Astronomy 288C

Special Projects in Astronomy:
Astronomy Research Techniques
Calibration
Calibration

- Absolute
- Relative
- Stability
- Offset
- Gain
Relative Calibration

• Time stability
• Detector to Detector
• Band to band
• Differential receivers
Differential Receivers

Differential receivers (often single mode heterodyne systems) intrinsically look at the difference between different parts of the sky (different places or polarizations). This reduces the stability requirements by a factor of 1000. The gain estimation is often done using the dipole as a calibration source. Alternatively the motion of the Earth/spacecraft can be used as the motion is often known to high precision. The signal then is small (~30 km/s or .01% of the CMB temperature ~300 uK)

Must watch for differential gain errors
This in turn requires high gain stability in order to integrate long enough to sense the small signals.
Easier on spacecraft than on balloon craft.
Time Stability

- Offset stability critical to get signal
- Gain stability critical to measure gain
- 1/f drift in transistors
- Thermal drift in detector (thermal stability)
- Thermal drift in electronics (thermal stability)
- Magnetic pickup (fit out magnetic signature)
- Cosmic ray damage accumulation
Detector to Detector

- Same band?
- Pointing?
- Beam shape?
- Common mode errors?
Band to Band

• Requires knowledge of source spectrum
• Requires gain stability of all bands
• Variation can be used to estimate spectra of variable bands
• Need absolute calibration to estimate uniform background spectra
• Used for estimating source spectrum
Absolute Temperature

- Black body (how black, what temperature)
- Full beam (reflector temps, emissivity)
- Cold load extrapolation (77K-4.2K)
- Stability of transfer standards
Calibration Techniques: Chopping

- Dicke Switch-High speed chopping between source and reference
- Reference well known and near source intensity
- On-Off chopping for point sources on sky
- Lissajous patterns
- Polarization chopping
- Correlation receivers
Calibration Techniques: Coordinate Transformation

- Equatorial, Ecliptic, Galactic coordinates
- Magnetic, Earth limb, Solar, Lunar, Thermal, spin, coordinates
- Fourier transforms
- Simultaneous solutions, iterative solutions
- Calibration solutions: Induce signal
Calibration Techniques: Cross Calibration

- Use previous measurement to calibrate: DIRBE, FIRAS, WMAP
- Use other bands to calibrate
Calibration Techniques: Using models

- Use source models (Mars)
- Use line emission (C+)
- Use known source spectra (synchrotron)
- Use known spacecraft velocities
- Generate models of telescope
Calibration Problems
Solution

• Simultaneous solution may require large matrix inversion (eg $10^6 \times 10^6 \times 10^{18}$ operations)
• Iterative solutions may not converge or convergence may not be unique
• Solutions may require high mathematical precision
• Solutions may be hard to explain
Calibration Problems
Uncertainty

• Uncertainty is often the square of the solution problem \((10^{36} \text{ operations!})\)
• Uncertainty matrix is large
• Uncertainty is model dependant
• Uncertainty is not symmetric
• Uncertainty is hard to explain
Calibration Problems
Jackknifing

• Divide data into two sets and consider: \((A+B)/2\) and \((A-B)/2\)
• Do the two sets have the same errors?
• Are the errors correlated?
• Is there another way to divide the data?
Calibration Problems

$c^2$ tests

- $c^2$ or $c^2$/DOF
- 1% error sounds good but
- 1% of 100,000 DOF is 1000 which is huge $c^2$
- Is it plausible that the errors are aligned with what you want to measure
Calibration uncertainty
Hide or show

• Hiding calibration uncertainty dishonest?
• Hiding calibration uncertainty leads to confusion
• Hiding calibration uncertainty leads to data misuse
• Showing calibration uncertainty focuses on the uncertainty
• Showing calibration uncertainty may be hard
FIRAS uncertainty

- D uncertainty
- PEP uncertainty
- PUP uncertainty
- PTP uncertainty
- JCJ uncertainty
FIRAS Uncertainty

• D uncertainty: detector readout noise
• Measured by comparing multiple measurements of the same pixel
• Measured by looking at the imaginary part of the interferogram
• Almost independent, dependence understood as a result of apodization
• Easy to deal with
FIRAS Uncertainty

- PEP uncertainty: Calibration errors propagated to the gain(frequency)
- Correlated over the full sky
- Can be treated as an overall gain uncertainty
- Easy to describe
- Easy to apply
FIRAS Uncertainty

- PTP uncertainty: Error in calibrator thermometer propagated to the sky
- Simple temperature error
- Simple to apply for Temperature measurements
- Huge compared to other errors
- Does not apply to differential measurements
FIRAS Uncertainty

• PUP uncertainty: Errors of internal reference thermometer readout propagated to data
• Does not apply to absolute measurements
• Almost temperature but hot horn season
• Correlated in frequency but not in space (so much)
• Harder to apply to data
FIRAS Uncertainty

• JCJ uncertainty: Detector model errors propagated to sky measurements
• Model parameter dependant
• Nonlinear model => parameter dependent
• Frequency dependent
• Model dependent
• Post calibration corrections
• Complex shape, hard to apply, often confused
SCHEDULE – subject to revision

- Sep 9 Introduction and Overview, Astronomy Basics
- Sep 16 Astronomical Sources and Backgrounds
- Sep 23 IR & Microwave Astronomy
- Sep 30 Gamma-ray Generation and Detection
- Oct 7 IR & Microwave Data Analysis
- Oct 14 Gamma-ray Sources and Signatures
- Oct 21 The Research Process
- Oct 28 Foreground Subtraction
- Nov 1 Gamma-ray data analysis
- Nov 11 Microwave Ballooning
- Nov 18 Multi-wavelength Astronomy
- Nov 25 Science Communication and Paper Writing
- Dec 2 Dedicated Time for Research Projects
- Dec 9 Dedicated Time for Research Projects