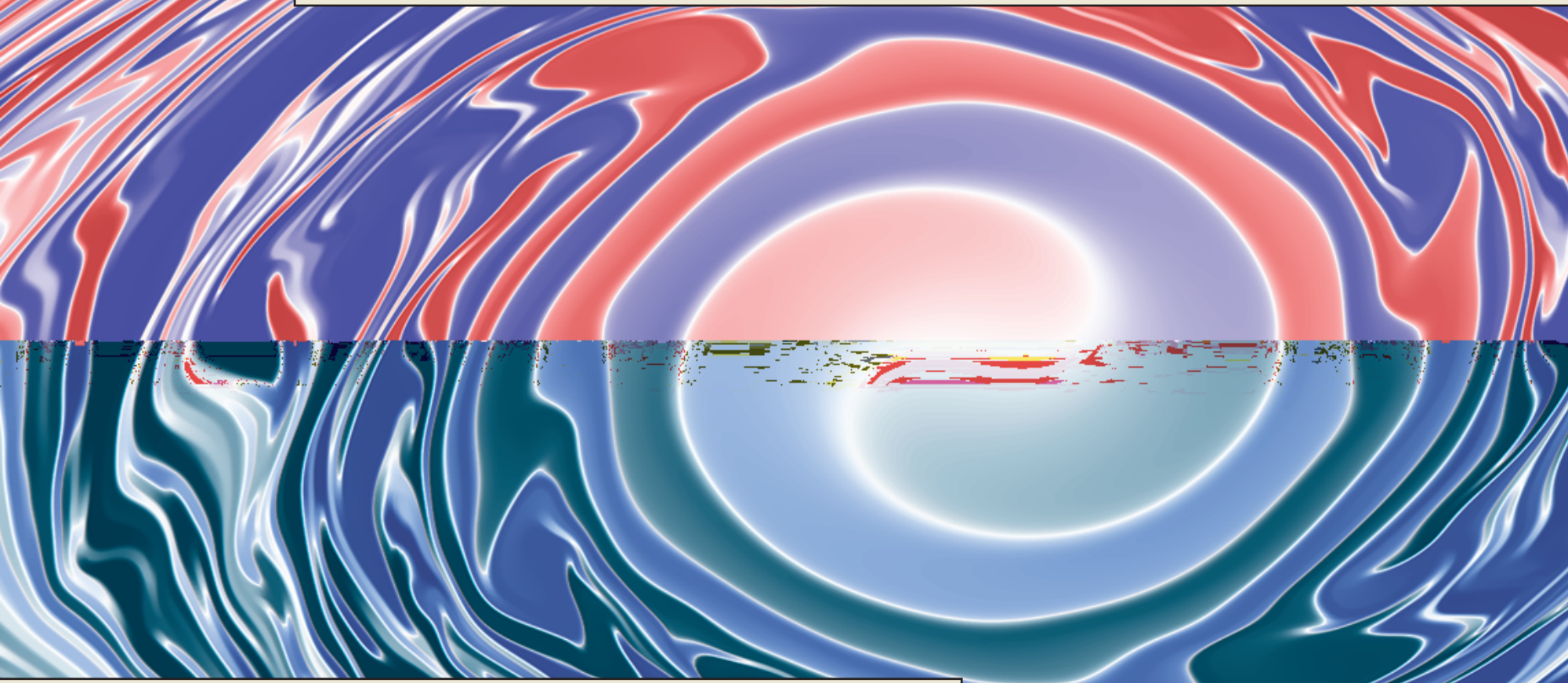
Magnetized Gas Clouds in the Galactic Center



Mike McCourt, Ryan O'Leary,
Ann-Marie Madigan, & Eliot Quataert

Outline

"Gas Clouds in the Galactic Center"

Dynamics of Magnetized Clouds

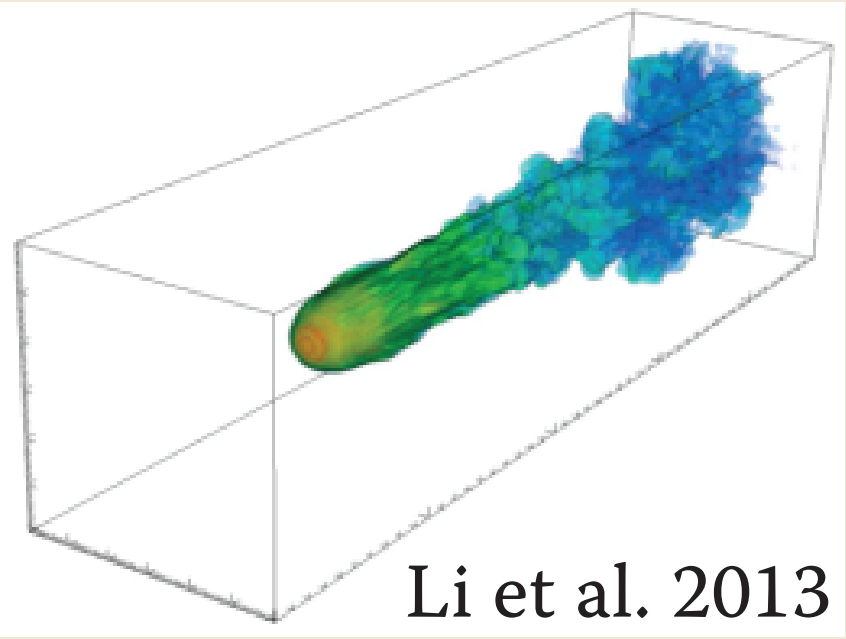
- Disruption (*McCourt, O'Leary, Madigan, & Quataert*)
- Acceleration

Making Gas Clouds Work for Us

- G2's twisted sister (*McCourt & Madigan, in prep.*)
- Using G2 to probe the accretion flow

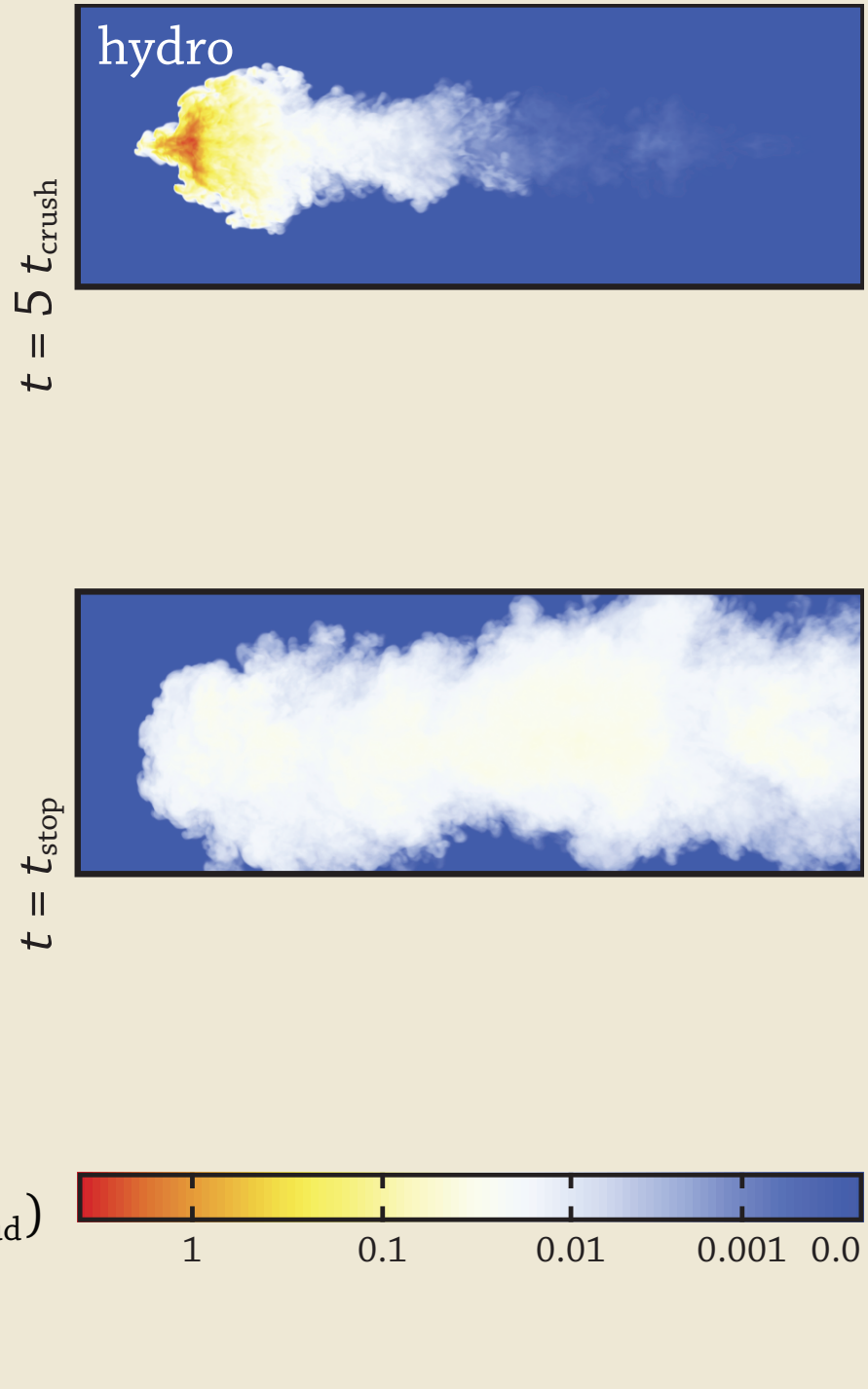
*Dynamics of **Magnetized** Gas Clouds in **Dilute** Plasmas*

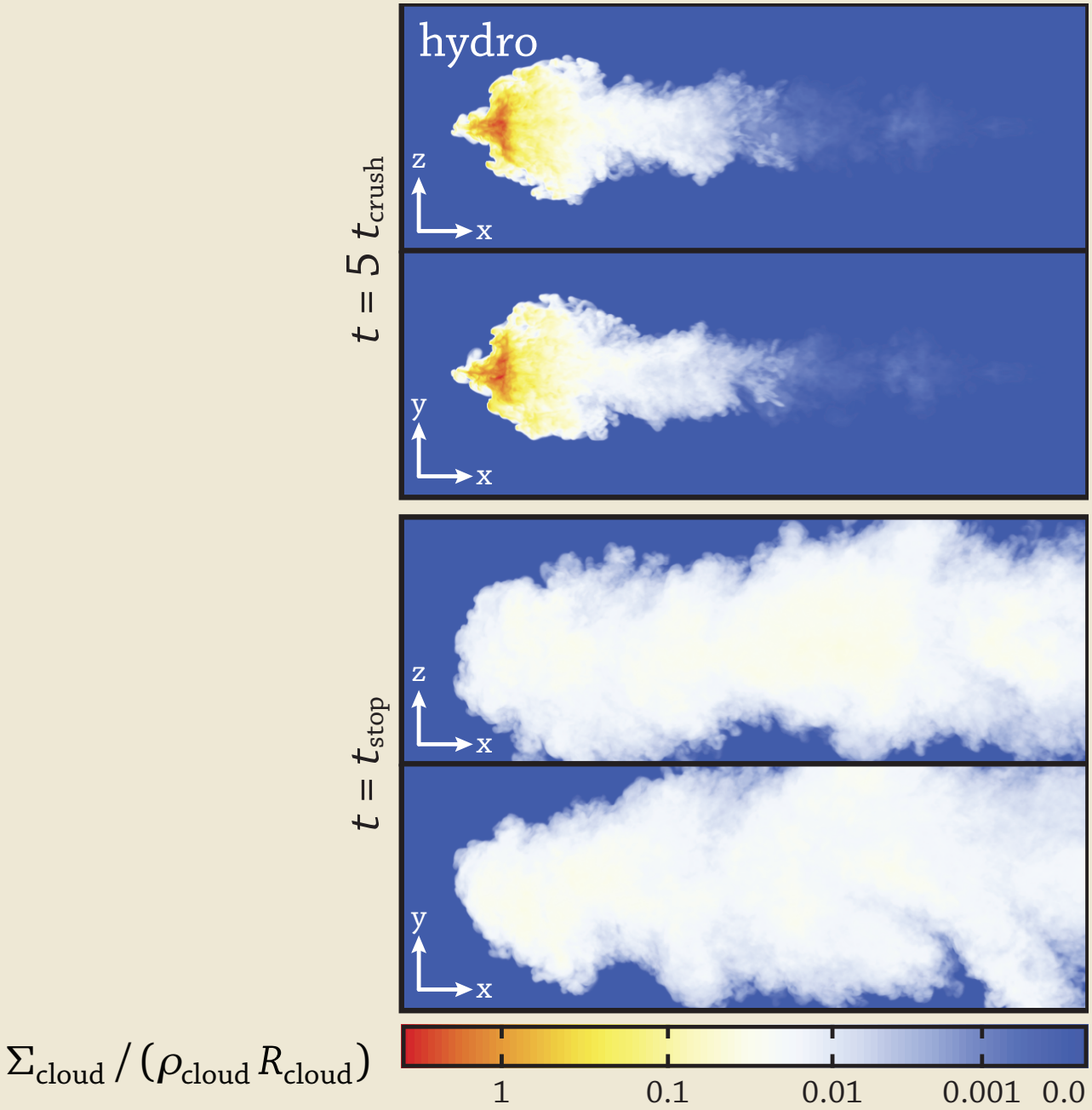
Background

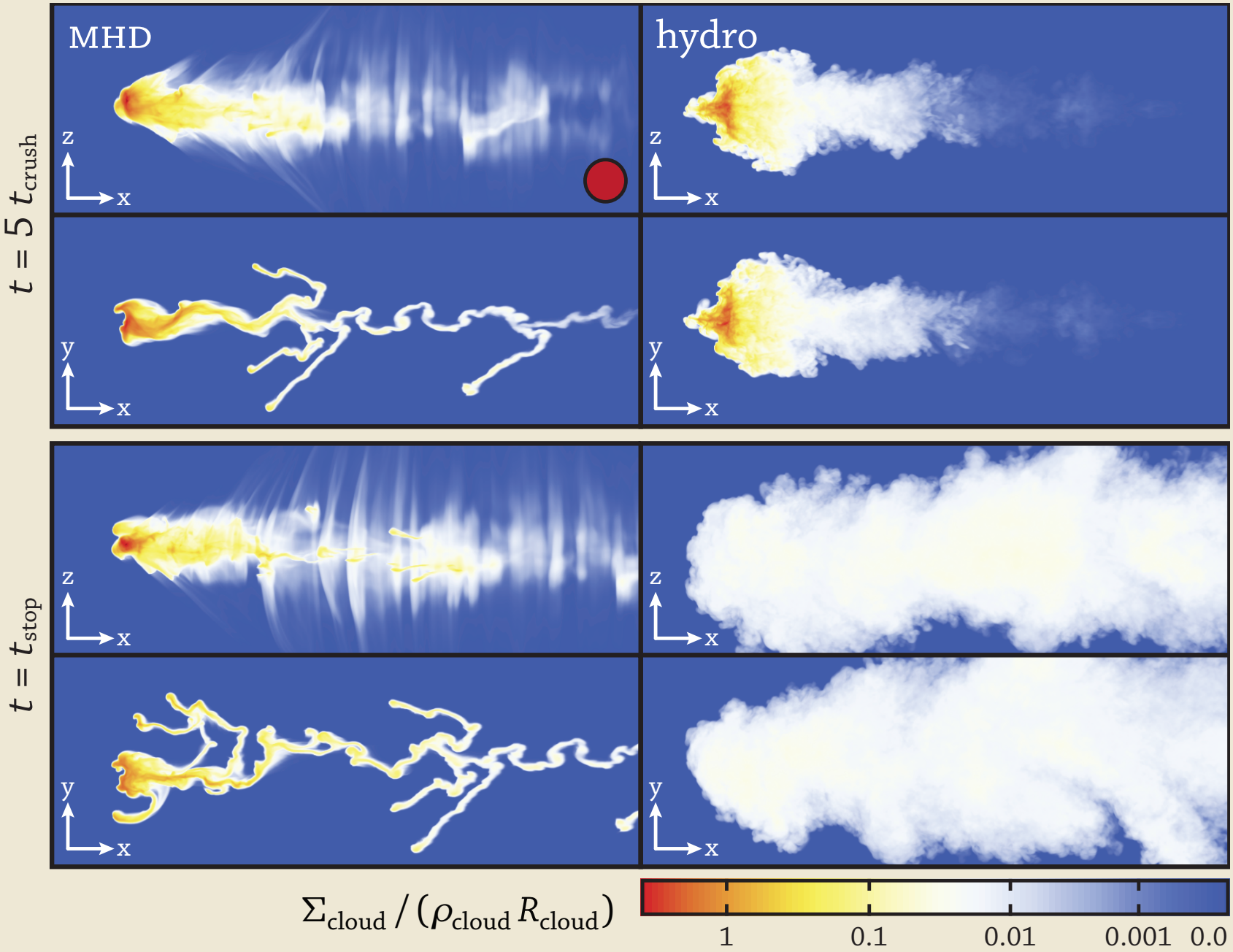


"Cloud Crushing:"

$$t_{\text{crush}} \sim \left(\frac{\rho_{\text{cloud}}}{\rho_{\text{wind}}}\right)^{1/2} \frac{R_{\text{cloud}}}{v_{\text{wind}}}$$


hydro
$t = 5\, t_{\rm crush}$
$t = t_{\rm stop}$
$\Sigma_{\rm cloud} / (\rho_{\rm cloud}\, R_{\rm cloud})$
1
0.1
0.01
0.001
0.0


hydro
$t = 5\ t_{\rm crush}$
$t = t_{\rm stop}$
z
x
y
x
z
x
y
x
$\Sigma_{\rm cloud} / (\rho_{\rm cloud}\, R_{\rm cloud})$
1
0.1
0.01
0.001
0.0


MHD
hydro
z
x
y
x
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$t = t_{\rm stop}$
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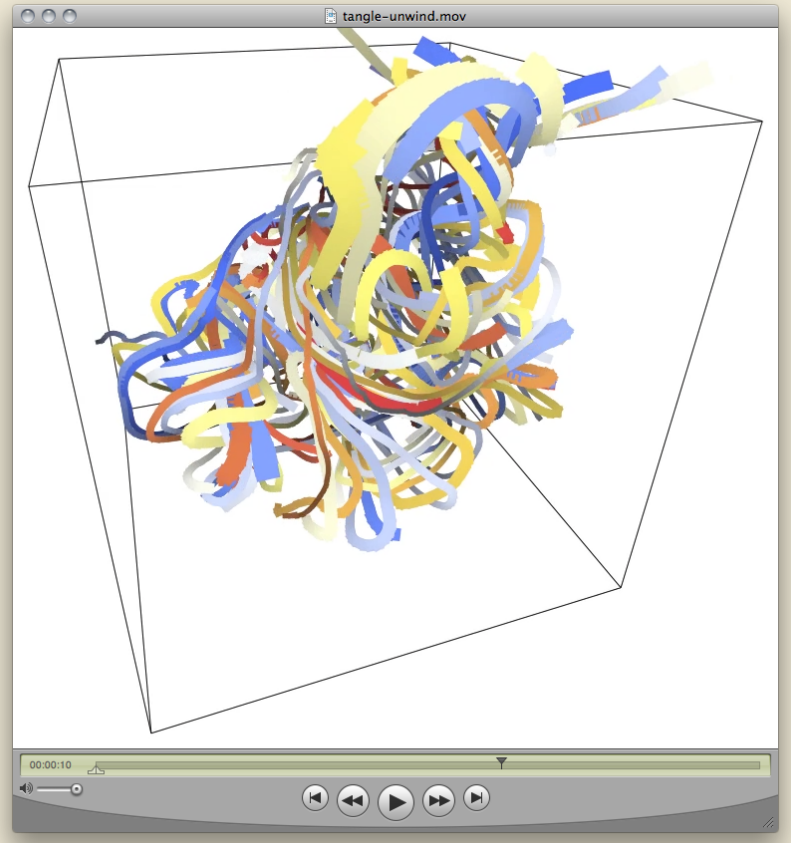
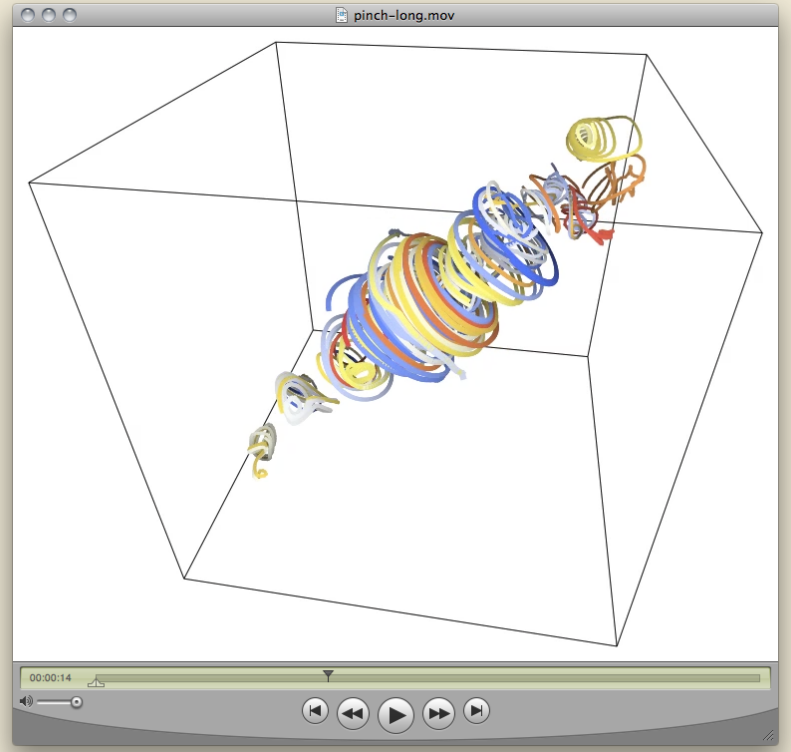
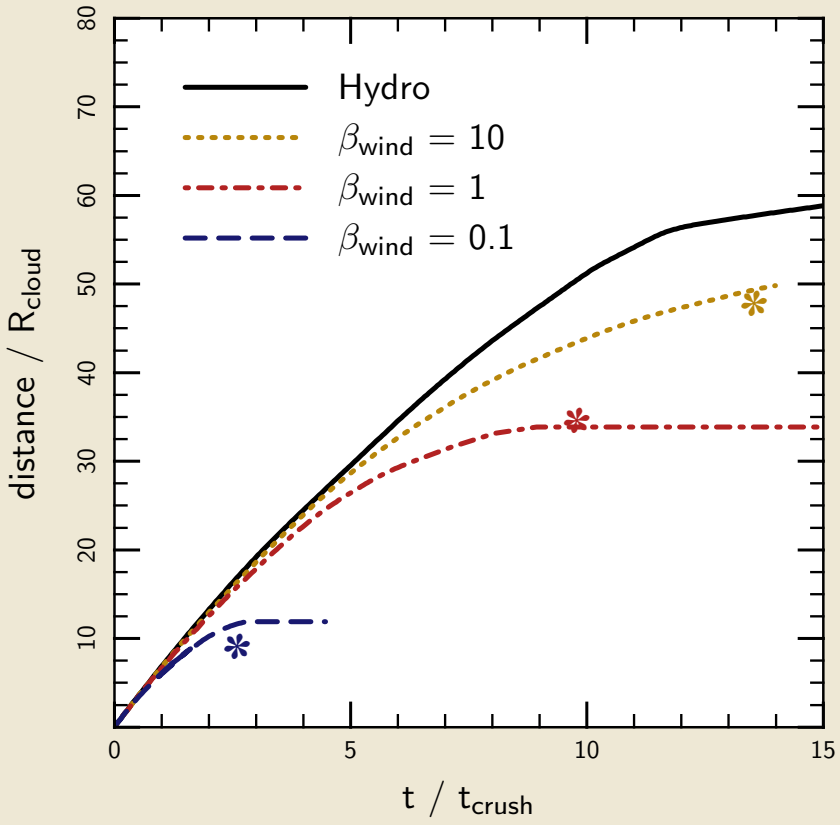
1
0.1
0.01
0.001
0.0

aside: initial conditions matter

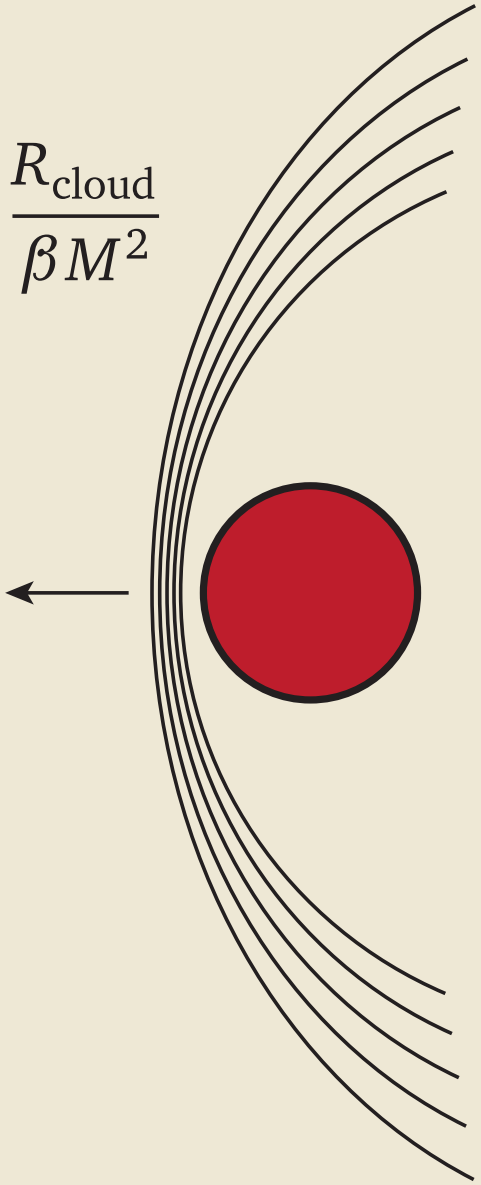




Magnetically-Enhanced Drag Force

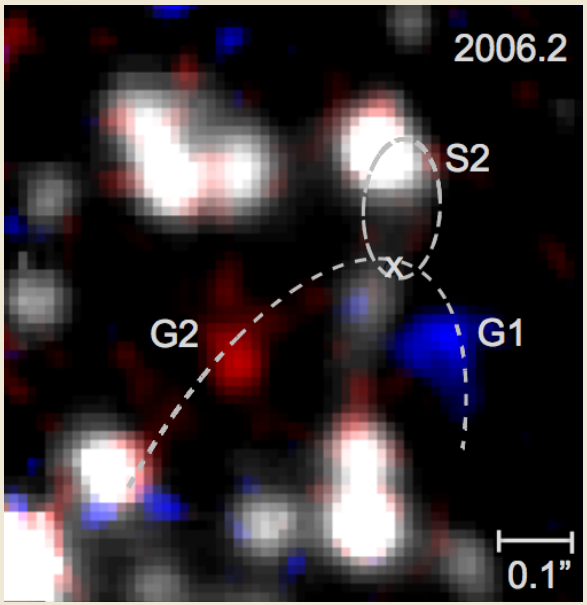


$$R_{curv} \sim \frac{R_{cloud}}{\beta M^2}$$



Putting Gas Clouds to Work: Probing the Galactic Center Accretion Flow

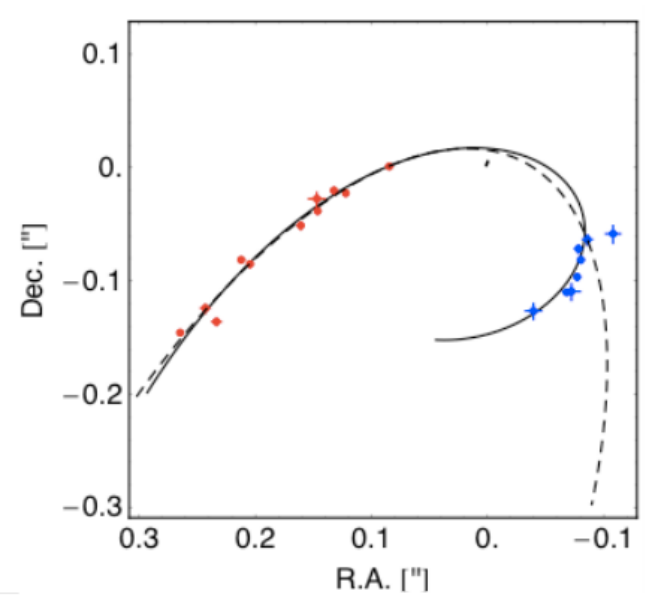
(Re-)Discovery of G1



	G2	G1
a	1.0 ± 0.2	0.4 ± 0.2
e	0.976 ± 0.007	0.86 ± 0.05

(Pfuhl et al. 2014)

(Re-)Discovery of G1



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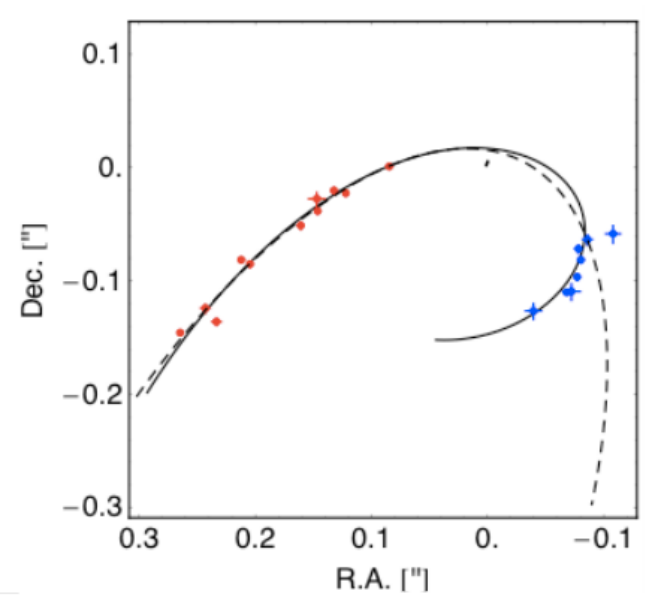

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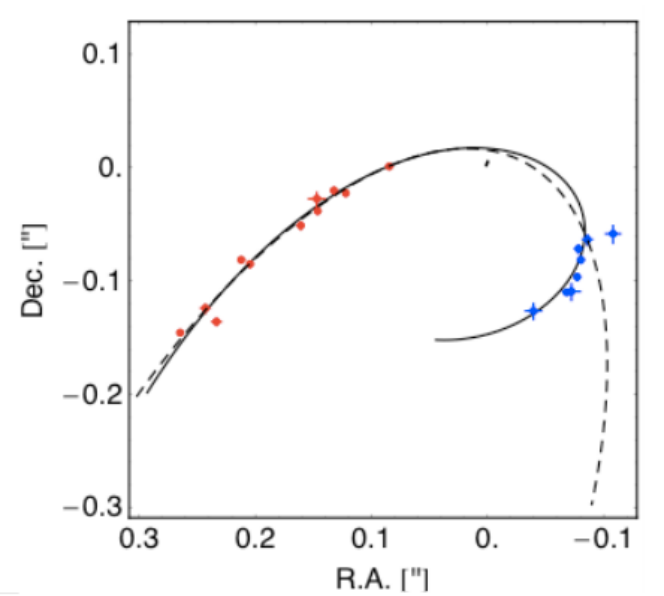
(Re-)Discovery of G1



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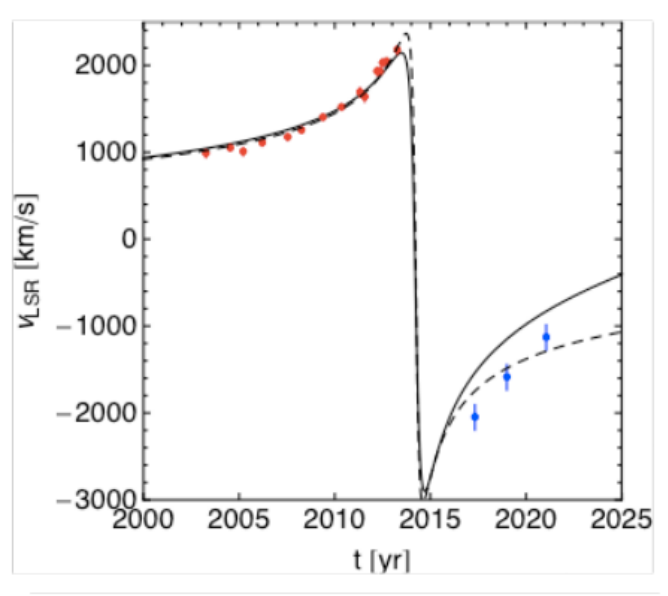
J	0.22	0.32
i	$62. \pm 2.$	$72. \pm 2.$
Ω	$8. \pm 4.$	$21. \pm 5.$
ω	$97. \pm 2.$	$109. \pm 8.$

(Pfuhl et al. 2014)

(Re-)Discovery of G1



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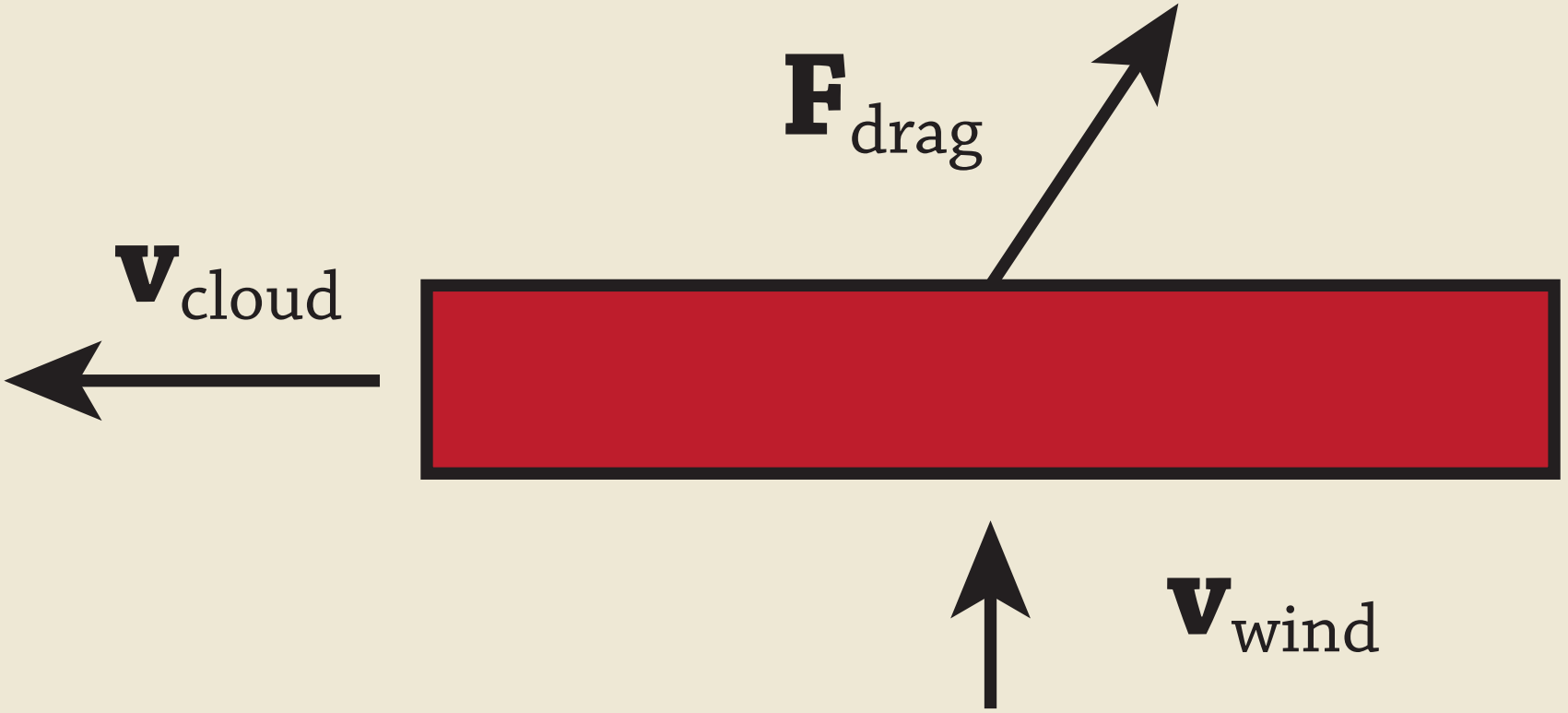
"Sometimes a man wants to be stupid if it lets him do a thing his cleverness forbids."

— *John Steinbeck*

"Sometimes a man wants to be stupid if it lets him do a thing his cleverness forbids."

— John Steinbeck

- Assume G1 and G2 are gas clouds,
- Assume they follow the same trajectory
- Assume they survive at least one pericenter passage


$\mathbf{F}_{\text{drag}}$
$\mathbf{v}_{\text{cloud}}$
$\mathbf{v}_{\text{wind}}$

A (too-)Simple Model

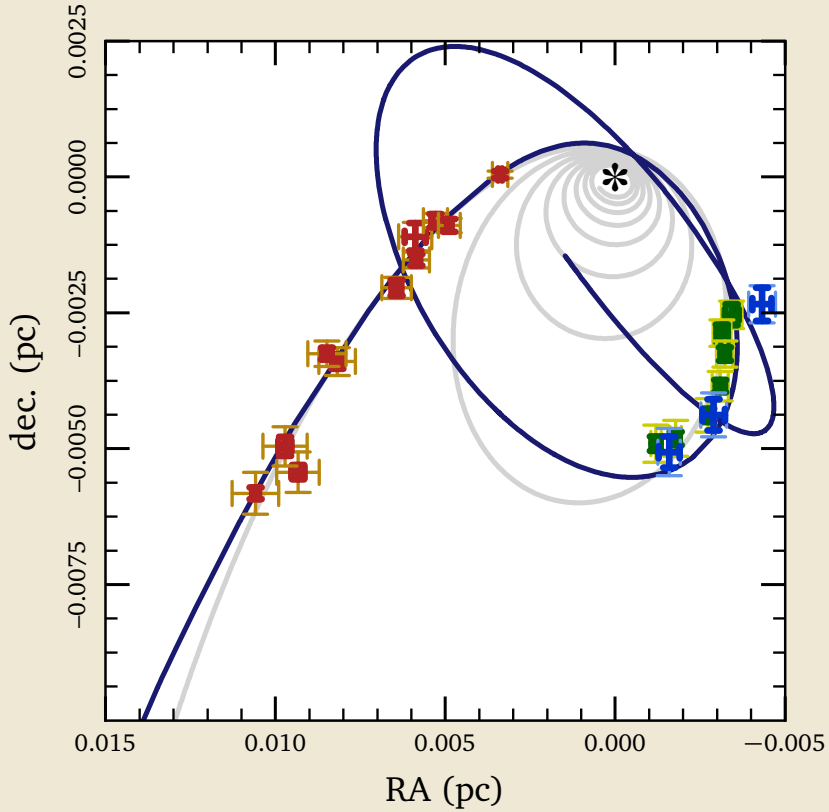
$$\frac{d^2 r}{dt^2} = -\frac{G M_\bullet \vec{r}}{r^3} - \frac{\rho_{\mathrm{bg}}(\vec{r})}{M_{\mathrm{cloud}}} \times \left(1 + \frac{2}{\beta M^2}\right) \times \; C^{-1} \cdot \mathrm{diag}\left(R_{\mathrm{cloud}}^2, R_{\mathrm{cloud}} L_{\mathrm{cloud}}, R_{\mathrm{cloud}} L_{\mathrm{cloud}}\right) \cdot (C \cdot \vec{v}_{\mathrm{rel}})^2$$

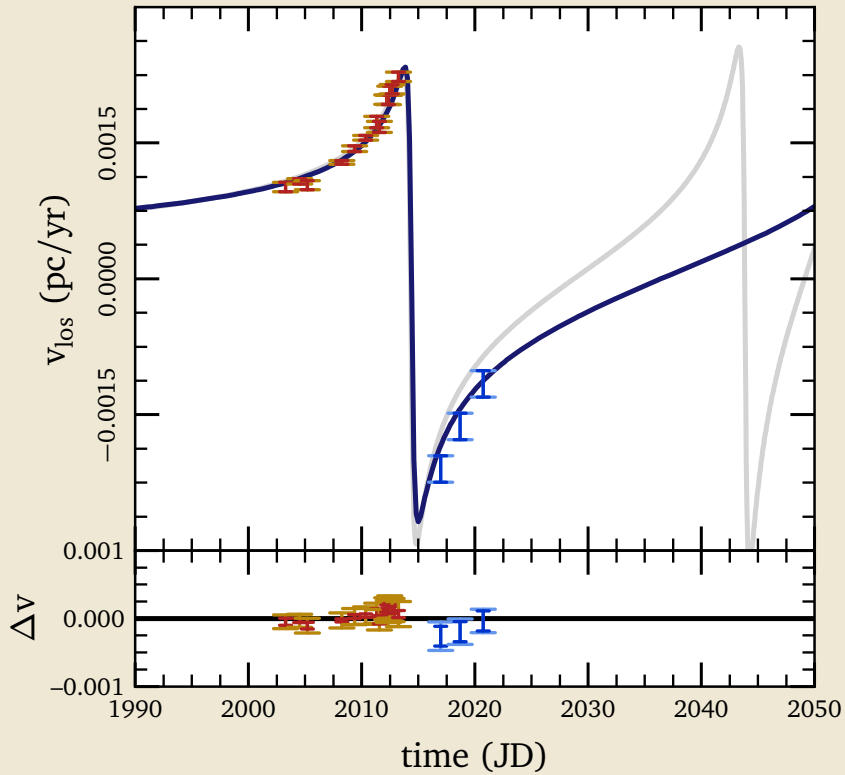
$$\rho_{\mathrm{bg}}(\vec{r}) = \rho_0 \left(\frac{r}{r_0}\right)^{-a}$$

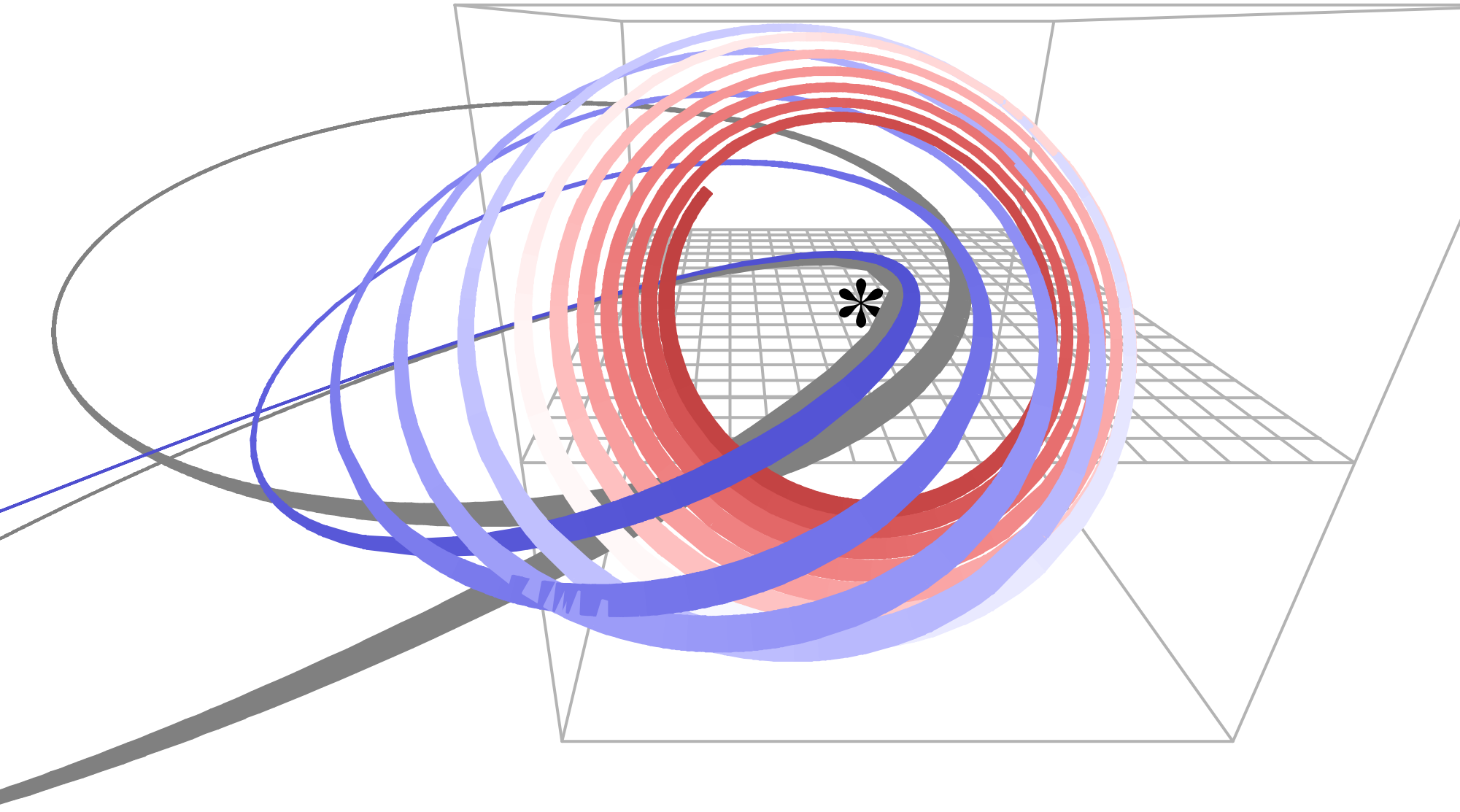
$$T_{\mathrm{bg}}(\vec{r}) = \frac{G M_\bullet}{r}$$

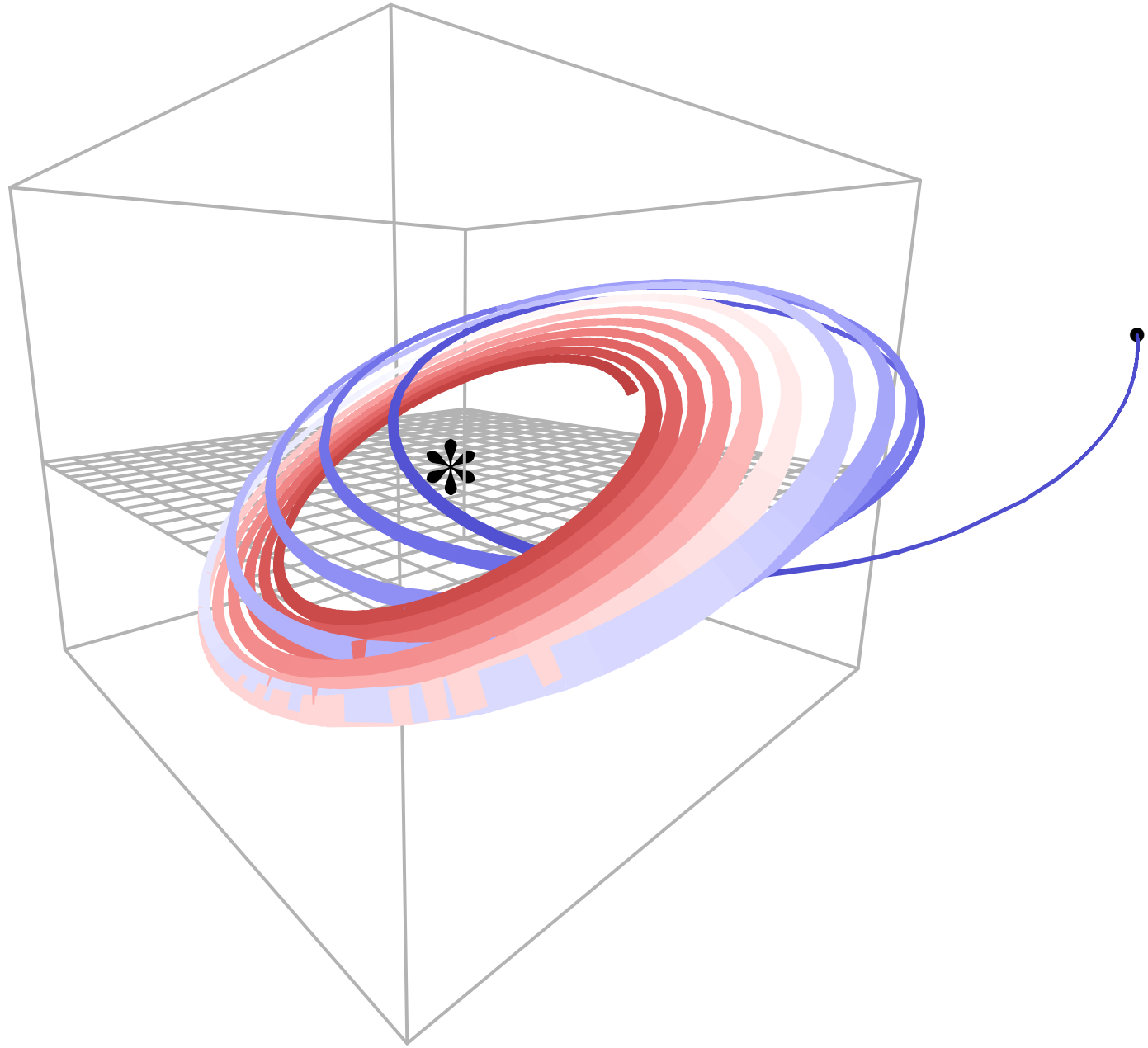
$$\vec{v}_{\mathrm{bg}}(\vec{r}) = f_{\mathrm{kep}} \left(\frac{G M_\bullet}{r}\right)^{1/2} \frac{\vec{J} \times \vec{r}}{J\, r}$$

Comparison with the Data

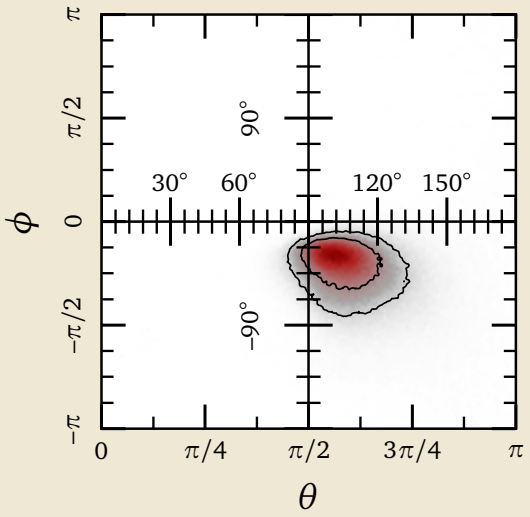


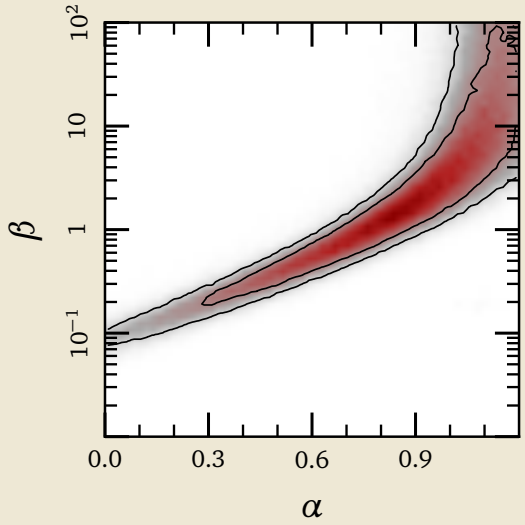


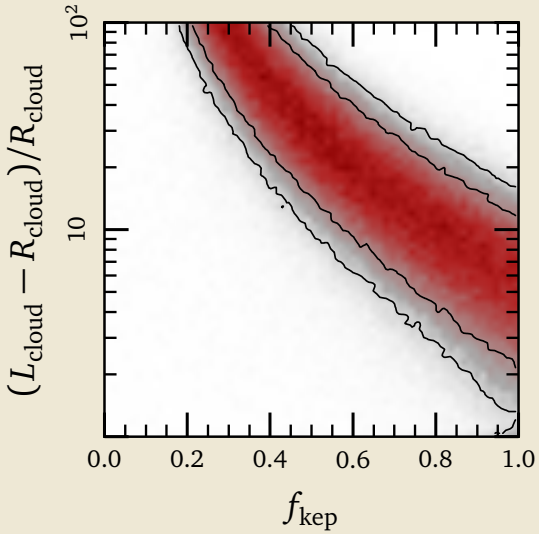




Making this Useful







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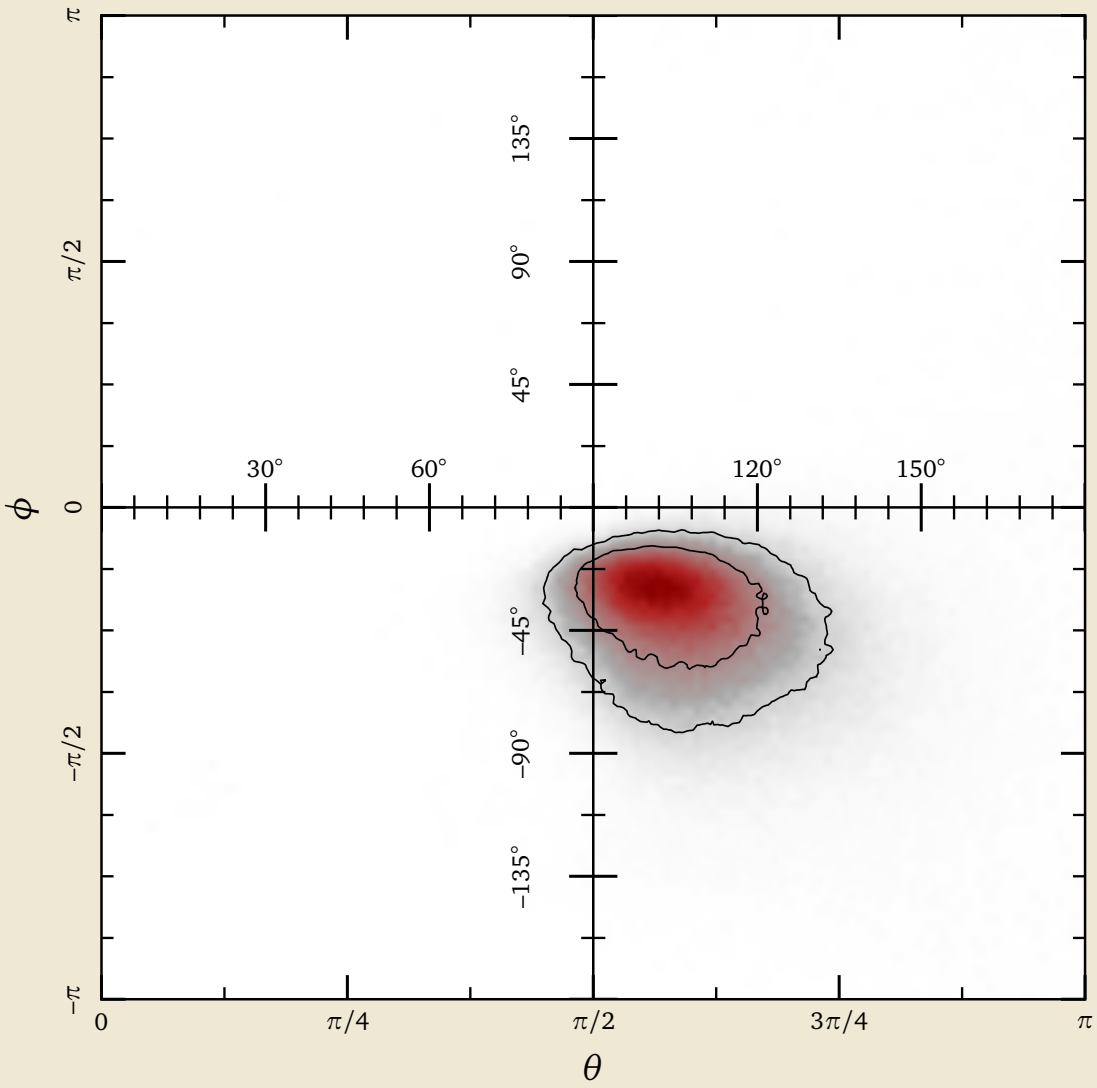

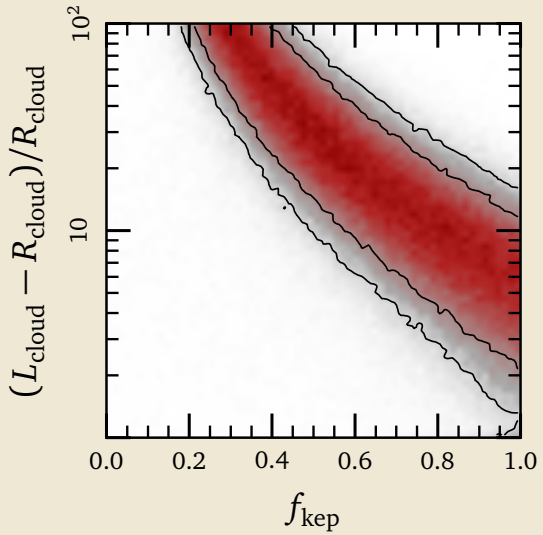

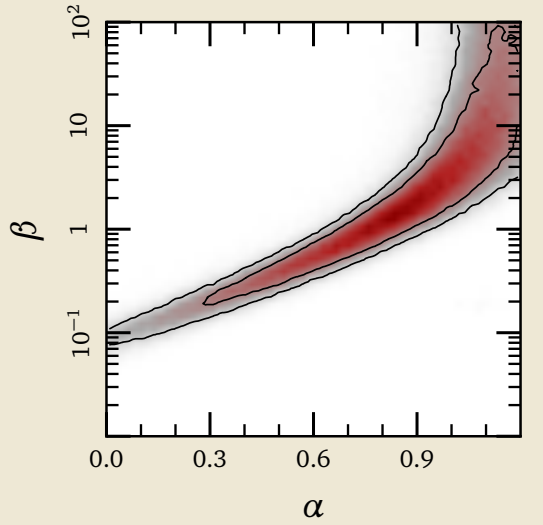

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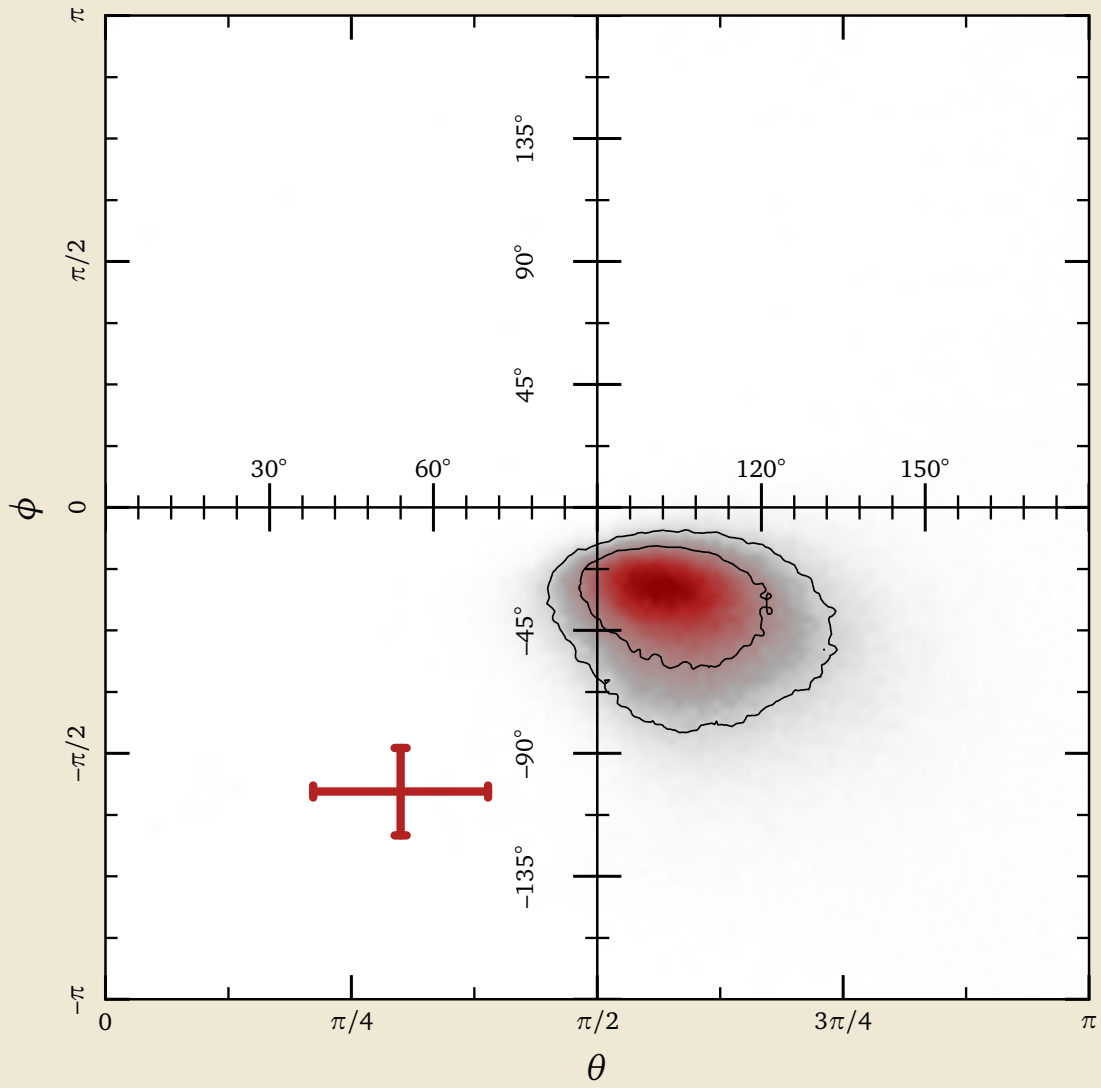

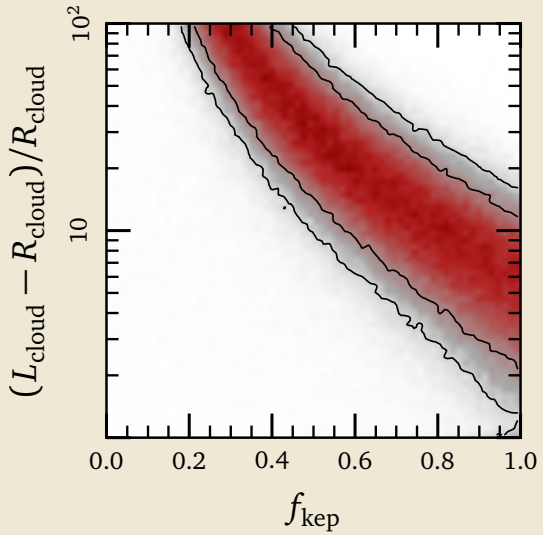

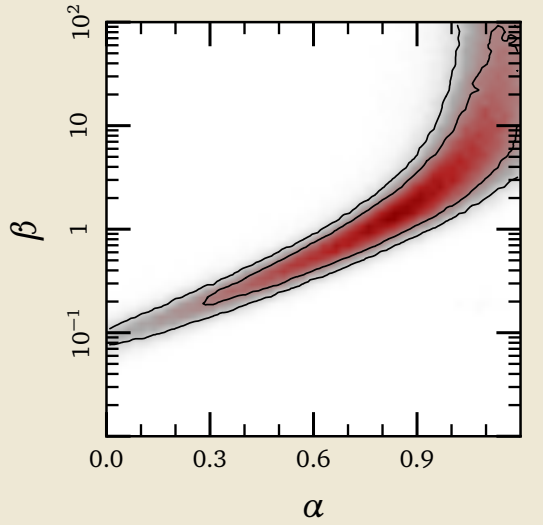

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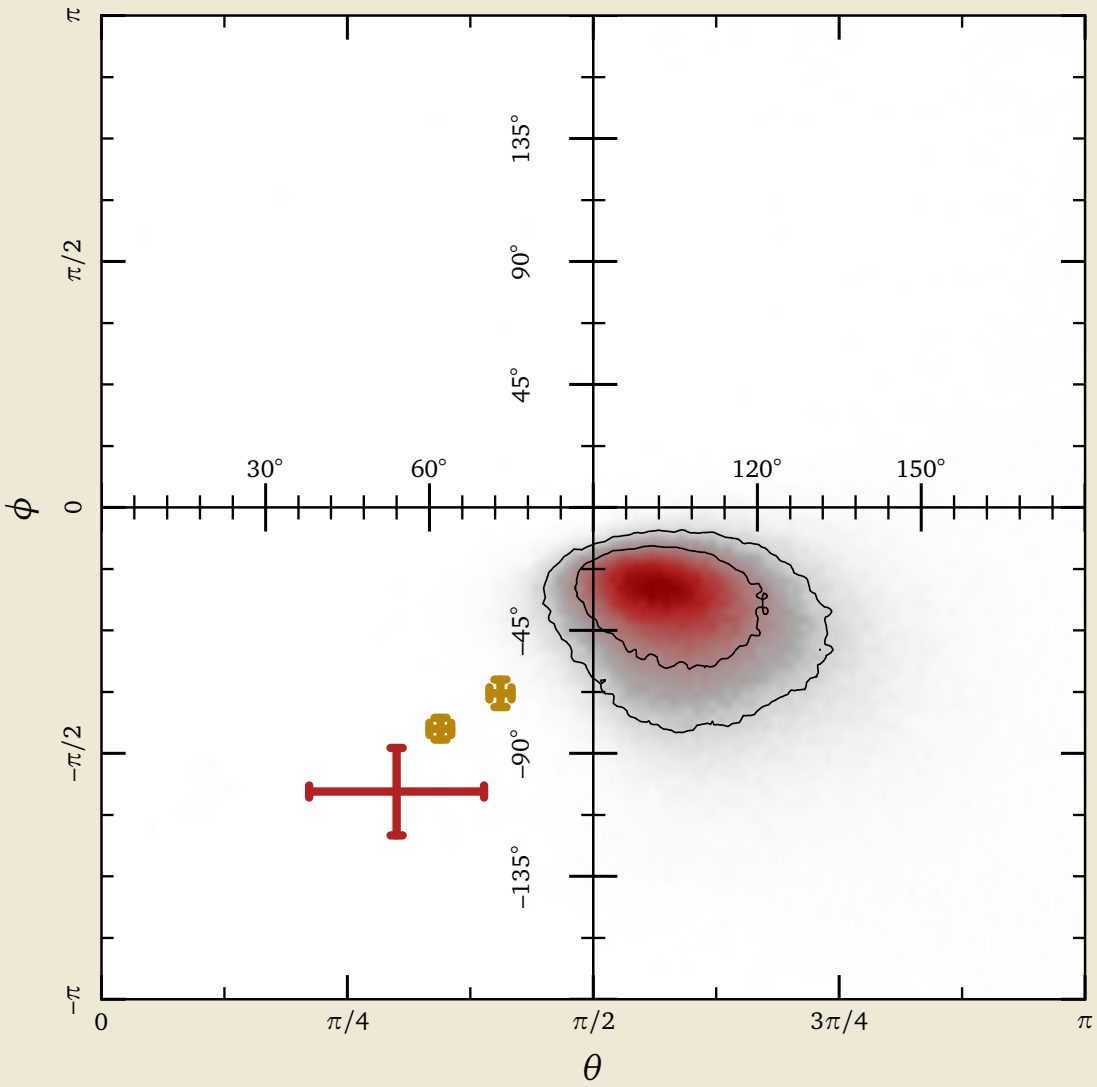

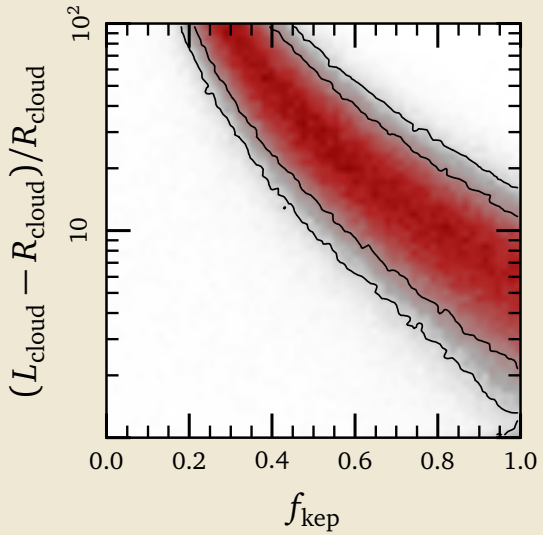

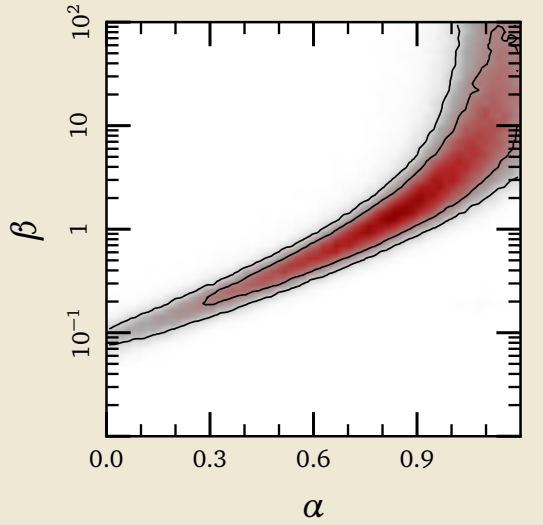

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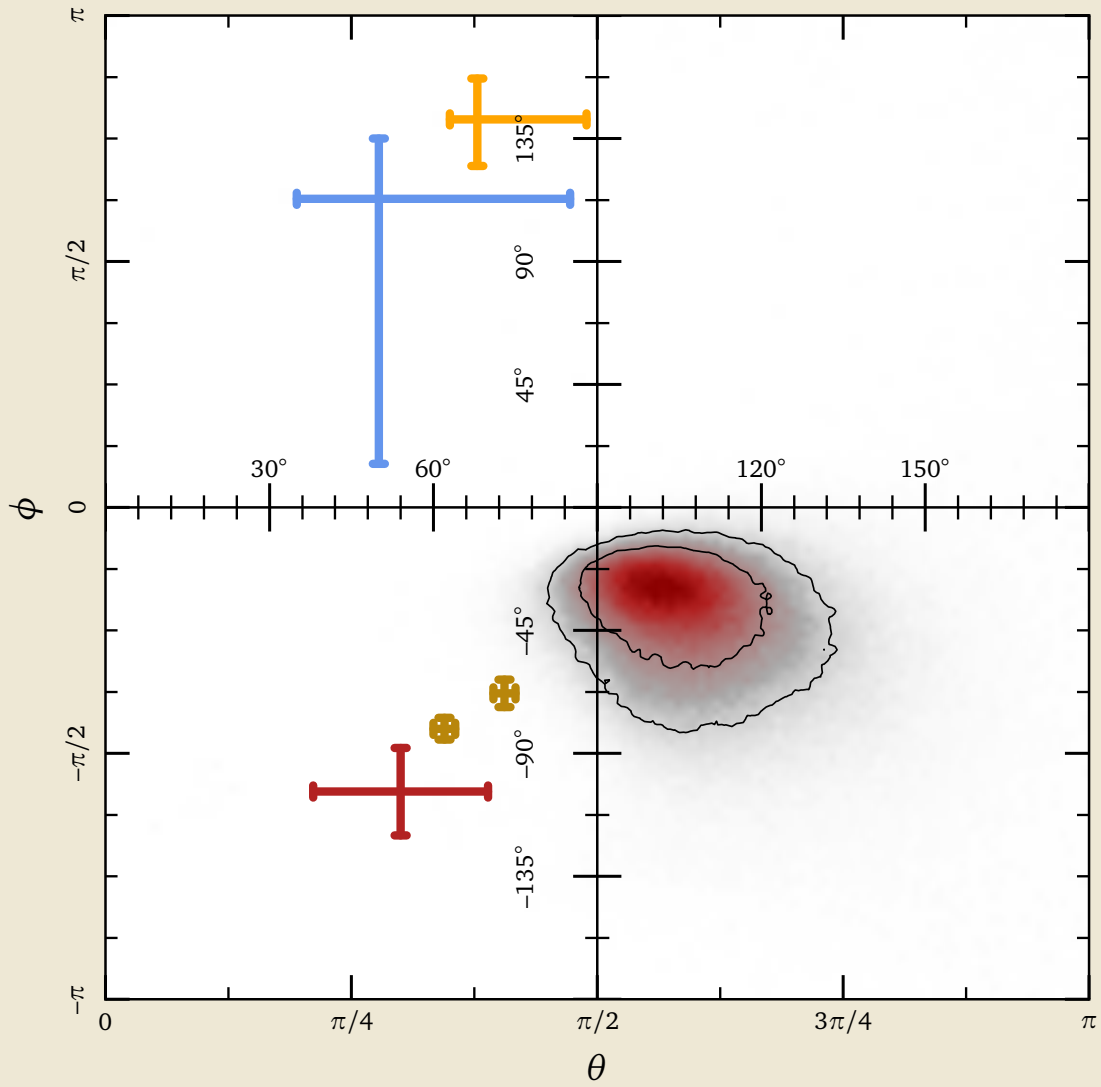

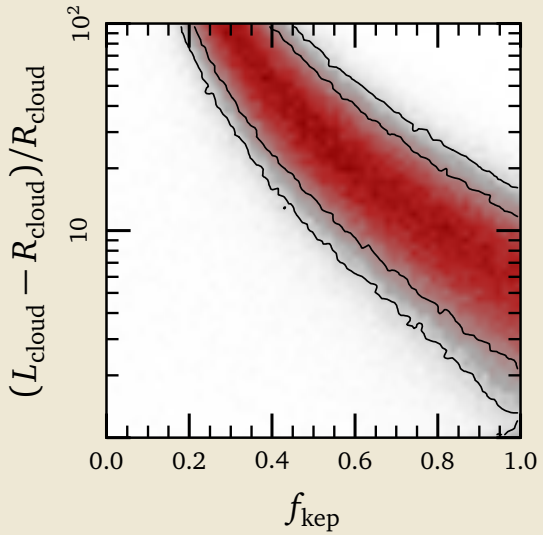

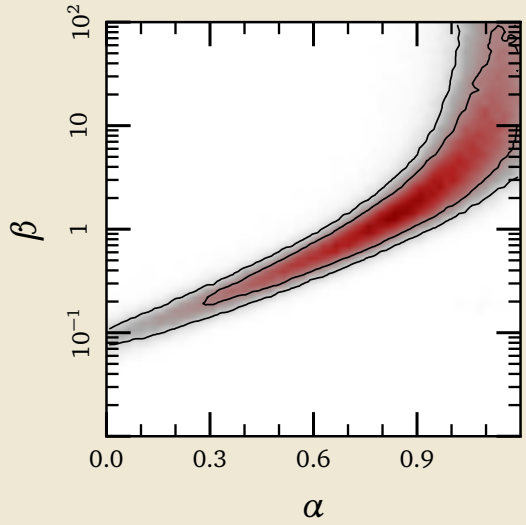

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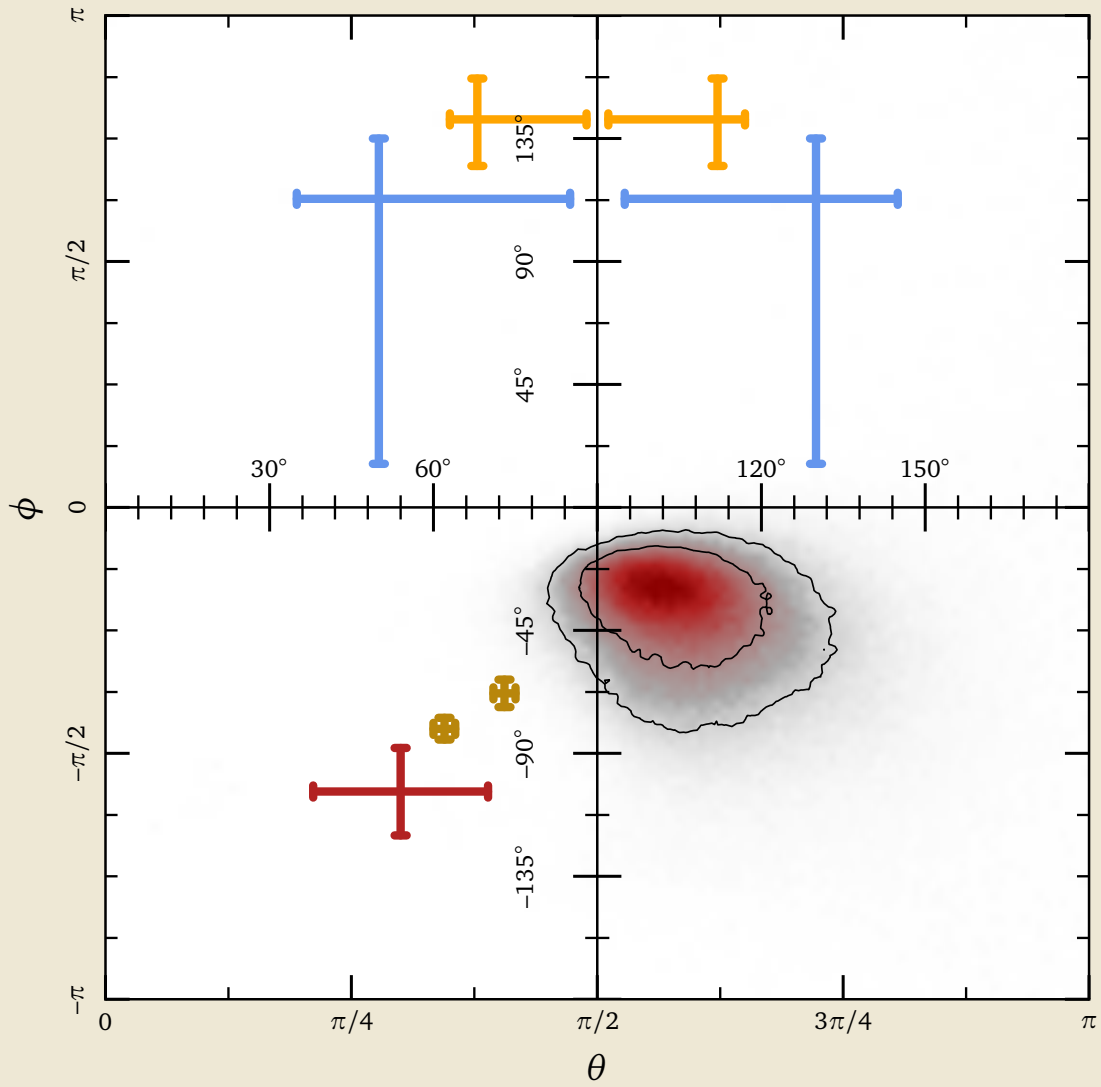

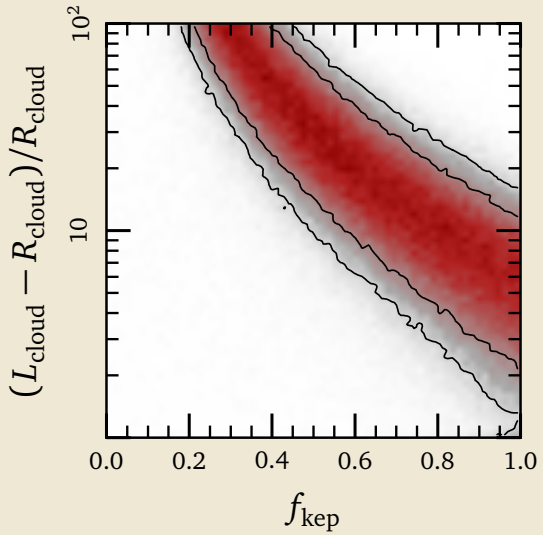

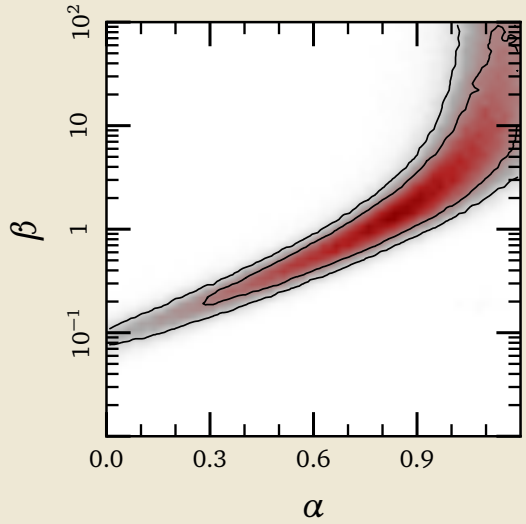

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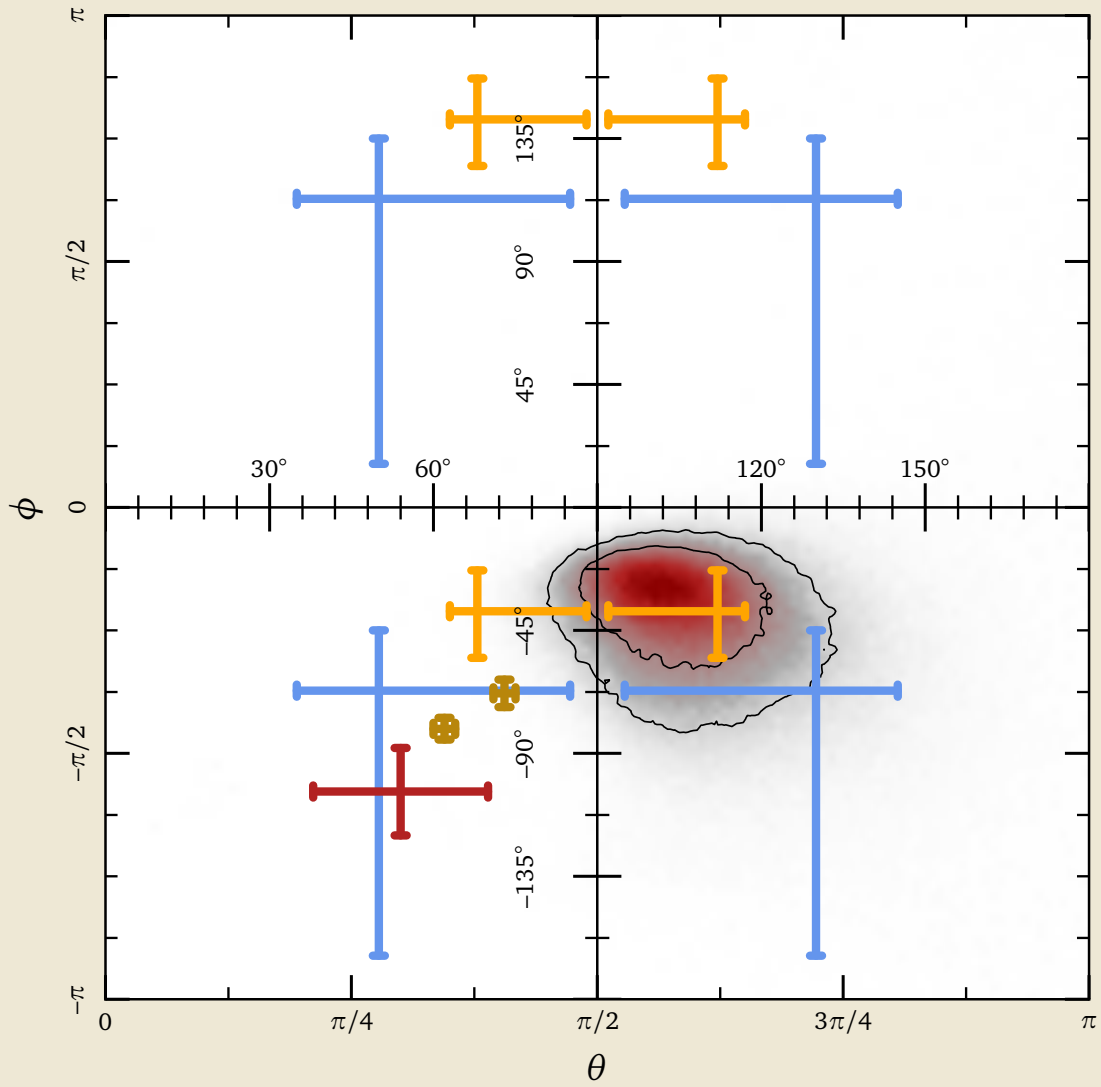
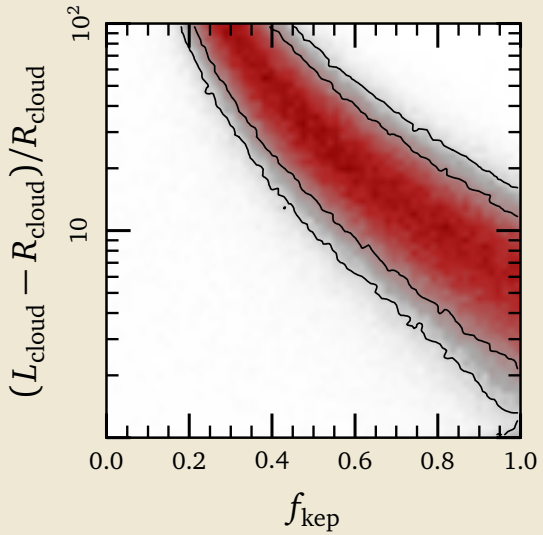
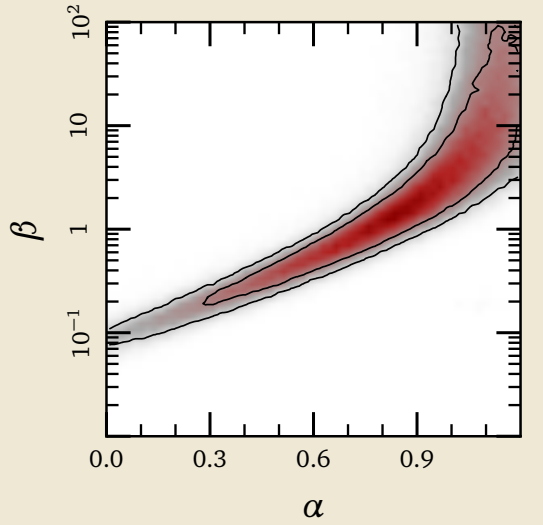
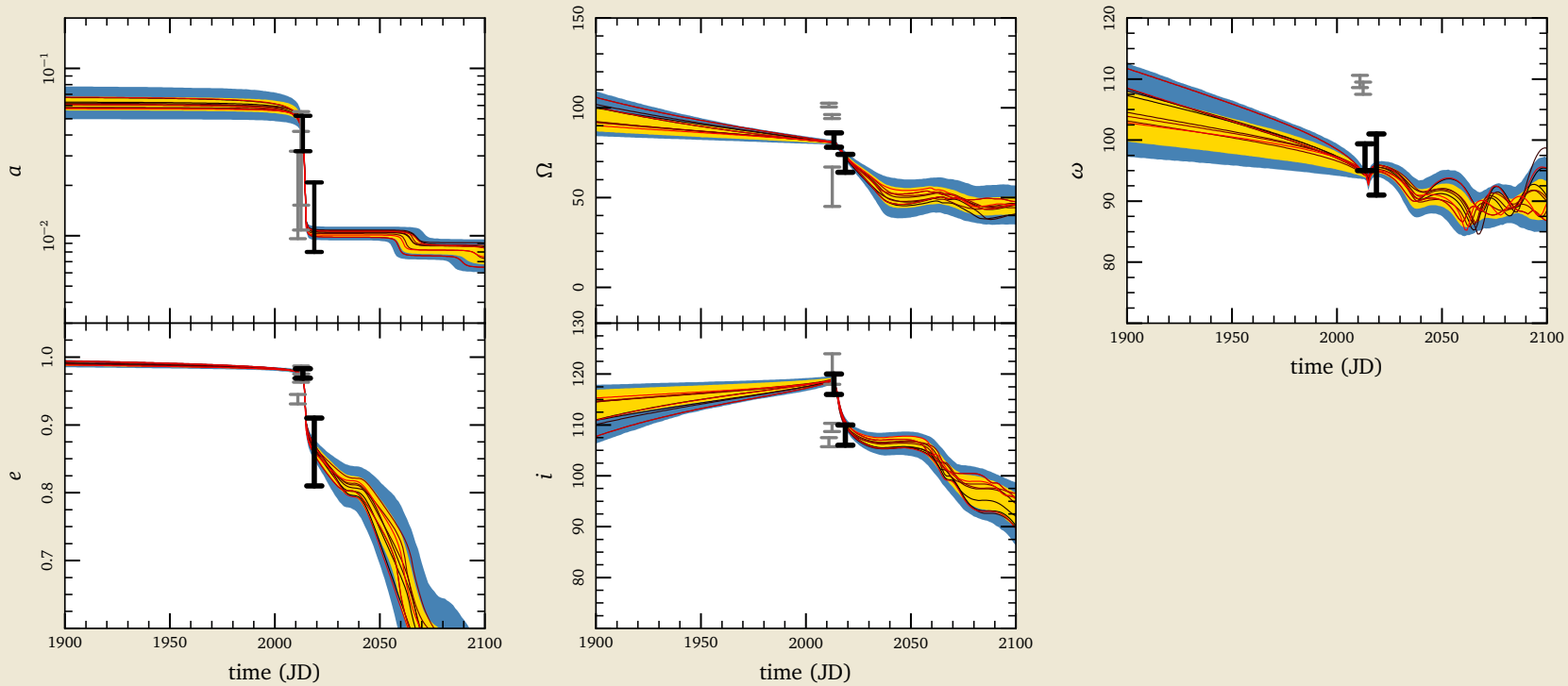






Future Evolution of G1 and G2

a testable prediction?



Summary

Magnetized Clouds

- Tangled magnetic fields *internal* to the clouds can inhibit disruption by shear instabilities.
- Magnetic fields *external* to the cloud can enhance the drag force, strongly coupling clouds to their environment.
- Depends on the internal structure of clouds; need to know how they formed to predict future evolution.

Accretion Flow

- Given enough assumptions, G1 and G2 can be used to constrain properties of the accretion flow in the galactic center.
- If it works, only constraint at intermediate radii.
- Find an orientation for the rotation axis consistent with EHT determinations at smaller scales.
- Please keep following G1!