Multi-\(\lambda\) spectroscopy requirements

Anita Richards with thanks to AstroGrid, IVOA & RadioNet

- Using VO standards and models
  - Science cases - SEDs from radio to Xray
    - Stellar IMFs, Gould Belt etc.
    - Obscured AGN and starbursts in GOODS
- Are data and tools available?
- Can you find them?
- Handling radio data
  - Spectral cubes
  - Polarization
- High-resolution radio maser spectra
  - Megamasers as magnetic & kinematic probes
- Summary
Science cases

• Identifying massive young stars
  • IMF (VOTech), Gould Belt (AstroGrid)
  • Data: UV-optical-IR-radio photometry, IR-mm lines
    - Waveband, resolution, sensitivity limits/saturation
    - Accuracy
  • Models: SVO, Mocassin
  • Tools
    - Astrometry
    - Convert to physical units, find $\lambda_{\text{eff}}$, dereddening
    - Fit data to models - YAFIT
    - Identifying lines (interactive only)

• Obscured AGN and starbursts in GOODS
  • Identify obscured AGN/QSO Padovani et al. 04
    - Similar requirements + X-ray (not yet counts>flux)
Science cases

- Obscured AGN and starbursts in GOODS
  - Identify obscured AGN/QSO Padovani et al. 04
  - Similar requirements + X-ray (not yet counts>flux)
High-z radio starbursts in HDF(N) host obscured AGN

- 18 X-ray-selected AGN have radio counterparts, 11 are radio starbursts (*Richards et al '07 in prep*)
- GOODS images and catalogues (*HST, Chandra*)
  - Cross-matching, astrometry
- Spitzer format issues
- Redshifts from literature, Team Keck
- Classify morphologies
- Radio source extractor/cutout server under dev.
- Make luminosities, spectral/photon indices
- Full radio-IR-X-ray fitting to SEDs
  - Classification
  - Redshift estimation
High-z radio starbursts in HDF(N) host obscured AGN

- Good images and catalogues (HST, Chandra)
- Cross-matching, astrometry
- Spitzer format issues
- Redshifts from literature, Team Kick
- Classify morphologies
- Radio source extractor/cutout server under development
- Make luminosities, spectral/photo indices
- Full radio-IR-X-ray fitting to SEDs - Classification - Redshift estimation

x-ray optical radio
Finding tools and data

• IVOA Registry standards and schema
  • Data collections
  • Tools and services
• URL, nature of service
  • Contact person
• Data Coverage
• Any limits on No. objects etc.
• Data quality/calibration state self-score
• Model is fine for data, just not used properly!
  • Description of tools is weaker
• Most fields often left blank
  • Is model too complex?
  • Are curators unaware of problems?
    - Lack of imagination that potential use is so wide?
VO Explorer

- AstroGrid workbench
- Only as good as the metadata!
Figure 1: UML class diagram for the spectral data model. The Coverage, Curation, DataID classes are shown in detail below in Section 4, both in diagram form and text descriptions. The text descriptions are definitive. The minimal required content is:

- Spectrum model version
- Target name
- Characterization Coverage.Location and Coverage.Bounds (Extent or Start/Stop range) descriptions of the location and extent of the data in the RA, Dec, time and spectral domains
- the Curation.Publisher field
- the descriptions of the spectral coordinate and flux fields including UCD and units (Spectrum.Char.SpectralAxis, Spectrum.Char.FluxAxis)
- For each point: the values of the spectral coordinate and flux.
Spectrum, Char etc. models

- Data models for complex relationships, detailed descriptions, uncertainties etc.
  - Used by VO experts
  - Scare small archives/tool developers?

- Stress heirarchical structure
  - Start with simple description
  - Add detail as required

- Need tools to fill in/validate
  - FITS header extracters e.g. VOQuest, AstroGrid tool
  - New Char tool CAMEA
  - DB data (including obs/image/spectrum logs)?
Char etc. models

- Data models for complex relationships, detailed descriptions, uncertainties etc.
- Used by VO experts
- Scare small archives/tool developers?
- Stress heirarchical structure
  - Start with simple description
  - Add detail as required
- Need tools to fill in/validate
  - FITS header extracters e.g. VOQuest, AstroGrid tool
  - New Char tool CAMEA
  - DB data (including obs/image/spectrum logs)?
# Data model MKN 273 @ 18 cm

<table>
<thead>
<tr>
<th>General frame/units</th>
<th>Spatial frame/units</th>
<th>Temporal</th>
<th>Spectral</th>
<th>Observable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>ICRF, deg</td>
<td>MJD</td>
<td>MHz</td>
<td>Jy/beam</td>
</tr>
<tr>
<td></td>
<td>13.123456 +55.987654</td>
<td>50613.5</td>
<td>1600</td>
<td>undef</td>
</tr>
<tr>
<td>Bounds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.92, +55.58</td>
<td>50613.0</td>
<td>1592</td>
<td>0.0002 0.5 (or function)</td>
</tr>
<tr>
<td></td>
<td>13.32, +56.38</td>
<td>50614.0</td>
<td>1608</td>
<td></td>
</tr>
<tr>
<td>Support</td>
<td>ICRF, deg</td>
<td>(scan listing URL)</td>
<td>1593</td>
<td>undef</td>
</tr>
<tr>
<td></td>
<td>13.123456 +55.987654</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>f(support, 1ary beam)</td>
<td>undef</td>
<td>(BP LUT URL)</td>
<td>1</td>
</tr>
<tr>
<td>Filling Factor</td>
<td>1</td>
<td>0.7</td>
<td>0.93</td>
<td>undef</td>
</tr>
<tr>
<td>Resolution</td>
<td>0”’.2 2”’.0</td>
<td>5 m</td>
<td>125 kHz</td>
<td>50 100 µJy/beam</td>
</tr>
<tr>
<td></td>
<td>0”’.2 2”’.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sampling</td>
<td>0”’.04 0”’.0625</td>
<td>16 s</td>
<td>125 kHz</td>
<td>undef</td>
</tr>
<tr>
<td></td>
<td>0”’.04 0”’.0625</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Data model MKN 273 @ 18 cm

<table>
<thead>
<tr>
<th>General frame/units</th>
<th>Spatial frame</th>
<th>Temporal MJD</th>
<th>Spectral MHz</th>
<th>Observable Jy/beam</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>ICRF, deg</td>
<td>50613.5</td>
<td>1600</td>
<td>undef</td>
</tr>
<tr>
<td></td>
<td>13.123456 +55.987654</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bounds</strong></td>
<td>ICRF, deg</td>
<td>50613.0</td>
<td>1592</td>
<td>0.0002 0.5 (or function)</td>
</tr>
<tr>
<td></td>
<td>12.92, +55.58 13.32, +56.38</td>
<td></td>
<td>1608</td>
<td></td>
</tr>
<tr>
<td><strong>Support</strong></td>
<td>ICRF, deg</td>
<td>(scan listing URL)</td>
<td>1593 1607</td>
<td>undef</td>
</tr>
<tr>
<td></td>
<td>13.123456 +55.987654 0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

• Also need
  • Line rest frequencies
    - e.g. 1665.359, 1667.402 MHz
  • Reference v, inferred velocity, convention
    - e.g. 1600.125 MHz, 12370 km/s, radio V_{LSR}
**OH megamaser polarization**

- Ultra-sensitive, very high ν-resolution Arecibo spectra
- Needed to measure Zeeman splitting ~10 kHz
- Masing region unresolved in arcmin beam
- Compare with high spatial resolution interferometry
- δν ≥125 kHz, total intensity, milli-arcsec beam
- Gaussian decomposition of spectrum wrt spatial features (*Robishaw & Heiles 2007*)
  - Typical magnetic field 3 mG in ULIRGS so far
    - Constrain equipartition
    - Contrast Starburst & Milky Way star formation
- Need published interferometric data for more sources!
OH megamasers polarization

- Ultra-sensitive, very high ν-resolution Arecibo spectra
- Needed to measure Zeeman splitting ~10 kHz
- Masing region unresolved in arcmin beam

Examples of Arecibo OH megamasers
OH megamasers spatial distribution

Identify spectral and spatial peaks in interferometric cube
Decompose spectrum

MKN 273 maser clump

1667 MHz
- Clump 1
- Clump 2

1665 MHz
- Clump 1
- Clump 2

\[ V_{\text{LSR}} \text{ w.r.t } 1667.359 \text{ MHz (km s}^{-1}\text{)} \]

- \( 1.05 \times 10^4 \)
- \( 1.1 \times 10^4 \)
- \( 1.15 \times 10^4 \)

Flux (Jy)

Observing frequency (MHz)

Maser component flux (mJy/beam)

Relative velocity (km s\(^{-1}\))

Markarian 273 MERLIN spectrum
More NGC 4258's

- $H_2O$ maser proper motions
- Sub-pc Keplerian disc
- Constrains distance, BH mass
- New candidates (*Braatz 07*)
- Full interpretation uses masers as probes of kinematics and environment
- Also need multi-$\lambda$ continuum (radio VLBI, HST, Spitzer...) to investigate cause of warps, accretion-jet ejection relation (BH feeding) etc. etc.
Datacube manipulation

- Aladin good for viewing
- GAIA more quantitative
- No VO tool understands Jy/beam yet
- Want to extract spectra, make moments, spectral index maps etc.
- VO interface to specialised software cf MERLINImager
- Interface in astronomical terms
  - Position, freq. resolution etc.
  - Not AIPS jargon!
Datacube manipulation

- Aladin good for viewing
- GAIA more quantitative
- No VO tool understands Jy/beam yet
- Want to extract spectra, make moments, spectral index maps etc.
- VO interface to specialised software cf MERLINImager
- Interface in astronomical terms
  - Position, freq. resolution etc.
  - Not AIPS jargon!
- AstroGrid CEA passes parameters to archive service
- RadioNet parselTongue (python-based) finds data, runs appropriate software to make data products
- AstroGrid manages data flow
  - SSA/SIAP-like list of products & metadata returned to user
  - Bulky data only moved when needed
Radio surveys (very incomplete list)

- Gathering information on RadioNet for DCA census
  - LEDA (incl. Nancay) - some VO available
  - Efflesberg/Bonn - some own web services
  - Many single-dish archives - need calibration etc.
- Arecibo, Puschino, NRAO, ATNF, Nobeyama...
- Dedicated surveys e.g. Methanol
  - Torun and other blind surveys - extracted parameters may be in literature
- JBO/Parkes MMB survey committed to VO publication (also CORNISH 5-GHz continuum) - GLIMPSE area
- Cubes:
  - HIPASS/HIJASS - ongoing
  - MERLIN, EVN, VLA pipelines will eventually do line data
- Need appropriate tools and interfaces
Summary and proposals

- Development of standards should be use-driven
- Provide simple levels, make complexity optional
  - Try for all appropriate data with minimum selection of waveband (radio, mm, IR, optical etc.)
  - $\lambda$ resolution desirable for spectra...
  - Full passband, photometry nice but don't hang up!
- Improve tool descriptions
  - Allow automated/workflow use
- Model should include (optional!) polarization, Jy/beam ...
- Specialised data handling best done at archives
- Must give non-experts at least some calibrated data
- Provide VO interfaces
  - e.g. remote user-steered non-jargon pipelines
  - Minimise moving massive datasets
- Results: from finding proto-planets to measuring BHs