Outline for Proposed Freshman Science Course

From the Big Bang to the Present

The Concordance Model of the Universe

1. The Big Bang
    - Bacon's Principal of Universality: The laws of the universe are the same everywhere, everytime. (Occam's Razor)
    - Cast of characters: fermions - the stuff of which the universe is made; bosons - the stuff that produces forces.
    - Forces
    - Energy: mc^2, kT, $\hbar\omega$
    - Particle creation and annihilation
2. The First Three Minutes
    - How to read graphs.
    - Volume, radius as a function of time.
    - Introduce Pressure. Pressure as a function of time.
    - Introduce Temperature. Temperature as a function of time.
    - Pressure-temperature-volume relation.
    - Freezing out of higher energy particles, one by one.
    - Quarks $\rightarrow$ hadrons.
    - Nuclear reactions I. Production of the light nuclei and comparison with observations. Neutron decay.
3. The Next 300,000 Years
    - Nothing happens while the universe continues to expand and cool.
    - The equilibrium $p^+ + e^- \leftrightarrow H \leftrightarrow \frac{1}{2}H_2$ and how it depends of P, T, and the environment.
    - Decoupling of radiation.
    - The 2000K background.
    - COBE

- Motion of the earth through the Universe

4. Dark Ages, Renaissance, Enlightenment

   - How atomic hydrogen absorbes any radiation emitted by the first radiating objects.
   - As gas condenses to form stars, a renaissance begins, with a new source of energy coming into play.
   - Radiation from the stars starts to sweep gas out regions around the stars.
   - As these empty regions begin to overlap photons begin to travel longer and longer distances before being absorbed.
   - Finally, when most of the intergalactic gas is swpted into denser regions of space, light can travel enormous distances.

5. Galaxies and Globular Clusters

   - First unit of condensation - galaxies.
   - Groups of galaxies. "The Finger of God"
   - Globular Clusters.
   - Types of galaxies.
   - Organization of galaxies and their clusters.
   - Dynamics of a cluster.
   - Passage through a flat disk and star formation.
   - Spiral's arms and the stuff that goes on there: star formation.
   - Interstellar/intergalactic gas/molecules.

6. Nucleosynthesis

   - Simple nuclear reactions: strong force, weak force.
   - Proton - neutron conversion, neutrinos.
   - Alpha decay.
   - Chart of the nuclides.
   - The CNO cycle in the sun.
   - Structure of the sun.
   - Hydrogen burning regions, energy production, mass conversion and rate of mass conversion.
   - Mass loss by energy radiation, mass gain by absorption of protoplanetary stuff (estimate).

7. The Life of a Star

    - Too small a mass: brown dwarfs.
    - Evolution dependence on mass.
    - Nuclear burning, concentric shell burning models.
    - Endpoint of stellar evolution. Small mass (Sun).
    - Supernova, element production - where the heavies come from.
    - Gloss on BBFH.
    - End points of stellar evolution:
        - white dwarfs (quantum mechanics - electron degeneracy),
        - neutron stars (quantum mechanics - neutron degeneracy),
        - black holes.
    - Starquakes.

8. Black Holes

    - What they are - and are not (tunnels to the future).
    - Sizes of black holes: 6 size scales.
    - What you see if you fall into one.
    - Are there black holes? Experimental "observation" of black holes.
    - Tidal forces.
    - Accretion disks. Beamed radiation. More experimental stuff.

9. Stellar Accretion Disks - Solar Accretion Disks

    - Physical geometry.
    - Temperature - density profile.
    - Input element profile.
    - Changes in element profile due to temperature/pressure variations.
    - Chemical reactions and chemical profile.
    - Condensation.
    - Planet formation.
    - Composition of the planets as a function of distance from the sun.

10. Inner Planets

    - Chemical composition of Mercury, Venus, Earth, Mars, Proto-asteroid belt.

- Heat due to gravitational contraction, chemical reaction, bombardment.
- Fractionation.
- Estimates of chemical profile of inner planets.
- Iron currents in Earth core - source of magnetic fields,
- Oscillations of magnetic fields (experimental evidence).
- Current magnetic field variations

11. Outer Planets

    - Chemical composition of Jupiter, Saturn, Uranus, Neptune, Pluto.
    - Giant gas balls.
    - Structure of the gas giants
    - Planetary mysteries -satellites of Jupiter, rings of Jupiter, Saturn, Uranus.
    - Io and volcanism.
    - Asteroids and the Oort cloud.

12. ExtraSolar Planets

    - What does the spectrum look like?
    - How do we find them?
    - How can we know all this stuff?
    - Which ones might be habitable?
    - What are the parent stars like?
    - How do we look for life on these planets?

13. Our Sun

    - The interior
    - Nuclear reactions
    - Turbulence and diffusion
    - Looking into the interior of the sun
    - Solar surface
    - Magnetic fields
    - Corona and its mysteries
    - Solar storms and their economic impact
    - Solar wind

- Past and future of the sun

The Concordance Model of the Earth

1. History and Evolution of the Earth
    - Motion of the solar system in the galaxy
    - Motion of Earth around sun, Moon around Earth.
    - Early history; formation and bombardment.
    - Formation of the moon. Evidence.
    - Fractionation.
    - Motion of the core. Core instability.
    - Swirling hot stuff leads to motion of the skin.
    - Plate tectonics. Ring of fire.
    - Creation and annihilation of crust.
    - Offsetting fractures.
    - Collision of plate boundaries.
    - Subduction and mountain formation.
    - Volcanism.
    - Change of the earth's atmosphere.
2. Evidence of Earth History
    - Great land mass movement.
    - Formation of Atlantic and Pacific from earlier oceans and land masses.
    - Magnetic field reversals.
    - Asteroid impact and the probability of impact today.
    - The great extinctions - asteroids, geologically, pathogenically induced?
    - Alternation of cold and warm epochs.
    - Initiation of Ice-Age regime - Evidence.
    - Milankovich cycles
    - Climate and its evolution: water and air currents, how affected b y plate tectonics
3. Energy

- Where does it come from - where does it go?
- Solar
- Nuclear
- Tidal (gravitational)
- Geothermal
- Water cycle (graviational)
- Chemical
  - Coal
  - Oil
  - Gas
  - Bio (wood, ...)

4. Formation of the Atmosphere

   - Origin of atmospheres
     - Mercury
     - Venus
     - Earth
     - Mars
   - Evolution of atmospheres on Venus, Earth, Mars
   - Water and its multiple interactions. Water cycles
   - Introduction of oxygen
   - Ozone
   - Greenhouse gases
   - Effects of volcanic activity
   - Albedo and its variation

The Concordance Model of Life

1. Life

   - What is life?
   - Chemical elements in living organisms
   - Inorganic/organic molecules
   - Isomerism

- Functional groups
- Primitive environment
- How did life form? Miller experiment; Prebiotic soup, ...
- Limits to synthesis
- Problems: of polymerization; energy flow
- Tests of current hypotheses

2. Biological Ages of the Earth

   - Precambrian
   - Cambrian
   - Silurian
   - Devonian
   - Carboniferous
   - Permian
   - Triassic
   - Jurassic
   - Cretacious
   - Tertiary

3. Precambrian Life

   - Earliest traces

4. Evolution of the Biosphere

   - What the fossiles tell us
   - Bones and skin
   - Diversity and disparity
   - Permissivity and decimation
   - Contingency and convergence
   - Unity and diversity
   - Cambrian explosion

5. Theory of Evolution

   - Mechanisms: genetic code, genetic variability
   - Mistakes and mutations

- Adaptations: adaptive strategies, natural selection
- Extinction of species.
- Evolutionary niches
- Coevolution
- Genetic distance between species
- RNA, DNA

6. Living Species

   - Viruses, bacteria, plant and animal kingdoms
   - Conquest of various niches: sea, land, air
   - Development of sexuality - advantanges and disadvantages
   - Biosphere crises - causes of extinctions
   - Cellular organization of higher animals
   - Organs and their functions
   - Evolution of the mammalian tree

7. History and Evolution of Mankind

   - Source of origins
   - Dispersion throughout world
   - Pre historic evidence
   - Neanderthals, Homo sapiens
   - Hunters/gatherers/farmers
   - Settlements worldwide
   - Evidence of language
   - "Genetic" analysis of language

8. Genetics: The Chemistry of Life - Central Dogma

   - DNA: Information bank. Replication of DNA
   - Transcription: DNA $\rightarrow$ RNA, enzymes
   - RNA carries coded information to ribosomes
   - Ribosomes: read instructions for protein synthesis through translation process
   - Proteins: involved in all biological processes
   - No feedback - Proteins $\rightarrow$ RNA $\rightarrow$ DNA

The Cell

1. Structure and Function
    - Surface: Membranes and Lipids
    - Vesicles
    - Lysosomes
    - Endoplasmic reticulum
    - Golgi apparatus
    - Mitochondria
    - Chloroplasts
    - Ribosomes - synthesis of proteins
    - Nucleus
2. Functions of the Nucleus
    - Genetic information - transcription and editing
    - DNA replication and repair
    - Genetic rearrangements - recombination
    - Mitosis and meiosis
3. Chemistry of the Cell
    - Carbohydrates: saccharides
    - Proteins: amino acids, peptides
    - Lipids
    - Nucleic acids
    - Enzymes
    - Energy producers
    - Energy transporters
    - Stem cells
    - Differentiation and specialization
4. Energy
    - Sources
    - Flow
    - Work
    - Electron transfer

- Biosynthesis
- Information

5. Signalling Pathways

    - Nerves
    - Synapses and signals
    - Synaptic integration and memory
    - Types of nereves
    - Sensory neurons
    - The Brain

Evolution

1. History and Evolution of Life

    - Statistics and Sexual reproduction
    - Genes and chromosomes
    - Expression of genes
    - Communication among cells
    - Single cell → many cells → organs → organism
    - Patterns of early development
    - determination, differentiation, pattern formation, development

2. Immune System

    - Innate
    - Acquired
    - Limitations of the immune system
    - Attacks on the immune system

3. Energy

    - Sources
    - How energy is transported
    - How energy is used
    - ATP: glycolysis, respiration
    - Transformation of light into energy
    - Photosynthesis

4. Populations

   - Structure of populations
   - Growth of populations
   - Age profiles
   - Limits of population growth
   - Interacting populations
   - Balanced populations
   - Cyclic variations in populations
   - Energy flow in ecosystems
   - Nutrients in ecosystems
   - Human populations growth
   - diseases, catastrophes

Sources

André Brahic, Michel Hoffert, André Schaaf, Marc Tardy,
Sciences de la Terre et de L'universe,
Paris: Vuibert, 1998.

For Physics - many books and papers in my personal collection

Karl F. Kuhn and Theo Koupelis,
In Quest of the Universe,
Boston: Jones and Bartlett, 2003

For Chemistry - many books in my personal collection

For Biology:
Sidney Liebes, Elisabet Sahtouris, Brian Swimme,
A Walk Through Time. From Stardust to Us: The Evolution of Life on Earth