Assembling the ngEHT:
Community-Driven Science to a Global Instrument

June 22-25, 2022
Granada, Spain

Wednesday, June 22

8:00 - 9:00 (CEST) 6:00 - 7:00 (UT)

Registration opens

9:00 - 9:30 (CEST) 7:00 - 7:30 (UT)

Breaking News and the Exciting Future of Black Hole Imaging [Auditorium]

- *Conference Welcome and Path to the Future* (10 m, Jose Gomez)
- *EHT* (Huib van Langevelde) + *ngEHT* (Shep Doeleman)

9:30 - 10:30 (CEST) 7:30 - 8:30 (UT)

Presentation of SgrA* results [Auditorium]

Moderator: Thomas Krichbaum

- *Overview* (Geoff Bower)
- *From Observations to Images* (Kazu Akiyama)
- *Variability, Morphology and Bl*ack Hole mass (Dom Pesce)
- *Astrophysical Interpretation* (Michi Baubock)
- *Testing Strong Gravity* (Mariafelicia de Laurentis)

10:30 - 11:00 (CEST) 8:30 - 9:00 (UT)

Coffee Break

11:00 - 13:00 (CEST) 9:00 - 11:00 (UT)

A Decade of Discovery in Black Hole Science: Invited Talks [Auditorium]

Moderator: Daryl Haggard

- *The richness and power of near infrared interferometry* (Frank Eisenhauer)
- *VLBI: A Historical Perspective* (Jim Moran)
- *MWL observations of SgrA* and other LLAGN* (Sera Markoff)
- *Black Holes and their Cosmic Context* (Priya Natarajan)

13:00 - 14:30 (CEST) 11:00 - 12:30 (UT)

Lunch Break

14:30 - 16:00 (CEST) 12:30 - 14:00 (UT)

The Next Generation of Black Hole Imaging [Auditorium]

Moderator: Avery Broderick

- *EHT Capabilities: Current and Planned* (Remo Tilanus)
- *ngEHT Introduction and Vision* (Shep Doeleman)

- *Key Science Goals of the ngEHT* (Michael Johnson)
- *System and Operations Concept for the ngEHT* (Janice Houston)

16:00 - 16:10 (CEST) 14:00 - 14:10 (UT)

Group Picture

16:10 - 16:30 (CEST) 14:10 - 14:30 (UT)

Coffee Break

16:30 - 17:30 (CEST) 14:30 - 15:30 (UT)

Panel Discussion [Auditorium]

Moderator: José L. Gómez

(Sera Markoff, Priya Natarajan, Frank Eisenhauer, Jim Moran)

18:00 - 19:00 (CEST) 16:00 - 17:00 (UT)

Outreach Seminar (in Spanish): [Auditorium]

Fotografiando agujeros negros (Jose Gomez)

21:00 (CEST) 19:00 (UT)

Conference Dinner (EHT + ngEHT) at Restaurant "La Chumbera"

Thursday, June 23

9:00 - 10:30 (CEST) 7:00 - 8:30 (UT)

ngEHT State of the Project [Auditorium]

Moderator: Jose Gomez

- *Overall Project Goals, Timeline, and PAC Report* (Shep Doeleman)
- *Level-0 Science Goals & Science Req. Review Report* (Michael Johnson)
- *System Requirements: Status and Review Report* (Aaron Oppenheimer)
- Q & A and Discussion

10:30 - 11:00 (CEST) 8:30 - 9:00 (UT)

Coffee Break

11:00 - 13:00 (CEST) 9:00 - 11:00 (UT)

Summary Presentations from SWGs [Auditorium]

Moderator: Michael Johnson

- *Fundamental Physics* (Ziri Younsi)
- *Black Holes and their Cosmic Context* (Jose Gomez)
- *Jet Launching* (Matt Lister)
- *Accretion* (Angelo Ricarte)
- *Transients* (Daryl Haggard)
- *New Horizons* (Andrei Lobanov)

13:00 - 14:30 (CEST) 11:00 - 12:30 (UT)

Lunch Break

14:30 - 16:00 (CEST) 12:30 - 14:00 (UT)

Parallel Sessions: Contributed Talks and White Paper Discussion

1. **Fundamental Physics I** [Auditorium]
   Moderator: Ziri Younsi
   - *Future Prospects for Constraining Black Hole Spacetime: Horizon-scale Variability of Astrophysical Jet*
     (Kotaro Moriyama)
   - *Stringent axion constraints with EHT/ngEHT polarimetric measurements*
     (Xiao Xue)
   - *Photon ring detection with ngEHT*
     (Shahar Hadar)
   - *Accretion flows onto Proca stars*
     (Hector Olivares)
2. **Jets + Accretion I** [Curie Room]
   Moderator: Matt Lister
   - *Verification of The Jet-Disk Structure in M87: Separation among the Total Intensity, Linear and Circular Polarization Components*
     (Yuh Tsunetoe)
   - *Imaging warps and flares around black holes*
     (Koushik Chatterjee)
   - *Direct Observational Signatures of Frame Dragging in Retrograde Accretion Flows*
     (Angelo Ricarte)
   - *Pattern Speed of Horizon-Scale Features*
     (Michi Baubock)
   - *Probing Accretion Turbulence in the Galactic Center with ngEHT Polarimetry*
     (Chunchong "Rufus" Ni)
   - *Using GRMHD simulations to test and improve semi-analytical accretion flow models*
3. (Boris Georgiev)**Algorithms and Inference** [Sagan Room]
   Moderator: Dom Pesce
   - *DoG-HiT: A novel VLBI Multiscale Imaging Approach*
     (Hendrik Mueller)
   - *Multifrequency imaging with the ngEHT*
     (Andrew Chael)
   - *Multi-Domain Imaging of Dynamical Sources with simulated ngEHT Data*
     (Jakob Knollmuller)
   - *Hybrid Modeling the Photon Ring using ngEHT*
     (Paul Tiede)

- *AI for regularization in radio-interferometric imaging*
  (Yves Wiaux)

4. **Sites I** [Einstein Room]
   Moderator: Ranjani Srinivasan
   - *The African extension to the Event Horizon Telescope: making movies of Sgr A**
     (Noemi La Bella)
   - *Extraterrestrial extension of ngEHT*
     (Leonid Gurvits)
   - *Future Plan for the Greenland Telescope*
     (Ming-Tang Chen)
   - *MIT Haystack 37m telescope as part of evolving EHT arrays at 230 GHz*
     (Ganesh Rajagopalan)
   - *Current Status of the LLAMA Observatory*
     (Manuel Fernandez Lopez)

16:00 - 16:30 (CEST) 14:00 - 14:30 (UT)

Coffee Break

16:30 - 17:30 (CEST) 14:30 - 15:30 (UT)

Contributed Talks and White Paper Discussion

1. **Fundamental Physics II** [Auditorium]
   Moderator: Ziri Younsi
   - *Zooming into the Quantum Regime: The EHT and Quadratic Gravity*
     (Michael Florian Wondrak)
   - *Spacetime Characterisation using Photon Polarization*
     (Aditya Tamar)
   - *Axion Constraints with Closure Trace Information*
     (Avery Broderick)
2. **Black Holes and Cosmic Context I** [Sagan Room]
   Moderators: Jose Gomez, Priya Natarajan
   Discussion of BHCC White Papers
3. **History, Philosophy, and Culture** [Curie Room]
   Moderator: Peter Galison
   Discussion of HPC White Papers
4. **Antennas, Instrumentation, and Software I** [Einstein Room]
   Moderator: Dom Pesce
   - *Characterization of Frequency Phase Transfer Calibration performance for ngEHT, using simulation studies*
     (Maria J. Rioja)

- *ngEHT Multi-Frequency Array Configuration considerations for optimized SgrA* observations, with frequency phase transfer*
  (Richard Dodson)
- *Modeling software correlator performance*
  (Colin Lonsdale)
- *Design considerations for the ngEHT Antennas*
  (Nimesh Patel)

18:00 (CEST) 16:00 (UT)

Poster session + Lightning Talks [Auditorium]

Moderator: Guang-Yao Zhao

(Abhishek Joshi, Roman Burridge, Micaela Menegaldo, Kiana Salehi, Alejandra Jimenez Rosales)

21:30 (CEST) 19:30 (UT)

Social activities: private night tour of the Alhambra

Friday, June 24

9:00 - 10:30 (CEST) 7:00 - 8:30 (UT)

Exploring History, Philosophy, and Culture with the ngEHT [Auditorium]

Moderator: Gopal Narayanan

- *Introduction & The Complementary of Robustness and Sensitivity* (Peter Galison)
- *Philosophical Reflections on Astrophysical Inference* (Juliusz Doboszewski)
- *Theory and Observation: Bridging the Gap* (Jamee Elder)
- *Scientific Collaborations: What Makes Them Work?* (Niels Martens)

10:30 - 11:00 (CEST) 8:30 - 9:00 (UT)

Coffee Break

11:00 - 13:00 (CEST) 9:00 - 11:00 (UT)

Summary Technical Presentations [Auditorium]

Moderator: Nimesh Patel

- *Analysis Challenges* (Freek Roelofs and Jakob Knollmüller)
- *Site Selection* (Daniel Palumbo)
- *ngEHT Data Management* (Mark Kettenis)
- *86 GHz Task Force* (Sara Issaoun)
- *UMass Dual Band Receiver Prototype* (Gopal Narayanan)
- *BDC/DBE Development, Including Firmware* (Ranjani Srinivasan, Manuel Fernandez, and Emilia Mamani)

13:00 - 14:30 (CEST) 11:00 - 12:30 (UT)

Lunch Break

14:30 - 16:00 (CEST) 12:30 - 14:00 (UT)

Parallel Sessions: Contributed Talks and White Paper Discussion

1. **Fundamental Physics III** [Auditorium]
   Moderator: Shahar Hadar
   - *Shadow of compact object without photon sphere*
     (Ashok Joshi)
   - *Photon Ring Symmetries in Simulated Linear Polarization Images of Messier 87**
     (Daniel Palumbo)
   - *Image of the thin accretion disk around compact objects in the Einstein–Gauss–Bonnet gravity*
     (Galin Gyulchev)
   - *Observational signatures of exotic compact objects: image of the thin accretion disk and linear polarization*
     (Petya Nedkova)
   - *Photon Rings in Spherically-Symmetric Black Hole Spacetimes*
     (Prashant Kocherlakota)
2. **Jets + Accretion II** [Curie Room]
   Moderator: Gibwa Musoke
   - *Plasmoid identification in 2D GRMHD simulations*
     (Jesse Vos)
   - *Non-thermal emission at event horizon and jet launching scales*
     (Alejandro Cruz Osorio)
   - *Analytical Model of Disk Evaporation and State Transitions in Accreting Black Holes*
     (Hyerin Cho)
   - *Effects of Opacity on Variability in Black Hole Images*
     (Zachary Gelles)
   - *Formation of limb-brightened jets by angular-dependent energy extraction from rotating black holes*
     (Kouichi Hirotani)
   - *Testing the Cosmic Battery mechanism with ngEHT*
     (Ioannis Myserlis)
3. **Black holes and Cosmic Context II** [Sagan Room]
   Moderator: Thalia Traianou
   - *Supermassive black hole binaries revealed through their periodic variability*
     (Ioannis Liodakis)
   - *Zooming into the heart of the super-massive binary black hole system OJ287*

(Rocco Lico)
- *VLBI scale probing of giant radio galaxies*
(Pratik Dabhade)
- *Multi-frequency MOJAVE VLBA Timelapse Imaging*
(Matthew Lister)
- *The filamentary structure of 3C279 probed by RadioAstron*
(Antonio Fuentes)
- *Exploring high resolution 3C279 inner structure with RadioAstron*
(Teresa Toscano)

4. **Sites II** [Einstein Room]
Ranjani Srinivasan
    - *Prospects for installing a new ngEHT antenna in Canary Islands*
    (Jose Gomez)
    - *Benefits of Kilimanjaro as an ngEHT site*
    (Noorali Jiwaji)
    - *Millimeter Astronomy at the Owens Valley Radio Observatory*
    (Nitika Yadlapalli)

16:00 - 16:30 (CEST) 14:00 - 14:30 (UT)

Coffee Break

16:30 - 17:30 (CEST) 14:30 - 15:30 (UT)

Contributed Talks and White Paper Discussion

1. **Fundamental Physics IV** [Auditorium]
Moderator: Ziri Younsi
Discussion of Fundamental Physics SWG White Paper
2. **Jets + Accretion III** [Sagan Room]
Moderators: Matt Lister and Angelo Ricarte
Discussion of Jets/Accretion White Papers
3. **Antennas, Instrumentation, and Software II** [Curie Room]
Moderator: Jonathan Weintroub
    - *SAO VLBI Digital Back End development*
    (Ranjani Srinivasan)
    - *Firmware for the ngEHT*
    (Emilia Mamani)
    - *Takeaways from the DBE technical working group*
    (Jonathan Weintroub)
    - *Progress on the Haystack Observatory Postprocessing System (HOPS)*
    (Dan Hoak)

18:00 - 19:00 (CEST) 16:00 - 17:00 (UT)

Junior Scientist Fireside Chat

19:00 (CEST) 17:00 (UT)

Social activities: private tour of Albaicin and Sacromonte

Saturday, June 25

10:00 - 10:30 (CEST) 8:00 - 8:30 (UT)

Coffee Break

10:30 - 12:00 (CEST) 8:30 - 10:00 (UT)

Looking Forward: ngEHT Phase 2 Science [Auditorium]

Moderator: Svetlana Jorstad

- *Major Unresolved Problems in AGN Jets: ngEHT Insights* (Alan Marscher)
- *Studying BH Energy extraction with the ngEHT* (George Wong)
- *From Visibilities to Gravity* (Avery Broderick)

12:00 - 12:10 (CEST) 10:00 - 10:10 (UT)

Conference Summary & Next Steps [Auditorium]

- *Next Steps for the ngEHT* (5 m, Shep Doeleman)
- *Final Remarks* (5 m, Jose Gomez)

19:00 (CEST) 17:00 (UT)

Social activities: private tour of Granada city center

Participants

Mr. Aaron Oppenheimer, CfA
Mr. Abhishek Joshi, University of Illinois at Urbana-Champaign
Prof. Alan Marscher, Boston University
Dr. Alejandra Jiménez Rosales, Radboud University
Dr. Alejandro Cruz Osorio, Goethe-University Frankfurt / Institute for Theoretical Physics
Mr. Alejandro Mus, Universitat de València
Dr. Alex Tetarenko, Texas Tech University
Prof. Alok Chandra Gupta, ARIES, Nainital, India
Dr. Andrei Lobanov, Max-Planck-Institut für Radioastronomie
Dr. Andrew Chael, Princeton University
Dr. Angelo Ricarte, Harvard-Smithsonian Center for Astrophysics
Dr. Ann Thresher, UC San Diego

Mr. Antonio Fuentes, IAA-CSIC
Dr. Antxon Alberdi, IAA-CSIC
Dr. Ariel Luis Pola, CognitionBI LLC / National University of Cordoba (Argentina)
Mr. Aristomenis Yfantis, Radboud University
Mr. Ashok Joshi, International center for Cosmology(ICC), CHARUSAT University
Dr. Athanasios Bakopoulos, University of Patras -Greece
Prof. Avery Broderick, Perimeter Institute / University of Waterloo
Dr. Bong Won Sohn, Korea Astronomy and Space Science Institute
Mr. Boris Georgiev, University of Waterloo
Dr. Britt Jeter, ASIAA
Mr. Chunchong Ni, University of Waterloo/Perimeter Institute
Dr. Colin Lonsdale, MIT Haystack Observatory
Mr. Daniel Alejandro Tapia Alanis, Universidad Michoacana de San Nicolás de Hidalgo
Dr. Daniel Hoak, MIT Haystack Observatory
Mr. Daniel Palumbo, Center for Astrophysics | Harvard & Smithsonian
Prof. Daryl Haggard, McGill University
Dr. Diego Rubiera-Garcia Complutense, University of Madrid & IPARCOS
Dr. Dimitry Ayzenberg, University of Tübingen
Mr. Dominic Chang, Black Hole Initiative
Dr. Dominic Pesce, Center for Astrophysics | Harvard & Smithsonian
Mr. Dongjin Kim, MIT Haystack Observatory
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Mr. Ganesh Rajagopalan, MIT Haystack Observatory
Mr. Garret Fitzpatrick, Smithsonian Astrophysical Observatory
Dr. Geoffrey Bower, ASIAA
Dr. George Wong, Institute for Advanced Study
Mr. Georgios Filippos Paraschos, Max-Plack-Institute for Radioastronomy
Dr. Gibwa Musoke, University of Amsterdam
Prof. Gopal Narayanan, University of Massachusetts, Amherst
Mr. Greg Lindahl, SAO
Dr. Guang-Yao Zhao, Instituto de Astrofísica de Andalucía
Dr. Hector Olivares, Radboud University
Mr. Hendrik Mueller, MPIfR
Ms. Hui-Hsuan Chung, Max Planck Institute for Radio Astronomy

Prof. Huib van Langevelde, JIVE/Leiden
Ms. Hyerin Cho, Harvard
Dr. Ilje Cho, IAA-CSIC
Dr. Iniyan Natarajan, University of the Witwatersrand / SARAO
Dr. Ioannis Liodakis, Finnish Centre for Astronomy with ESO
Dr. Ioannis Myserlis, Institut de Radioastronomie Millimétrique (IRAM)
Dr. Ivan Marti Vidal, University of Valencia
Prof. Jae-Young Kim, Kyungpook National University
Dr. Jakob Knollmüller, Excellence Cluster ORIGINS, TUM
Dr. Jamee Elder, Black Hole Initiative, Harvard University
Prof. James Moran, CfA
Mr. Jan Röder, Max Planck Institute for Radio Astronomy
Ms. Janice Houston, CfA
Mr. Jesse Vos, Radboud University
Ms. Joana Kramer, Max Planck Institute for Radio Astronomy
Mr. Jonas Enander, Science Writer
Dr. Jonathan Weintroub, Center for Astrophysics | Harvard & Smithsonian
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Mr. Leon Sosapanta Salas, University of Amsterdam
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Ms. Marianna Foschi, Instituto de Astrofísica de Andalucía
Dr. Mark Kettenis, JIVE
Prof. Matthew Lister, Purdue University
Ms. Micaela Menegaldo, University of Pretoria

Mr. Michael Florian Wondrak, Radboud University
Dr. Michael Johnson, Center for Astrophysics | Harvard & Smithsonian
Dr. Michi Bauböck, University of Illinois
Dr. Ming-Tang Chen, ASIAA
Dr. Mislav Balokovic, Yale University
Dr. Niels Martens, University of Bonn
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Dr. Petya Nedkova, Sofia University
Dr. Philipp Frank, Max Planck Institute for Astrophysics
Dr. Prashant Kocherlakota, Institute for Theoretical Physics, Frankfurt
Dr. Pratik Dabhade, Observatoire de Paris
Prof. Priya Natarajan, Yale University & BHI
Dr. Rahul Kumar, University of KwaZulu Natal, Durban
Ms. Ranjani Srinivasan, SAO
Dr. Razieh Emami, CFA
Prof. Remo Tilanus, University of Arizona
Dr. Richard Dodson, ICRAR/UWA
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Prof. Sera Markoff, API/GRAPPA, University of Amsterdam
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Dr. Stergios Amarantidis, Instituto de Radioastronomía Milimétrica
Prof. Stoytcho Yazadjiev, Sofia University
Dr. Svetlana Jorstad, IAR, Boston University, Boston,USA
Ms. Teresa Toscano, Instituto de Astrofísica de Andalucía
Dr. Thalia Traianou, IAA-CSIC
Mr. Vincent Fish, MIT Haystack Observatory

Ms. Wanga Mulaudzi, Anton Pannekoek Institute for Astronomy
Dr. Xiao Xue, University of Hamburg, DESY
Mr. Yuh Tsunetoe, Kyoto University
Mr. Yutaro Kofuji, University of Tokyo
Prof. Yves Wiaux, Heriot-Watt Edinburgh
Mr. Zachary Gelles, Harvard
Dr. Ziri Younsi, University College London

Contributed Talks

FUNDAMENTAL PHYSICS I

Light and Ultra-light Species and Super Massive Black Holes (SMBH), in the era of ngEHT
Alexander Bonilla Rivera

The Standard Model (SM) is a very successful description of particle physics, connecting the weak, strong, and electromagnetic forces to the framework of gauge symmetries. Only the latter two are unbroken symmetries, i.e. bring with them conserved quantum numbers, color and electric charge, respectively. The search for additional forces has always driven particle physics, but has so far not been successful, resulting in tight bounds either on the strength or range of the new force. Baryon and lepton numbers are the only classically conserve quantities in the SM, taking into account that the lepton mixing pattern observed in neutrino oscillations proves the non-conservation of the individual lepton numbers Le,μ,τ or linear combinations there of. Classical symmetries of the Lagrangian can be broken at quantum level through triangle anomalies, which have to be canceled in order to obtain a valid quantum field theory. Cosmological and astrophysical data sets can be used to set limits on these new species that may emerge and that complement the work done in particle physics (i.e accelerators, reactors, atmospheric, ..., etc.). We will use a data point of M87 * and S2 (DA), to put constraints on the Z' boson. We will present preliminary results.

Future Prospects for Constraining Black Hole Spacetime: Horizon-scale Variability of Astrophysical Jet
Kotaro Moriyama

The Event Horizon Telescope (EHT) has ushered in a new era for observing the strong gravitational field and testing general relativity. Recent observations of the horizon scale images of the supermassive black hole M87* at the nearby galaxy M87 provide direct information in the vicinity of the black hole. The comparisons of the EHT observations and theoretical simulations enable us to constrain the spacetime, while it is not easy to decompose into the accretion flow properties and spacetime information because the radiation complexly depends on their effects. The next generation

EHT (ngEHT) projects are expected to explore the astrophysical jet dynamics around the black hole, one of the most promising topics for extracting spacetime information. We demonstrate that the black hole spacetime can be constrained by focusing on the dynamics of the jet under the observational environments of ngEHT projects. We utilize the three-dimensional general relativistic magnetohydrodynamic (GRMHD) simulation of magnetically arrested disks (MADs) with the numerical code BHAC. The simulated jet movies are calculated with the general-relativistic radiative transfer (GRRT) scheme of the numerical code BHOSS. Around the jet base, the launched jet has intermittent wave structures, which propagate with a relativistic time scale. The wave velocity and time development can be extracted from the simulated movies and show monotonic dependence on the black hole spacetime. We finally perform the synthetic observation of M87* and show the detectability of velocity features and the black hole spacetime information under the expected ngEHT observations.

Stringent axion constraints with EHT/ngEHT polarimetric measurements

Xiao Xue

An axion cloud surrounding a supermassive black hole can be naturally produced through the superradiance process. Its existence can be examined through the axion-induced birefringence effect. It predicts an oscillation of the electric vector position angle of linearly polarized radiations. Stringent constraints of the existence of the axion in a particular mass window have been imposed based on the recent Event Horizon Telescope measurement on M87*. The future Very-Long-Baseline Interferometry (VLBI) observations will be able to measure the vicinity of many supermassive black holes, thus it opens the possibility to search for the existence of axions in a wide mass regime. We study how different black hole properties and accretion flows influence the signatures of the axion-induced birefringence. We include the impacts of black hole inclination angles, spins, magnetic fields, plasma velocity distributions, and the thickness of the accretion flows. We pay special attention to characterize the washout effects induced by the finite thickness of the accretion flows and the lensed photons. Based on this study, we give prospects on how to optimize the axion search using future VLBI observations, such as the next-generation Event Horizon Telescope, to further increase the sensitivity.

Photon ring detection with ngEHT

Shahar Hadar

The photon ring is a universal feature of black hole images. It arises from near-critical light rays, which are strongly lensed near the black hole's photon shell - the region spanned by its bound (unstable) photon orbits. In the talk, I will review the structures of the ring and shell, and argue that detecting and measuring the ring can provide novel, increasingly precise tests of general relativity. I will describe two complementary methods to measure the ring: one using brightness one-point functions (time averaged images), and the other two-point functions (autocorrelations). I will then

focus on the latter and discuss the prospects for achieving this measurement with ngEHT, and in particular how they depend on the array's parameters.

Accretion flows onto Proca stars

Hector Olivares

Extensions to the standard model of particle physics that include weakly-interacting ultralight fundamental fields predict the existence of supermassive horizonless and surfaceless objects, which are able to mimic the appearance of supermassive black holes under some circumstances. Proca stars constitute a family of such objects that contain stable solutions which, according to semi-analytic models, can produce a central brightness depression similar in size to the shadow of a supermassive black hole of the same mass. To test this prediction, we study the properties of accretion flows around these objects by means of general relativistic magnetohydrodynamic simulations, and compare them with those around black holes and other horizonless, surfaceless objects simulated in the literature. We discuss the observable consequences for more general horizonless, surfacelss objects and the unique possibility offered by high-resolution very-long-baseline interferometry experiments such as the EHT and the ngEHT to find signatures of new fundamental fields.

JETS + ACCRETION I

Verification of The Jet-Disk Structure in M87: Separation among the Total Intensity, Linear and Circular Polarization Components

Yuh Tsunetoe

While the polarized emission from near the black hole can be a good tool to survey the magnetic structure possibly driving the LLAGN jets such as M87, observational and theoretical studies have suggested that they can be affected by the Faraday rotation and conversion. To study and quantify the relationship between these linear polarization (LP) and circular polarization (CP) components and the plasma properties, we calculated theoretical polarization images based on a moderately-magnetized (semi-MAD) general relativistic magnetohydrodynamics (GRMHD) model, and analyzed the correlation relations among the total intensity, LP and CP components on the images. Surveying the peak shifts of cross-correlation functions for the images at multi-wavelengths and for different model parameters, we found that, on the images at around 230~GHz, the LP intensity is distributed in downstream of the approaching jet compared to the total intensity, and the CP intensity appears in the counter-side jet. The reason for the former is that, the Faraday rotation of the LP vectors occurs in the disk around the equatorial plane, thus ``depolarizing'' the flux from near the black hole or the receding jet, whereas the LP vectors from downstream can survive to show an ordered distribution on the image. Meanwhile, the reason for the latter is that the Faraday conversion from the LP to CP component occurs only in an energetic region near the black hole or the

base of the twin jets. Further, we found that these tendencies become stronger at a lower frequency or for higher accretion rate because of the stronger Faraday effects, while the upwards CP distribution is suppressed at even lower frequency by the synchrotron self-absorption (SSA). Based on these results, we established a unified description with three pictures based on the optical thickness for the Faraday effects and the SSA.

Imaging warps and flares around black holes

Koushik Chatterjee

Over the previous two decades, general relativistic magneto-hydrodynamic (GRMHD) simulations have contributed immensely towards understanding the evolution of black hole accretion disks and relativistic jet launching. Advanced numerical algorithms that fully utilize the boom in computational resources over recent years have played a vital role in enabling simulations to capture disk turbulence and jet dynamics. I will be presenting my work on two such important advancements: the warping of jets by a spinning black hole, and the formation of small magnetized blobs, crucial for understanding the jet morphology of M87 as well as the flaring state of our own supermassive black hole, Sagittarius A* or Sgr A*, both of which are Event Horizon Telescope (EHT) targets. Using our group's in-house developed state of the art GPU-accelerated GRMHD code H-AMR and the raytracing code BHOSS, I would discuss how the misalignment of black hole spin and disk rotational axes substantially affects the jet's morphology and, thus, needs to be accounted for when interpreting the horizon-scale images of M87*. Next, with one of the highest resolution GRMHD simulations ever produced, I will show how capturing the small scale physics of plasmoids hold important implications for the time- and spatial- evolution of the image, and therefore, can be a potentially crucial ngEHT science target.

Direct Observational Signatures of Frame Dragging in Retrograde Accretion Flows

Angelo Ricarte

In a retrograde accretion disk around a black hole, infalling gas transitions from counter-rotating to co-rotating with the black hole at some radius. Using ray-traced images generated from general relativistic magnetohydrodynamics simulations, we demonstrate that this phenomenon can produce direct observational evidence of frame dragging that would be accessible to the next-generation Event Horizon Telescope (ngEHT), which aims to produce spatially resolved images on event horizon scales. In total intensity images, infalling streams exhibit "S"-shaped features due to the switch in the tangential velocity. In linear polarization, the handedness of spatially resolved polarization ticks also reflects a transition in the magnetic field geometry that occurs due to magnetic flux freezing. Searching for these signatures motivates continued monitoring and imaging of supermassive black holes with high spatial resolution.

Pattern Speed of Horizon-Scale Features

Michi Bauböck

We investigate the motion of features near the lensed ring in images of GRMHD simulations of SgrA*. This motion is often modeled as Keplerian, but depends on the balance of gravitational and magnetohydrodynamic forces near the horizon. We show preliminary results from our method for extracting the average motion of bright features by unwrapping ray-traced images along a fixed radius. These methods will inform the time-resolved analysis of ngEHT observations of SgrA*.

Signatures of the time-variability in the polarized images of M87*

Razieh Emami

The first polarized images of M87* from the Event Horizon Telescope Collaboration (EHTC) was entirely based on 2017 data and thus was static. There are however many plans to include multi-year data analysis of M87* both by the EHTC and then also using the next generation of the EHT. Here we focus on some of the statistical signatures of the variability of the image over multi-year based time scales. We use different metrics including the KDE of the UQ-loops, the correlation functions, the CDF etc and in each of them we explore how much the aforementioned metrics may inform us about the BH spin as well as the accretion to the BH.

Probing Accretion Turbulence in the Galactic Center with ngEHT Polarimetry

Chunchong "Rufus" Ni

The recent publication of the first high-resolution image of Centaurus A using the EHT 2017 data shows interesting structure of the jet. Furthermore, we are going to present the linear polarization structure in the jet of Cen A using the EHT 2017 data. We show the different structures of the polarization position angles and the linear polarization fraction at the apex, the sheath and the end of the jet, respectively, by qualitatively sampling the posterior distribution using Themis. Overall, Cen A presents a very low degree of polarization, with the resolved fractional linear polarization below 5%. From here, we should be able to infer the magnetic structure in the jet of Cen A.

Non-Imaging Signatures of Jet Variability using the ngEHT

Britt Jeter

As a successor to the EHT, the ngEHT project will be able to produce groundbreaking new observations of horizon-scale astrophysics. One of the primary improvements over the EHT will be the addition of more radio telescopes, to produce a total of 21 stations in the proposed ngEHT reference array. This will dramatically increase the u-v coverage and dynamic range of horizon-scale observations. Using a semi-analytical variable jet model as a synthetic data source, I will show that the ngEHT will be able to distinguish between different jet-launching mechanism through the use of regular source monitoring. I will also discuss how different array configurations and specification can improve the ability of the ngEHT to distinguish between different physical models of jet launching.

ALGORITHMS & INFERENCE

DoG-HiT: A novel VLBI Multiscale Imaging Approach

Hendrik Mueller

Reconstructing images from very long baseline interferometry (VLBI) data with sparse sampling of the Fourier domain (uv-coverage) constitutes an ill-posed deconvolution problem. It requires application of robust algorithms maximizing the information extraction from all of the sampled spatial scales and minimizing the influence of the unsampled scales on image quality. I present a new multiscale wavelet deconvolution algorithm DoG-HiT for imaging sparsely sampled interferometric data which combines the difference of Gaussian (DoG) wavelets and hard image thresholding (HiT). Based on DoG-HiT, we propose a multi-step imaging pipeline for analysis of interferometric data. We demonstrate the stability of DoG-HiT and benchmark its performance against image reconstructions made with CLEAN and Regularized Maximum-Likelihood (RML) methods using synthetic data. The comparison shows that DoG-HiT matches the superresolution achieved by the RML reconstructions and surpasses the sensitivity to extended emission reached by CLEAN.

Multifrequency imaging with the ngEHT

Andrew Chael

Observations with the ngEHT will be conducted at multiple frequency bands (230 and 345 GHz), each with a wide bandwidth. At these frequencies, ngEHT's primary black hole sources in Sgr A* and M87* are both transitioning from optically thin to optically thick. Resolved spectral index maps in the near-horizon and jet regions near these sources can constrain properties of the emitting plasma that are degenerate at one frequency. In addition, propagating structural information from data obtained at multiple frequencies is a powerful tool for image reconstruction, since gaps in spatial scales observed at one frequency can be filled in with information from other frequencies. I will present results from a new method of simultaneously reconstructing images at multiple frequencies with their spectral index maps. The method is based on existing Regularized Maximum Likelihood tools in the eht-imaging software package. I will show results of this method on simulated EHT and ngEHT data sets as well as real data from the VLBA, and illustrate how multifrequency image reconstruction can produce higher-quality and scientifically useful images than image reconstruction at a single frequency.

Multi-Domain Imaging of Dynamical Sources with simulated ngEHT Data

Jakob Knollmüller

Modern VLBI networks allow the observation of extended astrophysical objects on dynamical scales. However, the already sparse data is thinned out even further due to changes in the source structure. This limits the data integration time compared to static sources. The resolve algorithm

utilizes correlations along the spectral, temporal and spatial domain in order to interpolate between observations. The result is a holistic reconstruction, which takes all available information simultaneously into account and therefore provides a coherent view of the source. It is based on non-linear Gaussian processes with adaptive kernels along the different domains. We perform approximate Bayesian inference to obtain a set of approximate posterior samples that can be used for uncertainty quantification. In this talk we present our dynamic reconstructions of M87* and SgrA* from ngEHT Analysis Challenge 2 data.

Hybrid Modeling the Photon Ring using ngEHT

Paul Tiede

A detection of the n=1 photon ring would be a striking confirmation of the role of strong-lensing near the event horizon of a black hole. However, the expected width of the n=1 photon ring (~ 1 uas) is substantially below the nominal resolution of the ngEHT array. In this presentation, we will explore the prospects of detecting the n=1 photon ring and measuring its shape using the ngEHT reference array. Furthermore, we will compare how the ability to measure the photon ring changes across different array configurations and compare these results to the 2022 EHT array.

AI for regularization in radio-interferometric imaging

Yves Wiaux

In this talk, we discuss a new class of algorithms introduced for high resolution high dynamic range image reconstruction from visibility data in radio interferometry (arXiv:2202.12959), at the interface of convex optimization and deep learning. Inspired by plug-and-play methods, the approach consists in learning a prior image model by training a deep neural network as a denoiser, and substituting it for the handcrafted proximal regularization operator of an optimization algorithm. The resulting "AI for Regularization in Imaging" framework (AIRI) inherits the robustness and interpretability of optimization, and the learning power and speed of networks. Simulation results show that a first AIRI incarnation, relying on a basic denoiser architecture, is competitive in imaging quality with, and significantly faster than, the state-of-the-art optimisation algorithm SARA, while the traditional CLEAN algorithm offers much lower quality. The talk will further discuss the application of AIRI to real MeerKAT and ASKAP data, demonstrating that the new approach can reconstruct large fields of view containing complex intensity structure with diffuse and faint emission, with outstanding precision.

Using GRMHD simulations to test and improve semi-analytical accretion flow models

Boris Georgiev

We characterize the missing physics in semi-analytical accretion flow models due to variability by measuring them from GRMHD simulations. We find that due to the chosen initial conditions in the GRMHD simulations, most contributions to correlated variability terms fall below the noise level

associated with our ability to measure them, indicating that static GR hydrodynamics is a reasonable approximation to GRMHD. We apply these results to preliminary work on updating existing semi-analytical accretion flows in general gravity to include a spectrum of variability modes. These models can then be plugged into existing GRRT codes and modelling frameworks so that ngEHT data directly informs on accretion flow parameters of interest.

SITES I

The African extension to the Event Horizon Telescope: making movies of Sgr A*

Noemi La Bella

The Africa Millimetre Telescope (AMT), planned to be built in Namibia, will be a potential site for the Event Horizon Telescope (EHT) to produce reliable movies of Sgr A*. In this talk, we show synthetic dynamical reconstructions generated with the current EHT array plus additional sites in Africa. The AMT alone will already increase the east-west uv-coverage of the current configuration significantly. This gives us the chance to reconstruct images within the first hours of the observation and at least double the observing time yielding robust imaging information. Finally, we discuss the impact of adding more telescopes on the African continent, such as on Canary Island, on imaging gas and light dynamics near the event horizon.

Extraterrestrial extension of ngEHT

Leonid Gurvits

The ngEHT initiative is driven by a well-defined rationale: to address new scientific challenges by exploiting technological opportunities of global (sub)-millimeter VLBI systems to the maximum. However, the latter have two natural and irresistible limitations: the opacity of the Earth's atmosphere and the finite size of Earth. Both limitations can be overcome by placing a (sub)-millimeter VLBI array in space. A highly synergistic to the ngEHT development is represented by the several ongoing design studies of spaceborne submillimeter interferometers. The presentation will give an overview of them, with the focus on one of them called TeraHertz Exploration and Zooming-in for Astrophysics (THEZA). It was prepared in response to the ESA's call for its next major science program Voyage 2050 by a large group of participants of the present ngEHT conference [1]. The goal of the THEZA concept is to charter approaches for reaching the angular resolution of about 1 microarcsecond, an order of magnitude improvement over the Earth-based ngEHT. The presentation will address possible configurations of the spaceborne sub-millimeter interferometer. Such a space-borne facility, in synergy with Earth-based counterparts, will open up a new sizable area of hitherto unreachable parameters of astrophysical observing tools, thus expanding ultra-sharp studies from several exceptional sources to a broad variety of objects in the entire Universe. References: [1] Gurvits L.I. et al. 2021, THEZA: TeraHertz Exploration and Zooming-in for Astrophysics, Experimental Astronomy 51 (3), 559–594"

Future Plan for the Greenland Telescope

Ming-Tang Chen

The Greenland Telescope (GLT) has been conducting scientific observations in the Thule Air Base, a harbor in the northwestern corner of Greenland. Even though it has been participating in global mm/sub-mm VLBI observations since 201, the atmospheric conditions at the current site only allow very limited windows for observations in deep sub-mm wavelengths. To fully maximize the GLT's capability, we need to move to our final destination-- the Greenland summit. I will briefly report its current status and present our plan for deploying the telescope to the summit of Greenland in the near future.

Cost-effective opportunities to expand mm-VLBI in Southern Africa

Roger Deane

VLBI at mm wavelengths has a proud history and has experienced a recent surge ininterest, driven in part by horizon-scale black hole imaging with the EHT. The future of mm-VLBI science is bright, with GMVA/EHT upgrades/expansion; the power of the KVN-led frequency phase transfer technique; and ngVLA/ngEHT developments, amongst others. An important factor in the EHT's recent success was the calibration, imaging, and modeling enhancement made possible with quasi-redundant baselines due to pairs of independent stations at co-located sites (ALMA-APEX, SMA-JCMT). In this talk, I will make the case for a low-cost, small-aperture GMVA/ngEHT antenna in South Africa, at a site with well-established infrastructure and technical support. This would bolster the contribution of the larger aperture Africa mm Telescope in Namibia to the GMVA/(ng)EHT, as well as current and future European GMVA/EHT stations, amongst others (ALMA/APEX and the SPT). The frequency phase transfer technique would unlock several existing multi-wavelength astronomical sites in South Africa, including SKA1-mid and prospective in-country African VLBI Network locations. This co-location would yield substantially lower construction and operating costs. Increasing the number of mm-VLBI stations in the southern hemisphere at strategic geographic locations will help propel GMVA/EHT science into the next decade, especially for Sgr A*, a unique gravitational and astrophysical laboratory.

MIT Haystack 37m telescope as part of evolving EHT arrays at 230 GHz

Ganesh Rajagopalan

The MIT Haystack 37m telescope has undergone significant upgrades for radar operations up to 100 GHz, funded by the US Air Force. Its geographic location, <100 um surface accuracy and better than 1 millideg (rms) pointing and tracking accuracies are suitable for operations at frequencies as high as 230 GHz, making it an attractive addition to future EHT arrays. In this talk, we will describe our current work at 86 GHz to validate the Haystack antenna's VLBI capability, to improve system sensitivity and to understand all aspects of expected performance at 230 GHz. We will also outline a

feasibility study for a dual polarization 86 GHz/230 GHz dual band receiver at the focal plane. This work is funded by the grant supporting development of the ngEHT.

FUNDAMENTAL PHYSICS II

Zooming into the Quantum Regime: The EHT and Quadratic Gravity
Michael Florian Wondrak

While being the best tested theory in physics, GR is still incomplete at the quantum level and incompatible with the other fundamental forces. A criterion imposed on any viable quantum theory of gravity is that its action can be expanded in powers of curvature, starting with the GR term plus terms quadratic in curvature ("quadratic gravity"). Thus studying quadratic gravity corresponds to studying quantum corrections to gravity in general. We present the shadow of Schwarzschild-like objects in quadratic gravity (static, spherically symmetric, asymptotically flat). We investigated the phase space, identified three different types of solutions, and calculated the shadow radius and intensity profiles. For several some types, corrections to Schwarzschild reduce the shadow radius. Thus we found that quantum effects extend up to scales resolvable by the Event Horizon Telescope. Remarkably, the unstable photon orbit as in the Schwarzschild provides an intrinsic ruler in the image, which makes the need for independent mass measurements obsolete. At present, part of the quadratic gravity solutions can be already ruled out. With higher uv-coverage and resolution, the phase space of quadratic gravity can be even more constrained.

Spacetime Characterisation using Photon Polarization
Aditya Tamar

The polarization of photons is a powerful probe of strong field gravity, whose importance was accentuated by the observations by the EHT of M87's polarization signature. However, there are very limited investigations on how to embed the characteristics of spacetime geometry into polarization in a coordinate independent manner. Thus in this talk we shall discuss how spinors provide the appropriate geometric tool for studying polarization in general relativity. Then, based on the recent powerful results of distinct characterisation of Kerr spacetime using Killing spinors, we discuss how these results can place geometric, covariant conditions on the polarization vector that hold only and only for Kerr spacetime. This provides a potential avenue of directly anchoring spacetime properties into an astrophysical observable that can be richly probed by the ngEHT. The utility of spinors for radio astronomy instrumentation design and observables such as closure traces will also be briefly discussed.

Axion Constraints with Closure Trace Information
Avery Broderick

Black holes can attract light bosons to form bound states around them via black hole superradiance. Axion, and axion-like particles are candidate beyond-standard-model particles that can form such clouds around SMBHs and impact the polarization signal in a similar fashion to Faraday rotation via axion-photon coupling. With data from EHT M87 2017 observations, Chen et al. (2022) have already constrained the dimensionless axion-photon coupling to previously unexplored regions. With closure traces and conjugate closure trace products (CCTPs), it is possible to constrain the existence of axion clouds while avoiding the most dominant sources of systematic uncertainties, e.g., station gains and polarization leakages. Using a simple geometric model for the polarization map of M87, I will discuss the impact of an axion cloud in M87 on the CCTP phase. I will then present estimates of the accuracy with which an axion cloud may be excluded in M87 and Sgr A* by EHT and ngEHT.

ANTENNAS, INSTRUMENTATION, AND SOFTWARE I

Characterization of Frequency Phase Transfer Calibration performance for ngEHT, using simulation studies
María J. Rioja

A powerful proposed new feature in ngEHT is the capability for simultaneous multi-frequency observations at 85, 255 and 340 GHz. This enables application of frequency phase transfer and source/frequency phase referencing algorithms to compensate for the atmospheric effects; the benefits have been amply demonstrated in recent years upto 130 GHz using KVN. Here I will report on the impact of multi-frequency capabilities on the performance of ngEHT. We have performed frequency phase transfer simulations at the ngEHT frequencies with a complex and complete model of the atmosphere. The results show a massive improvement in the effective sensitivity of the array and a reduction on the weather constraints for the antenna site locations, by stabilizing the phases at the highest frequencies. We will make recommendations on guidelines to achieve the maximum benefits in different case scenarios. The enhanced performance from the multi-frequency capability enables unique science with ngEHT, expanding the astrophysical applications to include observations of weak objects, and possibly allow for ultra-precise astrometry measurements, such as ""core-shifts"" or the offset of the foot of the jet from the black hole itself, for example.

Modeling software correlator performance
Colin Lonsdale

The performance of software correlation systems depends on many factors, in addition to the properties of the hardware they run on. Among these are the details of how the data flows are partitioned and distributed, the number and magnitude of the processing jobs that are required in the chosen software architecture, and the parallelization and dynamic resource allocation tools employed. We describe a performance model that not only allows the characterization of existing

correlators and prediction of their performance in different scenarios, but also provides an understanding of the trade-offs inherent to the decisions associated with the software design.

Design considerations for the ngEHT Antennas

Nimesh Patel

The ngEHT array plans to deploy several new antennas, adding to the EHT array, which will significantly enhance the angular resolution and imaging fidelity in future observations of black hole shadows. Through high cadence time series of observations the ngEHT array will be able to to make black hole movies. We are currently in the process of defining the specifications of the new ngEHT antennas. The design goals for the new antenna must satisfy performance requirements driven by science goals, but also meet several operational requirements such as safe and reliable remote operations, minimal on-site operating staff, efficient monitoring and control, etc. The Greenland telescope in Thule, satisfies many of these requirements, including observations at all three ngEHT frequencies of 86, 230 and 345 GHz, but the ngEHT antenna would be of a smaller diameter, in the range of 6 to 10m. The NRAO VLBA is also a good model to follow in many aspects of the array design. While many details still need to be specified, the ngEHT antenna will be a standard altitude azimuth mount, cassegrain optics design, segmented dish of adjustable panels, with surface accuracy of 20 microns rms and all sky blind pointing accuracy of 2" rms.

FUNDAMENTAL PHYSICS III

Shadow of compact object without photon sphere

Ashok Joshi

It is generally believed that the shadows of a compact object arise due to the existence of the photon sphere. In this talk, I will show how a naked singularity can cast a shadow in the absence of the photon sphere. I will discuss some novel features of the shadow and the lightlike geodesics in that naked singularity spacetime. I will compare the shadow of the naked singularity with the shadow cast by the Schwarzschild black hole, where for the Schwarzschild spacetime the shadow is formed due to the presence of a photon sphere. It is seen, in particular, that the size of the shadow of the singularity is considerably smaller than that of a black hole. Our analysis shows that the shadow of this naked singularity is distinguishable from the shadow of a Schwarzschild black hole. These results are useful and important in the context of recent observations of the shadow of the M87 galactic center.

Photon Ring Symmetries in Simulated Linear Polarization Images of Messier 87*

Daniel Palumbo

The next generation analysis of supermassive black holes hinges on our understanding of the photon ring, the image feature corresponding to the sum of photons which wind multiple times

around the black hole before reaching the observer. In this talk, we outline a simple prediction for the behavior of linear polarization as it winds around the black hole in flat, Schwarzschild, and Kerr spacetimes. Using both a semianalytic toy model and a library of GRMHD simulations, we demonstrate behavior of near complex conjugation across adjacent photon ring indices "n" in the polarization scalar; this observation is related to more fundamental predictions by Himwich et al (2020) for the Penrose-Walker constant, and explains the Jimenez-Rosales et al (2021) result that photon rings are often diminished in total polarization. This relation will enable ngEHT measurements of the n=0 and n=1 photon rings to jointly constrain the magnetic field, emission geometry and spin of M87.

Image of the thin accretion disk around compact objects in the Einstein–Gauss–Bonnet gravity
Galin Gyulchev

We study the optical appearance of a thin accretion disk around compact objects within the Einstein-Gauss-Bonnet gravity. Considering static spherically symmetric black holes and naked singularities, we search for characteristic signatures which can arise in the observable images due to the modfication of general relativity. While the images of the Gauss-Bonnet black holes closely resemble the Schwarzschild black hole, naked singularities possess a distinctive feature. A series of bright rings are formed in the central part of the images with observable radiation 10^3 times larger than the rest of the flux, making them observationally significant. We elucidate the physical mechanism, which causes the appearance of the central rings, showing that the image is determined by the light ring structure of the spacetime. In a certain region of the parametric space, the Gauss-Bonnet naked singularities possess a stable and an unstable light ring. In addition, the gravitational field becomes repulsive in a certain neighbourhood of the singularity. This combination of features leads to the formation of the central rings implying that the effect is not specific to the Einstein-Gauss-Bonnet gravity but would also appear for any other compact object with the same characteristics of the photon dynamics.

Observational signatures of exotic compact objects: image of the thin accretion disk and linear polarization.
Petya Nedkova

Compact objects possessing no event horizon may often mimic black holes in their optical properties but in certain physical scenarios they exhibit clear-cut observational signatures. We discuss the optical appearance of the thin accretion disk around a certain class of naked singularities considering as a particular example the strongly naked Janis-Newman-Winicour singularity. These compact objects possess no photon sphere which results in the formation of a complex structure of bright rings in the central region of the disk image. Such structure is absent in the case of the Schwarzschild black hole, and implies the detection of an exotic compact object. We further discuss the possibility to distinguish horizonless compact objects by means of the linear polarization of the

radiation from the accretion disk. Considering the simplified model of an equatorial ring of magnetized fluid emitting synchrotron radiation, we obtain its polarized image for a class of static traversable wormholes and analyze the deviation of the observable polarization pattern from the Schwarzschild black hole for a range of physical parameters.

Photon Rings in Spherically-Symmetric Black Hole Spacetimes
Prashant Kocherlakota

The recent images of accreting supermassive black holes (BHs) obtained by the EHT as well as future observations at higher flux sensitivity and angular resolution herald new avenues with which to improve our understanding of accretion, emission processes, and of the spacetime metric in the strong gravitational field close to BH horizons. Due to the strong gravitational lensing close to the BH photon sphere, it becomes possible for light to loop around it multiple times before reaching a faraway observer. Such highly lensed photons appear within a narrow angular band on the observer's sky, called the photon ring, which can potentially be observed. The photon ring can typically be decomposed into a series of discrete photon subrings, that are organized self-similarly depending on the number of half-loops n executed around the BH. In this work, we explore the dependence of the observed photon n-ring locations on the morphology of the emitting region near the BH, and their variation with spacetime geometry. We demonstrate that an associated Lyapunov exponent, constructed from the locations of these n-rings, is insensitive to the emission physics and can be used as a characteristic of the spacetime geometry. Finally, we discuss how this exponent can also be obtained independently from the observed intensity profile close to the shadow boundary, when using analytic accretion-emission models. By investigating the impact of local emission physics on the intensity profile, we discuss how future strong-field measurements can be used to test the Kerr hypothesis and beyond.
Reference: Kocherlakota, Rezzolla, Wielgus, & Roy, in preparation

JETS + ACCRETION II

Plasmoid identification in 2D GRMHD simulations
Jesse Vos

The occurrence of plasmoids or, more aptly named, magnetic islands is a well-known phenomenon in plasma physics as it points towards a site of magnetic reconnection. It has been shown that this also happens within the accretion disk that surrounds a central black hole. Our aim is to quantify and investigate the plasmoid population that arises from our simulations to estimate what fraction of these objects would be observable with the ngEHT.

Non-thermal emission at event horizon and jet launching scales
Alejandro Cruz Osorio

Powerful radiation across the electromagnetic spectrum it's emitted in the vicinity of supermassive at AGNs cores, M87, and the Galactic Center. Numerical simulations showed the amount of accreted magnetized flux has a larger impact on the formation of a relativistic jet. I will present general relativistic magnetohydrodynamical and radiative transfer simulations. Relativistic jet is launching self-consistently, producing nonthermal emission. We will discuss the effects of the black hole spin, magnetic field strength, as well as thermodynamics properties of the plasma, particularly electron temperature and electron distribution function in the jet and accretion disc.

Analytical Model of Disk Evaporation and State Transitions in Accreting Black Holes
Hyerin Cho

A well-studied model of state transitions in black hole X-ray binaries postulates that gas evaporates from a thin accretion disk into a hot corona. We present a height-integrated version of this model which can be solved analytically and provides a physical understanding of different regimes. With radius r scaled to Schwarzschild units and coronal mass accretion rate $\dot{m}_c$ to Eddington units, the results are independent of black hole mass. Thus state transitions should be similar in X-ray binaries and AGN. The analytical solution consists of two power-law segments separated at a break radius, $r_b \sim10^3 \,(\alpha/0.3)^{-2}$, where α is the viscosity parameter. Gas evaporates from the disk to the corona for $r>r_b$, but condenses back for rr_b, and relativistic temperatures for $r \ll r_b$ where the current single-temperature approximation breaks down.

Effects of Opacity on Variability in Black Hole Images
Zachary Gelles

Variability in interferometric observations provides a unique window into the turbulent accretion flow surrounding supermassive black holes. Using novel ray-tracing techniques, I will describe how GRMHD simulations elucidate the connection between optical depth and variability in black hole images. I will explain how these images can be broken down into disk/wind, as well as photon ring/outer flow, with each of these domains providing a distinct contribution to the overall image variability. Finally, I will discuss how variability can illuminate a signature of light-bending, which can potentially be observed with the ngEHT.

Formation of limb-brightened jets by angular-dependent energy extraction from rotating black holes
Kouichi Hirotani

We demonstrate that the black hole's rotational energy is preferentially extracted from the middle latitudes by PIC simulations, provided that the accretion rate is much small compared to the Eddington limit. We then show that this middle-latitude concentration of the Poynting flux results in a formation of a limb-brightened jet in the downstream, assuming that the synchrotron emissivity is proportional to the local Poynting flux, which naturally peaks away from the jet symmetric axis. A pair

of jets appears one-sided due to relativistic beaming and the approaching jet appears limb-brightened in a wide range of observer's viewing angles and bulk Lorentz factors within a limited spatial range from the central engine.

Testing the Cosmic Battery mechanism with ngEHT

Ioannis Myserlis

The Cosmic Battery mechanism for producing poloidal magnetic flux in the vicinity of a black hole via the Poynting-Robertson effect on the accretion disk predicts a specific configuration for the large scale axial magnetic field: near the black hole it is parallel to the angular velocity Ω of the surrounding disk, while further away it is anti-parallel to Ω. Future ngEHT polarization observations of M87*, SgrA* and other targets, where the innermost accretion disk is observed in detail, offer an ideal opportunity to study the action of the Cosmic Battery, by deciding whether the field geometry is consistent with its premises. In this talk we will discuss the current status of observational evidence as well as the requirements of ngEHT observations to determine the magnetic field geometry around supermassive black holes that will help us test the Cosmic Battery mechanism in these systems.

BLACK HOLES AND COSMIC CONTEXT II

Multi-wavelength Variability and QPOs in Blazars

Alok Chandra Gupta

In the present talk I will discuss about recent results about multi-wavelength variability and QPOs in blazars.

Supermassive black hole binaries revealed through their periodic variability

Ioannis Liodakis

Supermassive black hole binaries (SMBHBs) are a direct consequence of hierarchical structure formation and hence should be a common occurrence in galactic nuclei. However, so far they have proven surprisingly elusive. Although a few candidates have been identified through the periodic signals possibly induced in their light curves due to the orbital motion of the SMBHB, we still lack confident detections. ngEHT can play a crucial role in confirming SMBHBs and paving the way for future gravitational wave experiments to resolve the gravitational wave background. I will discuss recent results and our current efforts to identify SMBHBs from a sample of ~1800 sources monitored by the Owens Valley Radio Observatory 40-m blazar program.

Zooming into the heart of the super-massive binary black hole system OJ287

Rocco Lico

In this talk we will review some recent results and ongoing works about high-resolution very long baseline interferometry (VLBI) observations of the blazar OJ287, one of the best super-massive

binary black hole system candidates. In particular we will focus on the results from an intensive multi-frequency campaign during 2017, featuring 22GHz RadioAstron space-VLBI, 86GHz GMVA+ALMA and 230GHz EHT observations.

VLBI scale probing of giant radio galaxies

Pratik Dabhade

The Giant Radio Galaxies (GRGs) represent an extreme and relatively rare class of active galaxies with linear sizes in the range of 0.7 Mpc to ~ 5 Mpc which places them among the largest single astrophysical objects known to us. It is still debated whether the large sizes of GRGs are due to the high efficiency of the radio jets ejected from the powerful central AGN or their sparser environments or a combination of both. Small sample studies over the years have enriched our knowledge about their radio properties and morphology; however, the nature of their AGN properties remained unexplored. To understand the formation, growth and evolution of GRGs, a project called the 'Search & Analysis of GRGs with Associated Nuclei' (SAGAN) was initiated. In order to study their properties from megaparsec to parsec (AGN) scales, multi-wavelength data of large samples selected at different flux density limits are needed. Hence, under the project SAGAN, we have as a first step (a) carried out an extensive search for GRGs from radio surveys like NVSS and LoTSS-DR1, (b) made a complete compendium of all known GRGs using current cosmological parameters, and (c) studied the AGN and environmental properties of the largest sample of GRGs to date. As a result of our search, we have found samples of GRGs from NVSS (162) and LoTSS (225), which almost doubled the known GRG population and a GRG-catalogue of ~820 sources has been compiled by us. The GRG-catalogue allowed us to probe the nature of accretion, feedback and excitation types of the AGN of GRGs. Using our GRG catalogue we were able to establish that the black hole mass and radio spectral index of GRGs and normal-sized radio galaxies (RGs) are similar. We classified the AGN excitation type of a large number of GRGs and found that GRGs do not have preferentially high or low excitation (or accretion mode) type AGN. We also find that GRGs with high excitation type AGN statistically have larger total radio power, jet kinetic power and Eddington ratio. Our environmental study of GRGs shows that only about 15% of GRGs reside at the centres of the clusters of galaxies, where the clusters tend to be of relatively low mass. We have also carried out a study of GRGs with GMRT at low frequencies to study its large scale radio properties and with the IRAM-30m millimetre wave telescope to study the molecular gas properties of the host galaxy. We have also carried out a survey of ~50 GRGs using VLBA to probe VLBI scale core-jet properties, unveiling its nature for the first time. The initial results of this study will be presented."

Multi-frequency MOJAVE VLBA Timelapse Imaging

Matthew Lister

The MOJAVE program has carried out monthly VLBA imaging of 25 blazars at 15 GHz, 24 GHz, and 43 GHz from 2019 August to 2021 August. The sample was chosen on the basis of strong

linearly polarized emission and transversely resolved jets, and include low, intermediate, and high-spectral peaked blazars. The expansion rates of the individual jets span a wide range from 25 microarcsec/y to 2.9 milliarcsec/y, and thus present an excellent data set with which to investigate reconstruction and interpolation methods for VLBI time lapse imaging. We present preliminary results and discuss future ngEHT applications for multi-epoch imaging of dynamic jet phenomena.

The filamentary structure of 3C279 probed by RadioAstron

Antonio fuentes

The EHT observed 3C279 in April 2017 at 1 mm, revealing the intriguing innermost structures present at the jet base. Comparable resolutions at centimeter wavelengths can only be achieved by extending the maximum baseline distance far beyond the Earth's diameter (ED). We will present 1 cm results obtained by a ground array of 23 antennas and the space radio-telescope RadioAstron in March 2014. With the successful detection of space-ground fringes up to 8 ED and a highly elliptical orbit perpendicular to the jet direction, we are able to probe, at angular resolutions similar to the EHT, the ultra-compact features of 3C279 close to the core and also the transverse extended jet emission. Total intensity images confirm the perpendicular nature of the core and the jet observed by the EHT and, in addition, large-scale helical filaments departing from the core and extending up to 1 mas. We interpret these filaments as produced by Kelvin-Helmholtz plasma instabilities threaded by a predominantly toroidal helical magnetic field, and propose a novel model in which moving components along the jet are a result of local changes in the properties of the plasma within the filaments as they evolve downstream the jet.

Exploring high resolution 3C279 inner structure with RadioAstron

Teresa Toscano

Blazar 3C279 is one of the most studied active galactic nuclei (AGN) due to the powerful radio jet emanating from its core. It has also been the target of numerous very long baseline interferometric (VLBI) observations and monitoring campaigns. Here we present a preliminary analysis space-VLBI observations of 3C279 carried out with RadioAstron at 1.3 cm, including a ground array with 16 radio telescopes spanning baselines distances up to several Earth diameters.

SITES II

Prospects for installing a new ngEHT antenna in Canary Islands

José L. Gómez

Canary Islands is the largest European observatory, and has excellent sky conditions for millimeter wave observations. The site provides also excellent additional uv-coverage for observations of M87* and SgrA*. We present the status of the project for installing a new dish in the Observatory of Teide.

Benefits of Kilimanjaro as an ngEHT site

Noorali Jiwaji

The iconic Mount Kilimanjaro in Tanzania is the world's tallest free-standing mountain and there has been interest for over a decade in use of the site for mm and submm wavelength Very Long Baseline Interferometry (VLBI). Over this time, developing local support for astronomy research on the mountain has required sustained effort in several key areas. Access to the region for research requires a process of obtaining permissions through official channels. The region is a highly visible and protected UNESCO heritage site, and it will be essential to work with local leaders at all levels of inclusivity, outreach and involvement as an integral part of exploring the astronomical potential without impacting on the aesthetics of the mountain and on the environment. We chart our efforts to build local support and to work with all stakeholders on use of the Saddle on Kilimanjaro, which will include economic benefits for increasing tourism and Tanzania's image globally. Recent efforts to initiate a science readiness study in collaboration with the Next Generation EHT (ngEHT) are elaborated. In particular, science simulations demonstrate the benefits of the Kilimanjaro saddle as an African ngEHT site.

Millimeter Astronomy at the Owens Valley Radio Observatory

Nitika Yadlapalli

The Owens Valley Radio Observatory has been identified as a promising site for a new ngEHT station, making use of decommissioned 10m CARMA dishes and existing infrastructure. Serving in part as a testbed for bringing online the ngEHT antenna is the Stokes Polarization Radio Interferometer for Time Domain Experiments (SPRITE), a single baseline millimeter interferometer also comprised of two 10m antennas. SPRITE is scheduled to start observing in the fall of 2022 and will focus on time-variability of millimeter sources as well as support EHT science goals by providing frequent monitoring of target sources. We will discuss the current status of commissioning for SPRITE and its implications for the success of the ngEHT antenna. Additionally, we will discuss SPRITE's utility in following up synchrotron millimeter transients (such as interacting supernova, GRB afterflows, and TDEs) and providing useful insights into the environments in which these events occur.

Current Status of the LLAMA Observatory

Manuel Fernandez Lopez

The Large Latin American Array (LLAMA) will be a millimeter and submillimeter 12m antenna installed in the northern border of Argentina. This bi-national project between Argentina and Brazil is getting momentum to get operational by the next few years. In this talk, I will present the current status of the project, and the perspective for LLAMA to be part of the ngEHT, which would make a 180km NW-SE baseline with ALMA and APEX.

ANTENNAS, INSTRUMENTATION, AND SOFTWARE

SAO VLBI Digital Back End development

Ranjani Srinivasan

We show the current status of the development for the Block Down Converter (BDC) and the Digital Back-End (DBE) for the next generation Event Horizon Telescope. The BDC is the down converting and signal conditioning unit which precedes the digitization stage. This is a purely RF analog processing block which uses Monolithic Microwave Integrated Circuit (MMIC) technology to provide a compact, low power and cost effective solution for the analog processing stage of the backend. A prototype has passed the design review process and is currently under production. The most relevant Analog to Digital Converter (ADC) metrics for the first Nyquist zone (sampling at 16.384 GHz) for all 4 ADCs on the 4 channel ADC board developed by SAO will be highlighted. Each ADC is a high speed single core 4 bit ADC from Adsantec, the 7123A, which has a nominal analog bandwidth of 20 GHz. The progress of the effort to design an integrated ADC/FPGA board in house will be presented. The integration will combine the 4 channel ADCs and with a suitable FPGA in order to achieve a total processing bandwidth of approximately 32 GHz on a single board. A brief overview of the DBE firmware requirements, the primary ones being the number of channels and the high speed 100 Gb output interface, will be presented. Results from the firmware development will be presented by our collaborators from the Argentine Institute of Radio Astronomy (IAR) and CognitionBI. The discussion will include the feasibility of channelizing the data as per the requirements on a single Virtex Ultrascale+ VU37P HBM FPGA which is fed by all 4 ADCs.

TBD

Emilia Mamami

TBD

Takeaways from the DBE technical working group

Jonathan Weintroub

TBD

Progress on the Haystack Observatory Postprocessing System (HOPS)

Dan Hoak

The HOPS software package is a widely-used tool for "fringe-finding": solving for residual delay and delay-rate solutions for VLBI data following correlation. The HOPS4 refactoring project is in the process of updating this software package to accommodate the requirements of the ngEHT and allow for greater flexibility and ease of use. On-going changes include establishing more versatile data structures, transparent and flexible data processing routines, updated plotting utilities and

graphical-user interfaces, and entry points for user extensions in other languages (eg Python). Here, we describe progress on the HOPS4 pipeline, explain the layout of new interfaces and data structures, and describe next steps to enable science with the ngEHT.