

1. (7 pts) Two lights attached to a space ship moving at half the speed of light (relative to the earth) flash on momentarily. An observer on the space ship notes that the flashes occur simultaneously. What conditions must be met for the flashes to occur simultaneously according to an observer on the earth?
2. (8 pts) Jimmy Neutron is Chasing Finbar Calamitous in a rocket ship. Right as Jimmy passes Earth, Carl, a friend of Jimmy who is watching from Earth, measures the velocity of Finbar's ship as  $0.851c$  and the velocity of Jimmy's ship as  $0.899c$ . At the same moment in time Carl notes that the two ships are  $1.89 \times 10^9$  meters apart. (a) According to Carl, how long will it take for Jimmy to catch Finbar? (b) How fast is Finbar traveling as measured by Jimmy? (c) According to Jimmy, how long will it take for him to overtake Finbar from the moment that he passes Earth? (Hint: in part (c) the distance between Jimmy and Finbar depends on the reference frame — it is not the same as measured by Jimmy and Carl. And you will probably make a mistake if you try to use length contraction, because there is no frame in which both Jimmy and Finbar are stationary. Use the Lorentz transformations to transform the two space-time events — Jimmy passing Earth and Jimmy catching up with Finbar — and find the time between them.)
3. (8 pts) Jimmy Neutron is returning from a trip to the center of the galaxy, traveling at a speed of  $0.871c$  relative to the Earth. Right as Jimmy flies past the Earth he verifies that his watch is synchronize with Carl's. Carl is standing still on the surface of the Earth. In both Carl's and Jimmy's frames the Earth is at a location  $x = 0$ ,  $y = 0$ , and  $z = 0$  at time  $t' = t = 0$ . Carl sets up his coordinate system such that Jimmy is moving in the  $+x$  direction, and Jimmy sets his up such that his  $y$  and  $z$  directions are the same as Carl's and such that Carl is moving in the  $-x$  direction. After Jimmy has passed Earth, Carl observes a supernova looking through a telescope. Taking into account the time that it took for light to reach him he determines that the supernova occurred at a time  $t = -1.45 \times 10^9$  seconds at a location of  $x = 3.29 \times 10^{17}$ m,  $y = 1.53 \times 10^{17}$ m, and  $z = 1.69 \times 10^{17}$ m. (a) As measured in Carl's reference frame, how far is Jimmy from the supernova when it occurs. (b) As measured in Jimmy's reference frame, how far is Jimmy from the supernova when it occurs?
4. (7 pts) Imagine that you are on a rocket ship bound for mars. Before it launches, you measure the distance from you to mars to be  $7.8 \times 10^{10}$  m (78 million kilometers). Then, in a period of 1 nanosecond you accelerate up to a speed of  $0.995 c$  going straight toward mars. (a) How far does mars appear to be from you now? (b) About how fast did mars "appear" to be moving toward you as you accelerated? (c) Why doesn't this violate the rule that nothing can travel faster than the speed of light?

**Extra problems I recommend you work (not to be turned in)**

- A meter stick is placed at an angle of  $20^\circ$  from the  $x$  axis. A rocket flies by at a speed of  $0.9c$  in the  $+x$  direction. How long, and at what angle to the  $x$  axis will the meter stick be as measured by someone in the rocket ship?
- If you were traveling in a rocket at  $0.9c$  relative to the Earth, what would you see if you held up a mirror in front of your face?
- You run a red light. You are pulled over. You explain to the traffic officer that you didn't know that the light was red — because you were moving the red light (at  $660$  nm) was Doppler shifted to appear green (at  $520$  nm). How fast were you going?