Perspectives from SWGs on SKA Data Processing and Science Analysis

on behalf of the SWG
Extragalactic Spectral Line

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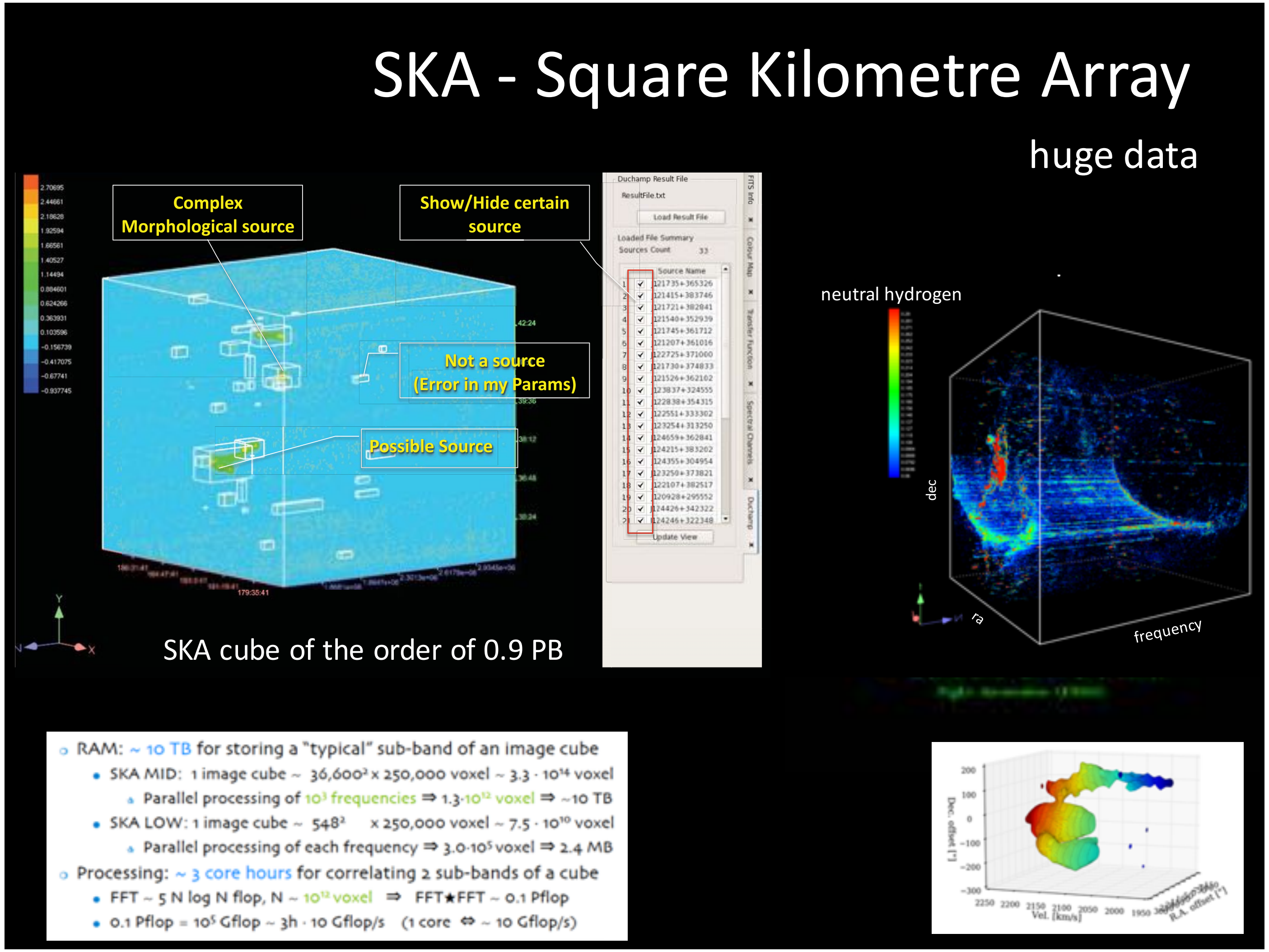
Extragalactic Spectral Line

The data analysis and its requirements are similar to the HI line requirements (see Lourdes talk)

- large sky coverage survey
- targeted observations
- stable bandwidth
- continuum subtraction
- source finding
- line detection (mom 0)
- velocity field (mom 1)
- line width (mom 2)



Extragalactic Spectral Line

List of important radio spectral lines (< 1 THz)

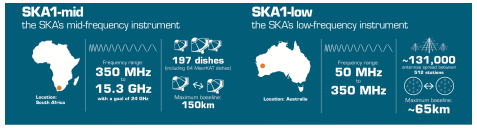
1. Deuterium (DI) 327.384 MHz
2. Hydrogen (HI) 1420.406 MHz
3. Hydroxyl radical (OH) 1612.231 MHz
4. Hydroxyl radical (OH) 1665.402 MHz
5. Hydroxyl radical (OH) 1667.359 MHz
6. Hydroxyl radical (OH) 1720.530 MHz
7. Methyladyne (CH) 3263.794 MHz
8. Methyladyne (CH) 3335.481 MHz
9. Methyladyne (CH) 3349.193 MH
10. Formaldehyde (H2CO) 4829.660 MHz
11. Methanol (CH2OH) 6668.518 MHz
12. Ionized Helium Isotope (3HeII) 8665.650 MHz
13. Methanol (CH3OH) 12.178 GHz
14. Formaldehyde (H2CO) 14.488 GHz
15. Cyclopropenylidene (C3H2) 18.343 GHz
16. Water Vapour (H2O) 22.235 GHz
17. Ammonia (NH3) 23.694 GHz
18. Ammonia (NH3) 23.723 GHz
19. Ammonia (NH3) 23.870 GHz
20. Silicon monoxide (SiO) 42.519 GHz
21. Silicon monoxide (SiO) 42.821 GHz
22. Silicon monoxide (SiO) 42.880 GHz
23. Silicon monoxide (SiO) 43.122 GHz
24. Silicon monoxide (SiO) 43.424 GHz
25. Carbon monosulphide (CS) 48.991 GHz
26. Deuterated formylium (DCO+) 72.039 GHz
27. Silicon monoxide (SiO) 86.243 GHz
28. Formylium (H13CO+) 86.754 GHz
29. Silicon monoxide (SiO) 86.847 GHz
30. Ethynyl radical (C2H) 87.300 GHz
31. Hydrogen cyanide (HCN) 88.632 GHz
32. Formylium (HCO+) 89.189 GHz
33. Hydrogen isocyanide (HNC) 90.664 GHz
34. Diazenylium (N2H) 93.174 GHz
35. Carbon monosulphide (CS) 97.981 GHz
36. Carbon monoxide (C18O) 109.782 GHz
37. Carbon monoxide (13CO) 110.201 GHz

41. Carbon monoxide (C17O) 112.359 GHz
42. Carbon monoxide (CO) 115.271 GHz
43. Formaldehyde (H213CO) 137.450 GHz
44. Formaldehyde (H2CO) 140.840 GHz
45. Carbon monosulphide (CS) 146.969 GHz
46. Water vapour (H2O) 183.310 GHz
47. Carbon monoxide (C18O) 219.560 GHz
48. Carbon monoxide (13CO) 220.399 GHz
49. Carbon monoxide (CO) 230.538 GHz
50. Carbon monosulphide (CS) 244.953 GHz
51. Hydrogen cyanide (HCN) 265.886 GHz
52. Formylium (HCO+) 267.557 GHz
53. Hydrogen isocyanide (HNC) 271.981 GHz
54. Dyazenulium (N2H+) 279.511 GHz
55. Carbon monoxide (C18O) 312.330 GHz
56. Carbon monoxide (13CO) 330.587 GHz
57. Carbon monosulphide (CS) 342.883 GHz
58. Carbon monoxide (CO) 345.796 GHz
59. Hydrogen cyanide (HCN) 354.484 GHz
60. Formylium (HCO+) 356.734 GHz
61. Dyazenulium (N2H+) 372.672 GHz
62. Water vapour (H2O) 380.197 GHz
63. Carbon monoxide (C18O) 439.088 GHz
64. Carbon monoxide (13CO) 440.765 GHz
65. Carbon monoxide (CO) 461.041 GHz
66. Heavy water (HDO) 464.925 GHz
67. Carbon (CI) 492.162 GHz
68. Water vapour (H218O) 547.676 GHz
69. Water vapour (H2O) 556.936 GHz
70. Ammonia (15NH3) 572.113 GHz
71. Ammonia (NH3) 572.498 GHz
72. Carbon monoxide (CO) 691.473 GHz
73. Hydrogen cyanide (HCN) 797.433 GHz
74. Formylium (HCO+) 802.653 GHz
75. Carbon monoxide (CO) 806.652 GHz
76. Carbon (CI) 809.350 GHz

Z < 10

Jason Hessels Lecture 2013

HCN, HCO+, CS, CN, formaldehyde, etc..



SKA1 Telescope Expected Performance – Imaging

Nominal Frequency	110 MHz	300 MHz	770 MHz	1.4 GHz	6.7 GHz	12.5 GHz
Range [GHz]	0.05-0.35	0.05-0.35	0.35-1.05	0.95-1.76	4.6-8.5	8.3-15.3
Telescope	Low	Low	Mid	Mid	Mid	Mid
FoV [arcmin]	327	120	109	60	12.5	6.7
Max. Resolution [arcsec]	11	4	0.7	0.4	0.08	0.04
Max. Bandwdith [GHz]	0.3	0.3	1	1	4	5
Cont. rms, 1 hr (μJy/beam)[a]	26	14	4.4	2	1.3	1.2
Line rms, 1 hr [μJy/beam][b]	1850	800	300	140	90	85
Resolution Range for Cont. and Line rms [arcsec][c]	12–600	6–300	1–145	0.6–78	0.13–17	0.07–9

cdms.astro.uni-koeln.de

Extragalactic Molecules (as of 11/2017)

2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	>8 atoms
OH	H_2O	H_2CO	c-C_3H_2	CH_3OH	CH_3CCH	HC_6H	c-C_6H_6*
CO	HCN	NH_3	HC_3N	CH_3CN	CH_3NH_2	C_{60}*(?)	
H_2*	HCO^+	HNCO	CH_2NH	HC_4H*	CH_3CHO		
CH	C_2H	C_2H_2*	NH_2CN	HC(O)NH_2			
CS	HNC	H_2CS?	l-C_3H_2				
CH^+	N_2H^+	$HOCO^+$	H_2CCN				
CN	OCS	c-C_3H	H_2CCO				
SO	HCO	H_3O^+	C_4H				
SiO	H_2S	l-C_3H					
CO^+	SO_2						
NO	HOC^+						
NS	C_2S						
NH	H_2O^+						
OH^+	HCS^+						
HF	H_2Cl^+						
SO^+	NH_2						
ArH^+							
CF^+ (2016)							
SH^+ (2017)							

RR lines Carbon Hydrogen (SKA MID/LOW)

Cross-check of the unknown

Extragalactic Spectral Line

difference to HI

Individual line width is of a few $km s^{-1}$

- H_2O Maser emission
- Zeeman splitting

The University of Manchester Jodrell Bank Observatory

e-MERLIN

MANCHESTER 1824

High-z line KSC

- Deep field band-5(+) dense gas tracer search (CO/CS/HCN)
  - **Tracing the molecular gas luminosity function**, overall gas reservoir (ground-state CO), plus HCN/HCO+ dense, SF gas
  - **Cosmic evolution of molecular gas density**
  - **Chart SFE at high-z** – resolved KS – continuum+gas tracers

  - Band 5(+) can directly target ground-state (low-excitation) molecular gas at high redshift
  - (At z>6 w/ SKA1, BAND 5+ => z>2.5 w/ extension to 24 GHz)
  - ie. Resolving a variety low J dense gas tracer from z~2→6.
  - Single deep pointing – Commensal with deep continuum pointing (band 5(+))
  - Depth/fov advantages compared to pre-SKA surveys (e.g. JVLA Ka survey 1sigma~55uJy → 6-sigma detection at knee of luminosity function.
  - SKA 10times => ~1uJy sensitivity. Can also probe HCN/CS

Rob Beswick

Heywood et al.: MESMER

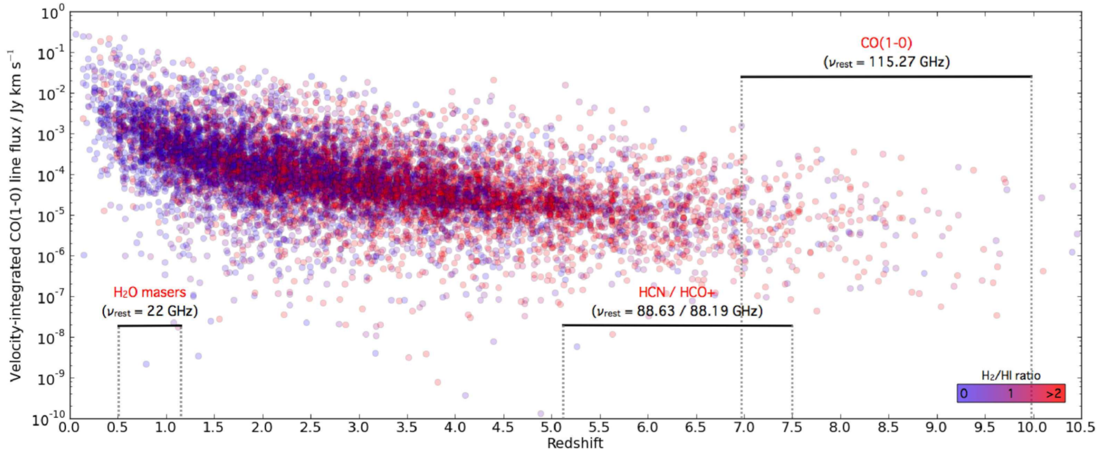


Fig. 1. The velocity-integrated CO(J=1→0) line flux for ~10,000 simulated galaxies as a function of redshift. Key predictions of the S^3-SAX simulation are the evolution with redshift of the line strength and the ratio of atomic to molecular gas (the latter represented by the colour gradient), and the cosmological decline in the source counts. The redshift ranges of some key spectral lines are plotted, as probed by an observation which covers 10.5 - 14.5 GHz. Note that the vertical positions of these markers has no significance.

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Redshifted intergalactic $^3He^+$ 8.7 GHz hyperfine absorption

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Motivated by recent interest in redshifted 21 cm emission of intergalactic hydrogen, we investigate the 8.7 GHz $^2S_{1/2}$ $F = 0 - 1$ hyperfine transition of $^3He^+$. While the primordial abundance of ^3He relative to hydrogen is 10^{-5}, the hyperfine spontaneous decay rate is 680 times larger. Furthermore, the antenna temperature is much lower at the frequencies relevant for the $^3He^+$ transition compared to that of $z > 6$ 21 cm emission. We find that the spin temperature of this 8.7 GHz line in the intergalactic medium is approximately the cosmic microwave background temperature, such that this transition is best observed in absorption against high-redshift, radio-bright quasars. We show that intergalactic 8.7 GHz absorption is a promising, unsaturated observable of the ionization history of intergalactic helium (for which He II → He III reionization is believed to complete at $z \sim 3$) and of the primordial ^3He abundance. Instruments must reach ~ 1 μJy RMS noise in bands of 1 MHz on a 1 Jy source to directly resolve this absorption. However, in combination with H I Lyα forest measurements, an instrument can statistically detect this absorption from $z > 3$ with 30 μJy RMS noise in 0.1 MHz spectral bands over 100 MHz, which may be within the reach of present instruments.

difference to HI

Narrow lines difficult to spot (RFI mitigation contaminants)

Polarisation properties are of big scientific interest

Sanity checks with other lines (link to molecular databases, etc.)

Multi-messenger cross-correlation

Intensity mapping techniques needed for CO but also for other lines

Stack of stacking methods to be developed