The Spectral Legacy Survey: a spectral imaging survey with JCMT

Gary Fuller, Frank Helmich, Rene Plume + SLS Collaboration

http://www.jb.man.ac.uk/research/sls

Outline

- Background
 - New JCMT instruments
 - JCMT Legacy programme
- The SLS
 - The 345GHz window and existing surveys
 - SLS goals and target sources
 - Early data
- Other Legacy Surveys

New JCMT Instruments I: SCUBA2

ARRAY - 2

- Simultaneous 850 and 450 micron cameras
- Each pixel twice as sensitive as SCUBA Transition Edge Sensor (TES) detectors
- Four 32x40 arrays at each wavelength 10240 pixels in total
- 7'x7' field of view 16x SCUBA fov
 100 times faster for mapping than SCUBA
- FTS and polarimeter modules
- Delivery to JCMT in Sept. 2006

New JCMT Instruments II: HARP-B/ACSIS

HARP-B:

- 325-375 GHz heterodyne camera
- 4x4 pixels 30" separation 2'x2' field of view
- $T_{rx} \sim 120 \text{ K}, T_{sys} \sim 320 \text{ K}$ (grade 3 weather, tau(225 GHz)~0.12)

ACSIS:

- 16 IF autocorrelator
- 2GHz per IF, 1MHz (0.9 km/s) channels





HARP-B/ACSIS Data

Commissioning started Dec 05.



(John Richer, Jane Buckle, Bill Dent, Remo Tilanus)

HARP-B/ACSIS Data II



2GHz BW centred at 345.796 GHz

The Legacy Survey Program

1) Spectral Legacy Survey (SLS) – molecular content of sources

2) Gould's Belt Survey-local (low mass) star formation

- 3) JCMT Plane Survey (JPS) massive star formation
- 4) SASSy All Sky/Off plane survey
- 5) Debris Disk
- 6) Local Galaxies
- 7) Cosmology

SLS: Exploring The Spectral Domain

- Only spectral lines probe
 - kinematics
 - physics
 - chemistry
 - evolution
- Poor understanding of molecular inventory and its evolution
- Typical source ?
- Typical spectrum ?

The 345 GHz Window



Lovas (2004) • 866 transitions • 82 species

Important spectral band: ALMA DRSP: >30% of observing time in this band

Two Atom Species	Three Atom Species	Four Atom Species
CO ¹³ CO C ¹⁷ O C ¹⁸ O	OCS OC ³⁴ S O ¹³ CS	CCCS
CS C ³⁴ S C ³³ S	HNC HN ¹³ C H ¹⁵ NC	H ₂ CS
CN CO ⁺ NO NS	HCO+ H ¹³ CO+ HC ¹⁸ O+ DCO ⁺	HDCO
SiO ²⁹ SiO ³⁰ SiO	HCN H ¹³ CN HC ¹⁵ N DCN	HNCO
SIS SI33S SI34S 29SIS 30SIS	H2O HDO HCO+ SiC ₂	H3O+
SO 33SO S18O 34SO	HDS C2H HNO HCS+	NH2D NHD2
SO ⁺ SO2 ³⁴ SO2	$HCO H_2D^+$	H ₂ CO H ₂ C ¹⁸ O H ₂ ¹³ CO D ₂ CO
	_	
Five Atom Species	Six or More Atom Species	
HCCCN HCC ¹³ CN HC ¹³ CCN H ¹³ CCCN	CH2CHCN	CH3OH ¹³ CH3OH
HCOOH HCOOD	CH3CCH	NH2CHO
CH2CO NH2CN	CH3CH2CN CH3OCHO	t-CH3CH2OH
CH2NH c-C3H2	CH3CN ¹³ CH3CN	CH3OCH3

But poorly explored...

Source	Frequency Range	Noise	Reference
	(GHz)	(K)	
High Mass Sources			
Orion KL	325 - 360	0.15	Schilke et al. 1997, Jewell et al. 1996
G34.3+0.15	330 - 365	0.05	Macdonald et al. 1996, Thompson et al. 1999
G5.89-0.39	330 - 360	0.06	Thompson & Macdonald 1999
W3 IRS5, IRS4, OH	334 - 365	0.03	Helmich & van Dishoeck 1997
Sgr B2	330 - 355	0.06	Sutton et al. 1991
IRAS 23385-6053	330 - 360	0.03	Thompson & Macdonald 2003
	(incomplete)		
Low M	lass Sources		
IRAS 16293-2422	330 - 365	0.018	Caux et al. in progress

- Complete census of species
- Comparison of species
- Trace range of excitation
- New/unexpected species
- Defining the continuum

All current are of single positions BUT none of the sources are isolated point sources

 \rightarrow Need imaging



AFGL2591 van der Tak et al (1999)

Clearly not a point source

Helmich & van Dishoeck (1996)

3 sources

- Line profiles
- Isotopomers important CS



Helmich & van Dishoeck (1996)

3 sources

- Line profiles
- Isotopomers important CS



Helmich & van Dishoeck (1996)

3 sources

Not simply line rich vs. line poor
W3 IRS5 - S and Si rich
W3(H₂O) – Ten times richer in organics like CH₃OH, CH₃OCH₃ and CH₃OCHO

Images:

- Separate core from envelope emission
- Origin of line profiles
- Outflow
- Separating/deblending lines
- Pointing corrections
- Cross calibration



Goals For The SLS

- Complete spectral coverage 330-360 GHz, 2'x2' field
- Molecular inventory of sources
- Evolution of molecular inventory with time and environment
- Use molecular observations to study structure and evolution of sources
- Ultimately define a characteristic molecular spectrum for different types of objects and environments

Survey a sample of sources spanning a range of evolutionary stages of star formation and environments:

- High mass sources
- Low mass sources
- Outflows
- Photon Dominated Regions (PDRs)

High Mass Sources

- IRAS 20126+4101
- AFGL2591
- W49
- (IRAS18182-1433, IRAS 21307+5049)
 - Noise level 0.025 K (in 2.5 km/s channel)

IRAS20126+4104

2μm image (Sridharan, Williams & Fuller 2005)



- Embedded young $10^4 L_{\odot}$ source at 1.7 kpc
- 5-7 M_o central source in 200M_o core
- Keplerian disk, 5000 AU in radius CH_3CN , OH masers
- Outflow CH₃OH, SiO, H₂O masers precessing?
- Target for HIFI on Herschel

AFGL 2591

- $2x10^4$ Lo at 1 kpc
- Infrared bright
- Very well studied
- Rich molecular spectrum
- Source structure well characterized (van der Tak et al 1999)





- Distant: 11.4 kpc
- Luminous: $10^7 L_{2}$
- Cluster of UCHII regions embedded in 10^5 M_{\circ} cloud



Stepping stone to extragalactic star formation regions

(De Pree et al. 2003)



(Martin et al.)

Low Mass Source: NGC1333 IRAS4

- 30" binary resolved and imaged
- Class 0 sources infall, outflow, rotation
- Differences between components
- Depletion, high deuterium fractionation
- (L1157, L1544)





(Di Franesco et al. 2001)

(Blake et al. 1995)

PDR: Orion Bar

- Dense gas exposed to $10^4 G_{o}$
- Dense clumps $\sim 10^6$ cm⁻³
- Inter-clump $\sim 10^4$ cm⁻³
- No (internal) star formation



(Lis & Schilke 2003)

Technical Details

- Fully sampled maps (15" beam) covering 2'x2'
- 330 360 GHz, 1km/s channels
- 38 frequency settings per source (10% overlap)
 - SSB no need for deconvolution
 - 25-40 minutes per setting (high mass sources)
 - 3-4 hours per setting (low mass source)
- 0.025 K rms for high mass sources (2.5 km/s channels)
- 0.015 K for low mass
- 187 hours, grade 4 weather
- Survey to start in 2nd half of 2007 and run for 2 years

Analysis & Products

- Calibrated cubes
- Identifications of lines in spectra
- Maps of each species
- LTE column densities and temperatures of important species
- Eventually models and abundance profiles

Limitations

- Sources
 - Only one low mass object
 - No starless cores
 - Only 3 high mass objects
 - Biased sample
 - Only star forming regions

- 'Limited' Frequency coverage
 - Want coverage up to 373 GHz
 - Other bands
 - excitation mismatch
 - species with too few lines
 - 230 GHz 180 hours



First SLS Data: 230GHz Observations

• Single point spectral survey of AFGL2591 211-279 GHz



Image SLS footprint in at six frequency settings:
 DCO⁺/DCN, CH₃OH, HCN, H¹³CN, ¹³CO/C¹⁸O, ¹³CS









AFGL2591 H¹³CO⁺ J=3-2: colour CH₃OH 5-4: white contours

> Orion Bar HCN J=3-2: white contours and spectrum C¹⁸O J=2-1: colour scale and red spectrum



Collaboration Members

• Helen Roberts, Survey Manager (Queens Belfast)

John Richer Jane Buckle Jeremy Yates Mark Thompson Janet Bowey Jennifer Hatchell Serena Viti Jonathan Rawlings Tom Millar Toby Moore Glenn White

Cecilia Ceccarelli Emmanuel Caux Peter Schilke Xander Tielens Markus Roellig Volker Ossenkopf Henry Matthews George Mitchell Andy Gibb Michiel Hogerheijde Floris van der Tak Ewine van Dishoeck Marco Spaans

Harold Butner Jan Wouterloot Ming Zhu Per Friberg Bernd Weferling





JCMT Plane Survey

Toby Moore (LJMU), Russ Shipman, Rene Plume

- Map star formation throughout the Galactic Plane
- $|b| < 1^{\circ}, (0) \ 10^{\circ} < l < 250^{\circ}$
- 450 um and 850um (8" and 14" resolution
- Mass sensitivity $1M_{\odot}$ at 3 kpc, $40M_{\odot}$ at 20 kpc
- First 2 years:
 - $10^{\circ} < 1 < 65^{\circ} GLIMPSE$
 - 102.5°<l<141.5° FCRAO Outer Galaxy survey

Gould's Belt Survey

Derek Ward-Thompson, Jenny Hatchell, Doug Johnstone, Michiel Hogerheijde



- Survey of local star formation
- Map 700 sq. deg of local clouds
- Deep (3 mJy) survey of Av>3 regions, 100 sq. deg
 0.08 M_o per beam
- Shallow (10 mJy) Av<1 regions, 600 sq. deg
- Detect every Class 0 and I source

http://www.astro.cf.ac.uk/pub/David.Nutter/Scuba2/



Mark Thompson, Tim Jenness, Steve Serjeant

- SCUBA2 'All' Sky Survey
- -30°<δ<+70°, 30 mJy at 850μm
- Initially
 - 0°<1<270°, |b|<5° GP Wide
 - 10° wide strip perpendicular to Galactic Plane through Galactic poles and ecliptic north pole