Wie entstehen Sterne?

von
Robi Banerjee
(Hamburger Sternwarte, Uni HH)

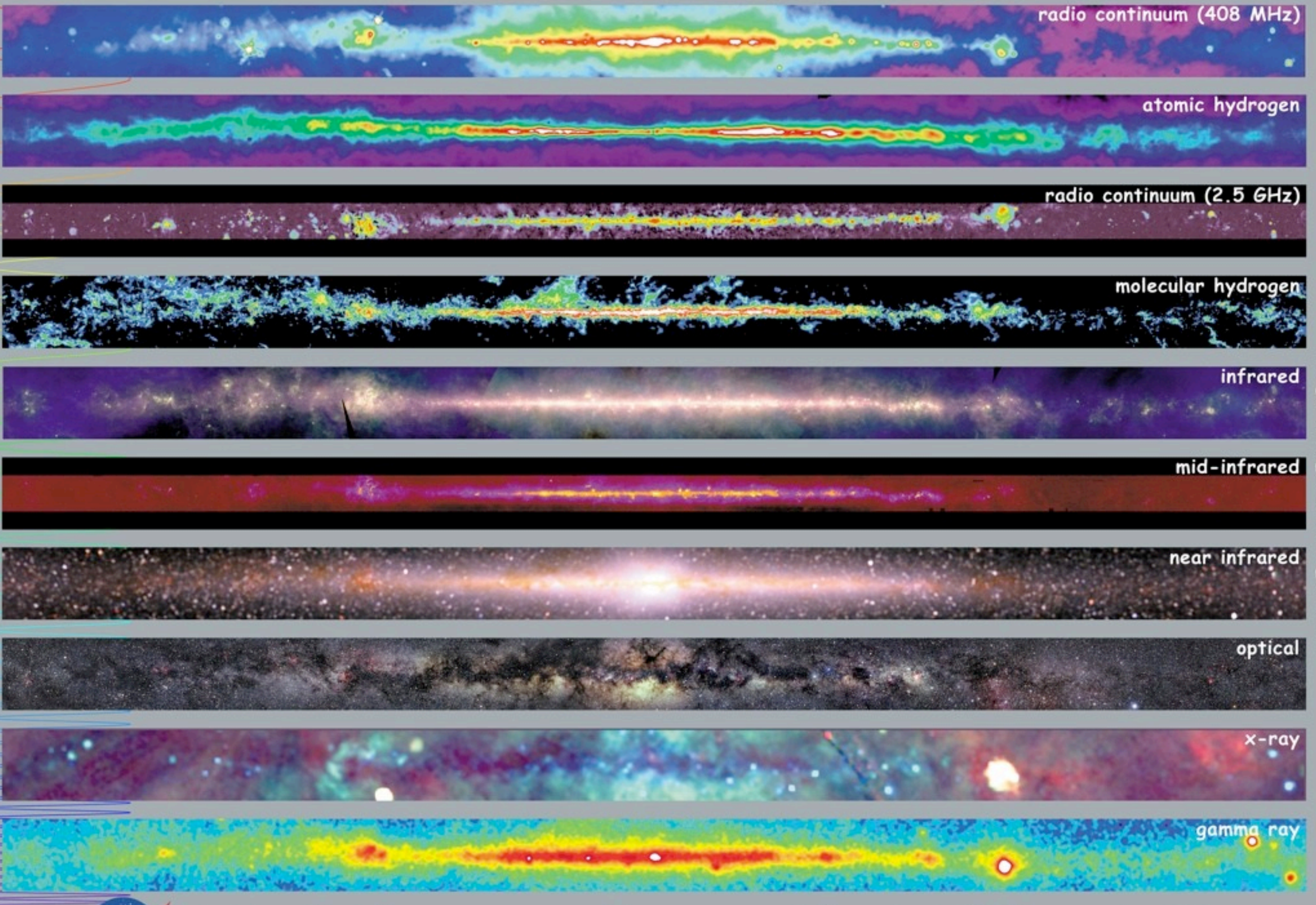
Orion Nebel, Aufnahme: Very Large Teleskop (VLT), ESO Chile


© 1998 D.Meozzi

Typische Galaxie

- Sterne: ~ 100 Milliarden
- Insterstellare Medium (ISM): atomares Gas, ionisiert, neutral, T ~ tausend - Million Grad
- **Molekülwolken**: < 1% des Volumens; H_2, CO, Staub
- Sternentstehungsrate heute: 3-5/Jahr
- Lebensdauer von Sternen: Millionen - Milliarden Jahre

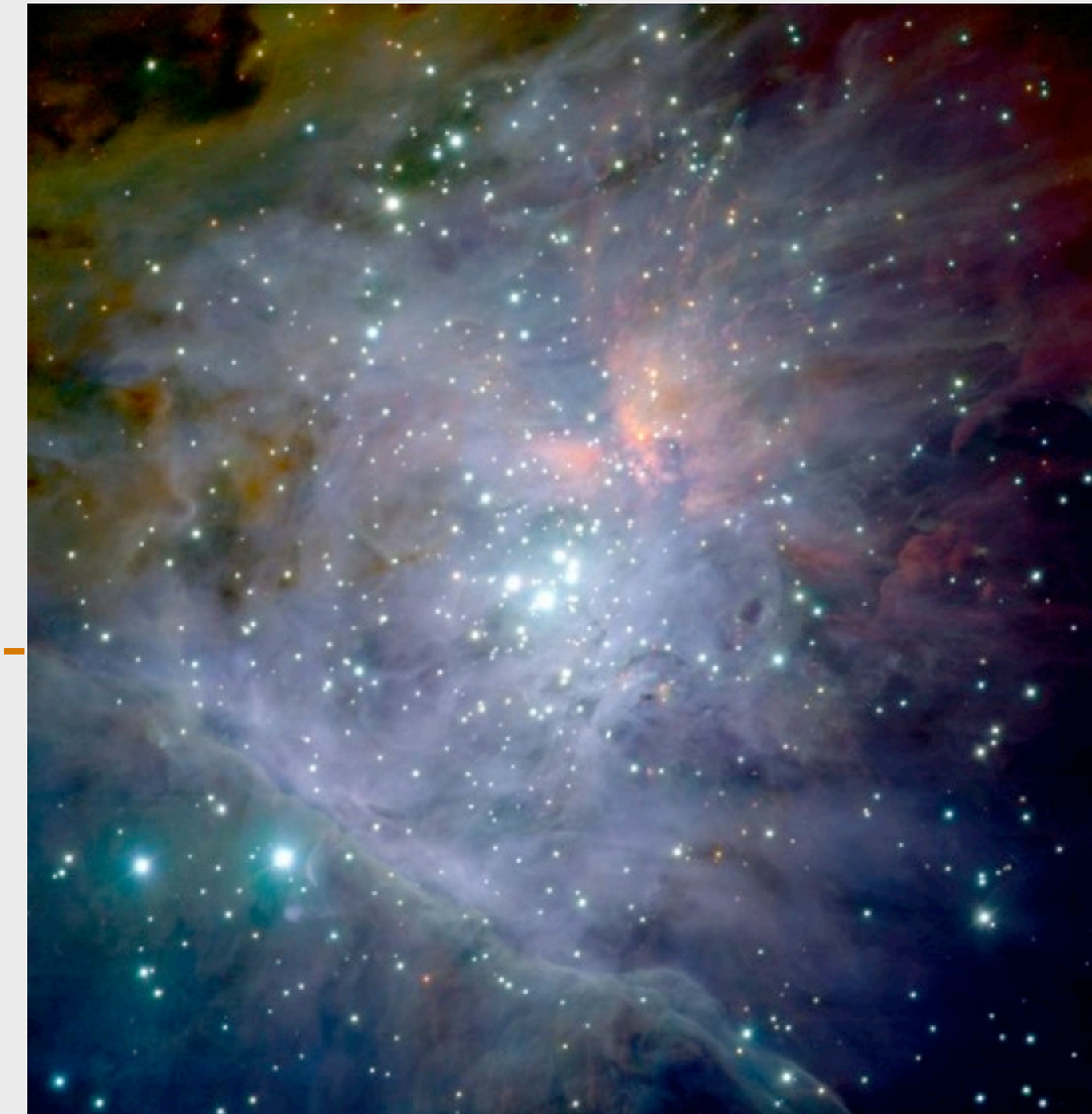
Edward Barnard 1920er: Entdeckung von Dunkelwolken



Multiwavelength Milky Way

Molekülwolken: Sternentstehungsgebiete

- vorwiegend Moleküle: H_2, CO + Staub (~ 1%)
- Ausdehnung ~ 10 - 100 pc
- Masse ~ 10^5 M_{sol} (GMCs)
- Dichte: 100 - 10^6 cm^{-3}
- kalt (10 - 20 K)
- chaotische Geschwindigkeits-fluktuationen, d.h. Überschall-Turbulenz
- Magnetfelder, B ~ 10 µG



Hubble Teleskop: Sternentstehungsgebiet 30 Dor/Tarantelnebel in der Großen Magellanschen Wolke

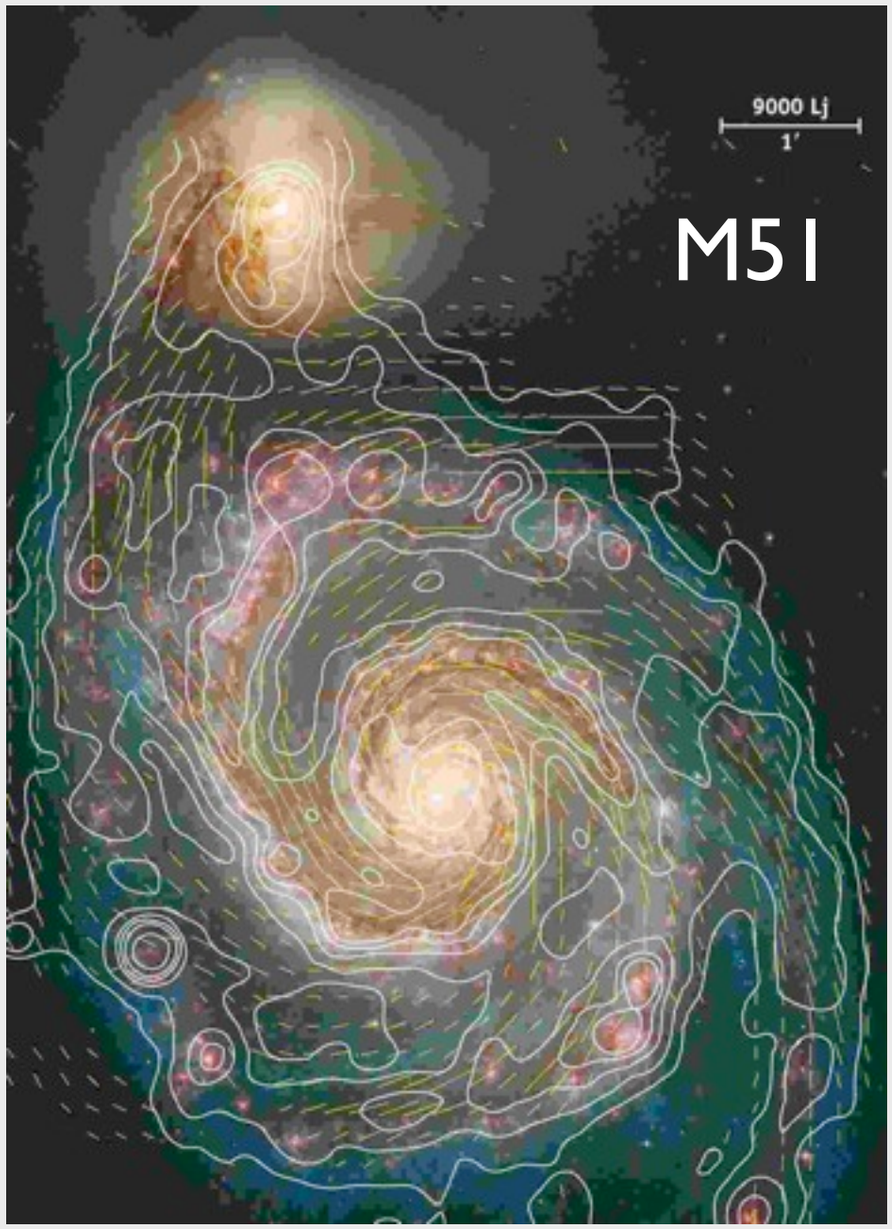

Thomas Preibisch - Munich Observatory

ESA Herschel Teleskop: Sternentstehungsgebiet Rosettennebel

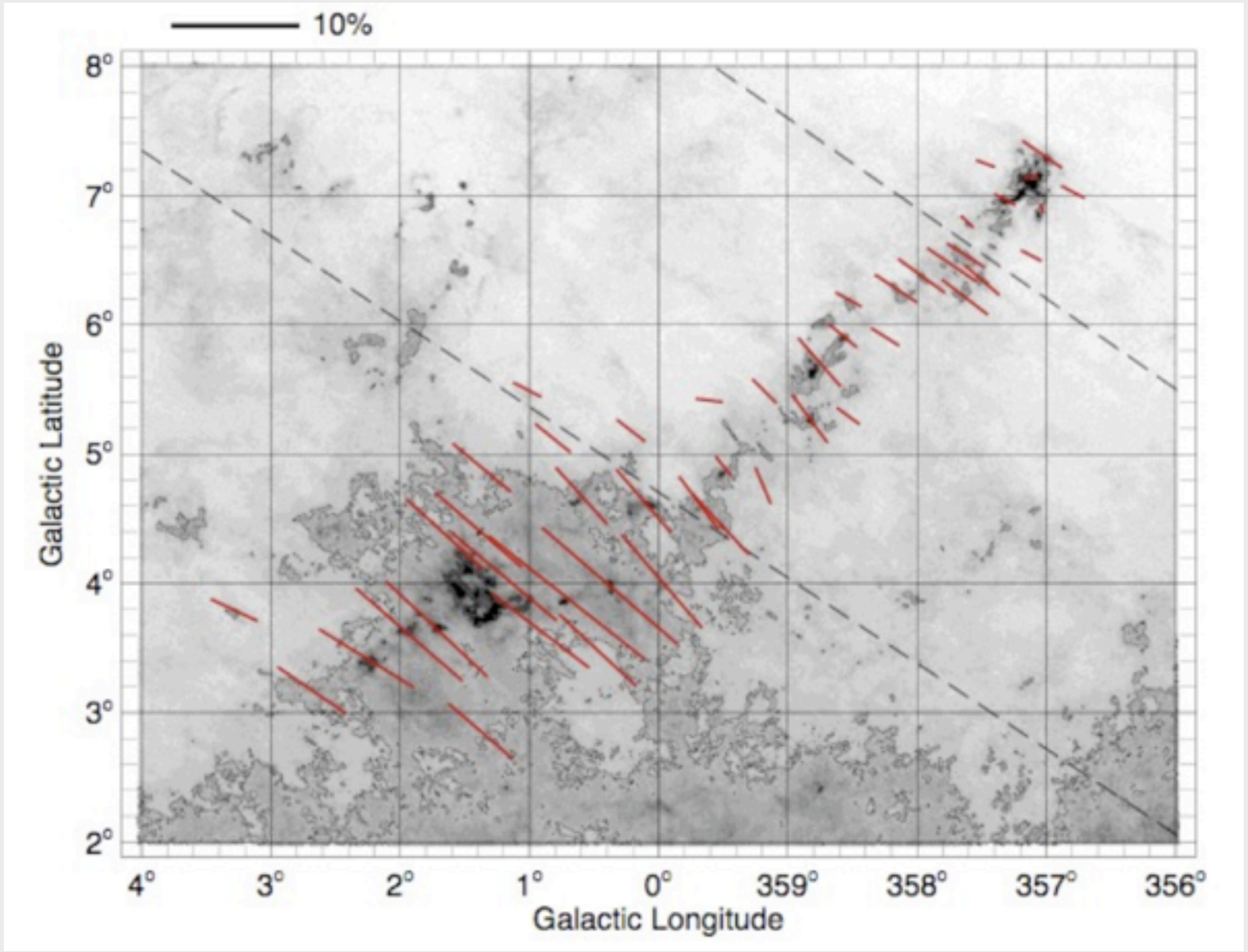
Hubble Teleskop:
"Säulen der Schöpfung"
im Adlernebel

ESO APEX: Taurus Molekülwolke

Magnetfelder

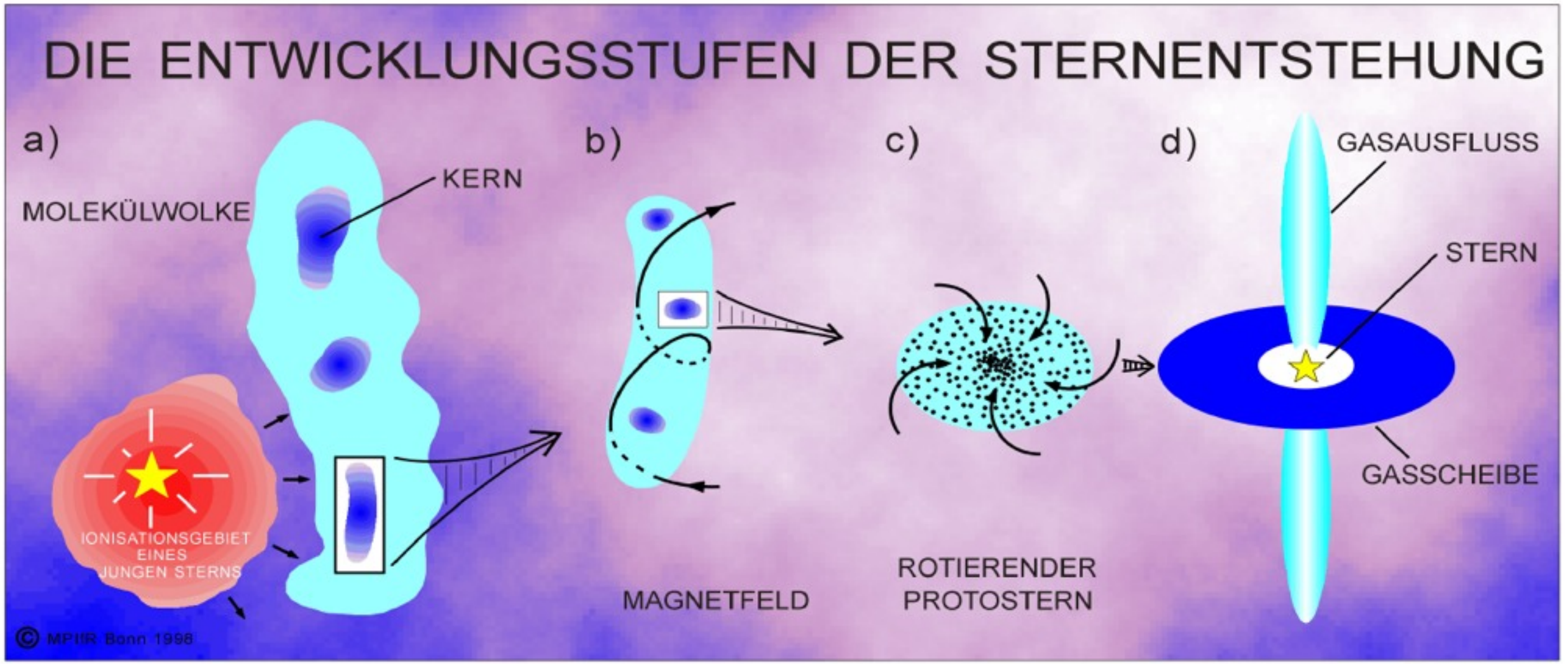


Galaktisches B-Feld (e.g. *R.Beck 2001*)
großskalige Komponente: ~ 4μG
Gesamtstärke: ~ 10 μG



Polarisationkarte des Pfeifennebels
F.O.Alves, Franco, Girart 2008

Sternentstehung schematisch



Modellierung

Modellierung

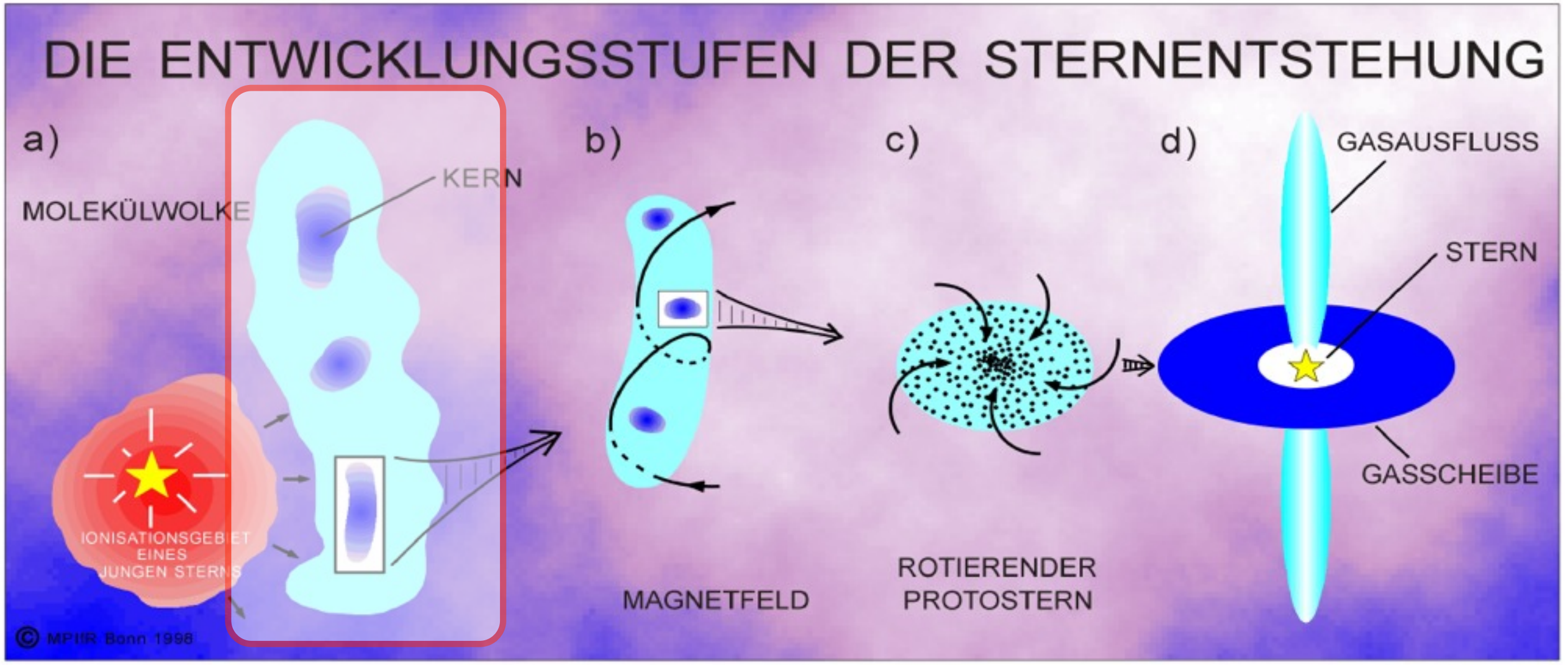
- riesige Längenskalen: 100 pc - 1 R_{sun} (9 Größenordnungen!!)
  Lösungen: **adaptives Gitter** / Teilchen basierend
- unterschiedlichste Zeitskalen: 1 Millionen Jahre - Sekunden
- verschiedenste Prozesse: Gravitation, Hydrodynamik, Thermodynamik, Strahlung, Magnetfelder, ...

Modellierung in Supercomputern

Hochleistungsrechenzentrum Nord (HLRN)

JUGENE Supercomputer, Jülich Forschungszentrum

Entstehung von Molekülwolken



Entstehung von Molekülwolken

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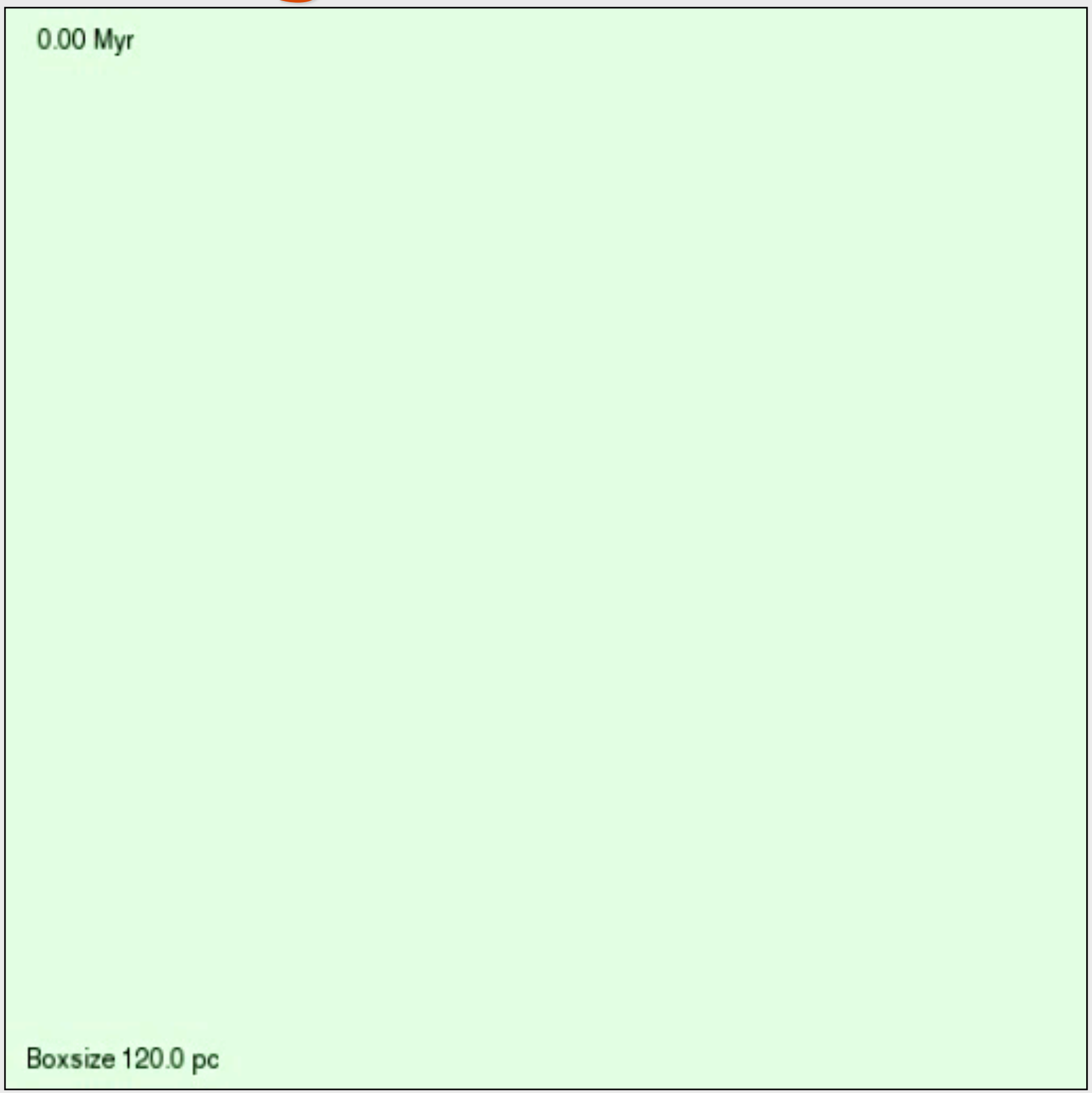
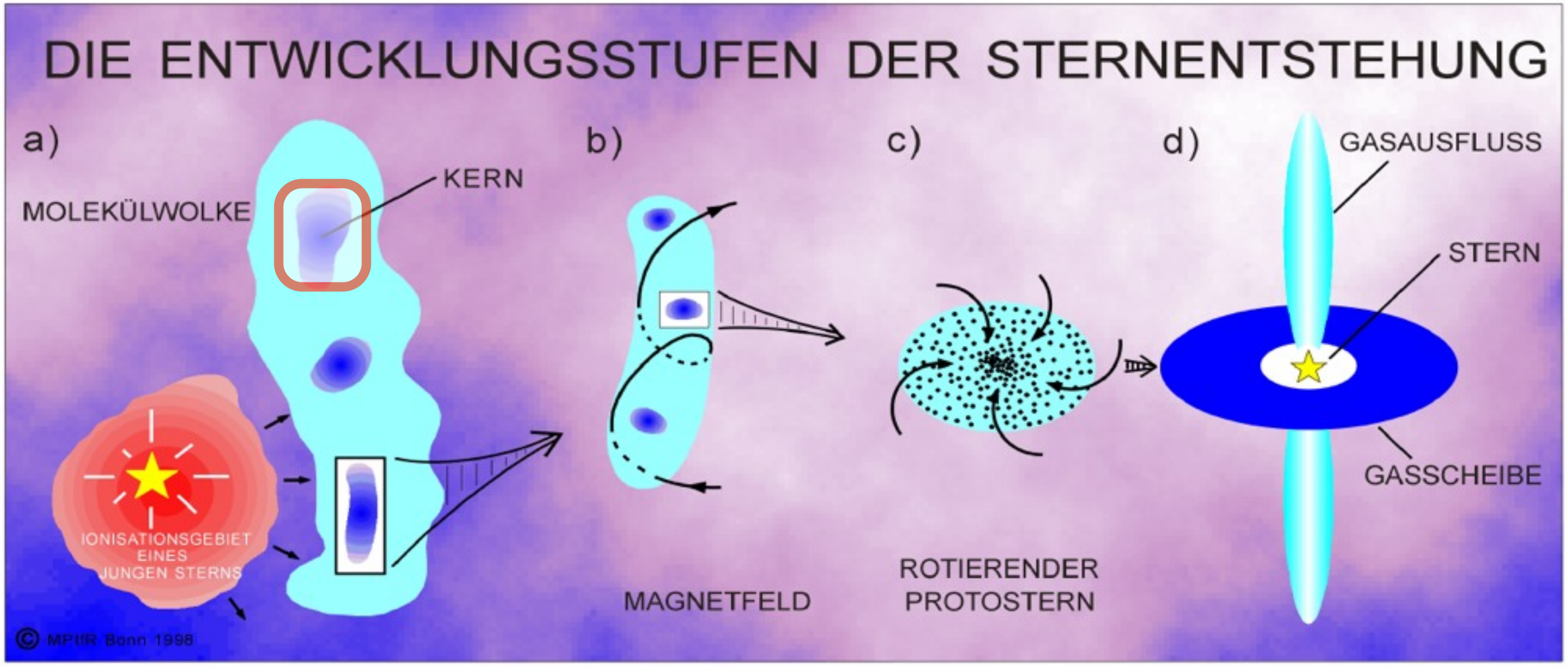
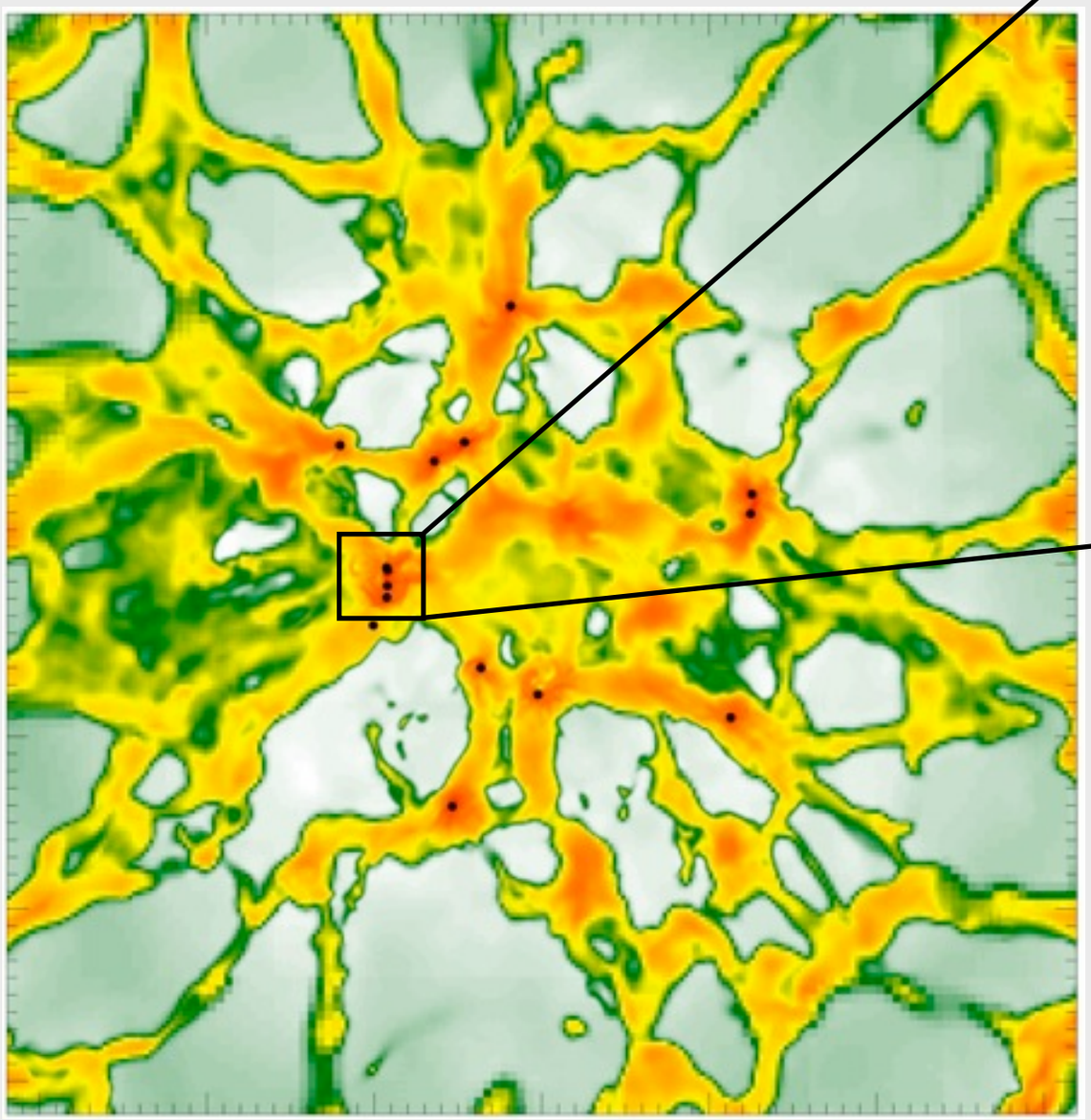
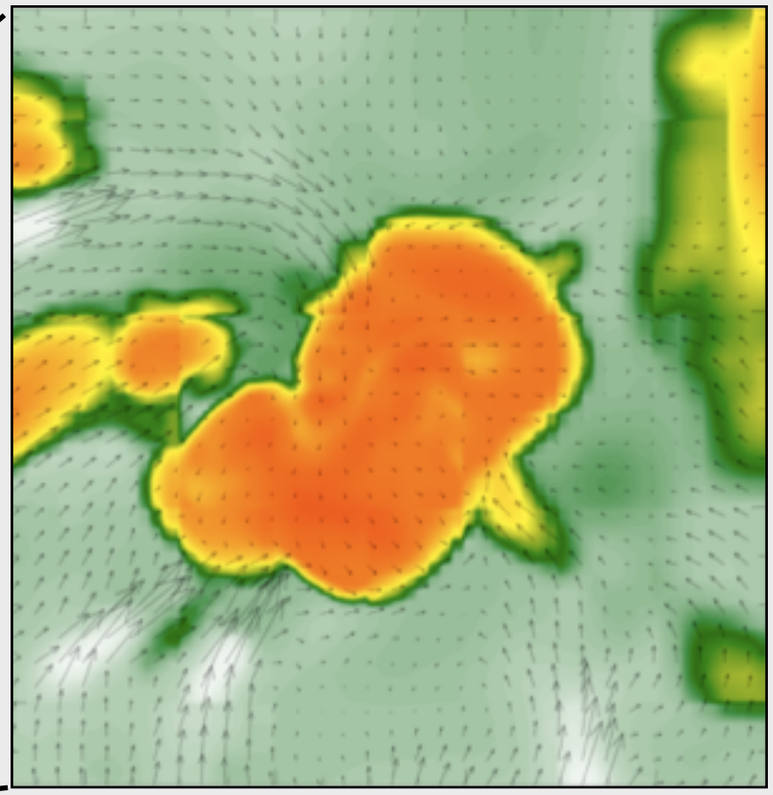


Kollaps von prästellaren Kernen



Kollaps von prästellaren Kernen





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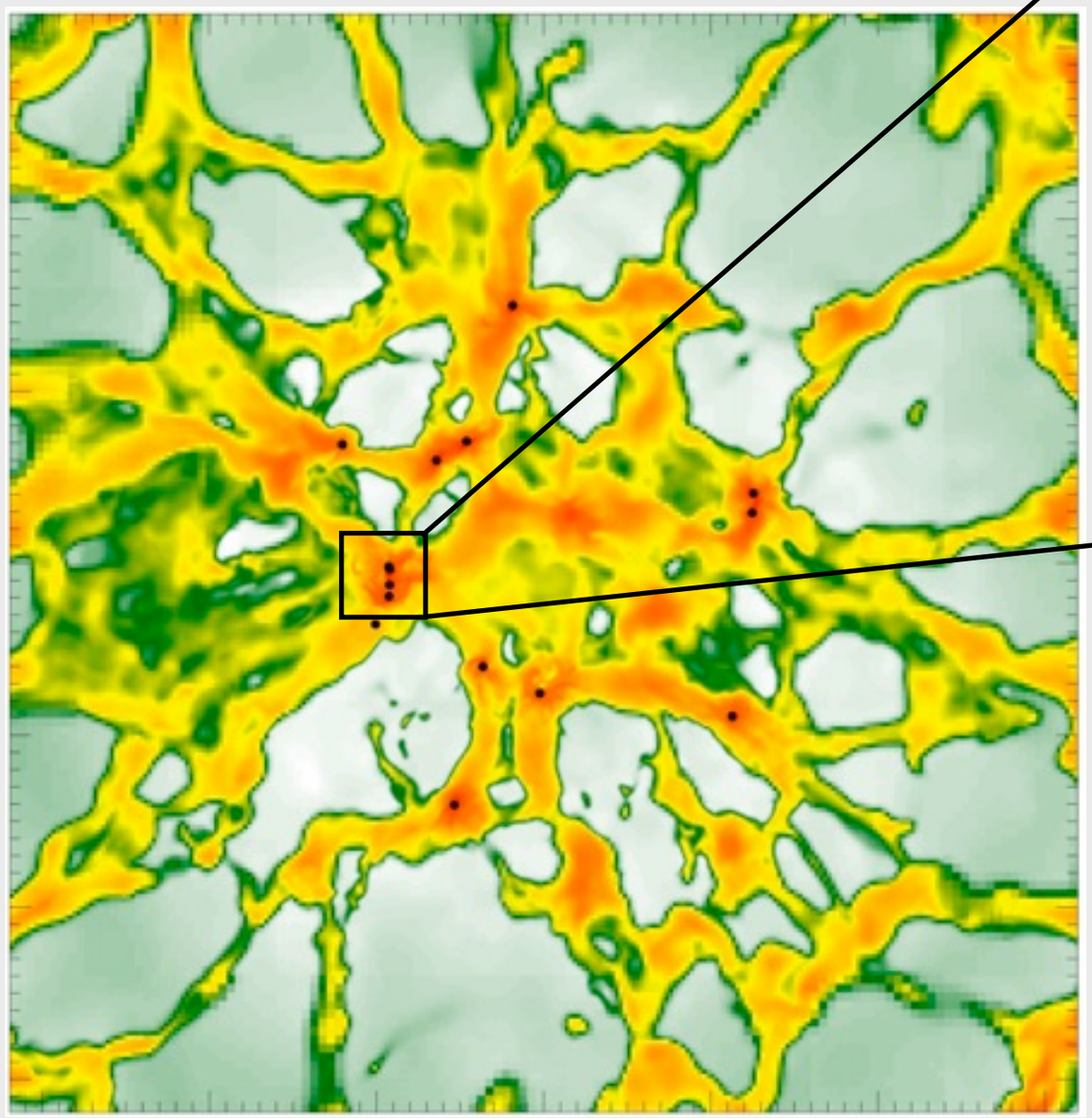
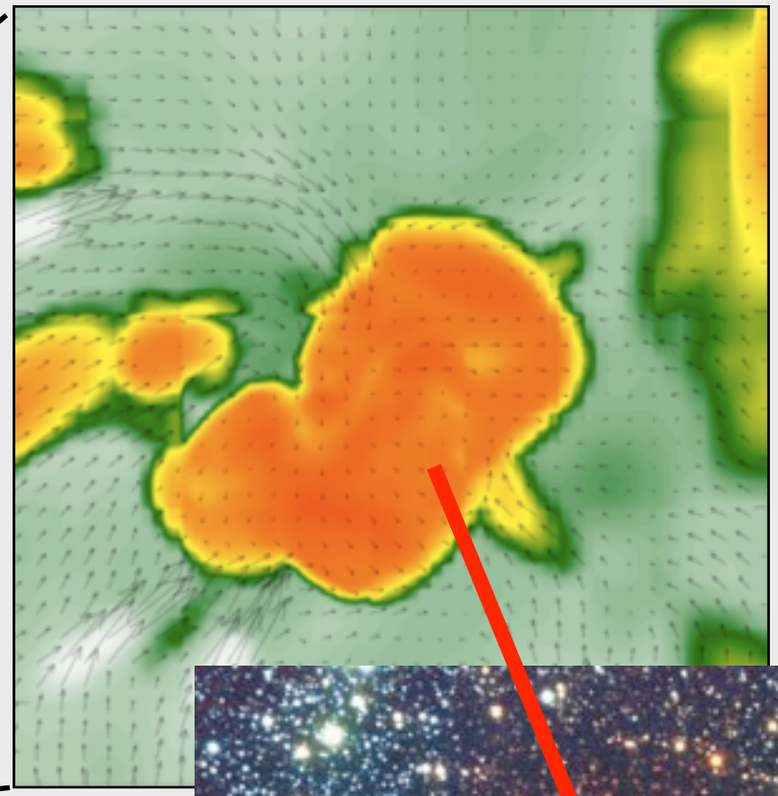
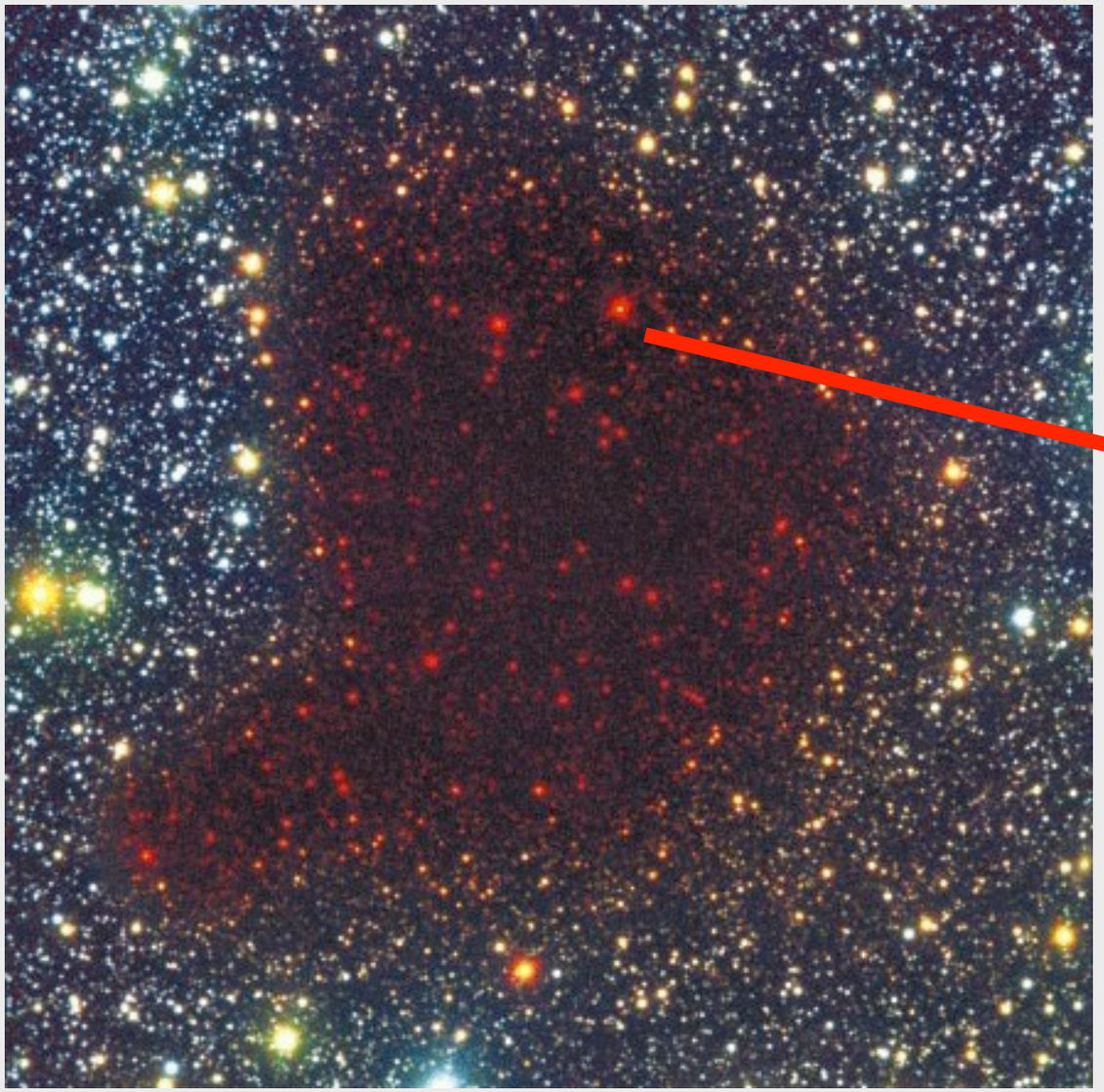




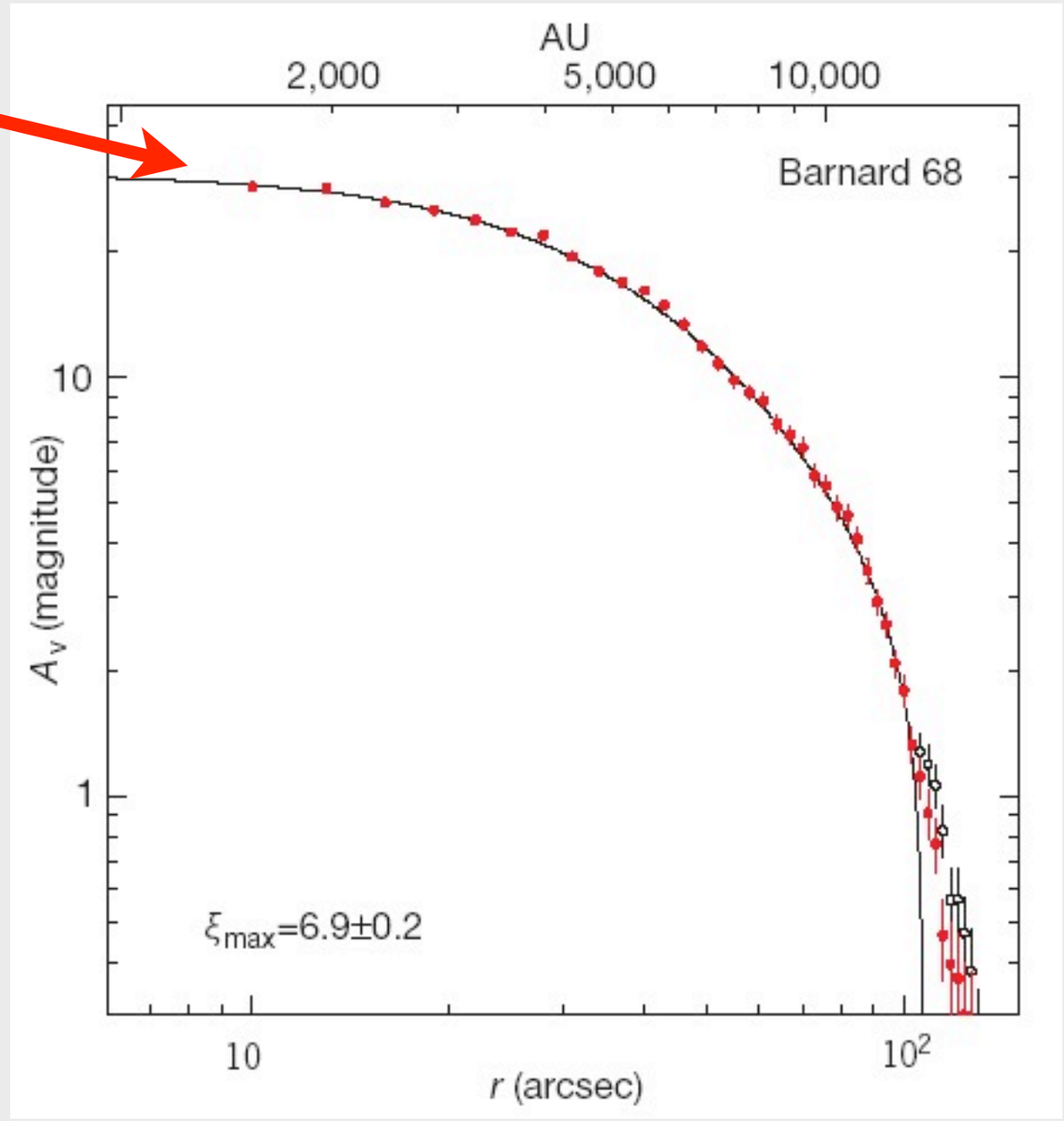
Bok Globule B 68: Alves et al. 2001

Kollaps von prästellaren Kernen

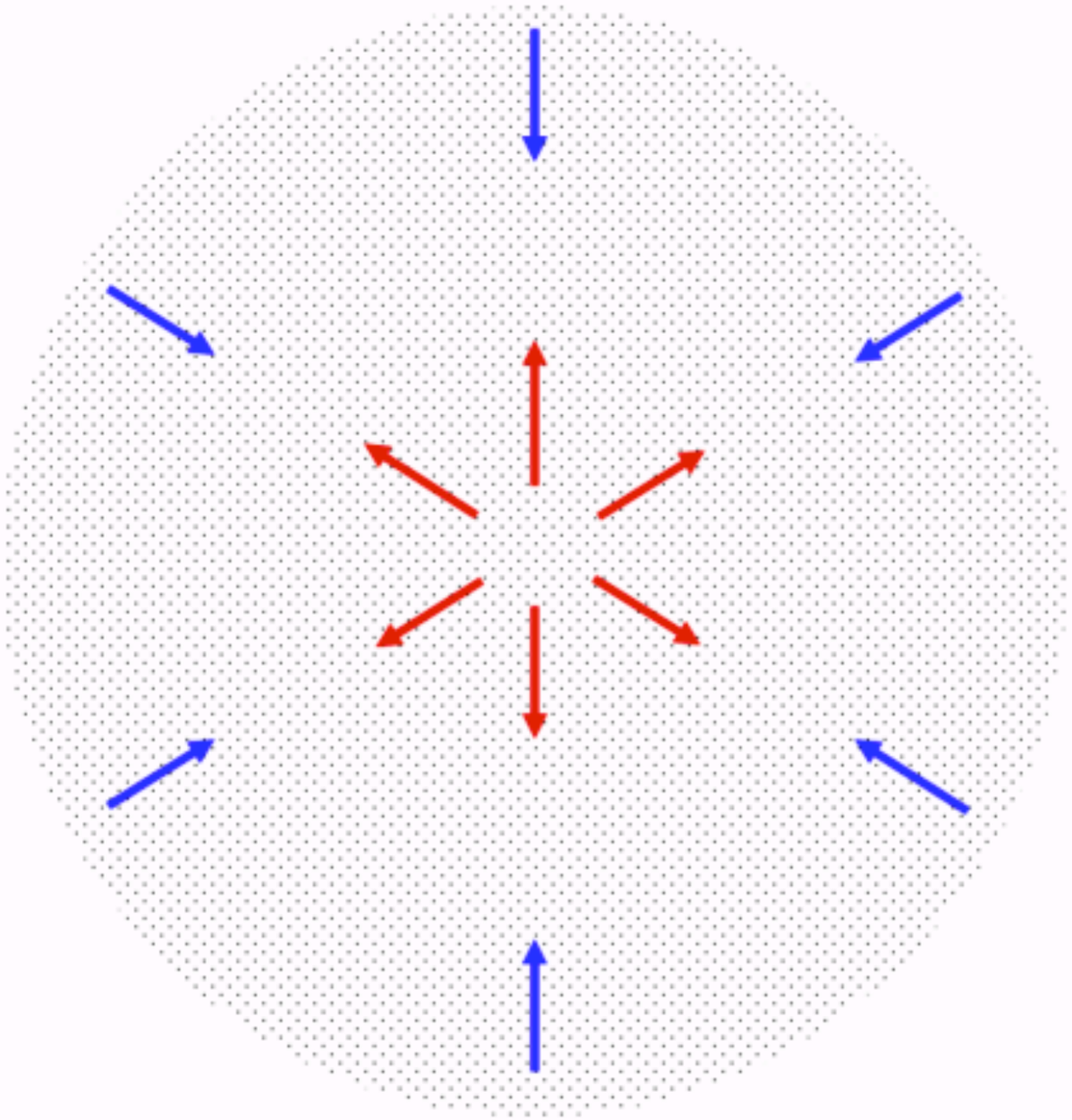


Dichteverteilung folgt hydrostatischem **Gleichgewicht**

Bonnor-Ebert-Sphäre



Gravitations-Instabilität

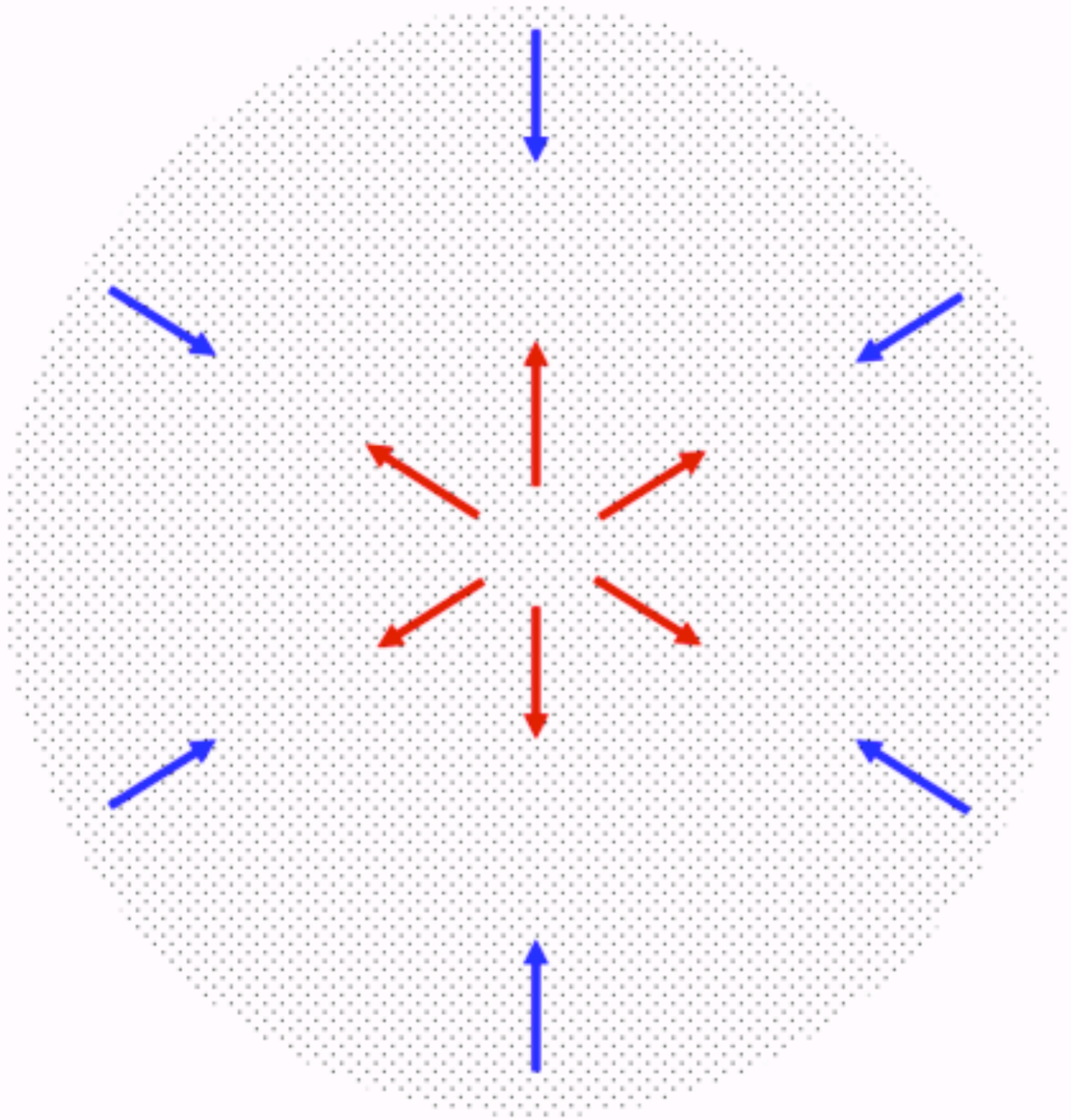


Gravitationsdruck

Druck durch Teilchenbewegung (Thermischer Druck)

Gravitations-Instabilität

Kollaps: $M_{Kern} > M_{Jeans} \approx 1\ M_{Sonne}$



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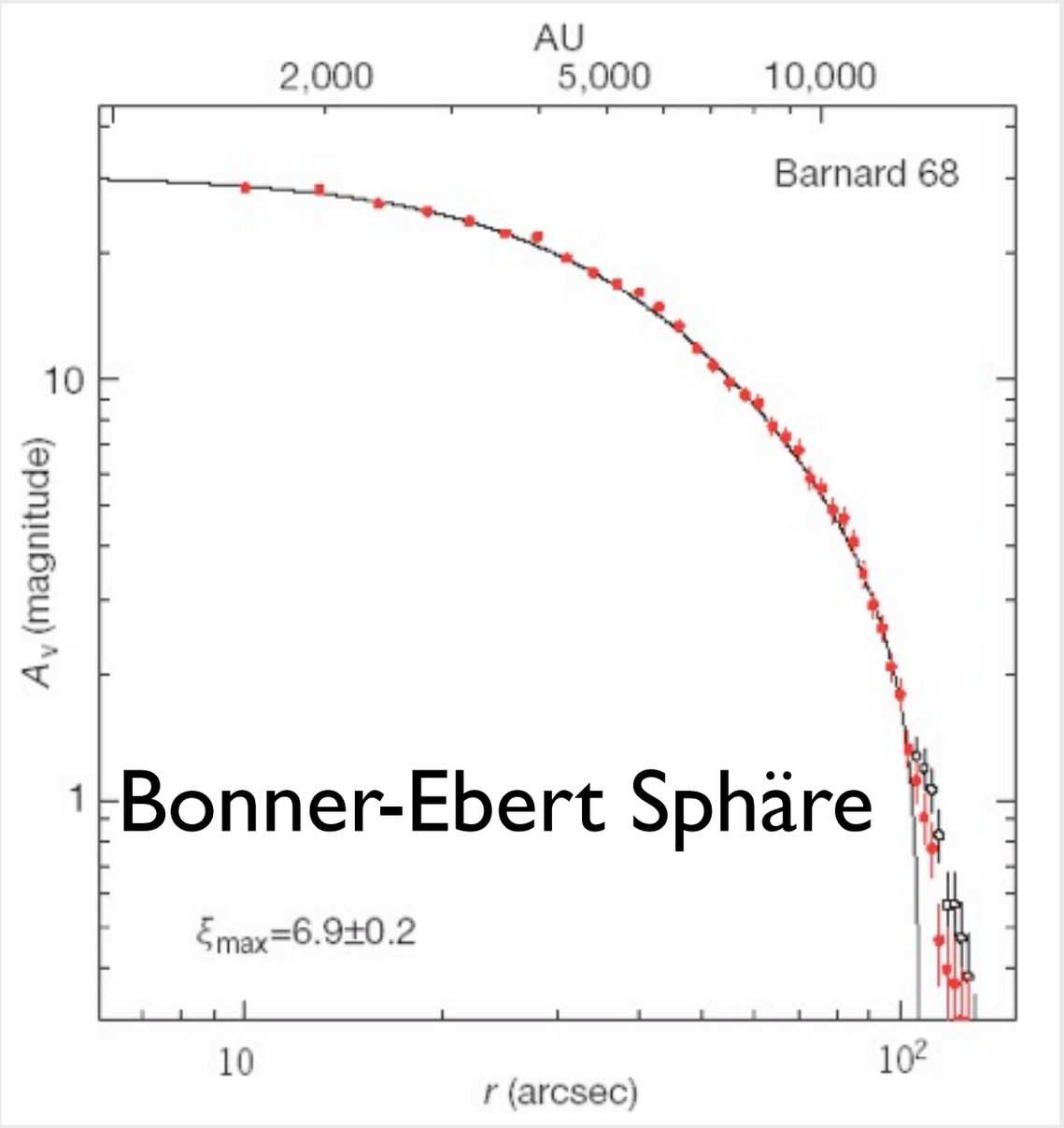
Kollaps von prästellaren Kernen



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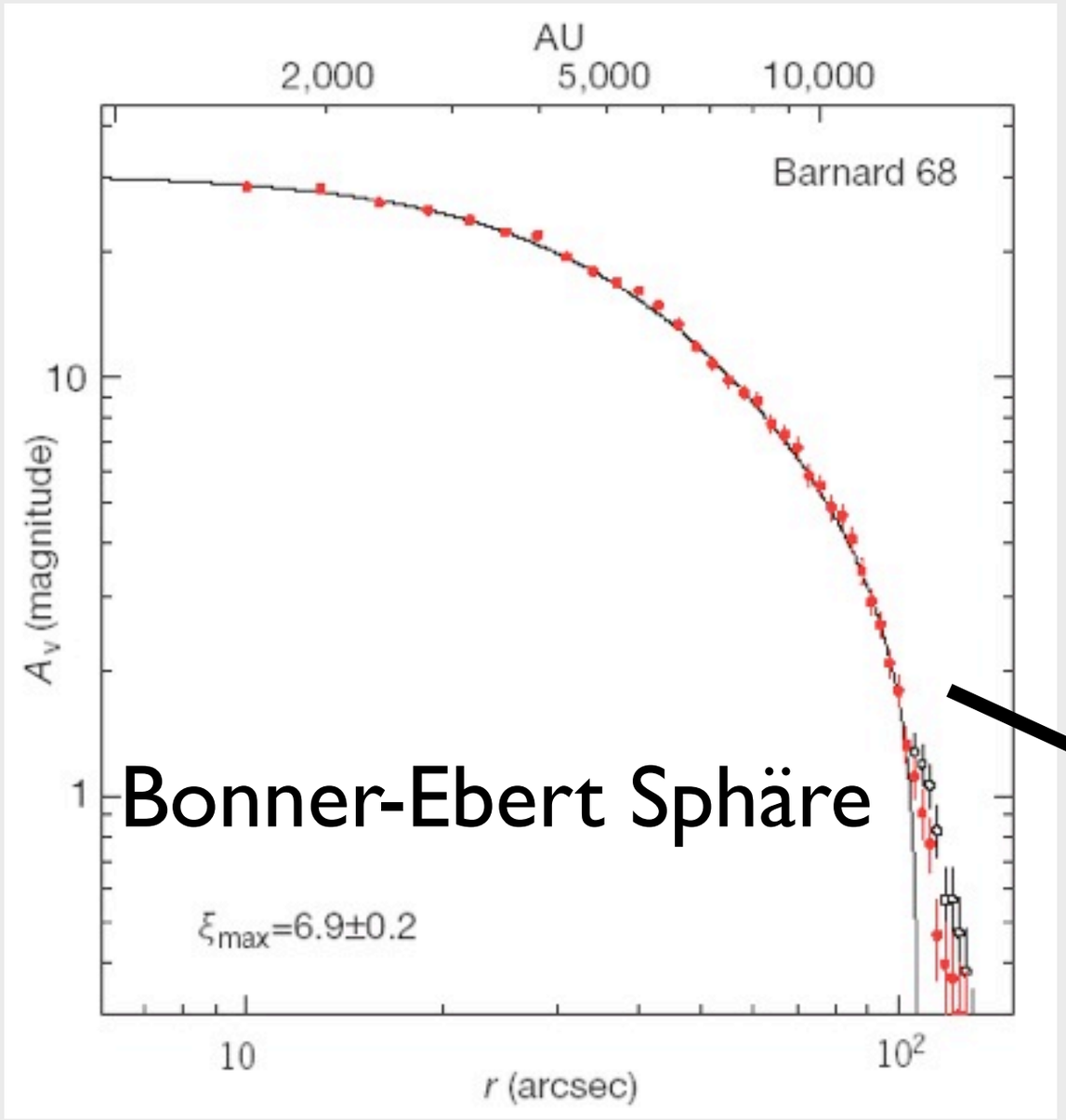
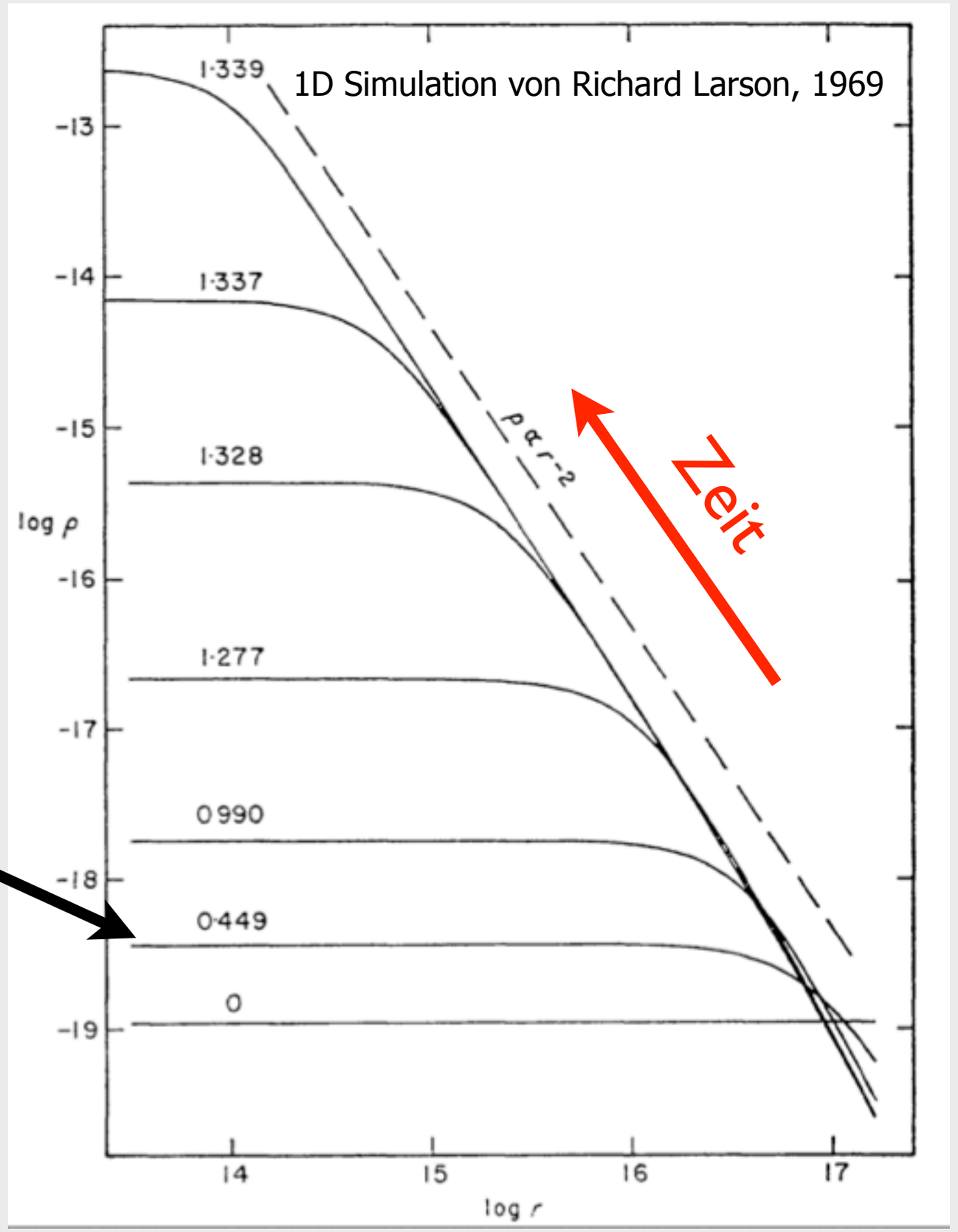
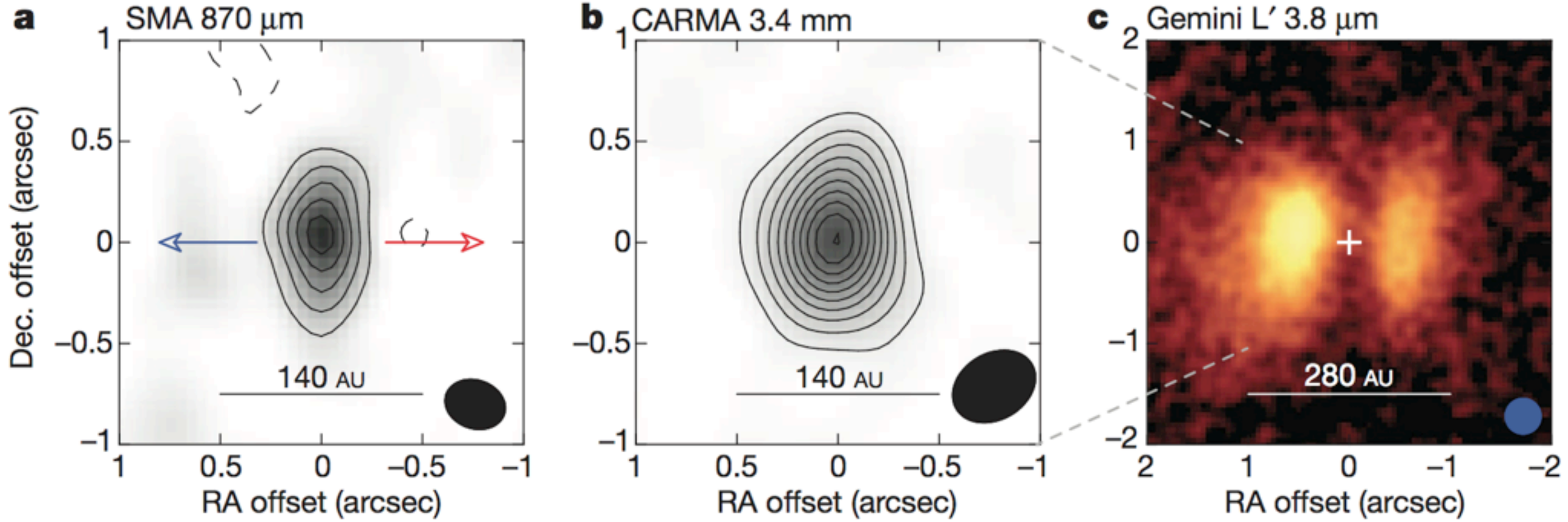
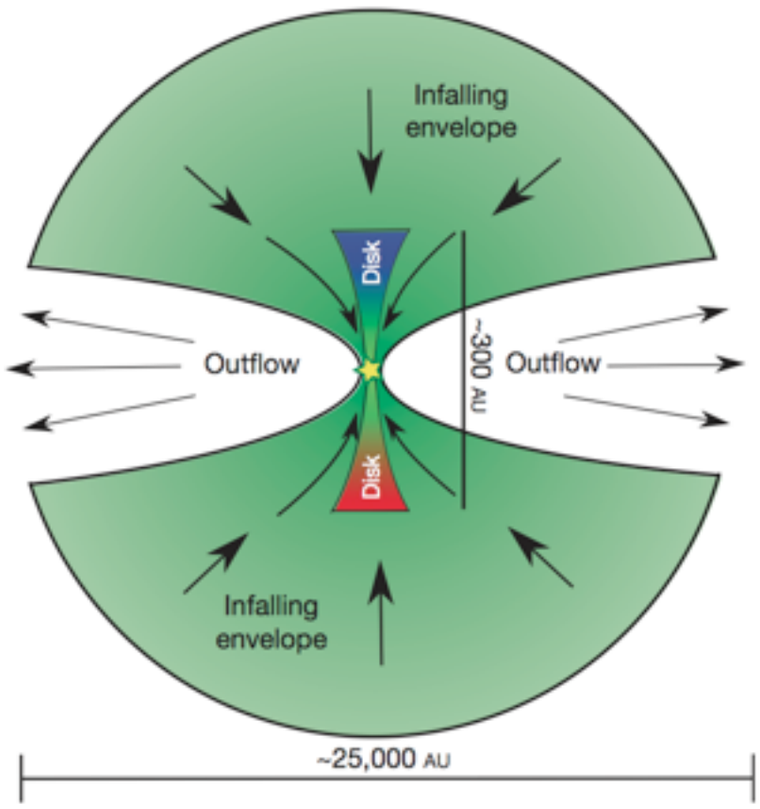


Bonner-Ebert Sphäre



Protosterne



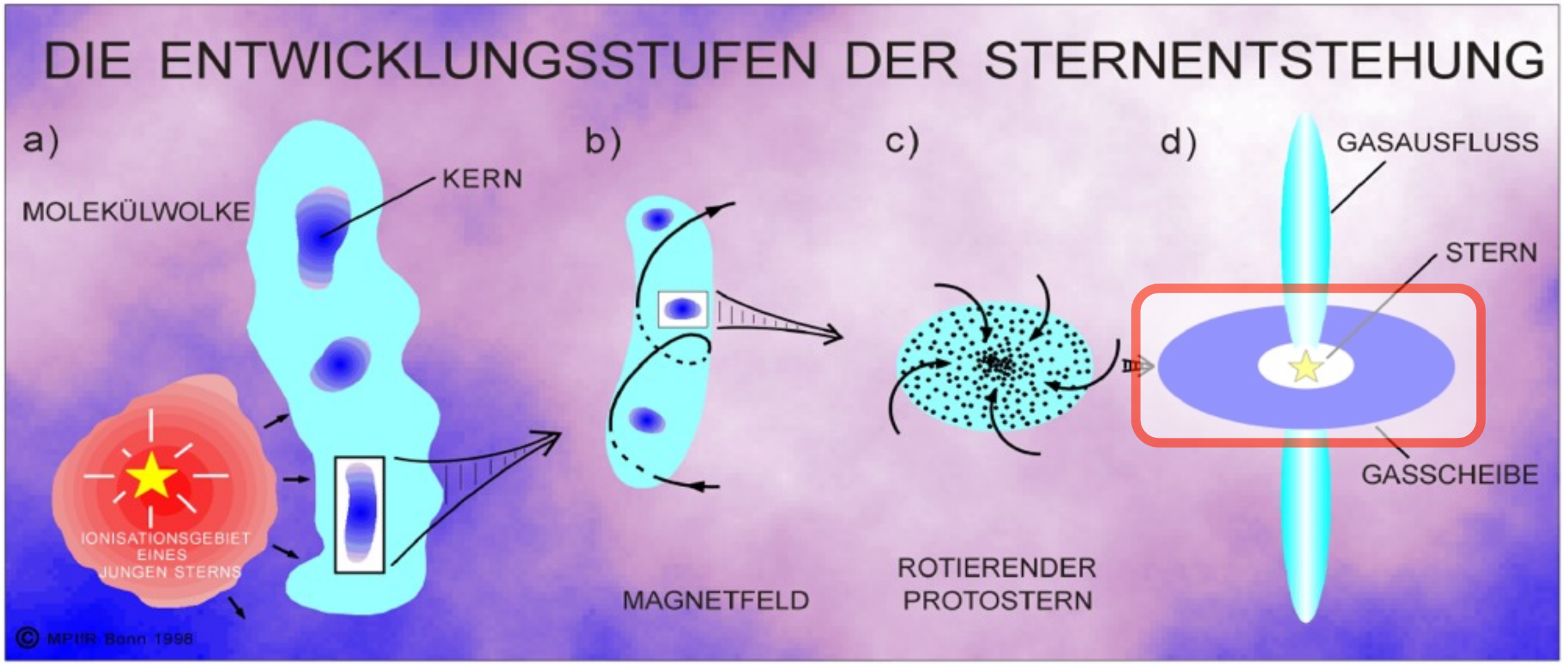


Tobin et al., Nature 2012

L1527 IRS:
jüngster bis dahin beobachtete Protostern

Alter < 300.000 Jahre
Masse ~ 0.2 $M_\odot$

Scheiben


DIE ENTWICKLUNGSSTUFEN DER STERNENTSTEHUNG
a)
b)
c)
d)
MOLEKÜLWOLKE
KERN
GASAUSFLUSS
STERN
GASSCHEIBE
IONISATIONSGEBIET
EINES
JUNGEN STERNS
MAGNETFELD
ROTIERENDER
PROTOSTERN
© MPIfR Bonn 1998

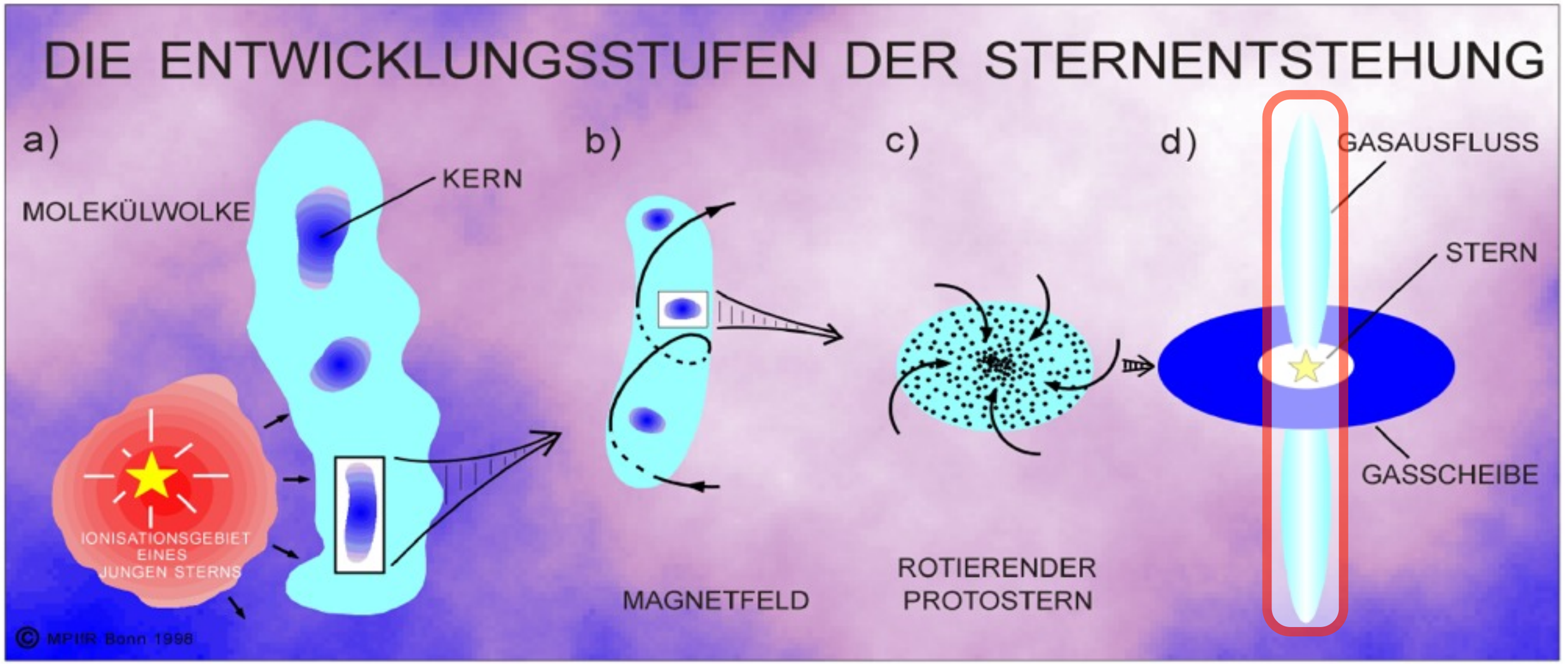
Scheiben

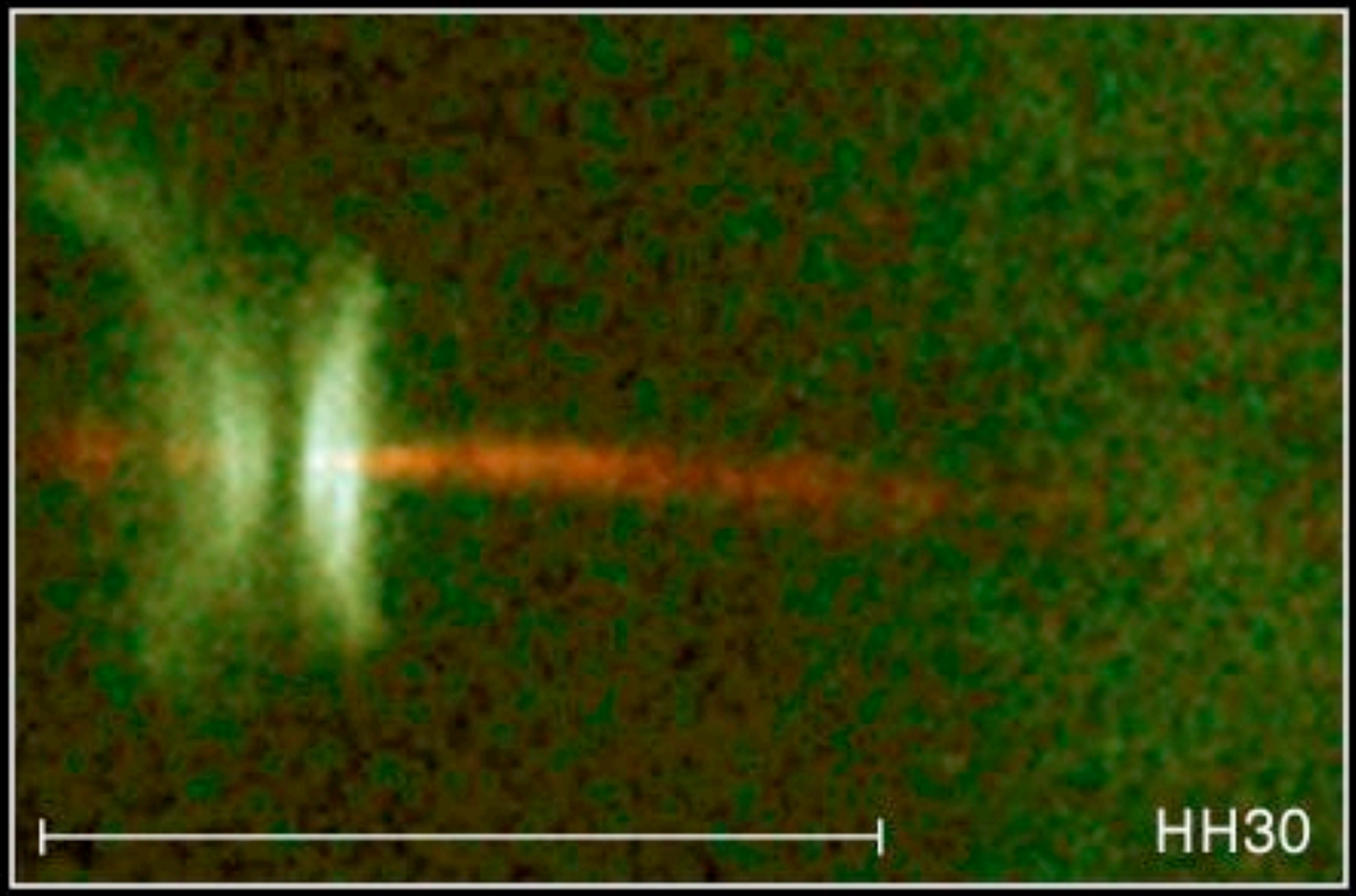

Protoplanetary Disks
Orion Nebula
HST · WFPC2
PRC95-45b · ST ScI OPO · November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

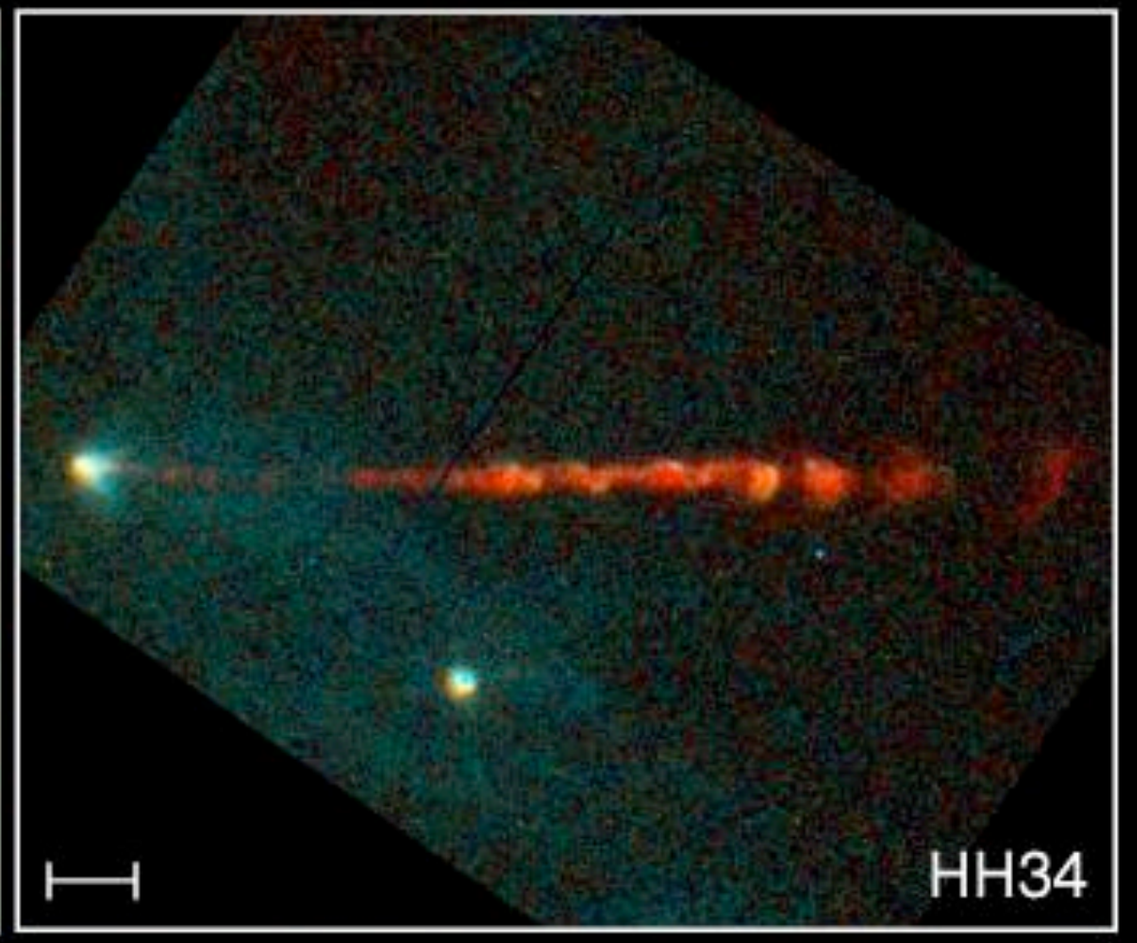
Simulation: Paul Clark (Uni Heidelberg)

Simulation: Paul Clark (Uni Heidelberg)

Jets & Gasausflüsse







Jets from Young Stars

HST · WFPC2

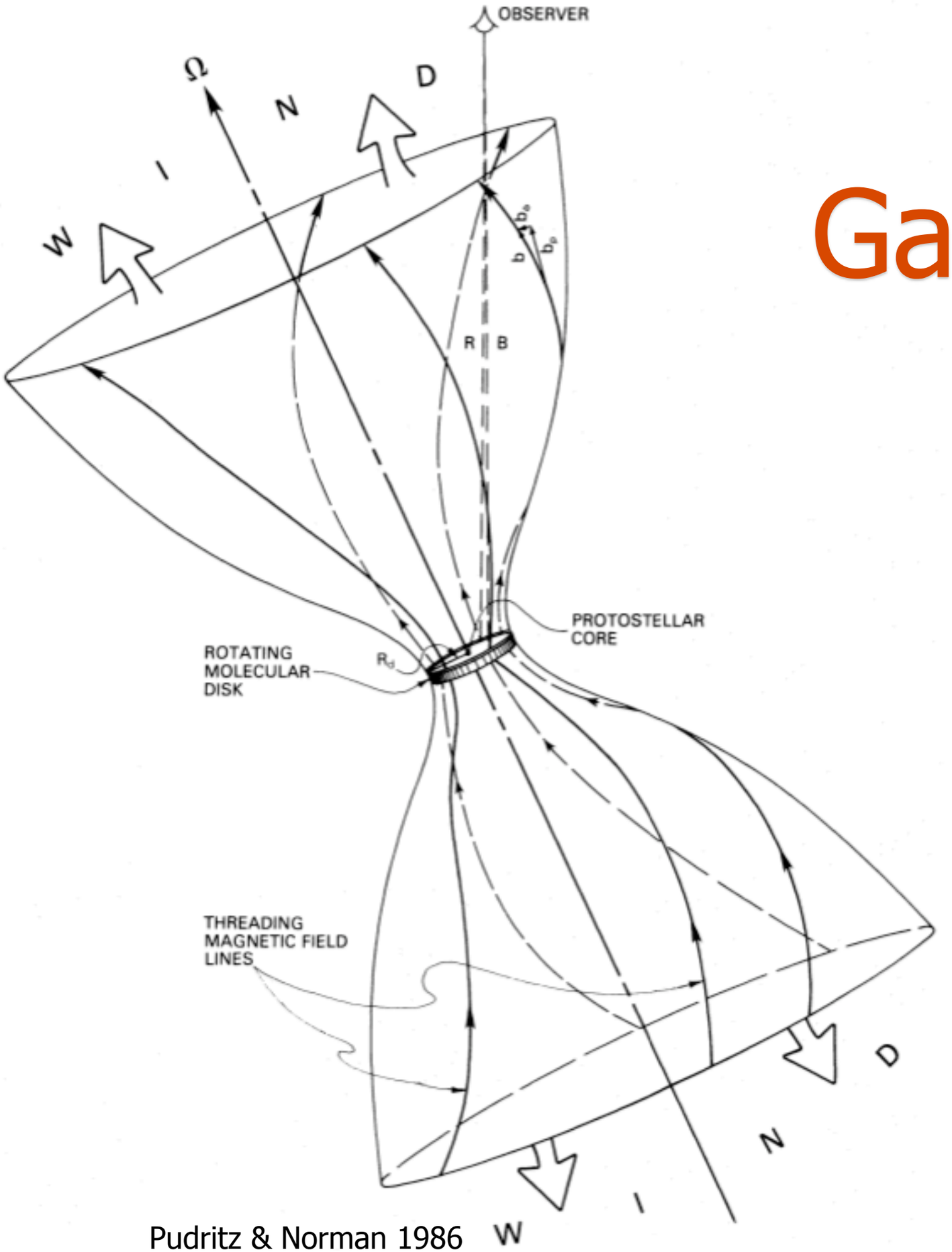
PRC95-24a · ST ScI OPO · June 6, 1995

C. Burrows (ST ScI), J. Hester (AZ State U.), J. Morse (ST ScI), NASA

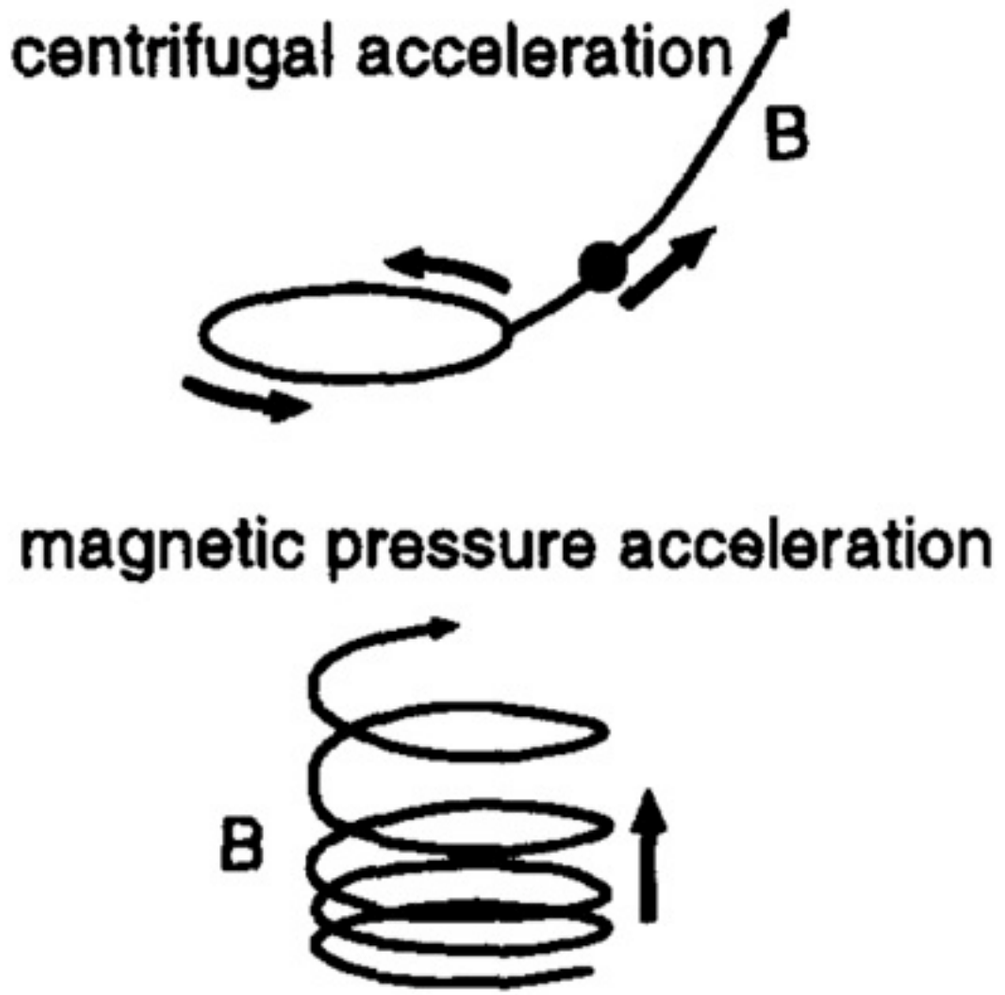
"Mystic Mountain" in Carina Nebula, *HST, NASA, ESA*

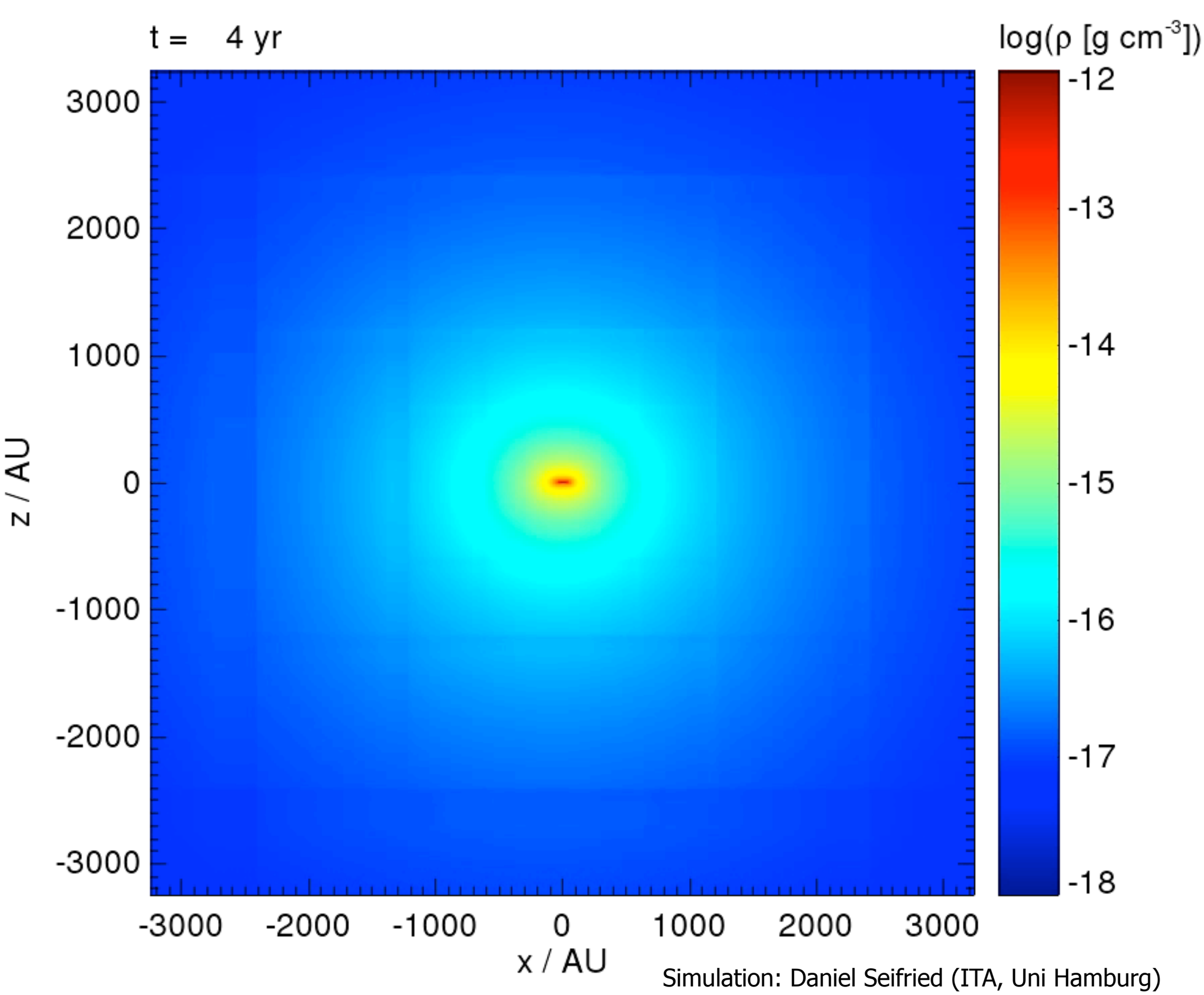
HH 34, Aufnahme: VLT

Jets & Gasausflüsse

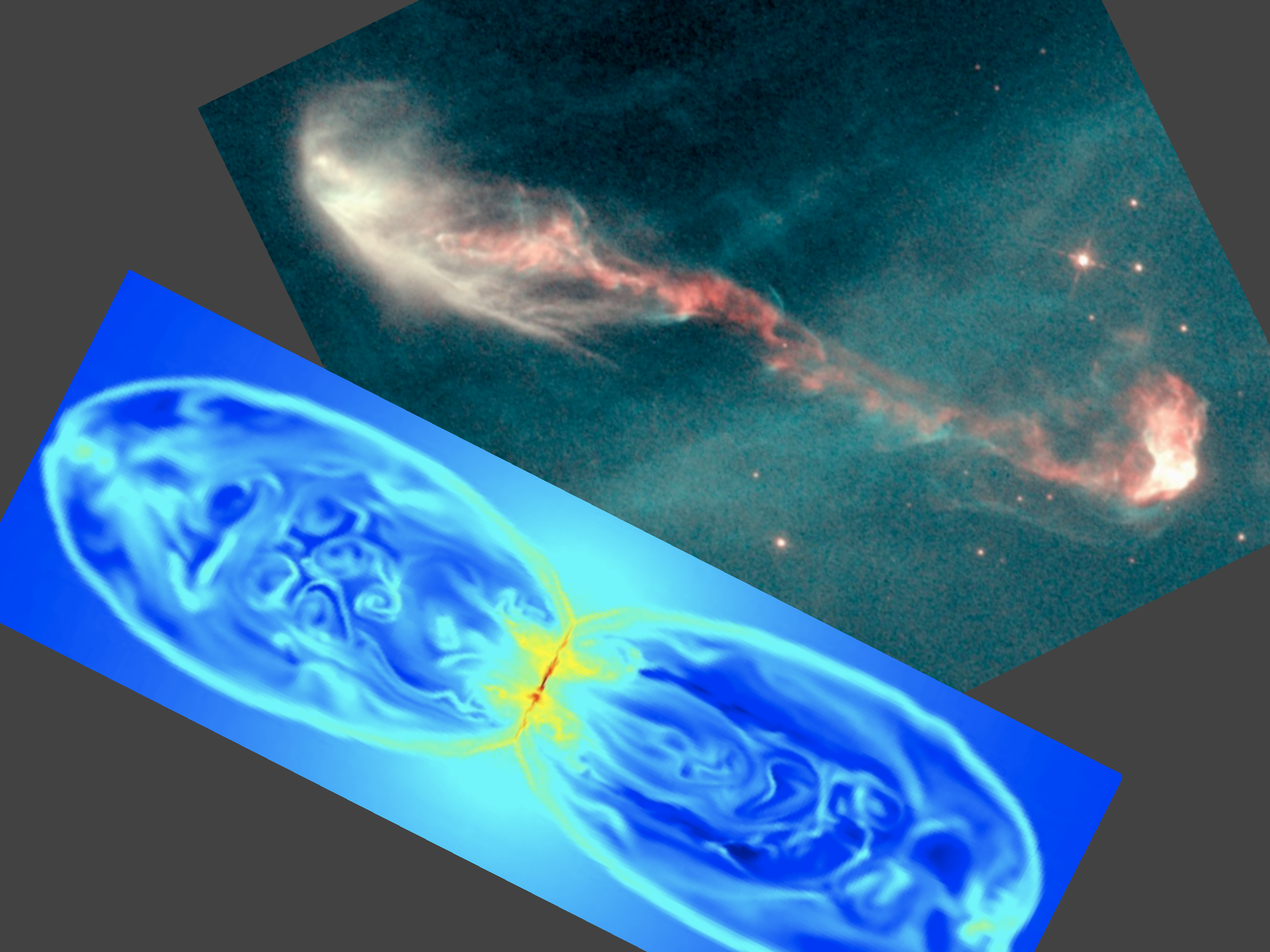


Pudritz & Norman 1986





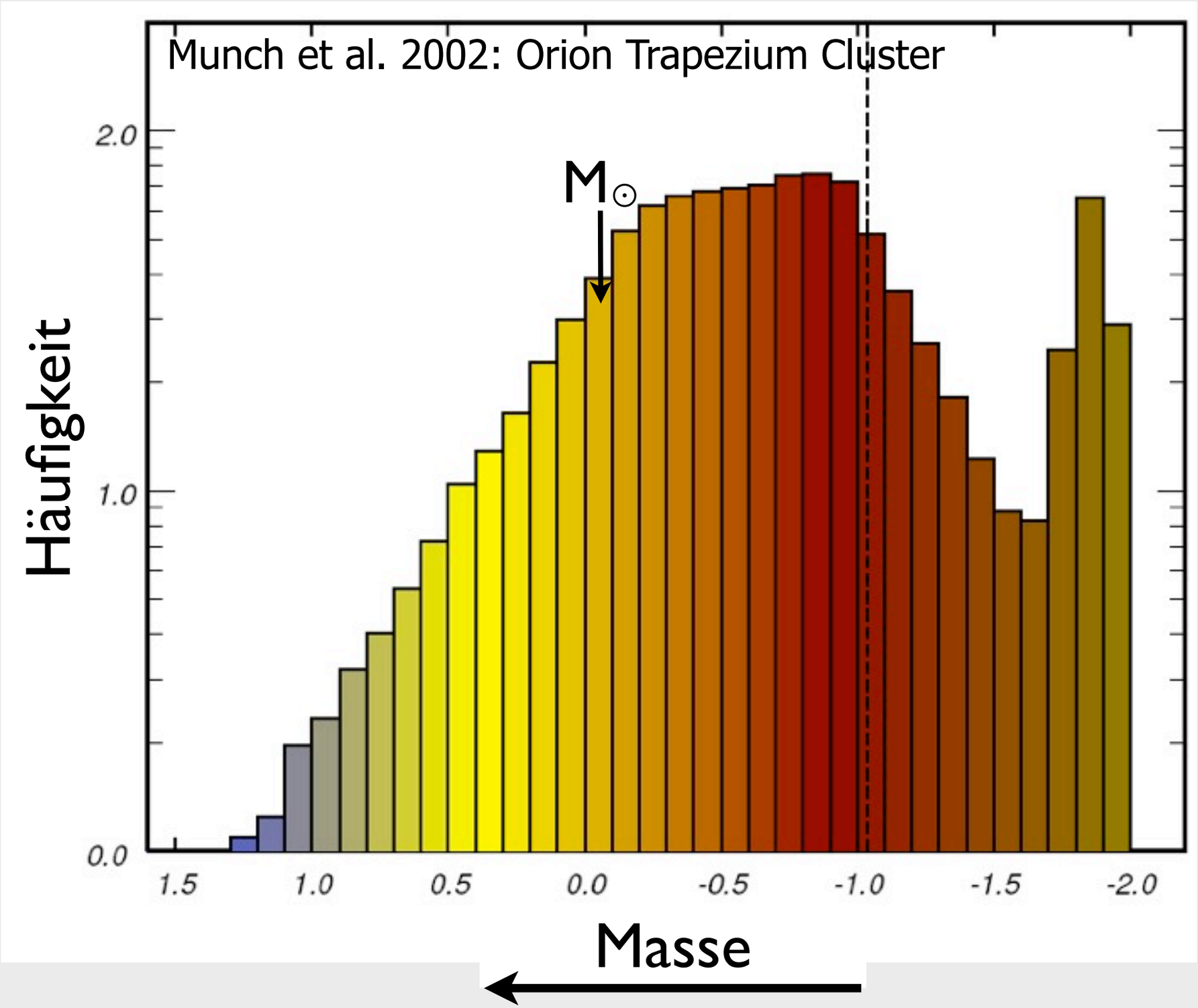
Simulation: Daniel Seifried (ITA, Uni Hamburg)



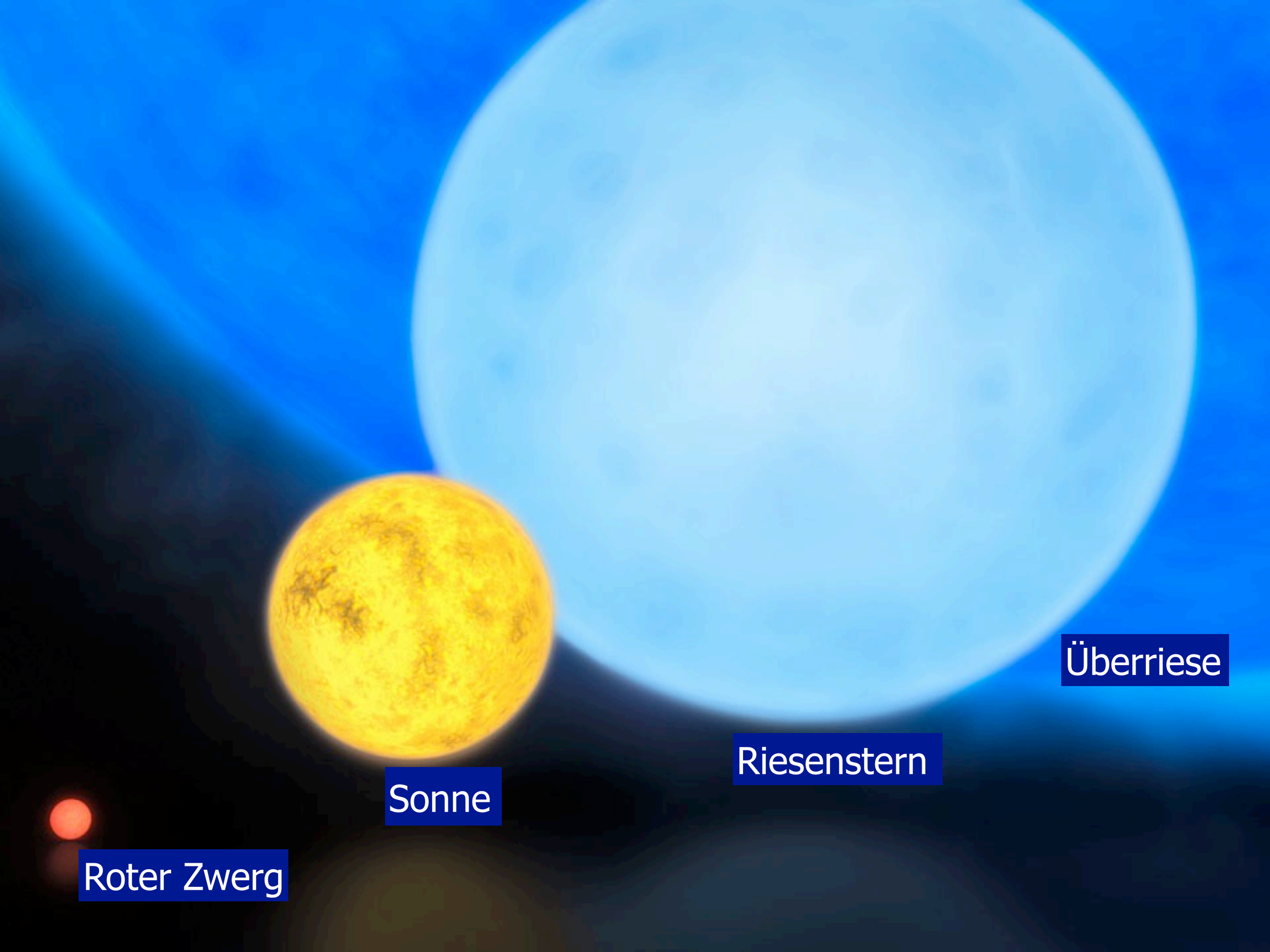
Turbulenz und Fragmentierung

Simulation: Paul Clark (Uni Heidelberg)

Massenverteilung der Sterne



- **Universelle** Massenverteilung der Sterne (IMF)?


Überriese
Riesenstern
Sonne
Roter Zwerg

Sternhaufen

M54, HST @ $D \sim 27$ kpc


Image by: M.Schneide

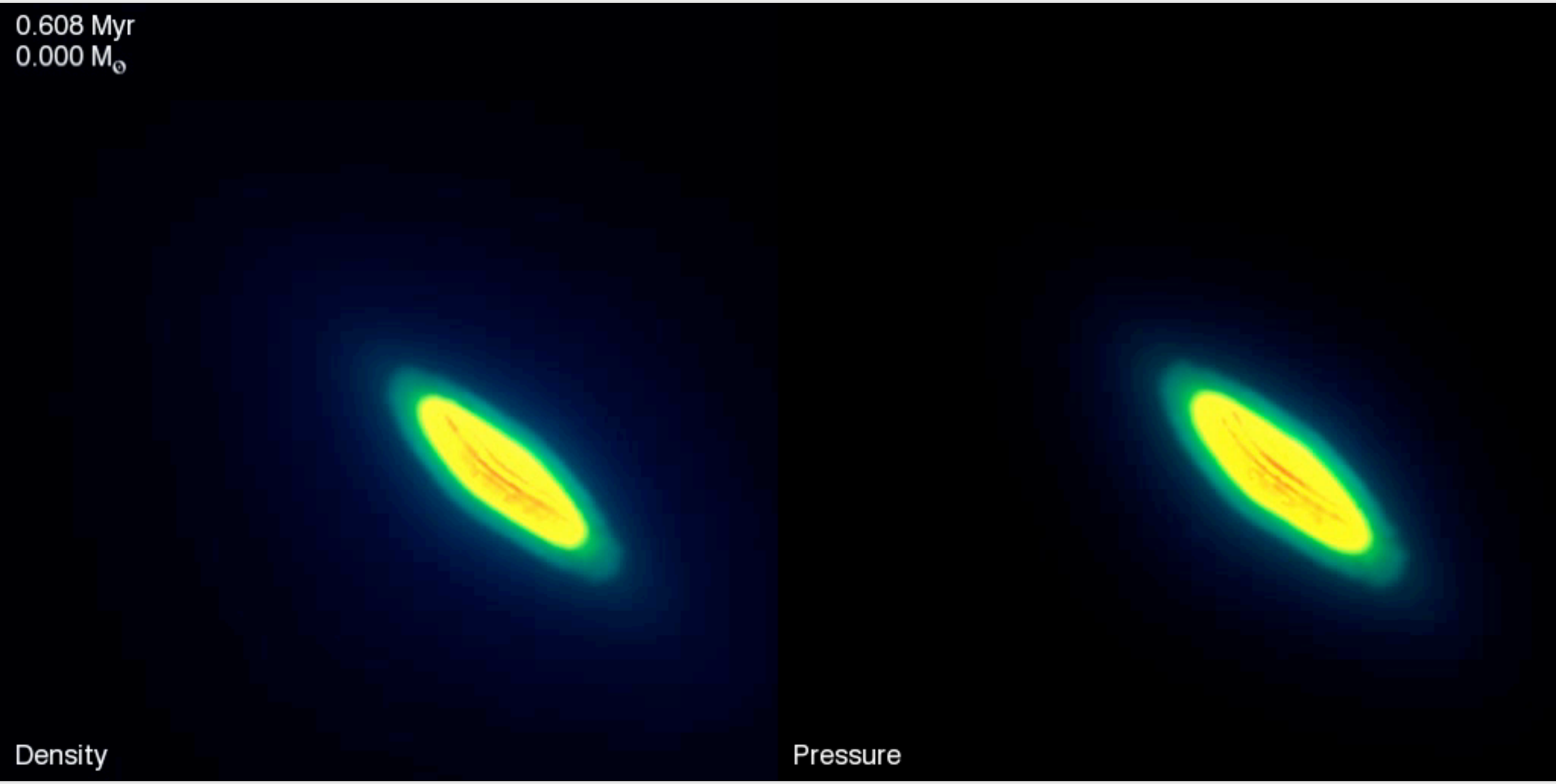
Massereiche Sterne

Trapez Sternhaufen, NICMOS IDT, NASA WFPC2

Massereiche Sterne

RCW 120, Aufnahme: Herschel Statellit

Entstehung massereicher Sterne

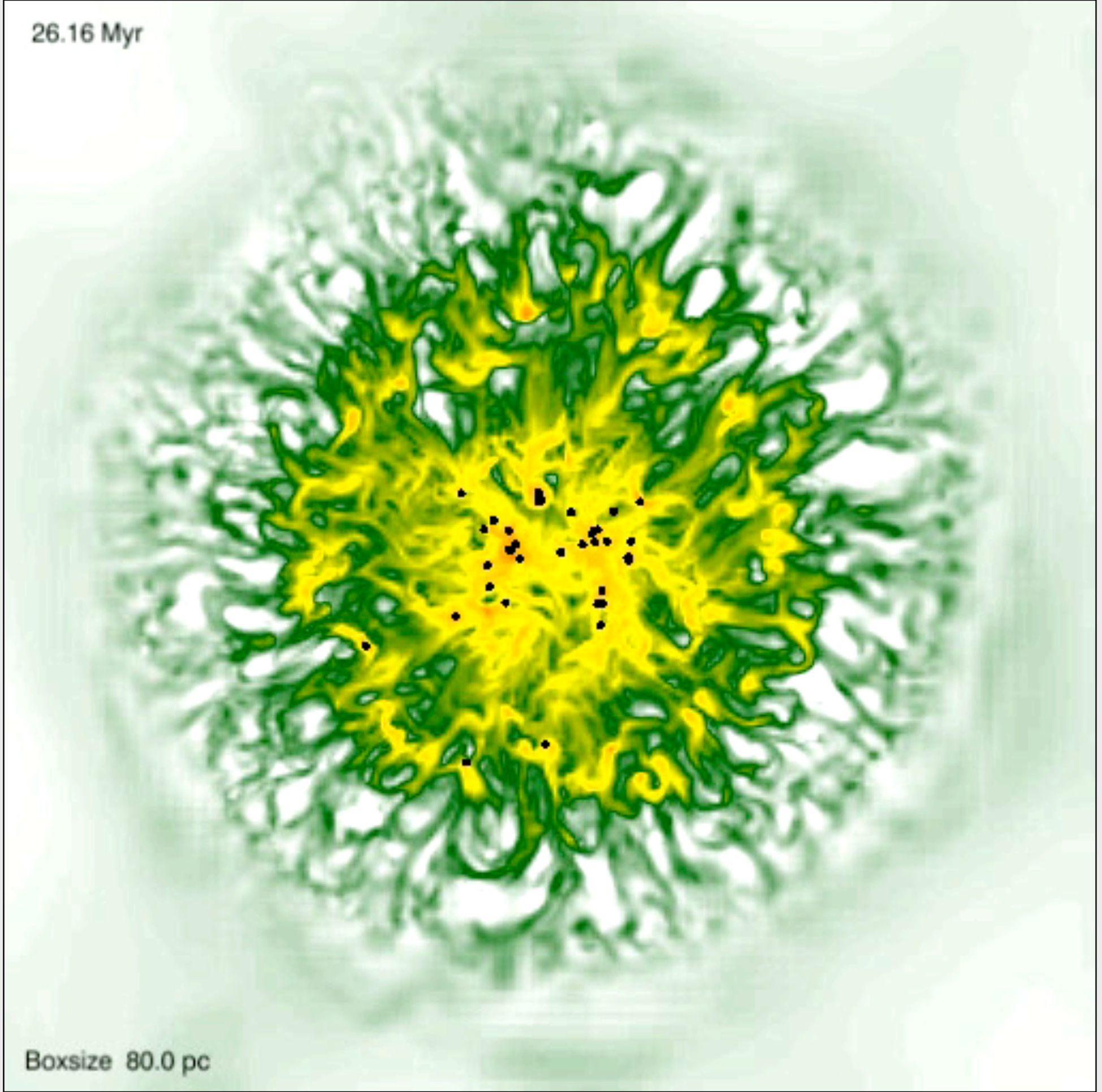


Simulation: Thomas Peters (ITA, Uni Heidelberg), Visualisierung: Herwig Zilken (Jülich)

Hubble Space Telescope: R 136 in LMC (30 Dor / Tarantelnebel)

Supernovae

Krebs Nebel, Aufnahme: HST


26.16 Myr
Boxsize 80.0 pc

Vielen Dank für Ihre Aufmerksamkeit