SETTING CONSTRAINTS ON DARK MATTER WITH OJ 287

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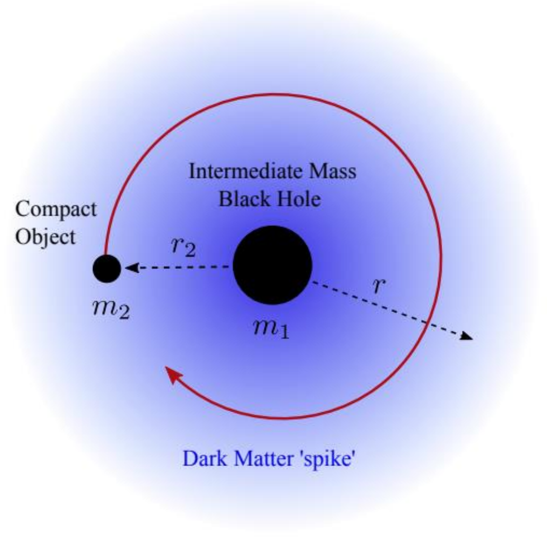
arXiv 2207.10021 Malcolm Fairbairn
(with John Ellis and **Ahmad Alackhar**)

DARK MATTER AROUND BLACK HOLES

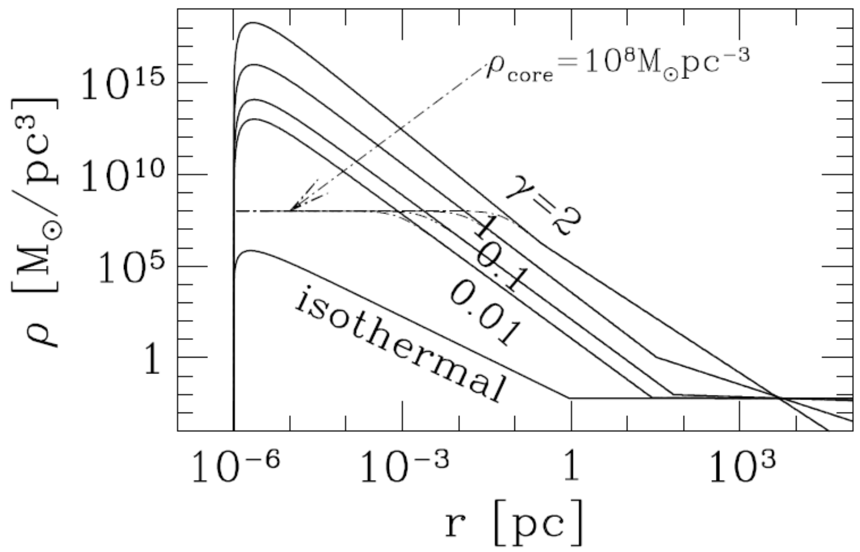
- DM overdensity around a BH may significantly alter the dynamics of BH's merger with another compact object
- The strong gravitational potential of a BH is theorised to lead to a significant increase in the concentration of DM in the central region
- Creation of a "spike" in the dark matter density- Gondolo & Silk 1999
- OJ287: accurate timing of outbursts constraints DM distribution

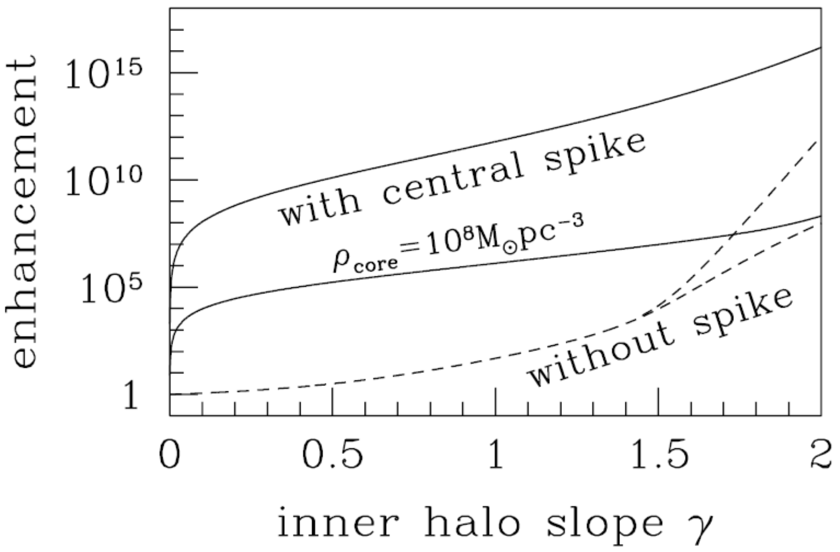


Kavanagh et al. 2021

Dark Matter spike at Centre of Galaxy?

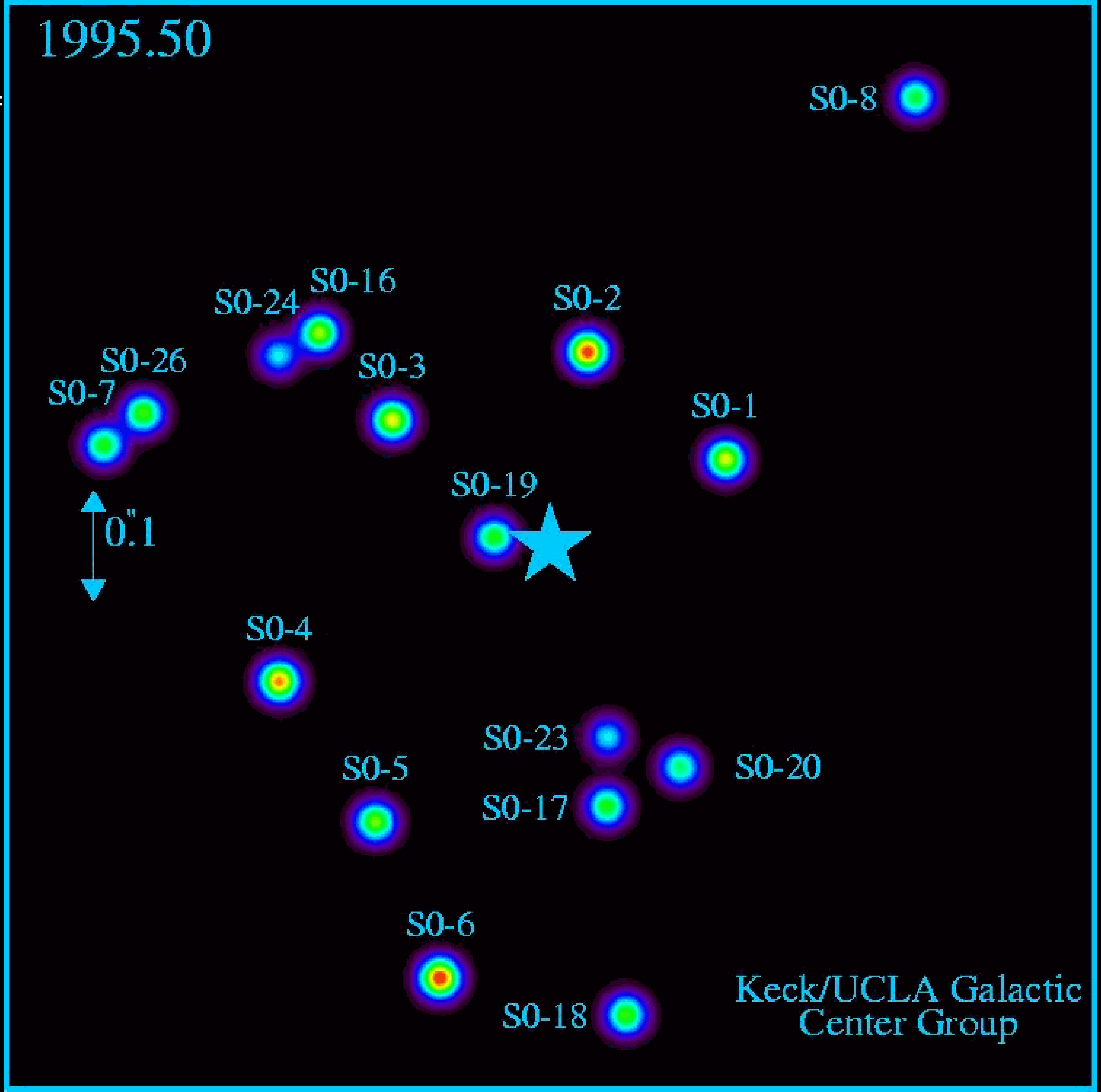
Adiabatic contraction of dark matter during formation of black hole leads to spike at centre of galaxy (Gondolo+Silk '99)



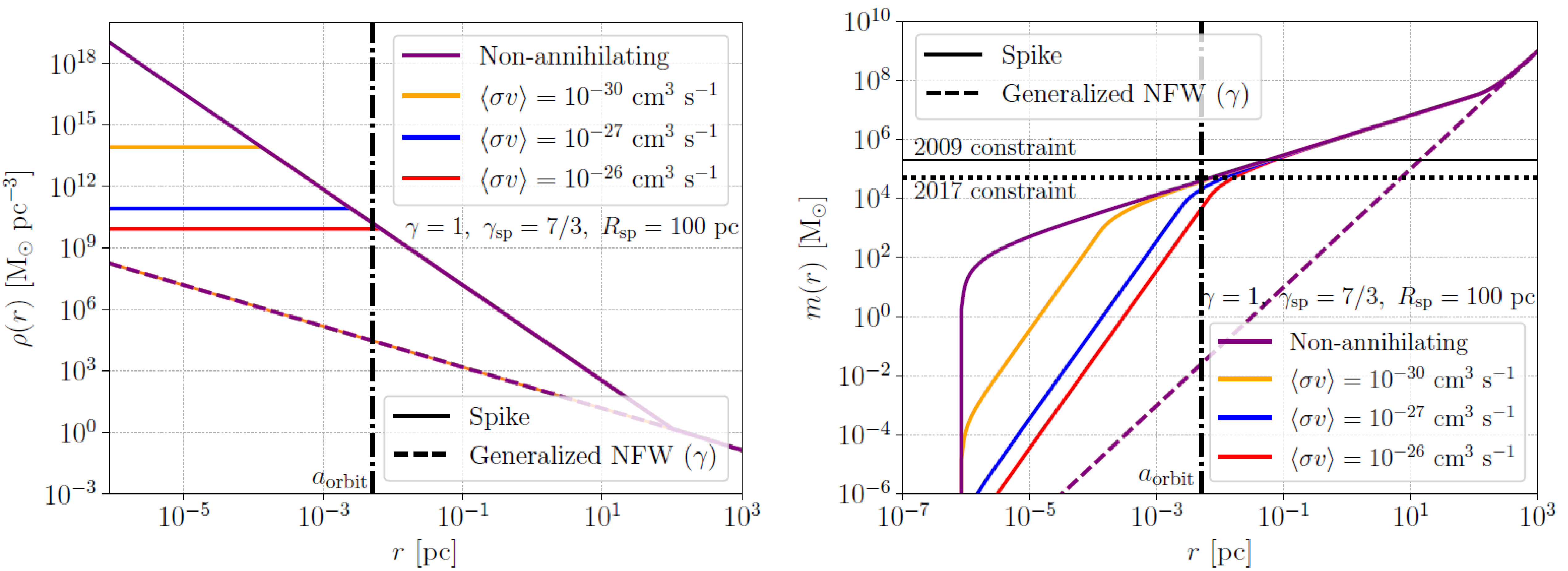


Closest approach of S0-16 is
0.0002 pc
=45 AU
=600 Rsch

0.04 pc

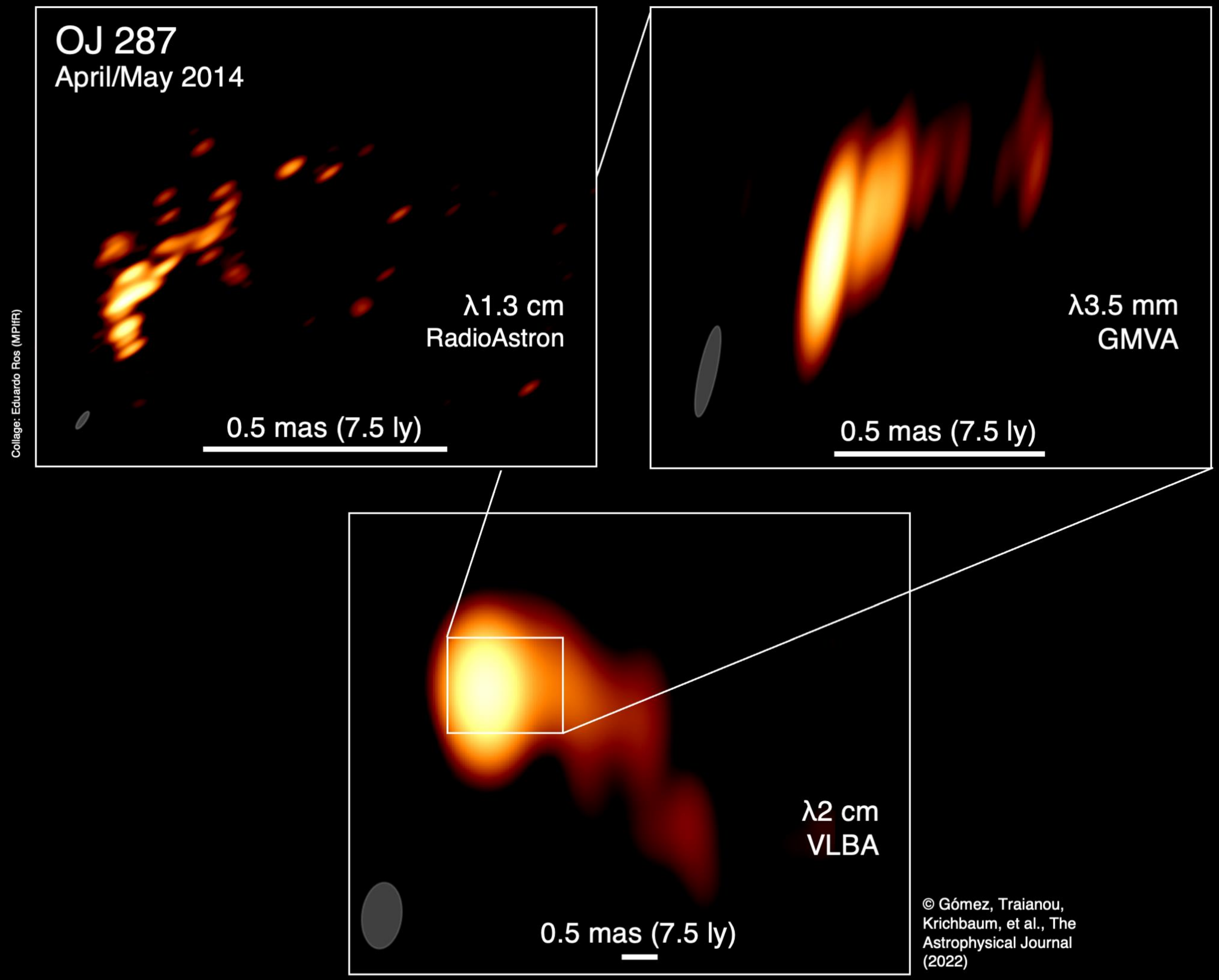


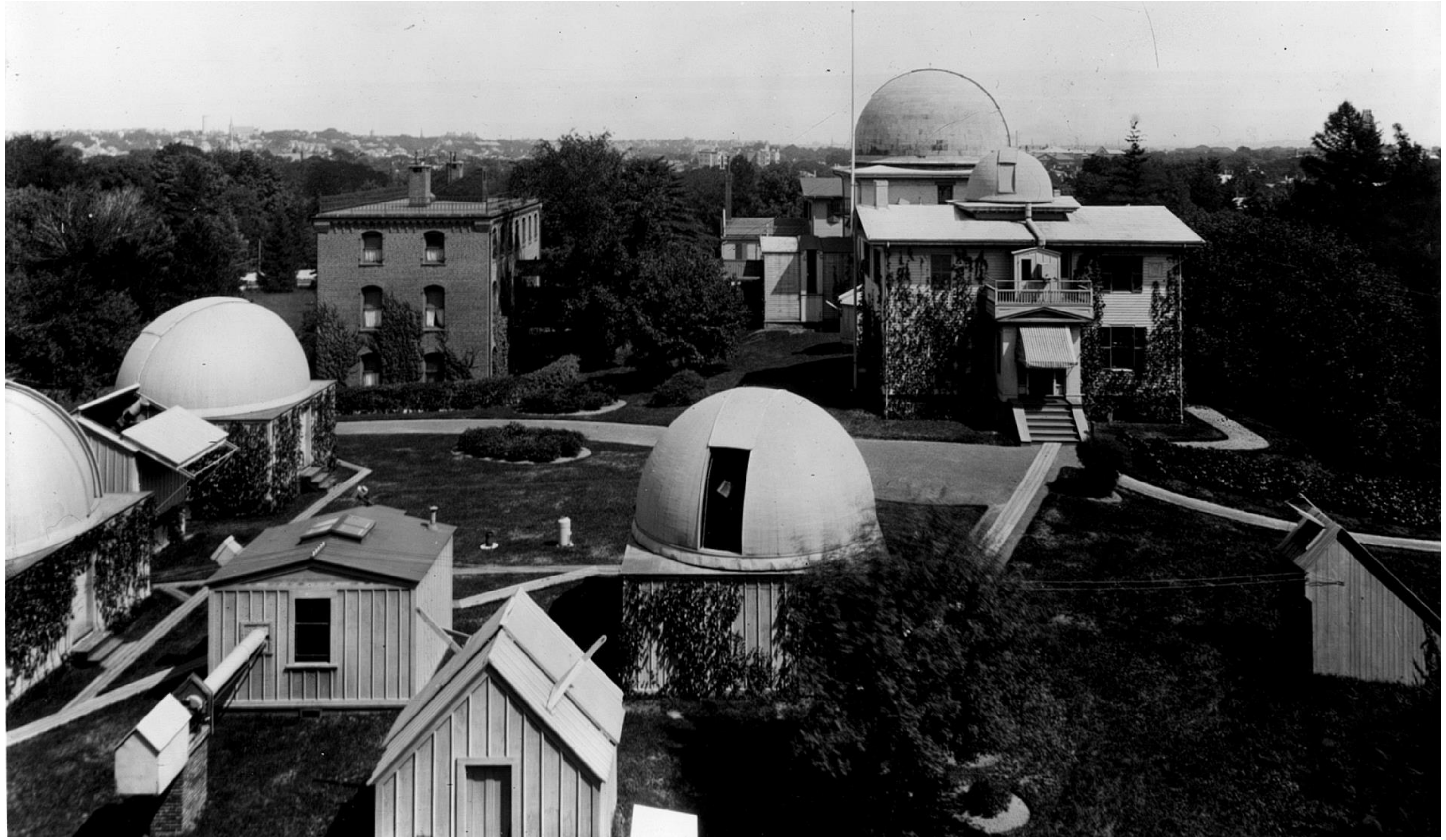
Constraints from Sag A*



Lacroix 1801.01308

OJ287 is a BL-Lac object

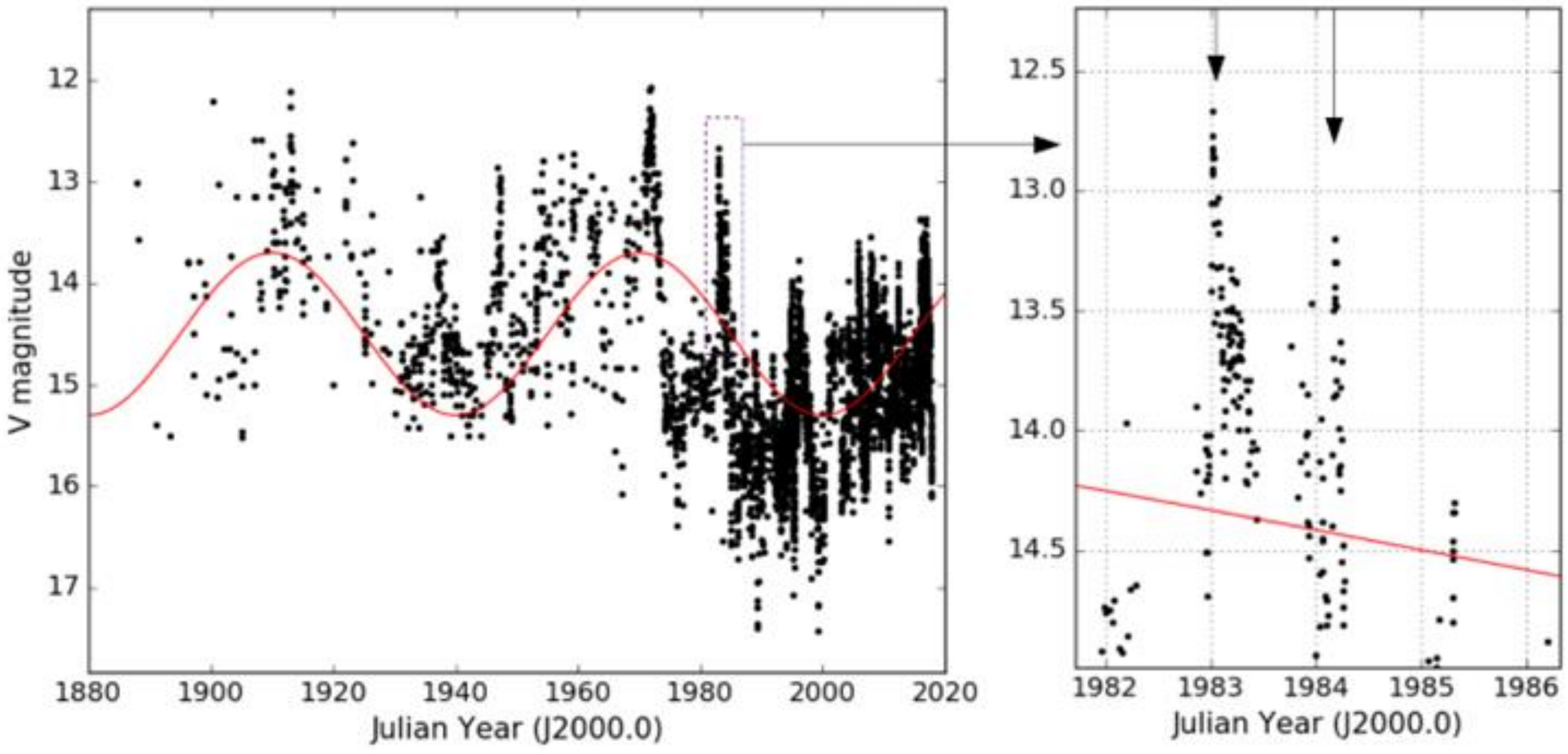




Outbursts of OJ287 discovered back to 1891 on photographic plates.

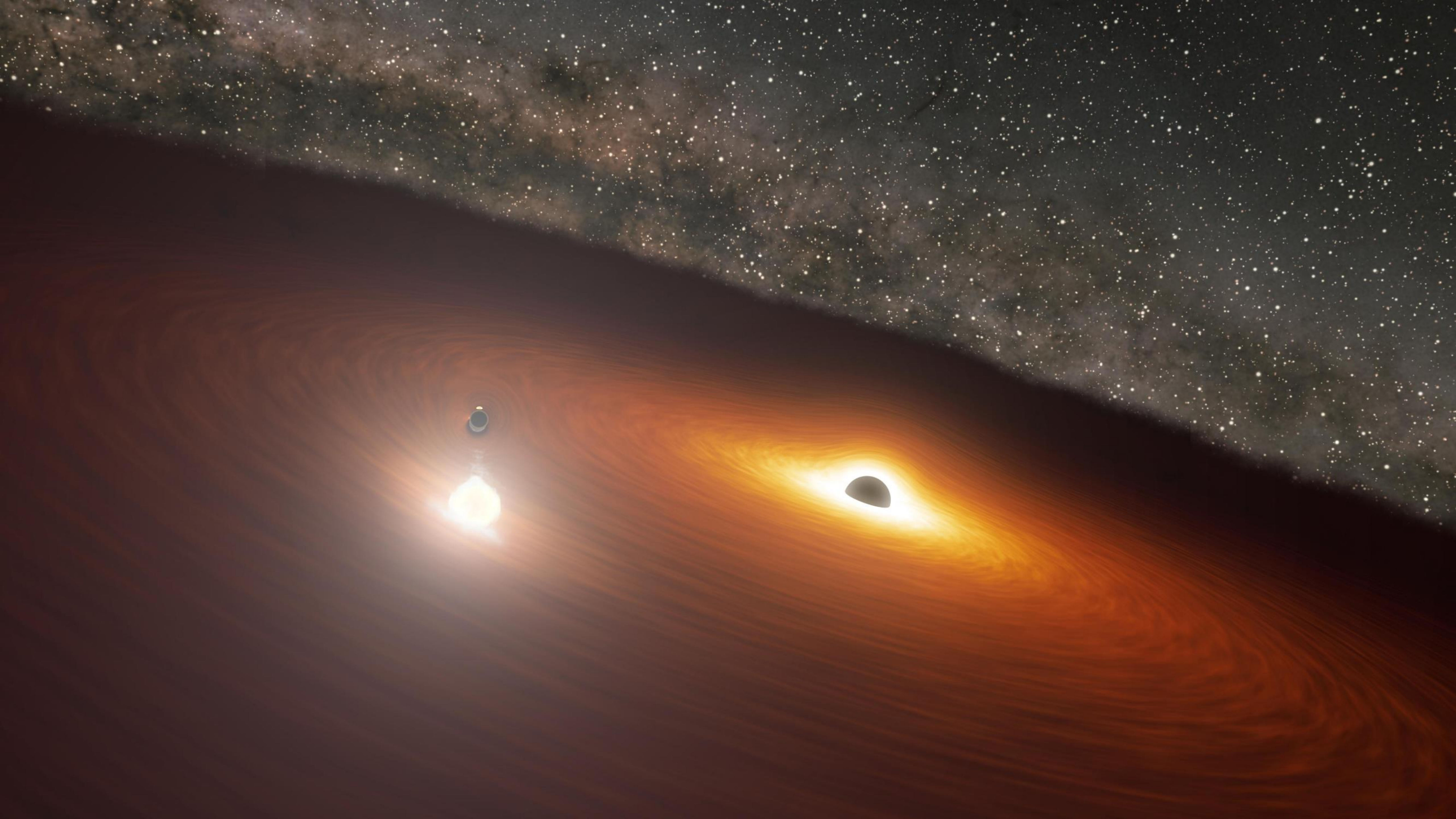
Harvard College Observatory 1899

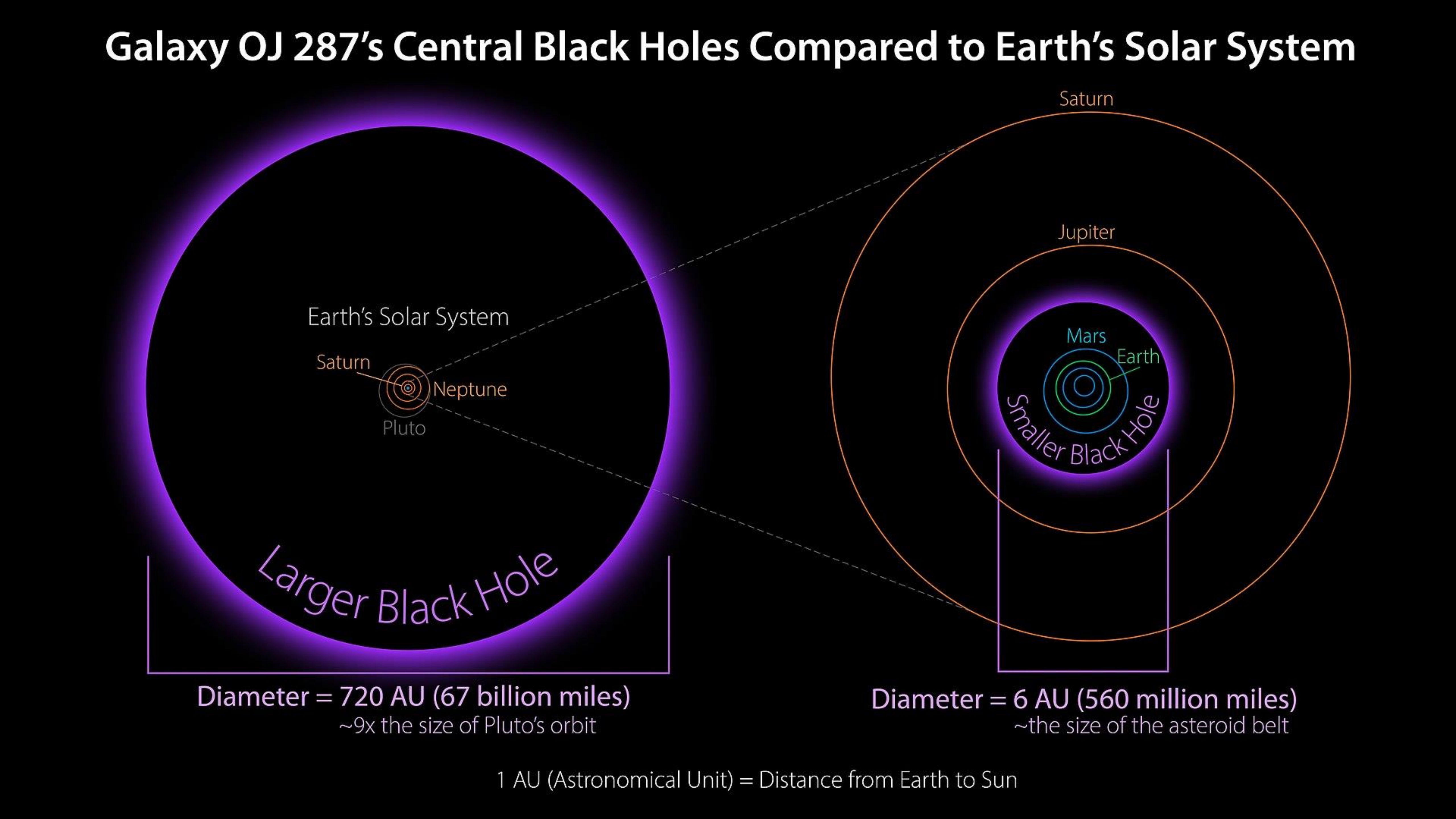
OJ 287



- BL Lac object (z=0.306)- one of the most extensively-monitored blazars
- variations with timescales of $\sim \mathbf{60}$ and $\sim \mathbf{12}$ **years**
- A feasible model of OJ 287 must at least explain and predict:

advance of pericenter  ***orbital period timescale***




Galaxy OJ 287's Central Black Holes Compared to Earth's Solar System
Earth's Solar System
Saturn
Neptune
Pluto
Larger Black Hole
Diameter = 720 AU (67 billion miles)
~9x the size of Pluto's orbit
Saturn
Jupiter
Mars
Earth
Smaller Black Hole
Diameter = 6 AU (560 million miles)
~the size of the asteroid belt
1 AU (Astronomical Unit) = Distance from Earth to Sun

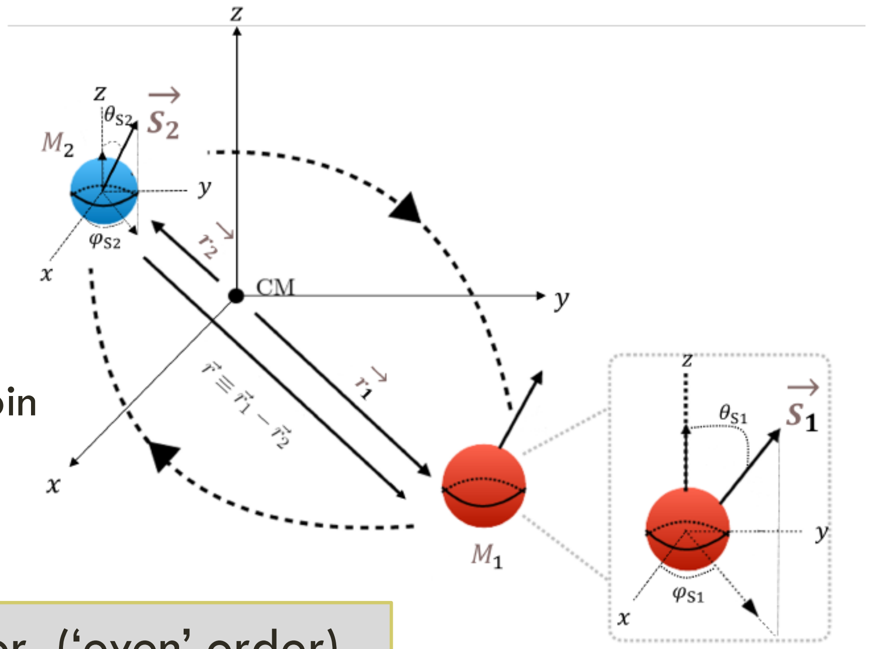
DETERMINING THE RELATIVISTIC BBH ORBIT

$\epsilon \sim (v/c)^2 \sim GM/rc^2$

PN numerical integration scheme:

EOM:

- Relative two-body COM motion
- Precessional dynamics of primary BH spin



$$\ddot{\mathbf{x}} \equiv \frac{d^2\mathbf{x}}{dt^2} = \ddot{\mathbf{x}}_0 + \ddot{\mathbf{x}}_{1\mathrm{PN}} + \ddot{\mathbf{x}}_{2\mathrm{PN}} + \ddot{\mathbf{x}}_{3\mathrm{PN}}$$

Conservative sector ('even' order)

$$+ \ddot{\mathbf{x}}_{2.5\mathrm{PN}} + \ddot{\mathbf{x}}_{3.5\mathrm{PN}} + \ddot{\mathbf{x}}_{4\mathrm{PN(tail)}} + \ddot{\mathbf{x}}_{4.5\mathrm{PN}}$$

Dissipative radiative sector ('odd' order terms)

$$+ \ddot{\mathbf{x}}_{\mathrm{SO}} + \ddot{\mathbf{x}}_{\mathrm{SS}} + \ddot{\mathbf{x}}_{\mathrm{Q}} + \ddot{\mathbf{x}}_{4\mathrm{PN(SO-RR)}}$$

Spin-related contributions

$$\frac{d\mathbf{s}_1}{dt} = (\boldsymbol{\Omega}_{\mathrm{SO}} + \boldsymbol{\Omega}_{\mathrm{SS}} + \boldsymbol{\Omega}_{\mathrm{Q}}) \times \mathbf{s}_1,$$

$$\mathbf{S}_i = \frac{Gm_i^2\chi_i}{c}\mathbf{s}_i$$

Spitzer Observations of the Predicted Eddington Flare from Blazar OJ 287

Seppo Laine, Lankeswar Dey, Mauri Valtonen, A. Gopakumar, Stanislaw Zola, S. Komossa, Mark Kidger, Pauli Pihajoki, Jose L. Gómez, Daniel Caton, Stefano Ciprini, Marek Drozdz, Kosmas Gazeas, Vira Godunova, Shirin Haque, Felix Hildebrandt, Rene Hudec, Helen Jermak, Albert K.H. Kong, Harry Lehto, Alexios Liakos, Katsura Matsumoto, Markus Mugrauer, Tapio Pursimo, Daniel E. Reichart, Andrii Simon, Michal Siwak, Eda Sonbas

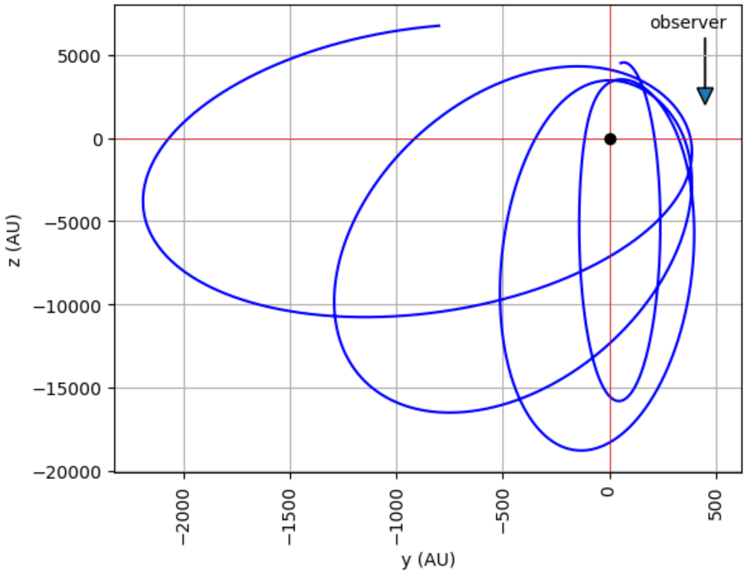
Binary black hole (BH) central engine description for the unique blazar OJ 287 predicted that the next secondary BH impact-induced bremsstrahlung flare should peak on 2019 July 31. This prediction was based on detailed general relativistic modeling of the secondary BH trajectory around the primary BH and its accretion disk. The expected flare was termed the Eddington flare to commemorate the centennial celebrations of now-famous solar eclipse observations to test general relativity by Sir Arthur Eddington. We analyze the multi-epoch Spitzer observations of the expected flare between 2019 July 31 and 2019 September 6, as well as baseline observations during 2019 February-March. Observed Spitzer flux density variations during the predicted outburst time display a strong similarity with the observed optical pericenter flare from OJ 287 during 2007 September. The predicted flare appears comparable to the 2007 flare after subtracting the expected higher base-level Spitzer flux densities at 3.55 and 4.49 μm compared to the optical R-band. Comparing the 2019 and 2007 outburst lightcurves and the previously calculated predictions, we find that the Eddington flare arrived within 4 hours of the predicted time. Our Spitzer observations are well consistent with the presence of a nano-Hertz gravitational wave emitting spinning massive binary BH that inspirals along a general relativistic eccentric orbit in OJ 287. These multi-epoch Spitzer observations provide a parametric constraint on the celebrated BH no-hair theorem.

ORBIT SOLUTION

Parameter	Value	Unit
M_1	1.8329×10^{10}	$M_\odot$
M_2	1.5038×10^{8}	$M_\odot$
e_0 (e_{init})	0.732 (0.694)	
γ	1.310	
χ_1	0.389	
a	12648.086	
ω_0	28.938	deg
θ_{S1}	170.320	deg
ψ_{S1}	108.692	deg

Convergent trial orbit

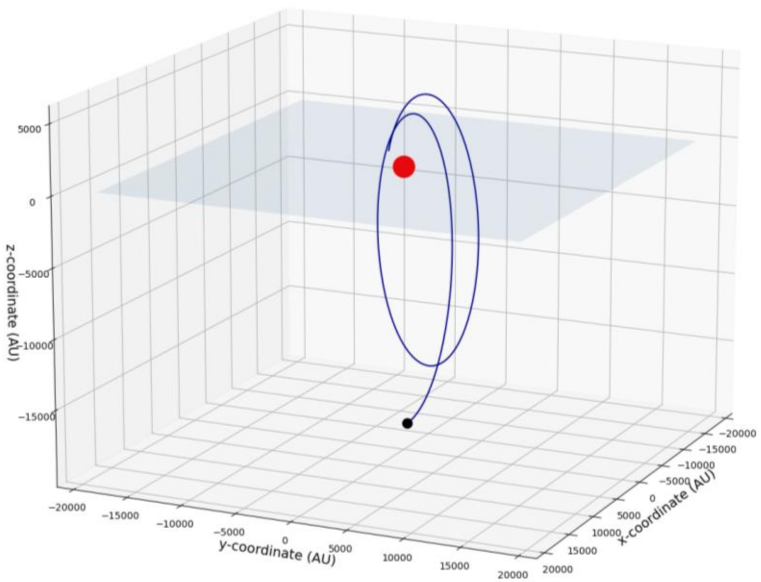
$\chi^2 \approx 0.259$

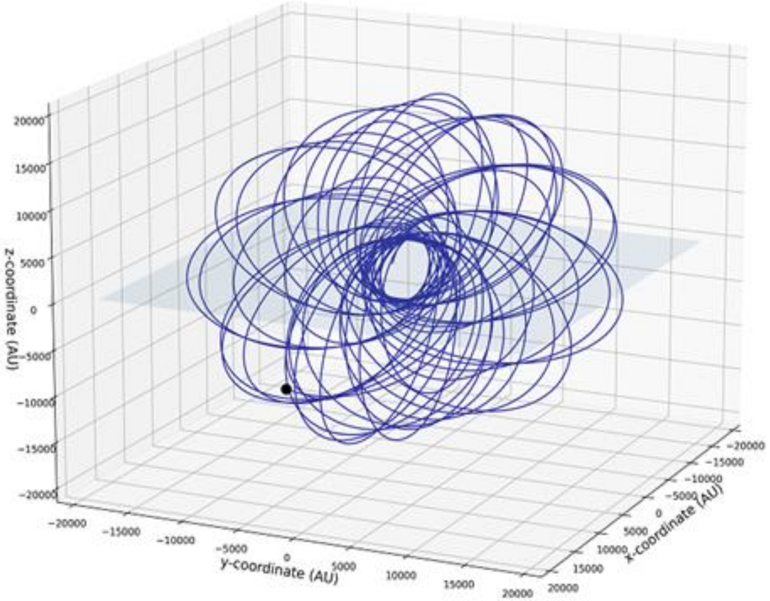


Projection on y-z plane

- Precession of the pericenter
- Precession of the orbital plane
- Gravitational radiation

ICs





$t = 0$

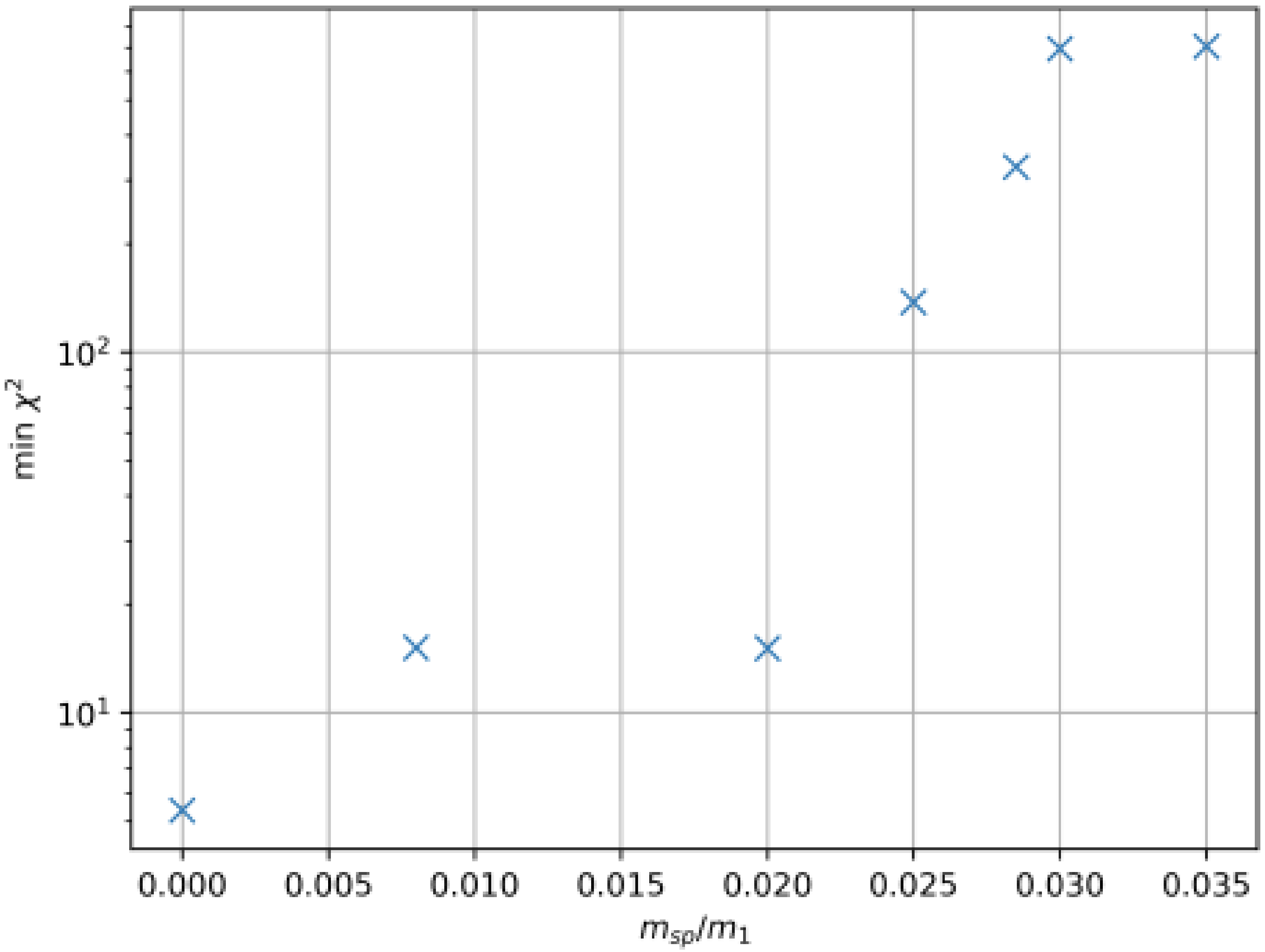
1912.980

2019.569

$t = 360\ yr$

RESULTS

Total mass of spike cannot be more than around 3% of mass of primary.



CONCLUSIONS

OJ287 is a remarkable, extreme object

Its highly relativistic nature makes it very sensitive to initial conditions and the presence of any spike

We predict that we can rule out any spike with mass greater than 3% of the black hole within the orbit of the secondary