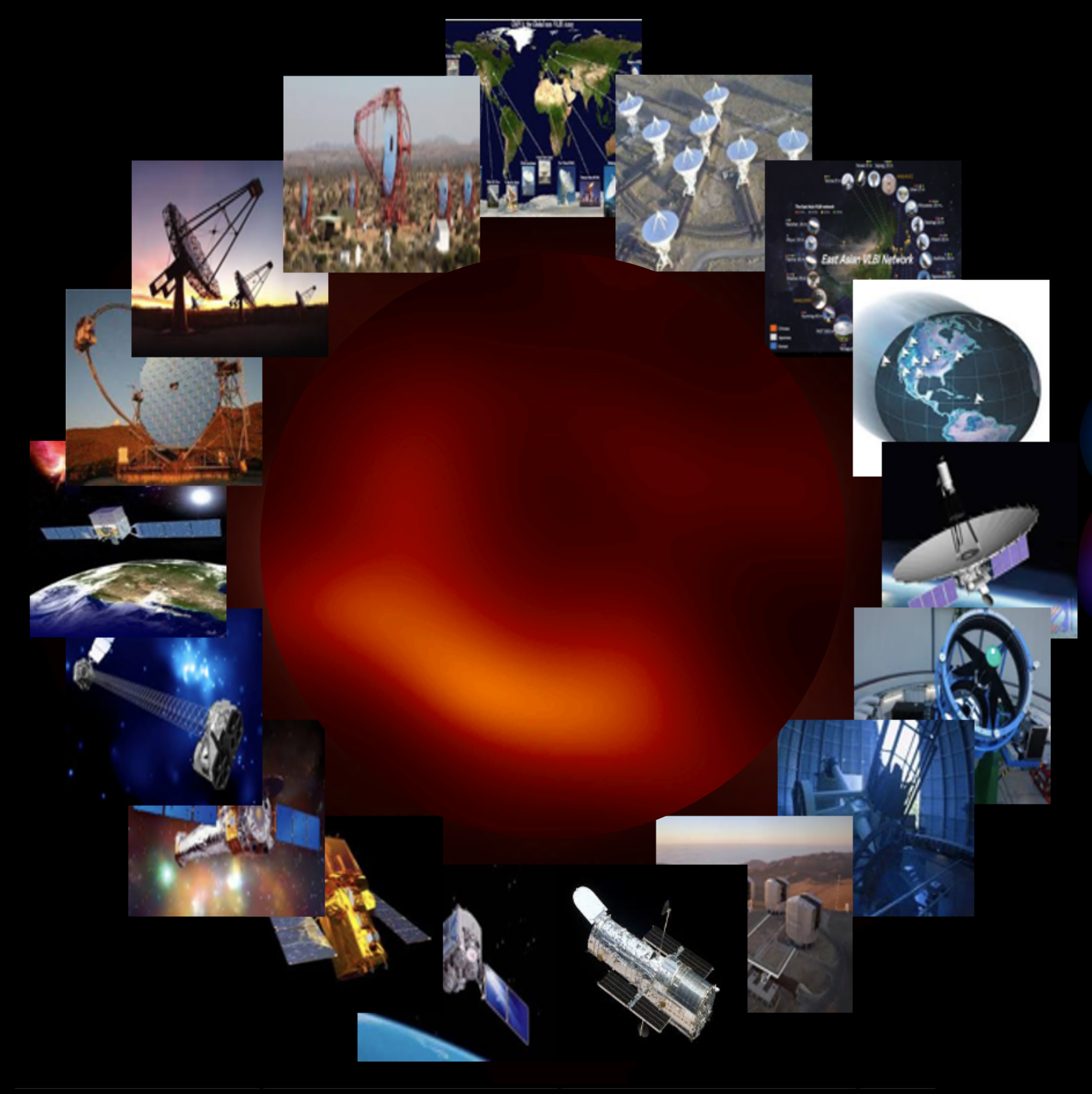
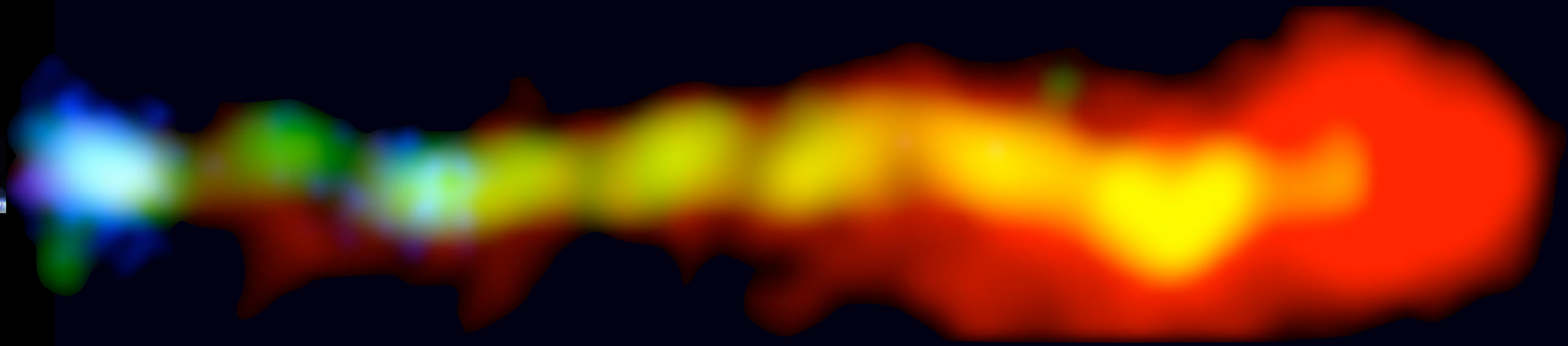
EHT(++) in the era of multi-messenger transients





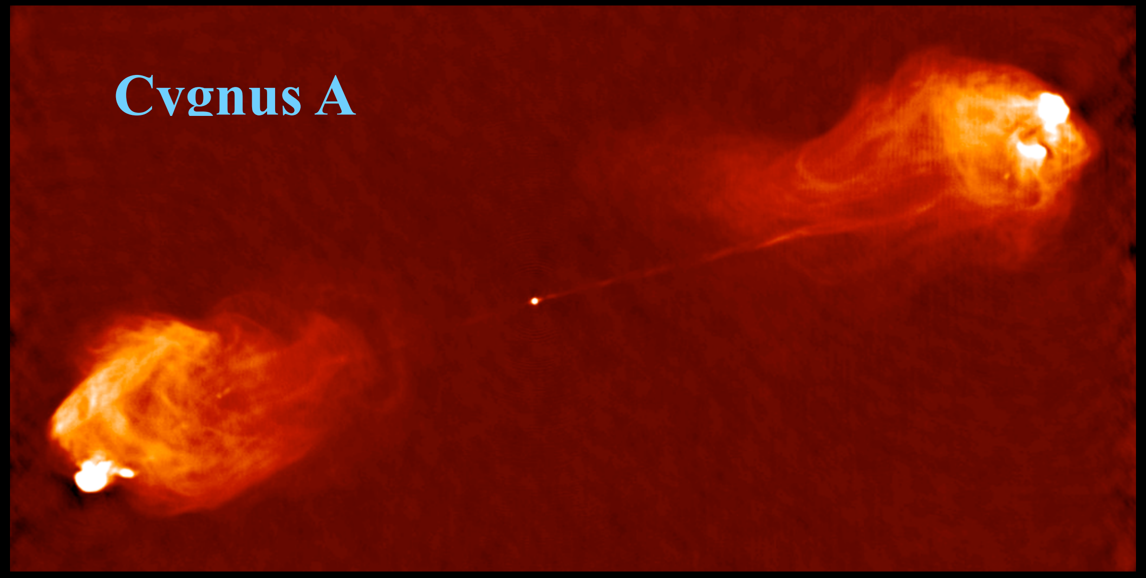
3C273 (Jester++2006):
Blue: X-rays (Chandra), Green: Optical (HST) , Yellow: Optical & Peak Radio, Red: Radio (VLA)

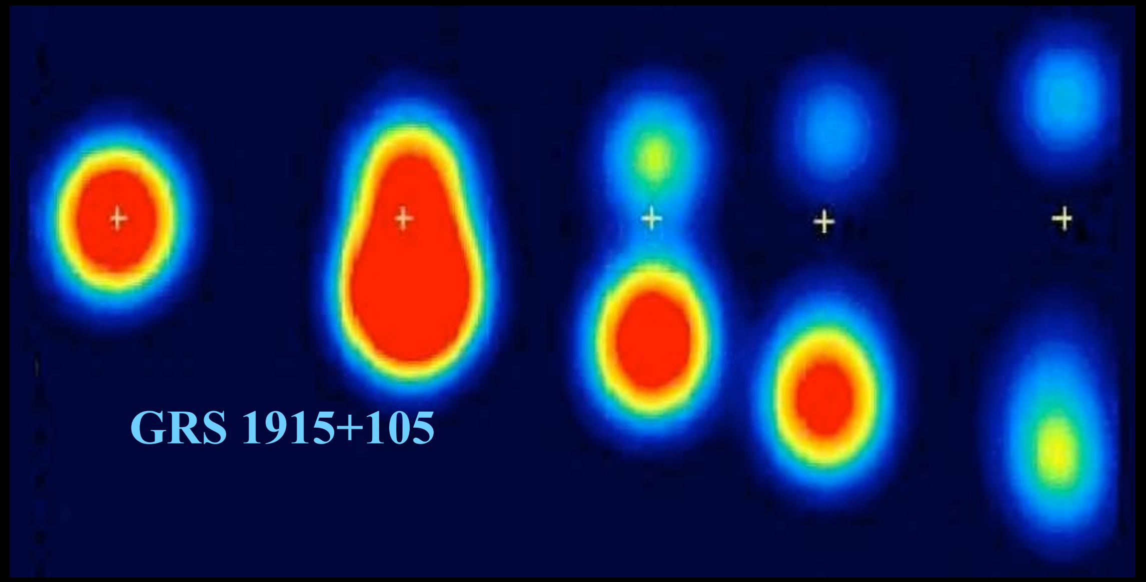
Sera Markoff (API/GRAPPA, University of Amsterdam)

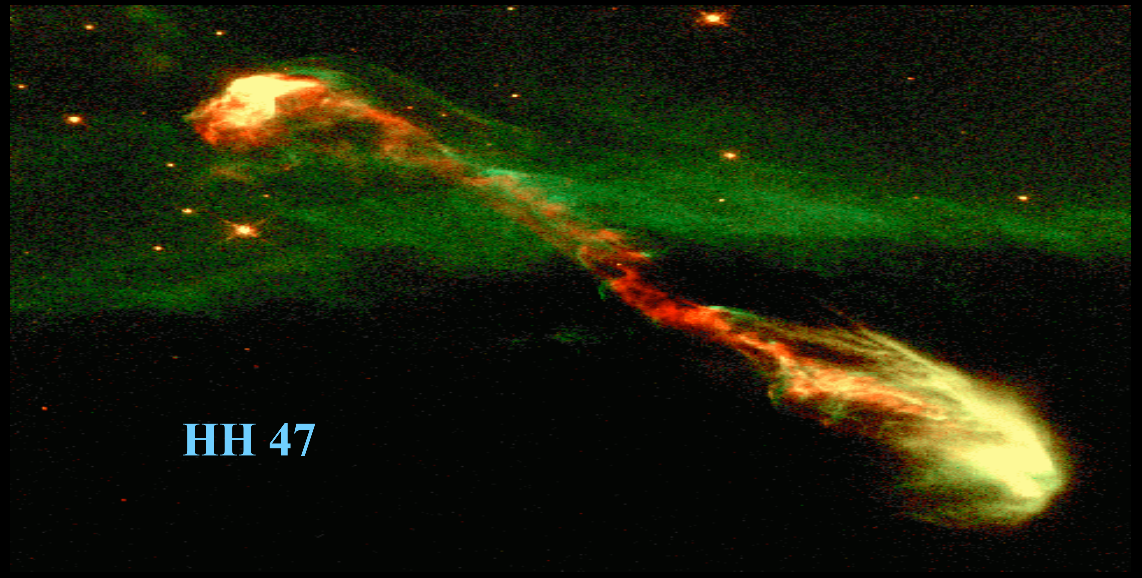
Co-coordinator: EHT Multiwavelength Science WG & ngEHT Transients Science WG + Member CTAC

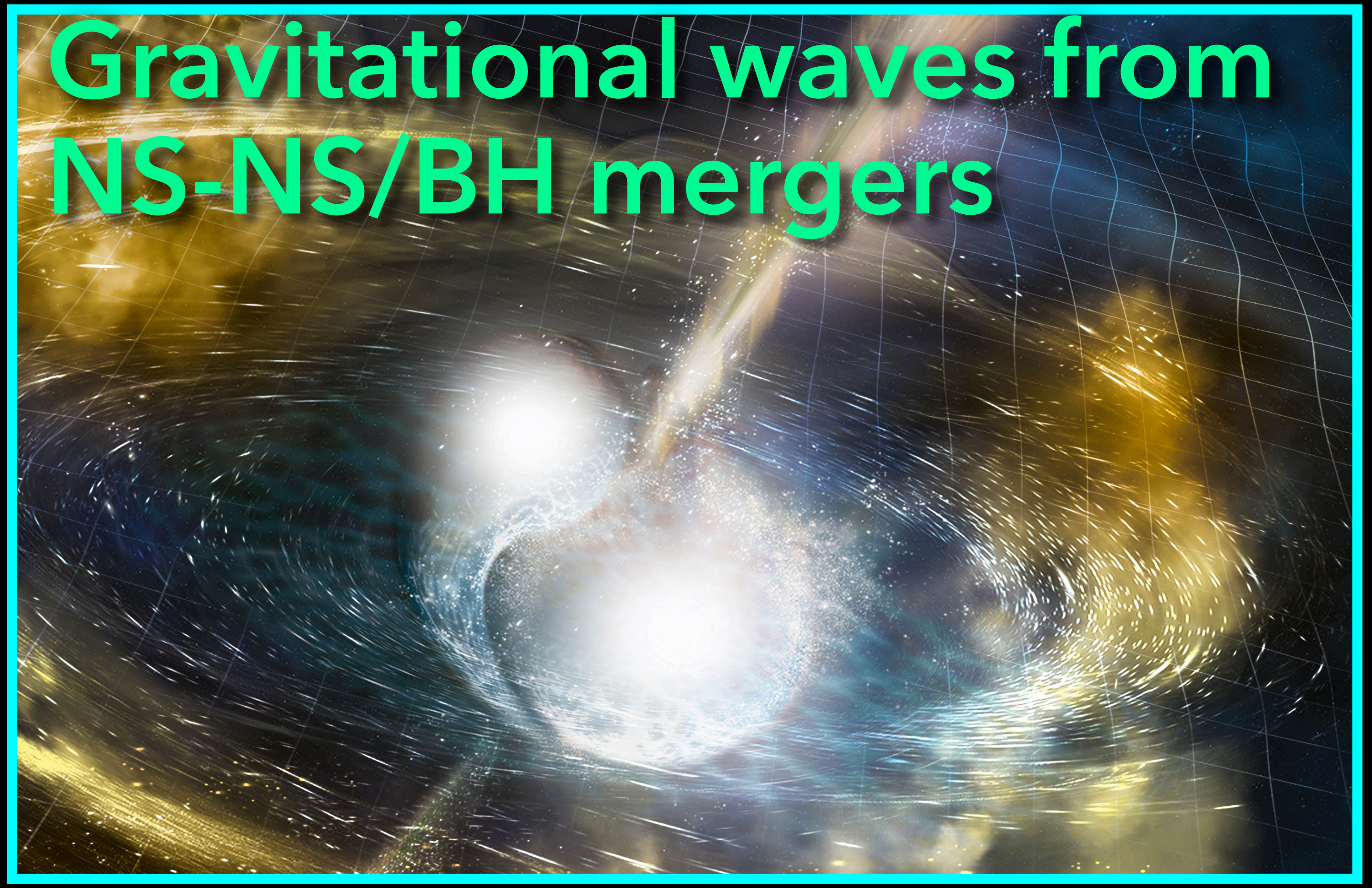
+ several current/former members of the 'jetsetters' group @ U Amsterdam (K. Chatterjee, D. v. Eijnatten, C. Hesp, M. Liska, M. Lucchini, W. Mulaudzi, G. Musoke, R. Plotkin, L. Sosapanta Salas, D.-S. Yoon)
+ J. Davelaar, S. Phillipov, B. Ripperda, S. Tchekhovskoy, Z. Younsi

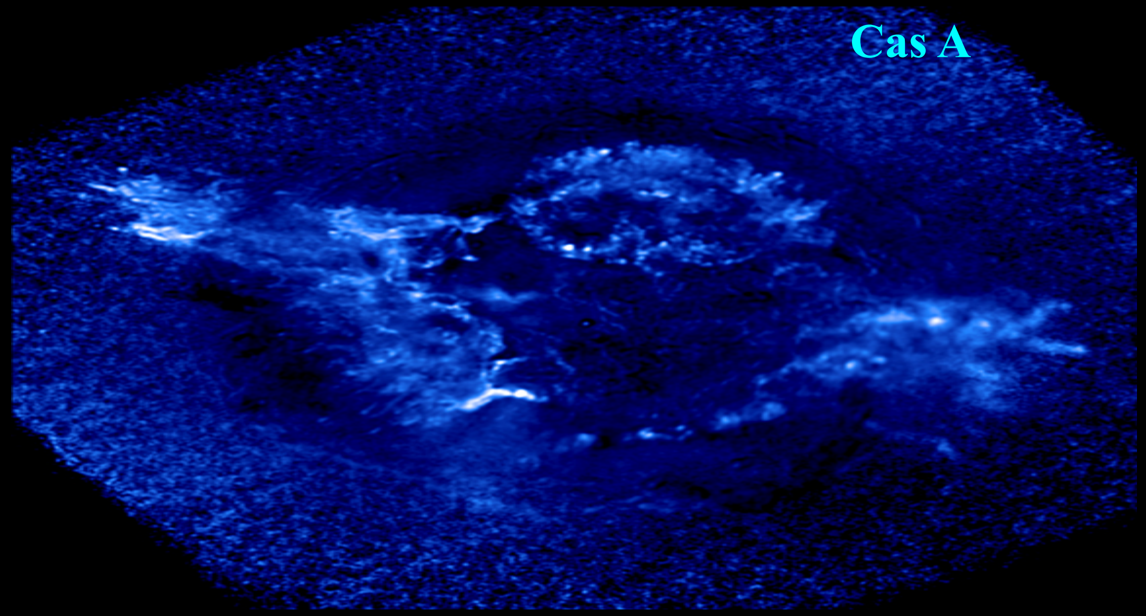
For all high-energy classes, "core problem" is macroscopic ⇔ microscopic coupling

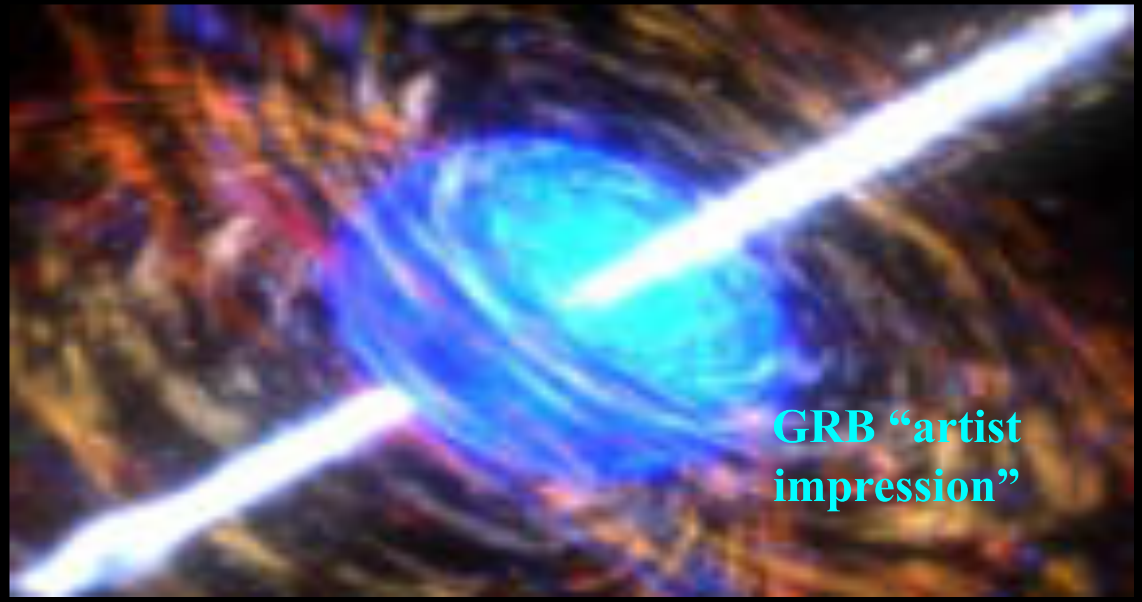


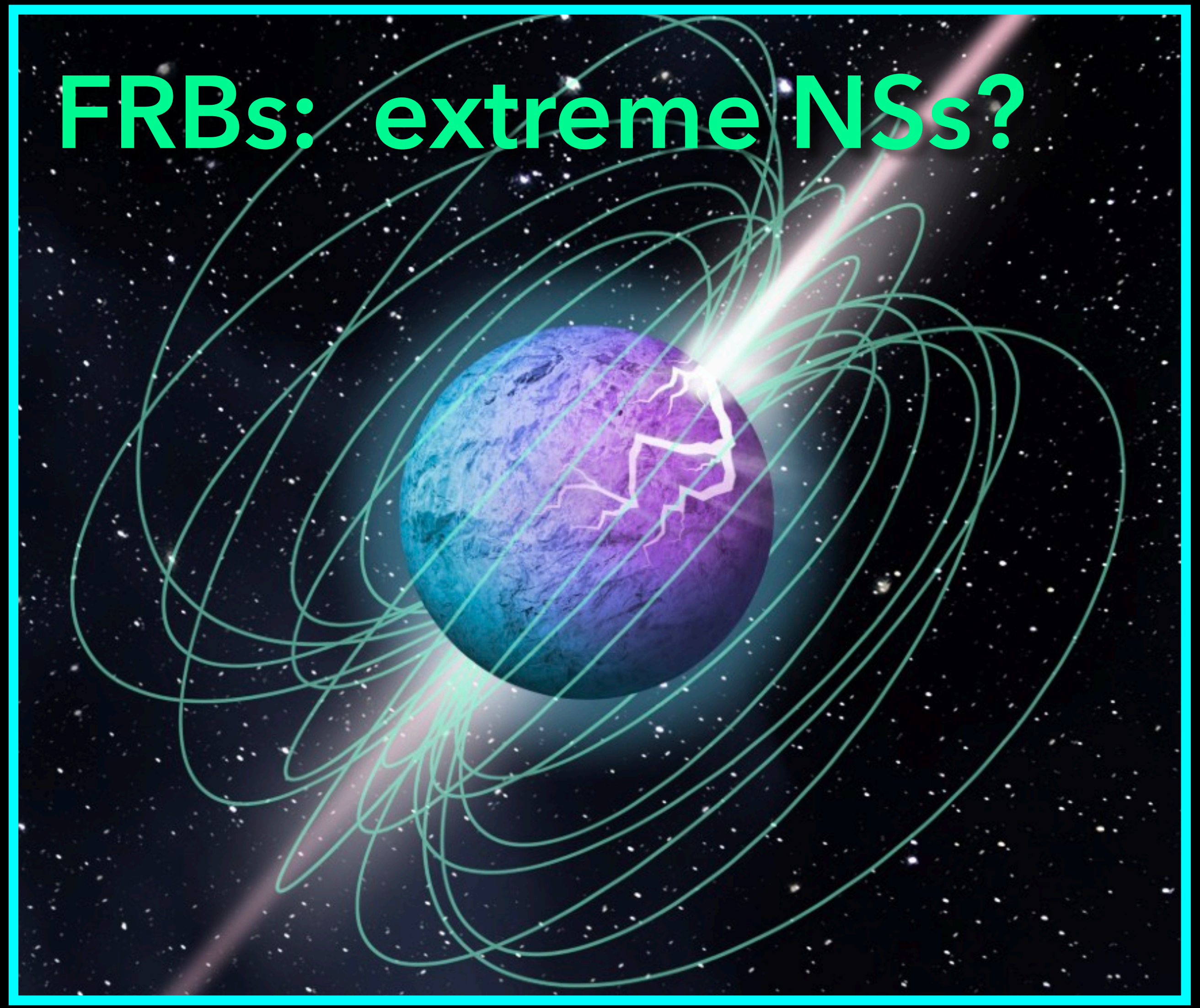


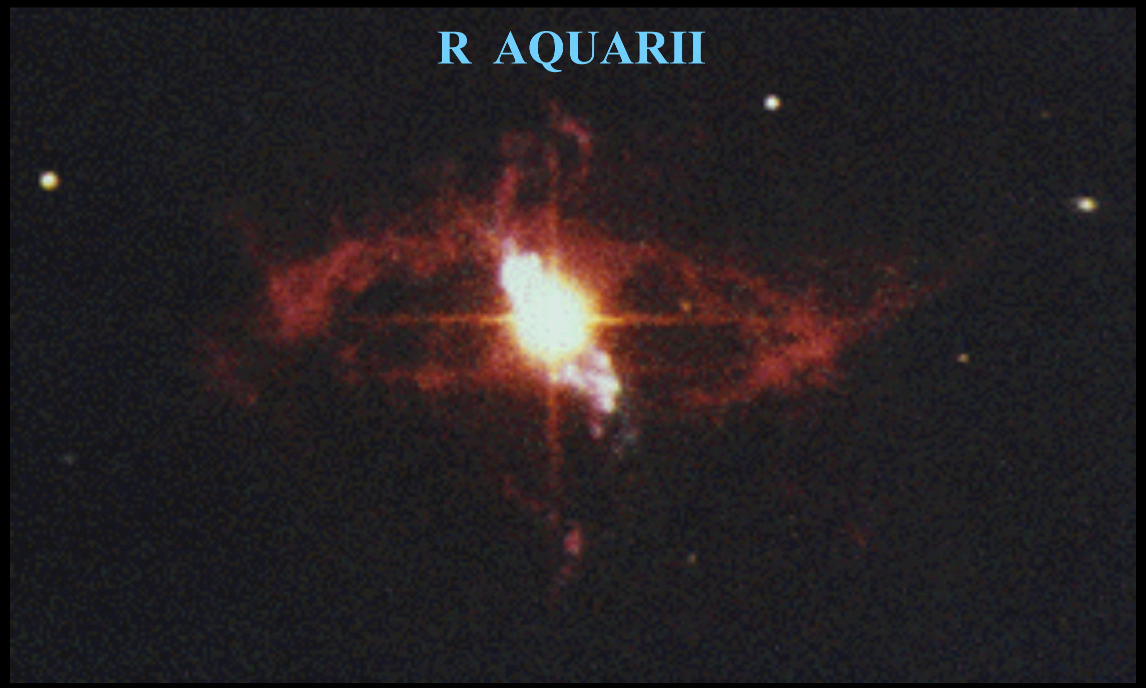


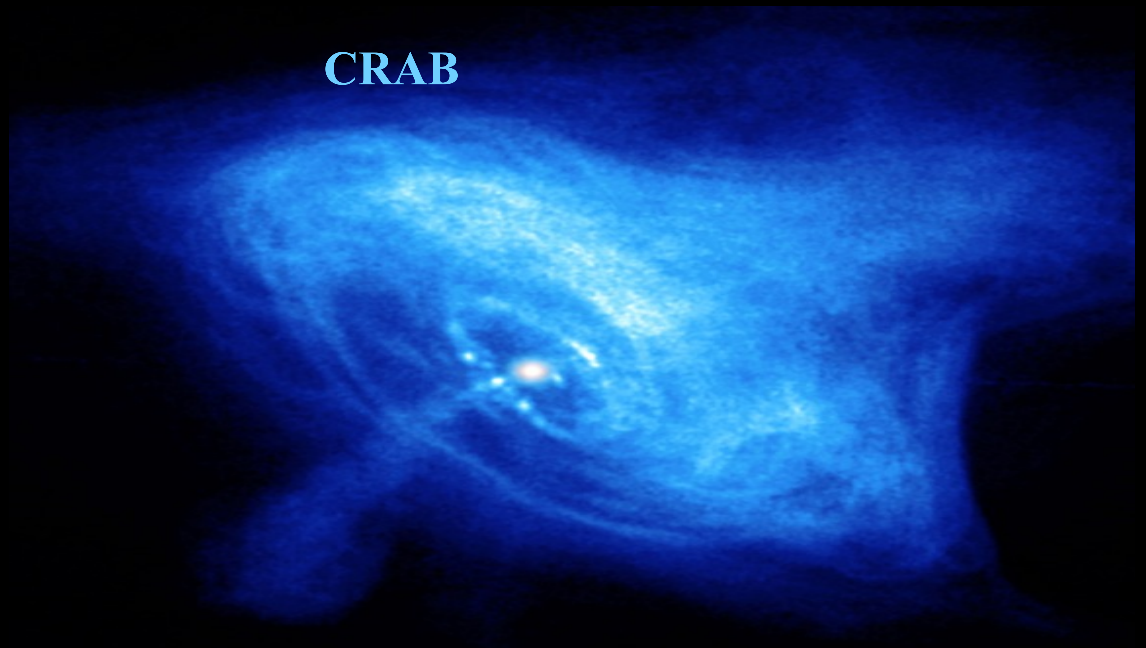






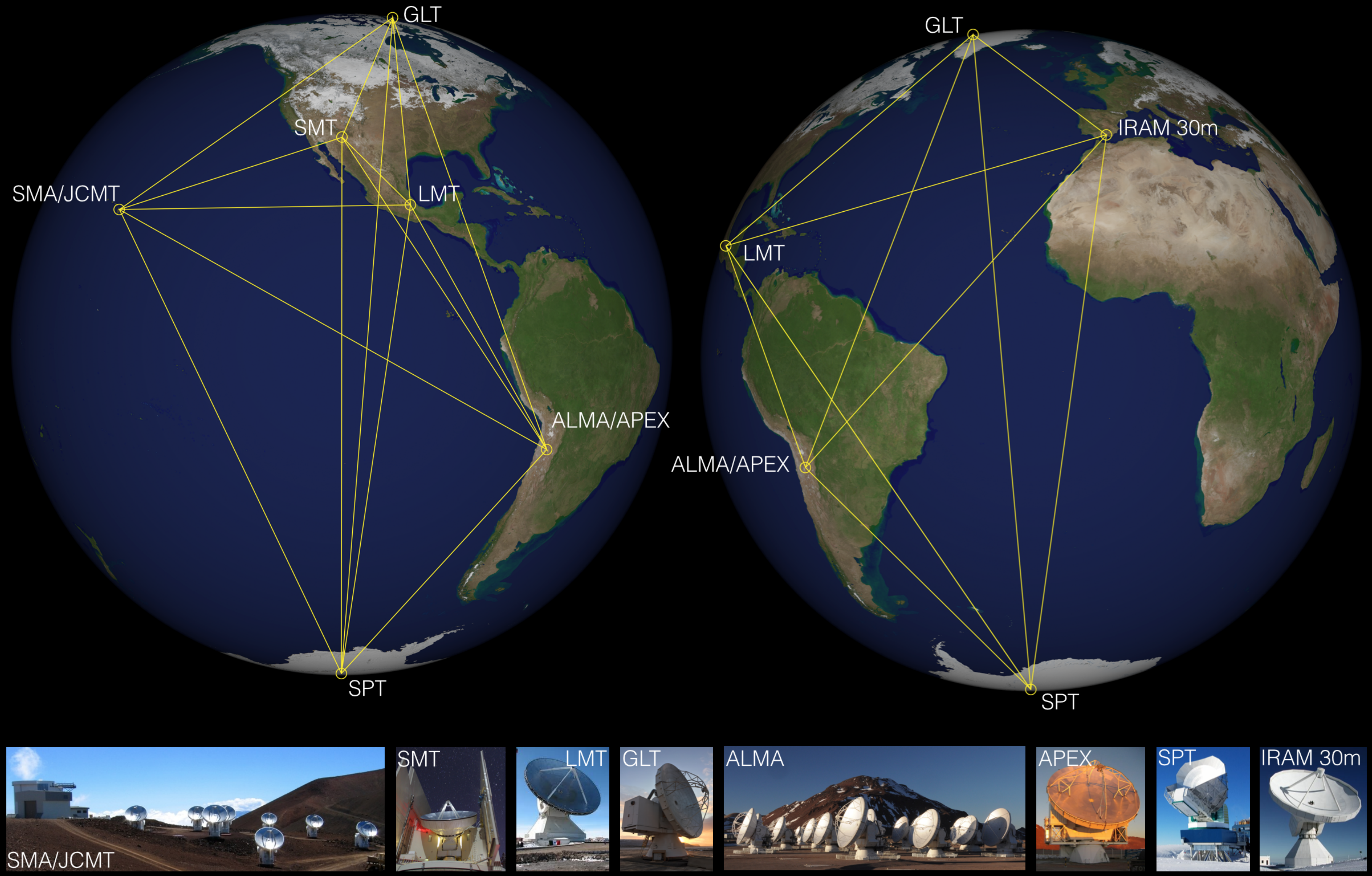


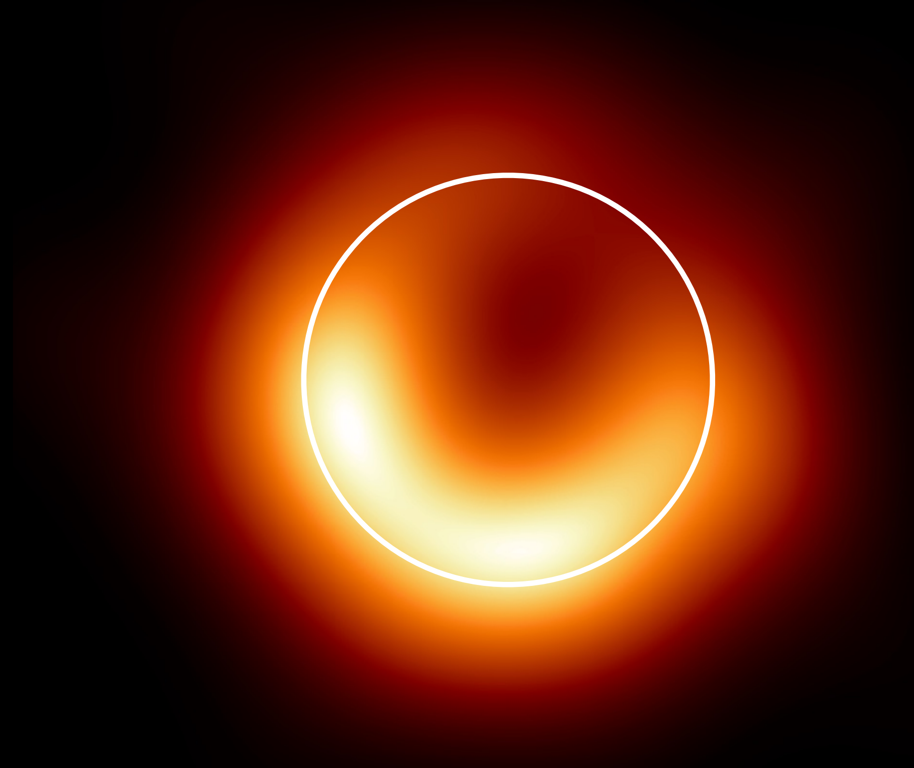




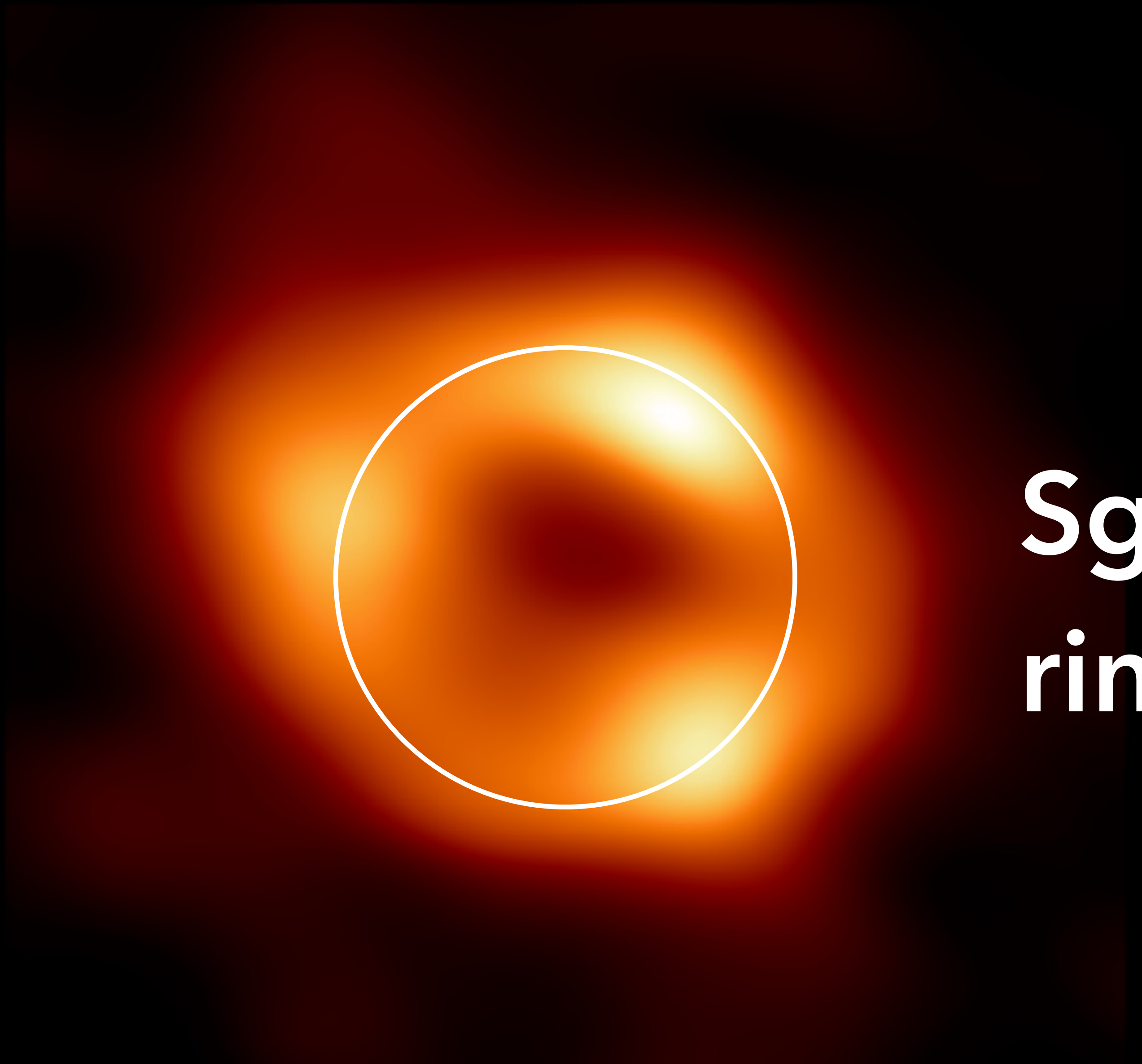
How does the Event Horizon Telescope (EHT) factor in??

Event Horizon Telescope





M87*
ring ≈ 42 μas



Sgr A*
ring≈ 52 μas

EHTC M87* paper I (2019); Sgr A* paper I (2022)

How does the Event Horizon Telescope (EHT) factor in??

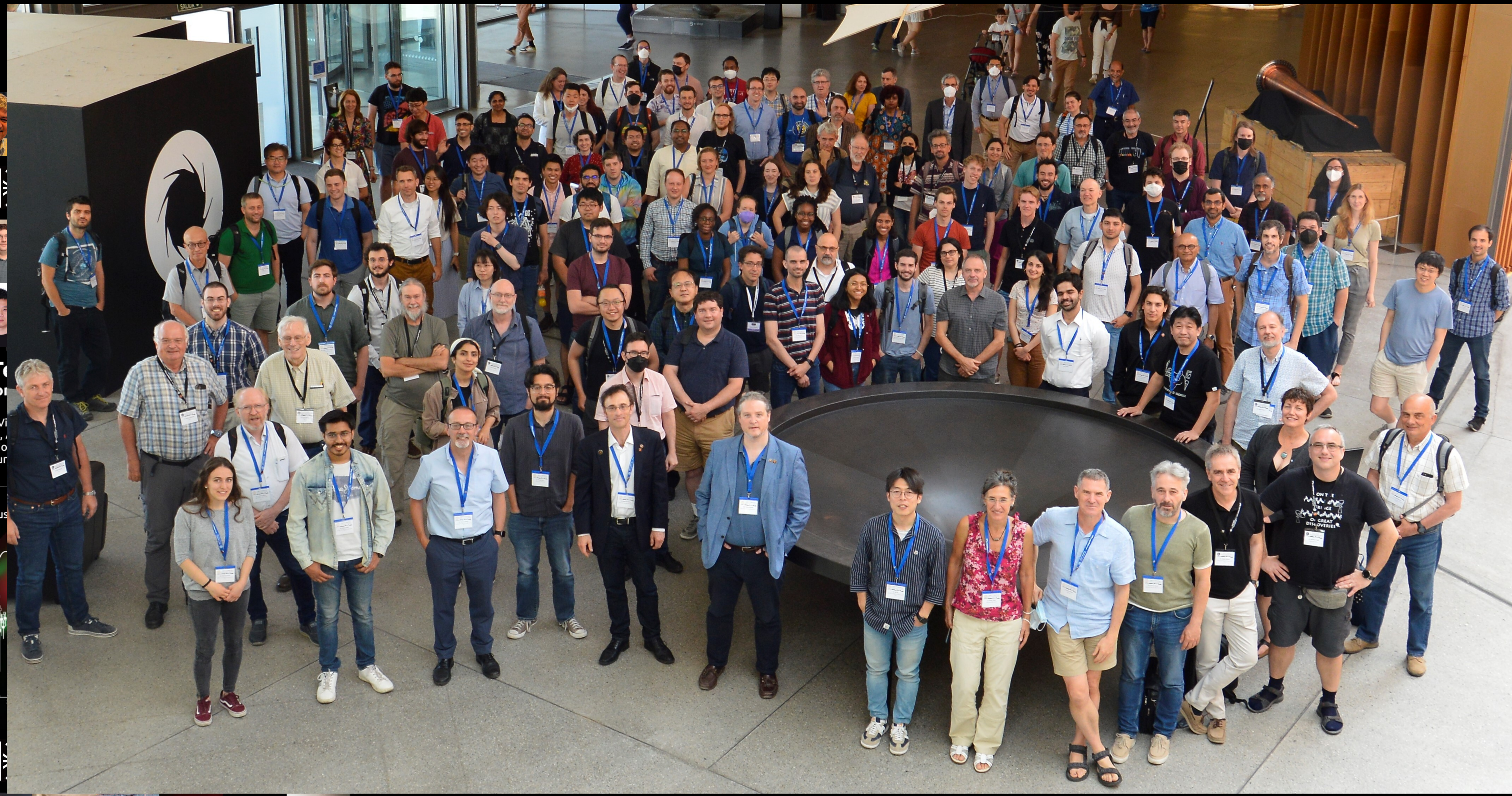
Event Horizon Telescope

VLBI imaging + MWL observations offers a new approach to solving longstanding questions

Sgr A*
ring≈ 52 μas

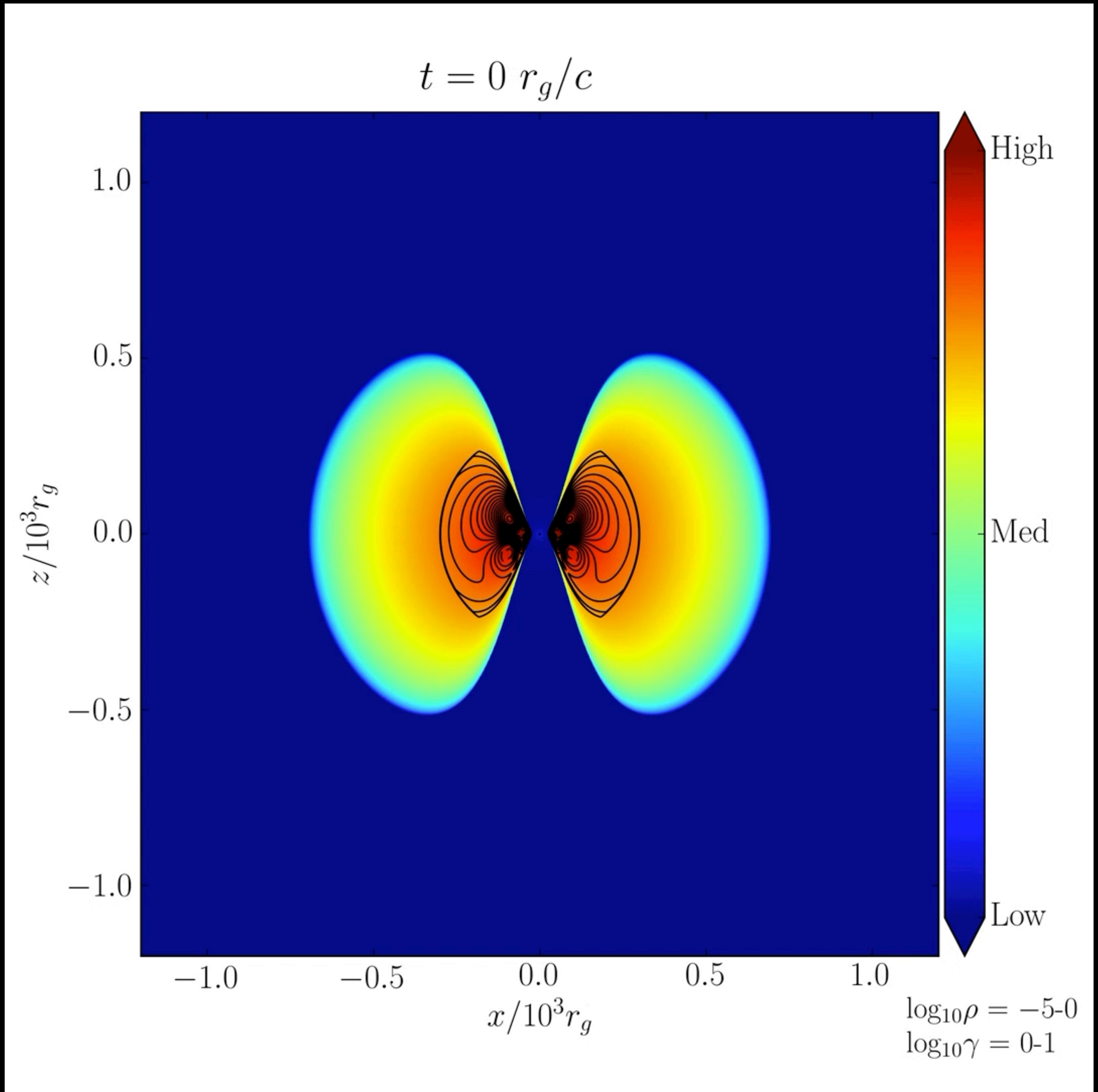
EHTC M87* paper I (2019); Sgr A* paper I (2022)

The Event Horizon Telescope (EHT) Collaboration is comprised of >300 members from >80 institutes….



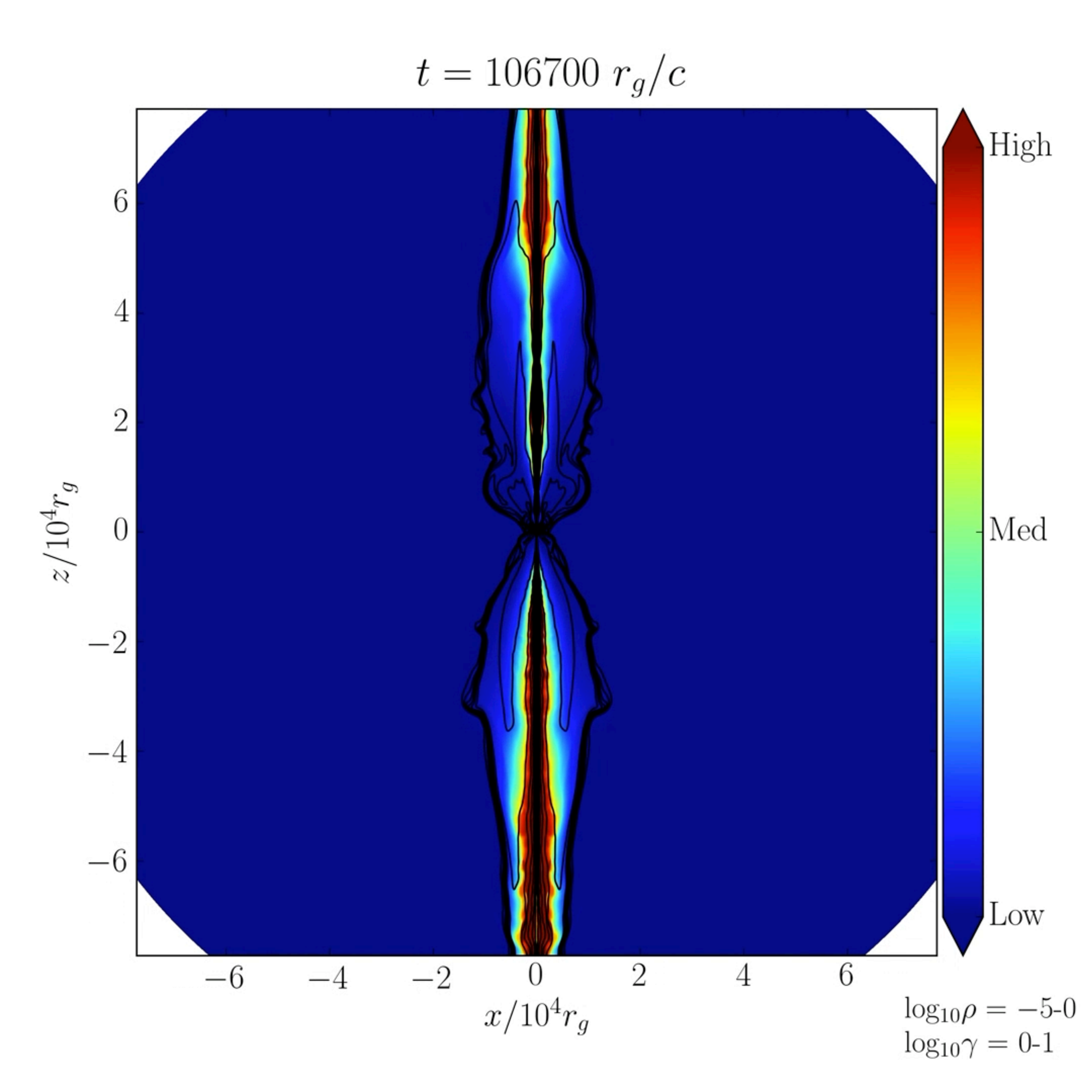
…across 19 time zones!

GRMHD simulations + GR ray-tracing ➠ synthetic EHT images



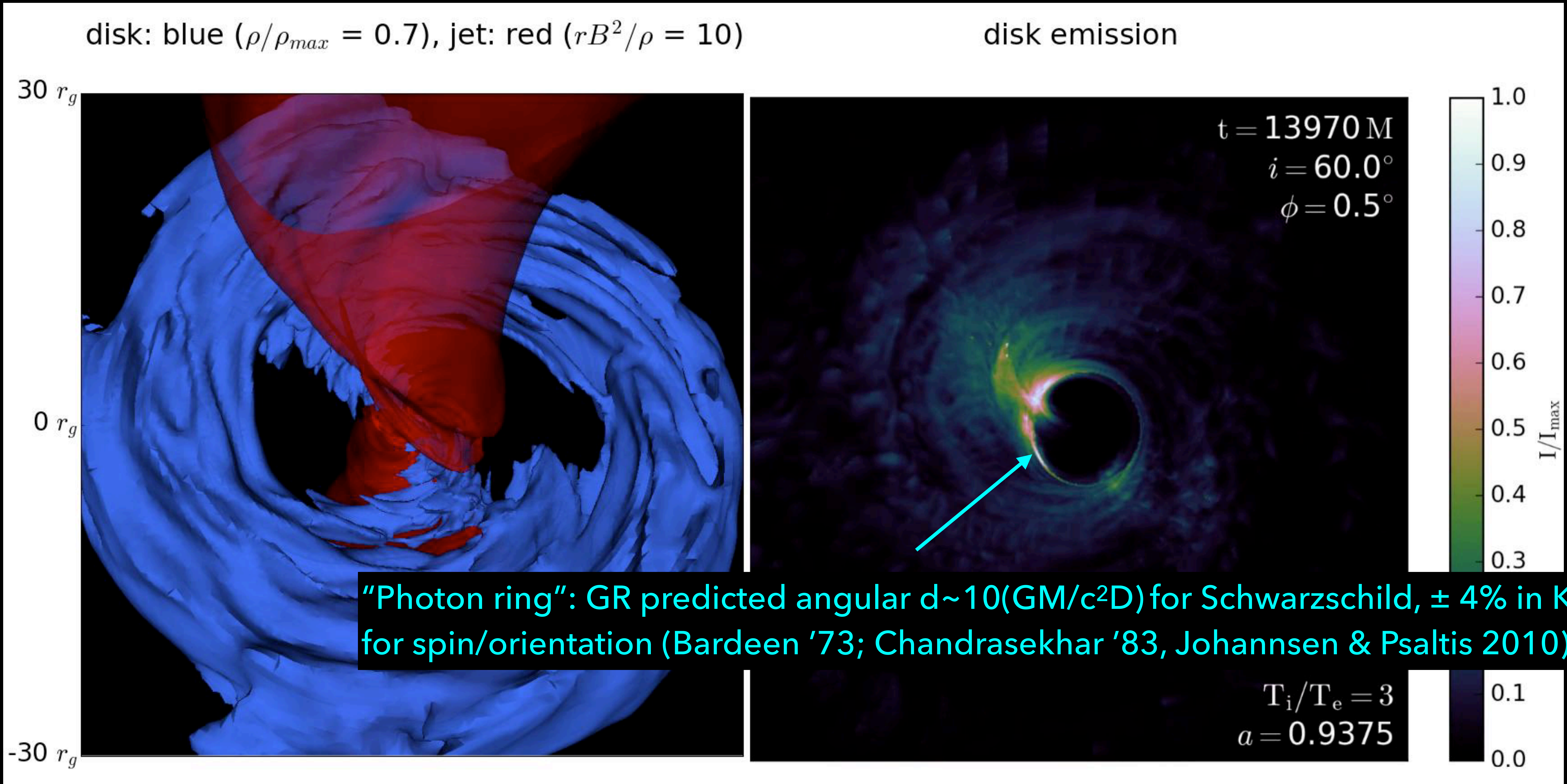
(2D 6000x800x1 resolution; Chatterjee, Liska, Tchekhovskoy & SM 2019, using H-AMR: Liska, Chatterjee, Tchekhovskoy+ 2019)

GRMHD simulations + GR ray-tracing ➟ synthetic EHT images



(2D 6000x800x1 resolution; Chatterjee, Liska, Tchekhovskoy & SM 2019, using H-AMR: Liska, Chatterjee, Tchekhovskoy+ 2019)

GRMHD simulations + GR ray-tracing ➟ synthetic EHT images

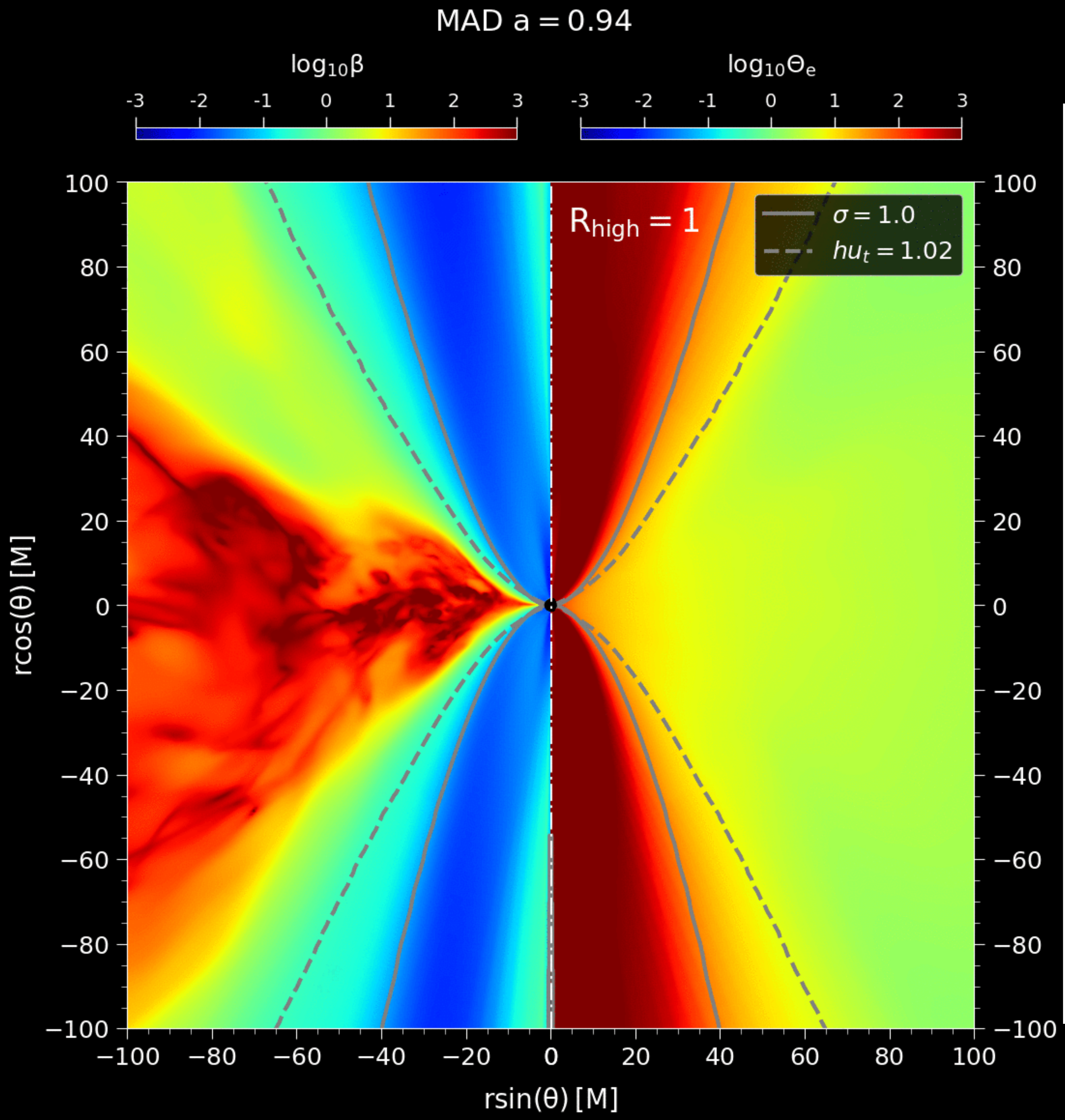


"Photon ring": GR predicted angular d~10(GM/c^2D) for Schwarzschild, ± 4% in Kerr for spin/orientation (Bardeen '73; Chandrasekhar '83, Johannsen & Psaltis 2010)

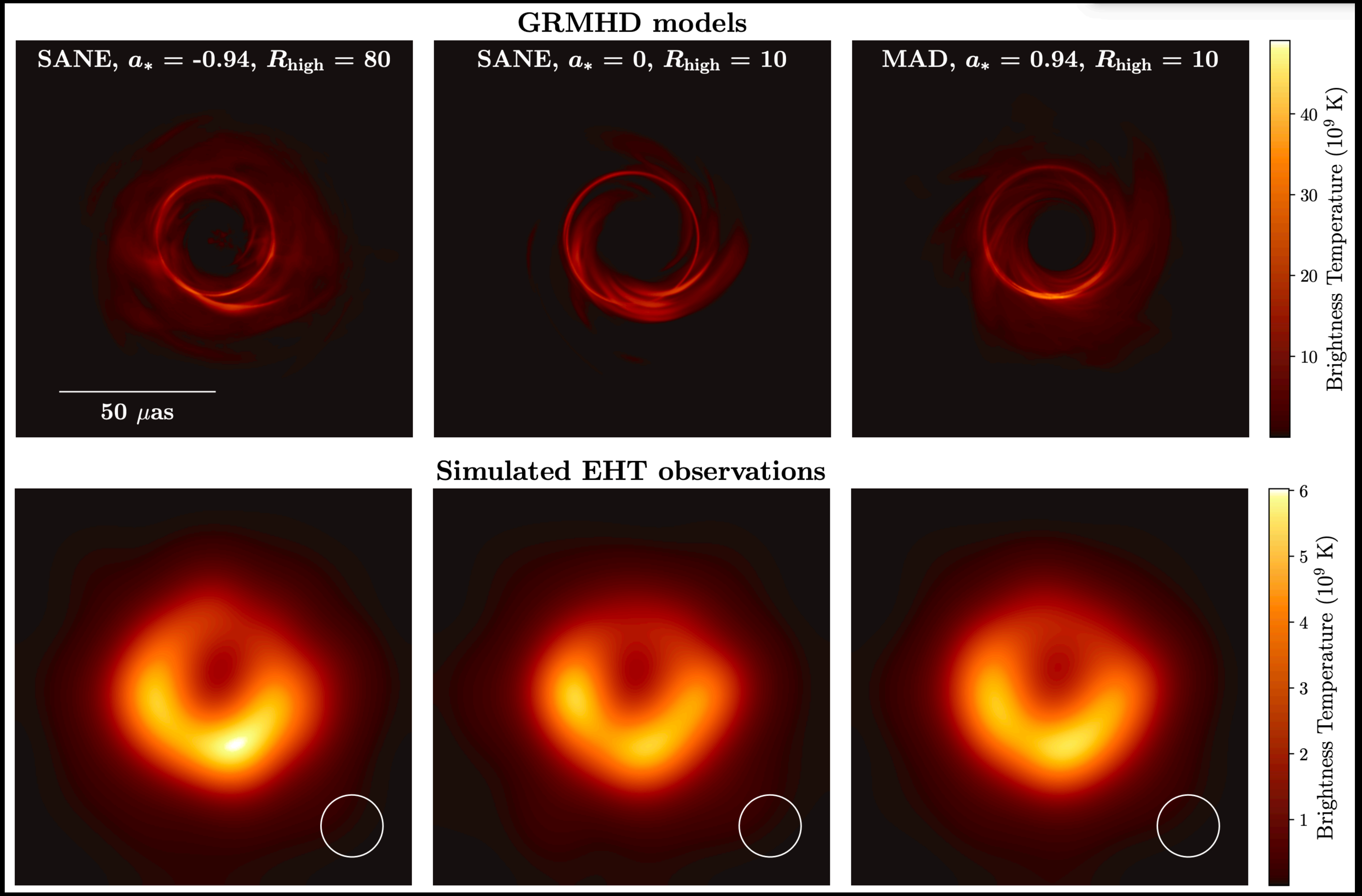
(2D 6000x800x1 resolution; Chatterjee, Liska, Tchekhovskoy & SM 2019, using H-AMR: Liska, Chatterjee, Tchekhovskoy+ 2019)

(Liska, Hesp, Tchekhovskoy, Ingram, vd Klis, SM+ 2018; Chatterjee, Younsi, Liska, Tchekhovskoy, SM 2020, using H-AMR)

Degeneracy introduced by models for electron microphysics

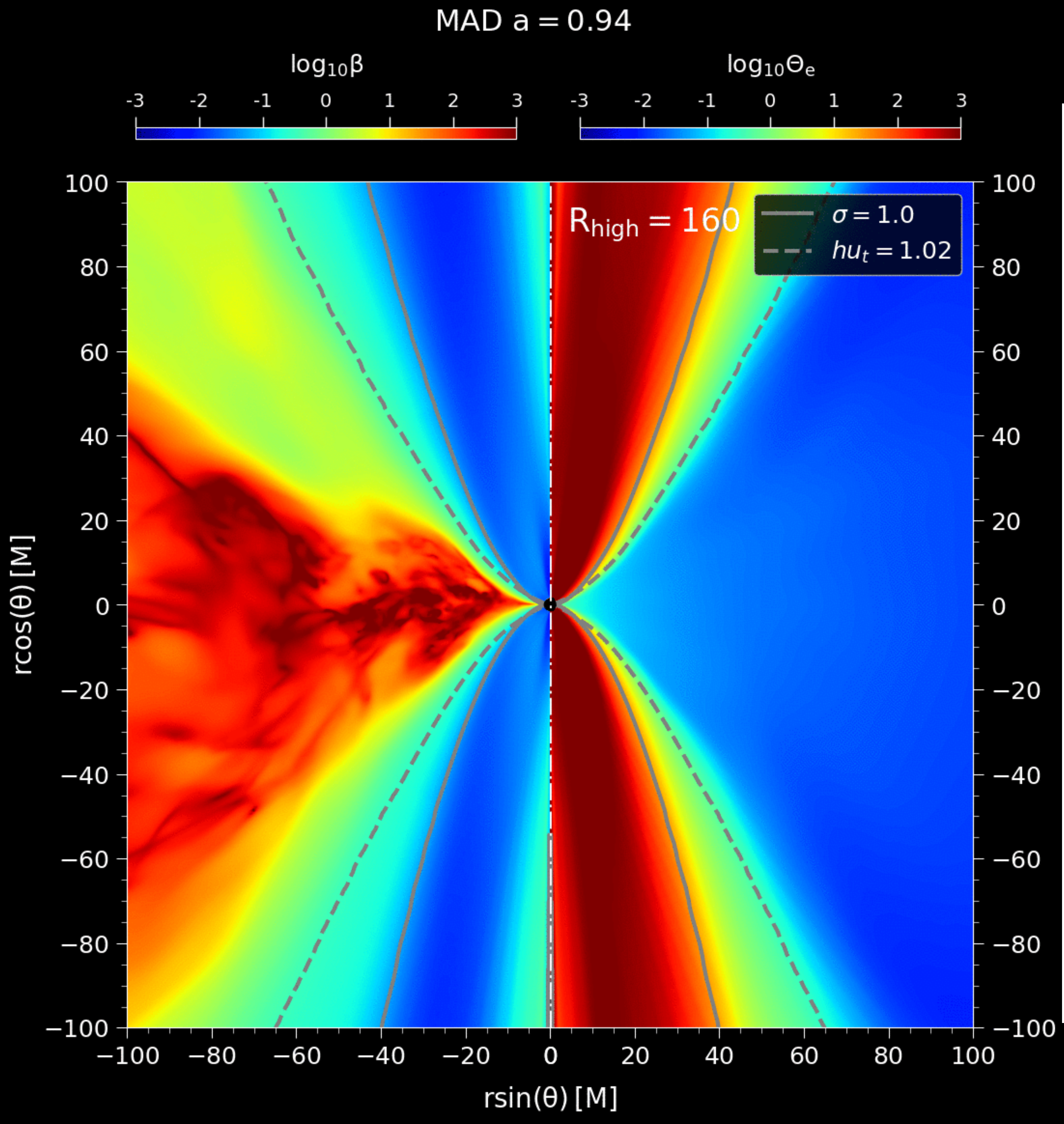


(Mizuno, Fromm, Younsi++21)

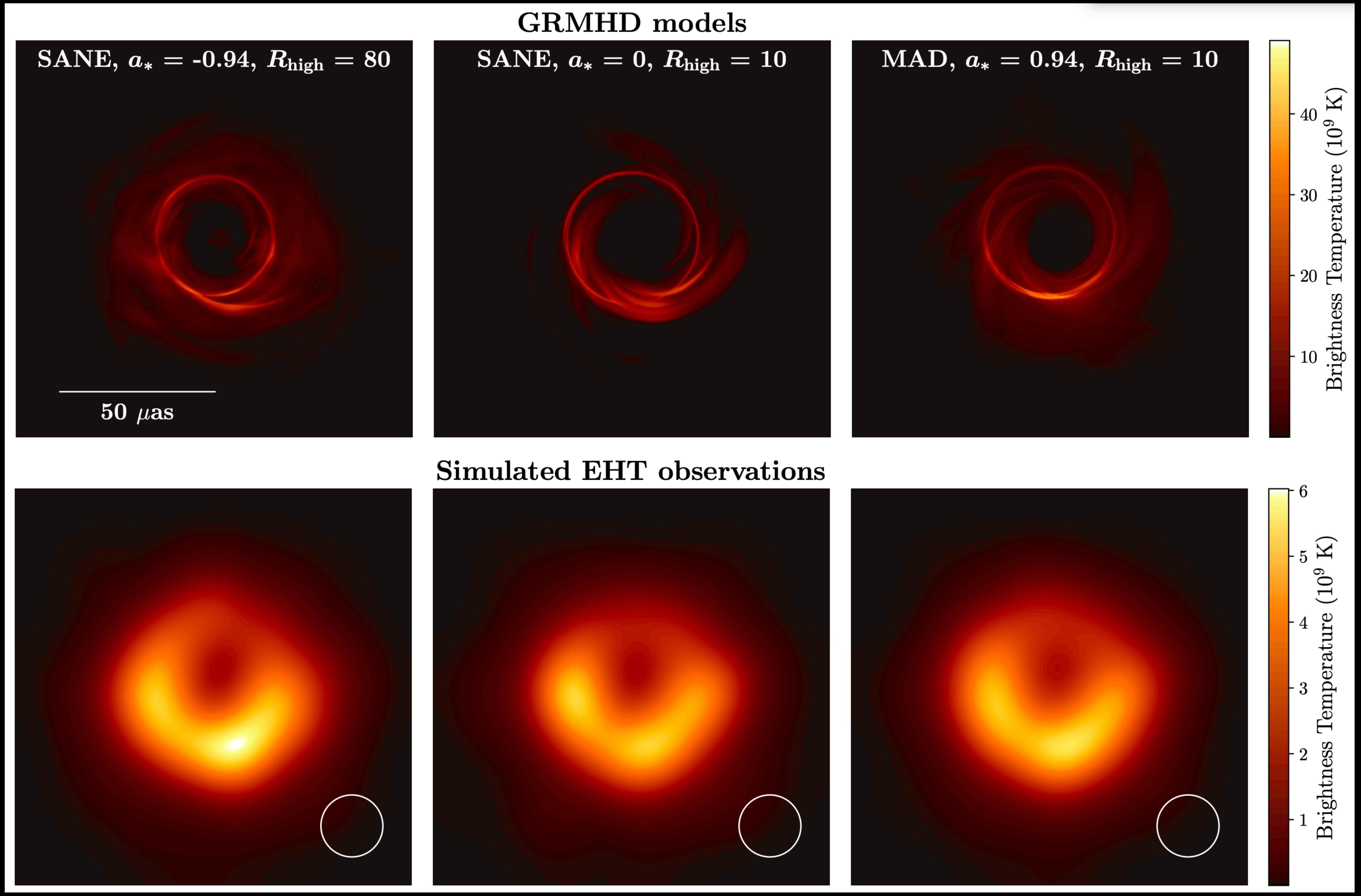


EHT Collaboration 2019, Papers V-VI

Degeneracy introduced by models for electron microphysics



(Mizuno, Fromm, Younsi++21)



EHT Collaboration 2019, Papers V-VI

Degeneracy i… microphysics

(Paper V; EHT Collaboration 2019)

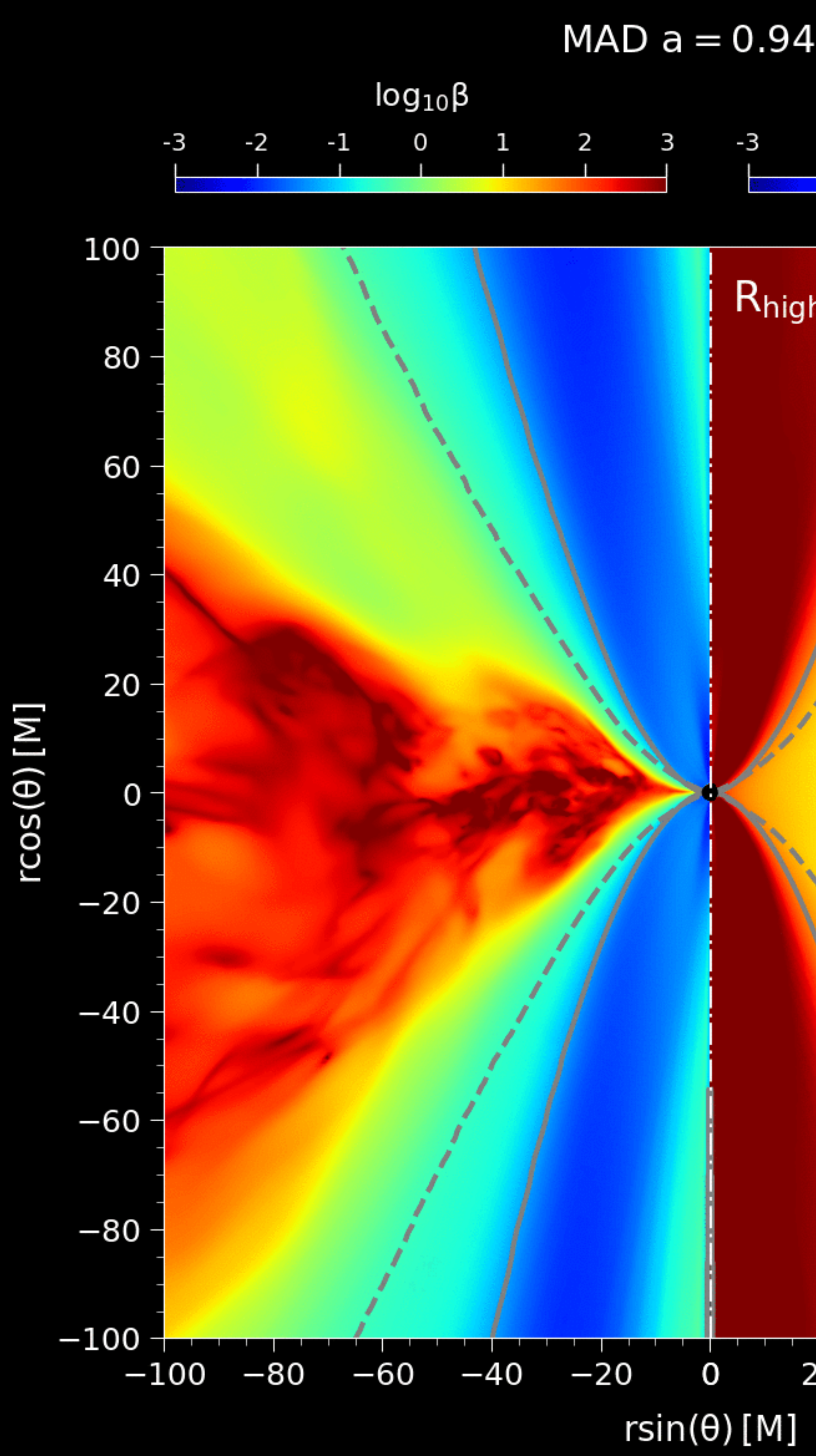


Table 2. Rejection Table

flux[1]	a_*[2]	$R_{\rm high}$[3]	AIS[4]	ϵ[5]	L_X[6]	$P_{\rm jet}$[7]	
SANE	-0.94	1	Fail	Pass	Pass	Pass	Fail
SANE	-0.94	10	Pass	Pass	Pass	Pass	**Pass**
SANE	-0.94	20	Pass	Pass	Pass	Pass	**Pass**
SANE	-0.94	40	Pass	Pass	Pass	Pass	**Pass**
SANE	-0.94	80	Pass	Pass	Pass	Pass	**Pass**
SANE	-0.94	160	Fail	Pass	Pass	Pass	Fail
SANE	-0.5	1	Pass	Pass	Fail	Fail	Fail
SANE	-0.5	10	Pass	Pass	Fail	Fail	Fail
SANE	-0.5	20	Pass	Pass	Pass	Fail	Fail
SANE	-0.5	40	Pass	Pass	Pass	Fail	Fail
SANE	-0.5	80	Fail	Pass	Pass	Fail	Fail
SANE	-0.5	160	Pass	Pass	Pass	Fail	Fail
SANE	0	1	Pass	Pass	Pass	Fail	Fail
SANE	0	10	Pass	Pass	Pass	Fail	Fail
SANE	0	20	Pass	Pass	Fail	Fail	Fail
SANE	0	40	Pass	Pass	Pass	Fail	Fail
SANE	0	80	Pass	Pass	Pass	Fail	Fail
SANE	0	160	Pass	Pass	Pass	Fail	Fail
SANE	+0.5	1	Pass	Pass	Pass	Fail	Fail
SANE	+0.5	10	Pass	Pass	Pass	Fail	Fail
SANE	+0.5	20	Pass	Pass	Pass	Fail	Fail
SANE	+0.5	40	Pass	Pass	Pass	Fail	Fail
SANE	+0.5	80	Pass	Pass	Pass	Fail	Fail
SANE	+0.5	160	Pass	Pass	Pass	Fail	Fail
SANE	+0.94	1	Pass	Fail	Pass	Fail	Fail
SANE	+0.94	10	Pass	Fail	Pass	Fail	Fail
SANE	+0.94	20	Pass	Pass	Pass	Fail	Fail
SANE	+0.94	40	Pass	Pass	Pass	Fail	Fail
SANE	+0.94	80	Pass	Pass	Pass	Pass	**Pass**
SANE	+0.94	160	Pass	Pass	Pass	Pass	**Pass**
MAD	-0.94	1	Fail	Fail	Pass	Pass	Fail
MAD	-0.94	10	Fail	Pass	Pass	Pass	Fail
MAD	-0.94	20	Fail	Pass	Pass	Pass	Fail
MAD	-0.94	40	Fail	Pass	Pass	Pass	Fail
MAD	-0.94	80	Fail	Pass	Pass	Pass	Fail
MAD	-0.94	160	Fail	Pass	Pass	Pass	Fail
MAD	-0.5	1	Pass	Fail	Pass	Fail	Fail
MAD	-0.5	10	Pass	Pass	Pass	Fail	Fail
MAD	-0.5	20	Pass	Pass	Pass	Pass	**Pass**

Table 2 *(continued)*

flux[1]	a_*[2]	$R_{\rm high}$[3]	AIS[4]	ϵ[5]	L_X[6]	$P_{\rm jet}$[7]	
MAD	-0.5	40	Pass	Pass	Pass	Pass	**Pass**
MAD	-0.5	80	Pass	Pass	Pass	Pass	**Pass**
MAD	-0.5	160	Pass	Pass	Pass	Pass	**Pass**
MAD	0	1	Pass	Fail	Pass	Fail	Fail
MAD	0	10	Pass	Pass	Pass	Fail	Fail
MAD	0	20	Pass	Pass	Pass	Fail	Fail
MAD	0	40	Pass	Pass	Pass	Fail	Fail
MAD	0	80	Pass	Pass	Pass	Fail	Fail
MAD	0	160	Pass	Pass	Pass	Fail	Fail
MAD	+0.5	1	Pass	Fail	Pass	Fail	Fail
MAD	+0.5	10	Pass	Pass	Pass	Pass	**Pass**
MAD	+0.5	20	Pass	Pass	Pass	Pass	**Pass**
MAD	+0.5	40	Pass	Pass	Pass	Pass	**Pass**
MAD	+0.5	80	Pass	Pass	Pass	Pass	**Pass**
MAD	+0.5	160	Pass	Pass	Pass	Pass	**Pass**
MAD	+0.94	1	Pass	Fail	Fail	Pass	Fail
MAD	+0.94	10	Pass	Fail	Pass	Pass	Fail
MAD	+0.94	20	Pass	Pass	Pass	Pass	**Pass**
MAD	+0.94	40	Pass	Pass	Pass	Pass	**Pass**
MAD	+0.94	80	Pass	Pass	Pass	Pass	**Pass**
MAD	+0.94	160	Pass	Pass	Pass	Pass	**Pass**

[1] flux: net magnetic flux on the black hole (MAD, SANE).

[2] a_*: dimensionless black hole spin.

[3] $R_{\rm high}$: electron temperature parameter, see equation (8).

[4] Average Image Scoring (THEMIS-AIS), models are rejected if $p \leq 0.01$, see Section 4 and Table 1.

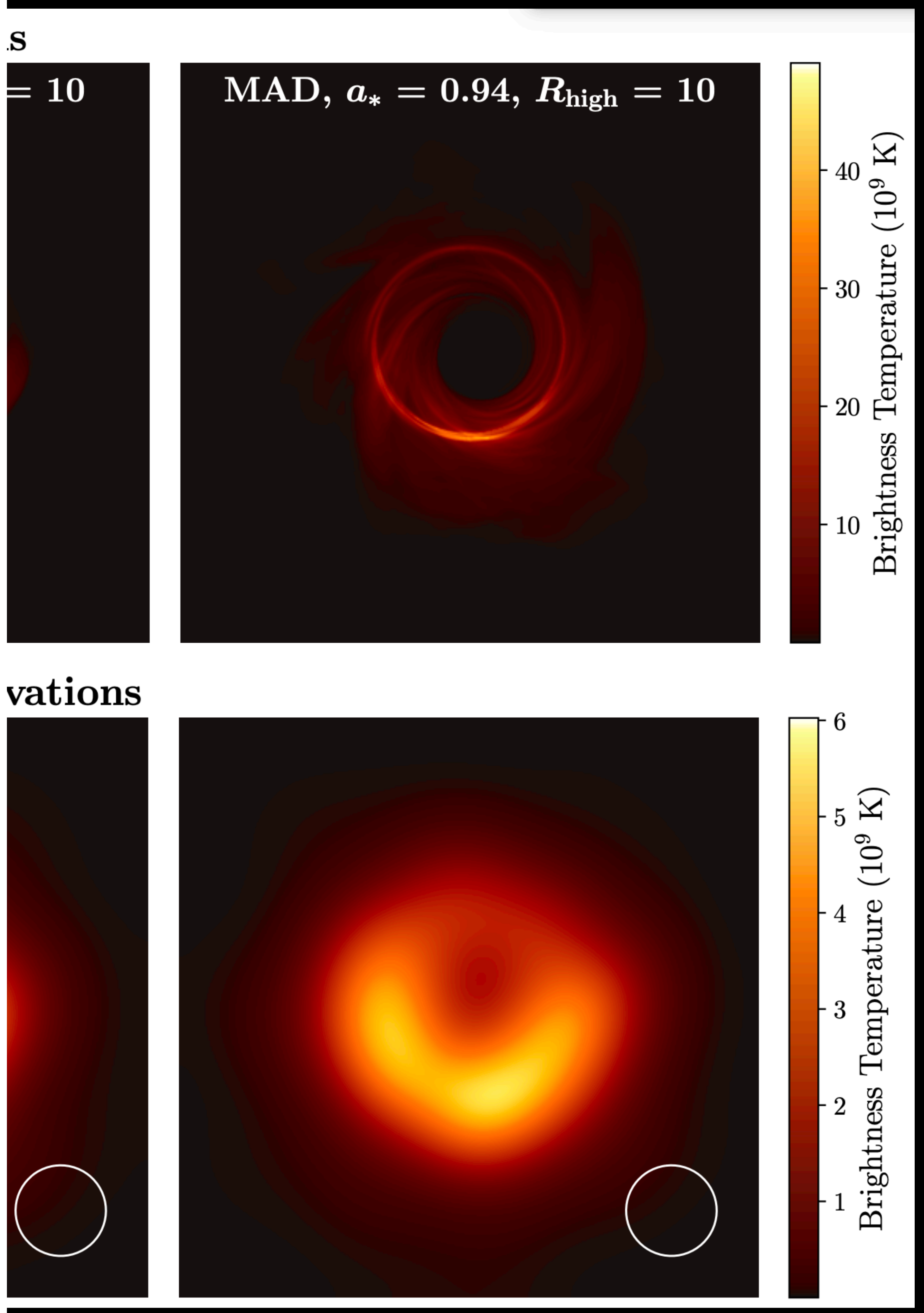
[5] ϵ: radiative efficiency, models are rejected if ϵ is larger than the corresponding thin disk efficiency, see Section 6.1.

[6] L_X: X-ray luminosity; models are rejected if $\langle L_X \rangle 10^{-2\sigma} > 4.4 \times 10^{40}$ erg sec^{-1}. See Section 6.2.

[7] $P_{\rm jet}$: jet power, models are rejected if $P_{\rm jet} \leq 10^{42}$ erg sec^{-1}, see Section 6.3.

7. DISCUSSION

We have interpreted the EHT2017 data using a limited library of models with attendant limitations. Many of the limitations stem from the GRMHD model, which treats the plasma as an ideal fluid governed by equations that encode conservation laws for particle number, momentum, and energy. The eDF, in particular, is de-



(Mizuno, Fromm, Younsi++21)

19, Papers V-VI


Degeneracy in ... microphysics
MAD a = 0.94
log10β
rcos(θ) [M]
rsin(θ) [M]
(Mizuno, Fromm, Younsi++21)
(Paper V; EHT Collaboration 2019)
Table 2. Rejection Table
flux[1] a*[2] Rhigh[3] AIS[4] ε[5] Lx[6] Pjet[7]
SANE -0.94 1 Fail Pass Pass Pass Fail
SANE -0.94 10 Pass Pass Pass Pass Pass
SANE -0.94 20 Pass Pass Pass Pass Pass
SANE -0.94 40 Pass Pass Pass Pass Pass
SANE -0.94 80 Pass Pass Pass Pass Pass
SANE -0.94 160 Fail Pass Pass Pass Fail
SANE -0.5 1 Pass Pass Fail Fail Fail
SANE -0.5 10 Pass Pass Fail Fail Fail
SANE -0.5 20 Pass Pass Pass Fail Fail
SANE -0.5 40 Pass Pass Pass Fail Fail
SANE -0.5 80 Fail Pass Pass Fail Fail
SANE -0.5 160 Pass Pass Pass Fail Fail
SANE 0 1 Pass Pass Pass Fail Fail
SANE +0.94 40 Pass Pass Pass Fail Fail
SANE +0.94 80 Pass Pass Pass Pass Pass
SANE +0.94 160 Pass Pass Pass Pass Pass
MAD -0.94 1 Fail Fail Pass Pass Fail
MAD -0.94 10 Fail Pass Pass Pass Fail
MAD -0.94 20 Fail Pass Pass Pass Fail
MAD -0.94 40 Fail Pass Pass Pass Fail
MAD -0.94 80 Fail Pass Pass Pass Fail
MAD -0.94 160 Fail Pass Pass Pass Fail
MAD -0.5 1 Pass Fail Pass Fail Fail
MAD -0.5 10 Pass Pass Pass Fail Fail
MAD -0.5 20 Pass Pass Pass Pass Pass
Table 2 (continued)
MAD -0.5 40 Pass Pass Pass Pass Pass
MAD -0.5 80 Pass Pass Pass Pass Pass
MAD -0.5 160 Pass Pass Pass Pass Pass
MAD 0 1 Pass Fail Pass Fail Fail
MAD 0 10 Pass Pass Pass Fail Fail
MAD 0 20 Pass Pass Pass Fail Fail
MAD 0 40 Pass Pass Pass Fail Fail
MAD 0 80 Pass Pass Pass Fail Fail
MAD 0 160 Pass Pass Pass Fail Fail
MAD +0.5 1 Pass Fail Pass Fail Fail
[3] Rhigh: electron temperature parameter, see equation (8).
[4] Average Image Scoring (THEMIS-AIS), models are rejected if p ≤ 0.01, see Section 4 and Table 1.
[5] ε: radiative efficiency, models are rejected if ε is larger than the corresponding thin disk efficiency, see Section 6.1.
[6] Lx: X-ray luminosity; models are rejected if ⟨Lx⟩10^−2σ > 4.4 × 10^40 erg sec^−1. See Section 6.2.
[7] Pjet: jet power, models are rejected if Pjet ≤ 10^42 erg sec^−1, see Section 6.3.
7. DISCUSSION
We have interpreted the EHT2017 data using a limited library of models with attendant limitations. Many of the limitations stem from the GRMHD model, which treats the plasma as an ideal fluid governed by equations that encode conservation laws for particle number, momentum, and energy. The eDF, in particular, is de-
Brightness Temperature (10^9 K)
...19, Papers V-VI
Breaking degeneracy crucial to connecting to larger scales. Luckily we also have multiwavelength data!

Next: simultaneous EHT/VLBI image + multiwavelength modelling

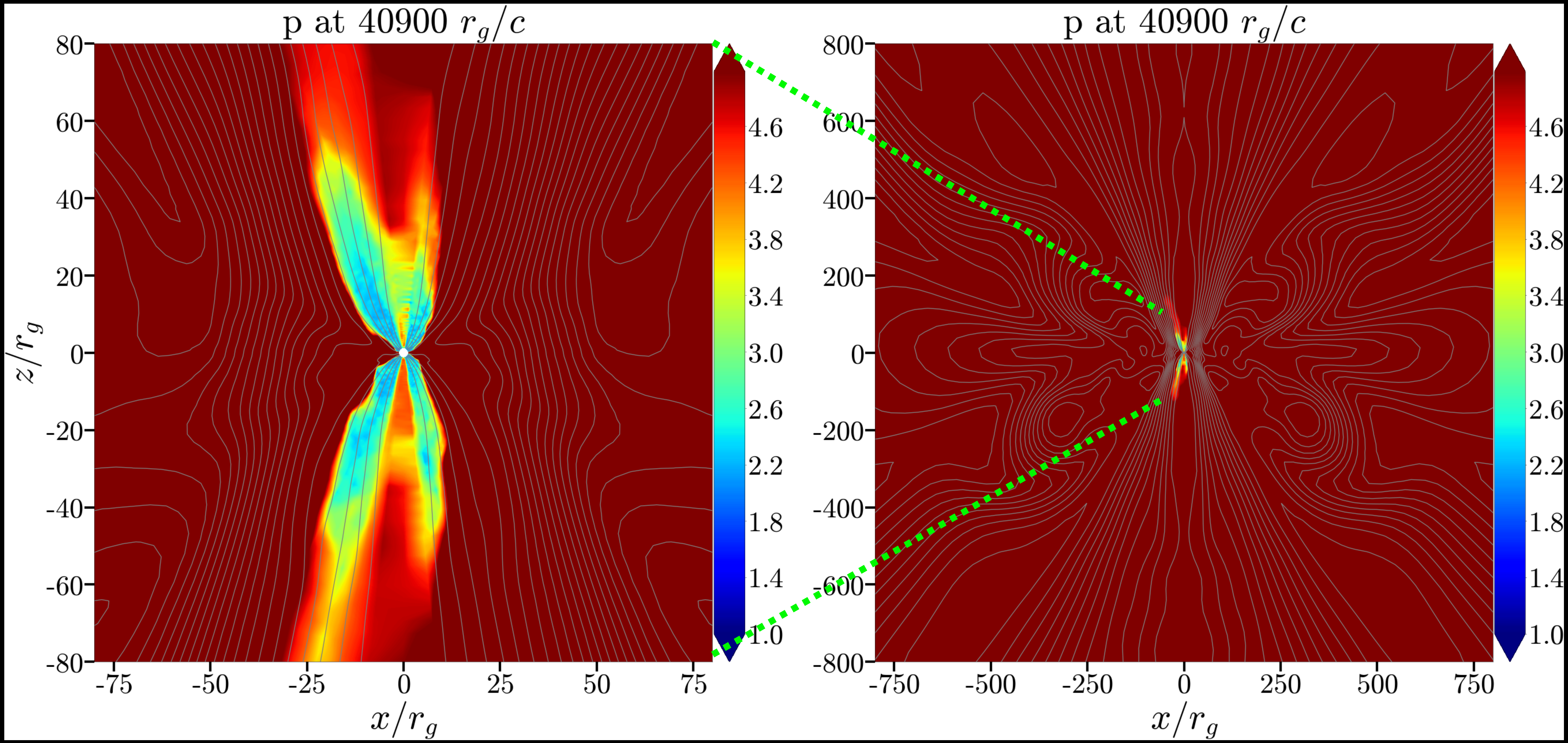
EHT 2017
M87 MWL
Campaign

(EHT Multiwavelength Science WG, EHTC, Fermi-LAT, HESS, MAGIC, VERITAS, EAVN, EAVN 2021, ApJL)

Next: simultaneous EHT/VLBI image + multiwavelength modelling

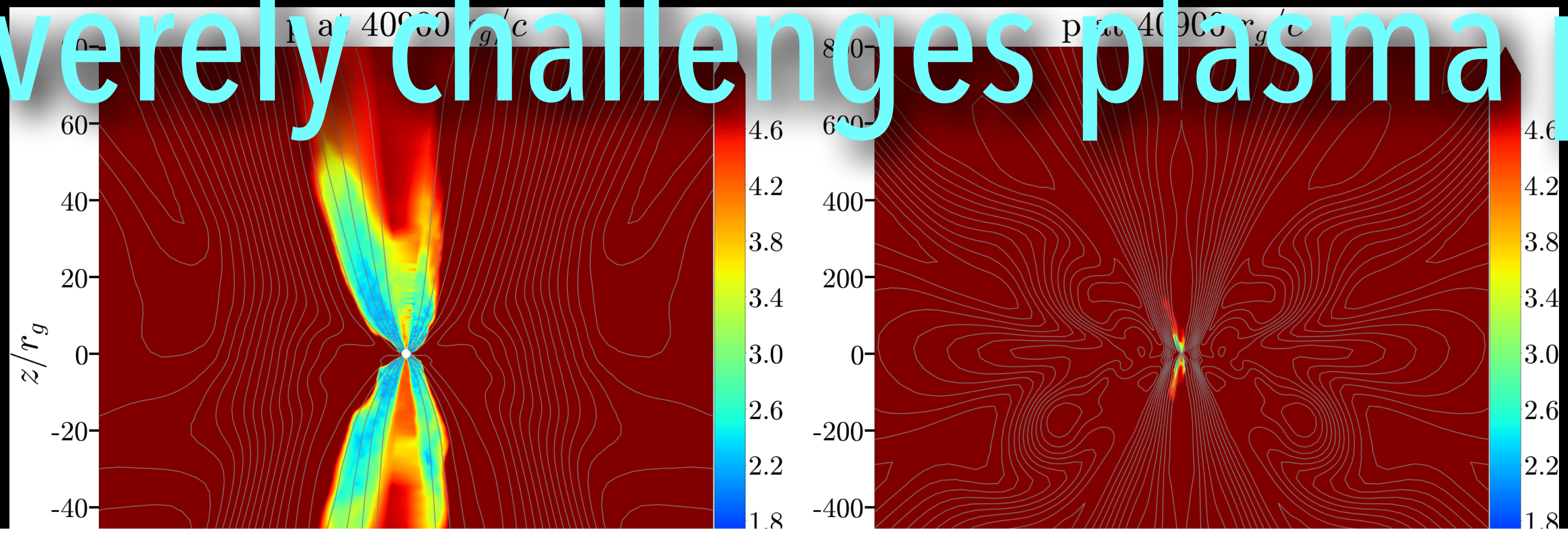
(EHT Multiwavelength Science WG, EHTC, Fermi-LAT, HESS, MAGIC, VERITAS, EAVN, EAVN 2021, ApJL)

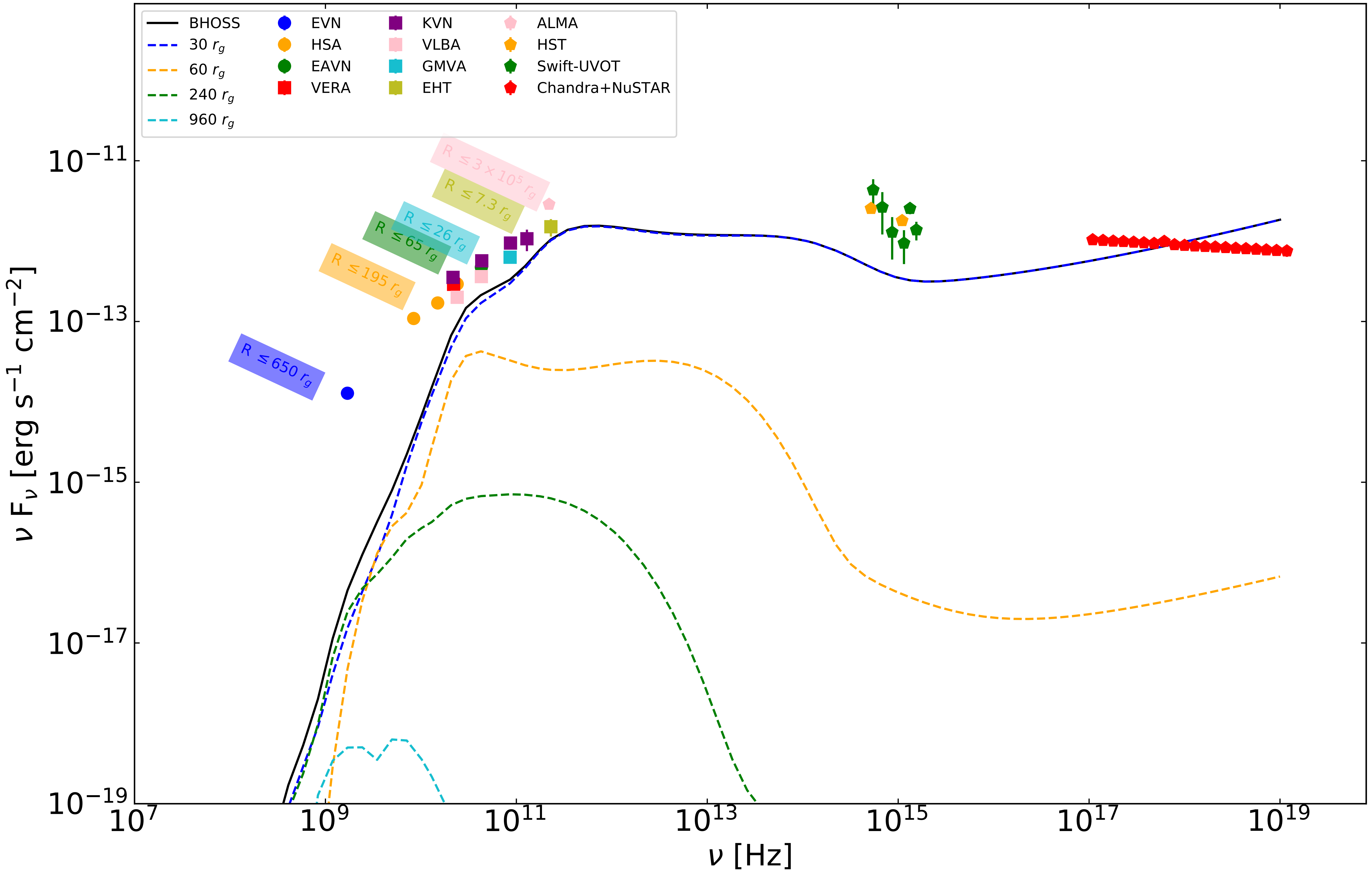
Fitting all constraints severely challenges plasma physics-inspired models

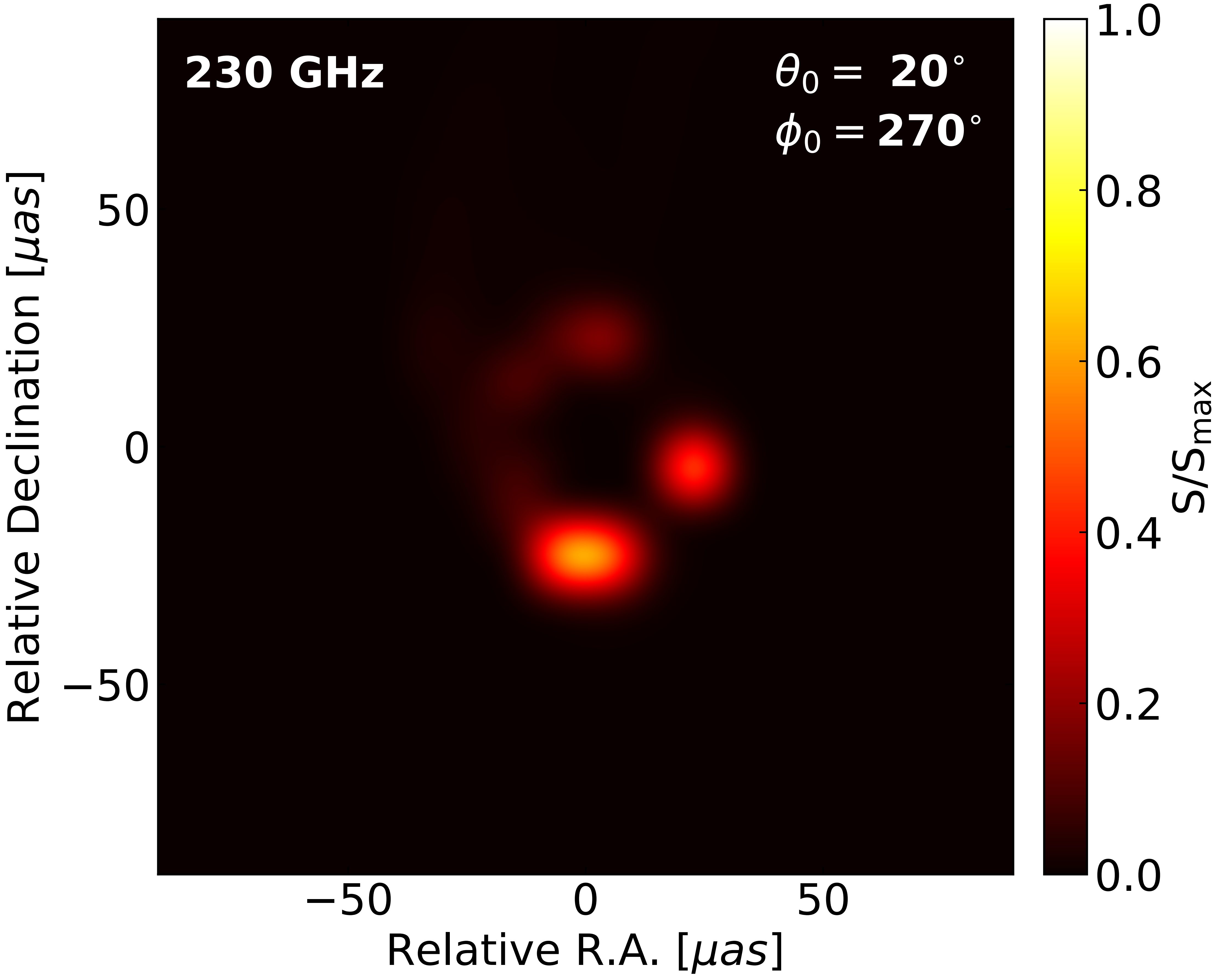


(Work in progress by UvA PhD student Wanga Mulaudzi)

Fitting all constraints severely challenges plasma physics-inspired models

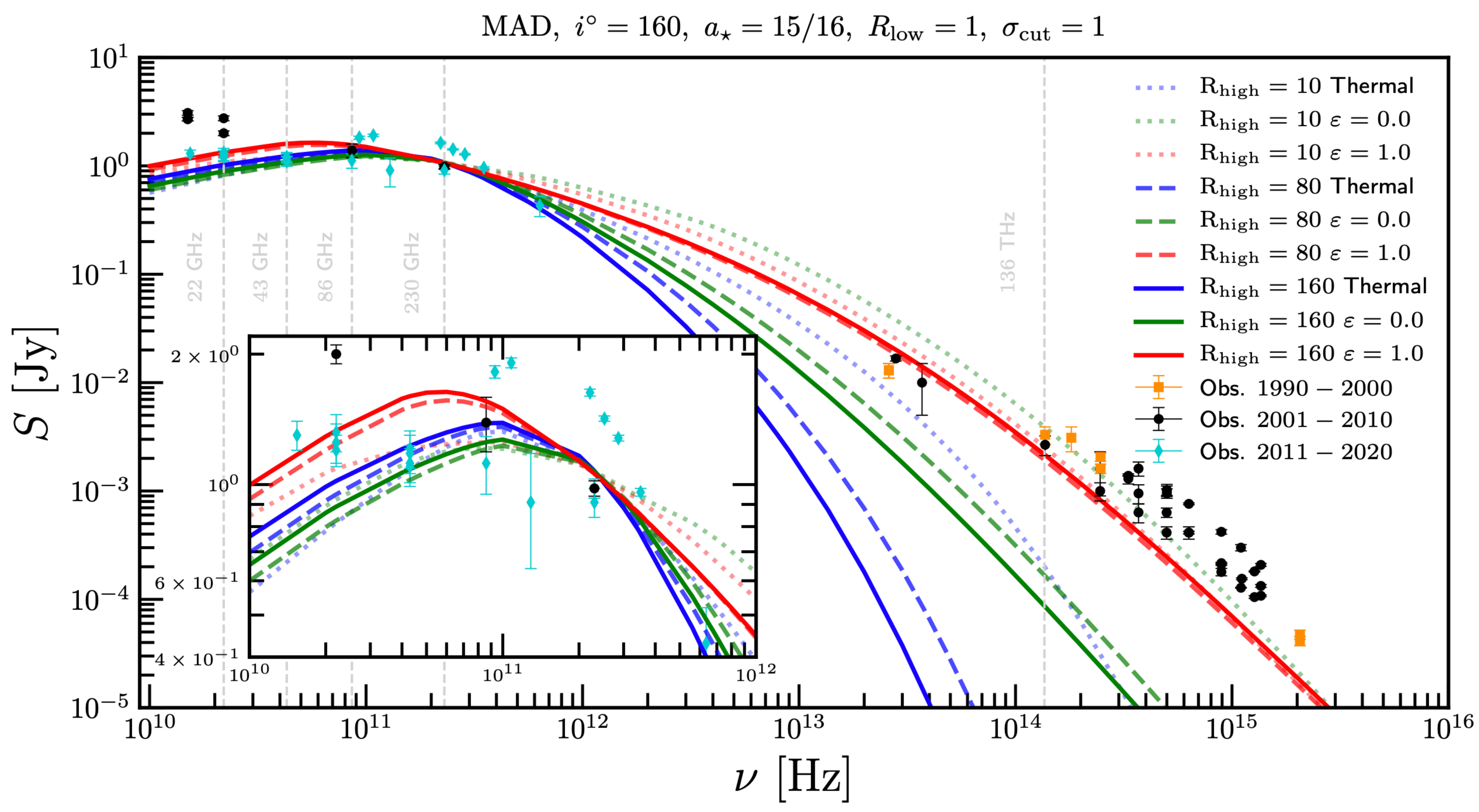


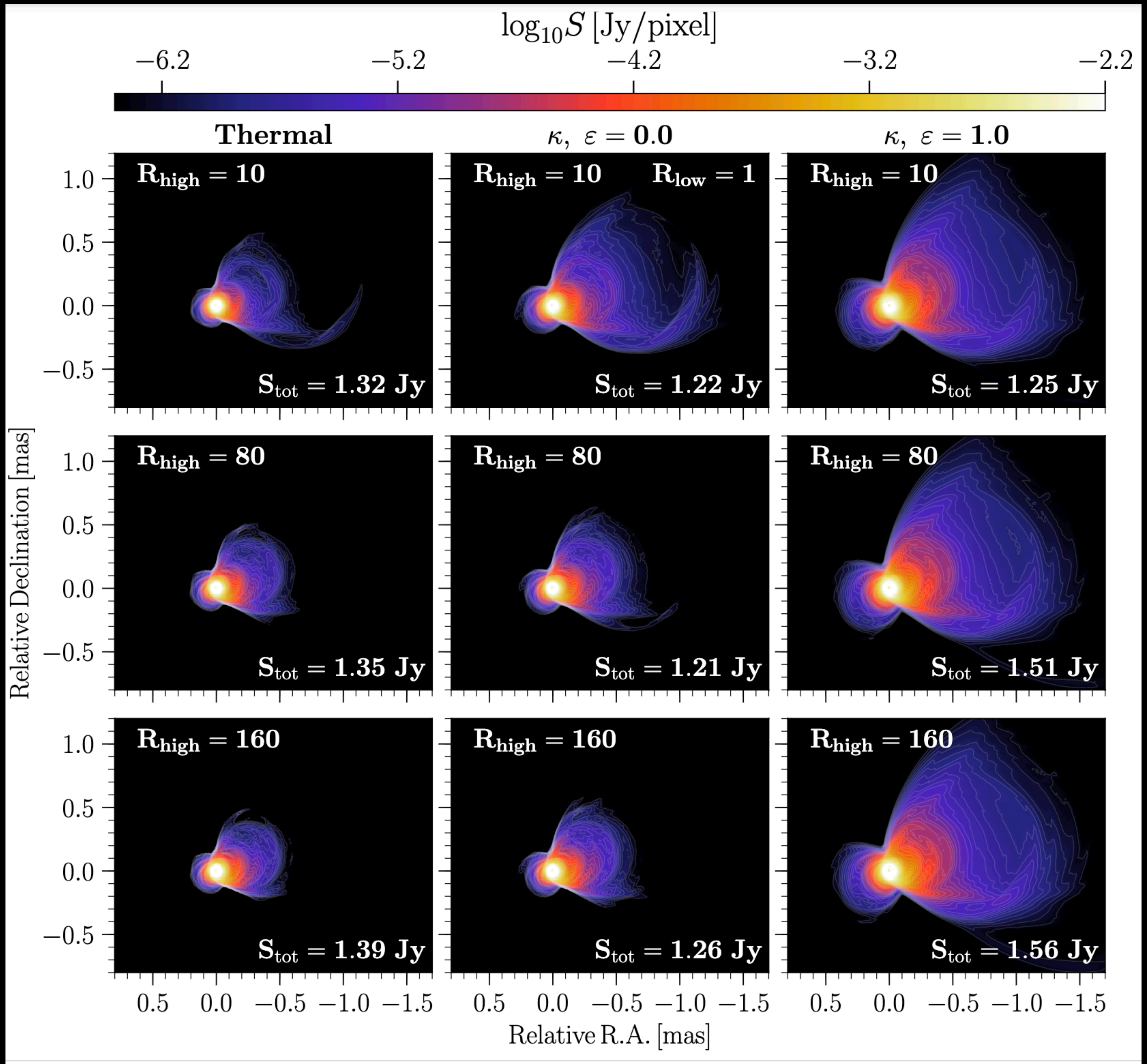




(Work in progress by UvA PhD student Wanga Mulaudzi)

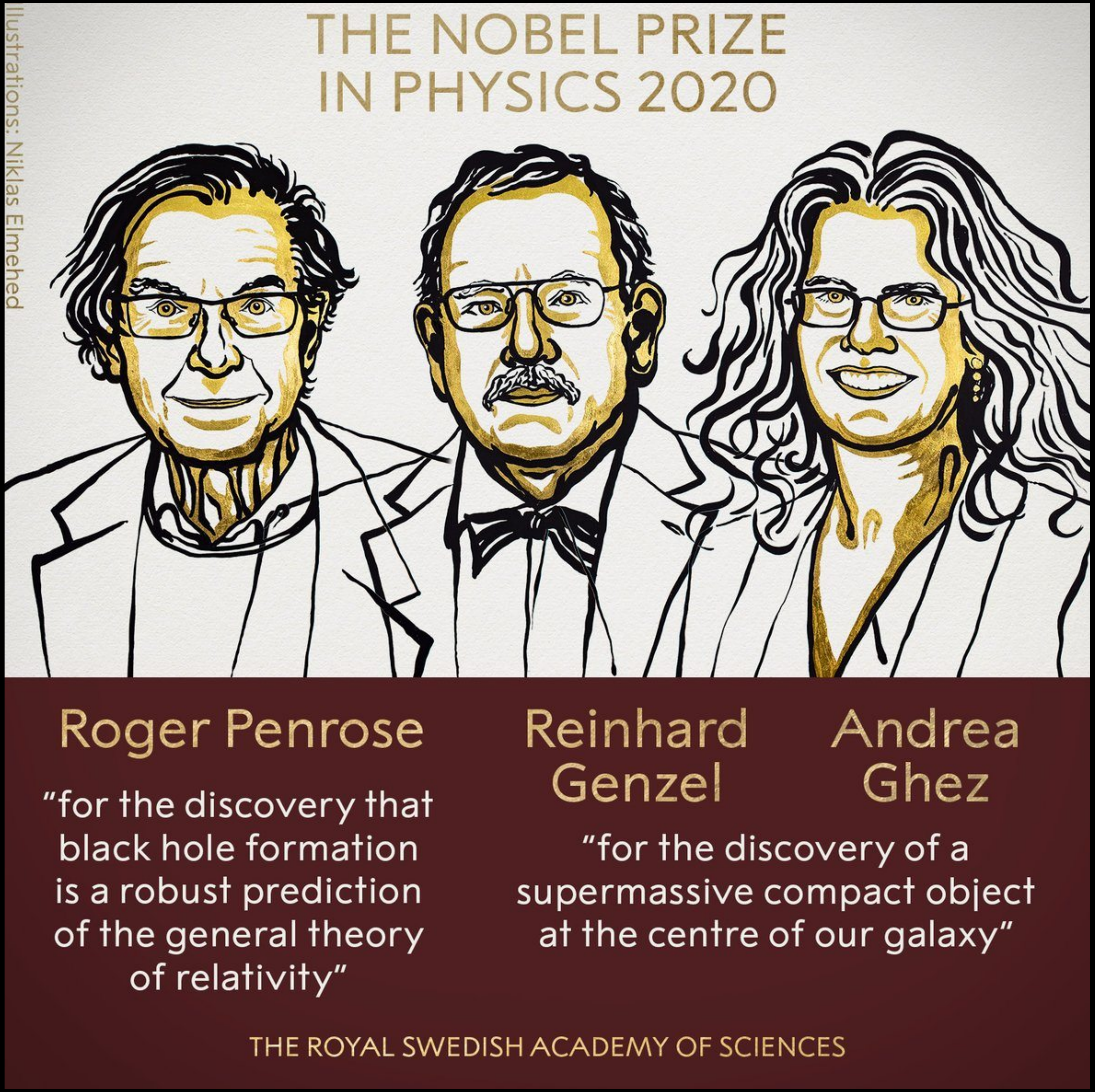
The new horizon: combined image + SED modelling





Radio to optical SED fitting by Fromm++22

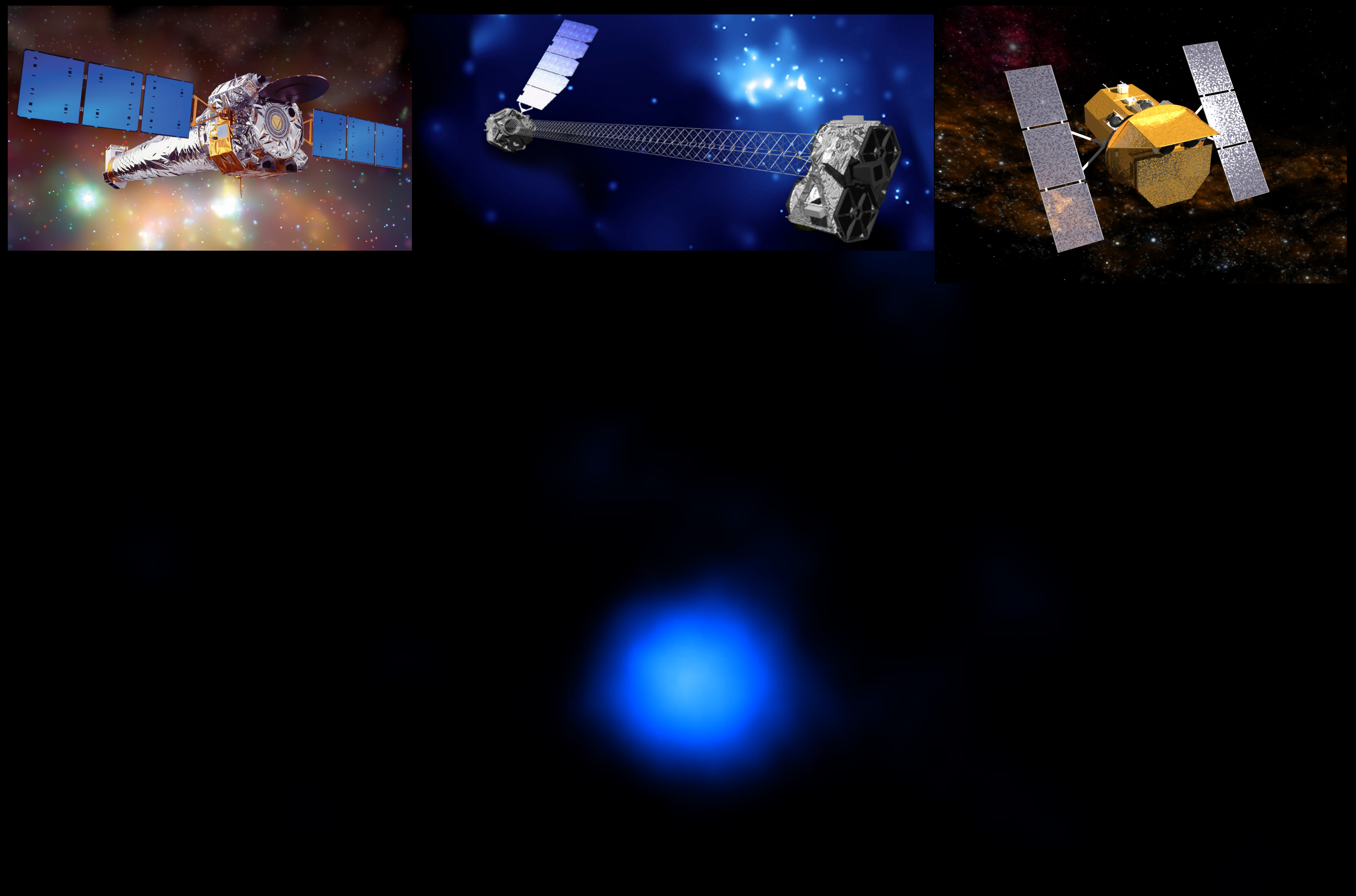
Sgr A*: much better prior information compared to M87*



Keck Observatory

Sgr A* has exquisite multi-wavelength constraints

X-ray flare from NASA's Chandra X-ray Observatory, + NuSTAR & Swift (space)



Credit: NASA/CXC/Amherst College/D.Haggard et al.

Infrared flare from the Keck Observatory + VLT/GRAVITY (ground)

Sgr A* has exquisite multi-wavelength constraints

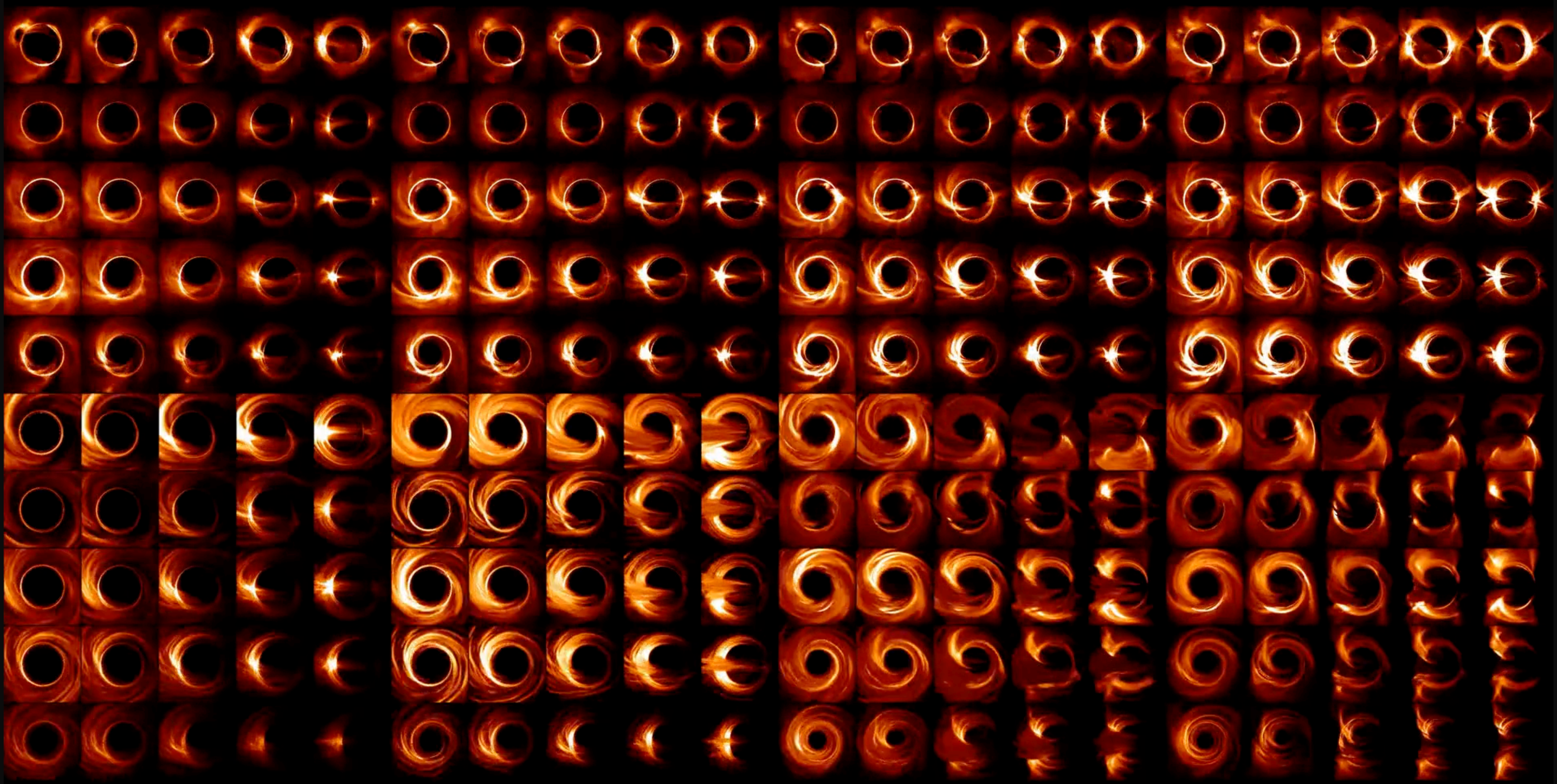
EHTC + Multiwavelength Partners, Sgr A* Paper II 2022; Wielgus, EHT++2022

Sgr A* has exquisite multi-wavelength constraints

EHTC + Multiwavelength Partners, Sgr A* Paper II 2022; Wielgus, EHT++2022

Sgr A*: Over 200 simulations, 1.8 Million images, ~PByte of data!

11 Constraints of 3 types : EHT images + Multi-wavelength + Variability



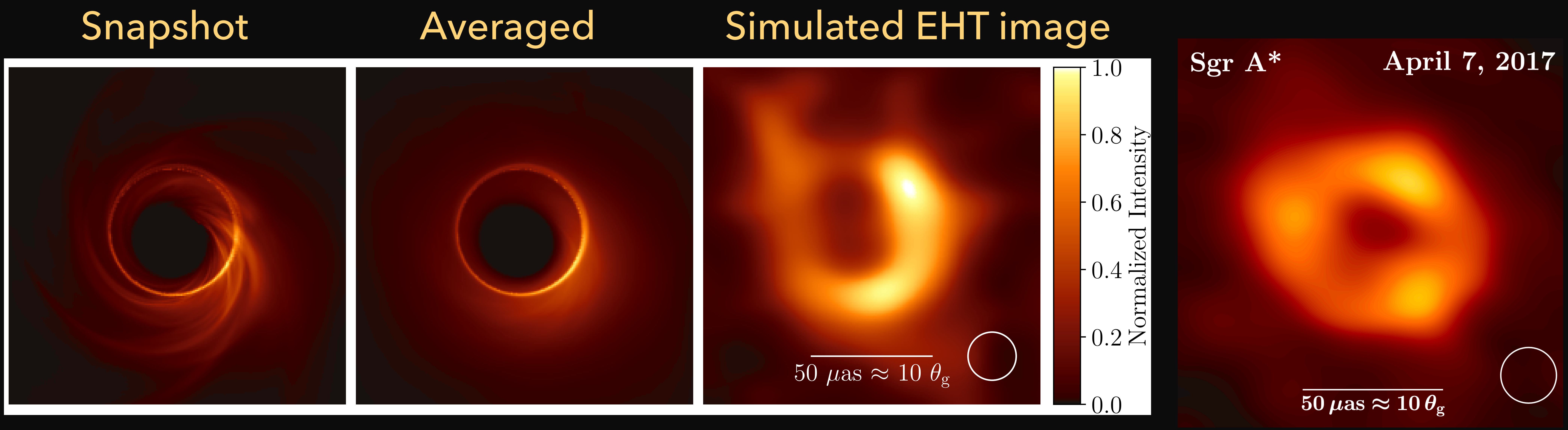
Visualization credit: Ben Prather, University of Illinois at Urbana-Champaign.
Image library credit: EHT Theory Working Group, CK Chan. EHTC Sgr A* Paper I, Paper V (2022)

Sgr A*: Over 200 simulations, 1.8 Million images, ~PByte of data!

11 Constraints of 3 types : EHT images + Multi-wavelength + Variability

Visualization credit: Ben Prather, University of Illinois at Urbana-Champaign.
Image library credit: EHT Theory Working Group, CK Chan. EHTC Sgr A* Paper I, Paper V (2022)

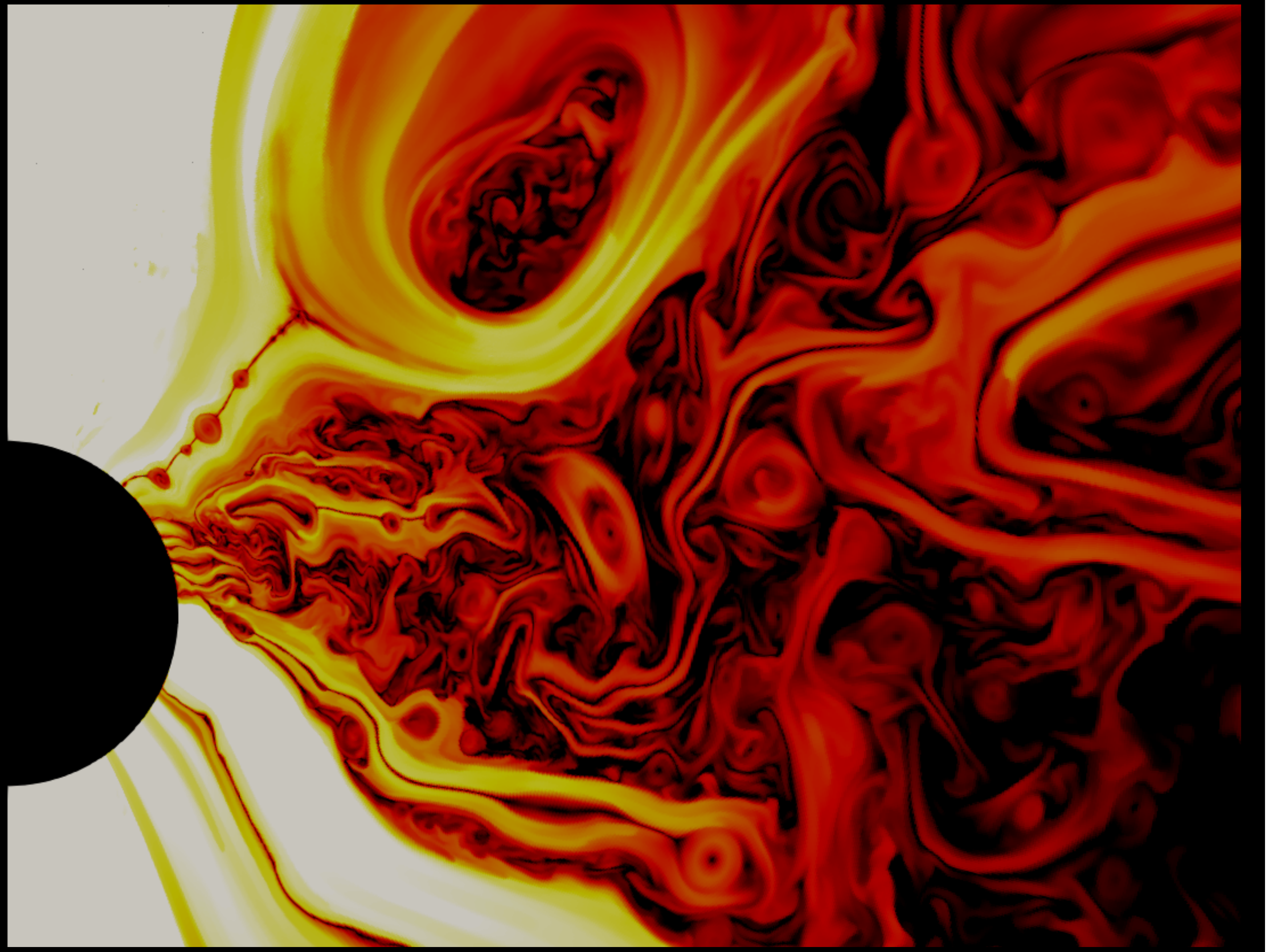
Sgr A*: Over 200 simulations, 1.8 Million images, ~PByte of data!



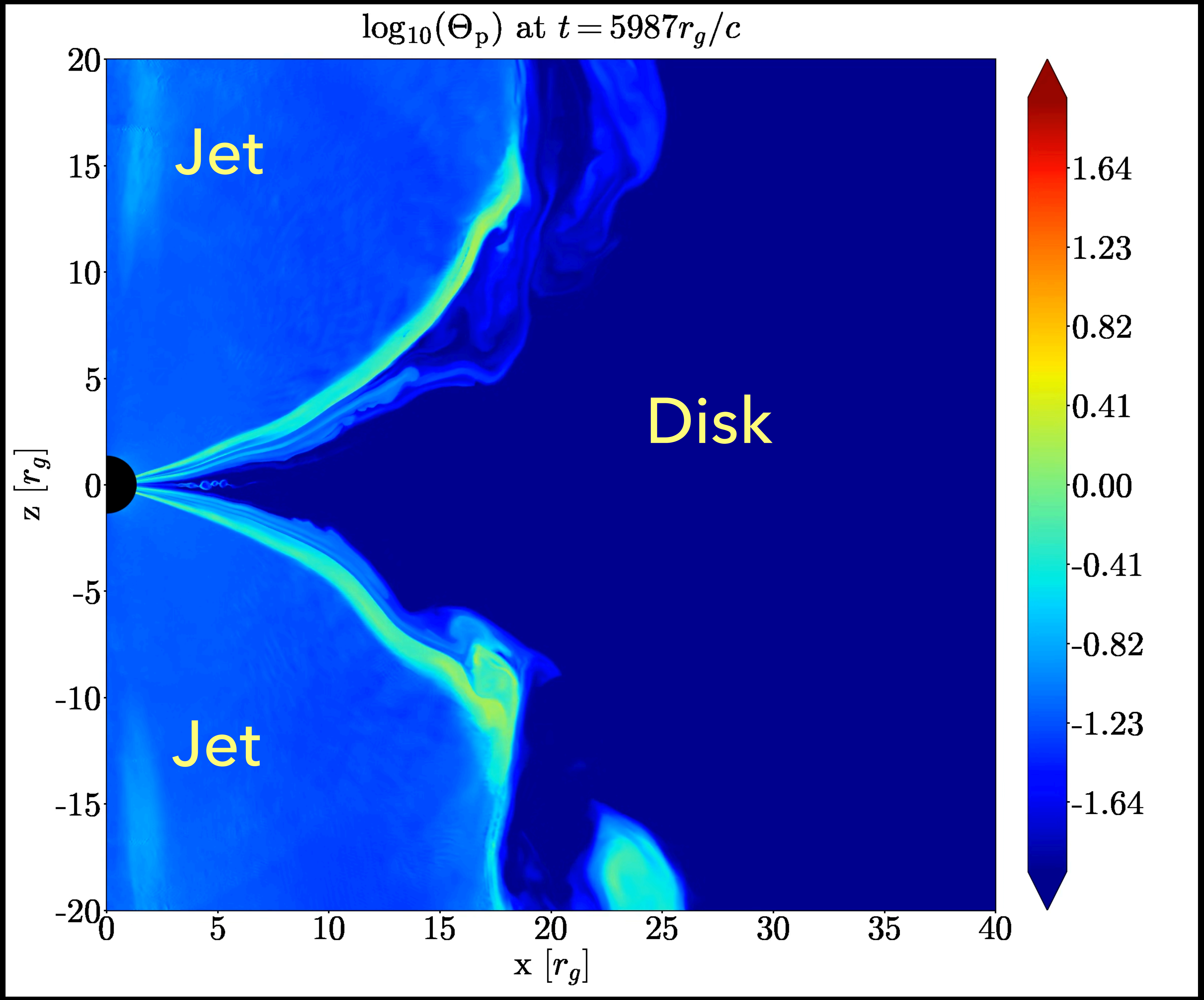
- "Best bet models" favour a prograde spin (a~0.5-9.4), lower inclination (≤ 30°), cool electrons compared to ions, and turbulent, strongly magnetised accretion flows (similar to M87*?!) ➠ jets??

Visualization credit: Ben Prather, University of Illinois at Urbana-Champaign.
Image library credit: EHT Theory Working Group, CK Chan. EHTC Sgr A* Paper I, Paper V (2022)

We now have tools to study sites/mechanisms *(not hadronic accel. yet…)*

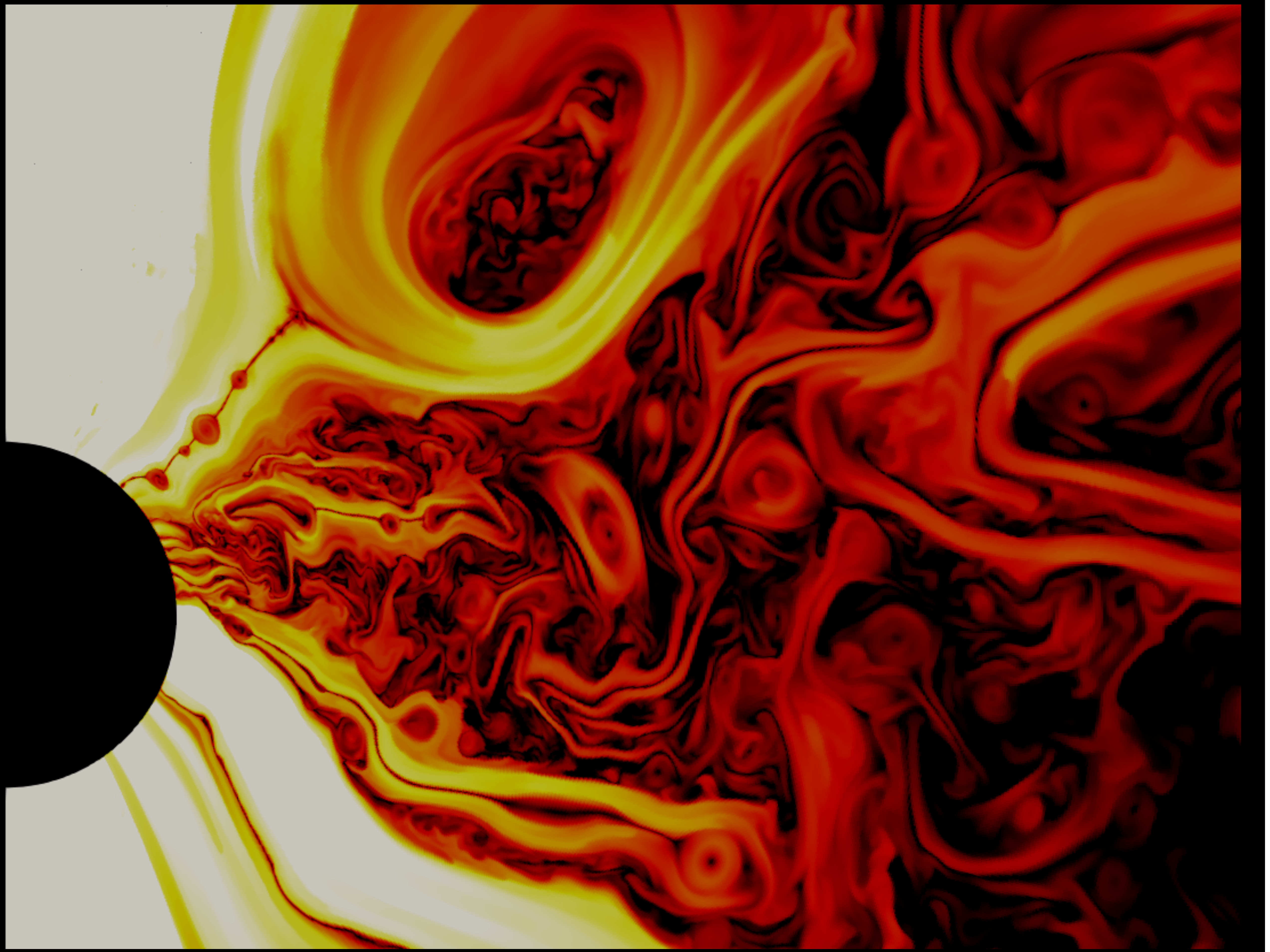


Ripperda, Bacchini & Philippov 2020, resistive 2D GRMHD w/ effective resolution of 12288x6144

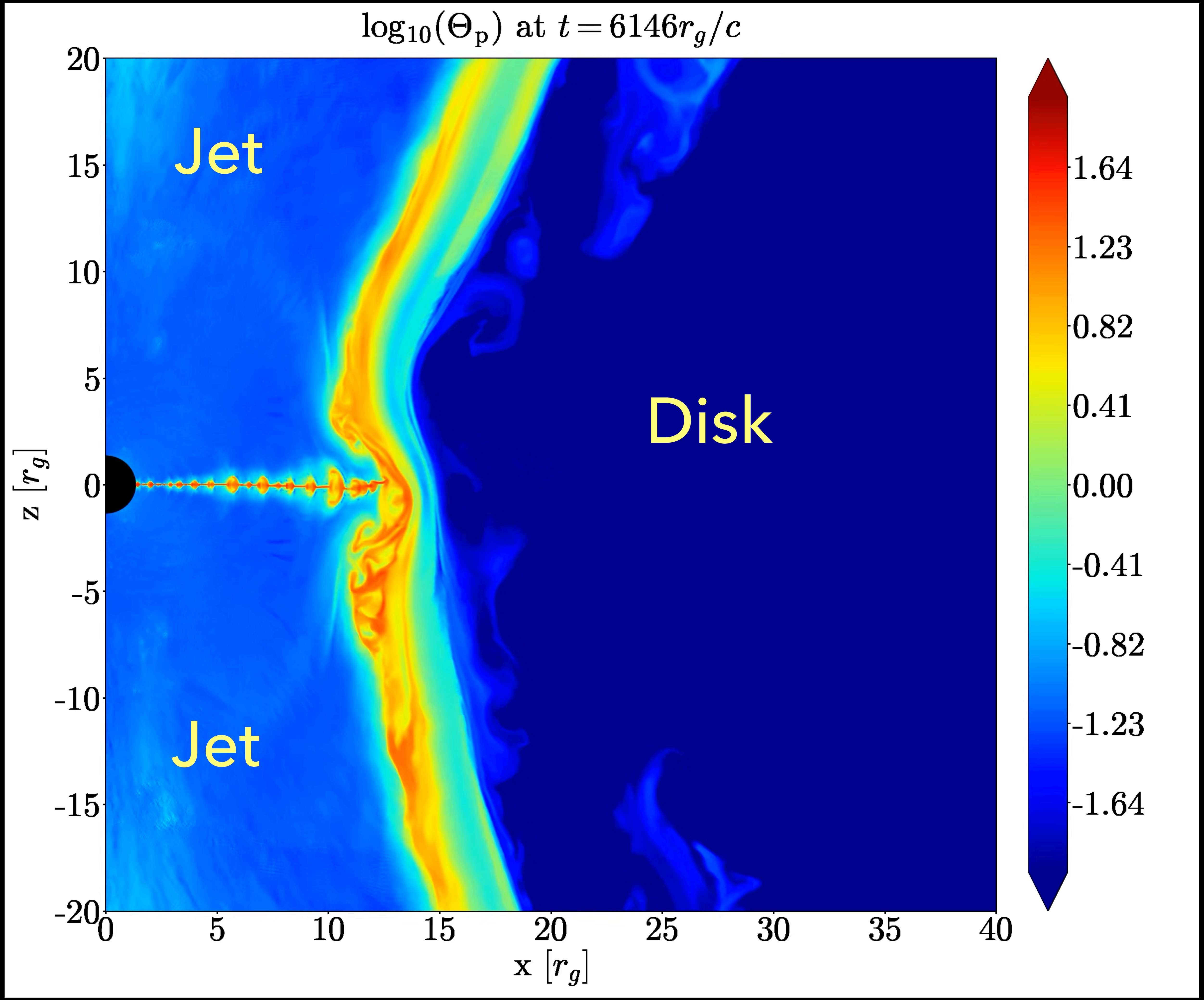


(5400x2300x2300) with H-AMR (Liska++ 2019) yields similar results: Ripperda, Liska, Chatterjee, Musoke, Philippov, SM++ 2022

We now have tools to study sites/mechanisms *(not hadronic accel. yet…)*



Ripperda, Bacchini & Philippov 2020, resistive 2D GRMHD w/ effective resolution of 12288x6144



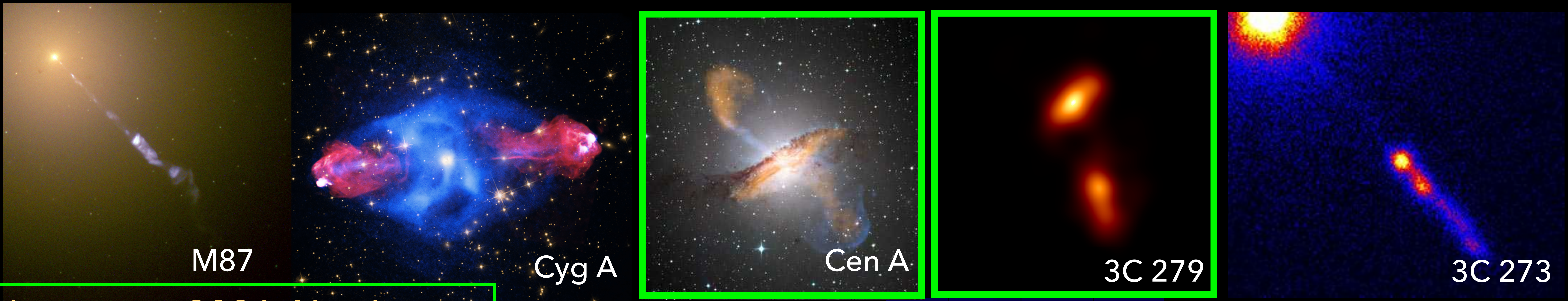
(5400x2300x2300) with H-AMR (Liska++ 2019) yields similar results: Ripperda, Liska, Chatterjee, Musoke, Philippov, SM++ 2022

Next decade(s): EHT++ + MWL monitoring for many AGN!

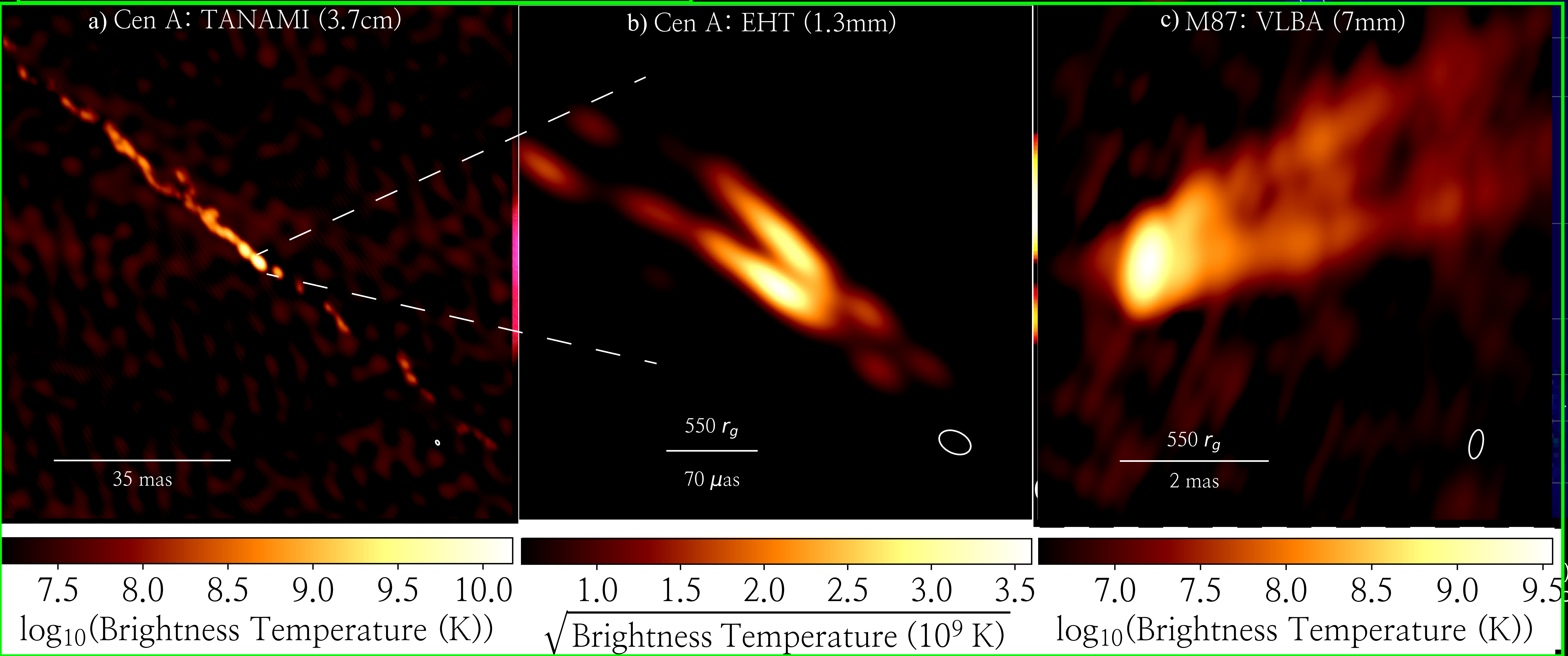
Credits: (M87: HST), (Cyg A: Chandra/HST/VLA (Cyg A), (Cen A: ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss++(Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)), (NGC 1265: M. Gendron-Marsolais++; S. Dagnello, NRAO/AUI/NSF; SDSS),(3C279, EHT),(3C293, Chandra),(Mrk501, Giroletti/VLBA/HO/RO/HALCA),(NGC1068; Kadler/VLBA), (NRAO530, Zhao++/JVLA), (OJ287, Marscher&Jorstad/Chandra/VLA)

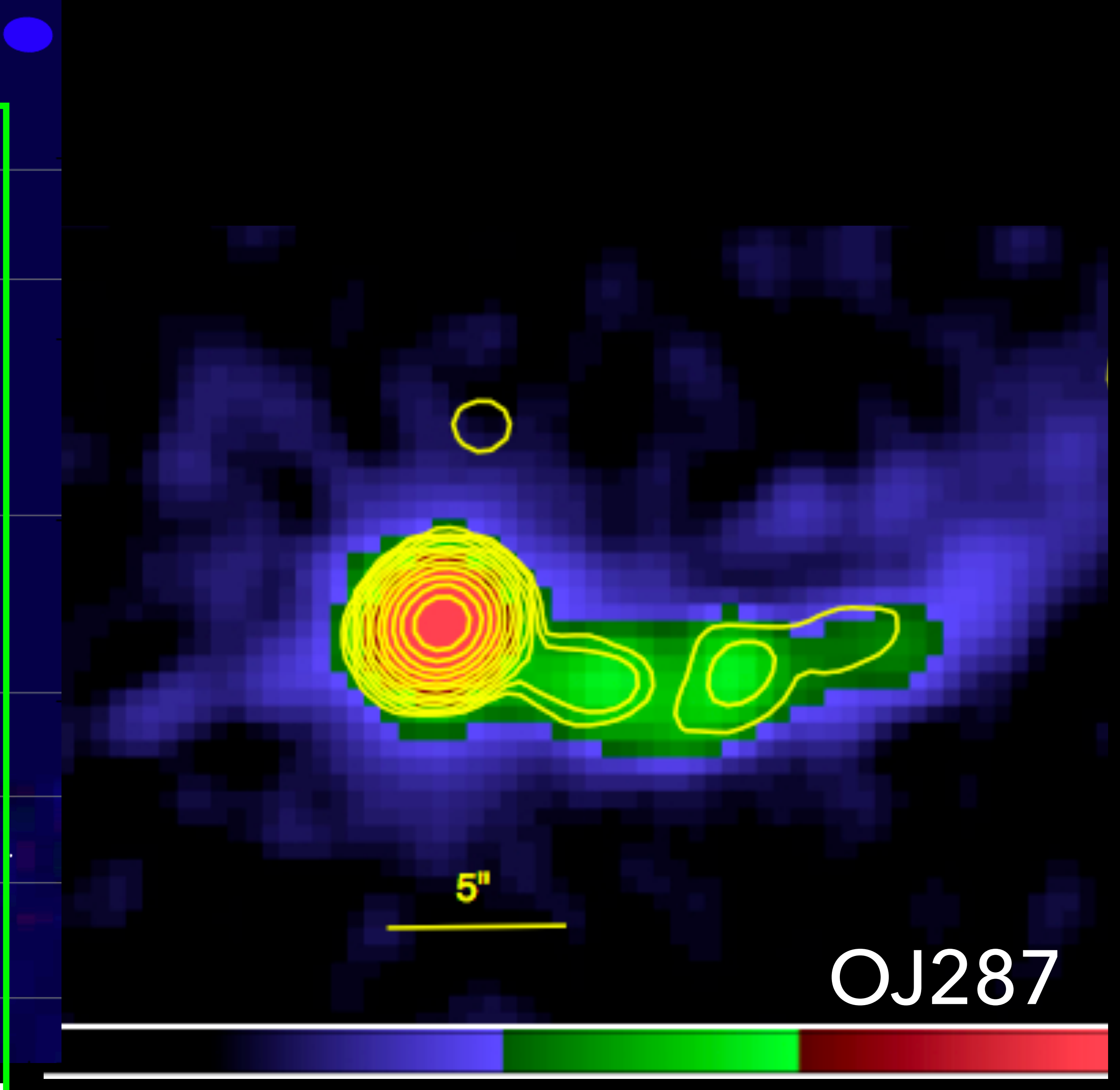
(Slide adapted from M. Moscibrodzka)

Next decade(s): EHT++ + MWL monitoring for many AGN!



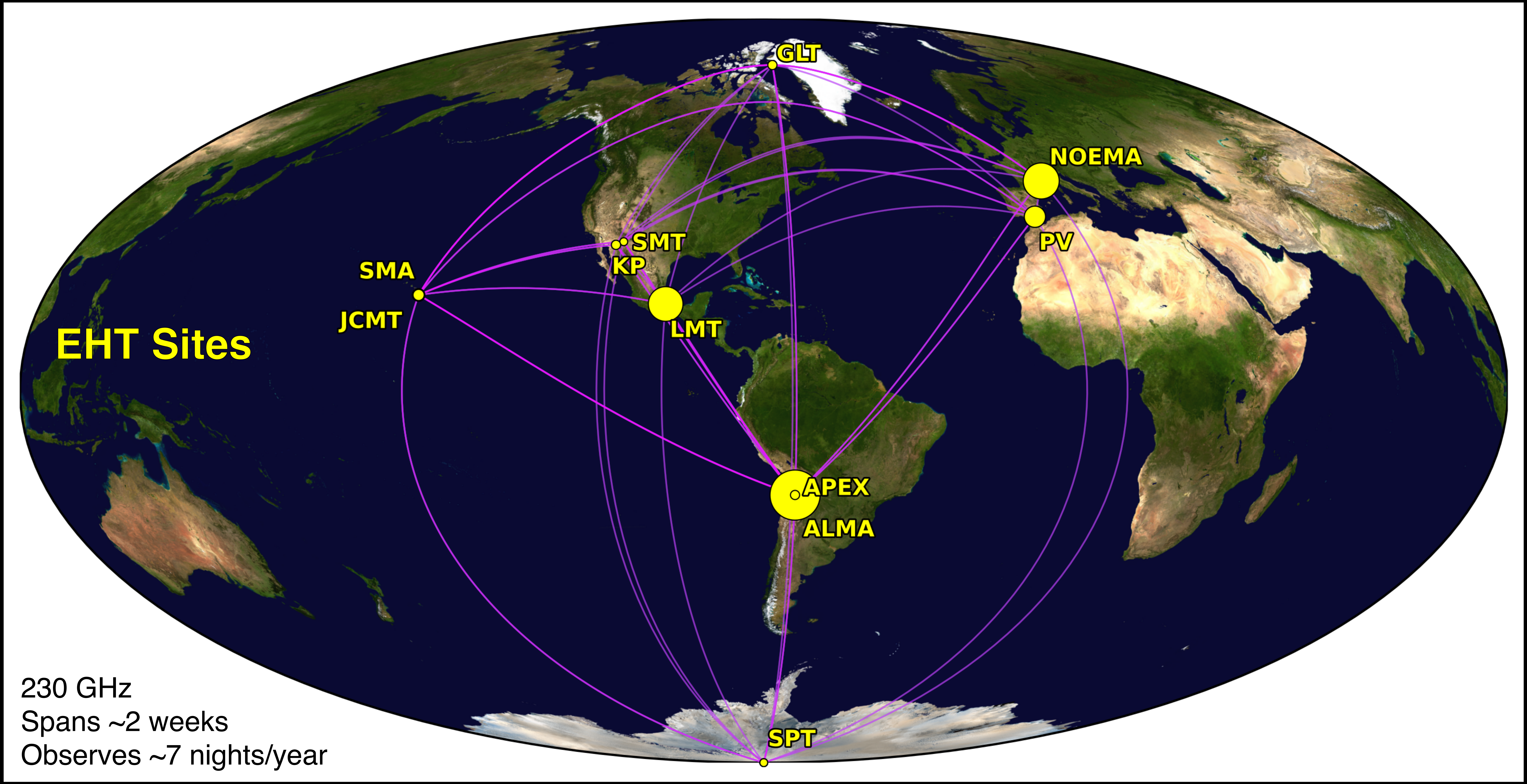
Janssen++2021, Nat.Astro

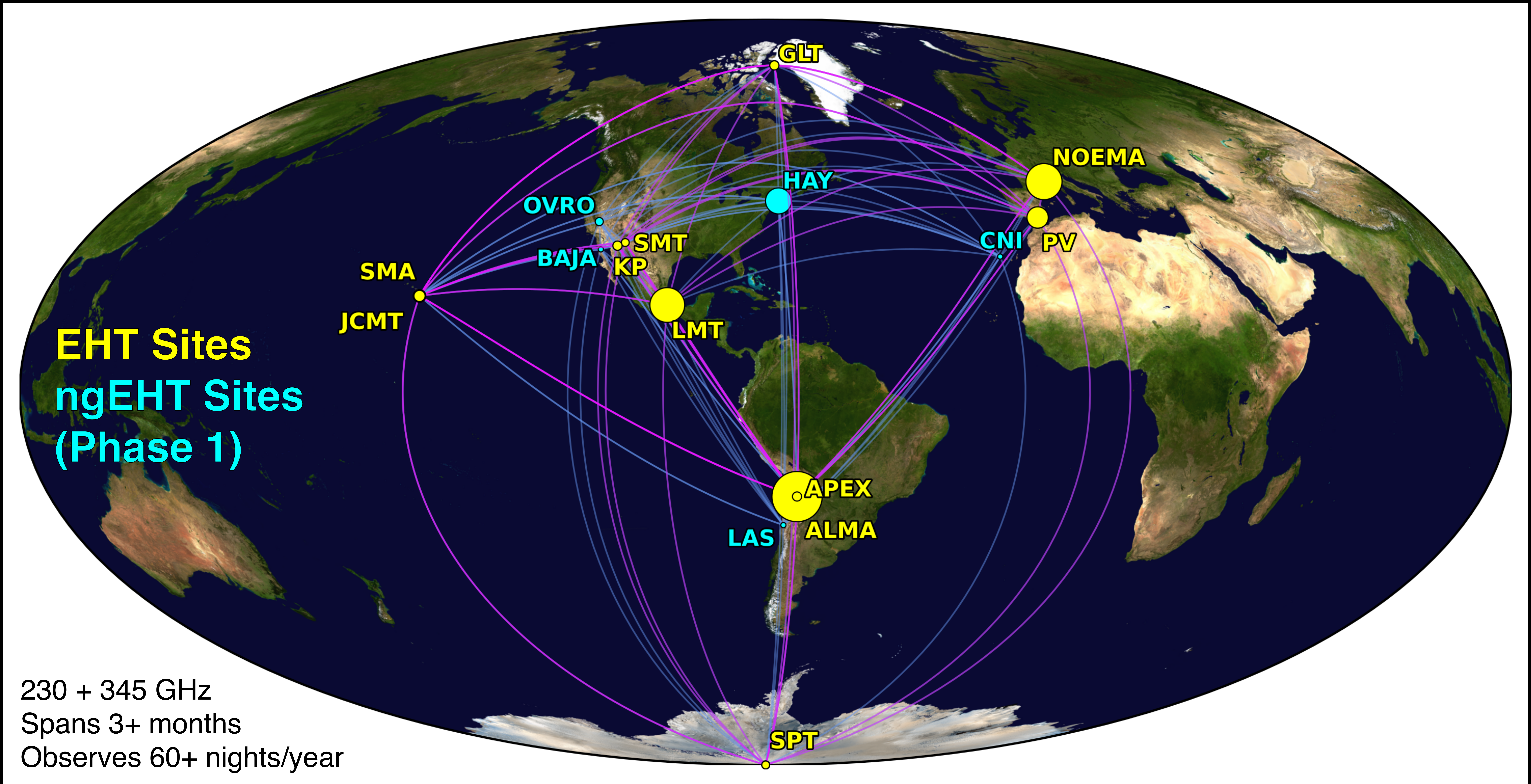


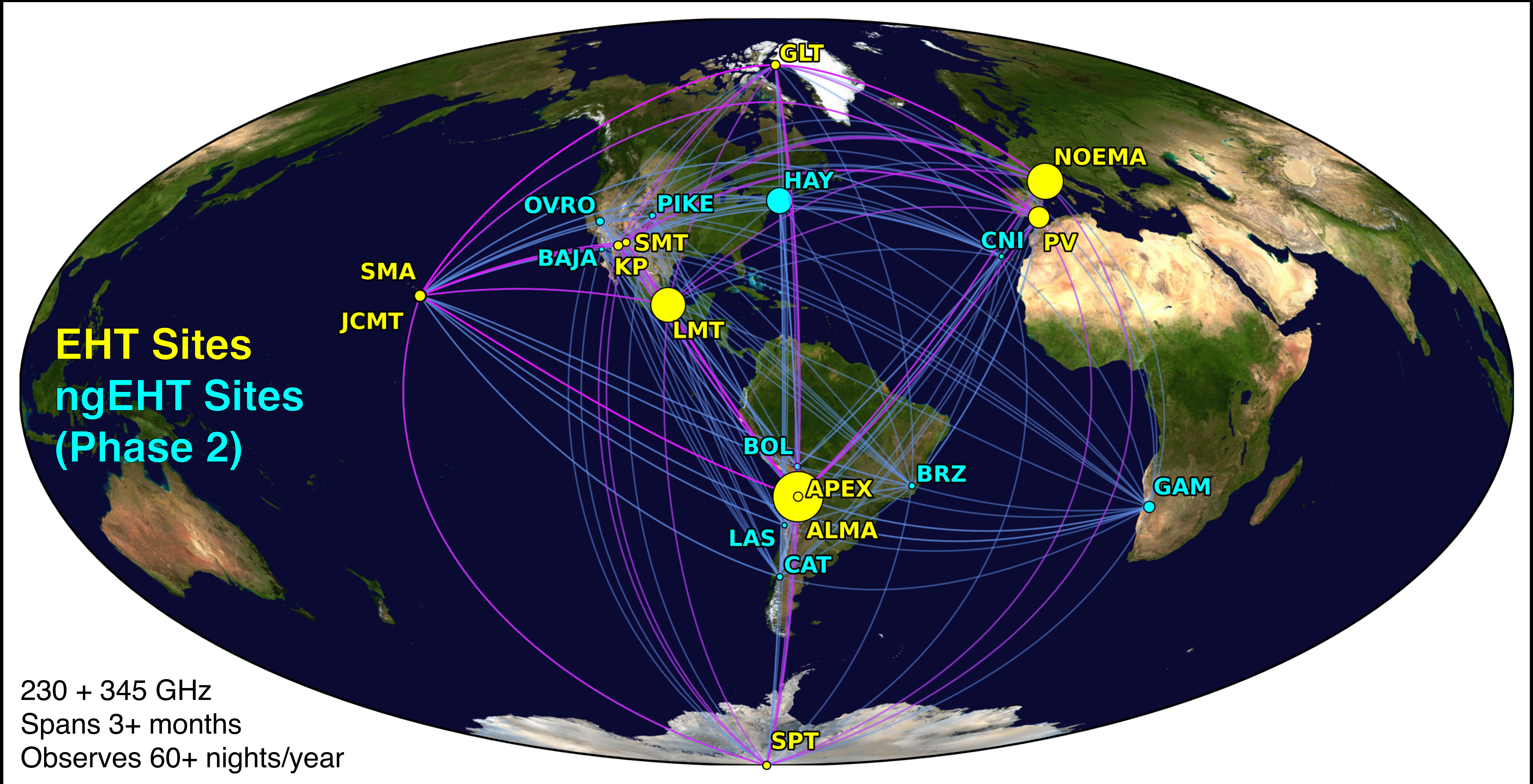


), (NGC 1265: M. Gendron-Marsolais++; S. Dagnello, NRAO/
orstad/Chandra/VLA)

(Slide adapted from M. Moscibrodzka)

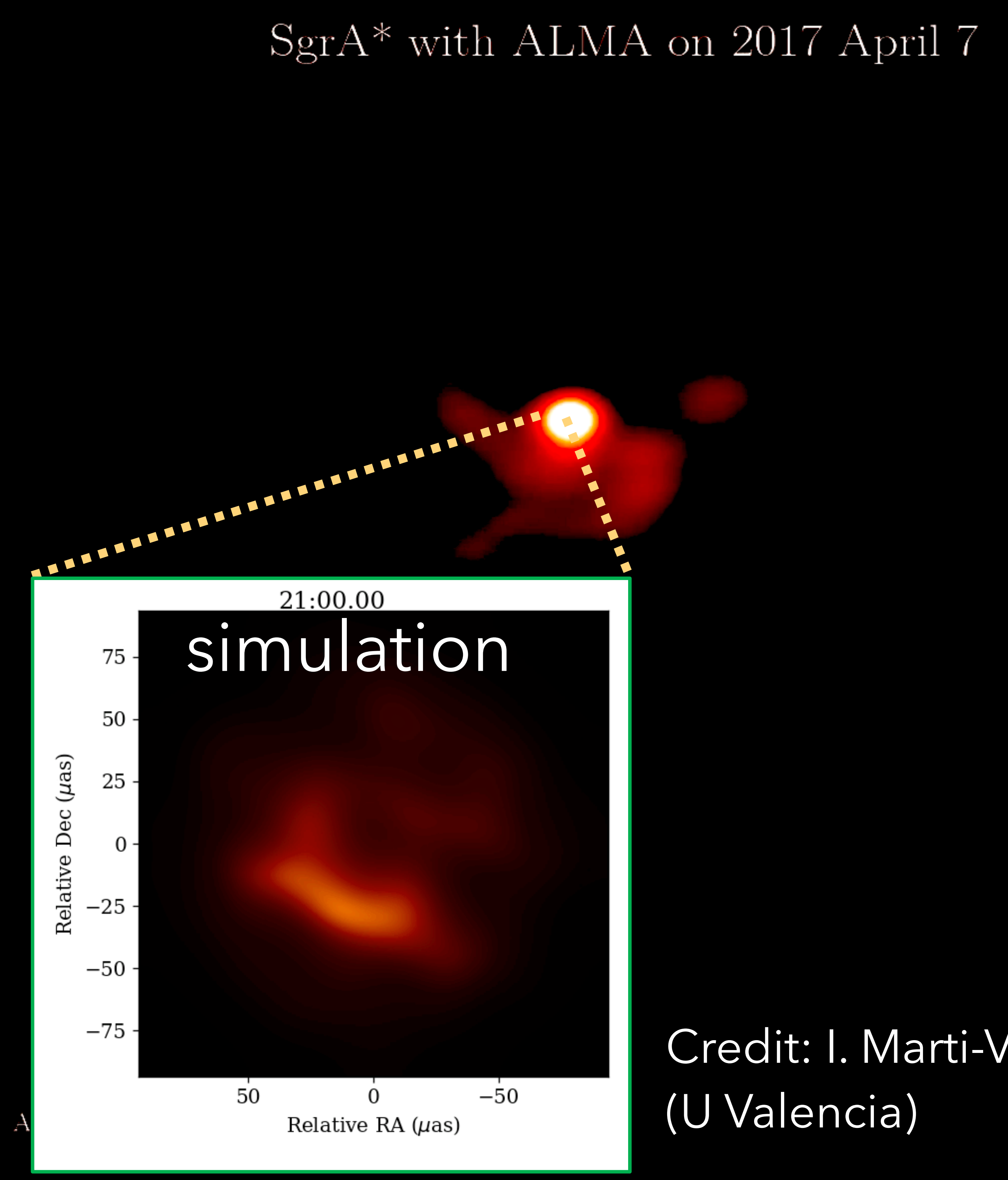

GLT
NOEMA
PV
SMT
KP
SMA
JCMT
LMT
EHT Sites
APEX
ALMA
SPT
230 GHz
Spans ~2 weeks
Observes ~7 nights/year


GLT
NOEMA
HAY
OVRO
SMT
CNI
PV
BAJA
KP
SMA
JCMT
LMT
EHT Sites
ngEHT Sites
(Phase 1)
APEX
LAS
ALMA
SPT
230 + 345 GHz
Spans 3+ months
Observes 60+ nights/year


GLT
NOEMA
HAY
OVRO
PIKE
SMT
BAJA
KP
SMA
JCMT
LMT
CNI
PV
EHT Sites
ngEHT Sites
(Phase 2)
BOL
APEX
BRZ
GAM
LAS
ALMA
CAT
SPT
230 + 345 GHz
Spans 3+ months
Observes 60+ nights/year

EHT expansion: dynamical movies (example for Sgr A*)

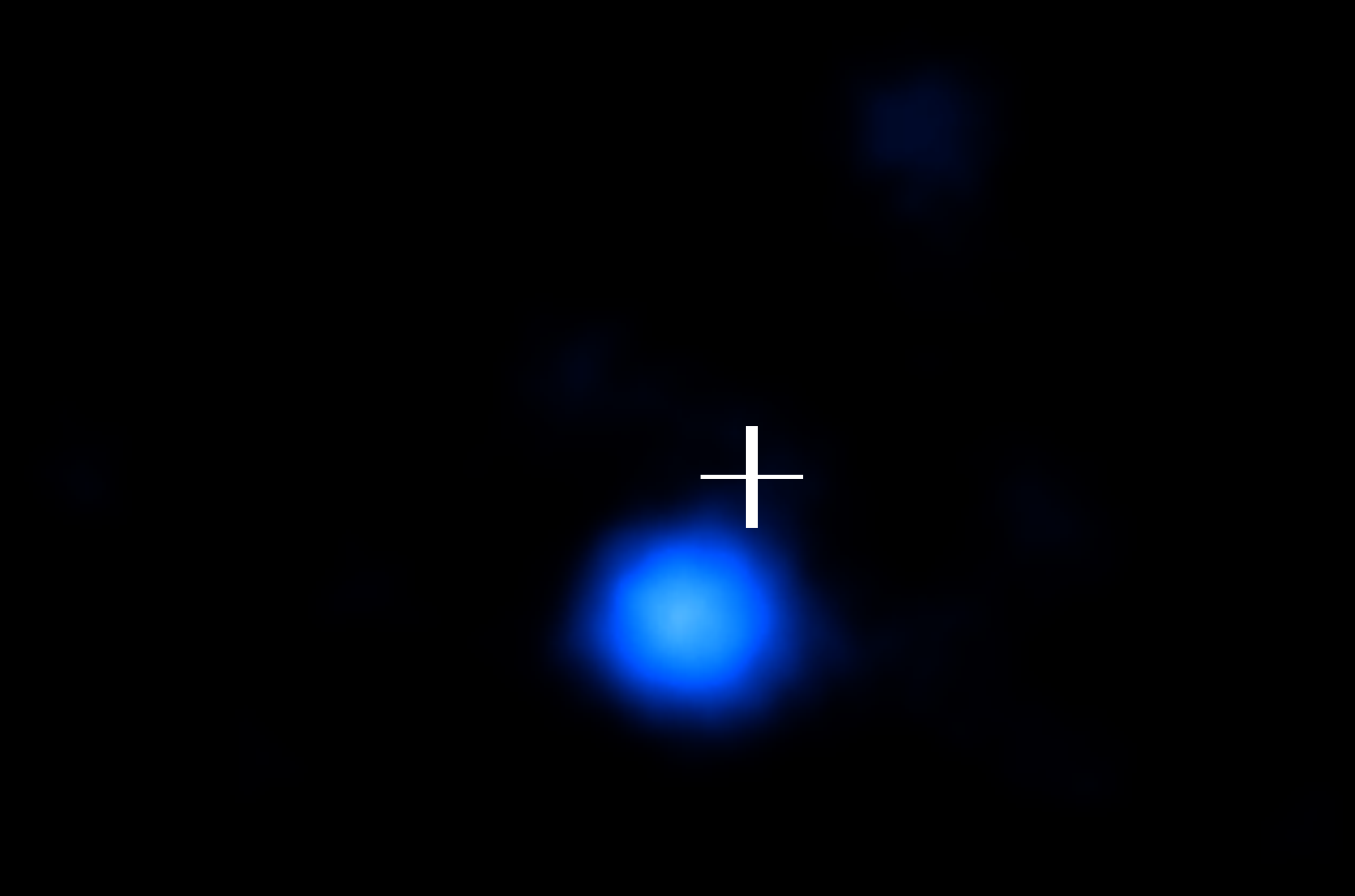
mm-radio (ALMA)



Credit: I. Marti-Vidal (U Valencia)

NIR (Keck & VLT/Gravity

X-ray (Chandra, NuSTAR, Swift)

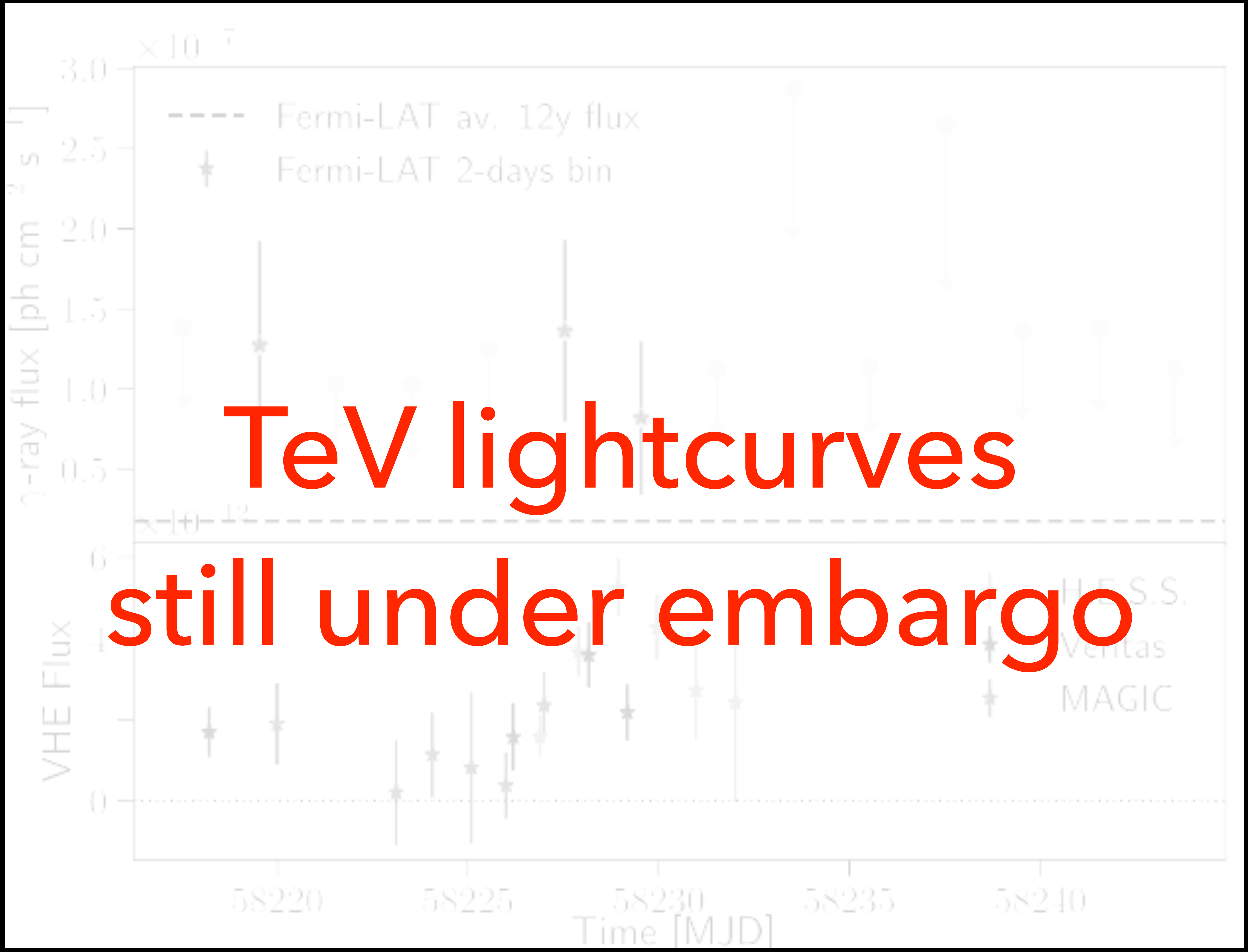


Credit: NASA/CXC/D.Haggard et al.

Sgr A* Paper II 2022; Wielgus, EHT++2022

M87 2018 MWL paper: localising γ-ray flares??

- Most significant γ-ray flare since 2010! (tho sampling is not great…)
- Enhanced activity in higher energy bands overall, in core not knots
- Waiting on M87 imaging to know if anything interesting happened in EHT images/core flux
- SED modeling/comparisons with 2017 to come

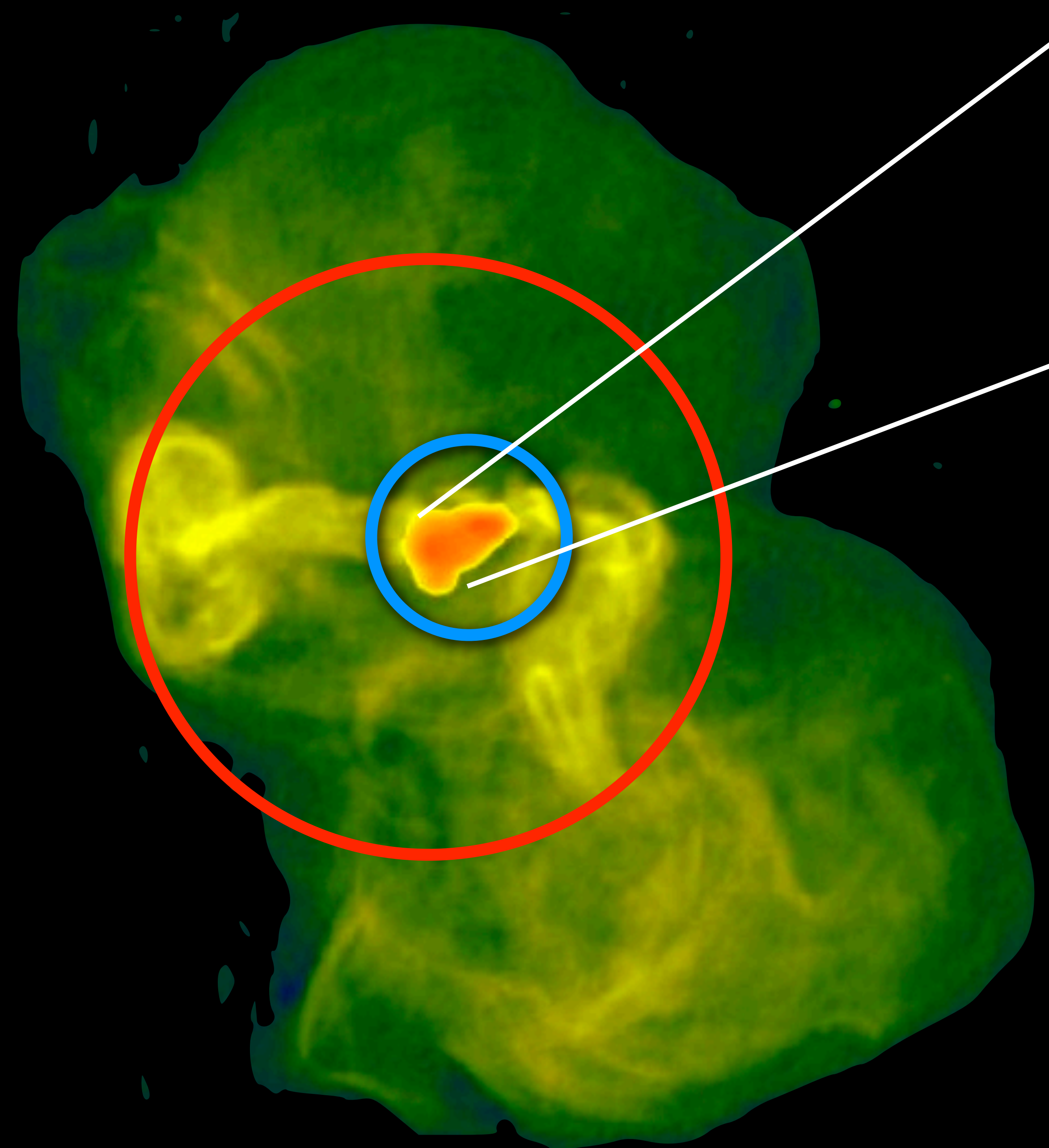


Cherenkov Telescope Array (CTA): Full N/S sky coverage with unprecedented sensitivity

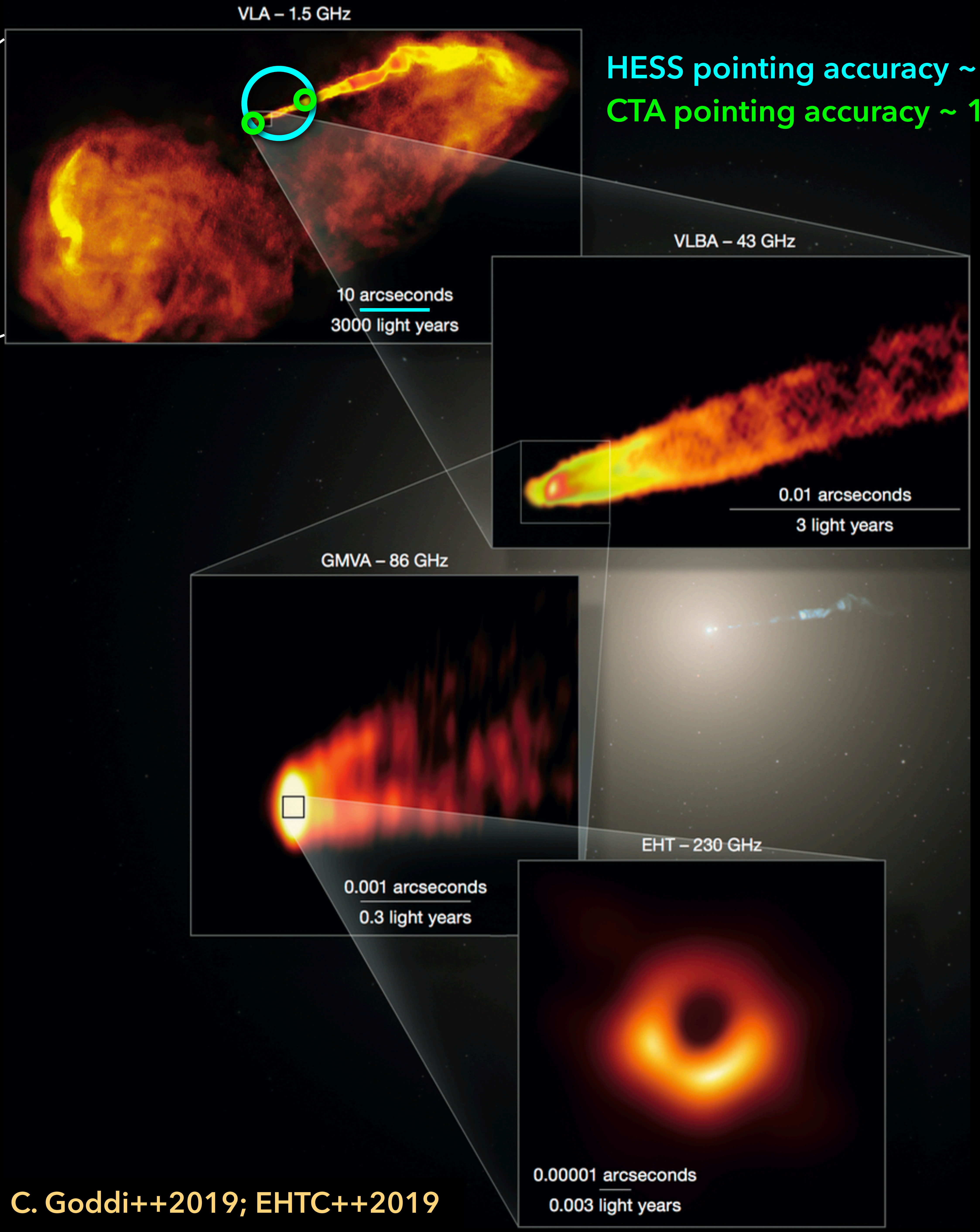
- 10x more sensitive, 3-5x better pointing accuracy, 2.5x larger FoV, and many orders of magnitude better at detecting fast transients!
- Largest (open) observatory in the VHE gamma-rays with two sites in both hemispheres for full sky access (~2027)

Understanding = localising!

M87



NRAO/VLA 90cm image



HESS pointing accuracy ~10″

CTA pointing accuracy ~ 1-3″

Hess/Magic/Veritas (TeV) angular resolution

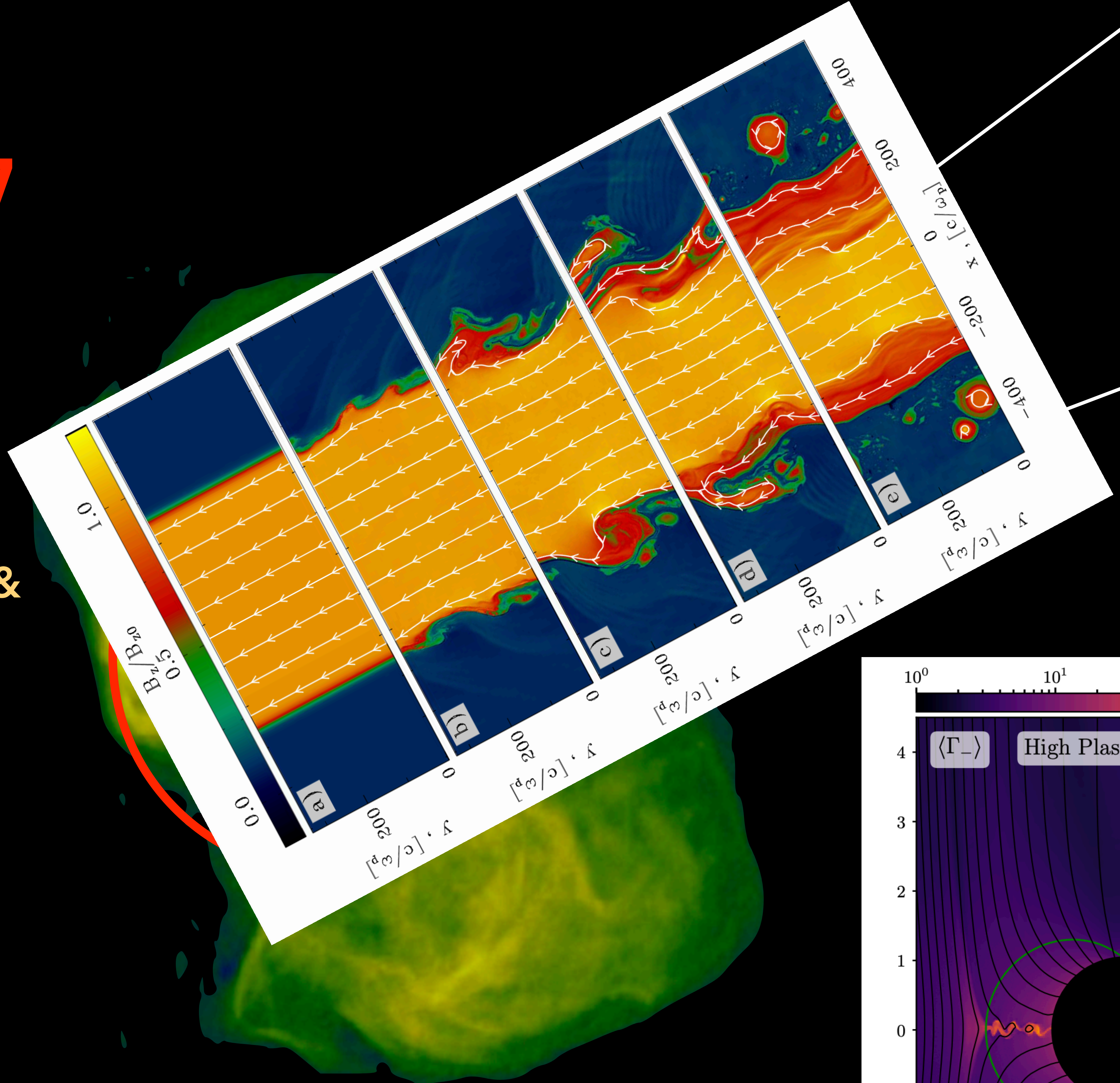
CTA (TeV) angular resolution

C. Goddi++2019; EHTC++2019

Understanding = localising!

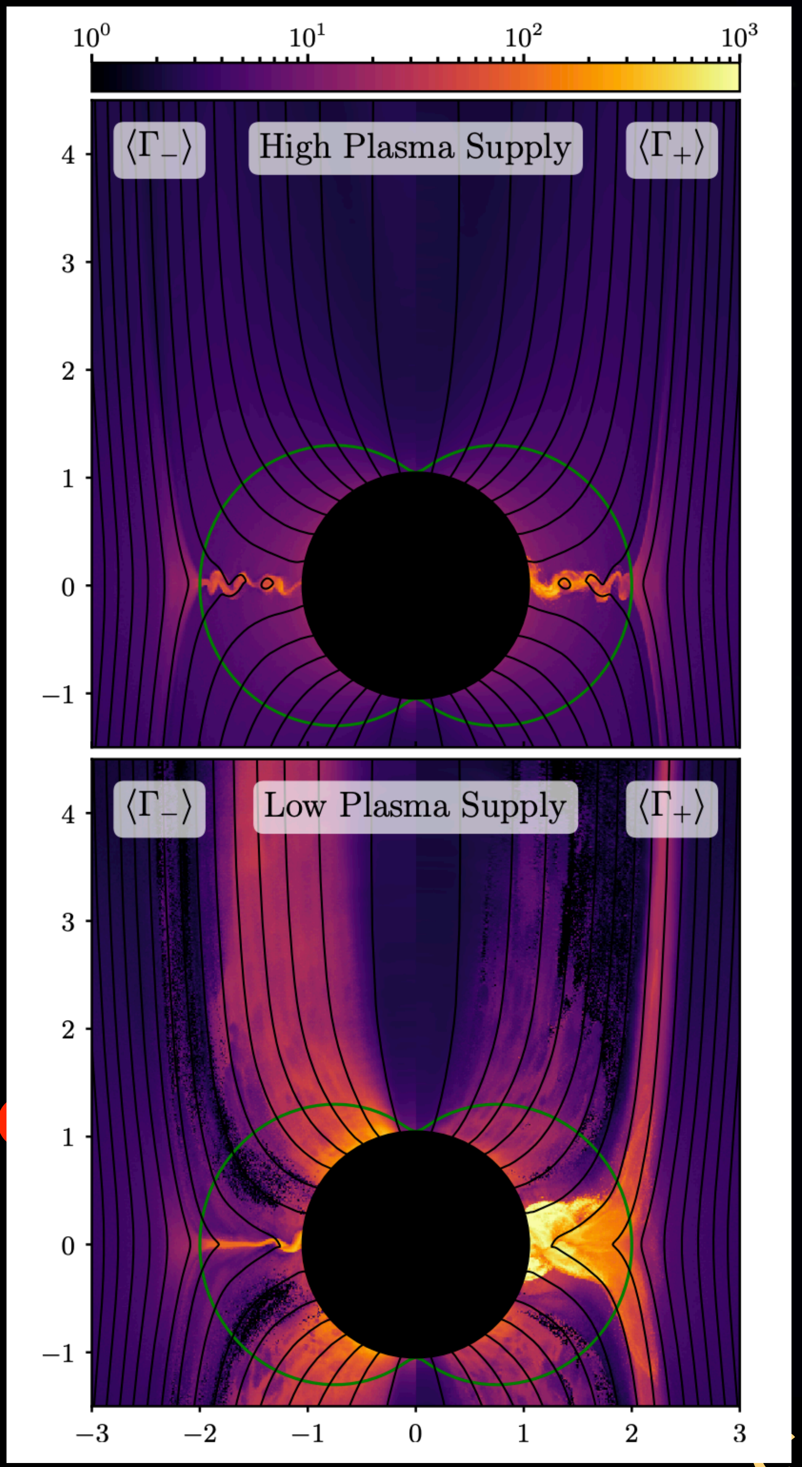
HESS pointing accuracy ~10″
CTA pointing accuracy ~ 1-3″

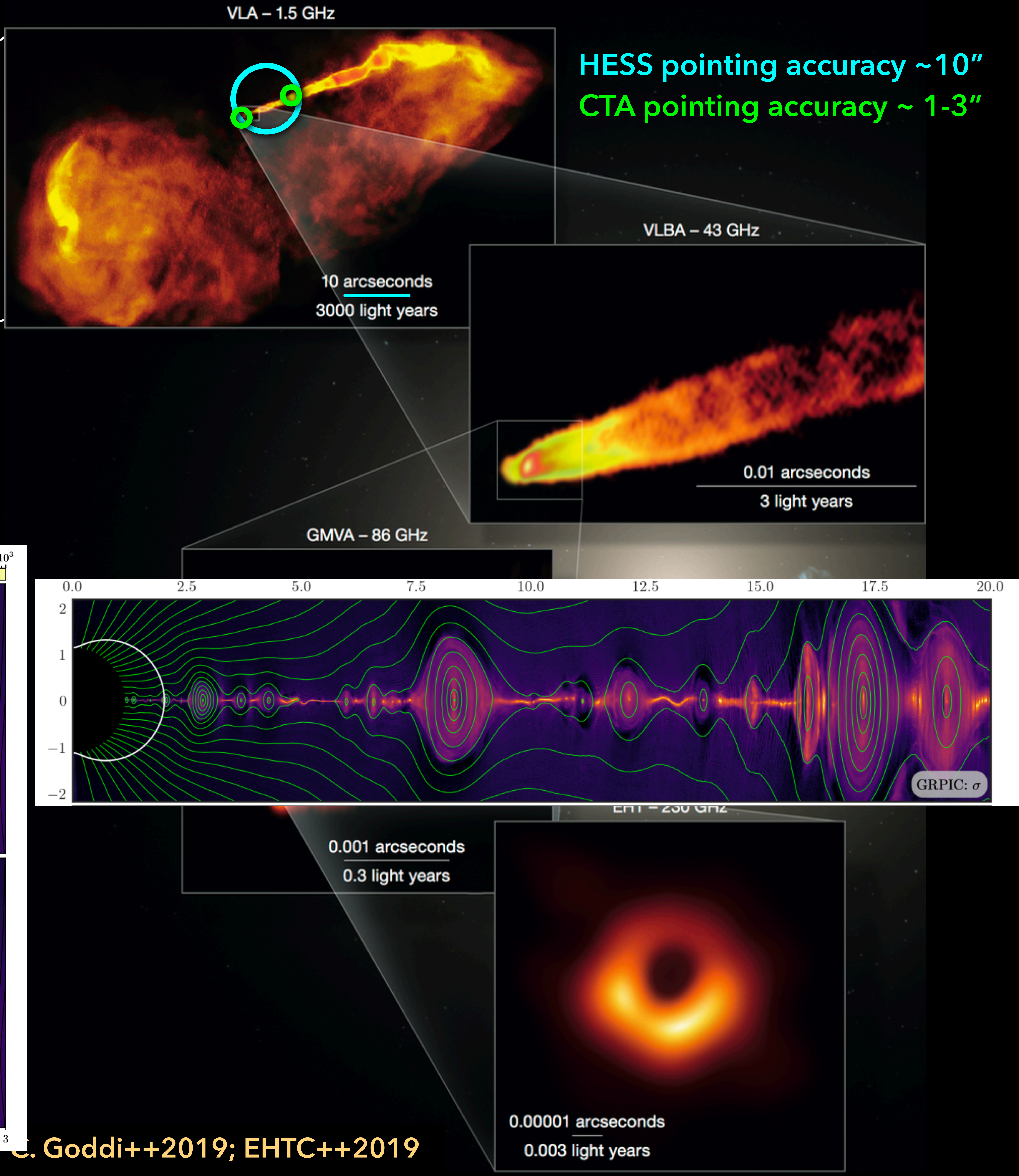
M87



Sironi, Brown & Narayan 2021

NRAO/VLA 90cm image





Hess/Magic/Veritas (TeV) angular res

CTA (TeV) angular resolution

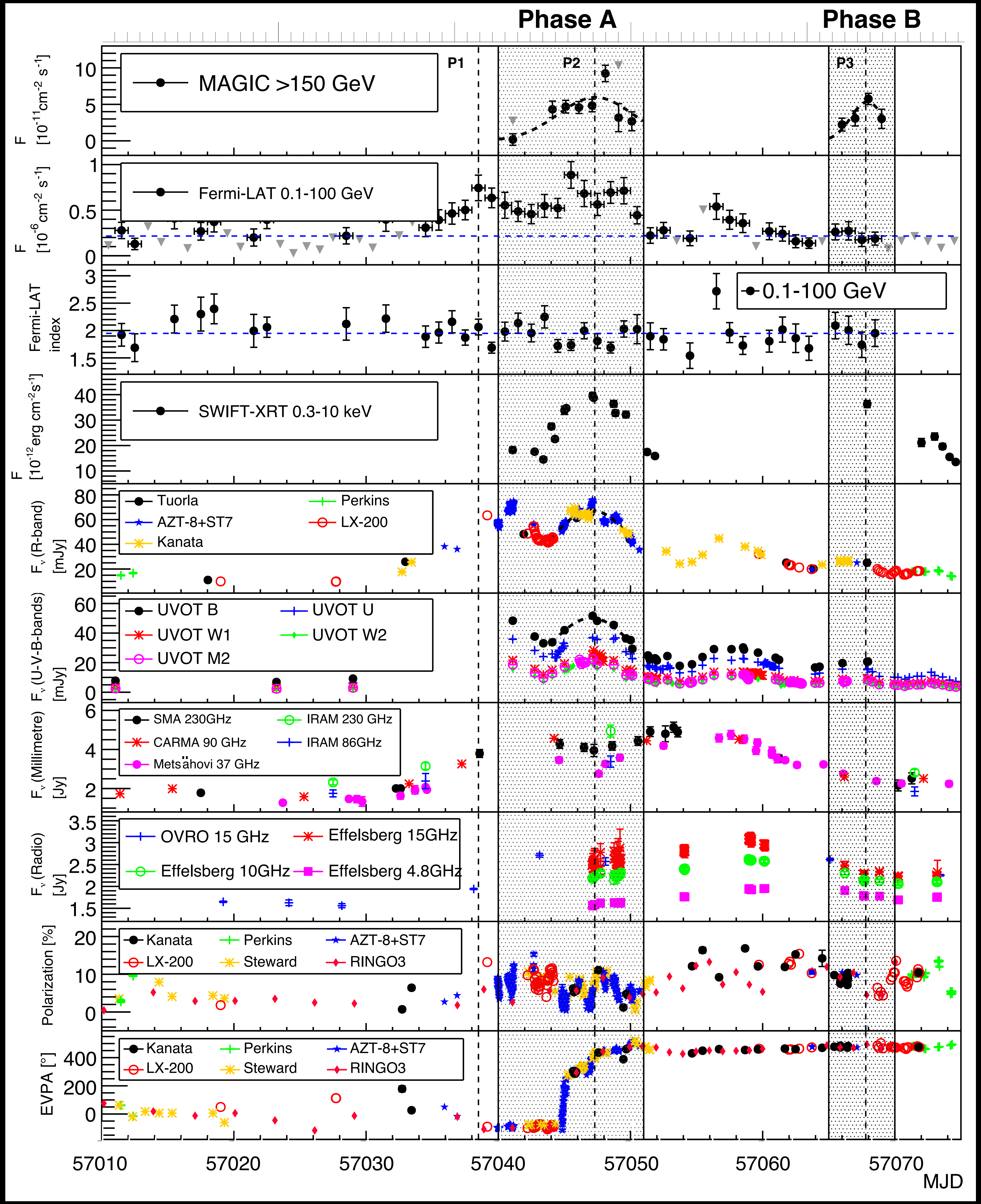
Parfrey, Philippov & Cerutti 2019,
Crinquand, Cerutti++2020,
Bransgrove, Ripperda & Philippov 2021,

C. Goddi++2019; EHTC++2019

Thinking ahead to EHT++: A high cadence month in the life of S5 0716+714

- Complex stochastic behavior, requires many samples to resolve (EHT 2017 Sgr A* data is case in point!): weekly over years!
- Different particle acceleration methods predict different variability signatures
- Illustrates the need for agile observing, ToO capabilities, automated/dynamical scheduling

➠ ngEHT++ AGN plans should optimise overlap with CTA/optical (with polarisation!) monitoring programs!

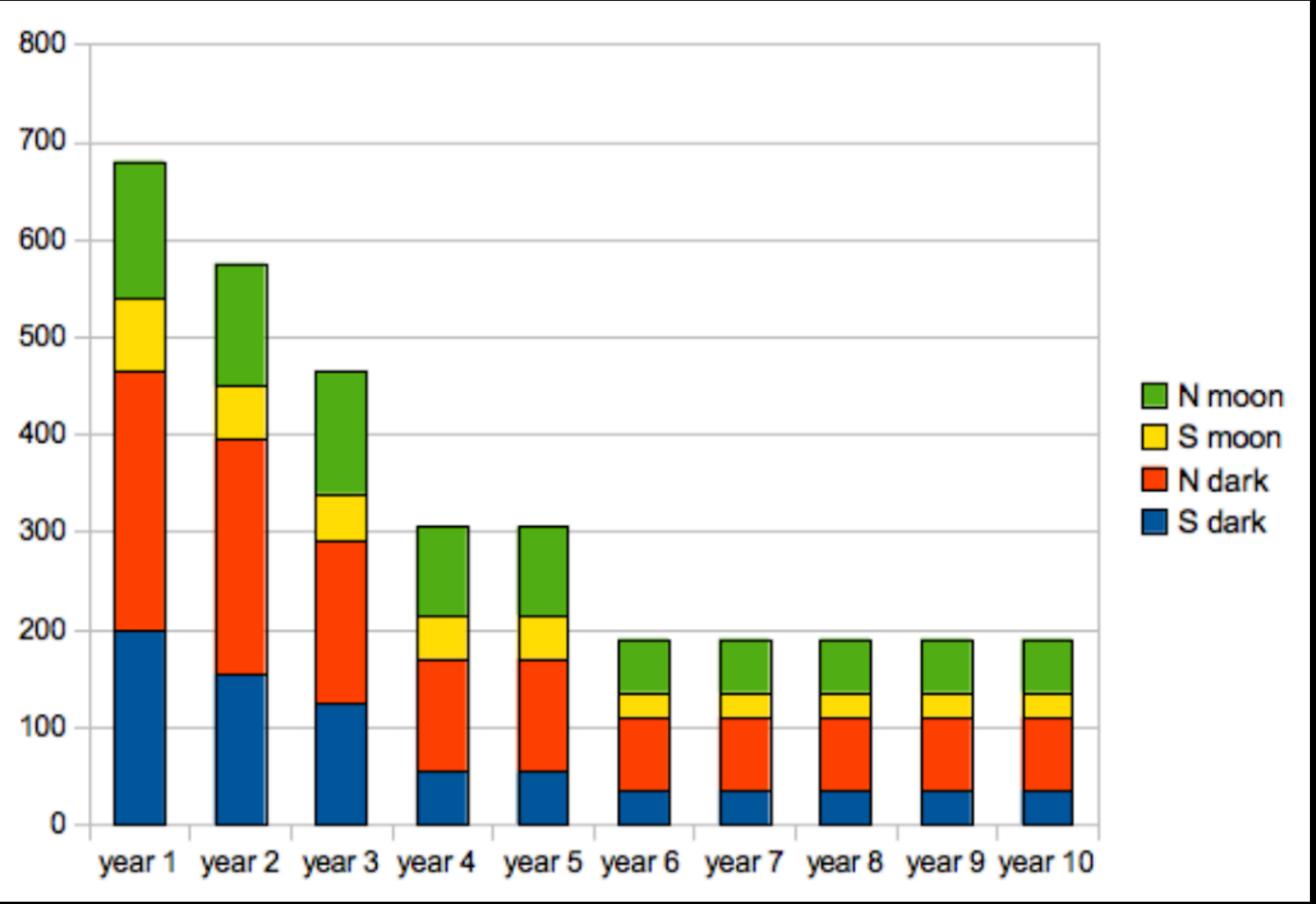


(MAGIC collaboration 2018)

The CTA AGN KSP: a decade of intense VHE γ-ray monitoring

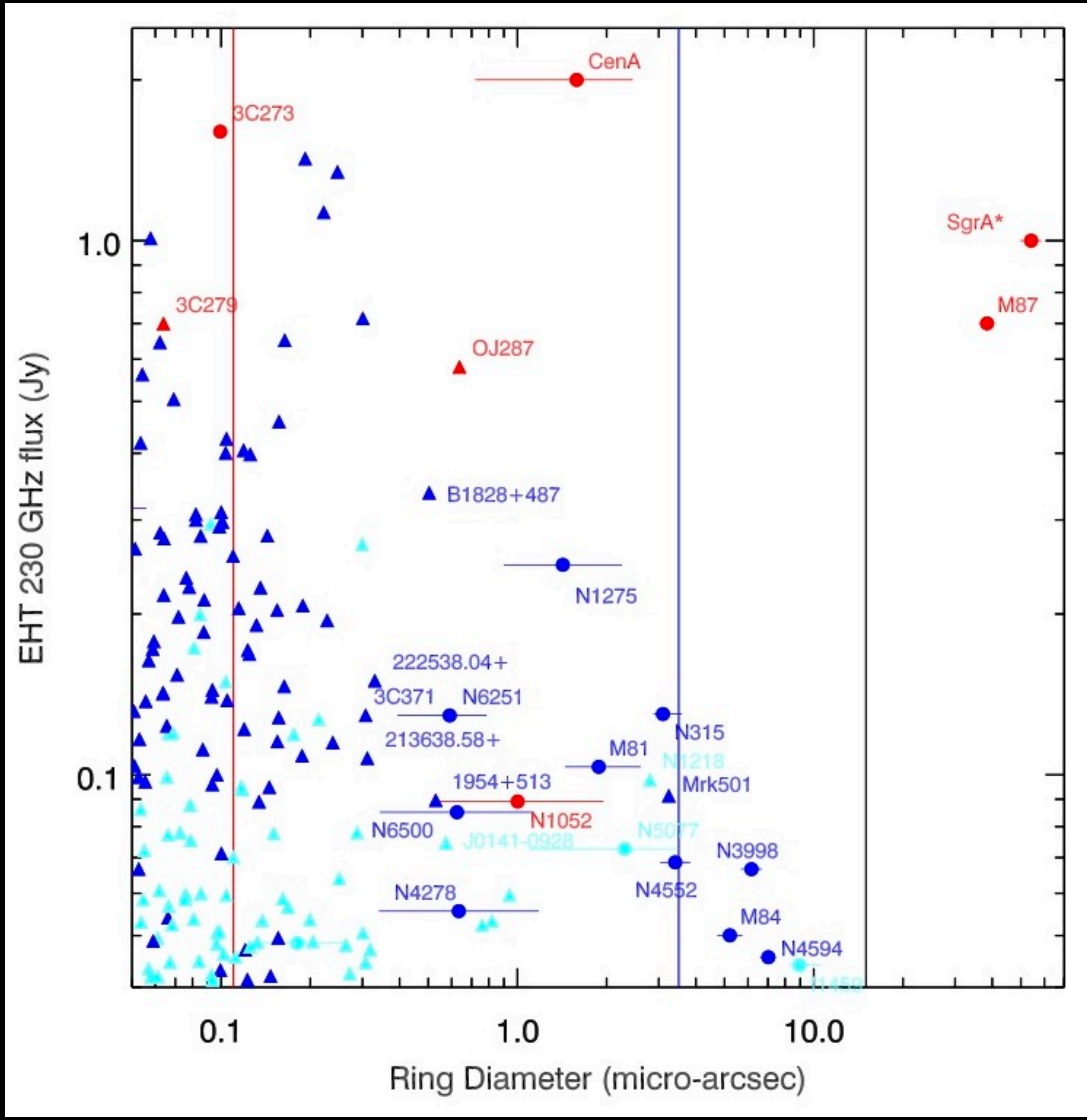
- Deep exposures: M87 (100 hrs) and Cen A (150 hrs)
- Longterm monitoring: 2-3 sources per AGN class, 15-20 total "prominent" VHE AGN (mostly blazars/radio galaxies/LLAGN), spectra at least weekly for 30 minutes, for ~10 years
- AGN Flares: triggered externally or internally (CTA realtime analysis mode, regular 12min snapshots of ~80 AGN)
- High quality spectra: ~80 sources
- Many of these also potential neutrino sources monitored by eg. MOJAVE

Programme	total N [h]	total S [h]	duration [yr]	observation mode
Long-term monitoring	1110	390	10 †	full array
AGN flares				
snapshots	1200	475	10 ∗	LSTs
snapshots	138	68	10 ∗	MSTs (assuming 10 sub-arrays)
verification ext. trig.	300	150	10 ∗	LSTs or MST sub-arrays
follow-up of triggers	725	475	10 ∗	full array
High-quality spectra				
redshift sample	195	135	3	full array
M 87 and Cen A	100	150	3	full array



See "Science with CTA" ebook: arXiv:1709.07997

Science plans: defining the 'golden' MWL-ngEHT sample



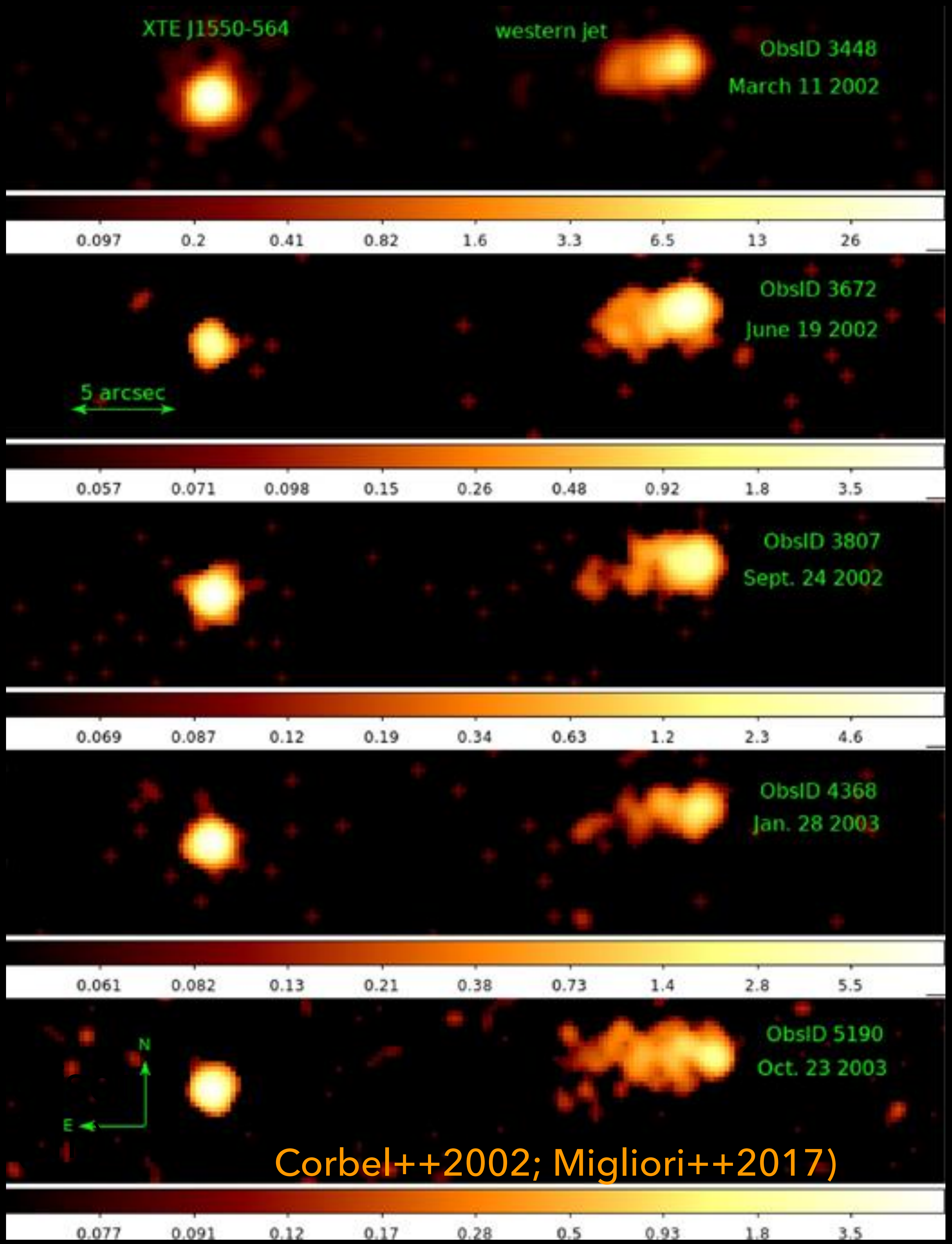
Sera VHE sources
Notes:
may be filtered, eg, by declination and literature vlbi flux and frequency limits. Check.
- Snu, freq, Res are observed fluxes. Snu is most often peak (not total) flux.
- resolution (Res) is indicative only since original compilations (or NED) often do not specify resolution. When Res was not available: VLBA set to 1mas, GMVA to 0.1mas, VLA to 1arcsec
- extrapolated 230GHz flux in the EHT FOV (exflux230)is based on an assumed spectral slope (about -0.4) and resolved flux fraction which depends on the resolution of the observed flux.
- source code (last column): 0= directly measured mbh (incl. detailed RM). Else estimated mbh: 1=M-sigma 2=M-Lbulge,3=single-epoch RM, 4=optical luminosity, 5=FP-derived sigma (FP-sigma), 6=Blazar compilation (mix)
nutilde is from Janssen et al eqn 12

Name	z	ring micro	ringhi micro	Dist Mpc	Mbh Msun	Mbhhi Msun	S_nu mJy	Freq GHz	Res arcsec	exflux230 mJy	ra deg	dec, deg,	nutilde, GHz	230GHzflux mJy	230GHz res arcsec
2MASXJ00135605-185	0.0950	******	******	363.5	Inf	Inf	12.0	8.4	0.00100	2.2	3	-18	*****	******	********
WISEJ015239.60+014	0.0800	******	******	311.4	Inf	Inf	48.0	8.4	0.00100	8.9	28	1	*****	******	********
TXS0506+056	******	******	******	******	Inf	Inf	220.0	23.0	0.00100	61.3	77	5	*****	640.0	1.00000
1ES0502+675	0.4160	******	******	1134.8	Inf	Inf	39.0	15.0	0.00100	9.2	76	67	*****	******	********
PMNJ0816-1311	******	******	******	******	Inf	Inf	18.0	8.4	0.00100	3.4	124	-13	*****	******	********
PKS0301-243	0.2660	******	******	843.8	Inf	Inf	118.0	15.0	0.00100	27.7	45	-24	*****	******	********
1H1914-194	0.1370	******	******	499.7	Inf	Inf	164.0	15.0	0.00100	38.5	289	-19	*****	******	********
PKS0521-36	0.0550	******	******	220.5	Inf	Inf	297.0	86.0	0.00067	170.8	80	-36	*****	6300.0	1.00000
PKS1424+240	******	******	******	******	Inf	Inf	76.0	23.0	0.00100	21.2	216	23	*****	333.0	1.00000
1ES1101-232	0.1860	******	******	642.7	Inf	Inf	20.0	8.4	0.00100	3.7	165	-23	*****	******	********
PG1553+113	0.3600	******	******	1037.6	Inf	Inf	130.0	15.0	0.00100	30.5	238	11	*****	191.0	1.00000
PKS1440-389	******	******	******	******	Inf	Inf	68.0	8.4	0.00100	12.7	220	-39	*****	******	********
VERJ0521+211	******	******	******	******	Inf	Inf	193.0	15.0	0.00100	45.3	80	21	*****	207.0	1.00000
VERJ0648+152	0.1790	******	******	623.2	Inf	Inf	22.0	8.4	0.00100	4.1	102	15	*****	******	********
1RXSJ101015.9-3119	0.1430	******	******	518.1	Inf	Inf	18.0	8.4	0.00100	3.4	152	-31	*****	******	********
2MASXJ22500577+382	0.1190	******	******	443.0	Inf	Inf	43.0	8.4	0.00100	8.0	342	38	*****	******	********
M87	0.0042	38.44	40.82	16.7	6.15E+09	6.53E+09	700.0	230.0	0.00002	700.0	187	12	188	700.0	0.00002
Mrk501	0.0330	3.24	9.72	135.8	4.22E+09	1.27E+10	159.0	86.0	0.00048	91.4	253	39	759	279.0	1.00000
NGC1275	0.0176	1.42	2.25	70.0	9.55E+08	1.51E+09	430.0	86.0	0.00010	247.2	49	41	2874	8760.0	1.00000
PKS0625-35	0.0562	0.92	1.83	214.3	1.89E+09	3.76E+09	172.0	8.4	0.00100	32.0	96	-35	1592	105.0	1.00000
IC310	0.0188	0.37	0.39	77.8	2.78E+08	2.93E+08	59.0	15.0	0.00100	13.9	49	41	2810	******	********
1ES2344+514	0.0440	0.37	1.10	178.7	6.31E+08	1.89E+09	96.0	15.0	0.00100	22.5	356	51	3406	******	********
1ES0229+200	0.1400	0.36	1.07	509.0	1.74E+09	5.21E+09	29.0	8.4	0.00100	5.4	38	20	1690	******	********
1ES1426+428	0.1293	0.30	0.89	475.6	1.35E+09	4.05E+09	21.0	15.0	0.00100	4.9	217	42	1957	******	********
OR103	1.8379	0.26	0.78	1739.6	4.37E+09	1.31E+10	298.0	86.0	0.00024	171.3	226	10	10887	411.0	1.00000
BLLac	0.0690	0.19	0.58	272.1	5.01E+08	1.50E+09	2480.0	86.0	0.00070	1425.9	330	42	*****	2720.0	1.00000
1ES0806+524	0.1371	0.17	0.50	500.0	7.94E+08	2.38E+09	71.0	15.0	0.00100	16.7	122	52	6183	******	********
NRAO530	0.9000	0.13	0.39	1607.0	2.00E+09	5.99E+09	2300.0	23.0	0.00100	641.0	263	-13	*****	1070.0	1.00000
PKS1741-038	1.0540	0.12	0.37	1671.4	2.00E+09	5.99E+09	293.0	86.0	0.00024	168.5	265	-3	22758	1736.0	1.00000
PKS2155-304	0.1160	0.12	0.36	433.3	5.01E+08	1.50E+09	159.0	8.4	0.00100	29.6	329	-30	11220	205.0	1.00000
PKS2005-489	0.0700	0.12	0.35	275.7	3.09E+08	9.27E+08	271.0	230.0	1.00000	108.4	302	-48	21898	271.0	1.00000
Mrk180	0.0460	0.09	0.27	186.4	1.62E+08	4.87E+08	84.0	15.0	0.00100	19.7	174	70	12947	******	********
1ES0347-121	0.1850	0.07	0.22	639.9	4.47E+08	1.34E+09	18.0	4.8	0.00100	2.7	57	-11	5866	******	********
H2356-309	0.1654	0.07	0.21	584.5	3.98E+08	1.19E+09	18.0	8.4	0.00100	3.4	359	-30	6716	******	********
TXS1055+567	0.1432	0.07	0.21	518.9	3.47E+08	1.04E+09	103.0	15.0	0.00100	24.2	164	56	17472	******	********
1ES1959+650	0.0470	0.07	0.20	190.2	1.23E+08	3.69E+08	112.0	15.0	0.00100	26.3	299	65	19919	******	********
PKS1222+216	0.4338	0.07	0.20	1163.2	7.41E+08	2.22E+09	494.0	86.0	0.00017	284.0	186	21	-9855	198.0	1.00000
APLib	0.0490	0.07	0.20	197.9	1.26E+08	3.78E+08	430.0	23.0	0.00100	119.8	229	-24	*****	1620.0	1.00000
PG1218+304	0.1836	0.07	0.20	636.0	3.98E+08	1.19E+09	62.0	15.0	0.00100	14.6	185	30	14515	******	********
3C279	0.5362	0.06	0.19	1305.7	8.00E+08	1.60E+09	1000.0	230.0	0.00002	1000.0	194	-5	*****	1000.0	0.00002
Mrk421	0.0310	0.06	0.67	127.9	6.80E+07	8.16E+08	169.0	86.0	0.00013	97.2	166	38	*****	141.0	1.00000
NGC1068	0.0038	0.06	0.06	15.9	8.39E+06	8.83E+06	1900.0	4.8	10.50000	80.8	40	0	*****	******	********
PKS0548-322	0.0690	0.05	0.16	272.1	1.41E+08	4.24E+08	21.0	8.4	0.00100	3.9	87	-32	9910	******	********
1ES0414+009	0.2870	0.04	0.13	890.8	3.63E+08	1.09E+09	30.0	8.4	0.00100	5.6	64	1	13924	******	********
3C66A	0.3400	0.04	0.12	999.8	3.98E+08	1.19E+09	398.0	15.0	0.00100	93.5	35	43	*****	******	********
6C070609+591309	0.1250	0.04	0.12	462.2	1.82E+08	5.46E+08	28.0	8.4	0.00100	5.2	107	59	14502	******	********
PKS1510-089	0.3600	0.04	0.12	1037.6	3.98E+08	1.19E+09	576.0	86.0	0.00022	331.2	228	-9	*****	722.0	1.00000
1ES1011+496	0.2120	0.03	0.09	712.2	2.00E+08	5.99E+08	94.0	15.0	0.00100	22.1	153	49	*****	******	********
1ES1215+303	0.1300	0.03	0.09	477.9	1.32E+08	3.95E+08	247.0	15.0	0.00100	58.0	184	30	-1336	153.0	1.00000
WCom	0.1029	0.02	0.05	390.1	6.31E+07	1.89E+08	104.0	86.0	0.00019	59.8	185	28	*****	341.0	1.00000
8C0716+714	0.3000	0.01	0.04	918.8	1.26E+08	3.78E+08	1132.0	86.0	0.00005	650.9	110	71	-5275	******	********
RBS0413	0.1900	0.01	0.04	653.6	8.91E+07	2.67E+08	19.0	8.4	0.00100	3.5	49	18	*****	******	********
MS1221.8+2452	0.2180	0.01	0.04	727.6	9.33E+07	2.80E+08	34.0	8.4	0.00100	6.3	186	24	*****	******	********

(EvenT Horizon and EnviRons=ETHER sample; Ramakrishnan, Nagar++)

Transient XRBs reveal jet dynamics from launch to termination

Before 2018 only source seen to decelerate but not tracked from launch: XTE J1550-564



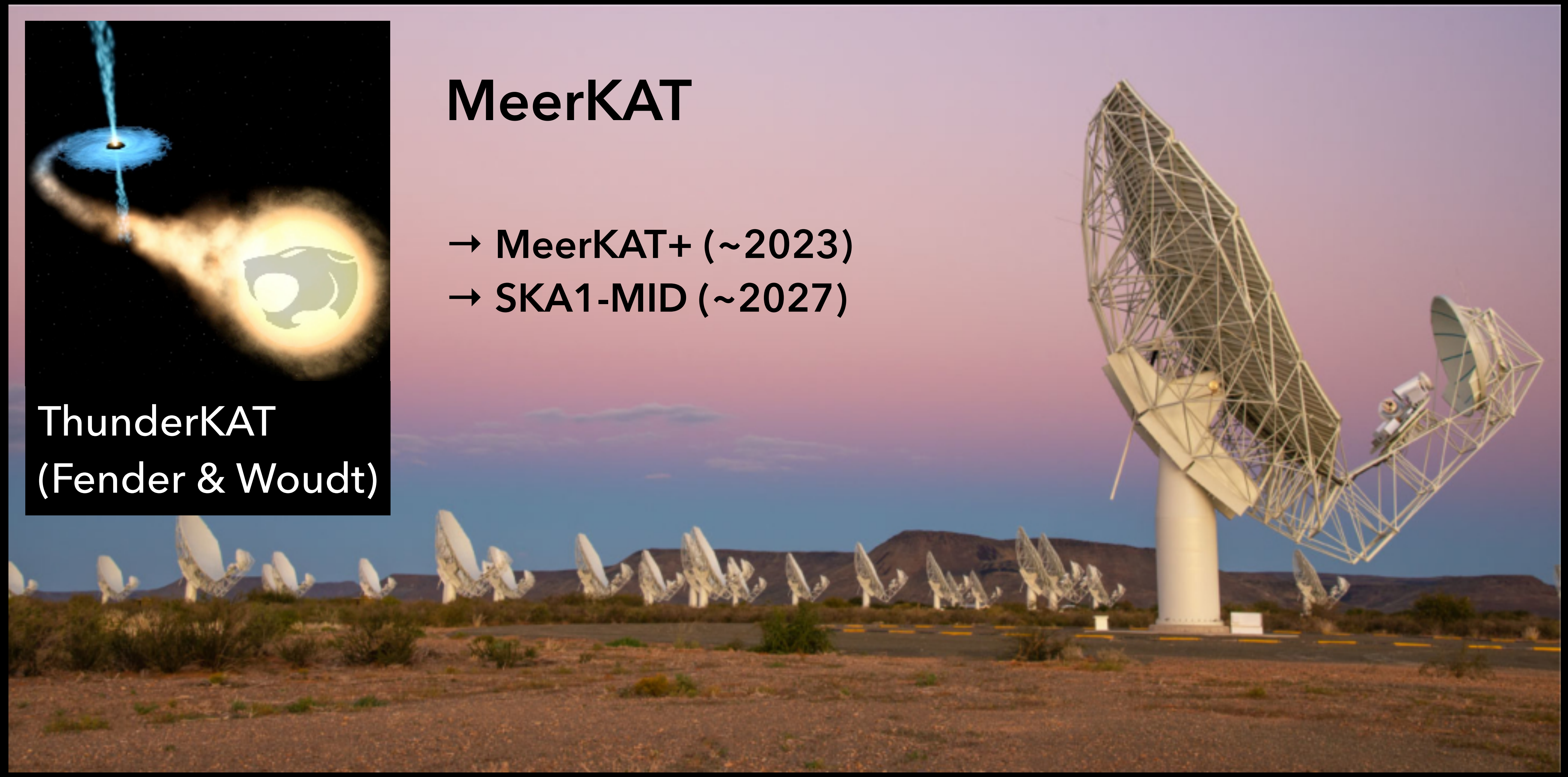
Corbel++2002; Migliori++2017)

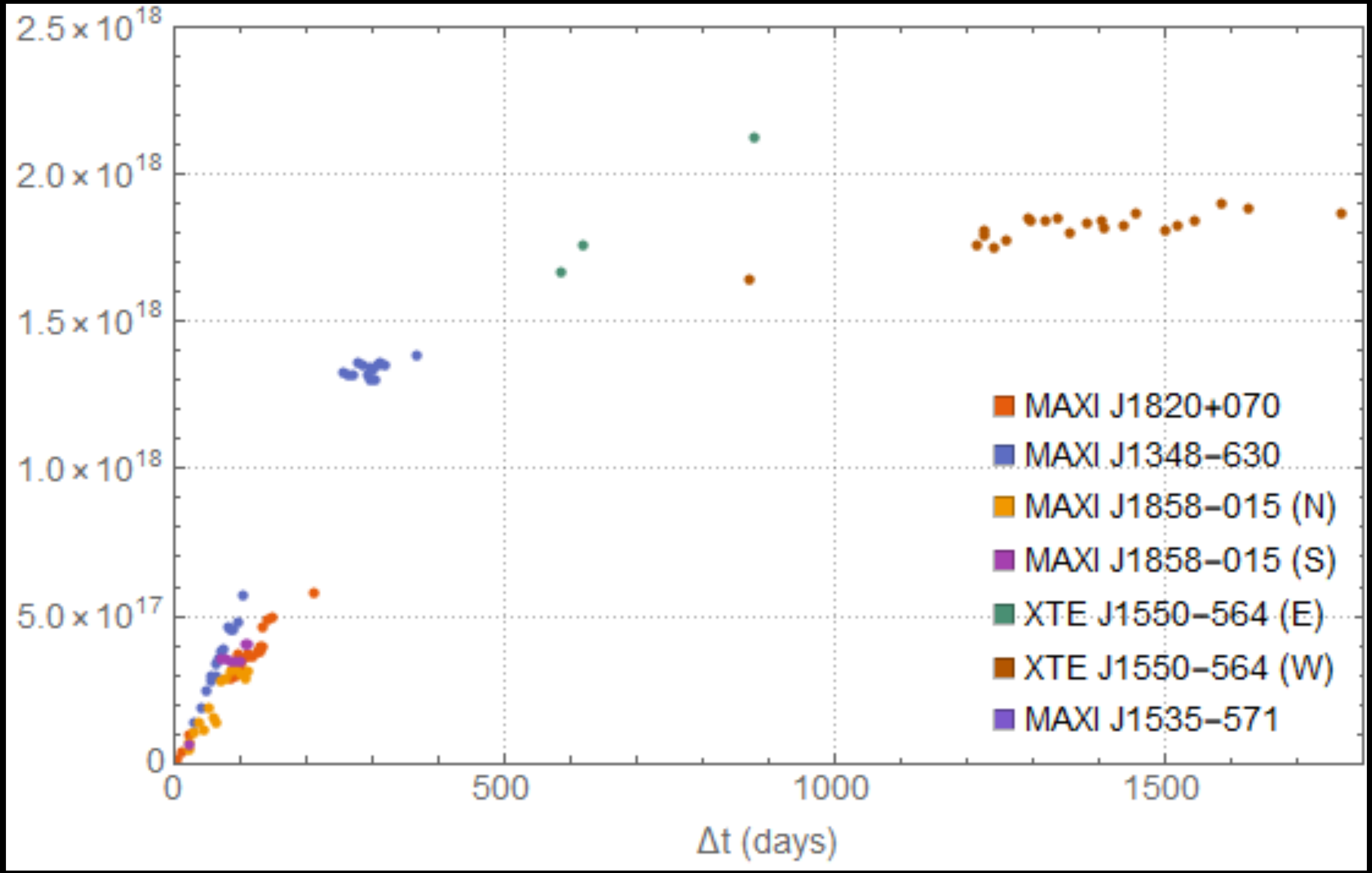
(Slide adapted fr Rob Fender, see ngEHT Transients WP soon….)

Transient XRBs reveal jet dynamics from launch to termination

Before 2018 only source seen to decelerate but not tracked from launch: XTE J1550-564

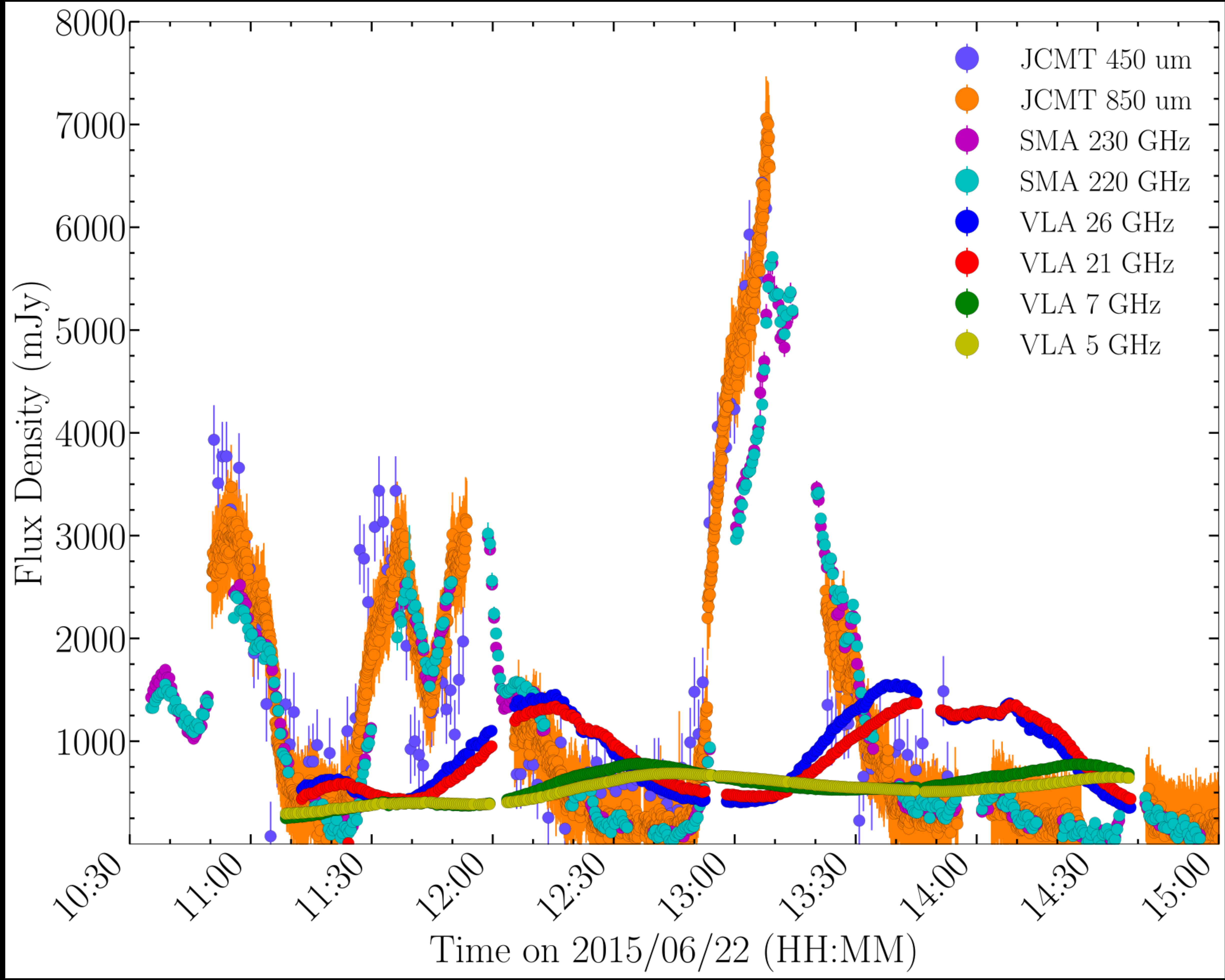
Since ThunderKAT already > 4 new sources tracked from launch (Russell++2019; Bright+2020; Espinasse++2020; Wood++2021; Carotenuto++2021, 2022; Tremou++2022)





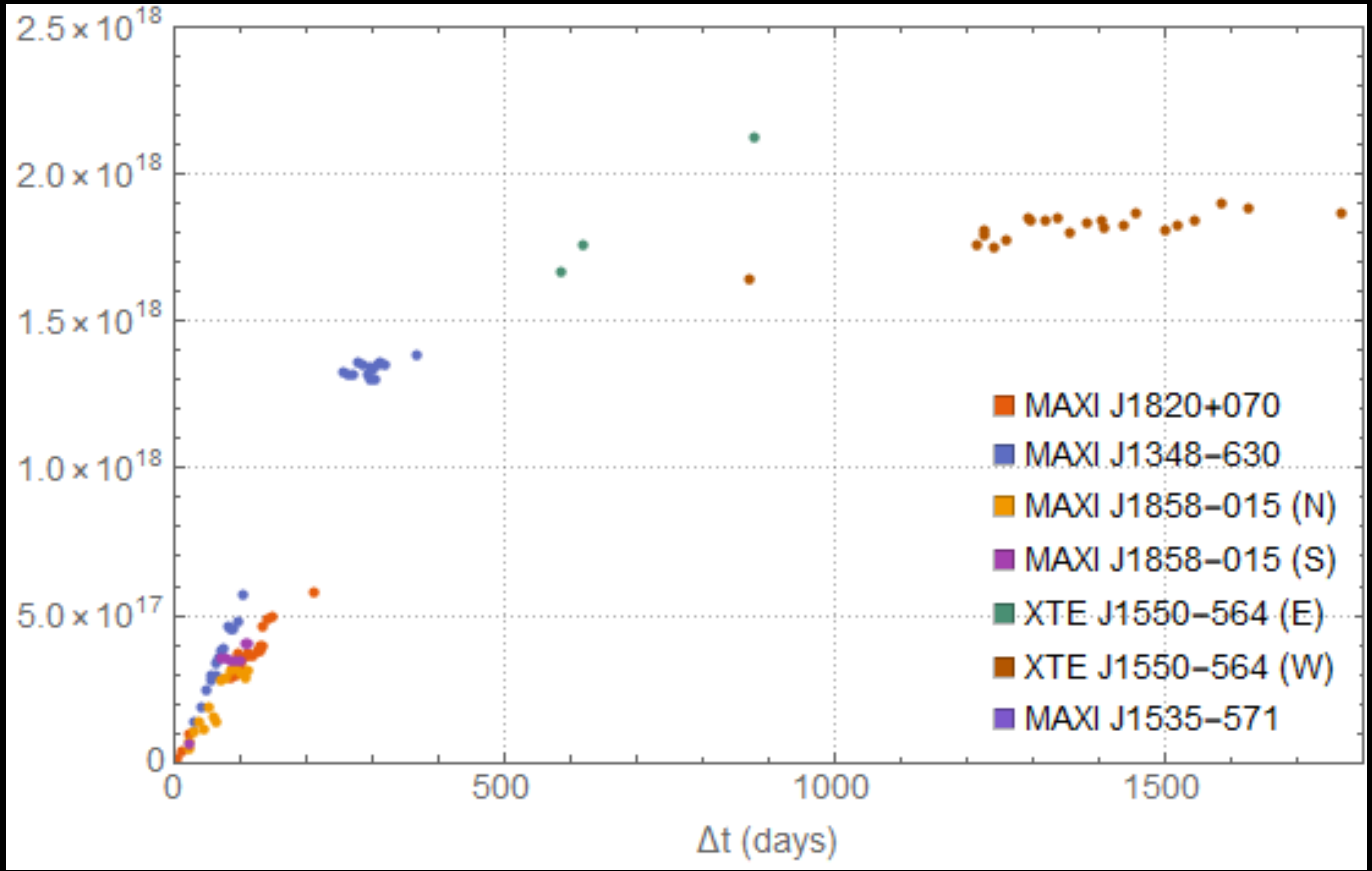
(Slide adapted fr Rob Fender, see ngEHT Transients WP soon….)

Transient XRBs reveal jet dynamics from launch to termination



Miller-Jones++2019; Tetarenko++2017, 2019

Since ThunderKAT already > 4 new sources tracked from launch (Russell++2019; Bright+2020; Espinasse++2020; Wood++2021; Carotenuto++2021, 2022; Tremou++2022)



(Slide adapted fr Rob Fender, see ngEHT Transients WP soon….)

Summary

- ★ To accurately model, and eventually predict, MWL/MM transients we need improved understanding of macro/micro coupling
- ★ Combining global mm-VLBI imaging (EHT) with MWL monitoring, can break current degeneracies for SMBHs, but key for all sources!
- ★ EHT++ (ngEHT, etc.) aims for agile/subarray operations, ToOs and MWL-coordination. CTA is a key strategic partner for pinpointing particle acceleration, hadronic content, jet power
- ★ EHT++/ngEHT will give us access to a population of black hole systems, both supermassive (and stellar mass!)