SN Ia Progenitors

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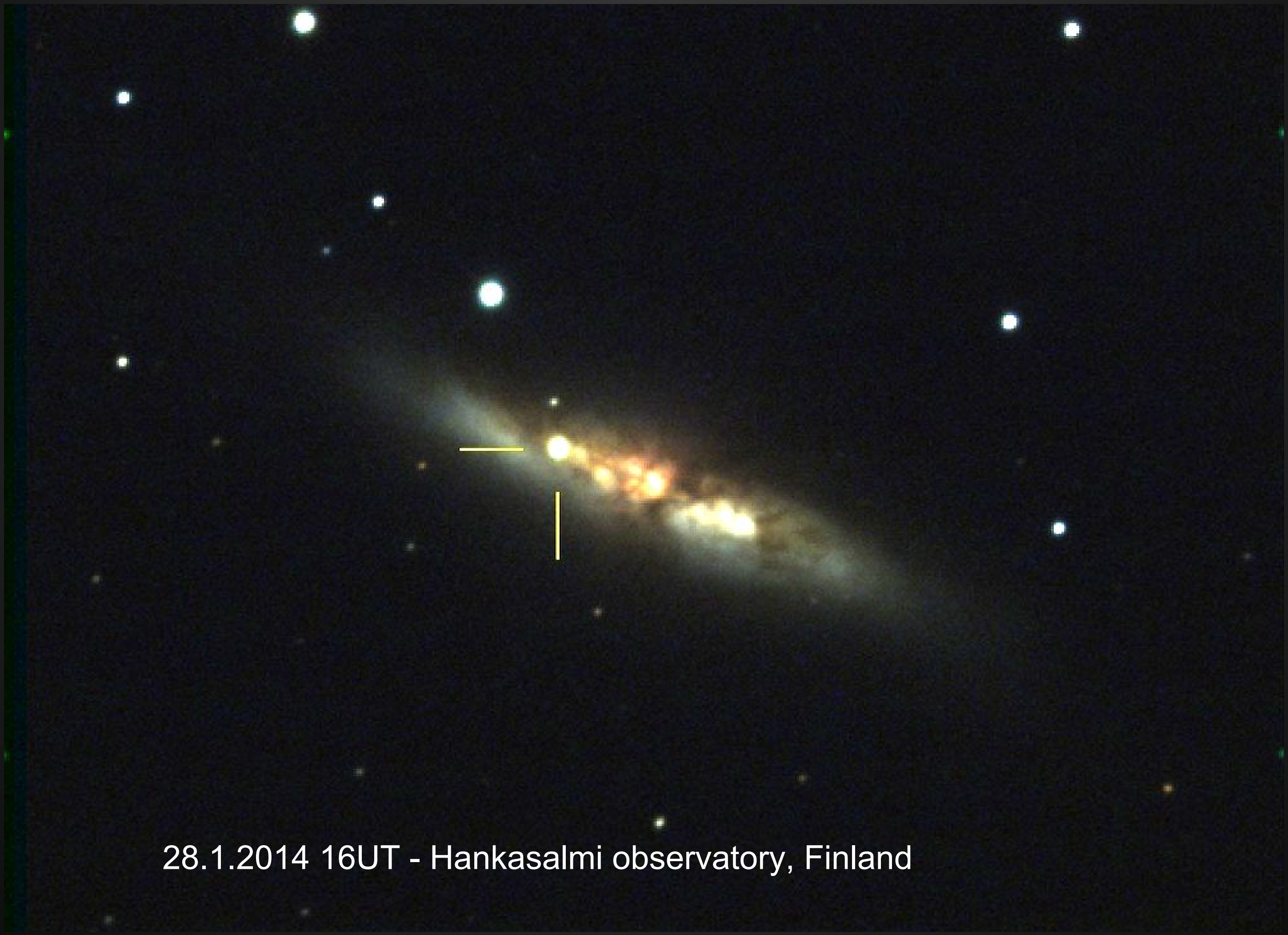
European Conference for Amateur Variable Star Observers
17./18. September 2016 - DESY, Hamburg, Germany

SN 2014J

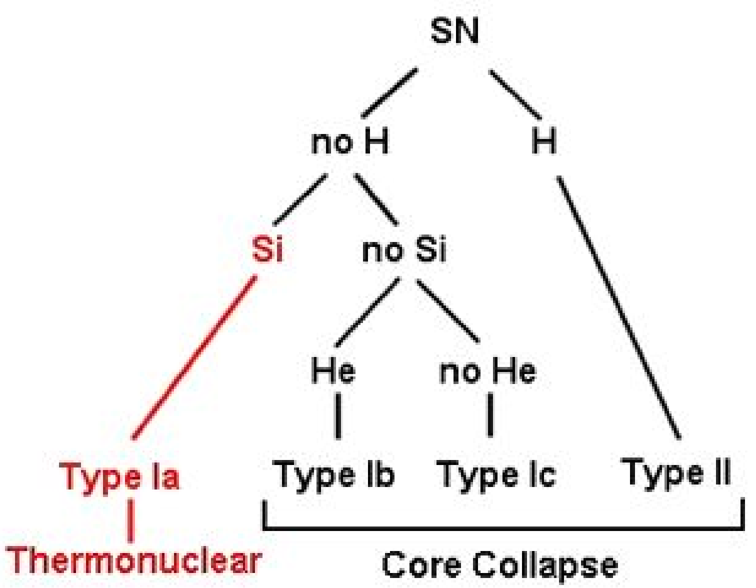
SN 2014J in Messier 82

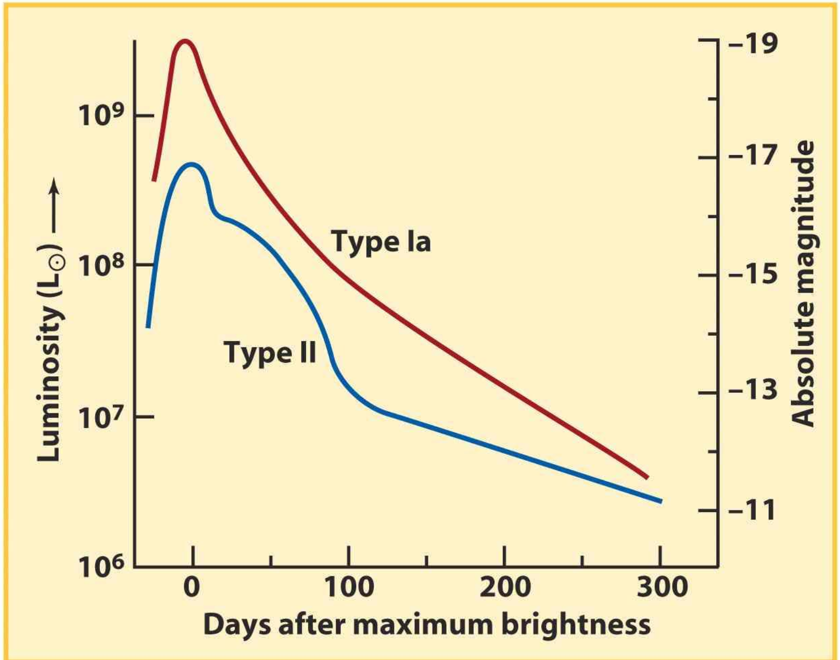


Different Supernovae

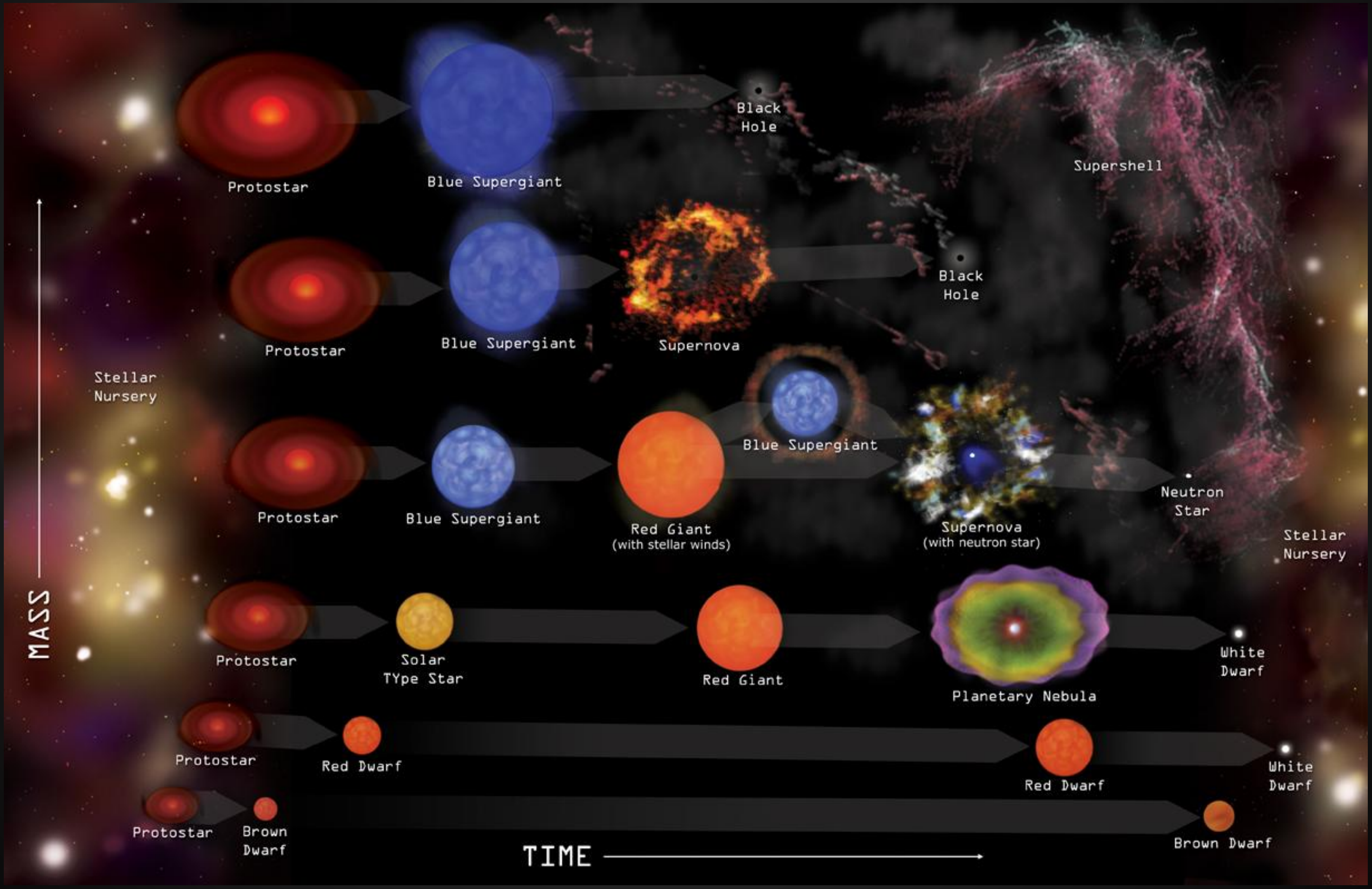
Ia - No hydrogen - White dwarf (CO) - binary star

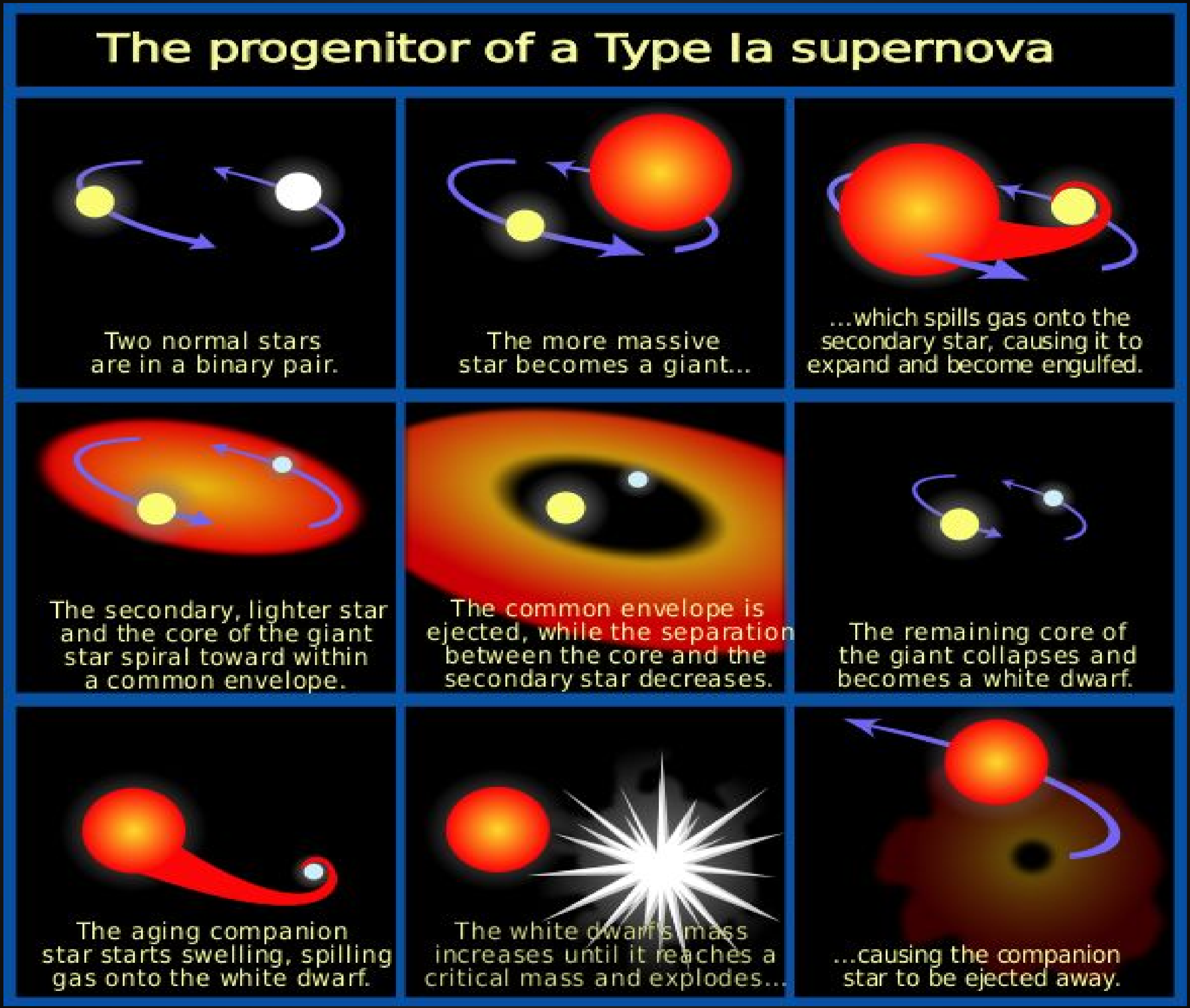
II - Hydrogen - Core collapse of a massive star





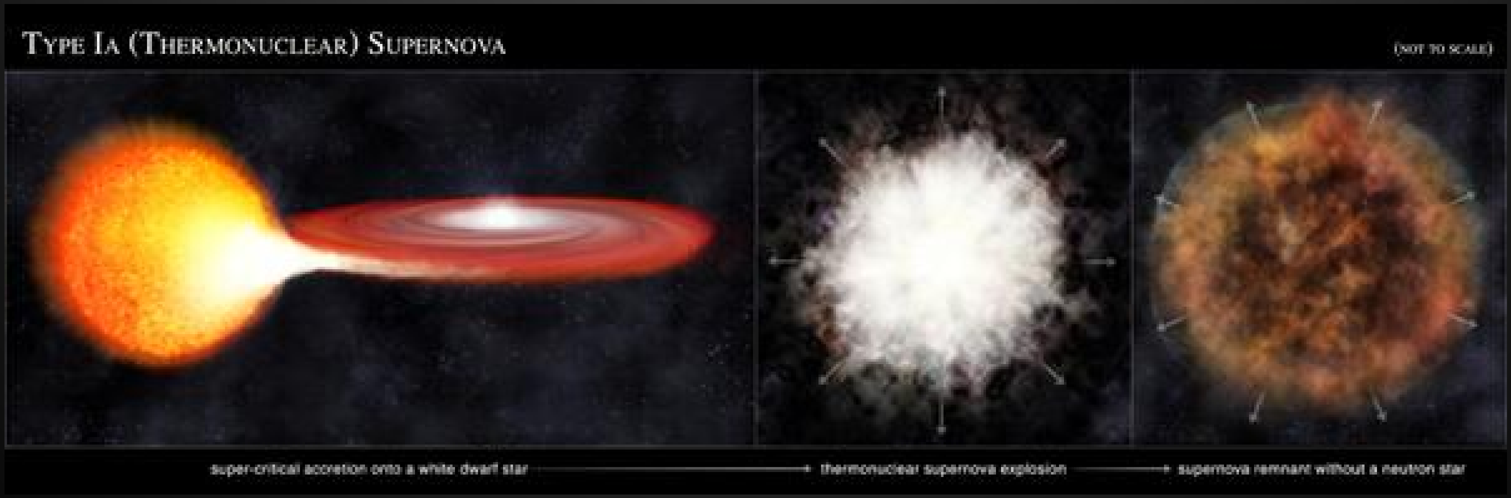
Stellar evolution - a single star




The progenitor of a Type Ia supernova
Two normal stars are in a binary pair.
The more massive star becomes a giant...
...which spills gas onto the secondary star, causing it to expand and become engulfed.
The secondary, lighter star and the core of the giant star spiral toward within a common envelope.
The common envelope is ejected, while the separation between the core and the secondary star decreases.
The remaining core of the giant collapses and becomes a white dwarf.
The aging companion star starts swelling, spilling gas onto the white dwarf.
The white dwarf's mass increases until it reaches a critical mass and explodes...
...causing the companion star to be ejected away.

Type Ia supernova

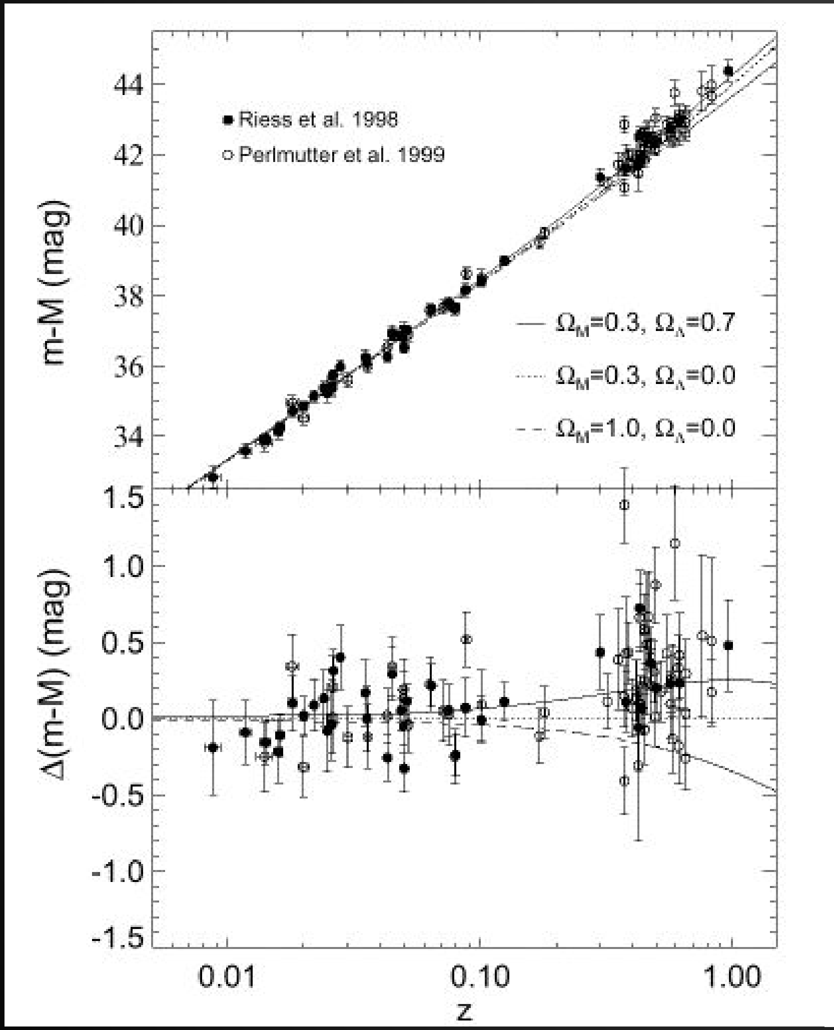
- If mass is added to a white dwarf it will become hotter, smaller and heavier
- When the mass exceeds the critical limit of 1.4 solar mass it will explode as a type Ia supernova (thermonuclear runaway).
- This type is an important cosmic standard candle (assuming equal mass → equal luminosity).

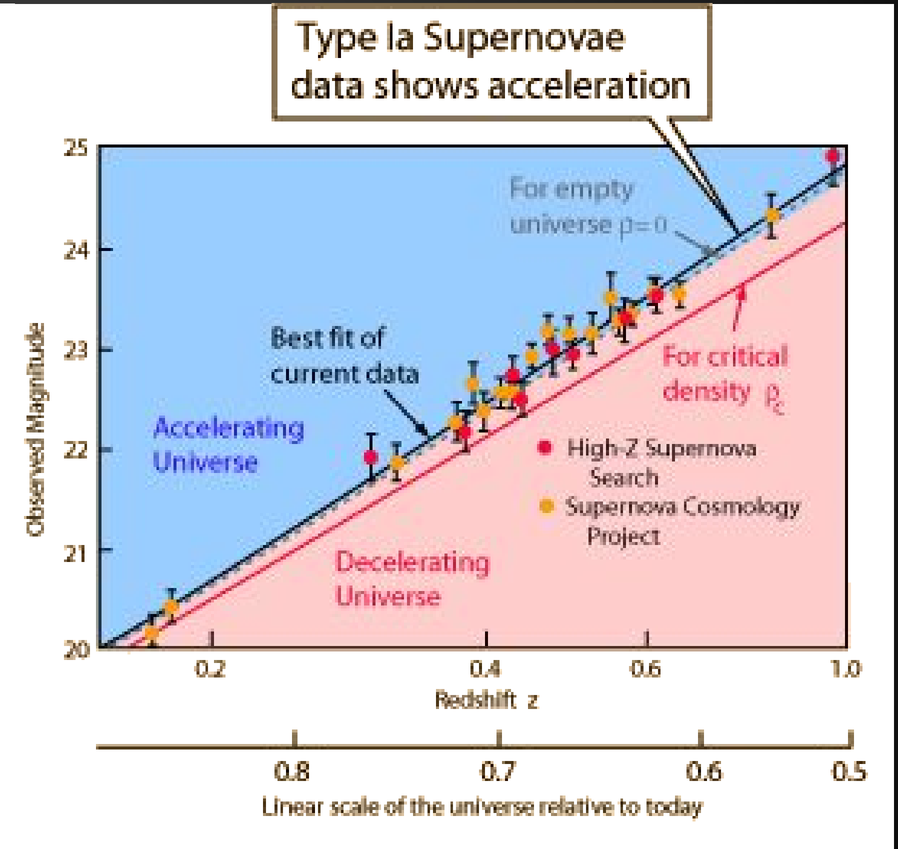


Measuring Expanding Universe

- It is possible to measure the expansion speed of the Universe by measuring type Ia supernovae
- Measuring the apparent brightness and the redshift the distance can be calculated with two independent methods
- Two research groups (*The Supernova Cosmology Project* & *The High-z Supernova Search Team*) tried to measure the change of the expansion rate
- Surprising result: the expansion rate did not decrease as expected but was increasing. Universe is accelerating!

Accelerating Universe





The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2011

with one half to

Saul Perlmutter
The Supernova Cosmology Project

and the other half jointly to

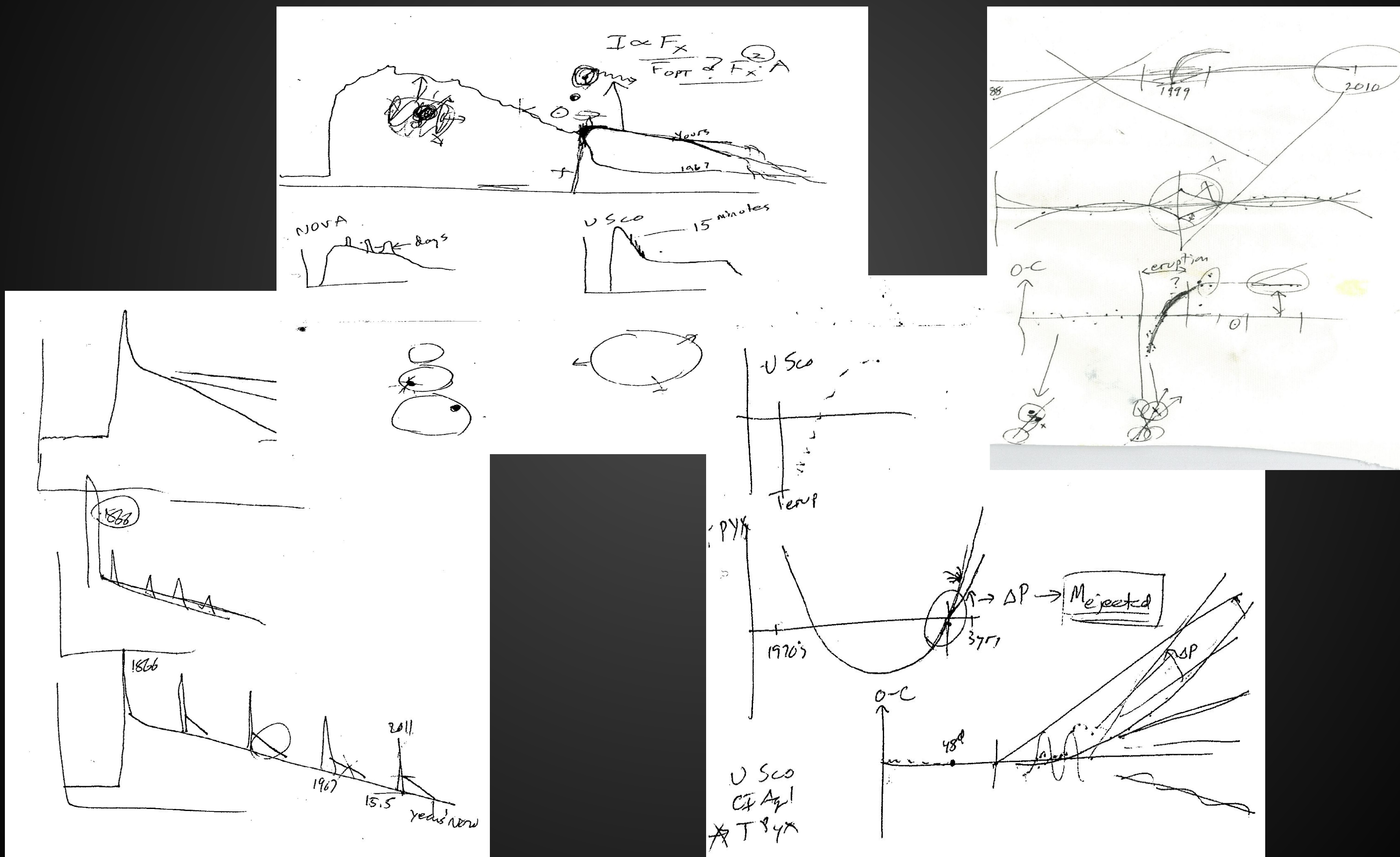
Brian P. Schmidt and Adam G. Riess
The High-z Supernova Search Team

"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"

Bradley E. Schaefer

Professor, Department of Physics and Astronomy, Louisiana State University, USA

"Napkin astrophysics" by Brad

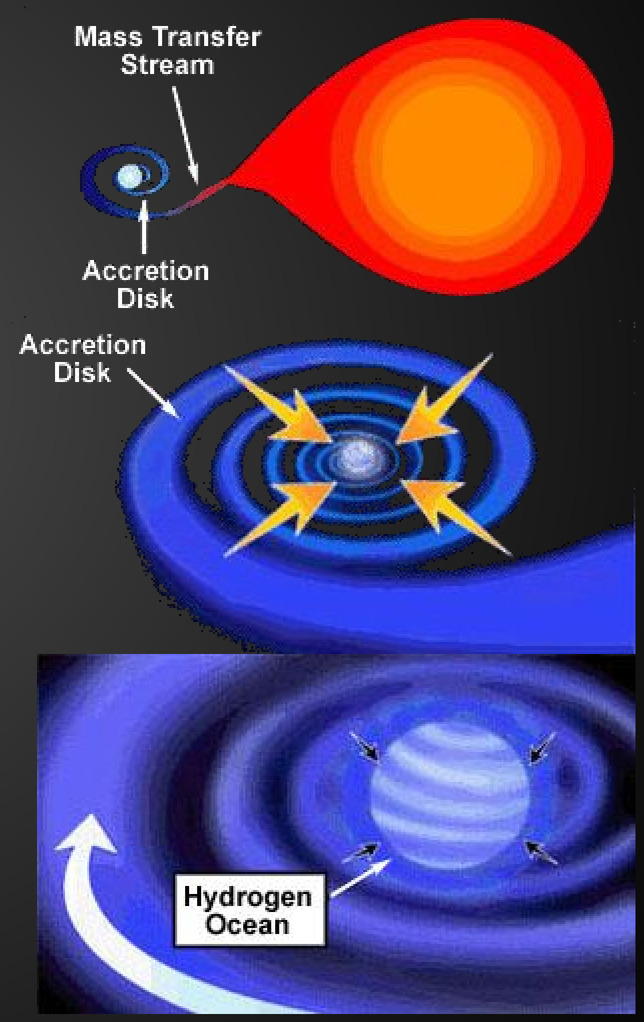


Nova Outburst(s)

White dwarf accretes mass from the donor star as it fills its Roche lobe. Mass transfer stream flows through the Lagrange point L1 as star evolves to a red giant and the orbit shrinks by gravitational radiation. Usually (not magnetic WD) the falling matter forms an accretion disk around the white dwarf.

As friction slows the matter in the disk it eventually falls on the white dwarf. On the surface of the white dwarf the matter forms an ocean of hydrogen.

The high gravity of the WD pulls the hydrogen to very high density and the high temperature eventually ignites the fusion. This will start a very fast rise of temperature and runaway chain reaction of thermonuclear fusion. **The explosion ejects matter from the white dwarf and the cycle starts over.**



Recurrent Novae?

- Nova outbursts repeat less than 100 years
- White dwarf mass > 1.2 M_{sun}
- High mass transfer ~10^{-7} M_{sun}/y
- Known RNe:
  - **T Pyx**
  - IM Nor
  - CI Aql
  - V2487 Oph
  - **U Sco**
  - M31N 2008-12a
  - V394 CrA
  - T CrB
  - RS Oph
  - V745 Sco
  - V3890 Sgr

The Big Question

- All novae are recurring, but for a "classical nova" the interval is thousands of years
- When the white dwarf mass increases the matter transfer increases and the nova outburst interval decreases (more frequent)
- So the recurrent novae must be very close to the SN limit!
- **But is more mass accreted between the nova events than lost in the nova outbursts?**

Period change?

- Orbital period is a very accurate tool to measure the mass change

$$T = 2\pi\sqrt{\frac{a^3}{G(M_1 + M_2)}}$$

- Needs accurate period measurements (eclipse timings) **before and after** the nova eruption
- The small number of RNe and infrequent nova events makes the task difficult
- the change is small (<1s)

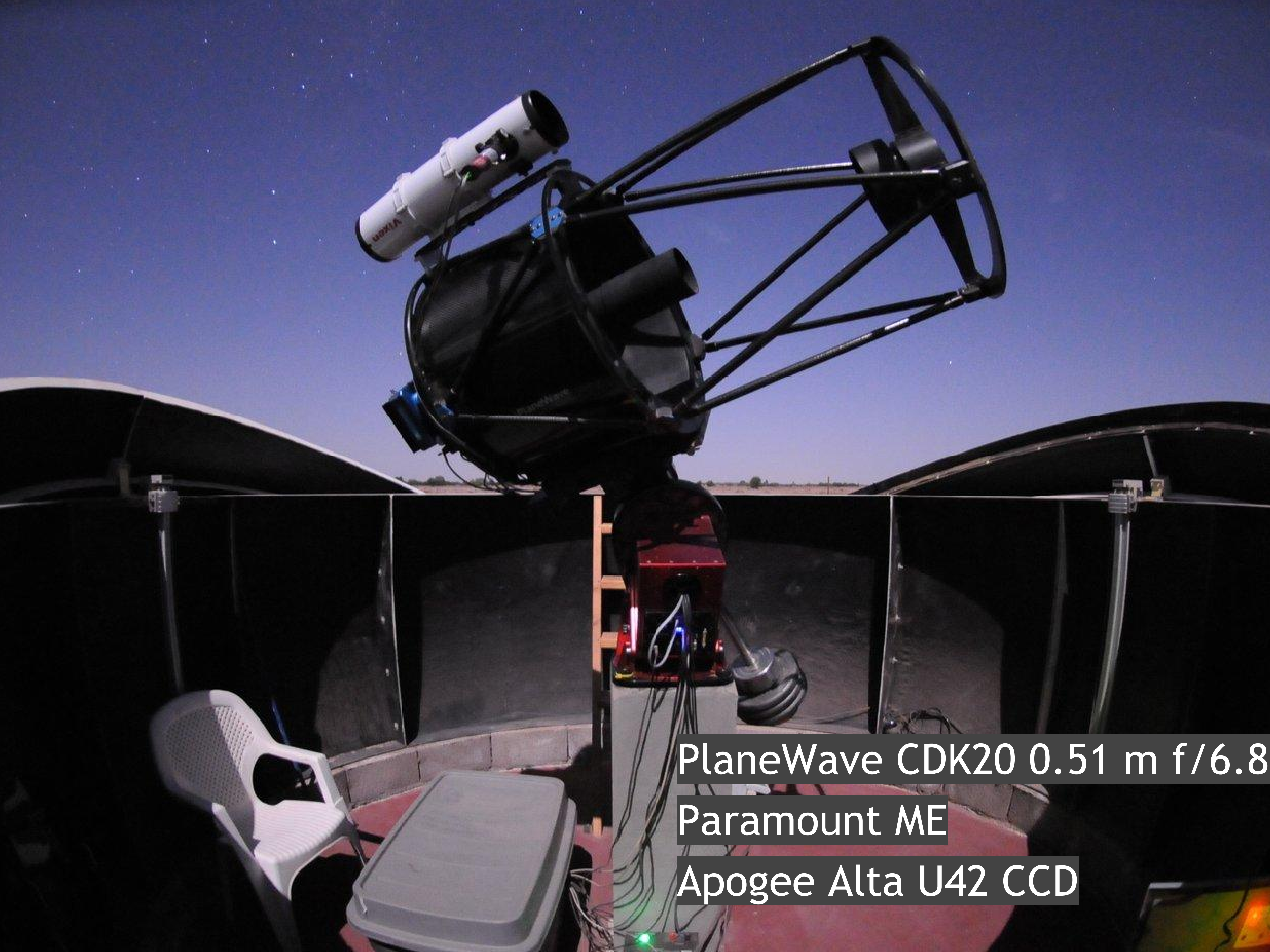
The four better known RNe

Name	Magnitude range	Fades 3 mags (d)	Outbursts
RS Oph	4.8 - 11.0	14	2006, 1985, 1967, 1958
T Crb	2.5 - 10.8	6	1946, 1866
T Pyx	6.4 - 15.5	62	2011, 1967, 1944, 1920, 1902
U Sco	7.5 - 17.6	2.6	2010, 1999, 1987, 1979

T Pyxidis

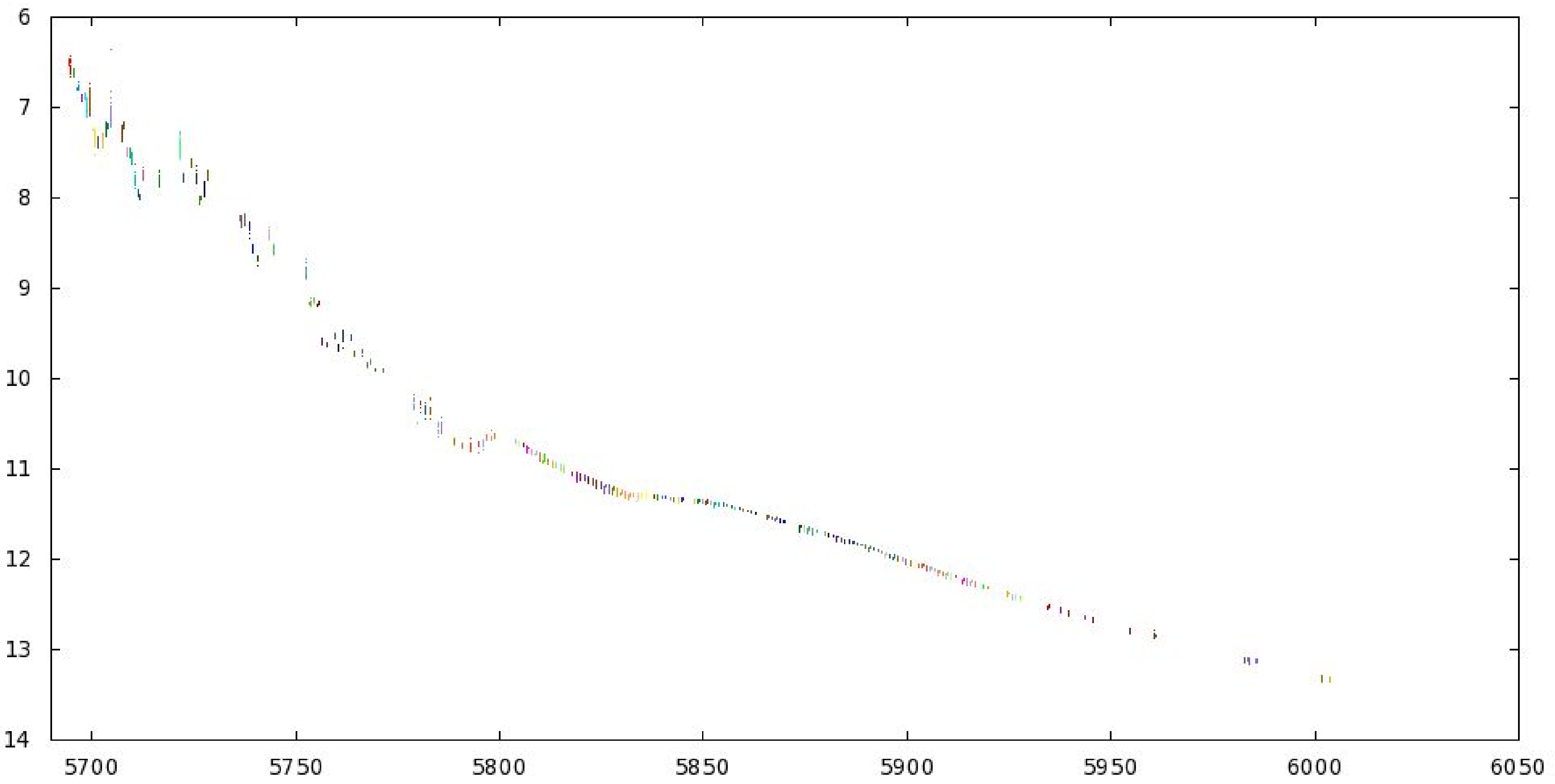
- In Pyxis (Mariner's compass), declination -32 degrees, not observable from Finland
- Previous outbursts: 1902, 1920, 1944, 1967
- The next outburst was expected to be in 1986
- Brad Schaefer predicted in 2009 that the next outburst will come in **2052 +/- 3**
- In 2010 he revised his prediction to thousands or millions of years into the future
- **Outburst was detected April 14, 2011 !**

Caisey Harlingten's observatory in San Pedro de Atacama, Chile

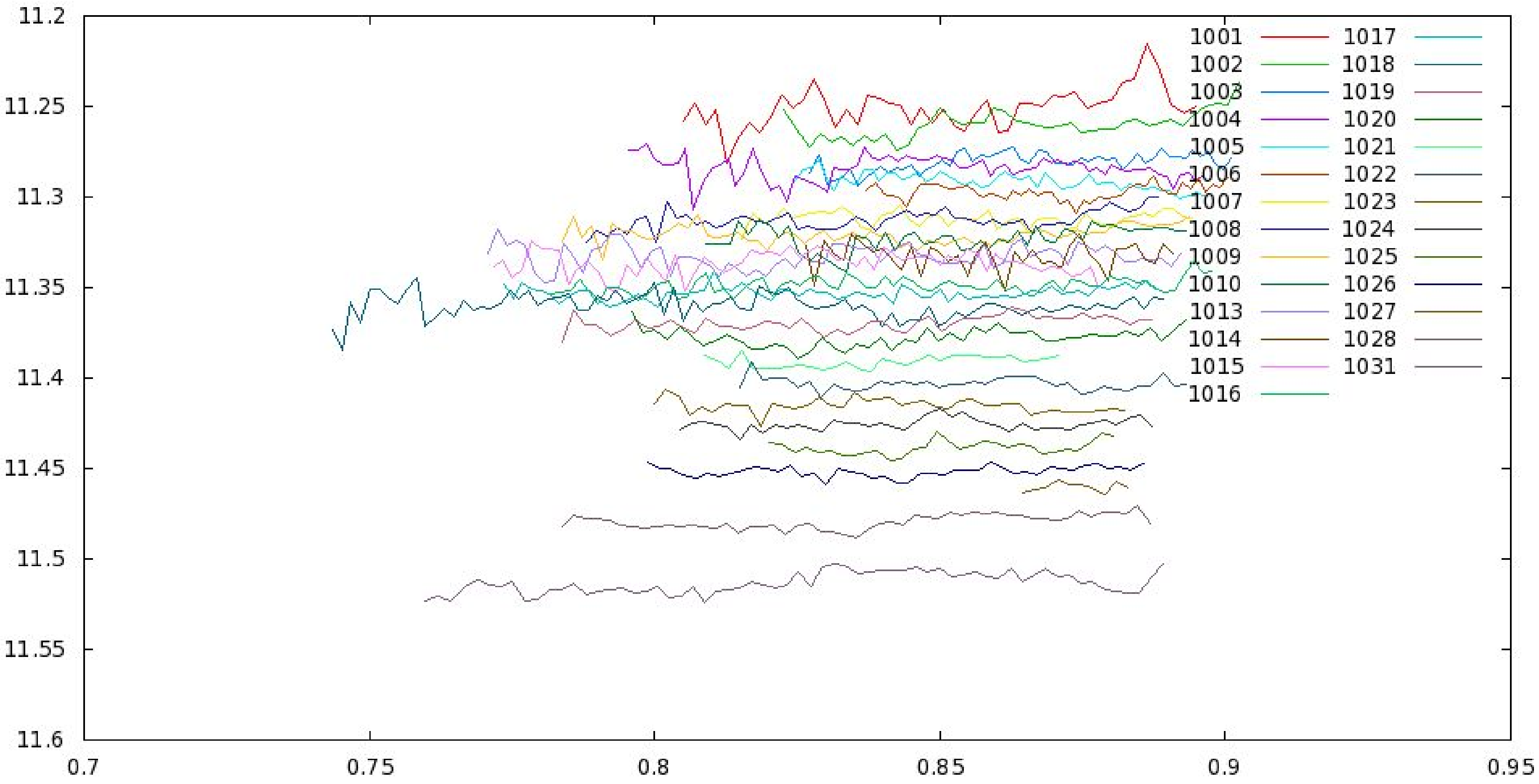

PlaneWave CDK20 0.51 m f/6.8
Paramount ME
Apogee Alta U42 CCD

My light curve of T Pyx

200+ observing nights, > 60.000 data points



October 2011: Periodic signal?



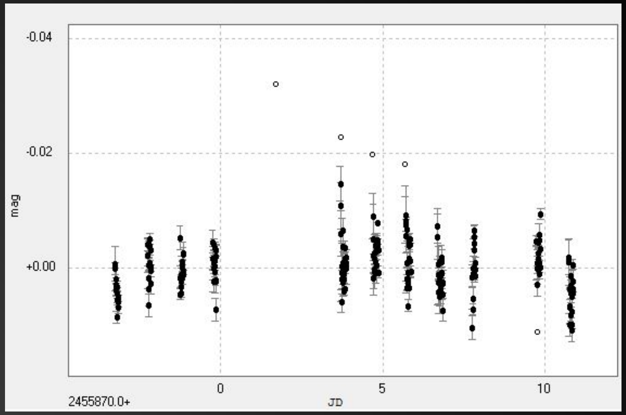
Finding the period

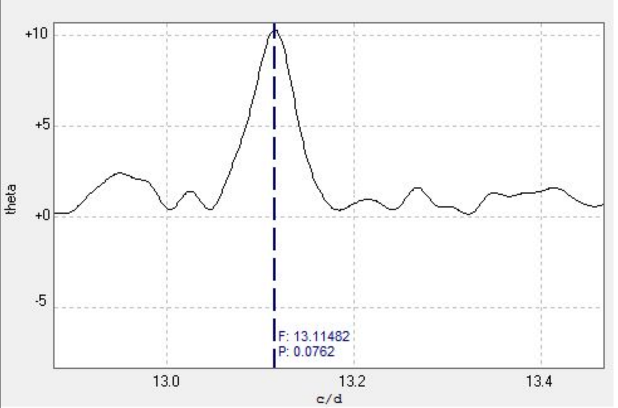
Analyzing the data with PERANSO:

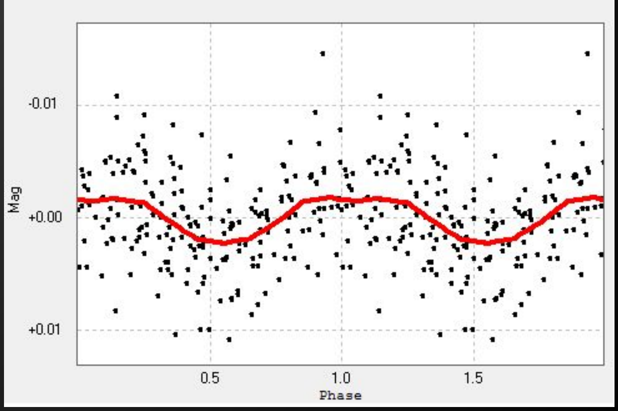
- detrend
- subtract the average magnitude
- ANOVA period search

➡ phase plot & folded light curve

Result: a clear 0.0762 day (1.8h) period!







ATel #3782: Detection of Photometric Modulation on the Orbital Period in the Eruption Tail of the Recurrent Nova T Pyx

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Detection of Photometric Modulation on the Orbital Period in the Eruption Tail of the Recurrent Nova T Pyx

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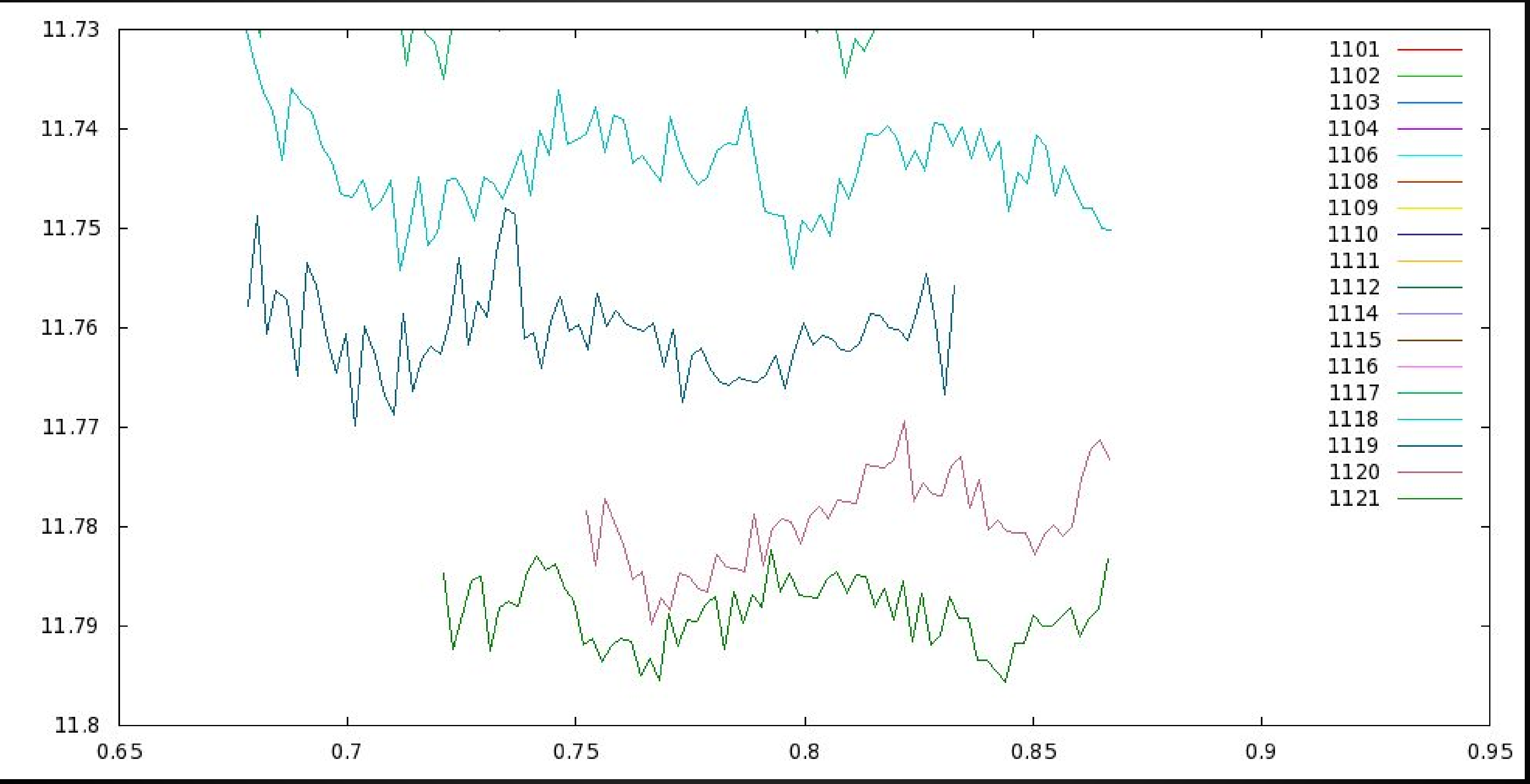
Oksanen, A.; Schaefer, B. E.

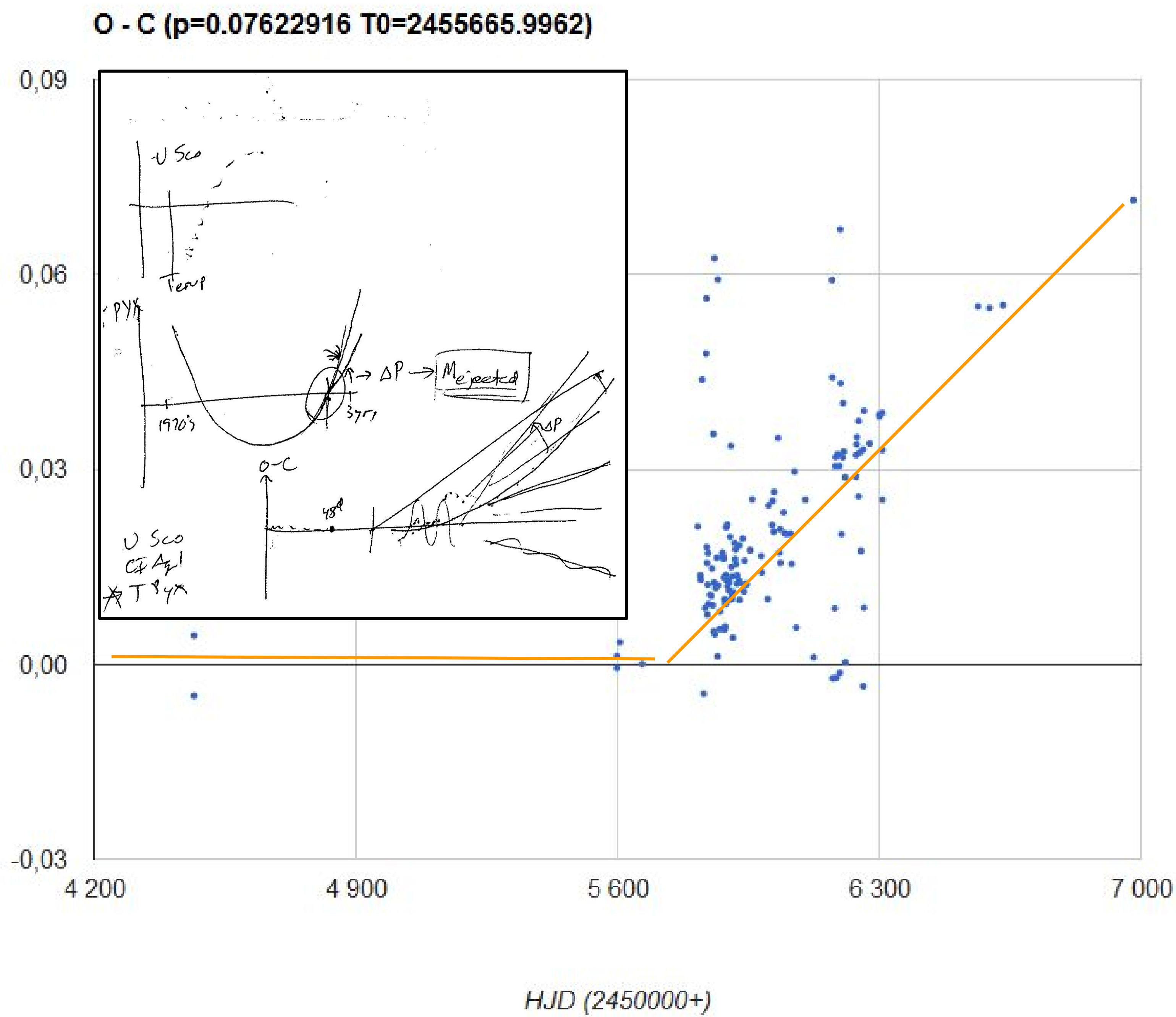
The Astronomer's Telegram, #3782

We report on the detection of photometric modulation with the orbital period for the recurrent nova T Pyx, now in the tail of an eruption (IAUC #9205, ATel #3549, ATel #3647). Our V-band observations are made with the 0.5-m telescope at the Caisey Harlingten Observatory near San Pedro de Atacama in Chile with 30-second time resolution (see ATel #3707). We have corrected our photometry for an airmass effect where the strong line emissions visible in the T Pyx spectrum have small differential effects with respect to the comparison stars.

Keywords: Optical, Nova

The amplitude increased in November 2011

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U Sco
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U Sco
CI Aql
T Pyx

Period change

Cornell University Library

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Astrophysics > Solar and Stellar Astrophysics

The Death Spiral of T Pyxidis

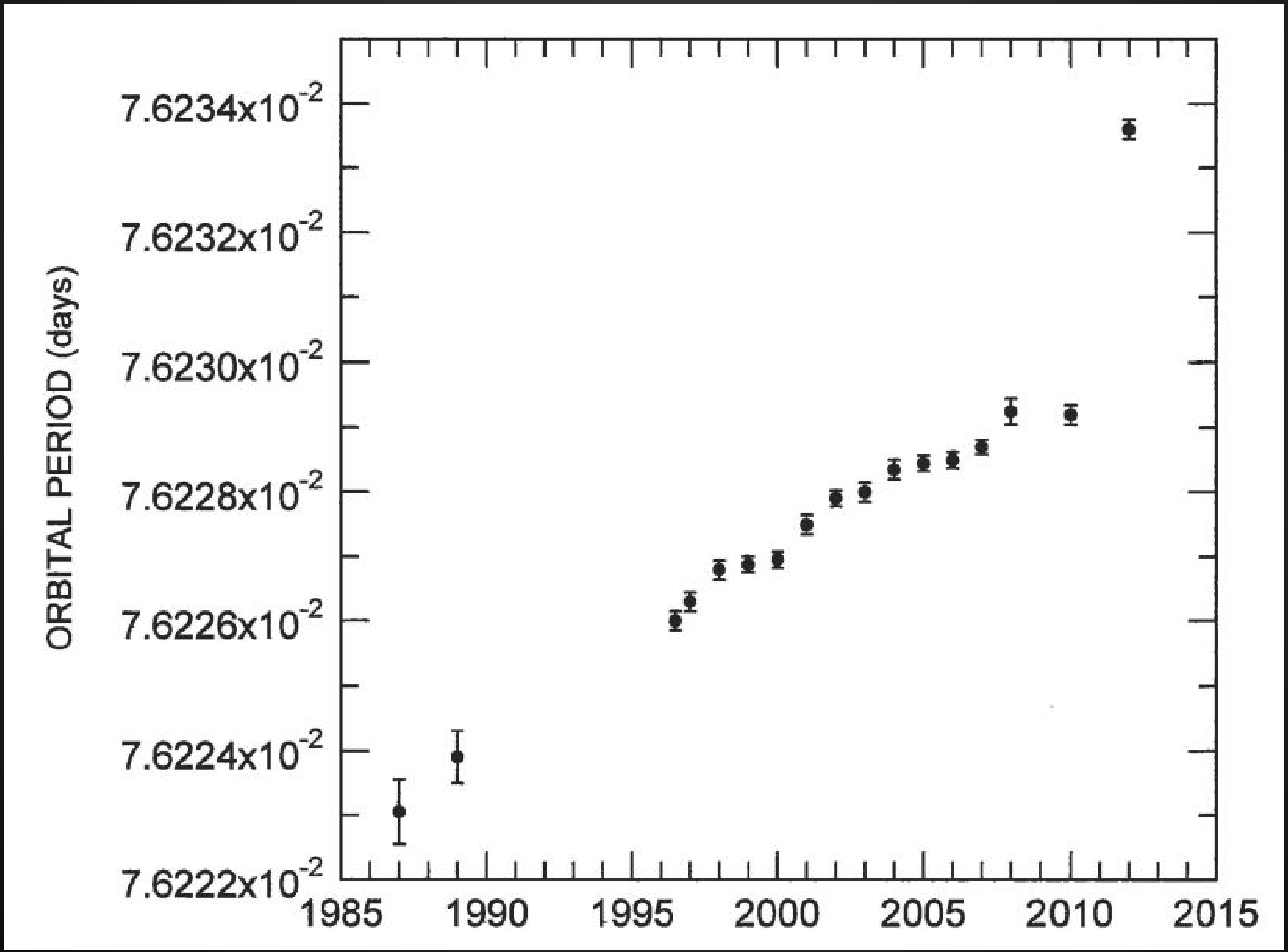
Joseph Patterson (1), Arto Oksanen (2), Berto Monard (2), Robert Rea (2), Franz-Josef Hambsch (2), Jennie McCormick (2), Peter Nelson (2), Jonathan Kemp (1), William Allen (2), Thomas Krajci (2), Simon Lowther (2), Shawn Dvorak (2), Thomas Richards (2), Gordon Myers (2), Greg Bolt (2) ((1) Columbia Univ., (2) Center for Backyard Astrophysics)

(Submitted on 4 Mar 2013)

We report a long campaign to track the 1.8 hr photometric wave in the recurrent nova T Pyxidis, using the global telescope network of the Center for Backyard Astrophysics. During 1996-2011, that wave was highly stable in amplitude and waveform, resembling the orbital wave commonly seen in supersoft binaries. The period, however, was found to increase on a timescale P/P-dot=3x10^5 yr. This suggests a mass transfer rate of ~10^-7 M_sol/yr in quiescence. The orbital signal became vanishingly weak (<0.003 mag) near maximum light of the 2011 eruption. After it returned to visibility near V=11, the orbital period had increased by 0.0054(6) %. This is a measure of the mass ejected in the nova outburst. For a plausible choice of binary parameters, that mass is at least 3x10^-5 M_sol, and probably more. This represents >300 yr of accretion at the pre-outburst rate, but the time between outbursts was only 45 yr. Thus the erupting white dwarf seems to have ejected at least 6x more mass than it accreted. If this eruption is typical, the white dwarf must be eroding, rather than growing, in mass -- dashing the star's hopes of ever becoming famous via a supernova explosion. Instead, it seems likely that the binary dynamics are basically a suicide pact between the eroding white dwarf and the low-mass secondary, excited and rapidly whittled down, probably by the white dwarf's EUV radiation.

Comments: PDF, 7 pages, 3 figures; to appear in Stella Novae: Past and Future Decades conference proceedings; more info at this http URL
Subjects: **Solar and Stellar Astrophysics (astro-ph.SR)**
Cite as: arXiv:1303.0736 **[astro-ph.SR]**
(or **arXiv:1303.0736v1 [astro-ph.SR]** for this version)

The variation of P orb



Mass loss >> accretion !!

During eruption, mass loss should increase $P_{\rm orb}$, and angular-momentum loss should decrease it. It's an open question which will dominate. But our observations show $\frac{\Delta P}{P} = +5.4 \times 10^{-5}$, indicating that mass loss wins. For the minimum plausible prescription for angular-momentum loss (radial ejection from the white dwarf), this implies a mass loss

$$\Delta M = 3.0 \times 10^{-5}\, m_1(1+q)\, M_\odot. \tag{3}$$

For $m_1 \approx 1$, this represents about 250 years of accretion, yet only 45 years elapsed since the 1966 outburst. So it appears that the white dwarf ejected at least $\sim$ 5–6 $\times$ more matter than it accreted.

Nature paper

The Orbital Period Changes Across The Eruptions of Three Recurrent Nova

Bradley E. Schaefer *Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803*

Arto Oksanen *Caisey Harlingten Observatory (San Pedro de Atacama), Verkkoniementie 30, FI-40950 Muurame, Finland*

ABSTRACT

We report a series of timings of minima in the light curves of three recurrent novae (RNe) across their recent eruptions, T Pyxidis in 2011, U Scorpii in 2010, and CI Aquilae in 2000, along with measures of the resultant change in the orbital period. The fractional changes in the orbital periods are 2.4±1.6, 22.5±1.1, and 52.9±3.9 parts per million, respectively.

This result, that the white dwarf is losing mass over time, is highly confident for T Pyx and U Sco, but is weak for CI Aql. With their white dwarfs decreasing in mass over each eruption cycle, U Sco and T Pyx cannot be progenitors of Type Ia supernovae.

Nature paper

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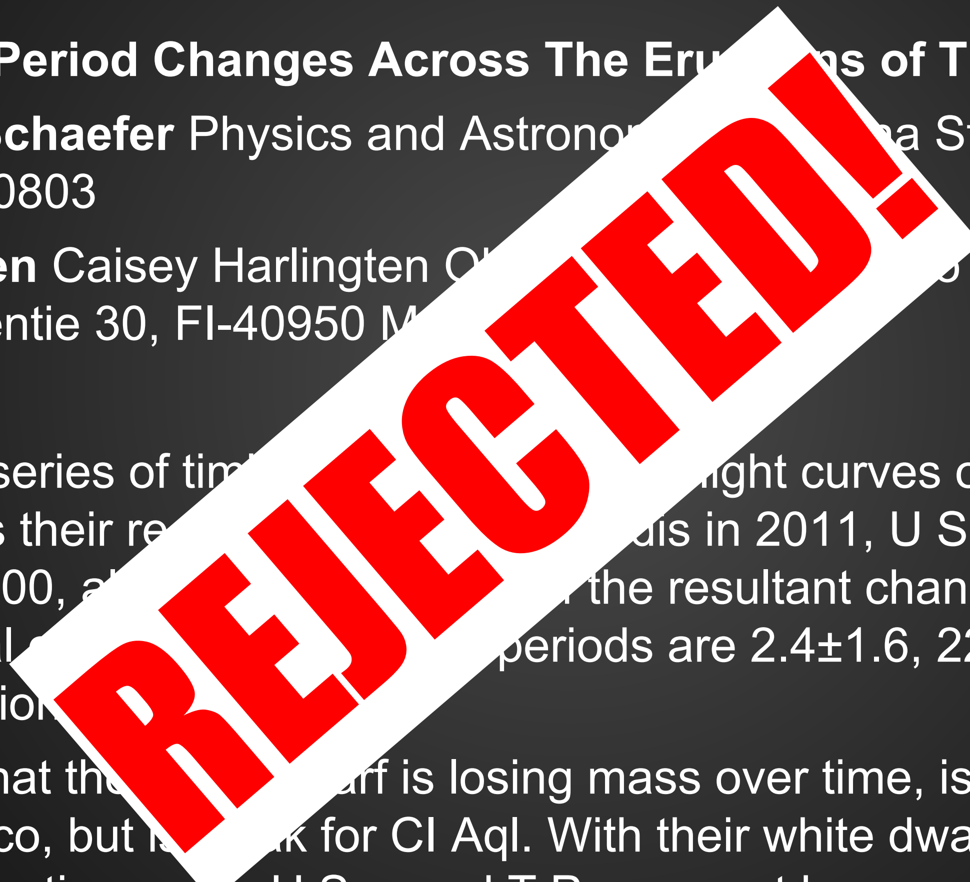
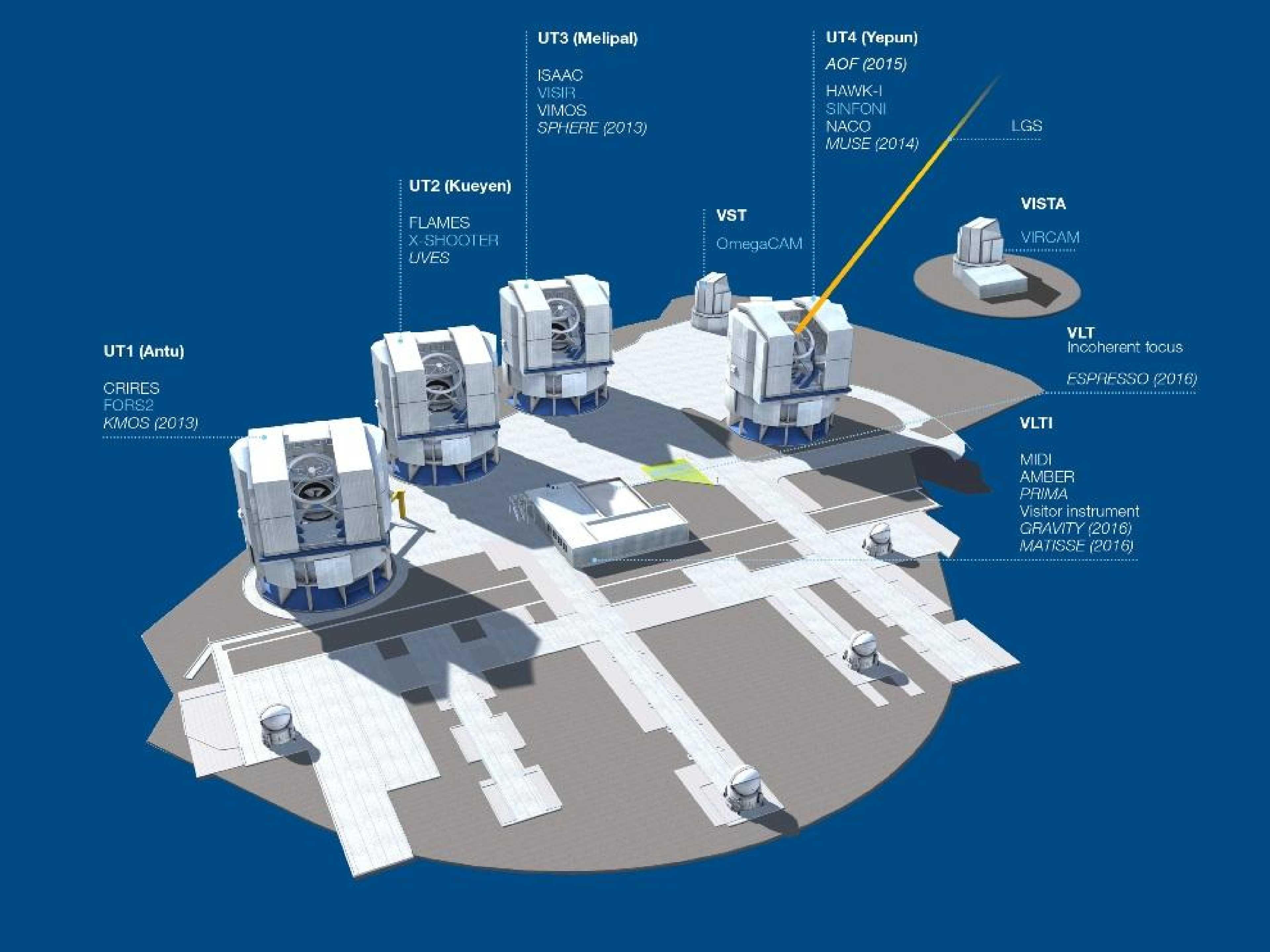


Additional observations

- CHO - time series photometry (A. Oksanen, continues)
- NOT FastTrack - spectropolarimetry (S. Katajainen, A. Oksanen, B. Schaefer, in April 2012)
- VLT - spectropolarimetry (S. Katajainen, A. Oksanen, B. Schaefer, in February 2013)





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UT2 (Kueyen)
FLAMES
X-SHOOTER
UVES
VST
OmegaCAM
VISTA
VIRCAM
UT1 (Antu)
CRIRES
FORS2
KMOS (2013)
VLT
Incoherent focus
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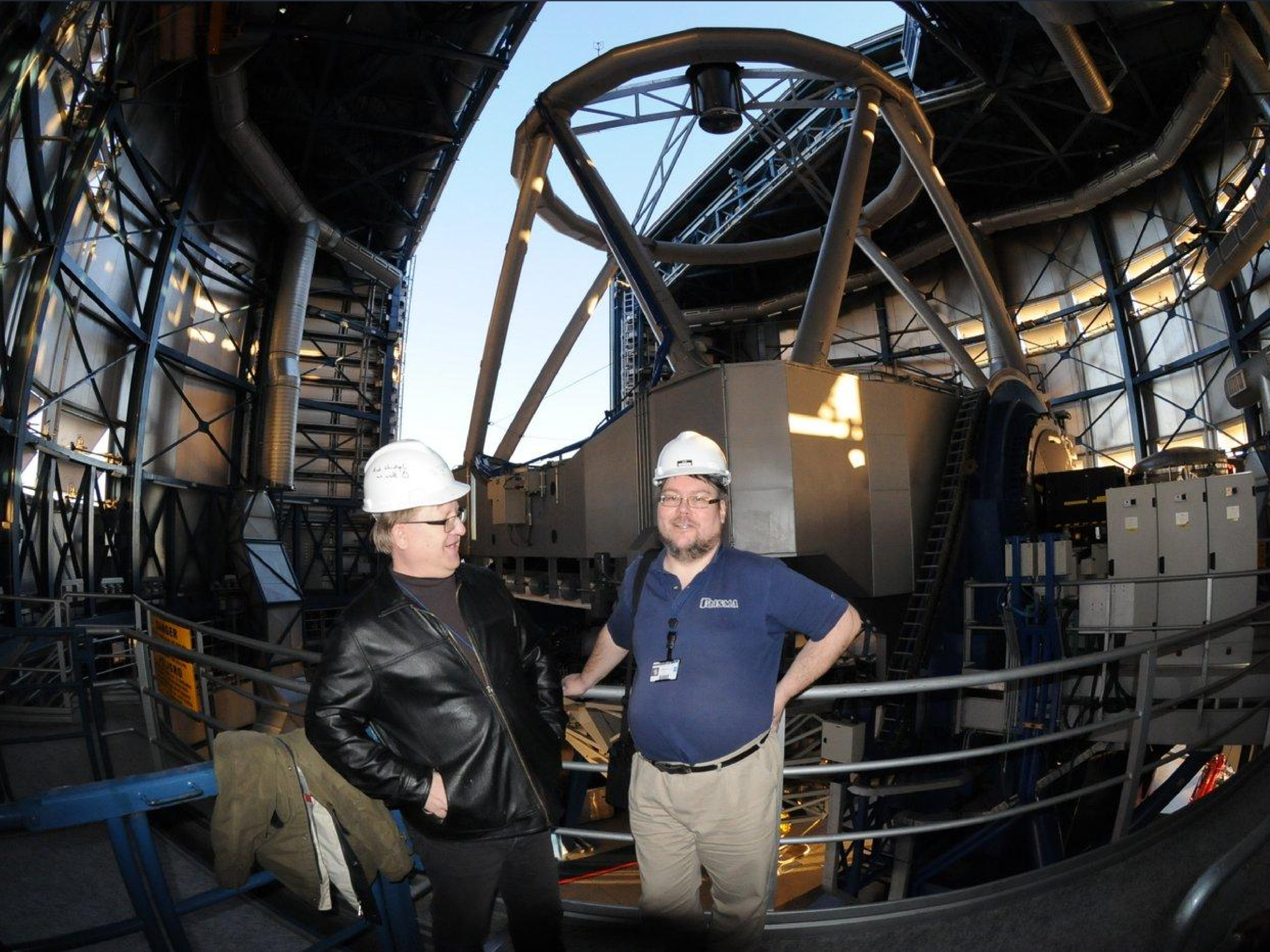
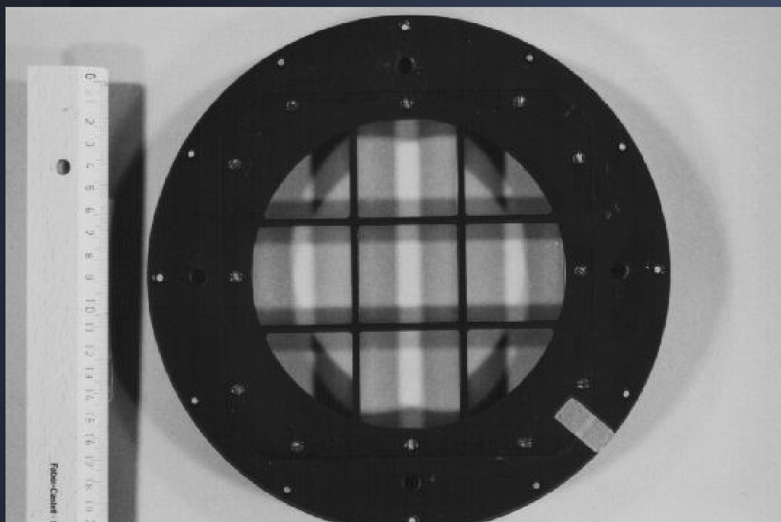
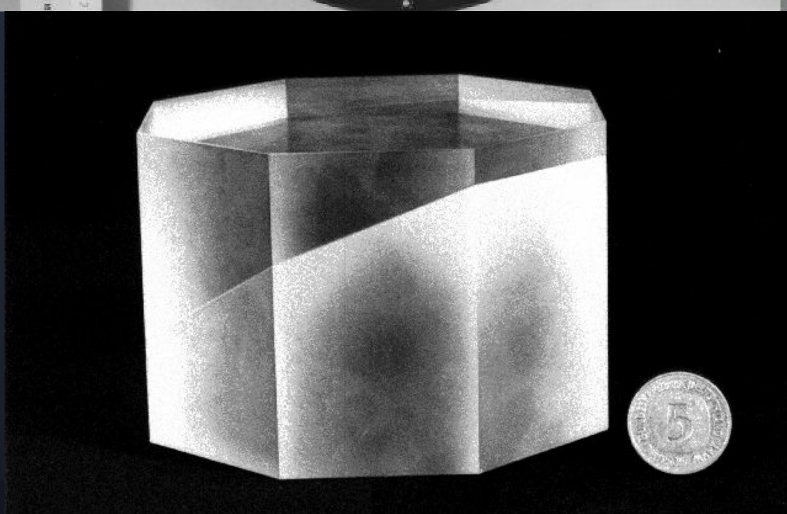
PRIMA
Visitor instrument
GRAVITY (2016)
MATISSE (2016)


Arto Oksanen

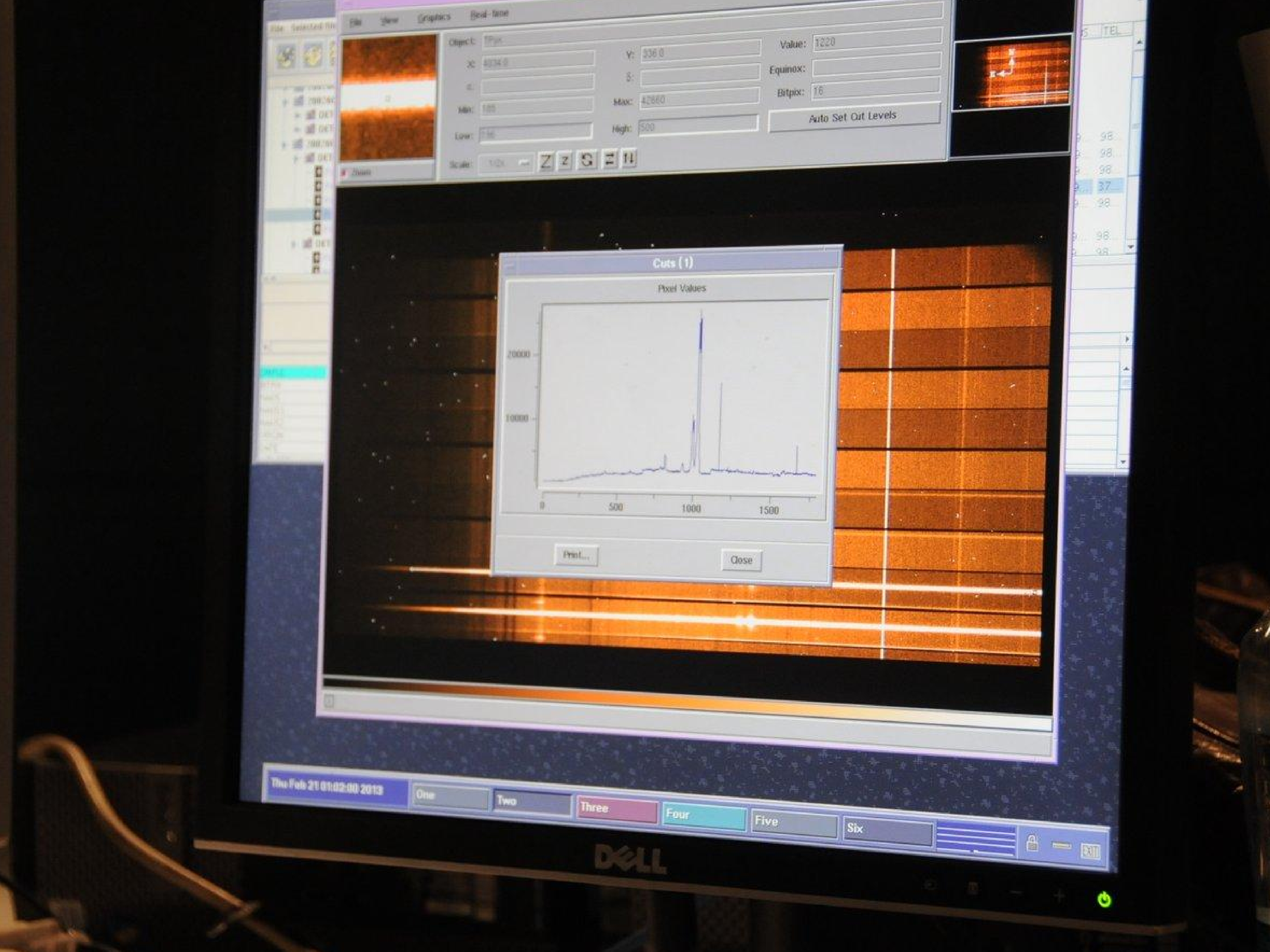

DANGER

FORS2






UT1 ANTU
May the FORS be with you
But if you
CRIRES
the Thing will return!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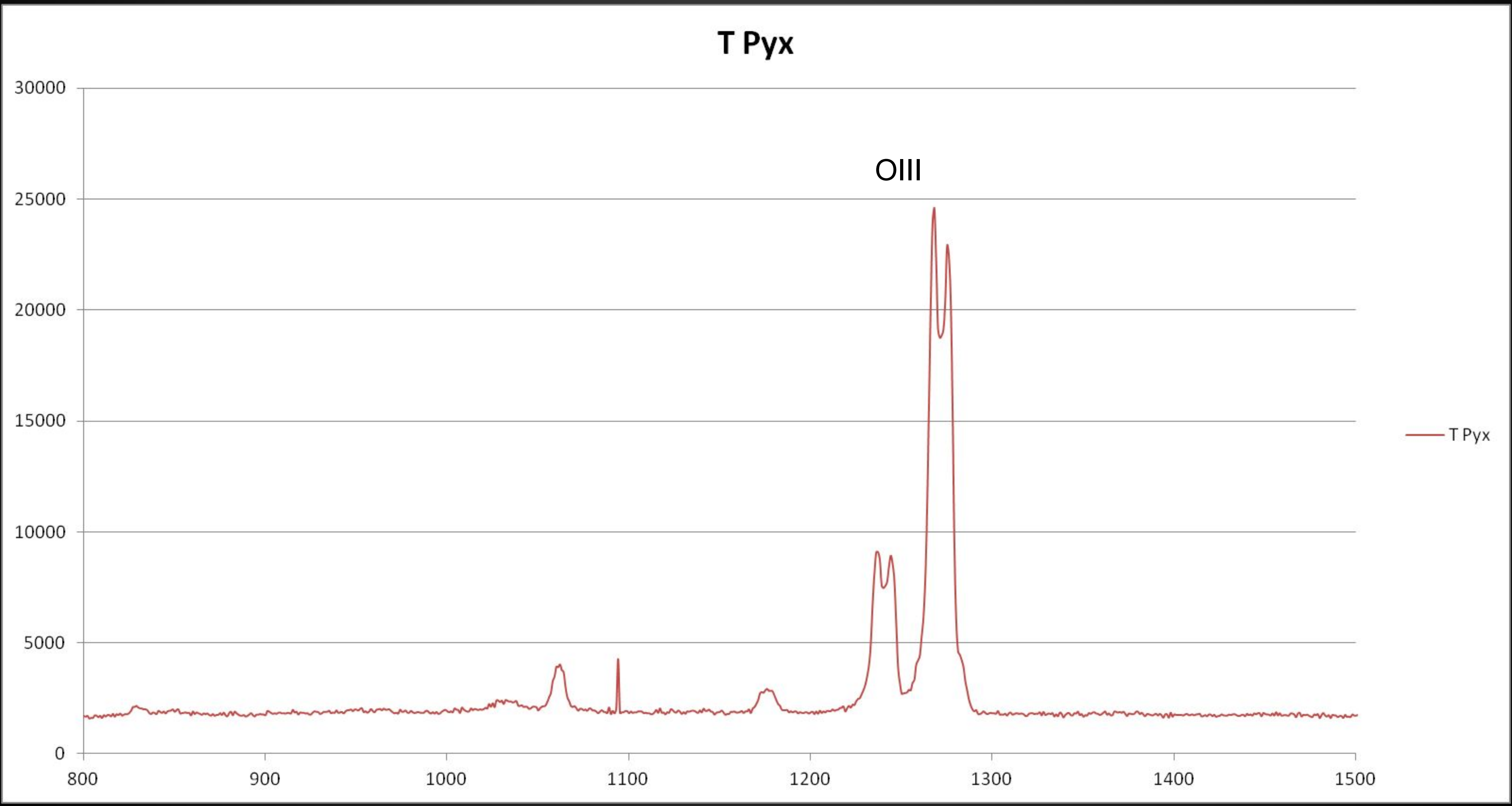
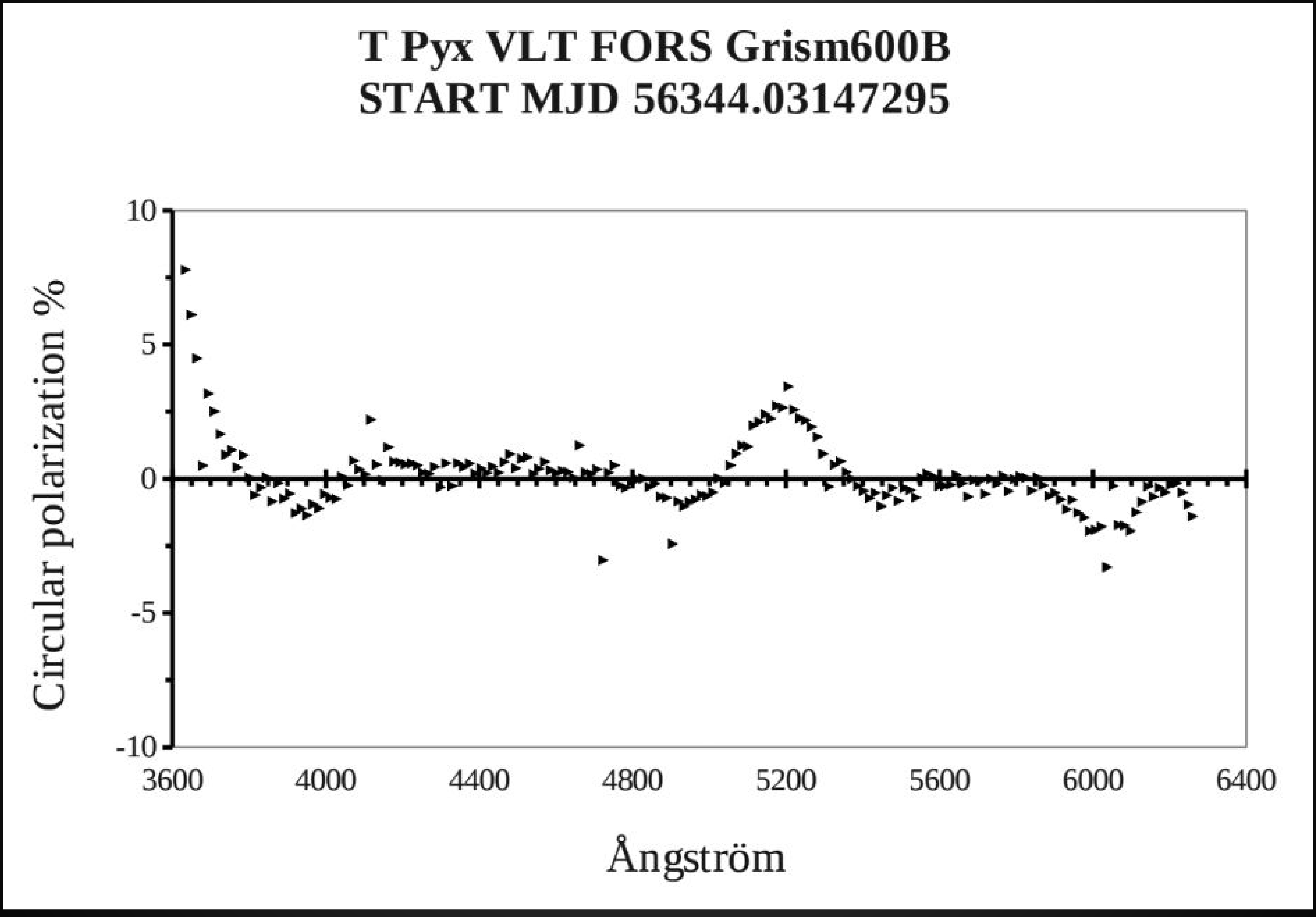
One raw spectra (blue)

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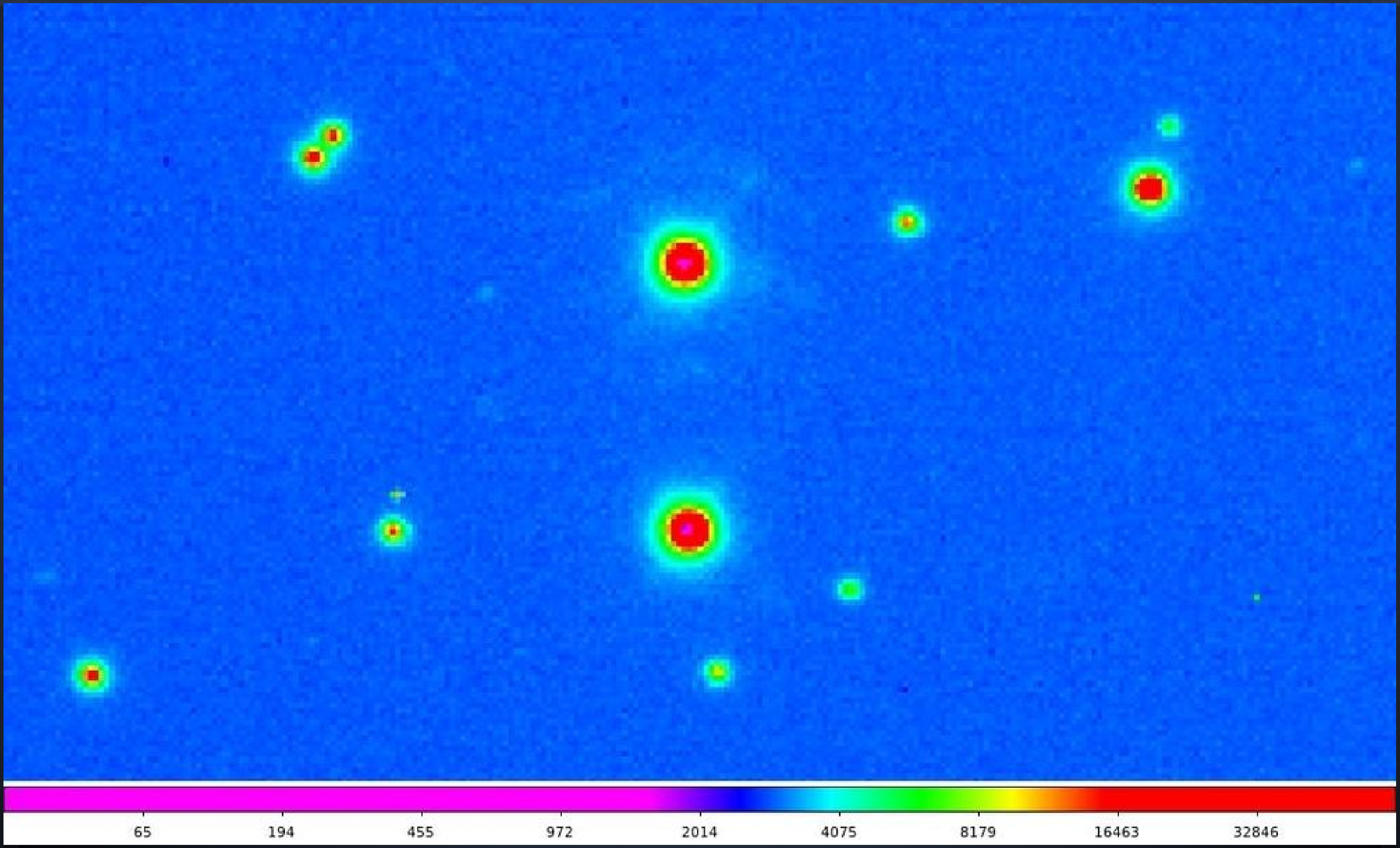
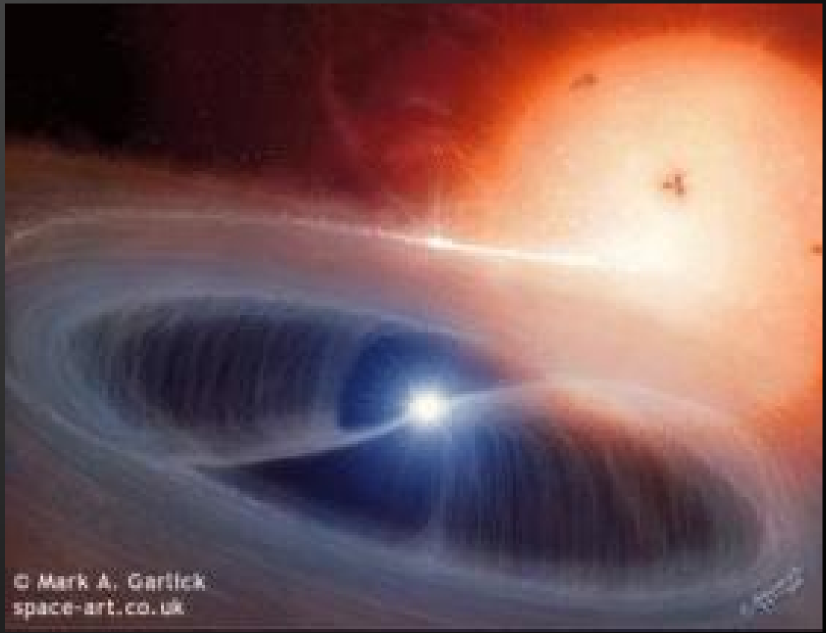
“Pretty picture” of the nova shell



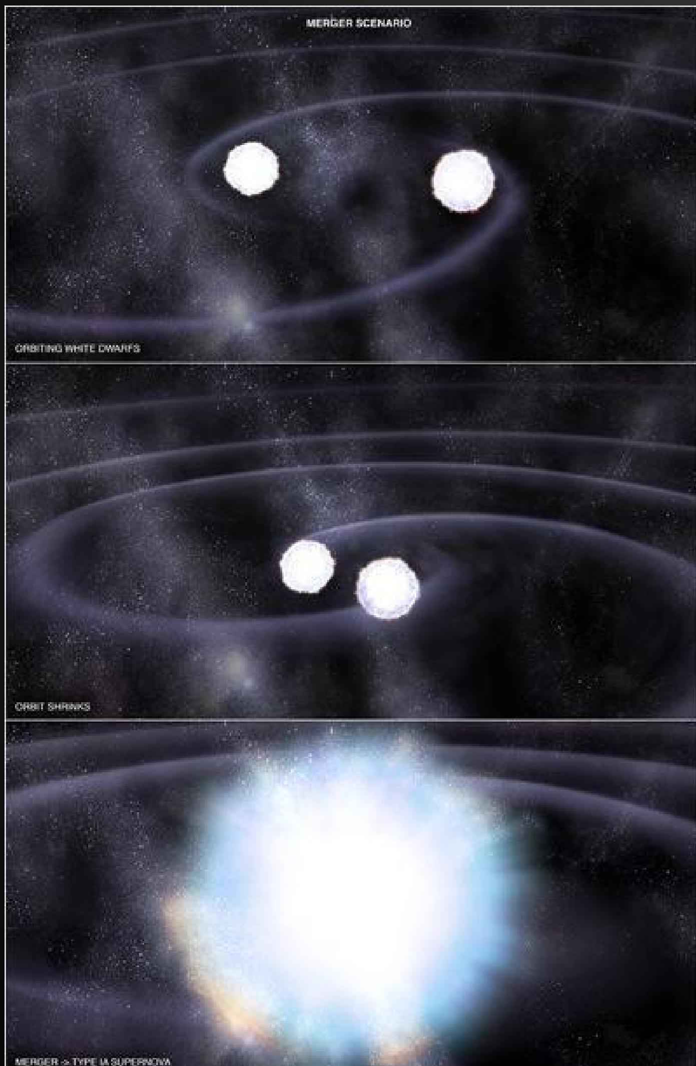
Open questions

???

- Did the period change? Yes!
- Did the WD gain mass ? No!
- Will T Pyx become a SN Ia ? No!
- Is T Pyxidis magnetic? (yes)
- What causes the optical signal?
- Why the eruption happened now?
- Why the light curves are different between the outbursts?
- Will any CV become SN Ia ??



The Double-Degenerate scenario



- Binary star of two white dwarfs
- Gravitational radiation makes the orbit smaller and smaller
- Not a standard candle! The total mass can be (much) more than 1.4 Solar masses.
- Can these be so numerous that it explains the observed number of SN Ia, especially in the young Universe?

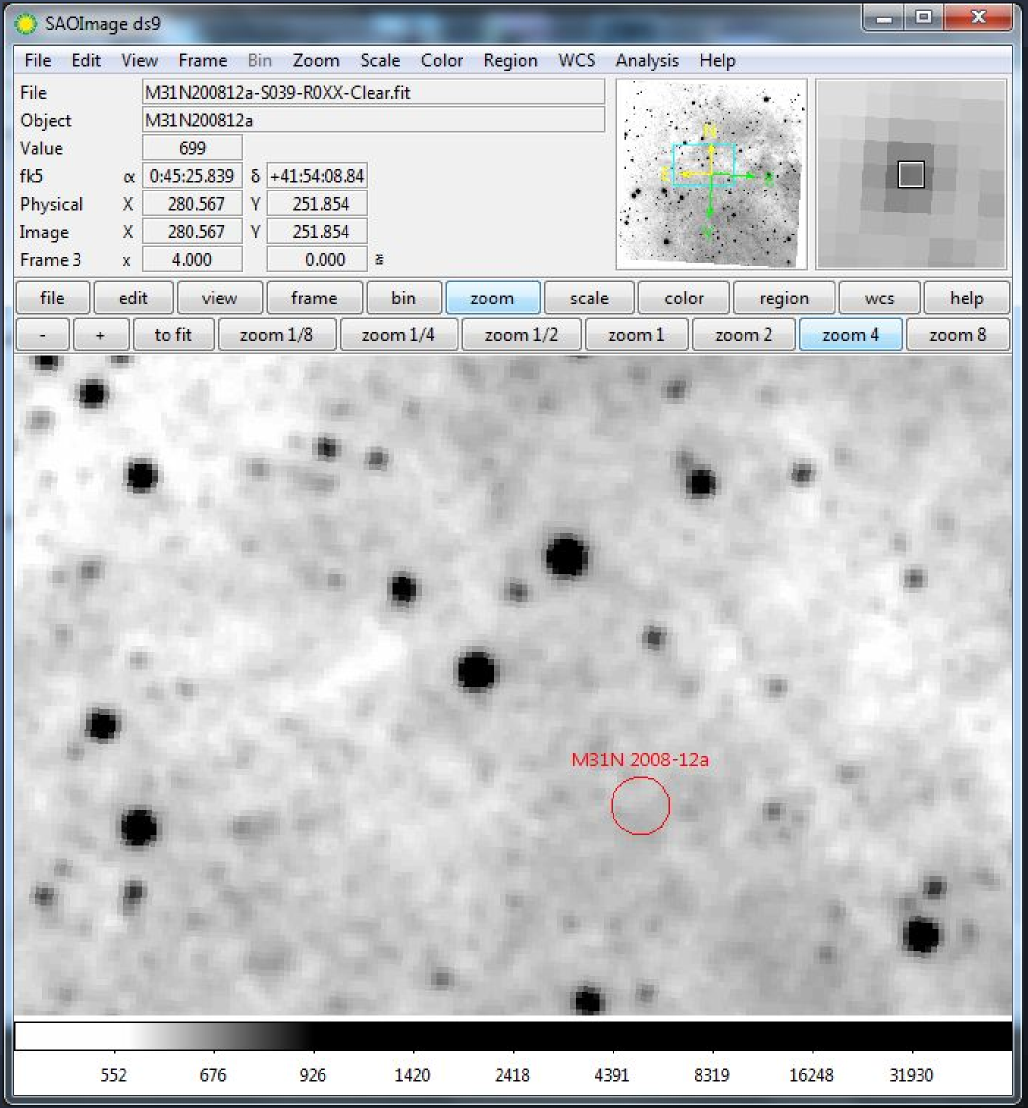
M31N 2008-12a

Recurring nova in M31

Outbursts:

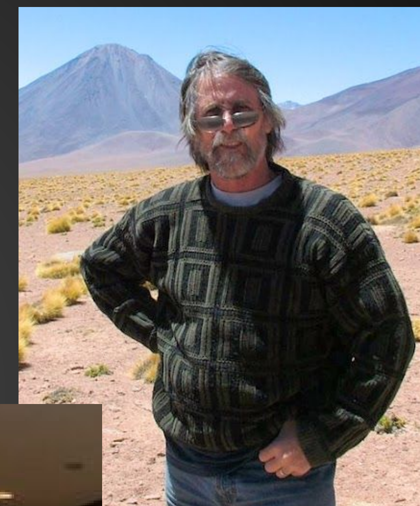
- 2008 Dec. 26
- 2009 Dec. 03
- 2010 Nov. 20
- 2011 Oct. 23
- 2012 Oct. 19
- 2013 Nov. 28
- 2014 Oct. 03

Intensive monitoring ongoing to detect the next outburst as early as possible.



Thank You!





Brad Schaefer Stella Kafka Caisey Harlingten
Seppo Katajainen Arne Henden

References:

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- http://chandra.harvard.edu
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- http://astronomy.villanova.edu/faculty/sion/CV/index.html
- http://www.aavso.org/v1500-cyg-nova-cygni-1975
- http://arxiv.org/ftp/arxiv/papers/1303/1303.0736.pdf
- http://www.aanda.org/articles/aa/pdf/2015/10/aa27168-15.pdf

Questions?

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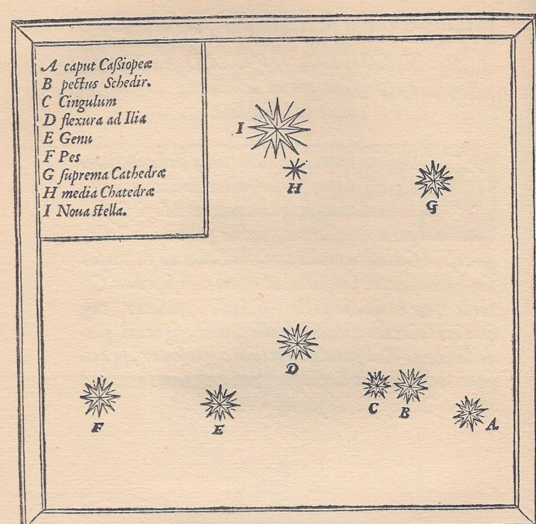
"In a world where I feel so small, I can't stop thinking big."

Nova?

Tyko Brahe discovered **a new bright star** in Cassiopeia on November 11, 1572. The observation was published in "De Nova Stella".



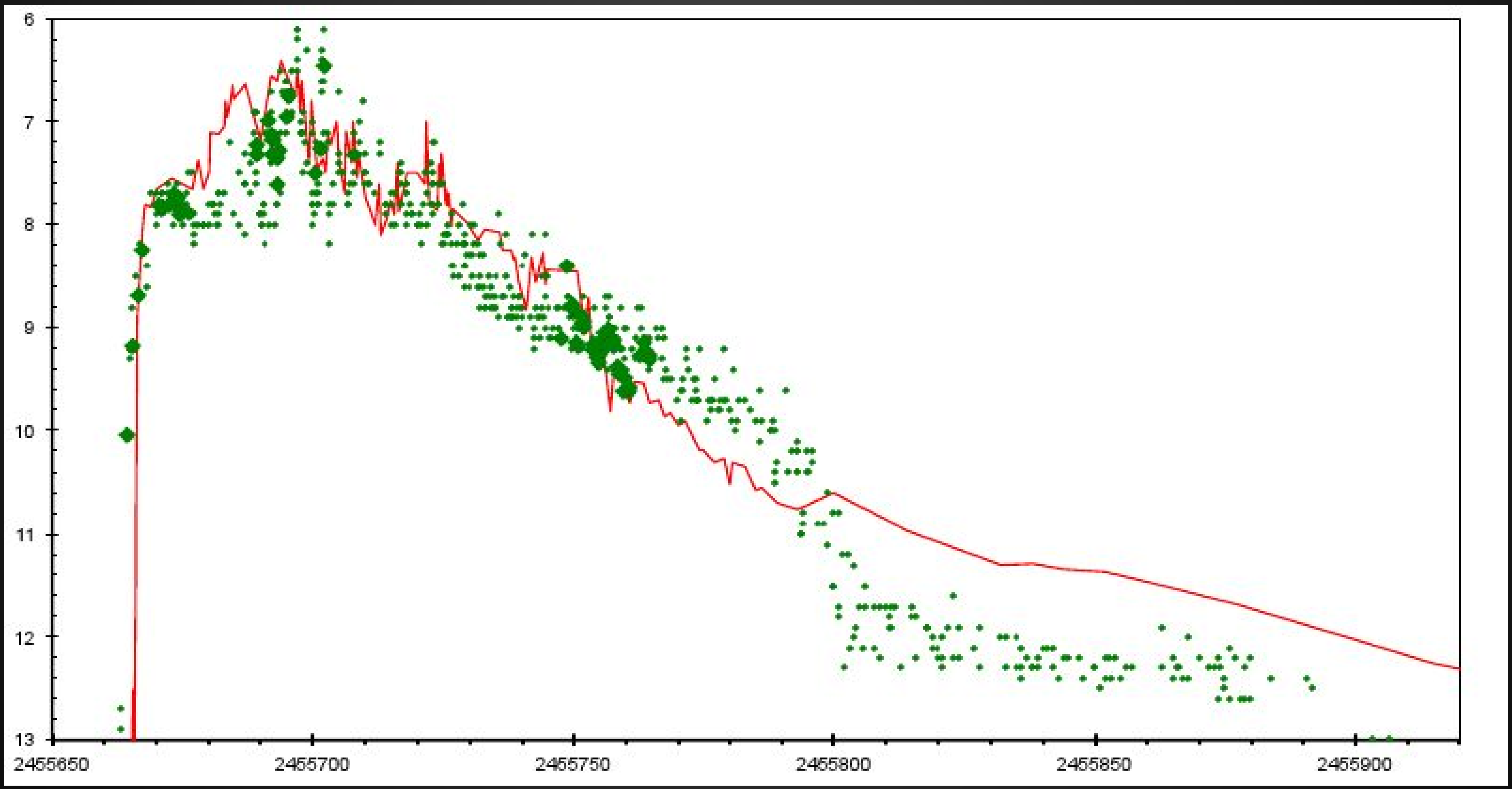
Diſtantiam verò huius ſtellæ à fixis aliquibus in hac Caßiopeiæ conſtellatione, exquiſito inſtrumento, & omnium minutorum capacj, aliquoties obſeruaui. Inueni autem eam diſtare ab ea, quæ eſt in pectore, Schedir appellata B, 7. partibus & 55. minutis: à ſuperiori verò

Supernova?

After it was realized that “spiral nebulae” are in fact other galaxies, the novae that were observed in those must have been “super” luminous. They were renamed to “supernovae”.

A nova will become 12 magnitudes brighter (100.000x), a supernova about 20 magnitudes (100.000.000x).

ATel #3707: Recurrent Nova T Pyx is Deviating from 1967 Eruption Light Curve



SNR 0509-67.5

- SN remnant in Large Magellanic Cloud
- SN Ia
- Brad Schaefer and Ashley Pagnotta used Hubble to search the ejected secondary star (Nature, 12 Jan 2012)
- Not found!!

Must have been a merge of two white dwarfs!