ON THE SCIENCE RETURN OF A SEISMIC OBSERVING PACKAGE AT THE ICY MOONS

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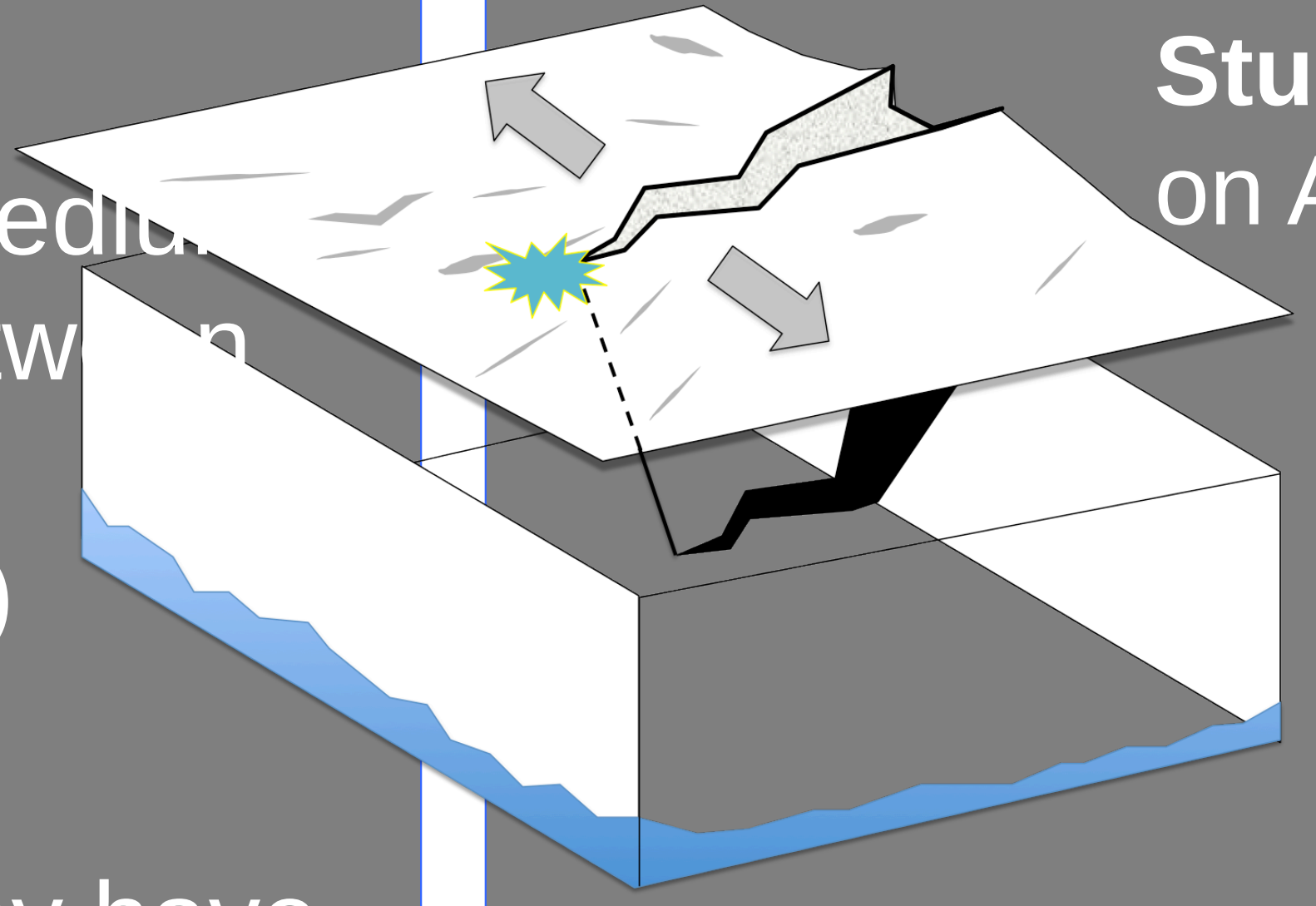
THE BASICS



What is seismology?

- Study of seismic waves (elastic waves) that propagate in a mediu
  - Include: body waves (interior), surface waves (interface betw n materials), and normal modes (standing waves)
- Used to study the movement of Earth's surface (earthquakes)

How can we retrieve seismic information?

Seismometers measure ground movement. In Earth studies, they have been built to measure ground motion between 500 Hz and 0.00118 Hz.

Some types of seismometers:

1. Inertial seismometer: pendulum used as inertial reference
   - Generally most sensitive to earthquakes
2. Strain seismometer: motion of ground point relative to another
   - Out-perform inertial seismometers at low-frequency (e.g., tides)
3. Optical seismometer: displacement measured by laser

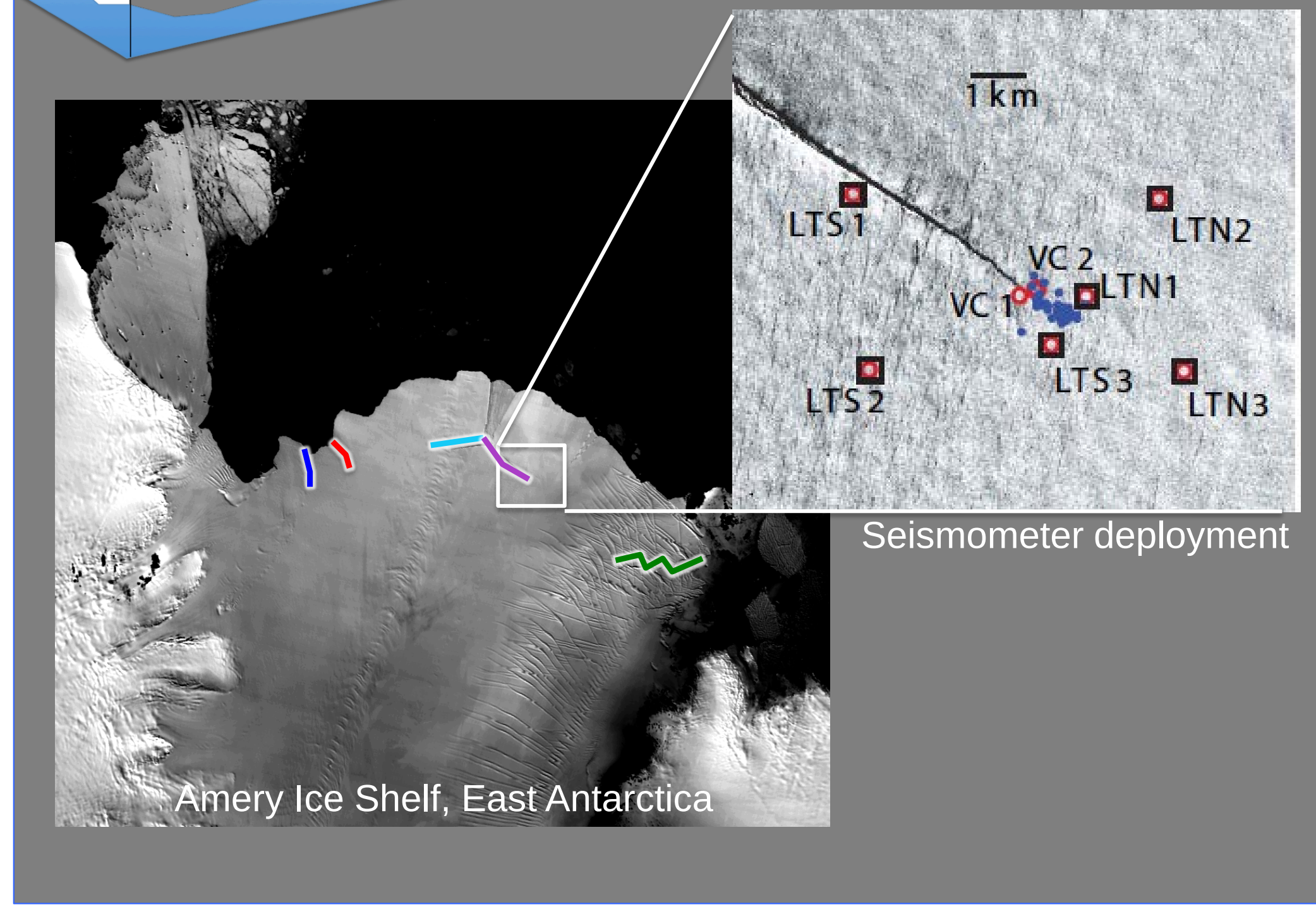
SEISMOMETRY ON ICE: ANTARCTICA ANALOGUE

Study design: Seismic network designed to detect high-frequency icequakes by fracturing on Amery Ice Shelf, East Antarctica

Instrumentation:

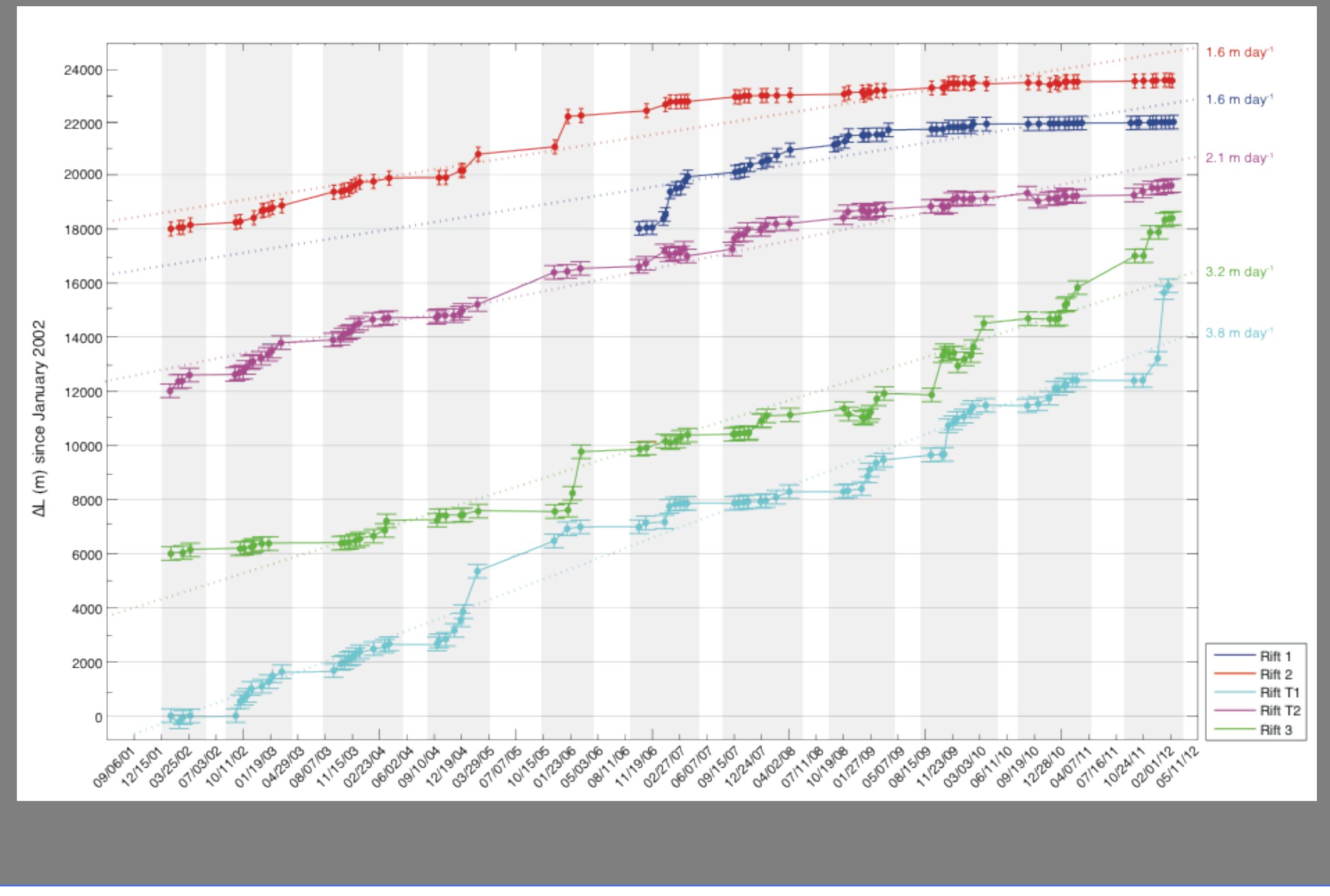
2002/2003 field season – 6 stations
- vertical-comp. L-4C seismometer (10Hz), dual-frequency GPS (0.03

2004/2005 and 2005/2006 field seasons – increase to 12 stations
- 3-axis L-28 seismometer and dual-frequency GPS (0.5Hz)

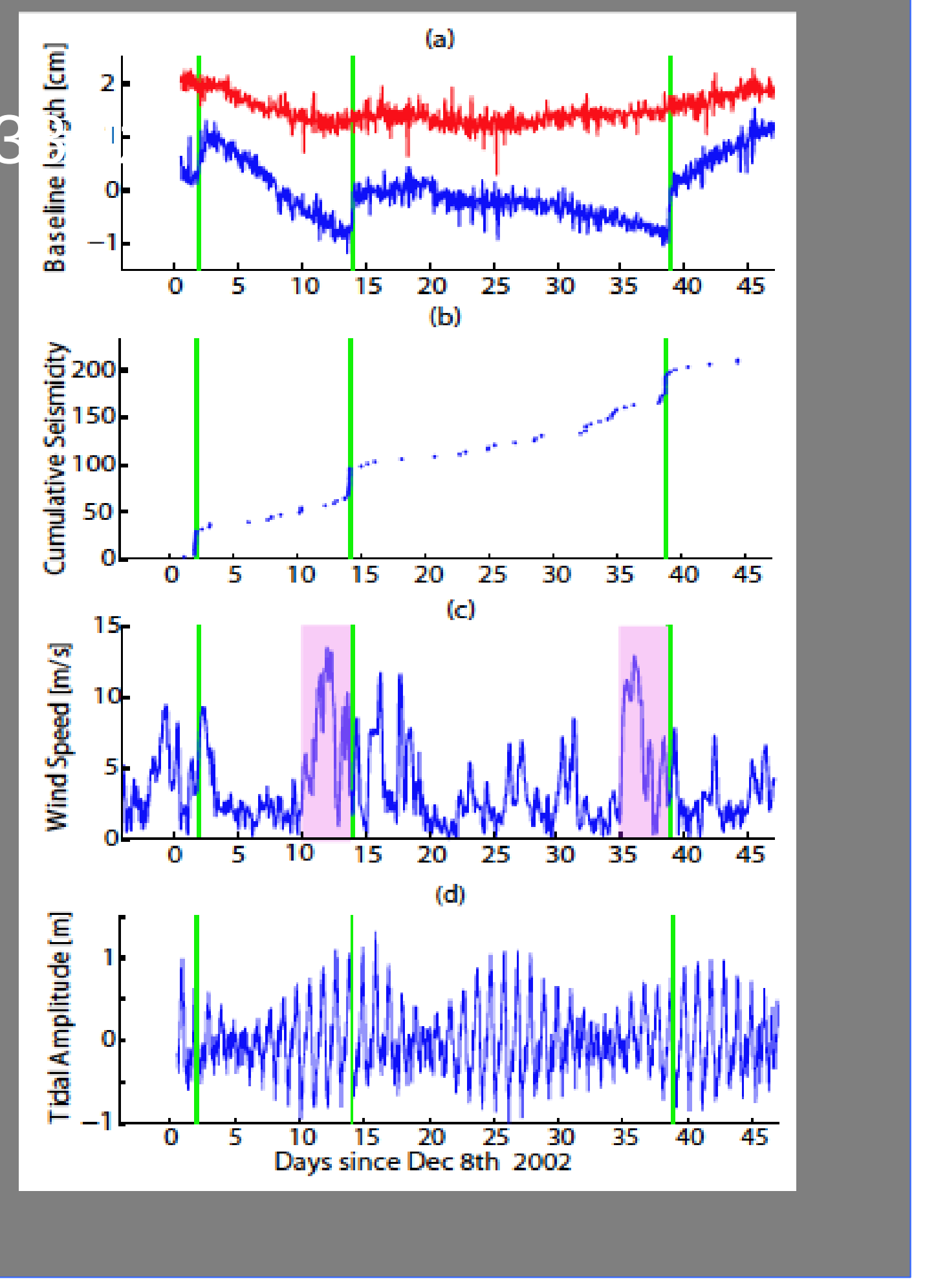


Seismometer deployment

Amery Ice Shelf, East Antarctica



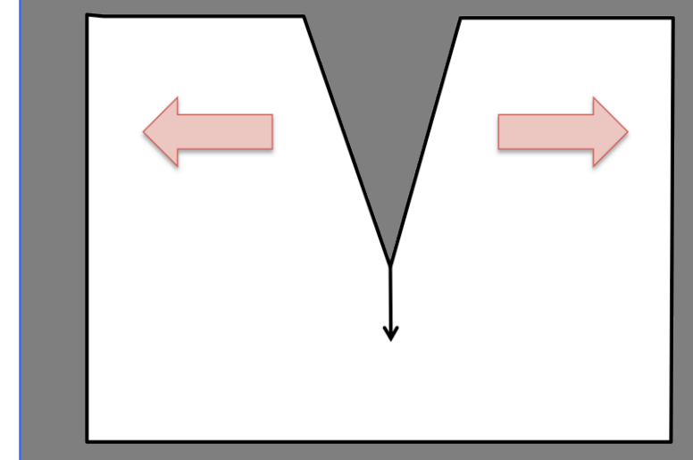
Observations:



OBSERVABLE SEISMICITY AT THE ICY MOONS

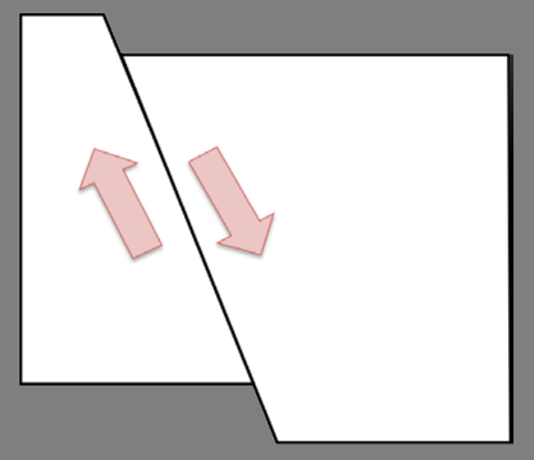
Fracture propagation in planetary ice shells: Sources of Seismic Energy

1. Tensile fracture



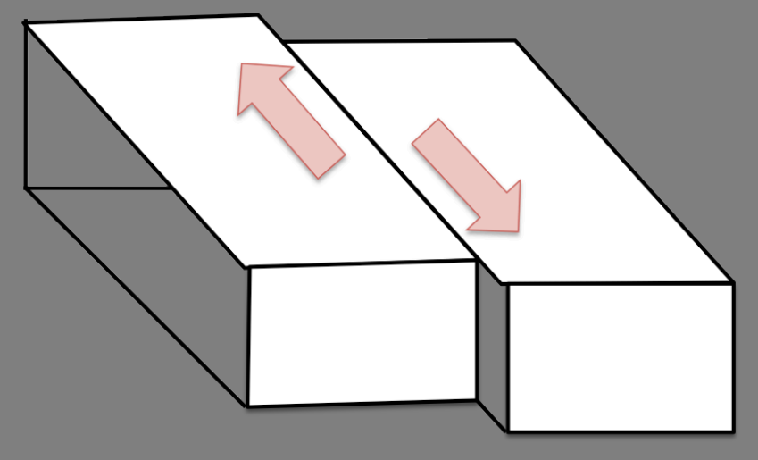
Seismic moment:
$M_W = 2$
(crack depth: 100m)
Aki and Richards (2002)

2. Normal faulting



Seismic moment:
M_W = 4 to 6
(varying B-D depth)
Nimmo and Schenk (2006)

3. Strike-slip faulting



Seismic moment:
M_W = 5.2 to 6.4
(vary length, depth)
Panning et al. (2006)

Observability of seismicity depends on existing level of tectonic activity and instrument sensitivity. Previous instrument sensitivity ranges:

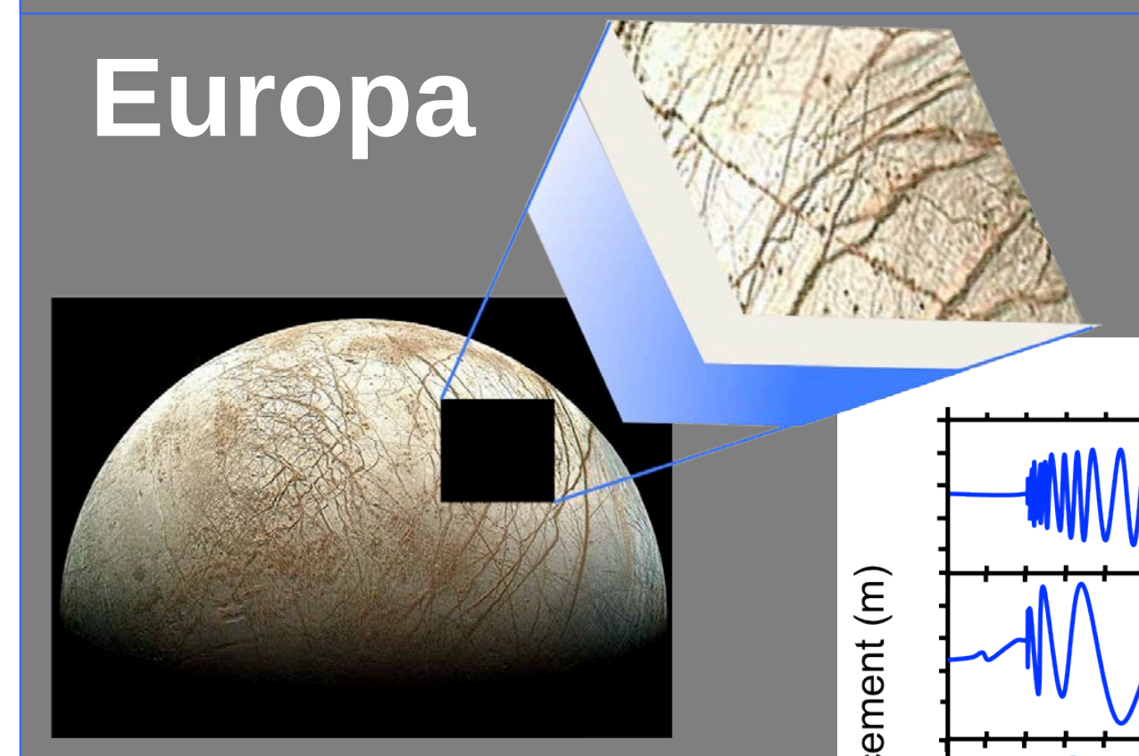
Apollo LP	Viking seismometer	NetLander (proposed, Mars)	OPTIMISM (Mars96, Mars)
0.0001 to 1 mHz	0.01 to 1 mHz	0.001 to 1 mHz	0.01 to 1 mHz
1e^{-6} to 1e^{-10} m/s^2	1e^{-4} to 1e^{-6} m/s^2	1e^{-9} to 1e^{-10} m/s^2	1e^{-6} to 1e^{-8} (4 s/sec) or 1e^{-5} to 1e^{-7} (.25 s/sec)
>11 kg, 4W	2.2 kg, 3.5 W	< 2 kg, < 1 W	< 2 kg, 70 mW

Panning et al. (2006): computed peak displacement, velocity, and acceleration for range of shell thicknesses

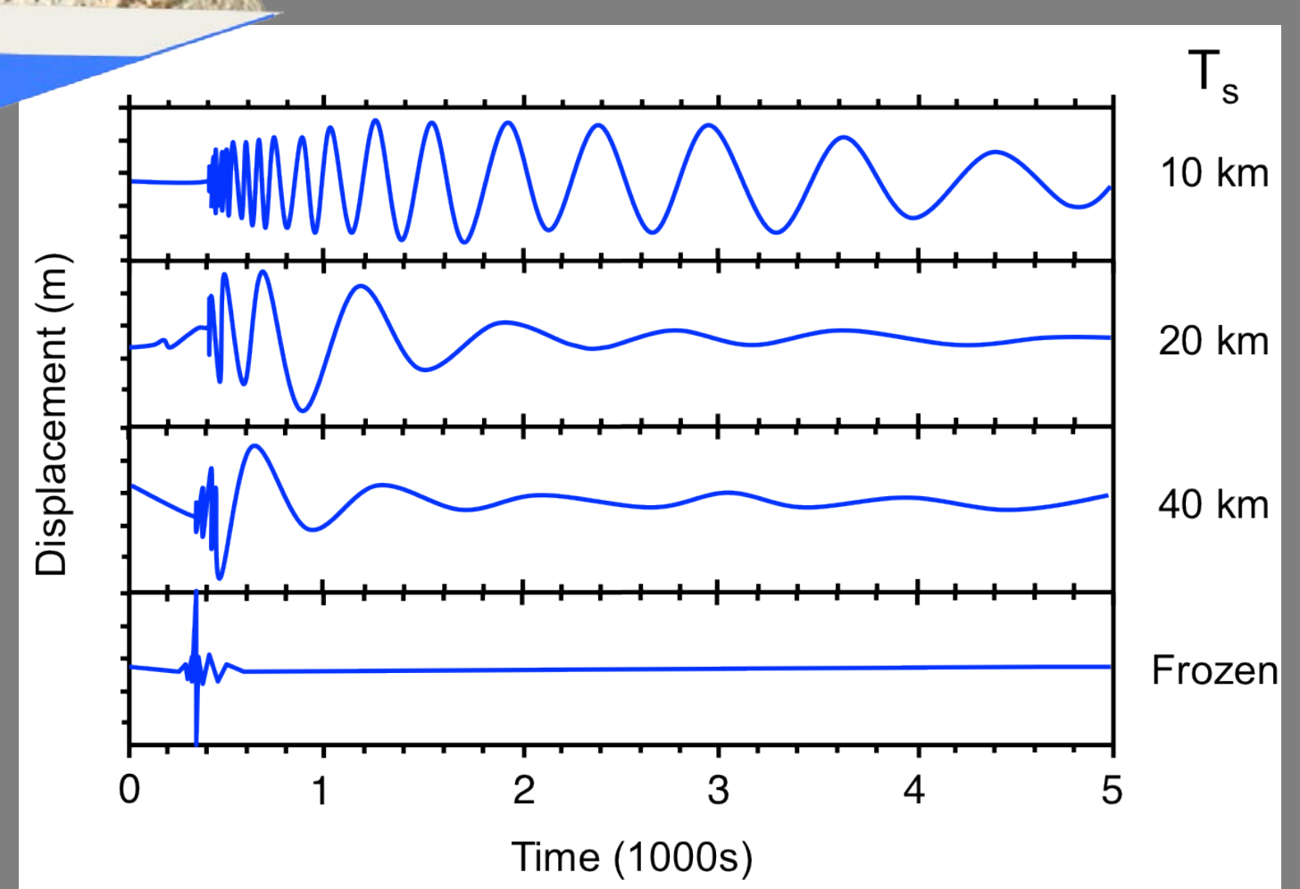
- Shell range: 5 – 60 km depth, seismometer placed 135 - 1640 km from source
- Broadband amplitudes ~smallest for 20 km shell, increase with shell thickness (decreased dispersion)
- Largest amplitude acceleration: < 70 km surface wave (approx. spacing of observed fractures at Europa)
- Any instrument must have: at least mm-scale accuracy, period range of 10 – 500 seconds

PLANETARY SEISMOMETRY

Europa

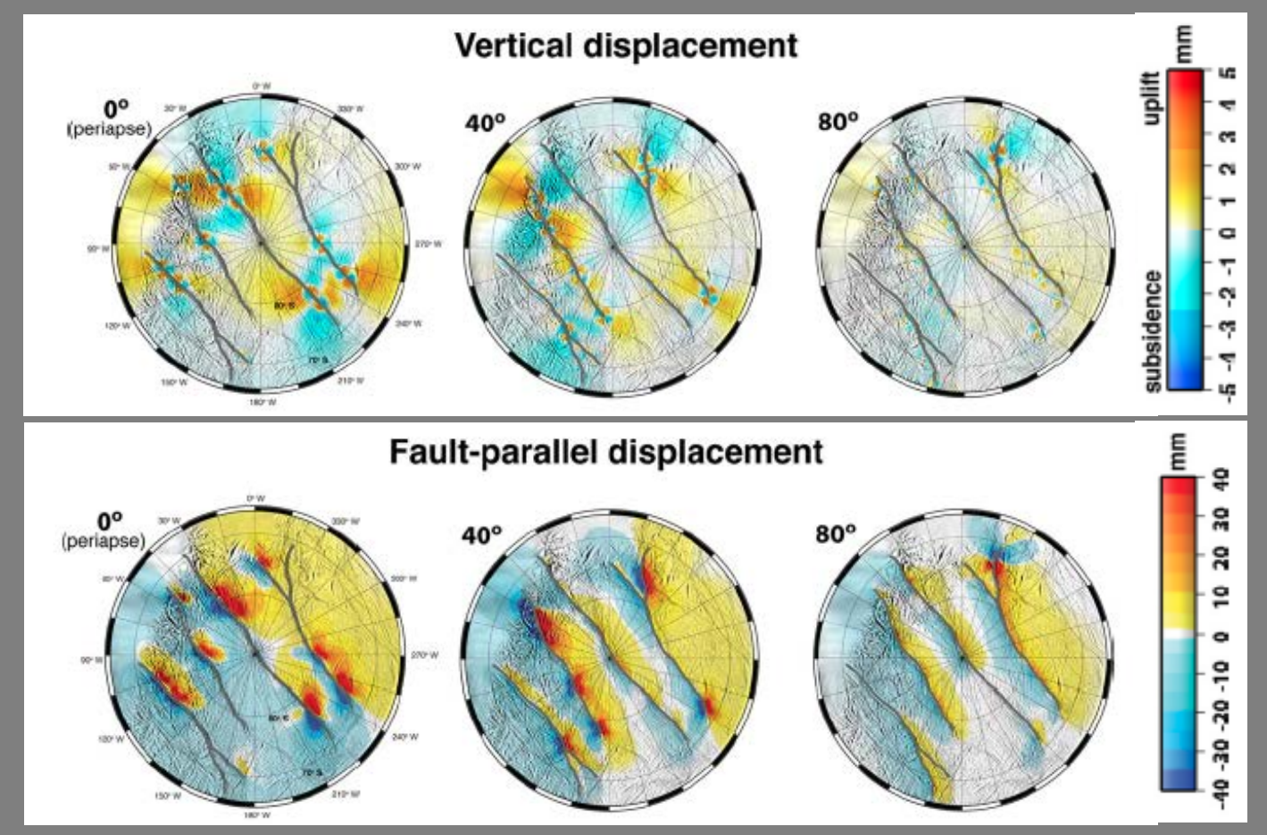


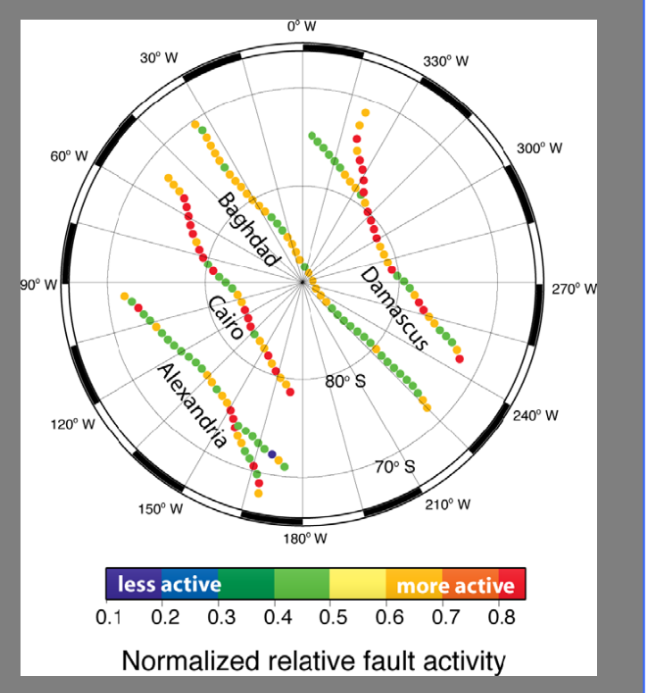
Synthetic seismogram:
A tensile fracture on Europa



Varied shell depth (T_s):
Seismic signal from tensile fracture
(Amery rift model)

Enceladus





Tiger stripe model by Smith-Konter and Pappalardo (2008): San Andreas fault model of stress accumulation and shear failure

What can we Learn?: Potential science return

Seismic measurements and the knowledge made possible with them would greatly enhance the current understanding of the icy moons.

What is not directly returned due to challenging measurement requirements (e.g., deep structure), can still be better constrained through observations:

1. Are the shells tectonically active?
2. Location of activity: regional or global?
3. Ice thickness: global shell and local anomalies
4. Constraints on thermal and chemical structures
5. Water ocean beneath ice shell

References: (1) Banerdt, W. B. and W. T. Pike (2001). *A miniaturized seismometer for subsurface probing on Mars*. Conference for the Geophysical detection of subsurface water on Mars, Houston, TX. (2) Bassis, J. N., H. A. Fricker, R. Coleman, Y. Bock, J. Behrens, D. Darnell, M. Okal, J.-B. Minster (2008). *Seismicity and deformation associated with ice-shelf rift propagation*, J. of Glac., Vol. 53, 183, pp. 523-536. (3) Knapmeyer, M. and 14 others (2012), *Planetary Seismometers: An Overview*. European Geosciences Union (EGU) General Assembly 2011, Vienna, Austria, April 22-27 2012. (4) Lognonné P. & B. Mosser, *Planetary Seismology*, 14, 239-302 Survey in Geophysic, 1993. (5) P. Lognonné et al.(2000). *The NetLander Very Broad Band seismometer*, Planet. Space Sc., 48,1289-1302. (6) Lognonné, P., V. N. Zharkov, J. F. Karczewski, B. Romanowicz, M. Menvielle, G. Poupinet, B. Brient, C. Cavoit, A. Desautez, D. Franqueville, J. Gagnepain-Beyneix, H. Richard, P. Schibler and N. Striebig (1998). *The seismi OPTIMISM experiment*, Planet. Space Sci., 46, pp. 739-747. (7) Mimoun, D. and the SEIS Team (2007). The SEIS Experiment: A planetary seismometer for Mars… and the Moon, 38th Lunar and Planetary Science Conference, No. 1338, p. 2204. (8) O'Neel, S., H. P. Marshall, D. E. McNamara, W. T. Pfeffer (2007). *Seismic detection and analysis of icequakes at Columbia Glacier, Alaska*. J. Geophys. Res., 112(F3), F03S23. (9) Panning, M., V. Lekic, M. Manga, F. Cammarano, B. Romanowicz (2006). *Long period seismology on Europa: 2. Predicted seismic response*. J. Geophys. Res., Vol. 111, E12008. (10) Smith-Konter, B. and R. Pappalardo (2008). *Tidally driven stress accumulation and shear failure of Enceladus' tiger stripes*. Icarus 198, pp. 435-451. (11) Walker, C. C., J. N. Bassis, H. A. Fricker, R. J. Czerwinski (2012). *Observations of intermittent rift propagation on the Amery Ice Shelf,* J. of Glac. (submitted). (12) Wielandt, E. (2004). *Design considerations for broadband seismometers*, Broadband Seismometer Workshop, Lake Tahoe, CA March 24-26, 2004.