HTRA Instrumentation I

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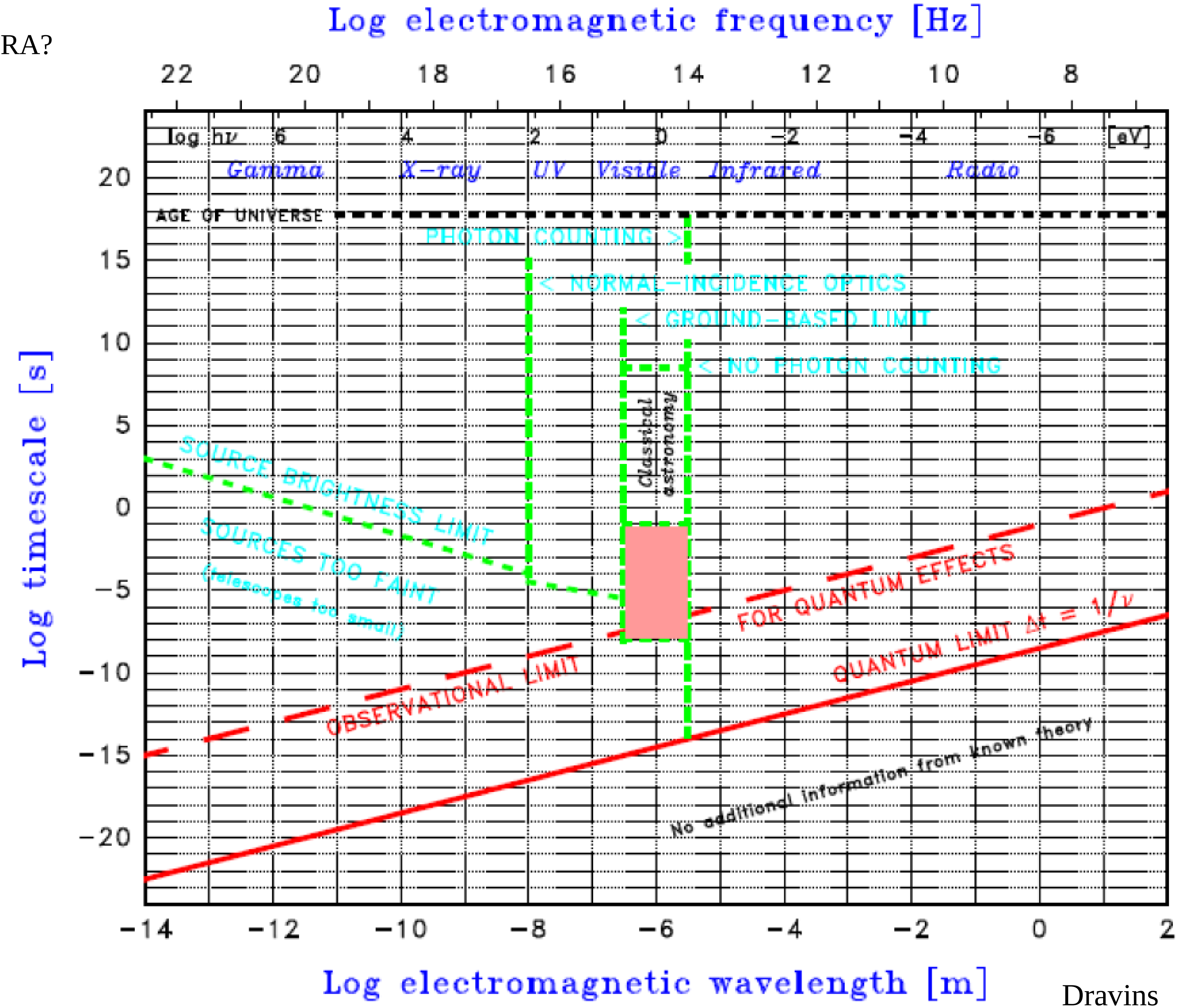
Lecture 1:

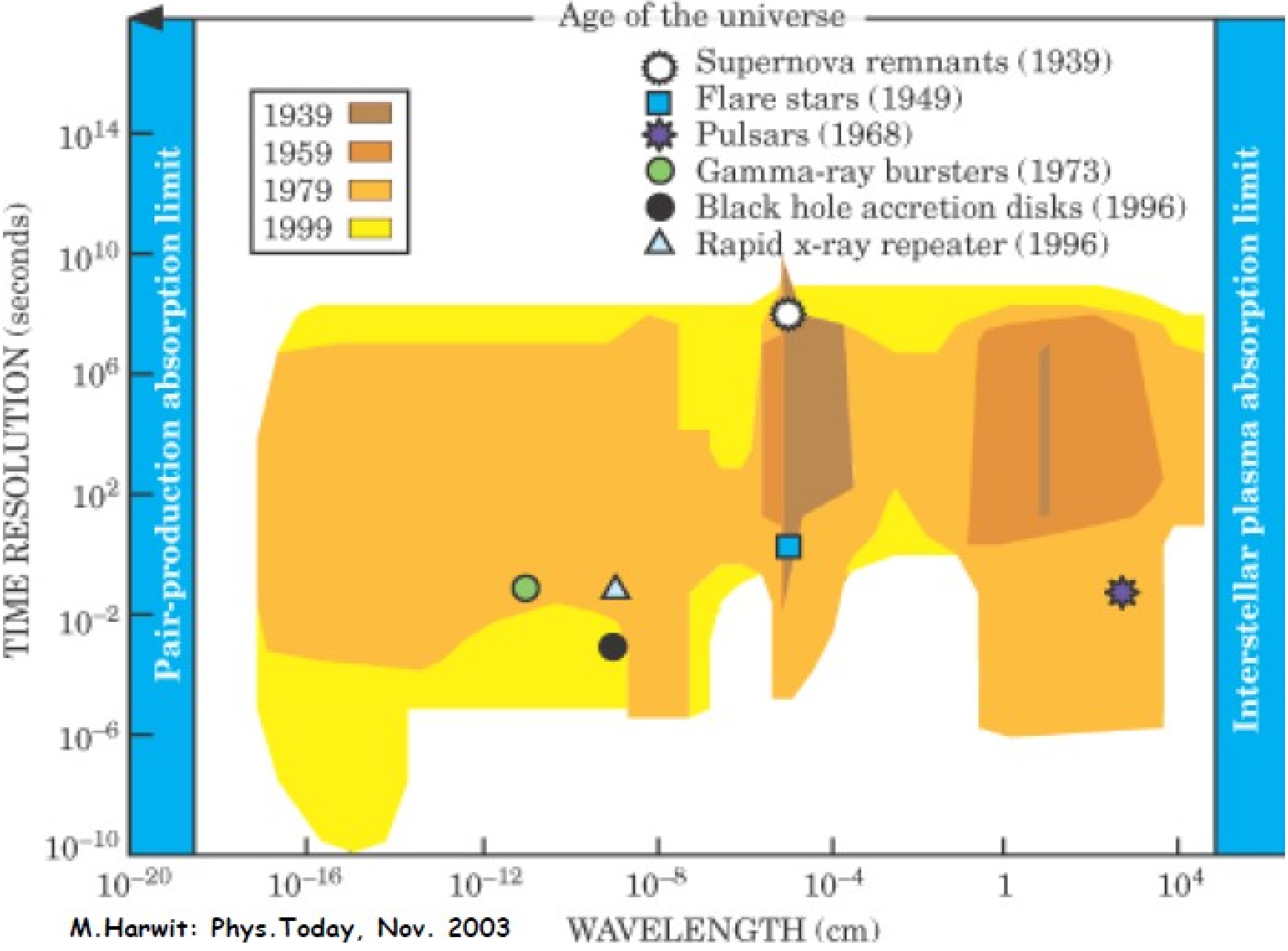
1. Introduction, basic concepts of HTRA
2. History (~60yrs) of HTRA
3. Space science developments → multi-wavelength
4. Fast timing in high-energy astrophysics
    - Since that's where it began, in X-ray and radio!

What is HTRA?



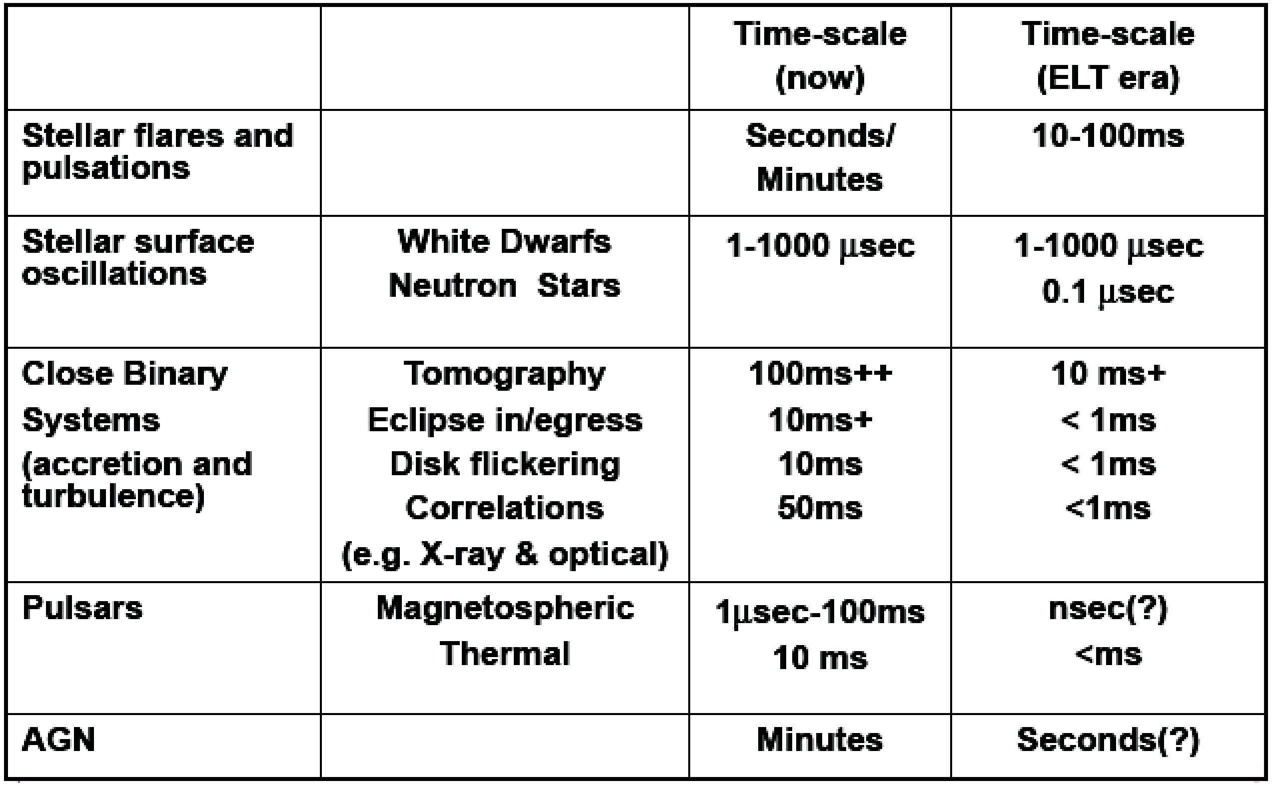
Dravins

And where have we reached now?



M.Harwit: Phys.Today, Nov. 2003

HTRA Science Drivers and Timescales



		Time-scale (now)	Time-scale (ELT era)
Stellar flares and pulsations		Seconds/ Minutes	10-100ms
Stellar surface oscillations	White Dwarfs Neutron Stars	1-1000 µsec	1-1000 µsec 0.1 µsec
Close Binary Systems (accretion and turbulence)	Tomography Eclipse in/egress Disk flickering Correlations (e.g. X-ray & optical)	100ms++ 10ms+ 10ms 50ms	10 ms+ < 1ms < 1ms <1ms
Pulsars	Magnetospheric Thermal	1µsec-100ms 10 ms	nsec(?) <ms
AGN		Minutes	Seconds(?)

A “History” of HTRA

Fast Photometry in the 50s and 60s: Cataclysmic Variables

- First coherent oscillation (P=71s) in CV DQ Her (Walker 1956) – PMT + chart recorder!
- This was an early glimpse of “high energy” processes near a compact object – as it is now recognised as rapidly spinning magnetic WD
- → High speed PMTs + first mini-computers in the 70s found many surprising phenomena on short τ (Warner & Nather Texas/UCT Photometer).
- → modern picture of Roche lobe overflow in accreting binaries

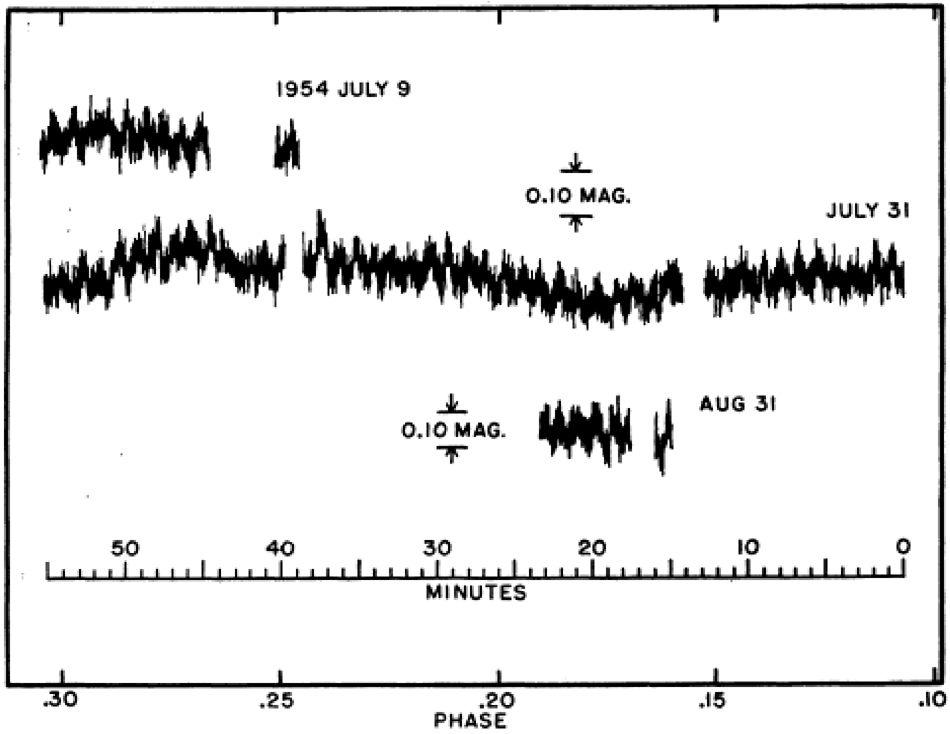
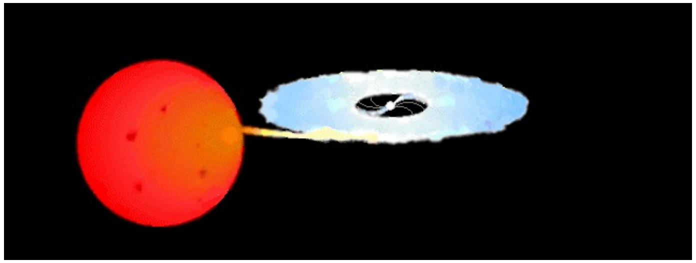
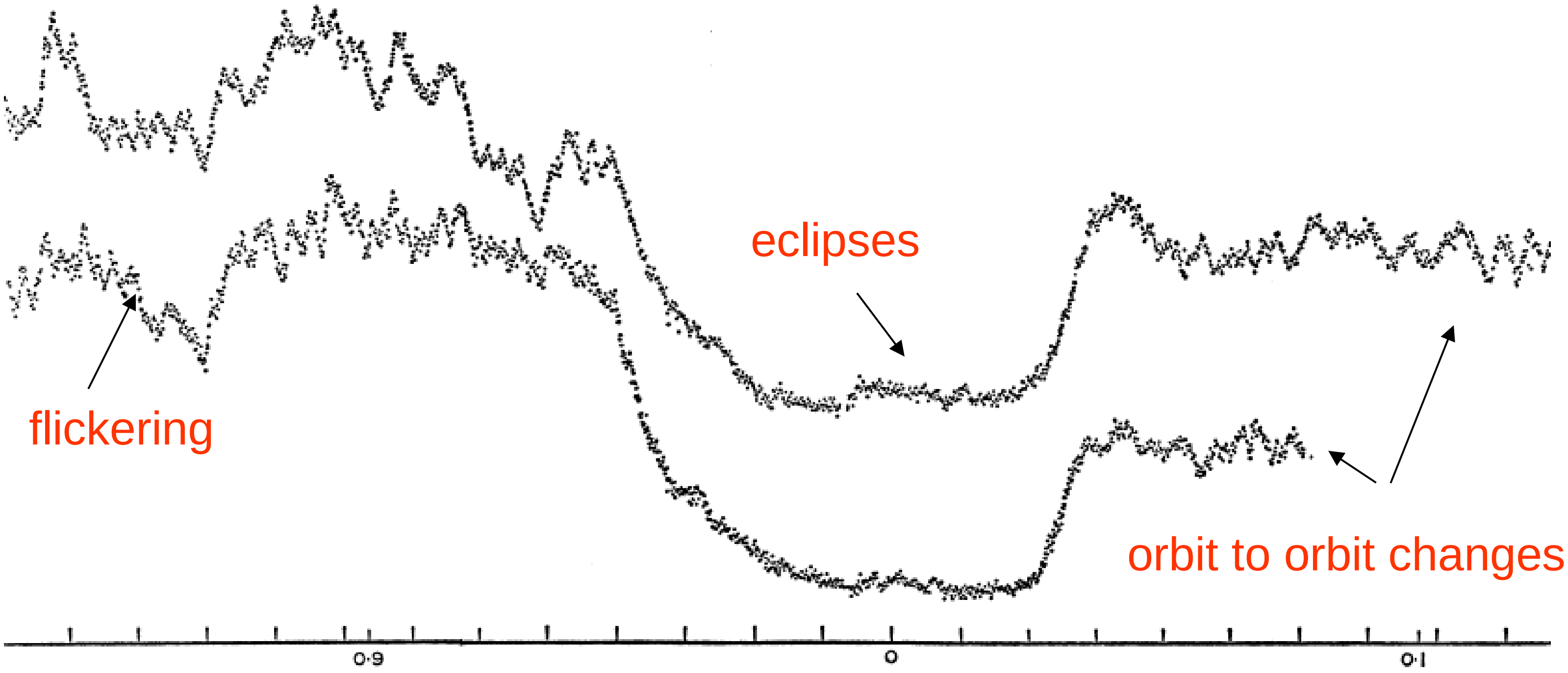


FIG. 6.—Tracings from Brown recorder sheets, showing rapid, periodic variations in ultraviolet light. The period of these fluctuations, determined from the observations on July 31, is $P = 1\,180$ minutes The abscissa is the phase in the 4-hour period.



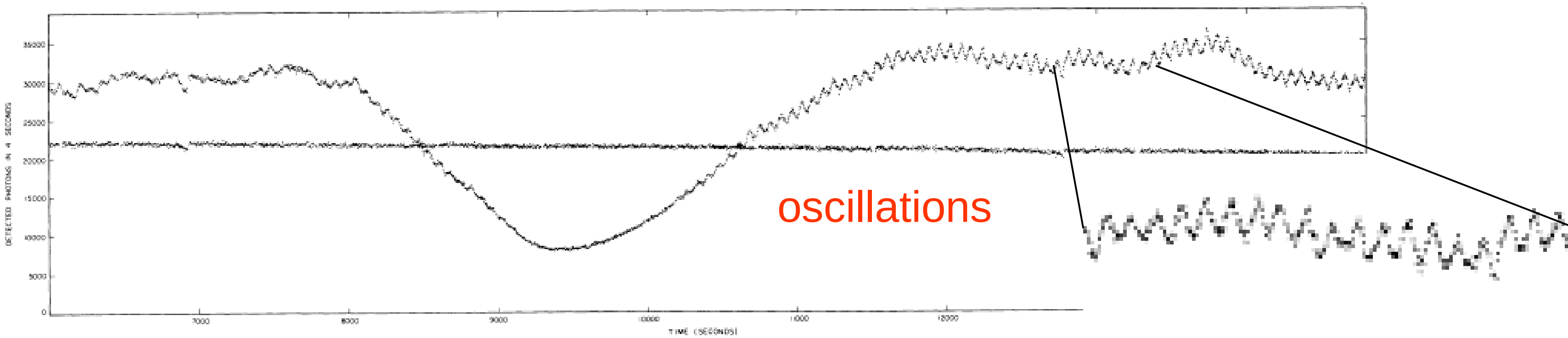
Variability in CVs



eclipses

flickering

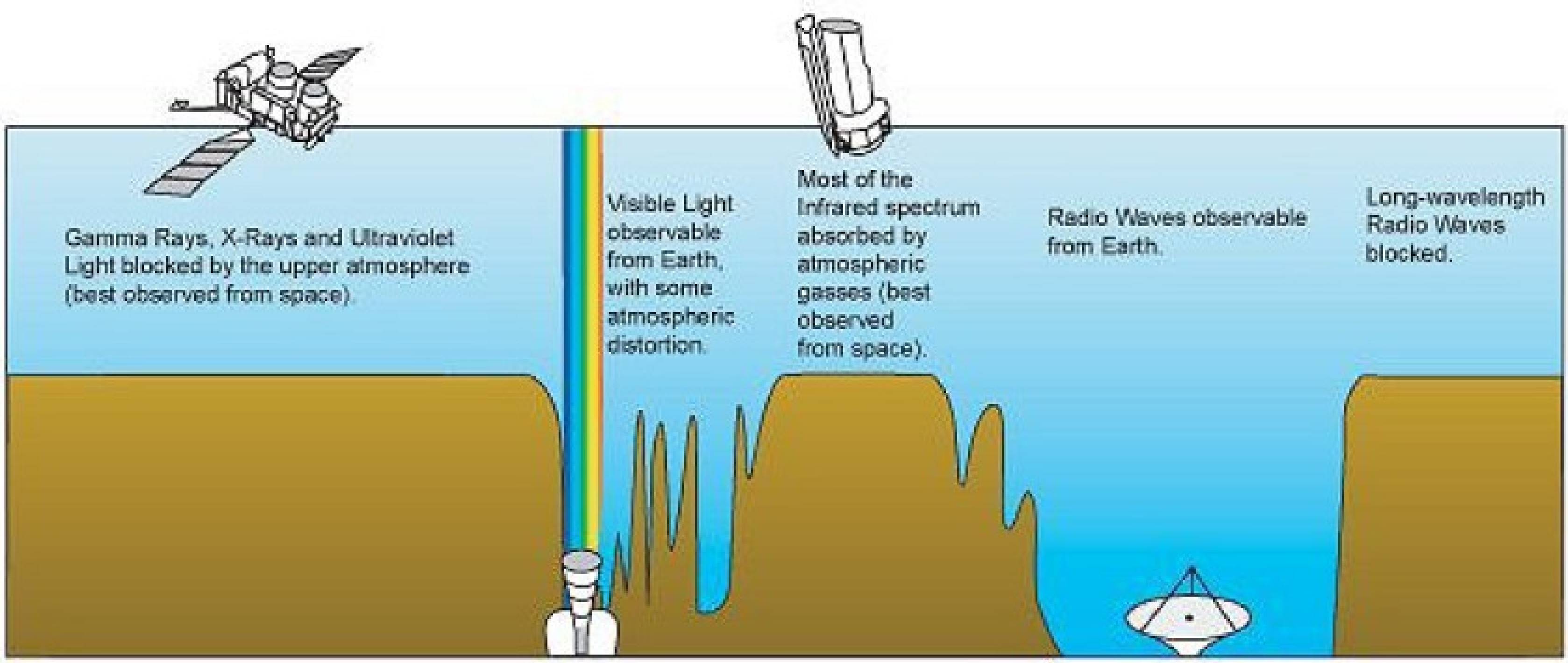
orbit to orbit changes



oscillations

Warner & Nather

- **1960s saw beginning of access to whole of electro-magnetic spectrum**



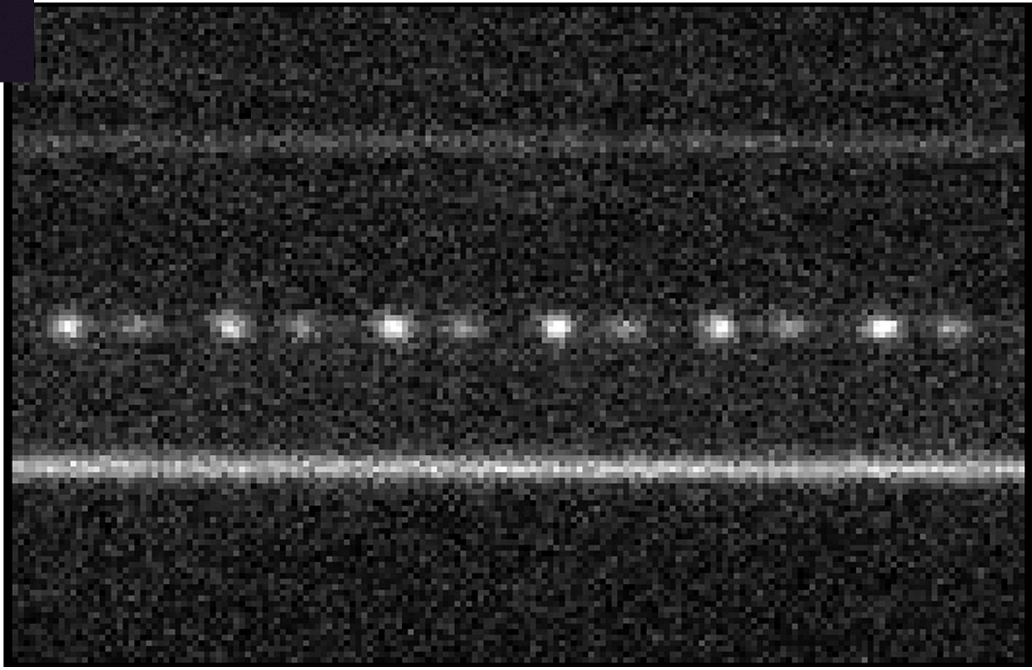
Schematic of transmission of the atmosphere as a function of wavelength

Some history of X-ray astronomy for context

- **Detection of the Sun in X-rays – 1948**
  - Subject approx 70 years old
  - But this detection held the search for cosmic sources back!
- **First detection of extra-solar source in 1961**
  - sounding rocket flight discovered Sco X-1
- **Detectors of increasing sophistication flown on sounding rockets in 60s, then first satellites (with Uhuru) in 70s**

Late 60s: discovery of radio pulsars
+ their optical counterparts

Trailed image of centre of
Crab Nebula:



Only extra-solar objects predicted in 1950s to be X-ray sources were SNRs!

But how were they identified, as all 1960s technology was non-imaging?

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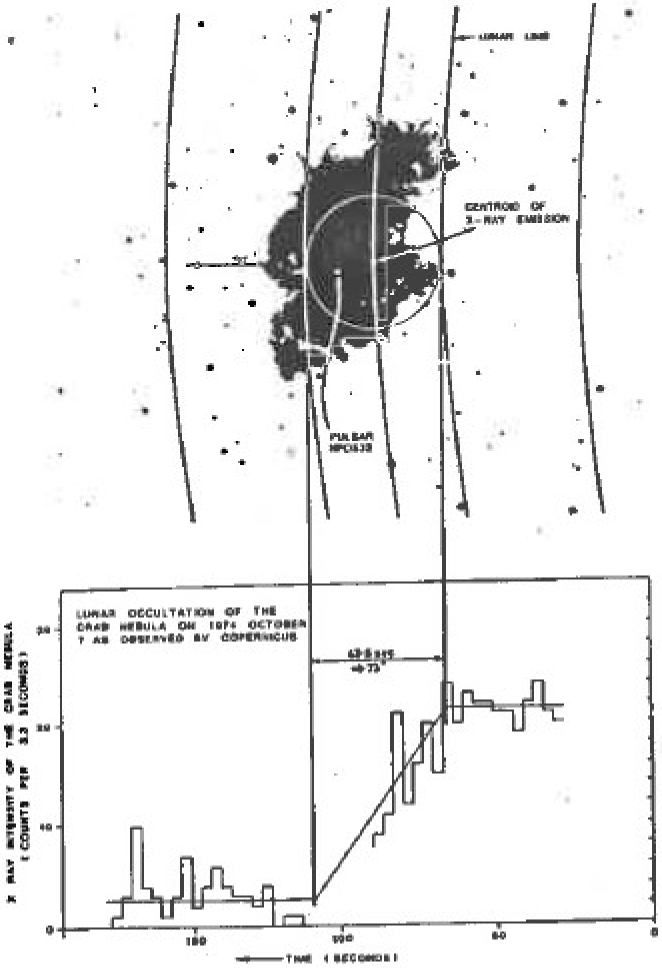
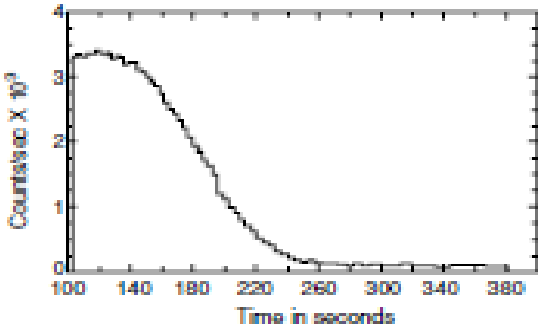
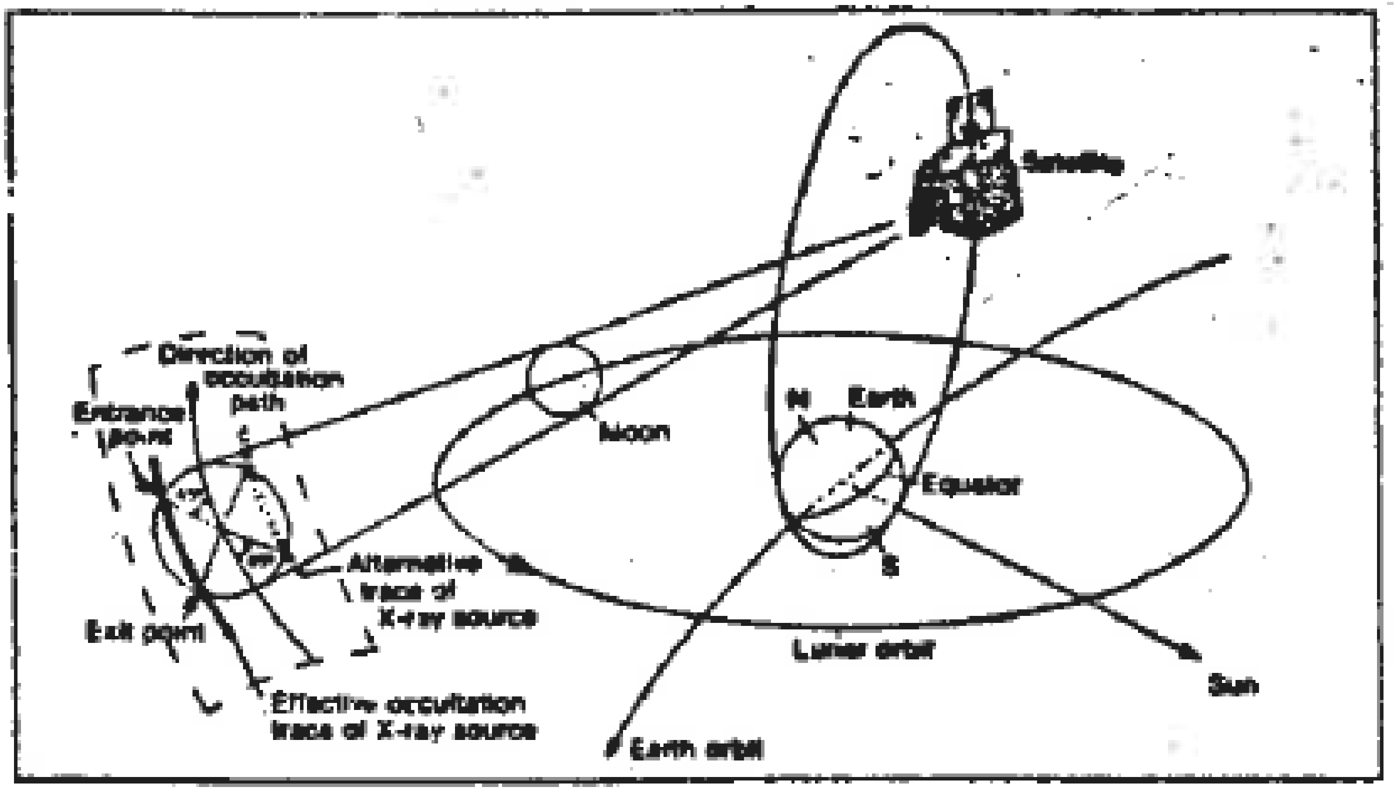


Lunar occultation!
→ basis for ESA's EXOSAT mission
i.e. turn temporal data into spatial info

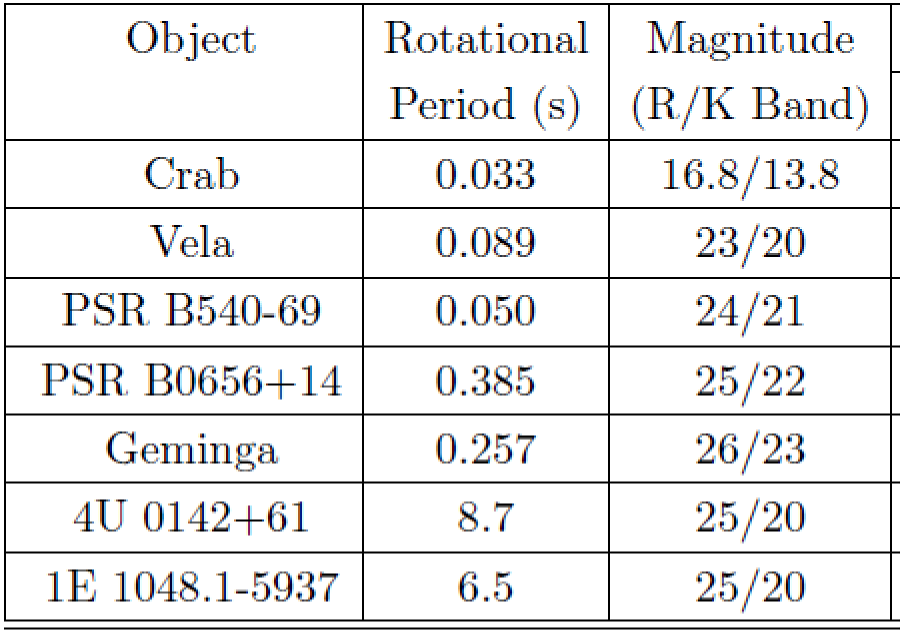


And a rocket-launched occultation
→ identified the pulsar too!

EXOSAT orbit (P=4d)



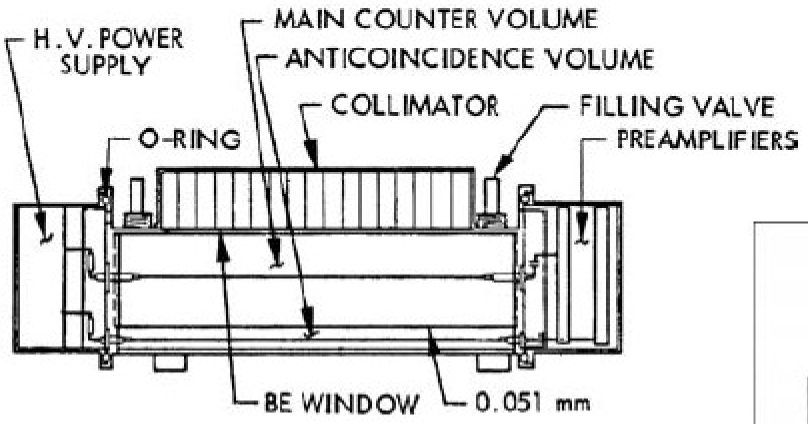
But other pulsars were not so easy!

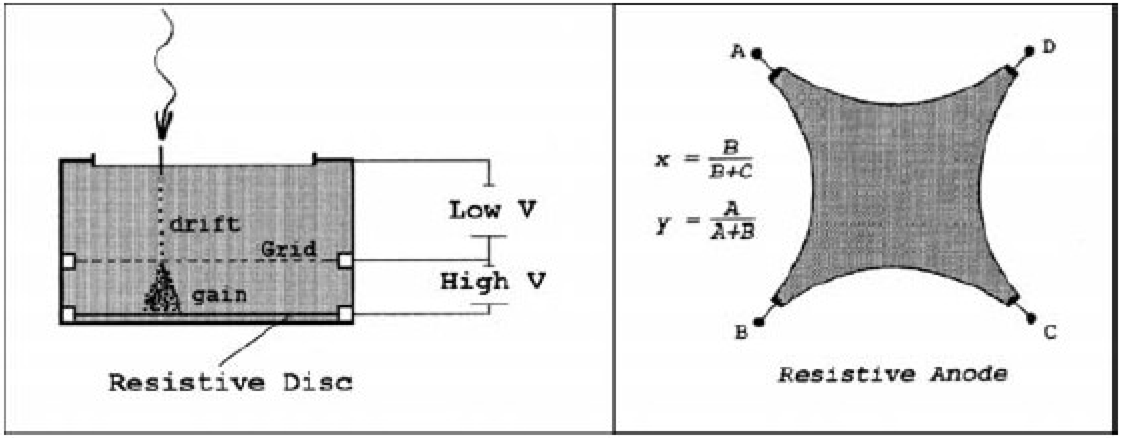


Object	Rotational Period (s)	Magnitude (R/K Band)
Crab	0.033	16.8/13.8
Vela	0.089	23/20
PSR B540-69	0.050	24/21
PSR B0656+14	0.385	25/22
Geminga	0.257	26/23
4U 0142+61	8.7	25/20
1E 1048.1-5937	6.5	25/20

Early X-ray technology: the Proportional Counter

V~2kV





X-ray enters sealed counter through thin window, ionises gas (Ar, Xe) → cloud of photoelectrons that are accelerated in E field, increasing ionisation, then collected by anode i.e. original cloud is multiplied → <u>one pulse per X-ray event</u>

Energy Range and Resolution of Proportional Counters

Number of initial photoelectrons $N = E/w$, where E = energy of X-ray, w = average ionization energy (26.2 eV for Ar, 21.5 eV for Xe)

Statistical process, so variance of N: $\sigma_N^2 = FN$, where F is the "Fano" factor, fluctuations are lower than expected from Poisson statistics ($F = 0.17$ for Ar, Xe)

Energy resolution (FWHM) is $$\frac{\Delta E}{E} = 2.35\frac{\sigma_N}{N} = 2.35\sqrt{\frac{wF}{E}}$$

N.B. Energy resolution is poor at low E!

Typically $\Delta E/E = 0.4E^{-1/2}$ and E range of detector is governed by
- window material and thickness at low E
- gas and its pressure at high E

Sensitivity of Proportional Counters:

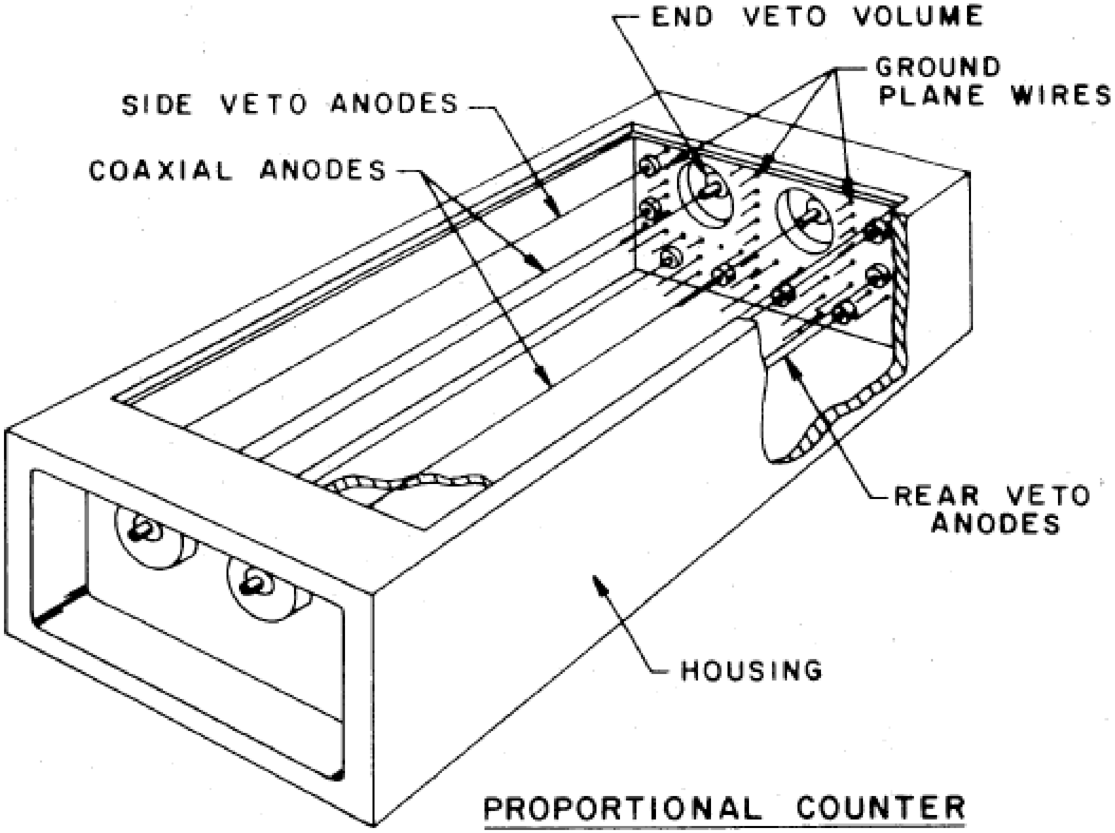
- Fluctuations in background signal: $$\Delta N = \sqrt{t\left(B_1 + \Omega A B_2\right)}$$
- *Where:*
  - *B*$_1$ is particle background (what is it due to?)
    - N.B. it depends on detector <u>volume</u>
  - Ω is detector solid angle
  - *A* is detector effective area

  → ΩAB_2 is rate of X-ray background (what is it due to?)
  - *t* is integration time
- So S/N ratio of source detection is: $$\sigma_n = \frac{SAt}{\sqrt{B_1 t + \Omega A B_2 t}}$$
- *Where:*
  - *S* is source flux (counts cm^{-2} s^{-1})
- And limiting sensitivity is $$S_{\min} = \sigma_n \sqrt{\frac{B_1 / A + \Omega B_2}{At}}$$

Typical PC Characteristics:

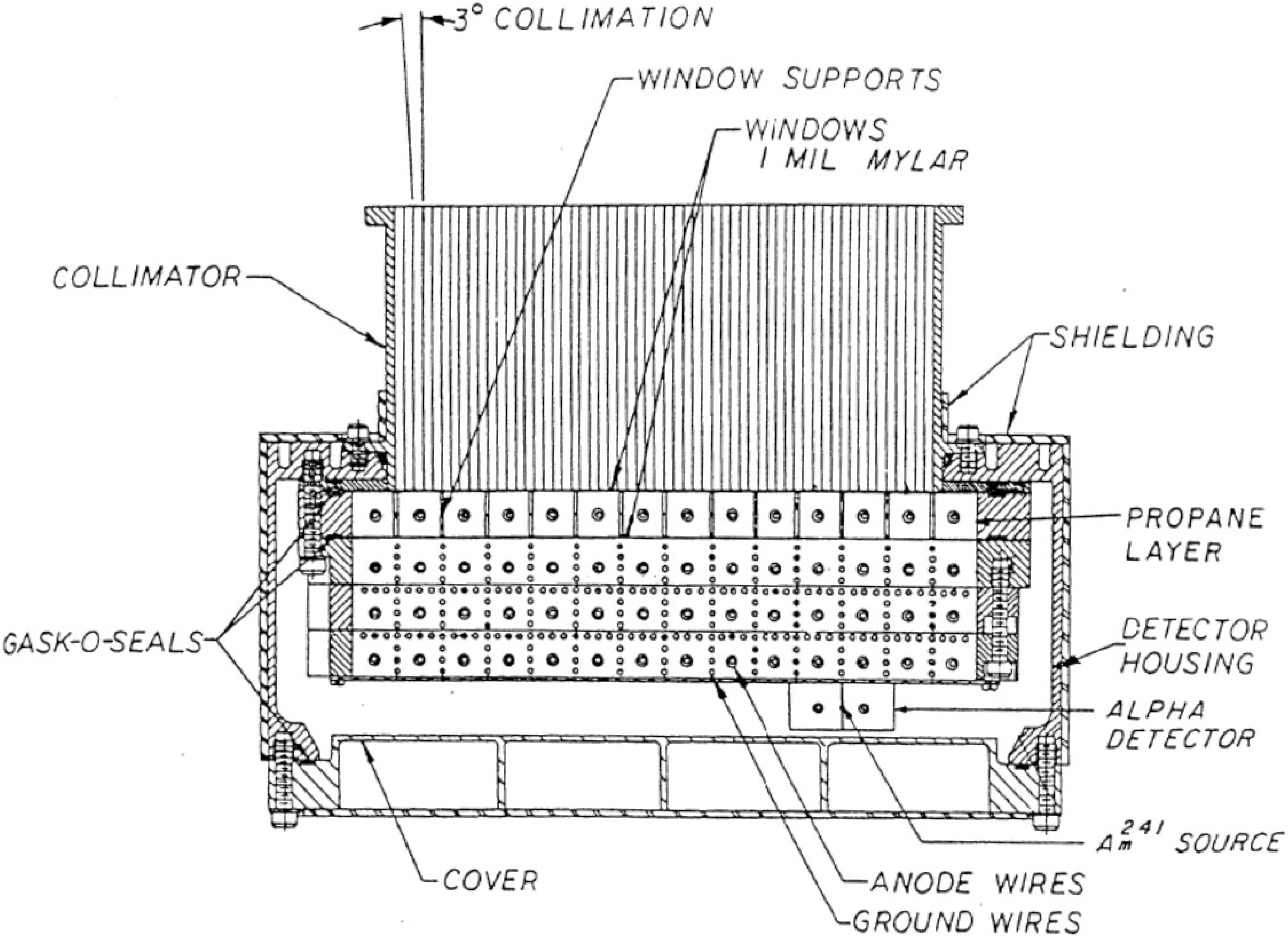
- Source sensitivity
  - Non-imaging: sensitivity α Area$^{1/2}$
    - limited by source confusion to ~mCrab
  - Imaging: depends on detector properties, but orders of magnitude better
- Timing Resolution
  - Typical anode-cathode spacing and ion mobility → ~ μsec
  - Timing variations: sensitivity α Area

Cosmic background rejection techniques



Dan Schwartz

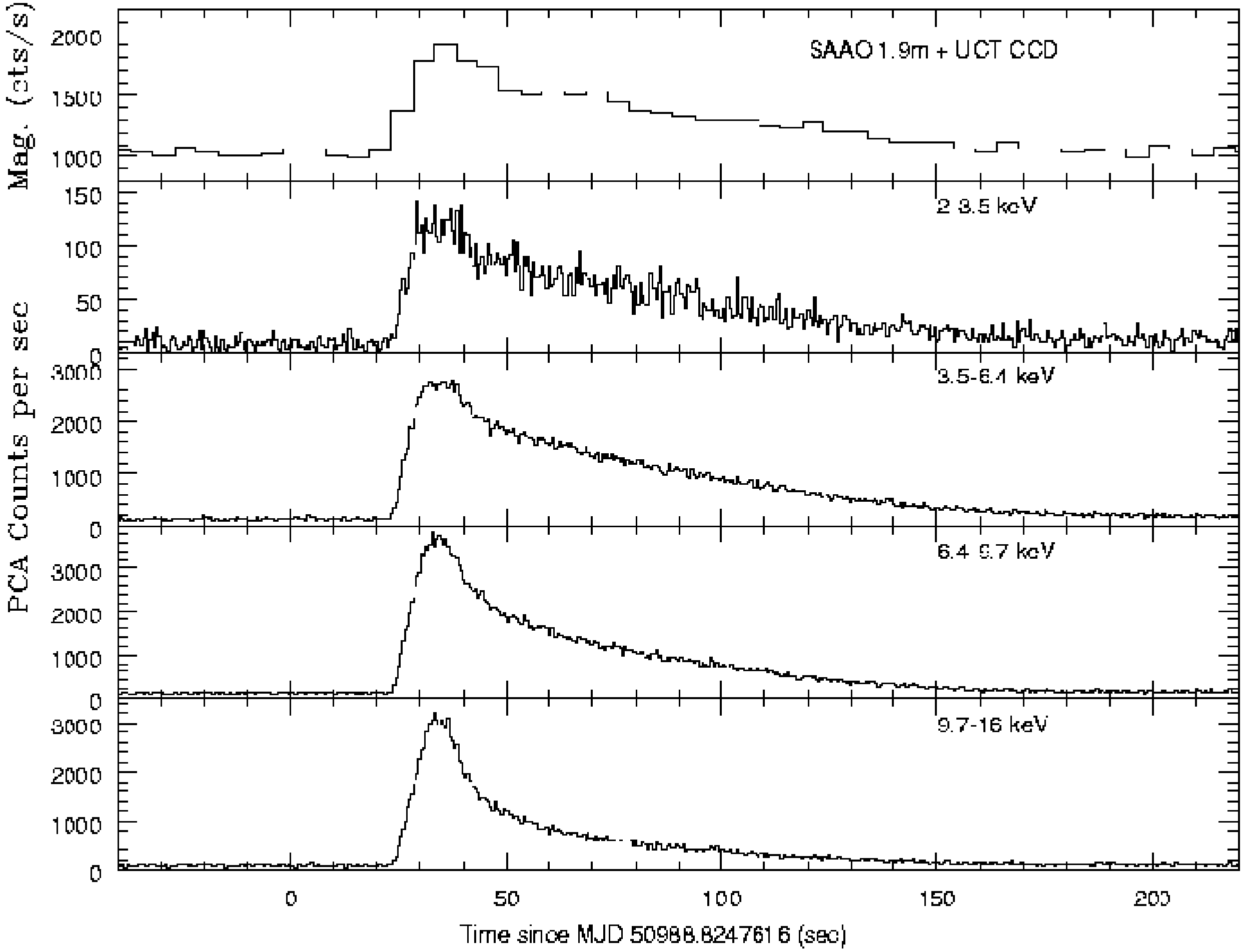
- Rise-time discrimination
  - Rise time of X-ray pulse is different from charged particle
- Anti-coincidence, or veto anodes (blind to X-rays)
  - Use sub-divided gas cells
  - Co-incident pulses indicate extended ionising source (cosmic rays, Solar particles)



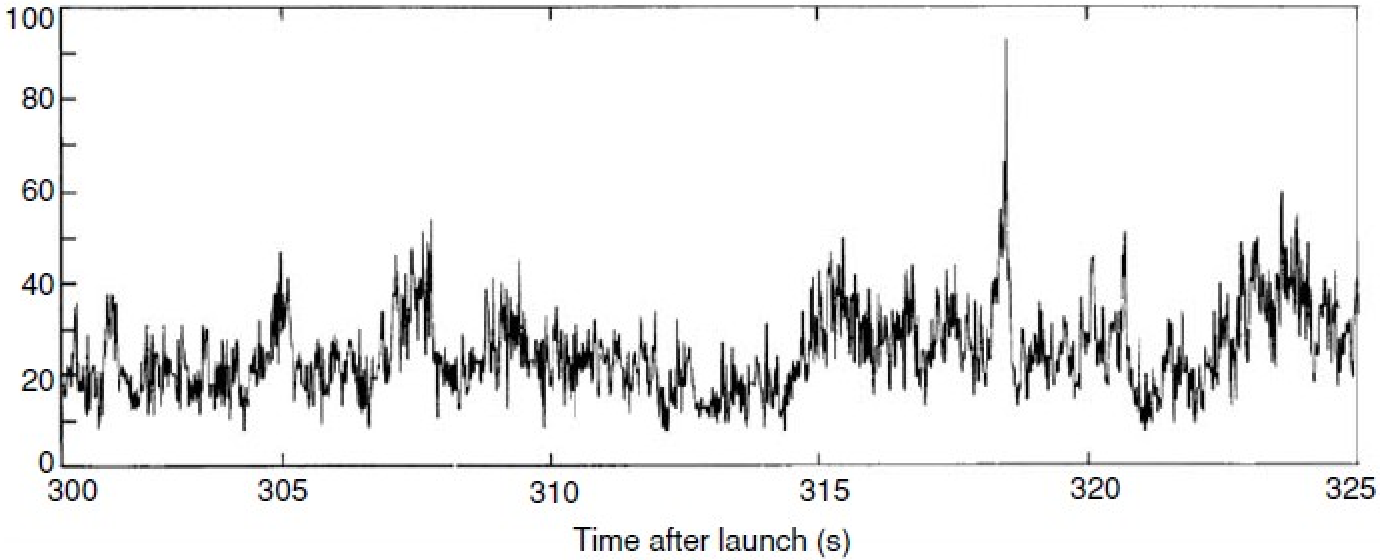
N.B. sensitive to gas leaks and micrometeoroids → gain drift

X-ray bursts discovered in mid-70s by ANS satellite, but could have been found earlier (with better background rejection!)

Simultaneous optical/X-ray observations of EXO0748-676 (Hynes, Homer)

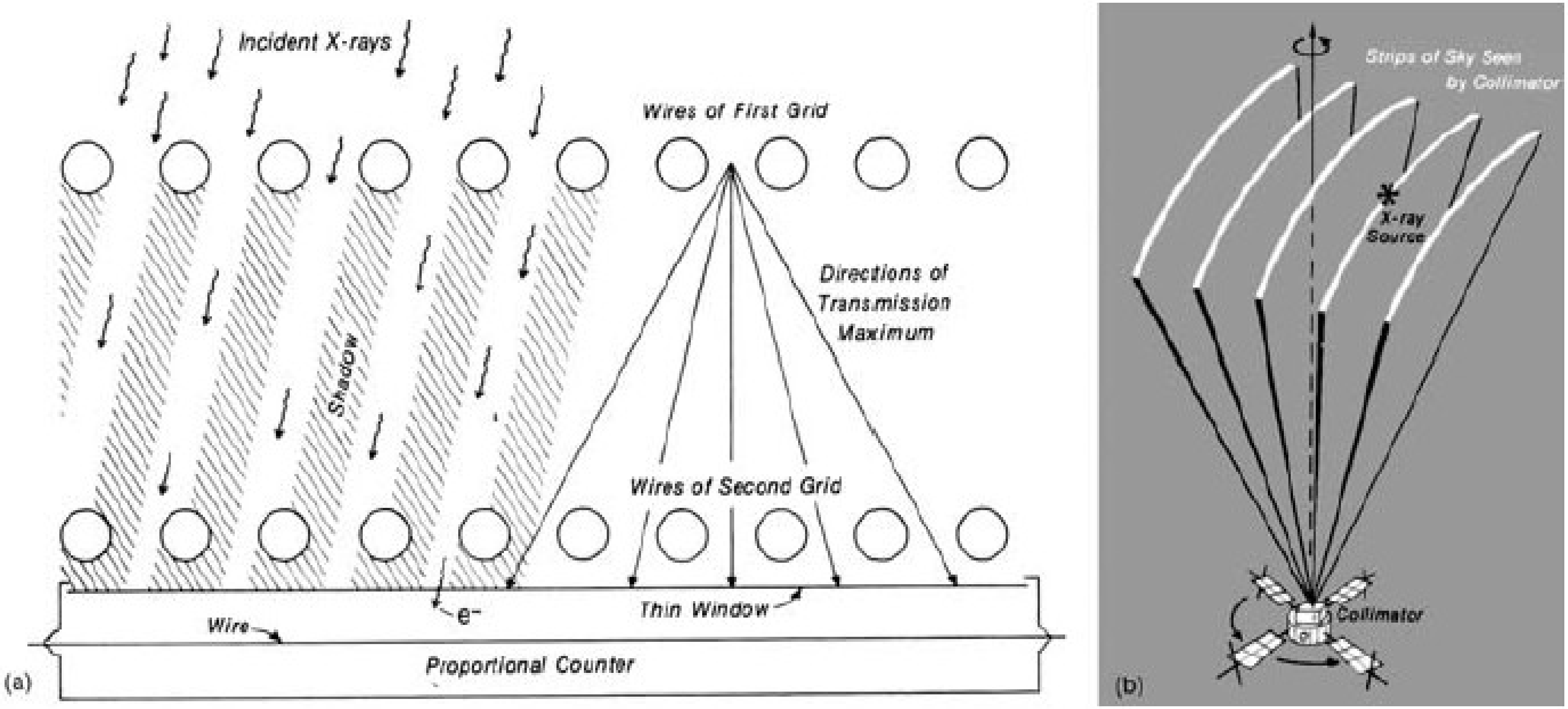


Cyg X-1 (Rothschild+74)



e.g. rocket-borne proportional counter observation of Cyg X-1 →
rapid, erratic variability/flickering – now the hallmark of BH XRBs

Use t resolution to derive spatial resolution: the <u>Modulation Collimator</u> (used in 60s and 70s to locate and identify bright X-ray sources)



Nature of the bright X-ray sources

- Concentrated towards Galactic plane and Galactic centre (found from 1960s rocket flights)

→ therefore some must be distant (10 kpc) and high luminosity (10^{38} erg/s)

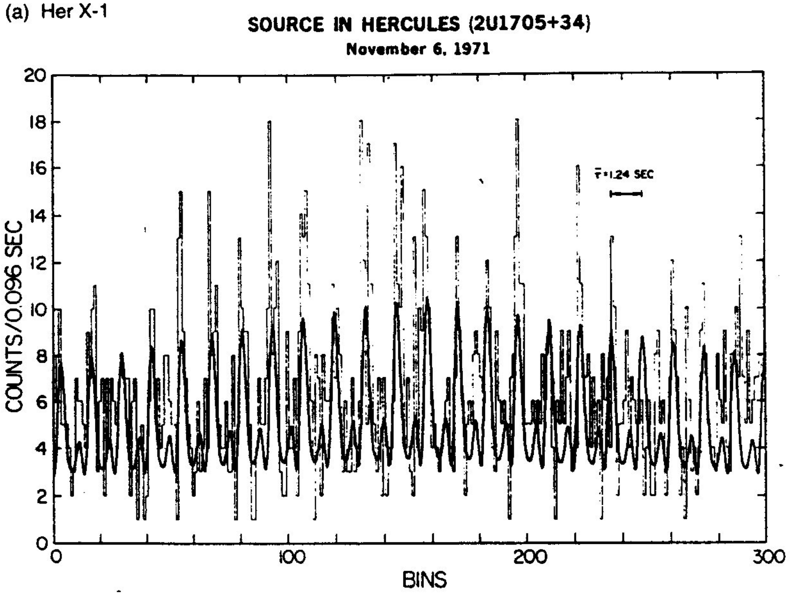
- Many highly variable on short timescales

→ therefore compact

- Non-varying, extended sources are SNRs

➢ Energy from gravitational accretion

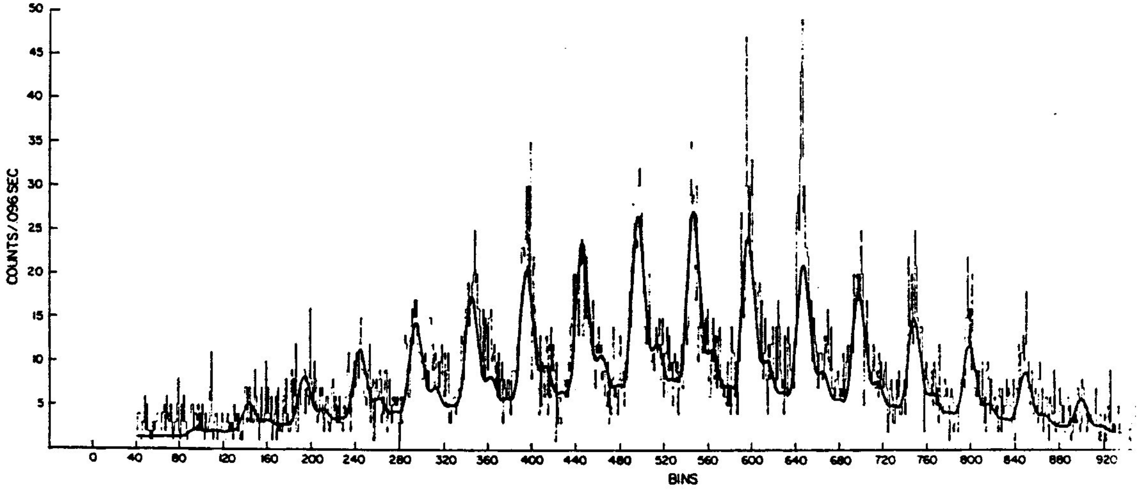
(a) Her X-1

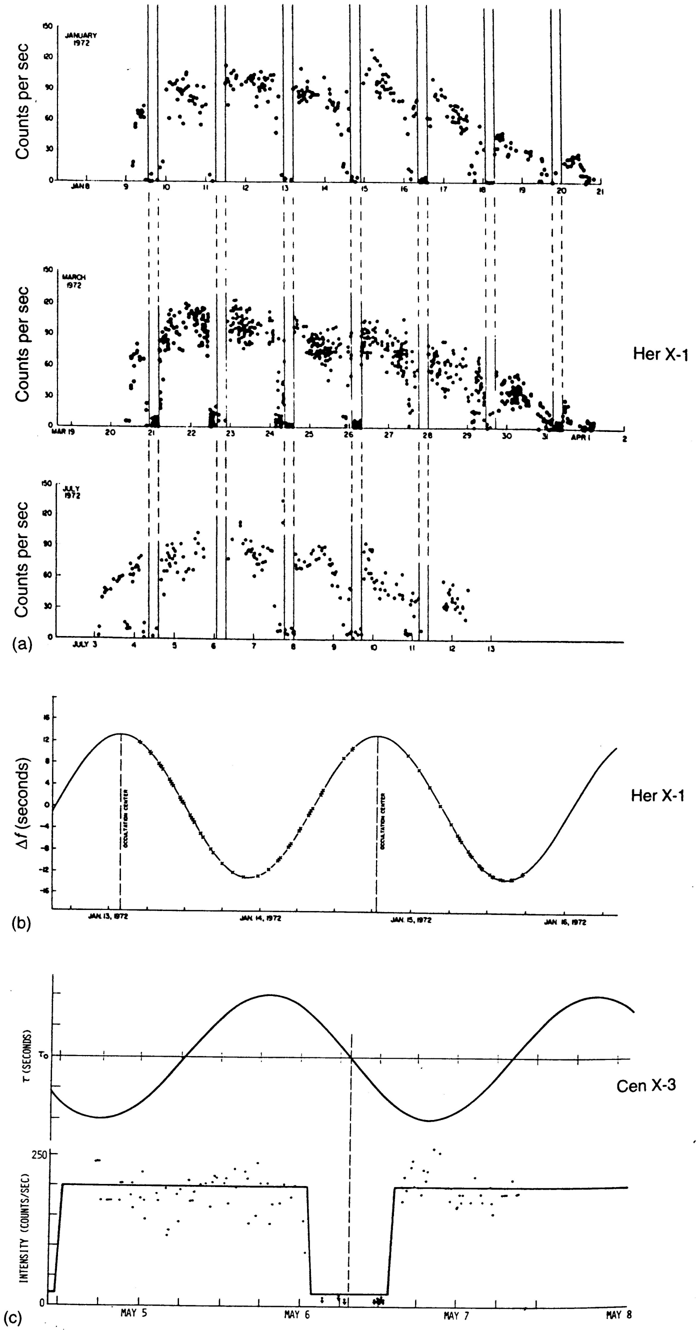


Key discovery was made by Uhuru satellite (simple PCs) in 1971

X-ray pulsations discovered from Her X-1 and Cen X-3

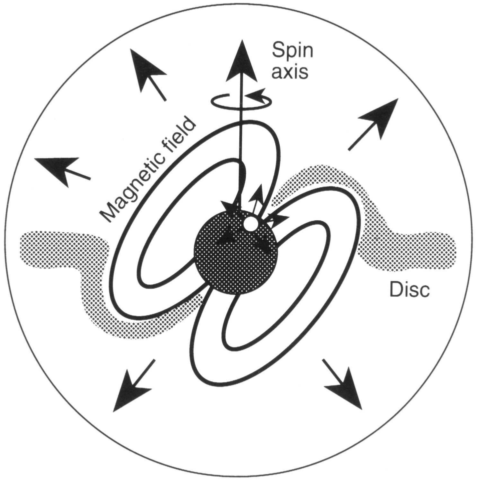
(b) Cen X-3

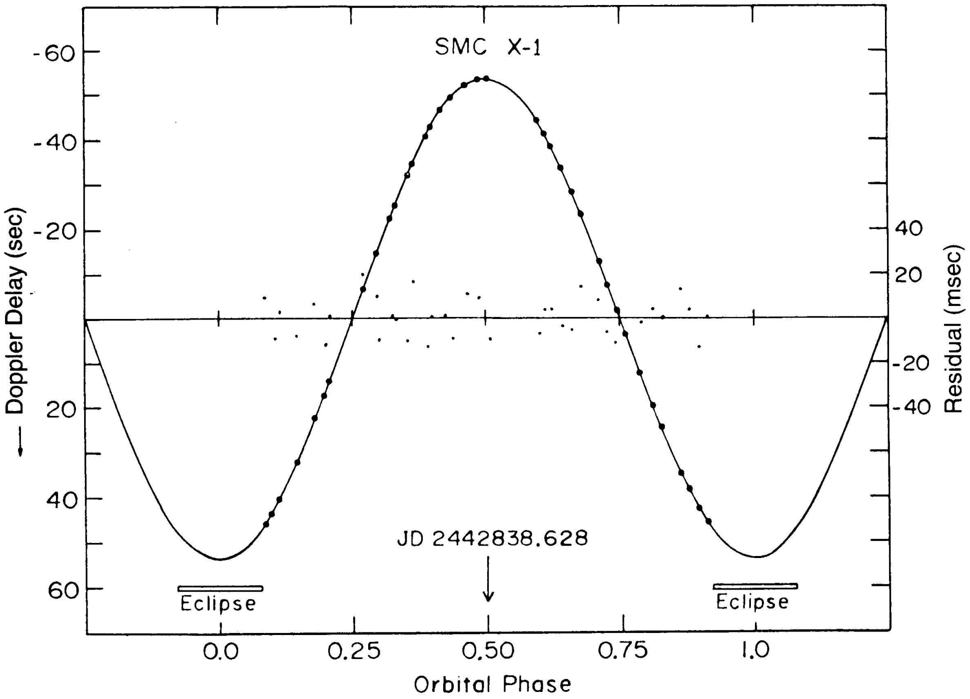


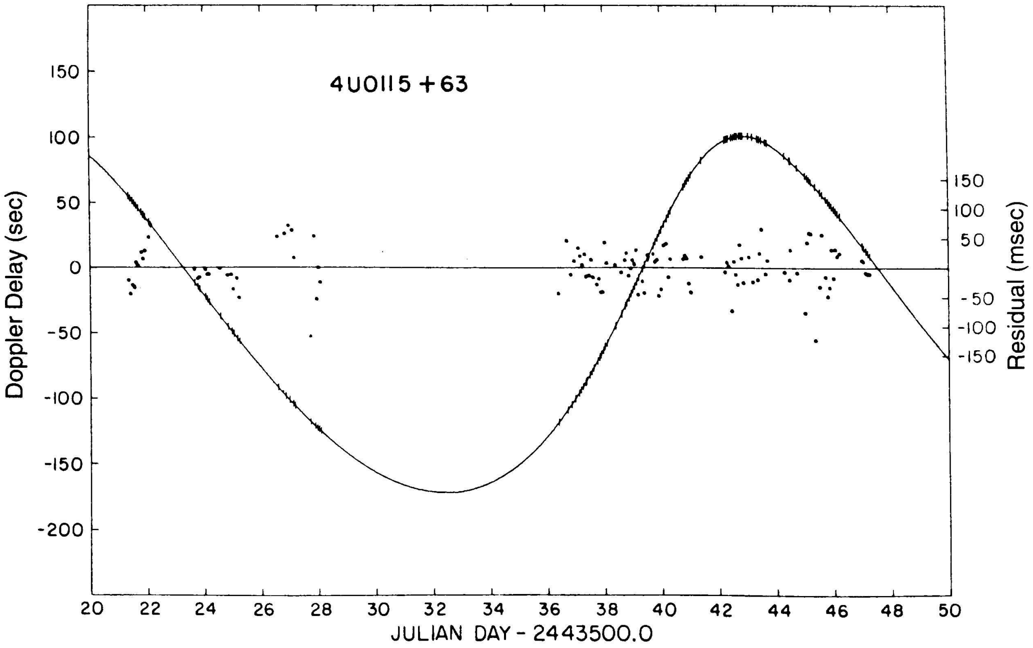


+ their binary nature was immediately apparent!

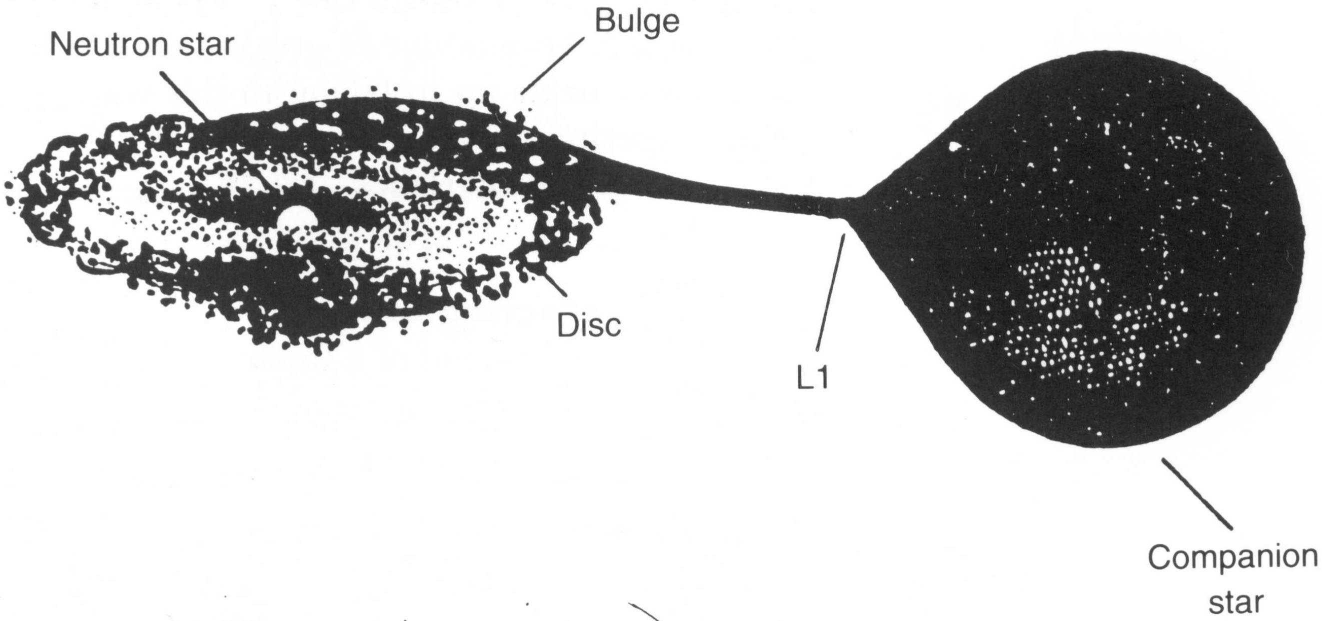
Note also the 35d cycle of Her X-1



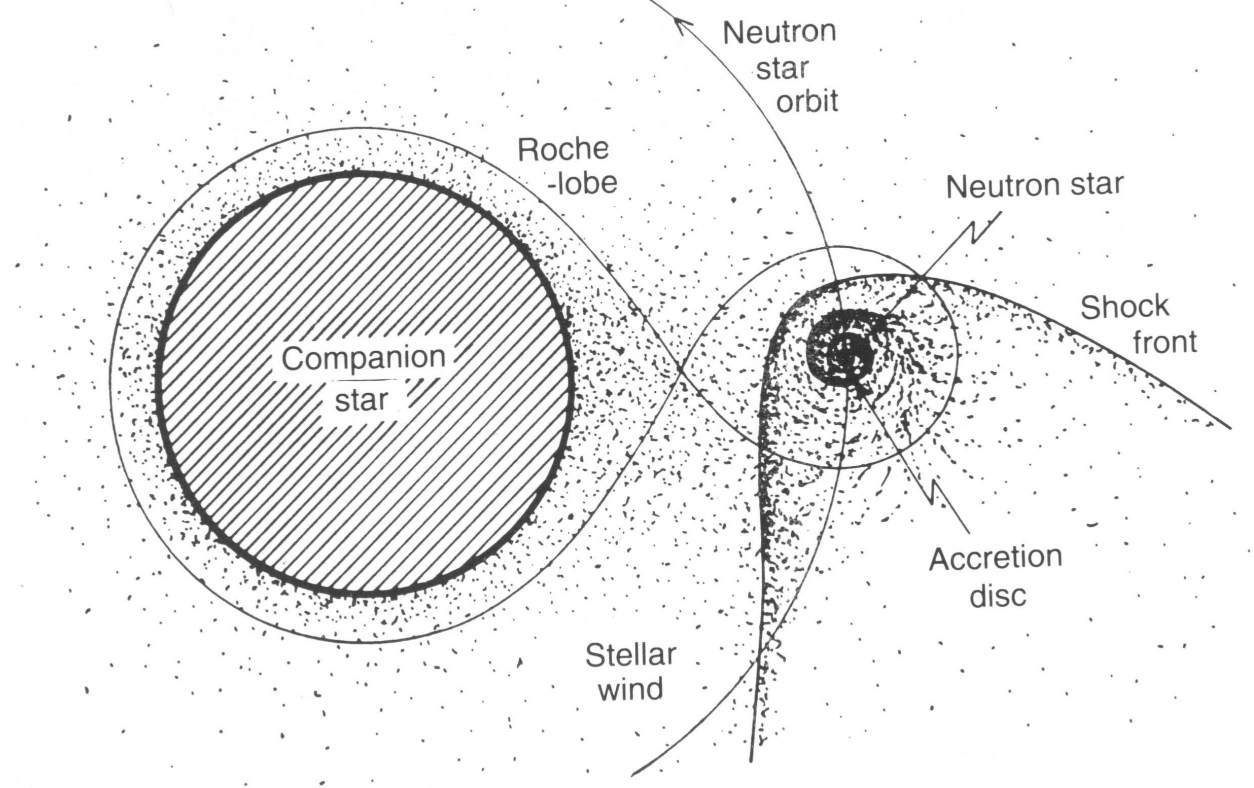




Both circular and eccentric orbit systems found


Neutron star
Bulge
Disc
L1
Companion star

LMXB


Neutron star orbit
Roche -lobe
Neutron star
Shock front
Companion star
Accretion disc
Stellar wind

HMXB

HEAO-A1 1977-79 all-sky survey

In Galactic coordinates