HELP-ing Radio Continuum Surveys

The Herschel Extragalactic Legacy Project

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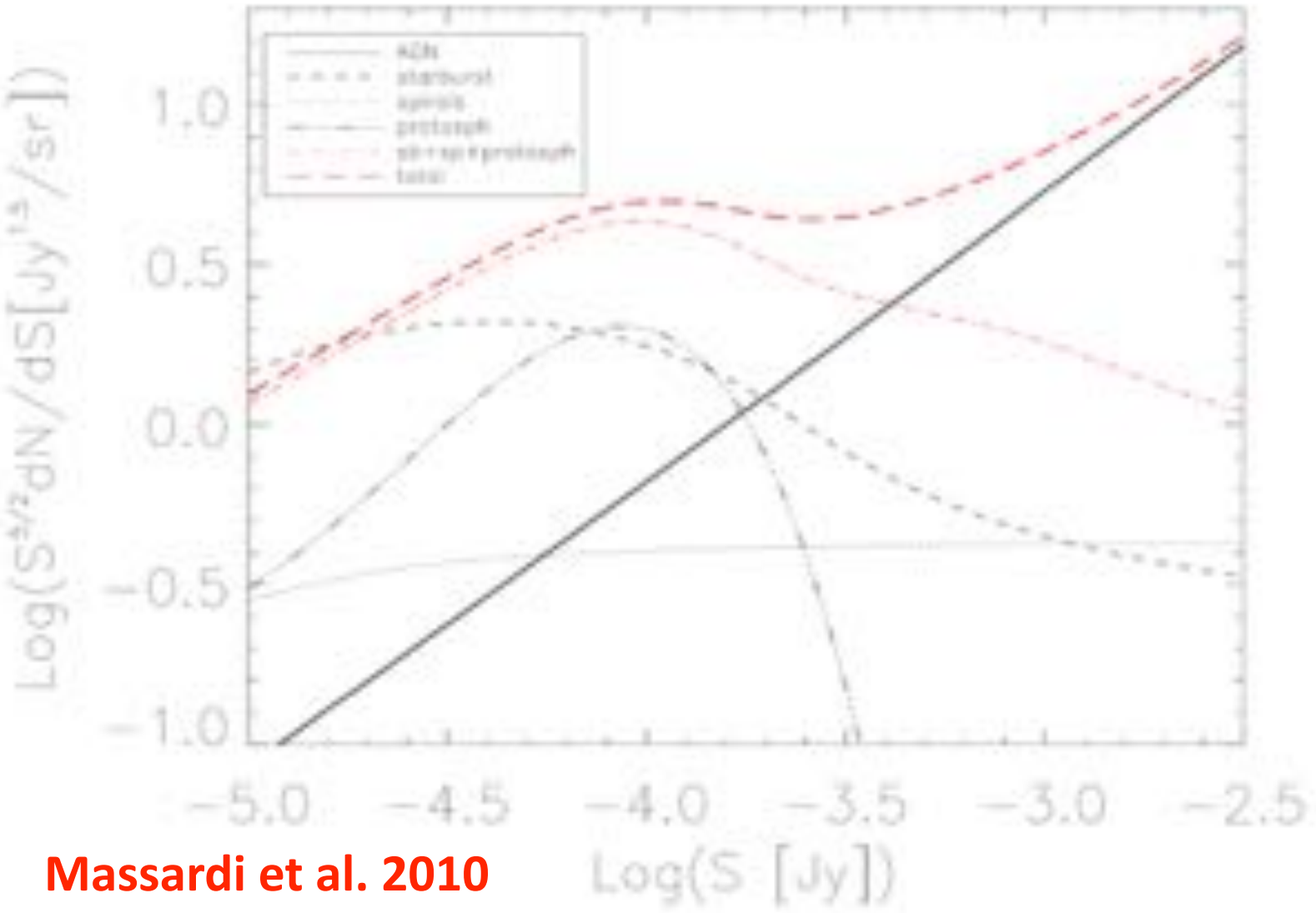
EC-REA - FP7-SPACE-2013

SA-DST - COINVEST-2014

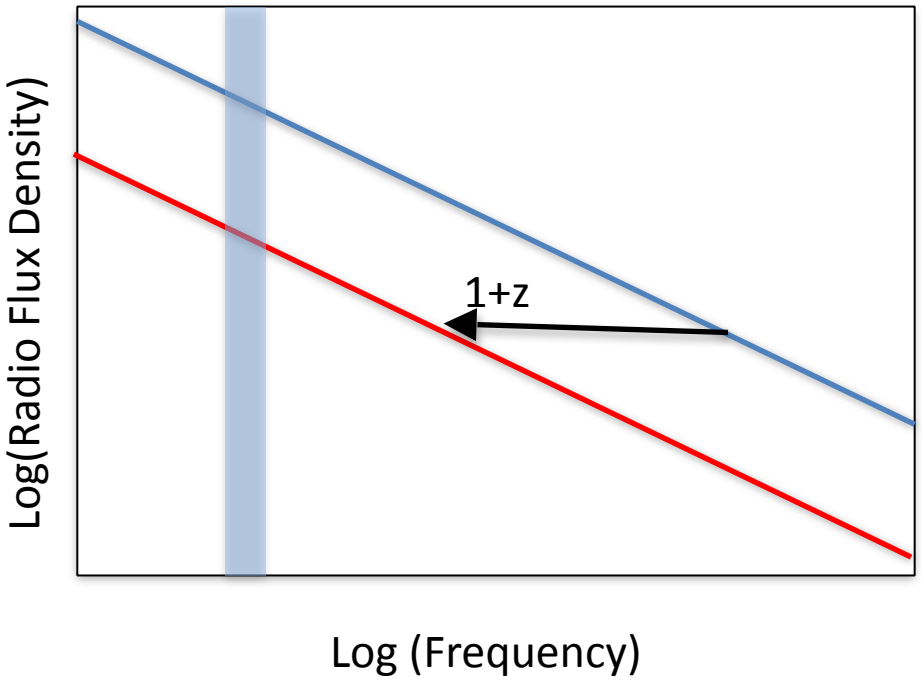
The Faint Radio Sky

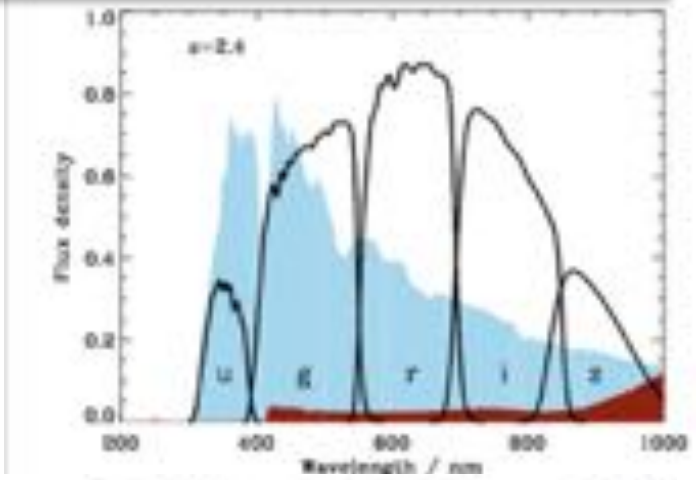


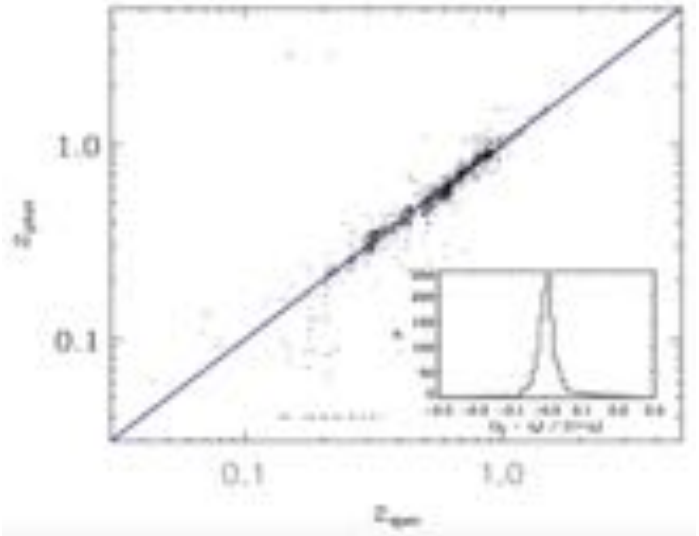
Massardi et al. 2010

But of course…

There's nothing as useless as a radio source (Jim Condon)





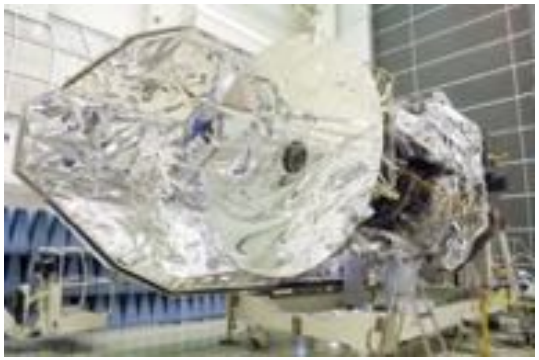


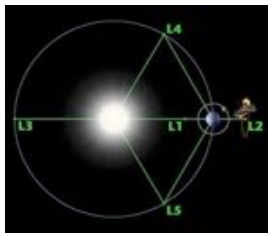
Radio provides no (or very little?) redshift information!

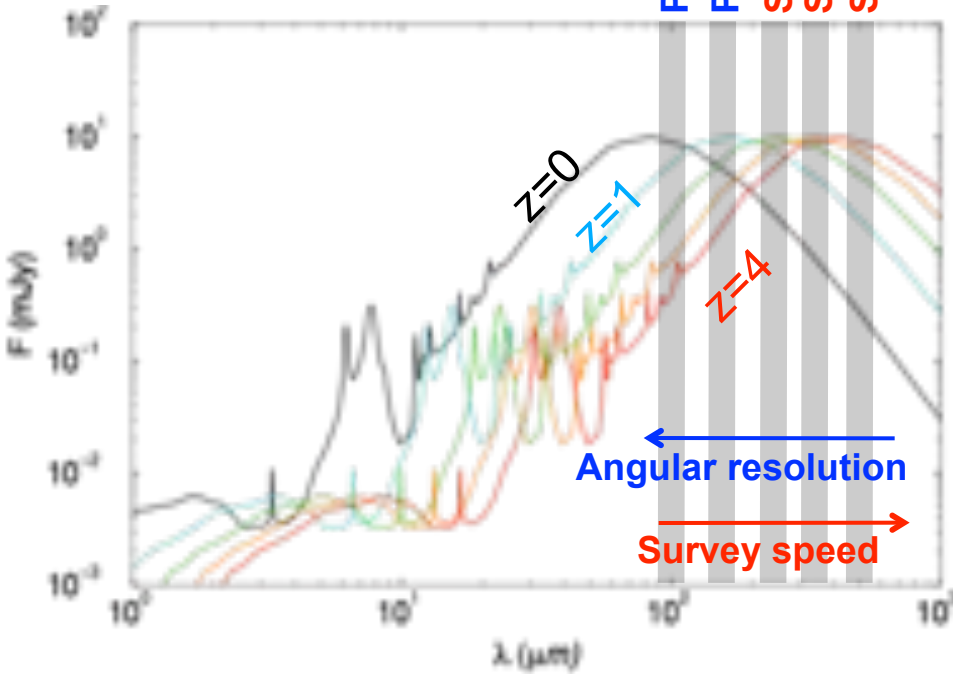
The Herschel Space Observatory

Herschel is a recently completed ESA cornerstone mission (2009-2013)

- large (3.5 m) aperture, low emissivity (~5%), passively cooled (70-90 K)
- cryogenically cooled focal plane science instruments with ~3.5 year lifetime (2009-2013)







Questions addressed by Herschel

- What is the history of Far-Infrared galaxies?
- How do they assemble and evolve over time?
- Where have luminous FIR systems gone today?
- How do FIR galaxies relate to dark matter?
- What is the role of dust in star formation?
- What is the connection between dusty star formation and AGNs?

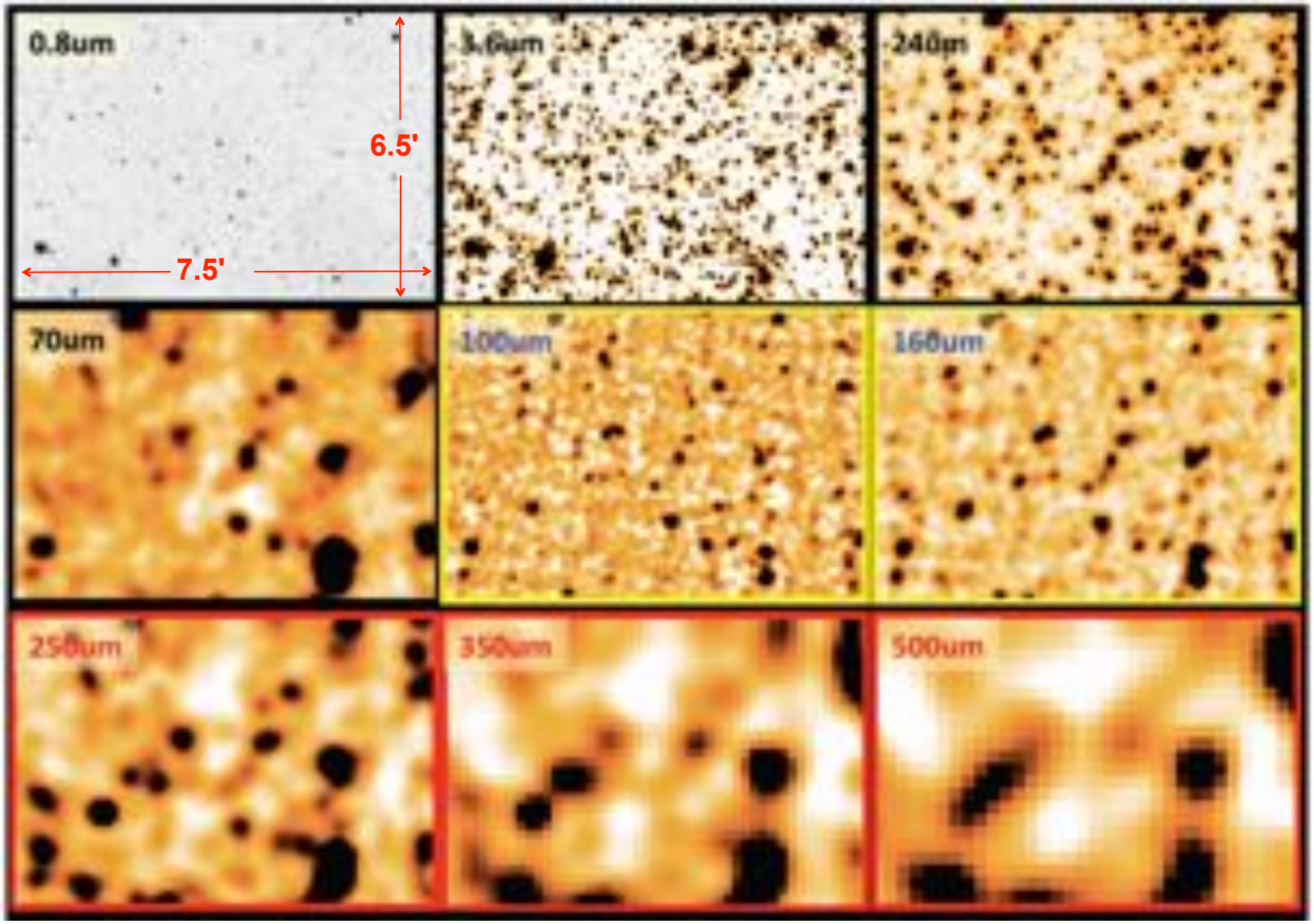
HERMES

ATLAS

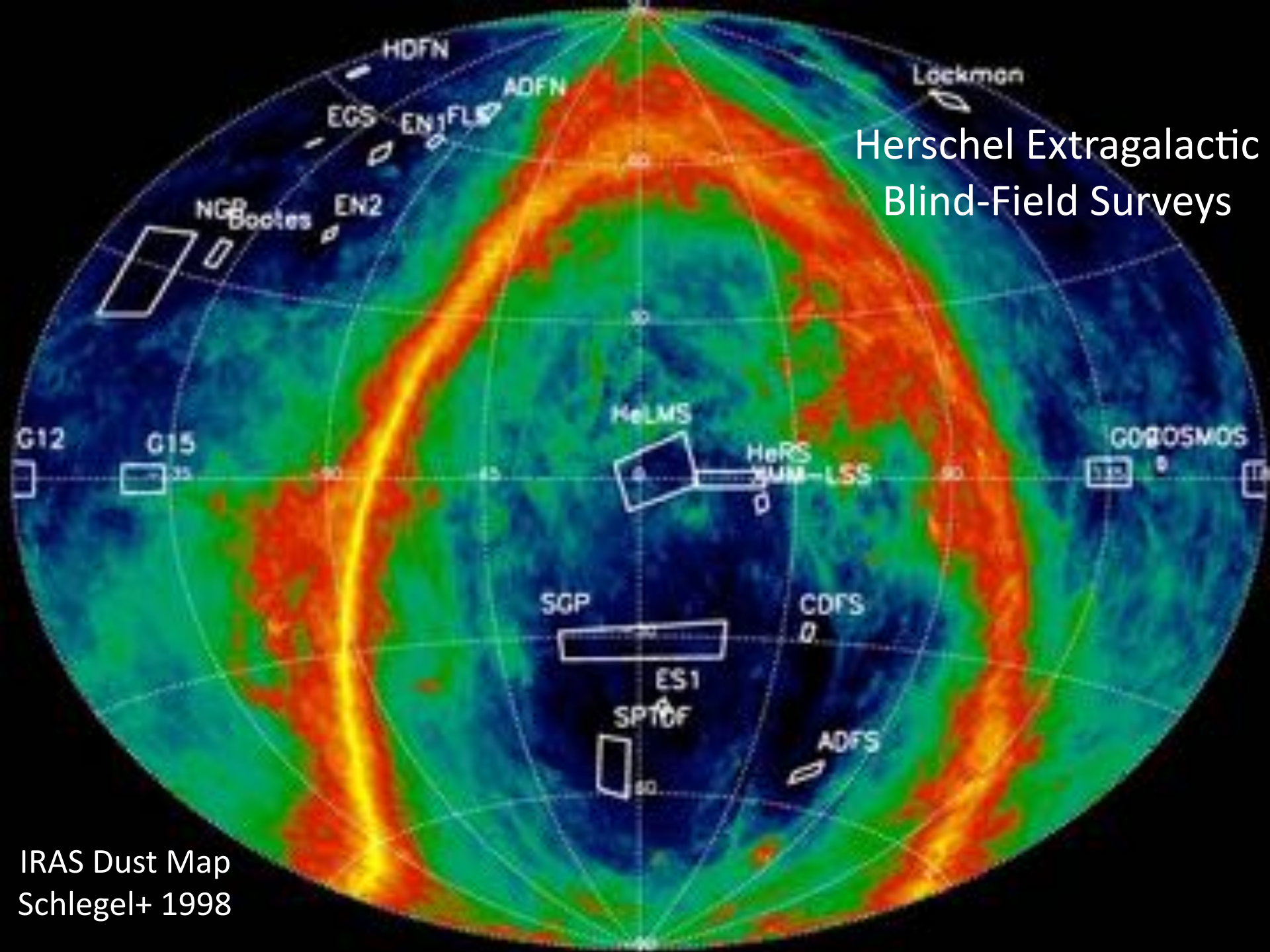
Herschel Extragalactic Imaging Surveys

- High-sensitivity (albeit with moderate resolution)
- Use PACS & SPIRE at 100-500 μm
- Observe the SED peak of IR galaxies at 1<z<4
- Detect Large and Uniform Samples of (U)LIRGs
- Derive IR "Bolometric" (8-1000 μm) Luminosity and use it as a Star Formation Rate Indicator

The Confusion Challenge



GOODS-N - David Elbaz


HDFN
ADFN
Lockman
EGS
EN1
FLS
NGP
Boötes
EN2
G12
G15
HeLMS
HeRS
SWIRE-LSS
COSMOS
SGP
CDFS
ES1
SPTDF
ADFS
Herschel Extragalactic
Blind-Field Surveys
IRAS Dust Map
Schlegel+ 1998

A Multi-Wavelength Catalog for Herschel Science
The Spitzer Multi-Wavelength Data Fusion

Spitzer Proprietary Catalogs (SWIRE, Bootes, XFLS)
IRAC (ch1 or ch2) selected
IRAC ch3/ch4 & MIPS 24/70/160 available in all fields } **MID/FAR-INFRARED**

GALEX FUV & NUV available in all fields } **UV** http://www.mattiavaccari.net/df/

SDSS ugriz available in the North (Astro/Photo Calibration)

Miscellaneous Optical (SWIRE, INTWFS, NDWFS, CFHTLS, VOICE) } **OPTICAL**

2MASS JHKs always available (Spitzer Astro Calibration)

UKIDSS DXS JK available over 24 deg^2 in XMM/LH/EN1

VIKING & IBIS available over 20 deg^2 in XMM & Bootes

VIDEO ZYJHK available over 12 deg^2 in ES1/XMM/CDFS } **NEAR-INFRARED**

Spec-Z available @ NED & Recent Literature + Proprietary Follow-Up
Photo-Z available from SDSS @ Low-Z as well as from SWIRE @ High-Z
(Rowan-Robinson+ 2013 with early version of data fusion) } **REDSHIFT**

A Multi-Wavelength Catalog for Herschel Science

The Spitzer Multi-Wavelength Wide-Area Data Fusion

Vaccari 2015

Based on an homogeneous source re-extraction of IRAC & MIPS maps (IRAC1 or IRAC2 selection) and including matched far-ultraviolet-to-sub-millimeter photometry and optical phot/spec-z info

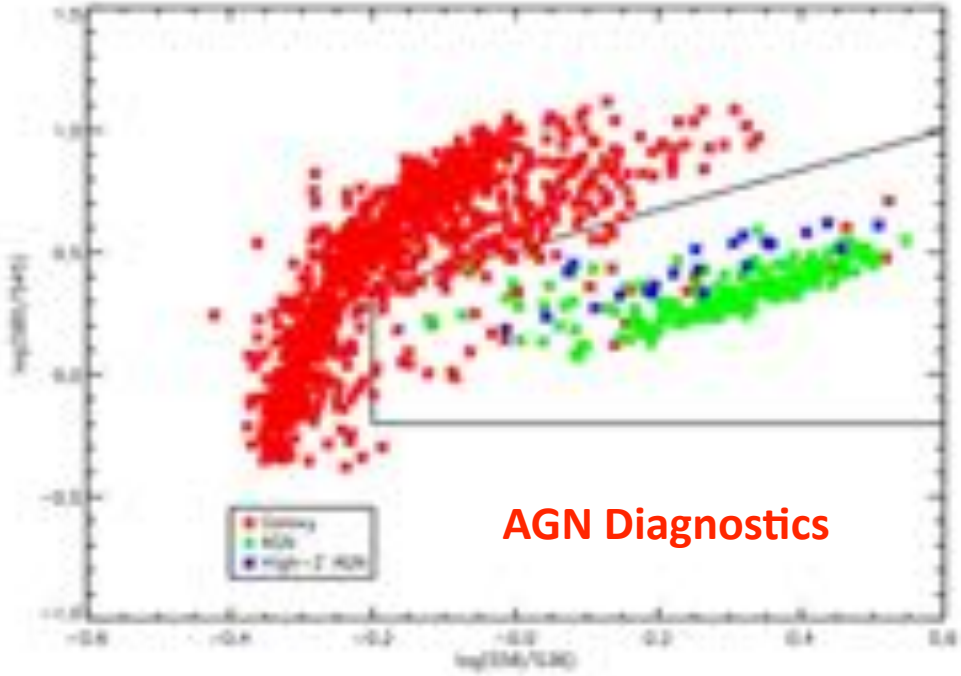
Field Name	IRAC 3.6/4.5 μm	MIPS 24 μm	MIPS 70 μm	MIPS 160 μm	GALEX FUV/NUV	SDSS *ugriz*	INTWFC *ugriz*	2MASS *J/H/K*	UKIDSS *J/K*	SpecZ -	Area deg^2
ES1	391,518	39,491	1,653	695	43,308	NA	NA	10,716	NA	10,092	7.00
XMM	497,404	62,914	3,137	1,379	66,168	147,583	NA	14,575	191689	42,919	9.35
CDFS	464,084	67,584	3,418	1,431	59,976	NA	NA	12,785	NA	28,166	8.15
LH	660,053	91,779	4,722	2,076	82,819	205,283	407,862	16,919	390,552	6,905	11.50
EN1	573,843	85,394	4,041	1,865	66,867	199,067	344,817	20,959	432,835	4,048	9.65
EN2	273,650	40,867	1,929	769	34,470	97,956	163,151	11,263	NA	1,276	4.40
BOOTES	1,301,829	117,083	4,609	2,921	100,918	227,132	NA	7,320	NA	20,808	11.10
XFLS	228,354	32,225	2,050	282	23,164	73,316	116,725	11,018	NA	2,724	4.00
Total	4,390,735	537,337	25,559	11,418	477,690	950,337	1,032,555	40,019	1,015,076	116,938	65.15

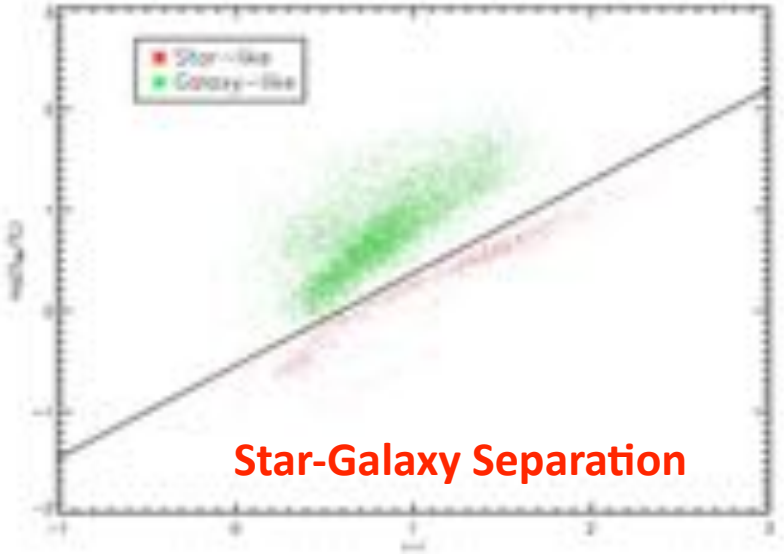
~ 4.4 million of IRAC sources | **65 deg^2** | **σ ~ 1 μJy in IRAC12** | http://www.mattiavaccari.net/df/

Channel	5 σ	ES1	XMM	CDFS	LH	EN1	EN2	Bootes	XFLS
IRAC1	μJy	4.76840	5.25900	4.55549	4.78744	4.26259	4.48797	3.05341	9.08400
IRAC2	μJy	8.04903	8.84478	7.13946	7.92854	7.40824	7.19349	4.71199	11.3045
IRAC3	μJy	44.5722	49.7808	39.2219	42.0780	40.7996	38.9273	24.8941	54.5668
IRAC4	μJy	48.0917	57.4191	42.1147	46.6329	44.3806	40.8671	26.9888	51.2335
MIPS1	μJy	412.782	345.791	285.696	299.489	286.682	277.815	232.498	332.984
MIPS2	mJy	20.1240	18.2400	14.6760	14.9760	15.1200	14.1420	14.8620	16.2000
MIPS3	mJy	102.135	92.8944	78.1688	85.3829	86.7785	83.4434	80.3084	103.469

A Multi-Wavelength Catalog for Herschel Science

The Spitzer Multi-Wavelength Wide-Area Data Fusion





Optical/Near-Infrared/Mid-Infrared Color-Color Diagnostic Diagrams

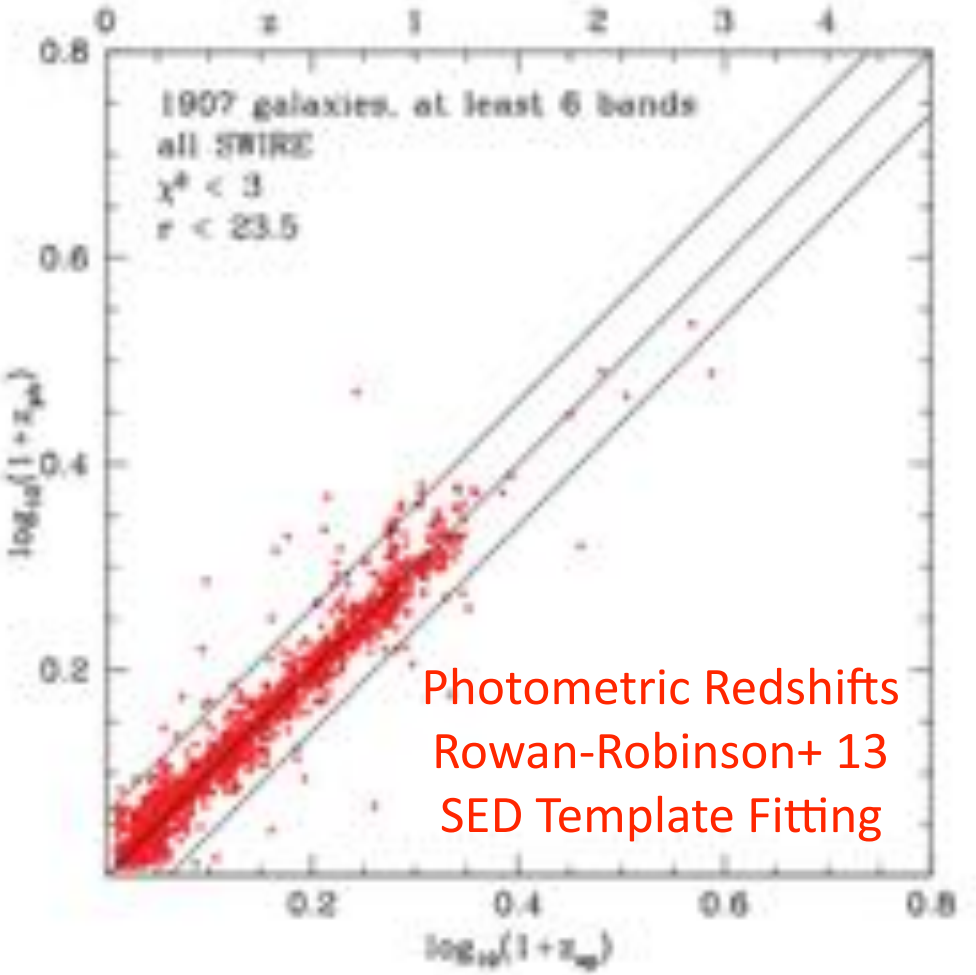
A Multi-Wavelength Catalog for Herschel Science

The Spitzer Multi-Wavelength Wide-Area Data Fusion

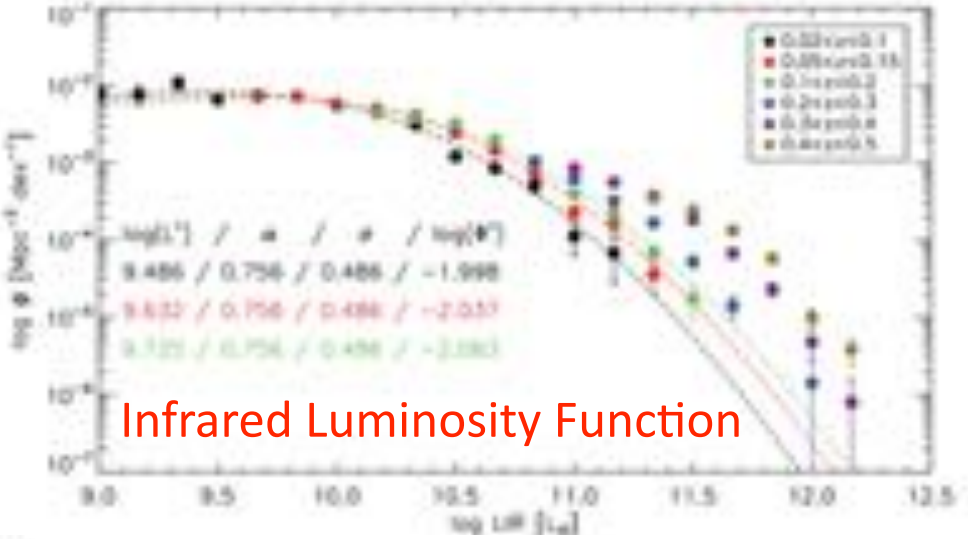
- **UV/Optical/NIR catalog-level Aperture Matching and SED template fitting χ^2 minimization (Rowan-Robinson+ 2013) returning good photometric redshifts and physical constraints**

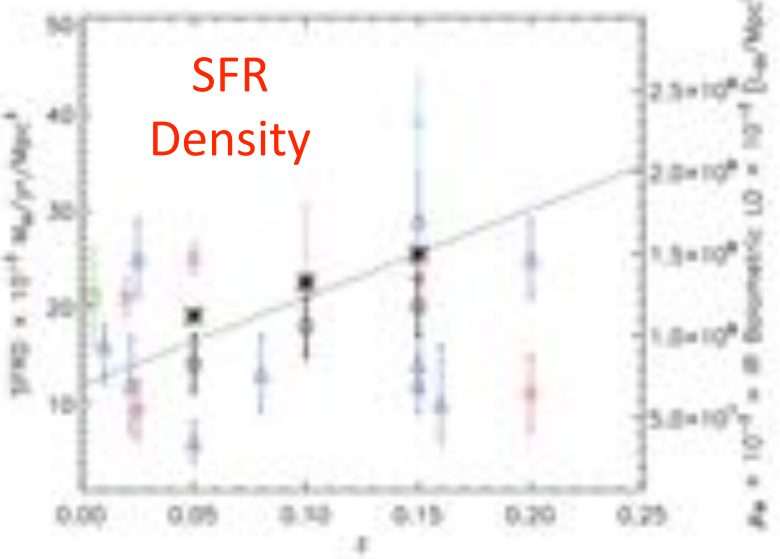
BUT

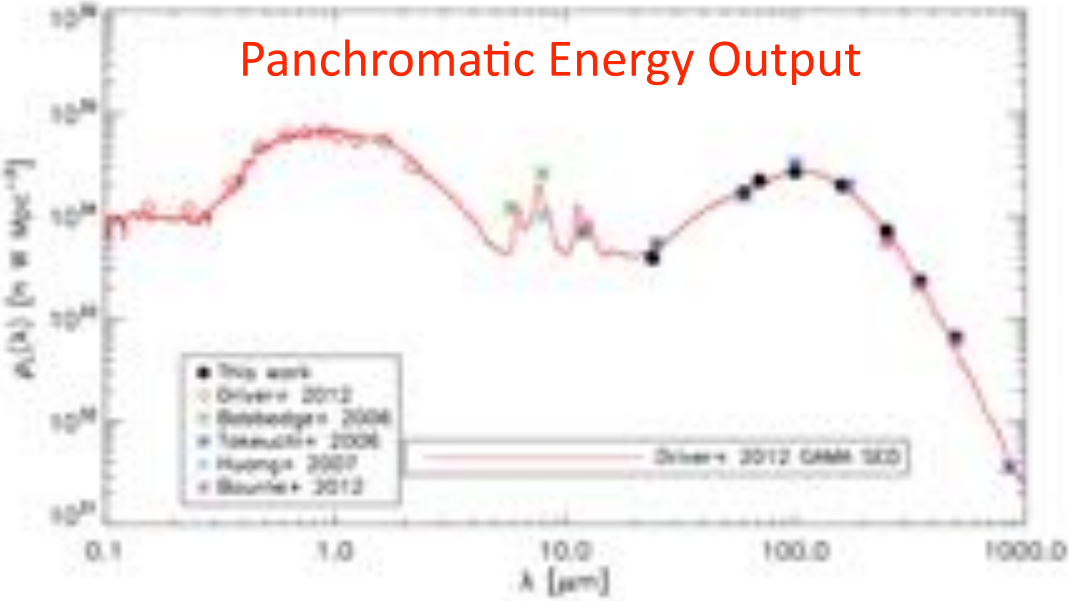
- **Image-level aperture matching and/or multi-band source extraction will be extremely beneficial for the optimal exploitation of VOICE, DES, VIDEO & SERVS data in equatorial/ southern fields**



The Herschel Local Luminosity Function and Panchromatic Energy Output



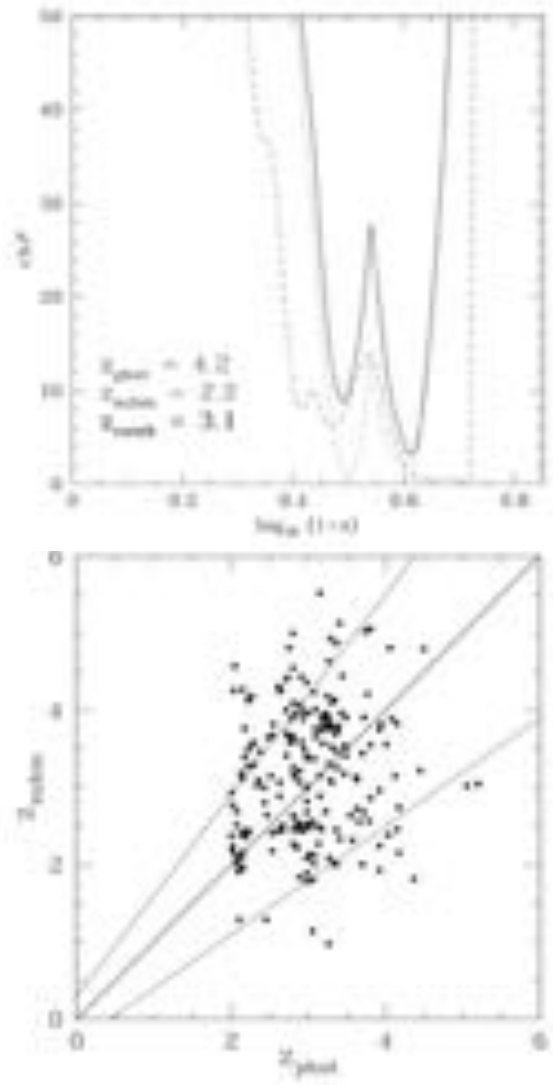


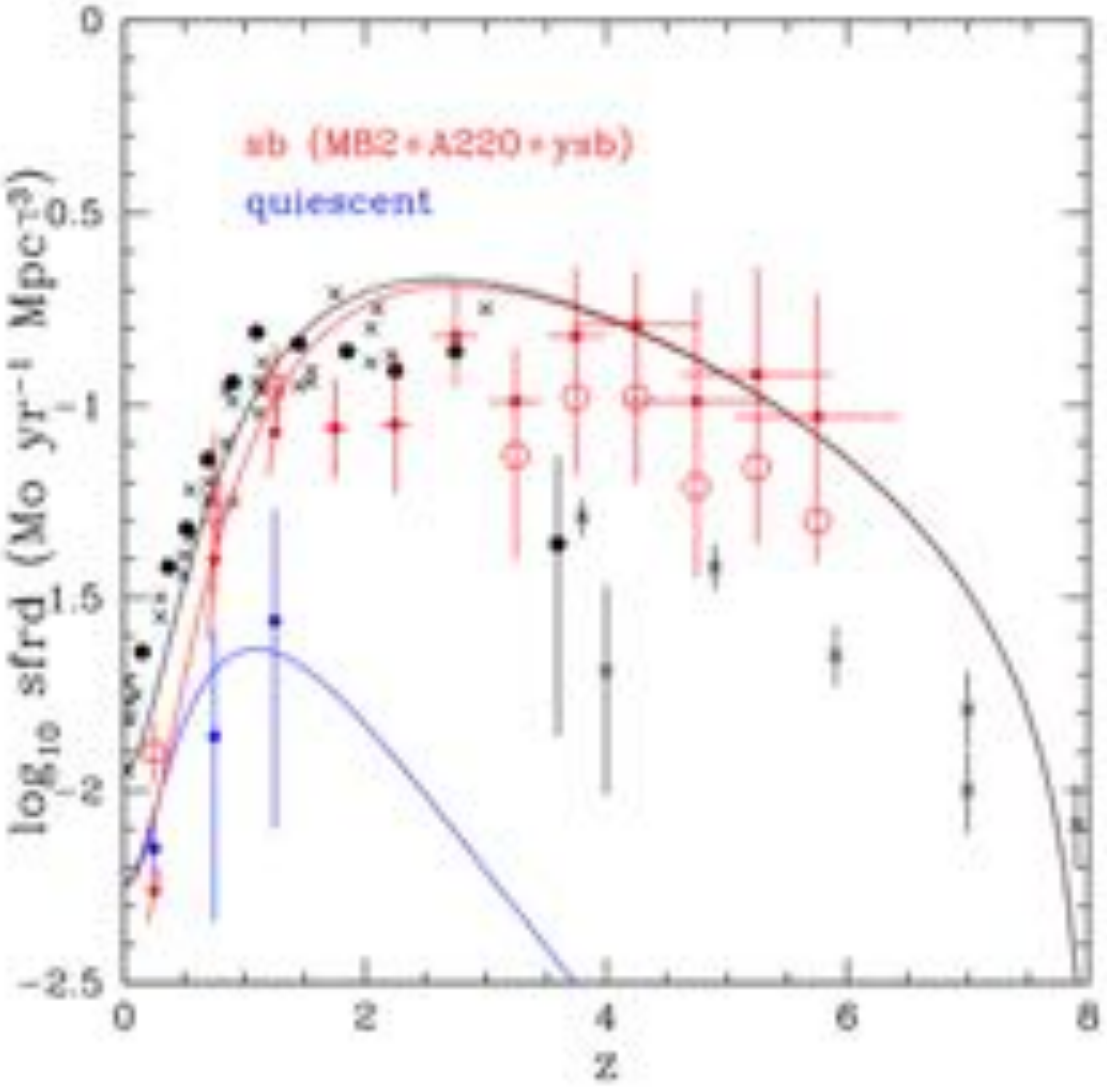


Marchetti, Vaccari et al. 2016

Local energy output	
λ (μm)	$\rho_L(\lambda)\,\lambda$ (10^{33} h W Mpc^{-3})
24	3.91 ± 0.69
60	16.87 ± 3.47
70	22.18 ± 4.77
90	25.93 ± 5.59
100	27.10 ± 5.79
160	19.95 ± 4.27
170	18.54 ± 4.00
250	6.98 ± 1.45
350	2.32 ± 0.46
500	0.58 ± 0.14

The 1<z<6 Star Formation Rate Density (from Herschel Wide-Area Shallow Surveys)





Rowan-Robinson et al. 2016

IR vs UV Estimates

The SERVS Data Fusion

Vaccari 2015

Field	IRAC1AND2	IRAC1	IRAC2	IRAC1OR2	$5\sigma_{IRAC1}$	$5\sigma_{IRAC2}$	Area
ES1	301,861	450,197	457,596	605,932	2.20	2.53	3.0
XMM	484,326	710,828	731,919	958,421	2.21	2.67	4.5
CDFS	425,970	620,841	634,320	829,191	2.12	2.48	4.5
LH	466,433	684,599	732,936	951,102	2.21	2.70	4.0
EN1	198,862	293,912	300,193	395,243	2.38	2.57	2.0
Total	1,877,452	2,760,377	2,856,964	3,739,889	-	-	18.0

Properties of SERVS full IRAC two-band Catalogs

Field	SDSS	INTWFC	CFHTLS	ESIS/VOICE	UKIDSS	VIDEO
ES1	-	-	-	X	-	X
XMM	X	-	X	-	X	X
CDFS	-	-	-	X	-	X
LH	X	X	-	-	X	-
EN1	X	X	-	-	X	-

Contents of the SERVS Data Fusion

(GALEX & IRAC34 & MIPS123 & SPIRE123 in all fields)

HELP Overview

- HELP = Herschel Extragalactic Legacy Project

- European Commission project funded (2014-17) to:
  - Bring together multi-λ surveys over more than 1000 deg^2
  - Lower the barriers to multi-λ statistical survey science
  - Provide a resource for astronomers to study the high redshift Universe akin to SDSS (also) using Herschel
  - Provide tools to make Herschel surveys easy to use

Meet The Team

http://herschel.sussex.ac.uk

- UK : Sussex (PI Seb Oliver), Cardiff & Cambridge
- France : LAM - Marseille & CEA - Saclay
- Netherlands (Leiden) & Cyprus (European University)
  - South Africa : UWC (Jarvis/Vaccari)

http://www.uwcastro.org/

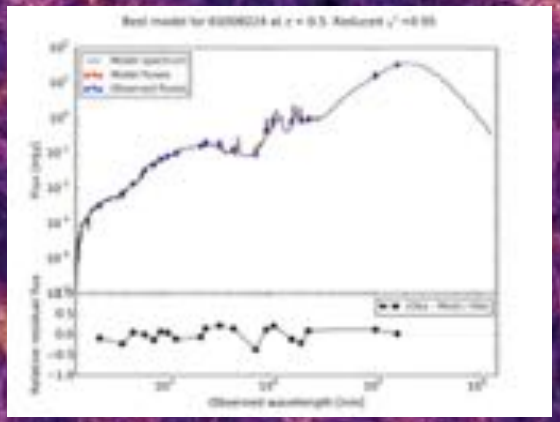
Need for Large Multi-λ Fields

3° at z=1

125 Mpc/h

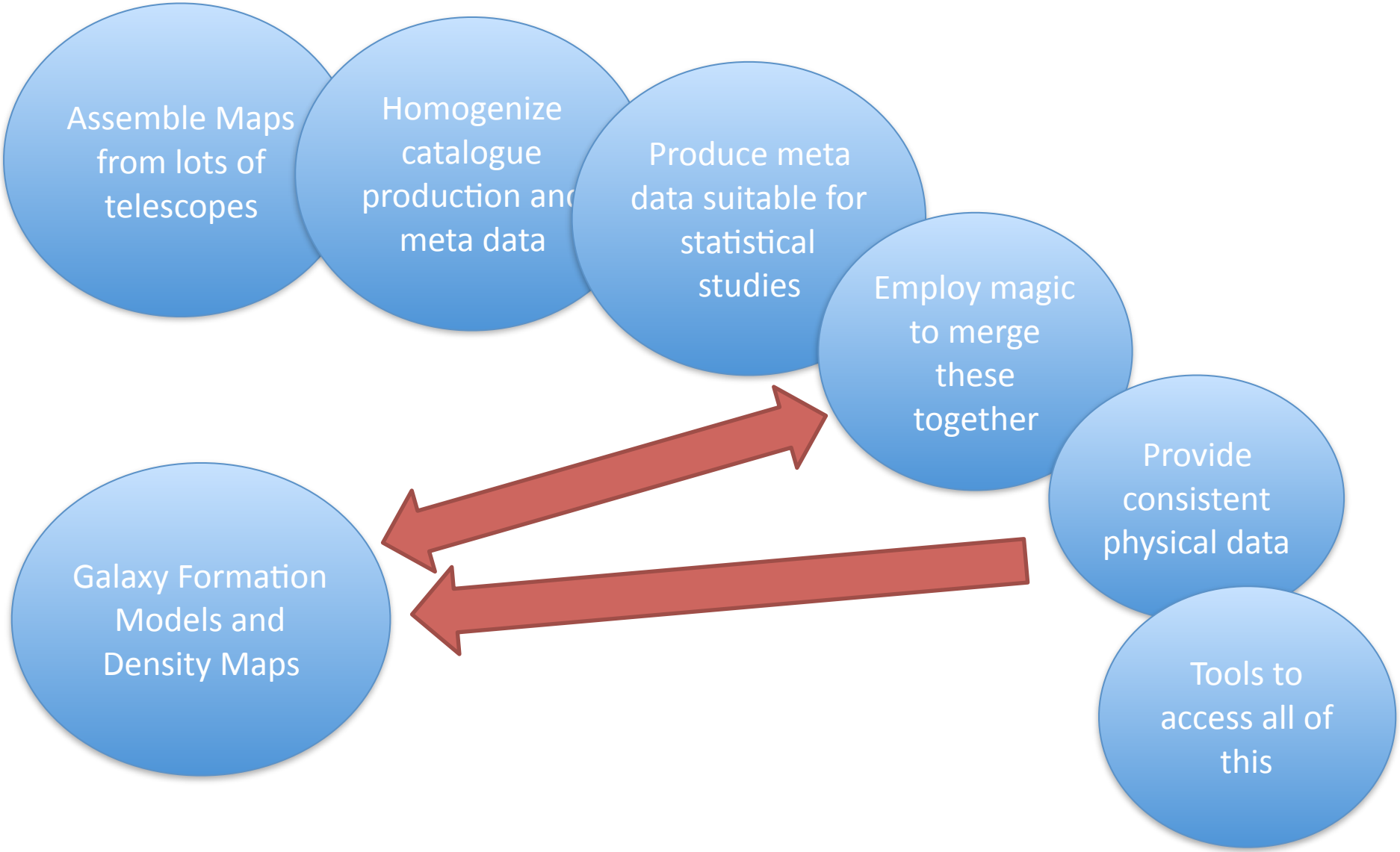
ASTRODEEP fields

Typical HerMES field



Δz=0.1 at z=1

Concept


Assemble Maps from lots of telescopes
Homogenize catalogue production and meta data
Produce meta data suitable for statistical studies
Employ magic to merge these together
Provide consistent physical data
Tools to access all of this
Galaxy Formation Models and Density Maps

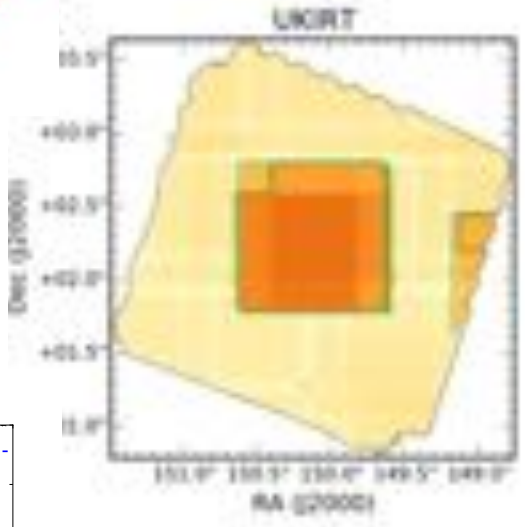
Implementation

- Define Optical/Near-Infrared/IRAC Master List
- Estimate Photometric Redshifts for Master List
- Match Master List against X-ray/UV/WISE/Radio
- Measure MIPS/PACS/SPIRE Forced Photometry
- Estimate Physical Parameters for All Sources

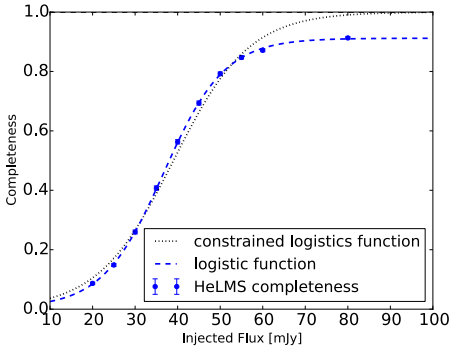
HELP Selection Functions

1. Binary Multi-Order Coverage MOCS

2. Scalar depth maps



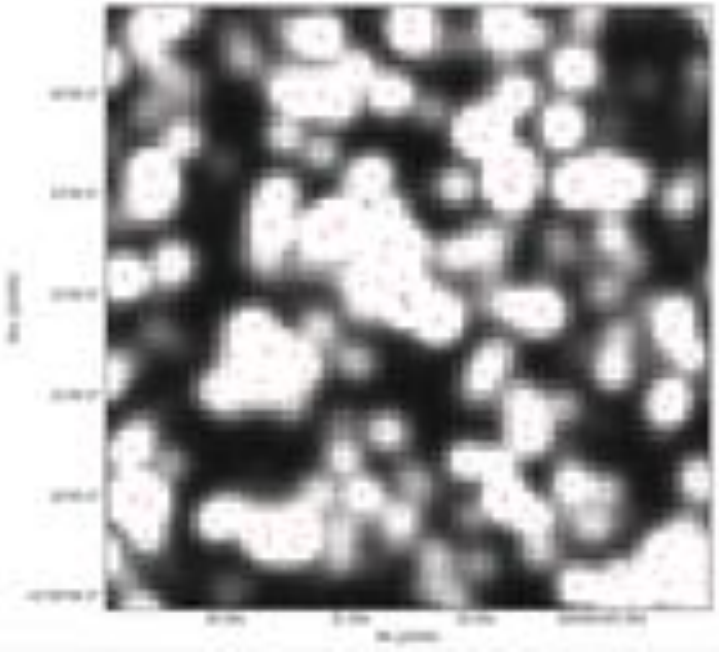
3. Completeness curves (parameter vector maps)

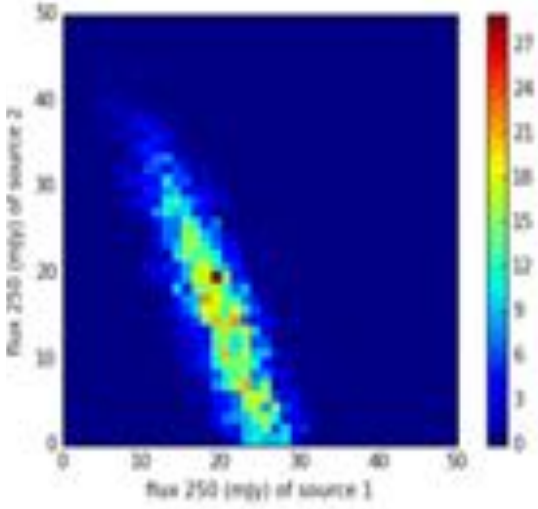


4. Likelihood functions

HELP's Magic : XID+

- Builds upon previous efforts such as DESPHOT by HerMES team
- Use STAN as Bayesian inference engine (http://mc-stan.org/)
- Use a MCMC based approach to fully map posterior

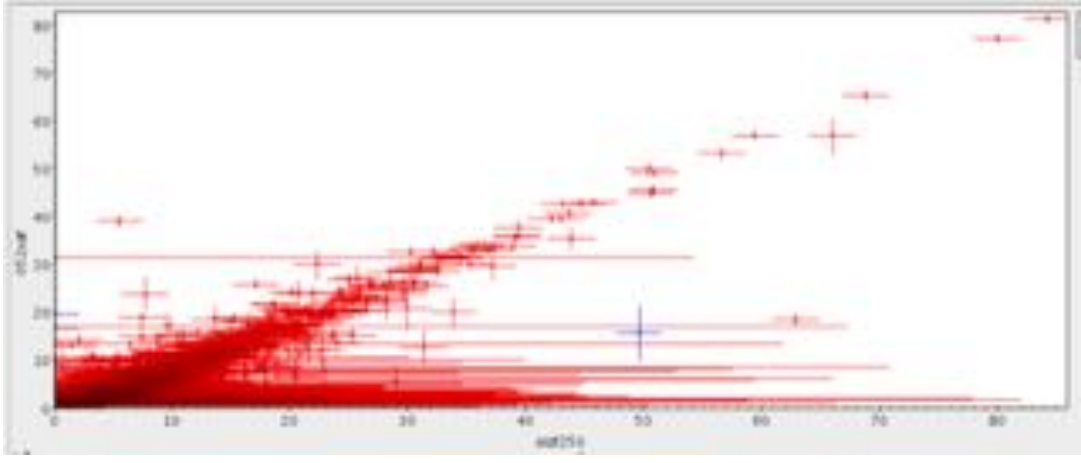




STAN

Hurley et al. 2016

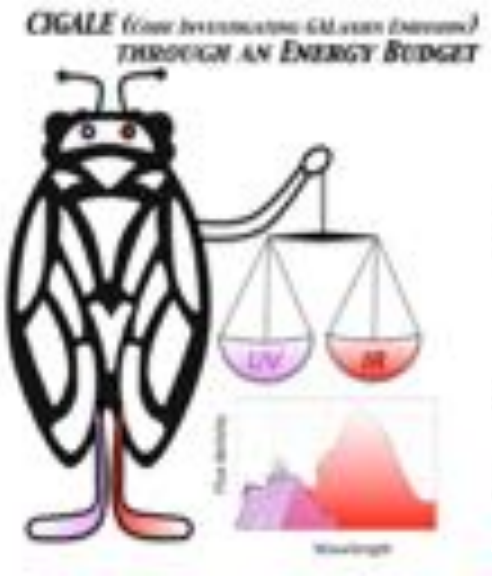
- Make use of any prior model
- Provide mapping of posterior
- Estimate reliable flux errors
- Measure all nearby sources

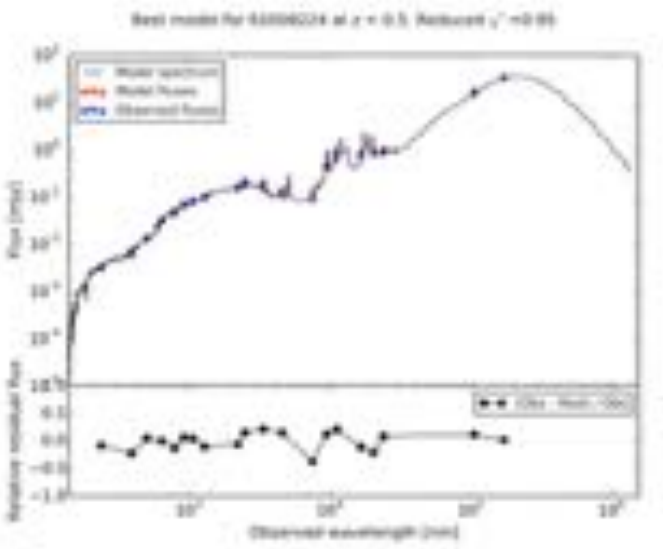


Consistent Physical Modeling Tools to investigate degeneracies etc.

- LePhare+
- Cigale+

http://gazpar.lam.fr

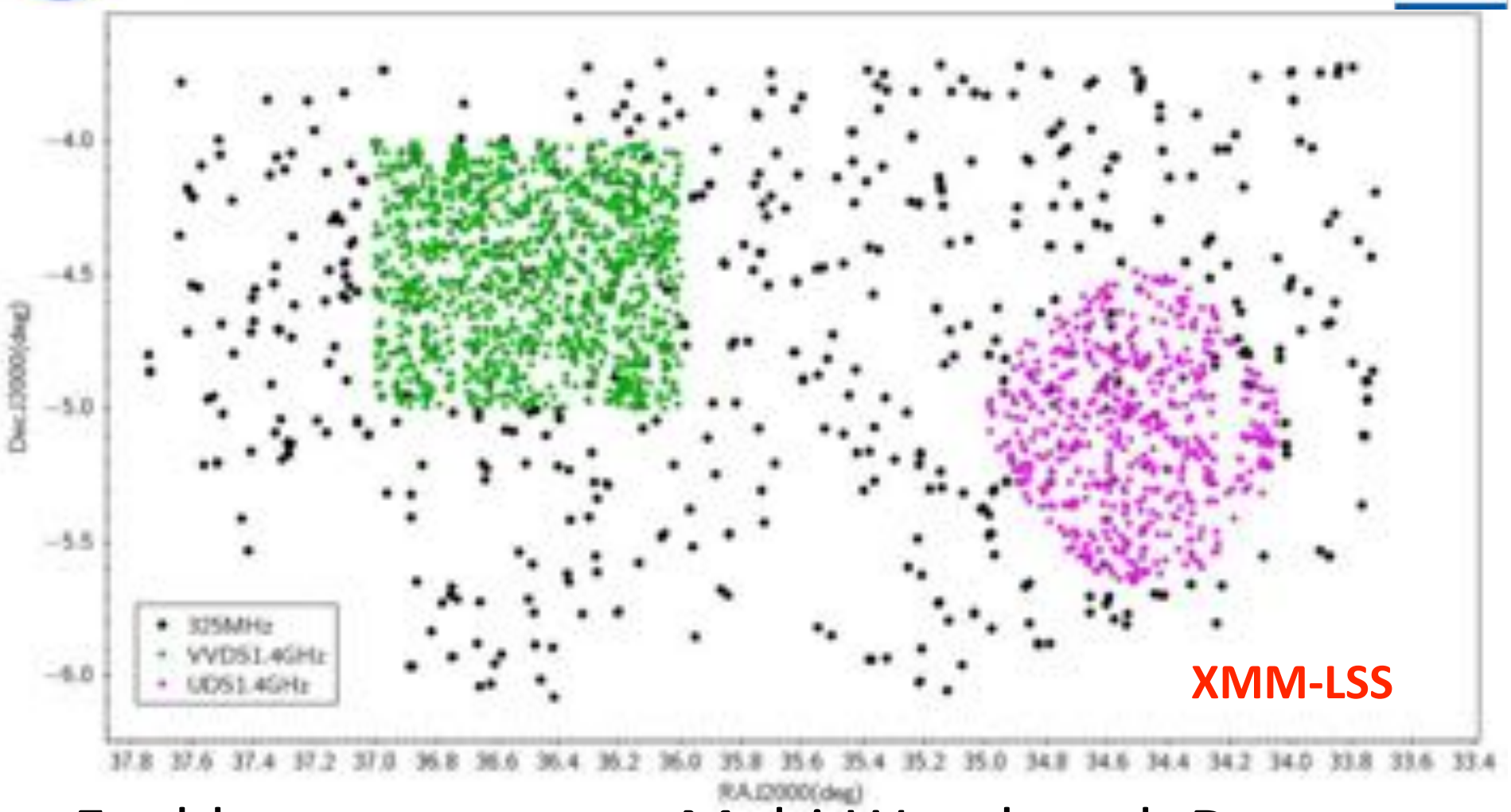




Status

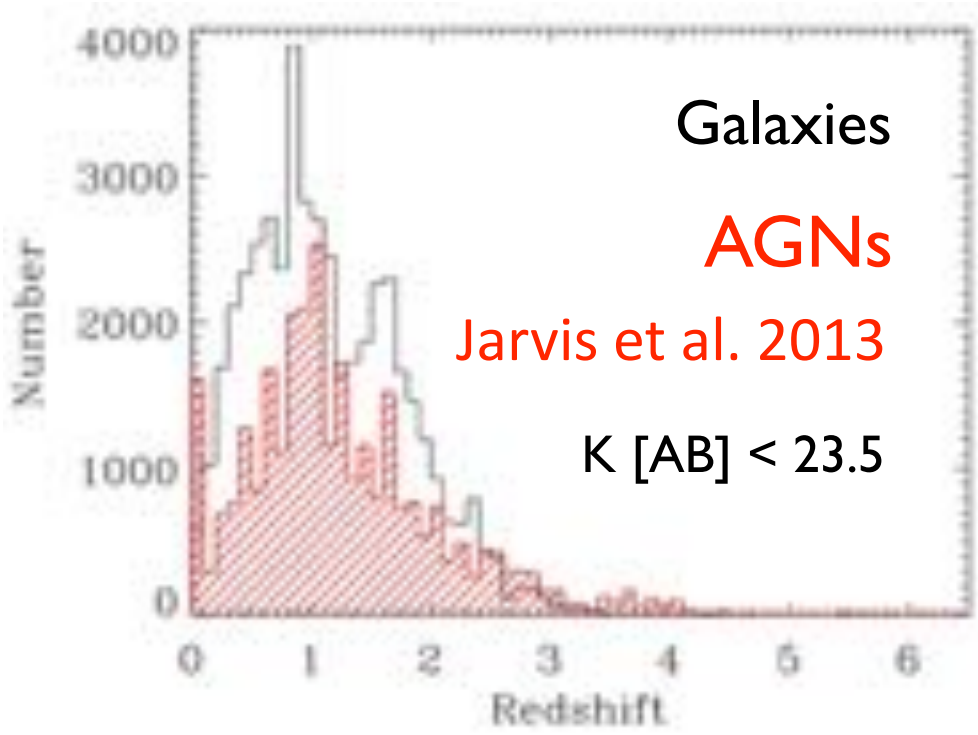
- Kick off meeting @ Sussex in April 2014
- Phase 1 completed in April 2015 with Data Workshop @ LAM/Marseille
  - SPIRE & Ancillary Data (Catalogs & Maps) assembled
  - Defined “challenges”, e.g. SPIRE prior & SED modeling challenges
  - Defined & Developed multi-wavelength photometry methods
  - Defined science goals and user requirements
- Phase 2 now running until end of 2015
  - XID+ Software Development
  - Complete challenges and define a first version of the HELP pipeline
  - End-to-End Data Reduction & SED Modeling on COSMOS Data/Sims
- Phase 3 now running until end of 2016
  - Fully-fledged SPIRE Prior Model Development
  - Expand analysis to all high-priority fields & wide range of simulations
  - Lorentz Centre Meeting in June 2016 (inviting external participation)
- Phase 4 (2017) will refine and expand analysis to all HELP fields

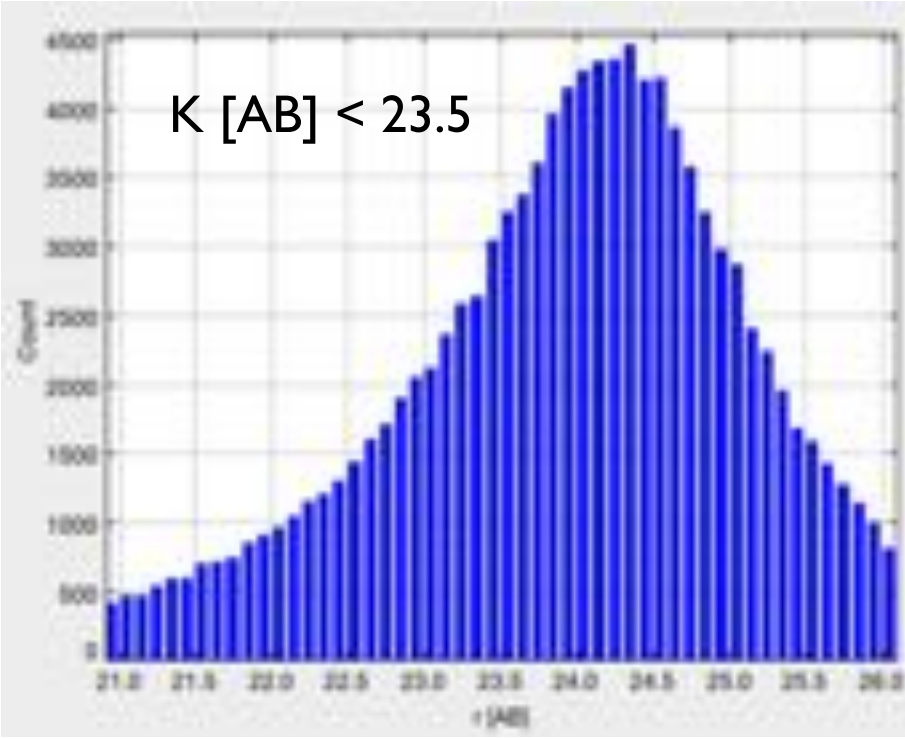
HELP & Radio Continuum Surveys



- Enable easy access to Multi-Wavelength Datasets
- Enable Timely Radio Survey Science Exploitation

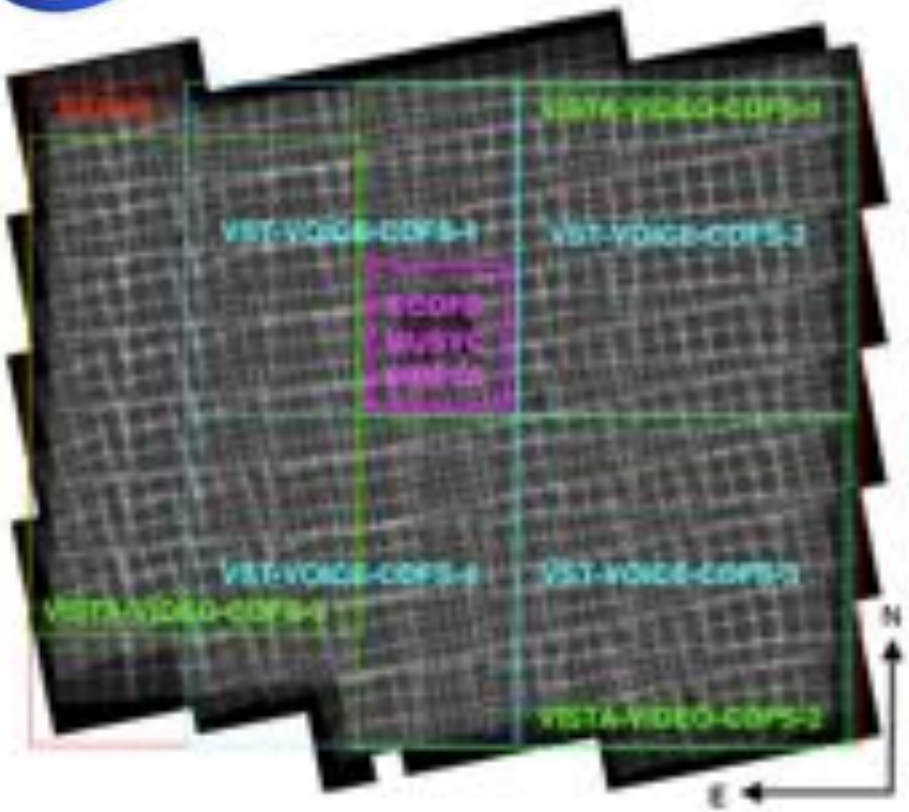
MIGHTEE Ancillary Data





- VIDEO Photometric Redshifts (CFHTLS, VOICE, DES, LSST…)
- High Source Density of High-Redshift Galaxies & AGNs up to z~4 eventually over the ~35 deg^2 mapped by MIGHTEE

LADUMA/MIGHTEE Ancillary Data



VST INAF GT VOICE Survey

CDFS - 4 deg^2

http://www.mattiavaccari.net/voice/

(PIs : Covone & Vaccari)

m_{AB}~26 in ugri

1) image/site quality

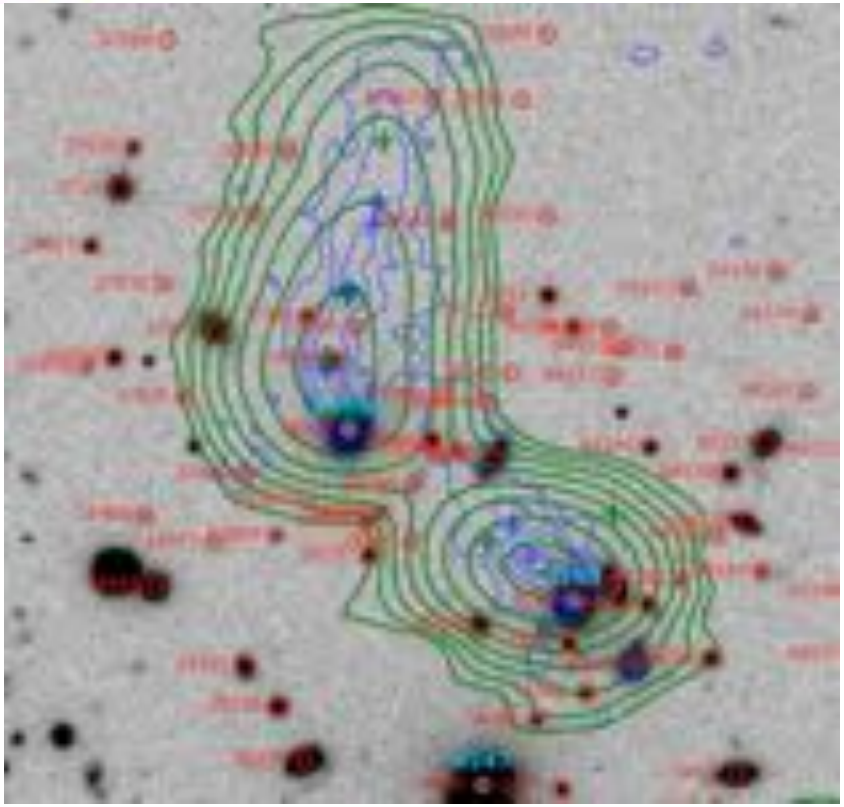
2) u-band sensitivity

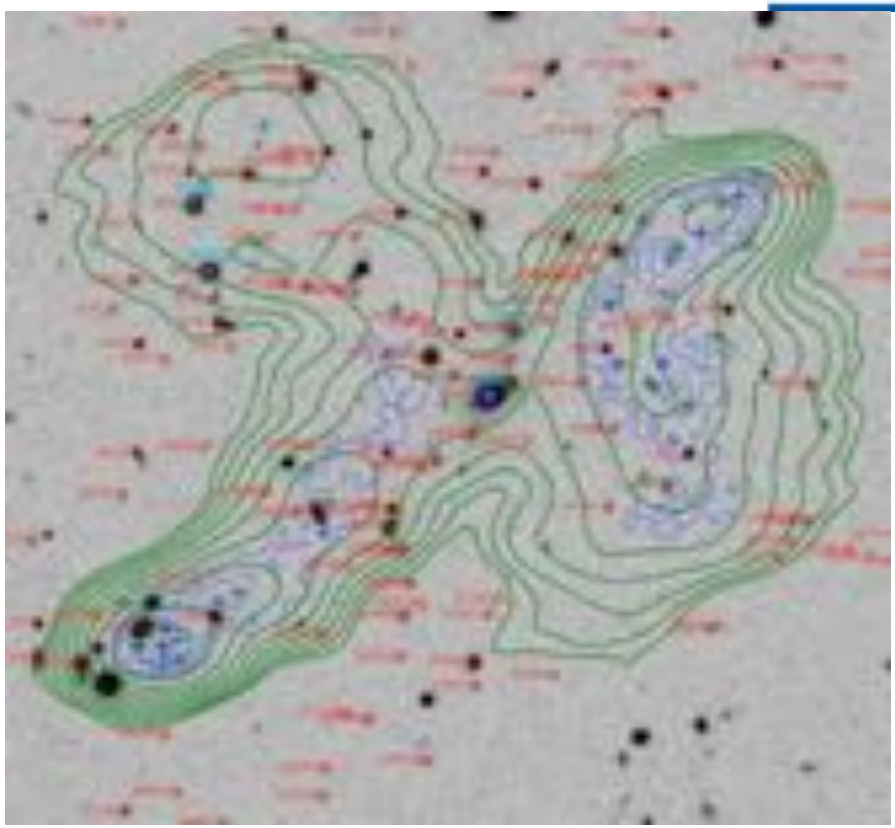
3) multi-wavelength

- gri Multi-Epoch for SN Search & AGN Variability Studies
- ugri Deep Stacks to be combined with ZYJHK & IRAC12
- Enabled improved selection/targeting for spec-z runs

Cappellaro et al. 2015 & Falocco et al. 2015

Radio XID & Classification Tools



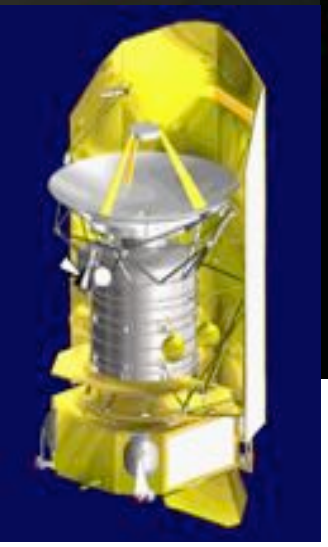


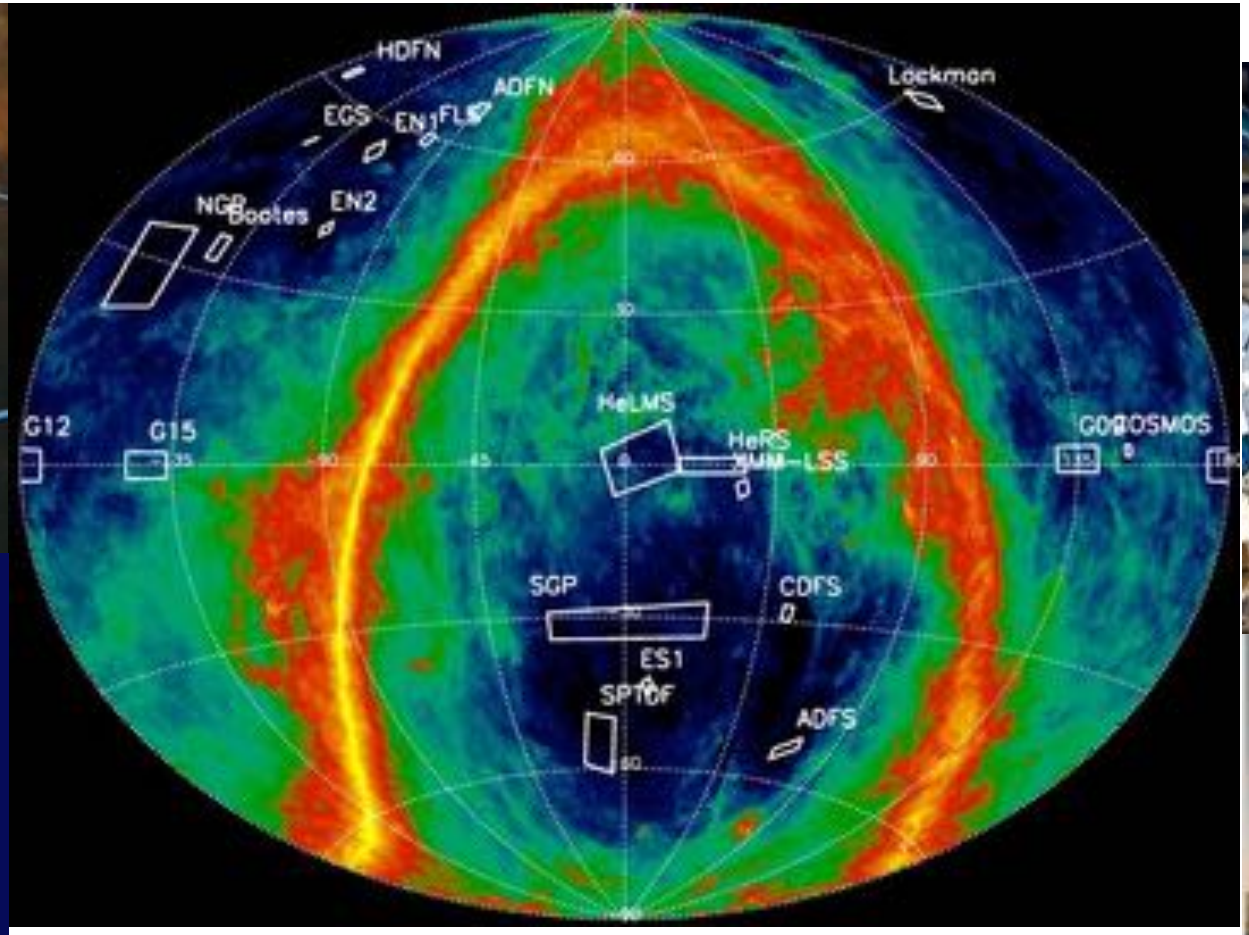
- Heywood et al. 2016 - JVLA BnC Survey of SDSS Stripe 82
- Several Astronomers to annotate Radio Contour Plots
- Checking Nearest-Neighbour / Likelihood Ratio Matches

Conclusion

- "Plug-and-play" multi-λ surveys over 1000 deg^2
- Open to data / science collaboration (talk to me!)
- Aims to lower barriers to statistical studies
- Enable easy access to and use of (Herschel) data
- "Value-added" data products (z, SFR, M_*, M_{dust} ...)
- Easy comparison against galaxy formation models
- To provide a resource for astronomers to study the high-z Universe not unlike SDSS at low-z
- Delivering on the promise of multi-λ surveys

Thanks!





http://herschel.sussex.ac.uk/

https://github.com/H-E-L-P