Population III Binaries

Matthew Turk (UCSD)
Tom Abel (Stanford)
Brian O'Shea (MSU)
Mike Norman (UCSD)

See also: Stacy et al, Clark et al

Cosmological Star Formation is an inherently multi-scale problem.

10^{6} $M_\odot$ Halo

10^{2} $M_\odot$ Star

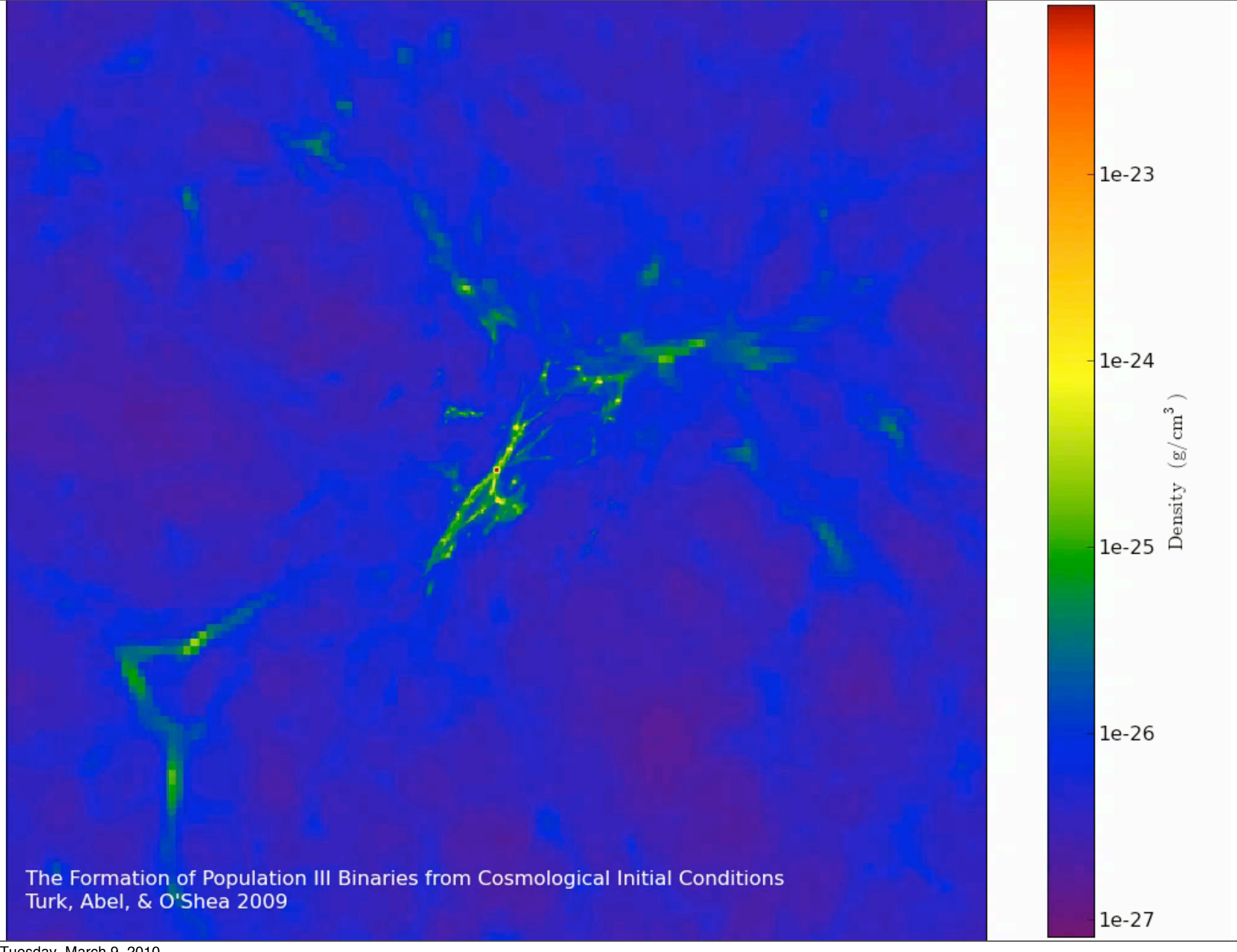
10^{-2} $M_\odot$ Protostar

Enzo

Adaptive Mesh Refinement

Modified chemistry solver valid at densities up to 10^{20} g/cc.

Up to 33 levels of refinement.


1e-23
1e-24
1e-25
1e-26
1e-27
Density (g/cm^3)
The Formation of Population III Binaries from Cosmological Initial Conditions
Turk, Abel, & O'Shea 2009

fragments at 10^{13} cm^{-3}

64 cells per Jeans Length

two bound clumps

463^3 cells

with Tom Abel, Brian O'Shea

X

Y

Z

(3500 AU)

-1146 years

-555 years

0 years

rho

h2

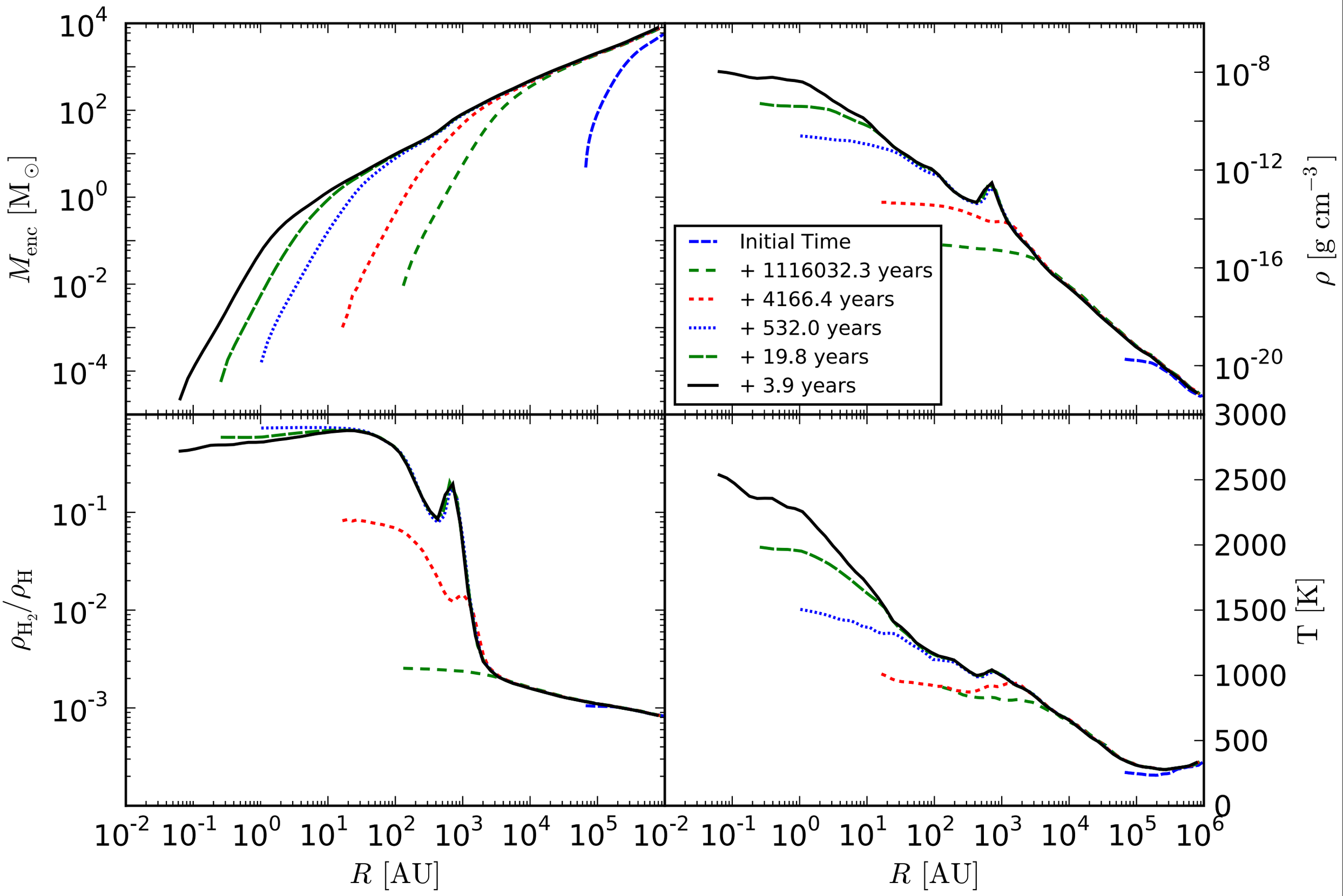
T

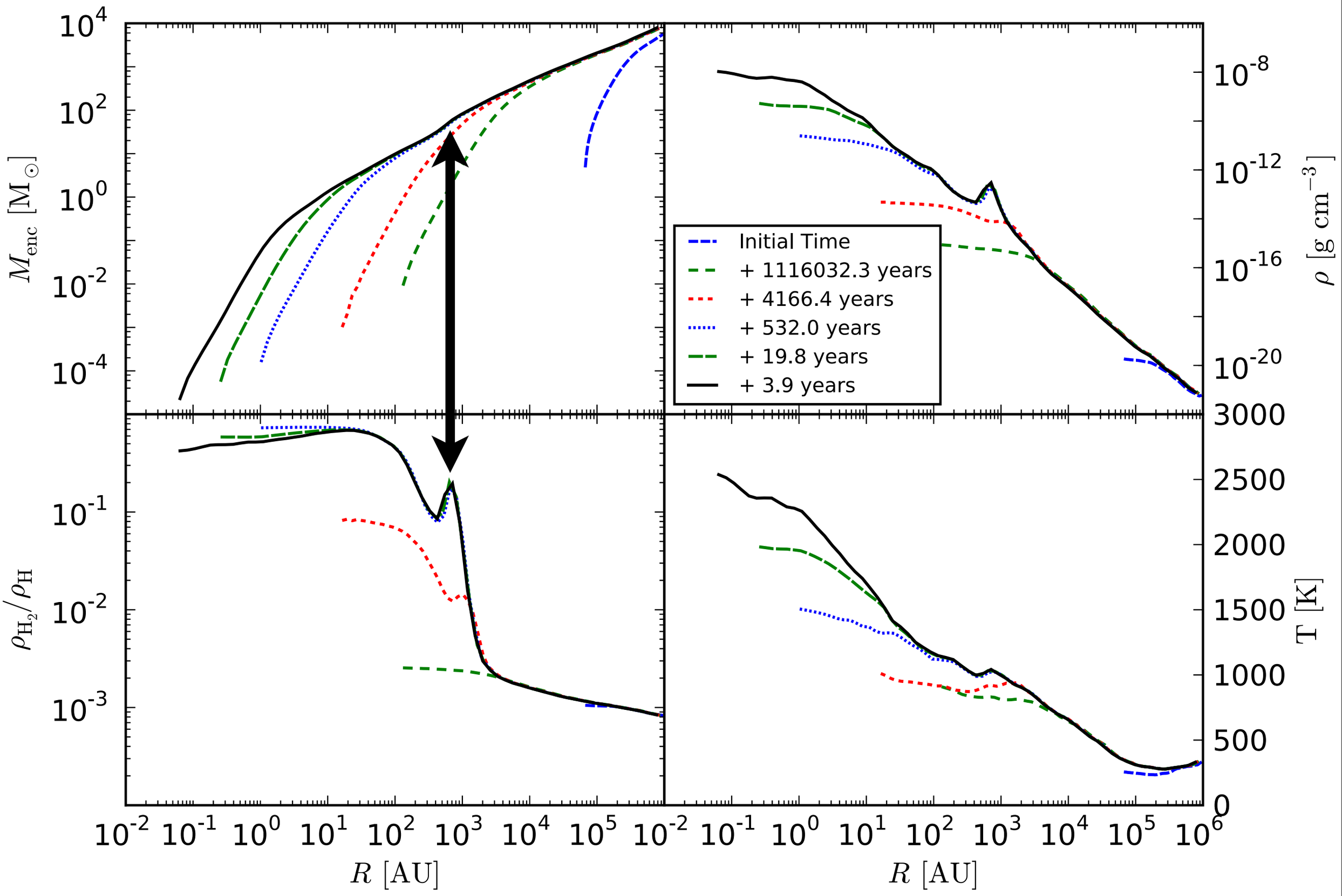
(3500 AU)

-1146 years

-555 years

0 years


$M_{\rm enc}$ [$M_\odot$]
ρ_{H_2}/ρ_H
ρ [g cm^{-3}]
T [K]
R [AU]
R [AU]
Initial Time
+ 1116032.3 years
+ 4166.4 years
+ 532.0 years
+ 19.8 years
+ 3.9 years


$M_{\rm enc}$ [$M_\odot$]
ρ_{H_2}/ρ_H
ρ [g cm^{-3}]
T [K]
R [AU]
R [AU]
Initial Time
+ 1116032.3 years
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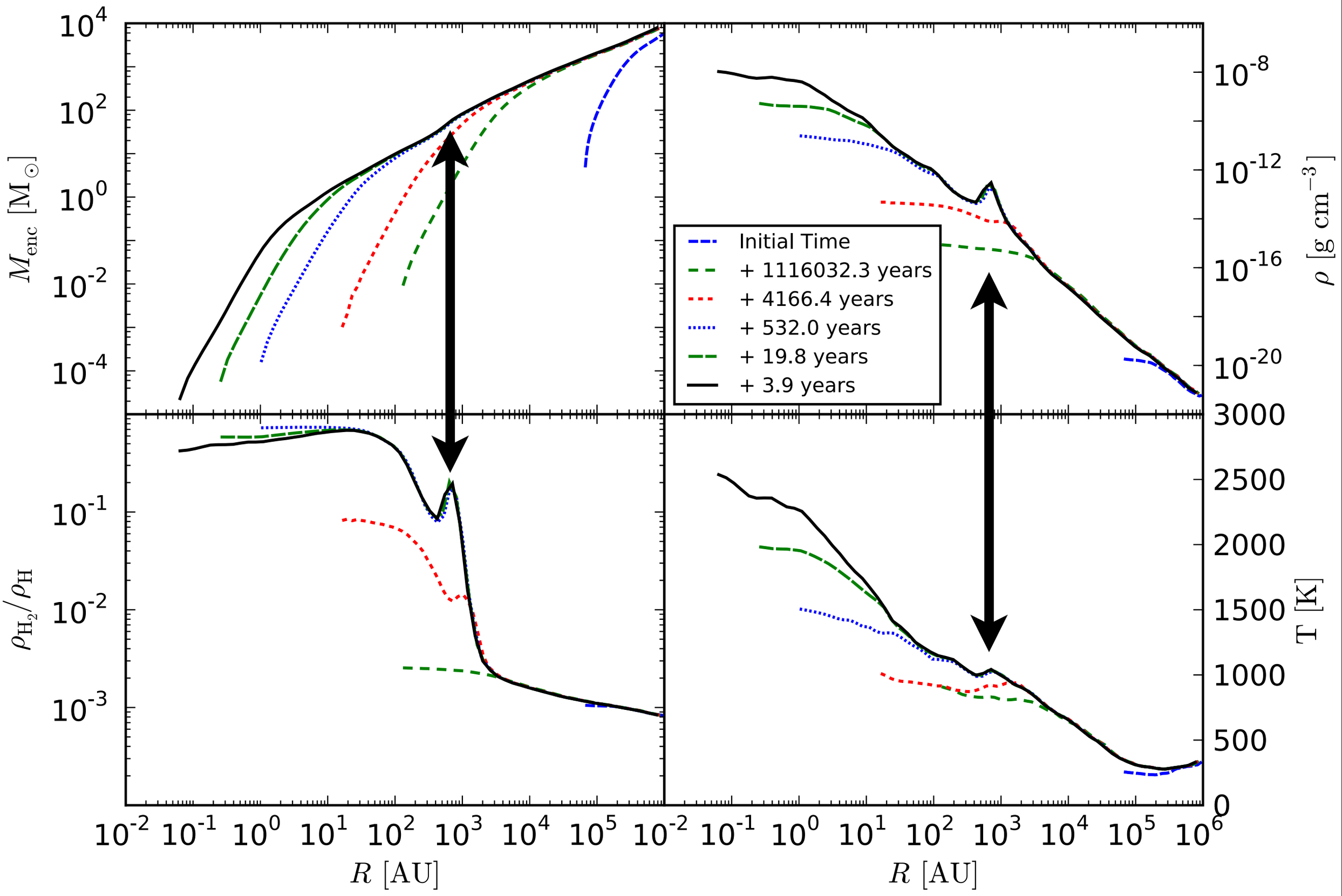
$M_{\rm enc}$ [$M_\odot$]
ρ_{H_2}/ρ_H
ρ [g cm^{-3}]
T [K]
R [AU]
R [AU]
Initial Time
+ 1116032.3 years
+ 4166.4 years
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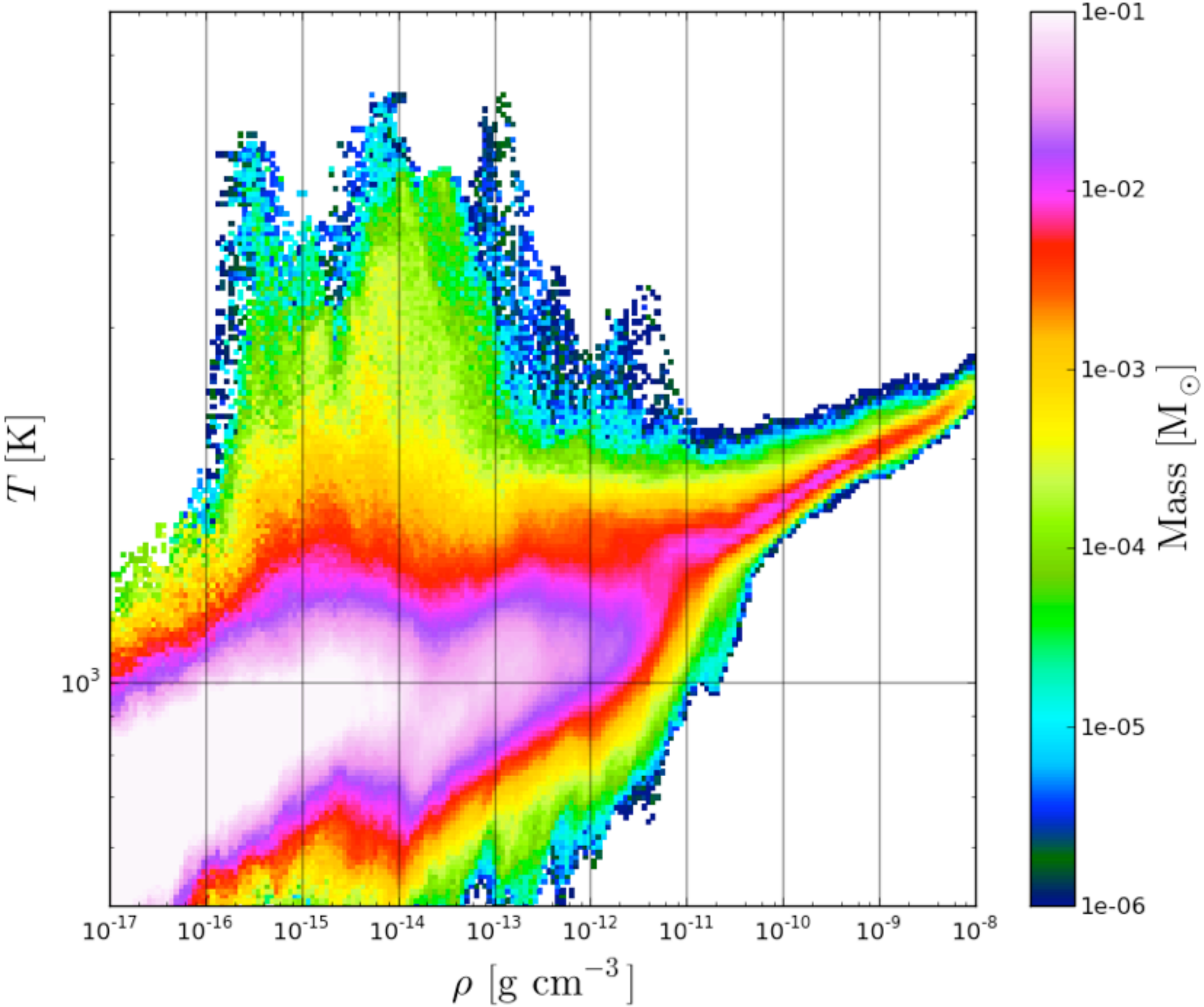
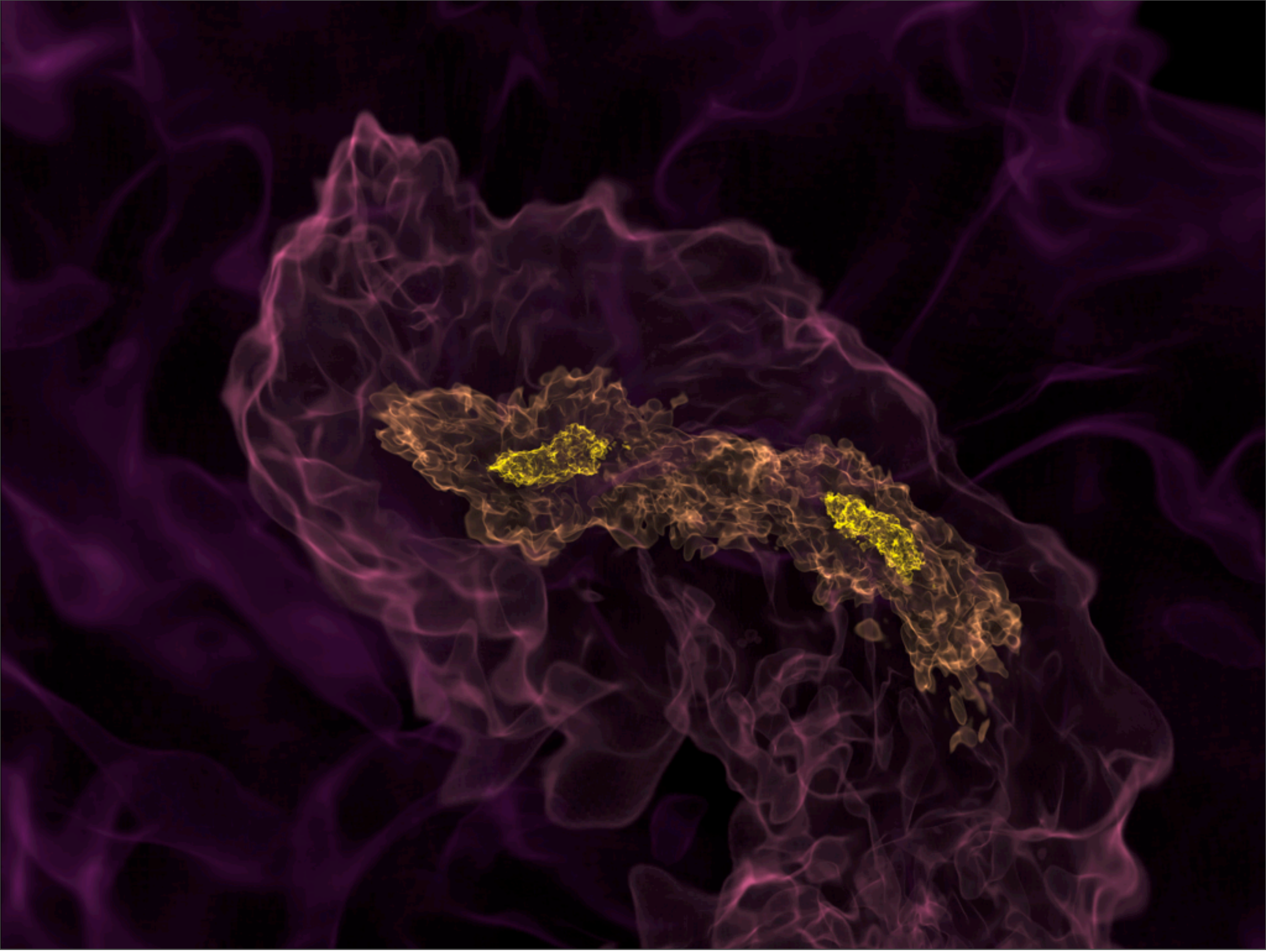
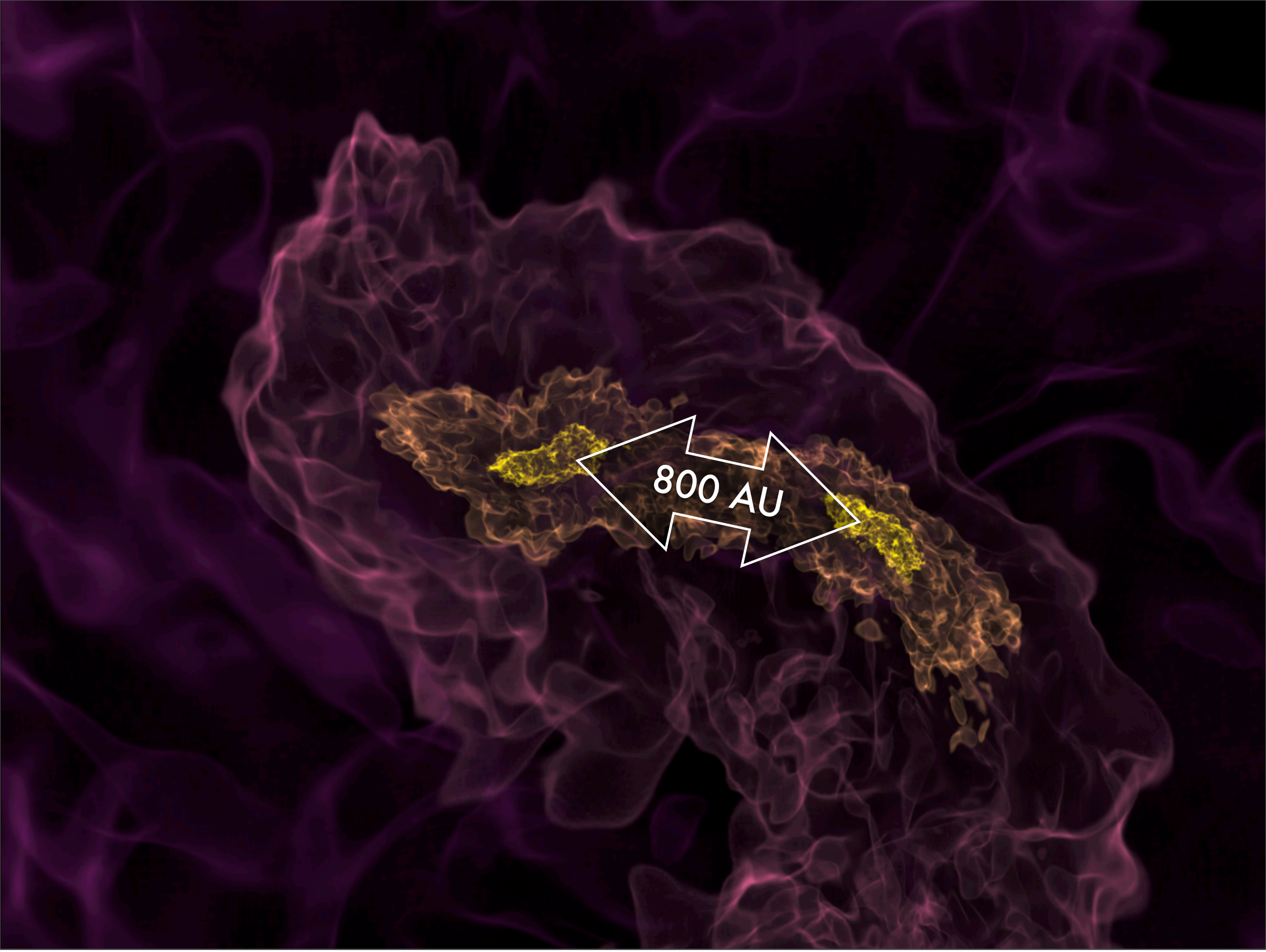
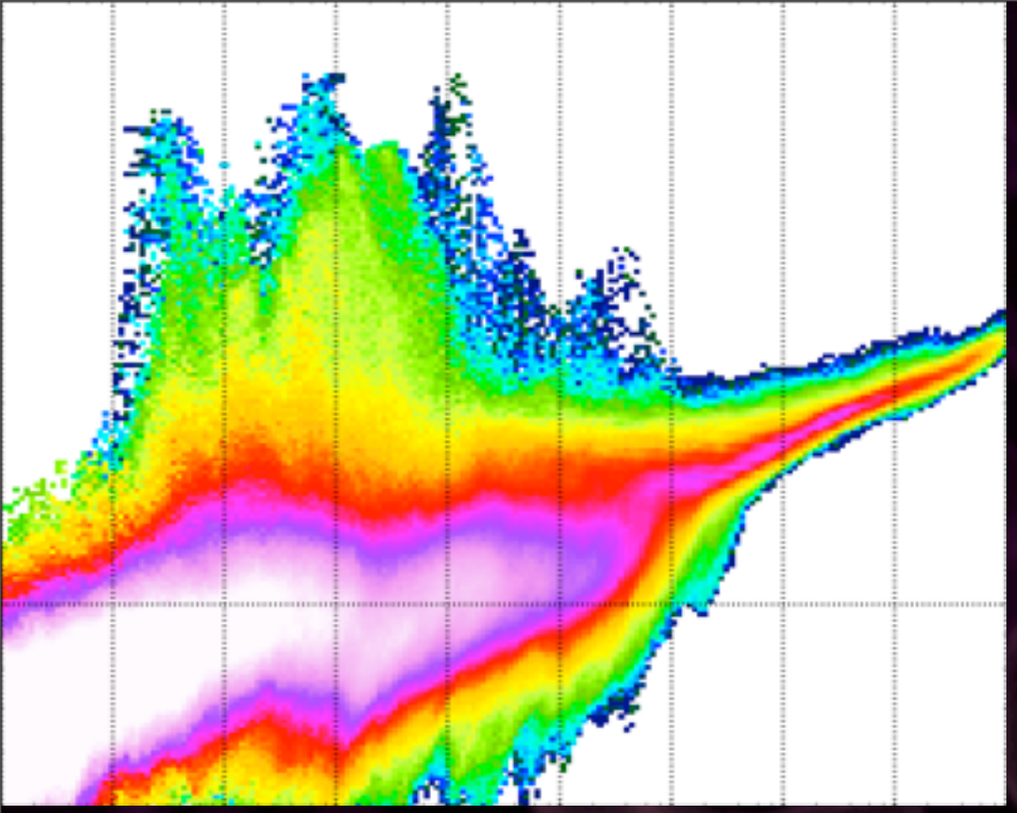
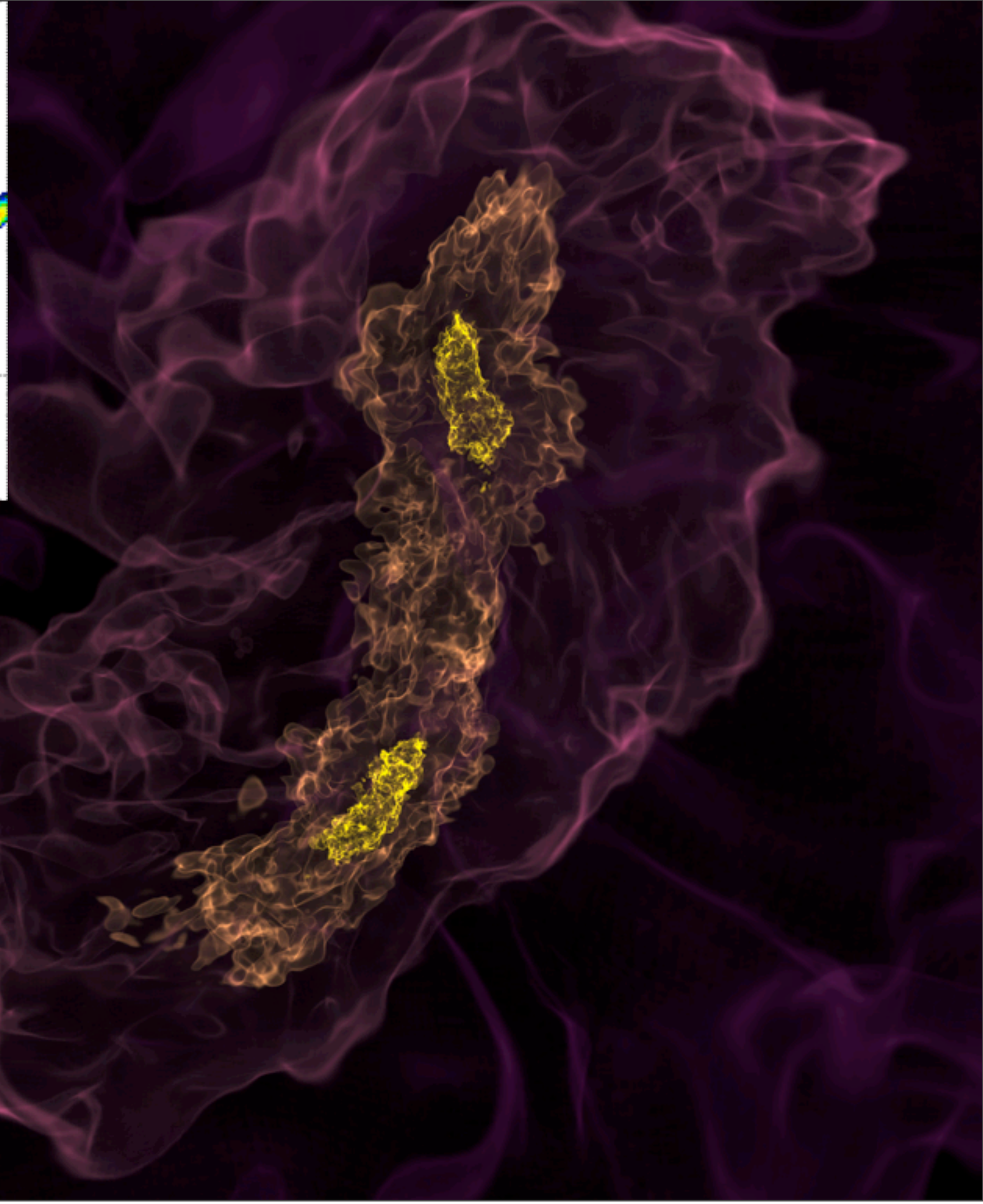
+ 3.9 years

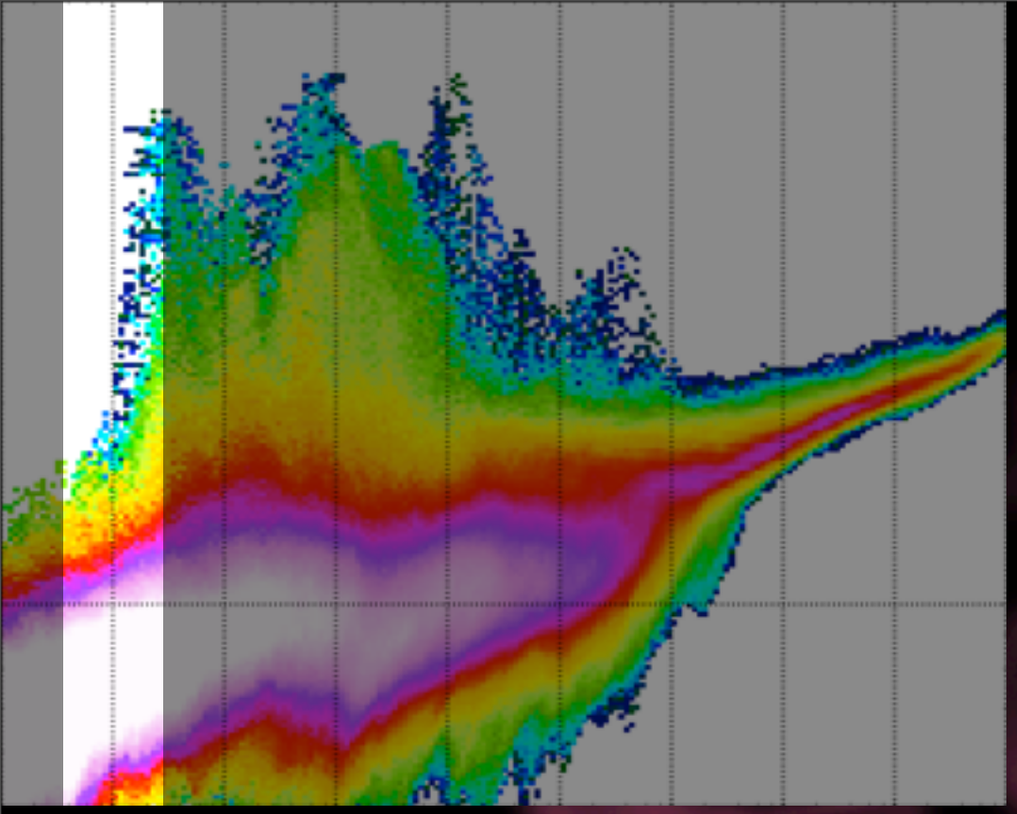

T [K]
10^3
10^{-17}
10^{-16}
10^{-15}
10^{-14}
10^{-13}
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
ρ [g cm^{-3}]
1e-01
1e-02
1e-03
1e-04
1e-05
1e-06
Mass [$M_\odot$]



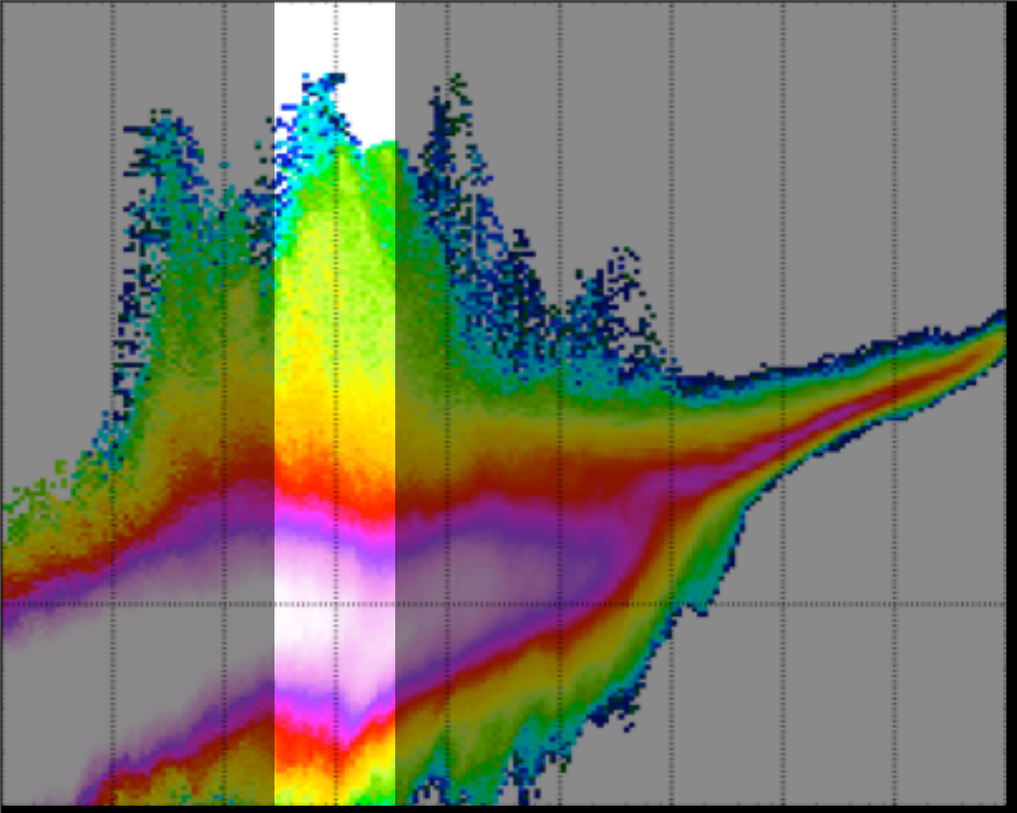

800 AU



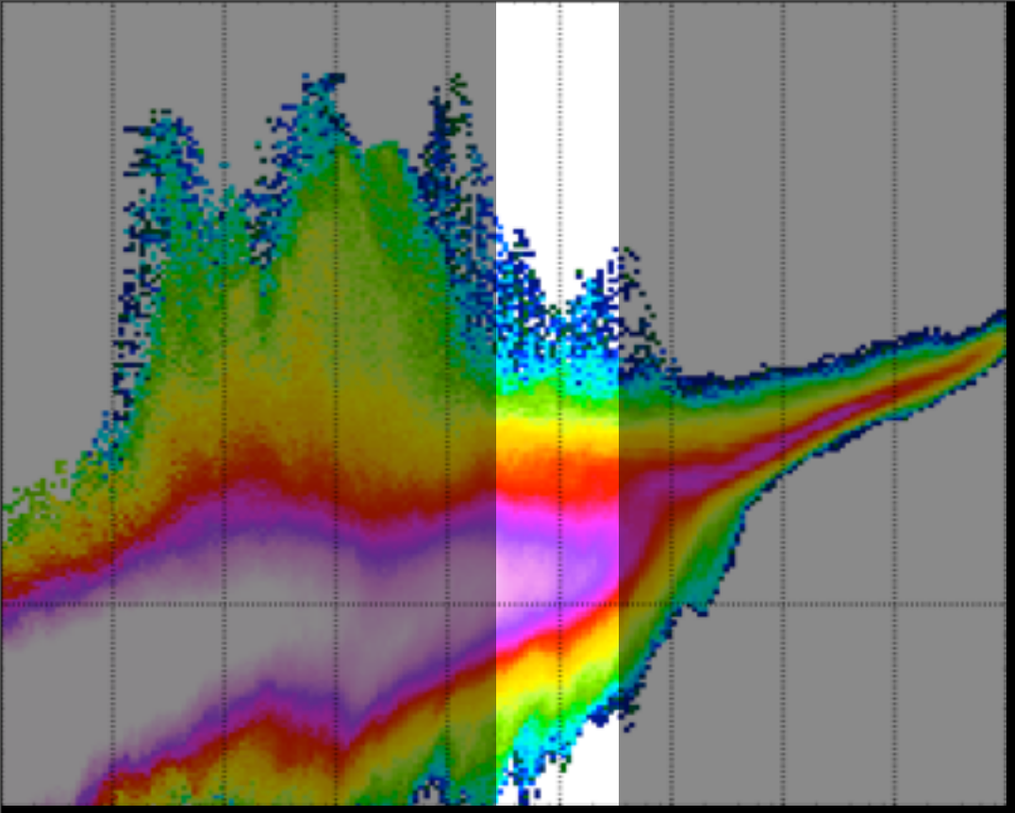


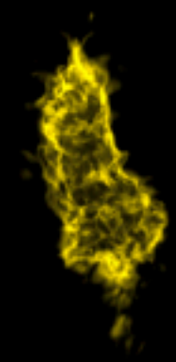


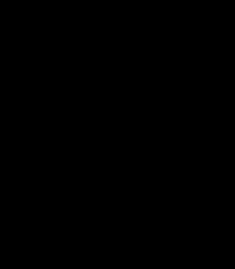
10^{-16} g/cc



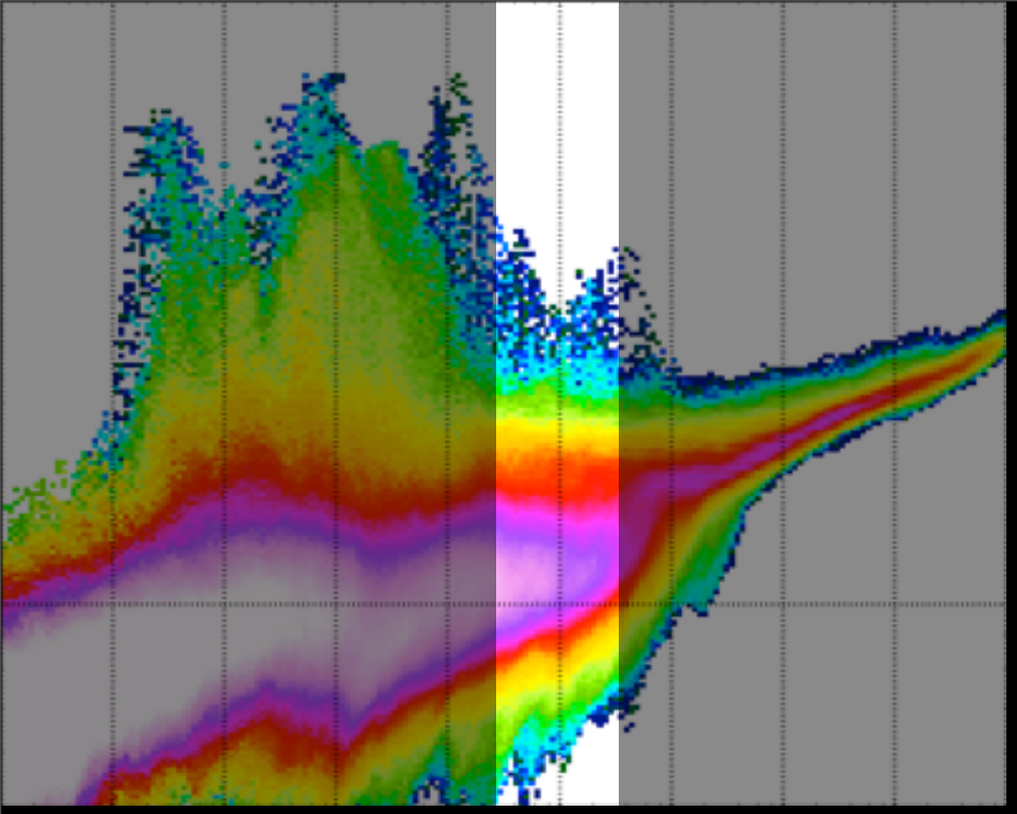

10^{-14} g/cc

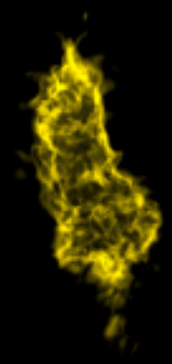




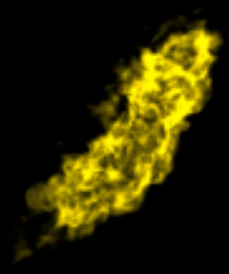


10^{-12} g/cc



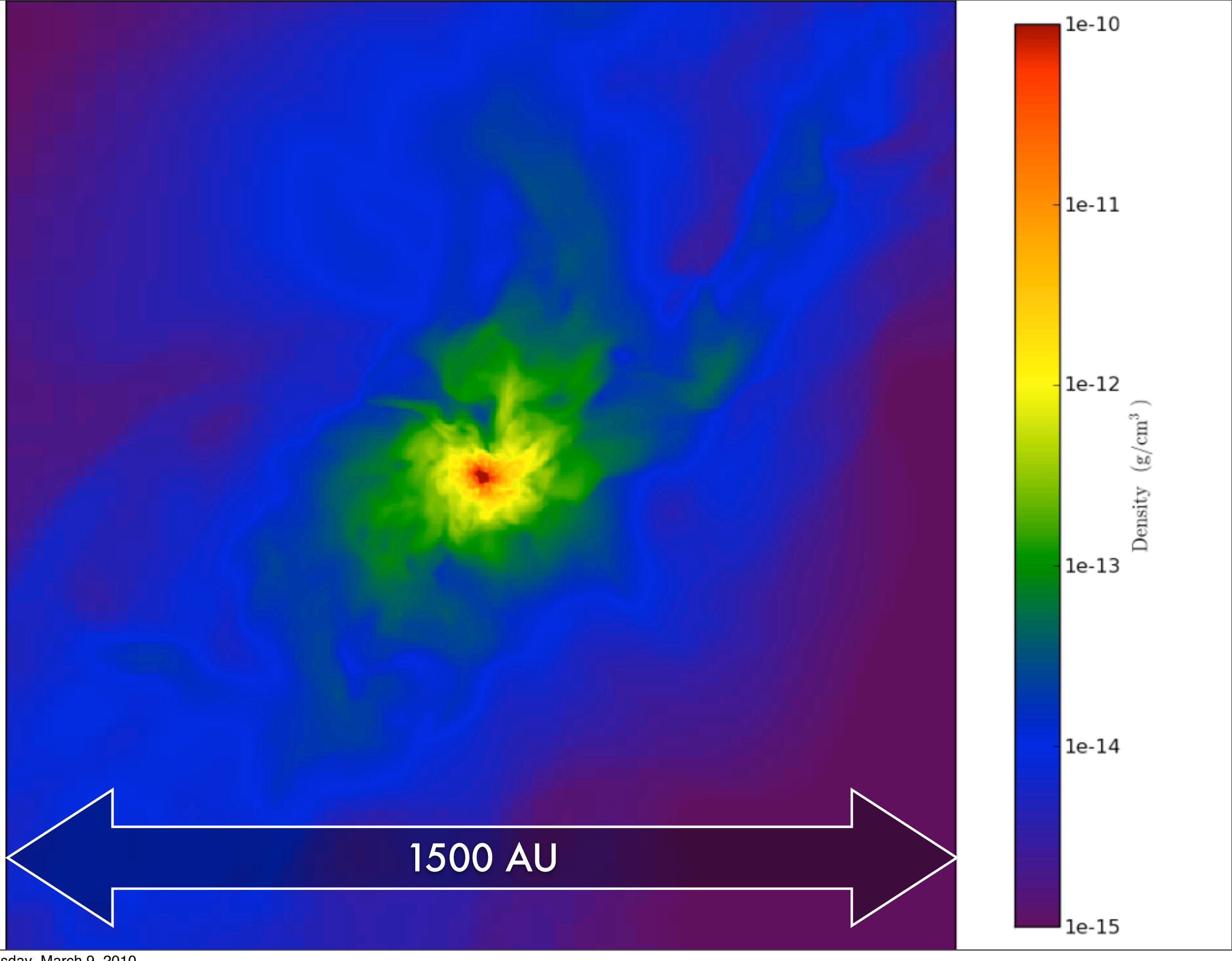


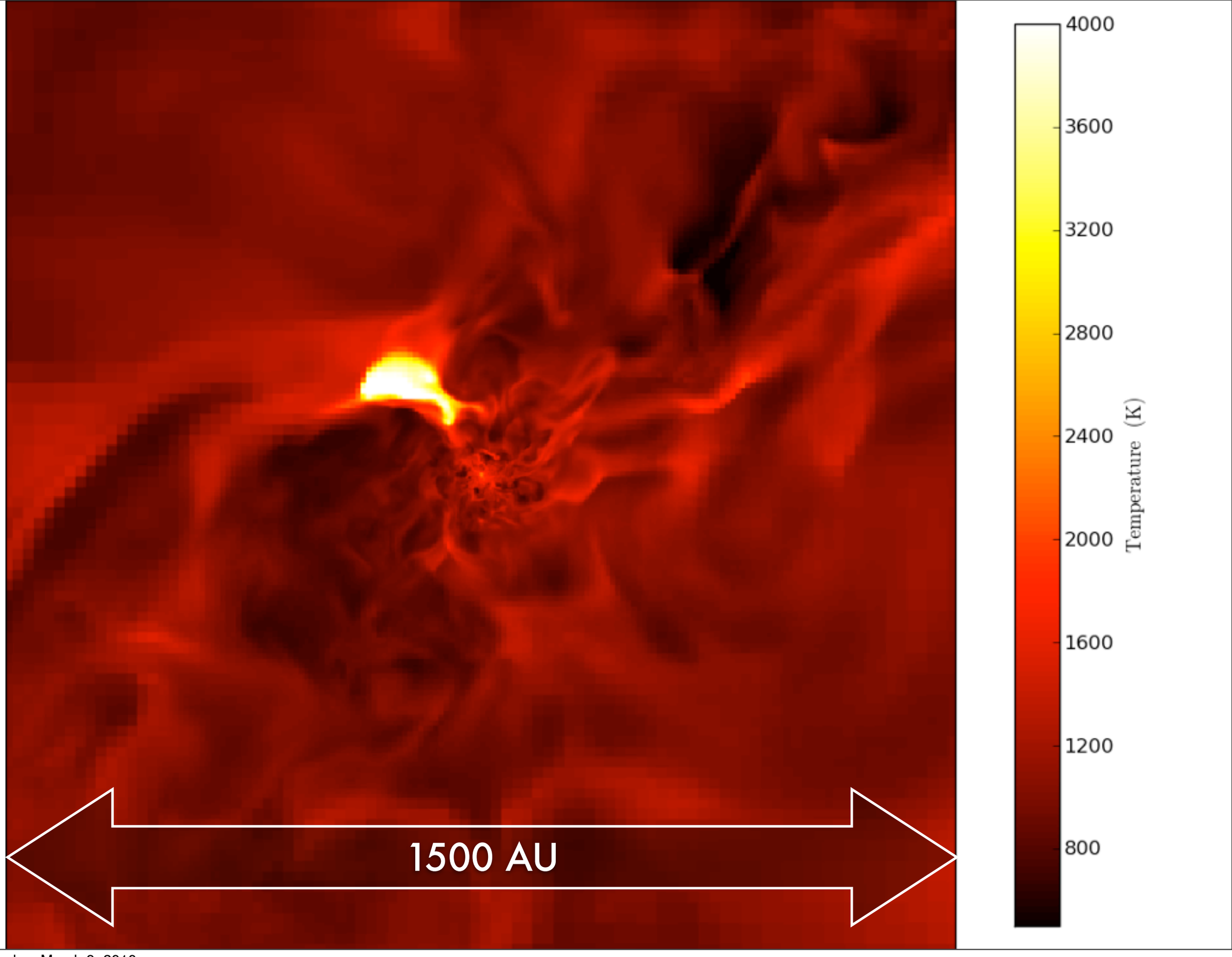
6.3 M⊙

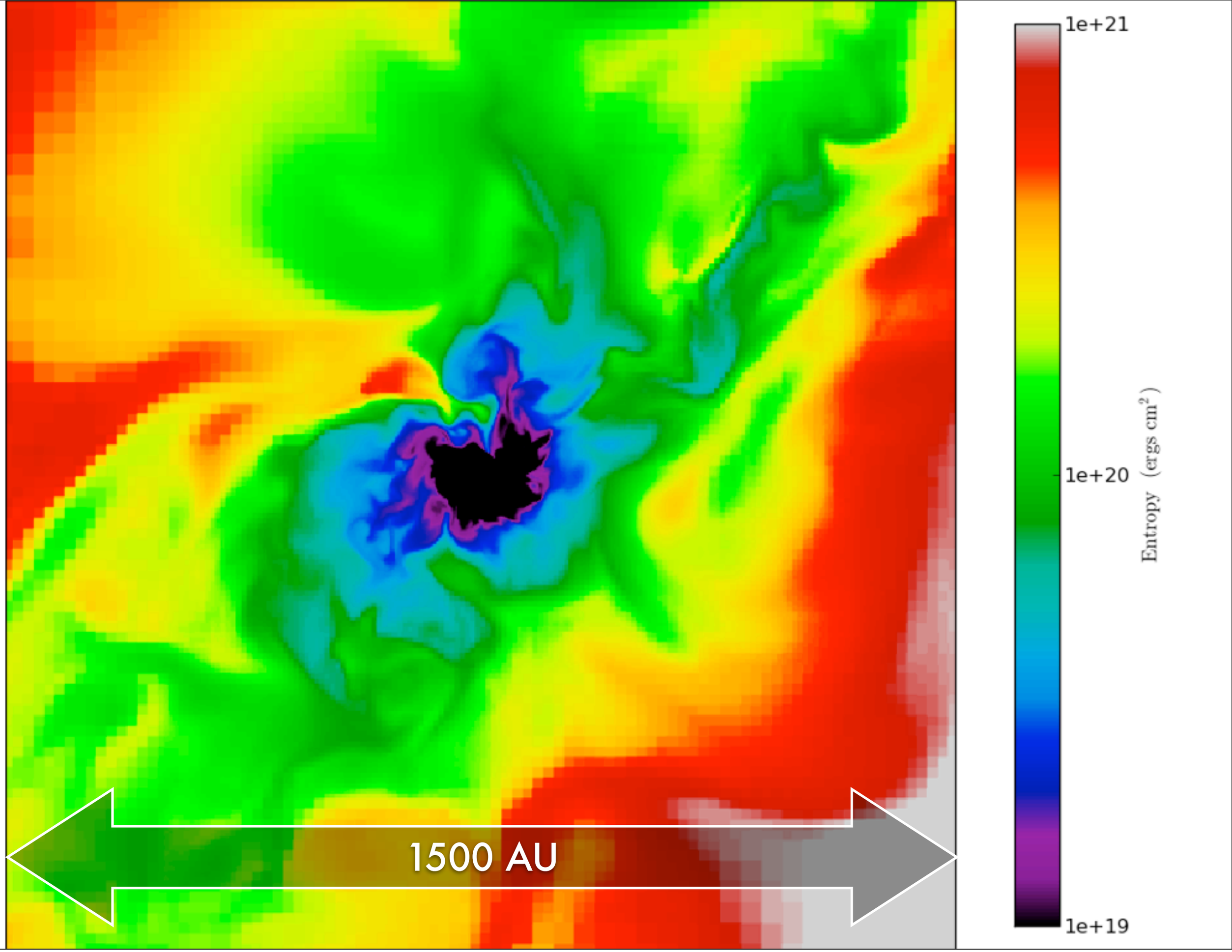


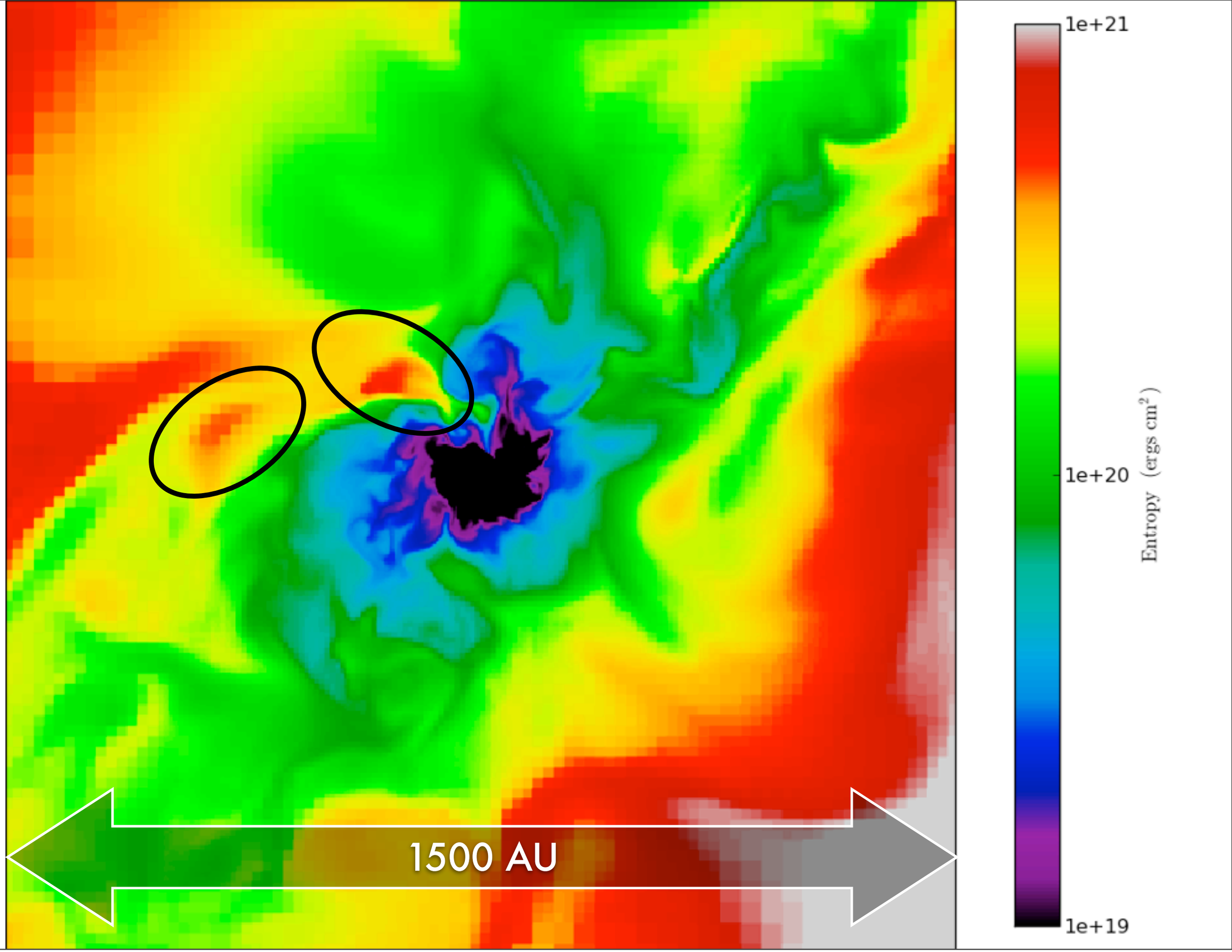
10 M⊙

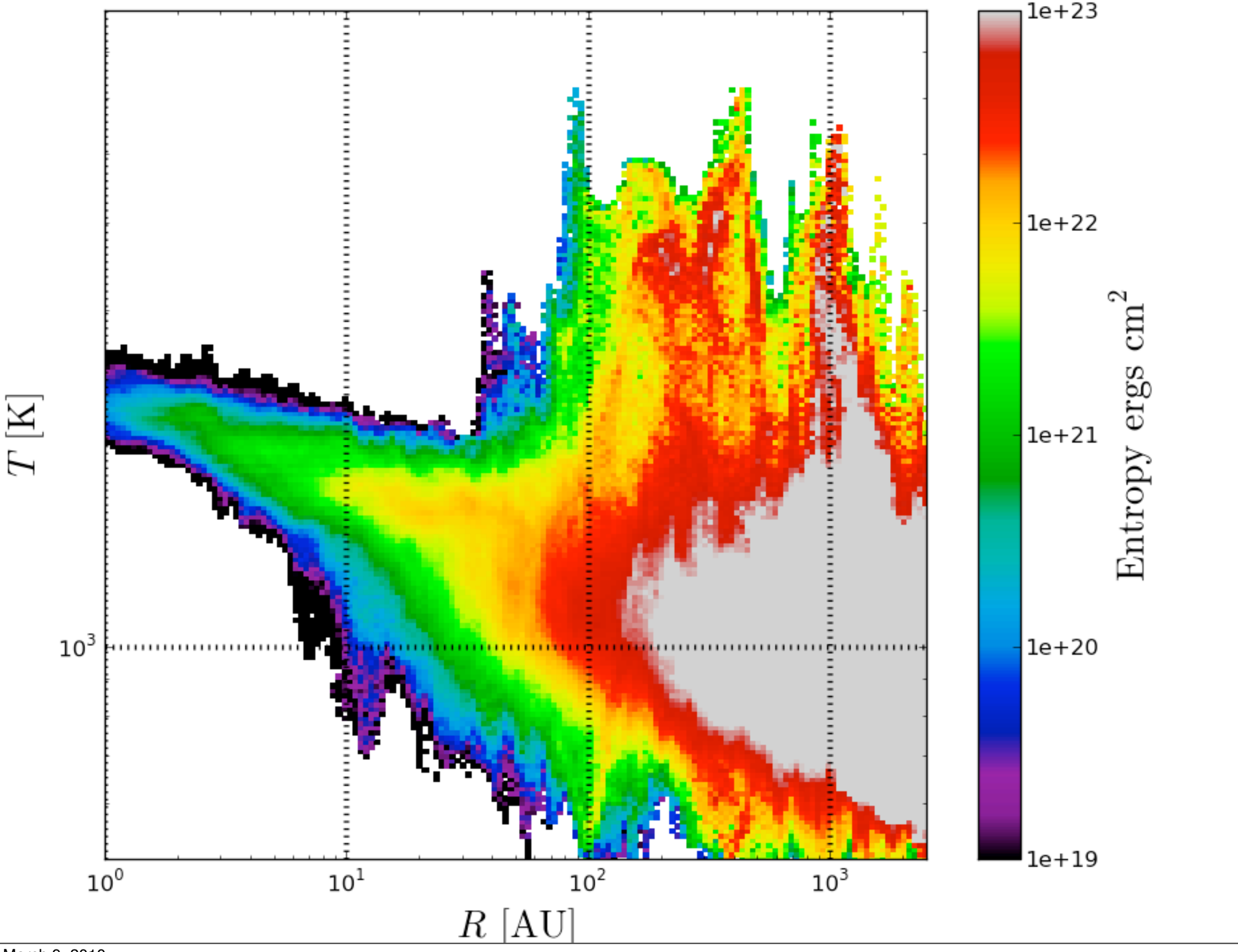
10^{-12} g/cc


1e-10
1e-11
1e-12
1e-13
1e-14
1e-15
Density (g/cm^3)
1500 AU

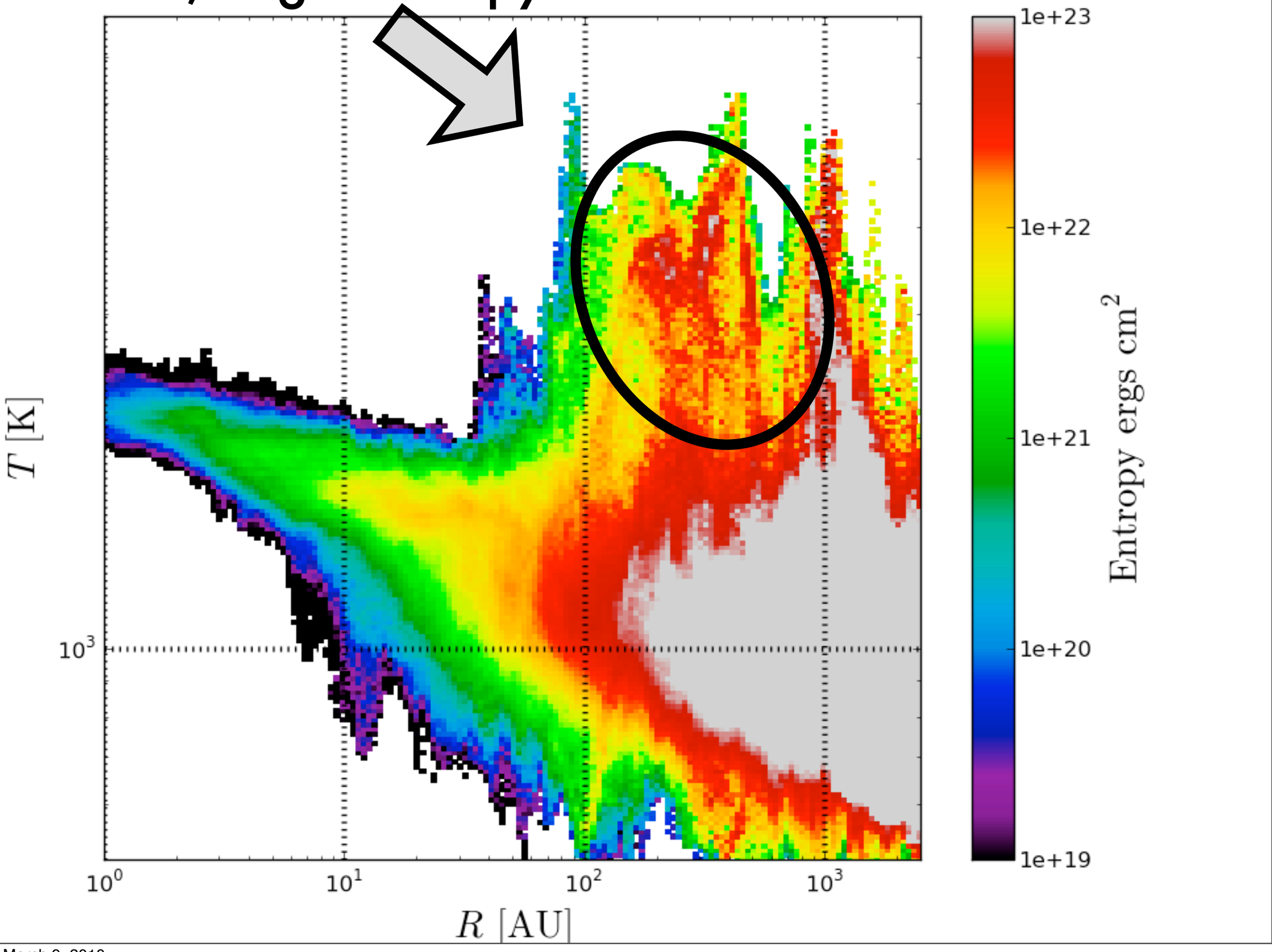

4000
3600
3200
2800
2400
2000
1600
1200
800
Temperature (K)
1500 AU

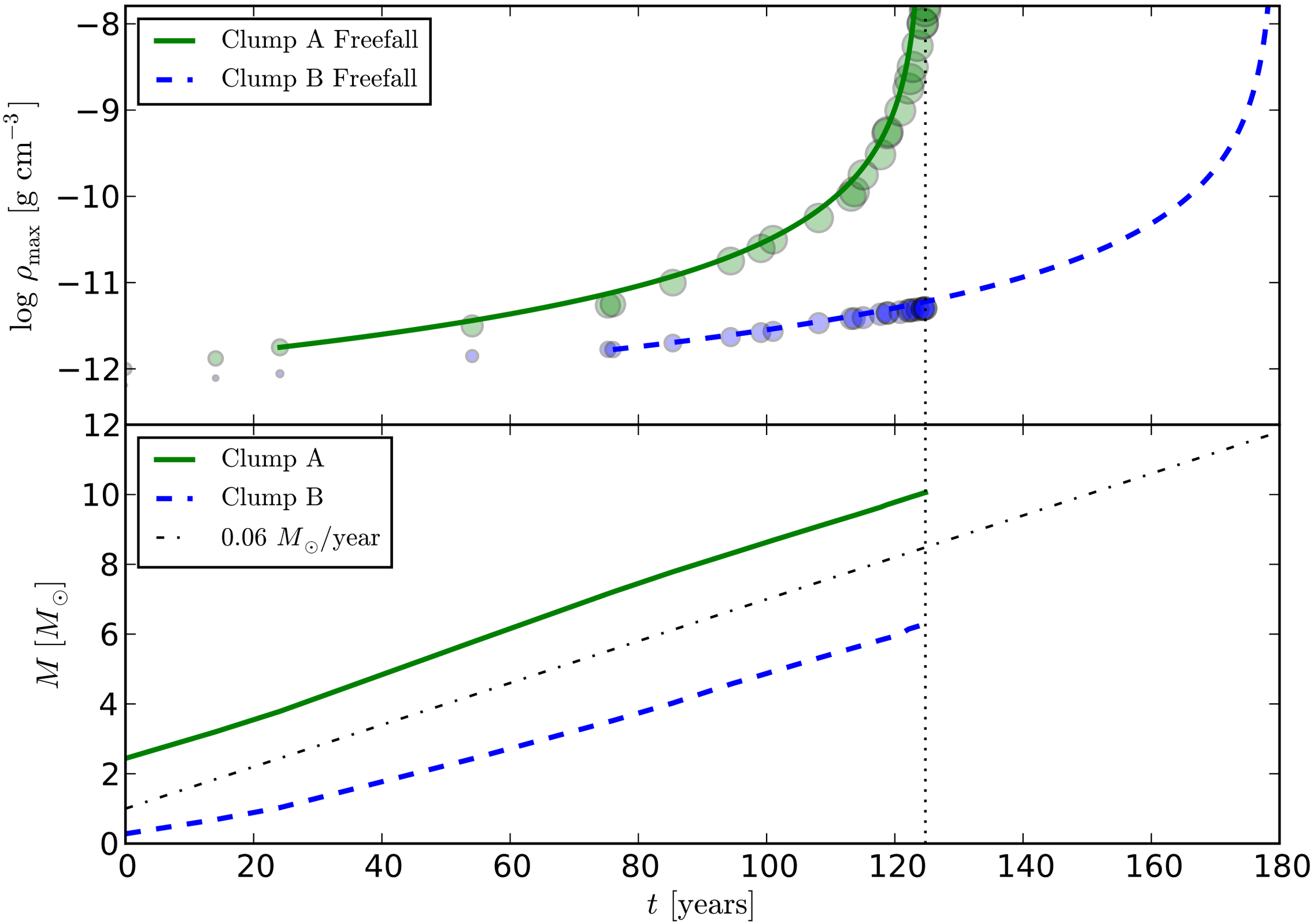

1e+21
1e+20
1e+19
Entropy (ergs cm^2)
1500 AU


1e+21
1e+20
1e+19
Entropy (ergs cm^2)
1500 AU


T [K]
10^3
10^0
10^1
10^2
10^3
R [AU]
1e+23
1e+22
1e+21
1e+20
1e+19
Entropy ergs cm^2

Confined, High Entropy




Clump A Freefall
Clump B Freefall
$\log \rho_{\max}$ [g cm^{-3}]
−8
−9
−10
−11
−12
Clump A
Clump B
0.06 $M_\odot$/year
M [$M_\odot$]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
160
180
t [years]

60 years

Clump A Freefall
Clump B Freefall

$\log \rho_{\rm max}$ [g cm^{-3}]

−8
−9
−10
−11
−12

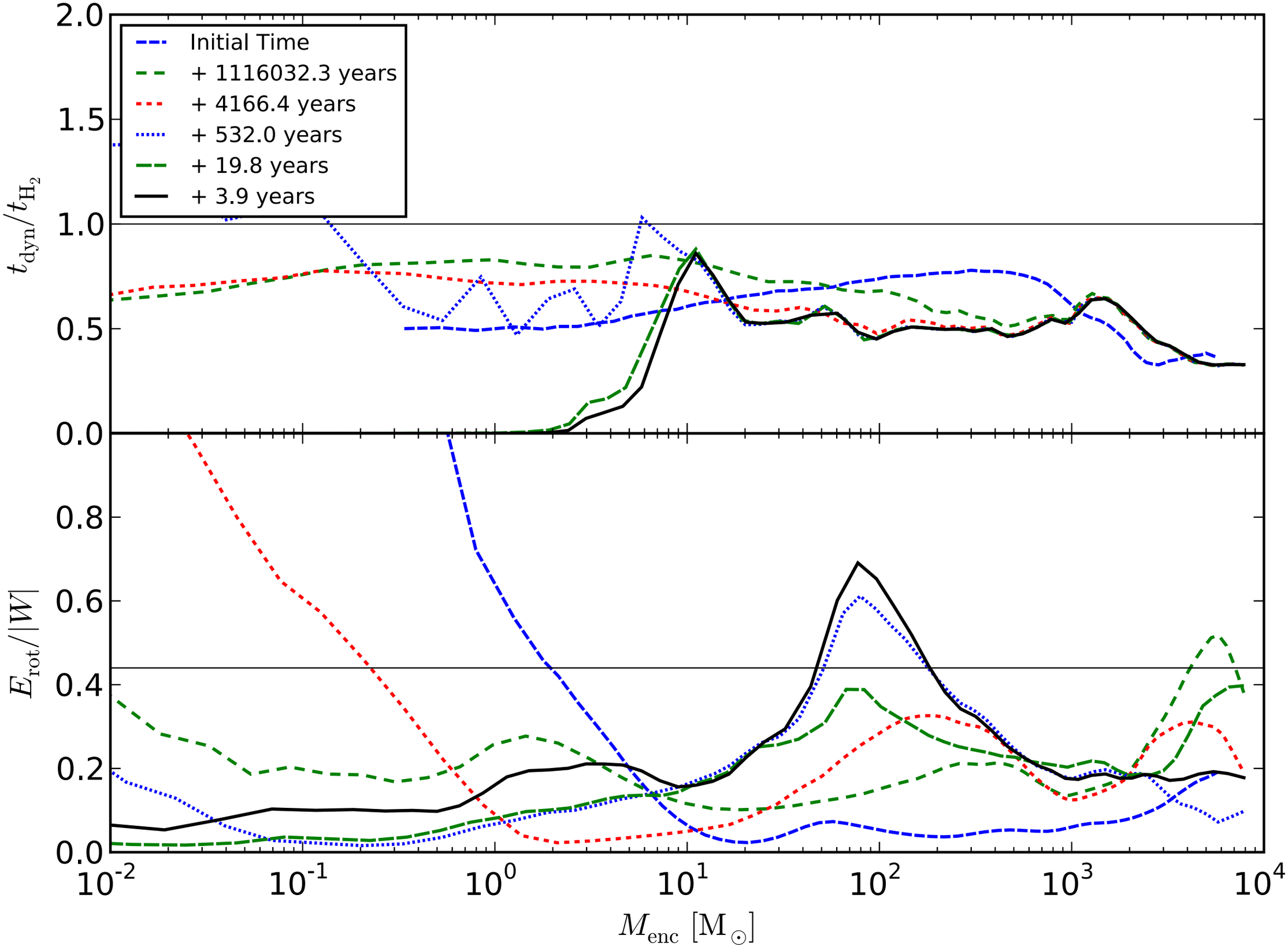
Clump A
Clump B
0.06 $M_\odot$/year

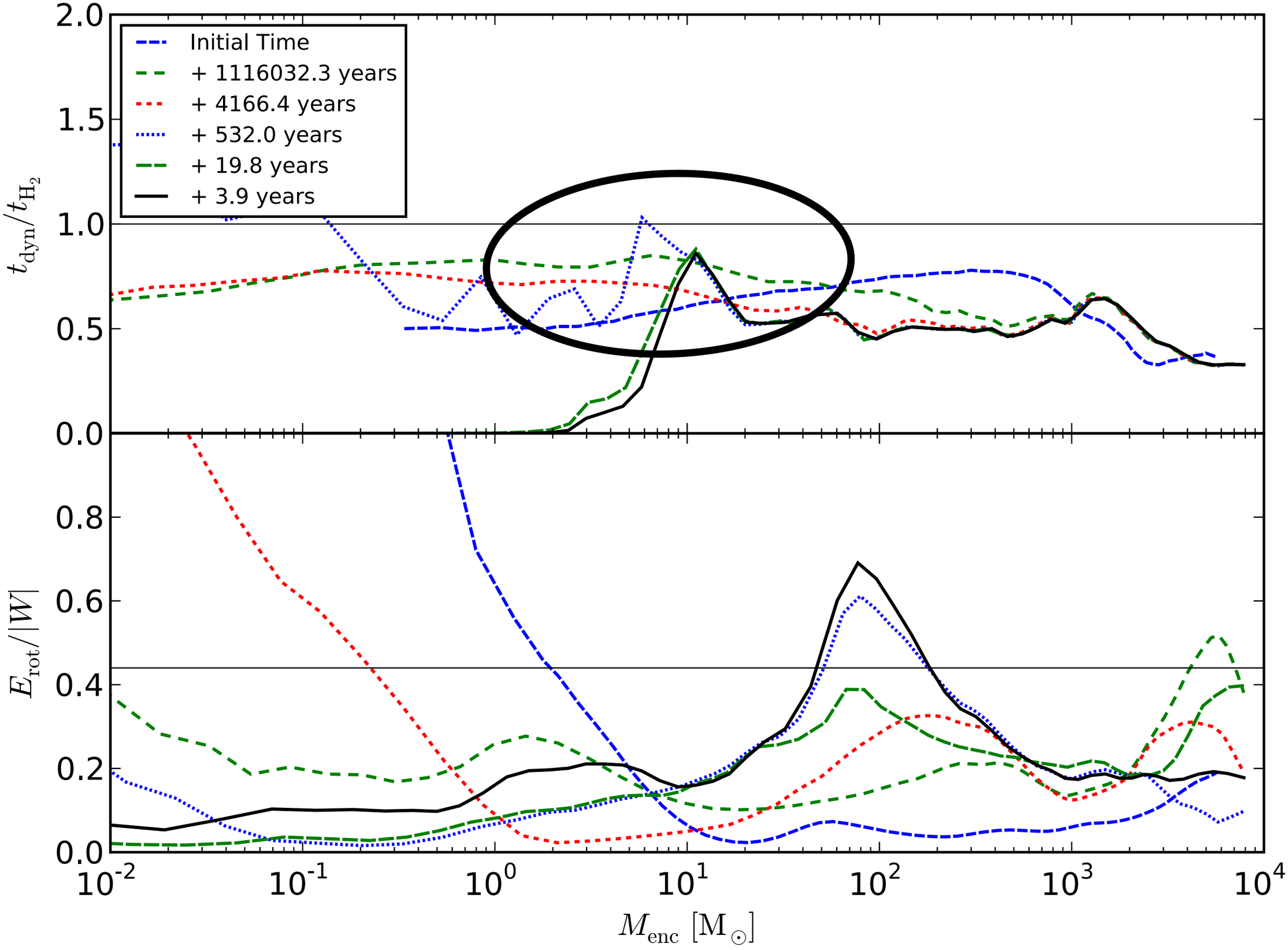
M [$M_\odot$]

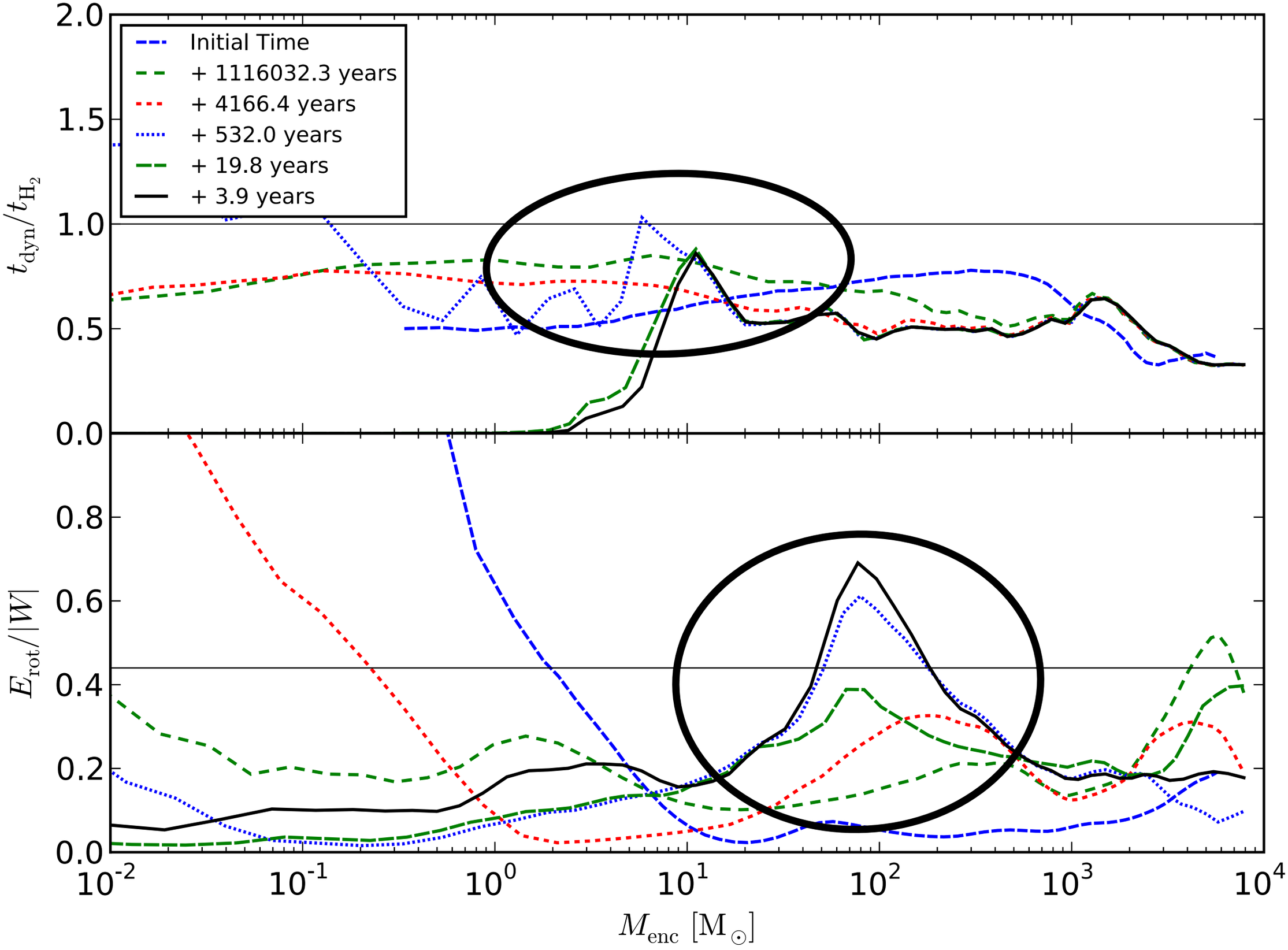
12
10
8
6
4
2
0

0 20 40 60 80 100 120 140 160 180

t [years]


Initial Time
+ 1116032.3 years
+ 4166.4 years
+ 532.0 years
+ 19.8 years
+ 3.9 years
$t_{\rm dyn}/t_{\rm H_2}$
$E_{\rm rot}/|W|$
$M_{\rm enc}$ [M$_\odot$]
2.0
1.5
1.0
0.5
0.0
0.8
0.6
0.4
0.2
0.0
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}


Initial Time
+ 1116032.3 years
+ 4166.4 years
+ 532.0 years
+ 19.8 years
+ 3.9 years
$t_{\rm dyn}/t_{\rm H_2}$
$E_{\rm rot}/|W|$
$M_{\rm enc}$ [M$_\odot$]
2.0
1.5
1.0
0.5
0.0
0.8
0.6
0.4
0.2
0.0
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}


Initial Time
+ 1116032.3 years
+ 4166.4 years
+ 532.0 years
+ 19.8 years
+ 3.9 years
$t_{\rm dyn}/t_{\rm H_2}$
$E_{\rm rot}/|W|$
$M_{\rm enc}$ [M$_\odot$]
2.0
1.5
1.0
0.5
0.0
0.8
0.6
0.4
0.2
0.0
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

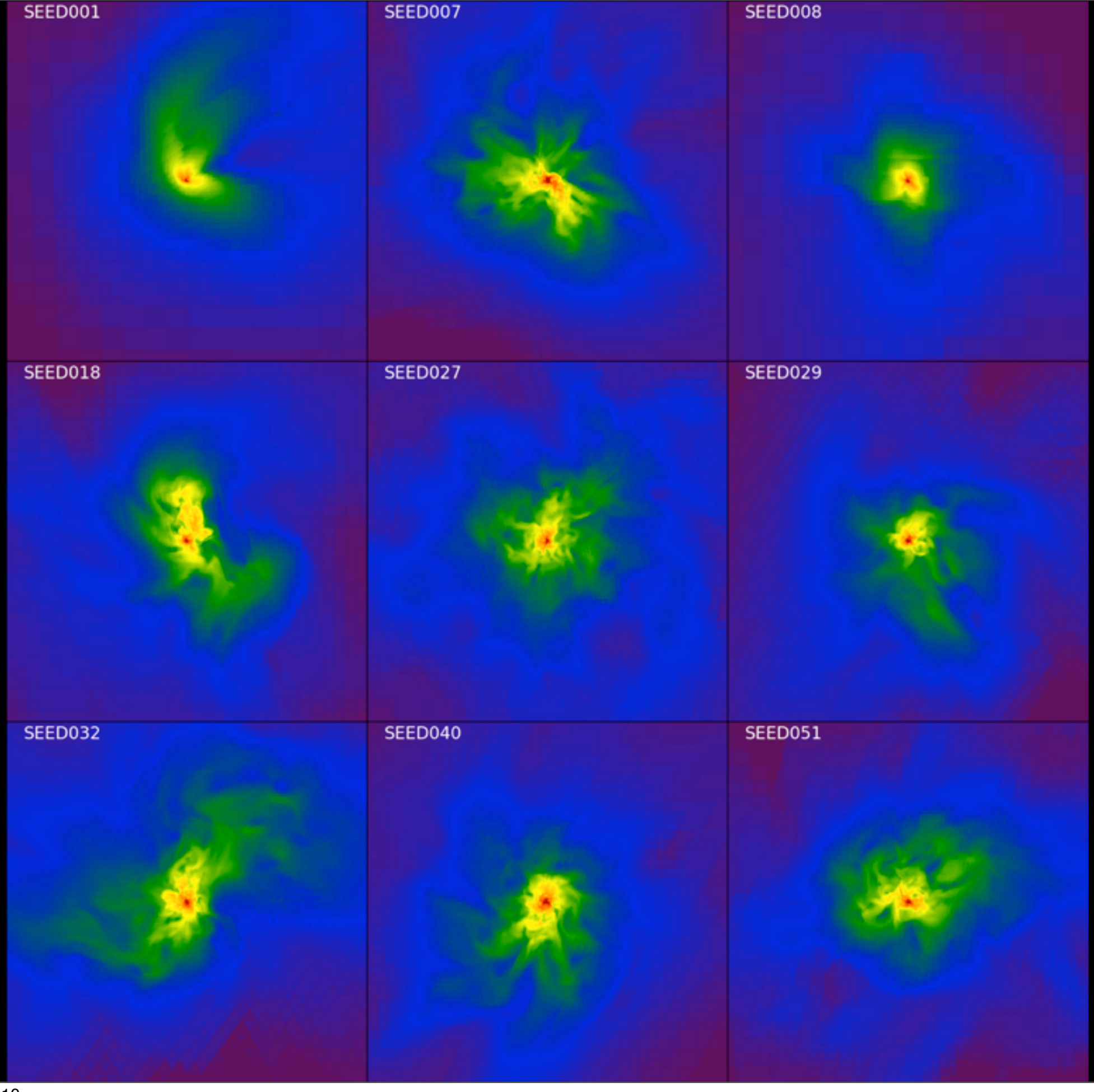
"Princeton Twist"

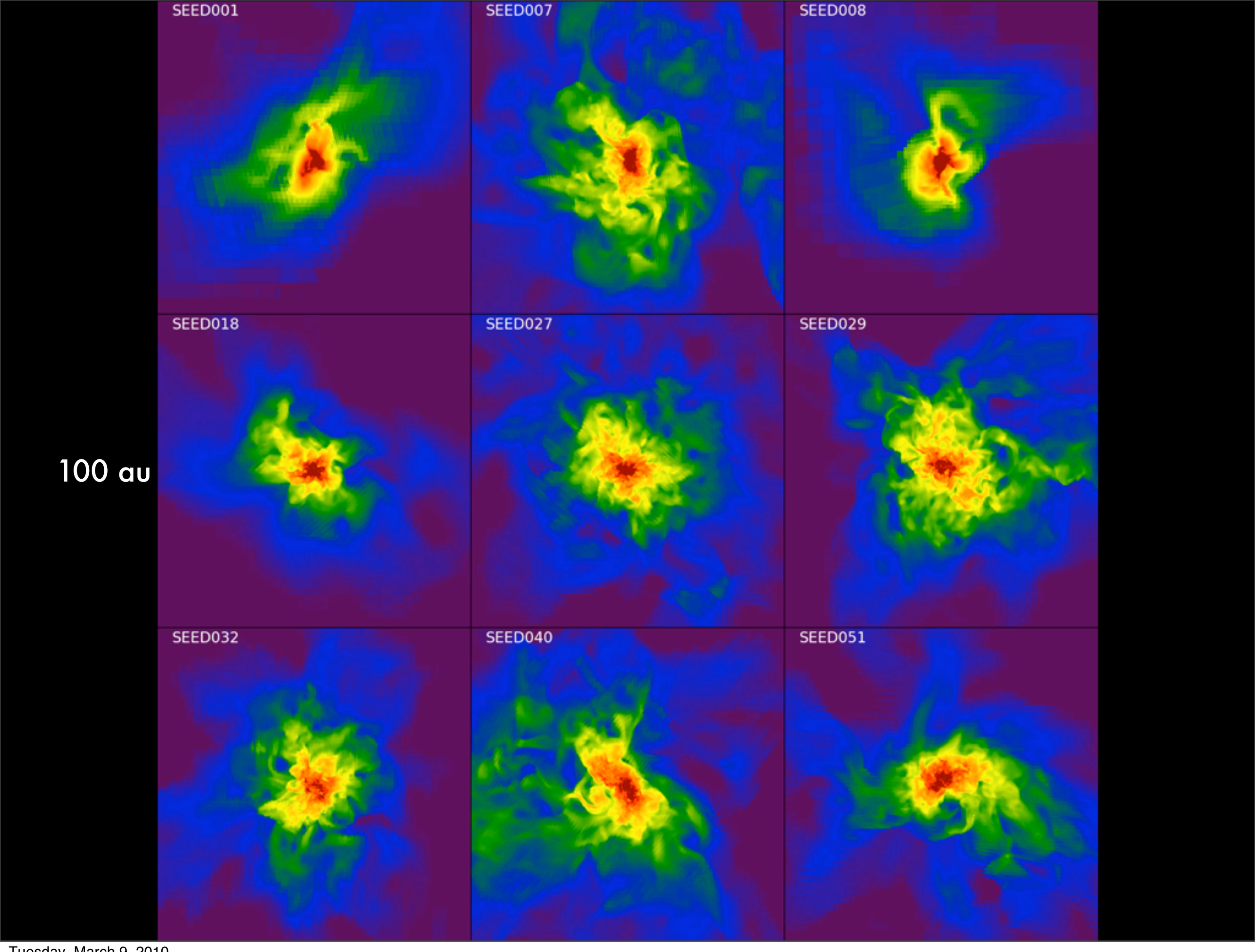
40 random seeds (10 done)

10^{-8} g/cc maximum density

track down fragmentation

with Mike Norman, Tom Abel


SEED001
SEED007
SEED008
SEED018
SEED027
SEED029
SEED032
SEED040
SEED051
5000 au


SEED001
SEED007
SEED008
SEED018
SEED027
SEED029
SEED032
SEED040
SEED051
100 au

SEED001

SEED007

SEED008

SEED018

SEED027

SEED029

500 au

SEED032

SEED040

SEED051

SEED001 SEED007 SEED008

SEED018 SEED027 SEED029

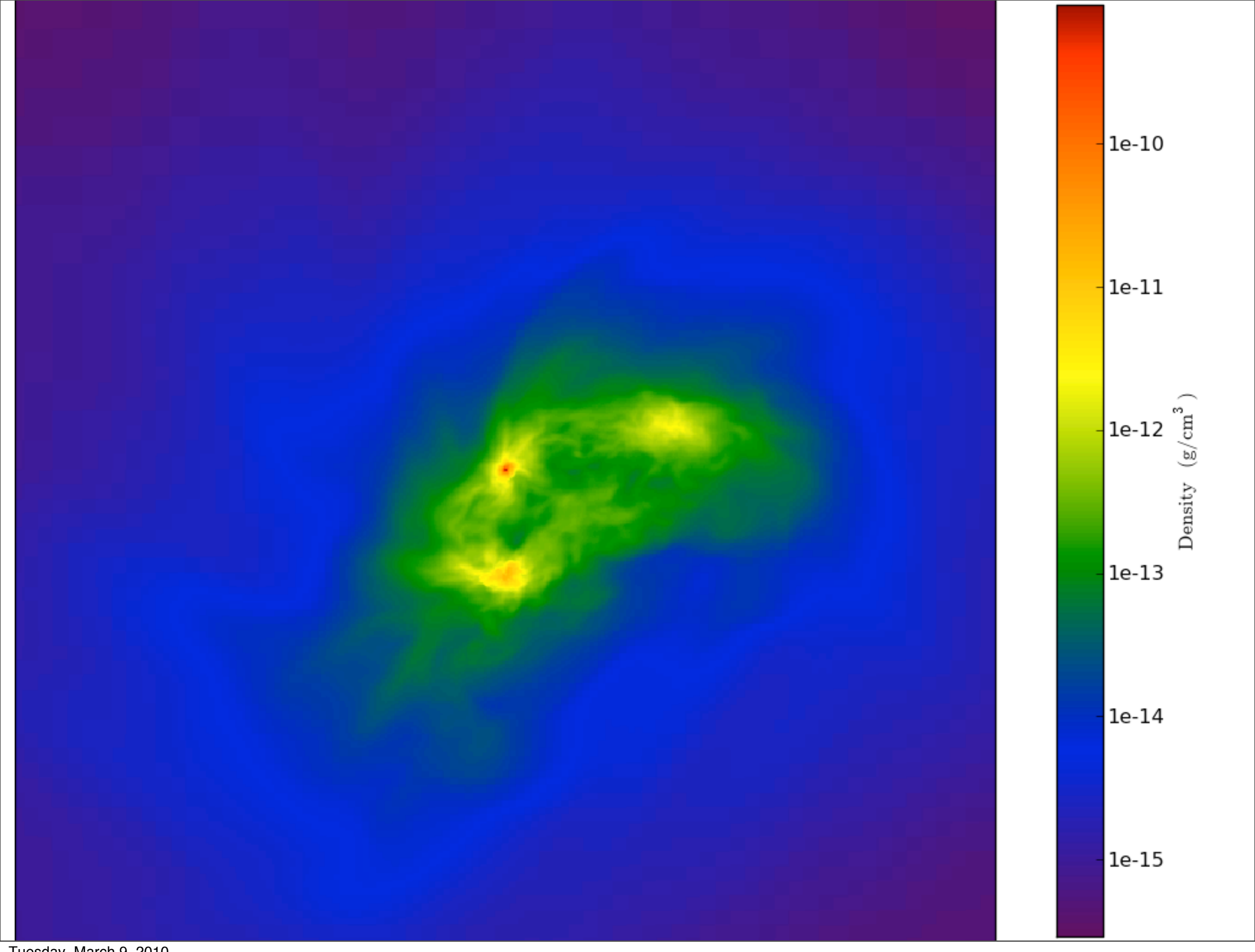
SEED032 SEED040 SEED051

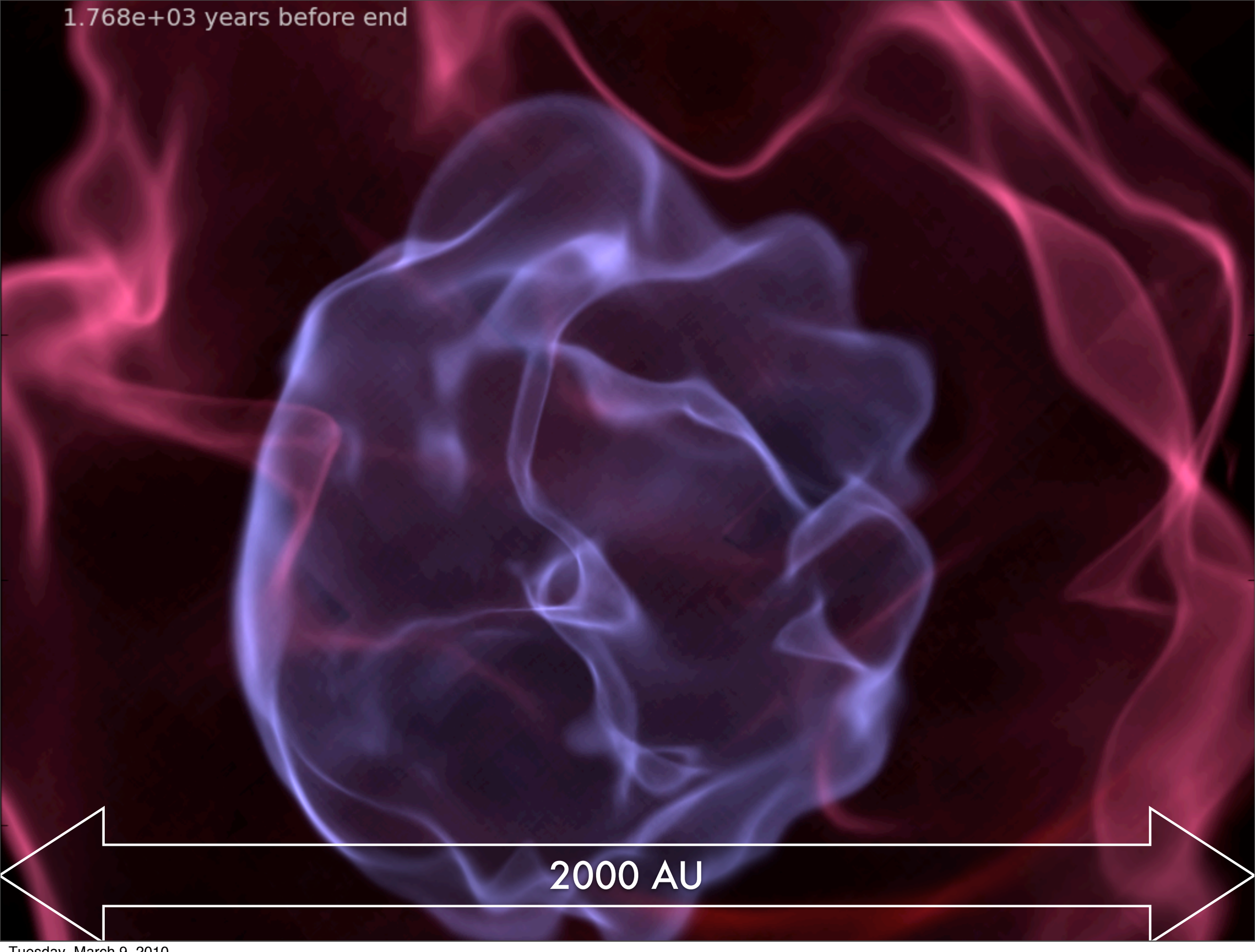
1 pc

rho v. T

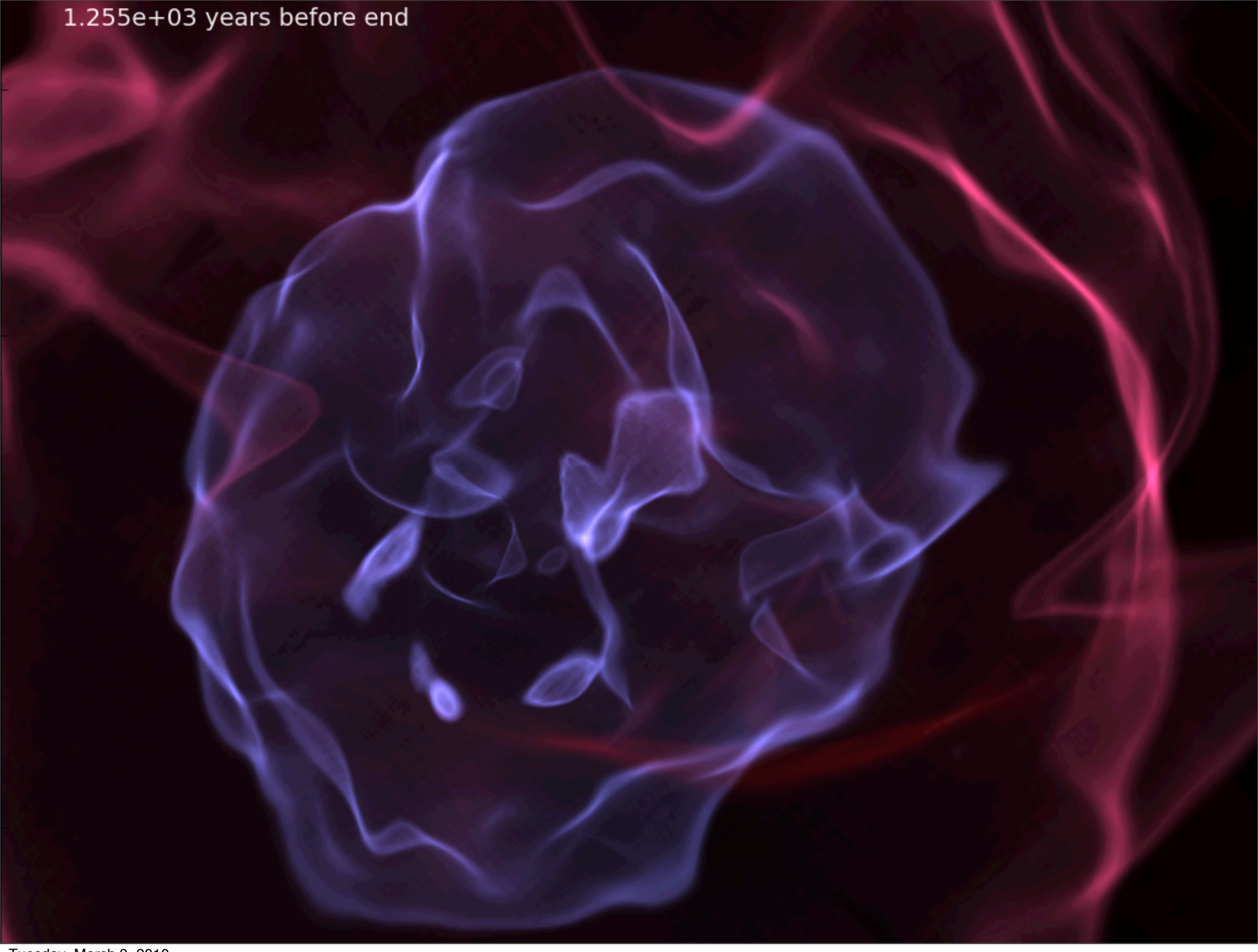
SEED018

A second case of early-time fragmentation.

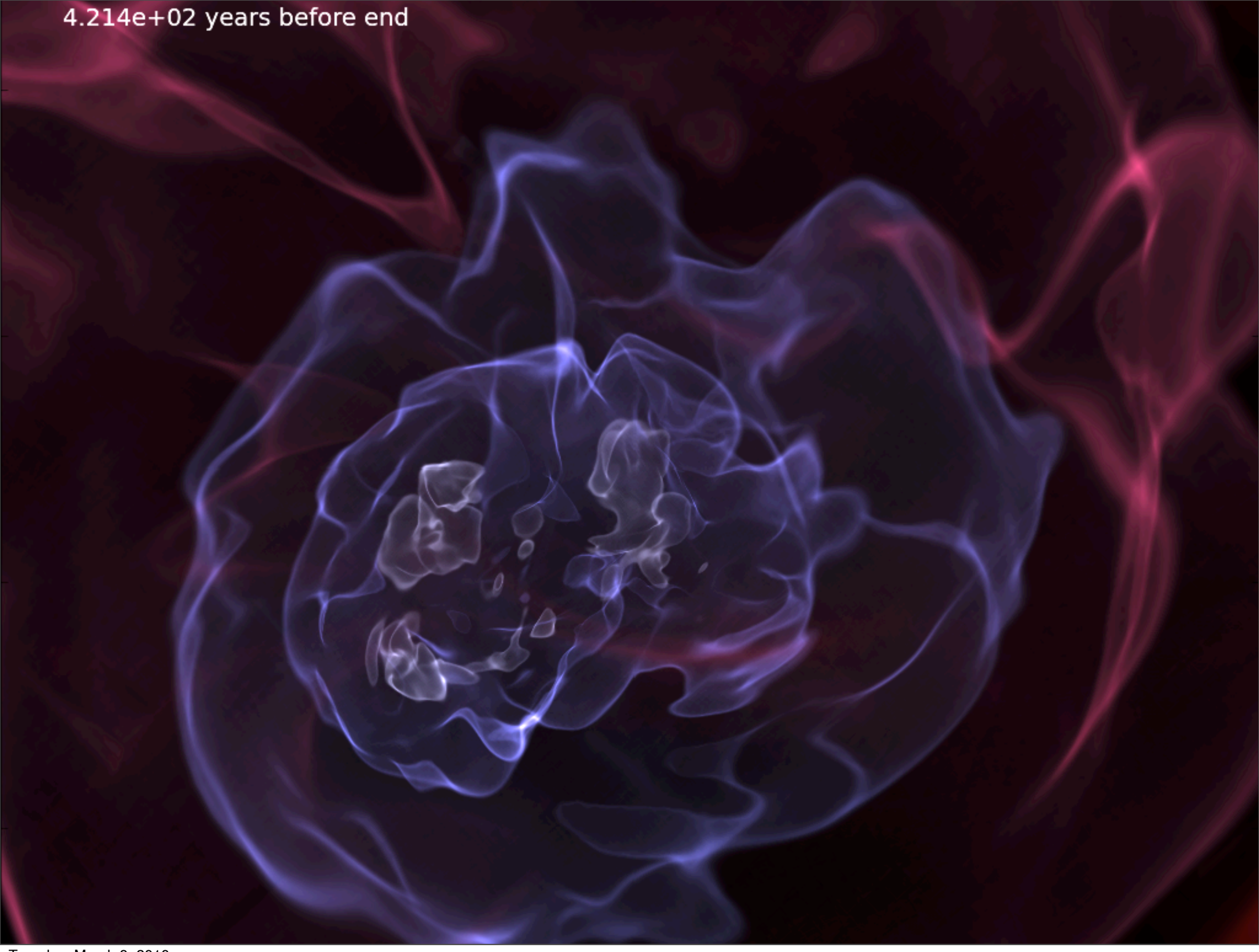

1e-10
1e-11
1e-12
1e-13
1e-14
1e-15
Density (g/cm^3)


1.768e+03 years before end
2000 AU

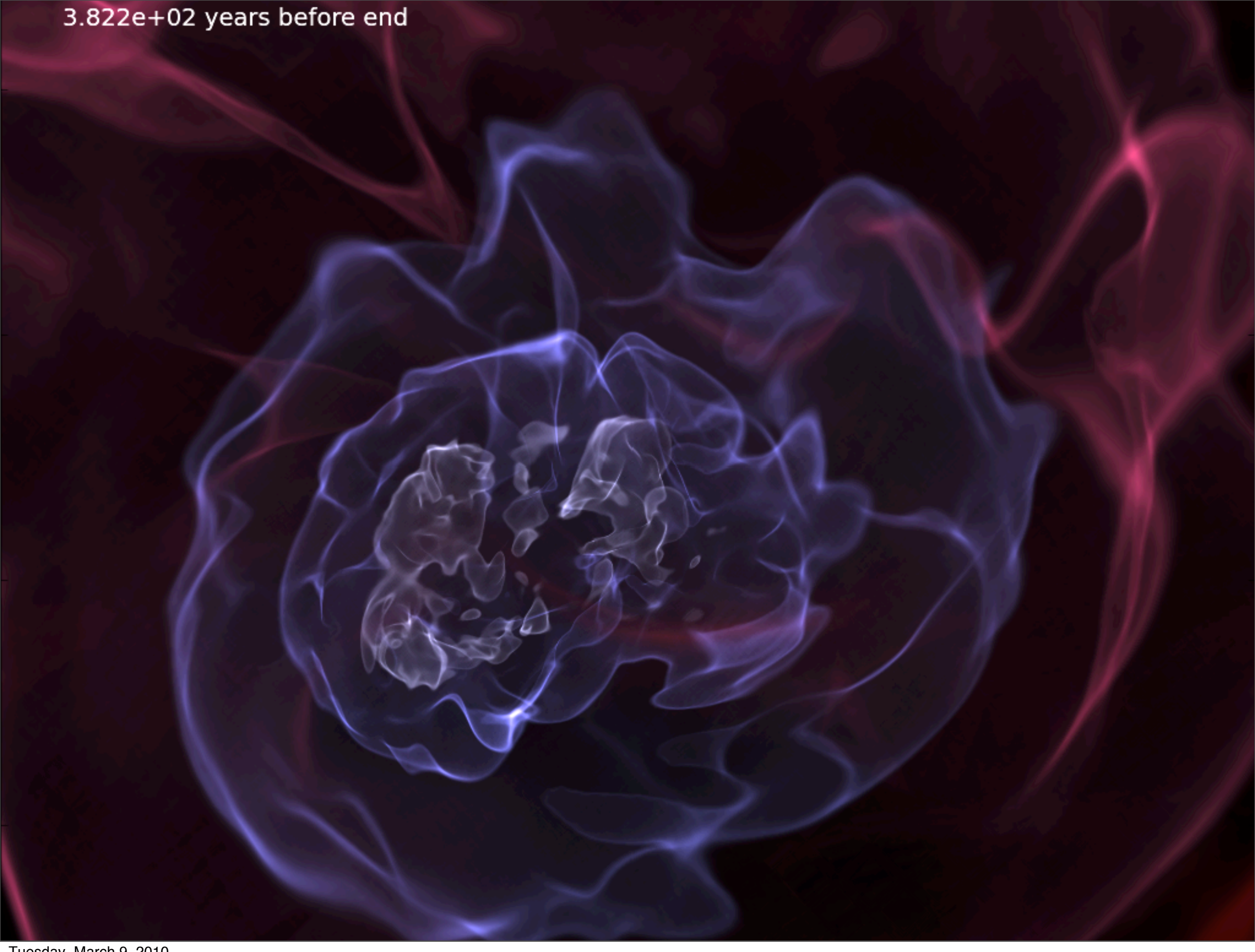
1.255e+03 years before end

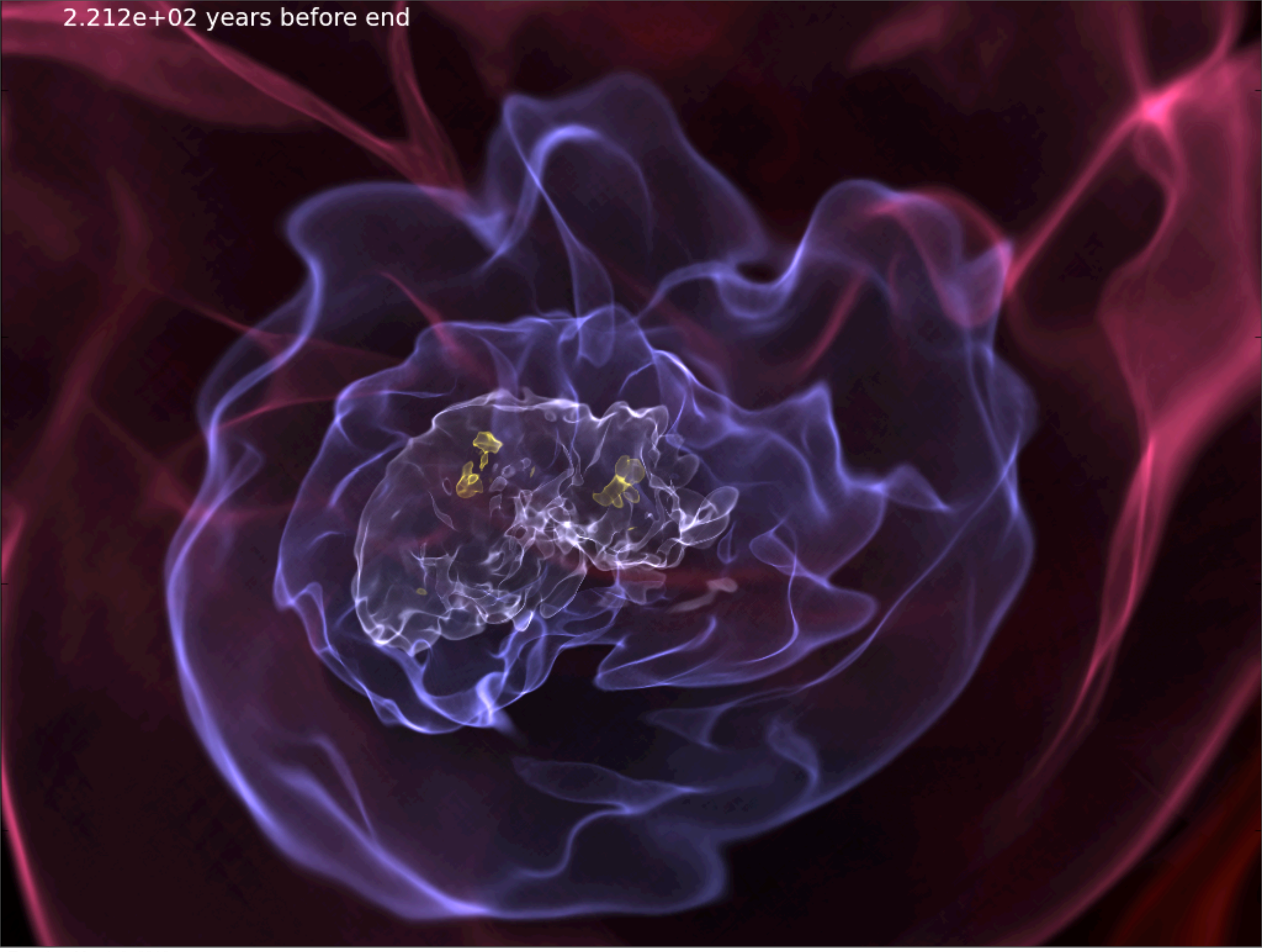


4.214e+02 years before end

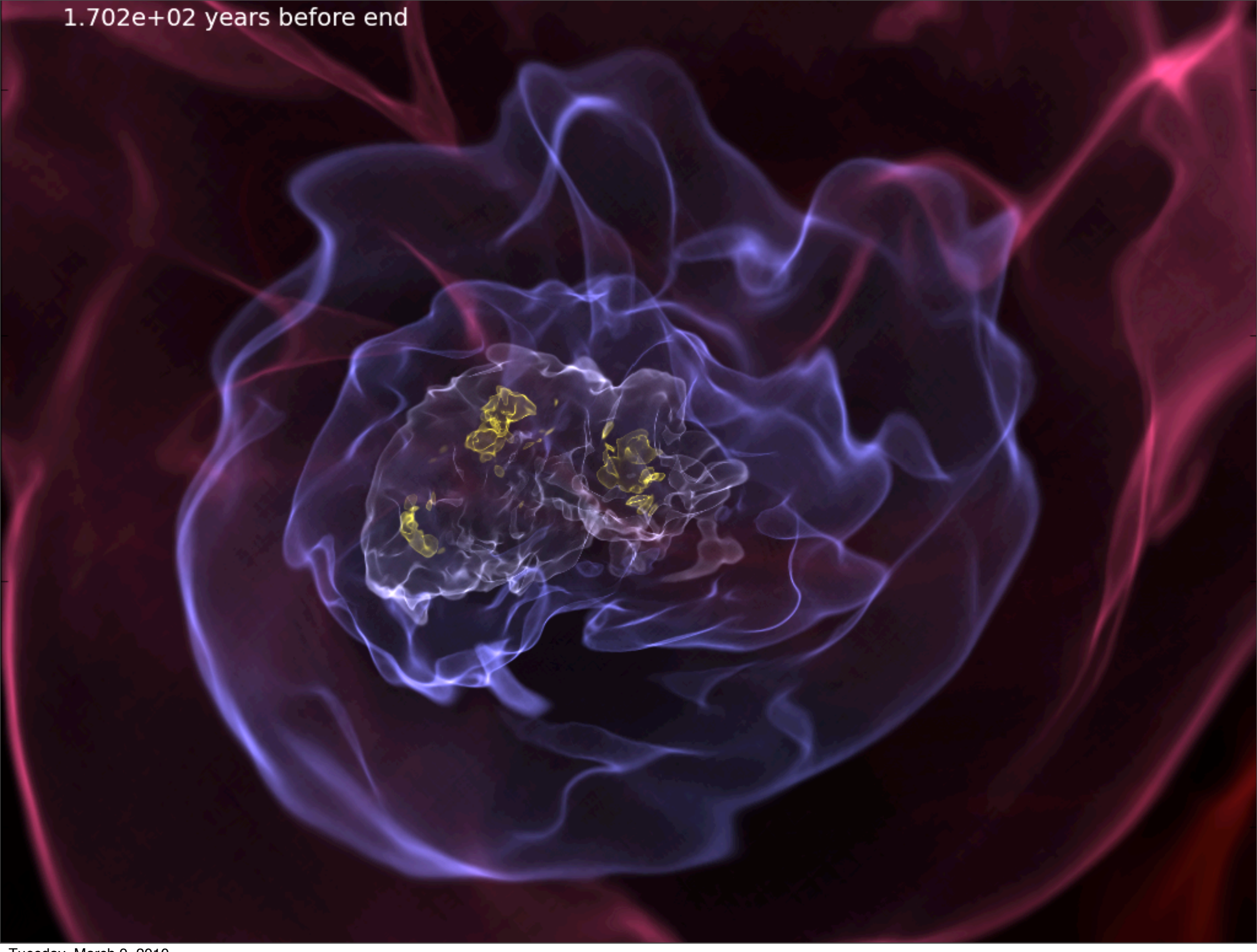


Tuesday, March 9, 2010

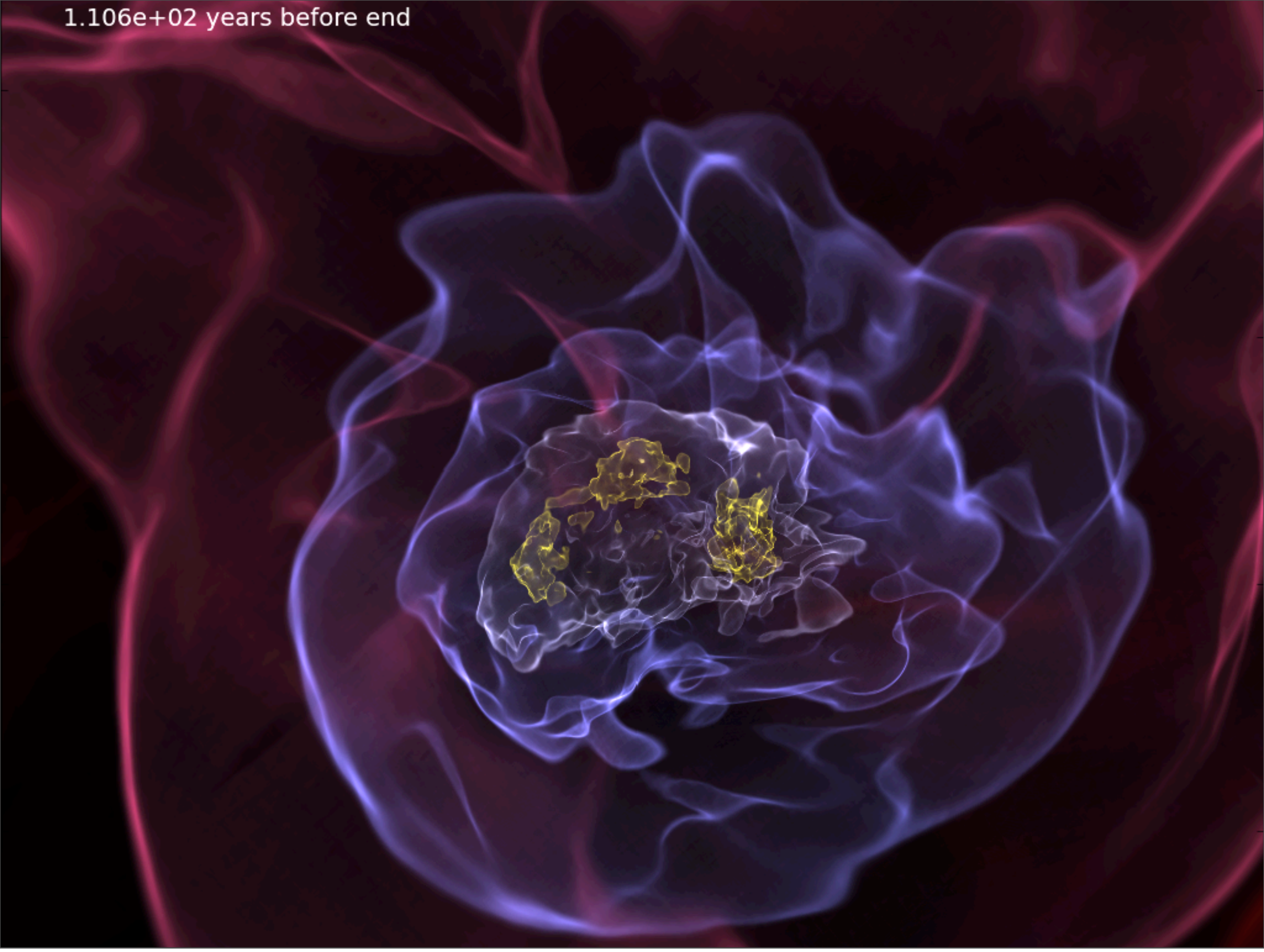

3.822e+02 years before end



Tuesday, March 9, 2010

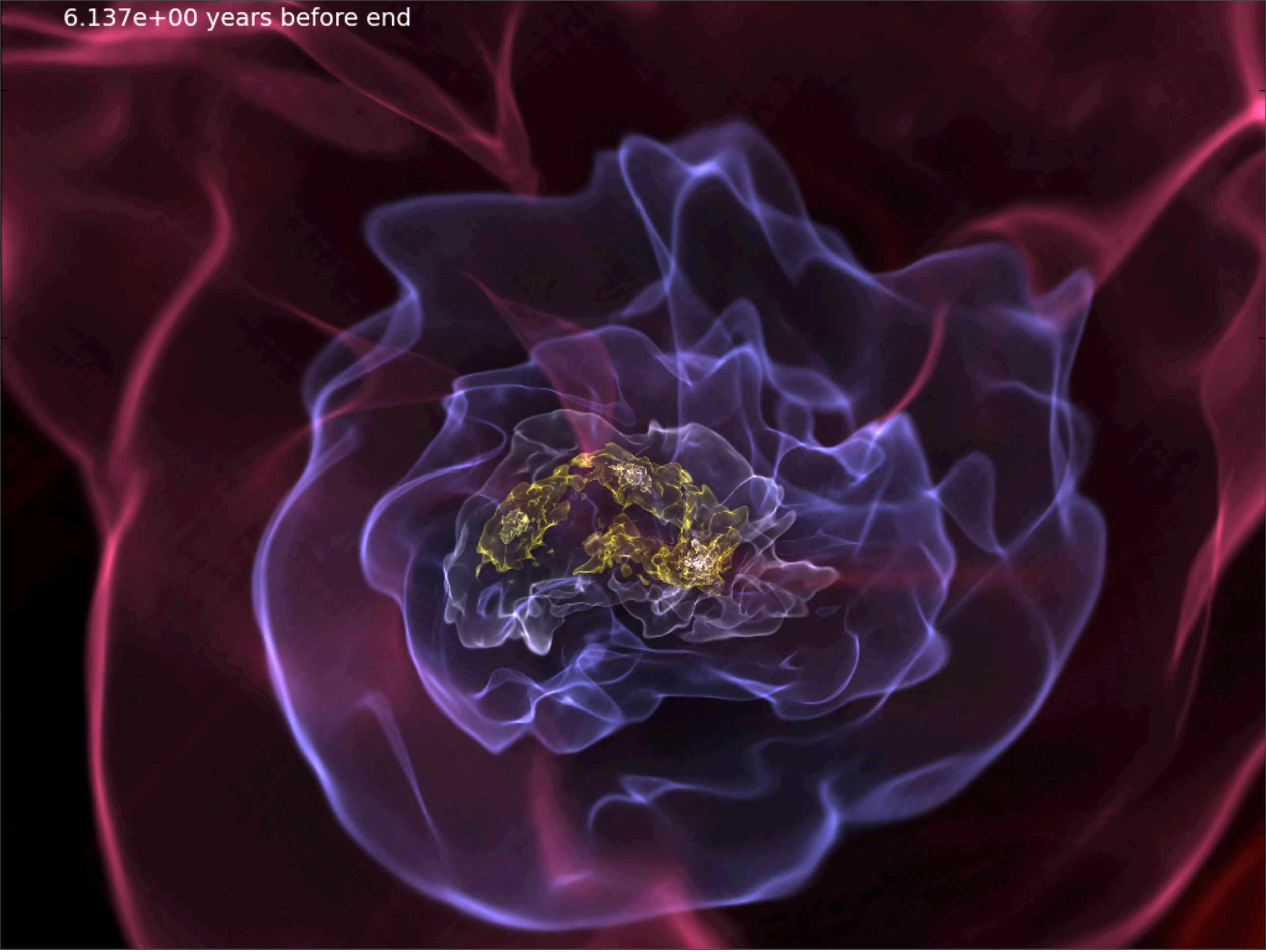

1.702e+02 years before end

1.106e+02 years before end



Tuesday, March 9, 2010

6.137e+00 years before end



Tuesday, March 9, 2010

A Brief Word About

H_2 Chemical Rates

three rate coefficients
branched at 10^2 cm^{-3}
16 cells per Jeans Length
stopped at ~10^{16} cm^{-3}

with Tom Abel, Paul Clark, Simon Glover,
Ralf Klessen, Thomas Greif, Volker Bromm

ABN02A 825059.2

1000 AU

250 AU

250 AU

250 AU

PSS83A

FH07A

ABN02S

PSS83S

FH07S

AMR

SPH

1e-22 1e-20 1e-18
Density [g cm^{-3}]

1e-15 1e-13 1e-11
Density [g cm^{-3}]

1e-15 1e-13 1e-11 1e-09
Density [g cm^{-3}]

800 1200 1600 2000 2400
T [K]

1e-02 1e-01
H_2/ρ

ABN02A 825059.2

1000 AU

250 AU

250 AU

250 AU

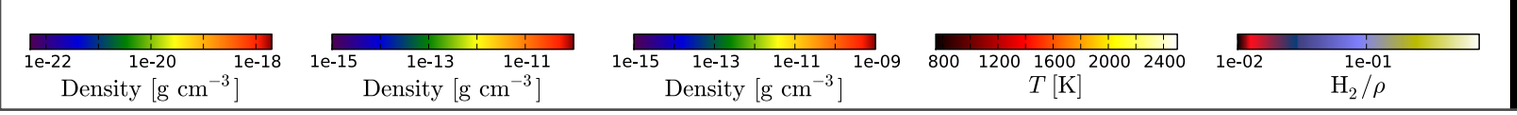
PSS83A

FH07A

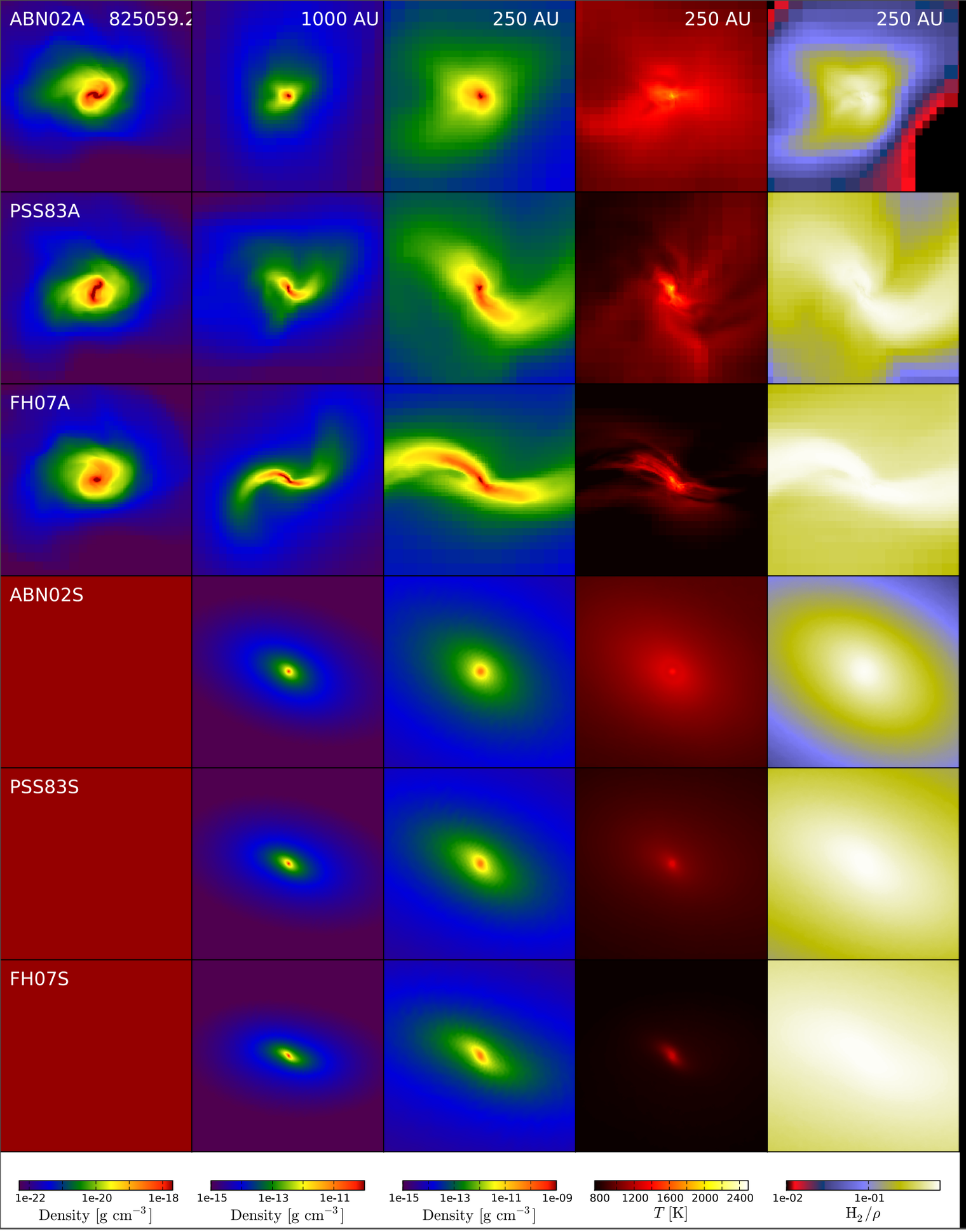
ABN02S

PSS83S

FH07S



Abel, Bryan, Norman 2002



Palla, Salpeter,
Stahler 1983

ABN02A 825059.2

1000 AU

250 AU

250 AU

250 AU

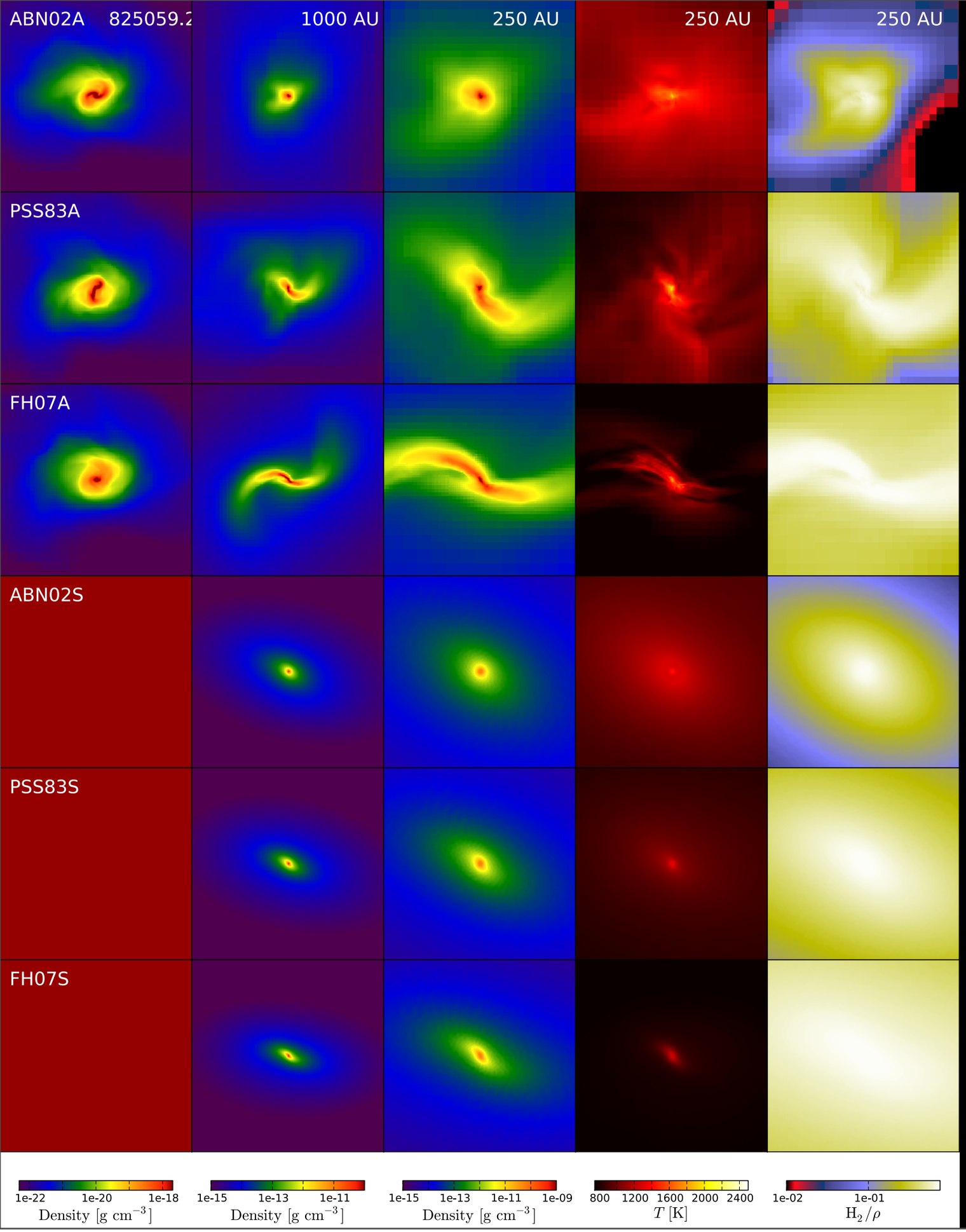
PSS83A

FH07A

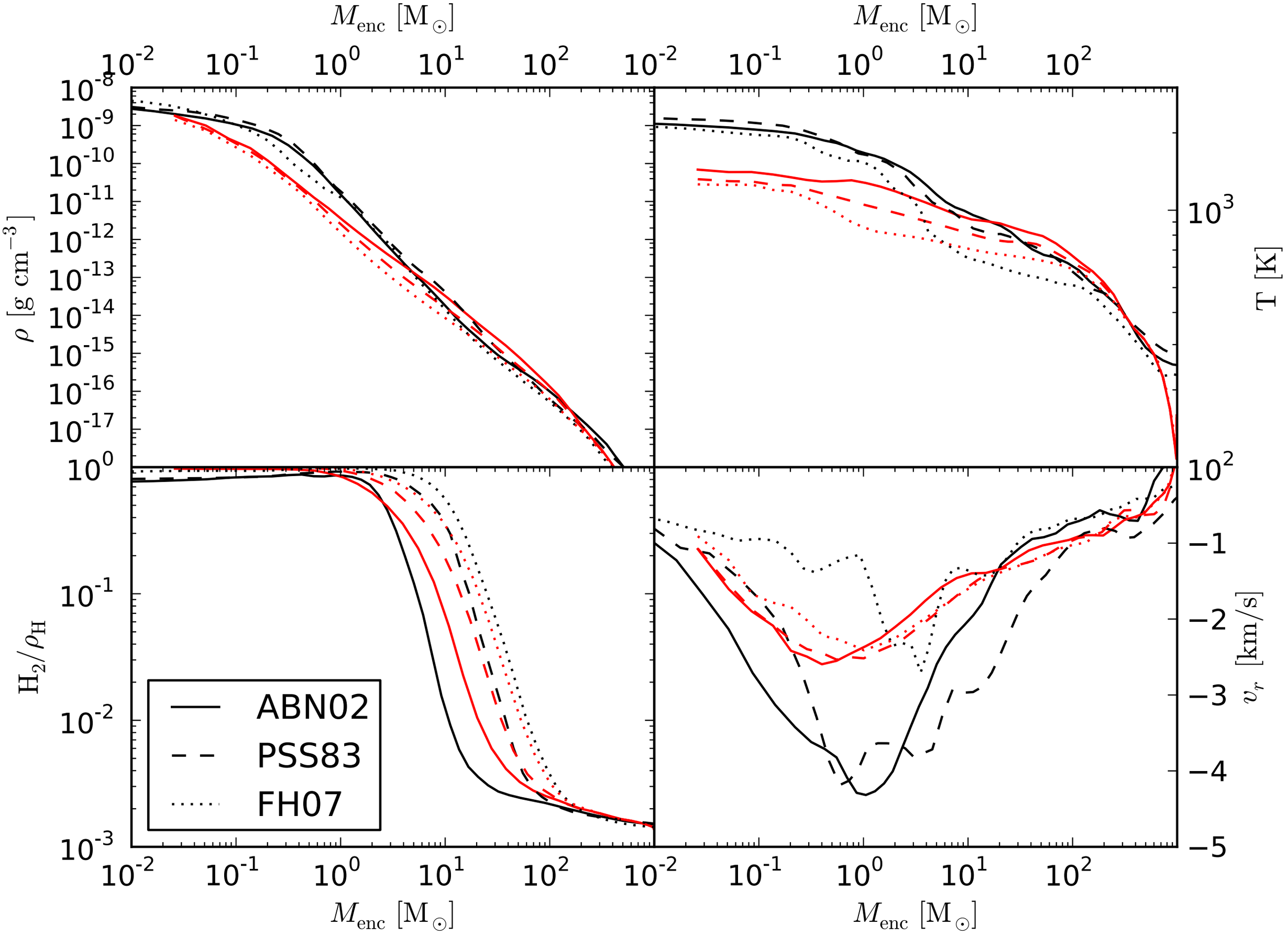
ABN02S

PSS83S

FH07S



Flower & Harris 2007


$M_{\rm enc}$ [M$_\odot$]
$M_{\rm enc}$ [M$_\odot$]
ρ [g cm^{-3}]
H$_2$/$\rho_{\rm H}$
T [K]
v_r [km/s]
ABN02
PSS83
FH07
$M_{\rm enc}$ [M$_\odot$]
$M_{\rm enc}$ [M$_\odot$]

We see early-time fragmentation. Still seems like about one out of five.

Three-body H_2 rates change the character of collapse, mostly at the disk-formation scale.

Thank you.

Collaborators:

Tom Abel
Brian O'Shea
Mike Norman
Paul Clark
Simon Glover
Ralf Klessen
Volker Bromm
Thomas Greif