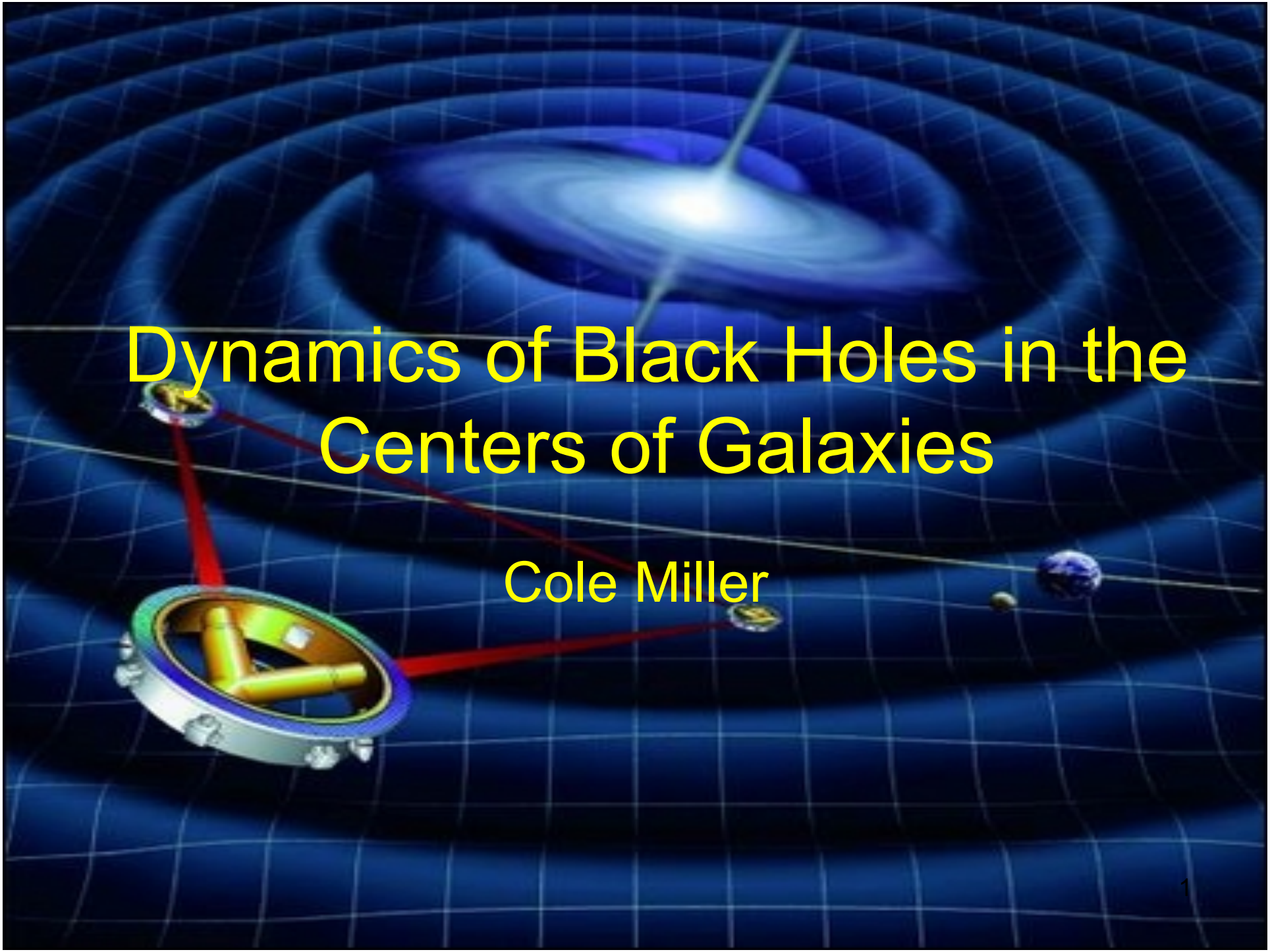


# Dynamics of Black Holes in the Centers of Galaxies

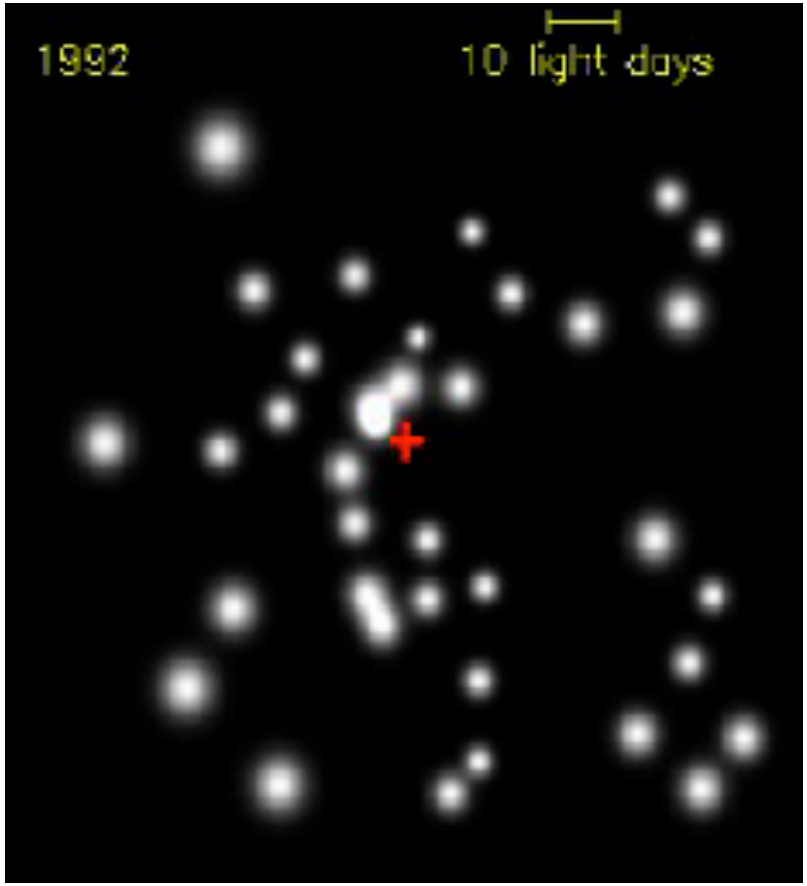
Cole Miller

# Outline

- Supermassive black holes
- Gravitational radiation
- Dynamics of black holes

# SMBH and Galactic Centers

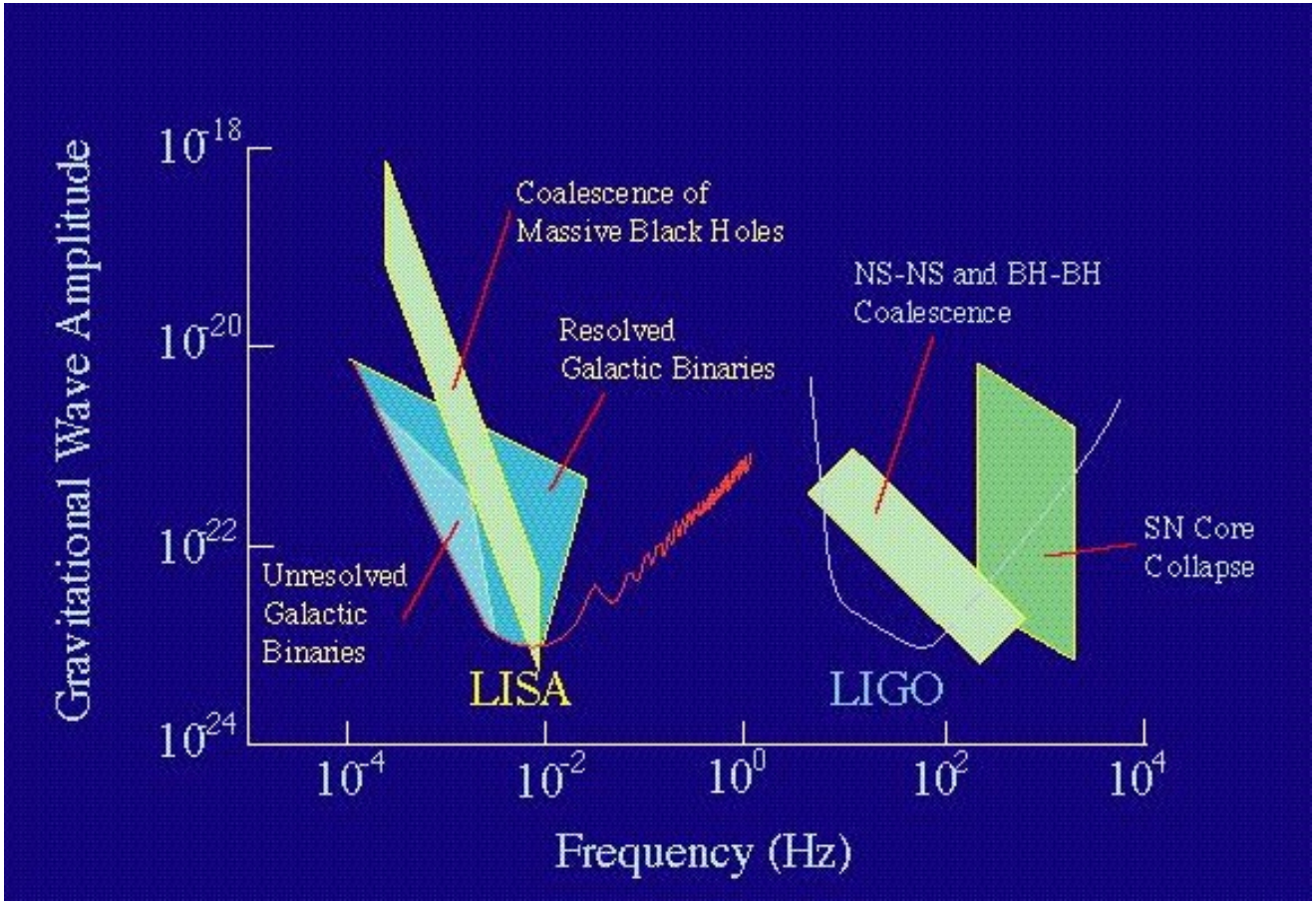
- All large galaxies with bulges appear to have SMBH in center
- Direct dynamical evidence for our MW
- M-$\sigma$ relation:
  $\sigma$=velocity dispersion
  $M_{BH} \sim \sigma^4$
- Co-evolution?




R. Genzel et al.

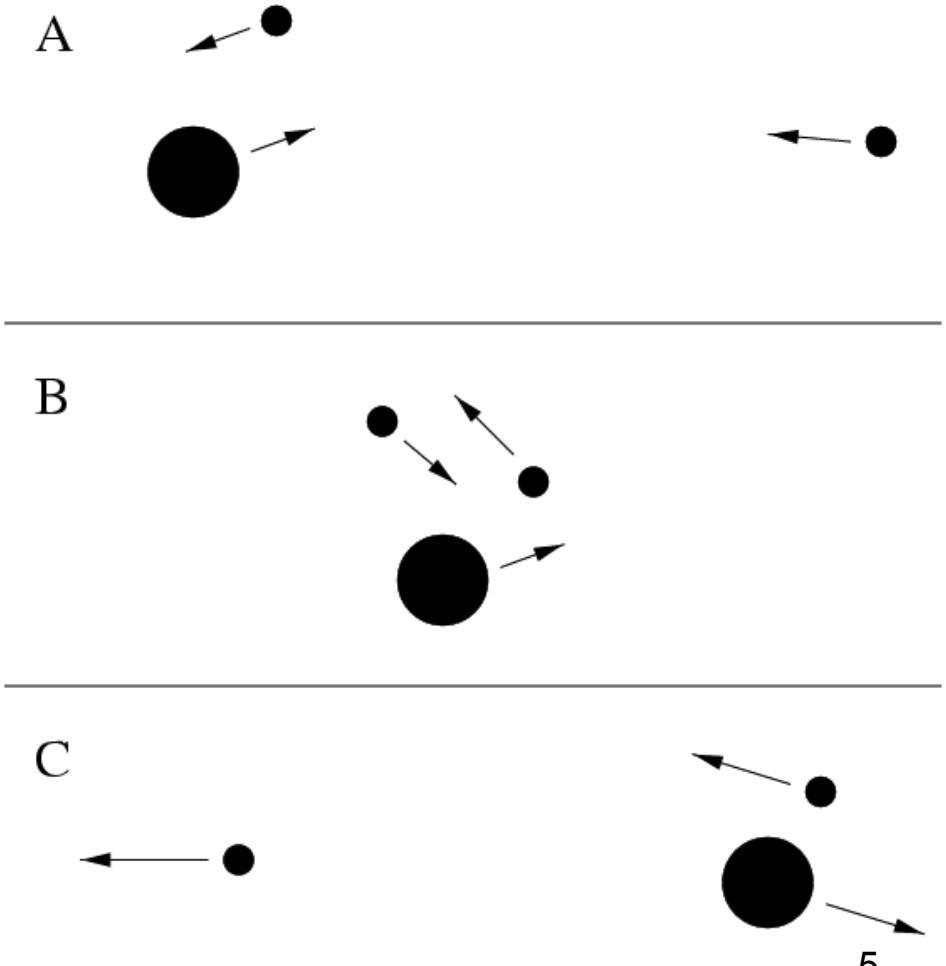
# Gravitational Radiation

- Produced by moving masses, e.g., BH-SMBH
- Contains info on strong gravity, SMBH evol
- Rates very uncertain!



# Stellar-mass BH Binaries: Dynamics in Galactic Centers

- Number densities are ~$10^{5\text{-}6}$ $pc^{-3}$
- Binaries present large cross section
- Tight binaries tighten, merge
- Heavy things swap in
- Expect massive binaries




McMillan, Portegies Zwart,Sigurdsson, Hernquist, Rasio, O'Leary, MCM, ...

# Extreme Mass Ratio Inspirals

High apocenter orbit

2-body relaxation causes it to plunge

Small pericenter means loss of energy

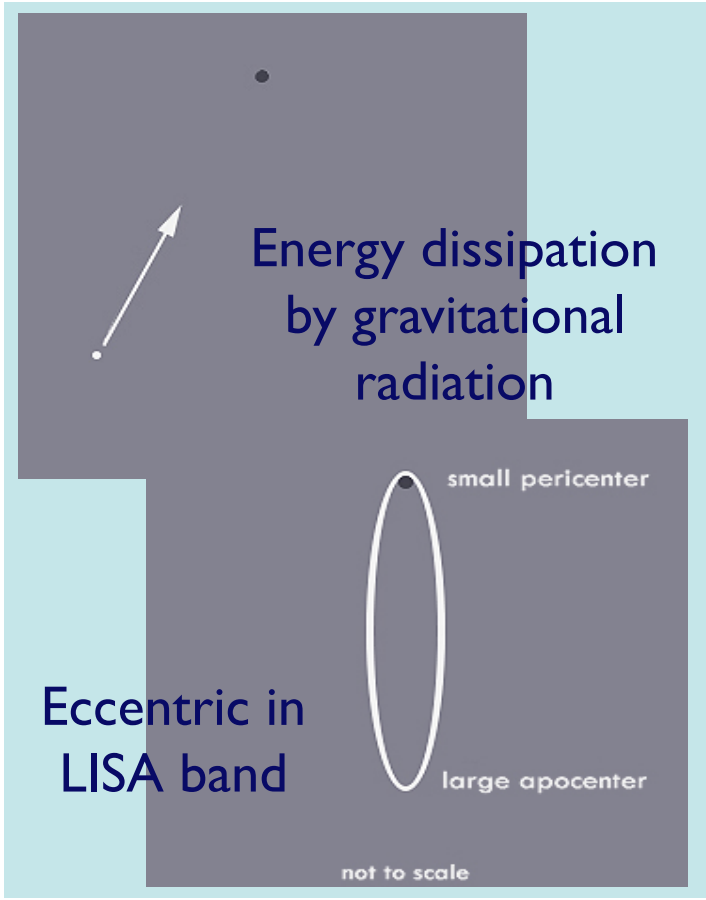
Inspiral over $10^{4-5}$ orb

Eccentric in LISA band

Arbitrary inclination

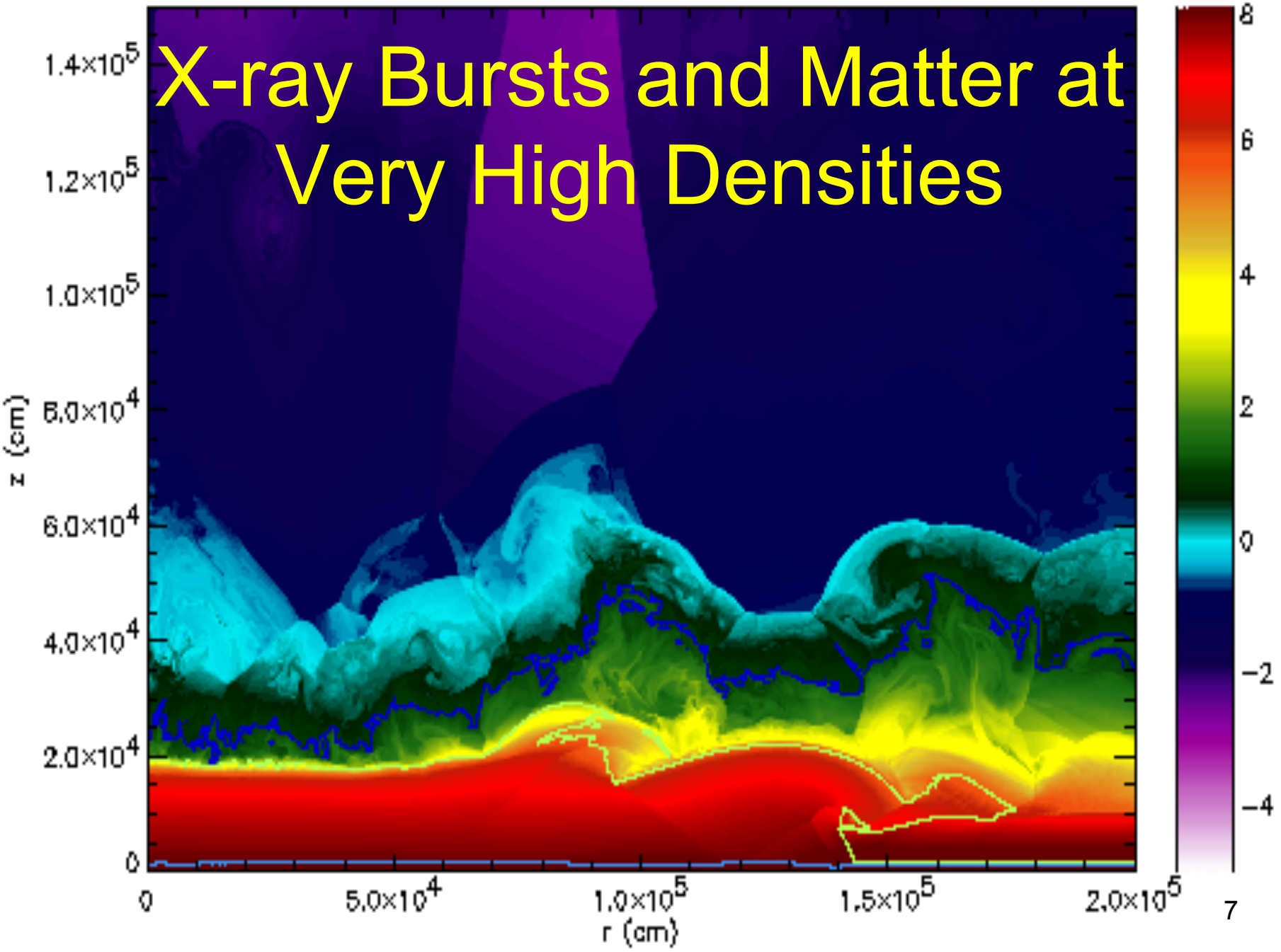
Bender, Freitag, Gair, ...

Now working with Sid Kumar




Courtesy V. Lauburg

# X-ray Bursts and Matter at Very High Densities



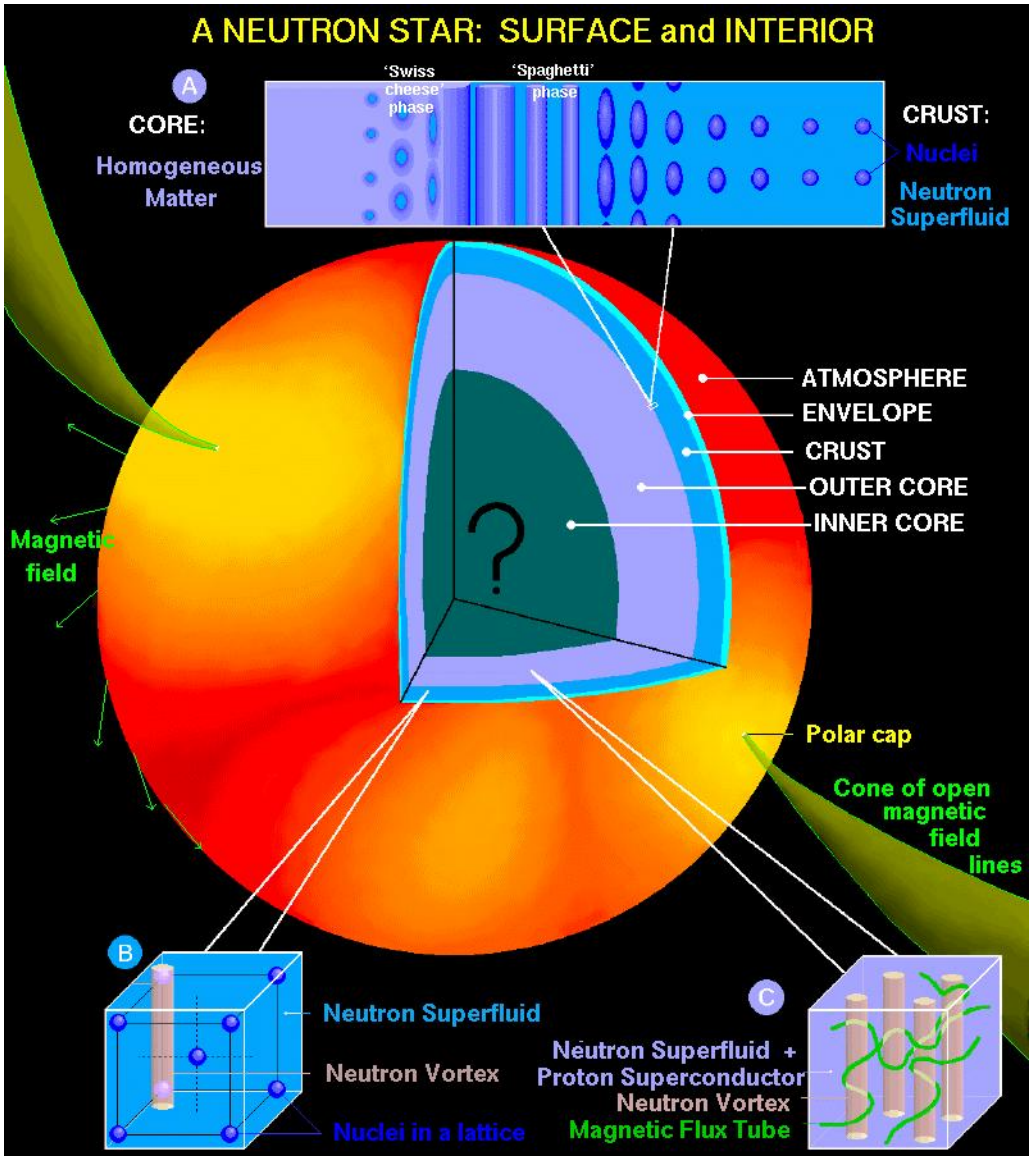
# Outline

- The interiors of neutron stars
- Thermonuclear X-ray bursts
- Light curves and X-ray timing

# The Interiors of NS

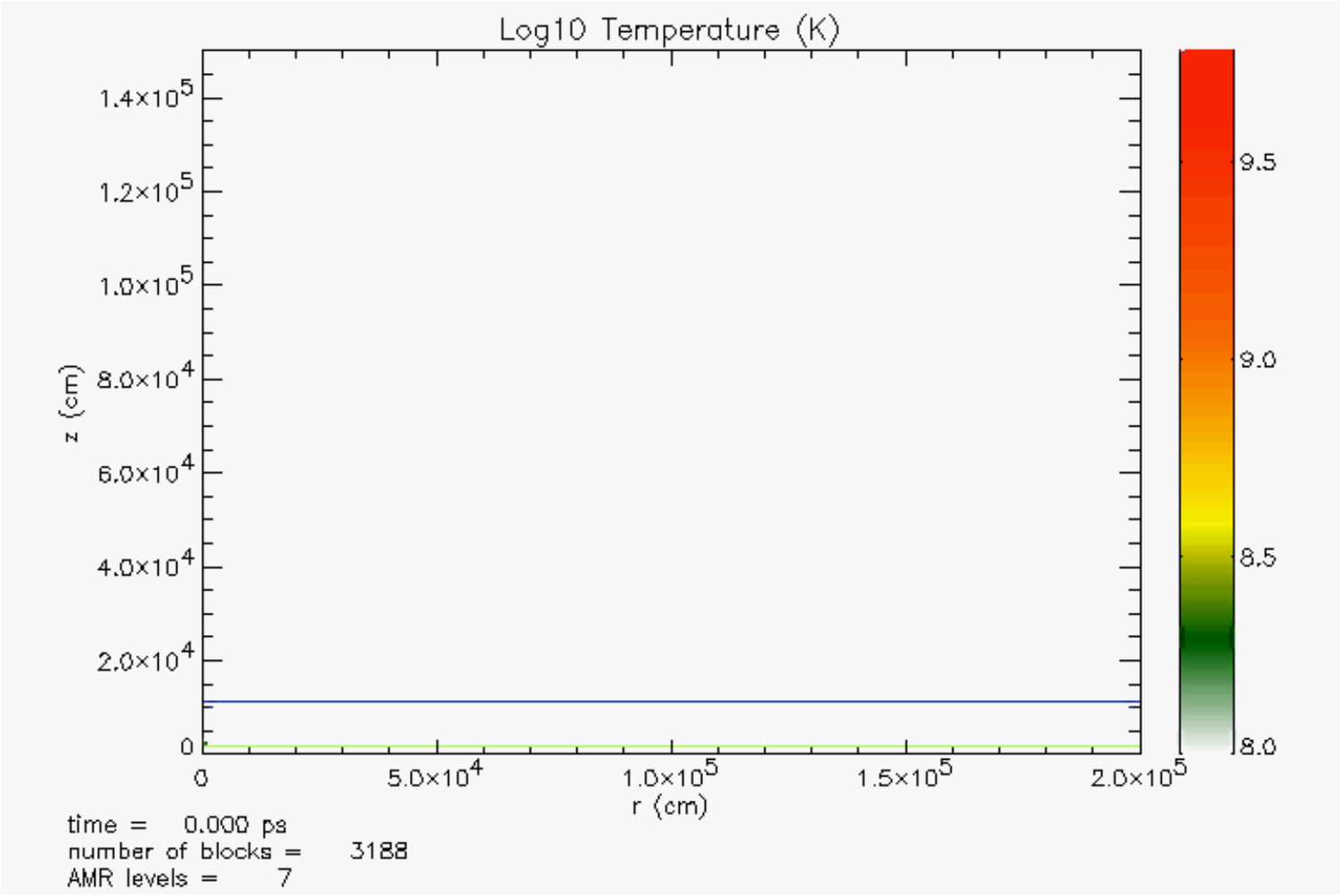
Cores of NS are at several times nuclear density. This is beyond what can be probed in labs.

Composition is thus unknown:
Nucleons?
Strange matter?
Quark matter?
Condensates?




http://www.astroscu.unam.mx/neutrones/NS-picture/NStar/NStar-I.gif

# Thermonuclear X-ray Bursts




NS in close binary can accrete from companion.

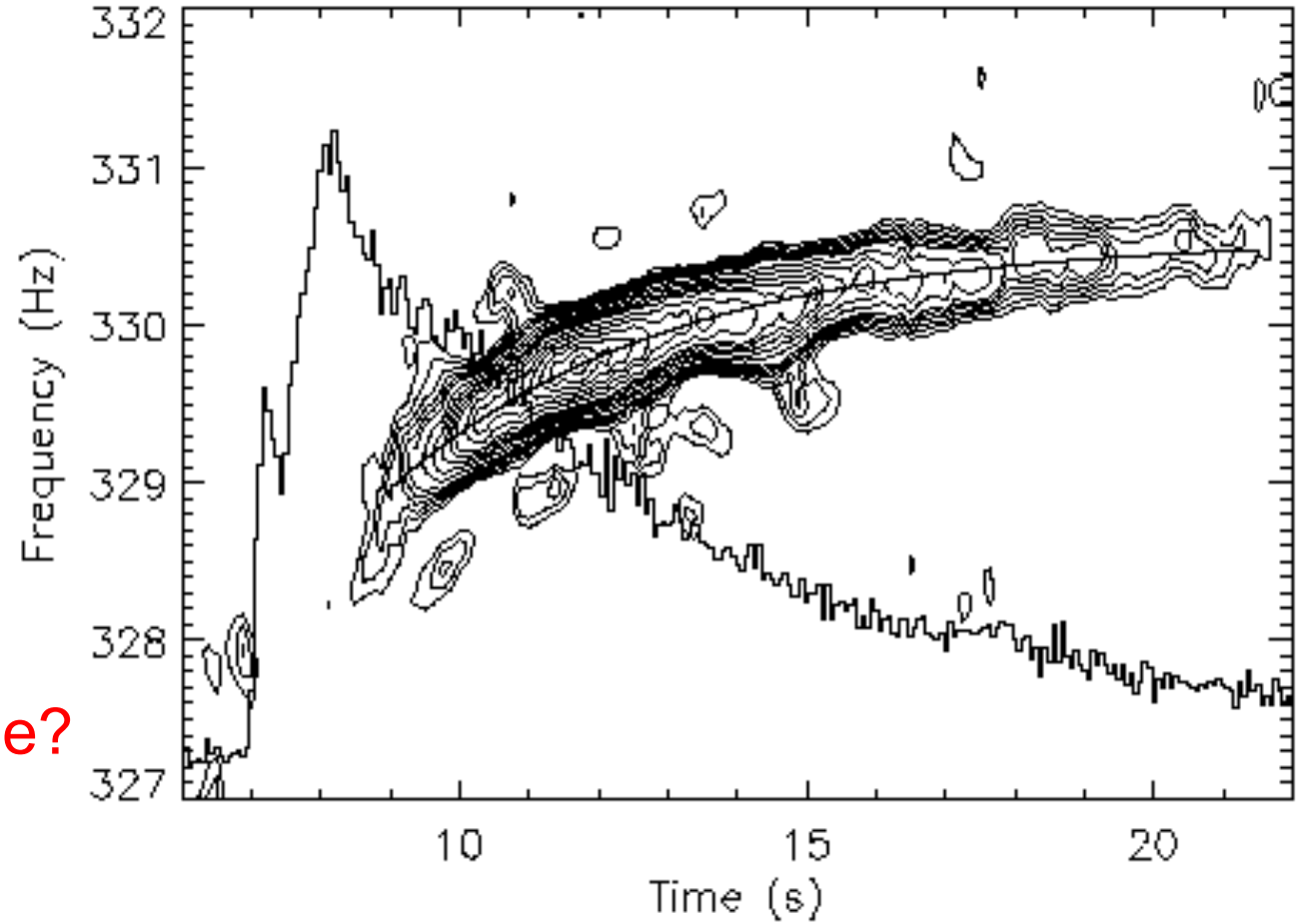
Pileup of H, He can be unstable to fusion.

# Burst Oscillations

Nearly coherent oscillations seen during bursts.

Basically at the spin frequency.
Rot. modulation

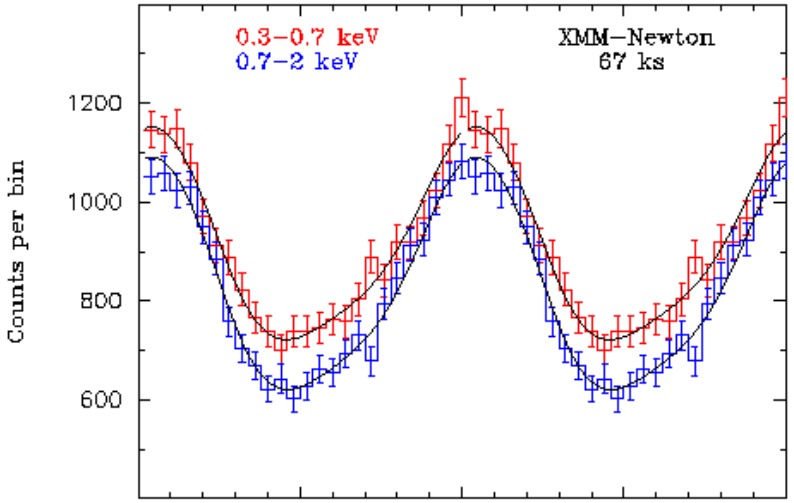
Puzzles:
Why does f change?
What keeps the asymmetry in the burst tail?

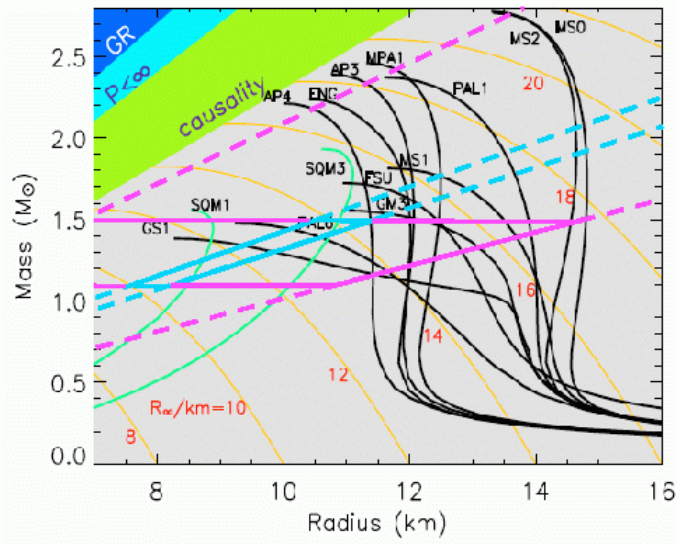



Strohmayer and Markwardt 1999

# Light Curves and NS

- Careful observation c light curves can constrain M, R
- Example on right: from millisecond PSR
- Bursts: similar, but have advantage and disadvantage of dynamic evolution




Courtesy of
Slavko Bogdanov