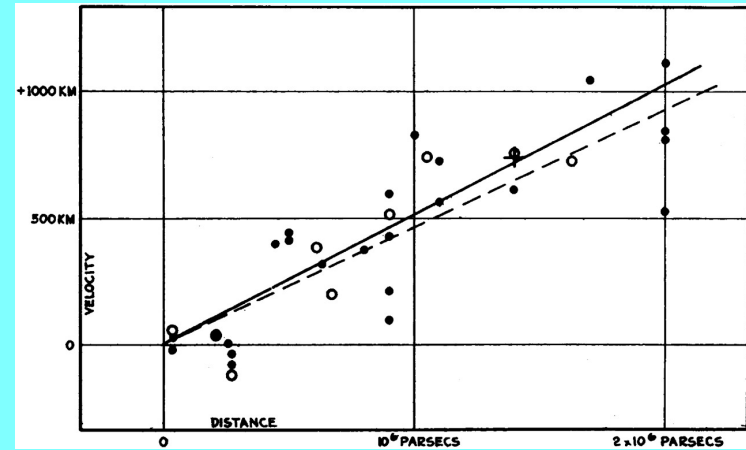


8.286 Lecture 3  
September 12, 2018

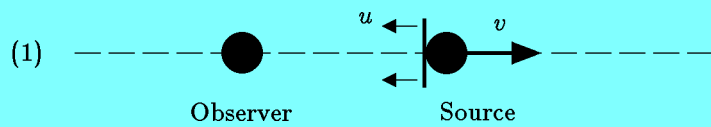
# THE DOPPLER EFFECT and SPECIAL RELATIVITY

## Hubble's Original 1929 Graph

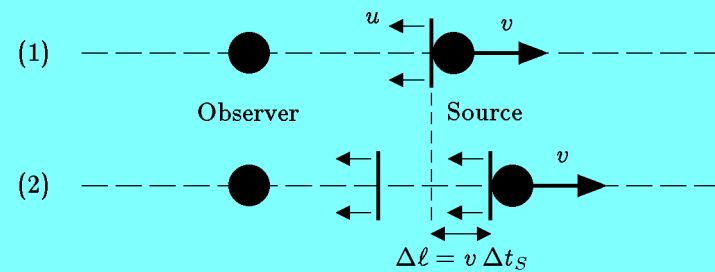


Mit Alan Guth  
Massachusetts Institute of Technology  
8.286 Lecture 3, September 12, 2018

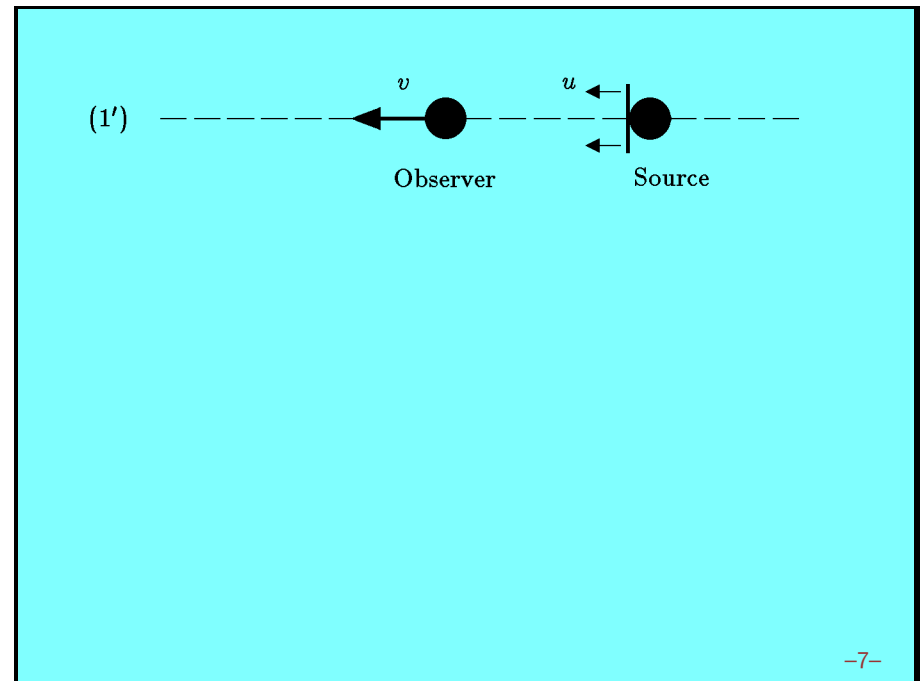
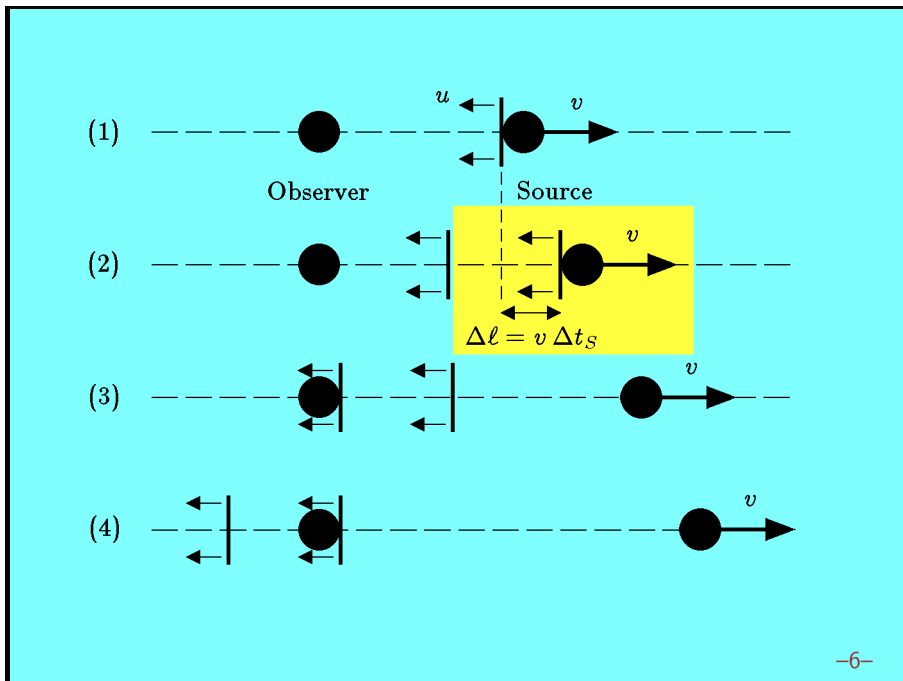
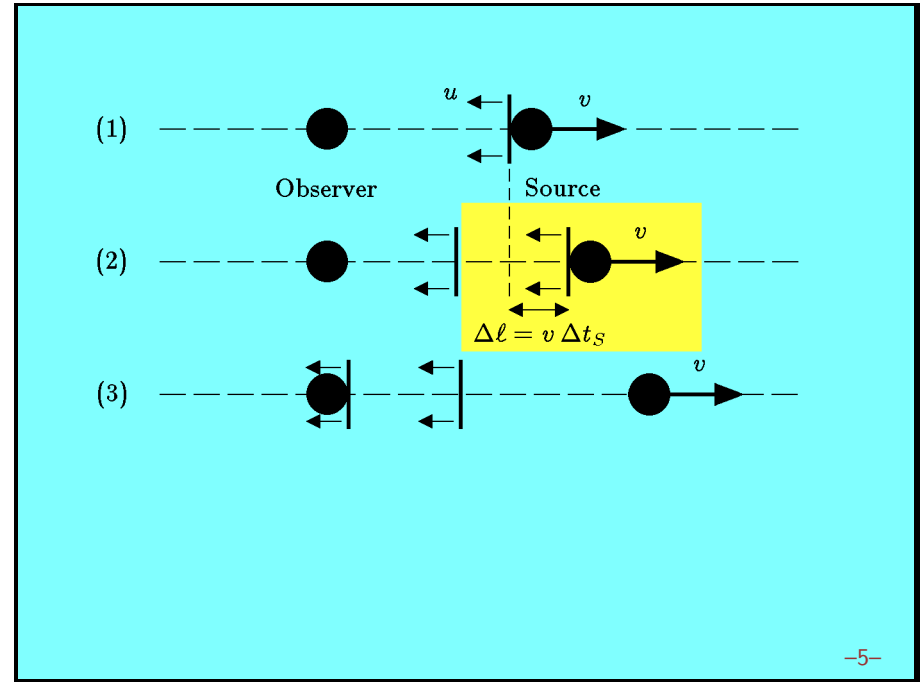
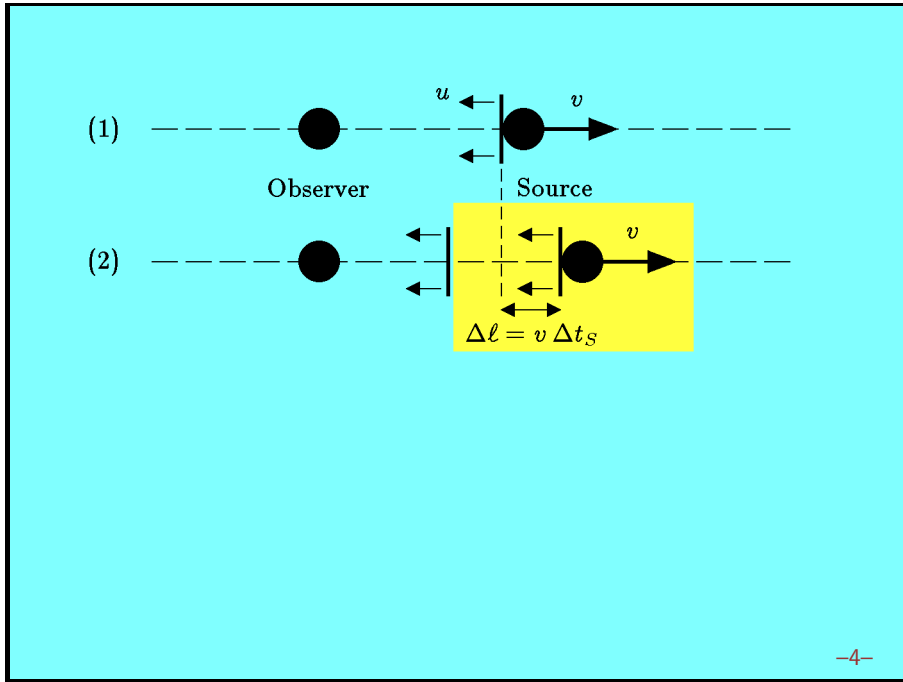
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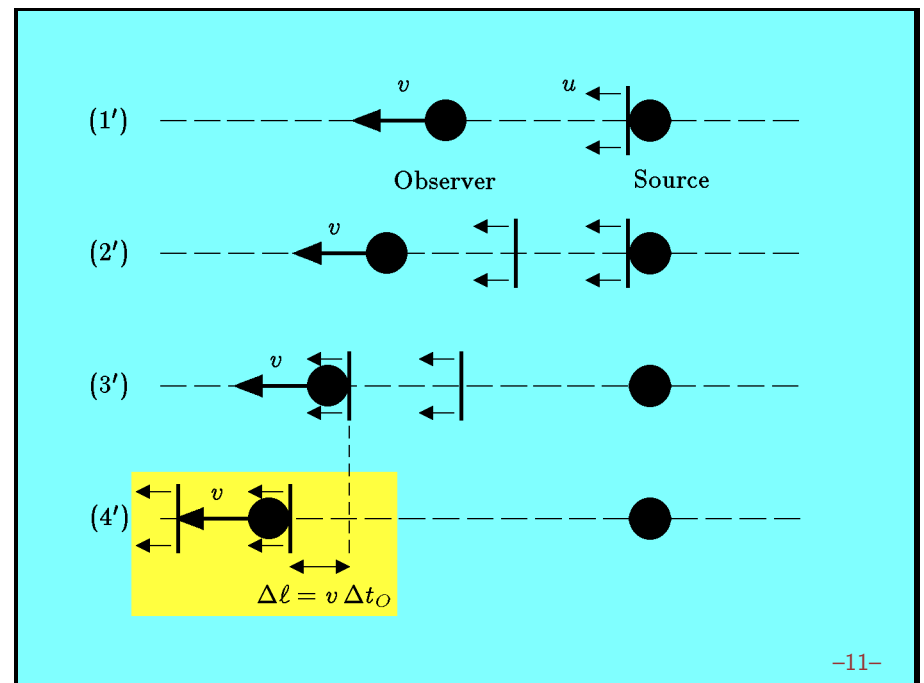
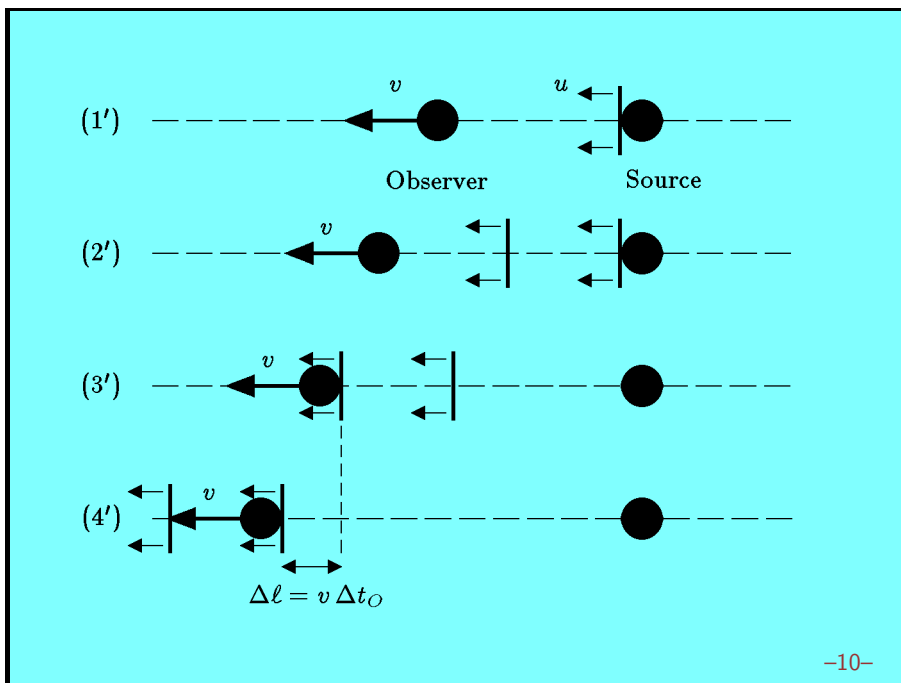
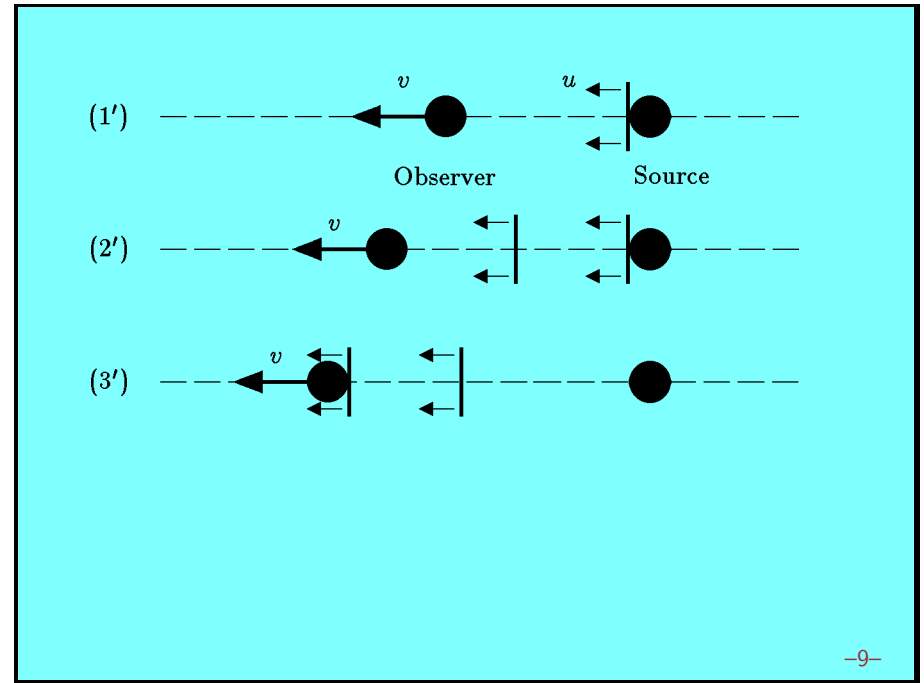
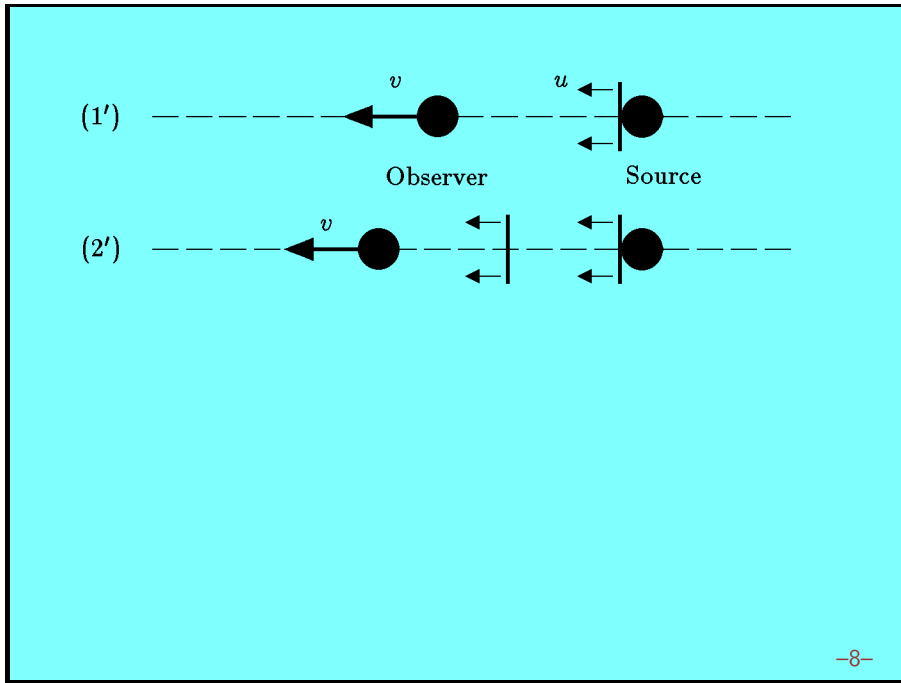


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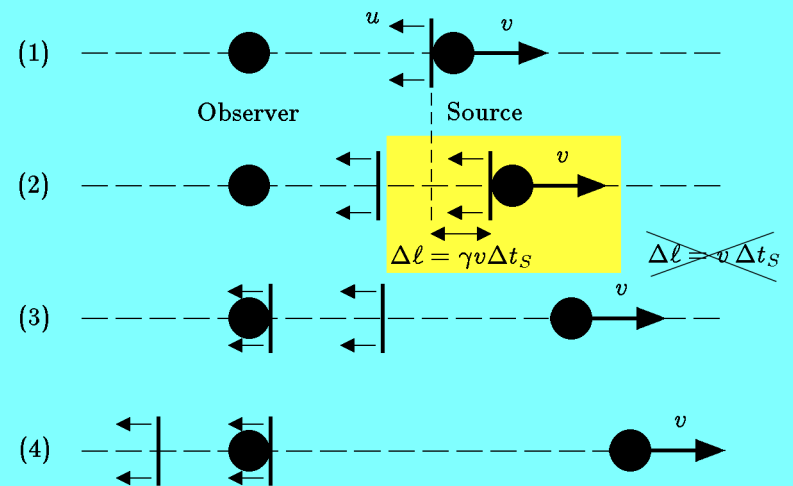
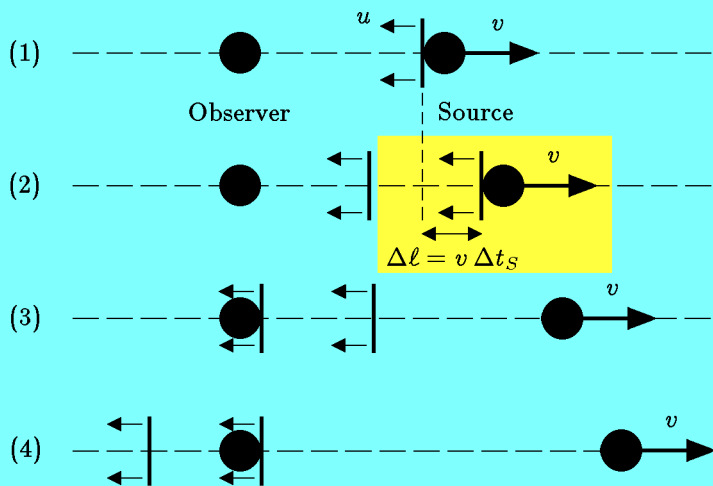
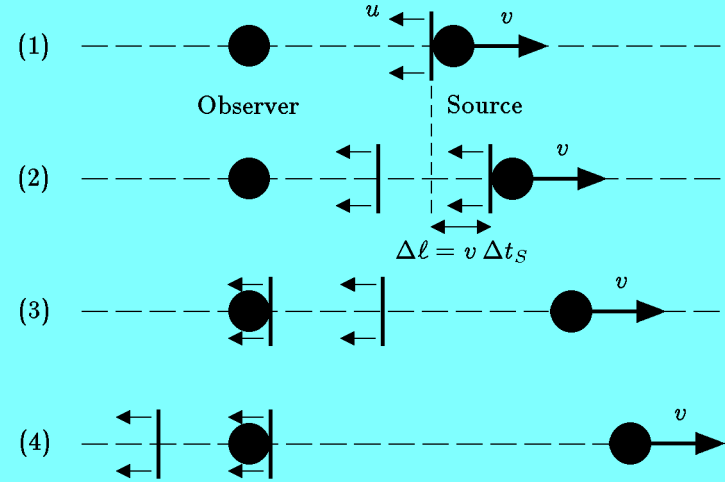
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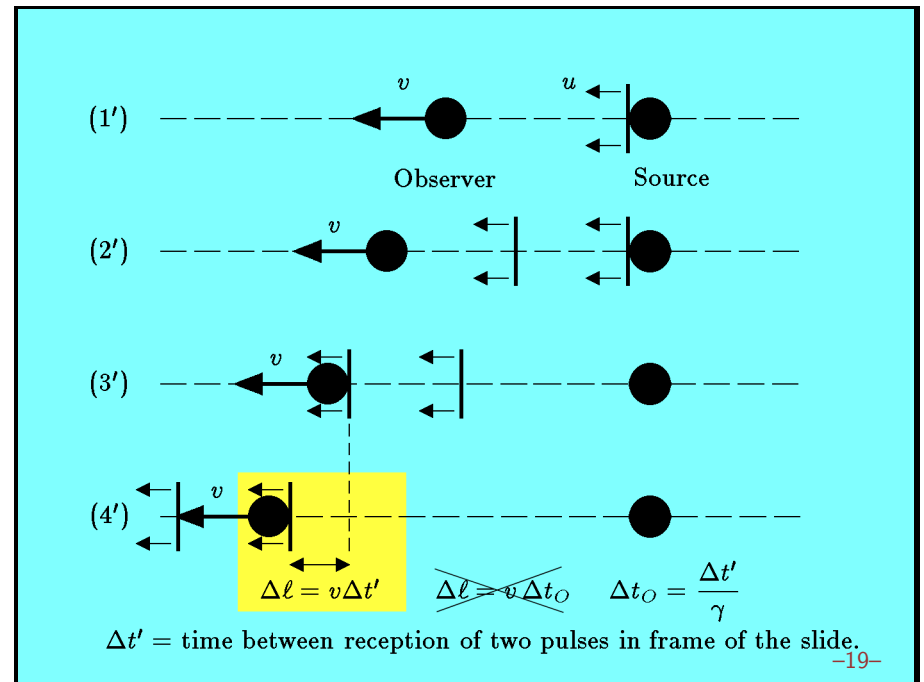
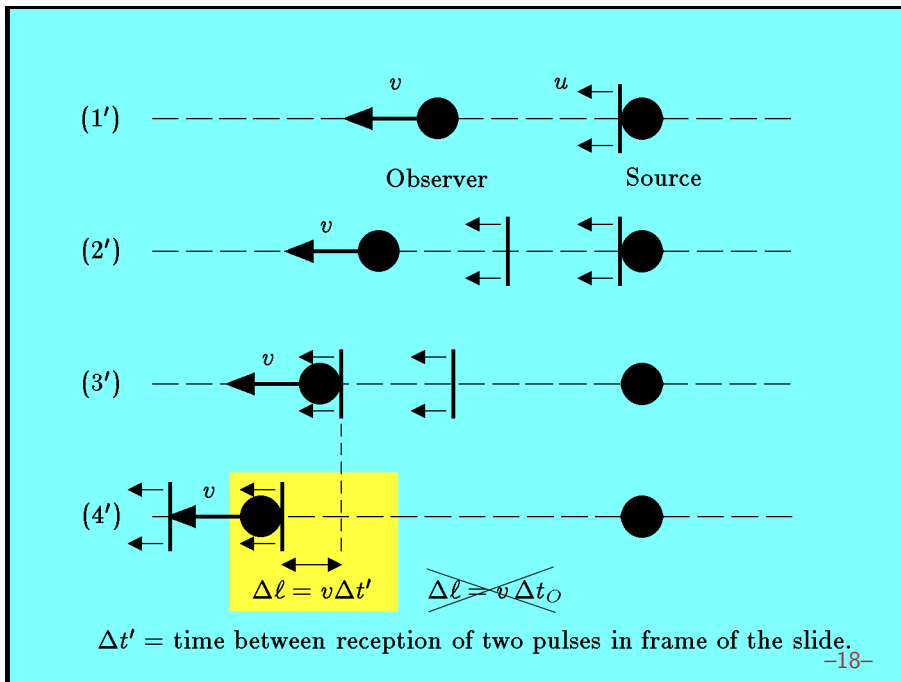
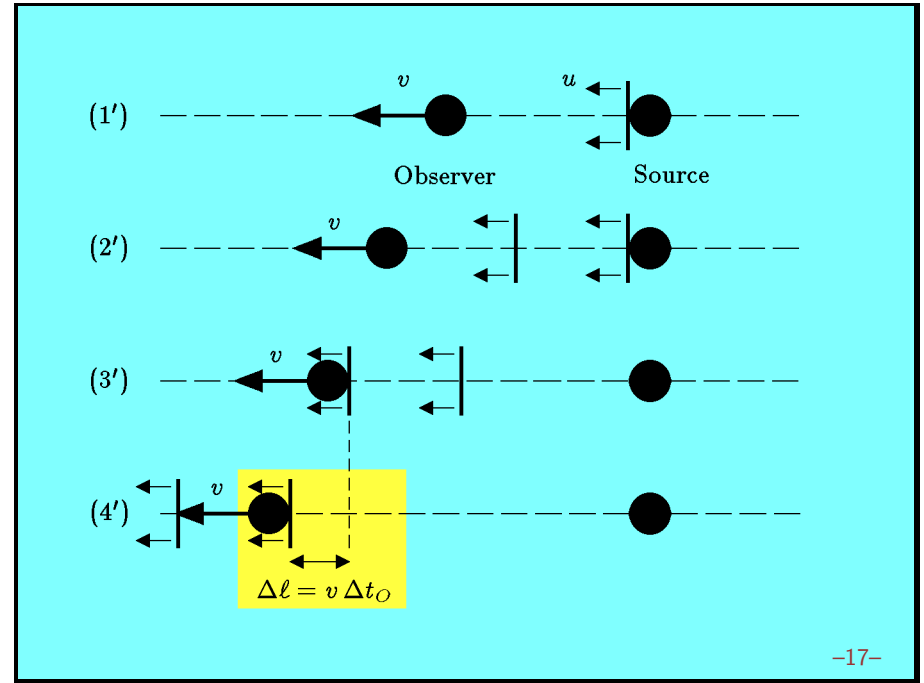
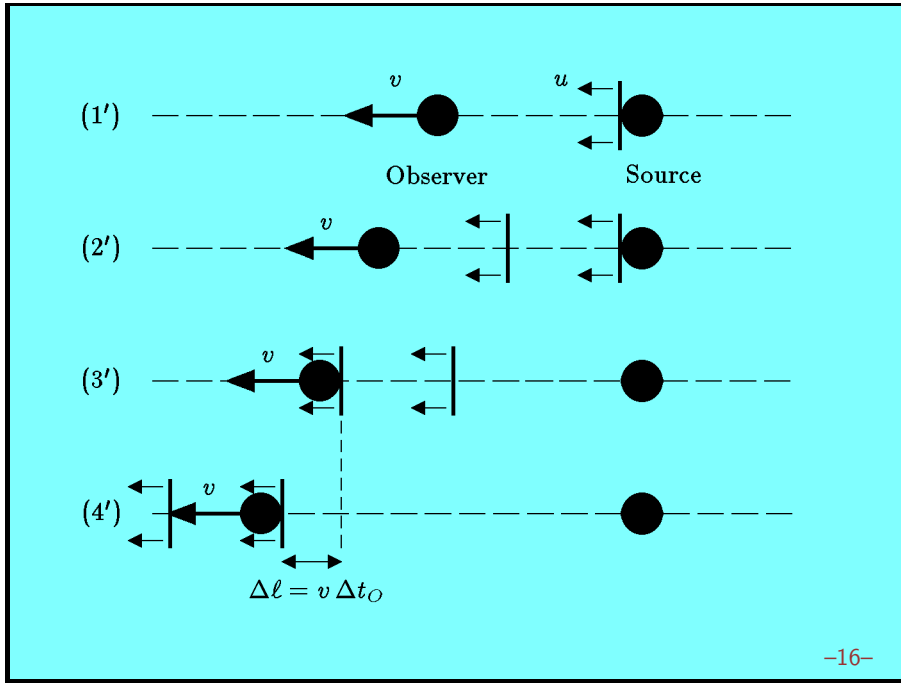




(1) TIME DILATION: Any clock which is moving at speed  $v$  relative to a given reference frame will “appear” (to an observer using that reference frame) to run slower than normal by a factor denoted by the Greek letter  $\gamma$  (gamma), and given by

$$\gamma \equiv \frac{1}{\sqrt{1 - \beta^2}}, \quad \beta \equiv v/c. \quad (1.10)$$



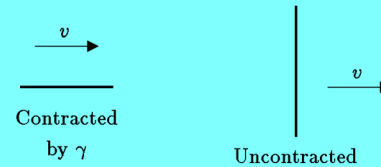


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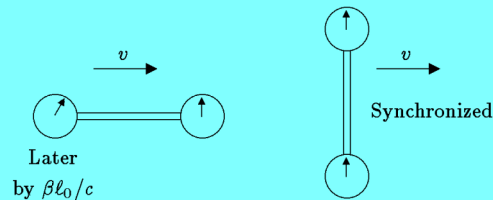
-20-

(2) **LORENTZ-FITZGERALD CONTRACTION:** Any rod which is moving at a speed  $v$  along its length relative to a given reference frame will “appear” (to an observer using that reference frame) to be shorter than its normal length by the same factor  $\gamma$ . A rod which is moving perpendicular to its length does not undergo a change in apparent length.



-21-

(3) **RELATIVITY OF SIMULTANEITY:** Suppose a rod which has rest length  $\ell_0$  is equipped with a clock at each end. The clocks can be synchronized in the rest frame of the system by using light pulses. (That is, a light pulse can be sent out from the center, and the clocks at both ends can be started when they receive the pulses.) If the system moves at speed  $v$  along its length, then the trailing clock will “appear” to read a time which is later than the leading clock by an amount  $\beta\ell_0/c$ . If, on the other hand, the system moves perpendicular to its length, then the synchronization of the clocks is not disturbed.



-22-