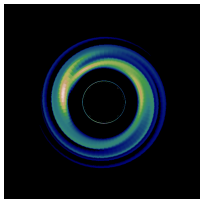


Studying the environment of Sagittarius A* with radiation flares

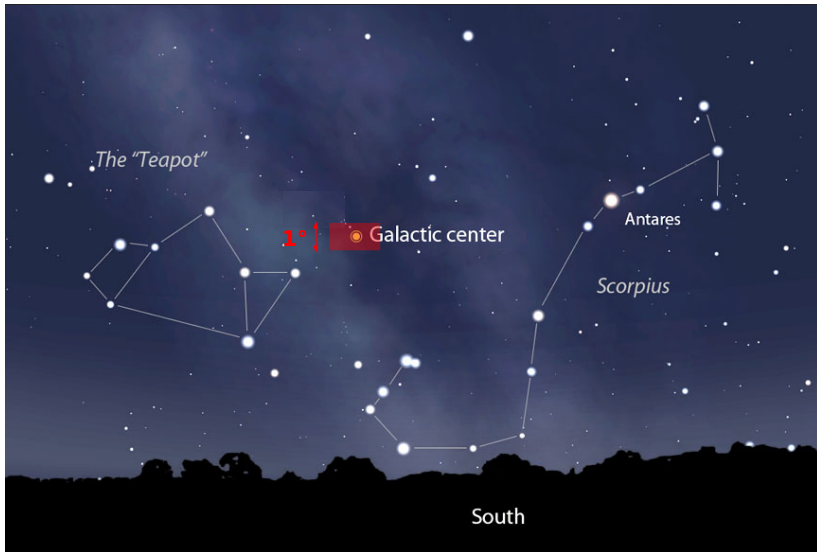
Frédéric Vincent¹

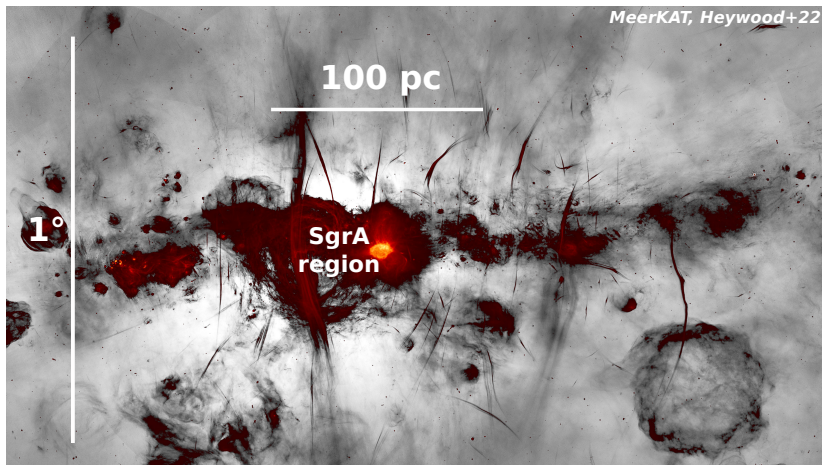
N. Aimar, A. Dmytriiev, M. Wielgus, I. El Mellah,
T. Paumard, G. Perrin, E. Gourgoulhon, A. Zech
[+ discussions with many others]

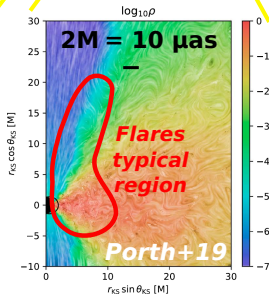
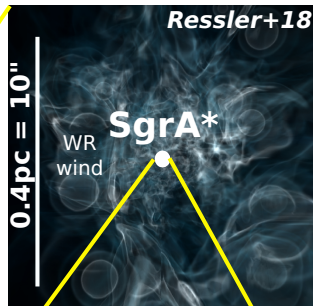
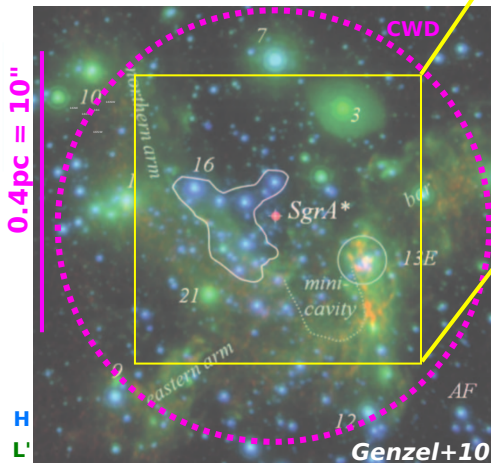
¹CNRS/Observatoire de Paris/LESIA



- 1 Context and definitions
- 2 Recent flare observations by GRAVITY and ALMA
- 3 Simulating flares







$M = GM/c^2 = \text{gravitational radius}$



Angular scale of the problem

- 10s of μas
- Grapefruit on the Moon...

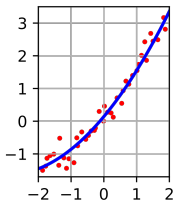
1. Observation



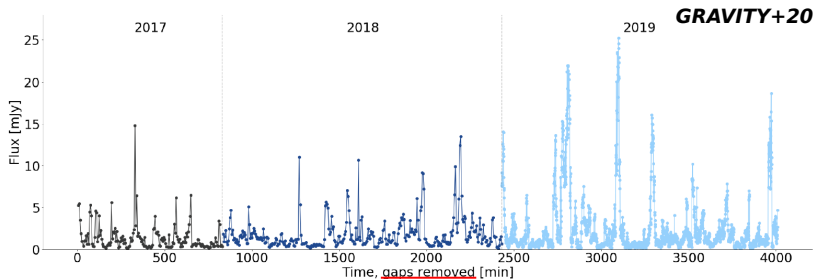
3. Plasma physics



2. Model fitting

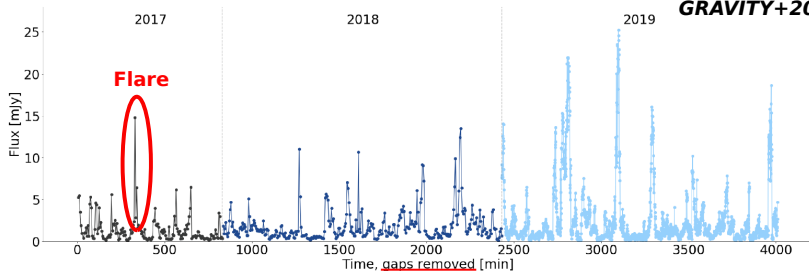


A tentative triple definition of flares



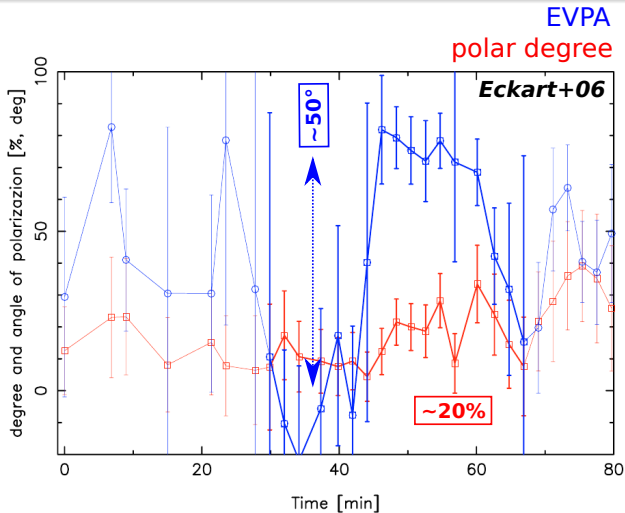
Observations

- Flare = **transient peaks** of flux on daily basis (4/day in IR)
- mm, IR (my personal bias), X ...



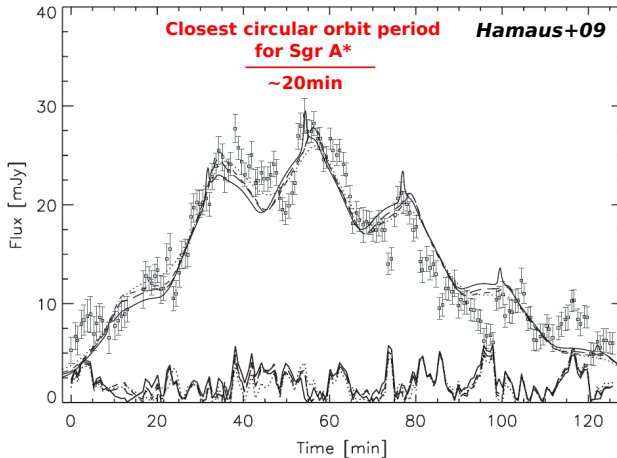
Observations

- Flare = **transient peaks** of flux on daily basis (4/day in IR)
- mm, IR (my personal bias), X ...



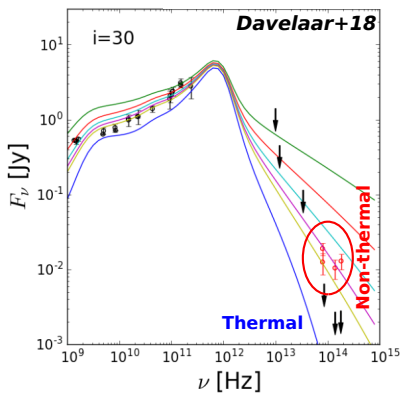
Observations

- ... IR linearly **polarized** (synchrotron) ...



Observations

- ... IR light curve **pseudo period** (at least some events)...
(So likely very close to BH!)



Observations + model

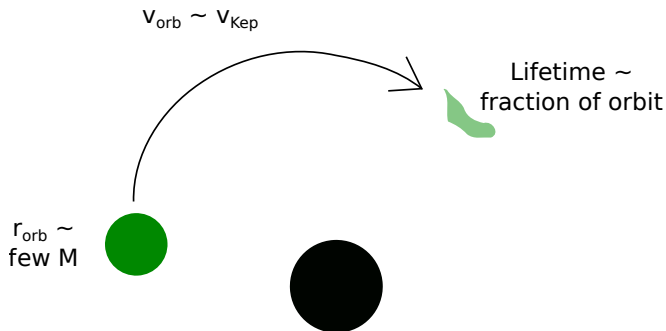
- ... IR flare likely **nonthermal**,
- likely **compact** (Gillessen+06)

1. Observational definition: **flare**

- Transient peaks of flux density
- polarized
- pseudo-periodic (at least some)

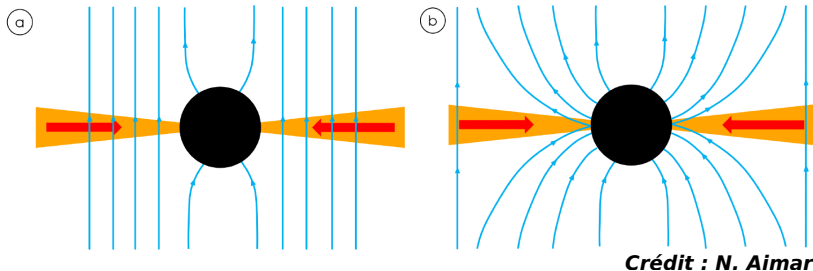
- nonthermal
- compact

≈ A hot “spot” of orbiting plasma!



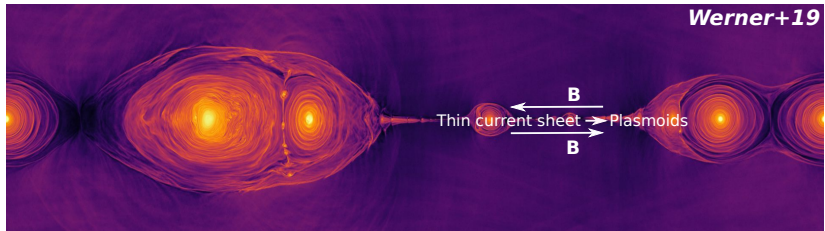
2. Modeling definition: **hotspot**

- Transient, compact, magnetized parcels of energized plasma, orbiting/ejected close to BH



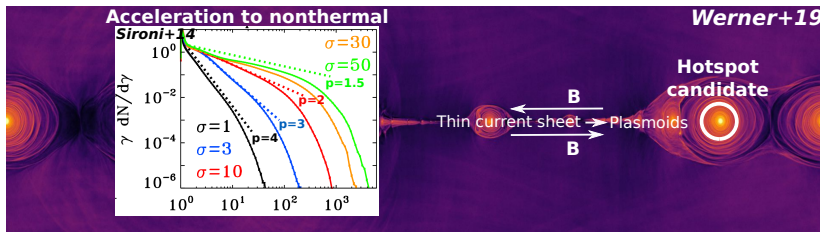
Plasma

- **Magnetically-dominated (MAD):** ordered vertical lines
- Accretion leads to antiparallel Blines
- **Reconnection:** $\vec{B} \rightarrow$ kinetic energy



Plasma

- **Plasmoid**: magnetic loop containing plasma
- Hotspot-like feature if macroscopic
- Accelerated particles to **nonthermal** tail



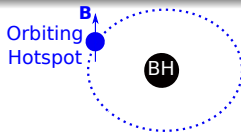
3. Plasma definition: **plasmoid-mediated reconnection**

- A **plausible hotspot** candidate (if survives to macro scale)
- Taps magnetic energy, accelerates particles to nonthermal
- (there are other options!)

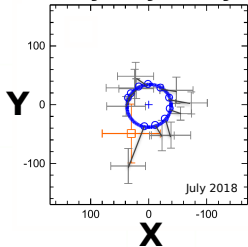
Flare recap

- **Obs:** Transient peaks of polarized nonthermal flux, pseudo-periodic, compact
- **Modeling:** A hotspot-like feature close to BH
- **Plasma:** Plasmoid-mediated reconnection in magnetized flow leads to such features (biased view here)

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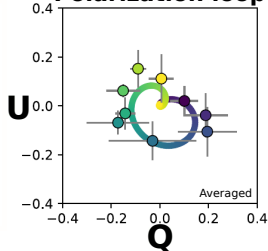
Sky trajectory



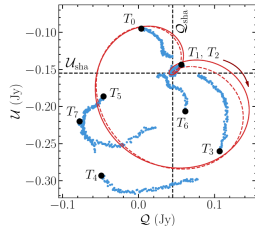
X

GRAVITY Coll. 2018,23

Polarization loop



Q

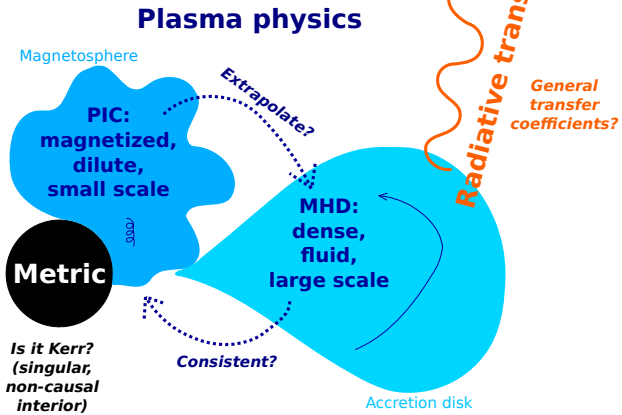


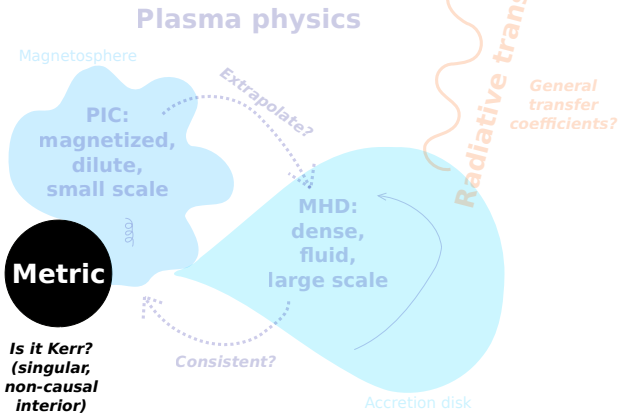
ALMA/Wielgus+22

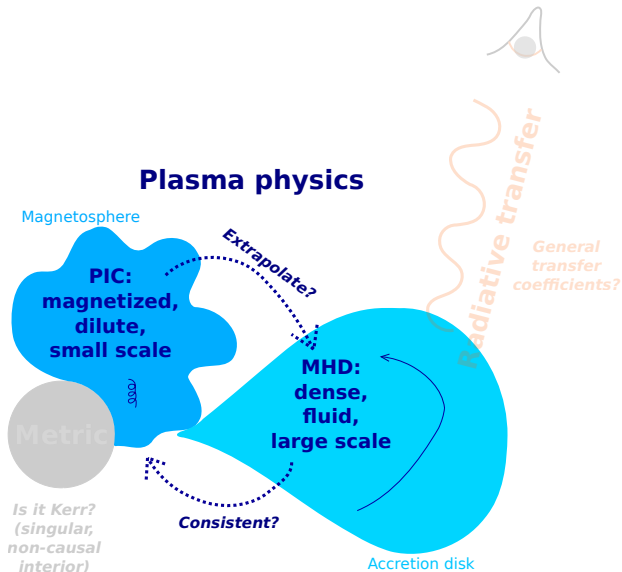
Observed polarized flares

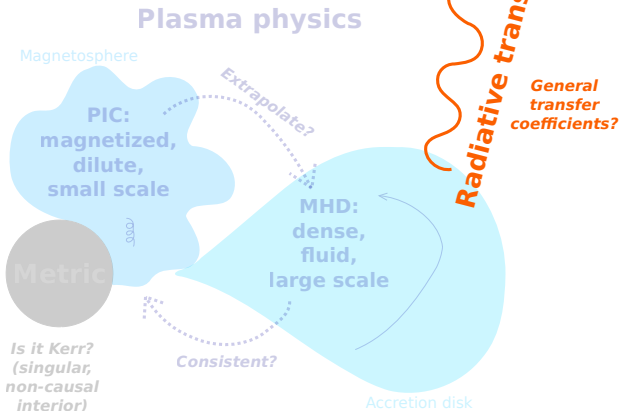
- Orbiting “hotspot”: **close** to BH ($r = 7M$), hint of **super-Keplerian** motion
- Polarization QU loops: vertical B-field, **MAD-like**

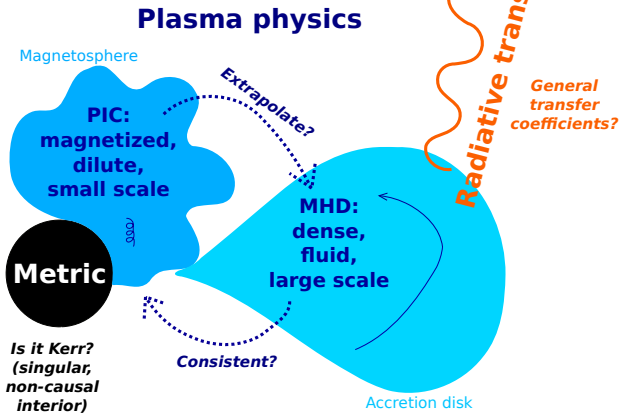
- 1 Context and definitions
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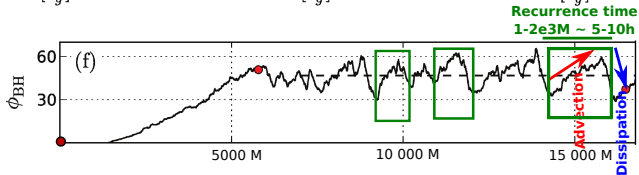
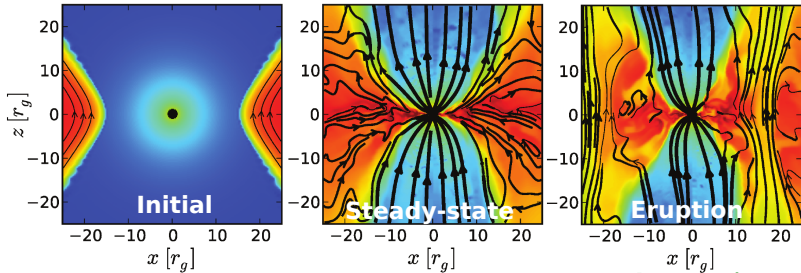








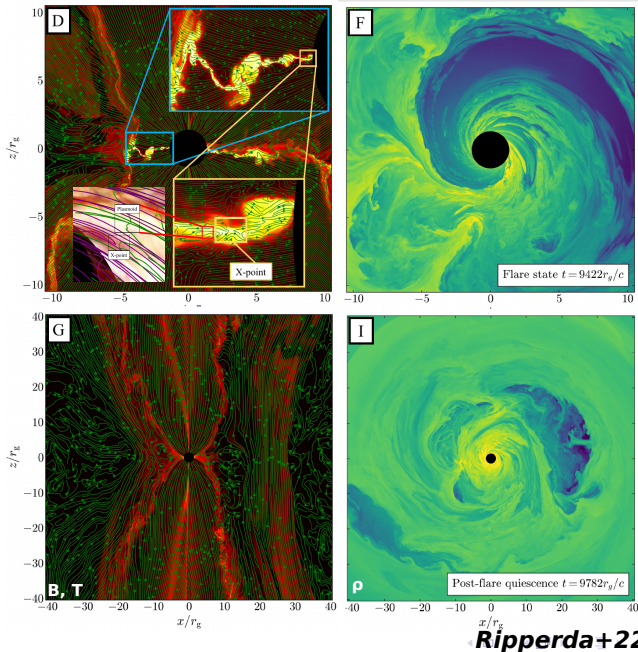


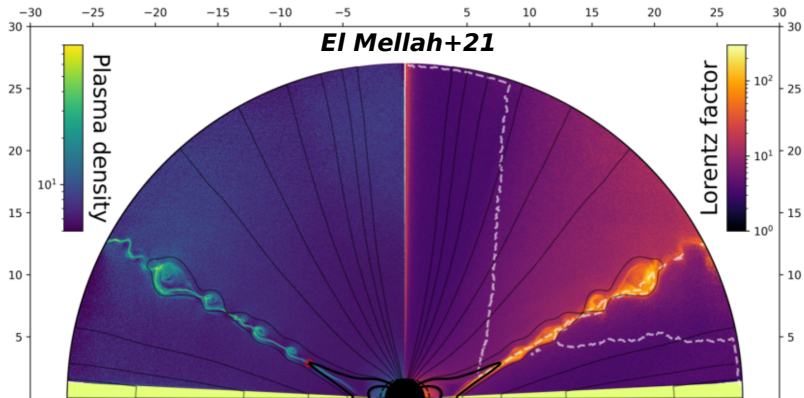


Tchekovskoy+11

MAD state

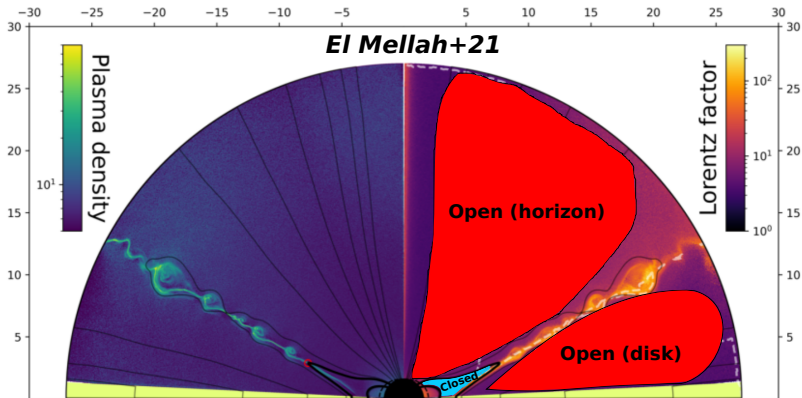
- Quasi-periodic eruptions, orbiting flux tubes
- **Sub-Keplerian** orbit (Porth+21)





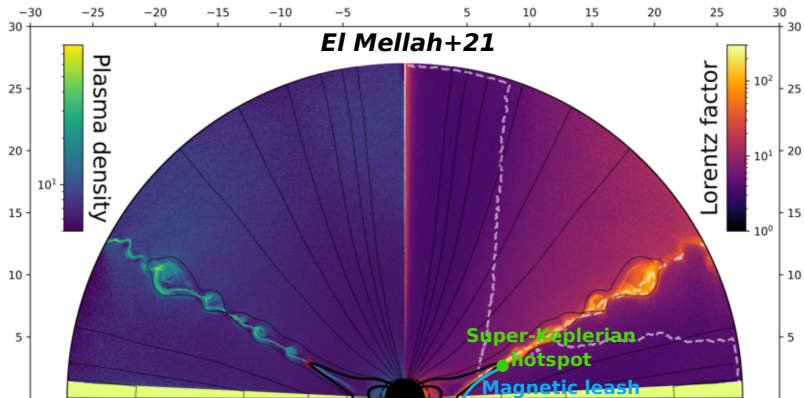
GRPIC reconnection in jet sheath

- Plasmoid creation at Y point
- **“Magnetic leash”** → **super-Keplerian**
- But too fast (few minutes recurrence time)



GRPIC reconnection in jet sheath

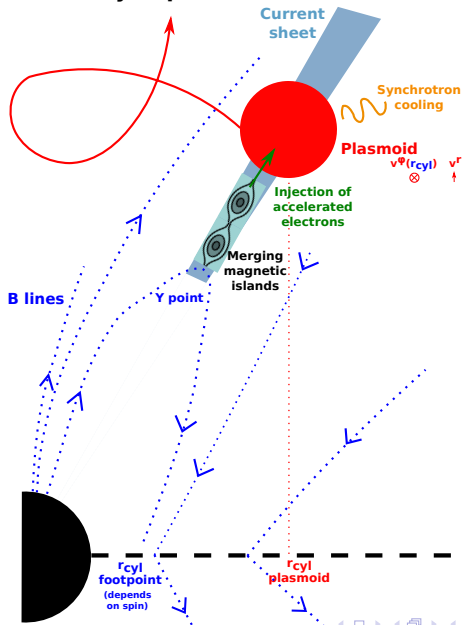
- Plasmoid creation at Y point
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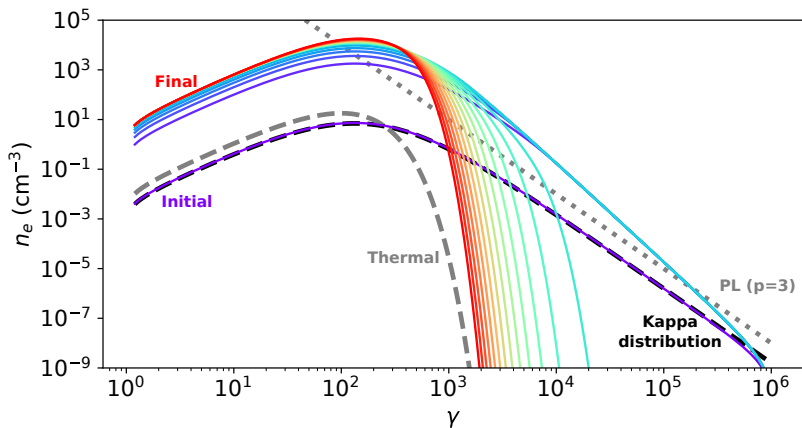


GRPIC reconnection in jet sheath

- Plasmoid creation at Y point
- **“Magnetic leash”** → **super-Keplerian**
- But too fast (few minutes recurrence time)

Semi-analytic plasmoid model



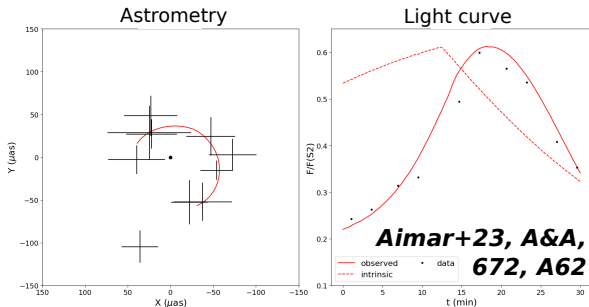


from EMBLEM code, **Dmytriiev+21**

Electron distribution evolution

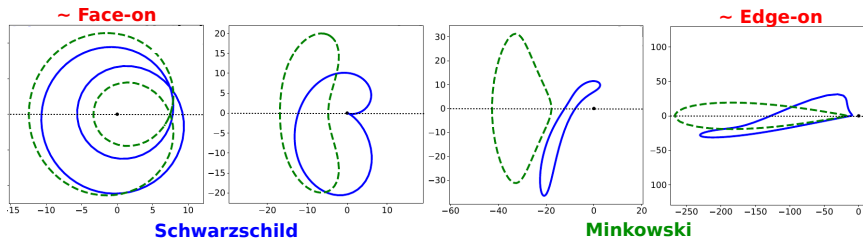
- Certainly wrong to assume it constant

Fit to GRAVITY 2018 flare data



Fitting GRAVITY data

- Consistent with obs constraints
- But need to assume a slower recurrence time



Polarization loops and curvature probing

- Flat-spacetime: **mirror symmetry**
- Curved spacetime: **asymmetric loop** (from light bending)
- *Quantifying curvature?*

Conclusion

- What are Sgr A* flares? **We don't know.**
- **Reconnection** exhaust (flux tube, plasmoids) in **strongly magnetized environment close to BH** is a promising candidate

Needed (Obs)

- More excellent quality astrometric IR data (**velocity**)
- **MWL** light curves and QU loops + **spectral index**

Needed (Simu)

- Kinetic **scale separation** problem??
- **PIC/MHD** simu of the full flow :)
- Polarized radiative transfer with proper **non-thermal eDF**