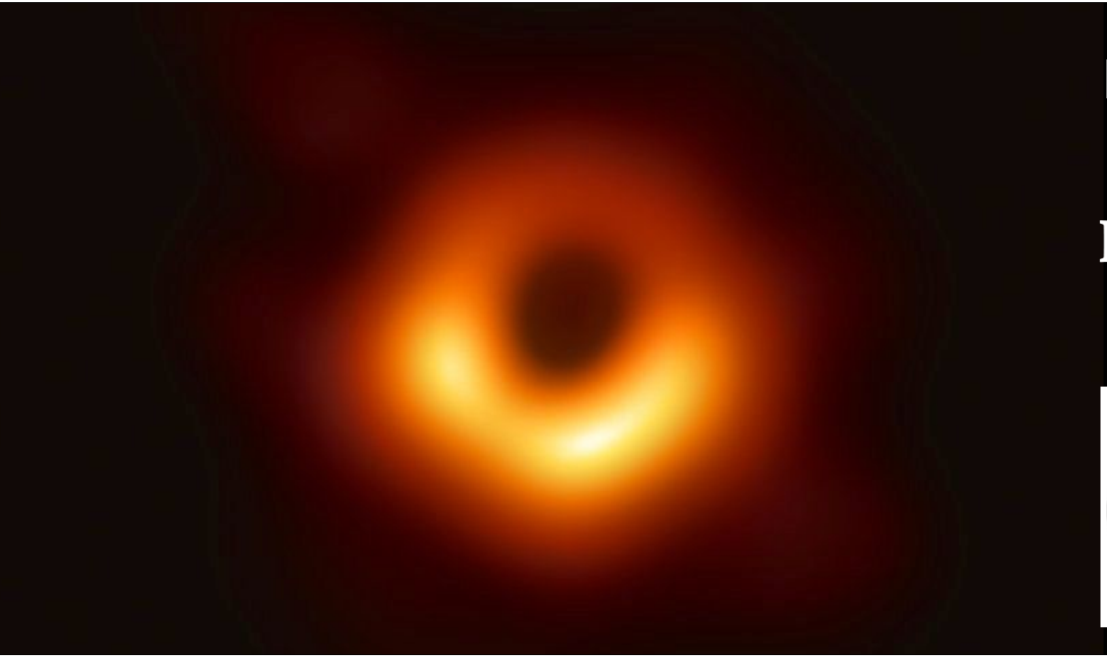
The first image of a black hole

The 2017 observations of the EHT



Michael Janssen

Radboud University
IN·DEI·NOMINE·FELICITER

BLACK HOLE CAM

European Research Council
erc

Event Horizon Telescope talks

EHT Collaboration et al. 2019, ApJL, 875, L1-6 (Papers I-VI): 204 pages

Michael Janssen		**History & observations**
Sara Issaoun		**Calibration & Imaging**
Shan-Shan Zhao		**Shadow and mass measurements**
Freek Roelofs		**Model comparisons & future outlook**

The EHT collaboration

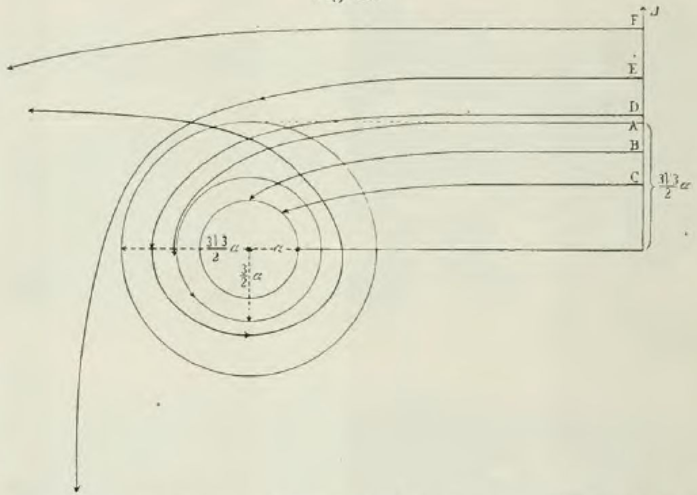
- 207 members, 59 institutes, 18 countries in Europe, Asia, Africa, North and South America (April 2019).
- Radboud University involvement via BlackHoleCam ERC synergy grant (H. Falcke, M. Kramer, L. Rezolla)

History: light in a black hole metric

— 226 —

Daraus ziehen wir in Anlehnung an Poincarés Zykeltheorie den überdies recht anschaulichen Schluß: Der Lichtstrahl, der im Unendlichen auf den Abstand $\Delta = \frac{3\sqrt{3}}{2}\alpha$ hinzielt, biegt sich nach innen und nähert sich auf einer Spirale asymptotisch dem Kreise $r = \frac{3}{2}\alpha$. Dann ergibt sich für die Gesamtheit der betrachteten Strahlen die Fig. 23. Sie zeigt uns die Kreise $r = \alpha$,

Fig. 23.



an welchem jeder herankommende Lichtstrahl endigt (ist doch dort die Lichtgeschwindigkeit 0), ferner $r = \frac{3}{2}\alpha$ und $r = \frac{3\sqrt{3}}{2}\alpha$.

Courtesy of E. Ros

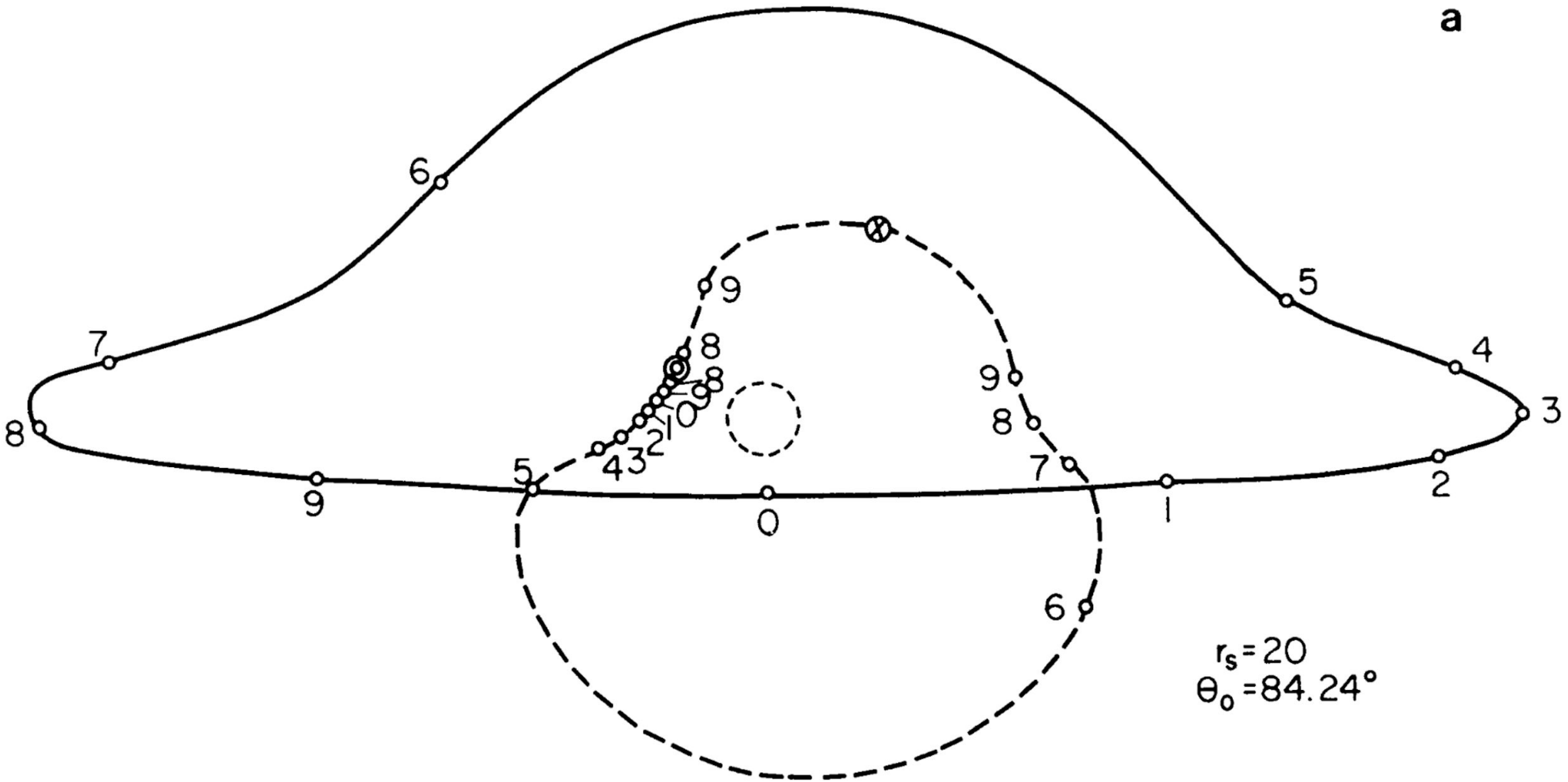
1915: Einstein's theory of general relativity

1916: Schwarzschild metric

David Hilbert (1916) lectures: "Die Grundlagen der Physik"
Published by **Max von Laue (1921)**: "Die Relativitätstheorie. Zweiter Band.", Vieweg, 1921

- Schwarzschild metric
- Photon orbit $1.5R_S$
- Cross section $5.2R_S$

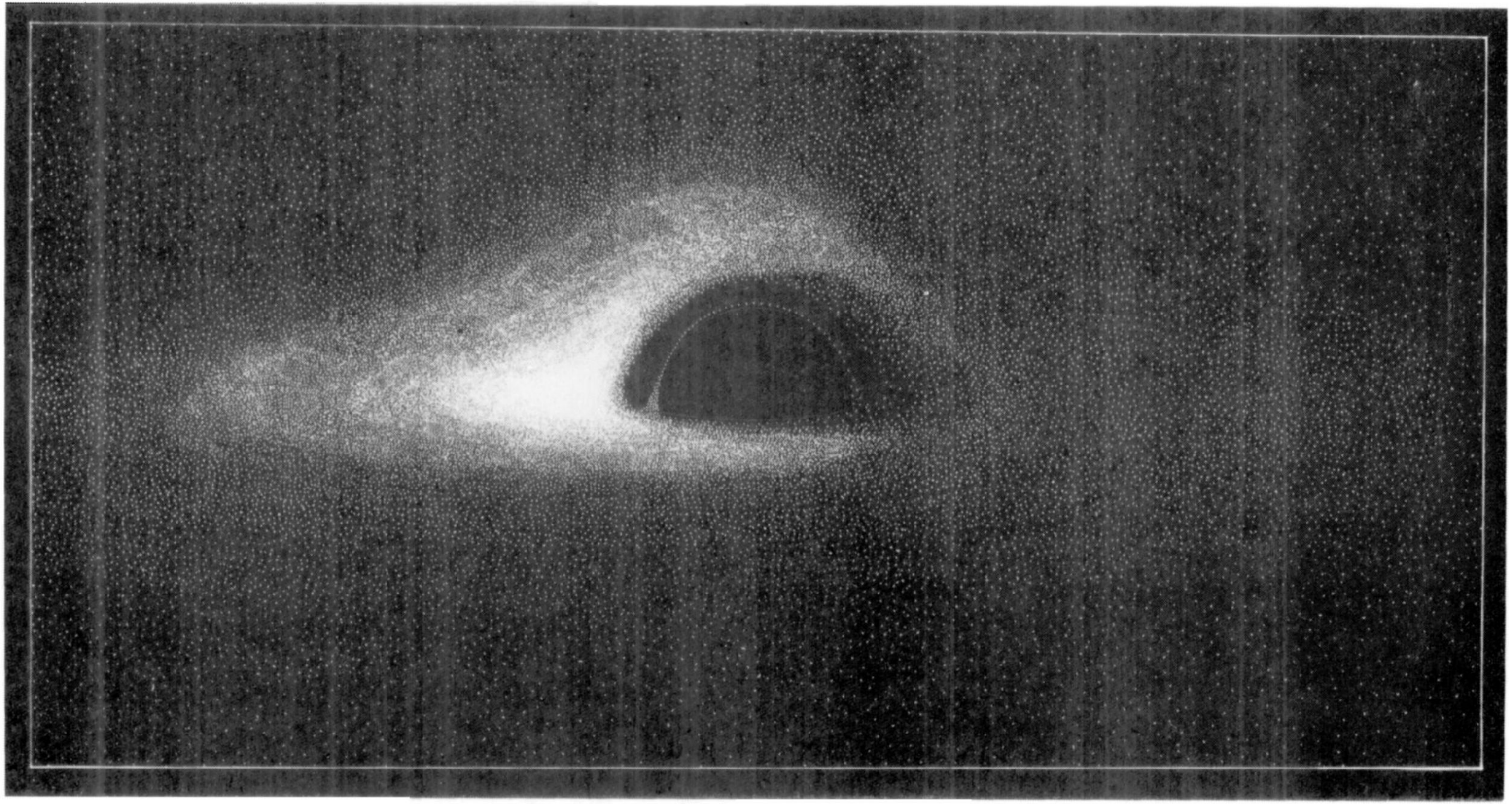
History: black hole imaging



"Image of a star orbiting a black hole"

Cunningham & Bardeen, 1973, ApJ, 183, 237

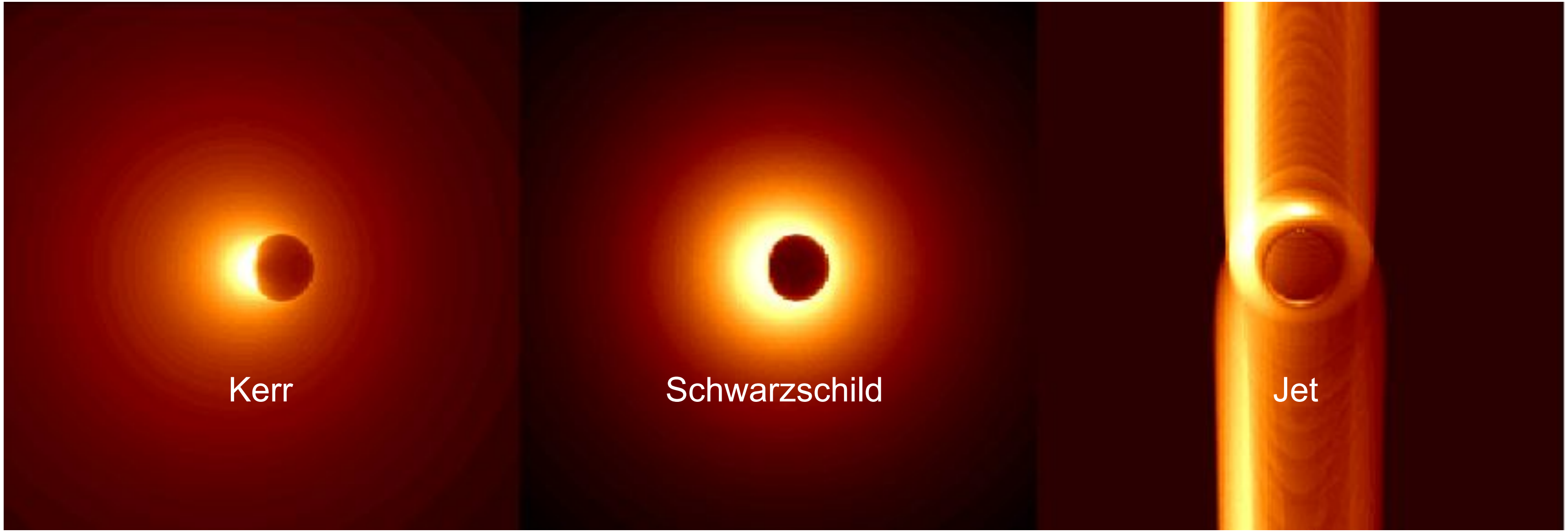
History: black hole imaging



Black hole + accretion disk; computer-calculated, hand-drawn

J. P. Luminet, 1979, ApJ, 75, 228

History: black hole imaging



Black hole ‘shadow’ observable with global mm VLBI

Falcke, Melia, Agol , 2000, ApJ & AIPC, 522, 317

The target: M87

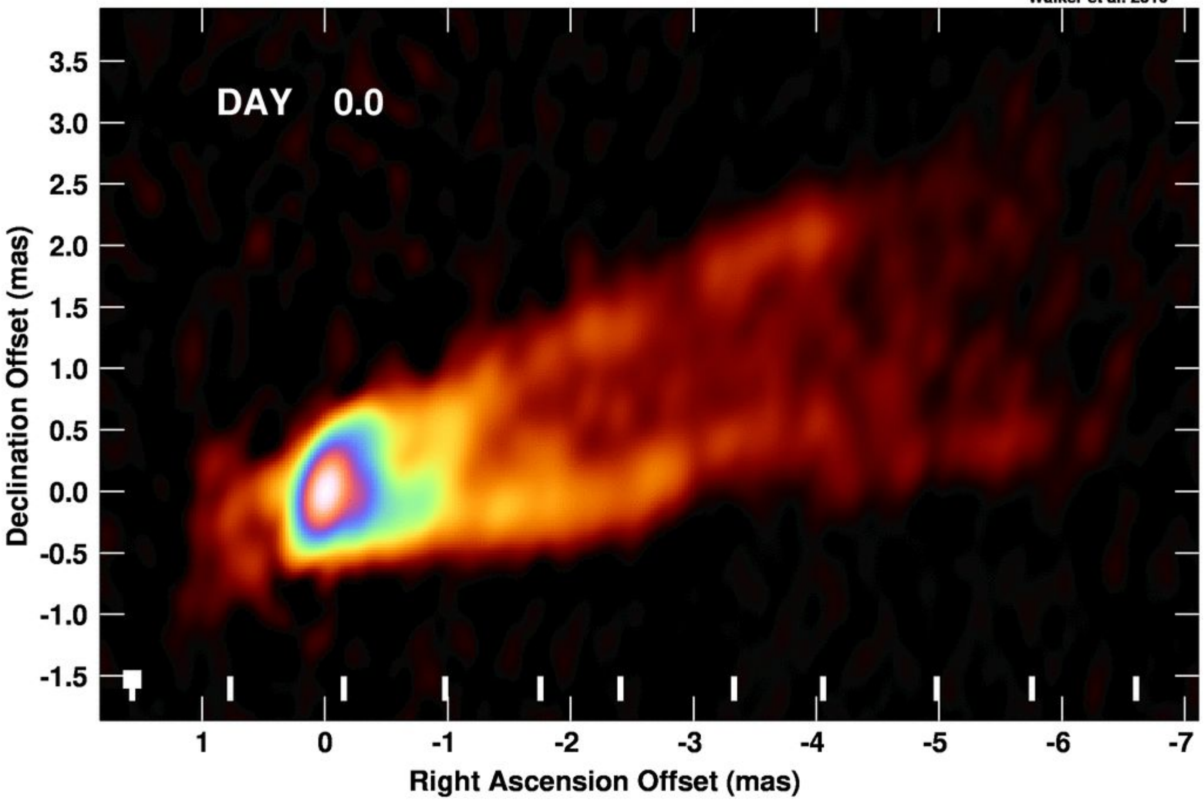
Messier 87

- (3 -- 7)x10^9 $M_\odot$
  - Different masses from gas-dynamical measurements and stellar dynamics

- 6x10^7 lightyear

- 20 - 40 μas

Walker et al. 2016



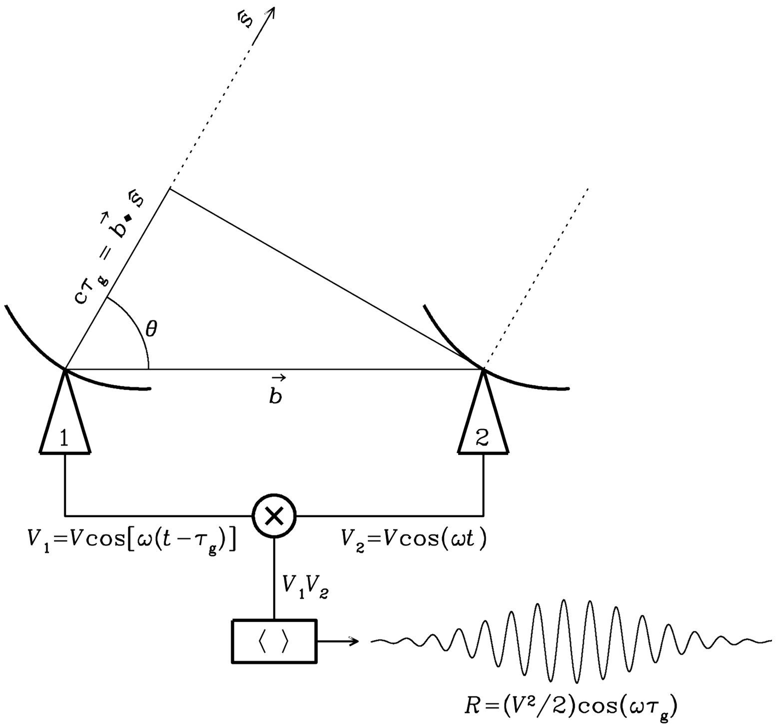
Achieving the highest resolution

- Angular resolution:
  $\Theta \sim \lambda / D$
  λ: observing wavelength, D: aperture size

- Synthesize virtual dish with interferometry
  → Fourier Transform: $D = b$.

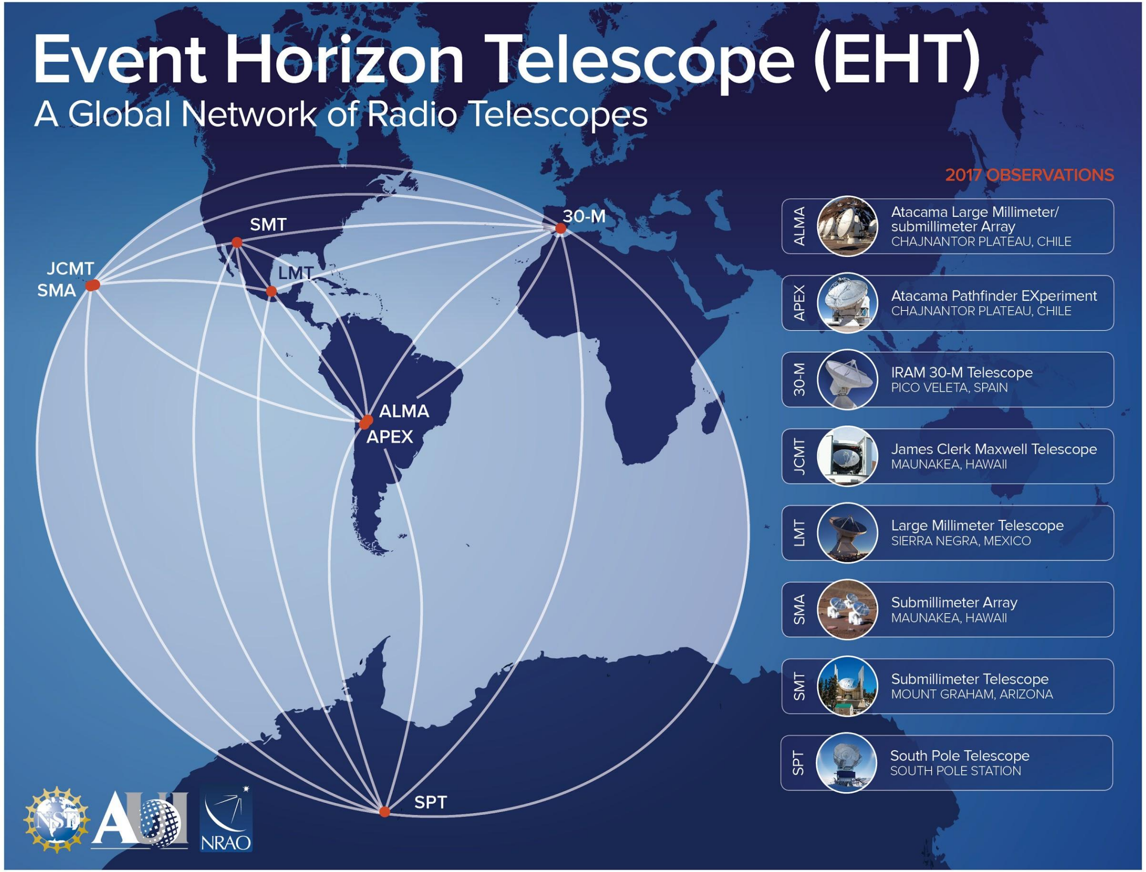
- Push towards longer baselines
  → Very Long Baseline Interferometry (VLBI).

- Push towards $\lambda\downarrow$
  → Higher resolution.
  → Emission from BH vicinity.
  → Correct for Earth atmosphere.



Credit: Scott Ransom, NRAO

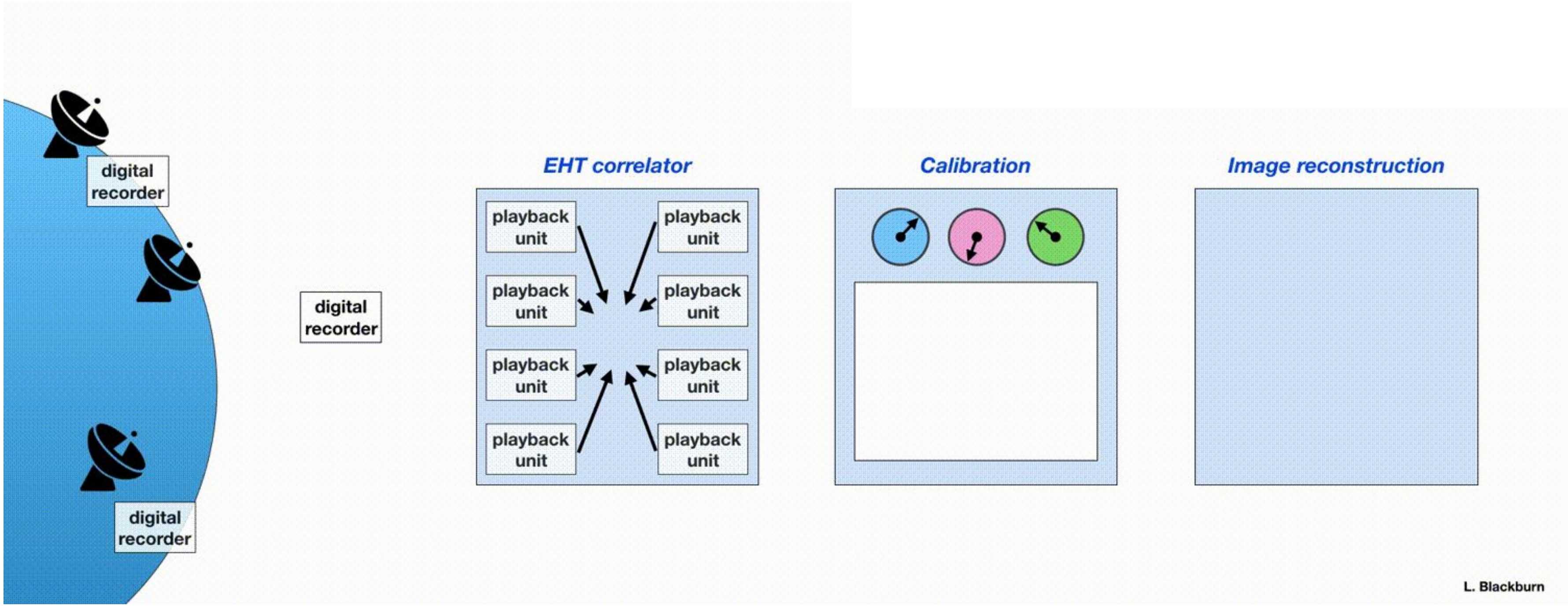
The 2017 EHT array



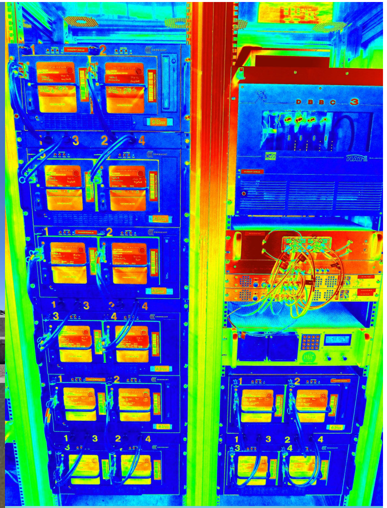
- Global 230 GHz (1.3 mm) array
- ~25 μas resolution
- Largest 1 mm VLBI experiment
- April 5 -11 2017 observations, triggered 5 nights, 4xM87
- ~4 PB raw data
- EHT Collaboration et al. 2019, ApJL, 875, L2 (Paper II)

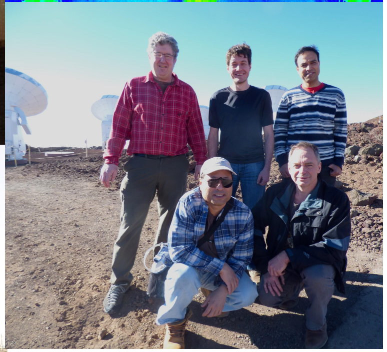
Credit: Nan Jenney, NRAO

The data path

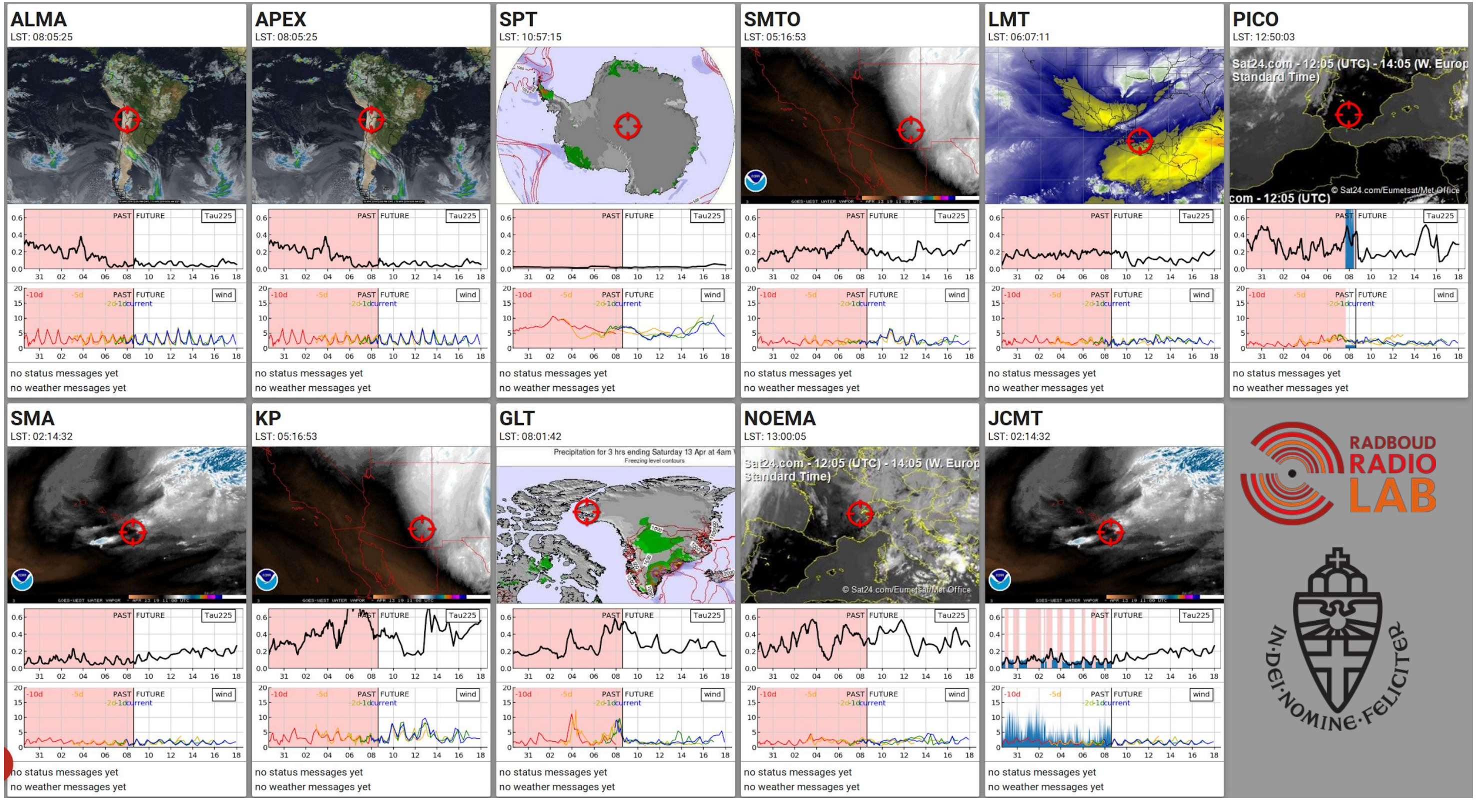


The 2017 observations





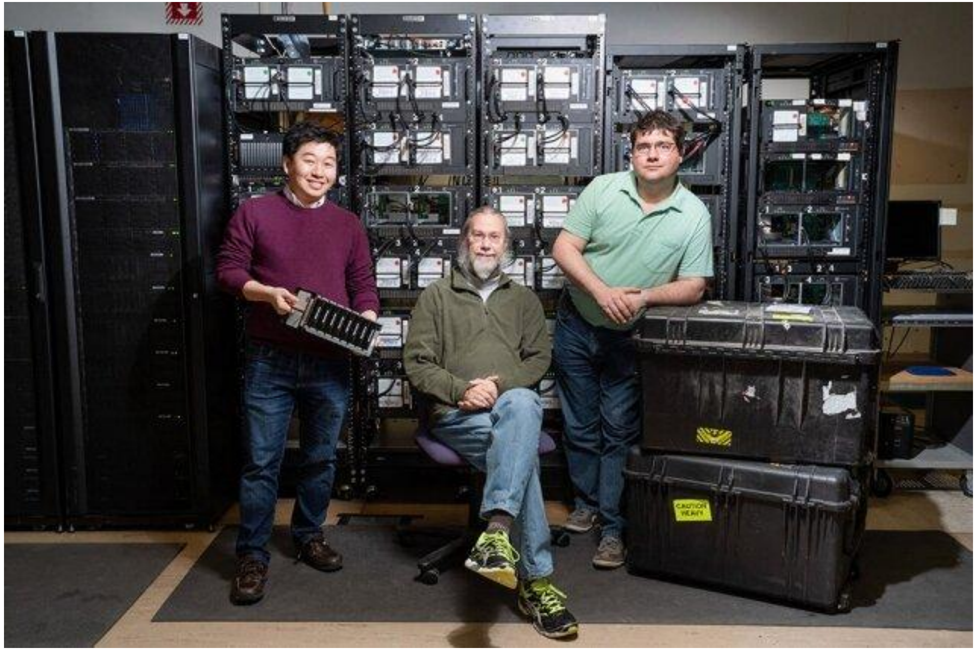
Observation coordination: VLBI monitor



Weather prediction with dutch meteorological model (KNMI).

Data correlation

Westford, MA, USA (MIT Haystack Observatory)



Credit: Bryce Vickmark

Bonn, Germany (Max Planck Institute for Radioastronomy)

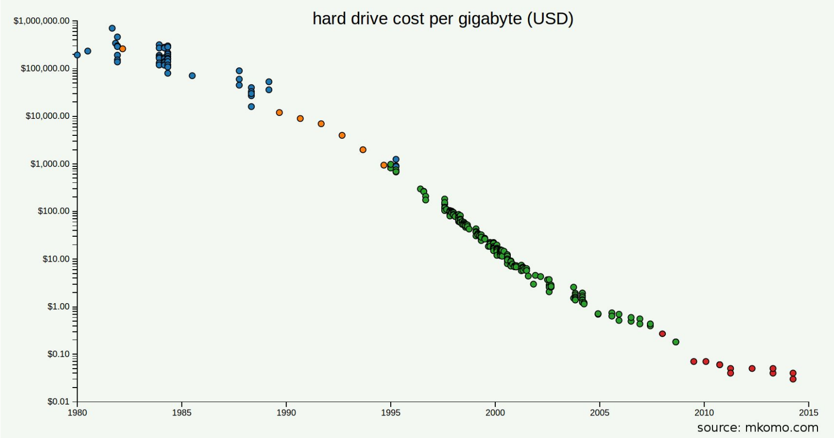
Credit: Arno Müskens

Prerequisite developments

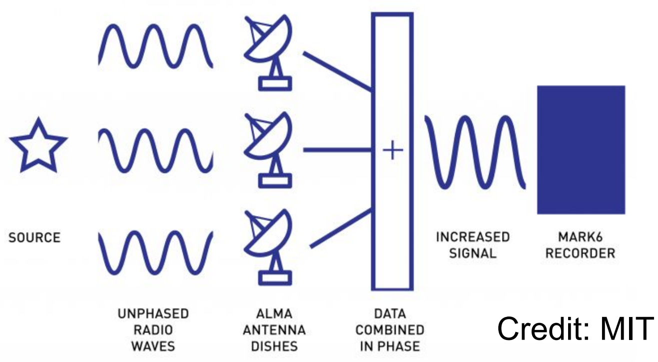
<u>Quest for sensitivity</u>

- Moore's law: High bandwidth recording
  - 2017: 32Gigabits/sec
    → 4 PB
  - Current: 64 Gigabits/sec

- Phased ALMA
  - Highly sensitive central station
  - Matthews et al. 2018, PASP, 130, 015002



Source: http://www.mkomo.com



Credit: MIT Haystack Observatory

Other sources

- **Sgr A***

- **AGN** (non-horizon scale science, probe jet launching region)
  - Jet science (BP vs BZ launching, jet collimation, Poynting zone, rotation measure, spectral index, outburst-ejection relations during flares)

  - 2017 & 2018 proposals:
    - 3C279, Krichbaum & Lobanov
    - 3C273, Savolainen
    - OJ287, Gómez
    - Centaurus A, Janssen, Ros, Kadler
    - Mrk 501, Koyama
    - Cygnus A, Kino
    - 1055+018, Ros & Alberdi
    - 1022+216, Ros & Kadler
    - 1510-089, MacDonald