Small Seed Black Hole Growth in Various Accretion Regimes

Hannalore J. Gerling-Dunsmore
Philip F. Hopkins
TAPIR, Caltech

Background

- The SMBH formation problem

Background

- The SMBH formation problem
  - BHs of mass $10^6 – 10^{10}\ M_\odot$

Background

- The SMBH formation problem
  - BHs of mass $10^6 – 10^{10}\ M_\odot$
  - Observations indicate SMBH form in < 1 Gyr

Background

- The SMBH formation problem
  - BHs of mass $10^6 - 10^{10}\ M_\odot$
  - Observations indicate SMBH form in < 1 Gyr
    - SMBH at z=7

Background

- The SMBH formation problem
  - BHs of mass $10^6 - 10^{10}\ M_\odot$
  - Observations indicate SMBH form in < 1 Gyr
  - BH dominates gravitational potential once $\sim 10^4\ M_\odot$

Background

- The SMBH formation problem
  - BHs of mass $10^6 - 10^{10}\ M_\odot$
  - Observations indicate SMBH form in < 1 Gyr
  - BH dominates gravitational potential once $\sim 10^4\ M_\odot$
- Proposed Mechanisms of SMBH Formation

Background

- The SMBH formation problem
  - BHs of mass $10^6 - 10^{10}\ M_\odot$
  - Observations indicate SMBH form in < 1 Gyr
  - BH dominates gravitational potential once $\sim 10^4\ M_\odot$
- Proposed Mechanisms of SMBH Formation
  - Direct collapse

Background

- The SMBH formation problem
  - BHs of mass $10^6 - 10^{10}\ M_\odot$
  - Observations indicate SMBH form in < 1 Gyr
  - BH dominates gravitational potential once $\sim 10^4\ M_\odot$
- Proposed Mechanisms of SMBH Formation
  - Direct collapse
  - Runaway merging

Background

- The SMBH formation problem
  - BHs of mass $10^6 - 10^{10}\ M_{\odot}$
  - Observations indicate SMBH form in < 1 Gyr
  - BH dominates gravitational potential once $\sim 10^4\ M_{\odot}$
- Proposed Mechanisms of SMBH Formation
  - Direct collapse
  - Runaway merging
  - Accretion onto small seed BHs

Latif & Ferrara, 2016

Accretion onto Small Seed BHs

- Rapid accretion onto 100 $M_{\odot}$ BHs

Accretion onto Small Seed BHs

- Rapid accretion onto 100 $M_{\odot}$ BHs
- Eddington limited

Accretion onto Small Seed BHs

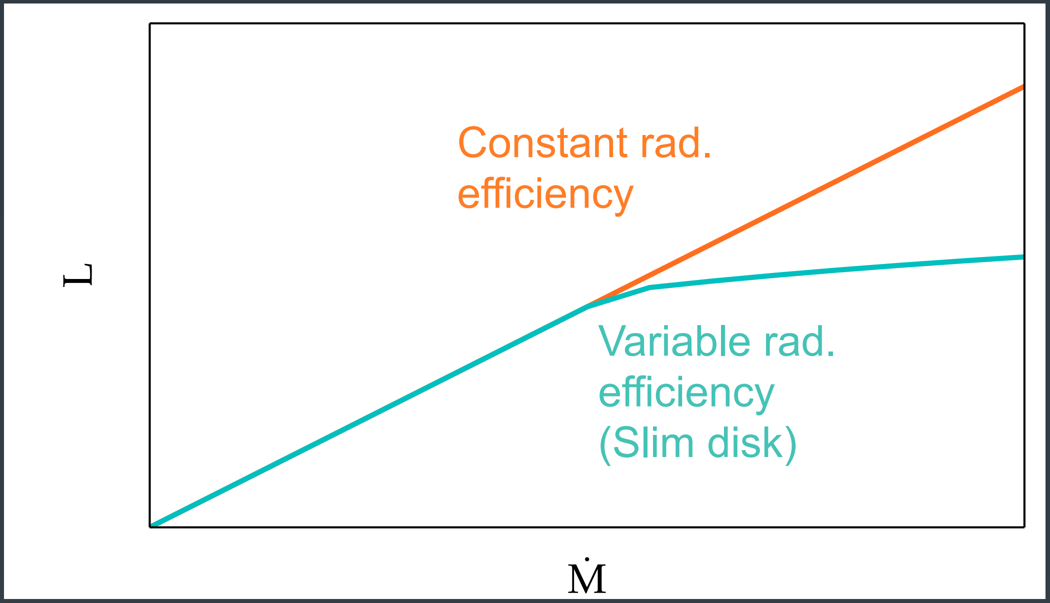
- Rapid accretion onto 100 $M_{\odot}$ BHs
- Eddington limited
  - Fails to grow BH rapidly

Accretion onto Small Seed BHs

- Rapid accretion onto 100 $M_{\odot}$ BHs
- Eddington limited
  - Fails to grow BH rapidly
- Super-Eddington

Accretion onto Small Seed BHs

- Rapid accretion onto 100 $M_{\odot}$ BHs
- Eddington limited
  - Fails to grow BH rapidly
- Super-Eddington



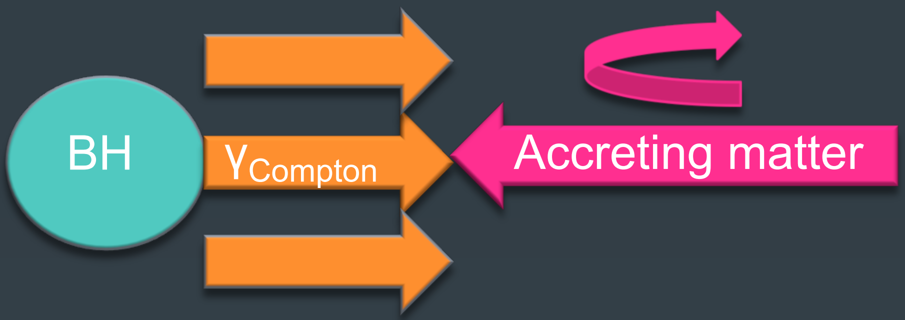
Begelman 1979

Accretion onto Small Seed BHs

- Rapid accretion onto 100 $M_{\odot}$ BHs
- Eddington limited
  - Fails to grow BH rapidly
- Super-Eddington
  - Compton heating shuts down growth

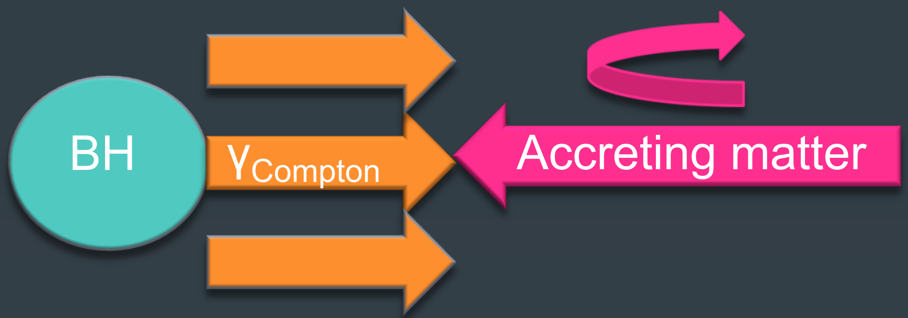
Accretion onto Small Seed BHs

- Rapid accretion onto 100 $M_\odot$ BHs
- Eddington limited
  - Fails to grow BH rapidly
- Super-Eddington
  - Compton heating shuts down growth



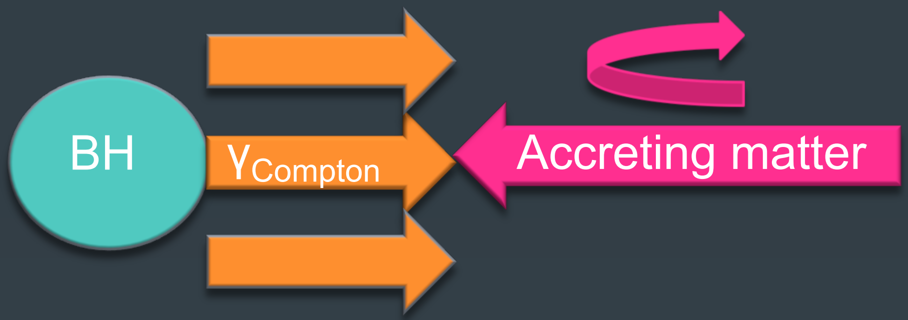
Accretion onto Small Seed BHs

- Rapid accretion onto 100 $M_\odot$ BHs
- Eddington limited
  - Fails to grow BH rapidly
- Super-Eddington
  - Compton heating shuts down growth
- Hyper-Eddington



Accretion onto Small Seed BHs

- Rapid accretion onto 100 $M_{\odot}$ BHs
- Eddington limited
  - Fails to grow BH rapidly
- Super-Eddington
  - Compton heating shuts down growth
- Hyper-Eddington
  - 100 – 1000x Eddington limit



Accretion onto Small Seed BHs

- Rapid accretion onto 100 $M_\odot$ BHs
- Eddington limited
  - Fails to grow BH rapidly
- Super-Eddington
  - Compton heating shuts down growth
- Hyper-Eddington
  - 100 – 1000x Eddington limit
  - Ram pressure smothers Compton heating

Accretion onto Small Seed BHs

- Rapid accretion onto 100 $M_\odot$ BHs
- Eddington limited
  - Fails to grow BH rapidly
- Super-Eddington
  - Compton heating shuts down growth
- Hyper-Eddington
  - 100 – 1000x Eddington limit
  - Ram pressure smothers Compton heating

Volonteri+ 2014
Sadowski+ 2015
Inayoshi+ 2016

Our Study

- Goal

Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH

Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)

Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)
  - 3D, MHD+gravity

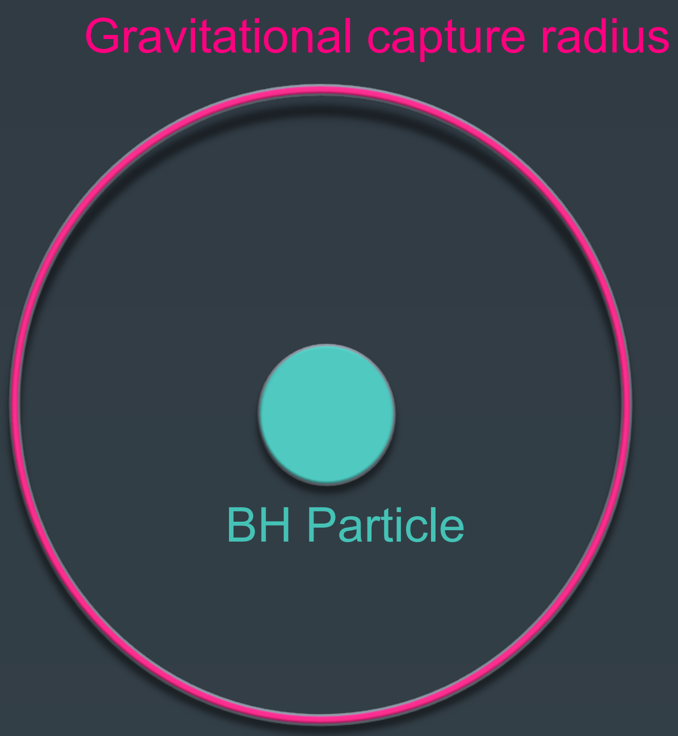
Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)
  - 3D, MHD+gravity
  - Accretion treatment

BH Particle

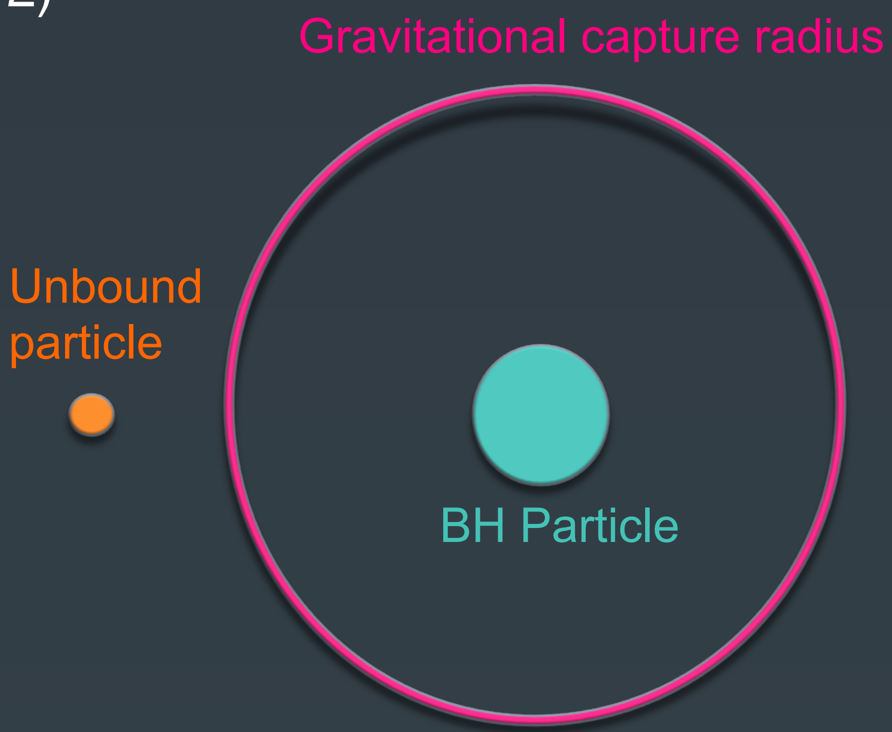
Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)
  - 3D, MHD+gravity
  - Accretion treatment



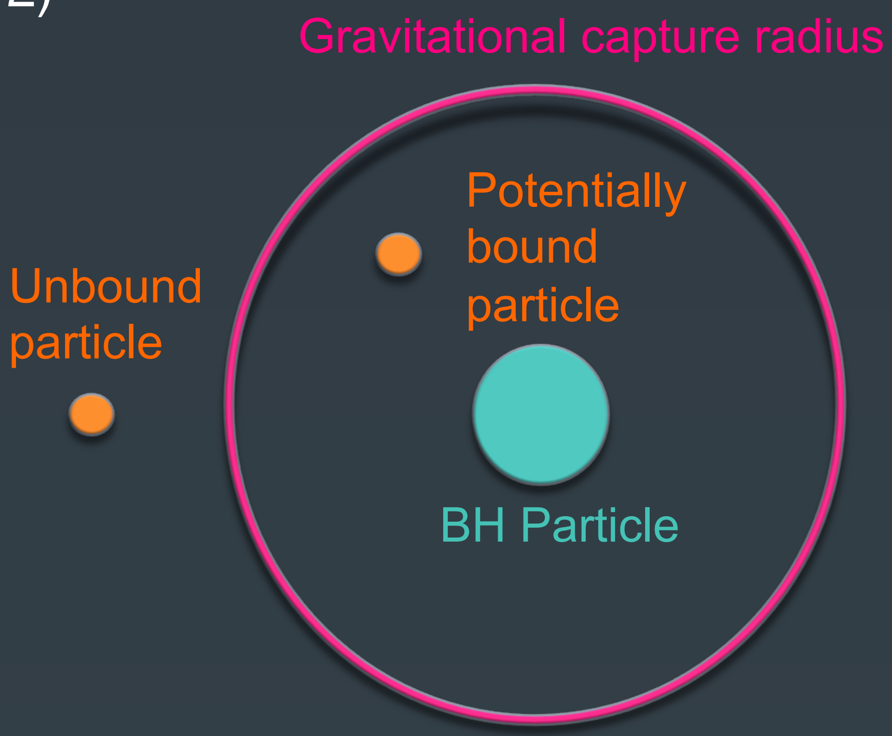
Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)
  - 3D, MHD+gravity
  - Accretion treatment



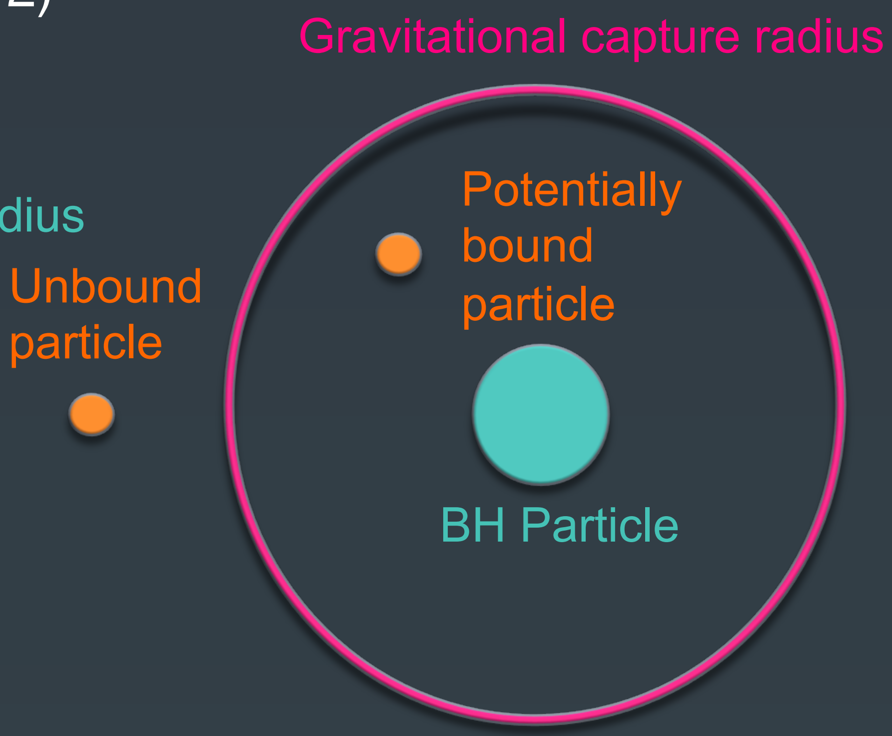
Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)
  - 3D, MHD+gravity
  - Accretion treatment



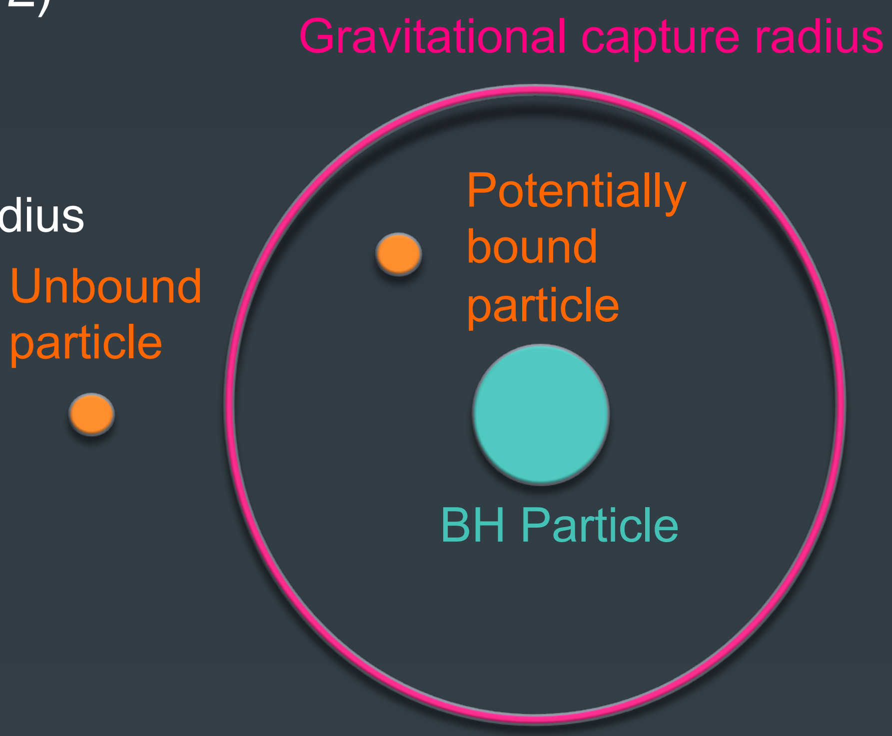
Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)
  - 3D, MHD+gravity
  - Accretion treatment
    - Particles within capture radius tested to see if bound



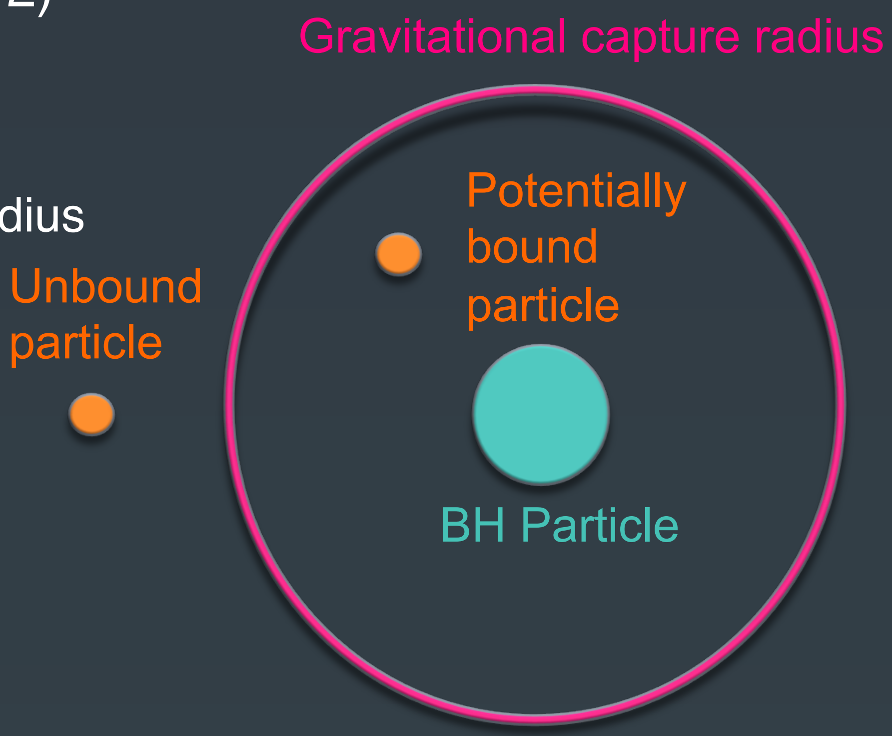
Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)
  - 3D, MHD+gravity
  - Accretion treatment
    - Particles within capture radius tested to see if bound
    - Bound particles added to reservoir



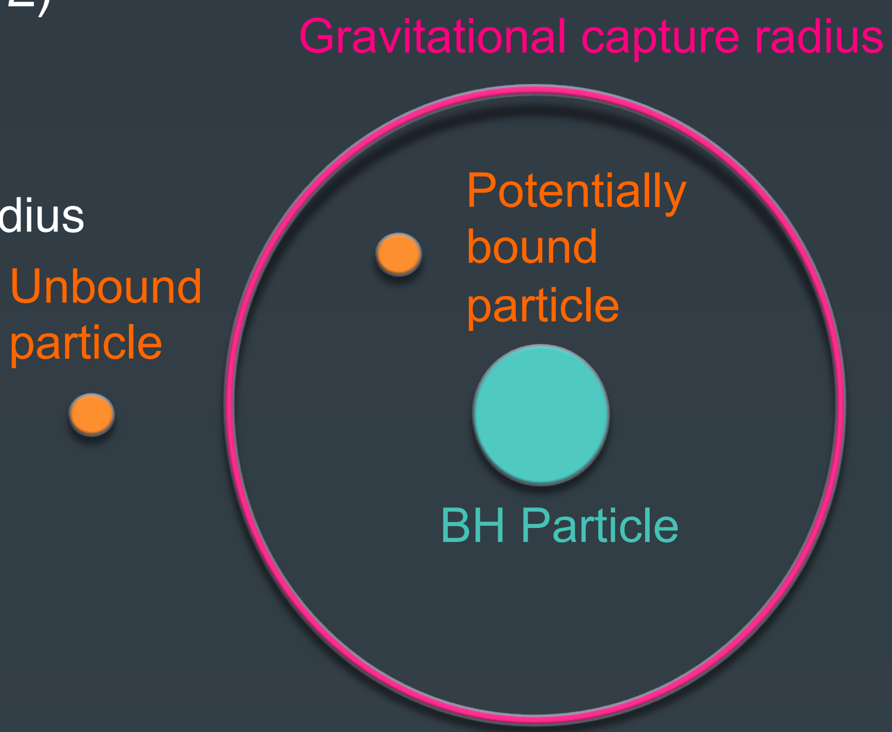
Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)
  - 3D, MHD+gravity
  - Accretion treatment
    - Particles within capture radius tested to see if bound
    - Bound particles added to reservoir
    - Transfer from reservoir to BH via slim disk



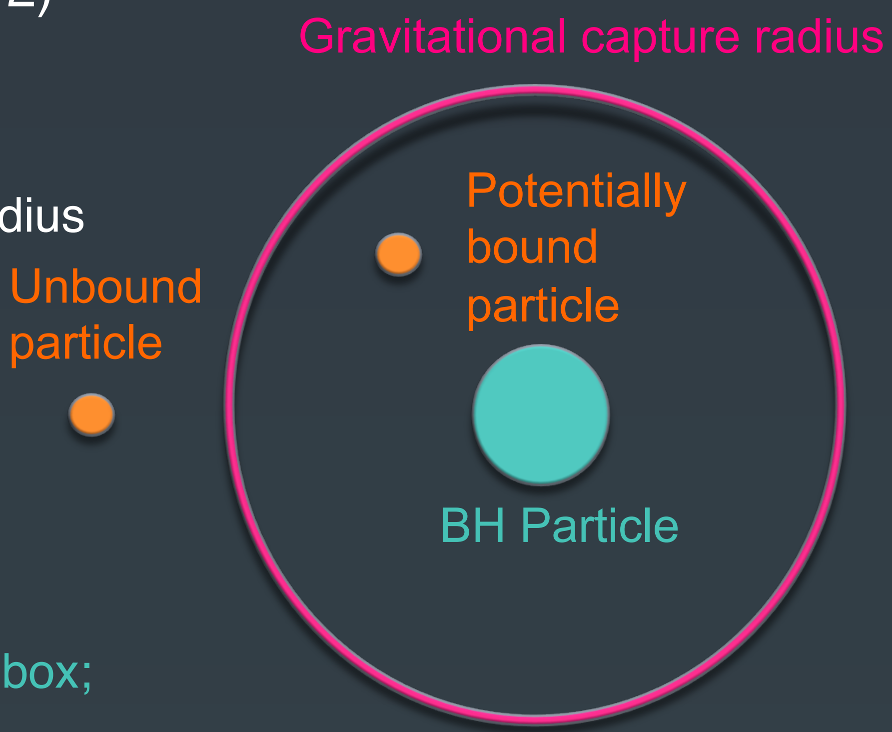
Our Study

- Goal
  - Determine environment in which a small seed BH can grow via hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)
  - 3D, MHD+gravity
  - Accretion treatment
    - Particles within capture radius tested to see if bound
    - Bound particles added to reservoir
    - Transfer from reservoir to BH via slim disk
- Set up



Our Study

- Goal
  - Determine environment in which a small seed BH can grow via Hyper-Eddington accretion to SMBH
- Using GIZMO (Hopkins 2012)
  - 3D, MHD+gravity
  - Accretion treatment
    - Particles within capture radius tested to see if bound
    - Bound particles added to reservoir
    - Transfer from reservoir to BH via slim disk
- Set up
  - 100 $M_\odot$ BH in 10 pc – 1 kpc box; vary initial density



Advances with this study

- Intermediate scale

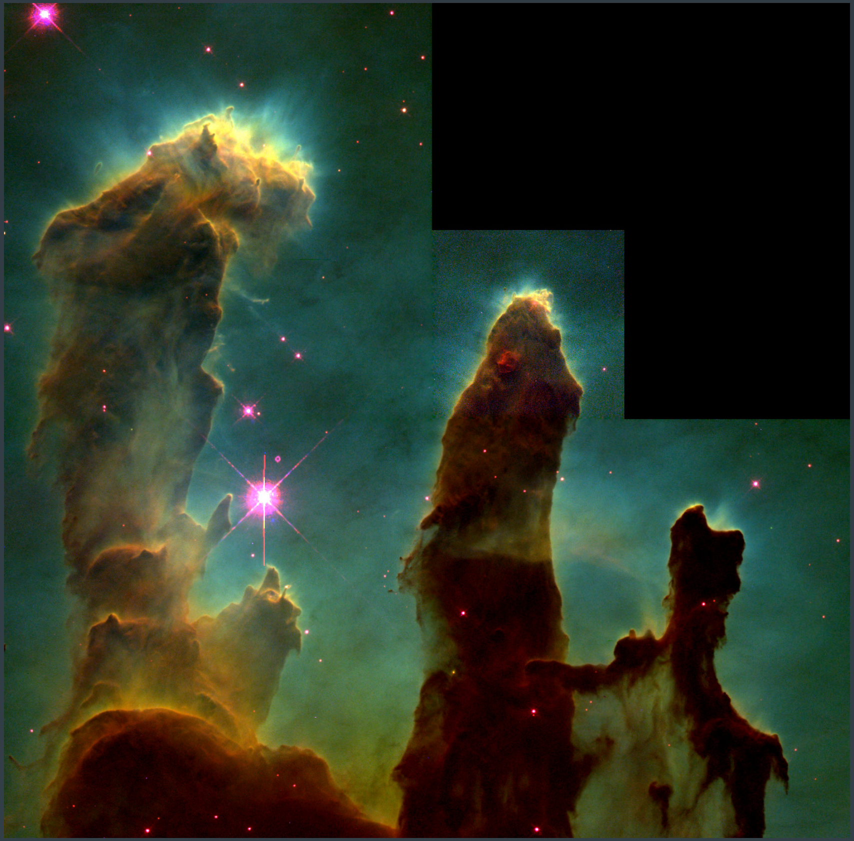
Advances with this study

- Intermediate scale
- Stellar feedback → inhomogeneous, turbulent environment

Advances with this study

- Intermediate scale
- Stellar feedback ➔ inhomogeneous, turbulent environment

Pillars of Creation

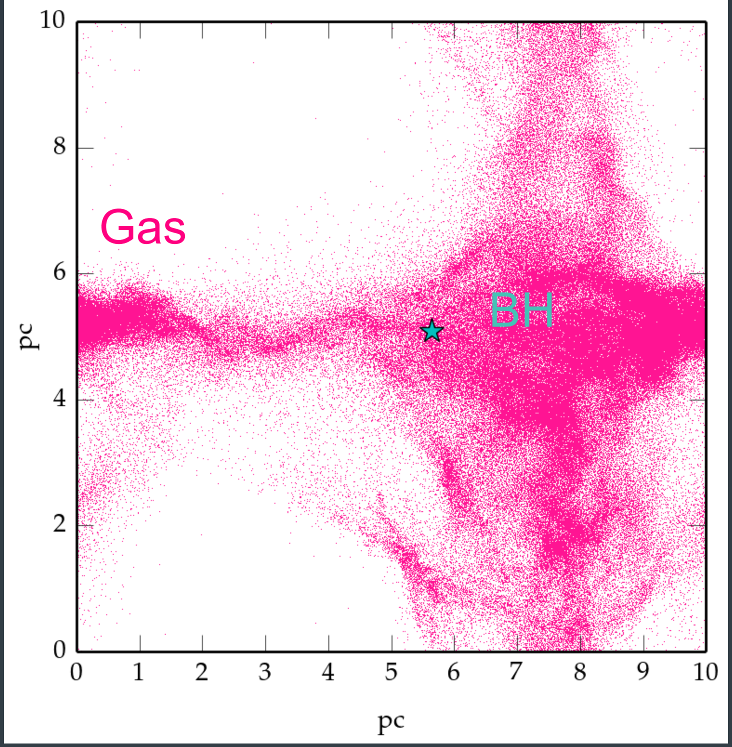


Credit: Jeff Hester and Paul Scowen (Arizona State University), and NASA/ESA

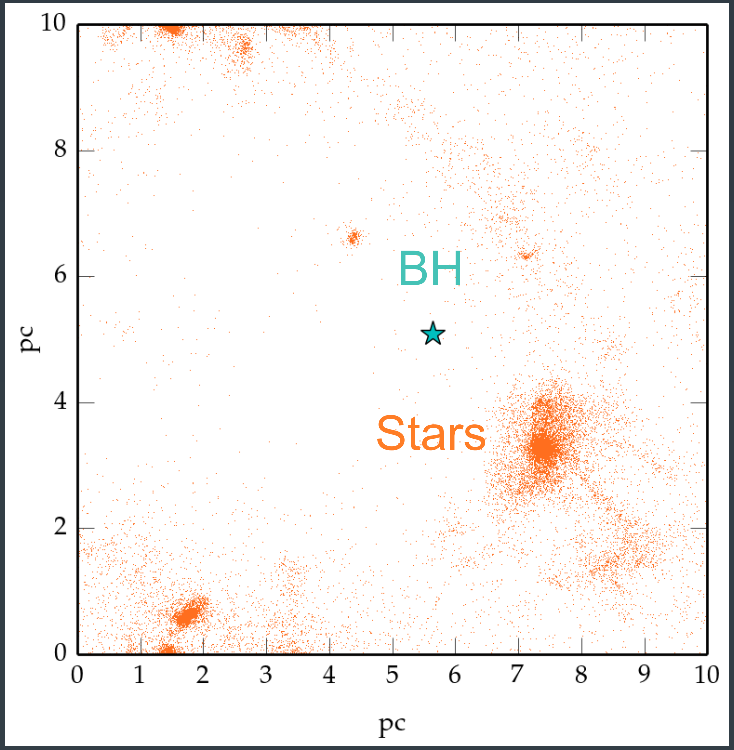
Structure Formation due to Stellar Feedback

10 pc GIZMO simulation

Gas Structure Formation

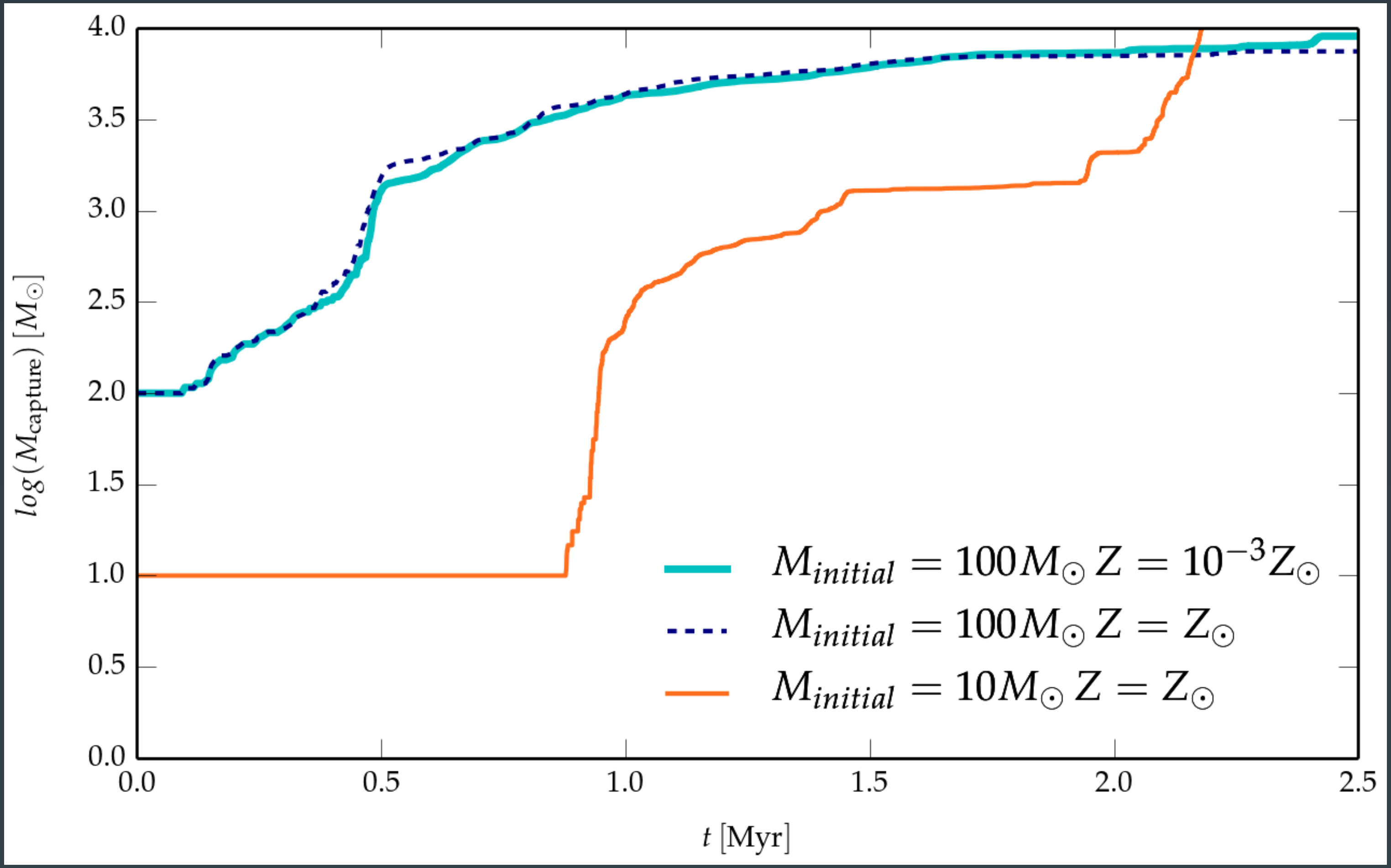


Star Formation

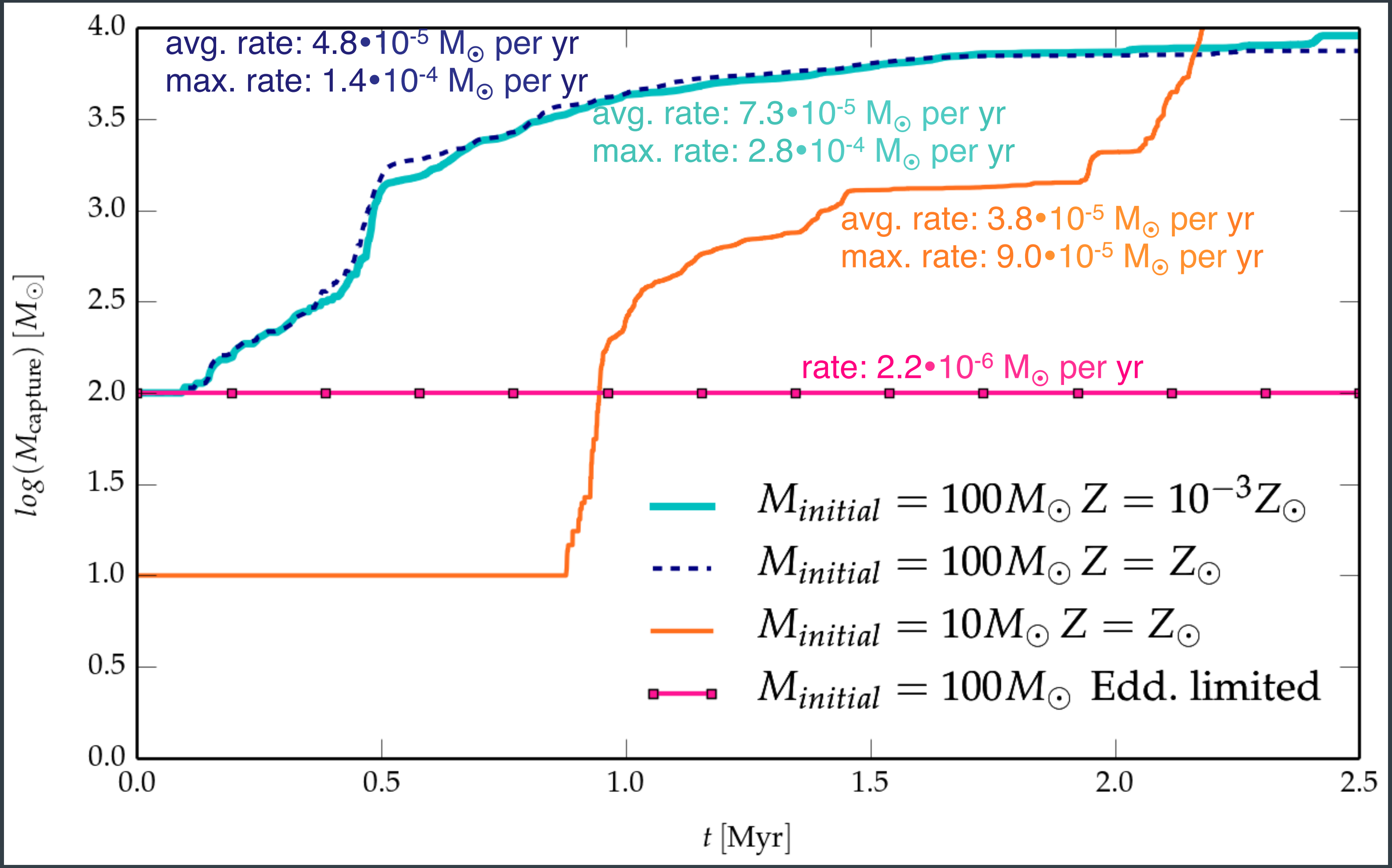


Results: BH + Disk growth

- Parameters: 10 pc box with 10^4 atoms/cm^3 density
- Mass res. : 0.8 $M_\odot$, Spatial res. : 0.1 pc



Simulated BH + Disk growth v. Eddington Limited growth



Discussion

- Intermediate scale Hyper-Eddington accretion

Discussion

- Intermediate scale Hyper-Eddington accretion
  - Growth occurs for both $Z = 10^{-3} Z_{\odot}$ and $Z = Z_{\odot}$

Discussion

- Intermediate scale Hyper-Eddington accretion
  - Growth occurs for both $Z = 10^{-3} Z_{\odot}$ and $Z = Z_{\odot}$
- Hyper-Eddington accretion in presence of stellar feedback

Discussion

- Intermediate scale Hyper-Eddington accretion
  - Growth occurs for both $Z = 10^{-3} Z_{\odot}$ and $Z = Z_{\odot}$
- Hyper-Eddington accretion in presence of stellar feedback
  - Turbulence and inhomogeneity do not prevent rapid growth

Discussion

- Intermediate scale Hyper-Eddington accretion
  - Growth occurs for both $Z = 10^{-3} Z_{\odot}$ and $Z = Z_{\odot}$
- Hyper-Eddington accretion in presence of stellar feedback
  - Turbulence and inhomogeneity do not prevent rapid growth
- Realistic environment

Discussion

- Intermediate scale Hyper-Eddington accretion
  - Growth occurs for both $Z = 10^{-3} Z_{\odot}$ and $Z = Z_{\odot}$
- Hyper-Eddington accretion in presence of stellar feedback
  - Turbulence and inhomogeneity do not prevent rapid growth
- Realistic environment
  - 10^4 atoms per cm^3 less than central density of ARP220

Discussion

ARP220

Credit:NASA, ESA, and C. Wilson (McMaster University, Hamilton, Ontario, Canada)

Discussion

- Intermediate scale Hyper-Eddington accretion
  - Growth occurs for both $Z = 10^{-3}\ Z_\odot$ and $Z = Z_\odot$
- Hyper-Eddington accretion in presence of stellar feedback
  - Turbulence and inhomogeneity do not prevent rapid growth
- Realistic environment
  - 10^4 atoms per cm^3 comparable to central density of ARP220
  - Only require SMBH formation once per Hubble time per galaxy

Summary

- Study
  - 100 $M_\odot$ seed
  - Intermediate scales (10pc – 1 kpc)
  - Including stellar feedback
- Results
  - Initial gas density: 10^4 atoms per cm^3
  - 10 pc box
  - Growth to 10^4 $M_\odot$ in $<10^7$ years with BH feedback, at both $Z = 10^{-3}$ $Z_\odot$ and $Z = Z_\odot$
- Further Work
  - Limit interesting parameter space
  - Higher resolution simulations
  - Observable phenomenology