The JVLA Deep Sky Survey
Finding the First Cosmic Explosions

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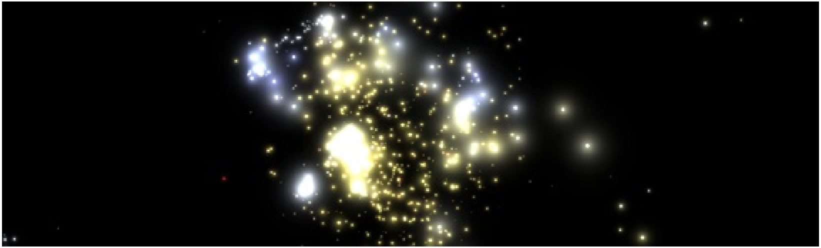
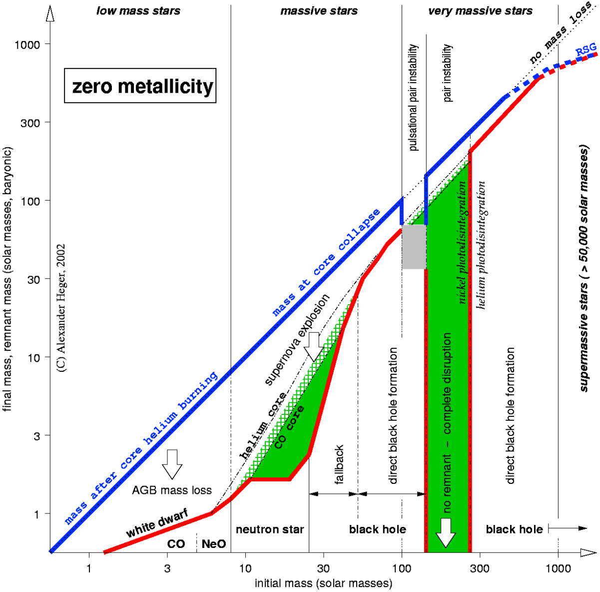
What are Pop III stars?



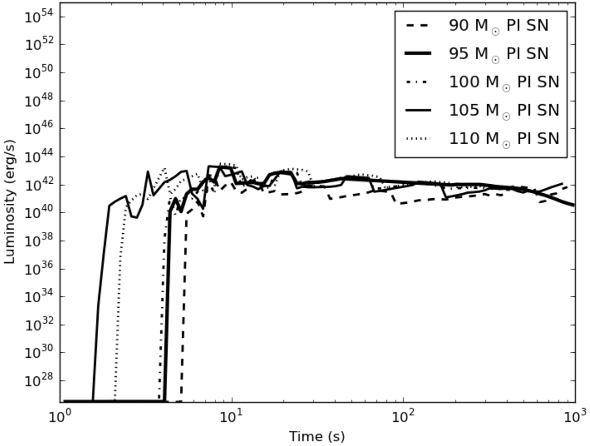
- first stars: formed from only H and He.
- thought to be massive (30 $M_\odot$ - 500 $M_\odot$).
- key to properties of **primeval galaxies**, early **cosmological reionization and chemical enrichment**, and the origin of **supermassive black holes**


low mass stars
massive stars
very massive stars
zero metallicity
no mass loss
RSG
pulsational pair instability
pair instability
mass at core collapse
mass after core helium burning
supernova explosion
helium core
CO core
nickel photodisintegration
helium photodisintegration
supermassive stars (> 50,000 solar masses)
(C) Alexander Heger, 2002
final mass, remnant mass (solar masses, baryonic)
1000
300
100
30
10
3
1
AGB mass loss
white dwarf
CO
NeO
neutron star
black hole
black hole
fallback
direct black hole formation
no remnant – complete disruption
direct black hole formation
1
3
10
30
100
300
1000
initial mass (solar masses)

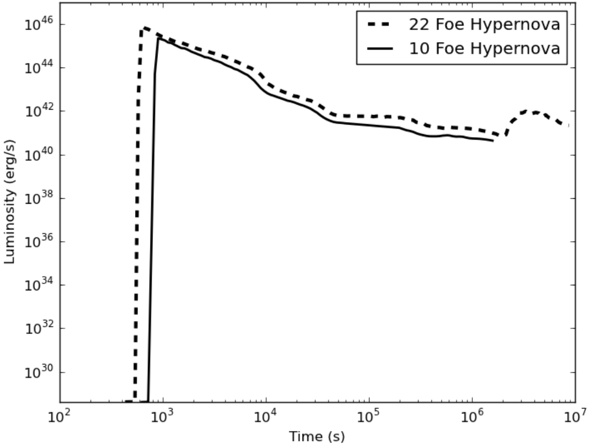
Los Alamos Supernova Light Curve Project

- progenitors are evolved in stellar evolution codes likes MESA, Kepler and Geneva to obtain the internal structure of the star at the time of death and then exploded
- these explosions are then modeled in the Los Alamos radiation hydrodynamics code RAGE
- RAGE profiles are post processed with the Los Alamos SPECTRUM code to obtain spectra and light curves

85 - 135 $M_\odot$ Progenitors



Hypernovae Explosions



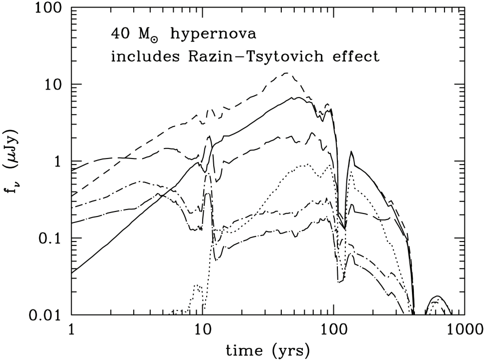


Figure: Whalen and Meiksin 2013

Curves correspond to 0.5 (dotted), 1.4 (solid), 3 (short-dashed), 10 (long-dashed), 25 (dot short-dashed) and 35 (dot long-dashed) GHz.

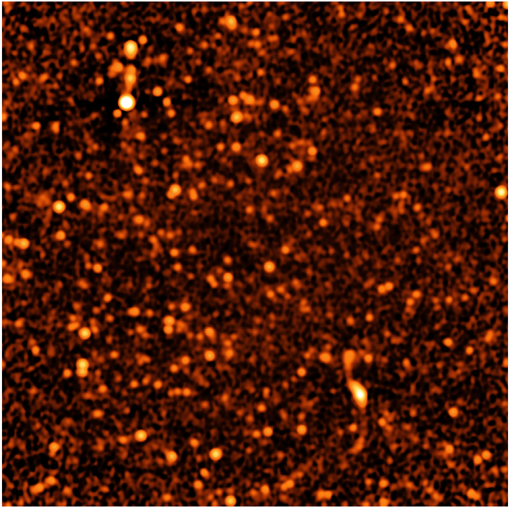


Figure: Condon et al. 2012

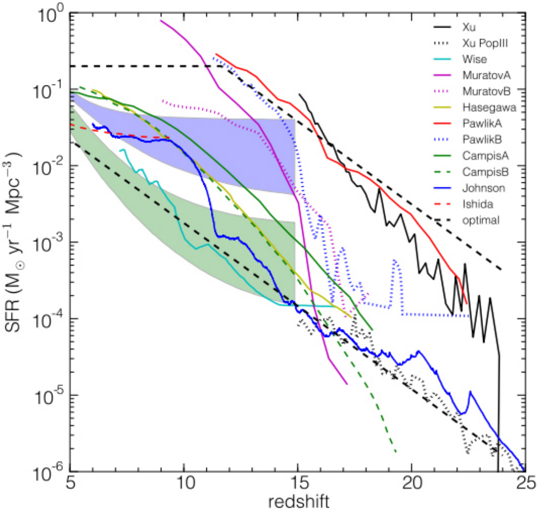


Figure: Whalen et al 2013

Birth of Supermassive Black Holes?

1. cloud kept from collapsing by LW background
2. catastrophic collapse from atomic cooling
3. supermassive star? ($\sim$ 55,500 $M_\odot$)
4. gravitational instability (Heger et al. 2014)

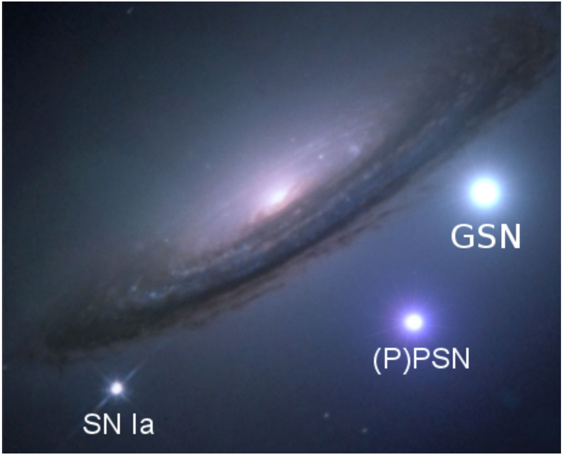


Figure: http://etacar.umn.edu/Workshop2012/Posters/KChen26.pdf

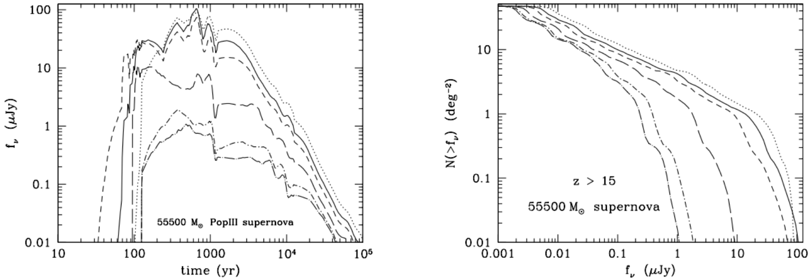


Figure: Whalen et al 2013

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Practical Considerations

- Optimistic estimates place supernovae (with flux $> \mu$Jy) at < 10 per square degree of sky
  - Need ~ 1 square degree of sky to reject claim with 90% certainty.
- A microjansky survey could detect
  - Pop III Gamma Ray Bursts
  - Pop III Hypernovae
  - Pop III Gravitational Instability Supernovae
- Most likely to be found in multi-epoch studies
- Multi-frequency observations to constrain redshift of explosions

Conclusion

- primordial SNe will be visible in the NIR to JWST, WFIRST and the TMT
- *but* some are visible in the radio *now* to JVLA
- we are currently devising surveys for the first cosmic explosions in the radio
- the detection of Pop III supernovae will be among the most spectacular discoveries in radio astronomy in the coming decade

RAGE model

$$
\begin{aligned}
\frac{\partial}{\partial t}\rho + \nabla\cdot\rho\mathbf{u} &= 0\\
\frac{\partial}{\partial t}\rho\mathbf{u} + \nabla\cdot(\rho\mathbf{u}\otimes\mathbf{u} + \mathrm{P}_e + \mathrm{P}_i) + \frac{1}{3}\nabla E_r &= 0\\
\frac{\partial}{\partial t}\rho e_i + \nabla\cdot(\rho e_i\mathbf{u}) + \nabla\cdot\mathbf{q}_i + \mathrm{P}_i : \nabla\mathbf{u} &= \gamma_{ei}(T_e - T_i) + \dot{S}_i\\
\frac{\partial}{\partial t}\rho e_e + \nabla\cdot(\rho e_e\mathbf{u}) + \nabla\cdot\mathbf{q}_e + \mathrm{P}_e : \nabla\mathbf{u} &= \gamma_{ei}(T_i - T_e) + c\sigma_a(E_r - at_e^4) + \dot{S}_e\\
\frac{\partial}{\partial t}\rho E + \nabla\cdot[(\rho E| + \mathrm{P})\cdot\mathbf{u}] + \nabla\cdot(\mathbf{q}_e + \mathbf{q}_i) &= c\sigma_a(E_r - aT_e^4) - \frac{1}{3}\mathbf{u}\cdot\nabla E_r + \dot{S}_i + \dot{S}_e\\
\frac{\partial}{\partial t}E_r + \frac{4}{3}\nabla\cdot(\mathbf{u}E_r) - \nabla\cdot(\kappa\nabla E_r) &= -c\sigma_a(E_r - aT_e^4) + \frac{1}{3}\mathbf{u}\cdot\nabla E_r
\end{aligned}
$$

- Accounts for up to 3 temperature plasma physics (we assume $T_e = T_i$).

Method (Special Extended Edition)

1. We include shock heating as an important source of luminosity through RHD.
2. We allow radiation and matter to be out of thermal equilibrium.
3. RHD accounts for radiation acceleration of shock waves and radiative losses.
4. We calculate spectra directly instead of using $L = 4\pi r^2 T^4$ to compute light curves.
5. SPECTRUM uses LANL OPLIB database which includes effects of **line and continuum opacities, fluorescence, Doppler shifting, time dilation and limb darkening**.