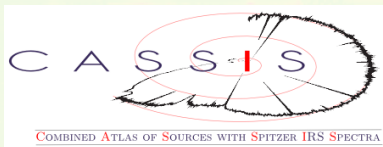


# Combined Atlas of Sources with Spitzer/IRS Spectra (CASSIS)

Vianney Lebouteiller

Laboratoire AIM - CEA, Saclay, France



June 26, 2017

# CASSIS “origins”

## Motivations

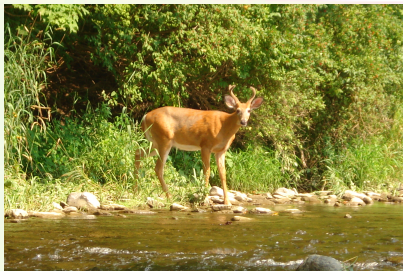
- Provide **science-ready\*** IRS spectra (5-38  $\mu\text{m}$ )
- Improve **legacy value** and maximize **scientific return** (easy access, facilitating homogeneous analysis of large consistent datasets...)
- Limit specific software need to non-standard extractions
- **Reference for future missions** (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...



- Arrival Guide
- Programs & Tips
- Orientation
- Academic Issues
- International Friendship Program
- Practical Matters
  - Housing
  - Healthcare
  - English Programs
  - Driving in the US
  - How to Buy a Used Car

## 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 25 mph (40 km/h), then the wind-chill temperature is -20°F (-29°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.

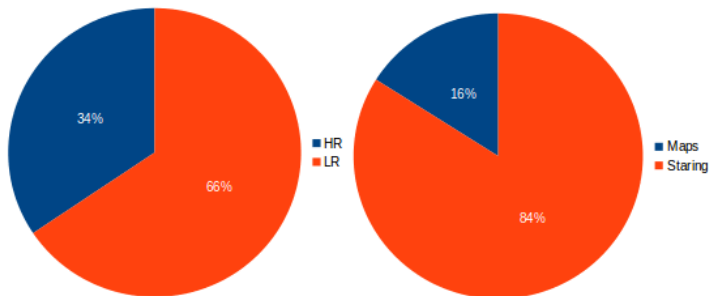
- Make a habit of listening to weather forecasts on TV or on the radio so that you will be able to dress appropriately each morning.
- On days that are bitter cold, limit the length of time that you are exposed to the cold. When you are out in very cold temperatures **BE AWARE OF THE POTENTIAL FOR FROSTBITE** which is an injury to the body caused by freezing. Most often, frostbite affects the nose, ears, cheeks, chin, 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:  $R \approx 600$ )

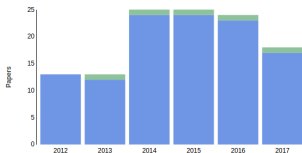
# CASSIS versions and history

## 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: <a href="http://cassis.sirtf.com">http://cassis.sirtf.com</a>
	Migration of data & website at Rochester University

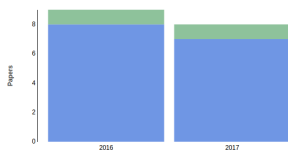
## Low-resolution (LR) pipeline

- 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



COMBINED ATLAS OF SOURCES WITH SPECTER IRIS SPECTRA

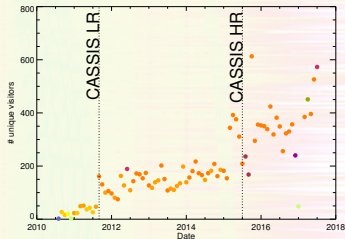
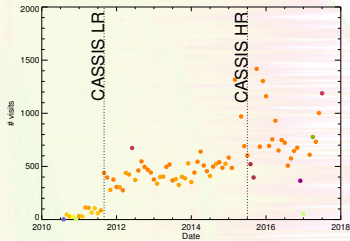
What is CASSIS? CASSIS papers Query form Create Documentation Contact/Feedback

**Current version:** low-resolution-LR? high-resolution-HR?

**Important announcements** (Full news & updates here)

- 2010 Nov 22: CASSIS now stands for "Combined Atlas of Sources with Spitzer IRIS spectra"
- LR is CASSIS; associated files
- 2013 Jun 29: First volume for high-resolution (HR)? See accompanying published paper
- 2013 May 27: LR? released. See Technical Note.
- 2014 Feb 26: LR? released. See Technical Note.
- 2013 Mar 26: LR? released. See Technical Note.
- 2011 Aug 17: CASSIS released (LR?). See accompanying published paper.

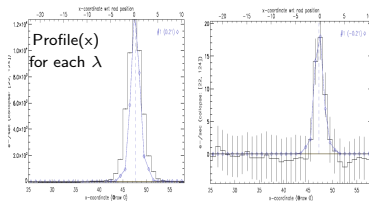
Search by position/name	Search by Program ID	Search by AORkey
Target: <input type="text"/> <input type="button" value="Resolve"/> <input type="button" value="Search for Spitzer Spectra"/>	Numeric Program ID: <input type="text"/> <input type="button" value="Search for Spitzer Spectra"/>	Numeric AORkey: <input type="text"/> <input type="button" value="Search for Spitzer Spectra"/>
You can search below by coordinates. Note that the query will be performed on the <i>observed</i> source coordinates, which might differ slightly from the requested and printed coordinates.	Search by Object List Provide a text file containing one object name per line. <input type="button" value="Choose File"/> No file chosen <input type="button" value="Search for Spitzer Spectra"/>	Search by AORkey List Provide a text file containing one AORkey per line. <input type="button" value="Choose File"/> No file chosen <input type="button" value="Search for Spitzer Spectra"/>
RA: <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> (decimal) deg		
DEC: <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> (decimal) deg		
Radius: <input type="text"/> " All coordinates J2000 <input type="button" value="Search for Spitzer Spectra"/>		



# 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**

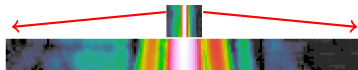




# Optimal extraction (LR)

## 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

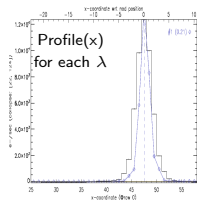
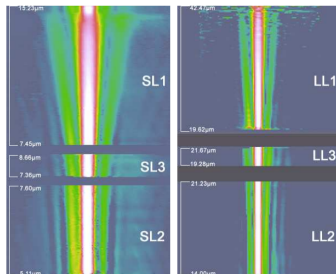
# Optimal extraction (LR)

## 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



# 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)

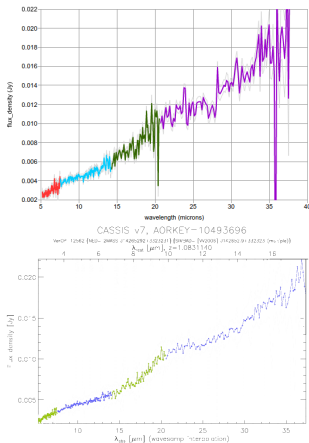
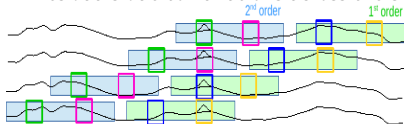
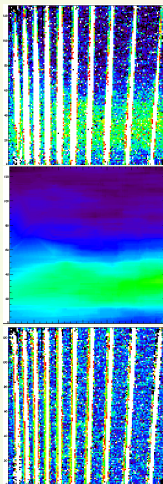


Fig.: AGN spectrum (top: SHA, bottom: CASSIS).

# HR pipeline

## Specificities

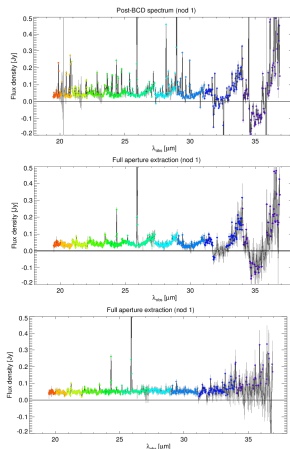
- Cross-dispersed echelle modules – larger fraction of bad pixels
- No systematic dedicated offset → rogue pixels & large-scale emission could be problematic
- Detector background gradient (→ 1D “zigzag” effect) → custom 2D surface interpolation
- Relative weights in series of exposures works well too,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



# HR pipeline

## 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!

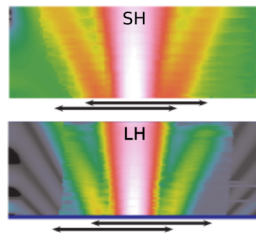
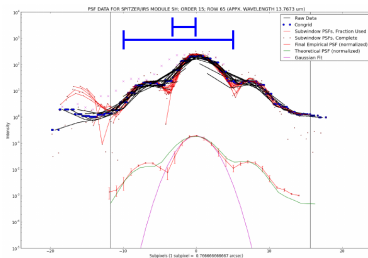


**Fig.:** LMC planetary nebula (top: SHA post-BCD, middle: CASSIS full aperture w/o correction, bottom: CASSIS full aperture).

# 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

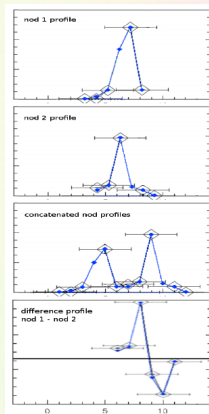
## Extraction methods

- **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

Profile(x) for each  $\lambda$



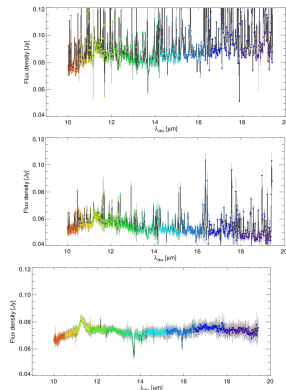
# HR results

## 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



**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  $22\mu\text{m}$  spectral energy distribution" (*Vika et al. 2017*)
- "Neon and [C II]  $158\mu\text{m}$  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

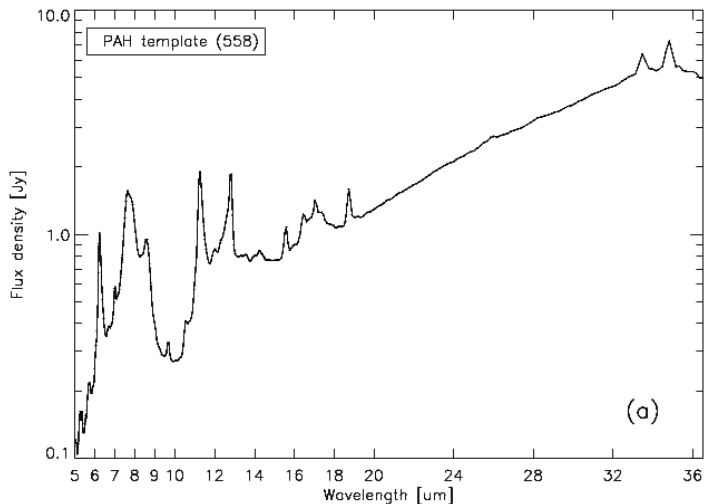
## Availability

- 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

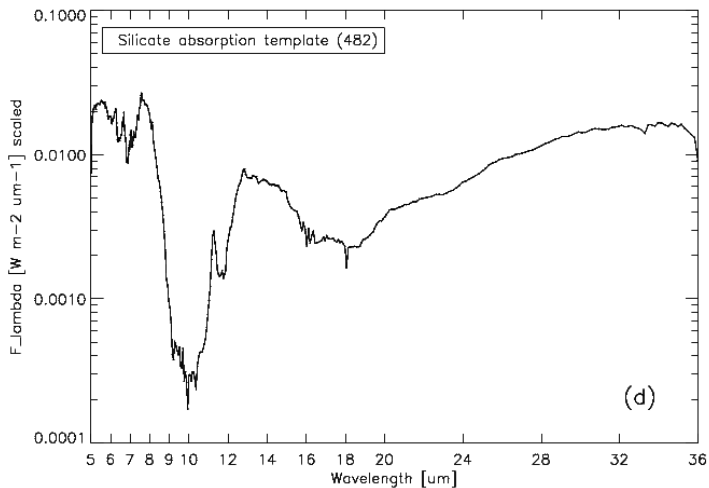
## Blind searches

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

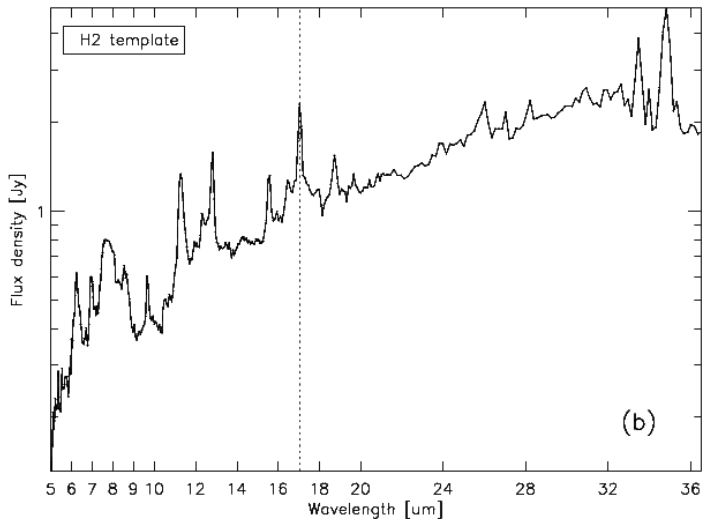
# Statistical analysis



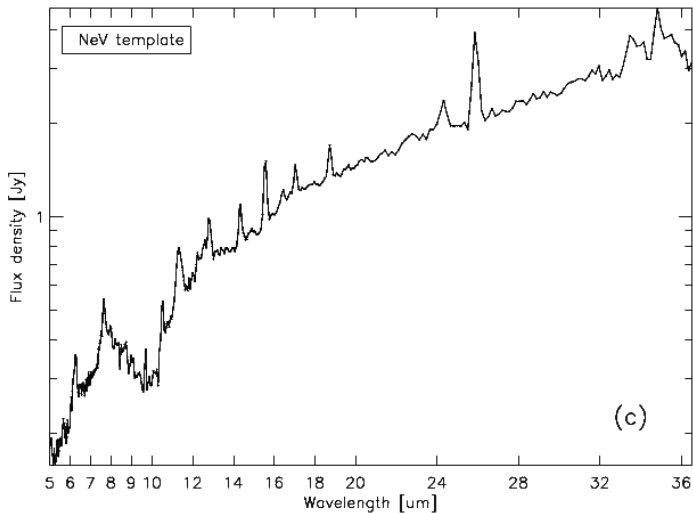
# Statistical analysis



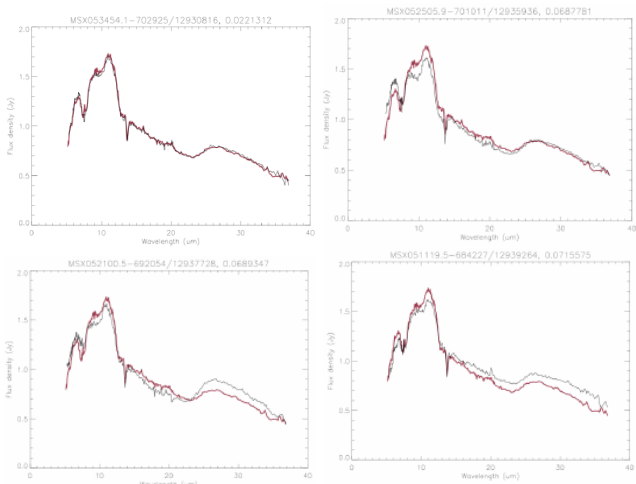
# Statistical analysis



# Statistical analysis



# Statistical analysis

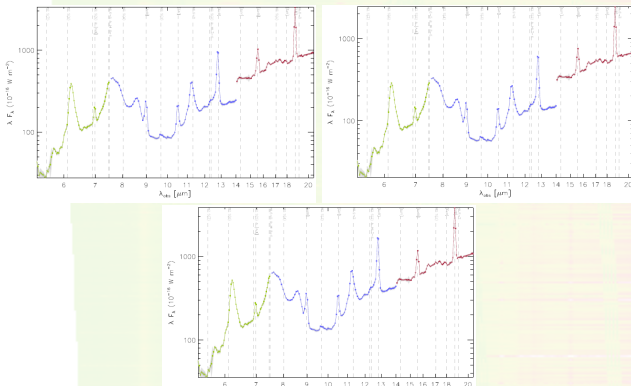




# Standard sources in CASSIS

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

## 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)

## 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

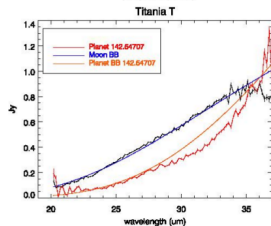
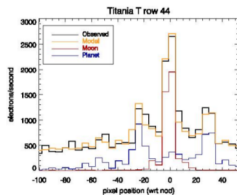
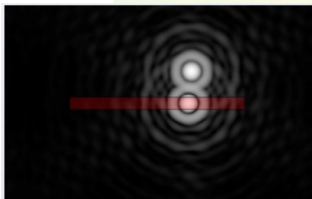
# Non-standard sources with AdOpt: sources not in slit

## Shift in dispersion direction

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

## Uranus' moons *(Zivick et al.; unpublished)*

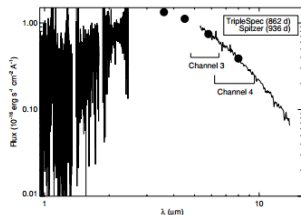
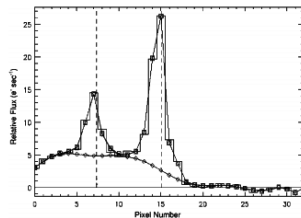
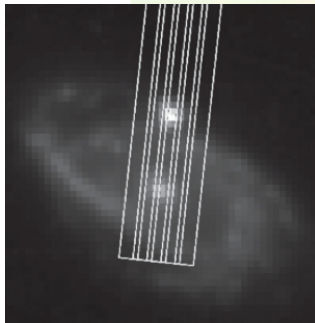
- Temperature in agreement with theoretical models
- No CO<sub>2</sub> absorption



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

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

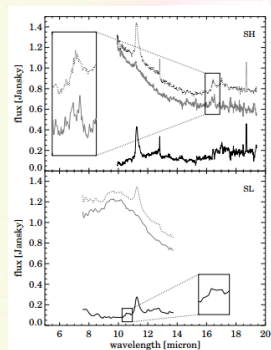
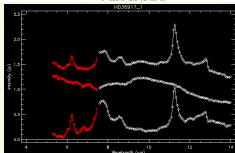
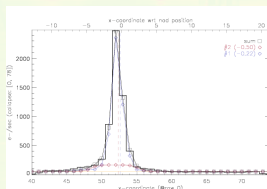
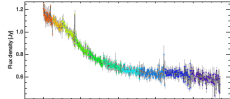
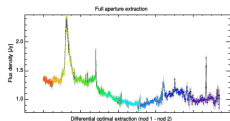
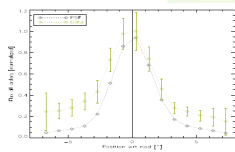
- No emission lines; warm dust component



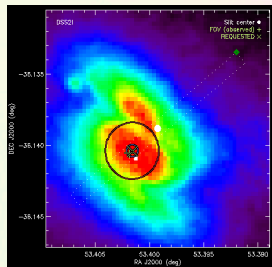
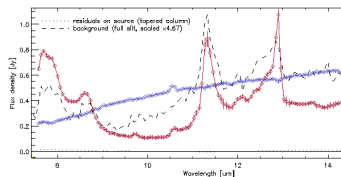
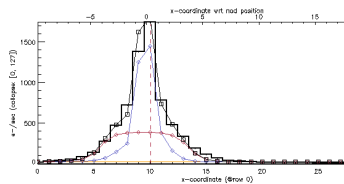
# Spatial decomposition with AdOpt: HR & LR

Example: Herbig Ae/Be star HD36917

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



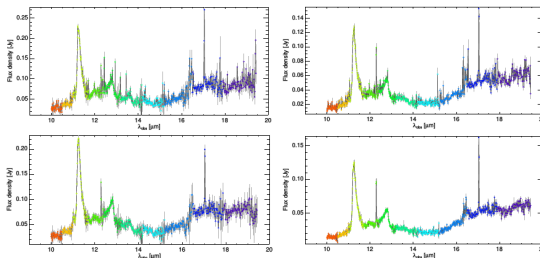
# Spatial decomposition with AdOpt: NGC1365



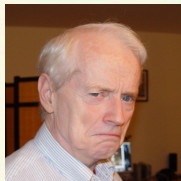
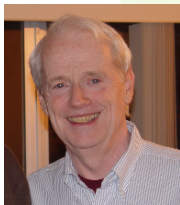
# Future

## CASSIS is not a frozen archive

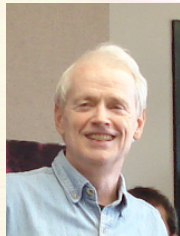
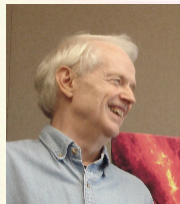
- HR extractions; effort with Rochester; ADAP proposal submitted
- Automatic decision for HR extraction method
- Use of dedicated backgrounds (for faint and/or extended sources)
- Integrated maps
- Complementing with other IR spectra (Herschel/PACS underway for extragalactic; D. Weedman)



*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.*

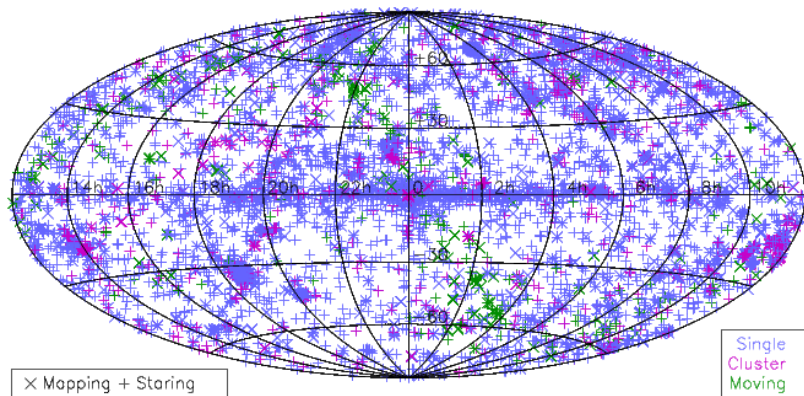


...and many thanks to Jim!

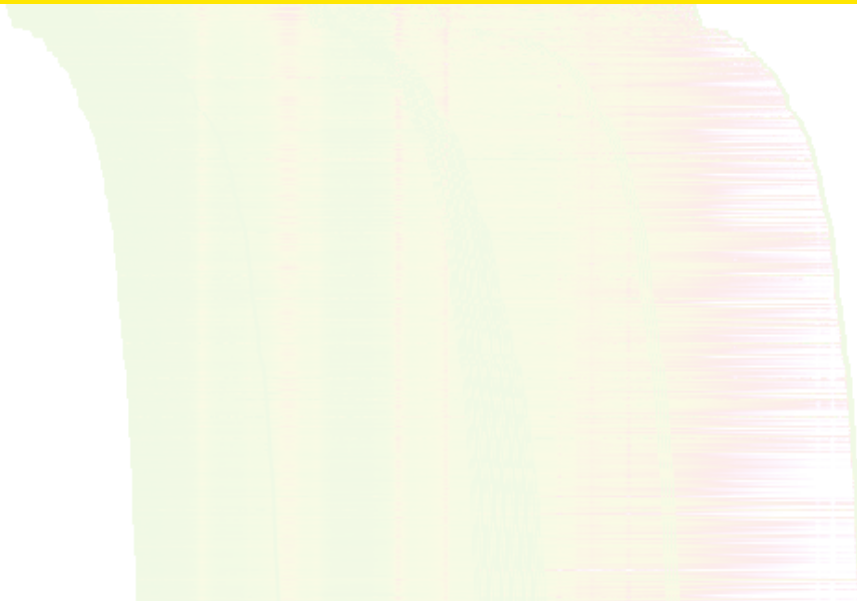




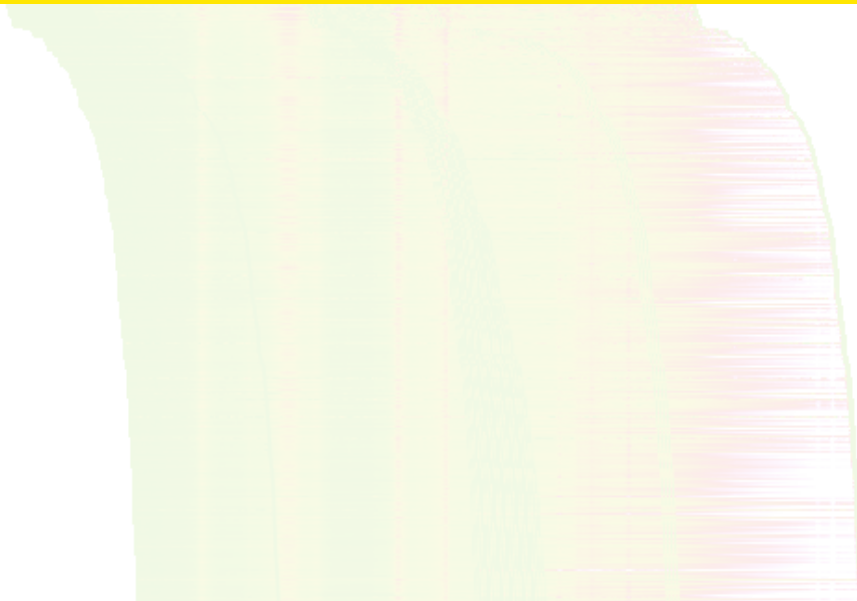
# Extra slides



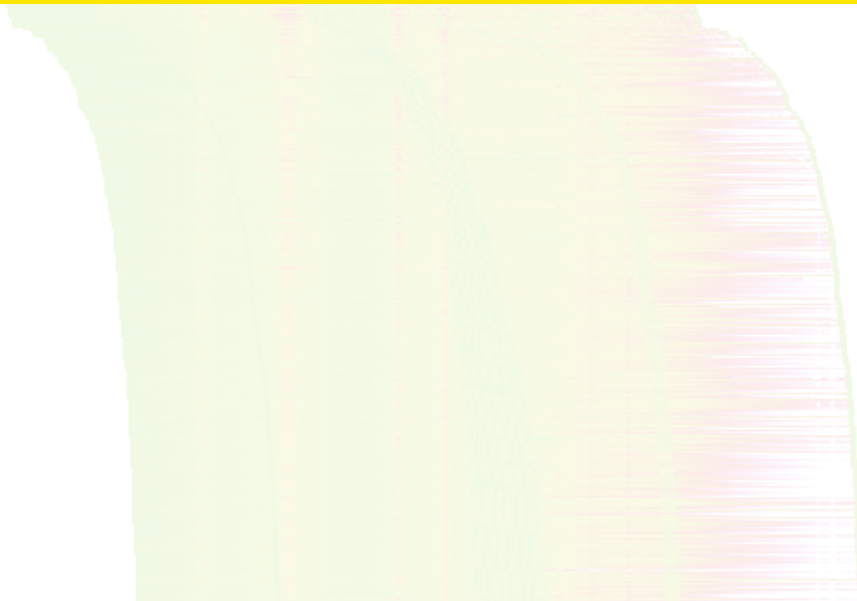
# Extra slides



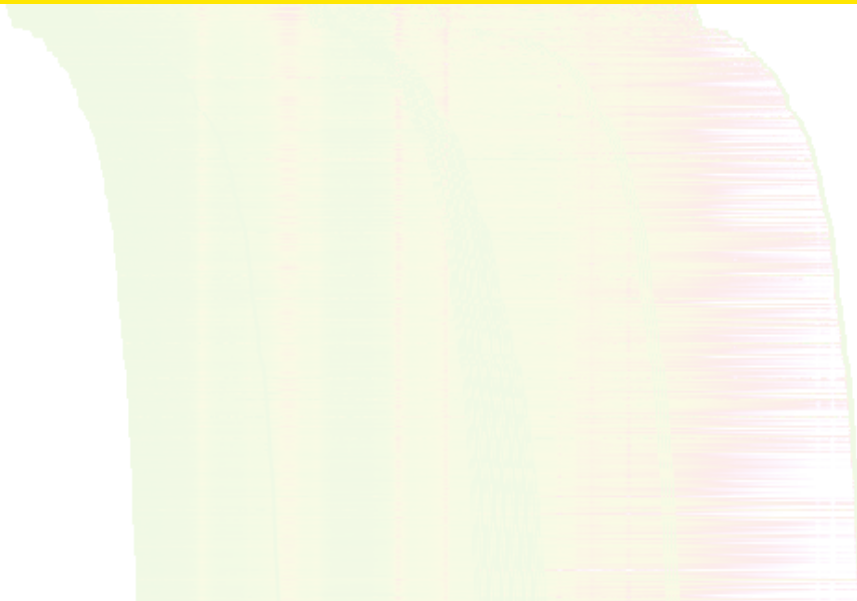
# Extra slides



# Extra slides



# Extra slides



# Extra slides

