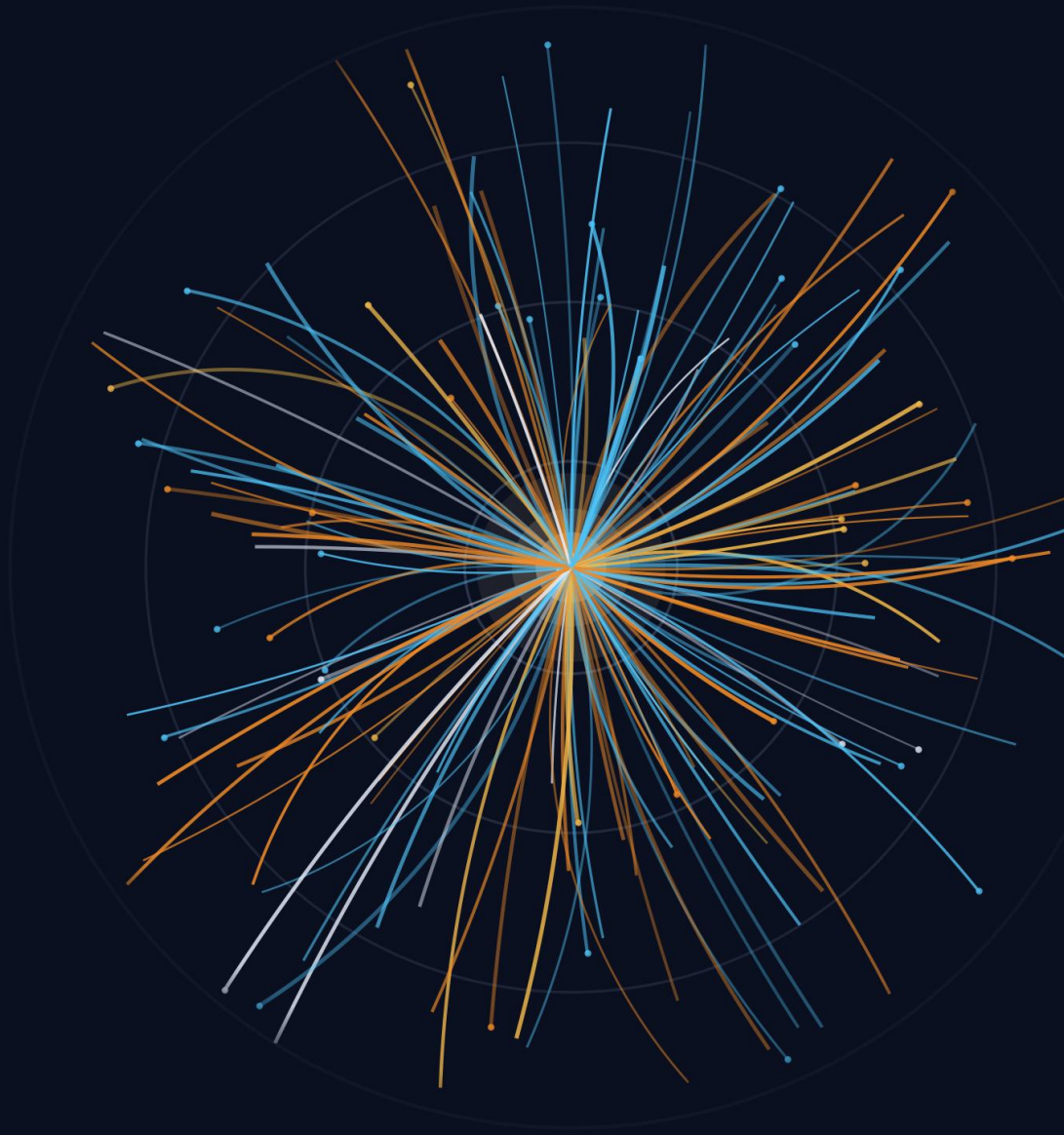
ACADEMIA EUROPAEA · NEW MEMBERS' CEREMONY 2026

Mapping the Space-Time Structure of the Little Bang

Hydrodynamics and femtoscopy of the quark-gluon plasma



Máté Csanád

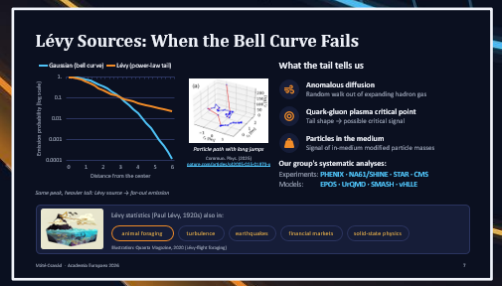
Eötvös Loránd University, Budapest

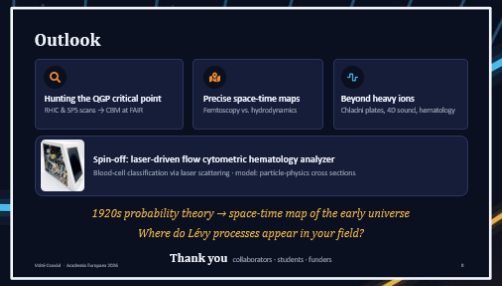
Space-time history

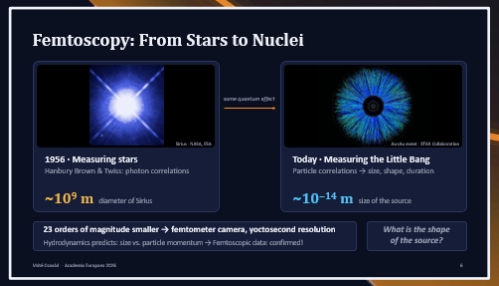
- Collision: Little Bang
- Perfect fluid → expansion
- Hadronization: quarks → hadrons
- Freeze-out → detectors

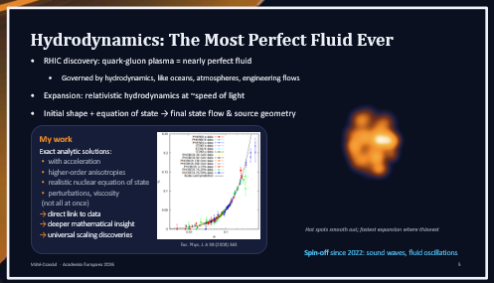
time

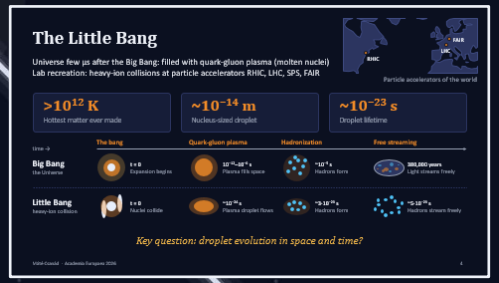
space

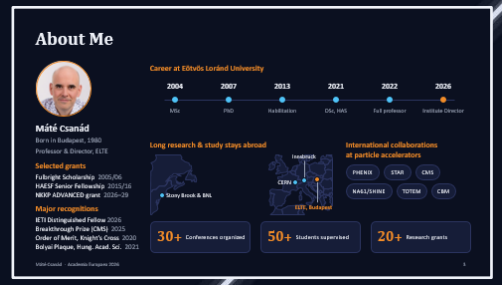












About Me

Máté Csanád

Born in Budapest, 1980

Professor & Director, ELTE

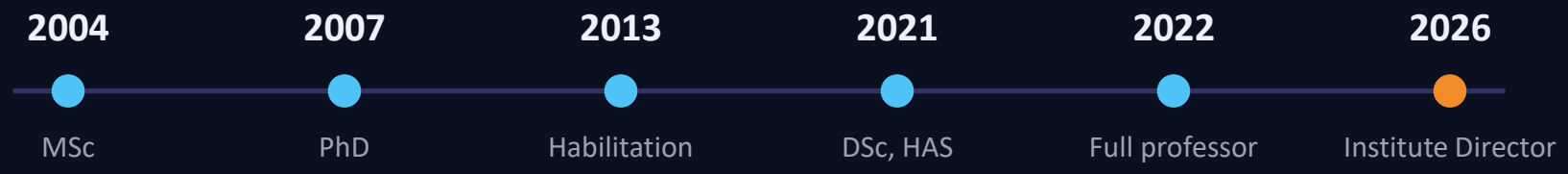
Selected grants

Fulbright Scholarship 2005/06
HAESF Senior Fellowship 2015/16
NKKP ADVANCED grant 2026–29

Major recognitions

IETI Distinguished Fellow 2026
Breakthrough Prize (CMS) 2025
Order of Merit, Knight's Cross 2020
Bolyai Plaque, Hung. Acad. Sci. 2021

Career at Eötvös Loránd University



Long research & study stays abroad

International collaborations at particle accelerators

PHENIX · STAR · CMS · NA61/SHINE · TOTEM · CBM

30+ Conferences organized

50+ Students supervised

20+ Research grants

The Little Bang

Universe few μs after the Big Bang: filled with quark-gluon plasma (molten nuclei)
Lab recreation: heavy-ion collisions at particle accelerators RHIC, LHC, SPS, FAIR

Particle accelerators of the world

$>10^{12}$ K
Hottest matter ever made

$\sim10^{-14}$ m
Nucleus-sized droplet

$\sim10^{-23}$ s
Droplet lifetime

time →

	The bang	Quark-gluon plasma	Hadronization	Free streaming
Big Bang the Universe	**t = 0** Expansion begins	**10^{-12}–10^{-6} s** Plasma fills space	**$\sim10^{-5}$ s** Hadrons form	**380,000 years** Light streams freely
Little Bang heavy-ion collision	**t = 0** Nuclei collide	**$\sim10^{-24}$ s** Plasma droplet flows	**$\sim3\cdot10^{-23}$ s** Hadrons form	**$\sim5\cdot10^{-23}$ s** Hadrons stream freely

Key question: droplet evolution in space and time?

Hydrodynamics: The Most Perfect Fluid Ever

- RHIC discovery: quark-gluon plasma = nearly perfect fluid
  - Governed by hydrodynamics, like oceans, atmospheres, engineering flows
- Expansion: relativistic hydrodynamics at ~speed of light
- Initial shape + equation of state → final state flow & source geometry

My work

Exact analytic solutions:

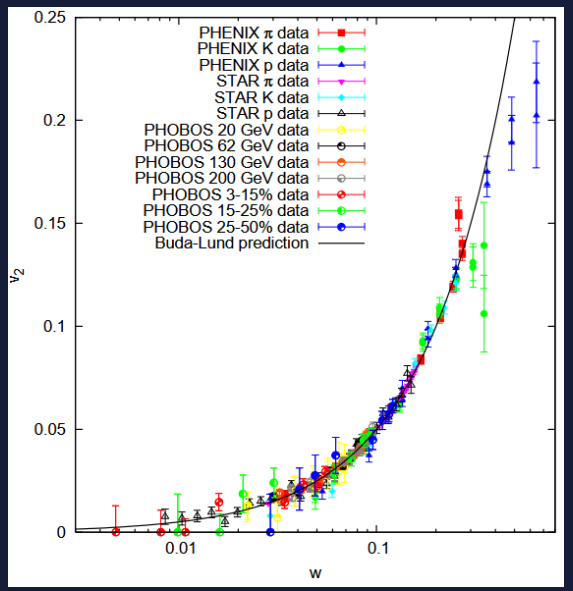
- with acceleration
- higher-order anisotropies
- realistic nuclear equation of state
- perturbations, viscosity

(not all at once)

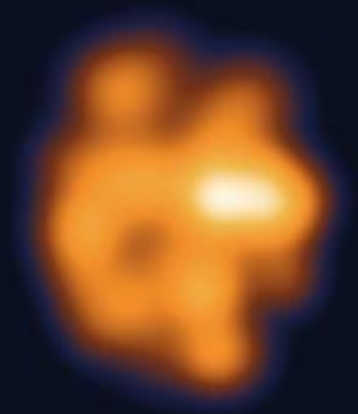
→ direct link to data

→ deeper mathematical insight

→ universal scaling discoveries



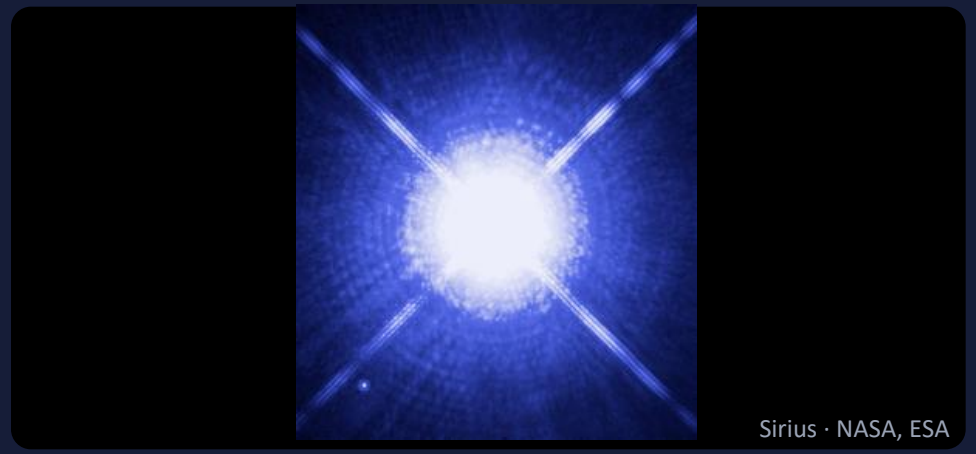
Eur. Phys. J. A 38 (2008) 363



Hot spots smooth out; fastest expansion where thinnest

Spin-off since 2022: sound waves, fluid oscillations

Femtoscopy: From Stars to Nuclei



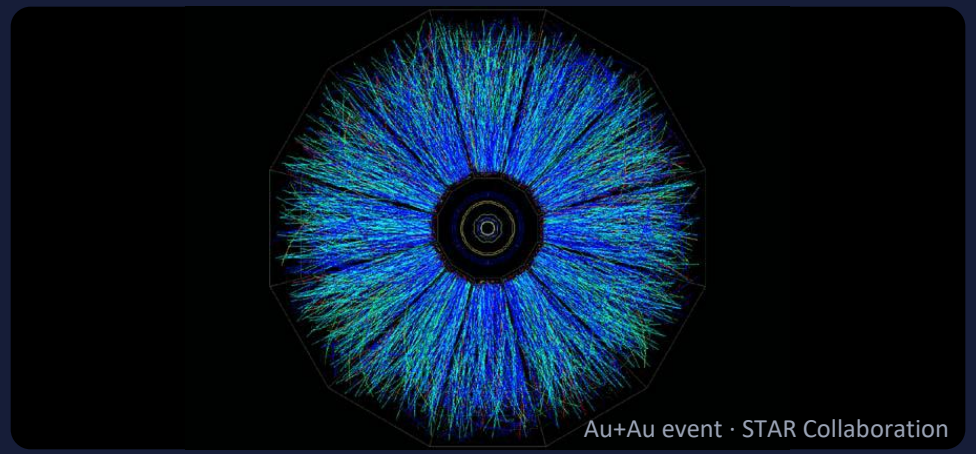
Sirius · NASA, ESA

1956 · Measuring stars

Hanbury Brown & Twiss: photon correlations

$\sim 10^{9}$ m diameter of Sirius

same quantum effect



Au+Au event · STAR Collaboration

Today · Measuring the Little Bang

Particle correlations → size, shape, duration

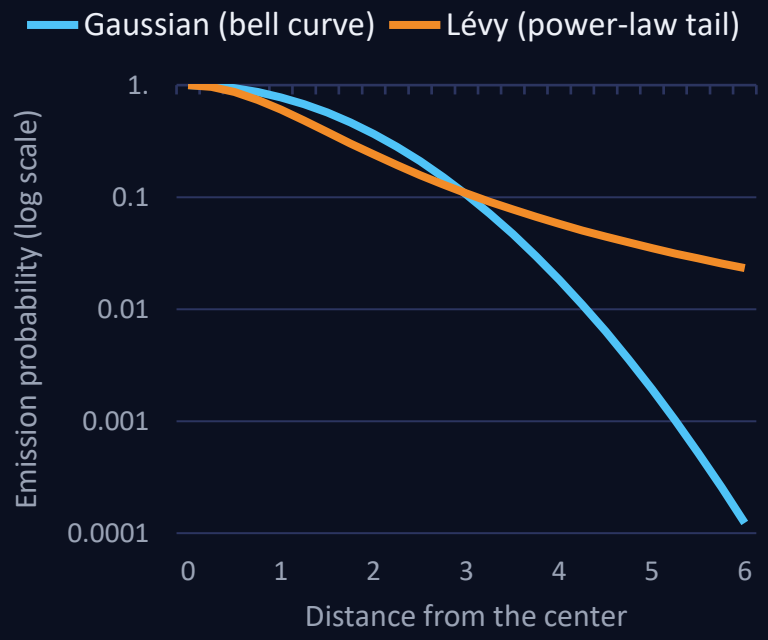
$\sim 10^{-14}$ m size of the source

23 orders of magnitude smaller → femtometer camera, yoctosecond resolution

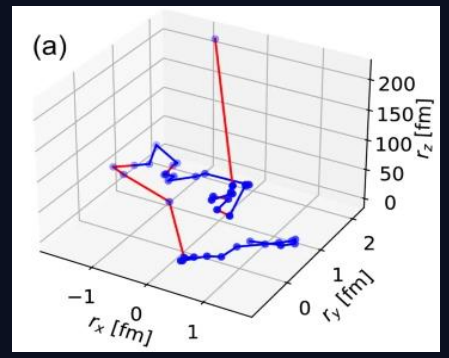
Hydrodynamics predicts: size vs. particle momentum → Femtoscopic data: confirmed!

What is the shape of the source?

Lévy Sources: When the Bell Curve Fails



Same peak, heavier tail: Lévy source → far-out emission



Particle path with long jumps

Commun. Phys. (2025)
nature.com/articles/s42005-025-01973-x

What the tail tells us

Anomalous diffusion
Random walk out of expanding hadron gas

Quark-gluon plasma critical point
Tail shape → possible critical signal

Particles in the medium
Signal of in-medium modified particle masses

Our group's systematic analyses:

Experiments: **PHENIX · NA61/SHINE · STAR · CMS**

Models: **EPOS · UrQMD · SMASH · vHLLE**

Lévy statistics (Paul Lévy, 1920s) also in:

animal foraging · turbulence · earthquakes · financial markets · solid-state physics

Illustration: Quanta Magazine, 2020 (Lévy-flight foraging)

Outlook

Hunting the QGP critical point
RHIC & SPS scans → CBM at FAIR

Precise space-time maps
Femtoscopy vs. hydrodynamics

Beyond heavy ions
Chladni plates, 4D sound, hematology

Spin-off: laser-driven flow cytometric hematology analyzer
Blood-cell classification via laser scattering · model: particle-physics cross sections

1920s probability theory → space-time map of the early universe

Where do Lévy processes appear in your field?

Thank you collaborators · students · funders