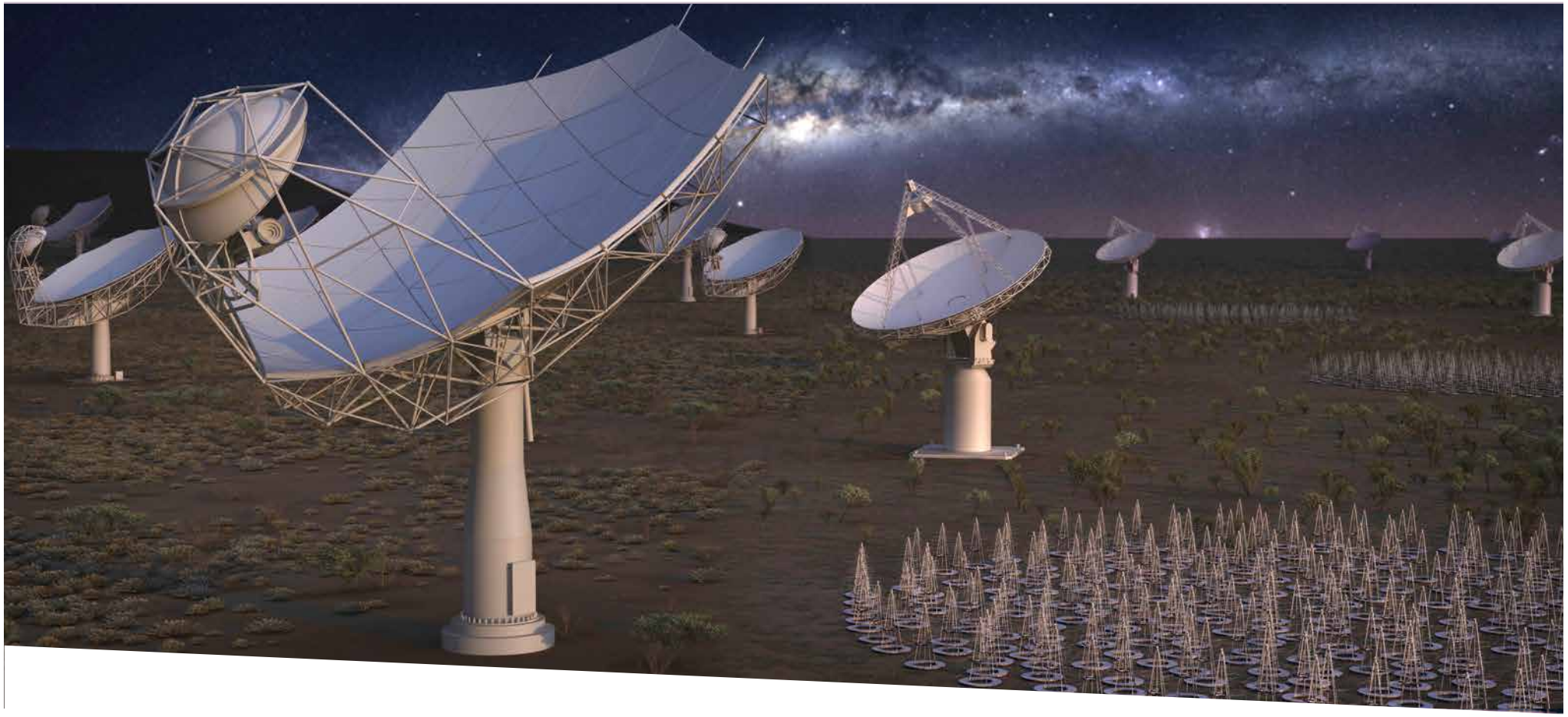
SKA SWG Update



SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

Robert Braun, Science Director

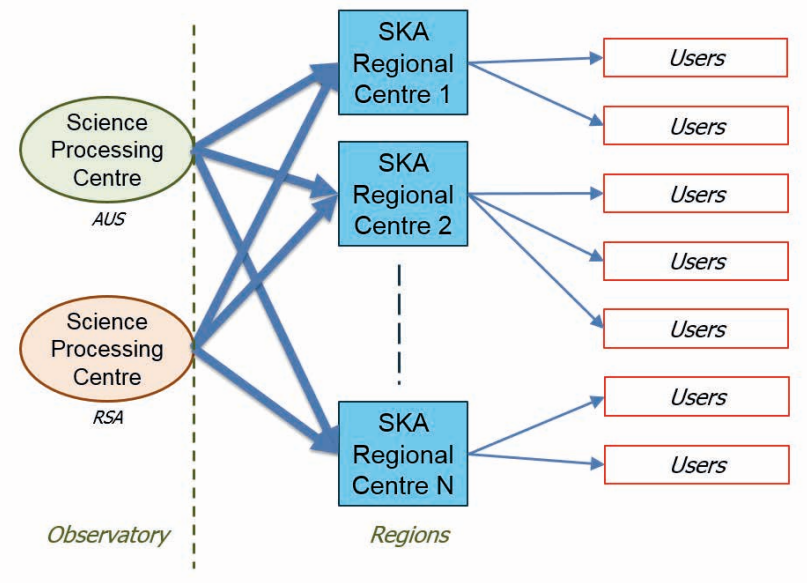
13 November 2018

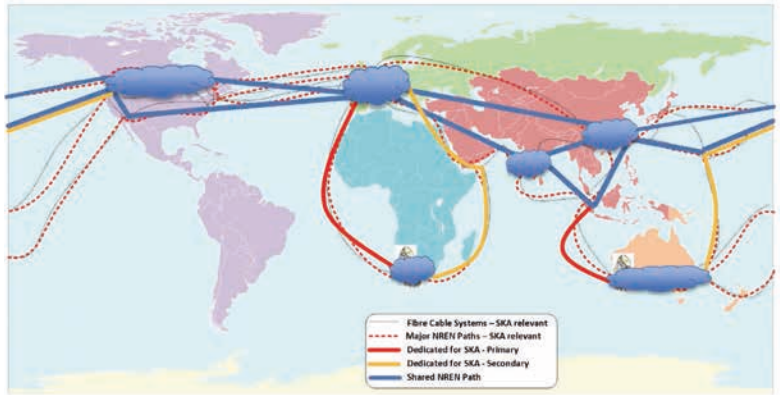
Science Update

- Science Data Challenges
  - First release imminent
- SWG Posters
  - Progress report
- SKA related meetings
  - AAS Splinter session
  - CTA 1st Science Symposium, 6 – 9 May, Bologna
- 2019 SKA Science Meeting and KSP Workshop
  - 8 – 12 April SKAO HQ

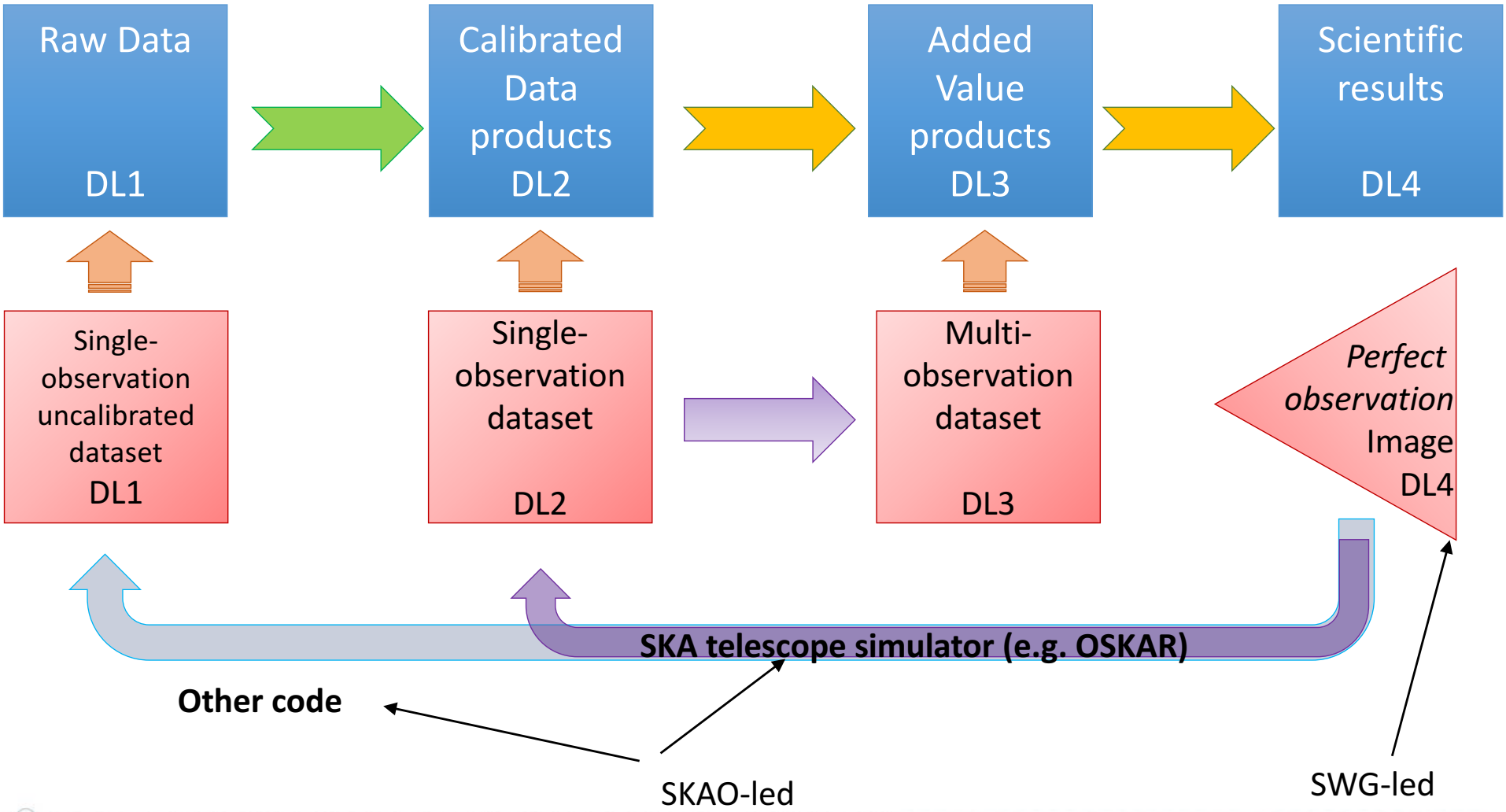
SKA Data Challenge “Flavours”

- 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

- Imminent release after final quality checks
- 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)

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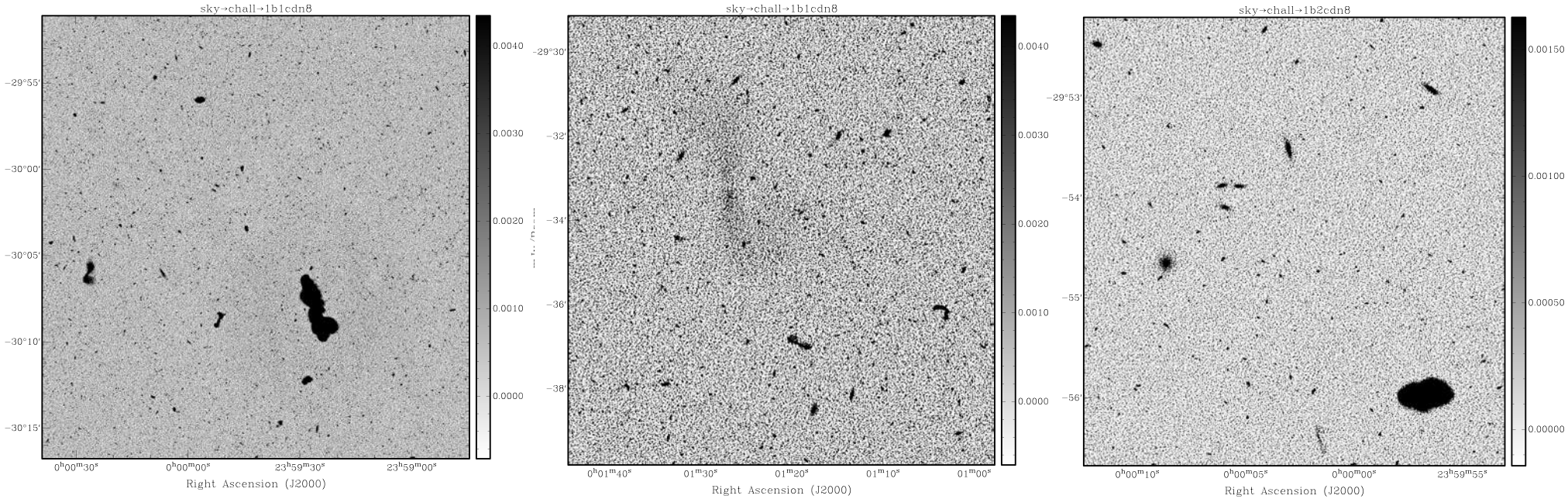

- Sample zoom-ins
- One pointing: **8^{h}**, 100^{h} and 1000^{h} observations
- Some 10^{7} embedded sources based on state-of-the-art T-RECS sky model (Bonaldi et al. 2018)
  - Star-forming galaxies represented as projected exponential disk
  - Active galactic nuclei source morphologies drawn from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

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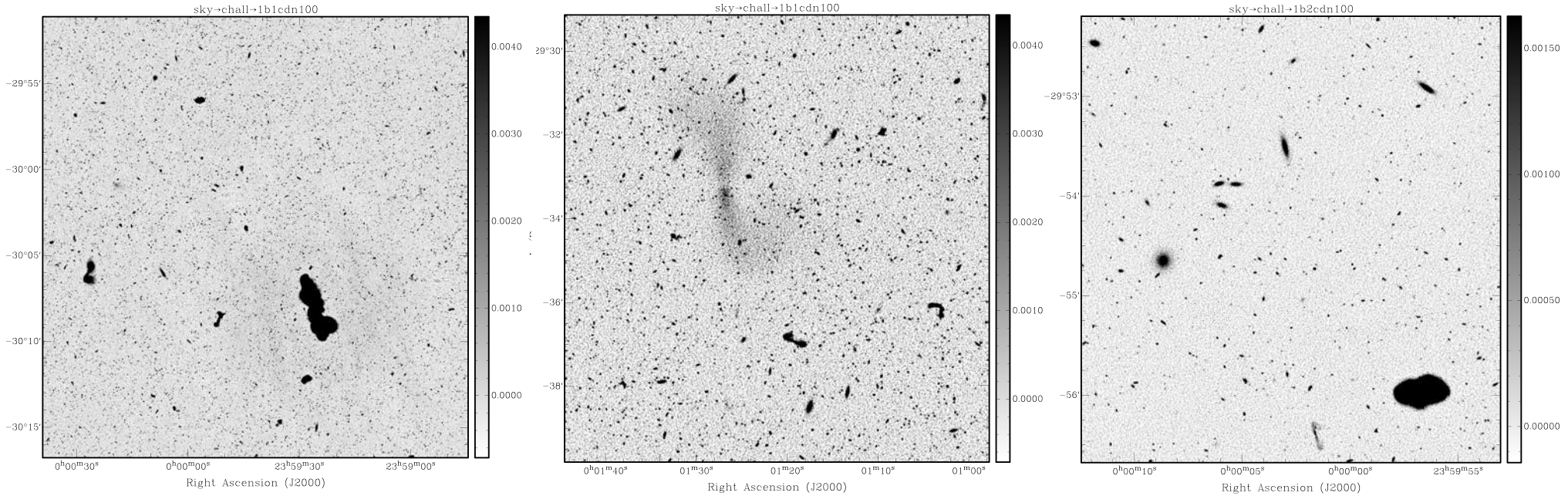

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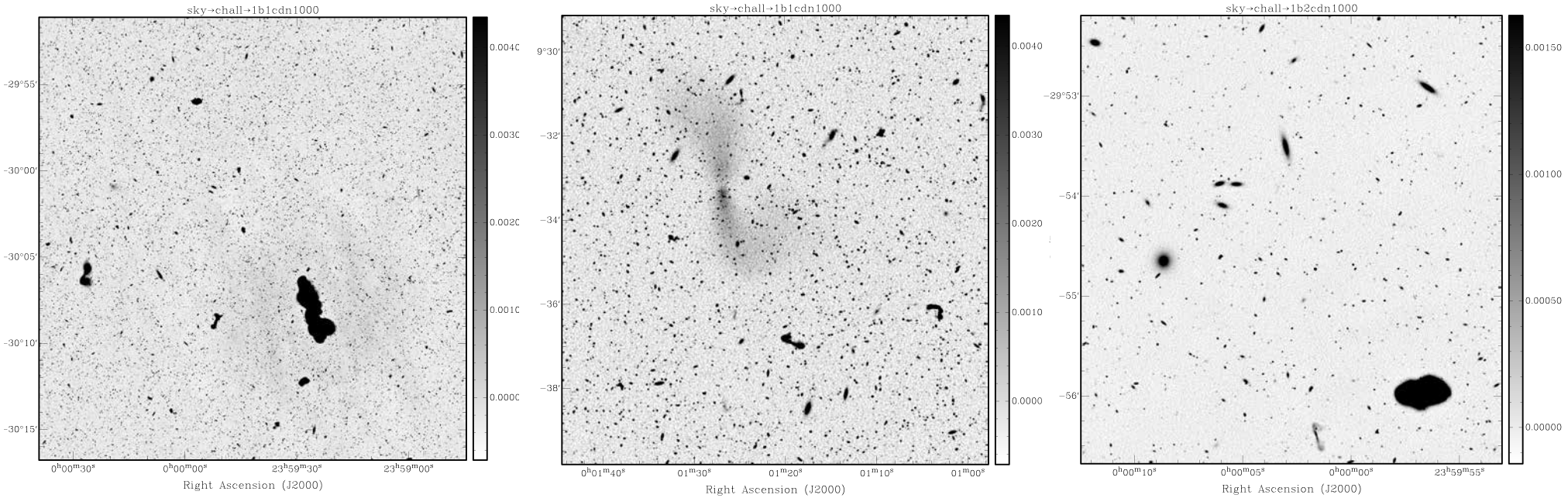

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First Science Data Challenge

- Source finding, identification, characterization etc.
- Results to be compared with simulation input catalog
- WG-specific analyses optionally done on the identified sources
- Advertising for SKAO Post-doc position for radio astronomy simulations: https://recruitment.skatelescope.org/category/ska-jobs/

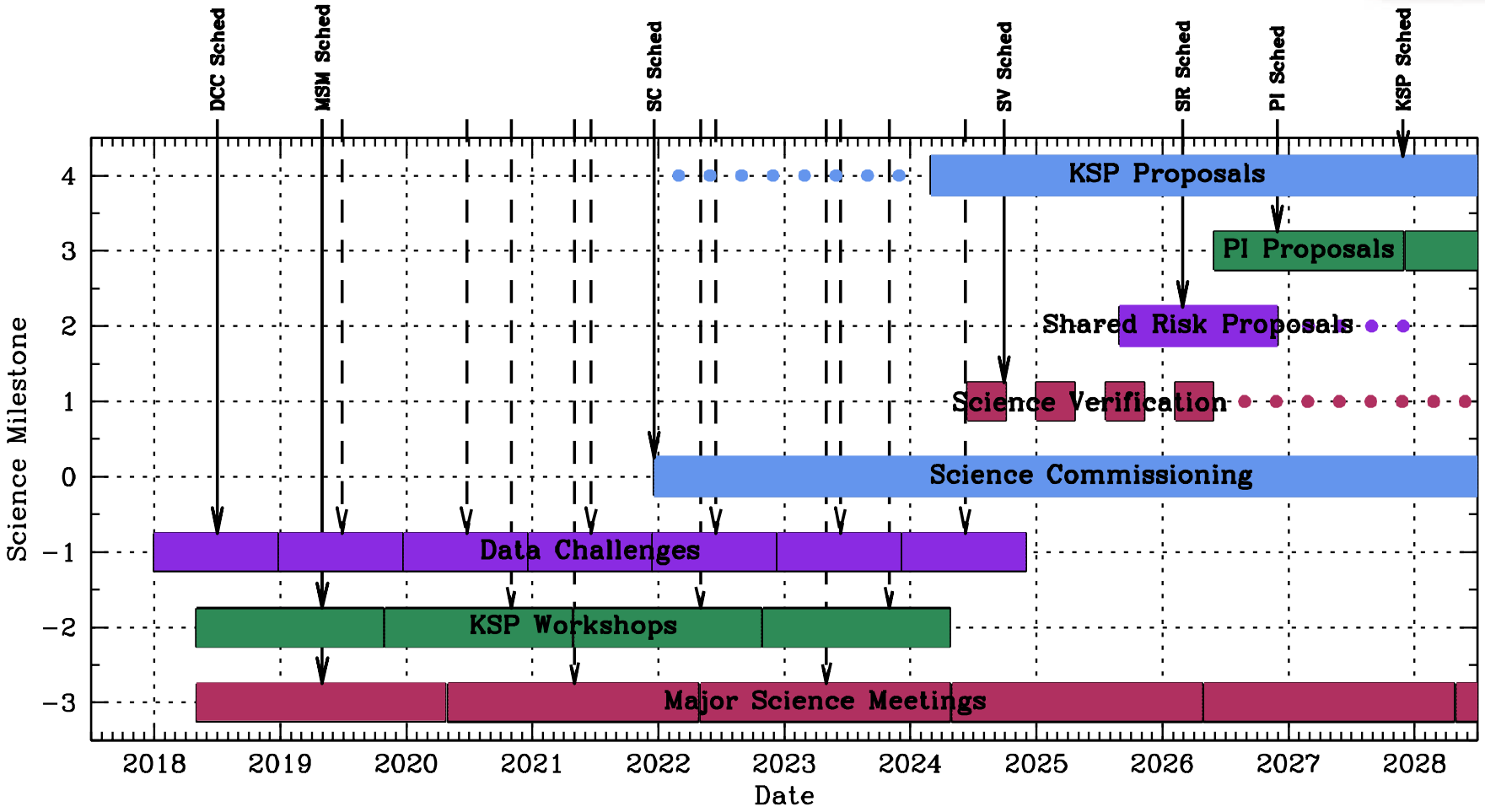
Challenge Definition

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 6 months

SWG Posters

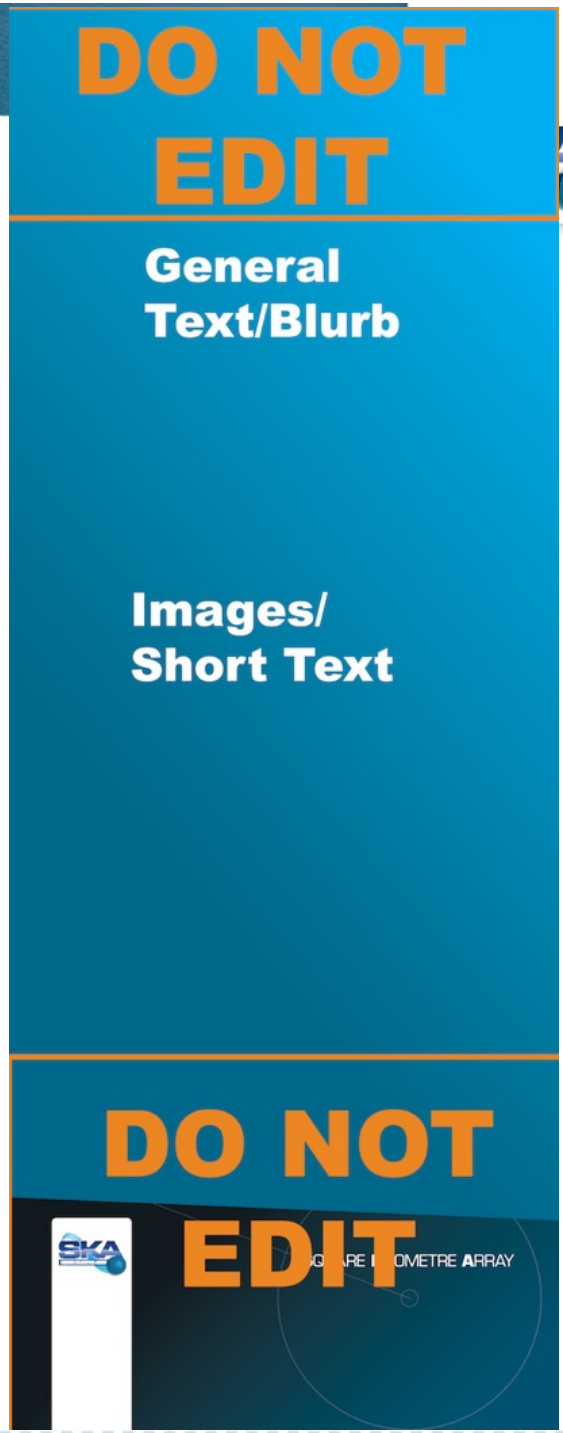
- Aim to have a poster (banner) for each SWG, similar to those put together by the Consortia (see next slide)
- First use would be AAS in January, then the April SKA meeting, ...
- Asking each SWG to produce a poster by mid-November
  - Suggest each SWG find someone from their core group to lead (can be co-chair)
- Size and template provided to SWG chairs.
- Process of transferring the first posters into Adobe InDesign has begun, will iterate with the SWGs before signing off on the final poster

Poster instructions as provided to SWG chairs

• The banner/poster will be designed on a large canvas, in portrait orientation.
• For the InDesign file, we have marked the areas that you should **not edit**, with the editable areas clear of these marks. The design file itself is already at the correct dimensions. Below are also the basic criteria for InDesign to follow:

- Font: **Eurostile Demi**
- Font sizes; smallest: 30pt
  Largest: 146pt

• Please provide a variety of relevant imagery, with all images provided being of the highest resolution possible. If the images are of poor quality, they can't be used. Please also provide the appropriate credits for each image.
• A main blurb of text detailing the general description of the SWG
• Text on what are the big questions (no more than 4, preferably less) they are trying to answer and the main science driver
• We don't need a detailed description of the SKA on these banners



First Draft examples (not yet transferred to InDesign)

Thank you for your efforts, please keep sending them in.

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Using SKA we will conduct deep HI observations of millions of galaxies out to redshift z>1. Our primary goals are to investigate the structure and dynamics of cold gas in and around galaxies, explore the gas-halo interface, discover plumes and streams of intergalactic gas, as well as map large-scale galaxy structures and their peculiar motions. Our key questions regarding galaxy formation and evolution are:

How do galaxies replenish their gas?

Current models of galaxy evolution predict that galaxies are embedded in an extended Cosmic Web of gaseous filaments. For galaxies to continue forming stars over a Hubble time, they must continue to accrete new gas to form stars. With its high sensitivity and resolution, the SKA will enable for the first time the study of this very low density gas to allow us to detect and image the gaseous interface between galaxies and the surrounding intergalactic medium.

[Image credit: ESO/L. Calçada/ESA/ AOES Medialab] Artist's impression of gas accretion from the Cosmic Web.

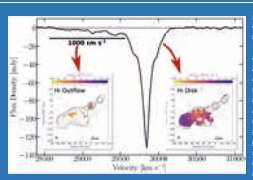
[Image credit: E. de Blok] NGC2822 is the closest gas-rich dwarf galaxy outside the Large and Small Magellanic Clouds. Optical background is a combination of B,V, R images (Massey et al., 2007), stars enhanced using near UV data (Hunter et al., 2010), red: H-alpha (de Blok 2006) blue: VLA observations of HI (de Blok, et al., 2000)

How are gas accretion, star formation, & feedback related?

The gas cycle of galaxies involves the accretion of gas, star formation and gas outflows (feedback). While observed global-scale relations link star formation and the molecular gas surface density, very little is known about the astrophysics contributing to star formation at sub-kpc scales. Stellar evolution processes such as supernovae expel gas from galaxy disks back into the halo creating holes and bubbles in galaxy disks. The resolution of the SKA will enable us to study the ISM structure and kinematics in nearby galaxies with unprecedented precision to better understand these fundamental processes.

How is the HI in galaxies linked to AGN activity?

Associated HI absorption around a radio source host galaxy can tell us about the structure of the central regions and feeding and feedback of AGN. The SKA will enable us to probe HI in absorption in AGN out to z>3 and to trace neutral gas outflows over cosmic time to investigate the role of AGN feedback in galaxy evolution.



[Image credit R. Schulz] HI absorption in 3C236 showing the integrated profile from WSRT (Morganti et al., 2005) and VLBI images (Schulz et al., 2016). Broad, shallow HI absorption is detected along with a narrow deep component which is associated with the circumnuclear disk. The shallow component is due to gas in a fast outflow of ~1000 km/s. The spatial distribution of the 2 components is shown in the VLBI images.

How is HI affected by galaxy interactions, environment & redshift?

Wide-field HI surveys to z>1 with the SKA will provide statistical samples (in emission and absorption) to study the role of environment on the gas content of galaxies and to investigate the processes leading to the build-up of stellar mass (including galaxy mergers and interactions) and the quenching of star formation over cosmic time. High precision observations will also shed light on the 3D shapes of galaxy disks, their interface with the intergalactic medium, their dark matter content and the cuspy halo problem, and the formation of tidal dwarf galaxies.

[Image credit: Chung et al., 2009] HI imaging of late-type galaxies in the Virgo galaxy cluster overlaid on the ROSAT X-ray image (Böhringer et al., 1994). The HI images have been enlarged by a factor of 10 for clarity.

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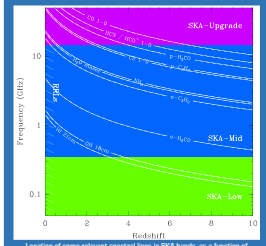

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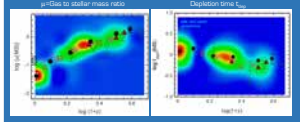
The Extragalactic Spectral Lines SWG focusses on the many astrophysically important lines besides the HI 21 cm line. With its unique sensitivity, SKA opens up the study of redshifted lines from distant galaxies or intrinsically weak lines from nearby galaxies, allowing us to trace material and various environments from the local to distant Universe. In a pan-chromatic multi-messengers astronomy era, the SKA ideally comes along with other existent facilities such as ALMA, or instruments being built like the ELT, matching their angular resolution in the low frequency domain.

The science with extragalactic spectral lines strongly advocates for an increased coverage toward high frequency (>15 GHz, SKA1 upgrade or SKA2).

The main science drivers are

- the study of molecular gas, of primordial importance for the evolution of galaxies, in the distant Universe,
- unique diagnostics from masers and radio recombination lines,
- absorption in the line of sight of background continuum sources.

Location of some relevant spectral lines in SKA bands, as a function of redshift.



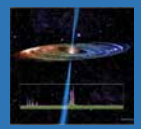
Galaxies on the main sequence (MS) have more gas at high-z and their star forming efficiency SFE = $1/t_{dep}$ is higher. From Tacconi et al 2018.

Redshifted CO lines and dense gas tracers (HCN, HCO⁺, HNC, CS ...)

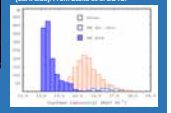
High-z galaxy surveys with have shown that the gas fraction strongly increases with redshift and the depletion time slightly decreases. Most of these studies were not able to observe the fundamental CO(1-0) line, which is the best proxy for molecular gas mass and kinematics, but only higher J (2-1, 3-2...) transitions. Expansion of SKA to frequencies above 15 GHz will be able to probe the CO(1-0) line at z > 2, while SKA1-Mid will cover this line for z > 7, offering an unprecedented tool to probe molecular gas in distant galaxies and study their evolution. Dense gas tracers are paramount to trace locations of star formation (SF), and scaling realtions between gas and SRF densities will be obtained at high-z with SKA.

Masers as tracers of AGN, starbursts, stars in Local Group (H_2O, OH, SiO...)

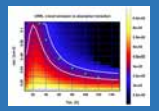
At sub-pc scale around AGN, water masers are so strong that VLBI resolution gives the black hole mass, & distance with a precise and accurate estimate of H_0 (e.g. NGC 4258, Greenhill et al. 1996, UGC 3789, Reid et al. 2013, and ref. therein). The 22GHz line will be observed at z=0 with SKA-High, and z>0.5 with SKA-Mid, providing a wealth of new H_2O maser sources from the local to distant Universe (e.g. Tarchi et al. 2013). More than 100 OH megamasers have been detected in starburst galaxies (e.g. Darling & Giovanelli 2002), at z<0.1-0.23. They are 2-4 orders of magnitude stronger then OH galactic masers. With SKA, the survey at all redshift up to z=5 will allow to follow the cosmic starburst history. OH masers in the Galaxy trace regions where new stars are born as well as evolved stars. With SKA at 18cm, it will be possible to explore them in the Local Group galaxies (e.g., Etoka et al 2015).



Above: Artist view of the nuclear disk around the NGC 4258 AGN, and at the bottom the H_2O maser spectrum. From Greenhill et al 1996.



Below: Histogram of the OH maser luminosity distribution, in the Galaxy (pink), in the LMC presently observed (light blue x10), and predicted with SKA (dark blue). From Etoka et al 2015.

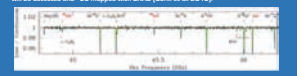


CRRL n(level value as a function of T_e and n_e. The white contours are for n = 340 and 400. The green circles highlight values of constant p_e = 0.04 × 85 = 3.4 K cm-3. n(level is a good indicator of p_e, for T_e= 20–140 K range. From Oonk et al 2017.

Radio Recombination Lines (RRLs)

RRLs are a unique tracer to determine the physical conditions of gas in galaxies, density and temperature. RRLs of hydrogen and carbon (HRRL and CRRL) have been detected in external galaxies at low frequencies (e.g., Morabito et al 2014). RRL trace dense and clumpy media at high frequency (corresponding to SKA-Mid) and diffuse media at low frequency, <350 MHz, corresponding to SKA-Low (e.g., Thompson et al. 2015). The non-LTE models necessary to interpret the data yield the electronic temperature and density and the abundance of carbon. By comparison with the HI 21 cm line, it is possible to derive the fraction of CNM, WNM and WIM along the line of sight.

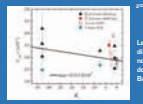
With SKA1-Low, ~100 nearby galaxies could be detected in the CRRL, while 400 will be detected and ~50 mapped with SKA2 (Oonk et al. 2015).



Up: Excerpt of an ATCA spectrum toward PKS1830-211, showing the richness of an z=0.89 absorber. From Muller et al 2013.

Absorption lines in intervening galaxies in front of quasars

SKA will give access to a plethora of bright background radio sources to probe molecular absorption along their line of sight. The absorption technique is extremely sensitive and molecules can be used as invaluable cosmological probes. Not only the chemical state of the absorbing gas can be explored in depth, (e.g., complex organic molecules, isotopologues), but molecules also reveal the ISM physics (e.g., cosmic-ray ionization, molecular gas fraction) and gas excitation (measurement of the CMB temperature as a function of redshift). Rare isotopologues give us the possibility to track isotopic ratios and enrichment by nucleosynthesis products over cosmic times. Finally, some molecules (e.g., NH_3, CH_3OH, CH) are sensitive tracers to test possible cosmological variations of the fundamental constants (e.g. proton-to-electron mass ratio μ, fine structure constant α).



Left: The velocity of CH_3OH lines with different sensitivity coefficients K_μ does not very significantly, constraining $\Delta\mu/\mu$ down to a few 10^{-7} at z=0.89. From Bagdonaite et al 2013.

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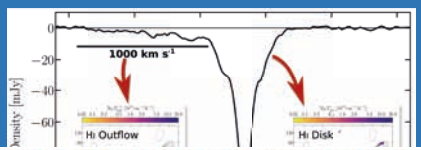

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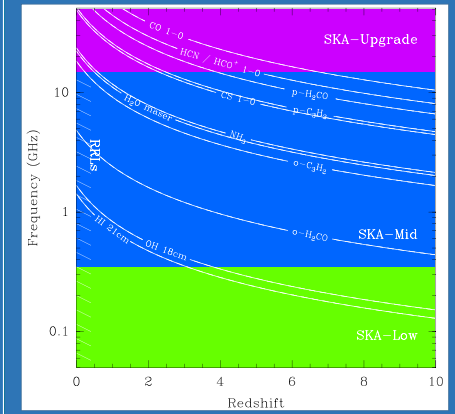

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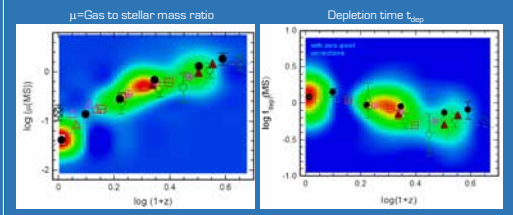

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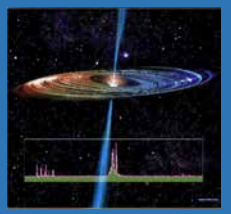

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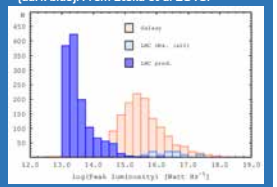

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AAS Splinter Session

Tuesday January 8, 9.00-11.30 (TBC)

1. Keynote. The SKA vision. Jocelyn Bell Burnell

2. Evolution of Galaxies
Kristine Spekkens (HI SWG member, SEAC member)

3. Cosmology and the Cosmic Dawn/EoR
James Aguirre (EoR & Cosmology SWG member)

4. A dynamical Universe: Gravitational Waves and Fast Radio Transients.
Ingrid Stairs (Pulsars SWG co-Chair)

5. Cradle of Life: formation of planets and search for ET life
Doug Johnstone (CoL SWG co-Chair)

6. SKA Current status. Joe McMullin (SKA Programme Director)

Science Topics extracted from list of Thematic Science Areas for Astro2020 (US Decadal review) White Papers.

Science Meeting

- 2019 SKA Science Meeting and KSP Workshop, 8 – 12 April
  - 302 desired registrations
  - HQ Auditorium capacity 160
  - Use Alderley Park back-up venue (232 capacity) for Mon – Wed and HQ for Thursday + Friday breakouts plus wrap-up

SQUARE KILOMETRE ARRAY

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