SWITZERLAND'S MOTIVATION TO JOIN THE MWA

MWA Project Meeting 26 July 2023

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A brief timeline

- **February 2023**: Formed a preliminary consortium of interested Swiss researchers
- **March 2023**: presented our membership application to the MWA board, which was approved unanimously
- **Currently**: moving towards Swiss accession to the MWA Collaboration
- **Near future**: EPFL signing the Deed of Accession, formation of formal Swiss consortium

Swiss MWA Consortium

ETH zürich — Swiss Federal Institute of Technology Zurich (ETHZ)

University of Basel

University of Zurich

University of Applied Sciences and Arts Northwestern Switzerland (FHNW)

International Space Science Institute (ISSI-Bern)

EPFL — Swiss Federal Institute of Technology Lausanne (EPFL)

Swiss National Supercomputing Center (CSCS)

In the rest of this talk…

- Switzerland's path to joining the **Square Kilometer Array Observatory**
- Technical & developmental projects related to **radio astronomy in Switzerland**
- Switzerland's interest in **MWA Science**
- Switzerland's interest in **MWA Technical developments**

Switzerland & the SKAO

- **Jan 2022**: Switzerland officially joined the Square Kilometer Array Observatory (SKAO) as a full member
- **Swiss SKA Consortium (SKACH)** founded to manage Swiss contribution and strategic direction as a member of the SKAO
- **Instrumentation**: time management, observatory control, radio receiver
- **Software development**: Co-design (benchmarking, optimization, refactoring) of the SKA calibration & imaging pipeline
- **SKA Regional Center** development and deployment, to be hosted by CSCS
- **Preparation for scientific analysis**: SKA science working groups, development of new analysis strategies and algorithms, data science, etc

Switzerland & the SKAO

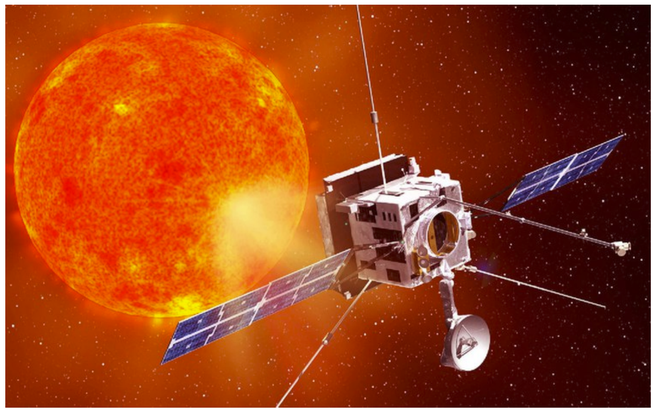
The **Swiss SKA Consortium** (SKACH): Over 100 individual members from participating institutions across Switzerland! This interdisciplinary group is made up of scientists, data scientists, engineers, project managers, outreach professionals, administrators, and students!

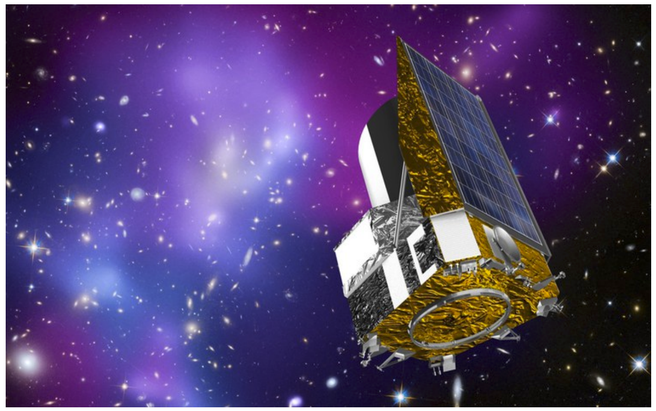
Vision: Further Swiss leadership in the global radio astronomy community.

Mission: Ensure meaningful contributions to the SKAO and SRCs through the development and delivery of cutting-edge Swiss solutions to key science goals, big data research, technology, and services.

Related Projects: Instruments

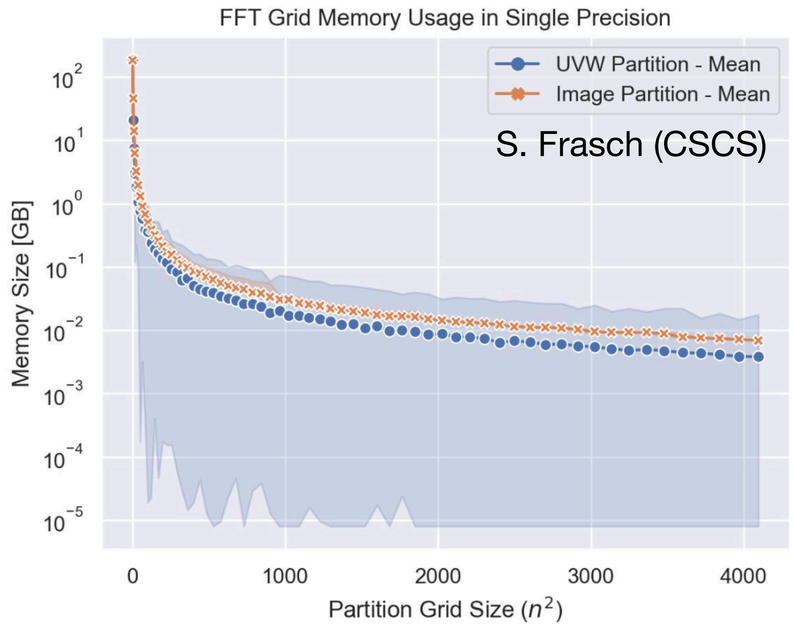
- Hydrogen Intensity and Real-time Analysis eXperiment (**HIRAX**)
  - Radio interferometer with a compact, redundant layout being built in the Karoo desert in South Africa
  - 256 6m dishes operating between 400-800 MHz
  - HI intensity mapping & survey the transient radio sky
  - See Crichton et al. 2021 for a recent overview
- **Swiss X-ray telescope** (STIX) on ESA's Solar Orbiter spacecraft
- **Euclid Space telescope**: software infrastructure development

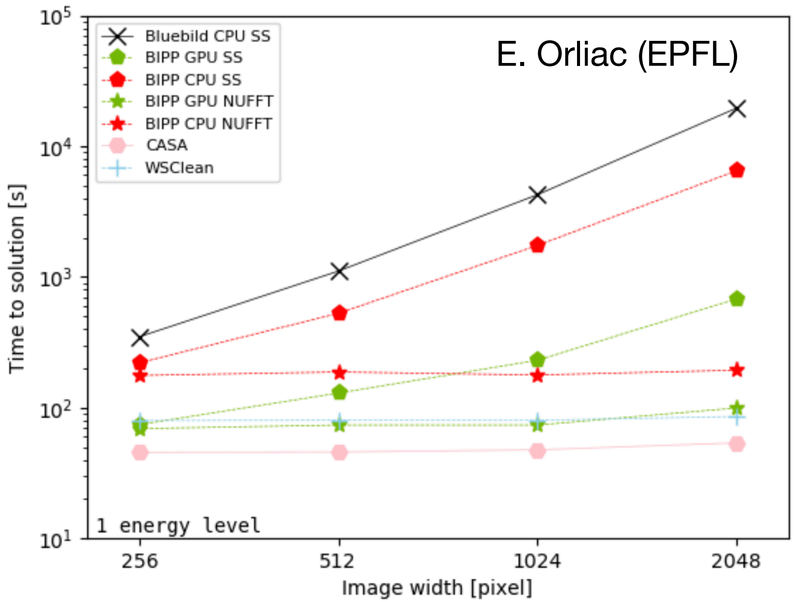




Related Projects: Pipelines & Imaging Software

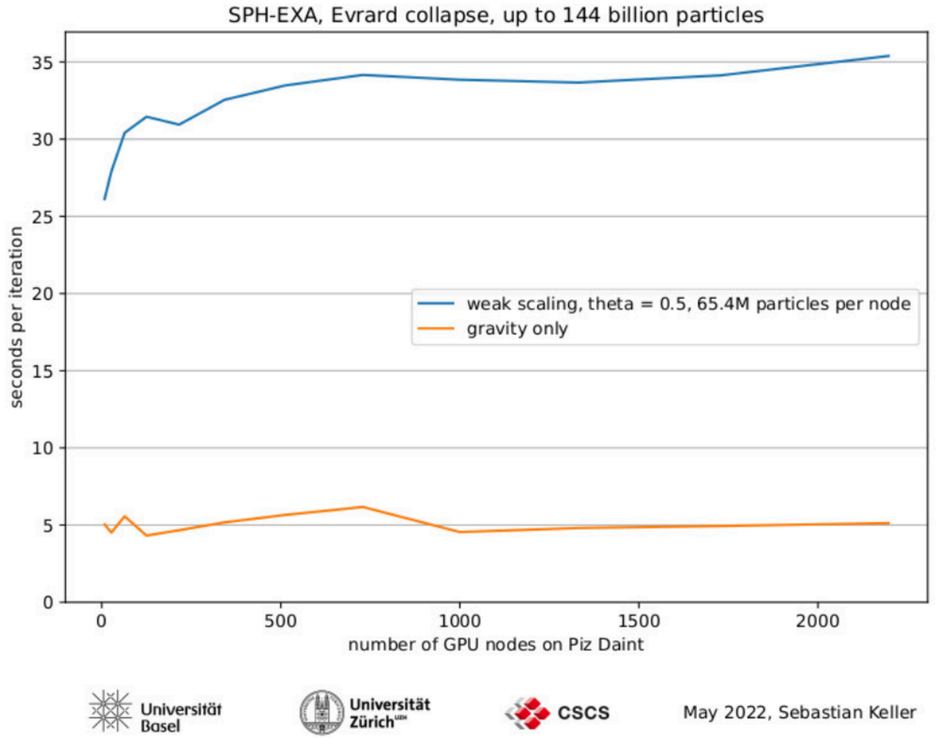
- **RADIOBLOCKS:** A New European Consortium to develop Next Generation Technologies for Radio Astronomy Infrastructures (press release)
  - Exploring HPC-friendly datasets for radio astronomy, tools for distributing workflows (Dask) & GPU development of LOFAR pipeline
- **Bluebild++**: HPC implementation of algorithm for radio-interferometric imaging (recent talk)
  - Use functional PCA to separate visibilities & sky image into different energy levels
  - HPC development by EPFL & CSCS, including parallelizing NUFFT via domain partitioning





Related Projects: Cosmological Simulations

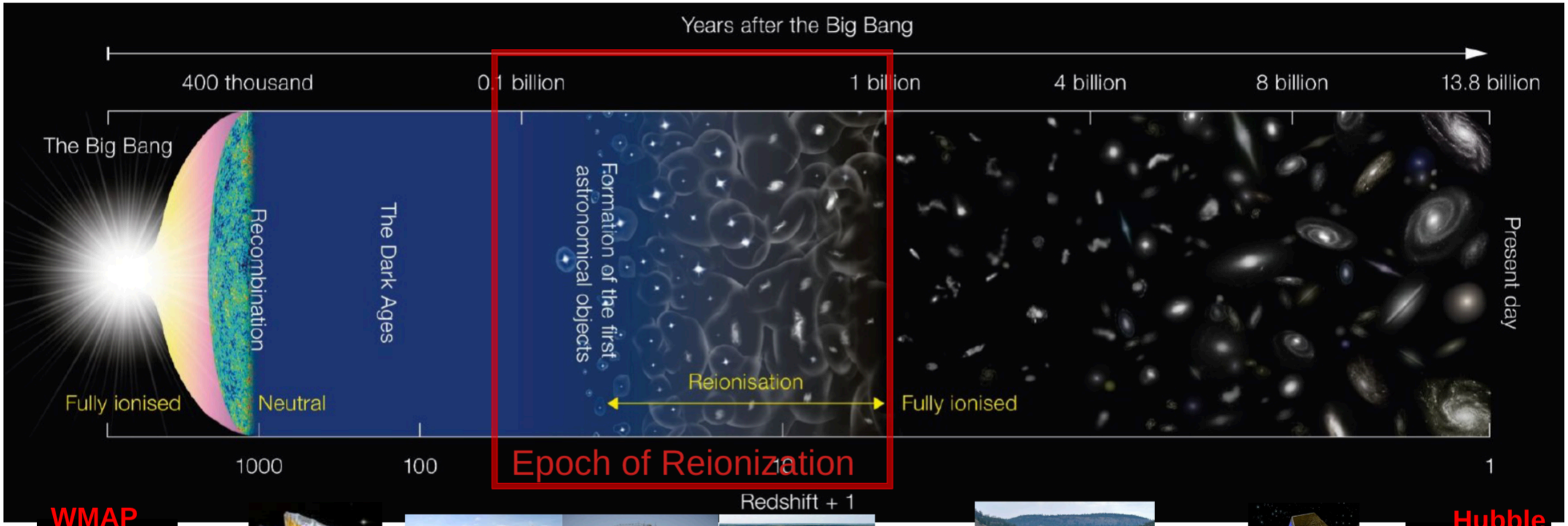
- **SPH-EXA:** A framework for Smoothed Particle Hydrodynamics and gravity at Exascale (recent slides)
  - Developing first trillion particle simulation of galaxy formation with SPH, gravity, and radiation running at Exascale
  - Interdisciplinary codesign between computer scientists, astrophysicists, cosmologists, and visualization specialists to implement the SPH method (and additional physics) for Exascale, instead of optimizing already existing codes

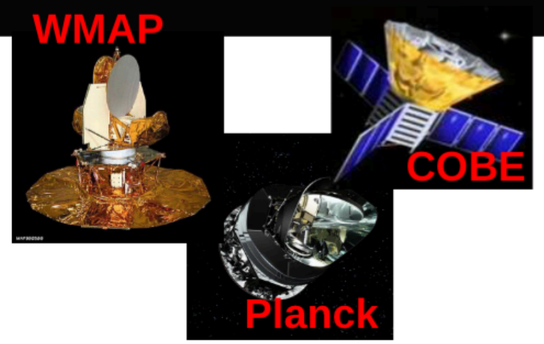


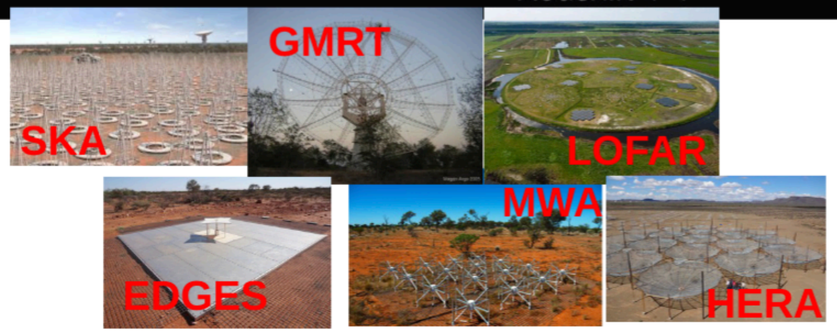
WHY MWA?

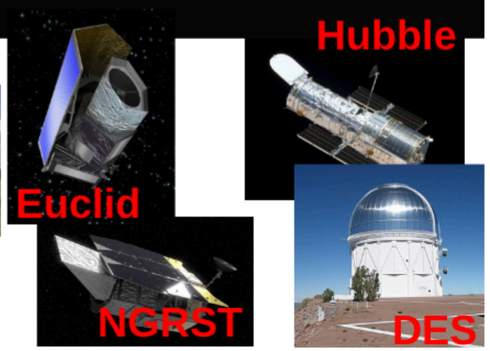
Epoch of Reionization

Early stages of galaxy formation/cosmic dawn



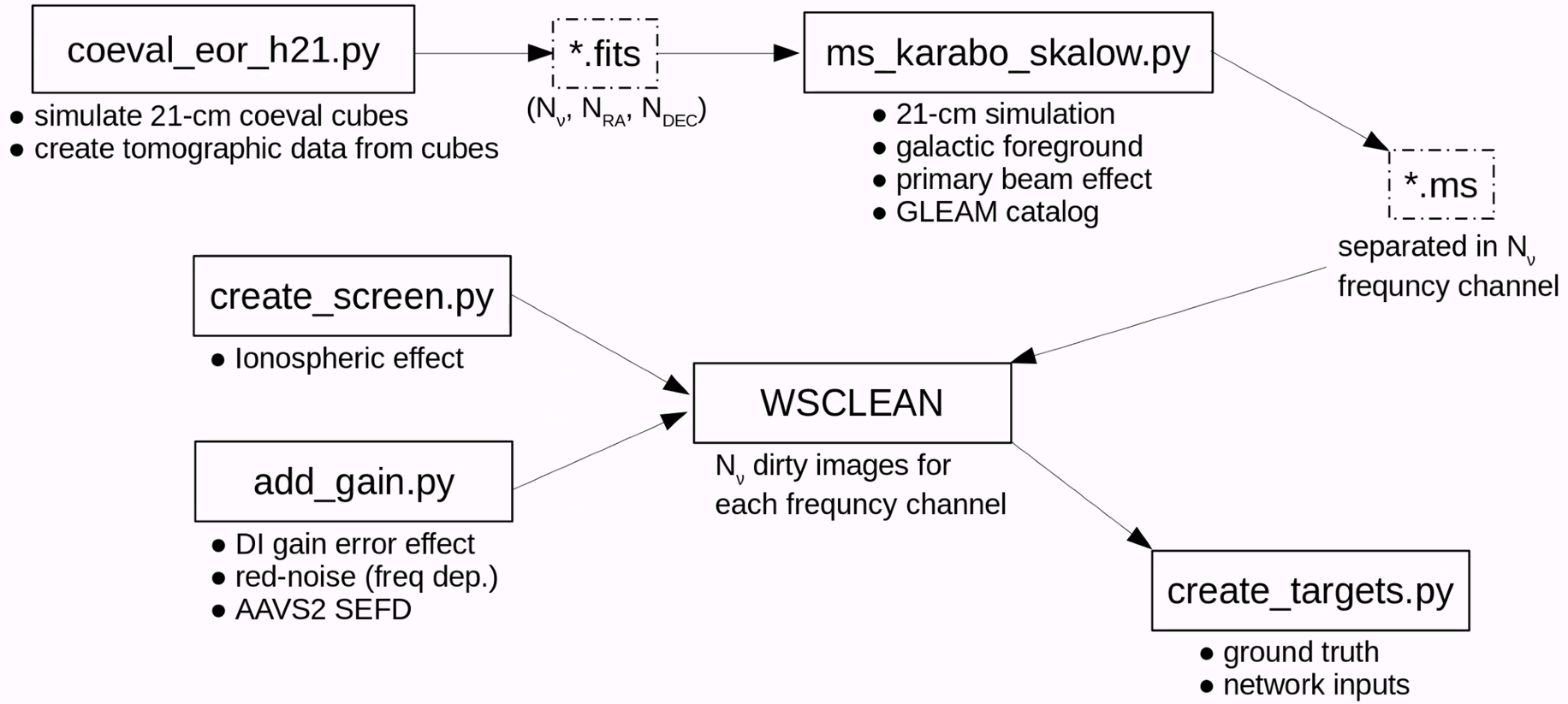






Epoch of Reionization

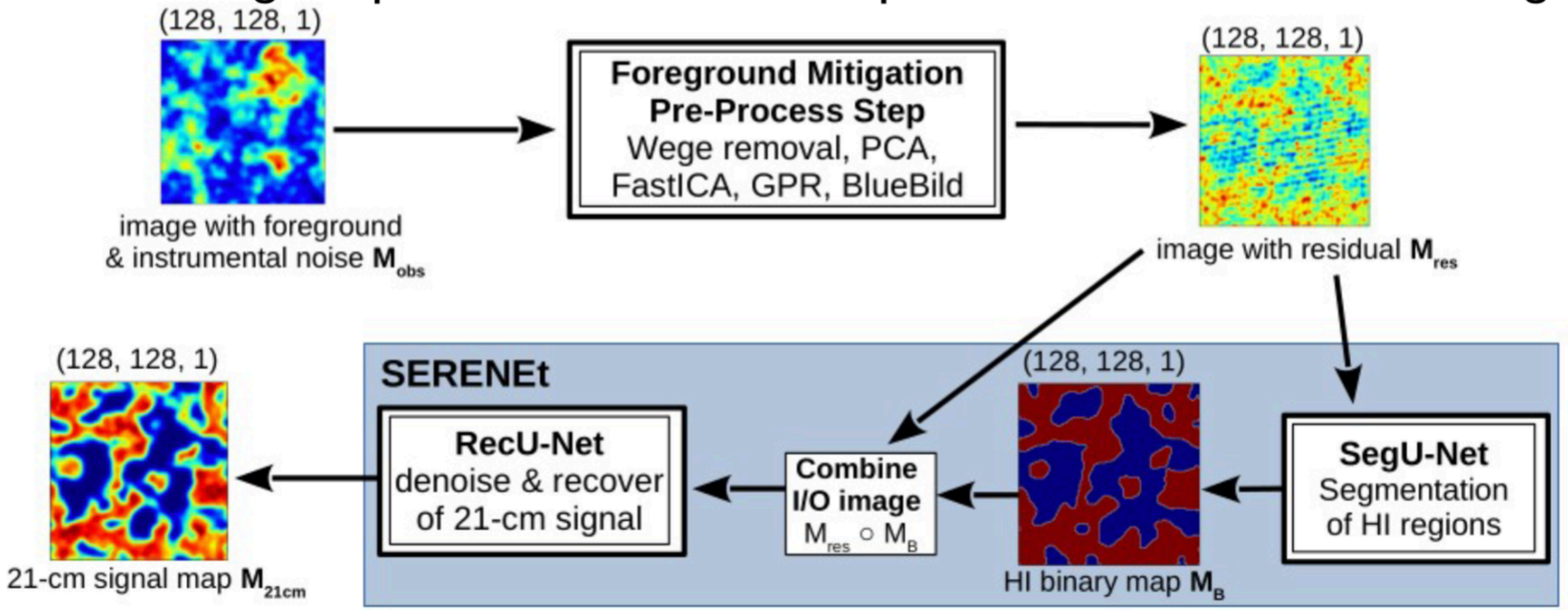
Mock Observation Pipeline



Epoch of Reionization

SEgmentation and REgression NEtwork

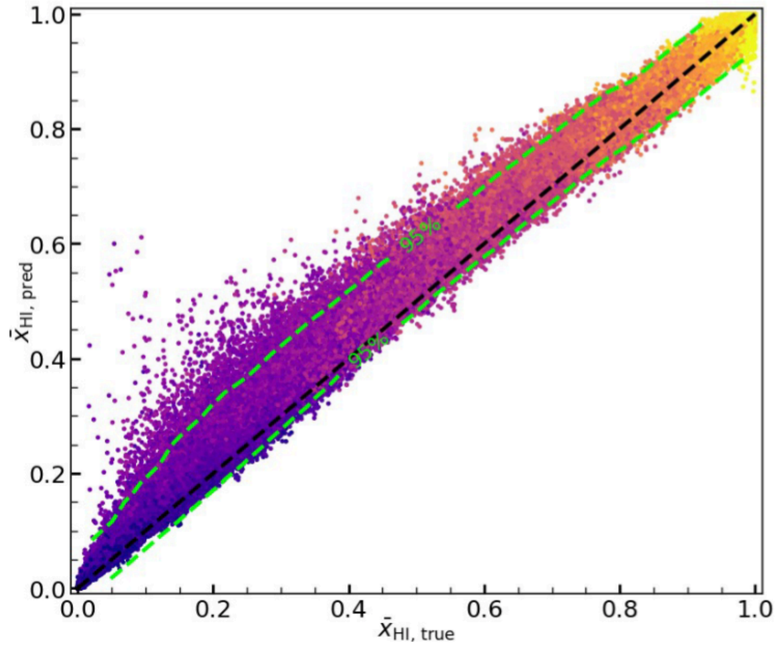
Combine the predicted binary maps of **SegU-Net** as additional input of **Rec-Unet** training step in order to include prior in the network training.



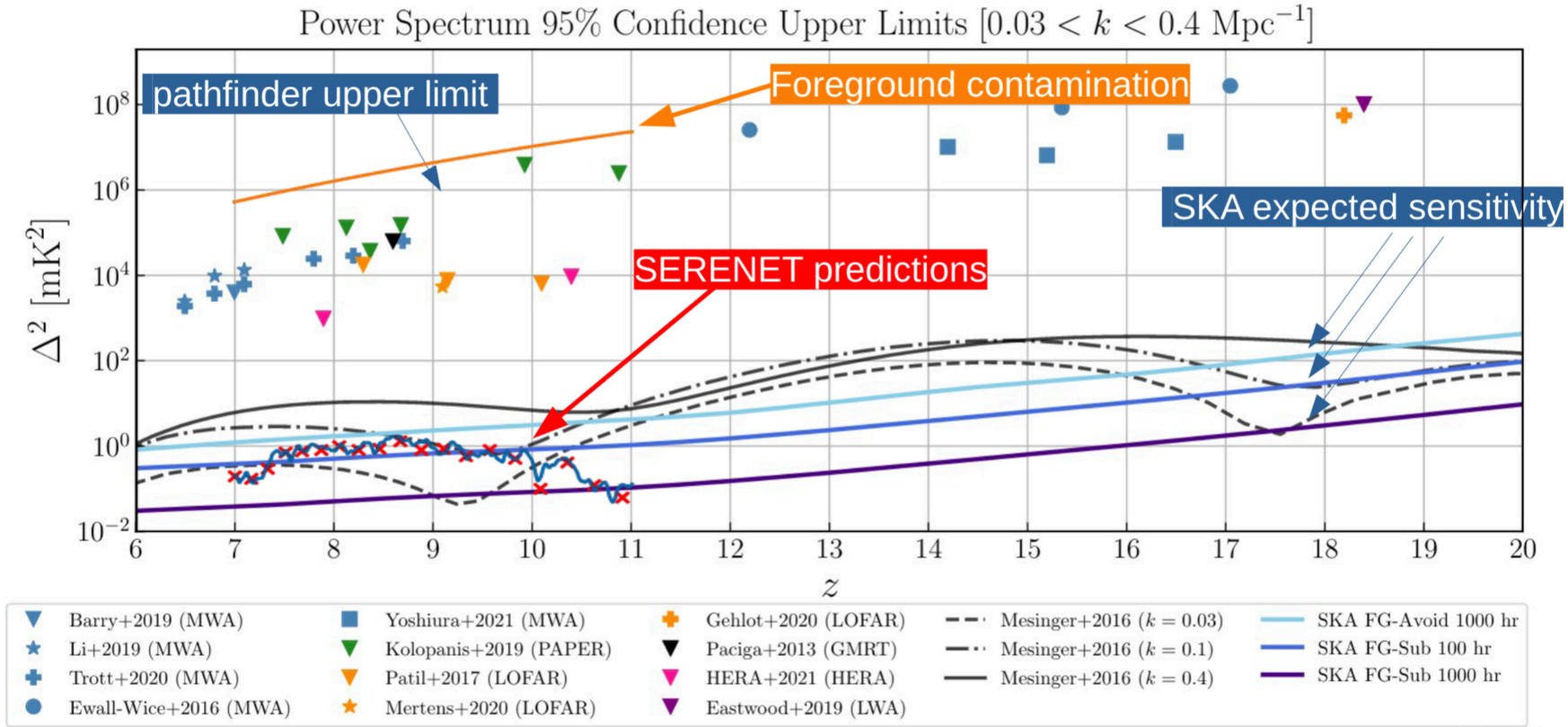
SKACH large HPC **70k hybrid-h** allocation projects at Pitz Daint @ CSCS (started 1th of August)

Epoch of Reionization

Segmentation network: reionization history



Regression network: comparison with current data



Barry+ (2022)

Solar Physics & Space Weather

Solar physics science cases

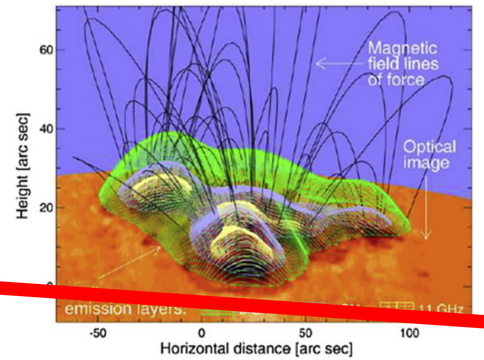
- Solar flares
- Magnetic tomography
- Plasma heating / Coronal heating
- Coronal turbulence
- Particle acceleration

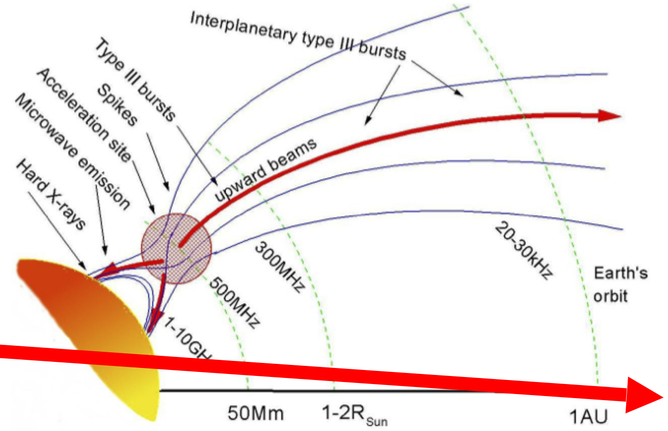
Space Weather

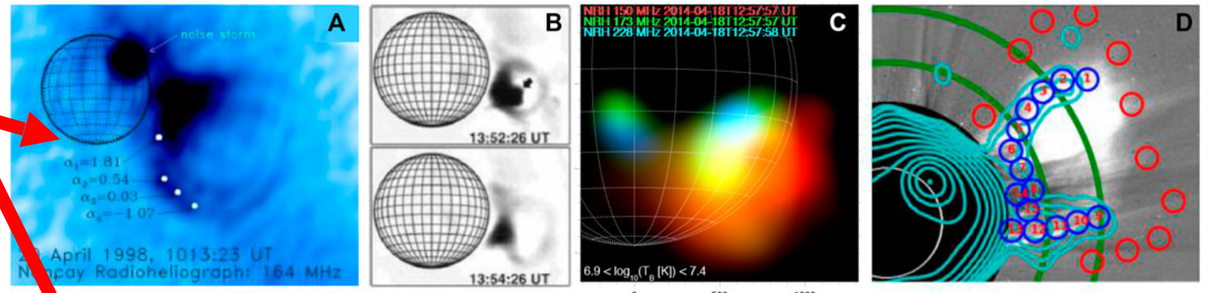
- Coronal Mass ejections
- Solar Wind
- Particle acceleration and transport in interplanetary medium
- Space weather prediction

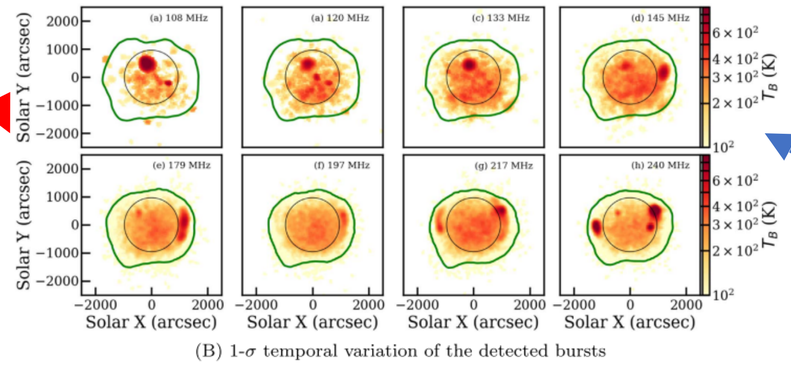
Swiss heliophysics Groups

- ETHZ / PMOD
- FHNW
- IRSOL
- University of Bern

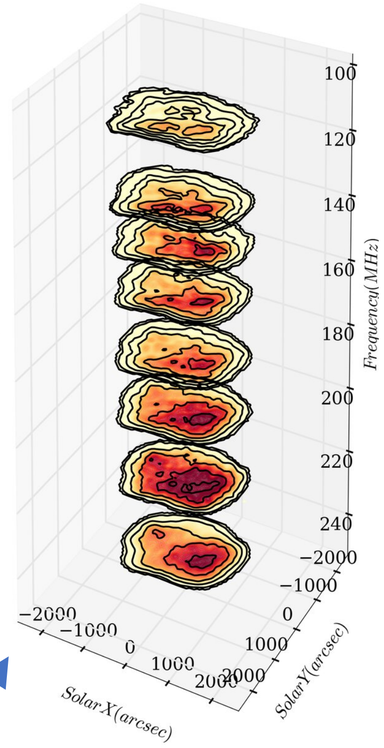


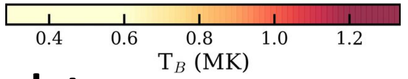






(B) 1-σ temporal variation of the detected bursts

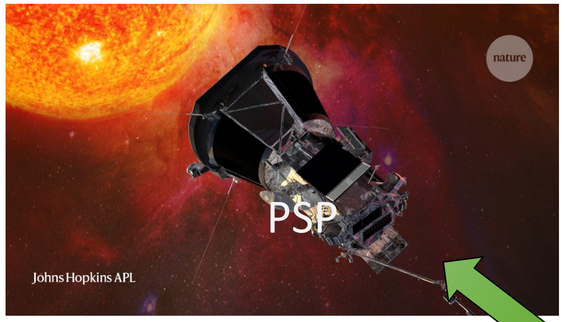


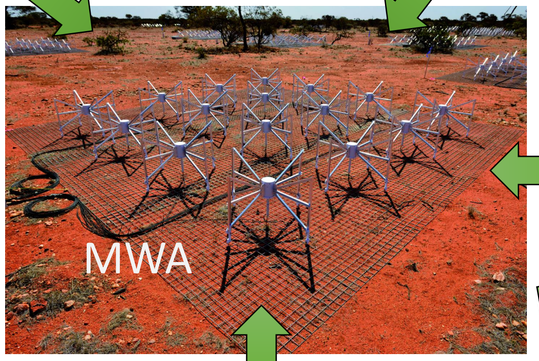


MWA Solar data

Heliophysics: Multiwavelength diagnostics with MWA

- Multi-wavelength observations include:
- X-rays / Radio simultaneous observation
- EUV observations / radio
- Fast Imaging Spectroscopy in radio
- Stereoscopy Window opens with space-based observatory





Synergies with other instruments

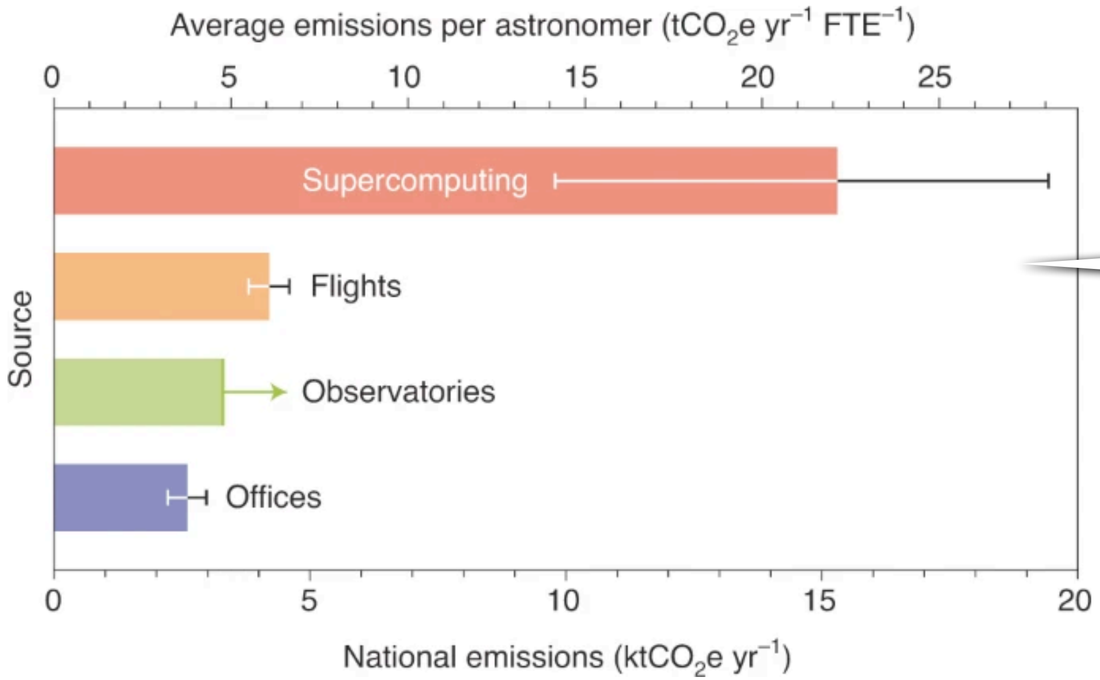
- Solar Orbiter – Spectrometer Telescope for Imaging X-rays (STIX)
- Parker Solar Probe
- Very Large Array
- Expanded Owens Valley telescope
- E-Callisto

Other Scientific Interests

- **Galaxy formation & evolution** (ISSI-Bern, EPFL-LASTRO, UZH)
  - Multi-frequency spectral modeling of low-redshift star-forming galaxy populations
    - Combine MWA data with data from other wide-area surveys (4MOST)
  - Low-frequency radio emission as a star-formation rate tracer
  - Radio AGN variability
  - High-redshift radio AGN galaxies and their environment

- **Transients** (EPFL-LASTRO)
  - Multi-wavelength analysis of quasars (combine with CTA observations)

High Performance Computing



~40% Computational/theoretical astrophysics (simulations)

~30% radio astronomy data reduction

~30% optical & infrared

https://www.nature.com/articles/s41550-020-1169-1

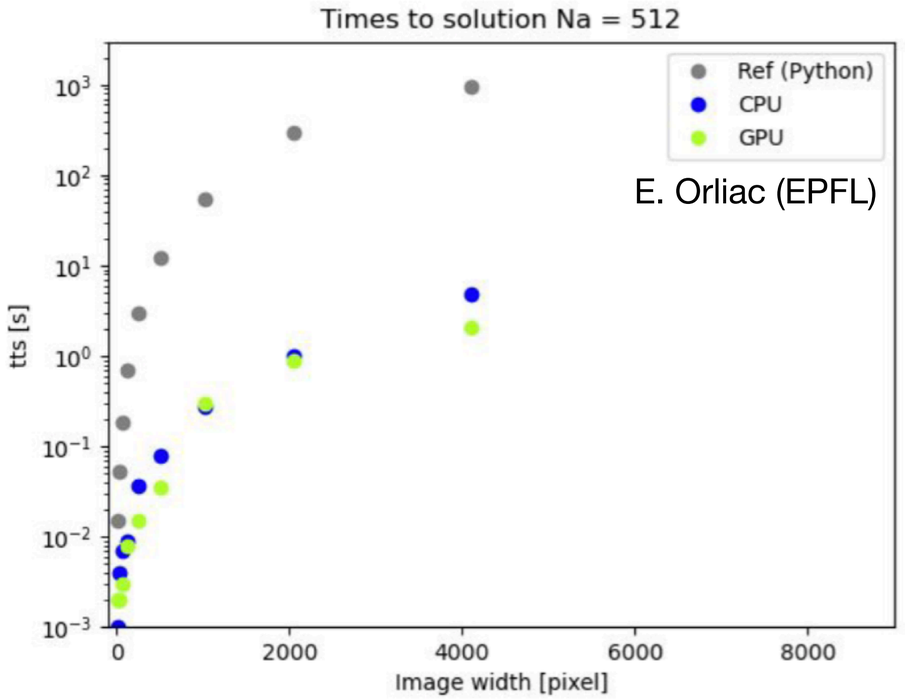
A. Stevens et al., "The imperative to reduce carbon emissions in astronomy" Nature Astronomy 2020

Better Flop/W hardware can make a huge difference

Rank	System	Cores	Rmax (PFlop/s)	Rpeak (PFlop/s)	Power (kW)
9	**Selene** - NVIDIA DGX A100, AMD EPYC 7742 64C 2.25GHz, NVIDIA A100, Mellanox HDR Infiniband, Nvidia NVIDIA Corporation United States	555,520	63.46	79.22	2,646
10	**Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Matrix-2000, NUDT National Super Computer Center in Guangzhou China	4,981,760	61.44	100.68	18,482

High Performance Computing

- **Performance tuning** for radio astronomy workflows: code refactoring, GPU acceleration, benchmarking
- **Energy efficient computing**: energy monitoring, optimizing for energy-to-solution



NUFFT refactoring (EPFL-SCITAS & CSCS)

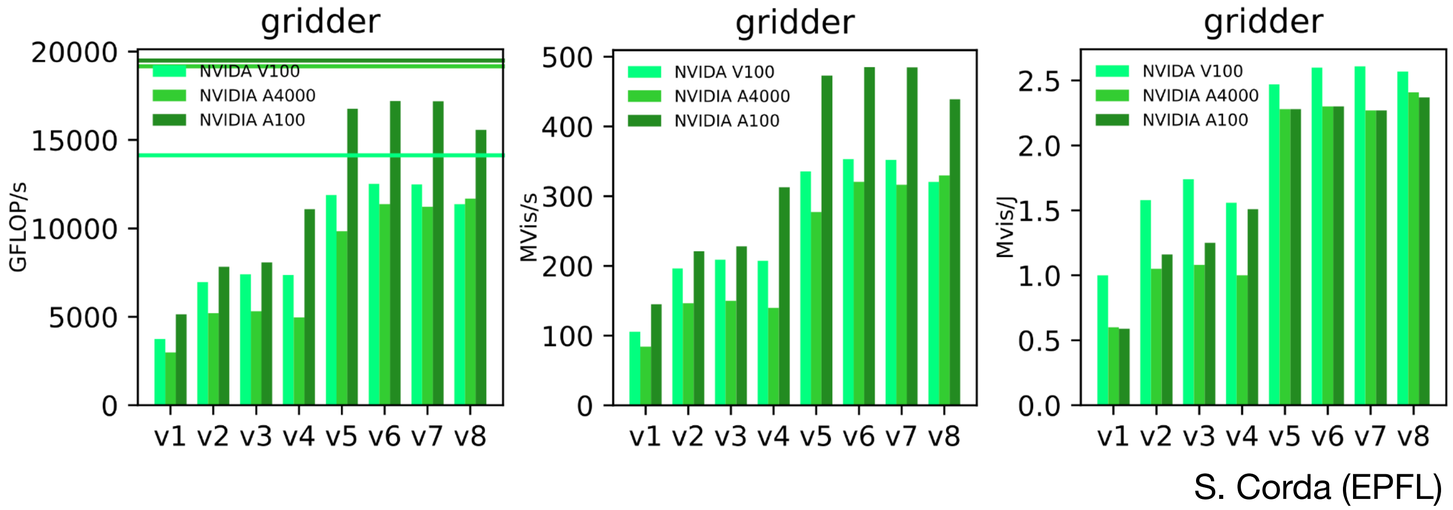
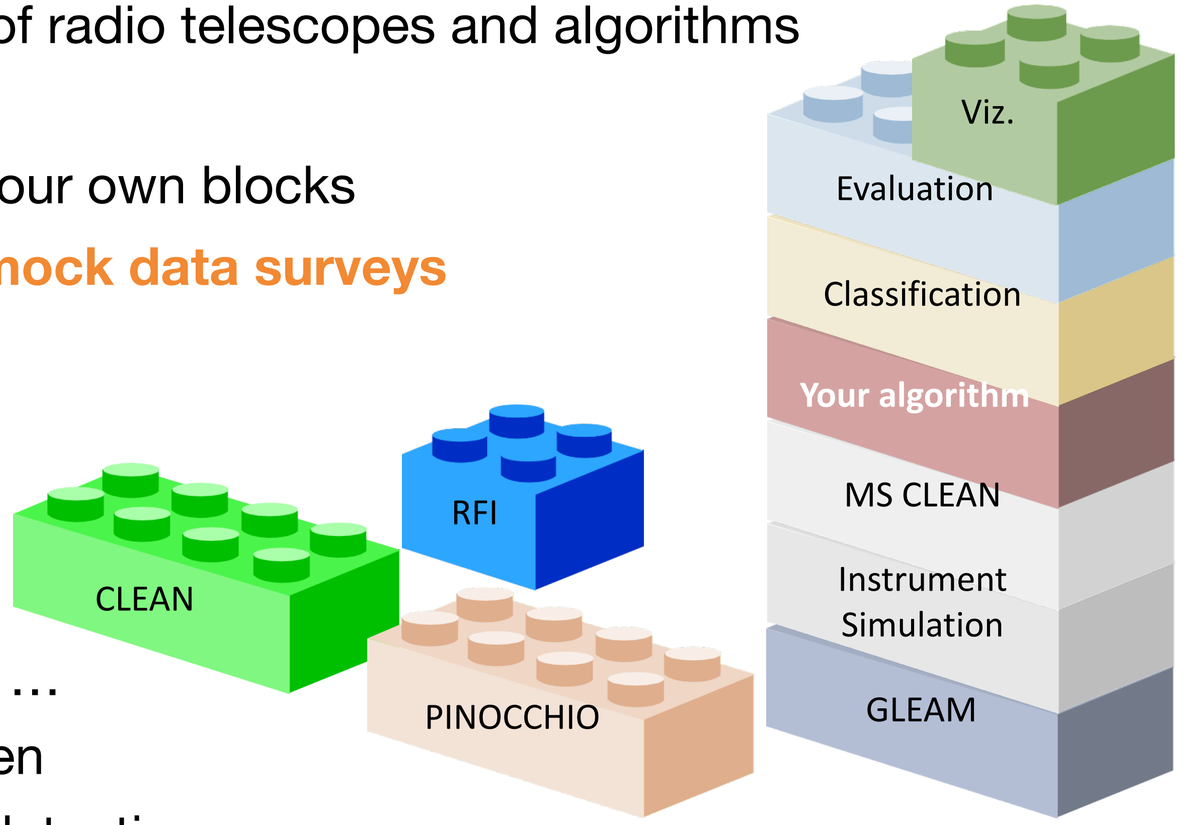


Image domain gridding benchmarking with energy efficiency measurement (EPFL-SCITAS)

Digital Twins

Karabo **The SKA Digital Twin**

- Software distribution for validation and benchmarking of radio telescopes and algorithms
- Fast and easy installation, configuration and ramp-up
- Build **custom** pipelines with our building blocks, add your own blocks
- Would like to include **MWA datasets for testing and mock data surveys**



Present features

- Includes OSKAR, RASCIL, Pinocchio (Dark Matter halo simulation), PyBDSF, MIGHTEE, GLEAM, Aratmospy, Bluebild, Eidos, Dask, Tools21cm, katbeam, configuration of ~20 telescopes, …
- Models system noise, primary beam, ionospheric screen
- Support for long observations, line emissions, source detection, parallelization, big catalogs, …

In conclusion

- Switzerland is on the path towards joining the MWA
- Alignment & synergies with several other projects in Switzerland
- Looking to contribute with our expertise in:
  - High performance computing
  - Digital twins
  - Cosmological simulations
  - Data science
  - Astrophysics & Cosmology

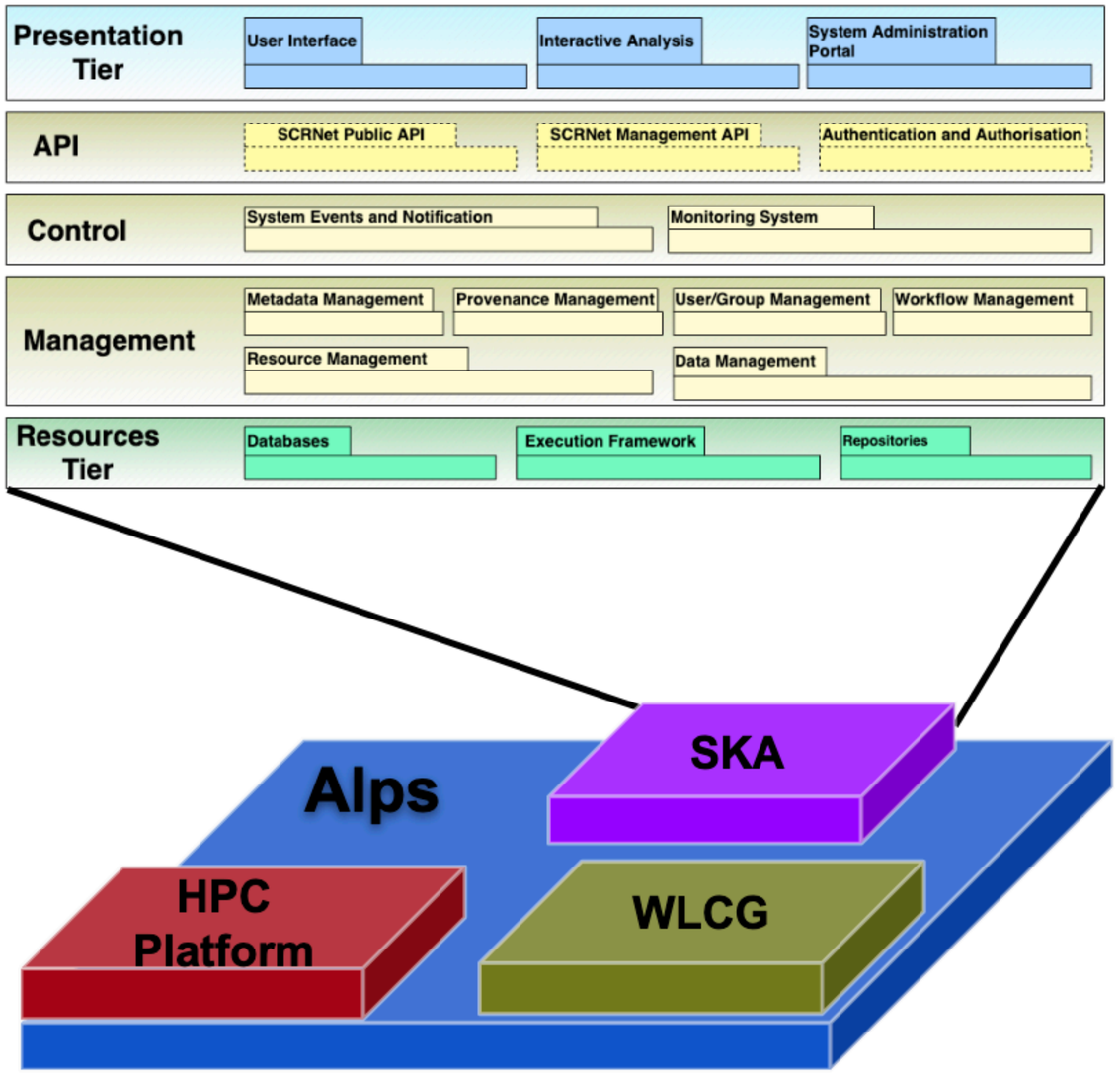

BACKUP SLIDES

Swiss SRC

Switzerland is in a unique position to contribute to the SRCNet thanks to Alps

Taking platforms further in Alps

- Very flexible infrastructure that allows for plenty of customization
  - Deploy services via container orchestrators (e.g. kubernetes)
- vCluster technology to deploy platforms in multiple infrastructures
- Customization comes at a cost
  - Similar platforms are easier to maintain
  - Great potential for decentralized management



Slide from Pablo Fernandez

NEW ALGORITHMS FOR IMAGING

Bluebild: leverage functional PCA to reconstruct image of sky. Highly parallelizable.

$$x_l = \int_{4\pi} S(\vec{r})\, g_l(\vec{r})\, \phi_l(\vec{r})\, d\Omega$$

Voltages

$$V_{lm} \equiv \mathbb{E}[x_l, x_m^*] = \sum_{p,q}^{N_{\text{pixel}}} \Psi_{lp}^*\, \mathbb{E}[S_p, S_q]\, \Psi_{mq}$$

Visibilities

$$V = \Psi^*\, B\, \Psi$$

Simplified notation

$$\widetilde{B} = \Psi G_\Psi^{-1}\, V\, G_\Psi^{-1} \Psi^*$$

Solve for B with pseudo inverse

$$B_D[x, y] = \sum_u \sum_v V[u, v] e^{-2\pi i (ux+vy)}$$

Typical imaging

Bluebild

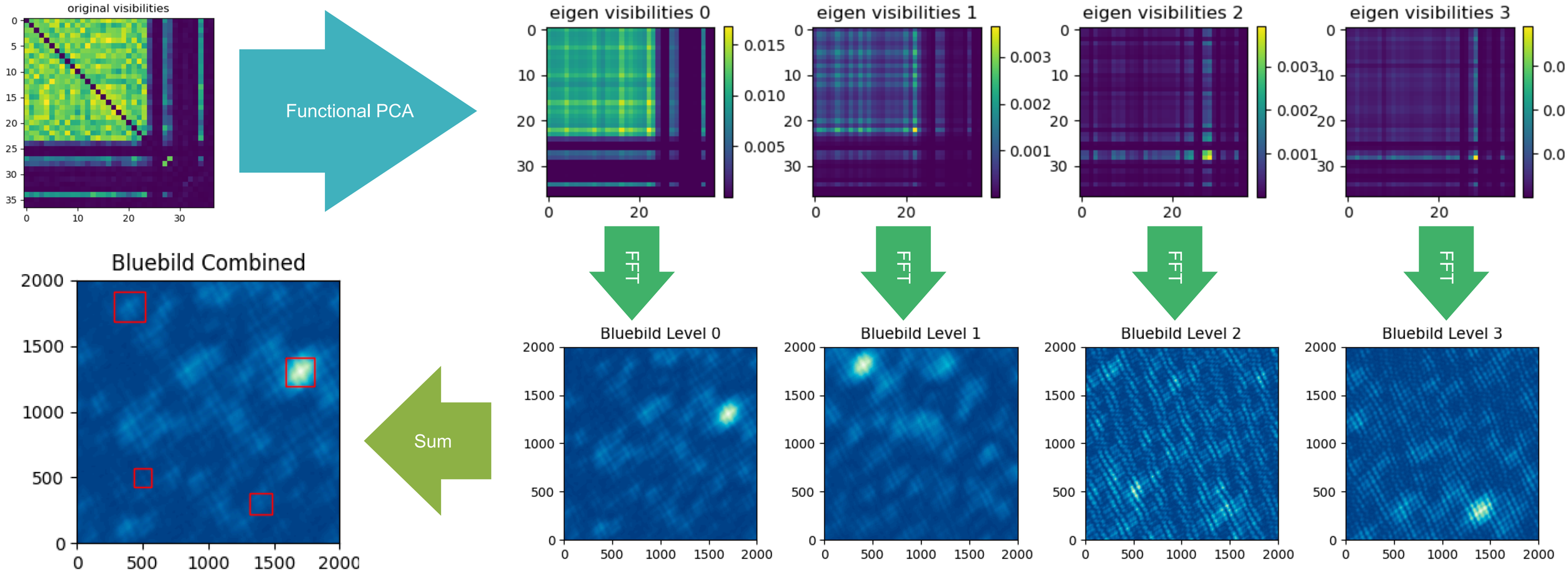
$$\widetilde{B} = \sum_a \lambda_a ||\epsilon_a||^2 = \Psi\, V'\, \Psi^*$$

$$V' = \alpha_a\, \text{diag}(\lambda_a)\, \alpha_a^*$$

$$V\alpha_a = \lambda_a G \Psi \alpha_a$$

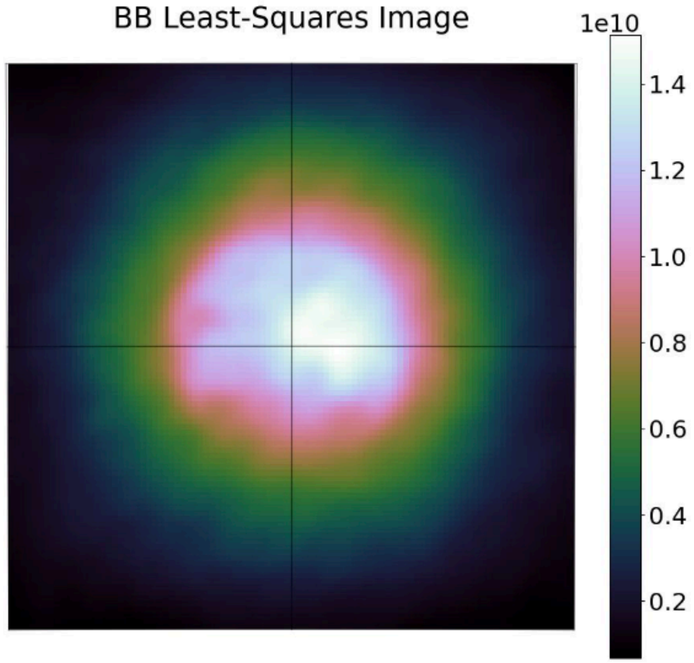
NEW ALGORITHMS FOR IMAGING

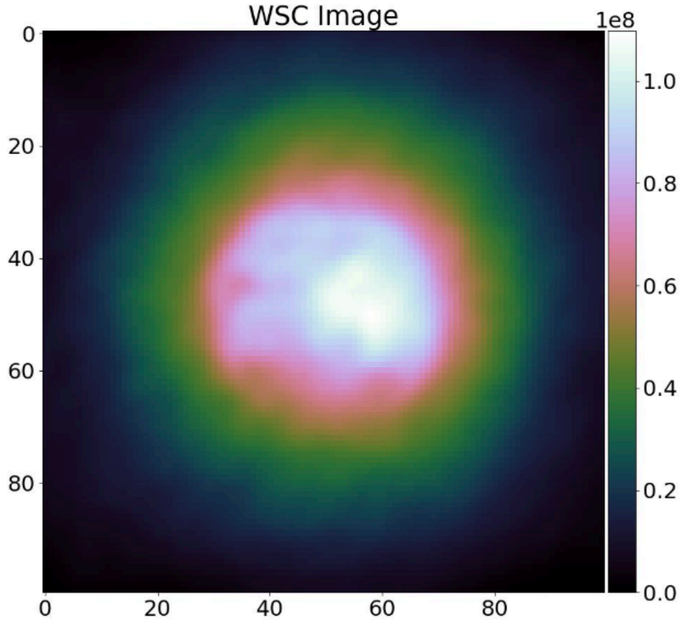
Bluebild: leverage functional PCA to reconstruct image of sky. Highly parallelizable.

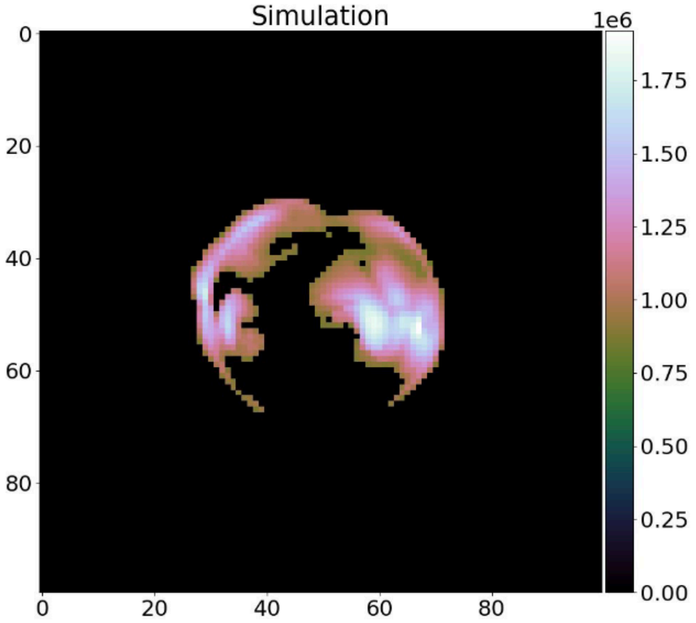


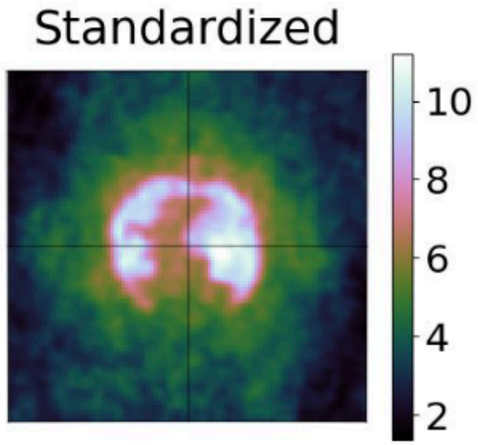
NEW ALGORITHMS FOR IMAGING

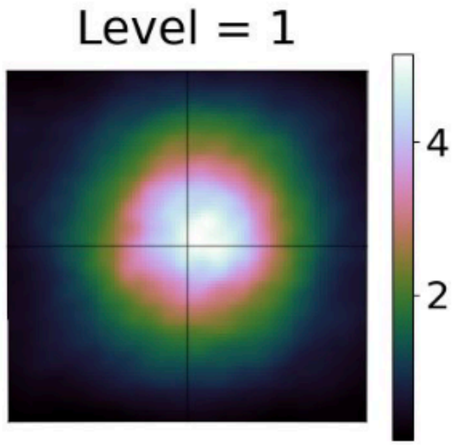
Shreyam Krishna: talk

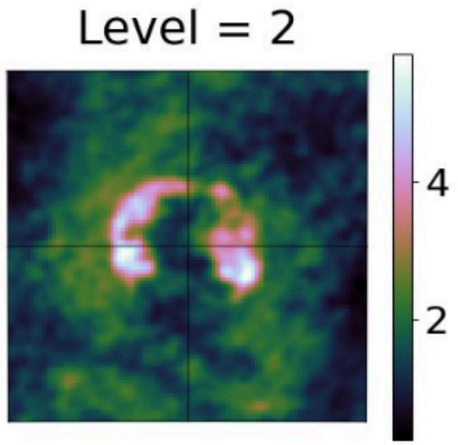


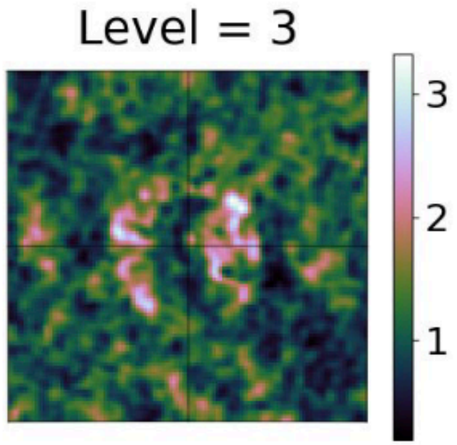




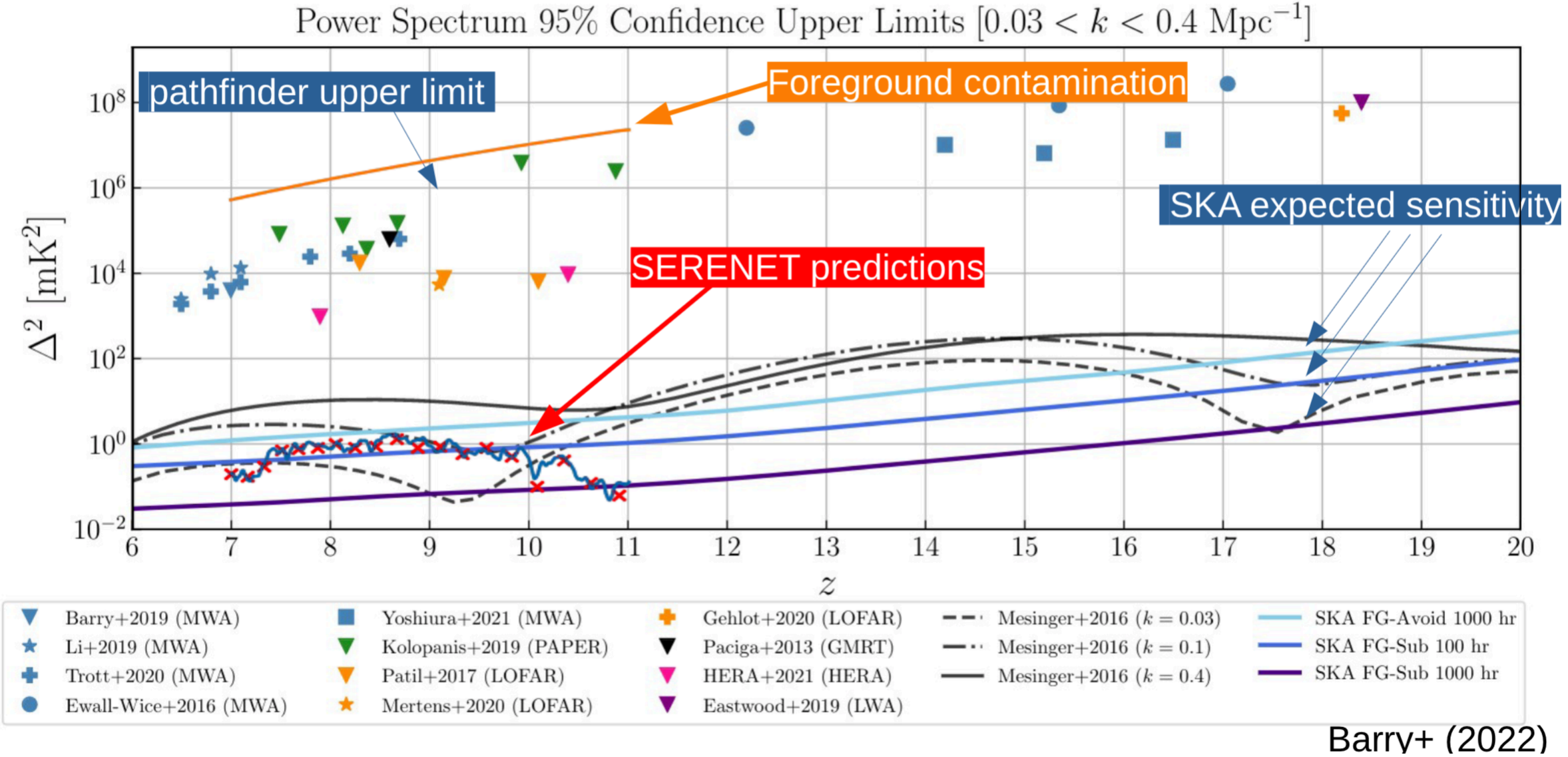








SERENEt: Comparison with Current Data



Barry+ (2022)