# Kilohertz quasi-periodic oscillations and broad iron emission lines as a probe of strong-field gravity


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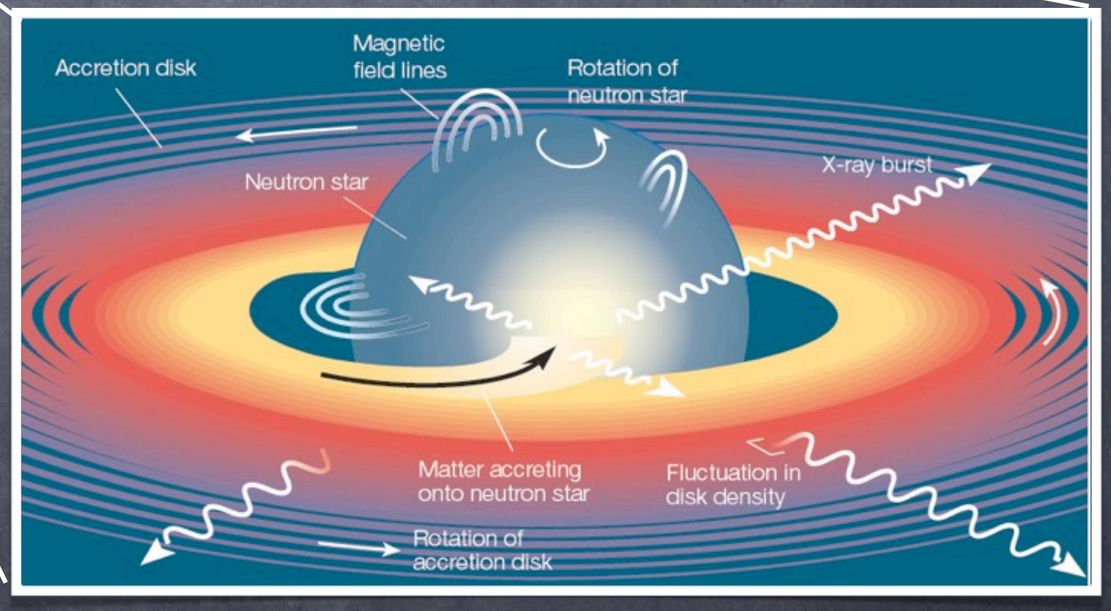
High Energy View of Accreting Objects: AGN and X-ray Binaries - Crete - 13/10/2010

# Outline

- Neutron star low-mass X-ray binaries
- High frequency quasi-periodic oscillations (kHz QPOs)
- XTE J1701-462 and properties of the kHz QPOs
- Relativistically-broadened iron lines
- 4U 1636-53 iron lines and kHz QPOs
- Summary

# NS low-mass X-ray binaries



# Motivations to study NS LMXBs

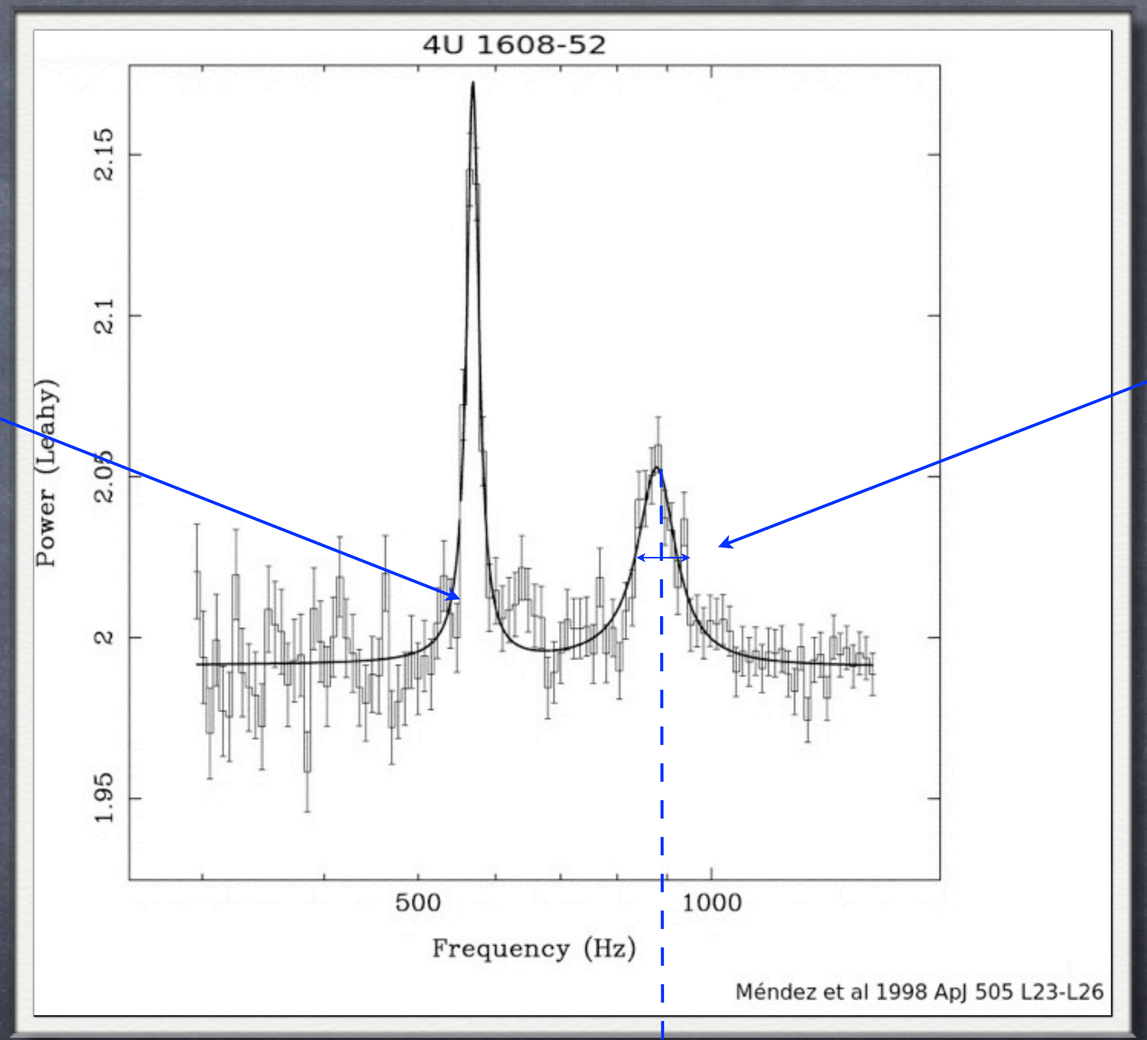
- Physics of the matter at ultra-high density
- Investigate GR in the strong-field regime
- Understanding the physics of NS atmosphere
- Physics of the plasma in strong-gravity regions

# KHz Quasi-Periodic Oscillations

$$P = \int P_\nu \, d\nu$$

$$rms\% \propto P^{1/2}$$

fractional root-mean-squared amplitude




$\nu_0$

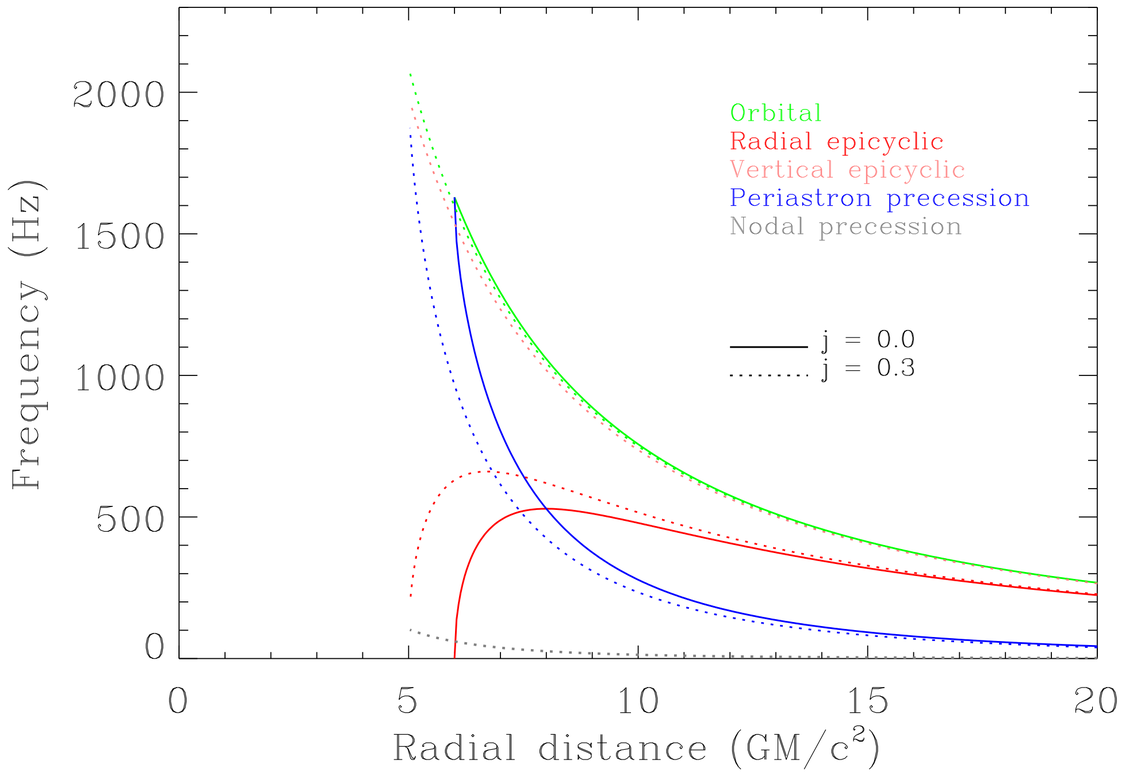
FWHM

$$Q = \frac{\nu_0}{\mathrm{FWHM}}$$

Coherence of the QPO

# KHz Quasi-Period Oscillations

## Possible candidates




(from Bhattacharyya 2010)

$$\nu_\phi = \nu_K \left(1 + j(r_g/r)^{3/2}\right)^{-1}$$

$$\nu_K = \frac{1}{2\pi}\sqrt{GM/r^3}$$

Keplerian Frequency

$$r_g = GM/c^2$$

Gravitational radius

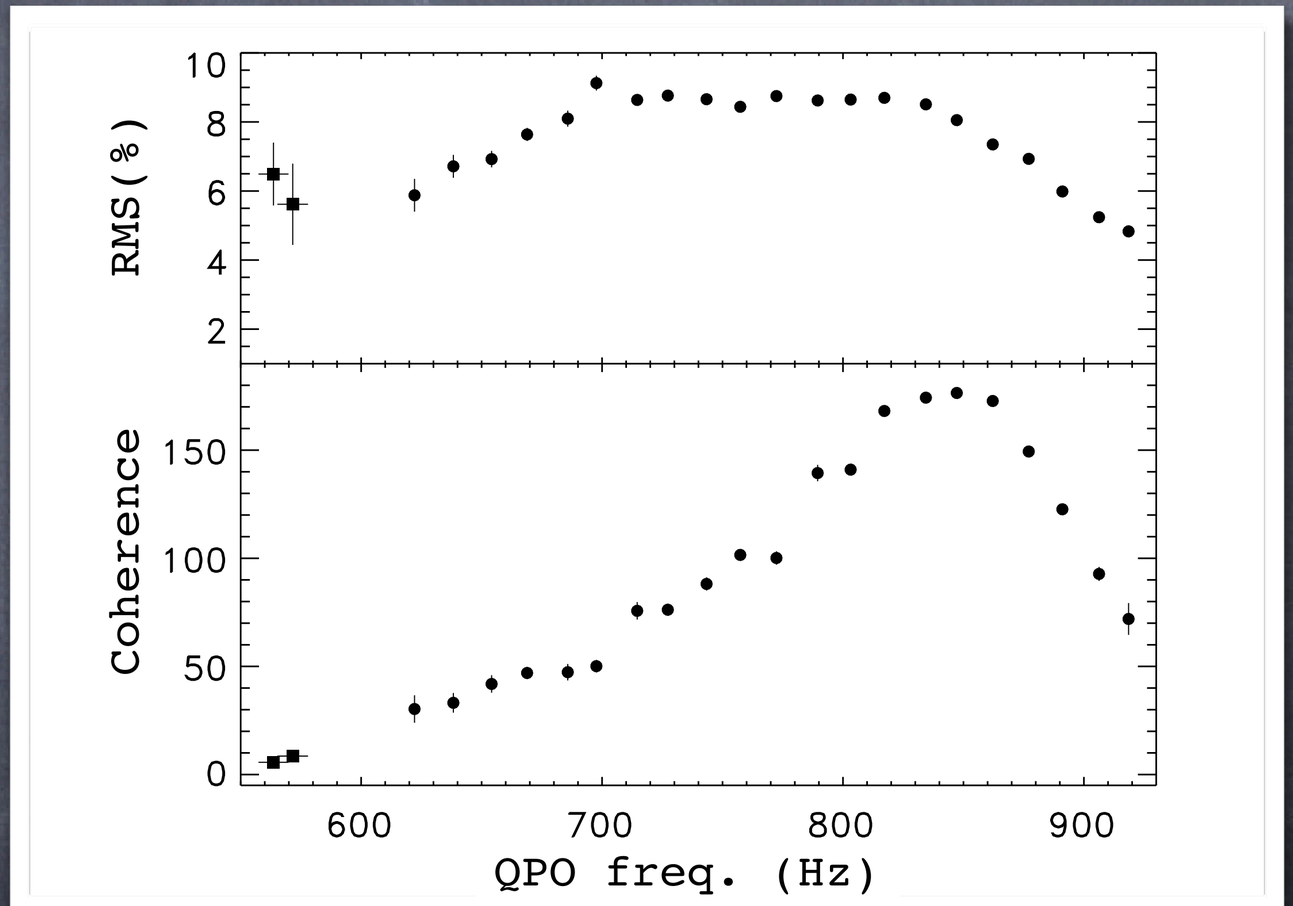
$$j = Jc/GM^2$$

Angular momentum parameter

Assuming Mass and Spin → Inner Radius of the Disk

# KHz Quasi-Period Oscillations

## 4U 1636-53

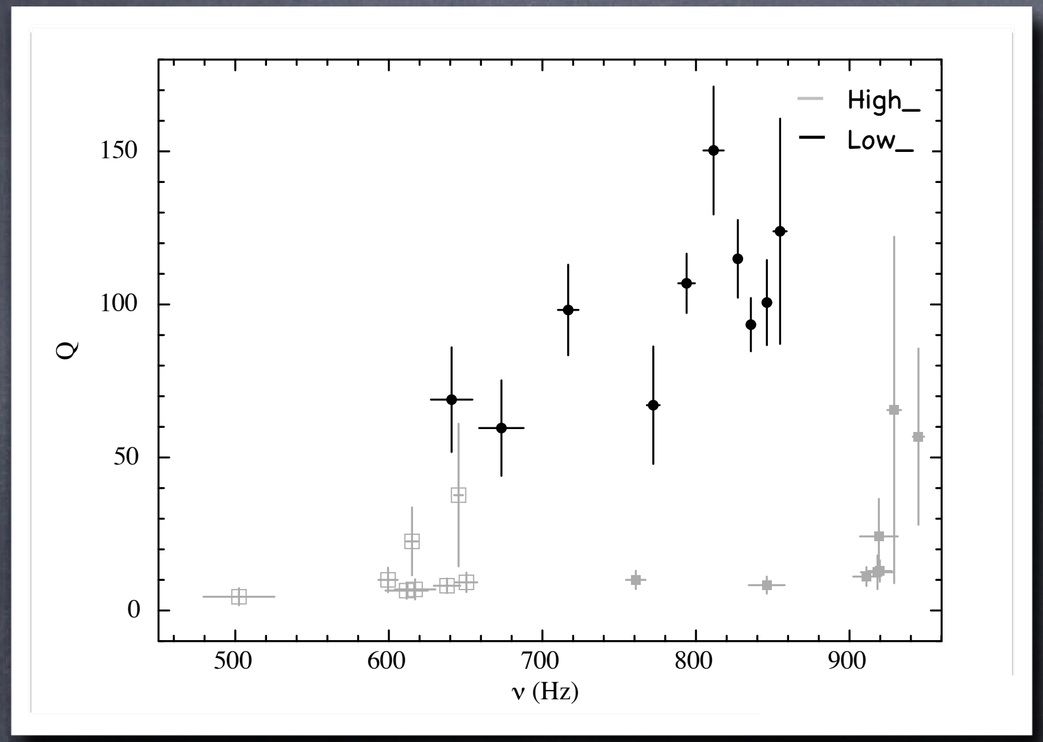


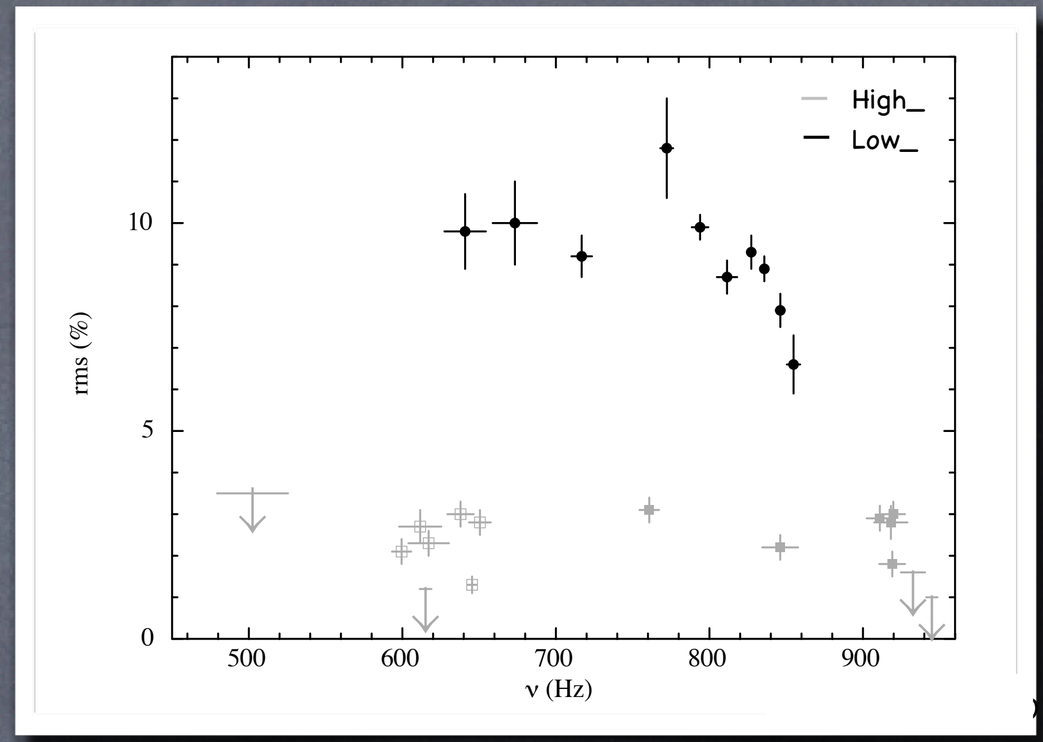

Drop of the quality factor Q and rms amplitude of the lower kHz QPO

Signatures of the ISCO

Barret, Olive & Miller 2005

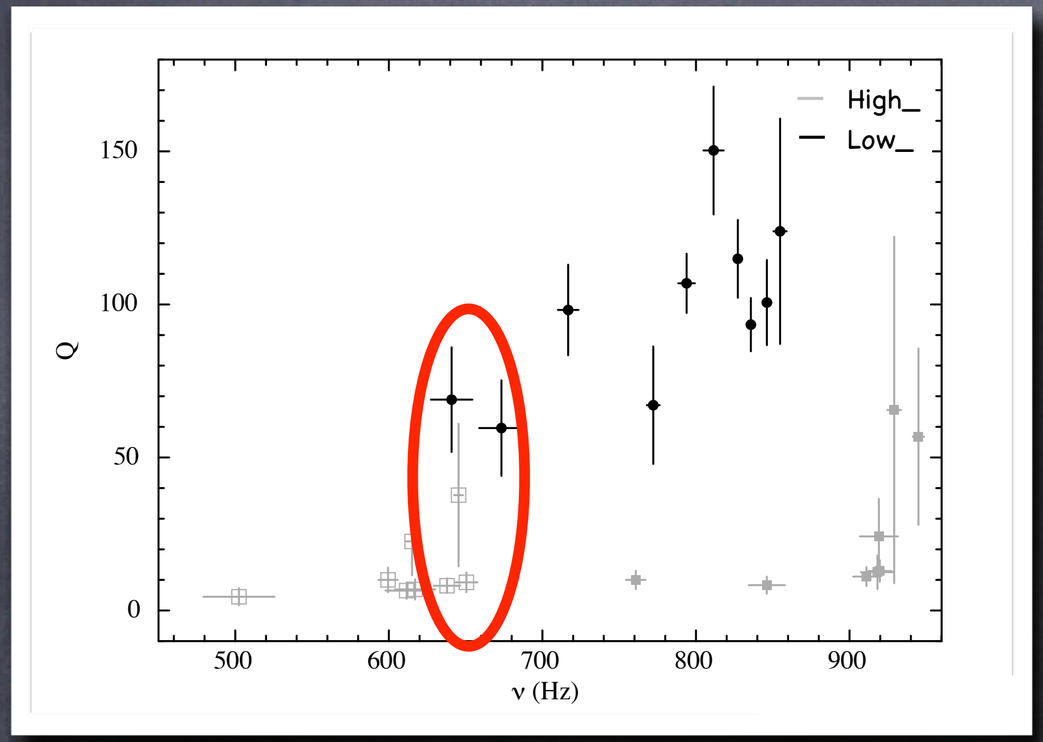
# XTE J1701-462

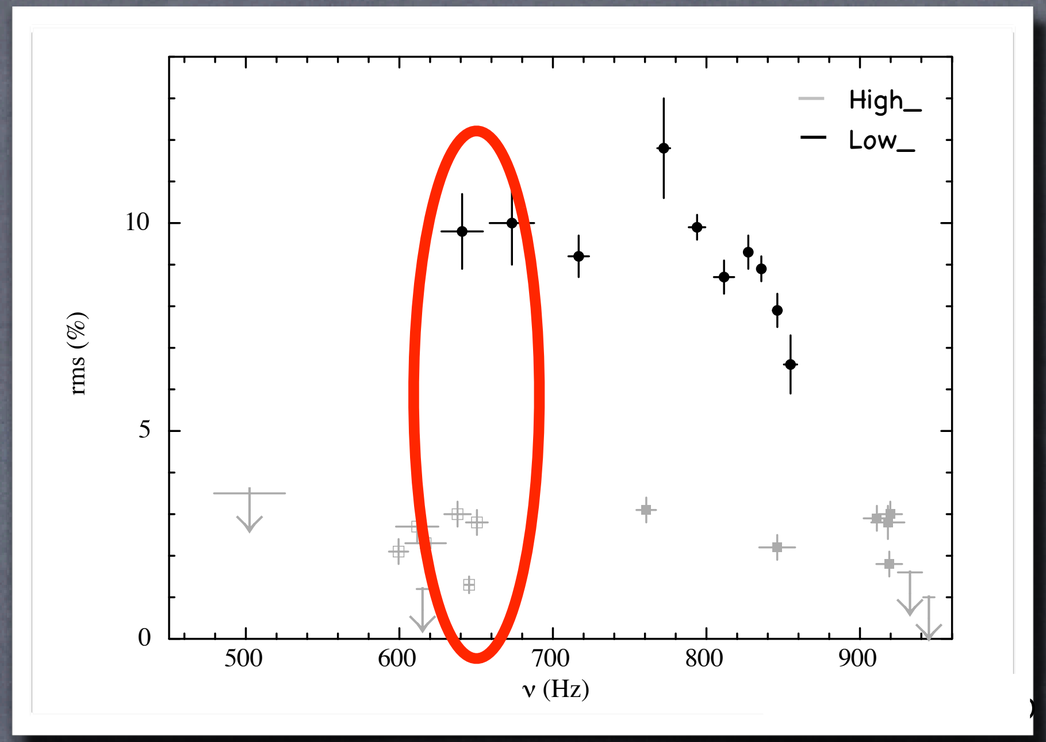



Sanna et al. 2010

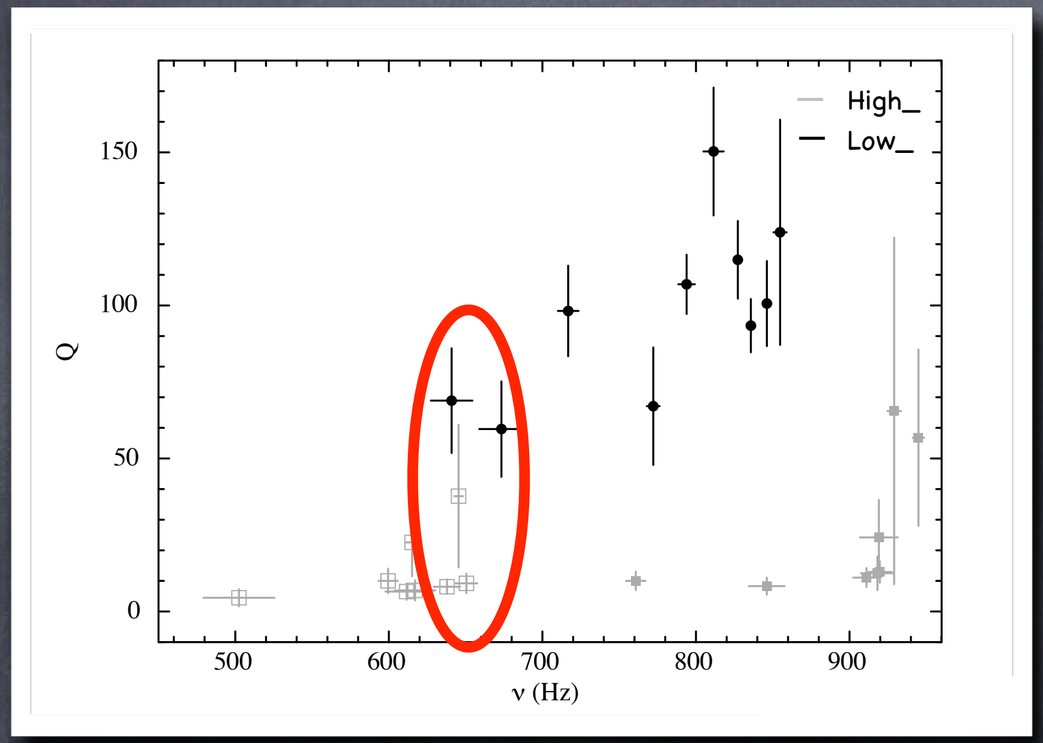
# XTE J1701-462

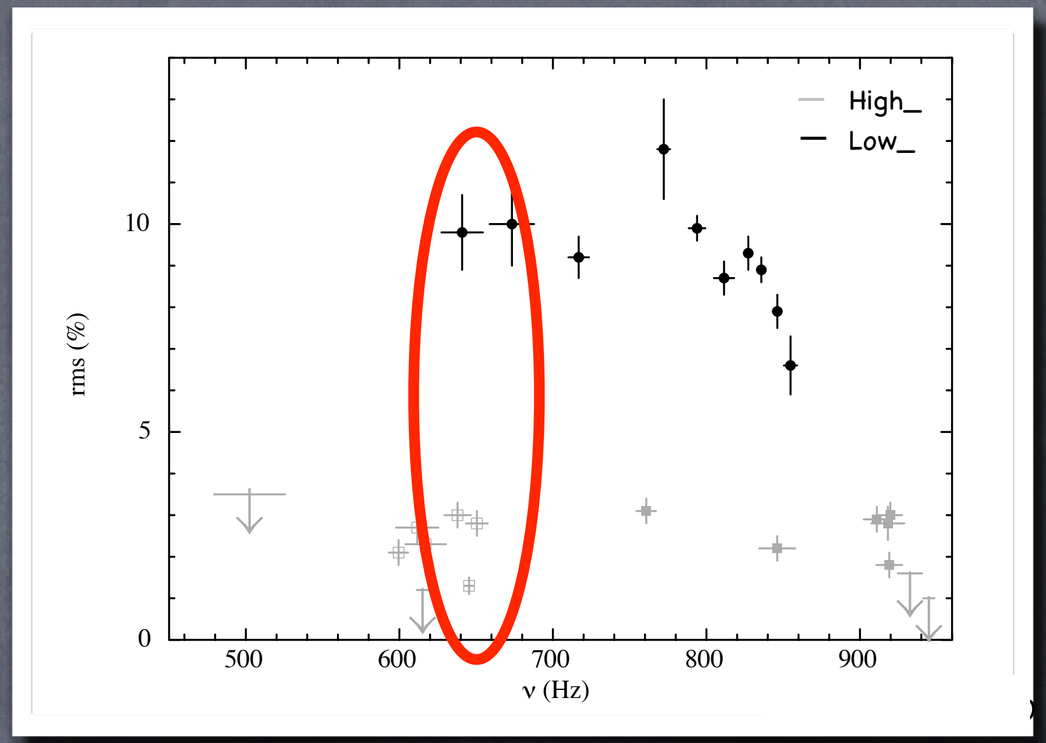



Sanna et al. 2010

# XTE J1701-462

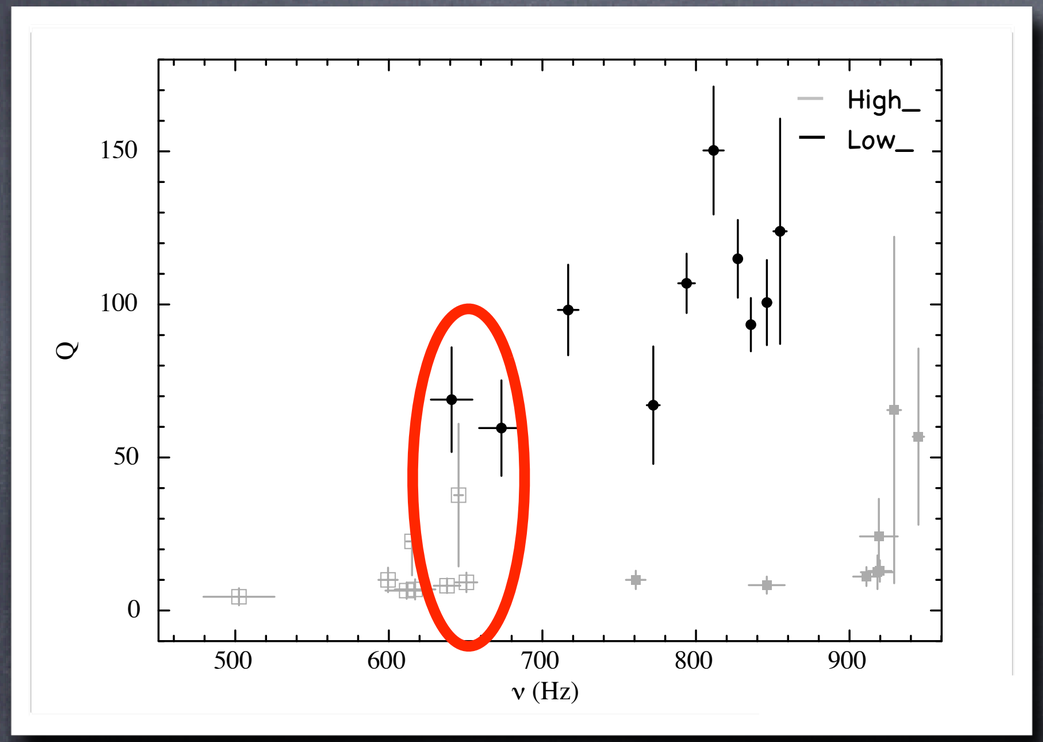


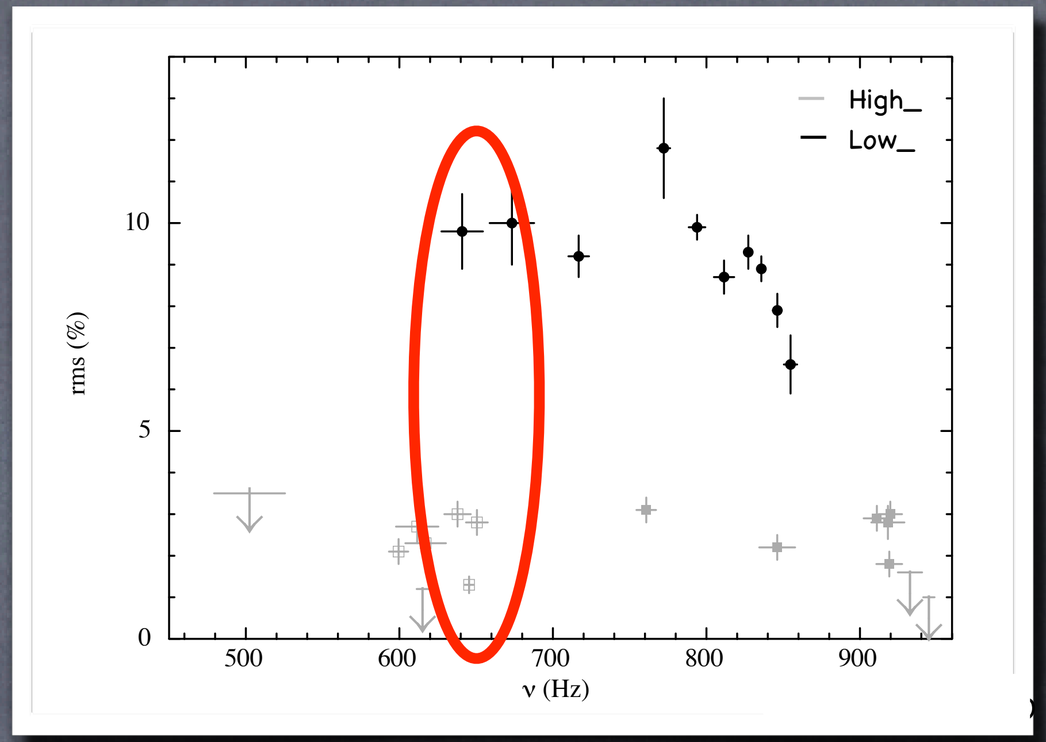




Sanna et al. 2010

Coherence and rms% seem not to be driven only by R disk

# XTE J1701-462



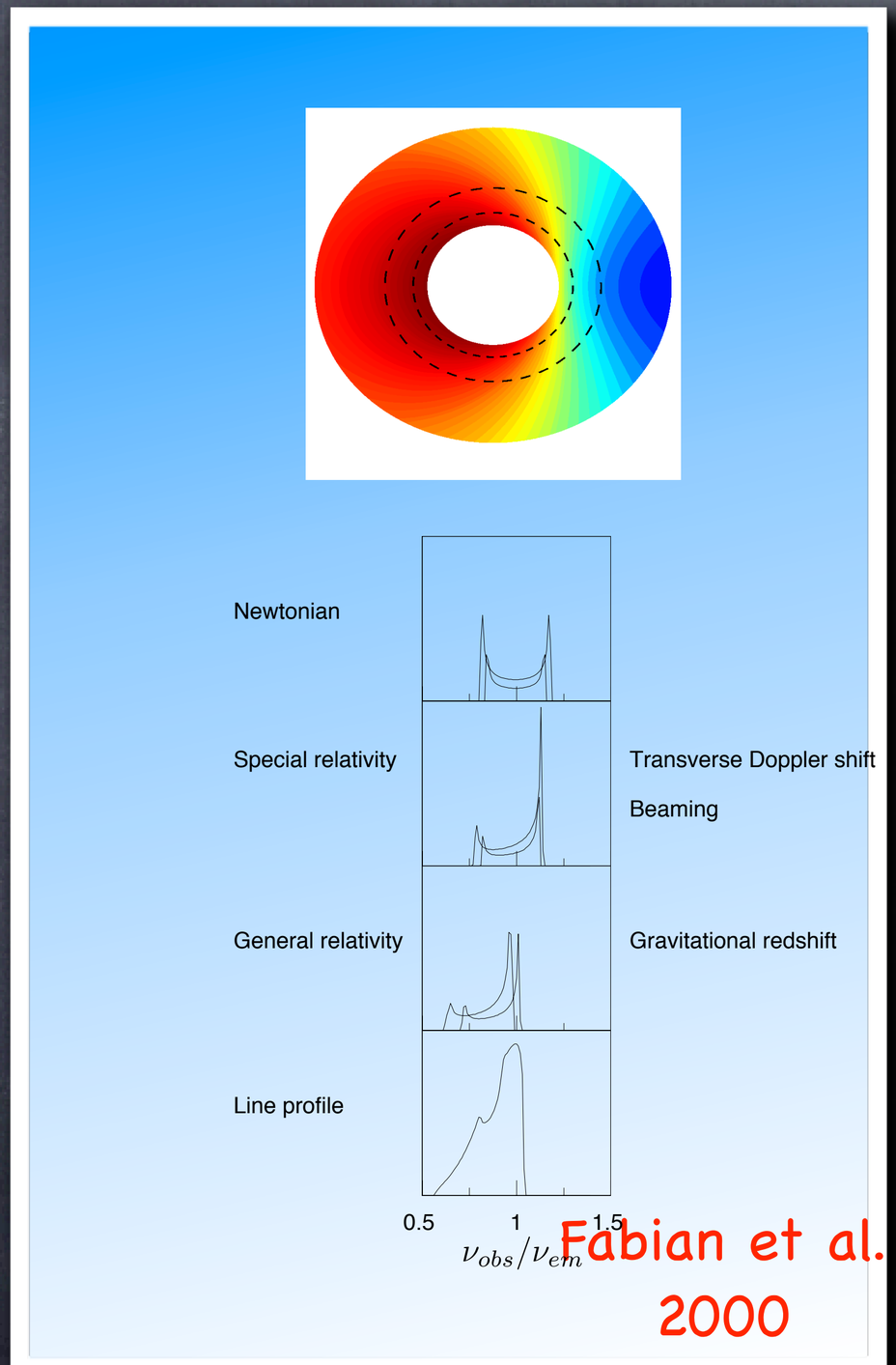




Sanna et al. 2010

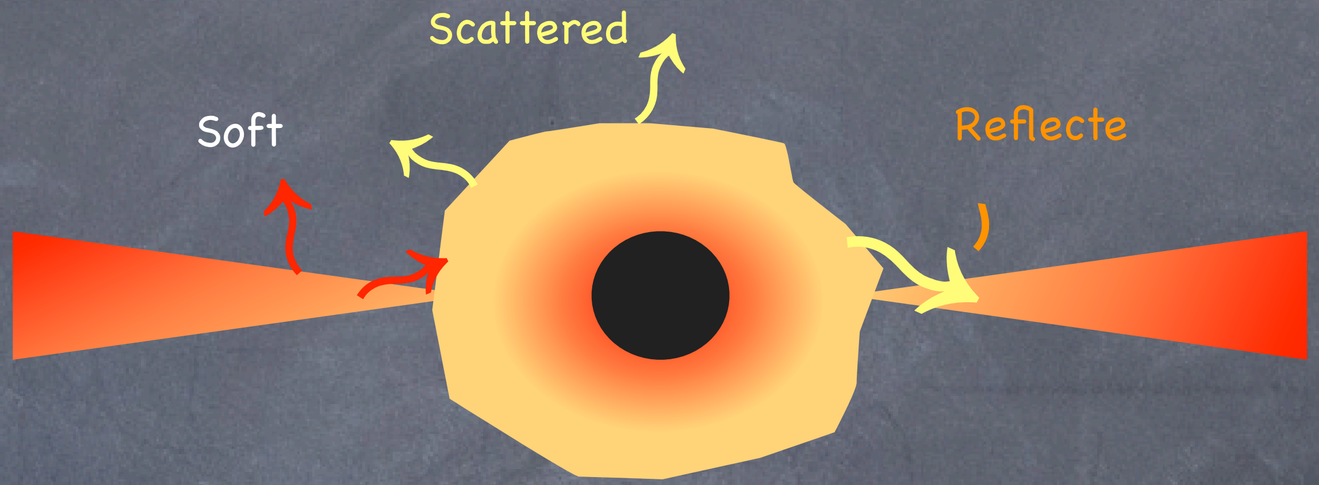
Coherence and rms% seem not to be driven only by R disk

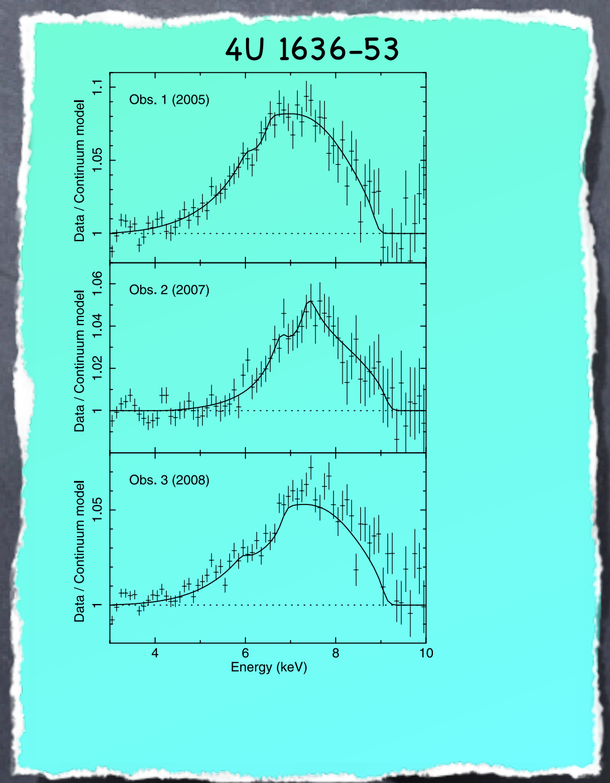
we suggest that changes in the properties of the accretion flow can explain those differences

# Relativistically broadened iron lines




Fabian et al. 2000



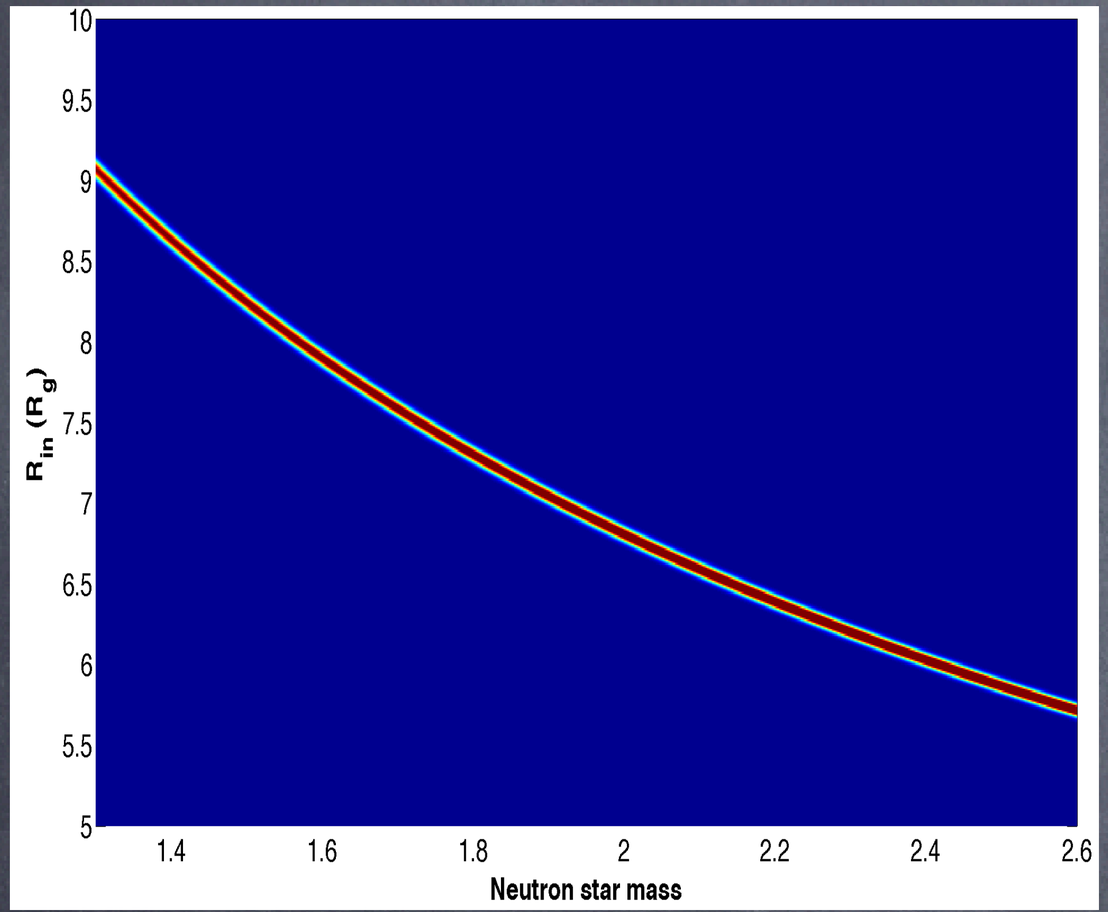




Pandel et al. 2008

# 4U 1636-53

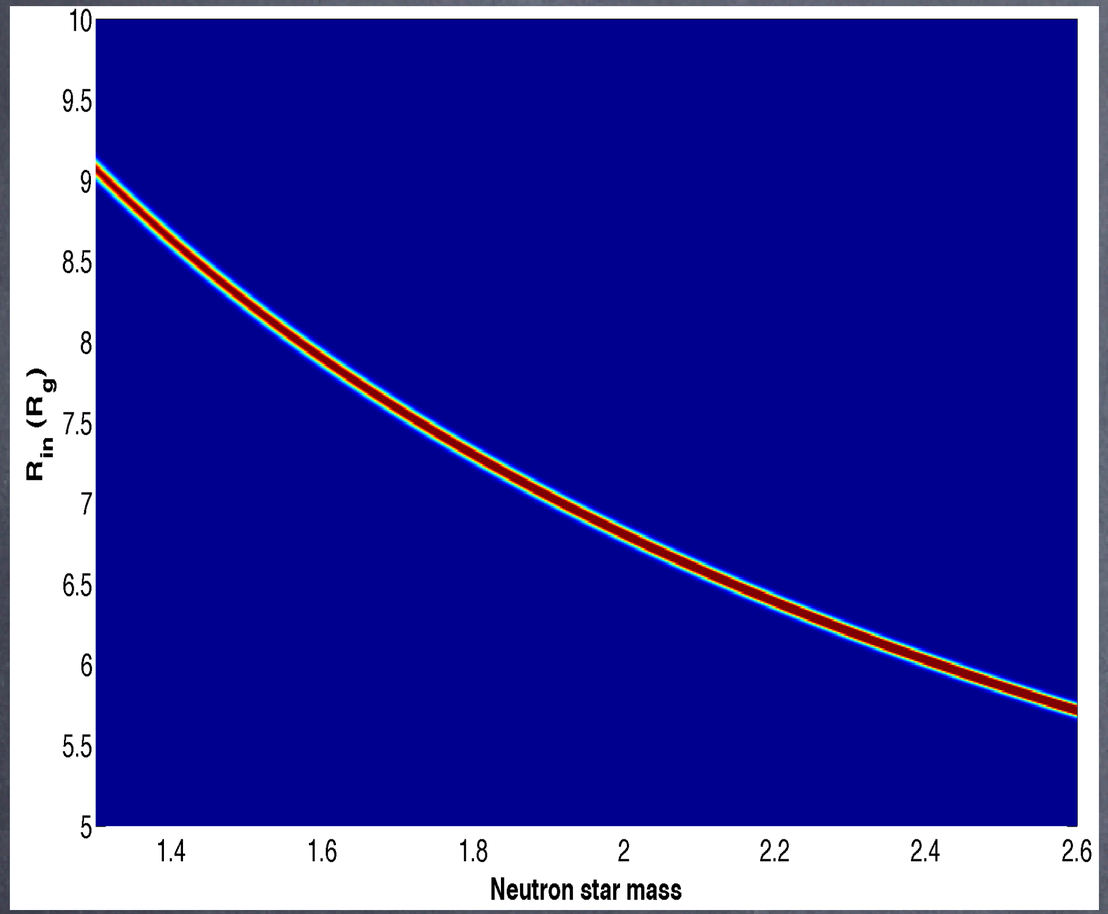
- shows strong broad iron emission line
- shows plenty of kHz QPOs
- we have simultaneous high-time resolution observations (RXTE) and moderate-energy resolution observations (XMM-Newton)

# kHz QPO

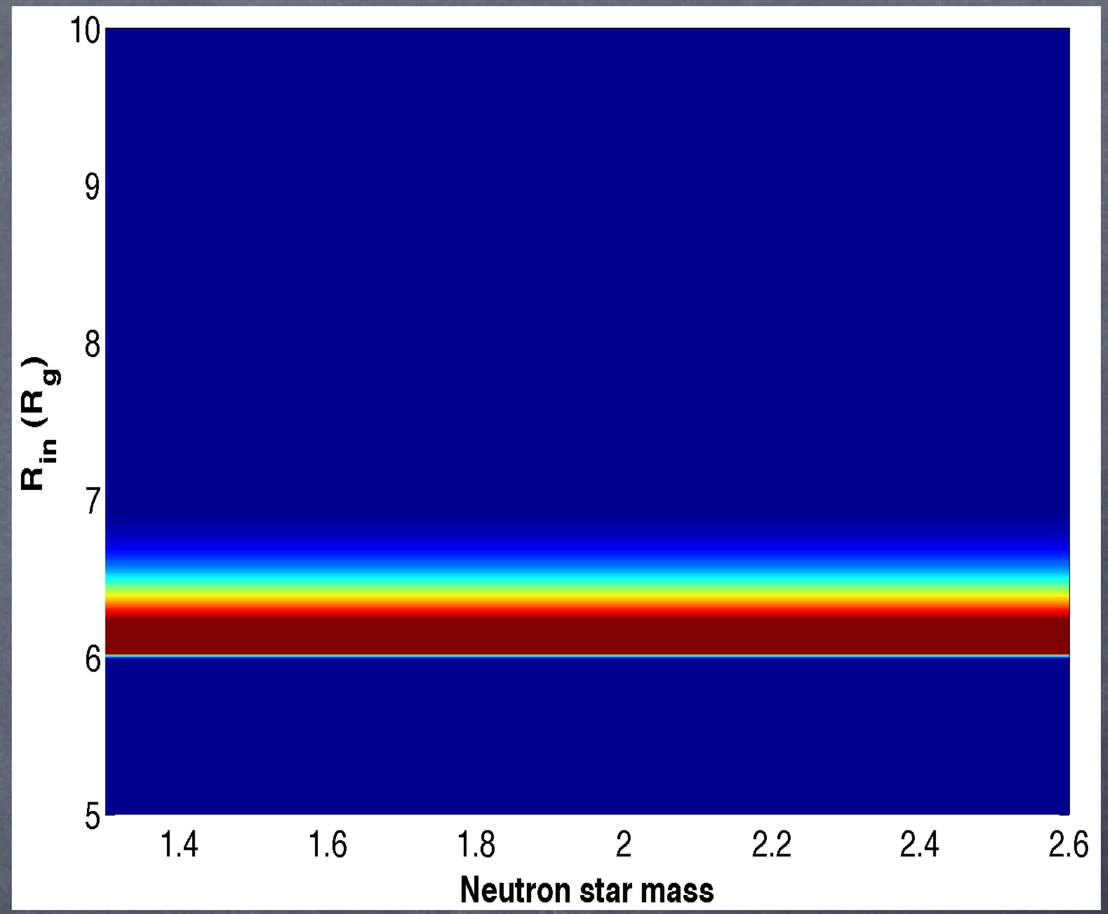


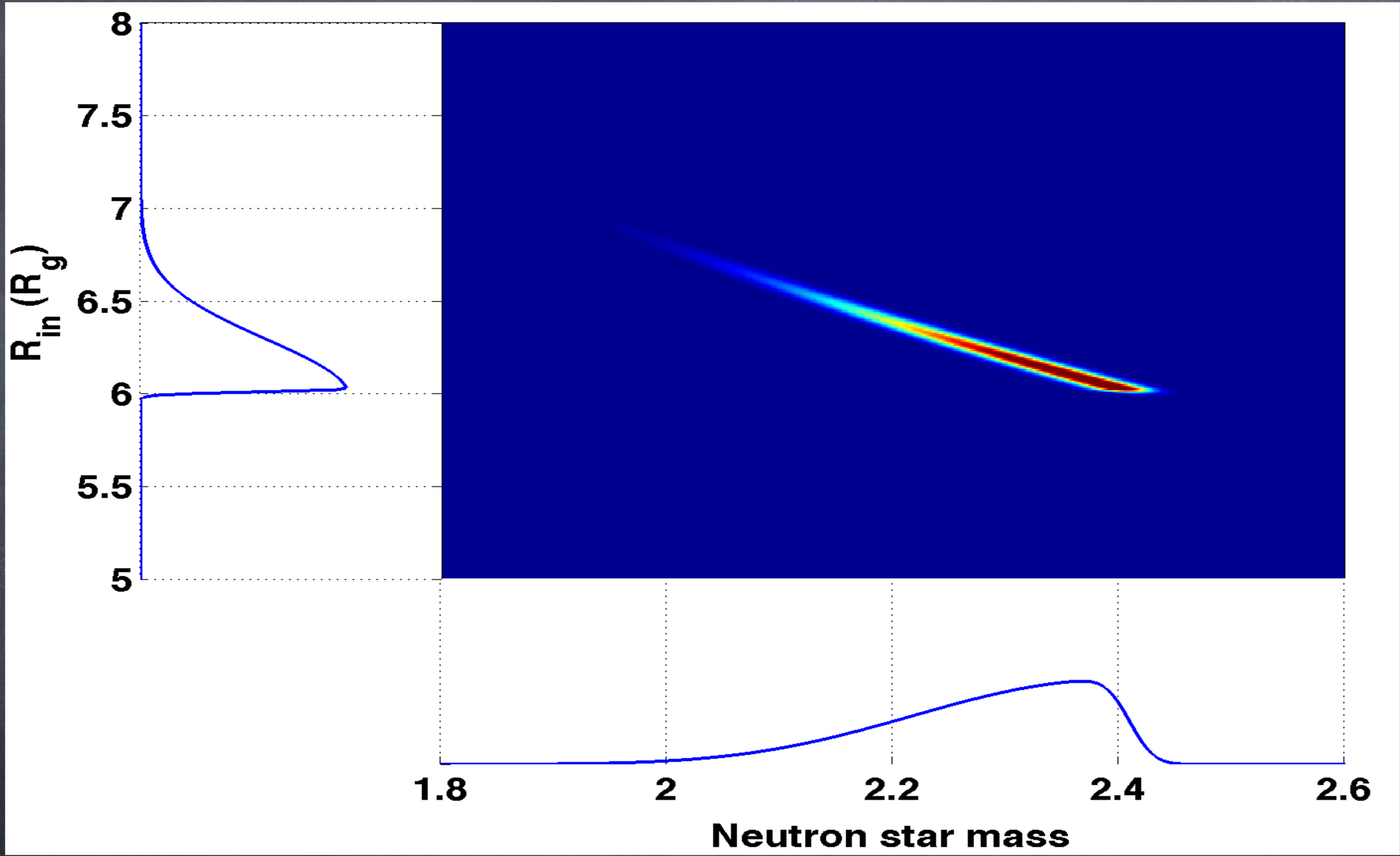

$$\nu_{QPO} = \frac{1}{2\pi}\sqrt{GM/r^3}$$

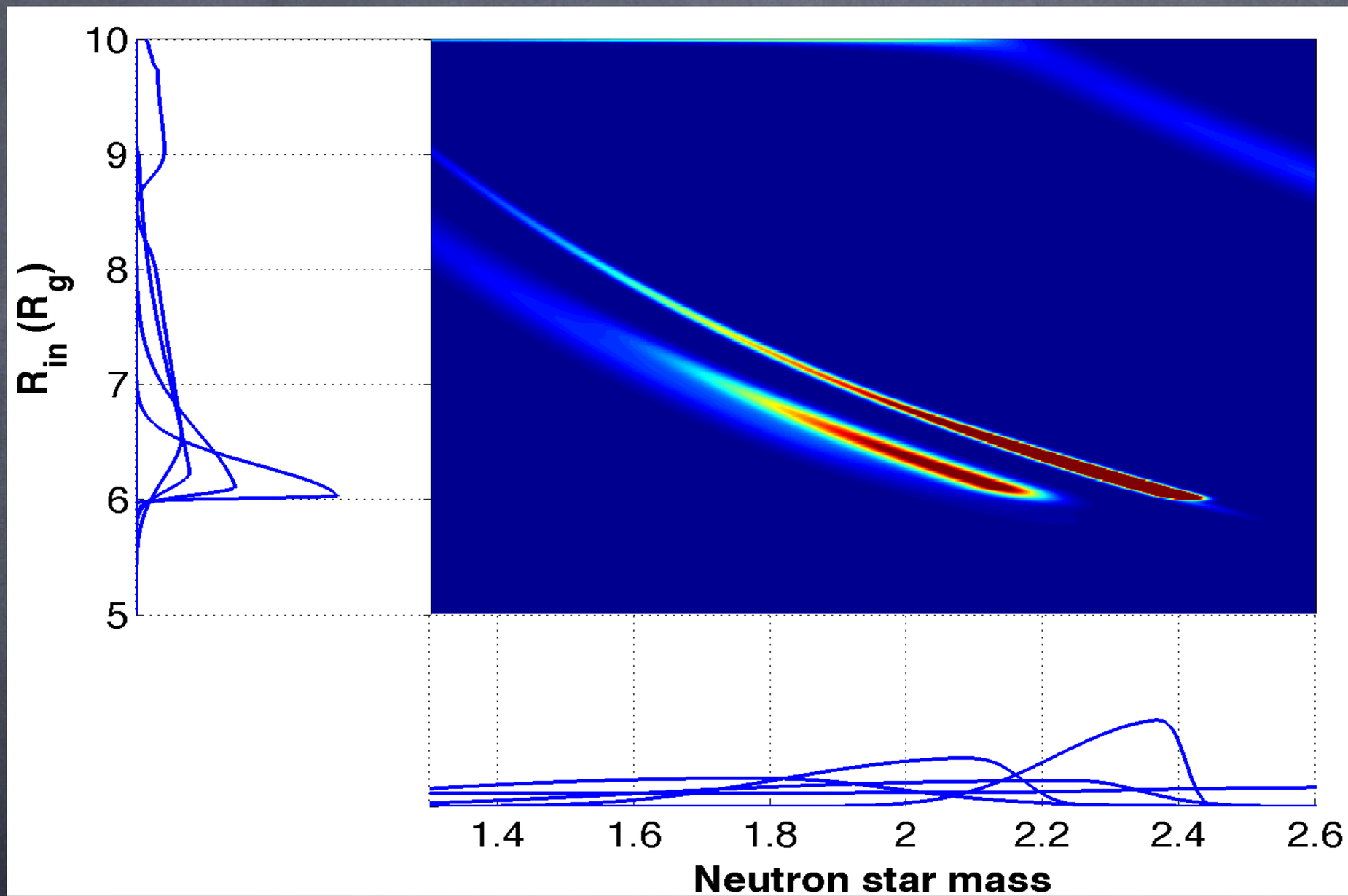
# kHz QPO

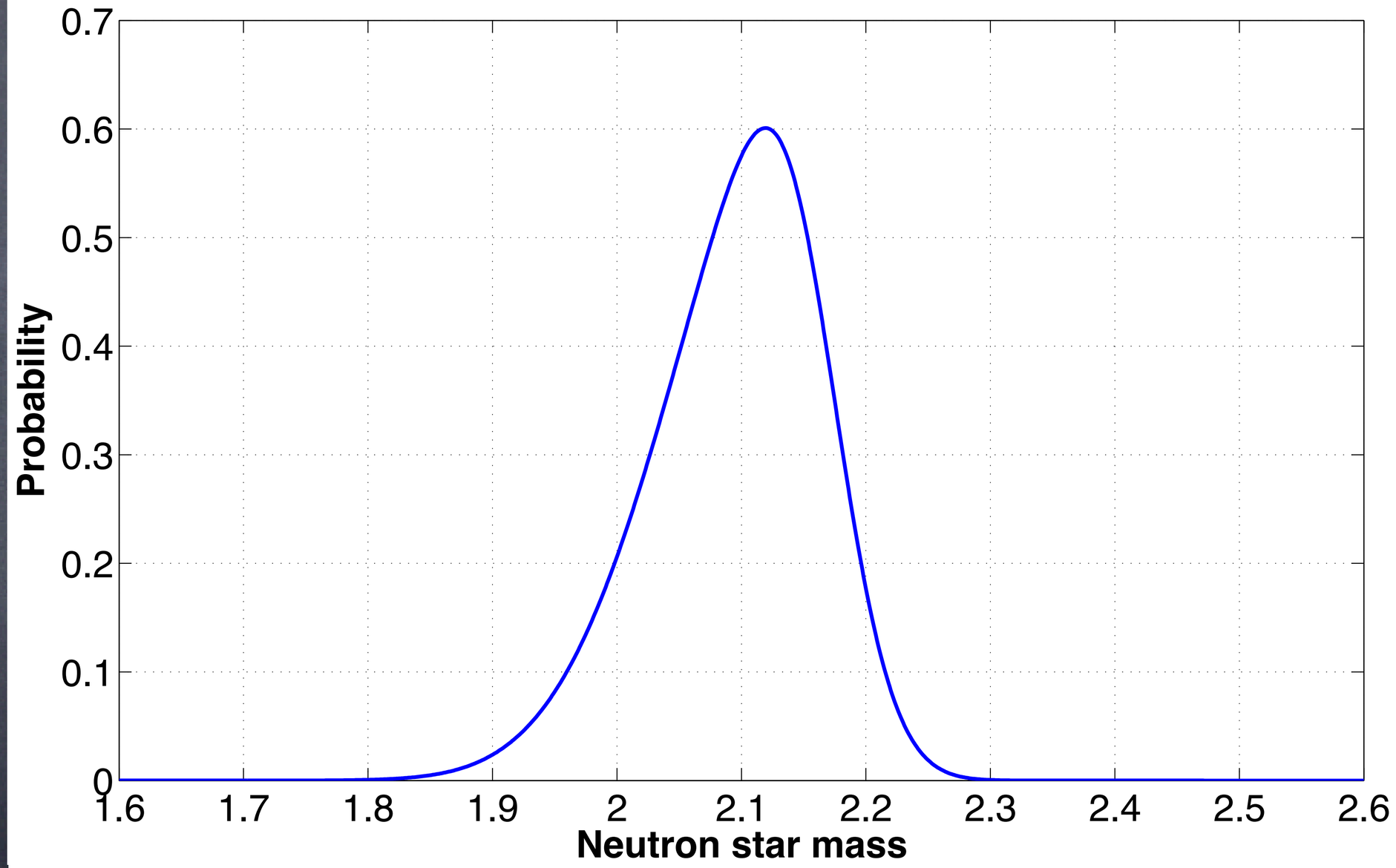



# Fe line

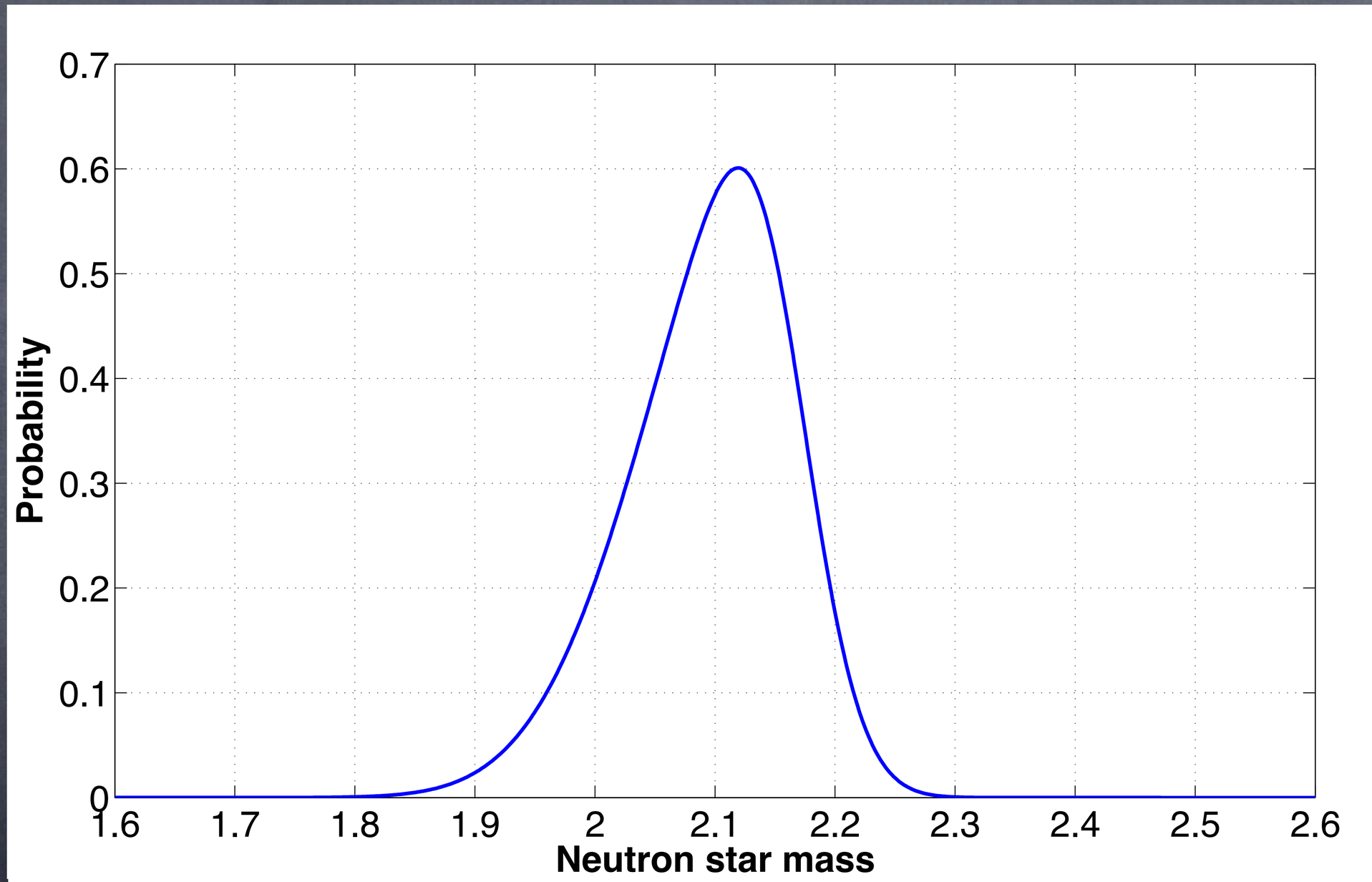



8
7.5
7
6.5
6
5.5
5
$R_{in}(R_g)$
1.8
2
2.2
2.4
2.6
Neutron star mass

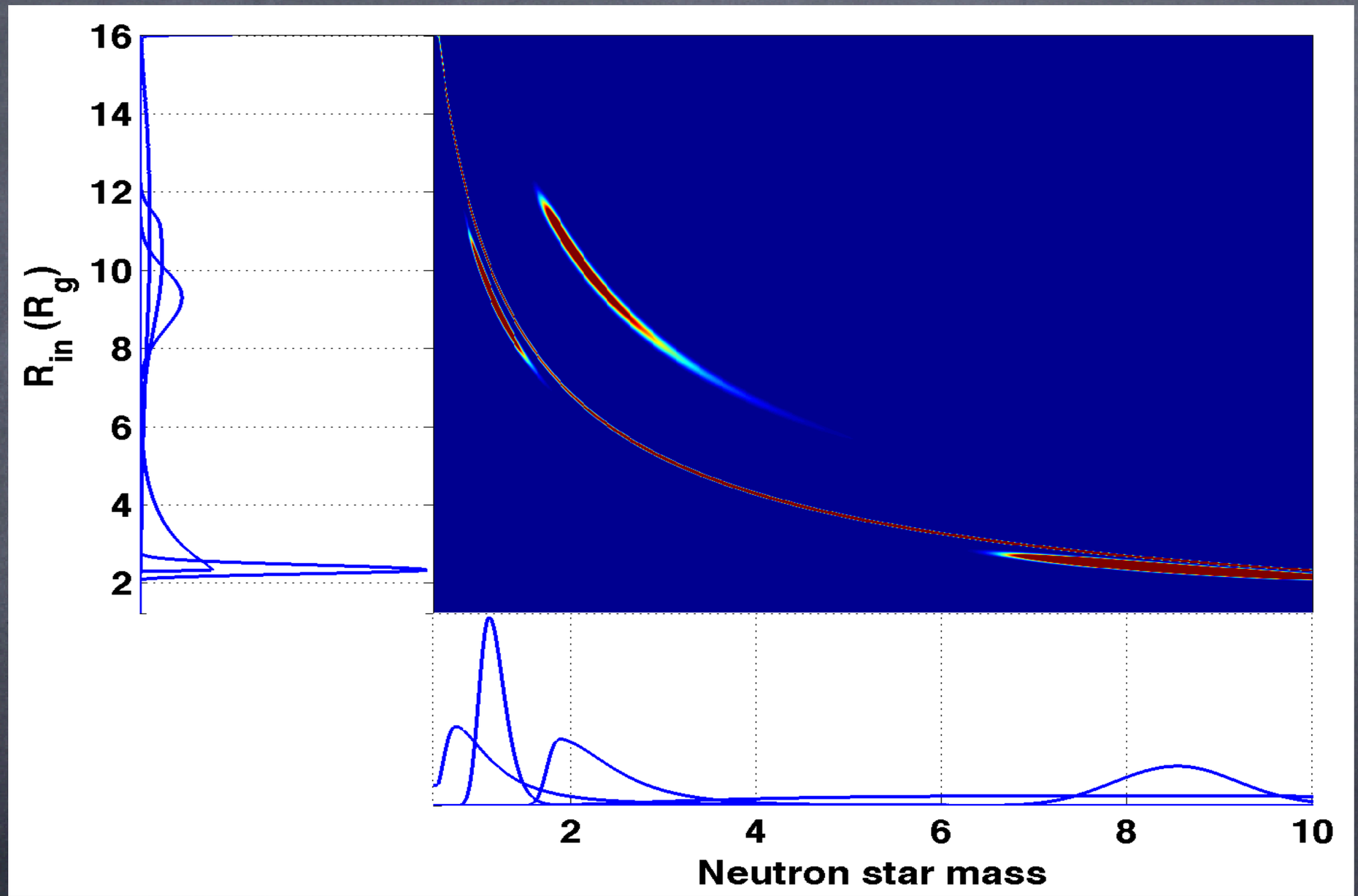

10
9
8
7
6
5
$R_{in}$ ($R_g$)
1.4
1.6
1.8
2
2.2
2.4
2.6
Neutron star mass


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Probability
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
Neutron star mass

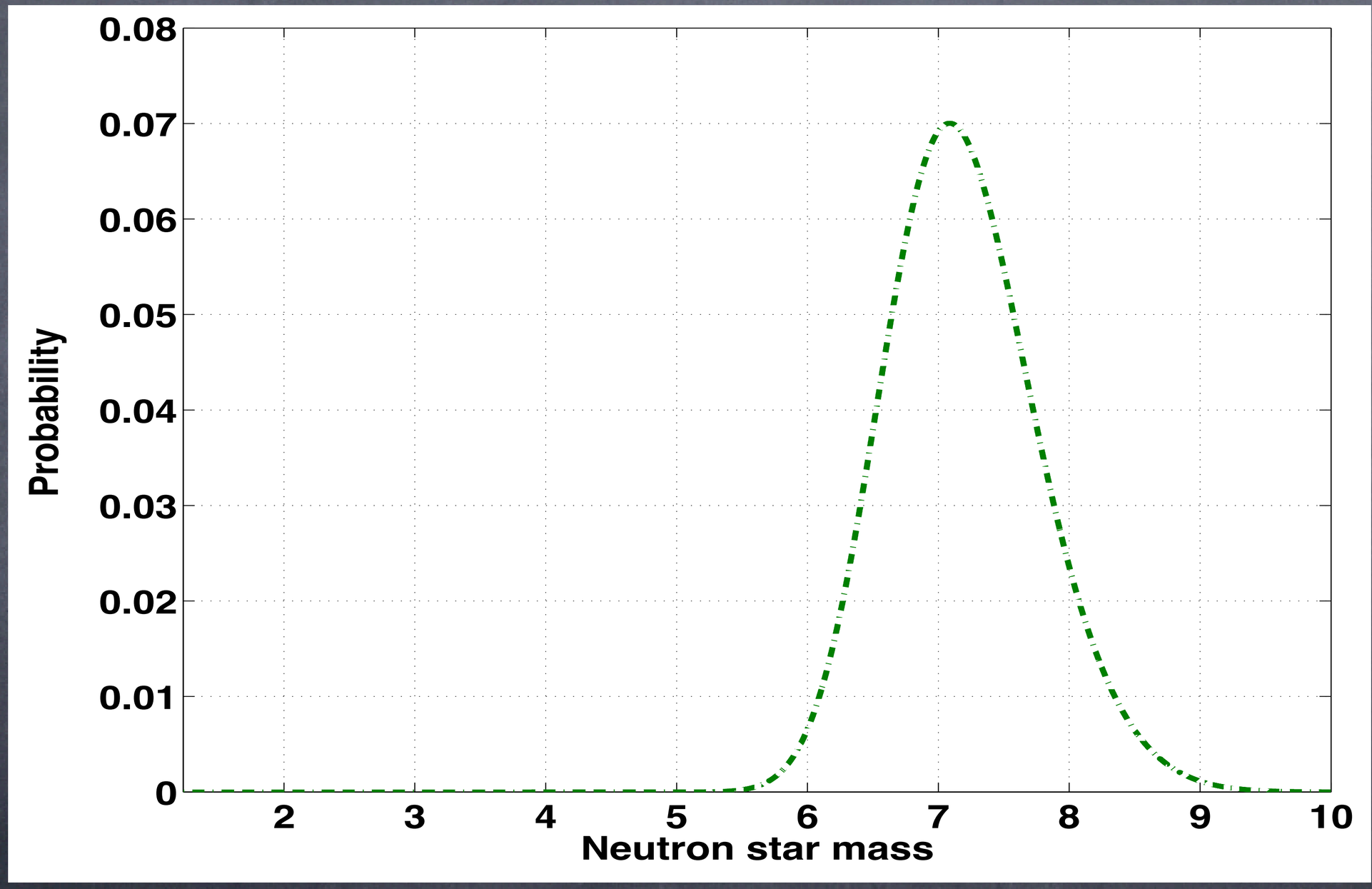
# DISKLINE


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Probability
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
Neutron star mass

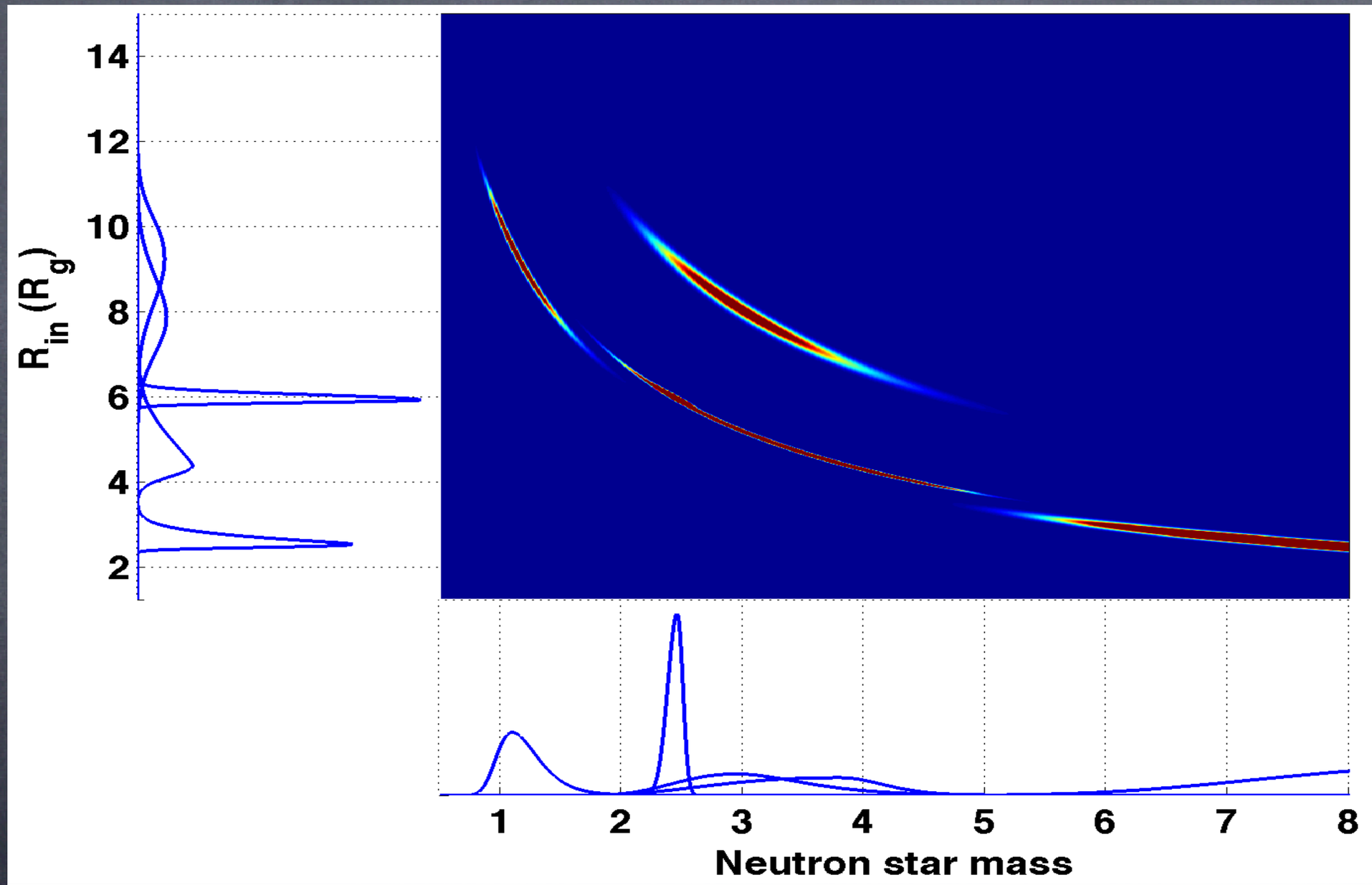
# Laor



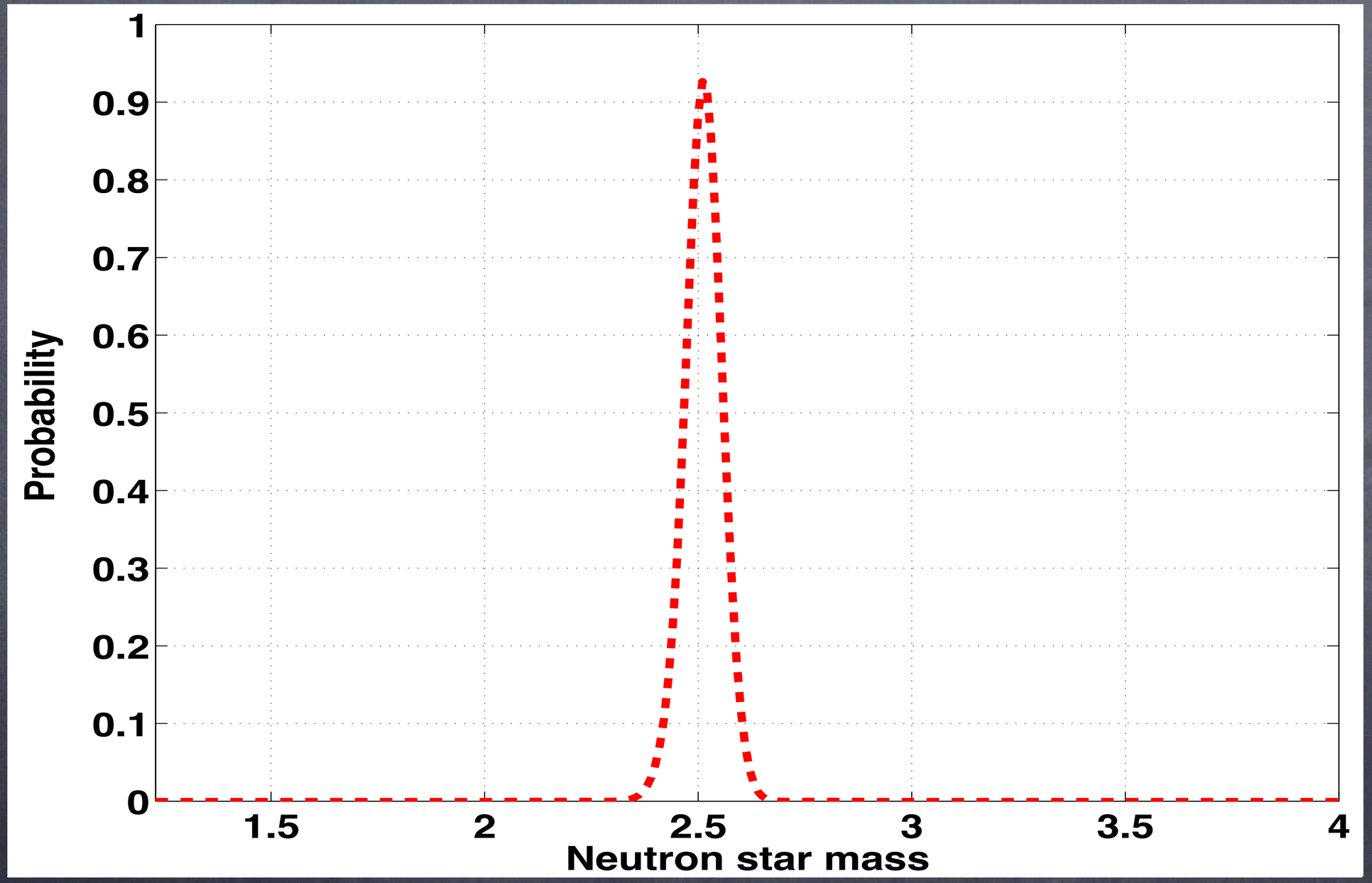
# Laor

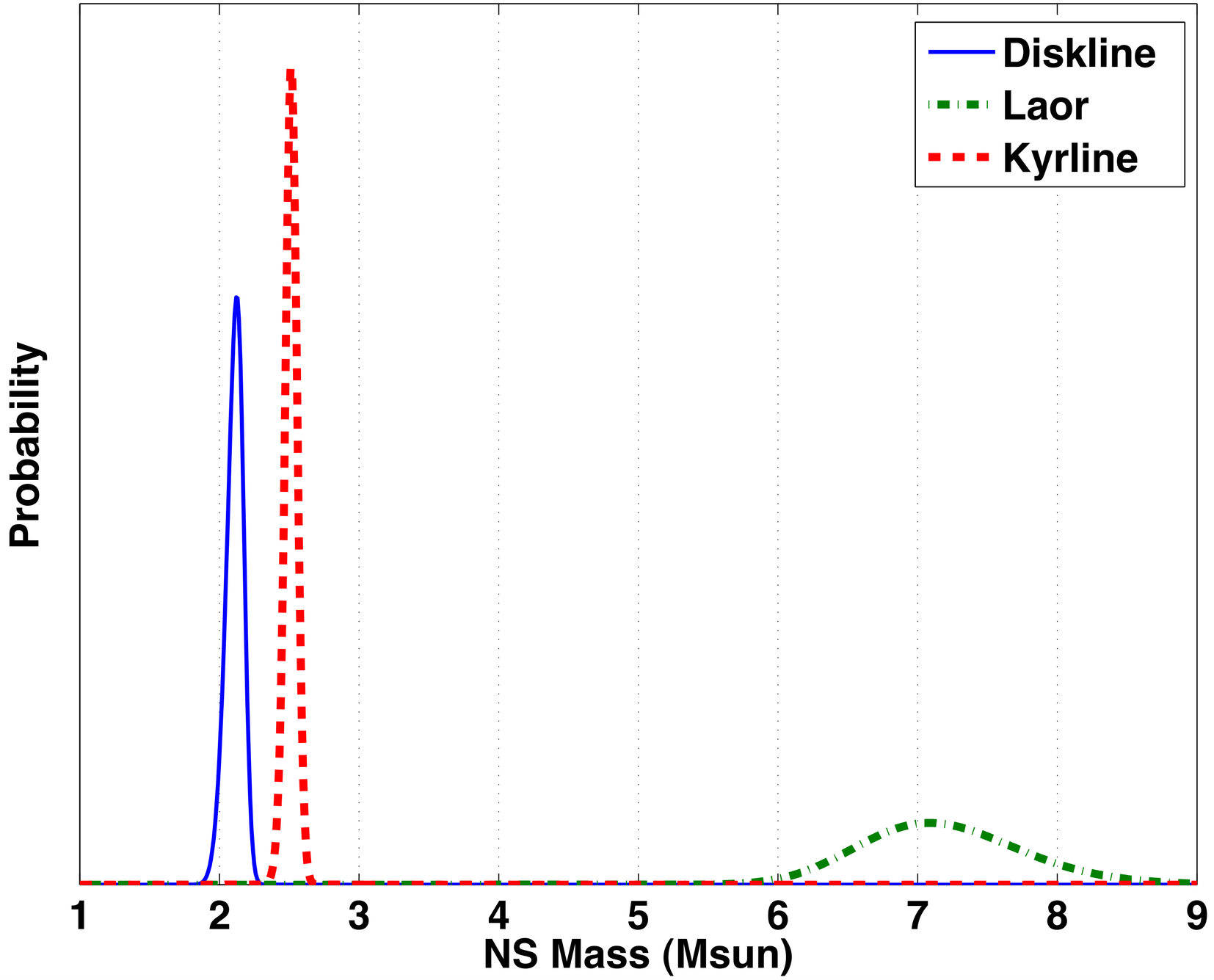

0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Probability
2
3
4
5
6
7
8
9
10
Neutron star mass

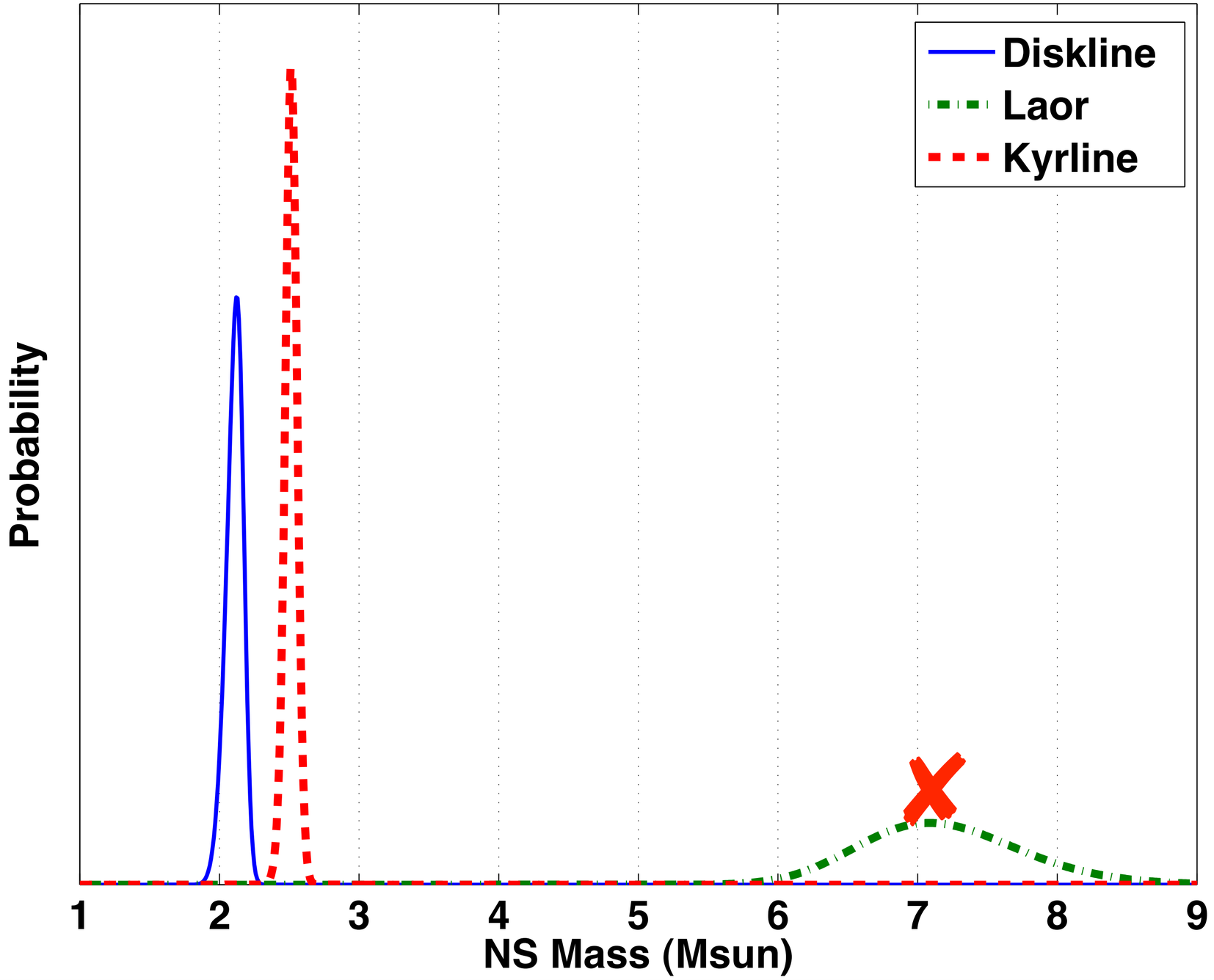
# Kyrline

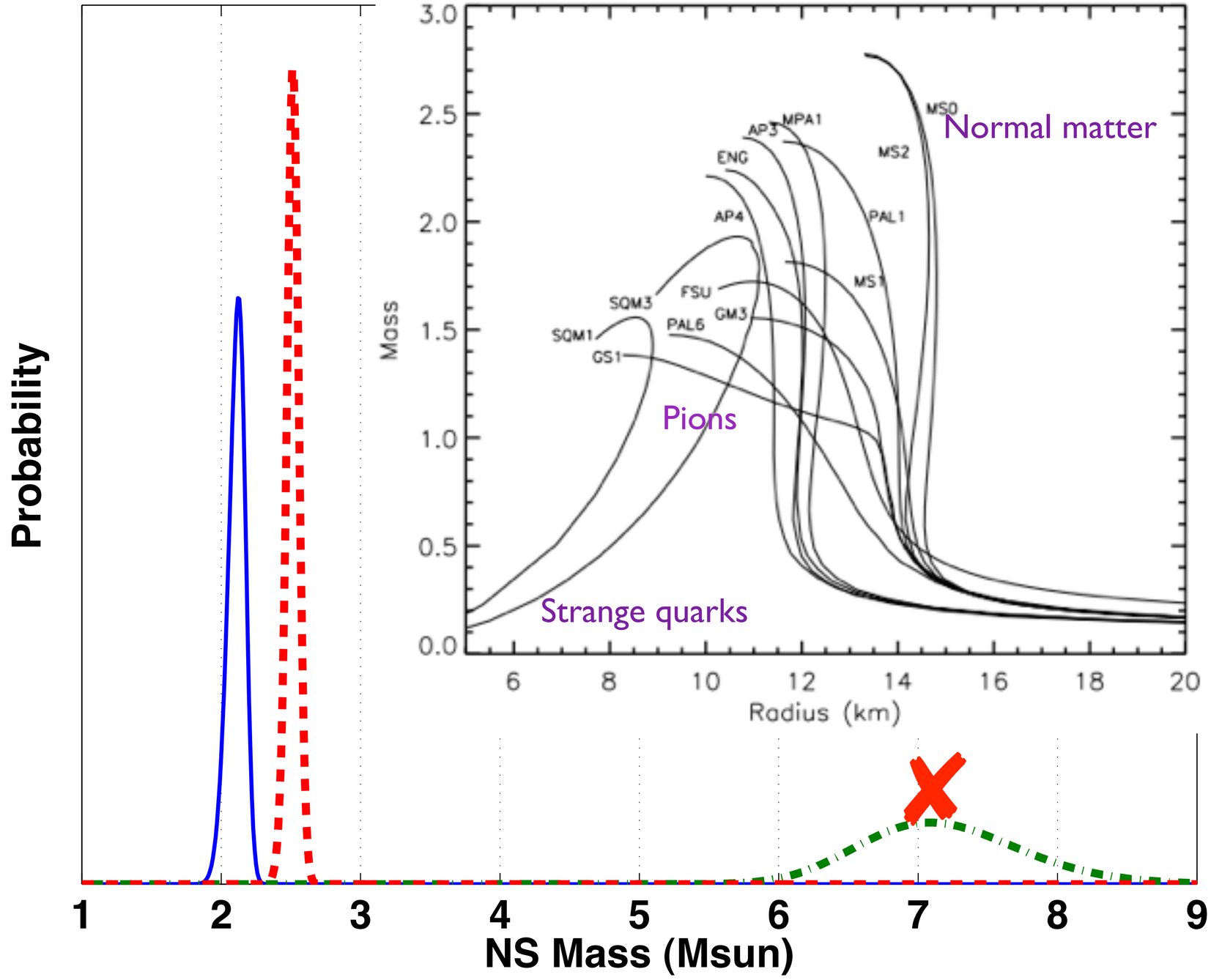


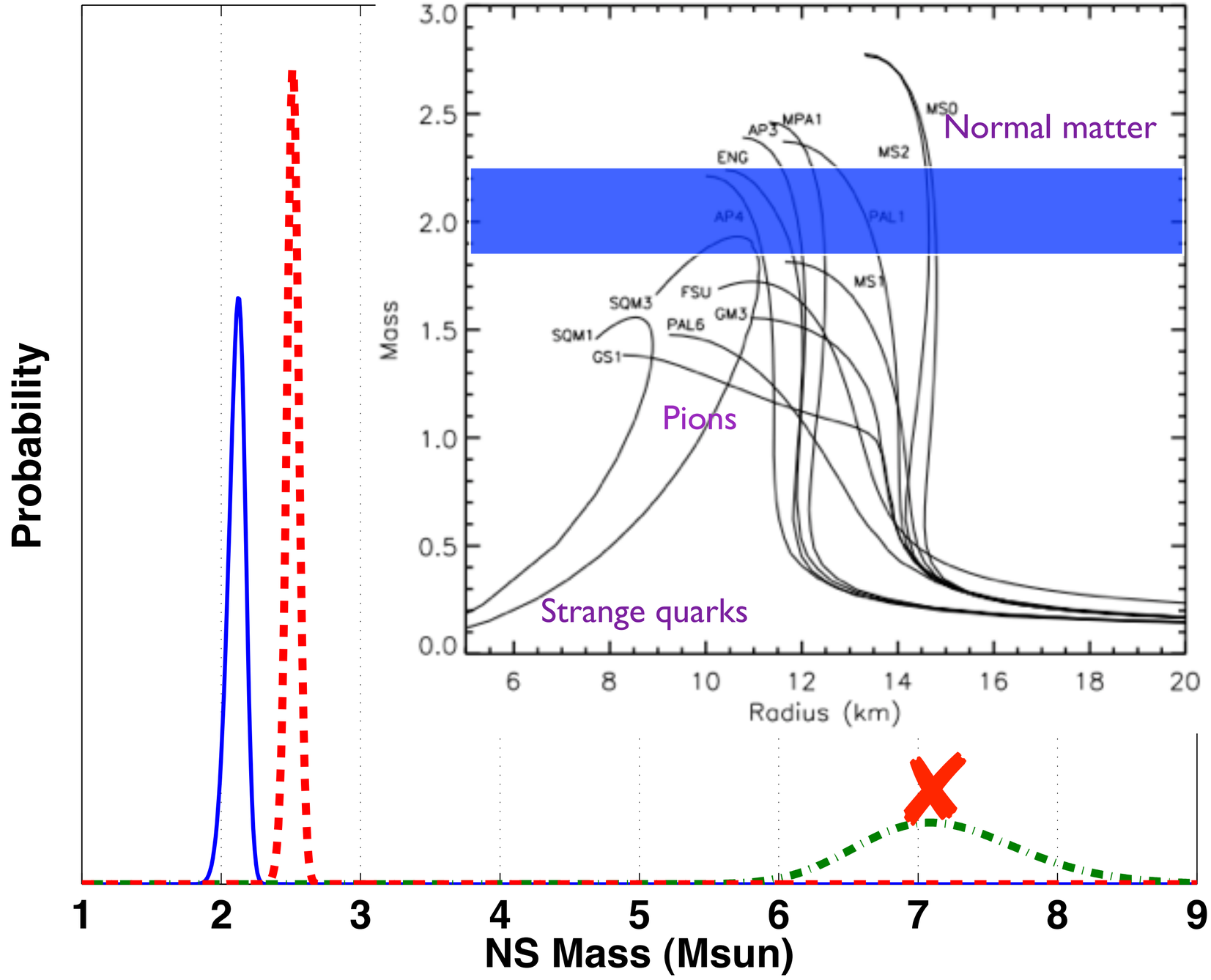
# Kyrline

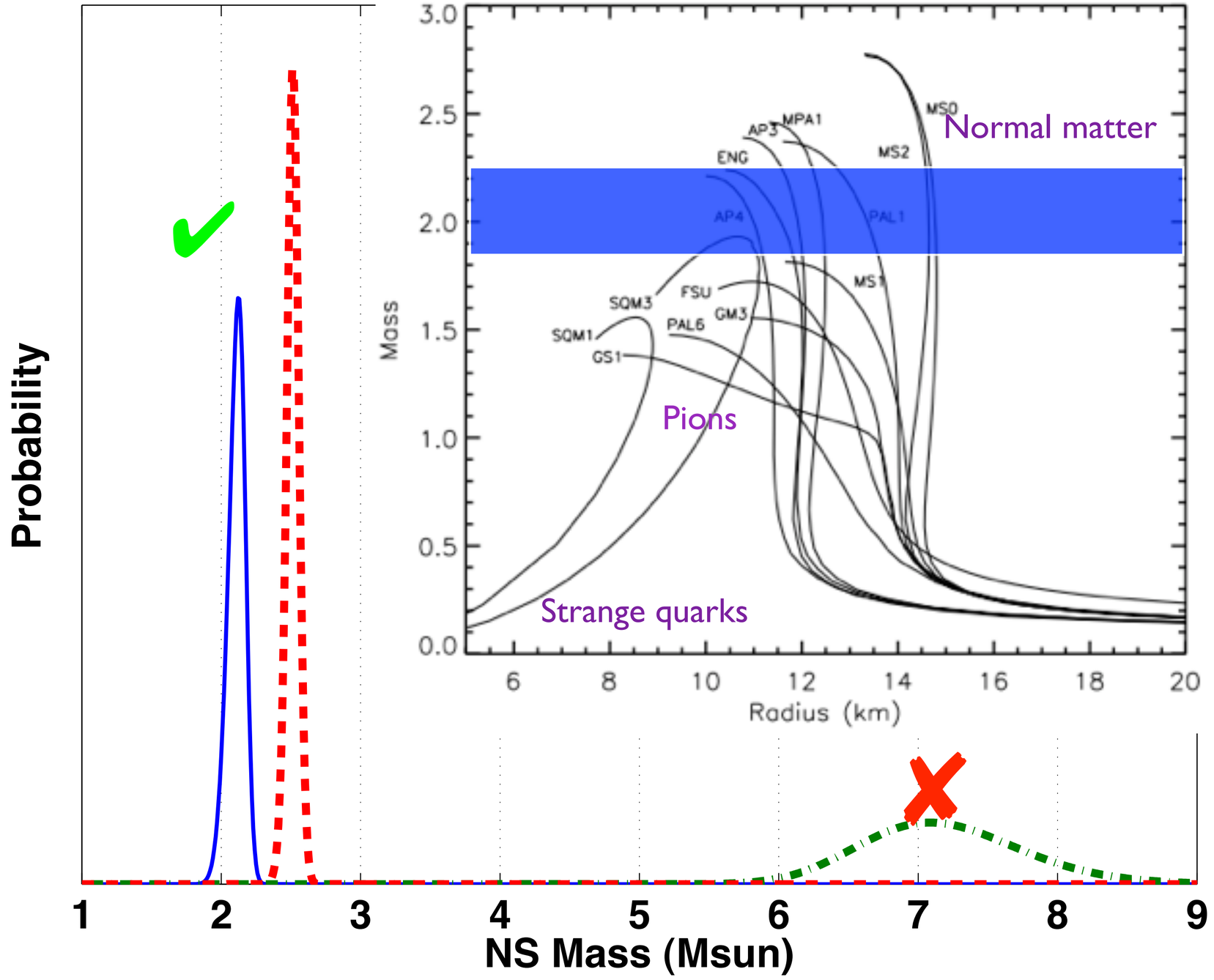

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Probability
1.5
2
2.5
3
3.5
4
Neutron star mass

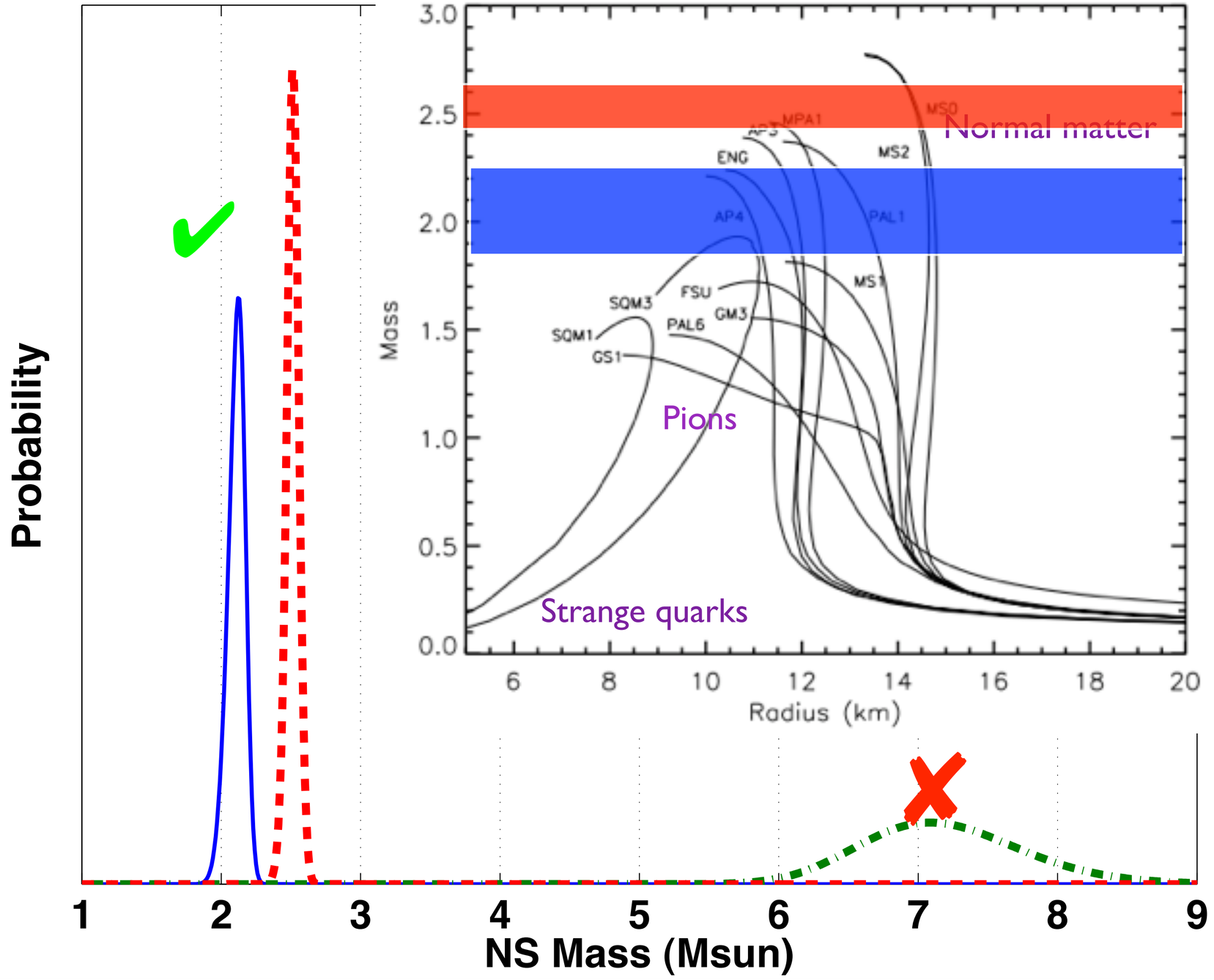

Diskline
Laor
Kyrline
Probability
1
2
3
4
5
6
7
8
9
NS Mass (Msun)

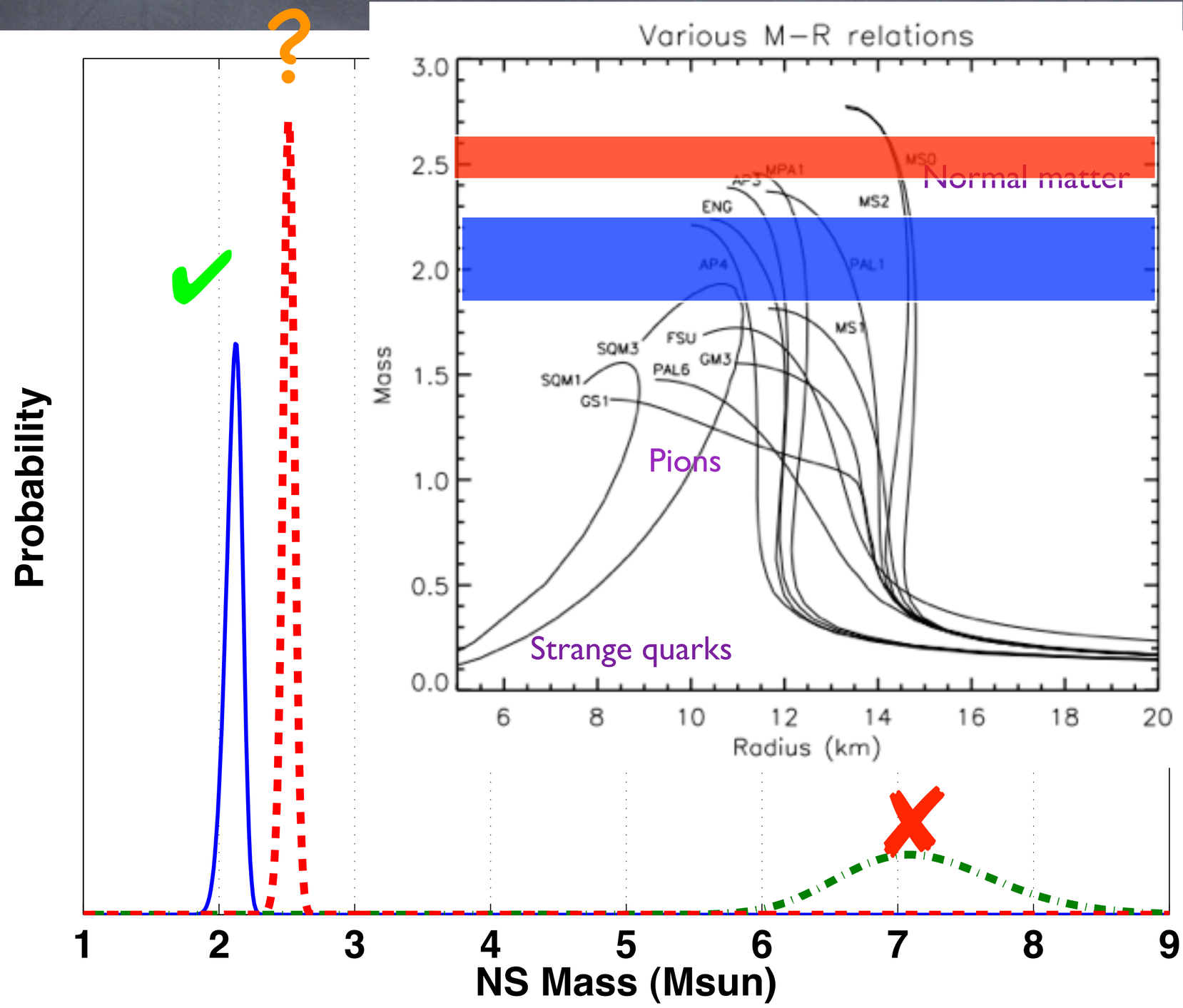

Diskline
Laor
Kyrline
Probability
1
2
3
4
5
6
7
8
9
NS Mass (Msun)


Various M−R relations
Mass
Radius (km)
MS0
MS2
PAL1
MS1
MPA1
AP3
ENG
AP4
FSU
GM3
PAL6
SQM3
SQM1
GS1
Normal matter
Pions
Strange quarks
Probability
NS Mass (Msun)


Various M−R relations
Mass
Radius (km)
MS0
MS2
MS1
MPA1
AP3
ENG
AP4
PAL1
SQM3
FSU
GM3
PAL6
SQM1
GS1
Normal matter
Pions
Strange quarks
Probability
NS Mass (Msun)


Various M−R relations
Mass
Radius (km)
MS0
MS2
MS1
MPA1
AP3
ENG
AP4
PAL1
SQM3
FSU
GM3
PAL6
SQM1
GS1
Normal matter
Pions
Strange quarks
Probability
NS Mass (Msun)


Various M−R relations
Mass
Radius (km)
Normal matter
Pions
Strange quarks
MS0
MPA1
ENG
MS2
AP4
PAL1
MS1
SQM3
FSU
GM3
PAL6
SQM1
GS1
Probability
NS Mass (Msun)


Probability
?
✔
✘
1
2
3
4
5
6
7
8
9
NS Mass (Msun)
Various M−R relations
Mass
Radius (km)
Normal matter
Pions
Strange quarks
MS0
MPA1
ENG
MS2
AP4
PAL1
MS1
SQM3
FSU
GM3
PAL6
SQM1
GS1

# Summary

- kHz QPOs diagnose dynamics of the accretion disk near the compact object, but QPO properties are not only driven by the geometry of the disk
- Relativistically broadened iron emission lines diagnose the dynamics of the accretion disk near the compact object
- We need to investigate how reliable are the models used to fit relativistic Fe lines in neutron-star systems
- We need other sources to test whether the previous results are a general behavior of LMXBs or only a peculiarity of 4U 1636-36