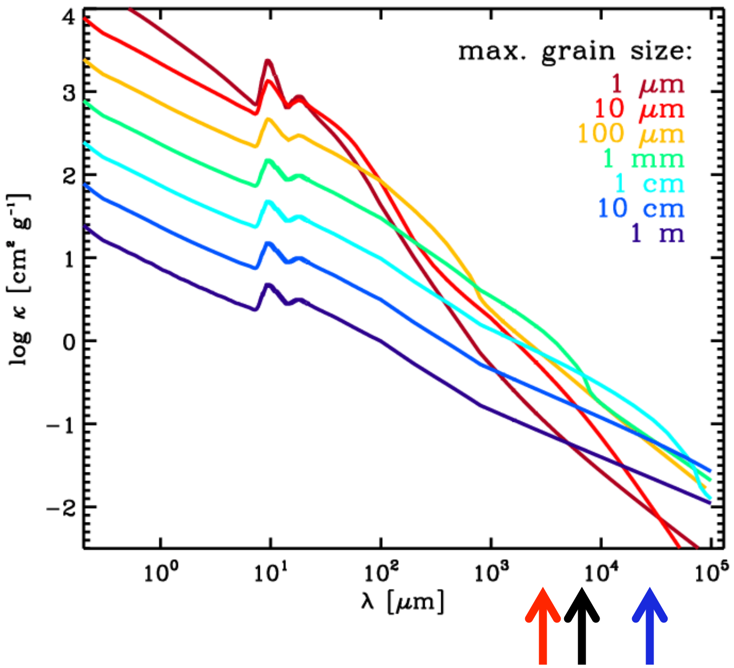
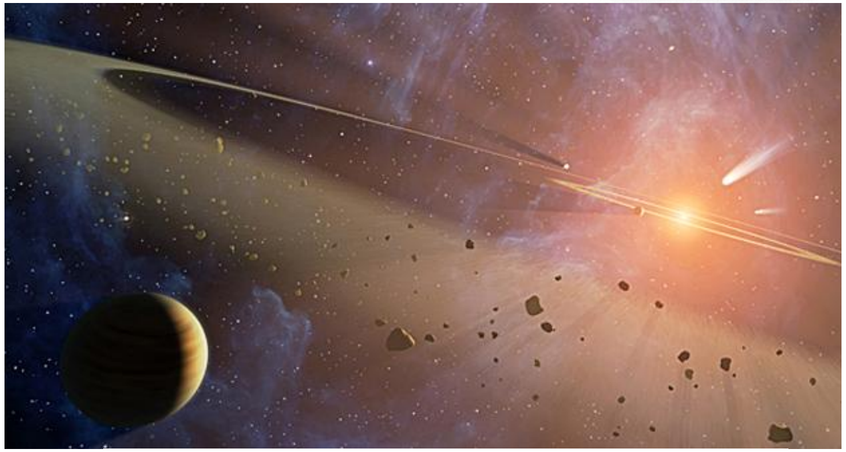
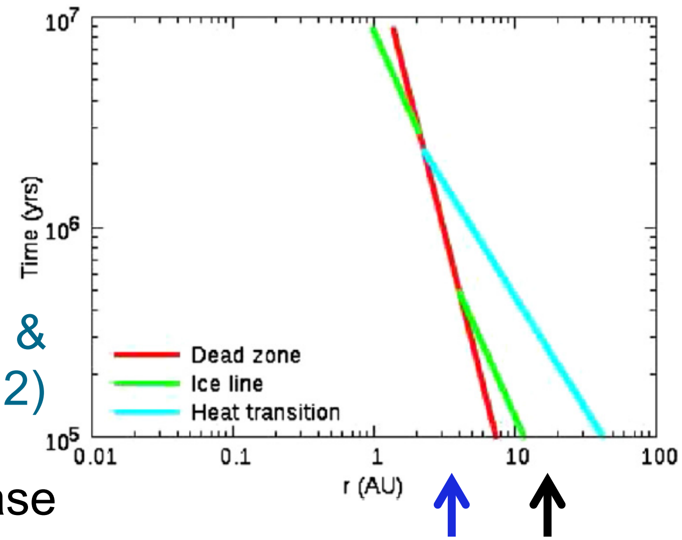
The Cradle of Life:
Understanding planet formation



ALMA JVLA SKA



(Hasegawa & Pudritz 2012)

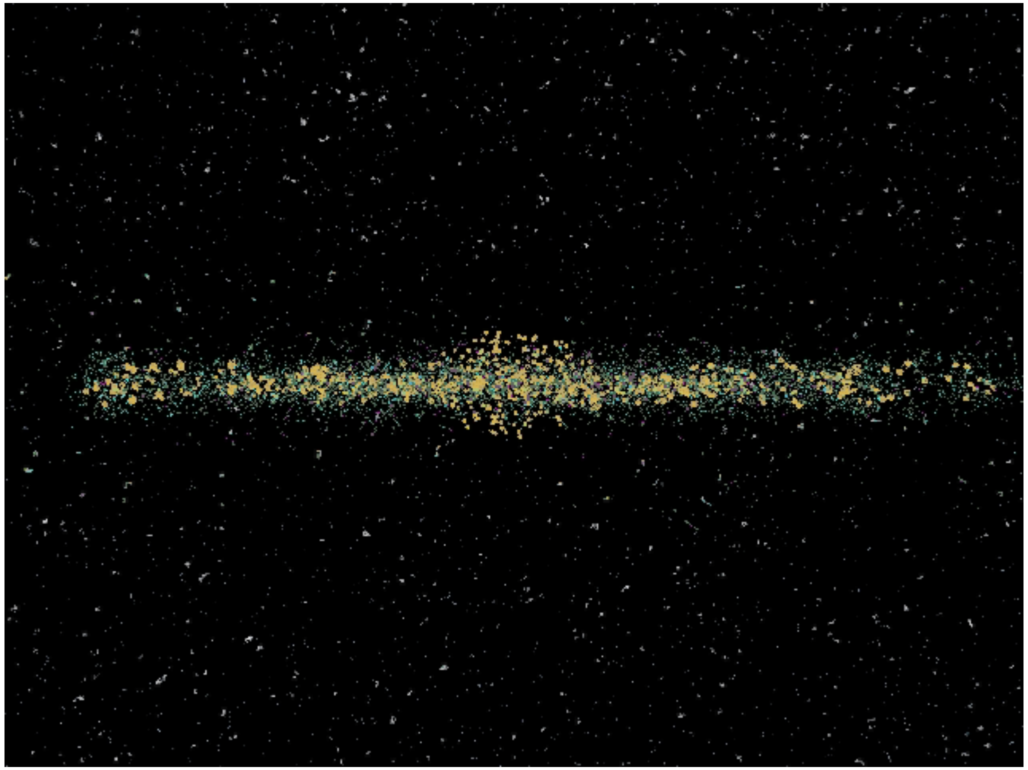


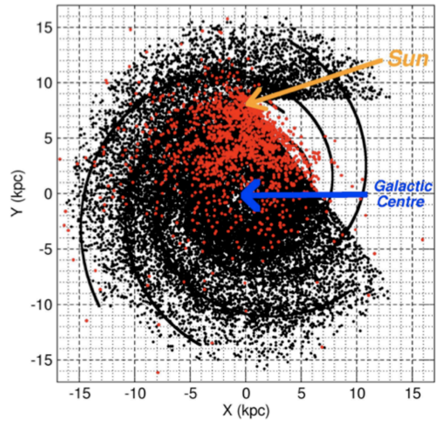
SKA JVLA

- Measuring grain growth through planetesimal phase
- Resolving proto-planetary disks at 100 pc (SKA1) or 300 pc (SKA2) inside the snow/ice line, sub-AU scales with SKA2

Finding all the pulsars in the Milky Way…

(Cordes et al. 2004, Kramer et al. 2004, Smits et al. 2008)

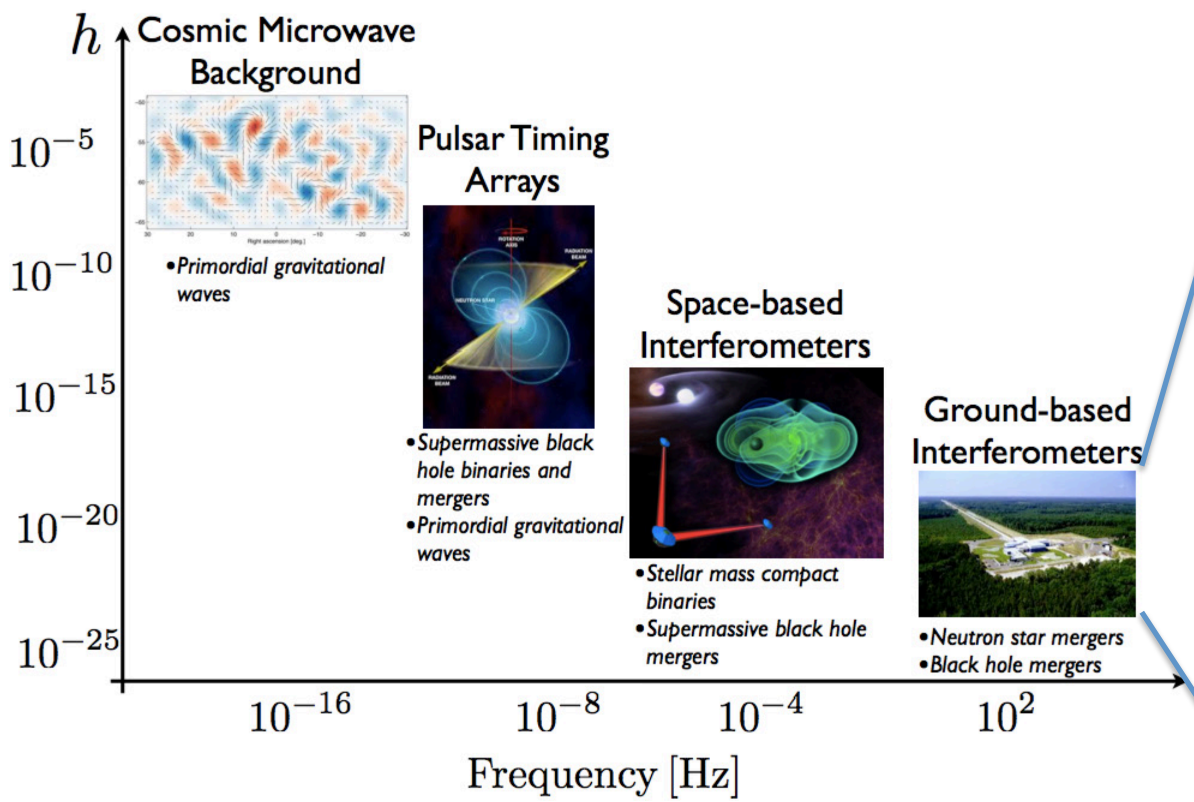


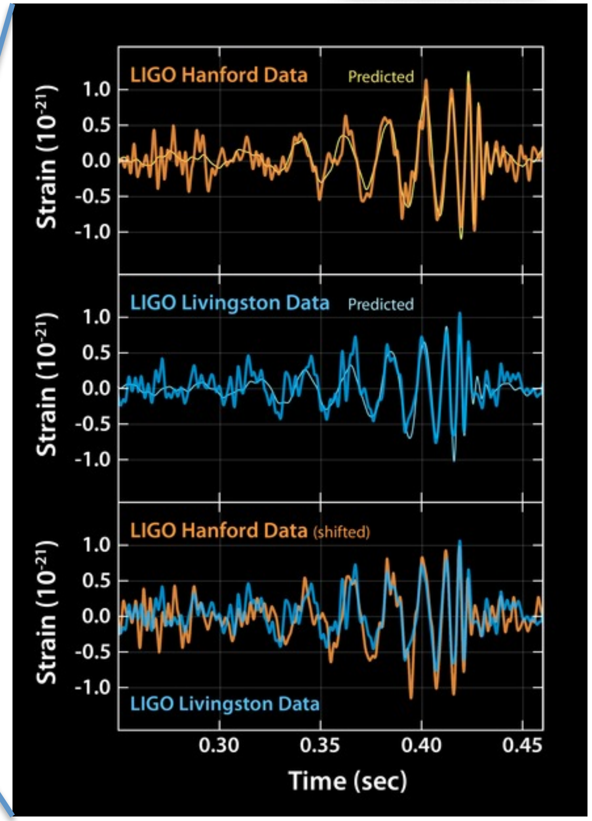


- ~40,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

- Timing precision is expected to increase by factor ~100: nHz Grav. Waves
- Rare and exotic pulsars and binary systems: including PSR-BH systems!
- Testing cosmic censorship and no-hair theorem
- **Current estimates are ~50% of population with SKA1, 100% with SKA2**

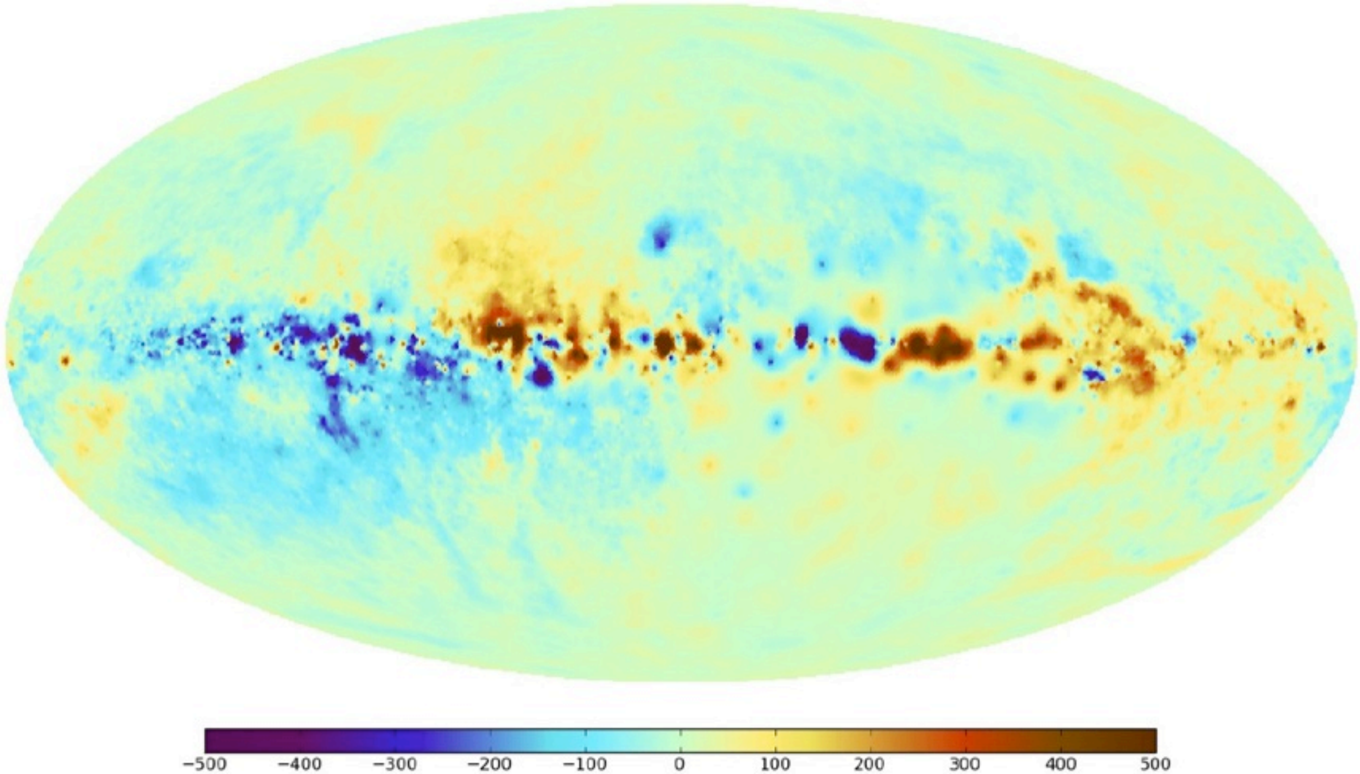
Finding all the pulsars in the Milky Way…





- Timing precision is expected to increase by factor ~100: nHz Grav. Waves
- Rare and exotic pulsars and binary systems: including PSR-BH systems!
- Testing cosmic censorship and no-hair theorem
- **Current estimates are ~50% of population with SKA1, 100% with SKA2**

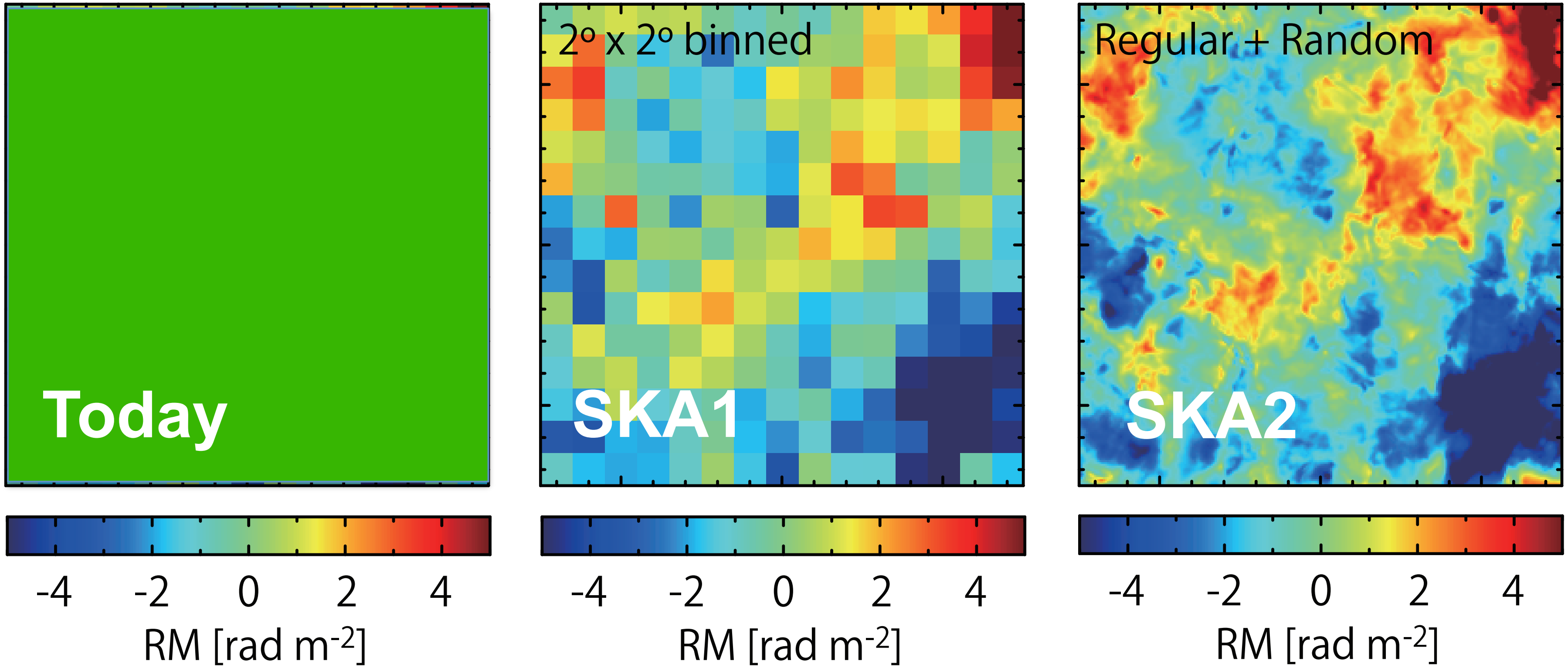
Headline Magnetism Science



Oppermann et al. (2012) ~40,000 extra-galactic RMs over 4π sr

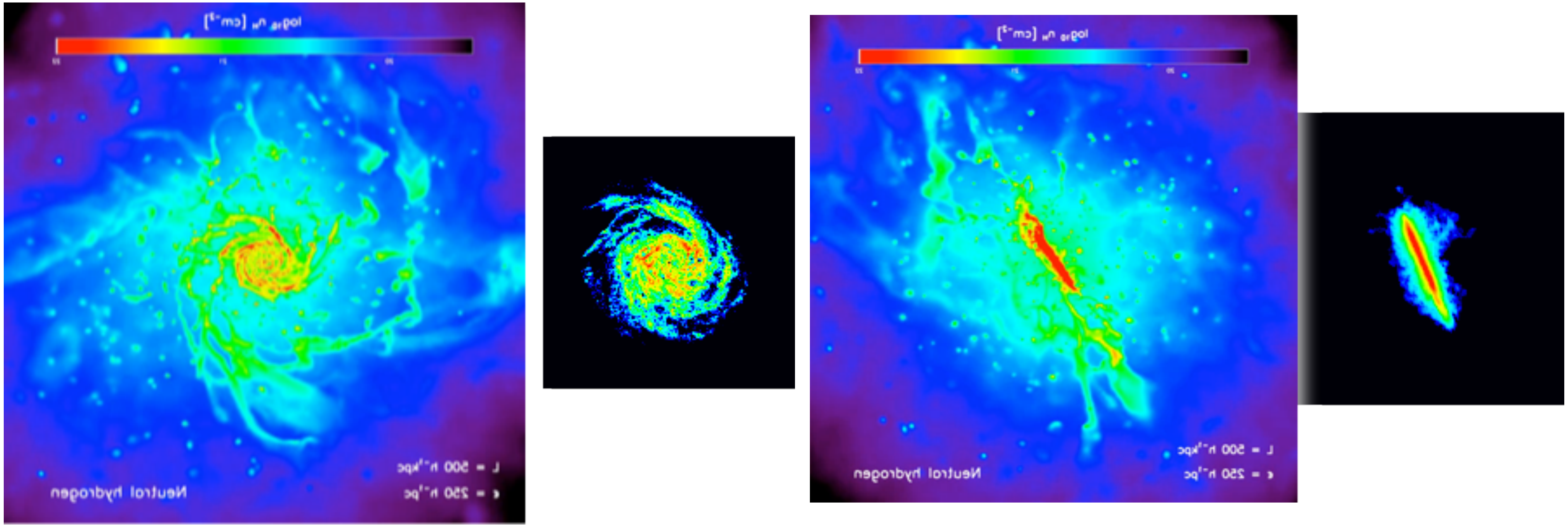
- 3D magnetic tomography of the Galaxy and distant universe; from current 1 RM deg^{-2}, SKA1: 300 deg^{-2} to SKA2: 5000 deg^{-2}

Headline Magnetism Science



- 3D magnetic tomography of the Galaxy and distant universe; from current 1 RM deg^{-2}, SKA1: 300 deg^{-2} to SKA2: 5000 deg^{-2}

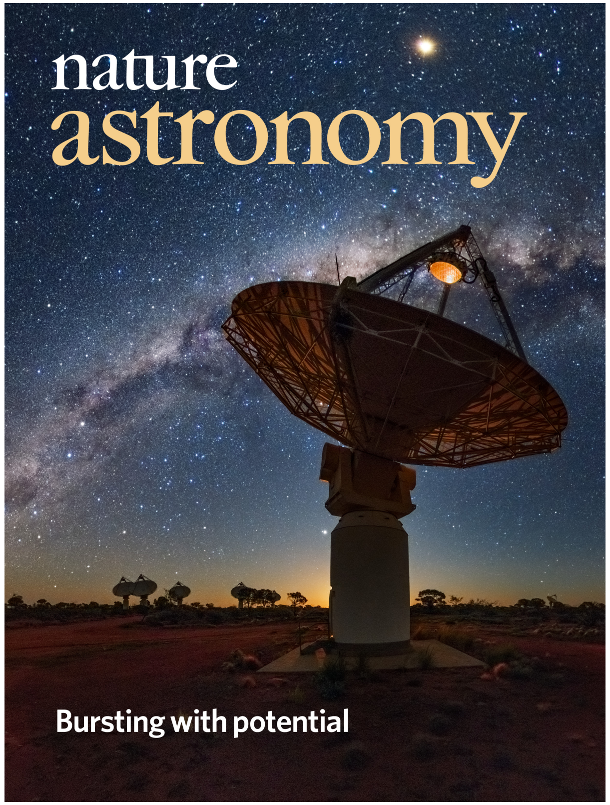
Galaxy HI Evolution:
out to z ~ 1 with SKA1 and z ~ 5 with SKA2

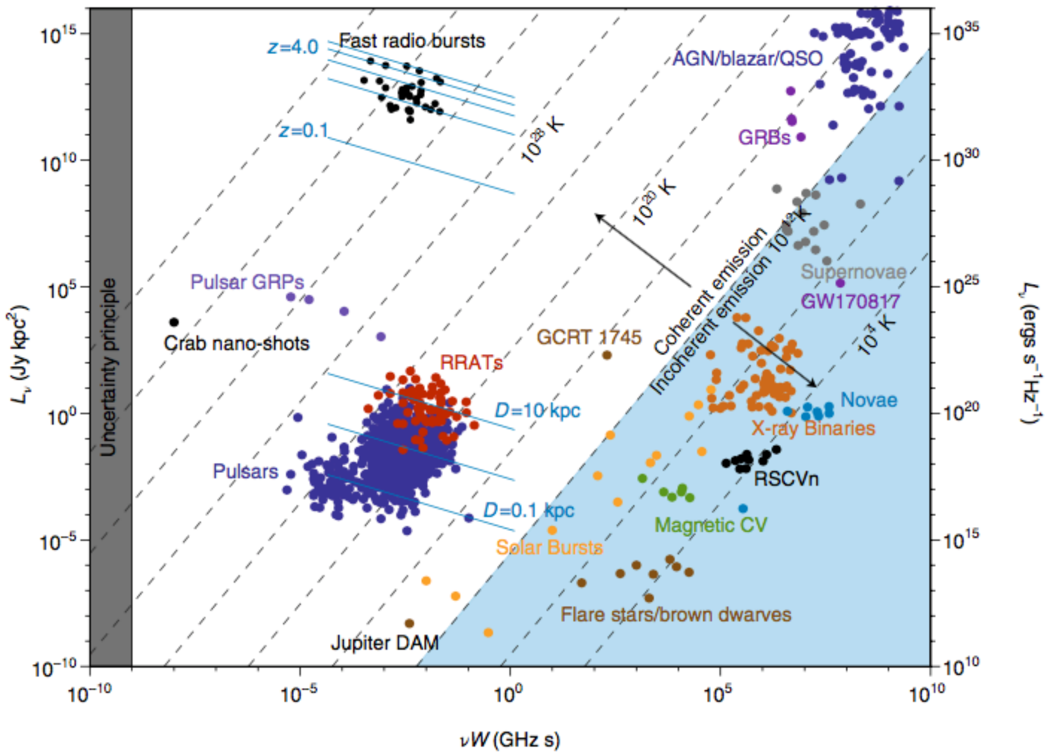


(Simulations: Schaye et al. 2010, Images: Oosterloo 2014)

- Understanding galaxy assembly and the baryon cycle
  - Determine the impact of galaxy environments
  - Probe gas inflow and removal, diffuse gas $N_{HI} < 10^{17}$ cm^{-2}
  - Measure angular momentum build-up

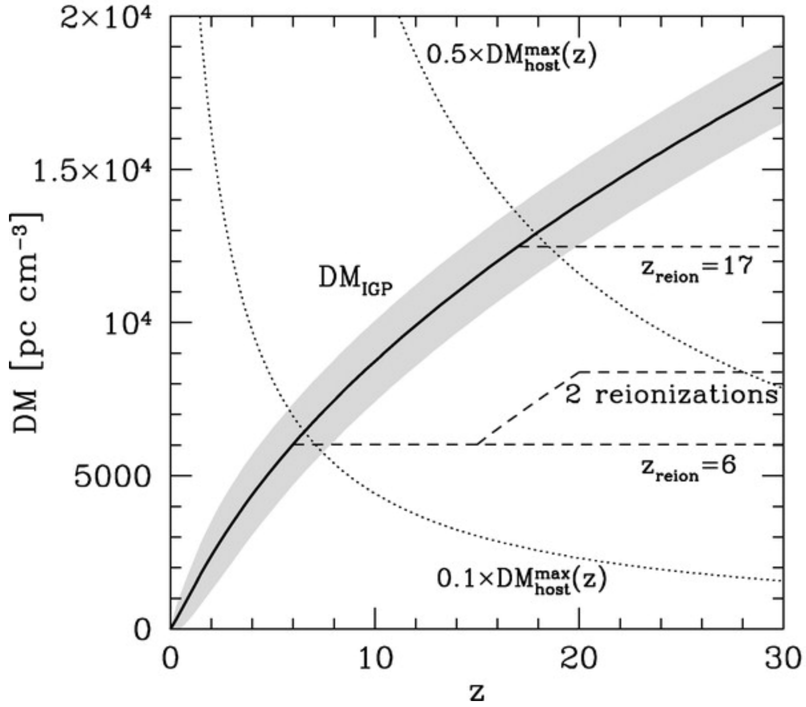
The Transient radio sky



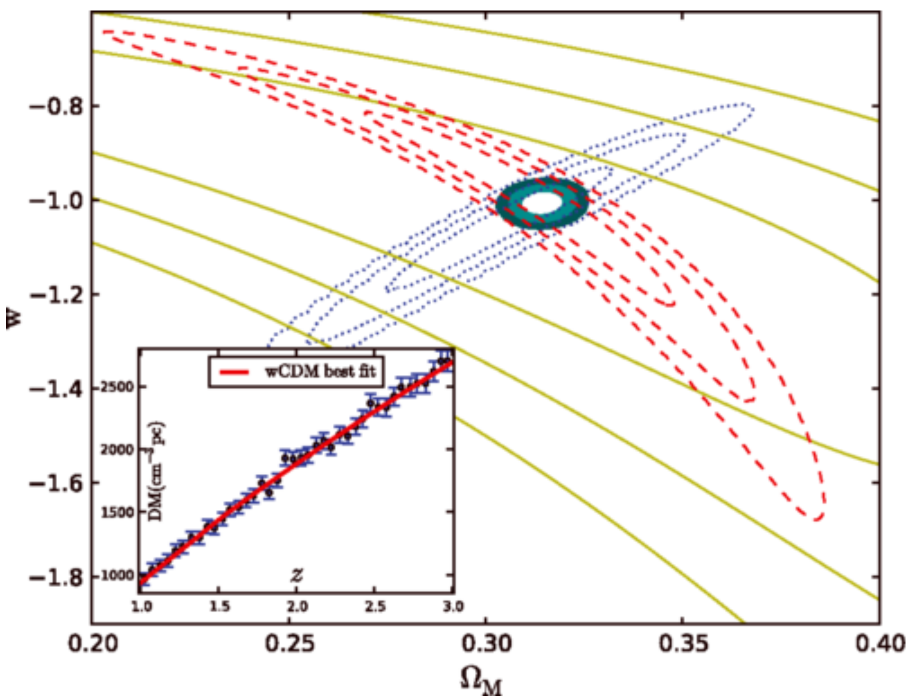


- More than 60 celestial “FRB” events now detected (after first “Lorimer” burst): S = 0.5 – 2 Jy, Δt = 1 – 6 msec, DM = 500 – 2000 cm^{-3} pc
- Estimated event rate: 3x10^{3} sky^{-1} day^{-1}
- Unknown origin – some, probably all at cosmological distances

Transients headline science:
Fast Radio Bursts as a cosmological probe



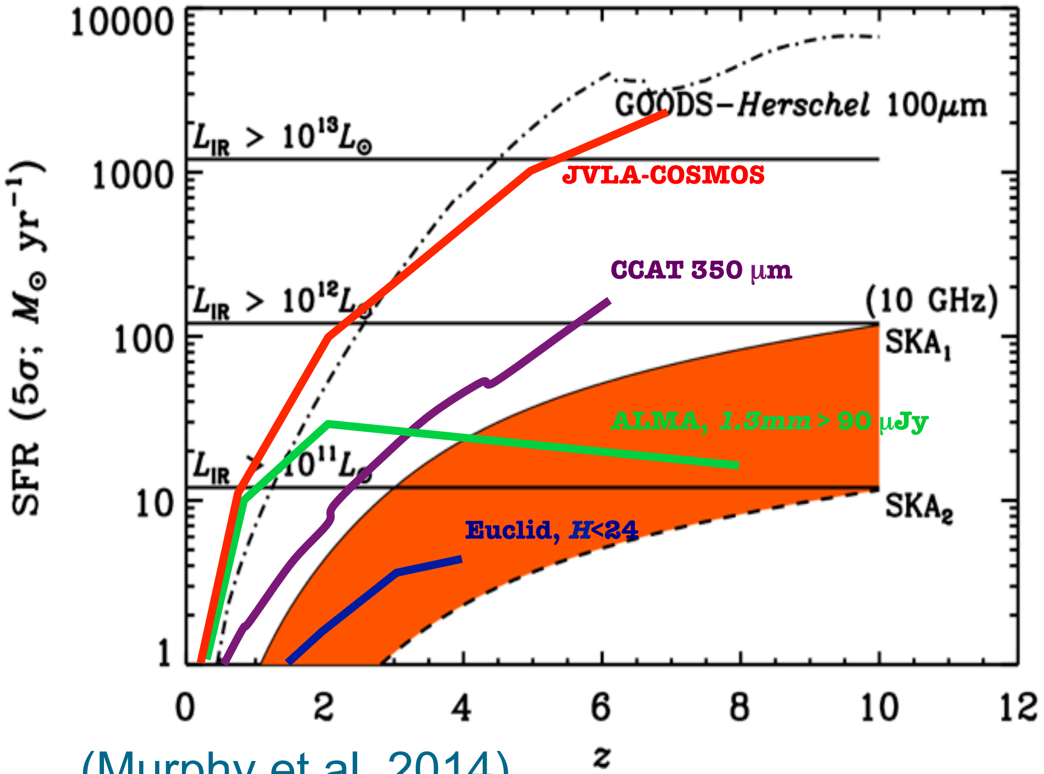
(Ioka 2003)



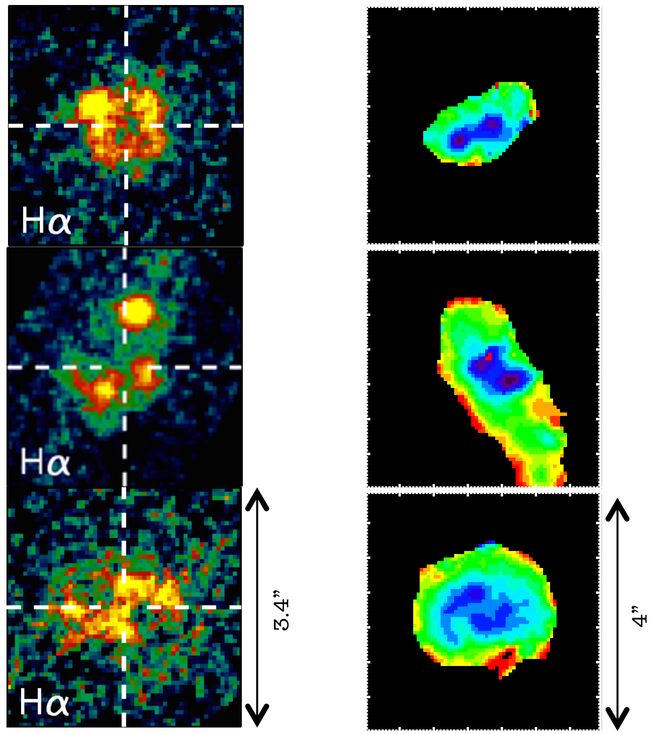
(Zhou et al. 2014)

- Prospects for fundamental contributions to cosmology with large samples (~1000) of spectroscopically identified FRBs out to z ~ 2 with SKA1 and z ~ 5 with SKA2

Galaxy Evolution Studies in the Radio Continuum: Understanding the Star Formation History of the Universe



(Murphy et al. 2014)



Wuyts et al 2013, **z~1**
Hα–based SFR-maps

Cibinel et al 2014, **z~2**
UV-based SFR-maps

- Unmatched sensitivity to star formation rates (10 $M_\odot$/yr) out to z ~ 4 with SKA1 and z ~ 10 with SKA2
- Resolved (sub-kpc) imaging of star forming disks out to z ~ 1 with SKA1 and z ~ 6 with SKA2

Cosmology with SKA1:

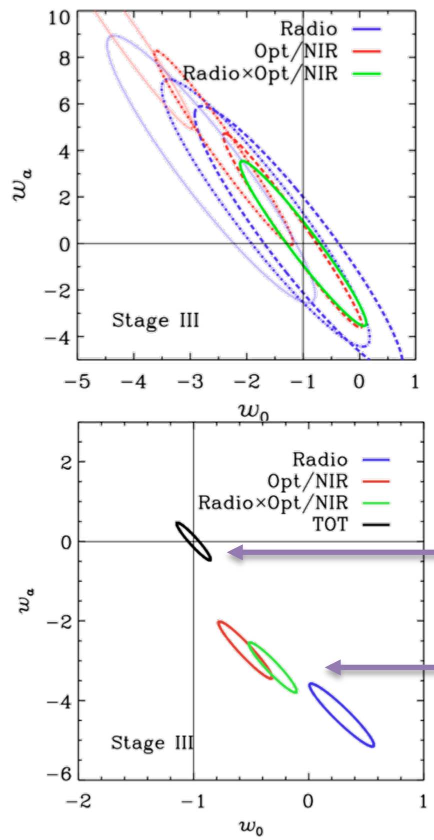
Publications of the Astronomical Society of Australia (PASA)
doi: 10.1017/pas.2018.xxx.

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[4,5,6,2], 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[21,36], Carlos A.P. Bengaly[9], Anna Bonaldi[22], Camille Bonvin[23], Michael L. Brown[2], Emma Chapman[24], Song Chen[9], Xuelei Chen[25], Steven Cunnington[1], Tamara M. Davis[27], Clive Dickinson[2], José Fonseca[9,36], Keith Grainge[2], Stuart Harper[2], Matt J. Jarvis[7,9], Roy Maartens[1,9], Natasha Maddox[28], Hamsa Padmanabhan[29], Jonathan R. Pritchard[24], 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[25], Daisuke Yamauchi[34], Joe Zuntz[35]

(Bacon et al. 2018, https://arxiv.org/abs/1811.02743)



Individual Experiments vs Combined

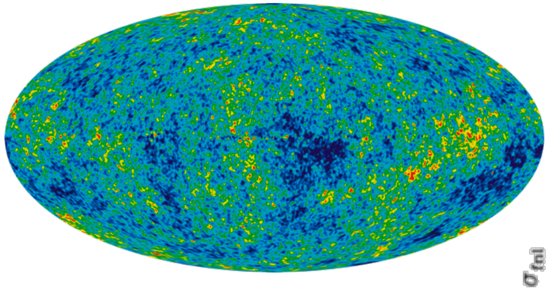
Uncorrelated Systematics

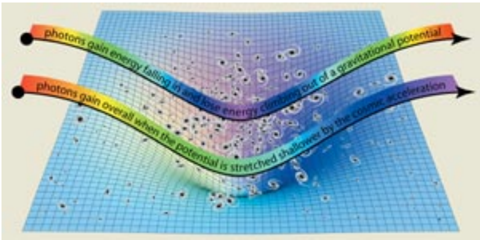
Correlated Systematics

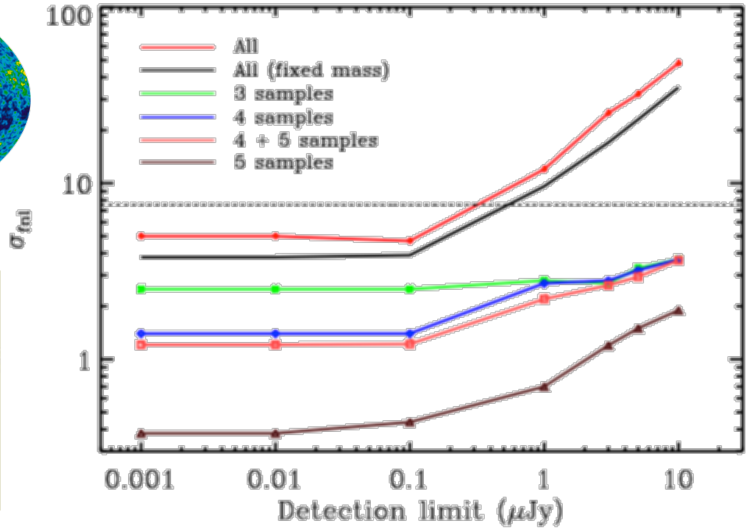
How to achieve precision cosmology?

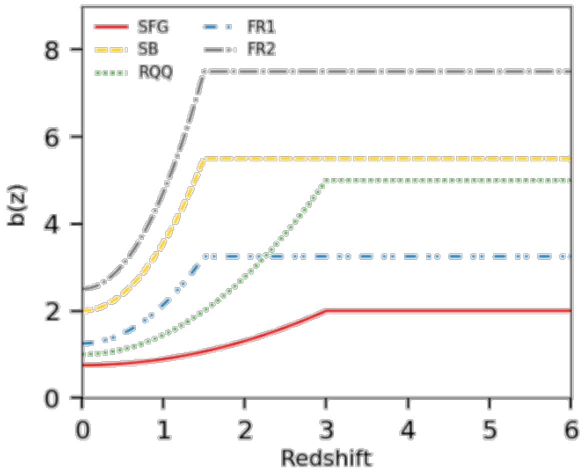
- Every experiment has its own random and systematic errors
- Use LSST **OR** Euclid **OR** SKA ? ✗
- Use LSST **AND** Euclid **AND** SKA ? ✓
- Maximise diversity of systematic errors !

Cosmology with SKA: Integrated Sachs-Wolfe effect





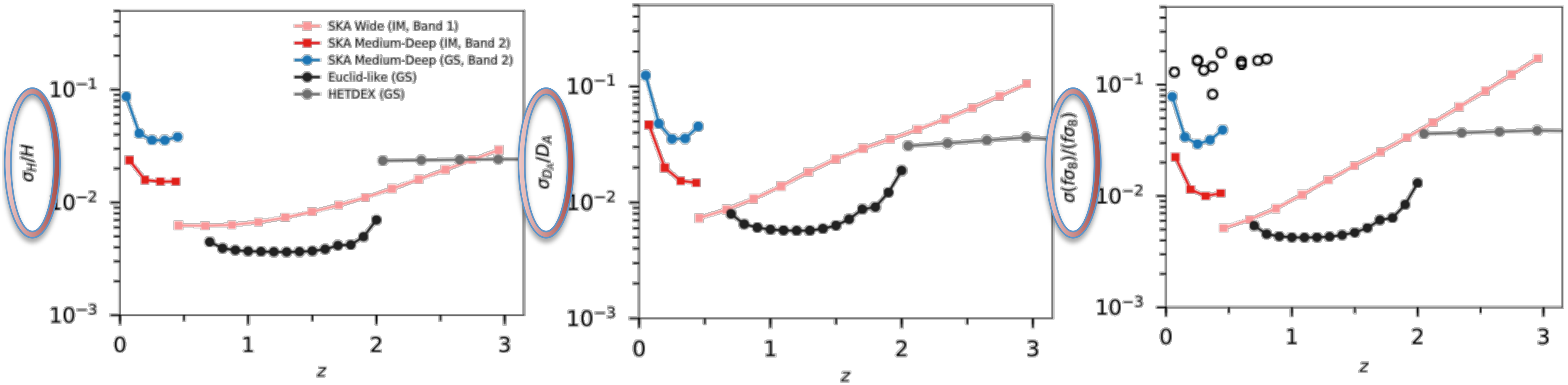




(Ferramacho et al. 2014)

- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect: correlation of foreground source populations (**of different bias**) with CMB structures
  - Uniquely probing the largest scales

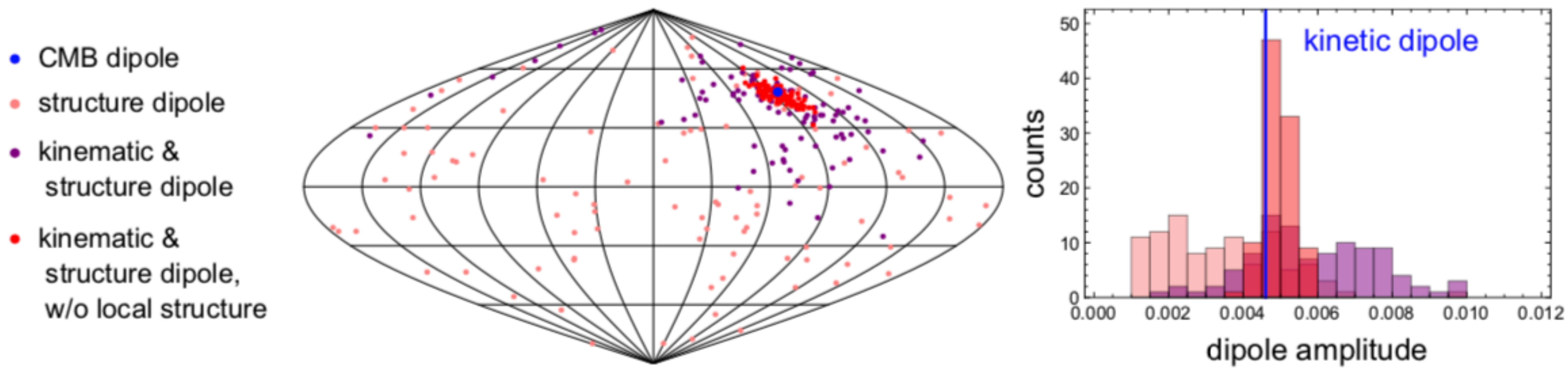
Cosmology with SKA:
Baryon Acoustic Oscillations



(SKA1 Cosmology Redbook)

- Constraining Dark Energy models with redshift-resolved BAO measurements
  - Intensity mapping is cutting edge with SKA1 at low z, complementary at high z
  - Eliminate systematics via multi-tracer correlations

Cosmology with SKA: Testing the Origin of the CMB Dipole



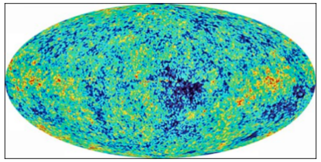
(SKA1 Cosmology Redbook 2018)

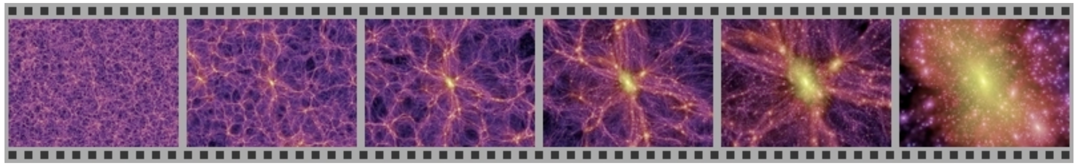
- CMB dipole assumed to be kinematic in origin, but alternate hypotheses limited by cosmic variance
- Wide-field surveys of radio continuum sources should provide highly significant detection of both direction and amplitude of a kinematic dipole

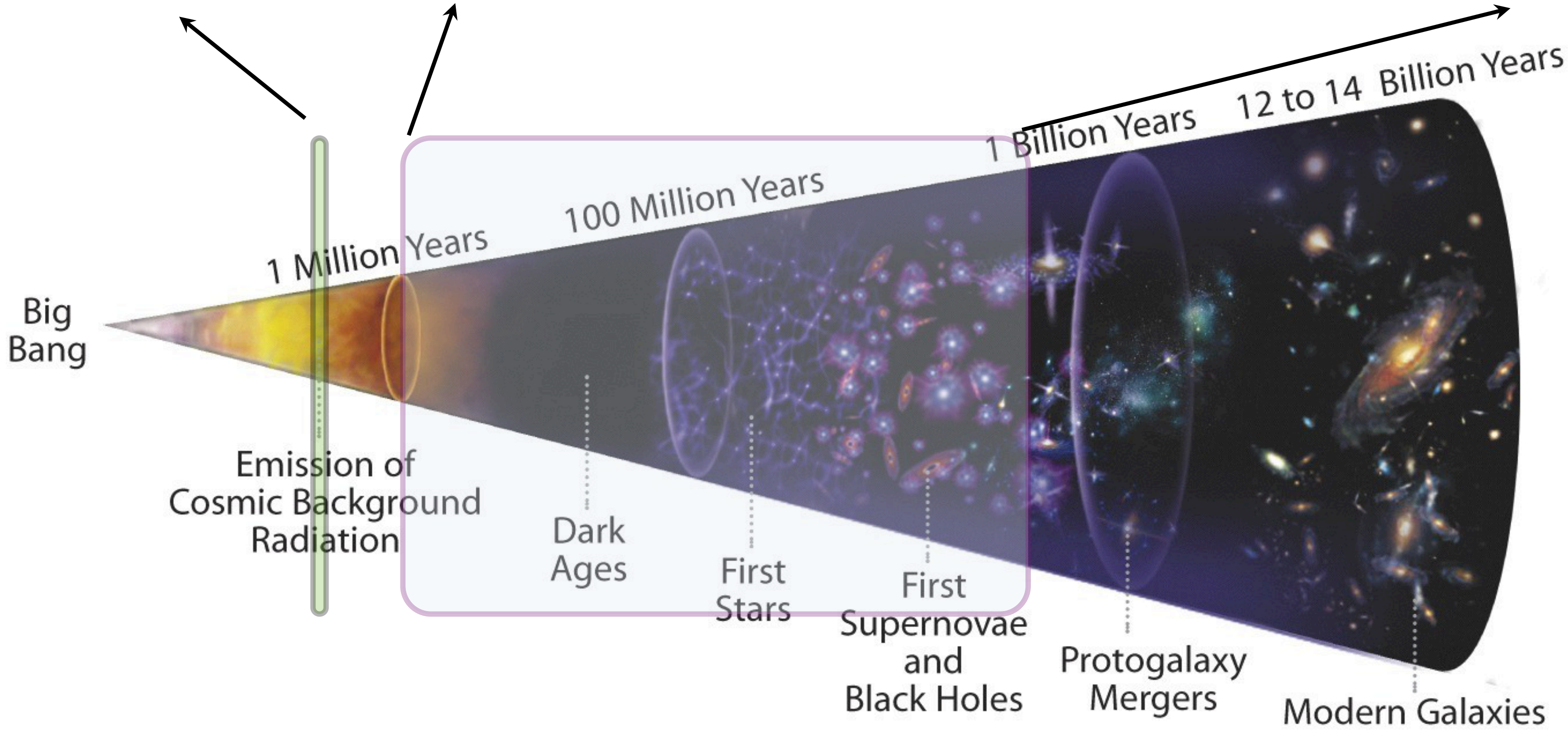
HI surveys of the Dark Ages, Cosmic-Dawn & EoR

CMB displays a single moment of the Universe. Its initial conditions at ~400,000 yrs

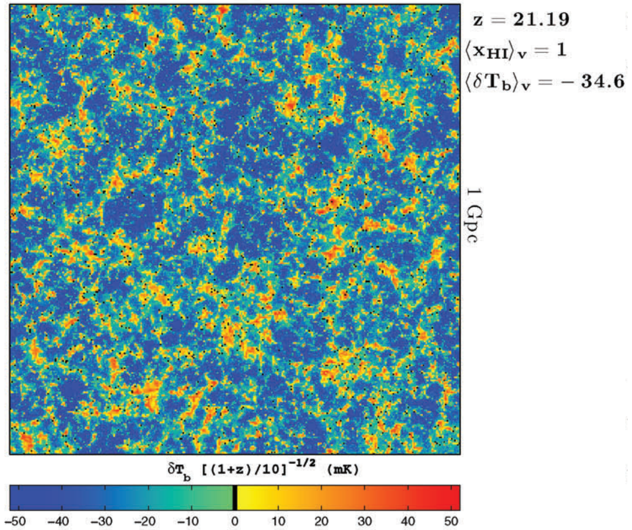
HI emission from the Dark Ages, Cosmic Dawn & EoR traces an evolving "movie" of baryonic and DM structure formation at $t_{univ} < 10^9$ years.



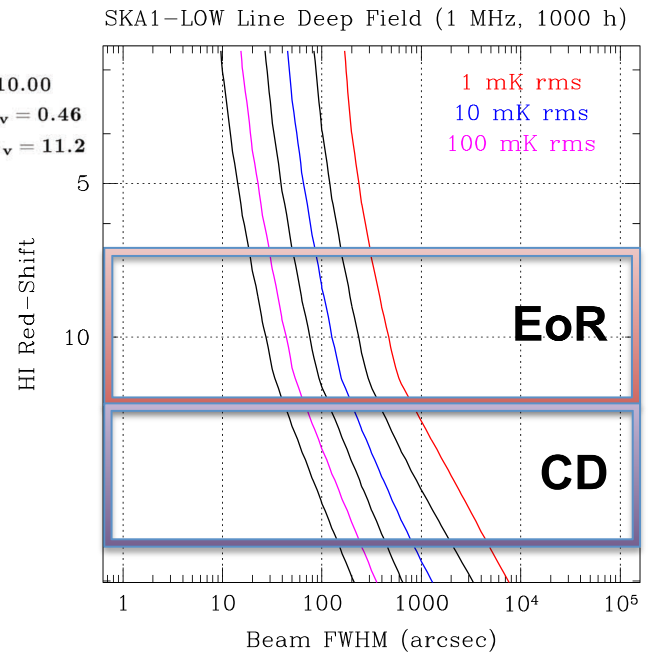




SKA1 surveys of the EoR & Cosmic-Dawn

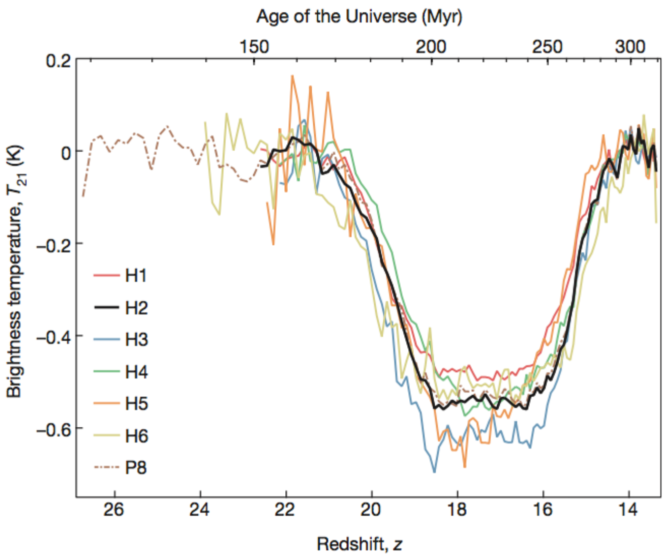


(Mesinger et al 2011)

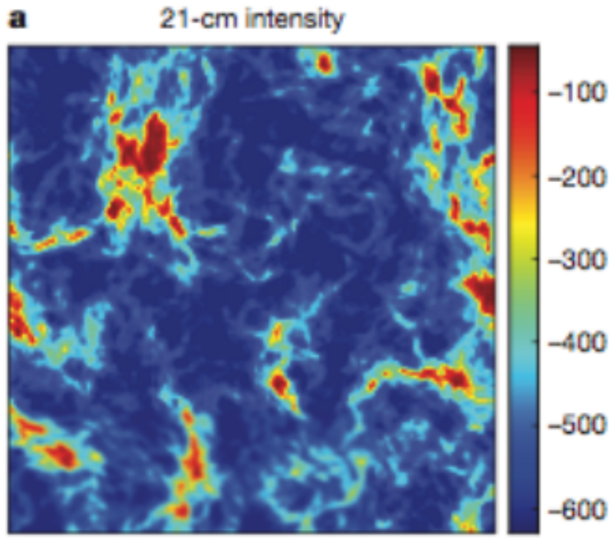


- Detecting EoR structures in imaging mode (as distinct from statistically) on 5 arcmin scales with 1 mK RMS
- Probing the Cosmic Dawn statistically (with pre-2018 predictions)

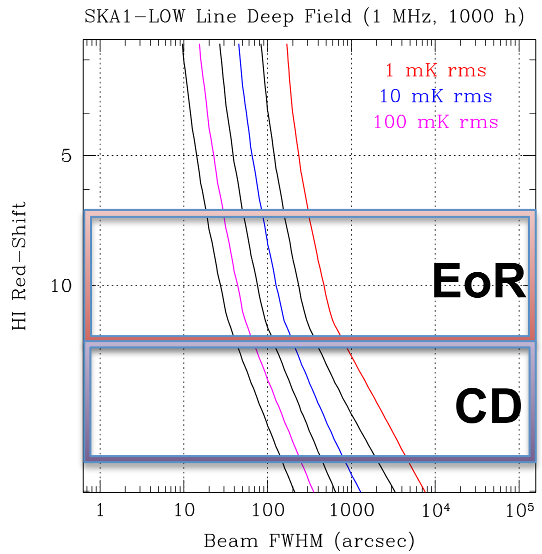
SKA1 surveys of the EoR & Cosmic-Dawn



(Bowman et al 2018)



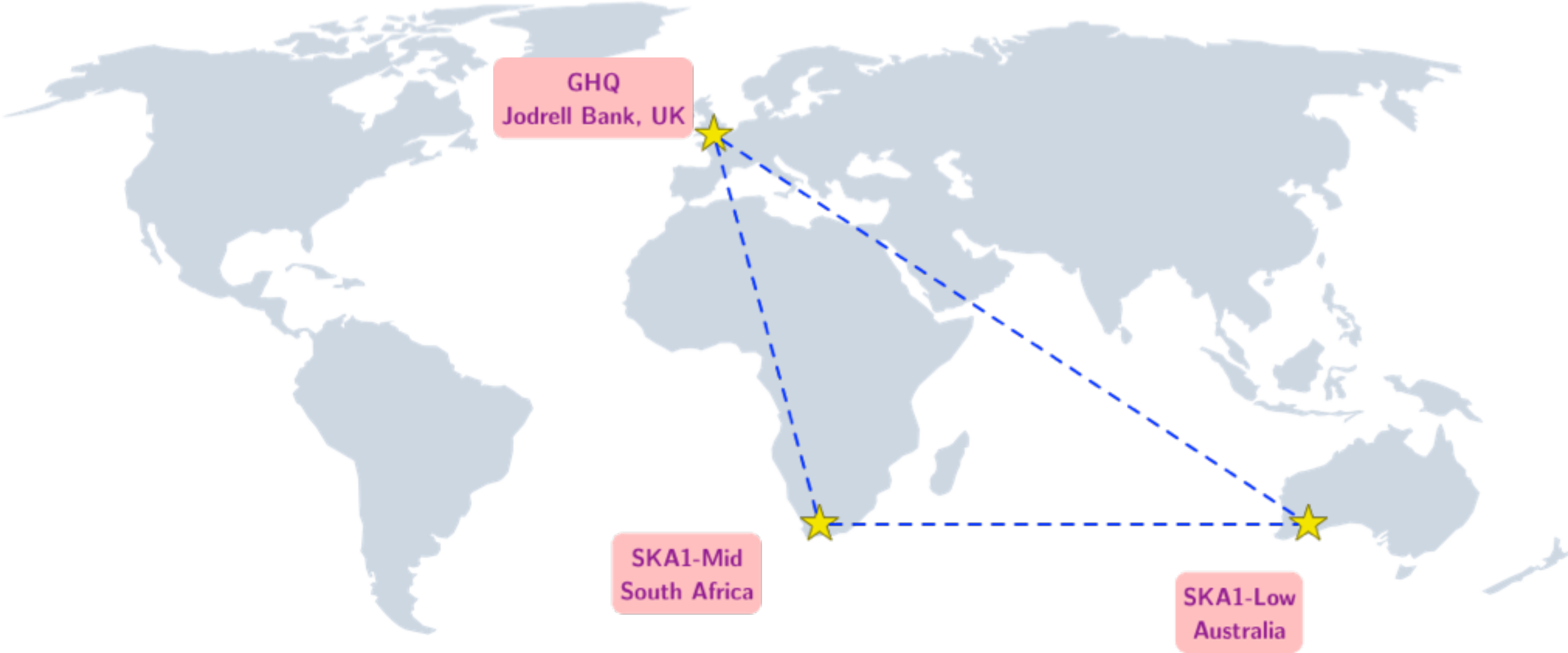
(Barkana 2018)



- Possible detection by Bowman et al (2018) of global Cosmic Dawn signature centred at 78 MHz
- If surprising depth is confirmed, then fluctuations also large:
  140 mK RMS @ 10s of arcmin predicted by Barkana (2018)
- Deep SKA integrations (3 mK RMS @ 10s of arcmin) may permit direct CD imaging: localisation in 3D of first post-big-bang heat sources

SKA and Big Data

The SKA Operational Model



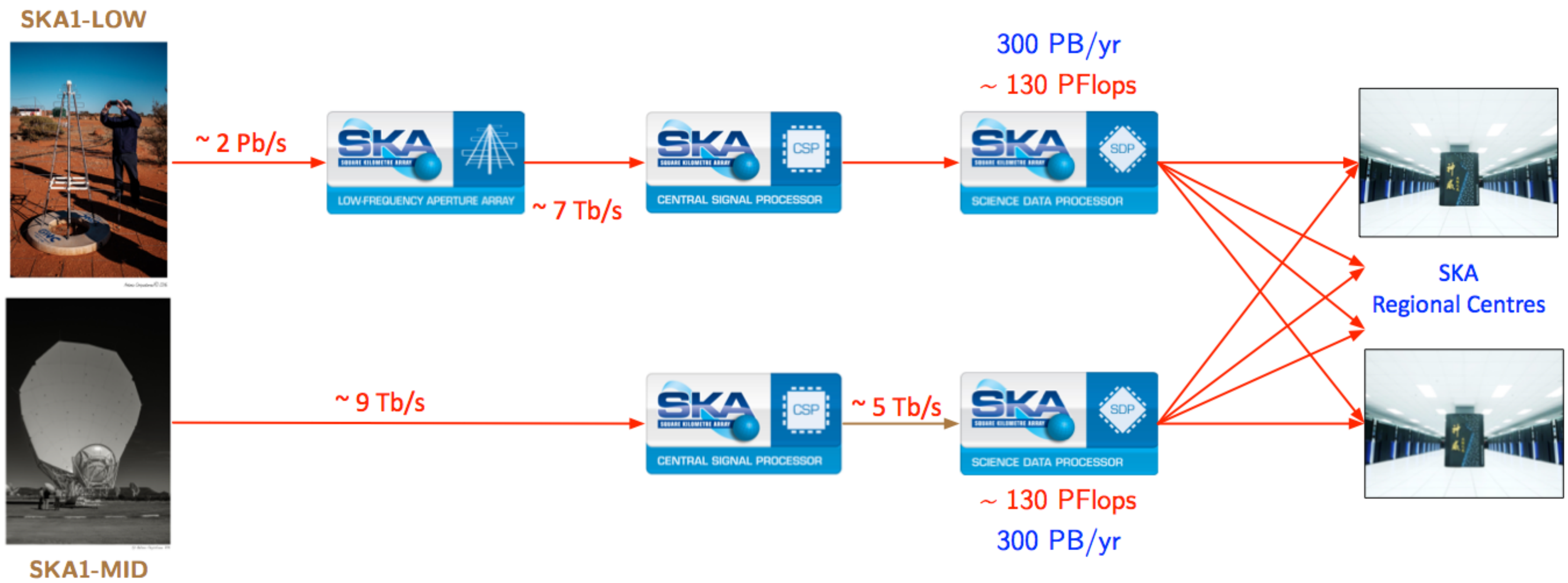
1 Observatory
The SKA

2 Telescopes
SKA1-LOW
SKA1-MID

3 Sites
Australia (LOW)
South Africa (MID)
United Kingdom (GHQ)

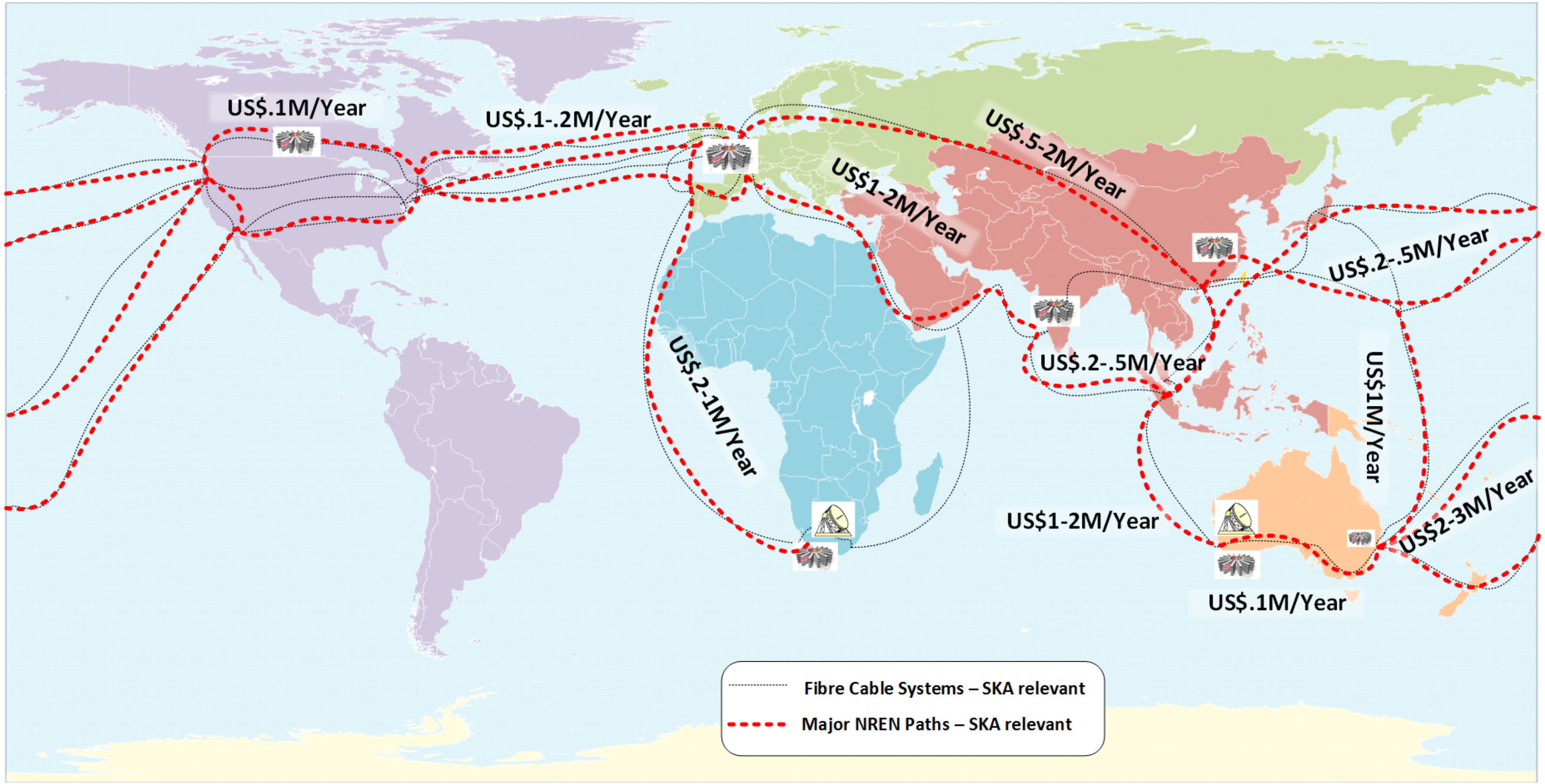
Principles
One observatory
Optimal operation
Minimise duplication
Autonomy & authority

The SKA Data Flow Challenge



- Digital data rates are reduced by factor ~100 within SDP via calibration and data product generation
- SDP output rate compatible with 100 Gb/s per site

The SKA Data Flow Challenge

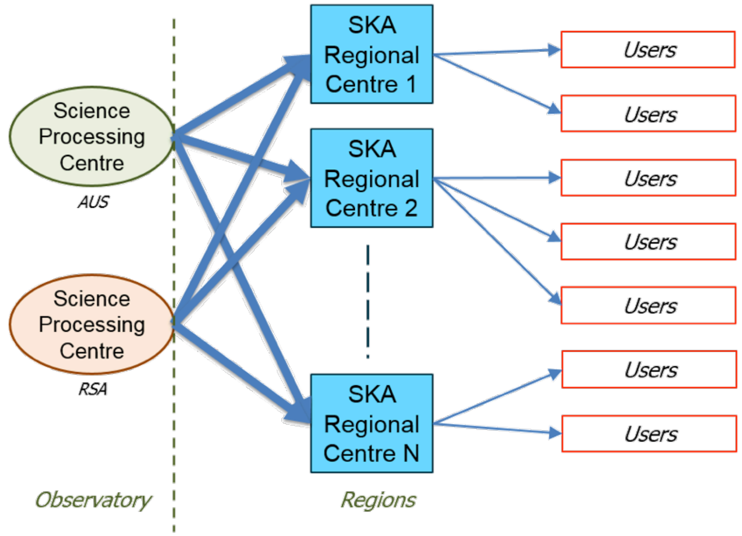


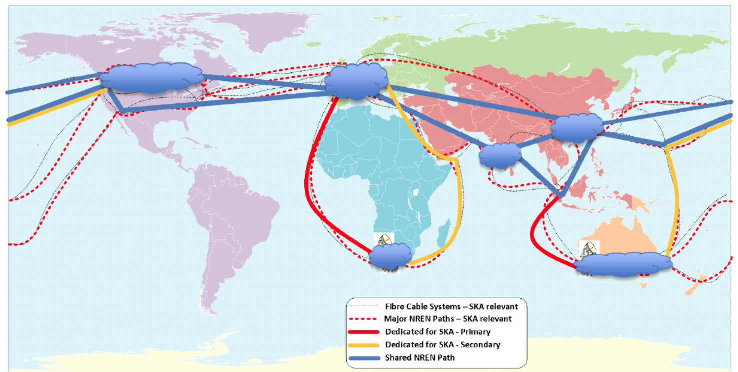
- Observatory Data Products flow from the Science Data Processors in Perth and Cape Town to SRCs around the globe

The SKA Data Flow Challenge

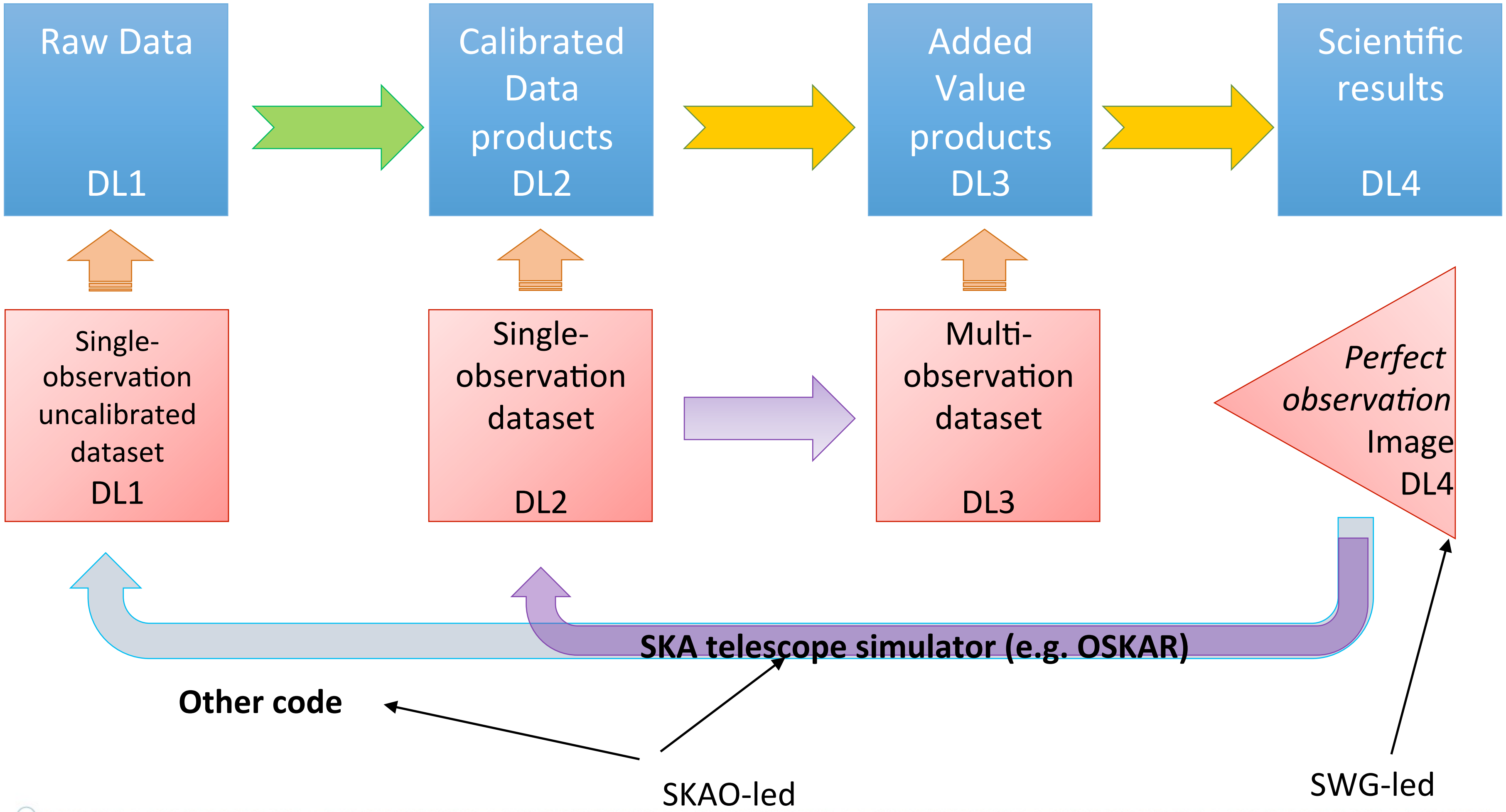
SKA Data Challenge "Flavours"

- SDP Challenges
  - Computation at scale
  - Pipeline framework
  - Network/data transport
- SRC Challenges
  - Pipeline optimisation
  - Added value data products
  - User interaction
- Science Challenges
  - Algorithms, analysis, visualisation
- Early Data Challenges by "flavour", ultimately end-to-end





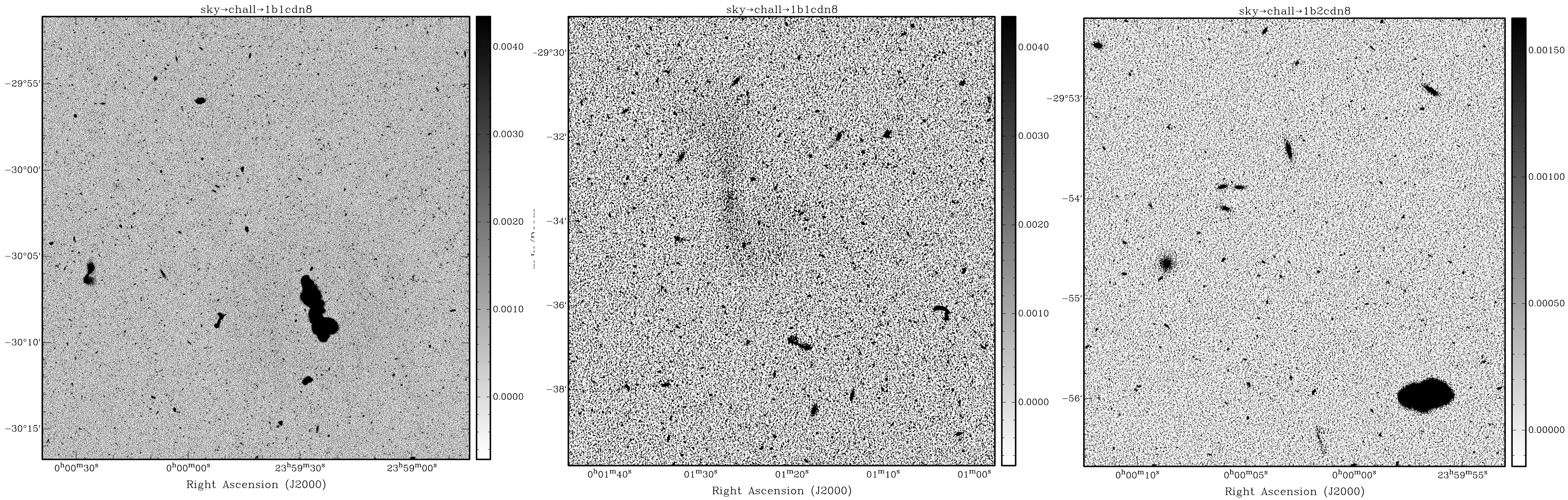
SKA Science Data Challenges: Simulations



Science Data Challenge #1

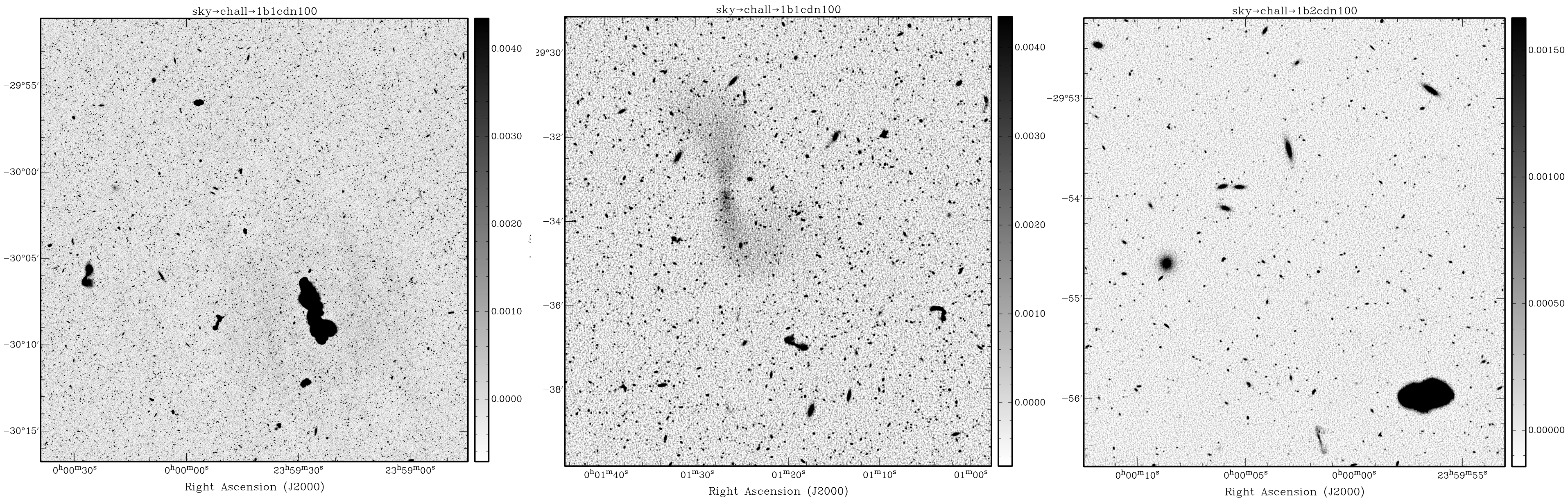
- November 26 release, March 15 deadline
- Continuum sub-band images ($\Delta\nu/\nu_c$ = 30%)
- SKA1-Mid, three frequencies: ν_c = 0.56, 1.4 and 9.2 GHz
- One pointing: 8^h, 100^h and 1000^h observations
- Data info:
  - Images of 32k pixels per side for the full FoV
  - 1.50, 0.60 and 0.091” FWHM resolution at 0.56, 1.4 and 9.2 GHz
  - Size of a single frequency slice: 4GB (x9 = 36GB total)

Science Data Challenge #1



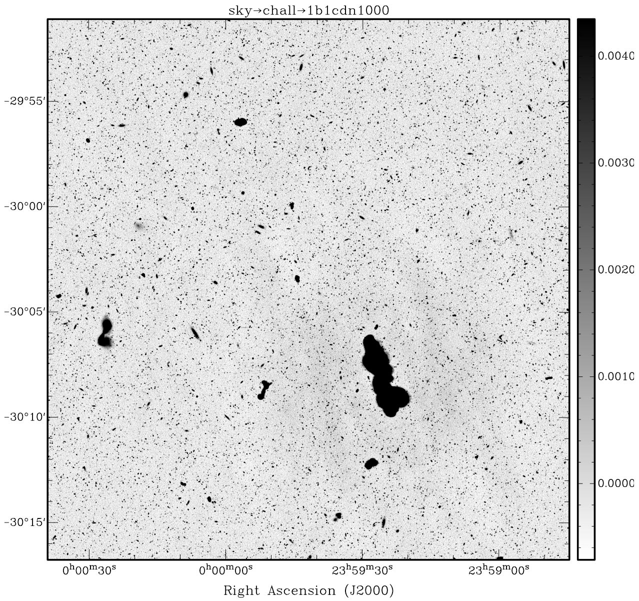
- Sample zoom-ins
- One pointing: **<u>8^h</u>**, 100^h and 1000^h observations
- Some 10^7 embedded sources based on state-of-the-art T-RECS sky model (Bonaldi et al. 2018)
  - Star-forming galaxies represented as projected exponential disk
  - Active galactic nuclei source morphologies drawn from DRAGNs atlas (Leahy et al.) of high resolution images

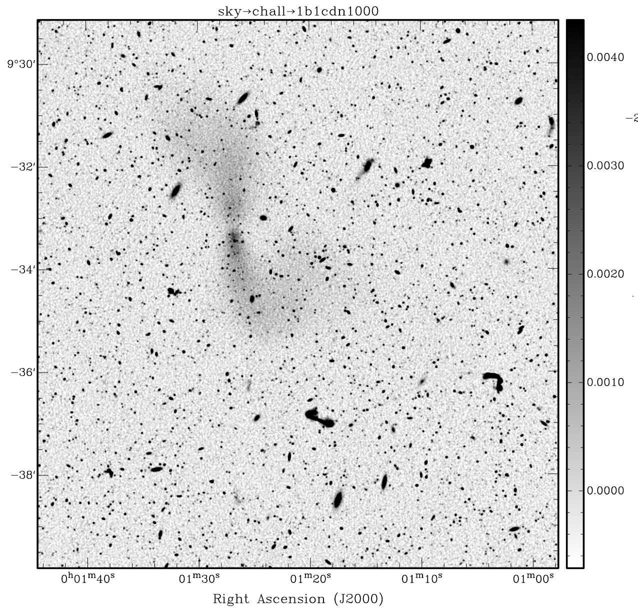
Science Data Challenge #1

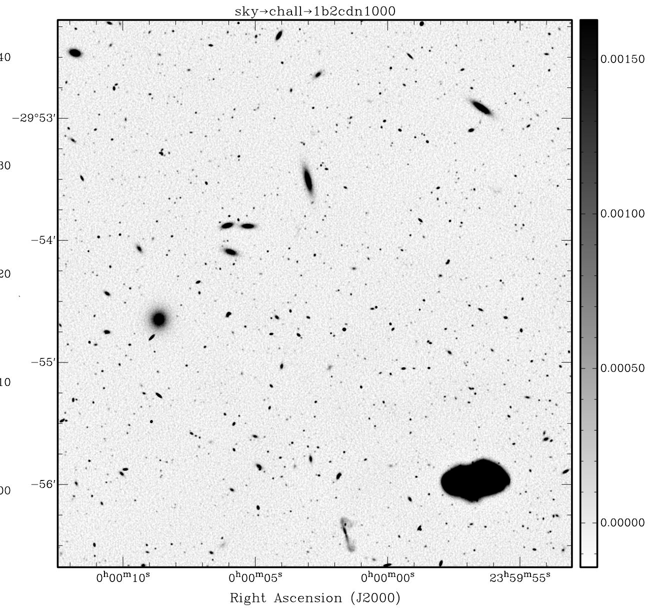


- Sample zoom-ins
- One pointing: 8^h, **<u>100^h</u>** and 1000^h observations
- Some 10^7 embedded sources based on state-of-the-art T-RECS sky model (Bonaldi et al. 2018)
  - Star-forming galaxies represented as projected exponential disk
  - Active galactic nuclei source morphologies drawn from DRAGNs atlas (Leahy et al.) of high resolution images

Science Data Challenge #1







- Sample zoom-ins
- One pointing: 8^h, 100^h and **1000^h** observations
- Some 10^7 embedded sources based on state-of-the-art T-RECS sky model (Bonaldi et al. 2018)
  - Star-forming galaxies represented as projected exponential disk
  - Active galactic nuclei source morphologies drawn from DRAGNs atlas (Leahy et al.) of high resolution images

First Science Data Challenge

- Source finding, identification, characterization etc.
  https://astronomers.skatelescope.org/ska-science-data-challenge-1/
- Results to be compared with simulation input catalog
- WG-specific analyses optionally done on the identified sources
- SKAO Post-doc for radio astronomy simulations joining Science Team in Q3

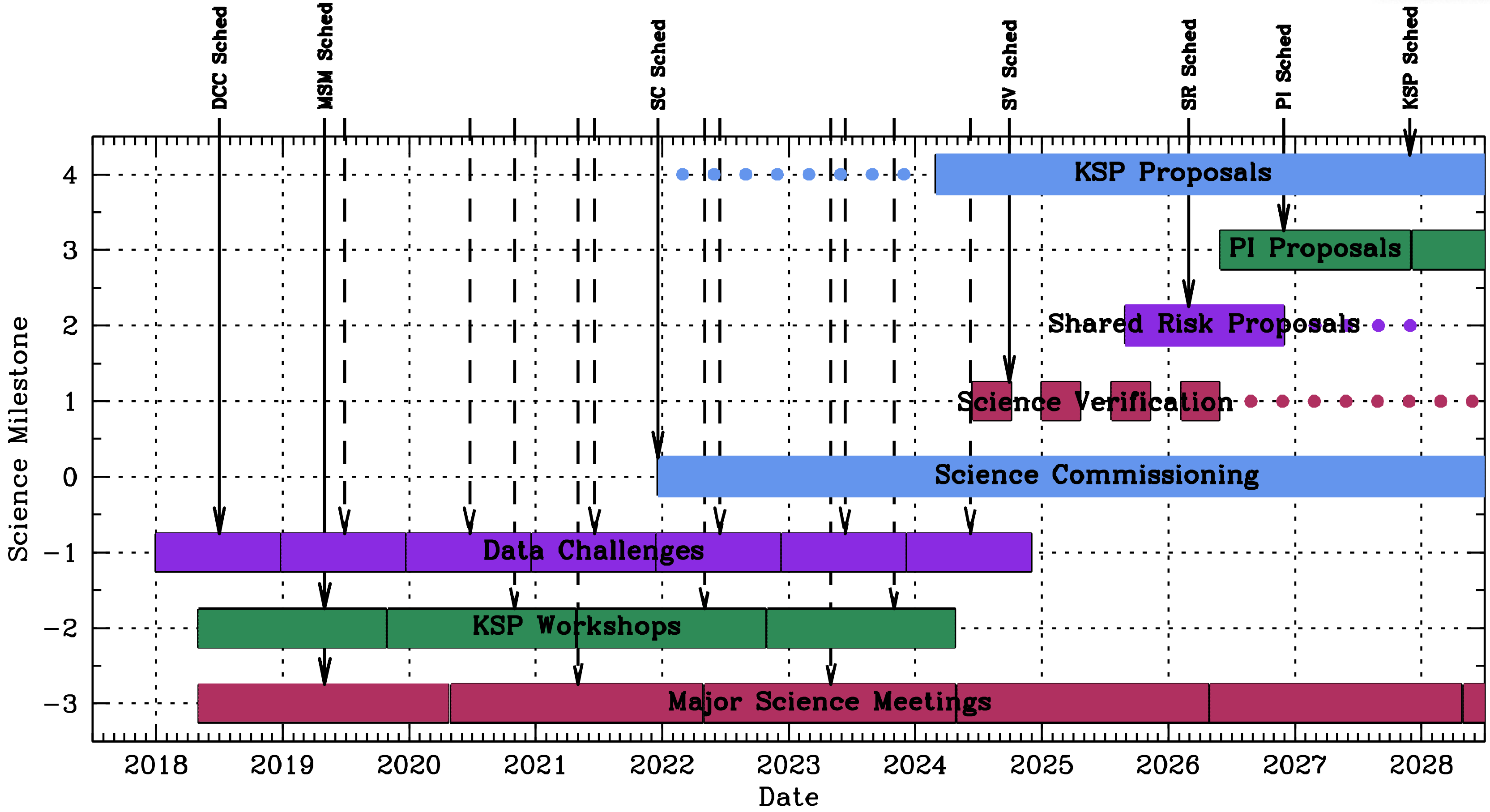
Challenge Definition

1. Source finding (RA, Dec): locate centroids and/or core positions
2. Source characterisation (integrated flux density, possible core fraction, major and minor axis size, major axis position angle) where size is one of (largest angular size, Gaussian FWHM, or exponential scale length)
3. Source identification (one of SFG, AGN-steep, AGN-flat)

Challenge Scoring

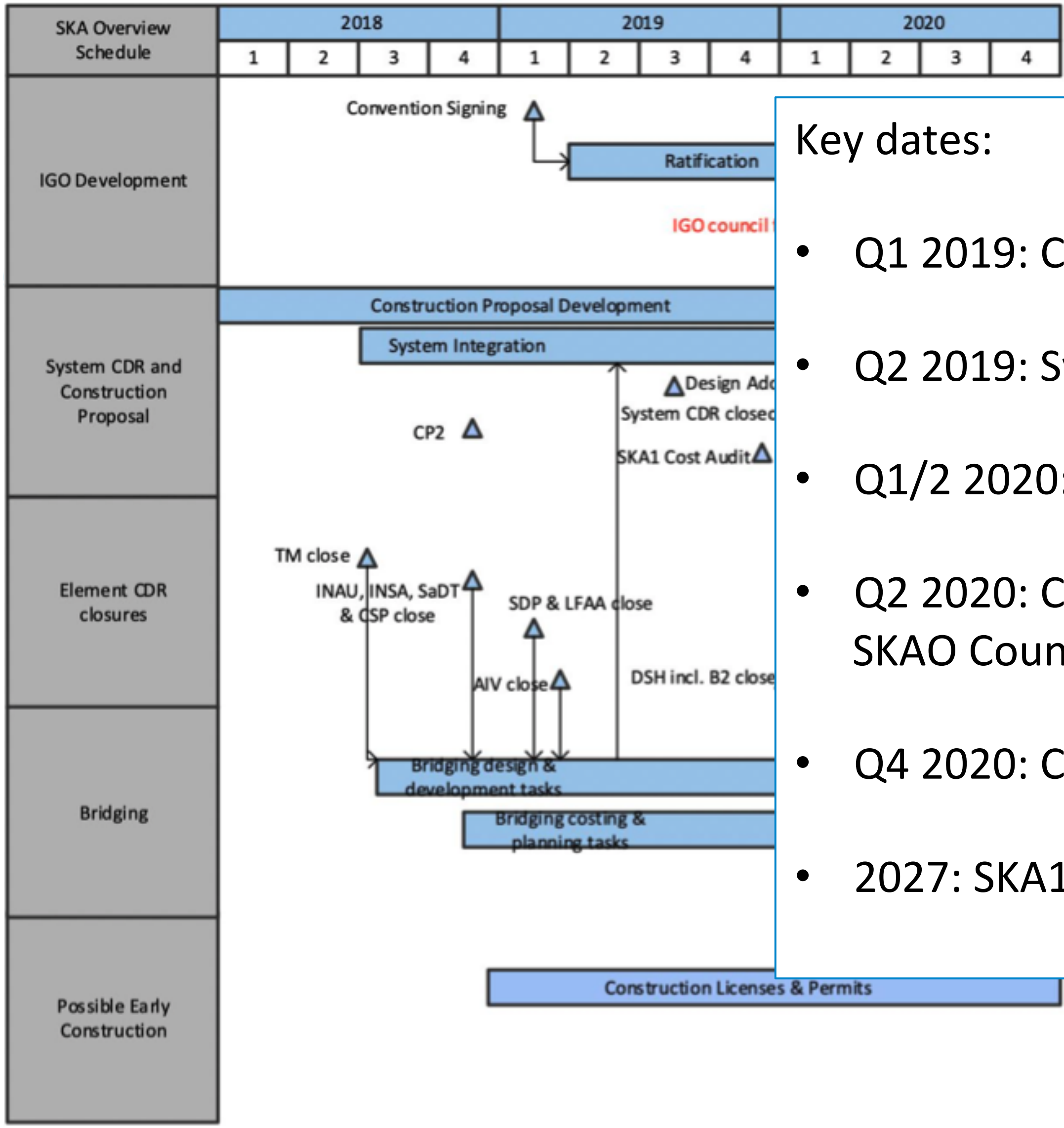
1. Reliability and completeness of sources found
2. Accuracy of property characterisation
3. Accuracy of population identification
4. Overall score based on the total number of real sources (less false positives) found in each of the three 1000h images multiplied by the fractional accuracy of the property characterisation and population identification

SKA1 Science Milestones (Doc #822)



- Overview of preparatory and scientific observing activities
- Increasingly realistic Data Challenges every 9 months

Timeline



Key dates:

- Q1 2019: Convention signing
- Q2 2019: System design final
- Q1/2 2020: SKA Observatory exists
- Q2 2020: Construction proposal submitted to SKAO Council
- Q4 2020: Construction begins
- 2027: SKA1 construction complete

Summary

- Overall progress is excellent:
  - Technical progress moving well, dealing with challenges
  - Precursors/pathfinders being delivered; delivering science
  - HQ construction complete
  - Data Challenges underway
  - Treaty establishing SKA Observatory to be signed 12 March
- SKA only possible through the drive, enthusiasm and support of the science and engineering community and governments of partner nations

SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

SKA SQUARE KILOMETRE ARRAY