

# Dust in BAGs

## The circumstellar dust shells of Sakurai's Object and other “Born Again” stars

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Chick Woodward (U. Minnesota)

# Dust in BAGs

- After a  $\sim$ solar mass star ejects PN and is approaching WD stage, it may re-ignite residual surface He in a *Very Late Thermal Pulse (VLTP)*....
- ....retrace its evolutionary track to RG region....
- ....and become a “Born-again Giant” (BAG)
- End-point of evolution of  $\sim 25\%$  of solar mass stars
- Expect star to be C-rich, dusty, and at the centre of a PN

# Dust in BAGs

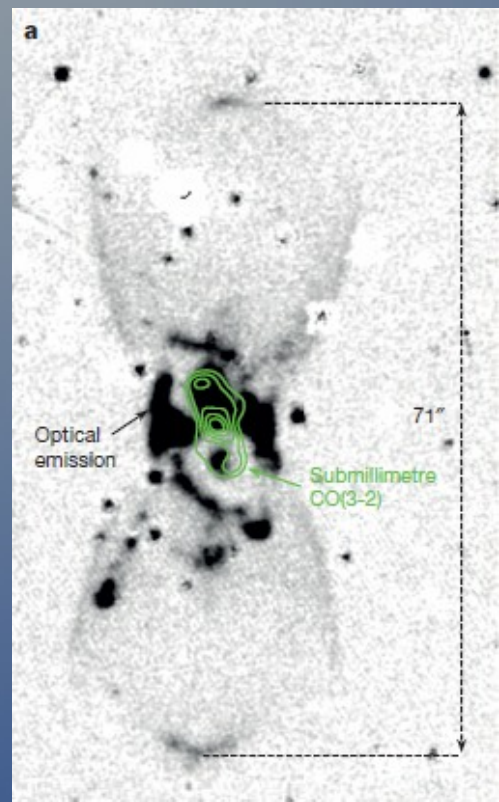
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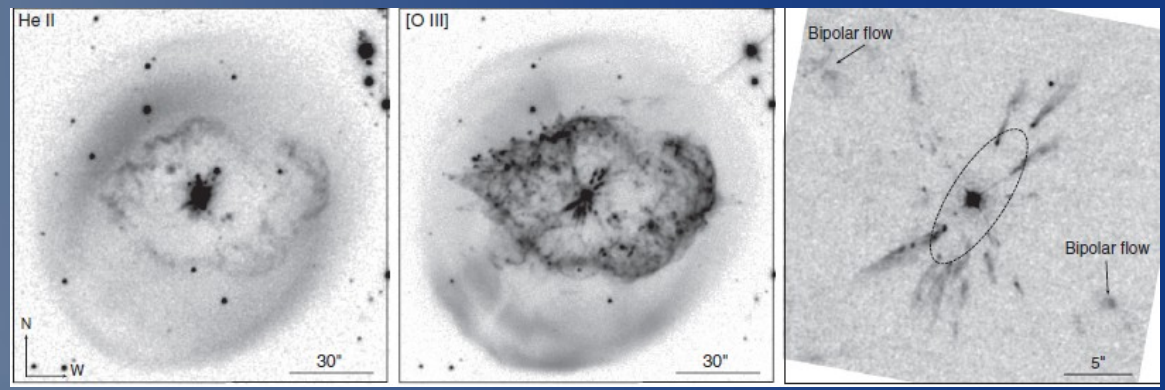
## Likely BAG stars (with VLTP date)

- Sakurai's object (V4334 Sgr) – 1996
- V705 Aql – 1918
- FG Sge – 1880
- CK Vul (?) – 1670

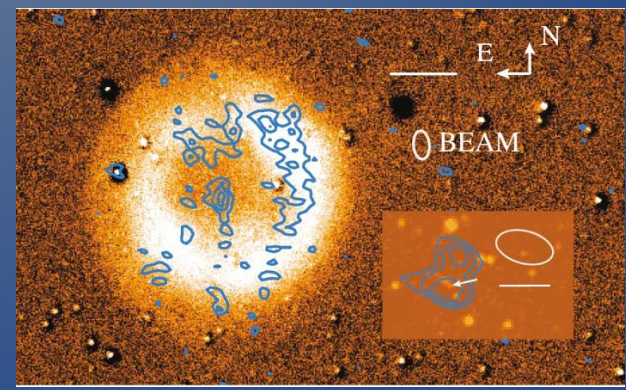
# Dust in BAGs



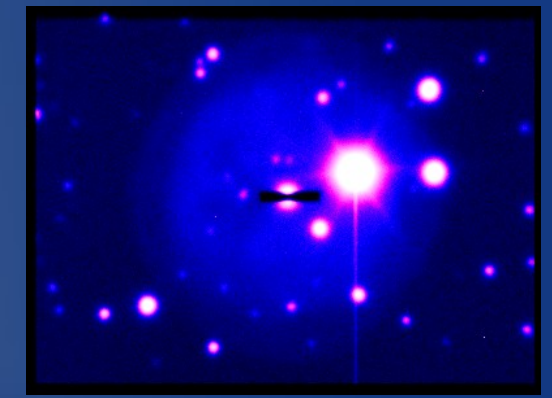
**CK Vul**



**V605 Aql**



**Sakurai's Object**



**FG Sge**

CK Vul.  $H\alpha + [NII]$  (Kamiński et al., 2015, Nature, 520, 322)

V605 Aql. HeII, [OIII] and HST WFPC2 F502N (Toalá et al., 2015, ApJ, 799, 67)

Sakurai's Object. [OIII] and 8.6 Ghz (Hajduk et al., 2005, Science, 308, 231)

FG Sge (<http://www.aloha.net/~joel/keckphot.htm>)

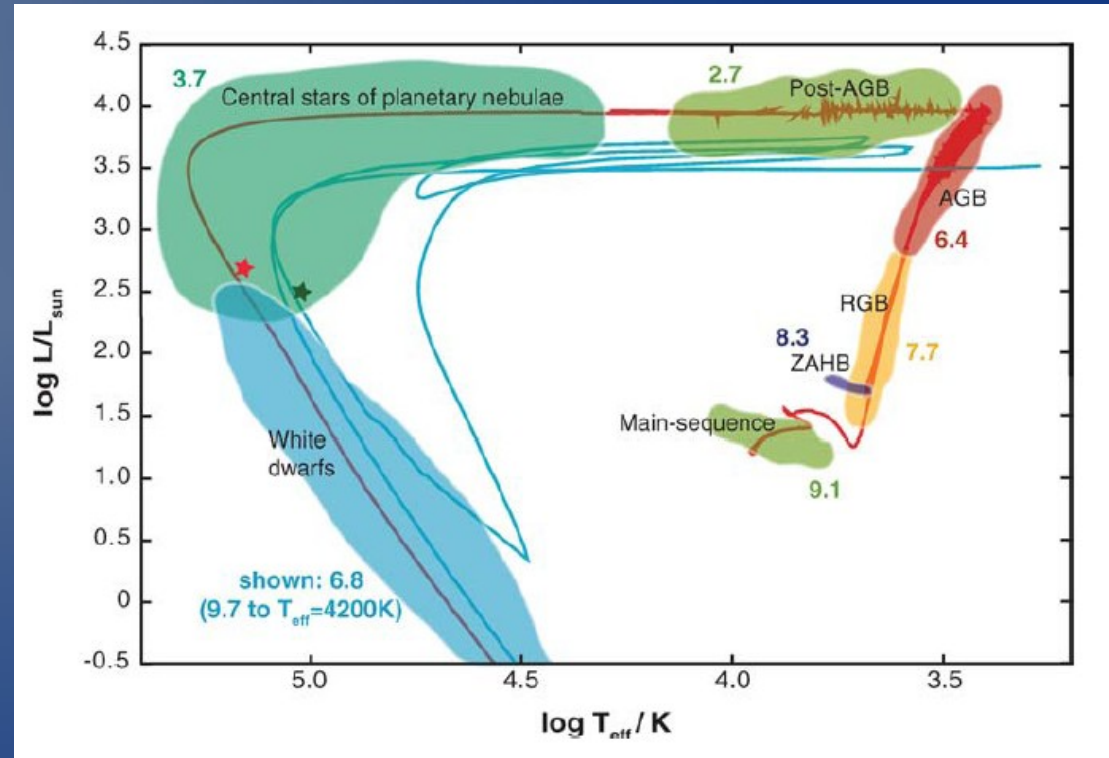


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Both the mythical phoenix and the BAG are reborn by arising from the ashes of their predecessors

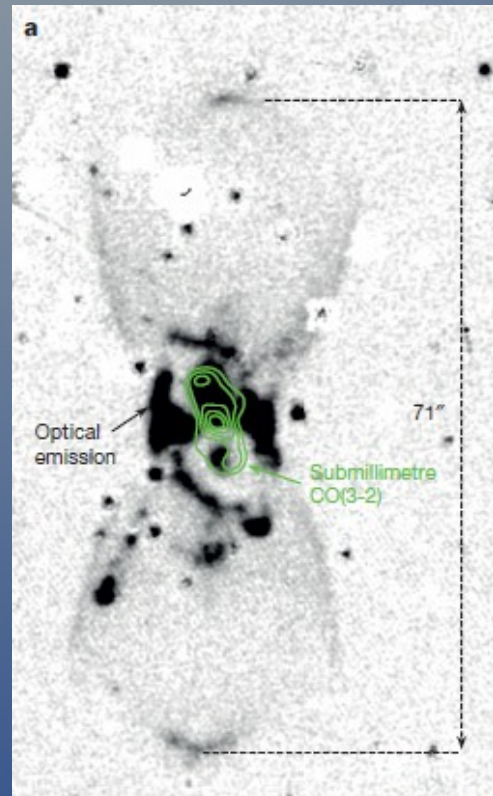


*Bilderbuch für Kinder,*  
(Bertuch, 1790-1830)



Predicted evolution of a  $2M_{\odot}$  solar  
metallicity star  
(Herwig, 2005, ARAA, 43, 435)

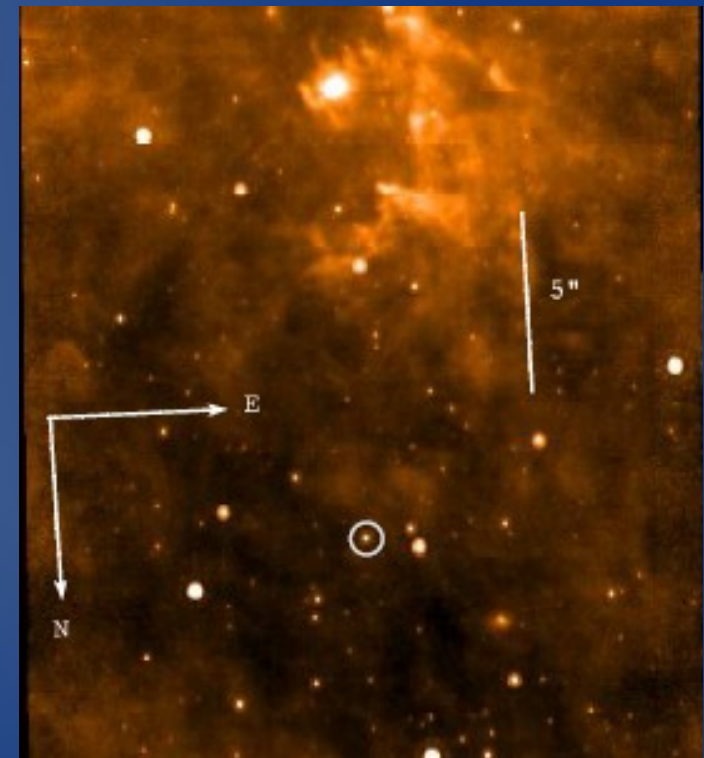
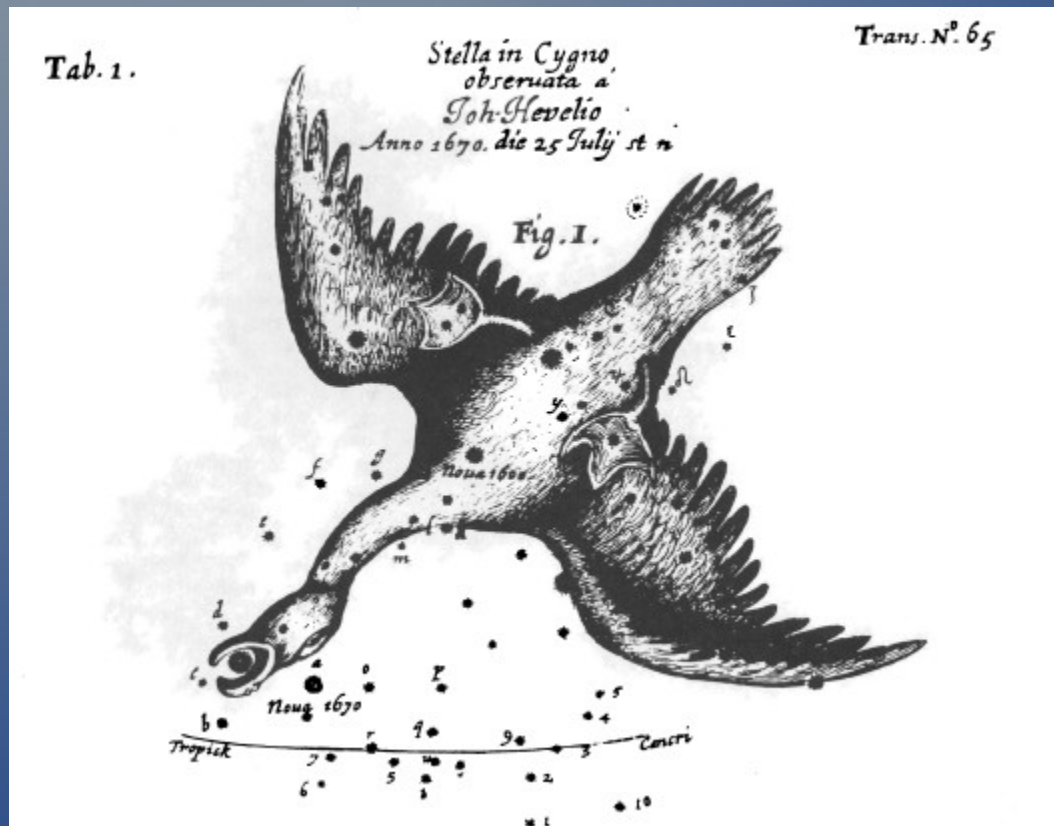
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# CK Vul

# Dust in BAGs

## CK Vul (“Nova Vul 1670”)



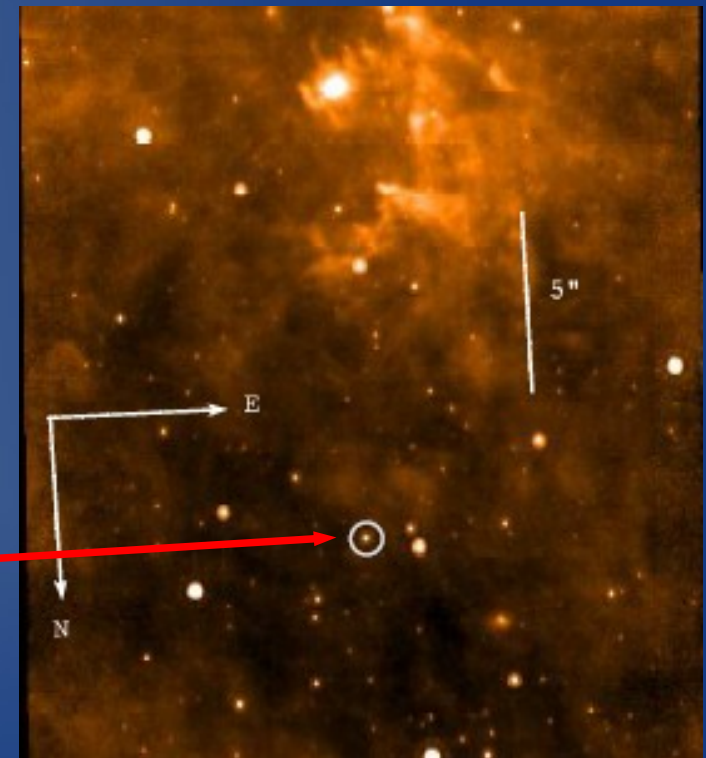
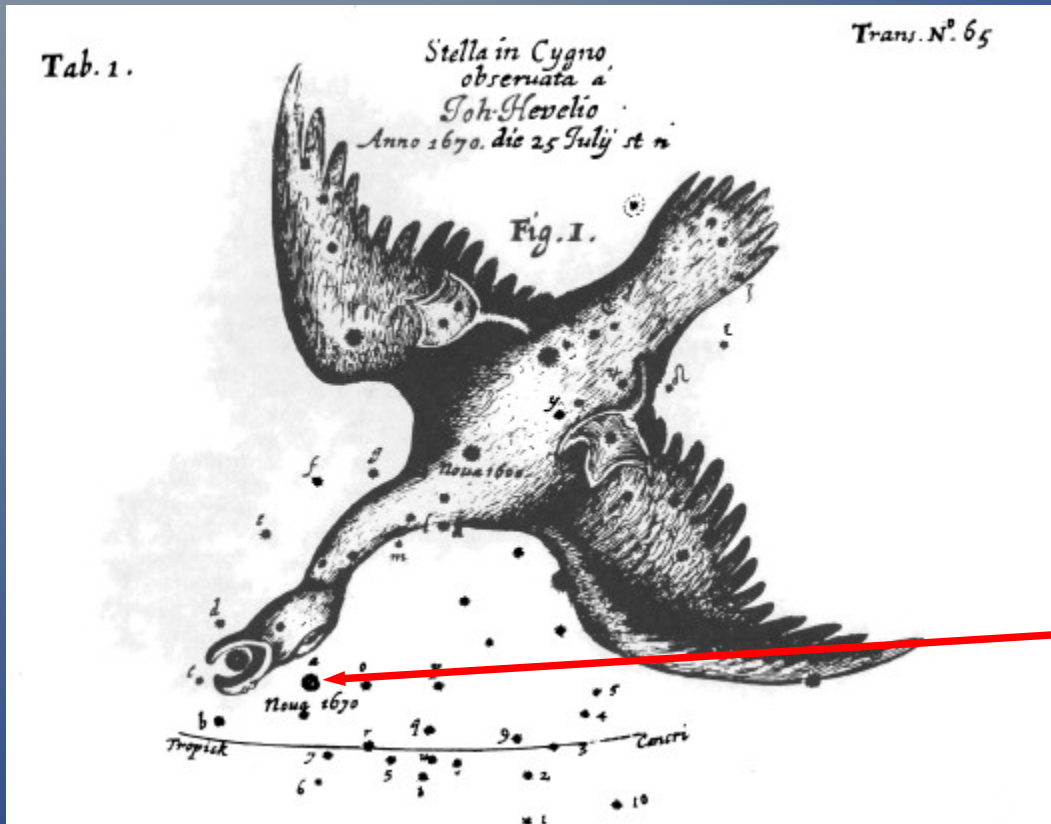
1670 finding chart for “Nova Vul 1670”  
(Hevelius, 1670, Phil. Trans. Roy Soc., 5, 2087)

24 μm finding chart  
(Spitzer Space Telescope MIPS)



# Dust in BAGs

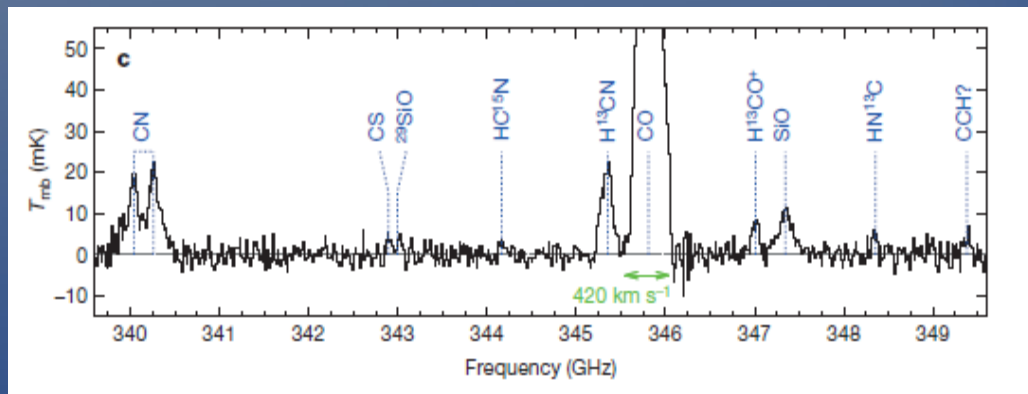
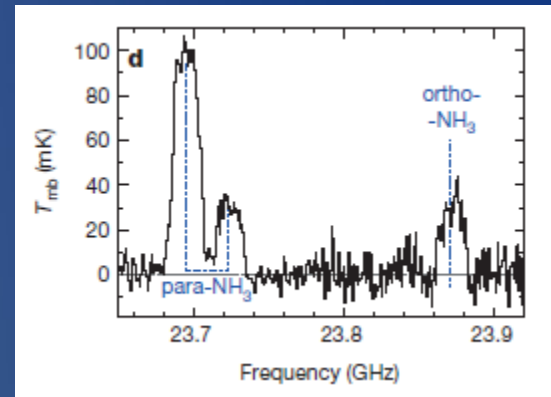
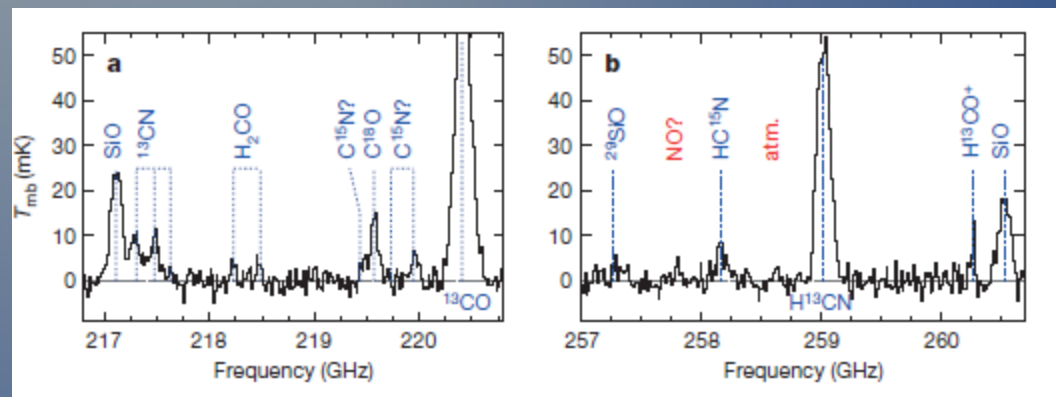
## CK Vul (“Nova Vul 1670”)



1670 finding chart for “Nova Vul 1670”  
(Hevelius, 1670, Phil. Trans. Roy Soc., 5, 2087)

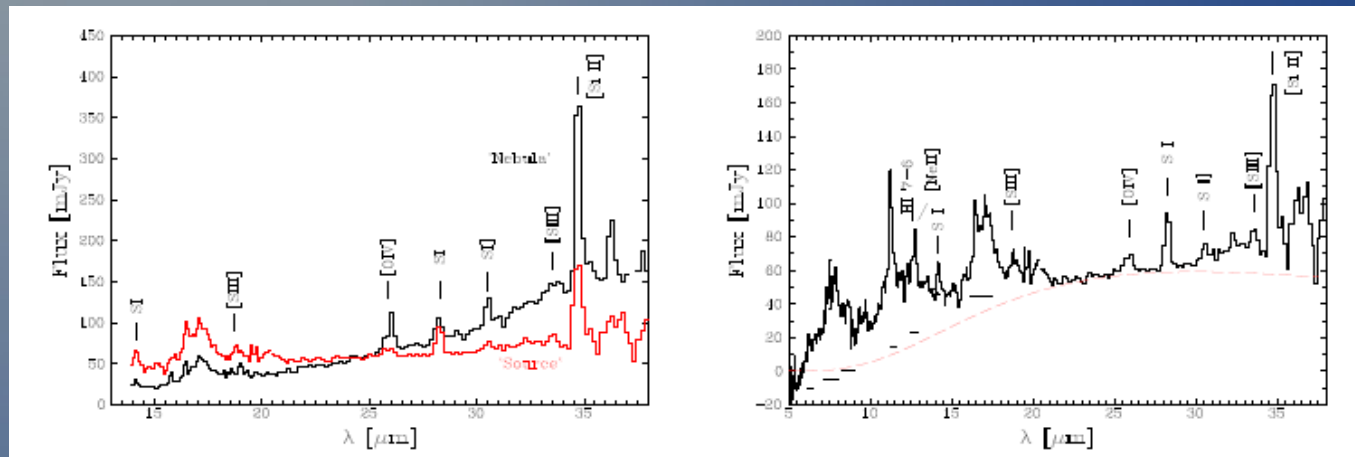
24  $\mu\text{m}$  finding chart  
(Spitzer Space Telescope MIPS)

# Dust in BAGs



**APEX 300 – 1300  $\mu\text{m}$   
spectra of CK Vul  
(Kamiński et al., 2015,  
Nature, 520, 322)**

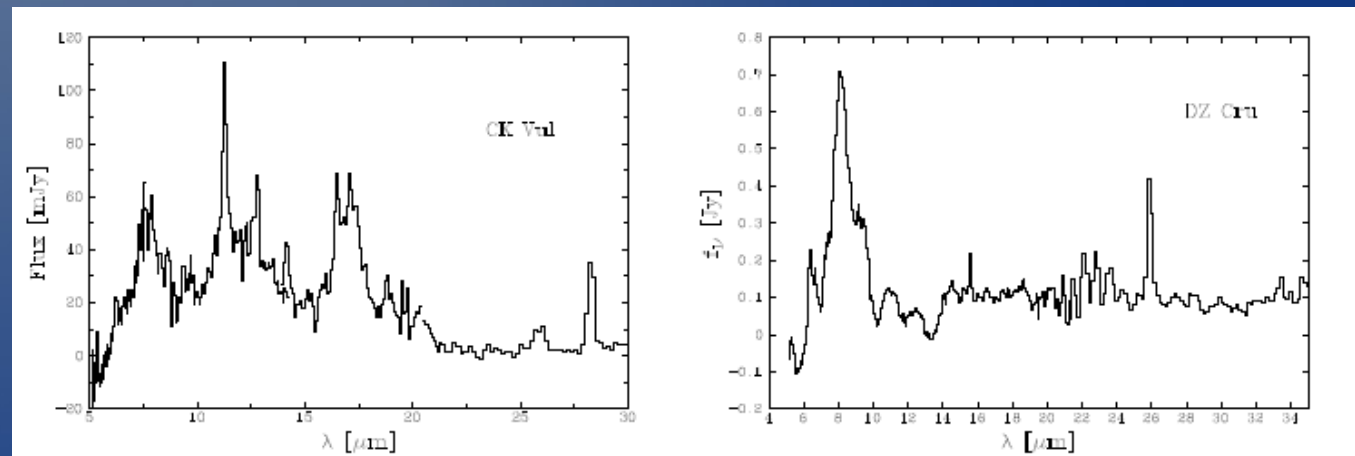
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SST IRS spectrum of CK Vul and nebulosity



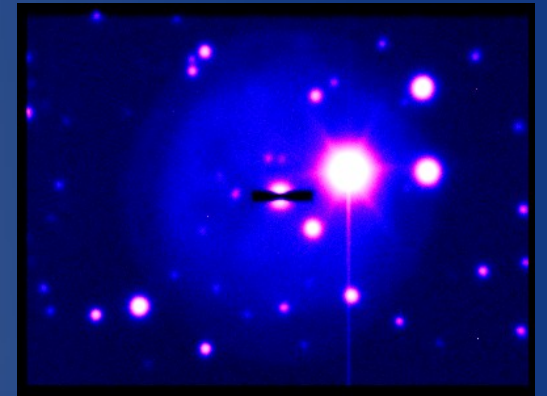
UIR emission in CK Vul and a classical nova



Evans et al., 2015, to be submitted

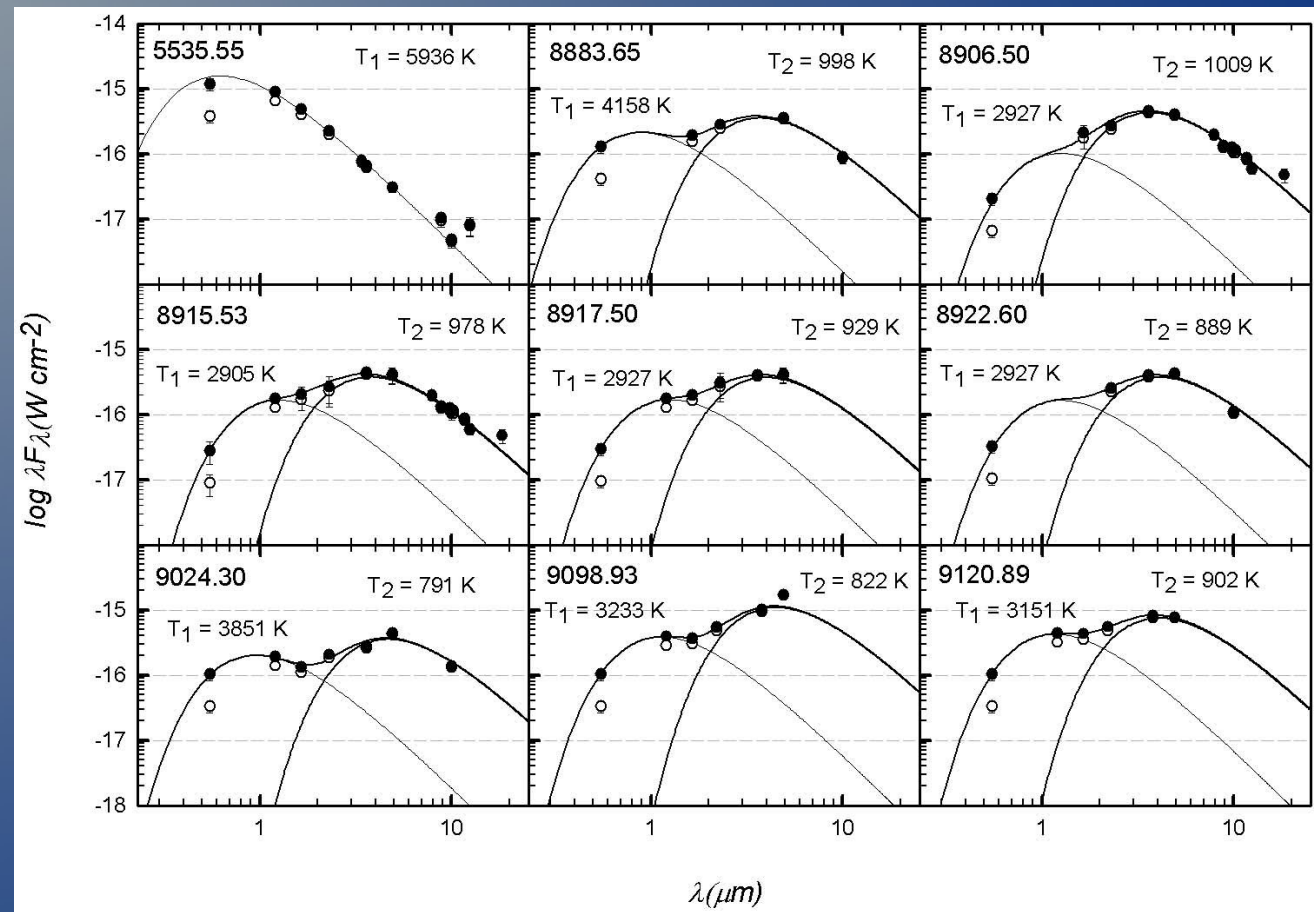
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FG Sge = H 1-5



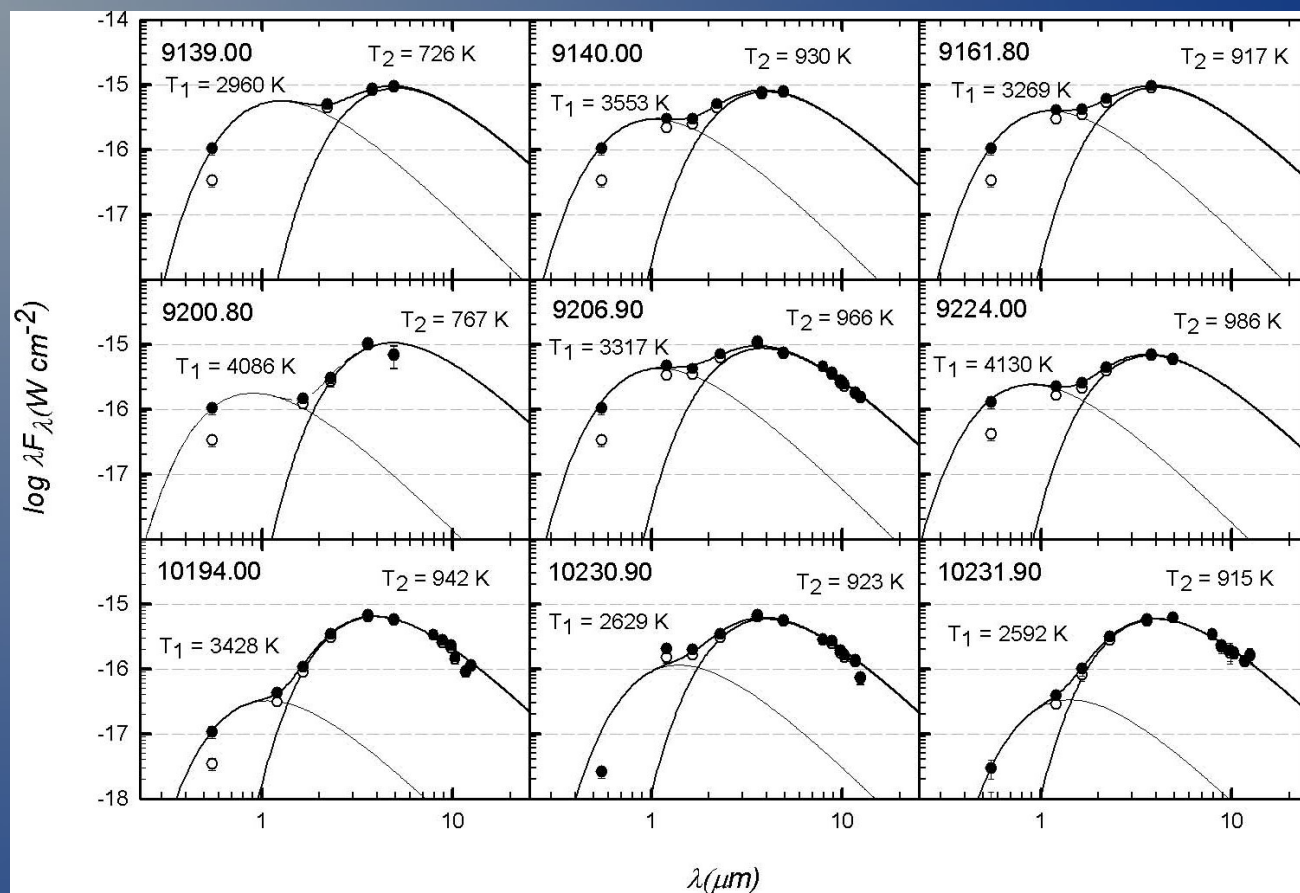


# Dust in BAGs



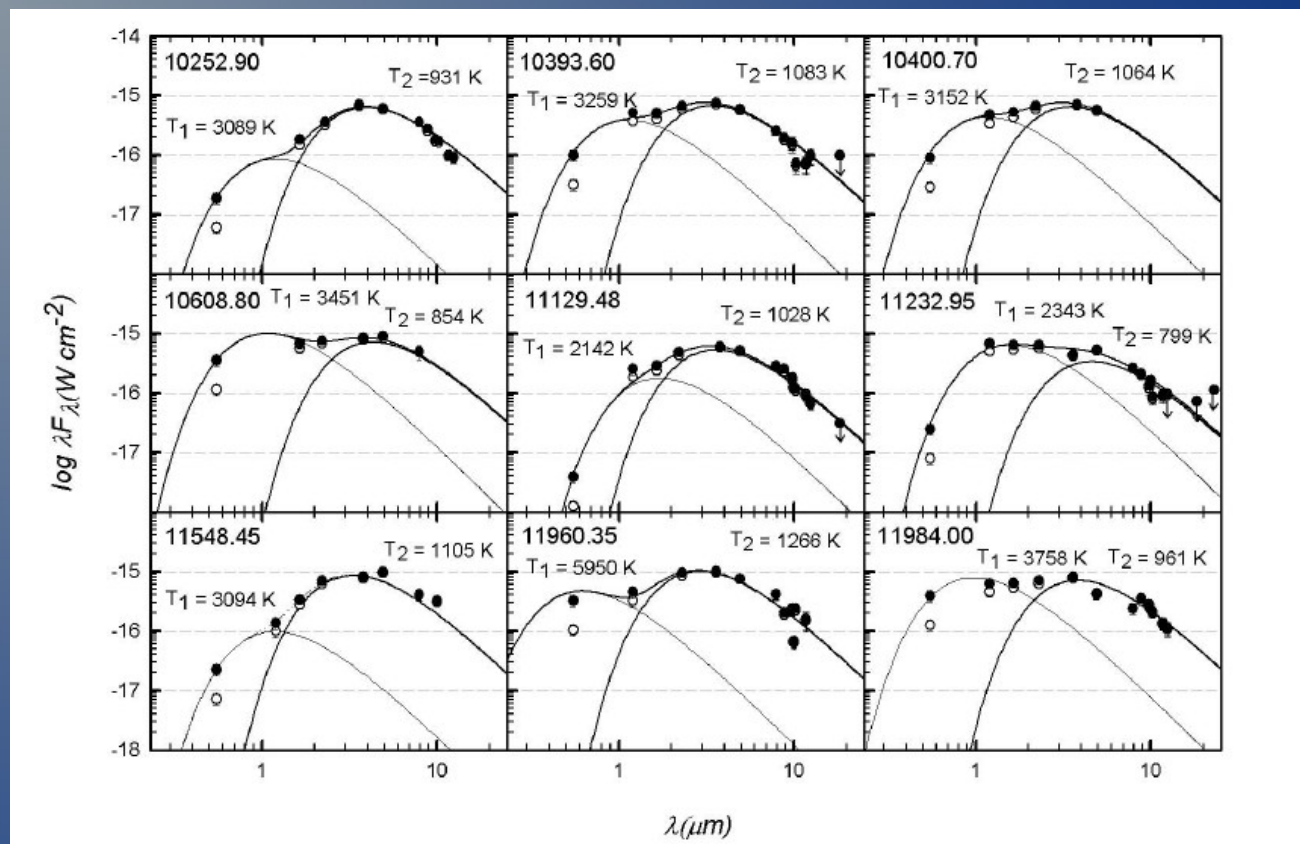
Evolution of the dust shell of FG Sge  
 MJD 45360 – 49121  
 Gehrz et al., 2005, ApJ, 623, 1105

# Dust in BAGs



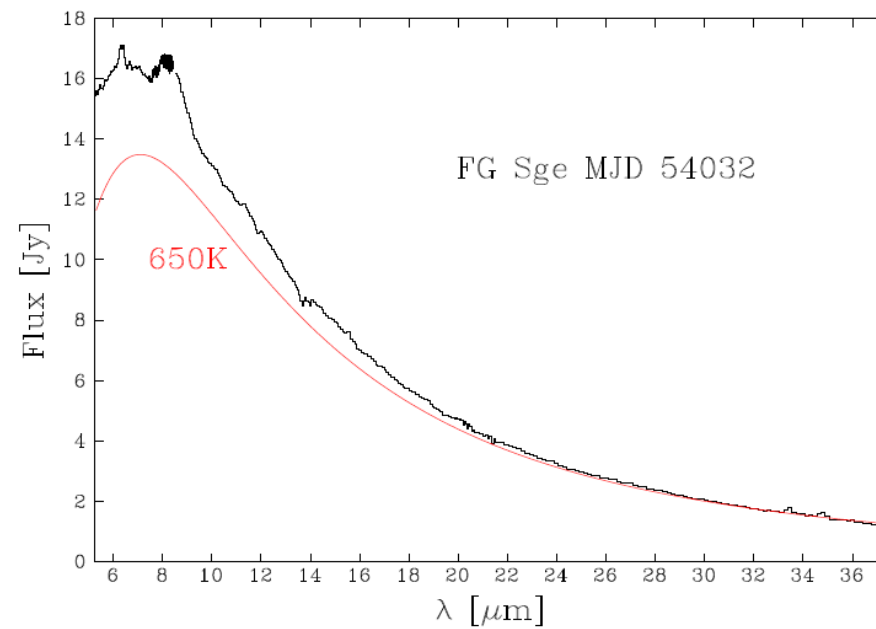
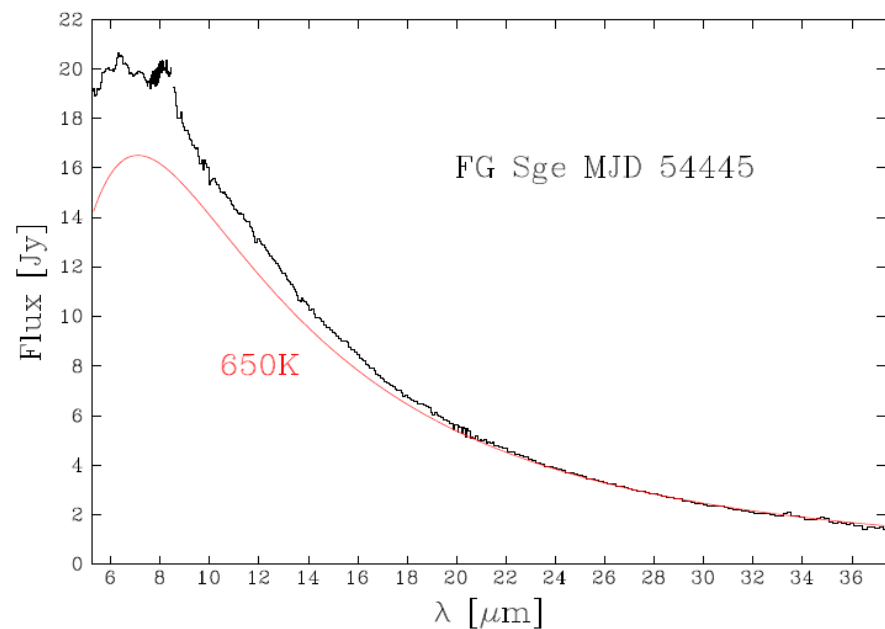
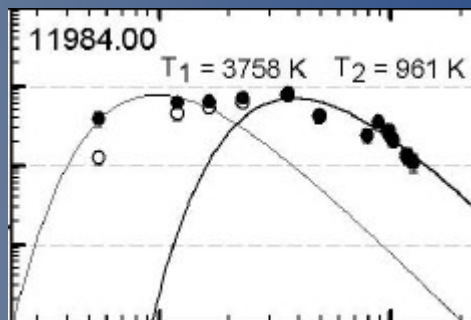
Evolution of the dust shell of FG Sge  
 MJD 49139 – 50232  
 Gehrz et al., 2005, ApJ, 623, 1105

# Dust in BAGs



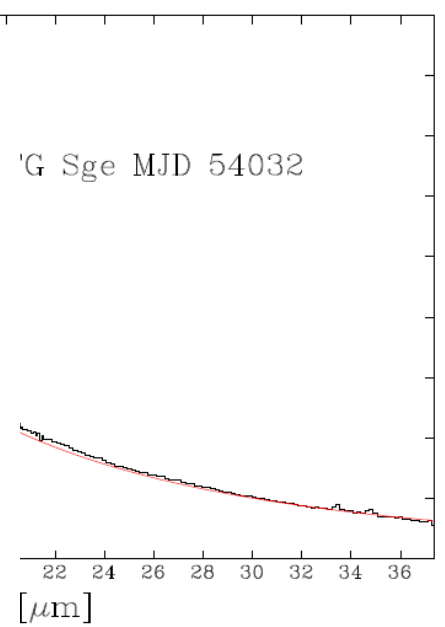
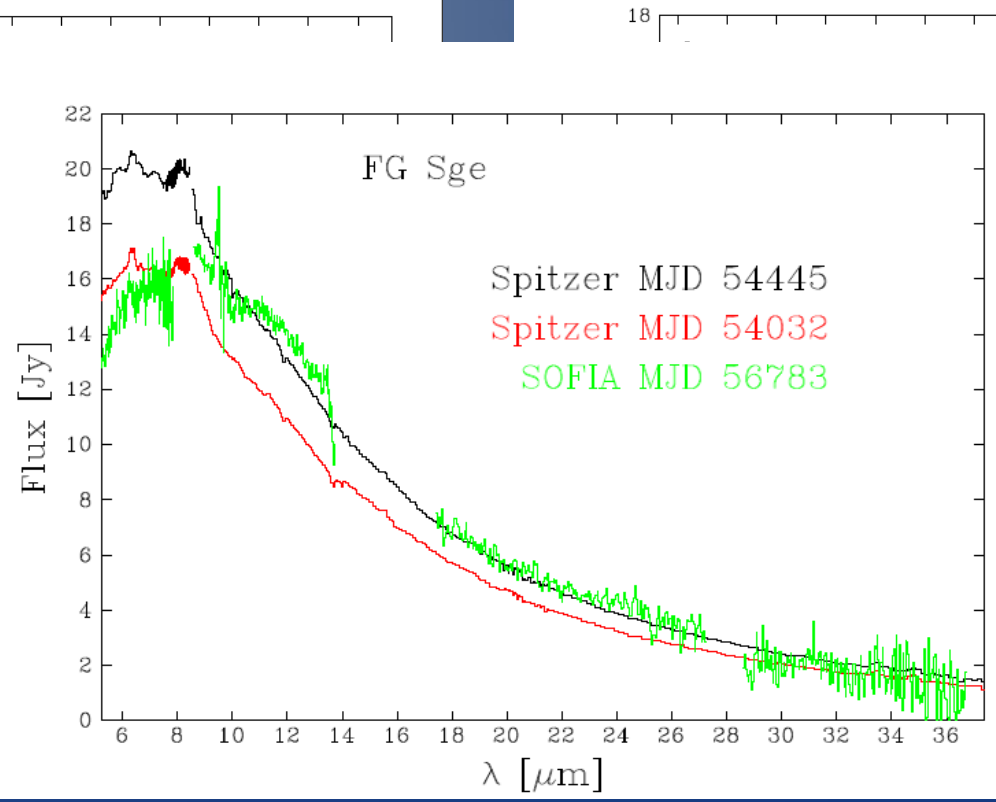
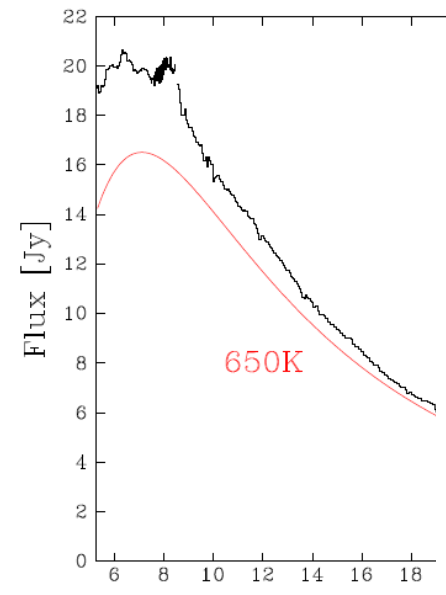
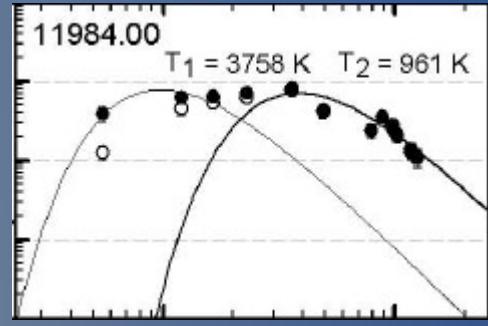
Evolution of the dust shell of FG Sge  
 MJD 50253 – 51984  
 Gehrz et al., 2005, ApJ, 623, 1105

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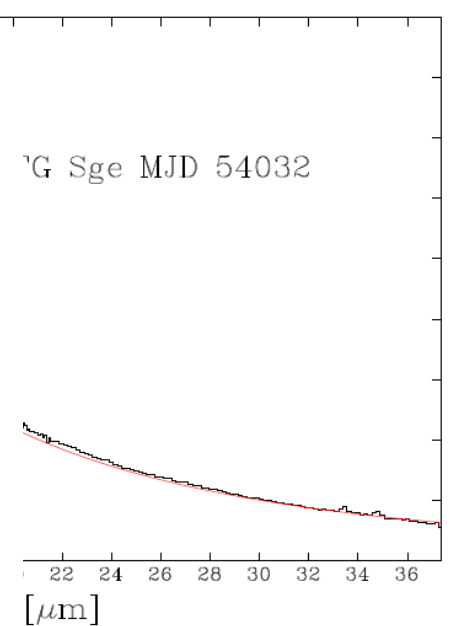
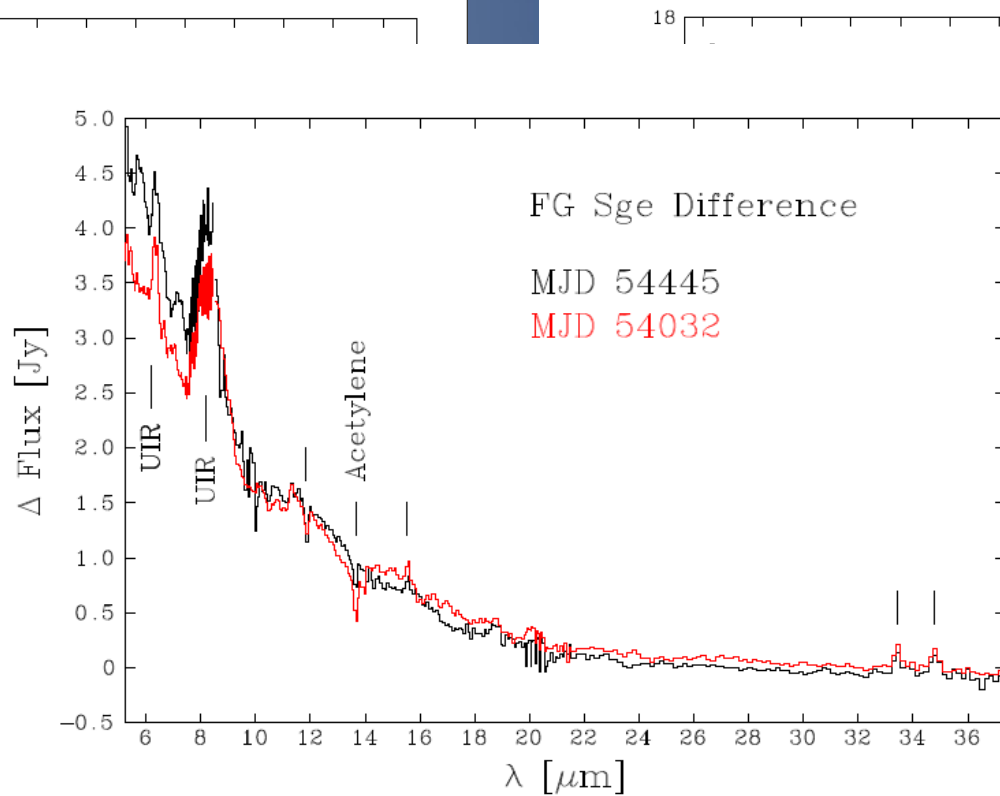
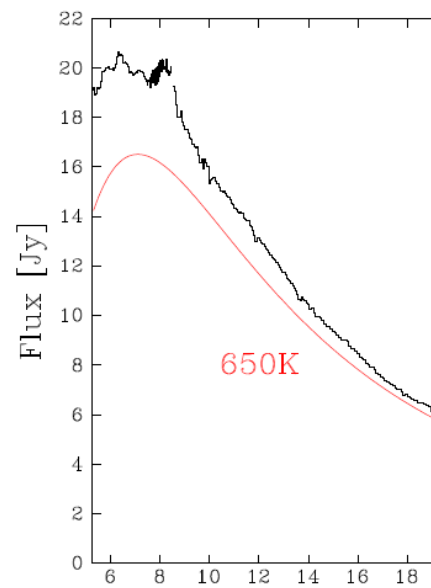




# Dust in BAGs

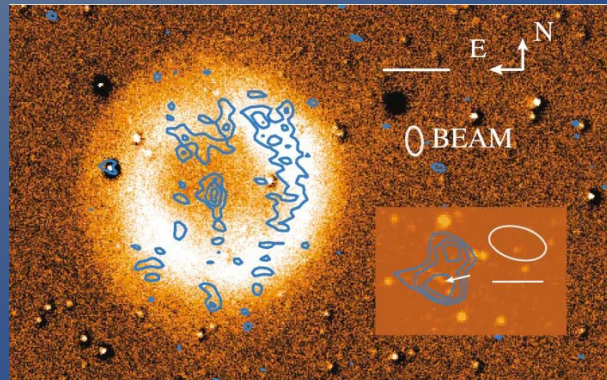


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## Sakurai's Object V4334 Sgr

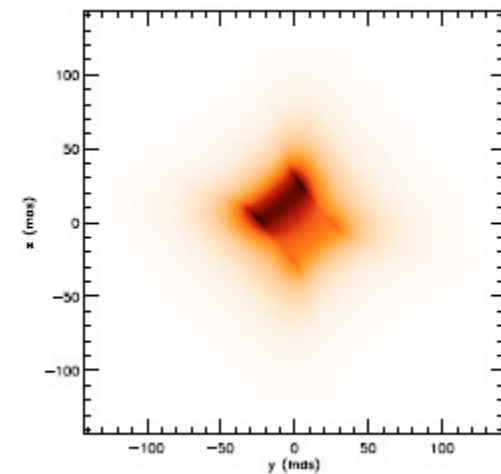
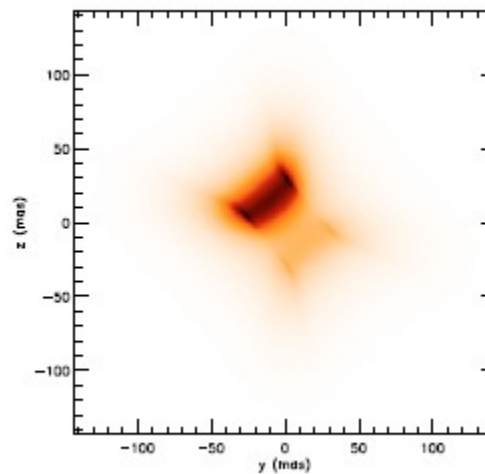
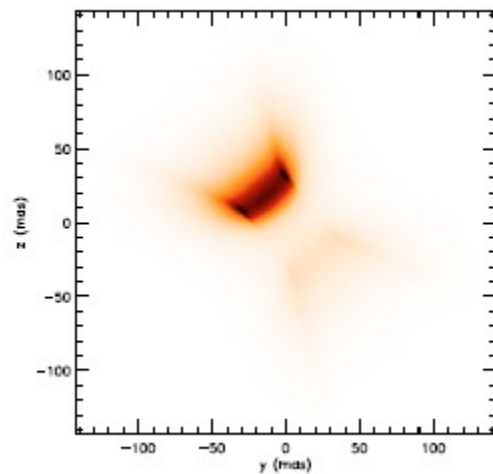


# Dust in BAGs

LETTER TO THE EDITOR

## A dense disk of dust around the born-again Sakurai's object<sup>\*,\*\*</sup>

O. Chesneau<sup>1</sup>, G. C. Clayton<sup>2</sup>, F. Lykou<sup>3</sup>, O. De Marco<sup>4</sup>, C. A. Hummel<sup>5</sup>,  
F. Kerber<sup>5</sup>, E. Lagadec<sup>3</sup>, J. Nordhaus<sup>6</sup>, A. A. Zijlstra<sup>3</sup>, and A. Evans<sup>7</sup>



Chesneau et al., 2009, A&A, 493, L17

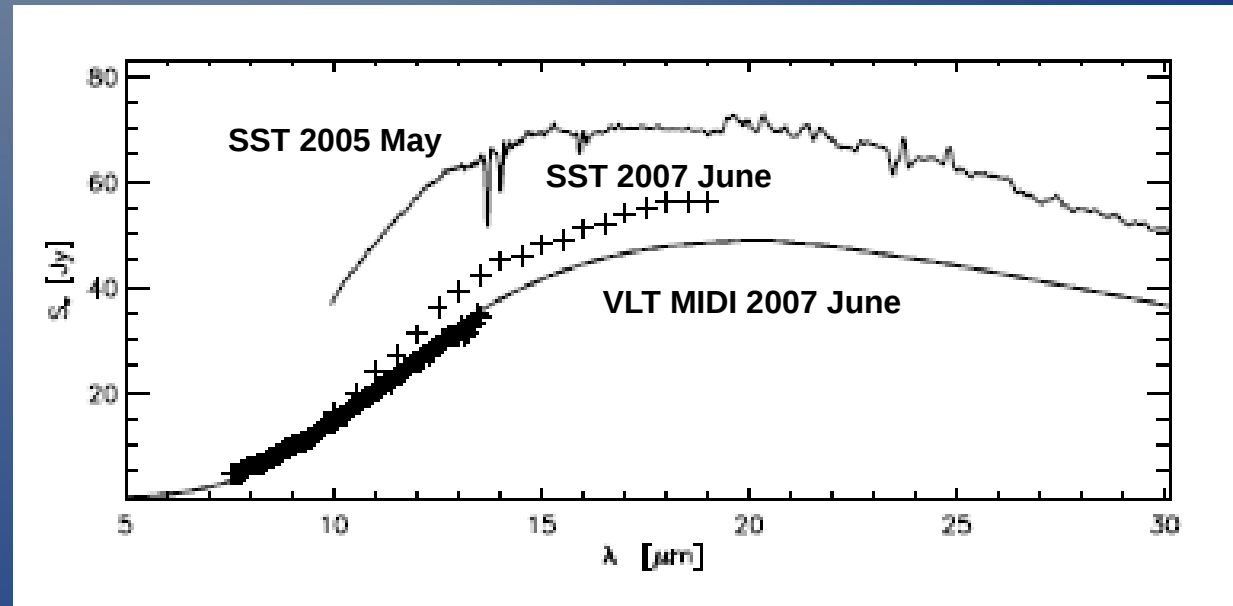


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F. Kerber<sup>5</sup>, E. Lagadec<sup>3</sup>, J. Nordhaus<sup>6</sup>, A. A. Zijlstra<sup>3</sup>, and A. Evans<sup>7</sup>

Dear Nye,

Thank your for this answer. It's my turn to be honest: I prefer to see you as co-author for the simple reason that the place needed for an acknowledgment in a letter is too large!!

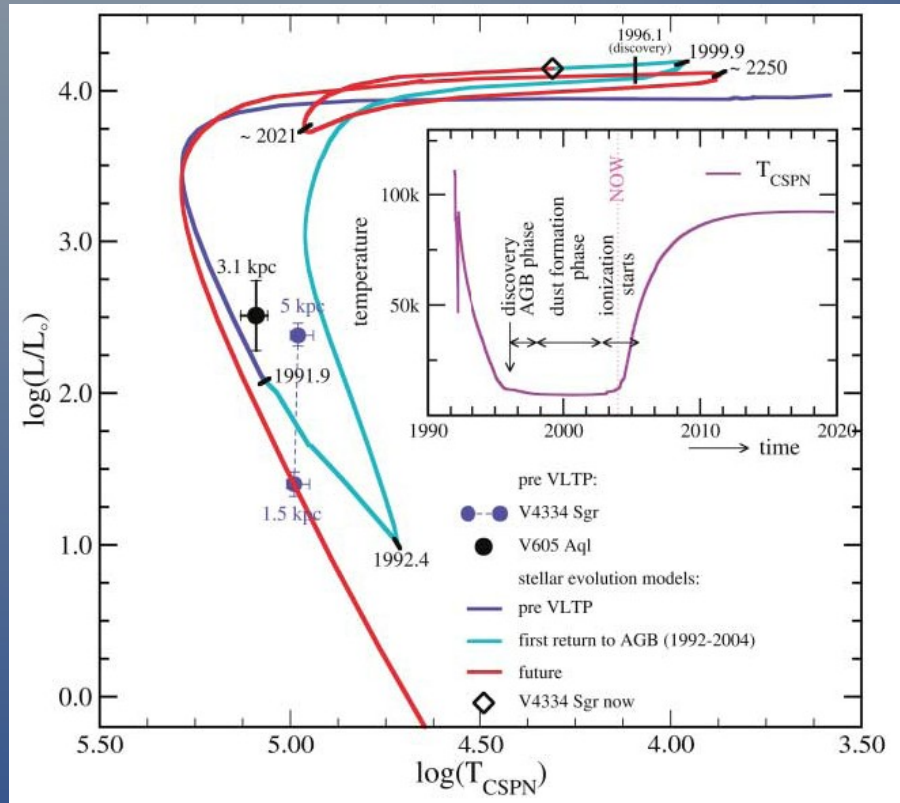
So don't feel uncomfortable with being co-author, I am very happy with to collaborate with you for the first time (and hopefully not the last, if the Nova proposal is accepted...),

Best regards,

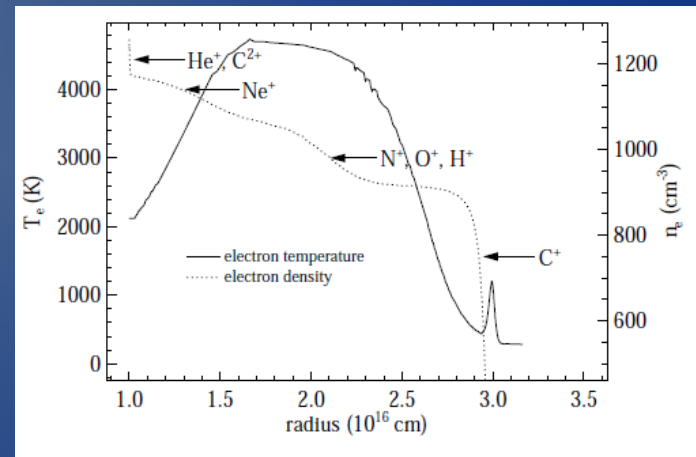
Olivier

**Chesneau et al., 2009, A&A, 493, L17**

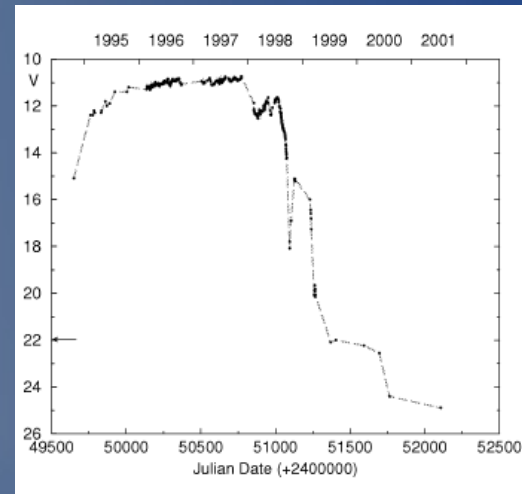
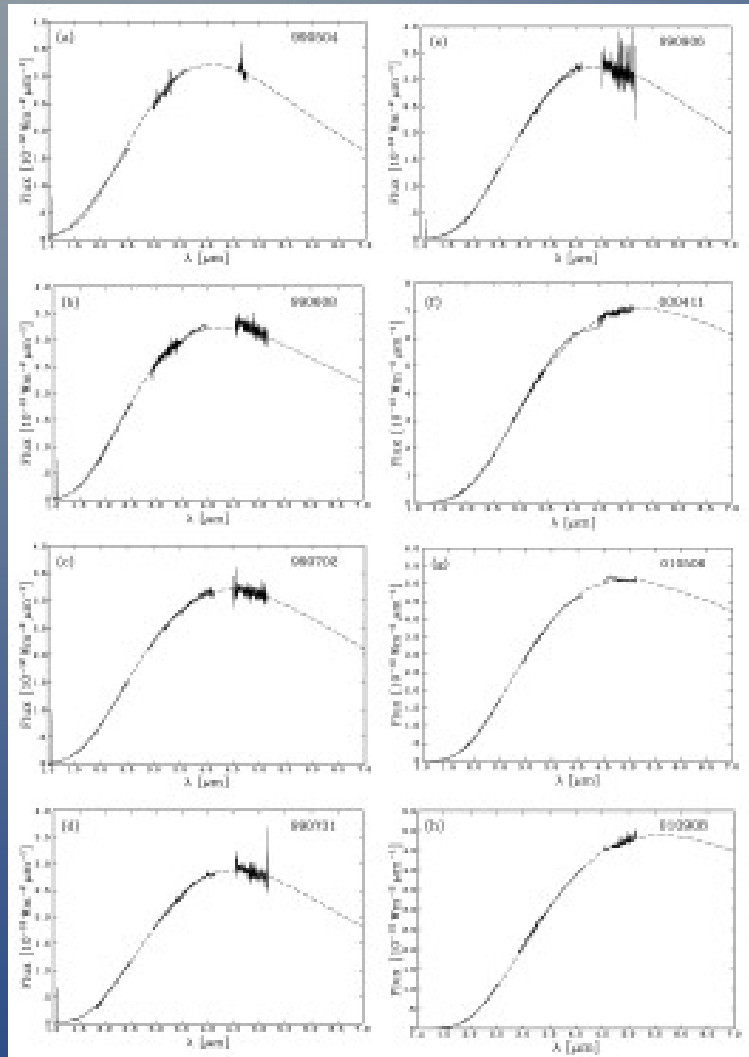
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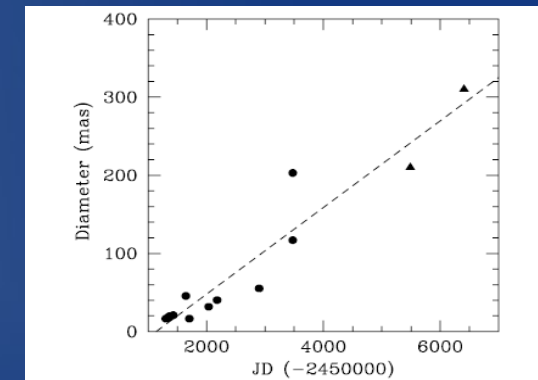
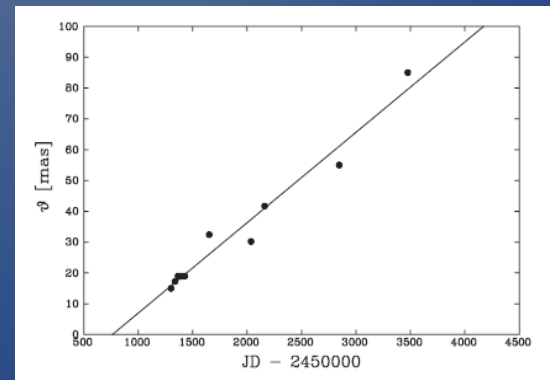
Left: Predicted evolution of BAG compared with observed evolution of Sakurai's Object.  
 Below: Predicted evolution of electron density and temperature.  
 From Hajduk et al., 2005, Science, 308, 231



# Dust in BAGs



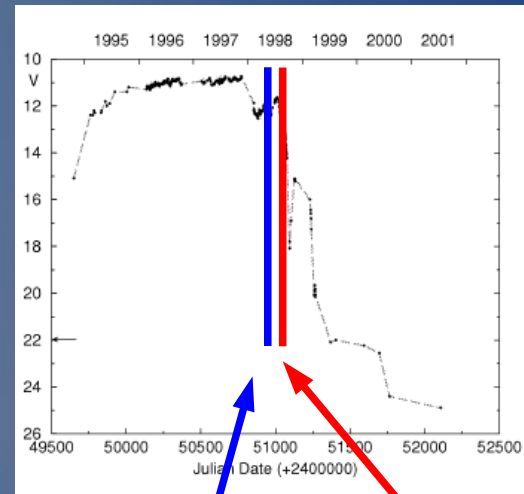
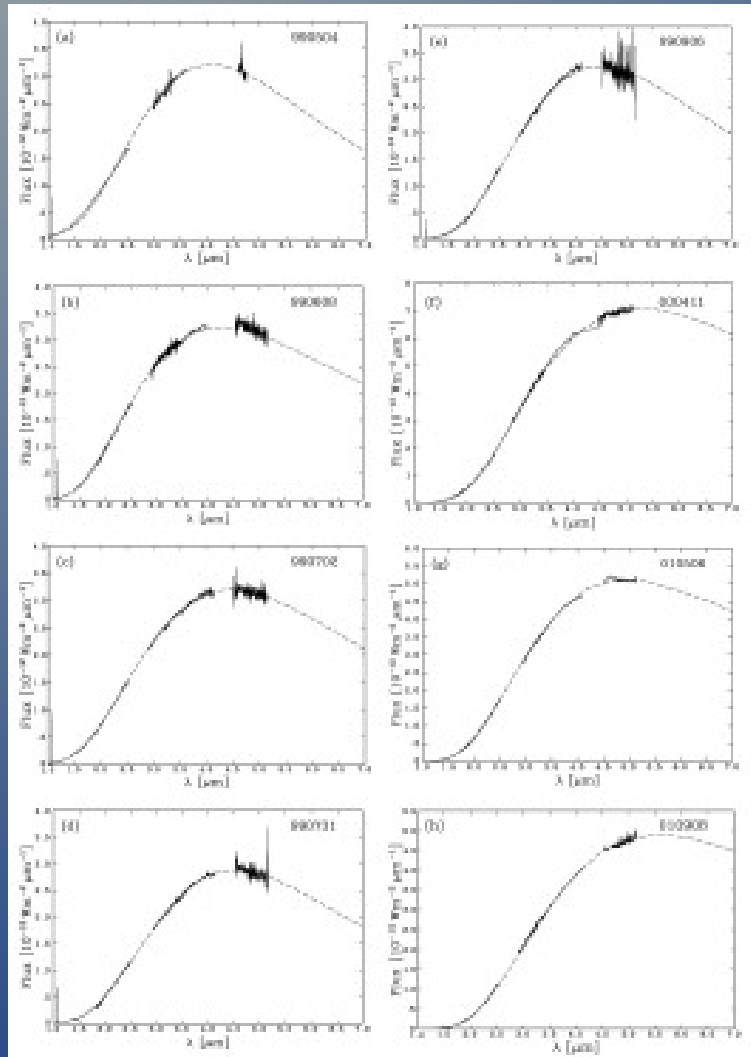
Early evolution of the dust shell of Sakurai's Object (Tyne et al., 2002, MNRAS, 334, 875)



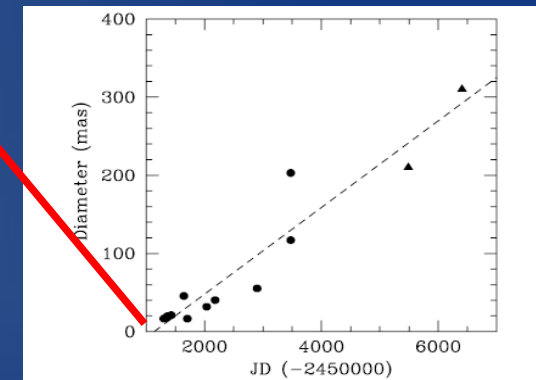
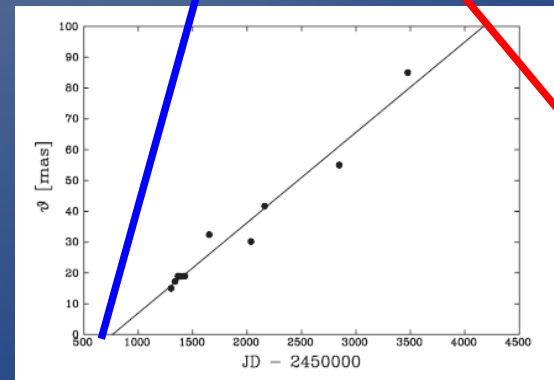
Expansion of the dust shell of Sakurai's Object

Evans et al. 2006, MNRAS, 373, L755. Hinkle & Joyce 2014 ApJ 785, 146

# Dust in BAGs



Early evolution of the dust shell of Sakurai's Object (Tyne et al., 2002, MNRAS, 334, 875)

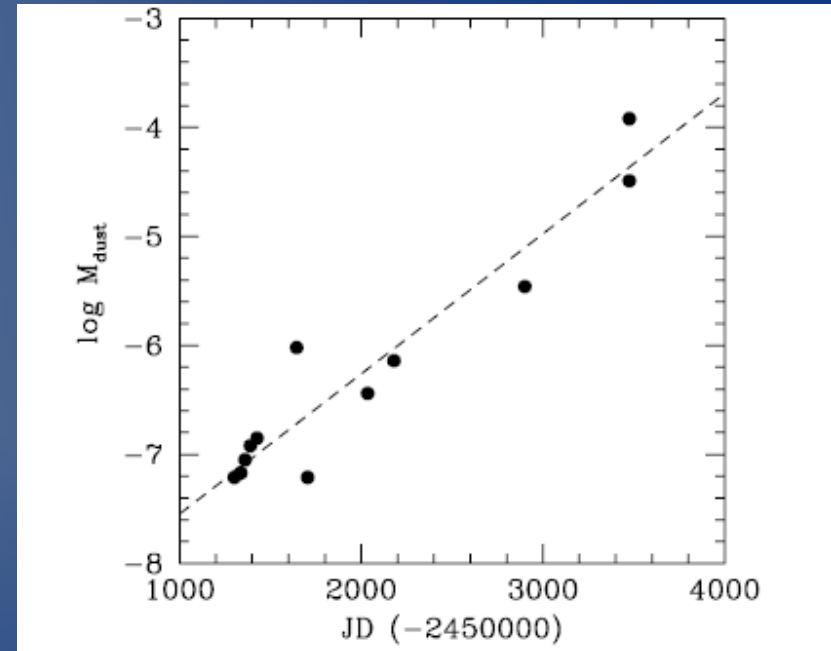
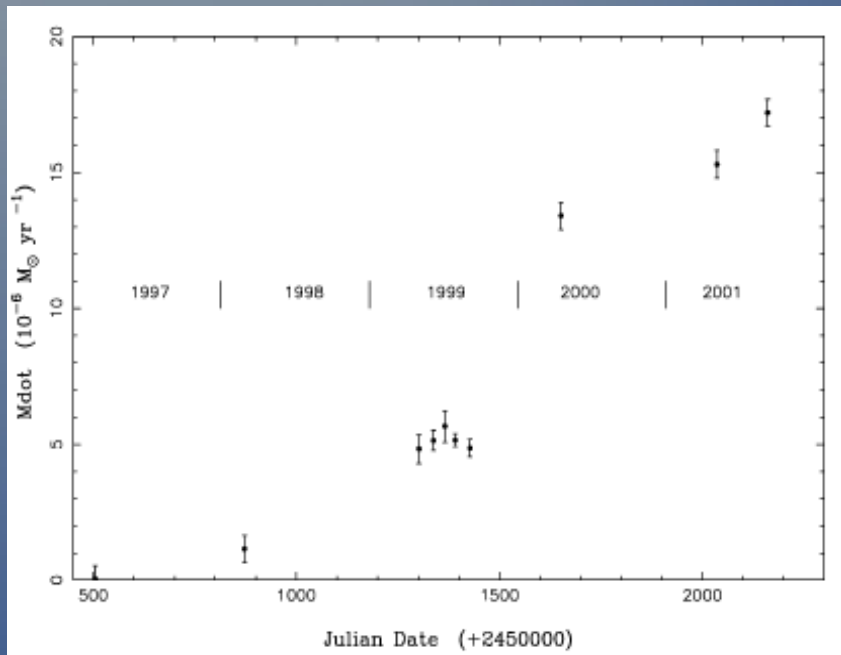


Expansion of the dust shell of Sakurai's Object

Evans et al. 2006, MNRAS, 373, L755. Hinkle & Joyce 2014 ApJ 785, 146

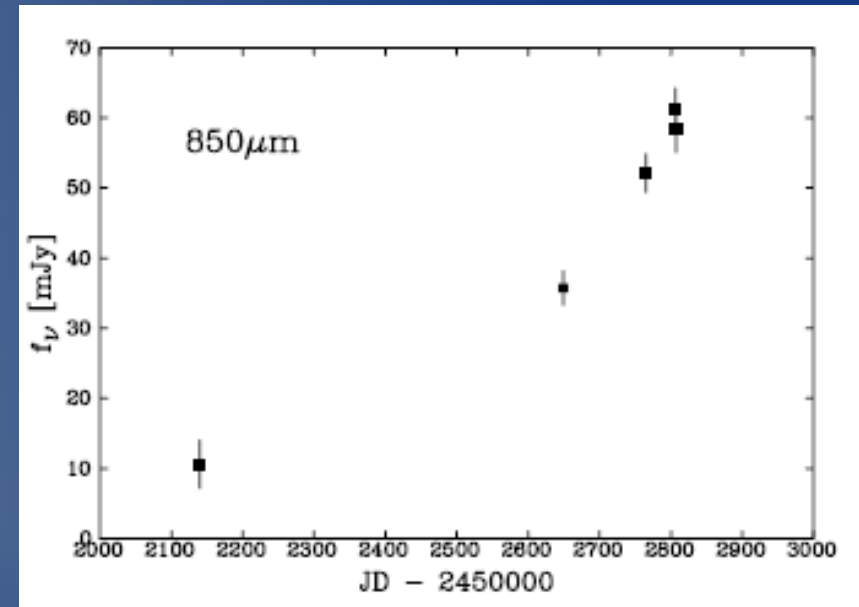
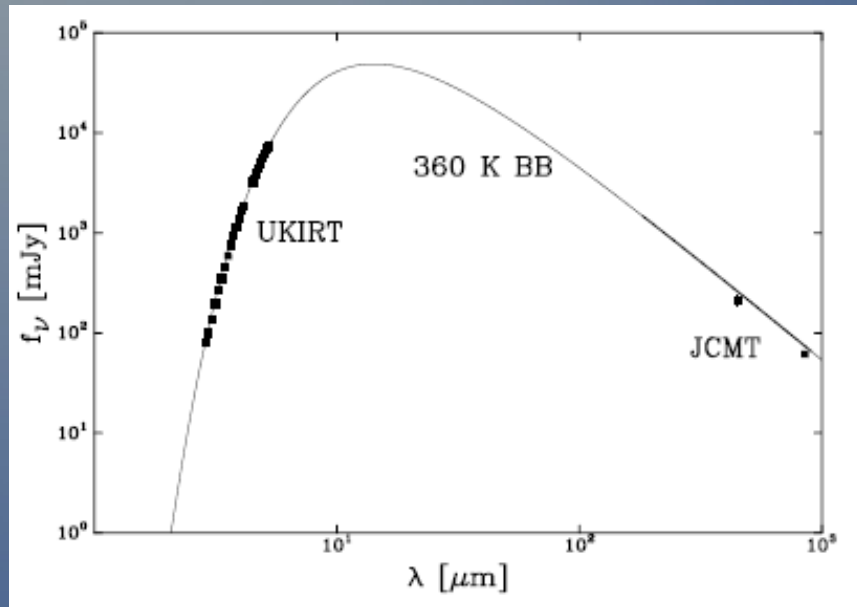


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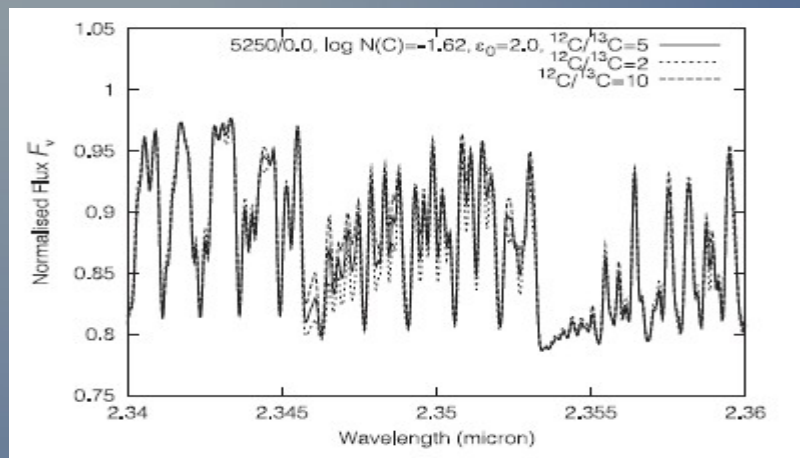
Evolution of mass-loss rate. Left, Tyne et al. 2002, MNRAS, 334, 875; right Hinkle & Joyce, 2014, ApJ, 785, 146

# Dust in BAGs

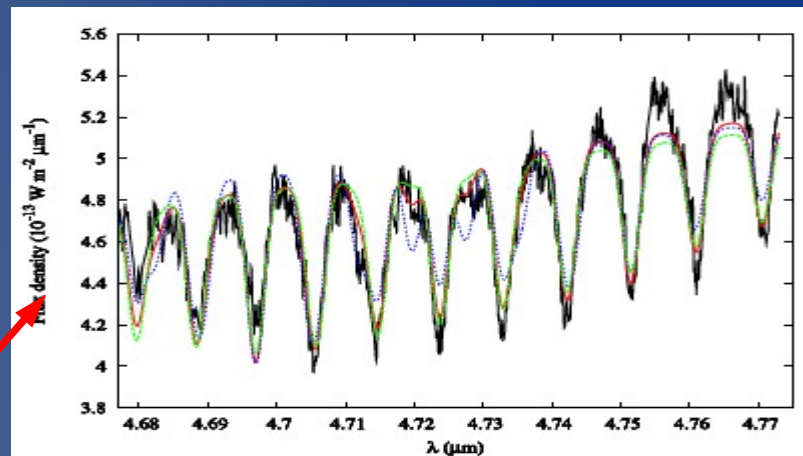


**Sum-mm observations of Sakurai's Object  
(Evans et al., 2004, MNRAS, 353, L41)**

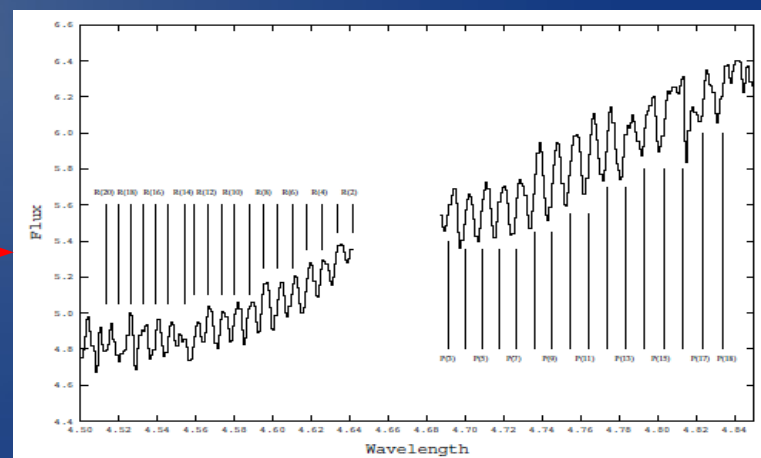
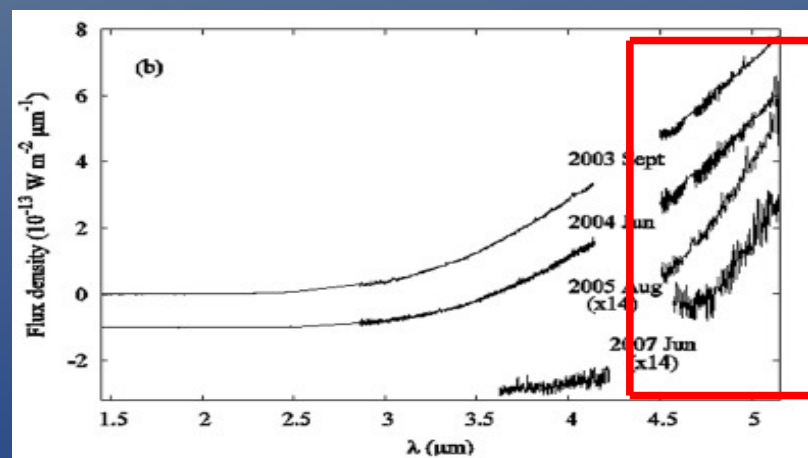
# Dust in BAGs



$^{12}C/^{13}C = 4 \pm 1$  from CO 1st overtone

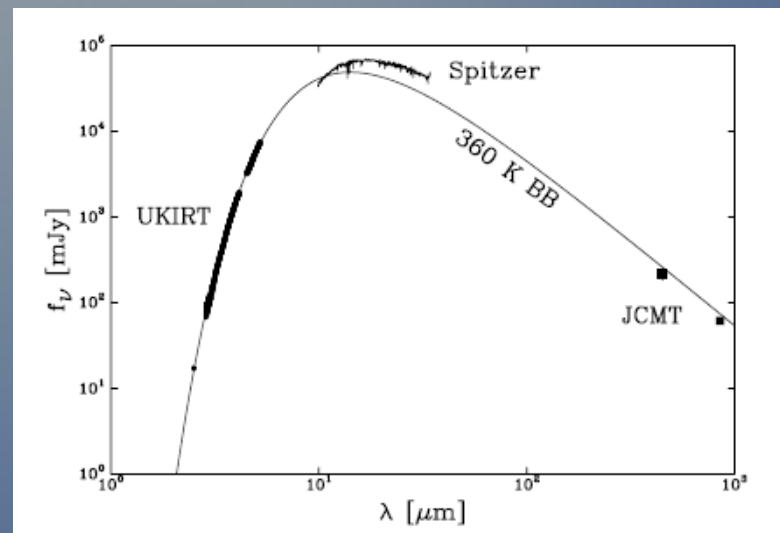


$^{12}C/^{13}C = 3.5^{+2.0}_{-1.5}$  from fundamental

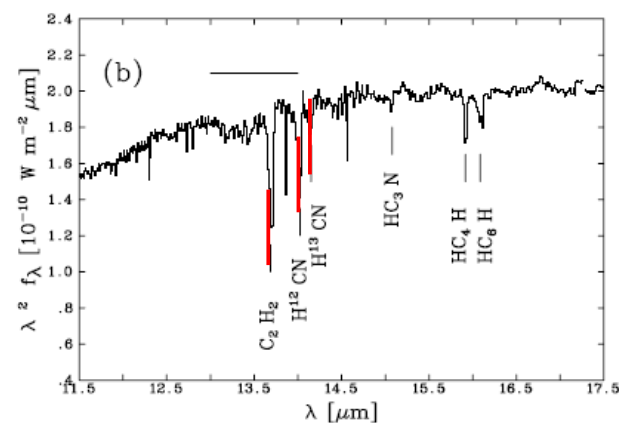
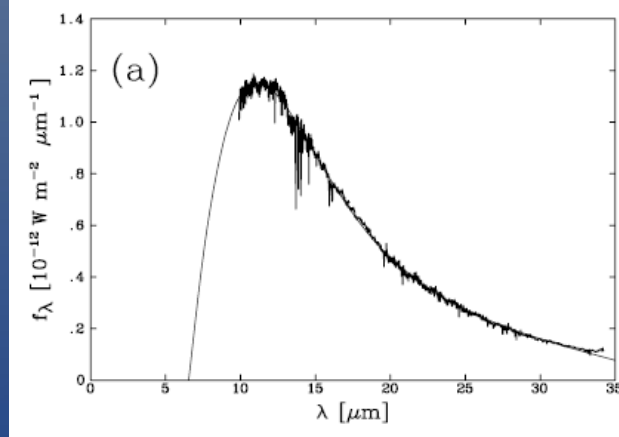


Eyres et al., 2004, MNRAS, 350, L9; Pavlenko et al. 2004, A&A, 417, L39;  
 Worters et al. 2009, MNRAS, 393, 108

# Dust in BAGs

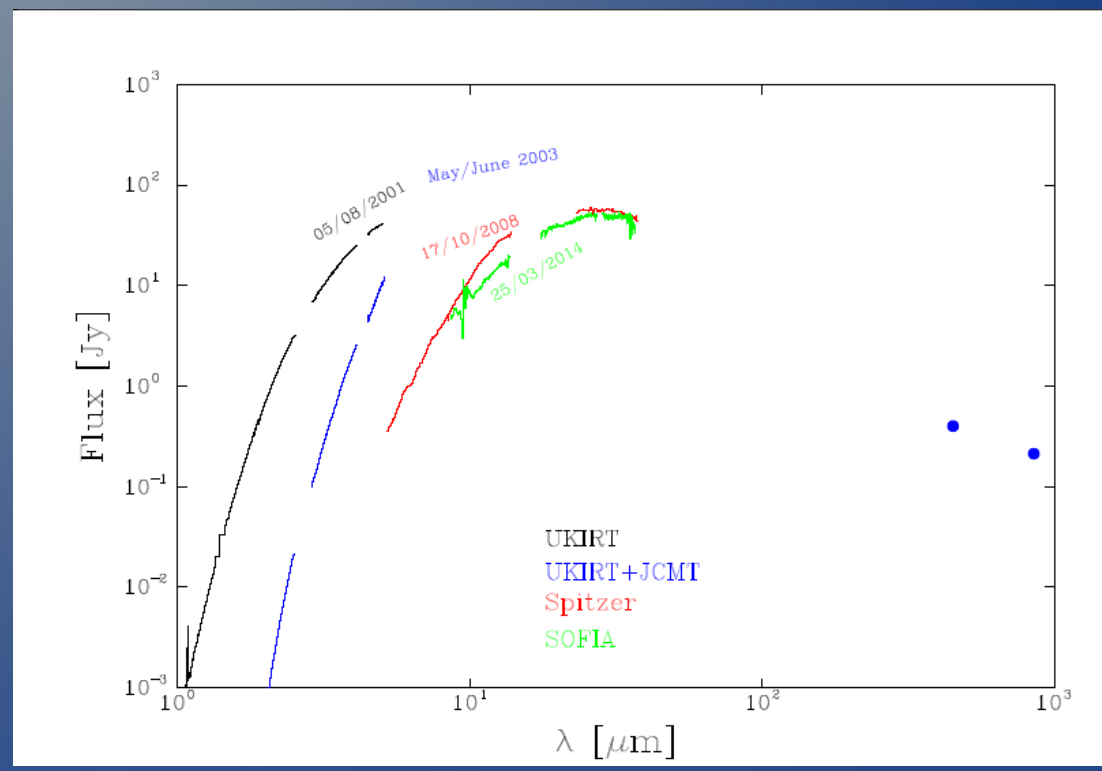


- ➔ Cooling of the dust shell 2003-2005
- ➔ Hydrocarbons –  $\text{H}^{12}\text{CN}$ ,  $\text{H}^{13}\text{CN}$ ,  $\text{HC}_3\text{N}$ , polyynes
- ➔  $^{12}\text{C}/^{13}\text{C} = 3.2^{+3.2}_{-1.6}$  from HCN



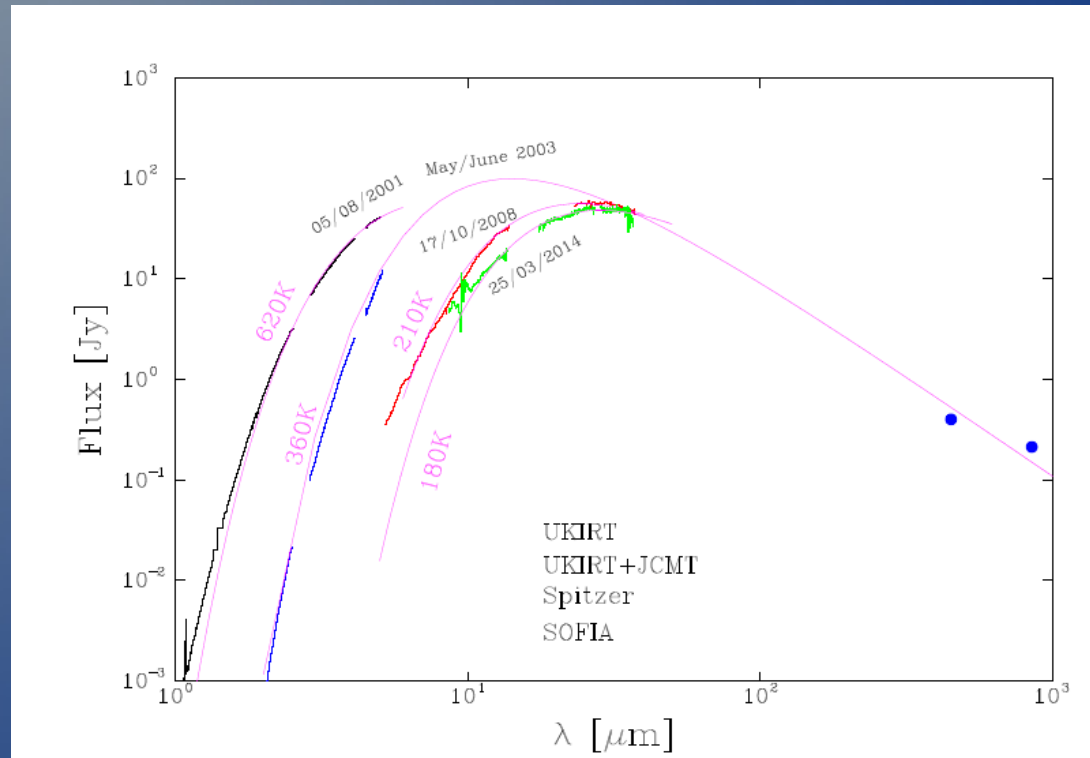
Ground-based and Spitzer Space Telescope Spectra of Sakurai's Object  
(Evans et al., 2006, MNRAS, 373, L75)

# Dust in BAGs





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# Dust in BAGs

- Rare events – have we properly understood them?
- Are the objects manifestations of the same phase of stellar evolution?
- Is there a link with novae?
- If they are indeed “Born-again” giants they provide us with an insight into the fate of the Sun
- SOFIA programme (Cycles 2 & 3, Cycle 4 to be applied for, deadline July 10)

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