Three Preludes on a Theme of Magnetars
Last Week!
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Advertisement #1.

ASAS-SN

Stanek, Kochanek, Shappee + Since circa 2015

5 mounts: Chile (2), Hawaii, Texas, South Africa

4 telescopes/mount; 14cm; 2k×2k CCDs

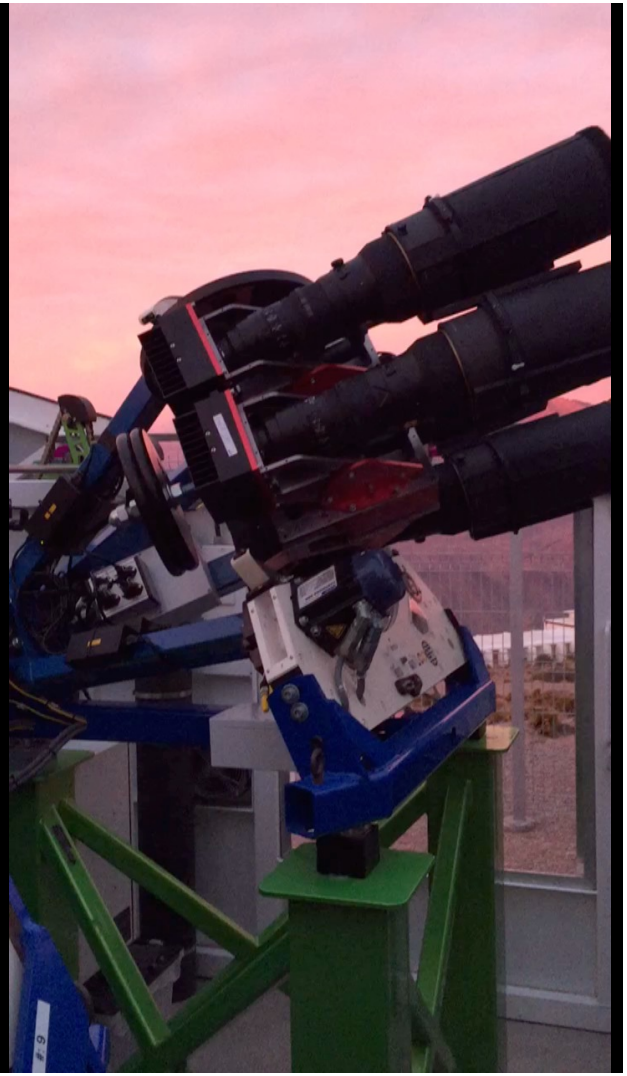
4.5º × 4.5º field-of-view, 8″ pixel scale

g-band filters; depth of 18.5 mag in 90 s

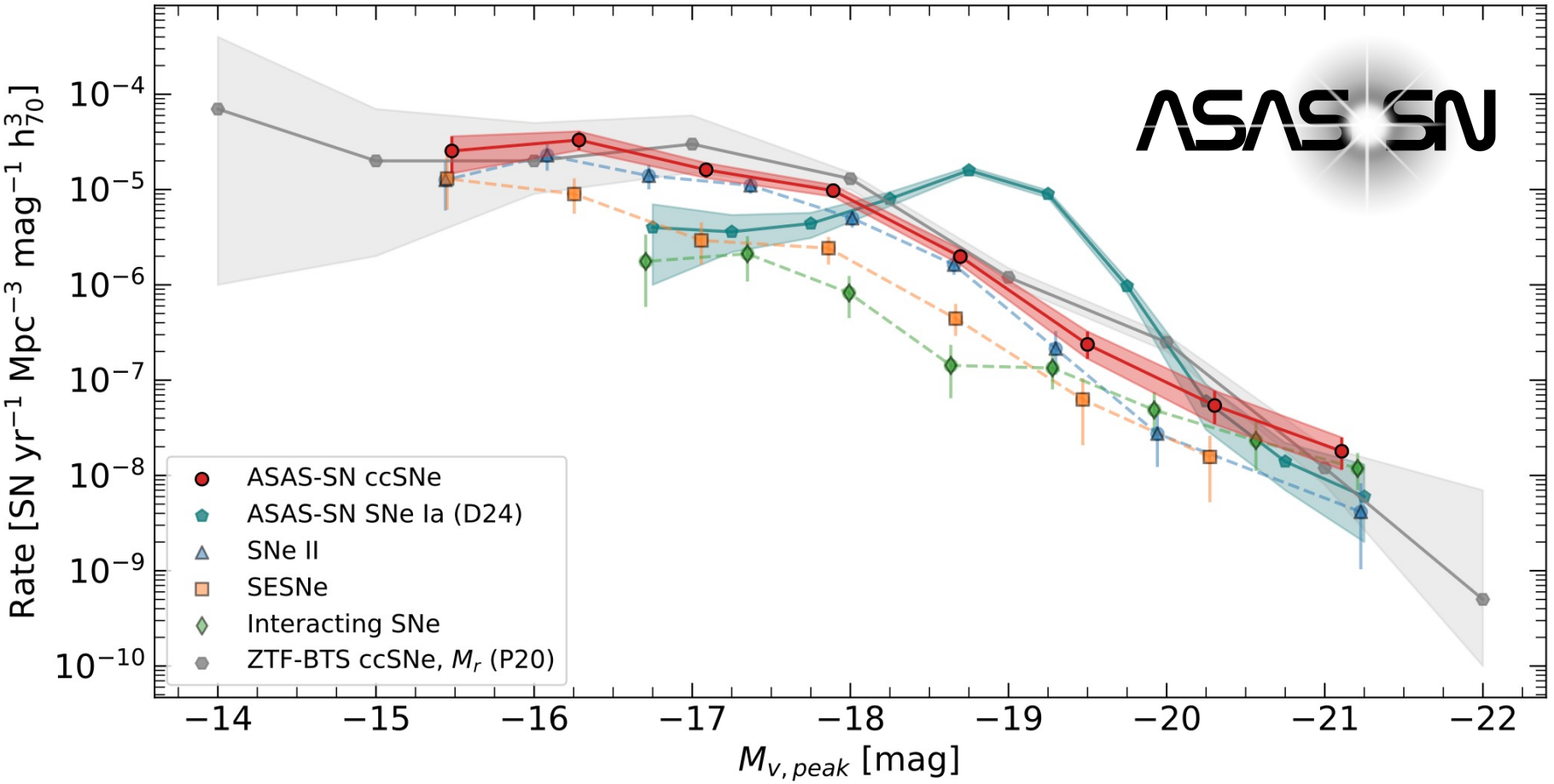
≈ 6500 images & 40,000 square degrees/night

Many Discoveries:

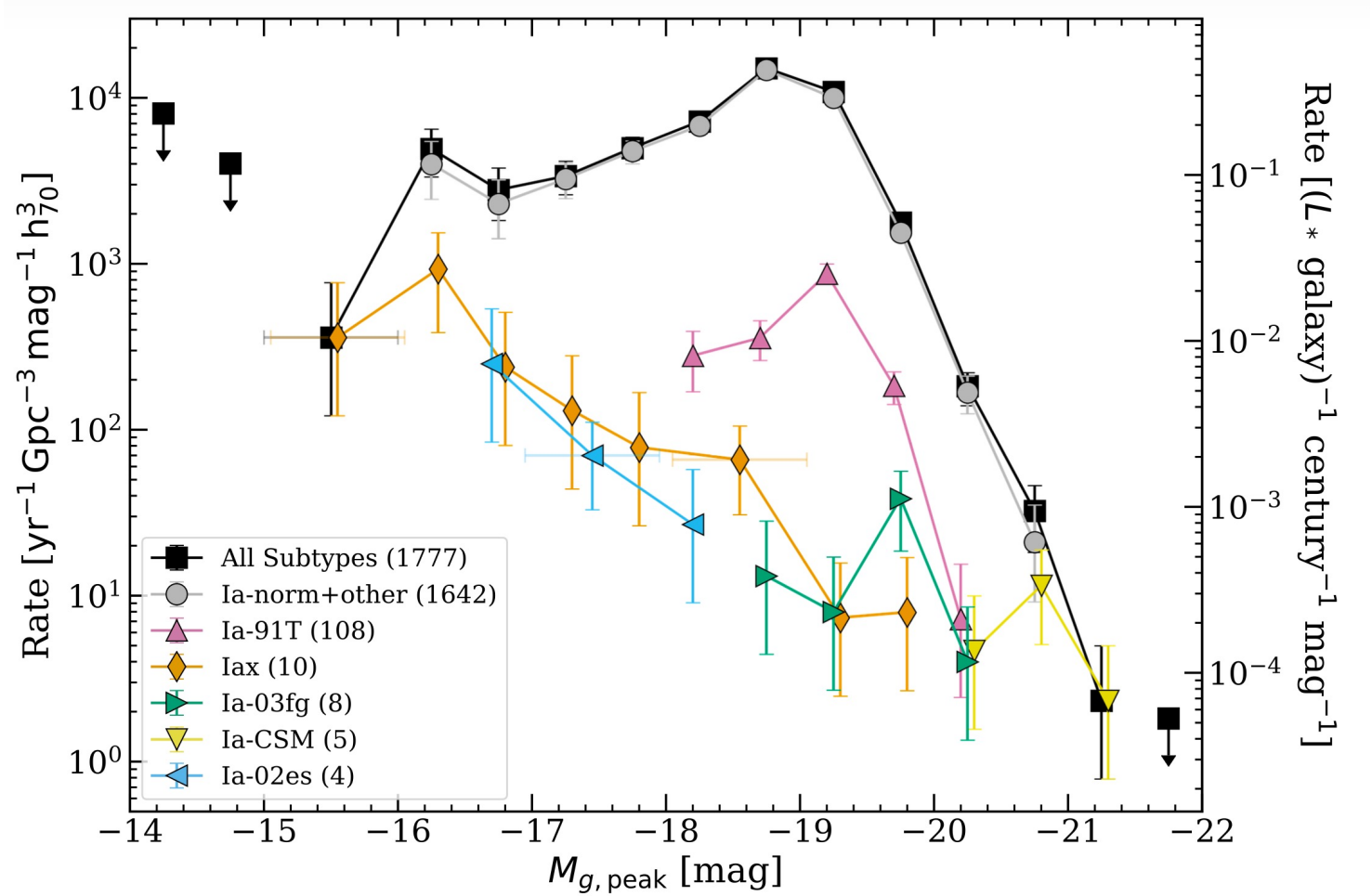
ASSASN14li,14ae, 15oi; 15lh; 14ko; heartbeats, binaries, variables; **Sky Patrol** … SN Rates …



Pessi et al. (2025): Type II Rates and Luminosity Functions

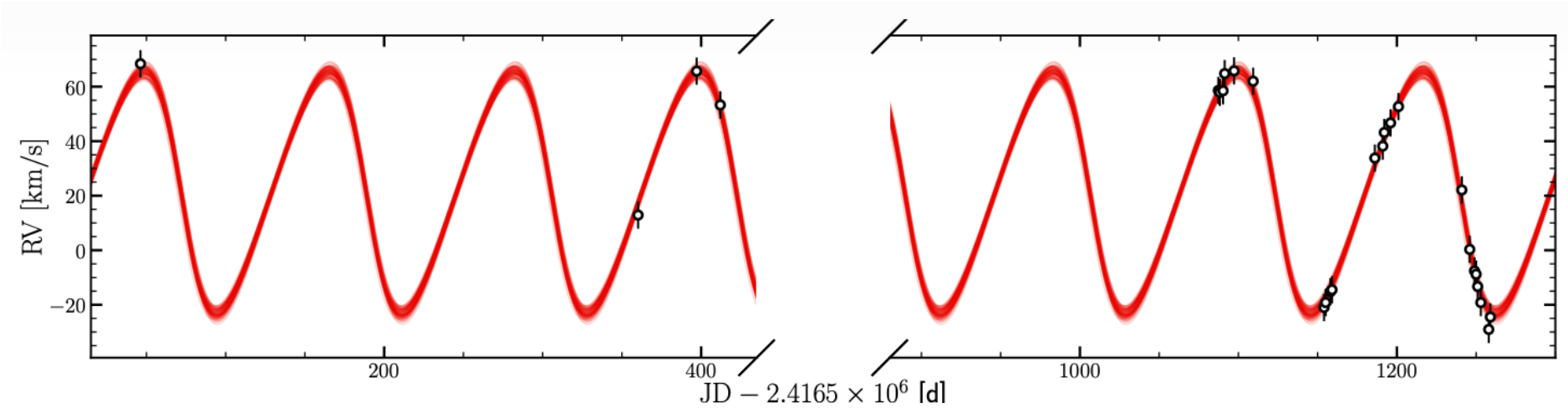


Desai et al. (2026): Type Ia Rates and Luminosity Functions



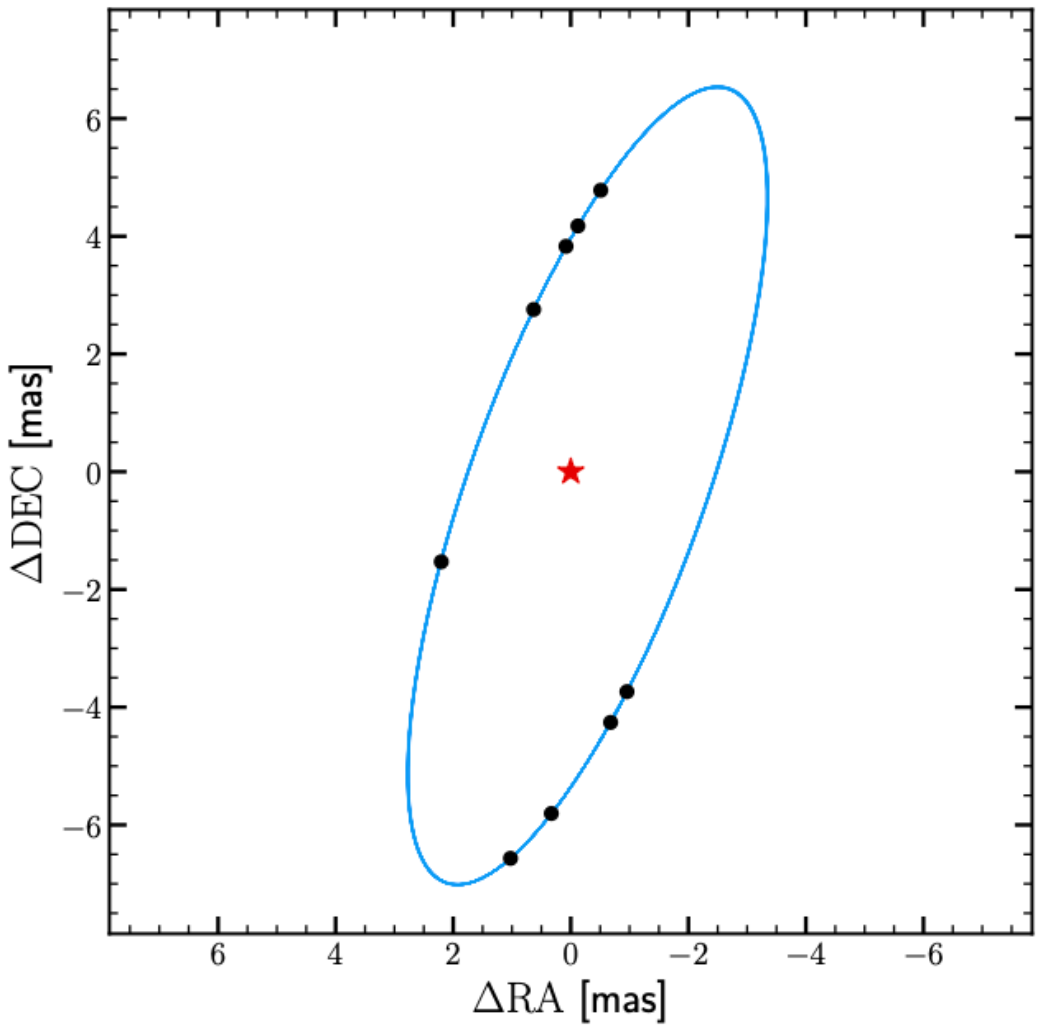
Advertisement #2.

Stellar-BH Binary Candidate Kappa Velorum (Markeb, HD 81188, 天社五)



V = 2.5 mag. B star M ~ $10M_{sun}$. Single-lined spectroscopic binary with large mass function $f(M) = 1.15M_{sun}$. P = 117 days (Curtis 1907).

Trimble & Thorne (1969) suggest possible BH companion.



Rowan, Kraus, Thompson 26

Direct imaging with VLTI/ GRAVITY gives astrometric orbit with ~ μas precision.

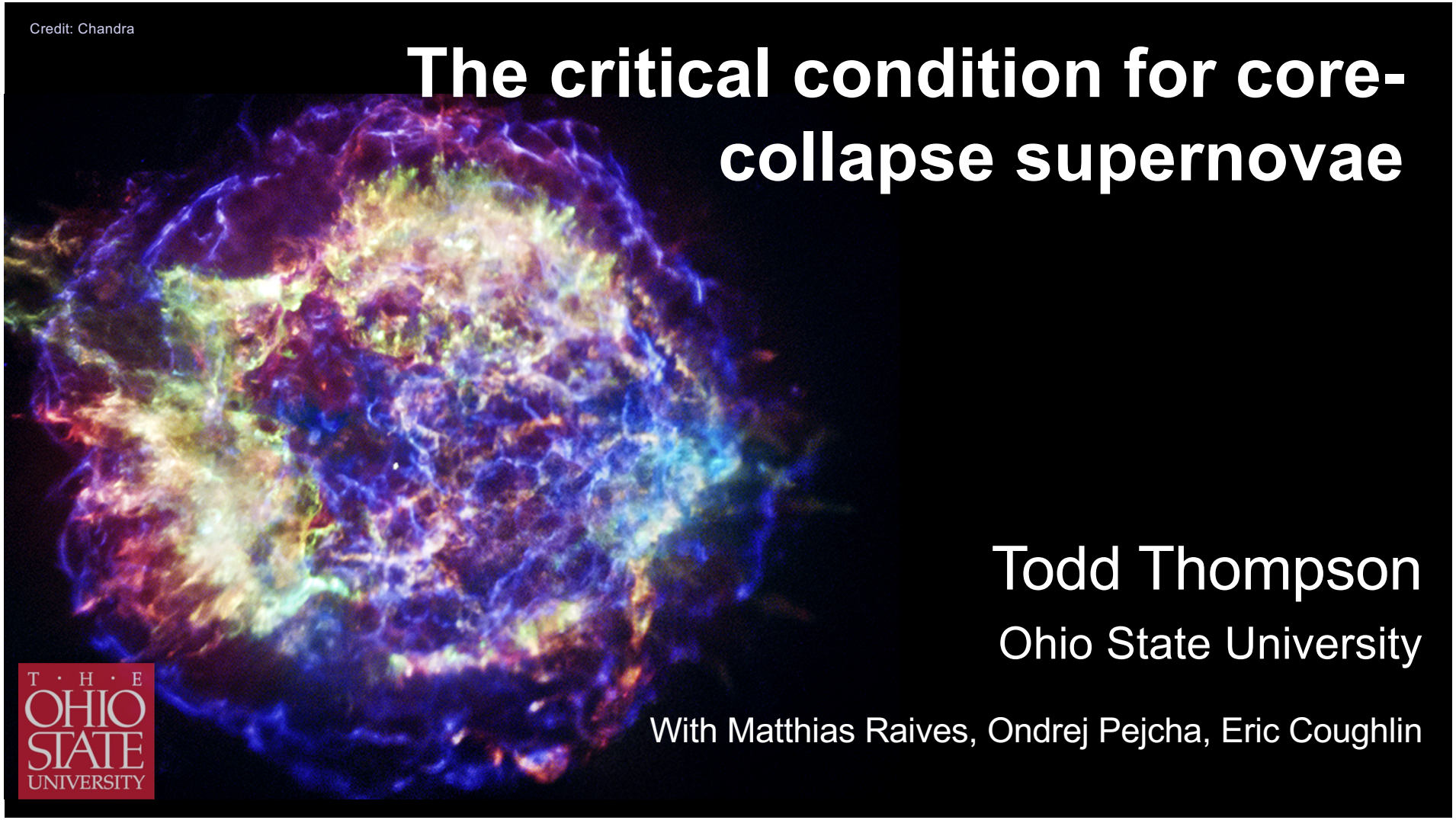
e = 0.176, i = 74.04°

Clear detection of the **stellar** secondary: 7-8 M_{sun}.

→ NOT A BH BINARY.

More systems in preparation.

Changing subjects again…

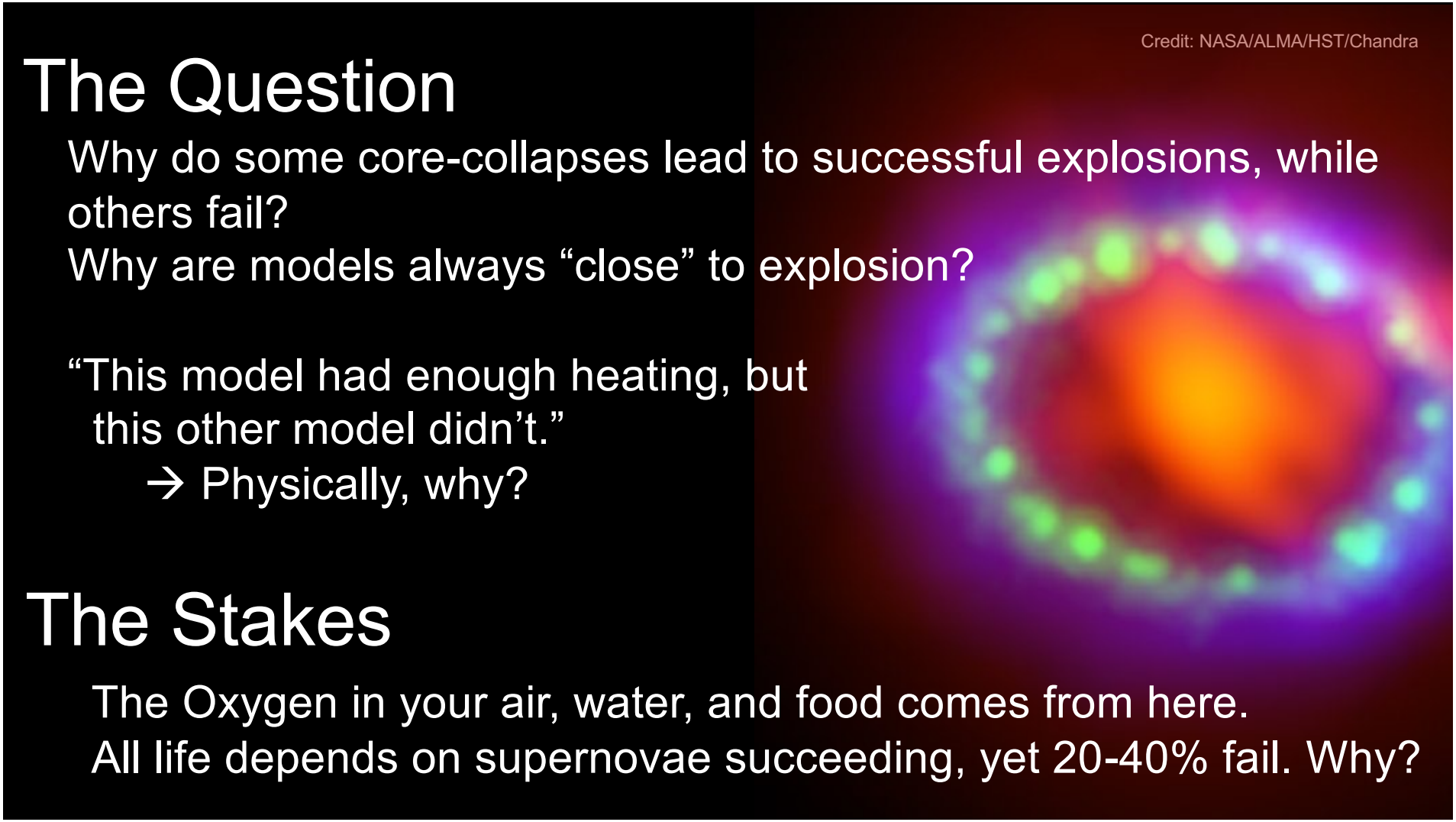


The critical condition for core-collapse supernovae

Todd Thompson

Ohio State University

With Matthias Raives, Ondrej Pejcha, Eric Coughlin



The Question

Why do some core-collapses lead to successful explosions, while others fail?

Why are models always “close” to explosion?

“This model had enough heating, but this other model didn’t.”

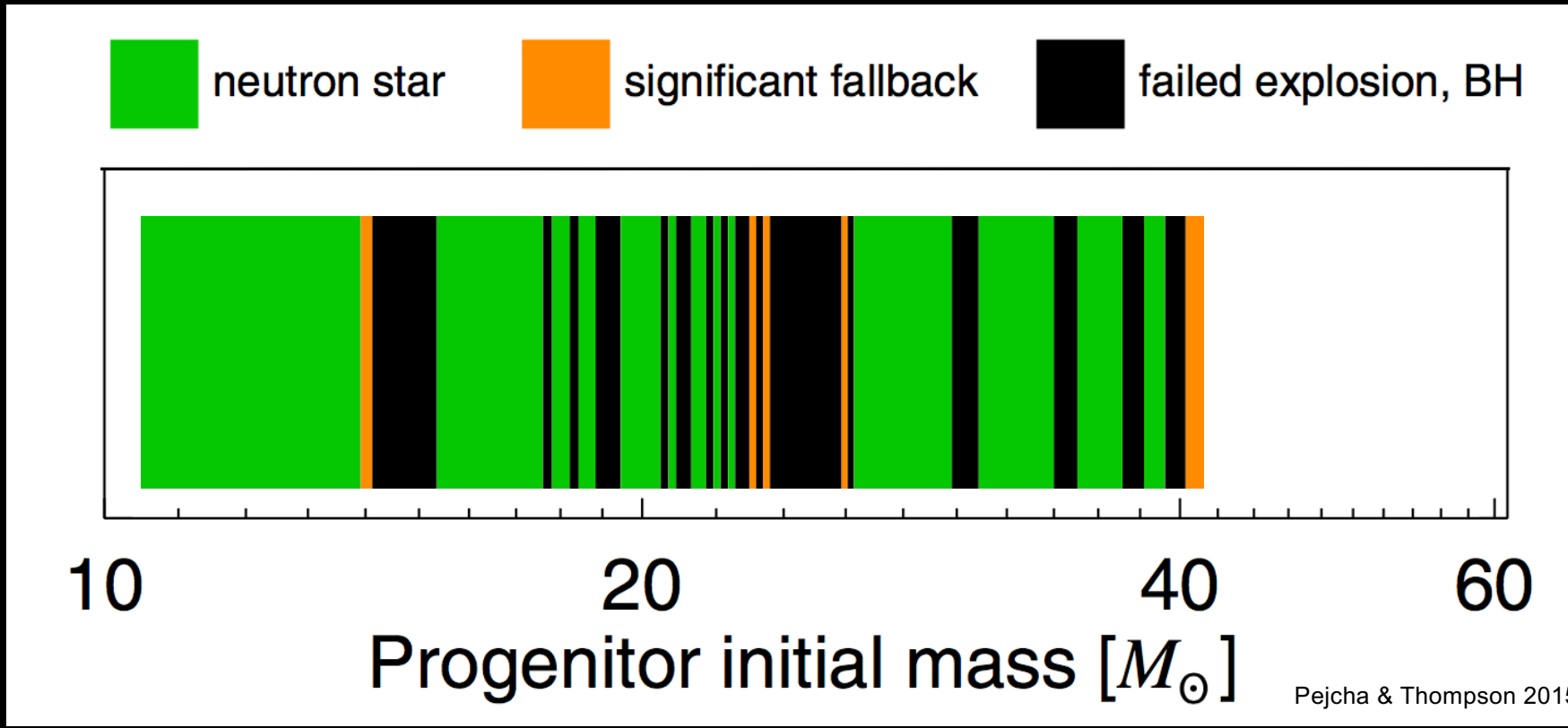
→ Physically, why?

The Stakes

The Oxygen in your air, water, and food comes from here.

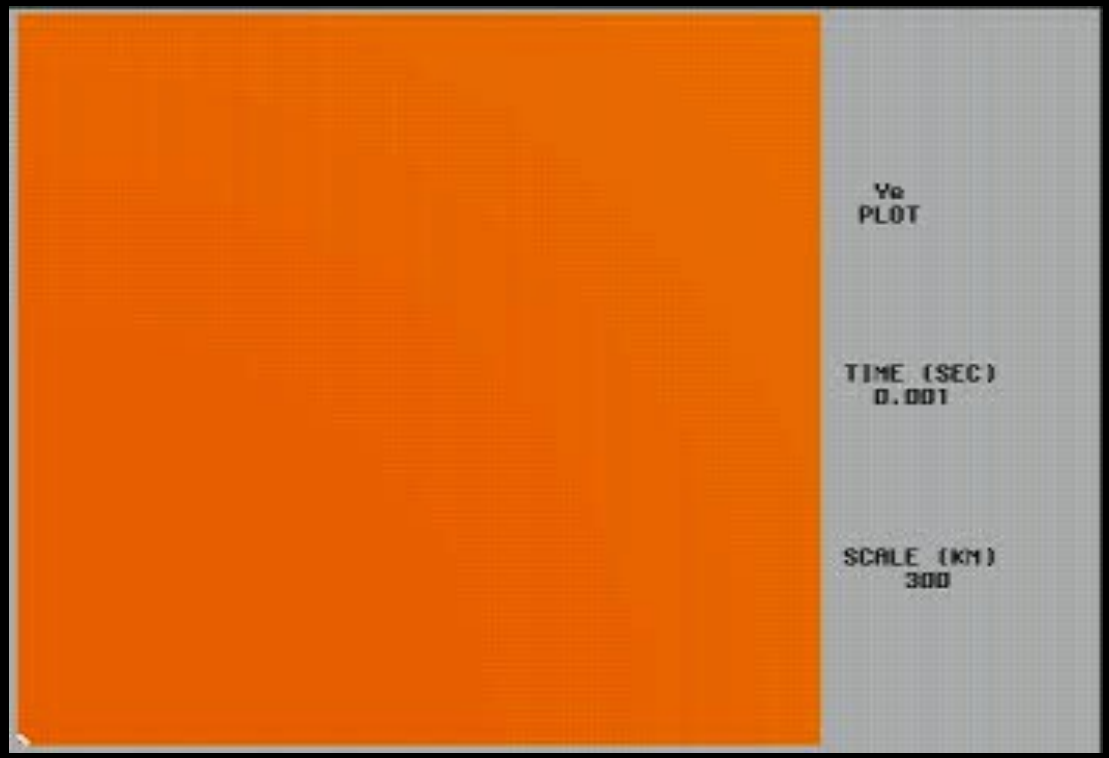
All life depends on supernovae succeeding, yet 20-40% fail. Why?

A complicated landscape of outcomes: 25% BHs(?)



Many groups find similar results → progenitor structure.

Collapse, Bounce, Stall, Wind-Driven Explosion, Cooling



300 km

Burrows et al. (1995)

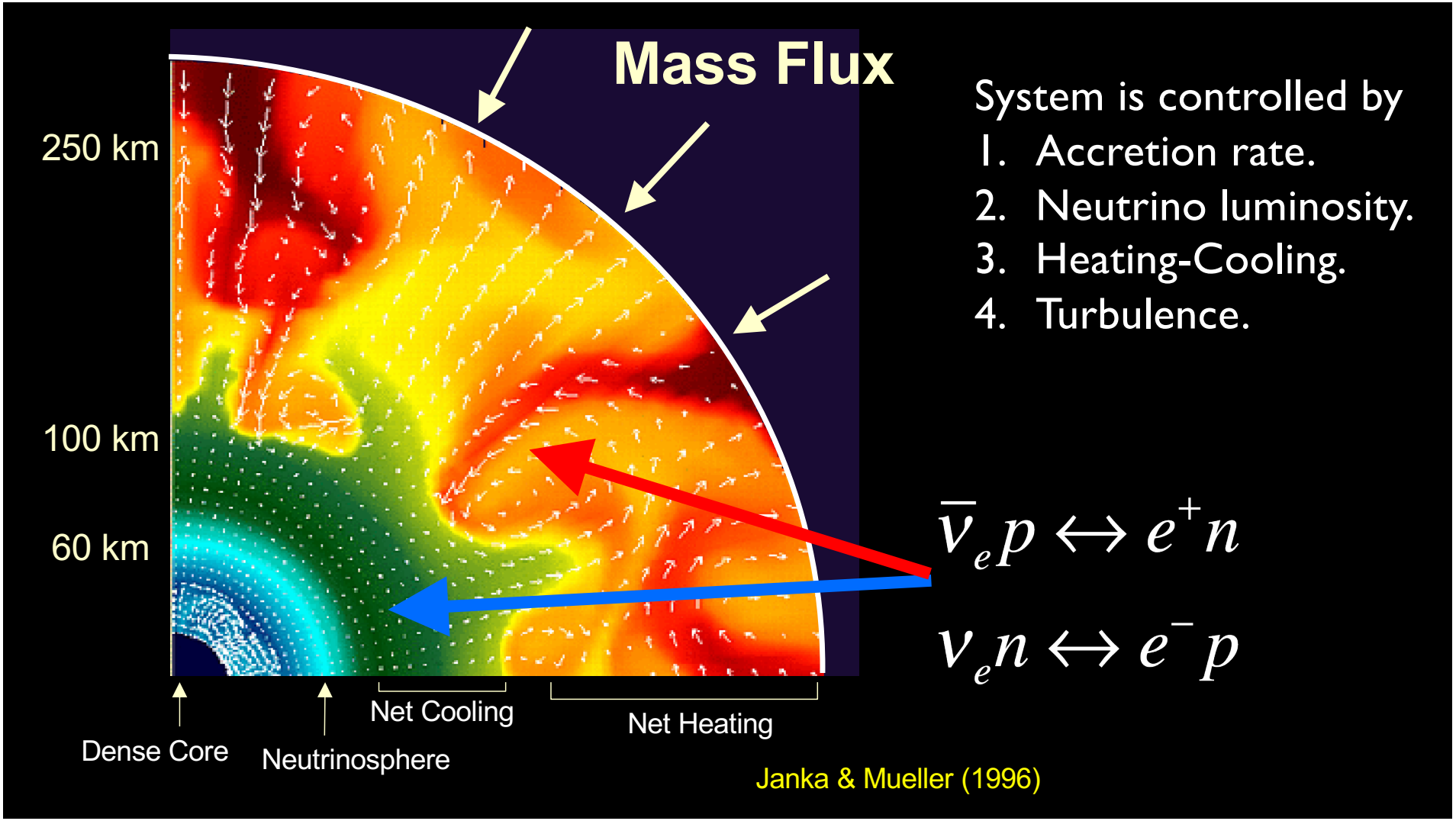
Electrons combine with protons to make a neutron star:

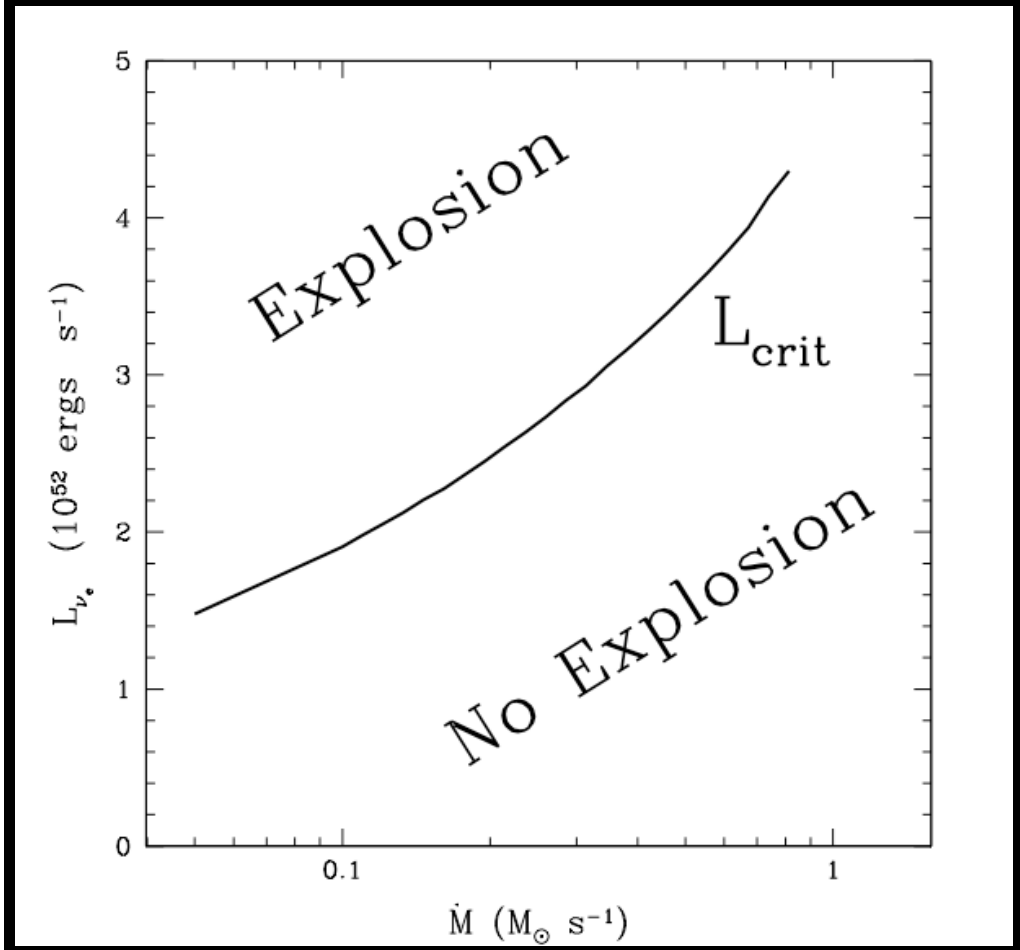
$e^- + p \rightarrow n + \nu_e$

Escaping neutrinos interact with infalling matter, heating it:

$\nu_e + n \rightarrow e^- + p$

Explosion in ~1 second, or a BH will form.


Mass Flux
250 km
100 km
60 km
Net Cooling
Net Heating
Dense Core
Neutrinosphere
$\bar{\nu}_e p \leftrightarrow e^+ n$
$\nu_e n \leftrightarrow e^- p$
System is controlled by
1. Accretion rate.
2. Neutrino luminosity.
3. Heating-Cooling.
4. Turbulence.
Janka & Mueller (1996)

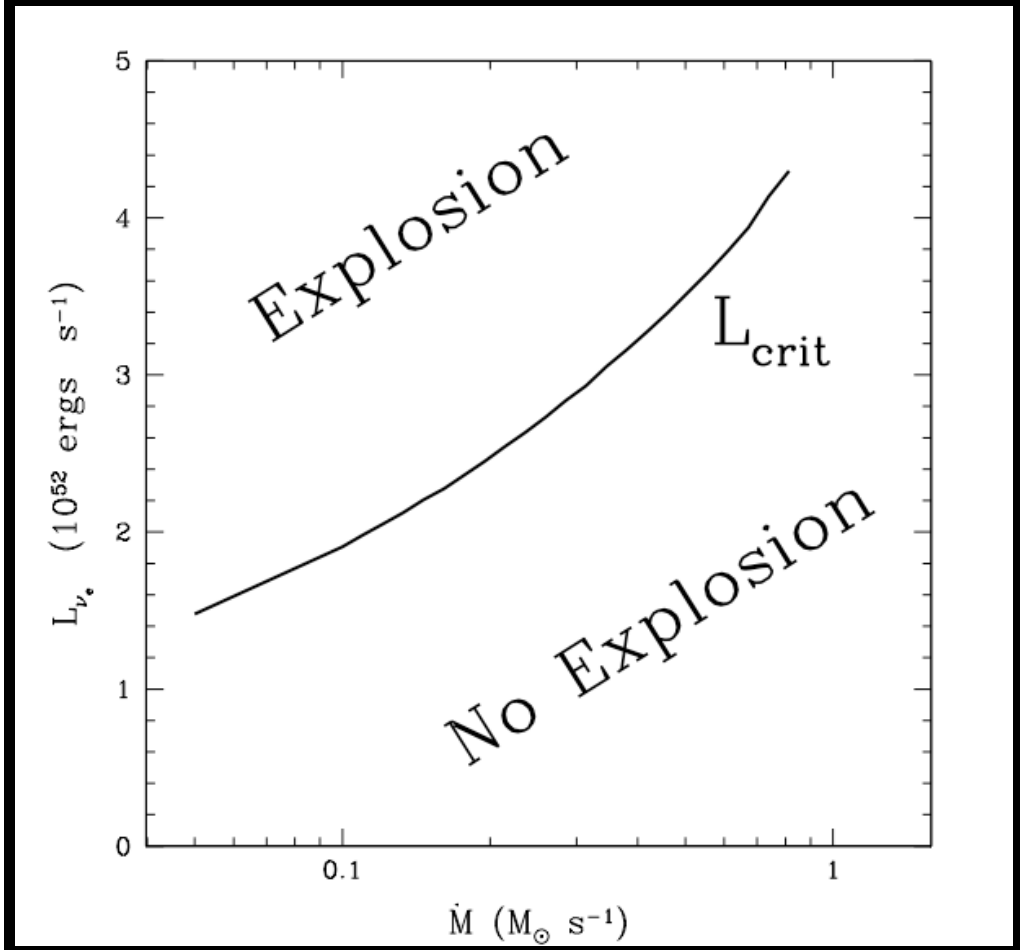


Critical Luminosity

At a given mass accretion rate, there is a critical luminosity above which no accretion solutions.

Burrows & Goshy (1993)
Yamasaki & Yamada (2005, 2006, 2007)
Pejcha & Thompson (2012, 2015)
Raives+(2018,2021)
Pochik & Thompson (2025)
Many additional works…

→ See recent review by Maltsev+(2025)



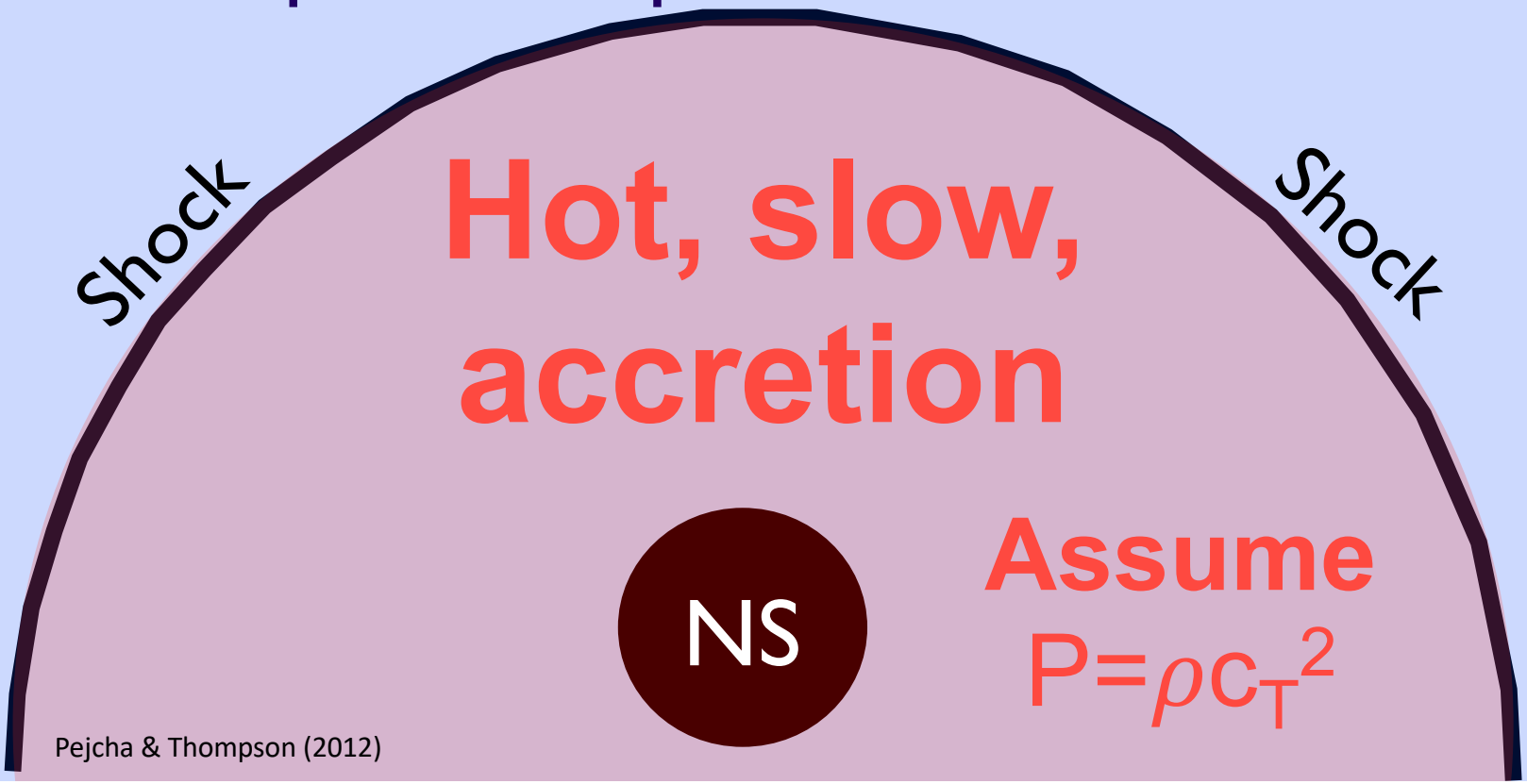
"Model X did not explode! It must have had insufficient neutrino heating. $L < L_{crit}$."

"Model Y explodes! It must have had sufficient neutrino heating. $L > L_{crit}$. Perhaps because of rapid change in Mdot."

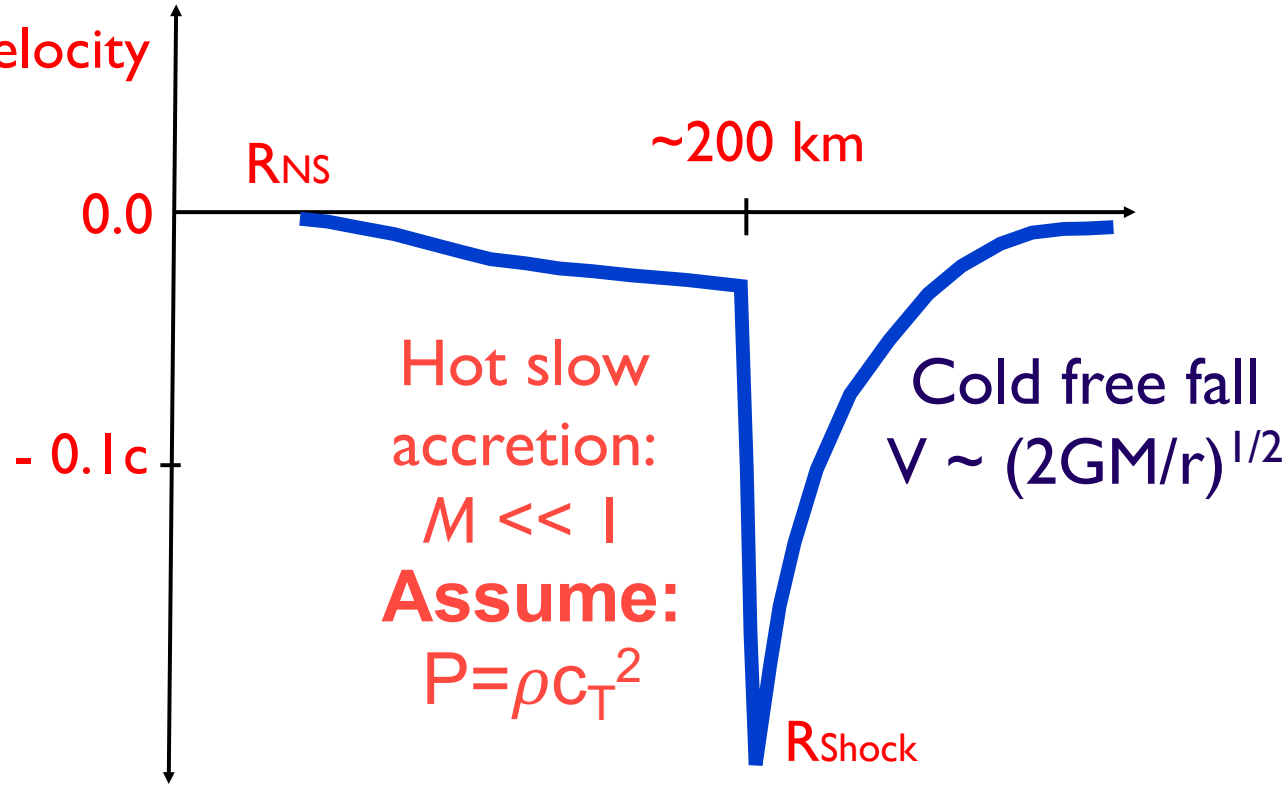
BUT, what is the physics of L_{crit}?

A radical approximation:

Cold supersonic pressure-less free fall

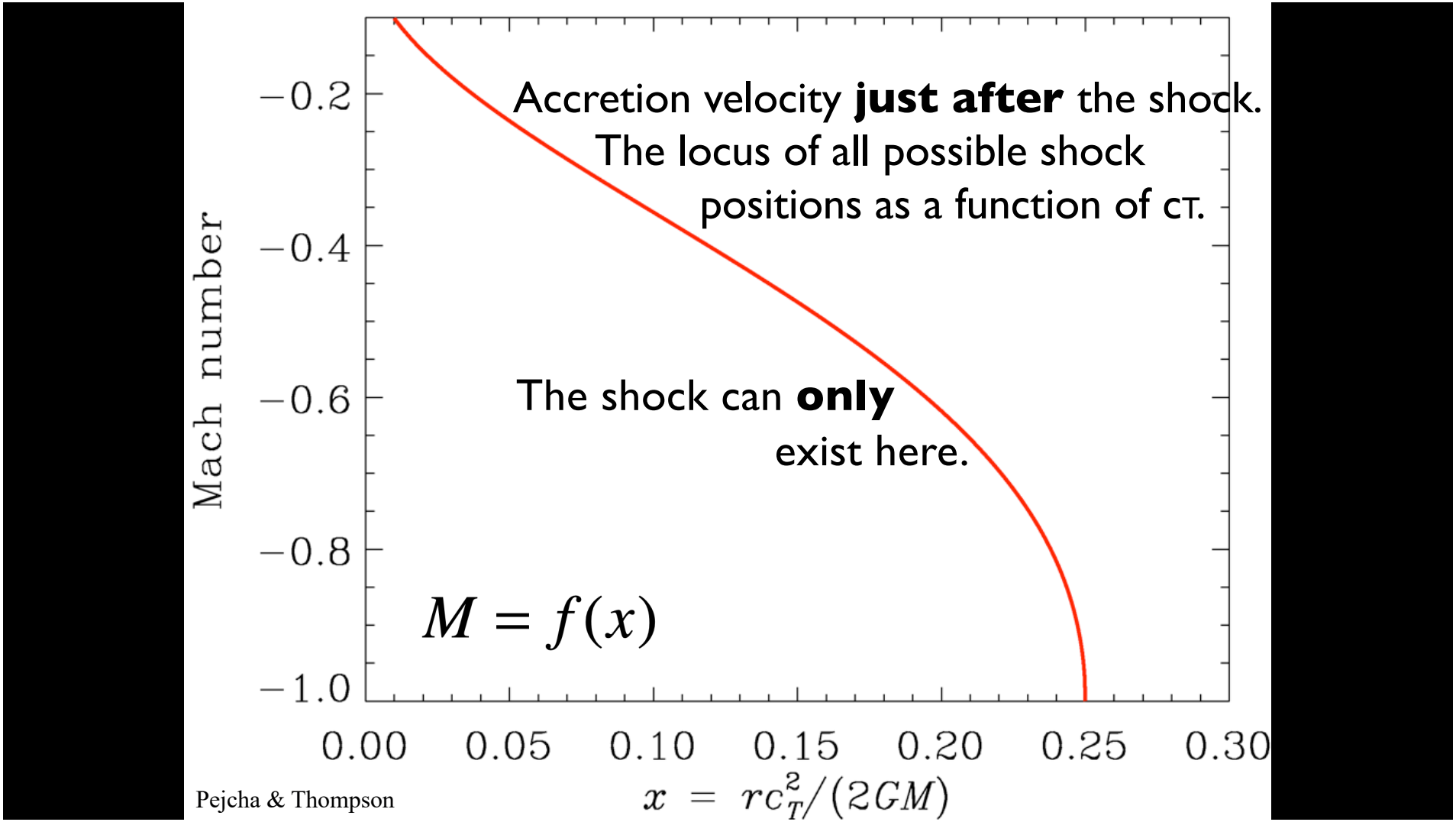


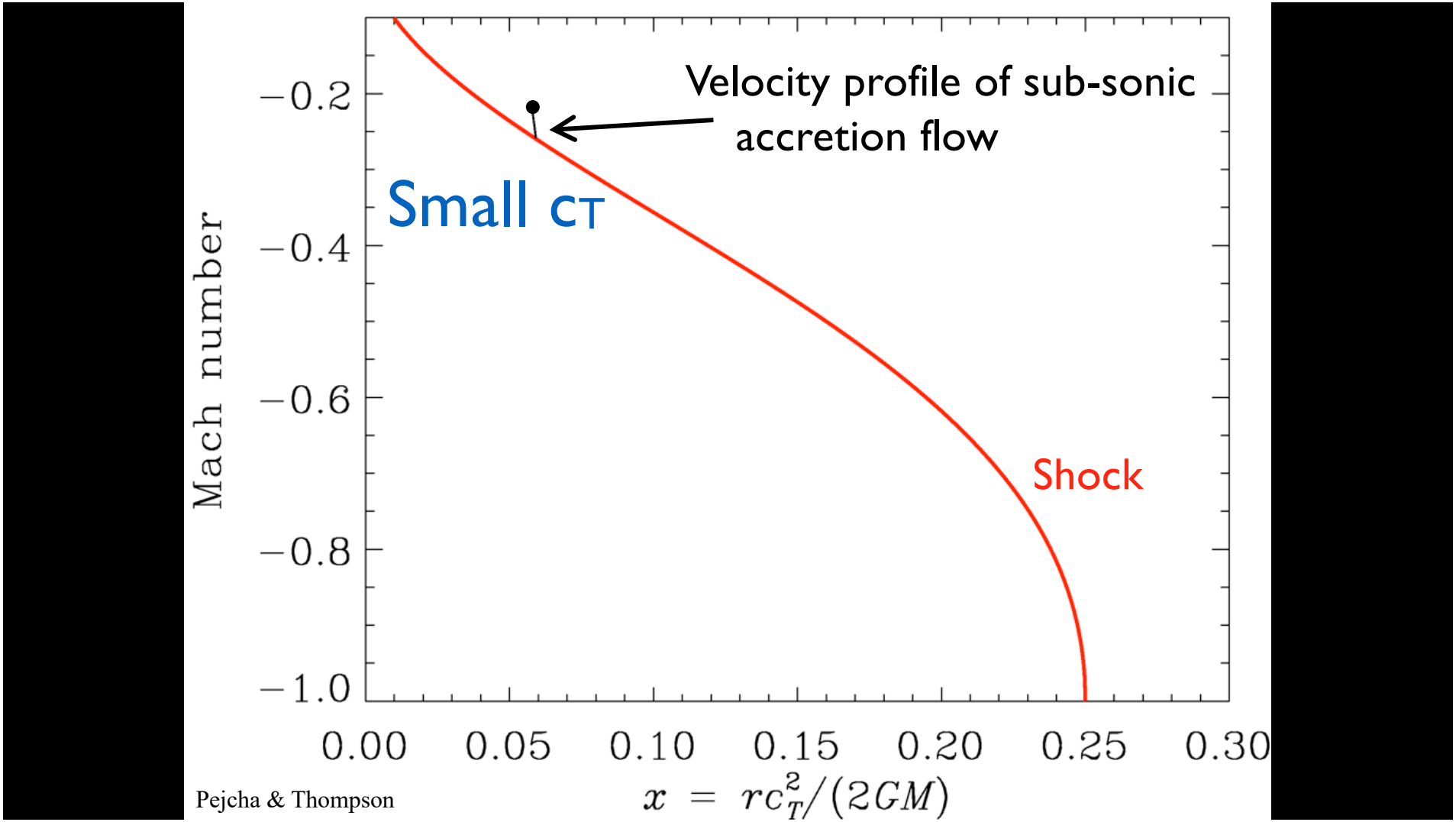
Pejcha & Thompson (2012)

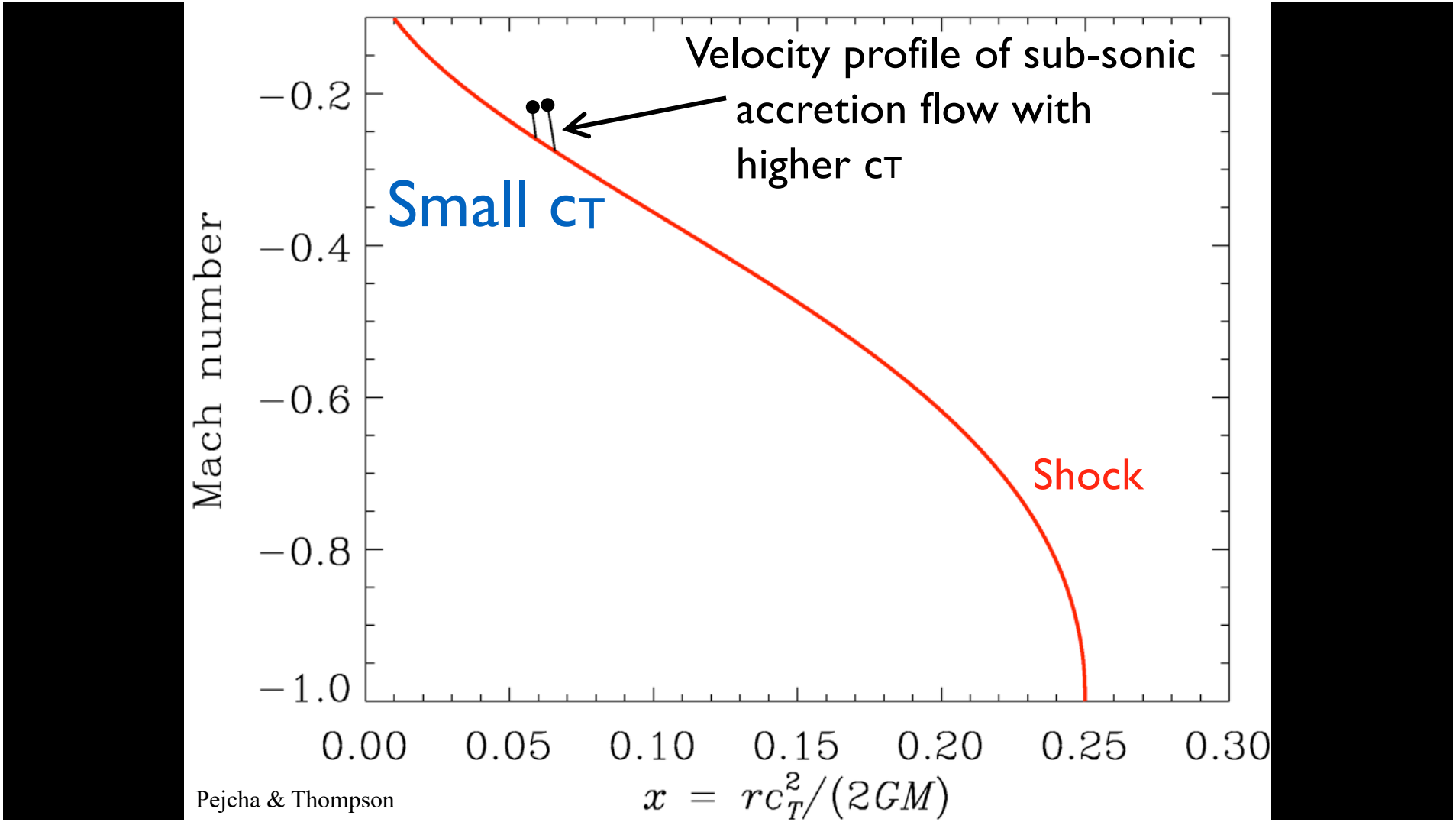


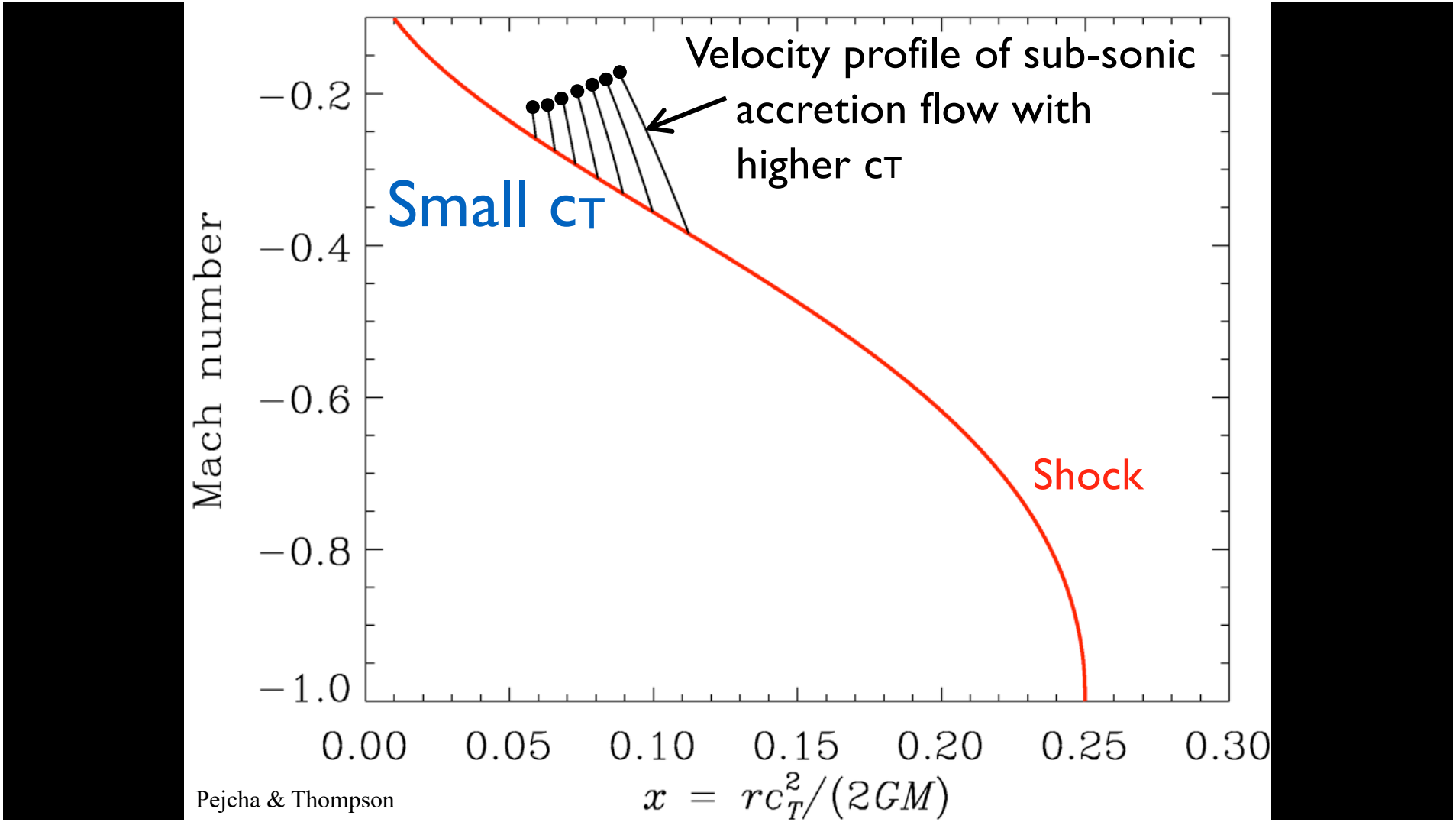
Write down Euler equations for steady flow with shock boundary conditions for given accretion rate.

Pejcha & Thompson (2012)

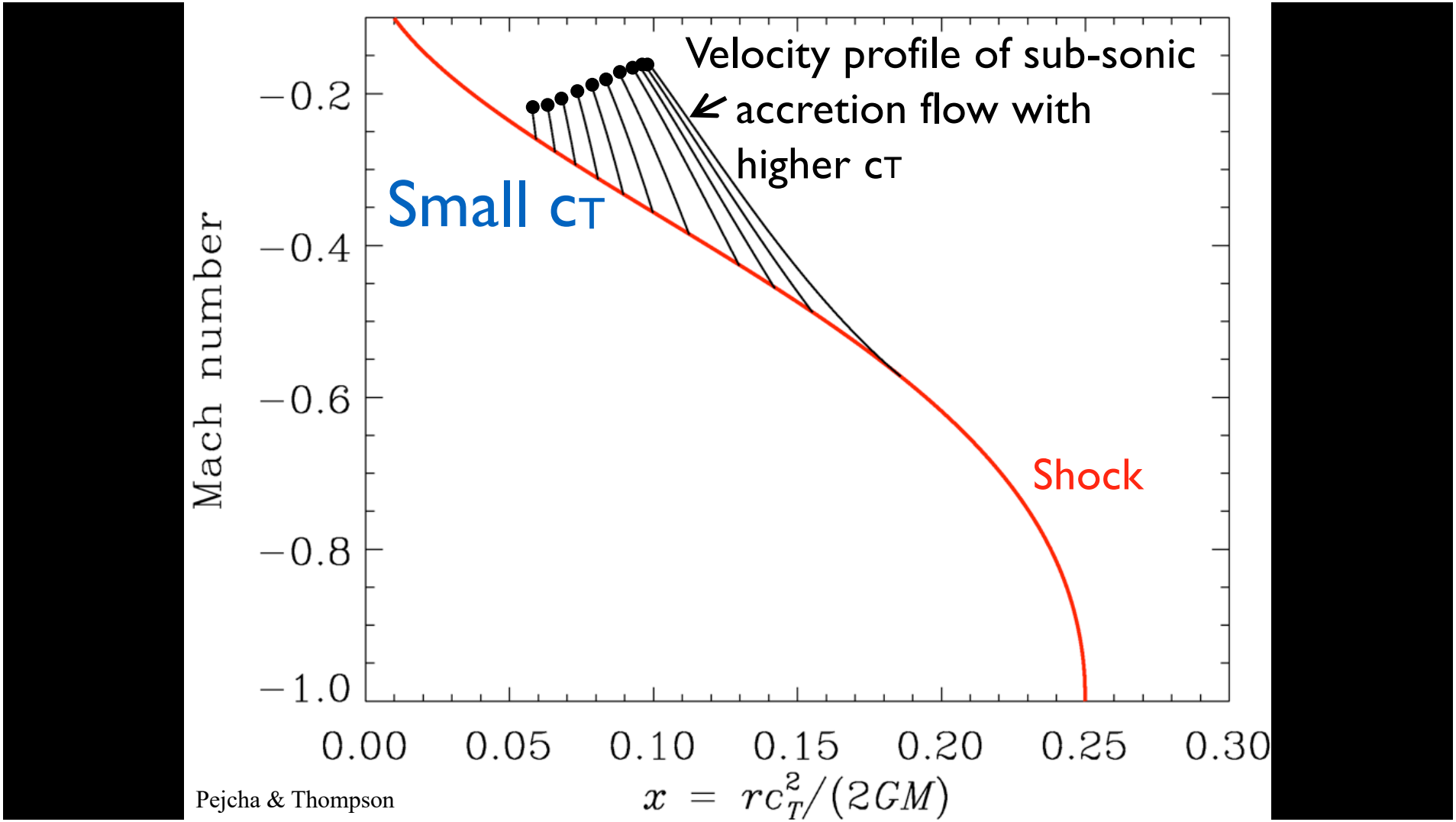

Accretion velocity **just after** the shock.
The locus of all possible shock positions as a function of cT.
The shock can **only** exist here.
$M = f(x)$
Mach number
−0.2
−0.4
−0.6
−0.8
−1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
$x = rc_T^2/(2GM)$
Pejcha & Thompson

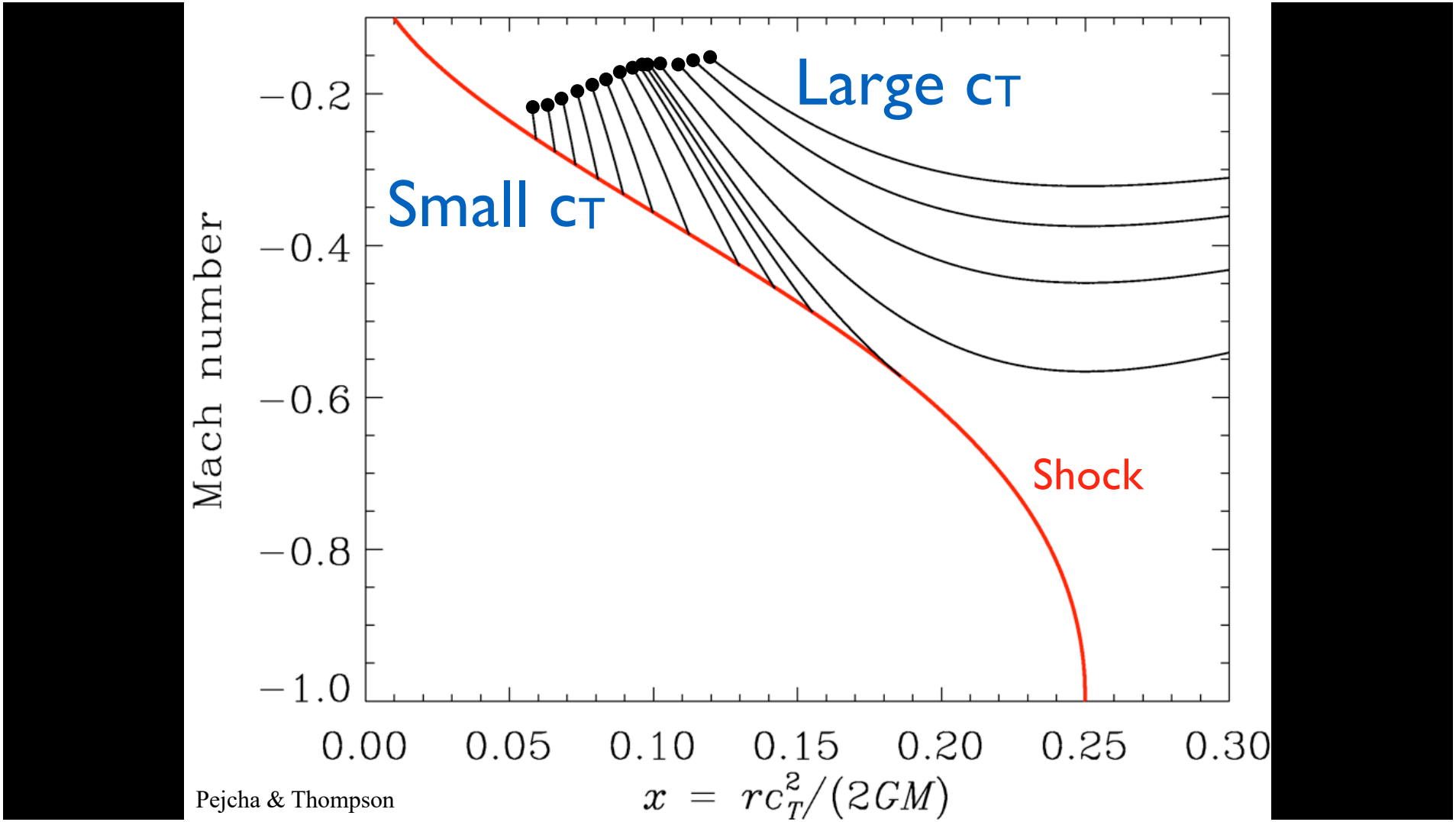

Velocity profile of sub-sonic accretion flow
Small c_T
Shock
Mach number
−0.2
−0.4
−0.6
−0.8
−1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
$x = rc_T^2/(2GM)$
Pejcha & Thompson


Velocity profile of sub-sonic accretion flow with higher cT
Small cT
Shock
Mach number
−0.2
−0.4
−0.6
−0.8
−1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
$x = rc_T^2/(2GM)$
Pejcha & Thompson

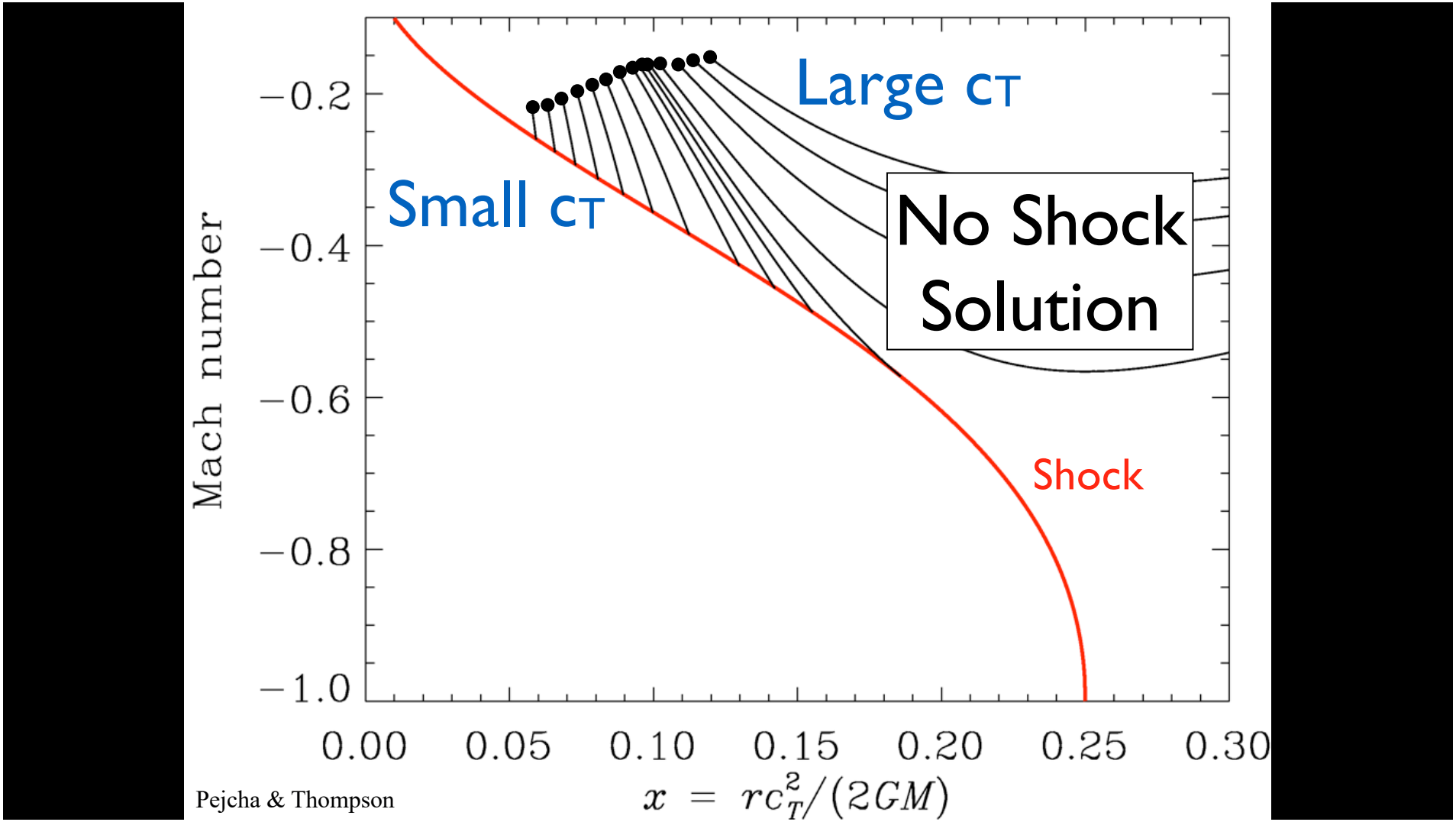


Pejcha & Thompson

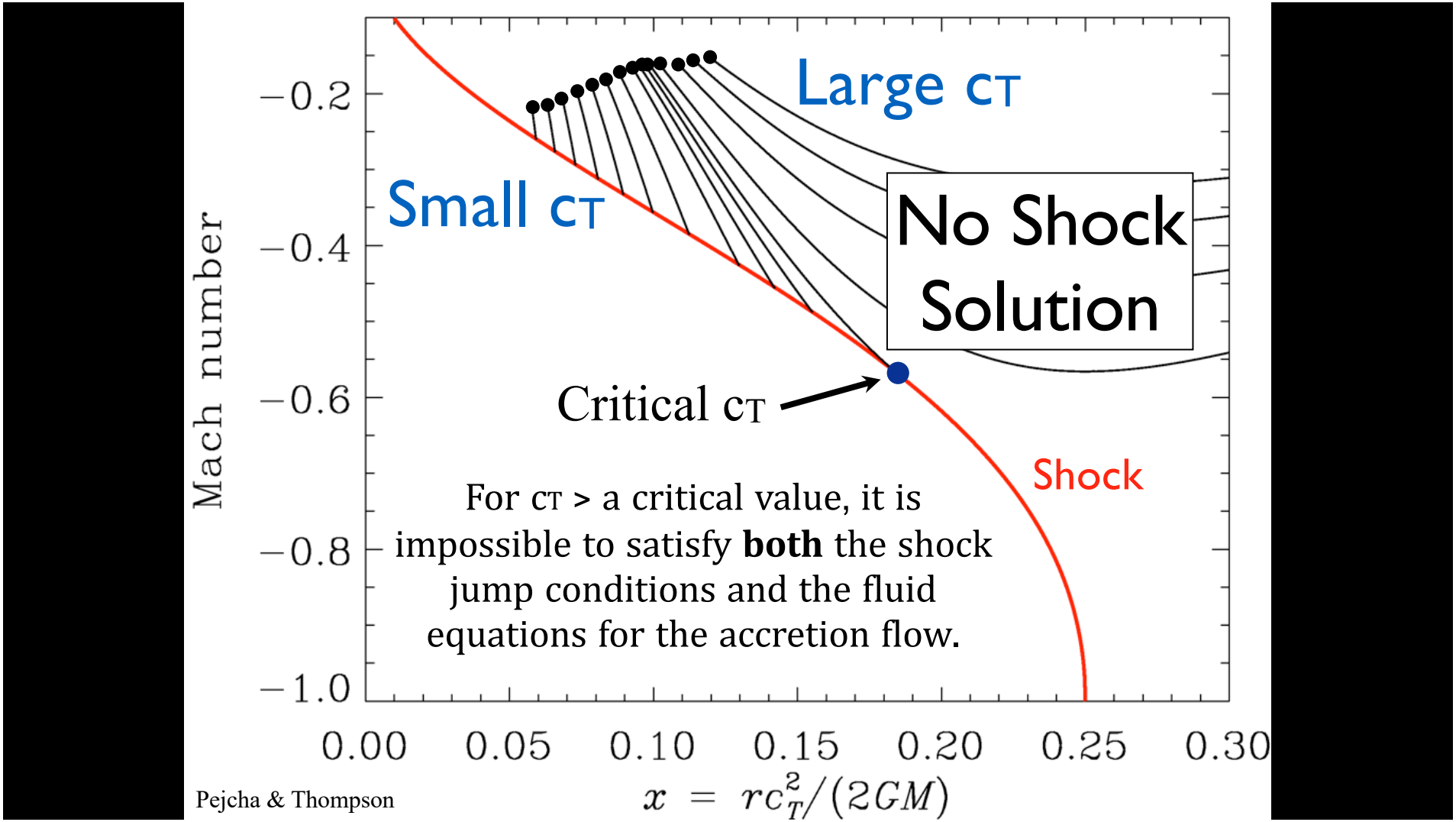

Velocity profile of sub-sonic
accretion flow with
higher cT
Small cT
Shock
Mach number
−0.2
−0.4
−0.6
−0.8
−1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
$x = rc_T^2/(2GM)$
Pejcha & Thompson

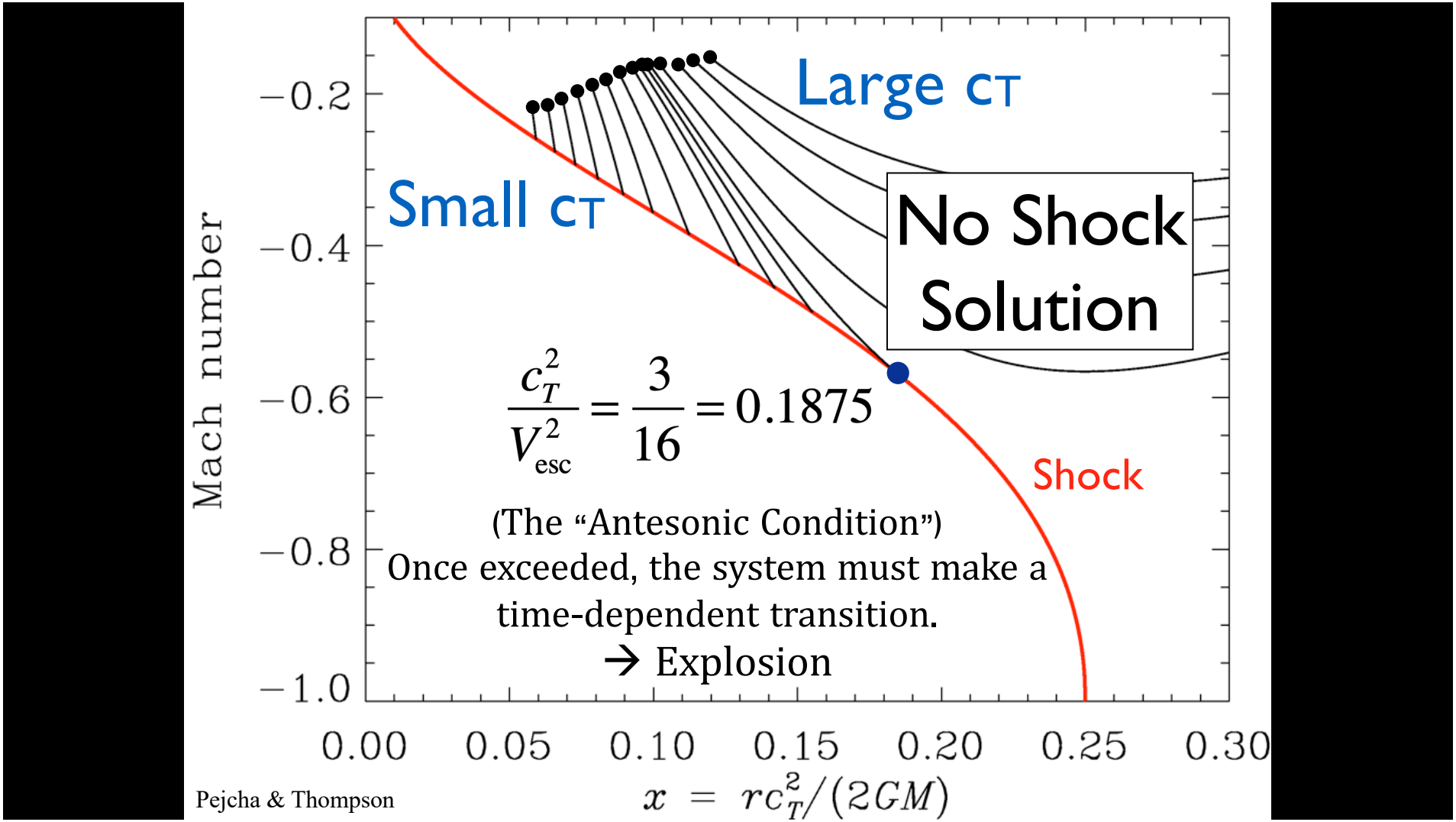


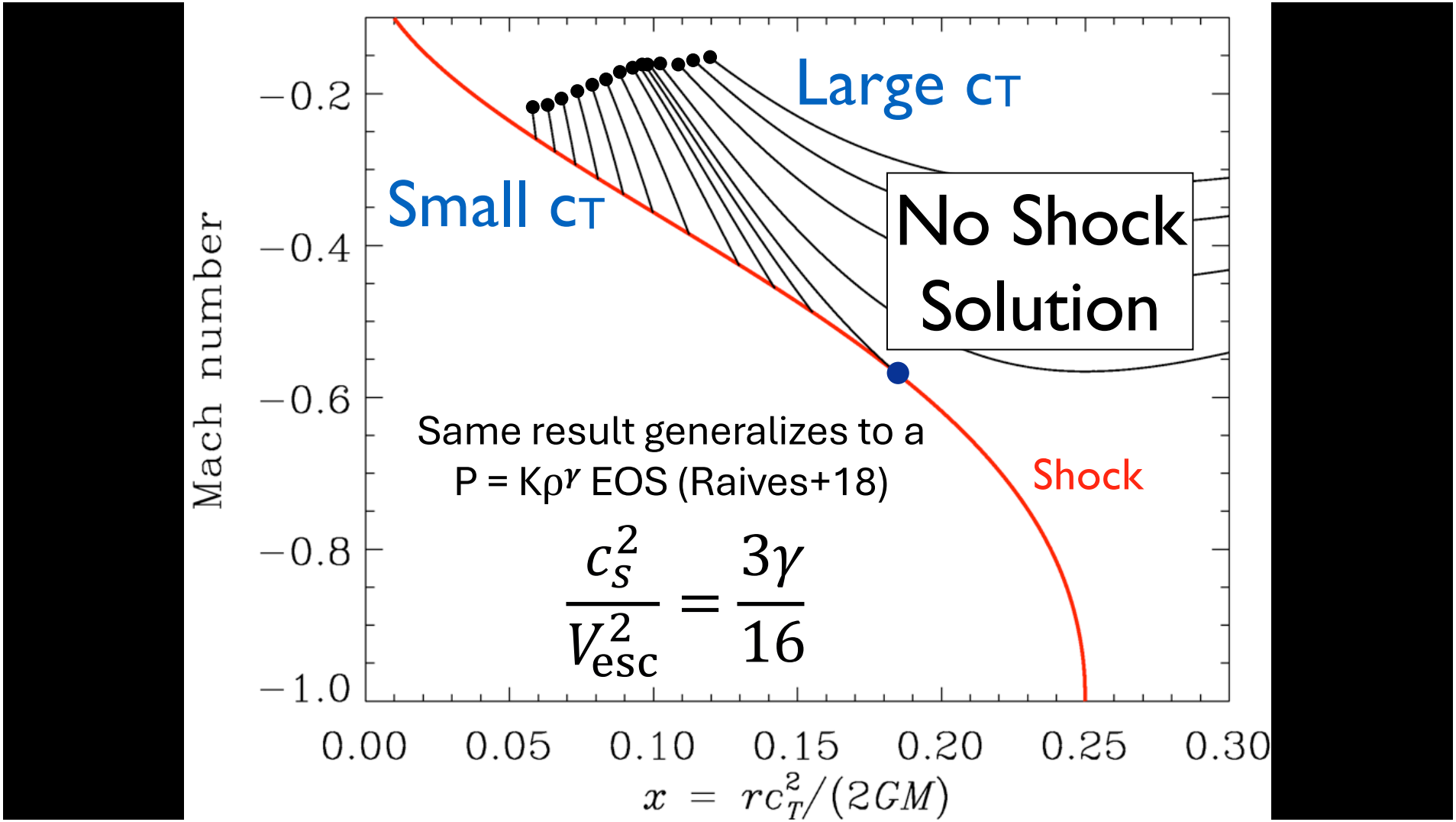
Pejcha & Thompson

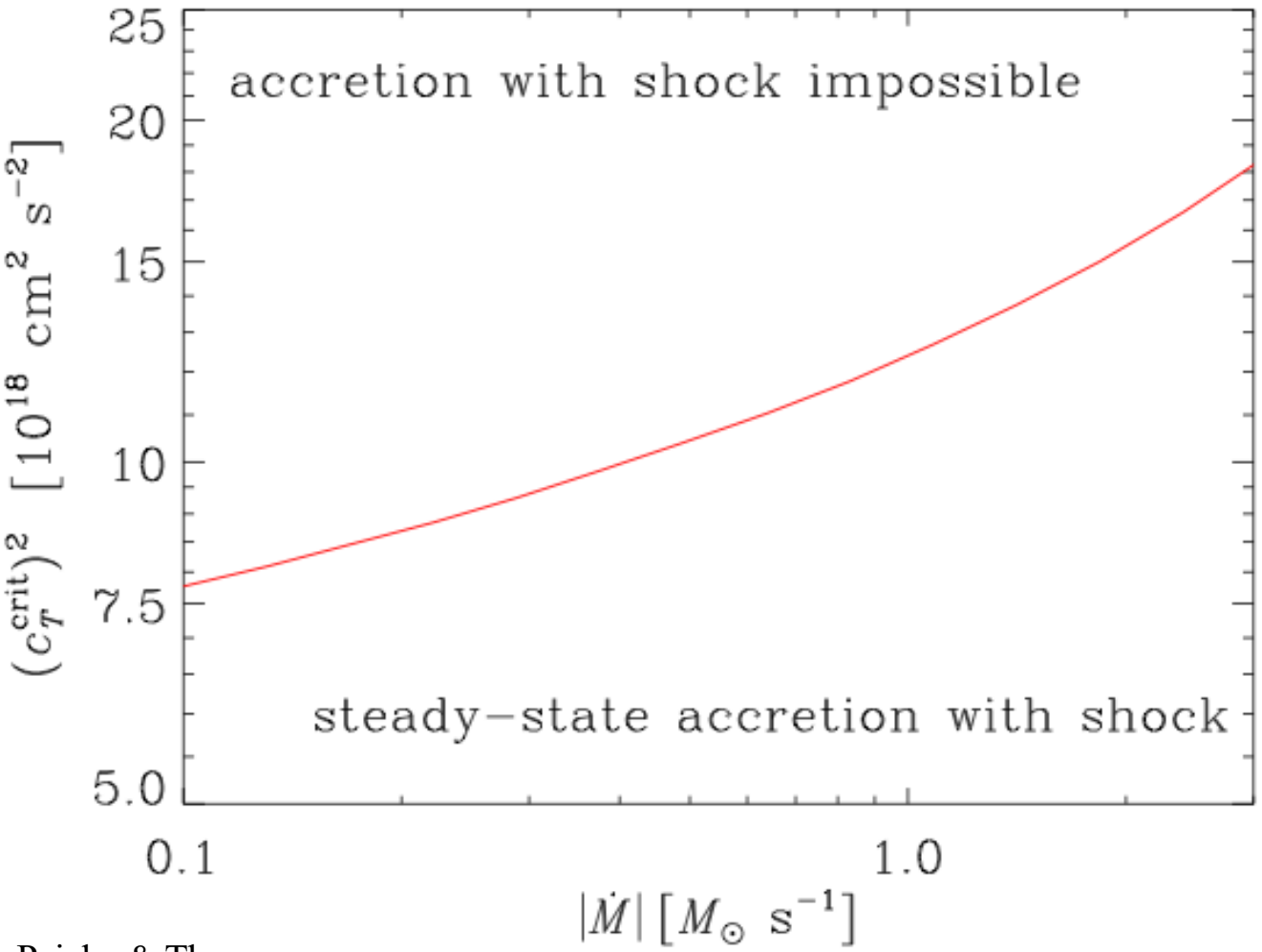


Pejcha & Thompson

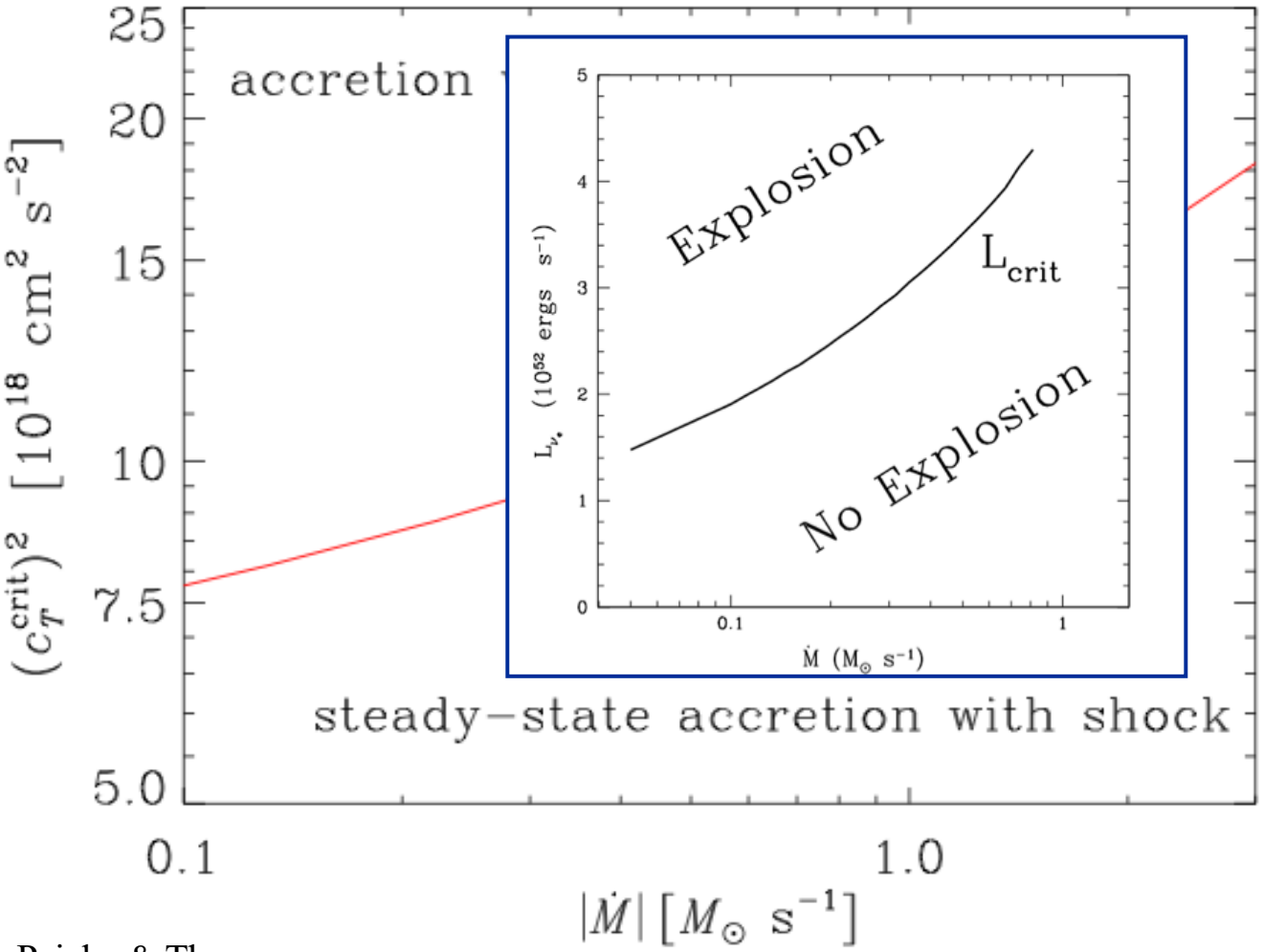

Large cT
Small cT
No Shock Solution
Critical cT
Shock
For cT > a critical value, it is impossible to satisfy **both** the shock jump conditions and the fluid equations for the accretion flow.
Mach number
−0.2
−0.4
−0.6
−0.8
−1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
$x = rc_T^2/(2GM)$
Pejcha & Thompson


Large cT
Small cT
No Shock Solution
Shock
$\frac{c_T^2}{V_{\rm esc}^2} = \frac{3}{16} = 0.1875$
(The "Antesonic Condition")
Once exceeded, the system must make a time-dependent transition.
→ Explosion
Mach number
−0.2
−0.4
−0.6
−0.8
−1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
$x = rc_T^2/(2GM)$
Pejcha & Thompson


Large cT
Small cT
No Shock Solution
Shock
Same result generalizes to a
P = Kρ^γ EOS (Raives+18)
$\frac{c_s^2}{V_{esc}^2} = \frac{3\gamma}{16}$
Mach number
−0.2
−0.4
−0.6
−0.8
−1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
$x = rc_T^2/(2GM)$

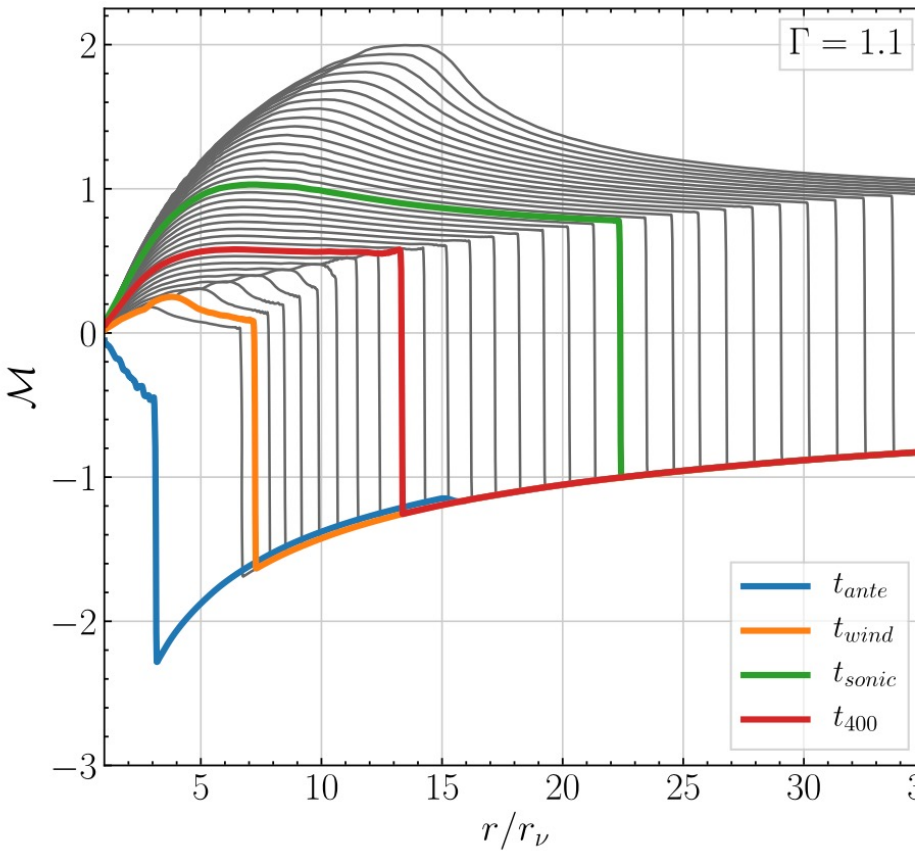


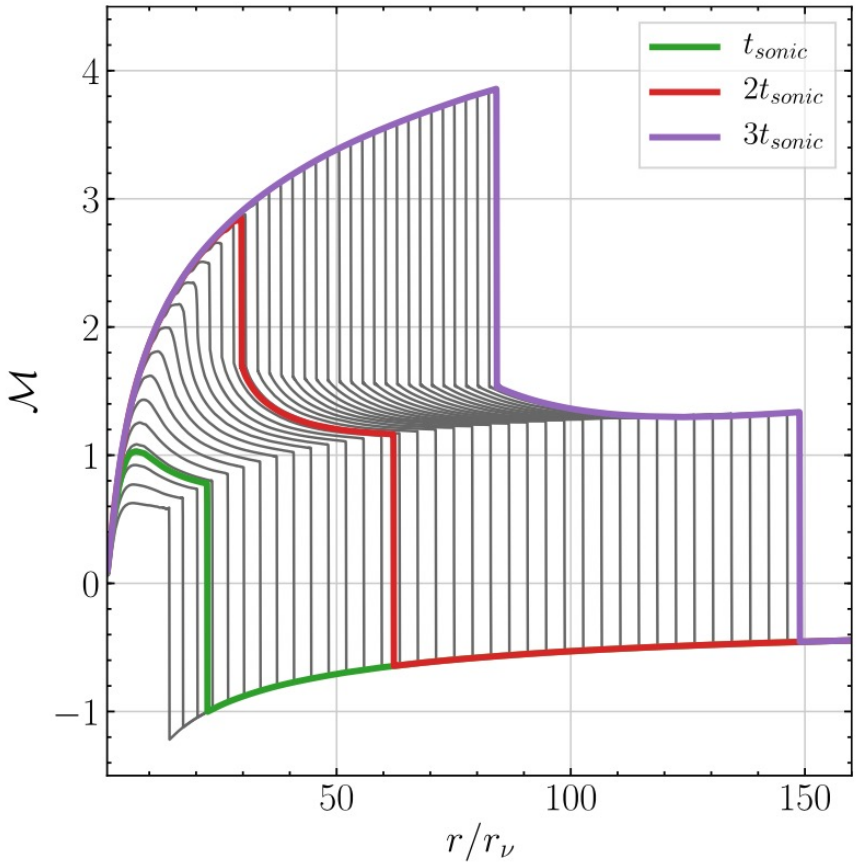
Pejcha & Thompson



Pejcha & Thompson

If exceeded, transition to wind-driven shell: “Explosion”





Raives et al. 2018; Pochik & Thompson 2025

Is the “antesonic” condition the answer?

Objection I: You need real physics.

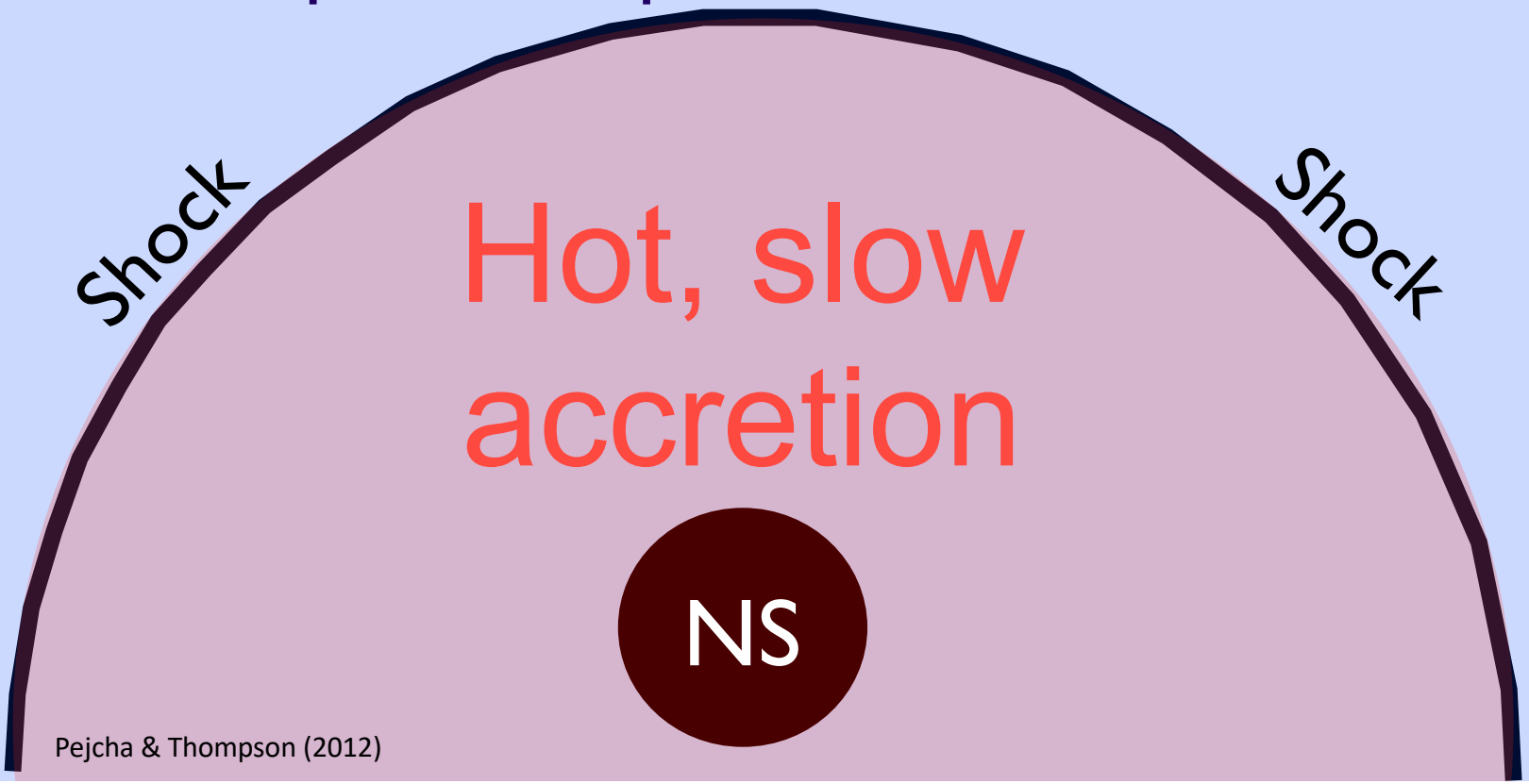
Response: In 1D models with real physics, condition unchanged. Ratio of c_s^2/V_{esc}^2 is ~constant across exploding models (Pochik & Thompson 2025).

Objection II: Normalization of L_{crit} is lower in 2D and 3D. Why?

Response: Many ideas. There might be a simple extension of this idea (Raives+2021, 2026, in prep).

Why are supernovae “close” to exploding?

Cold supersonic pressure-less free fall



Pejcha & Thompson (2012)

Why are supernovae “close” to explosion?

Shock heating. As material lands on the shock, it thermalizes its gravitational binding energy. For a shock at some radius corresponding to V_{esc}:

Shock heating: $$\frac{c_s^2}{V_{\rm esc}^2} = \frac{2\gamma(\gamma-1)}{(\gamma+1)^2} = \frac{8}{49} \approx 0.16 \quad (\gamma = \frac{4}{3})$$

Critical value “Antesonic”: $$\frac{c_s^2}{V_{\rm esc}^2} = \frac{3\gamma}{16} = \frac{1}{4} = 0.25 \quad (\gamma = \frac{4}{3})$$

Why do supernovae explode?

Hypothesis: **“**Antesonic” condition: $c_s^2/V_{esc}^2 = 3\gamma/16$.

→ Above this limit, it is impossible to simultaneously satisfy the shock jump conditions and the time-steady Euler equation at any radius. If exceeded, the system transitions to a thermal wind.

Why are supernovae “close” to explosion?

Shock-heating: $c_s^2/V_{esc}^2 = 2\gamma(\gamma\text{-}1)/(\gamma\text{+}1)^2$.

For γ = 4/3 this is 0.65 of c_s^2/V_{esc}^2 and 0.81 of c_s/V_{esc} required for explosion.

→ Supernovae are marginal because the specific thermal energy of the matter falling onto the shock and the specific thermal energy required for explosion are both approximately V_{esc}^2.

(Bonus question: What about γ = 5/3?)

Raives, Coughlin, Thompson 26, in prep