Detecting Topological Dark Matter with GNSS

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Dark Matter: What is it?

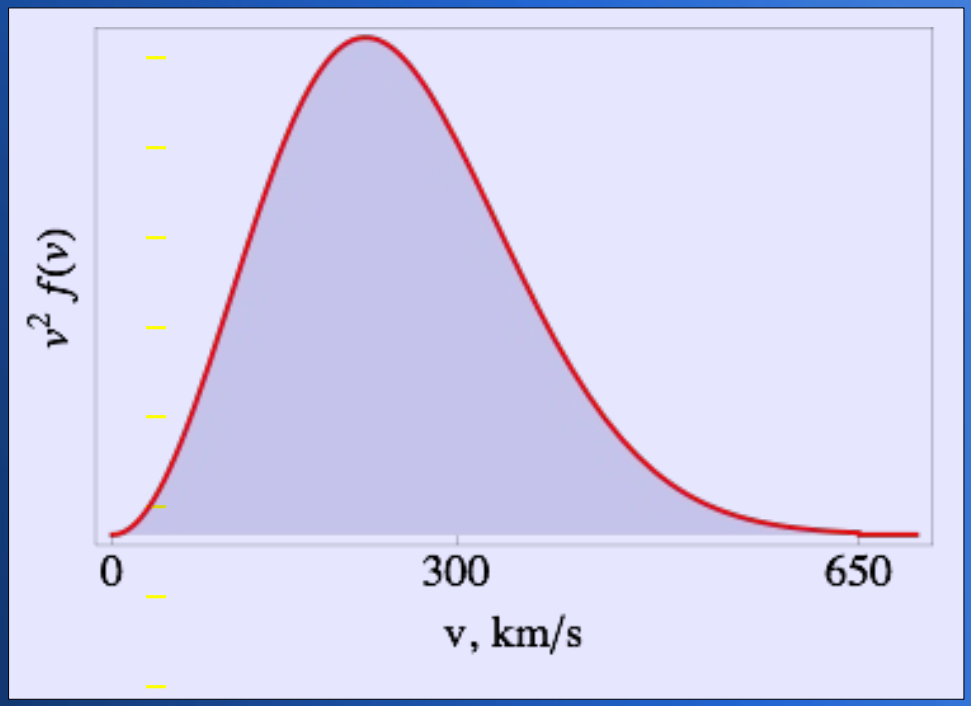
- Only 4% of the Universe is “ordinary”
  - 68% is “Dark Energy”
  - 27% is “Dark Matter”
- Multiple observational evidence:
  - galactic rotation curves
  - gravitational lensing
- Does not emit/absorb radiation
  - not dark clouds of ordinary matter
- Grand challenge to 21st century physics

What do we know about Dark Matter?

- Galactic DM halo

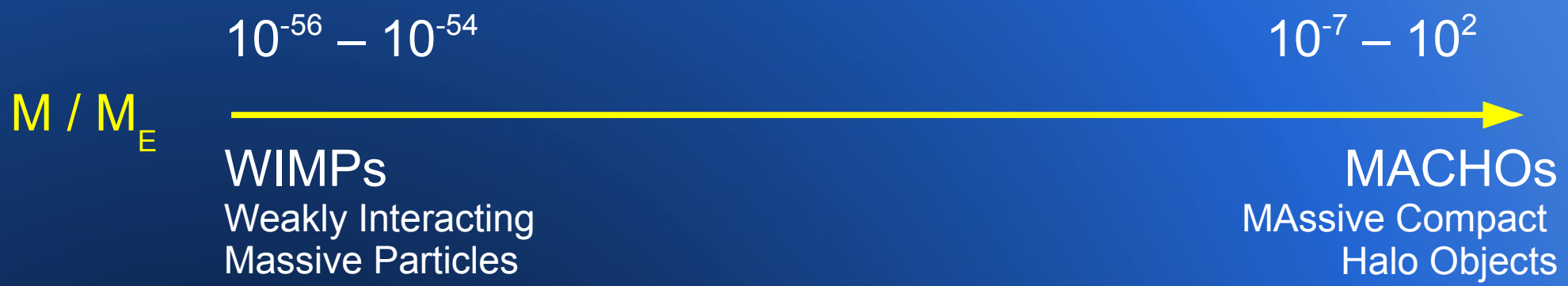
  - mass density 0.3 GeV/cm^3 = H atom every 3 cm^3
  - more spherical than disk-like
  - non-gravitational interactions must be small

- Velocity distribution



  - Models of 3-D distribution suggest a Maxwellian distribution - like a gas

Dark Matter Candidates: from WIMPs to MACHOs



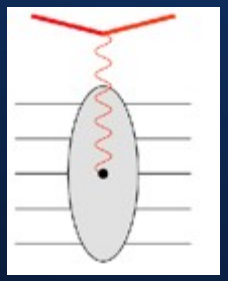
Dark Matter Candidates: from WIMPs to MACHOs

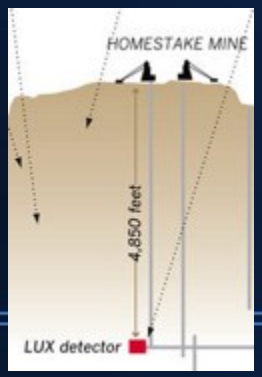
$10^{-56} – 10^{-54}$ $10^{-7} – 10^{2}$

M / M_E

WIMPs
Weakly Interacting
Massive Particles

MACHOs
MAssive Compact
Halo Objects





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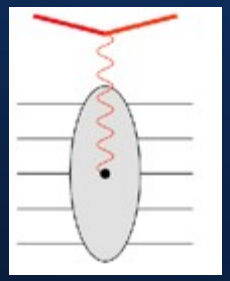

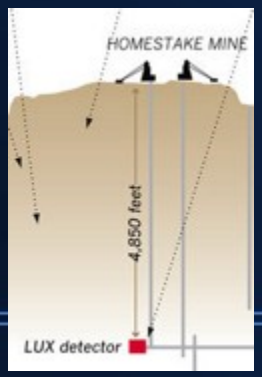

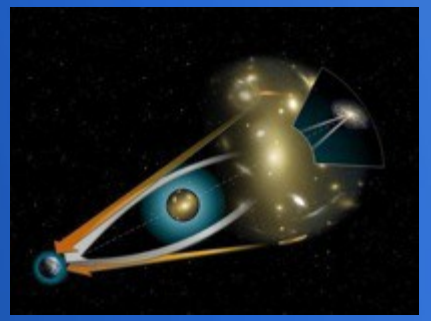

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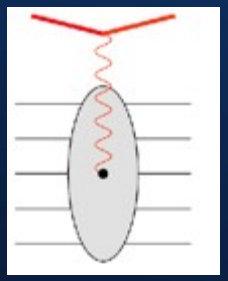

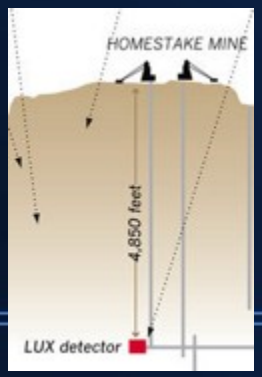

MACHOs
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Dark Matter Candidates: from WIMPs to MACHOs

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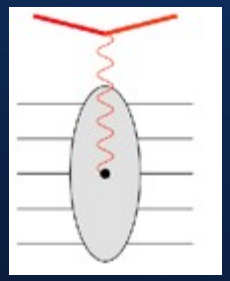

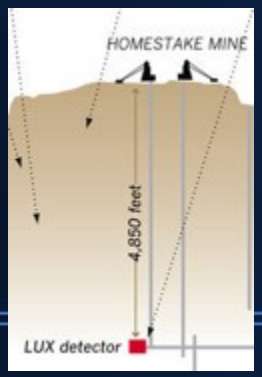

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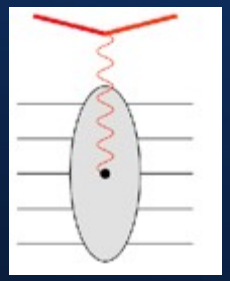
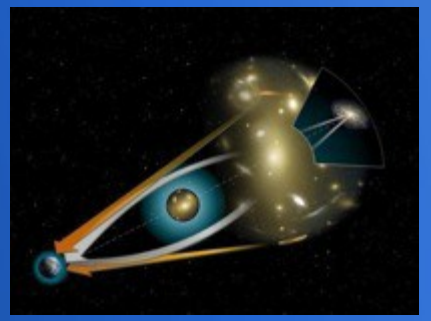
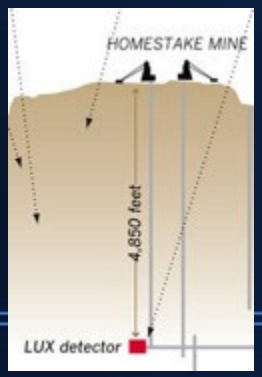




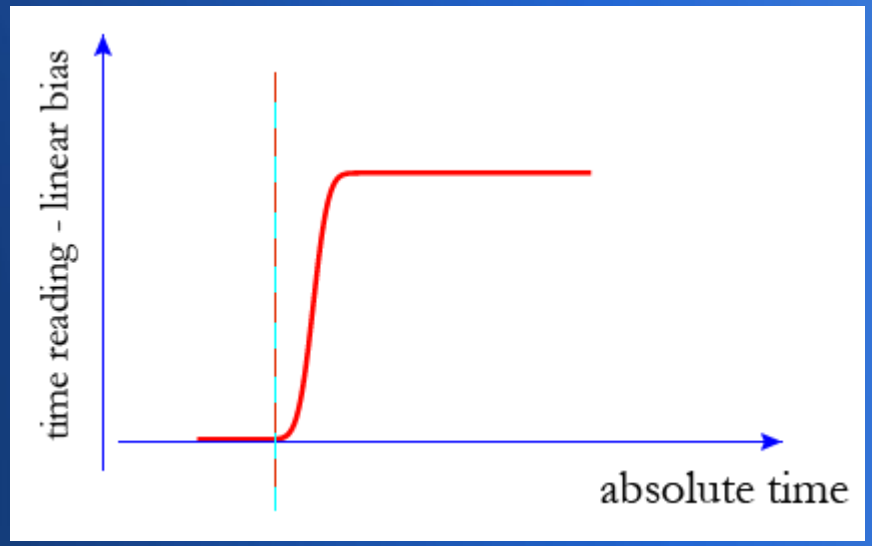


Topological Dark Matter (TDM)

- As the universe cooled, sequence of phase transitions
  - insufficient energy was available to generate heavy particle types, so such particle types would (if unstable) eventually decay away
  - leaving behind “ordinary” matter, plus perhaps WIMPS
- Cooling and topological defects
  - Consider ferromagnetism: as metal is cooled below the Curie temperature, magnetic domains spontaneously appear
- Leads to possibility of another type of dark matter
  - topological defects in a new type of light quantum field
  - monopoles, cosmic strings, domain walls,...
  - predicts modulation of fundamental constants, clock frequencies....

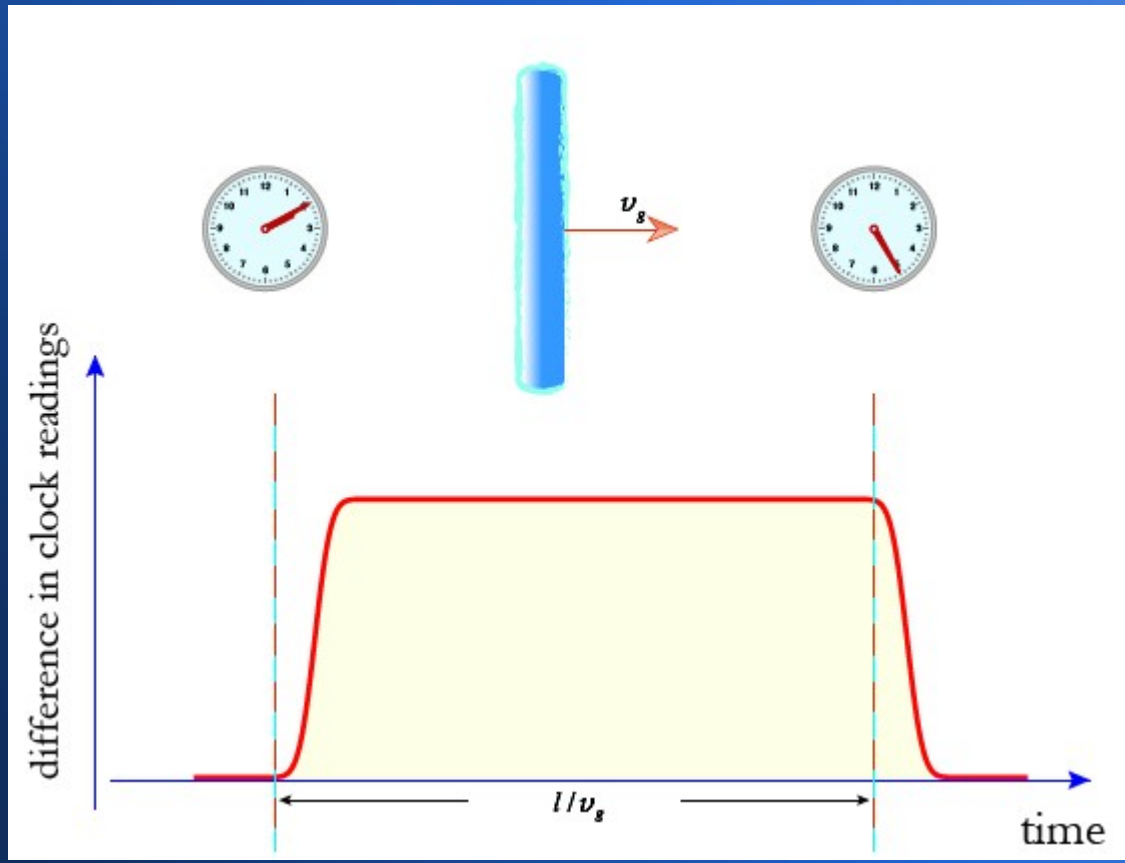
Detection by Atomic Clocks: Basic Idea

- Consider TDM as extended stable objects (e.g. domain walls)
- Passage of TDM creates transient in clock frequency
- Integral frequency = step in clock time



GPS as a Dark Matter detector: Dark Matter Signature

- Time difference between clocks separated far apart
- Integrated frequency difference = box car function
- Time width T = L/v
  - L(GPS) ~ 50,000 km
  - v ~ 300 km/s
  - T ~ 170 seconds



Data Analysis Demonstration
Using GIPSY OASIS II software from JPL

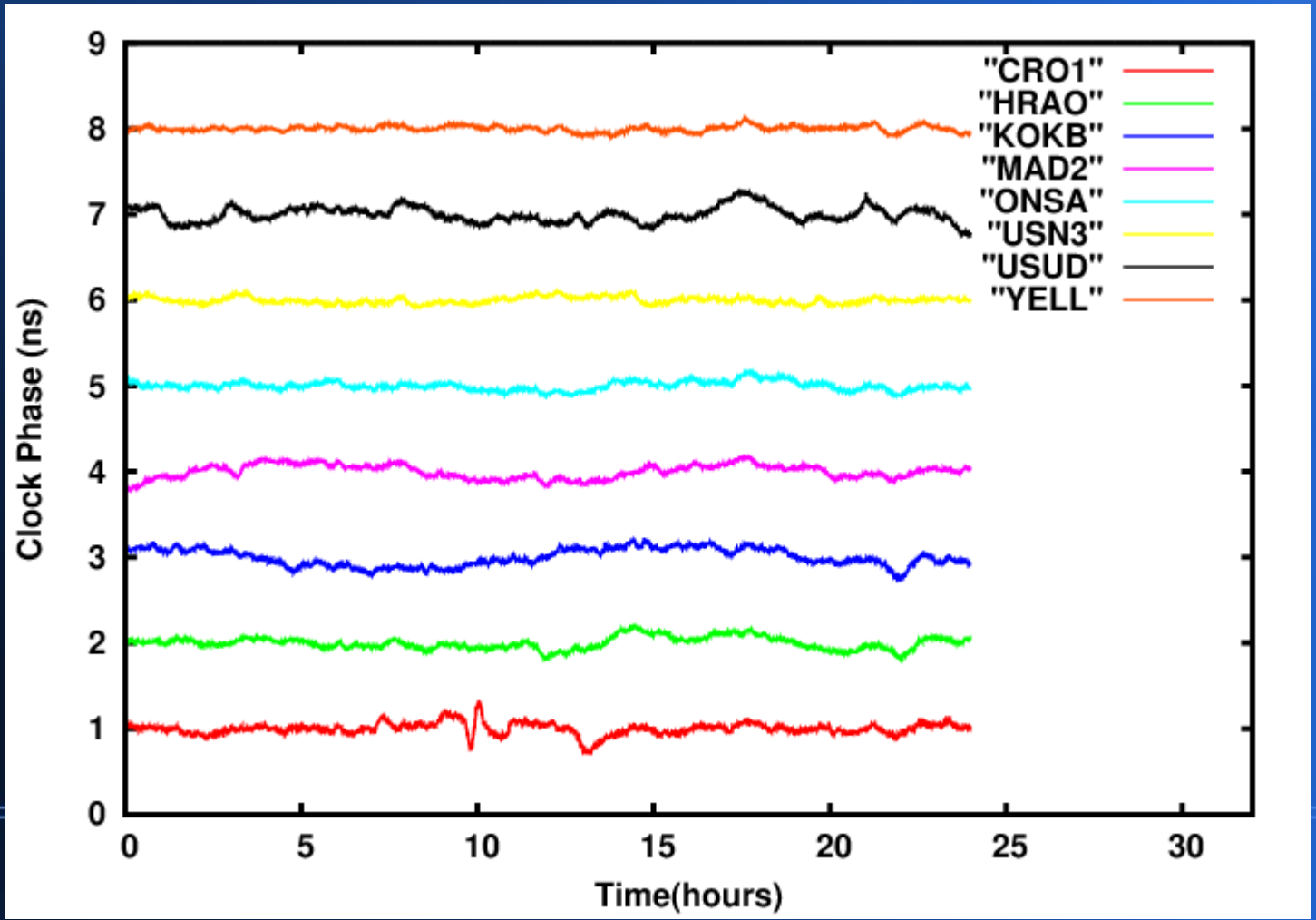
- 40 geodetic GPS stations
  - IGS-like analysis, except fix satellite orbits to published values
  - All clock biases (except reference) estimated every 30 sec

Station AMC2
reference clock

blue = H-maser
red = Rb
green = Cs
black = Quartz

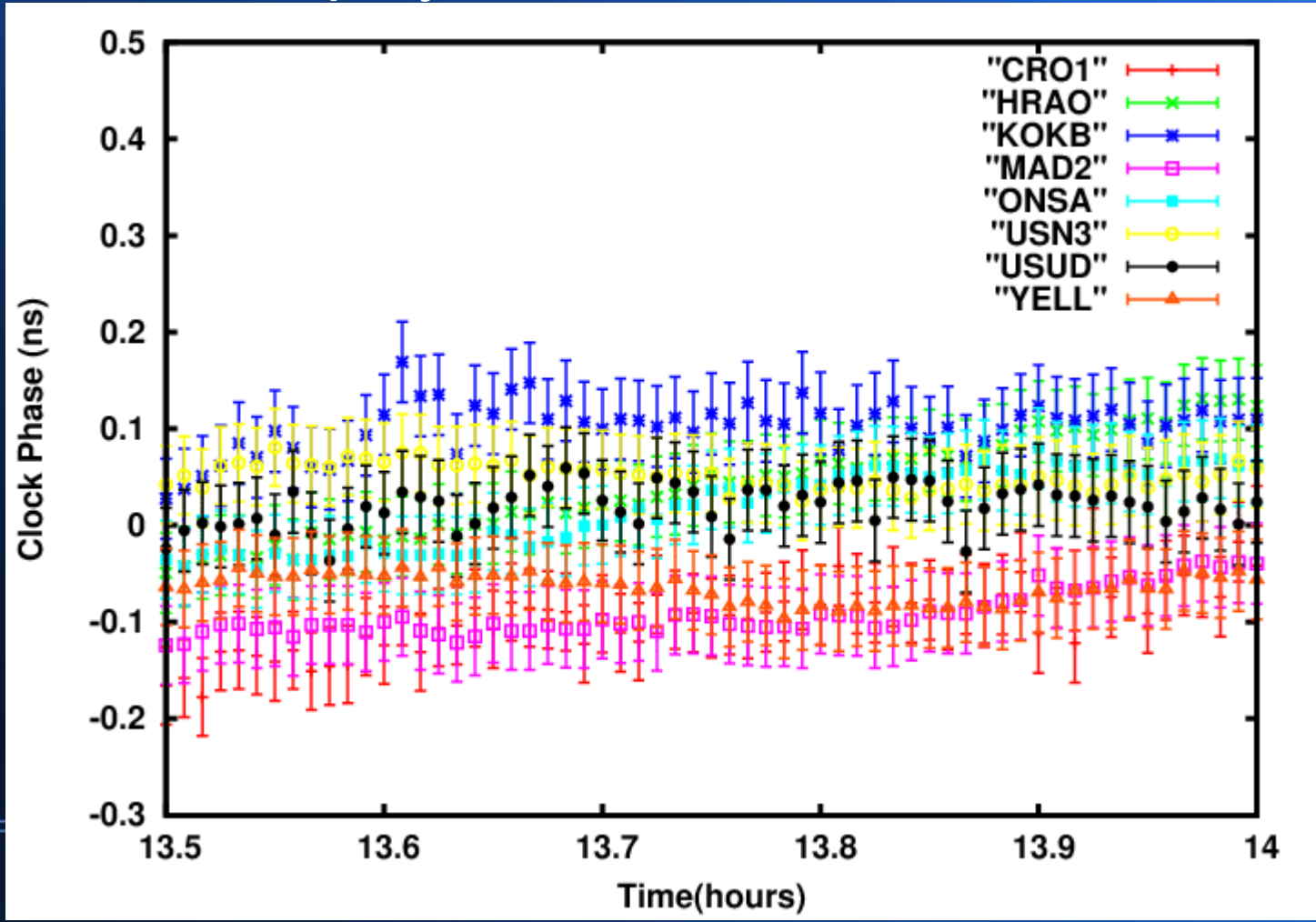
Results:
Top Performing H-Maser Stations

- 24 hours, 2nd order polynomial removed



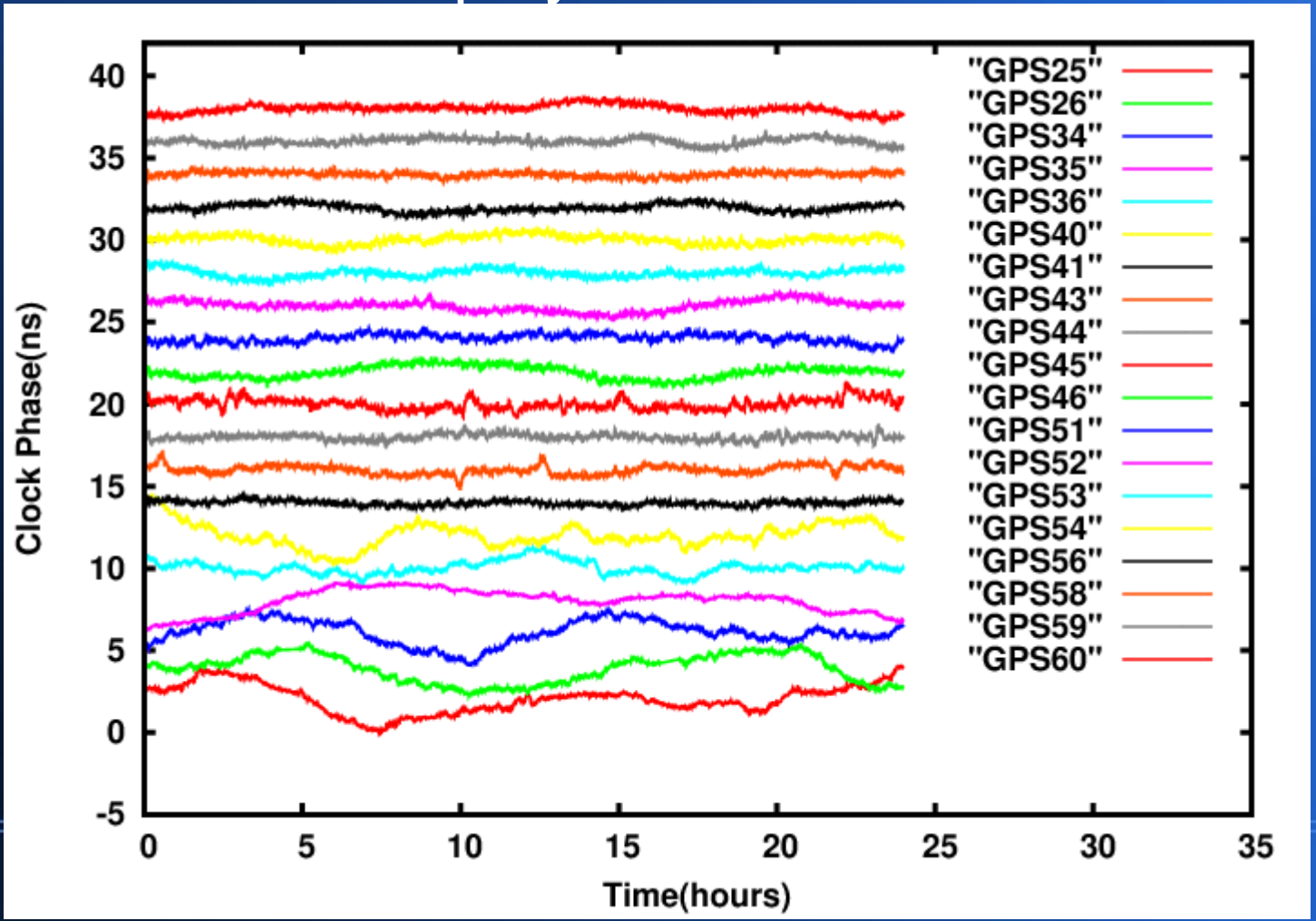
Results:
Top Performing H-Maser Stations

- 30 minutes, no polynomial removed



Results:
Satellite Rb Clocks

- 24 hour, 2nd order polynomial removed



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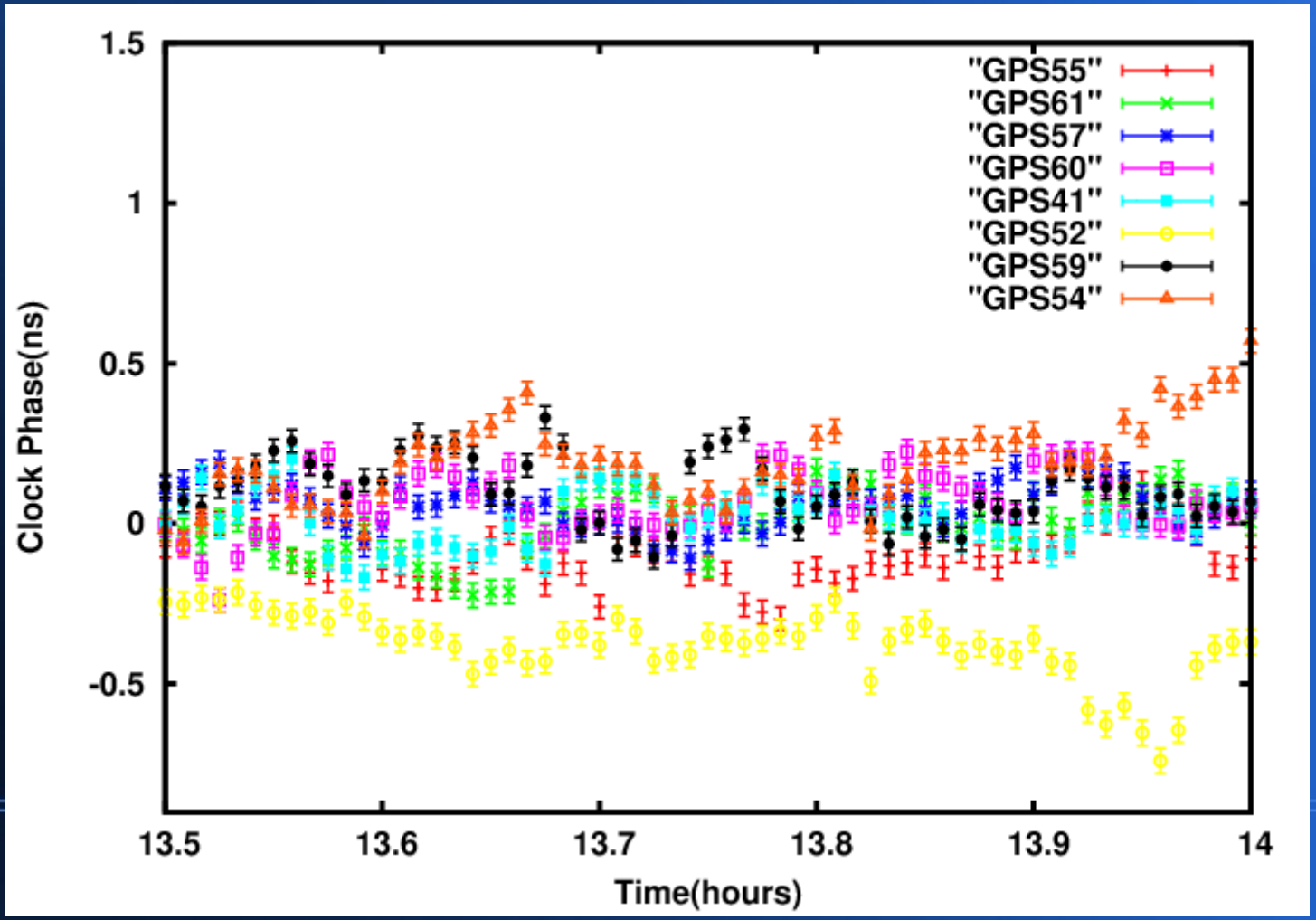
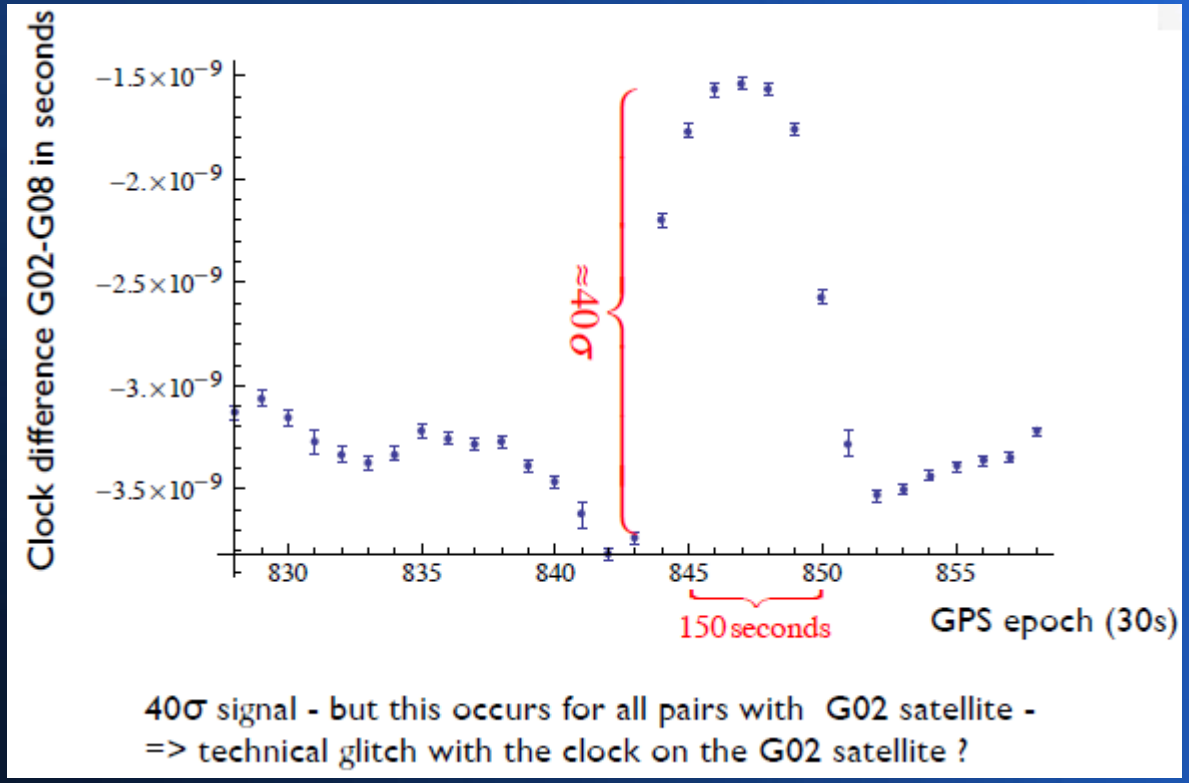


Quick Look at IGS Clock Products

- Example of interesting event on 2007-10-16



40σ signal - but this occurs for all pairs with G02 satellite -
=> technical glitch with the clock on the G02 satellite ?

Conclusions

- Atomic clocks in space and on the ground can be monitored with sub nanosecond precision
  - Best H-maser station clock estimates show ~ 0.1 ns residual scatter
  - Best Rb satellite clock estimates show ~ 1 ns residual scatter
  - Demonstrated every 30 sec, but possible every 1 sec
- GPS system may be used as a giant detector for topological dark matter (50,000 km aperture)
  - search for anomalies in clock behavior
  - search for spatially correlated patterns
  - sensitive to DM signal traversing GPS system in >100 s, i.e., velocities < 500 km/s, capturing galactic-scale velocities