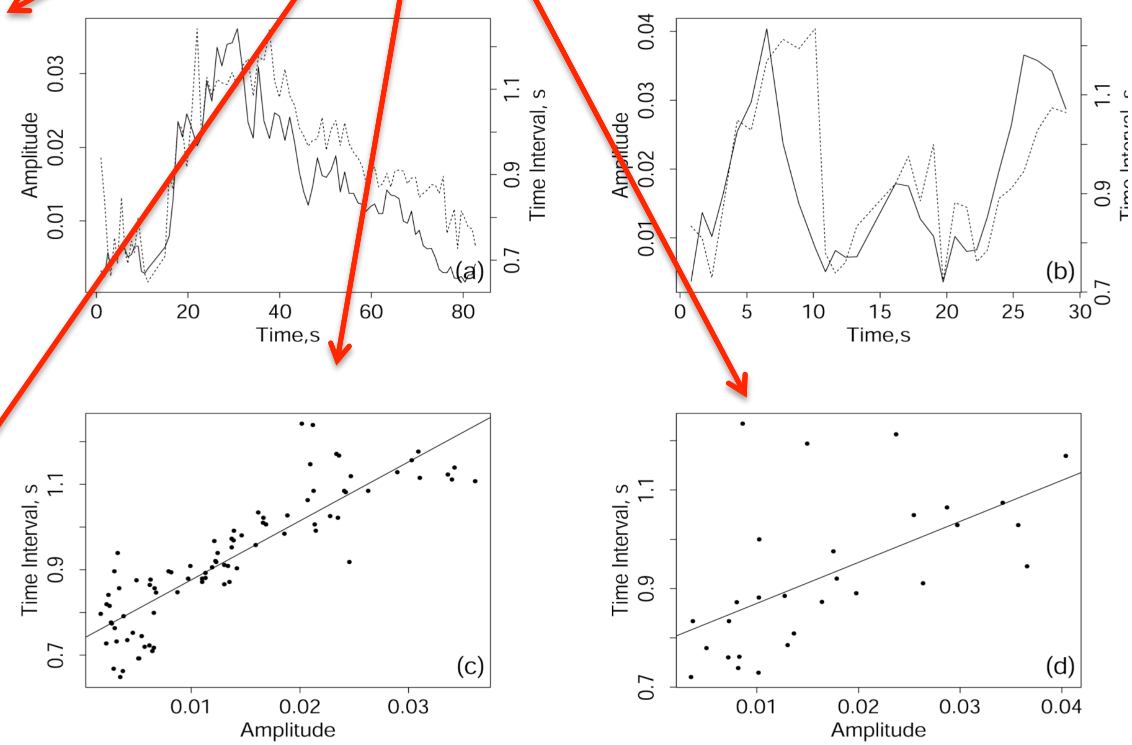
Chugging: Correlation of interval time and amplitude: indication of non-linear, feed back mechanism

Sangay



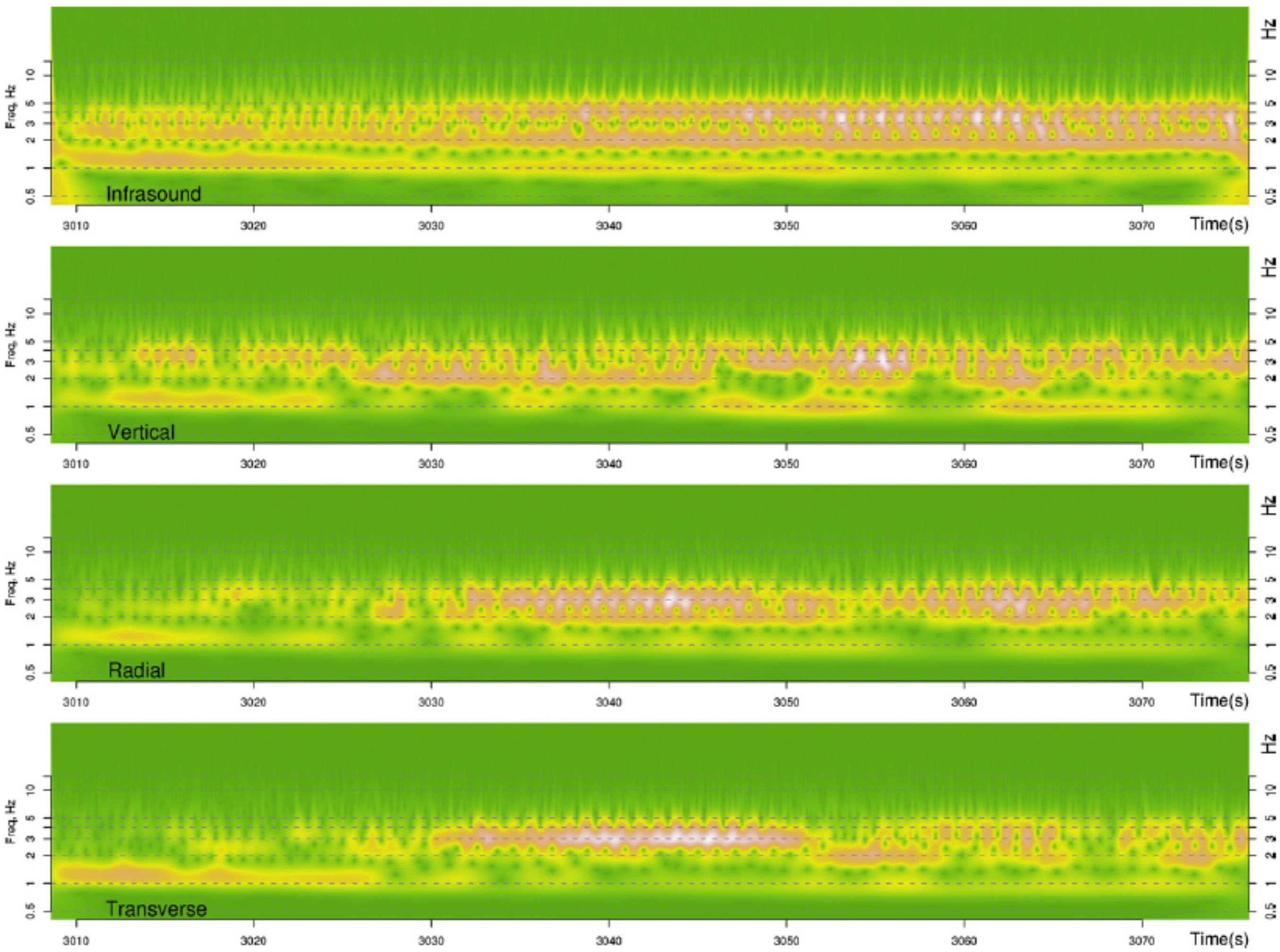
Linear Trends

Karymsky



Chugging studies: Combining high-quality data and novel data processing techniques to SAHT at Karymsky and Sangay volcanoes

J.M. Lees, M. Ruiz / Journal of Volcanology and Geothermal Research 176 (2008) 170–178

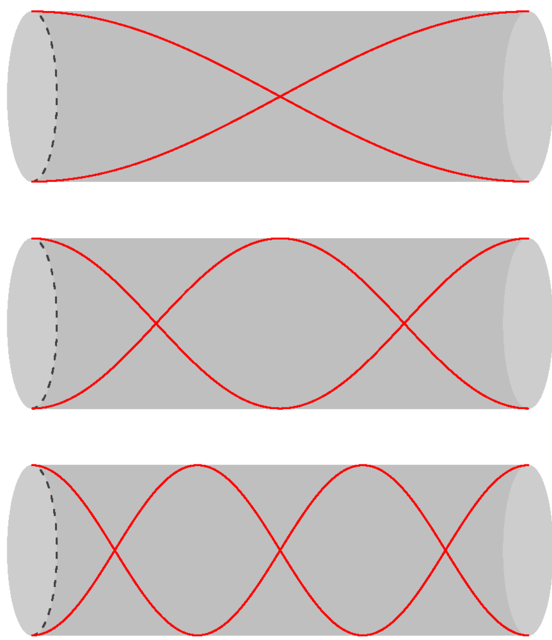


- Wavelet transform improves temporal resolution over FFT, allowing for identification of individual pulses or 'chugs'

Chugging: Model of a resonating cylindrical conduit

Open-Open

Open End Cylander Air Column: Fundamental and Harmonics



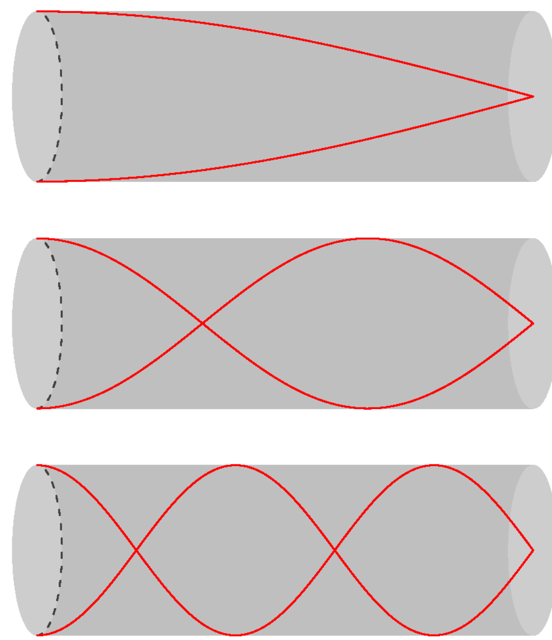
$$L = \frac{\lambda}{2}$$

$$f_n = nf_1$$
$$n = 2,3,4,\ldots$$

$$f_1 = \frac{v}{2L}$$

Open-Closed

1 Closed End Cylander Air Column: Fundamental and Harmonics



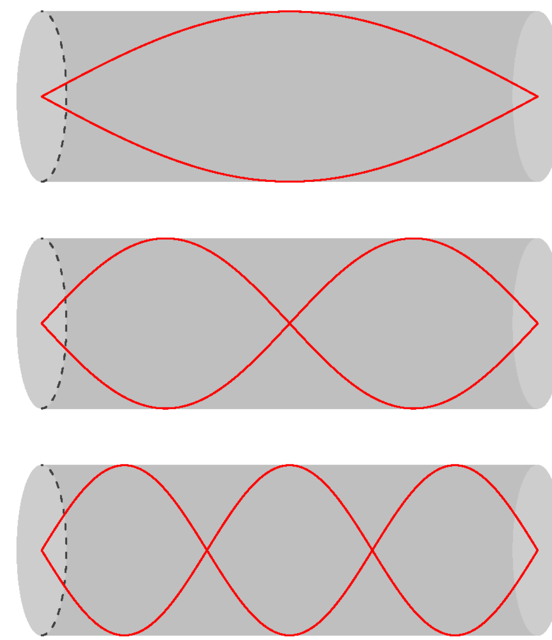
$$L = \frac{\lambda}{4}$$

$$f_n = nf_1$$
$$n = 3,5,7,\ldots$$

$$f_1 = \frac{v}{4L}$$

Closed-Closed

2 Closed Ends Cylander Air Column: Fundamental and Harmonics



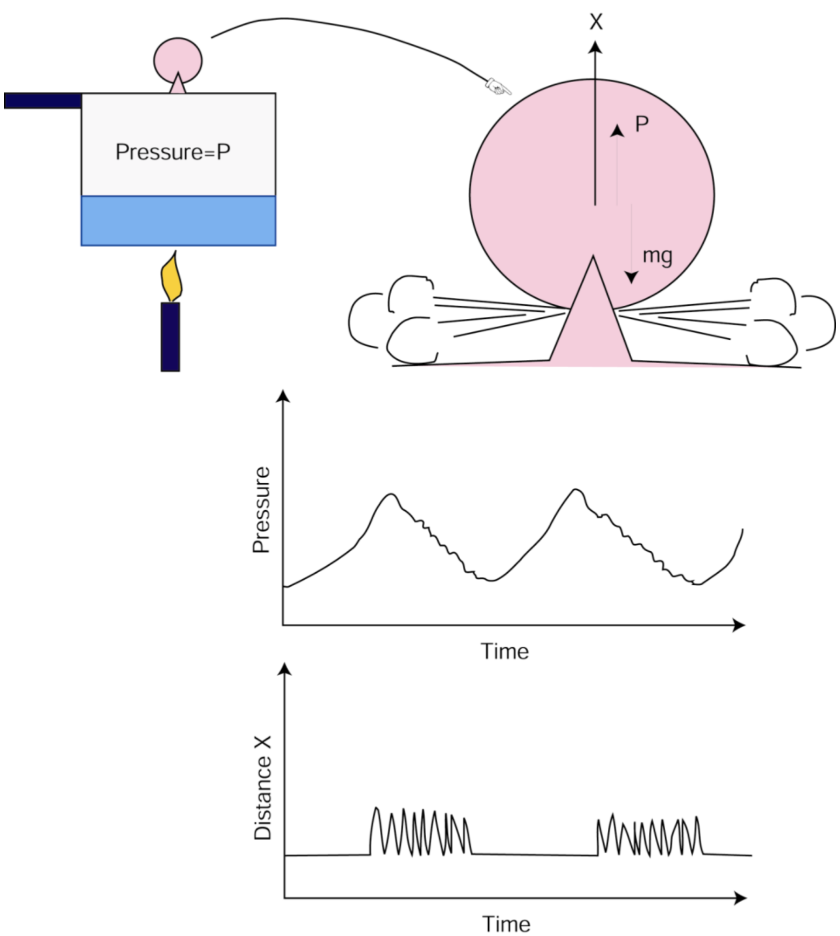
$$L = \frac{\lambda}{2}$$

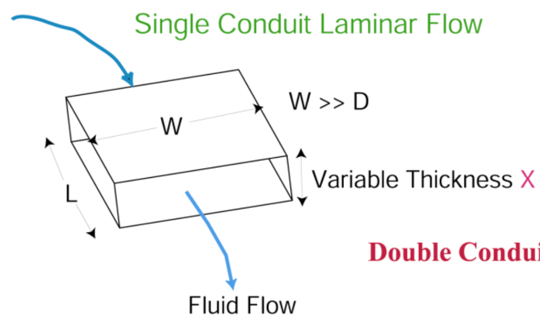
$$f_1 = \frac{v}{2L}$$

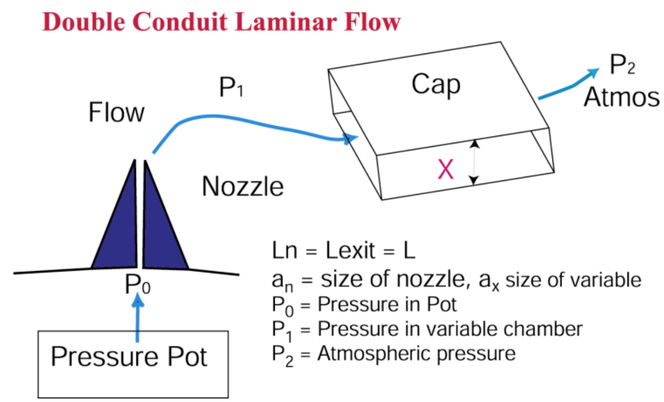
Chugging: Pressure Cooker Model

Chugging: Pressure Cooker Model *(Lees and Bolton, 1999)*

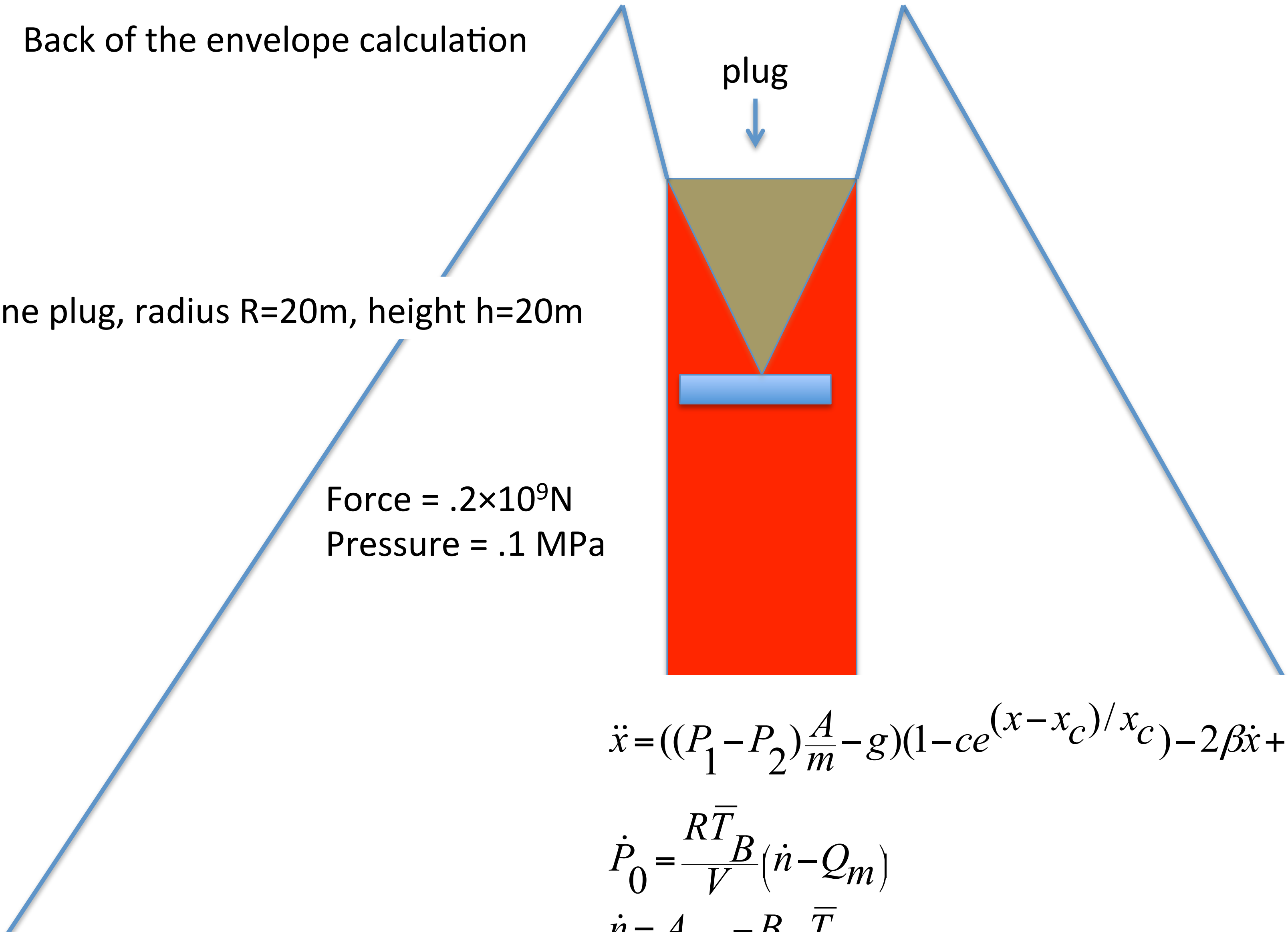
Pressure Cooker Model







Back of the envelope calculation



Cone plug, radius R=20m, height h=20m

Force = $.2 \times 10^9$N
Pressure = .1 MPa

$$\ddot{x} = ((P_1 - P_2)\frac{A}{m} - g)(1 - ce^{(x-x_c)/x_c}) - 2\beta\dot{x} + \frac{A}{m\rho}\left(\frac{3Q_m}{4a_n}\right)^2$$

$$\dot{P}_0 = \frac{R\overline{T}_B}{V}(\dot{n} - Q_m)$$

$$\dot{n} = A_{Qs} - B_{in}\overline{T}_B$$

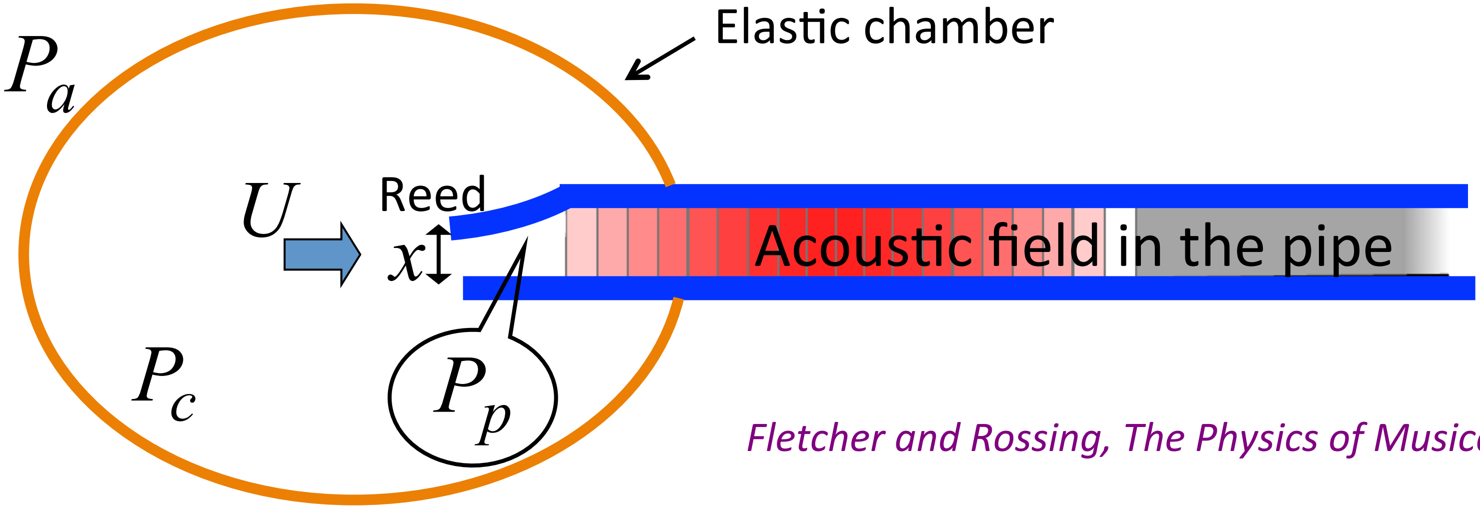
$$P_1 = \frac{P_0 a_n^3 - P_2 x^3}{a_n^3 + x^3}$$

Pressure Cooker,
Lees and Bolton, 1999

Directions for (your?) future studies: moving beyond the 'wow' factor

- Observations of vents producing SAHT (high-speed cameras, thermal, UV)
- Systematic study of SAHT characteristics at volcanoes worldwide *(e.g., McNutt and Nishimura, 2008)*
- Improved analogue models to test and update models for tremor generation

The harmonic tremor generator



Fletcher and Rossing, The Physics of Musical Instruments

Mass conservation in the chamber

$$\frac{d(\rho V_c)}{dt} = \frac{V_o}{c^2}\frac{dP_c}{dt} + \rho_o \frac{dV_c}{dt} = -\rho_o U$$

Elastic oscillation of the chamber

Essential to excite oscillation
(an elastic chamber is required)

$$\boxed{\frac{d^2 V_c}{dt^2}} + \omega_c^{\,2}(V_c - V_o) = \frac{V_o R_o}{M}(P_c - P_a)$$

Elastic oscillation of the reed

$$\frac{d^2 x}{dt^2} + 2\gamma \frac{dx}{dt} + \omega_r^2 (x - x_o) = -\frac{S}{m}(P_c - P_p)$$

Volume flux through the reed
(Bernoulli's law approximation)

$$U = Wx\sqrt{\frac{2(P_c - P_p)}{\rho}}$$