Astronomical Observational Uncertainties

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Introduction
Uncertainty in Astronomy

- Limits to current level of understanding of a phenomenon
- Phenomenon complexity
- Restrictions in instrumentation
- Observer bias
- Observer experience
- Observing conditions
Astrostatistics

- Astrostatics addresses uncertainty with statistical analyses and data mining of astronomical data.

- Astrostatistics community
  - Astronomers and astrophysicists
  - Statisticians
  - Computer information scientists

- Organizations
  - The International Astrostatistics Association (IAA)
  - International Statistics Institute (ISI) Astrostatistics Committee
  - Astrostatistics Working Groups of the International Astronomical Union (IAU)
  - American Astronomical Society (AAS)
Astrostatistics Projects

- Water on Mars
- Sunspot counts
- Mira masers
- Interstellar regional density and star formation
- Radio-Active Galactic Nuclei and the early universe
Locating Water on Mars
Water Location Hypothesis

- Impact crater ejection layer patterns indicate surface or subsurface water
- More than one layer surrounding an impact crater suggests water interacting with ejected soil
- Layers with radial patterns have little to no water in the soil
- Compare spatial distributions of multi-layer ejecta to radial ejecta spatial distributions
- Radial ejecta the "control" group
- May be applicable to other moons and planets
Radial ejecta spatial distribution

Mean Density of 1 < 3 km Craters/Degree

Latitude (-90,+90)

Longitude (-180,+180)
Double layer ejecta spatial distribution

Mean Density of $0 < 3.32$ km Craters/Degree

Latitude $(-90, +90)$

Longitude $(-180, +180)$
Sunspot Counts
Solar activity visually and in X-rays

A visible light image (left) and an X-ray image (right) of the sun.
Sunspot Numbers

- Sunspot counts vary by observer, weather conditions, place in the sunspot cycle, etc.
- Monthly estimates are from a mixed effects, loglinear model constructed from these Poisson-distributed count data.
- This model differs from existing models used by AAVSO and SILSO.
- The loglinear model methodology meets or exceeds established performance criteria.
- Loglinear model addresses uncertainty explicitly unlike the implicitness of AAVSO.
Daily sunspot counts for June, 2014

201406 RawMinAvgMax Minimum, Average, and Maximum vs Day

Counts: black dashed = minimum, red solid = average, blue dashed = maximum.
Sunspot counts from May 2010 through June 2014

Loglinear Mixed Model Fit, AAVSO, and SILSO Values vs Sequence
Boxes and whiskers represent unprocessed counts
Mira Masers and Proto-Planetary Nebulei
OH/IR Stars

- An OH/IR star is an evolved late type star showing OH maser emission which is bright at near infrared wavelengths.
- Miras with short pulsation periods (about one year) and low mass loss rates produce weak masers in the 1667 MHz line.
- Miras with a high mass loss rate and long pulsation periods (up to six years), the 1612 MHz hydroxyl masers becomes much stronger than the 1667 masers.
- Known as OH/IR stars for their strong hydroxyl (OH) masers and strong infrared (IR) emission from the shell of warm gas.
- The intensity of the maser follows the changing brightness of the star as it pulsates.
OH/IR Star: Asymptotic giant branch star with dust-rich wind and 18 cm OH maser emission
Proto-Planetary Nebula

- A proto-planetary nebula (PPN) is a star with rapid stellar evolution.
- Falls between the late asymptotic giant branch phase and the subsequent planetary nebula phase.
- A PPN emits strongly in infrared radiation.
- It is the second-from-the-last high-luminosity evolution phase in the life cycle of intermediate-mass stars (1-8 Solar masses).
Cat’s Eye Nebula

Example of young planetary nebula with bipolar structure (optical/X-ray image)
Observations with Arecibo

- OH/IR star (IRAS 16260+3454) in 18 cm (on, L-band) and 5 GHz (on, C-band)

- Calibration source (B1622+23) for 5 GHz (position switching)

- PPN (IRAS 18095+2704) in 18 cm (on) and 5 GHz (position switching, three 5 minute integrations)
Radio Telescope, Arecibo, PR
Calibrating the 5 GHz scale to mJy for each of the three lines and each of their polarizations

- **Traditional analysis**
  - Formed weighted average of the three integrations for each line
  - Removed polynomial baseline of order 2

- **Improved analysis**
  - Linear model of three integrations and six lines
  - Accounts for within and across variation

- Plotted intensity vs. velocity
Results: OH/IR Star

- **Lines Plotted**
  - 1612.2 MHz
  - 1665.4 MHz
  - 1667.4 MHz
  - 4660.2 MHz
  - 4750.7 MHz
  - 4765.6 MHz

- (Note: Scans displaced vertically by 20 mJy for display)
Results: Proto-Planetary Nebula

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  - 1612.2 MHz
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Intermediate- and High-Mass Star Formation
Hubble telescope image of “Pillars of Creation”, where stars are forming in the Eagle Nebula
We wish to understand the factors governing the transition from intermediate- to high-mass star formation.

Arvidsson, et. al., (2010), identified for the first time Intermediate-Mass Star-Forming Regions (IMSFRs) of from 5 to 8 solar-mass stars.

InfraRed Astronomical Satellite observations, Spitzer Space Telescope mid-InfraRed (IR) images, and millimeter continuum were used to compile a sample of 28 IMSFRs in the inner Milky Way.

IR luminosity and molecular mass of IMSFRs are consistent with known luminosity-mass relationships.

Peak mass column densities within IMSFRs are \( \sim 0.05 - 0.5 \, g/cm^2 \), lower than most Ultra-Compact HII regions (UCHII).
Column density of a simulated protostellar core 20,000 years after the beginning of gravitational collapse.

(http://www.nersc.gov/news/science/high-mass-star.php)
Histogram Overlaid with Fitted Gamma Distribution

IMSFR Distribution

Density

IMSFR

Fitted gamma(0.075, 1.565)
Histogram Overlaid with Fitted Gamma Distribution

UCHII Distribution

Fitted gamma(1.77, 1.483)
Box Plots of IMSFR and UCHII Data

Box Plot of Column Density by Region

Sample sizes: IMSFR = 28, UCHII = 33
Random Effects Model Means Also Clearly Different

**Box Plot of Natural Log of Column Density by Region**

- **Region**
  - IMSFR
  - UCHII

**Sample sizes**:
- IMSFR = 28
- UCHII = 33

**Note**: The box plot shows the distribution of the natural log of column density across different regions, highlighting the differences in means.
Region Demarcation

- Does high-mass star formation occur only if the mass column density is $\geq 1 \text{g/cm}^2$?
- Does intermediate-mass star formation only occur if the mass column density is $< 1 \text{g/cm}^2$?
- Given observation uncertainties of a factor of 2, is $1 \text{g/cm}^2$ a reasonable high mass threshold?
- What can be said of a threshold of $0.7 \text{g/cm}^2$?
- If the sample size is increased in each sample, how does the conclusion change?
Region Probabilities

Table: Includes Observing Error

<table>
<thead>
<tr>
<th>i</th>
<th>$\rho_i$</th>
<th>$P(\text{IMSFR} \mid \rho &gt; \rho_i)$</th>
<th>$P(\text{UCHII} \mid \rho &lt; \rho_i)$</th>
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<td>0.0000</td>
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<tr>
<td>6</td>
<td>2.00</td>
<td>0.0000</td>
<td>0.4860</td>
</tr>
</tbody>
</table>
Conclusion

- Decide a high-mass star formation threshold and the physics behind it
- Request a statistical argument (have a bunch of astrophysical ones) to address the threshold question
- Does the overlap of densities depend on the number of massive stars in the region?
- What is a suitable sample size (design)?
Intermediate and High Mass Star Formation
Radio-Active Galactic Nuclei Cosmology
Herschel AGN radiogalaxy
What is a Radio-Active Galactic Nucleus?

- An active galactic nucleus (AGN) is a compact region at the center of a galaxy that has a much higher than normal luminosity, specifically radio emission.
- A galaxy hosting an AGN is called an active galaxy.
- The radiation from AGN is believed to be a result of accretion of mass by a supermassive black hole at the centre of its host galaxy.
- Radio-AGN evolution is a function of cosmic time also puts constraints on models of the cosmos.
- Simulated radio-AGN universe catalogs are generated, then compared to the observed radio-AGN galaxy catalog.
- The simulated catalog has flux density and lobe separation effects are compared to the corresponding observed radio-AGN catalog.
Herschel AGN radiogalaxy

Sustaining Scatter Plot

Opposing Scatter Plot

Real

corr=0.79

Real

corr=0.05

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