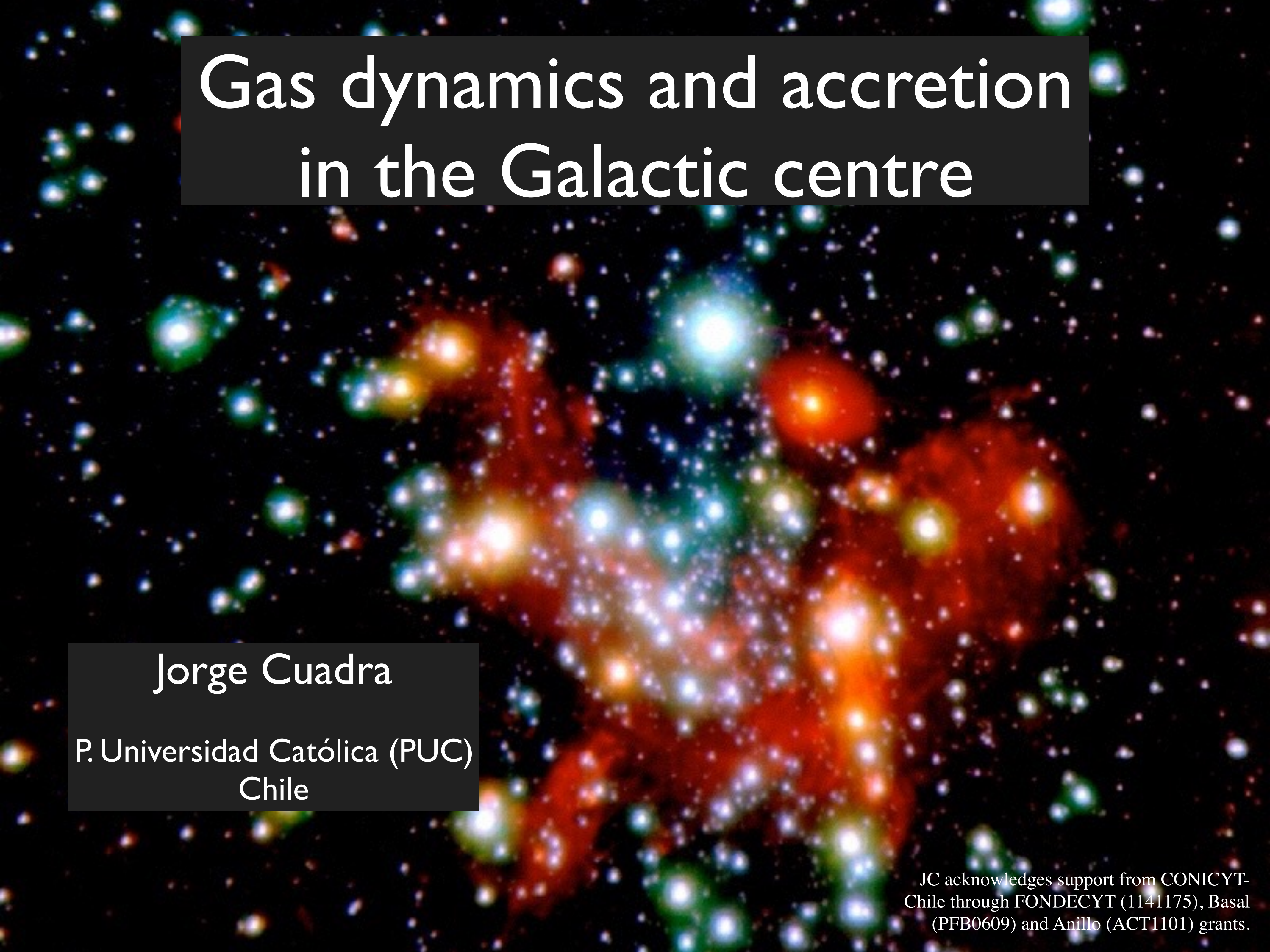
Gas dynamics and accretion in the Galactic centre



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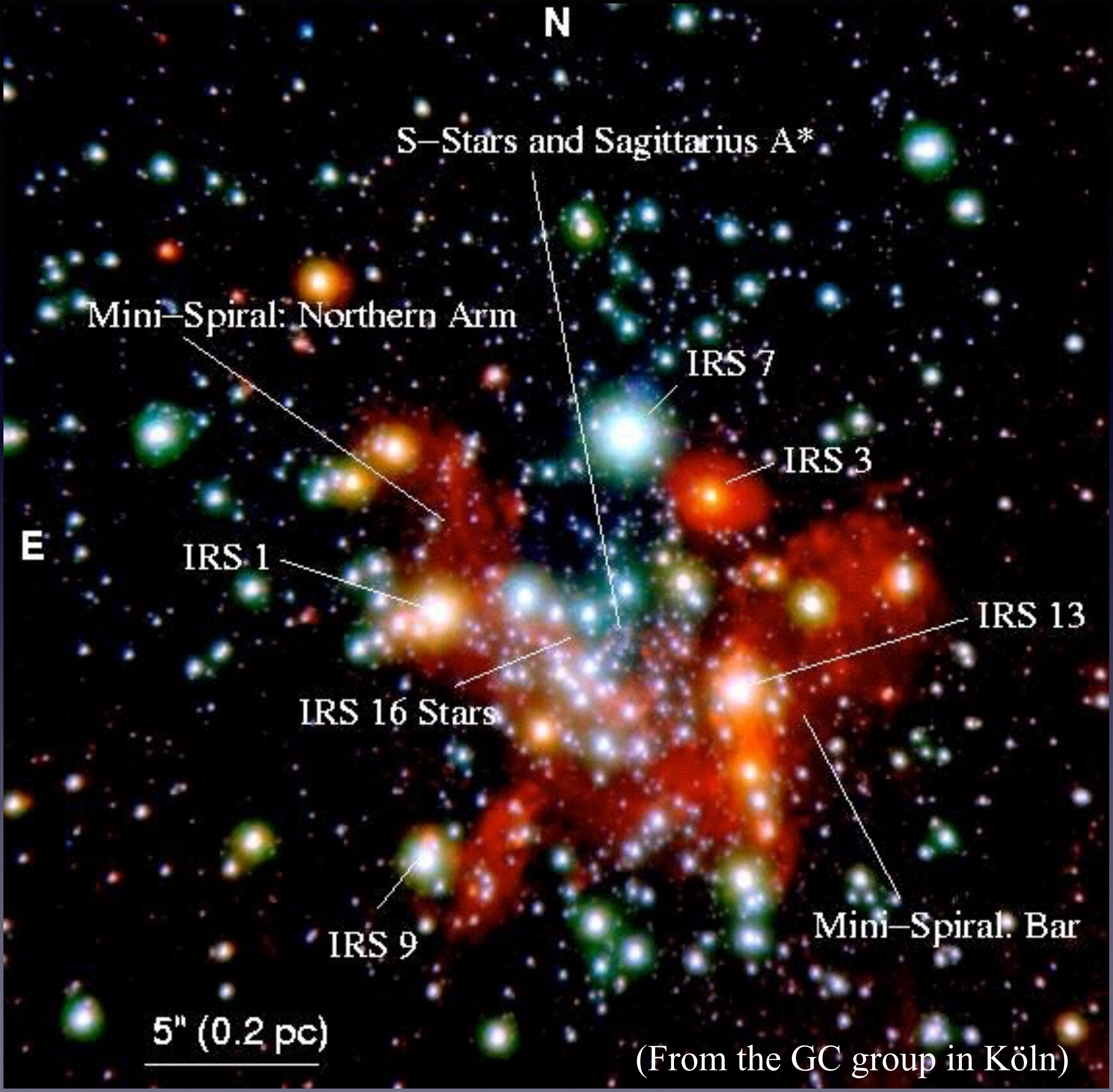


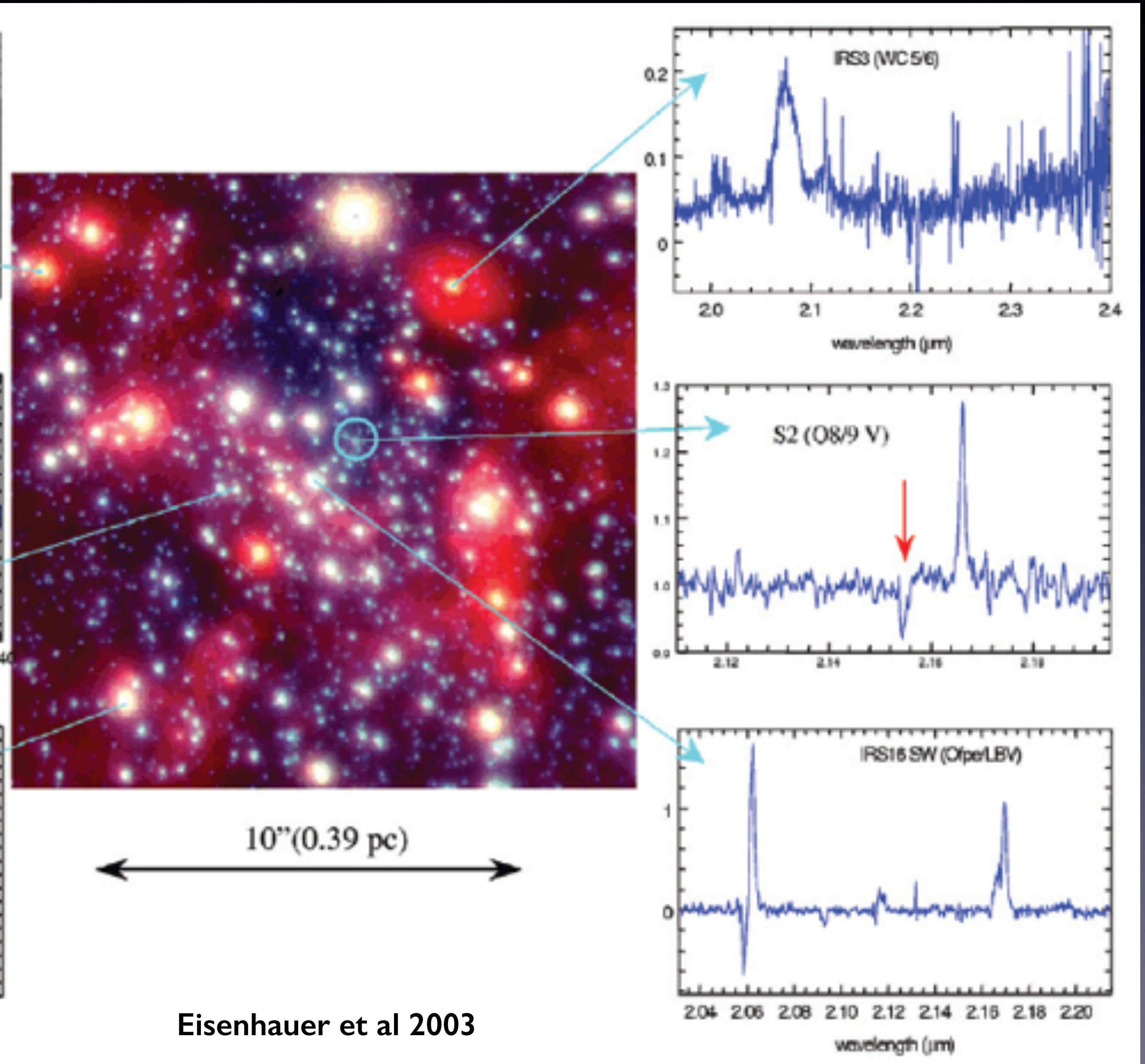
(From the GC group in Köln)

Mass losing stars in the GC

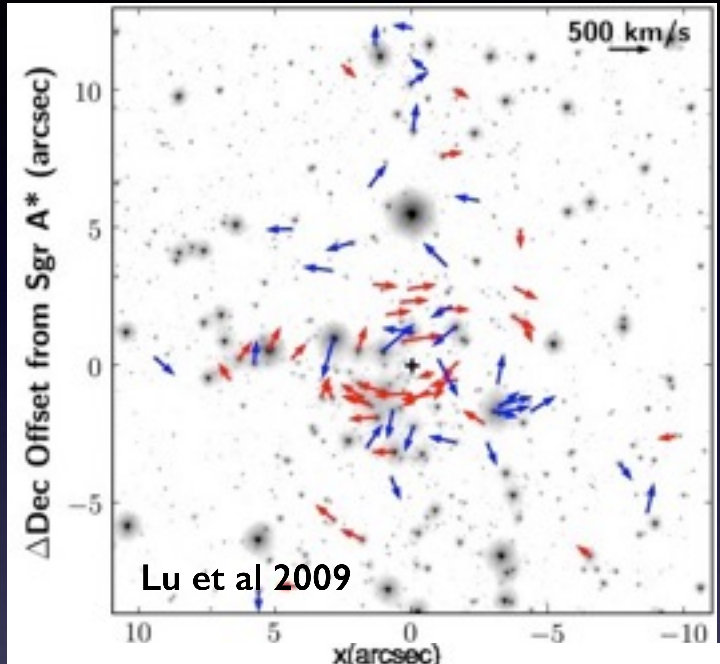
- Young massive stars.
- Many of them are Wolf-Rayet's.
- Mass loss rate up to $\sim 10^{-4}\ M_{\odot}/\ \mathrm{yr}$ each.
- Measured from individual spectra and confirmed by bow shocks.

Gemini Observatory/Francois Rigaut

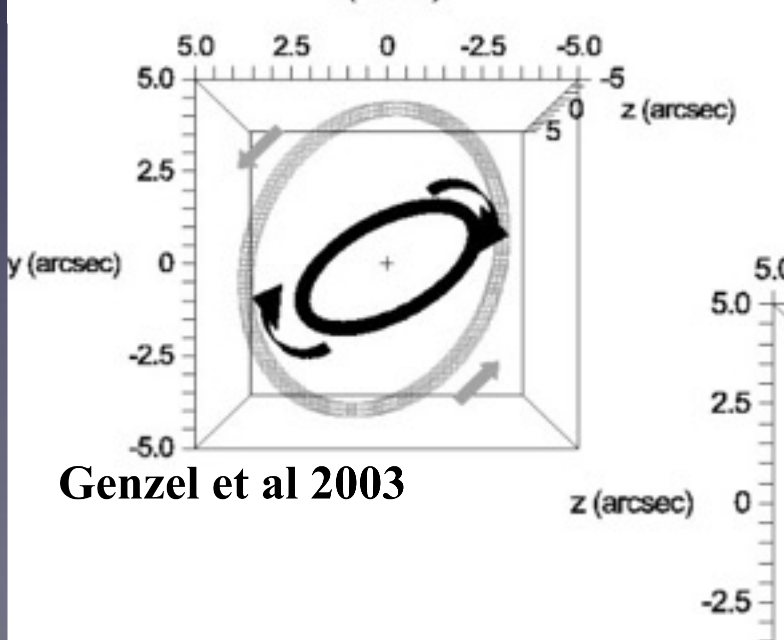
Data available:
stellar spectra and dynamics



Eisenhauer et al 2003



Lu et al 2009



Genzel et al 2003

Simulating the Galactic Centre Winds

- Use 30 Wolf-Rayet stars as gas sources.

(Paumard et al 2006)

- Measured 2d positions and 3d velocities.
  - Different assumptions for the 3d positions.

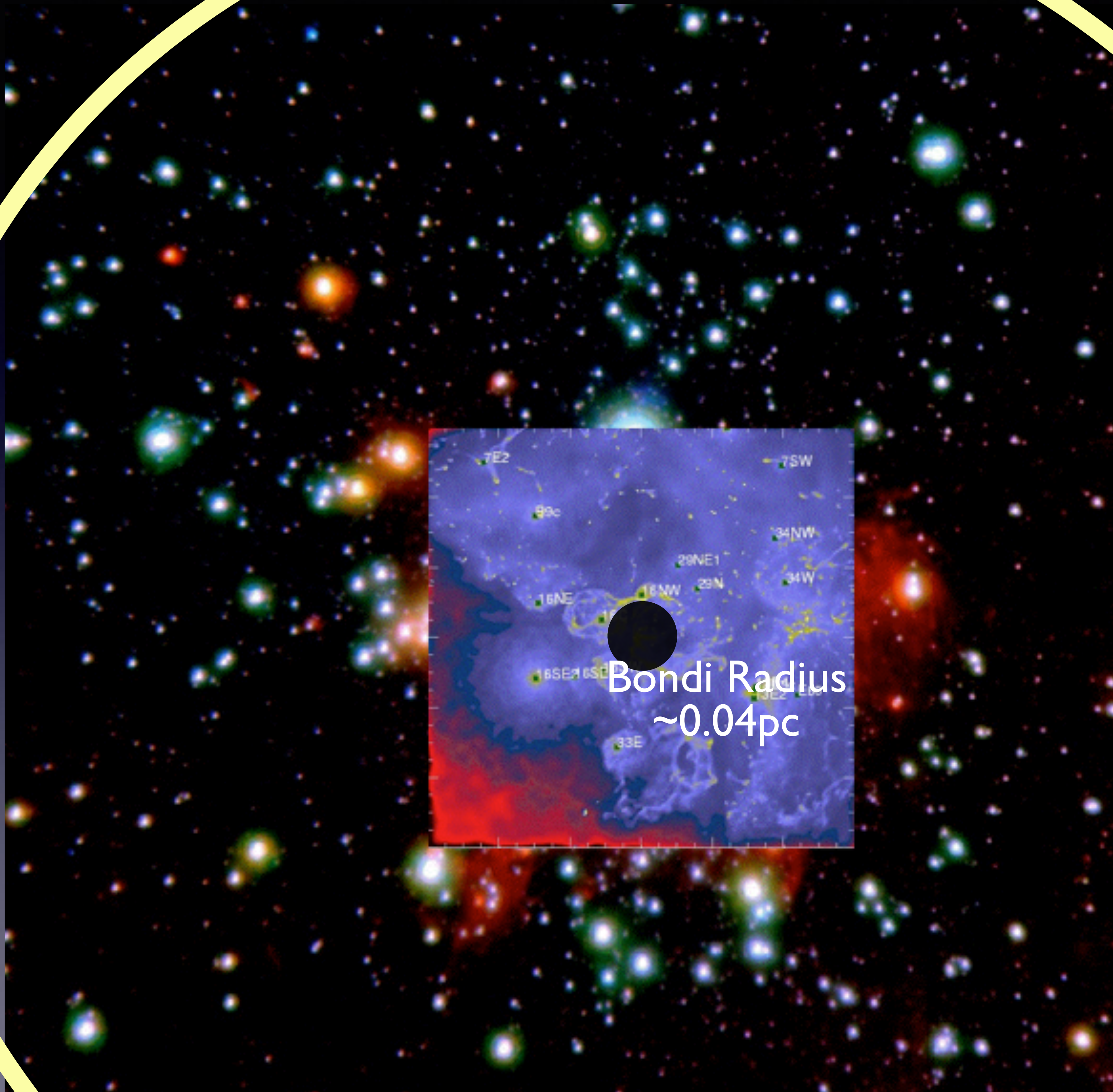
- Stellar wind properties measured for many of the stars.

(Paumard et al 2001, Martins et al 2007)

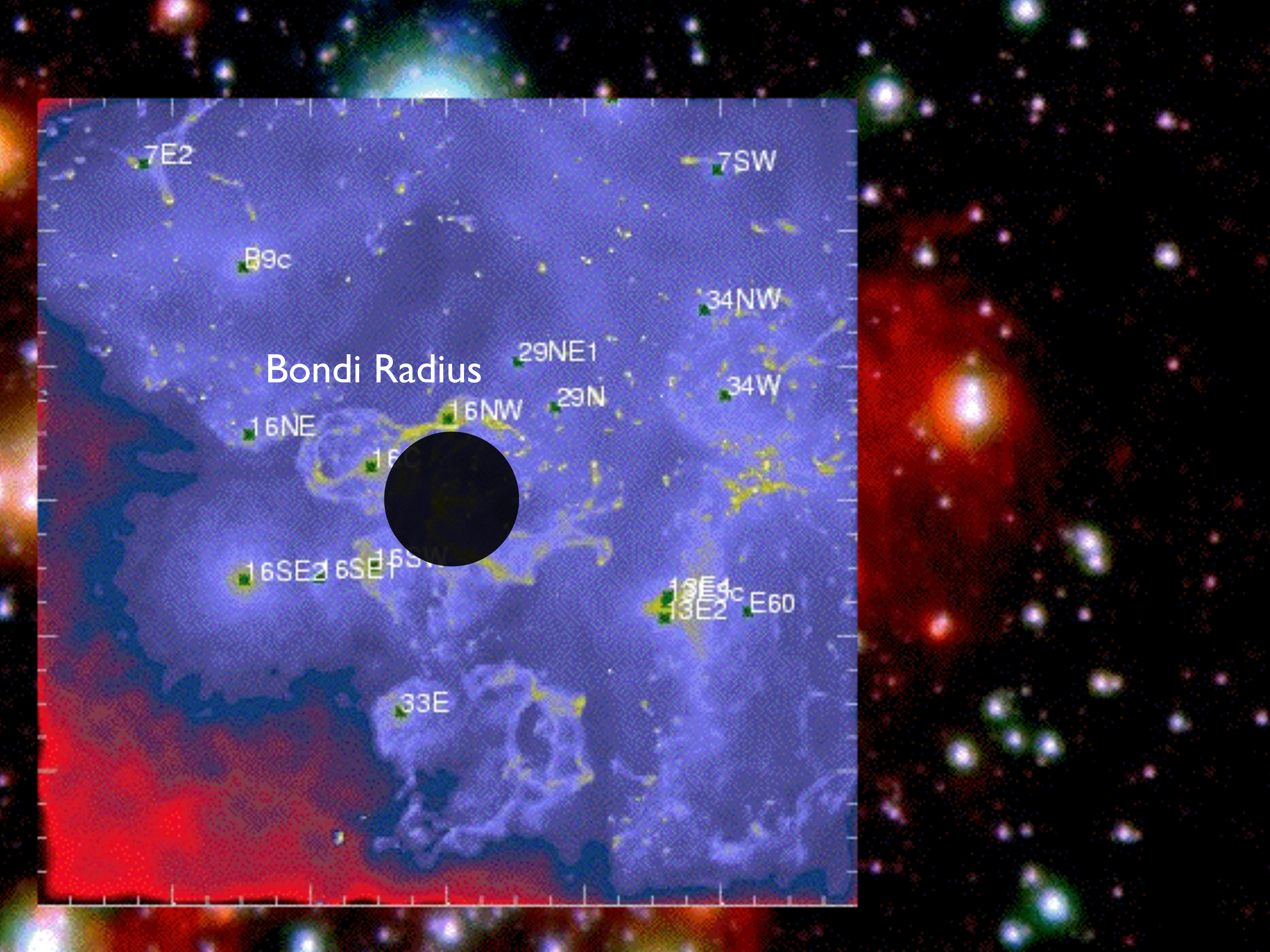
  - Typical mass loss rates ~ 10^{-5} M_{Sun} / yr .
  - Typical wind velocities ~ 600 - 2000 km/s (cooling can be important).

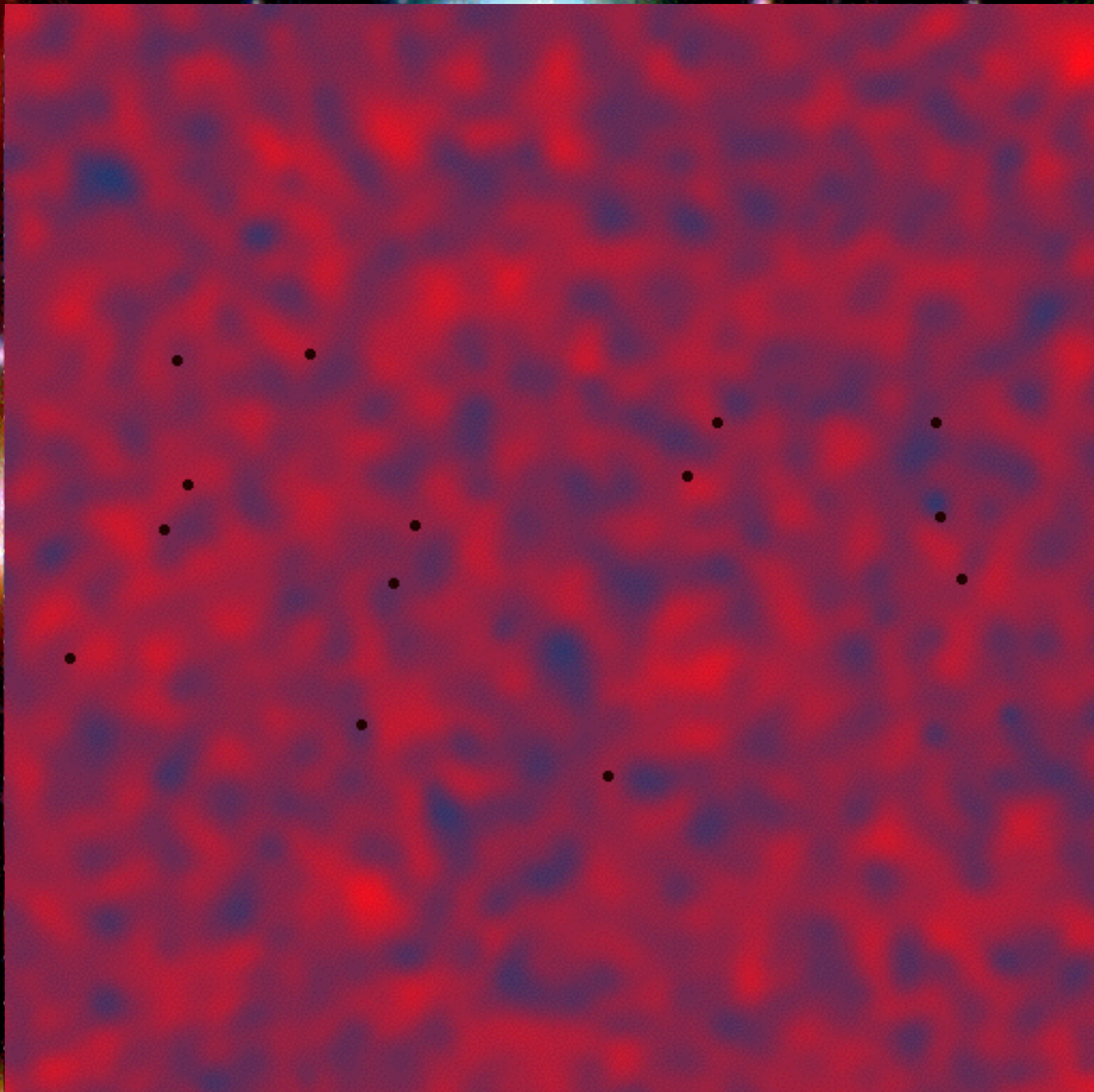
- Model using SPH code Gadget-2 (Springel 2005), starting ~1200 yr ago and let it evolve until the present time.

(Cuadra, Nayakshin, et al 2005, 2006, 2008, 2015)



Simulated
region
R~1pc


7E2
7SW
B9c
34NW
29NE1
Bondi Radius
34W
29N
16NW
16NE
16SE2
16SE1
13E2
E60
33E



Cooling instabilities drive clump formation.
(e.g., Vishniac 1994, Burkert & Lin 2000, Calderón et al 2015)

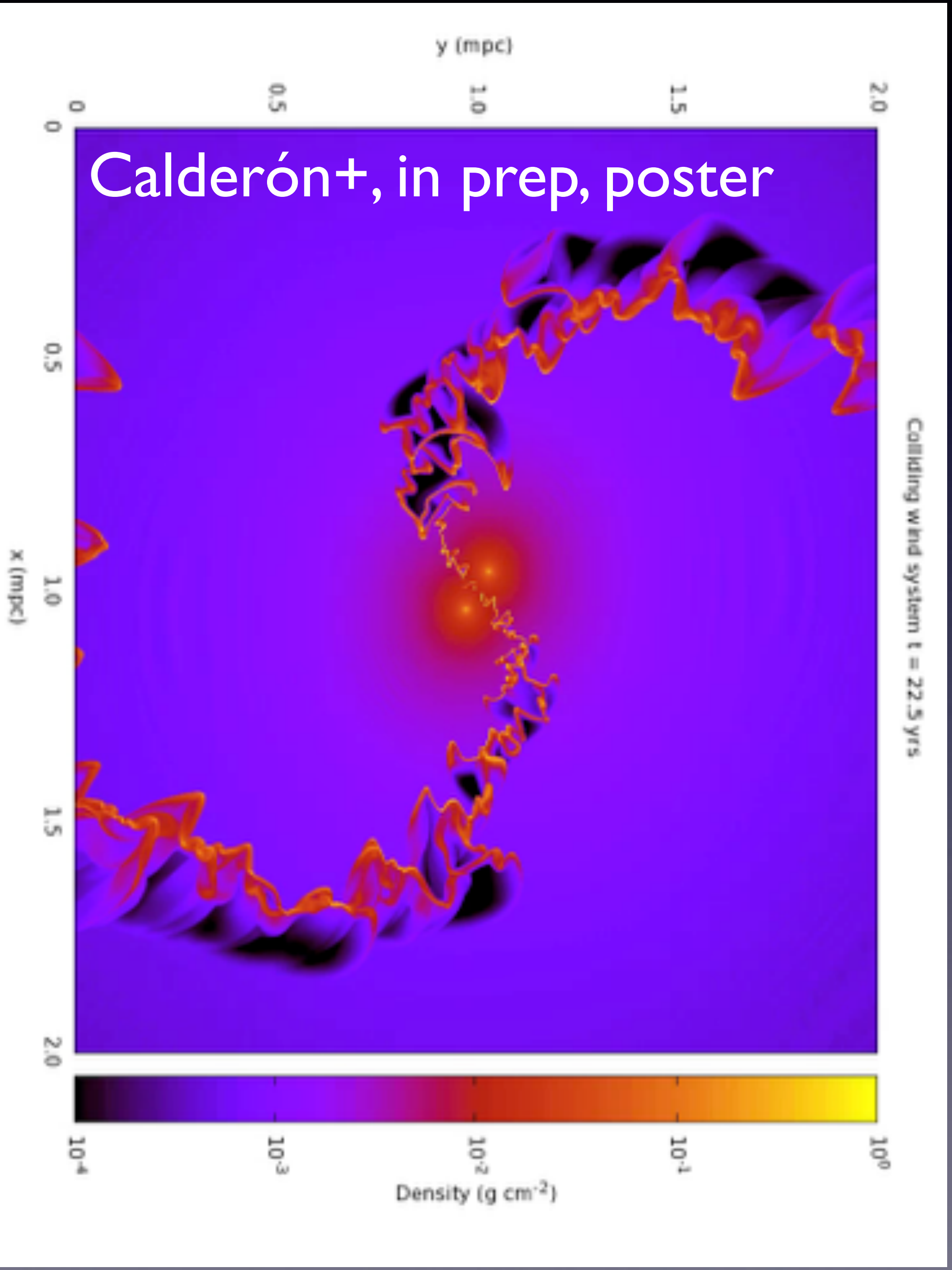
Many clumps form; a few in radial orbits produce a variable accretion rate.

Possible origin for G2. (Gillessen+ '12,'13)

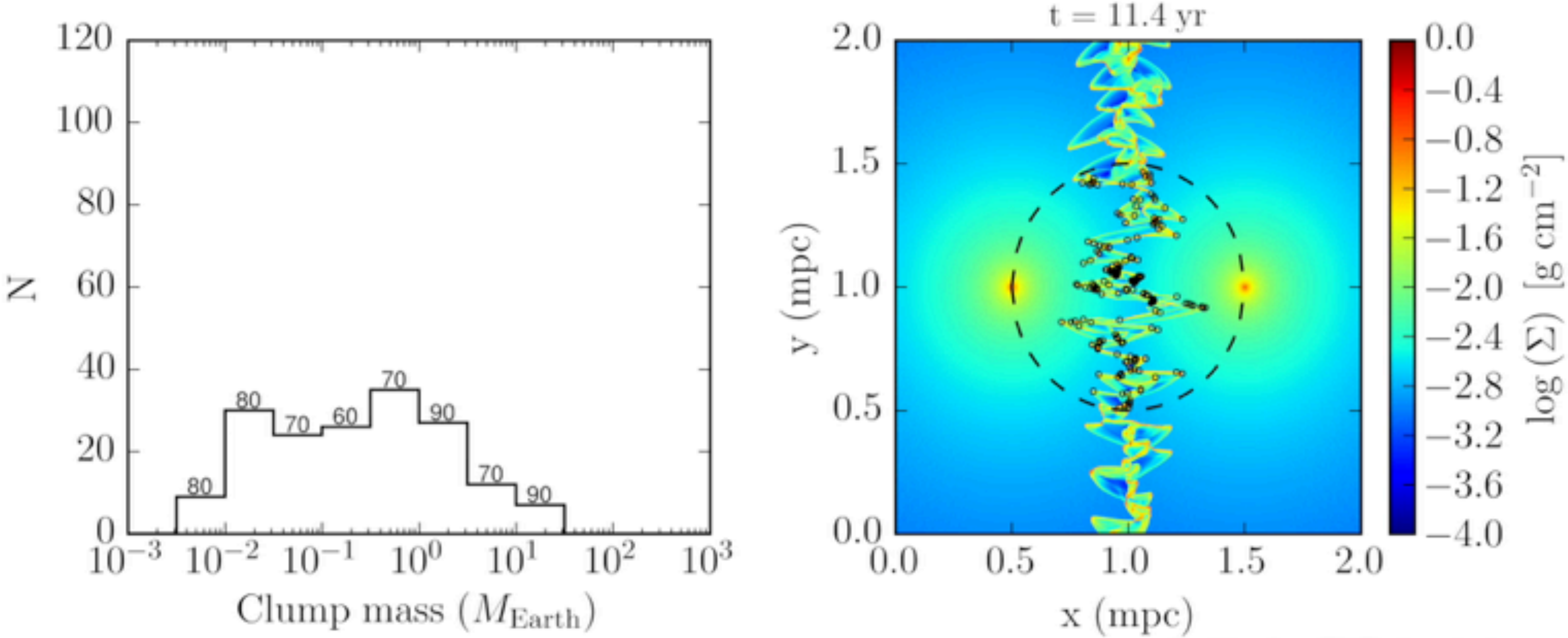
(Cuadra, Nayakshin, et al 2005, 2006, 2008, 2015)

Clump formation in wind collision shocks

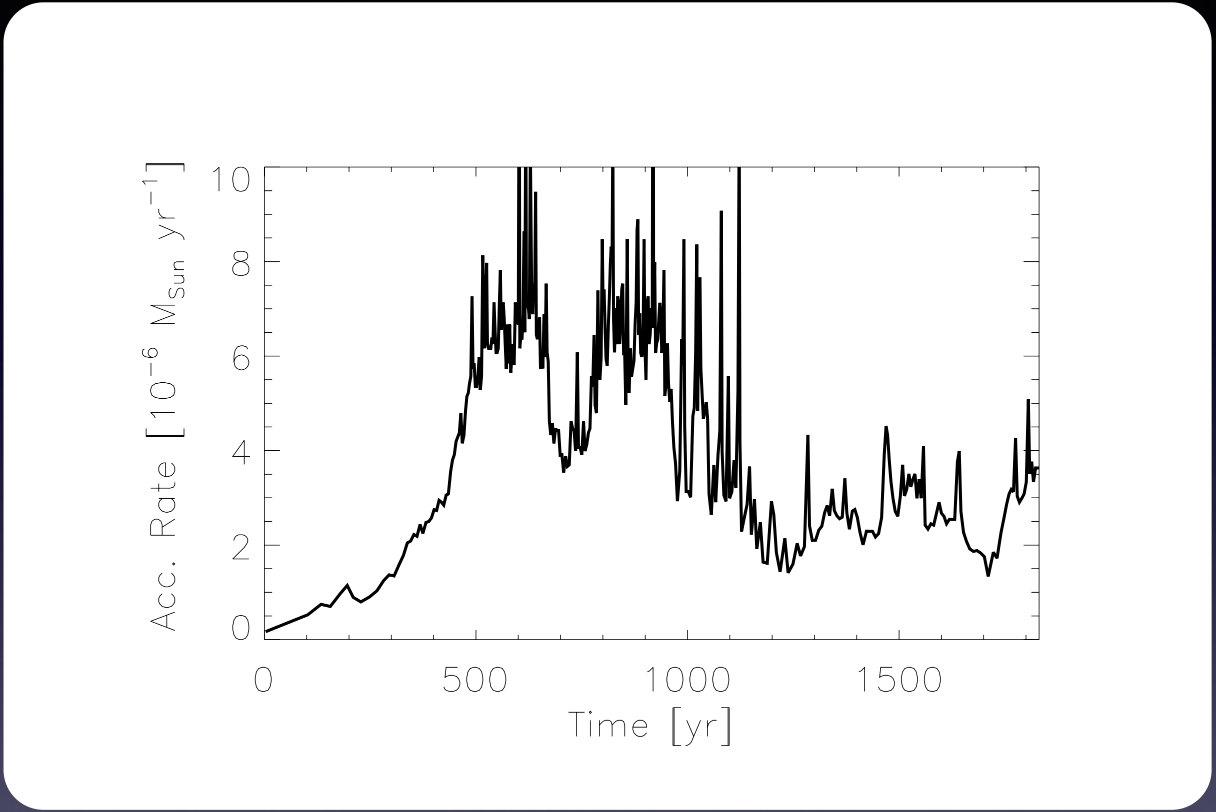
- Happens due to non-linear thin-shell instability. (Vishniac '94)
- Analytical models show is not as effective as it appears from SPH simulations. Still, close binaries are promising. (Calderón, Ballone, Cuadra+'15)
- Currently working on AMR models.



Get better estimates for clump masses, orbits, and rates

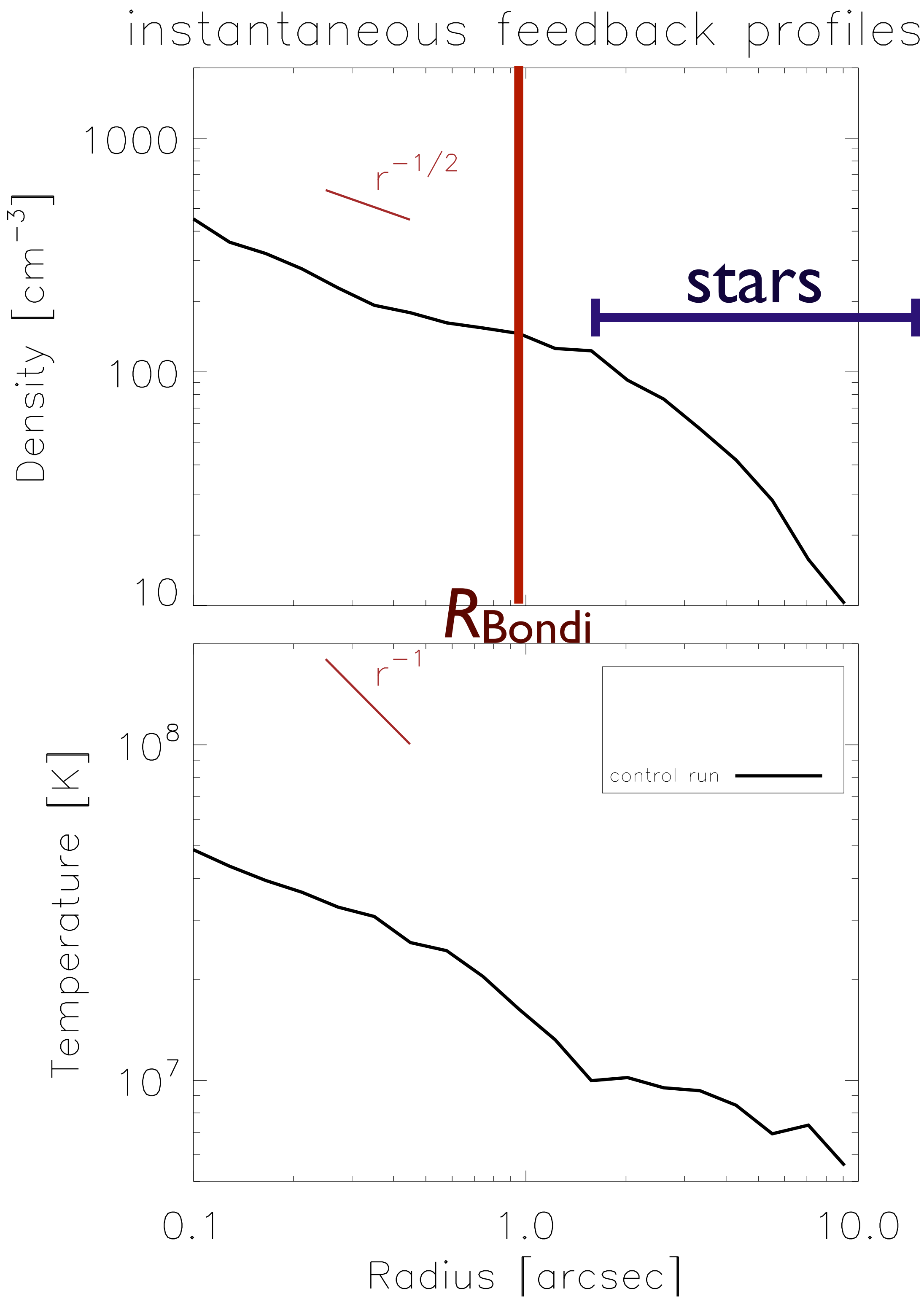


Calderón, PhD thesis in prep



Accretion rate as a function of time, measured at R_{sink} ~< 0.1 R_{Bondi}.

Consistent with Bondi estimate from x-rays.
(e.g., Baganoff+'03)



However, temperature profiles from simulations and observations (Wang+'13) don't match very well…

Adding an Outflow from Sgr A*

- From simulations and x-ray observations, we know accretion at Bondi radius ~$10^{-5\text{–}6}$ M_{sun}/yr.
  (e.g., Baganoff et al 2003)

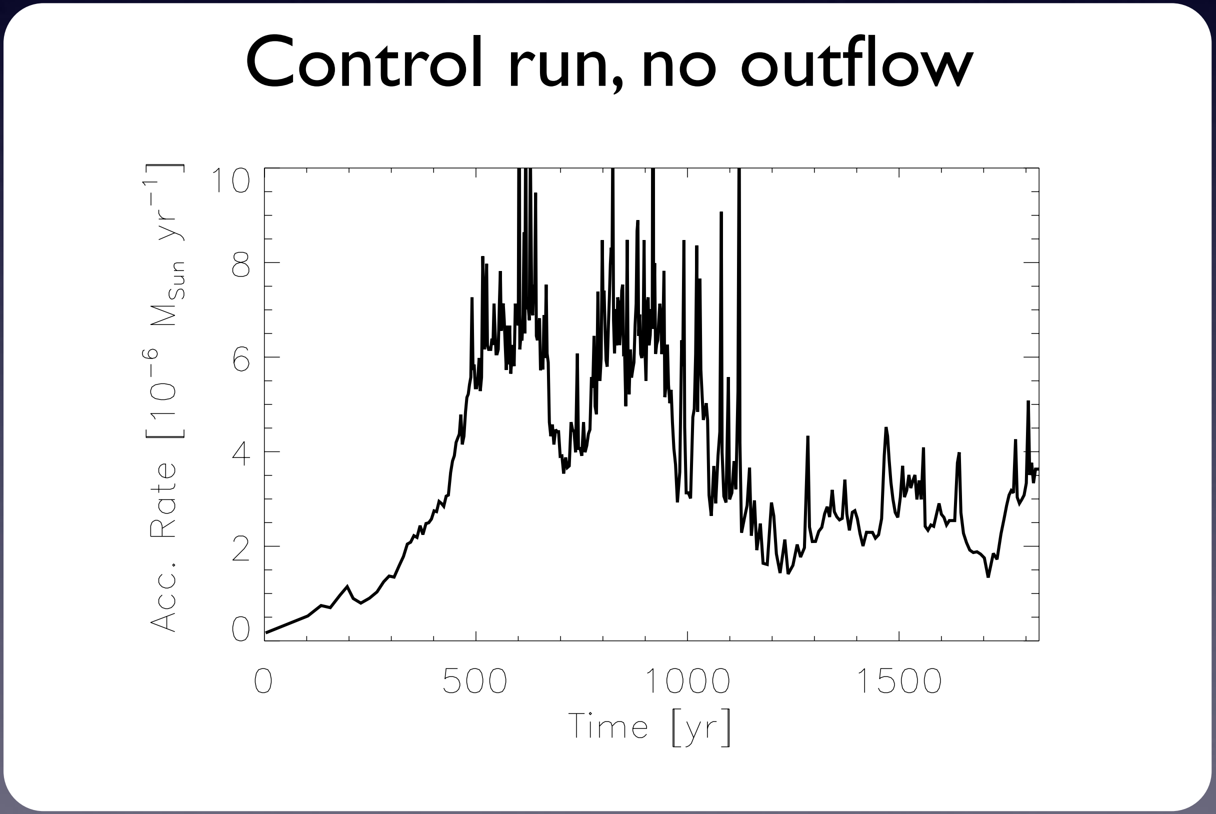
- Faraday rotation measurements imply accretion close to horizon ~ $10^{-7\text{–}9}$ M_{sun}/yr.
  (e.g., Marrone et al 2007)

- => Majority of captured gas must outflow!

- RIAF have hot, unbound particles
  => convection, outflows.
  (e.g., Blandford & Begelman '99; Narayan+ 2000; Quataert & Gruzinov 2000)

- Recent X-ray observations also imply outflow.
  (Wang et al 2013)

Instantaneous “mini-feedback” mode

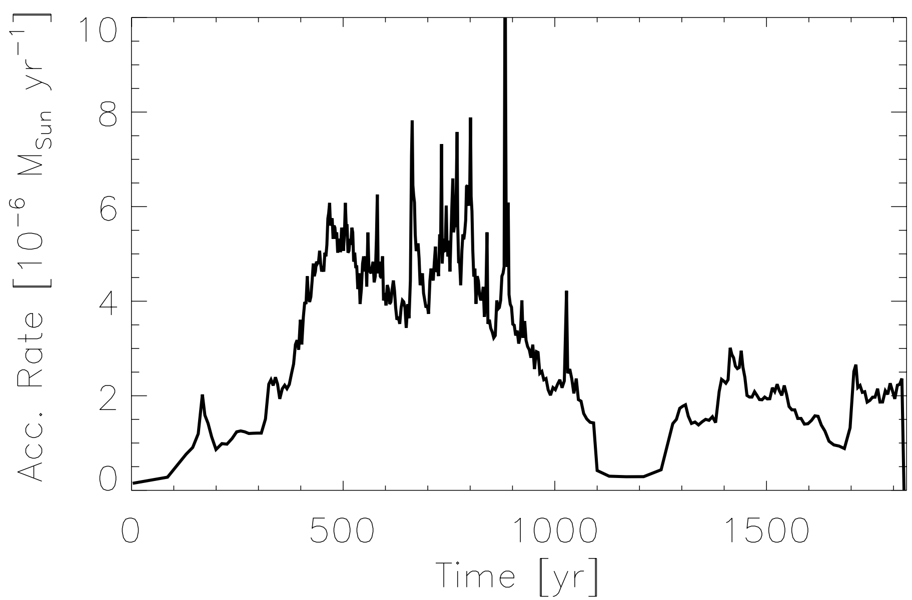


Capture rate as a function of time.

Instantaneous "mini-feedback" mode

Expel captured mass as soon as it enters 0.1" ≈ $10^4 R_{Sch}$.
Measure suppression of capture rate at that radius.

outflow vel = 2,000 km/s



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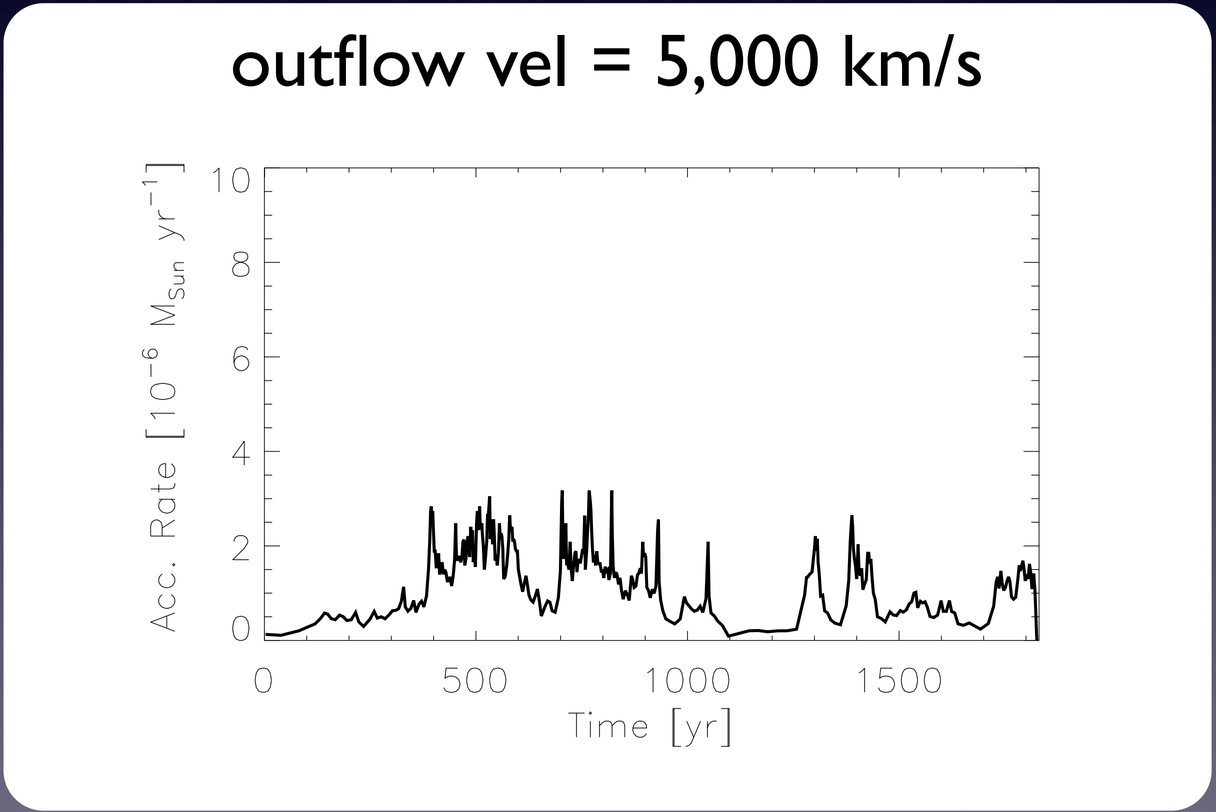

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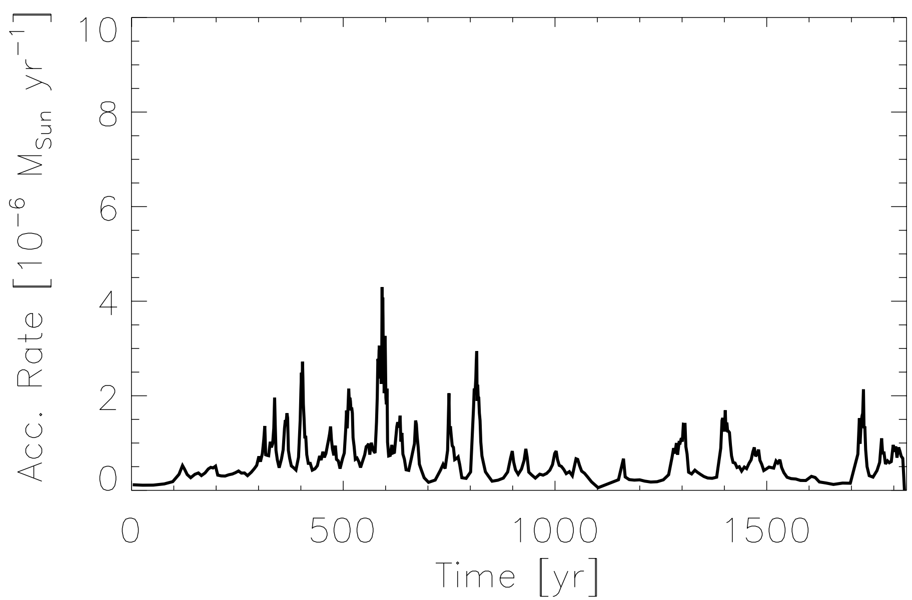

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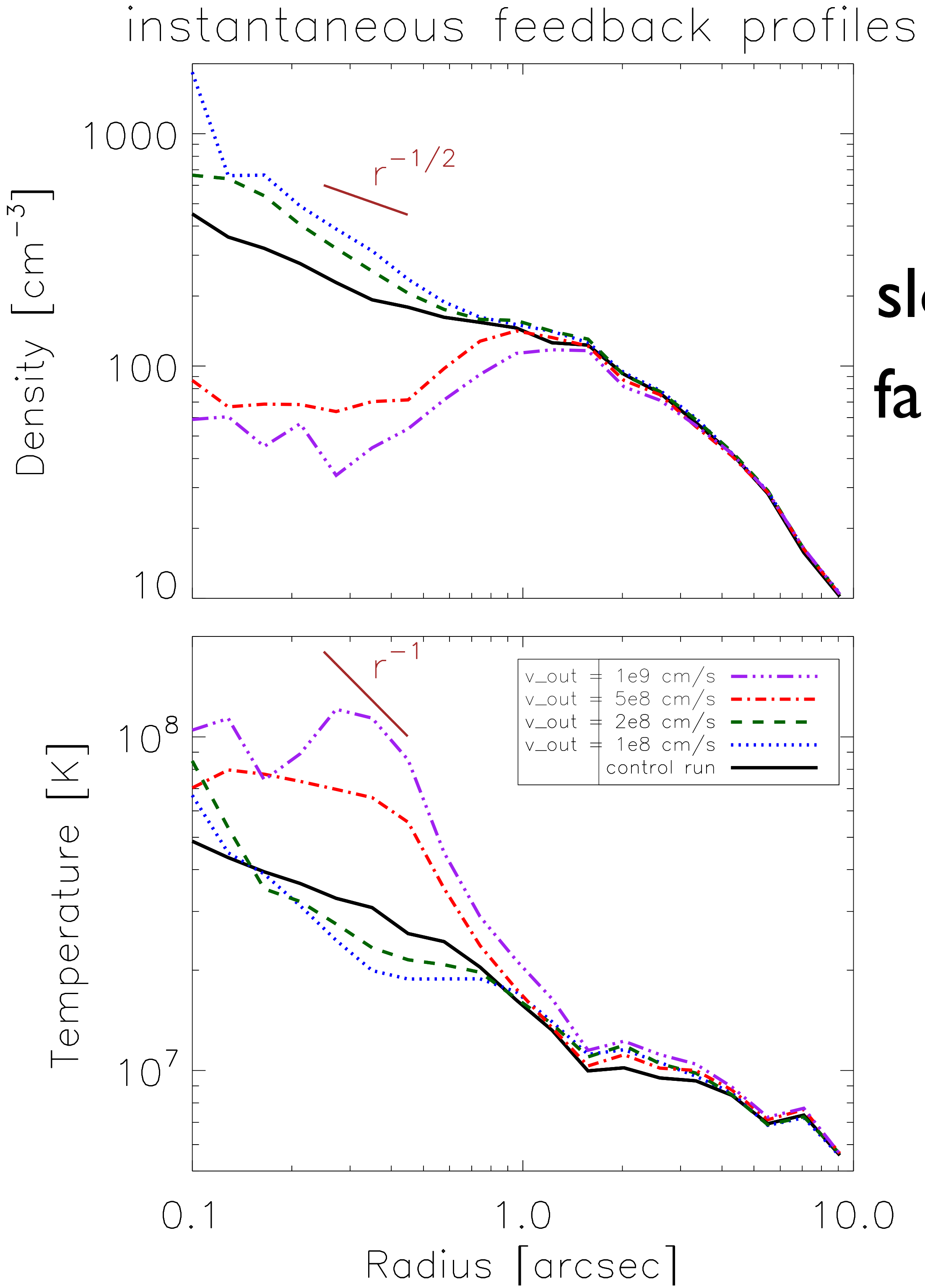


Control run, no outflow

slow outflow, 1000-2000 km/s

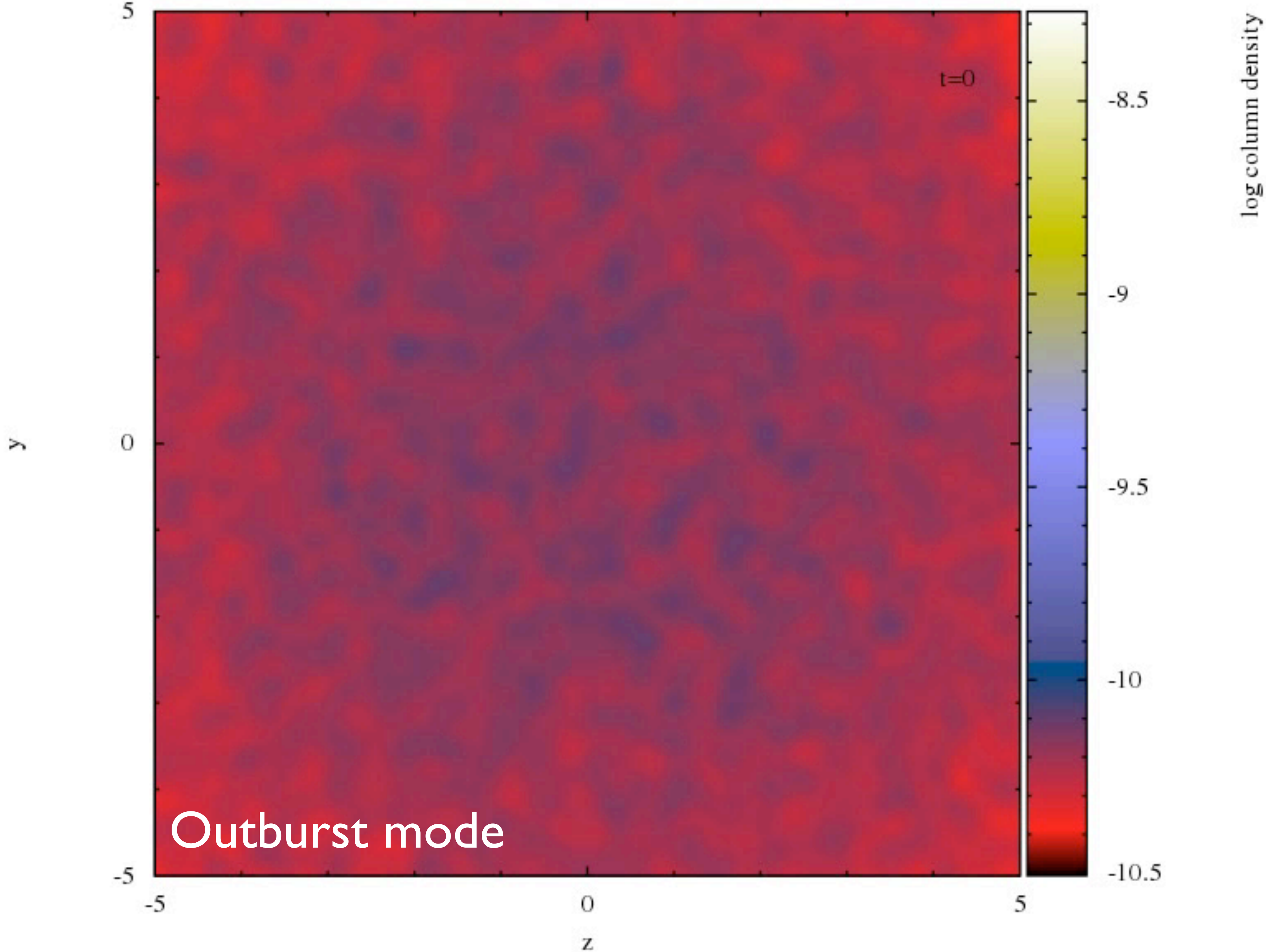
fast outflow, 5000-10000 km/s

None seems to fit observational constraints.
(Wang+'13)

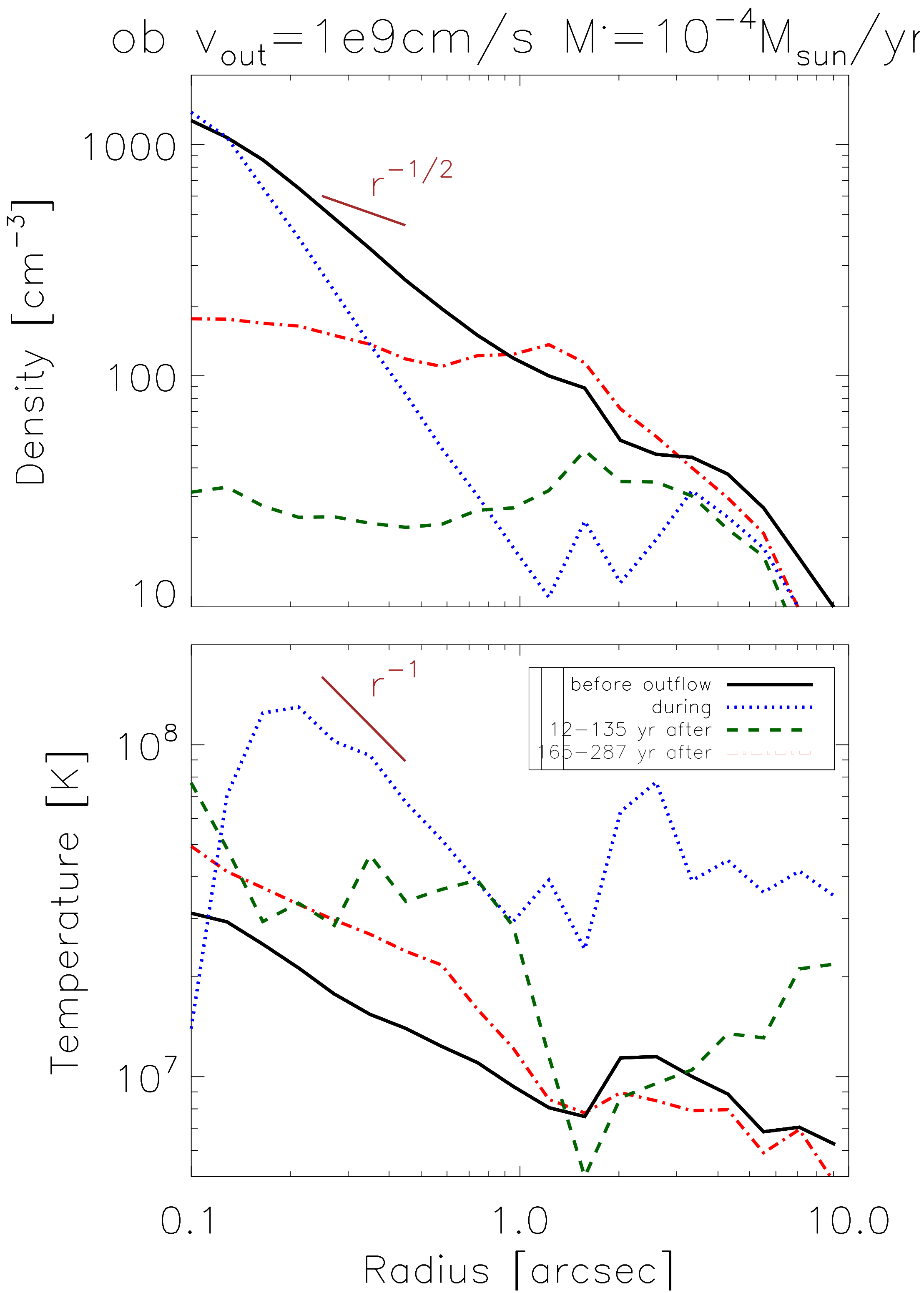
In any case, same physical conditions at Bondi radius give different capture rates there!

"Outburst" mode

- Sgr A* was more active in the past, as implied by X-ray echoes (e.g., Ponti+2010).
- Assume there was a relatively strong outflow, with mechanical power ~ 10^{39} erg/s.
- Have that outflow active for 300 yr and then turn it off.

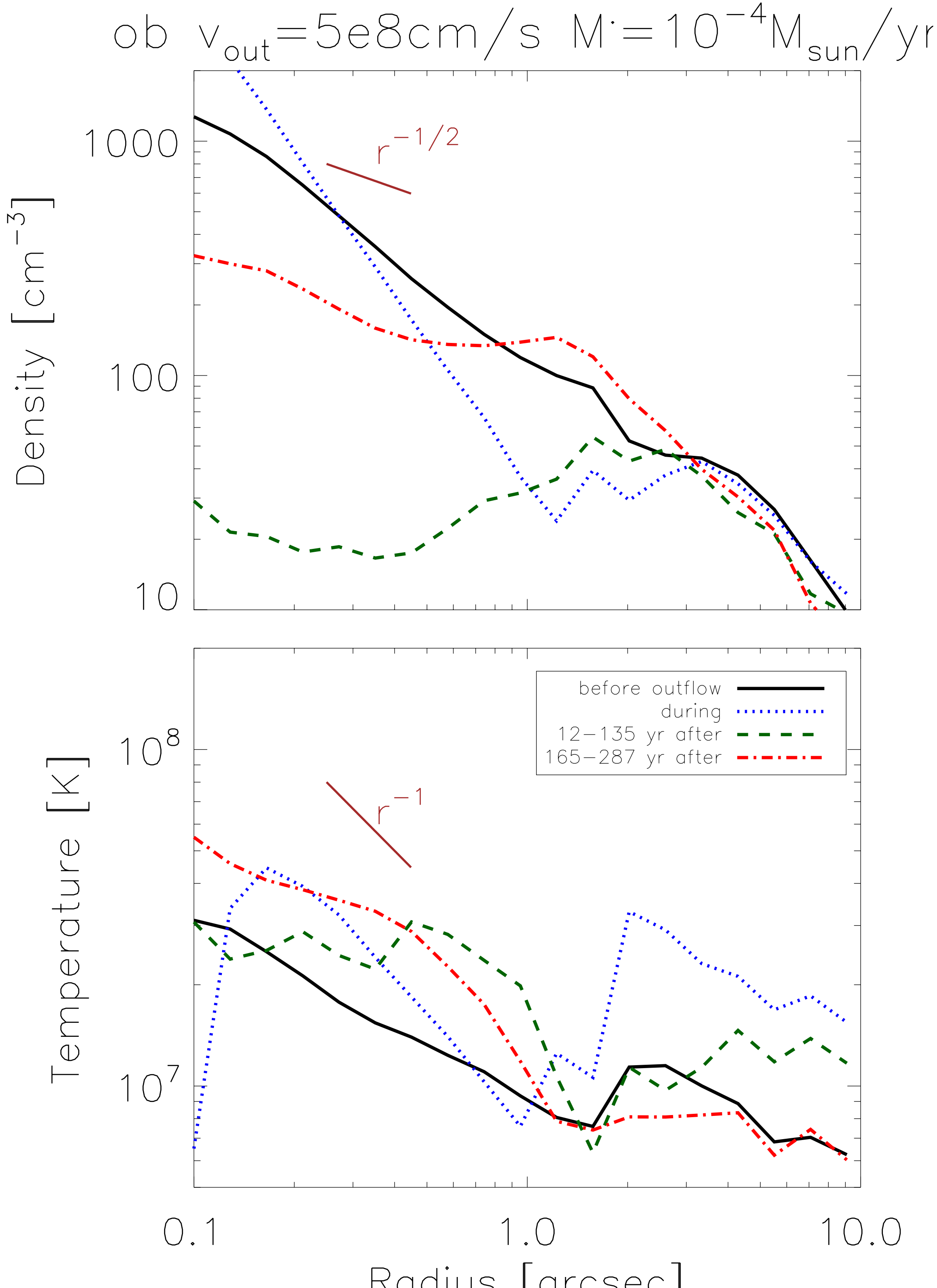


t=0
Outburst mode
y
z
5
0
-5
-5
0
5
-8.5
-9
-9.5
-10
-10.5
log column density



Outburst mode
vel = 10,000 km/s
$dM/dt = 10^{-4}\ M_{sun}/yr$

After ~200 yr
density profile
still too flat.



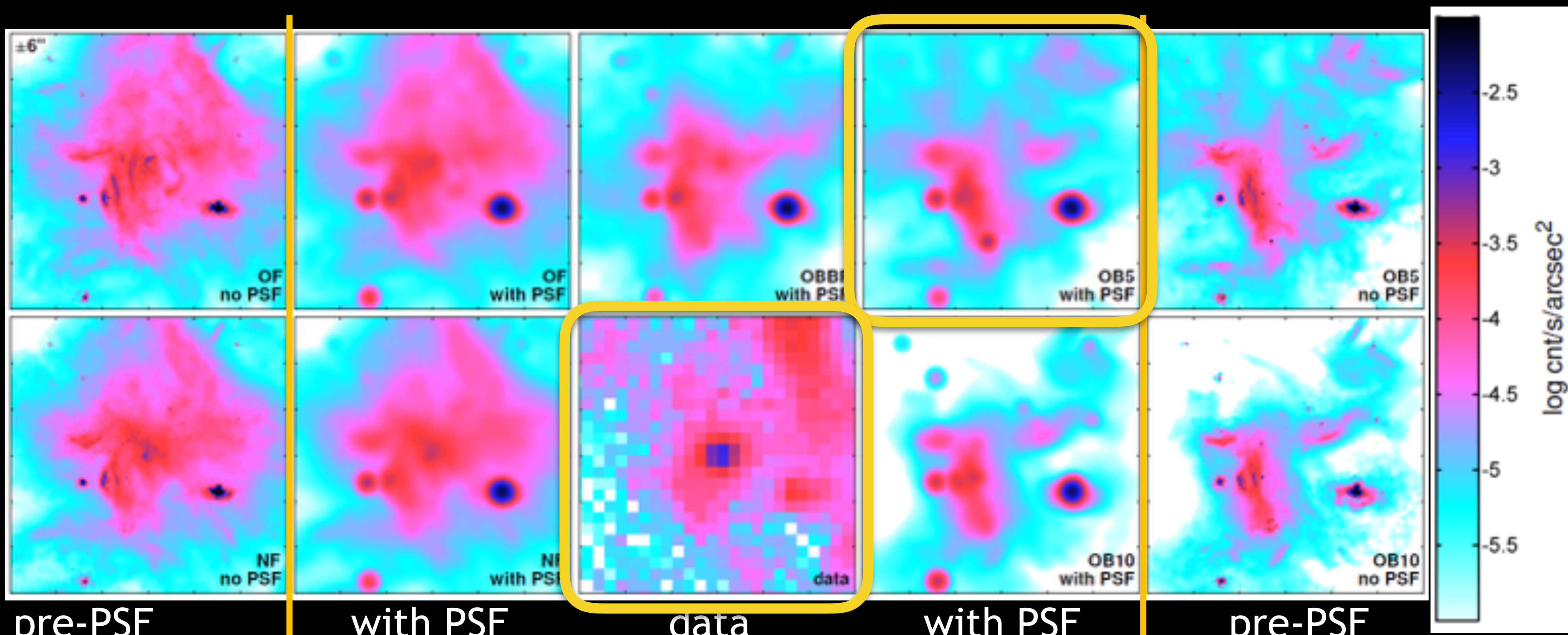
Outburst mode
vel = 5,000 km/s
dM/dt = 10^{-4} M_{sun}/yr

This model seems to match better the constraints.

Notice Sgr A* would then still be "recovering" from past outflow.

X-ray Image: Models vs. Data

(Russell, Wang, Cuadra 2016)

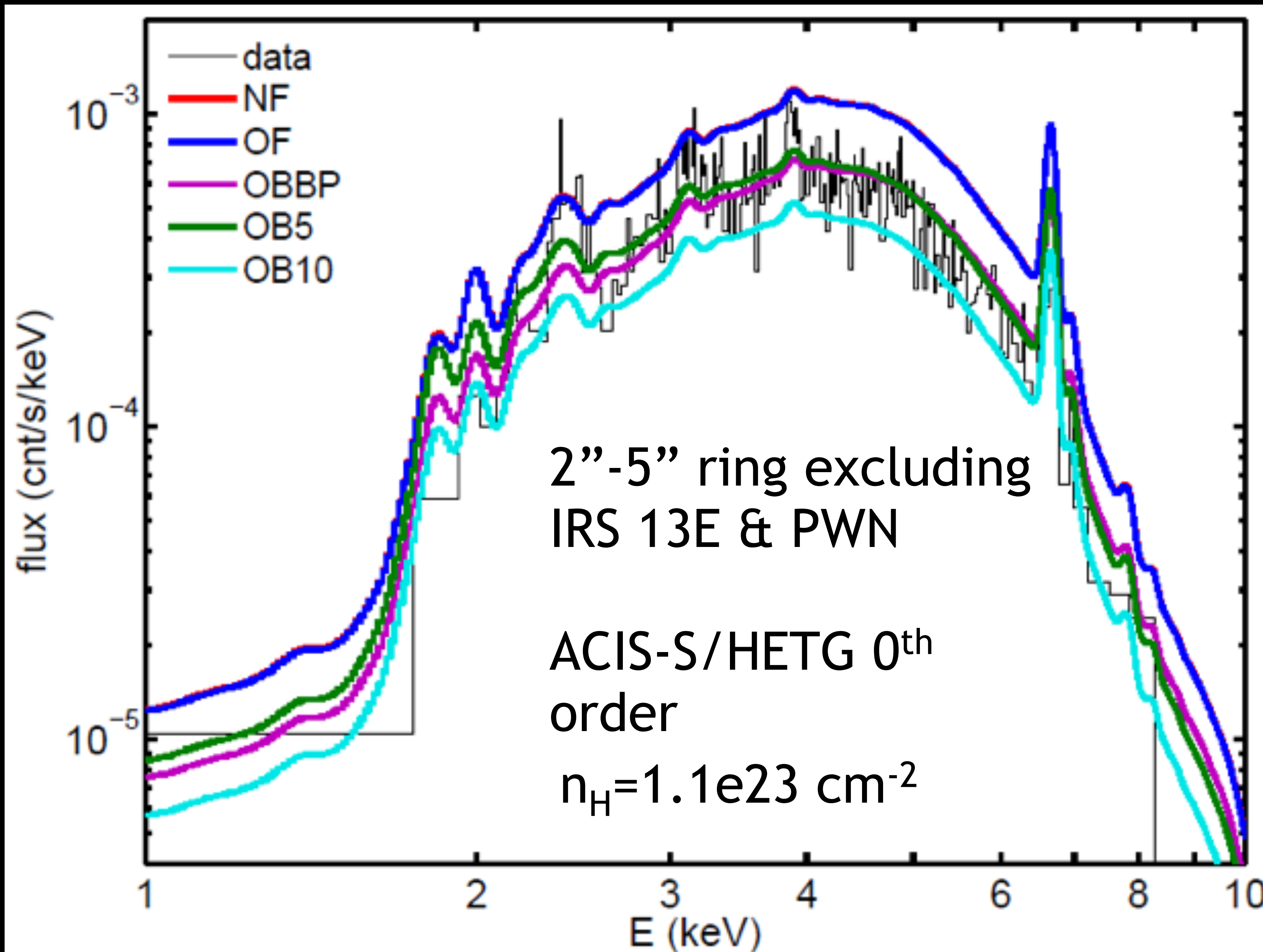


increasing
outflow
strength

4-9 keV
ACIS-S/HETG
0^{th} order

X-ray Spectra: Models vs. Data

(Russell+16)



Summary

- The Galactic centre provides a unique opportunity to model and observe the material feeding a SMBH.
- Models show that accretion rate is low, but variable at different time-scales.
- Formation and accretion of clumps. Related to G2?
- Outflows expected from SgrA* have impact on accretion and gas dynamics at Bondi radius and beyond.
- Observed X-ray emission consistent with strong outflow ($\dot{M}$~$10^{-4}M_{sun}$/yr, v~5000km/s $\rightarrow 10^{39}$erg/s) ~200 yr ago, but not later.