2/27/15 Ken Intriligator's Phys 4D Lecture outline

• A bit of history on the speed of light. Experiments: Galileo $\sim$ 1618 using eclipses of Jupiter's moon for the clock, $c \approx \infty$; Cassini and Romer $\sim$ 1676, $c \neq \infty$!, takes light about 10 minutes to travel 1au; Huygens, light travels about 16.6 earth diameters per second; 1809 Delambre found it takes light about 8 minutes and 12 seconds to travel 1 au (actual value is about 8 minutes and 19 seconds, pretty close!); Fizeau, direct measurement on earth 1849, got actual answer to within 5%(!). Theory: Maxwell $\sim$ 1862 $c = 1/\sqrt{\mu_0\epsilon_0}$.

• Recall Doppler effect for sound: $\omega_{listener} = \omega_{source}(1 - (v_{source}/v_s))/(1 + (v_{listener}/v_s))$. Not symmetric, since sound has a preferred frame: the rest frame of the air. Relativistic Doppler effect: $\omega = \omega'\sqrt{(1+\beta)/(1-\beta)}$. Let's see why.

• $x^\mu = (ct, x, y, z)$ is an example of a 4-vector, and every 4-vector transforms the same way between Lorentz frames:

$$\begin{pmatrix} a^0 \\ a^1 \\ a^2 \\ a^3 \end{pmatrix} = \begin{pmatrix} \gamma & \beta\gamma & 0 & 0 \\ \beta\gamma & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} a^{0'} \\ a^{1'} \\ a^{2'} \\ a^{3'} \end{pmatrix}$$

Then $a \cdot b \equiv a^0 b^0 - \vec{a} \cdot \vec{b}$ is the same in both frames, i.e. Lorentz (boost) invariant.

• $k^\mu \equiv (\omega/c, \vec{k})$ is an example of a 4-vector. Nice: therefore $k \cdot x = \omega t - \vec{k} \cdot \vec{x} = \omega' t' - \vec{k}' \cdot \vec{x}'$, and this is exactly the argument of a traveling wave $\sim \cos(\vec{k} \cdot \vec{x} - \omega t)$, so all observers properly agree upon the spacetime points where the wave has its highs and lows. Also $k \cdot k = k' \cdot k'$. For a light wave, $\omega = ck$ means $k \cdot k = 0$, so all observers properly agree on that. Now use Lorentz transformation to get relation between ω and ω'.

• Fizeau was amazing! In 1851 he measured the speed of light through moving water! $u_{expected} = (c/n) + v$, $u_{observed} \approx (c/n) + v(1 - n^{-2})$ supported the "partial frame dragging" hypothesis. Derive from Lorentz transform: $u_{actual} = ((c/n) + v)(1 + v/nc)^{-1} \approx u_{observed}$.

• Next topic: energy-momentum 4-vector $p^\mu = (E/c, \vec{p})$.