Combined Atlas of Sources with Spitzer/IRS Spectra (CASSIS)

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Motivations

- Provide science-ready* IRS spectra (5-38 µm)
- Improve legacy value and maximize scientific return (easy access, facilitating homogeneous analysis of large consistent datasets...)
- Limit specific software need to non-standard extractions
- Reference for future missions (complement in wavelength, reference for deeper/higher-resolution observations, sample building...)

How it was made possible

- Instrument knowledge and techniques accumulated over the years & well after the end of the cold mission
- Automation of reduction/extraction techniques + new methods (optimal extraction)
- Some inspiration from the FUSE spectral database at IAP
My involvement

August is a good month for job talks...

Fig.: #1: Ithaca in the summer is beautiful, people are cheerful, birds sing, girl’s skirts are short, Gorges are Gorges.
Back to Ithaca in later that year...

**Surviving Ithaca Winters**

**The Weather**

Ithaca winters are typical of those elsewhere in the northeastern United States—in general, extremely cold! When the strong winds of Ithaca combine with low temperatures it becomes harder to keep warm. For example, if the temperature is 20°F (-7°C) but the wind is blowing at a speed of 35 mph (56 kph), then the wind-chill temperature is -29°F (-35°C). The snow also makes winter uncomfortable. Ithaca can get as much as 125 inches (318 cm) in one winter. There are usually one or two days each winter when brisk winds combine with very low temperatures to produce potentially dangerous conditions.

- Make a habit of listening to weather forecasts on TV or on the radio so that you will be able to dress appropriately each morning.
- On days that are bitter cold, limit the length of time that you are exposed to the cold. When you are out in very cold temperatures BE AWARE OF THE POTENTIAL FOR FROSTBITE which is an injury to the body caused by freezing. Most often, frostbite affects the nose, ears, cheeks, chins, fingers, or toes, and can permanently damage the body. See Frostbite Symptoms to learn more about the signs of frostbite and how to treat.

*Fig.: #2: Ithaca in the winter is... different.*
IRS spectra: some statistics

- ~21,000 observations ("AORkeys"), ~14,500 distinct object names

**Priority #1**: staring observations in low-resolution mode (LR: SL & LL: $R \approx 60 - 127$)

**Priority #2**: staring observations in high-resolution mode (HR: SH & LH: $R \approx 600$)
CASSIS versions and history

Versions

2010  Test versions – announcement @ Jim’s 70th birthday Symposium
2011  Release of LR4
2013  LR5
2014  LR6
2015  LR7 (present version)
2015  HR1 (present version)
2016  New URL: http://cassis.sirtf.com
      Migration of data & website at Rochester University

Low-resolution (LR) pipeline

- VL et al., 2011, ApJS, 196, 8
- Many samples (up to several 100s)

High-resolution (HR) pipeline

- VL et al., 2015, ApJS, 218, 21
- $\frac{1}{2}$ small samples - $\frac{1}{2}$ single objects
Database and website development and maintenance: Don Barry

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**Database and website development and maintenance**

- Don Barry

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**CASSIS**

- Combined Atlas of Sources with Spitzer IRS Spectra

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**Search by position/name**

- Target:
  - Search for Spitzer Spectra

- RA
  - 00:00:00
  - 12h
  - 00.0
  - 60s

- DEC
  - 00:00:00
  - 12h
  - 00.0
  - 60s

- Radii
  - 20

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**Search by Program ID**

- Numeric Program ID

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**Search by A0Rkey**

- Numeric A0Rkey

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LR pipeline

Extraction methods

- **Regular**: integrates flux in spatial window
  - Window size scales with spatial extent
  - Default choice for *extended sources*
  - Also a good choice for bright point sources
- **Optimal**: scales the PSF
  - Default choice for *point sources*
Optimal extraction (LR)

Undersampled data
- **Empirical super-sampled PSF** reconstructed from scans of stars along slit (AdOpt; *VL et al. 2010*)
- Superior to analytical or simulated PSF
- Factor $\times 10$ sampling for SL (5 for LL)

Advantages
- **Optimal extraction anywhere in the slit**
- Precise source finder
- **Intrinsic spatial extent** to decide best extraction method
- **Extended emission calculated simultaneously** → isolate compact/point-source emission
Optimal extraction (LR)

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LR results

Many steps, many checks

- Automatic background subtraction (by-nod/order), Automatic fringes removal, intrapixel responsivity function...
- Pointing stability, outlier rejection, serendipitous sources in offset images...

Results

- Significant S/N improvement ($\times 2 - 3$) for faint sources
- Removal of extended emission (incl. residuals due to variations across the slit)

Fig.: AGN spectrum (top: SHA, bottom: CASSIS).
HR pipeline

Specificities

- Cross-dispersed echelle modules – larger fraction of bad pixels
- No systematic dedicated offset → rogue pixels & large-scale emission could be problematic
- Detector background gradient (→ 1D “zigzag” effect) → custom 2D surface interpolation
- Relative weights in series of exposures works well too, when possible!
HR pipeline

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Fig.: LMC planetary nebula (top: SHA post-BCD, middle: CASSIS full aperture w/o correction, bottom: CASSIS full aperture).
Optimal extraction (HR)

Algorithm by C. Goes

- Small apertures: empirical super-sampled PSF profile more difficult to establish and to apply
- PSF built "piece-by-piece" in sub-windows
- Significant improvement over analytical & simulated PSF
HR results

Extraction methods

- **Full aperture**: extended sources & bright point sources
- **Simultaneous nod extraction** (better baseline): (quasi-)point sources
- **Differential extraction**: pure point sources → eliminates the needs of an offset observation
- **Best method not yet decided automatically**

Limitations

- Minor: super-sampled PSF not good enough for very bright sources
- Some order tilts remain in some cases
- Noisy spectra if differential method cannot be used
HR results

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**Fig.**: Post-AGB star in the SMC (top: SHA, middle: CASSIS full aperture, bottom: CASSIS differential extraction).
Products & diagnostics

Low-resolution

- CASSIS LR7: \(\sim 12,300\) AORkeys, \(\sim 15,600\) spectra

High-resolution

- CASSIS HR1: \(\sim 7,000\) AORkeys, \(\sim 9,400\) spectra

Products

- FITS, VO format...
- Many diagnostics online (spatial extent, detection level...)
- Background subtraction methods and extraction methods can be compared
- Warnings when necessary (one bad nod, source in offset image...)

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A selection of CASSIS datasets

IDEOS (PI Spoon)
- LR and HR database
- IDEOS redshift machine  \textit{(Hernan-Caballero et al. 2016)}

Some recent CASSIS use for samples
- “The infrared to X-ray correlation spectra of unobscured type 1 active galactic nuclei”. \textit{(Garcia-Bernete et al. 2017)}
- “The complex evolutionary paths of local infrared bright galaxies: a high-angular resolution mid-infrared view”. \textit{(Alonso-Herrero et al. 2017)}
- “The nuclear and integrated far-infrared emission of nearby Seyfert galaxies”. \textit{(Garcia-Gonzalez et al. 2016)}
- “Hints on the Gradual Resizing of the Torus in AGNs through Decomposition of Spitzer/IRS Spectra”. \textit{(Gonzalez-Martin et al. 2017)}
- “Linking dust emission to fundamental properties in galaxies: the low-metallicity picture”. \textit{(Remy-Ruyer et al. 2015)}
- “The physical properties of Spitzer/IRS galaxies derived from their UV to 22\(\mu\)m spectral energy distribution” \textit{(Vika et al. 2017)}
- “Neon and [C II] 158\(\mu\)m emission line profiles in dusty starbursts and active galactic nuclei”. \textit{(Sargsyan et al. 2016)}
- “A complete census of silicate features in the mid-infrared spectra of active galaxies”. \textit{(Hatziminaoglou et al. 2015)}
- “The SAGE-Spec Spitzer Legacy program: The life-cycle of dust and gas in the Large Magellanic Cloud. Point source classification III.” \textit{(Jones et al. 2017)}
- “Spitzer infrared spectrograph point source classification in the Small Magellanic Cloud”. \textit{(Ruffle et al. 2015)}
- “Learning the fundamental mid-infrared spectral components of galaxies with non-negative matrix factorization”. \textit{(Hurley et al. 2014)}
Large datasets

Availability

- Possible to download large datasets based on list of RA/DEC or AORkeys; some limitations due to server capabilities
- Access to full SQL database on request

Blind searches

- Build samples based on
  - **Observational parameters** (RA/DEC, module, detection level, spatial extent...)
  - **Cross-correlated parameters** (NED/SIMBAD ID, NED redshift, IDEOS)
  - **Spectral parameters** measured on-the-fly (feature, continuum...)
  - **Spectral comparisons** (template/pattern matching)
Statistical analysis

[Graph showing flux density vs. wavelength with peaks at specific wavelengths, labeled as PAH template (558)]

(a)
Statistical analysis

![Graph showing silicate absorption template](image-url)
Statistical analysis
Statistical analysis
Standard sources in CASSIS

What is meant by “publication-ready” products

- No further steps for point sources well centered in apertures
- No stitching between SL & LL; left to users
- Partially-extended sources require special wavelength-dependent flux calibration (provided on request)
Standard sources in CASSIS

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Non-standard sources / unexpected results

- Offsets in dispersion direction
- Multiple sources
- Complex backgrounds
- Warning messages in CASSIS ⇒ use of SMART/AdOpt tool is advised in some cases
Non-standard sources with AdOpt: sources not in slit

Shift in dispersion direction

- $\approx 2\%$ of spectra with $\perp$ offset $> 2''$
- Manual extraction necessary for best results

Uranus’ moons (Zivick et al.; unpublished)

- Temperature in agreement with theoretical models
- No CO$_2$ absorption
Non-standard sources with AdOpt: several sources in the slit

Warm dust in Type IIn SN 2005ip \citep{Fox2010}  
- No emission lines; warm dust component
Spatial decomposition with AdOpt: HR & LR

Example: Herbig Ae/Be star HD36917
- Easy to do for any source with SMART/AdOpt
- Improvement over decomposition from Boersma et al. (2008)
Spatial decomposition with AdOpt: NGC1365

![Graphs and images related to spatial decomposition with AdOpt for NGC1365.]

- Histograms of x-coordinate with a mod pattern.
- Color-coded map of the galaxy with labeled markers.
- Wavelength versus flux density graph with different lines representing source and background.

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Future

CASSIS is not a frozen archive

- HR extractions; effort with Rochester; ADAP proposal submitted
- Automatic decision for HR extraction method
- Use of dedicated backgrounds (for faint and/or extended sources)
- Integrated maps
- Complementing with other IR spectra (Herschel/PACS underway for extragalactic; D. Weedman)
Many thanks especially to Don Barry, Dan Weedman, Dan Watson and the Rochester Department of Astronomy for allowing CASSIS to remain available to the community so that the IRS legacy can survive.

...and many thanks to Jim!