ANNOUNCEMENTS

• 1st HW now online; due Friday 10/4
• La Jolla Playhouse Without Walls Festival show – Our Star Will Die Alone – FrSa Oct 4-5 at 10:30pm outside Theatre & Dance Dept. – volunteers sought
• CASS Astrophysics Seminar: Wednesdays at 4pm in SERF 383 (Marlar Room)

OUTLINE

• [30 min] Course Information
• [SKIPPED] History of stellar astrophysics
• [30 min] What are stars? Why are they important?
• [20 min] Numbers worth knowing

INTERACTIVE ELEMENTS

• Writing exercise – what do you hope to get out of this class?
• Class mindmap of why stars are important
Course information

• Personnel
  o Me – observational astrophysicist who studies very cool, low mass stars and brown dwarfs
  o Petia former P160 student so excellent resource
• My office hours
  o Th 10a-12p in SERF 340
  o **Vote for optimal hours?**
  o You should all go to all of your professor’s office hours
• Expectations:
  o Lecture attendance is recommended but not required – will contribute to participation grade
  o Recitation attendance is recommended but not required – this is going to be devoted to HW help, some skills development for advanced problems, and make-up lectures
  o Come to class prepared = do reading in advance, come with questions; don’t expect to just “get it” by showing up to lecture (I’m not that good of a lecturer!)
  o Look over your homework early to get a feel of what you need to know before cramming
  o Form a study group
  o You will be expected to do some computational problems and “light coding” – language unimportant but be sure to provide an annotated copy of code as part of your solutions
  o We will have the opportunity to observe stars with a remote 1m telescope toward the end of the quarter
  o Chapters to be covered: 1,3,5,7,8-16
  o Will be required text for 161 & 162
  o Earlier editions are different! But cheaper
Alternate references

Grading

- 30% homeworks, best 6/7, assigned Thursdays, due Fridays at 5pm (1st now online)
  - should take ~2-4 hr/week
  - you can work together, you can get help, but you must submit your own assignment
  - accepted up to Monday at 5pm at 50% reduction
  - you MUST NOT refer to old solutions (they’ll be wrong!) you WILL be caught

- 20% midterm exam in week 5
  - equation sheet will be provided

- 30% term study
  - given list of primary sources covering stellar topics
  - choose one, and look up 3 more
  - use these to write a proposal (Nov 14th), report (due last class) and 5-7 min presentation (final exam)

- 10% observing labs
  - one local with small telescopes, one remote with the 1m Nickel telescope
  - there will be 2 viewing opportunities for each lab; sign ups will be made later in the quarter

- 10% participation
  - contributions to class discussion
  - in-class writing assignments

- grade scale: A > 90, B 80-90, C 70-80, D 60-70, F < 60

- grade appeals allowed up to 1 week after grade assignment, must be made in writing – close scrutiny does not always yield a positive derivative!

Riot act:

- no copying of old solutions (3 people caught in this class doing this)
papers must be your original work

All this information and more is on the webpage:
http://pono.ucsd.edu/~adam/teaching/phys160

QUESTIONS?

Writing exercise – what do you hope to get out of this class?

What is a star? [class input]

“Simple” definition: self-gravitating mass of plasma that produces energy through fusion reactions and remains in thermal and hydrodynamic near-equilibrium from long periods of time (millions-billions of years)

Why are stars important? [a class mindmap]

• Navigation (directions) -> Hawaiian star map
• Time keeping (night, seasons)
• Primary source of energy for most living things (except chemoautotrophs – first forms of life)
• Primary source of energy for human society (food, solar/wind/tidal/hydro – only geothermal different)
• Nuclear fusion, source of almost entire periodic table (> Li) – > periodic table sequence
• Planets are the “debris” of star formation process
• Tracer of our Galaxy – both spatially and chemically -> tidal tails, bulge/disk/halo, our location in Galaxy
• Tracer of other galaxies (in most wavelengths we see star light)
• Tracer of dark matter (stellar kinematics) -> velocity curve, lensing
• Tracer of dark energy (SN Ia explosions)
• Neutrino source
• Gravity – Newtonian & GR -> 1919 Eddington expedition
• Physics topics: nuclear, particle, thermo, classical mechanics, GR, E&M, radiation, condensed matter – all in one object!

History of our understanding of stars
• Large # BC: stars exist (we were more aware of them back then due to light pollution) – patterns, repeatability – but what are they?
• Stars change:
  o Supernovae (e.g., SN 185, SN 1006, SN 1054 observed by Chinese and Arabic astronomers, SN 1572 by Tycho Brahe)
  o **Question: why would these be important?** – heavens are mutable/changeable/not “perfect”
  o Stars move = proper motion – Edmond Halley 1667
  o Stellar parallax = distance of star – Friedrich Bessel 1838
• What makes them glow?
  o Gravitational contraction: Sir Kelvin 1864 => sun is 20 Myr old (problem for evolution)
  o Nuclear fusion: Arthur Eddington proposed in 1920, first “maps” of nuclear fusion by Hans Bethe, Fred Hoyle, Burbidges (@UCSD!) in 1940s-1950s
• Stellar spectroscopy
  o Isaac Newton 17th century (Sun)
  o Joseph von Fraunhofer & Angelo Secchi during 19th century (stars)
  o Stars are made of hydrogen – Cecilia Payne-Gaposchkin 1925
• Stars have planets: Giordano Bruno (1584); then 1990s
• The Sun and general relativity – 1919 Eddington experiment
• Sizes of stars – Albert Michelson 1921 using interferometer
Basic questions we need to ask first: where are they and what do they look like?

**Numbers worth knowing**

Sun: Astronomers oddly use cm-gram-second (cgs) units, I will try to stick with SI, but almost everything is scaled to the Sun:

- \[ M = 2.0 \times 10^{30} \, \text{kg} = 1 \, M_\odot \]
- \[ R = 7.0 \times 10^8 \, \text{m} = 1 \, R_\odot \]
  \[ \Rightarrow \text{Density} \approx 1.4 \, \text{g/cm}^3 \approx \text{slightly denser than water} \]
- Sun-Earth distance = 1 AU = 1.5\times 10^8 m
- \[ L = 3.9 \times 10^{26} \, \text{W} = 1 \, L_\odot \]
- Surface temperature \[ \approx 5800 \, \text{K} \]
- age \[ \approx 4.5 \, \text{Gyr} \]
- *spectral type = G2 V*
- 73% H, 25% He, 2% everything else by mass

**QUESTION: how do we know these numbers?**

Stars properties go around these values (Sun in the geometric mean)

- Masses = 0.07 – \( \approx 300 \, M_\odot \)
- Radii = 0.1 – 2000 \( R_\odot \)
- Luminosities = \( 10^{-5} – 10^7 \, L_\odot \)
- Temperatures = 300 – 40,000 K

Galaxy is a star system of \( \sim 10^{11} \) stars

**Distance scale for stars**

1 pc = 3.3 ly = 3\times 10^{16} \, \text{m} \( \approx \text{AU}^2! \) Only in m – scale for stars in Galaxy

[sketch the galaxy]

Nearest stars are \( \sim 1.3 \, \text{pc} = 4.3 \, \text{ly away} \) (\( \alpha, \text{Prox Centauri} \))
Sun is about ½ way out from center = 8.5 kpc – suburban star
Galaxy satellites ≈ 50-100 kpc
Nearest galaxies are ≈ 1 Mpc away
Visible universe ≈ 1 Gpc

Remember light time delay!!

Other fun numbers to impress people with
• $4\pi/3 \approx 4$
• $\log 2 \approx 0.3$, $\log \pi = 0.5$ (both to within <1%)
• $1 \text{ yr} \approx \pi \times 10^7 \text{ s}$
• $1 \text{ radian} \approx 60^\circ \approx 200,000''$
• $V_{\text{orb}} (\text{Earth}) \approx 30 \text{ km/s}; V_{\text{orb}} (\text{Sun}) \approx 220 \text{ km/s}$
• Solar constant $= L_\odot/4\pi(1 \text{ AU})^2 \approx 1300 \text{ W/m}^2$
• $1 \text{ W} \approx 6 \text{ eV/ps}$
• $1 \text{ eV} \times N_A \approx 10^5 \text{ J/mol}$
• $k \approx 9 \times 10^{-5} \text{ eV/K}$
Course Contact Information

• Instructor: Prof. Adam Burgasser (me!)
  – office hours: Th 10am-12pm in SERF 340

• Course TA: Ms. Petia Yanchulova
  – office hours MW 3-4pm in SERF 434

• website:
  http://pono.ucsd.edu/~adam/teaching/phys160/
## Course Syllabus (subject to change)

<table>
<thead>
<tr>
<th>Week (starting)</th>
<th>Chapters covered</th>
<th>Tuesday</th>
<th>Thursday</th>
</tr>
</thead>
<tbody>
<tr>
<td>0* (9/3)</td>
<td>NO LECTURE</td>
<td>Course introduction, cosmological context</td>
<td></td>
</tr>
<tr>
<td>1 (9/30)</td>
<td>1.3, 3.1-3.6</td>
<td>Observing Stars I: Magnitudes, blackbody radiation &amp; HR Diagram</td>
<td>Observing Stars II: Stellar astrometry and kinematics</td>
</tr>
<tr>
<td>3 (10/14)</td>
<td>8.1, 9.5</td>
<td>Stellar spectroscopy II: Boltzmann &amp; Saha eqns, line formation</td>
<td>Stellar interiors I: hydrostatic equilibrium, gravitational contraction</td>
</tr>
<tr>
<td>4 (10/21)</td>
<td>10.1-10.4</td>
<td>Stellar interiors II: nuclear energy</td>
<td>Stellar interiors III: energy transport, polytropes</td>
</tr>
<tr>
<td>5* (10/28)</td>
<td>10.5, 11.1-11.3</td>
<td>The Sun: interior structure, photosphere, magnetosphere</td>
<td>IN-CLASS EXAM</td>
</tr>
<tr>
<td>6 (11/4)</td>
<td>12.1-12.3</td>
<td>Brown Dwarfs</td>
<td>Star formation I: the interstellar medium, dark clouds, Jeans collapse</td>
</tr>
<tr>
<td>7 (11/11)</td>
<td>12.1-12.3 &amp; reading</td>
<td>Star formation II: pre-main sequence and main sequence evolution</td>
<td>Star formation III: disks &amp; jets, planet formation PROJECT OUTLINE DUE</td>
</tr>
<tr>
<td>9* (11/25)</td>
<td>16.1-16.5</td>
<td>Stellar death I: degenerate matter, white dwarfs, planetary nebulae</td>
<td>NO LECTURE</td>
</tr>
<tr>
<td>10* (12/2)</td>
<td>15.2-15.4, 16.6, 17.3</td>
<td>Stellar death II: supernovae, gamma ray bursts</td>
<td>Stellar death III: neutron stars and black holes PROJECT REPORT DUE</td>
</tr>
<tr>
<td>FINALS* (12/9)</td>
<td></td>
<td>PROJECT PRESENTATIONS THURSDAY 12/12 3-6PM</td>
<td></td>
</tr>
</tbody>
</table>
Expectations

• Class/recitation not required by strongly encouraged (participation grade will be based on contributions during these)
• Come to class prepared – do reading in advance, take a look at homework early – come with questions!
• Homeworks will involve computing and some programming – if you’ve never programmed, take an online course (e.g., google python)
• You may work on homeworks together but you cannot refer to past/online solutions (they are often wrong!)
• For your written course project, you must follow the university rules on plagiarism: see http://students.ucsd.edu/academics/academic-integrity/plagiarism.html
• Form a study group
Course text and other resources


• Secondary texts (available in SERF 3rd floor library)
  – *An Introduction to Stellar Astrophysics* by LeBlanc
  – *Stellar Structure and Evolution* by Kippenhahn & Weigert
  – *Structure and Evolution of Stars* by Schwarzschild
  – *Stellar Interiors: Physical Principles, Structure and Evolution* by Hansen, Kawaler & Trimble
  – *Principles of Stellar Evolution and Nucleosynthesis* by Clayton
  – *Sellar Astrophysics* Vol. 1-3 by Böhm-Vitense

• Websites:
  – Jim Kaler’s Stars site: http://stars.astro.illinois.edu/sow/sowlist.html
  – Astronomy picture of the day: http://antwrp.gsfc.nasa.gov/apod/astropix.html
Grading

• 40% Homework assignments
  – 7 assignments through quarter; lowest grade dropped
  – 4-6 written and calculation questions – may involve programming and data analysis
  – can work together but must hand in own assignment
  – cannot use online solutions, prior years’ solutions, etc.
  – assigned on Thursday and due following Friday at 5pm
  – late policy: 50% deduction up to Monday 5pm, 0% after that
  – first assignment now ONLINE due on Friday October 4th
Grading (cont)

• 20% Midterm exam
  – During lecture on Thursday Oct 31\textsuperscript{st}
  – Will cover material through week 5
  – essay and calculation questions
Grading (cont)

• 30% Term project
  – in-depth study of a topic covered in course
  – must be based on a primary source from a set that will be posted after the midterm (or one I approve)
  – 5% is a project proposal due Thurs Nov 14th in class: brief abstract describing topic, outline and sources – sell me on your project
  – 15% is a 5-10 page term paper due Thurs Dec 5th in class
  – 10% is a 5-7 min presentation during our “final” Thurs Dec 12th
  – this is an independent assignment; plagiarism rules will be strictly enforced
Grading (cont)

• 10% Class Participation
  – asking questions in class and participating in discussion
  – in-class assignments and exercises
  – come to class PREPARED – do the reading, look over the homework early
Grading (cont)

<table>
<thead>
<tr>
<th>Letter Grade</th>
<th>% Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≥ 90</td>
</tr>
<tr>
<td>B</td>
<td>80-90</td>
</tr>
<tr>
<td>C</td>
<td>70-80</td>
</tr>
<tr>
<td>D</td>
<td>60-70</td>
</tr>
<tr>
<td>F</td>
<td>&lt; 60</td>
</tr>
</tbody>
</table>

Grade appeals: must be sent in writing (email) no later than 1 week after grade is given

All grades will be posted on the course website
Other class activities

• Recitation section: W 2-3pm
  – homework help
  – make-up lectures
  – project help
• Local observing with small (10”) telescopes on campus – early in quarter
• Remote observing using the Nickel 1m Telescope (San Jose, CA) – at end of quarter
• MESA stellar coding software – we’ll get a chance to evolve a whole star!
No student shall...

- knowingly procure, provide, or accept any unauthorized material that contains questions or answers to any examination or assignment to be given at a subsequent time.
- complete, in part or in total, any examination or assignment for another person.
- knowingly allow any examination or assignment to be completed, in part or in total, for himself or herself by another person.
- plagiarize or copy the work of another person and submit it as his or her own work.
- employ aids excluded by the instructor in undertaking course work or in completing any exam or assignment.
- alter graded class assignments or examinations and then resubmit them for regrading.
- submit substantially the same material in more than one course without prior authorization.
Why are stars important?
Hawaiian Star Chart

Source: Polynesian Voyaging Society/Nainoa Thompson
http://pvs.kcc.hawaii.edu/ike/hookele/on_wayfinding.html
Elements after big bang

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Number</th>
<th>Mass Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Be</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Al</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>Silicon</td>
<td>Si</td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
<td>15</td>
<td>31</td>
</tr>
<tr>
<td>Sulfur</td>
<td>S</td>
<td>16</td>
<td>32</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl</td>
<td>17</td>
<td>35</td>
</tr>
<tr>
<td>Arsenic</td>
<td>As</td>
<td>33</td>
<td>75</td>
</tr>
<tr>
<td>Allegene</td>
<td>Se</td>
<td>34</td>
<td>80</td>
</tr>
<tr>
<td>Bromine</td>
<td>Br</td>
<td>35</td>
<td>79</td>
</tr>
<tr>
<td>Krypton</td>
<td>Kr</td>
<td>36</td>
<td>86</td>
</tr>
<tr>
<td>Rubidium</td>
<td>Rb</td>
<td>37</td>
<td>85</td>
</tr>
<tr>
<td>Strontium</td>
<td>Sr</td>
<td>38</td>
<td>88</td>
</tr>
<tr>
<td>Yttrium</td>
<td>Y</td>
<td>39</td>
<td>89</td>
</tr>
<tr>
<td>Zirconium</td>
<td>Zr</td>
<td>40</td>
<td>91</td>
</tr>
<tr>
<td>Niobium</td>
<td>Nb</td>
<td>41</td>
<td>92</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Mo</td>
<td>42</td>
<td>95</td>
</tr>
<tr>
<td>Technetium</td>
<td>Tc</td>
<td>43</td>
<td>98</td>
</tr>
<tr>
<td>Ruthenium</td>
<td>Ru</td>
<td>44</td>
<td>101</td>
</tr>
<tr>
<td>Rhodium</td>
<td>Rh</td>
<td>45</td>
<td>103</td>
</tr>
<tr>
<td>Palladium</td>
<td>Pd</td>
<td>46</td>
<td>104</td>
</tr>
<tr>
<td>Silver</td>
<td>Ag</td>
<td>47</td>
<td>107</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Cd</td>
<td>48</td>
<td>112</td>
</tr>
<tr>
<td>Indium</td>
<td>In</td>
<td>49</td>
<td>115</td>
</tr>
<tr>
<td>Tin</td>
<td>Sn</td>
<td>50</td>
<td>117</td>
</tr>
<tr>
<td>Antimony</td>
<td>Sb</td>
<td>51</td>
<td>121</td>
</tr>
<tr>
<td>Tellurium</td>
<td>Te</td>
<td>52</td>
<td>127</td>
</tr>
<tr>
<td>Iodine</td>
<td>I</td>
<td>53</td>
<td>126</td>
</tr>
<tr>
<td>Xenon</td>
<td>Xe</td>
<td>54</td>
<td>131</td>
</tr>
<tr>
<td>Rhenium</td>
<td>Re</td>
<td>75</td>
<td>186</td>
</tr>
<tr>
<td>Osmium</td>
<td>Os</td>
<td>76</td>
<td>190</td>
</tr>
<tr>
<td>Ruthenium</td>
<td>Ru</td>
<td>44</td>
<td>101</td>
</tr>
<tr>
<td>Iridium</td>
<td>Ir</td>
<td>77</td>
<td>192</td>
</tr>
<tr>
<td>Platinum</td>
<td>Pt</td>
<td>78</td>
<td>195</td>
</tr>
<tr>
<td>Gold</td>
<td>Au</td>
<td>79</td>
<td>197</td>
</tr>
<tr>
<td>Mercur</td>
<td>Hg</td>
<td>80</td>
<td>200</td>
</tr>
<tr>
<td>Thulium</td>
<td>Tm</td>
<td>69</td>
<td>168</td>
</tr>
<tr>
<td>Ytterbium</td>
<td>Yb</td>
<td>70</td>
<td>173</td>
</tr>
<tr>
<td>Lutetium</td>
<td>Lu</td>
<td>71</td>
<td>175</td>
</tr>
<tr>
<td>Lawrencium</td>
<td>Lr</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td>Rutherfordium</td>
<td>Rf</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>Dopplerium</td>
<td>Db</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>Seaborgium</td>
<td>Sg</td>
<td>106</td>
<td></td>
</tr>
<tr>
<td>Bohrium</td>
<td>Bh</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td>Hassium</td>
<td>Hs</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>Meitnerium</td>
<td>Mt</td>
<td>109</td>
<td></td>
</tr>
<tr>
<td>Seaborgium</td>
<td>Uun</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Ununnilium</td>
<td>Uuu</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>Unununnilium</td>
<td>Uub</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>Ununquadium</td>
<td>Uuq</td>
<td>113</td>
<td></td>
</tr>
</tbody>
</table>

*Lanthanide series

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Number</th>
<th>Mass Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lanthanum</td>
<td>La</td>
<td>57</td>
<td>138</td>
</tr>
<tr>
<td>Cerium</td>
<td>Ce</td>
<td>58</td>
<td>140</td>
</tr>
<tr>
<td>Praseodymium</td>
<td>Pr</td>
<td>59</td>
<td>140.92</td>
</tr>
<tr>
<td>Neodymium</td>
<td>Nd</td>
<td>60</td>
<td>144</td>
</tr>
<tr>
<td>Promethium</td>
<td>Pm</td>
<td>61</td>
<td>145.94</td>
</tr>
<tr>
<td>Samarium</td>
<td>Sm</td>
<td>62</td>
<td>150.41</td>
</tr>
<tr>
<td>Europium</td>
<td>Eu</td>
<td>63</td>
<td>151.96</td>
</tr>
<tr>
<td>Gadolinium</td>
<td>Gd</td>
<td>64</td>
<td>157.25</td>
</tr>
<tr>
<td>Terbium</td>
<td>Tb</td>
<td>65</td>
<td>158.93</td>
</tr>
<tr>
<td>Dysprosium</td>
<td>Dy</td>
<td>66</td>
<td>162.50</td>
</tr>
<tr>
<td>Holmium</td>
<td>Ho</td>
<td>67</td>
<td>164.93</td>
</tr>
<tr>
<td>Erbium</td>
<td>Er</td>
<td>68</td>
<td>167.26</td>
</tr>
<tr>
<td>Thulium</td>
<td>Tm</td>
<td>69</td>
<td>168.93</td>
</tr>
<tr>
<td>Ytterbium</td>
<td>Yb</td>
<td>70</td>
<td>173.04</td>
</tr>
</tbody>
</table>

**Actinide series

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Number</th>
<th>Mass Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actinium</td>
<td>Ac</td>
<td>89</td>
<td>227</td>
</tr>
<tr>
<td>Thorium</td>
<td>Th</td>
<td>90</td>
<td>232</td>
</tr>
<tr>
<td>Protactinium</td>
<td>Pa</td>
<td>91</td>
<td>231</td>
</tr>
<tr>
<td>Uranium</td>
<td>U</td>
<td>92</td>
<td>238</td>
</tr>
<tr>
<td>Neptunium</td>
<td>Np</td>
<td>93</td>
<td>239</td>
</tr>
<tr>
<td>Plutonium</td>
<td>Pu</td>
<td>94</td>
<td>244</td>
</tr>
<tr>
<td>Americium</td>
<td>Am</td>
<td>95</td>
<td>243</td>
</tr>
<tr>
<td>Curium</td>
<td>Cm</td>
<td>96</td>
<td>247</td>
</tr>
<tr>
<td>Berkelium</td>
<td>Bk</td>
<td>97</td>
<td>251</td>
</tr>
<tr>
<td>Californium</td>
<td>Cf</td>
<td>98</td>
<td>252</td>
</tr>
<tr>
<td>Einsteinium</td>
<td>Es</td>
<td>99</td>
<td>253</td>
</tr>
<tr>
<td>Fermium</td>
<td>Fm</td>
<td>100</td>
<td>257</td>
</tr>
<tr>
<td>Mendelevium</td>
<td>Md</td>
<td>101</td>
<td>258</td>
</tr>
<tr>
<td>Nobelium</td>
<td>No</td>
<td>102</td>
<td></td>
</tr>
</tbody>
</table>
Elements made in stars

Maximum binding energy per nucleon

* Lanthanide series
  - La
  - Ce
  - Pr
  - Nd
  - Pm
  - Sm
  - Eu
  - Gd
  - Tb
  - Dy
  - Ho
  - Er
  - Tm
  - Yb

** Actinide series
  - Ac
  - Th
  - Pa
  - U
  - Np
  - Pu
  - Am
  - Cm
  - Bk
  - Cf
  - Es
  - Fm
  - Md
  - No
Elements made in stellar death

Maximum binding energy per nucleon

* Lanthanide series
  La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb

** Actinide series
  Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No
From Martinez-Delgado et al. (2010)
Dark Matter: more mass than is visible traced by stellar velocities

M33 rotation curve

image courtesy the University of Sheffield
General Relativity:
Eddington’s 1919 Solar Eclipse Measurement Confirms GR

Supernovae: Tracers of Dark Energy

Stars cover a lot of physics!

Figure 1.1  Figure illustrating the various fields of physics that intervene in stars.

From An Introduction to Stellar Astrophysics by Francis LeBlanc
Numbers you should know: The Sun

Mass ≈ $2 \times 10^{30}$ kg = $1 \, M_{\odot}$
Radius ≈ $7 \times 10^8$ m = $1 \, R_{\odot}$
Distance = $1.5 \times 10^{11}$ m = $1 \, AU$
Luminosity = $4 \times 10^{26}$ W = $1 \, L_{\odot}$
Surface temperature = 5800 K
Age ≈ 4.5 Gyr
Spectral type = G2 V

All other stars are scaled to these parameters for convenience.

source: SOHO/EIT

How do we know these numbers?
Other stars

Masses: 0.005 - 300 M⊙
Radii: 0.1 - 2000 R⊙
Luminosities: 10⁻⁷ – 10⁷ L⊙
Temperatures: 300 – 40,000 K

Image courtesy ESO: http://www.eso.org/public/images/eso1030c/
More good numbers to just know

- $1 \text{ pc} \approx 3 \times 10^{16} \text{ m} \ (\approx 1 \text{ AU}^2!)$
- $1 \text{ yr} \approx \pi \times 10^7 \text{ s}$
- $\log 2 = 0.3; \log \pi = 0.5$ (accurate to within 1%)
- $1 \text{ radian} \approx 60^\circ \approx 200,000''$
- $V_{\text{orb}} \ (\text{Earth around Sun}) \approx 30 \text{ km/s}$
- $V_{\text{orb}} \ (\text{Sun around Galaxy}) \approx 220 \text{ km/s}$
- Solar constant: $L_\odot/4\pi(1 \text{ AU})^2 \approx 1300 \text{ W/m}^2$
- $m_p c^2 = 938 \text{ GeV}, \ m_n c^2 = 939 \text{ GeV}$ (note difference!)
- $1 \text{ W} \approx 6 \text{ eV/ps}$
- $1 \text{ eV} \times N_A \approx 10^5 \text{ J/mol}$
- $k \approx 9 \times 10^{-5} \text{ eV/K}$