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

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

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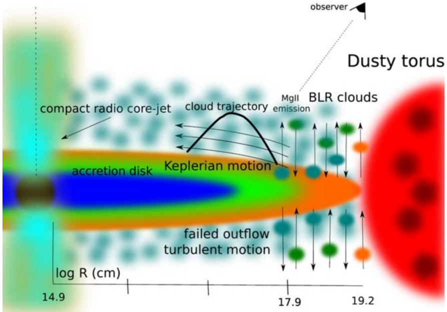
Transits in AGN: analogous to exoplanets

- Are they observed?



Transits in AGN: analogous to exoplanets

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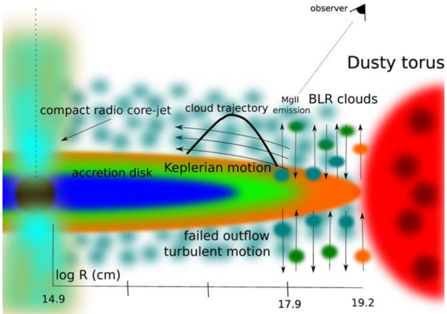

Transits in AGN: analogous to exoplanets

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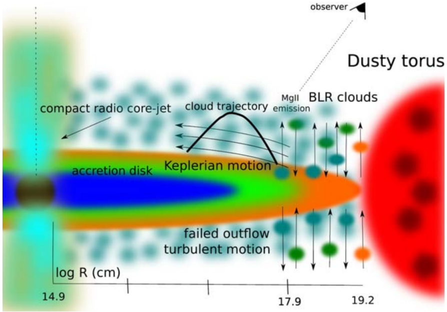
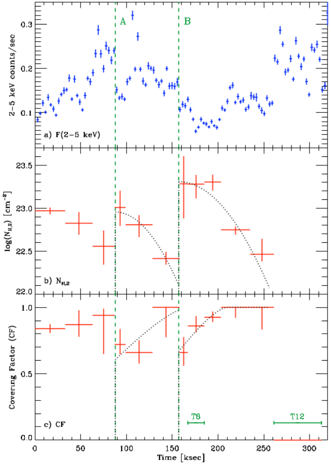
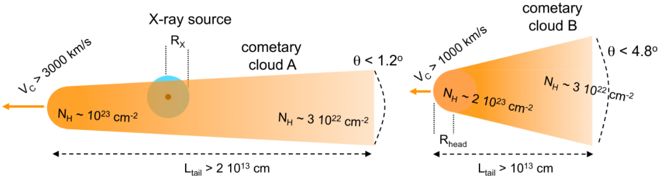
- Yes, so far mostly in the X-ray domain: asymmetric eclipses of the compact X-ray emission region due to passages of comet-shaped broad-line region (BLR) clouds
- Geometrically limited because the BLR clouds form a flattened structure surrounding the accretion disc at a distance of several 1000 gravitational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



Broad-line region cloud transits

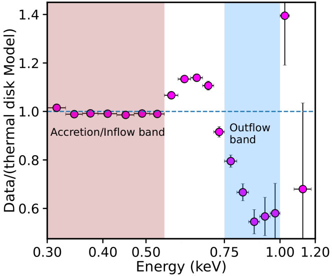




Maiolino et al. (2010): indication of the cometary geometry of clouds for NGC1365; transits lasting a few hours to days coincident with the BLR location

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**

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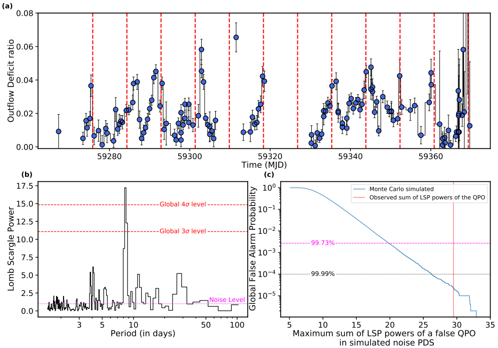

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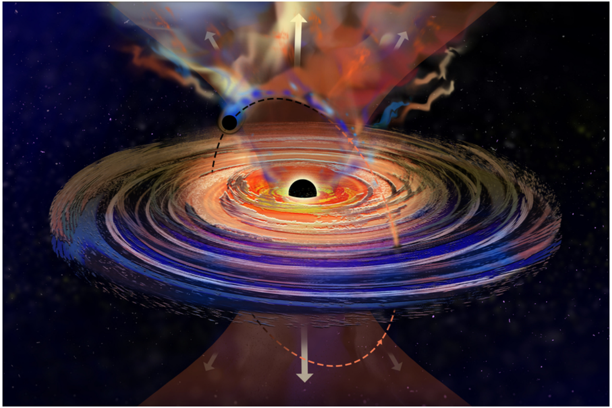

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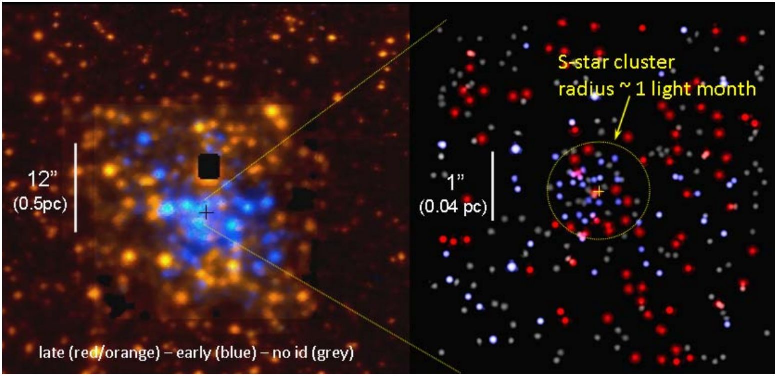
Stellar transits in AGN

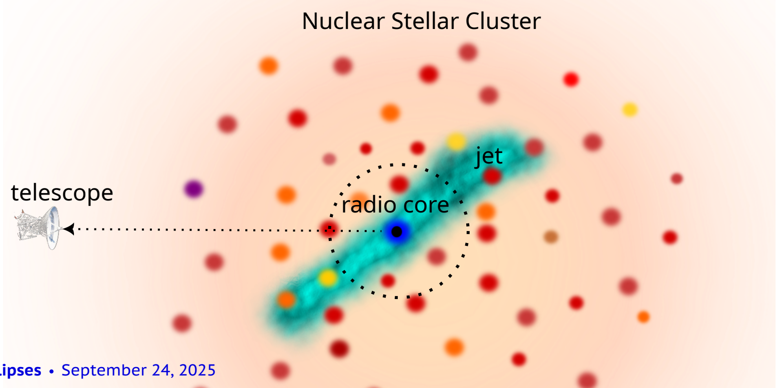
- SMBH typically surrounded by dense nuclear star clusters (NSCs)
- dominated by evolved (larger) red giants and supergiants
- the best studied case - the Galactic center



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

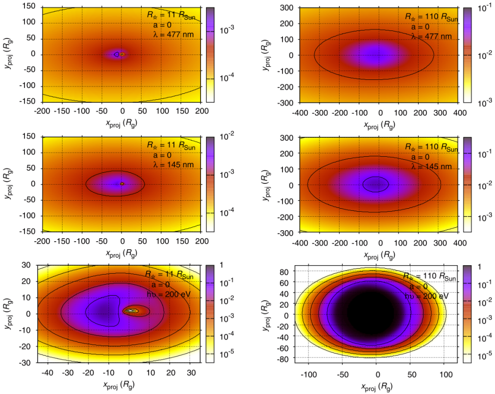
Stellar transits in AGN

- 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



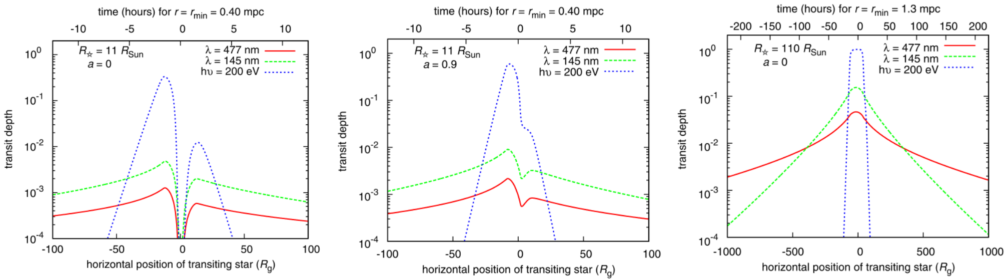
Stellar transits in AGN: X-ray, UV, and optical domain

- discussed and analyzed by Béky and Kocsis (2013)
- transit durations of a few weeks and orbital periods of a few years
- possibiltity 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?

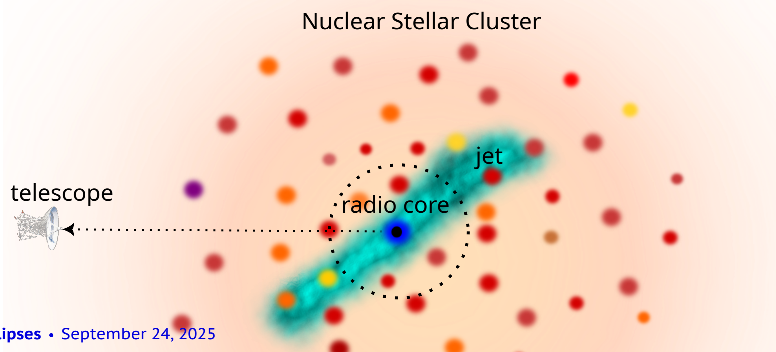
- long-term monitoring of radio-loud AGN
- high resolution at the level of $\sim 0.1\,\mathrm{mas}$ and better using long-baseline interferometry techniques
- brightest radio components: radio cores with core sizes $\theta \sim 0.1\,\mathrm{mas}$ at $\nu \sim 10\,\mathrm{GHz}$
- to eclipse the core, one would need obstacles of the size $l \approx \theta D_{\mathrm{A}} \sim 0.18\,\mathrm{pc}$ 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

$$n_{\mathrm{e}} \geq \frac{4\pi^2\nu^2 m_{\mathrm{e}}\epsilon_0}{e^2} = 1.23 \times 10^{12} \left(\frac{\nu}{10\,\mathrm{GHz}}\right)^2 \mathrm{cm}^{-3}\,. \tag{1}$$

$$\theta_{\mathrm{ESE}} \approx \frac{r_{\mathrm{e}}c^2}{2\pi\nu_{\mathrm{GHz}}^2}\frac{\Delta n_{\mathrm{e}}}{L} l_{\mathrm{obs}} \approx 16 \left(\frac{\nu_{\mathrm{GHz}}}{5\,\mathrm{GHz}}\right)^{-2} \left(\frac{\Delta n_{\mathrm{e}}}{10^3\,\mathrm{cm}^{-3}}\right) \left(\frac{L}{1\,\mathrm{AU}}\right)^{-1} \left(\frac{l_{\mathrm{obs}}}{49\,\mathrm{AU}}\right) \mathrm{mas}\,, \tag{2}$$

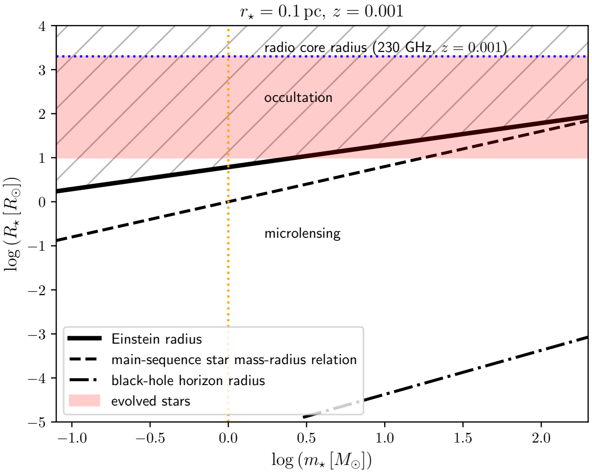
Stellar transits in AGN: what about radio domain?

- 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 $\nu = 230\,\mathrm{GHz}$, we obtain $l \sim 4000\,R_{\odot}$
- large red supergiants can (partially) eclipse the radio core in the mm domain



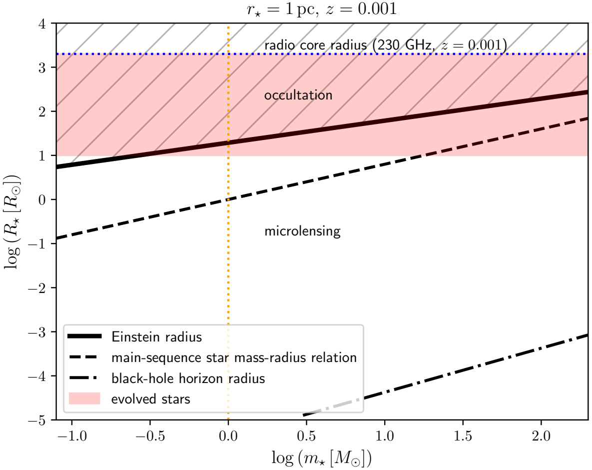
Stellar transits in AGN: what about radio domain?

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

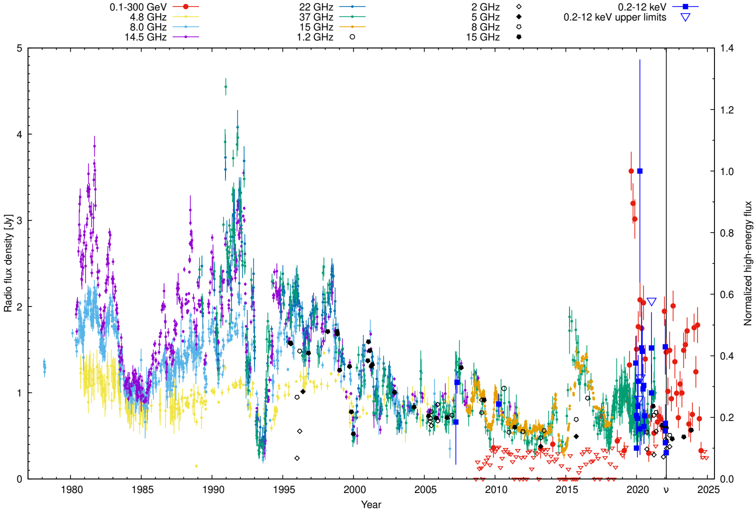


Stellar transits in AGN: what about radio domain?

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

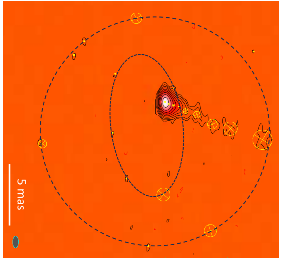


Detections of dips in PKS 1413+135



Detections of dips in PKS 1413+135

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



- core with the angular size $\theta \sim 1$ mas: obstacle on the scale of $\sim 6\,{\rm pc}$, **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

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

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