Special Relativity (SR), It is NOT that hard.

The book makes these ideas seem harder than they actually are.

Keep in mind that SR simply tells us how the world really is. Its effects become obvious only at high velocities but have been measured a much slower speeds.

So take the principle of relativity (which does make sense) and the constant speed of light as simply the way the universe behaves and consider the derived equations based on them as the tools for making predictions.

Remember these ideas are true only for uniform motion–no acceleration. That is all there is to it.

Spacetime

Spacetime is one of the ideas that drops out of SR.

The spacetime interval (distance) is

\[ d = \sqrt{x^2 + y^2 + z^2 - c^2 t^2} \]

It is a constant for all observers.

Spacetime forms an underlying structure in the Universe which becomes obvious in general relativity (GR).

The factor named gamma is the transformation factor in SR. It is shown below.

\[ \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \]

We use gamma to calculate the differences in time mass and length we measure due to relative motion. Thus for time we have we have

\[ t_{\text{moving}} = t_{\text{rest}} \frac{1}{\gamma} \]

And for mass we have

\[ m_{\text{moving}} = m_{\text{rest}} \times \gamma = m_0 \gamma \]

The consequences of SR

1. Time dilation–moving clocks run slow
2. Length contraction–moving objects appear shorter in length
3. Mass increase–moving masses grow larger (in mass not size)
4. Mass is another form of stored energy
5. Only spacetime and c are absolute

Evidence

1. Subatomic particle lifetimes are longer at speeds close to that of light in exact agreement with relativity predictions.
2. Particle masses at speeds close to that of light are greater in exact agreement with relativity predictions.
3. Clocks in airplanes and GPS satellites run slower than stationary ones in exact agreement with relativity predictions.
4. Nuclear power is possible because \( E = mc^2 \) is true
5. Orbiting binary stars as described in the textbook are consistent with the predictions of relativity.
6. There is much, much more.
Astrophysical Consequences of Special Relativity

1. \( E = mc^2 \) predicts the source of nuclear energy-nuclear fission in reactors as well as nuclear fusion in stars and bombs.
2. Our cell phone and GPS satellites must take special relativity (and general relativity) into account in order to work properly.

General Relativity (GR)

This theory is based on the Equivalence Principle that says:

The effects of gravity are exactly equivalent to the effects of acceleration.

This idea and some serious mathematics give us GR.

GR makes these predictions:

1. The major axis of Mercury's orbit should rotate in space at a faster rate than Newton predicted.
2. Mass bends the path of light traveling near it. (gravitational lensing)
3. Time passes slower in a gravitational field. The stronger the gravity, the more slowly time passes. (gravitational red shift)
4. Black holes can exist in spacetime and the interiors are not part of the observable universe. (supernova, x-ray binaries, quasars)
5. Large masses that undergo rapid changes in motion (acceleration) or structure emit gravitational waves that travel at the speed of light. (merging black holes pairs have been seen)

Quantum Mechanics (QM)

If you like weird, then QM has plenty for you.

You can't understand astronomy in the 21st century without QM.

The idea that lead physics into QM is that everything comes is discreet minimum packages, such as the photon that is a package of light.

The main ideas of QM:

1. Matter and radiant energy have a duel nature-both particle and wave.
2. The uncertainty principle specifies a limit on how well we can know both the position and velocity of a particle. Simply "we can’t know both where a particle is and at the same time know where it is going."
3. Two particles (unless then are bosons) cannot occupy the same space. In serious physics language it is stated as "Two fermions of the same type cannot occupy the same quantum state at the same time."
4. The Schrödinger wave equation accurately predicts the probability of finding the location of a particle under study.

QM in Astronomy. These are some key concepts that depend on QM.

1. Spectral lines & Planck curves come straight from QM
2. Degeneracy pressure supports massive planets and weird star from collapsing. (both electron degeneracy pressure and neutron degeneracy pressure)
3. Quantum tunneling is possible. (makes fusion energy possible)
4. Virtual particles exist and are real. (vacuum energy, quantum foam)
5. Black holes have a temperature radiate energy. (Hawking radiation)