Axion Stars:
Toward the Planck Scale

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PATRAS Axion Workshop
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JE, Street, Suranyi, Wijewardhana (2011.09087)

Why Approach $f \simeq M_P$?

- Axion theory: two mass scales — m **Axion mass**, f **Decay constant**

◉ Many axion models predict (or allow) $f \simeq M_P$

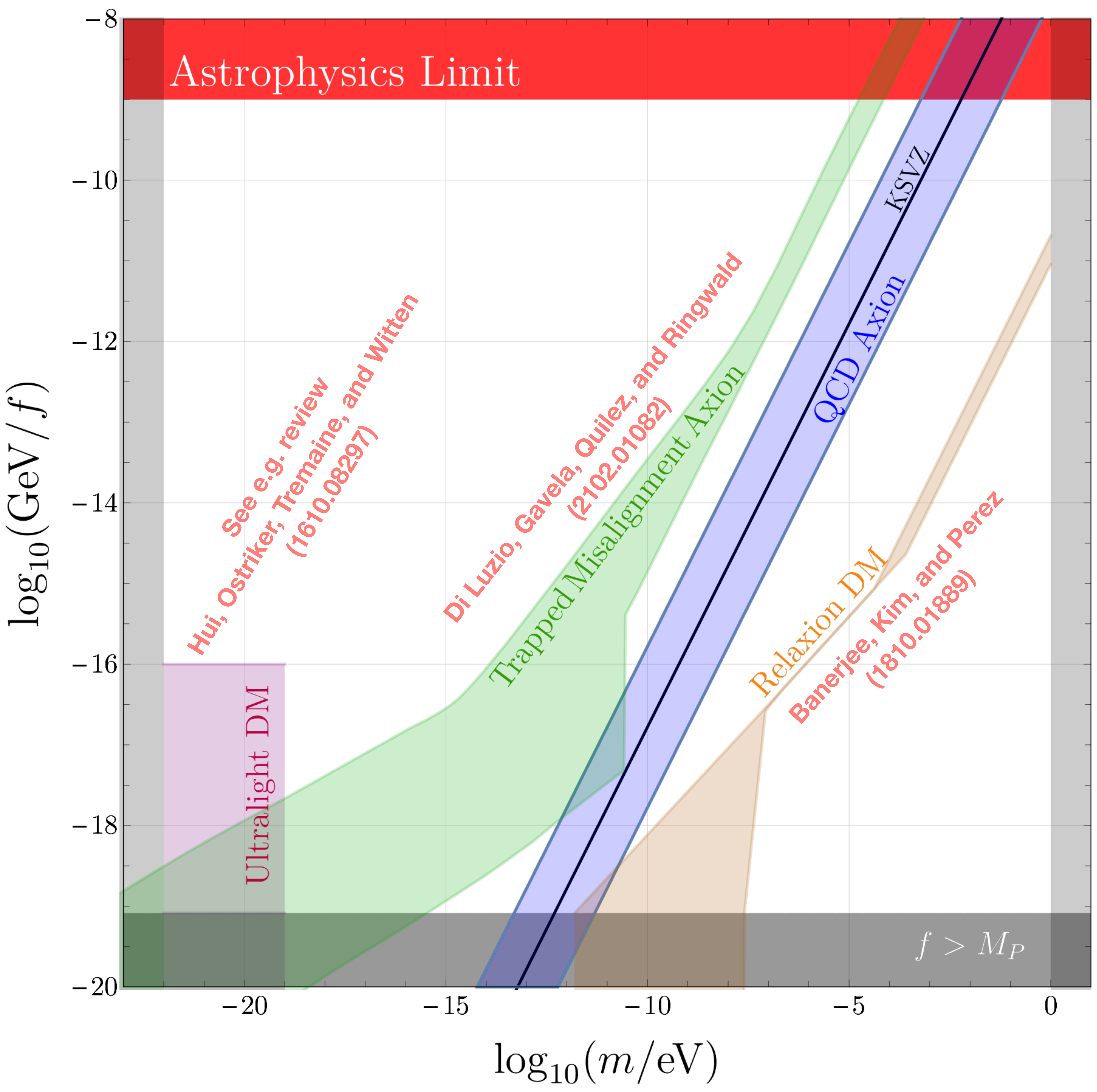
◉ Axion stars may be neutron star mimickers if $m \sim 10^{-10}\,\mathrm{eV}$ and $f \sim M_P$

Clough, Dietrich, Niemeyer (1808.04668)
with Day, Coughlin (1808.04746)

◉ Axion star collapse near $f \sim M_P$ may lead to black hole formation

Helfer, Marsh, Clough, Fairbairn, Lim, Becerril (1609.04724)
Chavanis (1710.06268)
Michel and Moss (1802.10085)

Could explain e.g. intermediate mass black holes??

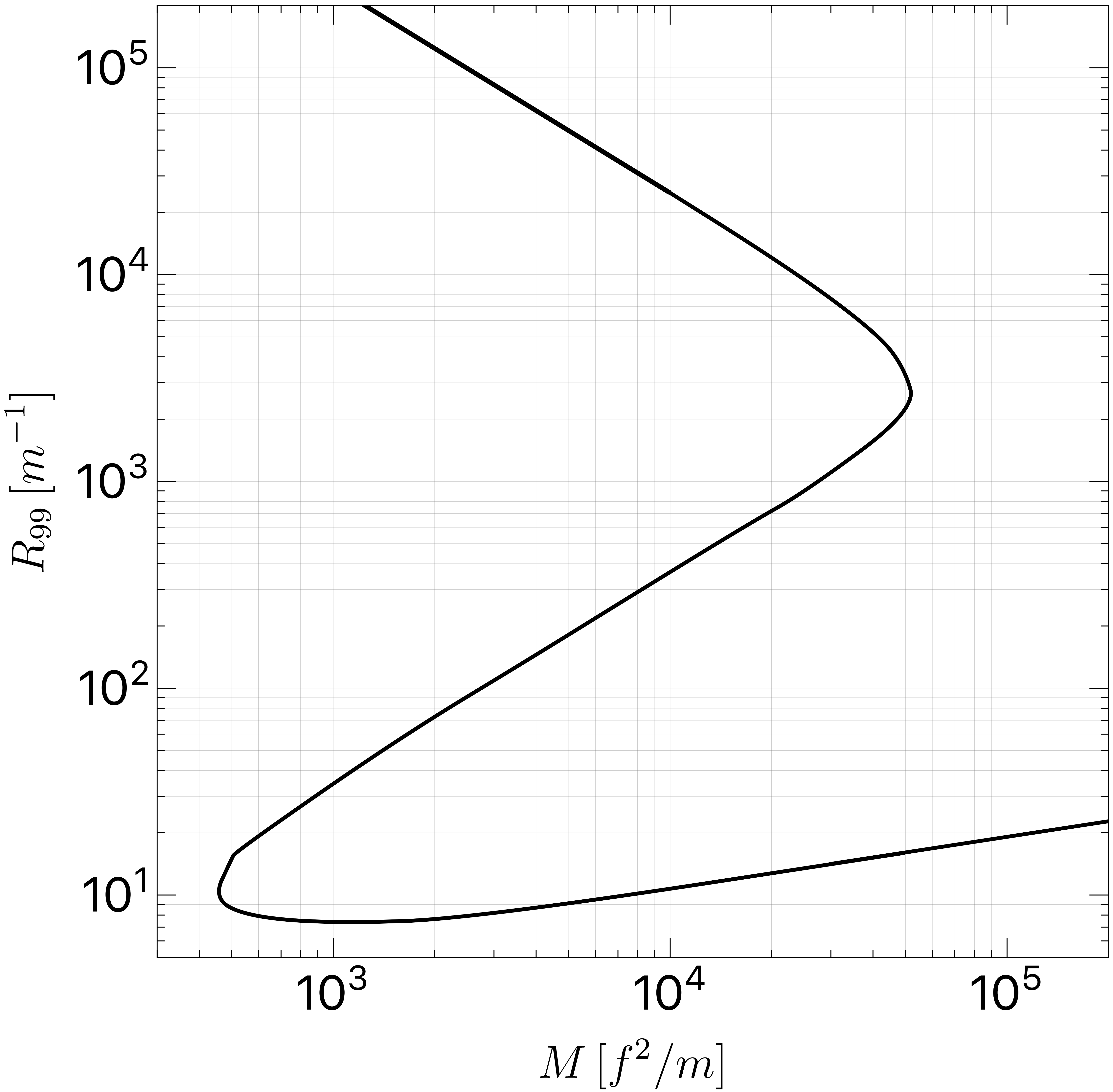


- Axion UV Potential

$$V(\phi) = m^2 f^2 \left[1 - \cos\left(\frac{\phi}{f}\right)\right]$$

- Axion Stars: Three forces

$\left(\partial_\mu \phi\right)^2$	$g^{\mu\nu}$	$V(\phi)$
Gradient	**Gravity**	**Self-int.s**



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Gradient	**Gravity**	**Self-int.s**
$\nabla^2\psi$	$V_g(\psi)$	$-(m^2/f^2)\psi^4$
(repulsive)	**(attractive)**	**(attractive)**
$\propto M\,R^{-2}$	$\propto M^2\,R^{-1}$	$\propto M^2\,R^{-3}$

Non-relativistic Limit

$\Delta = \sqrt{1 - \epsilon^2/m^2} \ll 1$

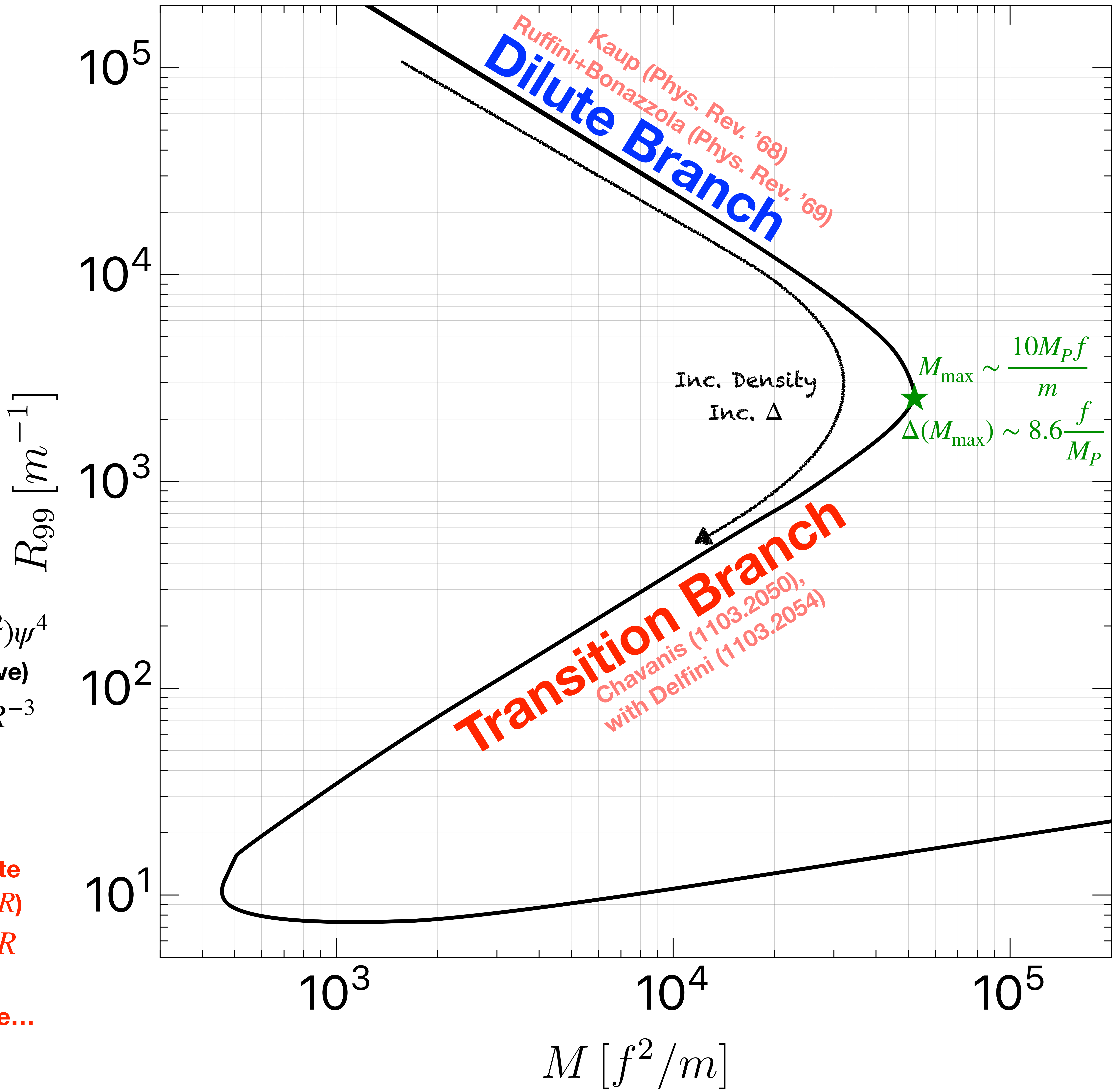
Energy eigenvalue

Dilute limit
(Large R)
$M = (G\,m^2\,R)^{-1}$

Less-dilute
(Medium R)
$M = f^2\,R$

Under perturbations…

Stable! **Unstable…**



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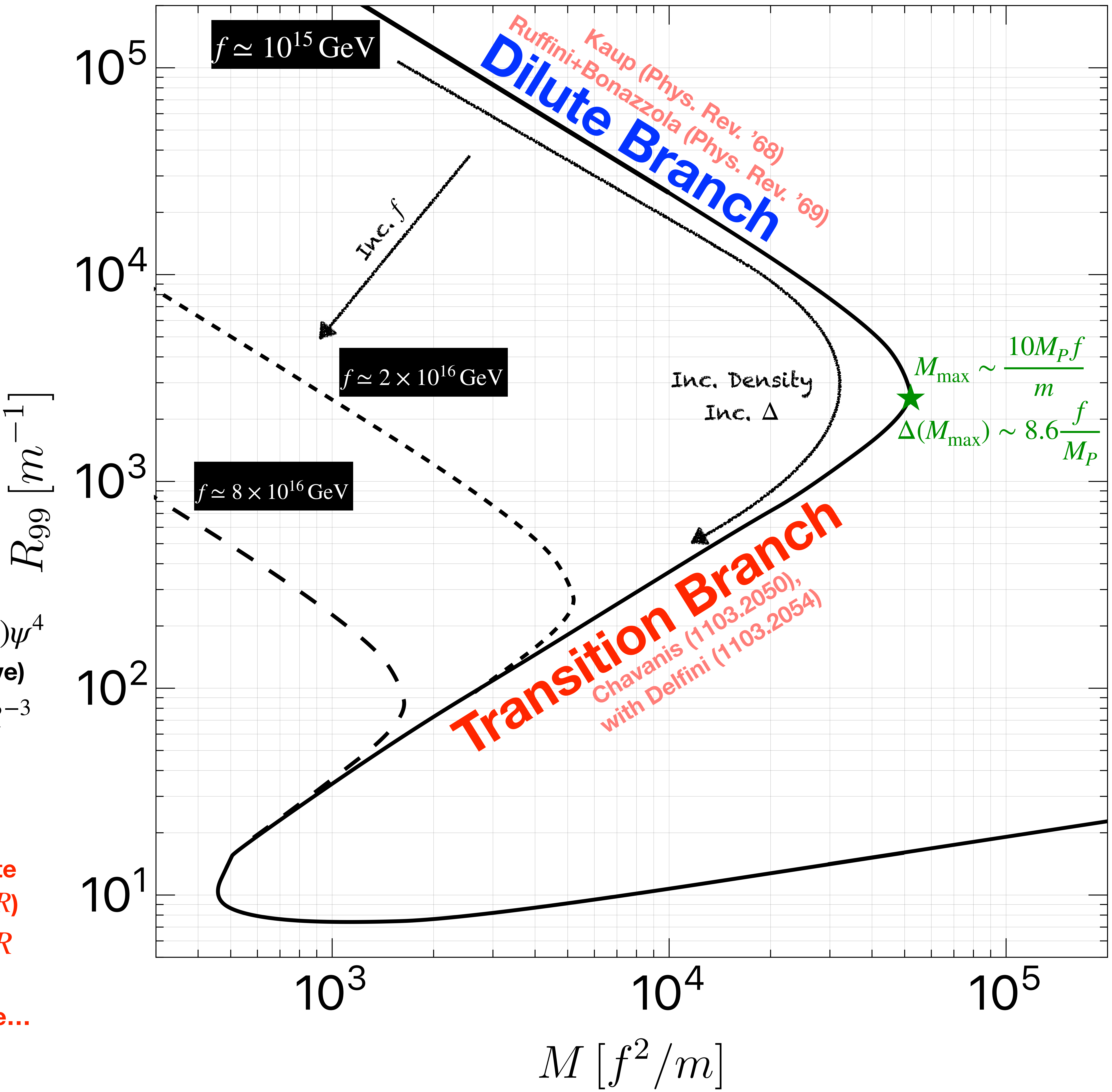

- Keep increasing f: what happens?
Transition Branch Shrinks

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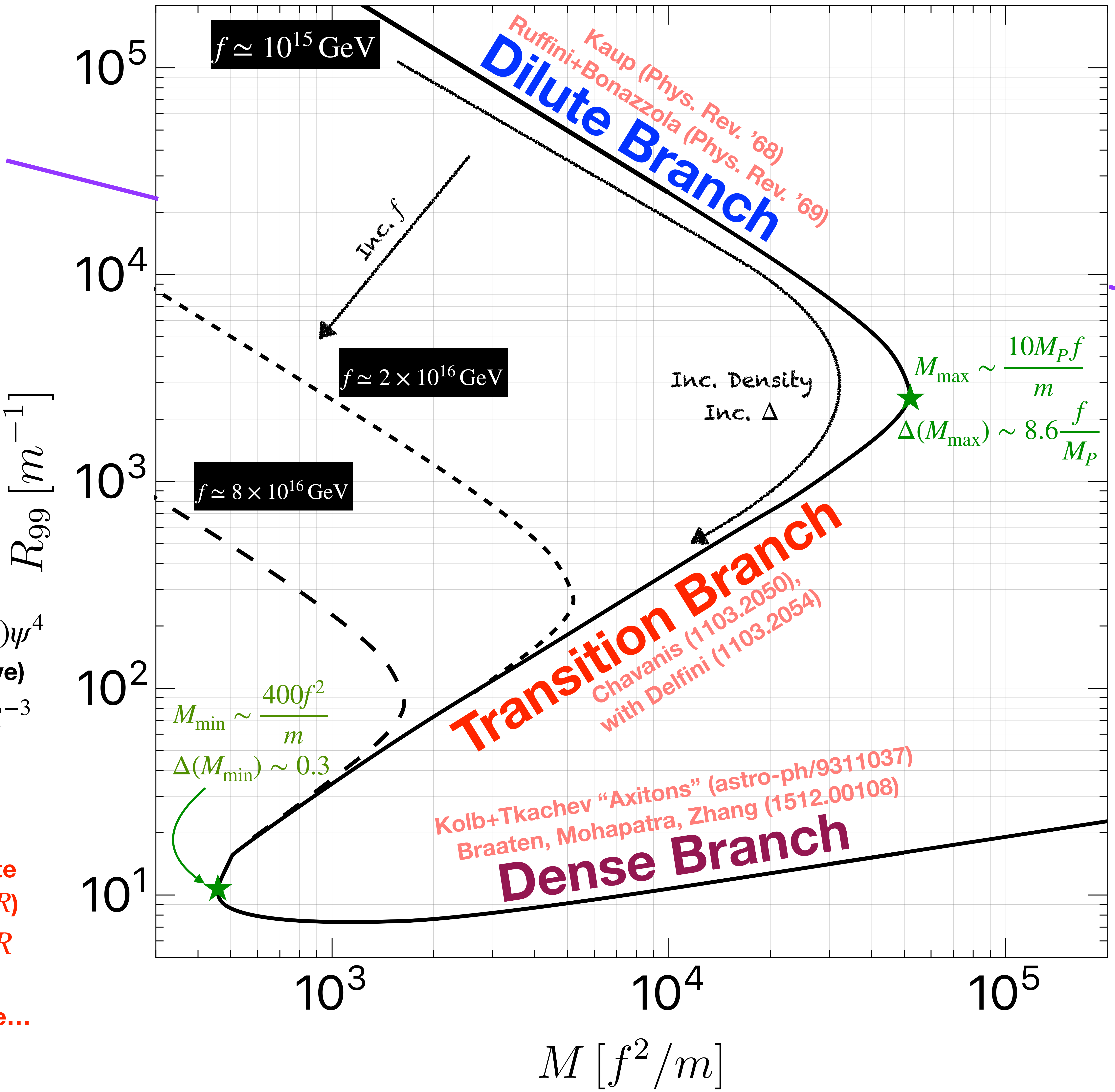

- Keep increasing f: what happens?
  Transition Branch Shrinks

- Keep increasing Δ: what happens?

Higher orders: $+\phi^6, -\phi^8, \ldots$

Naively, balance $-\phi^4$ against $+\phi^6$

Dense
(Small R)
$M = m^2 f^2 R^3$

Perturbations…
Stable!

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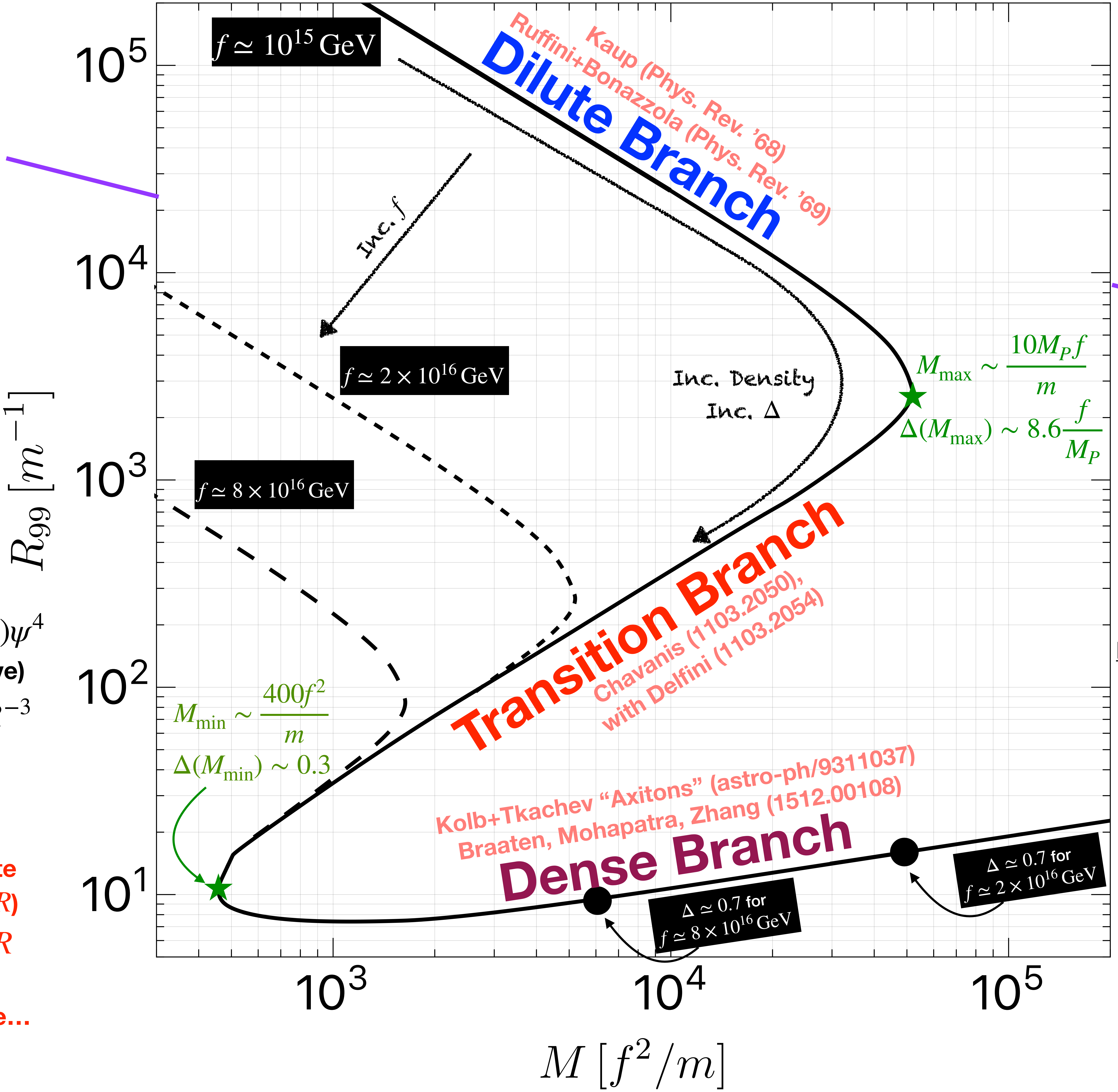

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Perturbations…

Stable!

HOWEVER

Larger Δ ⇔ Breakdown of NR appx

Backreaction: **Higher harmonic modes in scalar field expansion**

Vissinelli, Baum, Redondo, Freese, Wilczek (1710.08910)

→ **"Integrate out" modes of $3\epsilon, 5\epsilon, \ldots$**

→ **Expansion in $\Delta \ll 1$**

JE, Suranyi, Wijewardhana (1712.04941)

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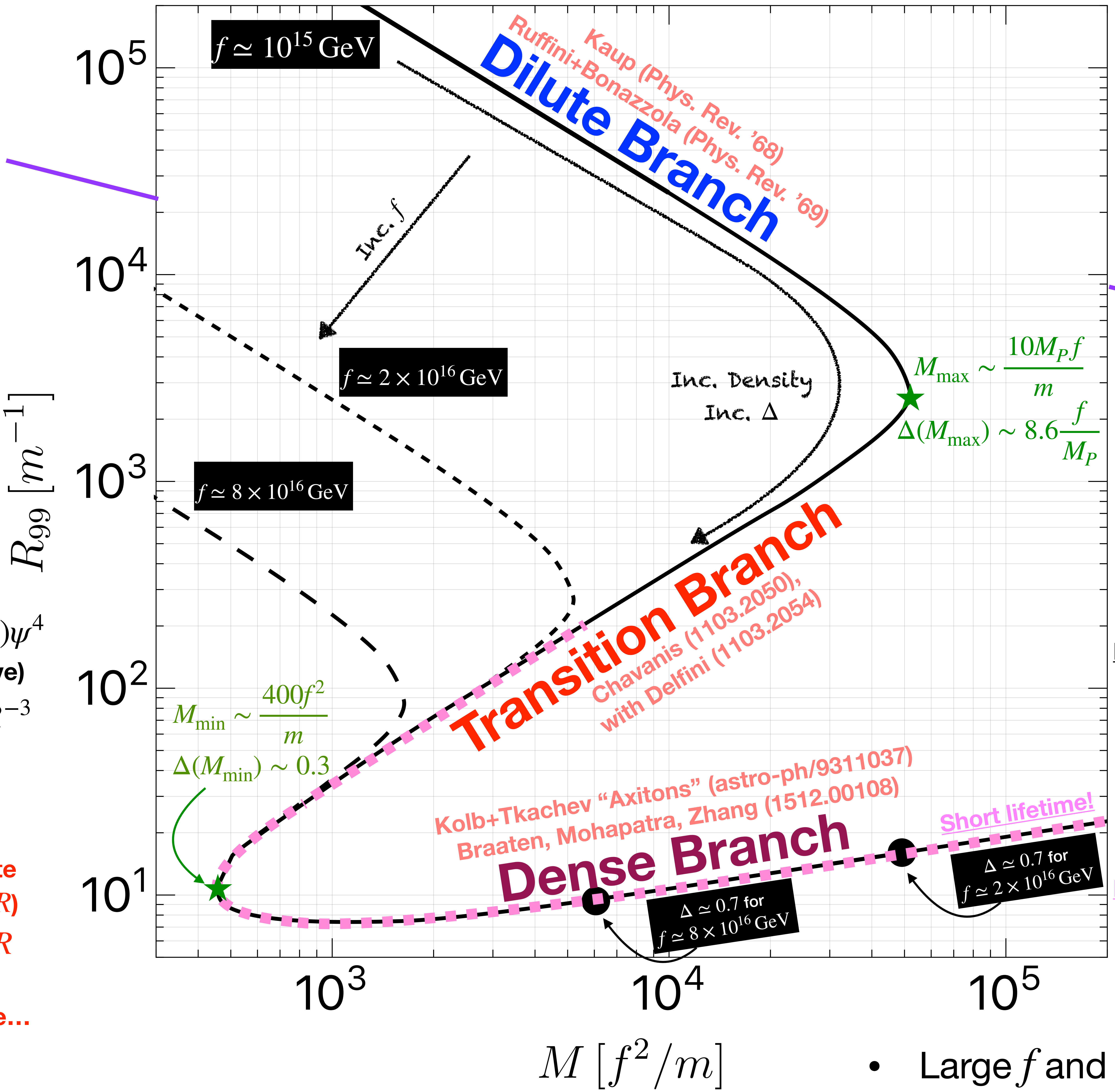

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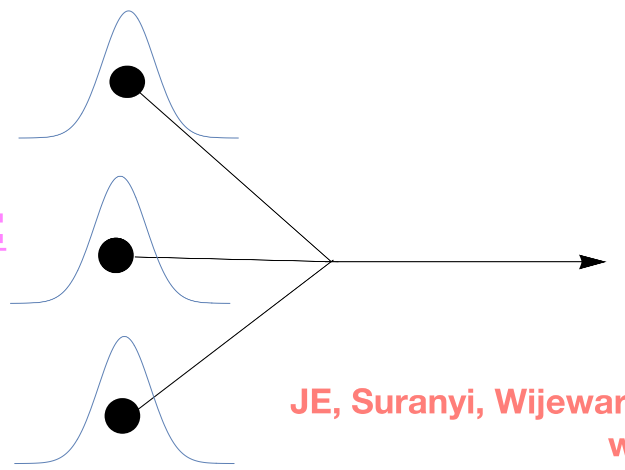
Decay:



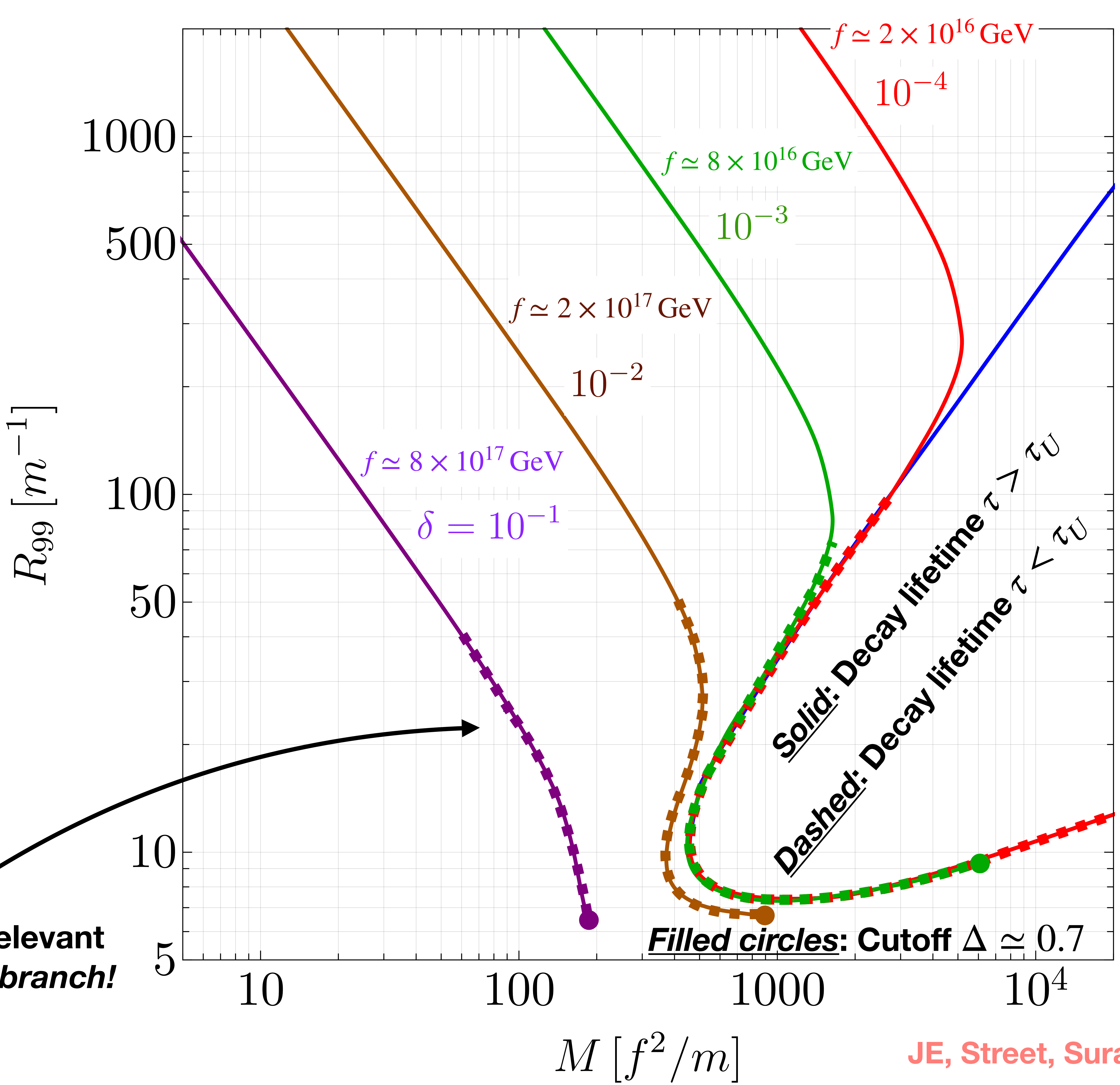
$\omega_p \sim 3m$

$p \sim \sqrt{8}\, m$

JE, Suranyi, Wijewardhana (1512.01709) with Ma (1705.05385)

- Large f and large Δ: what happens??

$$\delta = \frac{8\pi f^2}{M_P^2}$$



Decay becomes relevant *even on the dilute branch!*

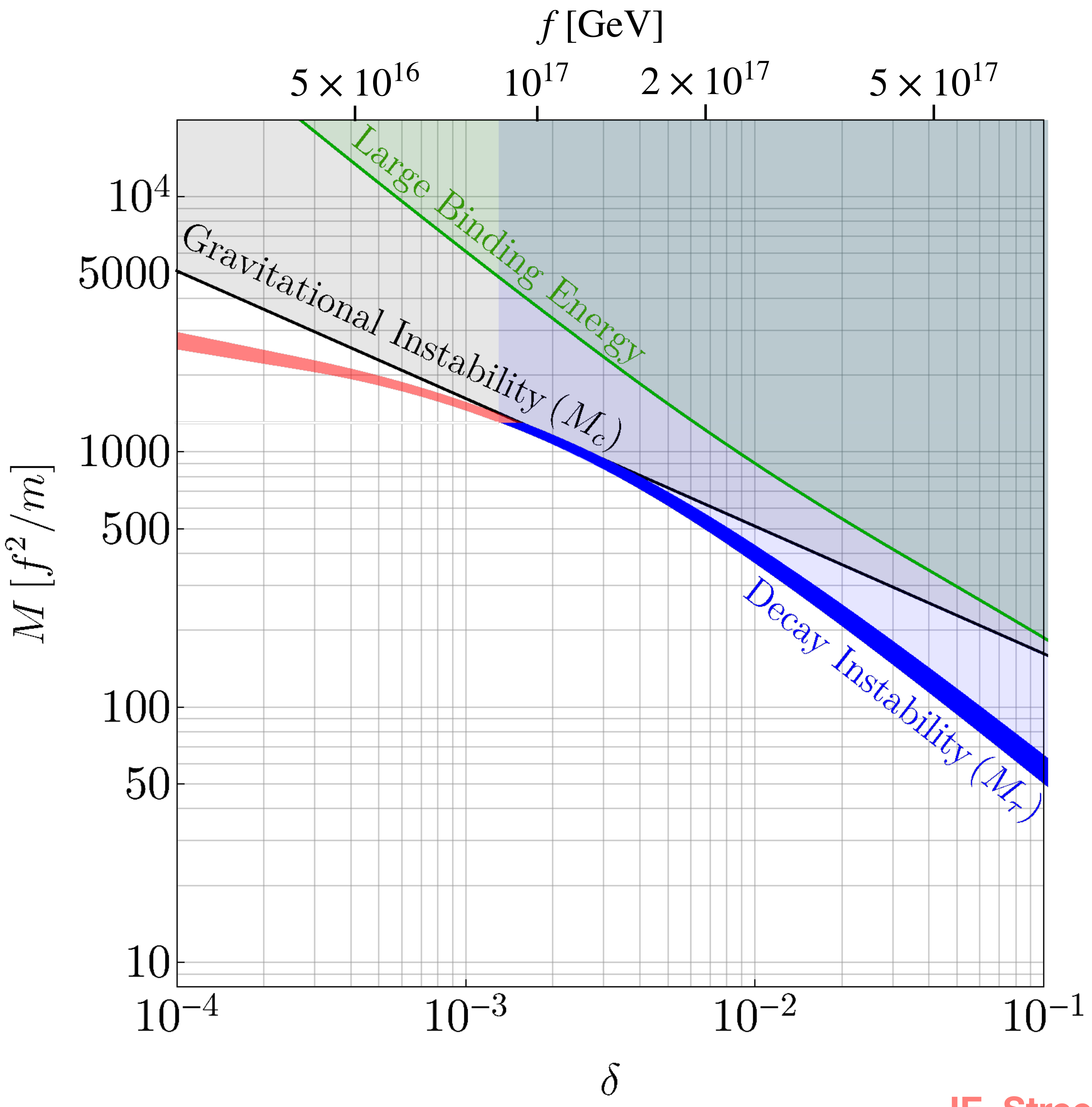
Conclusions:

1. **Can't naively extrapolate to large values of f**
2. **Decay important near $M_{\rm max}$ *on dilute branch* (!) whenever $f \gtrsim 10^{17}$ GeV**
3. **Existence of transition/dense branches inconsistent with perturbative approaches for $f \gtrsim 10^{18}$ GeV**
4. **Truly Planck-scale axion stars out of reach; need post-Newtonian gravitational terms**

THANK YOU!!

JE, Street, Suranyi, Wijewardhana (2011.09087)

Bonus Round



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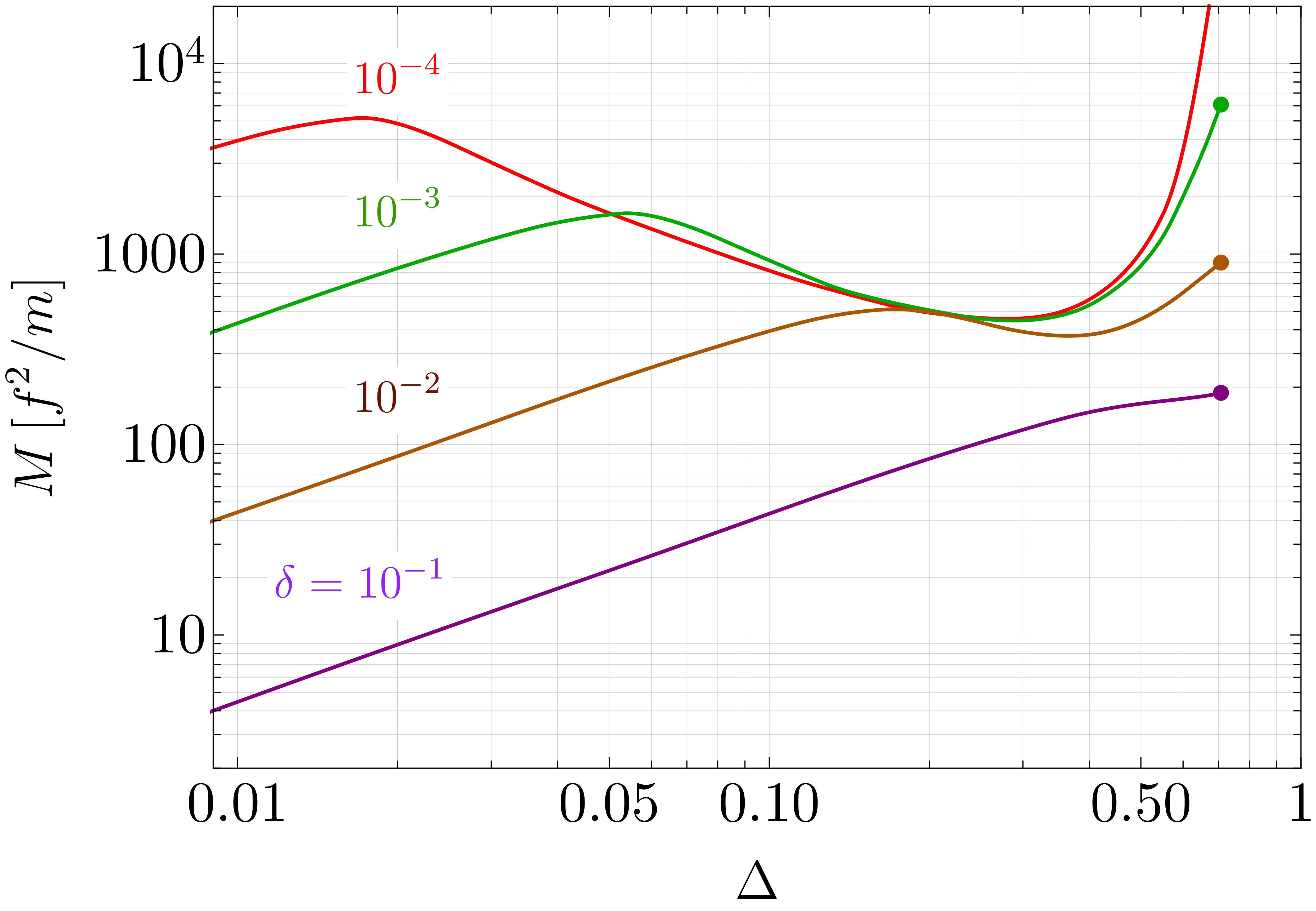
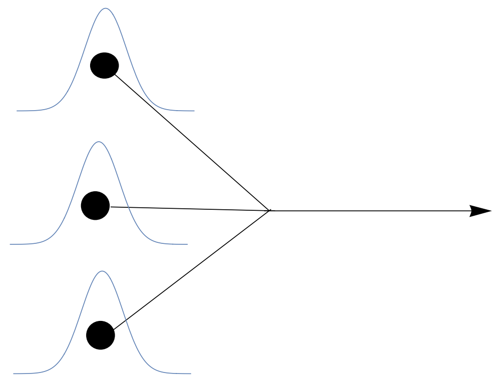
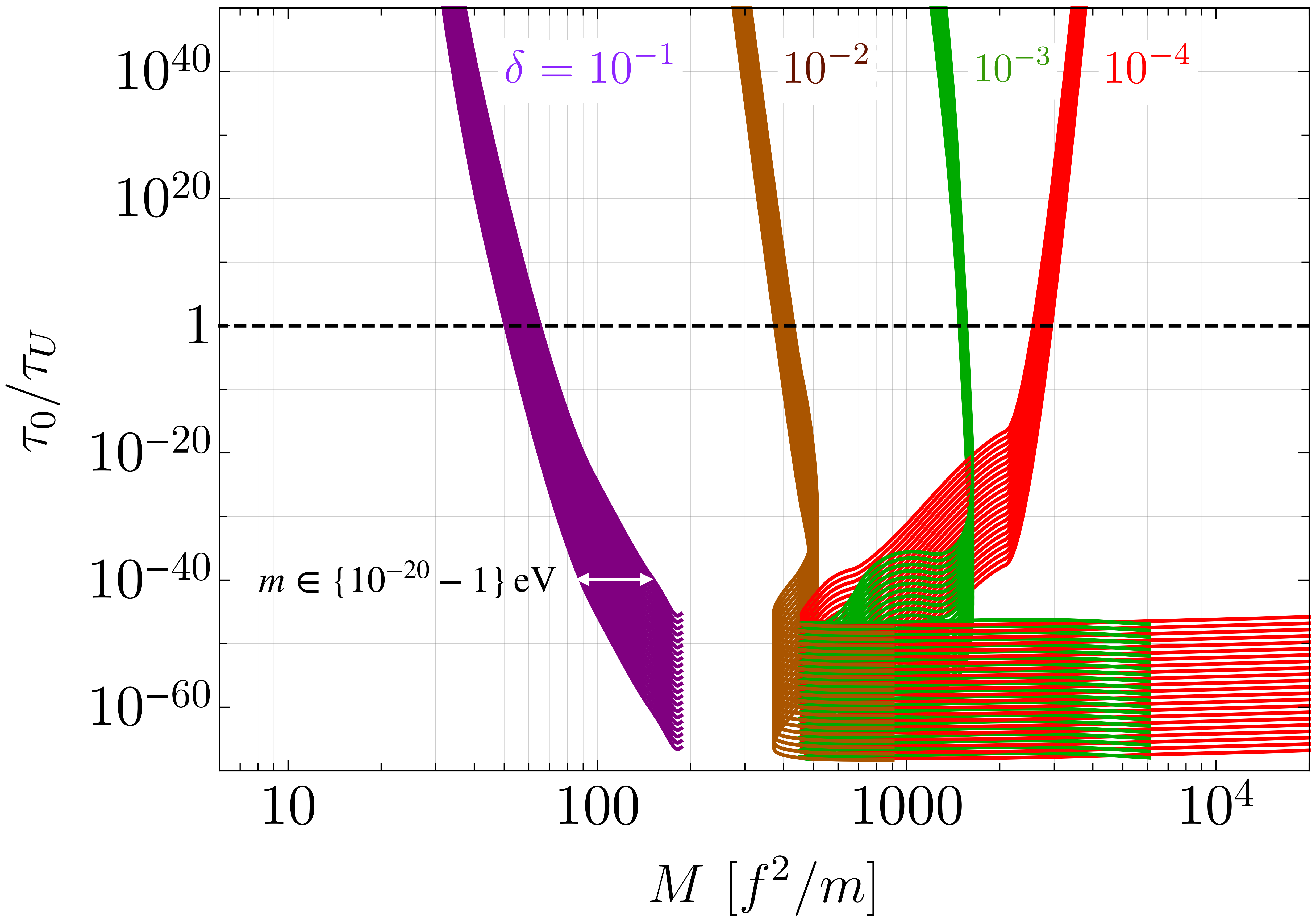
Mass-Δ



Lifetime-Mass





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