Designing an observational program for the One Degree Imager on the WIYN 3.5m telescope that will probe the physical properties of the Kuiper Belt objects in the outer solar system.
Probing Planetary Interiors

- Mean density/surface density
- Moment of inertia \((I = kMR^2)\)
  - Hollow sphere, \(k = 0.67\)
  - Sphere with a core, \(k=0.35\)
  - Homogeneous sphere, \(k=0.4\)
- Magnetic field \(\rightarrow\) how?
- Geological activity (e.g. seismic data)
- Mean crater density
- Physics of matter at various densities
  - How large/small can you make a gravitationally bound object out of H and He? Si? Fe?
Ways of studying planetary interiors

- **In situ probes of interior**
  - “Earth”quakes
  - Variation of sound speed in different media

- **Remote probes of the interior**
  - Geological activity → indicates molten interior
  - Past geological activity/crater density → indicates previously molten interior
  - Global magnetic field → dynamo
  - gravity
  - Moment of inertia ($I=kMR^2$, where $0 < k < 1$)
    - $L = I \times \omega$ (angular momentum) → this is observable
    - $I = \iiint \rho(r) d_c \, dr$ ($d_c = \text{distance from axis in question}$)
    - So angular mo reflects the distribution of mass within the planet → requires accurate measurements of $L$
Distribution of Elements in Earth

- Starting assumption $\rightarrow$ accretion (of what?)
  - Net loss of volatiles
  - Chemical differentiation (but can you estimate the degree to which the Earth was molten enough to allow for differentiation?)

- Current best guess
  - Inner core – largely Fe
  - Outer core – lower density, maybe some K?
  - Mantle – partially molten, chemically inhomogeneous
What’s a “basalt”?  
- One flavor of igneous rock

Mid-Ocean Ridge Basalt (MORB)
- Depleted in “incompatibles”
- Differentiated → primitive?

Ocean Island Basalt (OIB)
- Less depleted/not primitive
- Originates deeper in mantle → recycled crust?
Heat Sources

- Accretion $\rightarrow$ kinetic energy of impacts $\rightarrow$ melting
  - $v_{\text{collision}} \sim v_{\text{escape}} \rightarrow E_{\text{accretion}} \sim GM/R$
  - Per mass $\rightarrow E/m = (GM/r^2)dr = -GM/R_s$
  - Heating via conductivity $= \rho c_p \Delta T$, but some gets radiated away so
    - $\rho \Delta Tc_p = [(GM/R) - \sigma(T_4^4(r) - T_\infty^4)]$

- Differentiation $\rightarrow$ just gravity
- Radioactivity $\rightarrow$ very important
Sources of Heating

- Accretion – kinetic energy of impacts $\rightarrow$ melting
- Differentiation – release of gravitational thermal heat
- Radioactivity (particularly K, Ur, Th)
Radioactivity

- **Key elements: K, Ur, Th**
  - $^{238}\text{U} \to ^{206}\text{Pb} + 8\text{He} + 6\beta$ (4.5 Gyr, $\sim 3$ J g$^{-1}$ yr$^{-1}$)
  - $^{235}\text{U} \to ^{207}\text{Pb} + 7\text{He} + 7\beta$ (0.7 Gyr, $\sim 19$ J g$^{-1}$ yr$^{-1}$)
  - $^{237}\text{Th}$, $^{40}\text{K}$ both yield $\sim 0.9$ J g$^{-1}$ yr$^{-1}$

- **Lifetime is limited**
  - $-(dP/dt) = (dD/dt)\lambda P \to -\ln(P) = \lambda t + \text{constant}$
  - $\ln(P) - \ln(P_0) = \lambda \to t = (1/\lambda)\ln((D-D_0)/P + 1)$

- For Earth radioactive heating was $\sim 10$ times more important right after formation than it is now
Distribution of Elements

- **Starting assumption → formation by accretion**
  - Net loss of volatiles

- **Differentiation**
  - Chemical → siderophiles vs lithophiles
  - Physical → denser material sinks

- **Inner core density → solid Fe**

- **Outer core density → lower density, liquid, Fe plus something else (K?)**

- **Mantle → partially molten, chemical inhomogeneous**
  - Mid-ocean ridge basalt (MORB) → differentiation, more pristine?
  - Ocean Island Basalt (OIB) → less depleted, not primitive?
Chemical Heterogeneity

- Implies differentiation
  - Accretion heats, Fe sinks
  - Differentiation (20-30 Myr post formation)
  - Density isn’t only parameter → chemically, which elements stick to which other elements?
- Guiding question → what do elemental ratios tell us about the history of the accretion/differentiation process?
- Relative (not absolute) abundances are key
Case Study: Mercury

- Hey! There’s a magnetic field!!!!
  - Mariner 10 flybys detected field – but it’s weak (a factor of 10000 too weak for a normal dynamo)
- One solution – convective circulation in the mantle
- Another solution – its all residual
The interesting part is: how do you build a model of the interior of a terrestrial planet?
The interesting part is: how do you build a model of the interior of a terrestrial planet?

- Heat transport — convection and conduction
  - Do it in 1-dimension with shell overlaying core
- Inner core growth/cooling
  - Growth $\Rightarrow$ release of gravitational heat
- Composition
  - Radioactive heating, chemical differentiation
- Response of lithosphere
Mercury

In the end you get .....