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

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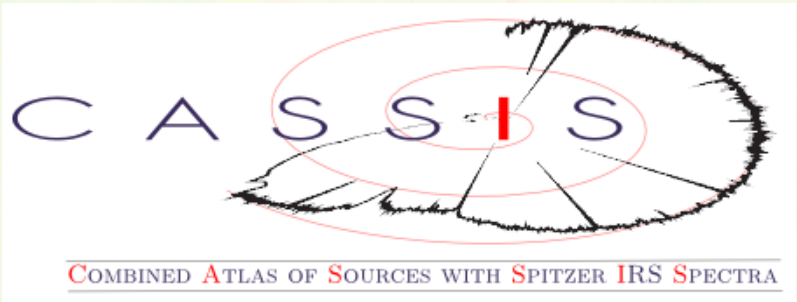


June 26, 2017

CASSIS "origins"

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
- **ISC team** (@Cornell>2005): J. Houck, D. Barry, J. Bernard-Salas, N. Chitrakar, D. Devost, M. Devost, E. Furlan, C. Goes, S. Guiles-Gutenkunst, P. Hall, L. Hao, J. Higdon, S. Higdon, V. Lebouteiller, D. Levitan, G. Sloan, H. Spoon, K. Uchida, D. Weedman, D. Whelan, Y. Wu... + **Rochester** + Gimme! coffee
- 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...

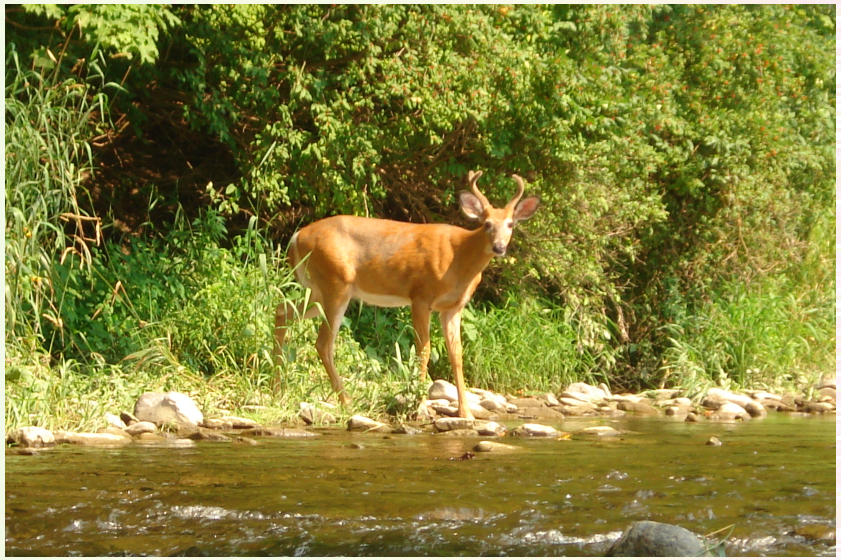


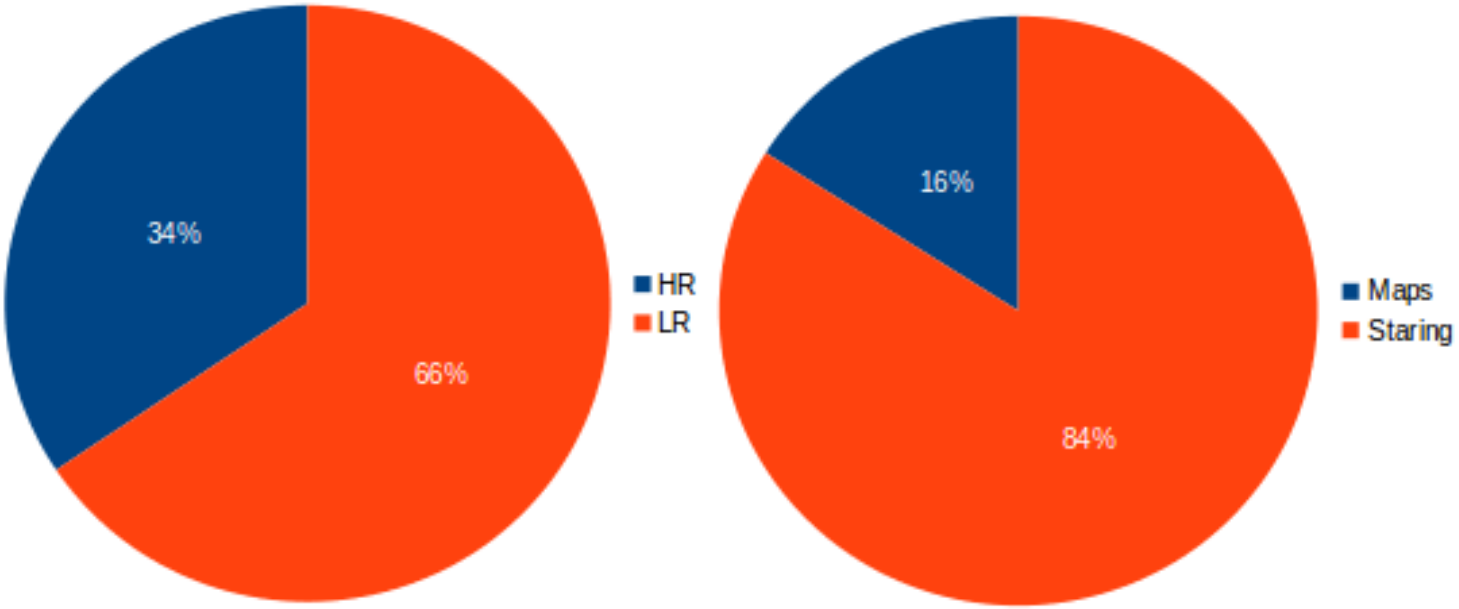
Fig.: *#1: Ithaca in the summer is beautiful, people are cheerful, birds sing, ~~girl's skirts are short~~, Gorges are Gorges.*

Back to Ithaca in later that year...

Fig.: *#2: Ithaca in the winter is... different.*

IRS spectra: some statistics

- $\sim 21,000$ observations ("AORkeys"), $\sim 14,500$ 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: $R \approx 600$)

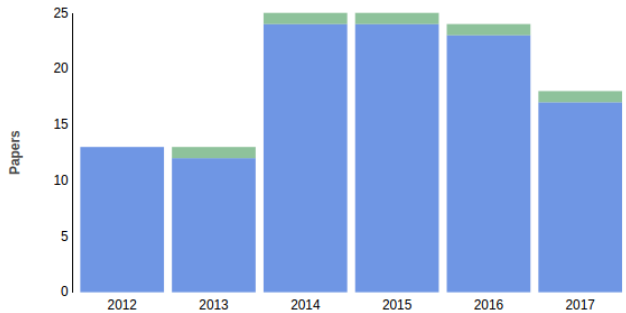
CASSIS versions and history

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

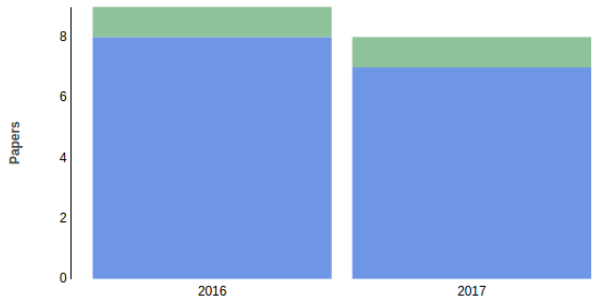
Low-resolution (LR) pipeline

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



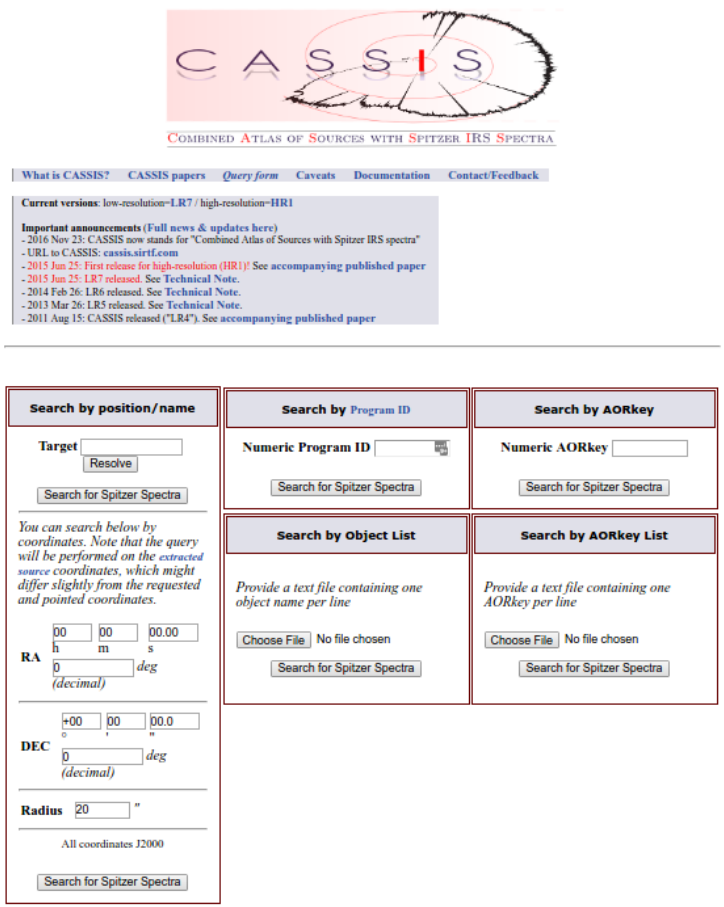
High-resolution (HR) pipeline

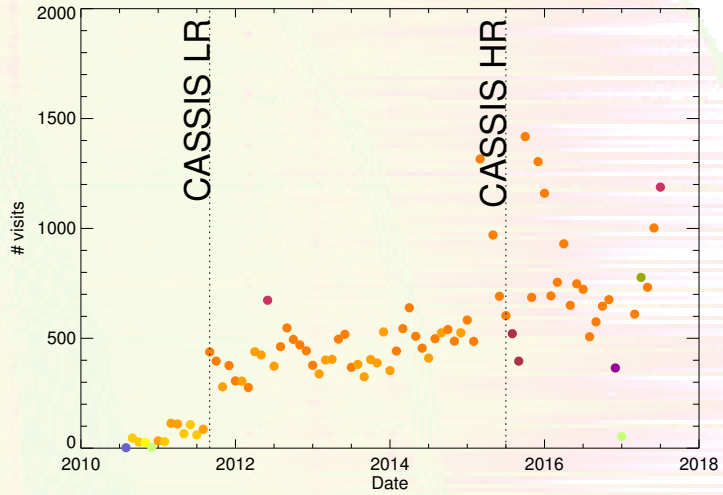
- VL et al., 2015, ApJS, 218, 21
- $\frac{1}{2}$ small samples - $\frac{1}{2}$ single objects

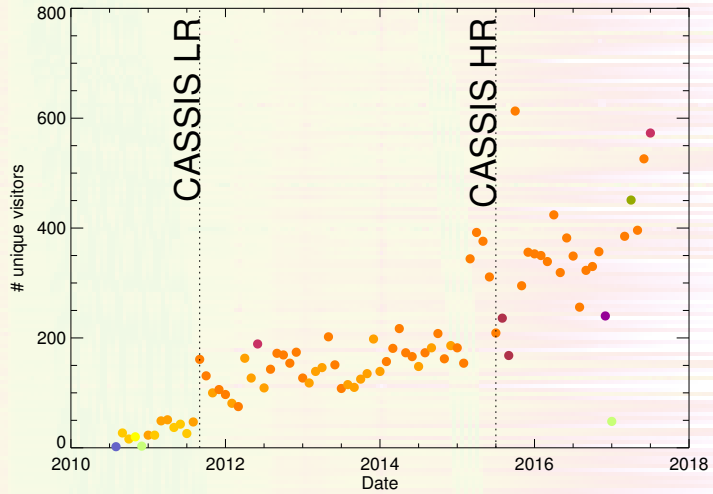


cassis.sirtf.com

Database and website development and maintenance: Don Barry



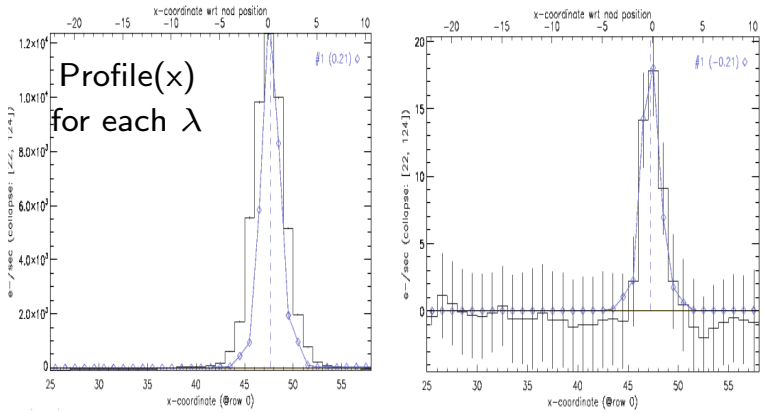




LR pipeline

Extraction methods

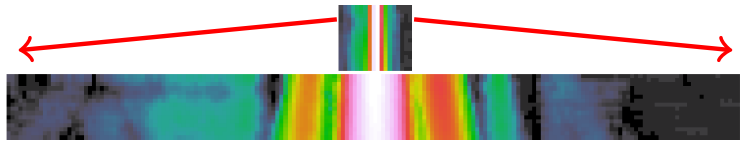
- Regular: integrates flux in spatial window
  - Window size scales with spatial extent
  - Default choice for extended sources
  - Also a good choice for bright point sources
- Optimal: scales the PSF
  - Default choice for point sources



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 $\rightarrow$ isolate compact/point-source emission

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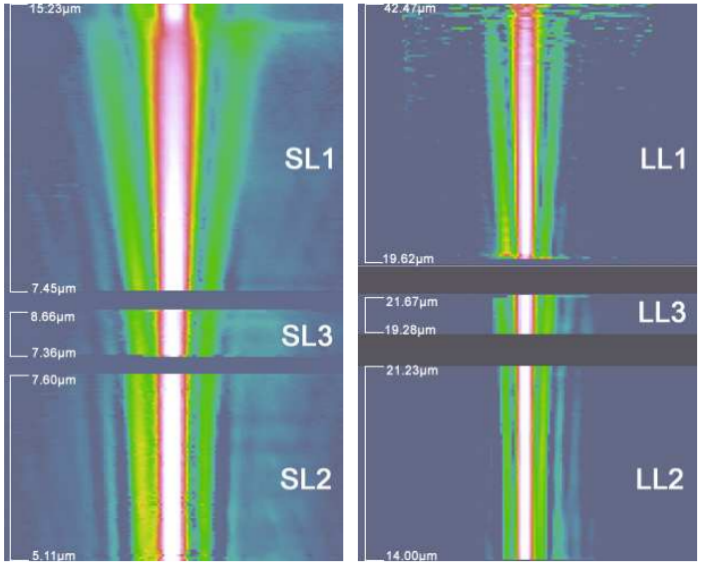
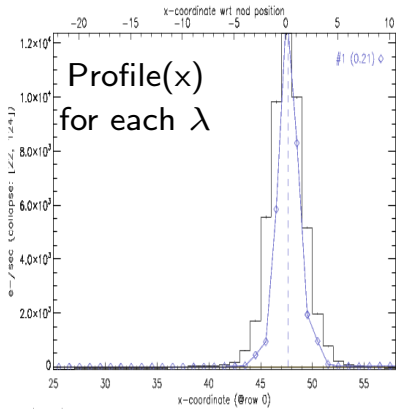




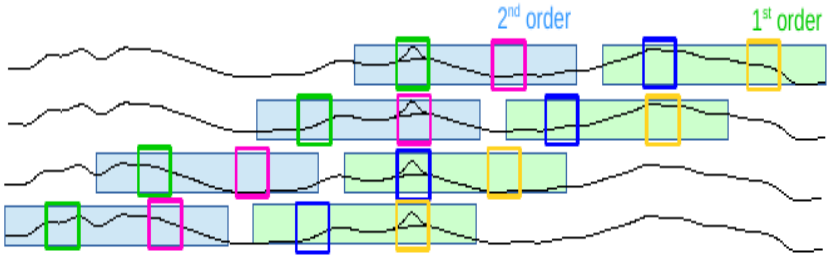
LR results

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)



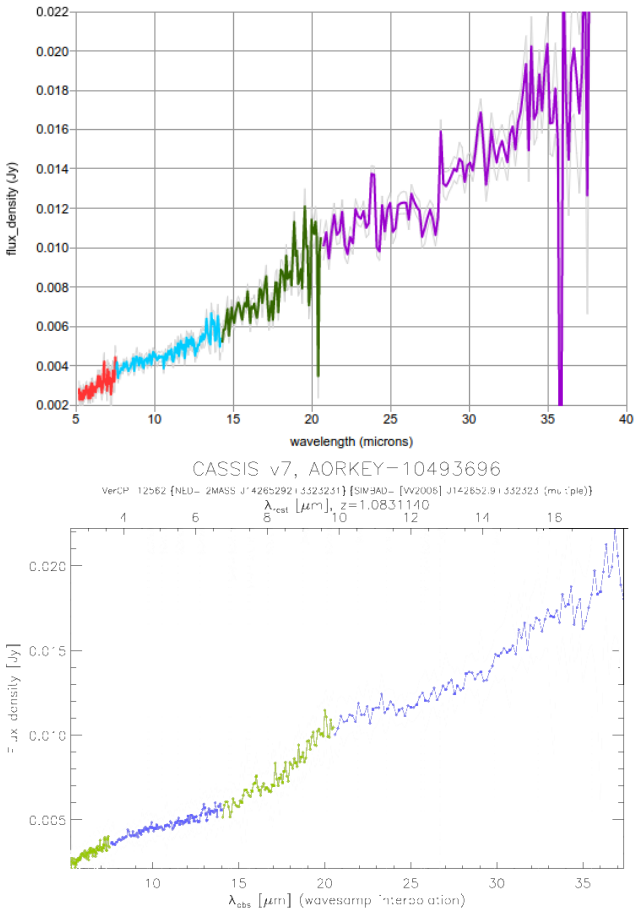
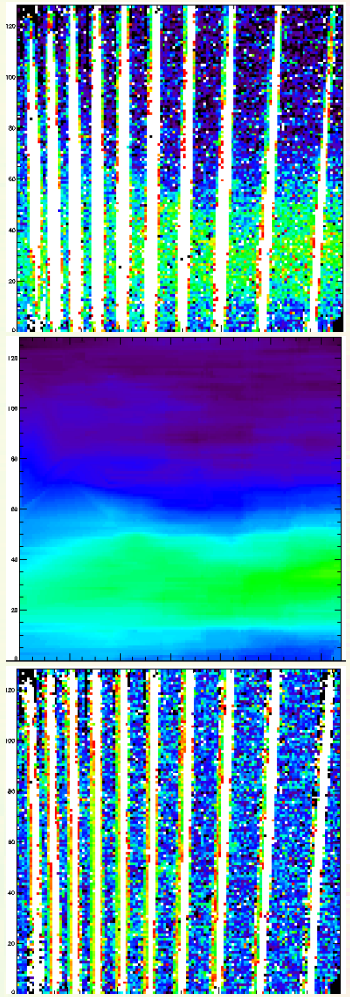


Fig.: *AGN spectrum (top: SHA, bottom: CASSIS).*

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!



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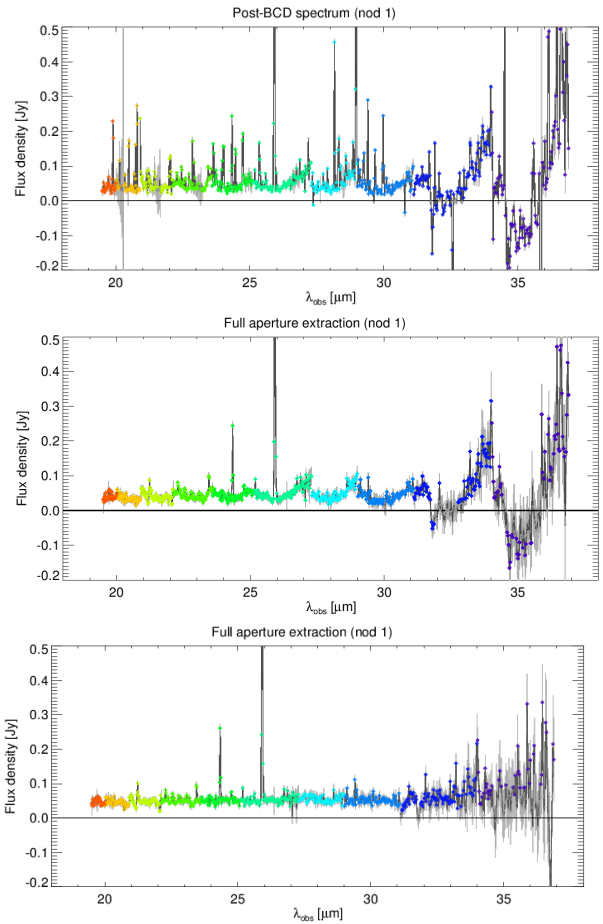
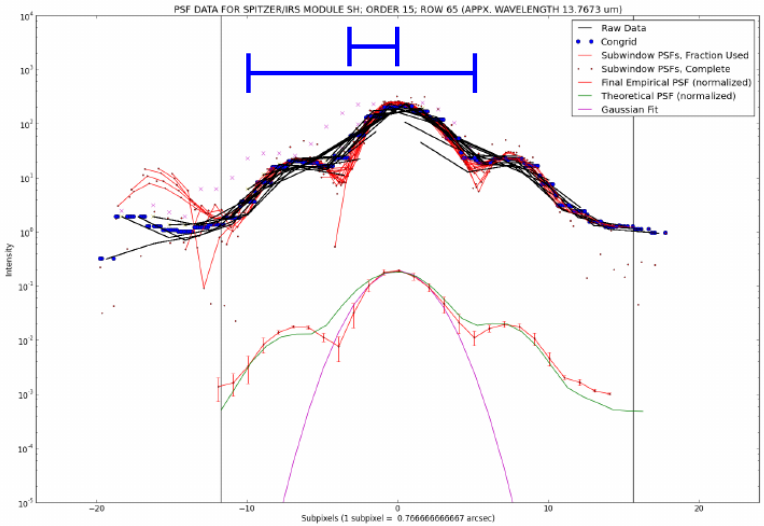


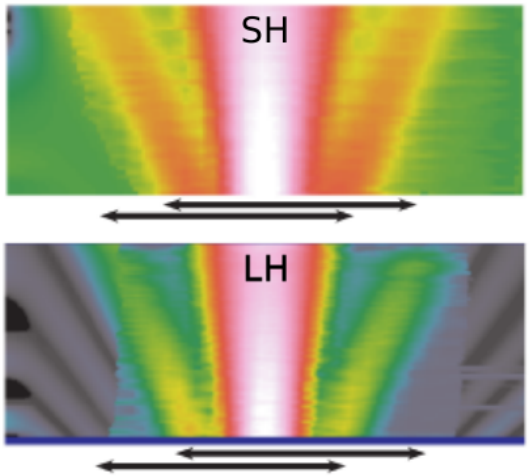
Fig.: *LMC planetary nebula (top: SHA post-BCD, middle: CASSIS full aperture w/o correction, bottom: CASSIS full aperture).*

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

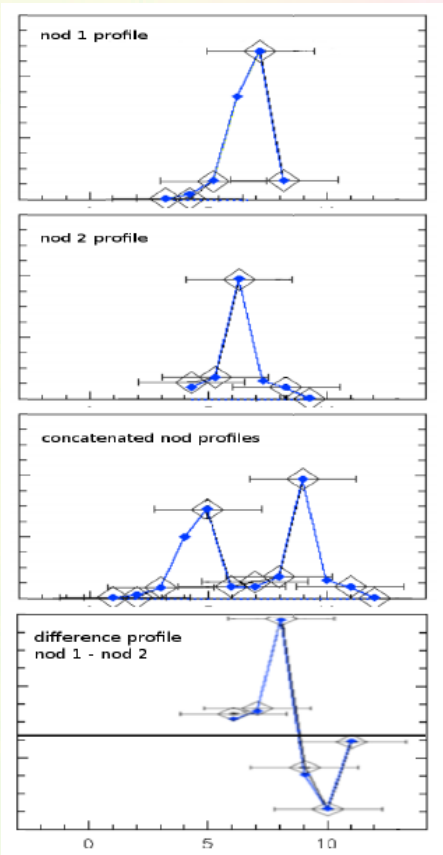
Extraction methods

- **Full aperture**: extended sources & bright point sources
- **Simultaneous nod extraction** (better baseline): (quasi-)point sources
- **Differential extraction**: pure point sources $\rightarrow$ 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

Profile(x) for each λ



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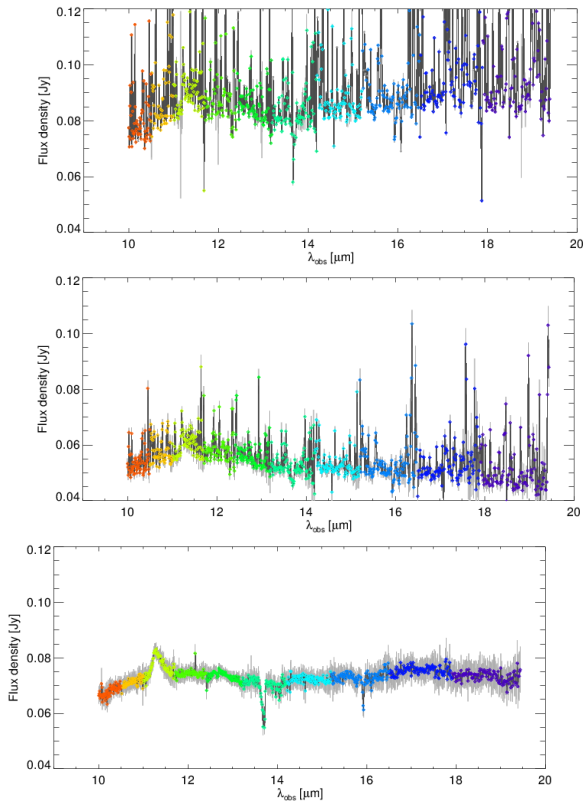


Fig.: *Post-AGB star in the SMC (top: SHA, middle: CASSIS full aperture, bottom: CASSIS differential extraction).*

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...)

A selection of CASSIS datasets

IDEOS (PI Spoon)

- LR and HR database
- IDEOS redshift machine *(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". *(Garcia-Bernete et al. 2017)*
- "The complex evolutionary paths of local infrared bright galaxies: a high-angular resolution mid-infrared view". *(Alonso-Herrero et al. 2017)*
- "The nuclear and integrated far-infrared emission of nearby Seyfert galaxies". *(Garcia-Gonzalez et al. 2016)*
- "Hints on the Gradual Resizing of the Torus in AGNs through Decomposition of Spitzer/IRS Spectra". *(Gonzalez-Martin et al. 2017)*
- "Linking dust emission to fundamental properties in galaxies: the low-metallicity picture". *(Remy-Ruyer et al. 2015)*
- "The physical properties of Spitzer/IRS galaxies derived from their UV to 22μm spectral energy distribution" *(Vika et al. 2017)*
- "Neon and [C II] 158 μm emission line profiles in dusty starbursts and active galactic nuclei". *(Sargsyan et al. 2016)*
- "A complete census of silicate features in the mid-infrared spectra of active galaxies". *(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." *(Jones et al. 2017)*
- "Spitzer infrared spectrograph point source classification in the Small Magellanic Cloud". *(Ruffle et al. 2015)*
- "Learning the fundamental mid-infrared spectral components of galaxies with non-negative matrix factorization". *(Hurley et al. 2014)*

Large datasets

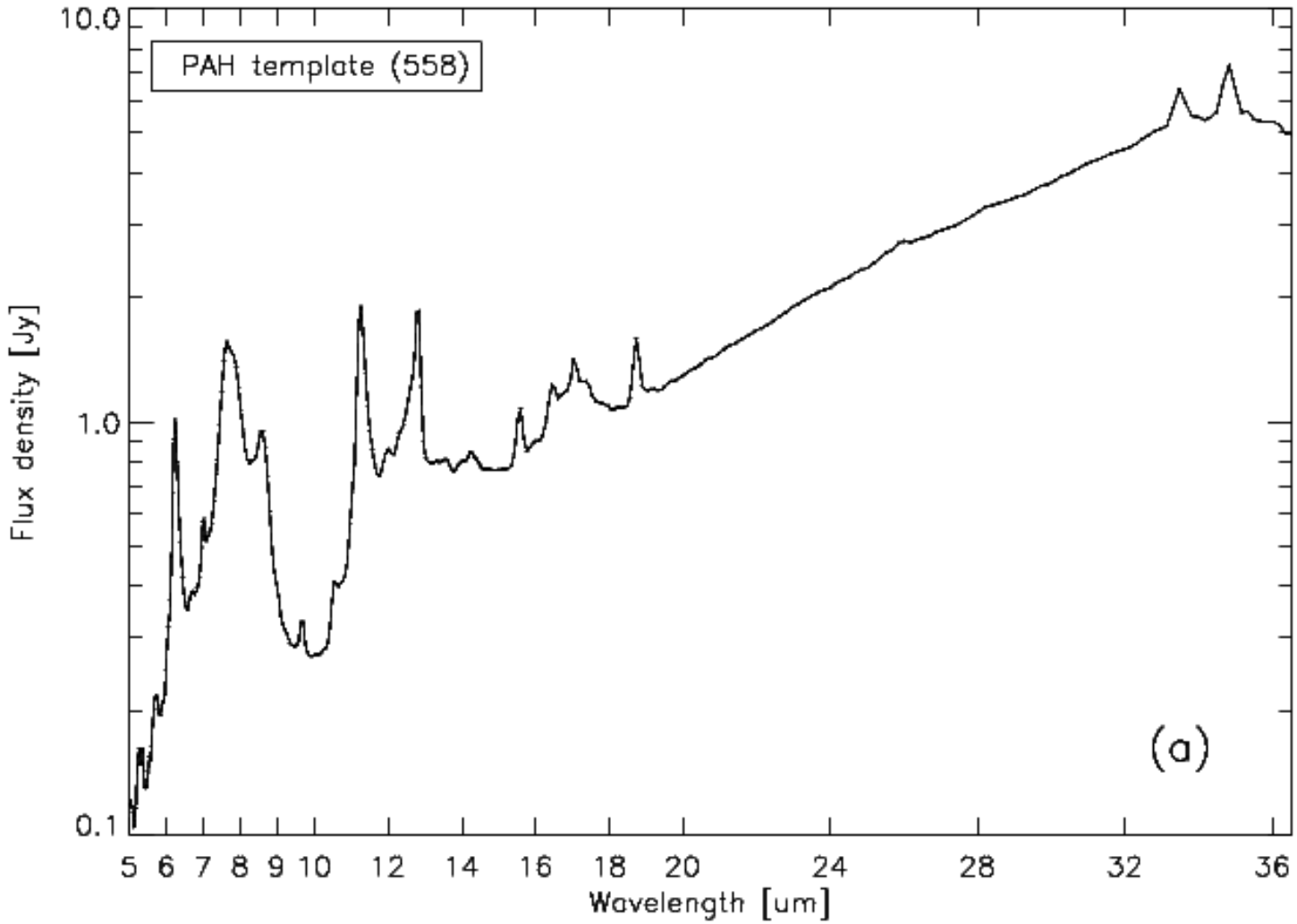
Availability

- 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, continumm...)
  - **Spectral comparisons** (template/pattern matching)

Statistical analysis



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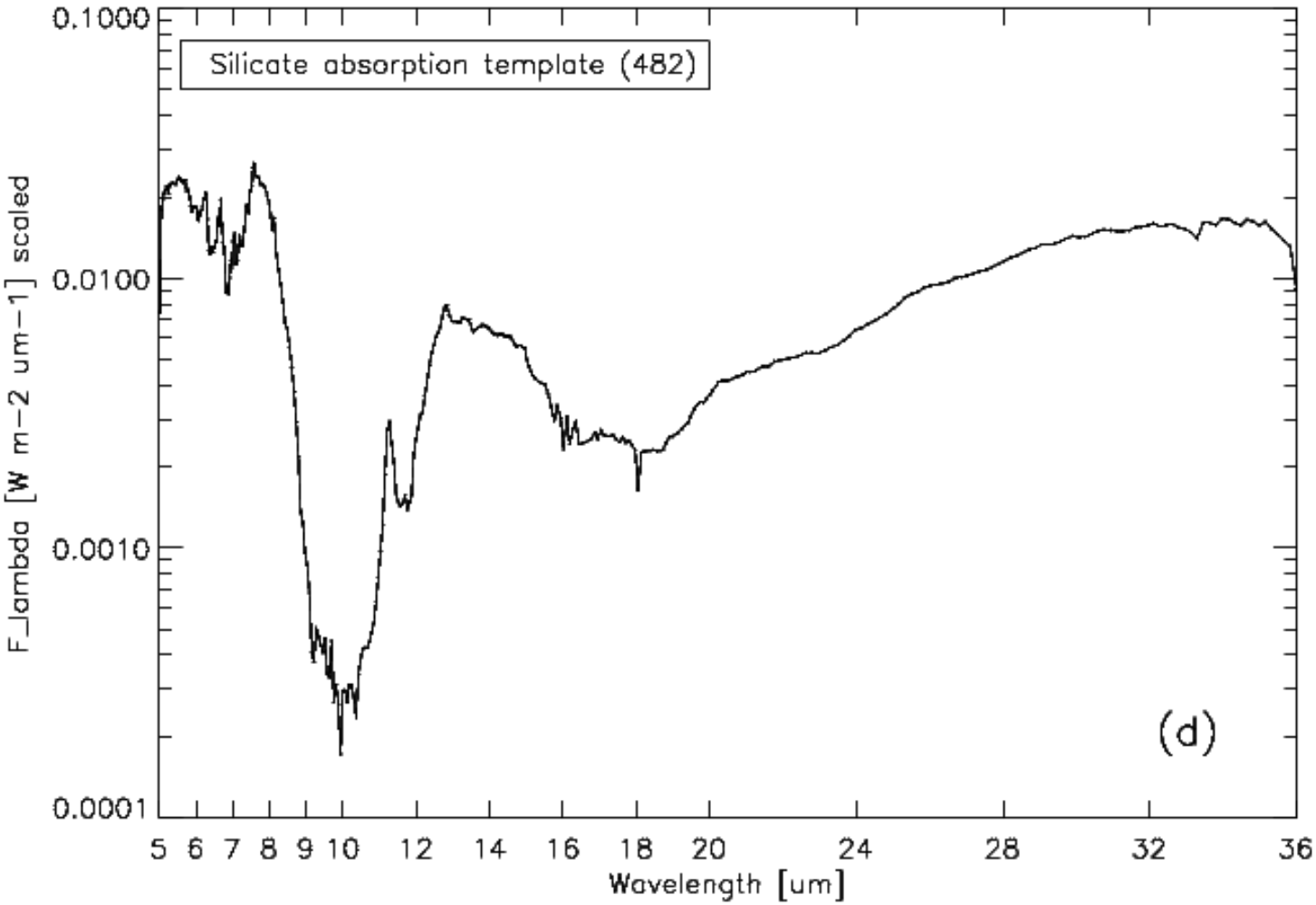

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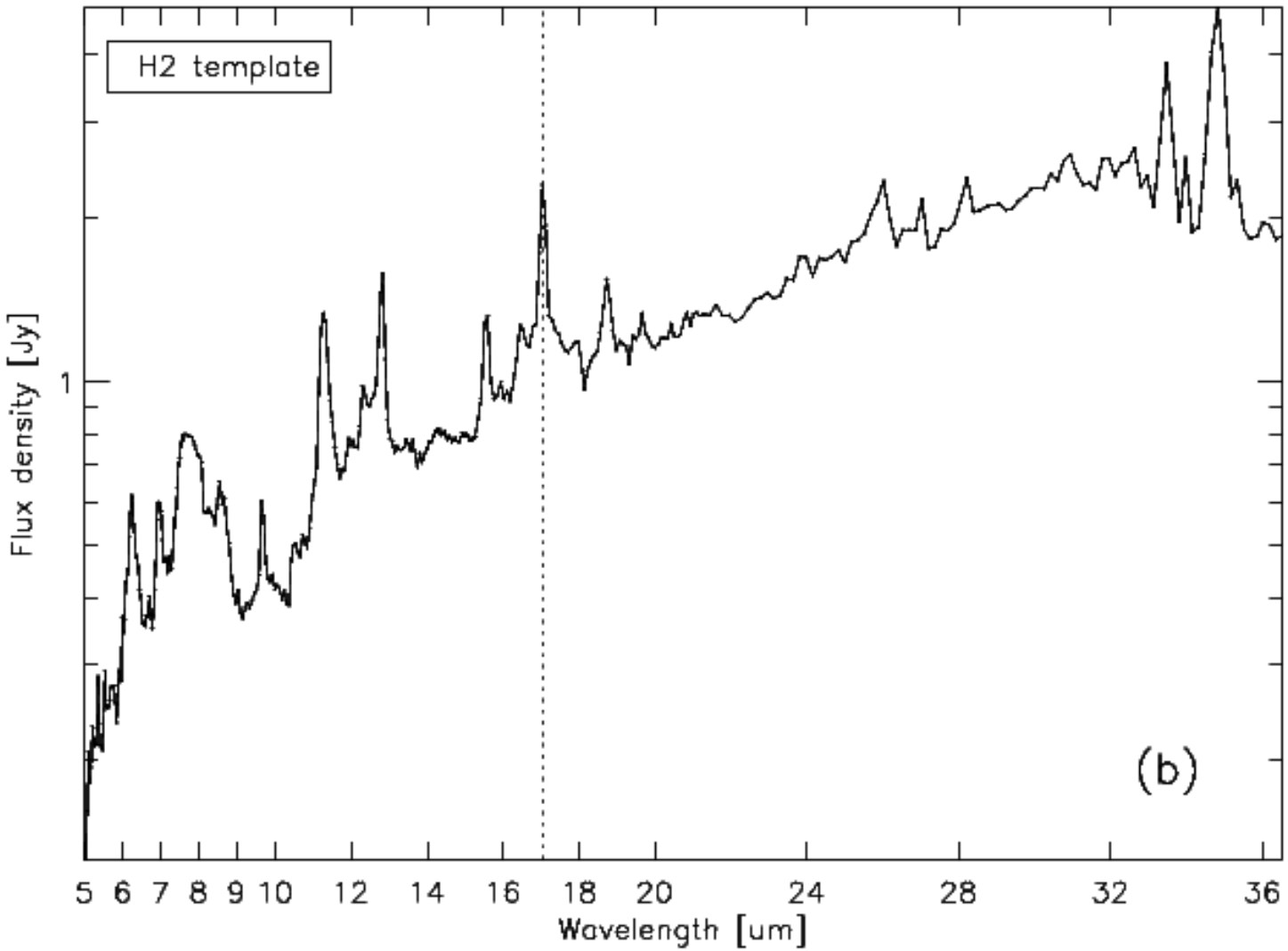

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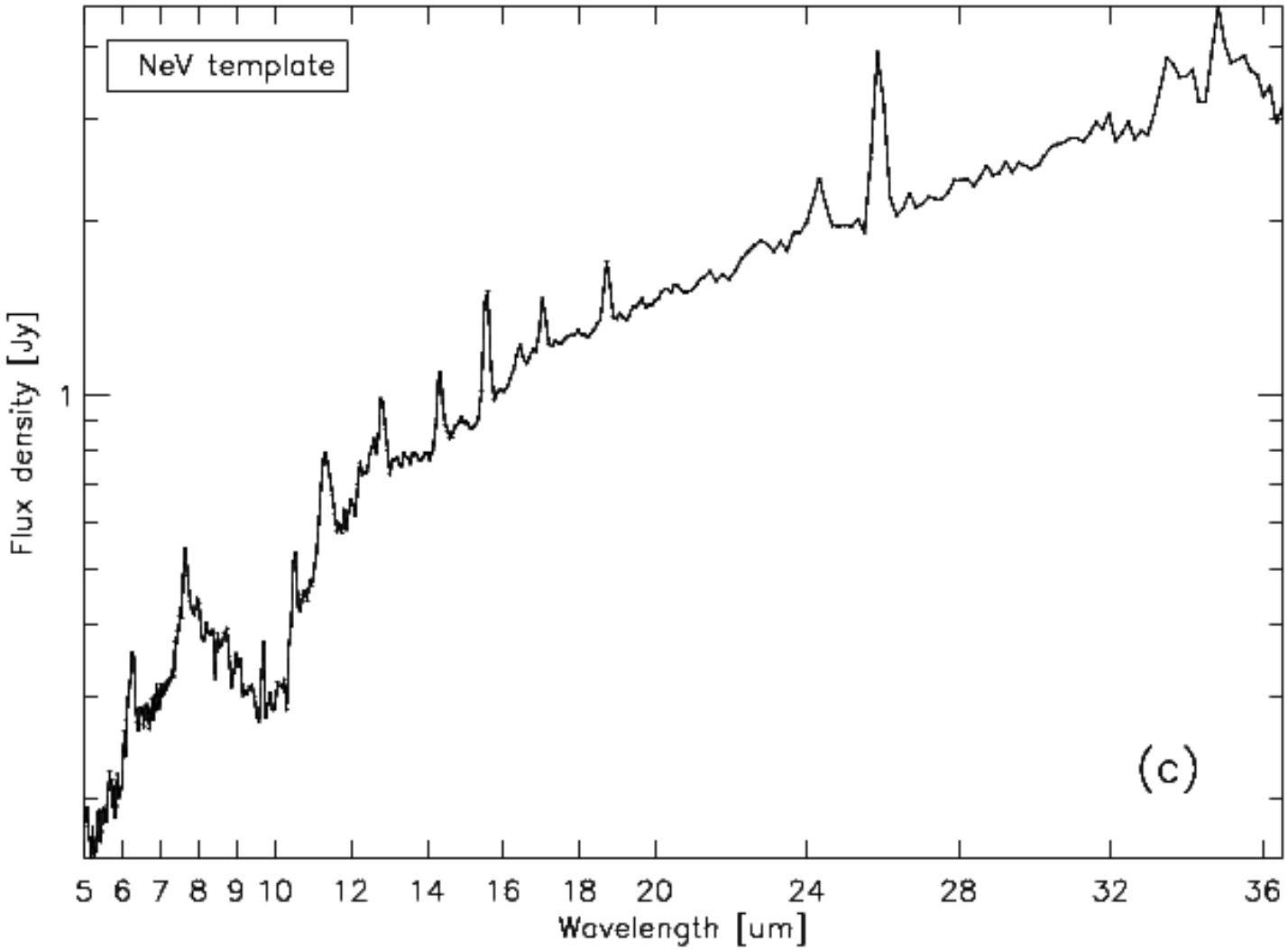

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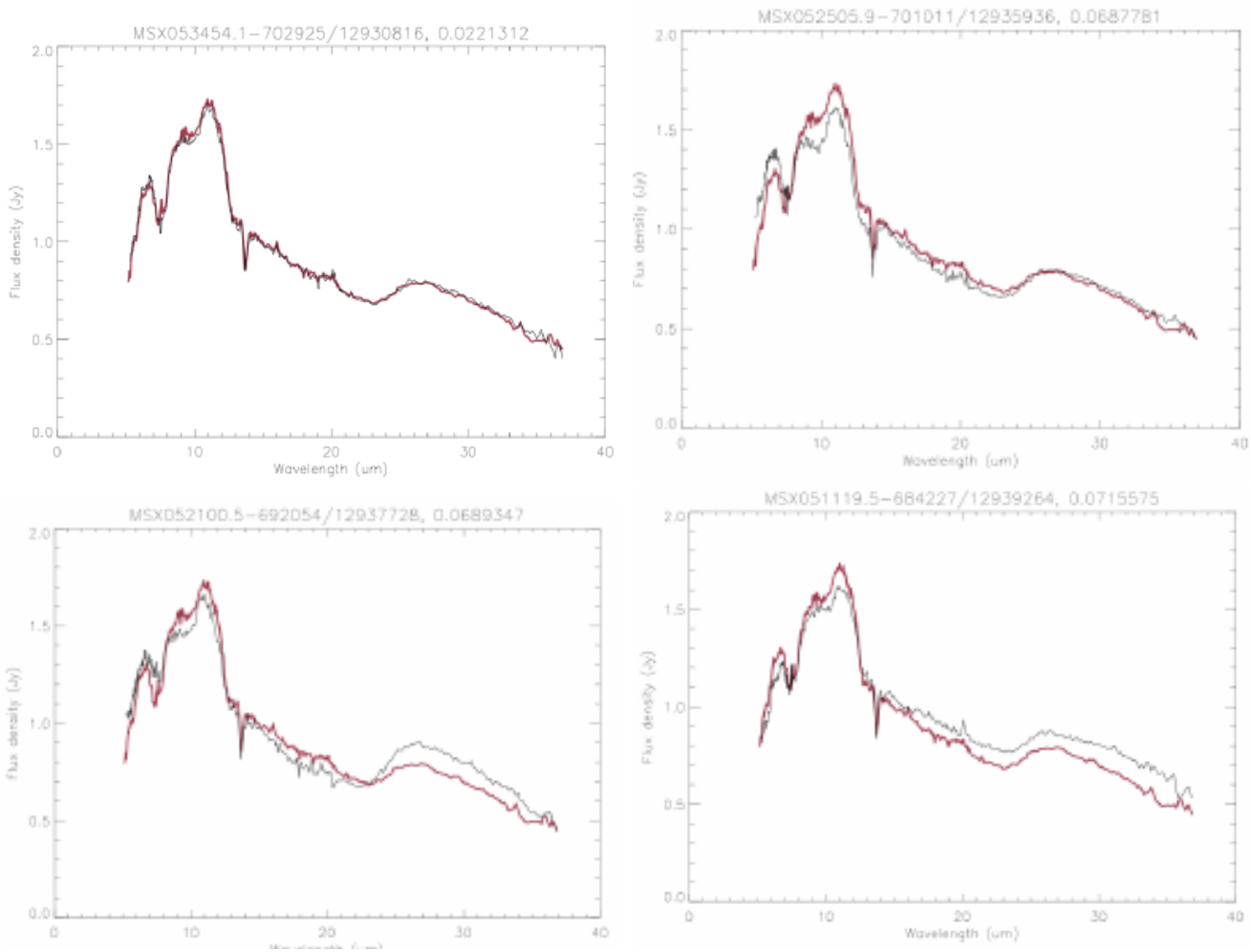
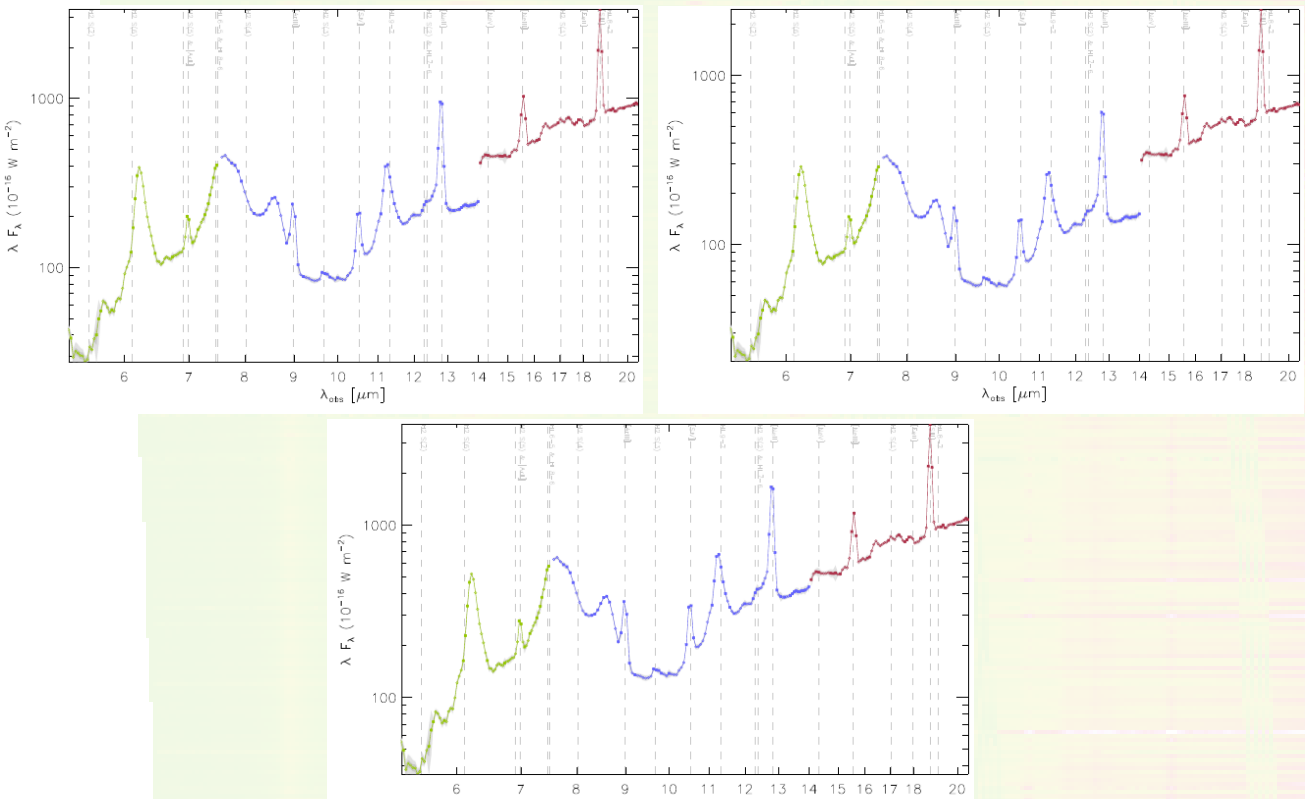


Standard sources in CASSIS

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)



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Non-standard sources / unexpected results

- Offsets in dispersion direction
- Multiple sources
- Complex backgrounds
- Warning messages in CASSIS $\Rightarrow$ use of `SMART/AdOpt` tool is advised in some cases

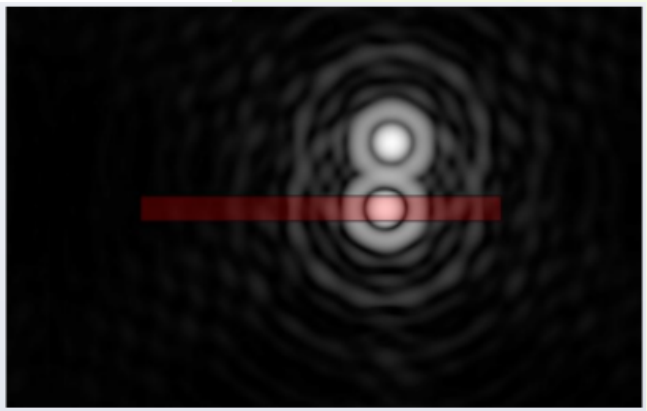
Non-standard sources with AdOpt: sources not in slit

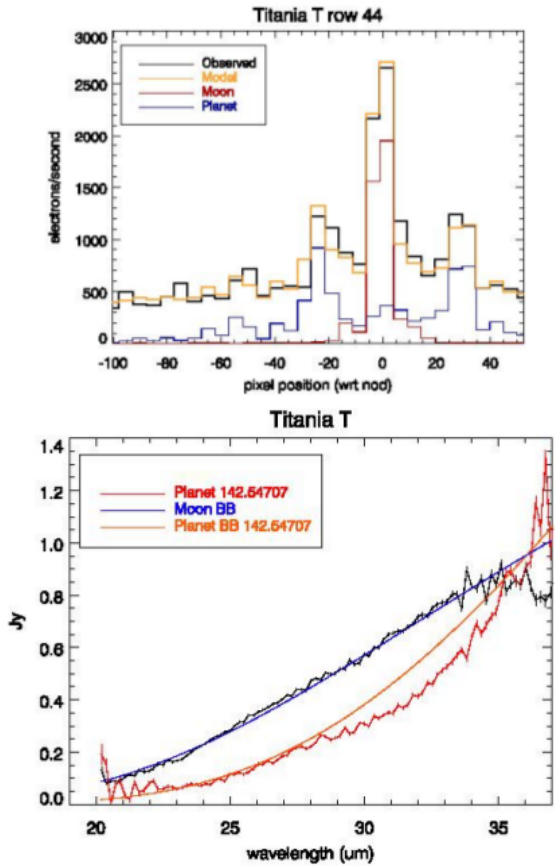
Shift in dispersion direction

- $\approx 2\%$ 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

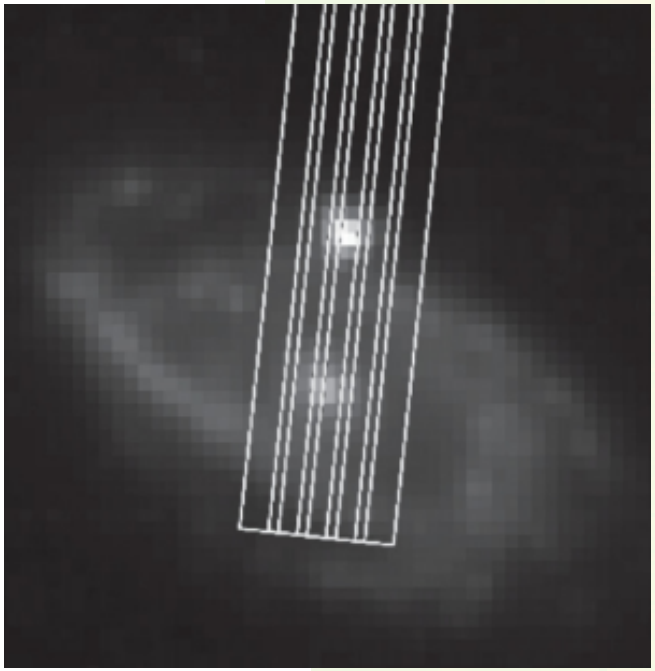


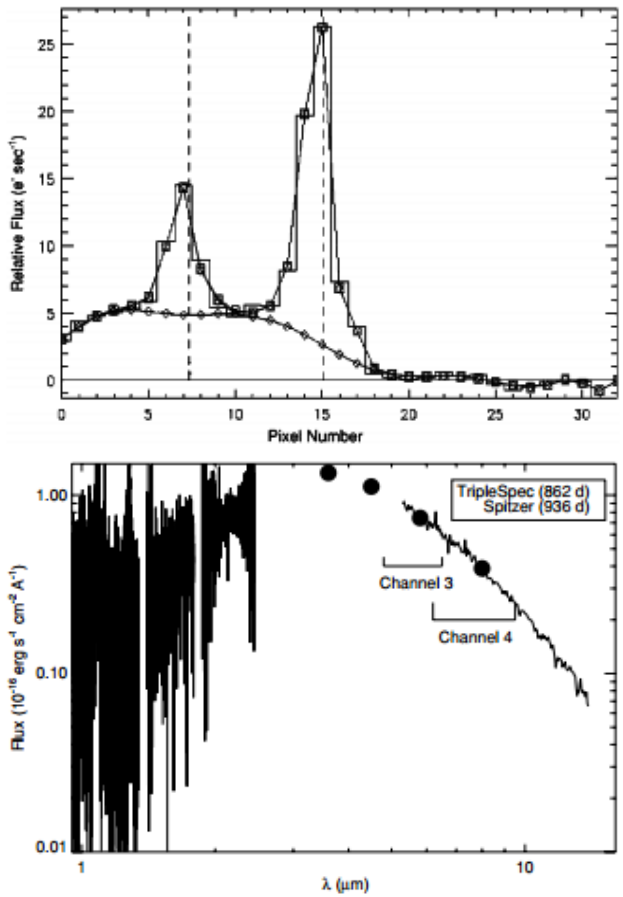


Non-standard sources with AdOpt: several sources in the slit

Warm dust in Type IIn SN 2005ip *(Fox et al. 2010)*

- No emission lines; warm dust component

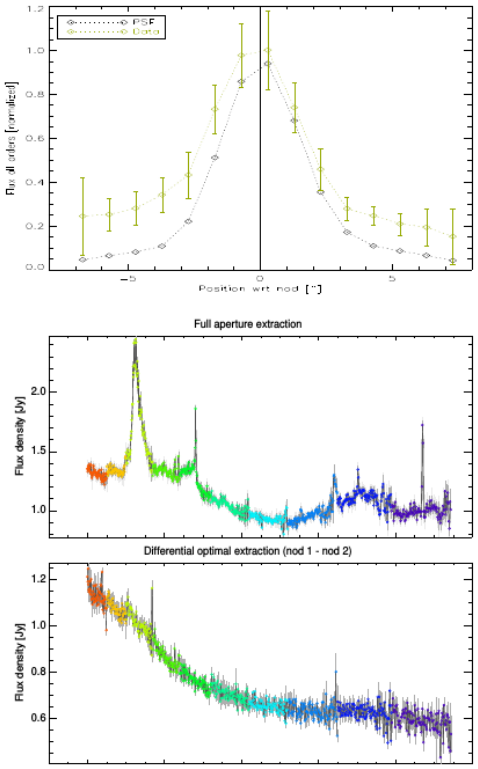


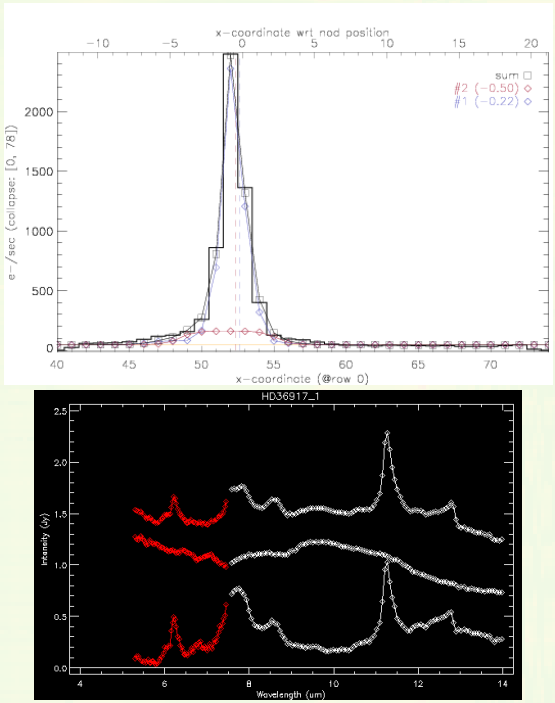


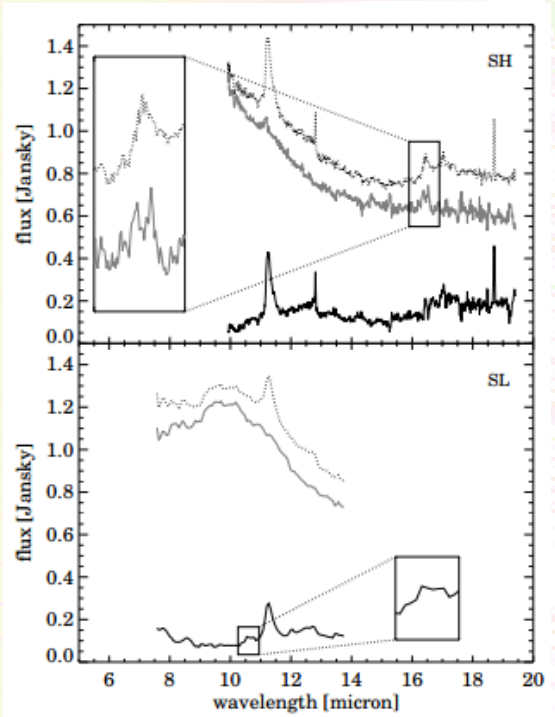
Spatial decomposition with AdOpt: HR & LR

Example: Herbig Ae/Be star HD36917

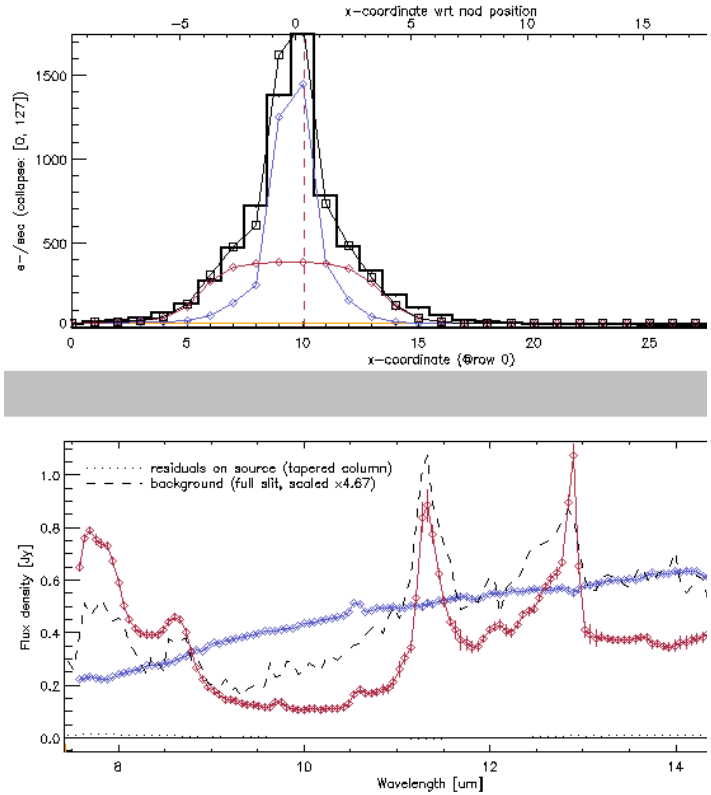
- Easy to do for any source with `SMART/AdOpt`
- Improvement over decomposition from *Boersma et al. (2008)*

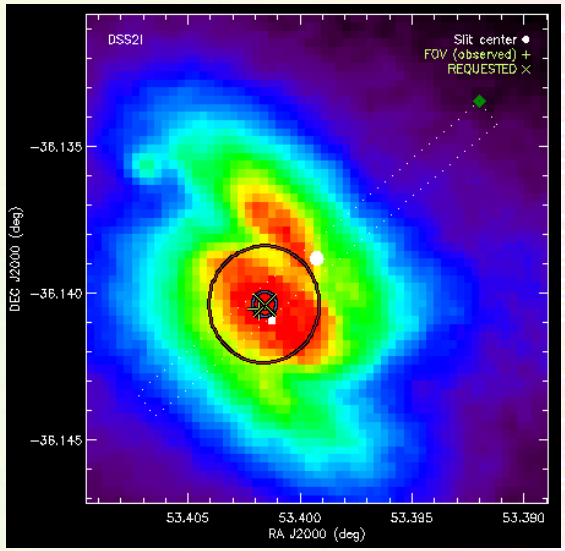






Spatial decomposition with AdOpt: NGC1365

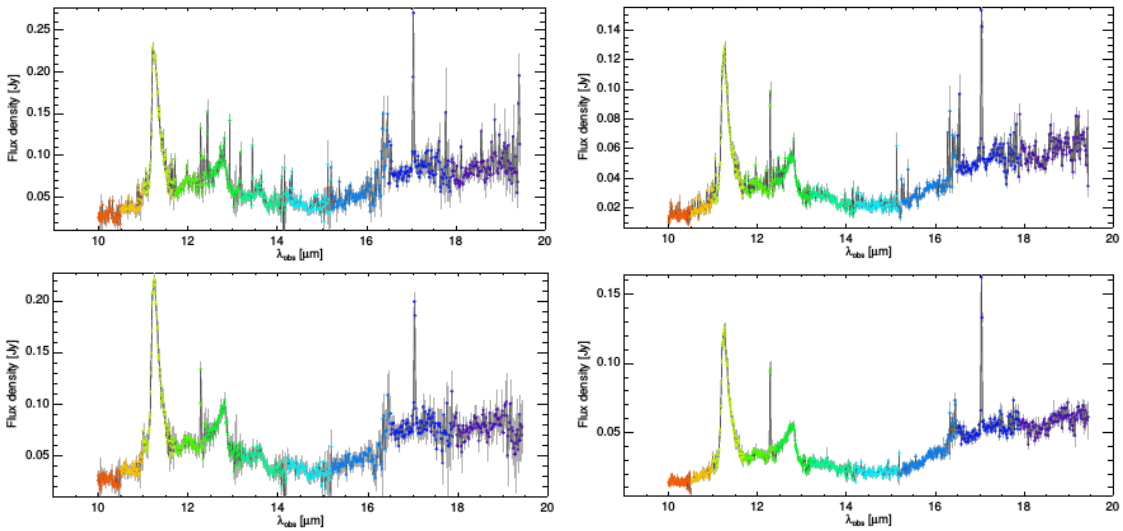




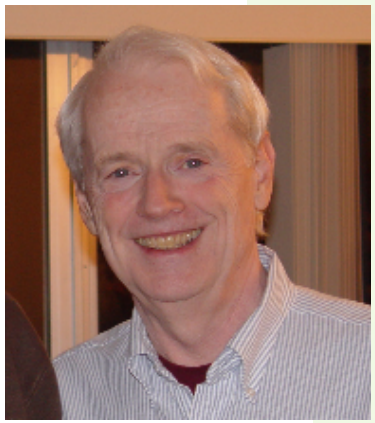
Future

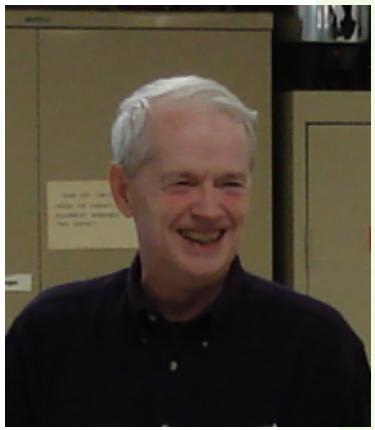
CASSIS is not a frozen archive

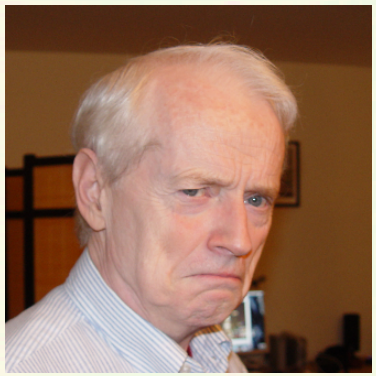
- HR extractions; effort with Rochester; ADAP proposal submitted
- Automatic decision for HR extraction method
- Use of dedicated backgrounds (for faint and/or extended sources)
- Integrated maps
- Complementing with other IR spectra (Herschel/PACS underway for extragalactic; D. Weedman)



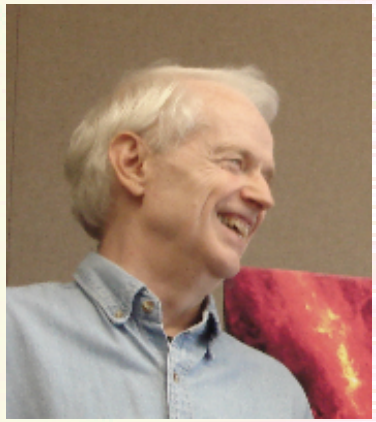
Many thanks especially to Don Barry, Dan Weedman, Dan Watson and the Rochester Department of Astronomy for allowing CASSIS to remain available to the community so that the IRS legacy can survive.



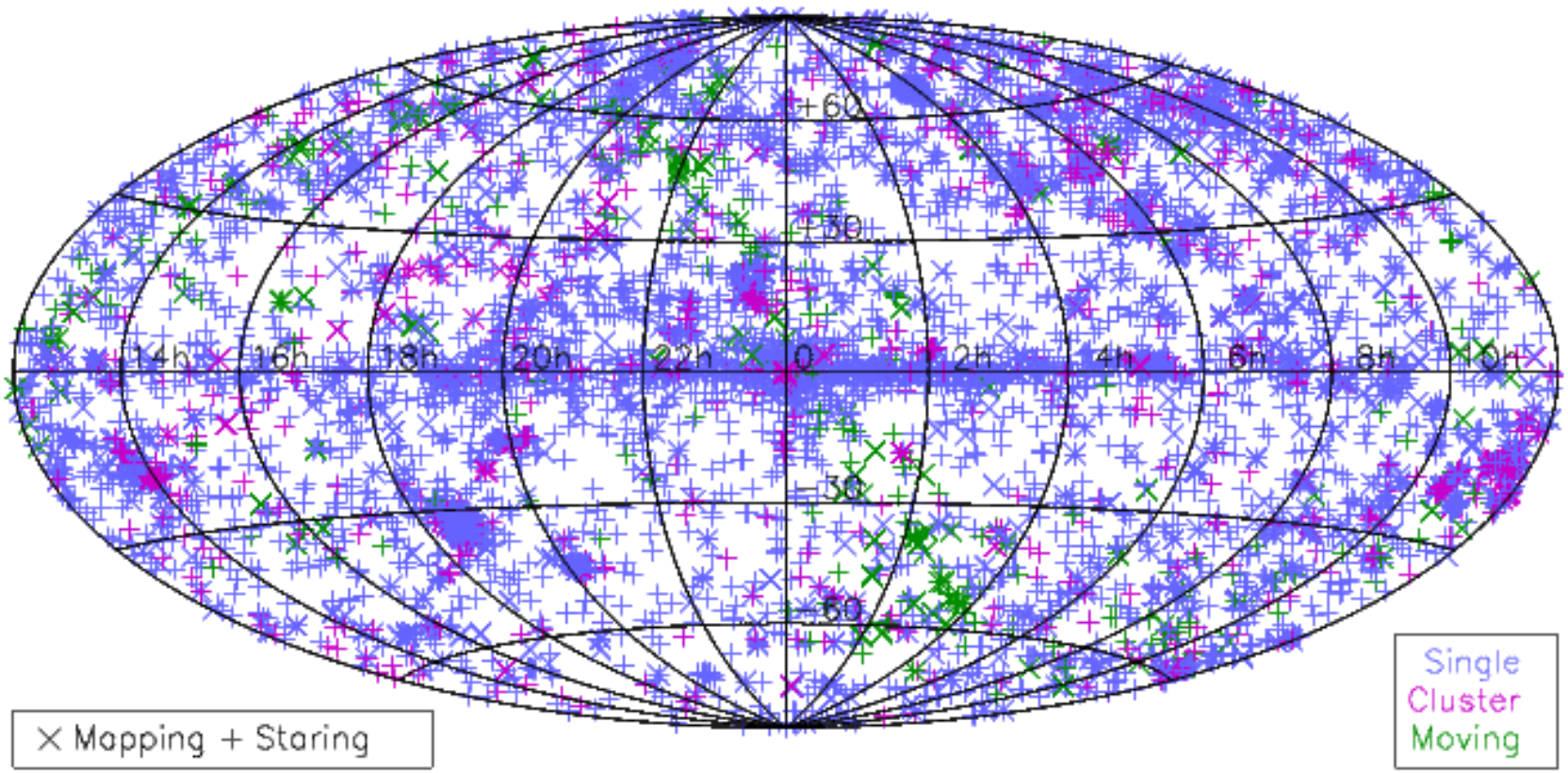




...and many thanks to Jim!



Extra slides



Extra slides

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