

Can we detect eclipses of galactic nuclei and what are they useful for?

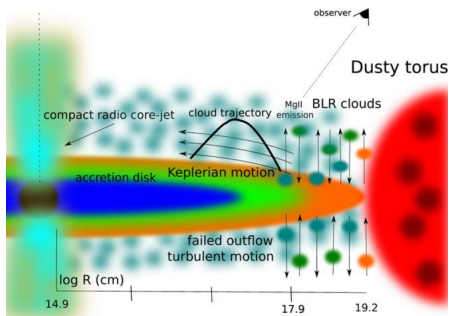
Michal Zajaček (Masaryk University)

TATRA ASTRO SUMMIT – *Astronomical Institute, Slovak Academy of Sciences*

September 24, 2025

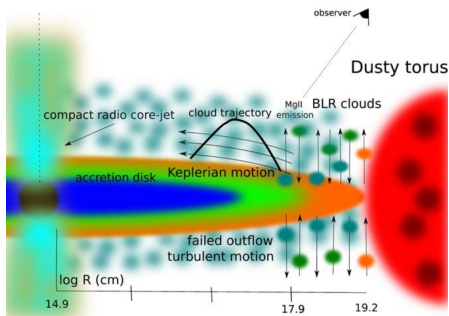
Transits in AGN: analogous to exoplanets

- Are they observed?



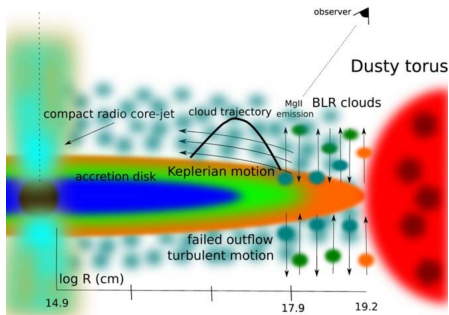
Transits in AGN: analogous to exoplanets

- Are they observed?
- Yes, so far mostly in the X-ray domain: asymmetric eclipses of the compact X-ray emission region due to passages of comet-shaped broad-line region (BLR) clouds

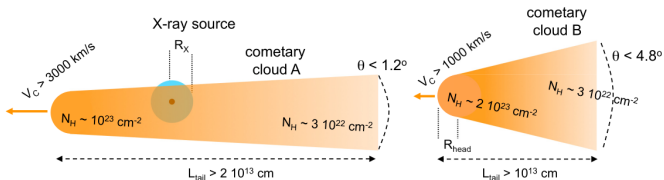
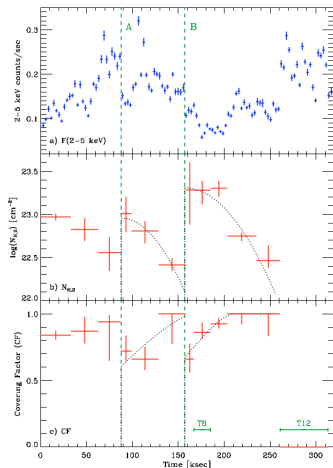


Transits in AGN: analogous to exoplanets

- Are they observed?
- Yes, so far mostly in the X-ray domain: asymmetric eclipses of the compact X-ray emission region due to passages of comet-shaped broad-line region (BLR) clouds
- Geometrically limited because the BLR clouds form a flattened structure surrounding the accretion disc at a distance of several 1000 gravitational radii from the SMBH



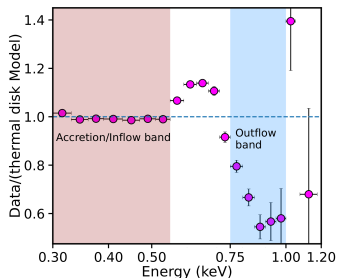
Broad-line region cloud transits



Maiolino et al. (2010): indication of the cometary geometry of clouds for NGC1365; transits lasting a few hours to days coincident with the BLR location

Detection of periodic absorption in ASASSN-20qc

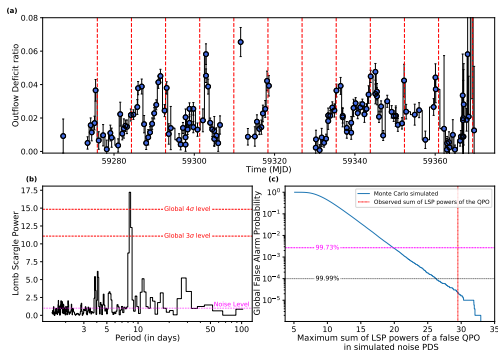
- absorption at energies 0.75 – 1 keV in the X-ray domain due to recurrent, periodic ultrafast nuclear outflow
- plausibly launched by an orbiting heavier companion: intermediate-mass black hole (IMBH)



See **Pasham et al., 2024**

Detection of periodic absorption in ASASSN-20qc

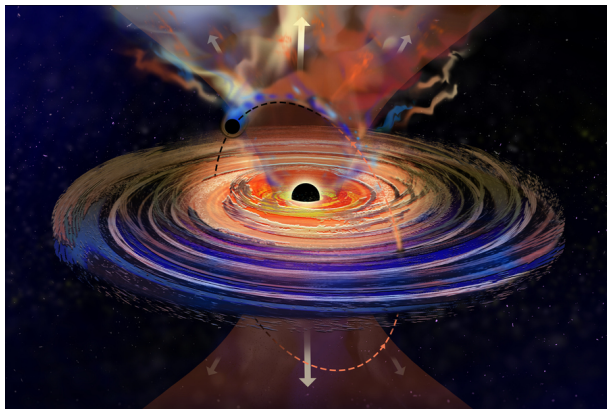
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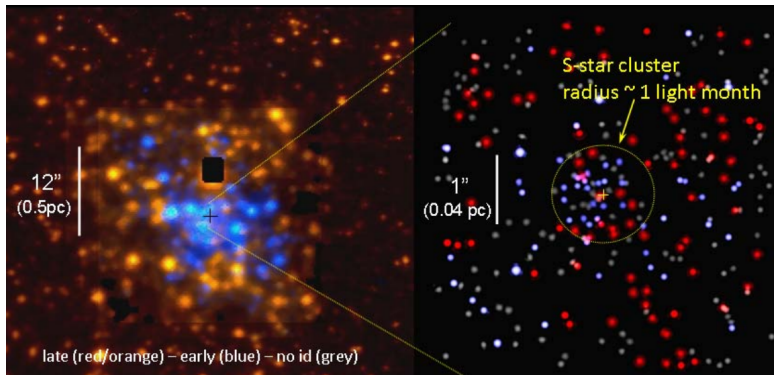
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Stellar transits in AGN

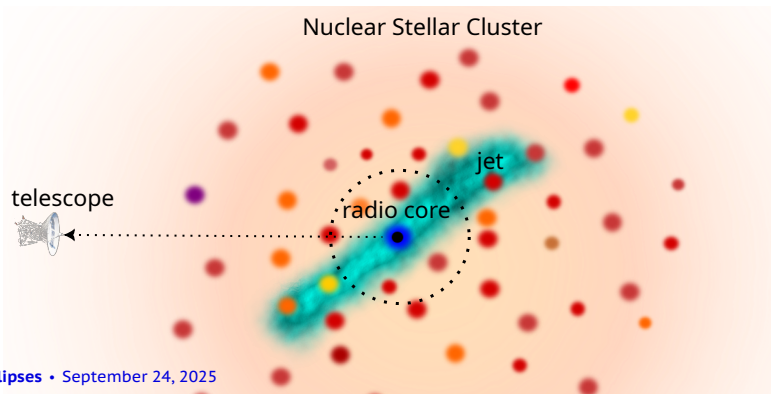
- SMBH typically surrounded by dense nuclear star clusters (NSCs)
- dominated by evolved (larger) red giants and supergiants
- the best studied case - the Galactic center



Milky Way Nuclear Star Cluster (Genzel et al. 2010)

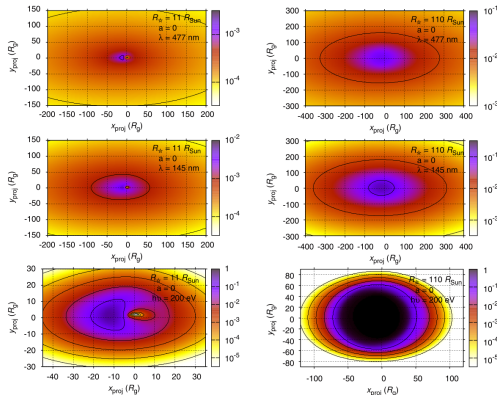
Stellar transits in AGN

- SMBH typically surrounded by dense nuclear star clusters (NSCs)
- transit recurrence and duration depend on the star-SMBH distance in the sphere of influence
- eclipse depth is given by the ratio of angular sizes of the nuclear emission and the stellar body



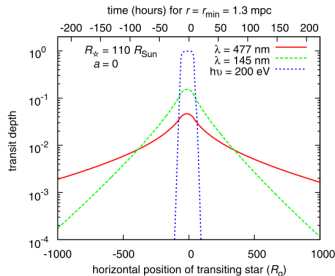
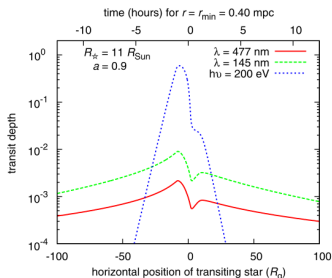
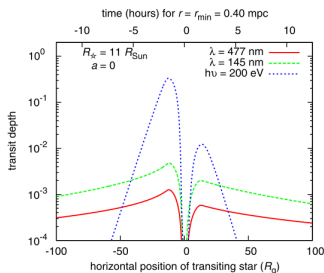
Stellar transits in AGN: X-ray, UV, and optical domain

- discussed and analyzed by Béky and Kocsis (2013)
- transit durations of a few weeks and orbital periods of a few years
- possibility to constrain accretion disk orientation, SMBH mass, and spin



Stellar transits in AGN: X-ray, UV, and optical domain

- based on the light-curve shapes of a stellar transit, it is possible to infer the SMBH spin as well as a stellar type (size)



Calculations of “inverted” transit light curves for AGN Novikov-Thorne disks eclipsed by a star (Béky and Kocsis, 2013)

Transits in AGN: what about radio domain?

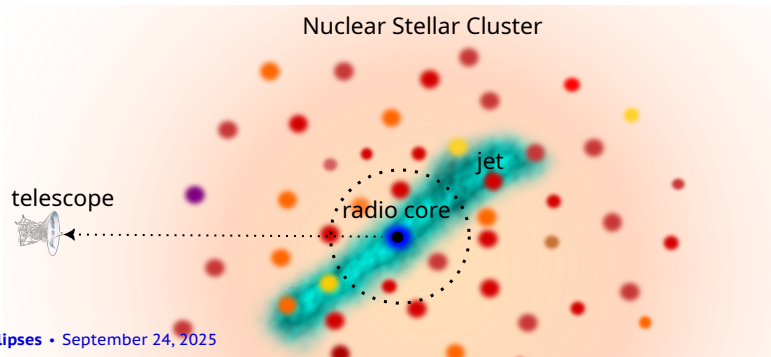
- long-term monitoring of radio-loud AGN
- high resolution at the level of ~ 0.1 mas and better using long-baseline interferometry techniques
- brightest radio components: radio cores with core sizes $\theta \sim 0.1$ mas at $\nu \sim 10$ GHz
- to eclipse the core, one would need obstacles of the size $l \approx \theta D_A \sim 0.18$ pc for the source at $z = 0.1$
- eclipse by foreground molecular clumps (stars too small)
- density requirements inferred from plasma frequency and extreme scattering conditions

$$n_e \geq \frac{4\pi^2 \nu^2 m_e \epsilon_0}{e^2} = 1.23 \times 10^{12} \left(\frac{\nu}{10 \text{ GHz}} \right)^2 \text{ cm}^{-3}. \quad (1)$$

$$\theta_{\text{ESE}} \approx \frac{r_e c^2}{2\pi \nu_{\text{GHz}}^2} \frac{\Delta n_e}{L} l_{\text{obs}} \approx 16 \left(\frac{\nu_{\text{GHz}}}{5 \text{ GHz}} \right)^{-2} \left(\frac{\Delta n_e}{10^3 \text{ cm}^{-3}} \right) \left(\frac{L}{1 \text{ AU}} \right)^{-1} \left(\frac{l_{\text{obs}}}{49 \text{ AU}} \right) \text{ mas}, \quad (2)$$

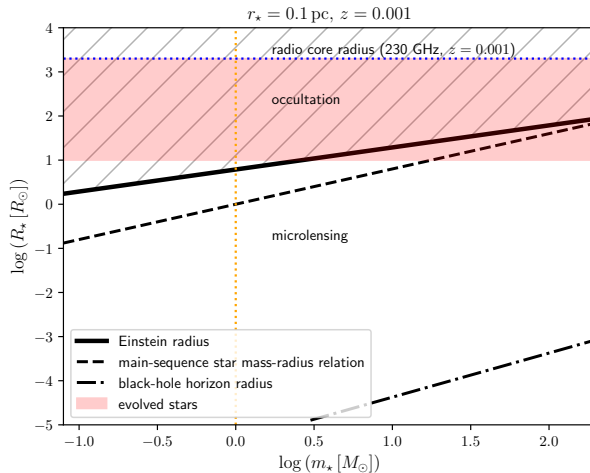
Stellar transits in AGN: what about radio domain?

- stellar transits in the radio domain become plausibly detected when (i) the observing frequency is increased to 100-230 GHz (mm domain) and (ii) the radio-loud source is relatively very close ($z \lesssim 0.001$)
- core-shift effect $\theta \propto \nu^{-1}$
- for $z = 0.001$ and $\nu = 230$ GHz, we obtain $l \sim 4000 R_{\odot}$
- large red supergiants can (partially) eclipse the radio core in the mm domain



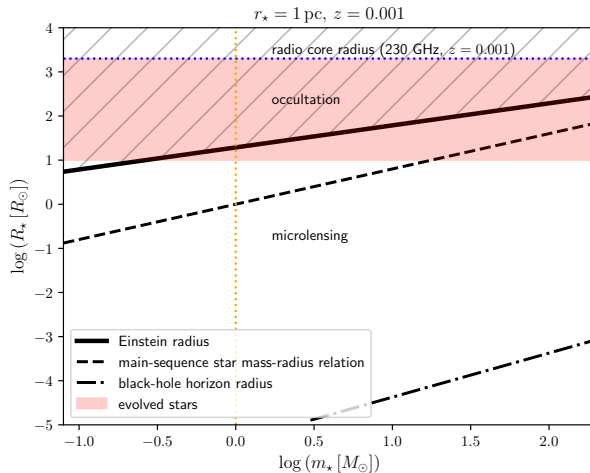
Stellar transits in AGN: what about radio domain?

- star orbiting at $r_{\star} \sim 0.1$ pc

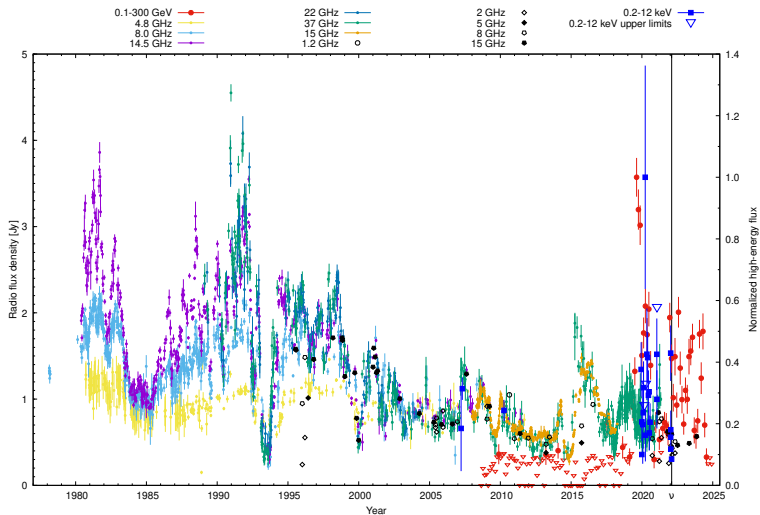


Stellar transits in AGN: what about radio domain?

- star orbiting at $r_{\star} \sim 1$ pc

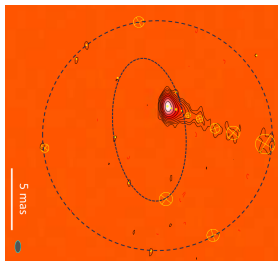


Detections of dips in PKS 1413+135



Detections of dips in PKS 1413+135

- duration $\tau_{\text{dip}} \approx 1$ year and the recurrence timescale of $\tau_{\text{rec}} \sim 5 - 10$ years
- redshift $z \sim 0.5$



- core with the angular size $\theta \sim 1$ mas: obstacle on the scale of ~ 6 pc, **not really a star but rather a denser cloud, circumnuclear clumpy ring(?)**; Britzen et al. (in prep)

Summary and Future prospects

- detecting stars in radio-loud galactic nuclei only possible in the mm domain for nearby sources ($z \lesssim 0.001$), such as Centaurus A
- stars with large cross-sections required ($R \gtrsim 1000 R_{\odot}$): red supergiants, inflated star (collision with the accretion disk and jet), stellar merger products
- To do: calculate mock light curves of eclipses
- To do: calculate likelihood and required cadences for monitoring

IAU Symposium 405 in Brno in 2026

TRAVERSING THE GALACTIC CENTER
IN SPACE AND TIME
BRNO
CZECH REPUBLIC
MAY 18-22 2026

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Invited speakers

LAURA COLZI
MICHAL DOVČIAK
FRANK EISENHÄUER
ANJA FELDMER-KRAUSE
SEBASTIANO VON FELLEBERG
MARIANNA FOSCHI
STEVEN LONGMORE
FREDERIC MARIN
SERGIO MARTIN
ALVARO MARTINEZ-ARRANZ
ALESSANDRA MASTROBUONO BATTISTI
MARK MORRIS
ISABELLA RAIMALA
NILS RYDE
MATTIA CARLO SORMANI
LADISLAV ŠUBR
HIROMASA SUZUKI
RUIZHI YANG
SHUO ZHANG

Opening talks

ANDREA GHEZ
REINHARD GENZEL
NOBEL LAUREATES 2020

SOC

BOŽENA CZERNY
ROLAND CROCKER
ANJA FELDMER-KRAUSE
ANDREA GHEZ
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JONATHAN HENSHAW
IZASKUN JIMÉNEZ SERRA
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Brno Observatory and Planetarium
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IAU Symposium 405

- website:
<https://gc2026.muni.cz>
- dates: May 18-22, 2026
- Venue: Brno Observatory and Planetarium

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IAU Symposium 405

Traversing the Galactic Center in Space and Time

Brno, Czech Republic
May 18-22, 2026

Image: X-ray: NASA/CXC/UMassD. Wang et al. Radio: MPP/SARAJEVO/AT

The Galactic Center (GC) plays a pivotal role in the evolution of the Milky Way. It is instrumental in mapping and understanding the central regions of quiescent galaxies since it is the closest galactic nucleus to us. It serves as a unique test bed for both stellar dynamics in an extremely dense environment as well as magnetohydrodynamics in the vicinity of the supermassive black hole Sagittarius A* (Sgr A*). It is fundamental for studying star formation, because the conditions of its interstellar medium (magnetic fields, temperature, turbulence) are unlike any other place in the Milky Way. Despite many detailed multiwavelength studies of the central regions of our Galaxy, we still have many open questions concerning its history and future evolution.

This symposium will bring together experts working on both observational and theoretical studies of the Galactic Center so that they can "traverse" this exciting region from Sgr A* and the surrounding dense nuclear star cluster to the central molecular zone and back, covering

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