Ancient Notions of the Night Sky

- Constellations represented animals and gods
- Babylonian and Chinese astronomers (21st c. BCE)
  - “Fixed stars” and “moving stars”
  - Moving stars were the abodes of gods
  - They believed the Earth was Flat but surrounded by a celestial sphere
  - Precise charts of the moving stars
  - Calendar (Zodiac) of 12 lunar months
- Homer (8th c. BC): “Silver orb in the sky”

The Course, in a Nutshell
Main Themes

- Historical antecedents of space travel
- Science and technology of travel to the moon
- Political and social forces that led to lunar travel
- The Apollo program
- Society's perception of space travel
- Enabling effects of industry and public opinion
- The New Space Race

Dreams, History, Business, and Policy

- Early History & Fiction
- Precursors to Space Flight
- Early Space Age
- Antecedents to Apollo
- Apollo & the Space Race
- Lunar Missions, Astronauts, & Science
- Building Spacecraft & Launch Vehicles
- Robotic Lunar Spacecraft
- Project Management
- Commercial Space Flight
- Social & Political Aspects of Space Flight
Science and Technology

- Introductory Concepts
- Orbital Motion
- Launch Dynamics & Staging
- Rocket Propulsion
- Interplanetary Travel
- Lunar Transfer
- Space Vehicle Design
- Spacecraft Attitude Dynamics
- Spacecraft Guidance & Control
- Atmospheric Re-Entry
- Communications & Tracking

Preliminaries

- Wednesday, 1:30-4:20 pm
- Seminar Room T3, Blair Hall
- ~ 5 homework assignments
- Information at https://blackboard.princeton.edu/
- Office hours
  - Any time the door (D-202, E-Quad) is open
  - Best to make appointment via e-mail
- Satisfies QR requirement
- Most reading on Electronic Reserve

*GRADING*

- Class participation: 20%
- Assignments: 30%
- Final Project: 50%
Reading

Excerpts from:

## A Timeline of Events Critical to Space Travel - I

<table>
<thead>
<tr>
<th>Date</th>
<th>Science Fact</th>
<th>Science Fiction</th>
<th>World Scene</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd-1st millennium BC</td>
<td>Babylonian &amp; Chinese Astronomer-Priests: Observational astronomy &amp; instruments, planets as abodes of the gods, prediction of eclipses, flat Earth. Fireworks invented by Chinese.</td>
<td>Homer: Odyssey illustrates lack of physical knowledge about Earth &amp; solar system; Moon as “silver shield in the sky,” reflecting land &amp; water below</td>
<td>Bronze Age Iron Age</td>
</tr>
</tbody>
</table>

## A Timeline of Events Critical to Space Travel – II

<table>
<thead>
<tr>
<th>Date</th>
<th>Science Fact</th>
<th>Science Fiction</th>
<th>World Scene</th>
</tr>
</thead>
</table>
Early Greek Astronomers

Pythagoras, 570-495 BCE
“The Earth is round”

Eratosthenes, 276-194 BCE
“The Earth’s circumference is 50 times the distance from Syene to Alexandria (~500 mi)”

He was wrong, of course ... by 0.2 %

Early Astronomy

- Claudius Ptolemy (90-168 A.D.)
- Noted retrograde motion of Mars
- Proposed epicyclic motion of planets
- Earth at the center of the world
## A Timeline of Events Critical to Space Travel – III

<table>
<thead>
<tr>
<th>Date</th>
<th>Science Fact</th>
<th>Science Fiction</th>
<th>World Scene</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd-3rd cent</td>
<td>Mayan astronomy and mathematics.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11th cent</td>
<td>European scholars first exposed to Arab work.</td>
<td></td>
<td>Fall of Spain (1085). European renaissance and craft guilds begin. Belief in more than one world is heretical (Franciscus Gratianus). Rise of the European cities.</td>
</tr>
</tbody>
</table>

---

## Fireworks and Rockets

7th c. BC (BCE)  
13th c. AD (CE)
**A Timeline of Events Critical to Space Travel – IV**

<table>
<thead>
<tr>
<th>Date</th>
<th>Science Fact</th>
<th>Science Fiction</th>
<th>World Scene</th>
</tr>
</thead>
<tbody>
<tr>
<td>13th cent</td>
<td>Rockets used at siege of Kai-Fung-Fu (1232). Greek fire (1250). Hassan er-Rammah: The Book of Fighting on Horseback with War Engines (1280).</td>
<td>Birth of the novel (fantasy vs. mime, dreams vs. reality). Shakespeare’s Hamlet (~1600) -- allegory for Danish astronomers?</td>
<td>Belief in more than one world is not heretical (Bishop of Paris). Empiricism. Science as extension of philosophy.</td>
</tr>
<tr>
<td>16th-17th cent</td>
<td>Kepler (1571-1630): Heliocentric solar system, elliptical orbits. Galileo (1564-1642): Astronomical use of the telescope (1609); Starry Messenger (1610); heavy = light. Rene Descartes (1596-1650): analytic geometry.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**The Astronomical Revolution**

**Galileo, 1564–1642**

- Constructed and used telescopes, 3x to 30x
- Conurred with Copernicus
- Accused of heresy by Inquisition (1633)

*Forced to recant, and spent the rest of his life under house arrest*

---

**The Astronomical Revolution**

**Kepler, 1571–1630**

- Planets move in ellipses
- “Magnetism” between Earth and Moon

**Newton, 1642–1727**

- Formalized the science
- Laws of motion and gravitation
Thomas Harriot (1560-1621)

- Traveled to “The Americas” with Sir Walter Raleigh in 1585
- Purported to have acquired a Dutch “trunke” or telescope in 1609, before Galileo
- Used his “perspective tube” to observe and draw the Moon in 1610
Orbits 101

Satellites

Escape and Capture
(Comets, Meteorites)

• Circular orbit: radius and velocity are constant
• Low Earth orbit: 17,000 mph = 24,000 ft/s = 7.3 km/s
• Super-circular velocities
  - Earth to Moon: 24,550 mph = 36,000 ft/s = 11.1 km/s
  - Escape: 25,000 mph = 36,600 ft/s = 11.3 km/s
• Near escape velocity, small changes have huge influence on apogee

Orbits 102
(2-Body Problem)

• e.g.,
  - Sun and Earth or
  - Earth and Moon or
  - Earth and Satellite

• Circular orbit: radius and velocity are constant
  • Low Earth orbit: 17,000 mph = 24,000 ft/s = 7.3 km/s
• Super-circular velocities
  - Earth to Moon: 24,550 mph = 36,000 ft/s = 11.1 km/s
  - Escape: 25,000 mph = 36,600 ft/s = 11.3 km/s
• Near escape velocity, small changes have huge influence on apogee
Creation of the Solar System
(4.6 billion years ago)

Accretion of the Planets
(4.5 billion years ago)
Theories for the Moon’s Creation
(4.1 billion years ago)

Accretion

Collision Spawning

The Earth and the Moon

Earth mass = 81.4 x Moon mass

Earth Orbit
Moon Orbit
Axial tilt to orbit 23.44°
Inclination 5.14°

4,641 km
Barycenter

1,738 km

6,378 km
Radius

384,405 km

Axial tilt to orbit 6.68°
**Earth-Moon Orbit**

*Orbital Period: 27-1/2 days*

*One side of Moon always faces Earth*

---

There is no "Dark Side"

*ALL SIDES are dark once a month*
A Voyage to the Moon
Cyrano de Bergerac
(1619-1655)

• Hercule-Savinien Cyrano de Bergerac
• “Comical History of the States and Empires of the Moon”, written about 1649, published 1656 or 1657, English translation, 1687

Cyrano’s A Voyage to the Moon

• How did Cyrano get to the Moon? and back?
• What might have been known about the moon and astronomy when he wrote the book?
• What about the Inquisition?
• Why was it called a “comical romance”? 
Kepler’s Laws

- **First Law (1609)** - The orbits of the planets are ellipses with the Sun at one focus.

- **Second Law (1609)** - The line joining a planet to the Sun sweeps out equal areas in equal times.

- **Third Law (1619)** - The square of the orbital period is directly proportional to the cube of the mean distance between the Sun and the planet.

Newton’s Laws, (1687)

- **First Law** - If no force acts on a particle, it remains at rest or continues to move in a straight line at constant velocity.

- **Second Law** - A particle acted upon by a force moves with an acceleration proportional to and in the direction of the force; the ratio of force to acceleration is constant for any particle.

- **Third Law** - For every action, there is an equal and opposite reaction.

- **Law of Gravitation** - Two particles attract each other with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between them.
Thomas Kuhn: The Structure of Scientific Revolutions, 1962

- **Advances in Science**
  - Not a steady, cumulative acquisition of knowledge
  - Peaceful interludes punctuated by intellectually violent revolutions

- **Paradigm**
  - Pre-Kuhn: A pattern, exemplar, or example (OED, 1483)
  - Post-Kuhn: “A collection of procedures or ideas that instruct scientists, implicitly, what to believe and how to work.” (Morgan, 2012)

- **Paradigm Shift**
  - One world view is replaced by another
  - Gödel’s theorem: for any axiomatic system there exist propositions that are either undecidable or not provably consistent
  - Theory rests on subjective framework
  - Propositions are true or false only within the context of a paradigm


---

Math Review

- **Scalars and Vectors**
- **Sums and Multiplication**
- **Inner Product**
- **Derivatives and Integrals**
- **Introduction to MATLAB**
Most Math Can Be Done on a Calculator

- But MATLAB makes it easier
- MATHEMATICA is a good alternative
- Wolfram ALPHA (on line)

Cartesian Reference Frame

- 3 dimensions
- Orthogonal axes, \((x, y, z)\)
- At the origin, all coordinates are zero
- \((i, j, k)\) represent unit distances in directions \((x, y, z)\)
- \((a_x, a_y, a_z)\) are the coordinates of the vector \(a\)
Scalars and Vectors

- **Scalar**: usually lower case: \( a, b, c, \ldots, x, y, z \)
- **Vector**: usually bold or with underline: \( \mathbf{x} \) or \( \underline{x} \)
  - Ordered set
  - **Column** of scalars
  - Dimension = \( n \times 1 \)

\[
\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} ; \quad \mathbf{y} = \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix}
\]

\( 3 \times 1 \)
\( 4 \times 1 \)

- **Transpose**: interchange rows and columns

\[
\mathbf{x}^T = \begin{bmatrix} x_1 & x_2 & x_3 \end{bmatrix}
\]

Multiplication of Vector by Scalar

- \( a\mathbf{x} = \mathbf{x}a = \begin{bmatrix} ax_1 \\ ax_2 \\ ax_3 \end{bmatrix} \)

\[
a(\mathbf{x} + \mathbf{y}) = (\mathbf{x} + \mathbf{y})a = (a\mathbf{x} + ay)
\]

\( \dim(x) = \dim(y) \)

- \( a\mathbf{x}^T = \begin{bmatrix} ax_1 & ax_2 & ax_3 \end{bmatrix} \)

- **Could we add** \((\mathbf{x} + a)\)?  
  - **Only if** \( \dim(x) = (1 \times 1) \)

... but, MATLAB lets you do add scalar to vector! This is called an **overloaded algorithm** [compiler-dependent]
Addition and Subtraction of Vectors

\[ \mathbf{x} = \begin{bmatrix} a \\ b \\ c \end{bmatrix} ; \quad \mathbf{y} = \begin{bmatrix} d \\ e \\ f \end{bmatrix} \]

\[ \mathbf{z} = \mathbf{x} + \mathbf{y} = \begin{bmatrix} a+d \\ b+e \\ c+f \end{bmatrix} \]

\[ \mathbf{z} = \mathbf{x} - \mathbf{y} = \begin{bmatrix} a-d \\ b-e \\ c-f \end{bmatrix} \]

Product of Vectors

The “dot” (inner or scalar) product is scalar

\[ \mathbf{z} = \mathbf{x}^T \mathbf{y} = \mathbf{x} \cdot \mathbf{y} = \begin{bmatrix} a & b & c \end{bmatrix} \begin{bmatrix} d \\ e \\ f \end{bmatrix} \]

\[ (1 \times m)(m \times 1) = (1 \times 1) \]

\[ = (ad + be + cf) \]
Reference Frame

- **Newtonian (Inertial) Frame of Reference**
  - **Unaccelerated Cartesian frame**
    - Origin referenced to inertial (non-moving) frame
  - **Right-hand rule**
  - **Origin can translate at constant linear velocity**
  - **Frame cannot rotate with respect to inertial origin**

- **Position: 3 dimensions**
  - What is a non-moving frame?
    - **Translation = Linear motion**

Derivative of a Function

- **Derivative of a function equals slope of the function with respect to changes in another variable**

  **Function:** \( x(t) = \frac{1}{2} at^2 \)

  **Slope of** \( x(t) = \frac{dx(t)}{dt} = at = v(t) \)
Integral of a Function

- **Integral of a function equals area under the function as another variable changes**

  Function: $v(t) = at$;

  \[ \text{Integral of } v(t) = x(T) = \int_0^T (at) \, dt = \frac{1}{2} \left[ aT^2 - a(0)^2 \right] + x(0) \]

= \begin{bmatrix} x(t) \\ y(t) \\ z(t) \end{bmatrix} = \begin{bmatrix} v_x(t) \\ v_y(t) \\ v_z(t) \end{bmatrix}

- **Linear momentum of a particle**

  \[ p(t) = m v(t) = m \begin{bmatrix} v_x(t) \\ v_y(t) \\ v_z(t) \end{bmatrix} \]

Velocity and Momentum

- **Velocity of a particle**

  \[ v(t) = \frac{dr(t)}{dt} = \dot{r}(t) = \begin{bmatrix} \dot{x}(t) \\ \dot{y}(t) \\ \dot{z}(t) \end{bmatrix} = \begin{bmatrix} v_x(t) \\ v_y(t) \\ v_z(t) \end{bmatrix} \]

- **Linear momentum of a particle**

  \[ p(t) = m v(t) = m \begin{bmatrix} v_x(t) \\ v_y(t) \\ v_z(t) \end{bmatrix} \]
Derivatives and Integrals of Vectors

Derivatives and integrals of vectors are vectors of derivatives and integrals

\[
\frac{dx}{dt} = \begin{bmatrix}
\frac{dx_1}{dt} \\
\frac{dx_2}{dt} \\
\frac{dx_3}{dt}
\end{bmatrix} \quad \int x \, dt = \begin{bmatrix}
\int x_1 \, dt \\
\int x_2 \, dt \\
\int x_3 \, dt
\end{bmatrix}
\]

\[
x(t) = \begin{bmatrix}
7 \\
8t \\
9t^2
\end{bmatrix} \quad \frac{dx(t)}{dt} = \begin{bmatrix}
0 \\
8 \\
18t
\end{bmatrix} \quad \int x(t) \, dt = \begin{bmatrix}
7t + x_1(0) \\
8t^2/2 + x_2(0) \\
9t^3/3 + x_3(0)
\end{bmatrix}
\]

Newton’s Laws of Motion: Dynamics of a Particle

- **First Law**
  - If no force acts on a particle,
   - it remains at rest
   - or continues to move in straight line at constant velocity,
  - Inertial reference frame
  - Momentum is conserved

\[
\frac{d}{dt}(mv) = 0 \quad \left[ \begin{array}{l}
mv_x \\
mv_y \\
mv_z
\end{array} \right] \frac{dt}{dt} = \left[ \begin{array}{l}
v_x \\
v_y \\
v_z
\end{array} \right] = m \left[ \begin{array}{l}
v_x \\
v_y \\
v_z
\end{array} \right]
\]

\[
\frac{d}{dt}\begin{bmatrix}
mv_x \\
mv_y \\
mv_z
\end{bmatrix} = 0 \quad \text{with}
\]

\[
\begin{bmatrix}
v_x \\
v_y \\
v_z
\end{bmatrix} = m \begin{bmatrix}
v_x \\
v_y \\
v_z
\end{bmatrix}
\]

\[\left[ \begin{array}{l}
v_x \\
v_y \\
v_z
\end{array} \right] = \left[ \begin{array}{l}
v_x \\
v_y \\
v_z
\end{array} \right] \]

\[\frac{d}{dt}\begin{bmatrix}
v_x \\
v_y \\
v_z
\end{bmatrix} \frac{dt}{dt} = \left[ \begin{array}{l}
v_x \\
v_y \\
v_z
\end{array} \right]
\]
Newton’s Laws of Motion: Dynamics of a Particle

• Second Law
  - Particle of fixed mass acted upon by force changes velocity with
    • acceleration proportional to and in direction of force
  - Inertial reference frame
  - Ratio of force to acceleration is the mass of the particle: \( F = ma \)

\[
\frac{d}{dt}[mv(t)] = m \frac{dv(t)}{dt} = ma(t) = \text{Force}
\]

\[
\text{Force} = \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix} = \text{force vector}
\]

\[
m \frac{d}{dt} \begin{bmatrix} v_x(t) \\ v_y(t) \\ v_z(t) \end{bmatrix} = \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix}
\]

Newton’s Laws of Motion: Dynamics of a Particle

• Third Law
  - For every action, there is an equal and opposite reaction

"Force on Rocket = Force on Exhaust Gasses"

https://www.youtube.com/watch?v=MpLb-bifrZ8
https://www.youtube.com/watch?v=B-jzkDviIwo
Next Time:

**Early History and Fiction**
*Rockets, Missiles, and Men in Space, Ch 1 & 2*
*A Voyage to the Moon, excerpts*
*Round the Moon, excerpts*
**Orbital Motion**
*Understanding Space, Sec 2.1, 2.2, Ch 4*

Supplemental Material
MATLAB Overview

**Command Window**
- >> prompt; ver describes setup
- Line-by-line input of MATLAB statements; immediate output of results
- Diagnostic statements to identify errors
- help function
- 'Up' cursor arrow to restore previous command line
- 'clear' to erase Workspace

**Menu Bar**
- File pull-down list to open file or create a new one using new Editor window
- Product 'Help Browser' for all functions and toolboxes

**Editor Window**
- Create and edit scripts and functions
- Save as name.m files
- Use % for comments
- Command-/ to comment out banks of code; Command-T to restore
- End each line with ';' to suppress printing in Command Window
- Cut-and-paste banks of code to test in Command Window

**Menu Bar**
- Debug pull-down list to run and save files from Script file
- Be sure edited functions are saved directly
**MATLAB Code for Math Review**

% FRS 148 Lecture 1: Math Review and Introduction to MATLAB
clear
disp(' ')
disp('===================================================')
disp('>>>FRS 148 Lecture 1: Math Review and MATLAB Introduction<<<')
disp('===================================================')
disp(' ')
disp(['Date and Time are ', num2str(datestr(now))]);
disp(' ')

% Scalars
disp(' ')
disp('Scalar Operations')
disp('=================')
a = 4 % Scalar
b = 5

disp(' ')
disp(['Number 1 = ',num2str(a),', Number 2 = ',num2str(b)])
disp(' ')
c = a + b % Addition
d = b - a % Subtraction
e = a * b % Multiplication
f = b / a % Division
g = a * (a + b) / (d - b) % All of the above
h = 10^a % Raise to a power of 10
k = log10(h) % Evaluate the base 10 logarithm
k = log(h) % Evaluate the natural logarithm
h = exp(k) % Raise to a power of e
k = log2(h) % Evaluate the base 2 algorithm
t = 1:1:10 % List the integers from 1 to 10
length(t) % Number of elements in t
y = log(t) % Compute a function of the list
plot(t,y),grid,xlabel('t'),ylabel('log_e(t)'),
title('Natural Logarithm of t')
MATLAB Code for Math Review

```matlab
% Plot the function with a grid
figure % Save previous figure and plot a new one
plot(t,y.*y,grid,title('Operation on Argument'),xlabel('t'),ylabel('y^2'))

% Operation on variable in plot argument list
length(t) % Number of elements in t
y1 = sin(t); % Compute sine of t
y2 = sin(2*t); % Compute sine of 2t
figure
plot(t,y1,t,y2,grid,title('Sine Example'),xlabel('Time, sec'),ylabel('Sine Waves'),legend('sin(t)','sin(2*t)'))
figure
plot3(t,y1,y2,grid,title('[y1,y2] vs. t'),xlabel('Time, sec'),ylabel('y1'),zlabel('y2'))

% Vectors
disp('Vector Operations')
disp('==*=*=*=*=*=*=*=*=*==')
x = [1; 2; 3] % Column Vector
y = [4; 5; 6; 7] % Column Vector

% Matrices
A = [1 2 3; 3 9 27; 2 4 16]
B = A'
C = A + B
D = A * B
E = inv(A)
F = eye(3)
H = A * E
K = E * A
```

% Vector Transpose
xT = x'
yT = y'

% Multiplication by Scalar
w = a * x
v = x * a
wT = a * xT

% Vector Addition
zz = [8; 9; 10]
u = x + zz

% Inner (Dot) Product
zzz = x' * x

% Matrices
disp('Matrices')
disp('==*=*=*=*=*=*=*=*=*==')
A = [1 2 3; 3 9 27; 2 4 16]
% "For" Loop
for i = 1:4
  a = 2 * i
end

% Nested "For" Loop
v = [];
for i = 1:3
  for j = 4:6
    b = i*j
    v = [v,b];
  end
end
% Build a vector
v
size(v)
size(v')
length(v)

% 2-Dimensional Function
M = zeros(100,100);
% Initialize matrix with zeros
size(M)
% Identify dimensions of the matrix
length(M)
for i = 1:100
  for j = 1:100
    M(i,j) = sin(0.1*i) * sin(0.1*j);
  end
end
M values

% Surface, Mesh, and Contour Plots of M
figure
surf([1:100],[1:100],M),grid on, title('Surface Plot')
% Oblique "3-D" view of M
figure
mesh([1:100],[1:100],M), title('Mesh Plot')
% Mesh without surface color
figure
contour([1:100],[1:100],M), title('Contour Plot')
% "2-D" cuts through the surface

% Symbolic Expressions
syms x y z z1 z2 z3 z4
y = x * x % Define Function
z = diff(y) % Differentiate Function
z1 = int(y) % Integrate Function
z2 = [x; y; z] % Column Vector
z3 = diff(z2) % Derivative of Column Vector
z4 = int(z2) % Integral of Column Vector
x = 4
y
subs(y) % Evaluate symbolic expression
a = pi
format long
a
format short
a
format longe
a
format shorte
a
format longg
f = vpa(a)
digits(64)
d = double(a)
digits
f = vpa(a)
g = vpa(a)