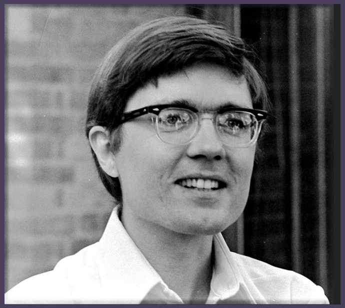
Conference Summary

Phil Myers
CfA

Frontiers in Star Formation: A Conference in Honor of Dr. Richard Larson
Yale University New Haven, Connecticut October 27, 2012

Introduction

Why we're here *a pioneering career*



What we heard

SF at first z = 10-50 first stars, first BHs, magnetic fields, pop II

Loeb, Stiavelli, Greif, Haiman, Turk, Glover

SF at its max z = 2-3 evolution, cold accretion, dust, winds, outflows

von Dokkum, Davé, Escala, Keres, Dwek, Veilleux

local SF now protostars, binaries, clusters, low and high-mass, GC

Goodman, Mac Low, Dunham, Offner, Kratter, Bonnell, Genzel

global SF now SF in galaxies, galaxy formation, IMF, ALMA

Krumholz, Evans, E. Ostriker, Bolatto, J. Ostriker, Covey, Riechers

Thanks to...

Conference Organizers

Hector Arce (Yale), Volker Bromm (UT Austin), Paolo Coppi (Yale)

Scientific Organizing Committee

Hector Arce (Yale), Volker Bromm (UT Austin), Paolo Coppi (Yale), Neal Evans (UT Austin), Alyssa Goodman (Harvard-CfA), Mordecai-Mark Mac Low (AMNH), Chris McKee (UC Berkeley), Priya Natarajan (Yale), Hans Zinnecker (SOFIA)

Local Organizing Committee

Hector Arce (Yale), Volker Bromm (UT Austin), Paolo Coppi (Yale), Jeff Kenney (Yale), Bob Zinn (Yale)

Yale Astronomy Staff

Victoria Misenti, Valerie Robalino

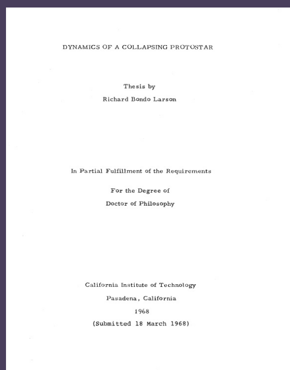
Banquet Speakers

Bromm Becklin Demarque Kenney Norman Zinnecker

Hector Arce

Victoria Misenti

A few images


DYNAMICS OF A COLLAPSING PROTOSTAR

Thesis by

Richard Bondo Larson

In Partial Fulfillment of the Requirements

For the Degree of

Doctor of Philosophy

California Institute of Technology

Pasadena, California

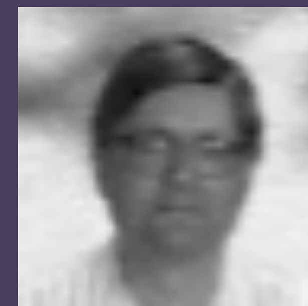
1968

(Submitted 18 March 1968)

1968 Ph. D.
thesis Caltech

1974 Cambridge

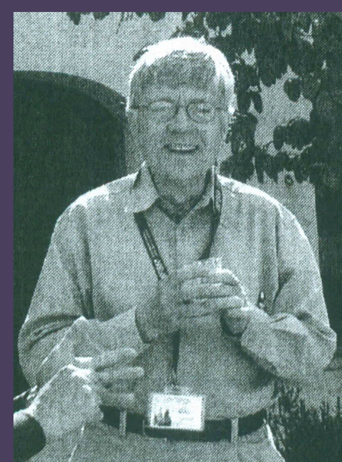
1983 Mexico City
Haro symposium



1992 Santa Cruz
globular clusters

1993 Ringberg
Structure and
Content MCs

1999 Nagoya
Star Formation 99
honoring Nakano



2005 Spineto
IMF 50 years later

2006 Washington
AURA meeting

NUMERICAL CALCULATIONS OF THE DYNAMICS OF A COLLAPSING PROTO-STAR*

1969; 911 citations
"grand slam on first pitch"

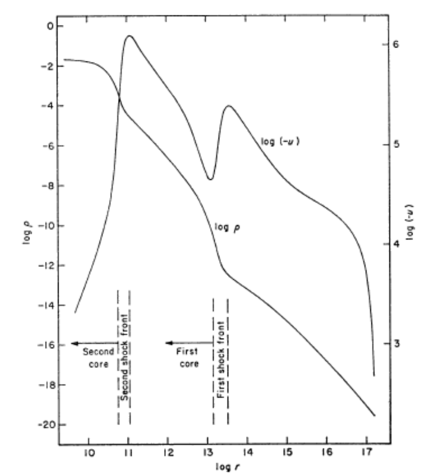


FIG. 2. *The density and velocity distributions at a time shortly after the formation of the second (stellar) core (CGS units). The shock fronts are represented by the regions of steep positive slope in the velocity curve.*

log ρ (r), $v(r)$ first and second core

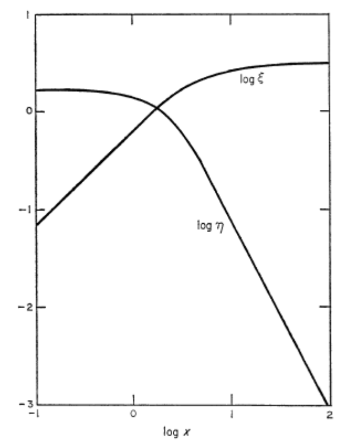


FIG. C1. *The numerically computed similarity solution for isothermal collapse (see equation (C5) for the definitions of the variables).*

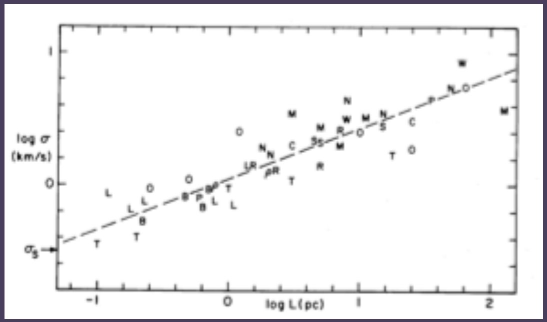
similarity solution Larson-Penston collapse

$\rho \longrightarrow r^{-2}$ $\quad v \longrightarrow 3.28\,\sigma$

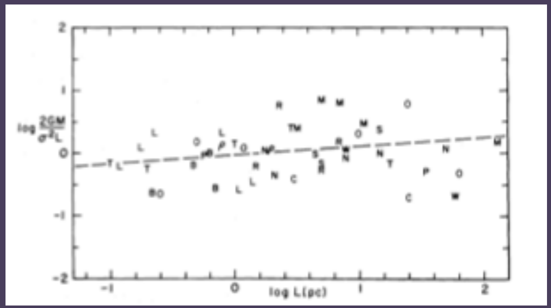
Turbulence and star formation in molecular clouds

1981 “Larson’s Laws” 1275 citations

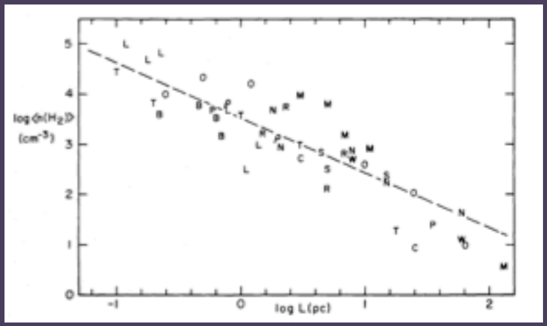
turbulence...



$\sigma \sim L^{0.4}$ power law



$GM/(L\sigma^2) \sim L^0$ virial equilibrium



$n \sim r^{-1}$ smallest clouds have mass ~ protostars

Turbulence and star formation in molecular clouds

...and star formation

the hierarchy of clumps of various sizes may terminate with objects so small that their internal velocities are no longer supersonic; this is predicted to occur for masses that are typically a few tenths of a solar mass. If these minimum-size clumps collapse and form stars of comparable mass, this would account for the apparent turnover of the stellar mass function at low masses.

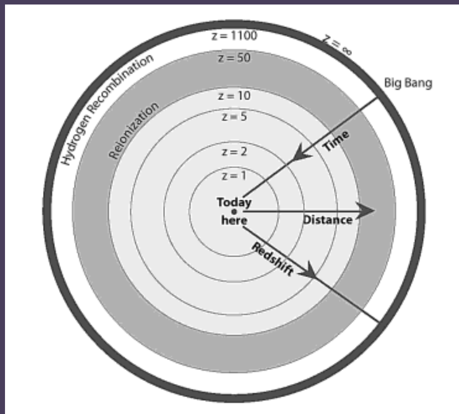
low mass stars

These massive clumps probably form groups or clusters of stars, and the most massive stars are probably built up by accretion from smaller pre-stellar condensations. The fact that the most massive stars appear to form only in the densest parts of the most massive clouds also suggests that accumulation processes are involved.

massive stars

The first stars

Loeb 2010



Garden of Eden for theorists! no metals, no dust, no B

Loeb: CDM ~ 80% in std model 1st stars < 500 Myr after big bang at $z \sim 10$ H, He T~ 10^4 K; with H_2, T ~ 200 K
New telescopes like ELT, PAPER

Stiavelli: JWST 8 G$ 2018 lensed objects Everything Spitzer can see, JWST can take spectrum Look for $Z \sim 10^{-3}\, Z_\odot$ as pop III signature

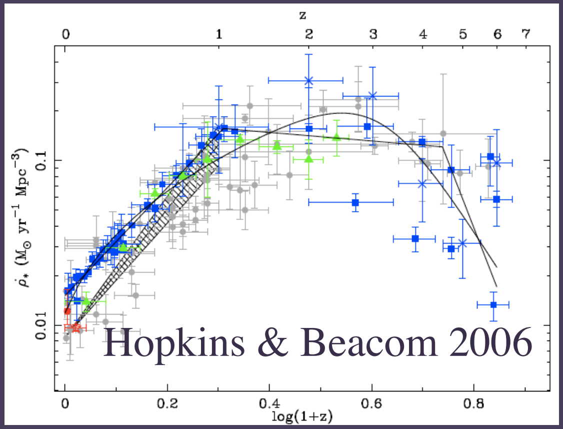
Greif: New sim: 250-500 kpc no sinks, 4 steps, last step zoom on 10 AU box. Disk forms and fragments within 1 AU. Cooling due to H_2 dissociation. Secondary ps migrate to merge with primary on ff time. Most massive ps forms first.

Haiman: Why SM BHs? $10^9\, M_\odot$ $z > 6$ stellar seeds vs. direct collapse—like debate in galactic star formation between "competitive accretion" vs. "massive cores."

Turk: B in pop III star formation. Importance of fine numerical resolution. Resolve Jeans length with 16, 32, 64 elements in each of 3D, gives more chance for B to grow. But no rad xfer.

Glover: pop III -> pop II IMF might change since metals -> cooling -> fragmentation. Question: how does dust form so early? Not enough time for AGB stars, not enough SNe?

Star formation at its maximum



Van Dokkum: with Herschel, better SEDs -> better L_{bol}.
~ half of all stars in universe formed during z = 1-3. Grow in mass, size with z. High star formation due to higher rates within galaxies, not more galaxies.

Davé: Galaxies are "gas processing factories." SFR ~ dM_{grav}/dt with recycling, enrichment. Average inflow sets scaling relations, mergers set scatter.

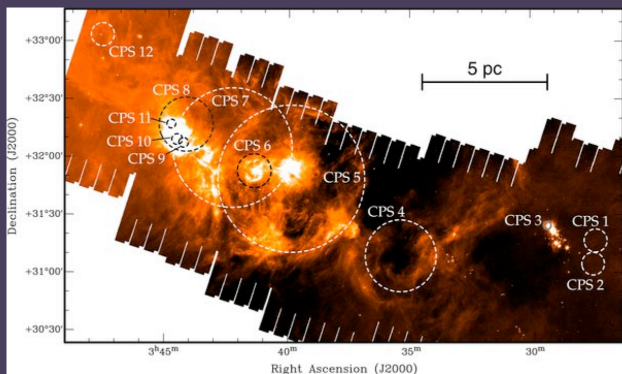
Escala: Co-evolution of BHs and galaxies. Must include MBHs in evolution sims. Can get SMBHs from mergers of massive protogalaxies. Can get SMBH from accretion through massive nuclear disk.

Keres: What fuels long-term star formation over Hubble time? Galaxies must be supplied with gas to form its stars. Cold accretion along IG filaments even with hot halo. IGM accretion >> mergers. Open issue – interaction of infalling gas and hot halo gas.

Dwek: Dust comes in many forms. Expect SNe dust for ages < 400 Myr, too young for AGB dust. However it's hard to distinguish observationally. JWST observations may help distinguish models.

Veilleux: New observations of galactic winds and outflows.Winds in molecular and atomic gas.Wide-angle winds, not jets, on kpc scales. Zone of influence 100-150 kpc, "pollute" CGM, maybe IGM.

“Local” star formation



Arce et al 11 Shells in Perseus cloud

Goodman: Visualization of clouds in MW, Orion, Perseus, over many scales and λs. B star winds more important than collimated outflows. First Larson core candidates. PDF of column density similar from cloud to cloud -> RL 3rd law.

MacLow: what sets IMF shape and mass scale? EOS, turbulent fluctuations, G. Recent work on hierarchy of collapses. Turbulence can promote local collapse but inhibit global collapse. Most star formation is due to gravity, not triggering,

Offner/Dunham: IMF may not be so discriminating, instead focus on PLF. Need broad λ coverage, correction for A_V. Local clouds: 7 VeLLOs, some may be low-L protostars, some 1st Larson cores. SF theory comparison – TC and CA better than IS if no variation in *dm*/*dt*. However variation or episodic accretion can get IS to fit observed PLF after all.

Kratter: Binaries matter! Multiple pathways to form binaries (which is most important?) Bate 2012 gets right binary distribution with questionable ICs. theories: capture/ejection, core breakup, disk fragmentation. Turbulent sim seems to work. Fragmentation-induced starvation. Maybe core frag for low M, core frag + disk frag for high M? ALMA will help to resolve.

Bonnell: How do massive stars form? Sims: convergent filaments due to large-scale collapse. Cluster forms at same time as cores. No massive prestellar cores. Massive stars draw from clump. Low mass stars from prestellar cores collapsing. Ionization has little effect on inhibiting sf. Hard to make isolated massive star. What are self-consistent ICs? Galactic model ram P, cooling-> similar to Schmidt-Kennicut law.

"Global" star formation

Krumholz: SF laws. Top-down: global law fundamental, large-scale gal gravity plus feedback. Bottom-up: local fundamental, sum up over galaxy. What sets threshold *n*? Local $\varepsilon_{ff} \sim 1\%$ due to bound fraction of lognormal pdf. Unify models.

Evans: *SFR* vs. Σ in galaxies and in solar nbd. Extinction threshold 120 $M_\odot$ pc^{-2} by 2 methods.   SF law for all gas & dense gas. Spec: H-> H_2 and H_2 -> stars at ~10, 120 $M_\odot$ pc^{-2}. Local test gives steeper law than $\varepsilon_{ff} \sim 1$ %. Caution: KS plot for sol nbd from M51. "Ask exgal Qs"

E. Ostriker: Galactic SFRs. Equilibrium requires SF feedback to maintain turbulence (top-down). $SFR \sim (P_{therm} + P_{turb})^{1.2}$

Bolatto: Magellanic clouds. *SFR* and *Z*. Surface density alone does not set level of SF. LMC linewidth-size, mass-size relations have scatter. *Z* affects SFR through molecular fraction. Relation of H_2 and SFR seems unchanged.

J. Ostriker: 2-phase formation massive gals. WMAP7 sets small errors. No feedback. Many minor mergers. Gets "red & dead" and hotter. High resolution essential. Early times & low mass: gas inflows; Late times & high mass: accr satellites.

Covey: Universality IMF. No obs of systematic IMF variations. BDs: log-normal may be better than Kroupa. Dense clusters with poor resn may bias obs. Goal: improve field star completeness, mass seg.

Riechers: ALMA match JWST resolution; proto-planetary disks, AGN, hi-*z* gals, deep fields, SZ effect

Special Thanks

Thanks Richard, for

your pioneering
contributions

teaching us so much
new about the universe

setting a great example

as a scientist
and as a person