Ada and SPARK

• The Ada language originally issued in 1983 has been revised in 1995, 2005 and 2012

• Although originally developed at the behest of the Defense Department, Ada has taken over the niche for very high integrity software, as SIGAda says: “When the software really has to work”

• As a result, Ada is used in all commercial airline avionics and all air traffic control systems worldwide, as well as high speed trains and nuclear power plants in Europe
Our ELaNa IV CubeSat

Vermont Lunar CubeSat
Software Controlled Hardware

Clyde Space EPS
Software Controlled Hardware

Astrodev Helium-100 transceiver
Software Controlled Hardware

ISIS AntS crossed dipole antenna
Software Controlled Hardware

IMU, GPS patch, camera & hysteresis board
NovAtel OEMV-1 GPS Board Mounted on University of Michigan Position and Time Board
Follow on CubeSat

Triple CubeSat Ion Drive Lunar or Interplanetary with fold outs
Control Program Architecture
Software Tool Chain

1. Ada Main
2. SPARK
3. Ada to C
4. C Main
5. C to Object
6. C Low Level
7. Object Code
## Subsystems Used in ELaNa IV CubeSat

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Interfacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna</td>
<td>$\text{I}^2\text{C}$</td>
</tr>
<tr>
<td>Radio</td>
<td>RS-232</td>
</tr>
<tr>
<td>Camera</td>
<td>SPI</td>
</tr>
<tr>
<td>EPS (Power Supply)</td>
<td>$\text{I}^2\text{C}$</td>
</tr>
<tr>
<td>Inertial Measurement Unit (IMU)</td>
<td>RS-232</td>
</tr>
<tr>
<td>GPS &amp; GEONS</td>
<td>SPI</td>
</tr>
</tbody>
</table>
# Student Participation

<table>
<thead>
<tr>
<th>Time</th>
<th>Students</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer 2011</td>
<td>2</td>
<td>Design and implementation of radio and interfacing subsystems</td>
</tr>
<tr>
<td>AY 2011-2012</td>
<td>0</td>
<td>Small enhancements</td>
</tr>
<tr>
<td>Summer 2012</td>
<td>1</td>
<td>Completed implementation of most subsystems</td>
</tr>
<tr>
<td>AY 2011-2012</td>
<td>4</td>
<td>File transfer, integration, camera, radio, IMU, navigation program</td>
</tr>
</tbody>
</table>
Control Software

• Control Software written in SPARK/Ada using Adacore’s GNAT Programming Studio & GNAT Pro compiler
• Praxis’ SPARK Toolset used to prove the correctness of the code
• Sofcheck’s AdaMagic compiles it to produce ANSI C intermediate code
• C code compiled to object code
• Software runs on CubeSat Kit MSP430 CPU
procedure Matrix_2 (J : in Natural)
    --# global in out Upper_Matrix; in In_Matrix, Diagonal;
    --# derives Upper_Matrix from Upper_Matrix, J, In_Matrix, Diagonal;
    --# pre J >= Diagonal'First and J < Diagonal'Last and
    --#  Upper_Matrix'First(1) = Upper_Matrix'First(2) and
    --#  Upper_Matrix'Last (1) = Upper_Matrix'Last (2) and
    --#  Diagonal'First = Upper_Matrix'First(1) and
    --#  Diagonal'Last = Upper_Matrix'Last (1);
    is
    begin
        Upper_Matrix (J, J) := 1.0;
        for I in reverse Natural range Diagonal'First .. J - 1 loop
            Upper_Matrix (I, J) := 0.0;
            for K in Natural range J + 1 .. Diagonal'Last loop
                Upper_Matrix (I, J) := Upper_Matrix (I, J) +
                (Diagonal (K) * (Upper_Matrix (I, K) * Upper_Matrix (J, K)));
            end loop;
            Upper_Matrix (I, J) := (In_Matrix (I, J) - Upper_Matrix (I, J)) / Diagonal (J);
        end loop;
    end Matrix_2;
procedure Get_From_Radio(Ch : out Character; Rx_Success : out Boolean)
--# global in out USCI_A1.State, Utility.Hardware; in Utility.Timer_Done;
--#     Ch from USCI_A1.State &
--#     Rx_Success from USCI_A1.State &
--#     Utility.Hardware from Utility.Hardware &
--#     null from Utility.Timer_Done;

is
    Finished : Boolean;
begin
    Utility.Start_B(Utility.Millisecond_Count_Type(20));

    loop
        Finished := Utility.Get_Timer_Finished;
        exit when Finished;
    end loop;

    if USCI_A1.Get_Rx_Buffer_Used > 0 then
        USCI_A1.Eat_Char(Ch);
        Rx_Success := True;
    else
        Ch := ' ';
        Rx_Success := False;
    end if;
end Get_From_Radio;
Navigation Components

• Converting the NASA Goddard GEONS navigation system to SPARK/Ada yields about 1% of the error rate of C software

• This process has already found a number of errors in the NASA GEONS software

• The GEONS software runs on the GPS board ARM processor

• Celestial navigation camera

• Novatel GPS on University of Michigan Position and Time Board

• Passive magnetic attitude control

• Inertial measurement unit (3 axis magnetometer, gyro and accelerometer)
NASA Launch Opportunity

• NASA’s 2010 CubeSat Launch Initiative

• Our project was in the first group selected for launch

• Our single-unit CubeSat will be launched as part of NASA’s ELaNa IV on an Air Force Minotaur 1 flight in September 2013 to a 500 km altitude, 40.5° inclination orbit

• It will test the Lunar navigation system in Low Earth Orbit

• Follow our project at www.cubesatlab.org
First two stages are Minuteman II first two stages, third and fourth stages are Pegasus second and third stages.
Acknowledgements

- NASA Vermont Space Grant Consortium
- NASA
- Vermont Technical College
- AdaCore, Inc. (GNAT Pro)
- Altran Praxis (SPARK)
- SofCheck (AdaMagic)
- Applied Graphics, Inc. (STK)
- LED Dynamics (PV boards)
- Microstrain (IMU)