Cosmology with the Square Kilometre Array

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Part Four

The planned (phase 1) surveys and their potential

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Acknowledgments & References

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I would like to thank for letting me steal here and there:

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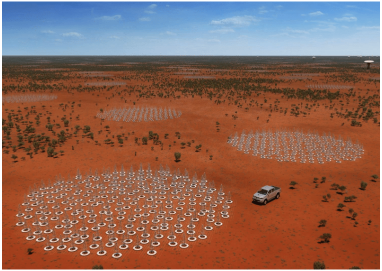
SKA specific material can be found at: `https://www.skatelescope.org` or `https://www.skaobservatory.org/`.

See also: Advancing Astrophysics with the Square Kilometre Array,

`https://pos.sissa.it/215/`

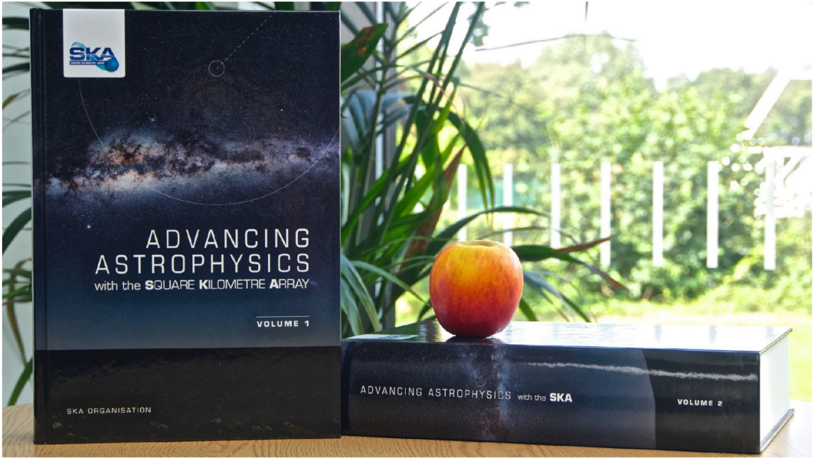
The SKA telescope: recap

- SKA-MID
  a dish array in South Africa
  - 133 15m dishes
  - Band 1: 350-1050 MHz
    $\Rightarrow 0.35 < z < 3$
    (MeerKAT UHF band only down to 580 MHz)
  - Band 2: 950-1075 MHz
    $\Rightarrow 0 < z < 0.5$
    (similar to MeerKAT L band)
- SKA-LOW: array of dipole antennas in Australia
  512 (224 core) stations with 256 dipoles
  350 MHz down to 50 MHz



SKA Science

[AASKA PoS(s), 2015]



SKA Cosmology

Publications of the Astronomical Society of Australia (2020), **37**, e007, 31 pages
doi:10.1017/pasa.2019.51

CAMBRIDGE UNIVERSITY PRESS

Research Paper

Cosmology with Phase 1 of the Square Kilometre Array Red Book 2018: Technical specifications and performance forecasts

Square Kilometre Array Cosmology Science Working Group: David J. Bacon [1], Richard A. Battye [2], Philip Bull [3], Stefano Camera [2,4,5,6], Pedro G. Ferreira [7], Ian Harrison [2,7], David Parkinson [8], Alkistis Pourtsidou [3], Mário G. Santos [9,10,11], Laura Wolz [12], Filipe Abdalla [13,14], Yashar Akrami [15,16], David Alonso [7], Sambatra Andrianomena [9,10,17], Mario Ballardini [9,18], José Luis Bernal [19,20], Daniele Bertacca [21,22], Carlos A. P. Bengaly [9], Anna Bonaldi [23], Camille Bonvin [24], Michael L. Brown [2], Emma Chapman [25], Song Chen [9], Xuelei Chen [26], Steven Cunnington [1], Tamara M. Davis [27], Clive Dickinson [2], José Fonseca [9,22], Keith Grainge [2], Stuart Harper [2], Matt J. Jarvis [7,9], Roy Maartens [1,9], Natasha Maddox [28], Hamsa Padmanabhan [29], Jonathan R. Pritchard [25], Alvise Raccanelli [19], Marzia Rivi [13,18], Sambit Roychowdhury [2], Martin Sahlén [30], Dominik J. Schwarz [31], Thilo M. Siewert [31], Matteo Viel [32], Francisco Villaescusa-Navarro [33], Yidong Xu [26], Daisuke Yamauchi [34] and Joe Zuntz [35]

Standard model extensions

focusing on where SKA can have an impact

- massive neutrinos parametrized with the sum of the masses $M_\nu = \sum m_\nu$
- modification of the dark sector equation of state $P/\rho = w(a) = w_0 + (1-a)w_a$ (Chevallier & Polarski 2001)
- warm dark matter paradigm (m_{WDM})

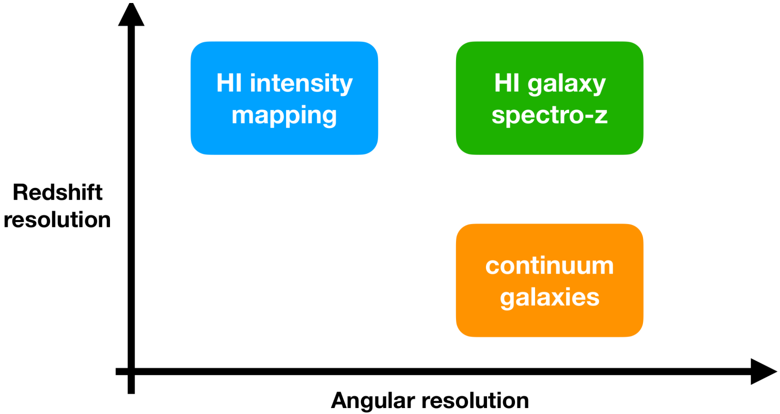
- Modify Gravity (μ_0,γ_0)
- Primordial non-Gaussianity (f_{NL})
- Cosmic Dipole
- ...

Observables

- Continuum:
  mostly synchrotron emission from galaxies
- 21cm line emission:
  spectroscopic galaxy redshift survey and intenisty mapping

Observables

- Continuum:
  mostly synchrotron emission from galaxies
  continuum galaxies
  (and weak lensing)
- 21cm line emission:
  spectroscopic galaxy redshift survey and intenisty mapping
  HI galaxy spectro-z
  HI intensity mapping



courtesy of Isabella Carucci

Proposed Cosmological Surveys

Medium Deep Band 2 with SKA-MID

5000 deg^2 and 10.000 h integration time
continuum weak leaning survey and HI galaxy survey out to $z \sim 0.4$

Wide Band 1 with SKA-MID

20000 deg^2 and 10.000 h integration time
continuum galaxy survey and HI Intensity Mapping out to $z \sim 3$

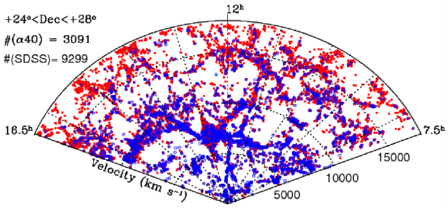
Deep SKA-LOW

100 deg^2 and 5.000 h integration time
following the EoR survey strategy up to the end of Reionization.

HI galaxies

Medium Deep - Band 2 - 21cm line

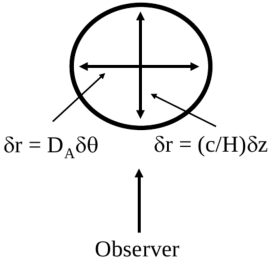
- Detection in Band 1 very difficult for cosmology (not for galaxy evolution)
- subset: 21cm line width (Tully-Fisher) and angular size (Doppler magnification)
- all HI galaxies also continuum (commensality)



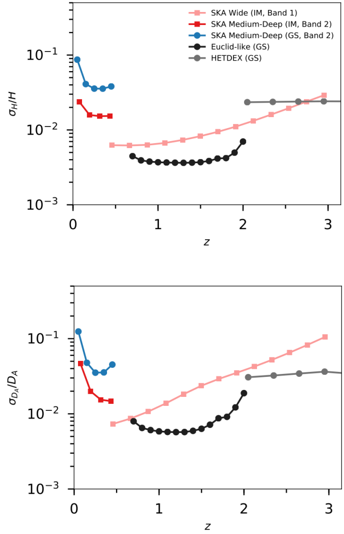
Haynes et al (2011)

3D galaxy clustering ⇒ BAO and RSD in 2-point correlation function

Baryon Acoustic Oscillations



- radial BAO scale sensitive to the expansion rate, $H(z)$
- transverse BAO scale sensitive to the angular diameter distance, $D_A(z)$
- complementary to **Euclid**



SKA Red Book 2019

Intensity Mapping

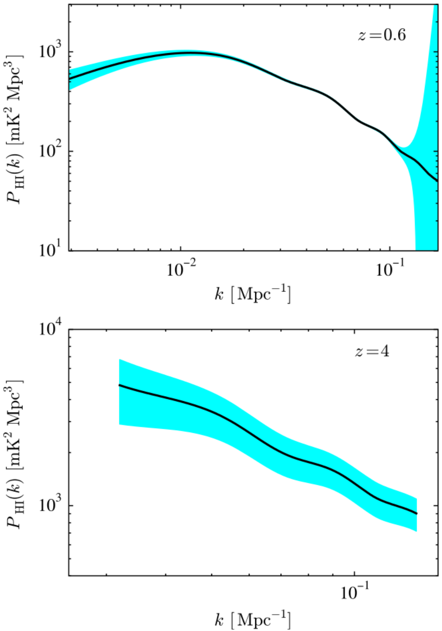
Medium Deep - Band 2 - 21cm line

Wide - Band 1 - 21cm line

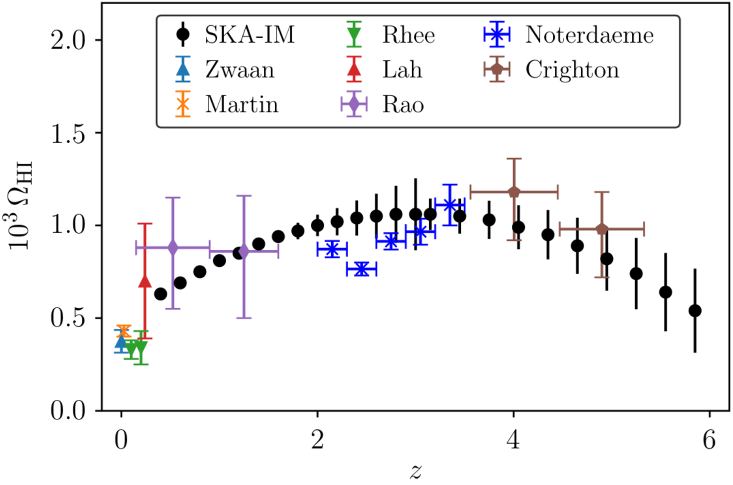
Deep - LOW - 21cm line

$$P_{HI} \propto \Omega_{\rm HI}^2 \left[(b_{\rm HI} + f\mu^2)^2 P_m(z,k) + P_{\rm SN} \right]$$

- BAO (as for plot previous slide)
- RSD (f(z) linear growth rate- useful to test alternative theory of gravity)



Intensity mapping

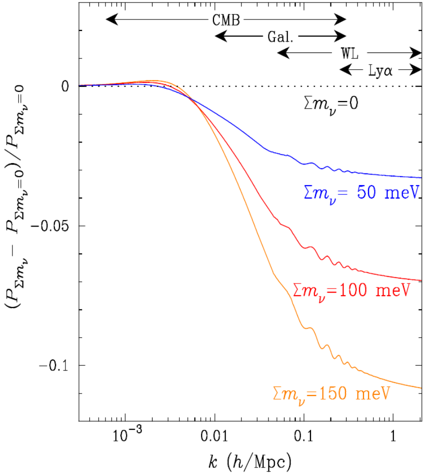


SKA Red Book (2019)

Neutrino mass effect on LSS

- oscillation exp: $M_\nu > 0$
- still relativistic at decoupling
- when non-rel contributes to structure formation
- transition from relativistic to non-relativistic $z \sim 2000 \frac{m_\nu}{1\text{eV}}$
- washes out structures with k bigger than $k_{\text{nr}} \simeq 0.018 \sqrt{\Omega_m \frac{m_\nu}{1\text{eV}}} \text{h/Mpc}$

Lesgourgues&Pastor (2006)



Abazajian et al. (2013)

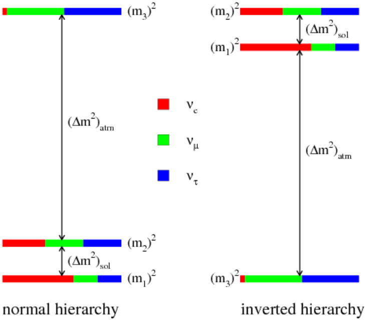
different probes, different scales

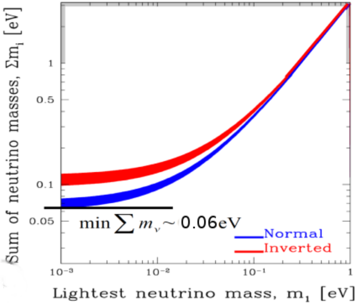
Hierarchy

- solar neutrino experiments: disappearance of $\nu_e \Rightarrow \Delta m^2_{12}$ (> 0)
- atmospheric neutrino experiments: disappearance of $\nu_\mu \Rightarrow |\Delta m^2_{23}|$

Which role for cosmology?

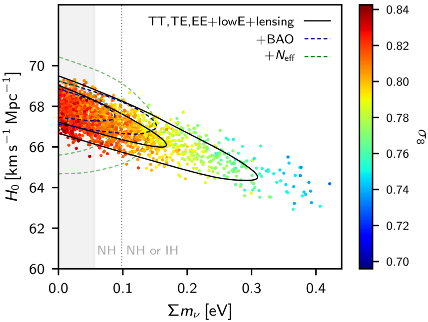
- Normal H: min $M_\nu \sim 0.06\text{eV}$
- Inverted H: min $M_\nu \sim 0.10\text{eV}$





Constraints from CMB

- $M_\nu < 0.26$eV (95%, Planck TT,TE,EE+lowE)
- $M_\nu < 0.12$eV (95%, Planck TT,TE,EE+lowE +lensing+BAO)
- higher M_ν increases H_0 tension and prefers lower σ_8
- IH under pressure



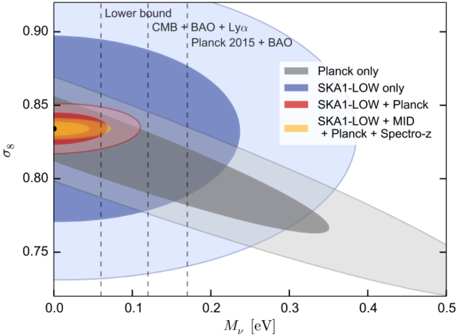
Planck 2018

SKA constraints on M_ν

Deep - LOW - 21cm line

Band 1 - 21cm line

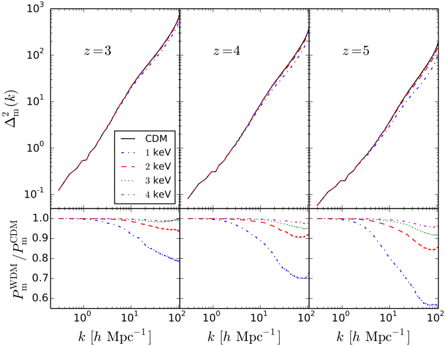
- SKA (both MID and LOW) not much improvement over Planck
- combination with Planck and spetro-z surveys breaks parameter degeneracies



Villaescusa-Navarro et al. (2015)

Warm Dark Matter

- WDM paradigm:
  DM particles have thermal velocities
- CDM preserved on large scales
- WDM can not cluster on scales smaller than its free streaming scale
  $\Rightarrow$ small scale cut-off in $P_m(k)$
- suppression on the abundance of low-mass dark matter halos

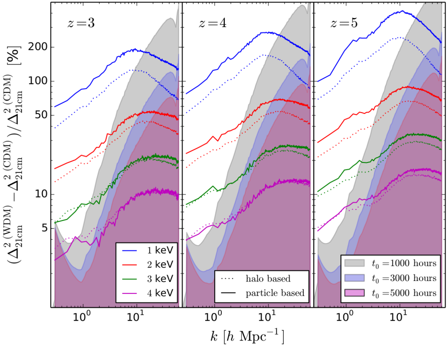


Carucci et al. (2015)

SKA and Warm Dark Matter

Deep - LOW - 21cm line

- naively expected a suppression of power
- increase of power at mildly non linear scales
- easier to see difference at higher redshift
- e.g. 1000h: 3keV can be ruled out at more than 2σ at $z = 5$



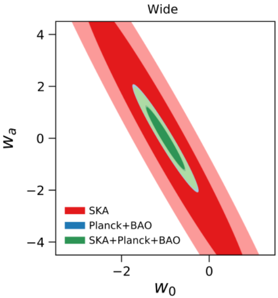
Carucci et al. (2015)

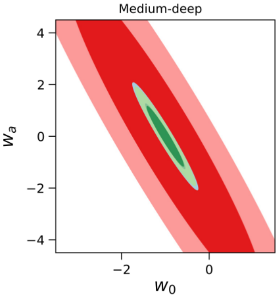
Continuum

Medium Deep - Band 2 - Continuum

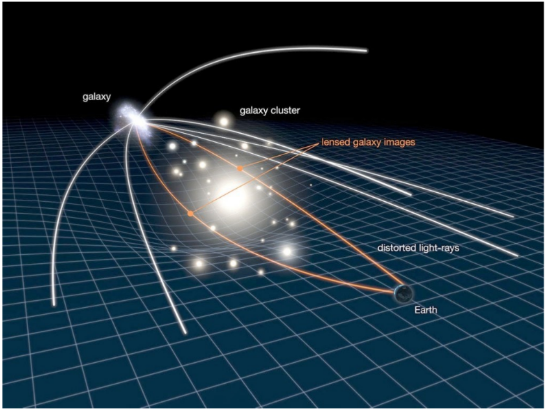
Wide - Band 1 - Continuum

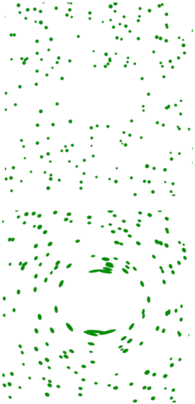
- SKA will detect million of galaxies of different types (e.g. SFG, FR1 & FR2, radio-quiet quasars)
- w0-wa constraint not much better than available ones but possible improvement with better knowledge of bias parameters for each population

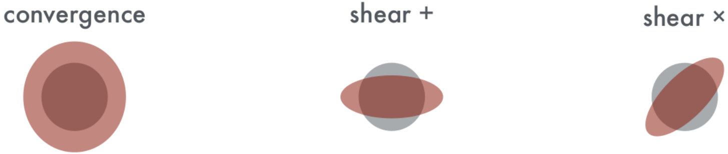




Weak lensing



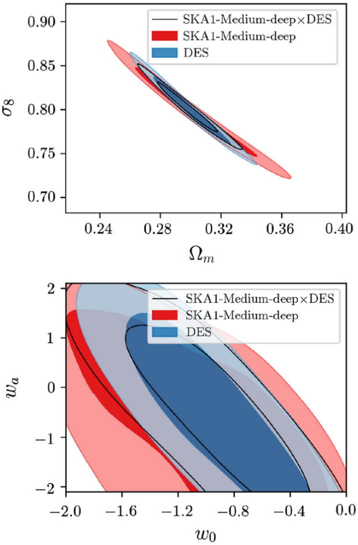




Radio Week Lensing

Medium Deep - Band 2 - Continuum

- statistical measurement of the shapes of millions of galaxies
- a marginal detection exist e.g. Chang, Refregier, & Helfand (2004)
- SKA comparable constraints with DES
- cross-correlation constraints retain almost all of the statistical power of the individual experiments



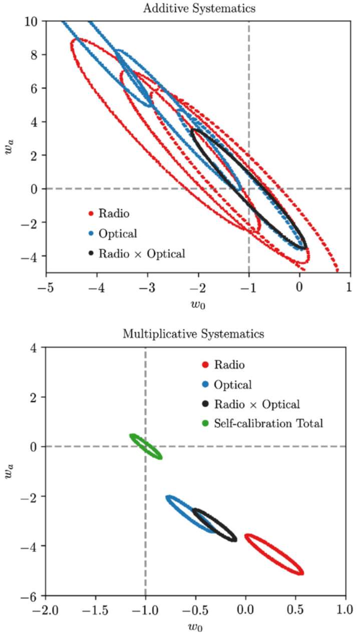
SKA Red Book (2019)

Cross-correlation

- complex shear at a given 3D position in the sky (θ, z)
- $\gamma_{\mathrm{obs}} = \gamma_{\mathrm{sig}} + \gamma_{\mathrm{sys}}$
- $\gamma_{\mathrm{sys}}(\theta, z) = \gamma_{\mathrm{mul}}(z)\gamma(\theta, z) + \gamma_{\mathrm{add}}(\theta, z)$
- cross correlation remove additive sys
- self-calibration: different systematics, same cosmology

powerful argument for performing weak lensing in the radio band

Camera et al. (2017)



The end

If you have questions, if you need clarifications, if you have complains and/or suggestions,
or if you think that SKA is your destiny :-)
please do not hesitate to contact me
spinemart@gmail.com or mspinelli@phys.ethz.ch

Thank to the Organizers for all the effort they put into this school and for letting me be part of it.
A last but not least thank to Laura Wolz that suggested my name for this.