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# Earthquake Risk & Recovery:

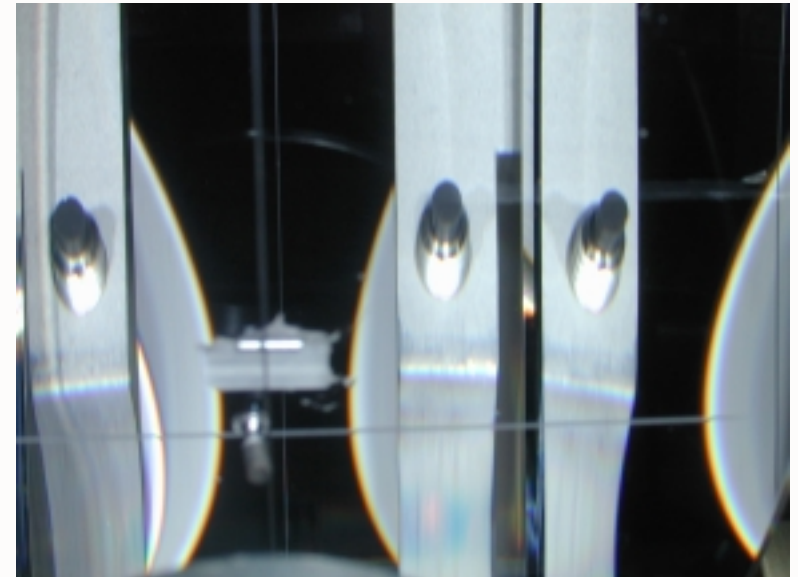
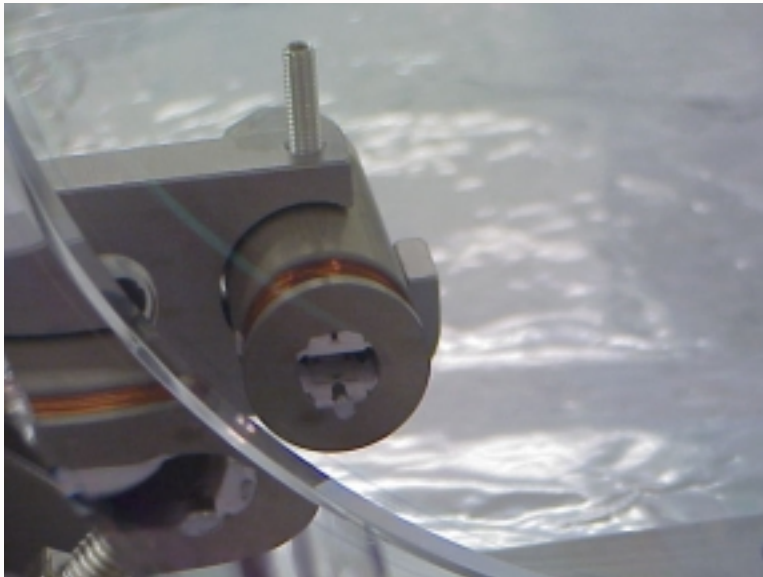
## Lessons from the 2/28/01 Olympia, WA quake

Dennis Coyne



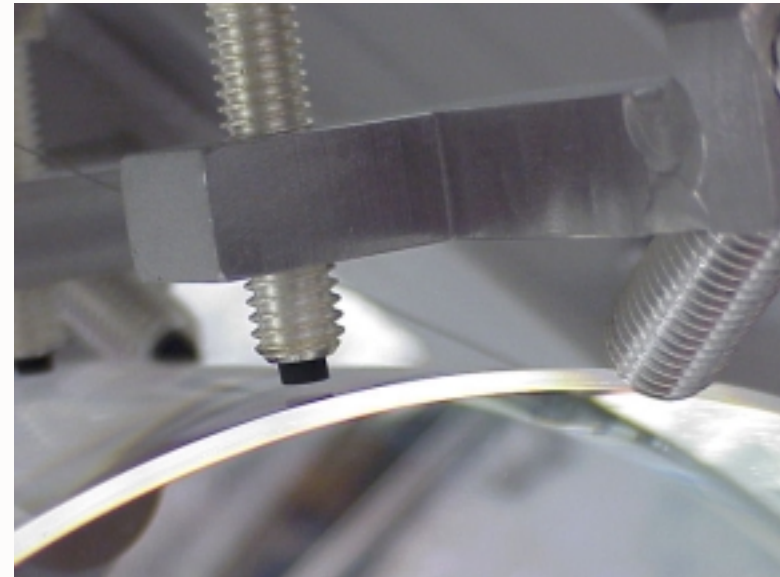
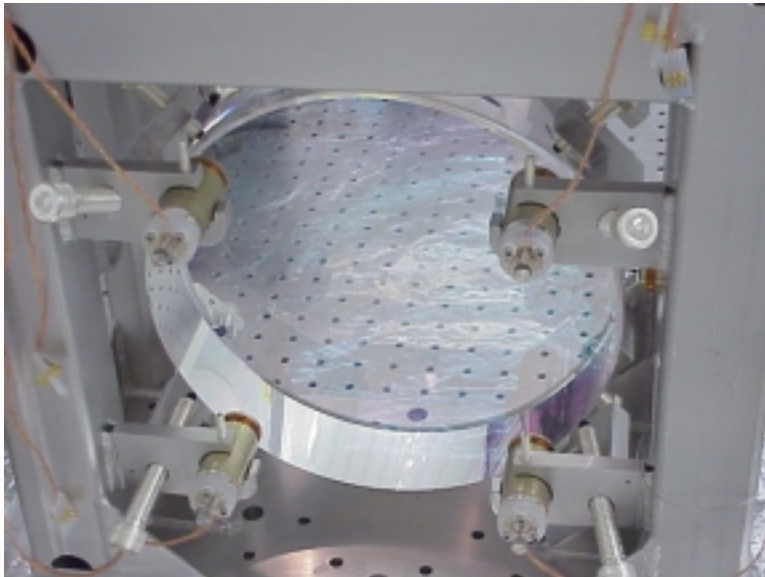
## 2/28/01 Olympia, WA Quake

- **6.8 Magnitude, 10 miles (20 km) NE of OLYMPIA, Washington**
- **Damage to LIGO:**
  - » 5 (of 12 free) large optics need magnet rebonding and re-hanging
  - » One large optic with bent side magnet standoff
  - » All 7 (free) Small Optics (2 km interferometer) needed re-bonding &/or re-hanging
  - » All optics (2 km & 4km interferometers) required re-alignment
  - » Approx. 10 weeks delay



## 2/28/01 Olympia, WA Quake

- Large Optic Earthquake/Handling Stops (16 total):
  - » Procedures did not ensure that top and bottom (8 total) stops were set to a proper distance
  - » Chamfer stops (8 total) are difficult to set to proper distance due to runout, blunt tip and coarse thread
  - » Have been re-worked for re-installation; Conical tip & revised procedures
  - » Re-design for future replacement in progress



## 2/28/01 Olympia, WA Quake

- New Sensor/Actuator heads (revised to reduce laser light coupling to local damping sensors)
- New Sensor/Actuator heads have less clearance to the magnet/standoff assemblies – aggravates problem
- Stops now set to 0.5 mm clearance





# 2/28/01 Olympia, WA Quake

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- Small Optics

- » Procedures did not ensure that stops (9? total) were set to a proper distance
- » Stops incorporated spring tips instead of flourel (low dissipation)
- » Have been re-worked for re-installation; flourel tips where possible & revised procedures
- » Re-design for future replacement in progress



# 2/28/01 Olympia, WA Quake: Recovery Plan

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- Earthquake occurred during 4 km interferometer installation at Hanford (recycling cavity alignment was nearly complete)
- Recovery Plan:
  - » Transferred staff & alignment, assembly tooling from Livingston to support accelerated re-work
  - » Transferred vacuum bake preparation work from Hanford to Livingston to free facility for optics preparation
  - » Accelerated the planned Sensor/Actuator replacement for the 2 km interferometer (mitigates laser light coupling to damping sensor)
  - » Developed procedures for alignment of the vertex with all optics installed
  - » Performed PSL/IO table re-layout in parallel to take advantage of downtime
  - » Focused commissioning staff at Livingston
  - » Expedited re-work of earthquake stops; Re-evaluation/re-design pending
  - » Long 2 km interferometer vertex exposure delays commissioning
    - Focus on installation/commissioning of digital suspension controls for the 4 km input optics and recycling cavity



# Actions Pending

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- Assessment of earthquake risk, with assistance from geophysics community
- Modeling of a representative suspension point acceleration time series (colored by the seismic isolation system)
- Re-design of earthquake stops
- Test of stops on shaker table with full suspension assemblies (large & small)



# 2/28/01 Olympia, WA Quake

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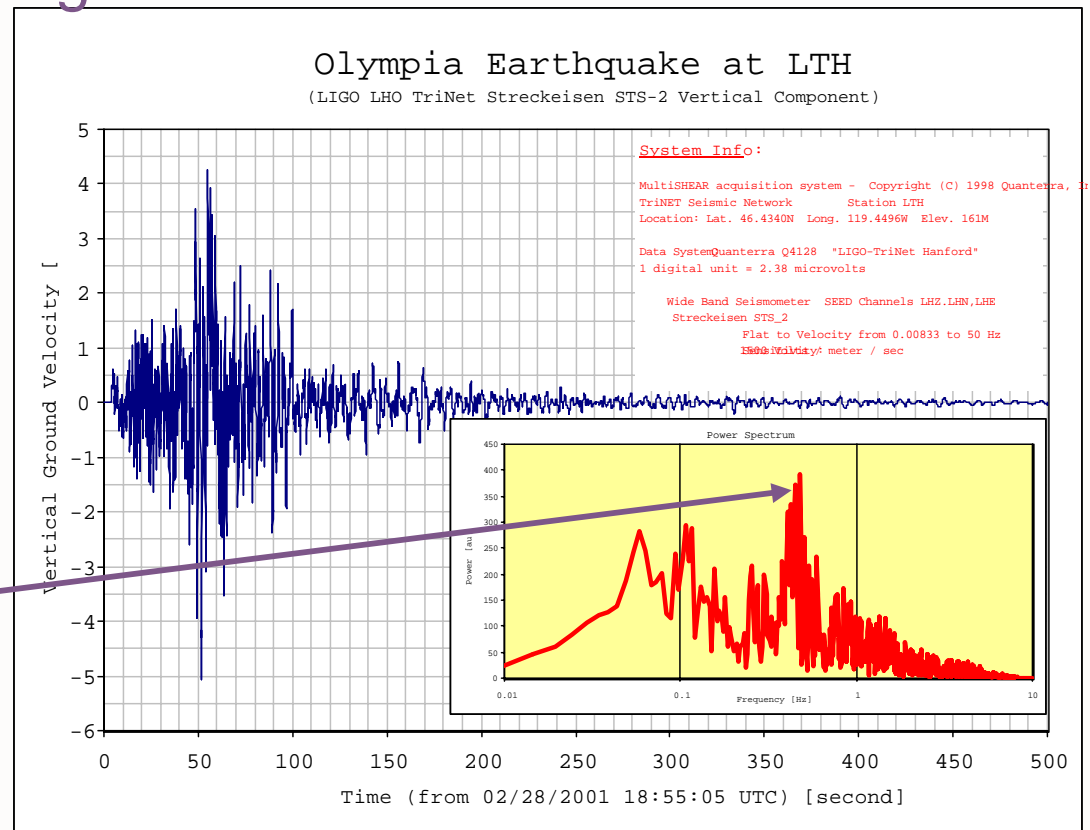
- TRINET Installation
  - » LIGO has a strong motion, seismometer installed at both sites, as part of the TRINET national network
  - » Provides a background (remote from buildings) baseline and visibility for large seismic events (PEM instruments saturate)





# Earthquake time plot & spectrum

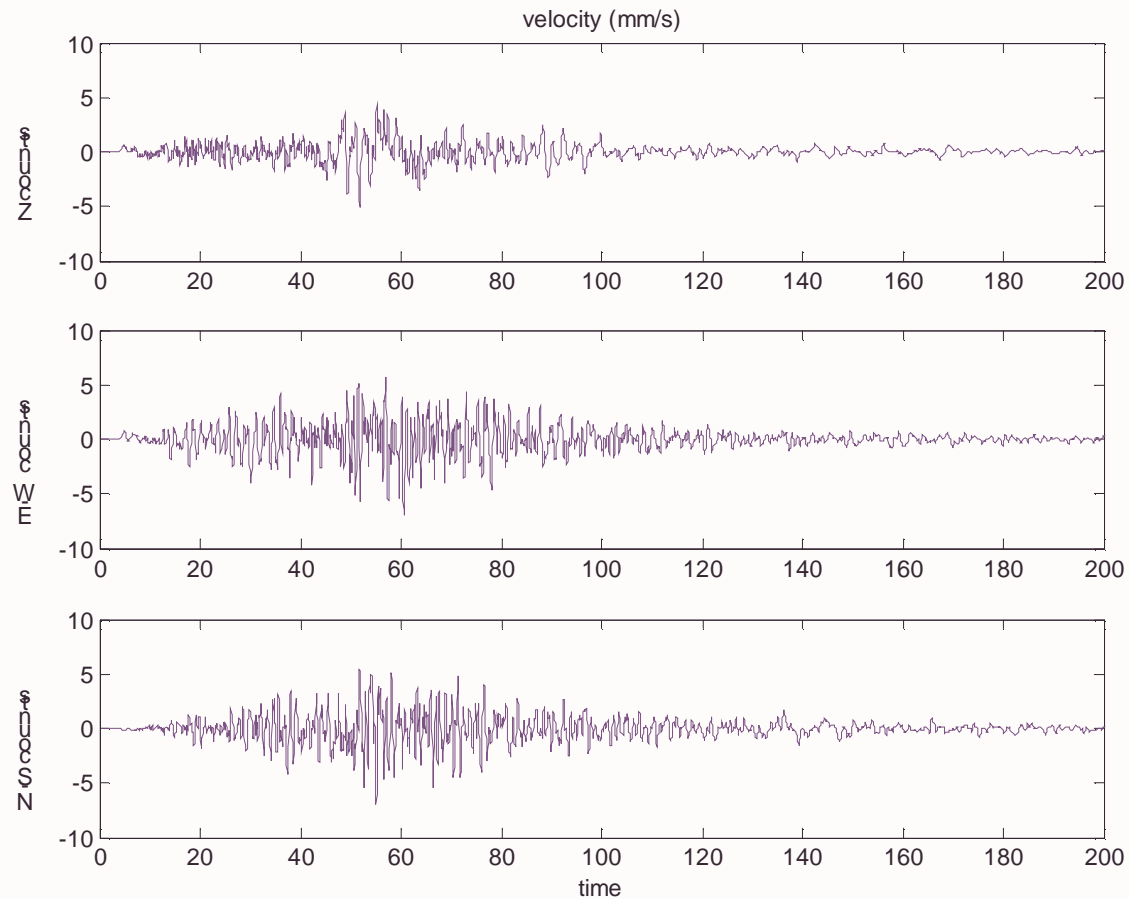
- Maximum displacement ~ 1 cm
- Peak acceleration ~ 2% g



Peak at ~0.7 Hz, which is equal to the suspension position mode

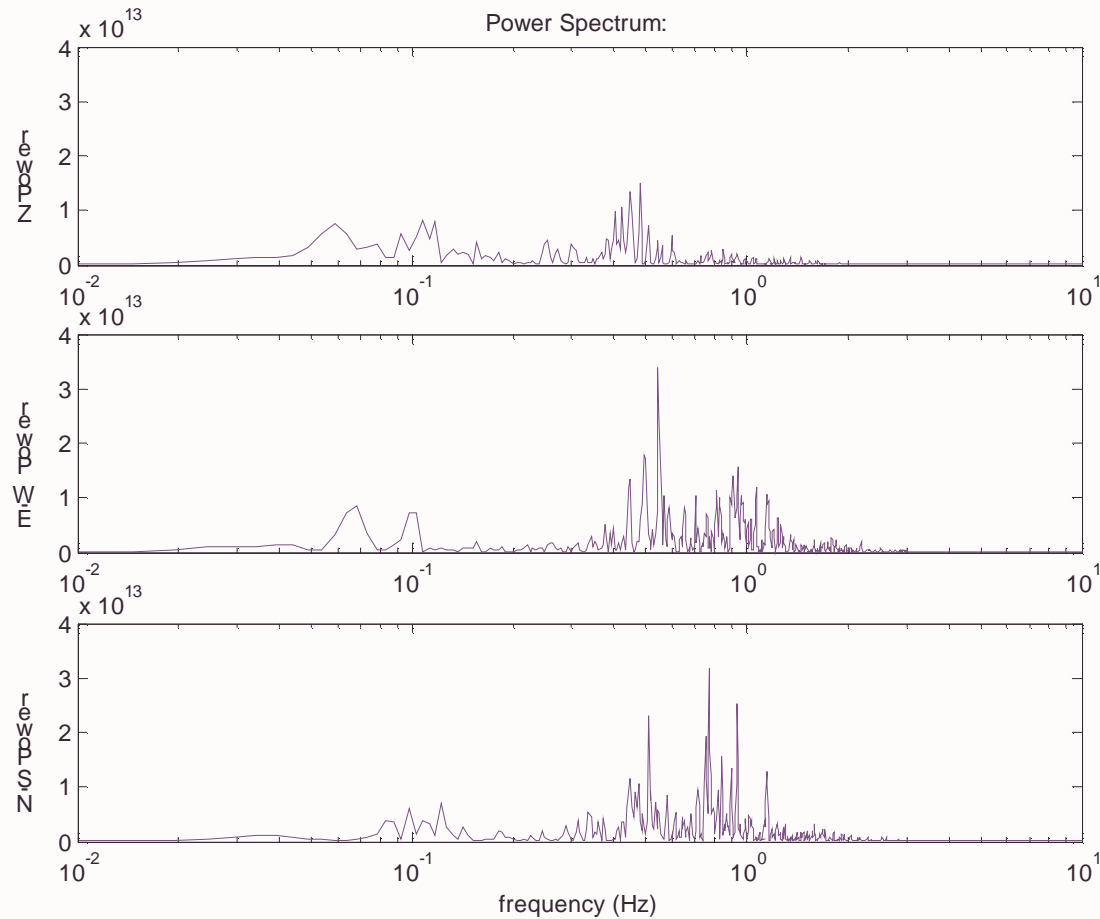


# Velocity Waveform

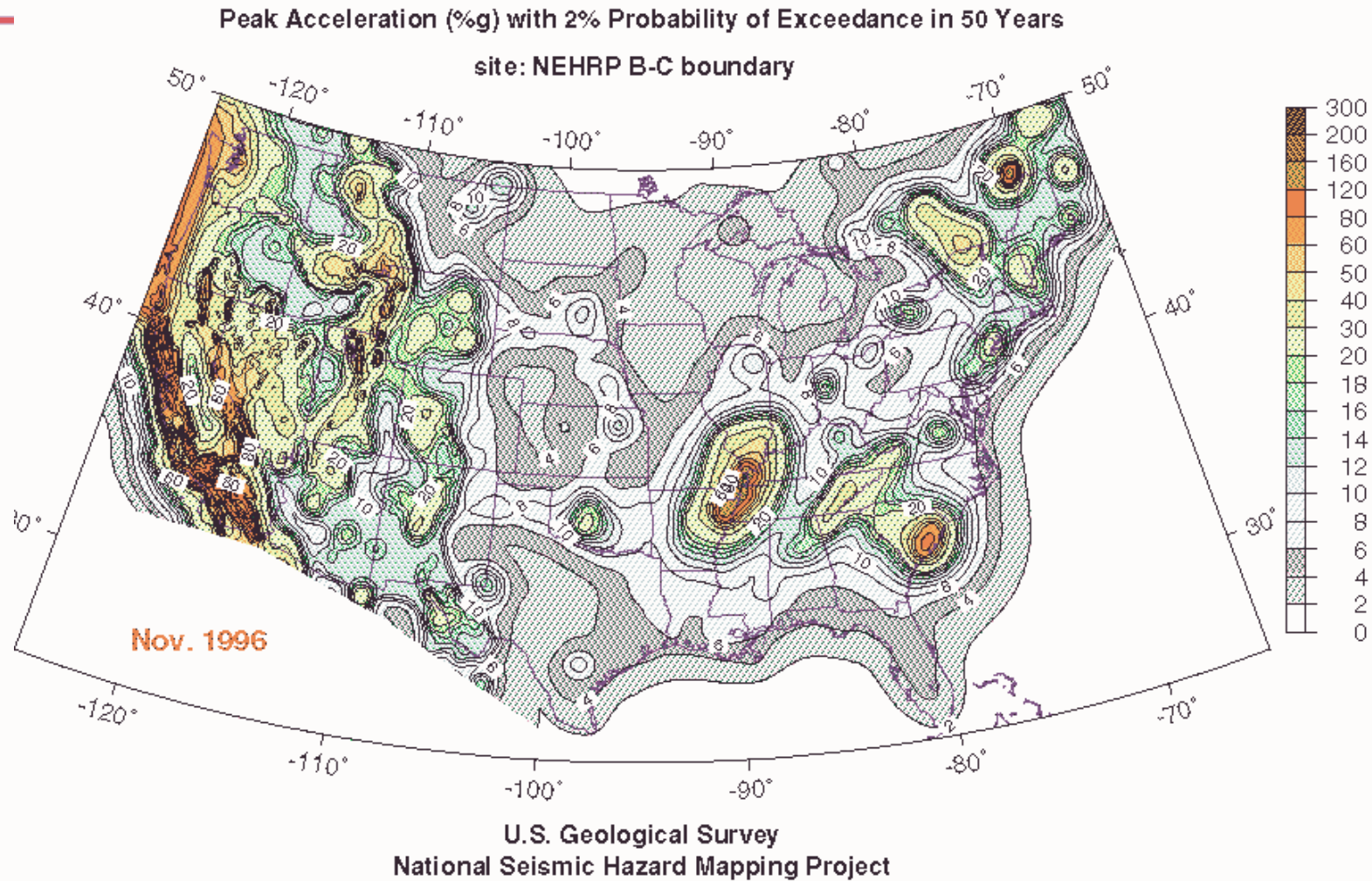




# Power Spectra



# Earthquake Risk



# Earthquake Risk

- Hanford

- » 46.4551 Lat. -119.4075 Long.
- » Distance to nearest grid point = 5.0 km
- » Probabilistic ground motion values:

Probability of Exceedance in 50 yr.	Peak Ground Acceleration (% g)
10%	8.5%
5%	12.3%
2%	19.4%

- Livingston

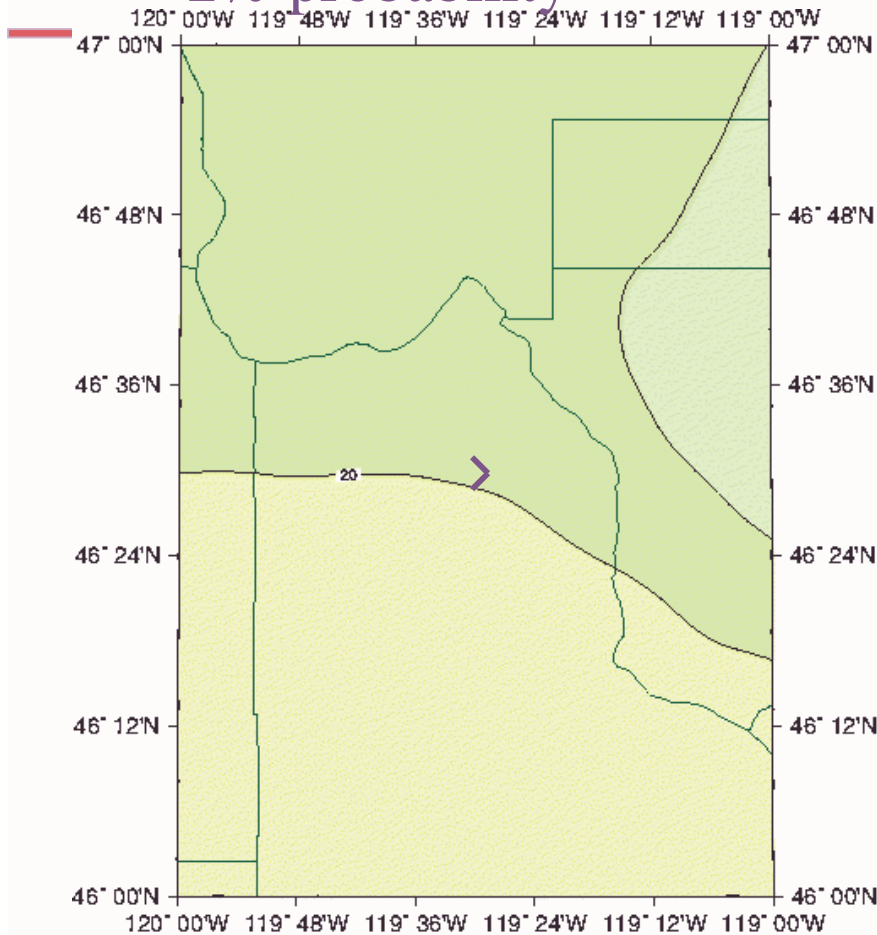
- » 30.563 Lat. -90.774 Long.
- » Distance to nearest grid point = 4.8 km
- » Probabilistic ground motion values-

Probability of Exceedance in 50 yr.	Peak Ground Acceleration (% g)
10%	1.8%
5%	3.4%
2%	6.7%



# % g Contours: Probability of Exceedance in 50 yr.

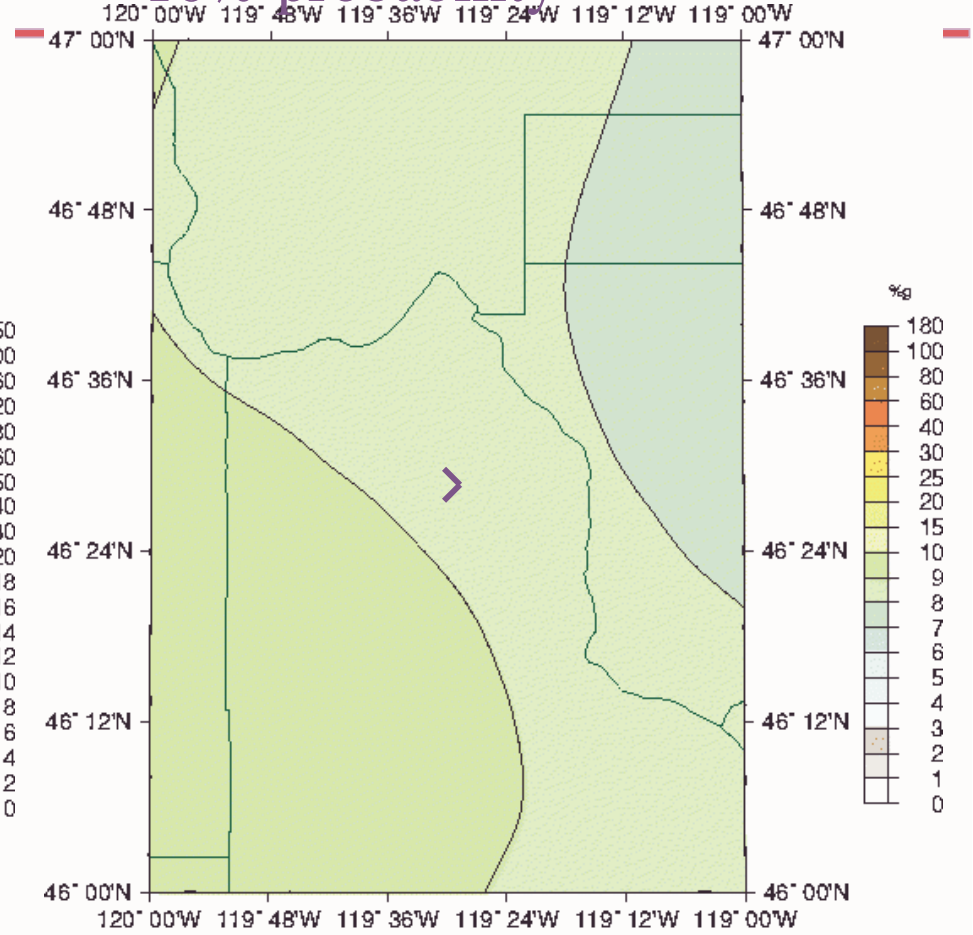
2% probability



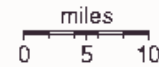
Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years  
site: NEHRP B-C boundary  
U.S. Geological Survey  
National Seismic Hazard Mapping Project  
Albers Conic Equal-Area Projection  
Standard Parallels: 29.5 and 45.5 degrees



10% probability



Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years  
site: NEHRP B-C boundary  
U.S. Geological Survey  
National Seismic Hazard Mapping Project  
Albers Conic Equal-Area Projection  
Standard Parallels: 29.5 and 45.5 degrees





# 2/28/01 Earthquake: Lessons Learned

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- Acceleration amplitude for a future quake may be ~10 x greater than the 2/28/2001 Olympia quake
  - » Olympia ground acceleration peak ~ 2% g
  - » 0.2% probability of exceedance in 5 yr: ~20% g
- Damage was due to impact of the magnet/standoff assembly with the sensor/actuator head
- Compliant & lossy stops set to a proper clearance will prevent impact of the magnet/standoff
- Re-alignment will be a risk for any significant seismic event for initial LIGO
- Requirements for mitigation of earthquake motion will be added to the advanced LIGO seismic system