# Variabilities & Instabilities ⋆ in Stars ⋆


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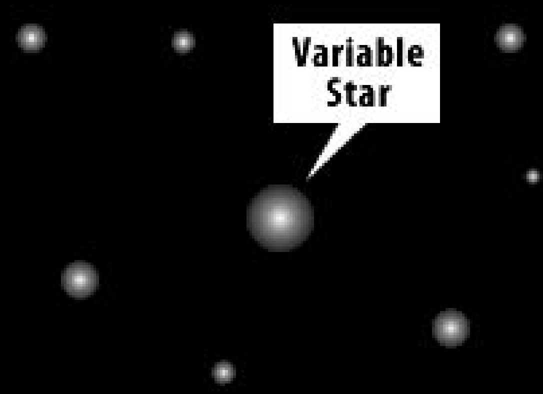

# There are more variable stars as one might expect !!!

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1. Algol
2. AM Canum Venaticorum
3. Ap Sterne
4. $\alpha^2$ Canum Venaticorum
5. $\alpha$ Cygni
6. BY Draconis
7. $\beta$ Cepheiden
8. $\beta$ Lyrae
9. Cepheiden
10. $\delta$ Scuti
11. FK Comae Berenike
12. FU Orionis
13. $\gamma$ Cassiopeiae
14. $\gamma$ Doradus
15. Herbig Ae/Be
16. Kataklysmische
17. Luminous Blue Variables
18. Novae
19. Mira
20. Orion
21. PV Telescopii
22. RR Lyrae
23. T Tauri
24. Sonnenartige Oszillationen
25. SX Arietis
26. SX Phoenicis
27. Symbiotische Novae
28. UV Ceti ↔ Flare Sterne
29. W Ursae Majoris
30. W Virginis
31. Wolf-Rayet
32. Yellow hypergiants
33. Z Andromedae
34. Zwergnovae

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**This is definite enough to fill an entire lecture**

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# Questions this lecture will adress

What kind of variabilities are known ?

Are all stars variable or just a some special types ?

What leads to the variability, which mechnismen are known ?

Can variability trigger instability or vice versa ?

# Topics and Structur of the lecture

- Formation of stars and stellare structure
- stellar evolution
- mass loss and stellar winds
- photometric & spectroscopic variabilities
- intrinstic & extrinstic variabilties
- timescales and amplitudes of the variabilities
- physical mechanism

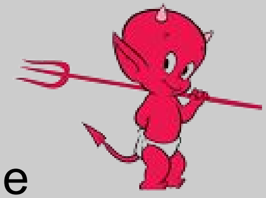
# History und Nomenclature

## 1. Stellar Variability and  the ancient egyptian calender

egypt 3000 years ago:

A calenders was made it contained marks of  “lucky” and  “unlucky” days. This draws back to observations and first notes about variability of the star **Algol.**
It was also named Demons Star.

A rather regular periode of 2.85 days was mentioned in the  calender.

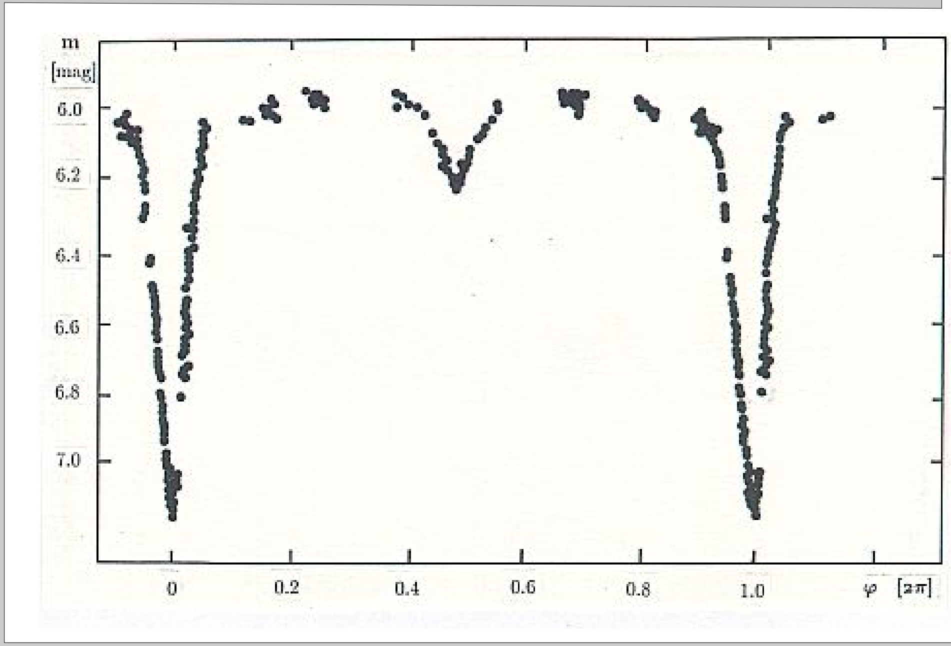


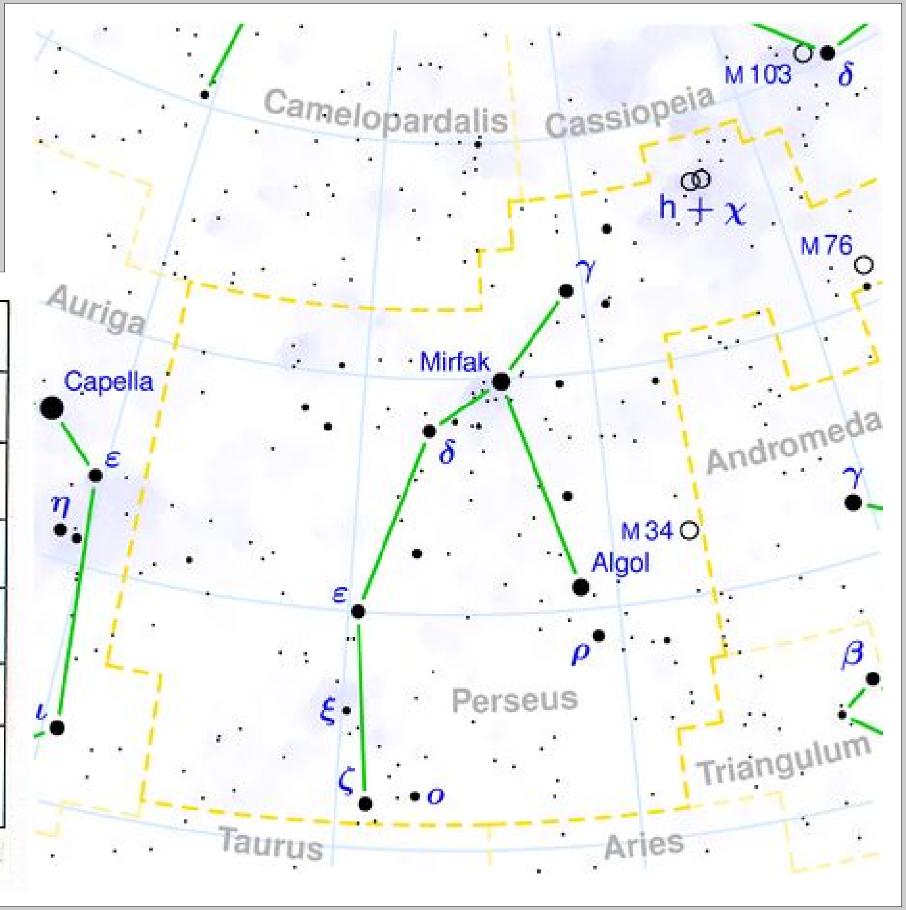
… its supposed to be the regular angry  “steaming”  of a demon
→ lucky and unlucky days

historic papyrus calendar dated 1271-1163 B.C..

# Historie und Nomenklatur

**Algol was the first Variable star known …**

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# nomenclature of stars

**nomenclature of stars**

name accoring to decreasing luminosity

**greek letter + constellation** followed by
**latin letter + constellation** (Bayer System)

$\alpha$ Cen … $\varepsilon$ Eri … $\omega$ Ser

A Cen ... E Eri … S Ser

End 18 century: naming according to this system in the largest Constellation - Serpent (snake) – reached **letter S**.
At the same time photography ↔ time sequences possible
→ the discovery of variable stars was easy and threfore booming.
Nomenclature was extended ↔ fine tuned.

Motivated by Friedrich W. Argelander it was now for non variable stars:

<u>non variable stars wil be given numbers like 4 Cyg</u>

… note no all of these are stars anymore 47 Tuc is a star cluster...

# Nomenklatur für Variable Sterne

For  Variable Stars the rule was now:

rule 1:  if the stars already had a name – **keep it**

rule 2:  star has no previous name = nely discocered

**lateinin letter > S + constellation**

→  R  to Z
→  RR, RS…RZ, SS, ST…SZ, TT…TZ to ZZ
→  AA, AB… AZ, BB, BC…BZ bis QZ  but without JJ...JZ

example:  RR Lyrae

leads to 334 per constellation, beyond that

**V + number + constellation**

→  V for Variable and a number  > 334

Example  V335, V336, …   **V383 Mon** →

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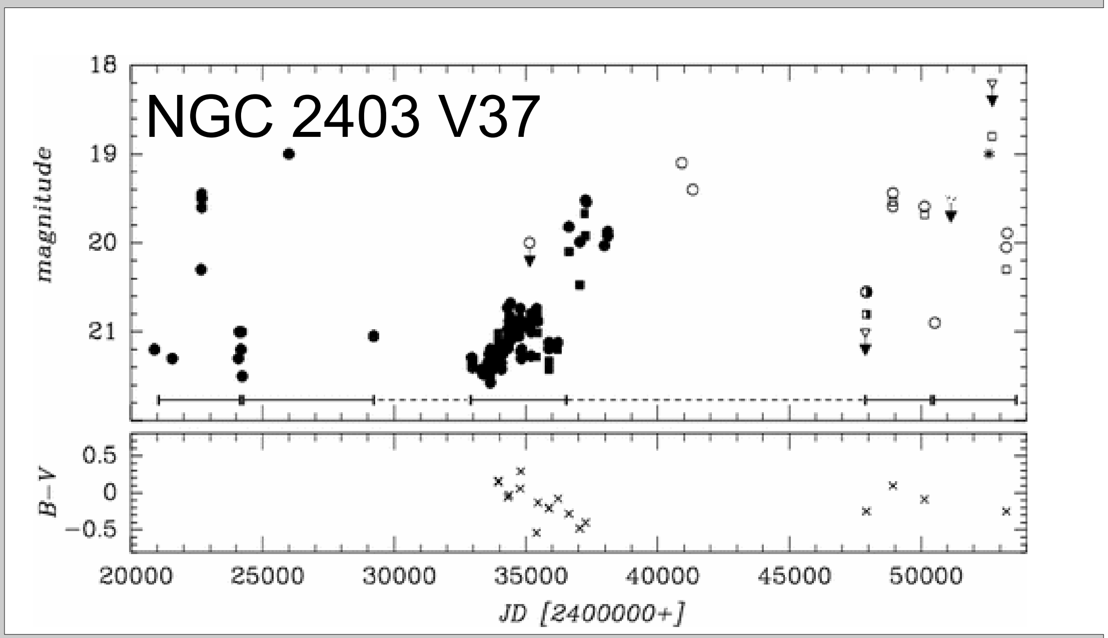
# Nomenklatur für Variable Sterne

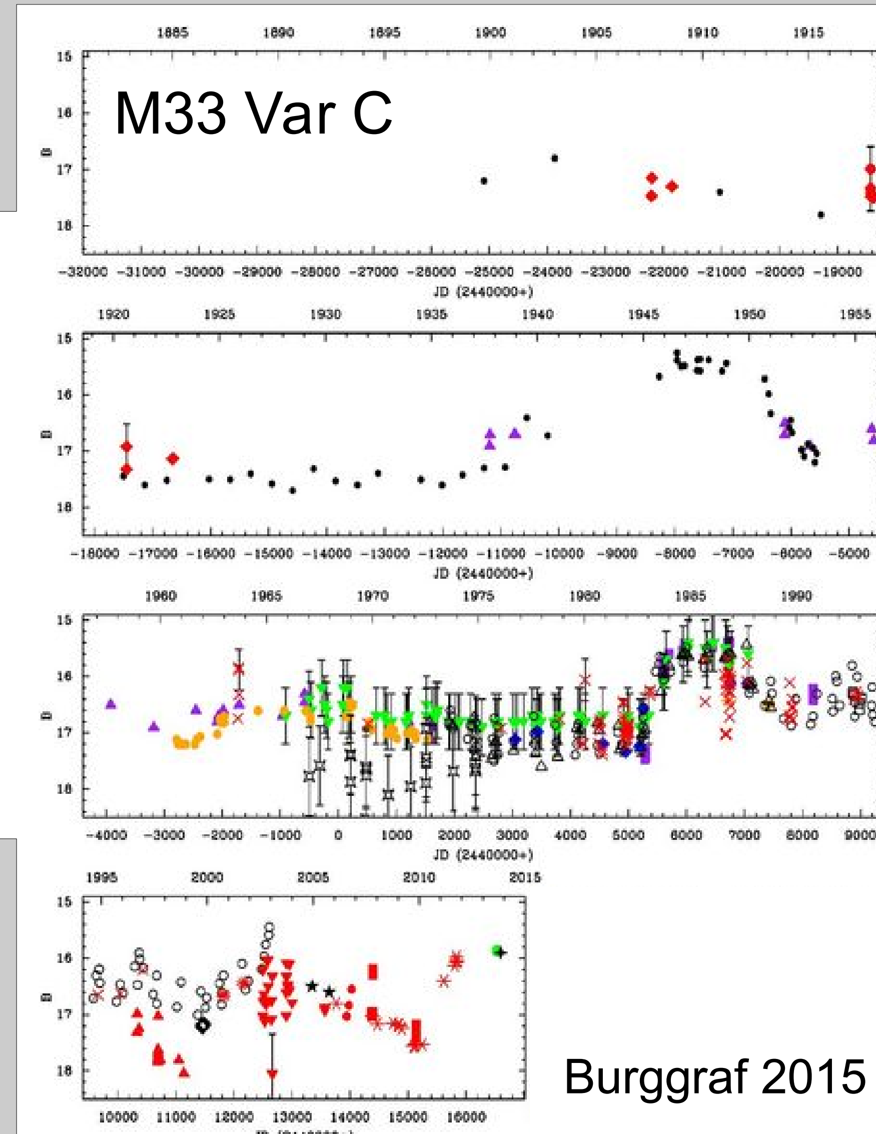
**in external Galaxien**

Galaxyname V1, V2 or  Var 1, Var 2  or/and  Var A , Var B

Examples:  NGC 2403 V37,  M33 Var C




Weis & Bomans  2005



**So let's start …**

**there's a lot to do**

| Type | Numb. Stars |
|---|---|
| | 563 |
| * | 92 |
| ACV | 331 |
| ACV+DSCT: | 1 |
| ACV+DSCTC | 1 |
| ACV: | 84 |
| ACVO | 33 |
| ACVO: | 2 |
| ACYG | 61 |
| ACYG: | 60 |
| AM | 13 |
| AM/XRM+E | 1 |
| AM: | 3 |
| BCEP | 123 |
| BCEP(B) | 2 |
| BCEP+E | 1 |
| BCEP+E: | 4 |
| BCEP+EA/D | 1 |
| BCEP+ELL: | 1 |
| BCEP: | 46 |
| BCEPS | 2 |
| BE | 250 |
| BE+BCEP: | 1 |
| BE: | 48 |
| BLBOO | 1 |
| BLLAC | 5 |
| BY | 820 |
| BY+UV | 15 |
| BY+UV: | 1 |
| BY: | 210 |
| BY:+E: | 1 |
| BY:+UV: | 1 |
| CEP | 129 |
| CEP(B) | 20 |
| CEP: | 52 |
| CST | 72 |
| CST: | 111 |
| CW | 3 |
| CW: | 3 |
| CWA | 114 |

| Type | Numb. Stars |
|---|---|
| CWA: | 22 |
| CWB | 96 |
| CWB: | 25 |
| DCEP | 524 |
| DCEP(B) | 1 |
| DCEP: | 12 |
| DCEPS | 58 |
| DCEPS(B) | 1 |
| DCEPS: | 7 |
| DSCT | 176 |
| DSCT(B) | 1 |
| DSCT(B:) | 1 |
| DSCT: | 40 |
| DSCTC | 376 |
| DSCTC(B) | 1 |
| DSCTC+E | 1 |
| DSCTC+E: | 1 |
| DSCTC+ELL | 1 |
| DSCTC+GDOR | 1 |
| DSCTC: | 95 |
| E | 486 |
| E+ACYG+X | [illegible] |
| E+AM | 3 |
| E+AM: | 1 |
| E+BE | 1 |
| E+DSCTC | 1 |
| E+IS: | 1 |
| E+NC | 1 |
| E+NL | 7 |
| E+RS | 1 |
| E+UGSU: | 1 |
| E+UV | 3 |
| E+WR | 1 |
| E+X | 2 |
| E+XB | 1 |
| E+XI | 1 |
| E+XJ | 1 |
| E+XM | 8 |
| E+XM: | 1 |
| E+XP | 1 |
| E+XPM | 1 |
| E+XPRM | 1 |
| E+XR | 1 |
| E+XRM | 1 |
| E/D | 5 |
| E/D/WR | 1 |
| E/D: | 1 |
| E/DM | 9 |
| E/DM: | 1 |
| E/DS | 3 |
| E/DS: | 2 |


| Type | Numb. Stars |
|---|---|
| CWA: | 22 |
| CWB | 96 |
| CWB: | 25 |
| DCEP | 524 |
| DCEP(B) | 1 |
| DCEP: | 12 |
| DCEPS | 58 |
| DCEPS(B) | 1 |
| DCEPS: | 7 |
| DSCT | 176 |
| DSCT(B) | 1 |
| DSCT(B:) | 1 |
| DSCT: | 40 |
| DSCTC | 376 |
| DSCTC(B) | 1 |
| DSCTC+E | 1 |
| DSCTC+E: | 1 |
| DSCTC+ELL | 1 |
| DSCTC+GDOR | 1 |
| DSCTC: | 95 |
| E | [illegible] |
| E+ACYG+X | [illegible] |
| E+AM | 3 |
| E+AM: | 1 |
| E+BE | 1 |
| E+DSCTC | 1 |
| E+IS: | 1 |
| E+NC | [illegible] |
| E+NL | [illegible] |
| E+RS | [illegible] |
| E+UGSU: | [illegible] |
| E+UV | 3 |
| E+WR | 1 |
| E+X | 2 |
| E+XB | 1 |
| E+XI | 1 |
| E+XJ | 1 |
| E+XM | 8 |
| E+XM: | 1 |
| E+XP | 1 |
| E+XPM | 1 |
| E+XPRM | 1 |
| E+XR | 1 |
| E+XRM | 1 |
| E/D | 5 |
| E/D/WR | 1 |
| E/D: | 1 |
| E/DM | 9 |
| E/DM: | 1 |
| E/DS | 3 |
| E/DS: | 2 |


| Type | Numb. Stars |
|---|---|
| E/DW | 2 |
| E/GS+GCAS | 1 |
| E/KE | 8 |
| E/KE: | 1 |
| E/KW | 1 |
| E/KW: | 7 |
| E/PSR | 1 |
| E/RS | 10 |
| E/RS: | 1 |
| E/SD | 68 |
| E/SD: | 81 |
| E/WD+NL | 1 |
| E/WR | 3 |
| E/WR+E: | 1 |
| E: | 286 |
| E:+DSCTC: | 1 |
| E:+NL | 1 |
| E:+SXARI | 1 |
| E:/GS | 1 |
| E:/GS+SR | 1 |
| E:/GS: | 1 |
| E:/PN | 1 |
| E:/RS | 5 |
| E:/RS: | 3 |
| E:/SD: | 6 |
| E:/WR | [illegible] |
| EA | 2733 |
| [illegible] | 1 |
| [illegible] | 1 |
| EA+AM: | 1 |
| EA+BCEP: | 2 |
| EA+BE | 2 |
| EA+BE: | 1 |
| EA+DSCT | 5 |
| EA+DSCT: | 2 |
| EA+DSCTC | 6 |
| EA+LPB | 1 |
| EA+LPB: | 2 |
| EA+NL | 11 |
| EA+NL: | 1 |
| EA+RPHS | 1 |
| EA+RS | 1 |
| EA+SRD | 1 |
| EA+UG | 1 |
| EA+UG: | 1 |
| EA+UGSU: | 1 |
| EA+UV | 1 |
| EA+UV+BY | 1 |
| EA+UV: | 1 |
| EA+XM | 2 |
| EA+ZAND | 1 |

| Type | Numb. Stars |
|---|---|
| EA+ZZ | 1 |
| EA/AR | 6 |
| EA/AR/RS | 7 |
| EA/AR: | 6 |
| EA/AR:/RS | 2 |
| EA/D | 110 |
| EA/D+BY | 1 |
| EA/D/RS | 6 |
| EA/D/RS+X | 1 |
| EA/D/WD | 1 |
| EA/D/WR | 1 |
| EA/D: | 16 |
| EA/D:/PN | 1 |
| EA/D:/RS | 1 |
| EA/D:/RS: | 1 |
| EA/DM | 221 |
| EA/DM+ACV: | 1 |
| EA/DM+UV | 1 |
| EA/DM/RS | 1 |
| [illegible] | 31 |
| EA/DS | 109 |
| EA/DS/RS | 2 |
| EA/DS: | 30 |
| EA/DW | 6 |
| EA/DW/RS: | [illegible] |
| EA/DW: | [illegible] |
| EA/GS | [illegible] |
| [illegible] | [illegible] |
| EA/GS+ZAND | 1 |
| EA/GS/D | 5 |
| EA/GS/RS | 2 |
| EA/GS/RS: | 1 |
| EA/GS/WD | 1 |
| EA/GS: | 10 |
| EA/K: | 2 |
| EA/KE | 42 |
| EA/KE: | 59 |
| EA/KW | 1 |
| EA/KW: | 1 |
| EA/NL | 1 |
| EA/PN | 1 |
| EA/RS | 59 |
| EA/RS: | 10 |
| EA/SD | 829 |
| EA/SD/RS | 1 |
| EA/SD/RS: | 1 |
| EA/SD: | 292 |
| EA/WD | 1 |
| EA/WD+NL | 4 |
| EA/WR | 4 |
| EA: | 160 |

| Type | Numb. Stars |
|---|---|
| EA:/GS | 1 |
| EA:/PN | 1 |
| EA:/SD: | 2 |
| EB | 673 |
| EB+* | 1 |
| EB+DSCTC | 1 |
| EB+EA | 1 |
| EB+EB | 1 |
| EB/AR | 3 |
| EB/AR/RS | 1 |
| EB/AR: | 3 |
| EB/D | 14 |
| EB/D/GS | 1 |
| EB/D: | 4 |
| EB/DM | 55 |
| EB/DM/WR | 1 |
| EB/DM: | 9 |
| EB/DS | 3 |
| EB/DW | 6 |
| EB/DW/RS | 1 |
| EB/GS | 11 |
| EB/GS+ACYG | 1 |
| EB/GS+SRD | 1 |
| EB/GS/D | 1 |
| [illegible] | 1 |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| EB/K | 2 |
| EB/K: | 1 |
| EB/KE | 152 |
| EB/KE: | 17 |
| EB/KW | 8 |
| EB/KW: | 5 |
| EB/RS | 3 |
| EB/SD | 42 |
| EB/SD: | 22 |
| EB/WR | 2 |
| EB: | 91 |
| EB:/D: | 1 |
| EB:/DM | 1 |
| EB:/DM: | 1 |
| EB:/DS: | 1 |
| EB:/GS | 1 |
| EB:/GS: | 1 |
| EB:/KE | 2 |
| EB:/KE: | 1 |
| EB:/KW: | 1 |
| EB:/RS | 1 |
| EC | 1 |
| ELL | 63 |
| ELL+BCEP | 1 |

| Type | Numb. Stars |
|---|---|
| ELL+BCEP: | 1 |
| ELL+DSCTC | 1 |
| ELL+RS | 1 |
| ELL+X | 1 |
| ELL+XF | 1 |
| ELL+XP | 1 |
| ELL+XPNG: | 1 |
| ELL/DM | 2 |
| ELL/DW: | 1 |
| ELL/KE | 1 |
| ELL/PN | 1 |
| ELL/RS | 2 |
| ELL/WR+* | 1 |
| ELL: | 83 |
| ELL:+BCEP | 1 |
| ELL:+DSCTC | 1 |
| ELL:+UV | 1 |
| ELL:+WR | 1 |
| EP | 7 |
| EP: | 27 |
| EW | 1445 |
| EW : | 1 |
| EW+EW | 2 |
| EW/D | 1 |
| EW/D: | 1 |
| EW/DM | 1 |
| EW/DM: | 1 |
| EW/DW | 12 |
| EW/DW/RS | 1 |
| EW/K | 4 |
| EW/KE | 61 |
| EW/KE: | 9 |
| EW/KW | 293 |
| EW/KW: | 4 |
| EW/RS | 3 |
| EW: | 130 |
| EW:/KE | 3 |
| EW:/KE: | 4 |
| EW:/KW | 4 |
| EW:/KW: | 7 |
| FKCOM | 8 |
| FKCOM: | 5 |
| FU | 10 |
| FU: | 12 |
| GAL | 8 |
| GAL: | 1 |
| GCAS | 101 |
| GCAS+BCEP | 1 |
| GCAS+BCEP: | 1 |
| GCAS+ELL | 1 |
| GCAS+UV: | 1 |

| Type | Numb. Stars |
|---|---|
| GCAS+XP | 1 |
| GCAS: | 34 |
| GCAS:+XP | 1 |
| GDOR | 57 |
| GDOR+DSCT | 1 |
| GDOR+DSCTC | 1 |
| GDOR: | 28 |
| I | 163 |
| I: | 47 |
| IA | 35 |
| IA: | 25 |
| IB | 70 |
| IB: | 19 |
| IN | 467 |
| IN(YY) | 3 |
| IN: | 66 |
| INA | 74 |
| INA: | 7 |
| INAT | 1 |
| INB | 691 |
| INB+BY | 1 |
| INB+E: | 2 |
| INB: | 31 |
| INB:+E: | 1 |
| INS | 263 |
| INS: | 95 |
| INSA | 21 |
| INSA: | 3 |
| INSB | 437 |
| INSB(YY) | 2 |
| INSB: | 5 |
| INST | 43 |
| INST(YY) | 10 |
| INT | 295 |
| INT(YY) | 8 |
| INT: | 6 |
| IS | 47 |
| IS: | 83 |
| ISA | 13 |
| ISA(YY) | 1 |
| ISA: | 11 |
| ISB | 32 |
| ISB: | 30 |
| IT | 75 |
| IT: | 10 |
| L | 425 |
| L: | 121 |
| LB | 2281 |
| LB+E: | 1 |
| LB: | 1068 |
| LBV | 1 |

| Type | Numb. Stars |
|---|---|
| LBV: | 3 |
| LC | 87 |
| LC+E: | 1 |
| LC: | 21 |
| LPB | 102 |
| LPB: | 45 |
| M | 6804 |
| M+NB: | 1 |
| M+ZAND | 2 |
| M: | 1270 |
| N | 60 |
| N+UG:+EA | 1 |
| N: | 31 |
| NA | 195 |
| NA+E | 2 |
| NA+E: | 1 |
| NA+EA | 5 |
| NA+XM: | 1 |
| NA+XP | 1 |
| NA: | 8 |
| NAB | 1 |
| NB | 37 |
| NB+EA | 3 |
| NB: | 1 |
| NC | 6 |
| NC+M | 2 |
| NC: | 4 |
| NL | 92 |
| NL+E | 1 |
| NL+X | 2 |
| NL+ZZ | 2 |
| NL+ZZ: | 2 |
| NL: | 26 |
| NR | 6 |
| NR+EA | 1 |
| NR: | 2 |
| PSR | 1 |
| PVTEL | 12 |
| PVTEL: | 3 |
| QSO | 7 |
| R | 15 |
| R/PN | 1 |
| R: | 2 |
| R:/PN | 1 |
| RCB | 31 |
| RCB: | 16 |
| RPHS | 39 |
| RPHS+ELL | 1 |
| RPHS: | 1 |
| RR | 1458 |
| RR(B) | 22 |

| Type | Numb. Stars |
|---|---|
| RR: | 292 |
| RRA | 1 |
| RRAB | 5405 |
| RRAB: | 38 |
| RRC | 636 |
| RRC: | 88 |
| RS | 374 |
| RS+DSCT: | 1 |
| RS+E | 2 |
| RS: | 89 |
| RV | 40 |
| RV: | 54 |
| RVA | 38 |
| RVA: | 4 |
| RVB | 14 |
| RVB+EA | 1 |
| RVB: | 2 |
| S: | 174 |
| SDOR | 13 |
| SDOR: | 6 |
| SN | 2 |
| SN+PSR | 1 |
| SNI | 3 |
| SNI: | 1 |
| SR | 1581 |
| SR+ZAND | 1 |
| SR: | 1273 |
| SR:+E | 1 |
| SRA | 1041 |
| SRA+EA | 1 |
| SRA: | 52 |
| SRB | 1854 |
| SRB: | 199 |
| SRC | 70 |
| SRC: | 12 |
| SRD | 150 |
| SRD+E: | 1 |
| SRD+EA | 1 |
| SRD: | 81 |
| SRS | 97 |
| SRS: | 11 |
| SXARI | 25 |
| SXARI: | 10 |
| SXPHE | 32 |
| SXPHE(B) | 2 |
| SXPHE: | 17 |
| UG | 151 |
| UG+E | 4 |
| UG+EA | 3 |
| UG: | 90 |
| UG:+E | 2 |

| Type | Numb. Stars |
|---|---|
| UG:+EW/WD | 1 |
| UGSS | 81 |
| UGSS+E | 1 |
| UGSS+E/WD | 1 |
| UGSS+EA | 2 |
| UGSS+ZZ: | 1 |
| UGSS: | 1 |
| UGSU | 88 |
| UGSU+E | 5 |
| UGSU+E+ZZ | 1 |
| UGSU+EA | 2 |
| UGSU: | 11 |
| UGZ | 26 |
| UGZ+E | 1 |
| UGZ+ZZ | 1 |
| UGZ: | 14 |
| UV | 1003 |
| UV+BY | 18 |
| UV+BY: | 4 |
| UV+EA | 1 |
| UV: | 31 |
| UV:+BY: | 1 |
| UVN | 532 |
| UVN(YY) | 1 |
| UVN+BY | 1 |
| UVN: | 16 |
| WR | 34 |
| WR: | 1 |
| X | 3 |
| X+BE | 1 |
| X+E | 1 |
| XB | 9 |
| XBI | 1 |
| XBN+E | 1 |
| XBND | 1 |
| XBP | 1 |
| XBPR | 1 |
| XF | 1 |
| XF: | 1 |
| XI | 7 |
| XI+E: | 1 |
| XI+RS | 1 |
| XJ | 1 |
| XJ: | 1 |
| XM | 56 |
| XM+E | 1 |
| XM+EA | 2 |
| XM+ELL | 1 |
| XM: | 1 |
| XN | 5 |
| XN+XP | 1 |

| Type | Numb. Stars |
|---|---|
| XN: | 1 |
| XND | 10 |
| XND+E: | 1 |
| XND+ELL | 1 |
| XND+ELL: | 2 |
| XNDR | 1 |
| XNG | 2 |
| XNGP | 2 |
| XP | 11 |
| XP: | 1 |
| XPM | 3 |
| XPM+ELL | 1 |
| XPNG | 1 |
| XPR | 2 |
| XPR+E | 1 |
| XR: | 1 |
| ZAND | 45 |
| ZAND+E | 1 |
| ZAND+M | 1 |
| ZAND+SR | 1 |
| ZAND: | 19 |
| ZZ | 6 |
| ZZ+NL | 2 |
| ZZ+UV: | 1 |
| ZZ: | 2 |
| ZZA | 39 |
| ZZB | 9 |
| ZZB: | 1 |
| ZZO | 10 |
| Total | 47970 |

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Total 47970 |

=====================================

(End) N.N. Samus [Moscow Inst. Astron.], O.V. Durlevich [Sternberg Astron. Inst., Moscow] 18-June-2015

# star formation

# stellare parameters

# stellar structure

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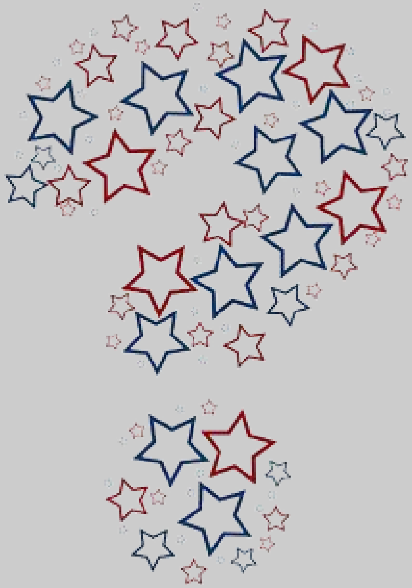
## star formation

## stellare parameters

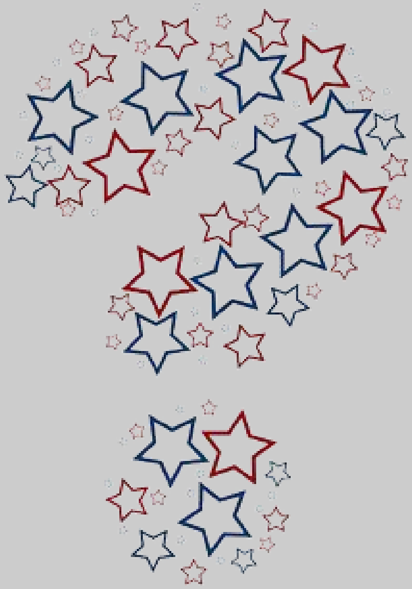
## stellar structure

# What is a star

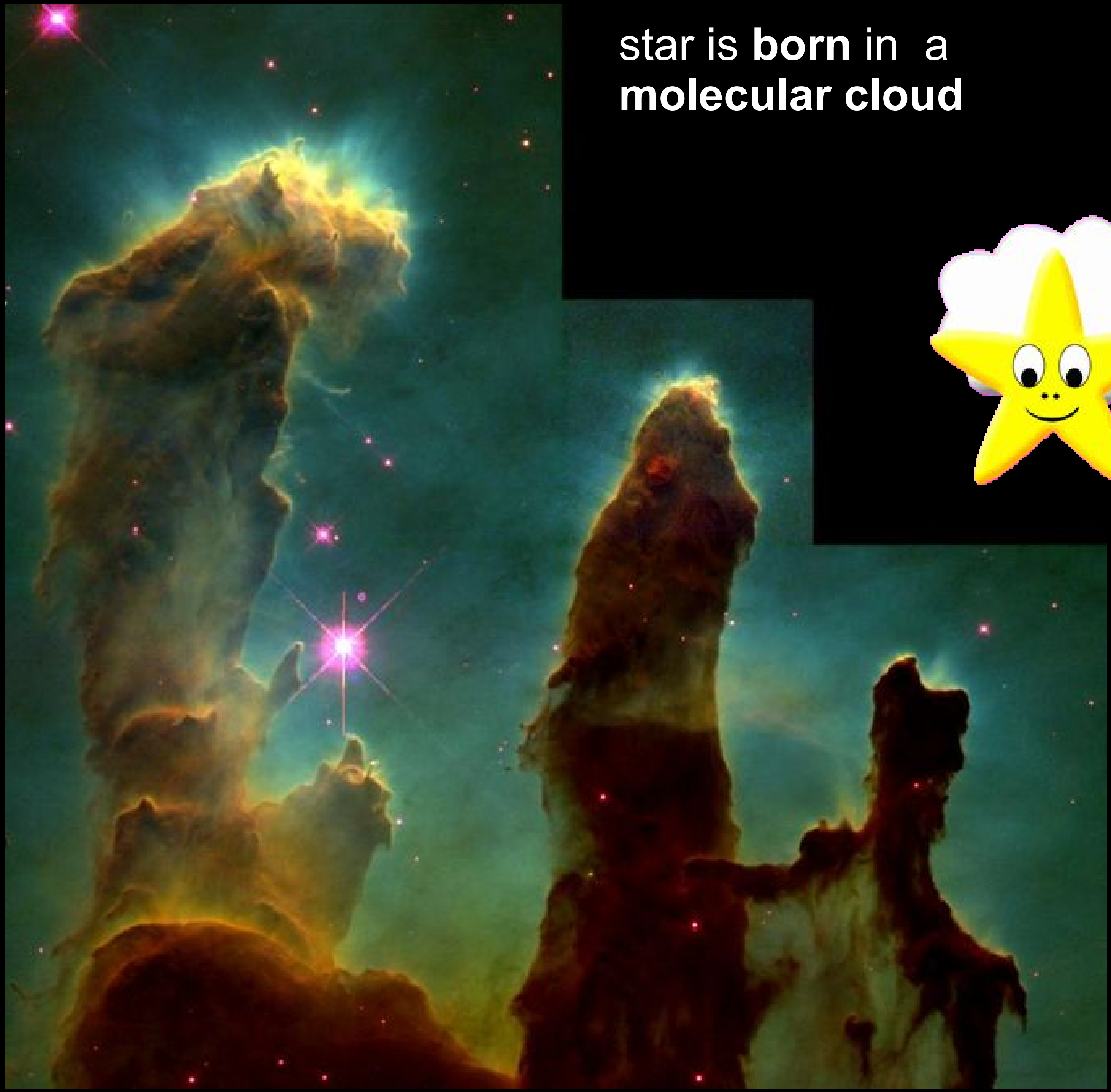


# star formation

# What is a star



# Stellar evolution – star formation



star is **born** in a
**molecular cloud**

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# star formation

Molecular clouds are stable, could gas/dust clouds

$$E_{pot} = \frac{-3\,G\,M^2}{5\,R} \qquad E_{kin} = \frac{3}{2}NkT \qquad N = \frac{M}{\mu m_H} \;\rightarrow\; E_{kin} = \frac{3}{2}\frac{M}{\mu m_H}kT$$

Virial Theorem: $E_{pot} = 2E_{kin}$ plus $M = V\rho$ & $V = 4/3\,\pi R^3$

$E_{pot} \leftrightarrow$ gravitation $E_{kin} \leftrightarrow$ ideal gas

→ Jeans Masse

$$M_{Jeans} = \left(\frac{5kT}{G\mu m_H}\right)^{3/2}\left(\frac{3}{4\pi\rho}\right)^{1/2}$$

stable if $M < M_{jeans}$ instable if $M > M_{jeans}$

→ if T low and $\rho$ high it beomes instabil → a collaps occurs

↔ if $T \approx 10\text{-}20$ K, $\rho \approx 10^4\ cm^{-3}$ ↔ cloud 10 - $1000M_\odot$

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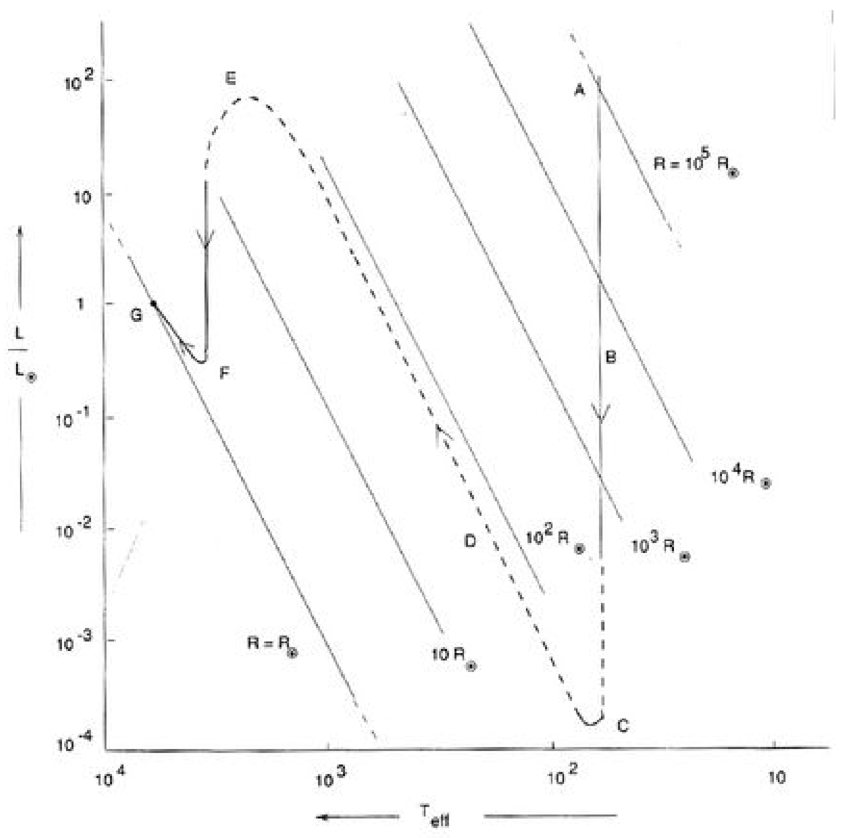
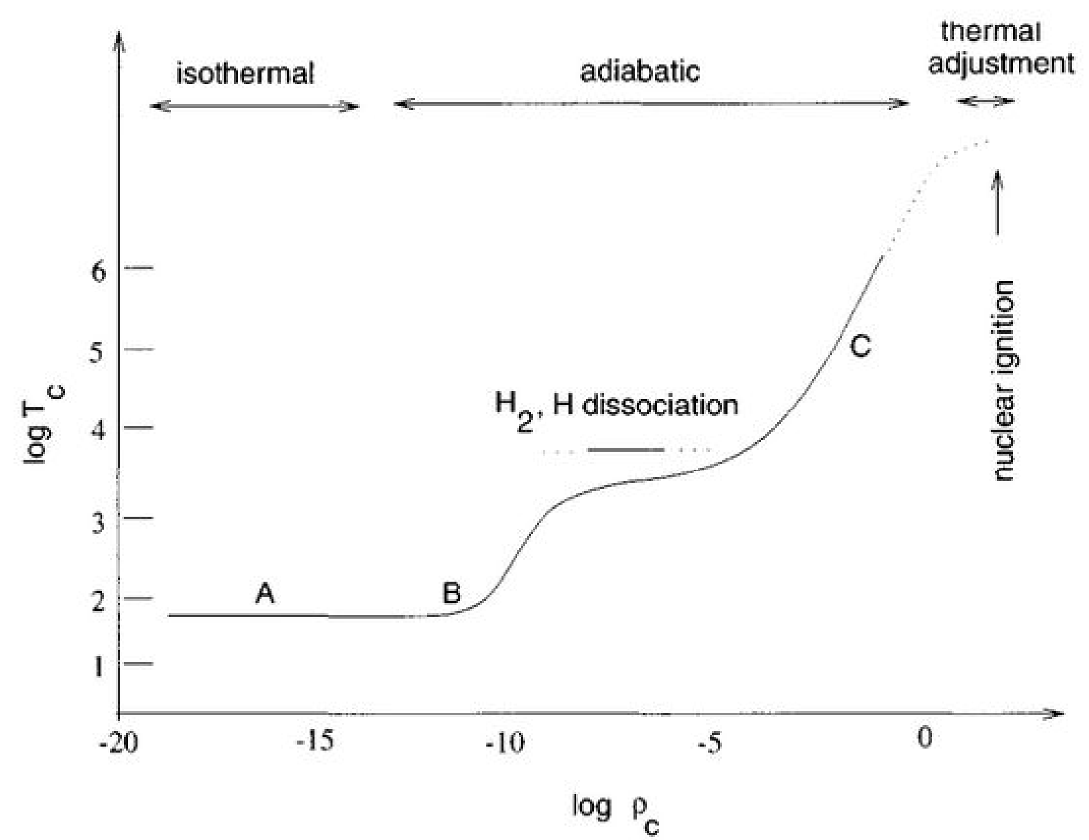
falls with free-free timeskala $t_{ff} \sim (\rho g)^{-1/2}$

# Starformation – for a star of 1 $M_\odot$

## evolution from molecular cloud to the main-sequence



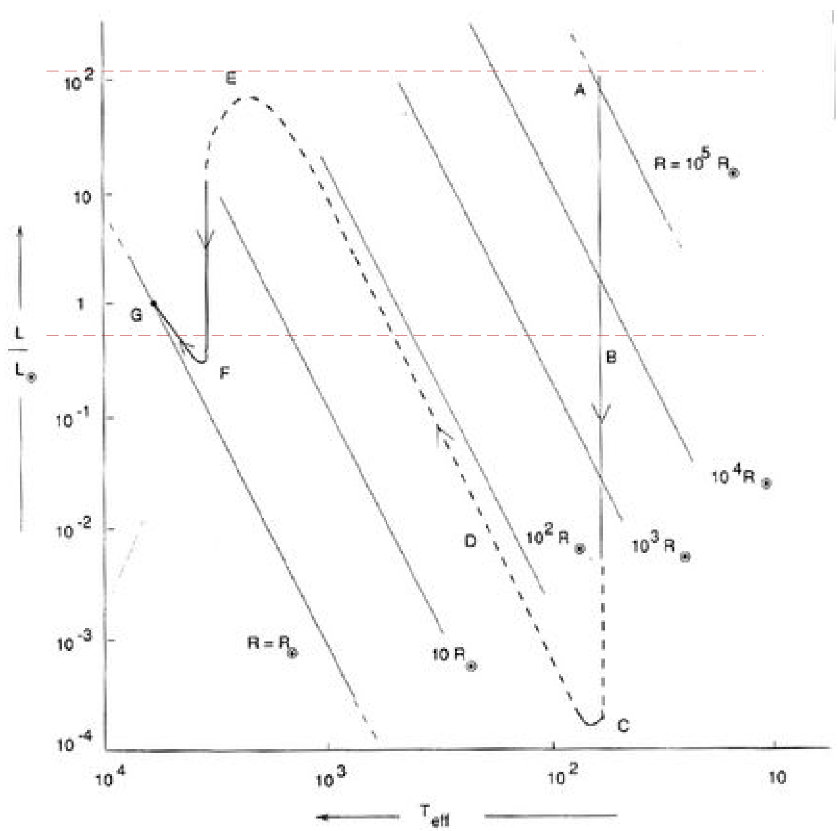

L $T_{eff}$ R plot ↔ HRD



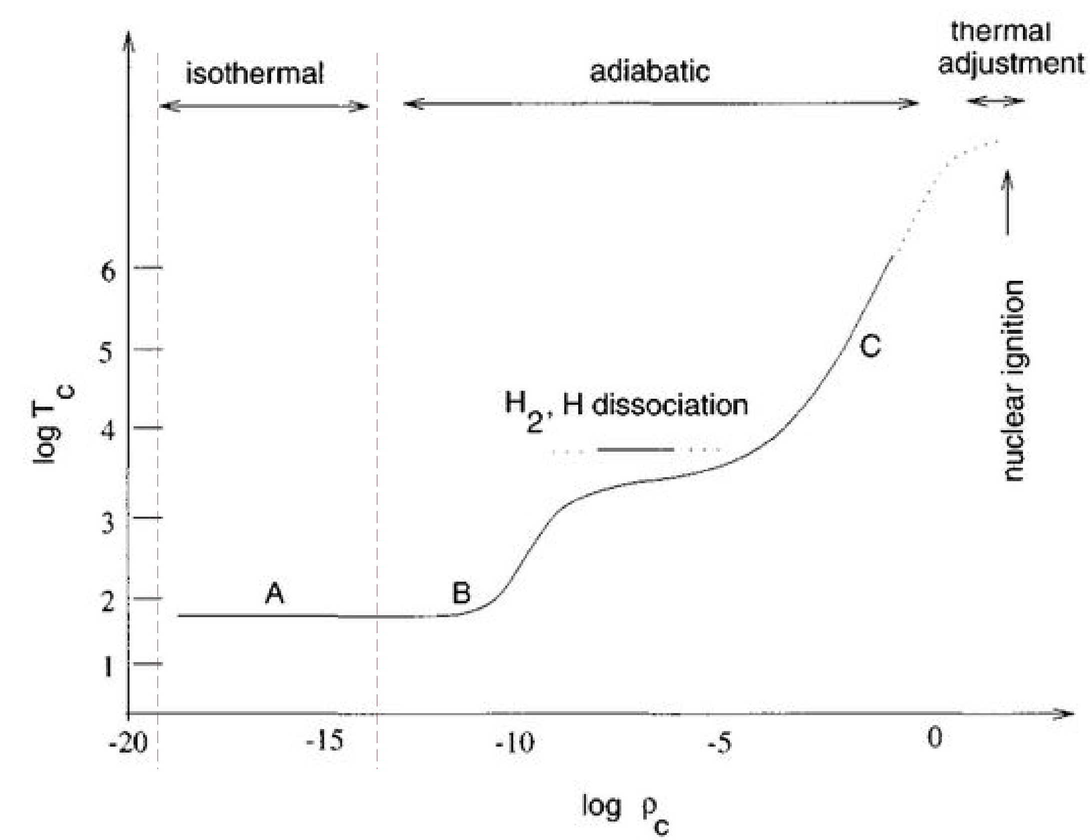

core temperature $T_C$ - density $\rho_C$ plot

# Starformation – for a star of 1 $M_\odot$

## evolution from molecular cloud to the main-sequence




L $T_{eff}$ R plot ↔ HRD




core temperature $T_C$ - density $\rho_C$ plot

molecular cloud **contracts isothermal (Phase A→ B)**

R and L shrink while ρ rises → forms a protostar

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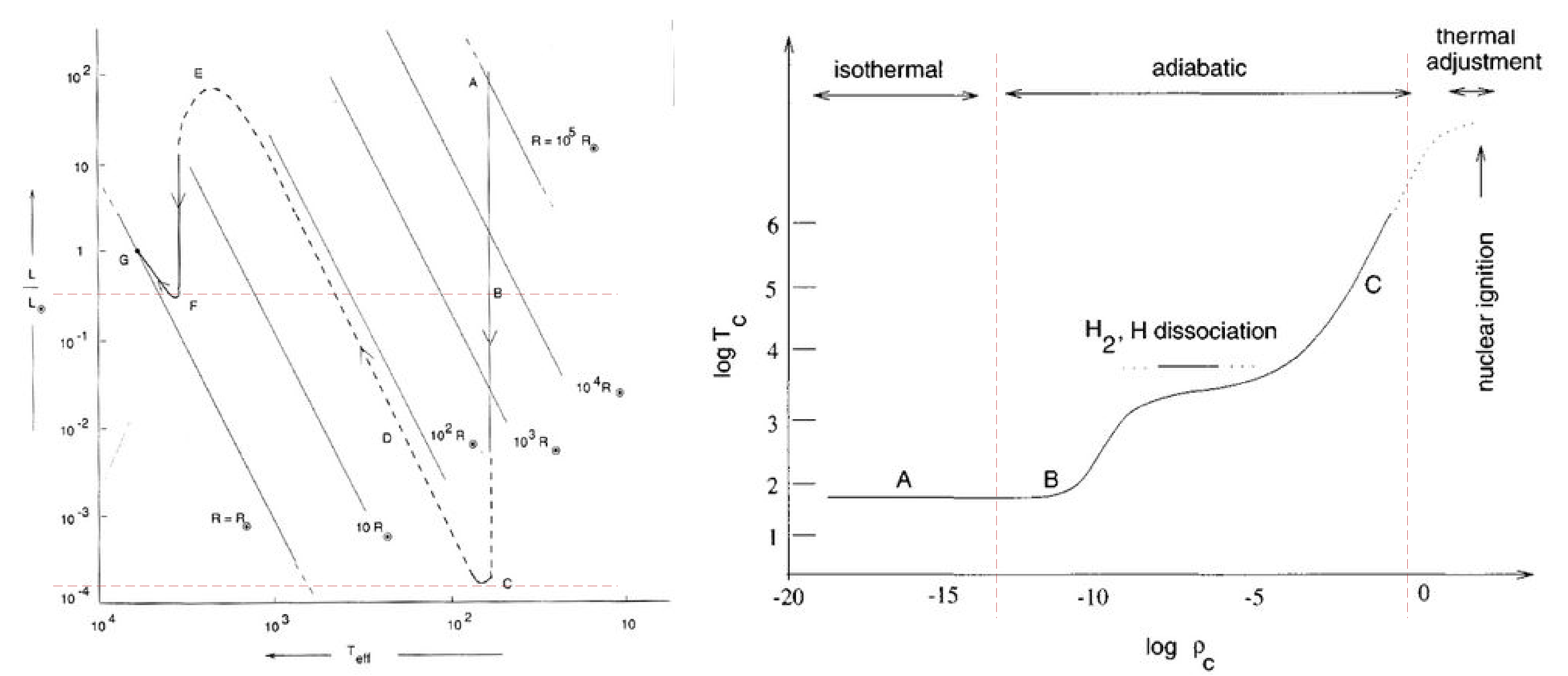
# Starformation – for a star of 1 $M_\odot$

## evolution from molecular cloud to the main-sequence



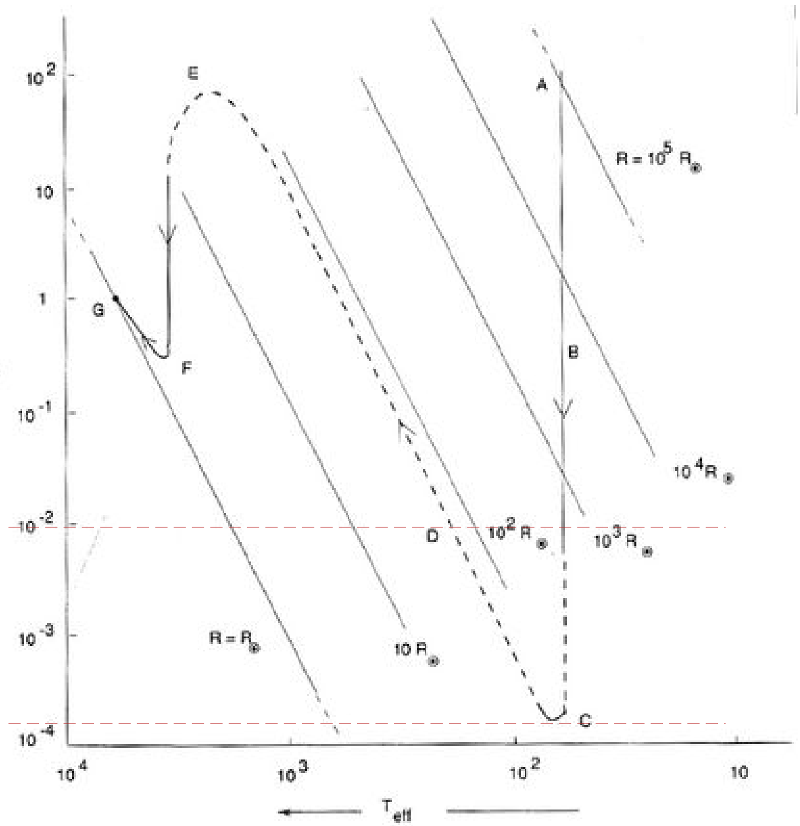

L $T_{eff}$ R plot ↔ HRD

core temperature $T_C$ - density $\rho_C$ plot

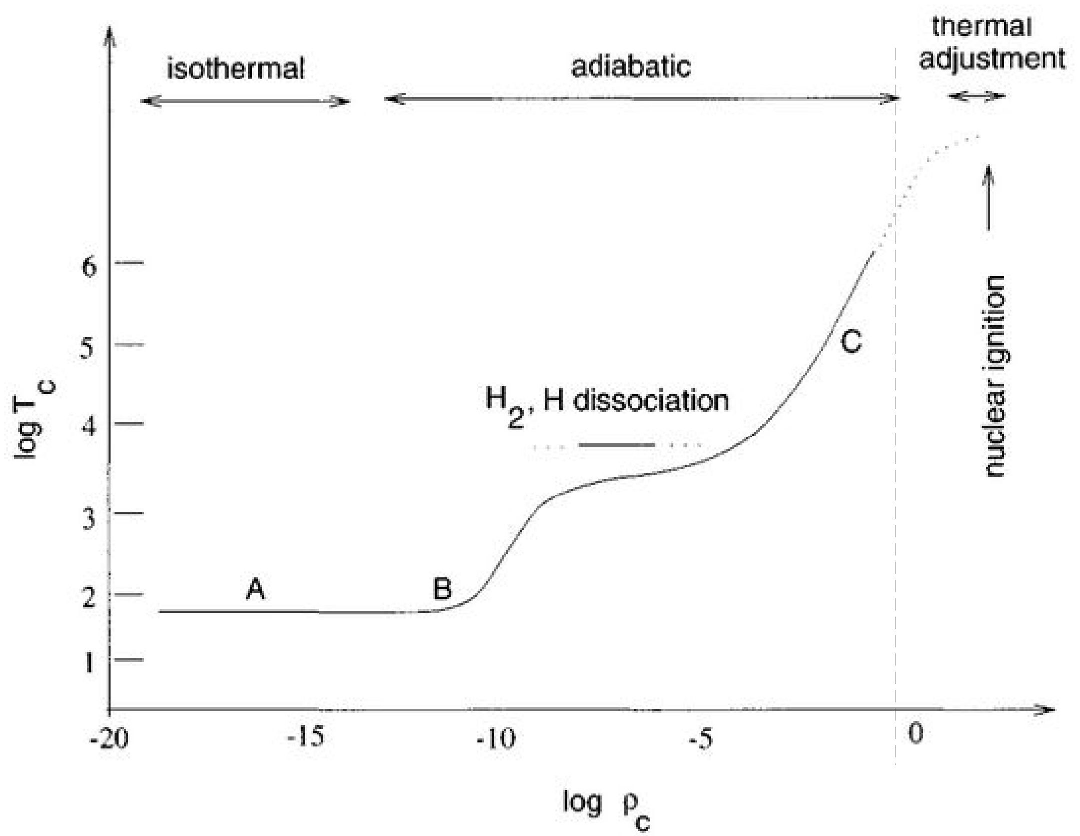
a **phase of adiabatic contraction (B → C)** follows where potential Energie is released

# Starformation – for a star of 1 $M_\odot$

## evolution from molecular cloud to the main-sequence




$L\ T_{eff} R$ plot ↔ HRD




core temperature $T_C$ - density $\rho_C$ plot

constant accretion till star reaches Hayashi Linie **(C → D)**
↔ fully convective protostar / pre-main-sequence star
and starts to adjust to thermal **equilibrium**

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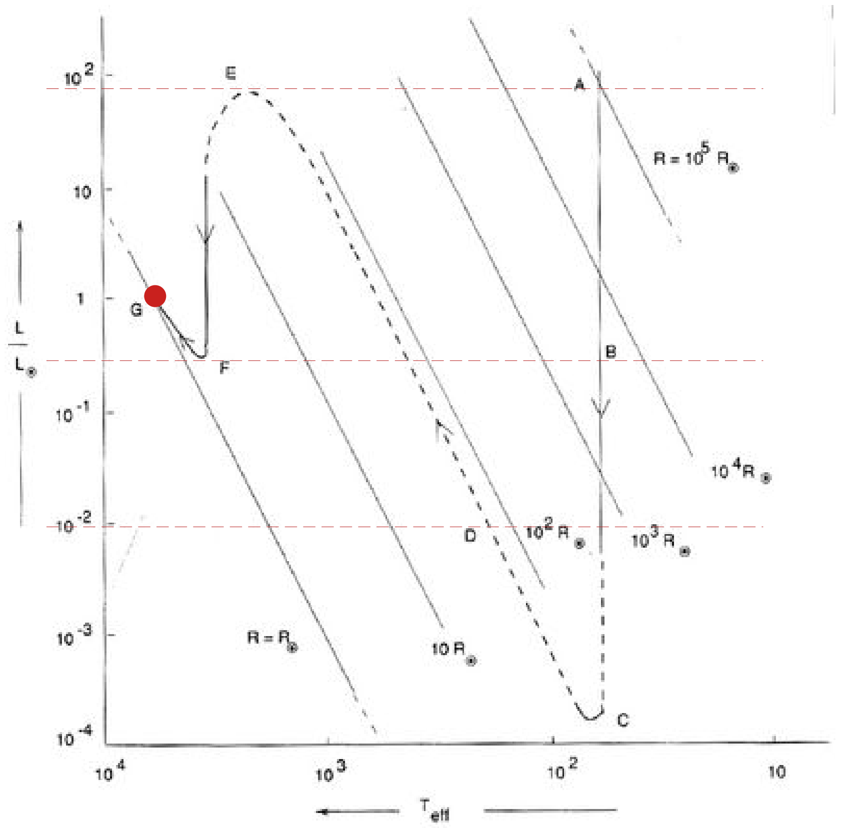
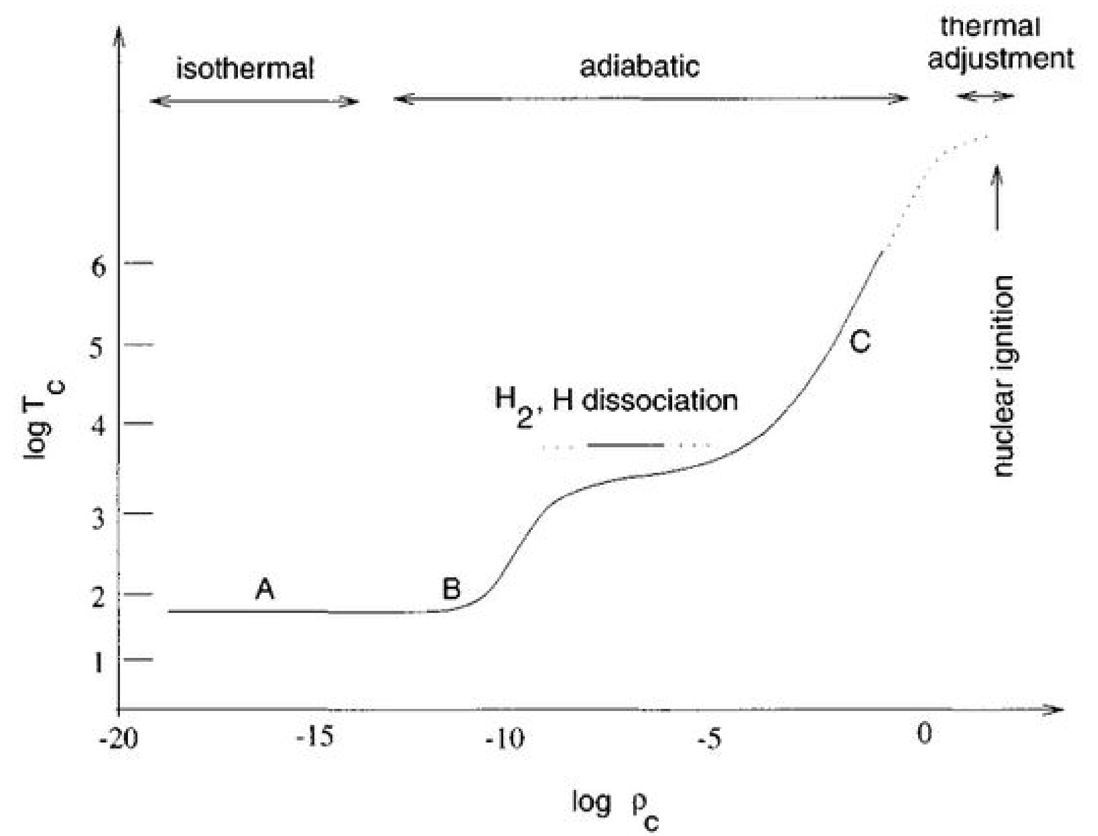
# Starformation – for a star of 1 $M_\odot$

## evolution from molecular cloud to the main-sequence




L $T_{eff}$ R plot ↔ HRD




core temperature $T_C$ - density $\rho_C$ plot

**pre-main-sequence star (D → E)** ↔ first (nuclear) burning stars <u>Deuterium burning</u>
→ complete adjustment to **equilibrium (F)**
→ <u>H-burning starts</u> **(G •)→ main-sequence star** is born

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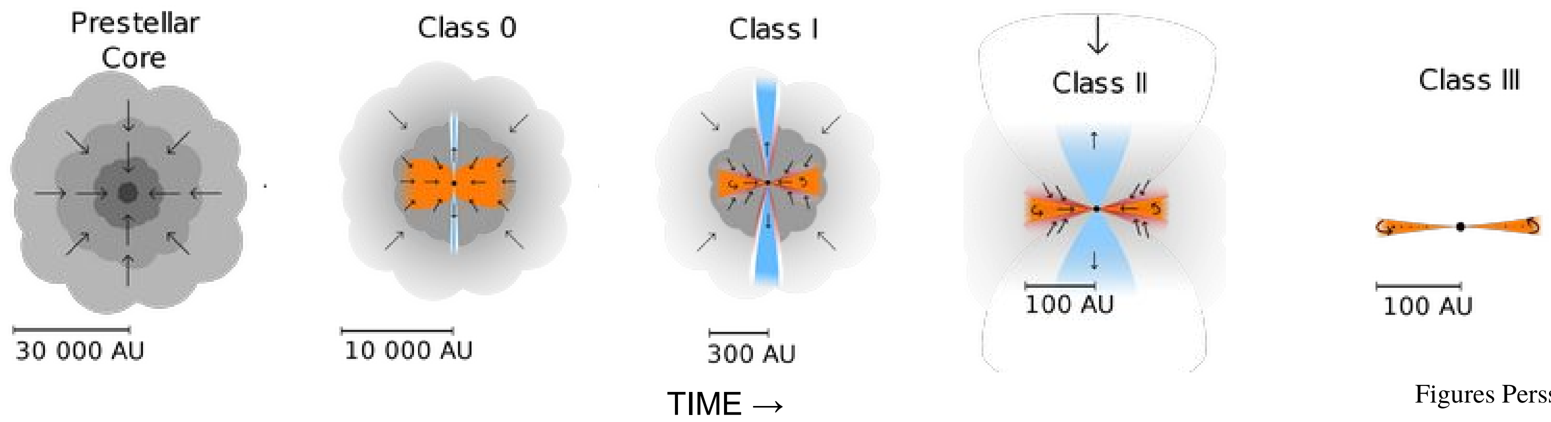
# Protostars - accretion disks

**Formation of a star** needs a **collapsing molecular cloud.**

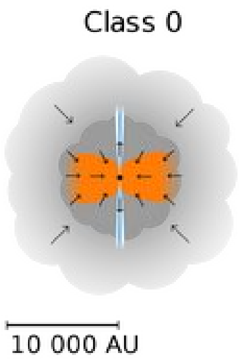
**During the formation process an accretion disk forms !**

The **molecular cloud**, the **protostar** and the **accretion disk** are observed but they emit at different wavelength. Depending on the state of the formation process (time within formation) one or the other dominates the spectrum.The individual states observed and corresponding spectra are labeled as protostellar **classes** from class 0 ↔ early to III ↔ late.

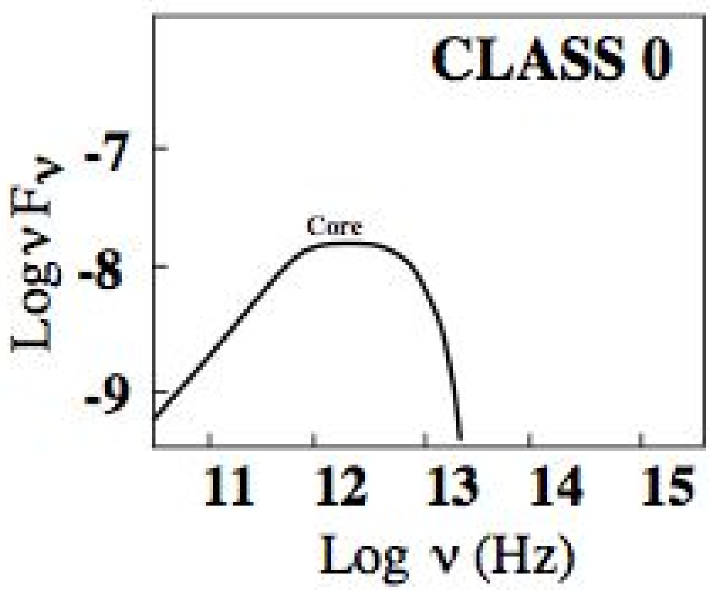


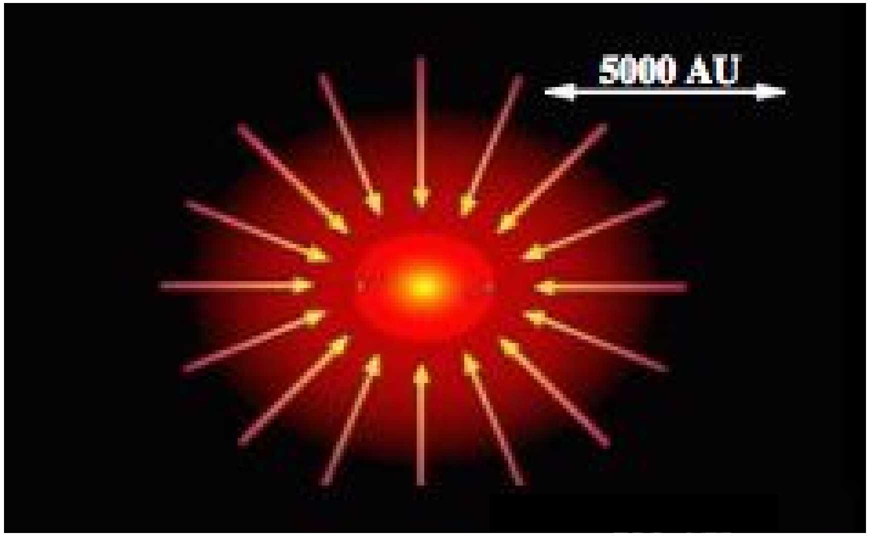

Figures Persson et al. (2014)

# Protostars – classes




**Class 0**
protostar still highly embedden, cloud emitts in mm regime $M_\star \ll M_{shell}$

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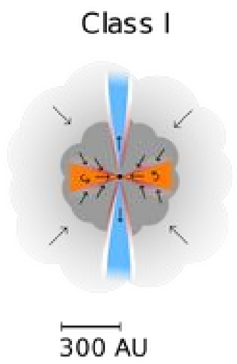
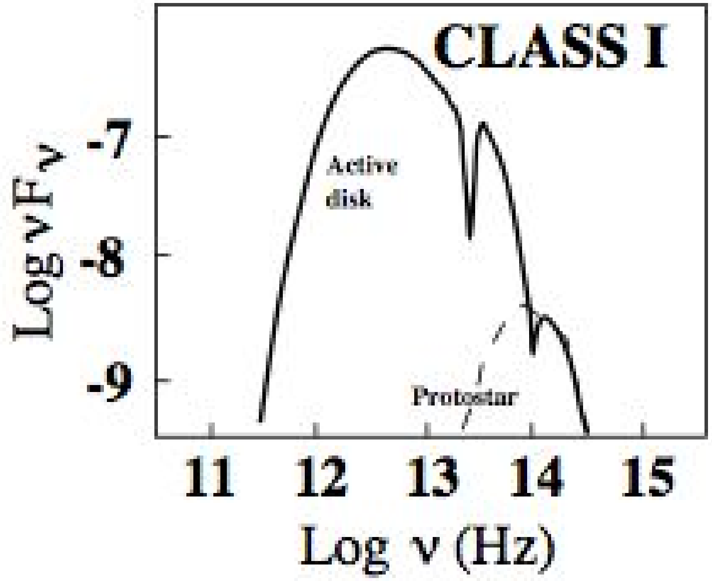
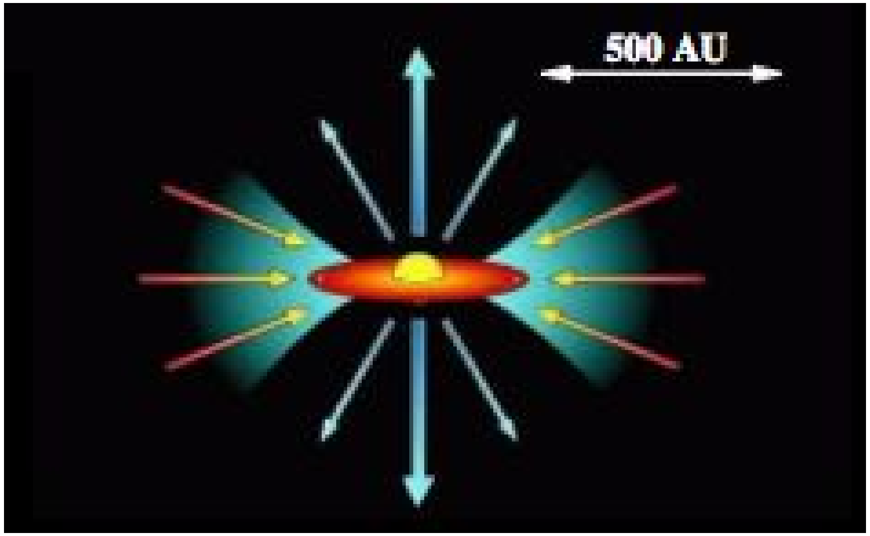
# Protostars – classes

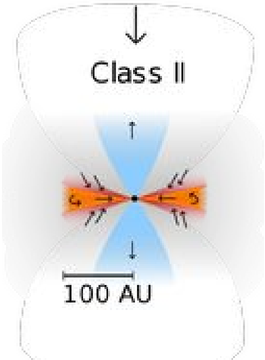



**Class I**
protostar slowly growth/heats up →emits in MIR regime, most of the emission from the accretion disk in NIR & mm

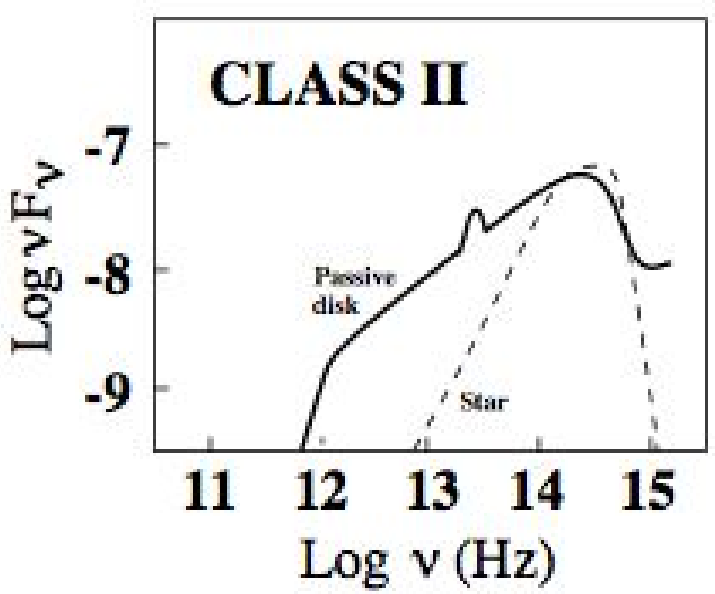


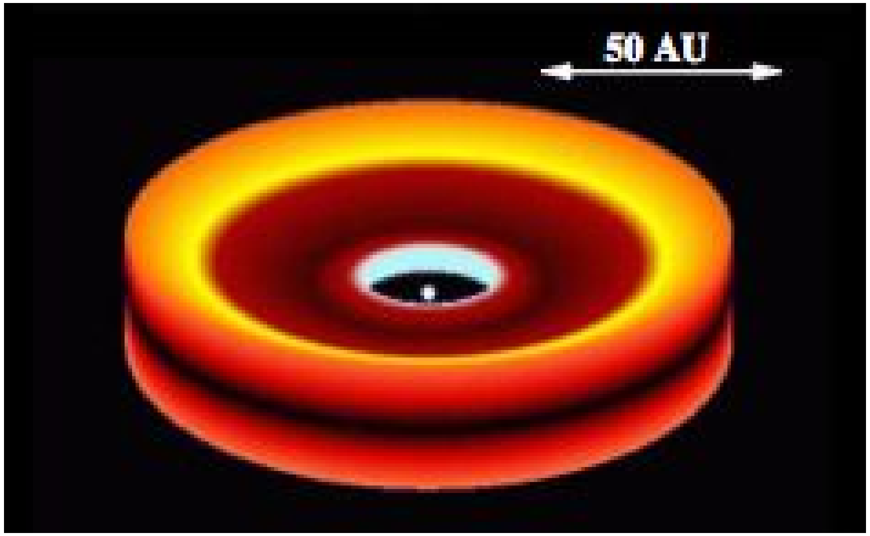



# Protostars – classes



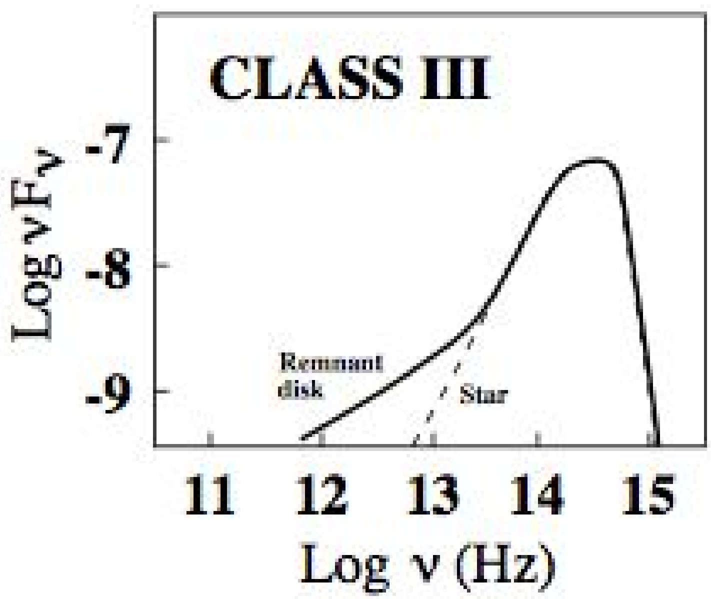

**Class II**
protostar heats up, MIR and NIR emission rises the accretion disk weakens. State ↔ T Tauri Stars



# Protostars – classes


**Class III**
protostar domininate the MIR and NIR regime.The remnant disk emits weakly. At that time planet formation may start.



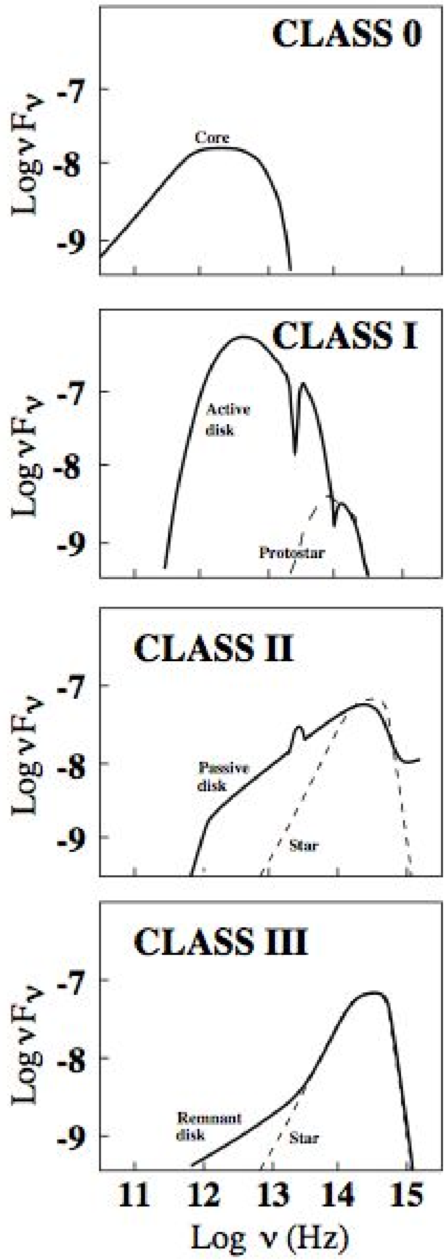

# Protostars - accretion disks

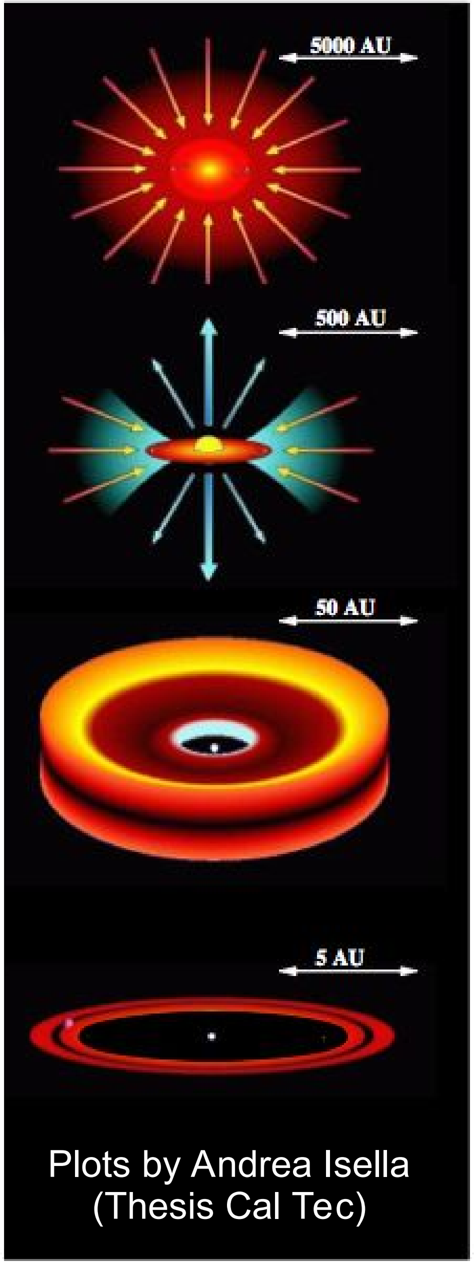
**Class 0**
protostar embedded cloud (mm) $M_\star \ll M_{shell}$

**Class I**
protostar growth (MIR), disk (NIR & mm)

**Class II**
protostar (MIR+NIR), less disk emission
T Tauri stars

**Class III**
protostar dominates (MIR+NIR) disk remnant
→ Planet formation



# Protostars - accretion disks

$t_{Class0+I}$ ~0.5Myrs

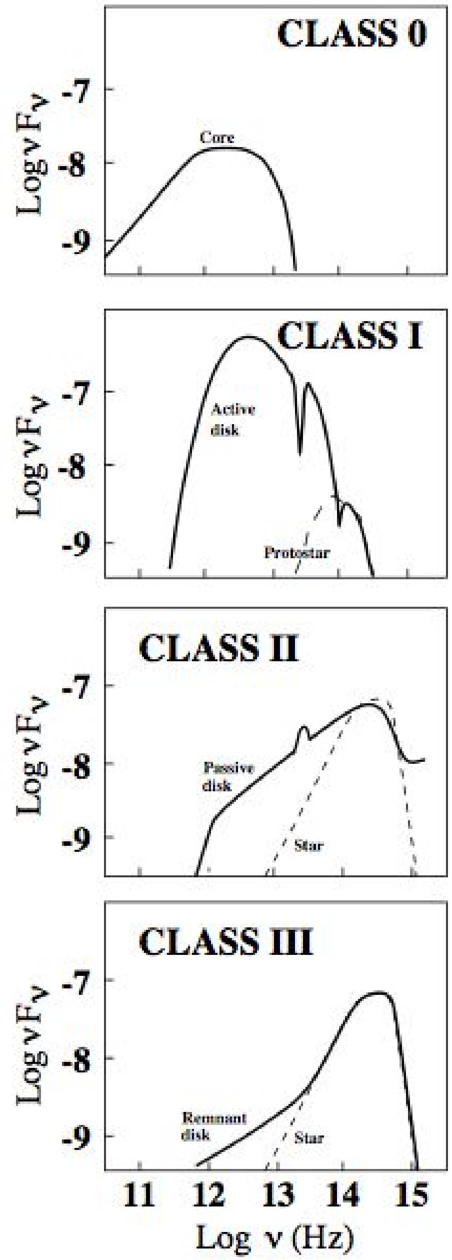
$t_{ClassIII}$ ~2Myrs

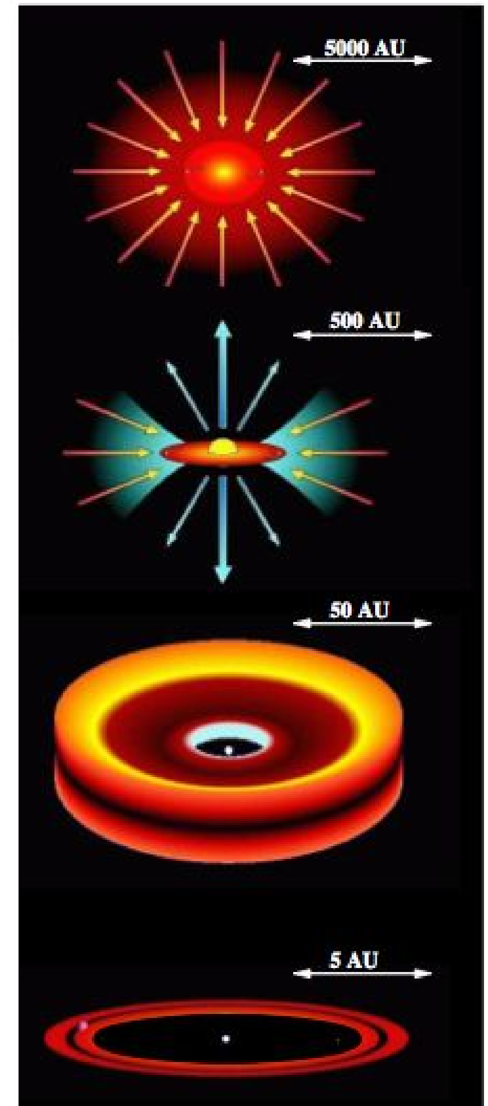
**Class 0**
protostar embedded cloud (mm) $M_\star \ll M_{shell}$

**Class I**
protostar growth (MIR), disk (NIR & mm)

**Class II**
protostar (MIR+NIR), less disk emission
T Tauri stars

**Class III**
protostar dominates (MIR+NIR) disk remnant
→ Planet formation




Plots by Andrea Isella (Thesis Cal Tec)

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# Protostar – T Tauri class

**T Tauri** stars

**pre-main-sequence star**
Stars **with** 0.3 – 3 $M_\odot$

<u>variability</u>

spectra → 'cool' show i.e. Ca II (H+K)
→ spectra still show Li (taken up in burnings)
↔ proofs a pre-main-sequence star
change in accretion rate ($10^{-6}$ $M_\odot$ $yr^{-1}$ - 6 $10^{-3}$ $M_\odot$ $yr^{-1}$) → variability

<u>accretion</u>

accretion disk → jets and mass loss

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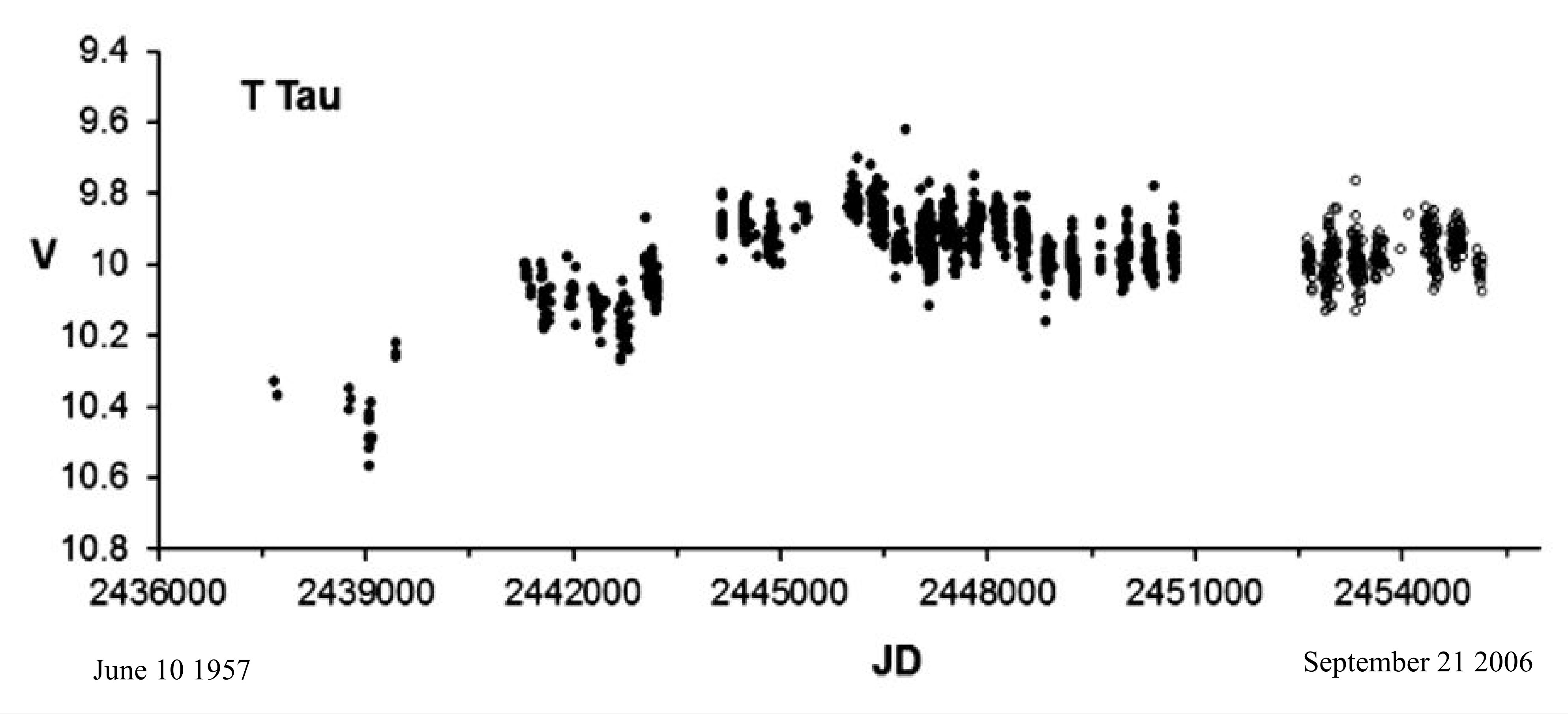
# Protostar – T Tauri class

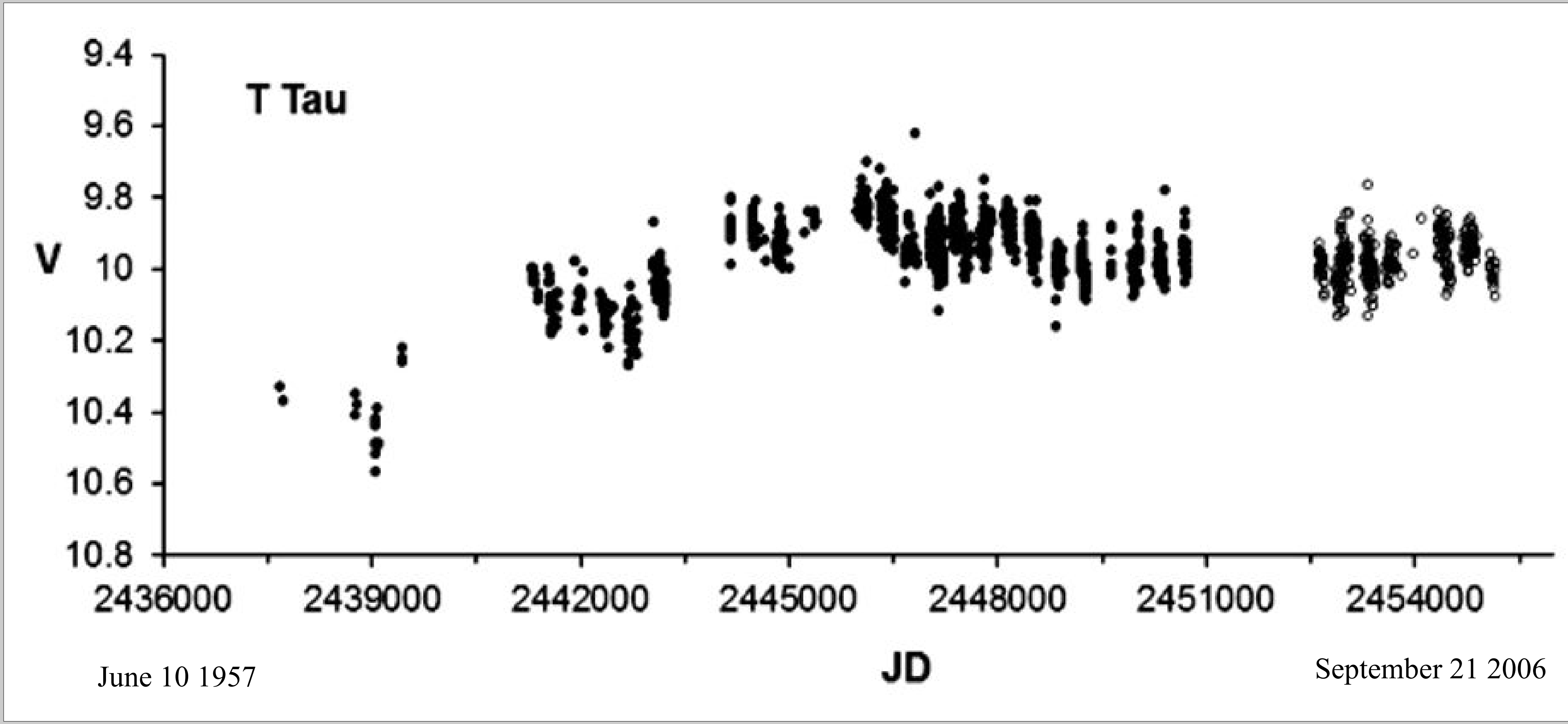
# Protostar – T Tauri class

**T Tauri** star **lightcurve** → **shows** **<u>variability</u>** **!!**



# Protostar – T Tauri class

**T Tauri** star **lightcurve** → **shows** **variability !!**

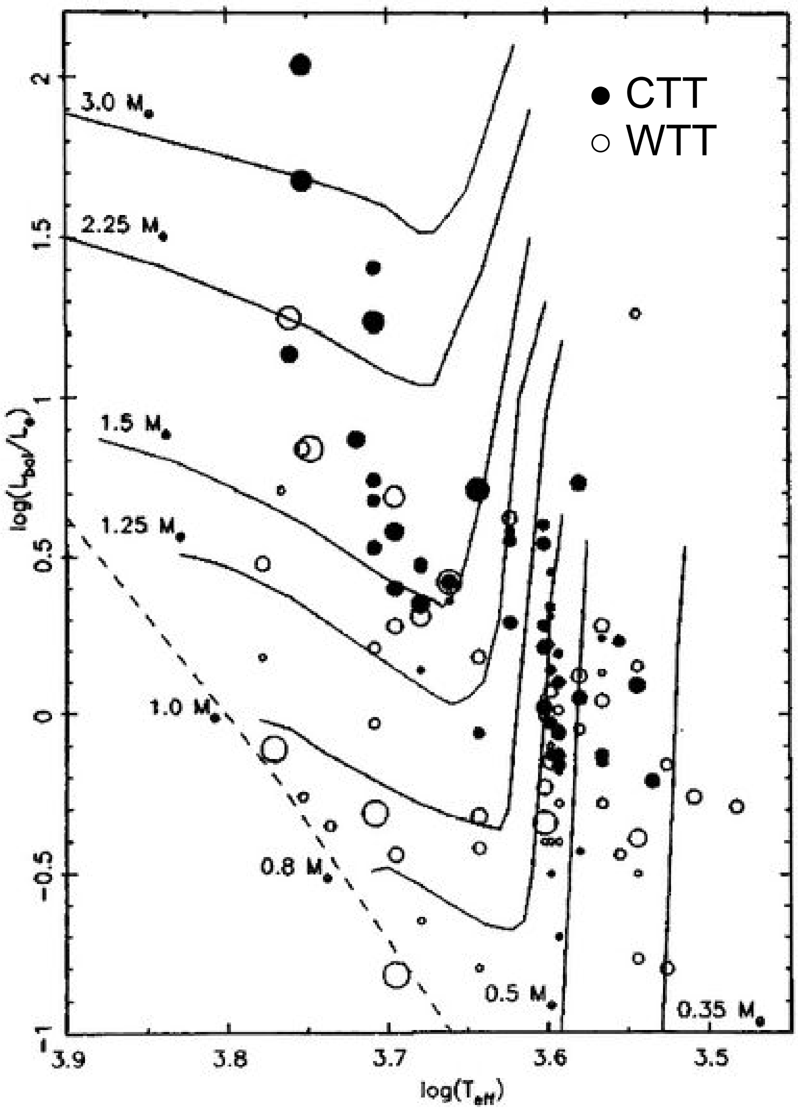



**variability ↔ caused by changes in the accretion rate**

# Protostar – T Tauri class

**T Tauri** stars **in HRD**

→ between **Hayashi Line** and **main-sequence**




classic T Tauri  and weak T Tauri Sterne

circlesize ↔  rotationstrength

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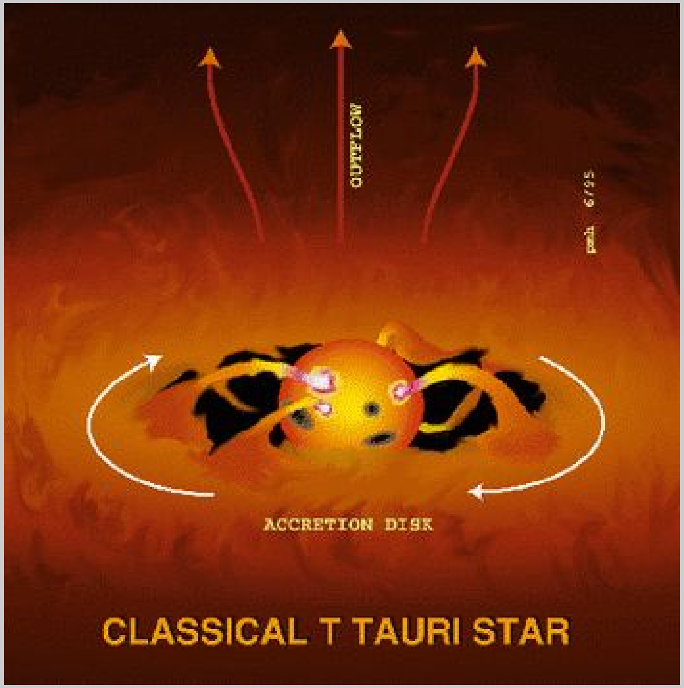
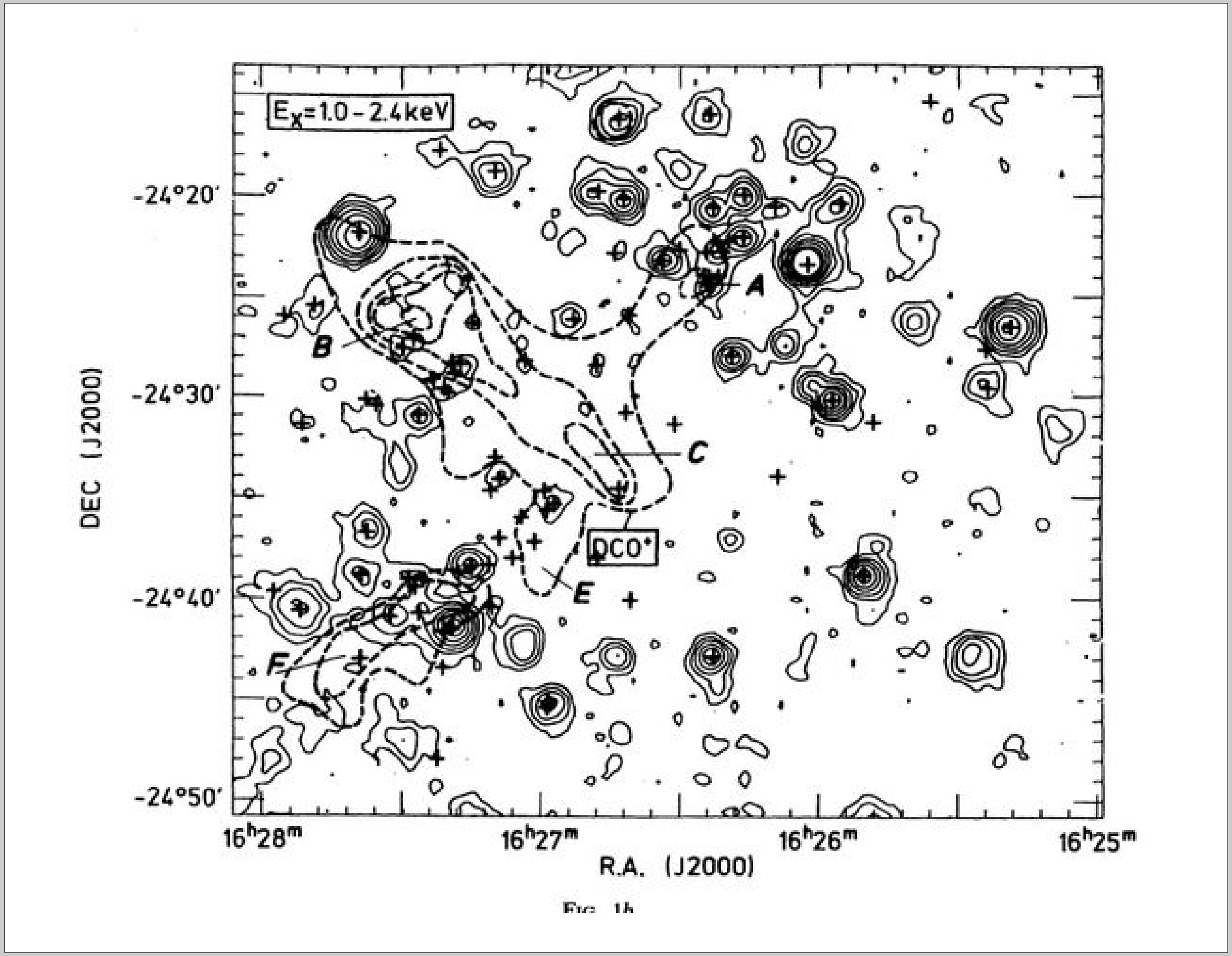
# Protostar – T Tauri class

**T Tauri** stars → **accretion** → **hot spots**

→ **even forms x-ray emission !!!**



# Protostar – Jets & Winds

**pre-main-sequence star** (T Tauri, Herbig-Haro,...)

**mass loss via**

- **winds**
- **jets**
- **clumps**

emission **molecular**
→ IR regime

**velocities**
(jet/wind)
typical **100-300 km/s**

**dimensionen $10^4$AU**
to a few **Parsec**

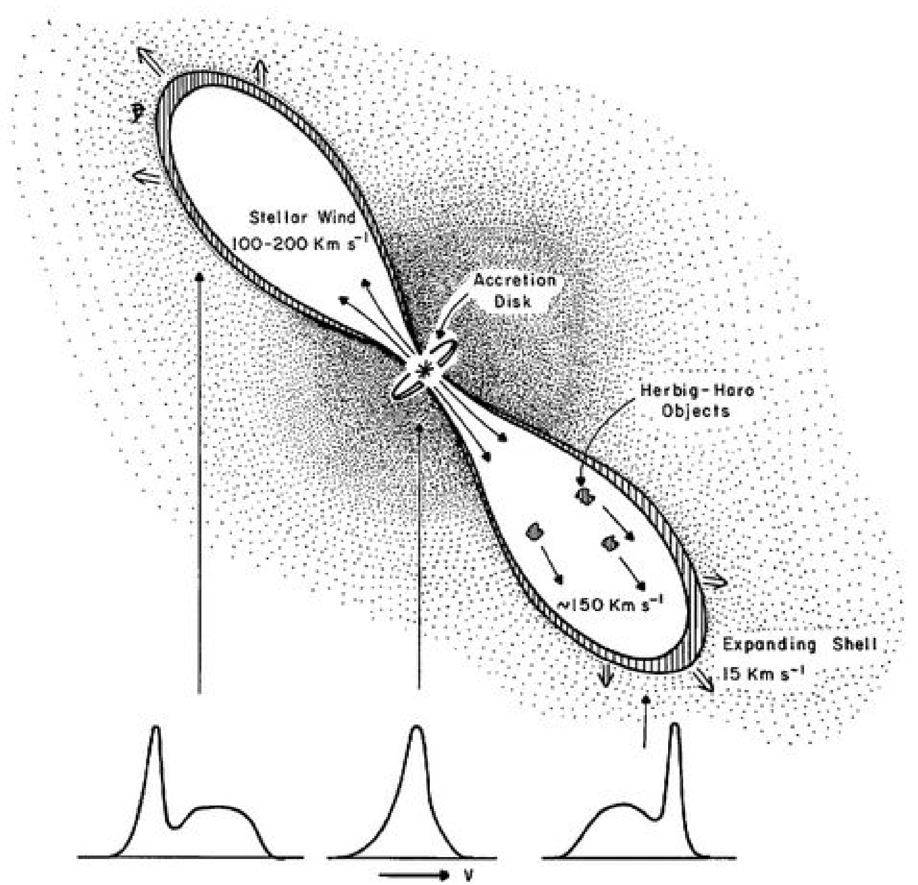



FIG. 5.—A schematic picture of the stellar wind driven shock model for L1551, indicating the CO line profiles which would be expected at different positions across the source. The Herbig-Haro objects are not necessarily located inside the shell; because of their high velocities, they may have been ejected through the shell and into the surrounding medium.

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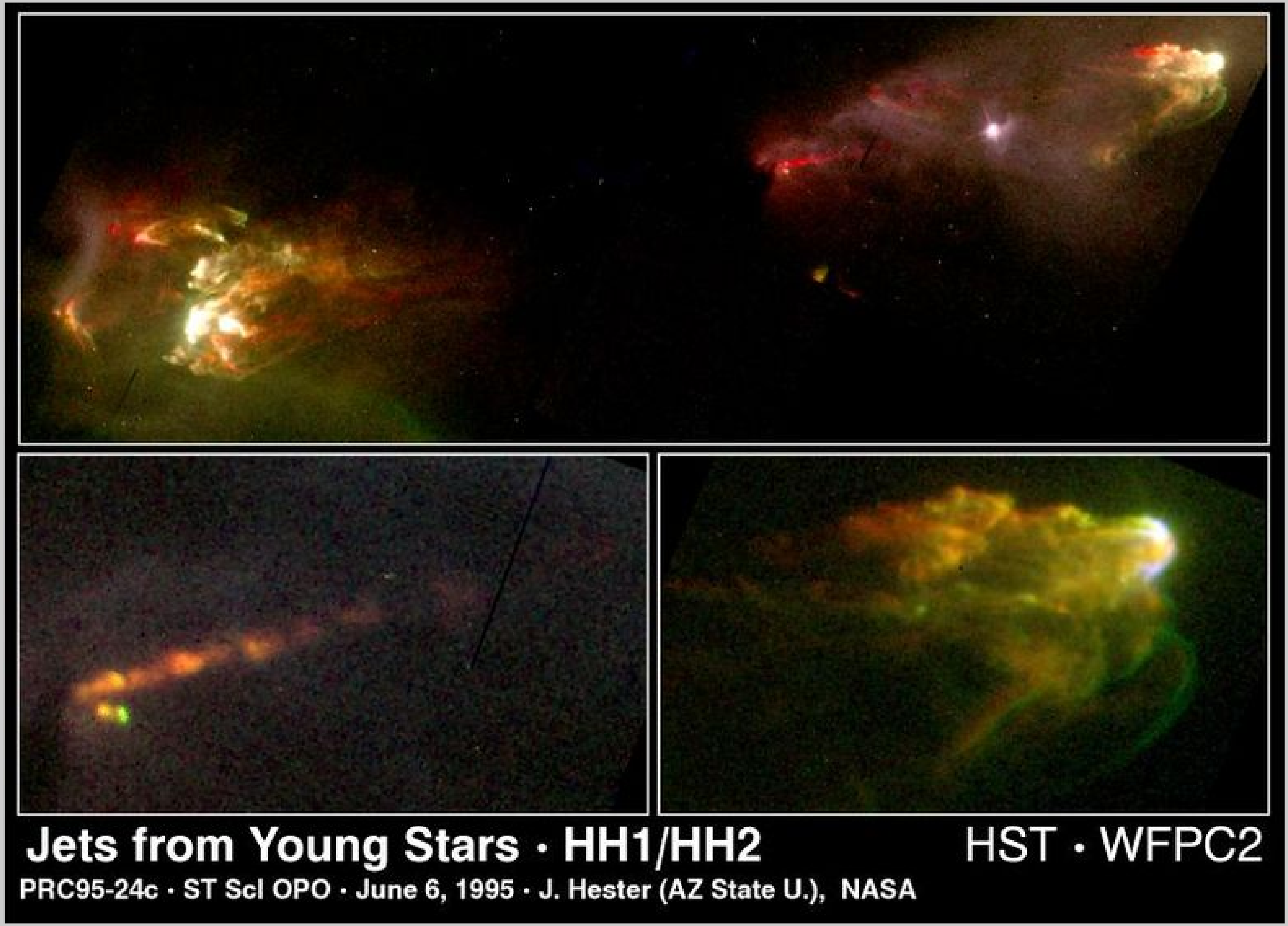
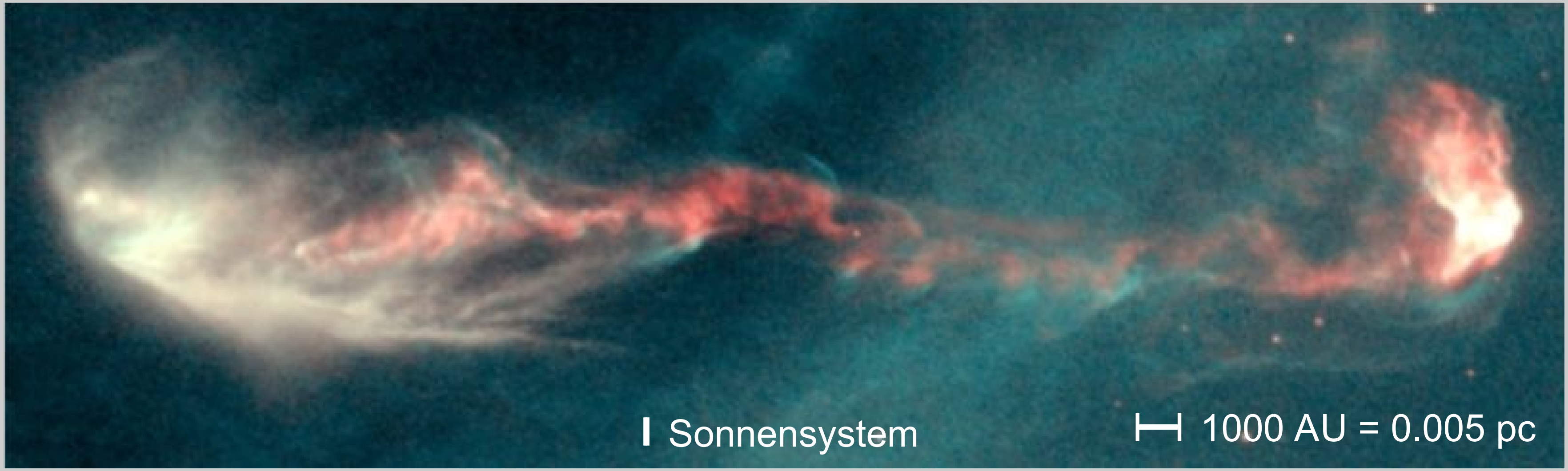
# Protostar – Jets – Herbig Haro stars

**Herbig Haro** stars like **T Tauri** but a bit more **massive**



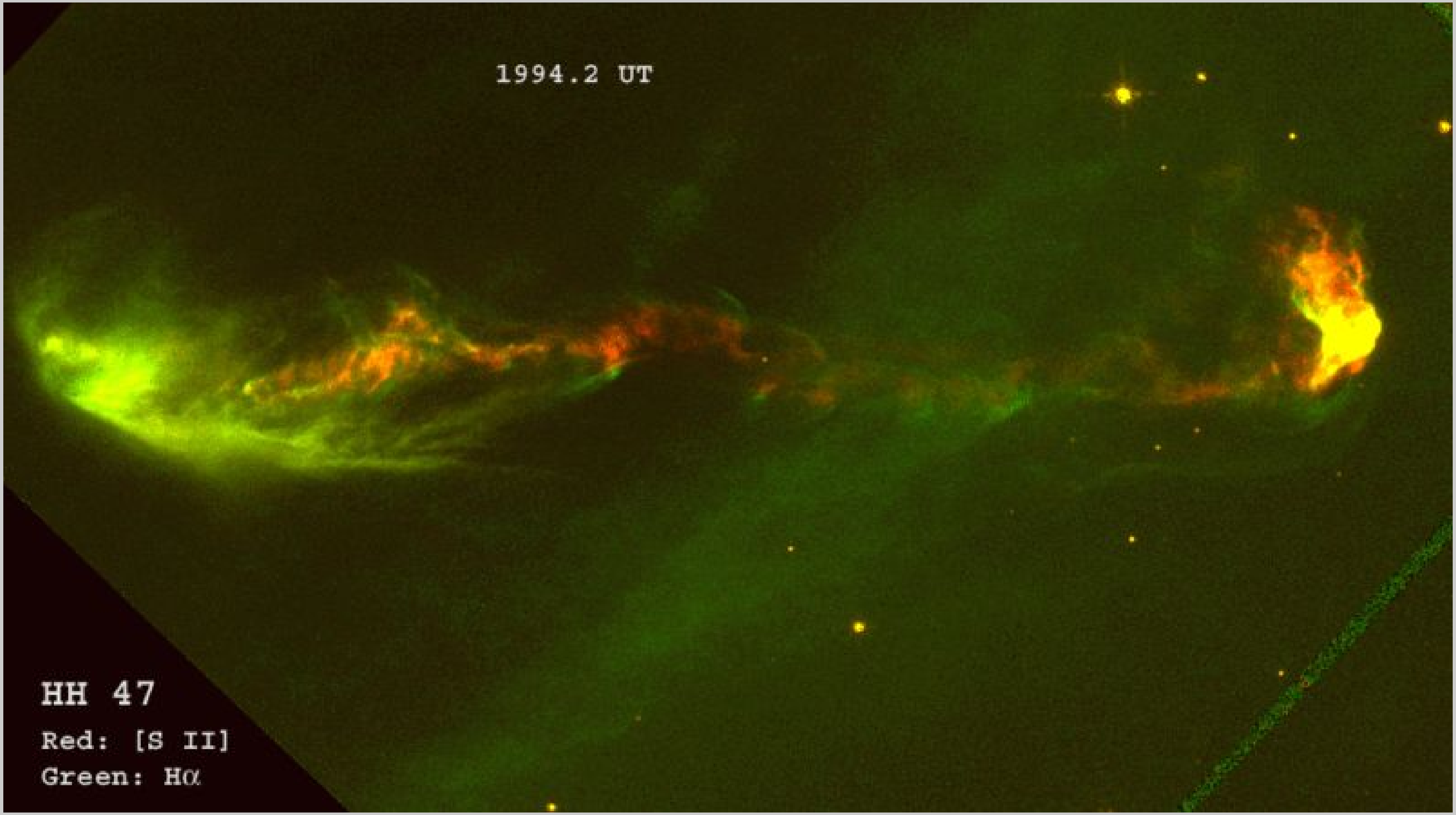
# Protostar – Jets – Herbig Haro stars

## Herbig Haro 47

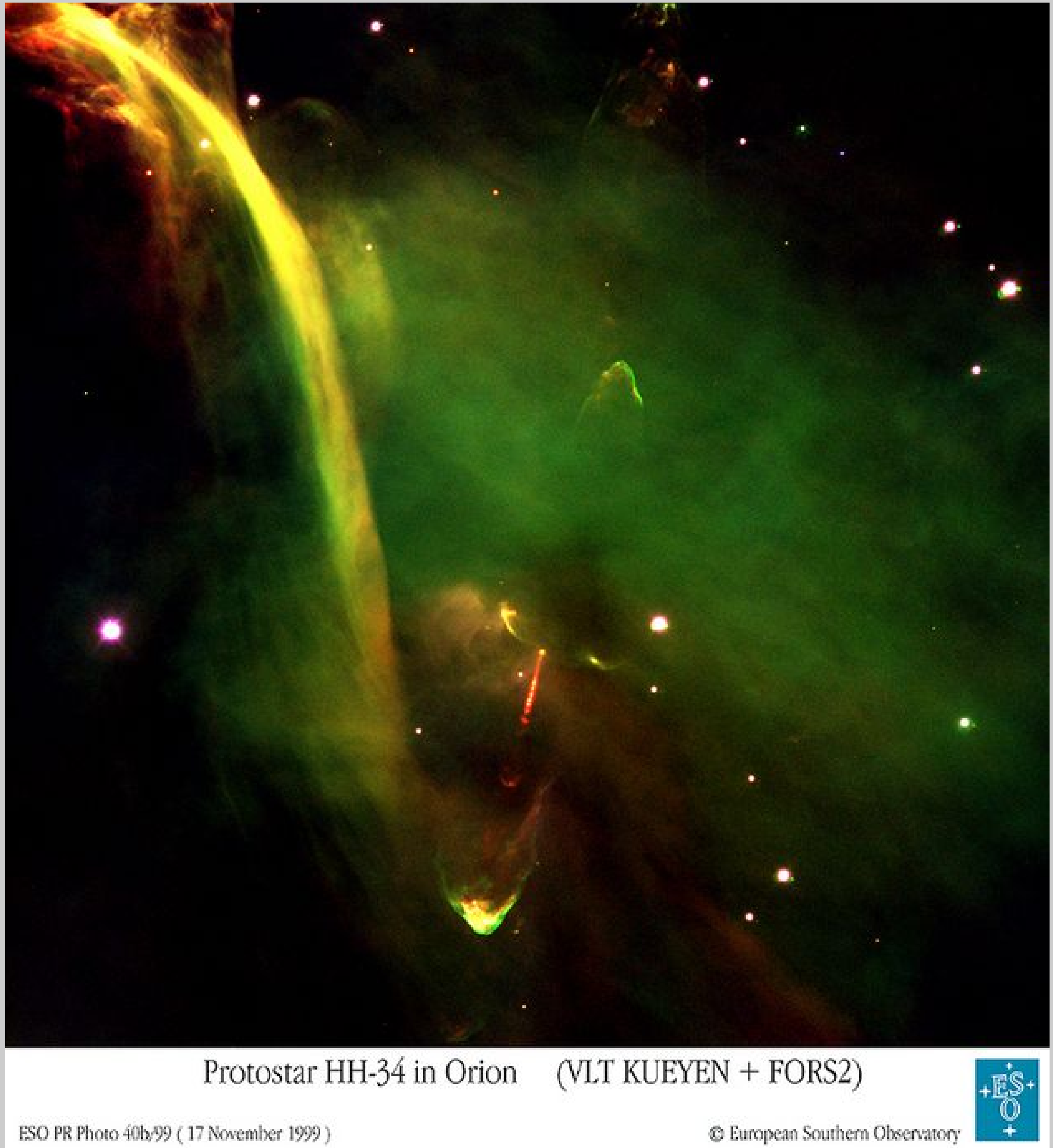


# Protostar – Jets – Herbig Haro stars

**Herbig Haro 47** Movement of the jets in 5 years



# Protostar – Jets – Herbig Haro stars

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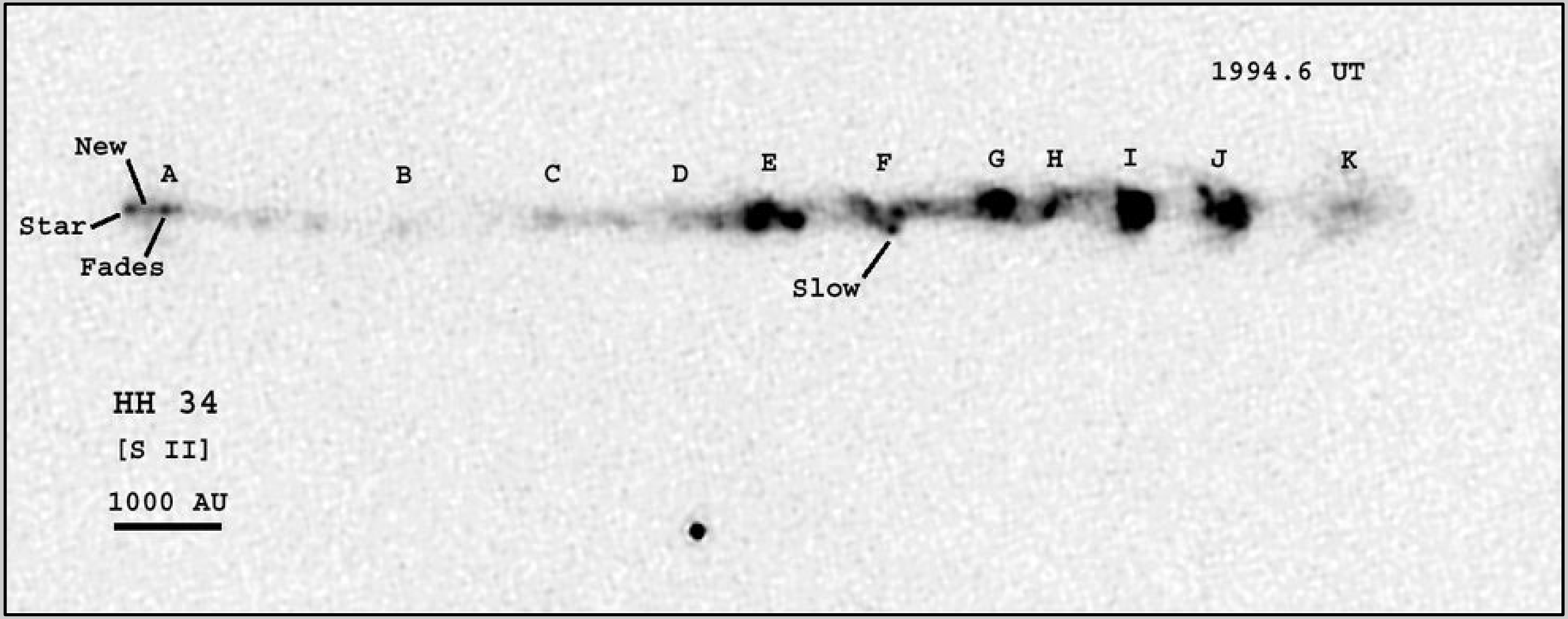
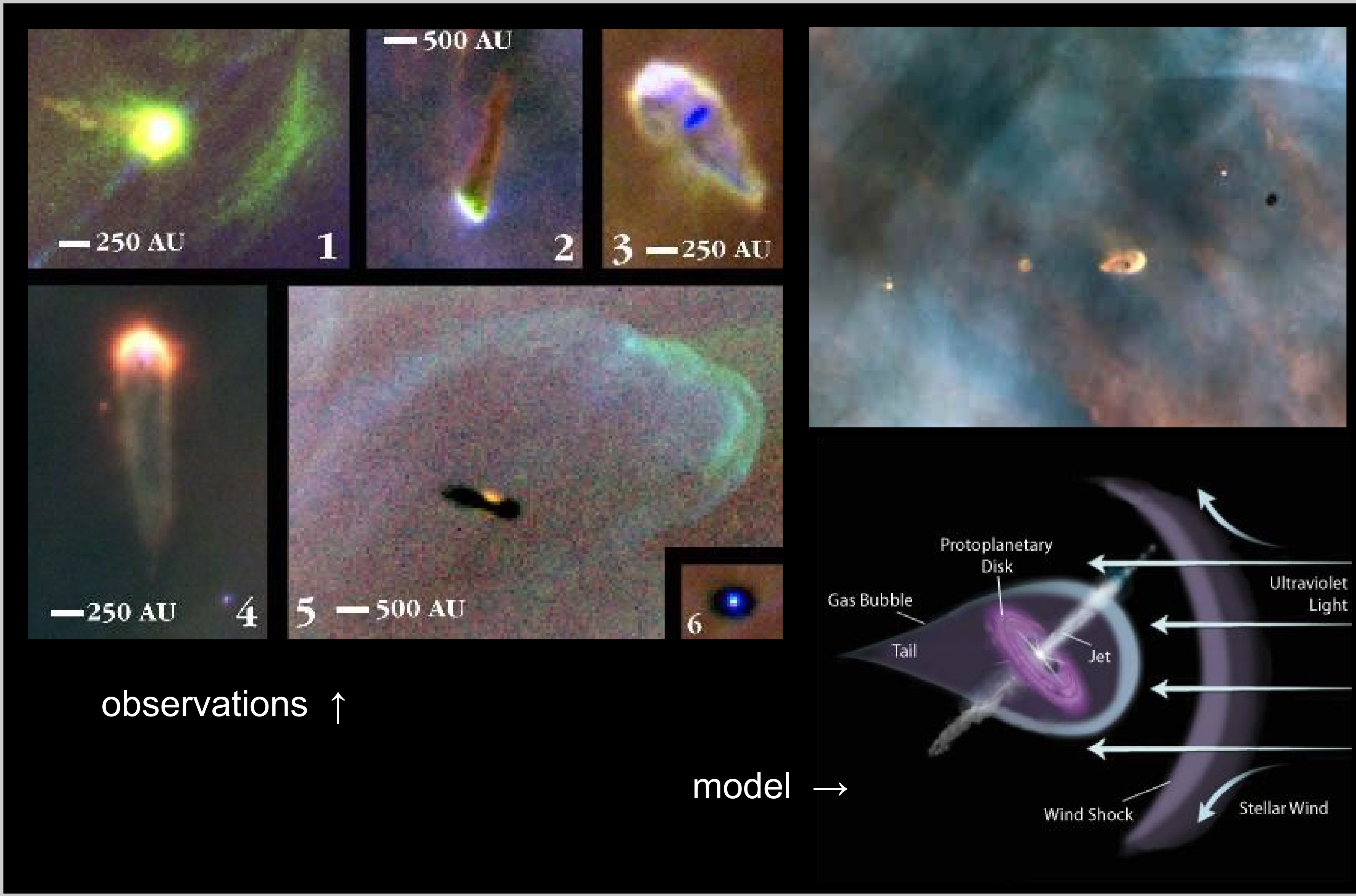
# Protostar – Jets – Herbig Haro stars



# Protostars in Orion

## Proplyds

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