# Relativistic Astrophysics: Progress, Promise and Prospects

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SCEECS
KIPAC
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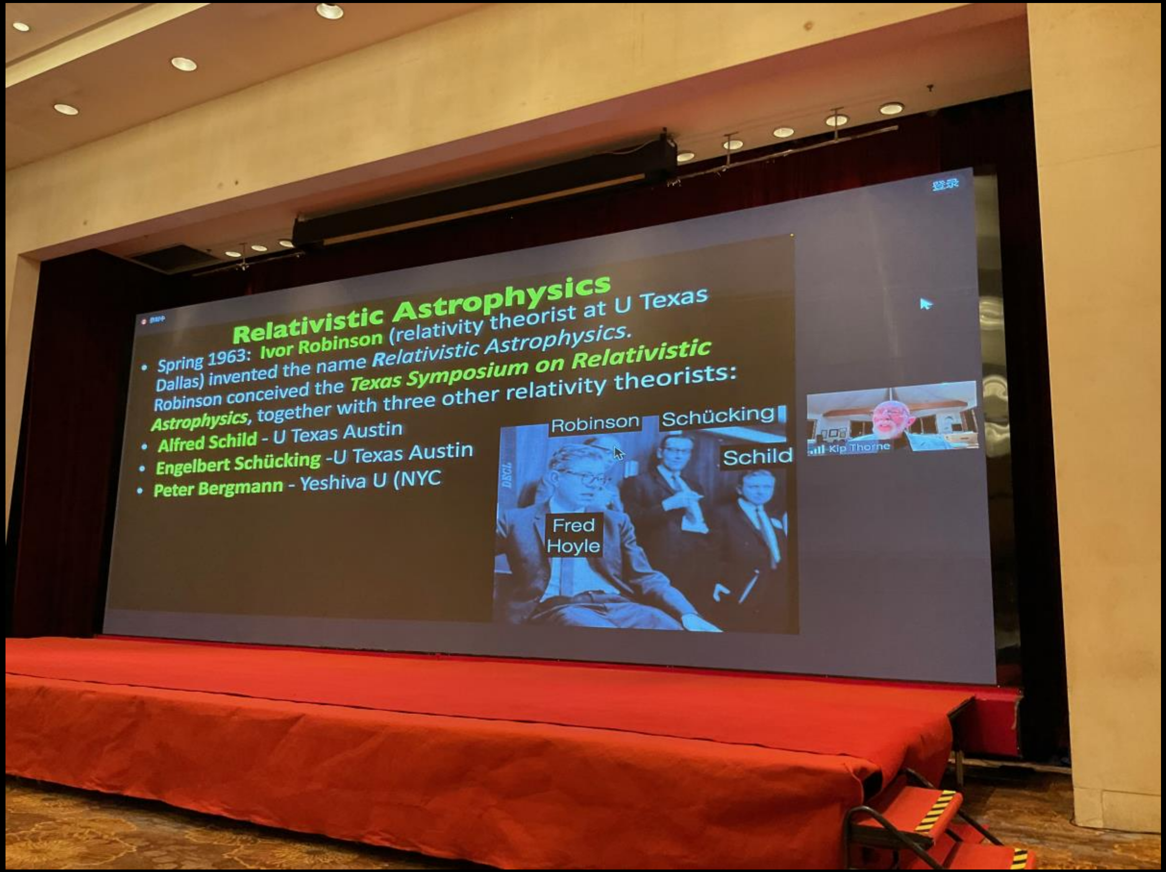
# Progress, Promise and Prospects

- Progress: Relativistic Astrophysics since Texas I in 1963
- Promise: Bold Aspirations
- Prospects: Realizable Projects amd Programs in the Near Term

# Relativistic Astrophysics

- Black Holes
- Neutron Stars
- Gravitational Waves
- Cosmology

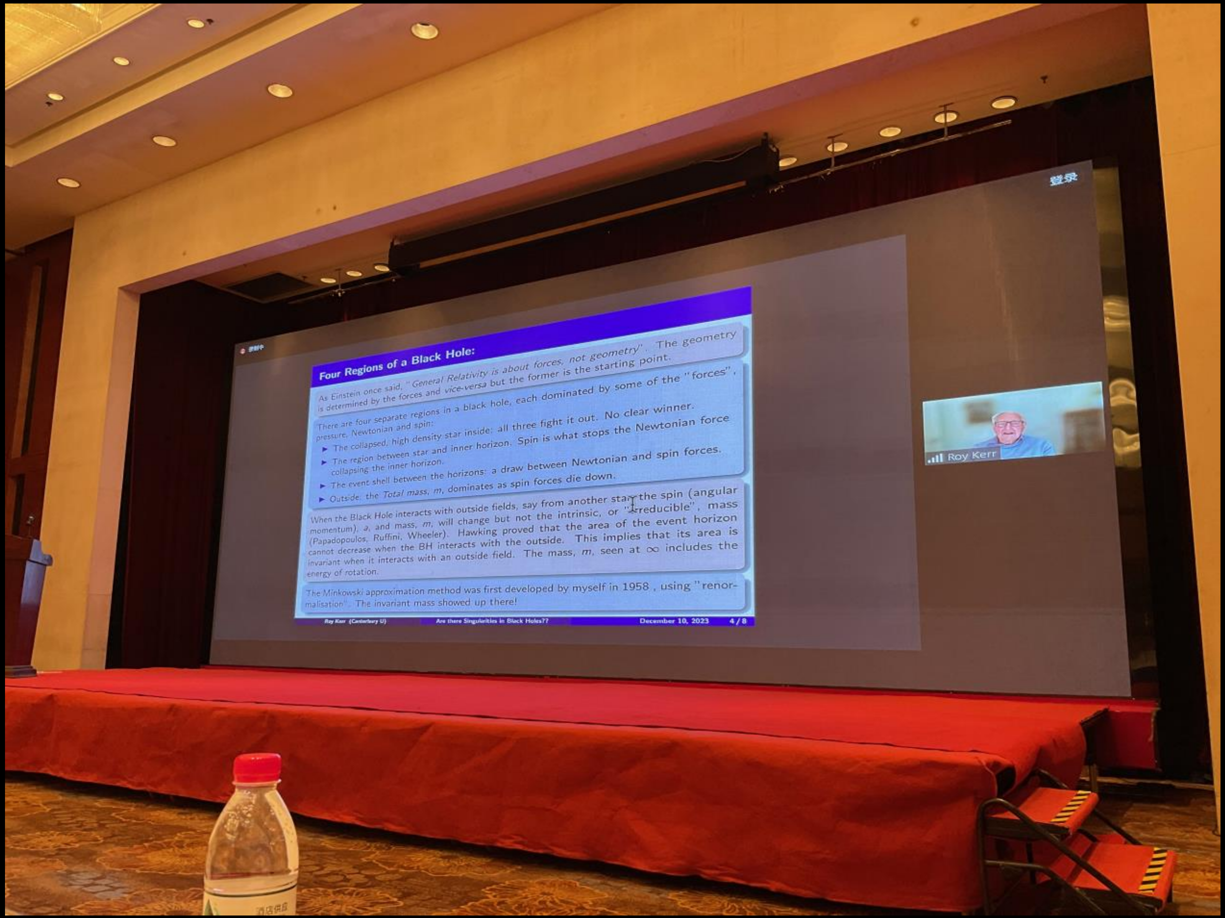


# Progress

# Black Holes

- Kerr metric
  - General Relativity
  - Event horizon, gravitational and rotational energy
  - Singularities
  - Kerr-Newman…


As Seen From Outside
Time slows to a halt!
FROZEN
My Comments:
Nobel-level research, but
No effort to understand more deeply.
With greater effort, Oppenheimer might well have discovered:
The event horizon, as a null surface in spacetime
The smooth connection across the horizon from exterior to interior …
i.e. our modern understanding of black holes and how they form.
"Star Cuts itself off from the Universe"
Kip Thorne


登录
Four Regions of a Black Hole:
As Einstein once said, "General Relativity is about forces, not geometry". The geometry is determined by the forces and vice-versa but the former is the starting point.
There are four separate regions in a black hole, each dominated by some of the "forces", pressure, Newtonian and spin:
The collapsed, high density star inside: all three fight it out. No clear winner.
The region between star and inner horizon. Spin is what stops the Newtonian force collapsing the inner horizon.
The event shell between the horizons: a draw between Newtonian and spin forces.
Outside, the Total mass, m, dominates as spin forces die down.
When the Black Hole interacts with outside fields, say from another star the spin (angular momentum), a, and mass, m, will change but not the intrinsic, or "reducible", mass (Papadopoulos, Ruffini, Wheeler). Hawking proved that the area of the event horizon cannot decrease when the BH interacts with the outside. This implies that its area is invariant when it interacts with an outside field. The mass, m, seen at ∞ includes the energy of rotation.
The Minkowski approximation method was first developed by myself in 1958 , using "renormalisation". The invariant mass showed up there!
Are there Singularities in Black Holes??
December 10, 2023
4 / 8
Roy Kerr

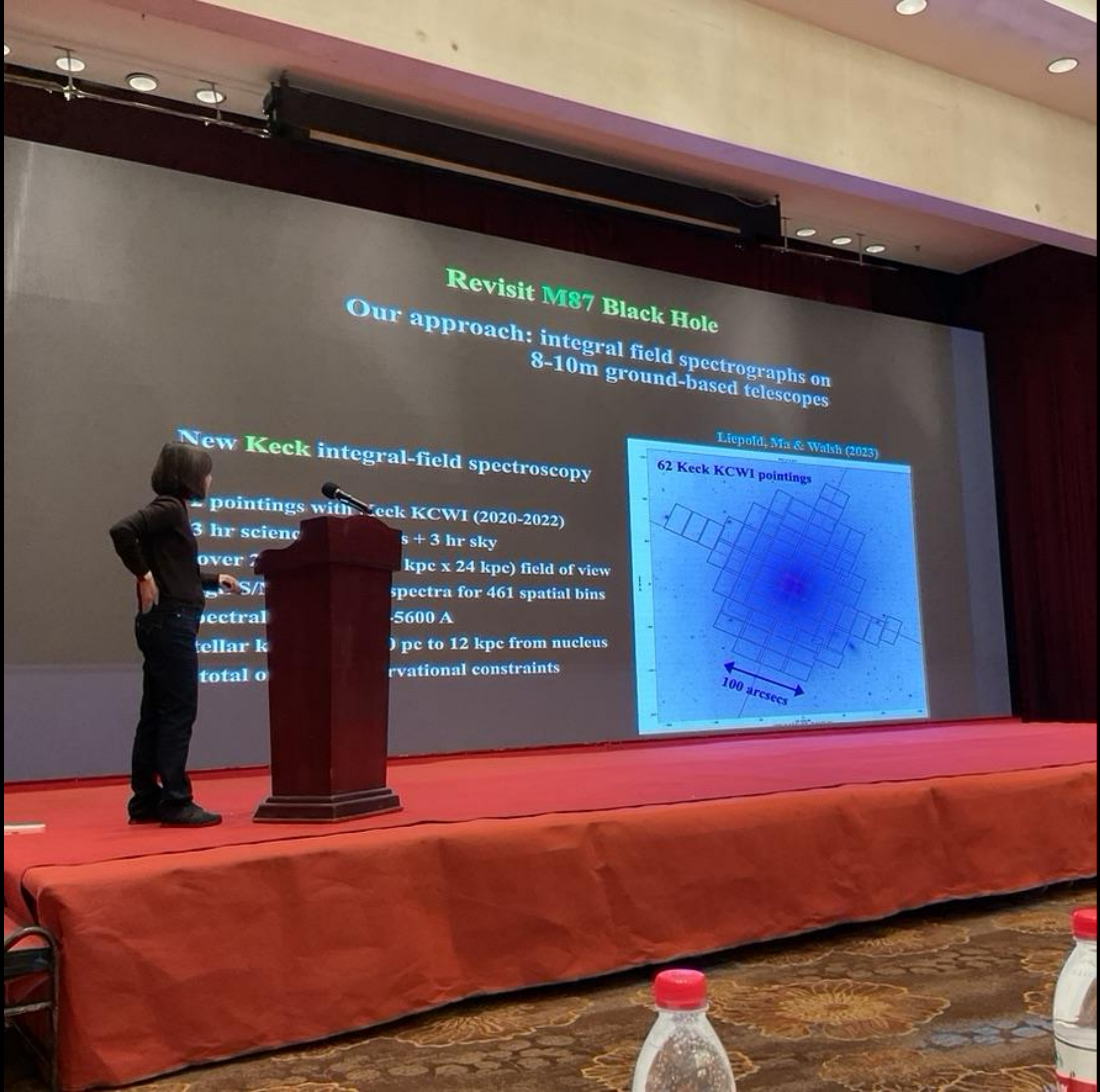
# Black Holes

- Kerr metric
  - General Relativity
  - Event horizon, gravitational and rotational energy
  - Singularities
  - Kerr-Newman…
- Active Galactic Nuclei
  - Prime Movers
  - Radio Sources, Jets, Blazars
  - EHT Imaging
  - 0.3 ZeV Cosmic Rays (Amaterasu); TeV $\gamma$, PeV $\nu$


正在发言：Texas
M87*
First polarized
image of a black hole
consistent with
left-handed
spiral in
magnetic field
EHTC+ 2021
ILLINOIS


正在发言： Texas
Jet and Black Hole!
Lu et al. 2023
GMVA 3mm image
ILLINOIS

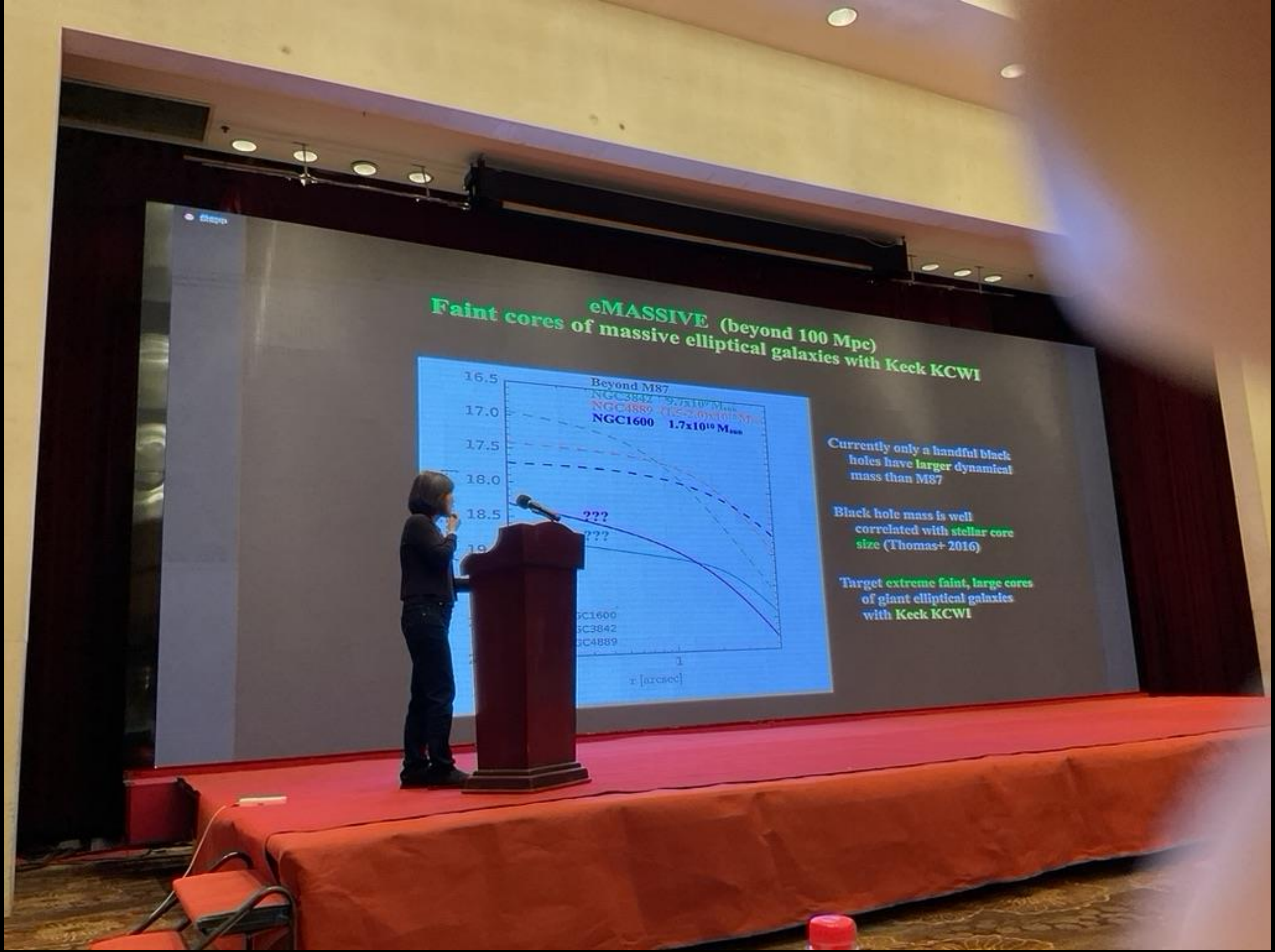

Parameter Space of shocks
"Magnetization" $\sigma \equiv \frac{B^2/4\pi}{(\gamma-1)nmc^2} = \frac{2}{M_A^2} = \left(\frac{\omega_c}{\omega_p}\right)^2 \left(\frac{c}{v}\right)^2 = \left[\frac{c/\omega_p}{R_L}\right]^2$
$M_A = \frac{v}{v_A}$ $M_s = \frac{v}{v_{th}}$ $\beta = \frac{M_A^2}{M_s^2}$ $\frac{m_i}{m_e}$
Magnetization
1
Solar
SNRs
Virial
relativistic
AGN jets
PWN
GRB
$10^{-2}$
1
$10^2$
$\gamma_{sh}\beta_{sh}$


Revisit M87 Black Hole
Our approach: integral field spectrographs on 8-10m ground-based telescopes
New Keck integral-field spectroscopy
Liepold, Ma & Walsh (2023)
62 Keck KCWI pointings
100 arcsecs

15 xii 2023


Revisit M87 Black Hole
Net angular momentum of stars
Our best-fit galaxy model
Net stellar L is nearly aligned with jet !
BH spin pointing towards us
approaching jet
accretion flow
$a_* > 0, i > 90°$
$a_* < 0, i > 90°$
$a_* > 0, i < 90°$

15 xii 2023


eMASSIVE (beyond 100 Mpc)
Faint cores of massive elliptical galaxies with Keck KCWI
Beyond M87
NGC1600 1.7x10^10 Msun
???
???
Currently only a handful black holes have larger dynamical mass than M87
Black hole mass is well correlated with stellar core size (Thomas+ 2016)
Target extreme faint, large cores of giant elliptical galaxies with Keck KCWI
r [arcsec]

# Black Holes

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  - General Relativity
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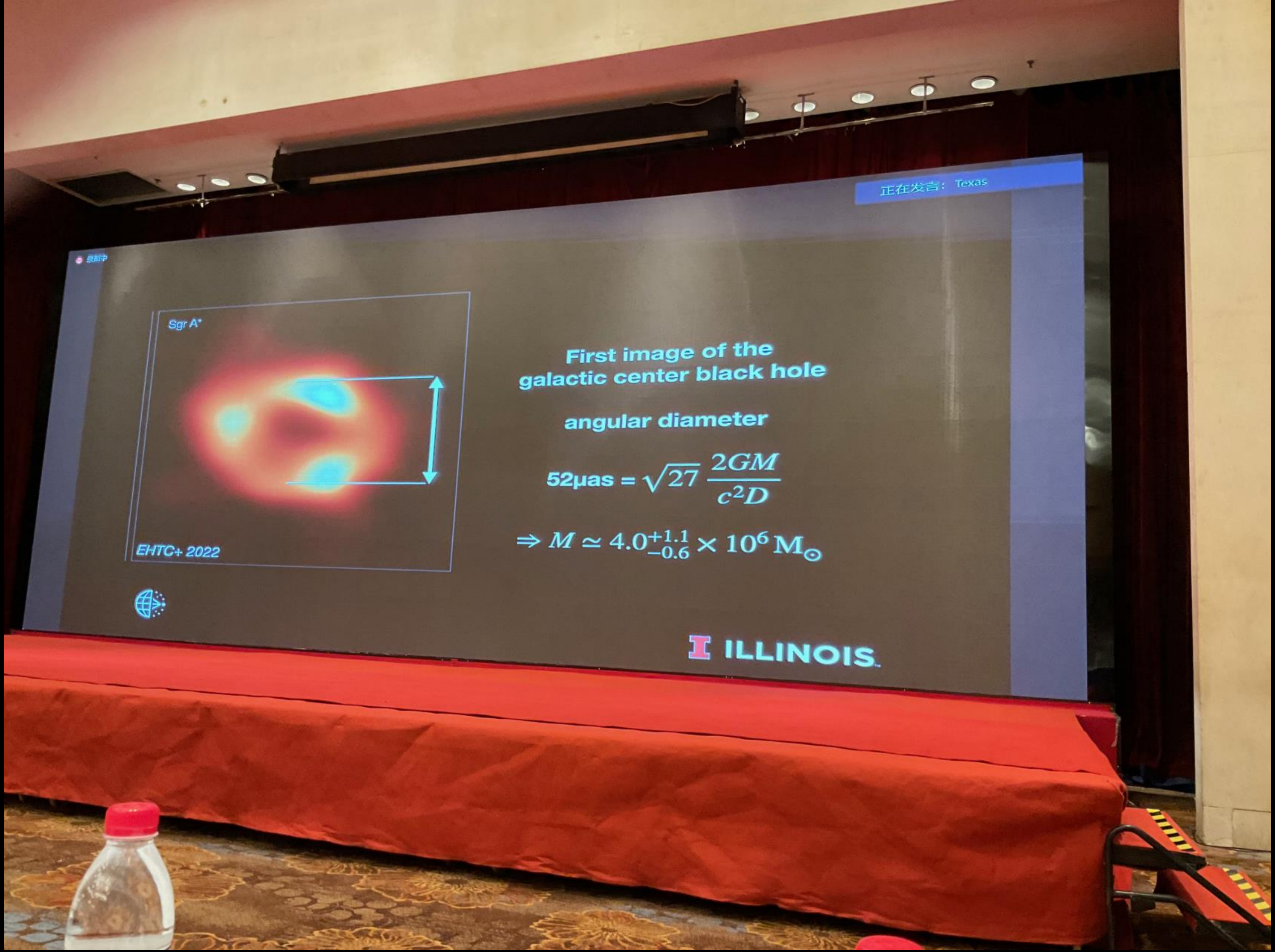
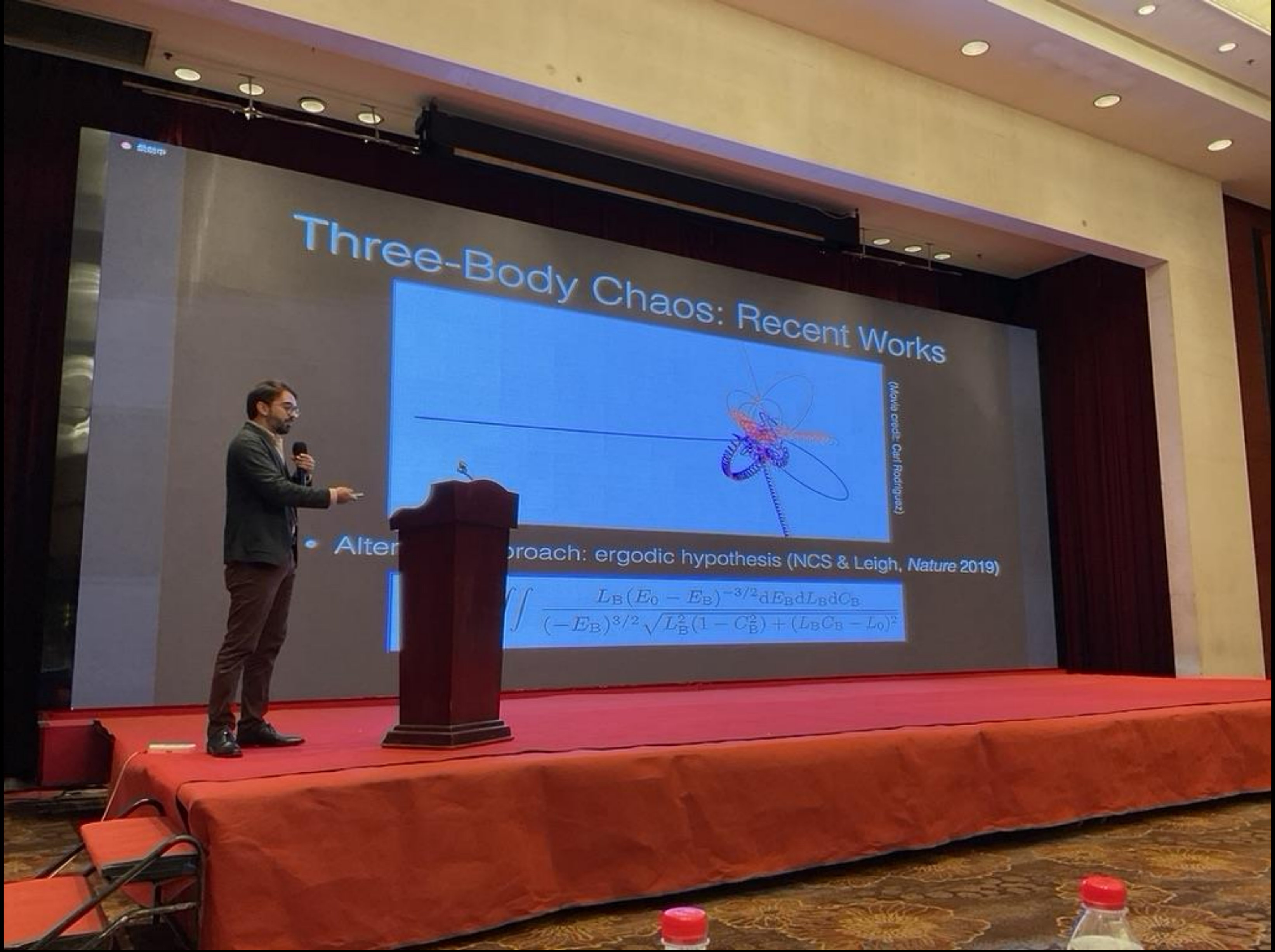
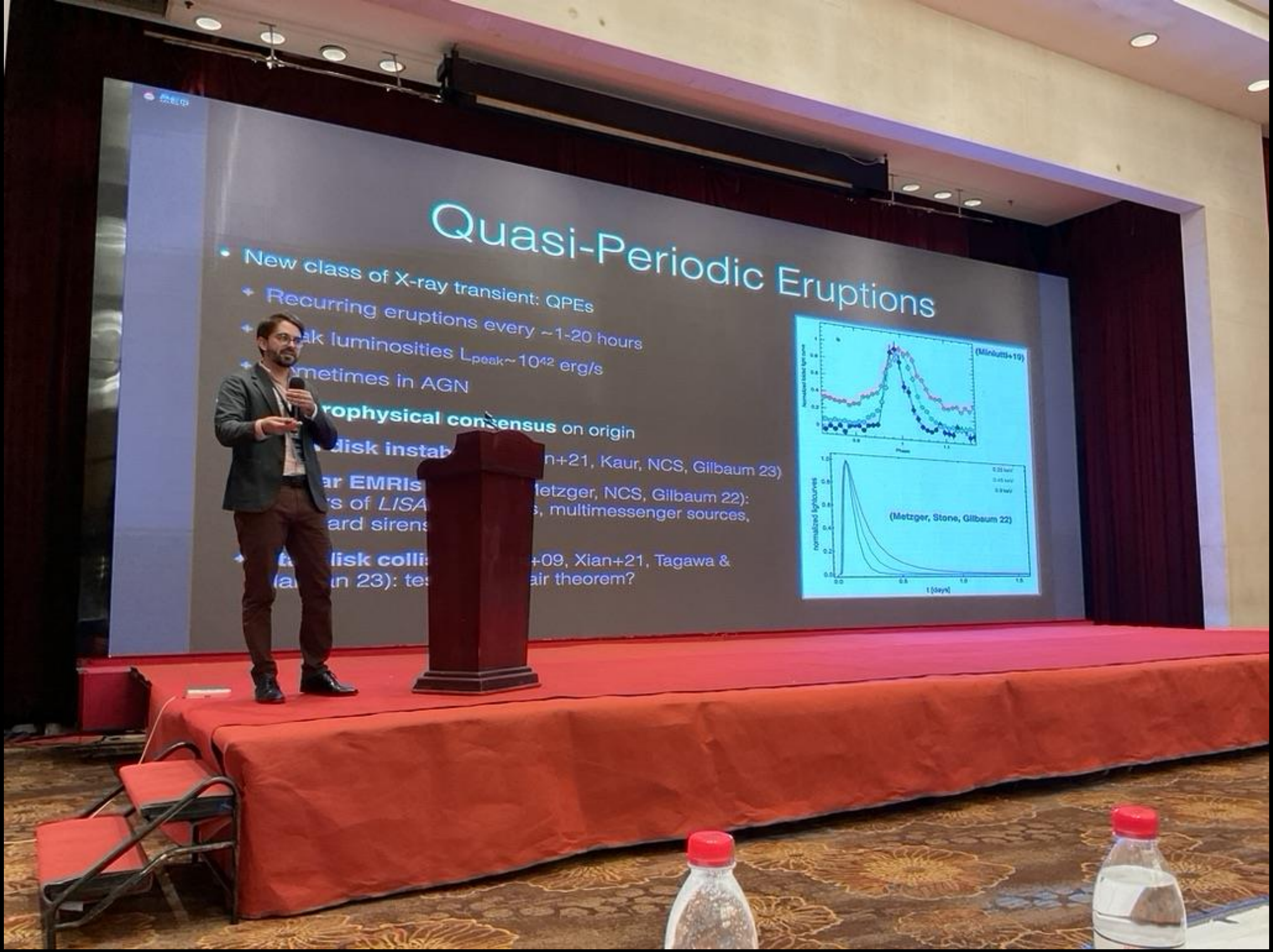
  - Singularities
  - Kerr-Newman…
- Active Galactic Nuclei
  - Prime Movers
  - Radio Sources, Jets, Blazars
  - EHT Imaging
  - 0.3 ZeV Cosmic Rays (Amaterasu); TeV $\gamma$, PeV $\nu$
- Dormant Galactic Nuclei
  - SgrA*
  - Tidal Disruption Events; Quas-Periodic Eruptions


正在发言：Texas
Sgr A*
EHTC+ 2022
First image of the galactic center black hole
angular diameter
52μas = $\sqrt{27}\,\frac{2GM}{c^2D}$
$\Rightarrow M \simeq 4.0^{+1.1}_{-0.6} \times 10^6\,M_\odot$
ILLINOIS


Tidal Disruption Events
Tidal Disruption Events (TDEs) appealing MBH probes
Occur in every galaxy with a MBH
to cosmological distances
free parameters -> MBH parameter estimation plausible
motivati
Farrar & Piran 14, Stein+21)
(Wen, Jonker, NCS+21)
(Rees 88)


Three-Body Chaos: Recent Works
(Movie credit: Carl Rodriguez)
Alter roach: ergodic hypothesis (NCS & Leigh, Nature 2019)


Quasi-Periodic Eruptions
New class of X-ray transient: QPEs
Recurring eruptions every ~1-20 hours
(Miniutti+19)
(Metzger, Stone, Gilbaum 22)

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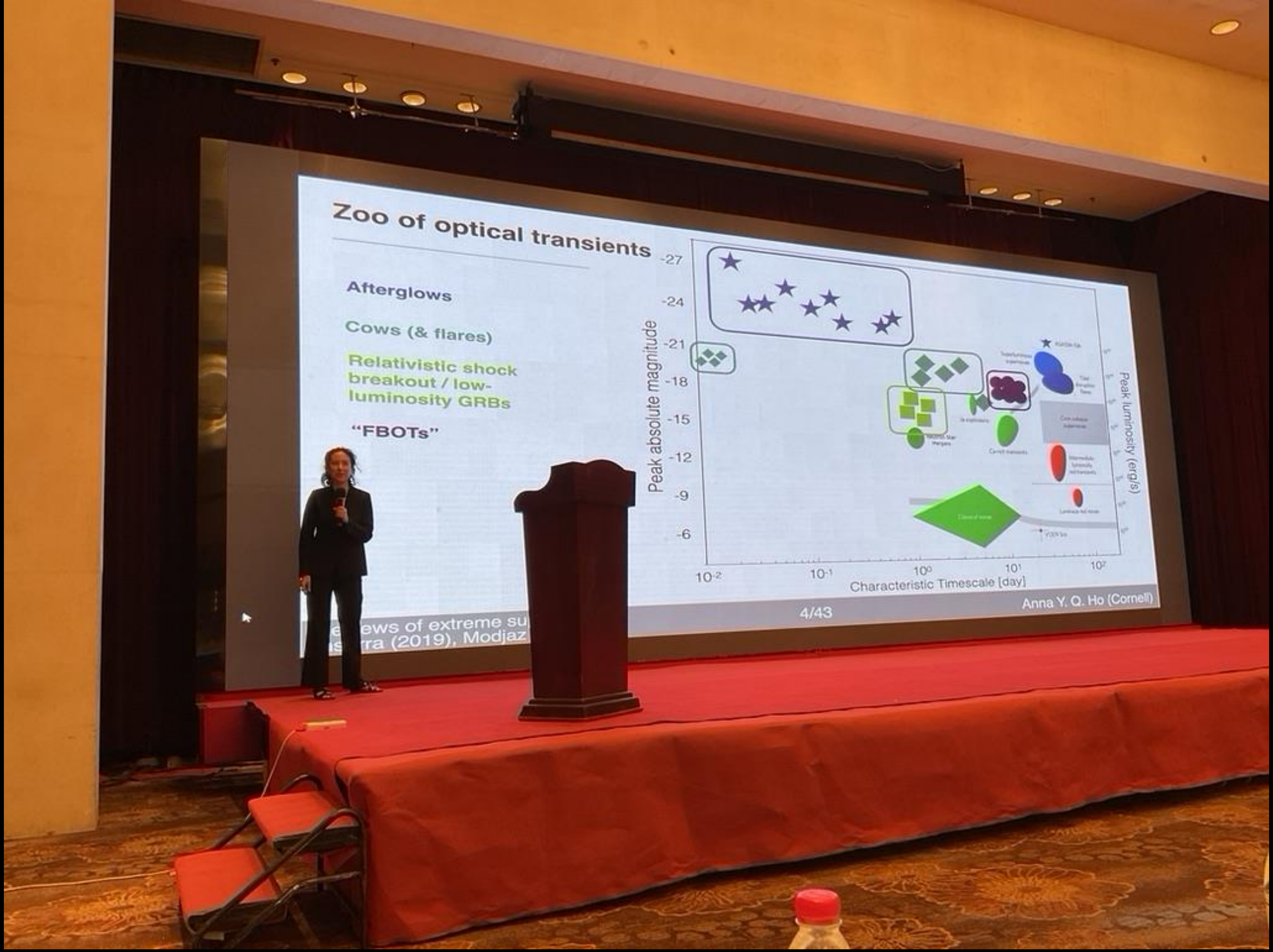
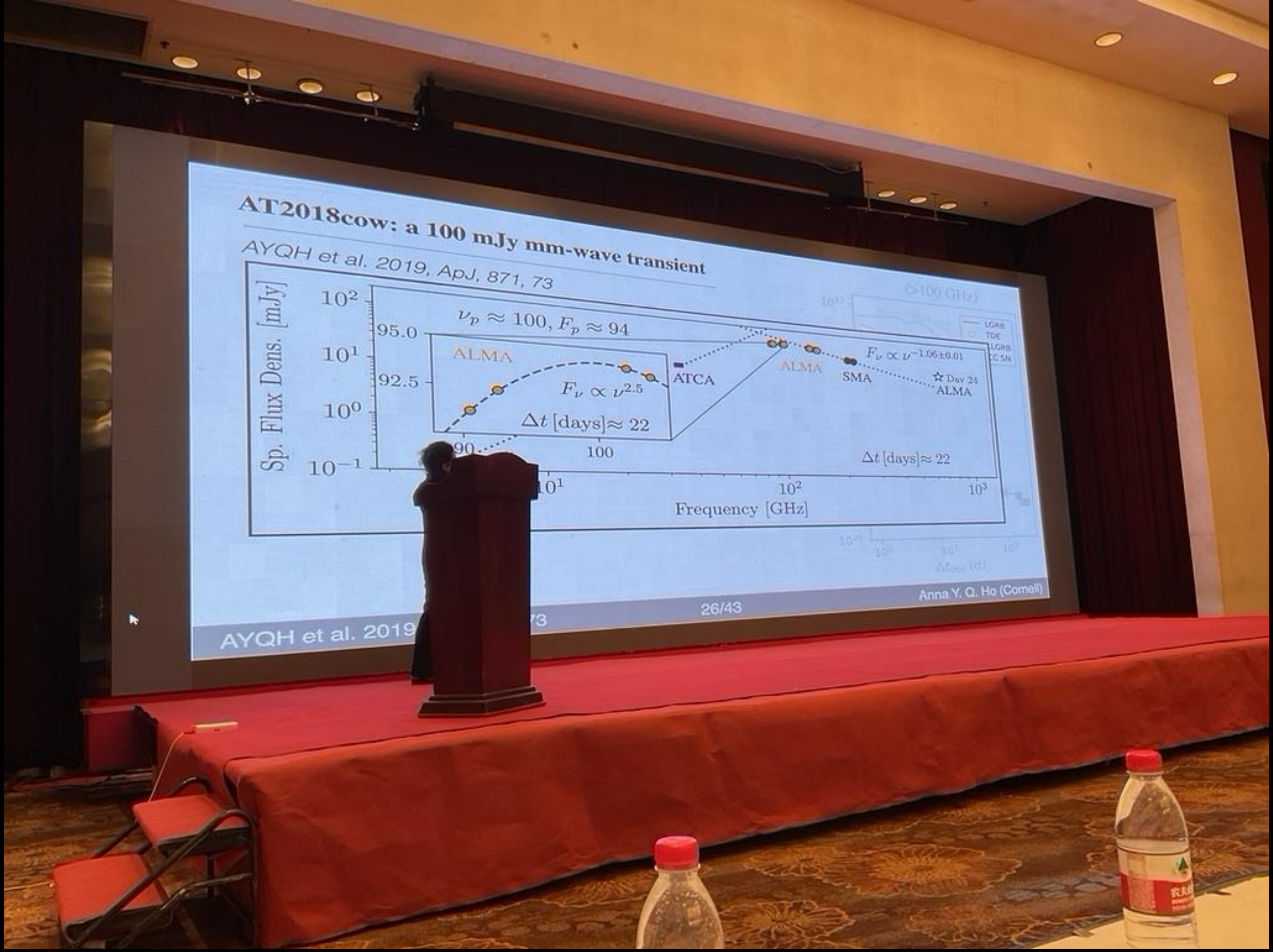
  - SgrA*
  - Tidal Disruption Events; Quas-Periodic Eruptions
- High Mass X-ray Binaries
  - Cyg X1, SS 433…
  - Galactic Superluminals
- Gamma Ray Bursts and Core-Collapse Supernovae
  - Long
  - Short
  - Jets


Zoo of optical transients
Afterglows
Cows (& flares)
Relativistic shock breakout / low-luminosity GRBs
"FBOTs"
Peak absolute magnitude
Peak luminosity (erg/s)
Characteristic Timescale [day]
4/43
Anna Y. Q. Ho (Cornell)


AT2018cow: a 100 mJy mm-wave transient
AYQH et al. 2019, ApJ, 871, 73
Sp. Flux Dens. [mJy]
$\nu_p \approx 100, F_p \approx 94$
ALMA
$F_\nu \propto \nu^{2.5}$
$\Delta t$ [days]$\approx 22$
ATCA
SMA
$F_\nu \propto \nu^{-1.06\pm0.01}$
Day 24 ALMA
Frequency [GHz]
26/43
Anna Y. Q. Ho (Cornell)

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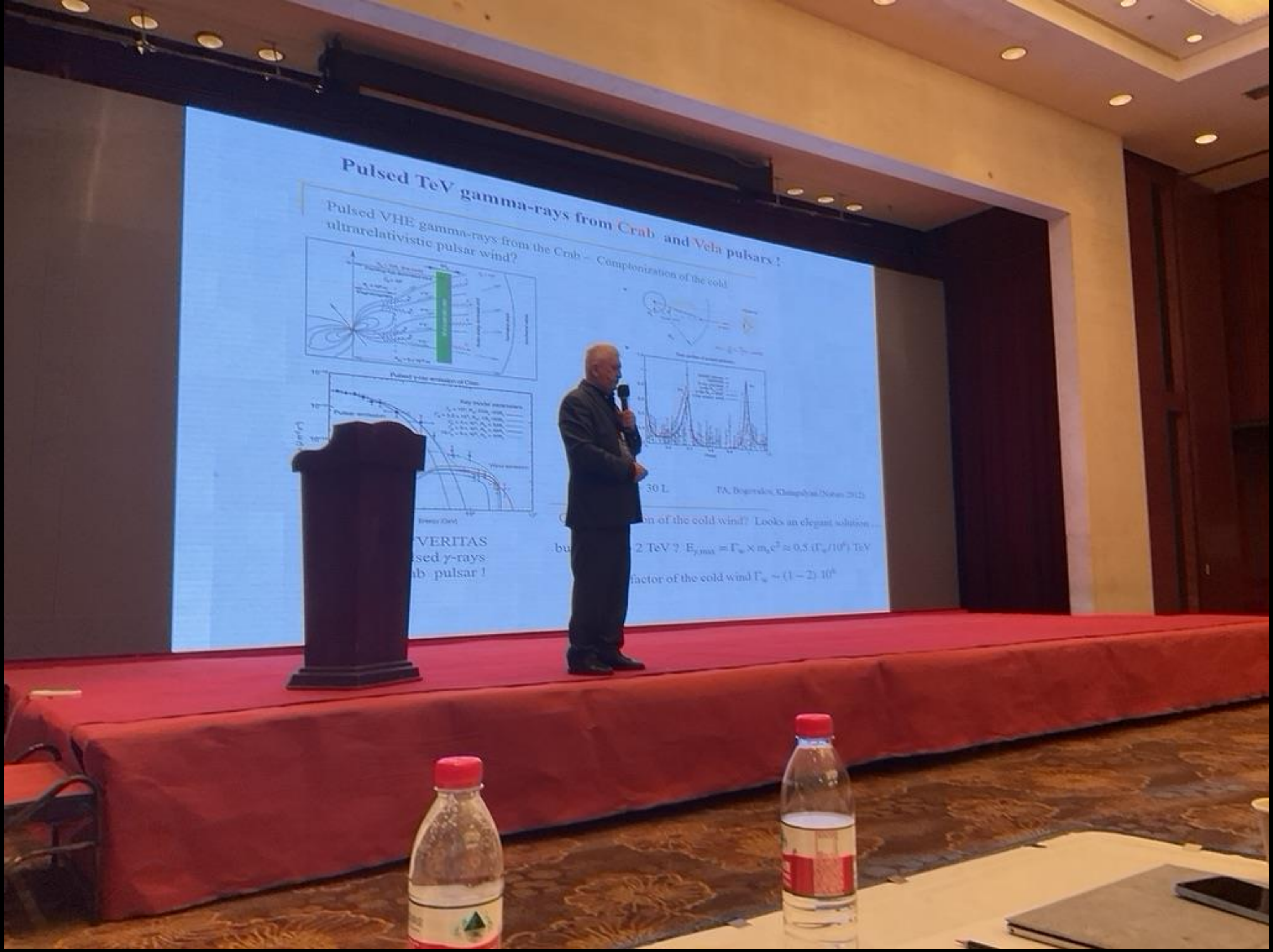
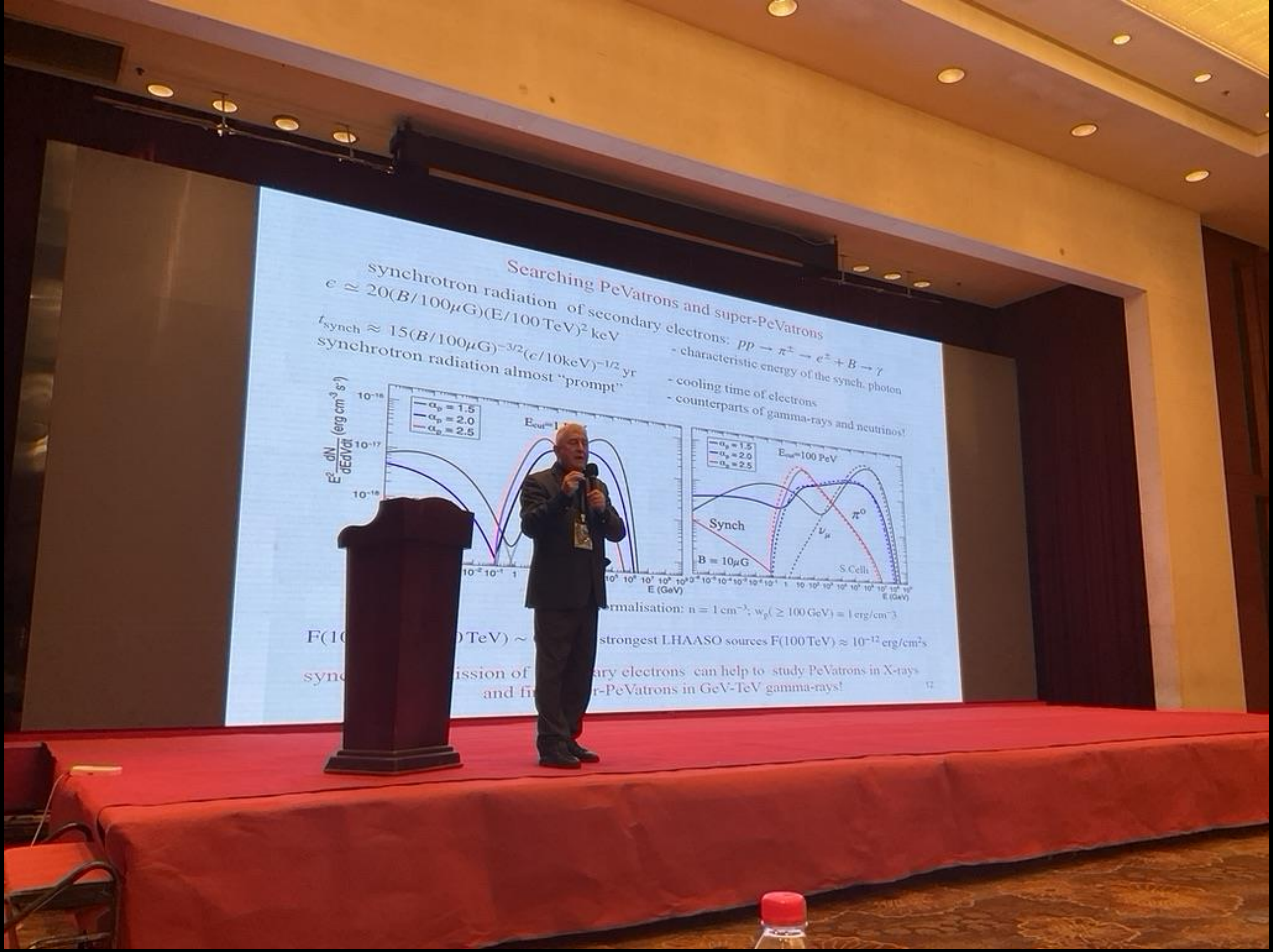
- High Mass X-ray Binaries
  - Cyg X1, SS 433…
  - Galactic Superluminals
- Gamma Ray Bursts
  - Long
  - Short
  - Jets
- Primordial Black Holes
  - QED in Curved Space Time
- Quantum Gravity
  - Wormholes, White Holes…

# Neutron Stars

- Low Mass X-ray Binaries
  - Sco-X1…
- Pulsars
  - Cosmic Laboratories, Astronomical Tools
  - Binary Pulsars and Tests of GR
  - Millisecond Pulsars
  - Pulsar Wind Nebulae; PeV $\gamma$; Pevatrons


Pulsed TeV gamma-rays from Crab and Vela pulsars !
Pulsed VHE gamma-rays from the Crab – Comptonization of the cold ultrarelativistic pulsar wind?


Searching PeVatrons and super-PeVatrons
synchrotron radiation of secondary electrons: pp → π± → e± + B → γ
- characteristic energy of the synch. photon
- cooling time of electrons
- counterparts of gamma-rays and neutrinos!
synchrotron radiation almost "prompt"
Synch
B = 10μG
E (GeV)
S.Celli
strongest LHAASO sources F(100 TeV) ≈ 10⁻¹² erg/cm²s
and fi
r-PeVatrons in GeV-TeV gamma-rays!


The ultimate goal is to identify origins of CRs
Scientific Goals
γ-ray astronomy:
Survey for sources (above 500 GeV)
Large High Altitude Air Shower Observatory
LHAASO
~25,000m
4,400m

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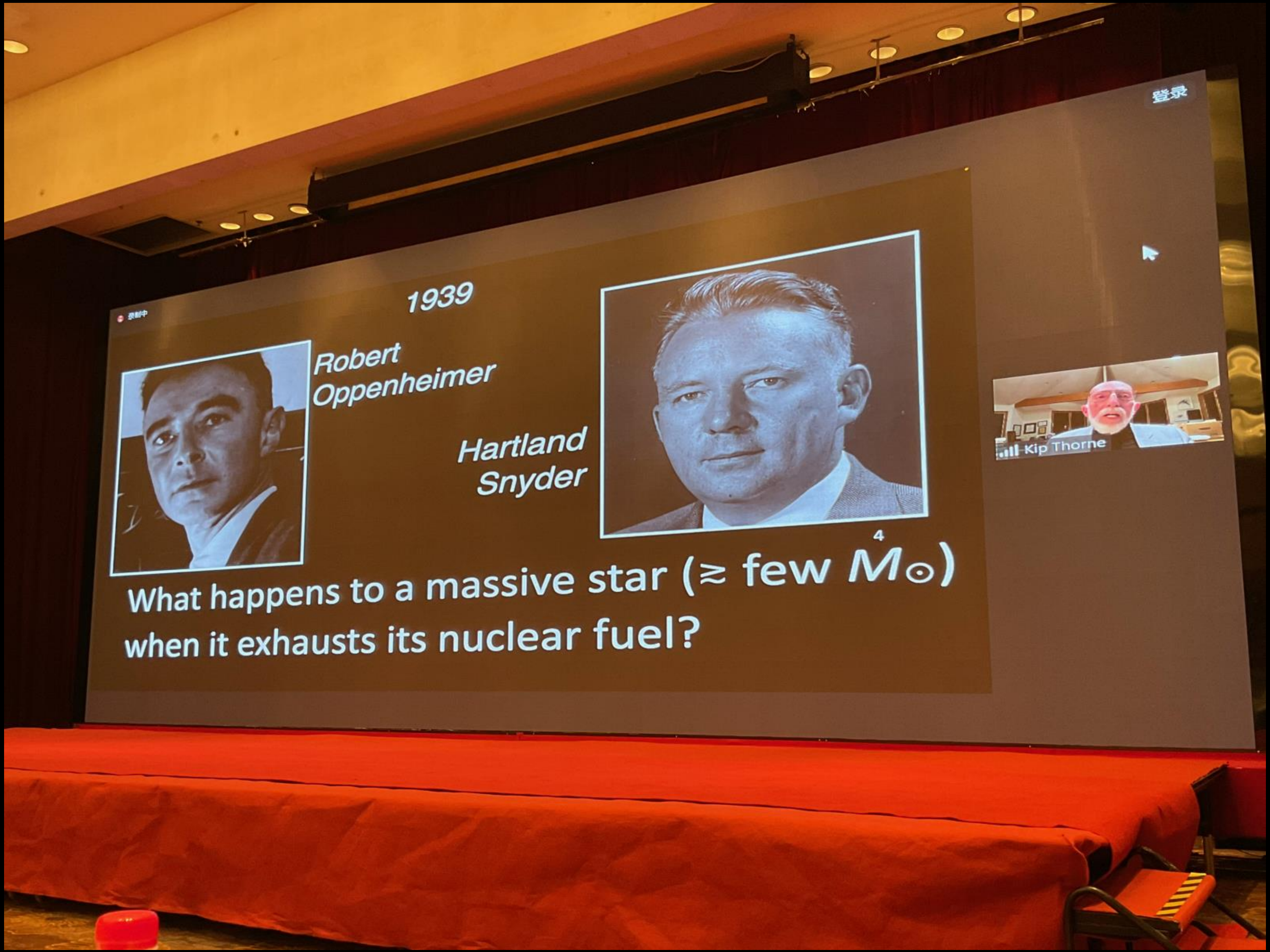
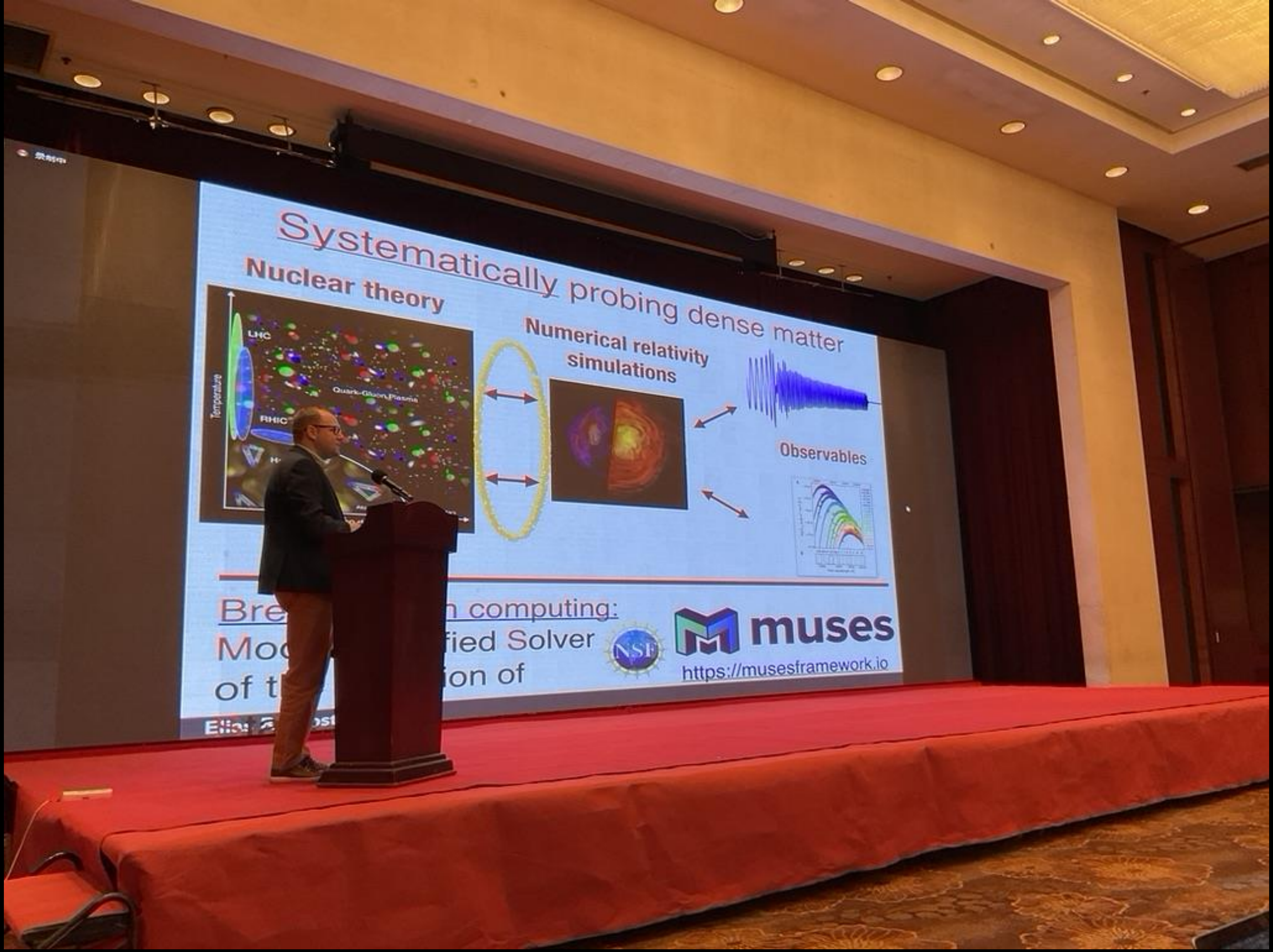
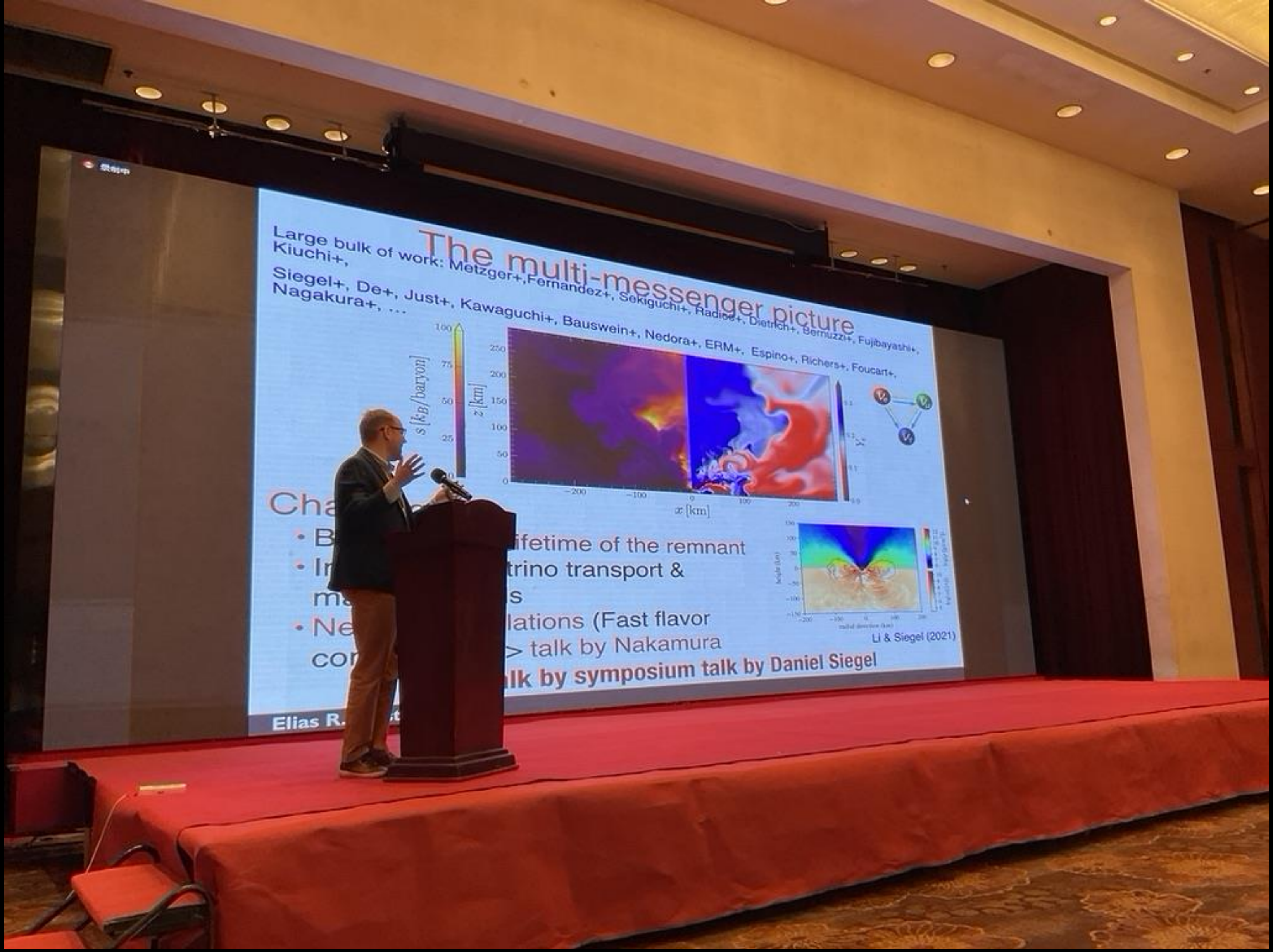
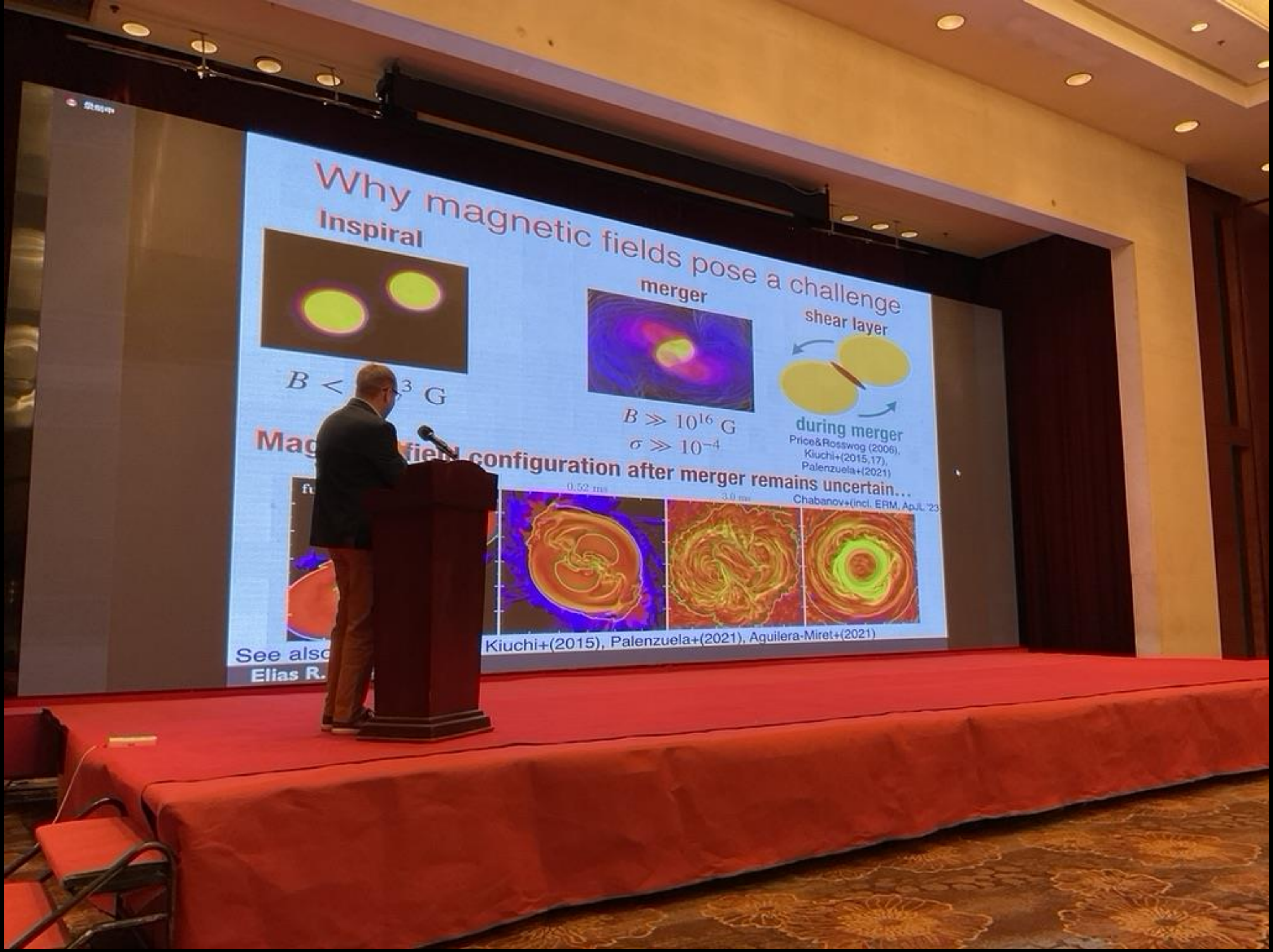
  - Binary Pulsars and Tests of GR
  - Millisecond Pulsars
  - Pulsar Wind Nebulae; PeV $\gamma$; Pevatrons
- Supernovae
  - Core collapse etc
  - Lensing
  - White Dwarf
  - Kilonovae; Multi-Messenger Astrophysics

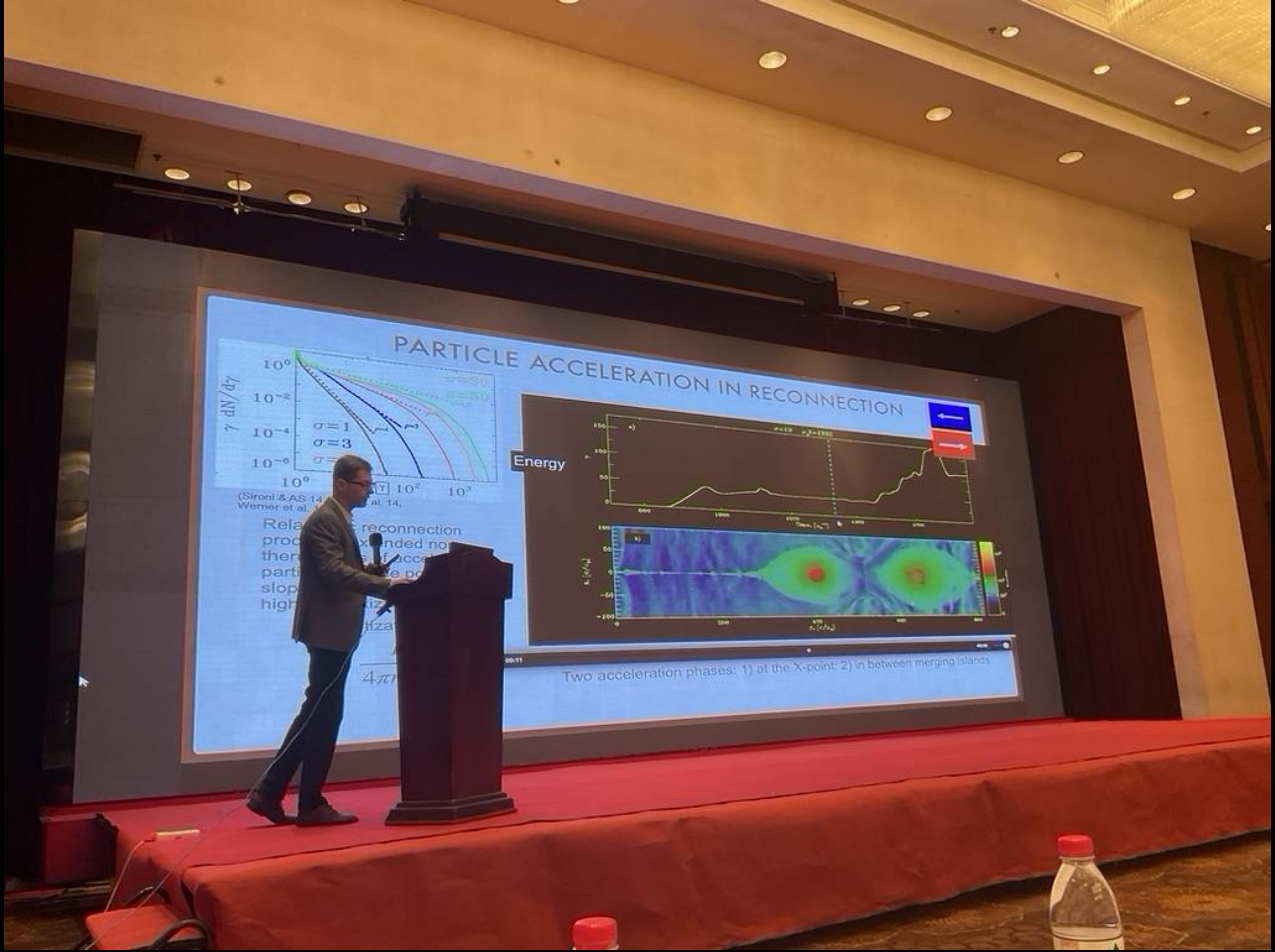


1939
Robert Oppenheimer
Hartland Snyder
What happens to a massive star (≳ few M⊙)
when it exhausts its nuclear fuel?
Kip Thorne
登录


Systematically probing dense matter
Nuclear theory
Numerical relativity
simulations
Observables
Quark-Gluon Plasma
LHC
muses
https://musesframework.io


The multi-messenger picture
Large bulk of work: Metzger+,Fernandez+, Sekiguchi+, Radice+, Dietrich+, Bernuzzi+, Fujibayashi+, Kiuchi+,
Siegel+, De+, Just+, Kawaguchi+, Bauswein+, Nedora+, ERM+, Espino+, Richers+, Foucart+, Nagakura+, ...
ifetime of the remnant
trino transport &
lations (Fast flavor
> talk by Nakamura
lk by symposium talk by Daniel Siegel
Li & Siegel (2021)
Elias R.


Why magnetic fields pose a challenge
Inspiral
merger
shear layer
$B \gg 10^{16}$ G
$\sigma \gg 10^{-4}$
during merger
Price&Rosswog (2006),
Kiuchi+(2015,17),
Palenzuela+(2021)
configuration after merger remains uncertain…
Chabanov+(incl. ERM, ApJL '23)
Kiuchi+(2015), Palenzuela+(2021), Aguilera-Miret+(2021)

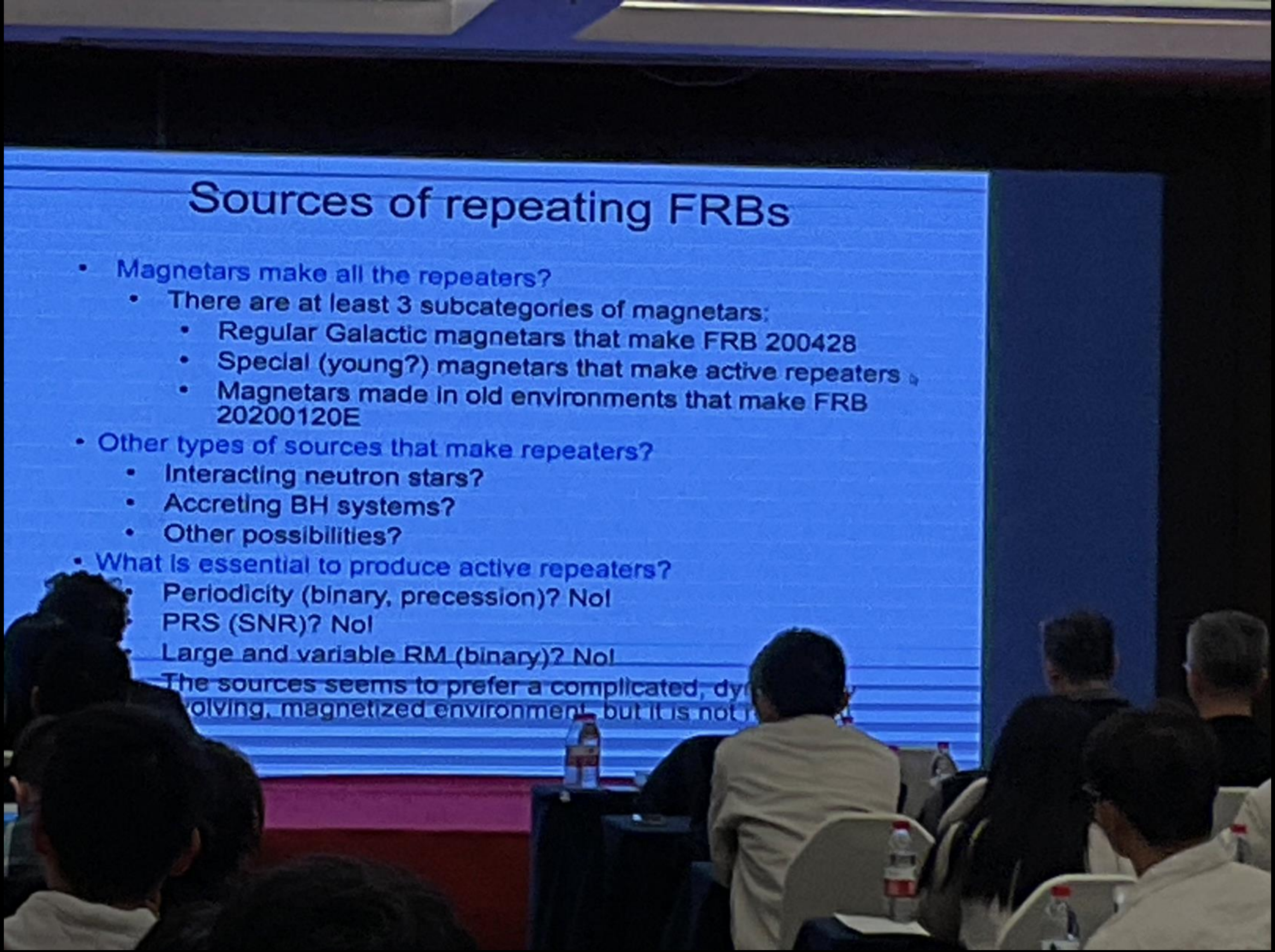

PARTICLE ACCELERATION IN RECONNECTION
Energy
Two acceleration phases: 1) at the X-point; 2) in between merging islands

# Neutron Stars

- Low Mass X-ray Binaries
  - Sco-X1…
- Pulsars
  - Cosmic Laboratories, Astronomical Tools
  - Binary Pulsars and Tests of GR
  - Millisecond Pulsars
  - Pulsar Wind Nebulae; PeV $\gamma$; Pevatrons
- Supernovae
  - Core collapse etc
  - Lensing
  - White Dwarf
  - Kilonovae; Multi-Messenger Astrophysics
- Magnetars
  - Soft Gamma Repeaters
  - Fast Radio Bursts


CHIME FINDS FRBS ALMOST EVERY DAY,
LOTS OF REPEATERS
- ONE IS IN A NEARBY SPIRAL
"ONLY" 170 Mpc AWAY, z = 0.0337
- ONE IS IN A GLOBULAR CLUSTER IN M81
3.6 Mpc AWAY

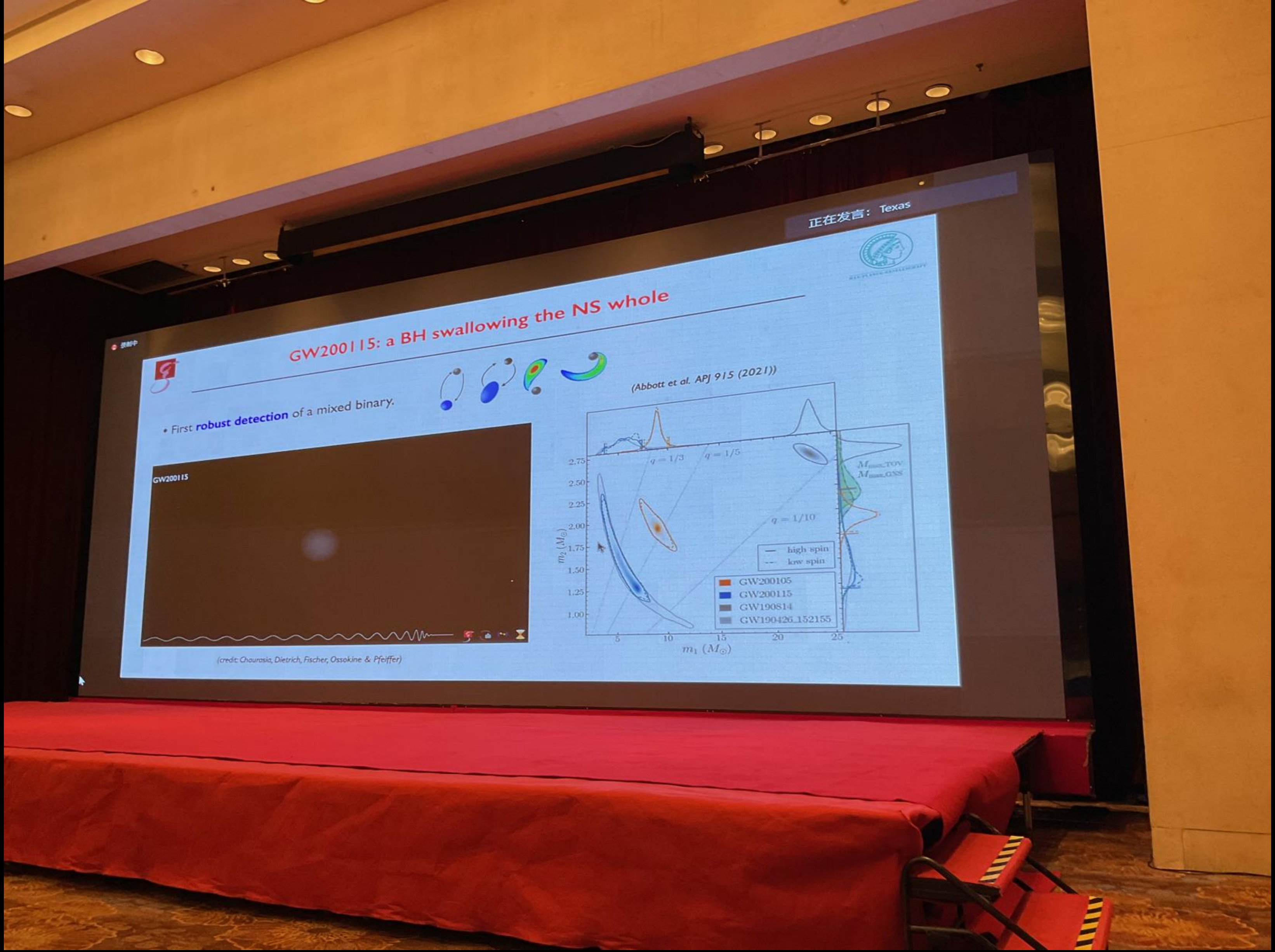

MULTIPLE FRB CLASSES?
CHIME/FRB, PLEUNIS ET AL. 2021
One-off events
Repeater bursts
Bandwidth [MHz]
Duration [ms]
REPEATERS HAVE BROADER PULSES AND ARE NARROW BAND
ONE-OFFS HAVE NARROWER PULSES AND ARE BROAD BAND
K. Aggarwal

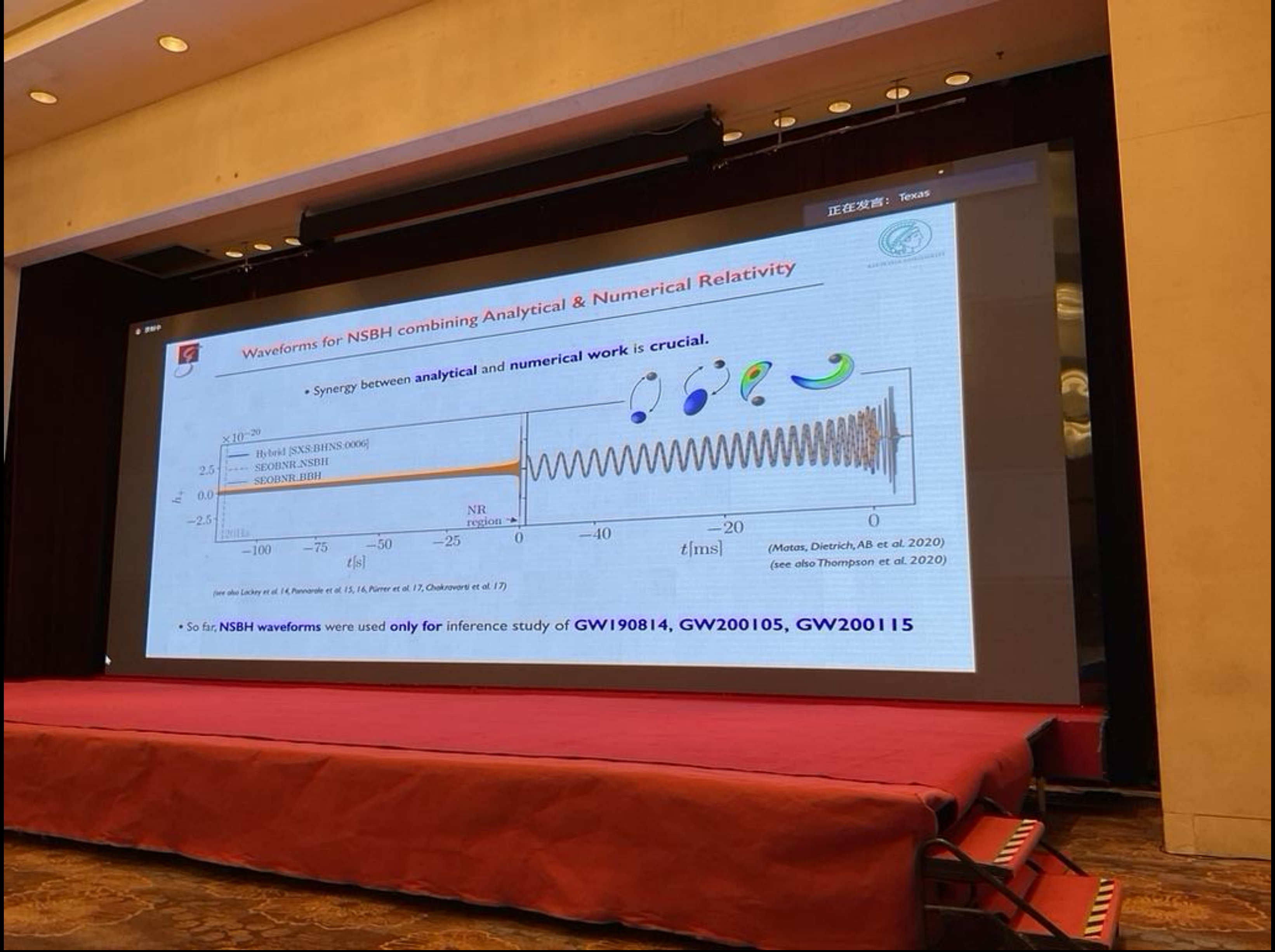

Sources of repeating FRBs
Magnetars make all the repeaters?
There are at least 3 subcategories of magnetars:
Regular Galactic magnetars that make FRB 200428
Special (young?) magnetars that make active repeaters
Magnetars made in old environments that make FRB 20200120E
Other types of sources that make repeaters?
Interacting neutron stars?
Accreting BH systems?
Other possibilities?
What is essential to produce active repeaters?
Periodicity (binary, precession)? No!
PRS (SNR)? No!
Large and variable RM (binary)? No!
The sources seems to prefer a complicated, dy
olving, magnetized environment, but it is not

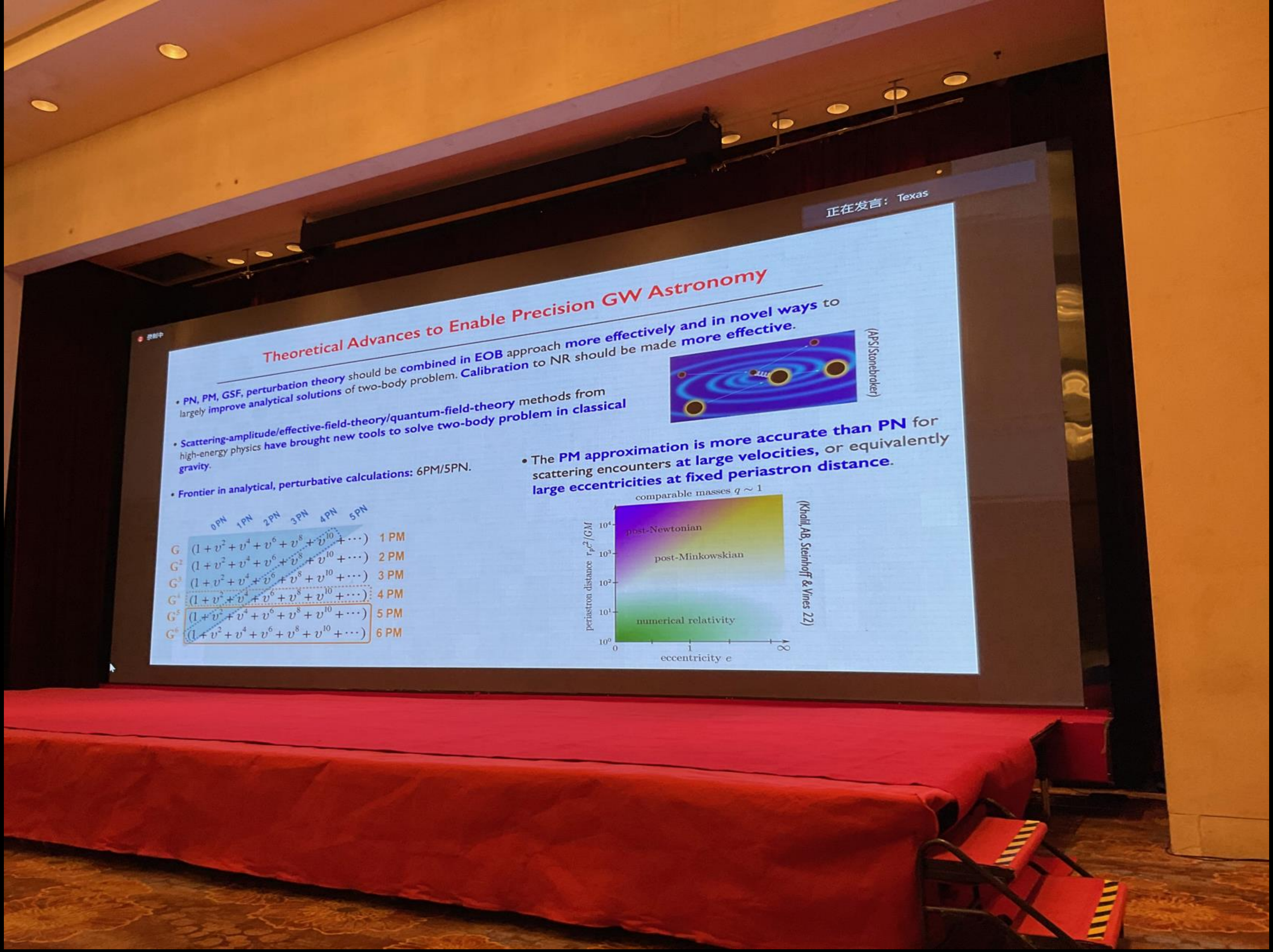
# Gravitational Waves

- Binary Pulsars
- LIGO – Virgo – KAGRA
  - BHB, NSB, BHNSB
  - Numerical relativity


正在发言： Texas
Discovering/Characterizing Black Holes & Neutron Stars in the Universe
• As today, GWs were observed by LIGO-Virgo detectors from about 100 coalescences, plus tens of events pulled out from public data with independent analysis. (Abbott et al. arXiv:2111.03634) (Nitz et al. 21, Olsen et al. 22, Mehta et al. 23)
Masses in the Stellar Graveyard
EM Neutron Stars
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern
Cygnus X-1
Pulsar
• How black holes and neutron stars form, which is their astrophysical environment, and how do they form binaries?
• How matter behaves under extreme density and pressure? Can dark matter make compact objects?
• What's the origin of the most energetic phenomena in our Universe?
• Is General Relativity violated? What is the nature of the observed dark objects?
• Can we discover new fundamental particles, and infer the cosmological model of our Universe through gravitational-wave observations?

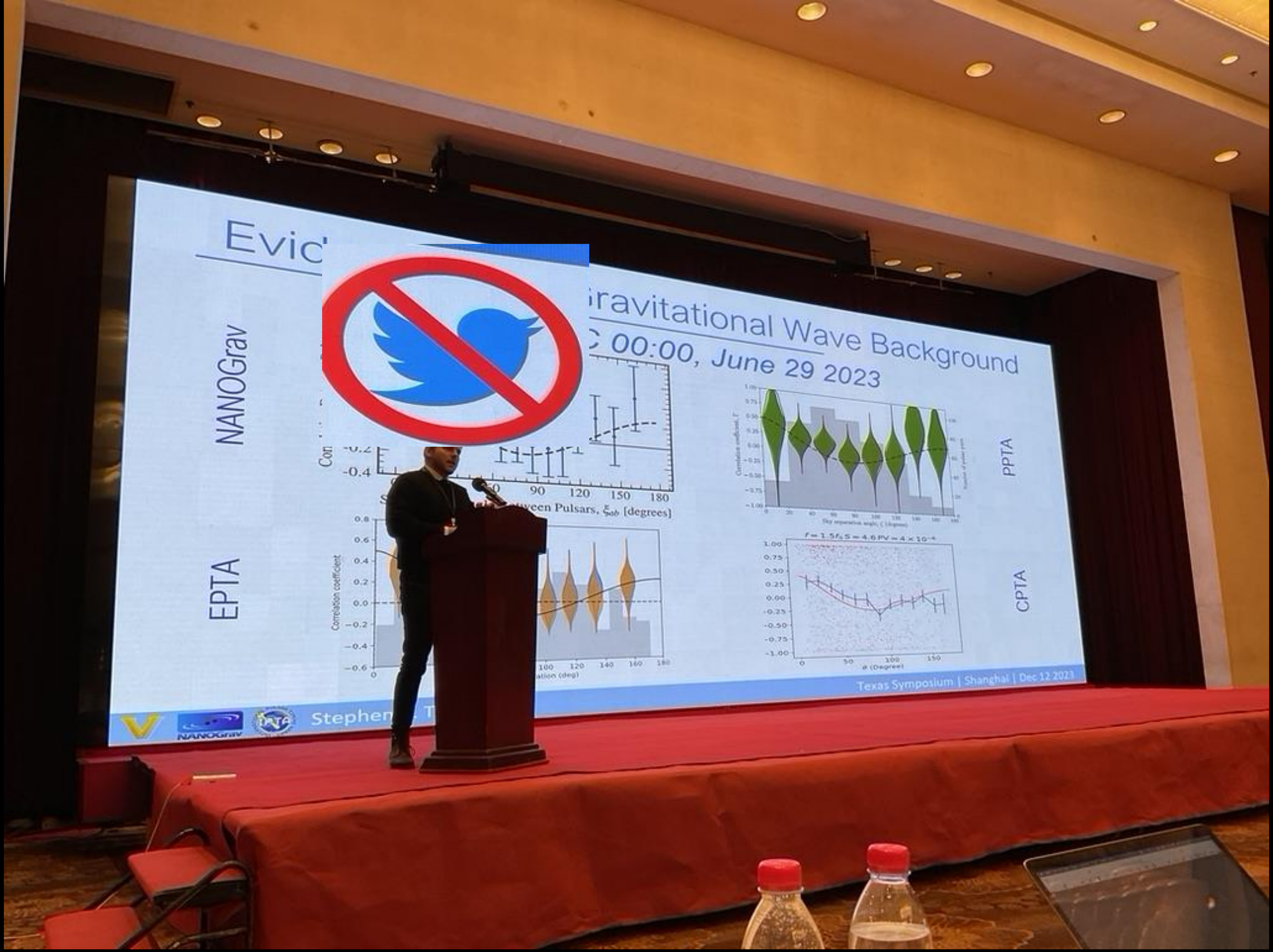

正在发言： Texas
GW200115: a BH swallowing the NS whole
• First robust detection of a mixed binary.
(Abbott et al. ApJ 915 (2021))
GW200115
(credit: Chaurasia, Dietrich, Fischer, Ossokine & Pfeiffer)
q = 1/3
q = 1/5
q = 1/10
high spin
low spin
GW200105
GW200115
GW190814
GW190426_152155
$m_1\ (M_\odot)$
$m_2\ (M_\odot)$


正在发言： Texas
Waveforms for NSBH combining Analytical & Numerical Relativity
• Synergy between analytical and numerical work is crucial.
Hybrid [SXS:BHNS:0006]
SEOBNR_NSBH
SEOBNR_BBH
NR region
t[s]
t[ms]
(Matas, Dietrich, AB et al. 2020)
(see also Thompson et al. 2020)
• So far, NSBH waveforms were used only for inference study of GW190814, GW200105, GW200115


正在发言： Texas
Theoretical Advances to Enable Precision GW Astronomy
• PN, PM, GSF, perturbation theory should be combined in EOB approach more effectively and in novel ways to largely improve analytical solutions of two-body problem. Calibration to NR should be made more effective.
(APS/Stonebraker)
• Scattering-amplitude/effective-field-theory/quantum-field-theory methods from high-energy physics have brought new tools to solve two-body problem in classical gravity.
• Frontier in analytical, perturbative calculations: 6PM/5PN.
0PN 1PN 2PN 3PN 4PN 5PN
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
• The PM approximation is more accurate than PN for scattering encounters at large velocities, or equivalently large eccentricities at fixed periastron distance.
comparable masses q ~ 1
post-Newtonian
post-Minkowskian
numerical relativity
periastron distance
eccentricity e
(Khalil, AB, Steinhoff & Vines 22)

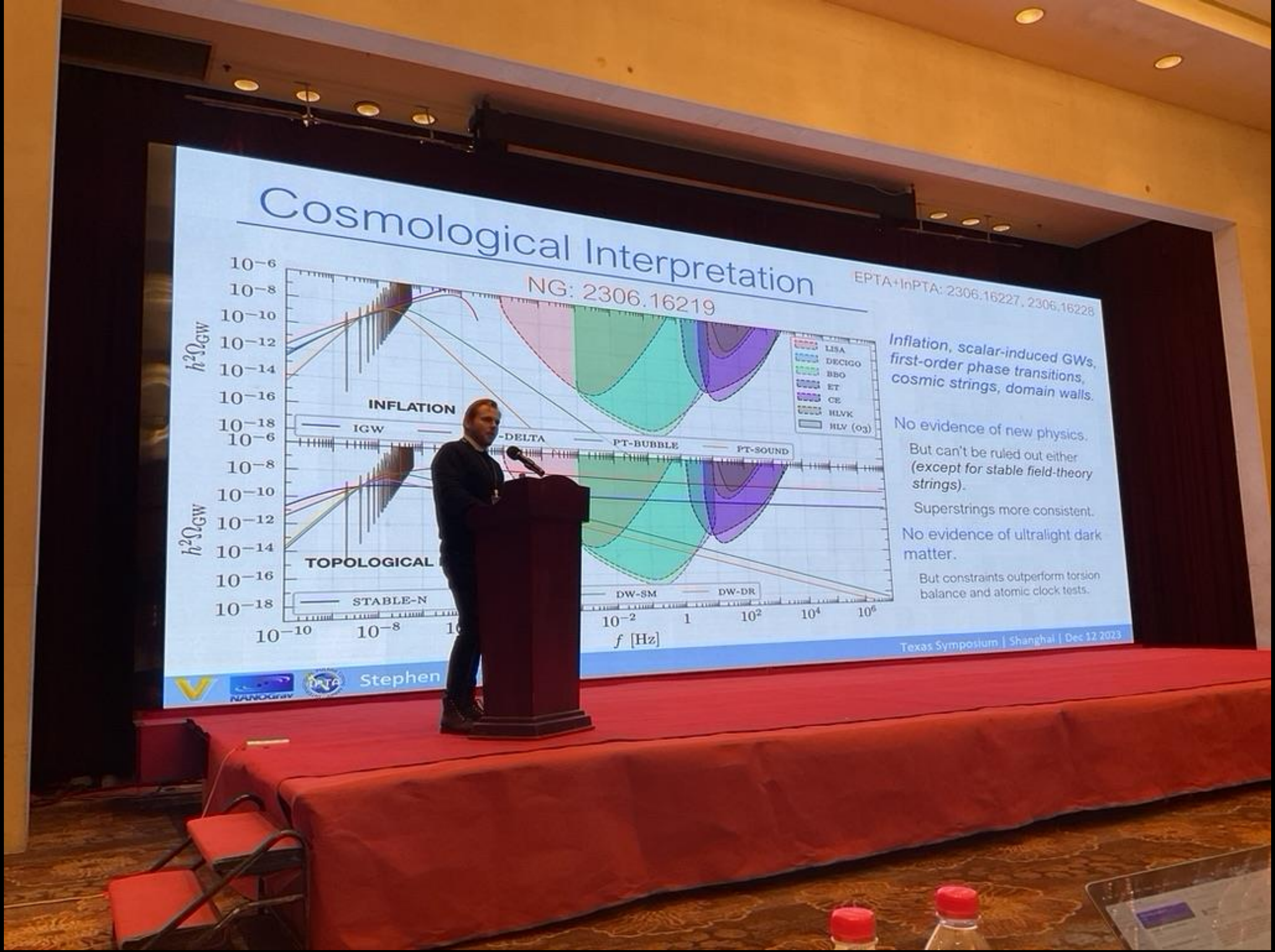
# Gravitational Waves

- Binary Pulsars
- LIGO – Virgo – KAGRA
  - BHB, NSB, BHNSB
  - Numerical relativity
- nHz Background
  - Binary Massive Black Holes
- LISA (Pathfinder, 2035+), TaiJi, TianQin, DECIGO
- B-Modes
- Atom Interferometry


Evid
ravitational Wave Background
00:00, June 29 2023
NANOGrav
PPTA
EPTA
CPTA
Texas Symposium | Shanghai | Dec 12 2023


Effelsberg
Lovell
Nançay
WSRT
SRT
EPTA
The IPTA
GBT
Arecibo
VLA
CHIME
NANOGrav
CPTA
FAST
PPTA
Parkes
InPTA
GMRT
MPTA
MeerKAT
All results consistent!
Agazie et al. (2023)
arXiv:2309.00693
Slide from Thankfu


Chinese pulsar timing array (CPTA) DR 1.0
K. J. Lee (李柯伽)
On behalf of CPTA team
Department of Astronomy, Peking university
National astronomical observatory, CAS
2023
32nd Texas Symposium on Relativistic Astrophysics
CPTA
NAOC


Cosmological Interpretation
NG: 2306.16219
EPTA+InPTA: 2306.16227, 2306.16228
INFLATION
TOPOLOGICAL
LISA
DECIGO
BBO
ET
CE
HLVK
HLV (O3)
IGW
PT-BUBBLE
PT-SOUND
STABLE-N
DW-SM
DW-DR
f [Hz]
Inflation, scalar-induced GWs, first-order phase transitions, cosmic strings, domain walls.
No evidence of new physics.
But can't be ruled out either (except for stable field-theory strings).
Superstrings more consistent.
No evidence of ultralight dark matter.
But constraints outperform torsion balance and atomic clock tests.
Texas Symposium | Shanghai | Dec 12 2023
Stephen

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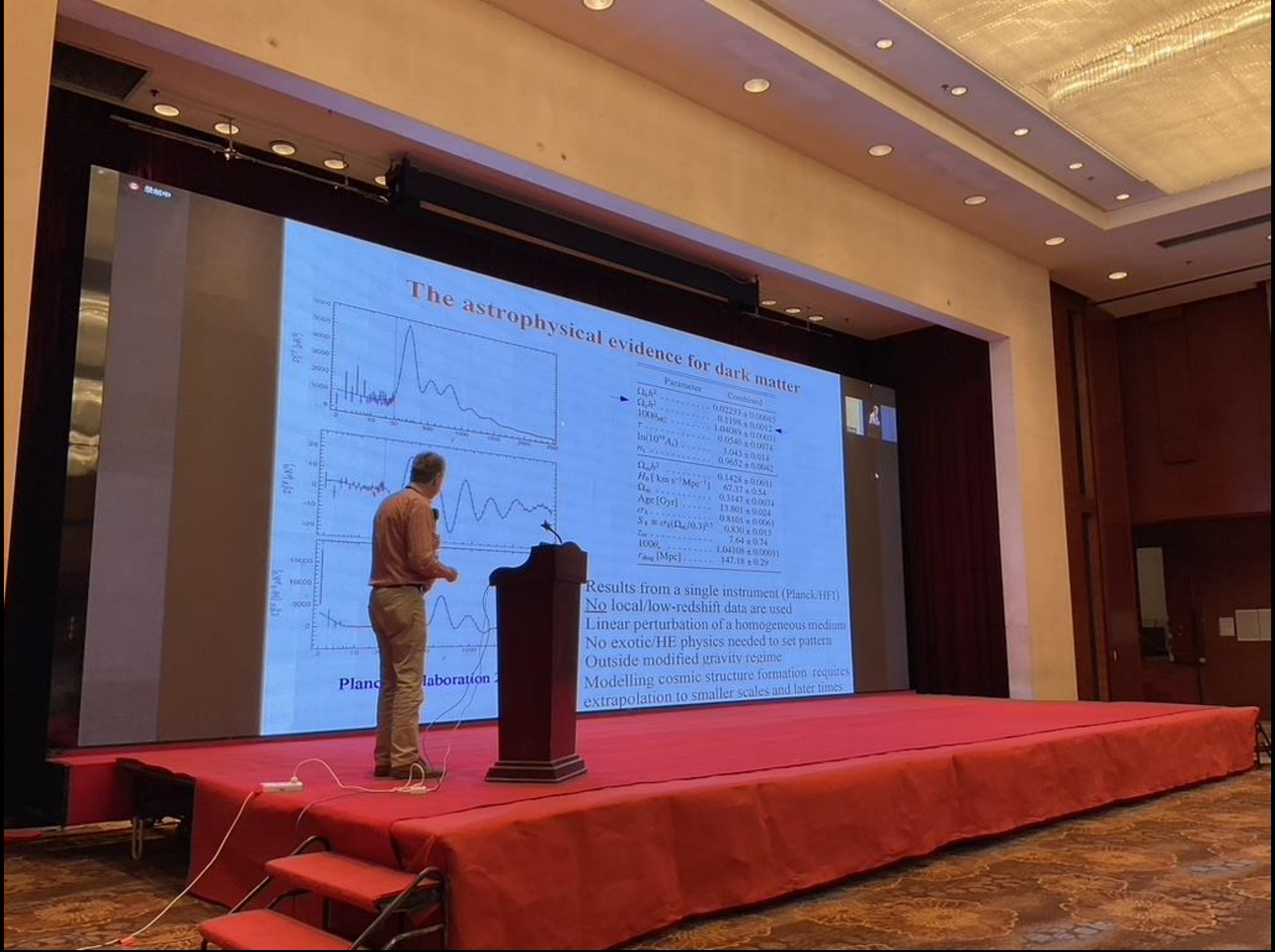
  - Binary Massive Black Holes
- LISA (Pathfinder, 2035+), TaiJi, TianQin, DECIGO
- B-Modes
- Atom Interferometry

# Cosmology

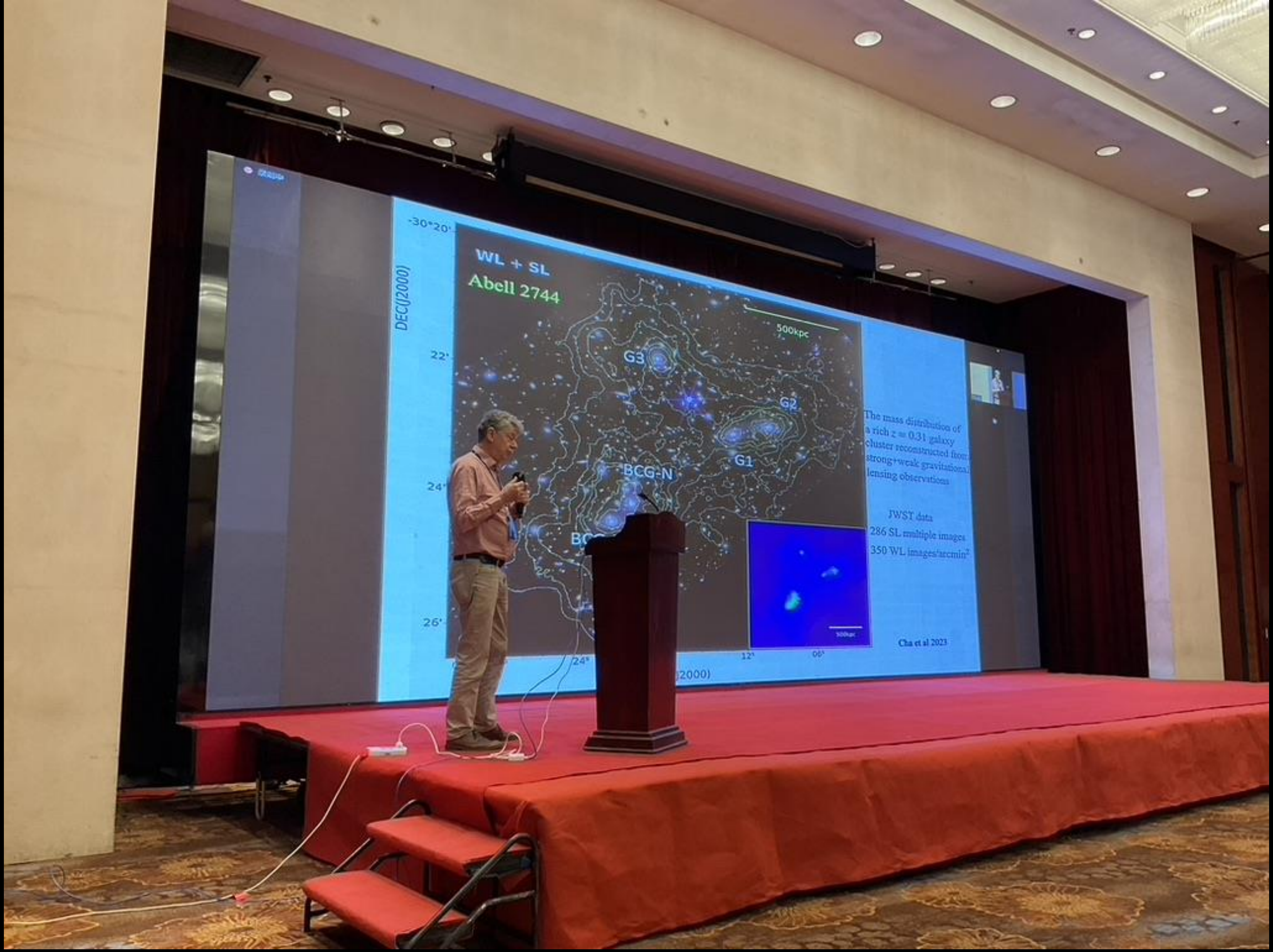
- Big Bang
  - Nucleosynthesis
  - Massive Neutrinos
  - Baryogenesis
  - Inflation
  - Alternatives
- Cosmic Microwave Background
  - Fluctuations, Polarization, Lensing

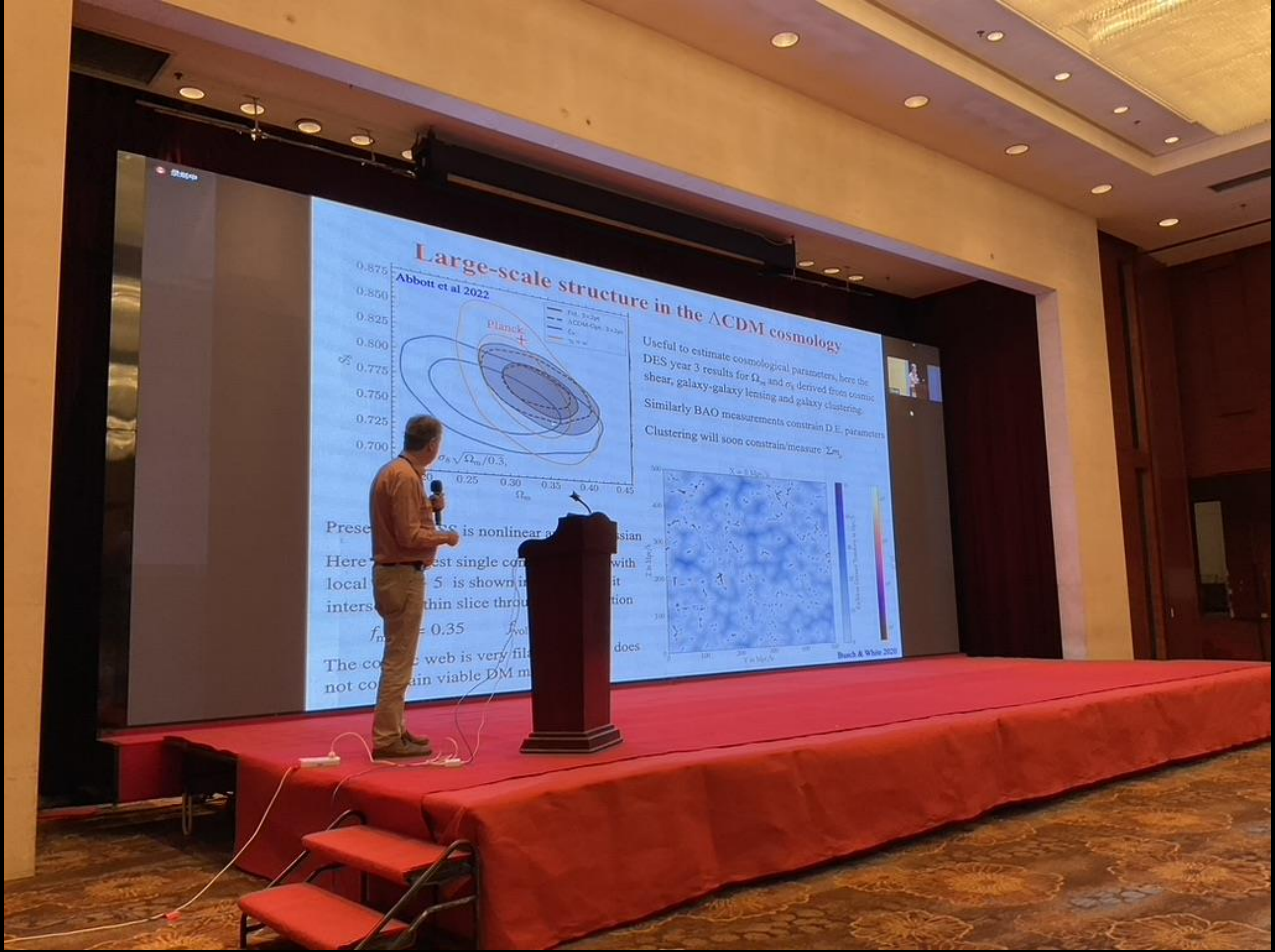

The astrophysical evidence for dark matter
Results from a single instrument (Planck/HFI)
No local/low-redshift data are used
Linear perturbation of a homogeneous medium
No exotic/HE physics needed to set pattern
Outside modified gravity regime
Modelling cosmic structure formation requires
extrapolation to smaller scales and later times

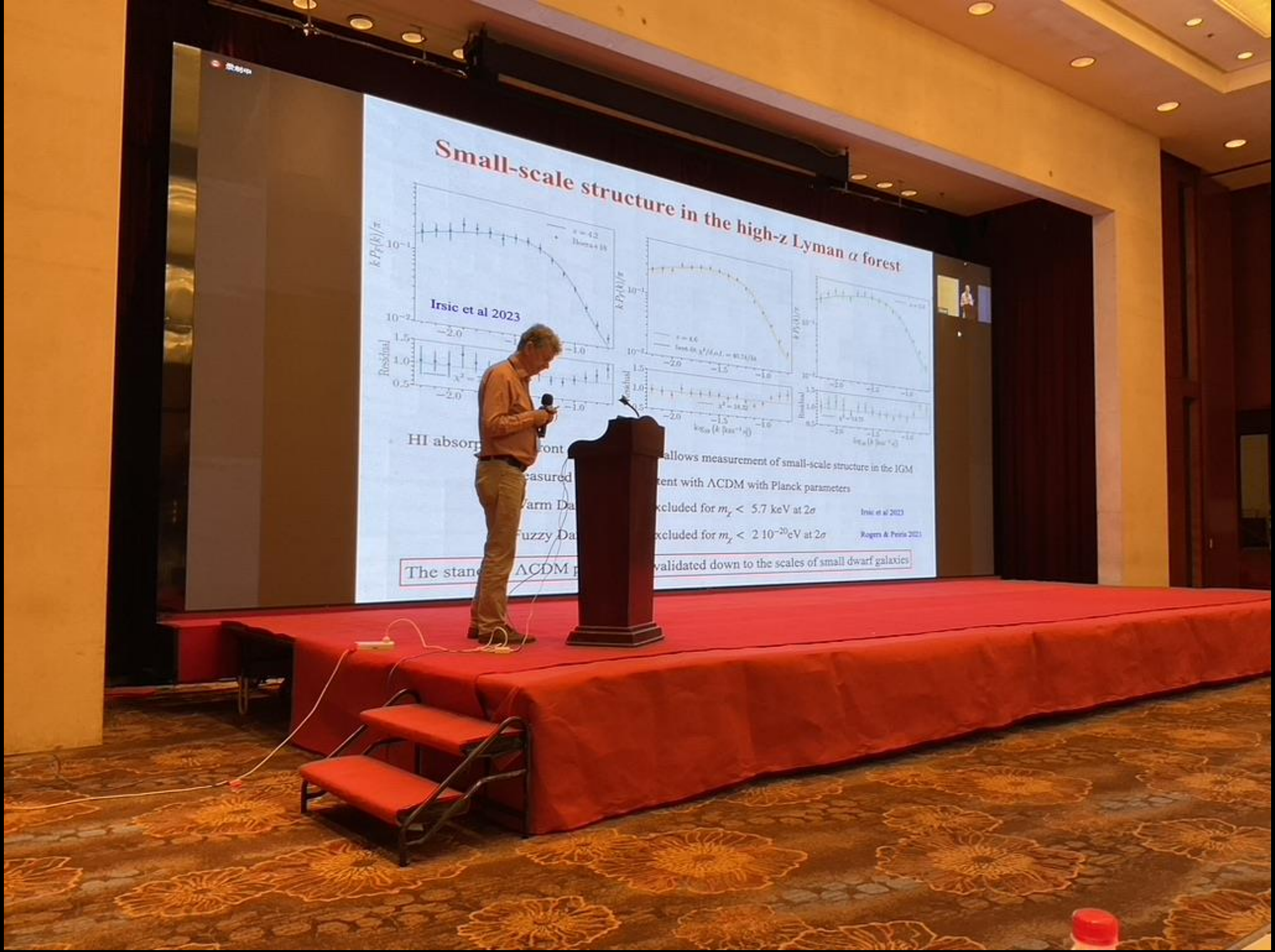

Baryon Acoustic Oscillations
DR9
DR10
DR11
Anderson et al.(2014)
k (h Mpc⁻¹)

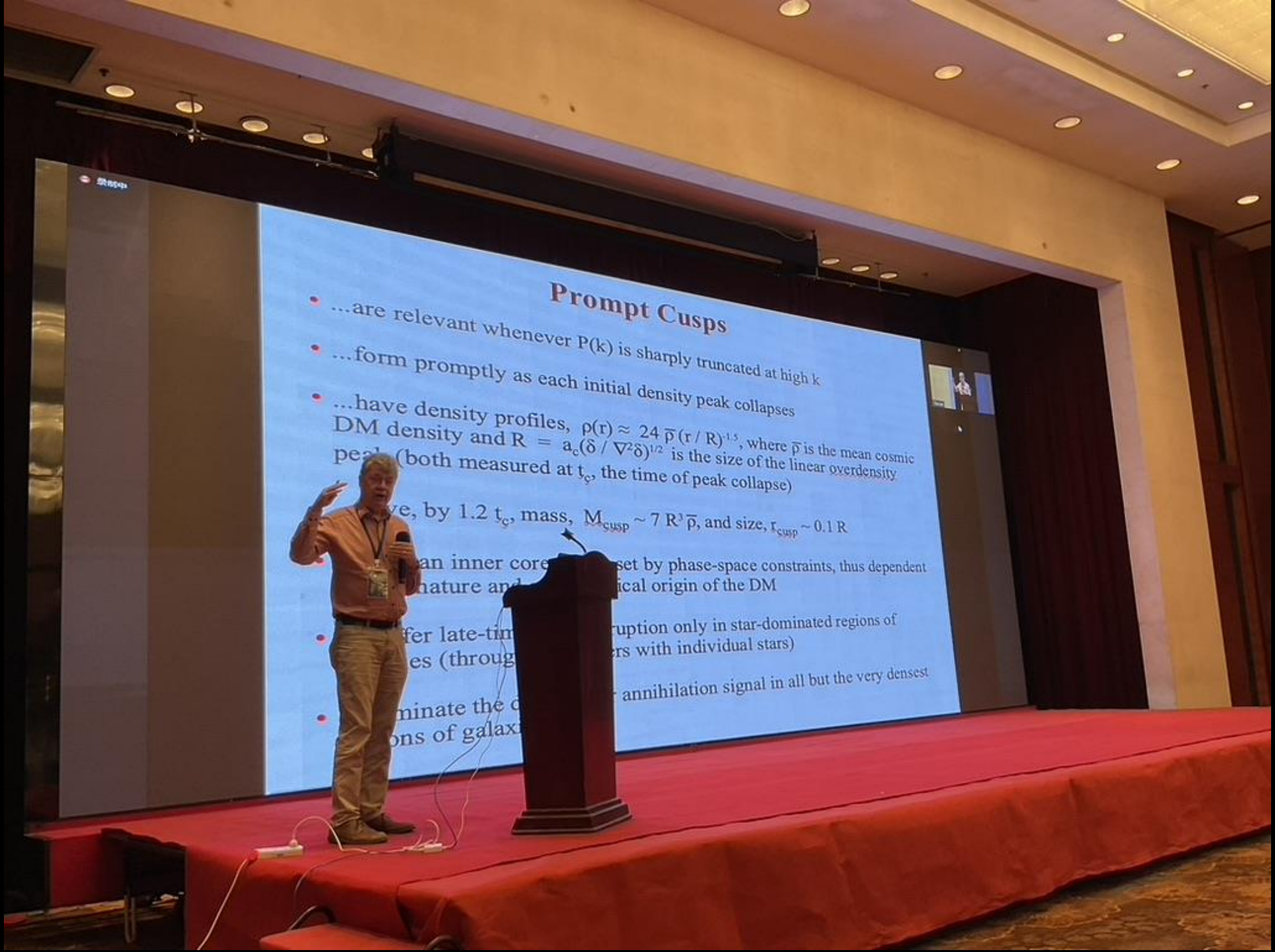
# Cosmology

- Big Bang
  - Nucleosynthesis
  - Massive Neutrinos
  - Baryogenesis
  - Inflation
  - Alternatives
- Cosmic Microwave Background
  - Fluctuations, Polarization, Lensing
- Dark Matter
  - CMB, Large Scale Structure, BAO; Clusters, Galaxies
  - WIMPs, Axions, Fields…
  - Direct and Indirect Detection,
  - Strong and Weak Lensing
- Cosmography
  - Hubble Constant
  - Cosmological Constant
  - Standard Model, Near Field Cosmology
  - Tensions

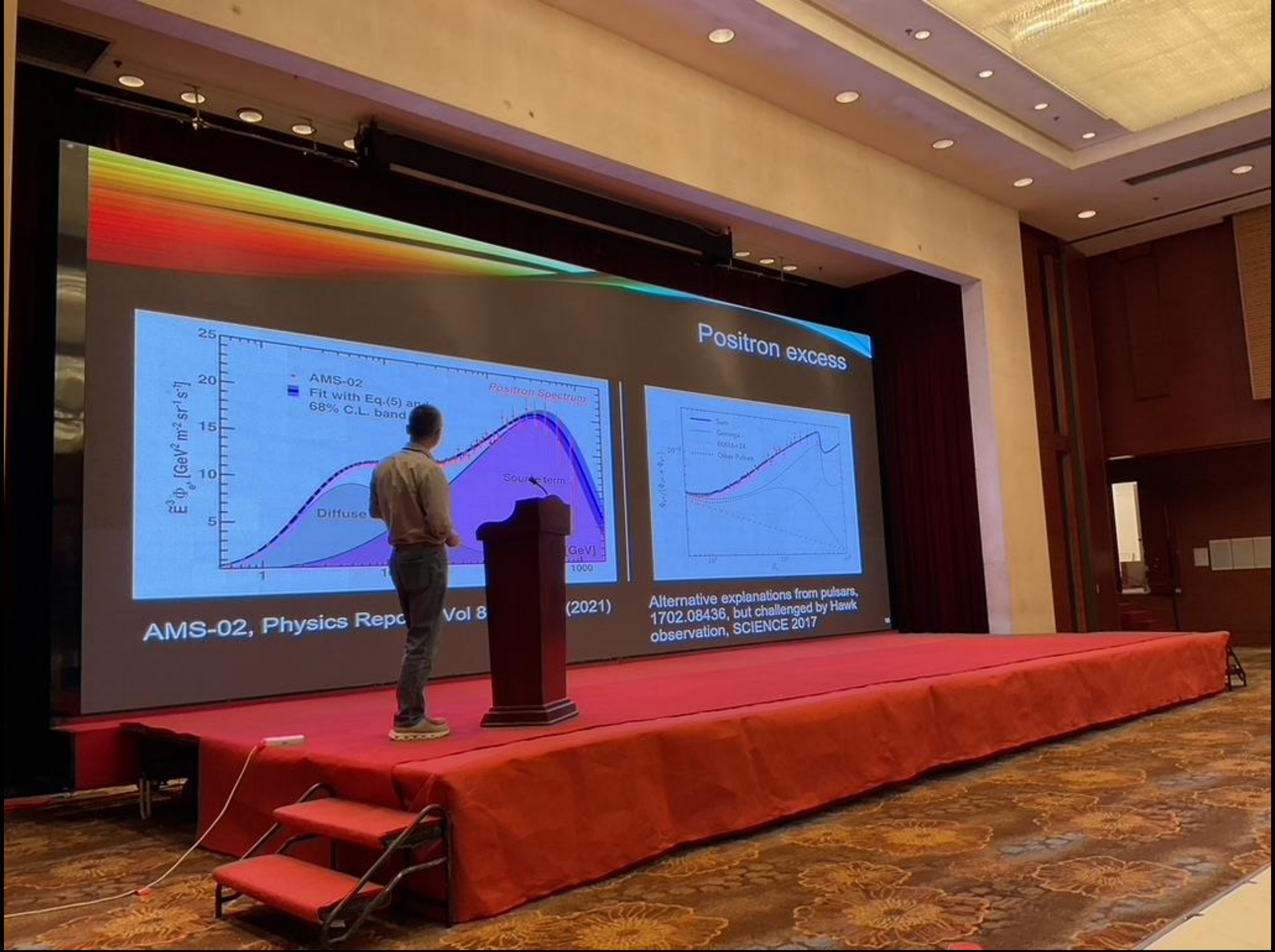

WL + SL
Abell 2744
500kpc
G3
G2
G1
BCG-N
DEC(J2000)
The mass distribution of a rich z = 0.31 galaxy cluster reconstructed from strong+weak gravitational lensing observations
JWST data
286 SL multiple images
350 WL images/arcmin²
Cha et al 2023


Large-scale structure in the ΛCDM cosmology
Abbott et al 2022
Planck
Useful to estimate cosmological parameters, here the DES year 3 results for Ωm and σ8 derived from cosmic shear, galaxy-galaxy lensing and galaxy clustering.
Similarly BAO measurements constrain D.E. parameters
Clustering will soon constrain/measure Σmν
Bunch & White 2020

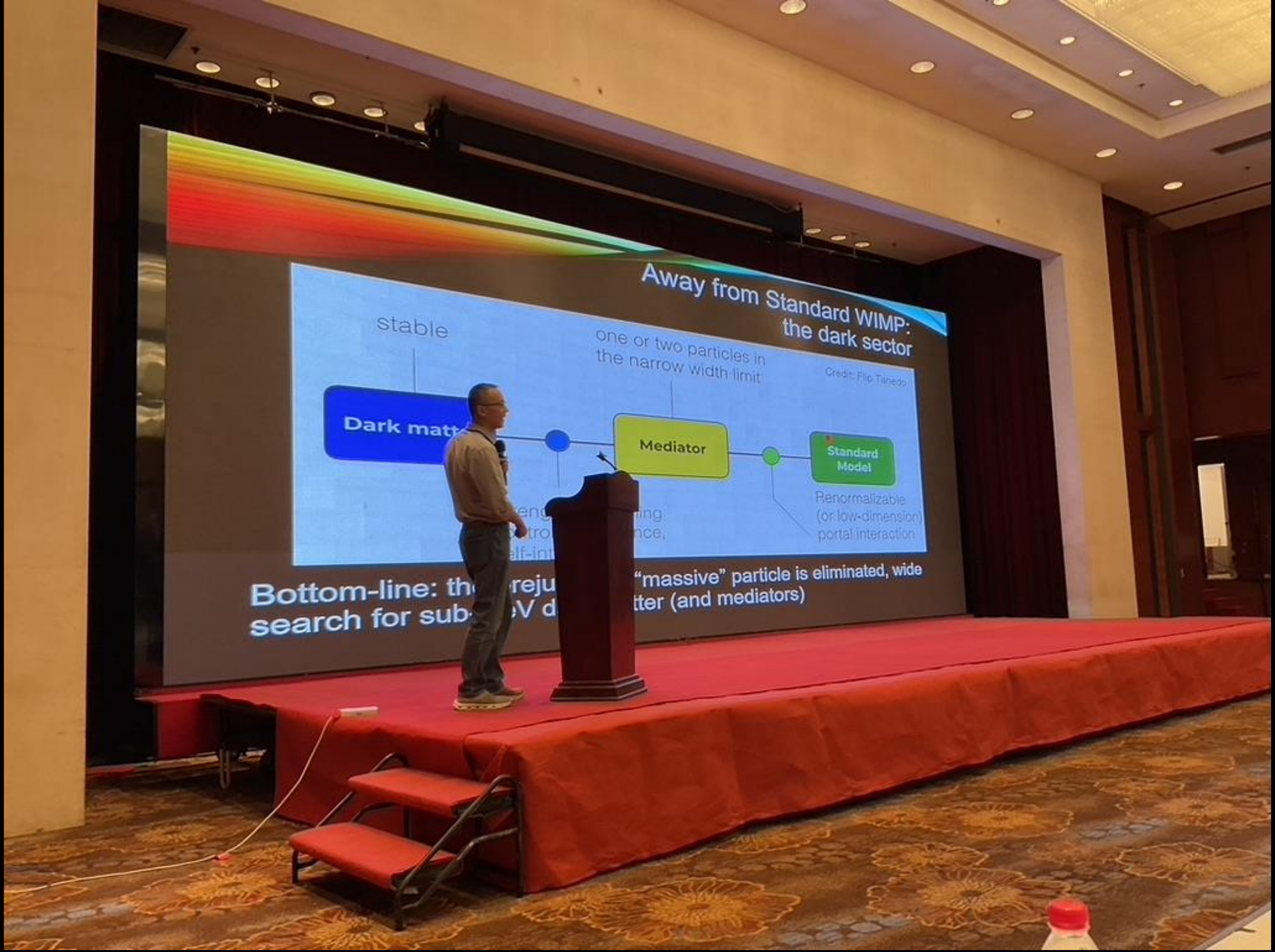

Small-scale structure in the high-z Lyman $\alpha$ forest
Irsic et al 2023
allows measurement of small-scale structure in the IGM
Irsic et al 2023
Rogers & Peiris 2021

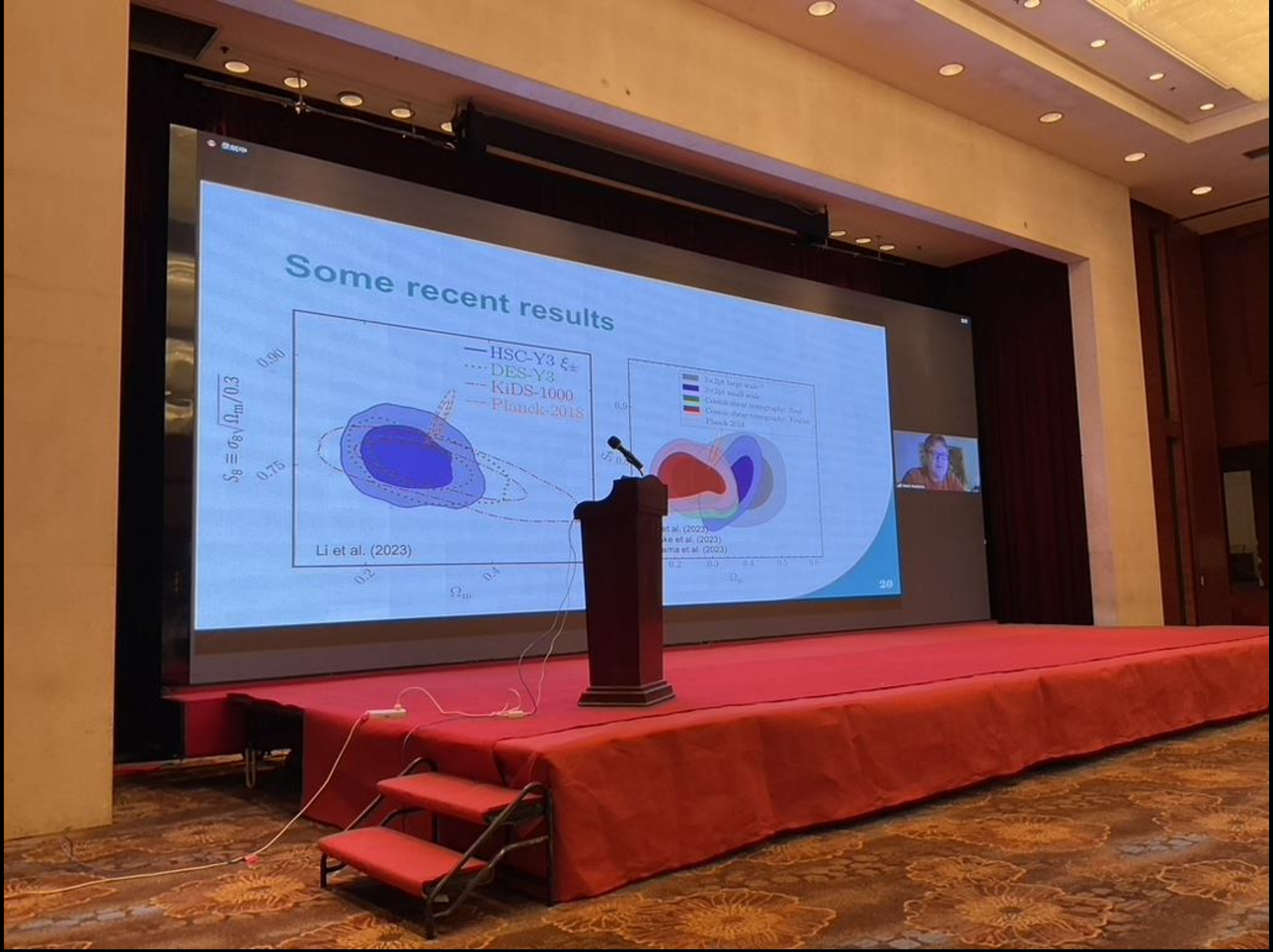

Prompt Cusps
...are relevant whenever P(k) is sharply truncated at high k
...form promptly as each initial density peak collapses
...have density profiles, $\rho(r) \approx 24\,\bar{\rho}\,(r/R)^{-1.5}$, where $\bar{\rho}$ is the mean cosmic
DM density and $R = a_c(\delta / \nabla^2\delta)^{1/2}$ is the size of the linear overdensity
(both measured at $t_c$, the time of peak collapse)
by 1.2 $t_c$, mass, $M_{cusp} \sim 7\,R^3\,\bar{\rho}$, and size, $r_{cusp} \sim 0.1\,R$
an inner core
set by phase-space constraints, thus dependent
nature and
ical origin of the DM
fer late-tim
uption only in star-dominated regions of
es (throug
rs with individual stars)
minate the
annihilation signal in all but the very densest
ons of galax

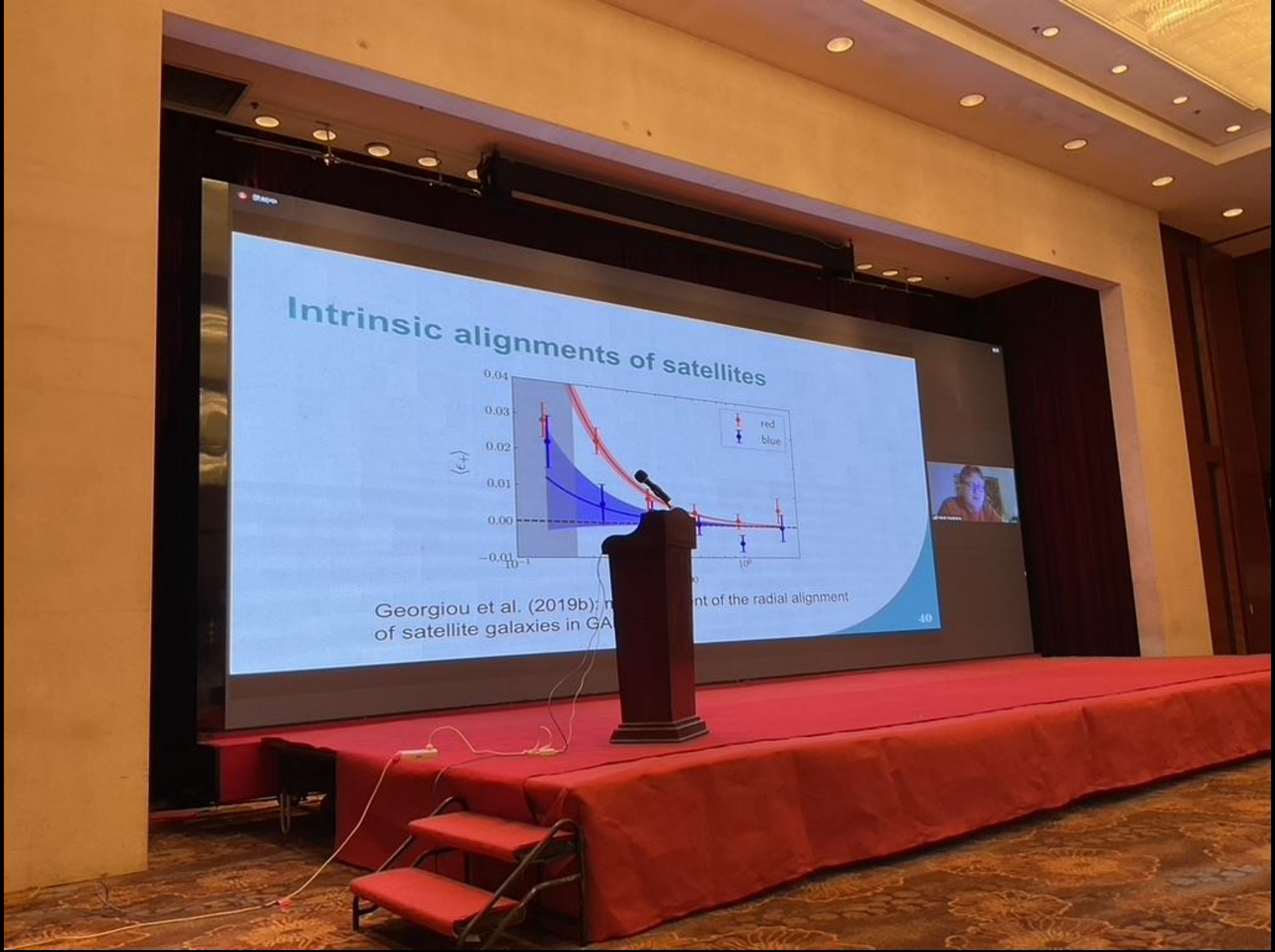

Liquid xenon experiments
LNGS, XENONnT, 6.5 ton
CJPL, PandaX-4T, 3.7 ton



Positron excess
AMS-02
Positron Spectrum
Source term
Diffuse
AMS-02, Physics Repo
Vol 8
(2021)
Alternative explanations from pulsars,
1702.08436, but challenged by Hawk
observation, SCIENCE 2017

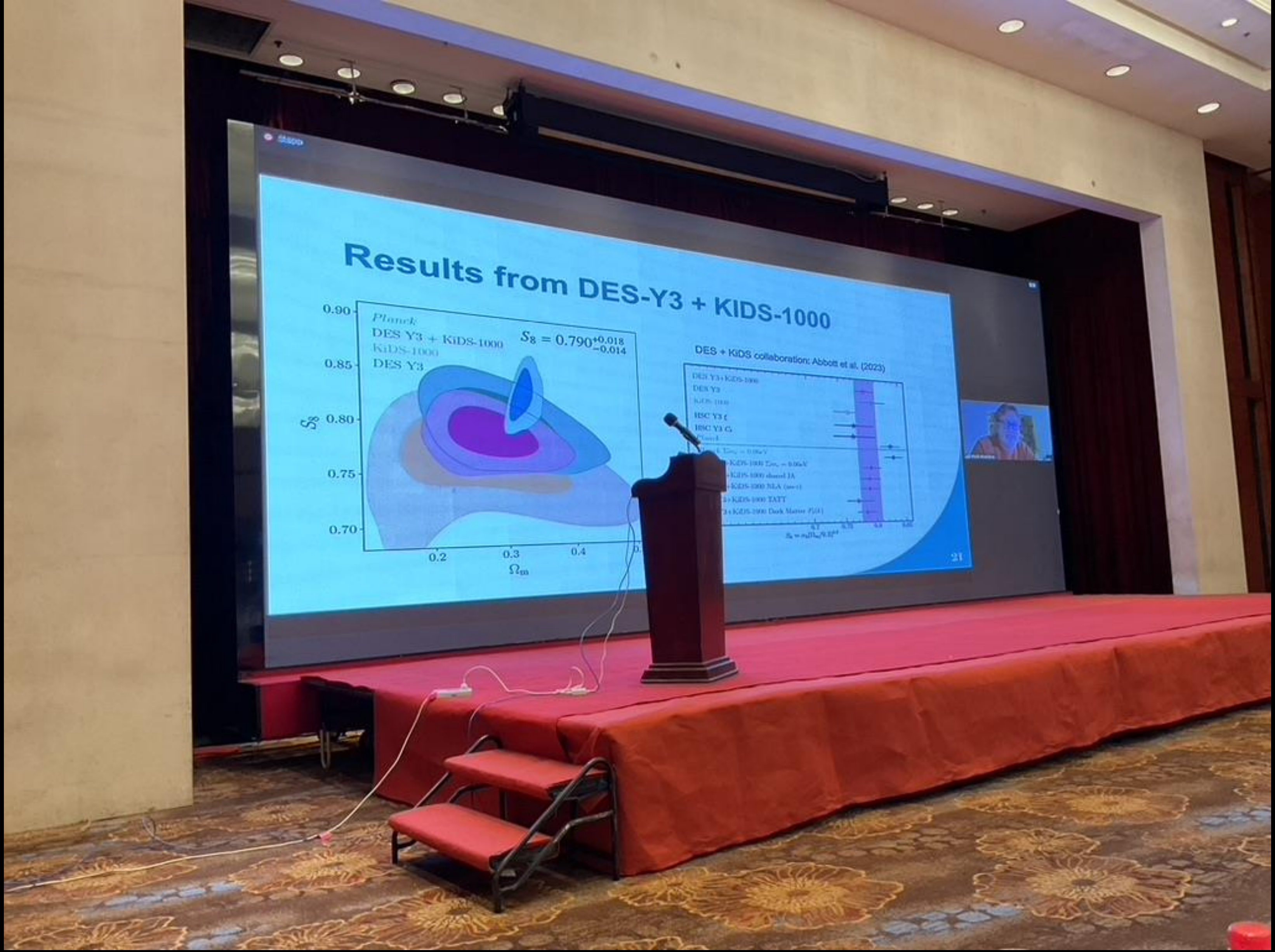

Away from Standard WIMP:
the dark sector
stable
one or two particles in
the narrow width limit
Credit: Flip Tanedo
Mediator
Standard
Model
Renormalizable
(or low-dimension)
portal interaction


Some recent results
HSC-Y3 $\xi_\pm$
DES-Y3
KiDS-1000
Planck-2018
$S_8 \equiv \sigma_8\sqrt{\Omega_m/0.3}$
Li et al. (2023)
$\Omega_m$
20


Intrinsic alignments of satellites
red
blue
Georgiou et al. (2019b);
nt of the radial alignment
of satellite galaxies in GA
40

# Cosmology

- Big Bang
  - Nucleosynthesis
  - Massive Neutrinos
  - Baryogenesis
  - Inflation
  - Alternatives
- Cosmic Microwave Background
  - Fluctuations, Polarization, Lensing
- Dark Matter
  - CMB, Large Scale Structure, BAO; Clusters, Galaxies
  - WIMPs, Axions, Fields…
  - Direct and Indirect Detection,
  - Strong and Weak Lensing
- Cosmography
  - Hubble Constant
  - Cosmological Constant
  - Standard Model, Near Field Cosmology
  - Tensions


Results from DES-Y3 + KIDS-1000
Planck
DES Y3 + KiDS-1000
KiDS-1000
DES Y3
$S_8 = 0.790^{+0.018}_{-0.014}$
DES + KiDS collaboration: Abbott et al. (2023)
21

# Cosmology

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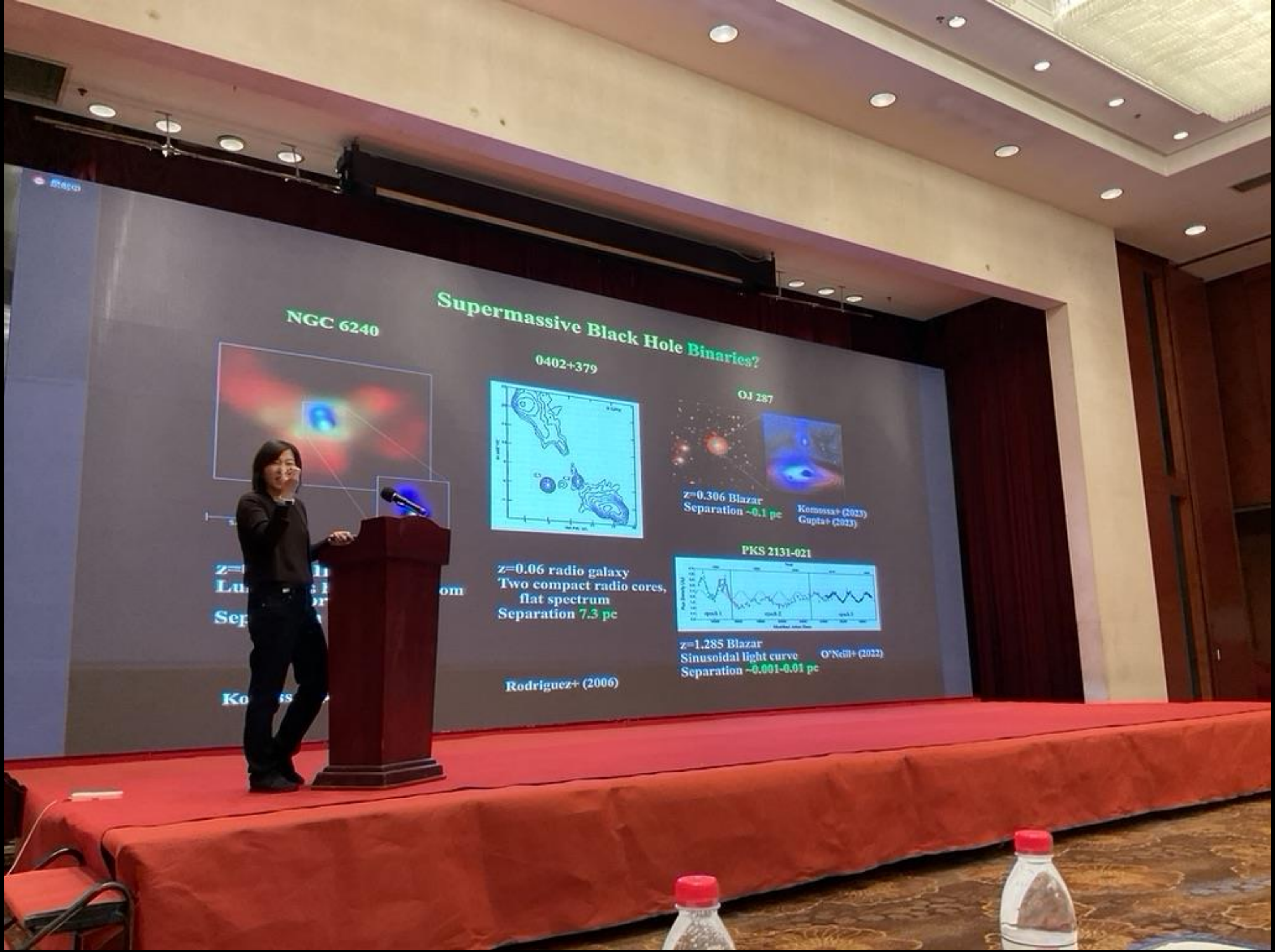
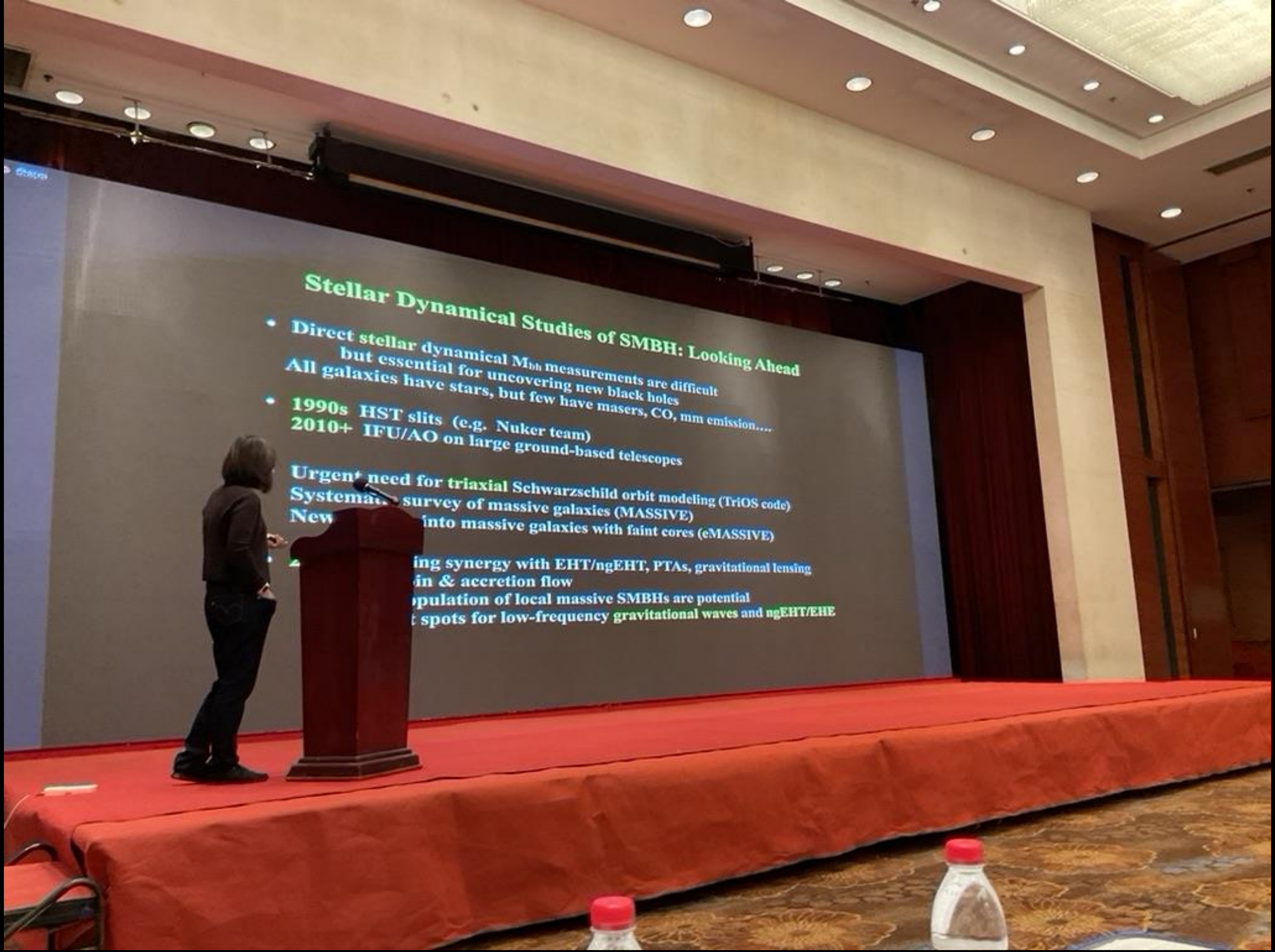
  - Direct and Indirect Detection,
  - Strong and Weak Lensing
- Cosmography
  - Hubble Constant
  - Cosmological Constant
  - Standard Model, Near Field Cosmology
  - Tensions
- Narrative History of Galaxies

# Promise

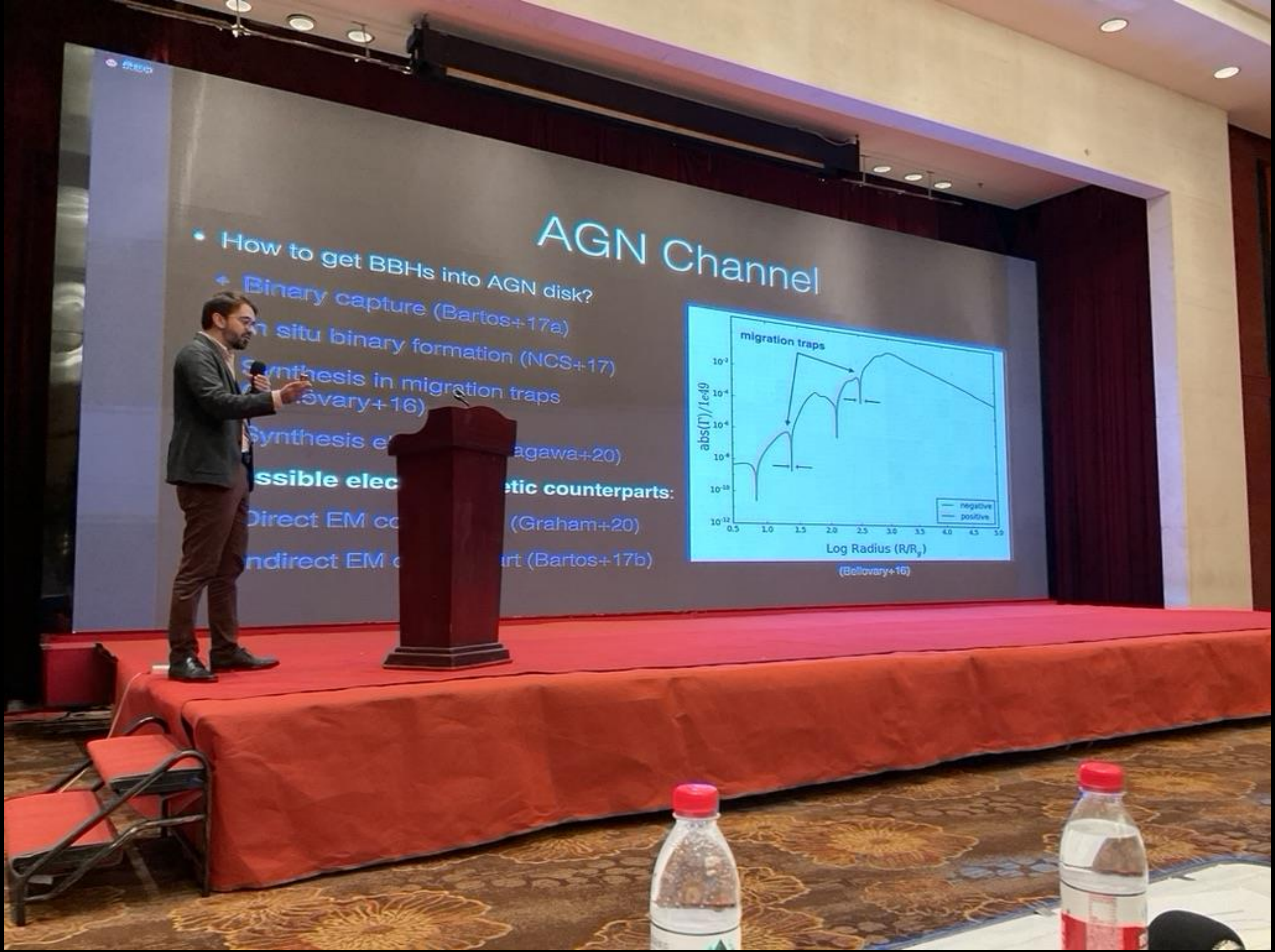
- Black Holes
  - Kerr; Magnetosphere; Jet, Disk, Wind Dynamics; Binaries; Environment; UHECR...
- Neutron Stars
  - (Magnetic) EoS; SQED Theory, Obs, Expt; FRB; knae, PWN; Emission, Transmission…
- Gravitational Waves
  - Open up pHz, $\mu$Hz, mHz Bands; Strong GR; nHz Background, Sources; BBH Provenance…
- Cosmology
  - Dark Matter; Inflation; Neutrinos; Standard Model; Archaeology…


正在发言：Texas
EHT New Capabilities
1. 345 GHz: $\Delta\theta \sim \lambda/D$
nominal resolution 20 μas → 13 μas
2. Agile Observing: repeated imaging of M87*
MOVIES!
3. new sites: African Millimetre Telescope
ngEHT ~4 new sites, higher UV covering fraction
4. Space! $\Delta\theta \sim \lambda/D$
geosynch nominal resolution 20 μas → 5 μas


Supermassive Black Hole Binaries?
NGC 6240
0402+379
OJ 287
z=0.306 Blazar
Separation ~0.1 pc
Komossa+ (2023)
Gupta+ (2023)
z=0.06 radio galaxy
Two compact radio cores,
flat spectrum
Separation 7.3 pc
Rodriguez+ (2006)
PKS 2131-021
z=1.285 Blazar
Sinusoidal light curve
Separation ~0.001-0.01 pc
O'Neill+ (2022)



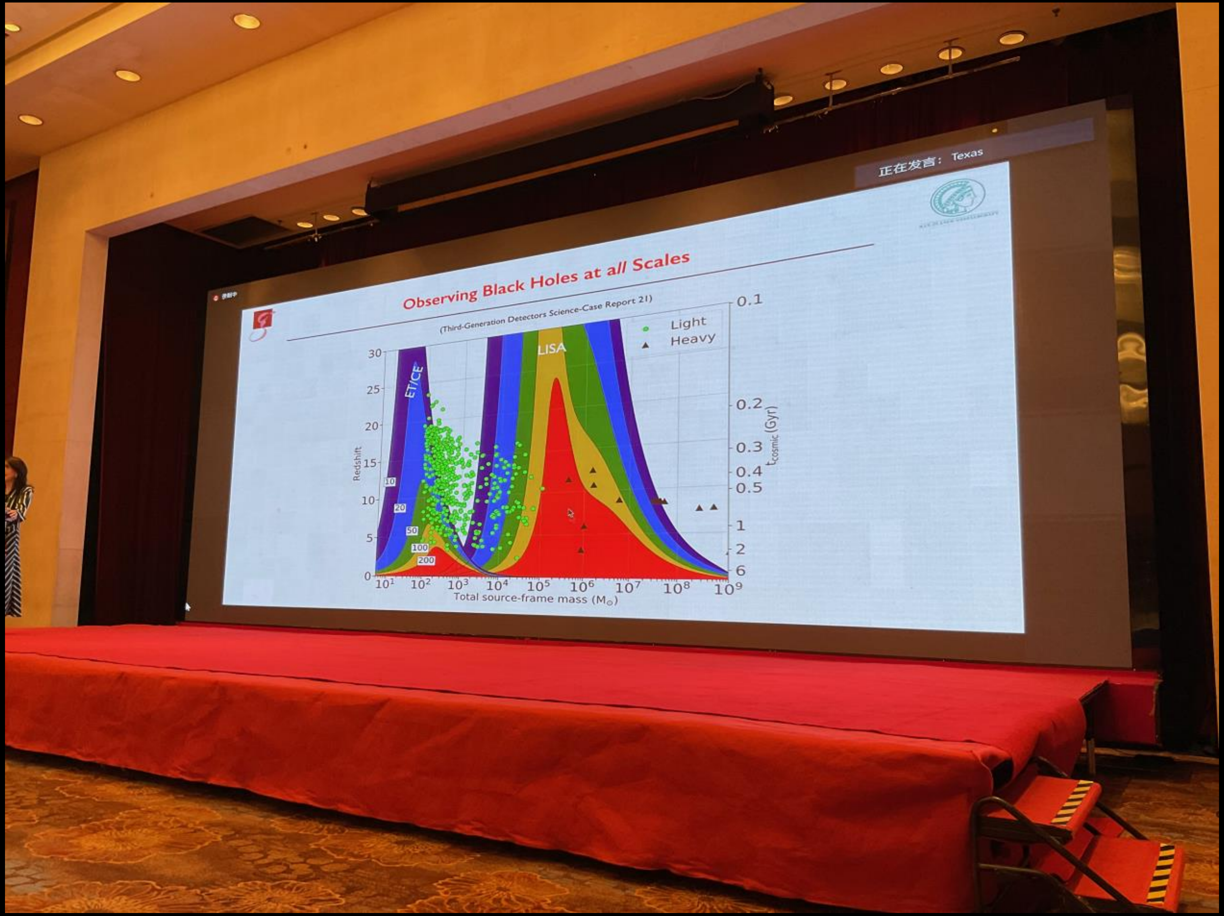
Stellar Dynamical Studies of SMBH: Looking Ahead
Direct stellar dynamical Mbh measurements are difficult
but essential for uncovering new black holes
All galaxies have stars, but few have masers, CO, mm emission....
1990s HST slits (e.g. Nuker team)
2010+ IFU/AO on large ground-based telescopes
Urgent need for triaxial Schwarzschild orbit modeling (TriOS code)
survey of massive galaxies (MASSIVE)
into massive galaxies with faint cores (eMASSIVE)
synergy with EHT/ngEHT, PTAs, gravitational lensing
& accretion flow
population of local massive SMBHs are potential
spots for low-frequency gravitational waves and ngEHT/EHE


AGN Channel
How to get BBHs into AGN disk?
Binary capture (Bartos+17a)
n situ binary formation (NCS+17)
Synthesis in migration traps
migration traps
Log Radius (R/R$_g$)
negative
positive
(Bellovary+16)
ssible elec
etic counterparts:
Direct EM co
(Graham+20)
ndirect EM c
rt (Bartos+17b)

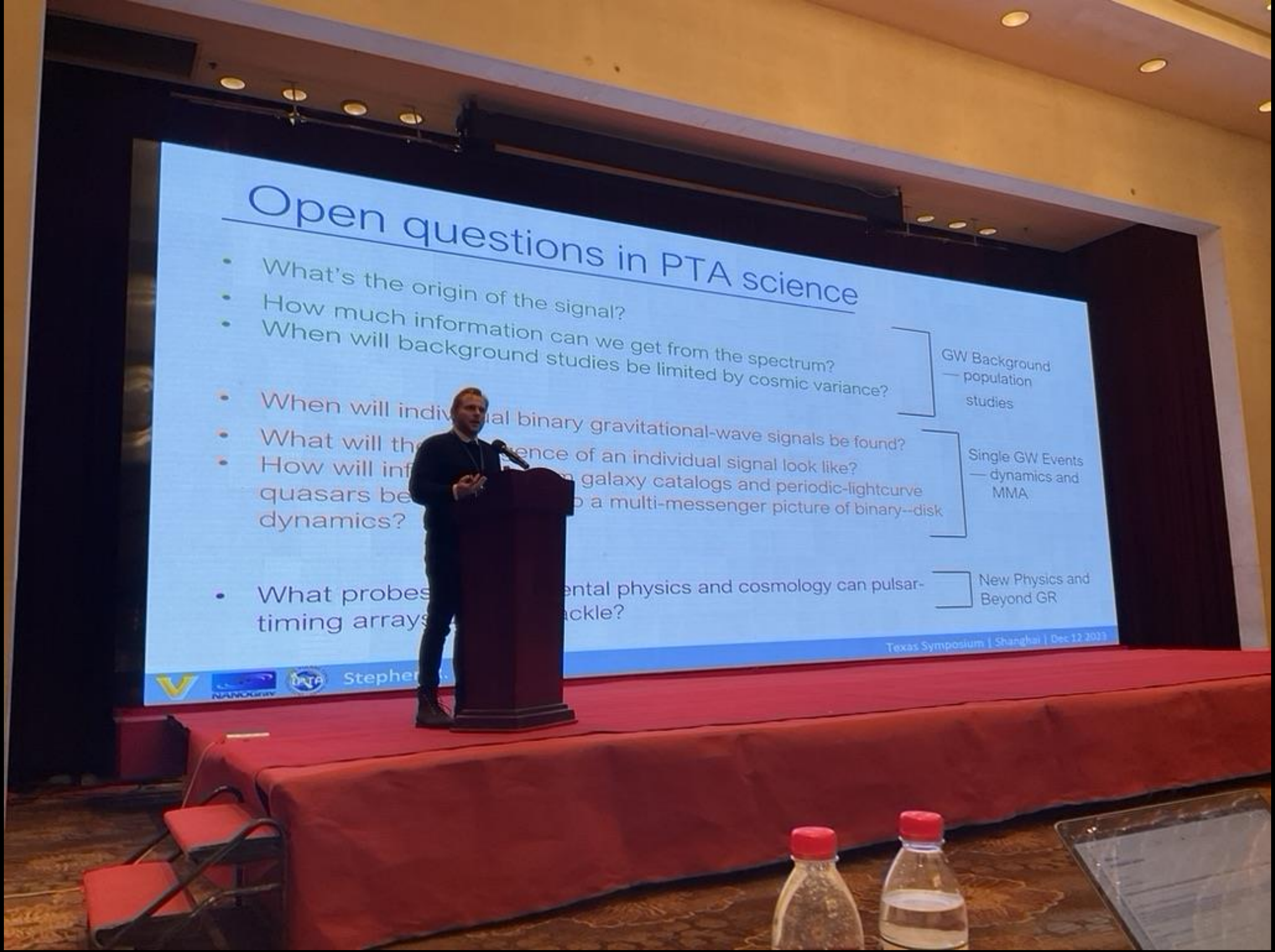

LOOK LEFT AND RIGHT
STILL MUCH TO EXPLORE
LOOK LEFT
望左
LOOK RIGHT
望右
LORIMER BURST
Localised FRBs
SGR 1935+2154
Pulsar GPs
Crab GPs
RRATs
Pulsars
Specific Luminosity
Burst timescale (ν W) [GHz s]

正在发言： Texas
Summary & Outlook
• The work at the interface between analytical and numerical relativity has been essential to detect GW signals, and infer unique information in astrophysics, cosmology and fundamental physics.
• With the greater accuracy of upgraded (O5, A#, Virgo nEXT, LIGO-India) and future facilities and missions (Einstein Telescope, Cosmic Explorer and LISA) come the even greater challenges for theoretical GW modeling.
• To correctly interpret future GW observations, and avoid drawing wrong scientific conclusions, the precision of theoretical GW predictions must improve by two orders of magnitude or more, depending on the binary's parameter space, and must include all physical effects (generic orbits, beyond-GR, matter/environment).
O1
O2
O3
O4
O5
A#
XG
LISA
Cumulative detections (SNR > 10)
SNR (BH binary)
GW150914-like
2015
2020
2025
2030
2035
2040
Year
(credit: Dhani)

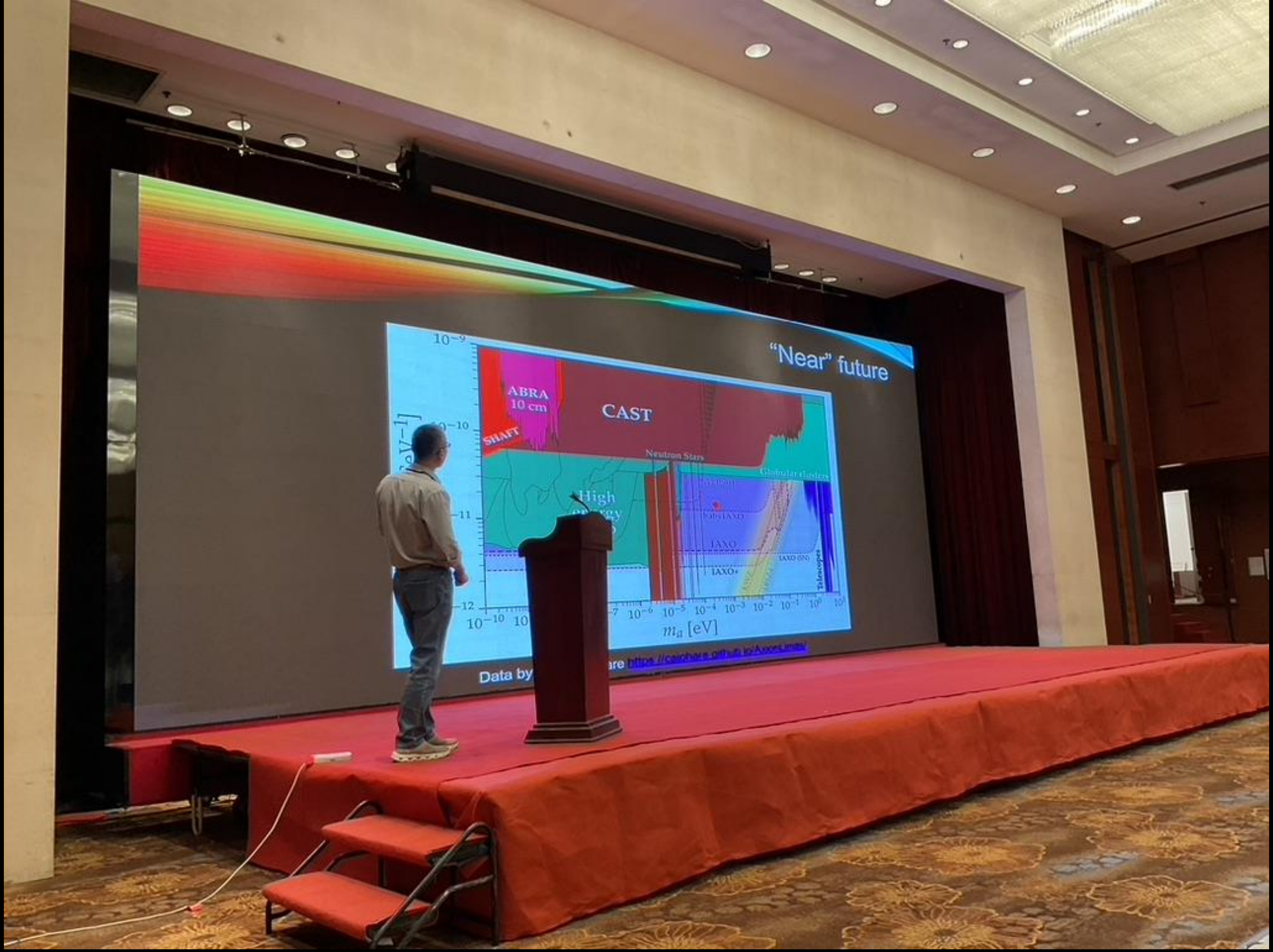

15 xii 2023

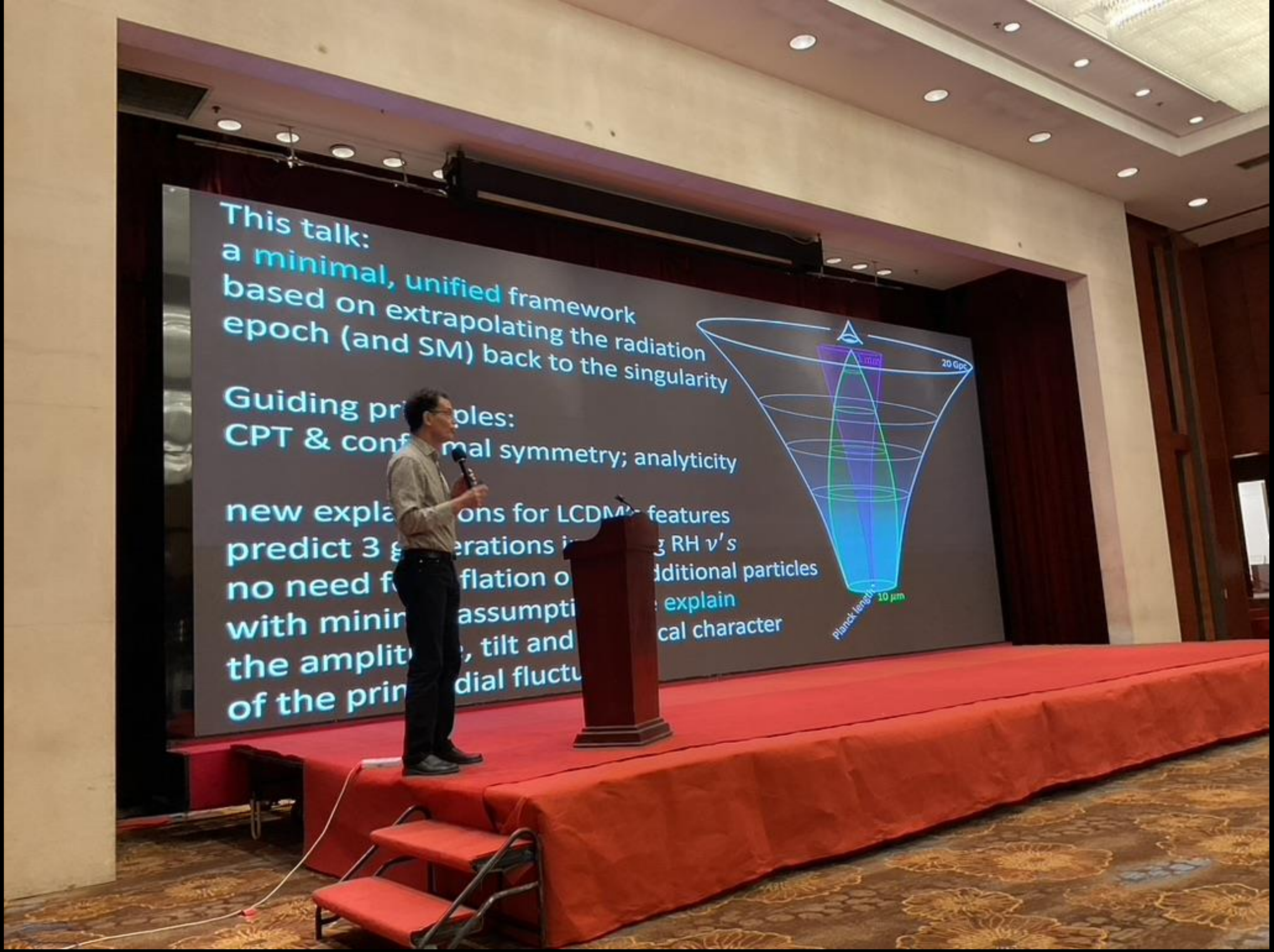


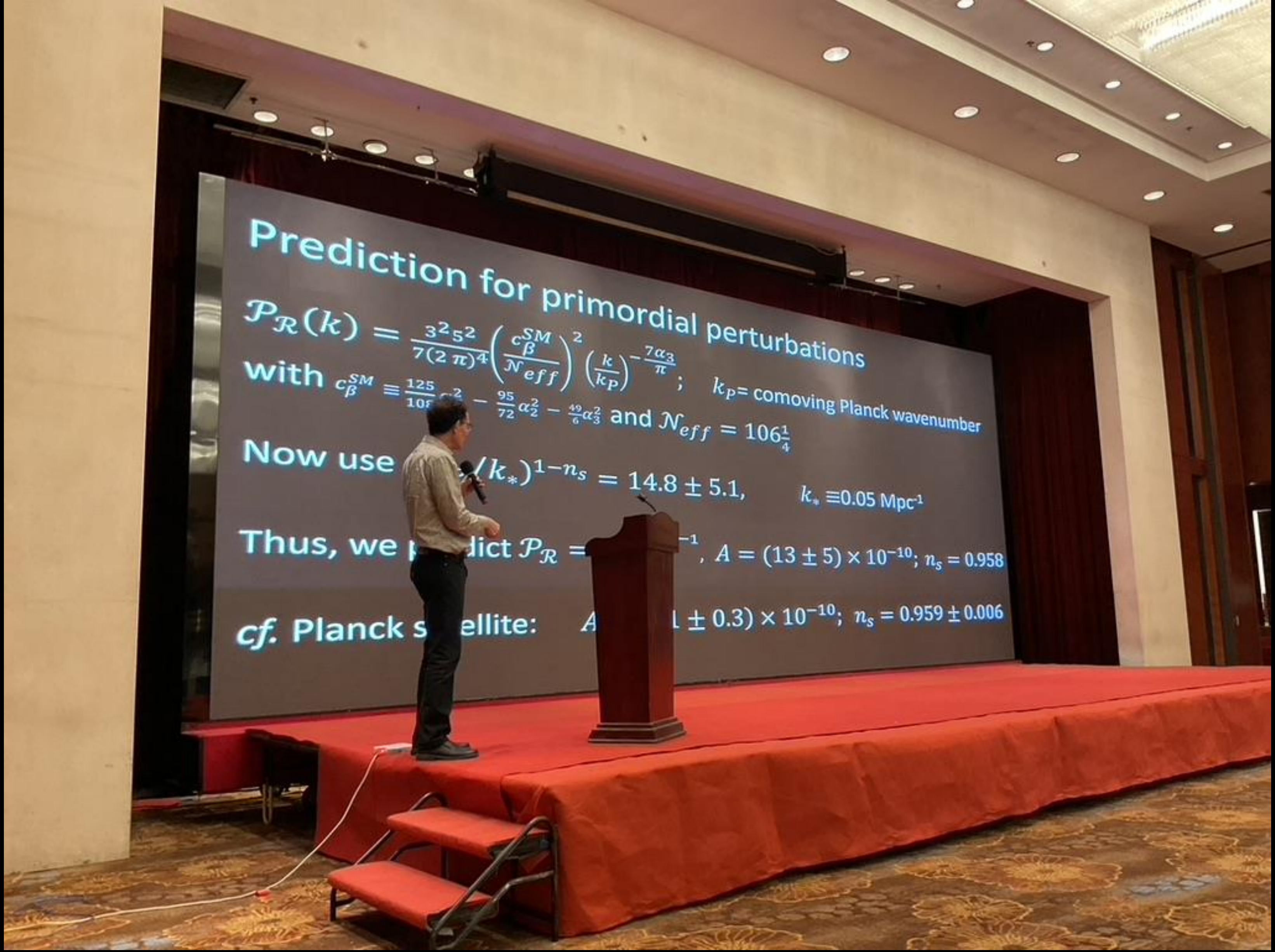
正在发言： Texas
Observing Black Holes at all Scales
(Third-Generation Detectors Science-Case Report 21)
Light
Heavy
ET/CE
LISA
Redshift
Total source-frame mass (M☉)
$t_{cosmic}$ (Gyr)


Open questions in PTA science
What's the origin of the signal?
How much information can we get from the spectrum?
When will background studies be limited by cosmic variance?
GW Background — population studies
Single GW Events — dynamics and MMA
quasars be
dynamics?
New Physics and Beyond GR
timing arrays
Texas Symposium | Shanghai | Dec 12 2023


Liquid xenon experiments
Sanford Lab , 7 ton
LNGS, XENONnT, 6.5 ton
CJPL, PandaX-4T, 3.7 ton


"Near" future
ABRA
10 cm
CAST
SHAFT
Neutron Stars
Globular clusters
High
IAXO
IAXO+
Telescopes
$m_a$ [eV]


This talk:
a minimal, unified framework
based on extrapolating the radiation
epoch (and SM) back to the singularity
Guiding pri ples:
CPT & conf mal symmetry; analyticity
new expla ons for LCDM features
predict 3 g erations i g RH $\nu's$
no need f flation o dditional particles
with mini assumpti explain
the amplit , tilt and cal character
of the prim dial fluctu
20 Gpc
10 μm
Planck length


Prediction for primordial perturbations
$\mathcal{P}_{\mathcal{R}}(k) = \frac{3^2 5^2}{7(2\pi)^4}\left(\frac{c_\beta^{SM}}{\mathcal{N}_{eff}}\right)^2 \left(\frac{k}{k_P}\right)^{-\frac{7\alpha_3}{\pi}}$; $k_P$= comoving Planck wavenumber
and $\mathcal{N}_{eff} = 106\frac{1}{4}$
$= 14.8 \pm 5.1,$ $k_* \equiv 0.05$ Mpc-1
$A = (13 \pm 5) \times 10^{-10}$; $n_s = 0.958$
$n_s = 0.959 \pm 0.006$

# Promise

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  - Kerr Spacetime; Magnetosphere;Jet, Disk, Wind Dynamics; Binaries; Environment; UHECR...
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  - (Magnetic) EoS; SQED Theory, Obs, Expt; FRB; knae, PWN; Emission, Transmission…
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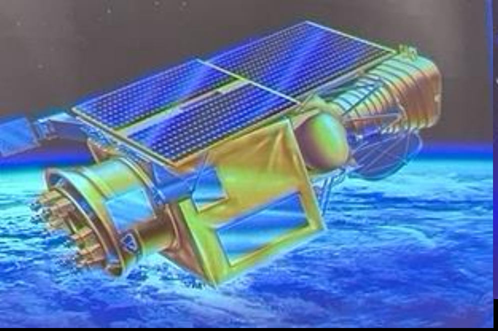
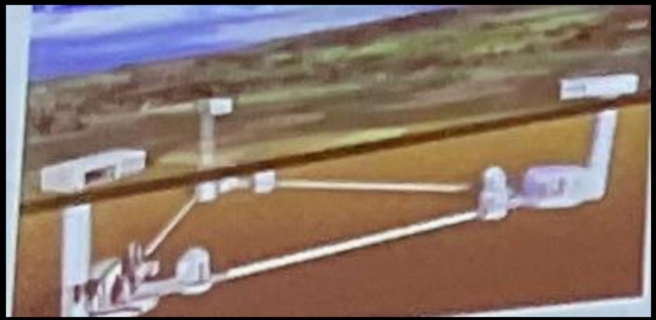
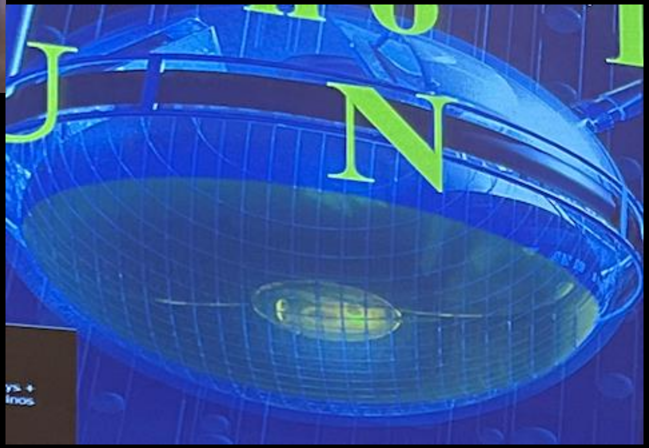
  - Dark Matter; Inflation; Neutrinos; Standard Model; Archaeology…

**Expect the Unexpected!**

# Prospects











# Scientific Discovery is "Logically Unscripted"

- CMB – antenna noise
- Quasars (massive BH) – radio source identifications
- Stellar BHs – X-ray source identifications
- Massive and mutable $\nu$'s – checking solar model
- Neutron stars – lunar X-rays
- Pulsars – interplanetary scintillation
- Gamma ray bursts – nuclear weapons monitoring
- Dark matter – galactic and stellar orbits
- Cosmic acceleration – supernova explosions
- Gravitational lenses – quasar follow up
- Gravitational radiation – pulsar timing
- Massive black hole binaries – LIGO….
- Fast Radio Bursts – transients e.g. NSB, PBH

BIG Surprises still Coming

# Top-Down and Bottom-Up Science

- Reductionist Approach
  - Celestial Mechanics, Stellar Atmospheres
  - EM, Plasma, for Modest Dynamic Range
  - Cosmological Subgrid Modeling?
  - Connect Data with Simulation using Machine Learning?
- Inductive Approach
  - Global Conservation Laws
  - Characteristic Length, Time, Mass, Energy Scales
- Special Sources vs Statistical Sample

Start with Best Observational Clues on Largest Scales

# The Future of Relativistic Astrophysicists

- Longstanding, global, existential crises
  - Climate, energy, disease, deforestation, flood, drought, fire, resource, inequality…
- Needs adaptive, corrective, innovative and rapid response
  - Problems are global
  - Space and ground
  - Monitoring requires new instruments and creates large, heterogeneous, datasets
  - Machine learning…
- Solutions will involve many fields of science
  - Atomic, biology, chemistry, computational, engineering, fluid, nuclear, plasma, radiation…
  - Progress at interfaces, requiring boldness to ”fail fast” and supply new insight
- Just like relativistic astrophysics!
- We need to become more broadly proficient
  - Learn new fields; resist specialization

We Need to Start Now

# Summary

- Relativistic Astrophysics has grown remarkably over sixty years
  - Largely unscripted
  - Still growing today
- Observational Discovery, Theoretical Foundation, Astrophysics
  - Two way streets
  - Data and simulation
  - Huge public interest
- Black Holes, Neutron Stars, Gravitational Radiation, Cosmology
  - Scientifically entangled
  - Connects to most other areas of physics
- Texas Conferences are great!

See you in Arizona State University in 2025