The **S**outh **P**ole **A**coustic **T**est **S**etup

Pressure and shear wave speed vs. depth

Freija Descamps
IceCube **A**coustic **N**eutrino **D**etection working group

Rome, 26 June 2008

ARENA 2008

Outline

Introduction
- SPATS goals
- Previous results

Sound speed results
- Methodology
- Shear waves
- Sound speed results

Conclusions and outlook

South Pole Acoustic Test Setup: goals

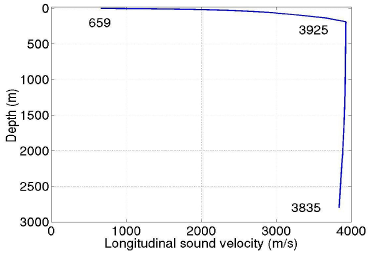
- What are the acoustic properties of the South Pole ice in the 1-100kHz region?

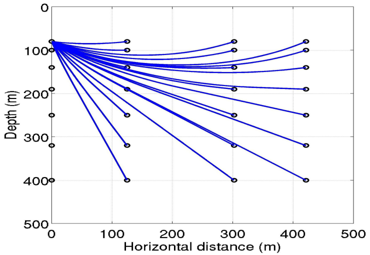
South Pole Acoustic Test Setup: goals

- What are the acoustic properties of the South Pole ice in the 1-100kHz region?

- **Noise**
- **Attenuation length**
- **Sound speed**

Speed-of-sound profile at South Pole





- **Neutrino astronomers**
  - What is the sound speed gradient?
  - What is the resulting refraction?

    → pointing resolution

    → background-event rejection

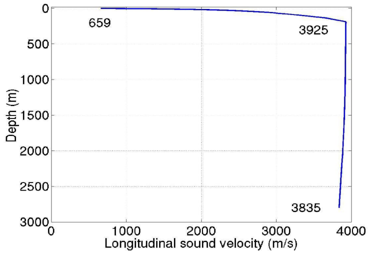
Model

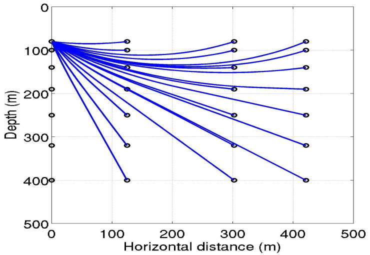
Assumed T-profile:

→ predicted v_s profile

→ ray tracing for source @-80m

Speed-of-sound profile at South Pole



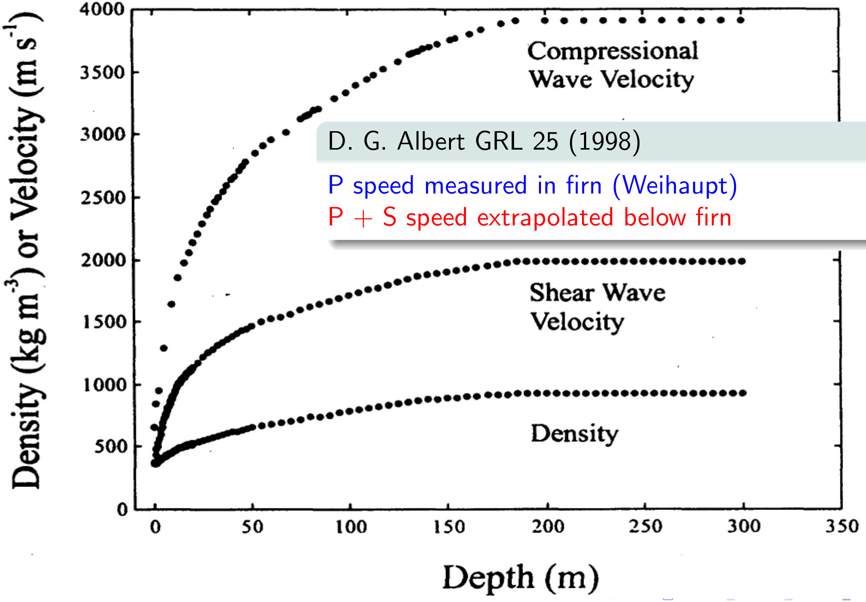


- **Neutrino astronomers**
  - What is the sound speed gradient?
  - What is the resulting refraction?
    $\longrightarrow$ pointing resolution
    $\longrightarrow$ background-event rejection
- **Glaciologists**
  - How do natural seismic signal propagate?
  - Ice Tomography: map ice-flow
  - SPRESSO scientists have already expressed interest in our results

Model

Assumed T-profile:
$\longrightarrow$ predicted v_s profile
$\longrightarrow$ ray tracing for source @-80m

Previous sound speed measurements at South Pole

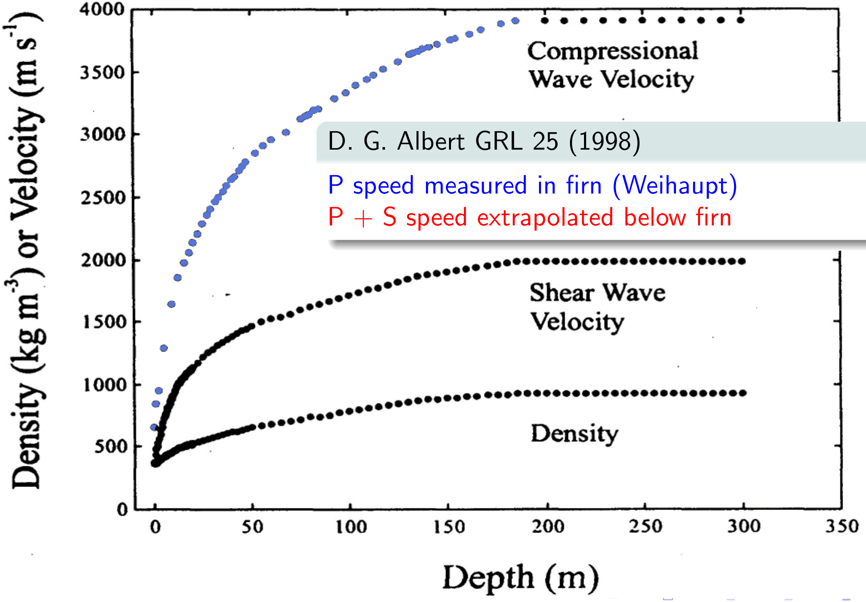


D. G. Albert GRL 25 (1998)

P speed measured in firn (Weihaupt)

P + S speed extrapolated below firn

Previous sound speed measurements at South Pole

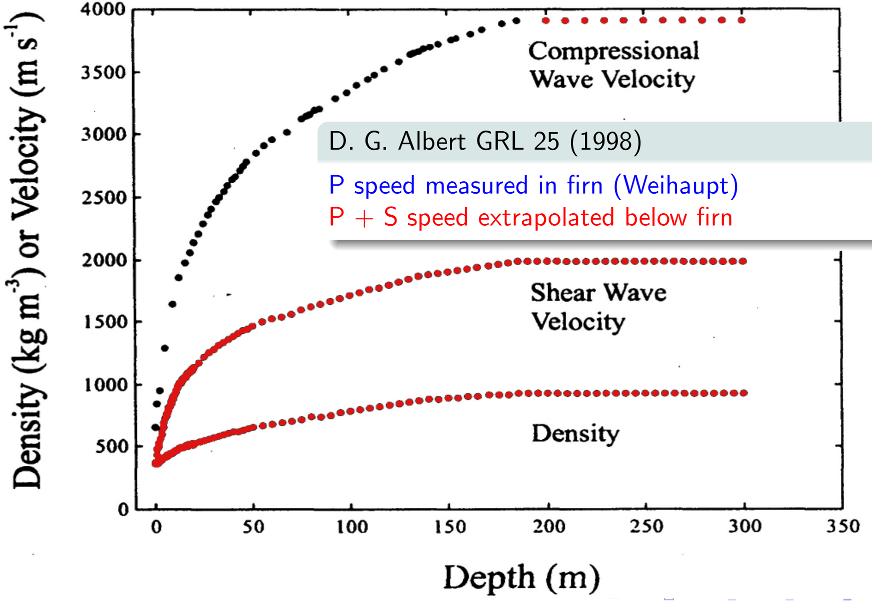


D. G. Albert GRL 25 (1998)

P speed measured in firn (Weihaupt)

P + S speed extrapolated below firn

Previous sound speed measurements at South Pole



D. G. Albert GRL 25 (1998)

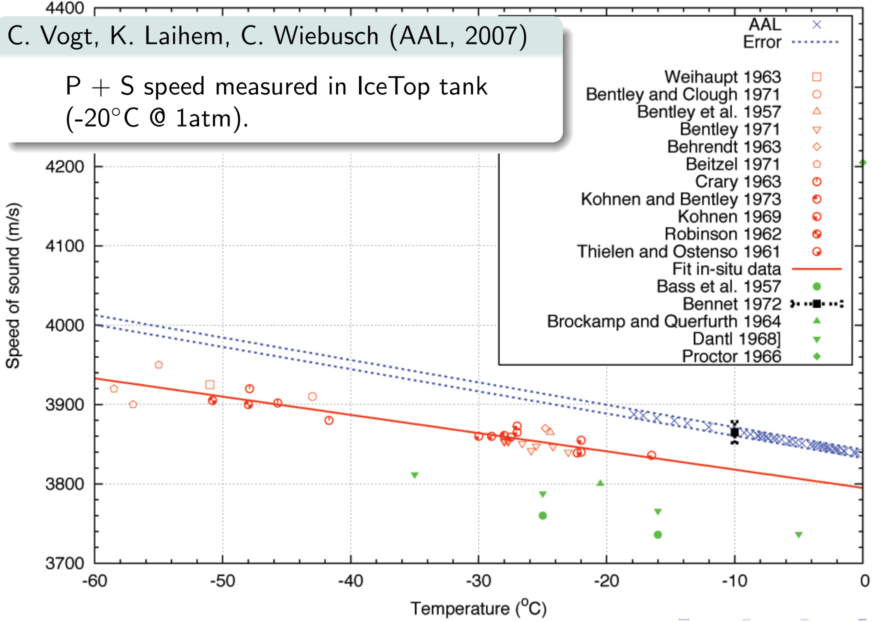
P speed measured in firn (Weihaupt)

P + S speed extrapolated below firn

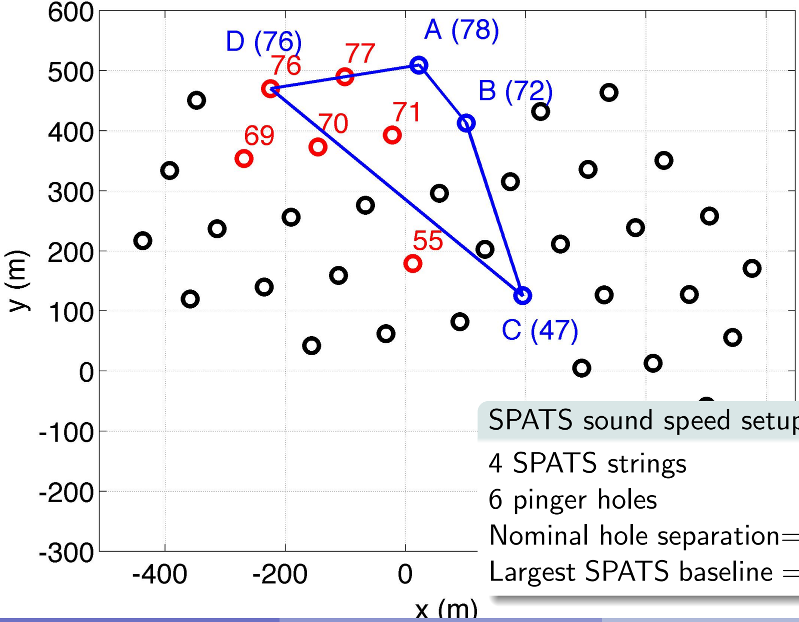
Lab and in-situ speed-of-sound measurements

C. Vogt, K. Laihem, C. Wiebusch (AAL, 2007)

P + S speed measured in IceTop tank (-20°C @ 1atm).



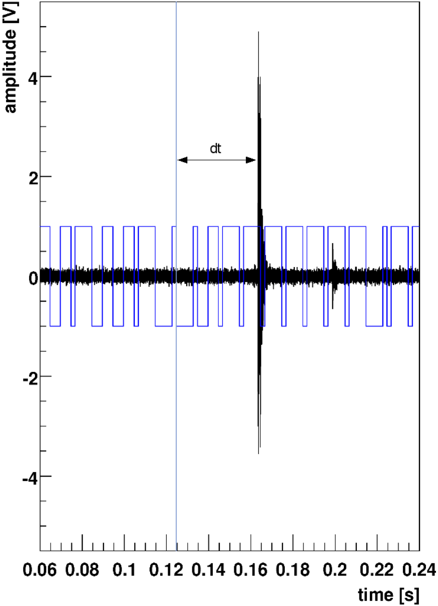
SPATS: The retrievable pinger



SPATS sound speed setup

- 4 SPATS strings
- 6 pinger holes
- Nominal hole separation= 125m
- Largest SPATS baseline = 543m

SPATS sound speed: methodology

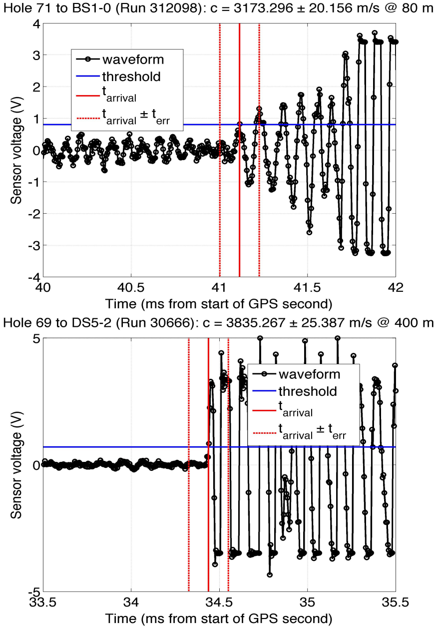


- Time from GPS second start to acoustic emission
- Automated determination of sensor pulse rising edge
- Measurement at all 9 SPATS instrumented depths (each using pinger + sensor at same depth)
- Fit for sound speed gradient in deep ice (250-500 m depth) gives radius of curvature
- All measurements currently for 125m horizontal distance

SPATS sound speed: error budget

For 125 m baseline:
34 ms time-of-flight:

- $\delta t_{monostable} = \pm 0.1$ ms $= 0.29\%$
- $\delta t_{arrival} = \pm 0.05$ ms $= 0.15\%$
- $\delta r = \pm 0.5\text{m}\sqrt{2} = \sim 0.57\%$
  - because two holes, each 0.5 m in any direction



SPATS sound speed: error budget

For 125 m baseline:

34 ms time-of-flight:

- $\delta t_{monostable} = \pm\, 0.1$ ms $= 0.29\%$
- $\delta t_{arrival} = \pm\, 0.05$ ms $= 0.15\%$
- $\delta r = \pm\, 0.5\text{m}\ \sqrt{2} = \sim 0.57\%$
  - because two holes, each 0.5 m in any direction

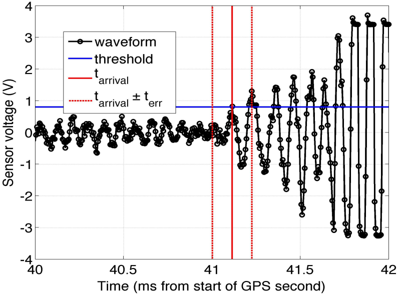
$\rightarrow$ error is dominated by baseline

$\Rightarrow$**Total error = 0.7% for 125 m baseline**

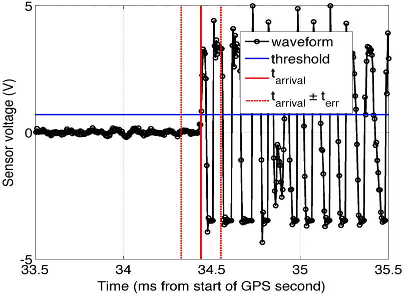
Best possible = 543 m

$\rightarrow$ 0.1% or 0.2%

Hole 71 to BS1-0 (Run 312098): c = 3173.296 ± 20.156 m/s @ 80 m

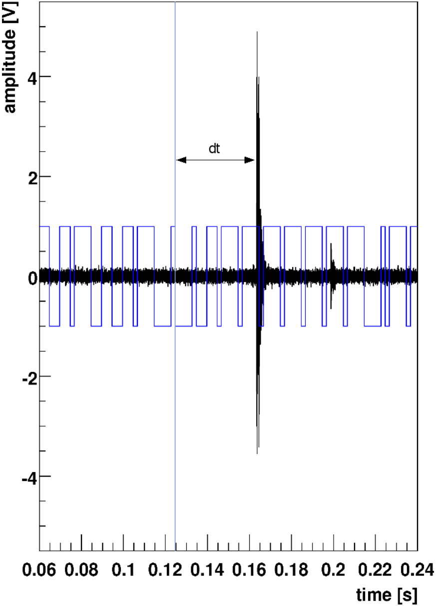


Hole 69 to DS5-2 (Run 30666): c = 3835.267 ± 25.387 m/s @ 400 m



SPATS shear waves

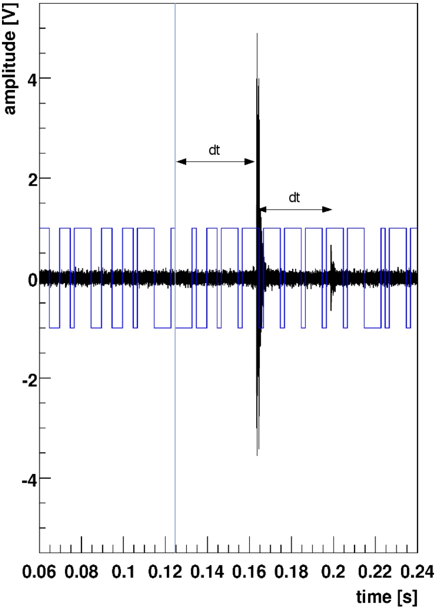
From both pinger and SPATS transmitter data:



SPATS shear waves

From both pinger and SPATS transmitter data:

- afterpulse
- varying relative amplitude
- only present for <200m paths
- speed consistent with half of pressure wave speed ...

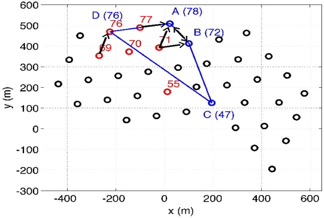


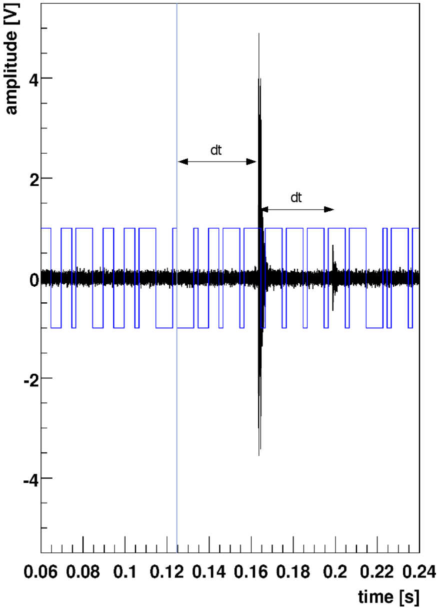
SPATS shear waves

From both pinger and SPATS transmitter data:

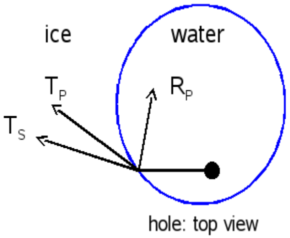
- afterpulse
- varying relative amplitude
- only present for <200m paths
- speed consistent with half of pressure wave speed ...

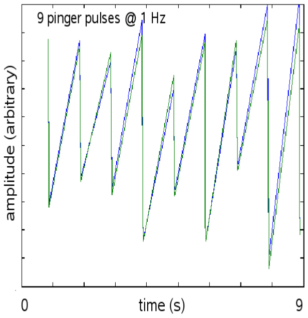
⇒ Detection of shear waves with SPATS!





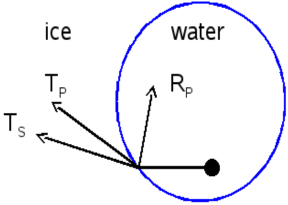
SPATS shear waves

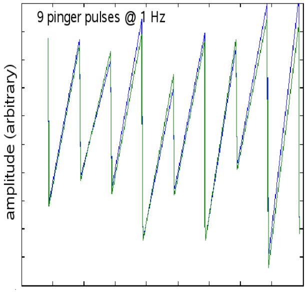




Mode conversion at water/ice interface:

SPATS shear waves





Mode conversion at water/ice interface:

Large incident angle:

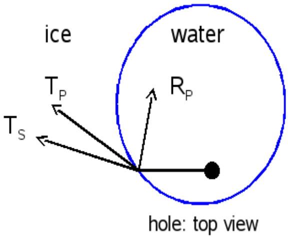
increase shear wave amplitude

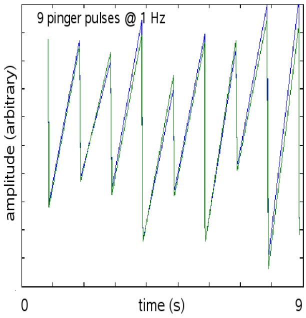
decrease pressure wave amplitude

$\longrightarrow$ 3D calculation of $\theta_{incident}$

$\longrightarrow$ $T_P(\theta_i)$, $R_P(\theta_i)$, $T_S(\theta_i)$

SPATS shear waves





Mode conversion at water/ice interface:

Large incident angle:

increase shear wave amplitude

decrease pressure wave amplitude

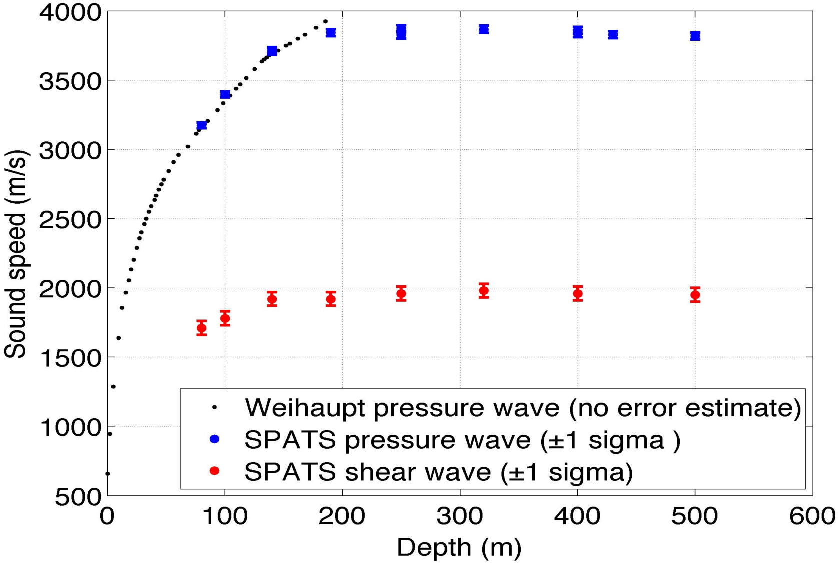
$\rightarrow$ 3D calculation of $\theta_{incident}$

$\rightarrow$ $T_P(\theta_i)$, $R_P(\theta_i)$, $T_S(\theta_i)$

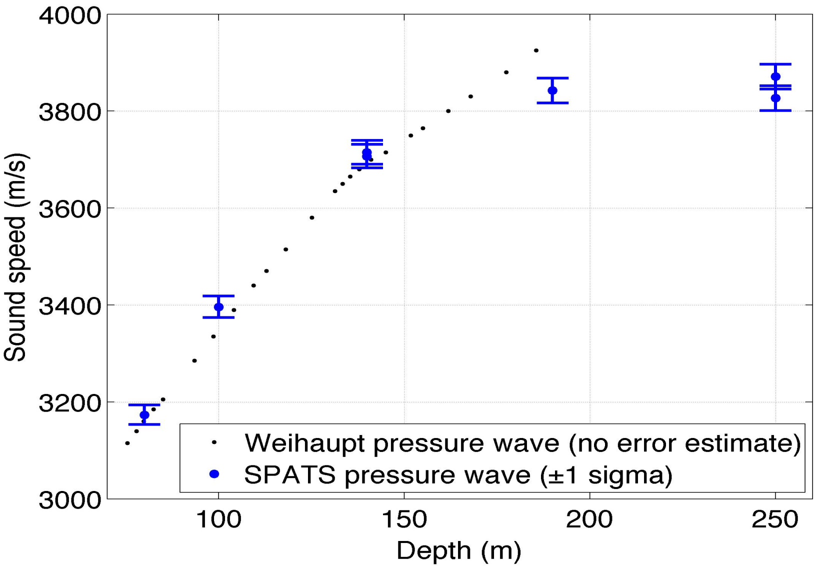
Anticorrelation P/S wave amplitudes:

$\rightarrow$ total energy is conserved?

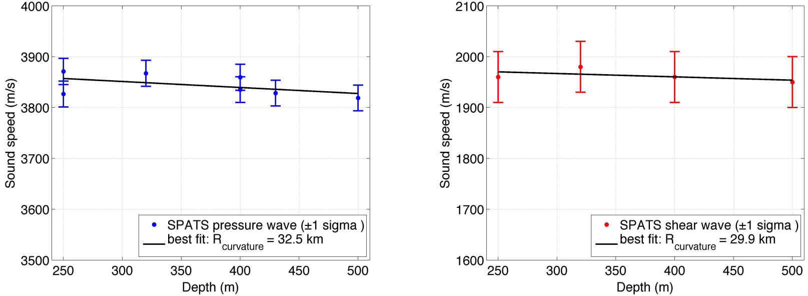
$v_{pressure}$ and v_{shear} vs. depth.



$v_{pressure}$ consistent with previous result **in firn**



$v_{pressure}$ and v_{shear} constant [250m,500m]



- consistent with no refraction, best fit gives slight refraction:

  $\Rightarrow$ **R_{curv} = 32.5km (P) and 29.9km (S)**

For a 32.5 km radius:

100 m path deflects 0.154 m, 3 km path deflects 138 m

1 km path deflects 15.4 m $\sim$ acoustic pancake width

Conclusions and outlook

SPATS pressure and shear waves

Sound speed results

Outlook

Conclusions and outlook

SPATS pressure and shear waves

- SPATS pinger data: precise timing achieved
- Shear waves have been detected in SPATS emitters and pinger data.

Sound speed results

Outlook

Conclusions and outlook

SPATS pressure and shear waves

- SPATS pinger data: precise timing achieved
- Shear waves have been detected in SPATS emitters and pinger data.

Sound speed results

- Both P and S wave speeds have been mapped vs. depth in firn and bulk

  First measurement of P speed in bulk ice

  First measurement of S speed in both firn and bulk ice
- Refraction is consistent with 0 between 250 and 500m depth.

Outlook

Conclusions and outlook

SPATS pressure and shear waves

- SPATS pinger data: precise timing achieved
- Shear waves have been detected in SPATS emitters and pinger data.

Sound speed results

- Both P and S wave speeds have been mapped vs. depth in firn and bulk

  First measurement of P speed in bulk ice

  First measurement of S speed in both firn and bulk ice
- Refraction is consistent with 0 between 250 and 500m depth.

Outlook

- Precision can be improved:

  Clock drift correction

  Larger baselines
- New pinger-runs with larger baselines 2008/2009 polar season