Discovery and *Surprise* from Entry Probes to *Giant Planets*

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2014 June 14

11th International Planetary Probes Workshop Short Course
Pasadena, CA, USA

Organization

- Giant planets of our solar system
- The *Galileo Probe* – the only entry probe mission (so far) to a giant planet
  - The mission
  - Expectations
  - Results
- Other giant planets
  - What science is important?
- A winding career path

Bulk Characteristics of the Giant Planets

Characteristic / Planet	Mass (Earth masses)	Equatorial radius (km)	Mean mass density (gm/cm^3)
Jupiter	317	71490	1.32
Saturn	95	60330	0.68
Uranus	14.5	25500	1.27
Neptune	17.1	24770	1.64

Bulk Characteristics of the Giant Planets

Characteristic / Planet	Atmospheric Helium Abundance	Icy Element Abundance (x Solar)	Tropopause Temperature (K)
Jupiter	11-12%	3-6	110
Saturn	13±5%	5-10?	90
Uranus	18%?	20-50?	50
Neptune	18%?	20-50?	50

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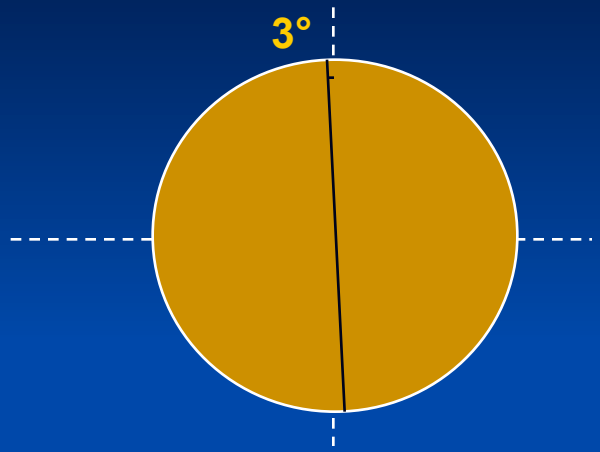
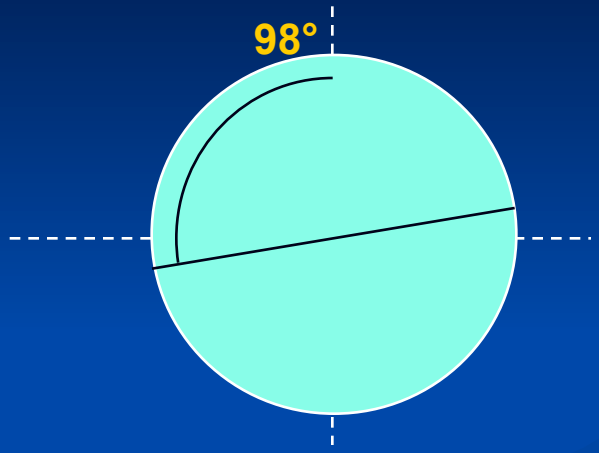
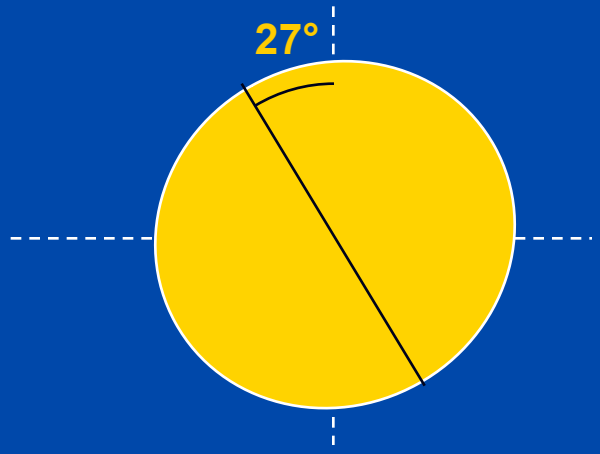
Obliquities of the Giant Planets



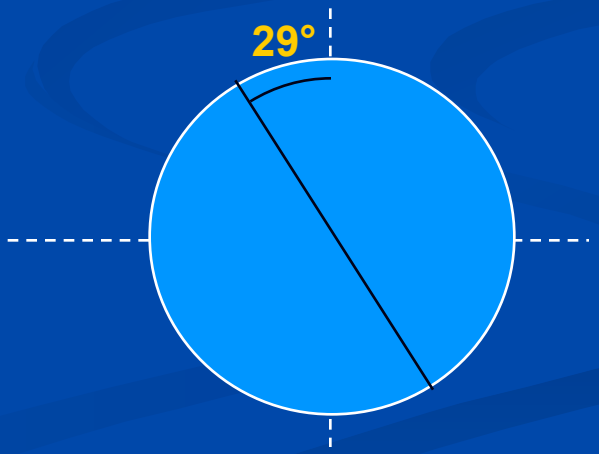
Jupiter



Uranus



Saturn



Neptune

Typical Atm-Relative Entry Speeds At the Giant Planets

Speeds in km/s; assume "typical" hyperbolic approach V_∞

Destination \ Entry Orbit Inclination	0° (prograde)	90° (polar)	180° (retrograde)
Jupiter	47.4	61.1	72.2
Saturn	26.5	37.5	46.2
Uranus	21.5	24.1	26.6
Neptune	25.4	28.2	30.8

Color-coded entry condition indicators assume shallow entry angle

The *Galileo Probe* Mission

- Primary Mission Elements
  - Jupiter orbiter, ~equatorial orbit for access to Galilean moons
  - Galileo Probe, for in situ measurements of Jupiter's atmosphere
- Timeline
  - Spacecraft construction began in 1977 for launch in early 1982
  - Problems with Space Shuttle slipped launch to 1984, then 1985, then 1986
  - Challenger disaster postponed launch
  - New mission design needed due to disqualification of Centaur upper stage for flight on Shuttle; modifications to S/C for Venus flyby trajectory
  - Launch 1989 October 18, VEEGA trajectory
  - HGA failed to deploy; significant operations redesign
  - Probe entry 1995 Dec. 7; orbit insertion Dec. 8, almost 8-year orbital tour
  - Disposal of spacecraft by Jupiter impact 2003 Sept. 21

Galileo Probe Science Objectives

- Science objectives for the *Galileo* mission as a whole
  - Study the composition, structure, and dynamics of the Jovian atmosphere, to a depth having a pressure of at least 10 bars
  - Study the composition, geology, surface morphology, and interior structure of the planet-sized Galilean moons Io, Europa, Ganymede, and Callisto
  - Determine the structure of, and characterize the plasma physics in, the vast Jovian magnetosphere
- Science objectives for the *Galileo Probe* mission
  - Determine the chemical composition of the Jovian atmosphere
  - Characterize the structure of the atmosphere to a depth of at least 10 bars
  - Measure the vertical profile of zonal wind speed
  - Investigate the nature of cloud particles and the location and structure of cloud layers
  - Examine the Jovian radiative heat balance
  - Study the nature of Jovian lightning activity
  - Measure the flux of energetic charged particles down to the top of the atmosphere

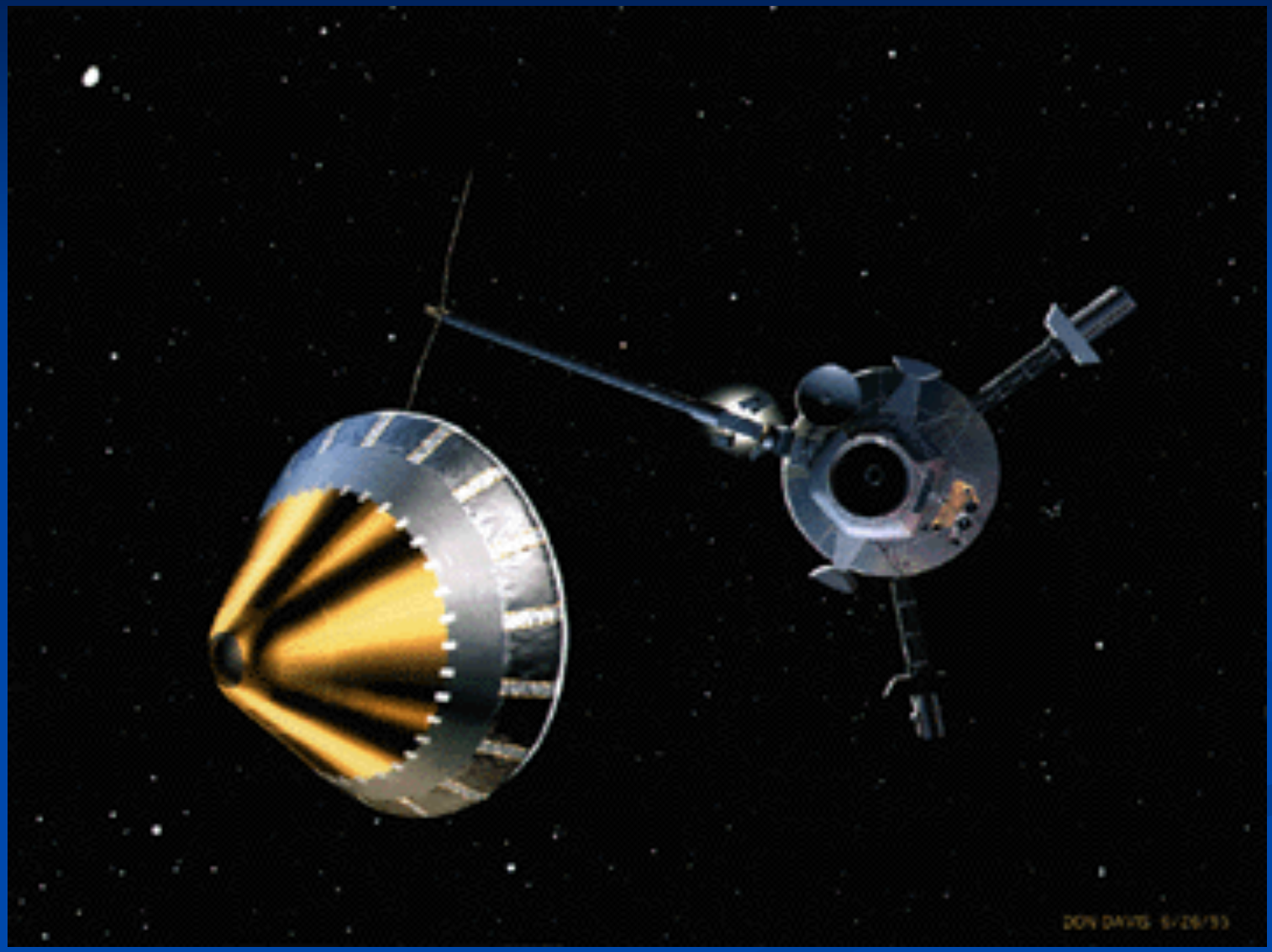
Galileo Probe Science Objectives

- Chemical composition – what is important?
  - Boundary conditions for understanding Jupiter
  - Clues to the materials and processes that formed Jupiter and the rest of the solar system from the protostellar cloud
  - D/H
  - He/H
  - Other noble gas abundances
  - Abundances of specific heavier elements: C, N, O, S; isotopic ratios
  - Species diagnostic of large-scale atmospheric circulation

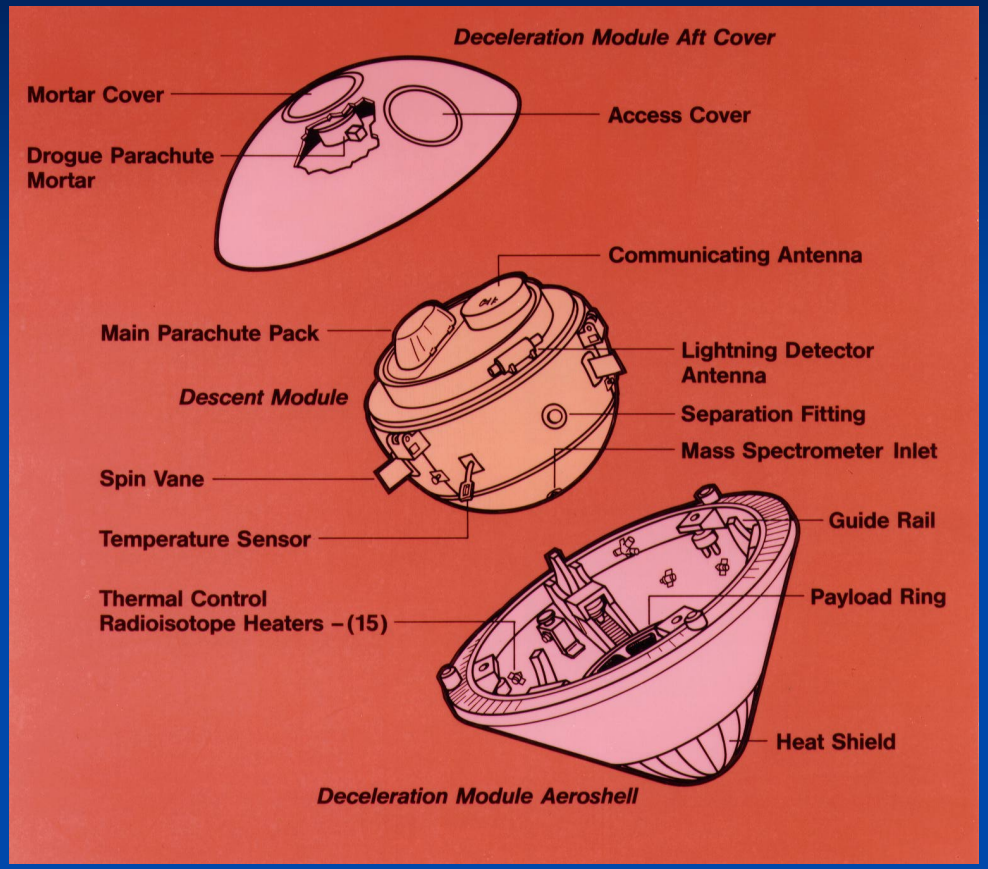
Galileo Probe Science Objectives

- Why are atmospheric structure and zonal winds important?
  - Along with direct measurements of radiative flux, they are indicators of energy balance
  - Indicators of atmospheric circulation drivers (*e.g.*, solar radiation or internal heat
- Why is measuring cloud characteristics important?
  - Indicators of atmospheric circulation, convection
  - Influence radiative heat transfer, both upward & downward
  - Latent heat release; available to drive winds, affect lapse rates, etc.

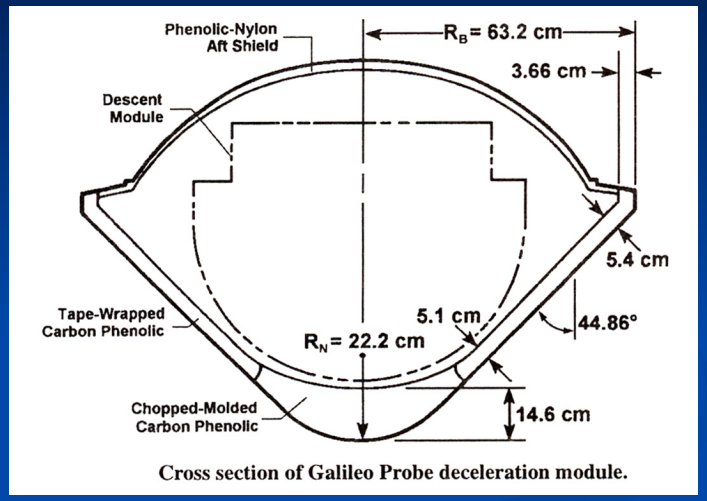
The *Galileo Probe* Mission: Hardware



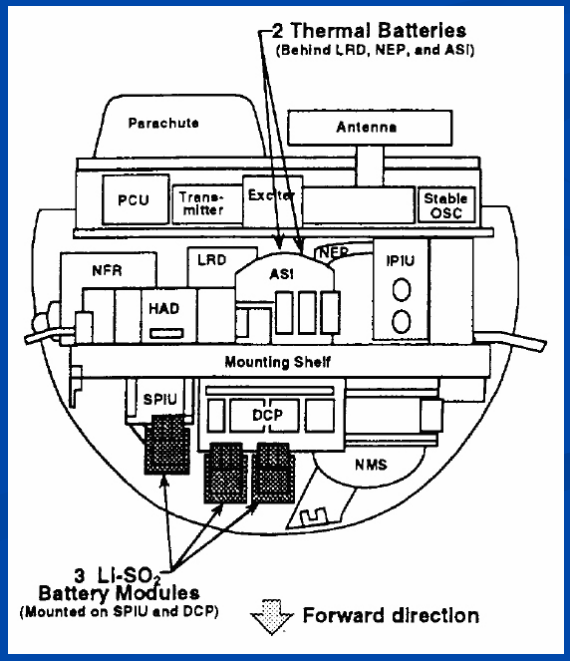
The *Galileo Probe* Mission: Hardware: Probe Design



Total mass: 339 kg



Cross section of Galileo Probe deceleration module.



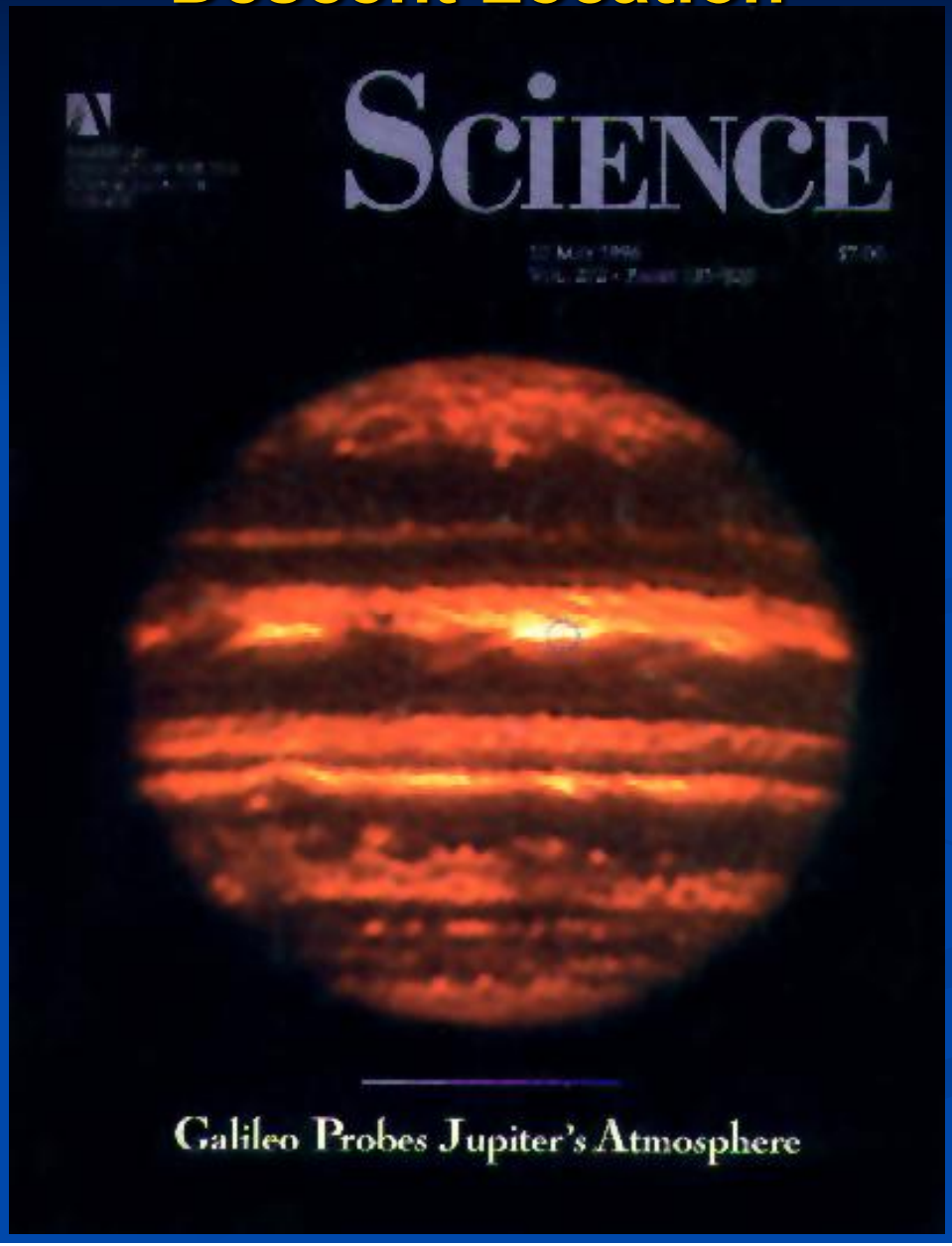
Ref: Galileo Probe Deceleration Module Final Report, Doc No. 84SDS2020, General Electric Re-entry Systems Operations, 1984
AIAA, "Project Galileo Mission and Spacecraft Design", Proc. 21st Aerospace Science Meeting, Reno, NV, January 10-13, 1983

The *Galileo Probe* Mission: Hardware: Instrument Complement

Instrument	Mass, Kg	Average Power, W
Atmospheric Structure Instrument (ASI)	4.1	6
Neutral Mass Spectrometer (NMS)	13.3	25
Nephelometer (NEP)	4.7	11
Lightning & Radio Emissions Detector (LRD) & Energetic Particle Instrument (EPI)	2.9	3
Helium Abundance Detector (HAD)	5	1
Net Flux Radiometer (NFR)	3.4	13
Doppler Wind Experiment (DWE)		

The *Galileo Probe* Mission: 1995 Dec. 7 -- Arrival Day!

Galileo Probe Results: Descent Location



Galileo Probe Results: Descent Location

Galileo Probe Expectations: Tropospheric Winds

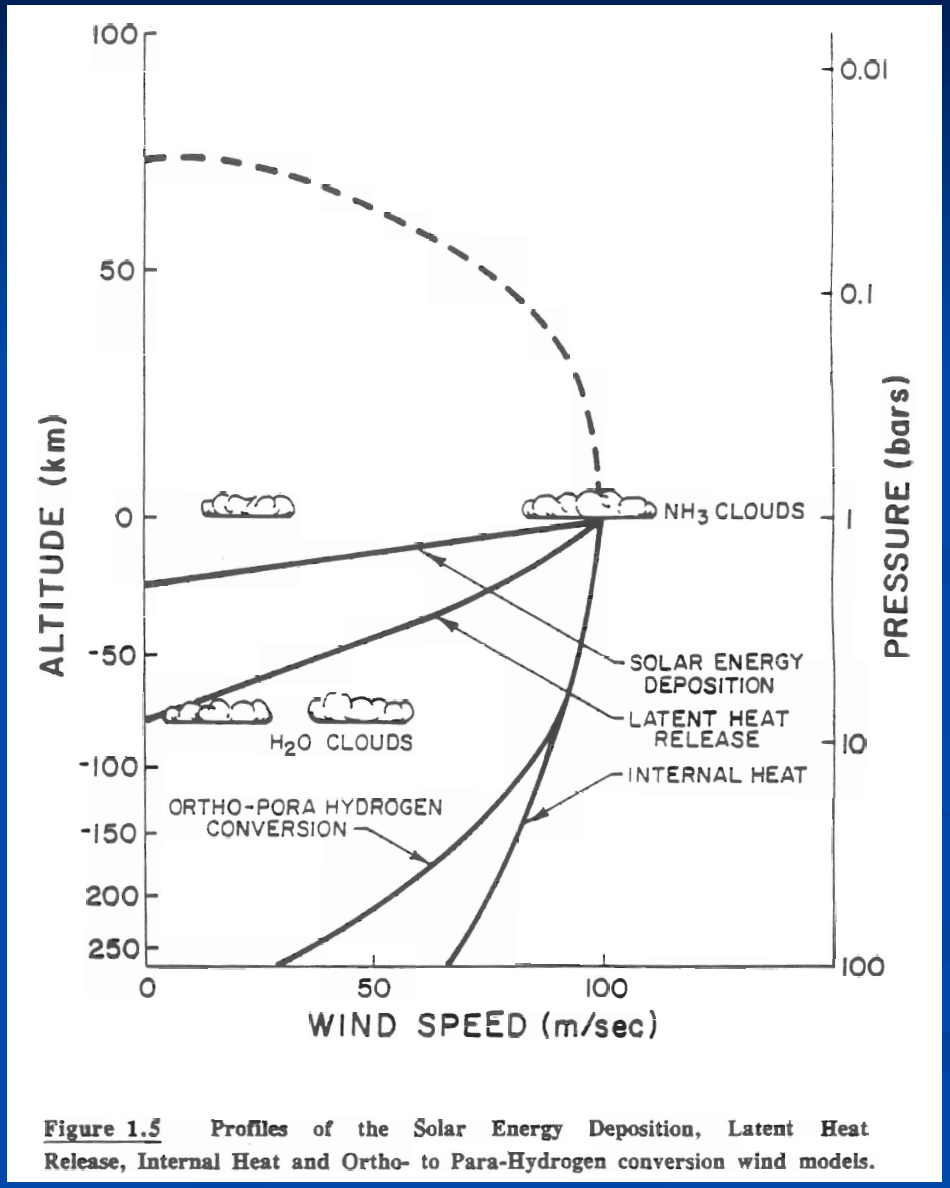
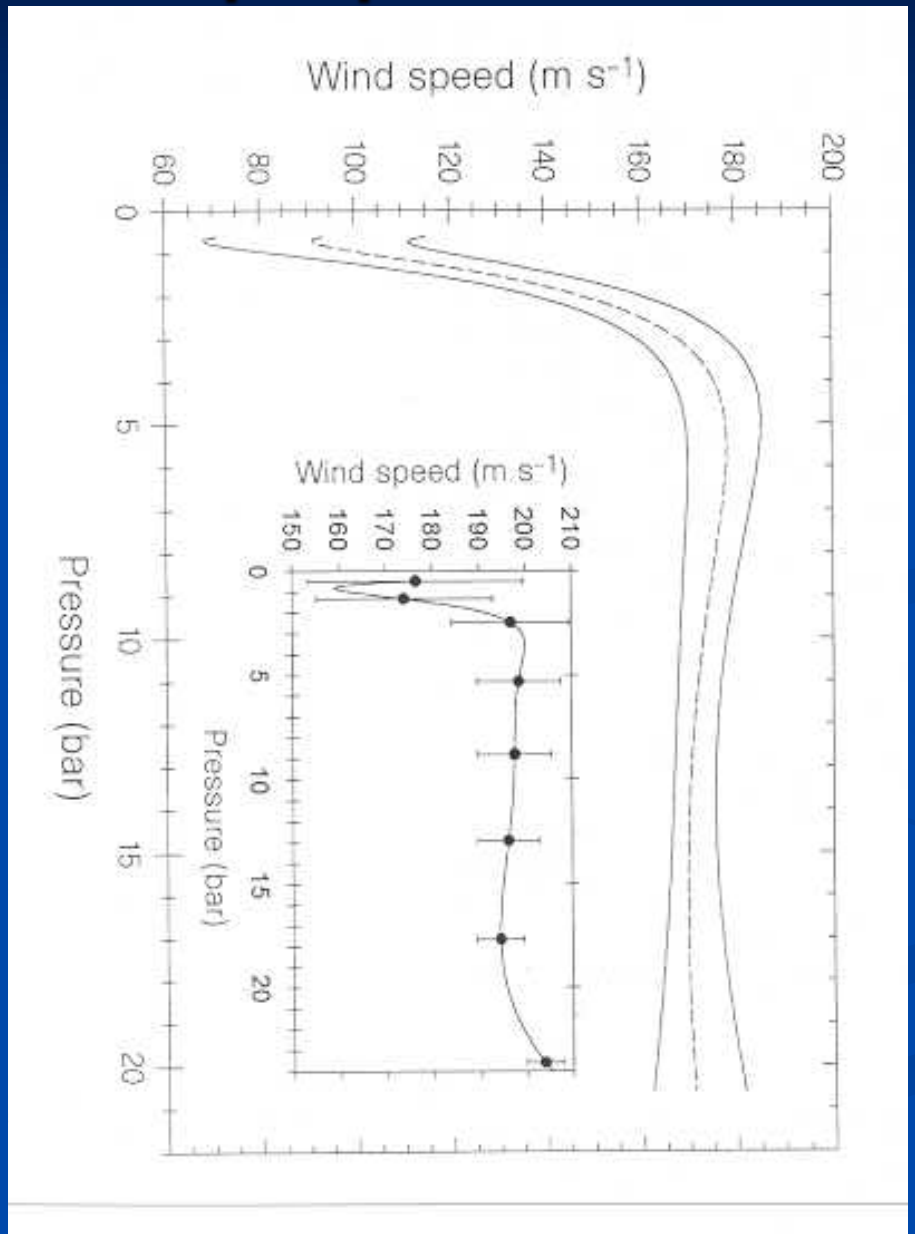
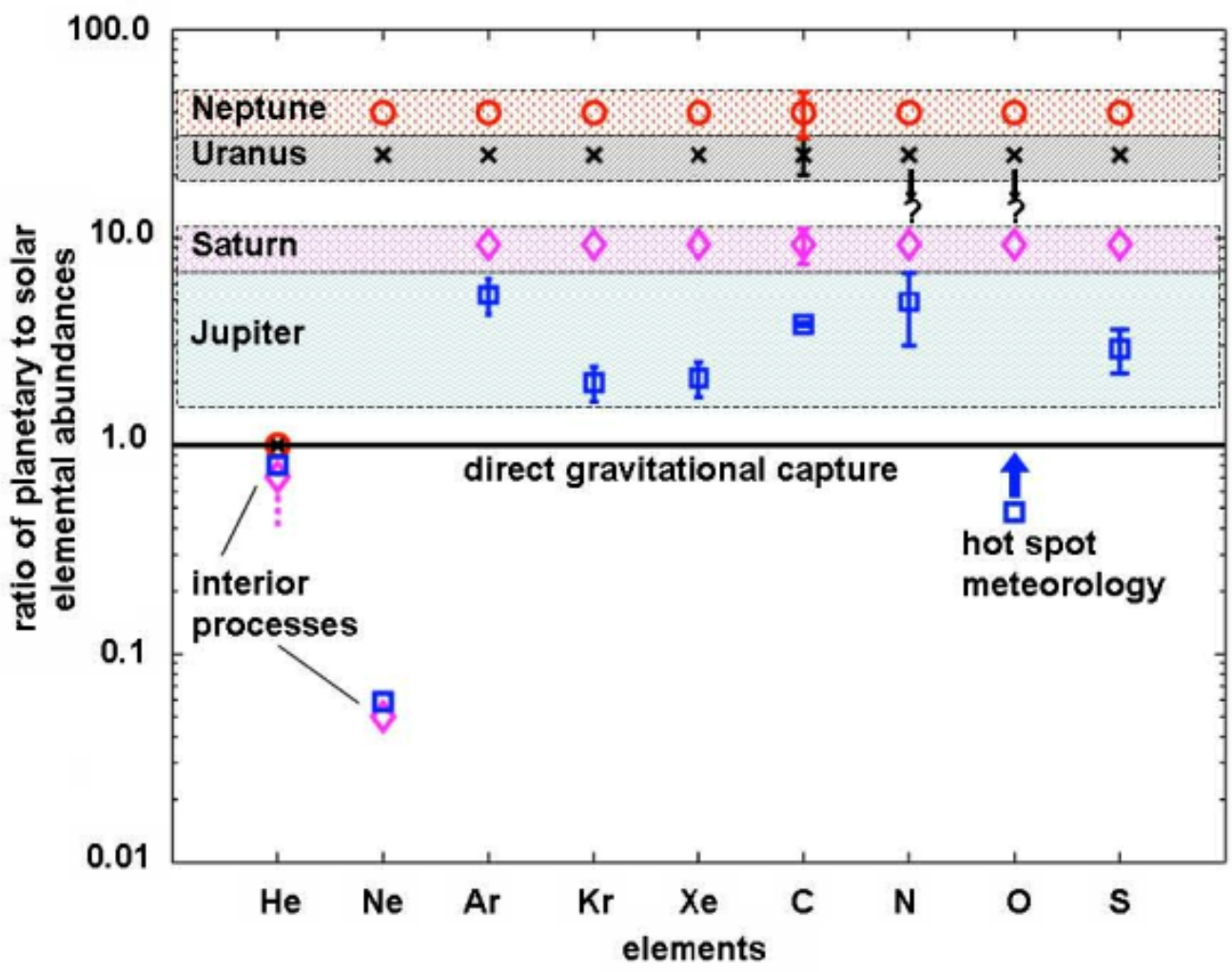


Figure 1.5 Profiles of the Solar Energy Deposition, Latent Heat Release, Internal Heat and Ortho- to Para-Hydrogen conversion wind models.

Galileo Probe Results: Tropospheric Winds



Galileo Probe Results: Composition



Isotopic Ratios: Solar (±) !

Atreya, 1999

Galileo Probe Results: Thermal Structure, Clouds, Lightning

- Atmospheric thermal structure: adiabatic
  - Not stably stratified, so upper troposphere is not solely radiative
- Clouds
  - No thick clouds observed!
  - Consequence of hot spot entry location
  - Clues to better interpretation of observational data from hot spots
- Lightning
  - No optical flashes observed
  - Radio emissions of distant lightning observed
    - Discharges more powerful (factor of 3-10) than on Earth
    - Radio signatures different from terrestrial lightning
    - Physics of lightning discharge at Jupiter is not well understood

Progress in Solar System Origins Research from Giant Planet Comparative Planetology

Data Set Needed for Meaningful Comparisons

Planet --> Investigation	Jupiter	Saturn
Atmospheric Composition		
Interior Structure		

Green Background: Data already in hand

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Planet --> / Investigation	Jupiter	Saturn
Atmospheric Composition	*Galileo Probe*	
Interior Structure	*Juno*	

Blue Background: Data planned from a mission already in flight

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Planet --> / Investigation	Jupiter	Saturn
Atmospheric Composition	*Galileo Probe*	
Interior Structure	*Juno*	*Cassini* Proximal Orbits

Blue Background: Data planned from a mission already in flight

Progress in Solar System Origins Research from Giant Planet Comparative Planetology

Data Set Needed for Meaningful Comparisons

Planet --> / Investigation	Jupiter	Saturn
Atmospheric Composition	*Galileo Probe*	Saturn Probe
Interior Structure	*Juno*	*Cassini* Proximal Orbits

Yellow Background: No mission yet approved to acquire data, but recommended by 2012 Decadal Survey

A Winding Career

Undergraduate:
Space Technology

A Winding Career

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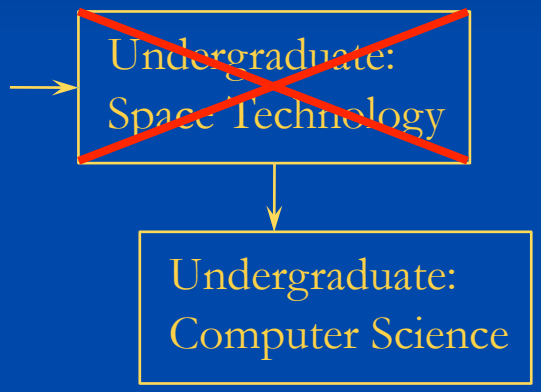

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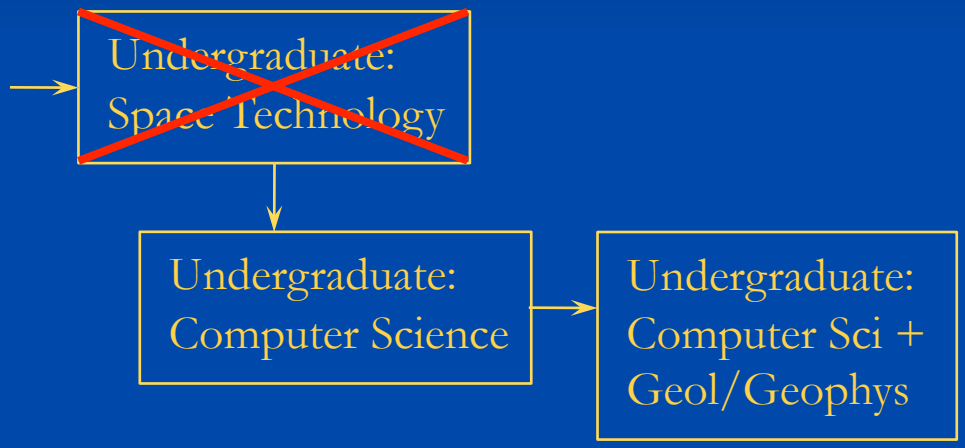

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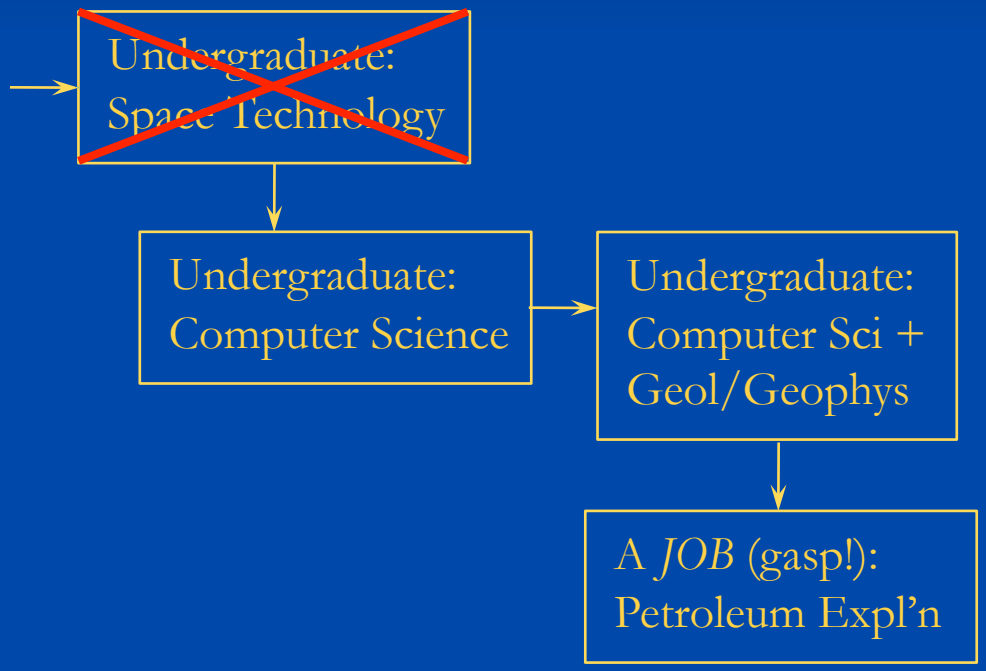

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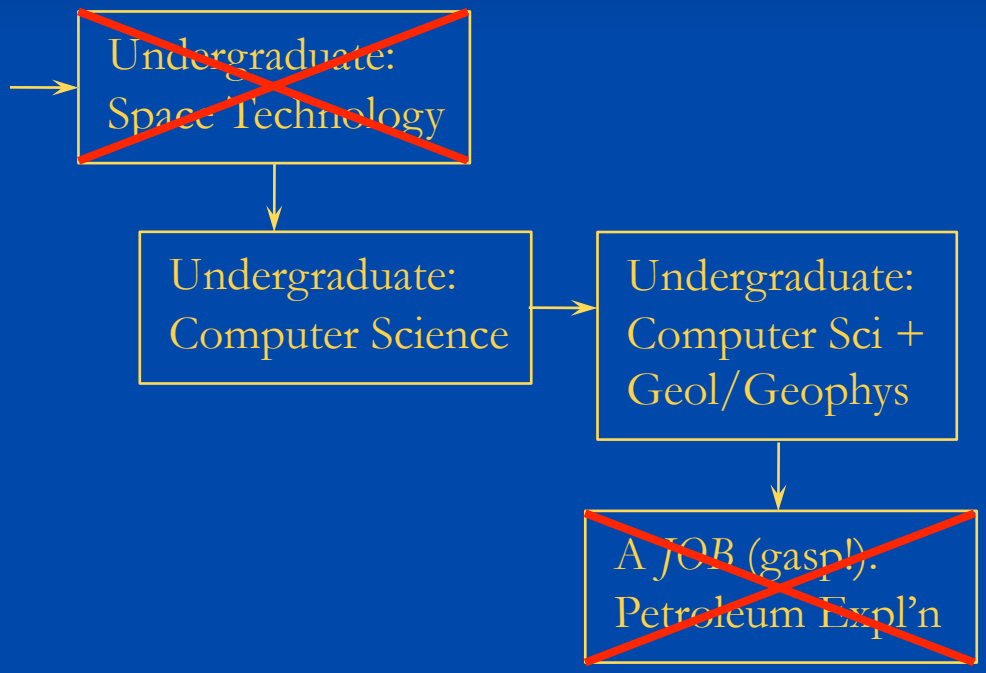

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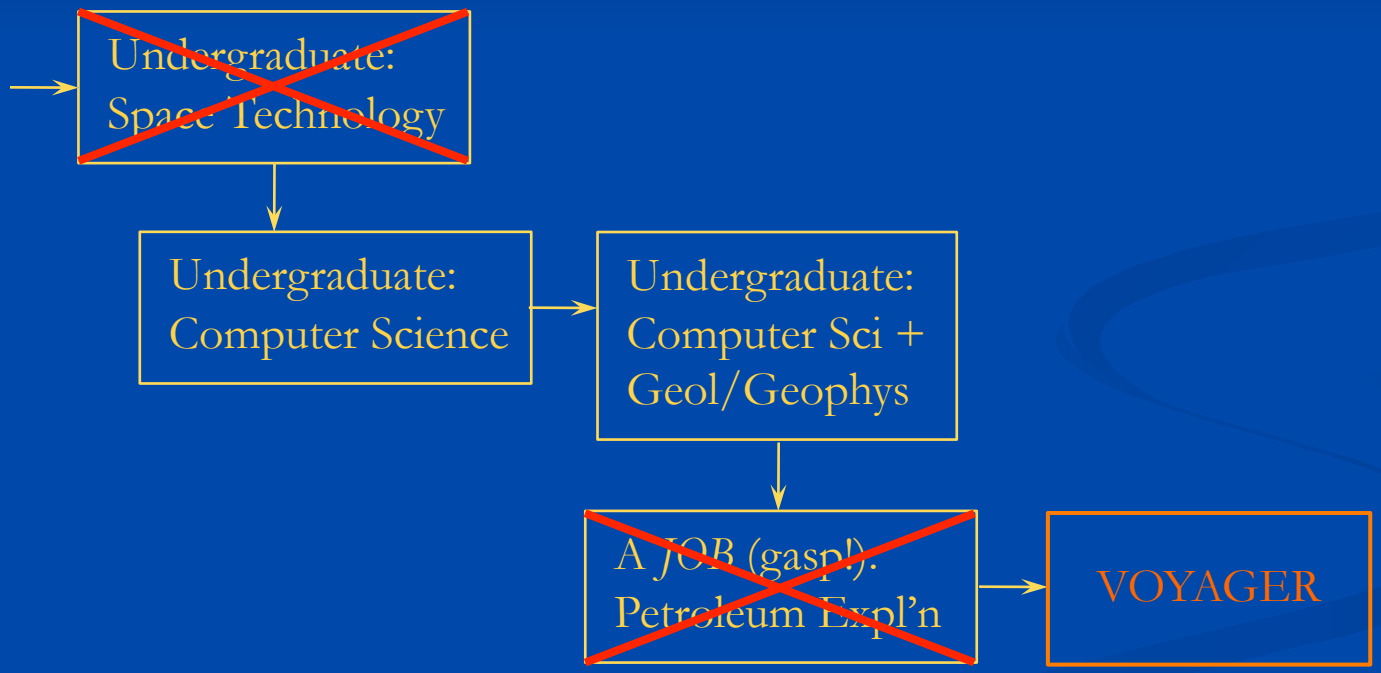

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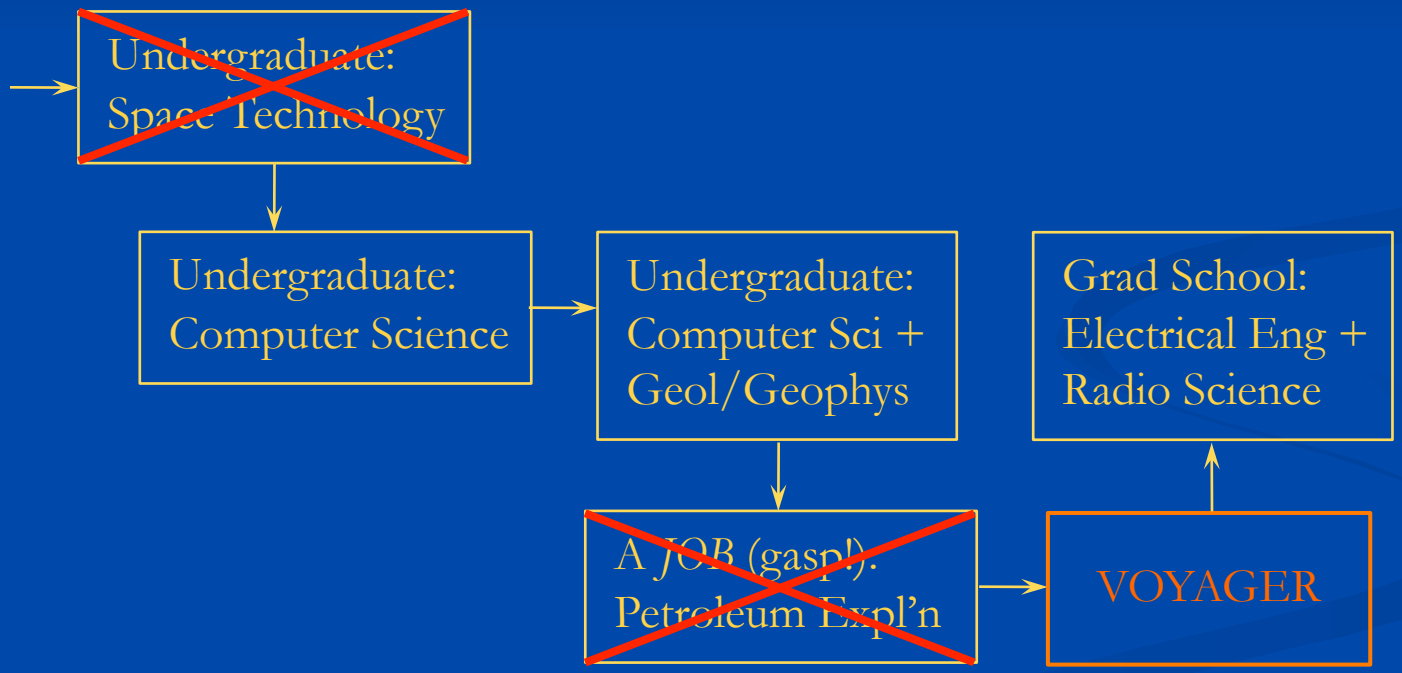

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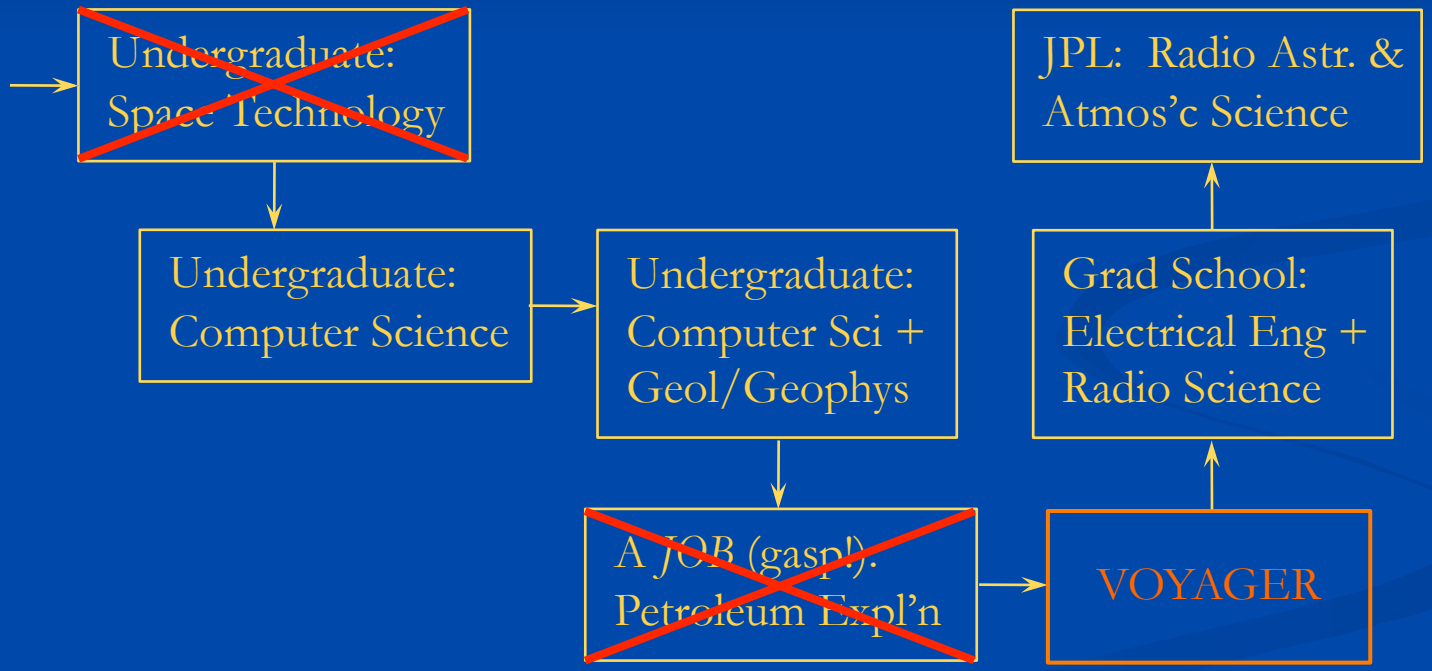

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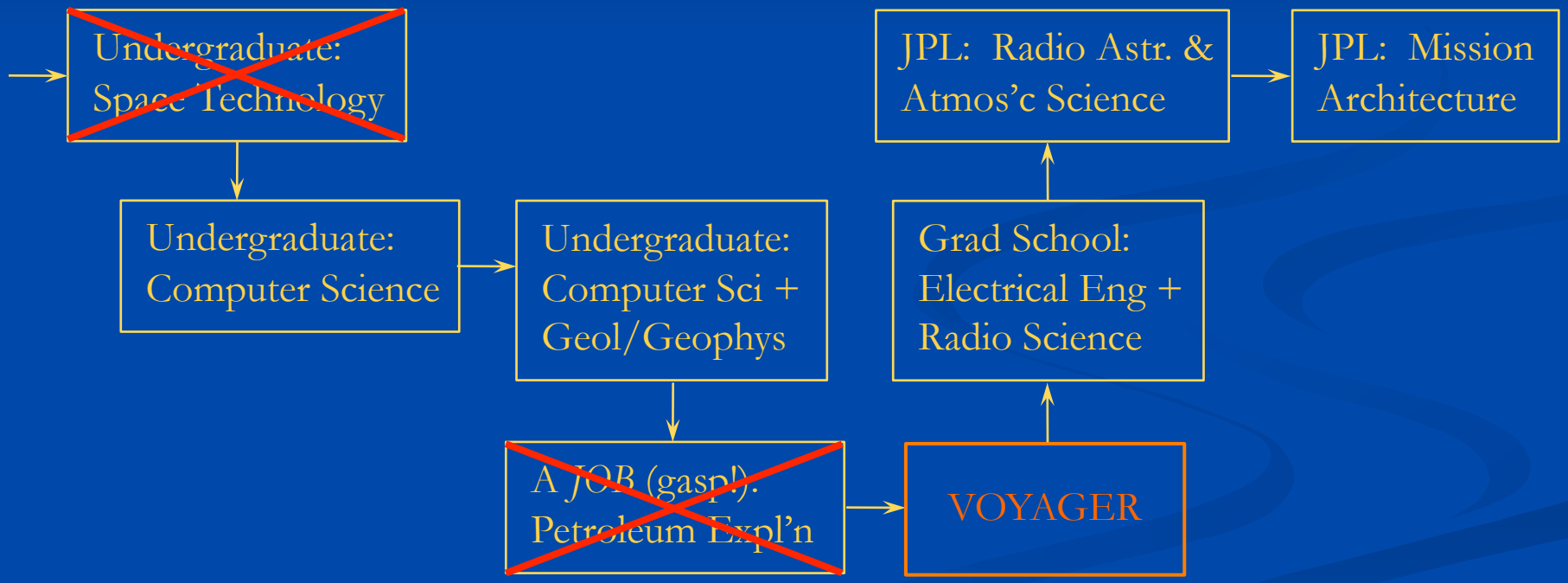

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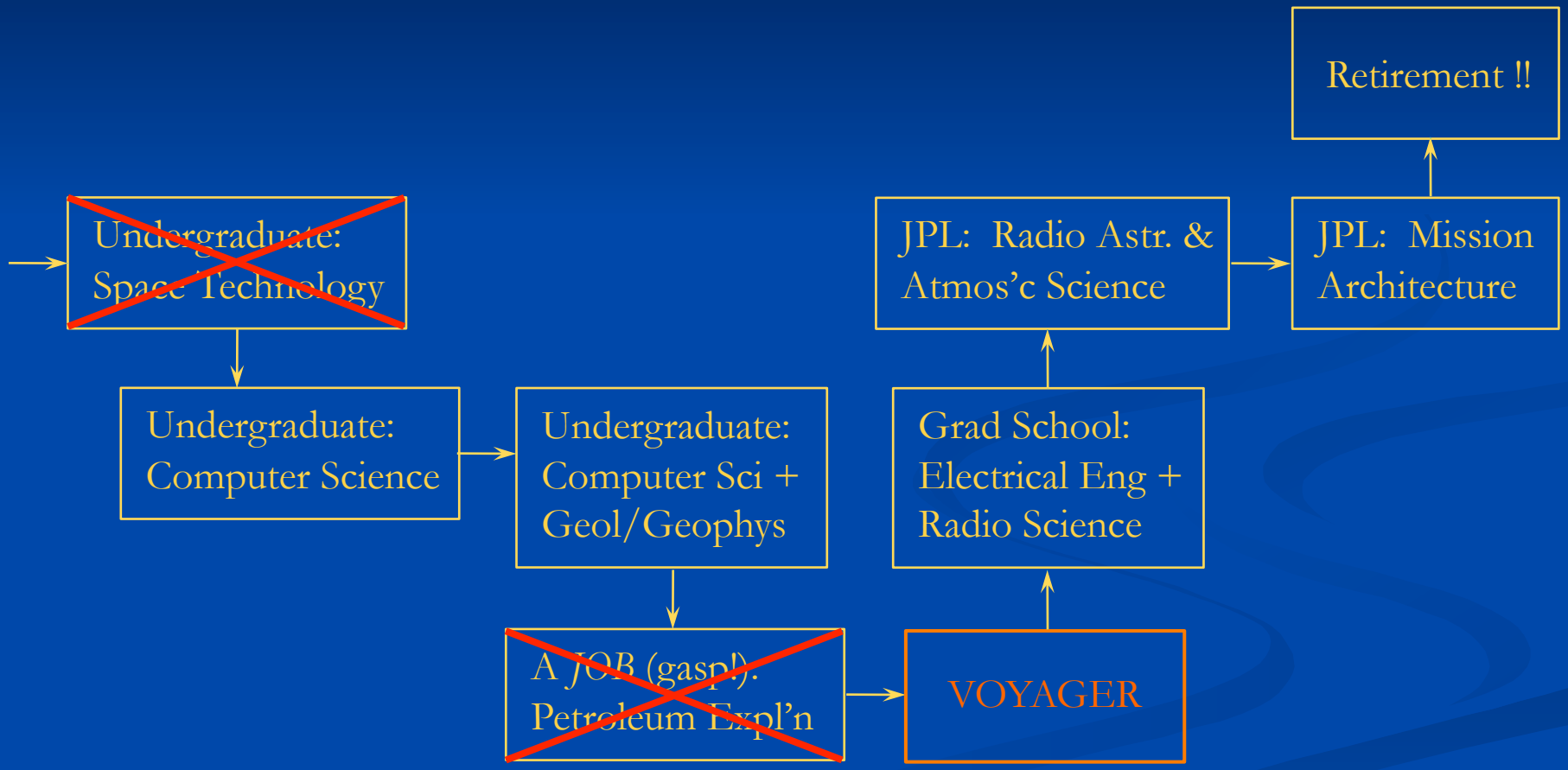

Questions?