Supercomputer Numerical Simulation of Astrophysical Processes

Francisco Raygoza

Mentors: Dr. John Sepikas, Dr. Neal Turner

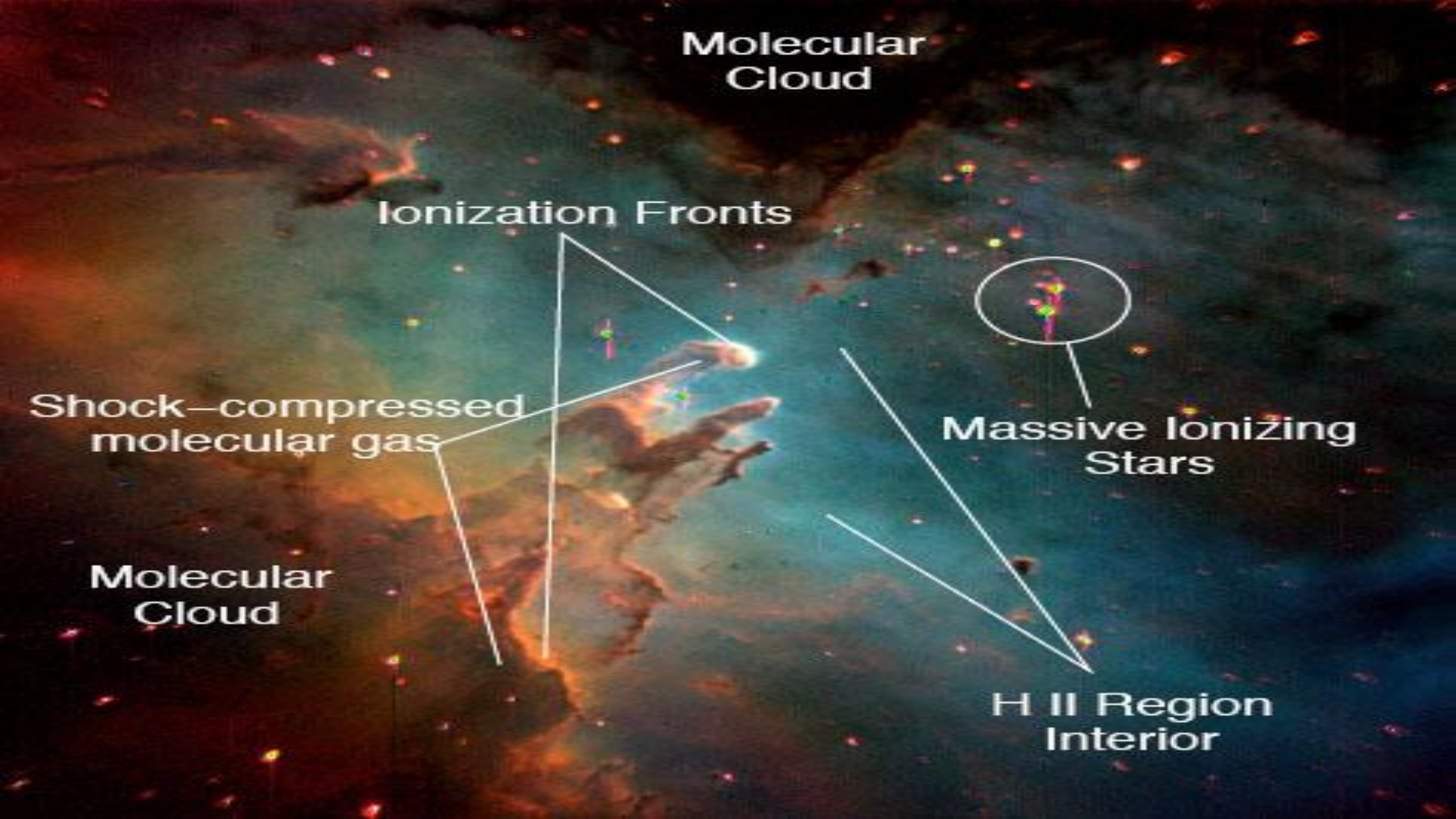
Pasadena City College

fraygoza@go.Pasadena.edu

Astrophysics and Space Sciences Section

NASA-Jet Propulsion Laboratory

California Institute of Technology


Molecular Cloud
Ionization Fronts
Shock–compressed molecular gas
Massive Ionizing Stars
Molecular Cloud
H II Region Interior

Two Primary Research Topics

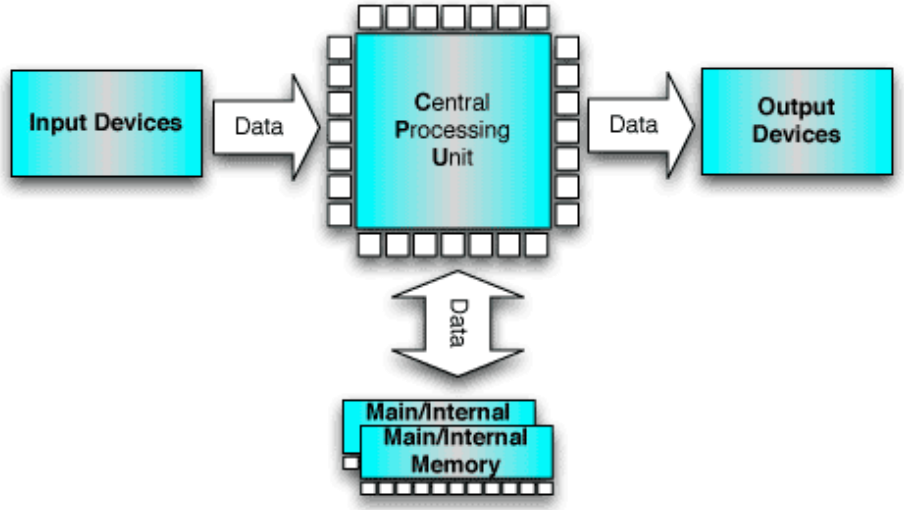
- Stellar Formation
- Pure Mathematics
  - Monte Carlo Analysis
- Follow up work with the Hubble and Spitzer Space Telescopes
- Prelude to the James Webb Space Telescope

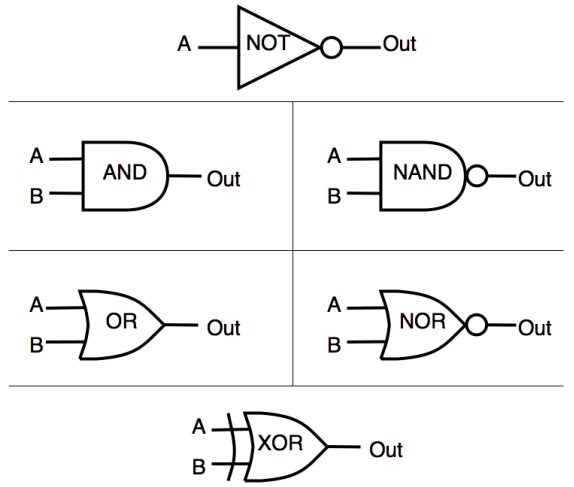
Mentor Directed me to an Additional New Research Direction

- Quantum Computers
- Promising Capabilites
  - Shor's Factoring Algorithm
    - Exponential improvement over classical algorithms
  - Quantum Search Algorithm
    - $\sqrt{N}$ improvement (N=Size of search space)
- Complements traditional Monte Carlo work

Pre-Quantum Computing: Classical Computing

- CPU
  - Can be constructed from NAND and/or NOR logic gates only
- Registers
  - Have just 2^N possible states per register
  - In ONE particular state at a given time
- Moore's Law





Supercomputers:
Parallel Processing

- Uses same CPU as standard computers
  - Just has many CPU's to spread the work
- N CPU's imply the work should be done in 1/N time
- Many problems not parallelizable
- STILL not fast enough for Astrophysics problems

Quantum Computing-Crash Course!

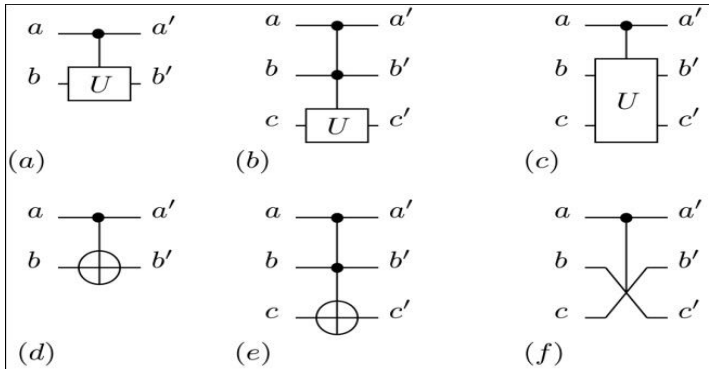
- Just like studying five minutes before an exam!
- Yuri Manin(1980)
- Richard Feynman-Are you even surprised?!(1982)
- David Deutch(1985)
  - Universal Quantum Machine

Quantum Computers- Super Parallel Processing

- Qubits
  - Simple two level system, the Spin of an electron
- Quantum Circuits
  - Quantum Logic Gates
- Quantum Computers can be ALL states at the same time

$$Not = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \qquad PhaseShift = \begin{bmatrix} 1 & 0 \\ 0 & e^{i\frac{\pi}{4}} \end{bmatrix}$$

$$H = \frac{\sqrt{2}}{2}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \qquad CNot = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$



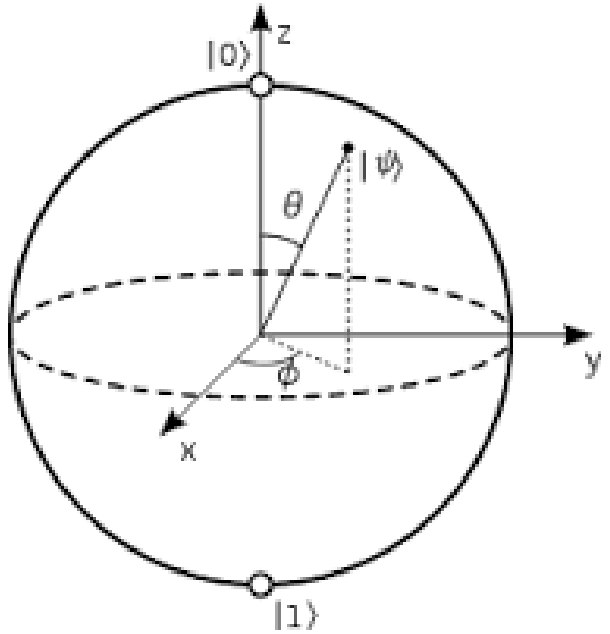
Quantum Mechanics

5 Axioms/Postulates of Quantum Mechanics

- States
- Observables
- Measurement
- Dynamics
- Composite Systems/Ensembles

States

- Normalized Vector in Hilbert Space
  - $|\Psi\rangle = \alpha|1\rangle + \beta|0\rangle$
  - $|\alpha|^2 + |\beta|^2 = 1$
- For 2 Qubits:
  - $|\Psi\rangle = \alpha|\downarrow\downarrow\rangle + \beta|\downarrow\uparrow\rangle + \gamma|\uparrow\downarrow\rangle + \delta|\uparrow\uparrow\rangle$
  - $|\alpha|^2 + |\beta|^2 + |\gamma|^2 + |\delta|^2 = 1$



Observables

- Physical quantities represented Linear Operators
  - Hermitian/Self-Adjoint
    - $\hat{A}^{\dagger} = \hat{A}$
    - Eigenvectors are real
    - Forms a basis in Hilbert Space
  - Position, Momentum, Angular Momentum, Spin

Measurements

- Enter the Observer
- Process by which information is extracted by the state
  - Given any observable, the measurement prepares an eigenstate of that observable
  - What we read is a value
- Not as straight forward as it may seem

Dynamics

- Time evolution of the State
  - Described by a Unitary Operator(Total energy operator of the system)

Composite Systems/Ensembles

- From one qubit to many
- Mathematical formalism to combine multiple Hilbert Spaces corresponding to multiple state vectors

Copenhagen Interpretation

Any given state: $|\Psi\rangle = \sum_i \alpha_i |\varphi_i\rangle$

- BEFORE a measurement is taken, the system is in all possible states
- AFTER a measurement is taken system in just one particular state (an Eigenstate of the system)
- Hopefully the state corresponds to the correct solution desired???

Implementing Quantum Computers

- Main requirements:
  - Be able to represent quantum information
  - Perform a universal family of unitary transformation
  - Be able to Prepare an Initial State
  - Be able to Measure the output result
- Some Applications:
  - Optical Photon
  - Neutral or Ion Traps
  - NMR
- Decoherence (noise)

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