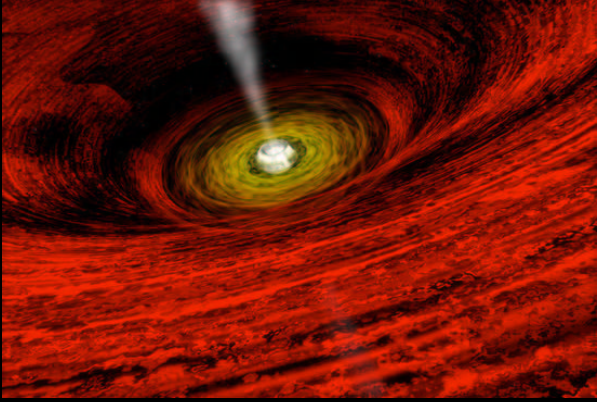


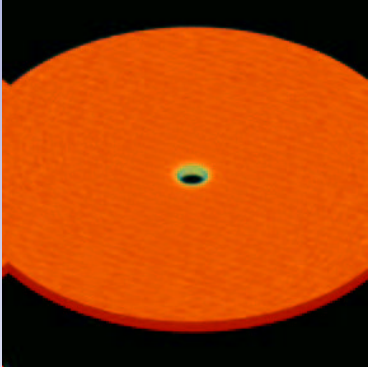
**MODELS OF BLACK-HOLE VARIABILITY**  
**PROBING STRONG FIELD GRAVITY**



CX HARVARD.EDU

**DIMITRIOS PSALTIS**  
**INSTITUTE FOR ADVANCED STUDY**

**TURBULENT DIFFUSION OF ANGULAR MOMENTUM**  
**IS RESPONSIBLE FOR HIGH ACCRETION RATES**



ACCRETION FLOWS ARE  
VERY VARIABLE!

**BUT:**

- **WHY DOES VARIABILITY APPEAR**  
**AT PARTICULAR FREQUENCIES?**

HAWLEY 2001

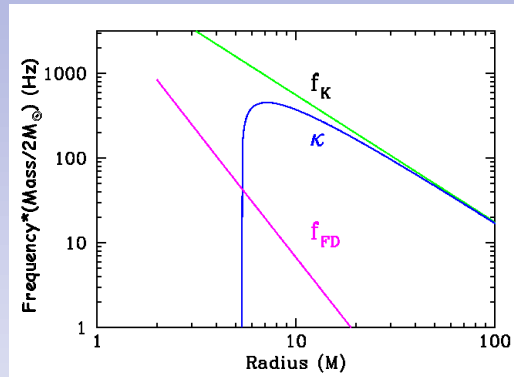
### CHARACTERISTIC FREQUENCIES IN A DISK

- DYNAMICAL FREQUENCIES

$$f_K = \left( \frac{1}{2\pi} \right) \frac{r^{-3/2}}{1 + \alpha \cdot r^{-3/2}}$$

$$\kappa \cong (1 - 6r^{-1})^{1/2} f_K$$

$$f_{FD} = f_k - f_{\perp} \cong 2\alpha f_K^2$$



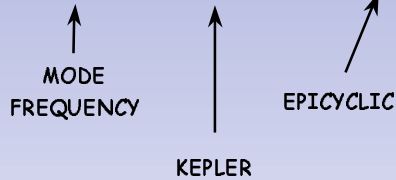
ALL HAVE STRONG DEPENDENCE ON RADIUS!

### TRAPPING OF GLOBAL MODES

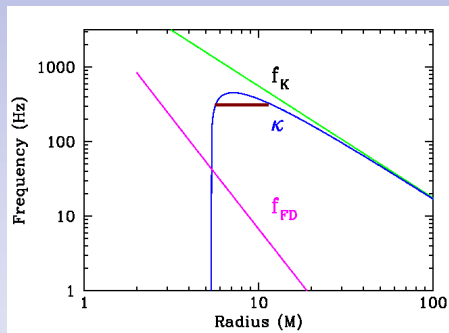
KATO, NOWAK, WAGONER, PEREZ, SILBERGLEIT, ORTEGA-RODRIGUEZ, ...

RADIAL DISPERSION RELATION:

$$\left[ f^2 - n f_K^2 \right] \left[ f^2 - \kappa^2 \right] = f^2 c_s^2 k_r^2$$



e.g., g-modes:  $f \leq \kappa$



A PURELY RELATIVISTIC EFFECT!

### GLOBAL DISK MODES

A NUMBER OF DISKSEISMIC MODES ARE TRAPPED

- **g-mode: INERTIAL-GRAVITY**  
 PEREZ et al. 1997  

$$f_g \approx \kappa + mf_K$$
- **c-mode: CORRUGATION**  
 SILBERGLEIT et al. 2001  

$$f_c \approx f_K - f_{\perp} \approx f_{FD}$$
- **p-mode: INERTIAL-PRESSURE**

NOWAK & LEHR 1997

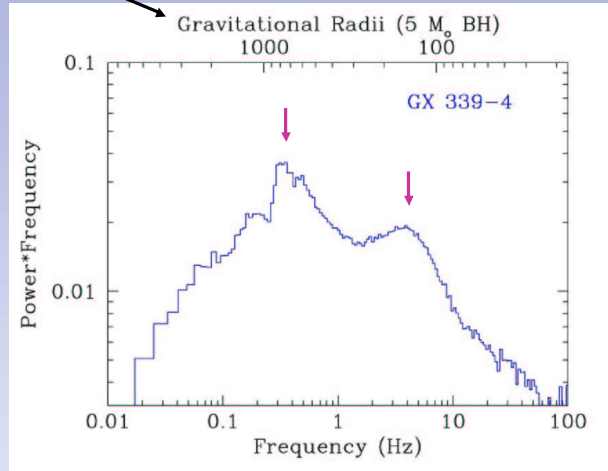
### WHAT ARE THE DIFFERENT OBSERVED QPOs?

- **LOWEST g- AND c- MODES**  
 WAGONER et al. 2001
- **VARIOUS RESONANT g-MODES**  
 KATO 2001; ABRAMOWICZ & KLUZNIAK 2001

MEASUREMENT OF BLACK-HOLE SPIN!

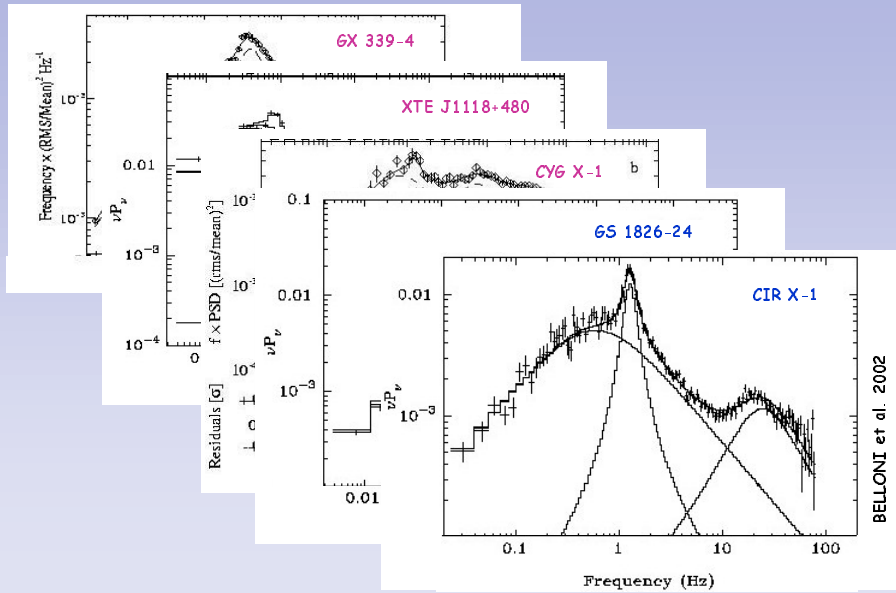
WHERE DOES THE BROAD-BAND VARIABILITY COME FROM?

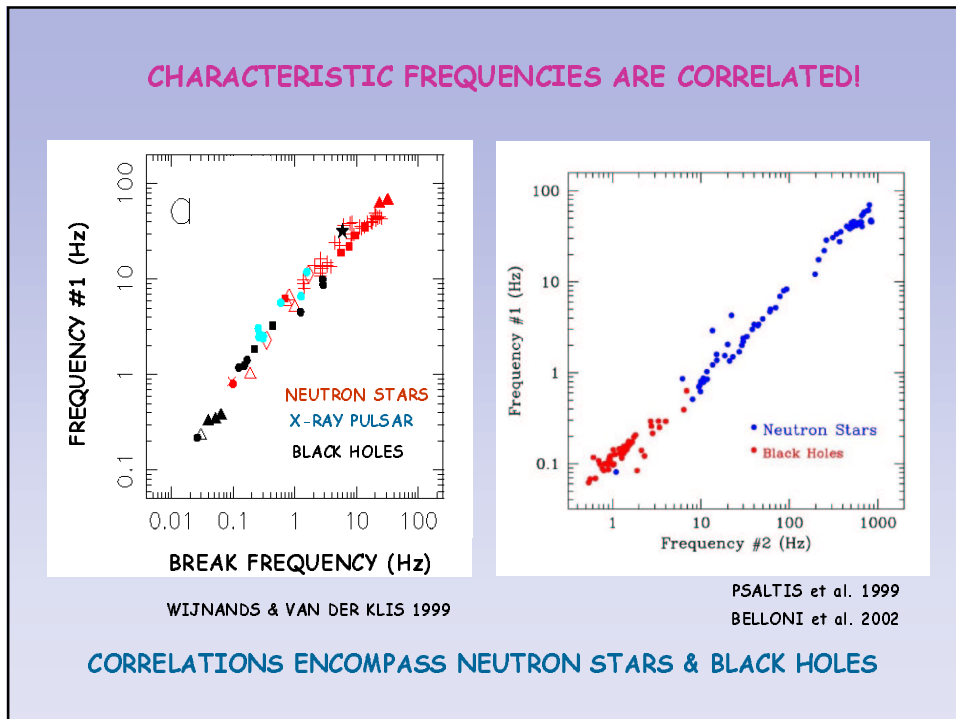
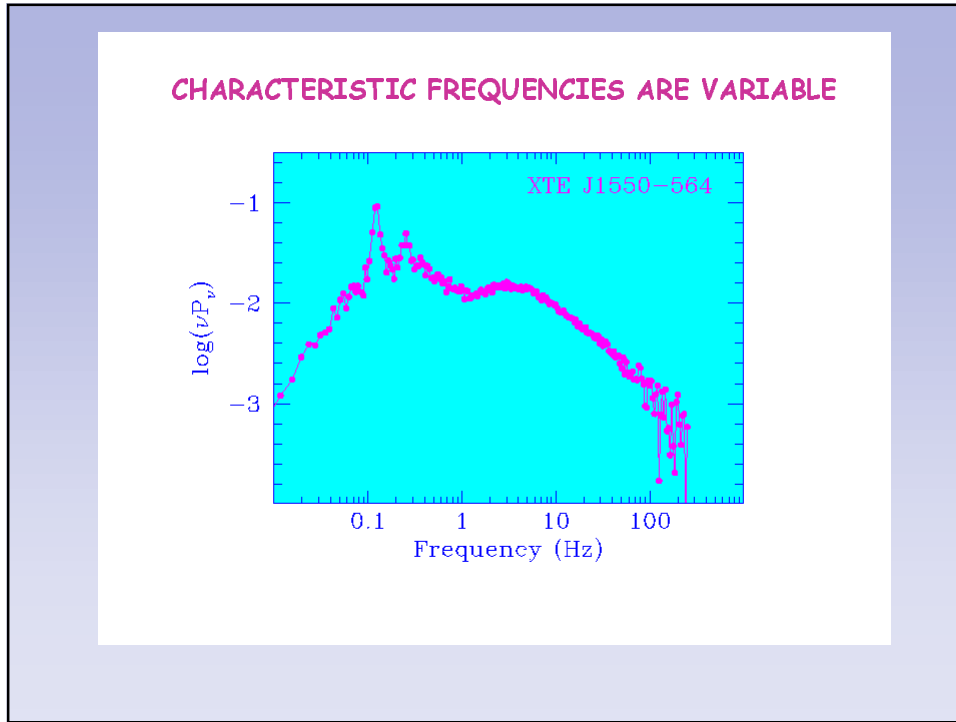
ASSUMING  $f=f_k$



SLOW PHENOMENA CLOSE TO THE BLACK HOLE!

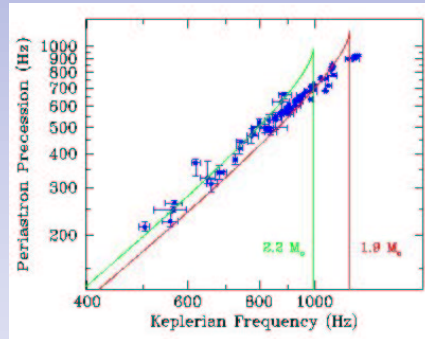
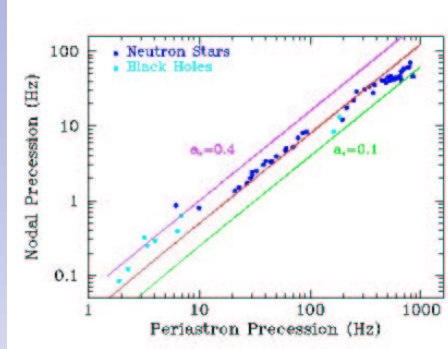
EVERY POWER SPECTRUM IS DESCRIBED BY ONLY A FEW FREQUENCIES!





**A SINGLE PARAMETER DETERMINES ALL FREQUENCIES?**

STELLA & VIETRI; PSALTIS & NORMAN



**A TUNABLE CLOCK NEAR THE BLACK-HOLE HORIZON,  
PROVIDES MEASURE OF BLACK-HOLE MASS AND SPIN!**

**A SHARP TRANSITION IN DISK PROPERTIES**

*e.g.*, DISK-MAGNETOSPHERE INTERACTION

QPO FREQUENCY AND TORQUE CORRELATIONS IN PULSARS  
FINGER ET AL. 1996

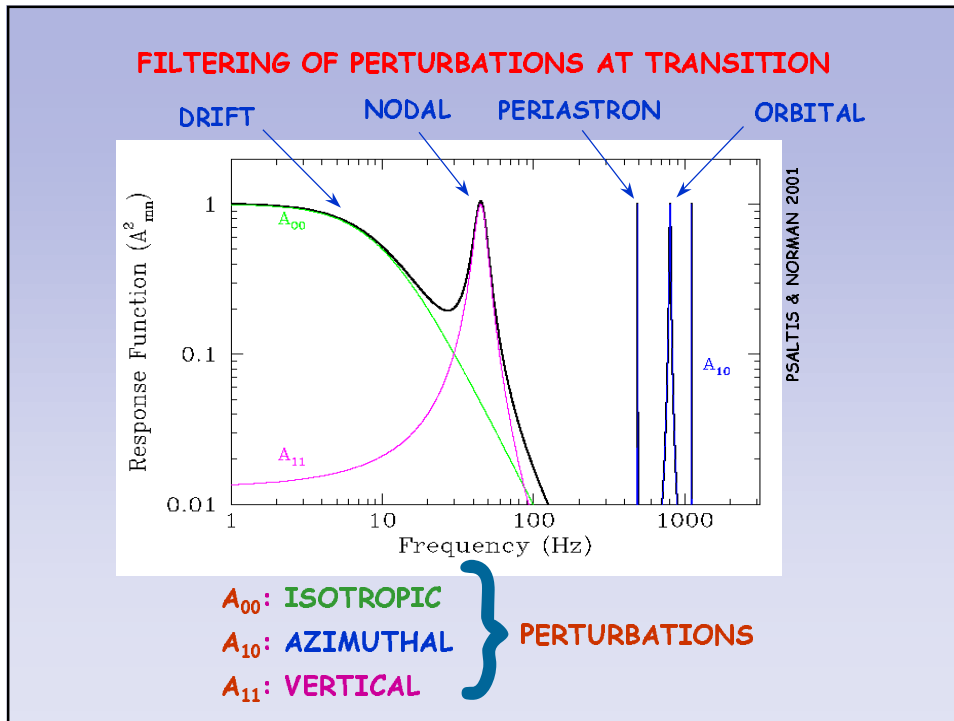
HEATING/COOLING FRONT

DWARF NOVAE OSCILLATIONS

YAMASHAKI ET AL. 1995

TRANSITION PRODUCED BY RADIATION DRAG

MILLER, LAMB, & PSALTIS 1998



**WHAT DO WE LEARN ABOUT DISK PHYSICS?**

- FOR ISOTROPIC TURBULANCE MODES HAVE:

$Q \sim 1/\alpha_{ss}$

HIGHEST OBSERVED COHERENCE FOR GRO J1655-40:  
STROHMAYER 2001

$Q > 23$

HENCE NEAR THE INNER BOUNDARY:

$\alpha_{ss} < 0.04$

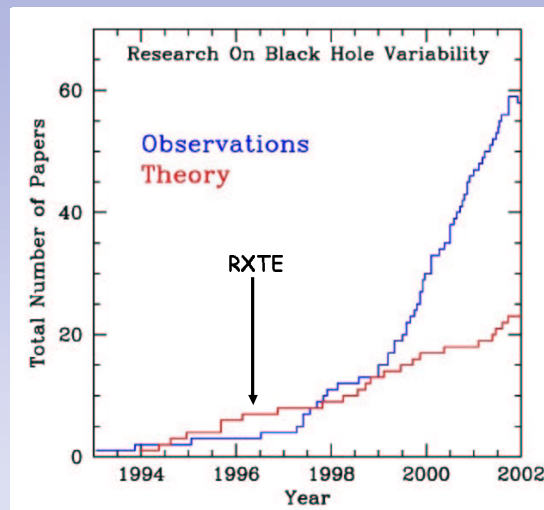
LOOK FOR ANSWERS  
IN MHD SIMULATIONS?

HAWLEY & KROLIK 2001

### CONCLUSIONS

- MODELS OF BLACK-HOLE VARIABILITY ARE MORE THAN WEATHER FORECAST
- VARIABILITY IS DESCRIBED BY A SMALL NUMBER OF CHARACTERISTIC FREQUENCIES
- POWER SPECTRA PROBE:
  - STRONG GRAVITATIONAL FIELDS
  - PHYSICAL PROPERTIES OF ACCRETION DISKS
  - MASSES AND SPINS OF BLACK HOLES

### A YOUNG RESEARCH FIELD WITH GREAT DATA!



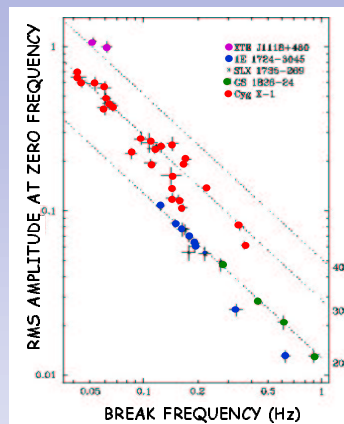
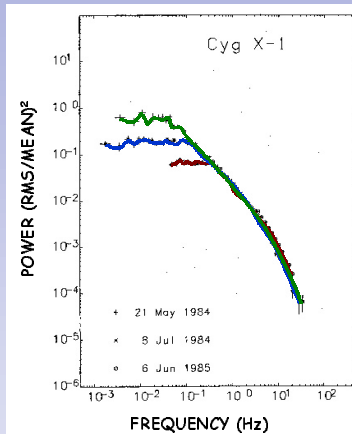
WITH ROOM+NEED FOR THEORETICAL MODELS!





### THE BELLONI-HASINGER EFFECT

BELLONI & HASINGER 1990; BELLONI, PSALTIS, & VAN DER KLIS 2002



FRACTIONAL RMS OF FIRST COMPONENT IS ~CONSTANT!

➤ SIMILAR EFFECT FOUND IN AGN

UTTLEY 2001